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). The primary focus of this project is enhancing the accuracy and utility of the existing uncertainty band algorithm (uBand) for predicting transmission loss uncertainty in a wide variety of ocean environments.

A long-term goal at the time of this project's proposal was the integration of the existing Field-Shifting algorithm (FS) with uBand. For the uncertain variables of greatest interest to NRL-SSC, however, a new reciprocity-based technique provides more accurate and efficient results than FS. At present, the long term goals for this project are: *a*) fully explore the applicability and utility of the reciprocity algorithm in transmission loss uncertainty estimation, *b*) integrate the reciprocity technique into the existing uBand algorithm, *c*) develop other techniques (possibly including FS) for uncertain variables or environments where the current version of uBand and the reciprocity approach perform sub-optimally.

OBJECTIVES

The specific objectives of this project are: *a*) develop tools based on reciprocity for efficiently predicting transmission loss uncertainty at multiple ranges in a range dependent environment with an uncertain source depth, *b*) integrate these findings into uBand to increase its accuracy and efficiency in environments with uncertain source depth, *c*) develop techniques to improve the performance of uBand for uncertain variables other than source depth.

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APPROACH

The research for this project is conducted through simulations of underwater acoustic propagation. Rigorous (but computationally inefficient) direct or Monte-Carlo simulations provide ground truth for all acoustic uncertainty information, and are used to evaluate the accuracy of various prediction techniques. Simulations in range-dependent environments are performed with the modal-sum propagation model KRAKEN. Simulations in range-dependent environments are currently performed using RAMGEO, but approval paperwork is underway to obtain the Navy 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 of approximately 10 km. Simulations are conducted in these environments, and the uncertainty predictions of various techniques are compared to direct simulation or Monte Carlo results.

WORK COMPLETED

As accurate transmission loss prediction in the presence of an uncertain source depth is one of the current weaknesses of uBand, work up to this point has focused on this environmental variable. Within the first few weeks, it was determined that the Field Shifting Algorithm (FS) was not an accurate or efficient tool for this application. Thus, a different technique was developed based on the acoustic reciprocity between a source and a receiver. In a range-independent environment, for a given receiver depth, reciprocity yields completely accurate (equal to the accuracy of the propagation model) transmission loss uncertainty predictions at all ranges with the computational burden of a single field calculation. In a range-dependent environment, each field calculation only provides accurate predictions at a particular range of interest. Current work is focused on using information from reciprocity to provide predictions of acceptable accuracy over a larger extent of source-receiver ranges with as few field calculations as possible.

RESULTS

To illustrate the implementation of reciprocity to generate uncertainty predictions, the following simulation is performed in a Pekeris waveguide using KRAKEN. The frequency is 100 Hz, the waveguide depth is 100 m, with a constant 1500 m/s speed of sound in the water column. The bottom sound speed, density, and absorption are 1700 m/s, 1.5 g/cm^3, and 0.5 dB/λ, respectively. The receiver range and depth are 5 km and 50 m. The source depth is uncertain, with a mean of 30 m and a standard deviation of 1 m.

Figure 1 shows the variation in transmission loss at the receiver as the source depth is varied over +/- 3 standard deviations from the mean. This result was obtained though direct calculations performed at many source depths between 27 and 33 m. Such direct calculations are too computationally inefficient to apply to a multi-variable problem in real time, but they provide reliable ground truth in this case.

Figure 2 shows transmission loss vs. source depth generated by applying the principle of reciprocity. Here, the source and receiver depths are switched, so that only one field calculation is performed, with one source placed at the known receiver depth of 50 m. By examining the transmission loss at various receiver depths in this single field, the exact same transmission loss vs. source depth relationship from Figure 1 is obtained with a single field calculation.

Interestingly, in a range-independent sound channel, this single field calculation with a source placed at the known receiver depth provides complete transmission loss vs. source depth information at all ranges. However, in a range-dependent environment, the principle of reciprocity only applies at the calculated range. The following calculations are performed with RAMGEO in a range-dependent environment with the same parameters as the Pekeris waveguide above, except the channel depth is 200 m at the source, and slopes up to 100 m at the receiver, over 10 km. In Figure 3, the black curve is generated by iteratively varying the source depth, while the blue curve is obtained from a single reciprocal field calculation. The curves are not identical, as in the range-independent case, but they are within the numerical and model implementation error of the propagation model (a few tenths of a dB).

