Signal and Noise in 3D Environments

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LONG-TERM GOALS

I have been developing fast acoustic models for complicated 3D environments. I have also been doing a great deal of work in modeling the noise field (the ocean soundscape) due to various sources including shipping and winds. The research described here combines those themes with the overarching goal of using the natural noise field or soundscape to learn about the ocean environment. I distinguish this from geoacoustic inversion and ocean tomography, in that the methods envisioned will rely on broader features of the soundscape.

OBJECTIVES

In the first phase of this effort we will focus on the 3D modeling solutions, documenting the models and the benchmark solutions. These models are designed for omnidirectional point sources. In the second phase we will focus on the more complicated noise fields, characterized by distributed sources due to, for instance, shipping traffic.

APPROACH

We envision the 3D model development will largely come to an end during the half of this proposed research. With recent progress in 3D models, I believe there is now a compelling need to do thorough benchmarking. Therefore, I have been promoting a workshop and special sessions in this area. Frederic Sturm and I broke the ice with that, with a special session we organized for the Underwater Acoustics conference in Greece in late June of 2014. This was followed by another session at the Underwater Acoustics Conference 2015. Marcia Isakson and Ying-Tsong Lin followed up with an ASA special session at the Pittsburgh ASA in May 2015.We are now trying to organize a collection of papers for JASA or another appropriate journal.

The key area that I believe needs to be explored further within the scope of this project is the experimental demonstration of 3D effects, to get a deeper understanding of when they occur and matter, as well as to demonstrate the value of the modeling process. So far we have made just some tentative efforts in that area, preferring to focus on the benchmarking against other solutions. The importance of 3D effects will be most clear when looked at through the prism of signal processing algorithms. The 3D environment causes beam splitting, which affects both the perceived bearing and the received level on a towed array.

To date we have emphasized the propagation of 'signals'. We have become increasingly interested in modeling 'noise' which can illuminate the ocean environment in revealing ways. In particular, we would like to use BELLHOP3D to exploit 'Ship Light' to develop a 2D (lat/long) map of the reflectivity of the seabed. The experimental concept is to deploy an array in an area of interest where there is a lot of shipping traffic and observe the variations in sound level as dozens of ships crisscross an area. The variations in intensity should allow us to infer the range-integrated transmission loss, which, over multiple propagation paths allows one to unravel the bottom map. We have partnered with CMRE for the REP-14 experiment that took place in late June. A preliminary analysis was done, illustrating the procedure; however, due to space limitations we will not present those results here.

WORK COMPLETED

We have continued this year with the development of 3D test cases and intermodel comparisons. Petrov and Sturm recently developed a new analytical (but approximate) solution for the wedge and together with Orlando Rodríguez we have been exchanging results with different models (analytic, 3DPE, BELLHOP3D, KRAKEN3D, and another 3D beam tracing model). We will discuss here work on KRAKEN3D, which is an adiabatic mode code that is normallly run in the Nx2D mode, but optionally treats horizontal refraction using Gaussian beams.

KRAKEN3D was originally developed around 1986 at NRL in support of the Wide-Area Acoustic Propogation program at NRL and it has been openly distibuted for decades as part of the Acoustics Toolbox. We will present test results on a simple wedge problem. In the course of this work we corrected the treatment of modal attenuation and fixed a known limitation when a ray crossed over multiple 'tiles' in a single step. (The numerical algorithm works by dividing the lat/lon coordinate into tiles and calculating the normal modes at the corners of the tiles.)

Within the scope of this work, I have also continued maintenance of the Ocean Acoustics Library. This continues to be an important resource for the community and I have added a number of things. Briand Dushaw (APLUW) has contributed a number of programs related to his research on Long-Range Acoustics, including an new versoin of EIGENRAY and a new OPENMP/MPI Parabolic Equation Model. Sean Reilly (URI and AEGIS) has provided an update of his Undersea Modeling Libarary with WaveQ3D. Orland Rodríguez has provides his Gaussian beam tracing code called TRACEO. The Acoustics Toolbox has been updated, providing also the first open distribution of BELLHOP3D for 3D Gaussian beam tracing. Finally, we have added a new Jobs Board listing open positions in underwater acoustics.

