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Understanding Wind Power in Forested Landscapes: High-Fidelity Aeroelastic Simulations

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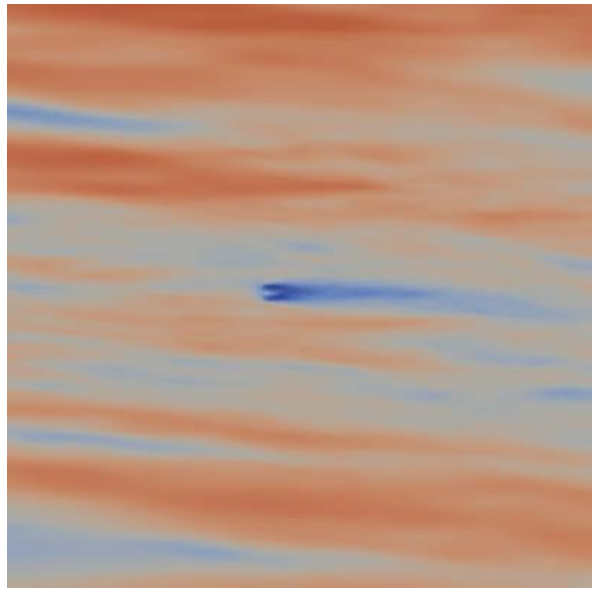
What will I talk about?

- Part of an ongoing research
- Effect of terrain features modeling choice on wind turbine performance and loads
- To show what we can do!
- 3 cases are simulated using LES based on Ryningsnäs site with only one turbine in the domain:

1. Flat surface + homogeneous forest
2. Only terrain
3. Terrain + realistic forest

- Note that these are only preliminary results.



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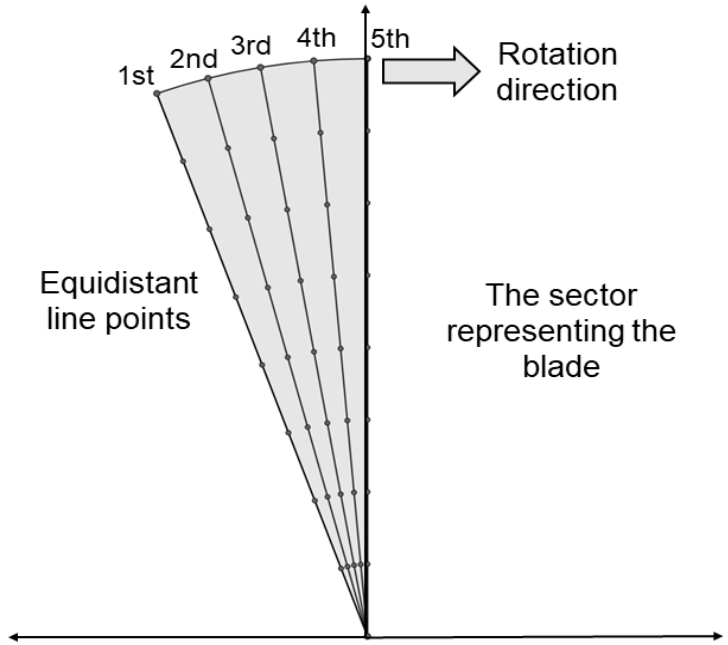
Aeroelastic setup

- Actuator sector model (ASM) for blades, IEA 3.4MW
- Why actuator sector?
- A disk (ADM) is fast (large Δt), no blade representation
- A line (ALM) for each blade is slow (small Δt), more accurate
- ASM is as fast as ADM and as accurate as ALM:
  - gives unsteady loads and wake profile
- Inflow is not the only imp. factor but also the turbine wake
- Flexible
- Aeroelastic calculations (deflections, loads):
- Blades: ElastoDyn (Euler-Bernoulli) modal approach or more advance GEBT (Beamdyn)
- Tower (drag line)
- Hub (drag point)
- For controller: Open Source ROSCO
- Pitch, torque, and yaw



