ACOUSTIC TRANSMISSION LOSS MEASUREMENTS IN QUEEN CHARLOTTE BASIN

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ABSTRACT

A transmission loss experiment was carried out during the winter in south Hecate Strait using a small airgun array source. Airgun pulses were recorded at horizontal receiver ranges between 20 m and 10 km using a bottom-mounted hydrophone recorder. Transmission loss values were computed by subtracting measured source levels from received sound levels in 1/3-octave bands. Transmission loss data were compared to predictions from a parabolic-equation (PE) sound propagation model coupled with an airgun array source level model. The measured transmission loss was characteristic of cylindrical spreading, with very little additional loss attributable to non-geometric terms. Mid-frequency (100-400 Hz) sound propagation was found to be best supported by the environment. The PE model predictions showed good agreement with the experimental data.

RÉSUMÉ

Une expérience ayant pour but de calculer les pertes de transmission acoustique a été menée au cours de l'hiver dans le sud du Détroit d'Hecate à l'aide d'un petit réseau de canons à air. Les impulsions des canons ont été mesurées par des enregistreurs posés sur le fond marin à des distances horizontales allant de 20 m à 10 km. Les valeurs de perte de transmission ont été calculées en soustrayant les niveaux sonores mesurés à la source de ceux reçus aux enregistreurs (niveaux exprimés en tiers d'octaves). Les résultats de perte de transmission obtenus ont été comparés aux prédictions d'un modèle de propagation du son utilisant l'équation parabolique. Les pertes de transmission mesurées étaient caractéristiques d'une propagation cylindrique avec une très faible contribution de termes supplémentaires non-géométriques. Il a également été trouvé que l'environnement facilitait la propagation du son en moyennes fréquences (100-400 Hz). Les prédictions issues du modèle d'équation parabolique concordaient avec les résultats expérimentaux.

1. INTRODUCTION

There is currently a moratorium on offshore oil and gas development in British Columbia, due to the environmental concerns associated with hydrocarbon exploration and extraction. In 2004, the Royal Society of Canada prepared a report [1] identifying knowledge gaps in science related to oil and gas development in the BC offshore. The impact of man-made noise on marine mammals and fish was identified as one key area of concern associated with offshore exploration activities. Underwater sound generated by seismic airgun surveys has the potential to negatively impact marine mammals and fish in the surrounding environment [2]. The need to further investigate the potential impacts of noise associated with seismic surveying was identified as a significant knowledge gap in the Royal Society report.

Assessing the potential impact of seismic exploration on marine mammals and fish requires estimates of the acoustic footprint of airgun survey activities. Acoustic propagation models—particularly those based on the parabolic-equation (PE) method—can be used to estimate the noise footprint of seismic surveys [3]. The accuracy of numerical models is limited, however, by environmental uncertainty. Required model inputs include the defining properties of the water column and ocean bottom that impact the sound transmission characteristics of the environment (bathymetry, sound speed profile, geoacoustics, etc.). When available, field measurements can be used to characterize the acoustic properties of specific environments helping to calibrate model inputs and serving as a means to validate model estimates.

This paper presents results of an airgun transmission loss study that was carried out in Hecate Strait in December 2006 to characterize airgun sound transmission in the BC offshore and to assess the accuracy of PE model estimates for this environment [3]. The goals of the study are as follows:

1. To measure source and received levels for airgun pulses at various source-receiver separations.
2. Determine the characteristic transmission loss in the environment from the airgun measurements.
3. Examine the sound transmission characteristics at the location as a function of sound frequency.

2. METHODS

2.1 Transmission Loss Experiment

The transmission loss experiment was carried out in Hecate Strait on 4 December 2006 at a location near a number of historical oil and gas exploration well sites (Figure 1). A small airgun array source was towed behind the study vessel (Silver Dawn I) along a transect that provided received level measurements at various source-receiver separation distances. An ocean bottom hydrophone (OBH) recorder system was used to collect transmission loss data as the vessel traversed the track.

