X-Wakes [Cross-Wakes]

Interaction of the wakes of large offshore-wind farms and wind farm clusters with the marine atmospheric boundary layer

Dr. Martin Dörenkämper – Fraunhofer IWES

02.04.2020 - EERA JP Wind / SET Wind Workshop - Webinar

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# Research on wind farm wakes in the German Bight

The road towards the X-Wakes project

- Key results of pre-projects: GW Wakes & WIPAFF

- X-Wakes project (11.2019-10.2022)

    - Complementary measurements over several scales in time and space

    - Simulations: Mesoscale, LES and industry models

GW-Wakes (2012-2016)

Results from Measurements

- Investigation of the deep array effect for two wind farms of different size

  - In small wind farms the wakes have not grown together, from about 5 turbines in a row, a wind farm wake rather than single wakes can be observed

- Focus: LiDAR measurements (focus on turbulence) in small and large offshore wind farms

- Validation of transient LES with the measured LiDAR data.
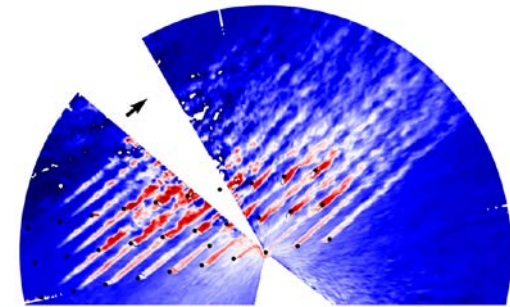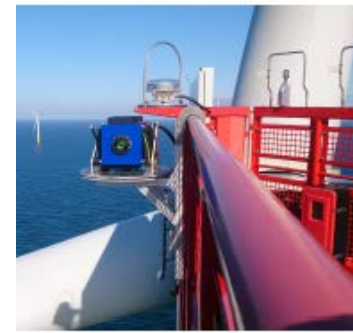
[Kühn et al., 2019; Vollmer et al.]
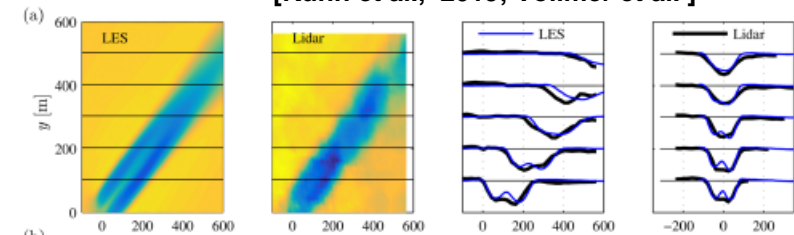
GW-Wakes (2012-2016)

Results from Modelling

- New engineering wake model flapFOAM: pre-calculated CFD fields increase the accuracy by keeping the speed of industry models

- LES models can be used to improve the parametrizations in mesoscale models

- Mesoscale scenarios: strong reduction of the wind resource even for the expansion plans for 2025
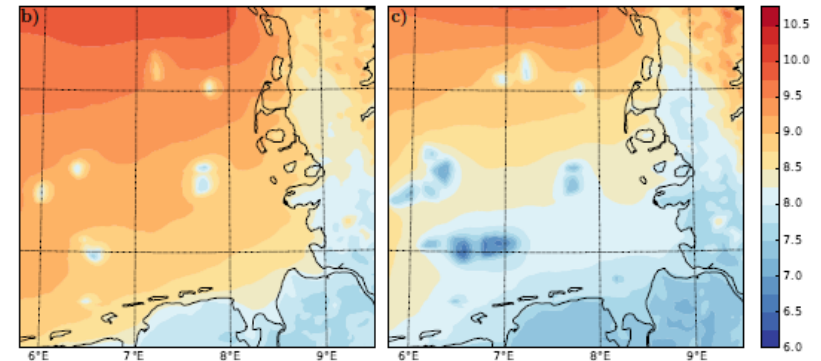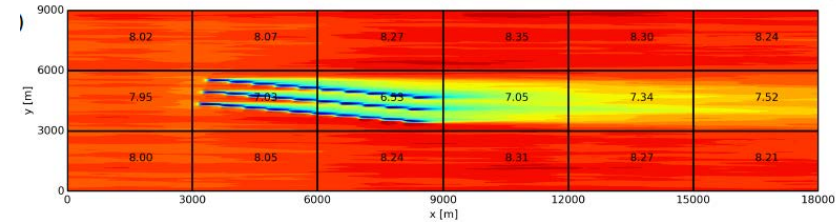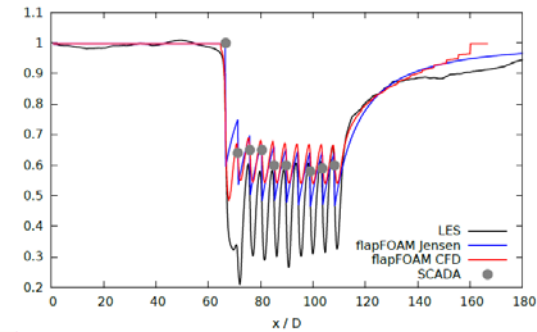
[Kühn et al., 2019]

