

# How small is small enough?

On the impact of numerical grid spacing on large-eddy simulation  
of a GW-scale wind farm

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# Motivation

- Mesoscale-coupled Large-Eddy Simulation (LES) based weather model (ASPIRE)
- Real-world Wind Resource & Energy Yield Assessments
- Affordable *and* accurate

*What is the impact of LES grid spacing?*

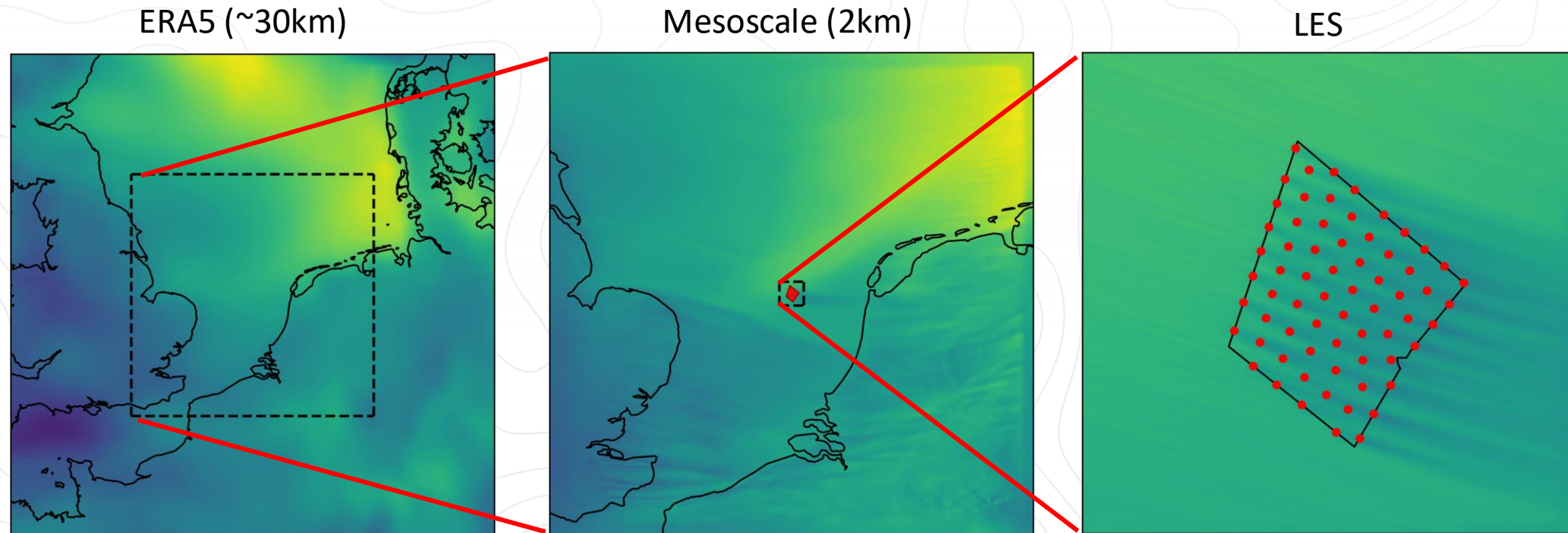
- Free-stream conditions?
- Wind farm production?
- Wake losses?
- Downstream wakes?
- Turbine-level production?



# Setup of the grid-refinement study (1 / 2)

*Aim: investigate sensitivity to LES grid spacing for practical EYA*

- Take a planned North Sea wind farm as a case study (67 turbines of 15 MW, ~1GW)
- The LES is nested in a Mesoscale model, which is nested in ERA5
- 30 days, selected from 2023, were simulated (K-means clustering)

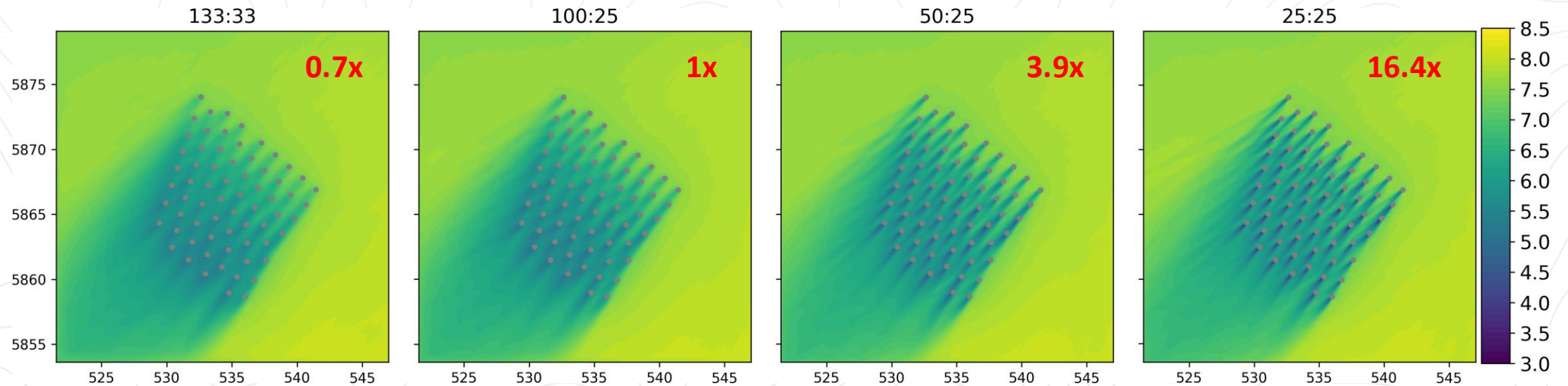


# Setup of grid-refinement study (2 / 2)

*Aim: investigate sensitivity to LES grid spacing for practical EYA*

- 4 LES grid spacings considered: 133m, 100m, 50m, and 25m.
- Horizontal (25.6km) and vertical (3km) domain size kept the same
- In addition: simulations with the turbine thrust set to 0 to obtain gross production
- Turbines are simulated by an Actuator Disk Model