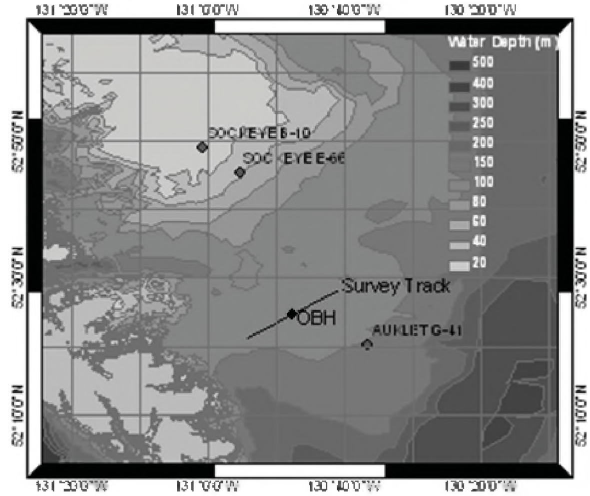

Figure 1. Map of study area showing OBH position (diamond) and survey track (line). Locations of historical oil and gas exploration wells are also indicated.

The towed acoustic source was a 30 in^3 airgun array consisting of two airguns (10 in^3 and 20 in^3) mounted side by side on a custom built frame, separated horizontally by 1 m. The array was towed at a depth of 4 m and the depth was monitored using an underwater depth sensor (JASCO AIM 2000). A calibrated reference hydrophone (Reson TC4034 with nominal sensitivity -218 dB re 1 V/µPa) mounted 1 m in front of the airgun array provided source level measurements. The signal from the source hydrophone was recorded at 25 kHz using a 16-bit laptop-based acquisition system (Quatech DAQP-16). This airgun array was much smaller than a typical industry array; however, the experiment was not intended to mimic a production seismic survey, but rather to characterize the sound transmission of a source signal characteristic of airgun pulses.

Acoustic data were collected using an OBH recorder system that was deployed on the seafloor (114 m depth). The system was mounted with a calibrated Reson TC4043 hydrophone (nominal sensitivity of -201 dB re V/µPa). A Sound Devices 722 24-bit digital hard-drive recorder inside the OBH pressure housing recorded data at 32 kHz during the experiment while the source vessel sailed along the a track that passed directly over the recorder. The source vessel travelled from southwest to northeast along one track, 20 km in length, providing measurements of airgun signals at horizontal ranges between 20 m and 10 km range to each side of the OBH. A dedicated marine mammal observer was on board the source vessel throughout the study. There were no marine mammal sightings reported while the airguns were active.

A CTD (conductivity-temperature-depth) cast was performed at the OBH location prior to the transmission loss experiment, using a Seabird SBE-19 profiler. Temperature and salinity measurements were used to derive the sound speed profile in the water column as a function of depth (Figure 2). The sound speed profile was an upward refracting profile, typical for this environment in winter conditions [4].

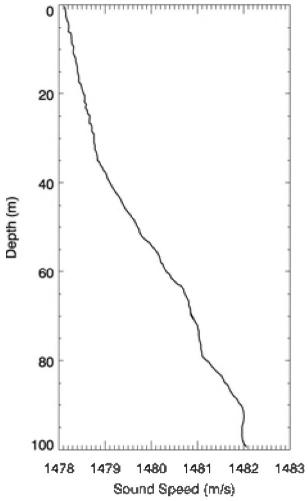

Figure 2. Sound speed profile at OBH location as computed from CTD cast data.

2.2 Data Processing

Acoustic data were processed using customized analysis software to obtain peak and rms sound pressure level (SPL) in dB re 1 µPa and sound exposure level (SEL) dB re 1 µPa^2·s for each airgun pulse. The source-receiver separation for each pulse was computed by matching the shot times with the vessel GPS navigation logs. Each pulse was transformed to the frequency domain to obtain the energy density spectrum (µPa^2·s) in 1-Hz bins. The spectrum was integrated inside standard 1/3-octave bands from 10 Hz to 2 kHz to obtain 1/3-octave band SEL values for each airgun pulse. Transmission loss versus range (in decibels) was computed by subtracting the SEL received at the OBH from that received at the 1 m reference range for each pulse.

The received sound level at distance r from an underwater sound source can be approximated by a simple transmission loss equation expressed in decibels that incorporates geometrical spreading, reflections from the surface and seafloor, and attenuation within the water column and sea bed as follows [5]:

$$RL = SL - n \log r - \alpha r. \qquad (1)$$

In Equation (1), *RL* is the received sound level, *SL* is the source level (referenced to 1 metre), *n* is a geometric spreading constant, *r* is the source-receiver separation in meters, and α is a general attenuation coefficient. The last two terms in Equation (1) describe the transmission loss. The geometric spreading term has a value of 10 for conditions of cylindrical spreading and a value of 20 for spherical spreading.

