Investigating the impact of offshore wind farm-induced wind wakes on wave characteristics through numerical modeling

Georgios Mastrogiorgos[1] , Supervisors: Johan Arnqvist[1], Frederik Brink[2] , Co-Supervisor: Lichuan Wu[1]

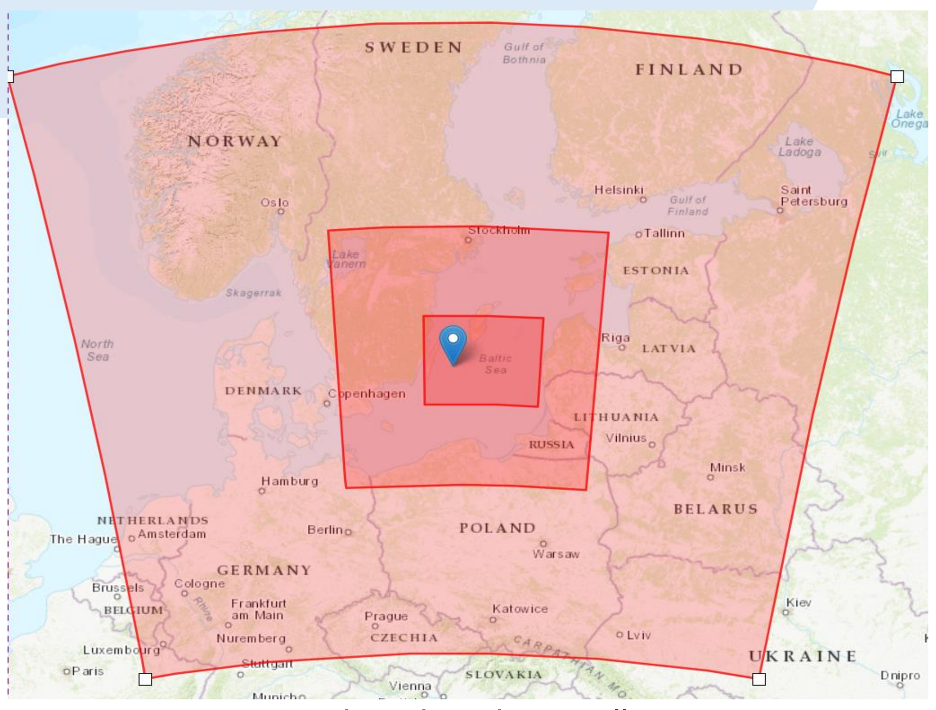
[1]Uppsala University, Department of Earth Sciences, [2] OX2, Wind power development

1 INTRODUCTION

- Offshore wind farms are rapidly expanding as a sustainable source of renewable energy as they offer significant advantages over onshore, including higher wind speeds, more consistent wind patterns, and lower turbulence levels, leading to increased energy production efficiency and reliability but with a higher cost.
- The wind turbines of the farm extract kinetic energy from the wind, creating wind wakes characterized by reduced wind speed and increased turbulence downstream of the turbines. These wind wakes can alter the wind-wave generation process, impacting the wave field.
- The Baltic Sea is a promising location for offshore wind energy due to its relatively shallow waters. However, it is a fetch-limited sea where wind-generated waves are predominant; thus, any changes in local wind patterns could have significant effects to wave characteristics, leading to the question:

What are the effects of wind farm-induced wind wakes on waves and how significant are they?

Aurora Wind Farm Photo: OX2



WRF domains: the smallest nested with a resolution of 1 km

2 METHODOLOGY

To answer the question an offline coupling of two numerical models was used:

1) Atmospheric Modeling with WRF:

•Data Input**:** ERA5 reanalysis data was used to provide initial and boundary conditions for the Weather Research and Forecasting (**WRF**) model.

•Simulations**:**
- Control Simulation: Conducted without the wind farm to represent natural atmospheric conditions for a day.
- Wind Farm Simulation: Incorporated the planned OX2 offshore wind farm Aurora. To model the wind farm, the Fitch parameterization scheme within WRF was used..

