Optimal open loop control of wind power plants

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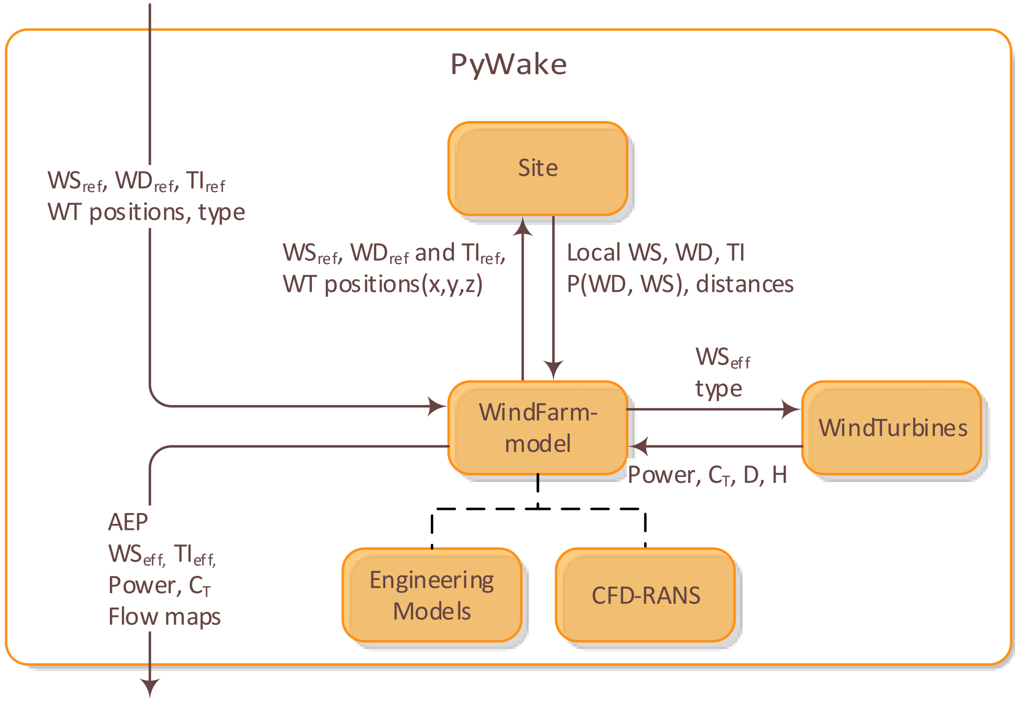
Introduction

- Wind farm control optimization - purpose
  - Increase the farm production
  - Decrease costs
- Wind farm control optimization – active wake control approaches
  - WT derating
  - WT wake steering via yaw control
- Previous work – **combined derating and wake deflection**
  - J. Park and K.H. Law, K.H., "A data-driven, cooperative wind farm control to maximize the total power production". Appl. Energy 165, 2016, 151–165
  - L. E. Andersson, E. C. Bradford and L. Imsland, "Distributed learning for wind farm optimization with Gaussian processes", 2020 American Control Conference (ACC)
  - W. Munters and J. Meyers, J., "Optimal dynamic induction and yaw control of wind farms: effects of turbine spacing and layout", J. Phys. Conf. Ser. 1037, 2018 (LES based)
- Research objective: Investigate the effect of optimal **integrated derating and wake deflection control** on a full-scale wind farm with respect to **AEP**

PyWake

- Open source python package developed by DTU Wind Energy (gitlab.windenergy.dtu.dk/TOPFARM/PyWake)
- AEP calculator for wind farms
- Fast and flexible



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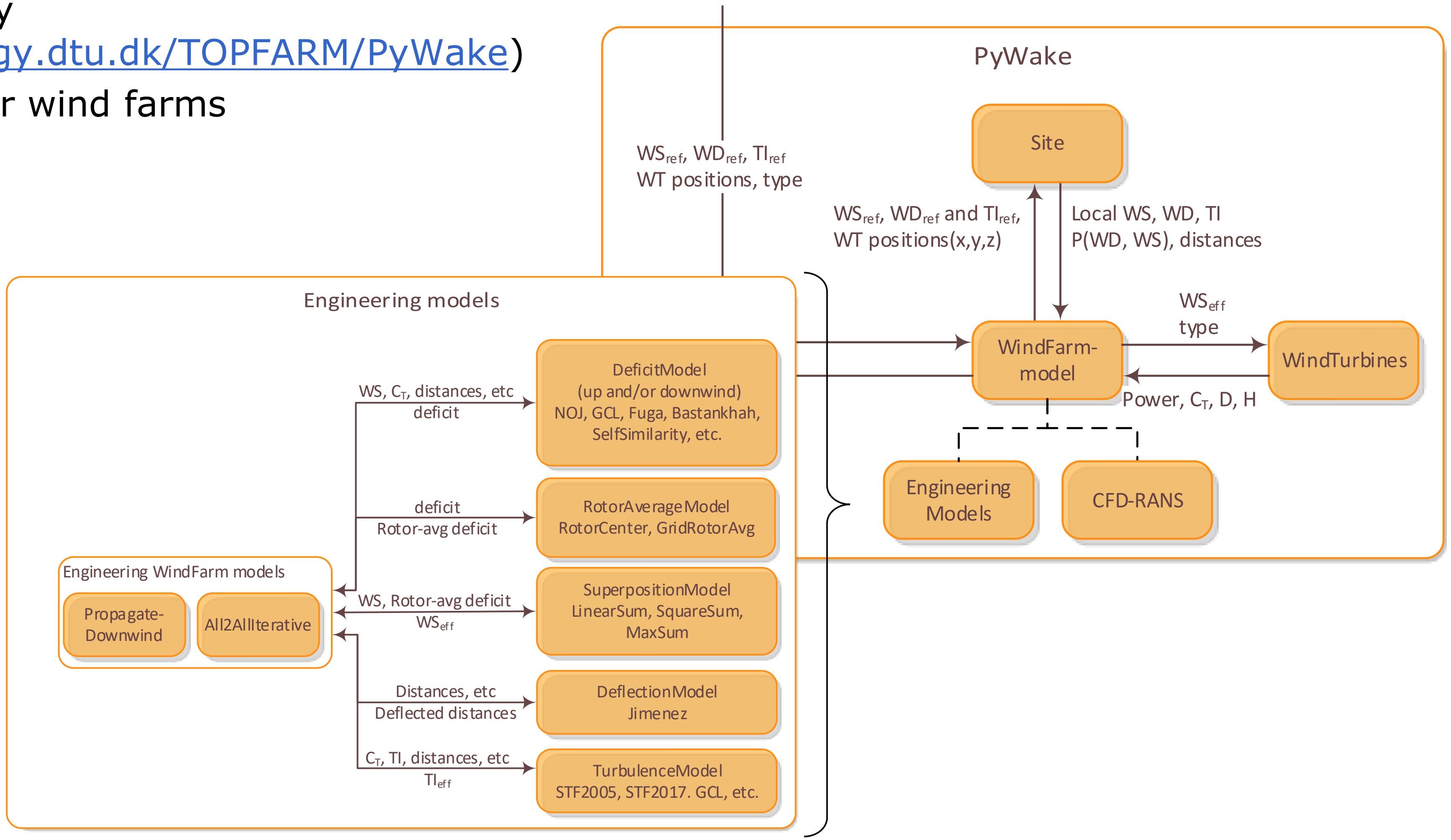
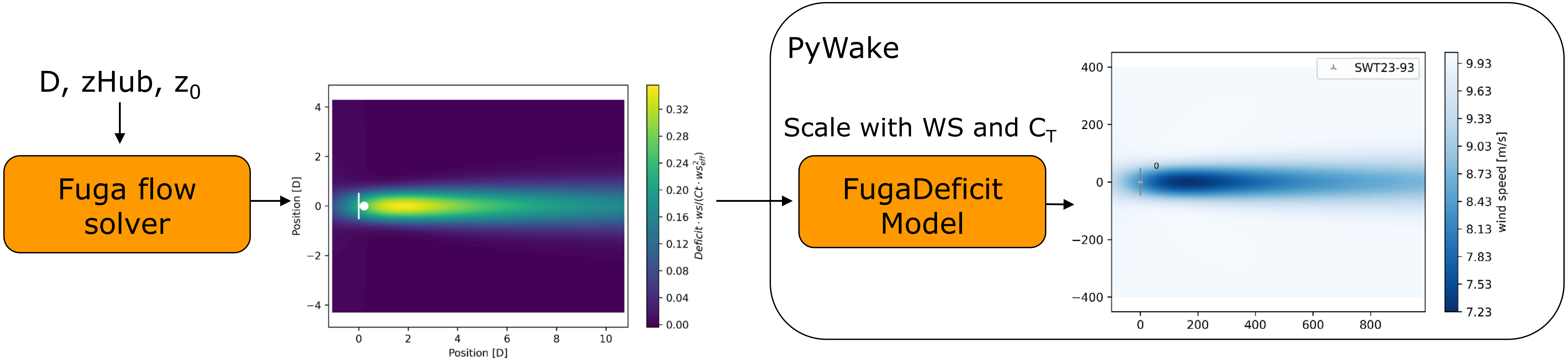


Fuga wake deficit model

- Commerical flow solver developed by DTU Wind Energy (wasp.dk/fuga)
- Linearized CFD RANS solver
- Mixed spectral domain and look-up tables
- Very fast compared to traditional RANS solvers



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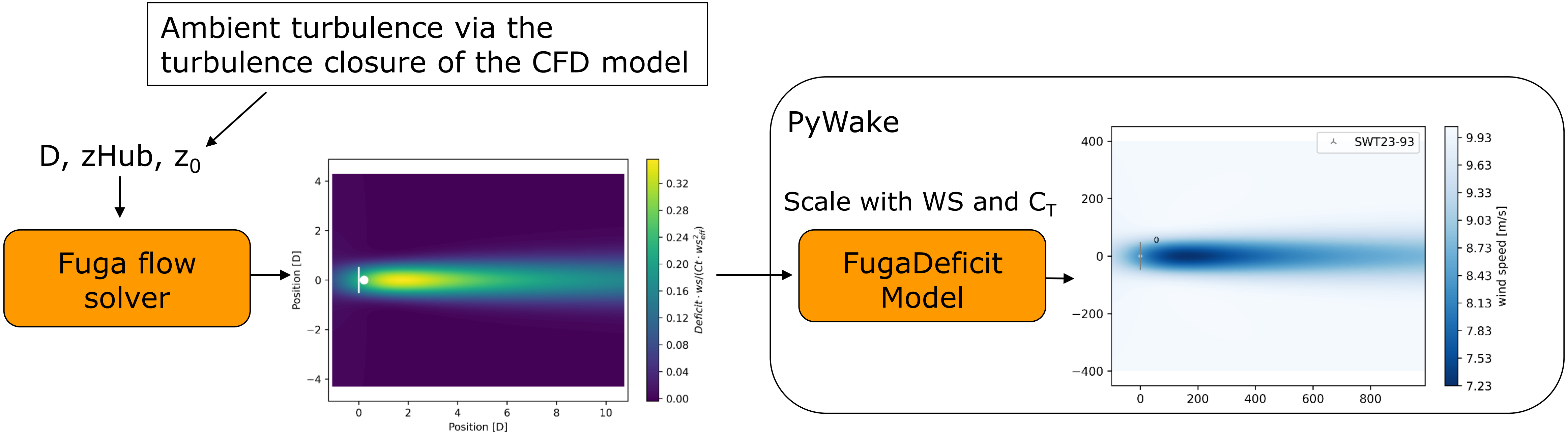
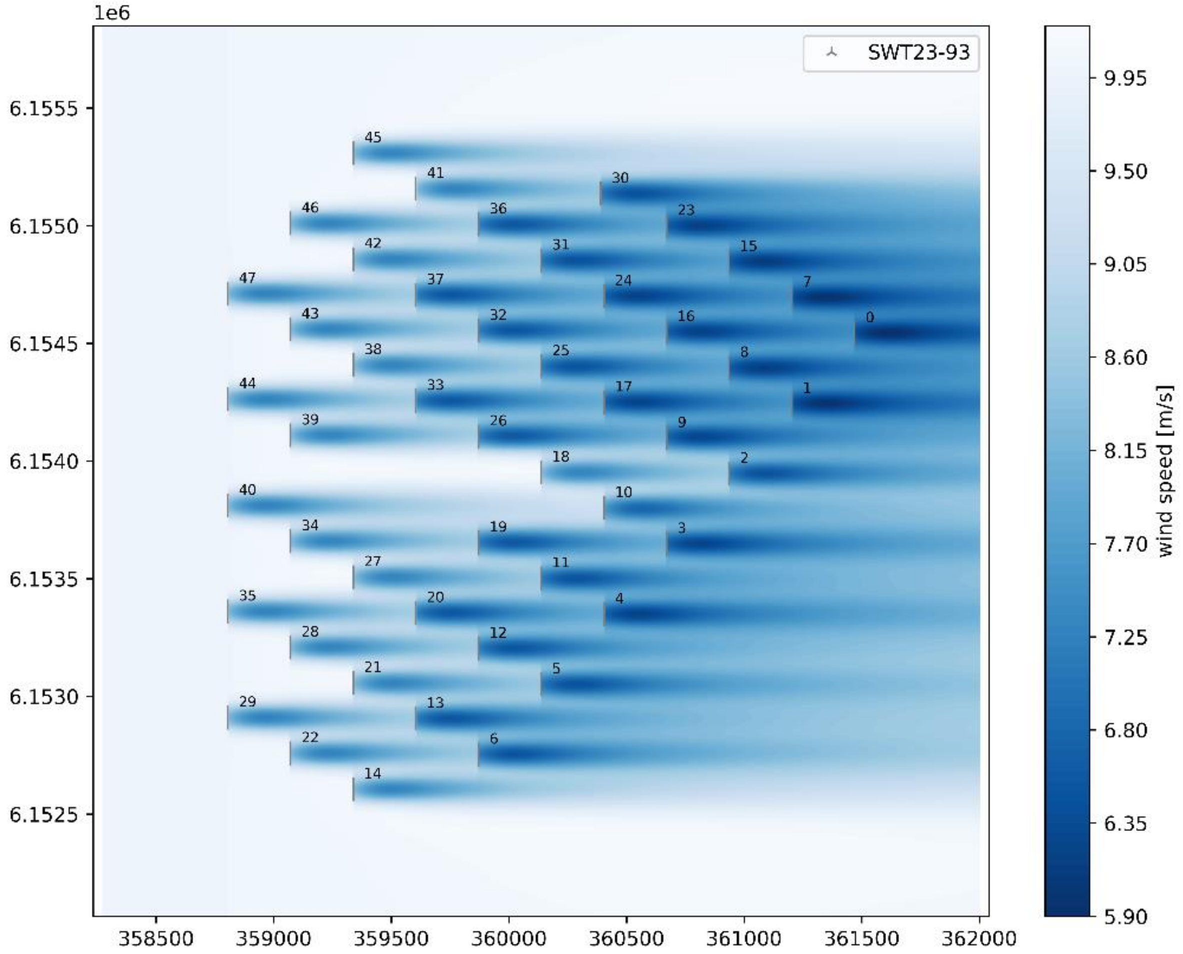


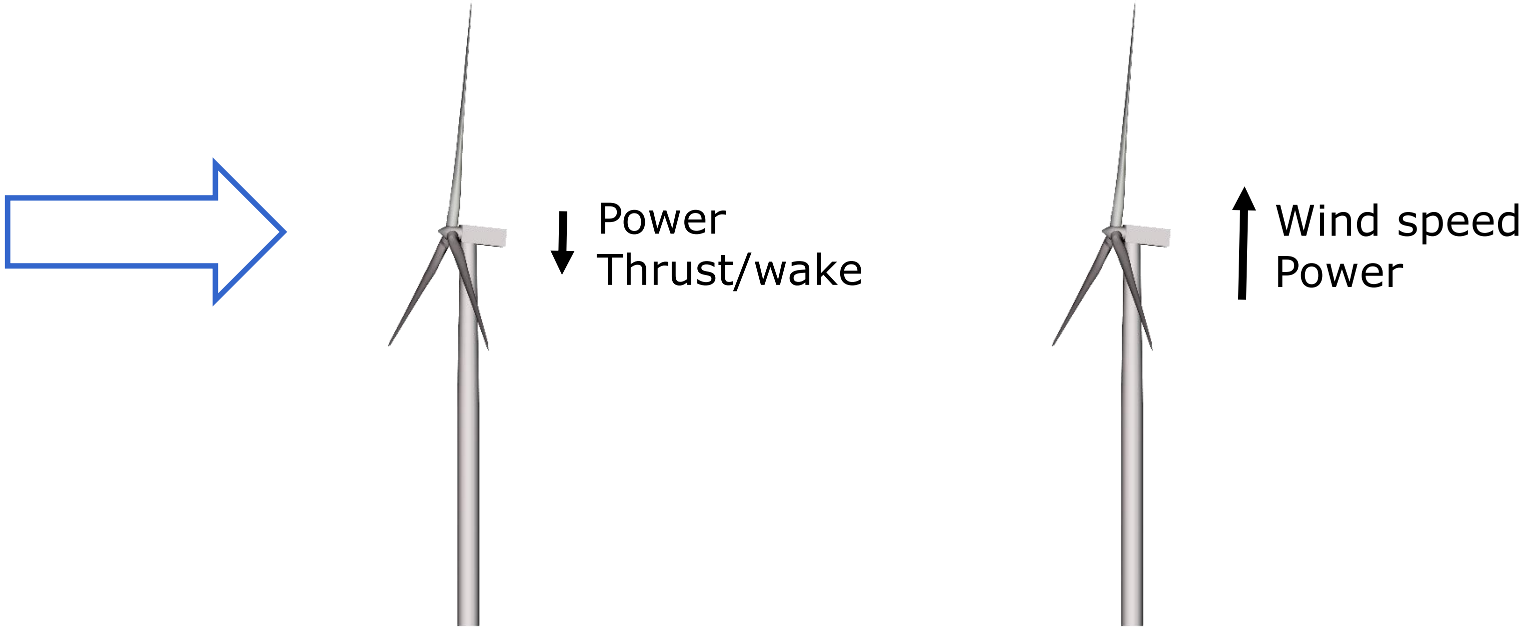
Fuga wake deficit model

- Linear model > consistent superposition of single wakes
- Same turbulence (dictated by z0) everywhere in the wind farm
- Wind direction and ambient wind speed known and constant over the wind farm area



Active wake control - derating

- Derating
  - Derate upstream turbines
  - Increase total wind farm power
  - Power(Cp) and thrust(Ct) function of
    - Wind speed
    - Rotor speed
    - Pitch angle



