whiffle

Model thy neighbours, but not too expensively!

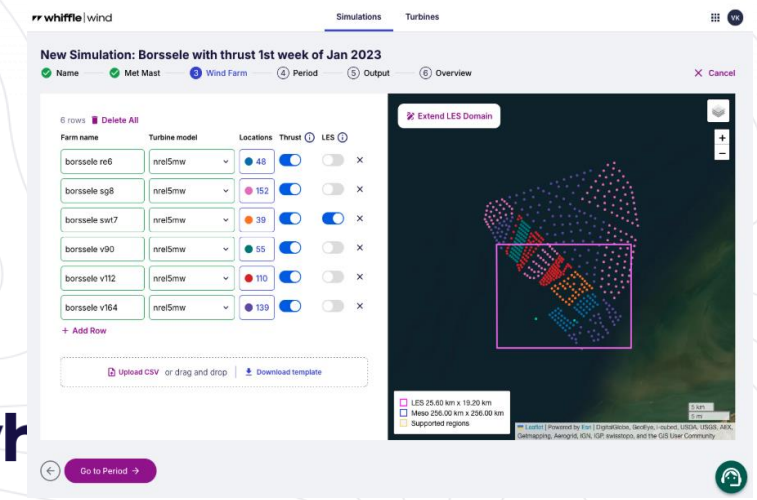
A multi-scale atmospheric modelling framework to capture internal and external wakes

