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Computations in wind energy research, an overview

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Scales of simulations

From 10^{-5} m to 3 km

Microscale

- Microscale covering scales from few meters to several kilometers
- Resolutions in the order of 10^{-5} m
- Used for optimization of turbine blade design and acoustics
- We use OpenFOAM, CFL3D

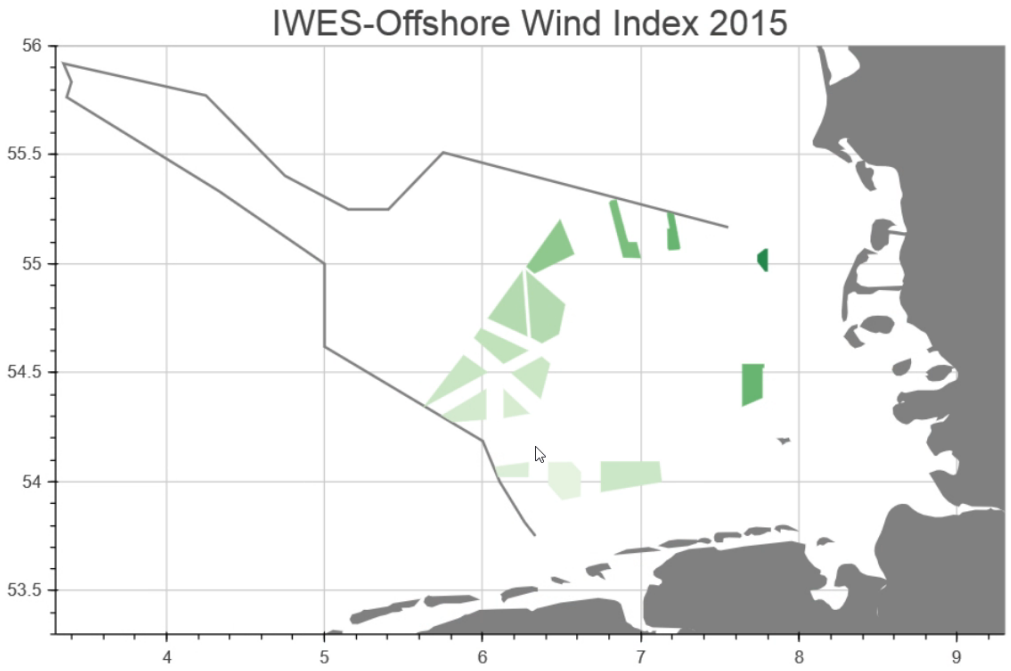
Mesoscale

- Mesoscale covering scales from some tens to several hundreds of kilometers
- Resolutions in the order of 1-3 km
- Used in wind energy applications in the last 10-15 years focusing on wind atlas or cluster wake modelling applications
- We use the WRF model (MPAS under investigation), FIWIND, PALM LES, FOXES

Scope

Mesoscale modeling

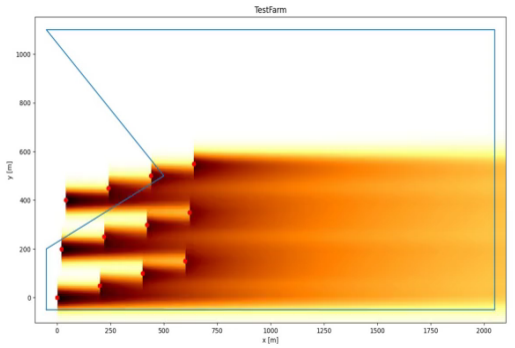
Post construction analysis

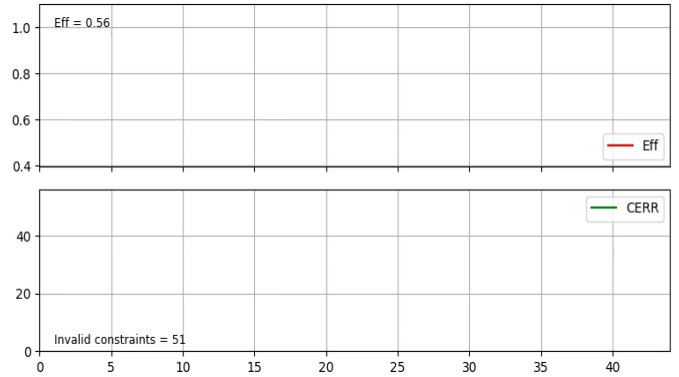


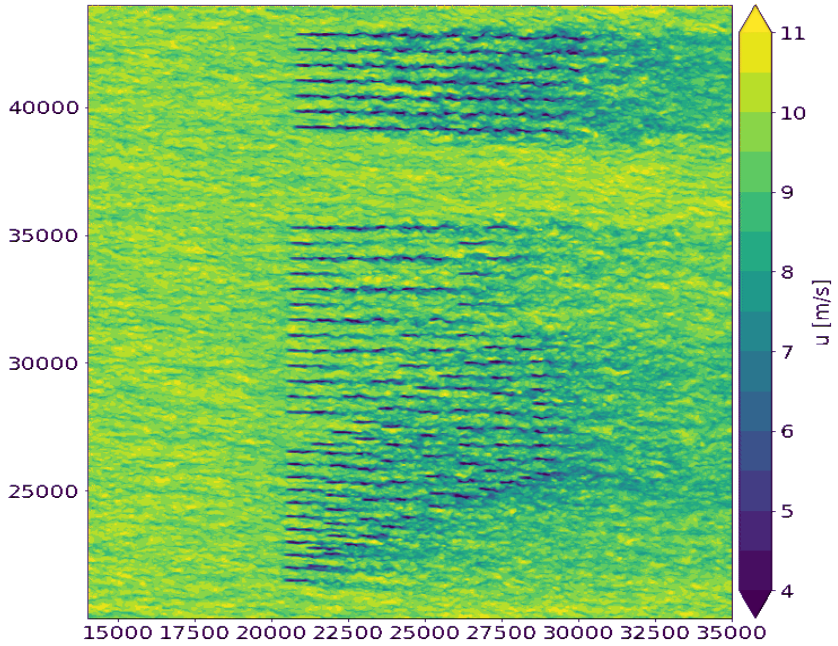
Relative local mesoscale wind and power analysis of time series calibrated by wind farm data

Wind farm optimization

Wind







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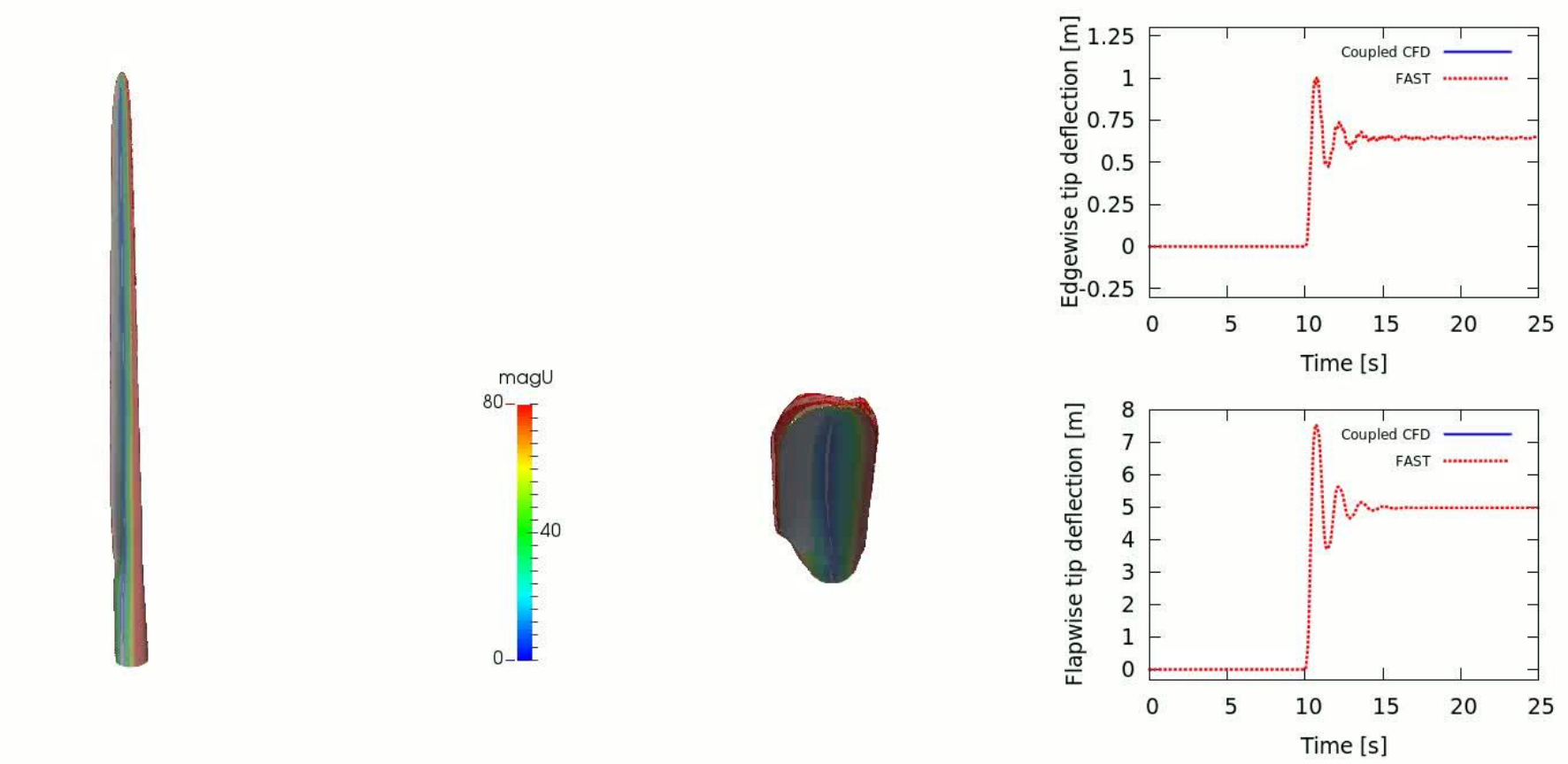
Scope