RESULTS

This particular wedge problem was set up originally in KRAKEN3D by Orlando Rodríguez (Univ. of Algarve) based on an example of Petrov and Sturm. The bathymetry is shown in Fig. 1 and defines a wedge going from 0 m to 200 m in depth. The source is placed at the (x,y) = (0,0) coordinate. Figure 2 shows the influence of a single beam with a launch angle of about 110 degrees. The horizontal refraction is clearly visible. Note that the beam describes the influence in the x-y plane; the depth dependence is given by the local mode function.

A fan of such beams was launched every degree in azimuth for each normal mode. The beams were then summed to yield the final pressure field represented as transmission loss in Figure 3. In initial tests there had been some raggedness and lack of symmetry. This latest result indicates that those flaws have been corrected. Finally, in Figure 4 we show a slice of the tranmission for the cross-slope line along x=0. The result shows excellent agreement with the reference solution based on an approximate analytic solution developed by Petrov and Sturm. Those results in term were cross-checked again a 3D Parabolic Equation model developed by Sturm. (There are different approximations in all these approaches so we do not expect perfect agreement.) Collectively these results lend confidence to all the different modeling approaches and provide a benchmark solution for other 3D models.

This problem with its low frequency and resulting low number of propagating modes is difficult for 3D ray/beam tracing models such as BELLHOP3D and initial results were not particularly good. However, work will be reported later on modifications that improve the accuracy of such models.

IMPACT/APPLICATIONS

Such 3D models are important in areas with strong variation in the bathymetry or oceanography. An application of significant ongoing Navy interest is the development of deployment strategies for nodes in harbor defense systems. The harbors generally present very complicated 3D environments.

RELATED PROJECTS

None.

REFERENCES

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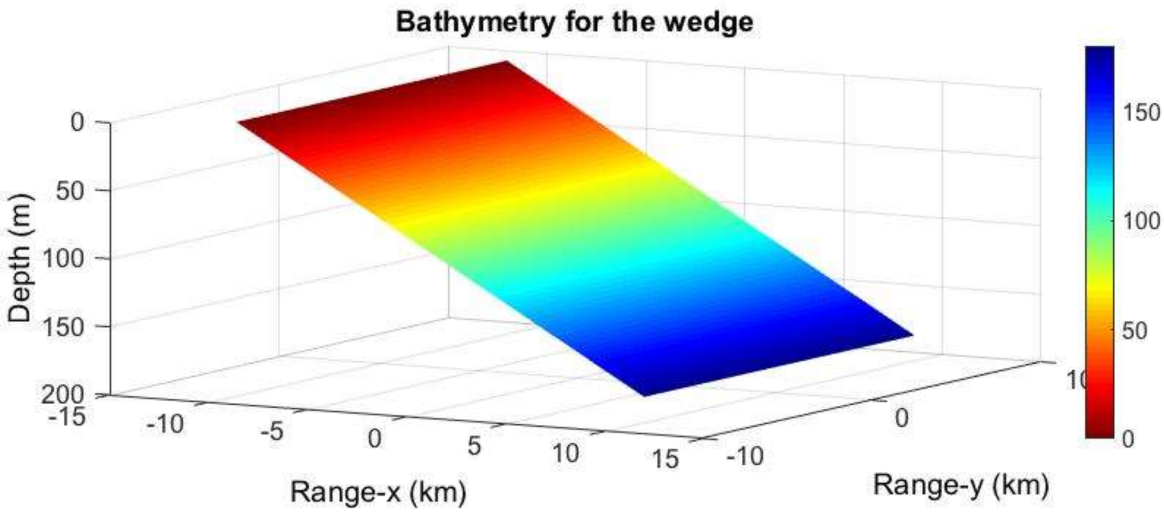