Transmission loss estimates as a function of range were computed directly by subtracting the measured received levels from measured source levels.

2.3 Acoustic Modelling

Acoustic transmission loss was modelled using the RAM split-step Pade PE code, version 1.5g [6]. RAM was configured to estimate transmission loss along the experimental track in a reciprocal sense, meaning that for the purposes of the modelling, the source was placed at the seafloor and the receiver was modeled at the true source depth. The reciprocity principle of acoustics permits this transposition [7].

The transmission loss model required a description of the bathymetry, sound speed profile, and geoacoustics along the survey track. Bathymetry data were interpolated from a high-resolution (100 m) dataset provided by the Canadian Hydrographic Service (Figure 3). The sound speed profile in water was computed from the CTD profiler data. Based on surficial geology maps published by the Geological Survey of Canada, the seabed type at the study location was estimated to be sand and gravel [8]. Seabed geoacoustic properties for this bottom type (sound speed, density and attenuation versus depth) were based on profiles derived from a prior modelling study of sound propagation in Hecate Strait [3, Tab. 4.4].

Airgun source levels used for the model-data comparisons were computed using JASCO's calibrated airgun array source model (AASM) that estimates directional sound levels based on the volume, depth, and position of the individual airguns in an array [3].

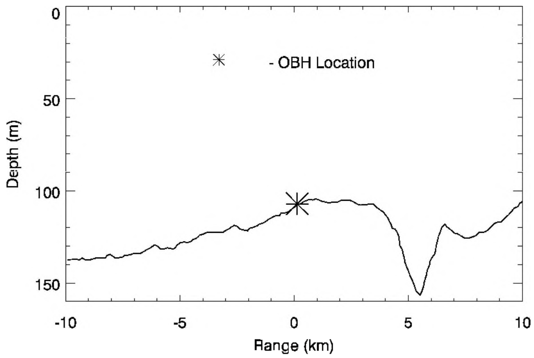

Figure 3. Bathymetry along experiment track. OBH recorder was deployed on the seabed at zero range, as indicated by the star symbol.

Modelled sound levels (SEL) were computed by combining source level estimates with computed 1/3-octave band transmission loss for each source-receiver pair. Broadband sound levels were computed by summing together the modelled 1/3-octave band levels.

5 RESULTS AND DISCUSSION

5.1 Airgun Source Levels

Source levels for the experiment were computed from the data received on the source hydrophone mounted on the airgun frame. Each individual airgun pulse was analyzed and the mean sound level over all shots was used to estimate the source characteristics (Table 1). The standard deviations show that the source level of the array was very consistent throughout the study. Using 1 second time windows, average 1/3-octave band source levels (dB re 1 µPa @ 1 m) were also computed for the airgun array (Figure 4). The dominant 1/3-octave band was observed to be at 20 Hz.

Table 1. Mean sound level of the 30 in^3 airgun array (± 1 standard deviation) as computed from the airgun pulses recorded at 1 m range.

Peak SPL (dB re 1 µPa @ 1 m)	rms SPL (dB re 1 µPa @ 1 m)	SEL (dB re 1 µPa^2·s @ 1 m)
231.5 ± 1.2	214.5 ± 0.7	206.1 ± 0.7

5.2 Transmission Loss Measurements

Transmission loss values were computed from the measured data in 1/3-octave bands from 20 Hz to 5 kHz (Figure 5). The data show that 1/3-octave bands with centre frequencies between 315–500 Hz exhibited the least transmission loss. The relatively high optimum frequency band for the transmission loss suggests that the bottom supports efficient shear wave propagation that increases the loss at low frequencies (< ~ 200 Hz) [9].

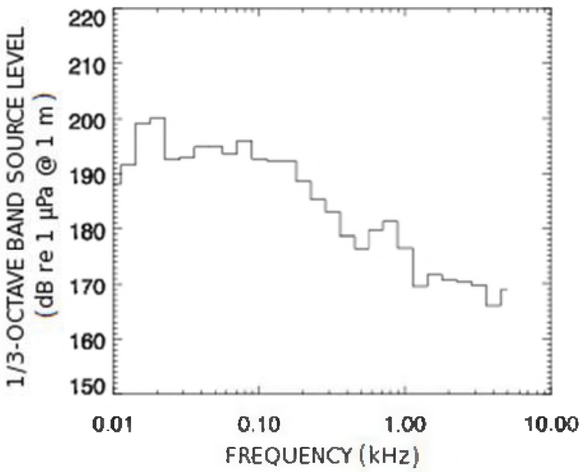

Figure 4. Mean 1/3-octave band source levels for the 30 in^3 airgun array.