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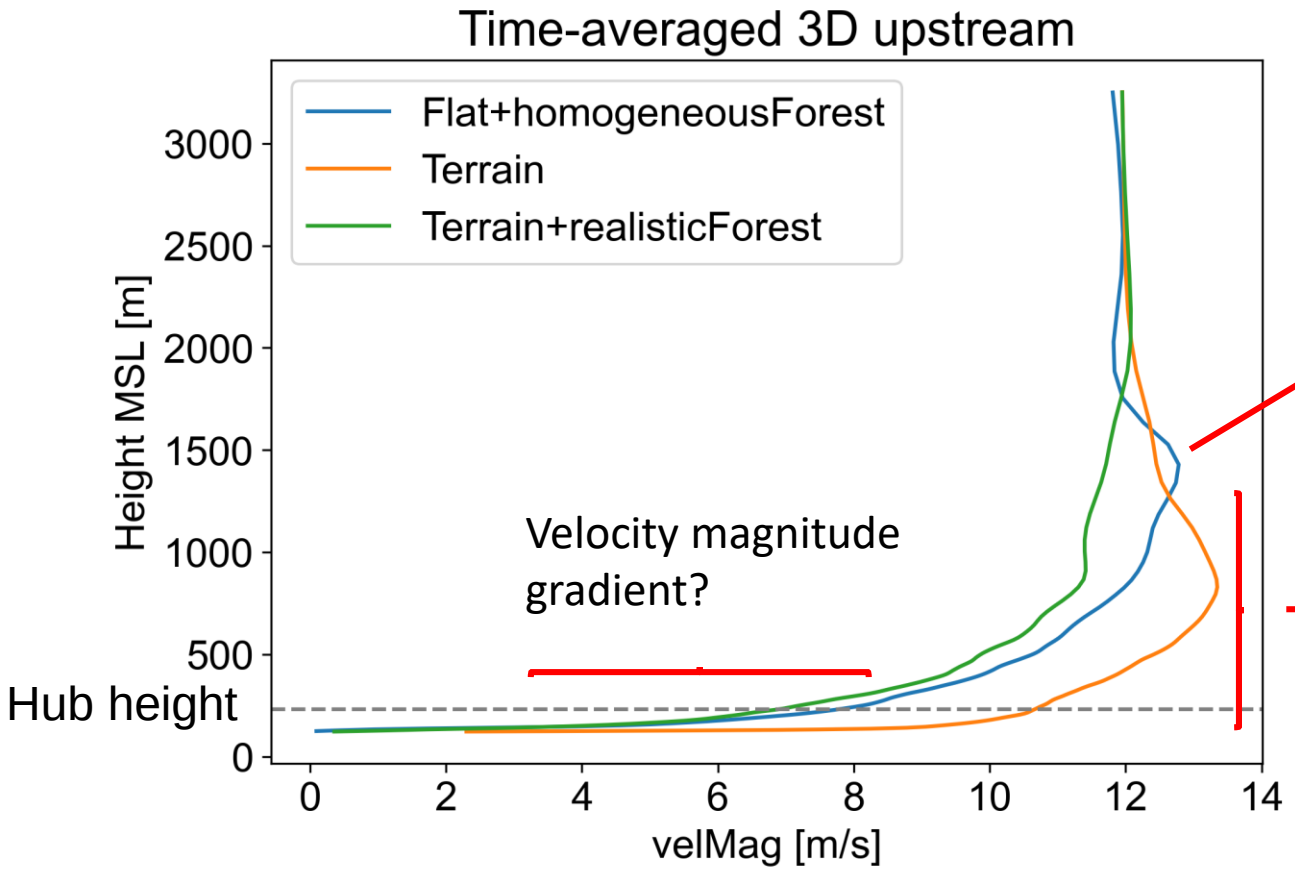
Results: inflow