Microscale modeling

Vortex induced vibration



Dose, B., Rahimi, H., Herráez, I., Stoevesandt, B., & Peinke, J. (2016, September). Fluid-structure coupled computations of the NREL 5MW wind turbine blade during standstill. In *Journal of Physics: Conference Series* (Vol. 753, No. 2, p. 022034). IOP Publishing.

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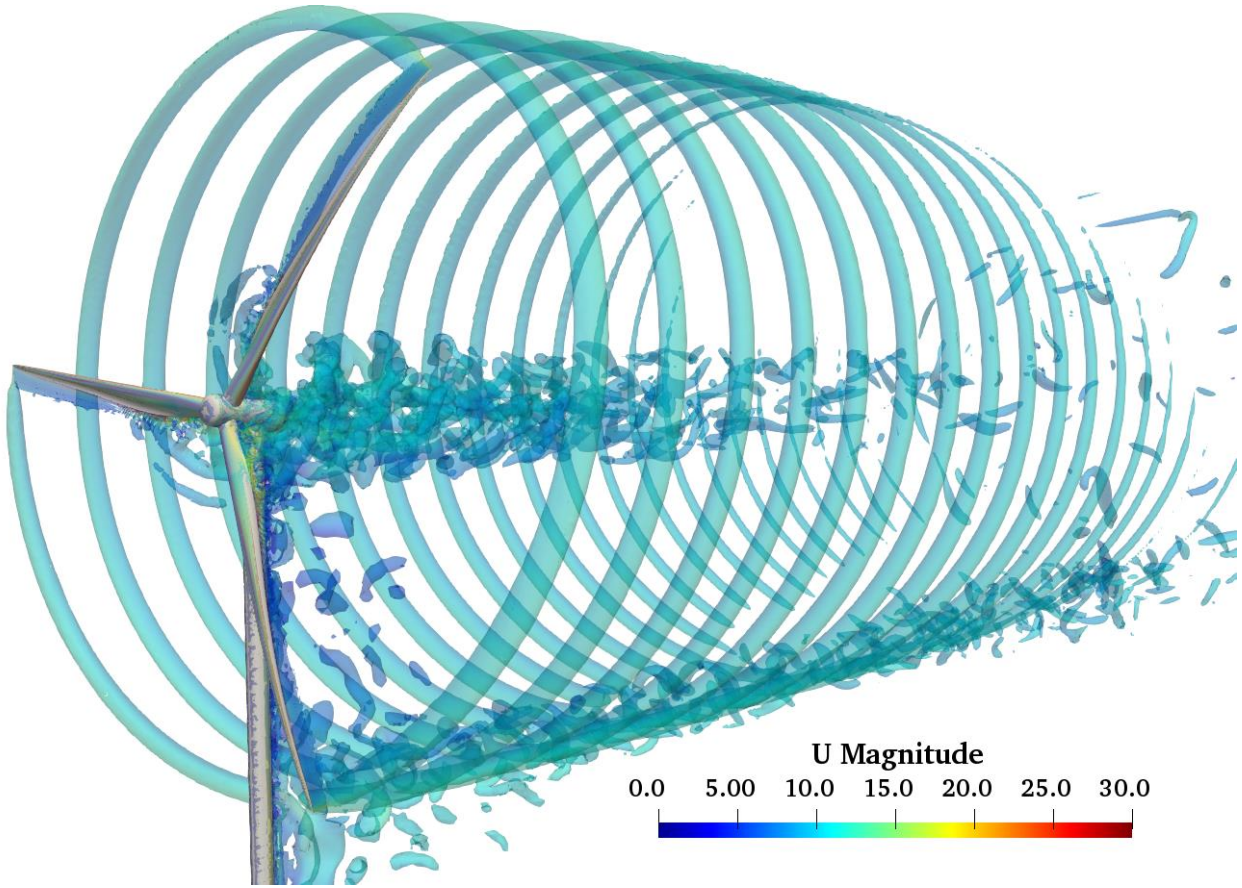
Microscale Modelling

Scope of microscale modeling

Aerodynamics

- Fluid-Structure Interaction (FSI) simulations of rotor blade
- Airfoil simulations for various applications:
  - Transition, stall, pitch, yaw and tilt
  - Blade Add-ons
  - Extrapolation Methods
- Turbulent inflow simulations
- Extreme operating scenarios
- Turbine acoustics
- Icing, rain erosion



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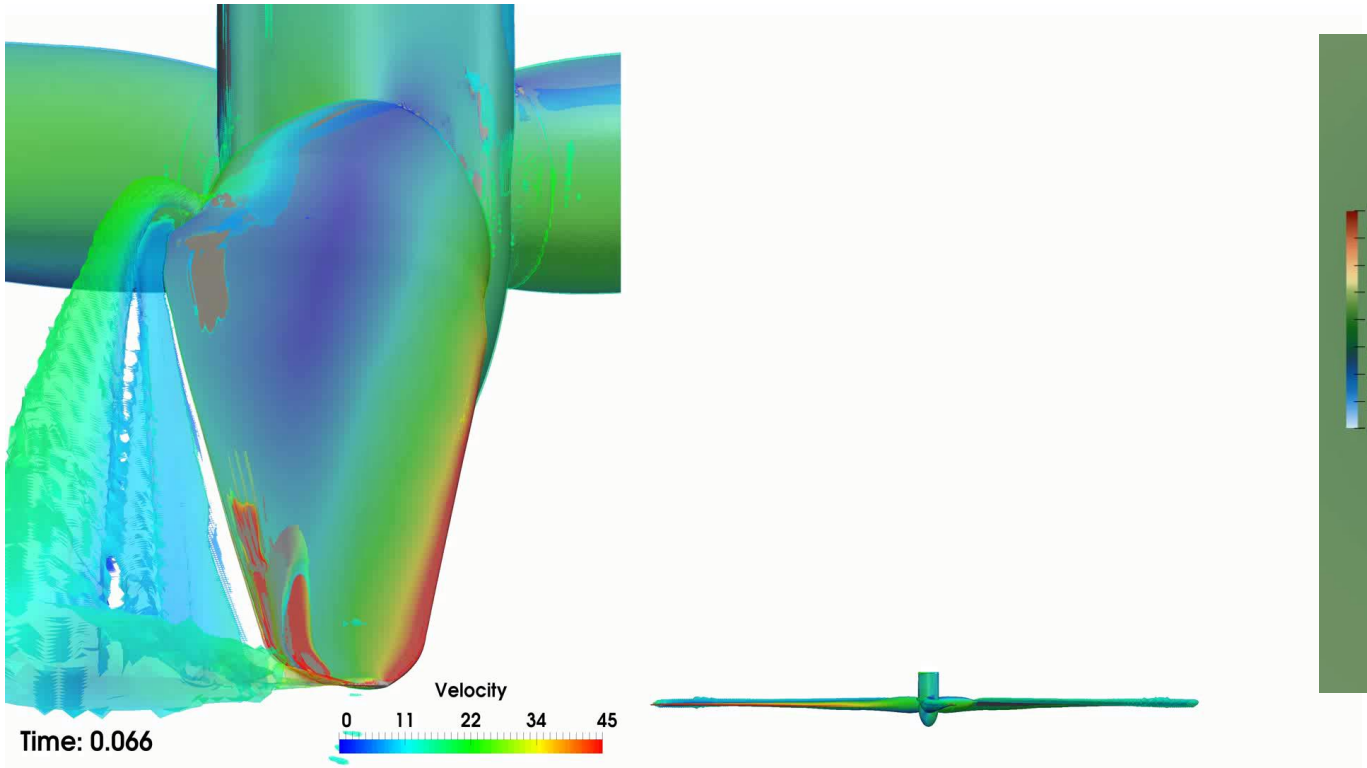
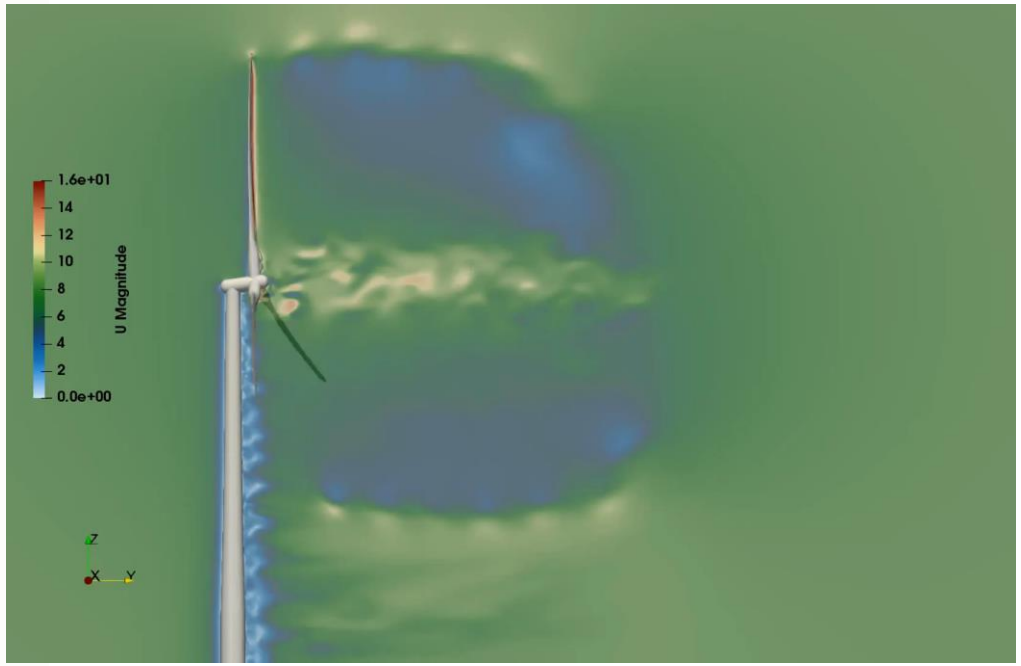
Full turbine simulations