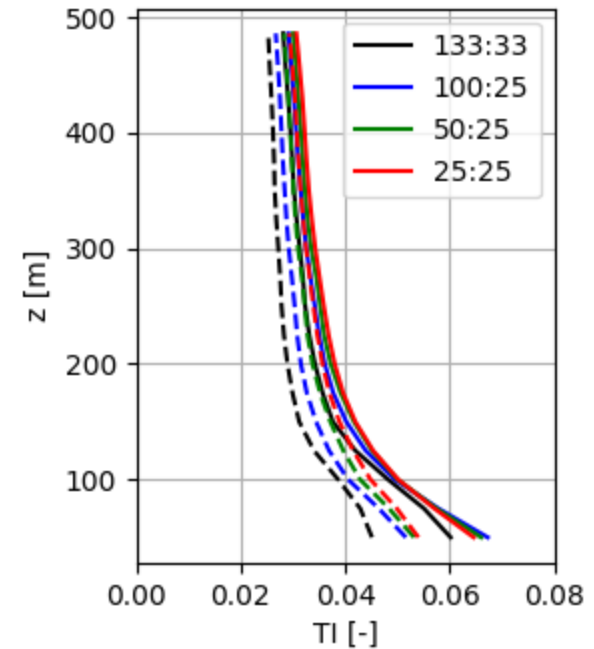
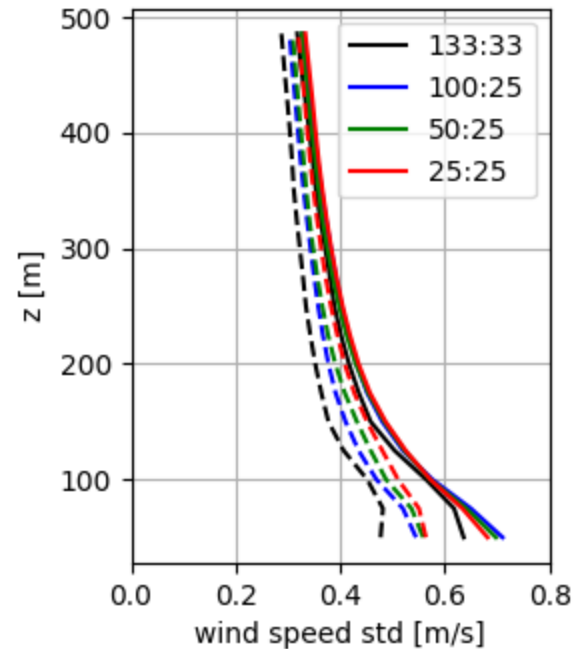
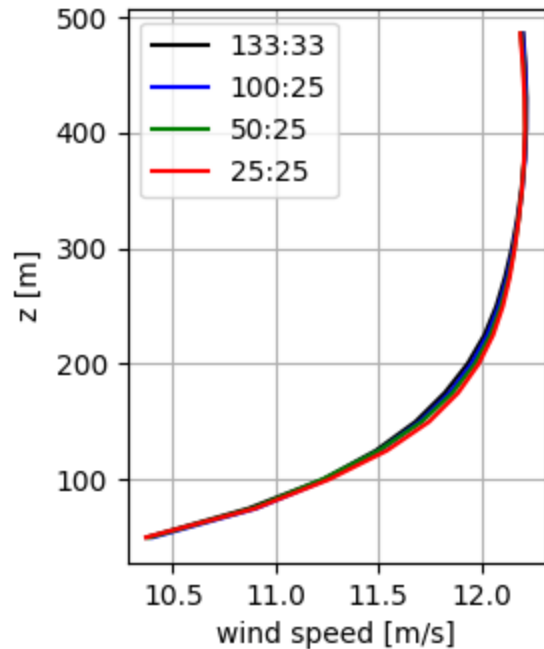
Simid	Nxy	$\Delta xy$	$\Delta z$
133:33	192	133 m	33 m
100:25	256	100 m	25 m
50:25	512	50 m	25 m
25:25	1024	25 m	25 m



Mean hubheight (150 m) wind speed for NE flow  
(wall-clock time w.r.t. 100:25)

