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ENERGY

Correcting for the impact of blockage on measured power curves

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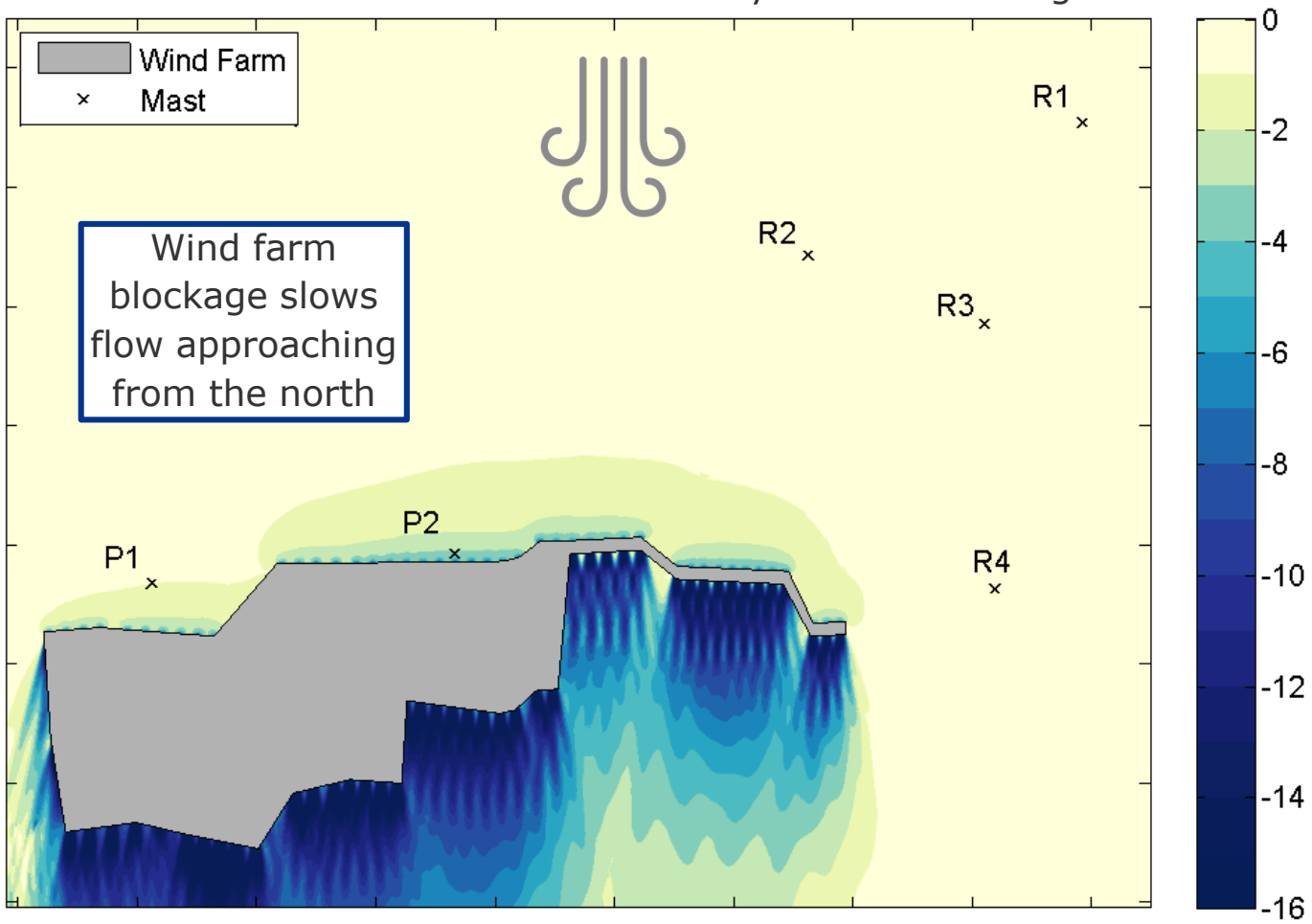
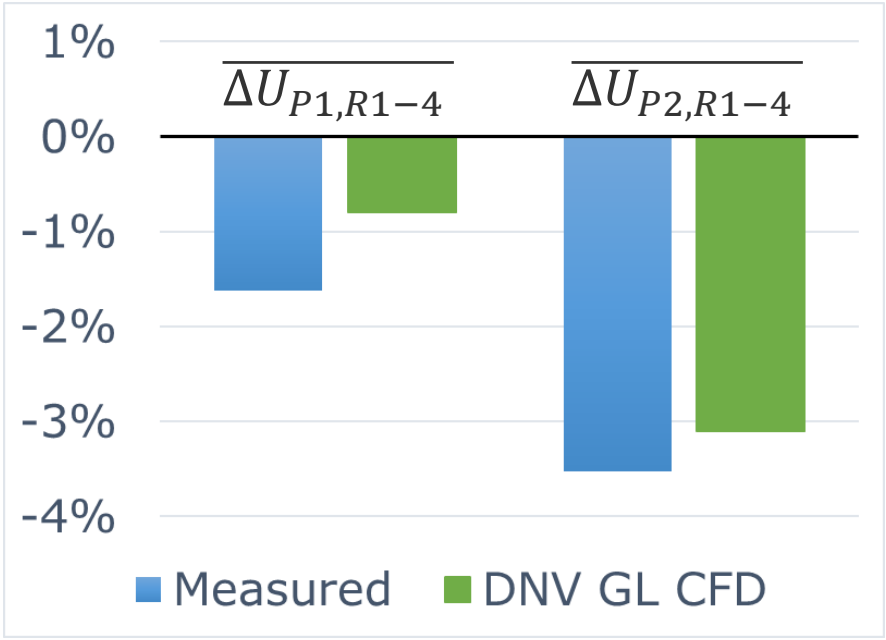
Background: Field observations and CFD → Blockage is important (2017-2018)

The influence of a wind farm on nearby flow at hub height



Colours = % change in hub-height wind speed relative to freestream

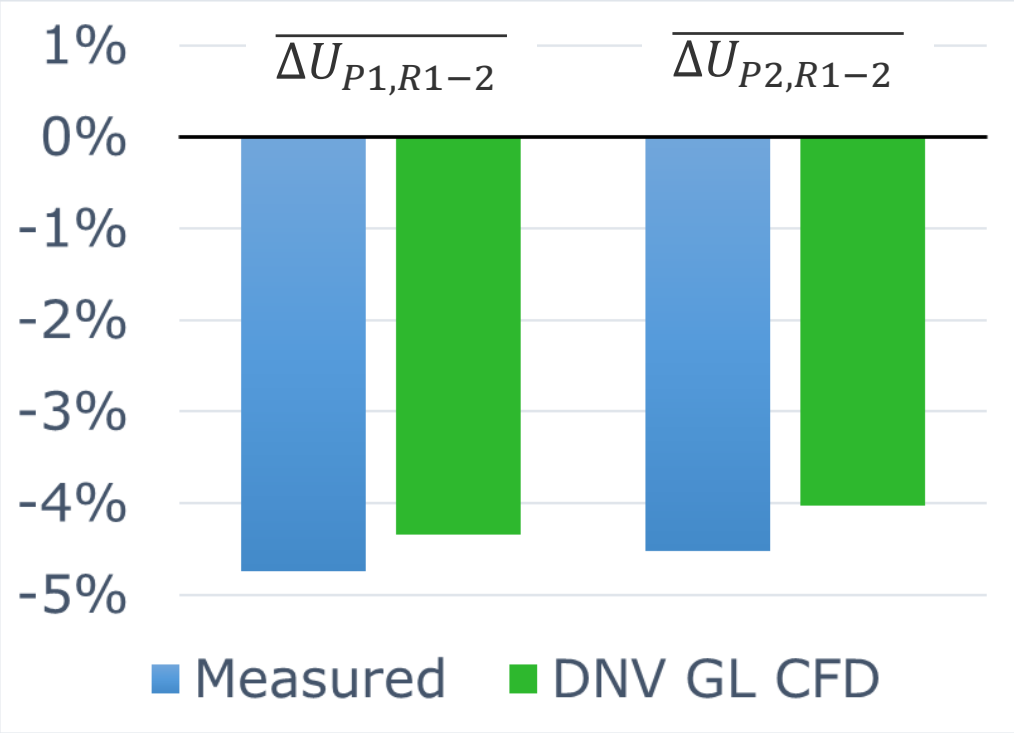
Change in wind speed after COD at perimeter mast relative to reference masts



Blockage effects cause upstream wind speed reductions that are more pronounced and far-reaching than commonly assumed