High fidelity for complex flow situations

NREL 5MW subjected to yawed inflow (30°, rated conditions)



IEA Task 40 Downwind



Rahimi, H., Martinez Garcia, A., Stoevesandt, B., Peinke, J., & Schepers, G. (2018). An engineering model for wind turbines under yawed conditions derived from high fidelity models. *Wind Energy*.

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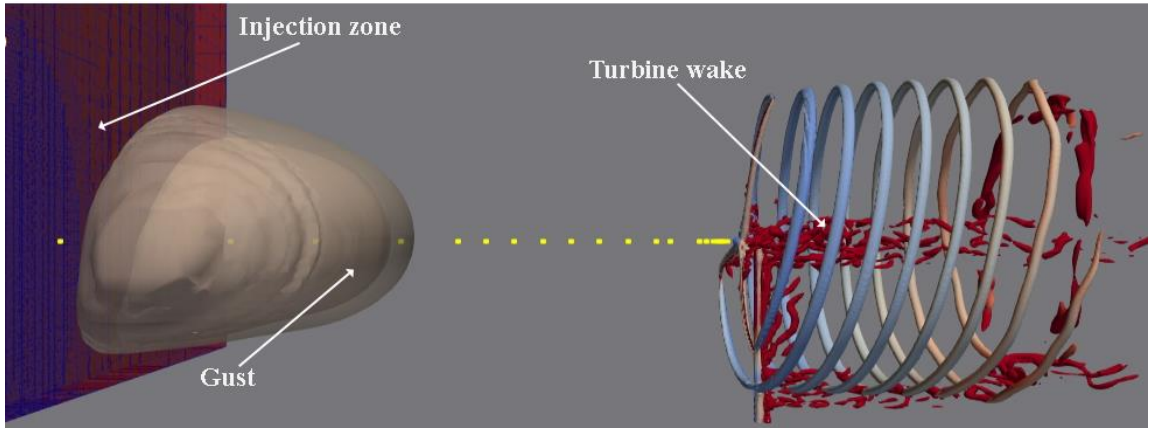
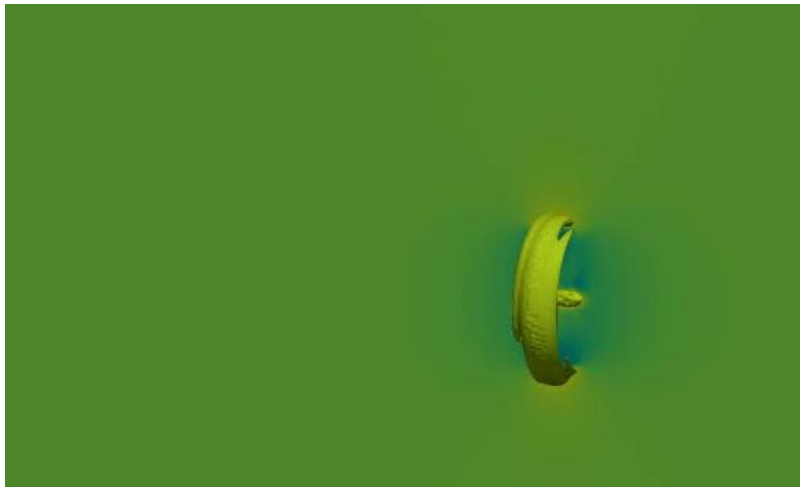
Extreme operating condition

High fidelity for complex flow situations





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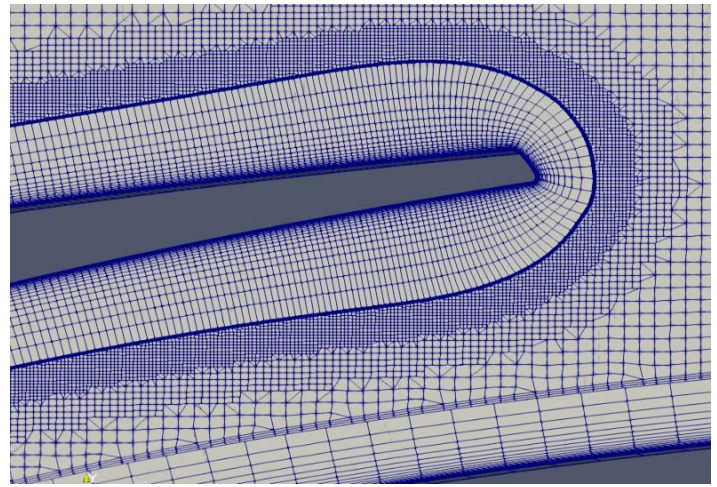
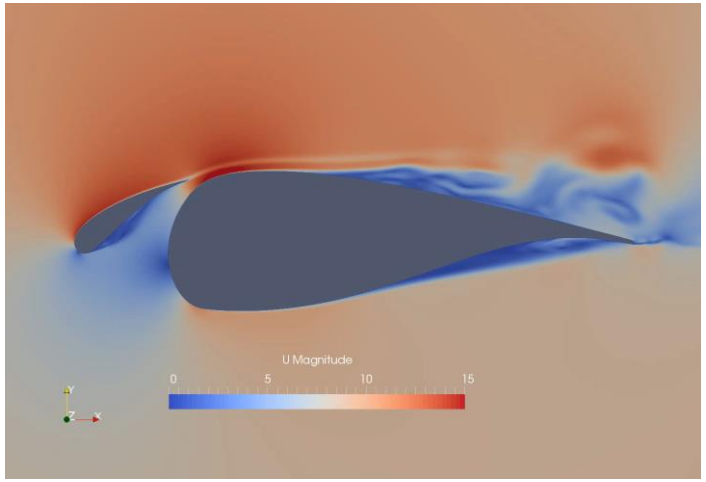
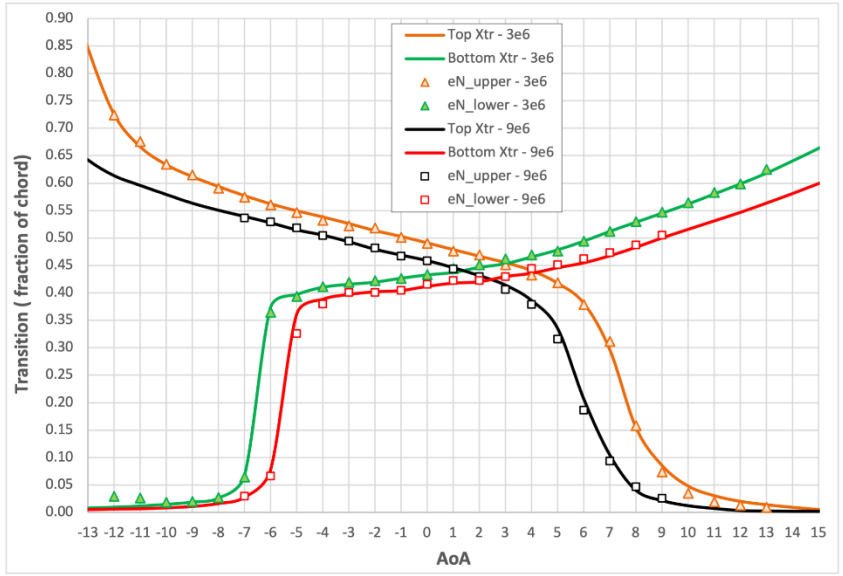
Detailed airfoil aerodynamics / add-ons

