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

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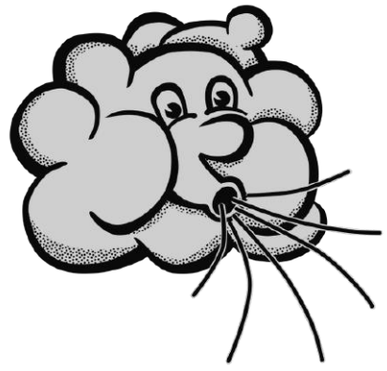
RAVE Conference 2015

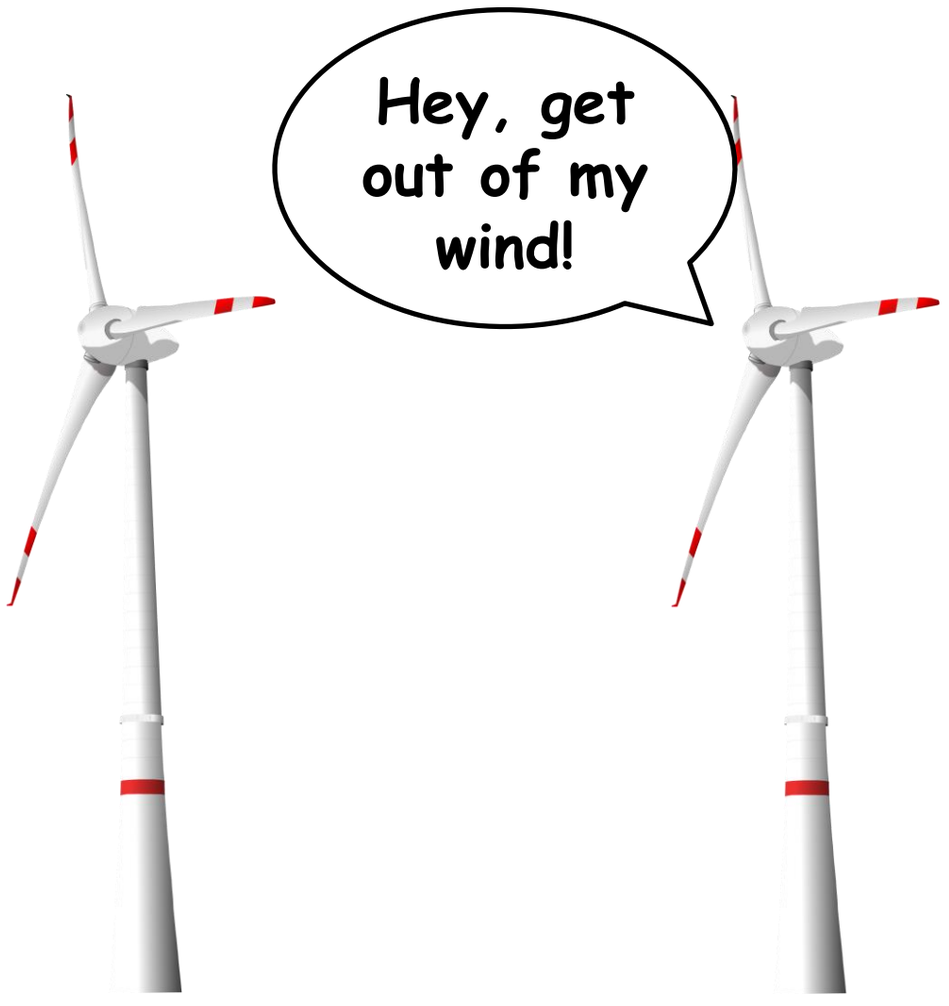
October 14th, 2015, Bremerhaven

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

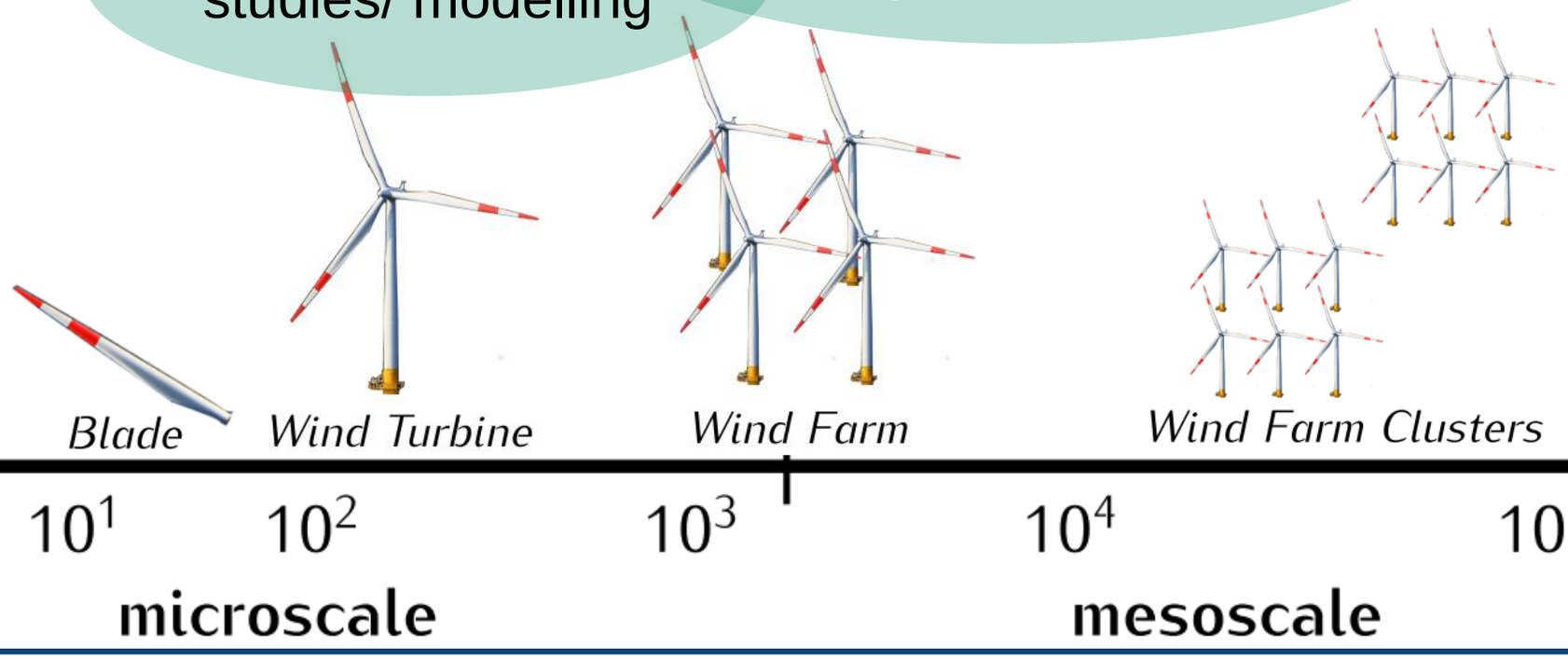
LES

meso-scale

Wake modeling

turbulence studies/ modelling

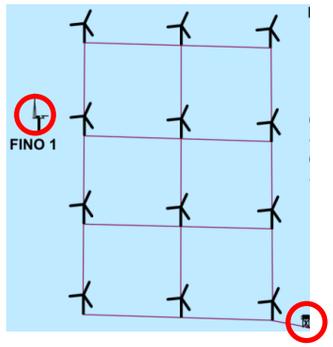
Wind farm optimization



Offshore lidar measurement campaigns

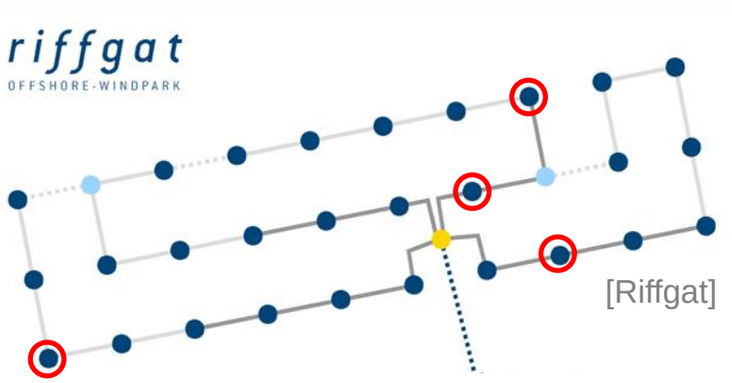
alpha ventus

- July 2013 until March 2014



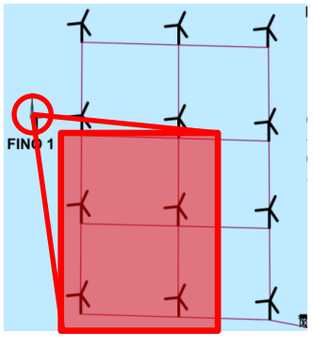
Riffgat

- since summer 2015



[Riffgat]