These calculation errors arise from the numerical implementation of the parabolic-equation approximation, and the details of the computational grid including its range and depth resolutions. In addition, due to the offset nature of the overall calculation error, the uncertainty bounds are still readily determined with greater precision than the model accuracy

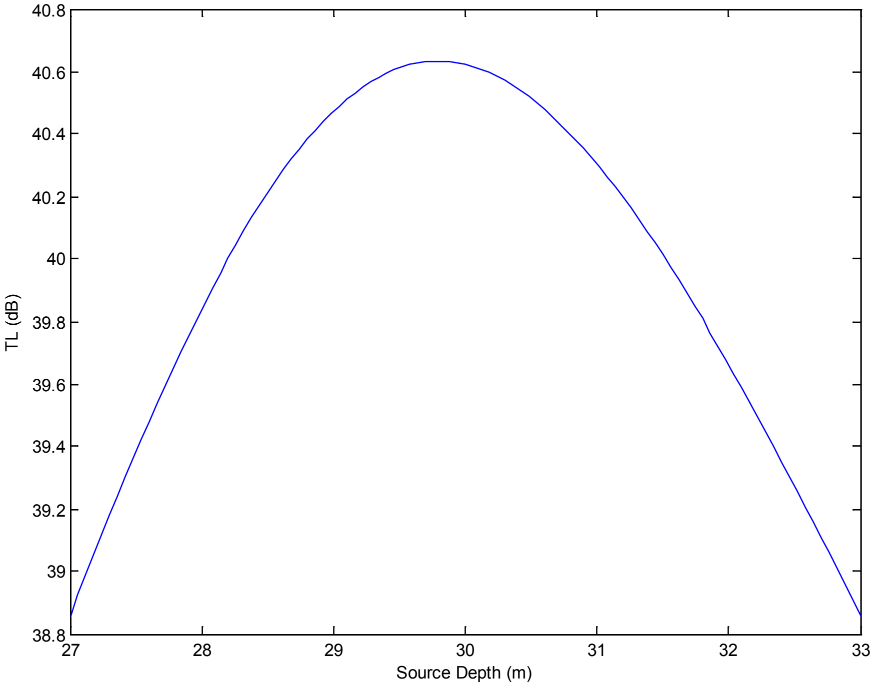

Figure 1. Transmission loss vs. uncertain source depth in a Pekeris waveguide obtained by through repetitive field calculations at source depths between 27 and 33 m.

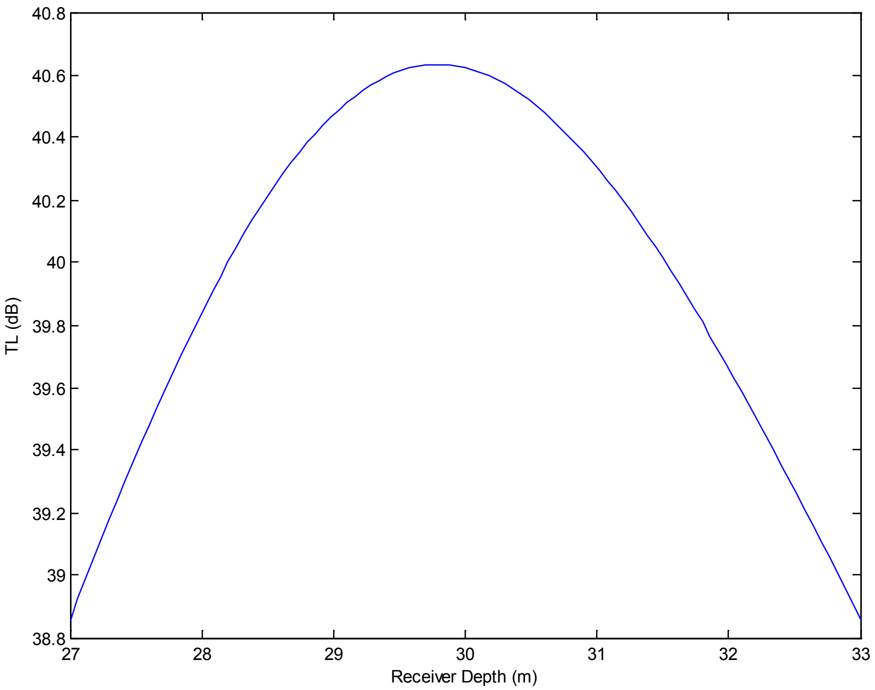

Figure 2. Transmission loss vs. receiver depth in a Pekeris waveguide obtained from one reciprocal field calculation where a single source is placed at the known receiver depth. This curve is identical to that in Figure 1, but is produced from only one field calculation.

