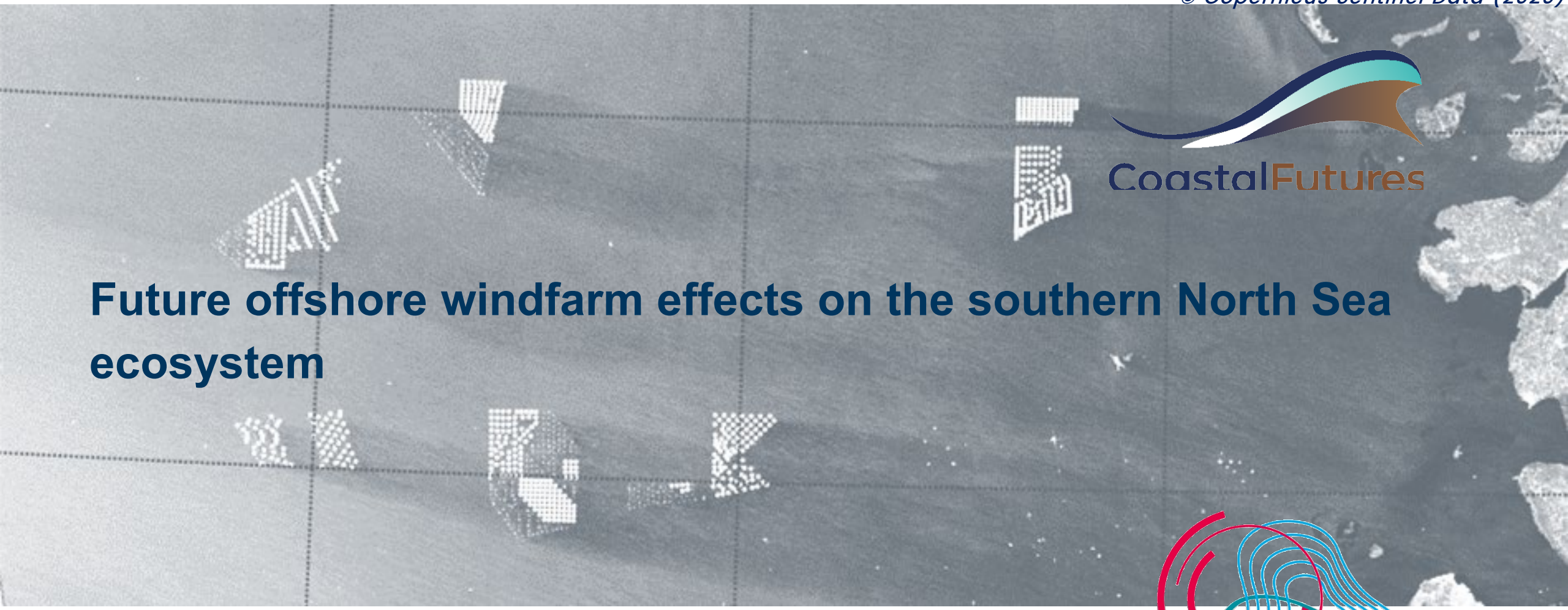

CoastalFutures

Future offshore windfarm effects on the southern North Sea ecosystem

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GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

DAM
DEUTSCHE ALLIANZ MEERESFORSCHUNG

Helmholtz-Zentrum hereon

Offshore Wind Energy Production – The Future

Hotspot North Sea

Future Development

Esbjerg Declaration: 150 GW by D, B, DK & NL, 20 GW H2 Elektrolysis capacity in 2030

Ostende Declaration: Establish the North Sea as Europe´s Green Power Plant

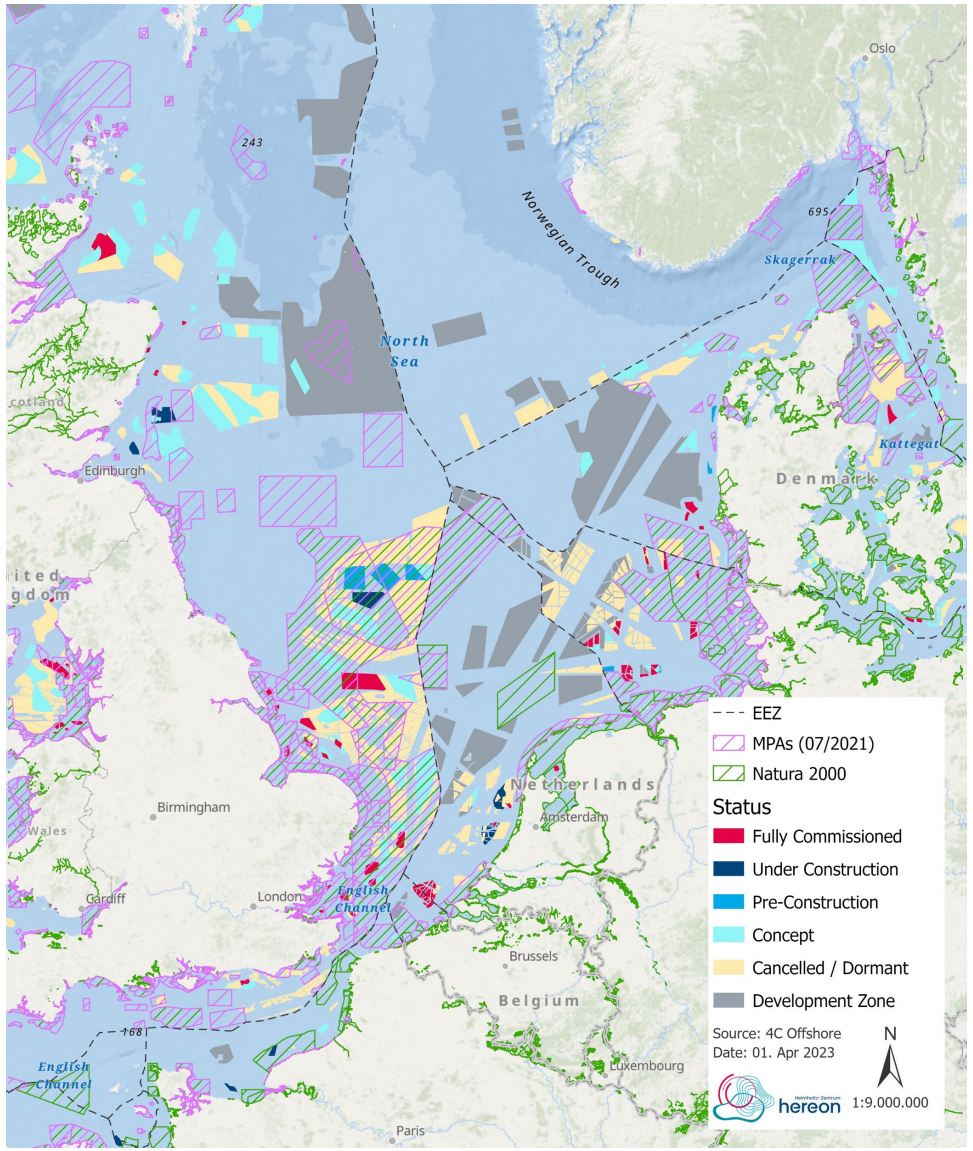
→ North Sea: 30 GW today, 118 GW in 2030

and >300 GW by 2050

-With increasing offshore wind energy production, wind farms become an integral part of the marine environment

Windspeed reduction due to energy extraction

Direct impacts by structures in the ocean



Atmospheric Wakes

Extraction of Energy by Wind Turbines – how strong is the effect?

From Satellite images

Wind wakes appear in 60% of the images

- Relative wind decrease 10-20%
- Up to 65 km in lee of OWF - depending on the athmospheric stability
- Superposition of wakes

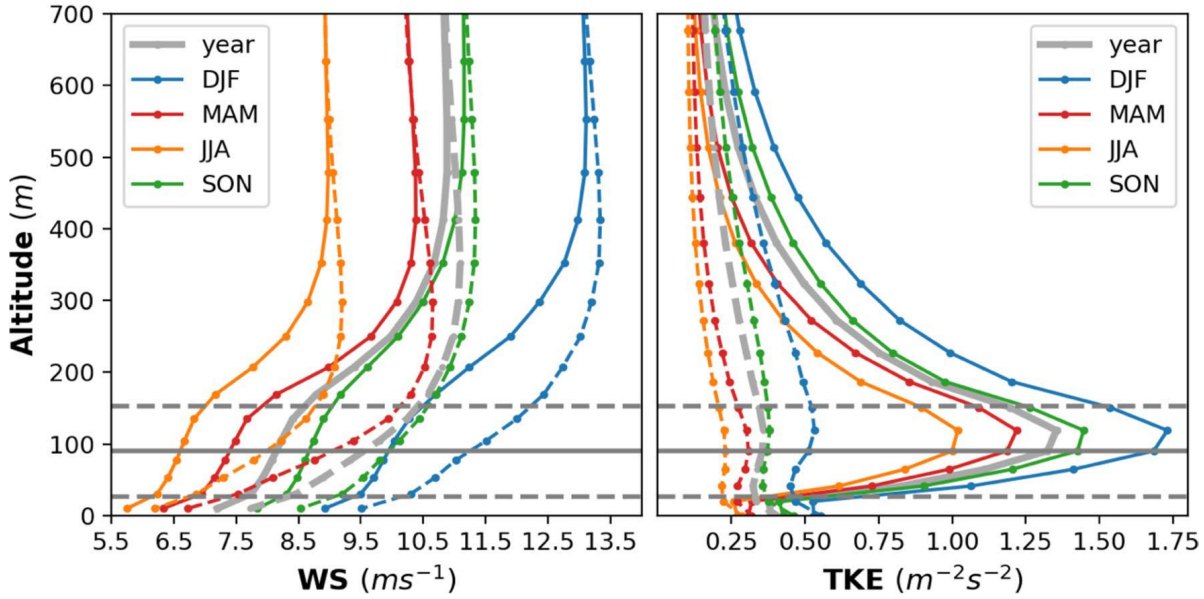


Fig. 3 | Wake Impact on Atmosphere

Akhtar et al., 2021

From numerical modelling

Generation of turbulent kinetic energy along atmospheric wakes

Alteration of wind forcing at the sea surface boundary

Akhtar, N., et al. Accelerating deployment of offshore wind energy alter wind climate and reduce future power generation potentials. Scientific Reports 11, 1–12 (2021).