Example: single lidar measurement at »alpha ventus«

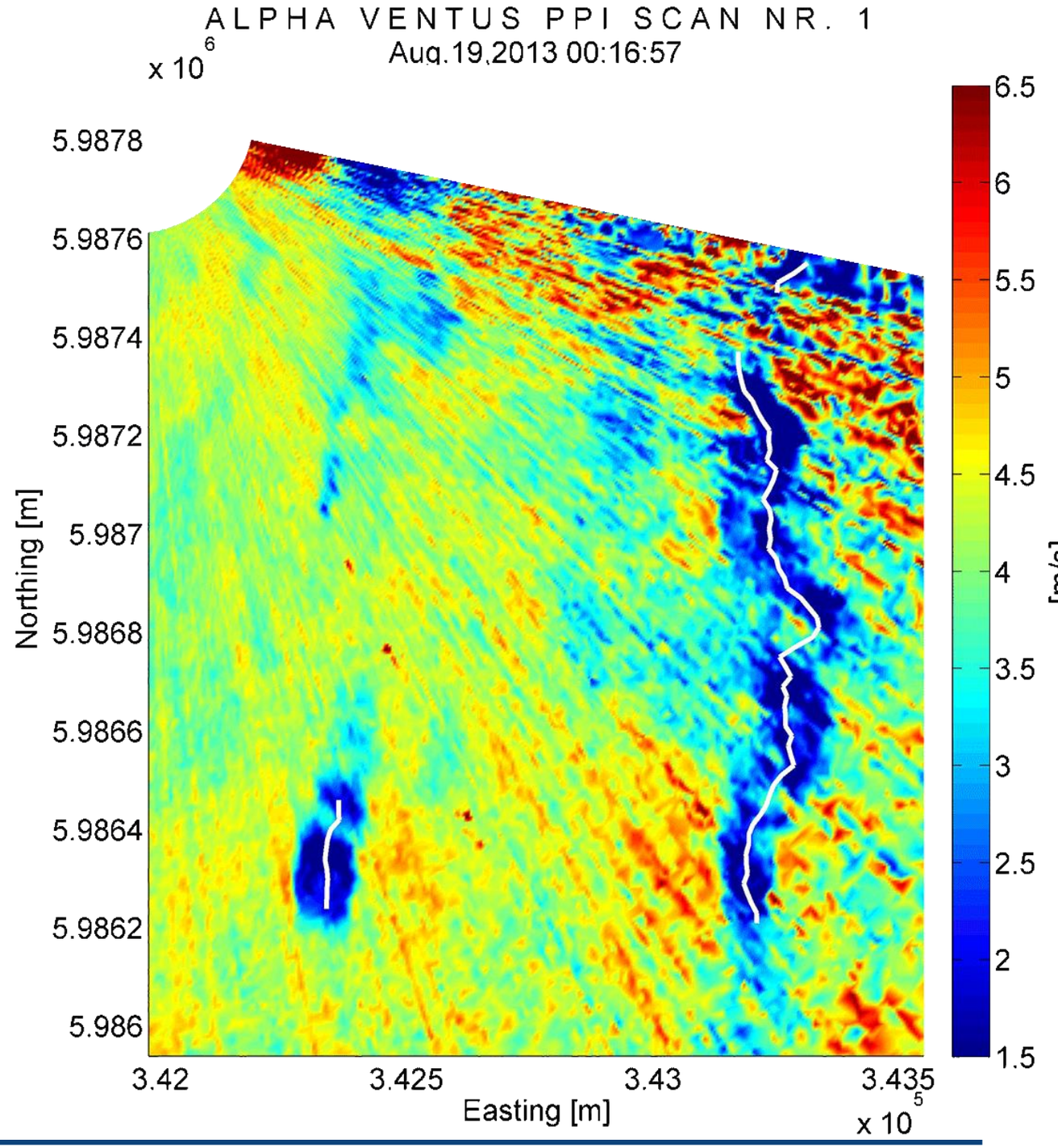


Lidar systems

- 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

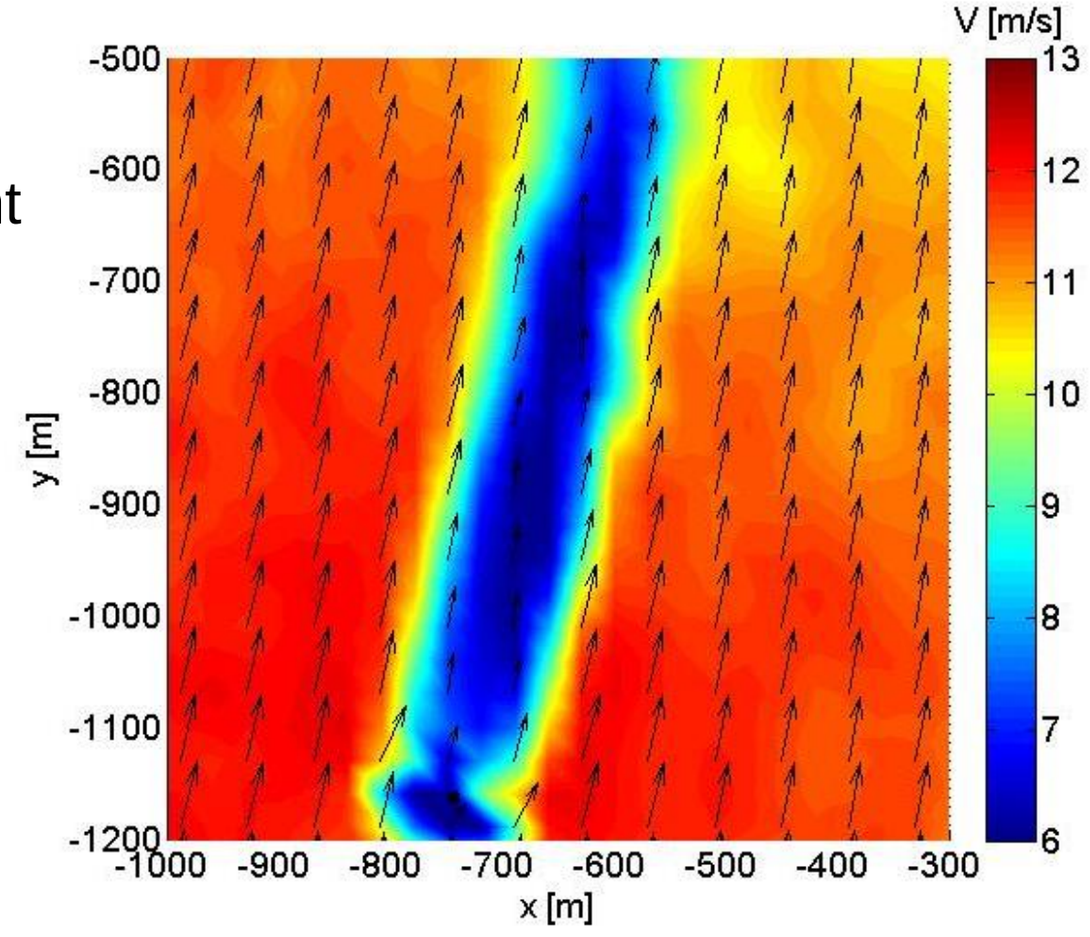
MuLiWEA: 2D wind field retrieval

- 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

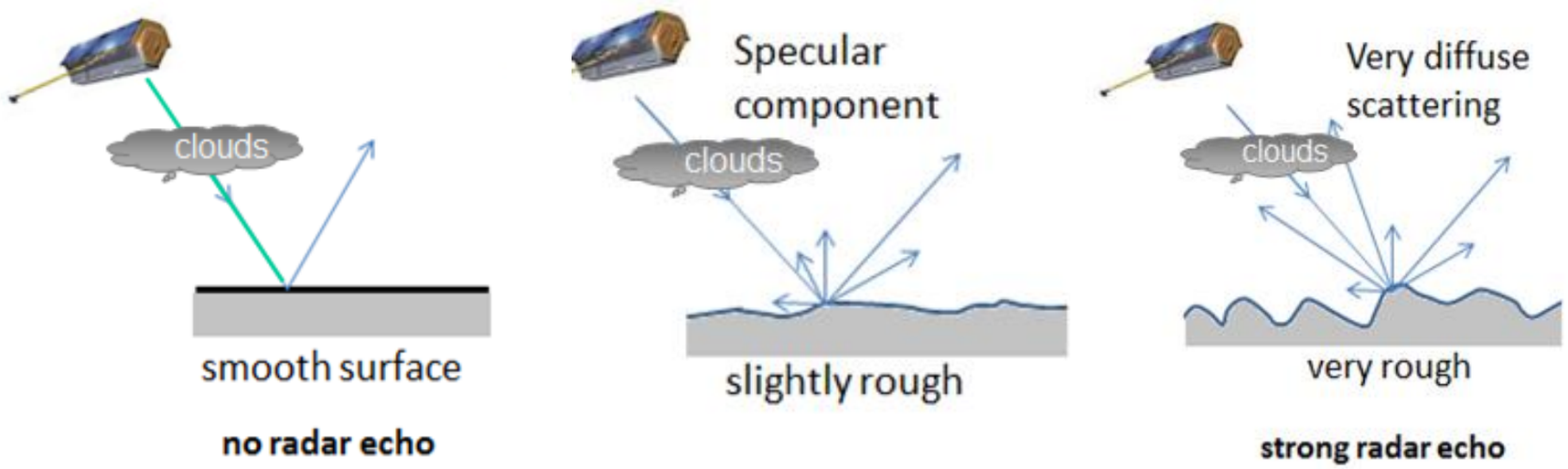