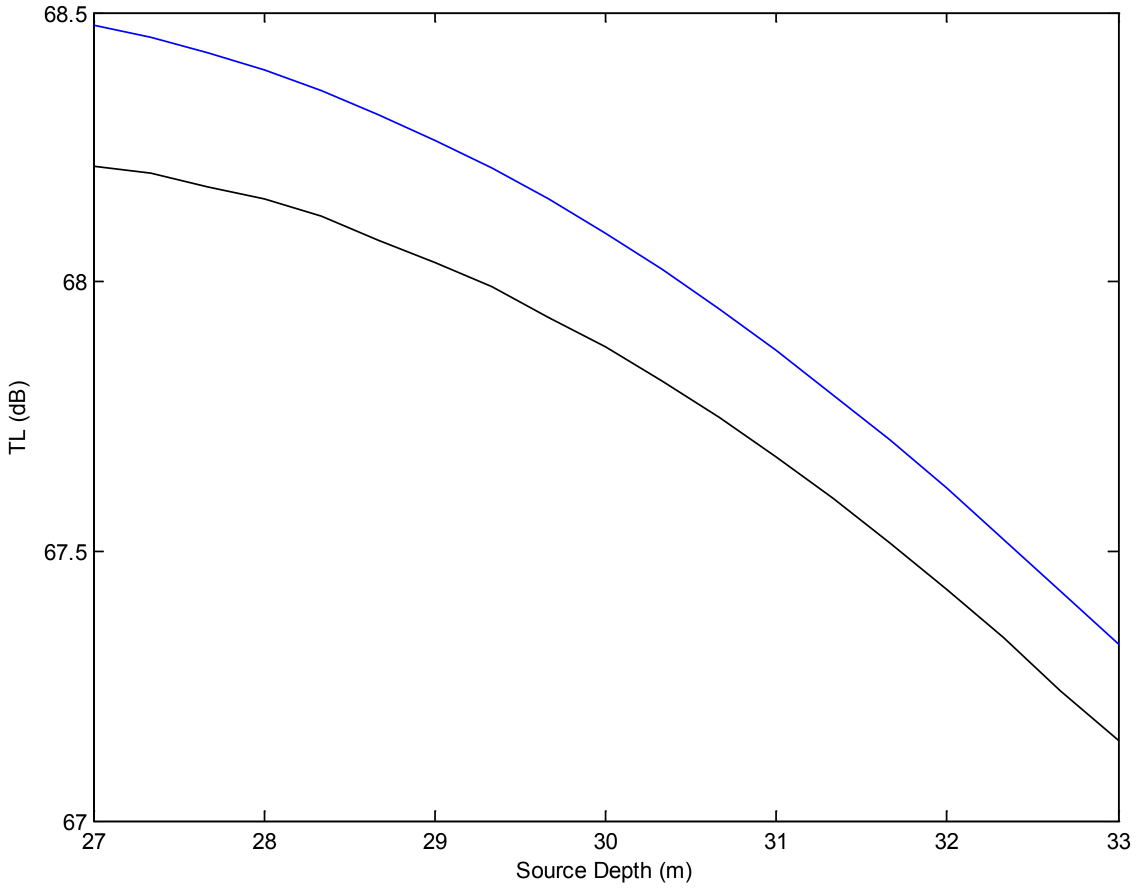

Figure 3. Transmission loss vs. uncertain source depth in a range-dependent sound channel. The black curve is obtained through iterative field calculations at several possible source depths, and the blue curve comes from the reciprocal field. The shape and uncertainty bounds match well, but there is a ~0.3 dB offset in the mean due to the overall calculation error in the simulations. Note that the compressed range of the vertical axis is small compared to any relevant overall TL value.

The goal of the present effort is to produce range-averaged transmission loss uncertainty bounds for sound channels with uncertain source depth, to incorporate these bounds into uBand's transmission loss predictions for multiple uncertain variables. Figure 4 is one such plot for the range-dependent environment outlined above. While the results shown on this figure were generated by iterating the source depth, the current research effort is to apply the principle of reciprocity, as described above, to obtain similar data with as few field calculations as possible.

