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Towards a realistic Approach of Sound Propagation in EIAs: How to represent moving Sources and moving Receivers

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ABSTRACT

Recent guidelines for marine mammal protection like those in the US or in Denmark impose dose-based criteria that require to accumulate the noise received by a marine mammal over time. Compared to a static receiver, fleeing animals receive a significantly lower noise dose because they move away from the zone of noise impacts. Animal movement models can therefore be useful to predict more realistic noise impacts on marine mammals. In addition, noise sources are not always static. During seismic exploration for example, air guns are towed behind a vessel and the locations of the air gun sounds are changing with the forward movement of the vessel. Here we present a feasible solution for noise impact assessments that compromises between realistic representations of mammal behavior and sound field on the one hand and computational resources on the other hand to provide the best possible accuracy in a realistic time frame. The approach consists of two steps: First, the sound field is derived from a number of detailed propagation simulations. Then, an Agent-Based Model (ABM) simulates animal movement and noise dose accumulation. Our study shows that noise impact assessments benefit from using a more dynamic approach.

Keywords: Underwater noise, Moving source, Agent Based Model (ABM)

1. INTRODUCTION

Authorities and regulators globally have defined sound exposure criteria to protect marine mammals from man-made noise. Impact pile driving as associated with the construction of offshore wind farms and seismic exploration undertaken for example by the oil and gas industry are known as major high level underwater sound sources.

Criteria often permit to assess the impact based on broadband levels or individual frequencies (1, 2) or even require using broadband levels (3) in order to limit the complexity of the assessment. Recent guidelines motivate however more detailed analysis that account for the susceptibility for noise induced hearing injury at different frequency bands (2) which requires to resolve the sound propagation spectrally.

Many impact assessments are based on the assumption of static sources and static receivers. The impact area in form of sound fields emanating from the source is then superimposed on mapped animal densities (based on literature assessments or baseline monitoring). The number of animals affected in the ‘impact zone’, is calculated and treated as a ‘take’ from the population. Regulators use the number of takes as the basis for their decision whether or not to grant a license to operate.

Real non-moving sources like pile-driving are of course well represented by the static assumption, but moving sources like air gun arrays are often represented by a static sound field that extrapolates the contours of the simulated sound fields at the beginning and the end of a survey line. For the consideration of single noise event metrics like peak sound pressure levels or single pulse sound expose levels (SEL), this approach appears justified, but for dose-like parameters like the cumulated sound exposure level (SEL_c), the changing distance between source and receiver while the source is moving needs to be taken into account.

The assumption of static receivers on the other hand, i.e. non-moving animals, means that animals ignore any approaching noise or increasing noise levels (soft-start) while at the same time

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experiencing effects on hearing. It may however be expected that animals try to escape that situation, and thus for moving animals, the number of affected individuals is expected to be lower than for static individuals. The animal movement can be modeled by agent-based models (ABM) that account for the behavioral response of each “agent”.

Here we show how both approaches are applied in EIAs, finding a compromise between the most realistic description and computational constraints.

2. MOVING SOURCE MODEL

The moving source model is based on static detail simulations at a number of representative locations. For an ideal coverage such a static model would be required at each individual air gun shot location. Depending on the environmental conditions, especially the complexity of the bathymetry, the number of detail simulations can be (and for computation time has to be) drastically reduced. For a totally flat sea floor and bot temporally and spatially constant environmental conditions, one detail simulation would be sufficient. For typical situation with limited variability of water depth and boundary conditions, a number of three to four details simulations is considered representative.

Each detail simulation should provide a noise map related to a single air gun shot. In their project work, the authors use the numerical underwater noise modelling software MIKE Underwater Acoustic Simulator (UAS) that is part of the current MIKE 2019 release. The model focuses on the noise propagation in the far field with the aim of providing a basis for conducting a risk assessment of environmental noise impacts. UAS applies the range-dependent acoustic model (RAM) algorithm developed by Collins (4). It accounts for the change in speed of sound and volume attenuation in the water column, and provides the option to apply the empirical model by Francois & Garrison (5, 6) which is based on information on salinity, temperature and pH in the water column. Furthermore, UAS includes sound propagation in the seabed. The bottom description is based on a number of constant-density and constant thickness layers. The sound source is modelled as an omnidirectional point source. A detailed description of the underwater acoustic model can be found in the Scientific Documentation for UAS in MIKE (7), including scientific model validation and model assumptions. MIKE UAS produces 2D transects that are combined into a 3D sound field. Maximum over depth levels are used to obtain sound maps at the representative locations.