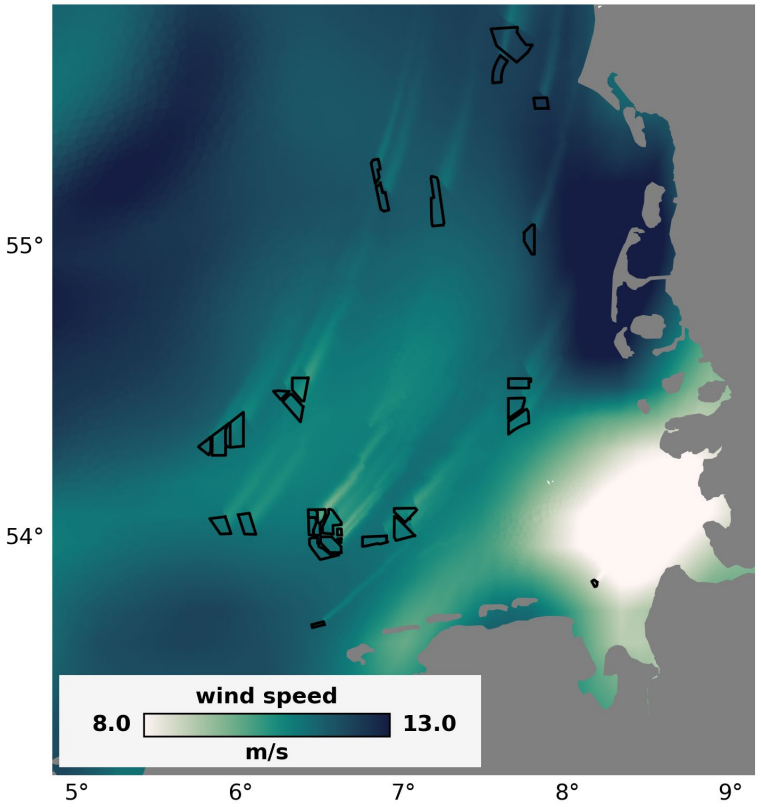
Djath et al. 2018; doi:10.1063/1.5020437; Djath & Schulz-Stellenfleth 2019:, doi:10.1127/metz/2019/0992. Platis et al. doi:10.1127/metz/2020/1023

Fig. 4 | Satellite wind wake example

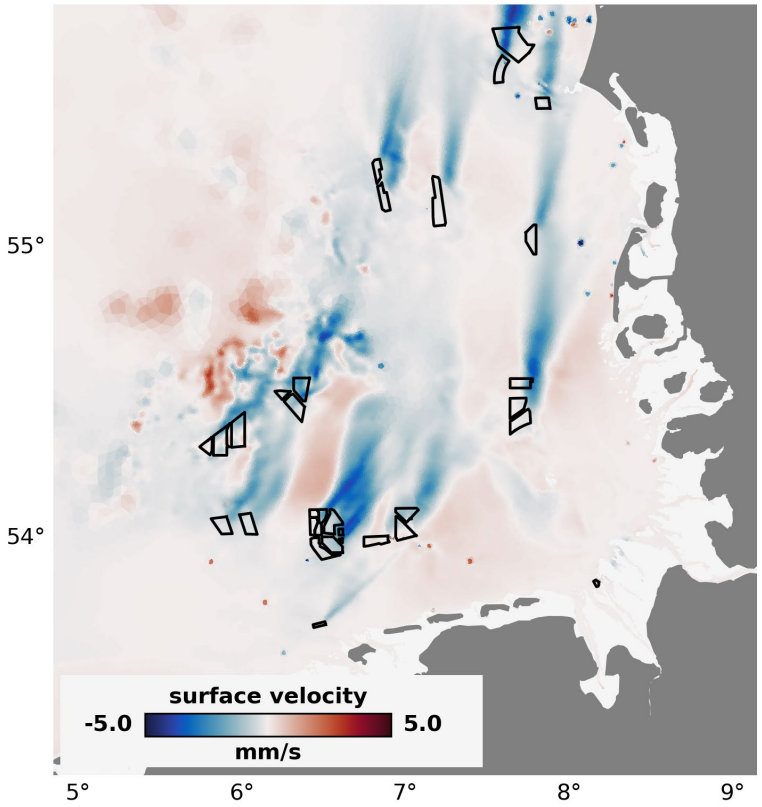
Current changes due to Energy extraction

Helmholtz-Zentrum hereon

Reduction in wind speed



Change in current velocities



Windenergy extraction

↓

Reduction of Windspeed at sea surface

↓

Change in sea surface currents

Christiansen et al. (2022), Emergence of Large-Scale Hydrodynamic Structures Due to Atmospheric Offshore Wind Farm Wakes, Front. Mar. Sci., https://doi.org/10.3389/fmars.2022.818501

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Wake Impact on Ocean Dynamics