Validation of LES with MuLiWEA will be shown in Session 10 by Lukas Vollmer

application on wake analysis in »alpha ventus«



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



Wind retrieval with space born synthetic aperture radar

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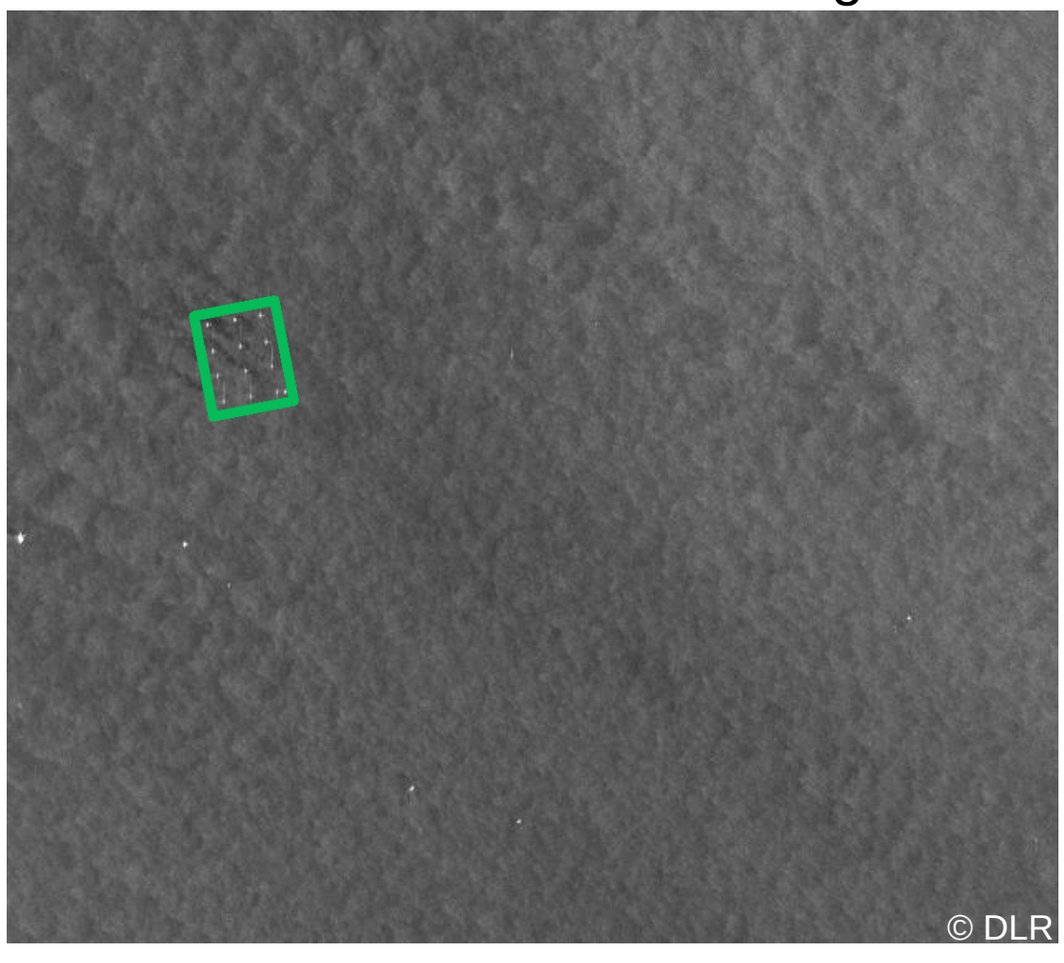
TerraSAR-X backscatter image