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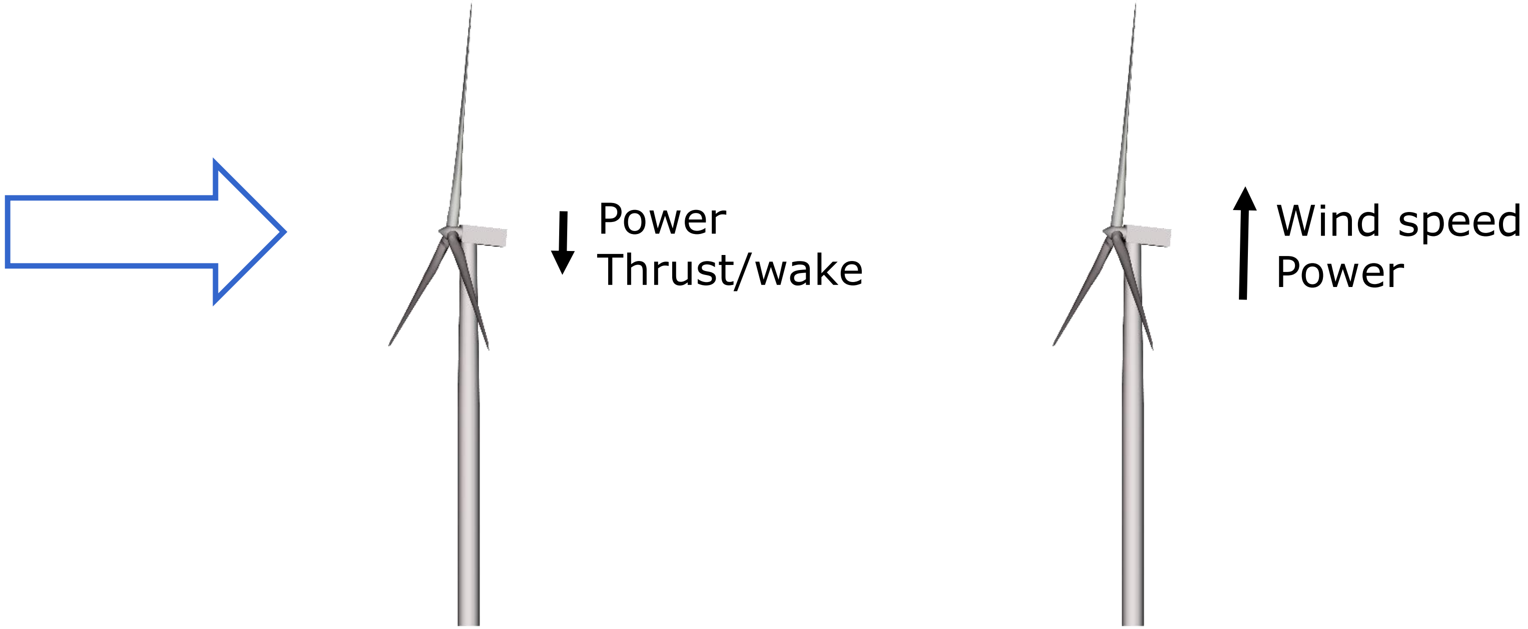
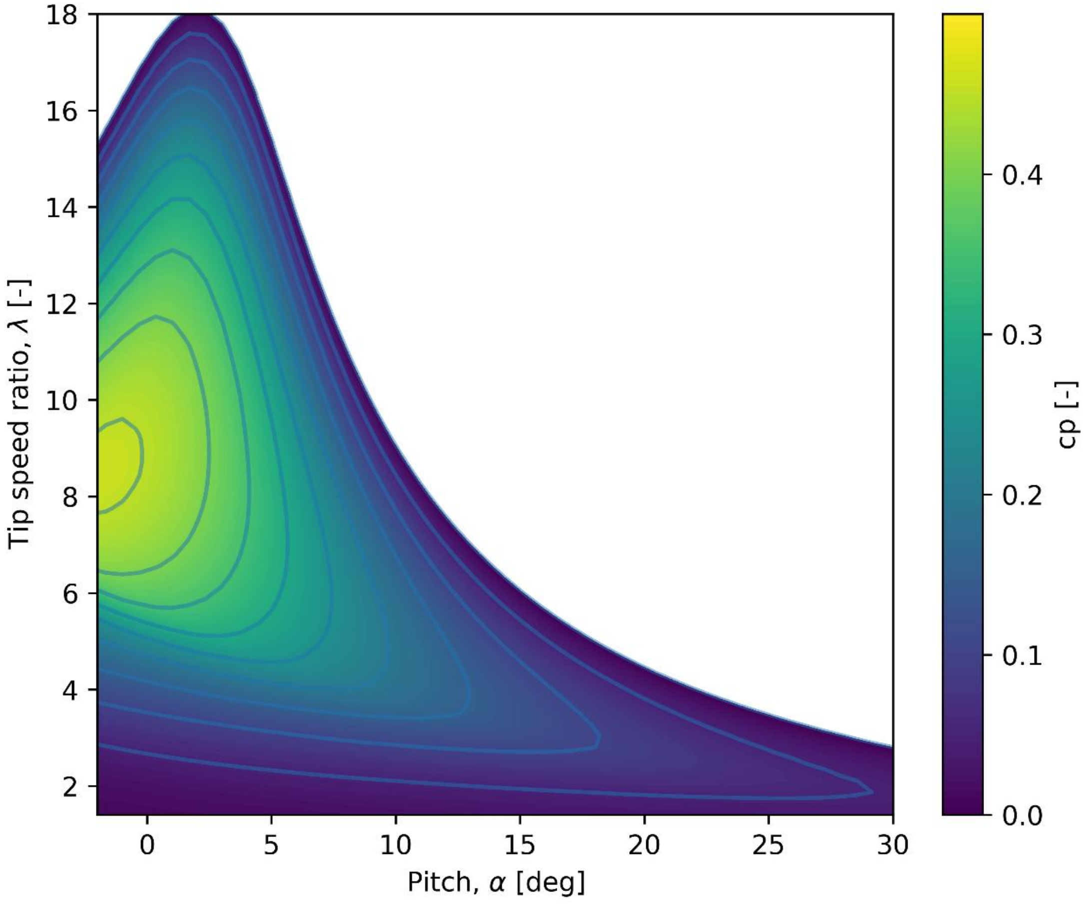
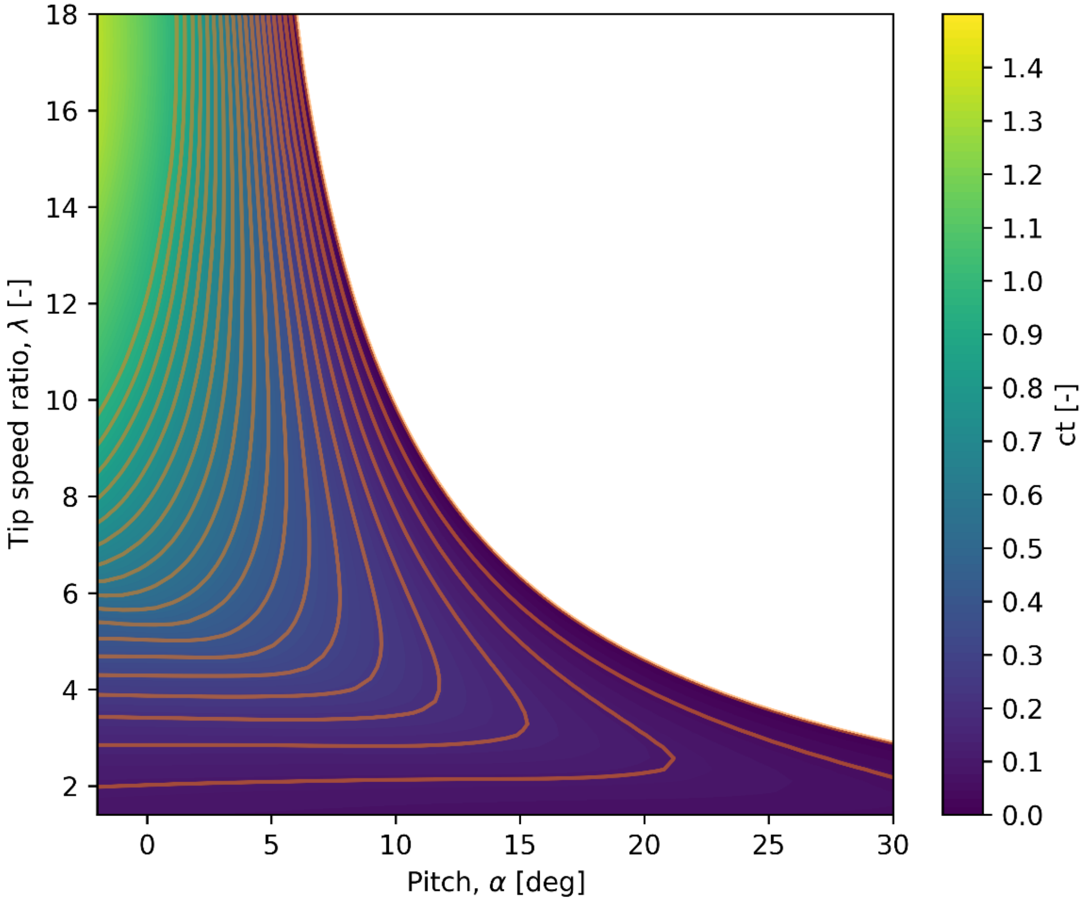
  (Wind speed and Rotor speed: Tip speedratio)



Active wake control - derating

- Power and thrust coefficients for range of rotor speeds, pitch and yaw angles
- Calculated using HAWC2Aero (HAWC2 BEM aerodynamic + stiff structure)





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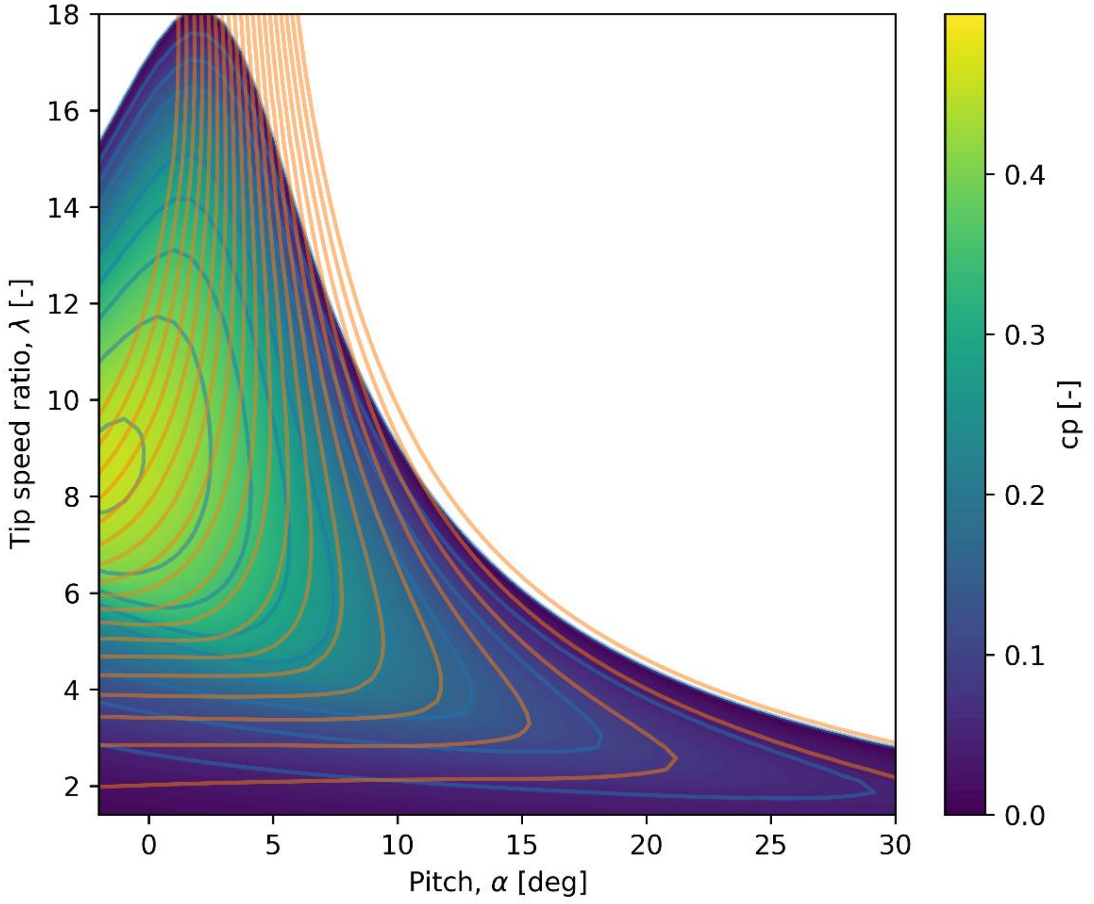
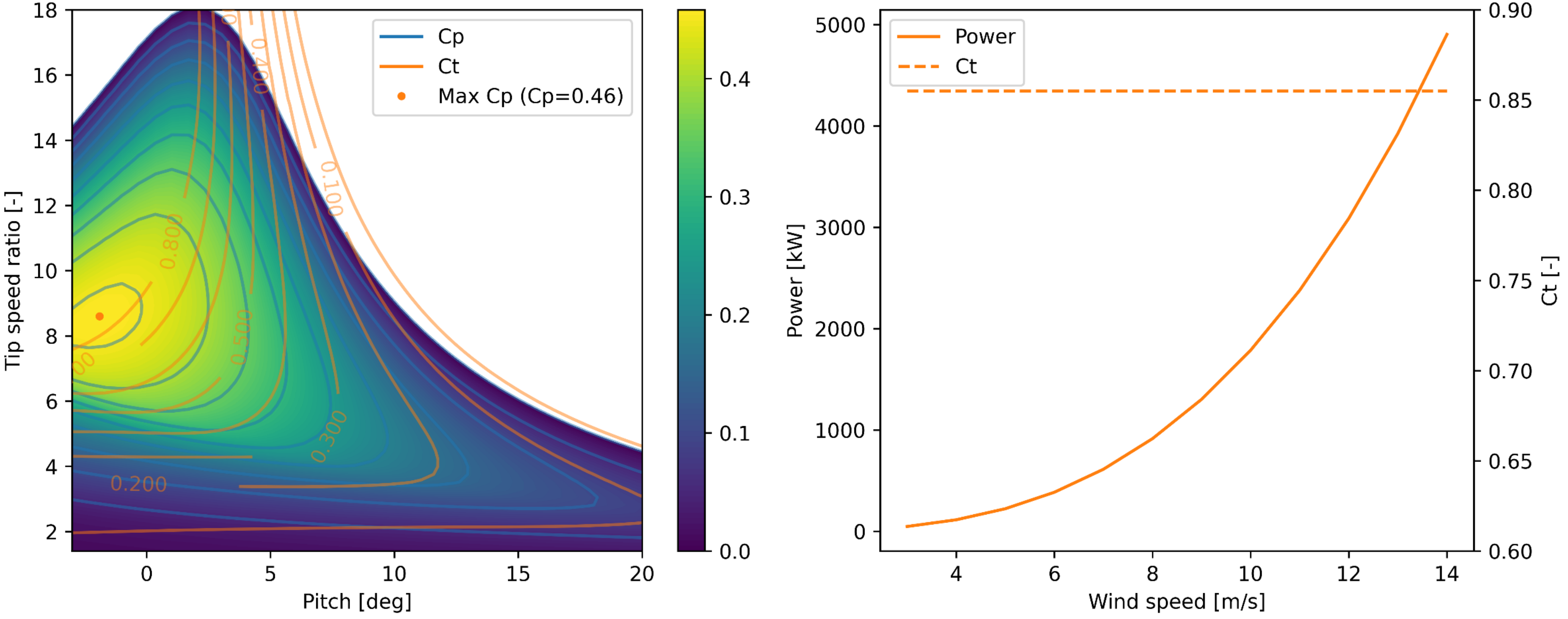


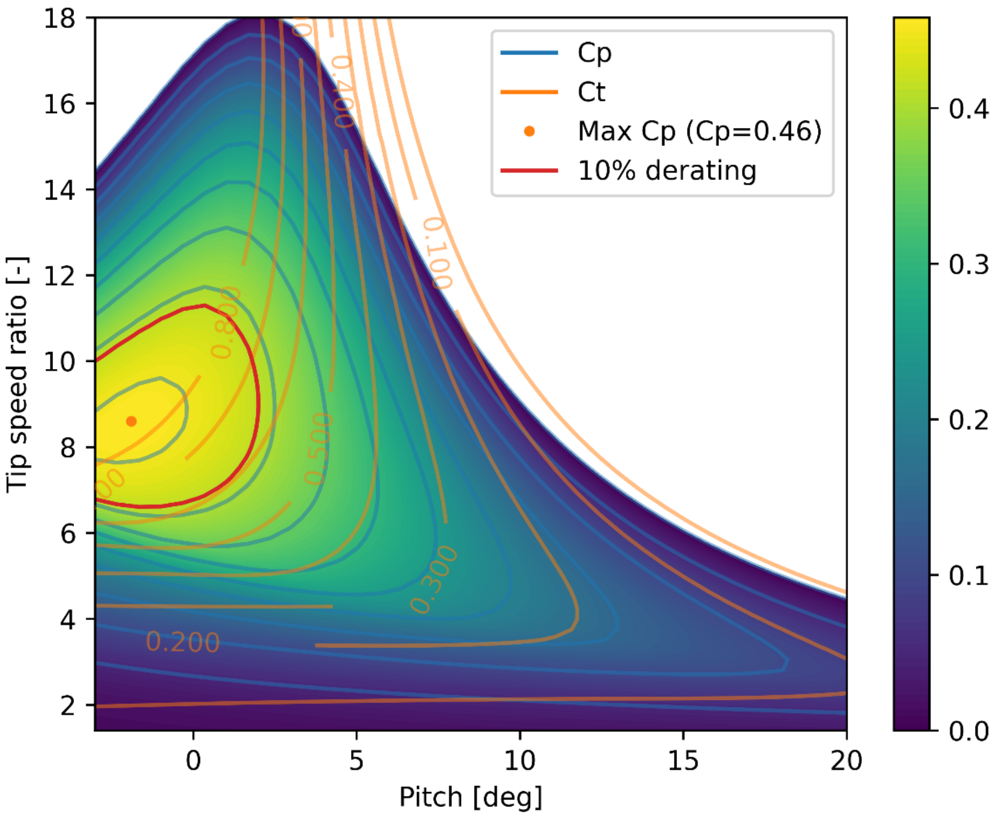
Active wake control - derating

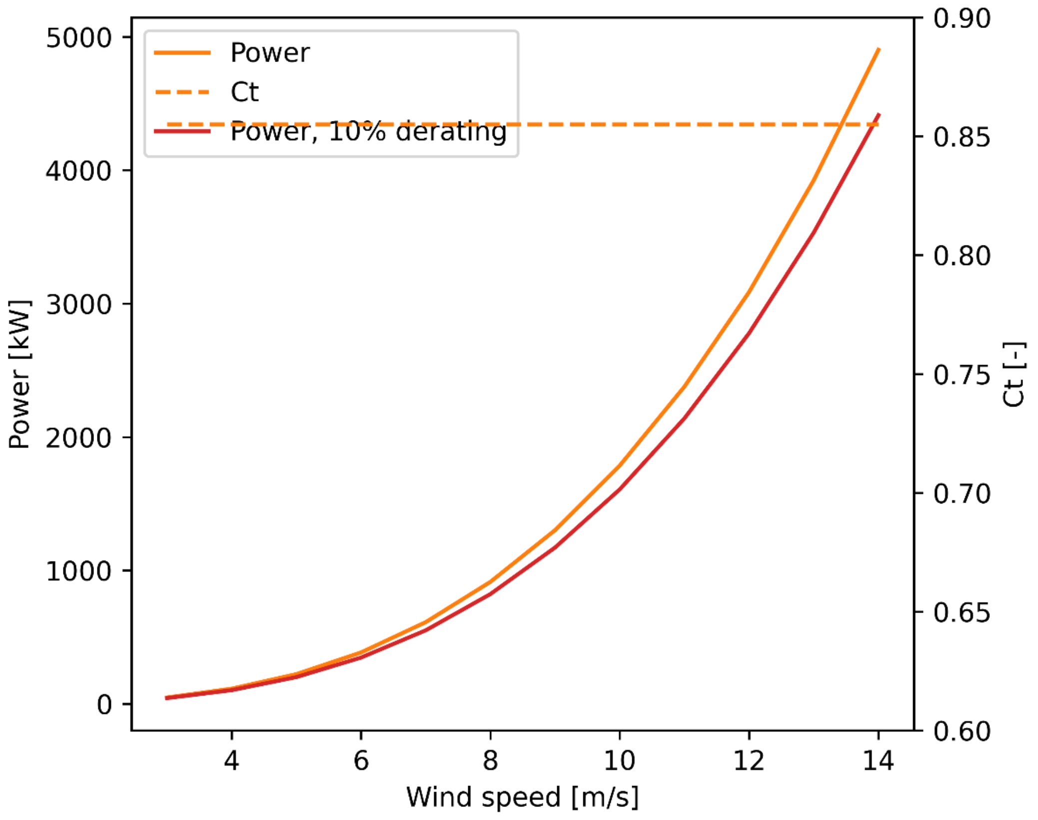
- Greedy operation
- Max Cp
- Constant Ct



Active wake control - derating

- 10% derating
- Ct???





