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Offshore wind farm cluster wakes as observed by long-range-scanning wind lidar measurements and wind modeling

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WIND ENERGY SCIENCE

X-WAKES

Offshore wind farm cluster wakes as observed by long-range-scanning wind lidar measurements and mesoscale modeling

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Outline

- Motivation
- Location
- Datasets
- Results:
  - Wind field modification by wind farm clusters
  - Directional and stability dependence of cluster wakes
  - Directional dependence of cluster wakes
- Summary

Motivation

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

⇓

As seen by a scanning lidar measurement campaign

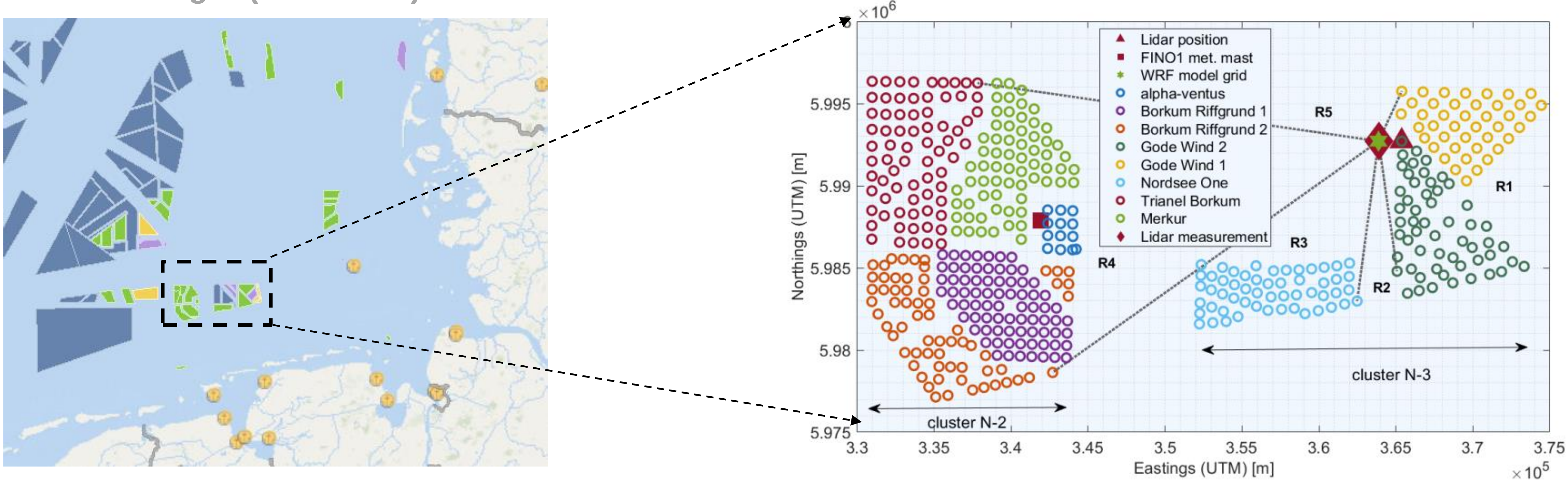
Main objectives:

(1) to demonstrate the performance of such a system and thus quantify cluster wake effects reliably and

(2) to obtain experimental data to validate the cluster wake effect simulated by the flow models involved in the X-Wakes (Interaction of the wake of large offshore wind farms and wind farm clusters with the marine atmospheric boundary layer) research project.

Location

German Bight (North Sea)



Map source: 4C Offshore (https://www.4coffshore.com/offshorewind/)

