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Title:	**Noise Prognosis for Offshore Test Site by North Sea Farmers (Eco-anchor)**
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Contents

1. Introduction

Background

In this project, two small-size piles are planned to be installed approximately 12km offshore of Scheveningen in the Dutch North Sea. The project aims to develop a nature friendly eco-anchor based on state of the art research which will be used to support seaweed arrays. The total length of the piles is about 9m, the diameter varies between 508mm and 609mm and the thickness equals 25.4mm [1]. The distance between each of the two piles to be installed is about 200-300m.

TUD has been asked to perform noise measurements during the installation of the two piles. In order to evaluate the noise emission during the installation of the monopiles, TU Delft (TUD) has volunteered to perform a preliminary noise prognosis and analysis of the sound levels to be expected during the installation of the piles. The main objective of this analysis is the proper choice and calibration process of the acoustic equipment to be deployed during the installation of the piles.

SILENCE BASIC

For the acoustic simulations, the TU Delft software package SILENCE BASIC is used. The software package SILENCE BASIC is a pile-water-soil coupled vibro-acoustic model [2] developed for the prediction of underwater noise emissions induced by offshore impact or vibratory pile driving. The model aims at capturing the noise generation and propagation at the vicinity of the pile [3,4] and at distances up to several kilometres from the pile. The complete system shown in figure 1 consists of the pile interacting with a layered acousto-elastic medium. The pile is described as a cylindrical shell, the fluid is modelled as an inviscid compressible medium, and the soil is described as a horizontally stratified elastic half-space.

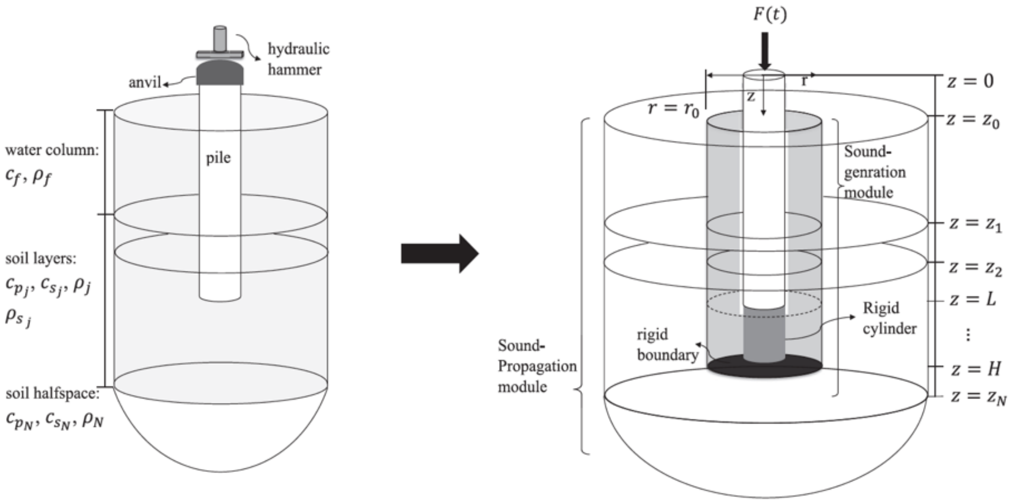

Figure 1 Configuration and modelling elements of the SILENCE BASIC software [2]

The model can be used for the noise prediction and sensitivity study. The modelling results consists of sound exposure level (SEL) with a reference time duration of 1 second, the peak pressure level ($\mathrm{L}_{p,pk}$), pressure evolution in time and other outputs such as one-third-octave frequency spectrum, energy fluxes over time, and cumulative energy for various distances from the pile.

2. Basic input

Input for the model

Based on the offshore geotechnical survey and other information made available by the client in the selected area [5,6], the geometry of the pile-water-soil system and the material properties are selected as shown in Tables 1 and 2. It is worth mentioning here that the uncertainties involved in the estimation of the properties of the seabed are not considered in this study. This is justified by the purpose of this study which is the rough estimation of the levels of noise to be expected and not the exact computation of those.