•Output: Extracted wind fields (10m wind speed and direction) from both simulations for use in wave modeling.

2) Wave Modeling with WaveWatch III:

•Input Data:
- Wind Fields: From the two WRF simulations.
- Bathymetry and Topography: ETOPO1 global relief model.

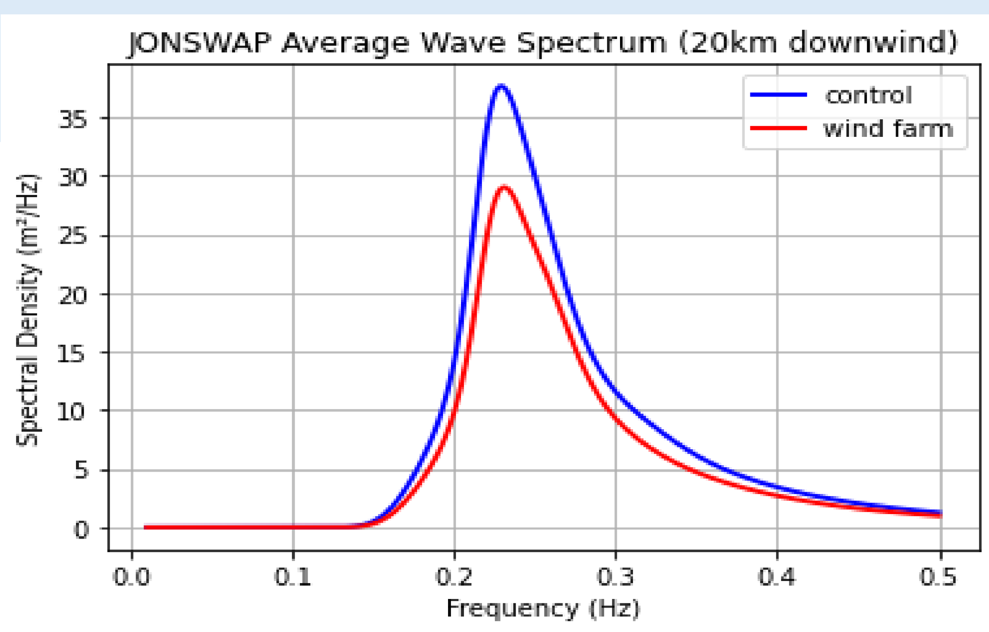
•Simulations:
- Control Simulation: Used wind fields from the control WRF simulation.
- Wind Farm Simulation: Used wind fields from the wind farm WRF simulation.

