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

Thursday, 11.05.2023 | Fourth International RAVE Workshop 2023

Fraunhofer IWES

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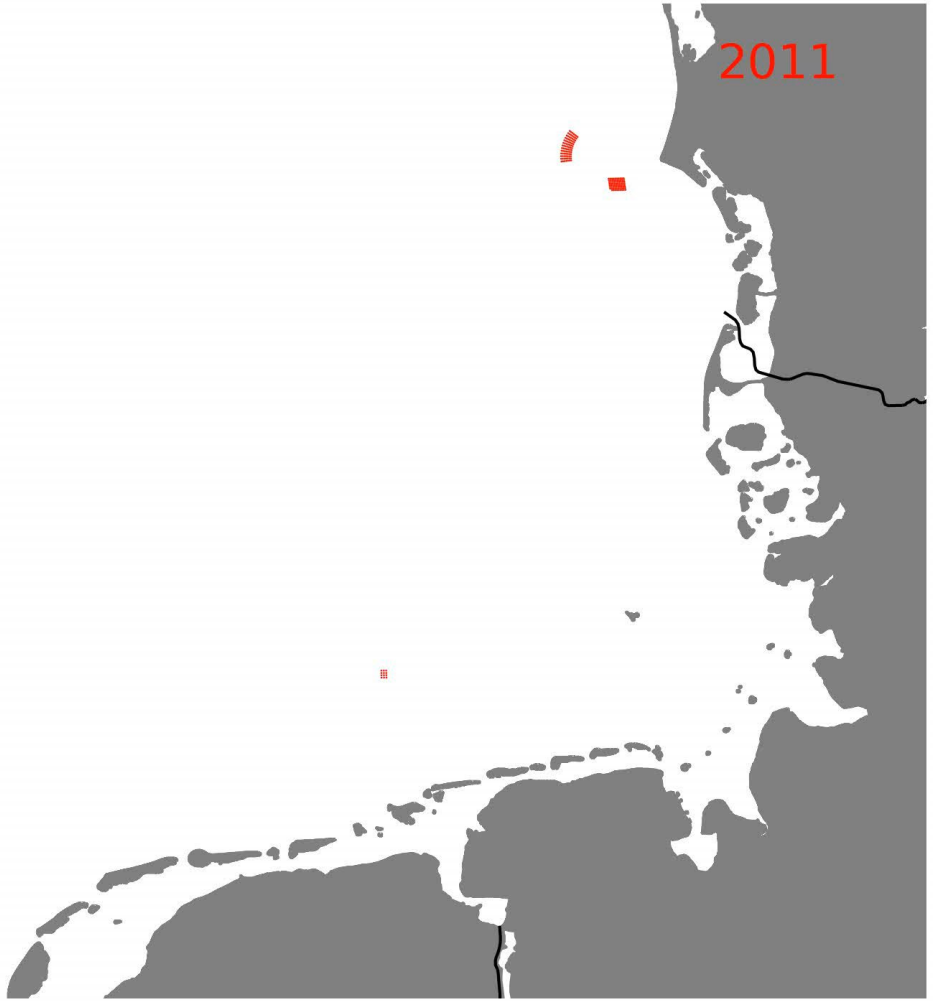
Motivation

Offshore Wind Energy in the German Bight

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

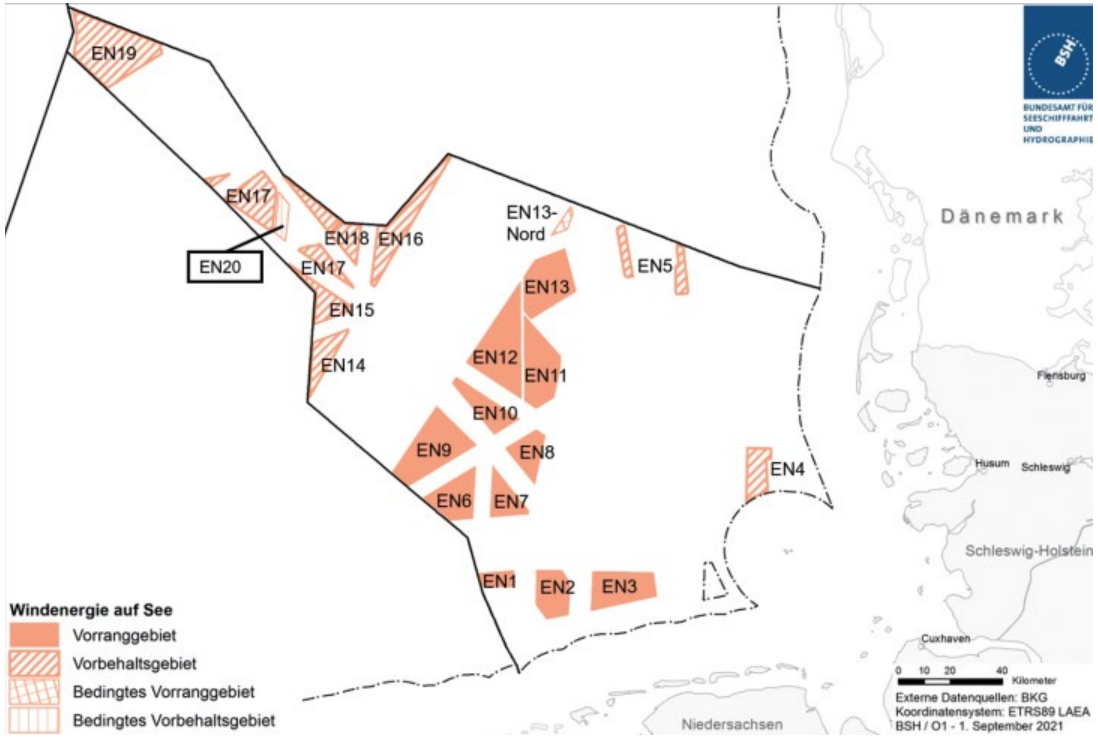
- Currently 7.7 GW out of which 6 GW are located in the German Bight



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
- Long term goals of the German government:
  - 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 and their interaction with the atmosphere affect the real-life wind farm operation?