# Free-stream conditions, mean profiles

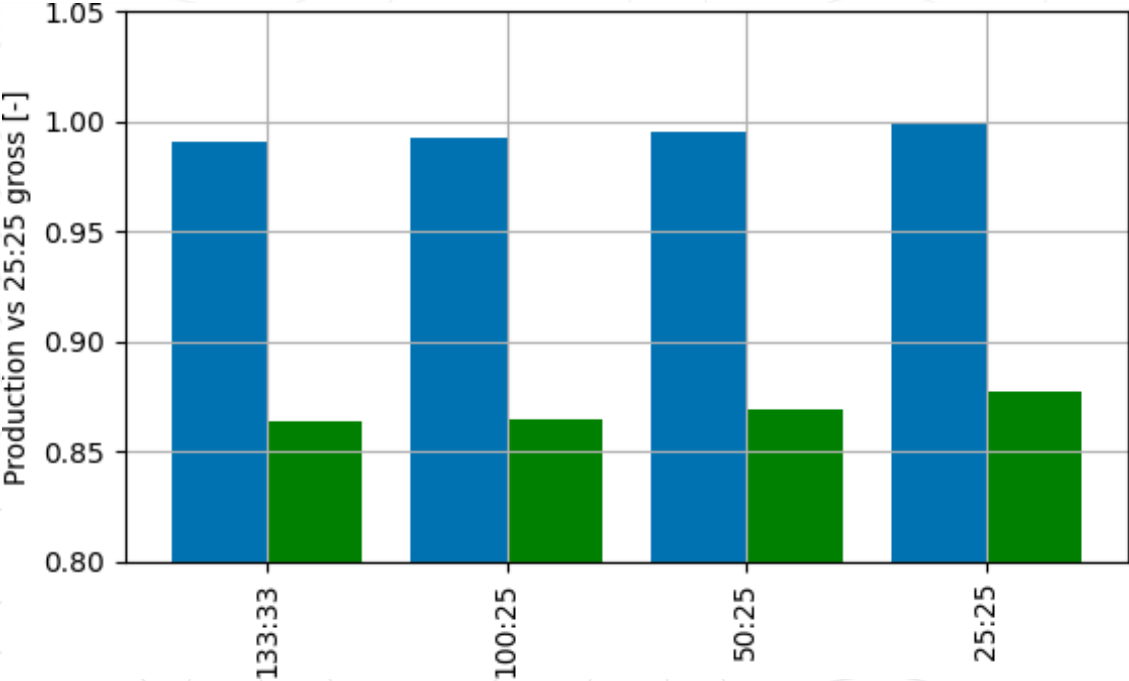
- Impact of LES grid spacing on free-stream wind speed small but non-zero
- Sum of resolved and subgrid turbulence remains constant, the distribution between the two changes



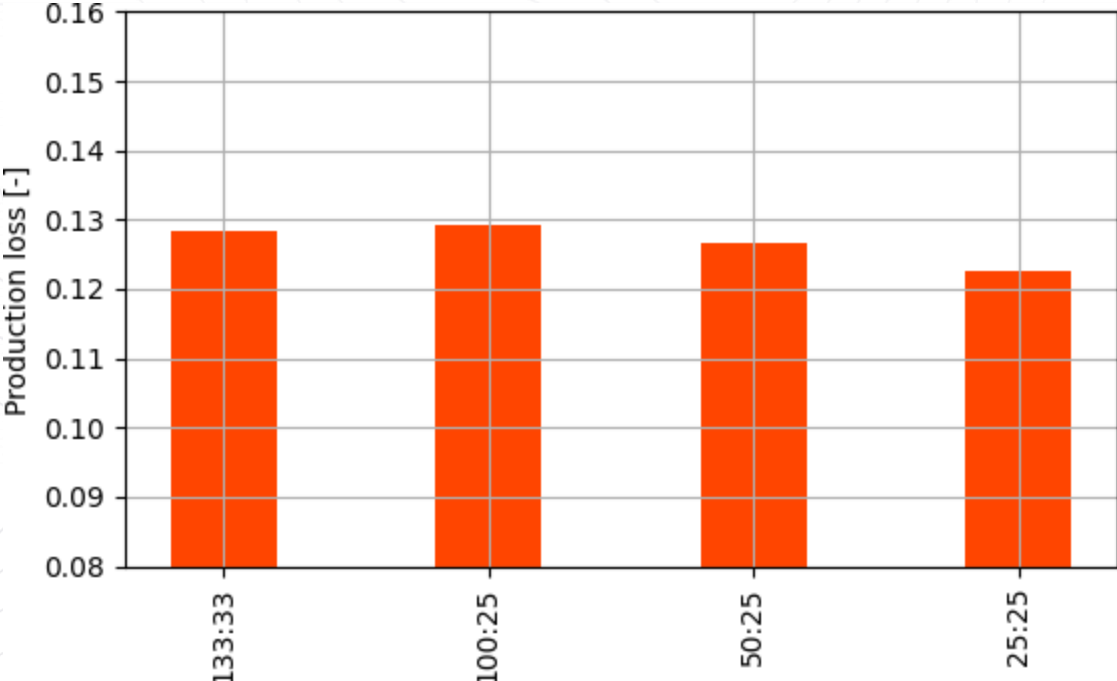
Dashed lines: resolved contribution only  
Solid lines: resolved + subgrid model contribution

# Wind farm production & losses

- The 0.9 % impact on gross production is associated with change in free-stream wind speed
- The impact on wake losses is within 0.6 %-point
- The waked production varies by 1.6 % between the 133 and 25 m grid spacing

