

# MODELLING AND MONITORING TECHNIQUES IN AMBIENT NOISE MANAGEMENT

Roberto Racca JASCO Applied Sciences (Canada), Victoria, British Columbia, Canada  
Christine Erbe JASCO Applied Sciences (Australia), Brisbane, Queensland, Australia  
Robin Burns JASCO Applied Sciences (UK), Droxford, Hampshire, UK

## 1 INTRODUCTION

When large-scale industrial operations are staged in proximity of sensitive natural habitats, it is imperative that the contributions of anthropogenic sound to the overall underwater ambient noise budget be characterized as accurately as possible so that appropriate management measures may be designed and put into practice for the safeguard of the species potentially at risk. Advanced numerical modelling of the aggregate acoustic footprint from multiple sources distributed over an area, as well as the cumulative influence of operations extending over time, does provide a predictive tool that enables noise management considerations to be applied at the planning stage. Examples of this approach include the acoustic modelling of alternative operational scenarios in the planning of offshore construction, so as to stage activities for least aggregate influence, and the forecasting of the cumulative noise footprint from a seismic survey to delineate areas of potential biological impact. A germane requirement to the model-based forecasting is the monitoring of the pre-activity ambient noise landscape and of the combined natural and anthropogenic sound field during industrial work. Such monitoring, which should be spatially and temporally extensive, serves the twin purposes of validating the assumptions and parametric conditions used in the predictive modelling and of providing spot reference measurements to ground truth and calibrate the estimated acoustic fields. An example of this type of monitoring is the basin-scale instrumentation of a sizable region of the arctic shelf seafloor with high-performance autonomous acoustic recorders capable of acquiring several months of digitized sound pressure data at rates adequate for characterization and analysis of natural noise, marine mammal vocalizations, and anthropogenic noise. The examples just outlined will be explored in some detail in this summary paper.

## 2 MODELLING AS A NOISE MANAGEMENT TOOL

### 2.1 Planning of an Offshore Pipeline

A multi-year construction program for the Sakhalin II project in the Russian Far East was planned and conducted according to principles of anthropogenic noise mitigation tailored to minimize exposure of the whales to levels considered disruptive to foraging and calf rearing. Prior to the route dredging and laying of a pipeline connecting two offshore platforms to Sakhalin Island different staging options were evaluated to minimize estimated noise footprints. For each phase of the planned construction, the aggregate underwater noise levels from the vessels to be involved in the operations were pre-assessed through modelling to ensure they would not exceed acceptable limits for the whale population feeding along shore. The modelling involved the storyboarding of construction scenarios in which numerous vessels would operate in large "spreads" (clusters) at various locations along the pipeline route. The construction season was then temporally subdivided into broad activity phases corresponding to a static distribution of spreads at given stations, based on the temporal-geographical progression of pipeline construction. The sound propagating from each individual source in a scenario was modelled to yield an aggregate footprint for that phase of construction. An advanced acoustic propagation modelling software, JASCO's Marine Operations Noise Model (MONM), was used to estimate the noise footprints of individual vessels in each

construction scenario, which were then added to produce aggregate noise level maps. MONM is a proprietary implementation of the widely used Parabolic Equation code RAM<sup>1</sup>, modified to account for shear-wave losses at the seabed – an important consideration in the shallow water, absorptive bottom environment on the Sakhalin shelf. MONM uses a complex density method to implement the shear-wave energy conversion in a significantly faster computational manner than other approaches. MONM has been used for a variety of environments and extensively validated against measurements. For each individual noise source in a scenario, MONM estimated frequency-specific transmission loss (TL) in third-octave bands along a fan of radials from the source location – also accounting for the depth of the principal sound emitters, usually the propellers or thrusters for a vessel. Combined with the measured source levels in the same bands, these yielded radial footprints of frequency-specific received levels that were then summed to give broadband levels. Finally, the radial footprints of all sources in a scenario were recast onto a common geo-referenced grid and summed into an aggregate noise level map for a given phase of an operation. Figure 1 shows a sample modelled noise level map of concurrent dredging and pipe-laying operations in the southern part of the pipeline, on the landfall segment. Only the principal vessels are labelled; additional vessels (such as barge support tugs) were in fact modelled to generate this map.

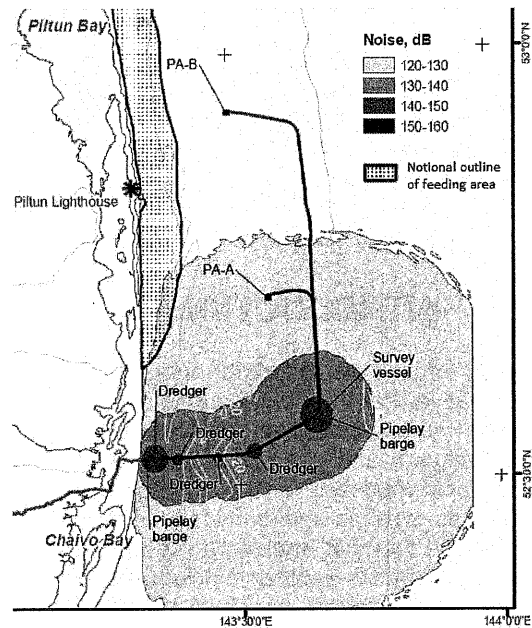


Figure 1: Modelled acoustic footprint of a representative pipeline construction phase.

