A complete model chain for icing of wind turbines

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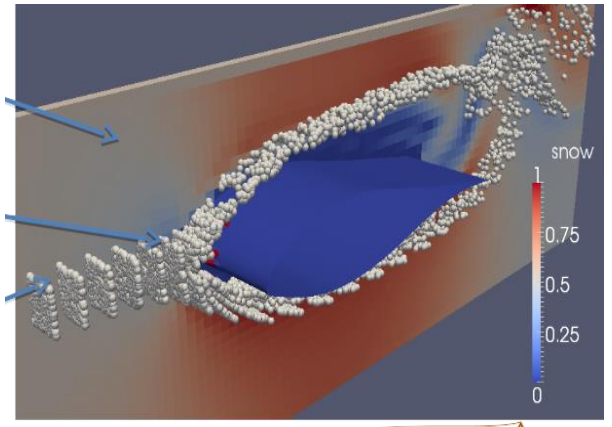
WIND ENERGY

Overview

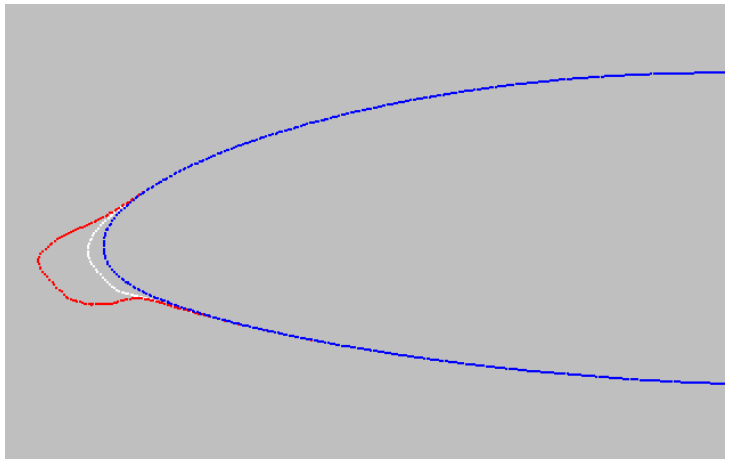
- The idea is to create a complete modelling chain for predicting production- and load variations for wind power sites under icing conditions.
- Starting from simulated meteorological data we will predict the ice accretion on and the change in aerodynamic loads of the turbine blades. This information will then be used in whole turbine simulations to predict the changes in production.

Method

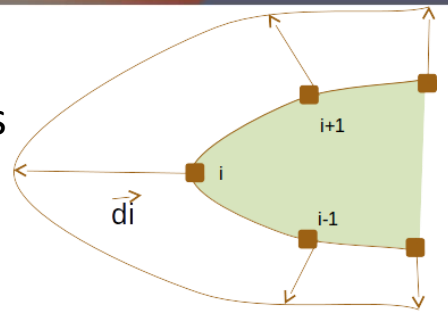
Based on meteorological data we perform two-phase simulations of flow around an blade section



Based on the number of droplets hitting the surface at different positions we can calculate the amount of ice

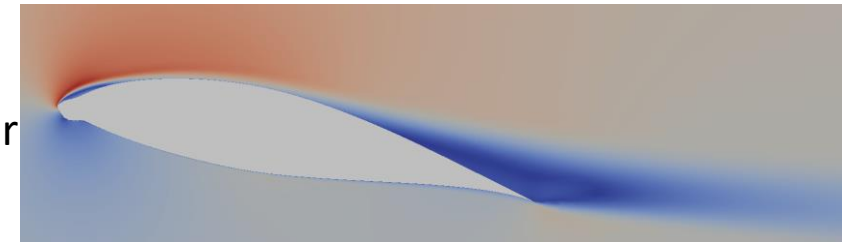


This information is used to alter the blade shape.

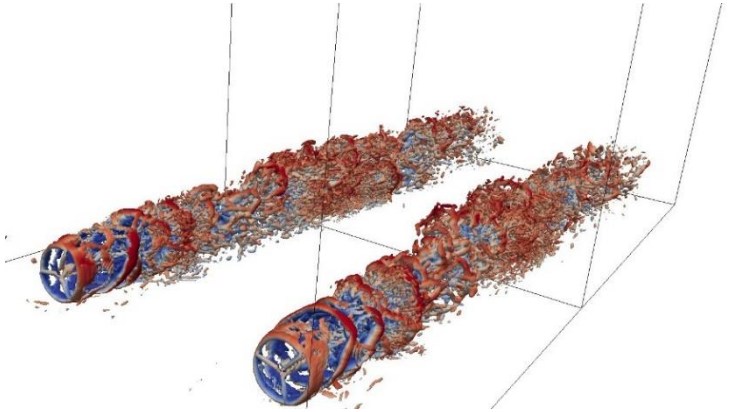


$$\vec{Di} \approx V_{ice\_i} / A_{dualcell}$$

The altered shape is then simulated either for continued ice accretion or to extract aerodynamic data

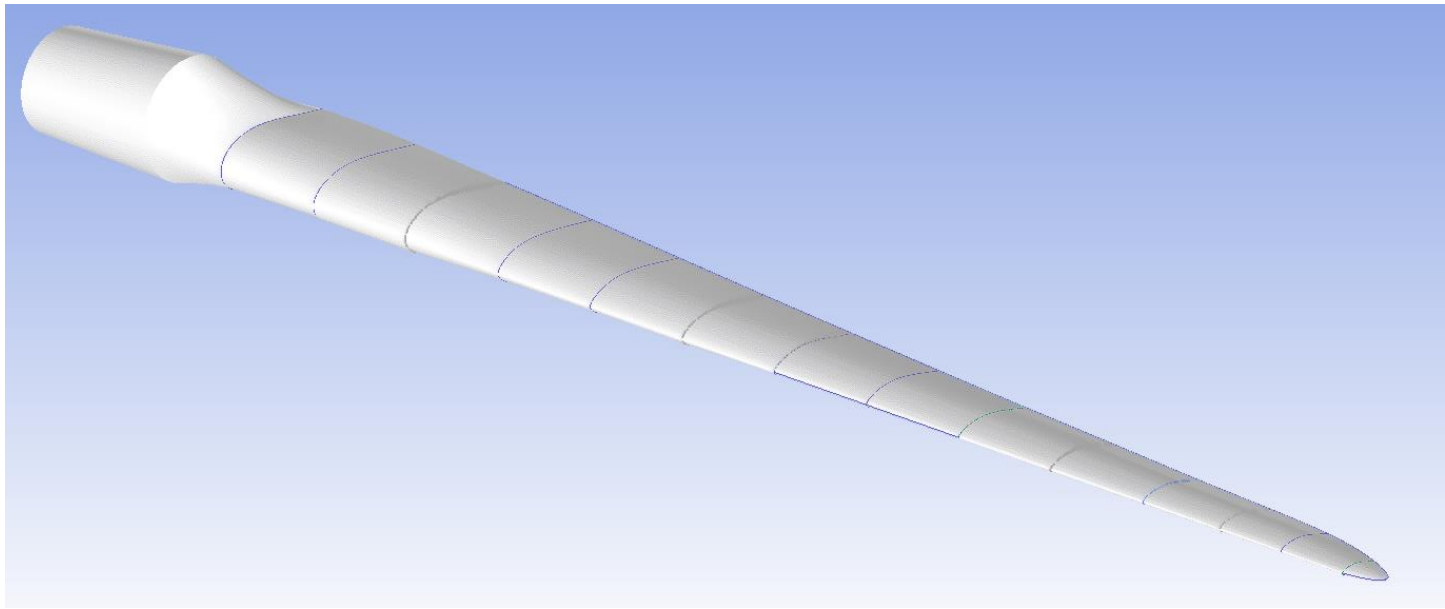


The aerodynamic data is input to the actuator line model used in the whole turbine simulations