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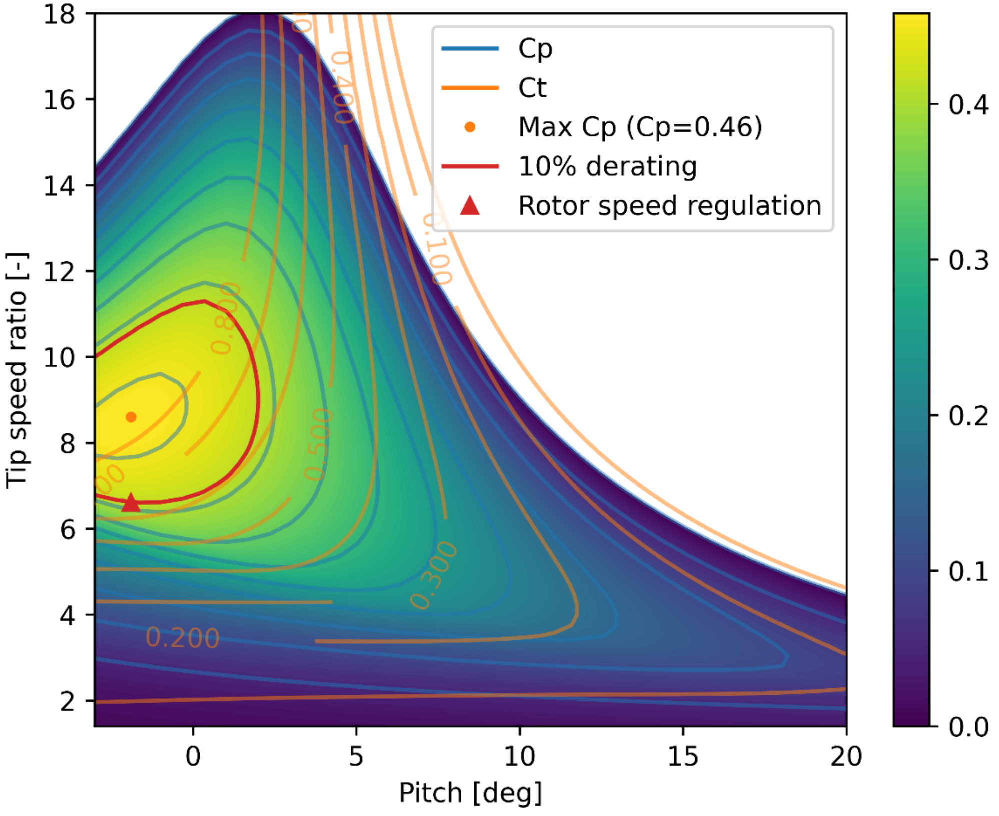

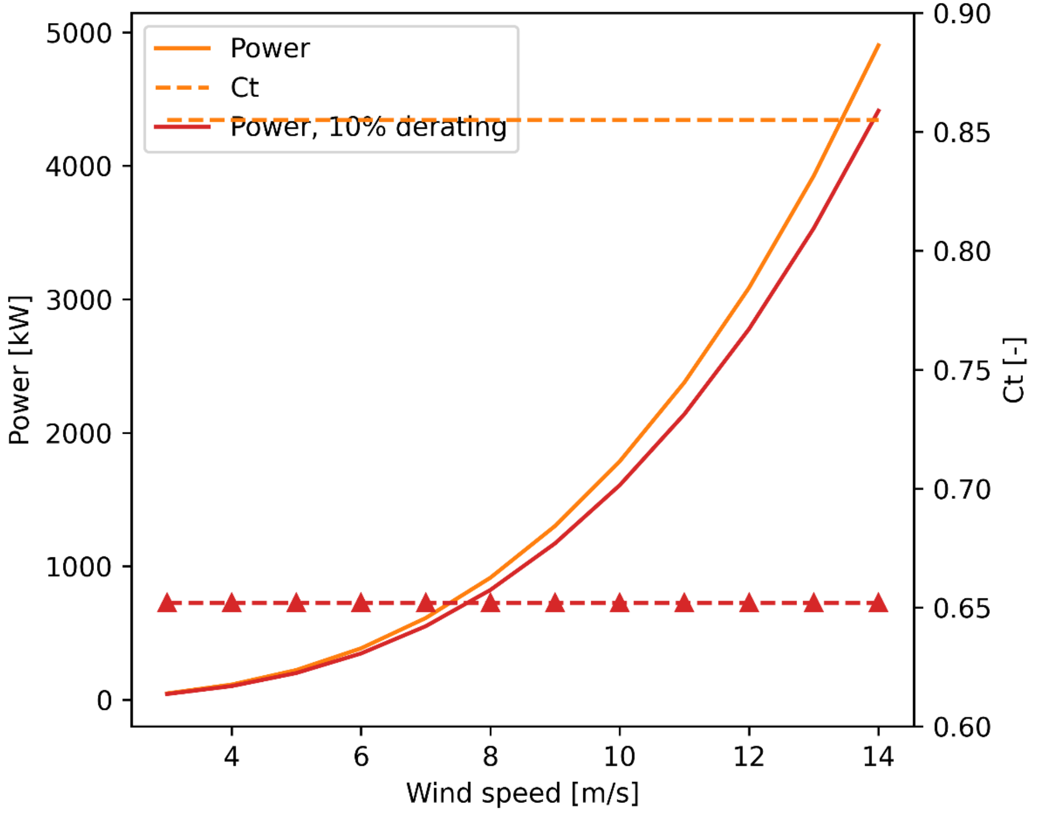

Active wake control - derating

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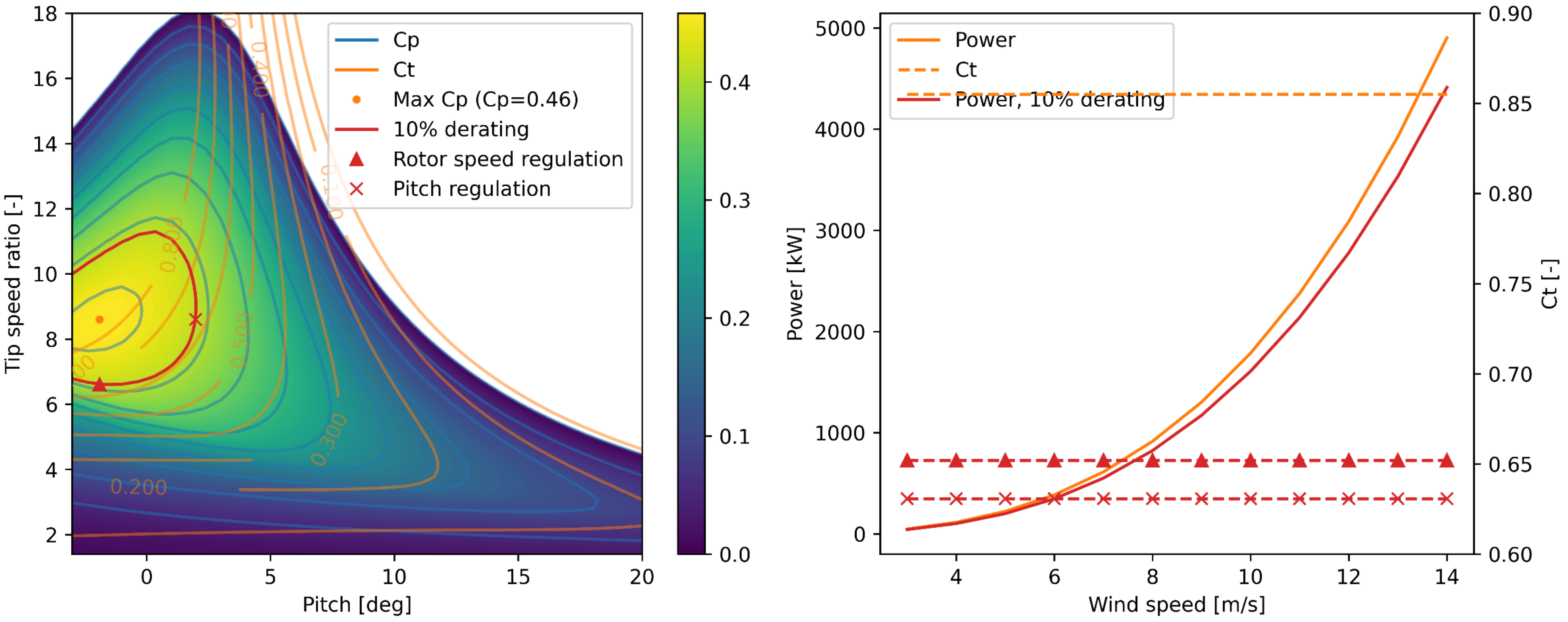
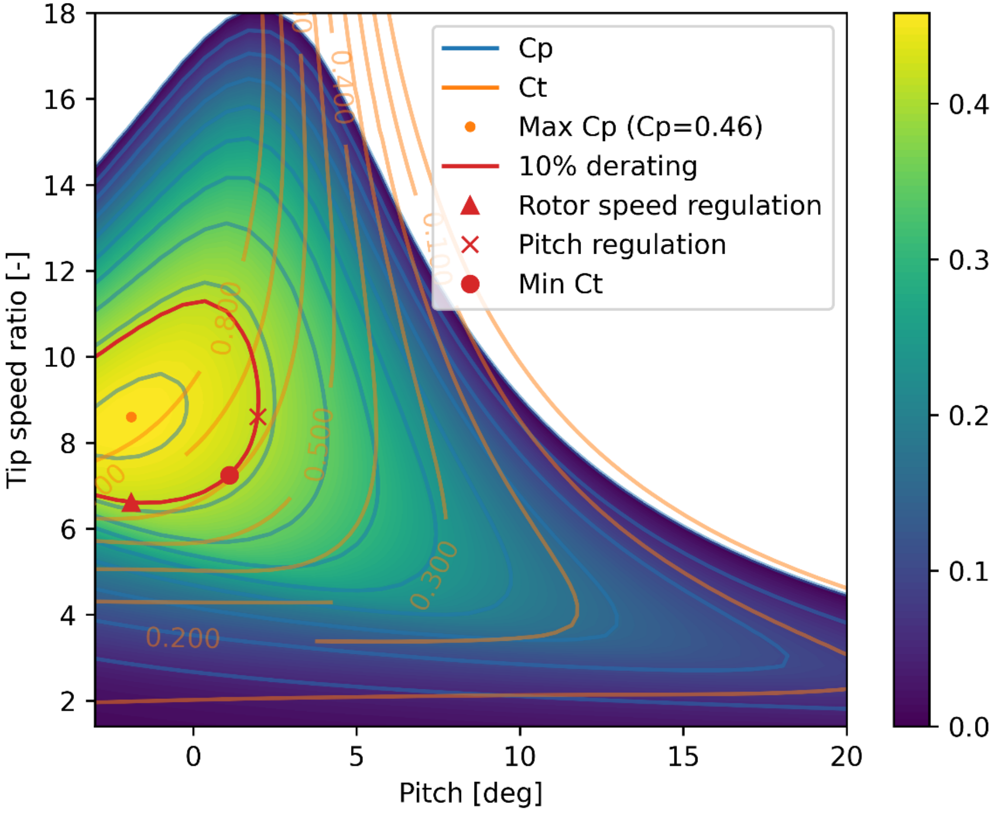
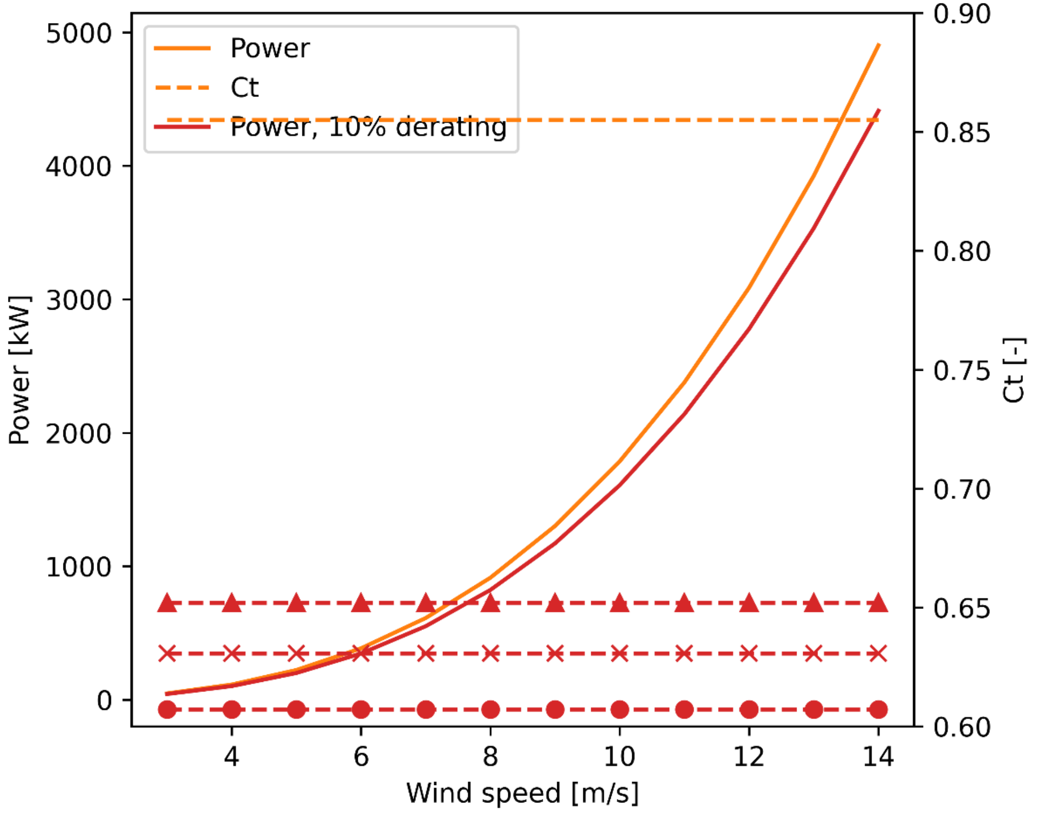


Active wake control - derating

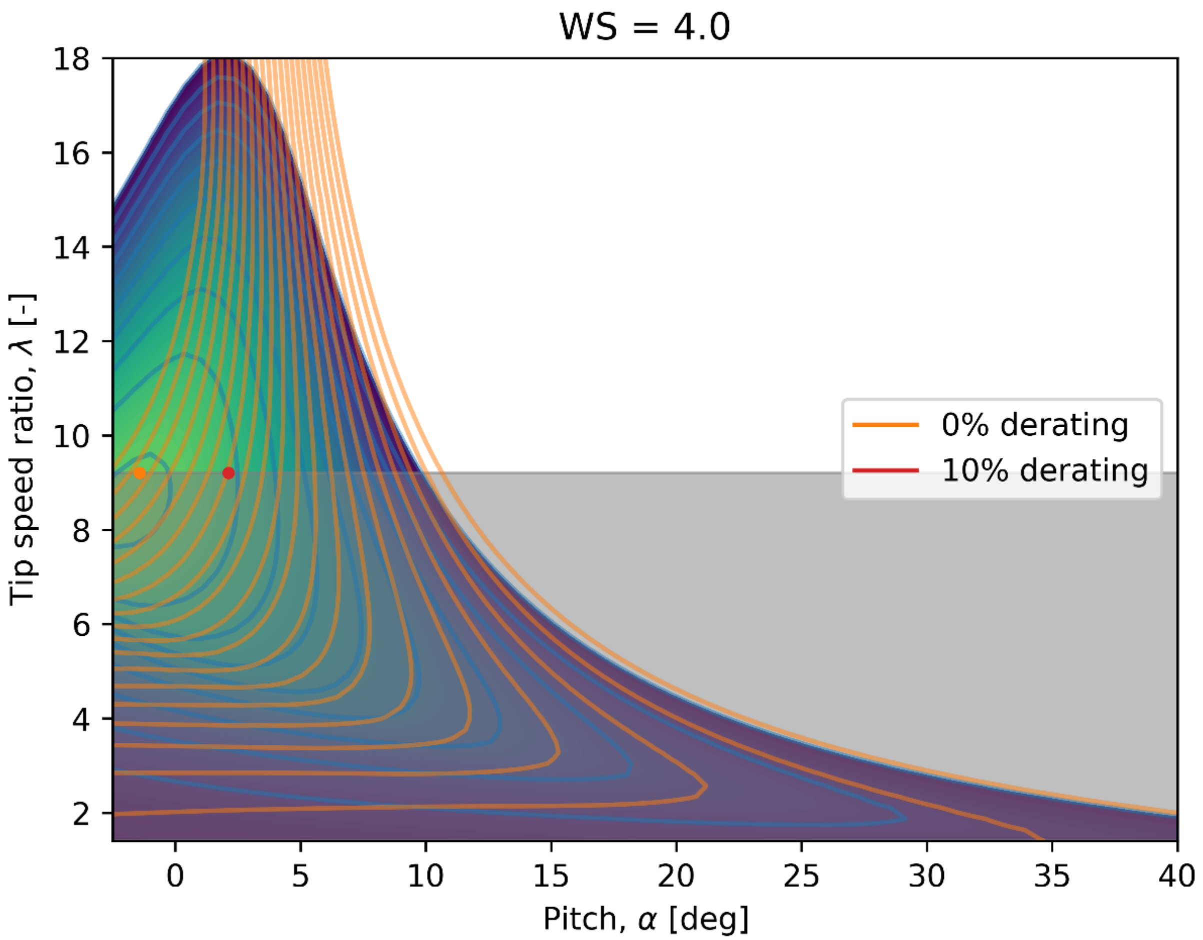
- 10% derating
- Minimum Ct

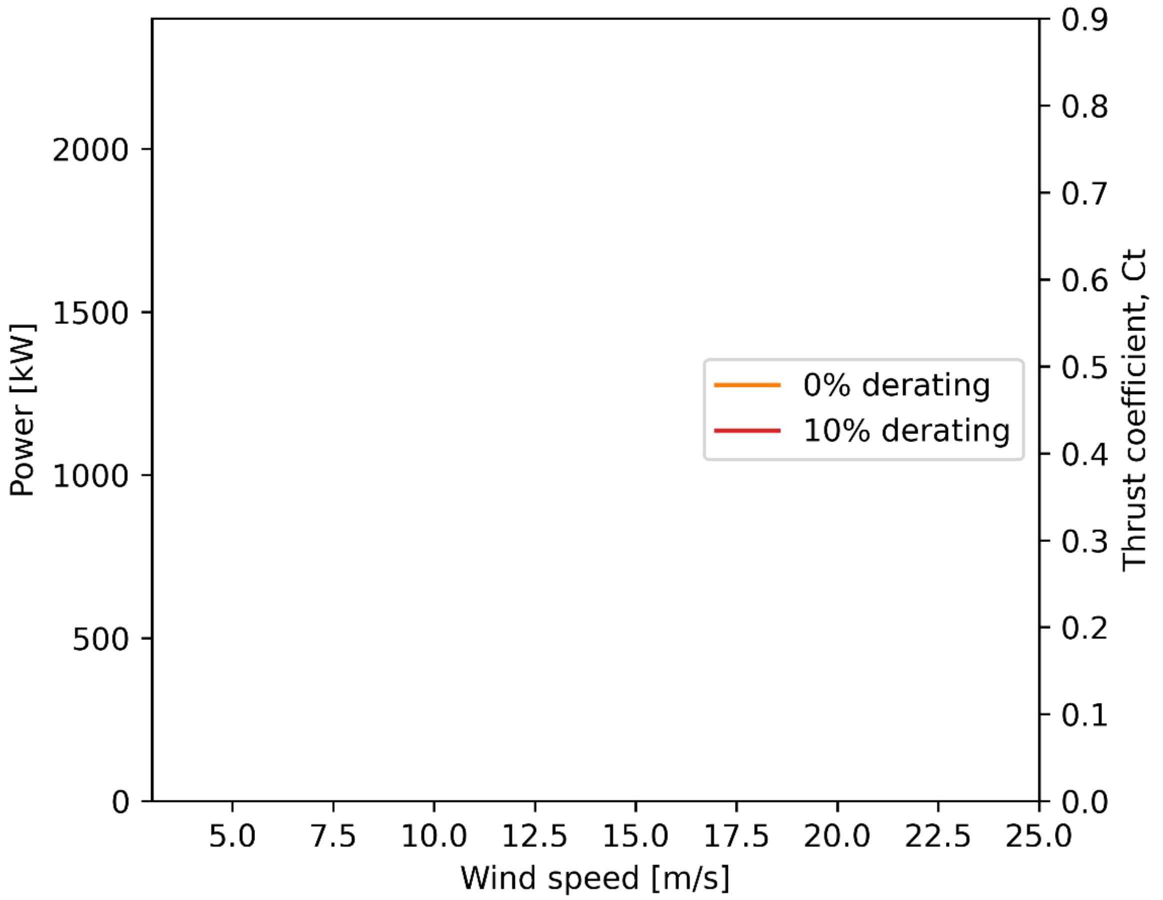




Active wake control - derating

- Rotor speed limits
- Max power limit





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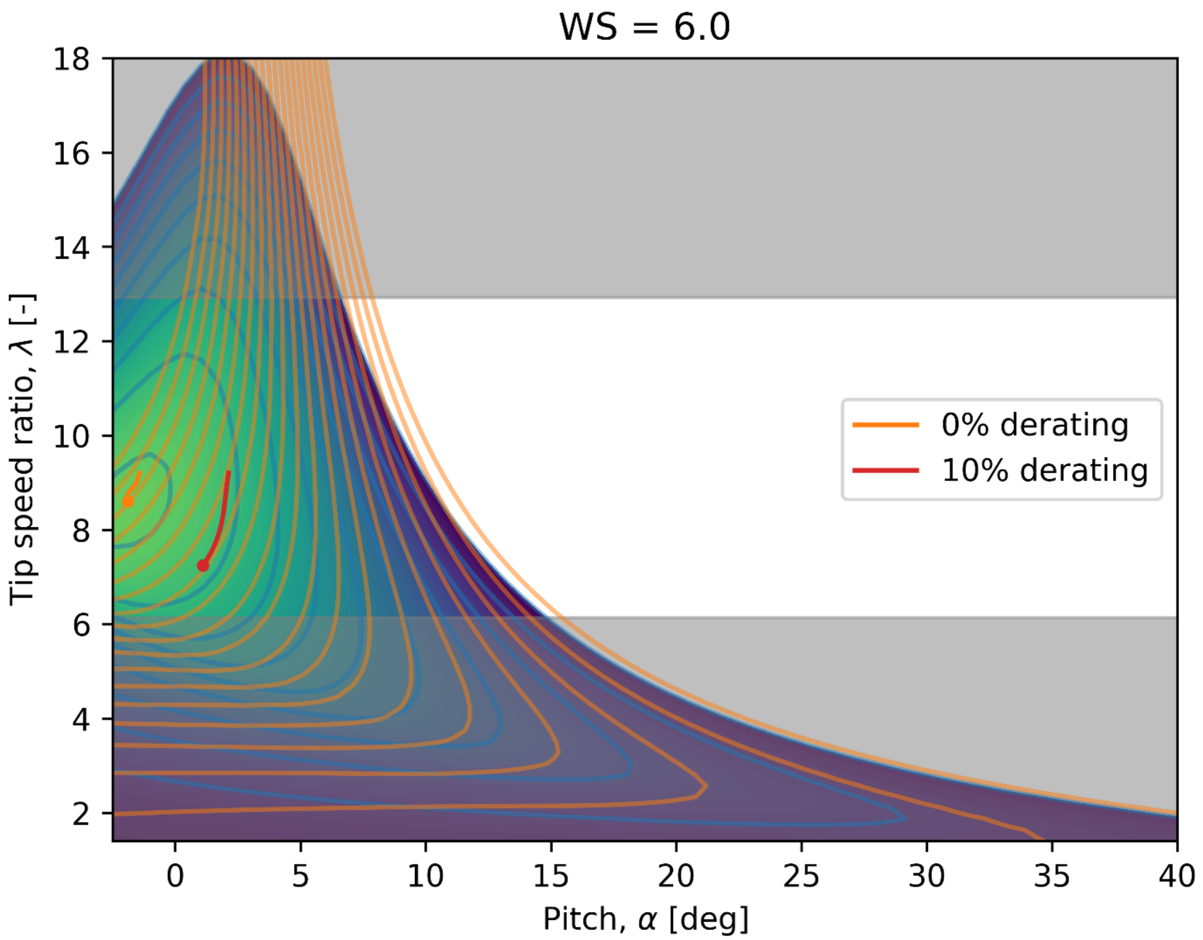