WIPAFF (2015-2019)

Methods and Partners

[Bärfuss et al., 2019]

WIPAFF (2015-2019)

WRF simulations and validation

- During offshore-oriented winds, the inflow conditions (wind speed and atmospheric stability) of offshore wind farms in the German Bight can not be captured accurately enough (due to coastal effects)

[Siedersleben et al., 2018a, b, 2019]
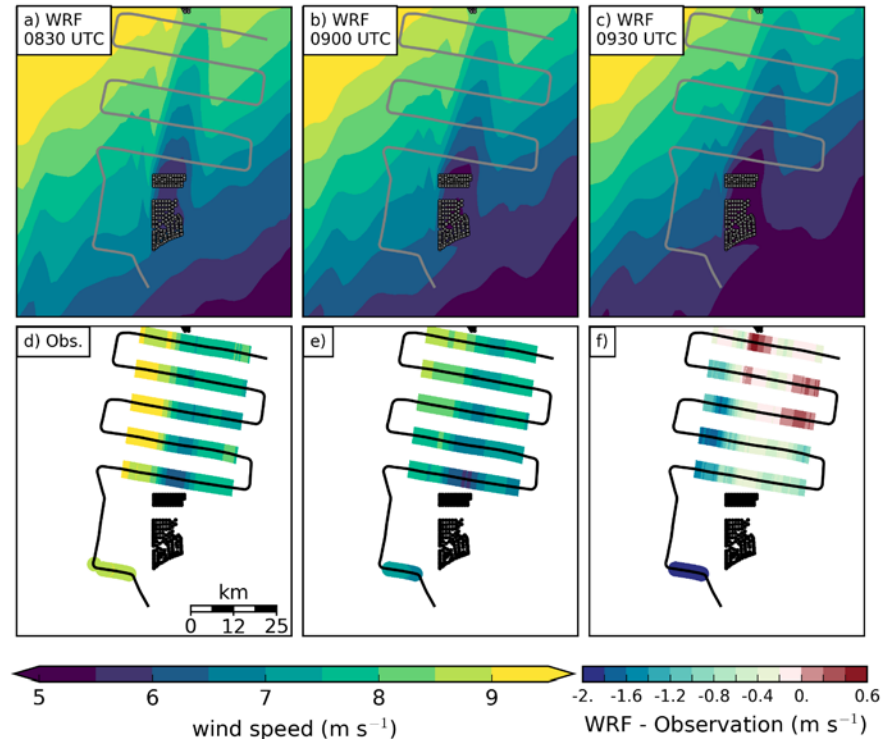
X-Wakes

Key Information

- Duration: 01.11.2019 – 31.10.2022

- Funded by the German Ministry of Economic Affairs and Energy – 3,4 million Euro funding

- Merge of two proposals (follow-up exploitation) of the consortia of GW-Wakes and WIPAFF

- Partners: all German research institutions with publications on offshore wakes in recent years

- Combination of comprehensive measurement and modelling activities

Project Partners

Participants: Research Institutes, Authorities & Industry Partners

- Fraunhofer IWES (Dr. Dörenkämper) – Project Coordination
- TU Braunschweig (Dr. Lampert) – Research Spokesperson
- Karlsruher Institute for Technology (Prof. Emeis)
- ForWind – University of Oldenburg (Dr. Heinemann, Prof. Kühn, Prof. Peinke)
- Eberhard Karls University Tübingen (Prof. Bange)
- Helmholtz-Center Geesthacht (Dr. Schulz-Stellenfleth)
- UL International GmbH (Dr. Cañadillas)

- Associated Partners:
  - Operators: EnBW, Ørsted, TenneT, RWE Renewables (ex. EON/Innogy), Vattenfall
  - Planning Authorities: BSH, DWD