The results of the detail simulations are mapped to individual source locations. Different mapping options are possible, for a test case depth-weighted averages were found to yield the best results. Due to storage and computational constraints, the ship track is re-sampled on a coarser grid (500–1000 m interval). Depending on vessel speed, each length interval corresponds to several minutes in time that the sound source needs to pass that length. With air gun pulse repetition rates of about 1 shot every 10 s, several air gun shots will be fired during that, say 5-min period. For cumulated SEL this re-sampling is accounted for with a 5-min cumulation. The re-sampled values are in the following referred to as 5-min values for simplicity. The 5-min cumulative SEL are derived using

$$\mathrm{SEL_{cum}} = \mathrm{SEL} + 10\ \log_{10} n \qquad (1)$$

where SEL is the single pulse sound exposure level and n is the number of pulses in the defined period (e.g., 5 min).

For each 5-min step, sound maps with peak and rms SPL as well as cumulated and non-cumulated SEL can be interpolated from the detail simulations. The result are sound map time series for each sound level. The time series are then interpolated on a common regular grid for further analysis. For sound levels that can be related to single air gun shots like the peak and rms SPL but also single-shot SEL, the maximum with respect to time of these sound map time series is derived. For cumulated sound levels, the 5-min SEL of the past 24 h (or any other duration) are cumulated at each grid point, then the maximum over the complete time series is computed.

The maps with maximum-over-time sound levels indicate the impact on the marine environment (e.g. disturbance or injury for different hearing groups within specific impact areas). The time series themselves provide an input for the moving animal ABM.

3. MOVING RECEIVER MODEL

Using ABM, the movements of a number of agents (animals) in response to noise and other environmental factors can be modelled and results post-processed statistically. Representing avoidance responses of individual marine mammals in relation to sound is thus achievable on fine spatiotemporal scales (8).

DHI's own software ABM lab (for more information, please see (https://www.mikepoweredbydhi.com/products/abm-lab) handles typical marine mammal behavior during, for example during migration and feeding. For the simulation of migration, a number of agents is continuously released. The agents have a defined movement speed that depends on the group type, e.g., mother and calf, single individual. During feeding, the movements of the agents can be set to a correlated random walk principle (e.g., 9).

ABM permits to set environmental conditions like the time series of the sound field and define a behavioral reaction to the sound field. Two responses are typically defined: avoidance and displacement. Avoidance behavior assumes that marine mammals will try to avoid the noise, but will return 1 hour after the noise ends (e.g., 10). The avoidance can, for example, be set to a sigmoid dose-response curve (e.g., 11, 12). The number of takes is calculated by post processing of the ABM output, where agent occurrence in one of the impact zones is calculated as a take. Displacement is treated in the same way as avoidance, but here the mammals are assumed to stay away from the noise for 24 hours, which corresponds to the lower estimate of displacement time due to pile driving for a very sensitive species, the harbor porpoise (*Phocoena phocoena*; 10).

In the dynamic assessment, the number of takes is derived by the agents entering a zone of impact. Once an individual agent enters a zone of impact, this is counted as a take. The counting is undertaken for the entire simulation period when the noise takes place. Individual agents can only be 'taken' once during the noise period (e.g., one continuous seismic survey or impact pile-driving of one pile). Thus, individual agents can be taken on subsequent noise periods but not more than once in the same noise period.

4. TEST CASE PHASE

The moving source model has already been applied in projects providing a more detail to the description of the actual processes like the proper accumulation of the noise dose for changing distances to the sound source. An ABM Demonstrator is currently developed for the North Atlantic right whale (*Eubalaena glacialis*) using simulated pile driving near a planned offshore wind farm site off the US East Coast. An assessment of the number of takes will be carried using the most recent set of impact criteria. Both the static and the dynamic (ABM) approach will be applied following several scenarios. The goal is to compare the number of takes between the two approaches.