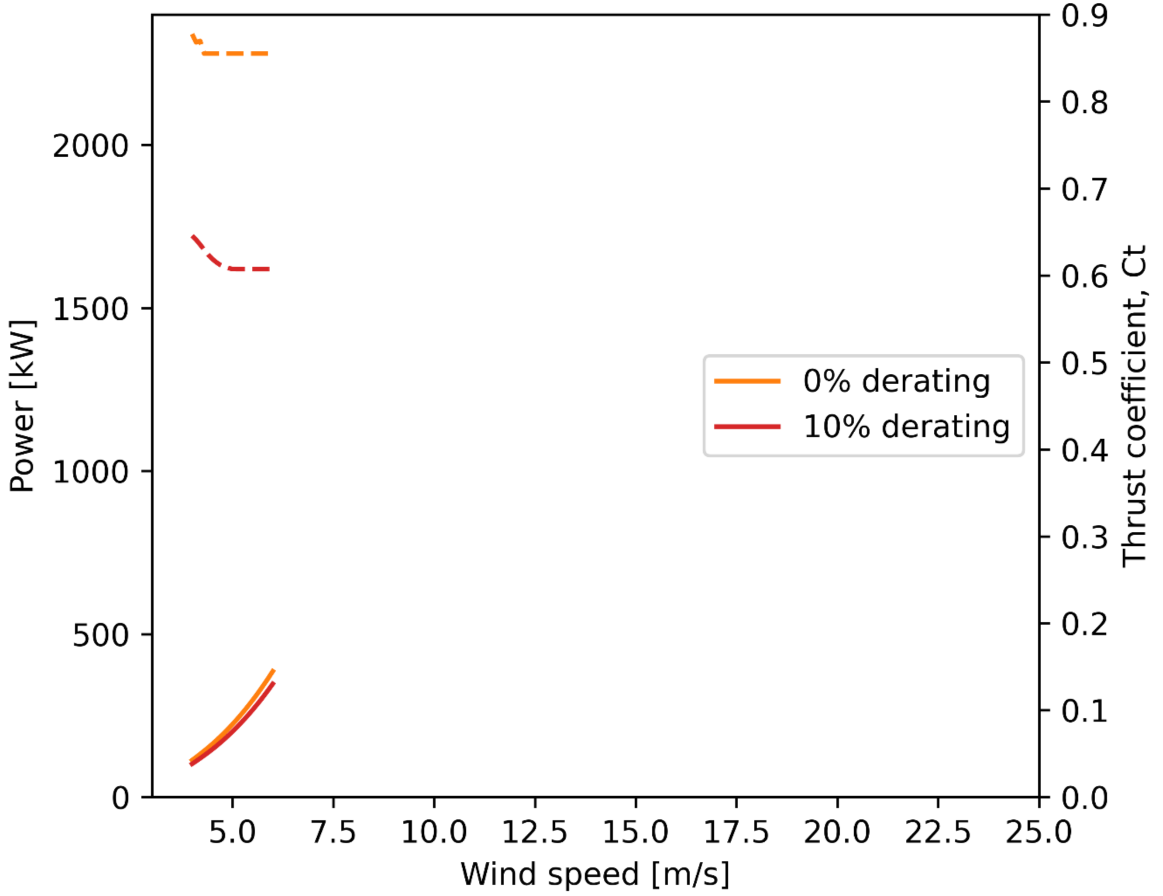

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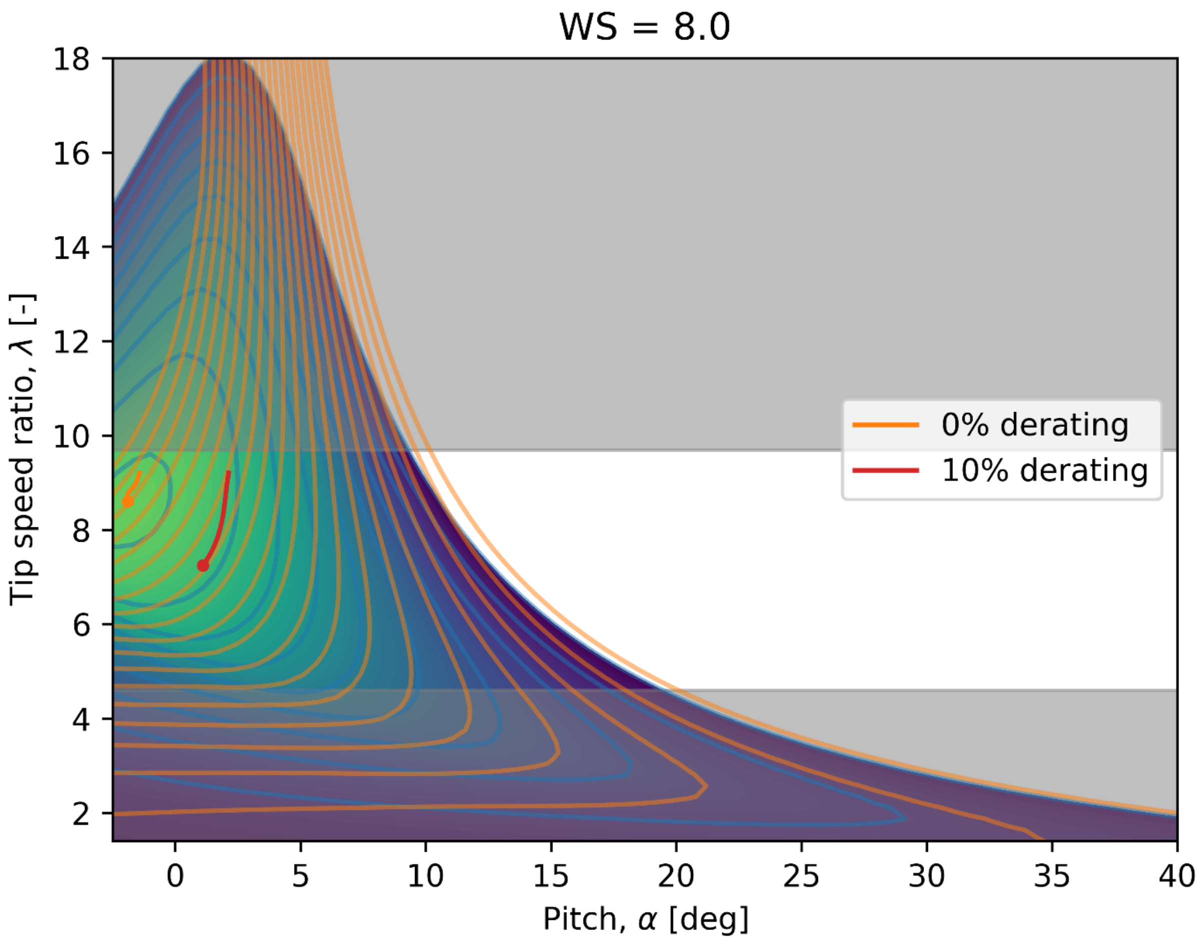

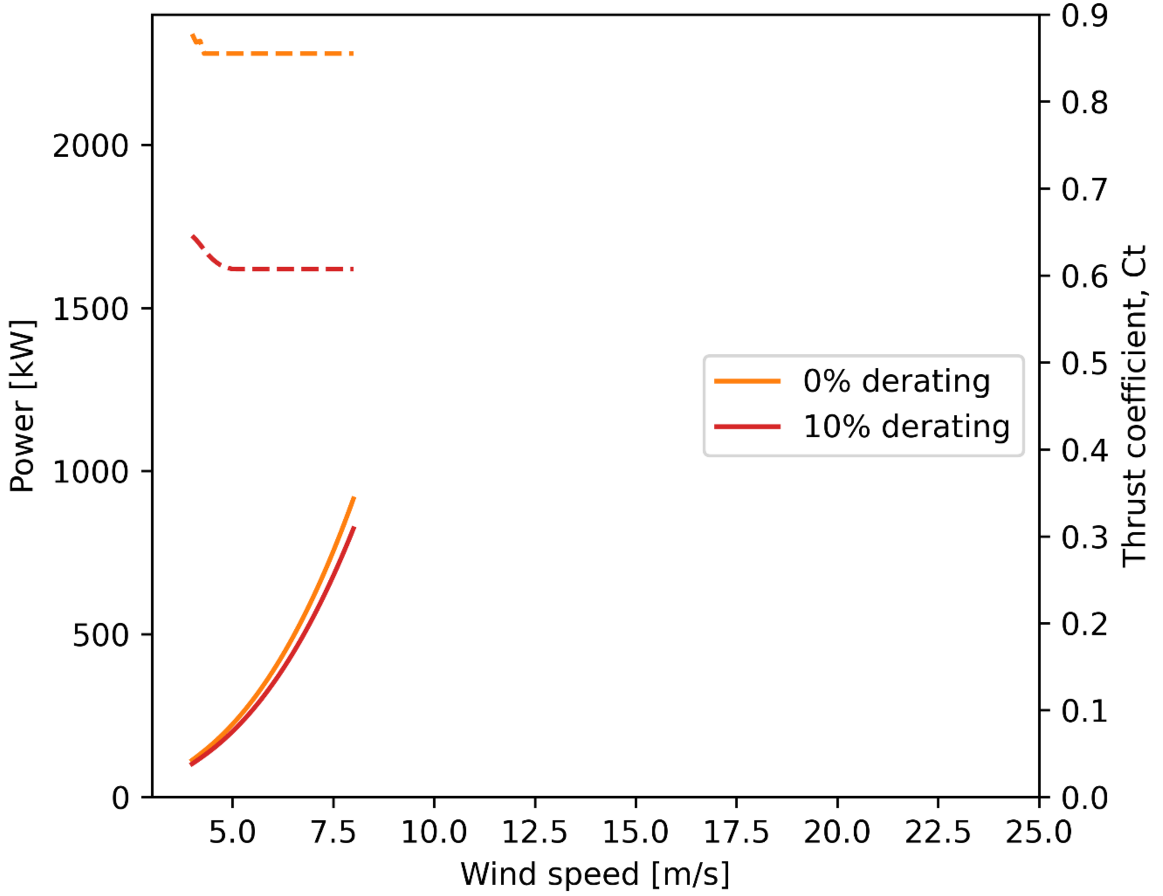

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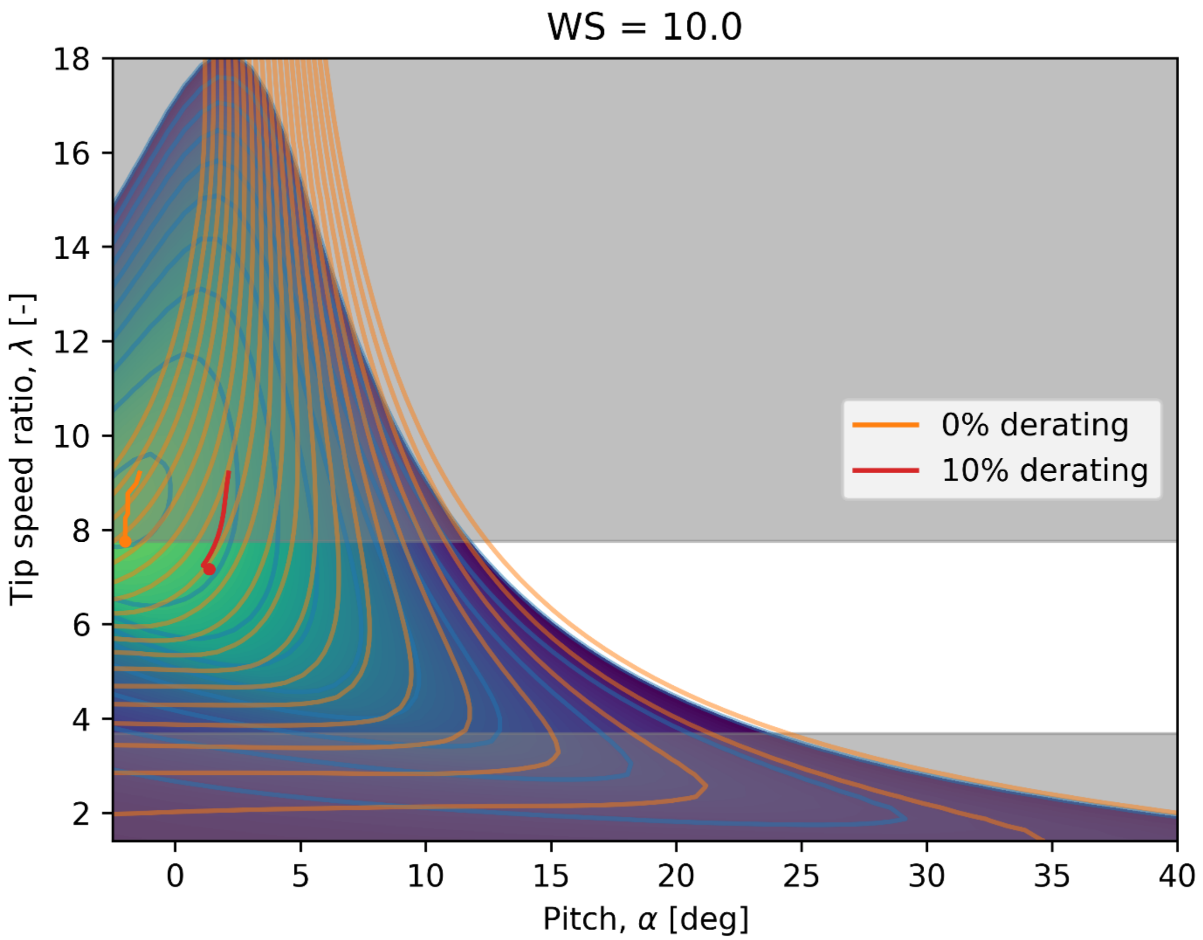

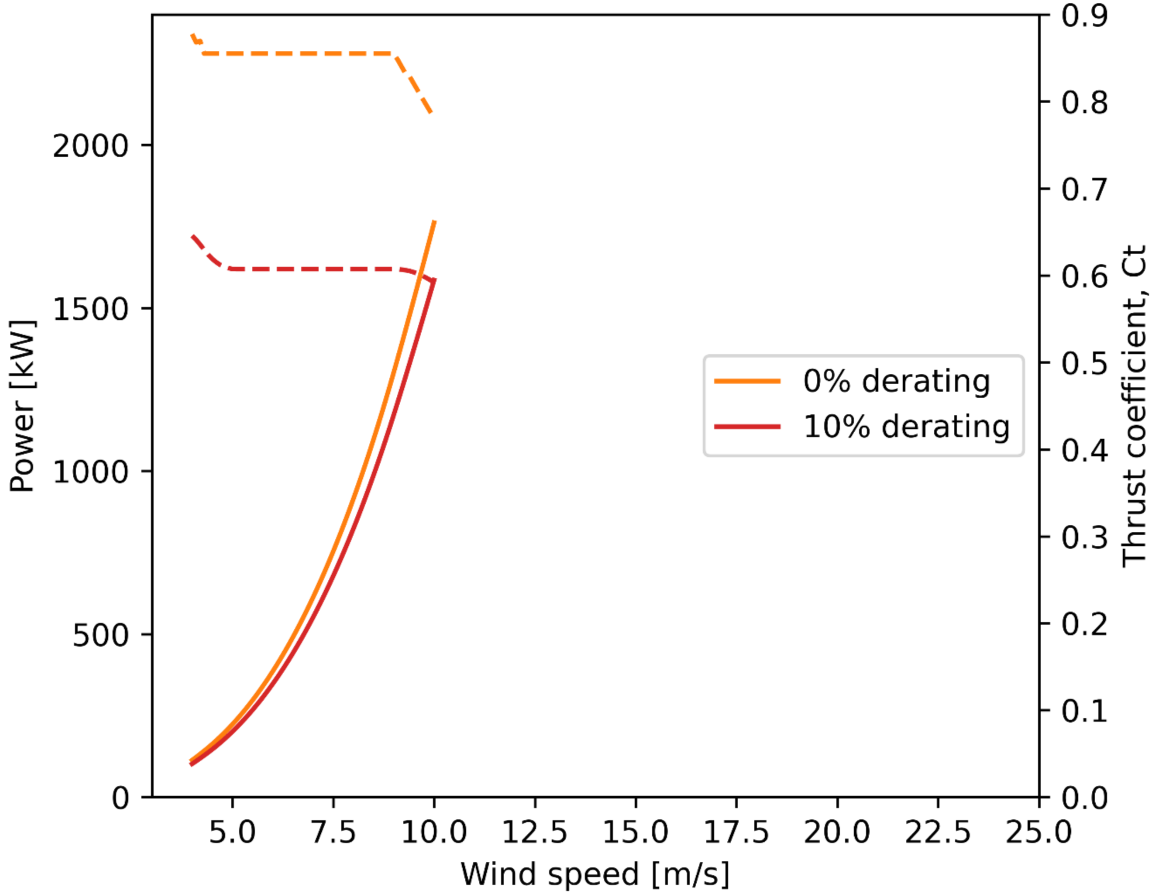

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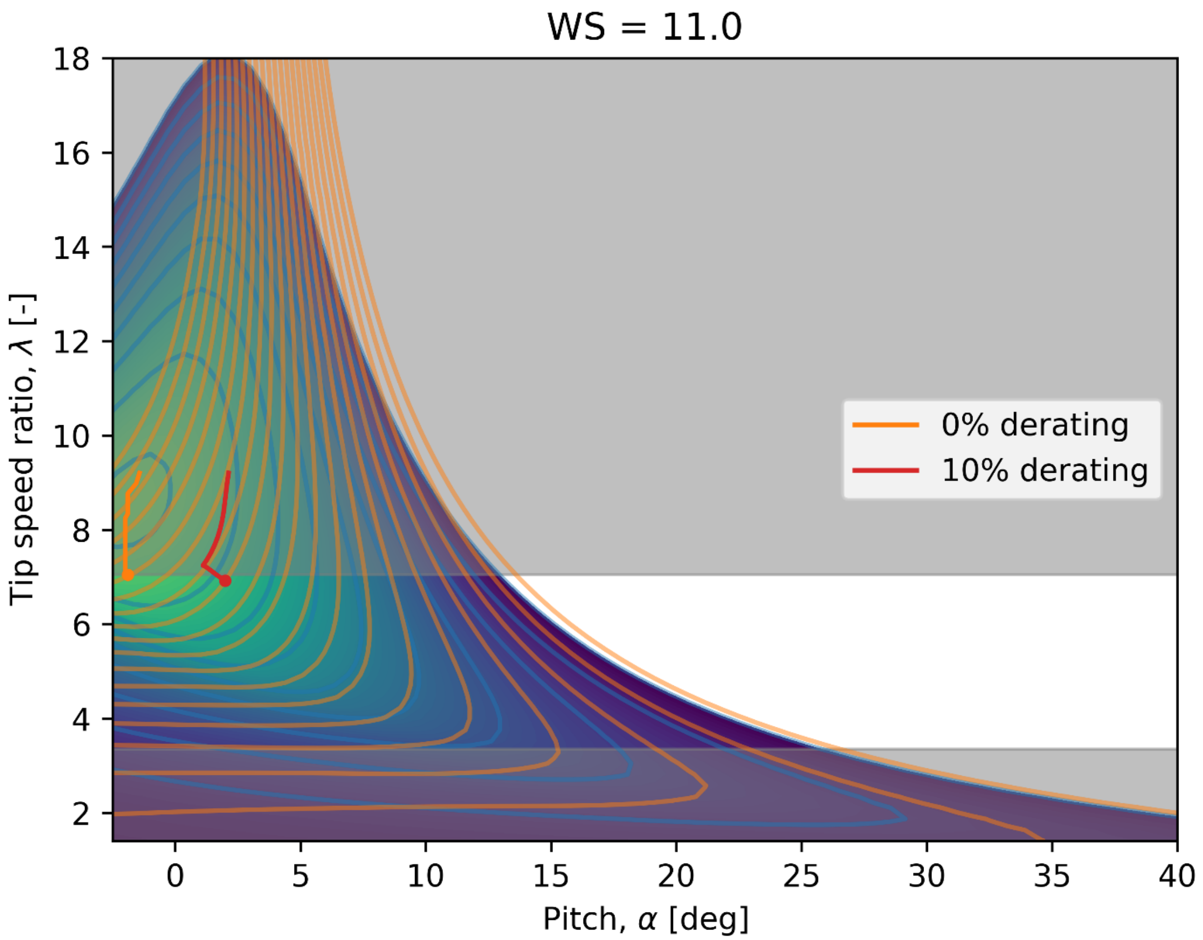