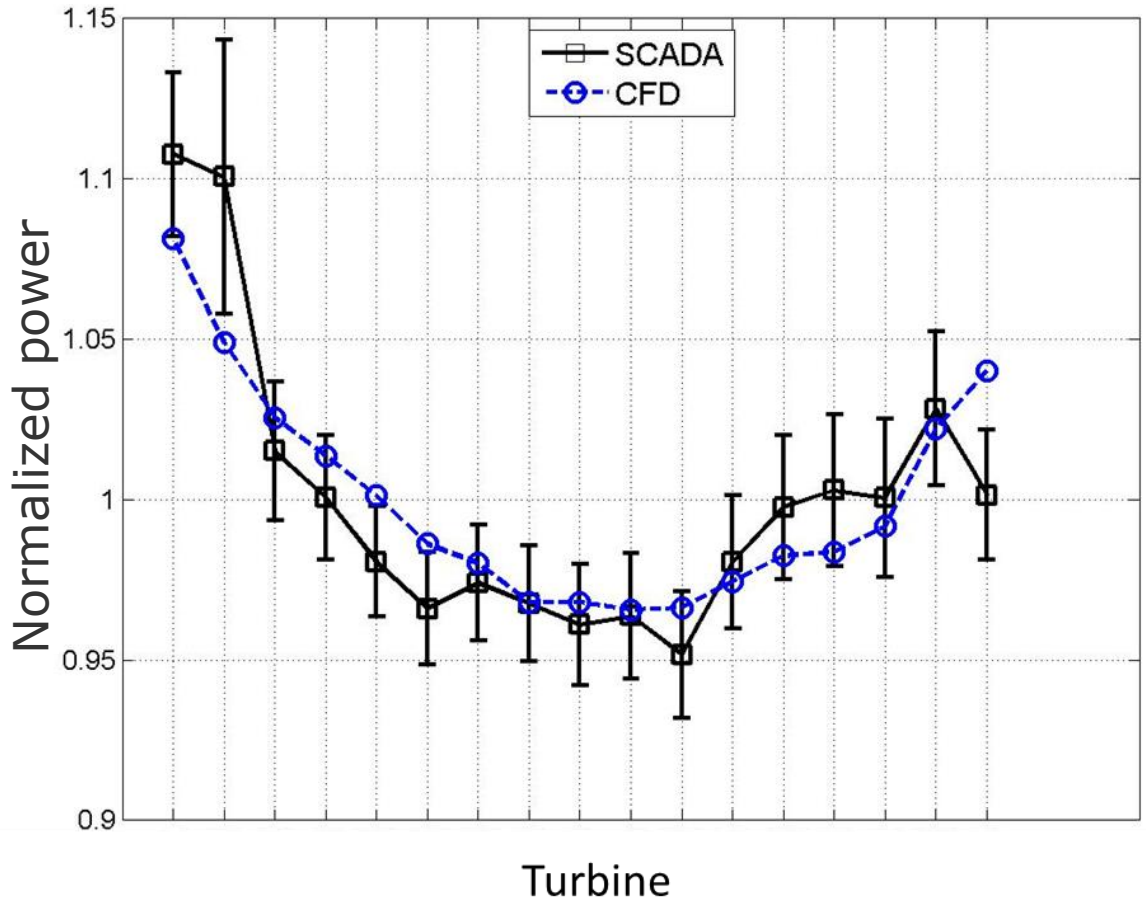
More recent evidence of wind-farm-scale blockage

Change in wind speed after COD at perimeter mast relative to reference masts, Wind Farm E



22 of 23 mast pairs across 5 wind farms reveal post-COD slowdowns at the perimeter masts

Production variation along a leading string of turbines, Wind Farm F

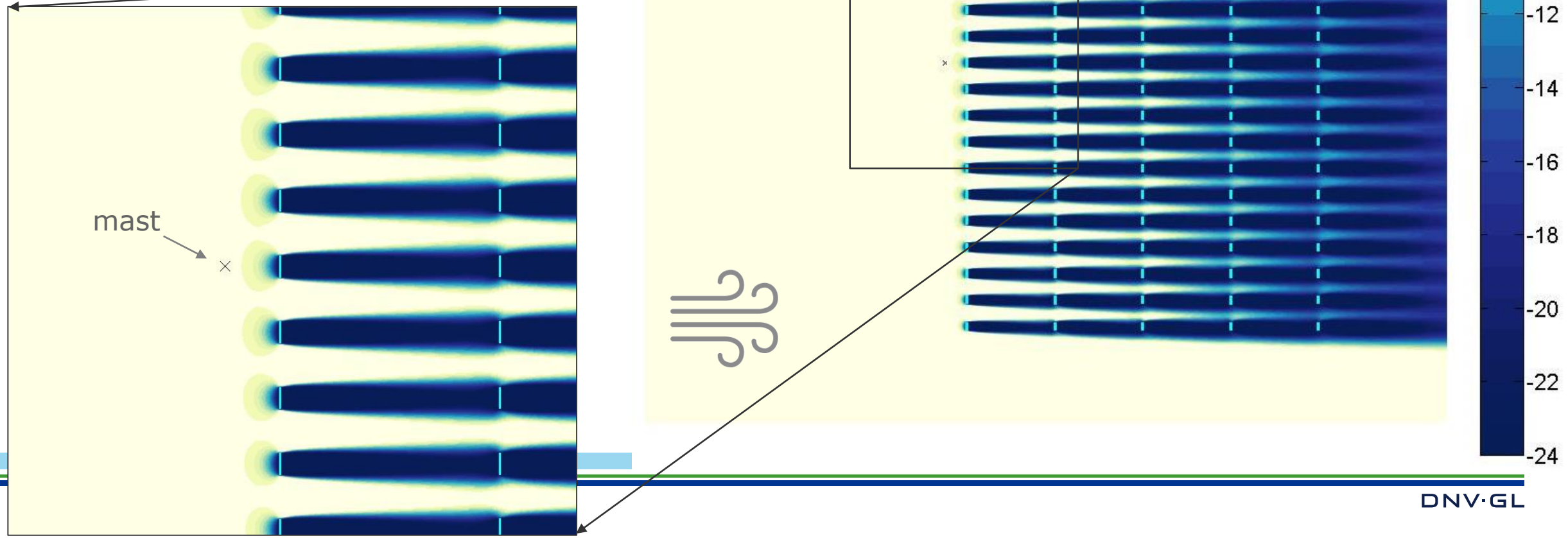


All results correspond to below rated conditions

Traditional assumptions in question

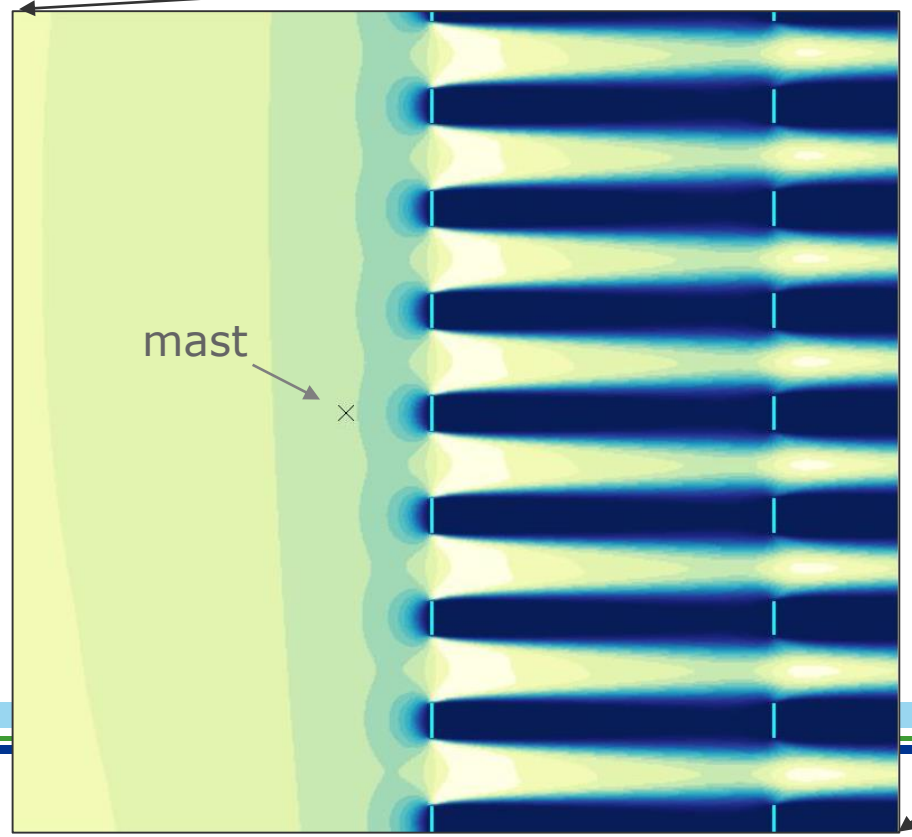
What is commonly assumed…

1) Measured power curves are a function of freestream wind speed
2) Turbines only impact downstream turbines (the wakes-only approach to turbine interaction)

