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EFFECT OF WAKE MEANDERING ON AEROELASTIC RESPONSE OF A WIND TURBINE PLACED IN A PARK

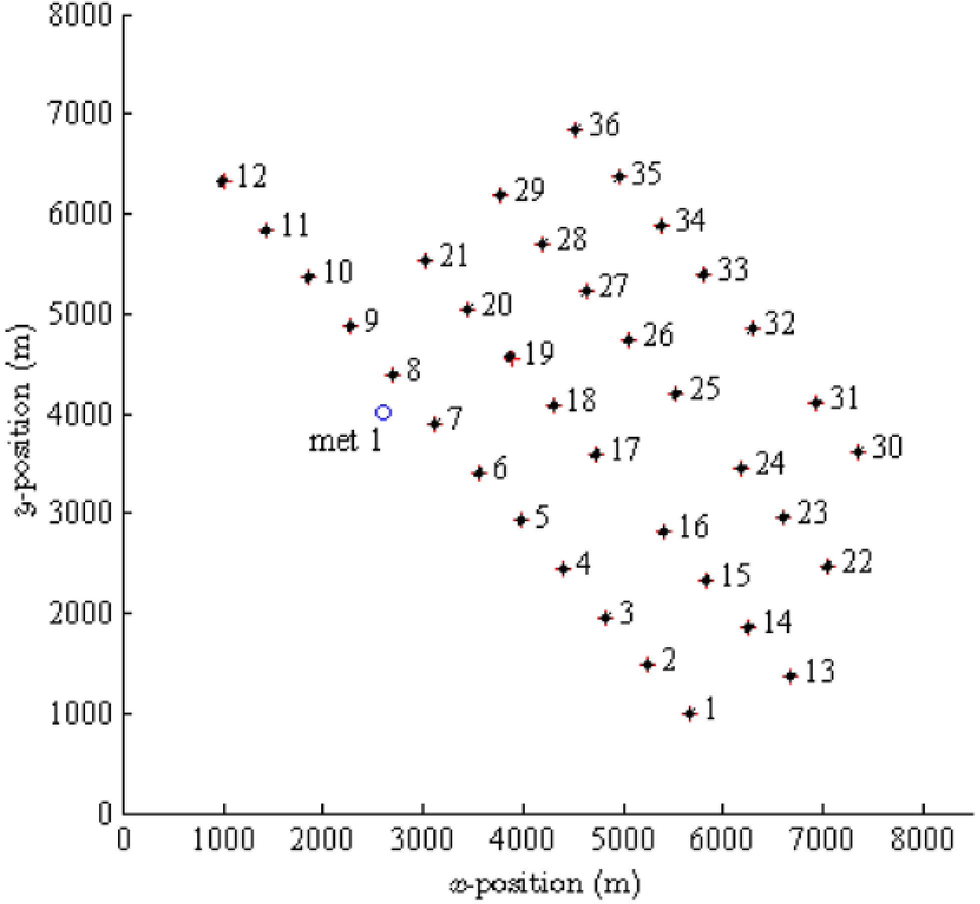
Balram Panjwani, Marit Kvittem, Lene Eliassen, Harald Ormberg, SINTEF, Norway

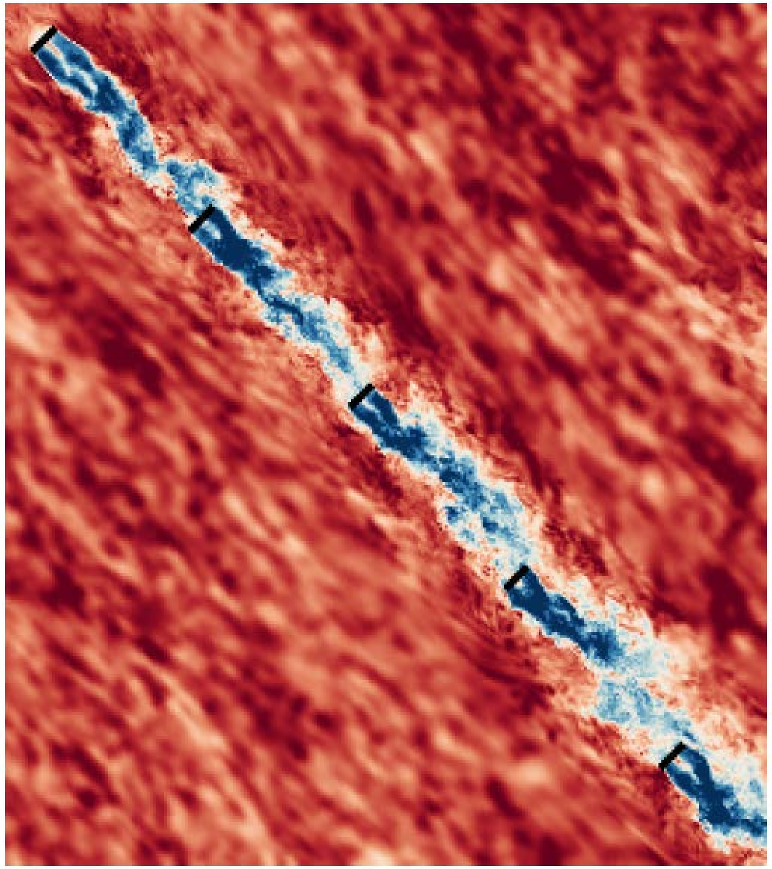
Marte Godvik, Equinor, Norway

Outline

- ❑Introduction
- ❑Standalone tool (**D**isturbed **I**nflow **W**ind **A**nalyzer: **DIWA**)
- ❑Benchmarking with literature data (HAWC2, SOWFA, FastFarm)
- ❑Power verifications
- ❑Aeroelastic simulations (SIMA-DIWA) and benchmarking with Lillgrund farm data
- ❑Aeroelastic simulation of NREL 5MW turbine
- ❑Conclusions

Why Meandering is important?





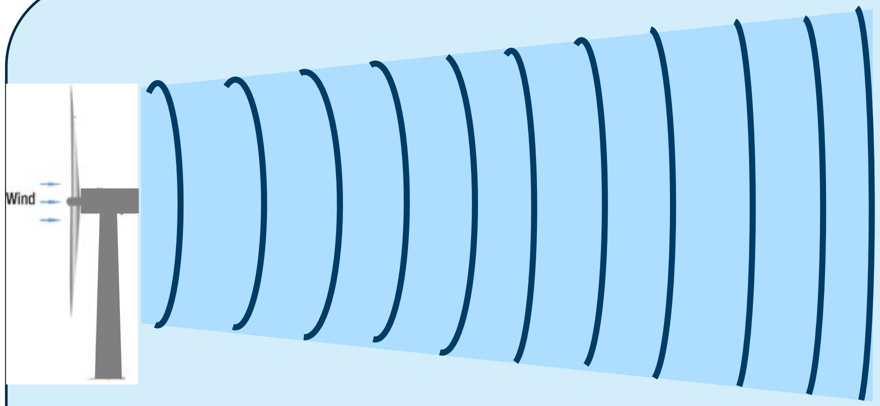
LES SOWFA results*

*M.J. Churchfield and P.J. Moriarty "A Comparison of the Dynamic Wake Meandering Model, Large-Eddy Simulation, and Field Data at the Egmond aan Zee Offshore Wind Plant"

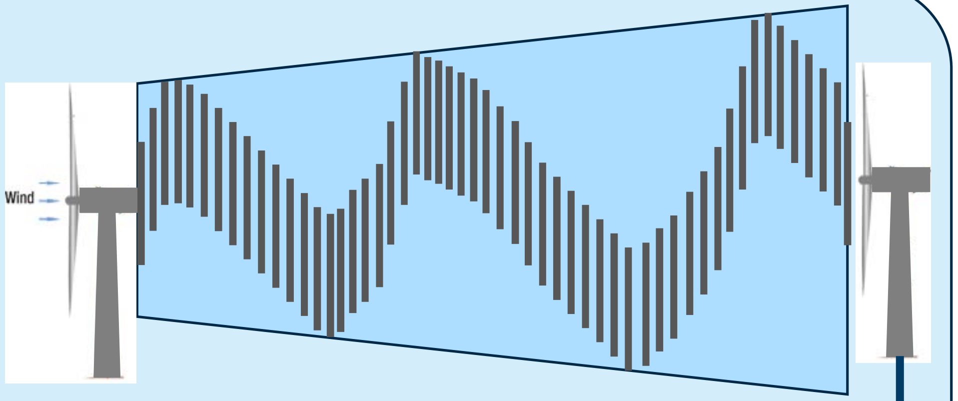
SIMA-DIWA Concept

inputs:

- Ambient wind conditions (wind speed, direction, and turbulence)
- Turbine properties (Blade geometry, turbine location, performance tables)
- Turbulence boxes (large scale and small scale structures)



Wake deficit and added wake turbulence in MFoR



Meandering of Wake deficits and added turbulence

Outputs:

- Turbulence boxes with total turbulence
- Mean wind and total turbulence
- Position of wake centre as a function of time
- Speed, Power and Thrust of an individual turbine and whole wind park

DIWA Standalone

❑Start Wake Deficit Models/Near Wake

- ❑Induction profiles based on Blade Element Method (BEM)
- ❑Near wake profiles and Near wake length model

$$r_{w,i+1} = \sqrt{\frac{(1-a_i)}{(1-2a_i)}\left(r_{t,i+1}^2 - r_{t,i}^2\right) + r_{w,i}^2}$$

$$U_w\left({}^{\left(r_{w,i+1} + r_{w,i+1}\right)}\!/_{2} \right) = U_0\left((1-2a_i)\right)$$