Set-up, ice accretion simulations

- Turbine: NREL 5MW
- Simulation tool: OpenFOAM
- Considering 14 sections along the blade
- Total time 4 hours
- Rime ice only



Ice accretion simulations

A first test case:

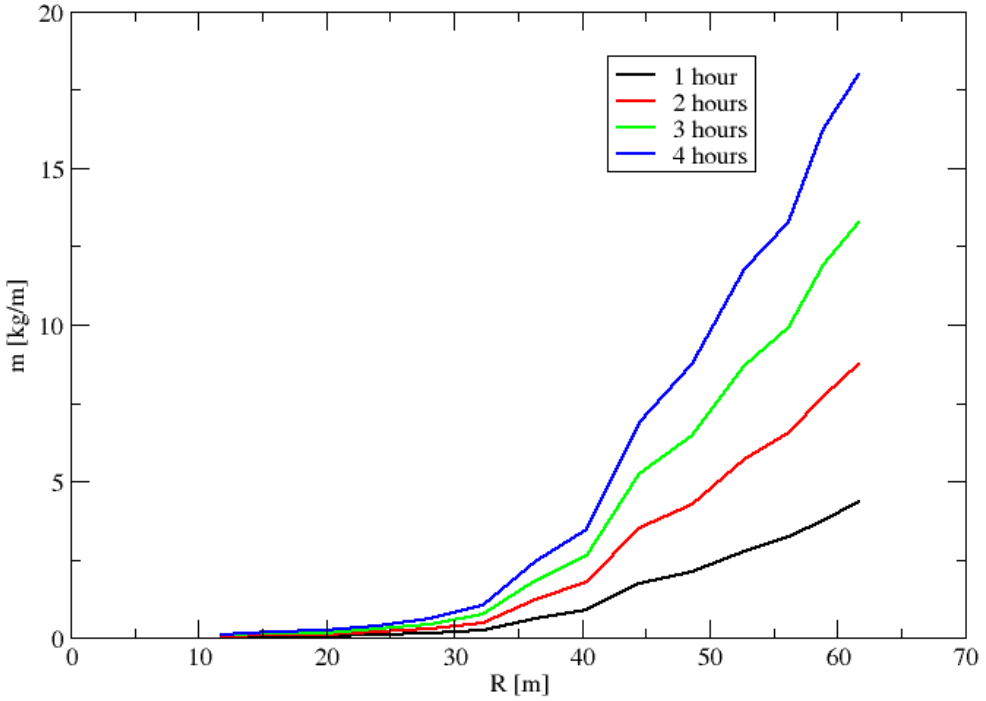
- 2D RANS using the SST k-ω model
- One-way Lagrangian particle tracking
- Updating the aerofoil shape every 150 s (icing time)
- Total time 4 hours
- Rime ice only, LWC= 0.5g/m^3
- Wind speed 10 m/s; Rotation 11 rpm

Procedure:

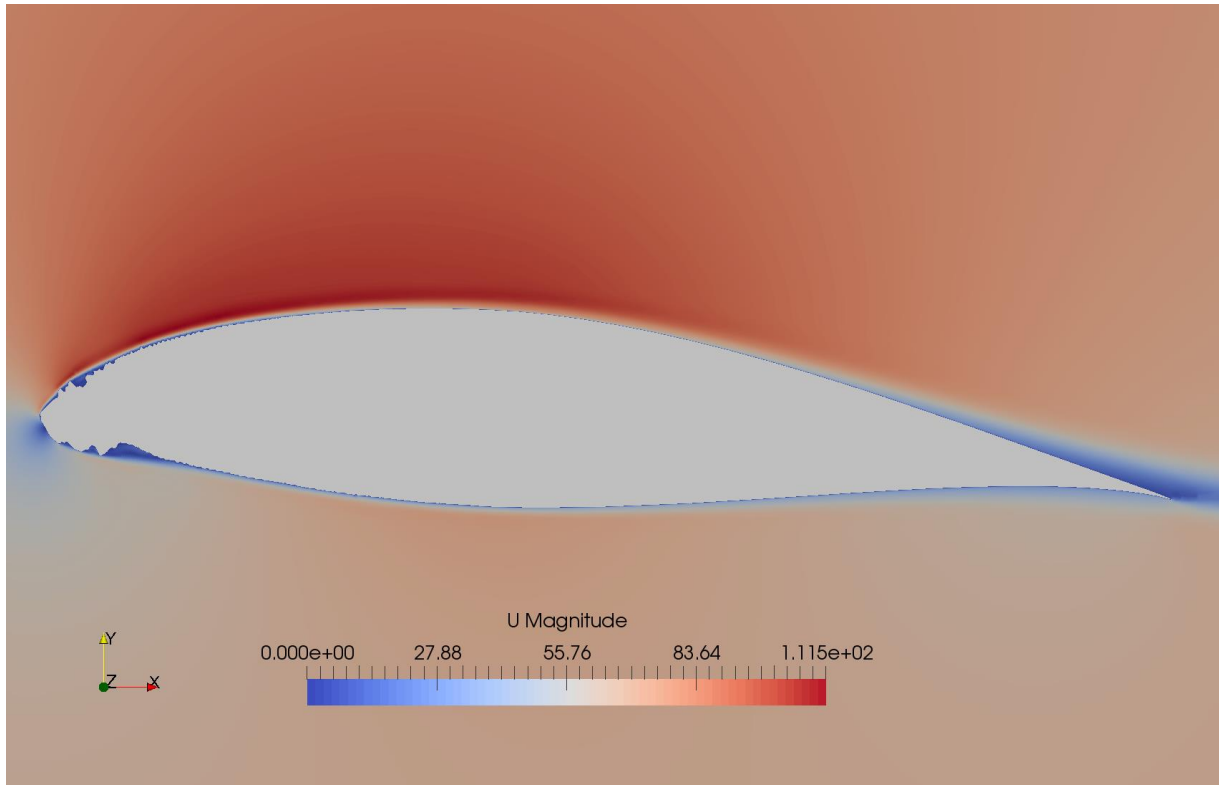
- Starting from a clean aerofoil the number of particles impacting on the surface is counted
- After a certain amount of time the shape of the aerofoil is altered based on the local ice amount
- The simulation is then continued with the new shape and so on
- After the accretion simulation aerodynamic data for each aerofoil section are created using further simulations varying the angle of attack from -20 to +20 degrees