Large-scale interrelated Anomalies

May - Sep

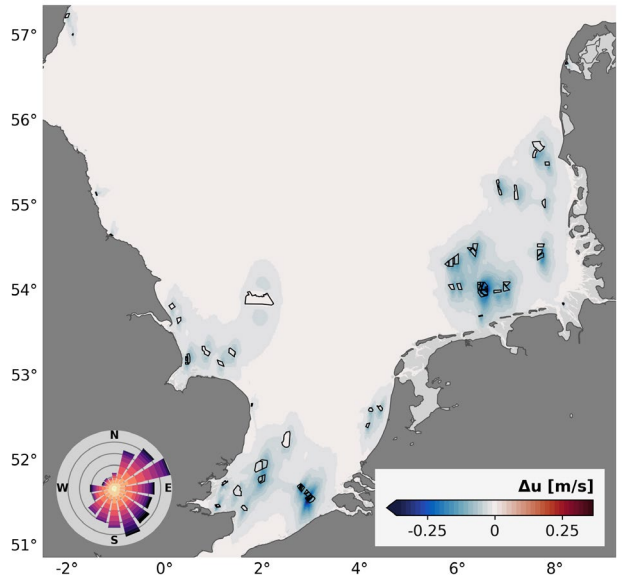


Fig. 12 | Mean change in wind speed

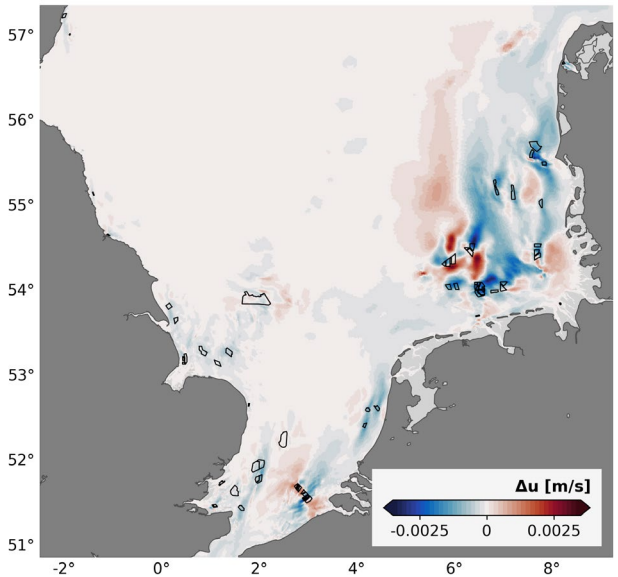


Fig. 13 | Mean change in horizontal flow

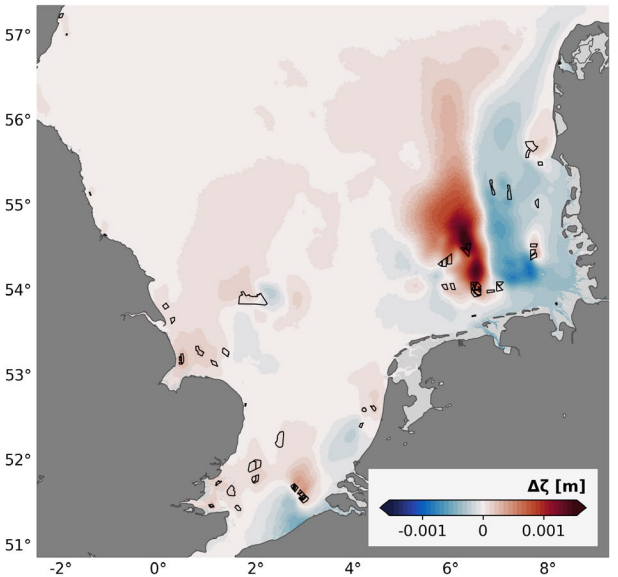


Fig. 14 | Mean change in sea level

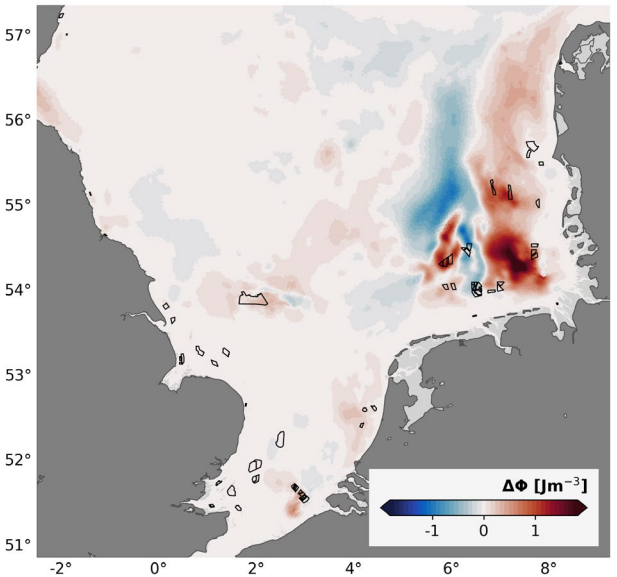


Fig. 15 | Mean change in stratification

Large areas of reduced wind speed | Change in wind forcing

Adaptation of sea surface elevation | Baroclinic changes

Anomalies in horizontal flow | Attenuation of wind-driven processes

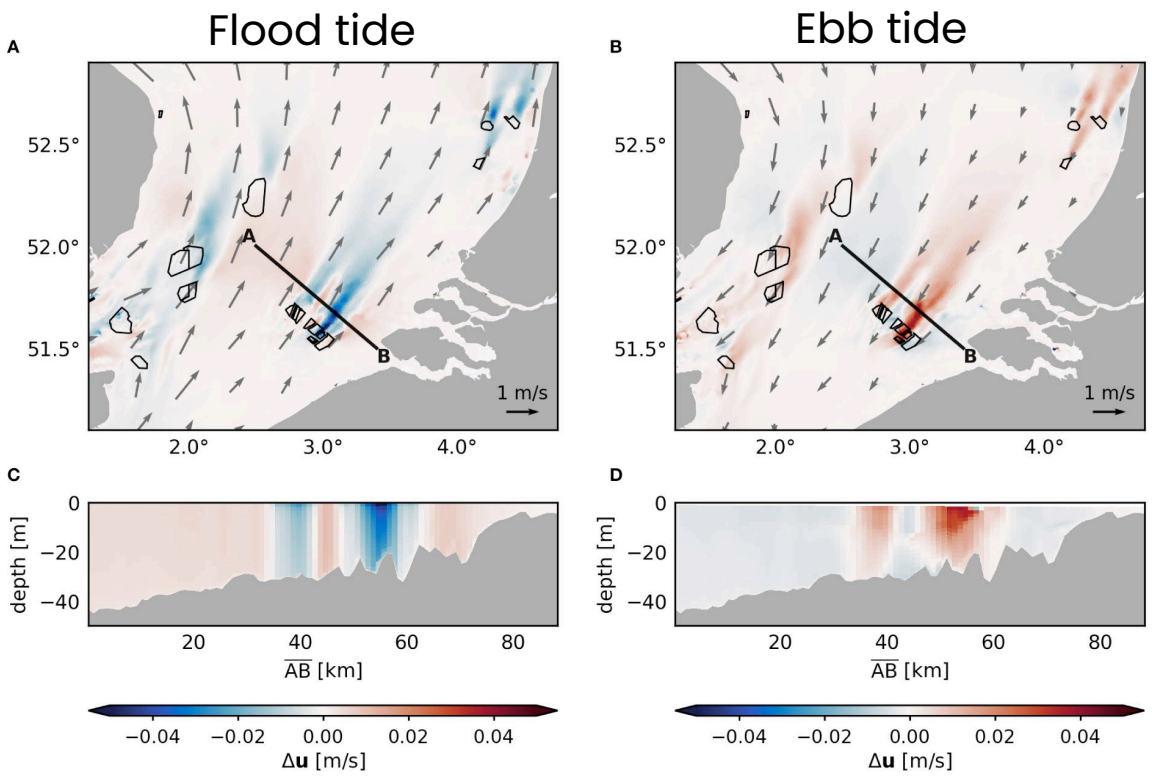
Impact on stratification development | Reduction of vertical mixing

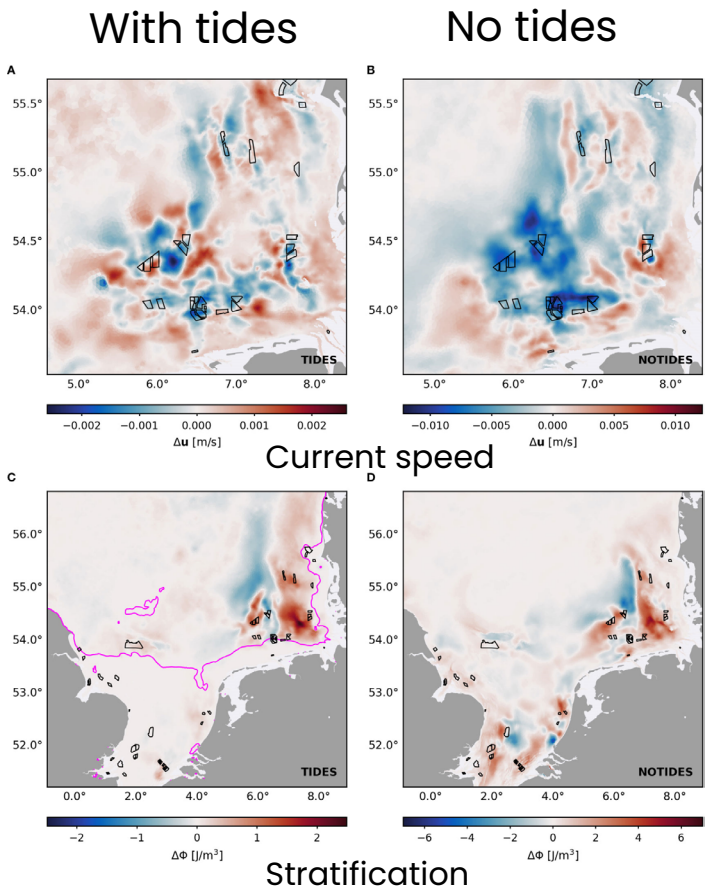
Christiansen, N., et al. Emergence of Large-Scale Hydrodynamic Structures Due to Atmospheric Offshore Wind Farm Wakes. Front Mar Sci 9, 1–17 (2022).

Influence of Tides

Large-scale interrelated Anomalies

Horizontal velocity changes Δu in the tidal scenario

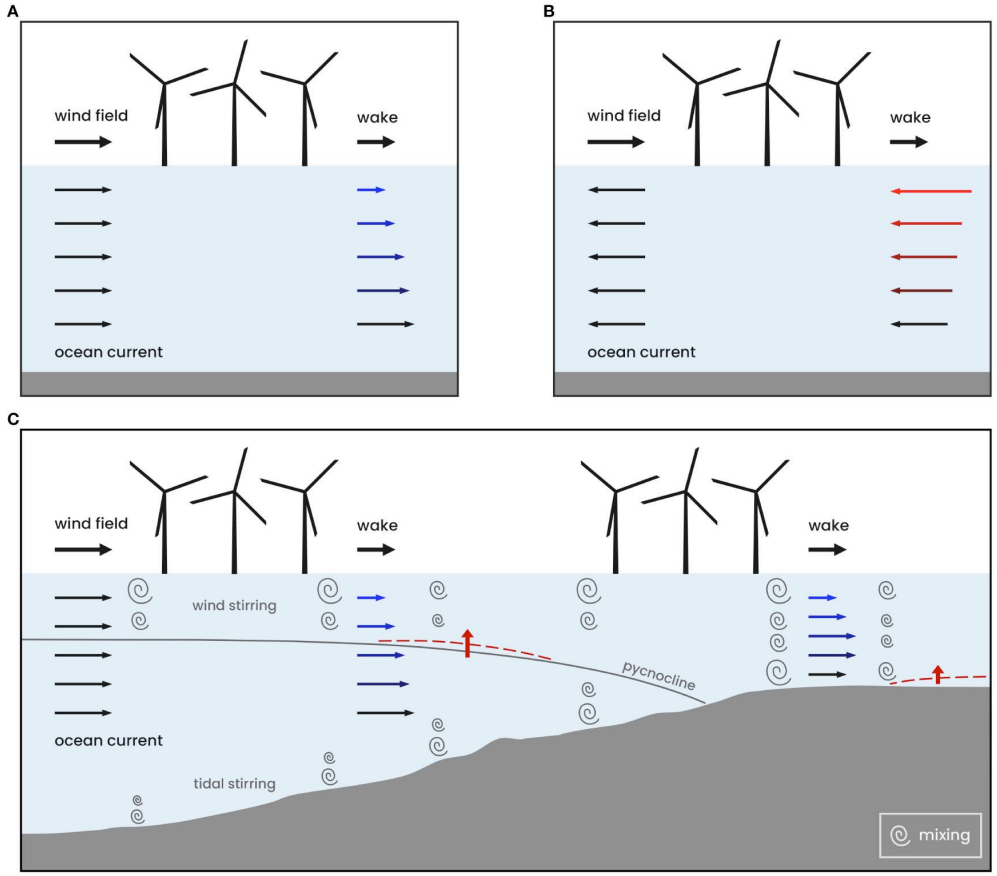




Christiansen N, Daewel U and Schrum C (2022) Tidal mitigation of offshore wind wake effects in coastal seas. Front. Mar. Sci. 9:1006647. doi: 10.3389/fmars.2022.1006647

Influence of Tides

Large-scale interrelated Anomalies



periodic tidal currents can mitigate the impact of the wind speed reduction over time due to opposing changes in the horizontal flow

