Anthropogenic Noise and the Marine Environment

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Introduction: The impact of anthropogenic noise on the marine environment is a subject of increasing concern to the United States Navy. Sources of noise include ambient noise from ship traffic, acoustic sources such as air guns used in petroleum exploration, and active sonar operations conducted for military operations. The Navy has acknowledged that the use of active sonar was a contributing factor to the cetacean strandings in the Bahamas in March 2000 (see Ref. 1 for a joint report by the Navy and the National Marine Fisheries Service). The Office of Naval Research (ONR) subsequently initiated the Effects of Sound on the Marine Environment (ESME) program to address these issues, and to explore comprehensive approaches for reducing the adverse effects of anthropogenic noise on the marine environment. NRL was designated as the ESME systems integrator, and during the process developed the ESME Software Workbench.[2]

The ESME workbench, written in MATLAB™, integrates data sets and computer models contributed by the ESME team of experts in the areas of oceanography, underwater acoustic propagation, and marine mammal physiology and behavior. Complex simulations can be rapidly constructed from an underlying set of conceptual models. Models are incorporated for simulating active acoustic sources and for simulating marine mammal movements. (A simulated marine mammal will be referred to as an "animat.") Additional models are provided for estimating the received time series along an animat's track, and for predicting the animat's cumulative acoustic exposure.

Background: The ESME workbench models the complete sound path: from the sound source(s) (active sonar or other acoustic sources), through the water column and the sea floor, to the simulated receivers (animats). Table 1 lists the key contributors and institutions. Mr. Shyu was the lead developer for the ESME workbench and was responsible for integrating the software modules and models into the workbench.

The ESME workbench includes a number of predefined data sets and/or parameter options for acoustic sources, bathymetry, sound velocity profiles, ocean surface conditions, species-specific animal movement, and sediment properties. The user can provide additional or alternative data sets, such as animal distribution and habitat preferences, or diving and group behavior. Acoustic sources can be specified as repetitive waveforms with known frequency characteristics (e.g., a constant frequency source, or as a frequency-modulated ramp or "chirp"), and as either an omnidirectional source or a beamformed (i.e., directional) source with some predefined radiation pattern. Source movements can be simulated to

Table 1 — ESME Workbench Contributors

Contributor	Organization	Module	Programming Language
H.-J. Shyu D. Armoza R. Hillson	Naval Research Laboratory	ESME MATLAB workbench development and system integration	MATLAB and Visual C++
M. Porter M. Siderius	Heat, Light, and Sound Research Inc.	Acoustic propagation loss (Bellhop, Kraken), and received time series generator	FORTRAN and MATLAB
D. Mountain A. Hubbard	Boston University	Mammalian auditory system model. Requires received time series as input	MATLAB
D. Ketten	WHOI/Harvard Medical School	Parameters for the Boston University auditory model	Text
J. Miller G. Potty	University of Rhode Island	Geoacoustic and sediment models	MATLAB
J. Finneran	SPAWAR	Temporary Threshold Shift (TTS) estimation functions. Requires received time series as input	MATLAB
D. Houser	Biomimetics, Inc.	Marine mammal movement models	Visual C++
G. Gawarkiewicz C. Linder	Woods Hole Oceanographic Institution (WHOI)	Sound speed profile data	Text format

create scenarios in which ships using active sonar move along predefined paths. Several different measures of acoustic exposure are included, including two models for estimating the likelihood of the animats incurring temporary threshold shifts (TTS's), a temporary decrease in auditory sensitivity. These sound exposure values may then be used to estimate the environmental risk of a given sound usage scenario by using either user-defined thresholds of risk or metrics set by legal and regulatory agencies.

The workbench also includes a sophisticated framework for simulating the movement behavior of marine mammals. Since all marine mammals must surface to breathe, the framework includes movement models of representative diving patterns for several species of marine mammals. Diving models, for example, are minimally specified for a species by entering a set of parameters—the average depth and duration of a typical dive, for example. The movement models also allow the user to select different hypothetical response patterns to an acoustic source, including avoidance behavior.

The workbench is menu-driven, with a graphical user interface. Figure 1 shows the main menu for the workbench, including schematic representations of sonar beamforming patterns. Figure 2 shows a simulated sound field. As required by certain models (Table 1), the workbench can compute the received acoustic waveform (i.e., time series) along the animat's track. For complex simulations involving moving platforms, and long simulated periods of time (e.g., hours rather than seconds), the instantaneous or cumulative acoustic energy (dB re 1 μPa^2-s) is typically computed for reasons of computational efficiency, rather than the received time series. Figure 3 provides a graphical representation of the instantaneous and cumulative acoustic exposure for a single animat.