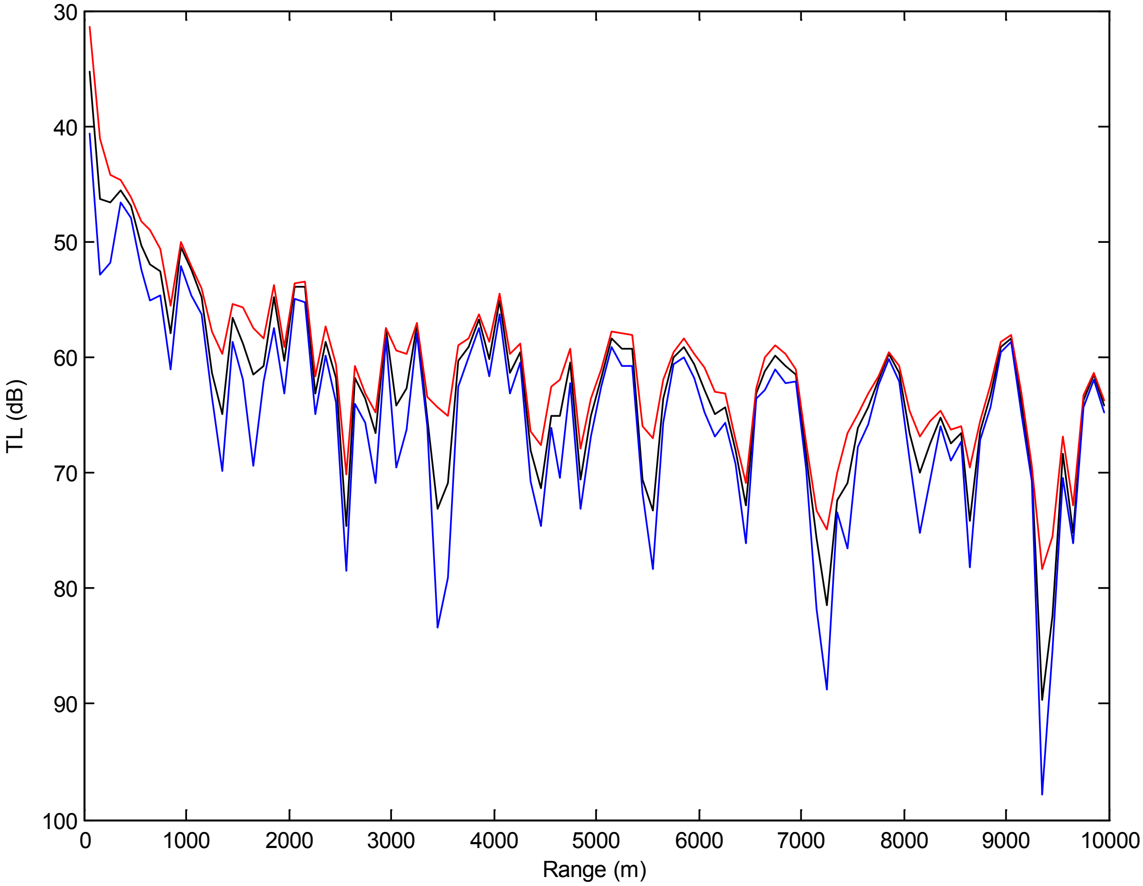

Figure 4. Ranged-averaged transmission loss in the same range-dependent sound channel as Figure 3. The black curve is the mean transmission loss, while the red and blue curves are the upper and lower 98% confidence bounds, respectively, arising from the uncertain source depth. The generic goal of this project is to efficiently and accurately predict the blue and red curves.

IMPACT/APPLICATION

This project seeks to improve existing Navy prediction capabilities by collaborating 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 in accuracy or efficiency, it is intended for the end result to be a robust and efficient computational tool for Navy-relevant transmission loss uncertainty prediction in imperfectly-known ocean environments.

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 recent past there has been a significant amount of ONR-funded research on acoustic uncertainty. Foremost among these is the Quantifying, Predicting, and Exploiting (QPE) Uncertainty program lead by Dr. James Lynch that has 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 is more closely conforms to Naval applications of acoustic uncertainty prediction than the QPE program and is less computational and mathematical than the NRL-DC efforts.

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PUBLICATIONS

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