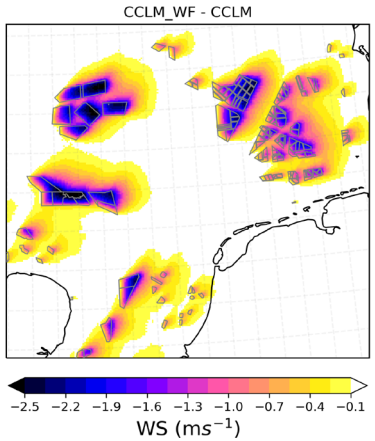
in well-mixed waters tidal stirring can influence the effects on vertical transport and attenuate the impact on temperature and salinity stratification

Christiansen N, Daewel U and Schrum C (2022) Tidal mitigation of offshore wind wake effects in coastal seas. Front. Mar. Sci. 9:1006647. doi: 10.3389/fmars.2022.1006647

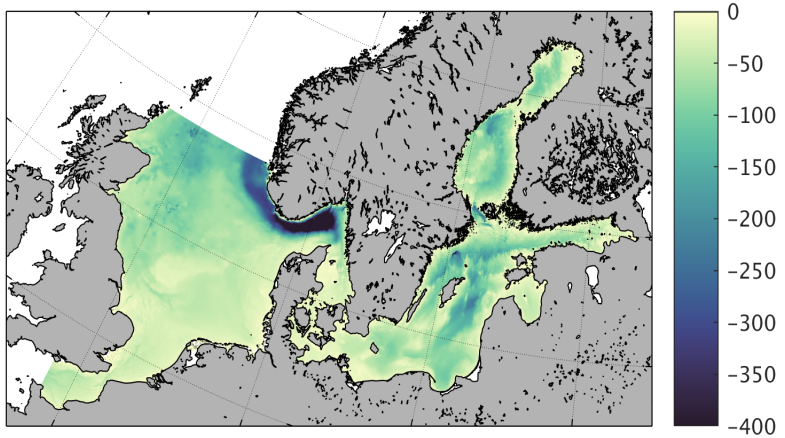
Windfarm effects upscaling to southern North Sea and impacts ecosystem productivity

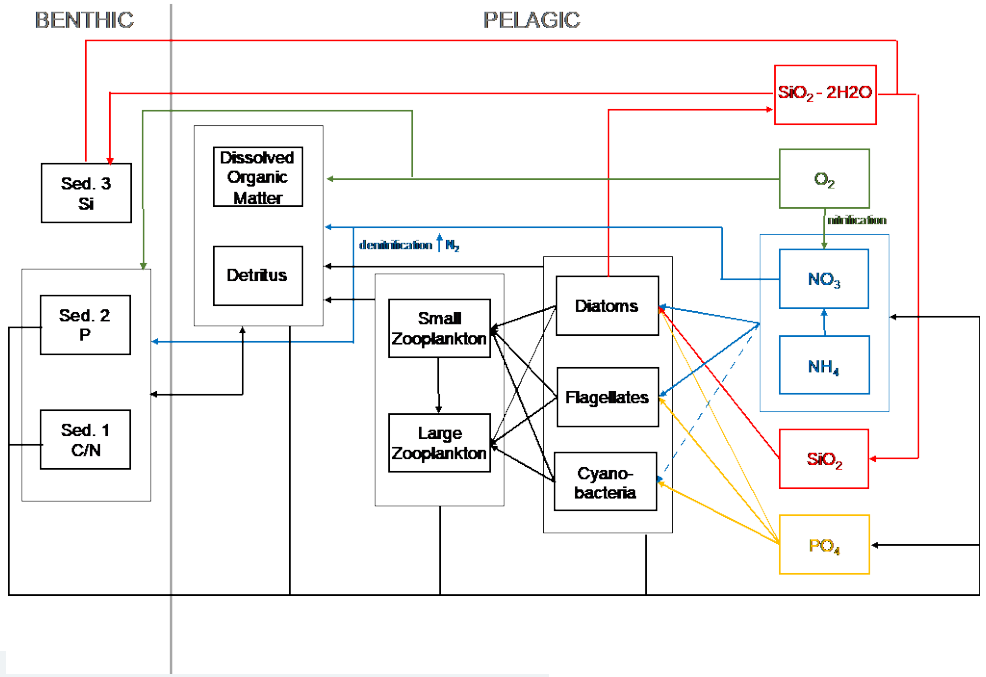
COSMO CLM + WF

ECOSMO



Akhtar et al., 2021;





Fully coupled physical-biogeochemical model -2km - 2010

REF: Reference Forcing COSMO-CLM without OWF parametrization

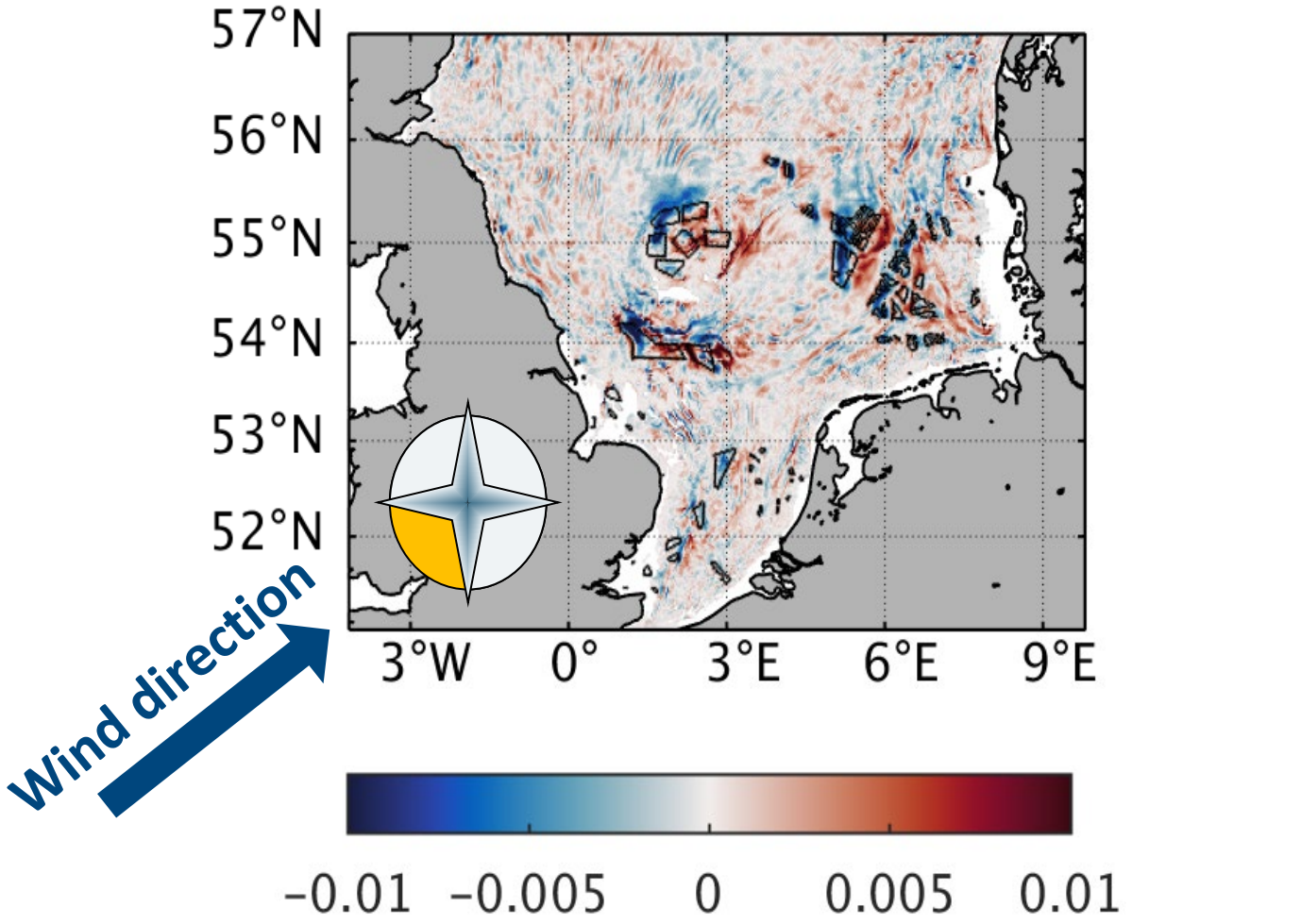
OWF: Scenario COSMO-CLM with OWF parameterization

Spinup 2008-2009 with reference forcing

Daewel, U., et al. Offshore wind farms are projected to impact primary production and bottom water deoxygenation in the North Sea. Commun Earth Environ 3, 1–8 (2022).

Akhtar, N., et al. Accelerating deployment of offshore wind energy alter wind climate and reduce future power generation potentials. Scientific Reports 11, 1–12 (2021).