Figure 1: *The ocean bottom is a penetrable halfspace forming a wedge that slopes from 0 m depth to 200 m depth.*

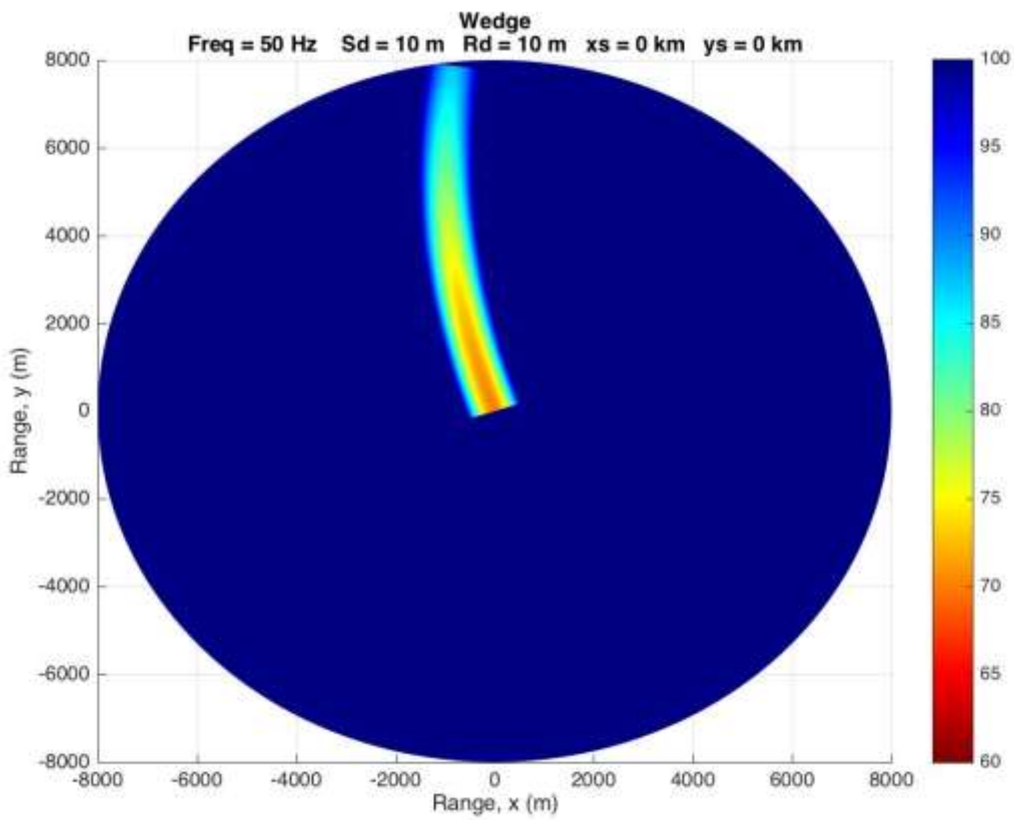

Figure 2: *The pressure field is built up with a series of individual beams that refract in the lat/lon plane. The depth dependence of the field is given by the local normal mode.*