Ice on the blade

Ice mass along the blade



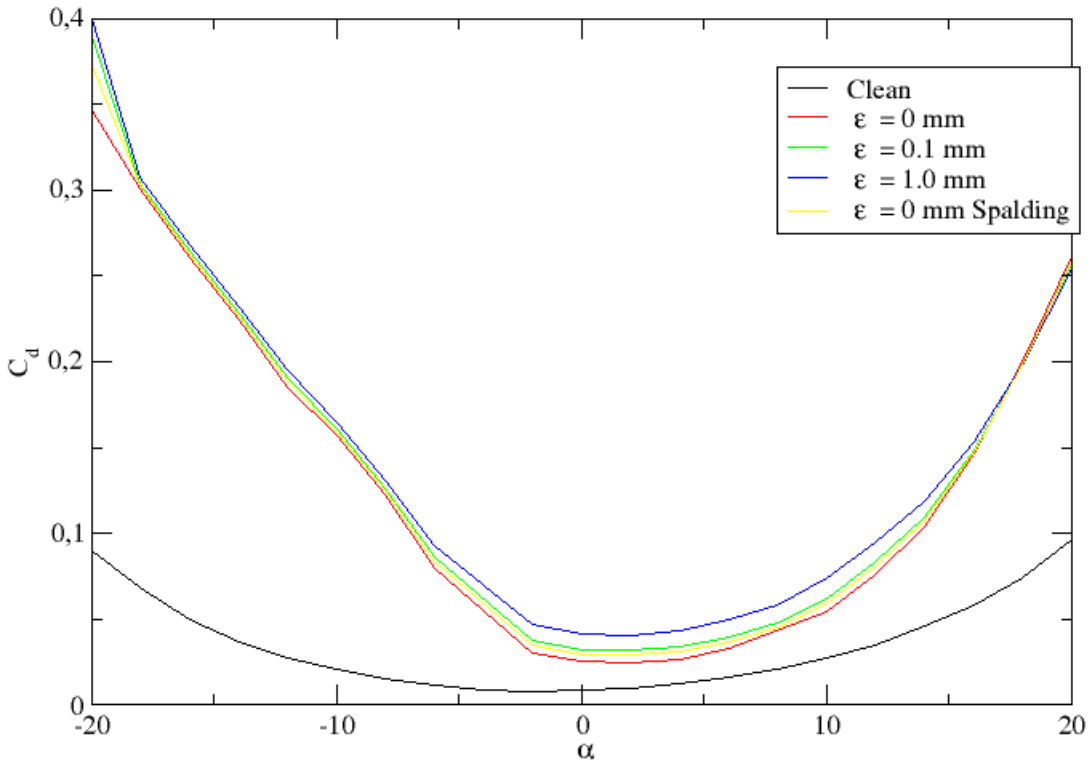
Iced blade profile on the outermost section after 1 hour



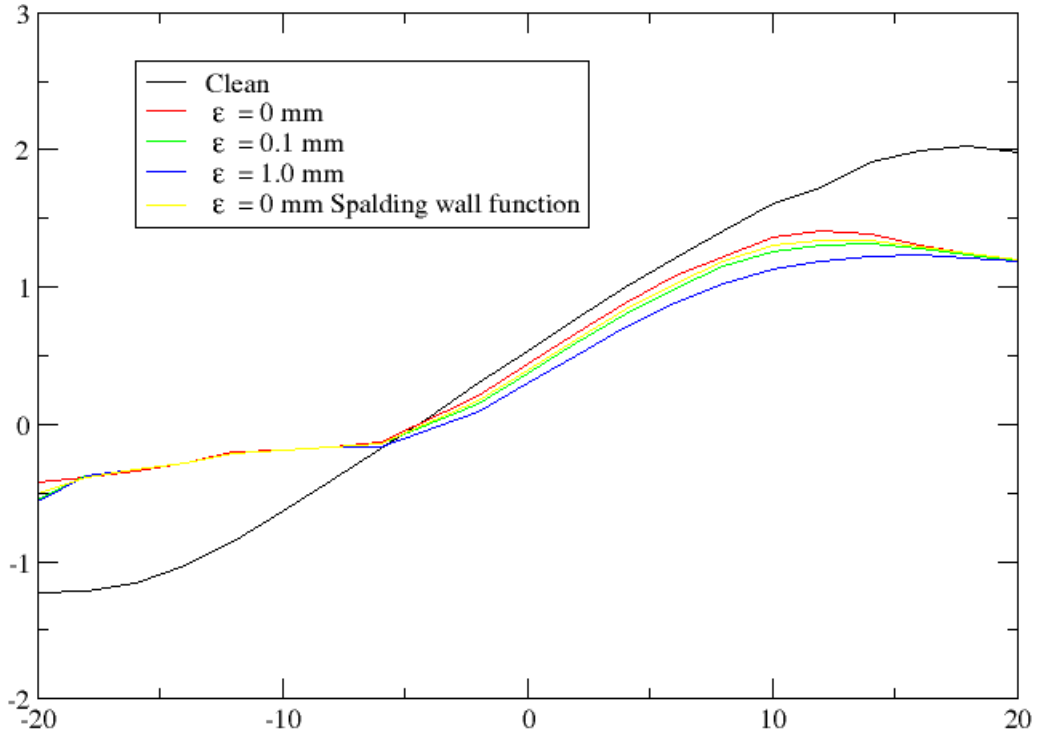
Aerodynamic forces

Comparing the aerodynamic performance of the iced aerofoil at some values of surface roughness. The figures show the outermost section