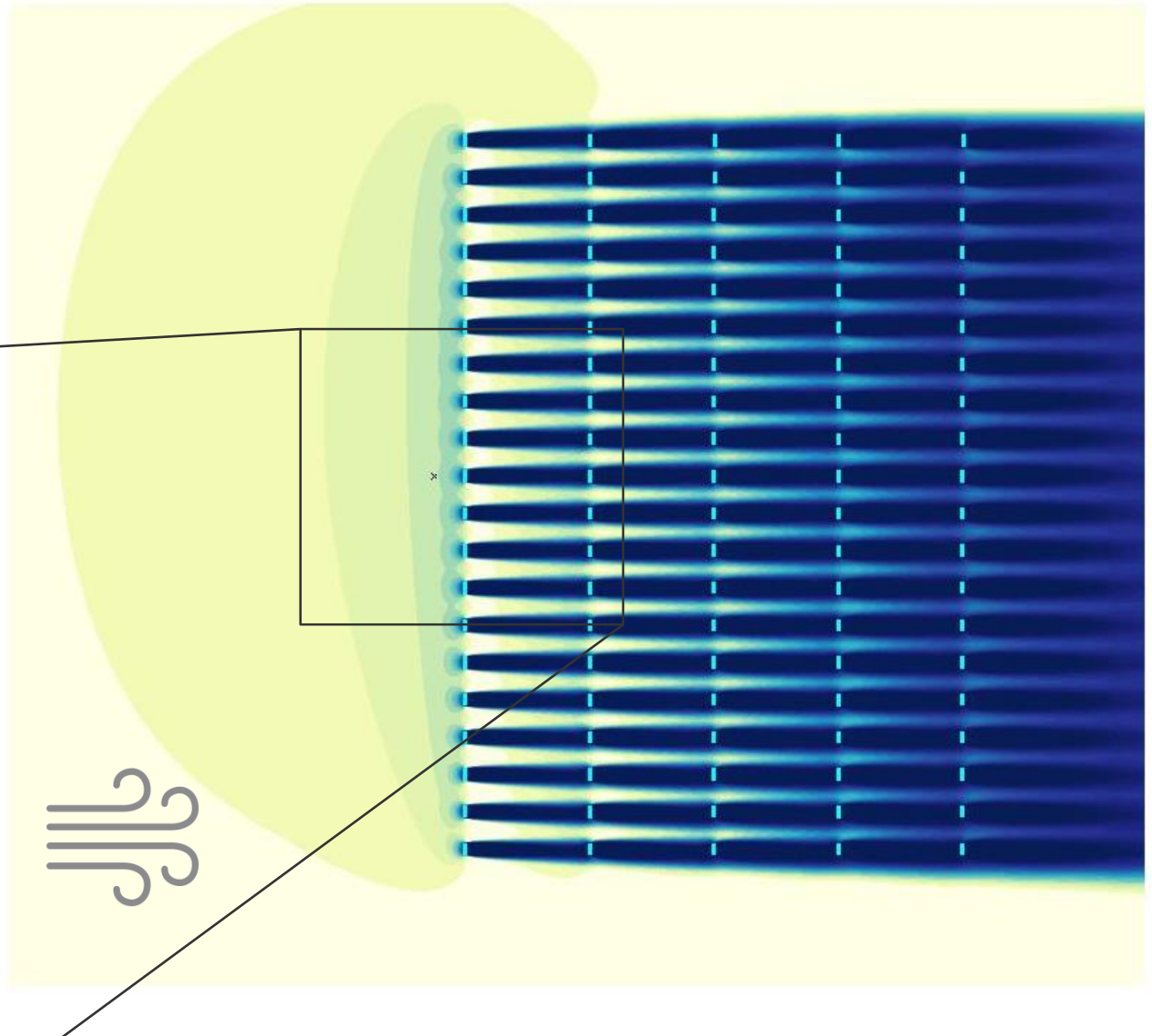


Assumptions are likely wrong…

1) Measured power curves are a function of freestream wind speed
2) Turbines only impact downstream turbines (the wakes-only approach to turbine interaction)



Percent change in wind speed relative to freestream
(flow from left to right)



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Blockage and turbine power curves

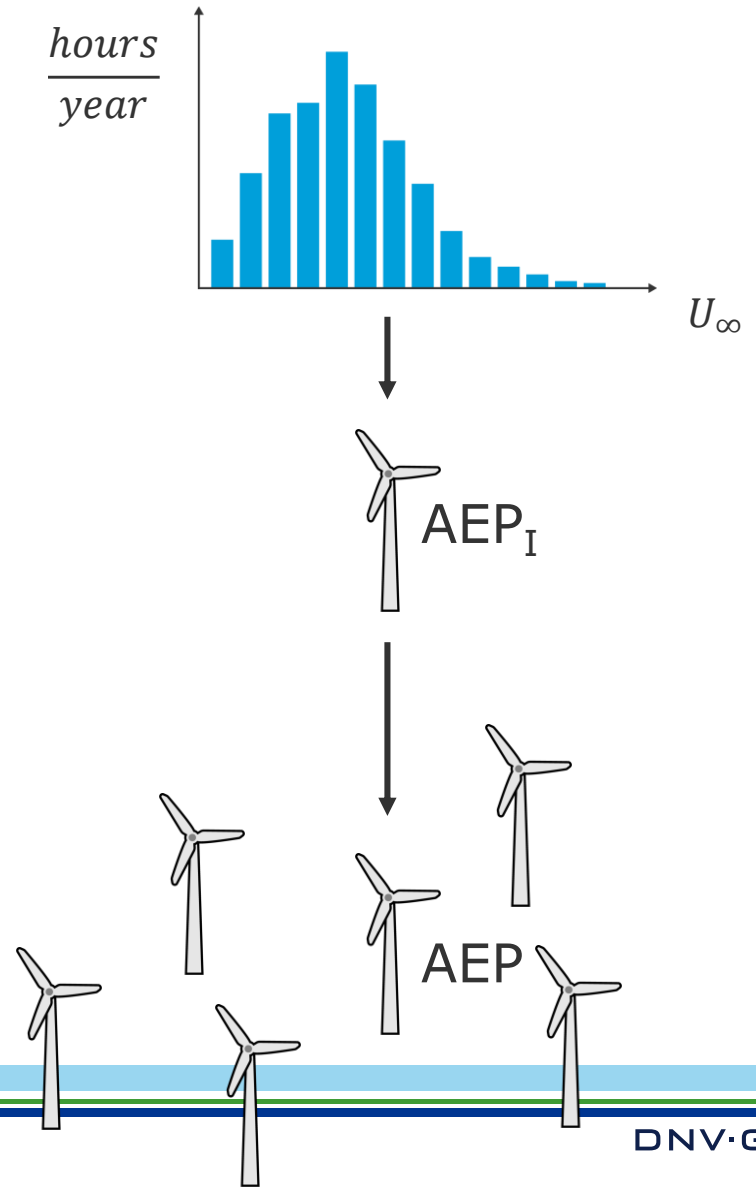
Theory

Accounting framework

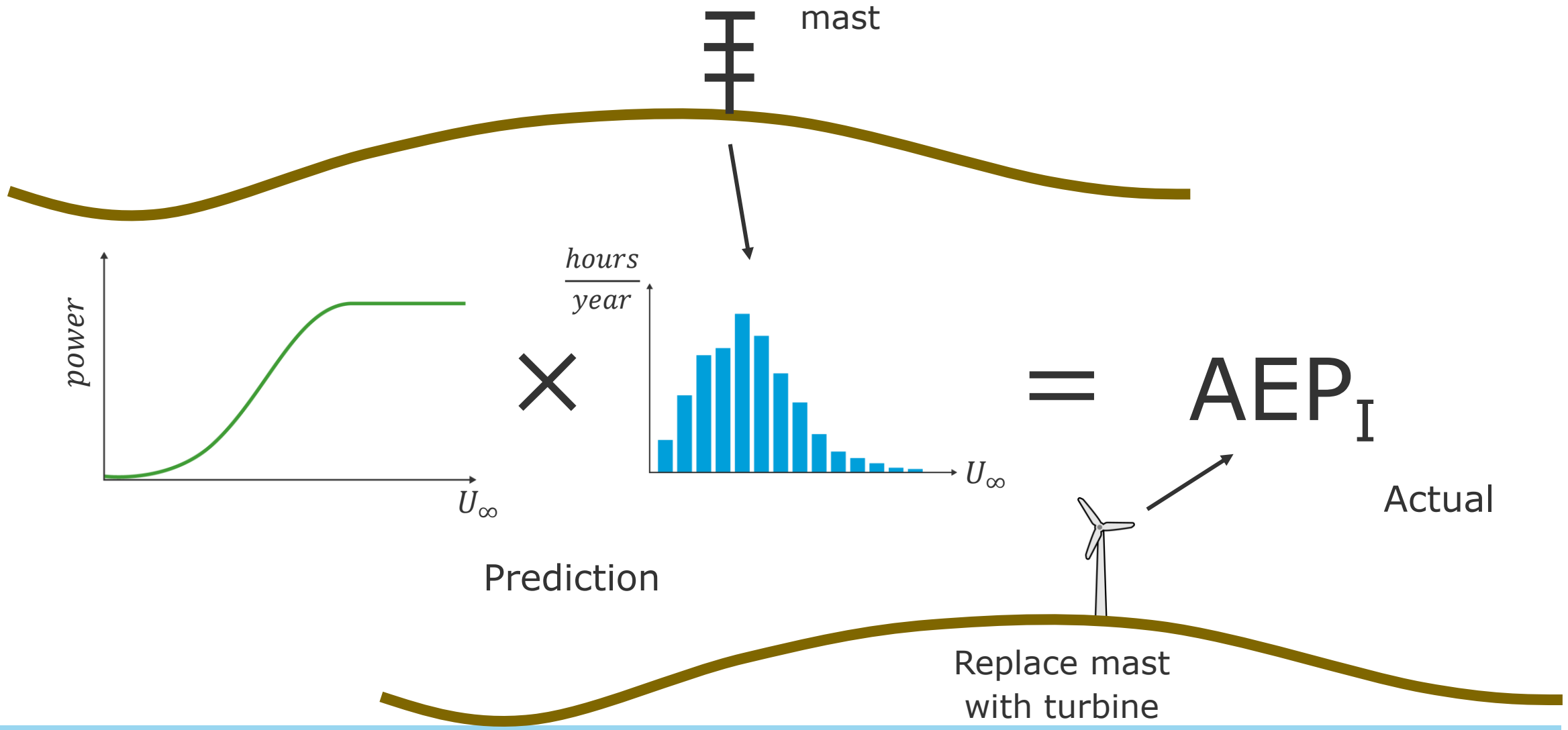
For a given freestream wind resource, accurate prediction of a turbine's energy production requires:

(1) A power curve that faithfully represents the turbine's production when operating in isolation

(2) An accurate estimate of how that production changes when the other wind farm turbines are present (i.e. the impact of turbine interaction effects)

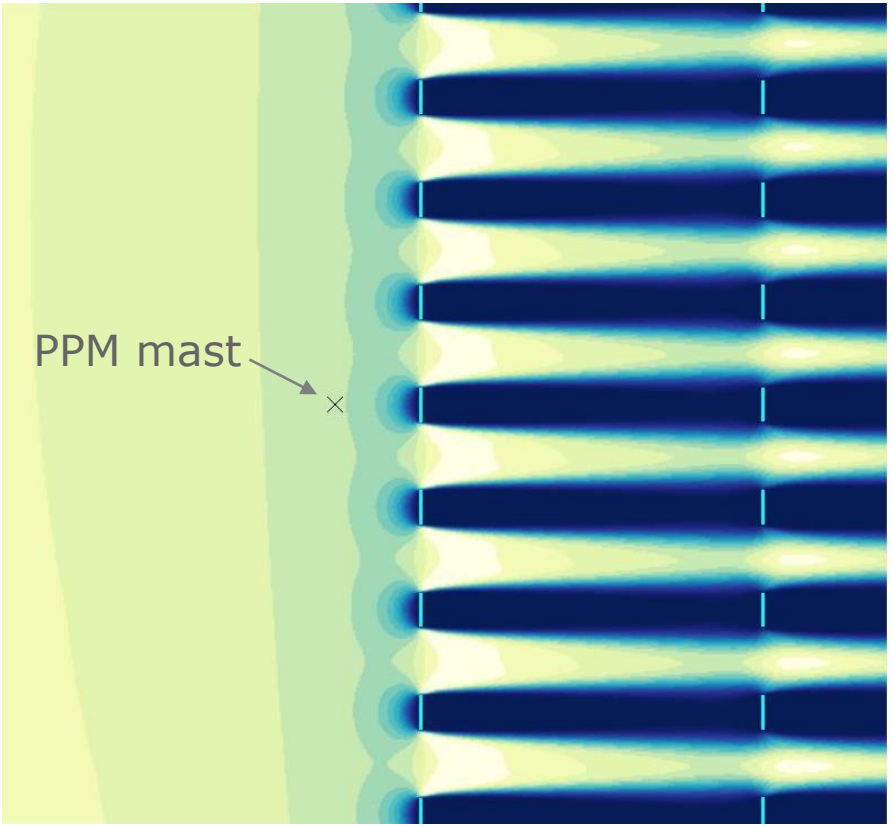


The power curve we need



Measured power curves vs. the power curves that we need

- The vast majority of power curve measurements occur at the perimeter of a wind farm
- The outcome of a power performance measurement (PPM) will differ from what we actually need (i.e. isolated turbine power vs freestream wind speed)
- The undue influence of blockage on the measured power curve should be corrected for



Power curve correction: How?

Input

Power curve consistent with results from typical power performance testing (in a wind farm)

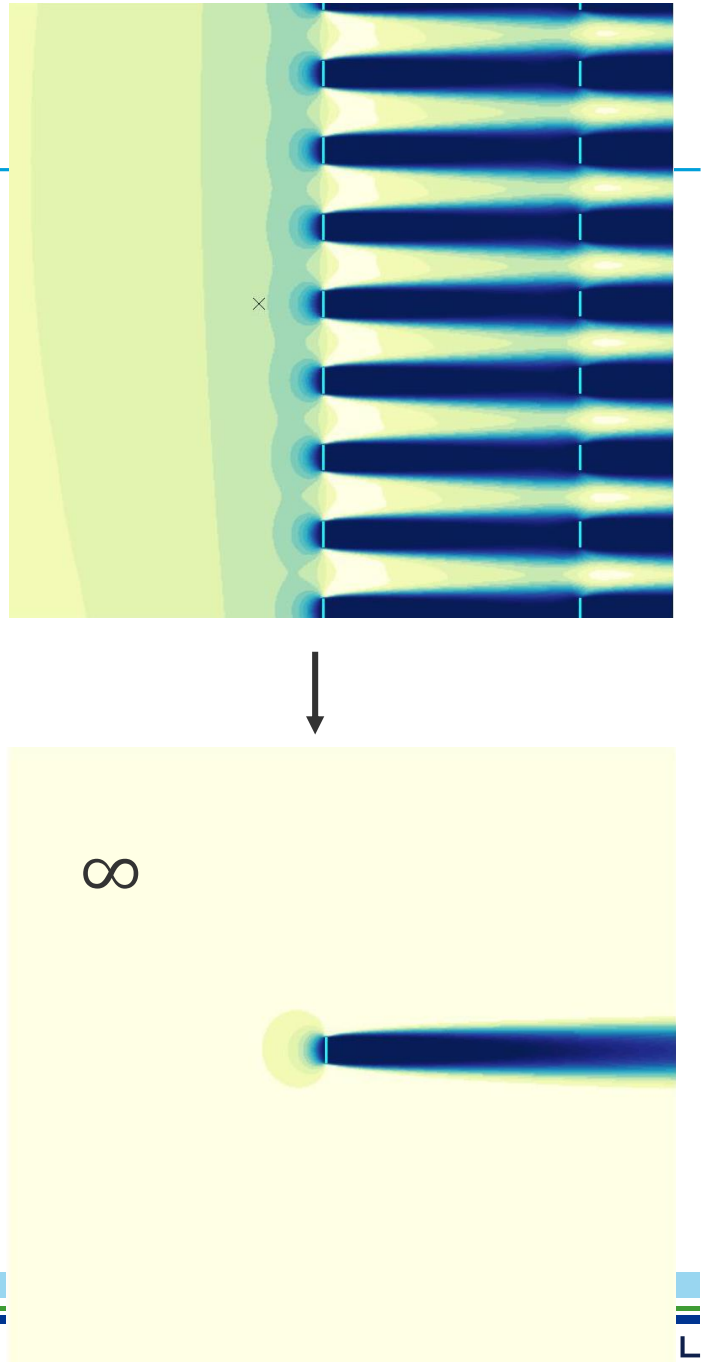
Process

a) Convert the measured power curve to what we would measure if the test took place on the turbine in isolation

b) Correct for the impact of induction from the isolated turbine on the mast wind speed