❑Far wake Model (MFoR)

- ❑Discretized thin shear Navier Stoke (NS) Equations

$$U\frac{\partial U}{\partial x} + V_r\frac{\partial U}{\partial r} = \frac{\nu_T}{r}\frac{\partial}{\partial r}\left(r\frac{\partial U}{\partial r}\right)$$

- Continuity equation $\frac{\partial U}{\partial x} + \frac{1}{r}\frac{\partial}{\partial r}\left(rV_r\right) = 0$

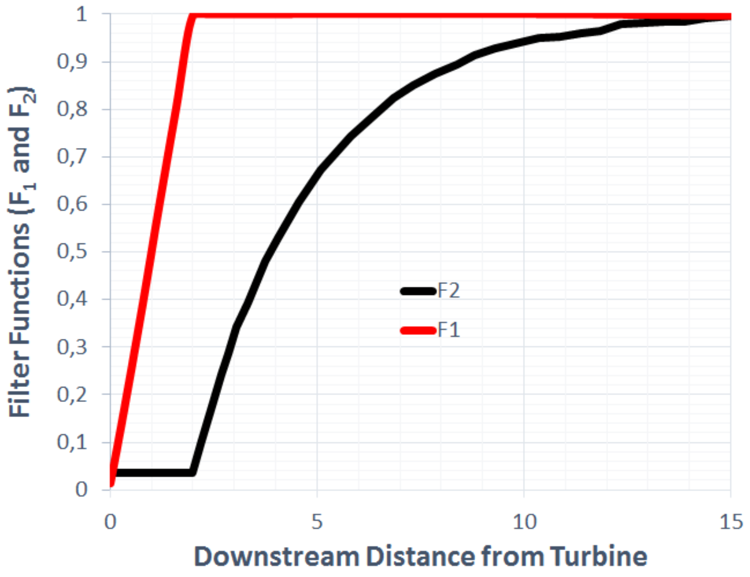
Eddy viscosity model

- ❑ **The eddy viscosity is modelled using the following algebraic equation**

$$\nu_t^{\star} = F_2 k_2 \left(\frac{b}{R}\right)\left(U_0 - U_{def,min}\right) + F_1 k_1 I_{amb}$$

- ❑ **Filter function plays important role in deficit calculations**
  - ❑ Three filter functions
  - ❑ FastFarm filter functions : 8 calibration parameters
- ❑ **Effect of atmospheric stability is introduced**

$$\nu_t = \nu_t^{*} \frac{du/dr_{total}}{du/dr_{dwm}}$$



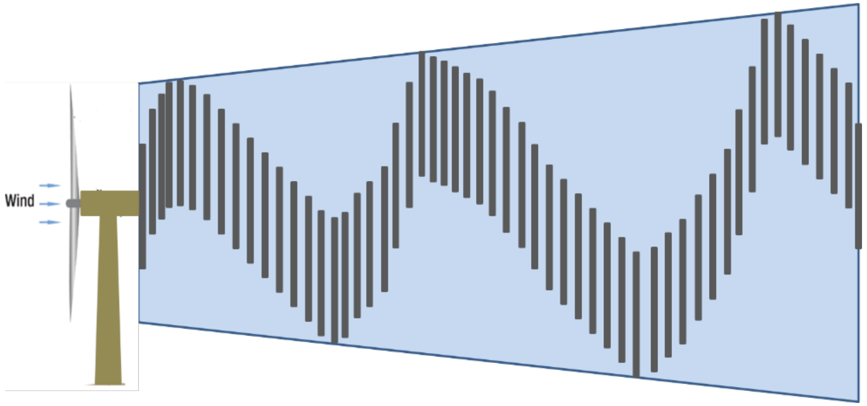
Wake meandering model in DIWA

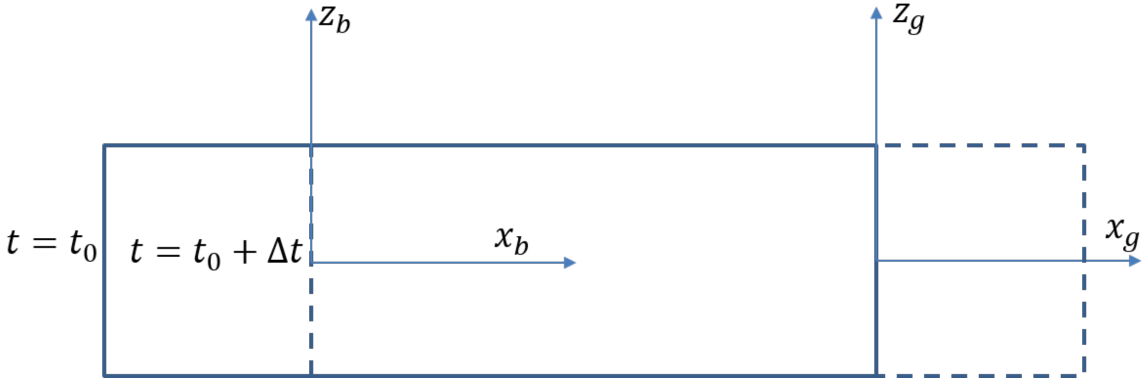
- Two hypothesis
  - Meandering due to large scale eddies (Plume behaviour)
  - intrinsic instabilities of the wakes (flow behind bluff bodies)
- Current implementation is based on the first hypothesis
- Wake deficits are assumed as a tracer and eddies larger than the rotor diameter are responsible for meandering
- Wake centre position of the deficit