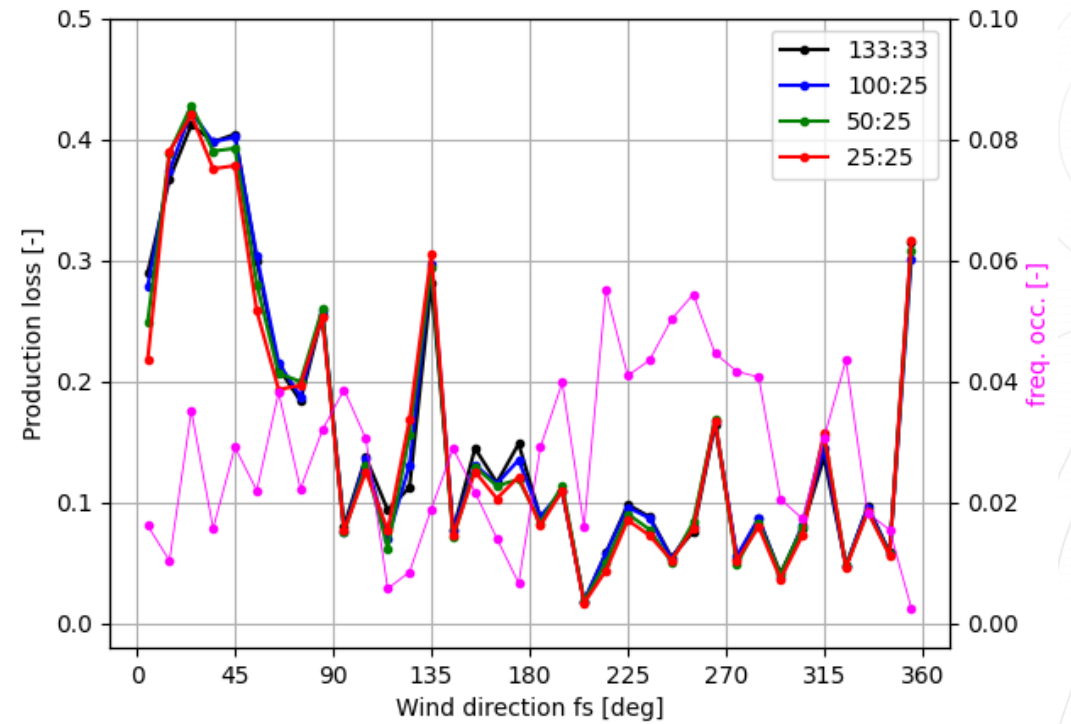
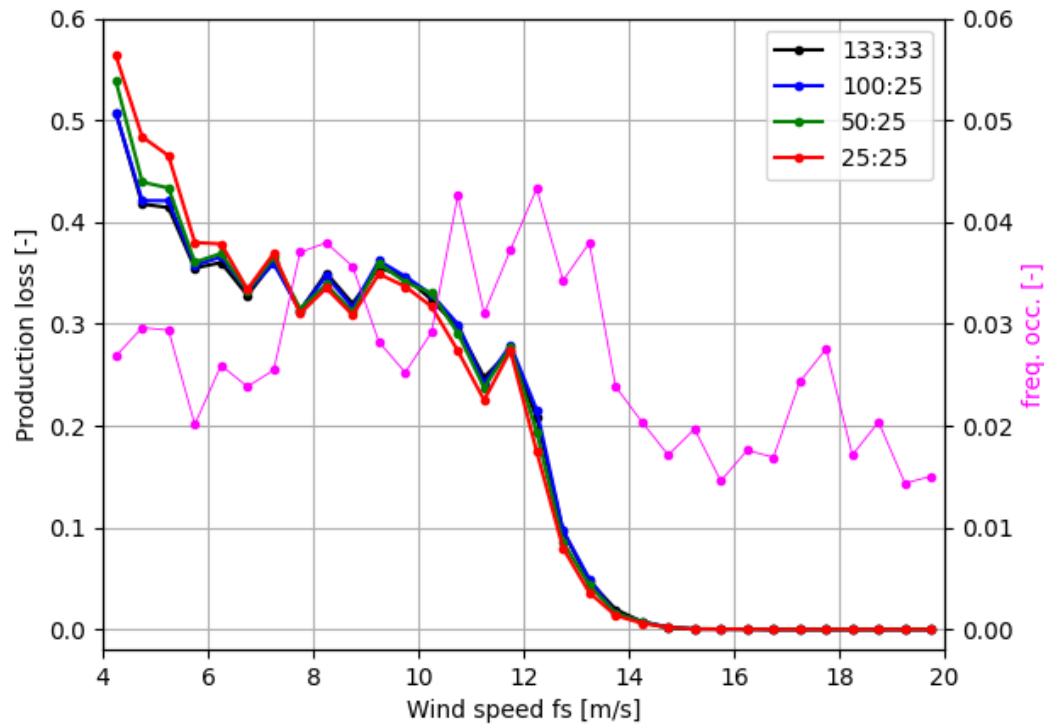
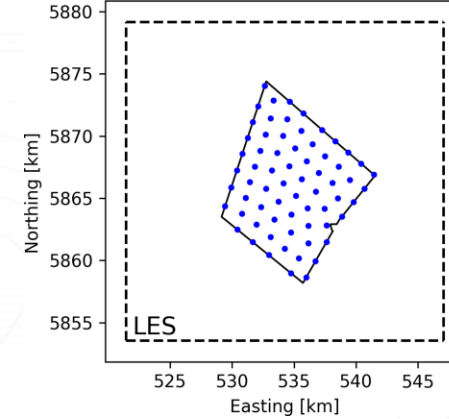