Estimated Change in vertical velocities



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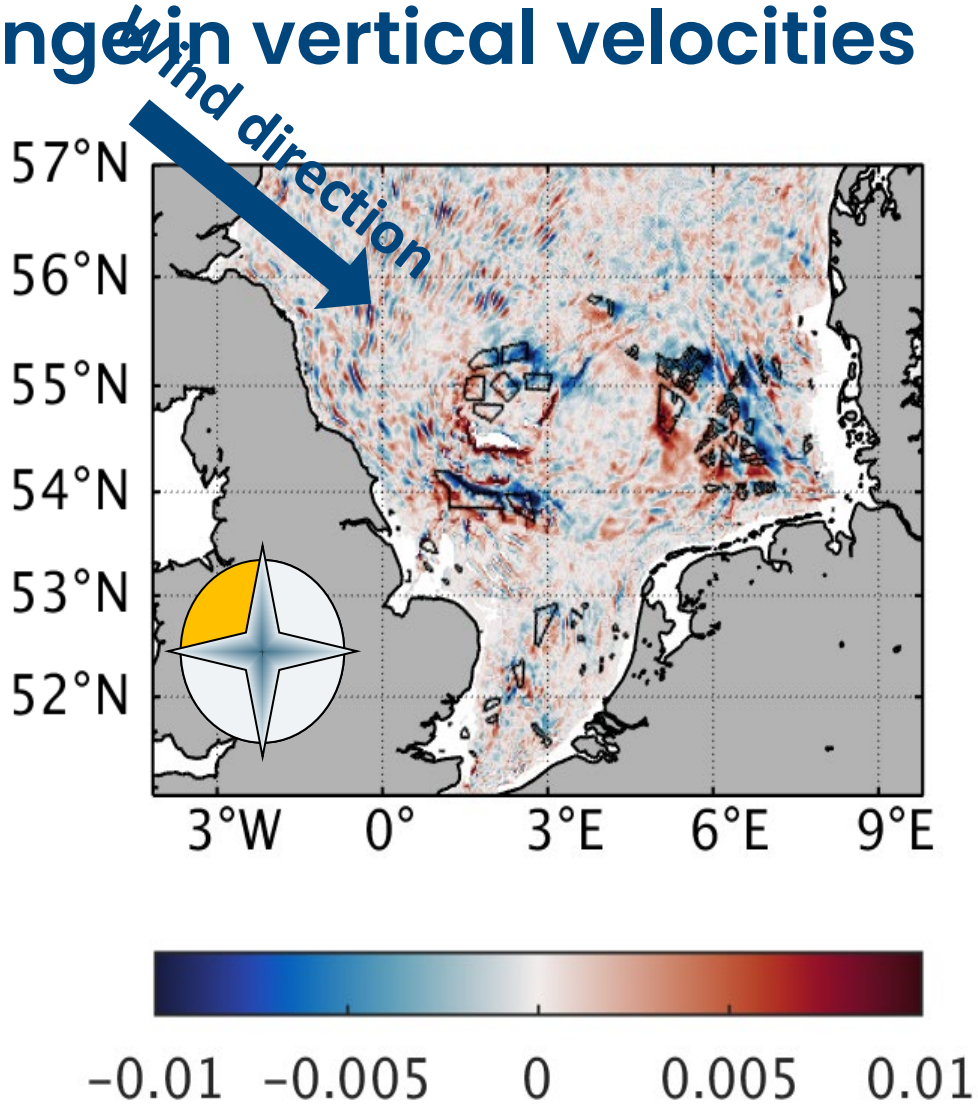
Estimated Change in vertical velocities



downwelling **upwelling**

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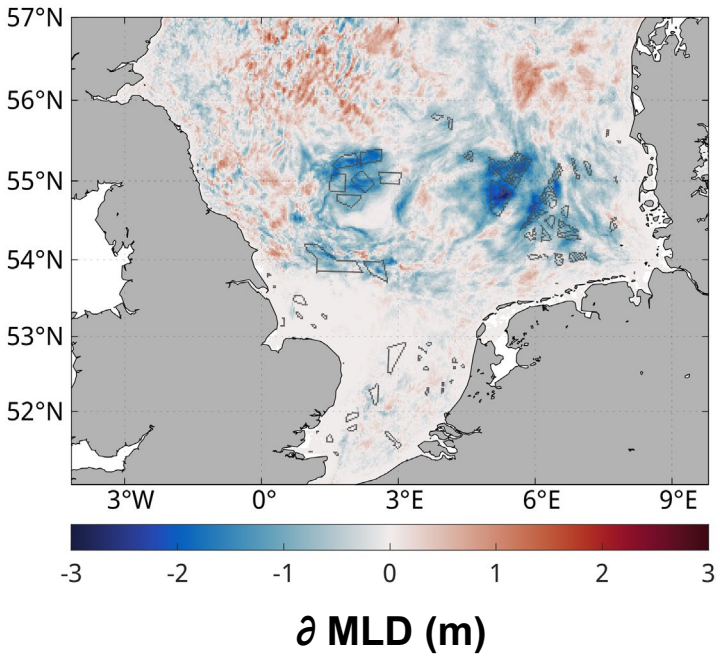
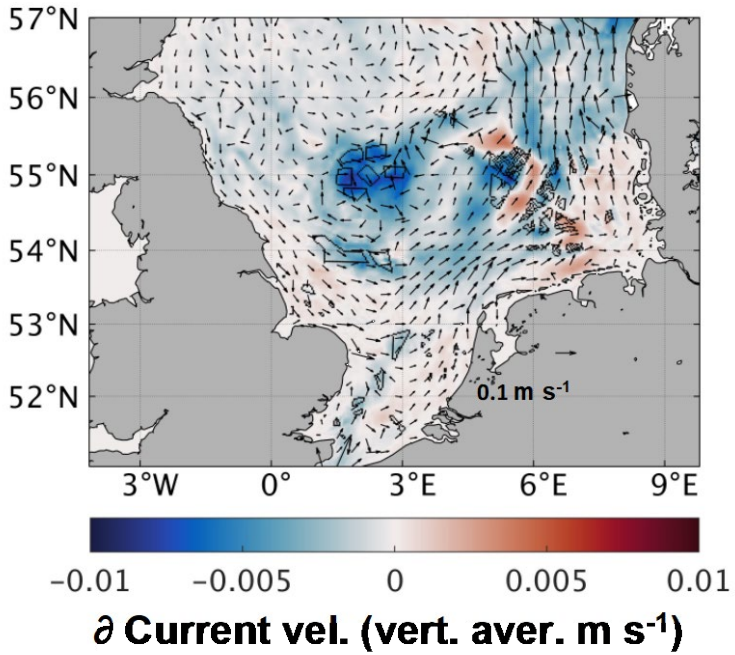
Wind wake effects on mean ocean state

Annual average in MLD and vertically averaged current velocities (OWF-REF)





Decrease in MLD at and around the OWFs due to decreased mixing

General reduction in residual current in the deeper areas of the southern NS

Local increase in current velocities

Daewel, U., et al. Offshore wind farms are projected to impact primary production and bottom water deoxygenation in the North Sea. Commun Earth Environ 3, 1–8 (2022).

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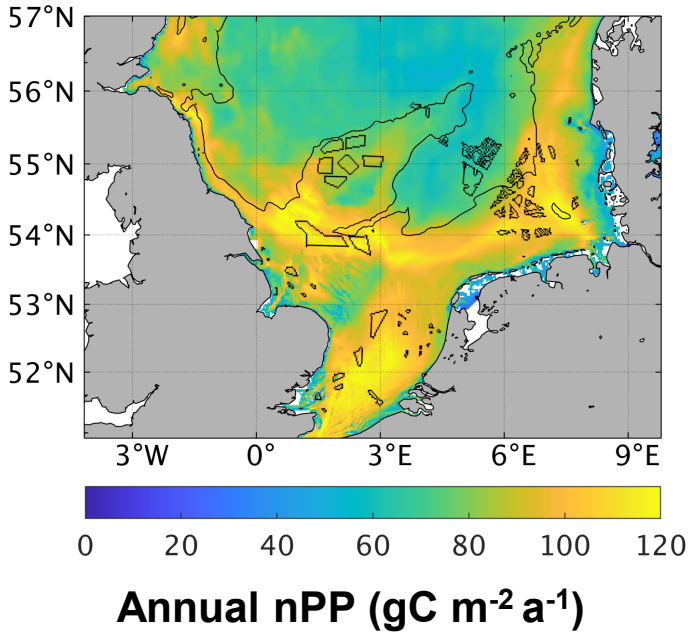
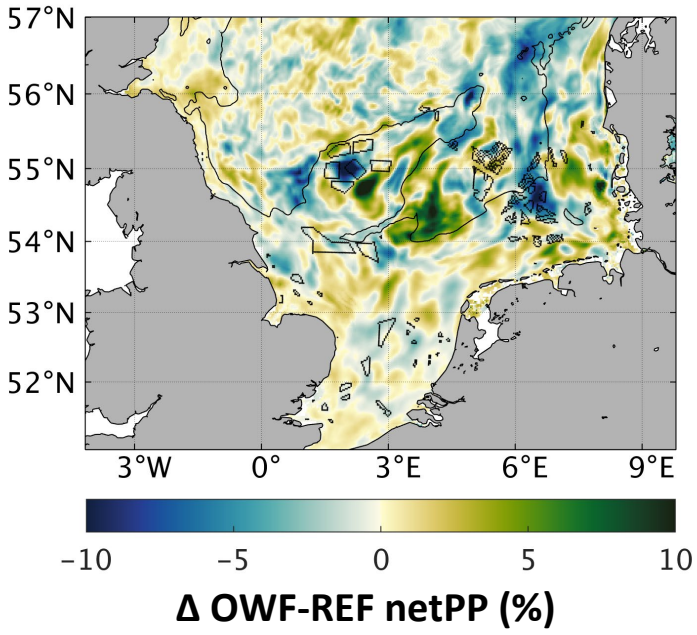
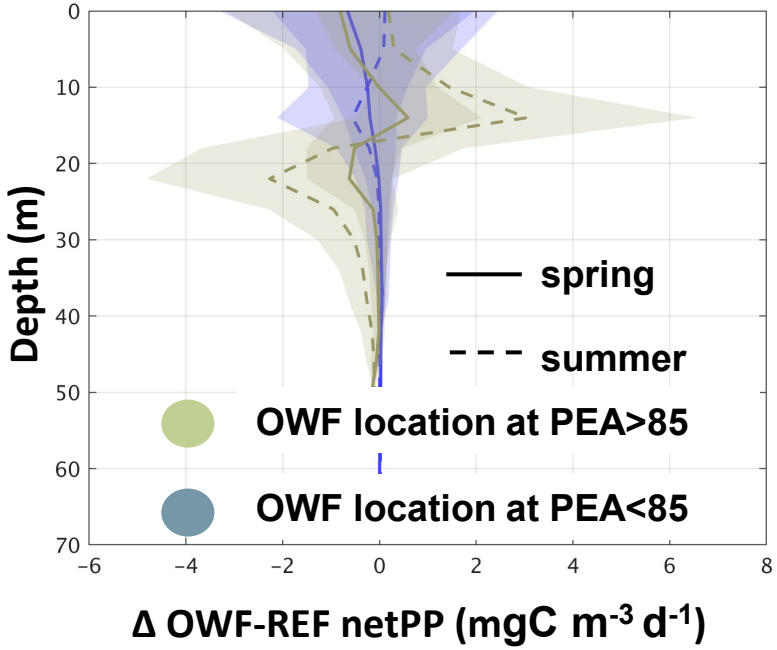
Windfarm effects on mean primary production







local increase & decrease in NPP of up to 10% while mean regional wide change is <1%