Conclusions: By integrating models and data sets provided by different subject matter experts, the ESME workbench provides the analyst with the ability to quickly construct and run scenarios for modeling acoustic exposure. Complex but realistic scenarios with moving platforms, beamformed acoustic sources, and multiple moving receivers (animats) can be rapidly generated. In addition, the ESME workbench provides a means for exploring the implications of alternative hypotheses—for example, by simulating different *hypothetical* behavioral response patterns to anthropogenic noise, and estimating the parametric variation in the estimated acoustic exposure. In general, we feel the workbench provides a useful approach to the problem

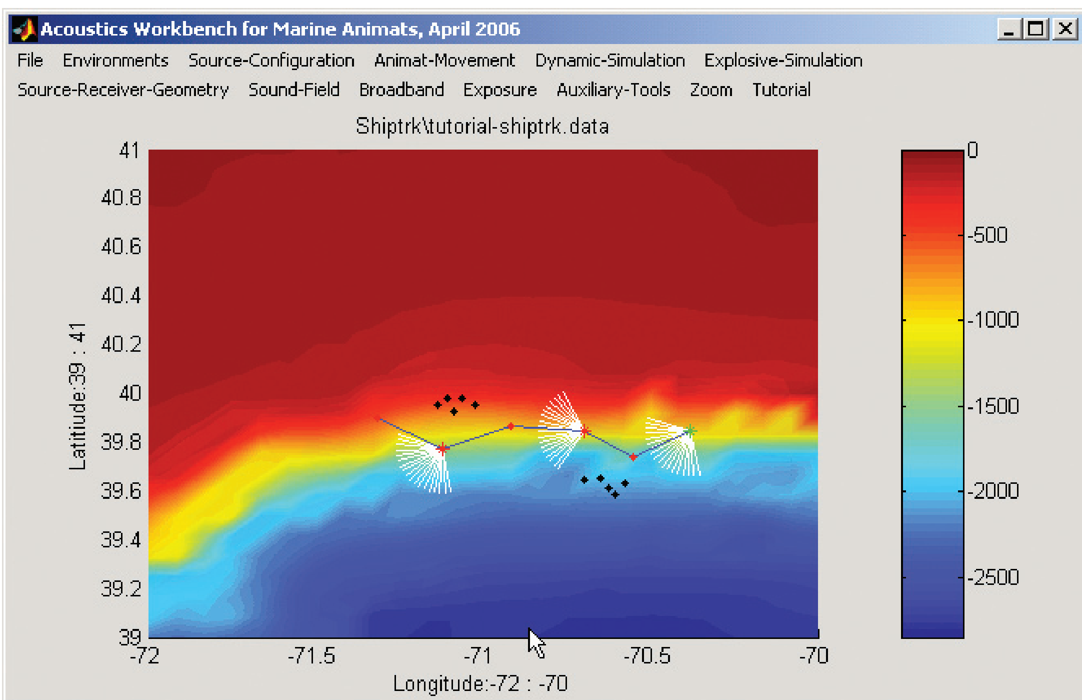

FIGURE 1
The ESME workbench main menu. The bathymetry is from the Mid-Atlantic Bight area. A simulated ship track (the blue line segments) with simulated sonar beam patterns (the white spotlights), and two pods of marine mammal animats (the 10 black dots) are shown. Resolution for the bathymetric database is 5 arc-minutes, and depth is in meters.