Gross production  
Waked production



# Losses as a function of wind speed & direction

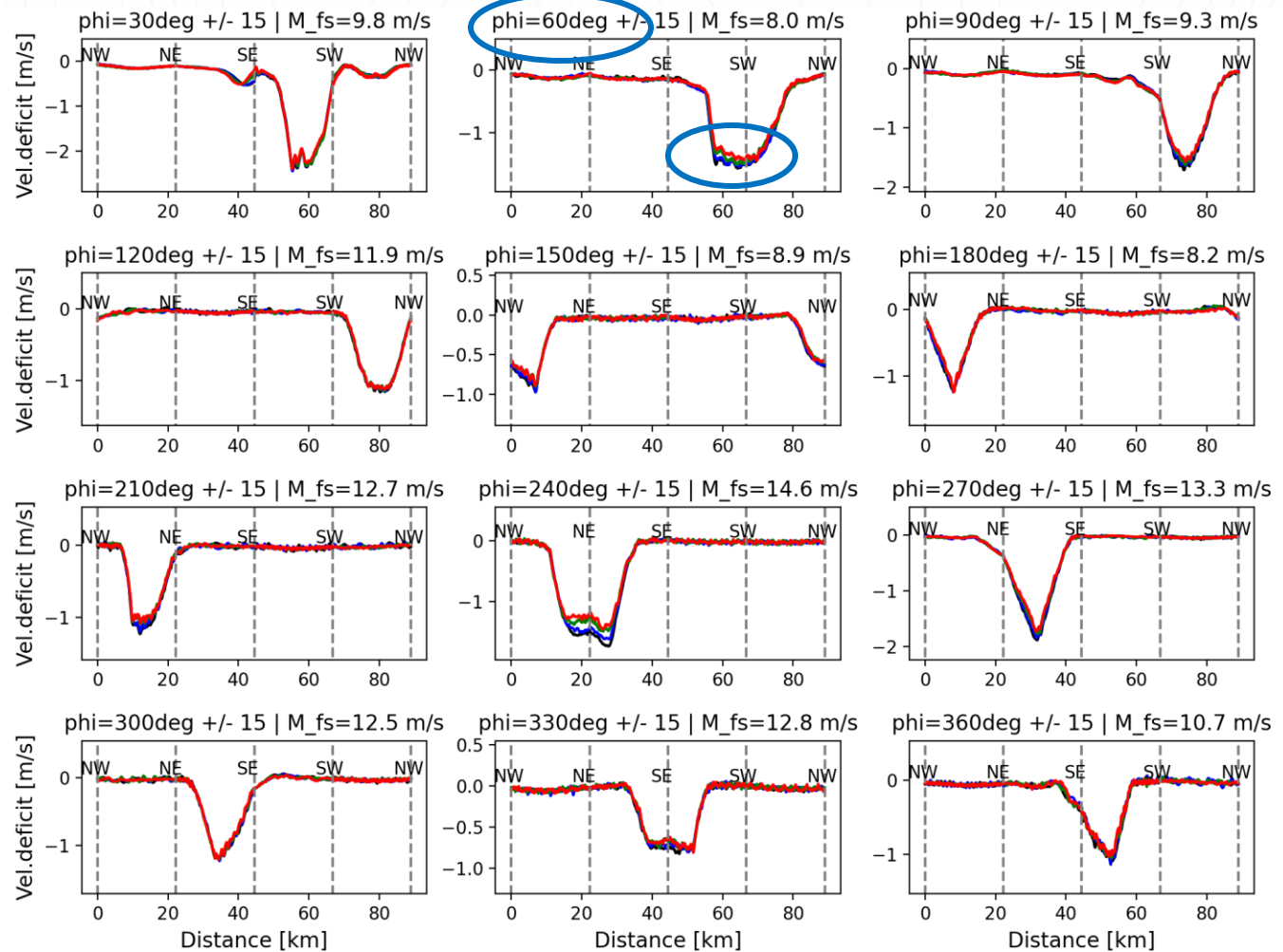
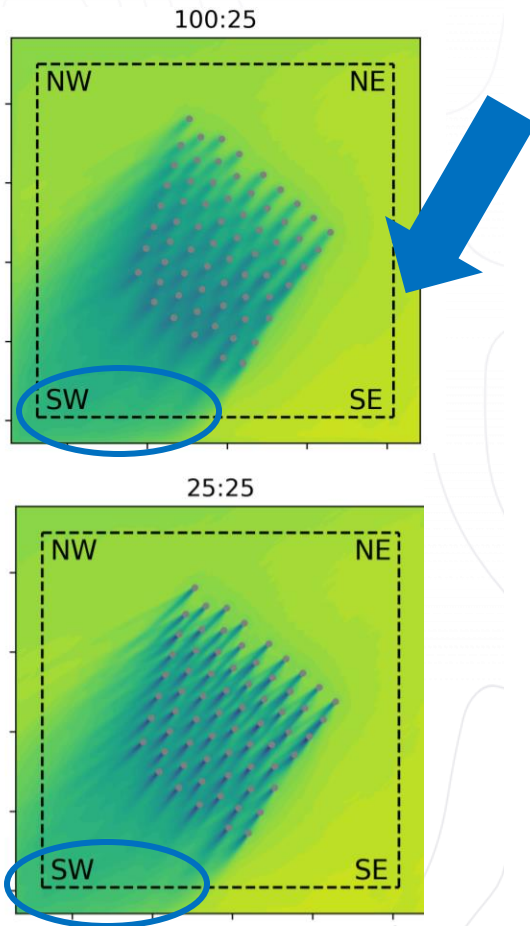
Generally good agreement, for some wind speeds and directions differences occur



Prod. Loss [-]	133:33	100:25	50:25	25:25
Overall	0.128	0.129	0.127	0.123
6 < U < 12 m/s	0.308	0.310	0.306	0.298