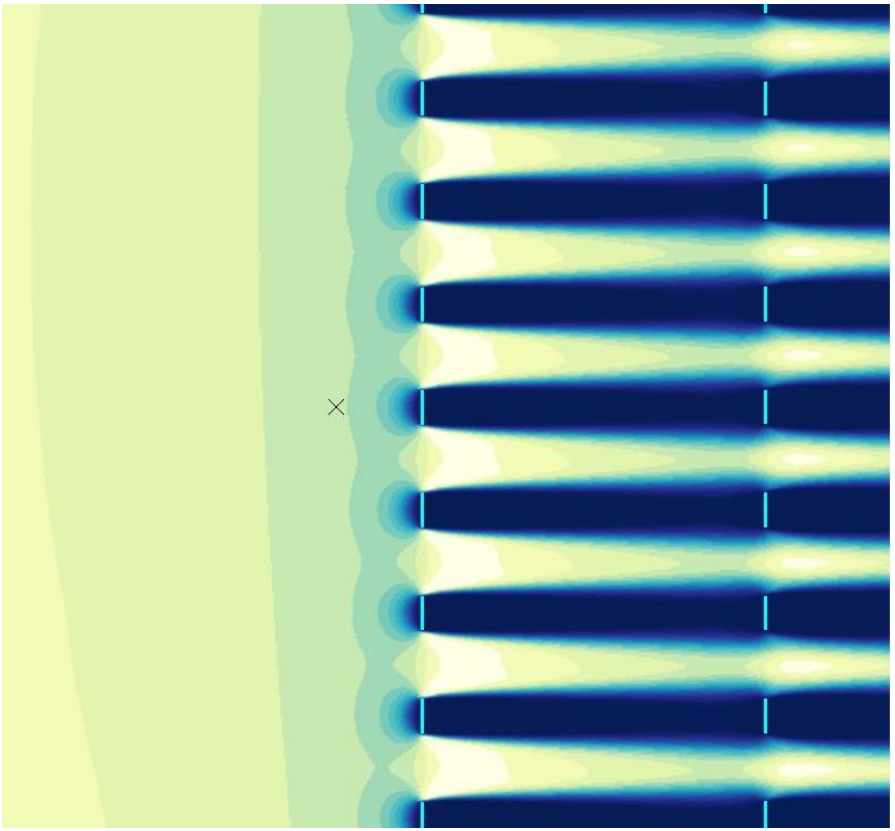
Output

A power curve that faithfully represents isolated turbine power as a function of freestream wind speed.



Power Curve Correction Step A: Test result for wind farm turbine → Test results for the turbine in isolation

- Turbine power is a function of the velocity distribution across the rotor face; the presence of other turbines does not change this function
- Relative to a test in isolation, neighbouring turbines can change the wind speed relationship between the mast wind speed and the rotor face
- To convert the wind farm test to an isolated test, we just convert the wind speed column of the power curve as follows:



$$U_{mast,isolated} = U_{mast,wind\ farm} \underbrace{\left(\frac{U_{rotor\ face}}{U_{mast}}\right)_{wind\ farm} \left(\frac{U_{mast}}{U_{rotor\ face}}\right)_{isolated}}$$

- Equal to 1.0 if the other wind farm turbines affect the wind speed at the mast and the test turbine rotor face equally (i.e. no correction)
- This correction factor varies with C_t

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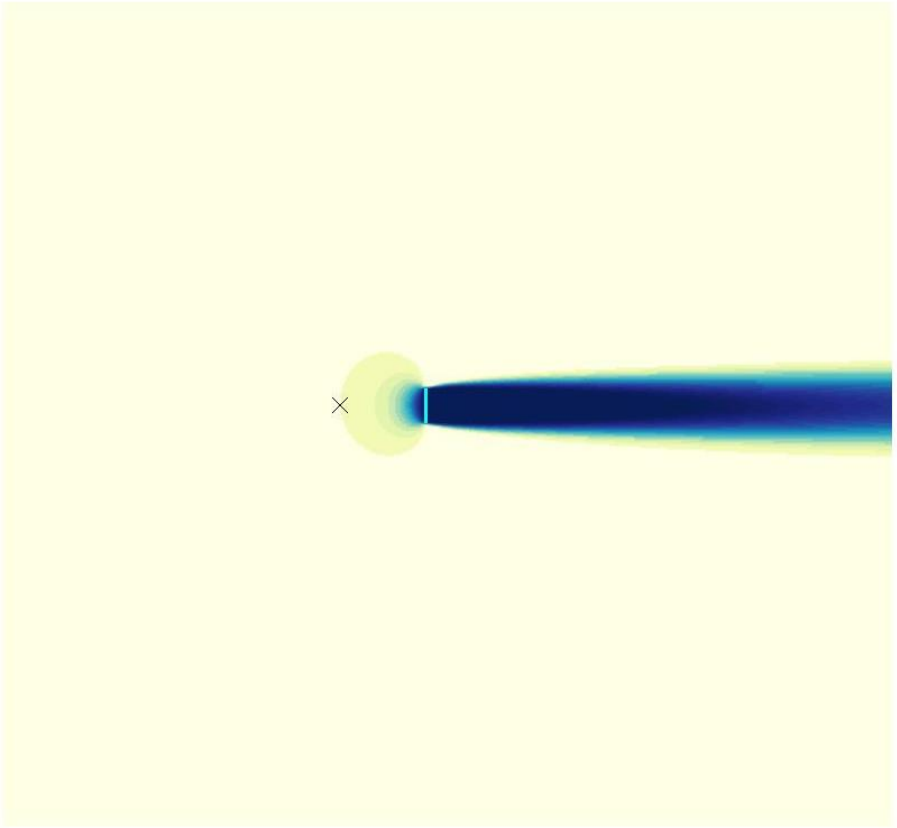

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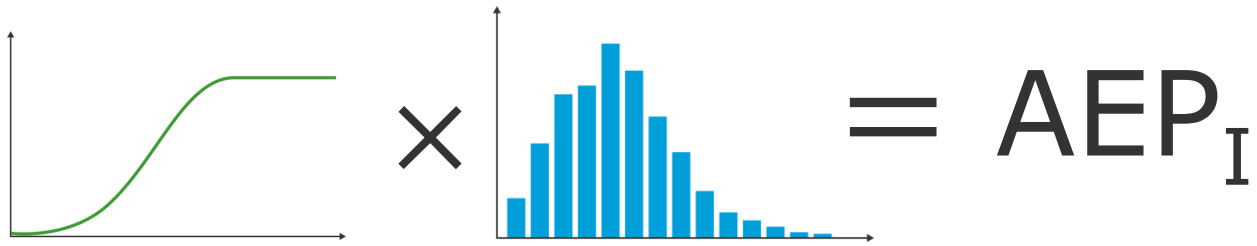
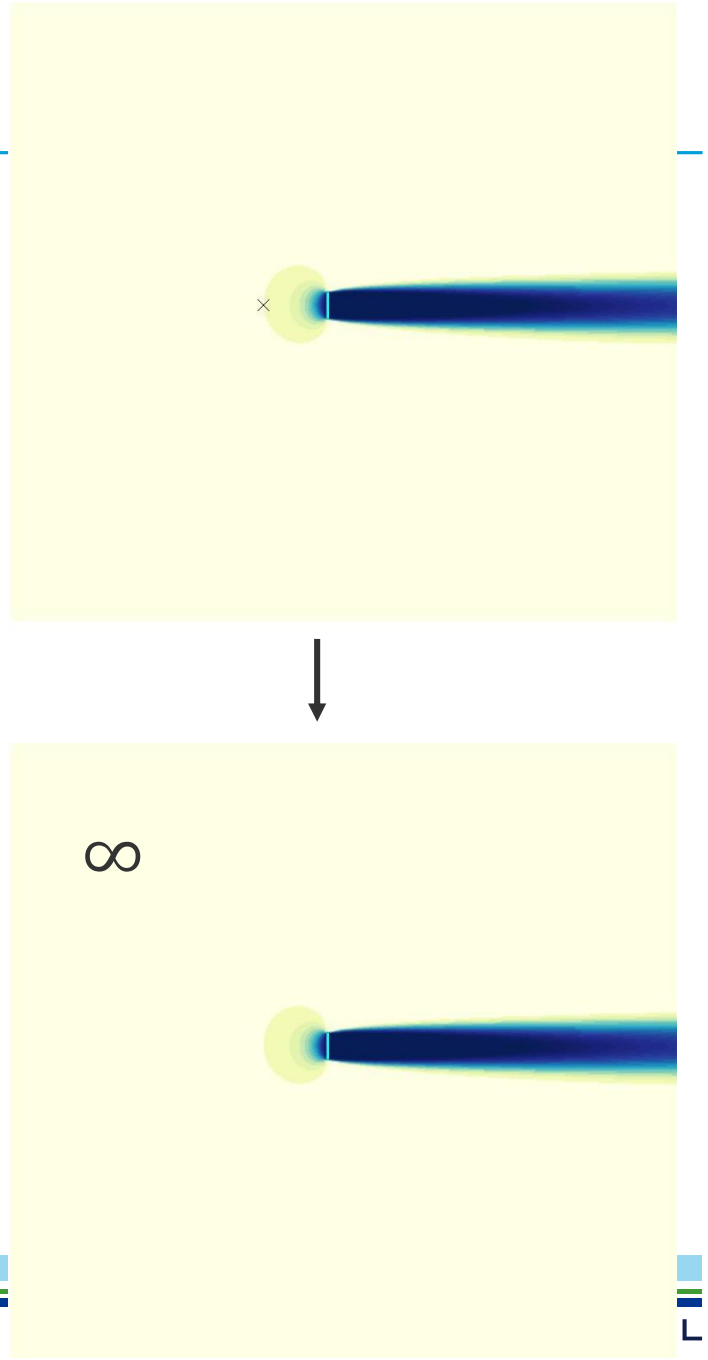
Power Curve Correction Step B: Remove the impact of local blockage (induction) on measured wind speed

- Use isolated turbine simulations to estimate the induction effect and replace the measured wind speeds in the power curve table with (higher) freestream wind speeds.

