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Simplistic underwater ambient noise modelling for shallow coastal areas: Lithuanian area of the Baltic Sea

Donatas Bagočius*, Aleksas Narščius

Marine Research Institute, Klaipėda University, H.Manto 84a, Klaipėda, Lithuania

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ABSTRACT

It is known that underwater sea soundscapes are produced by natural noise sources that occur on the water surface and subsurface water layers. Wind, water splashes, sprays, and breaking waves produce a bubble layer, which in turn produces downward directed sound radiation. There are several additional sources that contribute to underwater noise levels, mainly from commercial shipping, and various anthropogenic sources both out at sea and in coastal areas. Recent research projects have investigated the effects of shipping traffic on the ambient soundscape in the Baltic Sea, stressing the need for long term ambient soundscape monitoring using underwater noise measurements and modelling. Freely available underwater noise models allow for the evaluation of ambient noise levels produced on water surfaces as well, as the creation of soundscape maps. In this manuscript, a simplistic underwater noise model is presented, developed for evaluating and mapping the soundscape in shallow marine areas, and for investigating the noise levels in different seasons.

1. Introduction

To compute shipping noise levels, three parameters are generally required: shipping density, source levels of the ships, and sound transmission losses (Urick, 1983). A number of models exist for addressing underwater ambient noise (Etter, 2012). However, there has been a lack of simplistic analytical modelling tools developed for use by managers and for the assessment of the environmental status (Erbe et al., 2012). In pursuing the need to model the soundscape of the shallow areas of the Lithuanian Baltic Sea, a simplistic underwater noise model for evaluating a soundscape in the shallow sea environment was developed. The model is based on measurements obtained from vessel source spectra, automatic identification system (AIS) data, hydro-acoustic and geo-acoustic information, and environmental data such as bathymetry, sediment types, wind force, and precipitation intensity.

The model consists of the three modules. The first module determines the source sound pressure levels of the vessels from the AIS data at each spatial location. The second module computes the sound transmission losses from each vessel source, taking hydro-acoustical and geo-acoustical factors into account. The data are then stored in a spatial data grid composed of 100 × 100 m squared cells. In each cell, the noise footprint of all the surrounding and contributing sources are included. The third module adds the noise contributions from the environmental factors (wind and precipitation intensity) to the sound pressure values acquired in each data cell.

In this paper, the methods used for the development of the simplistic model and the first experimental results acquired within the Lithuanian marine area are presented.

2. Methods and materials

2.1. AIS data pre-processing

AIS transmitted data carries information necessary for the identification and location of ships. The position of the vessels, their speed, route, and heading can be derived from this data (Viola et al., 2017). For the purposes of the research AIS data for 2015 was provided by the Lithuanian Maritime Administration acquired at Lithuanian marine area. Local AIS receiver stations are installed at the Nida, Klaipėda, and Šventoji locations (28 m, 37 m, and 39 m above sea level) along the Lithuanian Baltic Sea coast, although some of the AIS data are collected by AIS receivers belonging to neighbouring countries at distances from the shore exceeding 65–75 km (35–40 NM). The AIS data were continuously stored on a server where actual data were only available for about 12 months. The local station AIS data records provided 7,453,284 separate AIS data lines with a time resolution of 240 s for the period of 2015. The necessary vessel data were retrieved from available web based marine databases, where the overall length of the ships (LOA), gross tonnage (GT), and vessel types were of particular interest. The AIS

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* Corresponding author.
E-mail address: donatas.bagocius@aad.am.lt (D. Bagočius).

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records from coastal radio stations, search and rescue aircraft, navigation aids, and other similar sources were rejected. Small sailing vessels less than 20 m were rejected on the assumption that they were wind powered. The amount of rejected sailing vessels accounted for approximately less than 5% of the total vessels included in the AIS data, however, large sailing vessels equipped with diesel engines were kept in the data set. Ship's data (LOA, GT, vessel type) were assigned to the original AIS data table. To decrease computational time, the AIS data were further filtered, reducing the time resolution of the individual AIS readings to 960 s.

2.2. Ship noise source levels

A number of ship source spectra models have been published (i.e.Ross, 2005; Wales and Heitmeyer, 2002, Wittekind, 2014). Based on the available ship data found in online marine databases empirical equation of the Research Ambient Noise Directionality Noise Model 3.1 was used (*see* Liefvendahl et al., 2015) to determine ship source noise levels:

$$NL = Lso + 60\mathrm{Lg}\left(\frac{v}{12}\right) + 20\mathrm{Lg}\left(\frac{ls}{300}\right) + df*dl + 3.0 \quad [1]$$

Where NL is the spectrum noise source level of an individual ship (dB re $1\mu Pa^2 m^2/Hz$), υ is the ship speed in knots (1 mile equalled to 1.852 km), ls is the ship length in ft (1 feet equalled to 0.3048 m), and Lso *(f)* is given by:

$$f < 500\mathrm{Hz}{:}\cdot Lso = -10Lg\left(10^{-1.06\, Lgf - 14.34} + 10^{3.32\, Lgf - 21.425}\right)$$

$$f > 500\ \mathrm{Hz}{:}\cdot Lso = 173.2 - 18.0Lg(f)$$

and

$$df = \begin{cases} 0.0 \le f \le 28.4, & |df = 8.1 \\ 28.4 < f \le 191.6, & |df = 22.3 - 9.77Lg(f) \\ f > 191.6, & |df = 0. \end{cases}$$

$$dl = ls^{1.15}/3643.0;$$

The ship source levels are computed using the model of an 'average' ship Lso *(f)* level, having a length of 300 ft with a speed of 12 knots, adding to the 'average' ship the contribution of actual vessels expressed as a function of their speed and length (Breeding et al., 1996).

