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Underwater Operational Noise from Floating Wind Turbines: A Case Study in Hywind Tampen Offshore Park

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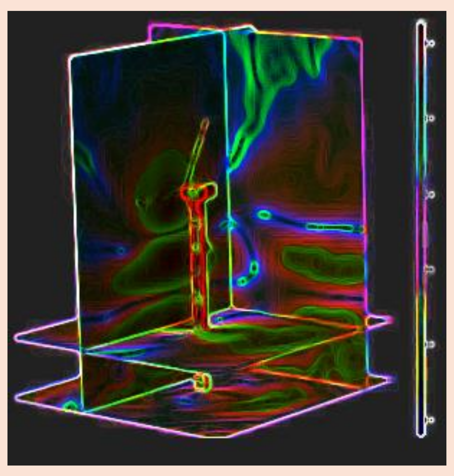
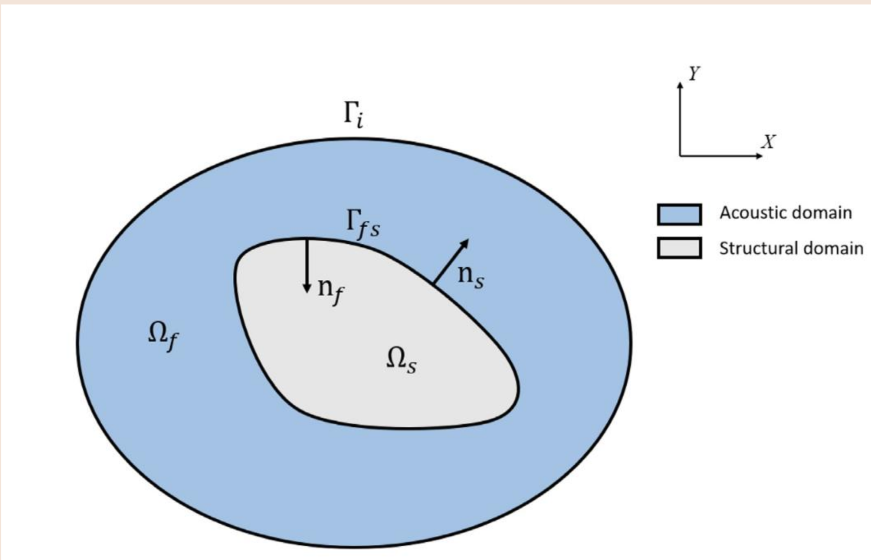
Introduction

Under the WindSYS project, we analyzed acoustic data from the Hywind Tampen floating offshore wind farm, consisting of 11 spar-buoy-supported turbines, each rated at 8 MW. Operational noise from one turbine revealed frequencies concentrated below 400 Hz, with tonal features between 25–80 Hz linked to rotational speed. Median one-third octave band levels below 400 Hz ranged from 95–100 dB re 1 µPa at ~500 m, comparable to noise from fixed offshore turbines and Hywind Scotland. Noise levels strongly correlated with wind speed and moderately with wave height, while impulsive sounds during high winds were linked to mooring lines. Source levels (25 Hz–20 kHz) increased with wind speed, consistent with findings at Hywind Scotland.



Theoretical background

Various methods exist to predict fluctuating pressure in both near- and far-fields, relying on computational fluid dynamics (CFD) models such as Large Eddy Simulations (LES), which are computationally expensive, and Detached Eddy Simulations (DES), which are less time-intensive. However, in this study, we utilize the Ffowcs Williams & Hawkings (FW-H) analogy to model the interaction between vibrations and the movement of floating wind turbine towers in the water, as well as the noise they generate and propagate into the far-field [2].



$$p'(\mathbf{x},t) = \frac{\partial}{\partial t}\int_{f=0}\left[\frac{Q_i n_i}{4\pi|\mathbf{x}-\mathbf{y}|}\right]_{\tau_e} \mathrm{d}S - \frac{\partial}{\partial x_i}\int_{f=0}\left[\frac{L_{ij} n_j}{4\pi|\mathbf{x}-\mathbf{y}|}\right]_{\tau_e} \mathrm{d}S + \frac{\partial^2}{\partial x_i \partial x_j}\int_{f>0}\left[\frac{T_{ij}}{4\pi|\mathbf{x}-\mathbf{y}|}\right]_{\tau_e} \mathrm{d}V$$