Drag

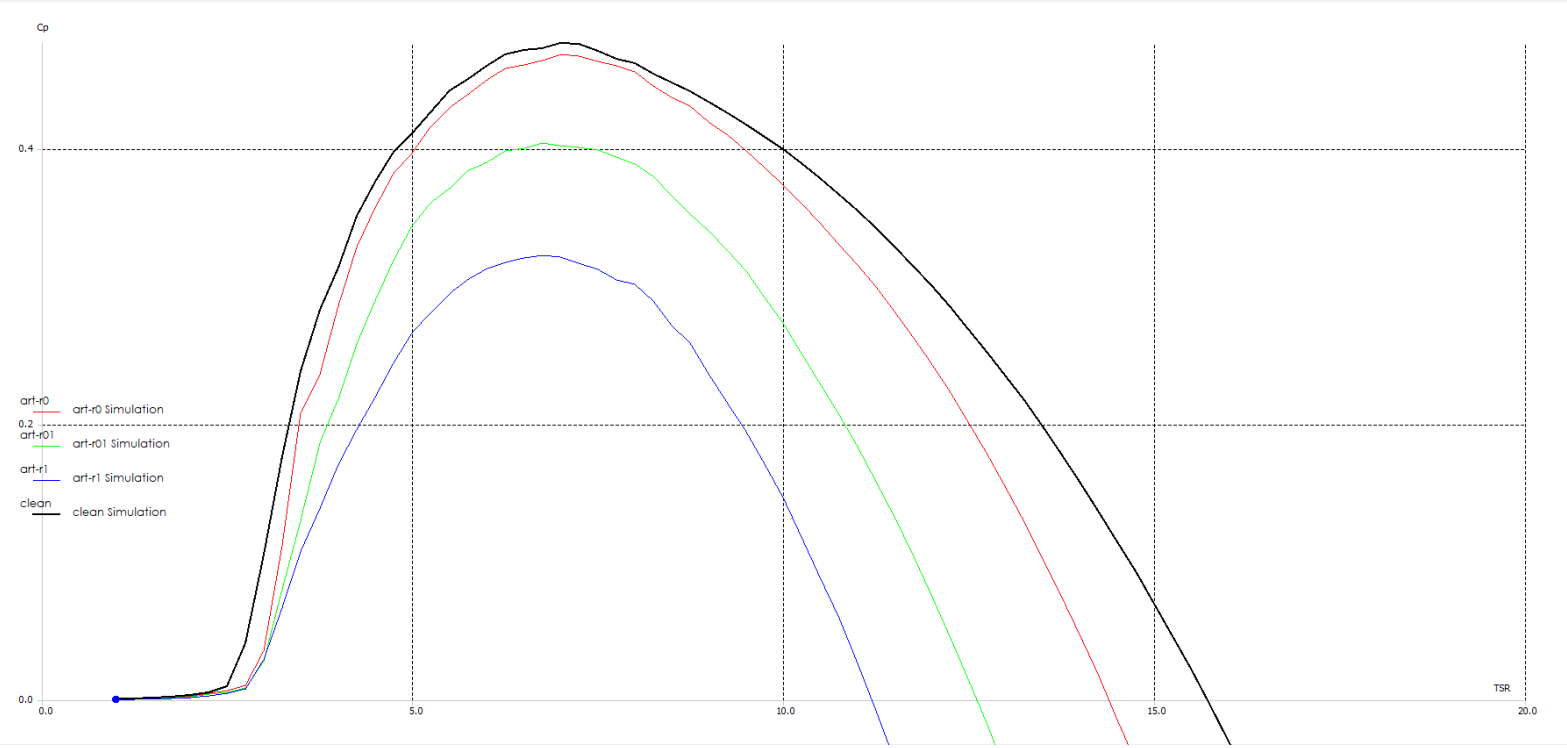


Lift



A first turbine check…

C_p-λ curves for the clean and iced turbine using BEM



Full turbine simulations

The aerodynamic data is used as input for simulations of the whole turbine

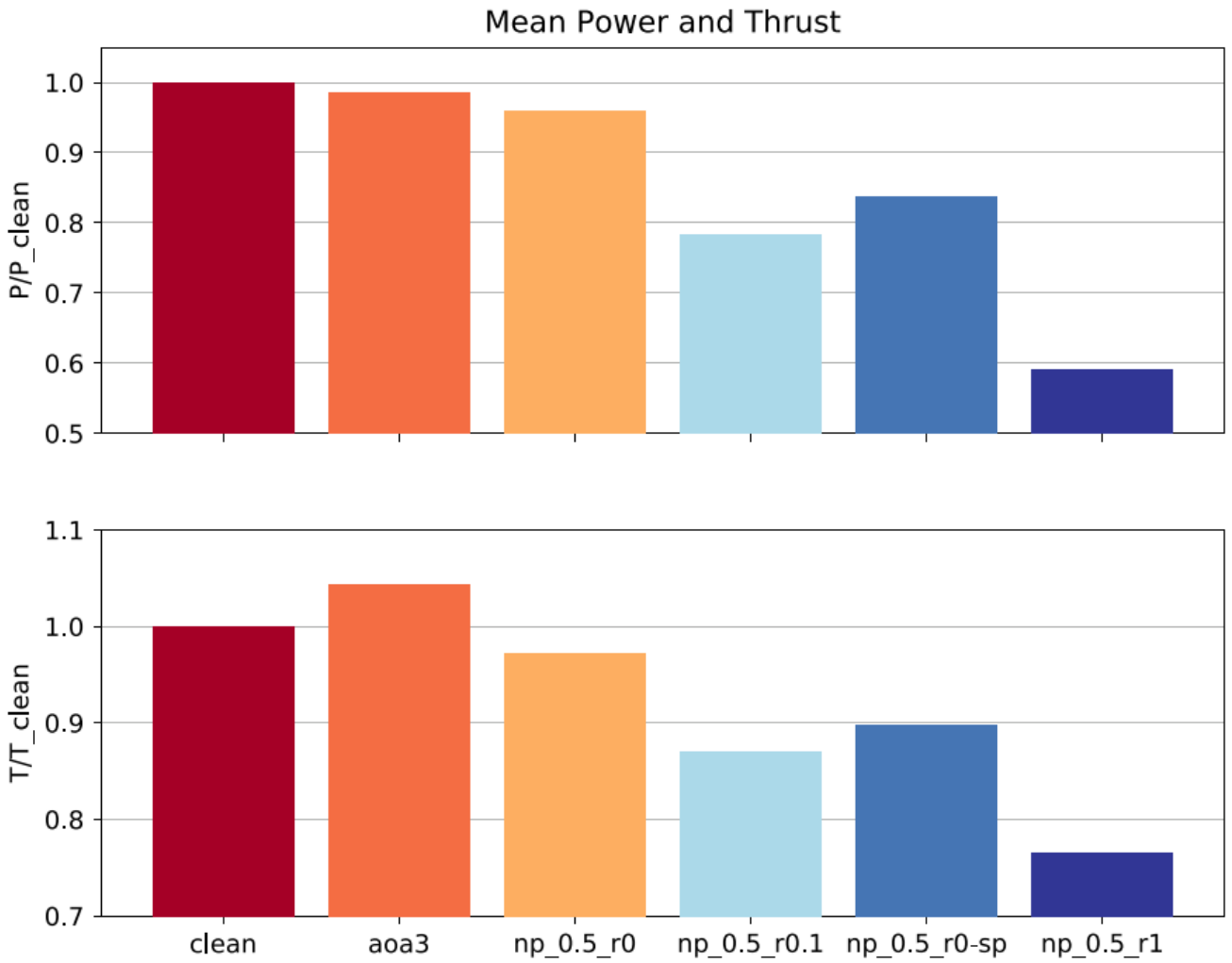
These simulations use LES to account for turbulence and an actuator line model to model the turbine.

