.

Out-of-Plane Effects in Ocean Acoustics

Michael B. Porter
Heat, Light, and Sound Research, Inc.
3366 N. Torrey Pines Court, Suite 310
La Jolla, CA 92037
phone: (858) 457-0800   fax: (858) 228-1734   email: mikeporter@hlsresearch.com

LONG-TERM GOALS

The focus of my current research is to develop improved models of signal and noise propagation in complex, three-dimensional environments.

OBJECTIVES

In recent years tremendous progress has been made in modeling both the ocean environment and its effects on sound. Global models of the 4D (space-time) oceanography are produced both regularly and frequently. They are also readily available through FNMOC Reachback Support. In fact, rather than just a deterministic forecast, the oceanographic models routinely provide ensemble forecasts representing a 'fuzzy' ocean, i.e. a distribution of possible realizations.

Interestingly, the sound models that propagate through such fields have really not kept up. Three-dimensional propagation modeling has, of course, been a research topic of interest for many decades. However, it has never really become a mainstream activity, partly because it used to be too time-consuming, partly because the environmental information was not available.

The community has now clearly recognized that the time is right to take a step up in the modeling capability and do fully three-dimensional modeling using ensemble forecasts of the ocean structure. The goal of this research is to do exactly that, leveraging the BELLHOP3D Gaussian beam tracing code. Further enhancements will be made to BELLHOP3D; however, a particular focus will be the assessment of 3D effects in various upcoming experiments. In the last year we have focused on underwater acoustic communications as the application of interest.

APPROACH

We will be investigating other 3D approaches; however, we BELLHOP3D is the main tool for this work. BELLHOP3D is an extension of the widely used BELLHOP model which operates in either a 2D or Nx2D mode (where 3D fields are contracted from multiple bearings). and we have been prototyping the time series simulator (VirTEX) using BELLHOP. Separately we have been working with FOR3D (3D parabolic equation model), which will be used to provide independent benchmark solutions.

We are also pursuing experimental opportunities to both validate the models and clarify under what circumstances 3D effects are important. In the near term we are pursuing collaborations with the NATO Center for Marine Research and Exploration (formerly NURC). In the longer term we are making plans with respect to the ONR OA Shelfbreak/ Slope/Canyon Field Experiment.

WORK COMPLETED

Within the context of BELLHOP and BELLHOP3D, the acoustic field can be viewed as the sum of a number of echoes due to boundary interactions or refraction in the ocean waveguide. The paths associated with these echoes are the eigenrays connecting the source and receiver as illustrated in Fig. 1. The received time series is a sum of repeated copies of the source waveform with the delay implied by the travel time along the eigenray and an amplitude determined by the strength of the echo. The Matlab post-processor of BELLHOP and BELLHOP3D arrivals information is called VirTEX.

In our original VirTEX code we treated a rough, moving sea surface by running BELLHOP every fraction of a second to capture freeze frames of the ocean. A regularly sampled receiver time series was then calculated by extracting the appropriate sample from the source time series, considering the propagation path for each eigenray. This process captures properly all the physics including Doppler effects. However, because BELLHOP needs to be run repeatedly, it is computationally intensive.