- 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
  - Interaction of **Several Wind Farm Clusters** with each others and the Marine Boundary Layer

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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 – 30.04.2023
- 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 & Modelling Activities

Measurements:

- 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
- SCADA data analysis

Modelling:

- Engineering Models (Commercial and Research)
- Large-Eddy-Simulations [PALM]
- Mesoscale Modelling [WRF]

WRF® Weather Research & Forecasting

FOXES
Farm Optimization and eXtended yield Evaluation Software
Fraunhofer IWES

Openwind
Most advanced software for creating & optimizing turbine layouts

palm

➔ **Improved understanding of atmospheric processes and model validation for scientific and industrial applications**

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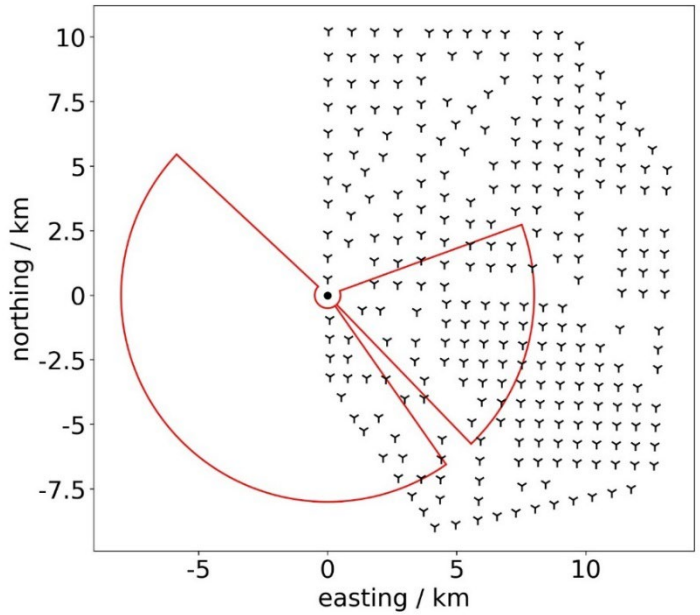
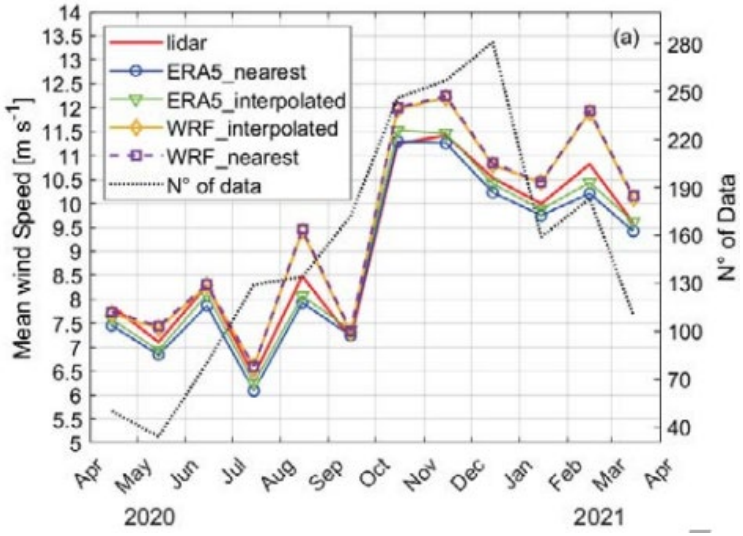
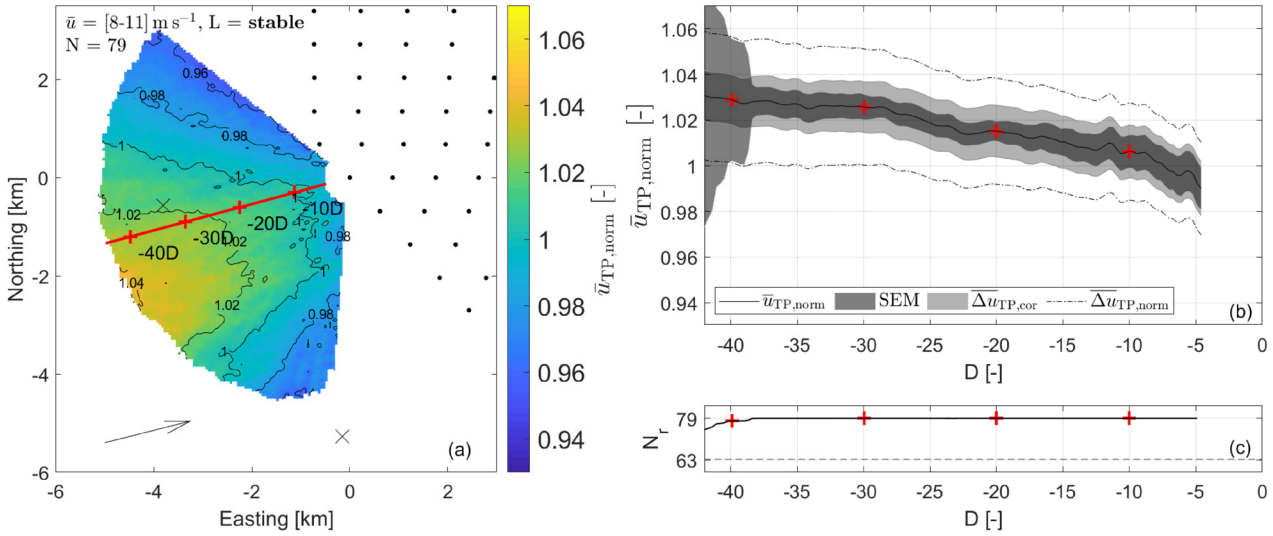
Lidar Measurements