$$x_{c+1} = x_c + U\Delta t$$

$$y_{c+1} = y_c + v_f\left(U[T - t_i], y_c, z_c\right)\Delta t$$

$$z_{c+1} = z_c + w_f\left(U[T - t_i], y_c, z_c\right)\Delta t$$

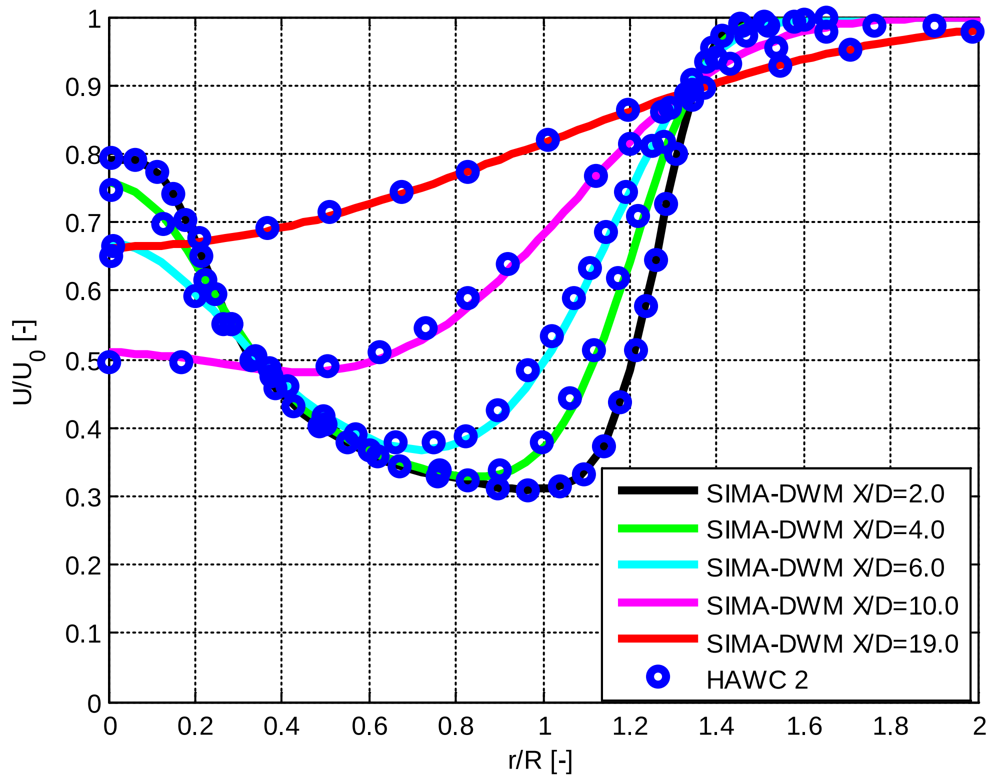


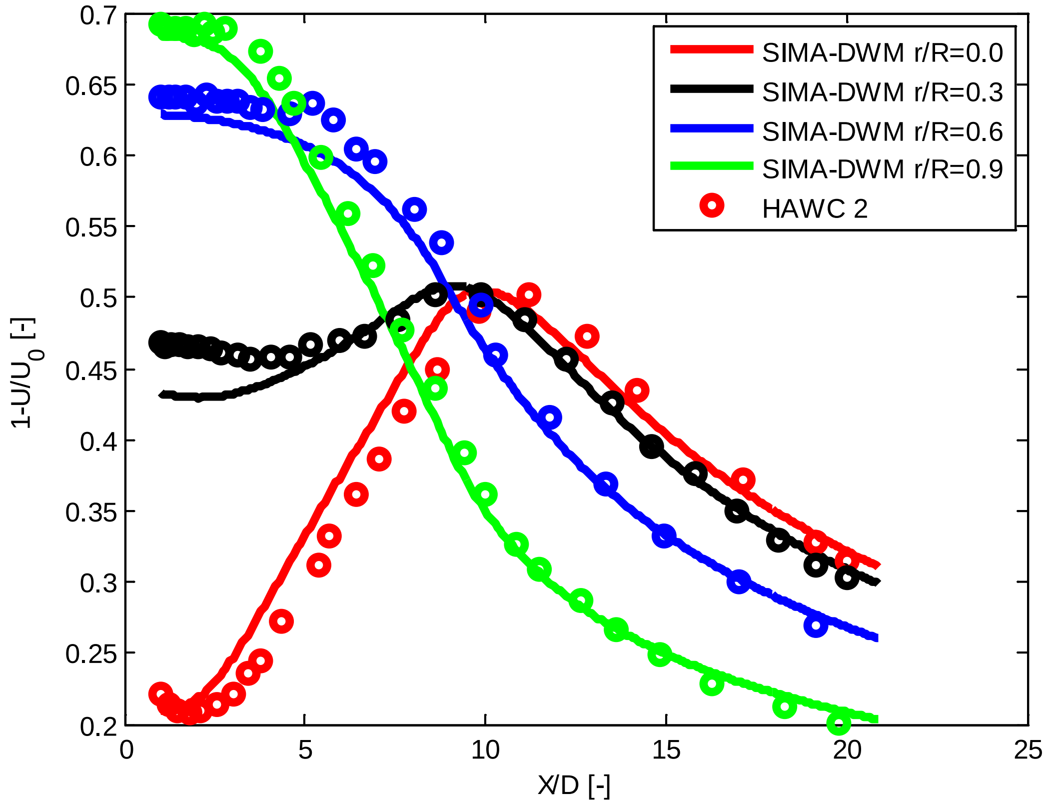


DIWA verification and validation

- Velocity Deficits and turbulence verification of a turbine with HAWC2 data **(Literature data)**
- Benchmarking with Fast Farm and SOWFA
- Power verification of a single (two turbines in row) and double wake scenario (three turbines in a row)
- Lillgrund wind farm

Verification without atmospheric Turbulence (NM 80 wind turbine)





Mean wind = 6 m/s, TI = 0

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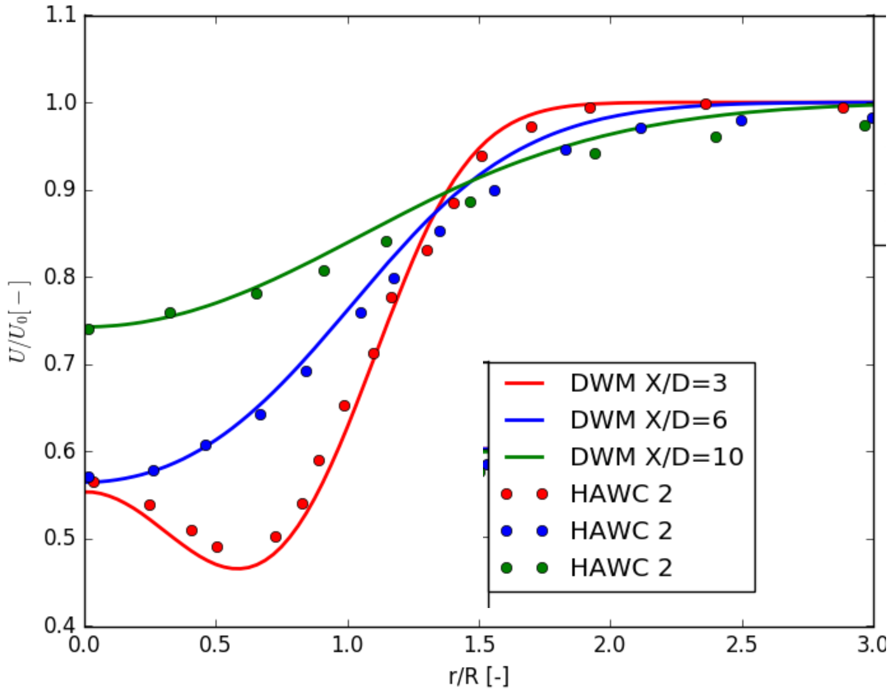
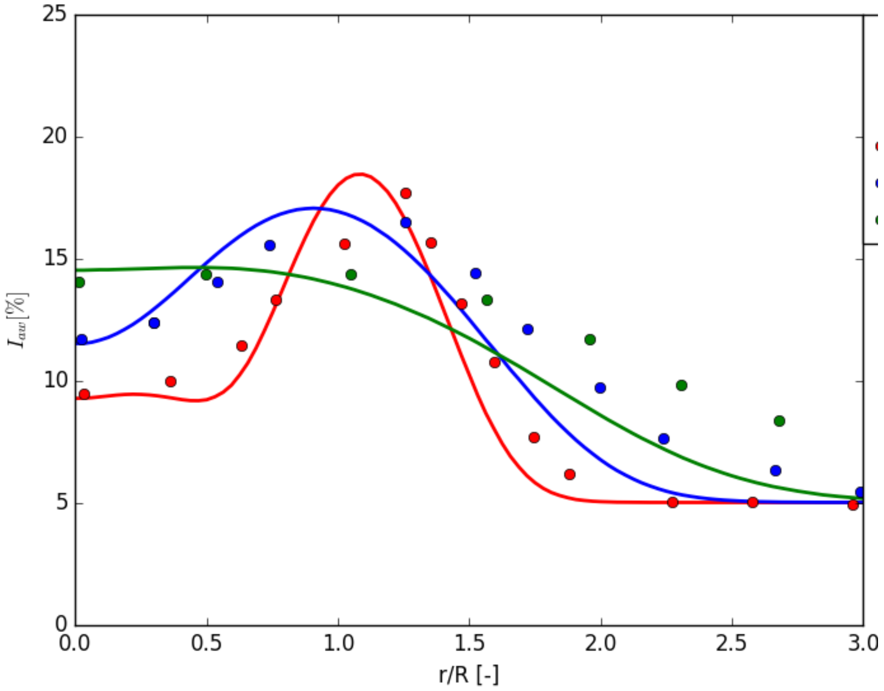
Mean velocity and total turbulence intensity (Wind speed 8 m/s TI 5%, NM80)