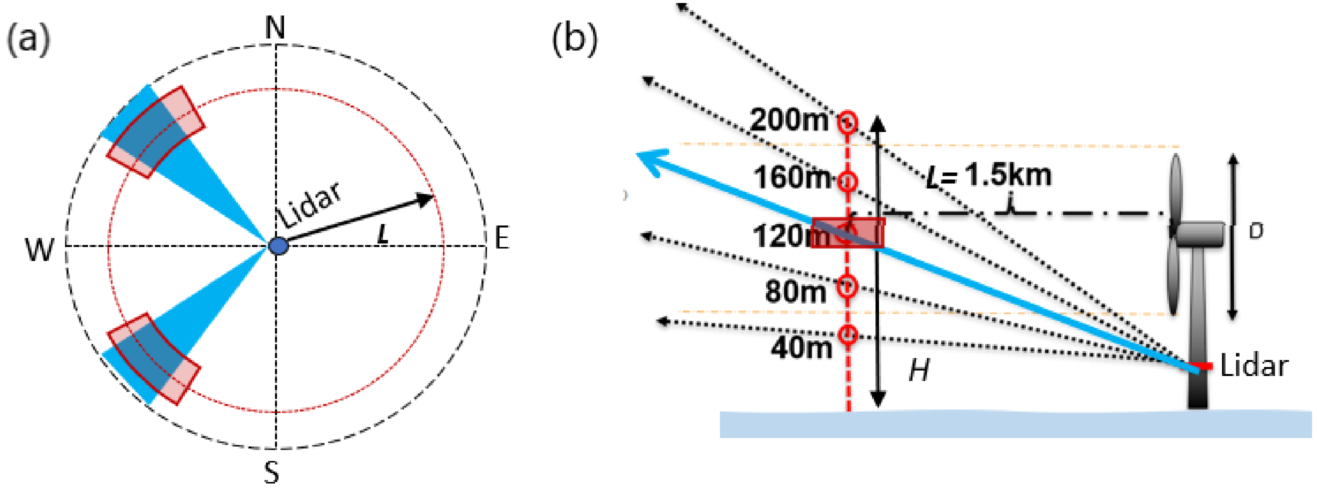
Datasets (I)

Long-range-scanning Doppler wind lidar system

- **Location**: Gode Wind 1
- **Duration**: Duration: 5 months – spring to autumn 2020
- **Scanning system**: StreamLine XR by Halo Photonics
  - **Scan set-up:** Consecutive PPIs scans at 5 fixed elevations
  - **Distance from the TP:** 1.5 km
- **Additional sensors**: Air temperature/SST, Humidity, pressure, precipitation

Scanning lidar set-up

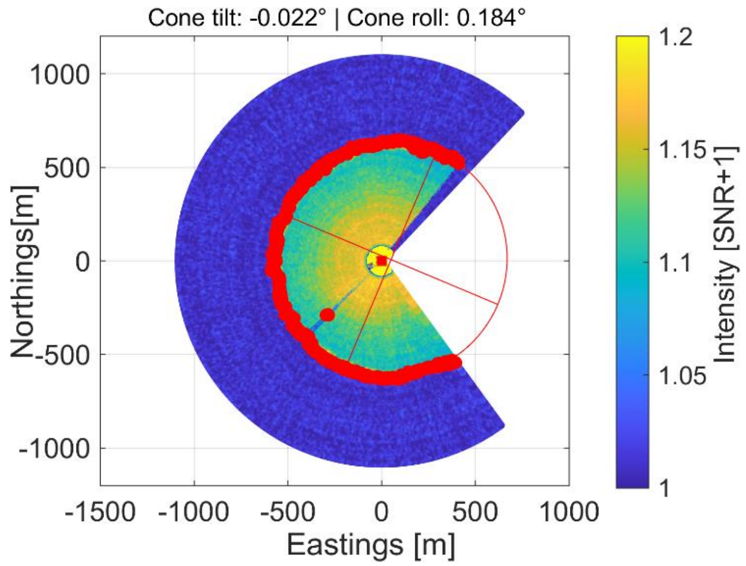
Partial velocity azimuth display (VAD) at several altitudes



Sketch of scanning for partial VAD.

Internal Inclinometer and compass need to be calibrated :