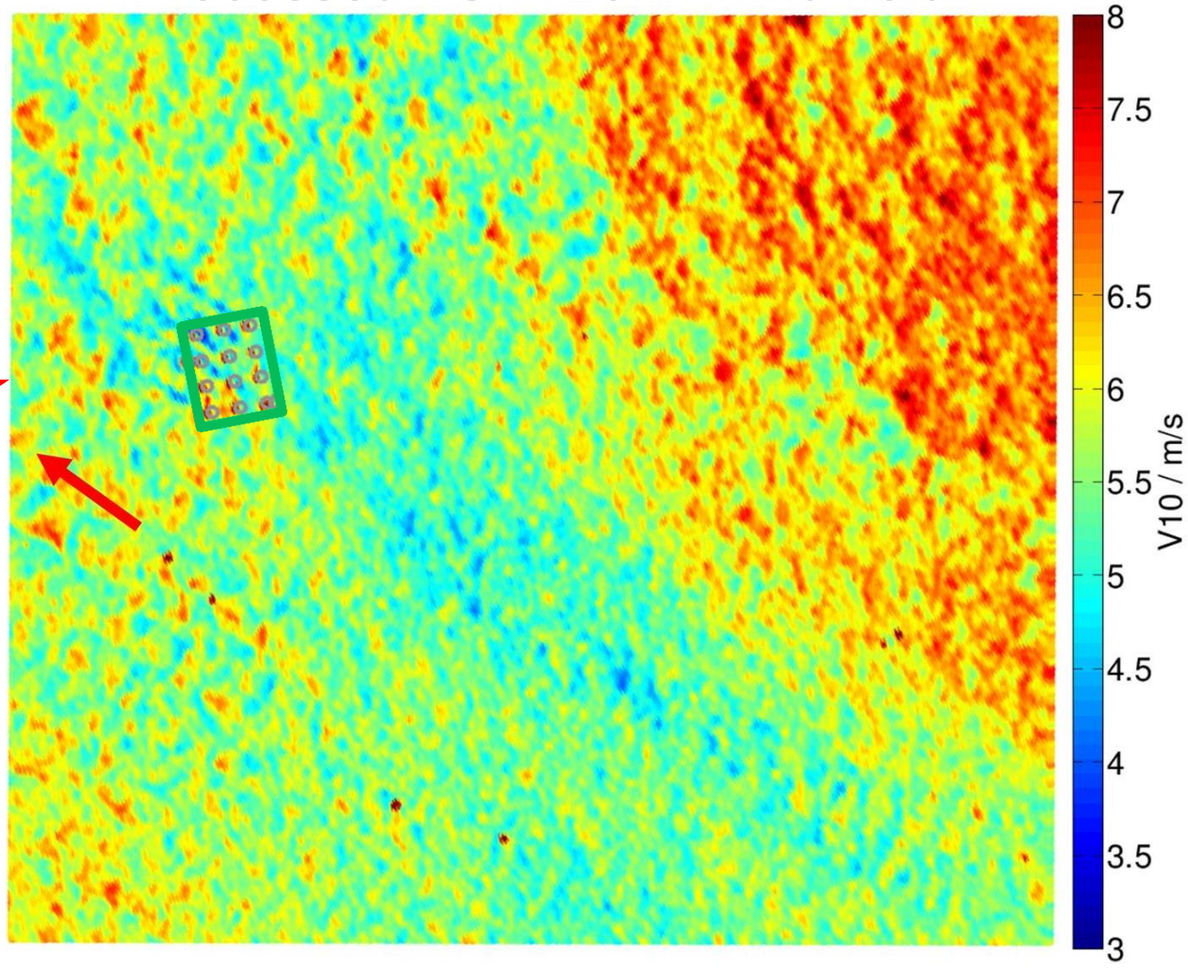


Wind direction

Image calib.