Mean velocity



Total turbulence intensity

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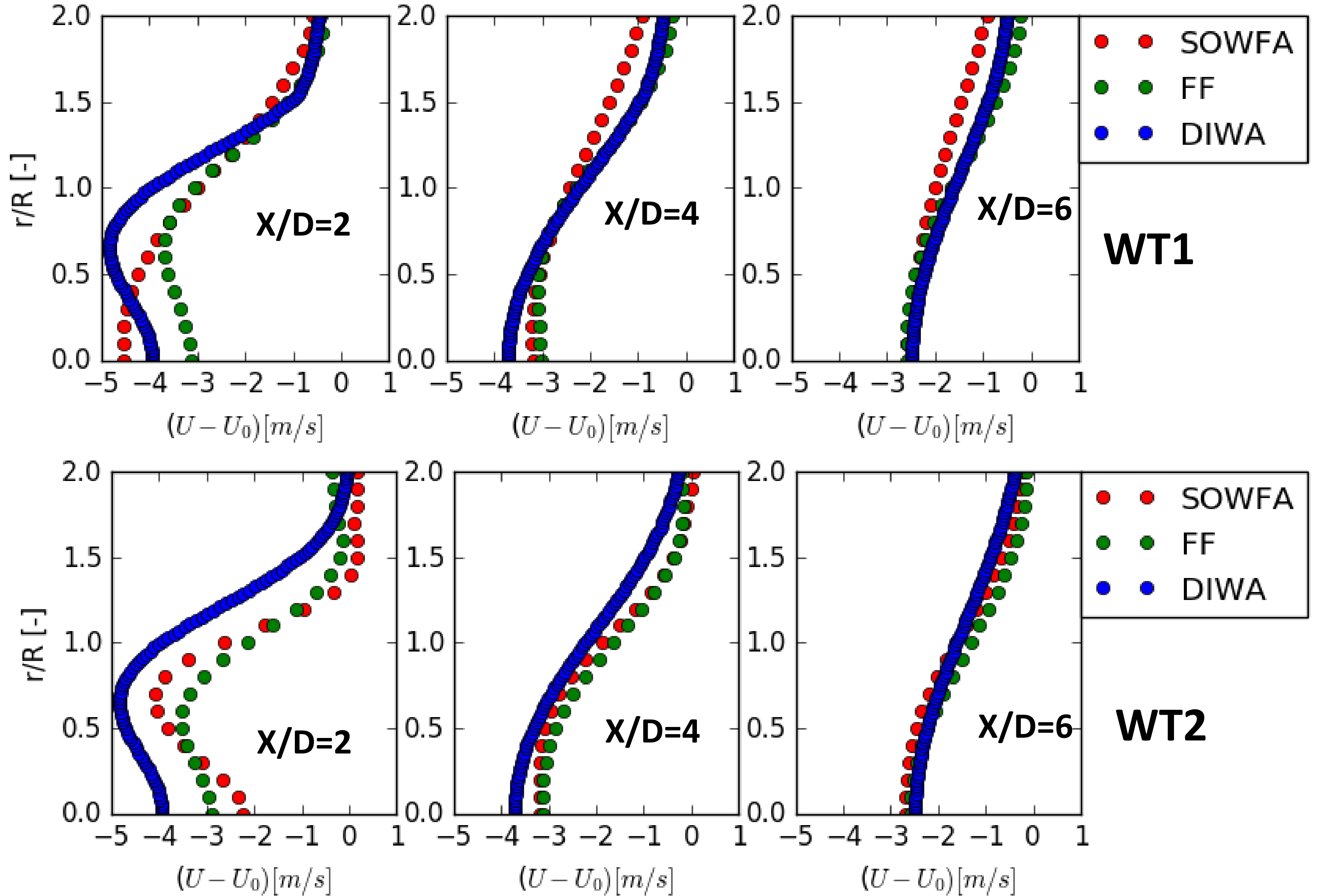
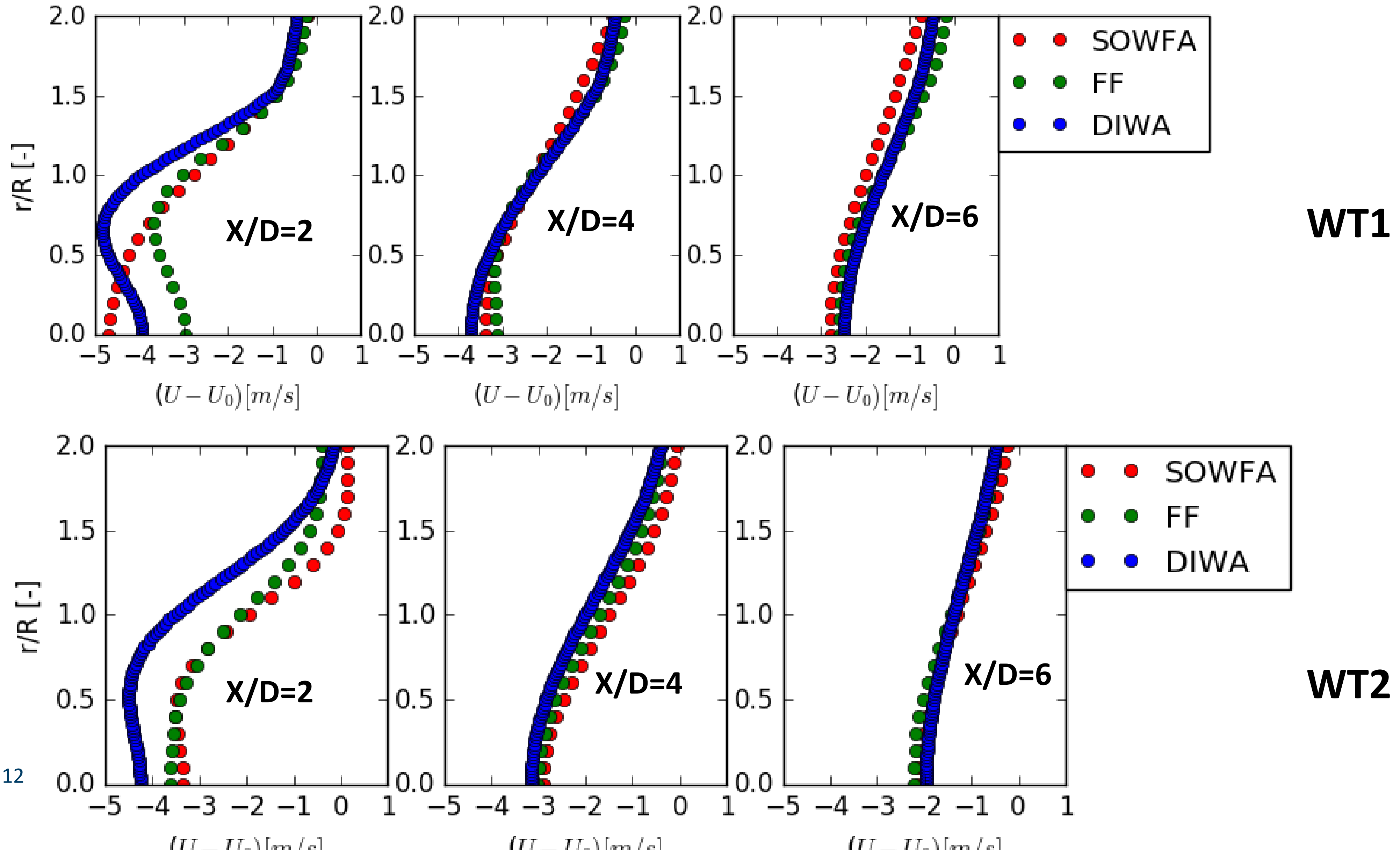
Validation with FastFarm (FF) and SOWFA (8 m/s, Ti = 6%)



Validation with FF and SOWFA (8 m/s, Ti = 10%)



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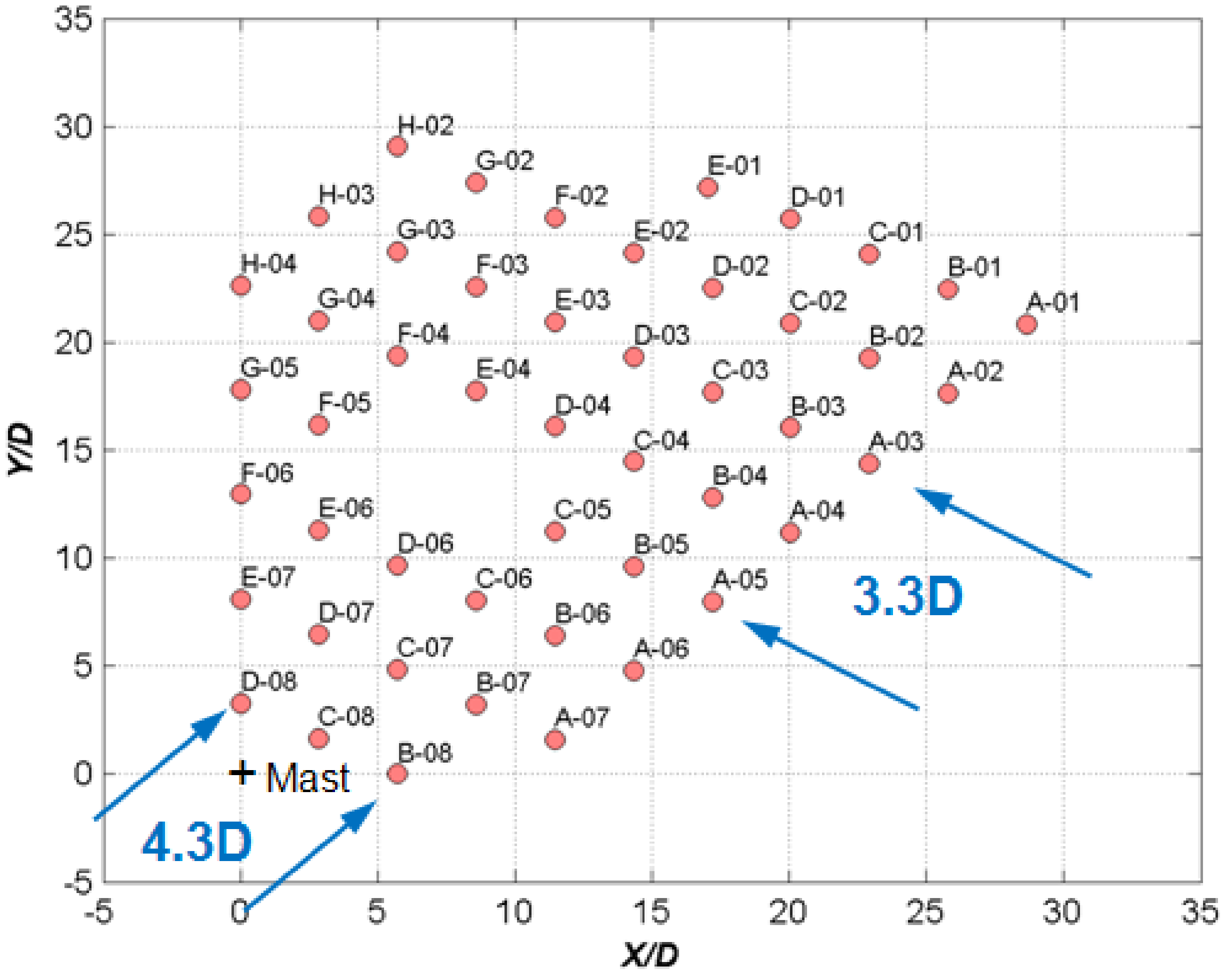
Flow visualization and power verification (Lillgrund Park)