The diff. illustrates the importance of inhomogeneity and elevation

Significant speed up without forest

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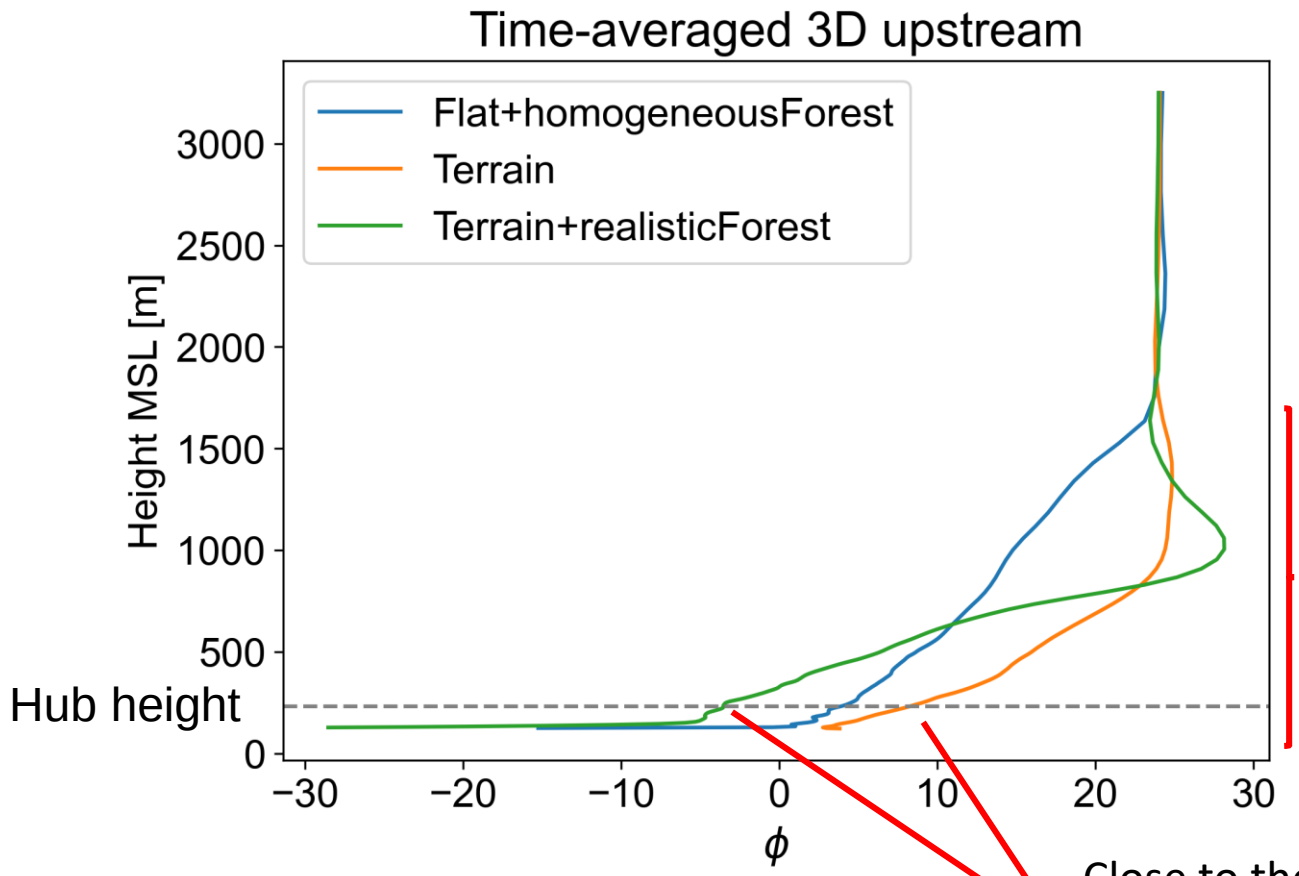
Results: inflow



Significant differences in the inflow angle

Close to the hub, Terrain and Realistic have similar directional shear!

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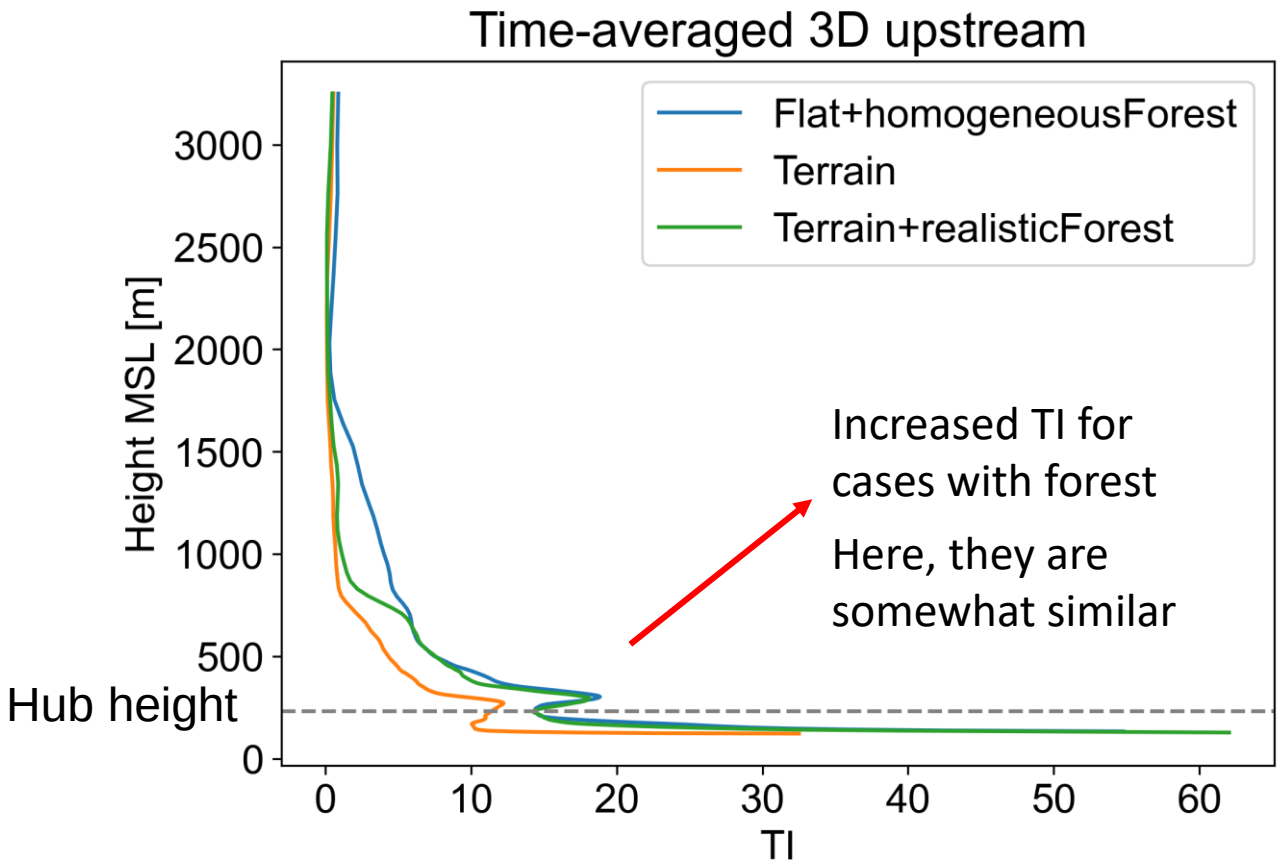
Results: inflow