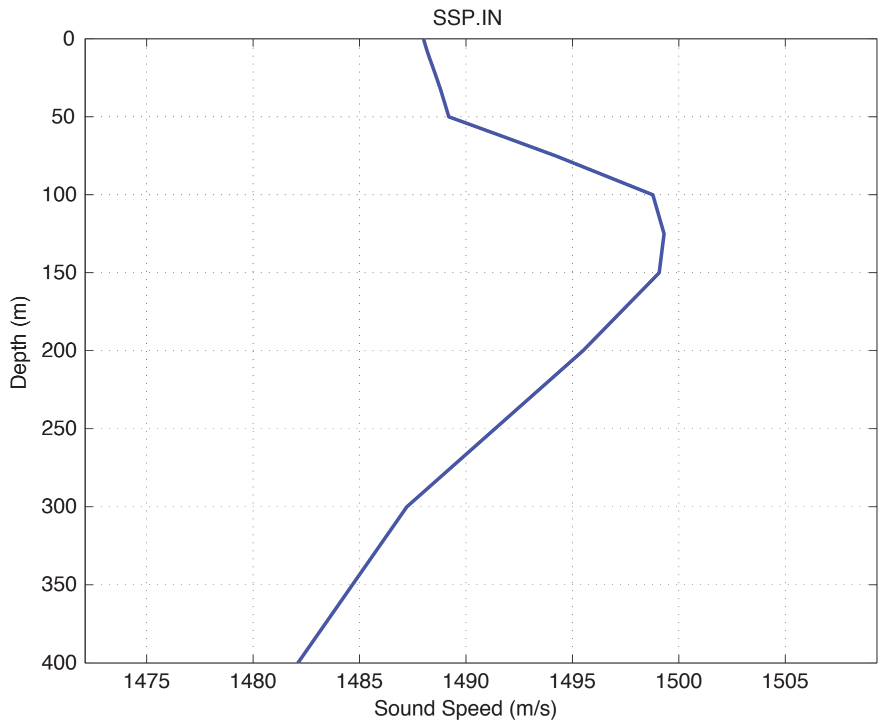

FIGURE 2(a)
Winter sound speed profile for the Mid-Atlantic Bight test site.

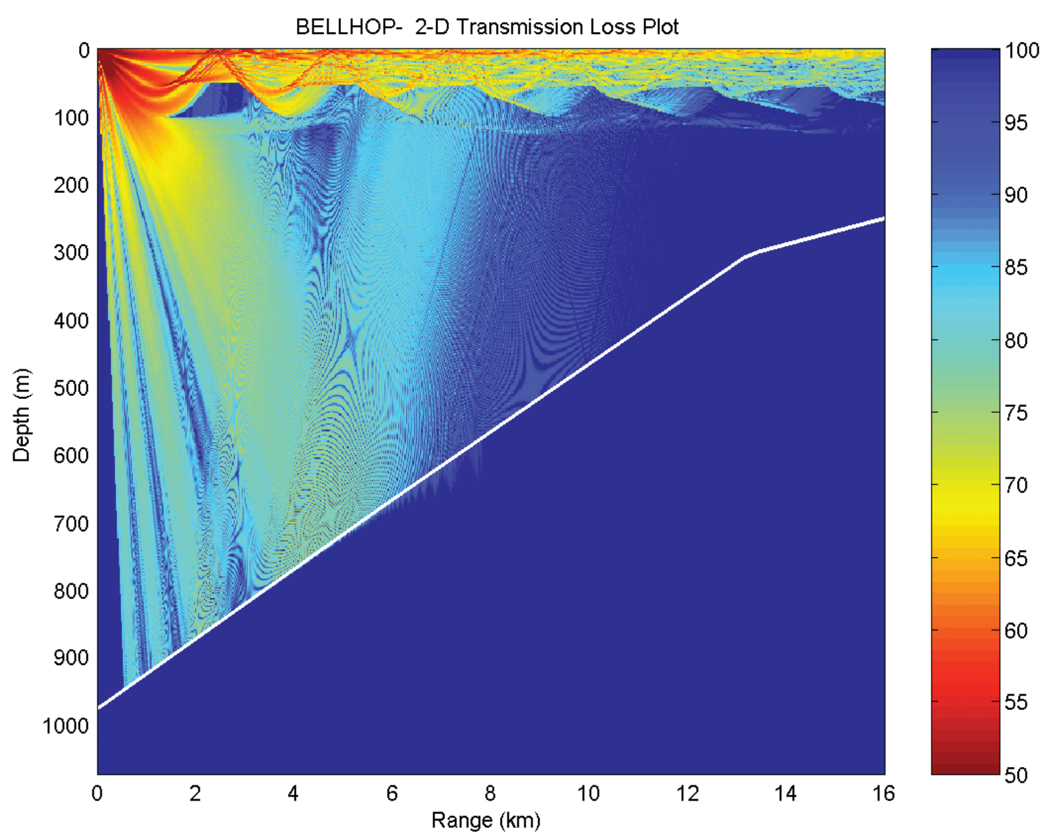

FIGURE 2(b)
A 2-d transmission loss plot generated using the sound speed profile shown in Fig. 2(a), illustrating simulated beamforming. A prominent surface duct is visible, a feature that reflects the structure of the winter sound speed profile. The scale shows the transmission loss in decibels (dB re 1 μPa^2-s). The greater the transmission loss, the lower the received sound level at a given location.