TABLE 1: GEOMETRY OF THE PILE-WATER-SOIL SYSTEM

Properties of the system	Value	Unit
Pile Length	9	m
Outer Diameter of pile	609	mm
Wall thickness of pile	25.4	mm
Density of pile	7850	kg/m^3
Final penetration depth	7.7	m
Water depth	19	m
Depth of upper soil layer	18	m
Depth of lower soil layer	∞	m

TABLE 2 PROPERTIES OF THE FLUID AND SOIL MEDIUM

Layer	ρ kg/m^3	C_L m/s	C_T m/s	α_p dB/λ	α_s dB/λ
Fluid	1000	1500	-	-	-
upper soil layer	1951	1731	295	0.91	1.86
lower soil layer	1901	1888	352	0.88	2.77

Piling Force

In this analysis, the hammer-anvil system are not modelled explicitly; they are replaced by a given forcing function exerted at the pile head as specified in Figure 2 based on the data provided by the hammer supplier [7]. Naturally, the force may be active for longer time windows during installation of the piles. Here we assume a time window of 4 seconds so that the system reaches the steady-state response (the response of the system does not alter anymore should the same force be sustained for longer time windows).

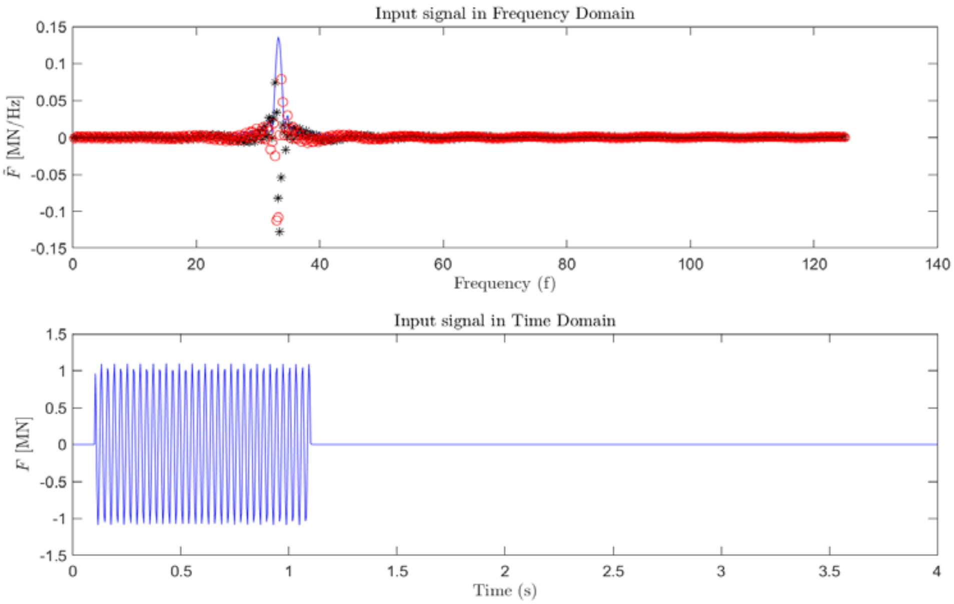

FIGURE 2. Force diagram for vibratory device (vibro-hammer) based on a driving frequency of 33.3Hz.

3. Noise prognosis for the test location

The prediction of the sound emission is presented as follows. First, the noise prediction for the initial installation state is presented. Second, the noise prediction for the final installation state is presented. Finally, the results from the analysis are summarised.

3.1. Methodology

At the initial installation state, the penetration depth of 2m is assumed in this analysis. Given the light self-weight of the pile compared to the monopiles with large dimensions, the self-penetration of the pile is relatively small and, in any case, a slightly different initial value is not expected to influence the predicted noise levels significantly. Thus, the assumption of 2m penetration depth at the starting state is valid for acoustic purposes. When the final penetration depth is reached, only a small area of the pile surface is in contact with the seawater. The critical state in terms of the noise emission can be any state in between the starting one and final stage of installation of the pile, so it is important to evaluate several states of installation in between. In this analysis, the initial and final installation states are investigated in detail due to time restrictions ad given the purpose of the study. In both the initial and final stage of penetration, the same forcing function is assumed at the pile head.