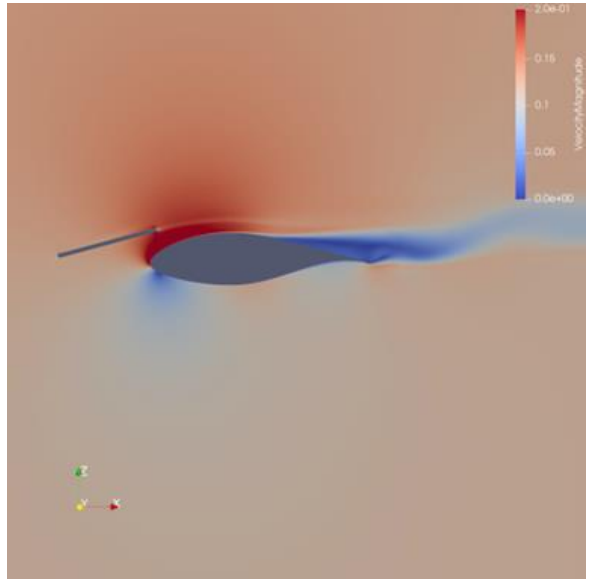
Challenging aerodynamics, up to Re = 15 million



- Airfoils are the backbone of wind turbine design
- Slats increase maximum CL
- Effect of aerodynamic sensors on airfoil performance
- Laminar-turbulent transition







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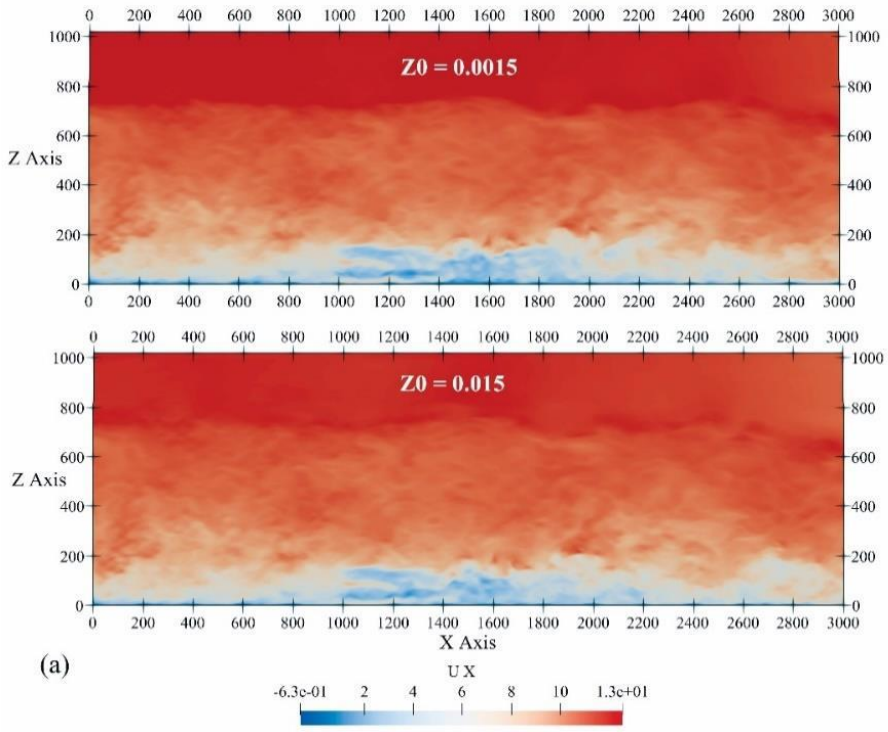
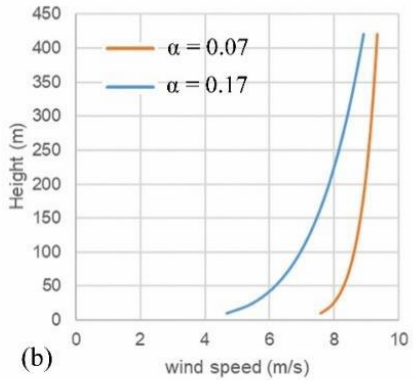
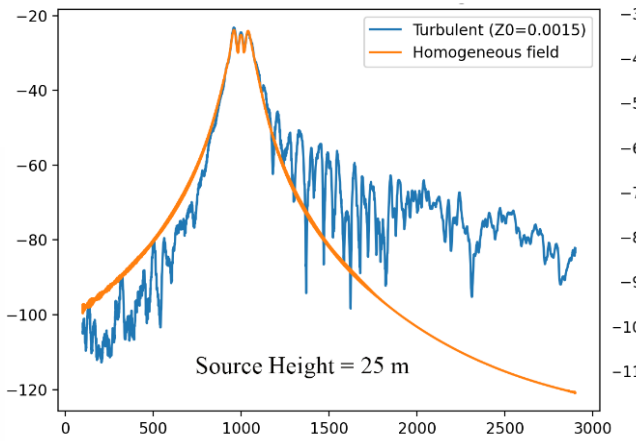
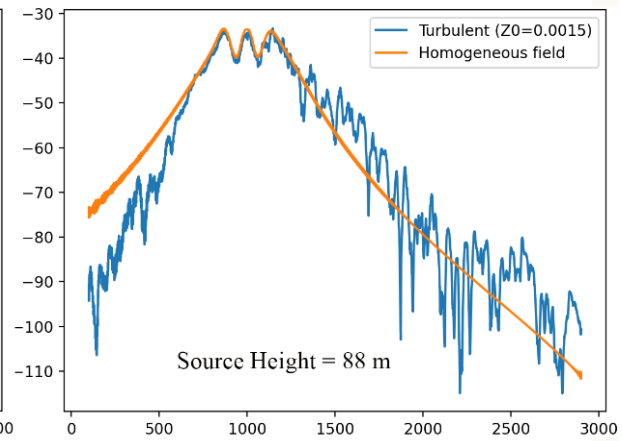
Acoustics from wind turbine