- Several Lidars placed in the German Bight area for
  - Global Blockage and Cluster Wake Effect (at Cluster N-2)
  - Coastal Effects (at Norderney)

- Some of the first measurements of global blockage with lidar data (Schneemann et al., 2021)





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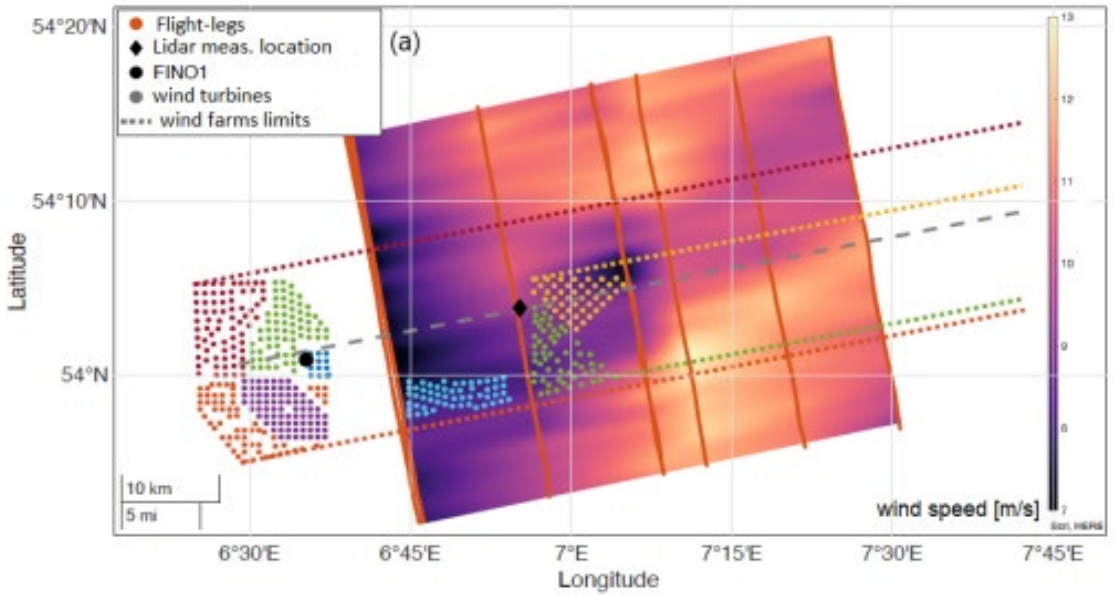
Airborne Measurements

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



- More than 40 manned flights conducted focusing on:
  - Global Blockage Effect
  - Coastal Effects
  - Large-scale Cluster Wake Effects

- UAS campaigns for coastal effects and first beyond visual line of sight (BVLOS) UAS operations west of Heligoland