The new VirTEX (Lite) developed this year uses what might be called a ray perturbation theory to estimate the changes in ray travel times due to a moving surface. Thus, the change in ray travel time for a moving surface is estimated from the vertical displacement as suggested in Fig. 2. BELLHOP needs to be run only once to get the eigenrays for the unperturbed or baseline problem, then we can delay, stretch, and contract the source time series due the the surface wave motion as illustrated in Fig. 3. We have described both VirTEX and VirTEX Lite for surface wave dynamics; however, the same process works and has been implemented for platform motion.
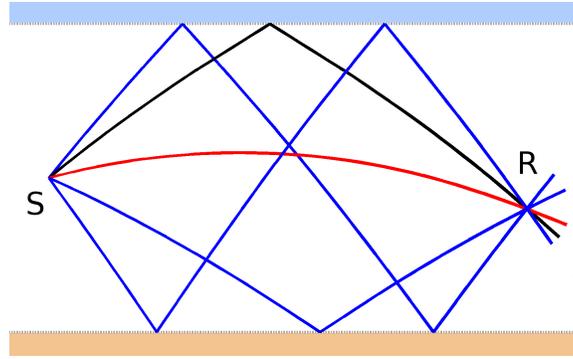
Figure 1: *Schematic of eigenrays connecting the source and receiver, including direct, bottom, and surface bounce paths and refractive effects.*
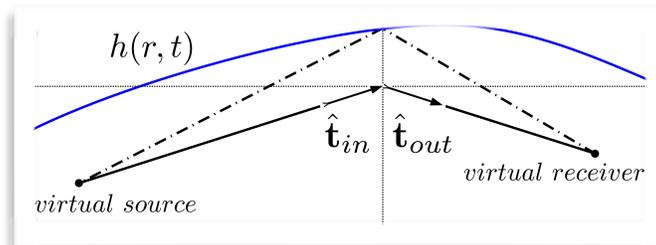

Figure 2: *Illustration of how the propagation delay along a surface-reflected eigenray is perturbed due to the surface wave motion.*
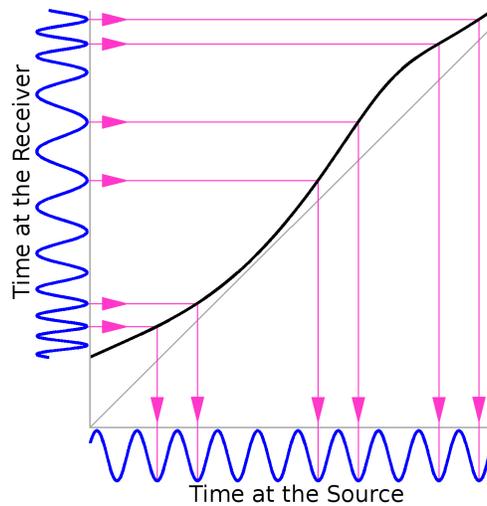

Figure 3: *Illustration of how the source time-series shown on the horizontal axis is warped using the time-varying propagation delay along an eigenray to compute the receiver time-series.*

As a test of the accuracy of VirTEX lite we simulate a Pekeris waveguide with a depth of 100 m and the air–sea interface takes the form of a gravity swell wave with a period of 8 s and amplitude of 2 m (4-m peak to trough). An m-sequence with a duration of 0.5 s is transmitted at 2-s intervals from a fixed source located at a depth of 75 m. The fixed receiver is located at 500 m in range and 50 m in depth. The predicted time series observed at the receiver were computed using VirTEX for sea-surface dynamics and the original VirTEX algorithms. The time series were then match filtered to produce the associated channel scattering functions [11], which shows in Fig. 4 the arrival in both time (horizontal axis) and Doppler (vertical axis). Results with VirTEX Lite (on the left) and the much slower VirTEX (on the right) are indistinguishable.
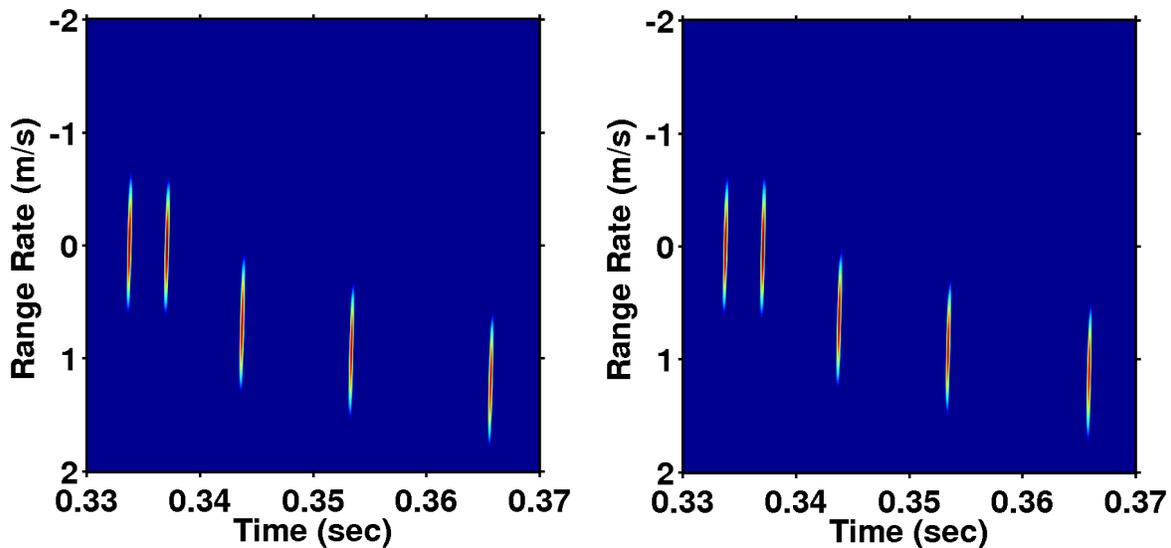

