X-Wakes

Recent results from modelling and measurements of large-scale wakes in interaction with the marine atmospheric boundary layer

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and The X-Wakes Consortium

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

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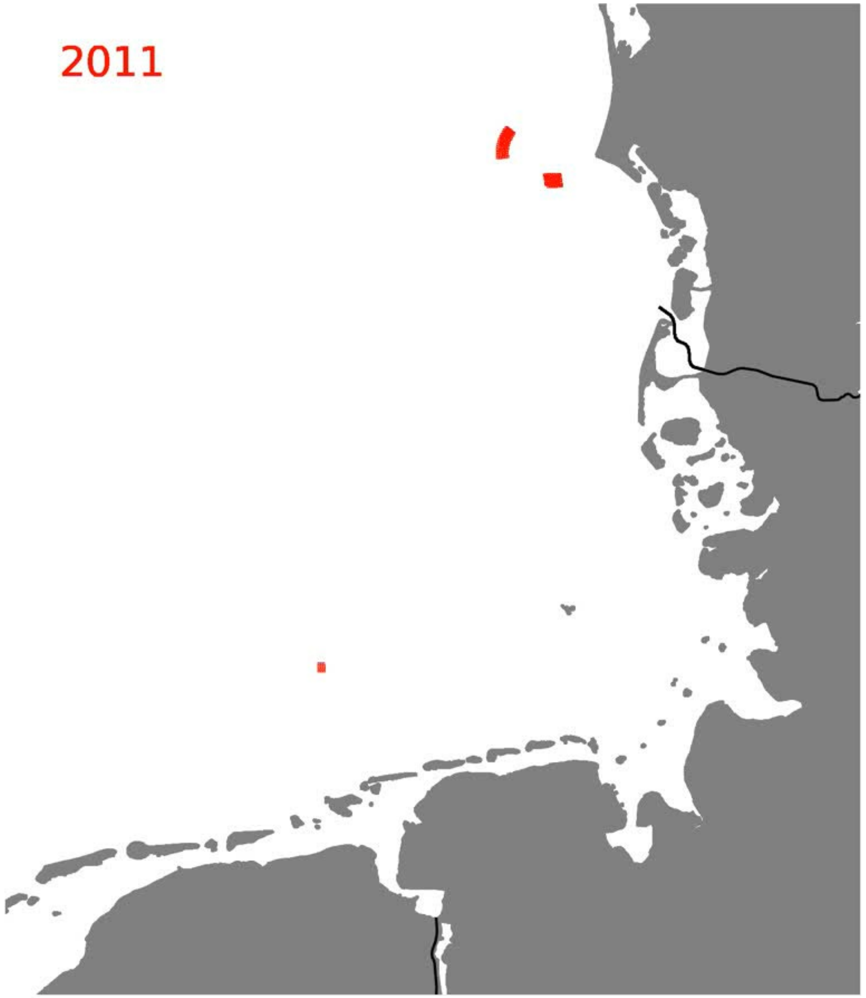
Motivation

Offshore Wind Energy in the German Bight

- Germany currently has second largest capacity of offshore wind farms connected to the grid
- Currently 7.7 GW out of which 6 GW are located in the German Bight



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Motivation

Offshore Wind Energy in the German Bight

- Germany currently has second largest capacity of offshore wind farms connected to the grid

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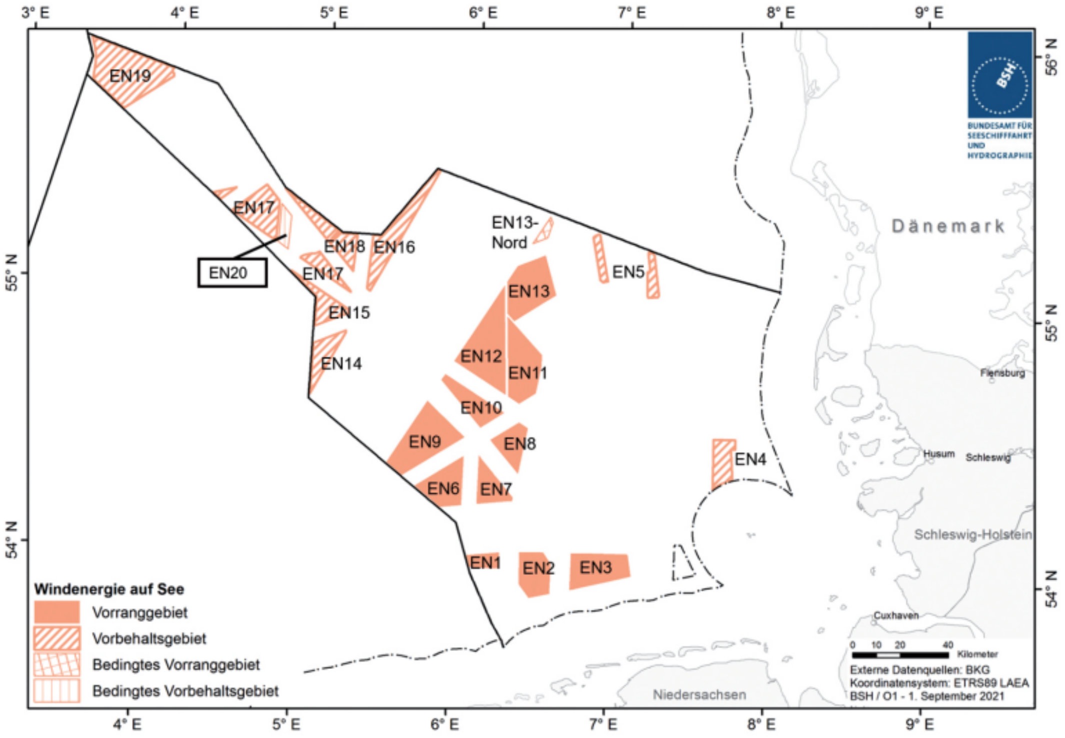
- Long term goals of the new German government (Nov. 2021) :
  - 2030 - 30 GW installed capacity
  - 2035 - 40 GW installed capacity
  - 2045 – 70 GW installed capacity

- Areas are very limited!