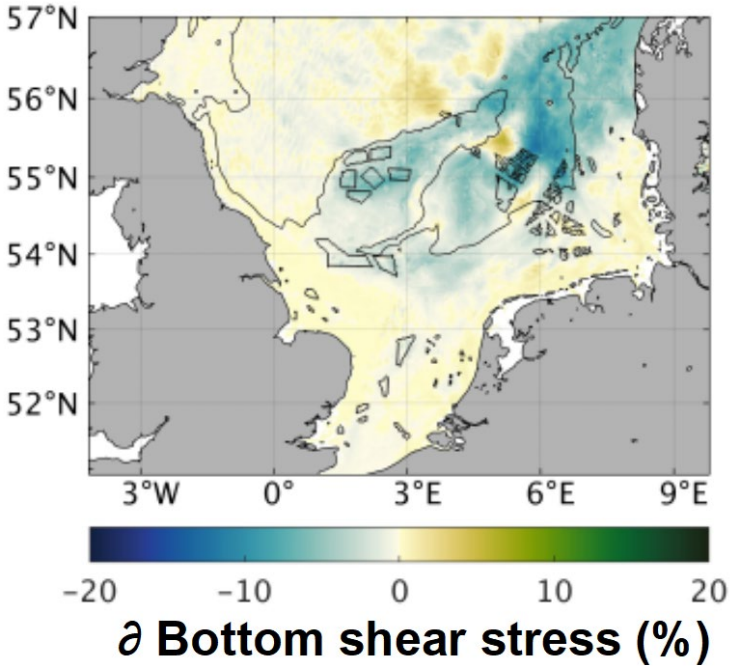
Mimima at the OWFs located inside frontal areas

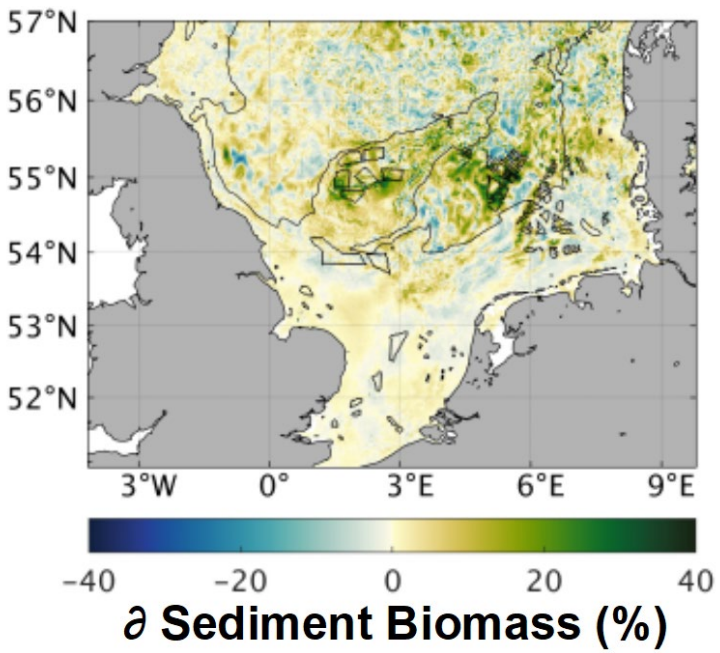
Change in horizontal & vertical distributional pattern

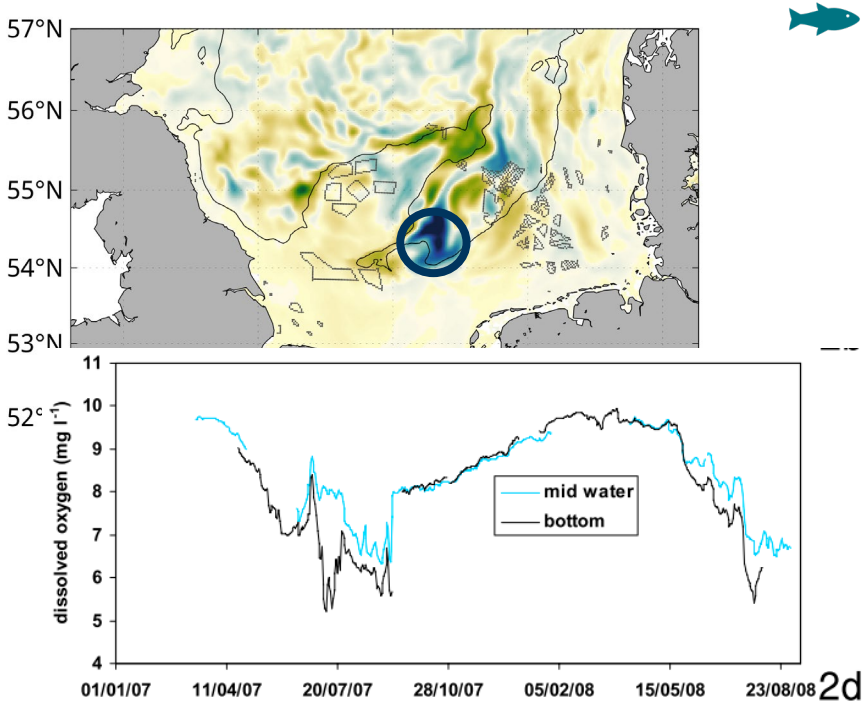
Daewel, U., et al. Offshore wind farms are projected to impact primary production and bottom water deoxygenation in the North Sea. Commun Earth Environ 3, 1–8 (2022).

Windwake effects on the ecosystem

Changes at the seafloor(OWF-REF)







Mooring data from Oyster Ground, Greenwood et al. 2010

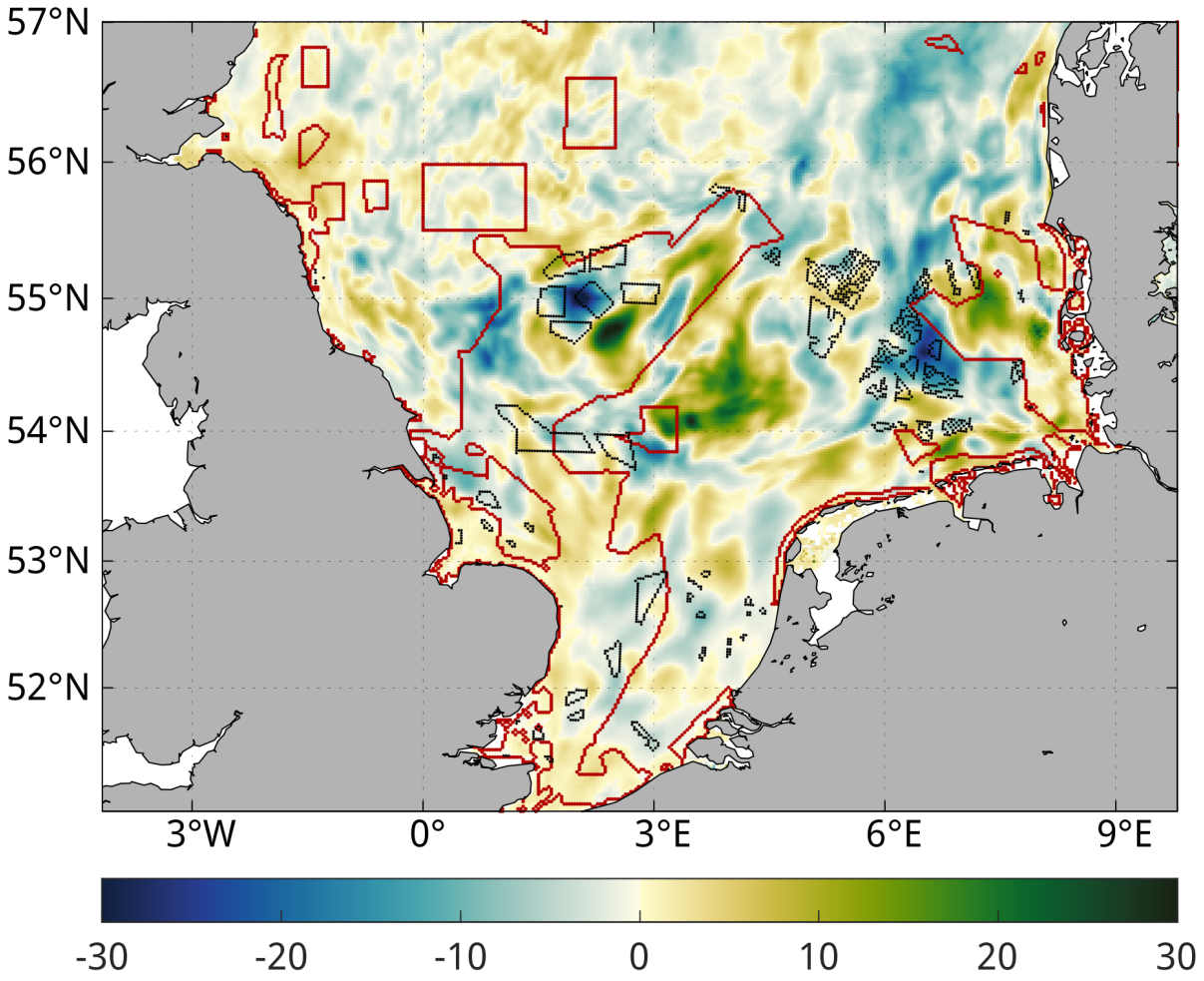
Mimima at the OWFs located inside frontal areas