One could argue that it is premature to use ABM simulations using data on avoidance and displacement as information of response to sound is limited in right whales and many other cetacean species. Yet, despite the scarcity of data, EIA investigators have already begun to use impact criteria to estimate a behavioral response zone (see for example 13). Furthermore, Skjellerup et al. (1) and NMFS (2) recommend the use of response movement for marine mammal EIAs. This new paradigm is already shifting towards dynamic approaches, and industry as well as regulators might want to use the most comprehensive and reliable technology when applying it. Furthermore, thanks to a variety of recent studies, data on behavioral response of marine mammals to underwater noise exposure are rapidly increasing (14). The way forward might be to apply a more holistic approach using the static and the dynamic approach in EIAs to provide regulators with a range of outcomes and scenarios including uncertainty quantification. Then, whenever data become available, the static approach can be gradually phased out to make room for more validated animal response models.

5. SUMMARY AND CONCLUSIONS

Moving source and moving receiver models have been introduced. Both models promise a more realistic representation of the noise transmission and accumulation process than the static approaches. While the application of the moving source model focusses on seismic studies of the oil & gas industry, the moving receiver model useful for any type of noise that might impact marine life including seismic studies but also construction work with impact pile driving.

REFERENCES

1. Skjellerup P, Maxon CM, Tarpgaard E, Thomsen F, Schack HB, Tougaard J, Teilmann J, Madsen KN, Mikaelsen MA, Heilskov NF. Marine mammals and underwater noise in relation to pile driving - Report of working group. Energinet.dk; 2015. p. 1-20.
2. NMFS. Revisions to: Technical Guidance for Assessing the Effects 500of Anthropogenic Sound on

Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts. Technical Memorandum No. NMFS-OPR-59. Silver Spring, MD, USA: U.S. Department of Commerce, NOAA; 2018. p. 167.

3. BSH. Offshore Wind Farms, Measuring Instructions for Underwater Sound, Current Procedures With Application Notes. Hamburg, Germany: German Federal Maritime and Hydrographic Agency; 2011.
4. Collins MD. A split-step Padé solution for the parabolic equation method. J Acoust Soc Am. 1993;93: 1736–1742.
5. Francois RE, Garrison GR. Sound absorption based on ocean measurements: Part I: Pure water and magnesium sulfate contributions. J Acoust Soc Am. 1982;72:896-907.
6. Francois RE, Garrison GR. Sound absorption based on ocean measurements. Part II: Boric acid contribution and equation for total absorption. J Acoust Soc Am. 1982;72: 1879-1890.
7. DHI. UAS in MIKE, Underwater Acoustic Simulation Module. Scientific Documentation (DHI, Hørsholm, Denmark: DHI; 2019.
8. Thomsen F, Hansen FT, Erichsen AC, Skov H, Heinänen S, Taaning M, Mortensen JB, Schack HB, Weissenberger J. A dynamic risk assessment model for acoustic disturbance using agent based modelling. Proc 20th Biennial Conference on the Biology of Marine Mammals; Society for Marine Mammalogy; Dunedin, NZ, 2013. p. 203.
9. Bovet P, Benhamou S. Spatial analysis of animals' movements using a correlated random walk model. J Theor Biol. 198;131: 419-433.
10. Brandt MJ, Diederichs A, Betke K, Nehls G. Responses of harbour porpoises to pile driving at the Horns Rev II offshore wind farm in the Danish North Sea. Mar Ecol Prog Ser. 2011;421:205-216.
11. Miller PJO, Antunes RN, Wensveen PJ, Samarra FIP, Catarina Alves A, Tyack PL, Kvadsheim PH, Kleivane L, Lam F-PA, Ainslie MA, Thomas L. Dose-response relationships for the onset of avoidance of sonar by free-ranging killer whales. J Acoust Soc Am. 2014;135:975-993.
12. Dunlop RA, Noad MJ, McCauley RD, Scott-Hayward L, Kniest E, Slade R, Paton D, Cato DH. Determining the behavioural dose–response relationship of marine mammals to air gun noise and source proximity. J Exp Biol. 2017;220: 2878-2886.
13. Dietz R, Galatius A, Mikkelsen L, Nabe-Nielsen J, Riget F, Schack H, Skov H, Sveegaard S, Teilmann J, Thomsen F. Investigations and preparation of environmental impact assessment for Kriegers Flak Offshore Wind Farm. Energinet.dk; 2015.
14. Thomsen F. Anthropogenic Underwater Noise - Synthesis of Information submitted to UN. Division for Ocean Affairs and the Law of the Sea, Office of Legal Affairs, United Nations, New York; 2018. p. 75.