- Hard target → north offset
- Sea surface leveling (SSL) → tilt & roll

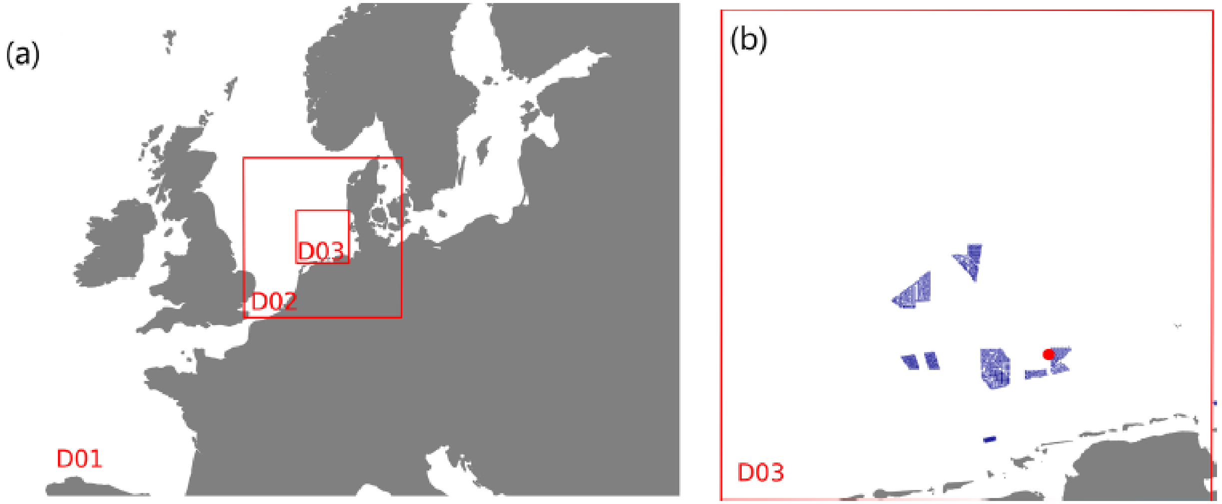


Example of backscattered signal intensity after SSL scanning.

Datasets (II)

Weather Research and Forecasting (WRF v. 4.2.1) model:

- Without the wind farm parameterization: Free wind
- With the wind farm parameterization: Model validation



Locations of the three WRF model domains (D01, D02, D03) with a grid sizes of 18, 6 and 2 km, respectively. Note that wind farms with a distance of more than 100 km from the site were ignored.

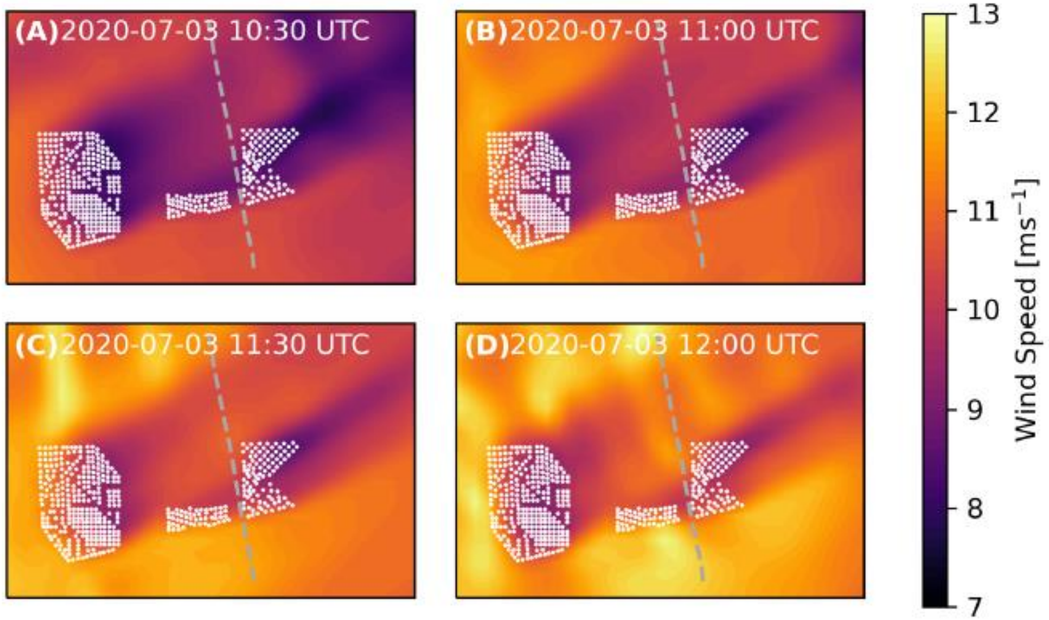
Parameter	Setting
WRF model version	4.2.1
Planetary boundary layer (PBL) scheme	MYNN level 2.5
Wind farm parametrization	Fitch et al. (2012)
Land use data	MODIS
Surface layer scheme	MYNN
Microphysics scheme	WRF single-moment five-class
Shortwave and long-wave radiation	RRTMG
Atmospheric boundary conditions	ERA5
Sea surface conditions	OSTIA
Horizontal resolution	18, 6 and 2 km
Vertical resolution	60 eta level
Nudging	Grid nudging above PBL
Model output interval	10 min
Nesting	One-way
Land surface model	Unified Noah Land Surface Model
Simulation duration	240 (+24 spin-up) hours

Relevant parameters of the mesoscale model set-up.