Different Modeling choice -> Significantly different inflow at the same geostrophic wind forcing

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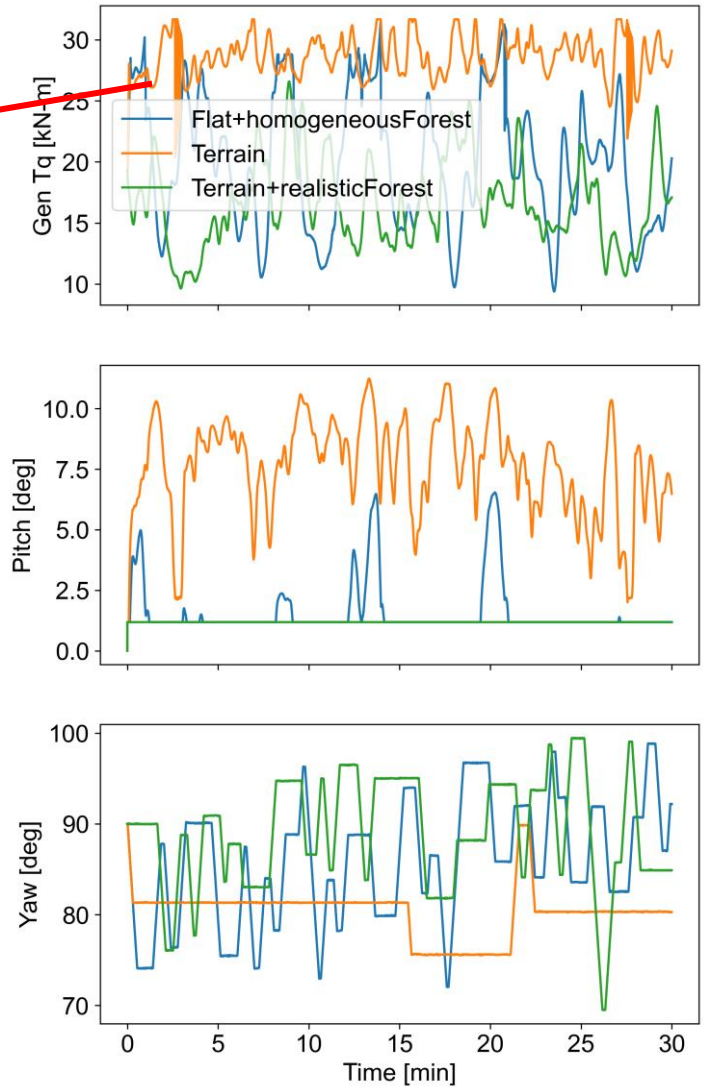
Results: controller outputs

GenTq fluctuations, the need for case specific calibration?

Diff. pitch actuation time series (different control region)

More yaw actuations occured in the case of forest simulations. Is it optimal?