Incid. angle

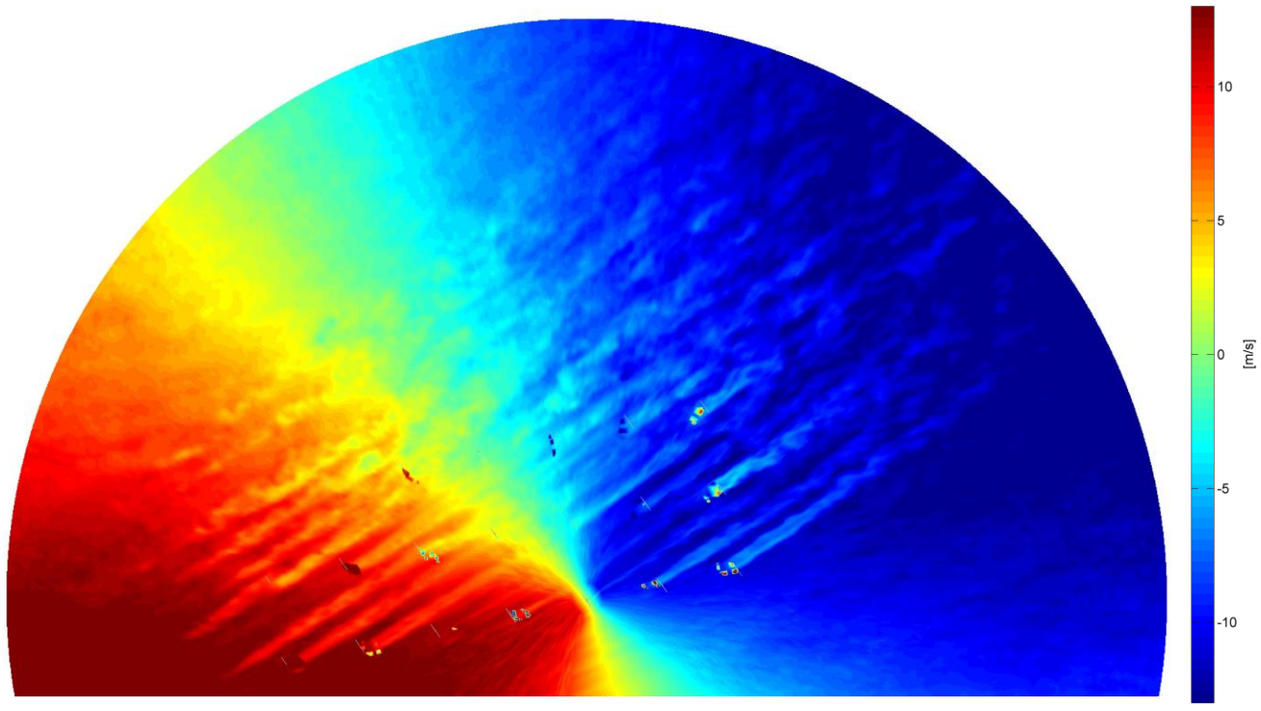
Processed TS-X 10 m wind field



Comparing long range lidar and SAR satellite

Scanning lidar

- Medium areal coverage
- Measurement of time series



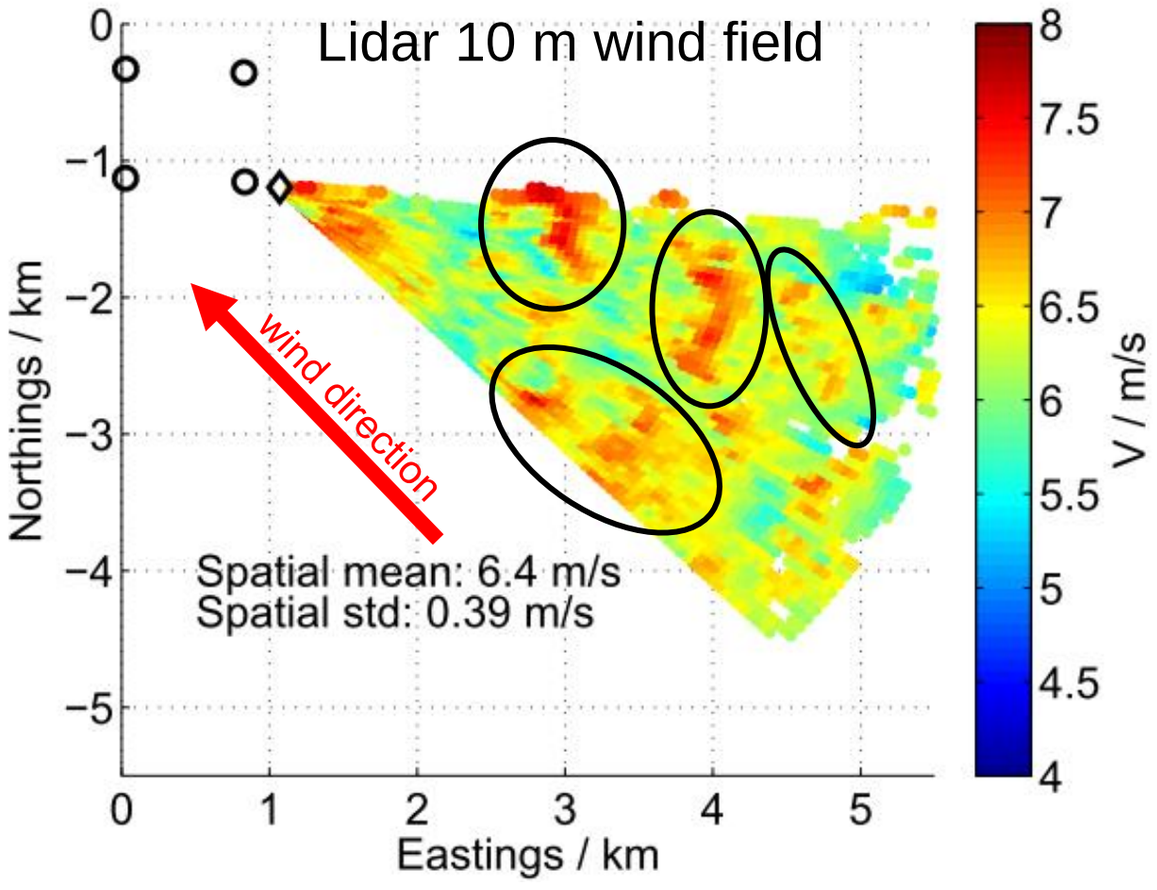
SAR

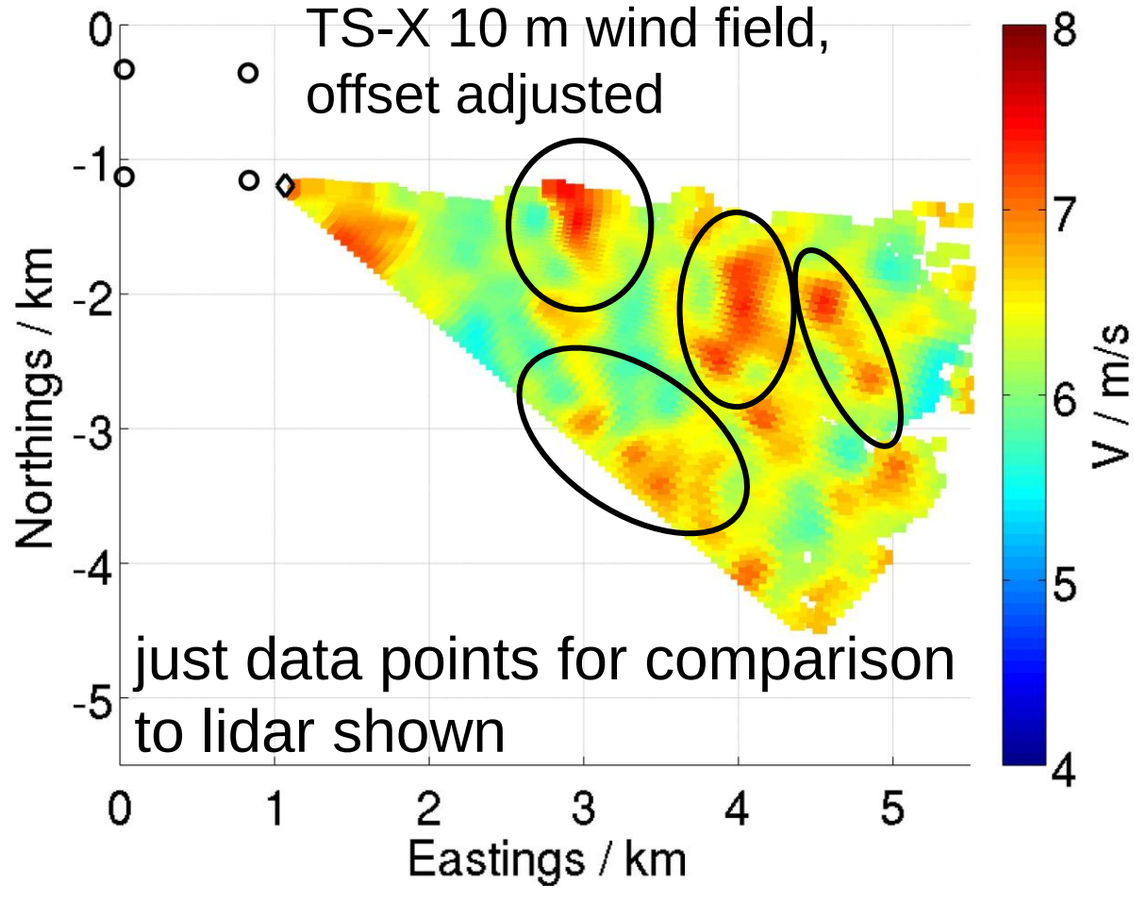
- Very high areal coverage possible
- No time series