- Data especially used for **model validation** and **investigation of fluxes**

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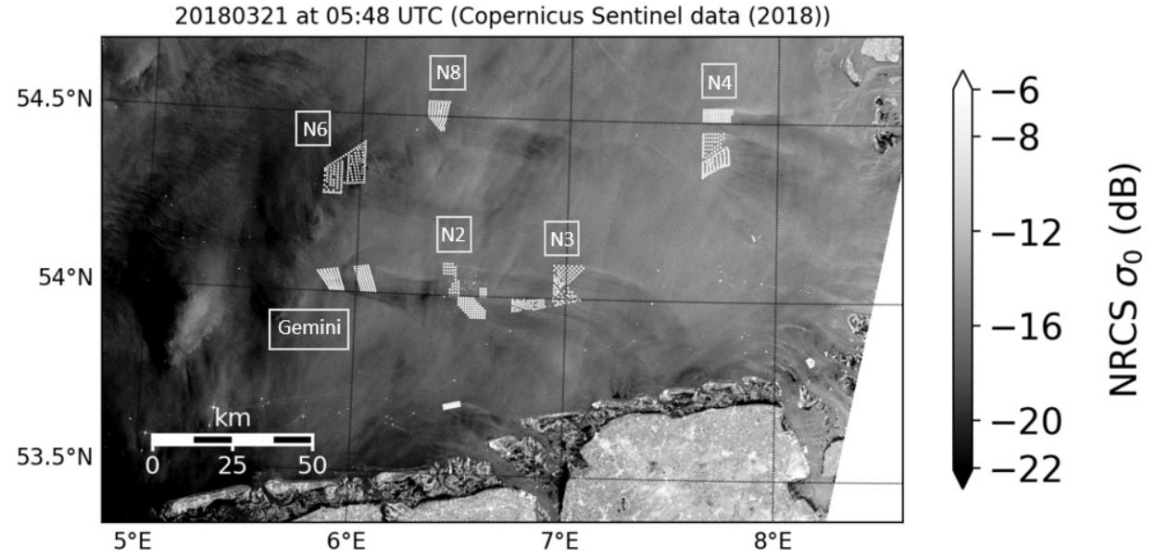
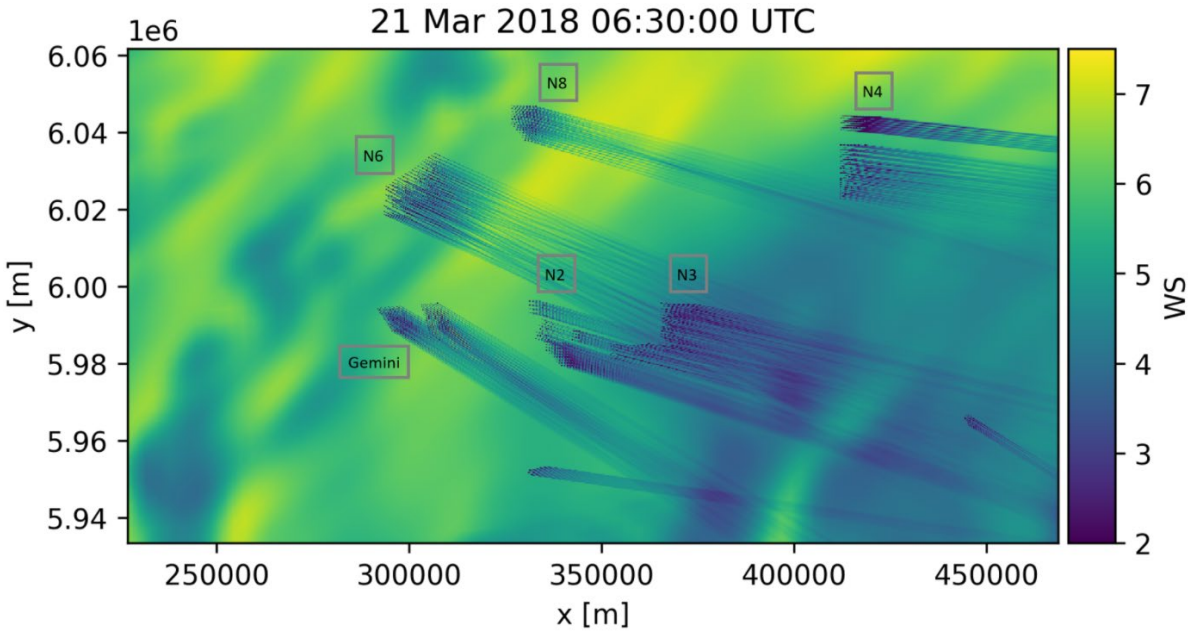
Results – Industry Model Development

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?





[von Brandis et al., 2023]

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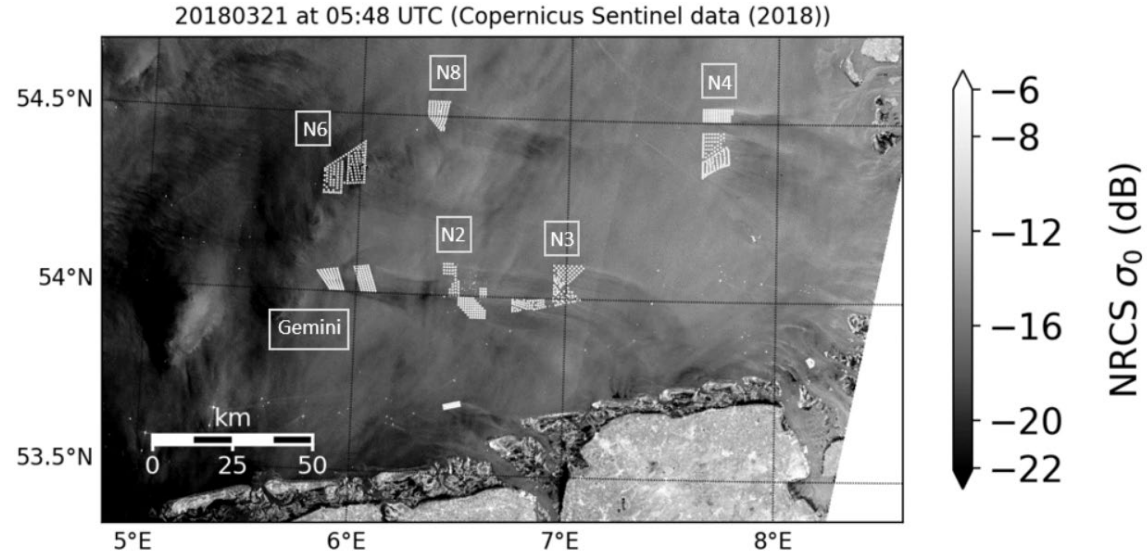