Full turbine simulations

Average power and thrust

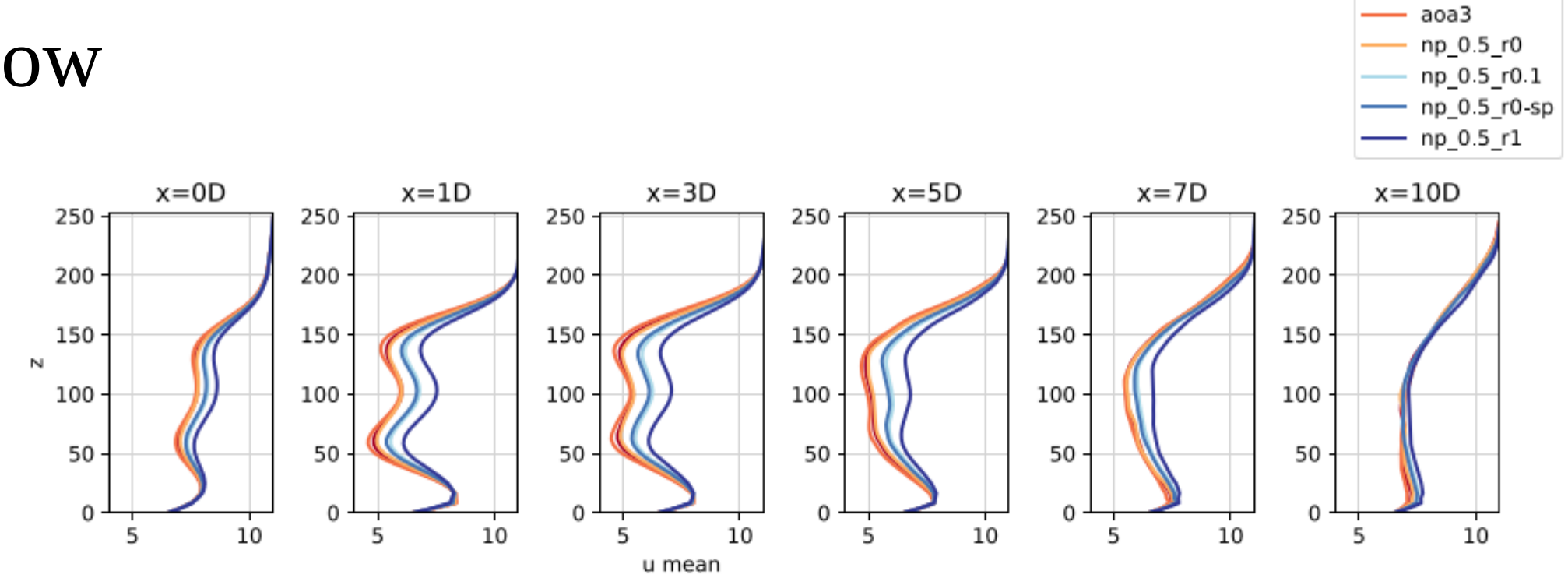
Influence of:

- Angle of attack during icing
- Surface roughness
- Wall function

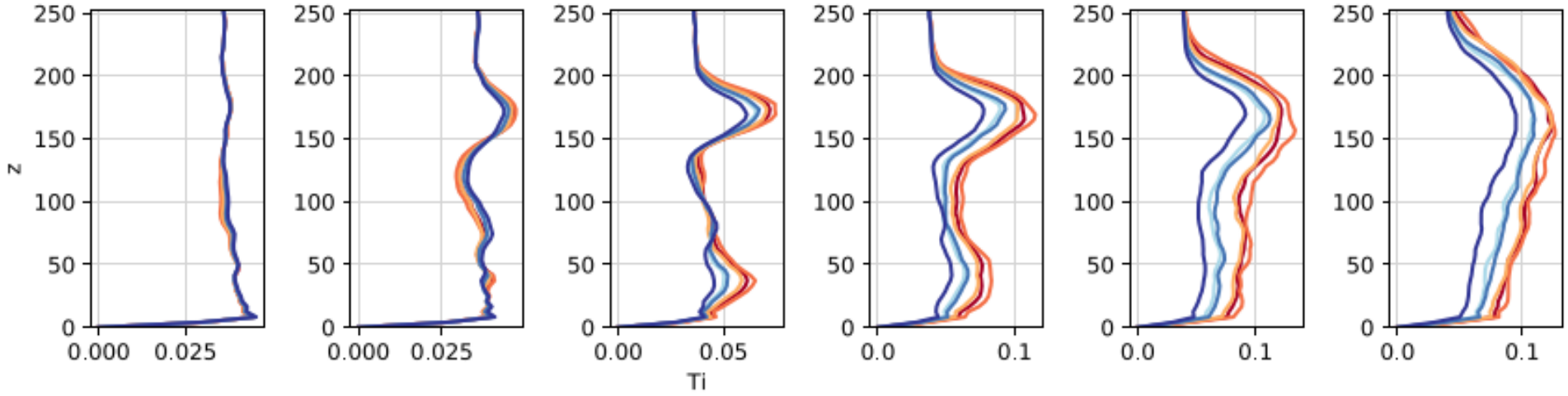


Wake flow

Average velocity



Turbulence intensity



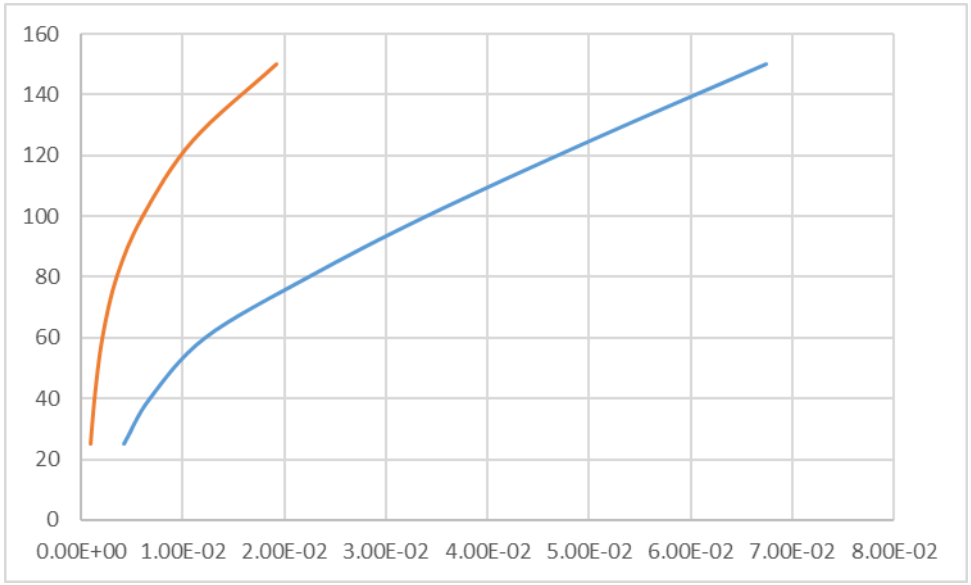
Coupling, meteorological data – ice accretion