Different Modeling choice -> Significantly different inflow -> Different controller response

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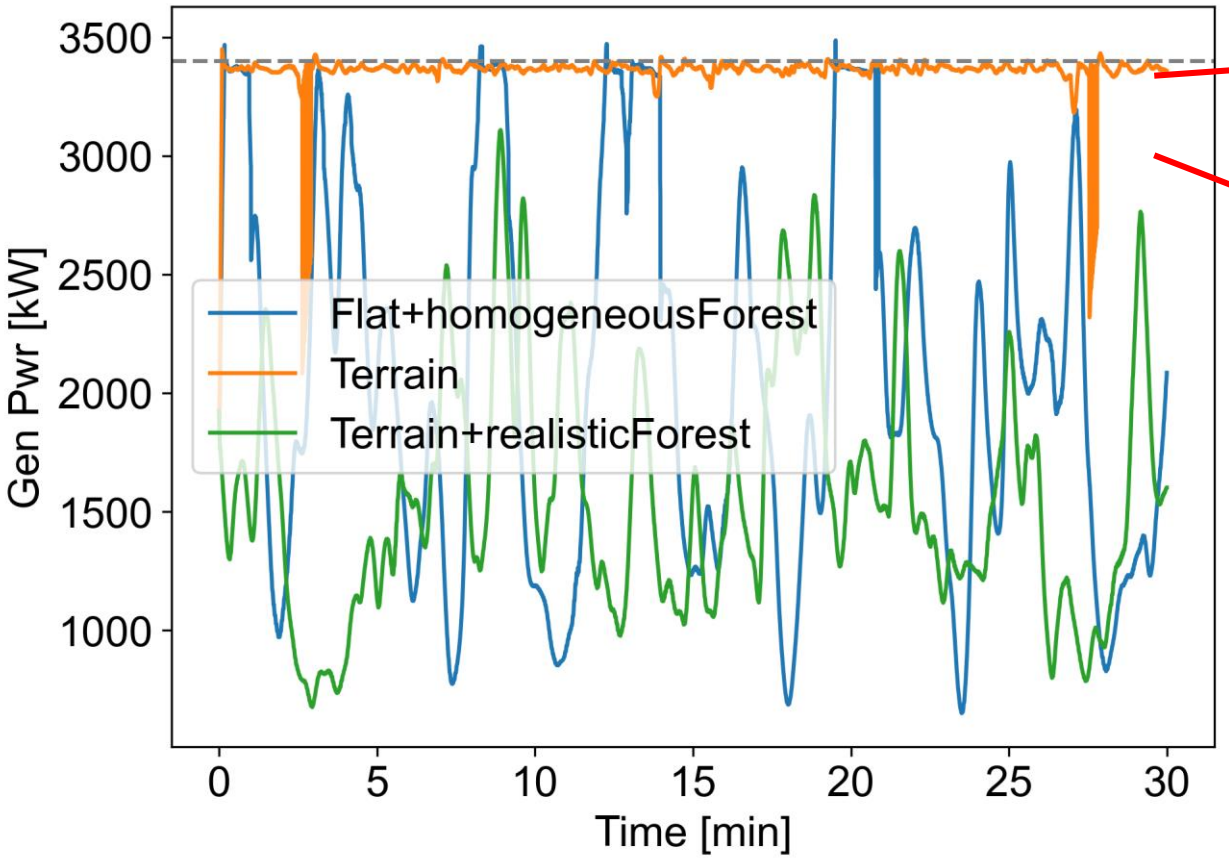
Results: generator power



Controller limits the power output to rated

Due to GenTq controller function

Significant impact on the power values

Different Modeling choice -> Significantly Diff. inflow -> Diff. controller response -> Diff. Power