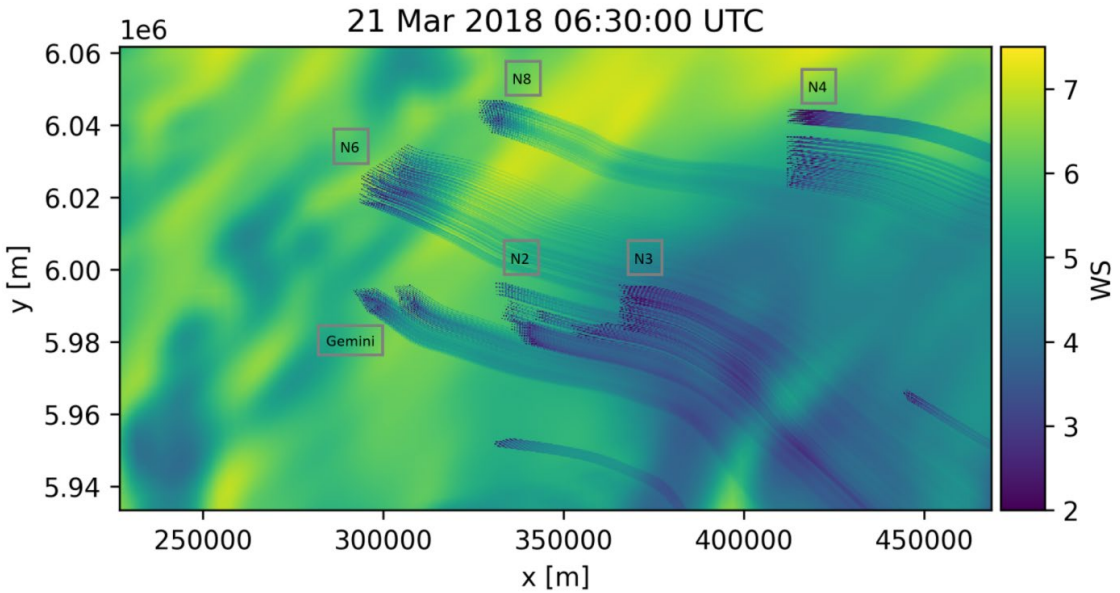

[von Brandis et al., 2023]

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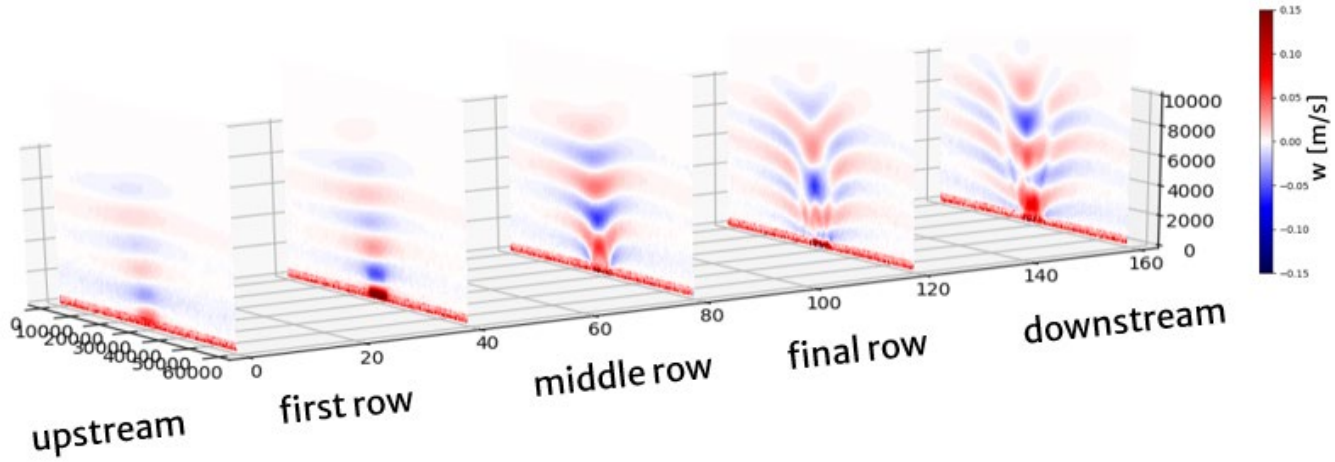
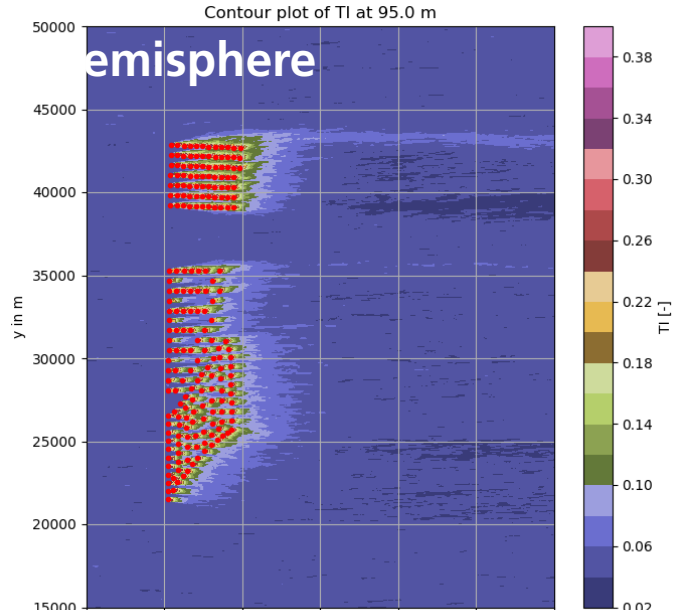
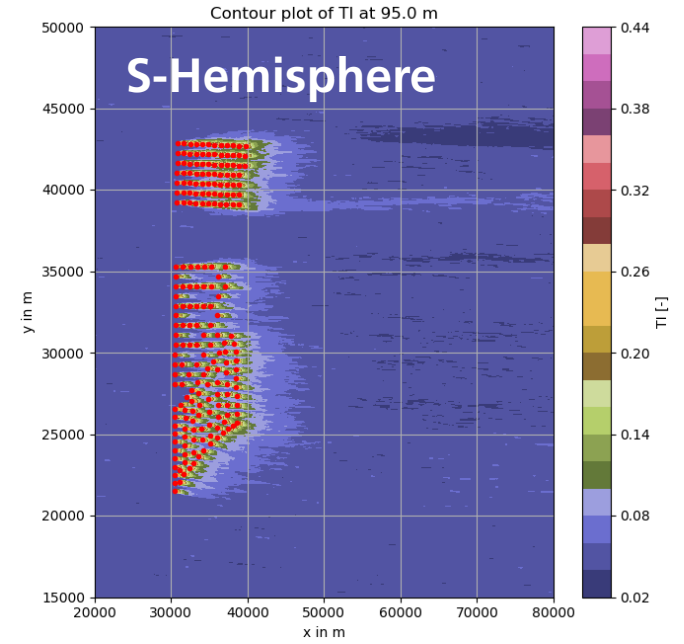
Results – Modelling