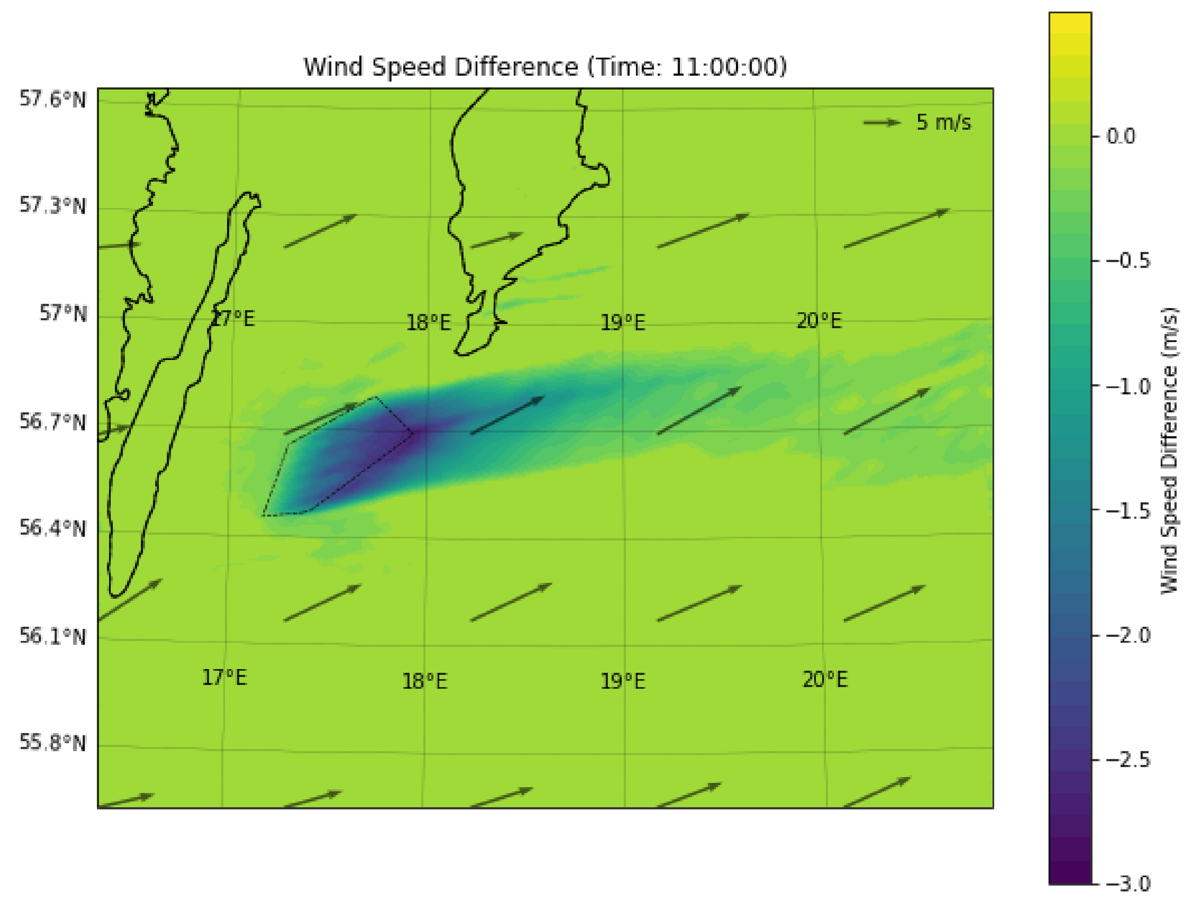
•Output Variables: Obtained wave variables that were analyzed and compared between the two simulations.