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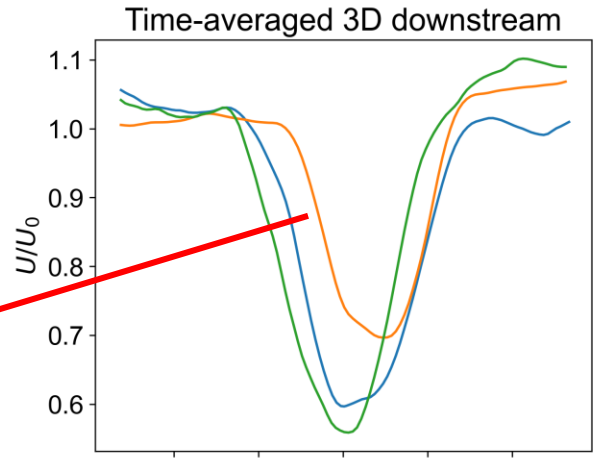
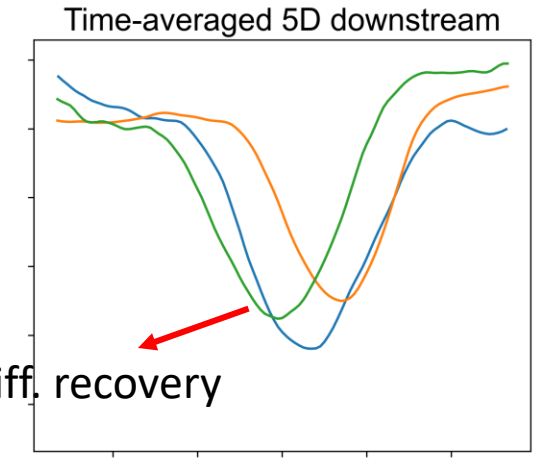
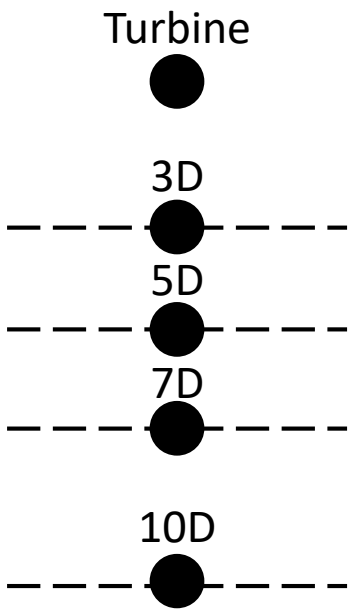
Results: wake flow

Lower deficit due to lower CT

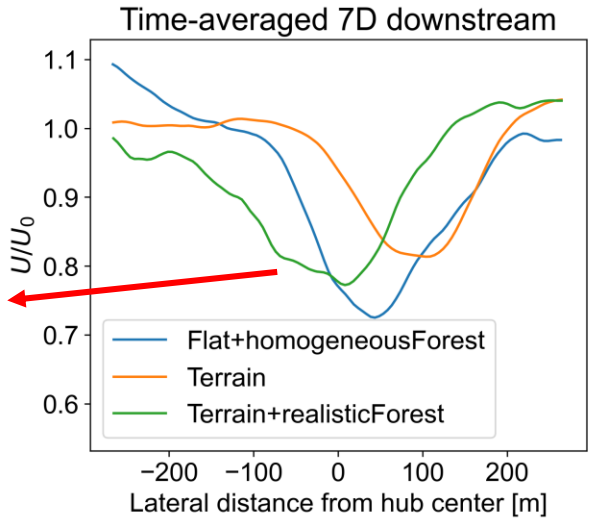


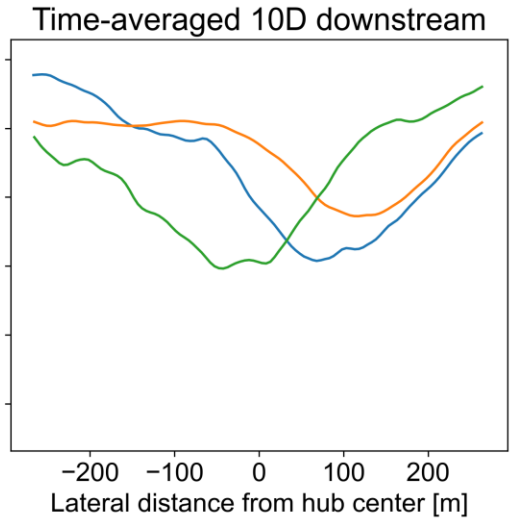


Diff. recovery



Wake location different due to yaw controller and Coriolis dependence on acceleration