- Origin of streaks at wind farm edges investigated: Coriolis force is key ingredient

- Large Eddy-Simulations of wind farm clusters used for development of fast engineering model, e.g. for global blockage modelling



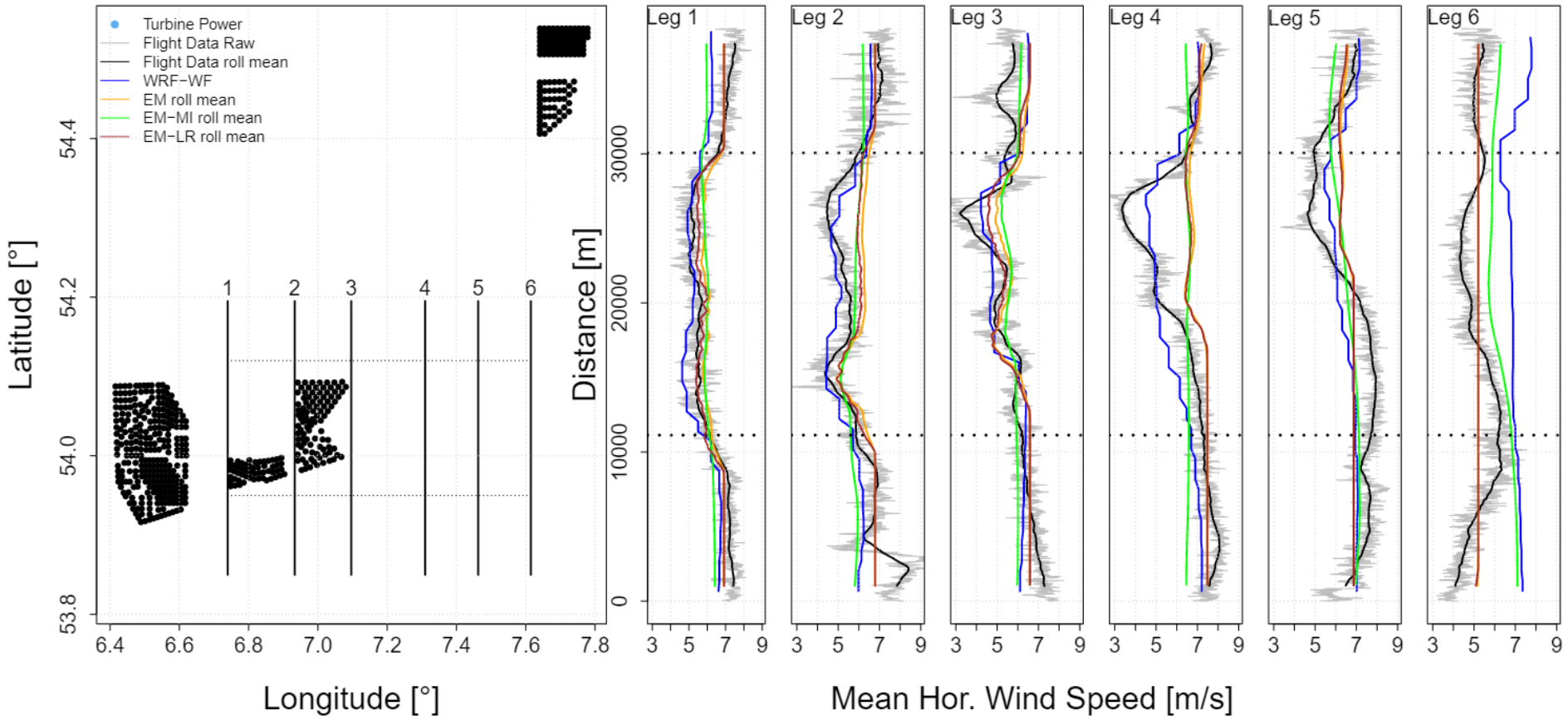




Model Validation

Flight Data and Engineering / Mesoscale Models

- Data from flight experiments enables validation of models of different fidelity levels