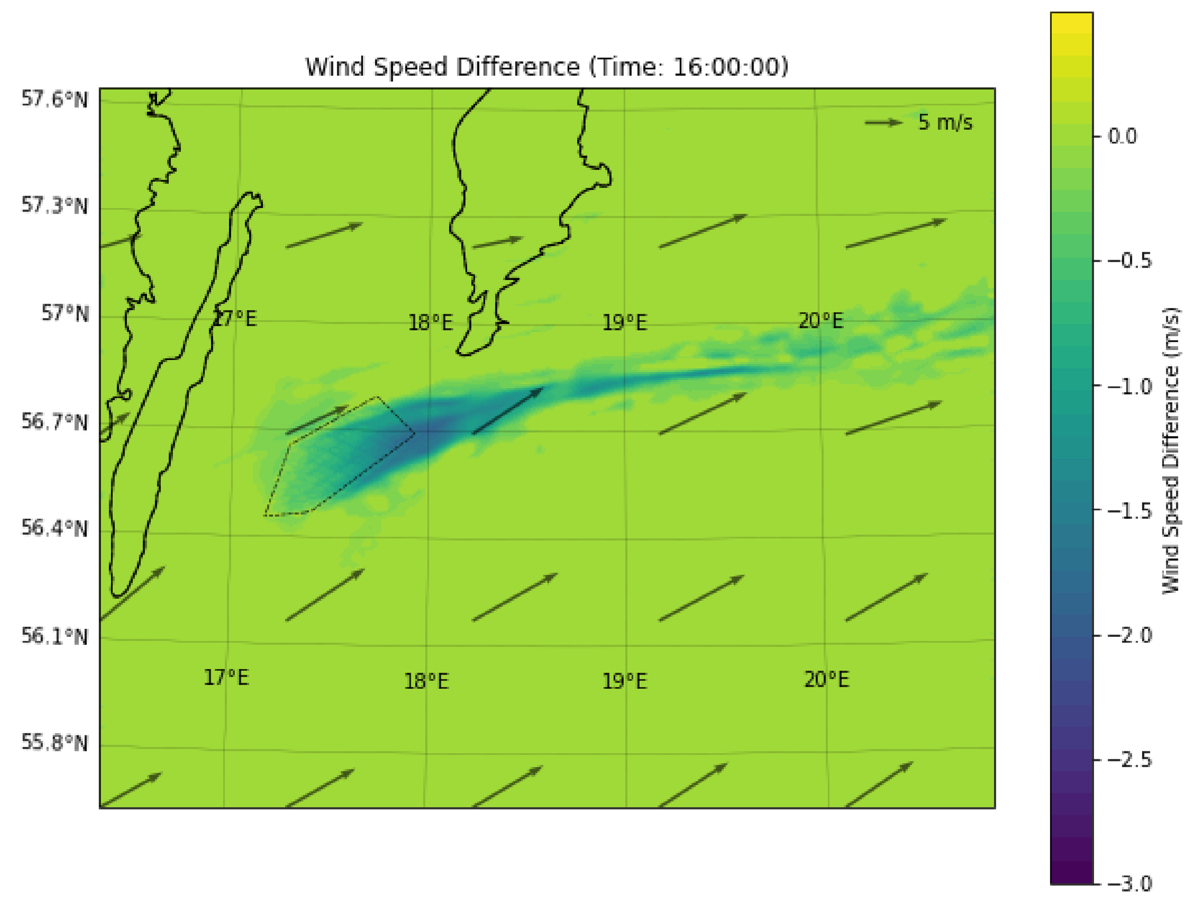
3 RESULTS

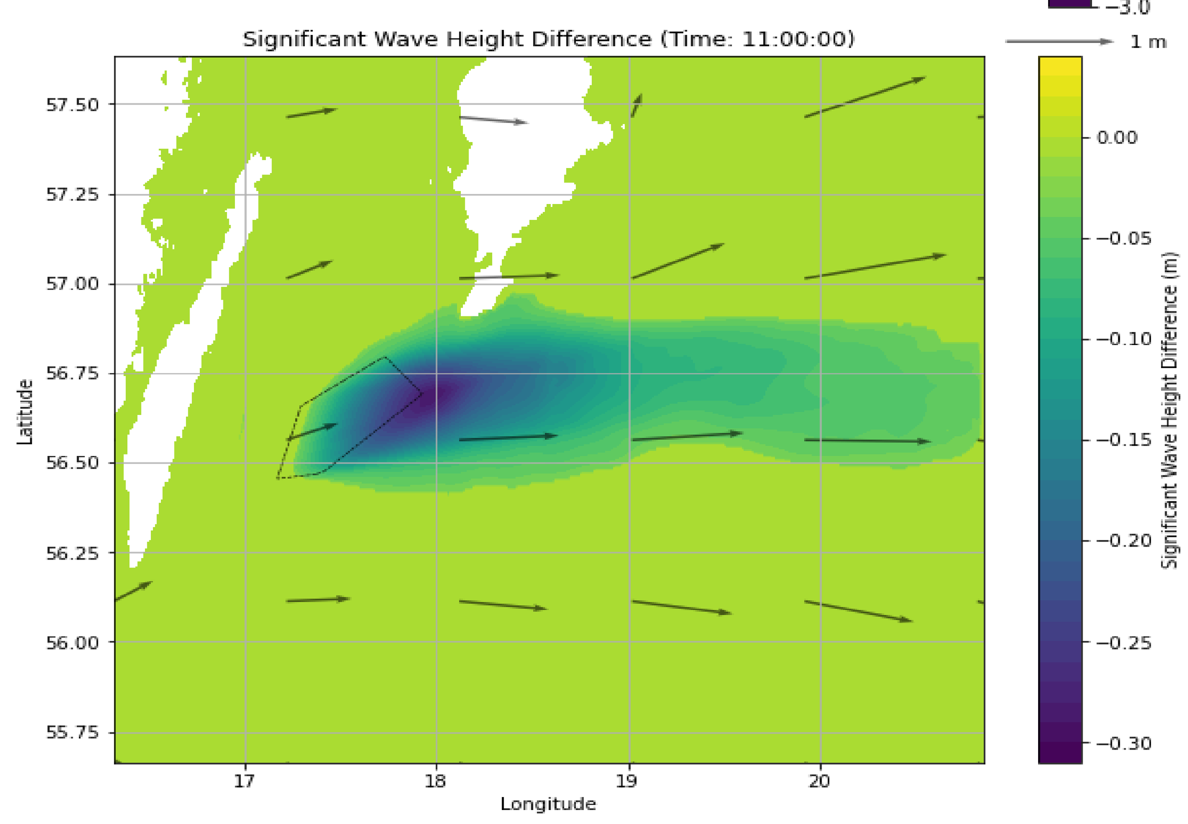
The results of the simulations indicate a noticeable impact of the offshore wind farm on wave characteristics, particularly significant wave height (Hs).