While noise levels are acquired using sound propagation modelling techniques, which uses more conservative approximations comparing to models such as Fast Field Program or Ray Program, the uncertainties of acquired results increases up to 0.5 dB. In such a case is recommended to apply low frequency correction (Veritas, 2014). Therefore, the low frequency correction was applied to the ship source spectral levels, using the equation (maximal value):

$$LF_{cor} = \max\left[0;\ 10Lg\left(\frac{1}{2} + \frac{1}{\left(\frac{4\pi f}{v_1} z\sin(\alpha)\right)^2}\right)\right] \quad [2]$$

Where LF_{cor} is the low frequency correction in dB for shallow waters, f is the sound frequency, z is the source depth, α is the average angle between the water surface and the line passing through the source and the imaginary hydrophone (10° for shallow water), and v_1 is the sound velocity in water (Ainslie, 2010).

2.3. Sound propagation

Due to the acoustically shallow nature of the Baltic Sea area, having a mean depth of ~54 m (Leppäranta and Myrberg, 2009), the shallow plane wave sound propagation loss formulas developed by Ainslie et al. (2014) were used for computations across the frequency range of 0.01–10 kHz (in 1 Hz bands). Model computes sound propagation losses in two steps: spherical sound propagation losses and the sound propagation losses in the region of the mode stripping with the transition range between these given by the equation:

$$r_t = \frac{H}{2tan\beta_0} \quad [3]$$

Where r_t is the transition range between the spherical propagation and the propagation of sound waves in the entire shallow sound channel, ensonified in a cylindrical mode, H is the water depth, and β_o is the critical grazing angle of the propagating sound wave (Lurton, 2010). Critical grazing angle was obtained using the equation (assuming the most effective propagation angle is lower than $\pi/4$):

$$\beta_0 = \arccos\left(\frac{v_1}{v_2}\right) \quad [4]$$

Where v_2 is the sound velocity in the sediments (Jensen et al., 2011). The accounted value for the sound velocity in the water column: 1436.6 m/s, a yearly average in the Lithuania area (SVP data provided by Lithuanian Maritime Administration) and the sound velocity in sandy sediments 1836 m/s (Chakraborty and Raju, 1994). For sound propagation losses near vicinity of the noise source, the model computes spherical transmission losses using frequency dependent equation:

$$TL = 40Lg\left(\frac{r}{r_0}\right) - 10Lg\left[4\left(\frac{kzD}{r_0}\right)^2\right] \quad [5]$$

Where r is the propagation distance, k is the acoustical wavenumber, z is the source depth (taken as typical mid-size merchant vessel draught of 6 m, MCR, 2011), D – the receiver depth (the receiver was assumed to be at the middle of the water column at any area $H/2$), and r_o is the 1 m reference distance. For sound propagation losses in the mode stripping region, the model computes transmission losses using the frequency and depth dependent equation:

$$TL = 25Lg\left(\frac{r}{r_0}\right) + 10Lg\left[4(kz)^{-2}\left(\frac{\eta^3 r_0}{\pi H}\right)^{1/2}\right] \quad [6]$$

Where η is the coefficient for a sandy or silty sediment type 0.3 Np/rad (Ainslie et al., 2014).

Sound propagation losses along uncoupled azimuthal radials of the length $\Delta r = 37040$ m (20 NM - distance assigned for experimental purposes) are computed for construction of acoustic image around each noise source. Vertical radials of sound propagation during the computations are separated by the angle φ, yielding 32 bearings every 11.25° (360°/φ) at each noise source position (*see* Jensen et al., 2011). As a result, the noise spectra within the 1 Hz bands are computed at every bearing with the range steps of 300 m with the recurring logarithmic summation of propagation losses at every next range step ($TL_{\Delta r} = TL_{r1} + TL_{r2} + \ldots .TL_{ri}$). In the areas with a shoaling bottom, model filters the noise spectra with a high-pass band filter applying the cut-off frequency equation:

$$fc = \frac{v_1/4H}{\sqrt{1 - v_1^2/v_2^2}} \quad [7]$$

Where fc is the cut-off frequency in the shallow water and H is the water depth (Au and Hastings, 2008). The bathymetry data grid for computations was extracted from Baltic Sea Topography Database (Seifert et al., 2001) having a resolution of 4.5 × 4.5 km.

2.4. Ducted sound propagation and noise directivity

Winter ducting can occur in shallow areas where the ducts less than 50 m deep are most common. These act as a sound waveguides at some frequency bands (Jensen et al., 2011). Assuming this feature, the available seasonal sound velocity profiling data were reviewed and