- 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

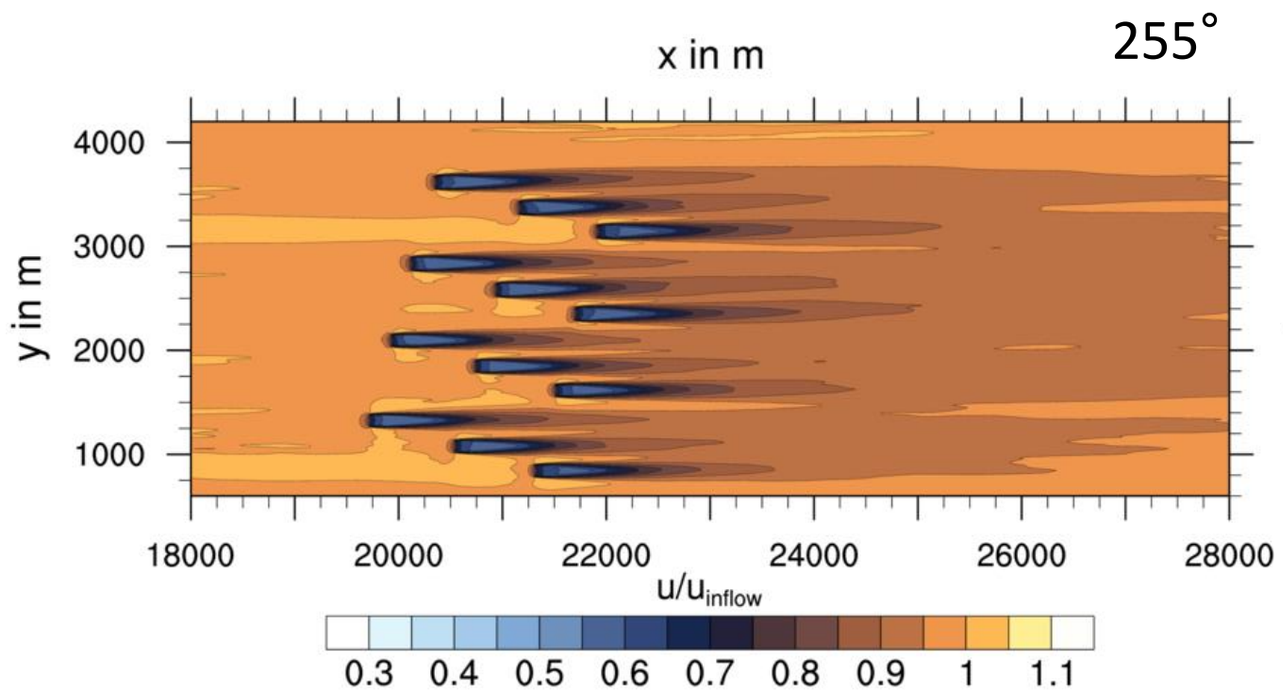
- Spatial structures compare well although Lidar measures Doppler shifts in the atmosphere and TS-X measures sea surface roughness
- Lidar and SAR can be a complementing couple for future offshore wind measurement

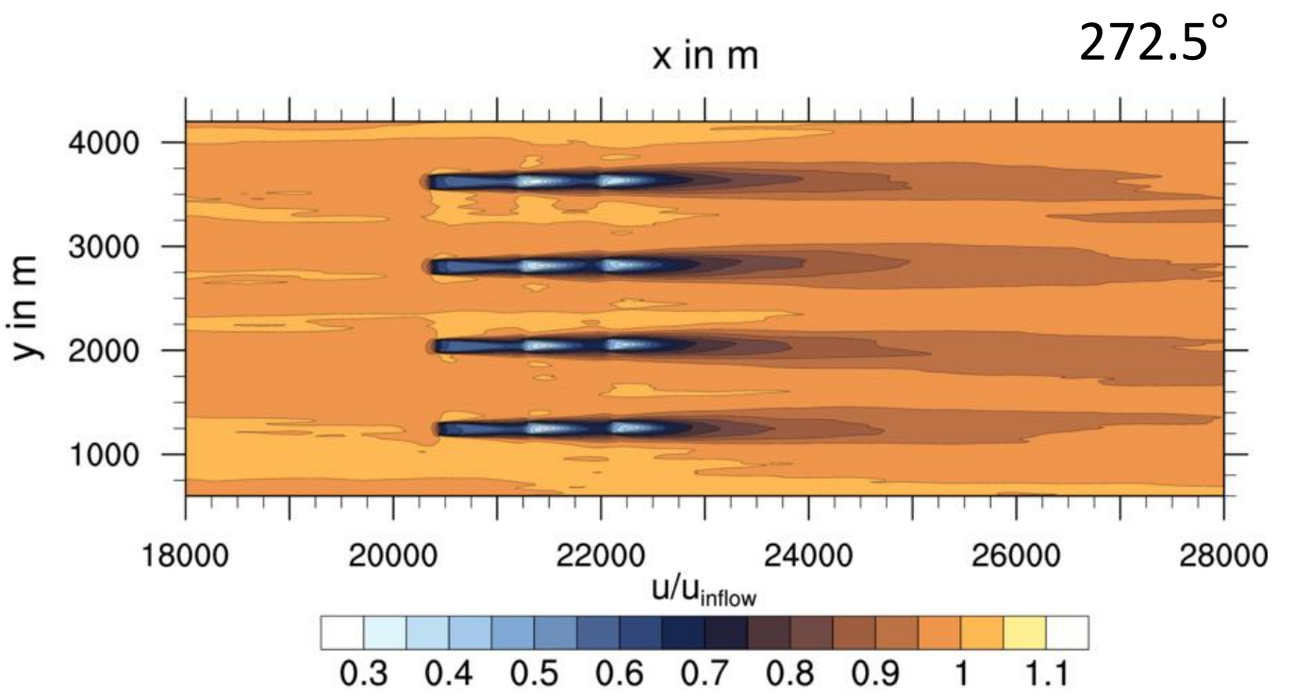




Further development of wind farm parameterizations for meso-scale models using LES