Figure 4: Plots of the 'scattering function' showing the arrival structure in both time and Doppler. The left plot is done with the new VirTEX Lite and is indistinguishable from the right plot done with the full VirTEX.

Recent work has focused on the application to time series simulation for acoustic communications. However, within the scope of this work, we have also continued maintenance of the Ocean Acoustics Library. This continues to be an important resource for the community and we've recently added a number of things including 1) HWT_3D_mm (a Huygens Wavefront Tracing in 3D for moving media from Zabotin, Godin, and Zabotina), 2) A new version of RAMSurf coded in C and vectorized (Folegot, Quiet Oceans, Inc.) 3) An updated bibliography of relevant books, 4) numerous updates to the Conferences listing.

Additional thrusts of this work are to a) examine 3D effects for noise modeling and b) develop more sophisticated approaches to modeling ocean dynamics. A particularly important application is for underwater acoustic communications and we have co-organized an Underwater Communications Conference and Workshop which proceedings in the Journal of Oceanic Engineering fully document that effort.

RESULTS

As mentioned above, the algorithm in VirTEX Lite is designed to handle both surface wave motion and platform motion. We tend to see the most dramatic effects with the latter since the Doppler effects due to platform motion tend to be stronger. As an example, we consider a deep water profile. This is shown in Fig. 5 along with the associated incoherent transmission loss in Fig. 6.

To understand modem performance we like to display 'performance maps' showing the simulated bit-error rate as a function of range and depth in the ocean waveguide. This sort of calculation is done using the actual source time series representing the modem packet. In this case, we chose to study a simple FSK modem scheme which is implemented in software. This general class of modems is used, for instance, by both Benthos and Woods Hole (micromodem). The plots in Fig. 7 show the anticipated bit-error rate for a fixed receiver (upper panel) and a moving receiver traveling a 5 m/s. We can see clearly the degradation in modem performance for the moving platform, which of course is due to the difficulty in tracking Doppler when decoding the received waveform.