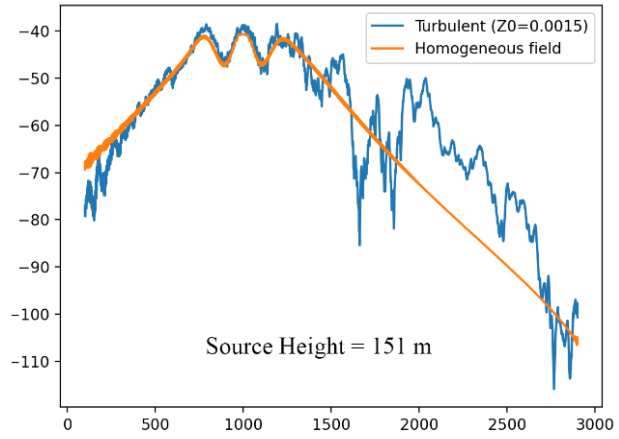
Far field propagation











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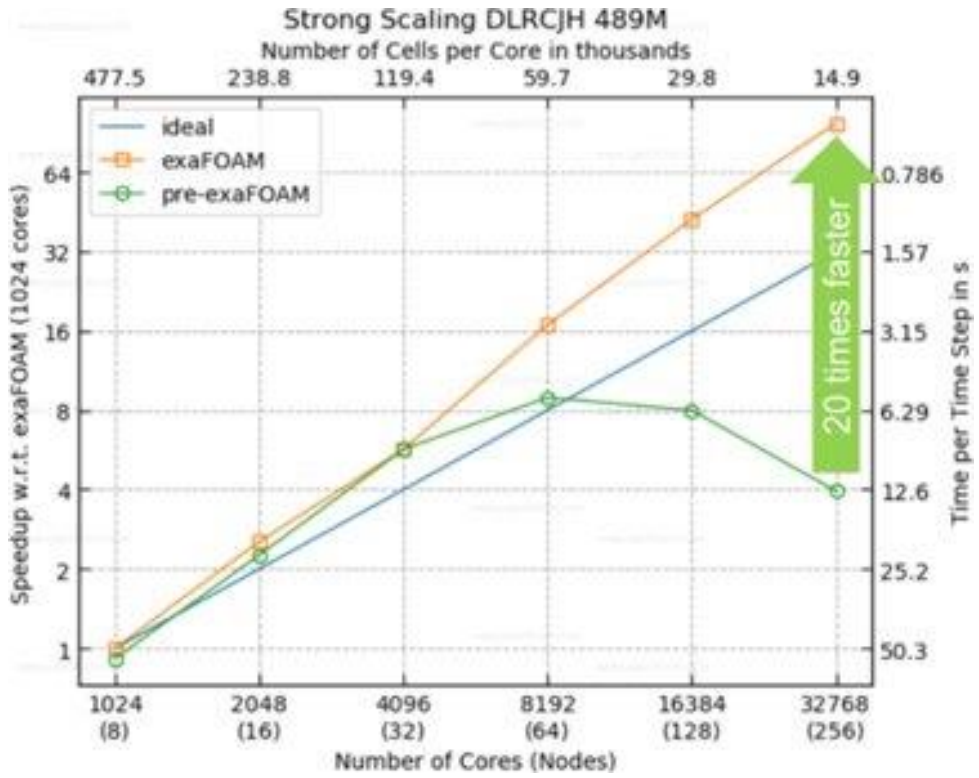
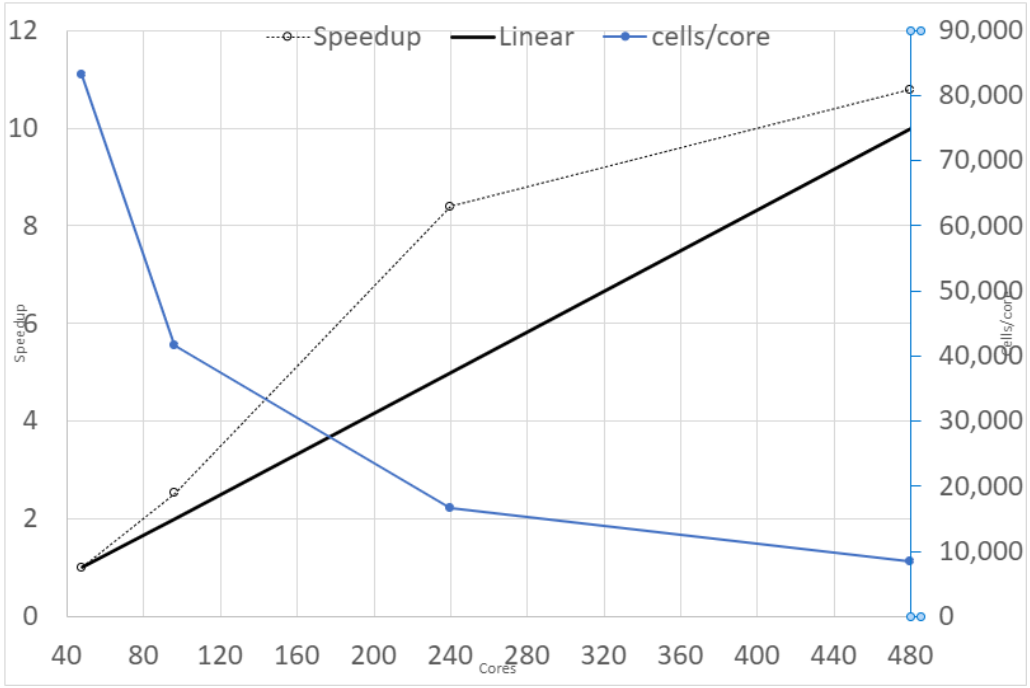
Scalablity

exaFOAM project



Scalability study-eddy



Older generation CPUs had an optimum of about 100k cells per core
The newer AMD EPYC solvers work best with about 8,200 cells per core

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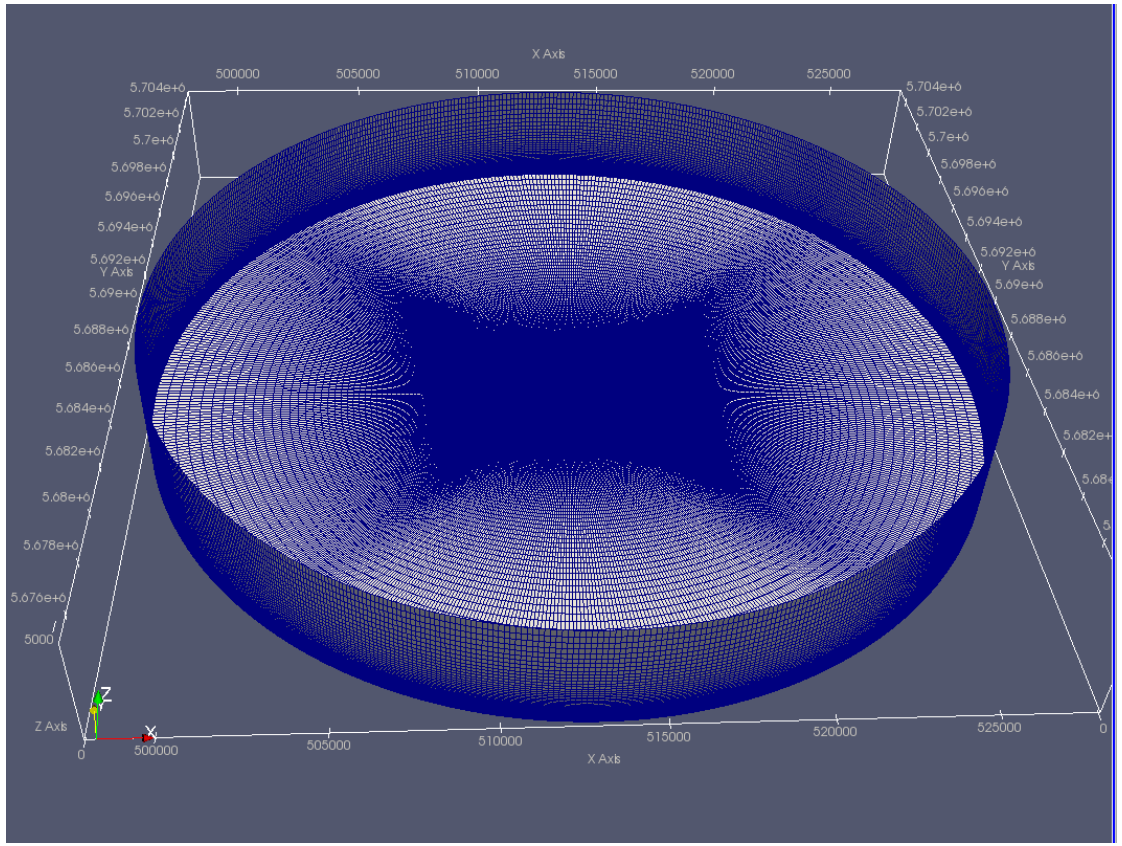
Mesoscale Wake Modelling

Onshore Siting CFD Process

Mesh cylindrical domain: One mesh, many wind directions



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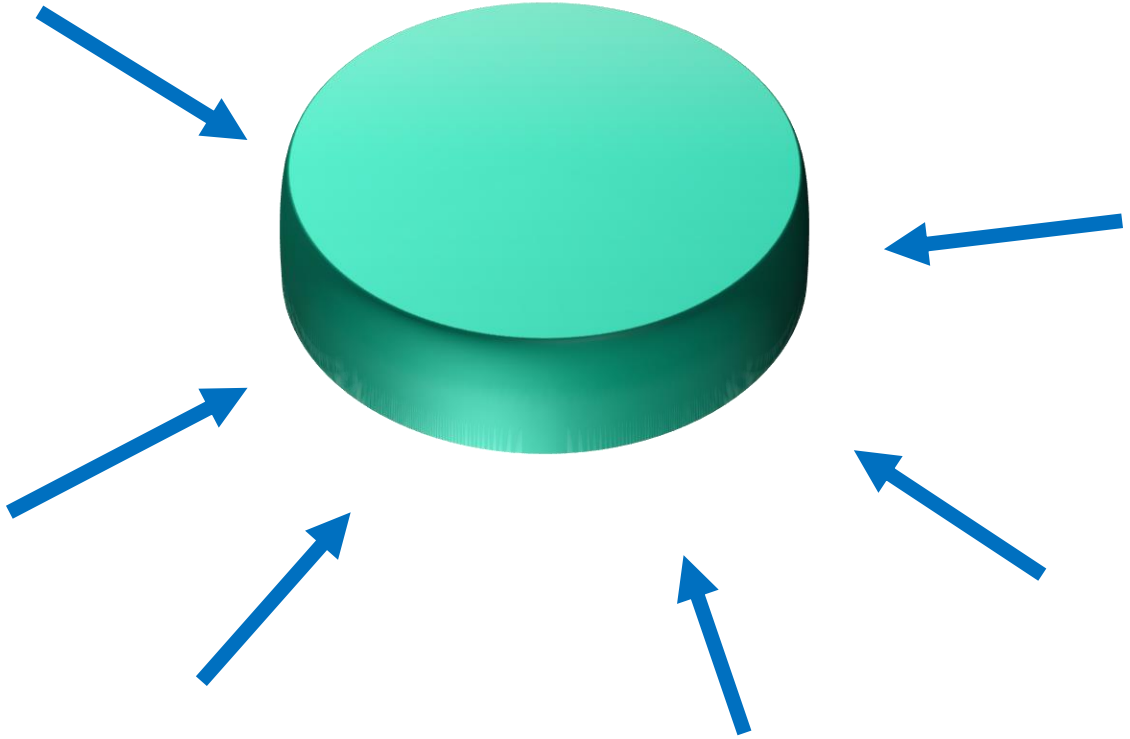
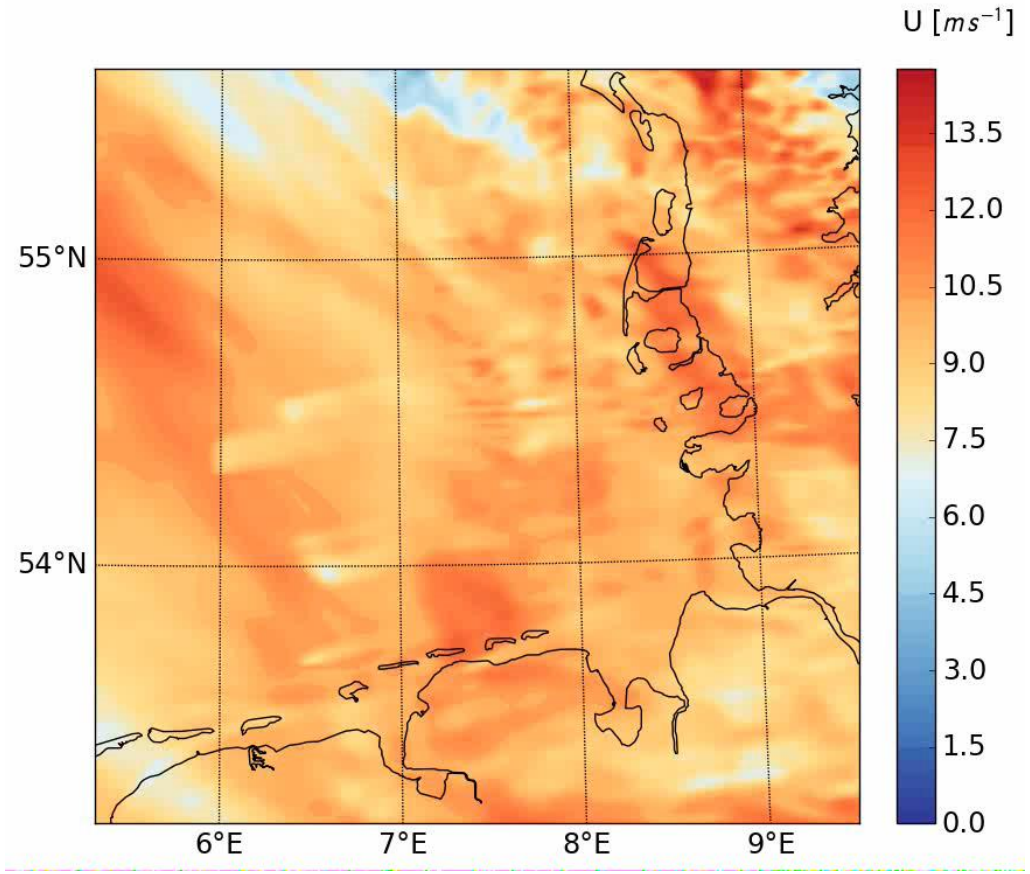
Onshore Siting CFD Process