- Now we have a power curve that makes this true:

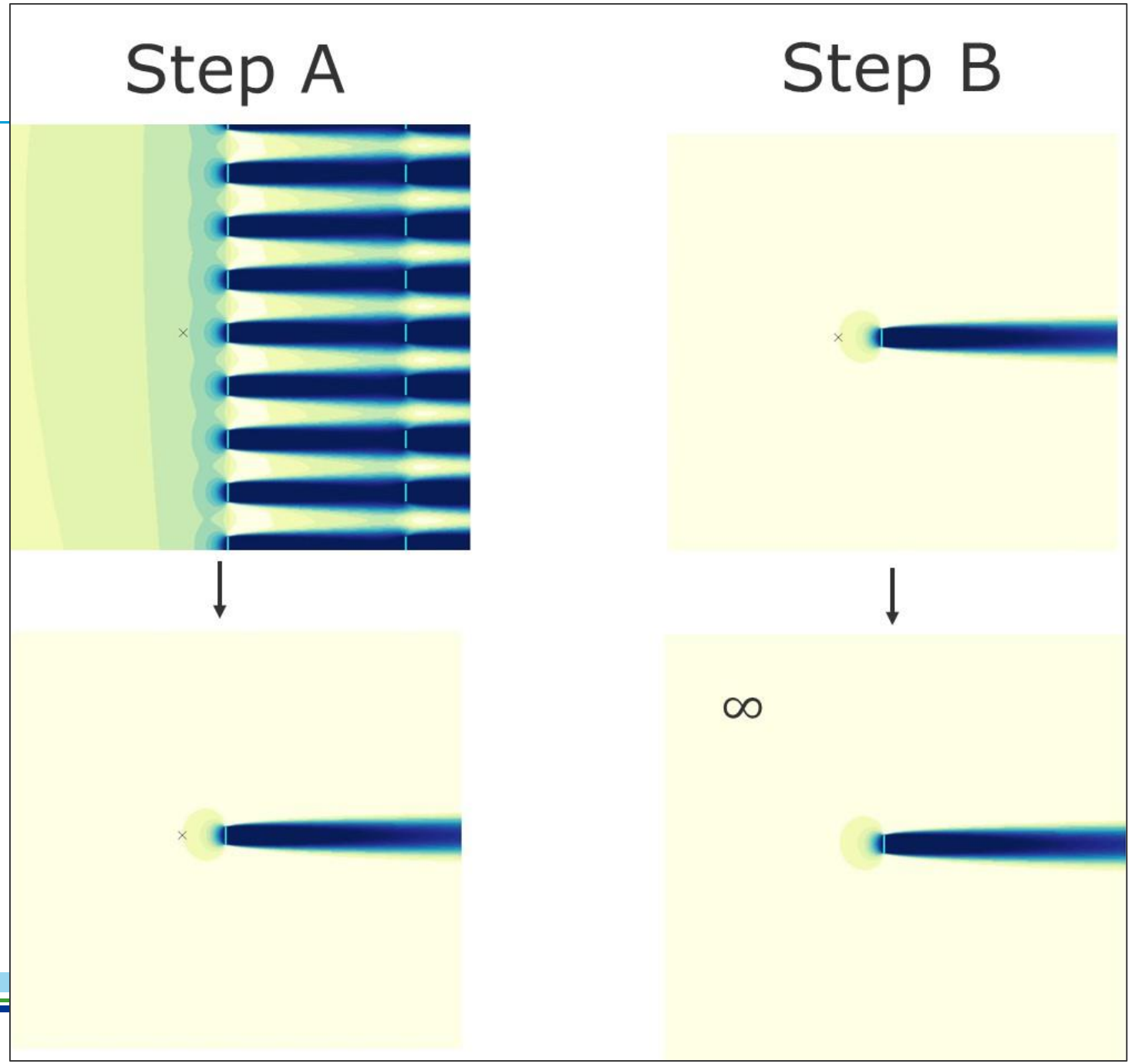




Quick recap of this method

- A measured power curve has two columns: wind speed and power
- We adjust only the wind speed* so that it corresponds to freestream wind speed when the test turbine is producing the same amount of power in isolation
- The power column stays the same

*There is another path to the same curve that involves adjusting both columns, but we are not using that approach.

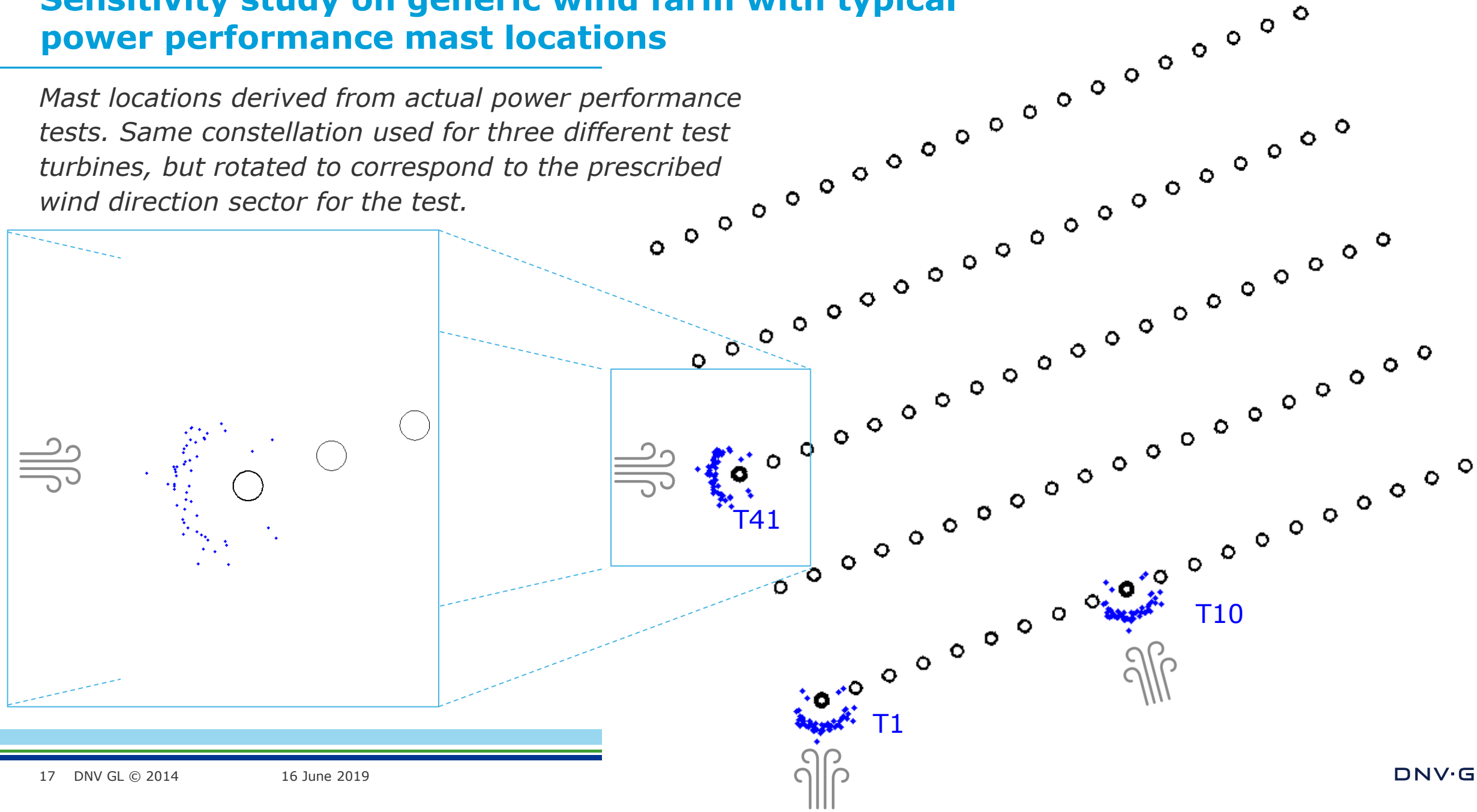


Blockage and turbine power curves

Simulation

Sensitivity study on generic wind farm with typical power performance mast locations

Mast locations derived from actual power performance tests. Same constellation used for three different test turbines, but rotated to correspond to the prescribed wind direction sector for the test.