3.2. Initial stages of penetration

Pressure evolution in time and frequency spectrum of the radiated noise
The evolution of the pressure field in time is shown for the bottom point positioned 2m above the seabed at various horizontal positions from the pile. As can be seen, higher pressure levels are found in the vicinity of the pile surface. The frequency spectrum of the pressure field in the near field is also shown in Figure 3.

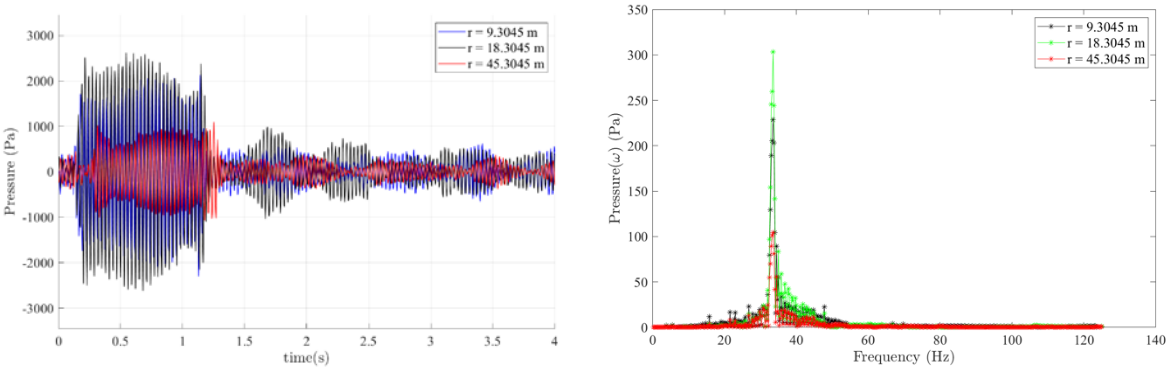

FIGURE 3. The evolution of the pressure field with time (left) and noise spectrum for the pressure field (right) for the bottom point positioned 2m above the seabed in the fluid and at various horizontal positions.

SPL and $L_{p,pk}$
For the evaluation of the noise from vibratory pile driving (continuous sound emission), the Sound Pressure Level (SPL_{1s}) and the Peak Level ($\mathrm{L}_{p,pk}$) are important. The SPL_{1s} in units of dB re 1 μPa is defined as:

$$\mathrm{SPL}_{1s} = 20 \log\left(\frac{p_{rms}}{p_0}\right), \qquad p_{rms} = \sqrt{\frac{1}{T_0}\int_{T_1}^{T_2} p^2(t)\, dt}$$

with T1 and T2 being the start and end time moments of the predicted time signature with the sound event in between and T_0 being 1 seconds in this analysis[1], p_0 being the reference underwater sound pressure level, 10^6 Pa.

The Peak Level ($L_{p,pk}$) in the unit of dB re 1 μPa is determined by the sound pressure peak in one time signature:

$$L_{p,pk} = 20\log(\frac{\max|p(t)|}{p_0})$$

The peak pressure level ($L_{p,pk}$) and the sound pressure level (SPL_{1s}) at radial distances up to 750 m are obtained here as shown in Figure 4. At 750m from the pile, the predicted SPL_{1s} and $L_{p,pk}$ are **137** dB and **158** dB, respectively. Taken into account the noise originating from the underwater presence of the vibratory device an additional of 2 dB are introduced in the predicted sound levels resulting at: SPL_{1s} =**139** dB and $L_{p,pk}$ =**160** dB[2].