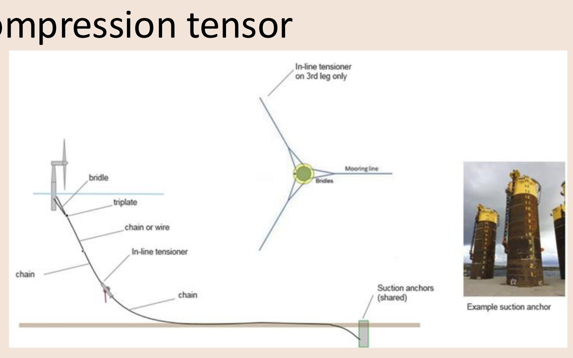
$$Q_i = \rho(u_i - v_i) + \rho_0 v_i$$
$$L_{ij} = \rho u_i (u_j - v_j) + P_{ij}$$

$$T_{ij} = \rho u_i u_j + \left[(p - p_0) - c_0^2(\rho - \rho_0)\right]\delta_{ij} - \sigma_{ij}$$

$$P_{ij} = (p - p_0)\delta_{ij} - \sigma_{ij}$$

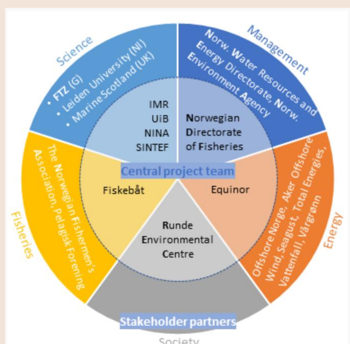
V represents the volume outside the control surface, T_{ij} is referred to as Lighthill's stress tensor, vectors ***u*** and ***v*** are the flow and the surface velocities, respectively, and P_{ij} The compression tensor

The vibration and motion of the turbine tower substructure, taking into account the mooring line, are estimated using the six degrees of freedom (6 DOF) structural response model.



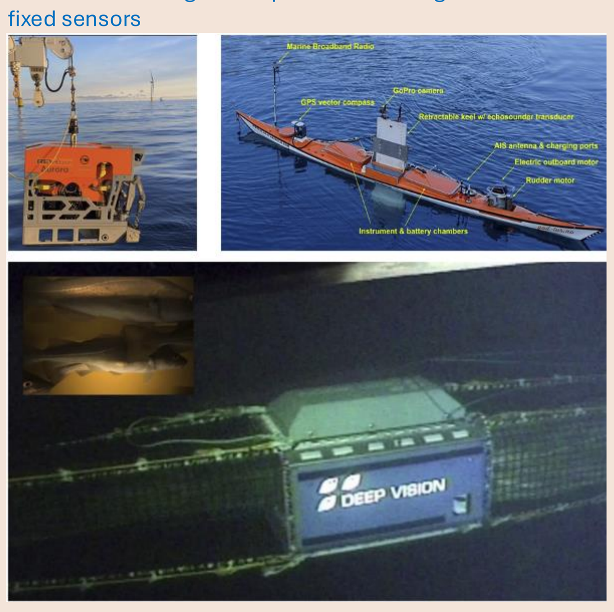
WindSYS project and the measurement site

WindSys, which stands for "Effects of Offshore Wind Farms (OWF) on the Marine Ecosystem, with a Focus on Pelagic Fish," is dedicated to assessing the environmental impact of floating wind turbines, particularly the underwater noise they generate. As the name implies, the project specifically focuses on understanding the effects of these turbines on marine life and co-existing industries. The initiative involves multiple stakeholders and partners from various sectors [1,3,4].