## 2.2 Estimation of Cumulative Footprint of a Seismic Survey

A 2D marine seismic survey was to be conducted over a shallow-depth island reef system on a steeply sloping area of continental shelf. In the center of the site lay a coral reef growing on limestone bedrock, about 5 m below the water surface at high tide. The proposed seismic survey encompassed six transects with a combined length of about 120 km, at a shot spacing of 25 m. The towed source array would consist of ten identical generator-injector (GI) airguns arranged in two lines. Extensive pre-survey modelling was used to estimate the cumulative acoustic exposure footprint near the seafloor, which may be an especially relevant measure of potential impact for a coral reef ecosystem because of the tendency of guest species not to flee upon perception of danger or to avoid elevated noise levels. The sound radiation directivity pattern of the source was estimated using JASCO's Airgun Array Source Model, AASM<sup>2</sup>. This full-waveform airgun array signature model is based on the physics of the oscillation and acoustic radiation of airgun bubbles. It solves a set of parallel differential equations that govern the airgun bubble oscillations and accounts for additional physical effects, including pressure interactions between airguns, port throttling, and bubble damping. The output of the model is a set of notional source signatures, corresponding to the individual airgun signals. These are then used to compute the directional levels of the array in the frequency domain by applying the appropriate phase delay to each notional source and summing the far-field contributions. As in the previous example, the propagation modelling was carried out in third-octave bands (between 10 Hz and 2 kHz) using the Parabolic Equation code RAM in its enhanced MONM implementation. A special challenge typical of this kind of modelling study, however, was posed by the large number of propagation transects between the shot points and a grid of receiver positions extending over the full area of interest, 20 km per side. Even down-sampling by a factor of ~30 the shot points (and later compensating by commensurate scaling of the summed energy levels), well over 20,000 shot-receiver pairs would have had to be modelled at a heavy computational cost. A powerful simplification<sup>3</sup> was introduced by using a neural

network approach to aggregate bottom depth profiles for all the shot-receiver traverses into clusters of similarly-shaped bathymetries, each represented by a median or central profile. The set of representative profiles was thus reduced to 64, and the sound propagation along each of these was modelled to yield matrices of transmission loss (TL) as a function of range and depth for each of the frequency bands. To evaluate received levels from a given shot point, each shot-receiver traverse was matched to its most representative profile by the same neural network approach. The source level of the array in the direction of the current traverse was obtained from the array orientation and the directivity pattern; combined with the TL for the representative profile this yielded the received per-pulse sound exposure level (SEL) energy metric per frequency band. The acoustic energy was then added over all frequencies to obtain the broadband per-pulse SEL for all shot-receiver pairs. The sum of this metric at a given receiver point over all shot locations in the survey yielded cumulative SEL. The sound exposure map at the seafloor is illustrated in Figure 2.

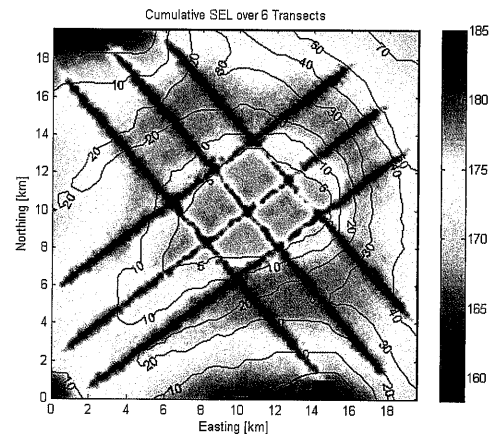


Figure 2: Cumulative SEL (dB re 1  $\mu\text{Pa}^2\text{-s}$ ) from the entire seismic survey, plotted at the seafloor.

### 3 MONITORING OF AMBIENT NOISE LANDSCAPE

The Arctic Ocean environment to the north of the North American continental landmass is host to a large number of species, some of them endangered, which live in a delicate seasonal balance regulated by the yearly cycle of sea ice covering and open water periods. Human activity, mostly linked to exploration for hydrocarbon resources, has been affecting noticeably the ambient noise landscape in regions like the Chukchi Sea off Alaska during the active summer season. A comprehensive and recurrent documentation of both the spatial extent of anthropogenic noise and the distribution, timing and characteristics of marine mammal vocalizations is a key to successful protection of the ecosystem components of the region through minimization of areas and periods of potentially noxious interaction. For the past five years an ambitious programme of acoustic monitoring has been taking place in these forbidding waters with an unparalleled spatial and temporal scope, which includes both a dense grid of autonomous recorders during the open water season (Figure 3) and a smaller deployment of instruments for overwinter recording of the ambient sound landscape and marine life vocalizations. This monitoring effort is coupled to an extensive off-line automated analysis of the acoustic records for identification of species and activities.

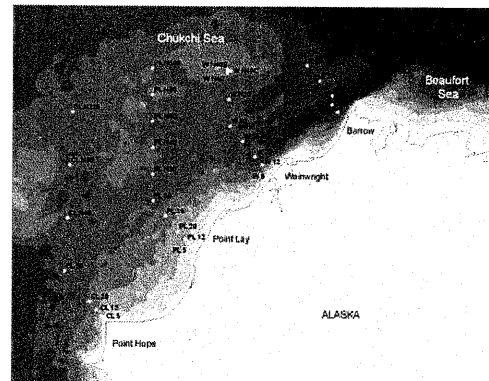


Figure 3: Subsea recorder deployment sites during the 2008 open water season.

### 4 REFERENCES

1. M. D. Collins. A split-step Padé solution for the parabolic equation method. *J. Acoust. Soc. Am.* 93: 1736-1742 (1993).
2. A. O. MacGillivray. *Acoustic Modelling Study of Seismic Airgun Noise in Queen Charlotte Basin*. M.Sc. Thesis. University of Victoria, Victoria, BC (2006).
3. C. Erbe and A. R. King. Modeling cumulative sound exposure around marine seismic surveys. *J. Acoust. Soc. Am.* 125: 2443-2451 (2009).