Model Validation

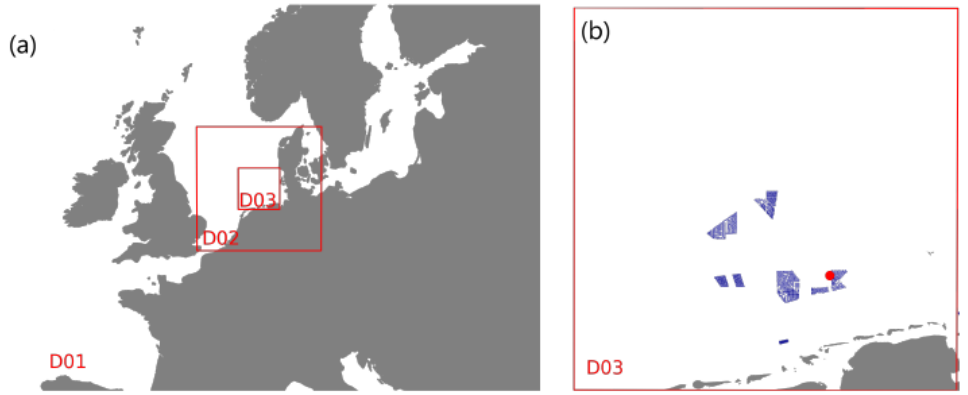
Scanning Lidar and Mesoscale Model

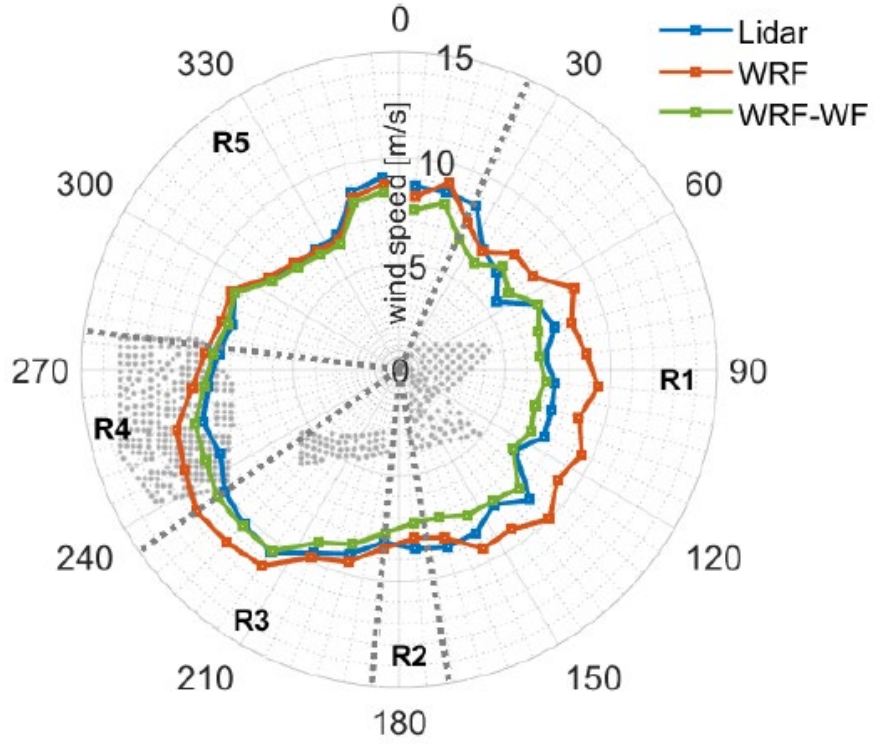
- Scanning lidar measurement campaign at GodeWind
- Duration: 5 months – spring to autumn 2020