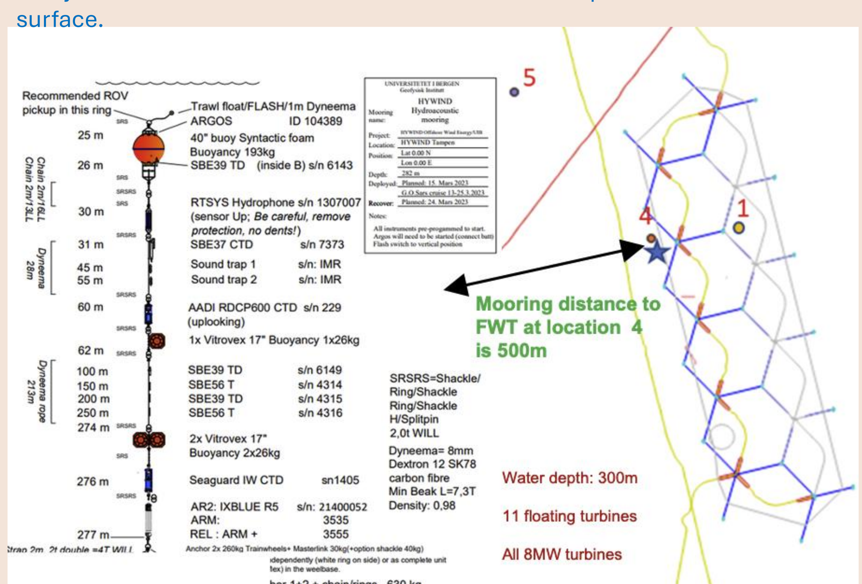


The primary objective of this study within the project is to measure the spatiotemporal patterns of underwater noise associated with the Hywind Tampen floating wind farm, focusing on a cruise conducted 13 to 28 March 2023.

Several measuring techniques from moving and bottom-fixed sensors

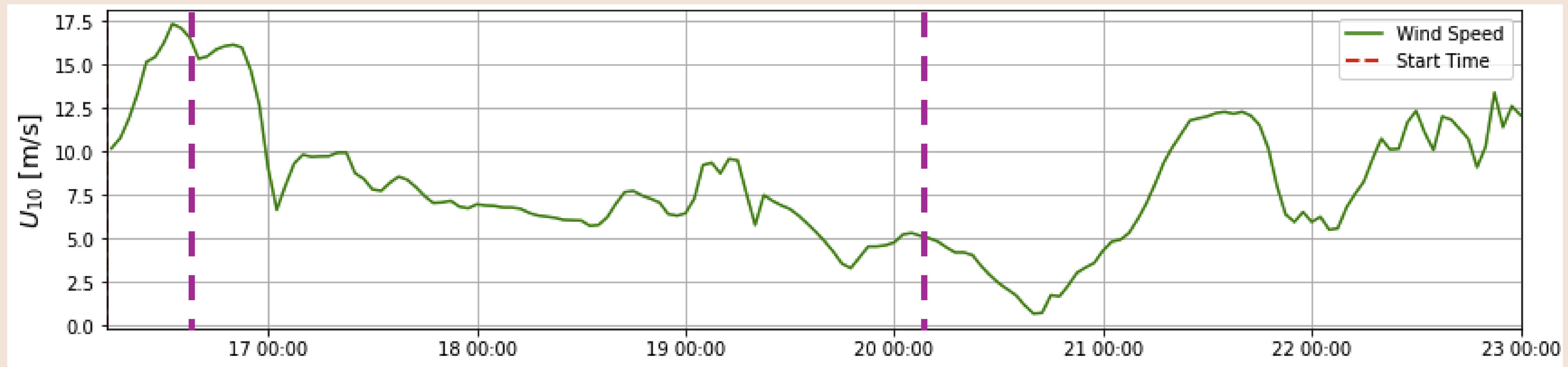


This study focuses on data from an oceanographic mooring system equipped with multiple sensors, including three noise recorders placed at different depths. The data analyzed here was recorded from the noise recorder positioned 55 meters below the sea surface.