# Wind farm wakes

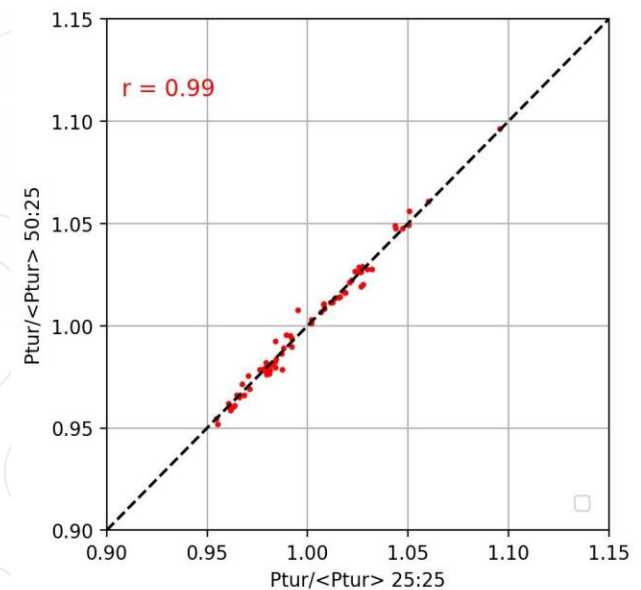
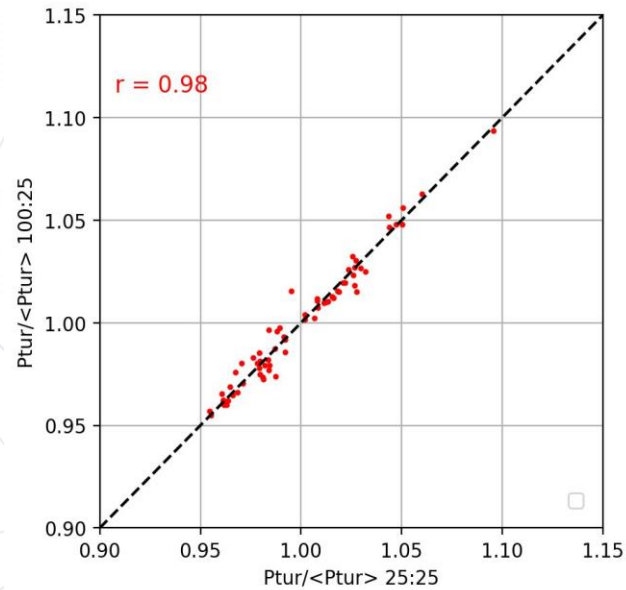
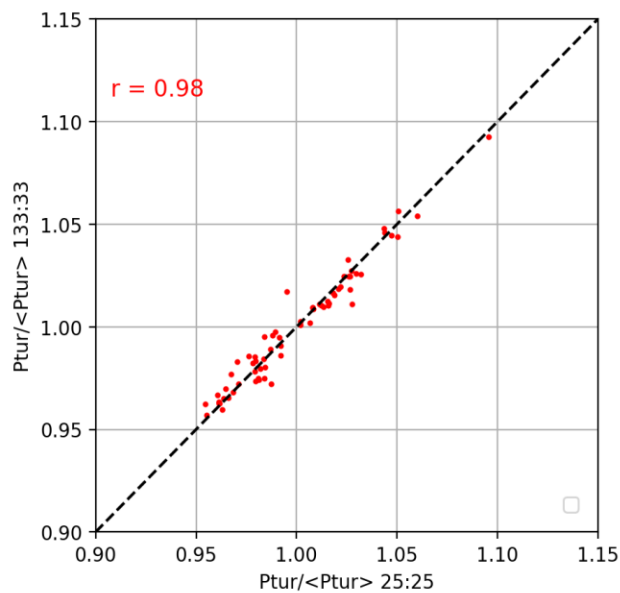
Velocity deficit along NW -> NE -> SE -> SW -> NW transects for 30° direction sectors



# Wind farm Pattern-of-Production

Pattern-of-production: For each turbine, calculate the mean turbine power ( $P_{tur}$ ) divided by mean power of all turbines ( $\langle P_{tur} \rangle$ ). Indicates how *spatial patterns* are represented.

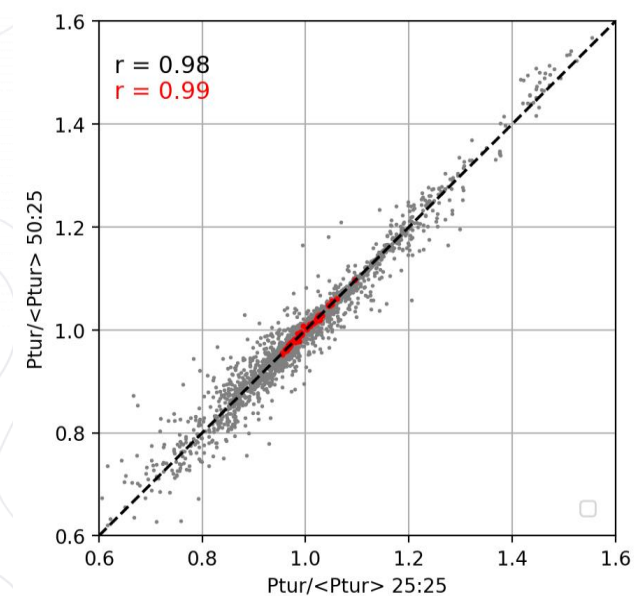
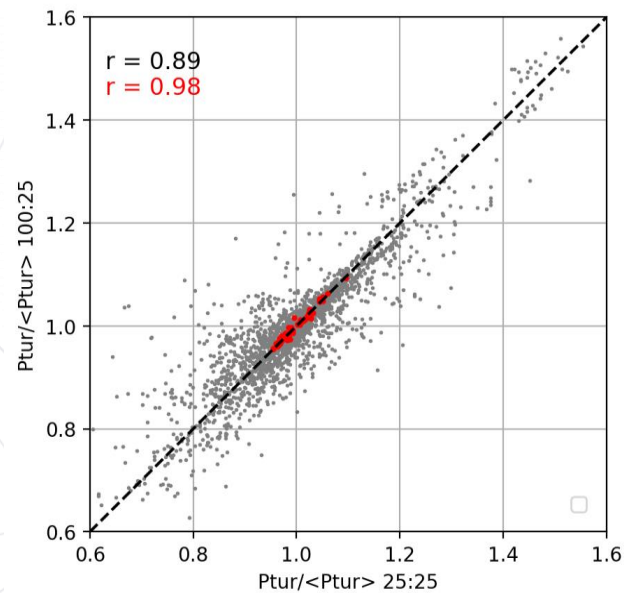
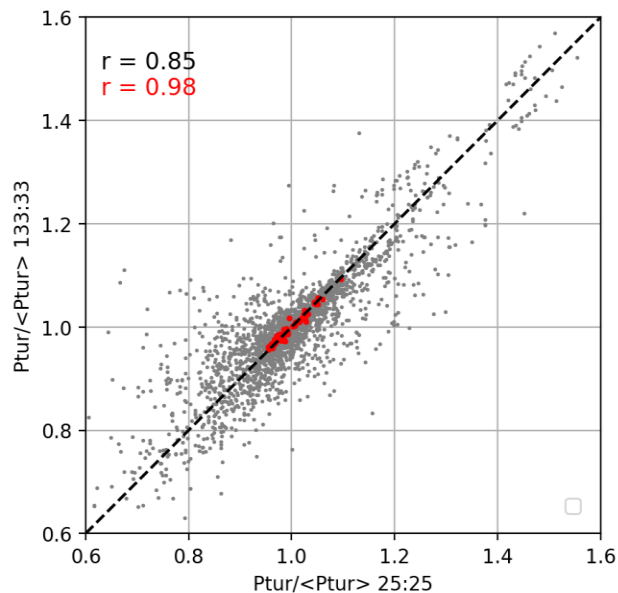
- Omni-directional PoP hardly sensitive to grid spacing