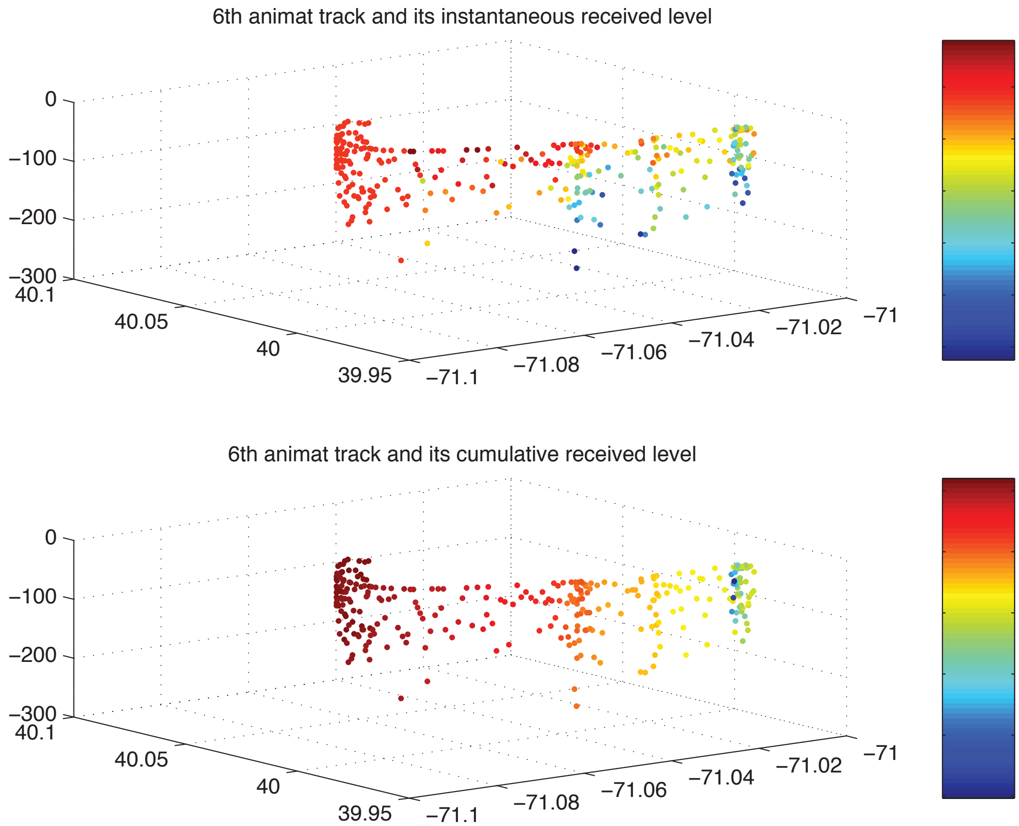

FIGURE 3
A track for a simulated marine mammal ("animat"). Latitude ranges from 26.1 to 26.35 degrees, and longitude from –77 to –78.1 degrees. The vertical axis corresponds to depth in meters. The colored dots represent the position of the animat during a sequence of dives. The ascending color scale, from blue to red, corresponds to the instantaneous received level (top) and cumulative acoustic energy exposure (bottom) in dB (re 1 μPa^2-s).

of estimating the effects of anthropogenic noise on the marine environment, given the ease and flexibility of the simulation framework and the increasing sophistication of the underlying data and models.

Simulation continues to provide a viable alternative to conducting experiments that are ethically, technically, or financially unfeasible. Continuing research in the areas of oceanography, underwater acoustic propagation, and cetacean behavior, physiology, and auditory processing will inevitably lead to improved models that enhance our ability to accurately predict the effects of sound on the marine environment.

Acknowledgments: The authors acknowledge the contributions of their ESME collaborators (cited in Table 1), and their sponsors at the Office of Naval Research, particularly Drs. Robert Gisiner and Scott Harper.

[Sponsored by ONR]

References

[1] *Joint Interim Report Bahamas Marine Mammal Stranding Event of 15-16 March 2000* at www.nmfs.noaa.gov/prot_res/overview/Interim_Bahamas_Report.pdf.

[2] H.-J. Shyu and R. Hillson, "A Software Workbench for Estimating the Effects of Sound Exposure in Marine Mammals," accepted for publication in the *IEEE J. Ocean. Eng.* (special issue on the ESME program). ★