The highest frequency bands (>1 kHz) showed the greatest loss at ranges less than approximately 3 km, beyond which the greatest loss was observed in the very low frequency bands (below approximately 100 Hz for the departure and below 50 Hz for the approach). Even though the propagation of low frequencies was not well supported in this environment, these bands contributed strongly to the received levels, since the source contained significant energy in these bands.

The empirical transmission loss equation (1) was separately fit to the transmission loss curves for 0.1 and 5 kHz, to derive the best least-squares fit for each band (Table 2). The spreading coefficient, n, was similar across the bands and the main difference arose in the α term, with the 2-5 kHz bands being well approximated by geometric spreading. The broadband transmission loss trend best matched the loss exhibited by the dominant 100–315 Hz bands.

Table 2. Least-squares coefficients for third-octave bands centred at 0.1 and 5 kHz.

Track		0.1 kHz	5 kHz
	SL	179	142
Approach	n	13.4	13
	α	0.001	0
	SL	175	143
Departure	n	10.8	11.7
	α	0.003	0

5.3 Model Data Comparison

Figure 6 presents a comparison of 1/3-octave band levels versus range, as predicted by the PE model, to data measured along the approach track. The overall features are in excellent agreement between the model and the hydrophone data. Both the model and the data indicate dominance of the mid-frequency components at long ranges. The model predicted slightly higher received levels in the 0.5–1 kHz range than was measured in the experiment. Along the departure track (not shown) the model data agreement was also good for most frequencies, however excess long range attenuation at 10-40 Hz was not reproduced by the PE model.

Comparison of the broadband received levels (Figure 7) showed the data and model were in good agreement along the approach track to the OBH location. The model-data agreement was also very good for the departure track until approximately 5 km range, beyond which the measured data exhibited stronger transmission loss than predicted by the model. This may have been due to potential three-dimensional effects from the bathymetry, as the sound traveled cross-slope, that the two-dimensional transmission loss model did not account for. This may have also been due to a range-dependent transition in the seabed geoacoustics along the departure track, which was not accounted for by the PE model.

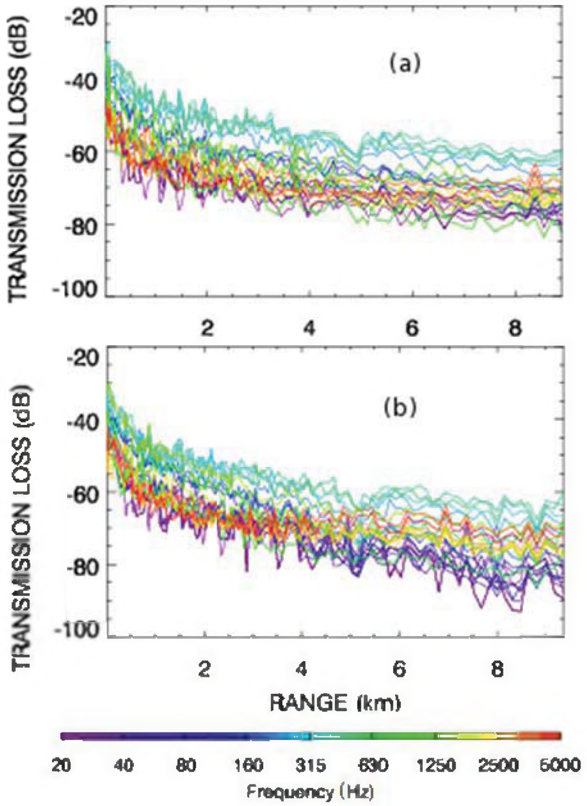

Figure 5. Transmission loss versus horizontal source-receiver separation, in 1/3-octave bands, as the vessel approached (a) and departed from (b) the OBH position.