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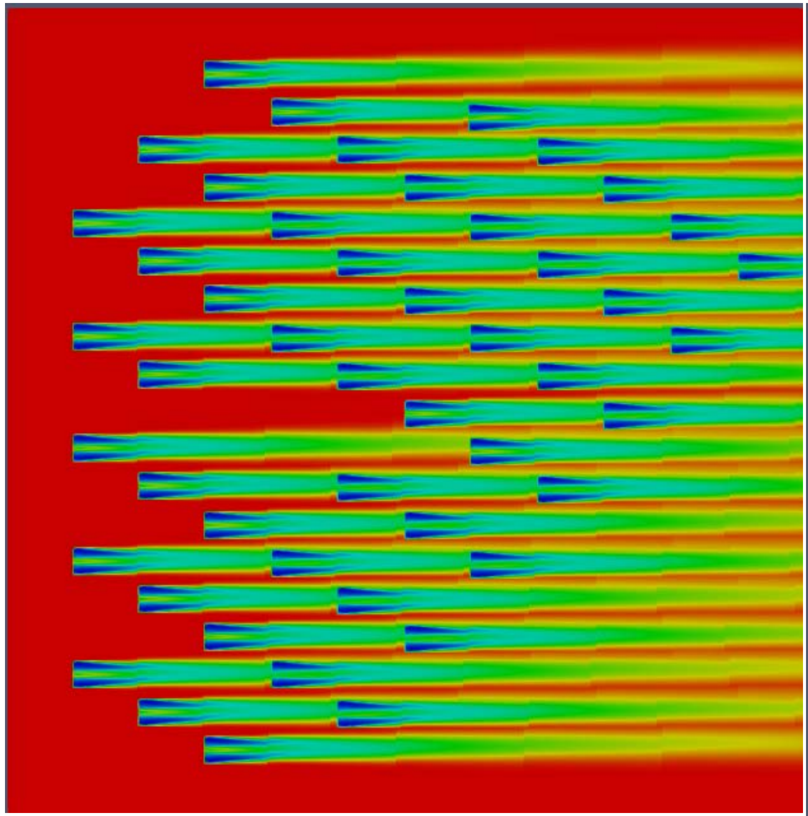
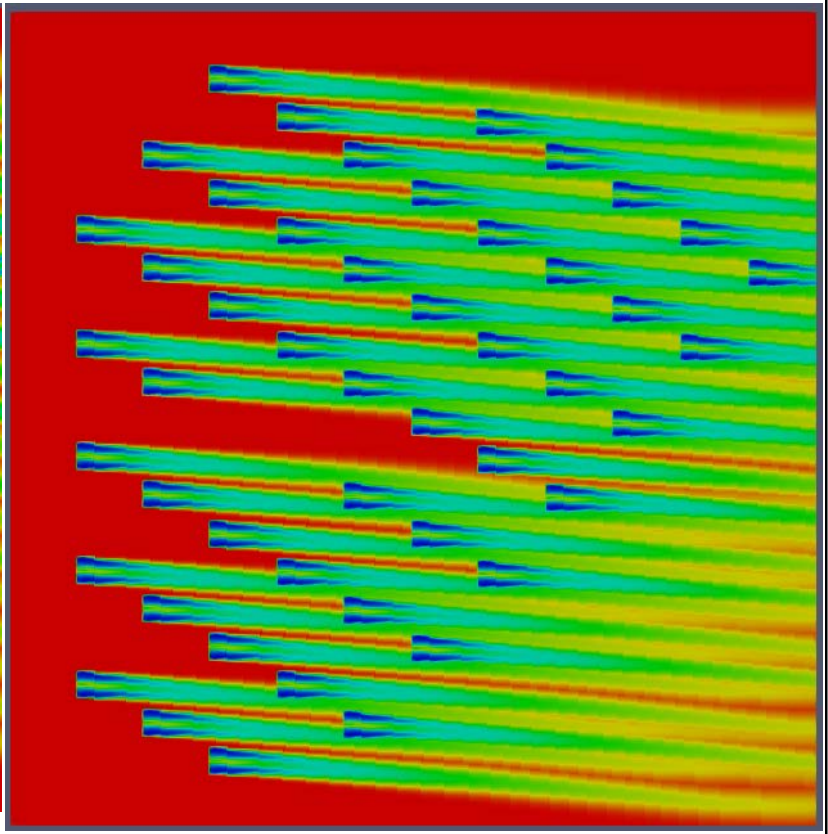
Visualization of flow field (Meandering)



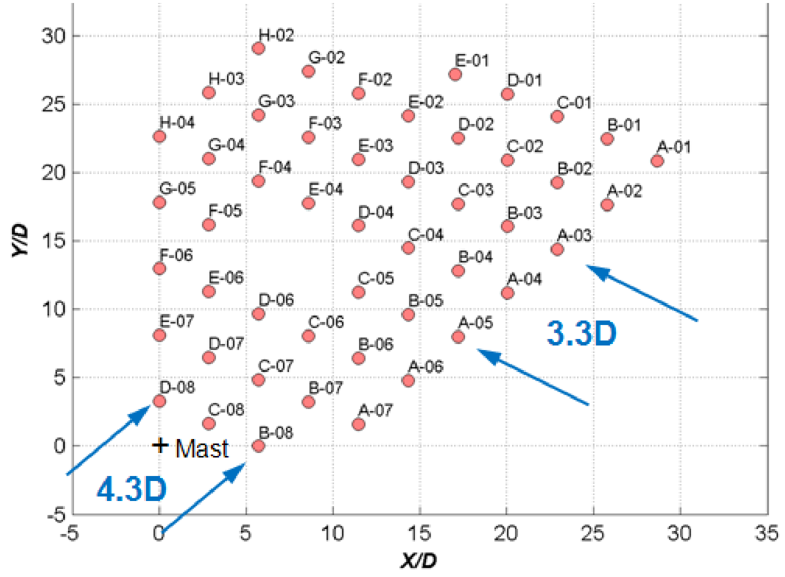
t=10s

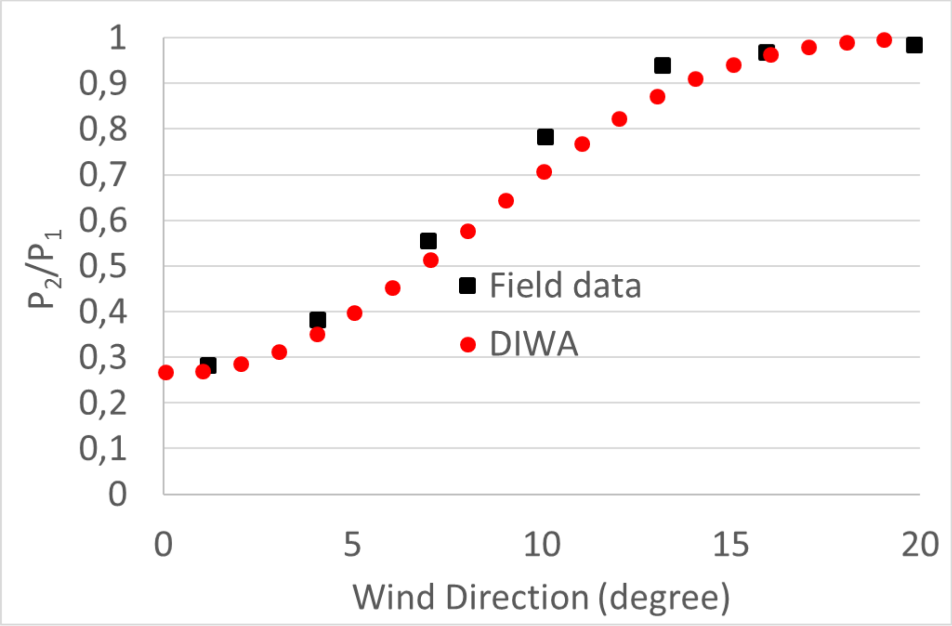


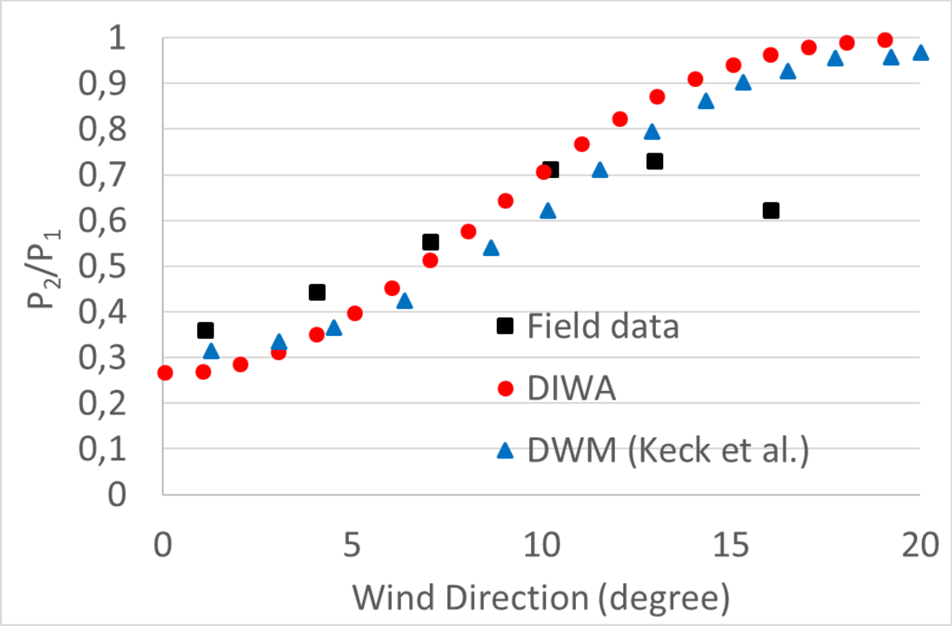
t=100s

Mean wind 8 m/s, TI=6%

Lillgrund Single wake (two/three turbines in row)