Mesh cylindrical domain: One mesh, many wind directions





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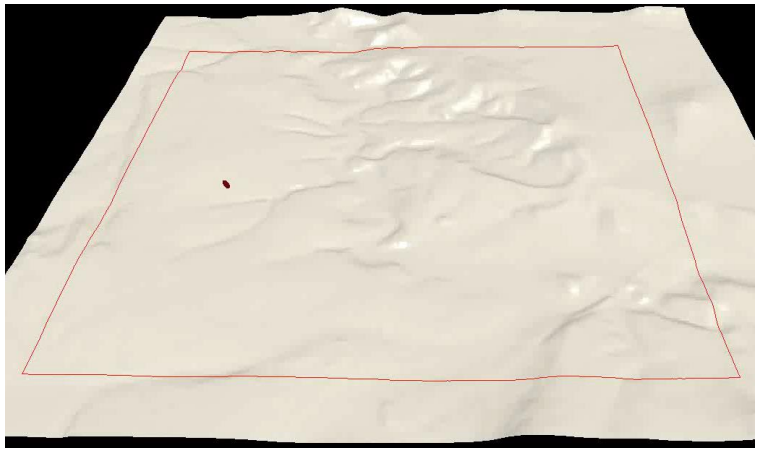
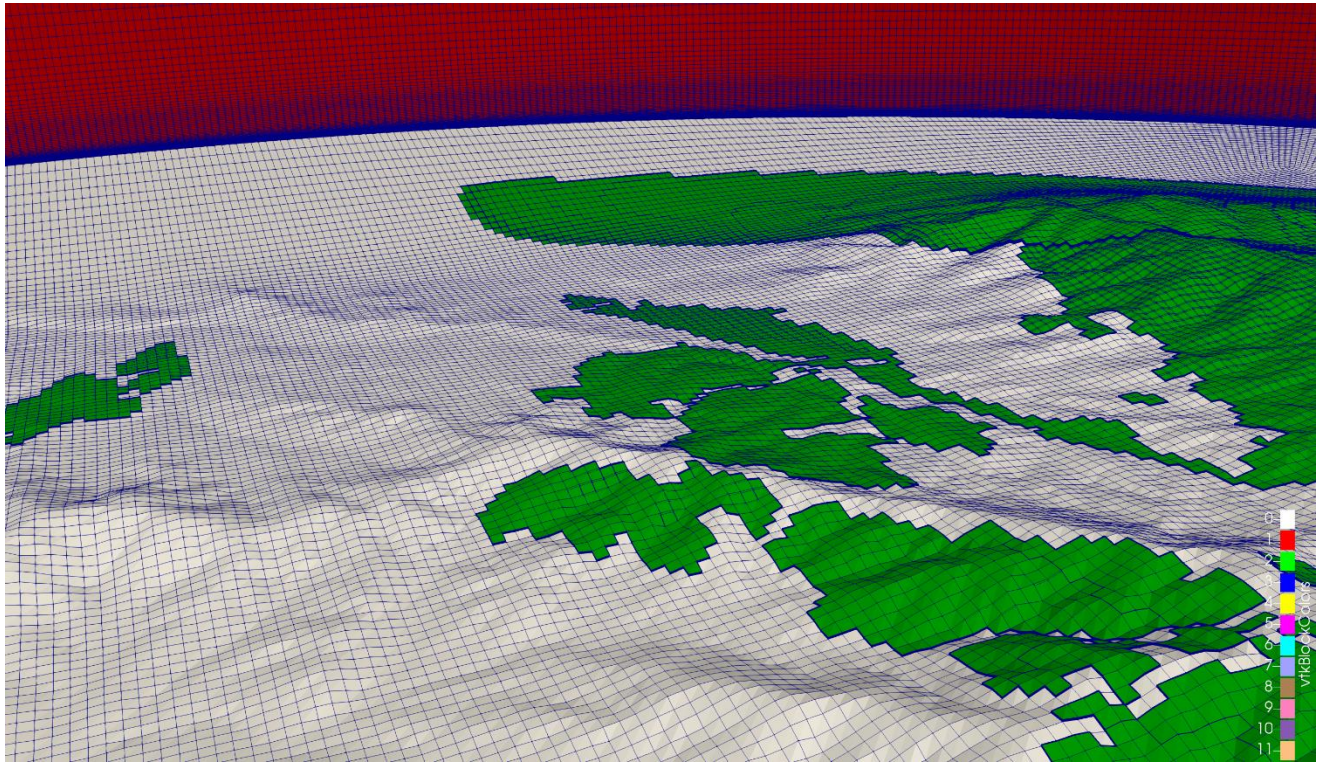
terrainMesher: Automatic meshing from STL, MAP, XYZ...



- Automatic inclusion of roughness and forest data
- Damping in outer regions
- OpenFOAM's checkMesh OK



