Investigation of flow conditions and turbulence characteristics in large offshore wind farms by remote sensing experiments and simulations


ForWind – University of Oldenburg, Institute of Physics, Germany

J. Schmidt

Fraunhofer IWES, Oldenburg, Germany

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Wind farm flow studies: motivation and objectives

Wakes
• reduced wind speeds
• increased turbulence
  ➢ increased loads
  ➢ reduced power output

Objectives
• understanding of
  – turbulence characteristics
  – wake effects in / of large wind farms
  – atmospheric stability effects
• flow measurements
• flow model validation
• development and test of engineering models
Wind farm flow studies: methodology

- Measurements
- Numerical simulations
- Modelling / optimization

- Lidar
- SAR
- LES
- meso-scale
- Wake modeling
- Turbulence studies/modelling
- Wind farm optimization

- Blade
- Wind Turbine
- Wind Farm
- Wind Farm Clusters

Microscale: $10^0$ to $10^2$ m
Mesoscale: $10^3$ to $10^5$ m
Offshore lidar measurement campaigns

alpha ventus
- July 2013 until March 2014

Riffgat
- since summer 2015
Example: single lidar measurement at »alpha ventus«

Lidar systems

- long-range lidar Leosphere Windcube200S with „all-sky“ scanner
- max. range up to 6.5 km
- up to 240 range gates per system

Example:

- consecutive lidar scans
- line of sight velocities transferred to absolute values assuming constant wind direction
- wake tracking applied to study wake dynamics
Multiple-lidar wind field evaluation algorithm (MuLiWEA)

Multiple scanning lidars
- overlapped PPI scans: 1D flow information

MuLiWEA: 2D wind field retrieval
- selection of measurement sets for each grid point
- construction of linear system for full wind field
- accounting for 2D continuity adjustment

Result: 2D wind vector field

Validation of LES with MuLiWEA will be shown in Session 10 by Lukas Vollmer
Wind retrieval with space born synthetic aperture radar

- synthetic aperture radar (SAR) provides wind information over the ocean measuring sea surface roughness
- here X-band SAR satellite TerraSAR-X used
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TerraSAR-X backscatter image

Processed TS-X 10 m wind field
Comparing long range lidar and SAR satellite

**Scanning lidar**
- Medium areal coverage
- Measurement of time series

**SAR**
- Very high areal coverage possible
- No time series

- SAR measurements just validated against point measurements up to now
- Can spatial structures measured with TS-X be reproduced from scanning lidar data?
Comparing long range lidar and SAR satellite

- Spatial structures compare well although Lidar measures Doppler shifts in the atmosphere and TS-X measures sea surface roughness
- Lidar and SAR can be a complementing couple for future offshore wind measurement
Further development of wind farm parameterizations for meso-scale models using LES

- data base on wind farm wakes generated with the means of LES (ADM)
- wake field highly dependant on wind direction → not covered by meso-scale models
Further development of wind farm parameterizations for meso-scale models using LES

- average wind speed to mimic meso-scale modelling

- mean deficit highlights dependency of wind farm wake on intra wind farm effects

- consequence: modification of parameterization by an effective rotor area
Wind farm software flapFOAM

- flapFOAM: „Farm layout program coupled to OpenFOAM“
- task: interface between results from simulations and application
- wind farm modeling, calculation and optimization based on wake models (analytic, numerically, CFD-based look up table)
- principle: overlay of single wakes
- low computational demands

Jensen model

Frandsen model

Larsen model

Ainslie model A

Ainslie model B

CFD-based model
Wind farm software flapFOAM
Example: optimization of annual energy production

Input
• CFD-based wake model
• number and type of turbines
• domain 8 x 8 km²
• wind rose

Result
• averaged wind field in optimised farm layout
Conclusions and outlook

Conclusions

• measurement campaign in »alphaventus« successfully completed
• measurements in »Riffgat« ongoing
• 2D wind field generated from dual lidar measurements
• SAR wind field structures compare well to lidar measurements
• wind farm parametrization in meso-scale model optimized
• wind farm optimisation tool FlapFOAM developed
• …

Outlook

• complete measurement campaign in »Riffgat«
• compare multiple overlapped wakes to single/double wakes
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Related contributions

• Session 2:
  Juan José Trujillo: Detailed validation of dynamic loading simulation of offshore wind turbines operating in wake

• Session 10
  Lukas Vollmer: Comparison of dual-Doppler lidar measurements and Large Eddy Simulations of an offshore wind turbine wake

• Poster 2759
  David Bastine: Characterization of wake turbulence using staring lidar measurements

• Poster 2783
  Juan José Trujillo: Comparison of simulations of the far wake of alpha ventus against ship-based lidar measurements