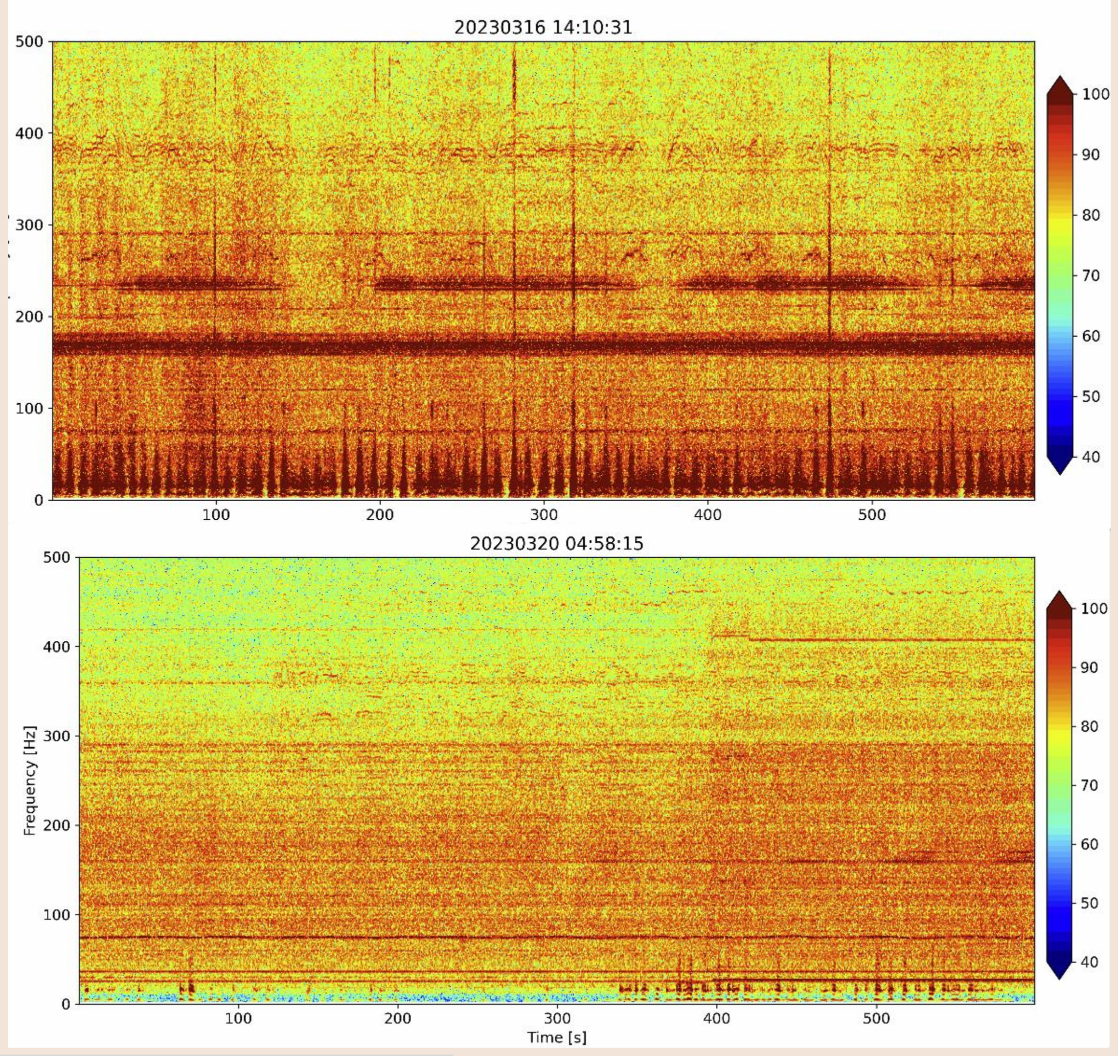


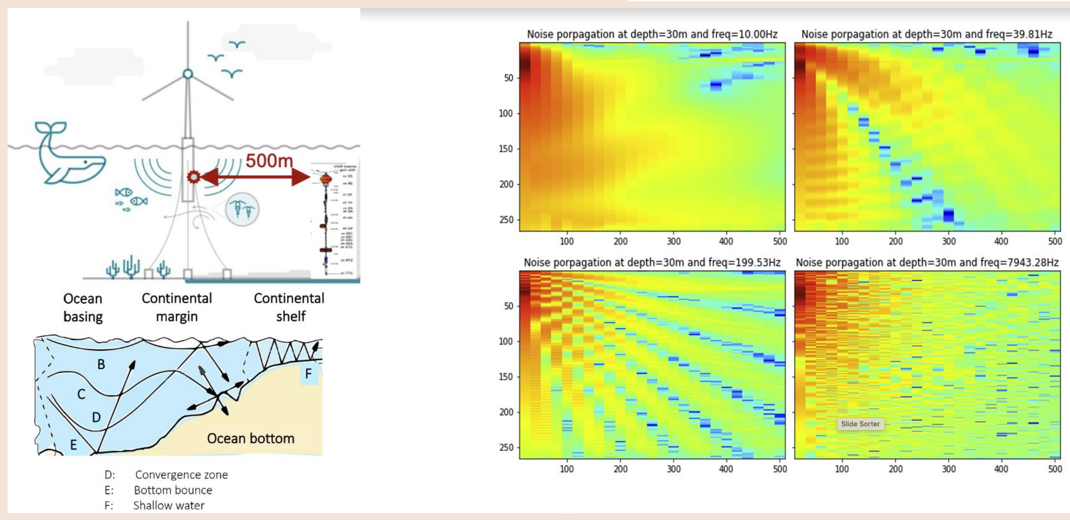
Results

The time series of wind speed for March 2023 highlights varying wind conditions, specifically two wind events: a high wind event (indicated by the left red dashed line) and a calm wind event (indicated by the right red dashed line).