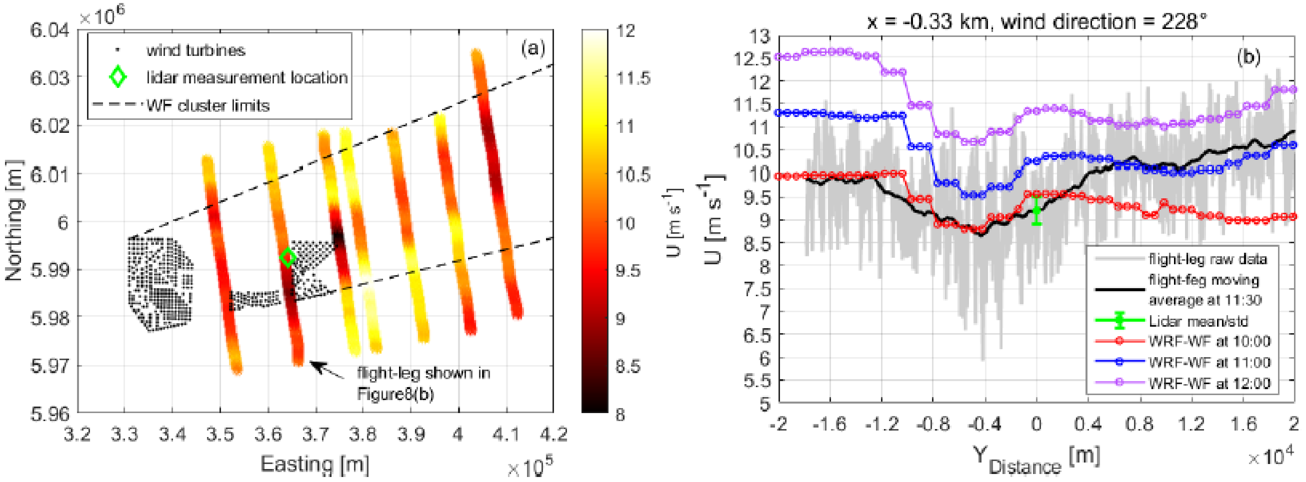
Wind field modification by wind farm clusters

Dornier 128 D-IBUF research aircraft of the Technische Universität (TU) Braunschweig

WRF with WF vs. Manned flight



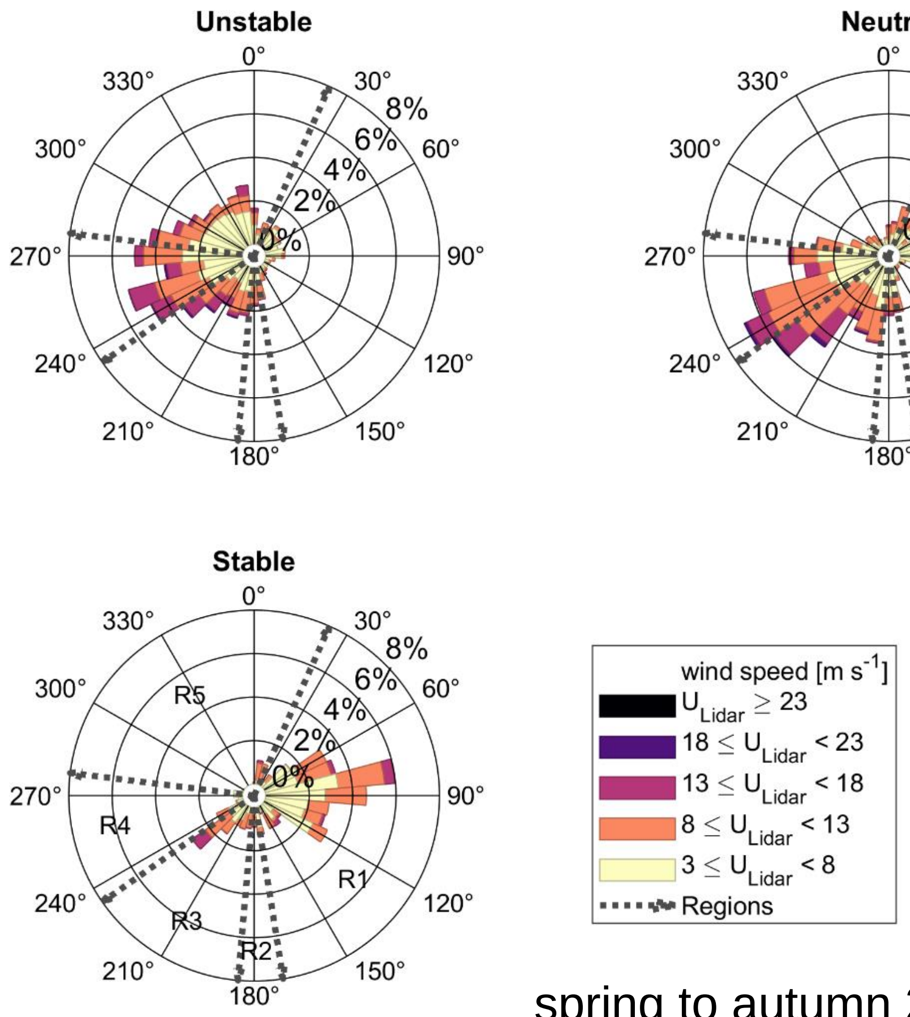
3 July 2020 (10:24–12:00 UTC)