- Two workshops (mid/end of project) will ensure further industry participation

Objectives of X-Wakes

Main Goals of the project

- Research Question: How do the results of GW-Wakes and WIPAFF 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 such as Global Blockage or Boundary Layer Interaction) on yields and real life wind farm operation

  - Understanding the process of wakes and wake interaction (including blockage)

  - Development and validation of indirect methods (satellite)

  - Better representation of cluster wakes and simulations

- Scenario calculations and rating of future wind farm expansion plans

Project Plan

X-Wakes consists of three large work packages with the following research activities:

- WP1: Coastal effects

- WP2: Interaction of wakes of single wind farms (scale 2 - 50 km)

- WP3: Interaction of wakes of wind farm clusters (scale 50 - 200 km)

all three WP with measurements (coordinated by TU Braunschweig) and modelling (coordinated by Fraunhofer IWES) activities

Further work package for development of recommendations for action for industry and planning authorities
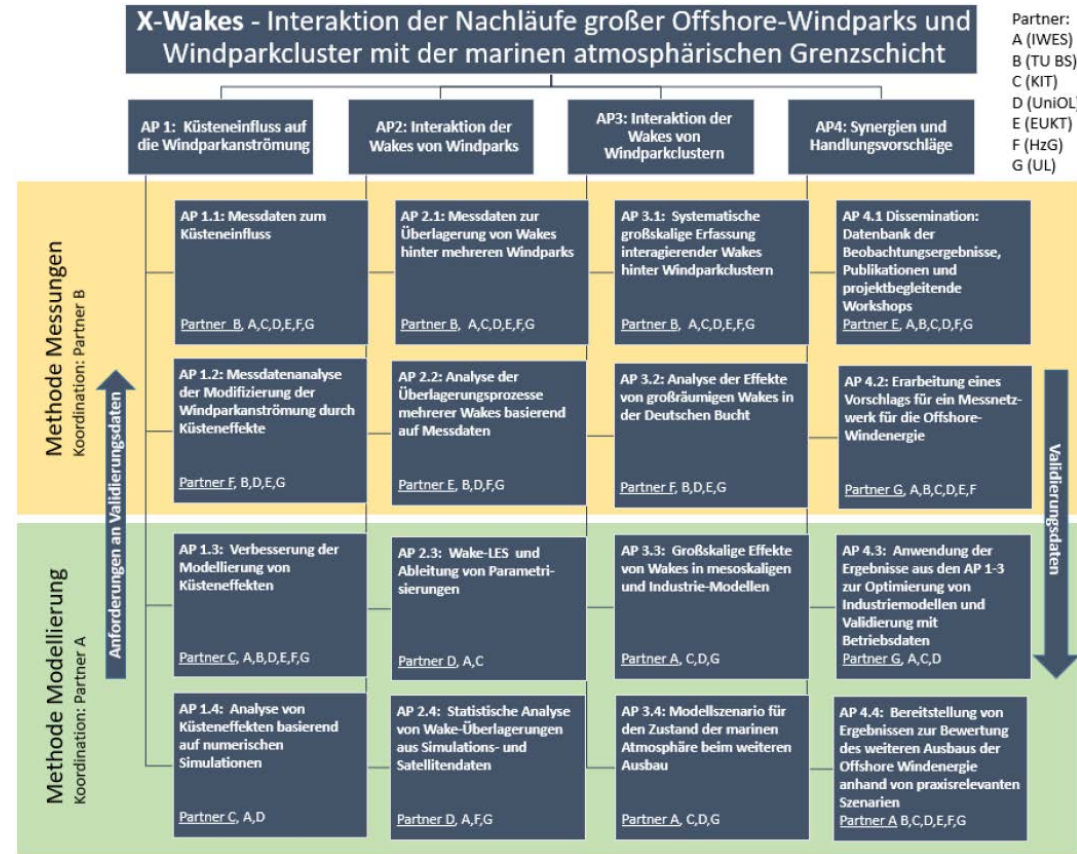
X-Wakes - Interaktion der Nachläufe großer Offshore-Windparks und Windparkcluster mit der marinen atmosphärischen Grenzschicht

Partner:
A (IWES)
B (TU BS)
C (KIT)
D (UniOL)
E (EUKT)
F (HzG)
G (UL)

Planned Measurements in X-Wakes

Campaigns & stationary measurements

- Analysis of flight data (research aircraft & unmanned airplanes)