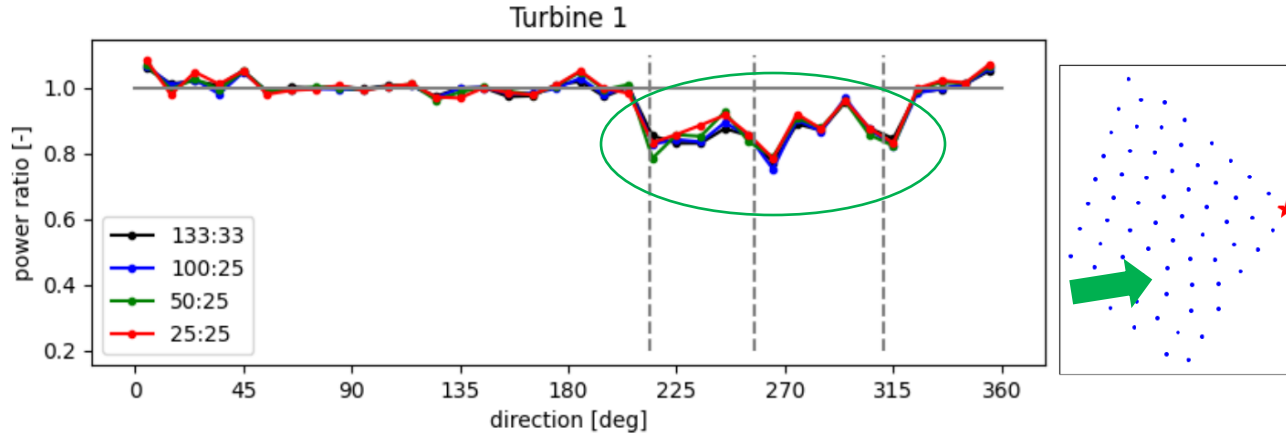
# Wind farm Pattern-of-Production

Pattern-of-production: For each turbine, calculate the mean turbine power ( $P_{tur}$ ) divided by mean power of all turbines ( $\langle P_{tur} \rangle$ ). Indicates how *spatial patterns* are represented.

- Omni-directional PoP hardly sensitive to grid spacing
- Directional (10-degree bins) PoP start to deviate from finest grid spacing