This result is not intended to make a general statement about how any modem will perform in this environment. Rather it is to show how the new VirTEX Lite can be used for any modem to understand or predict its performance. Because of the speed of the new algorithm it can actually be used on a vehicle. This could potentially allow the vehicle to make real-time changes to its position so as to maximize data rates or link reliability.
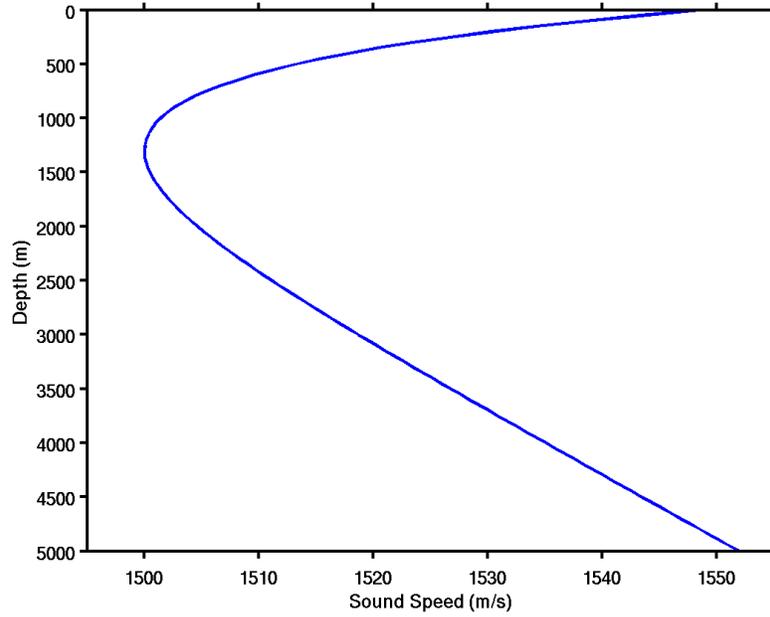
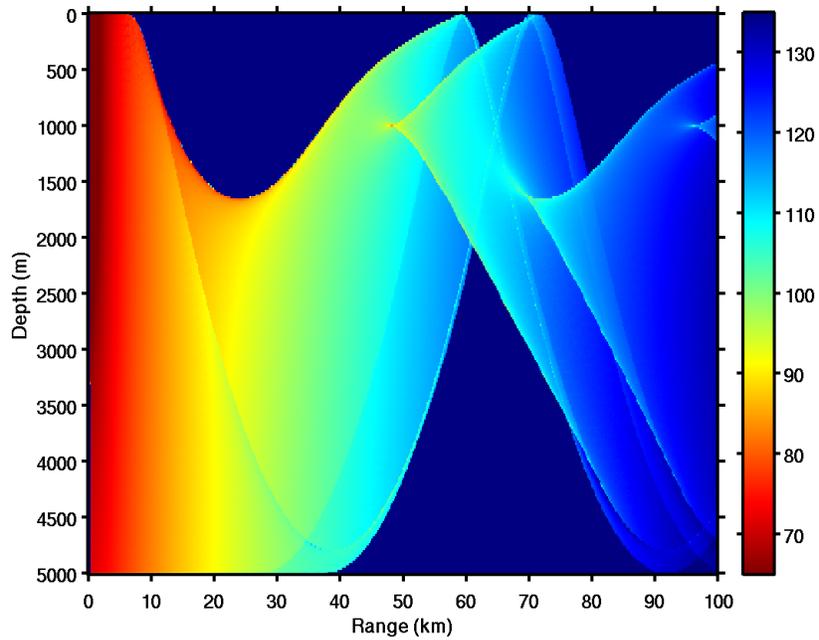*Figure 5: Soundspeed profile for the deep-water scenario.*