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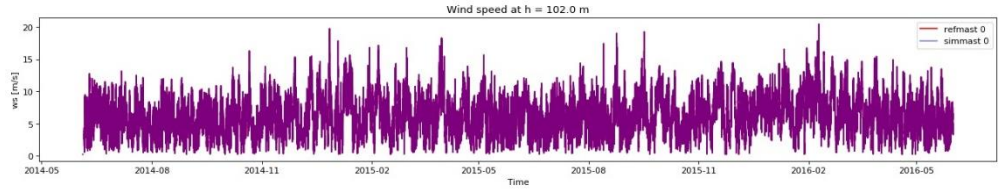
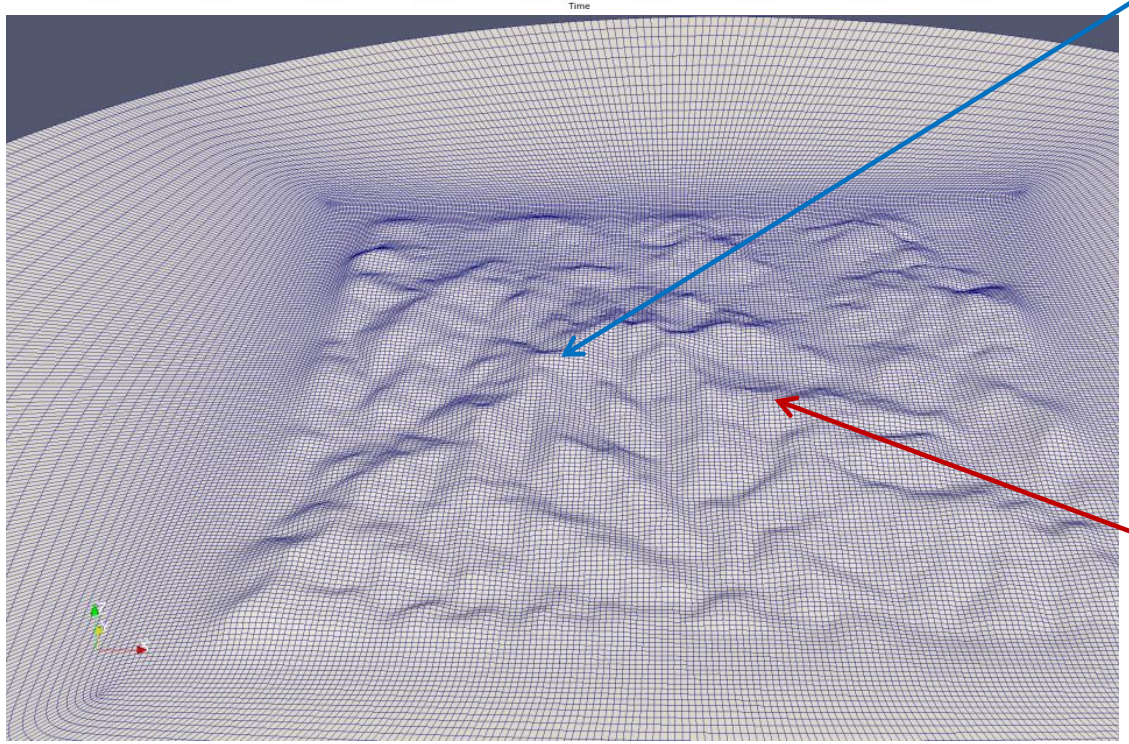
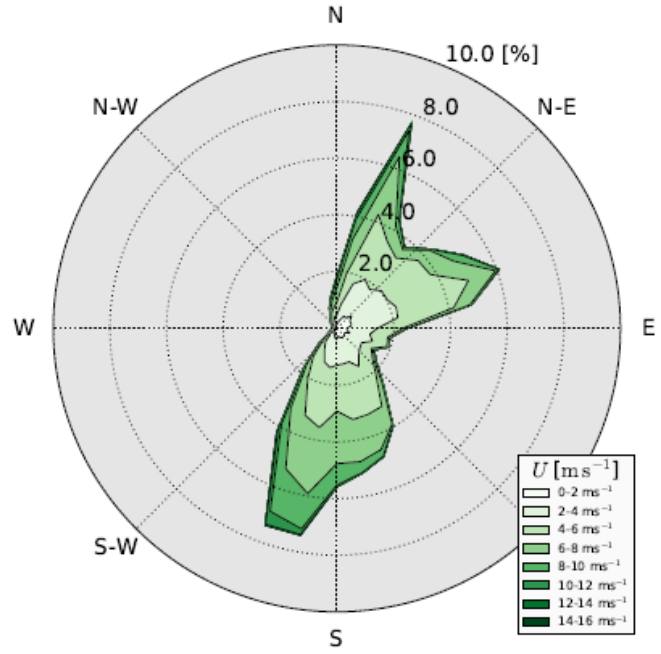
Onshore Siting CFD Process

- Input: One or many met mast time series
- Output: Predicted time series ***anywhere***

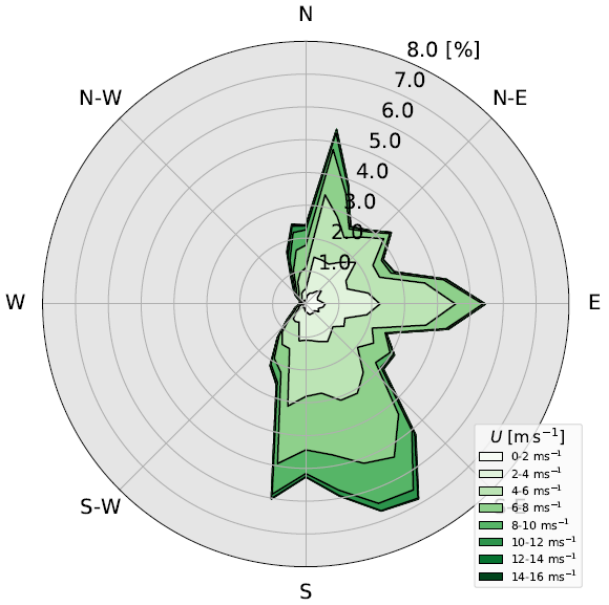




Reference:



Prediction at different point:



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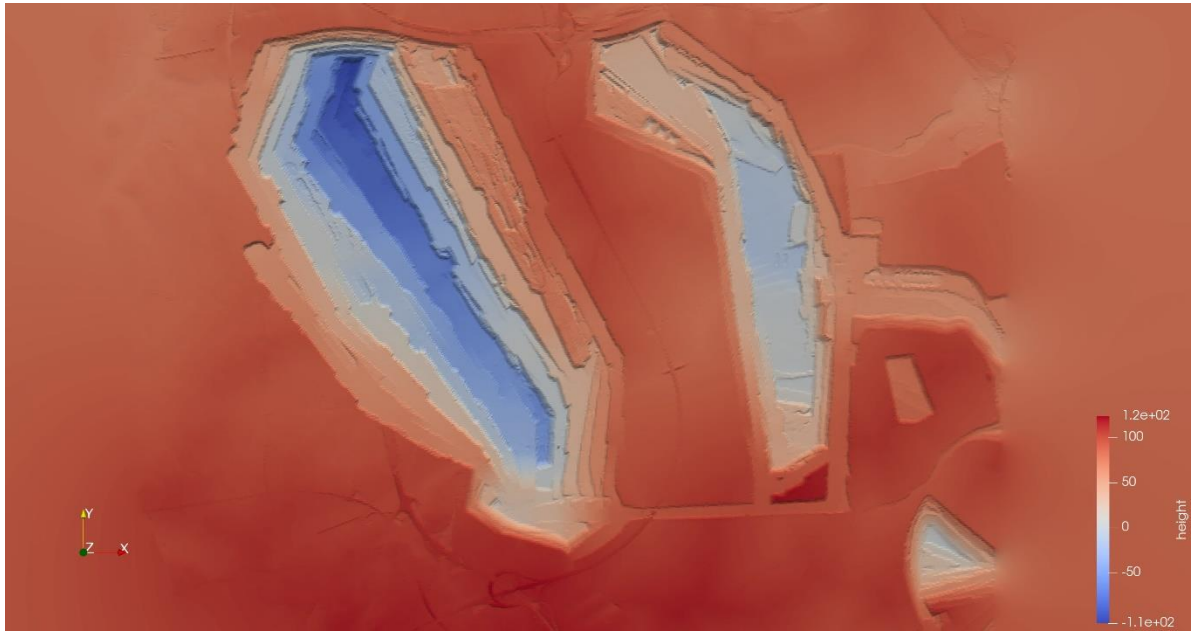
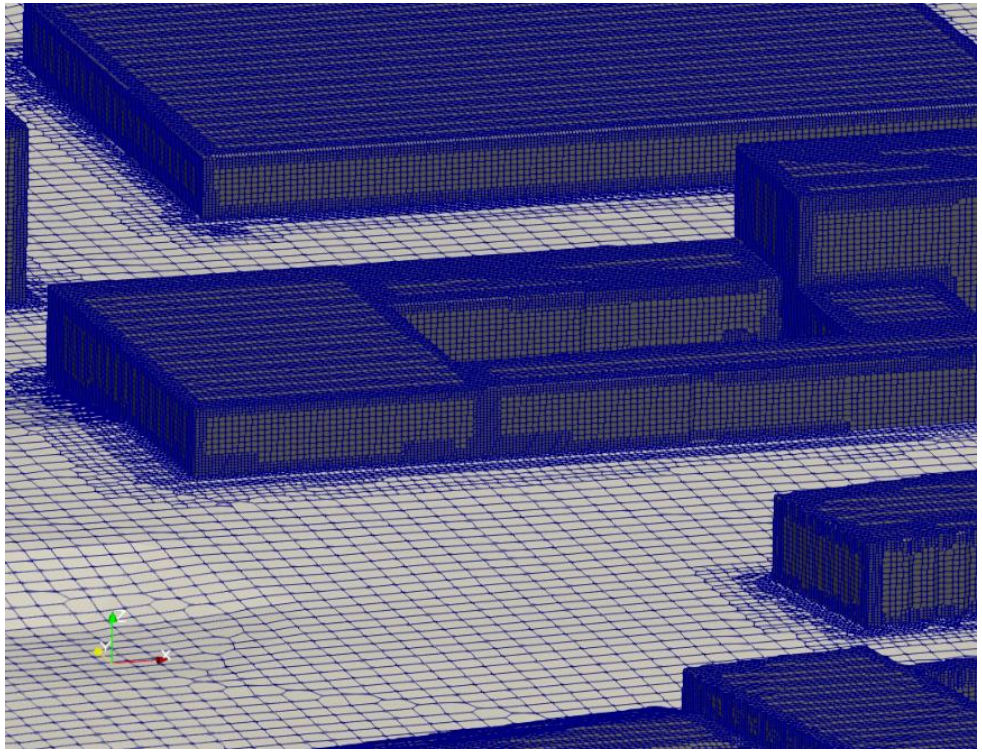
Urban wind flow