- 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



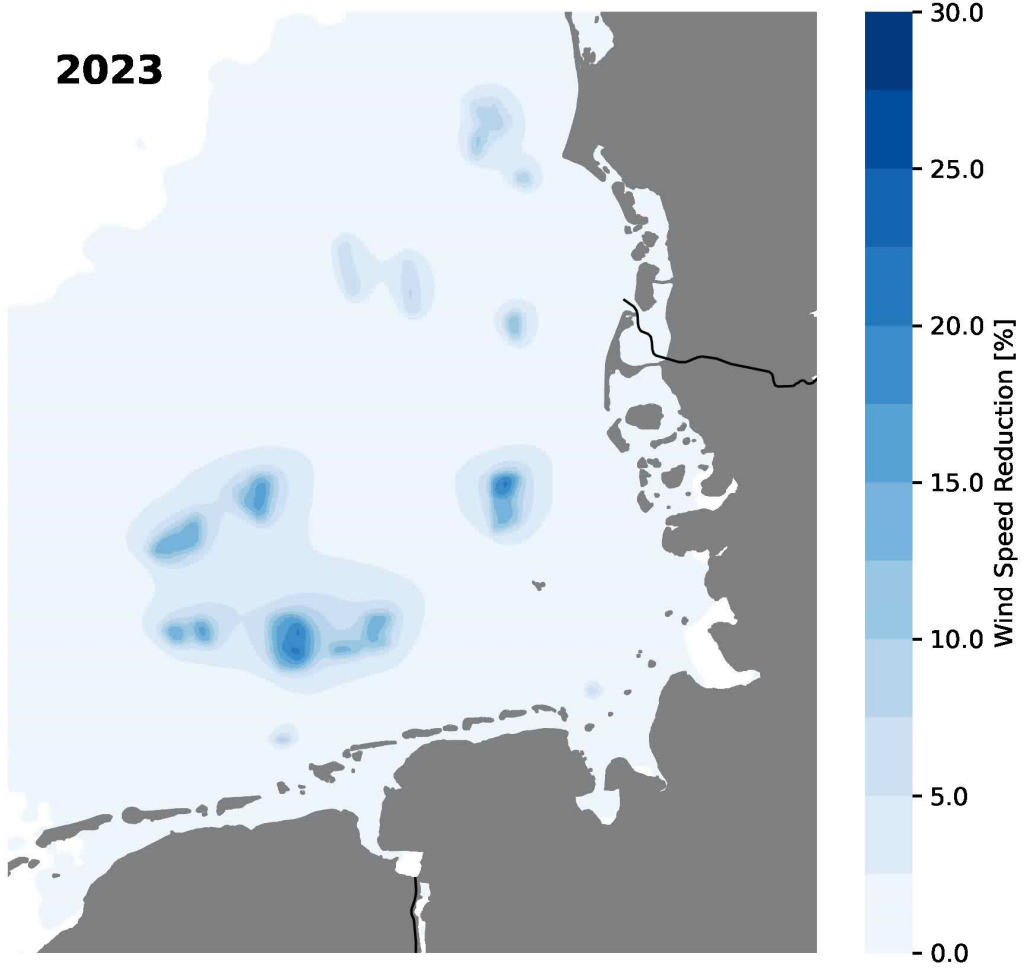


[Cañadillas, B et al. Wind Energ. Sci. Discuss. [preprint], 2022]

Wind Farm Expansion

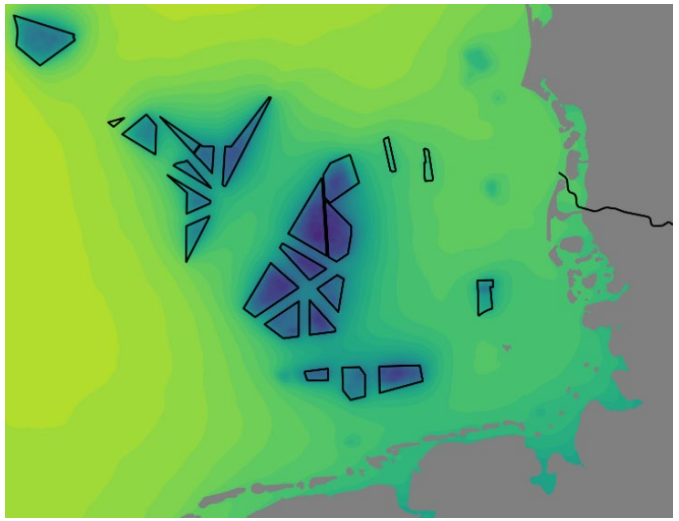
Future – 2023-2030

- Mesoscale model simulation **INCLUDING** wakes
- Reference year: 2006 – representative for the climatology
- Future turbine technology (2025-2030): 15 MW – IEA turbine
- Underlying time series data available upon request!

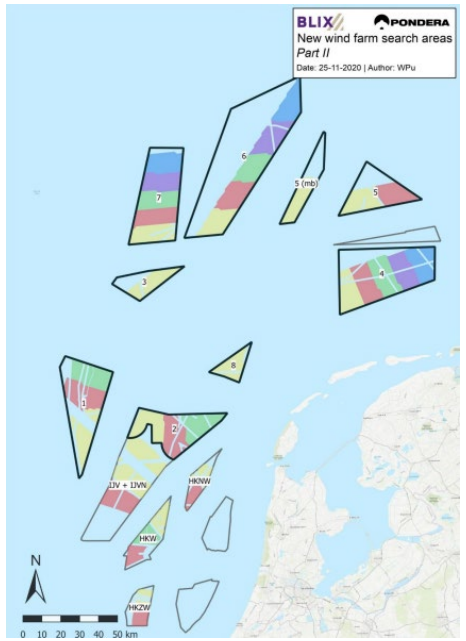


Conclusions

Offshore Wakes and Wind Resource Research



- Germany has ambitious plans for offshore wind farm expansion, but areas are very limited – need to plan wisely already now
- X-Wakes project focused on improving and validating 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
- Many results are publicly available, several publications in preparation



Public Resources

X-Wakes Project

- Coastal lidar measurement data (Norderney): https://doi.pangaea.de/10.1594/PANGAEA.953770
- Data from manned flights: https://doi.pangaea.de/10.1594/PANGAEA.955382
- OpenSource engineering model – FOXES: https://github.com/FraunhoferIWES/foxes
- Currently seven peer reviewed publications published, more than five further publications in review or advanced preparation: https://rave-offshore.de/en/x-wakes.html

Acknowledgements

The X-Wakes project was funded by the German ministry of Economic Affairs and Climate Action (BMWK) under grant number FKZ 03EE3008 (A-G) on the basis of a decision by the German Bundestag.

Computing resources were partly provided by the North-German Supercomputing Alliance (HLRN)

17

Questions?

Save the Date: Public Final Virtual Project Workshop – Monday June 26th, 2023!