Figure 6: Incoherent ransmission loss for the deep-water sound speed profile with the 5-kHz source at a depth of 1000 m.
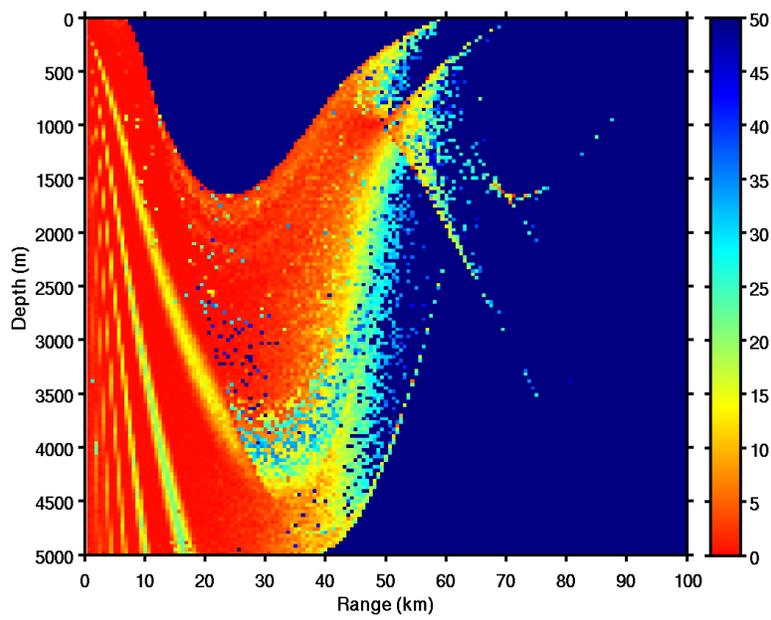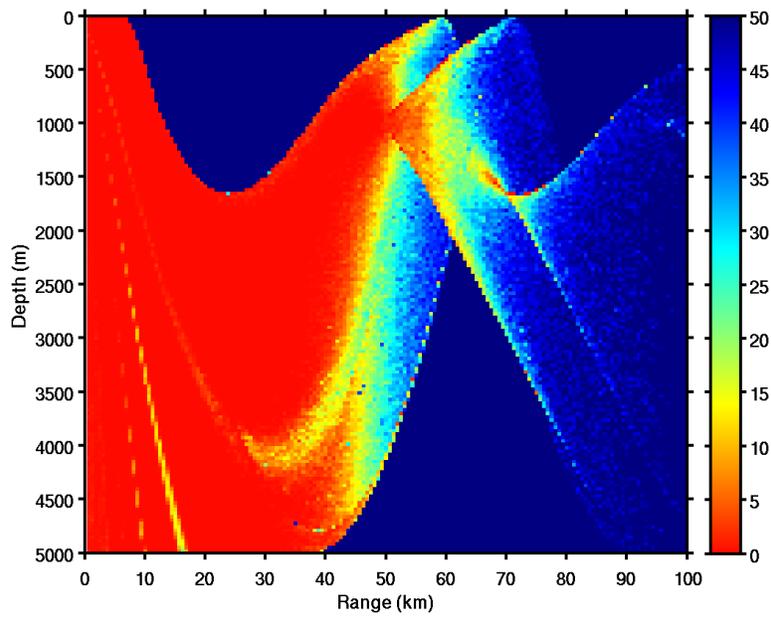
Figure 7: *Performance maps comparing of the Bit-Error Rate (in percent on the color bar) with no platform motion (top) vs. a platform moving at 5 m/s or about 10 knots.*

IMPACT/APPLICATIONS

Three-dimensional effects can be important whenever there is significant variation of the environment in latitude and longitude. Seamounts, canyons, and fjords are examples where the bathymetric variation may be important. Nonlinear internal waves are examples where the oceanography may be important. The limitations of Nx2D models have been recognized for years but we are only now at the point where we have both the environmental information to feed the acoustic models and the computational power to run them.

REFERENCES

Martin Siderius and Michael B. Porter, "Modeling broadband ocean acoustic transmissions with time-varying sea surfaces", *J. Acoust. Soc. Am.* **124:**137 - 150 (2008)

PUBLICATIONS

J. R. Potter, M. B. Porter, and J. C. Preisig, "UComms: A Conference and Workshop on Underwater Communications, Channel Modeling, and Validation," (Introductory editorial for the Special Issue), *J. Oceanic Engineering*, **38**(4): 603-613 (2013) [in press].

J.C. Peterson and M. B. Porter, "Ray/Beam Tracing for Modeling the Effects of Ocean and Platform Motion," *J. Oceanic Engineering*, **38**(4): 655-665 (2013) [in press].