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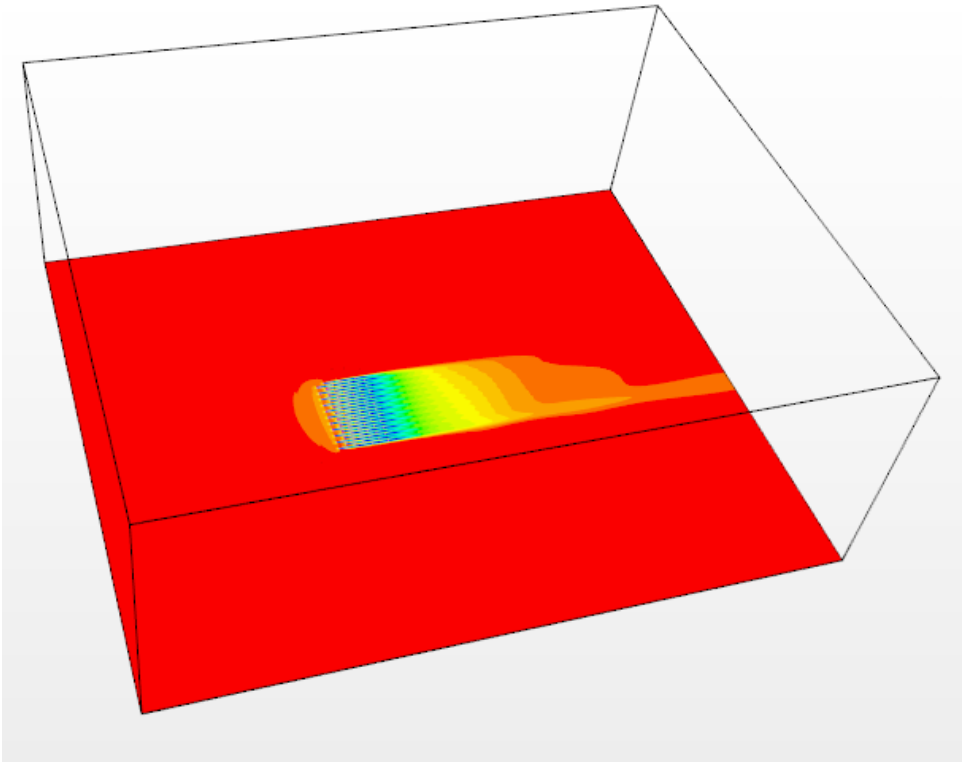
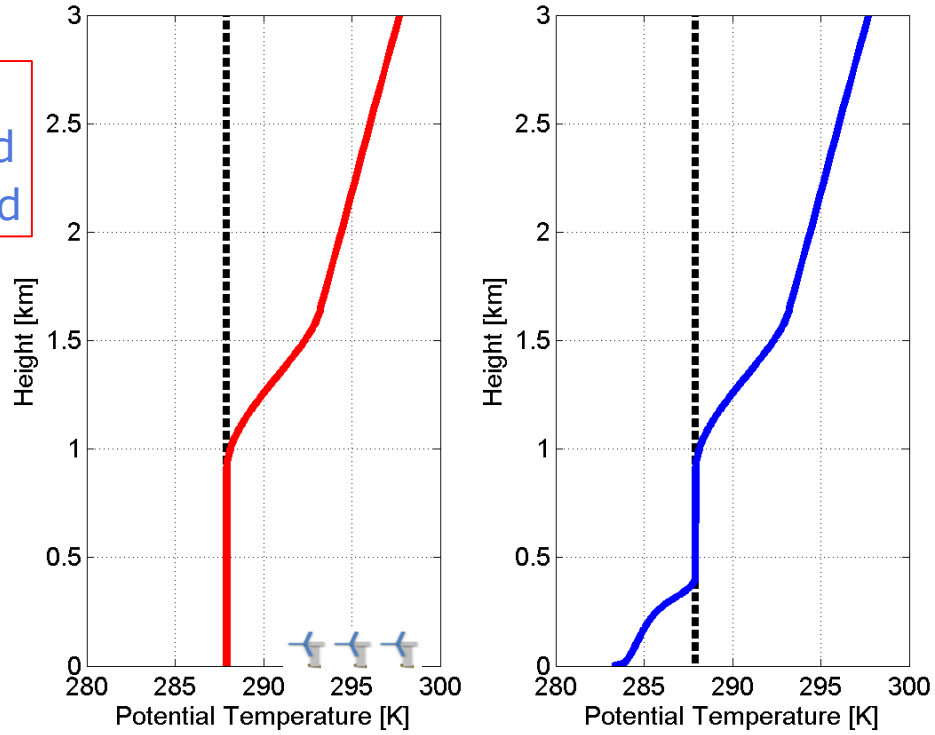
Flow modelling approach – Solver, domain, and boundary conditions

- STAR-CCM+, steady RANS, k-ε, buoyancy included
- All boundaries, except the ground, are at least 15 km from the wind farm
- Simulations: Wind farm, freestream, and isolated turbines
- Neutral BL and stable BL



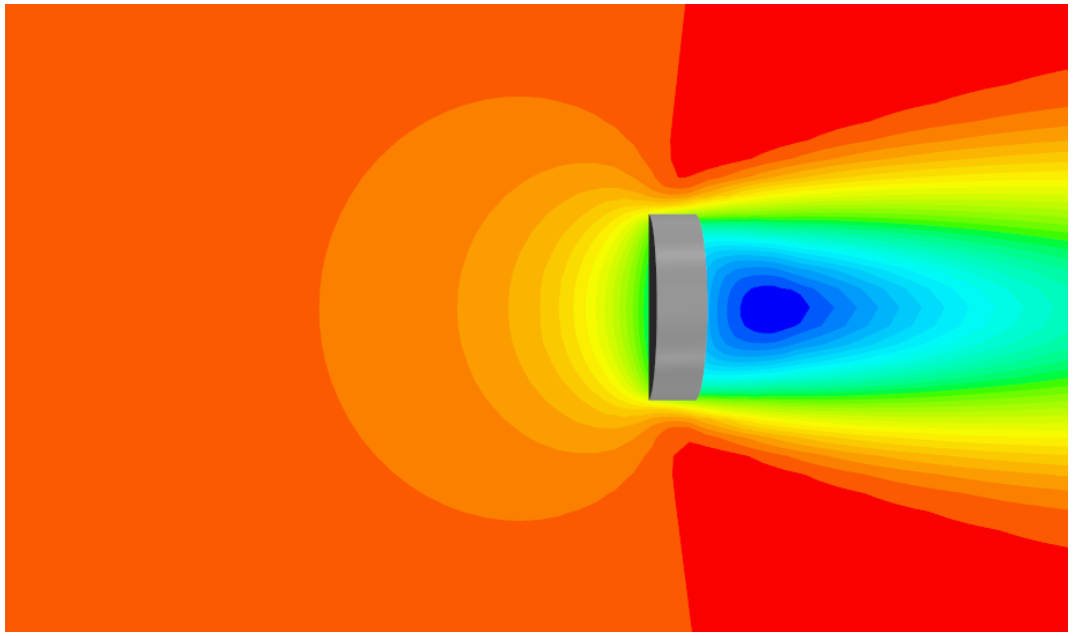
Atmospheric stability within and above BL simulated