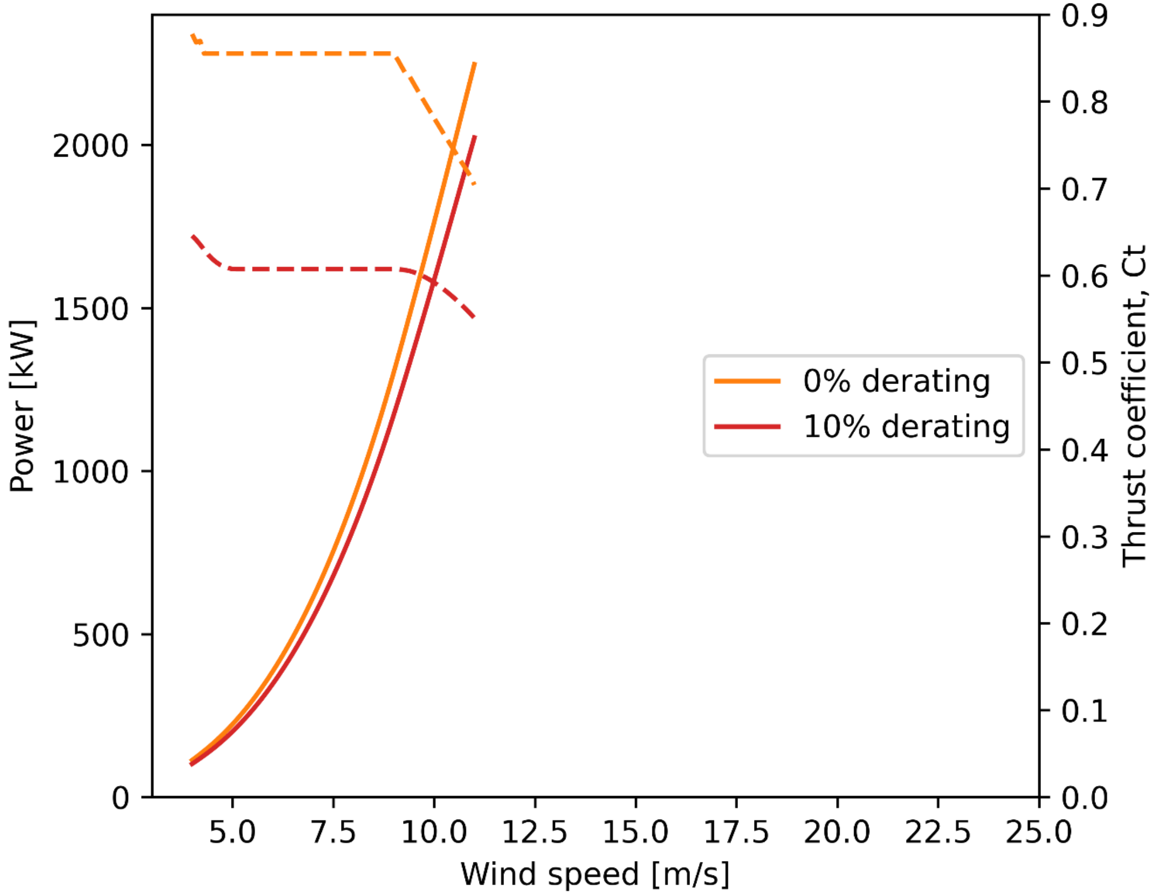

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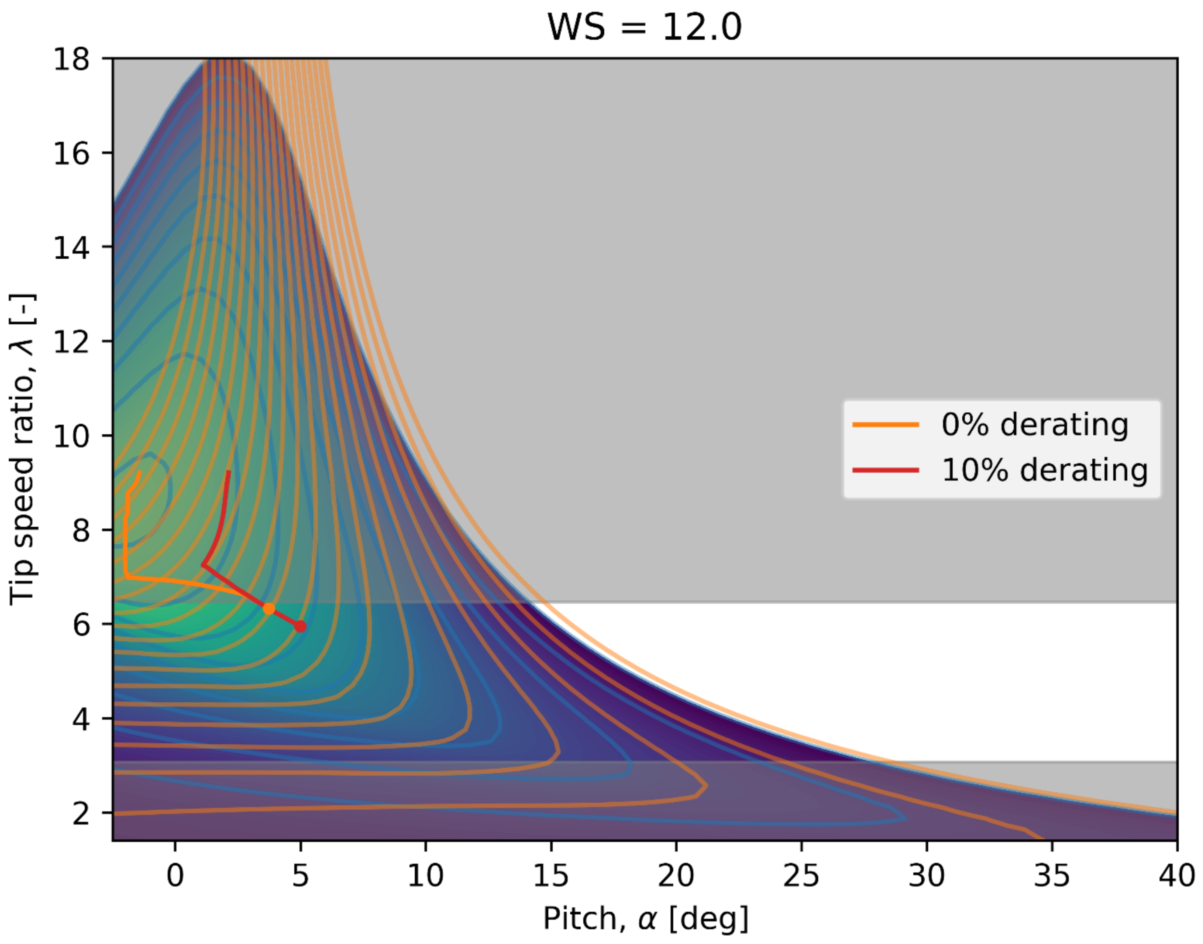

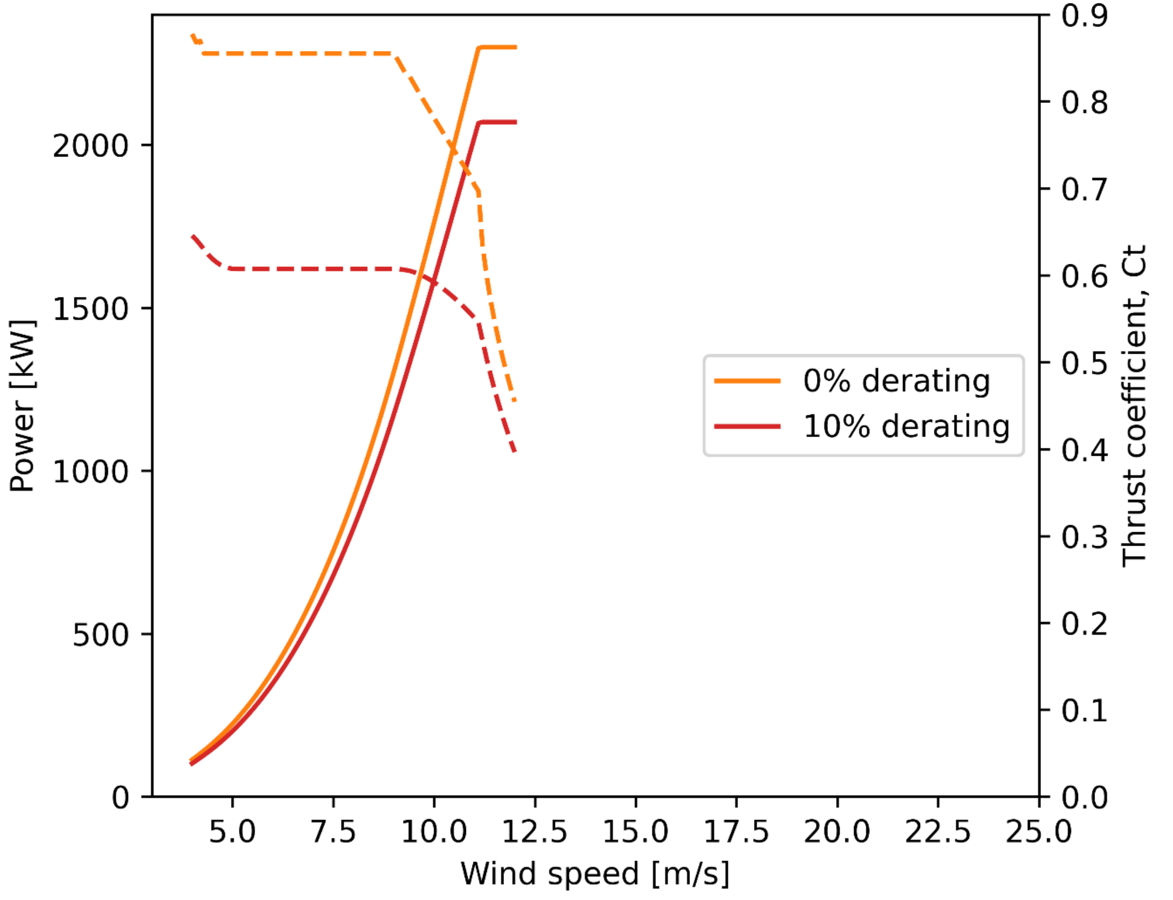

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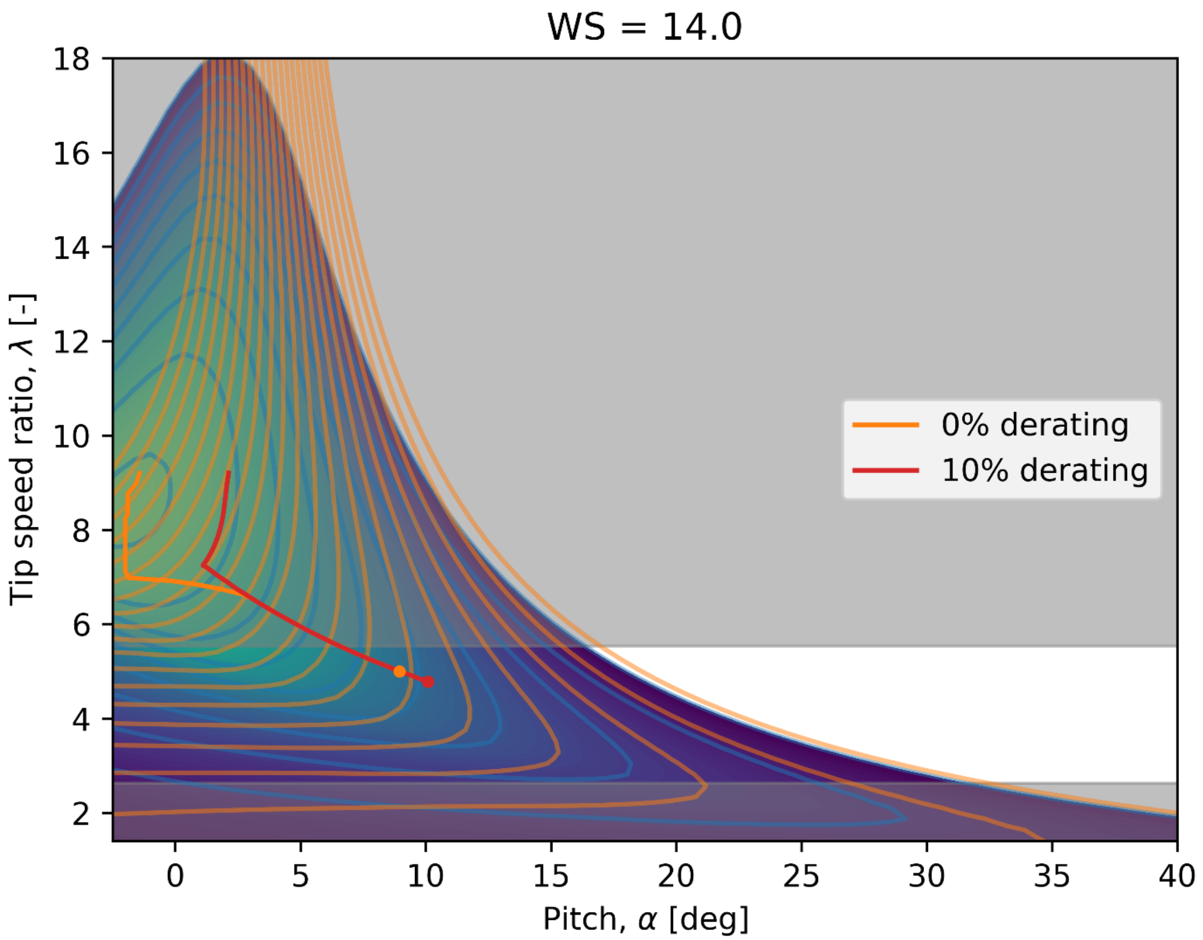