Meteorological data

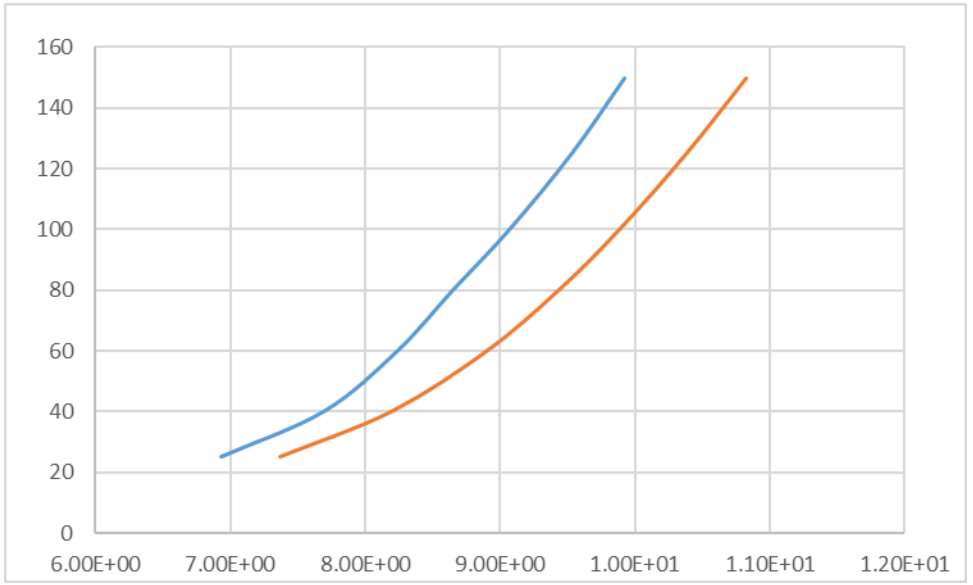
- Simulated data from SMHI
- 43 h with 1 hour resolution
- Spatial resolution in the vertical direction: 20 to 25 m

Example of data. LWC and wind speed at two time instances

LWC



Wind speed

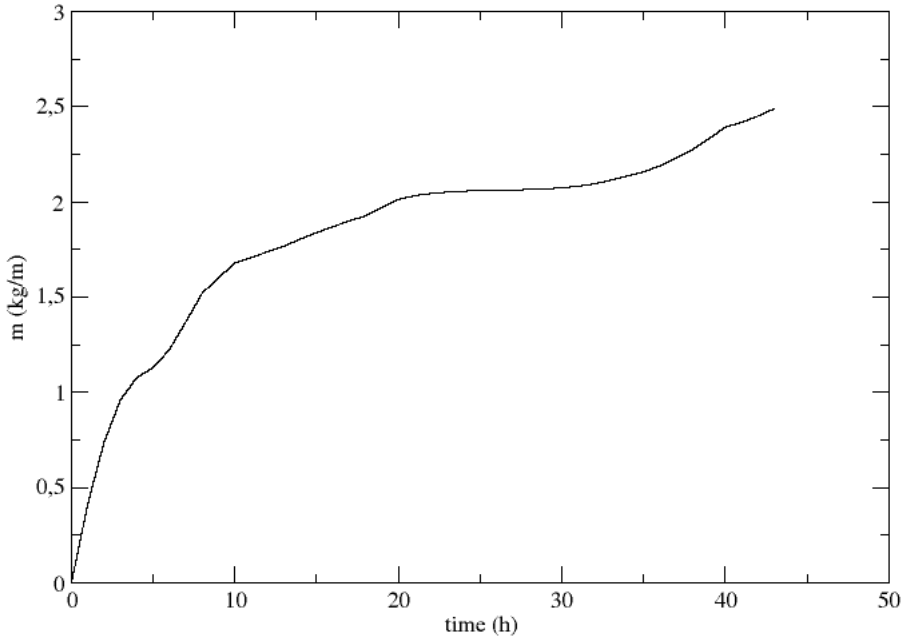


Aerodynamic forces

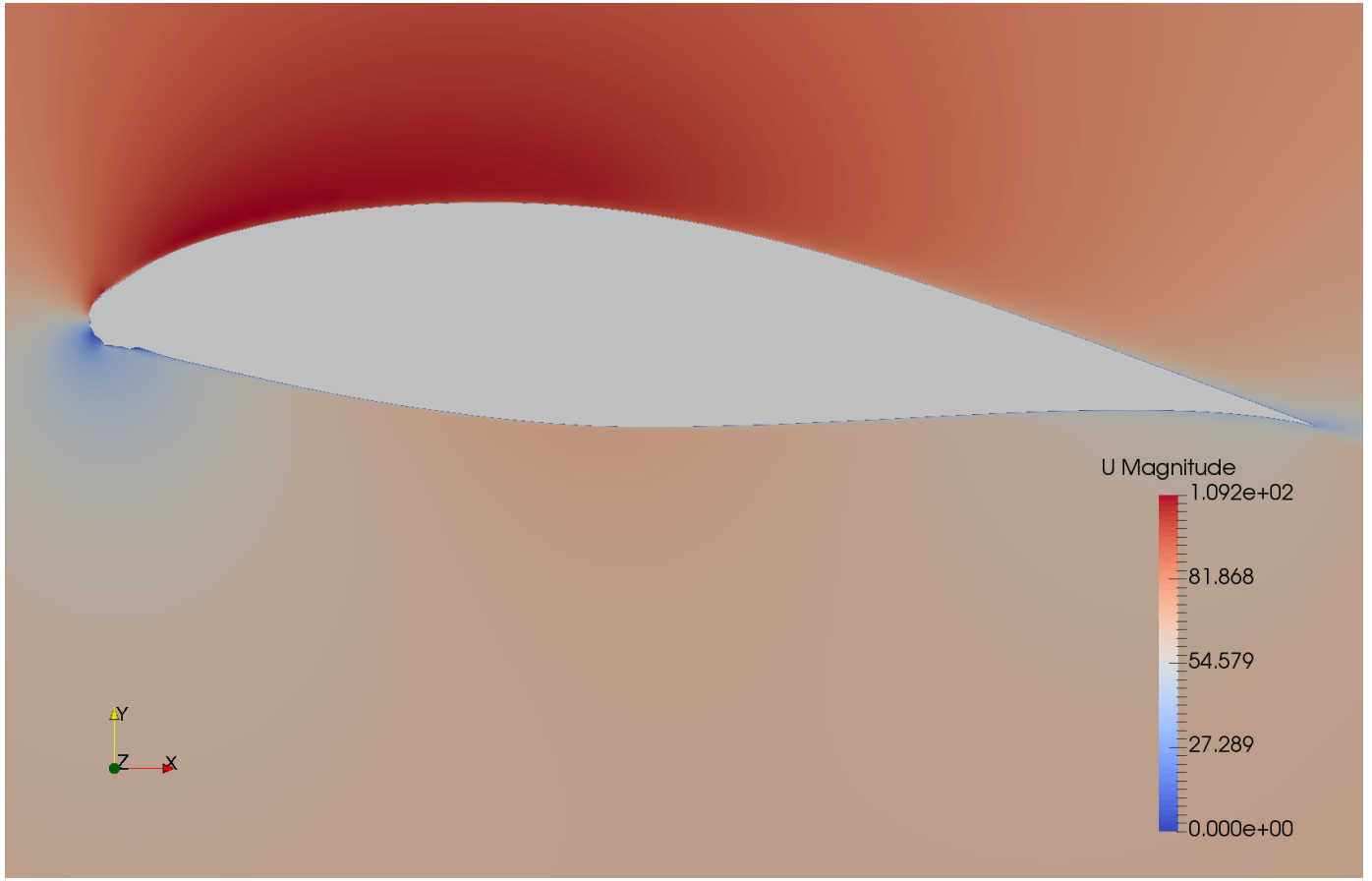
- Weighted average of LWC and wind speed for each blade section depending on time spent on each height segment
- The tip speed ratio is kept constant at 7.25, leads to an angle of attack of about 5 degrees in the outermost section
- The blade shape is altered every hour