[source: BSH.de]

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Goals of the Project

- Research Question: How do large wake effects affect the real-life wind farm operation?

  ➔ Integration of several large wind farm operators into the project

- Quantification of the impact of wakes and other large-scale effects on yields:

  - Impact of Coastal Effects on Wind Farm Wakes
  - Interaction of Single Wind Farm Clusters with the Marine Atmospheric Boundary Layer (MABL)
  - Interaction of Several Wind Farm Clusters with each others and the MABL

► Scenario calculations and rating of future wind farm expansion plans (up to the year 2030)

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The Project

- Budget: 4.3 Million Euro public funding by Ministry of Economic Affairs and Energy (BMWi)
- Duration: 01.11.2019 - 31.10.2022
- Coordination: Fraunhofer IWES (modelling) and TU Braunschweig (measurements)
- Funded partners: Research institutions / universities of former projects GW-Wakes and WIPAFF, UL International
- Associated partners: seven wind farm operators and the federal maritime and hydrographic agency (BSH)

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Measurement Activities

- Flight data (2 manned research aircrafts & UAV)
- Satellite Data Analysis (Sentinel-1A/B)
- Stationary measurements in windward, center and leeward of wind farm clusters with scanning and profiling lidars
- Support of GloBE (global blockage) project with high wind profile and ABL height measurements
- Analysis of SCADA data of several wind farms

➔ Improved understanding of atmospheric processes and collection of validation data for the model development

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Modelling Activities

- **Mesoscale Simulations** [WRF]
  - Improvement of simulations of coastal transition
  - Improvement of modelling of wind farms (layout impacts, curtailments)
  - Simulation of expansion scenarios of 2030 or later AFTER validation
- **Large-Eddy-Simulations** [PALM]
  - Investigation of boundary layer development inside large wind farm clusters
  - Derivation of parametrizations for cumulative effects (global blockage)
- **Industry Models** [OpenWind / flappy]
  - New methods for Global Blockage Modelling
  - Improved modelling of large-scale wake effects
  - Improved modelling of boundary layer interaction

➔ Reduction of uncertainty of industry (reduced order, i.e. fast) models

flappy

Openwind

Most advanced software for creating & optimizing turbine layouts

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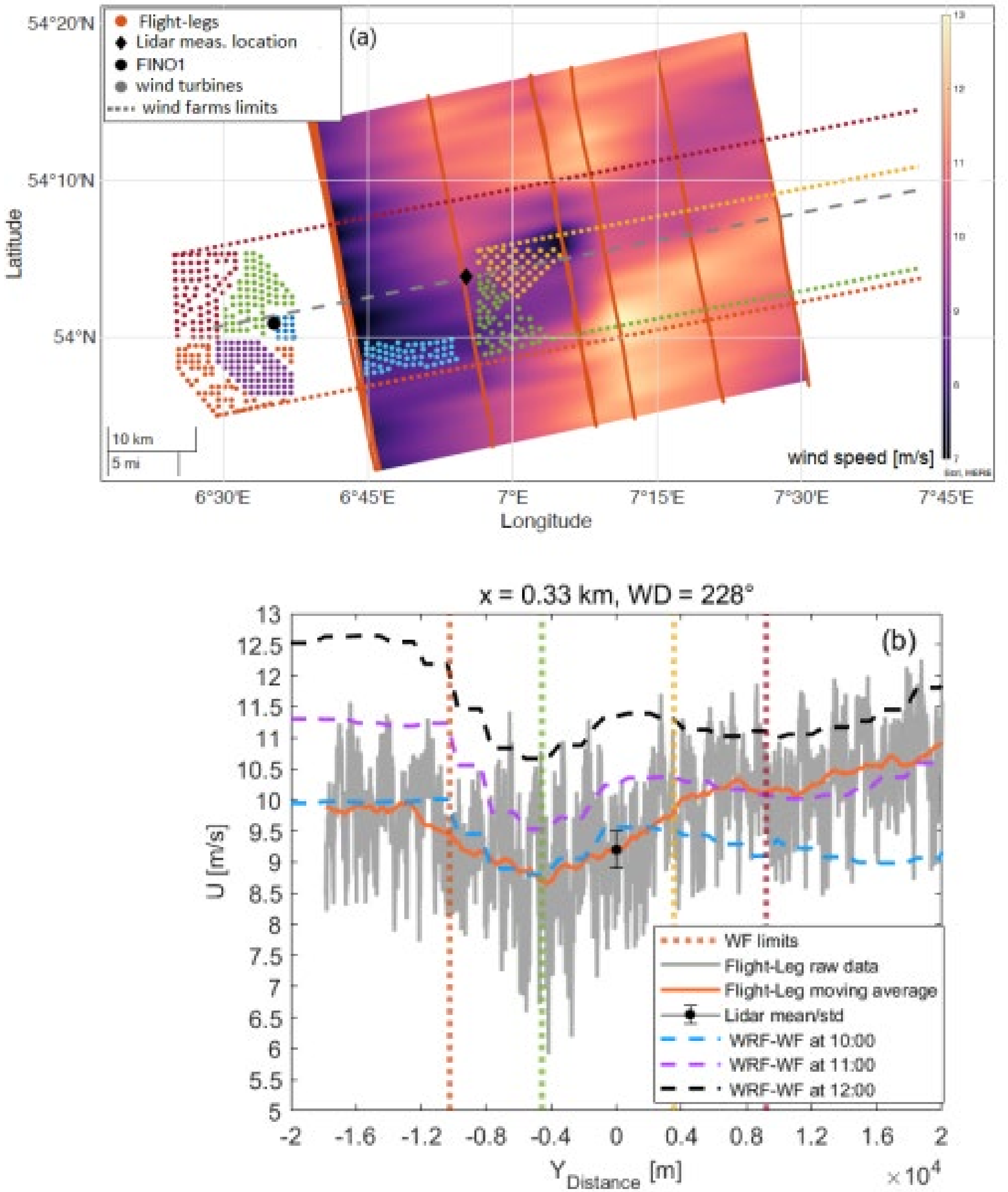
Results – Airborne Measurements

- More than 40 flights conducted in first two project years, focusing on:
  - Global Blockage Effect
  - Coastal Effects
  - Large-scale Cluster Wake Effects

- Data useful for **mesoscale** and **wake model validation**

- Several **benchmarking activities** are currently **planned**.