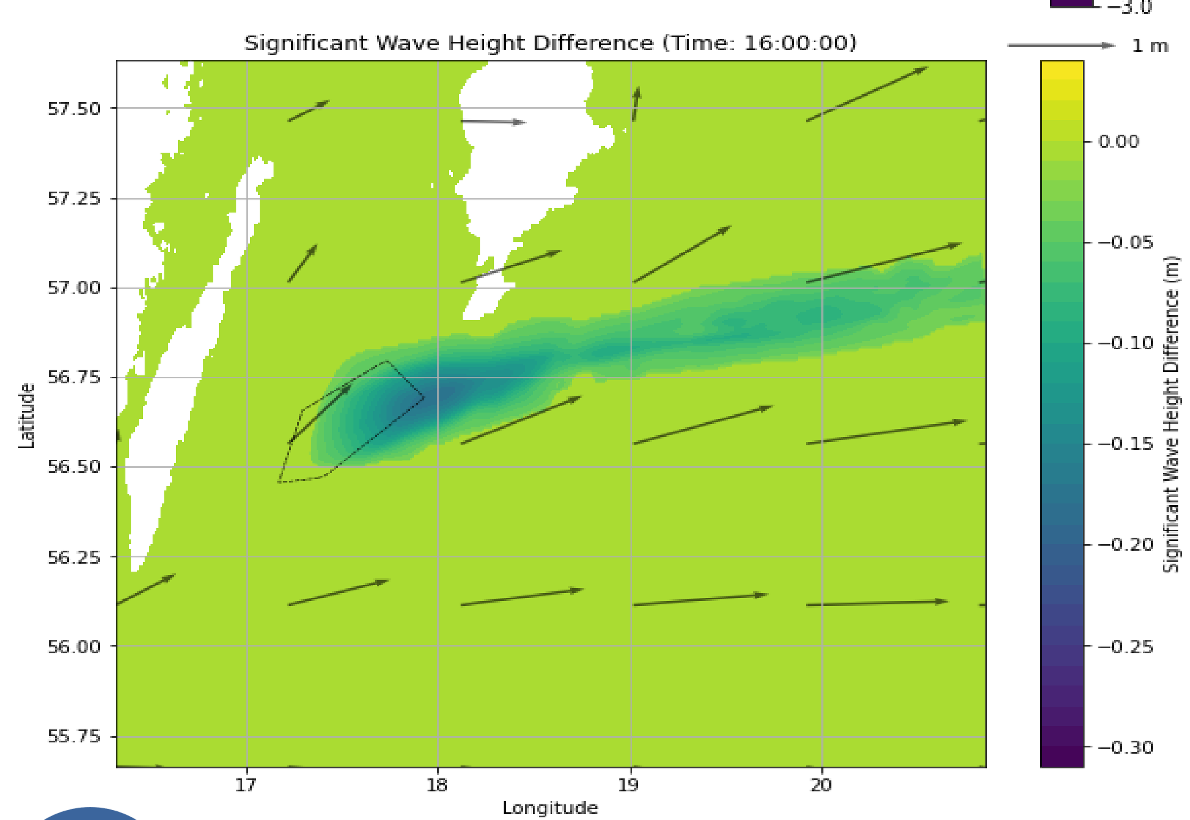
- The spatial maps show a reduction in Hs in the wake of the wind farm, with a maximum decrease of over 0.3 meters near the farm center.
- At the center of the farm, the mean percentage difference in Hs is -9.82%, while 20 km downwind, the reduction is more pronounced, with a mean difference of -12.54%. Further downwind at 85 km, the effect is still noticeable but diminished, with a mean difference of -2.63%.
- The period (Tm) shows a minor change, with the mean difference reaching only 0.5% and a maximum of 3%, while wave direction shows similarly minimal variation.
- The average wave spectrum at 20 km downwind shows a lower peak spectral density, indicating that the wind farm reduces wave energy in the dominant frequency range around 0.2-0.3 Hz.