Relevant parameters of the mesoscale model set-up.

Wind conditions – 5 months (scanning lidar)

X-WAKES



spring to autumn 2020

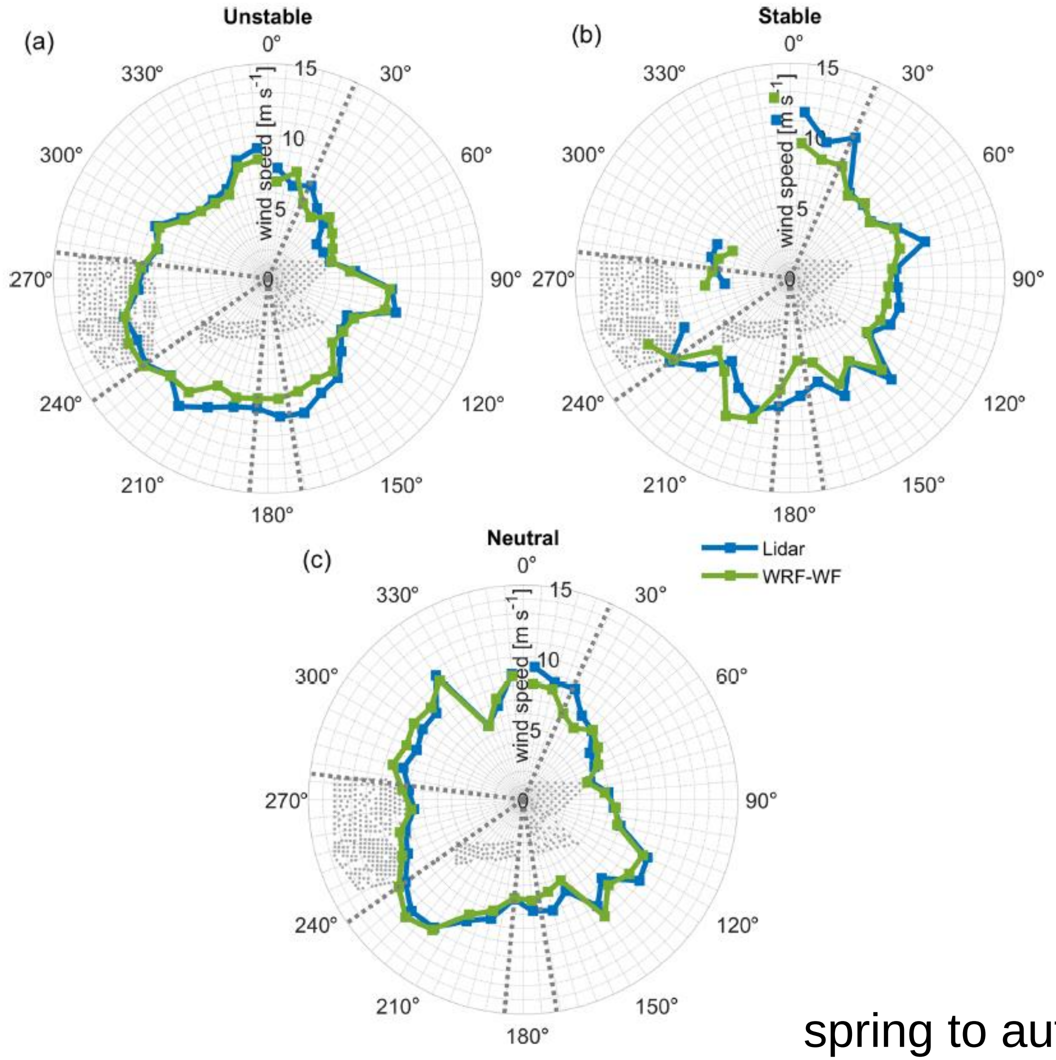
Atmospheric stability → lapse rate $\gamma = \frac{d\theta_v}{dz} \approx \frac{\Delta\theta_v}{\Delta z}$