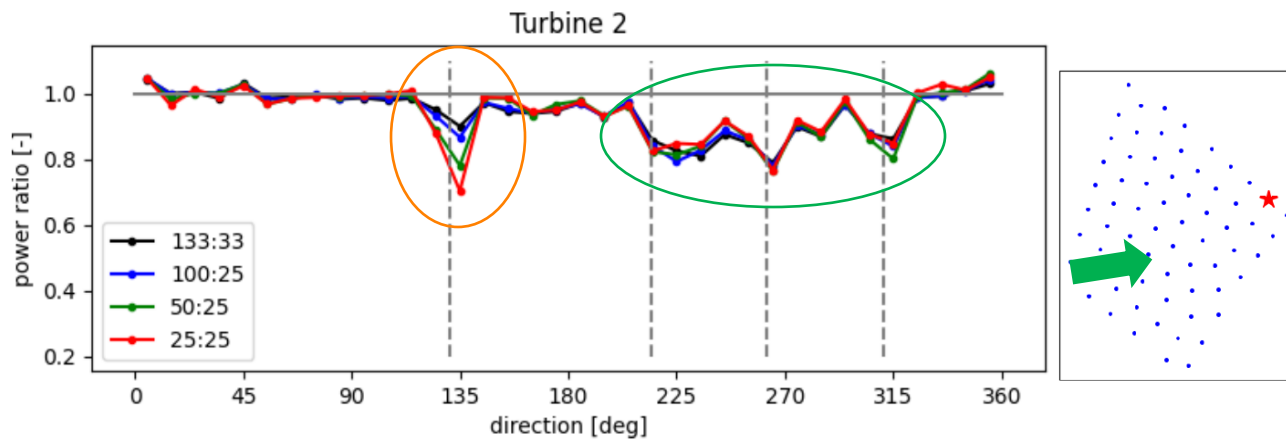


# Single vs merged turbine wakes



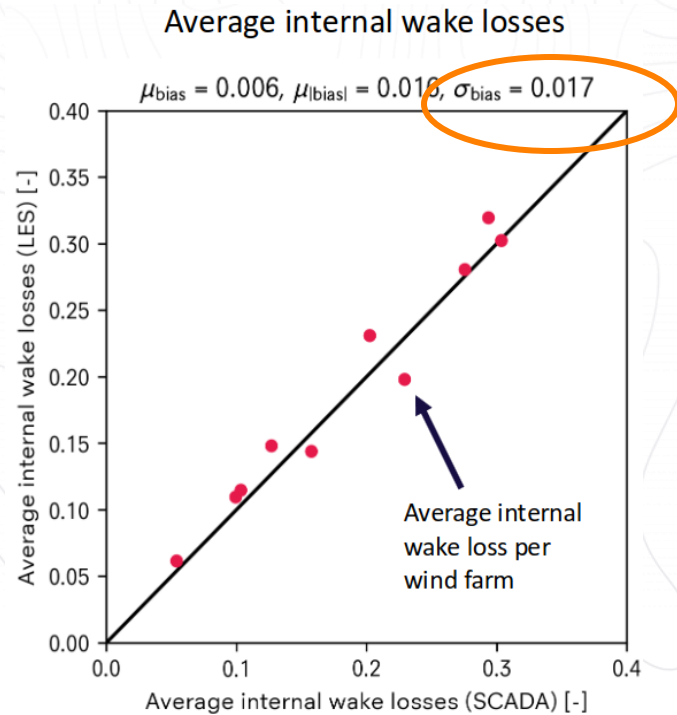
Power ratio: turbine power divided by mean power of first-row turbines

Merged turbines wakes: no impact of grid-spacing.



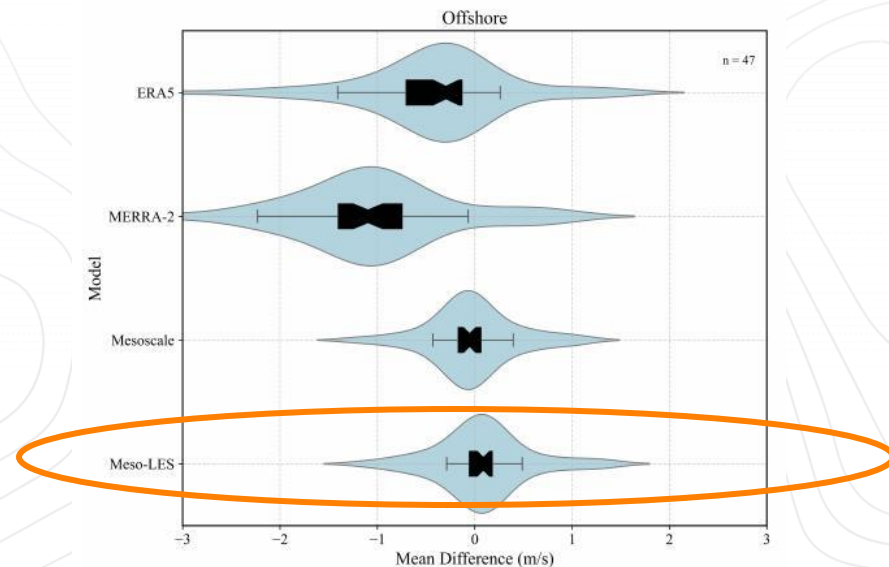
Single turbine wakes: coarser grid spacings smear out the wake, downstream turbine overestimates production.

# Impact of grid-spacing vs overall modeling uncertainty



Whiffle LES wake loss validation example from Van Dorp et al, Wind Europe Annual Event 2025

Considering the overall uncertainty in modeling both wind conditions and wind farm losses, the impact of grid spacing is limited



From Williams et al. 2026, Benchmarking Atmospheric Model Data for Wind Resource Assessment: A Comparative Study Across 170 Sites, <https://iopscience.iop.org/article/10.1088/1742-6596/3224/2/022040>

# Conclusions

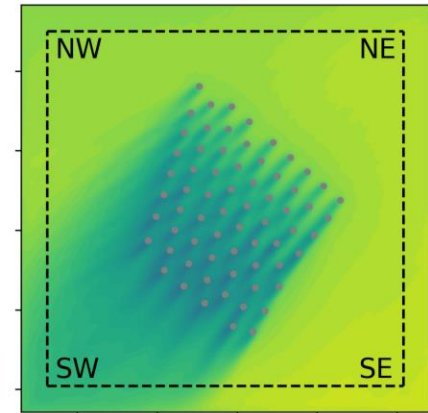
*What is the impact of LES grid spacing? It depends!*

- On a **wind farm level**, the impact of varying the grid spacing from 133 m to 25 m on modeled gross / waked production is 0.9 / 1.6 %. The modeled internal wake losses vary by 0.6 %-point. These differences are smaller than the overall modeling uncertainty.
- The impact of grid spacing on downstream wind farm wakes is modest.
- For simulating and studying wakes on an **individual turbine level** the impact of grid spacing is large.
- A 100 m-scale LES is sufficiently cost-effective for real world use in energy yield assessment. Currently, a 25 m-resolution setup is not (factor 16 more expensive).

See also: Baas et al. 2026, On the validity and value of real-weather, hectometric-scale large-eddy simulation for wind energy applications, <https://iopscience.iop.org/article/10.1088/1742-6596/3224/2/022040>



100:25



25:25