[Cañadillas, B et al. Wind Energ. Sci. Discuss. [preprint], 2022]

Technische Universität Braunschweig

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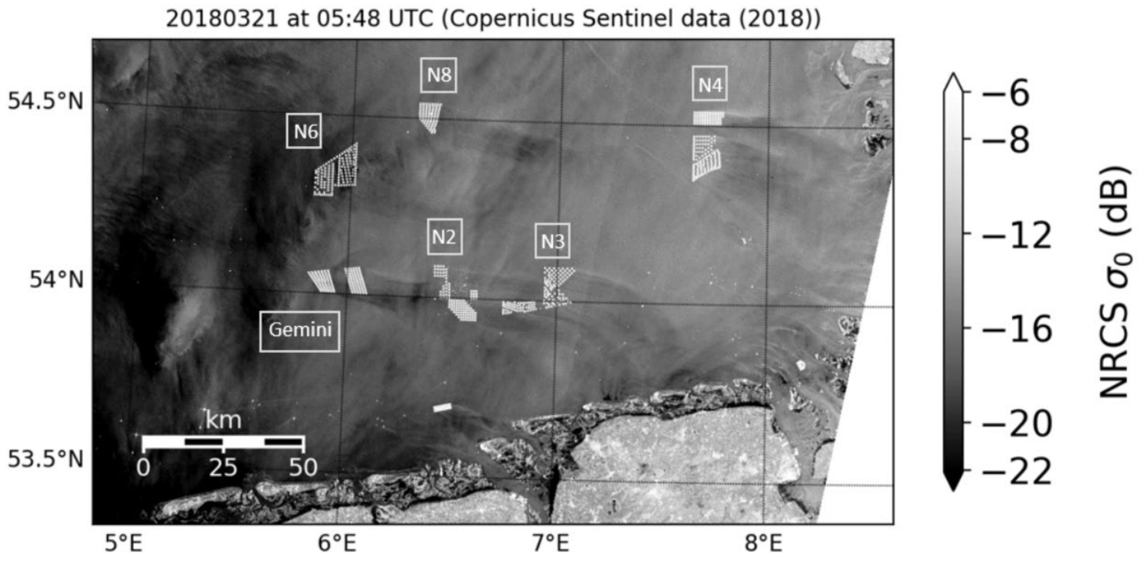
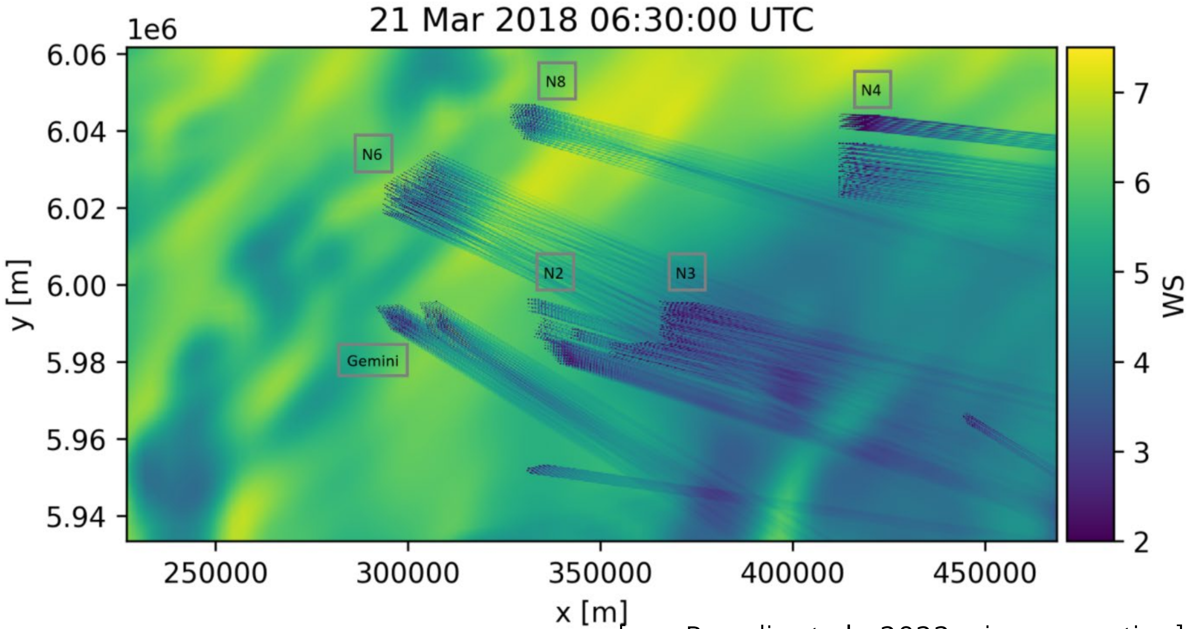
Results – Industry Model Development

How do engineering models need to be tuned to be able to capture large-scale wake effects well?

What is the performance of engineering and mesoscale cluster wake modelling on annual energy production (AEP), i.e. wind farm lifetime scale?