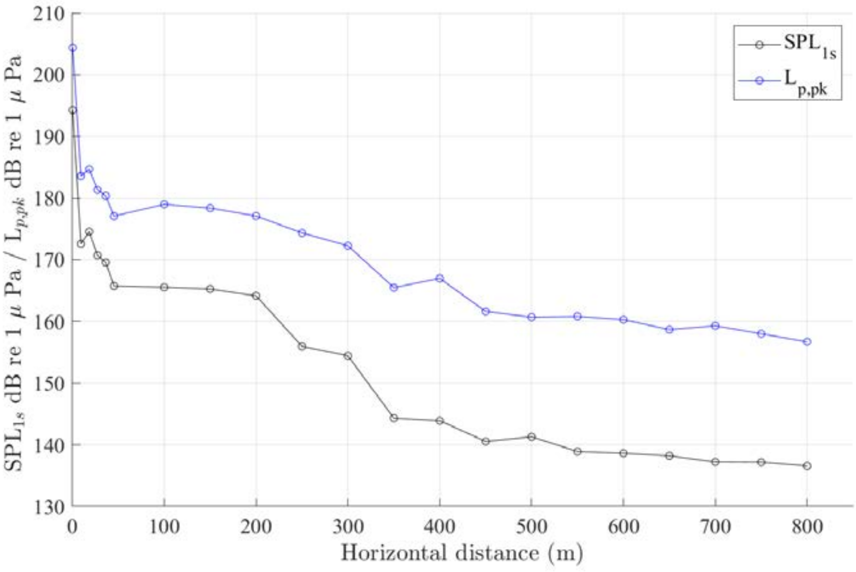

FIGURE 4. Pressure field at a point located at 2m above the seabed at various radial distances from the pile: comparison of SPL, and $L_{p,pk}$.

3.3. Final stage of penetration

Pressure evolution in time and frequency spectrum of the radiated noise

The evolution of the pressure field in time is shown for the bottom point positioned 2m above the seabed at various horizontal positions from the pile. As can be seen, higher pressure levels are found in the vicinity of the pile surface. The frequency spectrum of the pressure field in the near-field is also shown in Figure 5.

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[1] Instead of 1 seconds it would be better to calculate the cumulative SPEL over the whole duration of the installation. This can be done easily if the total duration of the installation time window is known given the pressure levels reported in this study.

[2] There is yet no scientific consensus as to the extra noise generated underwater when the hammer/vibratory device is placed underwater. Clearly when piling taking place above water, and given the large acoustic impedance mismatch between the air and the seawater, the noise generated by the vibratory device itself does not enter the seawater domain. In contract, when the hammer and/or vibratory device is placed underwater, as is the case here, there will be an additional noise contribution due to this extra noise source. In this study, we add an additional 2dBs in both the SPL_{1s} and the$L_{p,pk}$ to consider this extra noise contribution.

SPL and $L_{p,pk}$

The peak pressure level ($L_{p,pk}$) and sound pressure level (SPL_{1s}) at radial distances up to 750 m are obtained here as shown in Figure 6. At 750m from the pile, the predicted SPL_{1s} and $L_{p,pk}$ are **140** dB and **159** dB, respectively. Taken into account the noise originating from the underwater presence of the vibratory device an additional of 2 dB are introduced in the predicted sound levels resulting at: SPL_{1s} =**142** dB and $L_{p,pk}$ =**161** dB.