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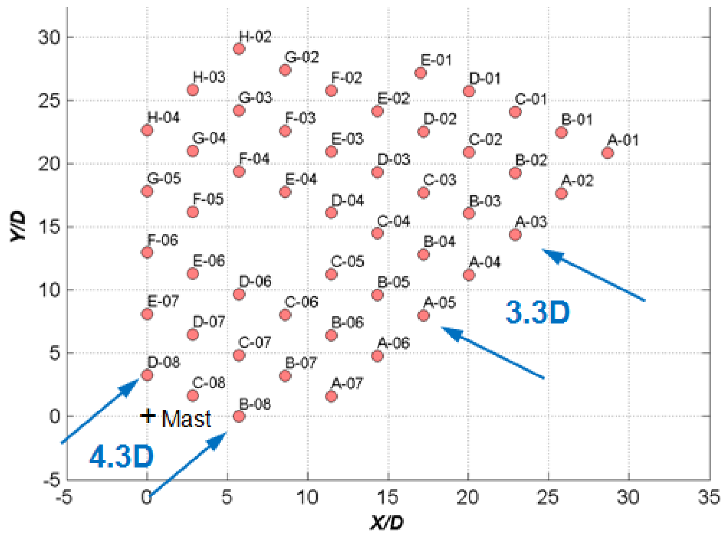
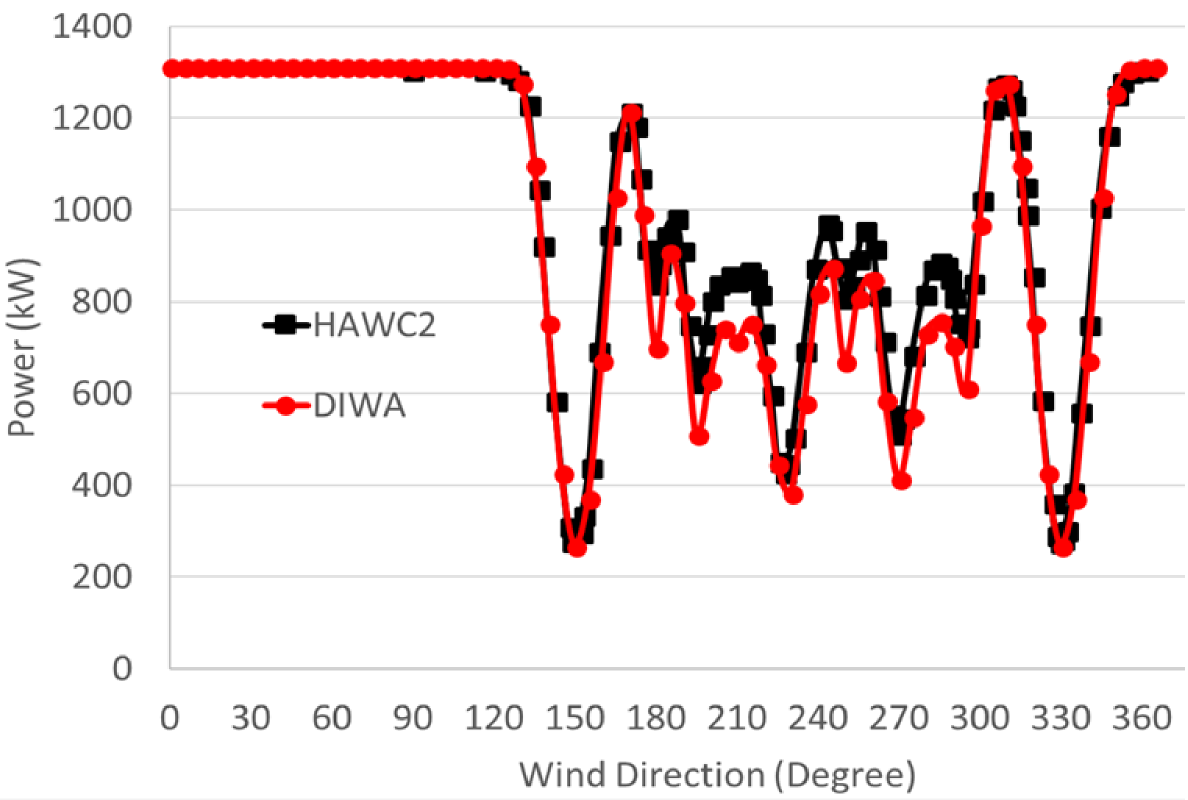
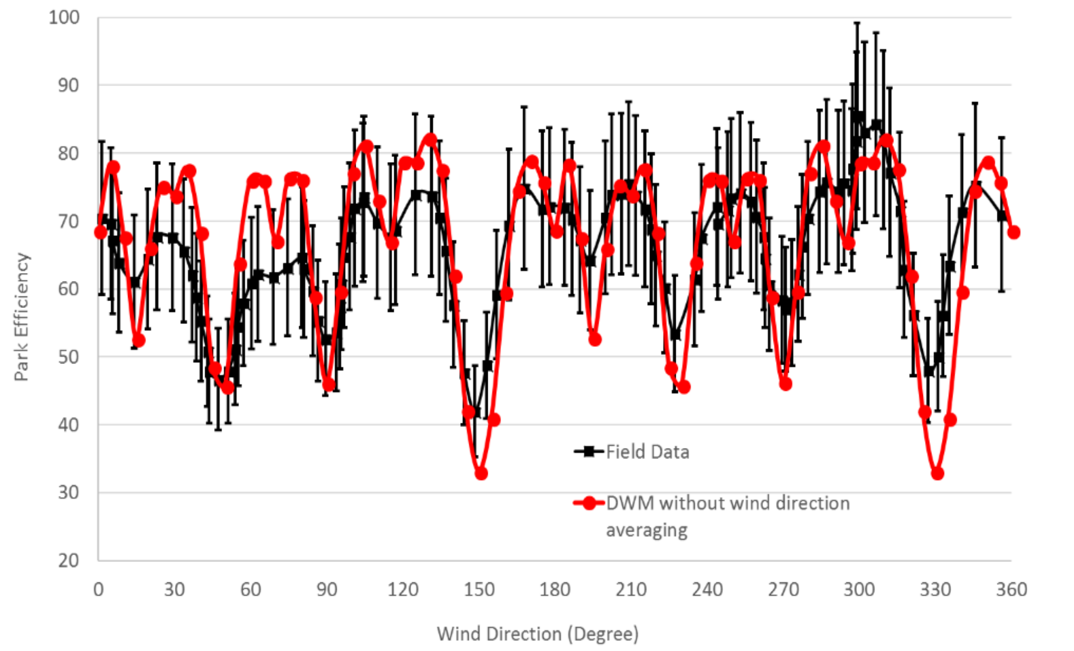
Power Verification: C8 turbine and full park (V=9 m/s; TI =6)







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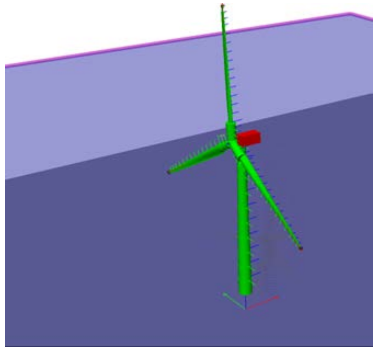
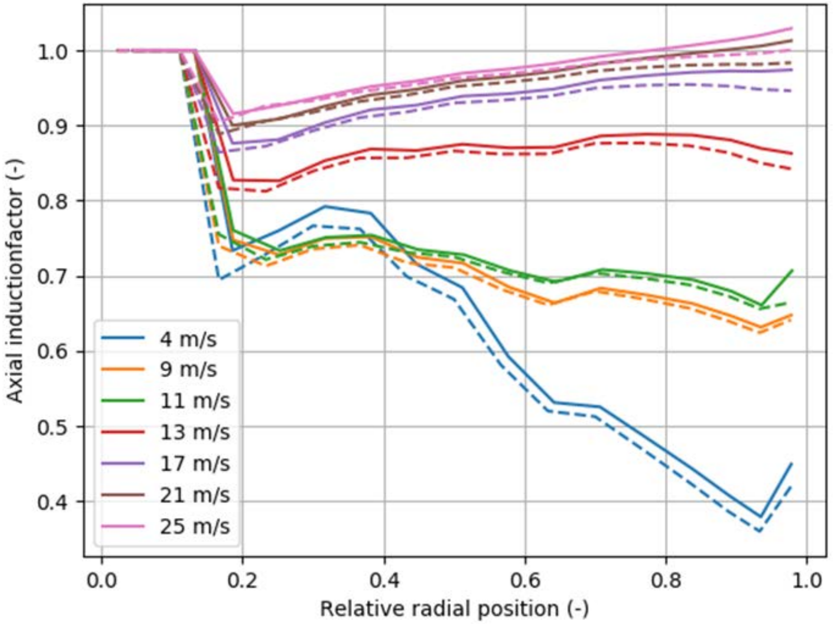
Aeroelastic simulations