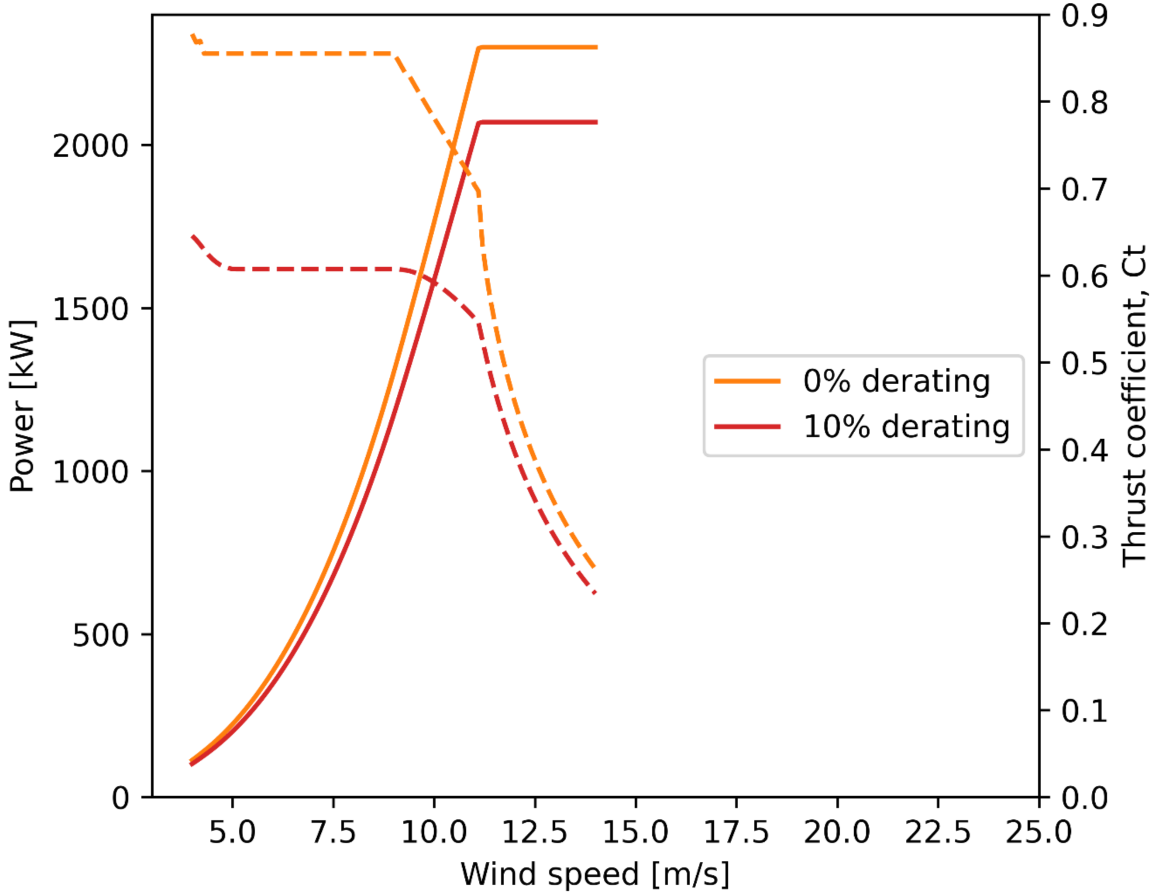

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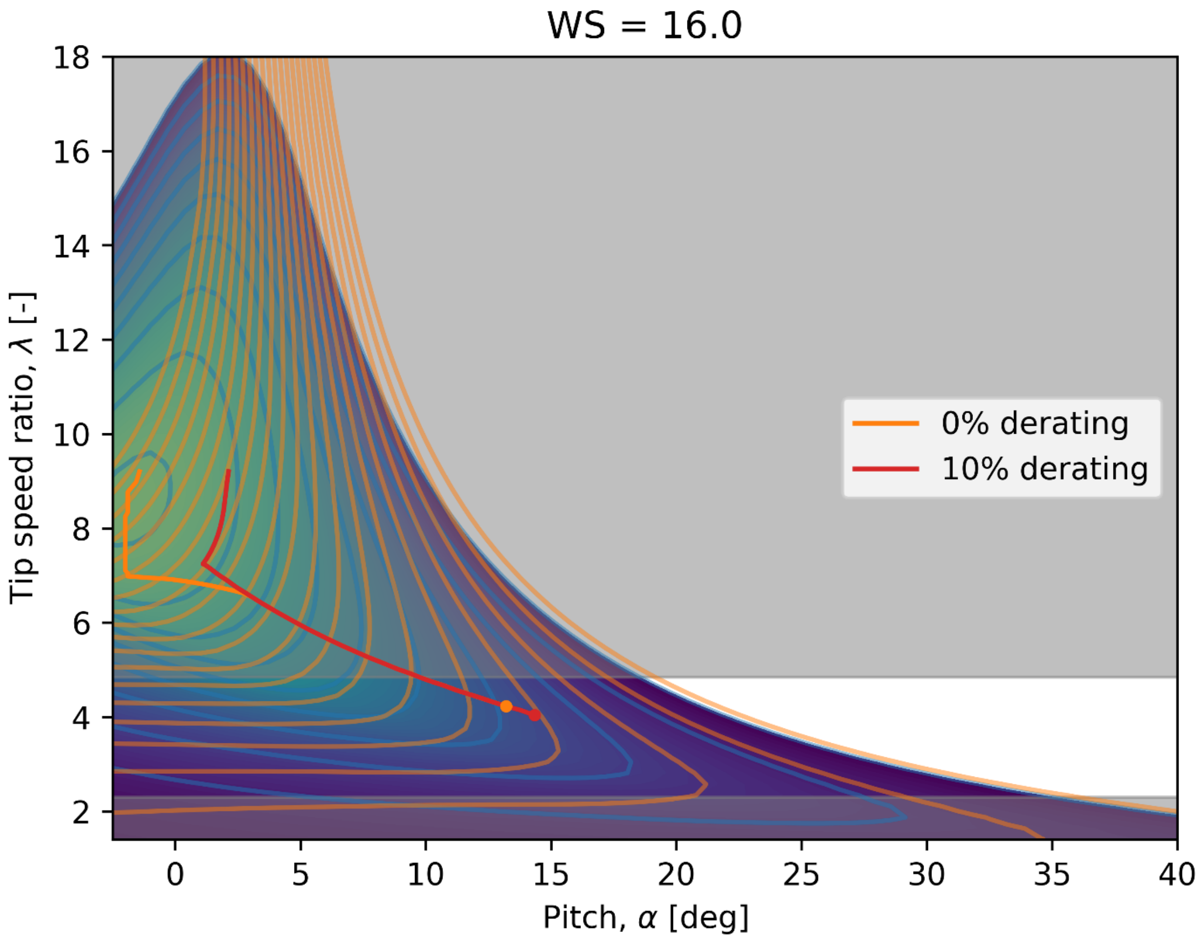
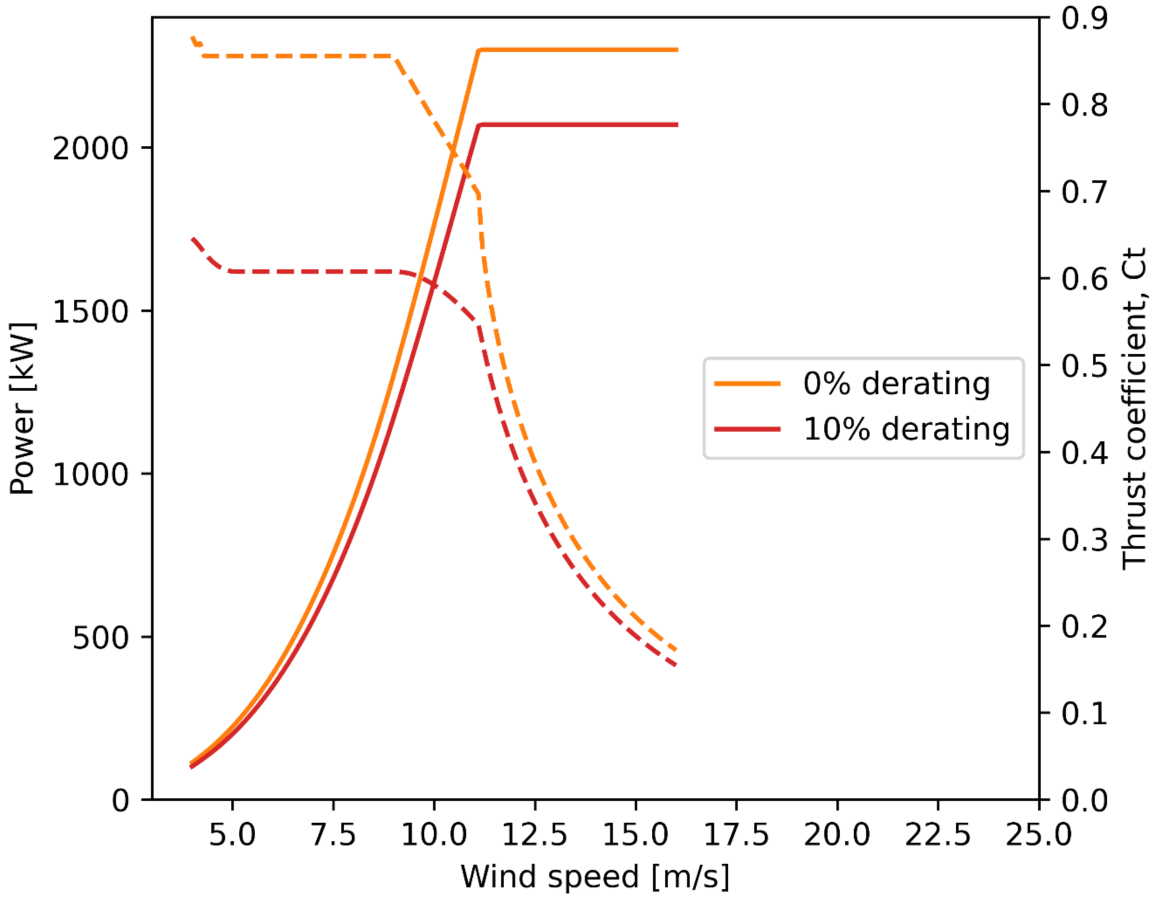
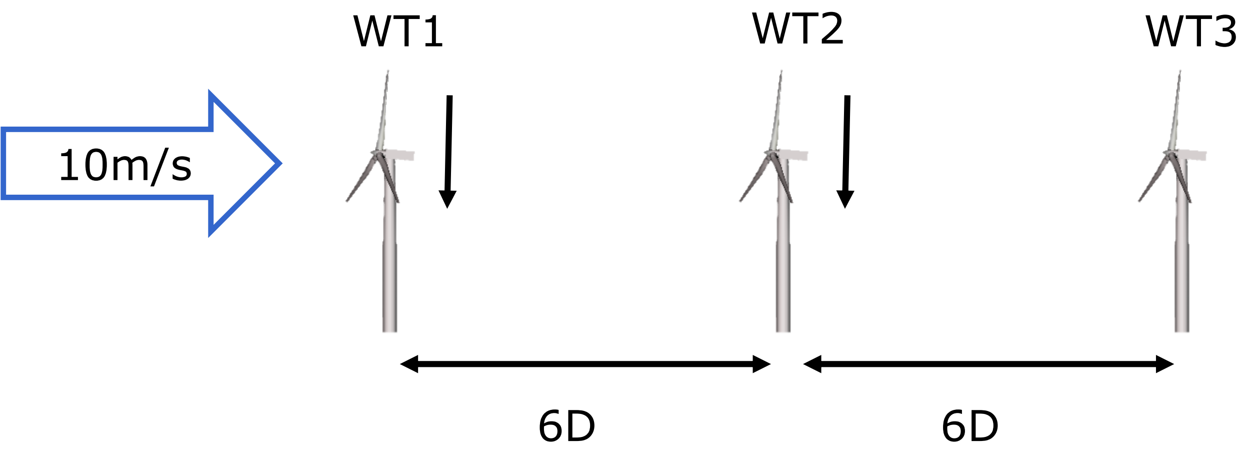
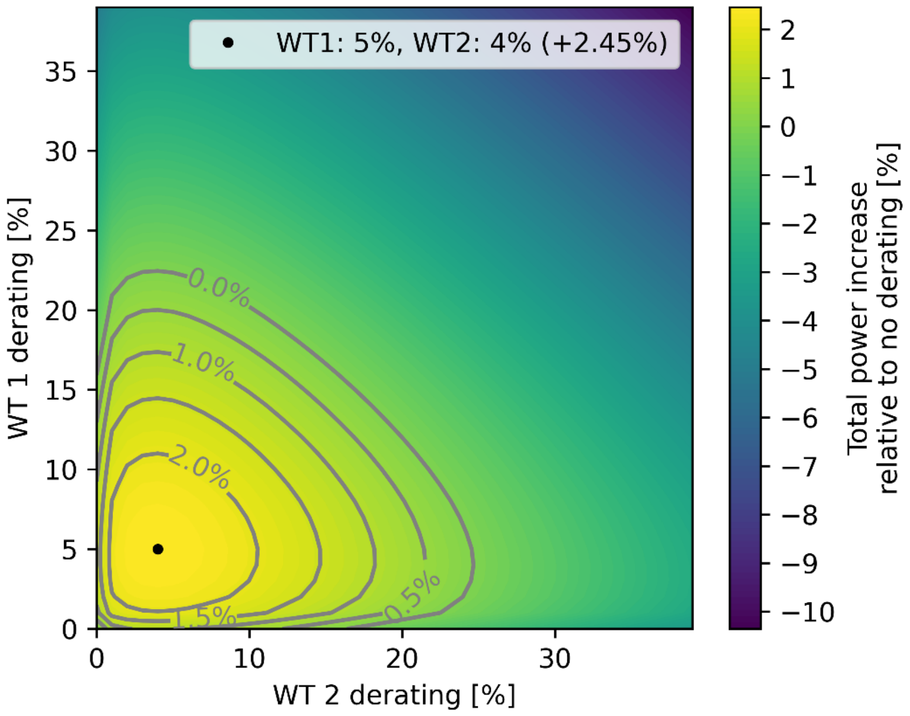




Derating, single row, 3 wind turbines





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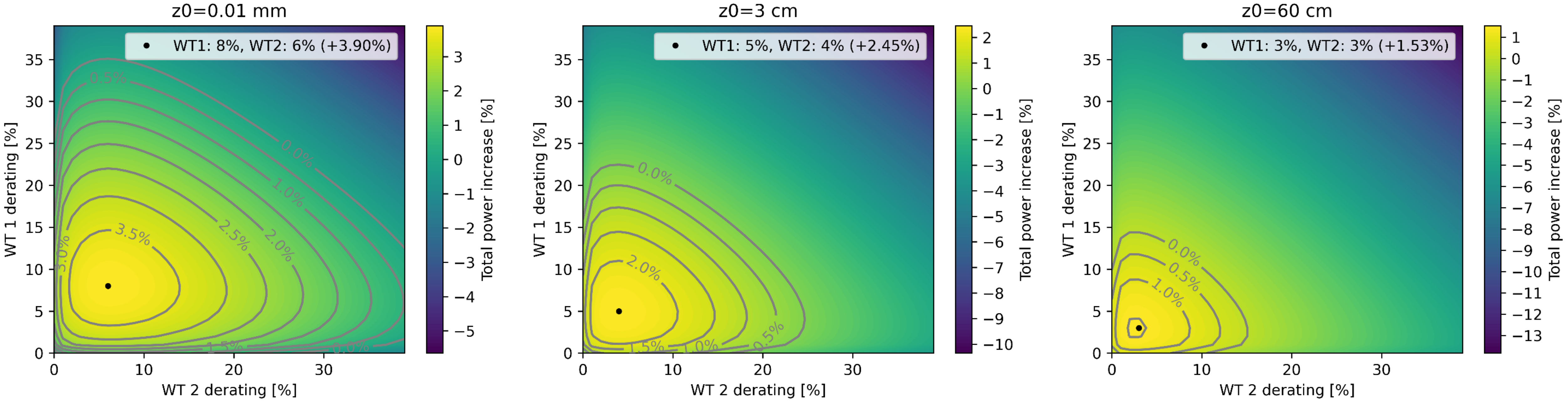

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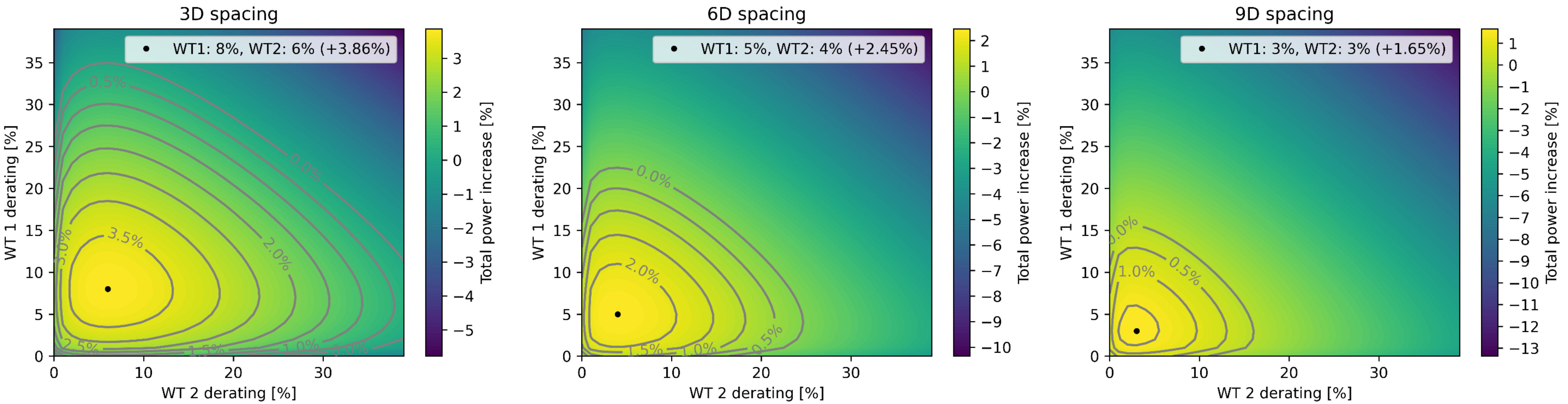
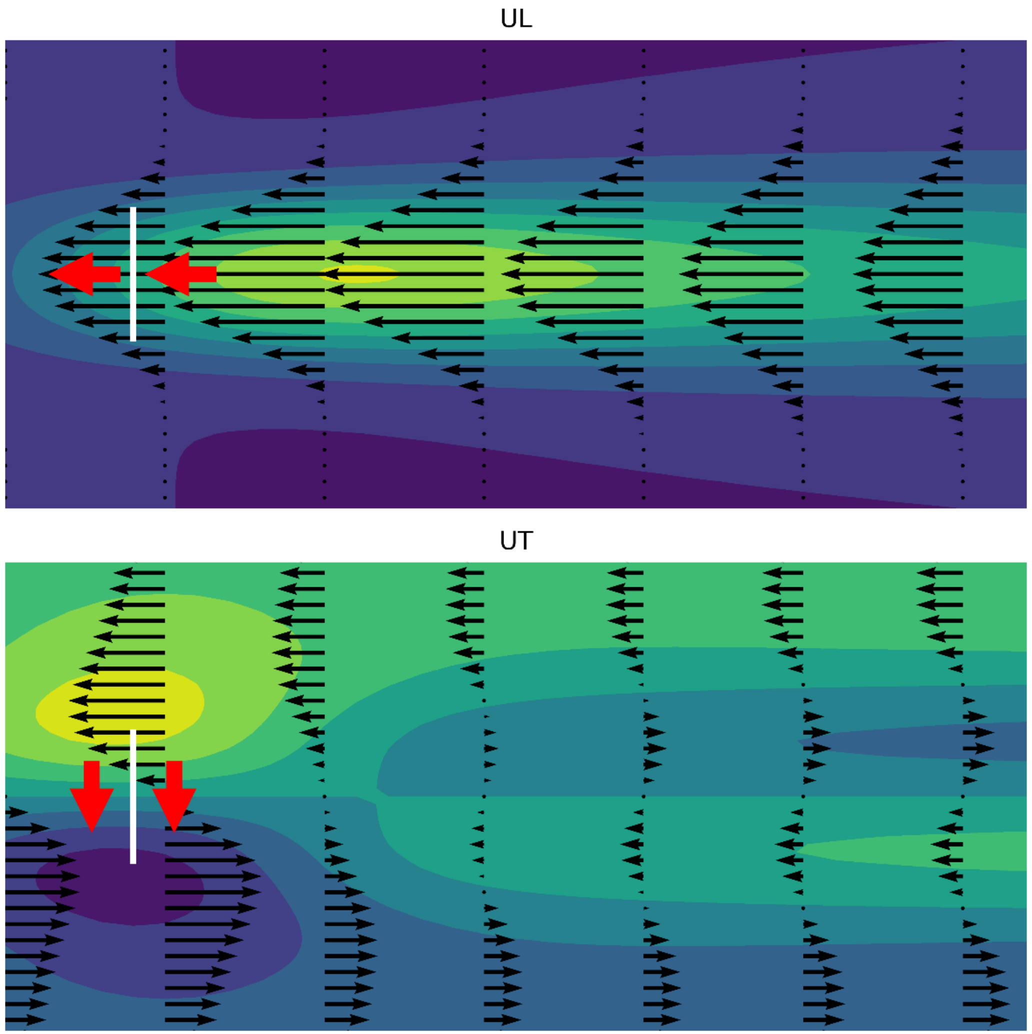


Fuga deficit parallel to mean wind



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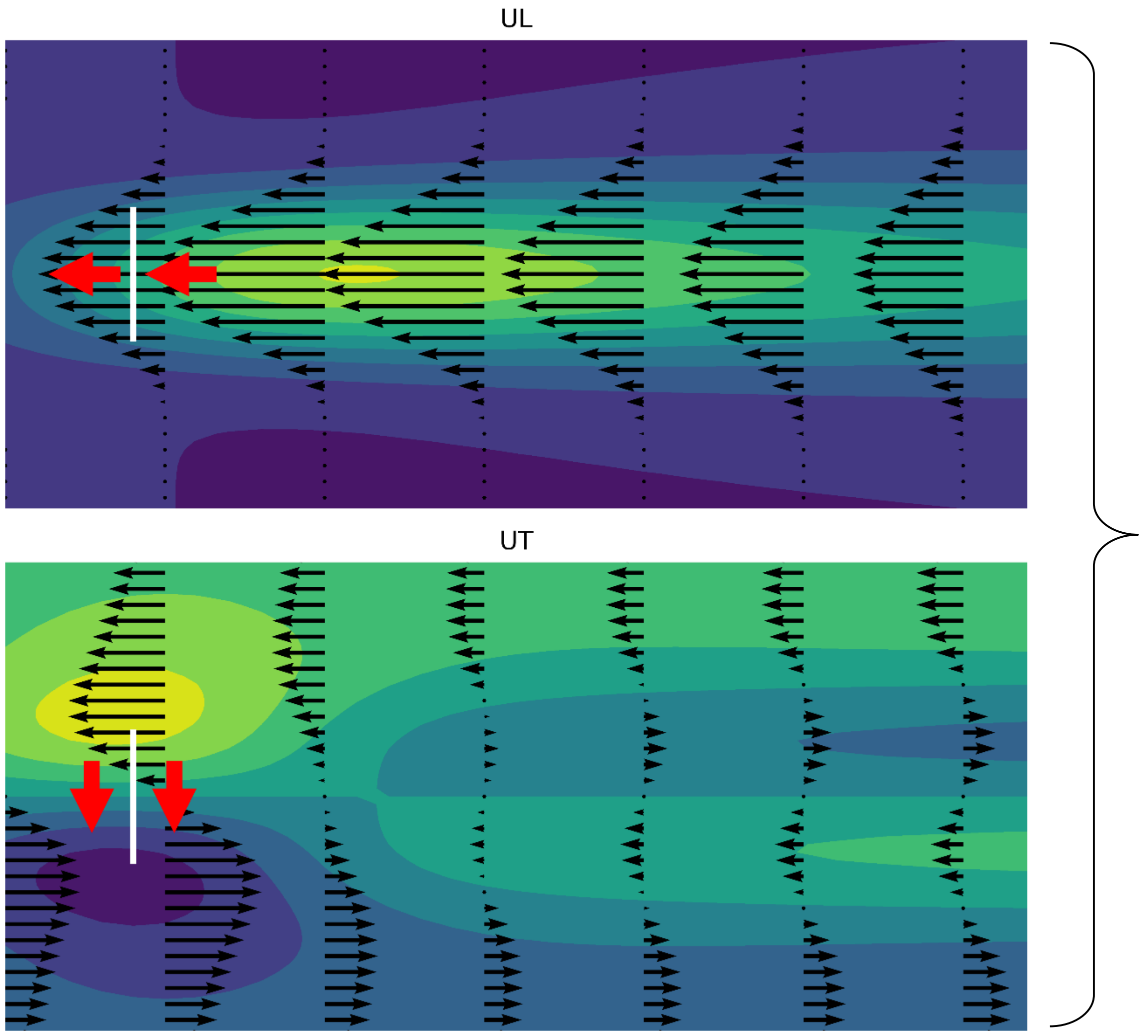
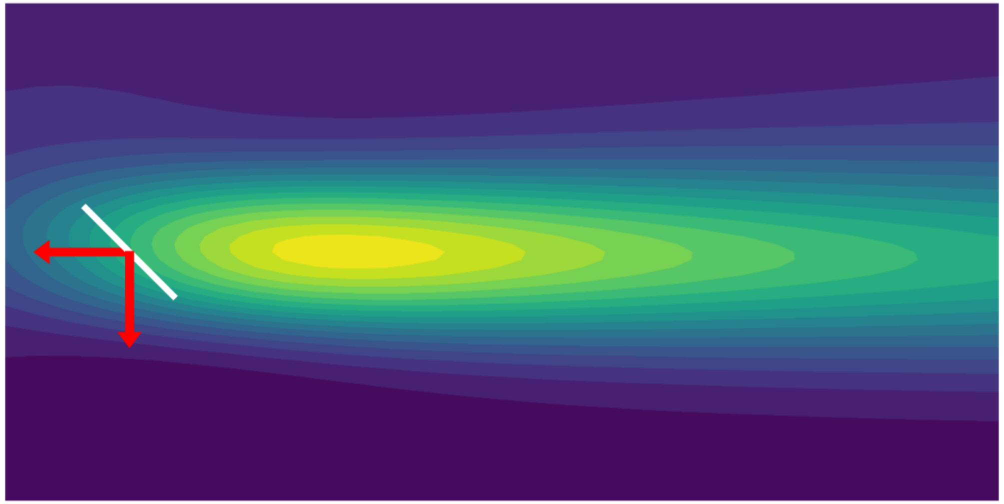
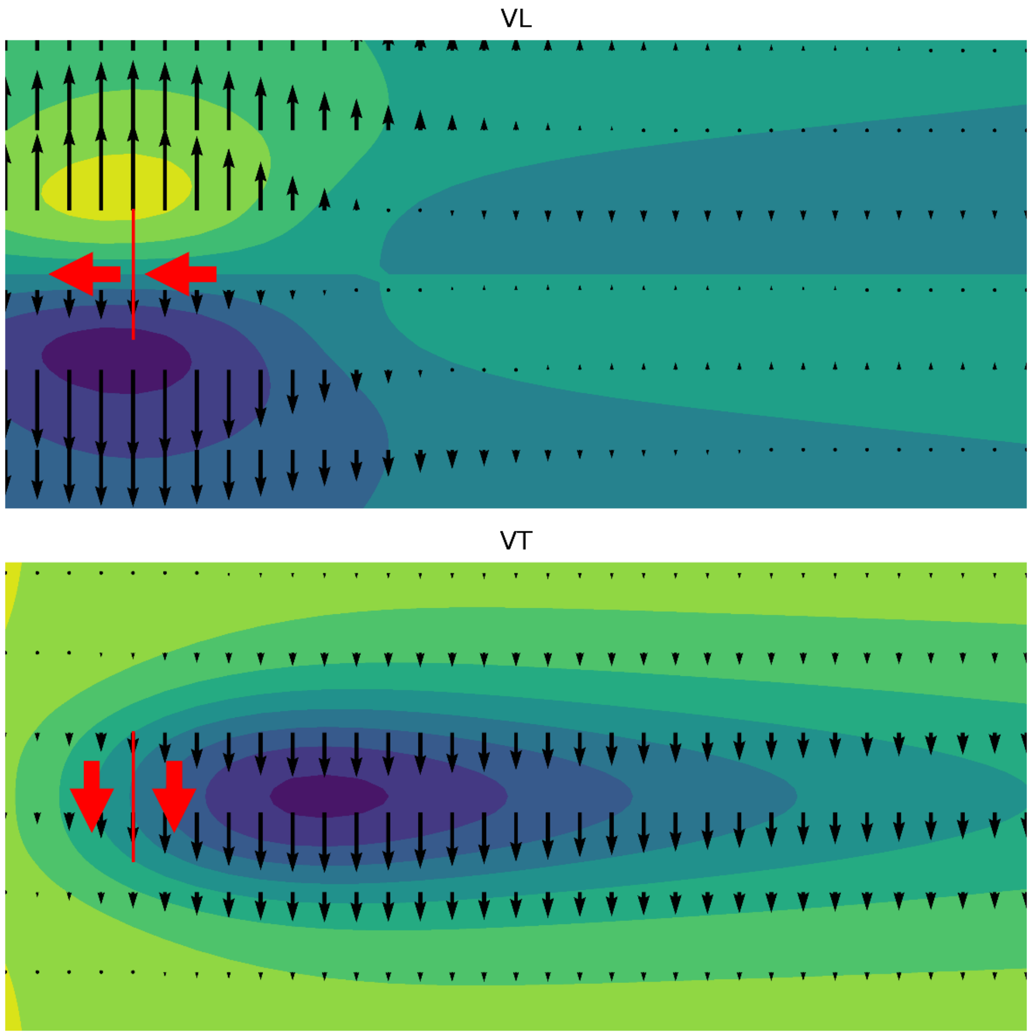