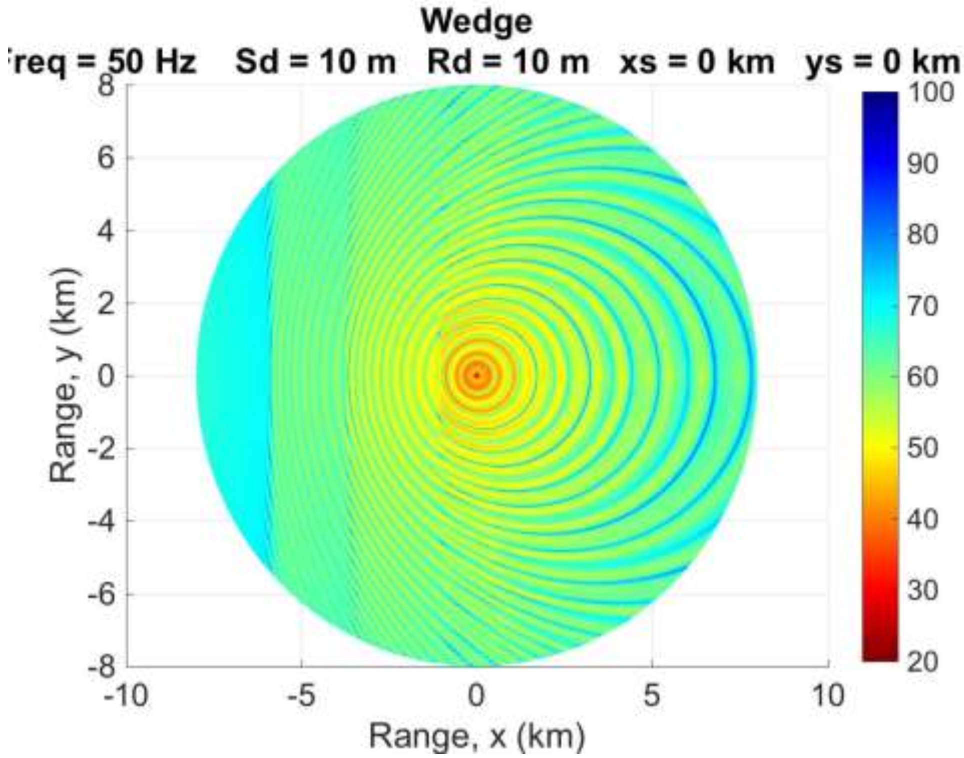

Figure 3: *The full pressure field, constructed from the sum of the beams, shows vertical bands associated with the cutoff depths of different modes.*

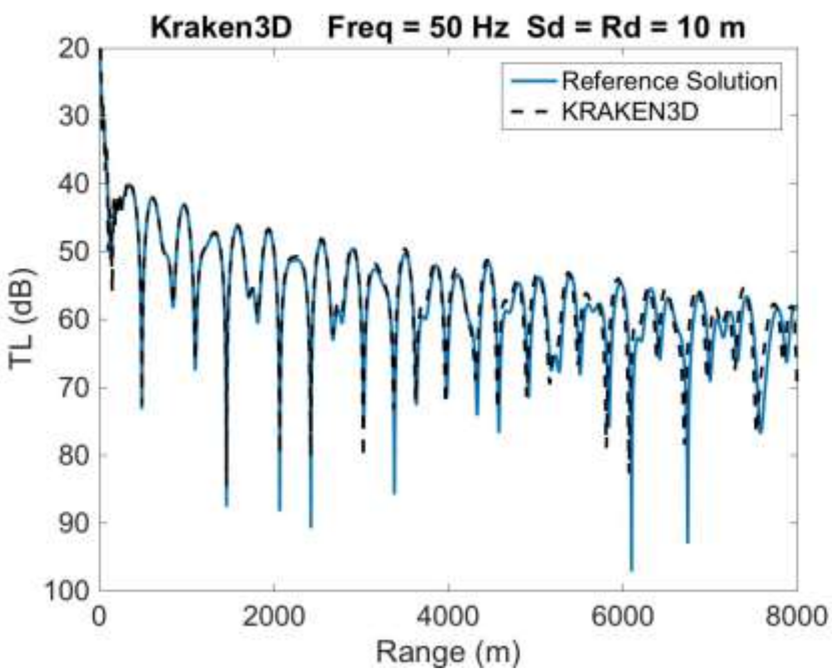

Figure 4: *A slice of the transmission loss along the line x=0 shows excellent agreement with an independent reference solution.*