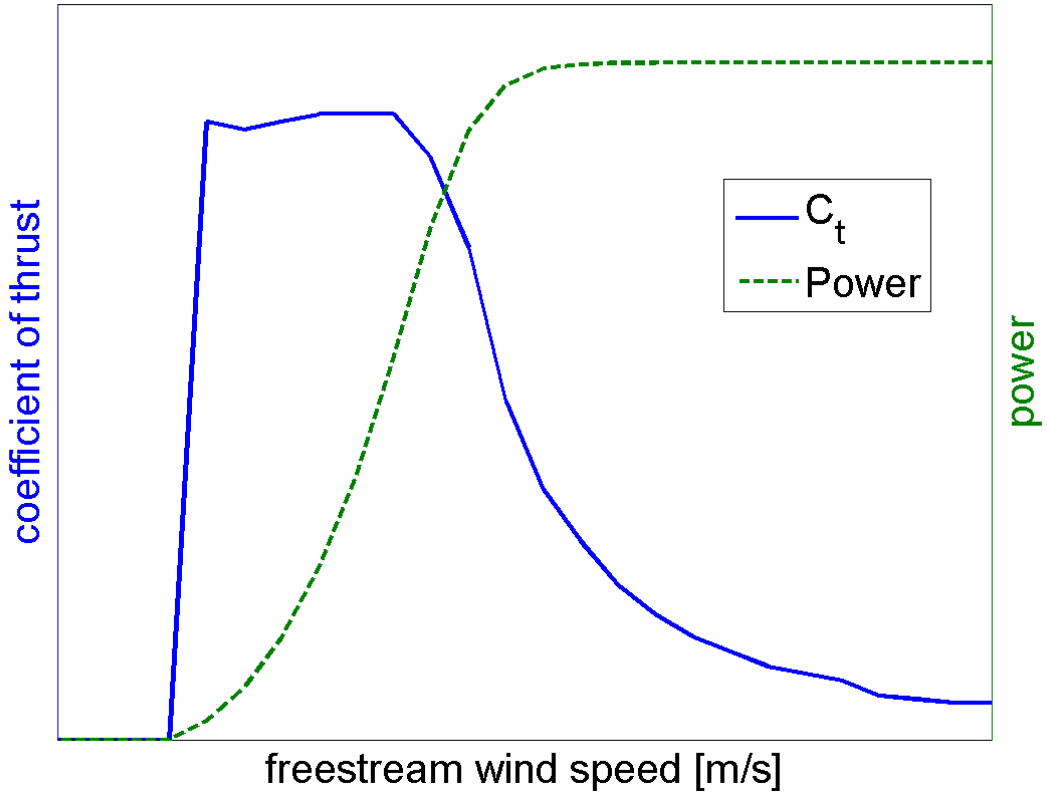
Neutral BL **Stable BL**



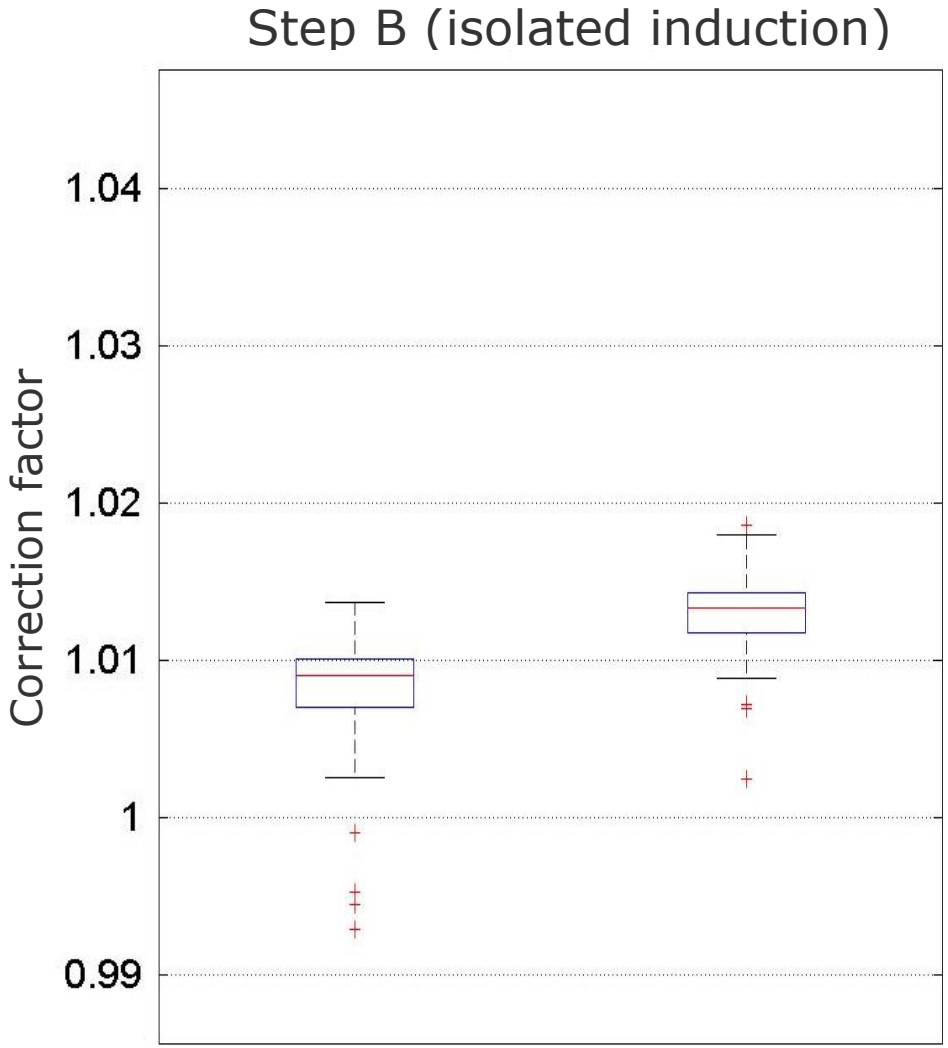
Flow modelling approach – Representing the wind turbines

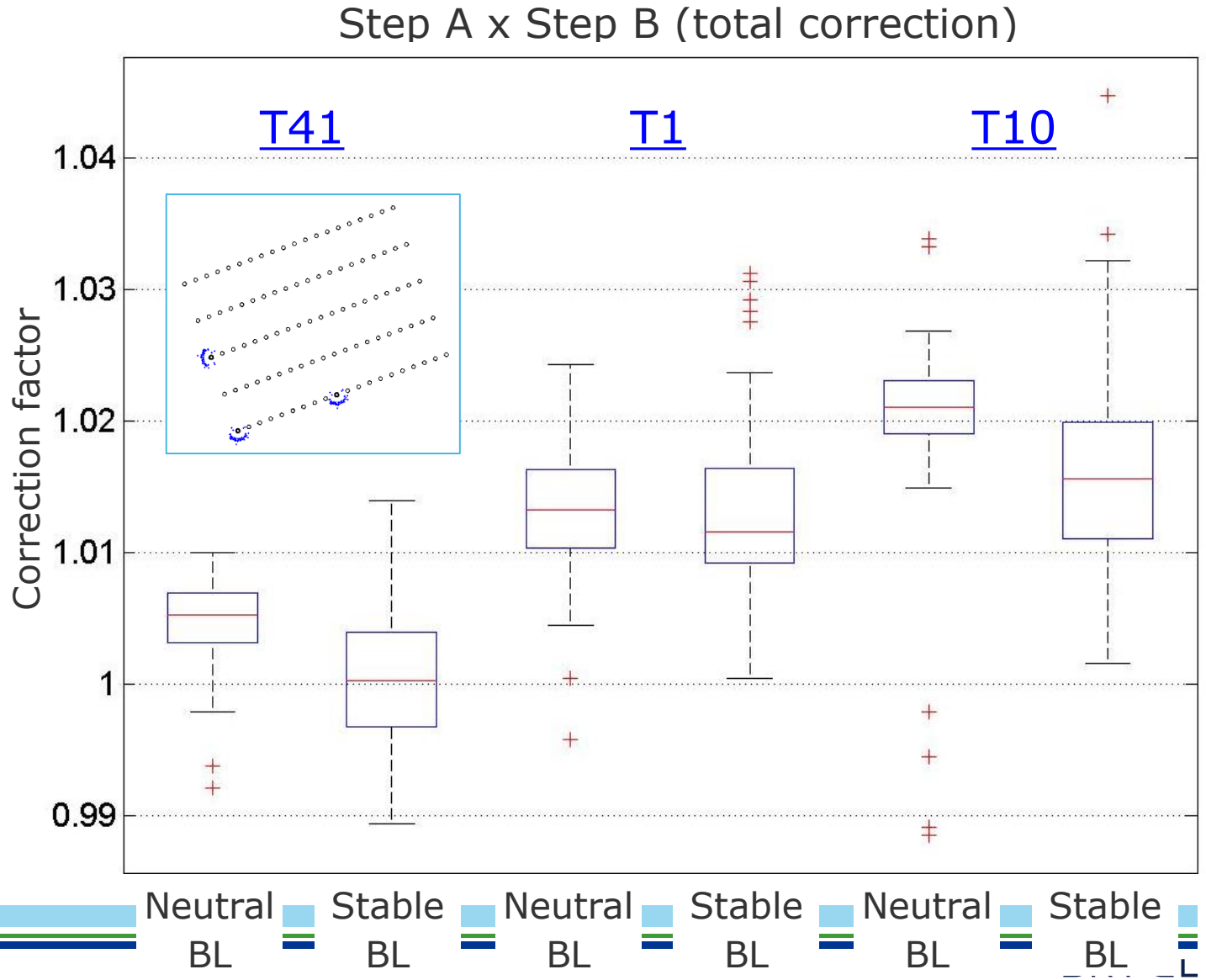
- Wind turbines represented with a simple actuator disk
- Body forces applied based on curves of C_t, power, and rotor speed
- Simulated wind speeds are close to peak C_t, where any blockage effect would be maximized





Results indicate significant sensitivity to mast position, test turbine location, and atmospheric stability





Summary

- Measurements show that blockage can significantly affect the wind speeds measured during a power performance test
- Simulations indicate that the impact of blockage on a measured power curve can also be significant
- Measured power curves should be corrected to remove the undue influence of blockage
- The correction factors can be quite sensitive to the details of the test configuration and site-specific factors, such as wind farm layout and atmospheric stability
- These findings suggest that power curves provided by OEMs should also be corrected because in general these curves are similar to or more energetic than measured curves

Thank you for listening

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Power curve correction alternative

- Proposed approach involves correcting the wind speed only in a two step process.

- An alternative involves correcting both wind speed and power
  - Correct mast wind speed to correspond to freestream
  - Correct wind farm turbine power to correspond to the power it would produce in isolation

- Perhaps more straightforward conceptually. Less straightforward to implement?