# Measuring large scale offshore wind farm effects with scanning lidar

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## Motivation: offshore wind energy utilization

Last 10 years:

- 7.77 GW of capacity installed in Germany
- Wind farm clustering •

Goals:

• 40 GW in Germany (2040), 300 GW in EU (2050)

Resulting flow effects can lead to wind speed deficits:

- $\rightarrow$  inter wind farm effect: cluster wakes
- $\rightarrow$  flow effect in large wind farms: global blockage

Understanding of these wind farm effects important for

- offshore wind resource assessment •
- offshore regional planning •







#### [Image: https://www.4coffshore.com/offshorewind/]



## **BMWi joint research project X-Wakes**

#### <u>Overview</u>

- Duration: 11. 2019 10. 2022
- German research institutions with publications on offshore wakes
- wind farm operators

#### **Objectives**

- Wind farm boundary layer interaction
- Global blockage
- Wind farm cluster wakes
- Coastal effects
- Comprehensive measurement and modelling











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### Background and objective: wind farm cluster wakes

- Cluster wakes form of wakes of many wind turbines
- Cluster wakes observed in SAR, Radar and flight measurements before
- Wakes last far downstream in stable stratification

Do cluster wakes have an impact on the power production of a far downstream wind farm?

Can we measure far downstream cluster wakes with scanning long range lidar?











## **Background and objective: global wind farm blockage**

- Wind speed deficit upstream ullet
- Wind farm induction zone different from simple superposition of wind turbine induction zones
- Wind farm experiences less wind than expected from resource assessment •
- Small effect compared to wakes ullet
- Various modelling studies but just one experimental study with free field data! ۲

#### <u>Can we find evidence for global blockage in long range lidar data in different atm. stabilities?</u>



### Methods: offshore wind farm Global Tech I

Global Tech I (GTI)

- 80 x Adwen AD5-116
- 400 MW
- Distance to coast > 100 km
- 10 minute average power data available
- Meteorological measurements for atmospheric stability estimates
- Measurement campaign August 2018 to January 2020
- Satellite synthetic aperture radar (SAR) wind measurements available for some single situations











## Methods: long range Doppler lidar and Global Tech I power data



- Accurate measurement
- Constant monitoring

Power data: z-score referring to upstream turbines  $\Delta P_i$ 

Wind Energy

**Research Alliance** 





Image: Stephan Voß, ForWind

$$=\frac{P_i-\overline{P}_{up}}{\sigma_{up}}$$



#### Results: BorWin cluster wake 6 February 2019, SAR



## Results: BorWin cluster wake 6 February 2019, lidar average



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#### Average lidar wind field

- 60 consecutive scans
- 157 minutes
- Power data average 170 min



## Results: BorWin cluster wake 6 February 2019, lidar average



#### Average lidar wind field

- 60 consecutive scans
- 157 minutes
- Power data average 170 min



## **Conclusion & Outlook cluster wakes**

- Cluster wake effects reach far downstream in stable and weakly unstable conditions
- <u>Cluster wakes influence a far downstream wind farm's power</u> •
- Lidar and SAR good combination for cluster wake observations •
- Cluster wakes impact on annual energy production (AEP) not assessed, yet! ullet
- X-Wakes: Validation of numerical models for AEP estimations planned •







## Methods: global blockage analysis

- Data of same lidar campaign in GTI
- Global blockage effect about one order of magnitude smaller than cluster wakes
- Detailed lidar data correction and uncertainty • assessment necessary
- Categorizing lidar scans by •
  - Wind direction
  - Wind speed / turbine thrust
  - Atmospheric stability











### **Results: global blockage (unstable stratification)**

Unstable stratification, high thrust coeff.

• no wind speed deficit visible









## **Results: global blockage (stable stratification)**

Unstable stratification, high thrust coeff.

• no wind speed deficit visible

Stable stratification, high thrust coeff.

wind speed deficit of approx.
4 % found









## **Conclusion & Outlook global blockage**

- Strong evidence for wind farm global blockage in stable stratification and high turbine thrust
- No sign of global blockage in unstable stratification or with low turbine thrust
- Lidar data uncertainty assessment important! •
- Global blockage impact on annual energy production (AEP) not assessed, yet!
- X-Wakes: model validation with measurement data and AEP analysis planned •







#### Literature and data availability

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- Schneemann, J.; Theuer, F.; Rott, A.; Dörenkämper, M. & Kühn, M.: Offshore wind farm global blockage measured with scanning lidar, Doi: 10.5194/wes-2020-124, 2020 (preprint in review)
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### Thank you for your time! Do you have questions?