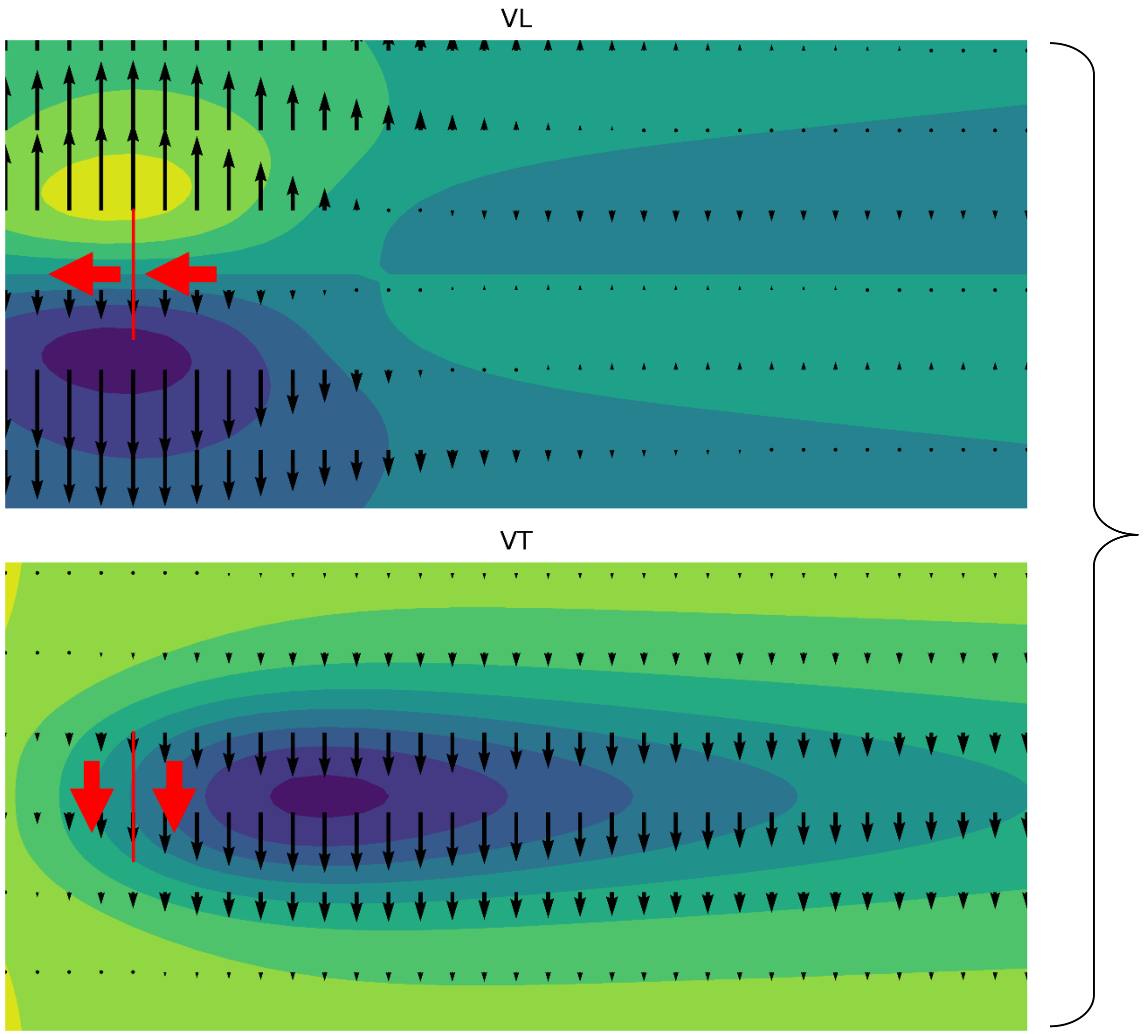
$$Deficit_U = \cos\theta_{yaw}\, UL + \sin\theta_{yaw}\, UT$$



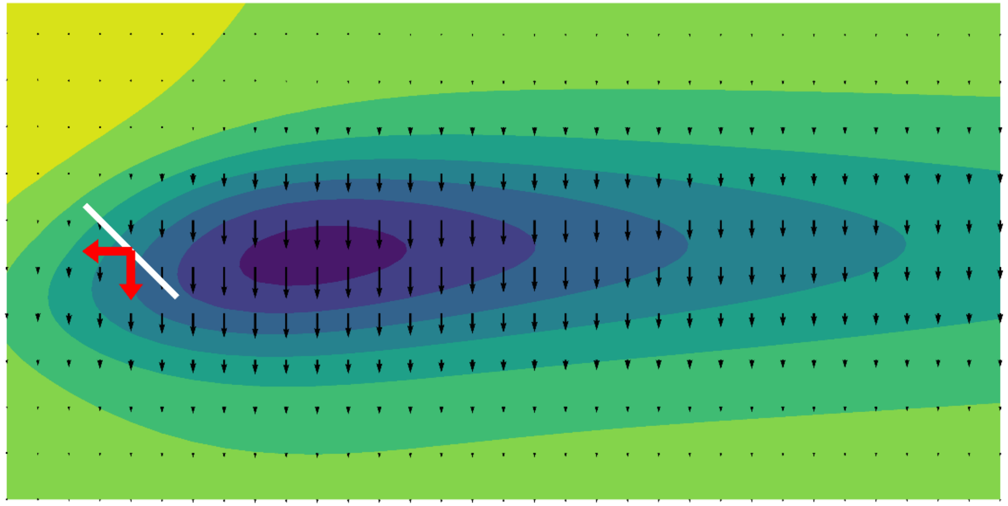
Fuga deficit perpendicular to mean wind



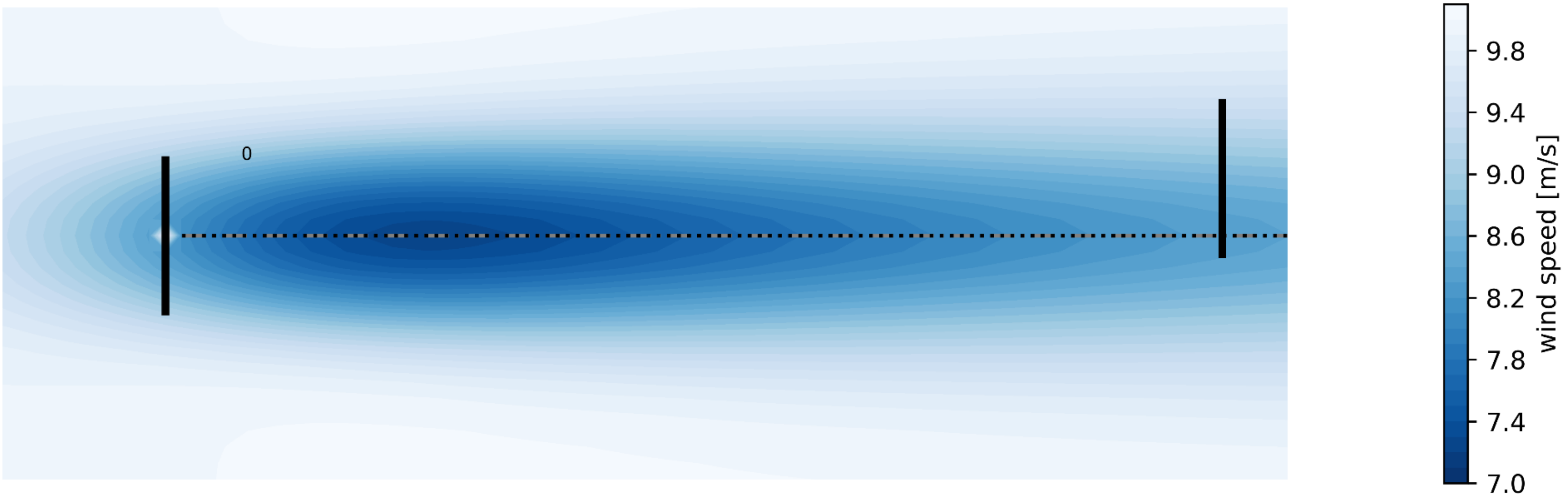
Fuga deficit perpendicular to mean wind



$$Deficit_V = \cos\theta_{yaw}\, VL + \sin\theta_{yaw}\, VT$$



Wake deflection



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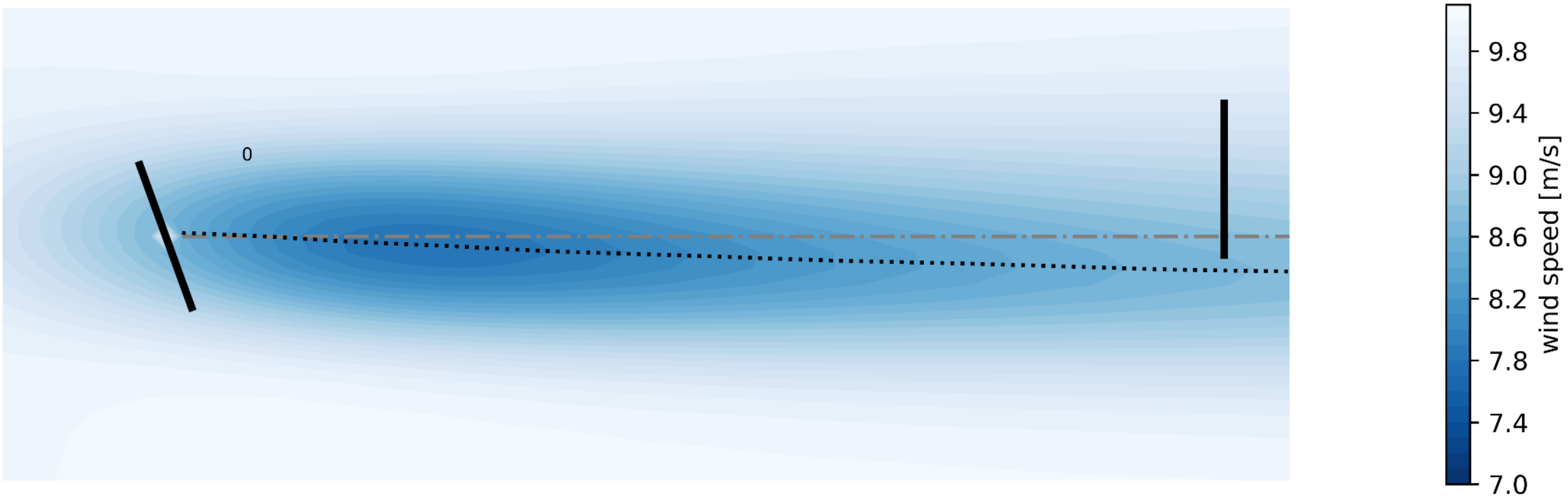
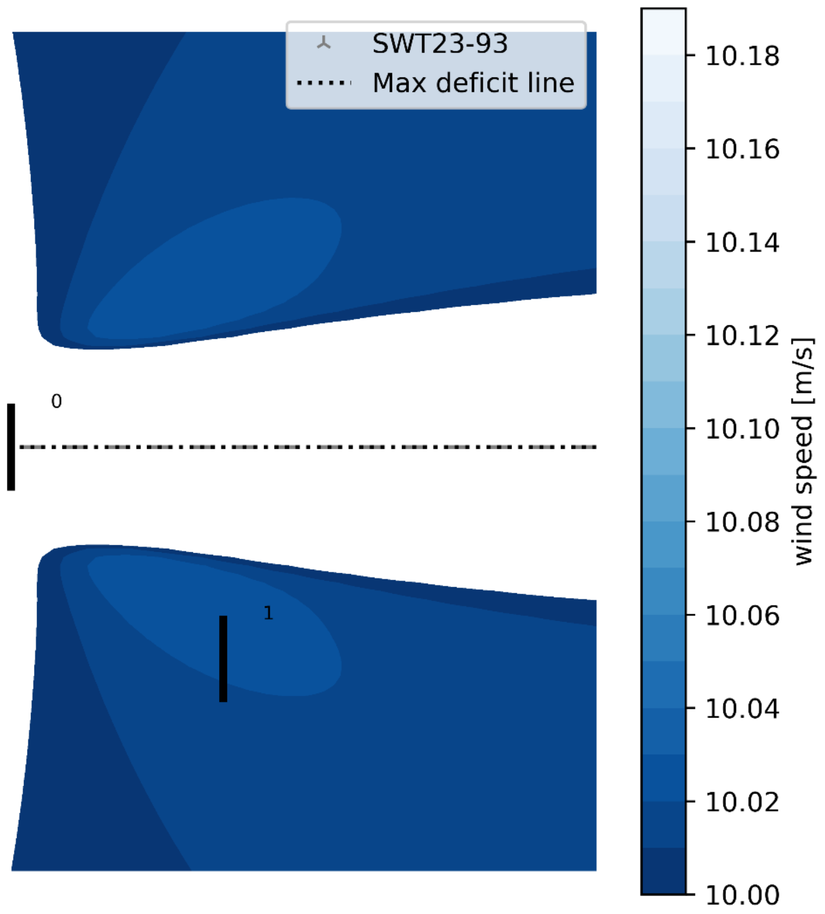


Speedup deflection



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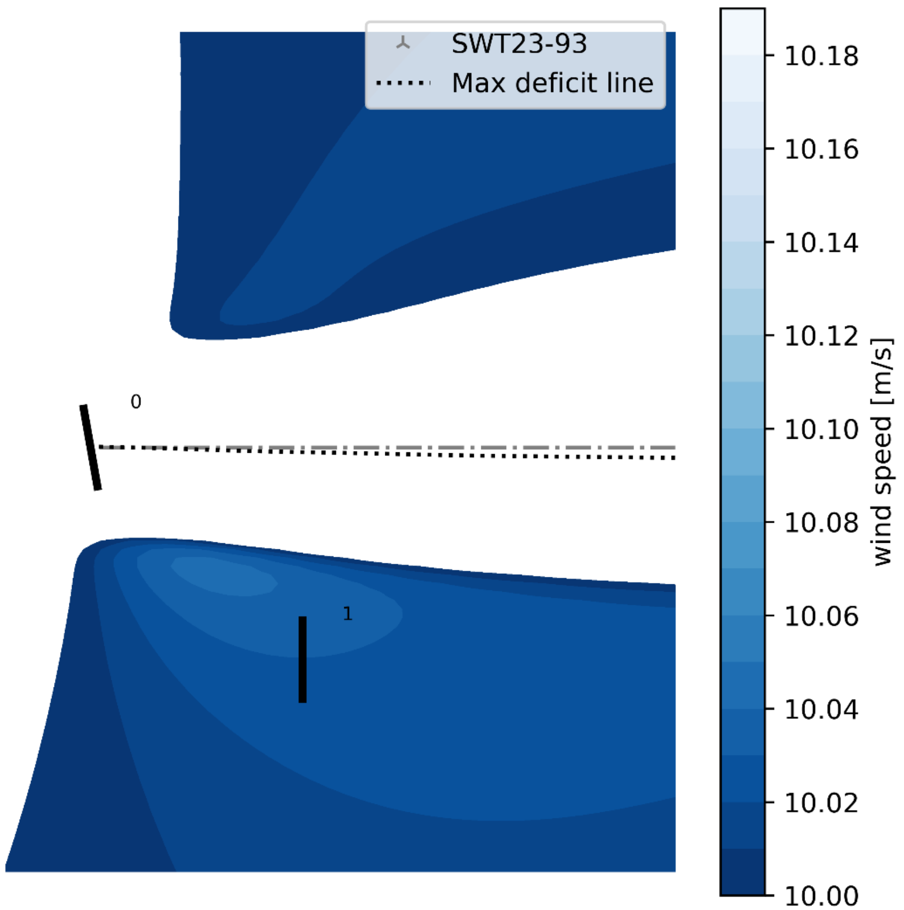
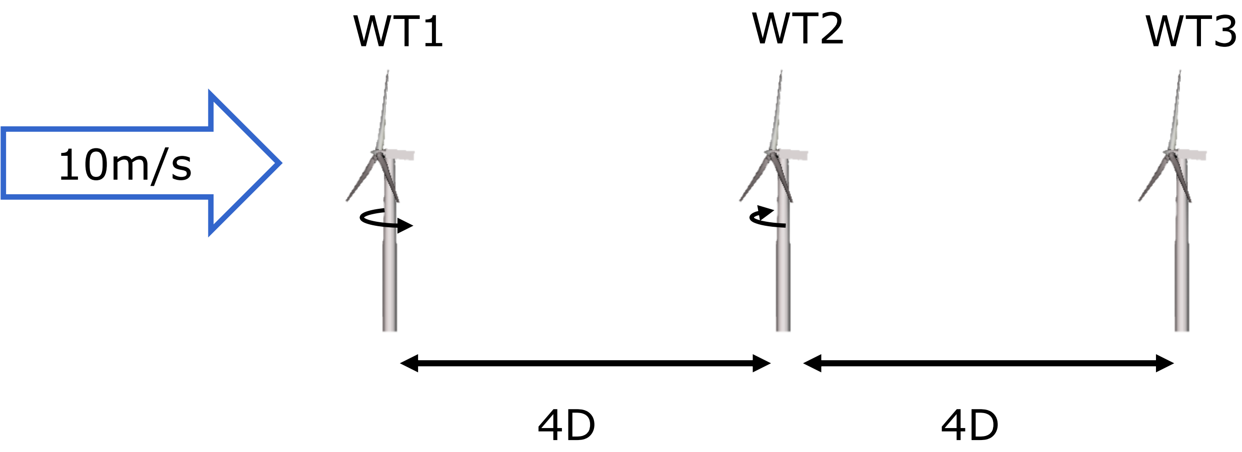
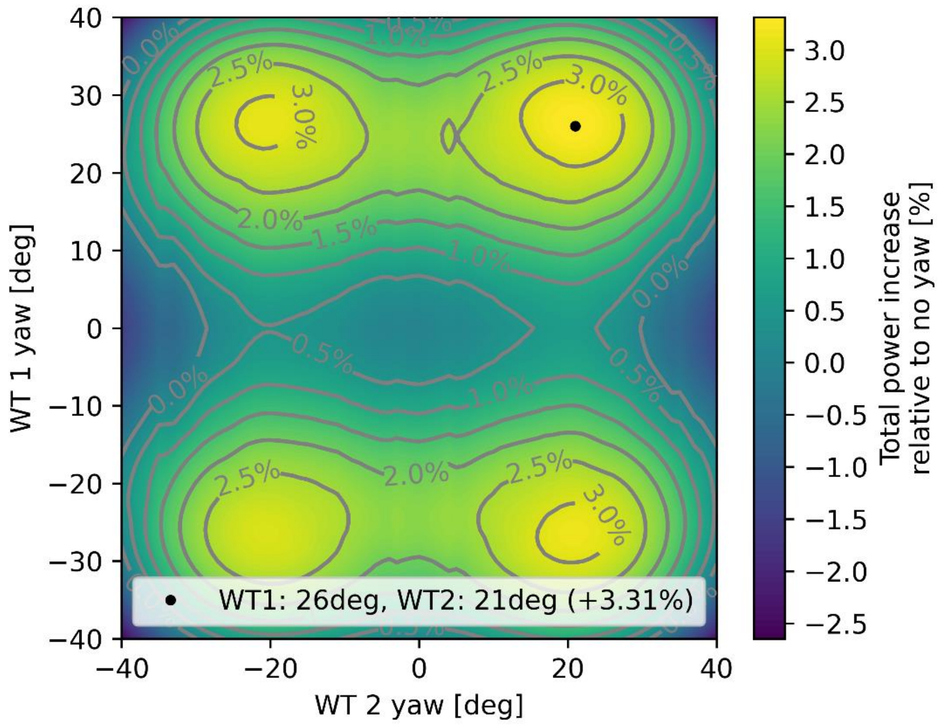