Re-distribution of organic carbon sediments

Reduction in bottom water oxygen at Oyster grounds (and area, where oxygen can become critical)

Greenwood, N. et al. Detection of low bottom water oxygen concentrations in the North Sea; Implications for monitoring and assessment of ecosystem health. Biogeosciences 7, 1357–1373 (2010). https://doi.org/10.5194/bg-7-1357-2010, 2010.

Impacts on ecosystems in MPAs



Δ OWF-REF netPP (mgC m-2 d-1)

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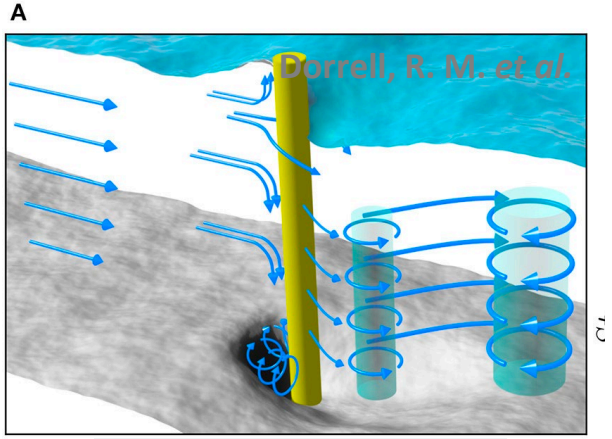
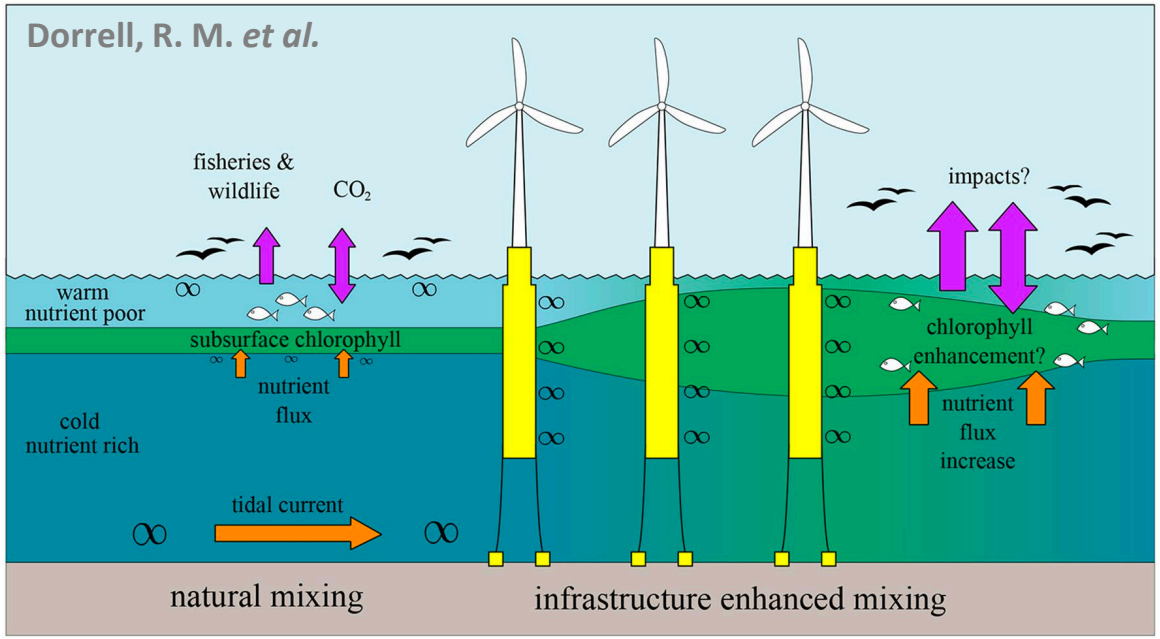
Effects on the marine environment

Direct impacts due to structures in the Ocean



Ocean current wakes (1-2 km)



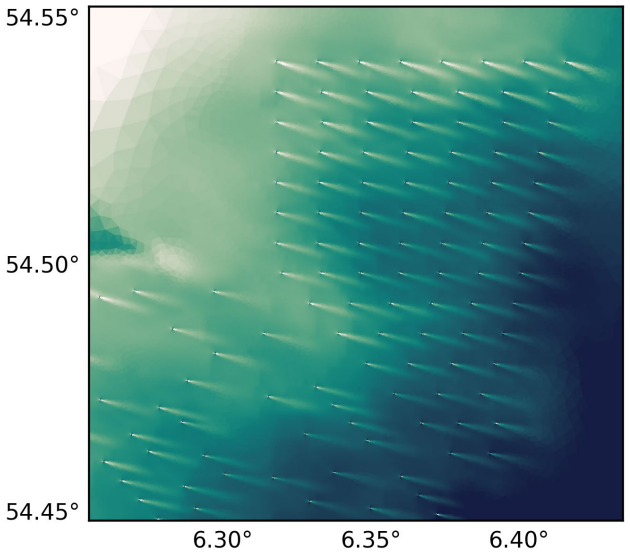
Increased turbulence and mixing behind the turbine in stratified waters - destratification, upward mixing of nutrients, increased productivity

Dorrell, R. M. *et al.* Anthropogenic Mixing in Seasonally Stratified Shelf Seas by Offshore Wind Farm Infrastructure. *Front Mar Sci* 9, 1–25 (2022).

Forster, R. M. *The effect of monopile-induced turbulence on local suspended sediment pattern around UK wind farms. An IECS report to The Crown Estate. ISBN*. (2018).

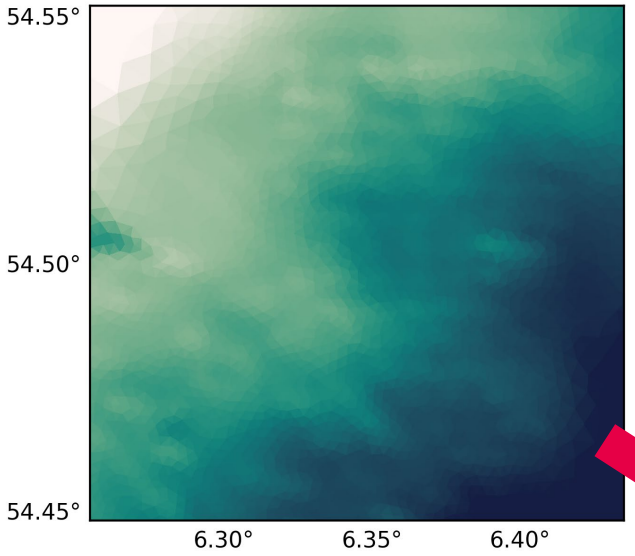
Parameterization of structure-induced mixing on different scales

Explicit integration in grid

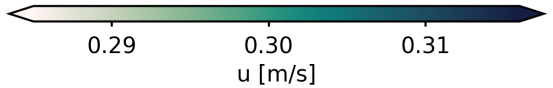


4 - 1000 m

Drag parameterization

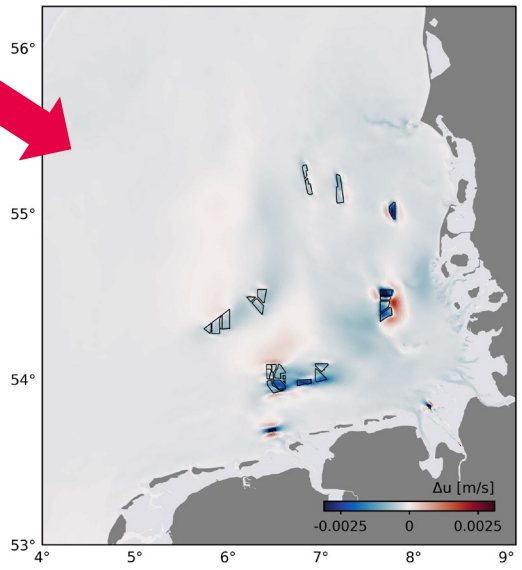


250 - 1000 m

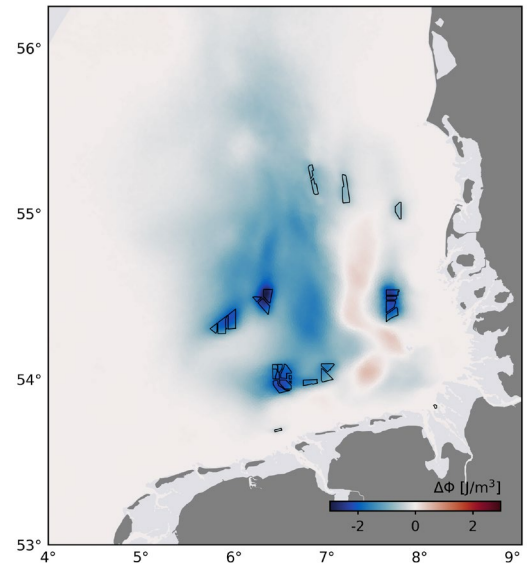


-same order of magnitude as the wind wake effects

Current Speed Changes



Stratification Changes



1000 m resolution @ OWFs, averaged between May-September

Christiansen N, et al. (2023) The large- scale impact of anthropogenic mixing by offshore wind turbine foundations in the shallow North Sea. Front. Mar. Sci. 10:1178330. doi: 10.3389/fmars.2023.1178330