Ice on the blade

Ice accretion on the outermost section



Iced blade profile on the outermost section after 12 hours



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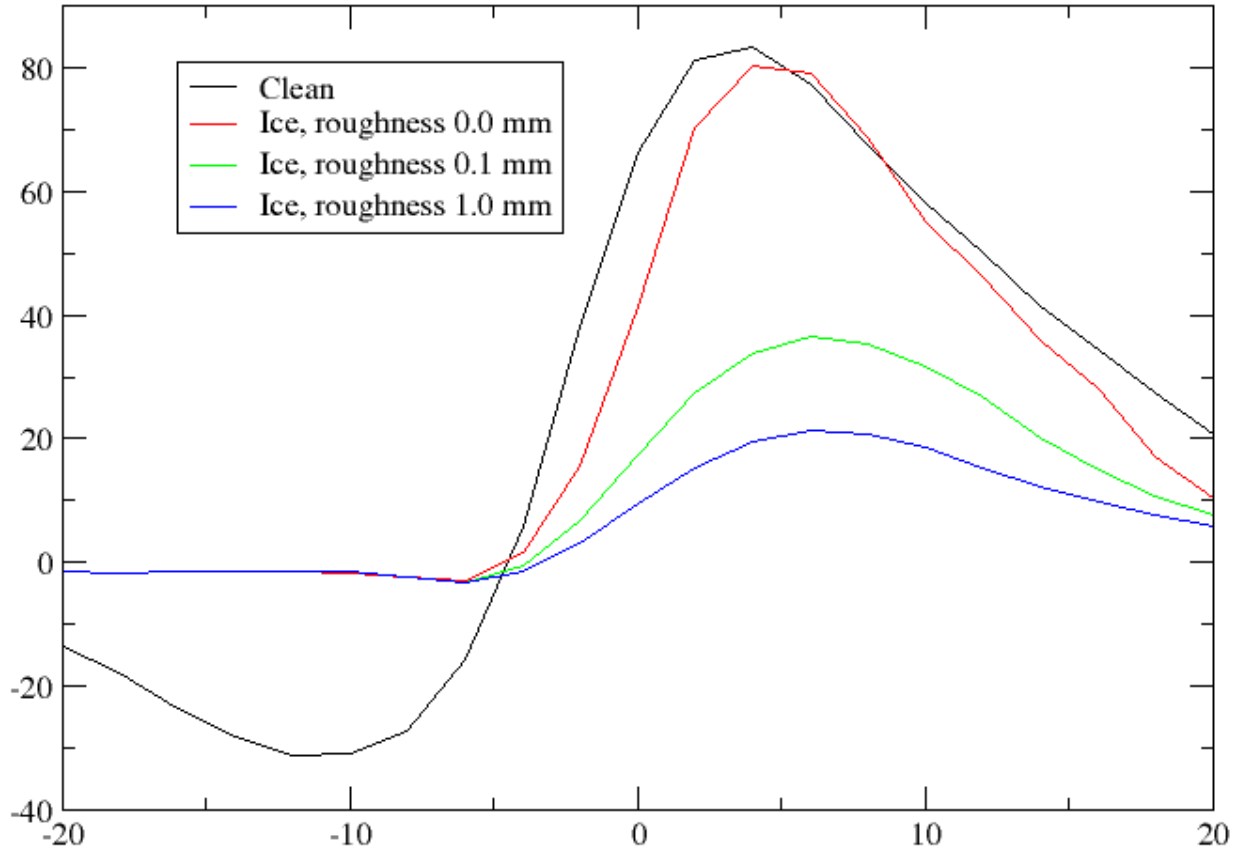
Comparing the aerodynamic performance of the iced aerofoil at some values of surface roughness. The figure shows the glide ratio at the outermost section