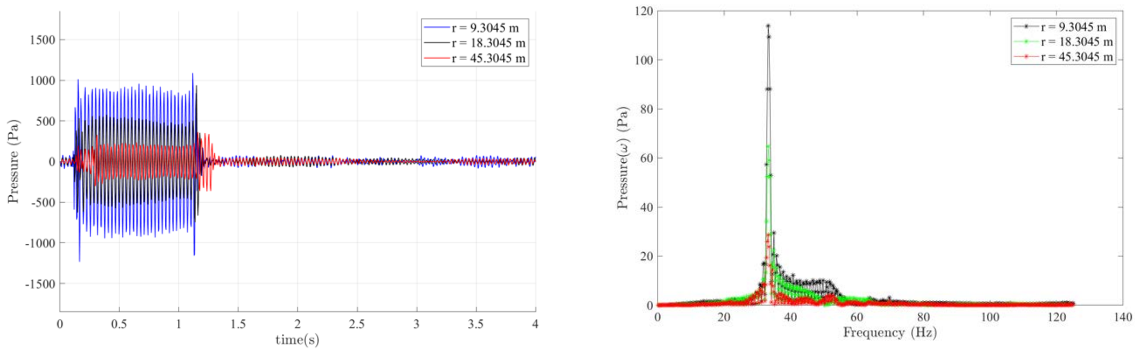

FIGURE 5. The evolution of the pressure field with time (left) and noise spectrum for the pressure field (right) for the bottom point positioned 2m above the seabed in the fluid and at various horizontal positions.

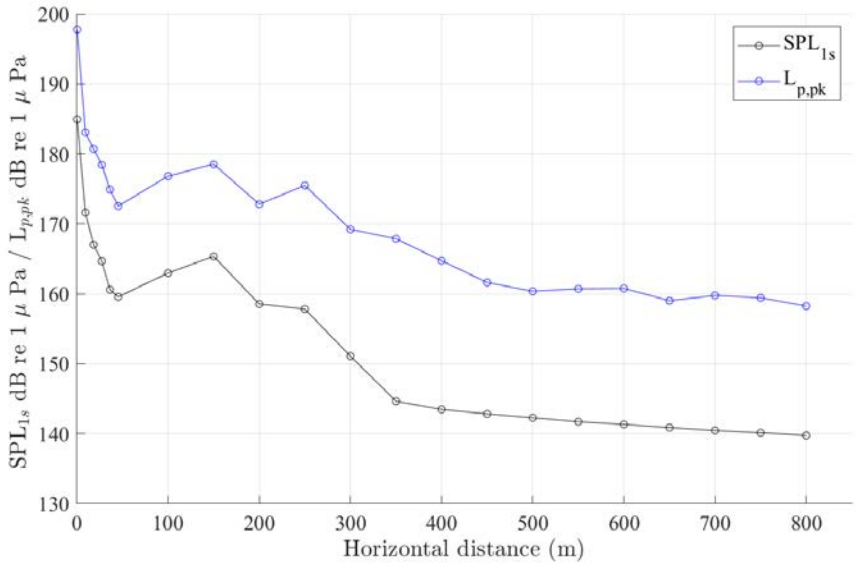

FIGURE 6. Pressure field at a point located at 2m above the seabed at various radial distances from the pile: comparison of SPL, and $L_{p,pk}$.

3.4. Overview of noise prognosis

The overview of the noise prognosis for both installation stages is given in Table 3. The mean predicted SPL_{1s} and $L_{p,pk}$ equal 140.5 dB and 160.5 dB, respectively.

TABLE 3: SUMMARY OF SOUND LEVELS FOR BOTH INSTALLATION STAGES

Case	$\mathbf{SPL_{1s}}$	$\mathbf{L_{p,pk}}$
Initial installation state	139.0	160.0
Final installation state	142.0	161.0
Mean values	**140.5**	**160.5**

3.5. Background Noise calculations

The monthly averaged background noise based on ships and wind are calculated in the test area. The monthly shipping density dataset from EMODNET data portal is used to estimate the ship distribution in the test area. The average source level of the ships is calculated for different ship categories. The mode-flux theory is used to calculate the propagation loss, which is suitable for modelling ship sound in shallow water environments. The monthly sound maps for the test area are shown in Figure 7. These results show monthly-averaged sound pressure levels based on multiple time snapshots over 2017, 2018, and 2019.