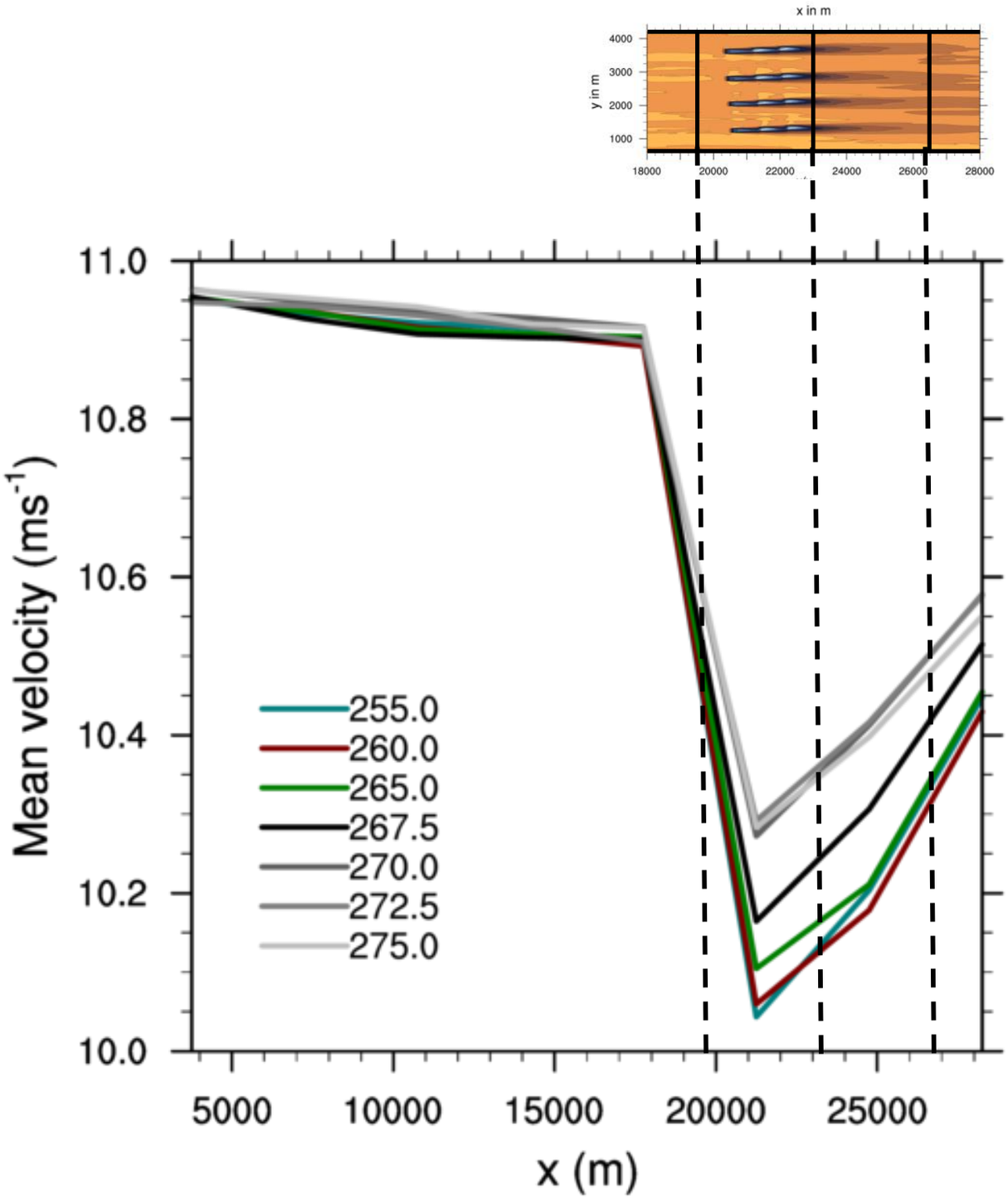
- data base on wind farm wakes generated with the means of LES (ADM)
- wake field highly dependant on wind direction → not covered by meso-scale models





Further development of wind farm parameterizations for meso-scale models using LES

- average wind speed to mimic meso-scale modelling

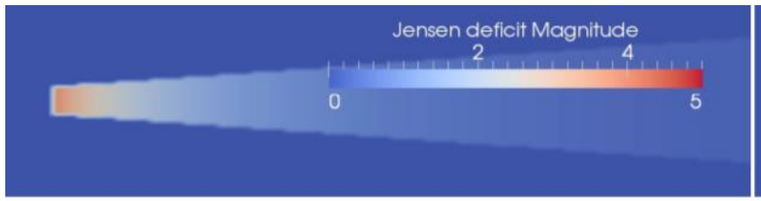


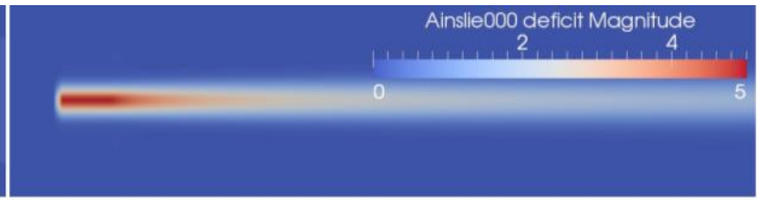
- mean deficit highlights dependency of wind farm wake on intra wind farm effects
- consequence: modification of parameterization by an effective rotor area