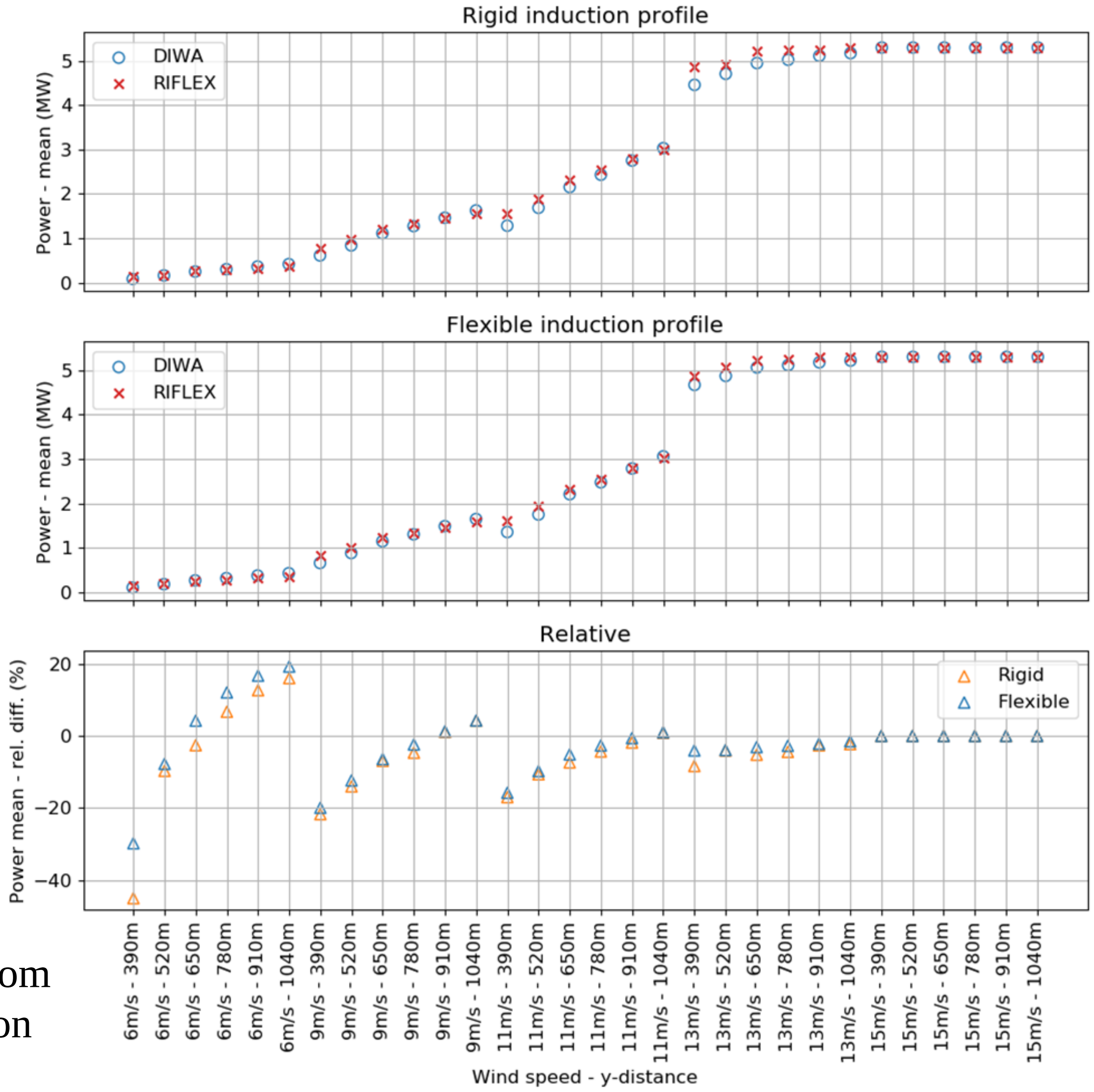
- SIMA Riflex is an advanced tool for static and dynamic analysis of structures.
- Wind boxes were created using DIWA code
- Two NREL 5MW turbines in a row
- Six simulations were performed for each wind direction
- Damage equivalent loads were calculated using SIMA-DIWA

NREL 5MW turbine

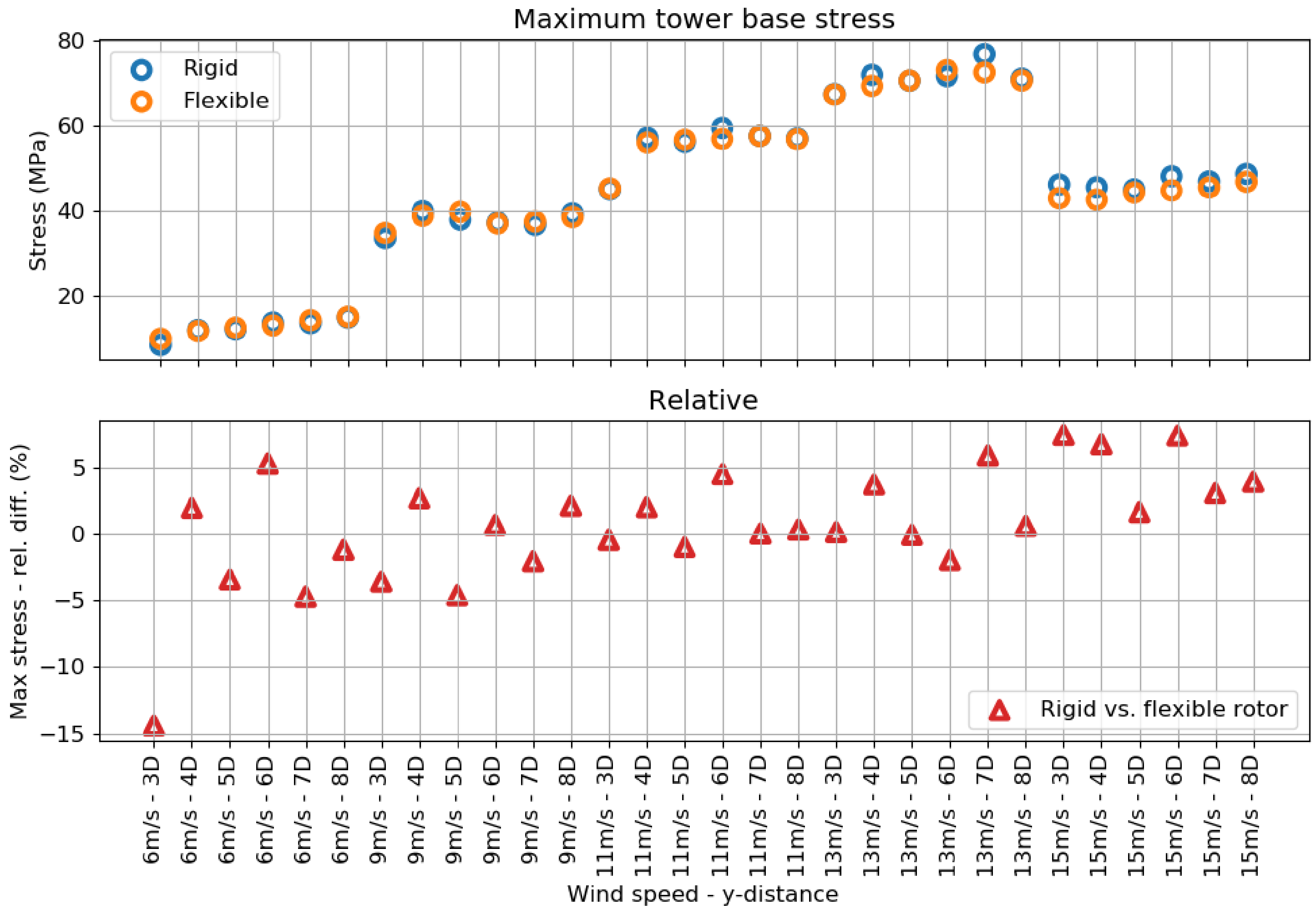




Axial induction profiles for the NREL 5MW derived from aeroelastic analysis. The dashed lines show the induction profiles for rigid blades calculated by DIWA.