What is the impact of the wind farm expansion on future wind farm yields **using well validated models?**



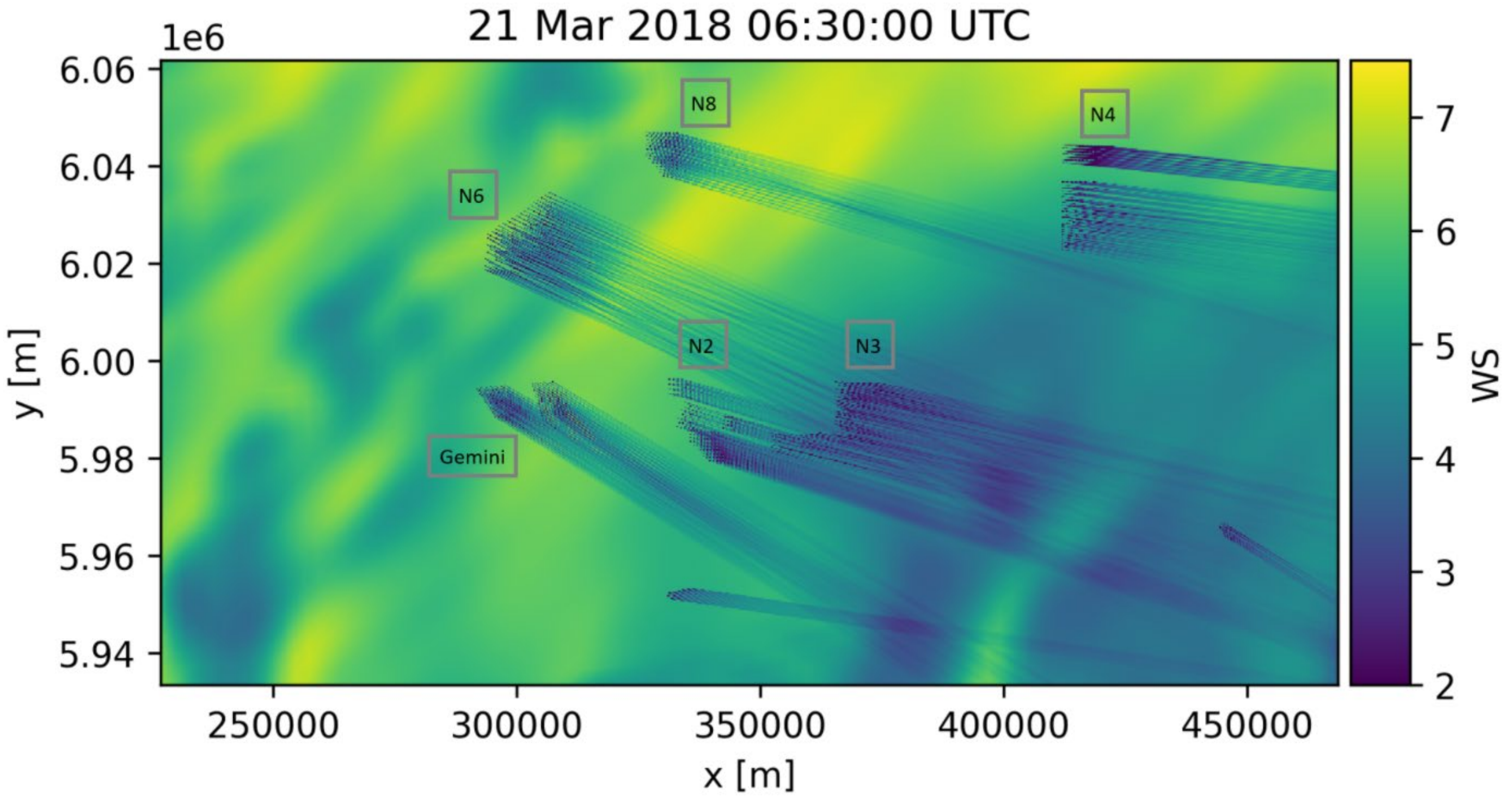


[von Brandis et al., 2022 – in preparation]

Large-Scale Effect

Large-Scale Turning

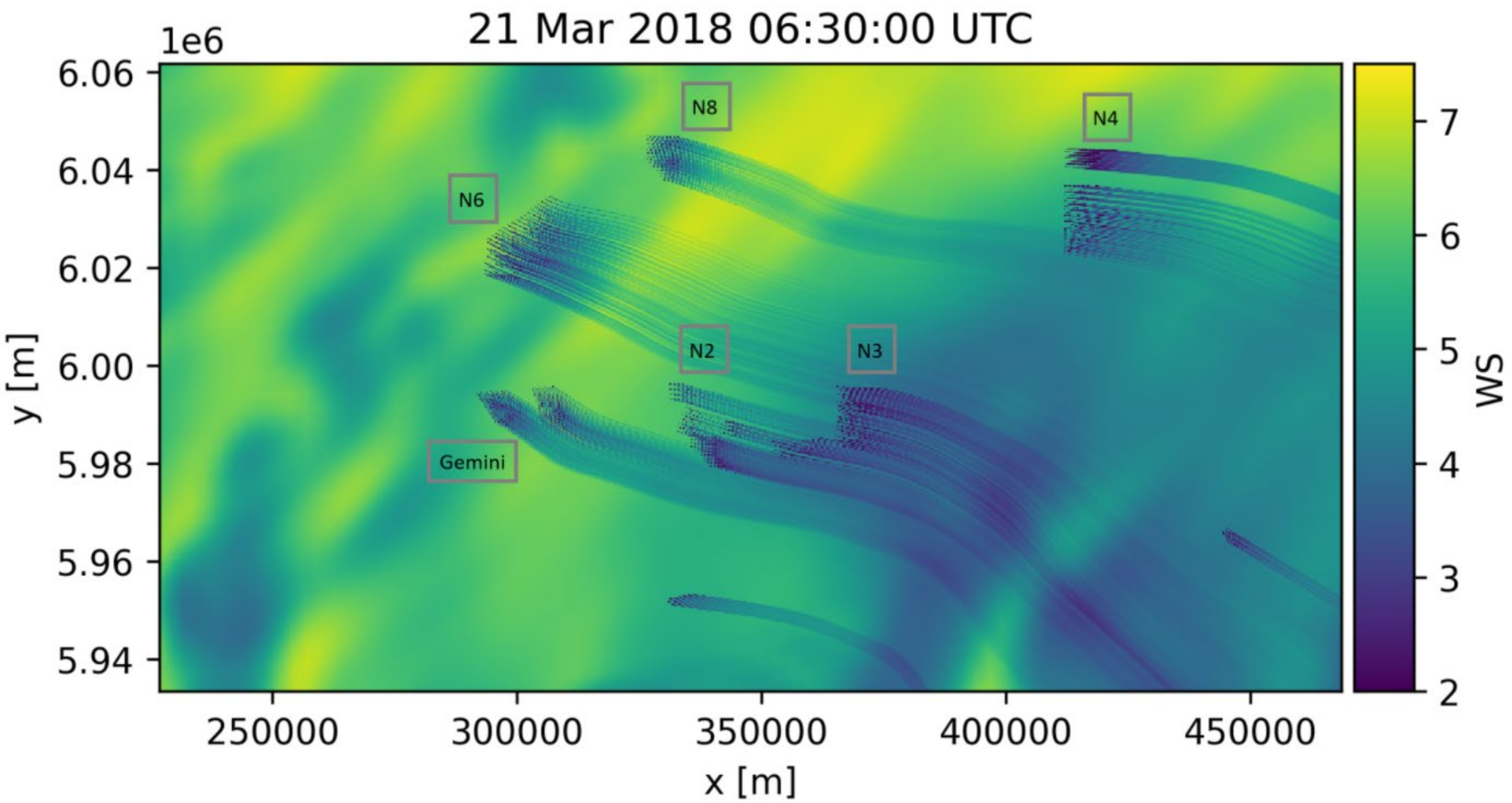
Idea: introduce this effect by coupling of mesoscale data with engineering models?