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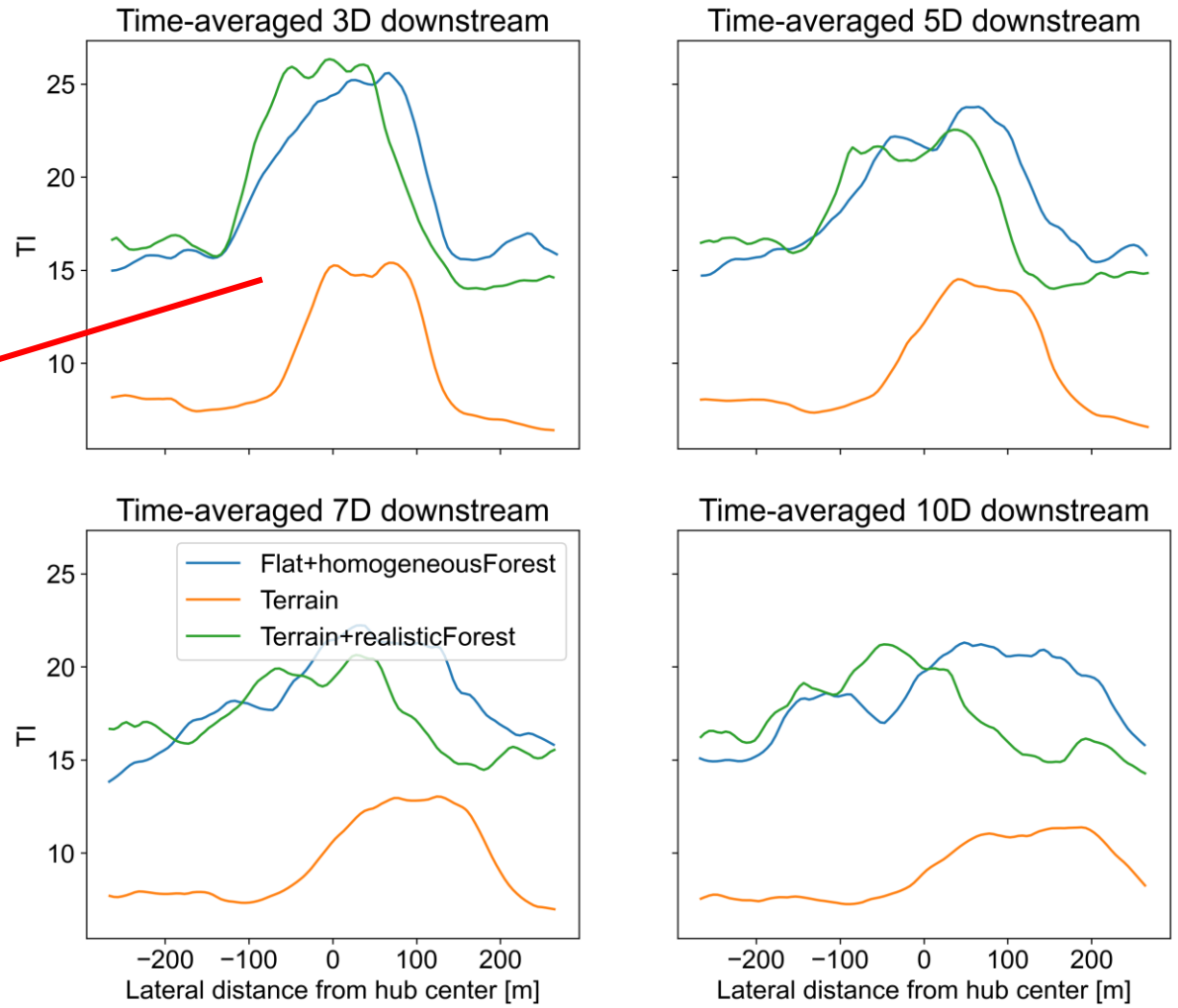
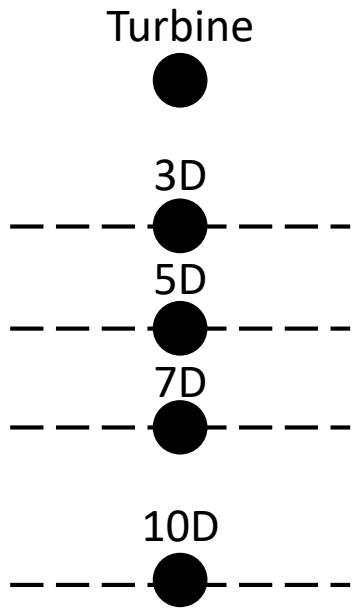
Results: wake flow

Significantly higher TI (around 10 percent) for the cases with Forest





Different Modeling choice -> Significantly Diff. inflow -> Diff. controller response -> Diff. Power -> Diff. Wake profile