- Pedestrian comfort
- Highway safety
- VAWT wind resource assessment





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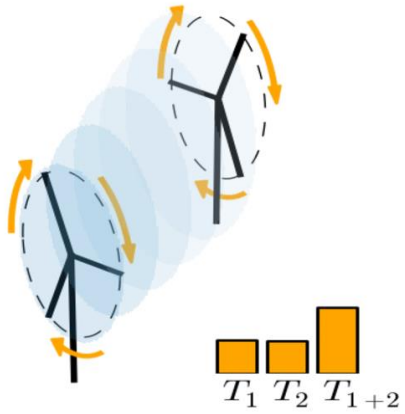
Wind Farm Control Optimization

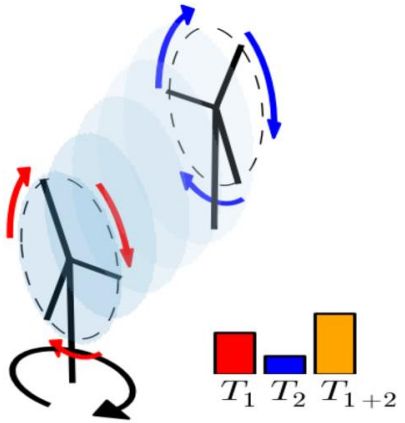
Optimizing wind farm control by wake steering and induction control

Use of flappy with load calculations for farm control evaluation and optimization

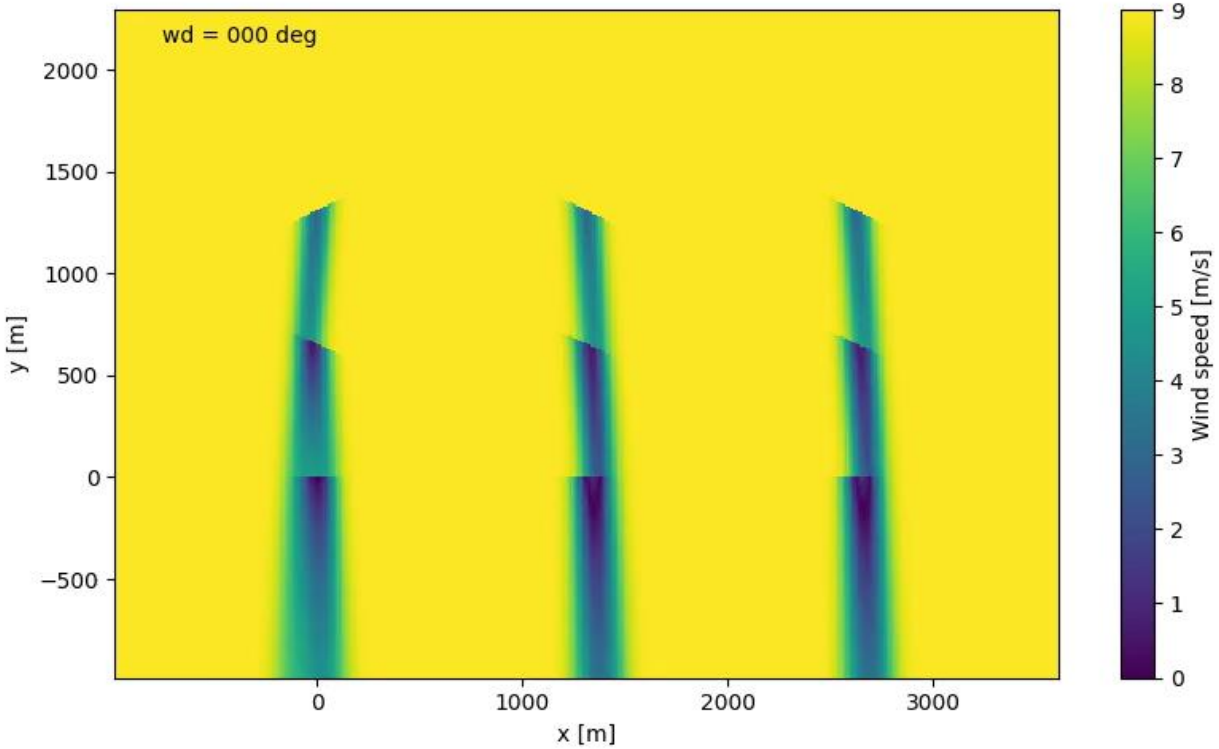
Use of wake steering or induction control



Induction control in a wind farm



Wake steering in a wind farm



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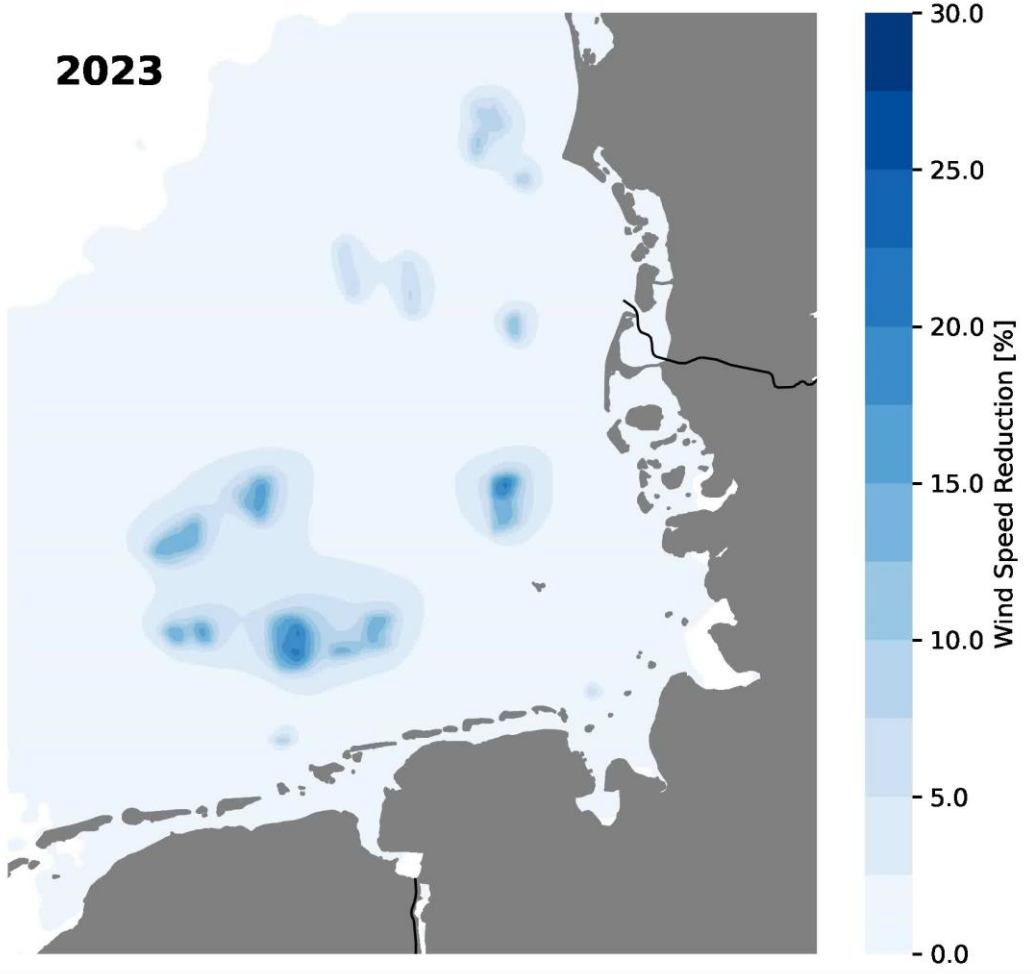
Mesoscale Wake Modelling

Future Scenarios

- **Time-dependent development** of wind fields according to planned wind farm expansion
- Decrease of wind conditions also in larger areas clearly visible
- **Expansion** of the wind farms from **2023 until 2030**
- Currently data from **20+ scenarios future scenarios for the German Bight available** also for further analyses
- **Results** of scenario calculations **can be considered for yield and wind farm layout calculations** in open-source tool FOXES



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Computational expense

HPC specification

Eddy	5,800 cores	200 teraflops
Storm	20,000 cores	900 teraflops

Blade-resolved microscale simulations

	5MW	15MW
Number of cells	20 million	80 million
Number of cores	240	840
Wall time	7 days	15-90 days

FIWIND terrain simulations

Number of cells	80 million
Number of cores	840
Wall time	7 days

Computational issues

- File sizes
- Number of files generated: 100+ per timestep (not including flow field). Collated approach does not help here.
- HPC Scaling limited to about 1,000 cores. Expecting significant improvement from exaFOAM project
- Long simulations (up to three months)

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Thank you for your time!

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