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

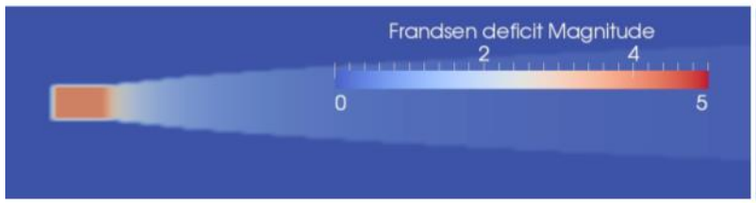
Jensen model

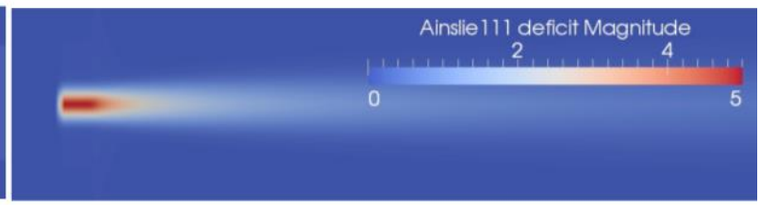




Ainslie model A

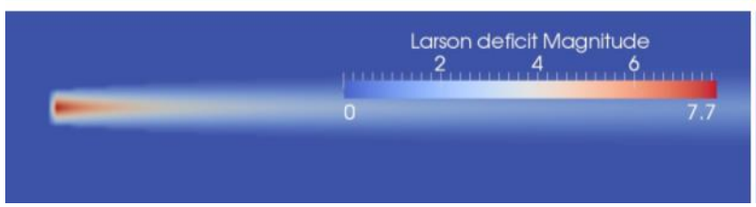
Frandsen model

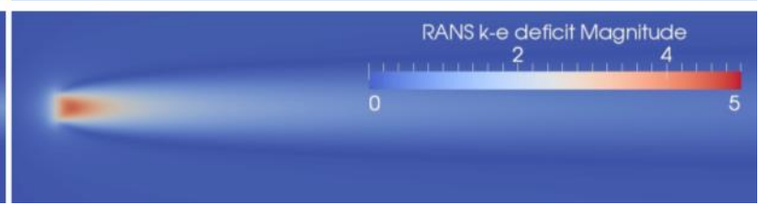




Ainslie model B

Larsen model





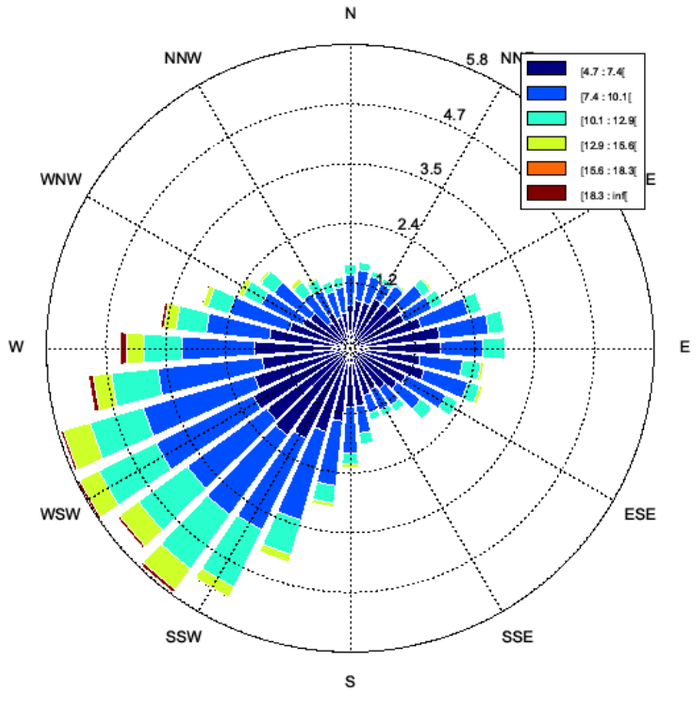
CFD-based model

Wind farm software flapFOAM

Example: optimization of annual energy production

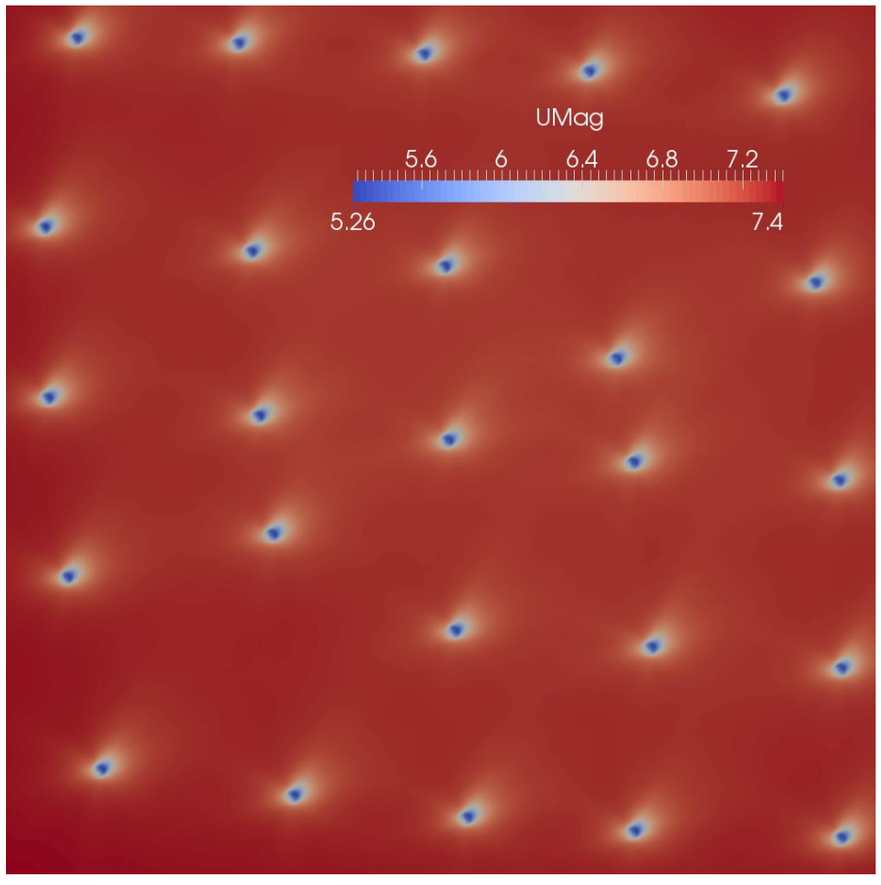
Input

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

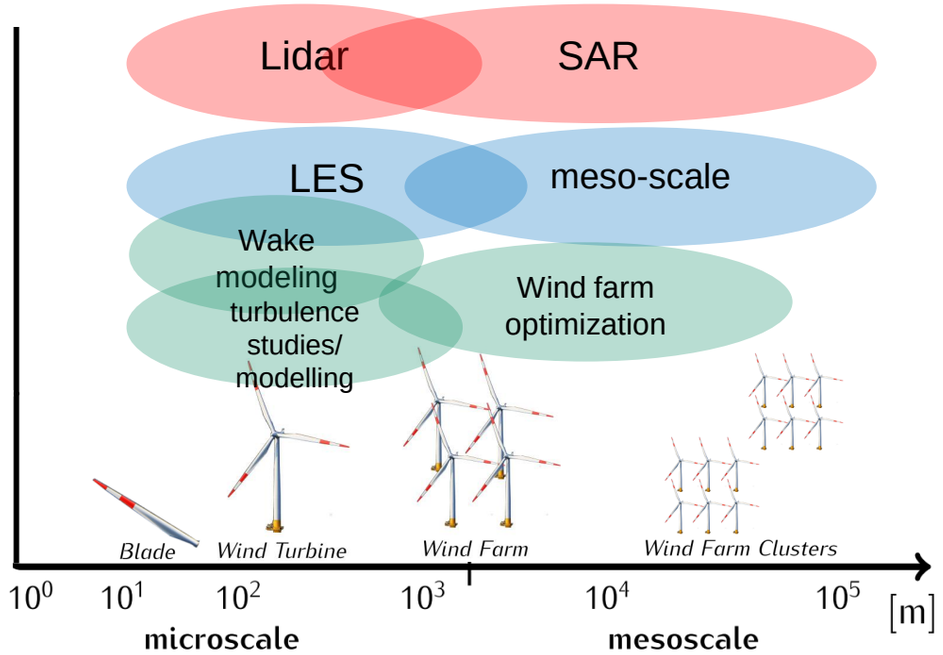


Result

- averaged wind field in optimised farm layout



Conclusions and outlook



Conclusions

- measurement campaign in »alpha ventus« 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

Acknowledgements

The RAVE project »GW Wakes« is funded by the Federal Ministry for Economic Affairs and Energy (BMWi) on the basis of a decision by the German Bundestag (grant number 0325397A).

Thanks to the DLR group “Maritime safety” for the ongoing fruitful cooperation in offshore wind retrieval using SAR and Lidar.

Further more we would like to thank

- Deutsche Offshore-Testfeld und Infrastruktur GmbH & Co. KG (DOTI),
- Offshore-Windpark RIFFGAT GmbH & Co. KG and
- Forschungs- und Entwicklungszentrum Fachhochschule Kiel GmbH

for their support and the possibility to access their offshore wind farms and platforms.

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