- Satellite data (Terra-SAR X, Sentinel-1A/B)

- Stationary measurements in windward, center and leeward of wind farm clusters

  - Scanning und profiling lidars

- Analysis of SCADA data of several wind farms

➜ **Goal: Improved understanding of atmospheric processes & collection of validation data for the model development**
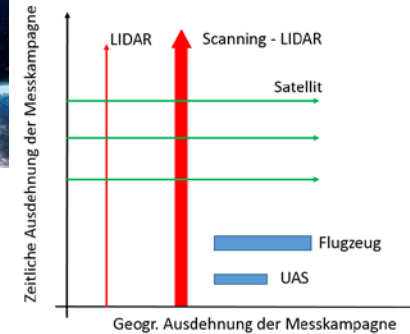
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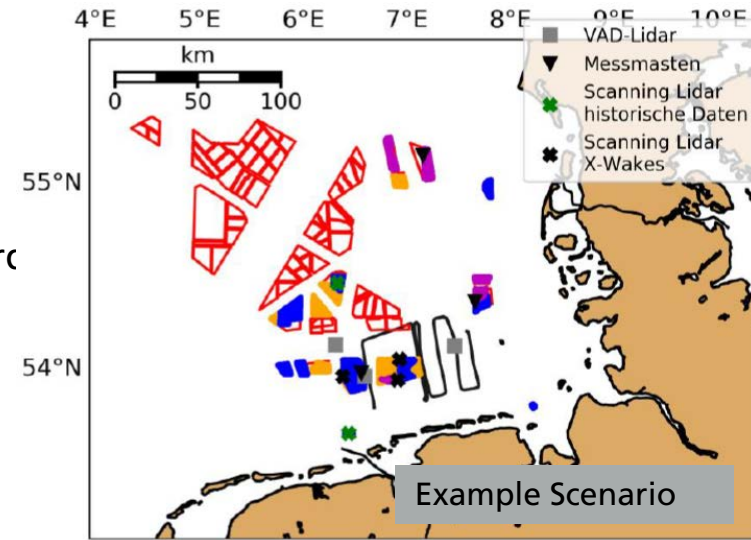
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Example Scenario

➜ **Goal: Improved understanding of atmospheric processes & collection of validation data for the model development**

Modelling Activities in X-Wakes 1/2

High Resolution (Research-)Models

- **Mesoscale Simulations** [WRF]
  - Improvement of simulations of coastal transition and its impact on wind farm inflow
  - Improvement of modelling of wind farms (layout impacts, like blockage and flow around wind farms, curtailments)
  - Derivations of parametrizations for large scale effects
  - Simulation of expansion scenarios of 2030 or later after validation

- **Large-Eddy-Simulations** [PALM]
  - Turbulence resolving simulations of large wind farms and single wind farm clusters
  - Nesting of LES in LES for large wind farms and wind farm clusters
  - Development/Validation of parametrizations for mesoscale and industry models
  - Improved interpretation of satellite radar data
  - Derivation of parametrizations for cumulative effects (global blockage)

Modelling Activities in X-Wakes 2/2

Industry Models

Industry Models [OpenWind / flapFOAM]

- Derivation and implementation of methods for industry models:
    - Coastal Effects and atmospheric stability
    - Wake interaction
    - Other cumulative effects (e.g. global blockage)
    - Boundary layer development in wind farm clusters
    - Large scale effects (e.g. large scale turning of wind, blockage)

flapFOAM5

Openwind

Most advanced software for creating
& optimizing turbine layouts
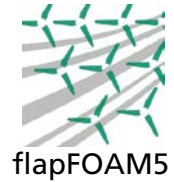
➔ **Goal: Reduction of uncertainty of industry (this means fast) models**

Expected Results

Results of X-Wakes

- **Understanding and simulation of**
  - Flows in **massively expanded large scale offshore areas** (e.g. German Bight)
  - Large-scale **interaction of wakes** of several wind farms
  - Interaction of **coastlines and wind farms**
  - Interaction of the **atmospheric boundary layer** with the wakes of large wind farm clusters

- **Development of tools for**
  - Simulation of large wind farm areas in **industry models**
  - Optimization of the **wind farm expansion**
  - **Continuous wake monitoring** from satellite data
  - Methods for future **Monitoring of winds** (suggest a wind measurement network)

➡️ **Main Goal: Improved yield estimated and energy ratings for future and existing offshore wind farms**

Questions?

