MODELLING EXPOSURE OF MARINE MAMMALS TO UNDERWATER NOISE FROM PULSED SOURCES IN LONG-DURATION SURVEYS

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1 Introduction

The current rate of geological and geophysical ocean exploration conducted through seismic surveys has brought about increased concern for marine species near such operations. Seismic surveys typically use sources capable of producing loud impulse sounds, and the surveys may run for weeks and cover hundreds of kilometers of acquisition track. Determining their potential effects on marine mammals requires an estimate of the sound levels to which those animals are exposed over prolonged periods. Approaches based on specific thresholds for instantaneous received levels have been commonly used, but more recent thinking has focused on cumulative exposure levels to provide accurate evaluation of the acoustic impact on marine mammal populations.

JASCO Applied Sciences has been involved in acoustic measurement and modelling for many years, and has built up an extensive set of source signatures and source modelling tools. JASCO has also developed and made use of acoustic wave propagation models and post-processing methods that have allowed us to provide accurate estimates of the acoustic field around a source. To estimate the impact of sound on a population of marine mammals, however, requires information on the probability of animals being exposed over time to given levels within the sound field. Such data can be obtained by combining the modelled acoustic field with animal movement patterns; in other words, departing from a static paradigm and considering the dynamic system of moving animals and moving sources. This approach entails a large amount of input data and considerable computer processing requirements.

The Effects of Sound on the Marine Environment (ESME) modelling package developed by the Office of Naval Research (ONR) and Boston University [1], is an open-source software that can be used to model the dynamic system of moving animals and sound sources. ESME integrates databases of acoustic environmental parameters, the Marine Mammal Movement and Behavior (3MB) model developed by Houser [2], and basic acoustic propagation tools (RAM-C, BELLHOP), within the structure of a graphical user interface (GUI). Our group began working with ESME as the operational framework for estimating sound exposure in a dynamic environment.

After initial alterations to the ESME code to incorporate JASCO's acoustic modelling tools for the estimation of the sound field, we were able to use ESME for small scale modelling projects. The biggest drawback of ESME, however, was performance. A 7-day modelling scenario with ~3000 simulated animals would take about 60 hours of computer time to execute. A project involving complex exposure scenarios played out over weeks or months would be prohibitive with ESME. We undertook therefore the development of a faster and more flexible system for combining simulated animal movement and acoustic fields.

2 Results

2.1 JEMS

The JASCO Exposure Modelling System (JEMS) was developed in the IDL programing language (Exelis, Herndon, VA) and, unlike ESME, uses a parallelized approach that allows independent processing blocks to execute on different machines. Each block has its own input and output and the interaction between blocks occurs through standardized interchange files. Specific project requirements are easily satisfied through the selection of processing blocks, including the seamless integration into JEMS of different modelling tools from JASCO's library.

The major inputs to JEMS are:

- acoustic field data,
- source pattern data, and
- animal movement data.

Execution of a processing block results in an output file that may be reused within or across different projects. Because each block runs separately, unit-level quality control procedures can be implemented by testing and verifying blocks before making them available for use.

2.2 Inputs

Acoustic data

The per-pulse acoustic field is modelled at selected locations (acoustic sampling points) within the exposure modelling area and passed to JEMS as a standard N × 2-D grid, where N is the number of radials modelled in a range-depth plane. The number of sampling points and their location are selected based on variation in the propagation environment (e.g., bathymetry and geoacoustic parameters) within the modelling region. Multiple acoustic data files can be included in a JEMS run to represent different sources, the same source at different locations, or different descriptions of a field (various metrics such as SEL, peak SPL, rms SPL, and frequency filtering in species-specific auditory bands).

Source pattern data

The pattern of the source movement is passed to JEMS in a table of coordinates indexed by time. Sources used for seismic exploration are often towed behind a vessel, so their geo-referenced sound field changes over time as the source moves. Additional indices can be used to specify the acoustic field dataset to be used at each source location to reflect changing propagation conditions. JEMS includes a collection of scripts to produce specific track patterns commonly used in seismic surveys, such as “snake track”, “race track”, spiral, and coil. Arbitrary shot patterns can be defined, or shot points can be based on a time interval or spatial reference including water depth or azimuthal location. Stationary sources are defined using constants for the location coordinates. No limit is placed on the number of sources or patterns used in a JEMS run.

Animal movement data

JEMS can use animal movement data from models such as the Marine Mammal Movement and Behavior (3MB) model [2]. 3MB simulates realistic, species-specific movement of individual animal “agents”, called animats. Individual animat tracks are logged by 3MB in a binary file as a triplet of coordinates (latitude, longitude, depth) and a specified time step. The size of the movement data files may reach several gigabytes for long simulation periods, but pre-loading of the file is not required. JEMS maintains a file pointer based on the time step to gain random access into the animal movement data file and extract the movement data needed at each time step.

2.3 Exposure modelling process

Source pattern data files are first loaded into memory along with the per-pulse acoustic field data. The process of exposure modelling is to step through the source data and load animal positions for the current time step. The received exposure level of every animat is logged for each time step, and the values are written into the exposure output file along with auxiliary information such as the source ID and coordinates, the coordinates of the animat, and the slant and horizontal ranges of the animat to the source.

2.4 Post-processing

The usefulness of this form of acoustic modelling is in determining the exposure probability function of a population of animals from which to estimate the potential impact. When many animats moving realistically are used to sample the sound fields of a survey, the probability of exposure for a real-world distribution of animals can be built up from the estimated received levels. In the post-processing stage, the exposure modelling output is analyzed to obtain datasets of acoustic metrics such as cumulative and maximum exposure for each animat, and fraction of animats exposed above specific thresholds.

3 Discussion

ESME is open-source code and can be freely modified, though revisions and additions of new features require the involvement of an experienced programmer and the use of specialized programming tools. ESME’s built-in databases simplify the setting up of scenarios, but make including data from other sources a cumbersome process.

JEMS’ design is based on a decentralized and modular approach. Ultimately, JEMS is a flexible infrastructure for convolving simulated animal movement data with simulated sound fields (from moving sources).

Advantages of the JEMS approach:

- processing speed;
- ease and flexibility to accommodate wide-ranging project requirements and incorporate various data types, such as new sources or motion patterns;
- natural entry points to perform quality control of all inputs using internal and external means;
- ability to reuse inputs that remain unchanged in subsequent scenarios;
- modelling scenarios set up through configuration files, making it easy to replicate scenarios or batch process multiple scenarios.

Shortfalls of JEMS still requiring development work, currently ongoing:

- can use only one CPU core per processing block (multiple instances of the code, however, can be executed on one machine if it is equipped with multiple cores);
- no feedback interaction with animal movement model, precluding simulation of aversion;
- no GUI interface.

4 Conclusion

The modularized approach used by JEMS allows greater flexibility in the implementation of new features and functionality. Changes to one component of the exposure modelling system do not require changes to the other components, as long as the same standard format is used to pass the data to the subsequent step. The input datasets required for the exposure modelling can be generated independently and in parallel on multiple computers. For subsequent scenario runs the input datasets that do not require changes can be reused without recalculation. With more than a 100 fold performance improvement over ESME, the approach is seen as more suitable for projects with a large number of exposure scenarios.

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References

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