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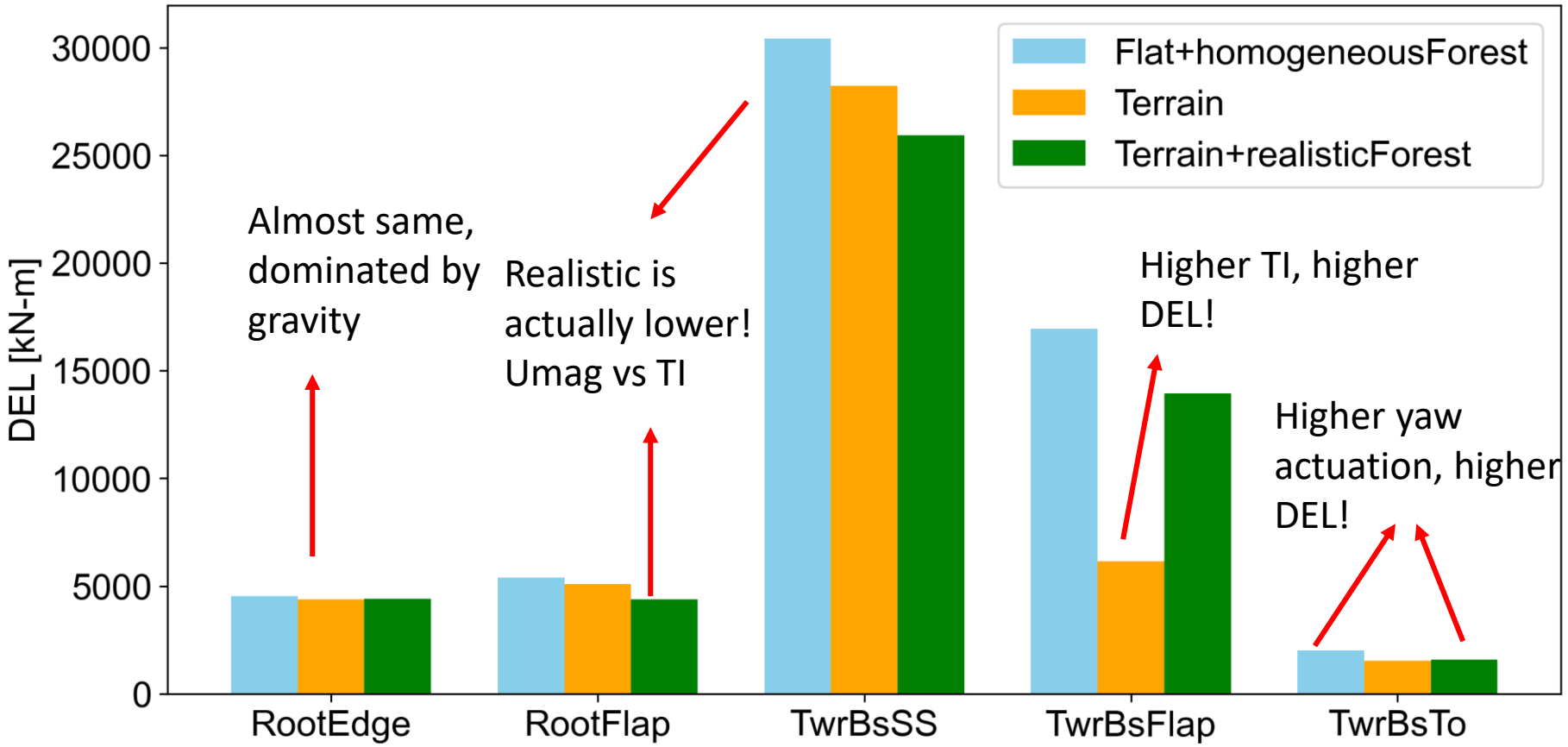
Results: DELs

Not to generalize!
Results for different hub velocities!



Different Modeling choice -> Significantly Diff. inflow -> Diff. controller response -> Diff. Power -> Diff. Wake profile -> Diff. loads

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Outlook

- General research questions
  - Improved day-ahead and minute-scale forecasting of wind energy over forested areas
  - Wake and park flows in forested areas
    - Faster wake recovery vs. blockage
  - Transient effects
    - Importance of LLJ, intermittent turbulence, canopy waves
  - Interactions with terrain
    - Specific aspects of (heterogenous) forests on flow separation and gravity waves
  - Fatigue load calculations and AEP predictions
    - Are more flow regimes necessary to reach acceptable accuracy?
      - High turbulence vs high shear and veer
- Specific topics / research objectives
  - Improved industrial models
    - Effective roughness calculation
    - Tuning of engineering wake models
    - Forest capability in RANS simulations
  - The role of the drag coefficient in CFD
  - The role of humidity fluxes and evapotranspiration on the diurnal cycle
  - The micro/meso coupling
  - The potential role and limits of ML/AI-methods
  - Methods to improve fatigue load calculations
    - Better and more adaptive synthetic turbulence models for forest and complex terrain
    - Faster LES through non-traditional techniques such as Lattice-Boltzmann methods

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