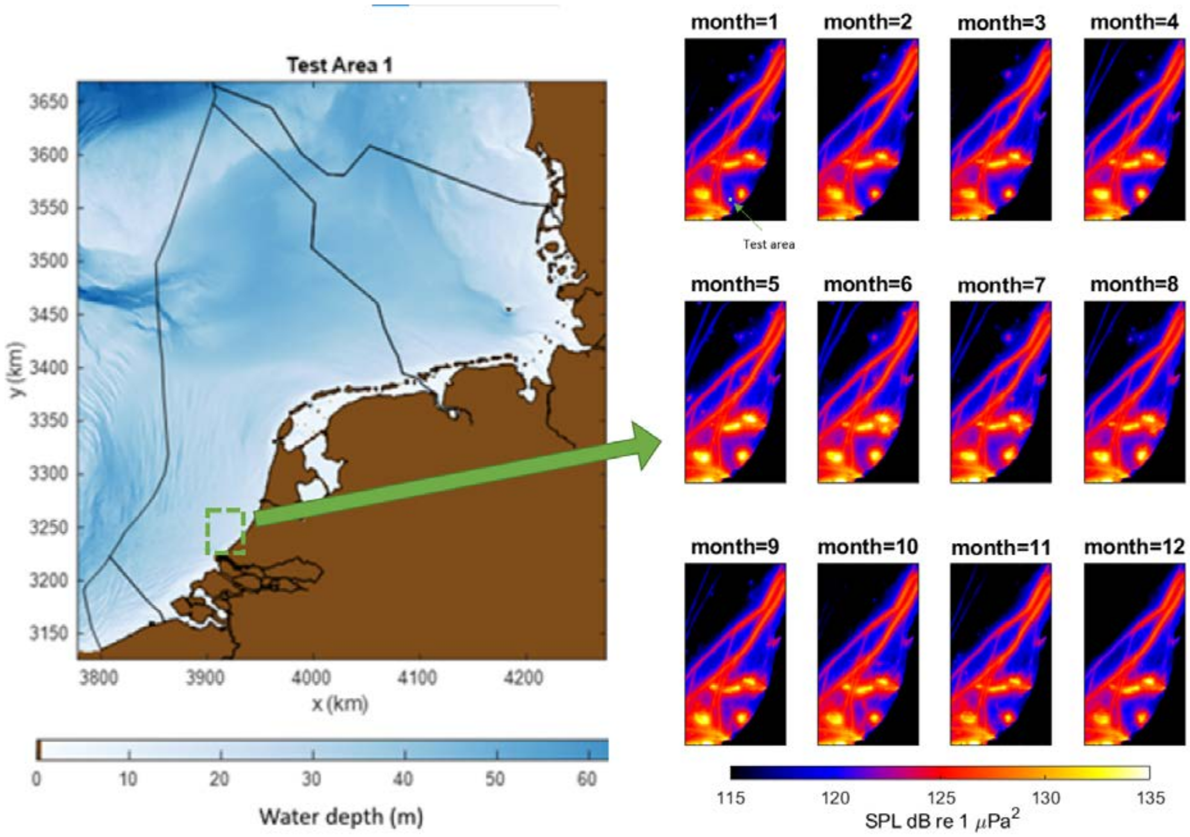

FIGURE 7. Monthly averaged SPL maps (right) for the shipping and wind based on 2017,2018 and 2019 shipping densities. The results are averaged over water depth. The frequency range is 100 Hz to 10 kHz. The bathymetry input and mapping area are also shown (left)

The monthly variation of the predicted average sound pressure levels around the test location is shown in Figure 8.