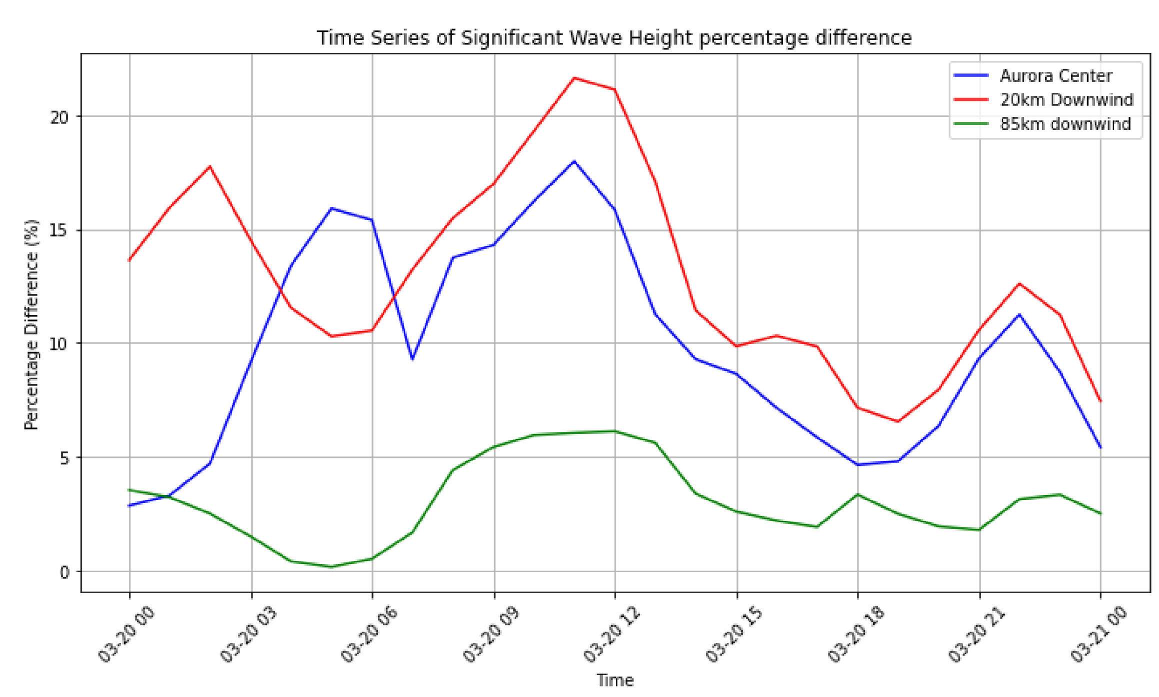












Acknowledgements

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4 ENVIRONMENTAL IMPACT/ FURTHER RESEARCH

This study shows that offshore wind farms can reduce wave heights which may influence local wave dynamics and coastal processes. The reduction in wave energy could potentially affect sediment transport, shoreline erosion, and marine habitats, as it might lead to reduced vertical mixing, potentially affecting local water temperatures and nutrient cycling. Further research is needed with longer simulations, to fully understand the long-term environmental impacts of these farms.