Wake steering, single row, 3 wind turbines





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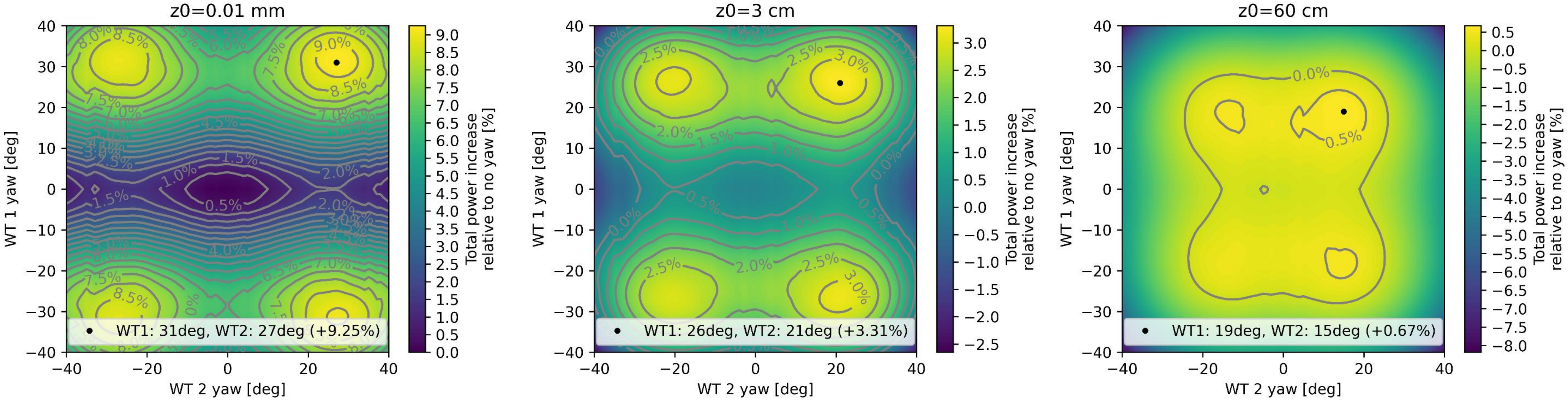

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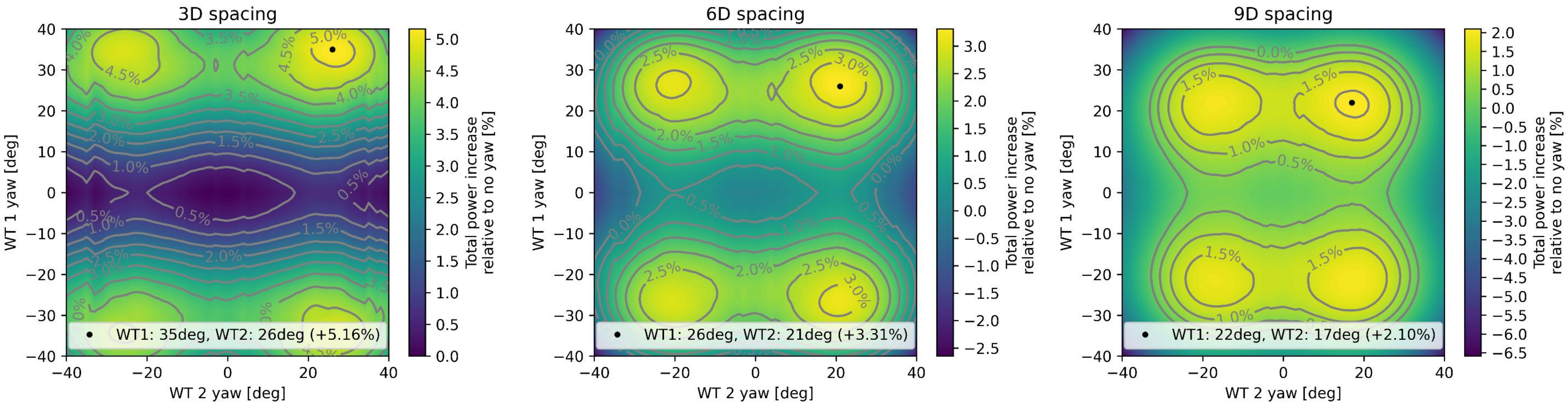
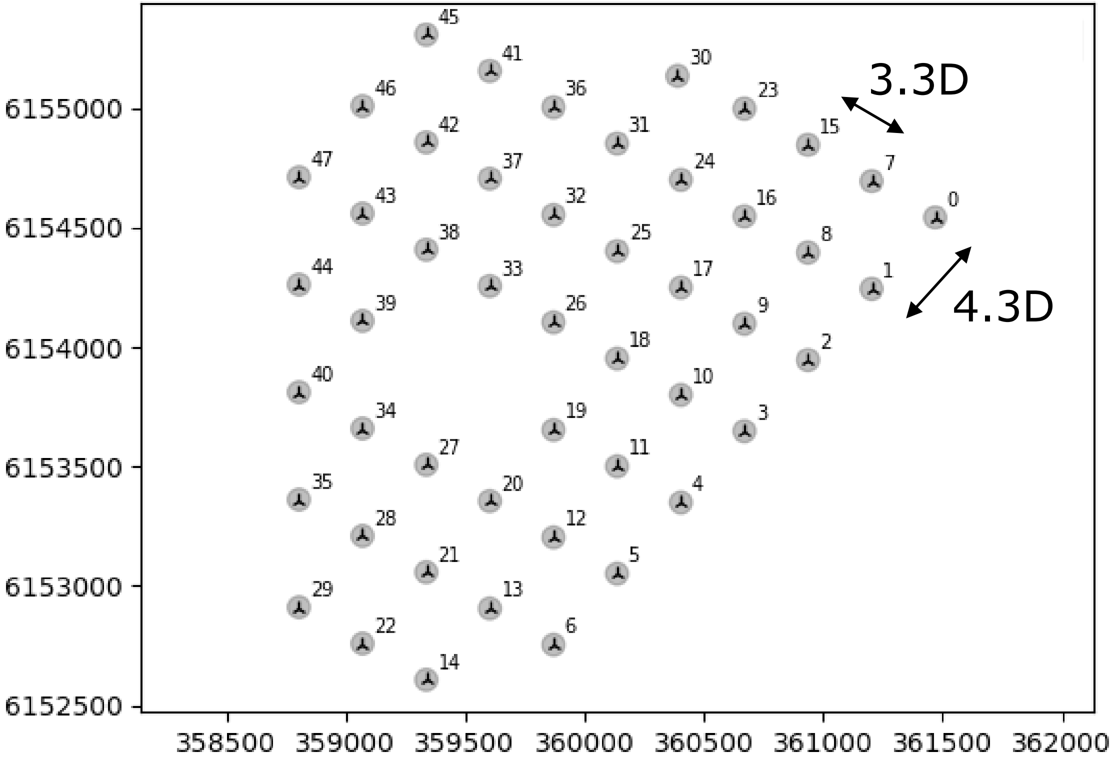
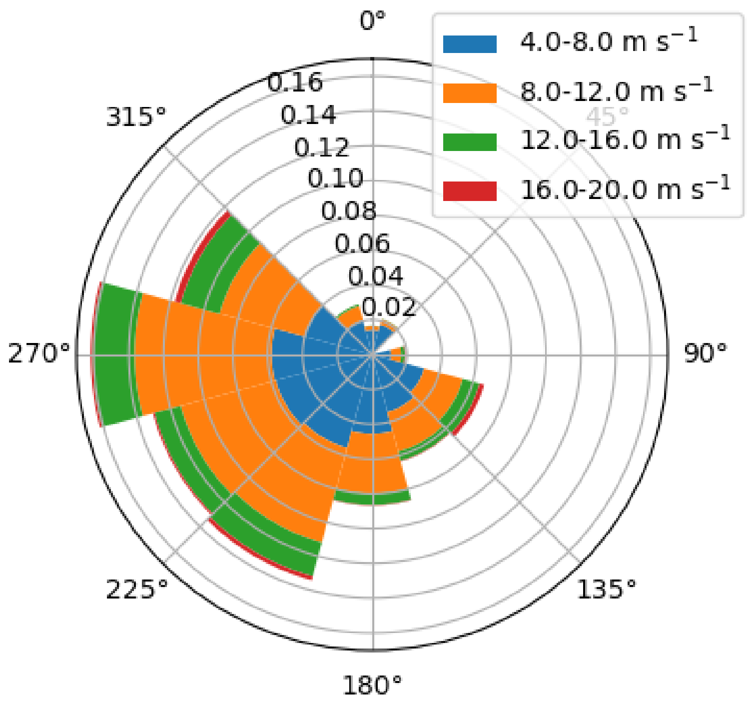


Lillgrund wind farm

- 48 Siemens 2.3MW wind turbines
- Offshore but close to Copenhagen and Malmø
- TI: 13% ~ z_0=3 cm





- AEP based on 7560 flow cases
  - 360 wd bins
  - 21 ws bins

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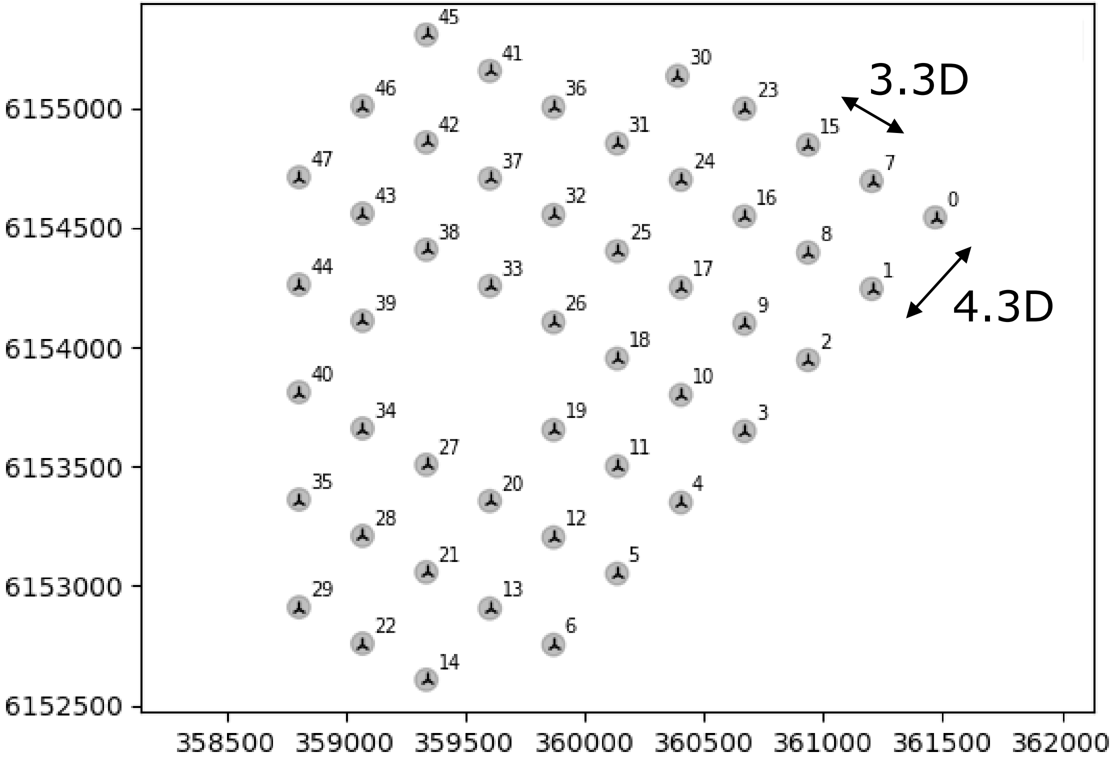
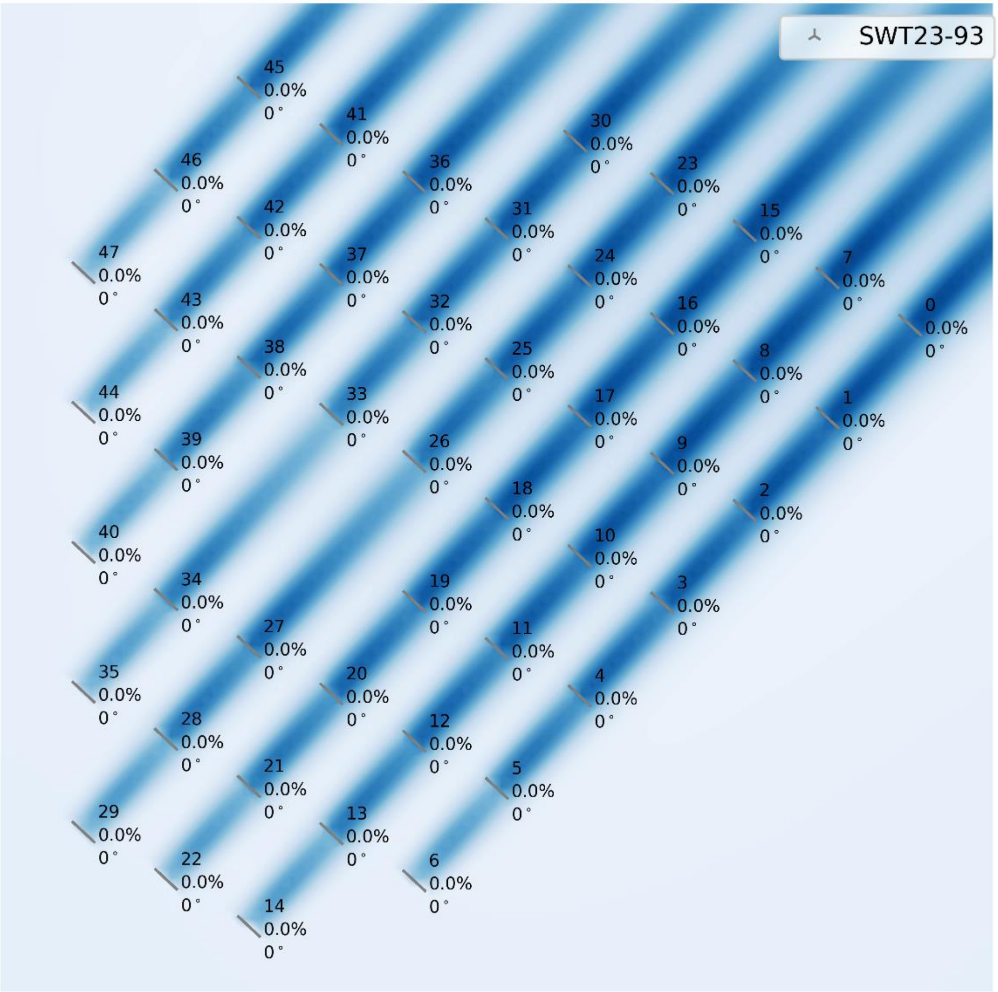
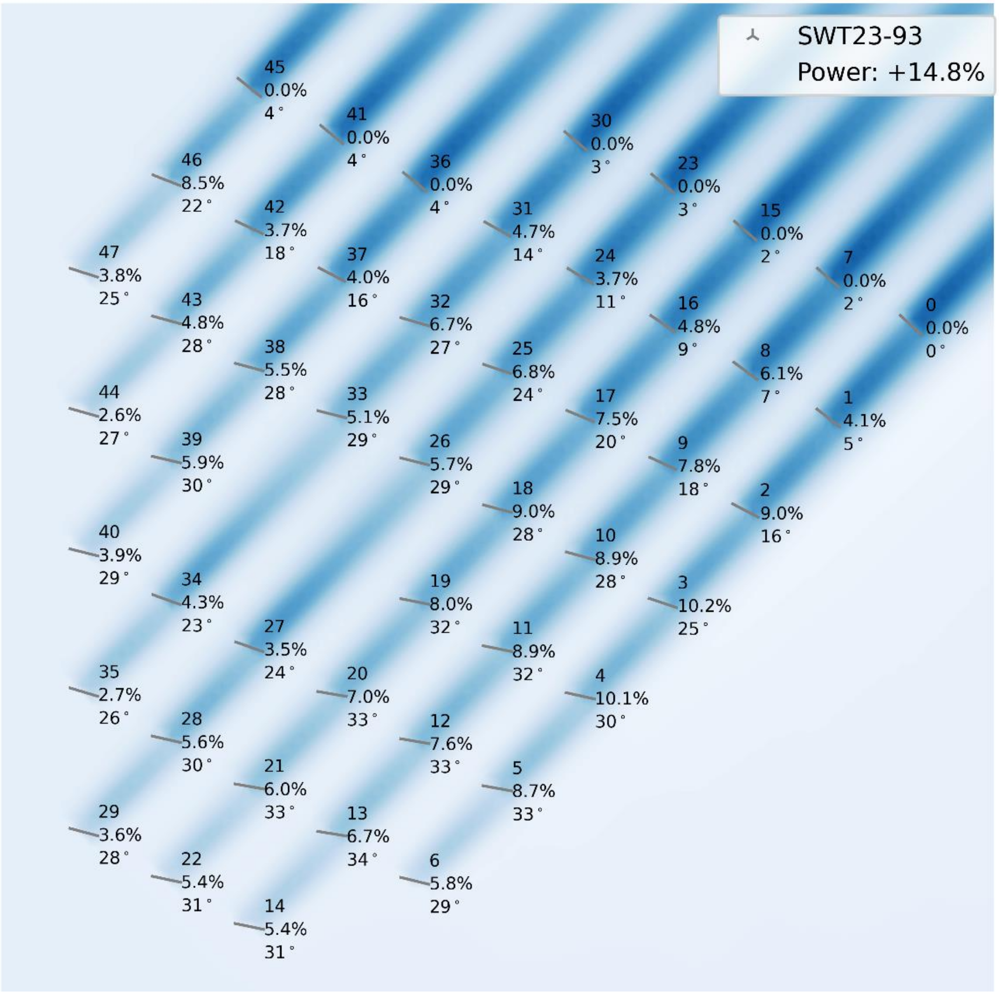


Wake Control	AEP [GWh]
-	340.6
Derating	345.6 (+1.5%)
Yaw control	347.3 (+2.0%)
Integrated derating+Yaw	349.0 (+2.4%)

Lillgrund wind farm

- 10 m/s, 223deg
- Lower covergence tolerance than in AEP result





Conclusions

- Potential AEP increase of 2.4% found for Lillgrund wind farm
- Highly dependent on
  - Wind farm layout
  - Site inflow conditions (wind direction, wind speed, turbulence)
  - Added turbulence modeling approach
  - Power/ct model
  - Derating strategy
- Future work:
  - Include uncertainty of wind direction and wind speed
  - Include added turbulence inside the wind farm
  - Include blockage
  - Consider rotor average wind speed instead of rotor center
  - Replace Fuga with non-linear RANS look-up-tables
  - Integrate loads surrogates to address reliability and overall LCOE

Thank you for your attention

This study is funded by

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