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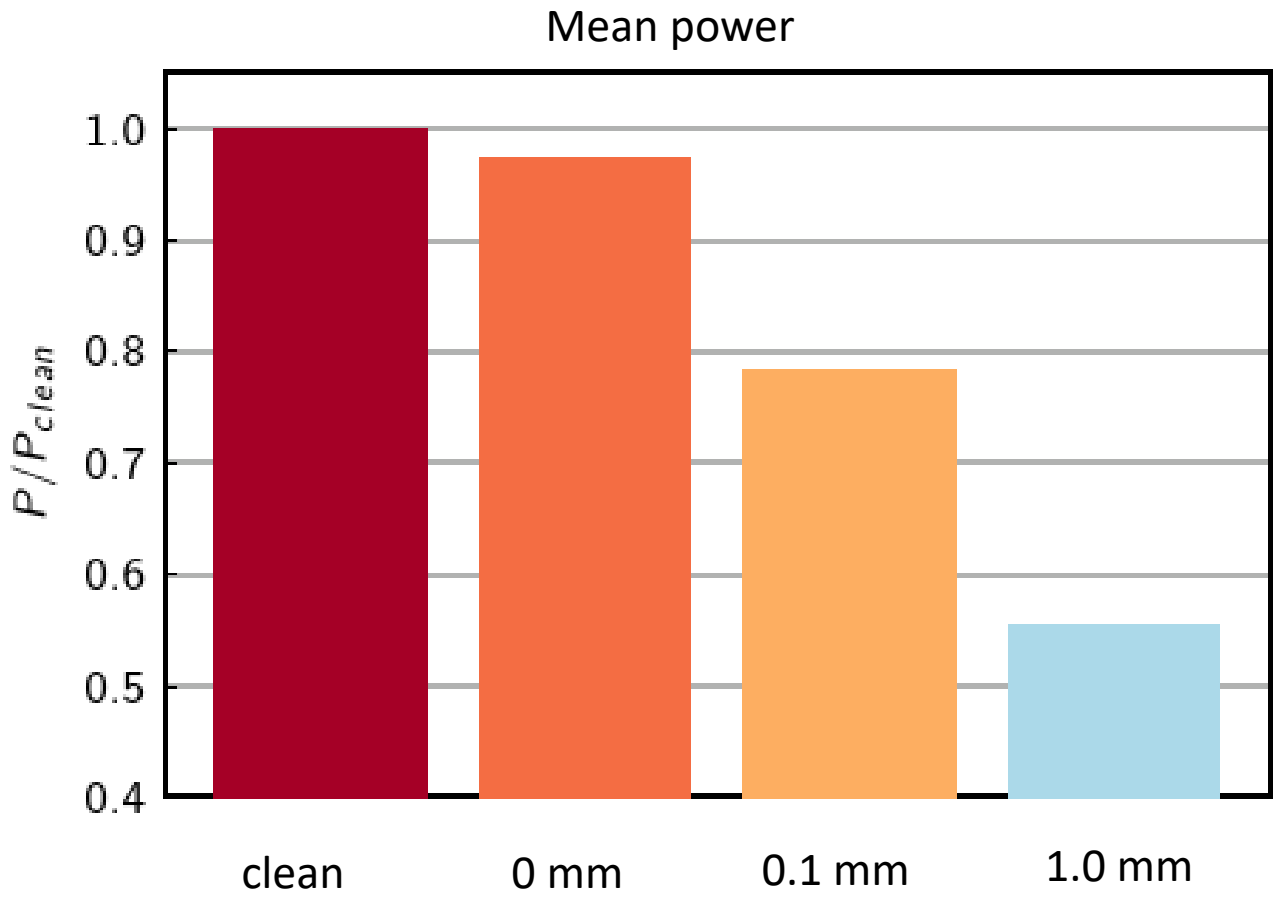
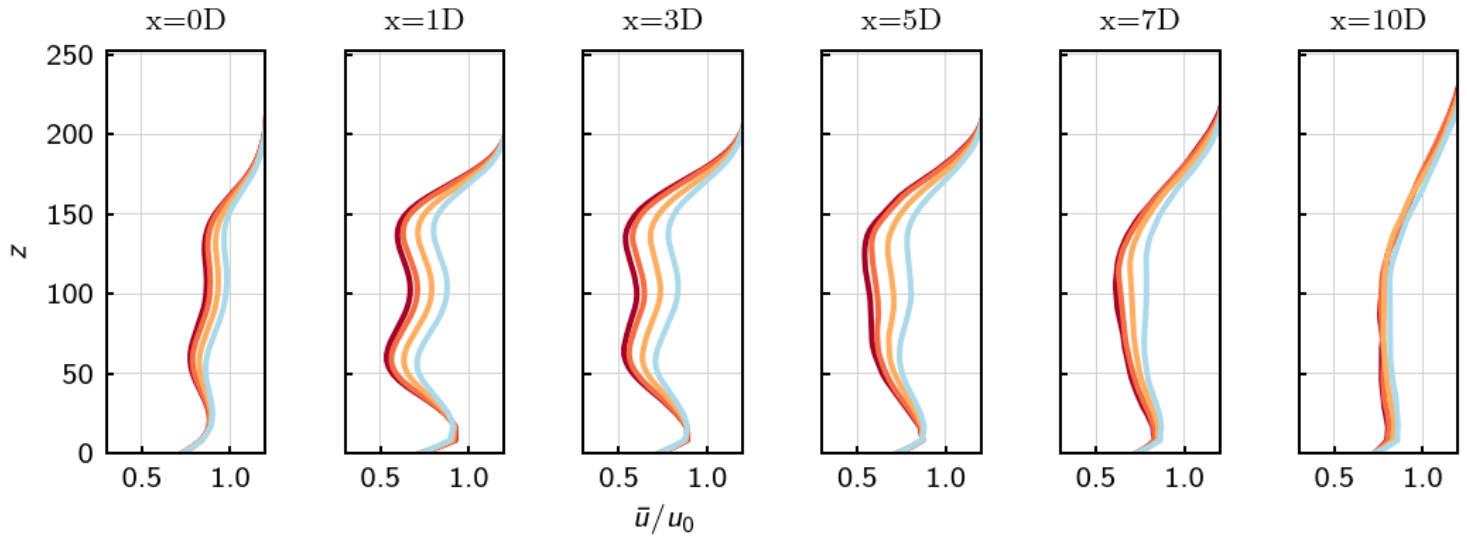


Wake flow

Average velocity



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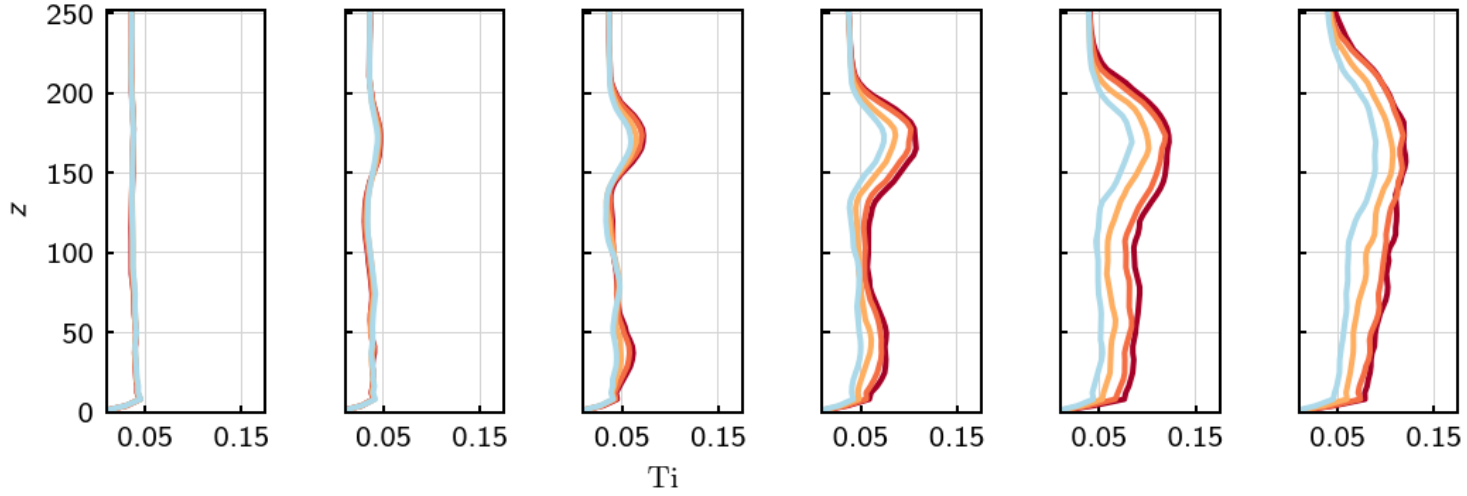

Conclusions

- Roughness height is important
- Wake effects are observed
- Validation is needed, ongoing
- Sensitivity to parameters and choices throughout the chain

Acknowledgement

- This project is financed by the Swedish Energy Agency, project no. 47053-1
- Computational resources are provided by SNIC@Lunarc