6. CONCLUSIONS

Acoustic measurements for south Hecate Strait showed that transmission loss in this environment is generally described as cylindrical spreading with very little additional loss attributable to non-geometric terms. Mid-frequency (100-400 Hz) sound propagation was found to be well supported in this depth regime (100-150 m). Comparison of the airgun measurements with sound levels predicted by the PE model showed good agreement between the model and the measured data. Both the model and the measurements indicated that the dominant sound transmission frequencies were between 100-400 Hz. The model slightly overestimated levels between 500 Hz and 1 kHz compared with the data, and did not predict the long range attenuation of some very low frequency energy as the sound traveled over a more complicated bathymetry along the departure track. The model-data mismatch along the departure track was attributed to environmental uncertainty and neglect of out-of-plane transmission loss effects by the two-dimensional PE model.

ACKNOWLEDGEMENTS

This work was funded by the British Columbia Ministry of Energy and Mines. We would like to acknowledge Roberto Racca for his participation in the field study. We thank Bob

MacDonald for his expert services operating the airguns during the survey, our Marine Mammal Observer Scott Toews, and Michel Jutras and the crew of the Silver Dawn I for their tremendous assistance working in this challenging environment.

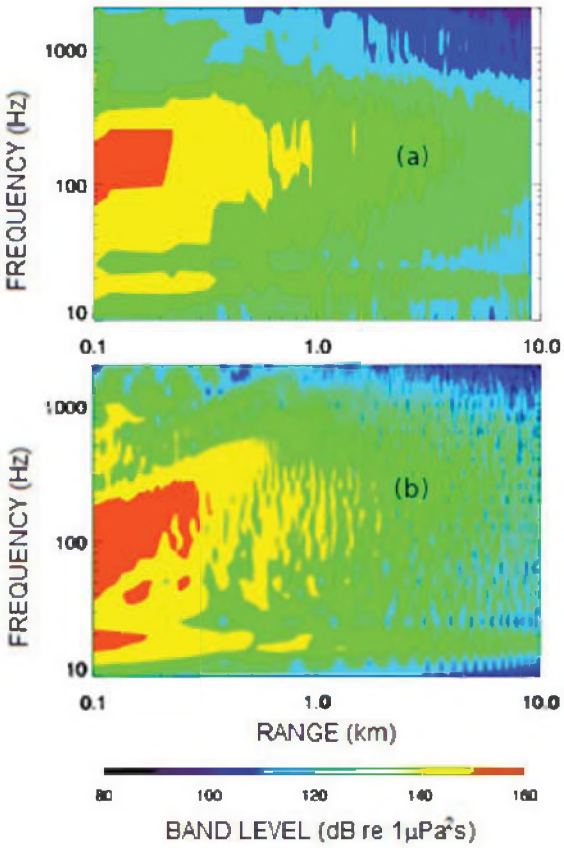

Figure 6. Contours of 1/3-octave band received levels (SEL) versus horizontal range and frequency, as calculated from the measurements (a), and as predicted by the PE model (b) for the approach track.

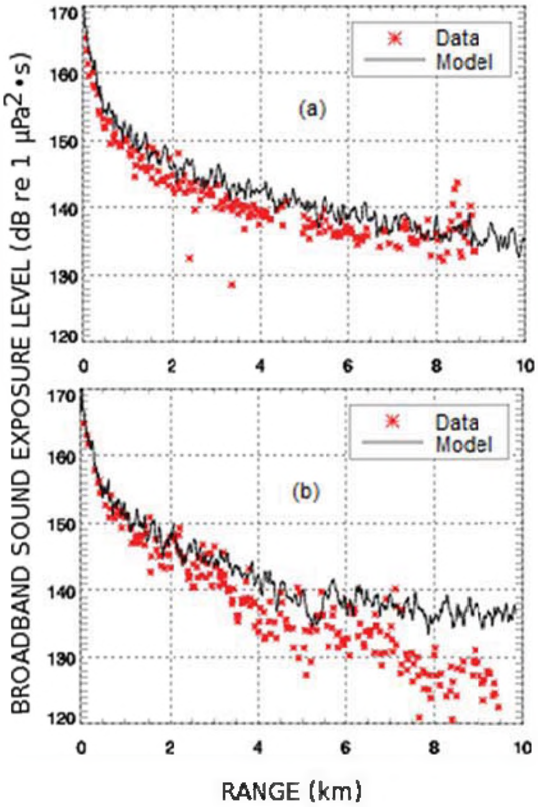

Figure 7. Broadband received levels (SEL) versus horizontal source-receiver separation as estimated by the PE model (line) and as measured in the experiment (star symbols), for the approach track (a) and the departure track (b).

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