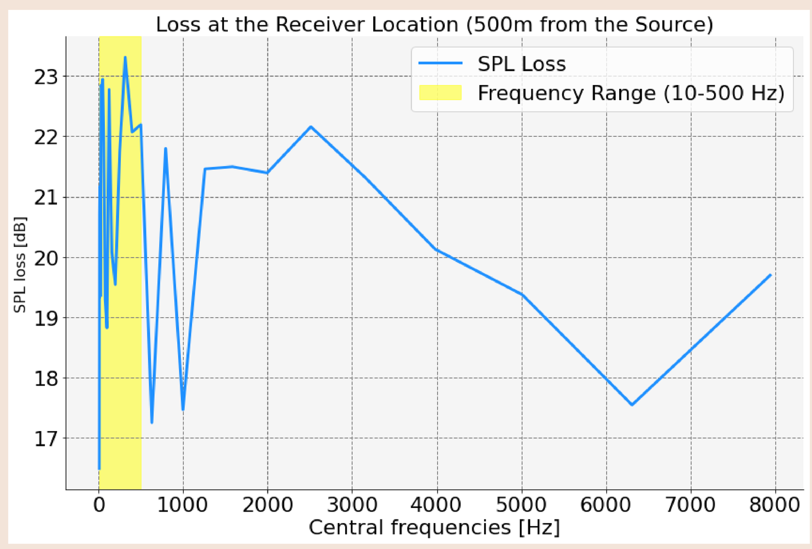
Noise emissions from floating offshore wind (FOW) turbines are mainly concentrated in frequencies below 200 Hz, with distinct tonal characteristics likely linked to rotational speed, particularly between 25 and 100 Hz at Hywind Tampen. In high wind conditions (top), turbine pitch control significantly influences the noise (not shown). Fluctuations around the tower, caused by underwater tonal emissions, and mooring system noise from both the floating turbines and oceanographic moorings, are prominent at frequencies below 10 Hz. In calm wind conditions (bottom), low-frequency tones are clearer and more distinct. Additionally, the noise level is several dB lower compared to high wind conditions.





The distance sensor measurements do not directly provide the turbine's source level, so propagation modeling is used, assuming that all recorded noise originates from the monitored wind turbine. However, the signal also contains ambient noise, which is included in the back-propagated signal, resulting in likely overestimated source levels.

levels were determined through backward propagation modeling from the nearest hydrophone, situated 500 m away at a depth of 55 m. The results presented here correspond to a single wind speed across decadal frequencies.



Hearing thresholds

We are currently studying the hearing thresholds of pelagic fish in the Hywind Tampen area. However, it is clear that turbine-emitted noise may interfere with the hearing range of species like cod, which have peak sensitivity in the 50–300 Hz range, with the highest sensitivity between 80–200 Hz and threshold levels as low as 75–80 dB re 1 µPa [5].

References

[1] JASCO Applied Sciences (UK) Ltd. (2022). *Hywind Scotland Floating Offshore Wind Farm: Sound Source Characterisation of Operational Floating Turbines.*
[2] Najafi-Yazdi, A., Brès, G. A., & Mongeau, L. (2011). An acoustic analogy formulation for moving sources in uniformly moving media. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 467(2125), 144-165.
[3] Mostafa, B. P. (2024, November 11). The Underwater Noise Emission of Floating Hywind Tampen Wind Turbines : WindSYS project. Science meet industry, Bergen. Zenodo. https://doi.org/10.5281/zenodo.14065613
[4] CRUISE REPORT HYWIND TAMPEN 13 TO 28 MARCH 2023- Cruise no. 2023001004 G.O. Sars, https://www.hi.no/hi/nettrapporter/toktrapport-en-2023-10
[5] Hawkins, A. D., & Chapman, C. J. (1975). Masked auditory thresholds in cod (Gadus morhua). *Journal of Comparative Physiology*, 103, 209–226.

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