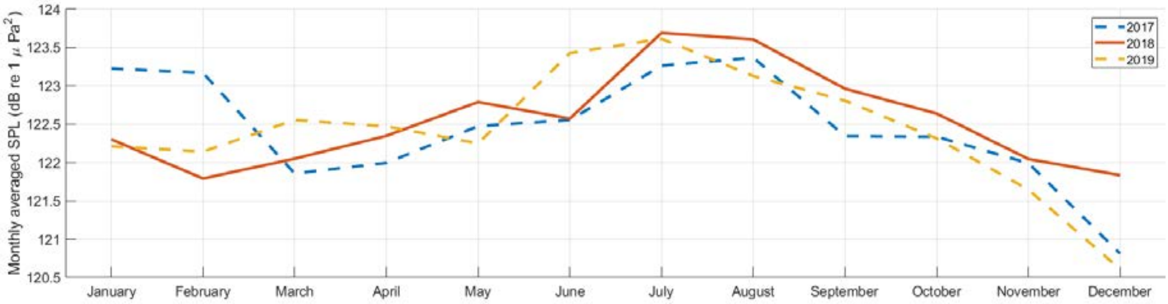

FIGURE 8. Monthly variation of predicted SPL around the test area

The predicted noise levels from the vibratory pile driving could be compared with the background noise. Since the ships are continuous sound sources, the difference between long-time and short-time averages are minor. However, when an individual ship is passing by close to the test location, the expected sound pressure levels could be higher depending on the ship's type, length, and speed. It should be noted that the test area is close to the nosiest spots in the Dutch North Sea, due to the high ship densities at the Port of Rotterdam. Thus, the exceedance of the noise levels due to vibratory pile driving activities seems relatively low compared to other locations in the entire map of Dutch North Sea, as shown in Figure 9.

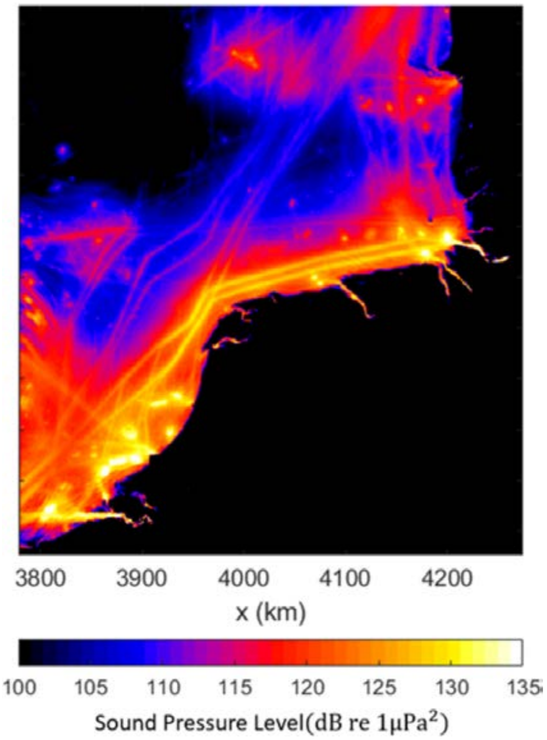

FIGURE 9. Monthly averaged SPL maps for the shipping and wind based on 2017, 2018 and 2019 shipping densities for the Southern North Sea.

4. Reference list

[1] Information for noise measurement TU Delft, PowerPoint Presentation, Zinzi Reimert (2021).

[2] Y. Peng, A. Tsouvalas, T. Stampoultzoglou, and A.V. Metrikine. A fast computational model for near- and far-field noise prediction due to offshore pile driving. The Journal of the Acoustical Society of America, 149(3):1772–1790, (2021).

[3] A. Tsouvalas and A. V. Metrikine. A semi-analytical model for the prediction of underwater noise from offshore pile driving. Journal of Sound and Vibration, 332(13):3232–3257, (2013).

[4] A. Tsouvalas and A. V. Metrikine. A three-dimensional vibroacoustic model for the prediction of underwater noise from offshore pile driving. Journal of Sound and Vibration, 333(8):2283–2311, (2014).

[5] ENECO LUCHTERDUINEN OFFSHORE WIND FARM PROJECT WTG&OHVS DESIGN REPORT - GEOTECHNICAL DESIGN, Ramboll, Document reference number: RAMB-ENG-DRE-1210-WTG&OHVS Design Report-Geotechnical Design-20130701-Rev. 1 (2013).

[6] Q4 Offshore Wind Farm Site Conditions Part 2: Hydrodynamic Site Conditions, Deltares, Document reference number: 1209624-000-HYE-0003, Sofia Caires, Reimer de Graaff, Bas Reijmerink, Jan-Joost Schouten (2014).

[7] Email exchange with Zinzi Reimmert (01-12-2021).