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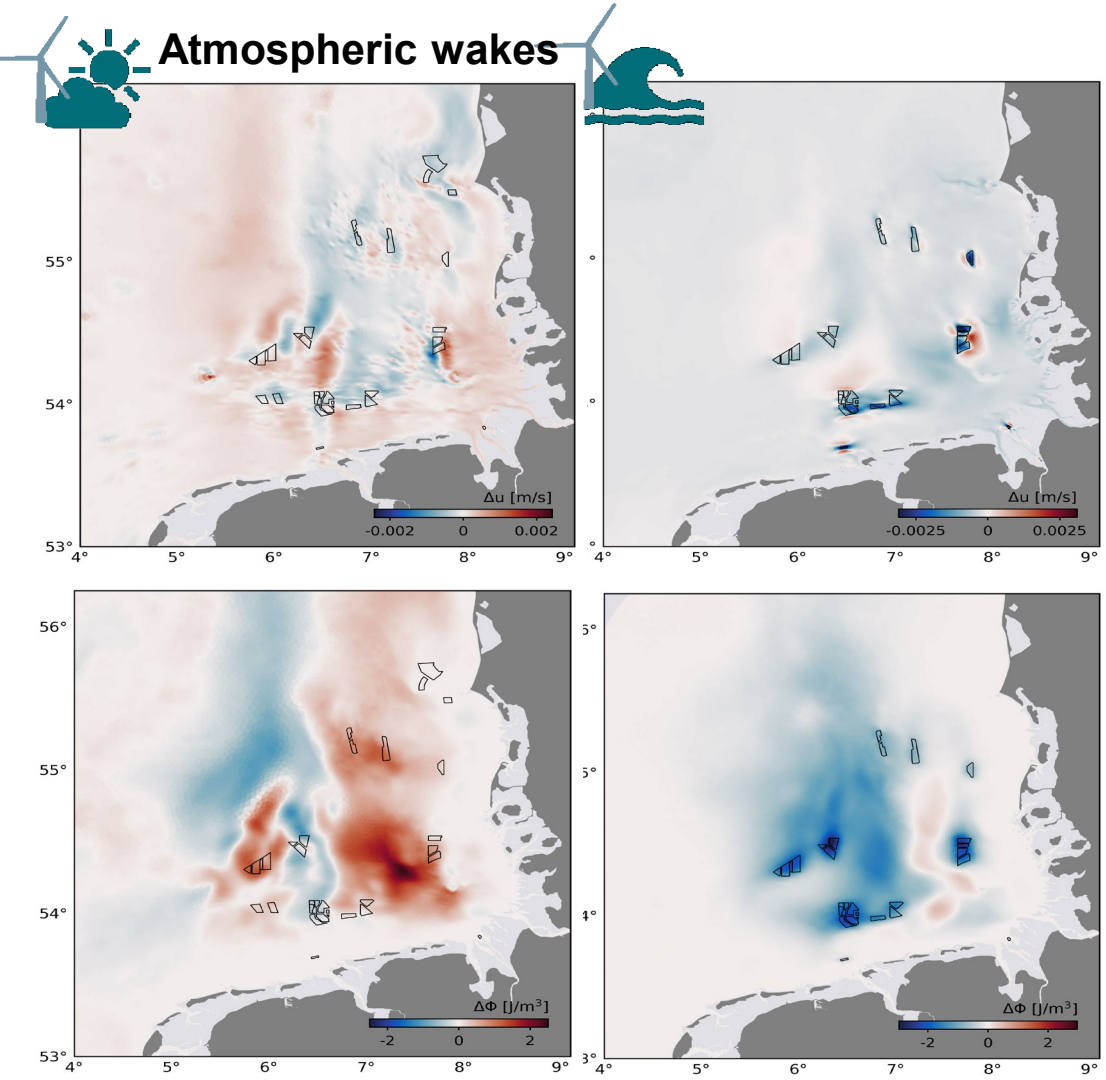
Impact of atmospheric wakes versus impact of oceanic mixing through the pile effect

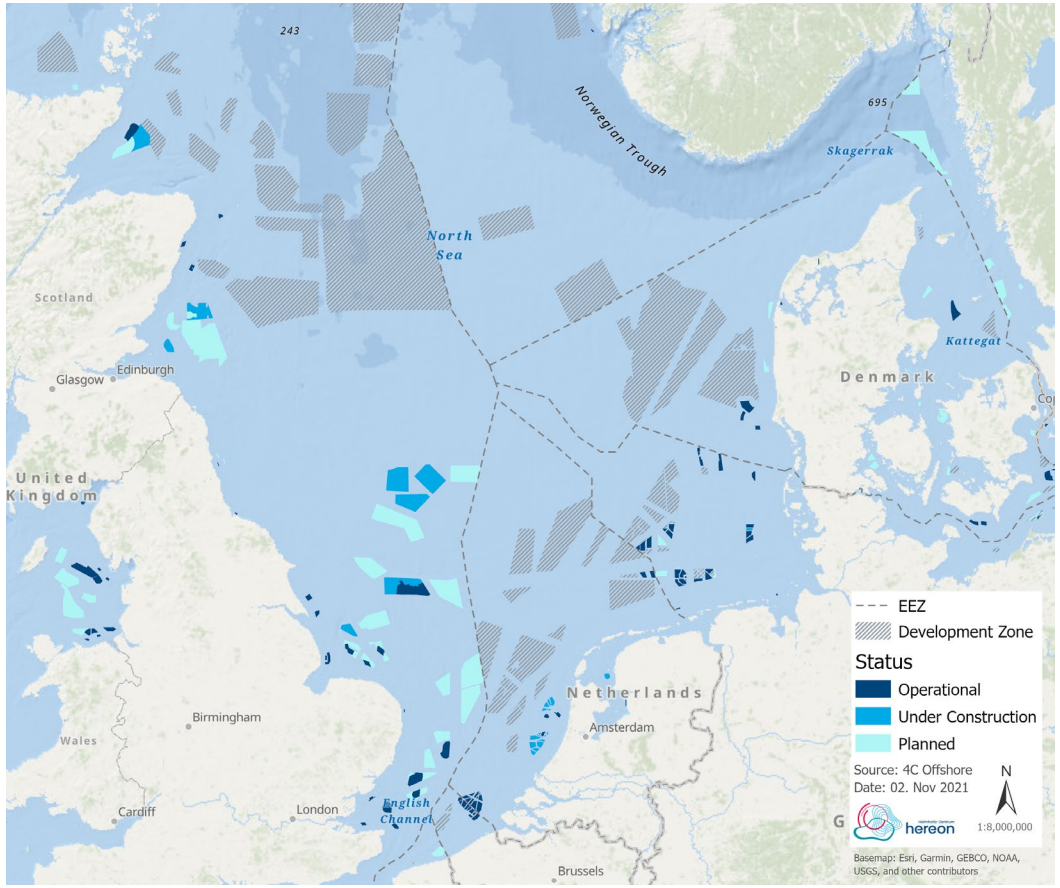


- Both disturbance effects are of a similar magnitude
- The residual flows are reduced by both effects
- The effects on stratification are opposite

Christiansen N, et al. (2023) The large- scale impact of anthropogenic mixing by offshore wind turbine foundations in the shallow North Sea. Front. Mar. Sci. 10:1178330. doi: 10.3389/fmars.2023.1178330

Summary

- OWF **alter physical conditions** in atmosphere and ocean
- Attenuation of wind forcing results in **large-scale anomalies** in the horizontal flow, affecting surface elevation and density distribution
- The Ecosystem responds with **large-scale structural changes** in (among others) **productivity, carbon sediment and bottom water oxygen**
- **Far field effects also impact areas without direct offshore windfarm constructions like e.g. Marine Protected Areas**



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What we do not know!

Is that a good or a bad thing?

What is the impact on the HTL / Fish / Benthos?

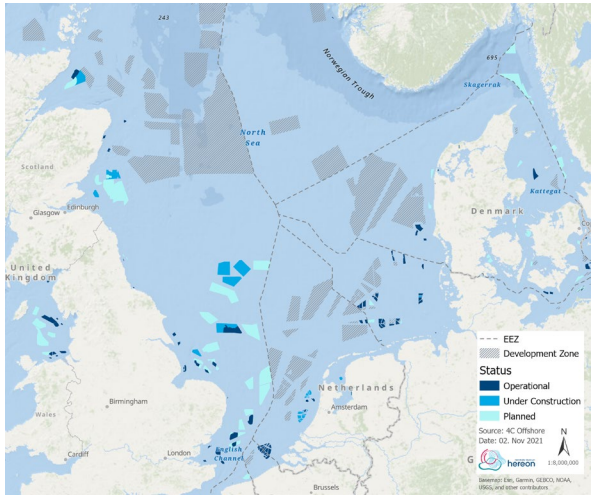
How do wind-wakes and ocean wakes interact?

How large are the interannual interactions?

How does that change with climate change impacts?

....

....



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