Rigid vs. flexible rotor in aeroelastic simulations



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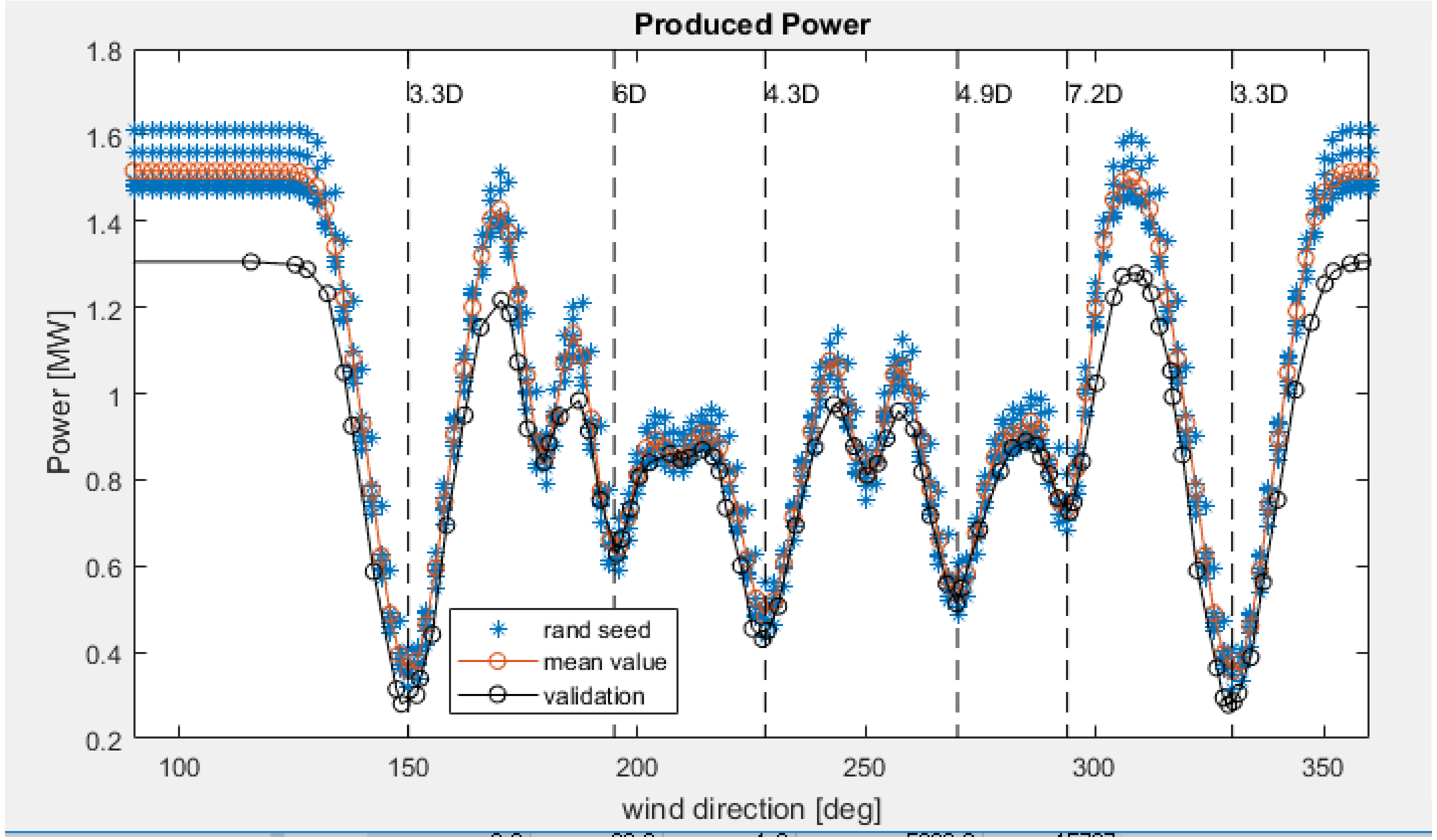
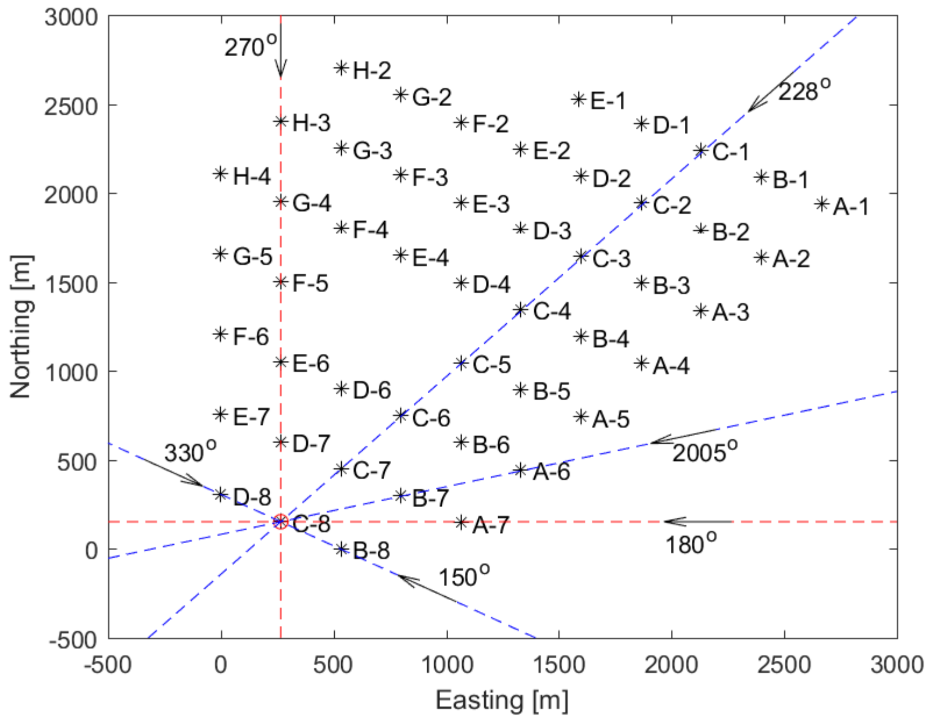
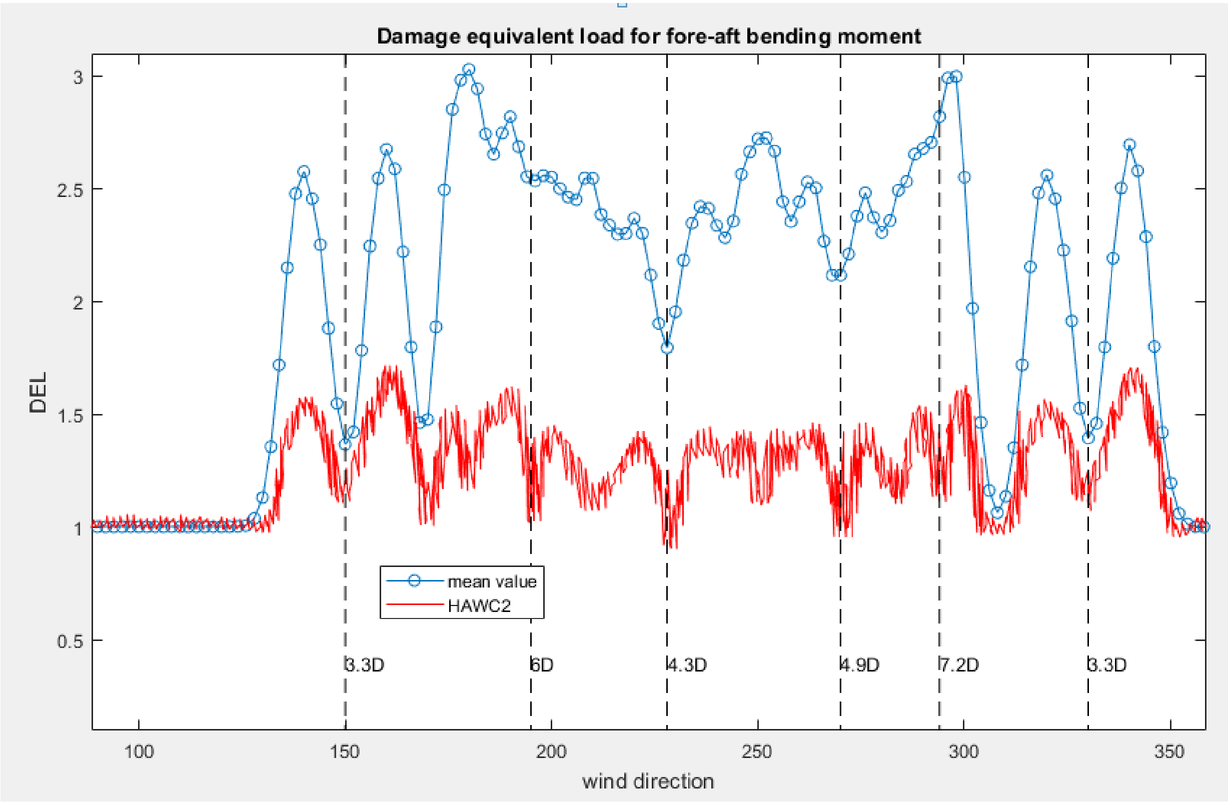
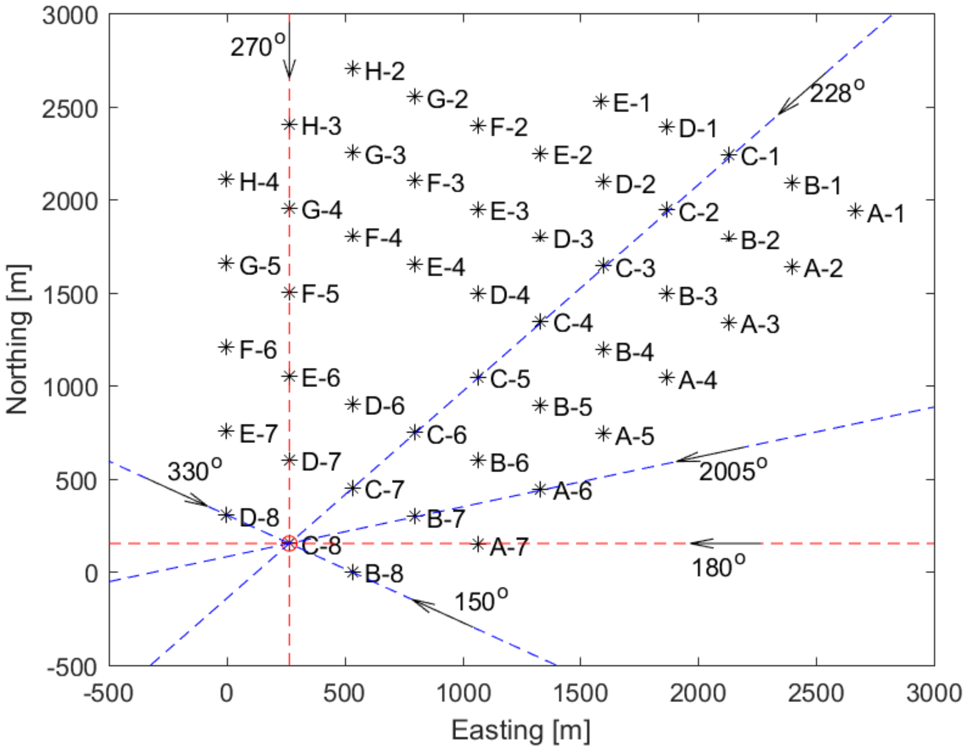
Benchmarking Lillgrund, power





Benchmarking Lillgrund, DEL (ongoing)





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Conclusions

- Two hypothesizes for the wake meandering are identified based on the literature study.
- Most of the design codes are based on the first hypothesis.
- "SIMA-DIWA" is benchmarked against the literature data
- The study indicates that the eddy viscosity model parameters play quite an important role in wake deficits.
- The trends of fatigue loads are predicted well, with a few exceptions.
- More work is needed towards improving the eddy viscosity model

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Teknologi for et bedre samfunn