High frequency of southwesterly wind directions

Stable stability mostly from eastern directions

Overall very inhomogeneous distribution of wind data

Directional and stability dependence of cluster wakes



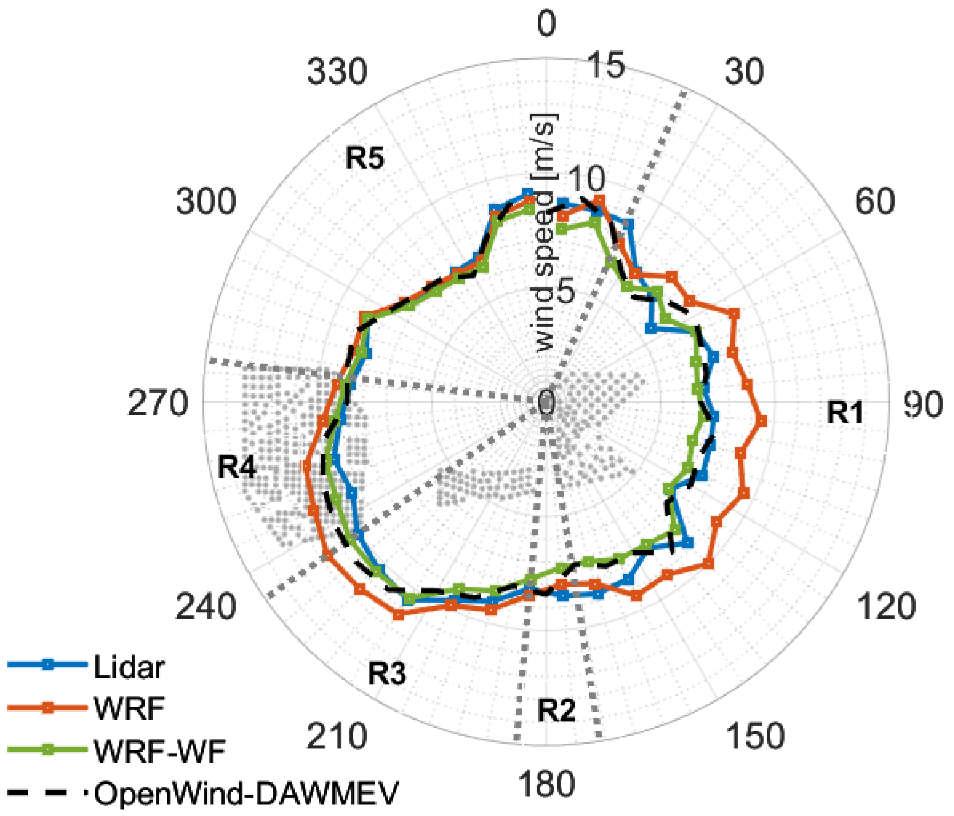
spring to autumn 2020

Wind farm cluster wake effects are enhanced by increasing atmospheric stability

Good agreement model-lidar for both the unstable and neutral atmospheric layers but less for the stable layers.

Data suitable for model validation in the time domain

Directional dependence of cluster wakes



spring to autumn 2020

Free Inflow from mesoscale simulation without wind farm

Good agreement between the three data sets in the free-wind region R5 (free wind)

Significant wind speed differences visible in region R1, R3 and R4

Reduced mean wind speed in the wake up to 30 % for mean wind speed of 10 m/s

Openwind mean values comparable with WRF-WF

Summary

The comparative multi-sensor and model approach proves to be an efficient way to analyze the complex flow situation in a modern offshore wind cluster, where phenomena at different length scales and timescales need to be addressed.

Lidar measurements combined with meteorological sensors reveal the strong directional and stability dependence of the wake strength in the direct vicinity of wind farm clusters.

Good agreement between WRF/Openwind model and the scanning lidar measurements is found for most of the WF-free regions in unstable conditions, with a relative deviation of around 2% in wind speed. As expected, the larger disagreements in wind speed (10%-20 %) are found for stable conditions for the WF regions.

Openwind model outputs, initialized with WRF (without wind farm), are comparable with WRF-WF.

This observational dataset allows for numerical model validations.

Questions?

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