Dr. Martin Dörenkämper - martin.doerenkaemper@iwes.fraunhofer.de

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and Energy

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by the German Bundestag

Thank you for your attention

Publications

GW-Wakes

Journal-Paper:

Bastine, D. and Witha, B. and Wächter, M. and Peinke, J.: Towards a Simplified Dynamic Wake Model using POD Analysis, Energies, doi 10.3390/en8020895

Bastine, D. and Vollmer, L. and Wächter, M. and Peinke, J.: Stochastic Wake Modelling Based on POD Analysis, Energies, doi 10.3390/en11030612

Schneemann, J., Rott, A., Dörenkämper, M., Steinfeld, G. and Kühn, M.: Cluster wakes impact on a far distant offshore wind farm's power, Wind Energy Science Discussions, doi 10.5194/wes-2019-39

Trabucchi, D., Trujillo, J.-J., Schnemann, J., Bitter, M. and Kühn, M.: Application of staring lidars to study the dynamics of wind turbine wakes, Meteorologische Zeitschrift, doi: 10.1127/metz/2014/0610

Van Dooren, M.F., Trabucchi, D. and Kühn, M.: A Methodology for the Reconstruction of 2D Horizontal Wind Fields of Wind Turbine Wakes Based on Dual-Doppler Lidar Measurements, Remote Sensing, doi 10.3390/rs8100809

Vollmer, L., Steinfeld, G., Kühn, M.: Transient LES of an offshore wind turbine, Wind Energy Science, doi: 10.5194/wes-2-603-2017

Doctoral Theses:

Bastine, D.: Stochastic Analysis and Modeling of Wind Turbine Wakes, University of Oldenburg, 2017.

Trujillo, J.-J.: Large scale dynamics of wind turbine wakes : measurement and modelling in the full field, University of Oldenburg, 2018.

Vollmer, L.: Influence of atmospheric stability on wind farm control, University of Oldenburg, 2018

Final Report:

Schnemann, J., Kühn, M. and Coauthors: Analyse der Abschattungsverluste und Nachlaufturbulenzcharakteristika großer Offshore-Windparks durch Vergleich von ``alpha ventus'' und ``Riffgat'' (``GW Wakes''), Technical Report, doi: 10.2314/GBV:886719402

Publications

WIPAFF

Journal-Paper:

Bärfuss, K., Hankers, R., Bitter, M., Feuerle, T., Schulz, H., Rausch, T., Platis, A., Bange, J., and Lampert, A.: In-situ airborne measurements of atmospheric and sea surface parameters related to offshore wind parks in the German Bight, PANGAEA, https://doi.pangaea.de/10.1594/PANGAEA.902845, 2019.

Cañadillas B. et al. Offshore wind farm wake recovery: Airborne measurements and its representation in engineering models. April, 2019. Wind Energy (submitted)

Emeis S, Siedersleben S, Lampert A, Platis A, Bange J, Djath B, Schulz-Stellenfleth J, Neumann T. Exploring the wakes of large offshore wind farms. Journal of Physics: Conference Series 2016, 753, 092014 (11 pp.) DOI: 10.1088/1742-596/753/9/092014, 2016.

Lampert, A., Bärfuss, K., Platis, A., Siedersleben, S., Djath, B., Canadillas, B., Hankers, R., Bitter, M., Feuerle, T., Schullz, H., Rausch, T., Angermann, M., Schwithal, A., Bange, J., Schulz-Stellenfleth, J., Neumann, T., and Emeis, S.: In-situ airborne measurements of atmospheric and sea surface parameters related to offshore wind parks in the German Bight, submitted to ESSD, 2019.

Platis, A., Siedersleben, S., Bange, J., Lampert, A., Bärfuss, K., Hankers, R., Canadillas, B., Foreman, R., Schulz-Stellenfleth, J., Djath, B., Neumann, T., and Emeis, S.: First in situ evidence of wakes in the far field behind offshore wind farms, Scientific Reports, doi 10.1038/s41598-018-20389-y, 2018.

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Siedersleben, S.K., Platis, A., Lundquist, J.K., Lampert, A., Bärfuss, K., Canadillas, B., Djath, B., Schulz-Stellenfleth, J., Neumann, T., Bange, J., and Emeis, S.: Evaluation of a Wind Farm Parametrization for Mesoscale Atmospheric Flow Models with Aircraft Measurements, Meteorologische Zeitschrift, PrePub DOI 10.1127/metz/2018/0900, 2018.