Large-Scale Effect

Large-Scale Turning

Solution: calculate streamline and deflect the wake according to the mesoscale background wind field data



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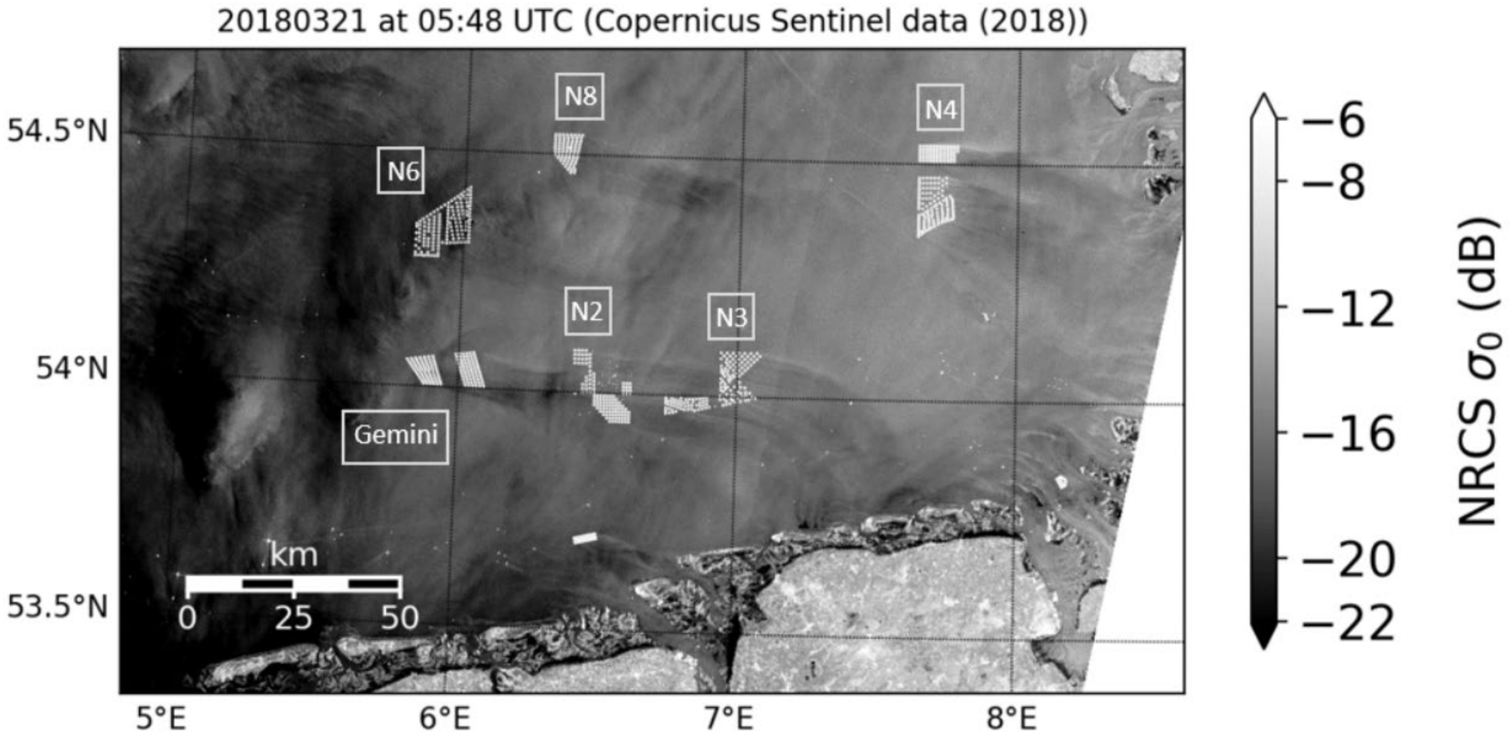


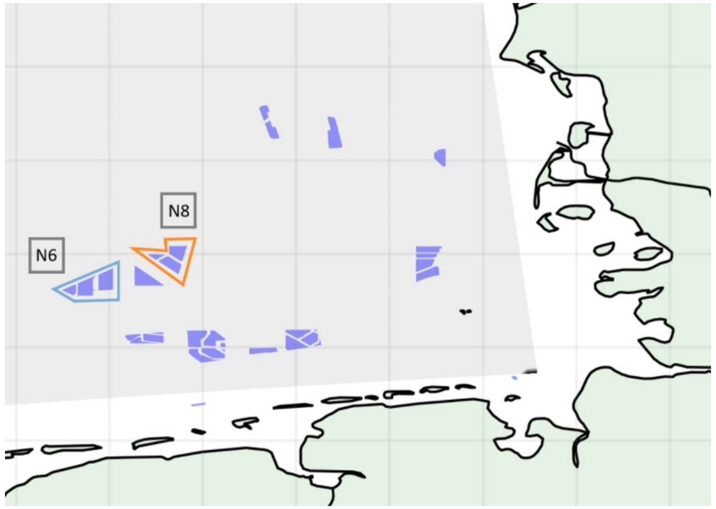
Large-Scale Effect

Large-Scale Turning

- Large-scale wake turning effect is wind speed and direction dependent and can result in over / underestimation in the order of 1%

- Potential to reduce and especially understand the wake modelling uncertainty

- Wake modelling uncertainty is still key contributor to overall uncertainty



WD [°] \ WS [m/s]	(2, 4]	(4, 6]	(6, 8]	(8, 10]	(10, 12]	(12, 14]	(14, 16]	(16, 18]	(18, 20]	(20, 22]	(22, 24]
(0, 20]	-0.014	0.197	0.100	0.035	0.045	0.061	0.003	0.029	0.008		
(20, 40]	-0.004	-0.003	-0.031	-0.016	-0.010	0.017	0.002	-0.002	0.000		
(40, 60]	-0.081	-0.013	-0.032	-0.001	0.009	-0.003	0.000	-0.002	-0.040		
(60, 80]	0.008	0.030	0.023	-0.005	0.012	0.009	-0.000	-0.000	0.000	0.000	0.000
(80, 100]	0.147	-0.013	-0.033	-0.035	-0.058	-0.001	-0.013	0.004	-0.000	0.000	0.000
(100, 120]	0.195	0.093	0.066	0.015	0.011	0.000	0.005	-0.001	0.000	0.000	
(120, 140]	0.338	0.150	0.072	-0.000	-0.000	0.028	0.016	0.013	0.005	-0.000	
(140, 160]	-0.118	-0.113	0.001	-0.024	-0.032	-0.004	-0.013	-0.035	-0.014	-0.000	
(160, 180]	0.123	0.166	0.074	0.060	0.008	-0.012	-0.008	-0.009	0.000	0.000	-0.000
(180, 200]	-0.062	-0.211	-0.180	-0.072	-0.062	-0.036	-0.005	-0.002	0.005	0.000	-0.000
(200, 220]	-0.718	-0.427	-0.251	-0.126	-0.035	-0.005	0.009	0.010	-0.001	0.000	0.000
(220, 240]	0.760	0.698	0.222	0.019	-0.112	-0.054	0.005	0.000	0.001	0.000	-0.041
(240, 260]	0.374	-0.555	-0.393	0.033	0.030	0.133	0.047	0.005	0.004	-0.005	-0.019
(260, 280]	-0.046	-0.086	0.010	0.115	0.091	0.049	0.026	0.008	0.004	0.002	-0.002
(280, 300]	0.412	0.289	0.066	0.056	0.080	-0.010	-0.001	0.007	-0.004	-0.003	0.000
(300, 320]	0.048	0.064	-0.020	-0.030	-0.033	-0.023	-0.046	-0.007	0.002	0.001	-0.000
(320, 340]	-0.021	-0.092	-0.079	-0.021	0.009	-0.014	-0.003	-0.018	-0.023	-0.000	-0.002
(340, 360]	0.035	0.102	0.051	0.041	-0.005	-0.008	-0.012	0.014	0.003	-0.105	0.000

Colour scale: σ_{Ep} [-] (0–12)

Helmholtz-Zentrum hereon · ForWind Center for Wind Energy Research Bremen Hannover Oldenburg · Fraunhofer IWES · X-WAKES

Mesoscale Model Validation

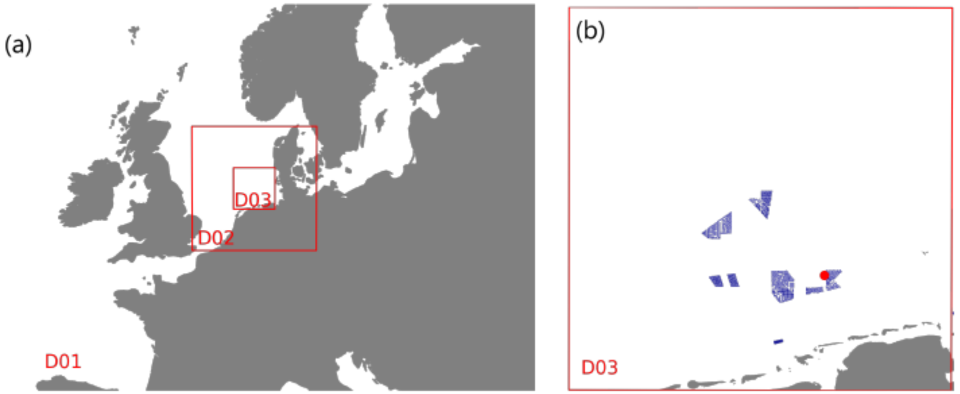
Scanning Lidar Campaign

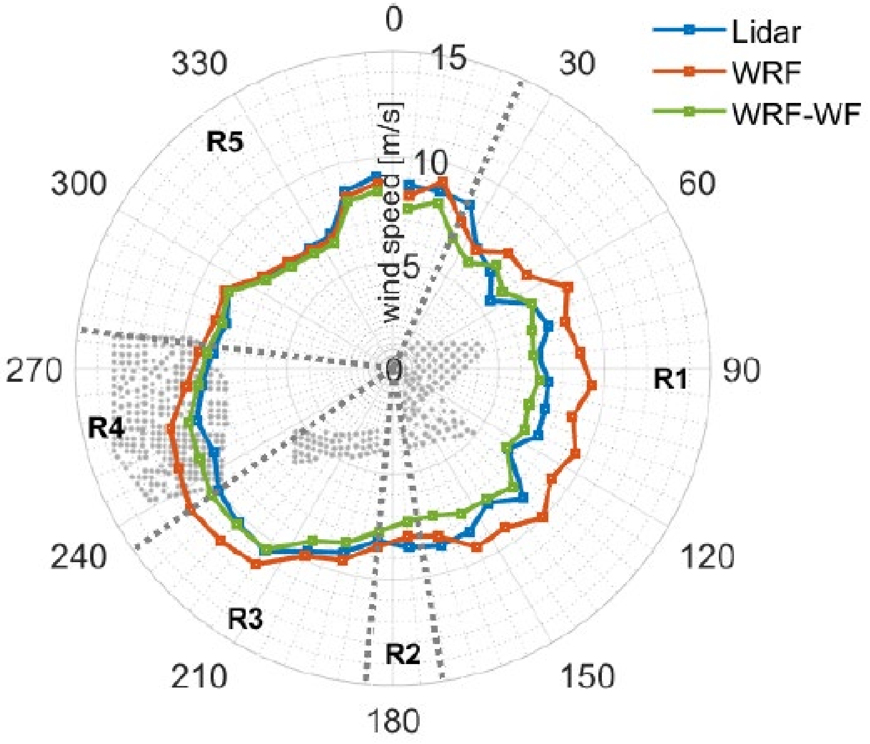
- Scanning lidar measurement campaign at GodeWind
- Duration: 5 months – spring to autumn 2020

- Mesoscale model simulations:
  - WRF (red): without wind farm parametrisation
  - WRF-WF (green): including wind farm parametriation

- Good agreement when using wind farm parametrisation
- Difference around 2% in wind speed on average

► Model setup is well suited for cluster wake modelling



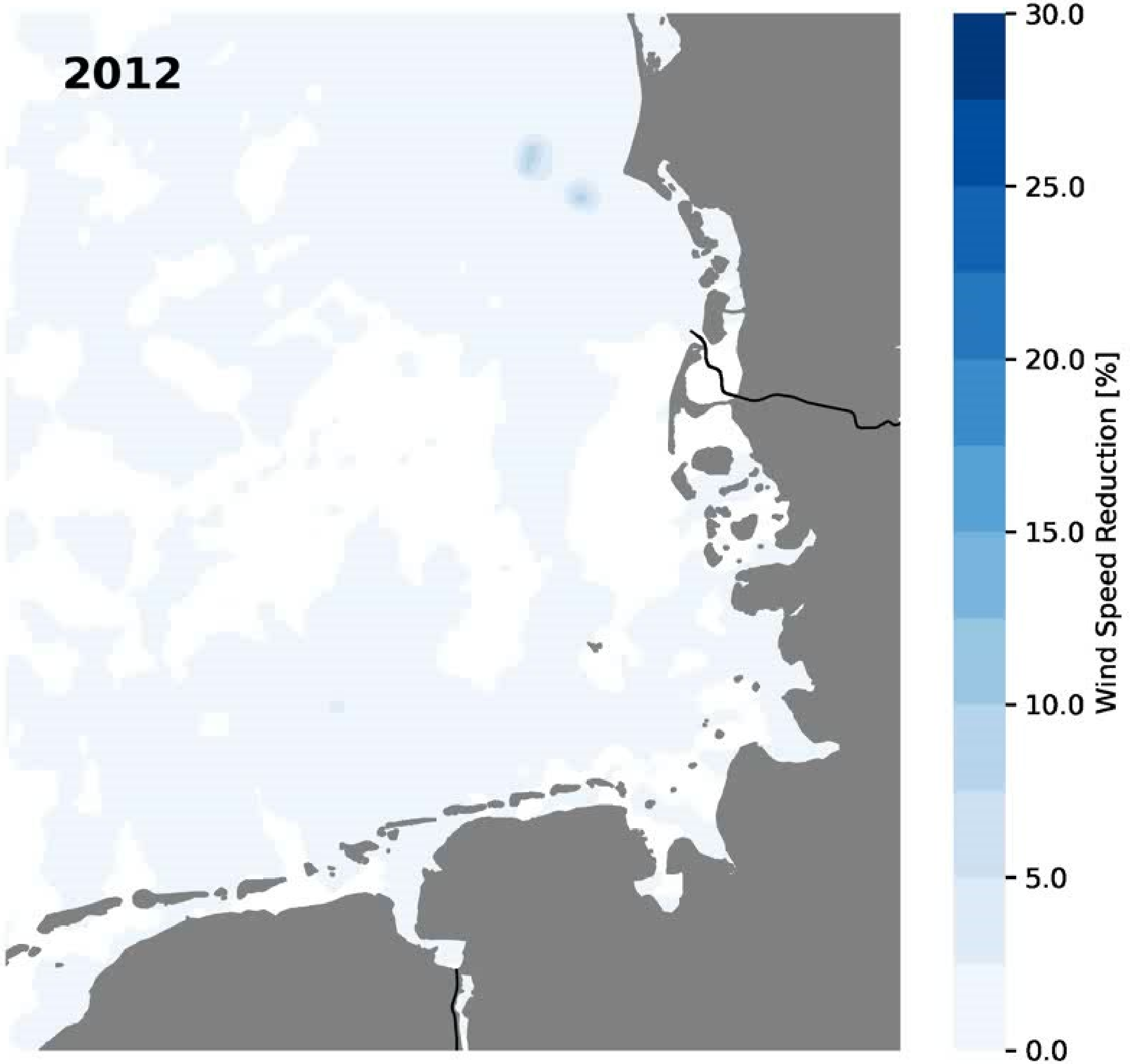


[Cañadillas, B et al. Wind Energ. Sci. Discuss. [preprint], 2022]

Wind Speed Reduction

Past - 2011-2020

- Mesoscale model simulation **INCLUDING** wakes
- Wind farms represented as realistically as possible in terms of hub height, diameter, thrust and power curves
- Wind farms wakes accounted for based on official commissioning date



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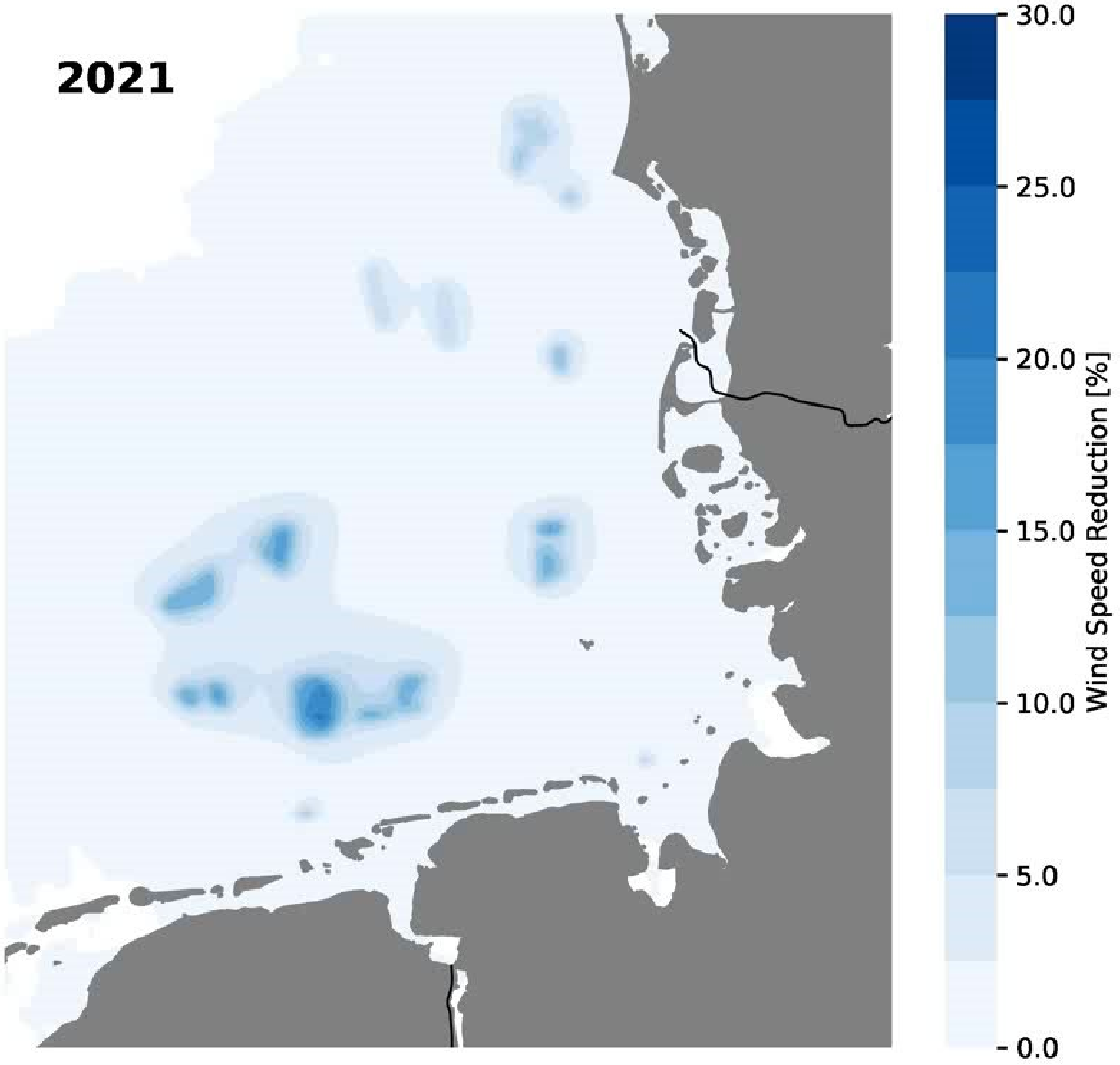
Wind Speed Reduction

Future – 2021-2027

- Mesoscale model simulation **INCLUDING** wakes
- Reference year: 2006 – representative for the climatology
- Future turbine technology (2025-2027): 15 MW – IEA turbine
- Wind speed reduction until 2030 (i.e. 30 GW) will be part of investigations in following months



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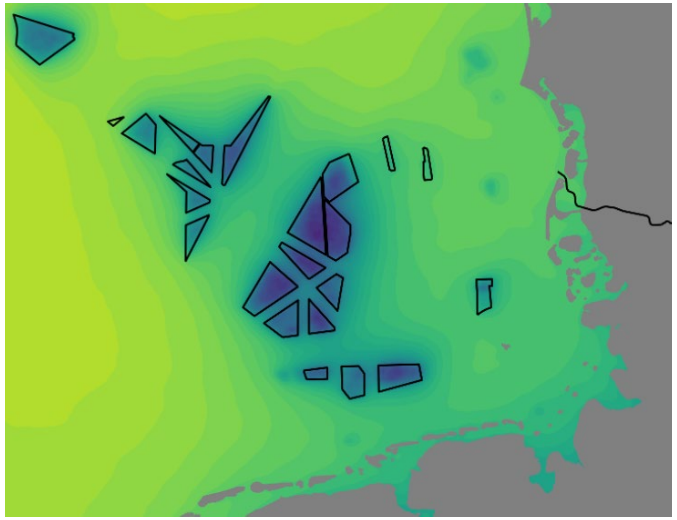
Conclusions

Offshore Wakes and Wind Resource Research

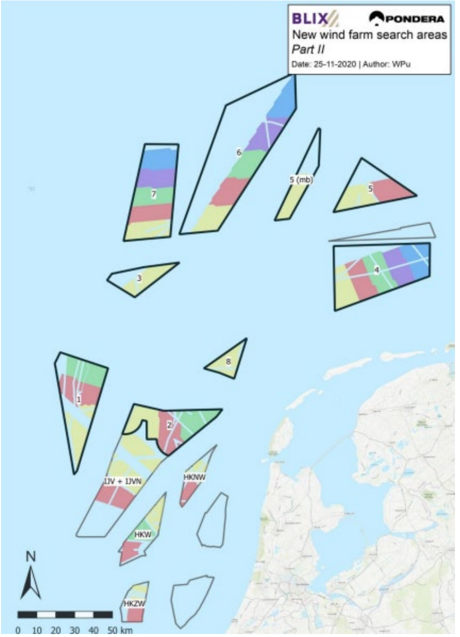


- New government has ambitious plans for offshore wind farm expansion, but areas are very limited – need to plan wisely already now

- X-Wakes focusing on improving models and transferring knowledge towards more efficient wind farm operation and planning

- Cross-border planning and joint research between North Sea / Baltic Sea states is extremely important

- Looking forward to collaborations within the community!



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Questions?

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Thank You

X-Wakes Consortium at Kick-Off Meeting (12-2019)