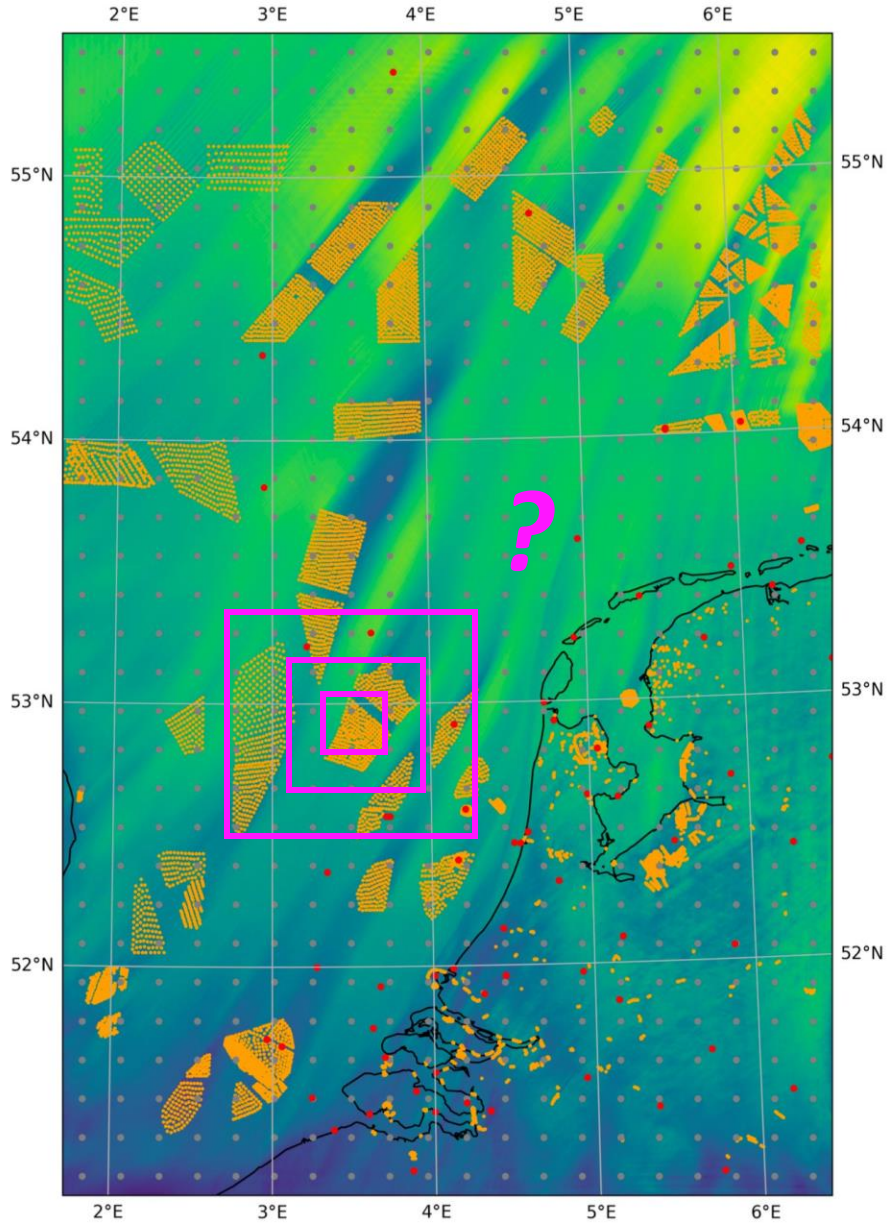
Peter Baas & Whiffle Team

Why?

- It's getting crowded offshore!
- Real-weather, mesoscale coupled large-eddy simulation (LES) model
- How to account for neighbouring external wind farms?
- Balancing accuracy with cost

- *How large should the LES domain be with respect to the wind farm of interest??*

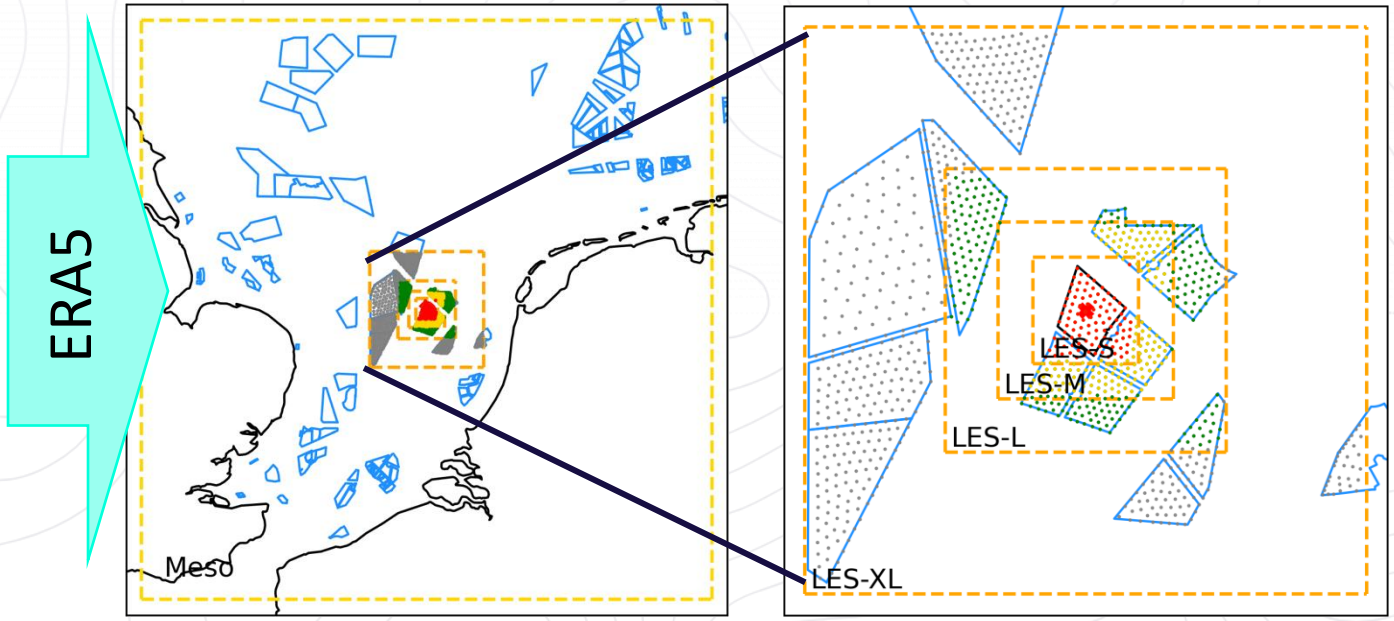




Setup of the study (1 / 2)

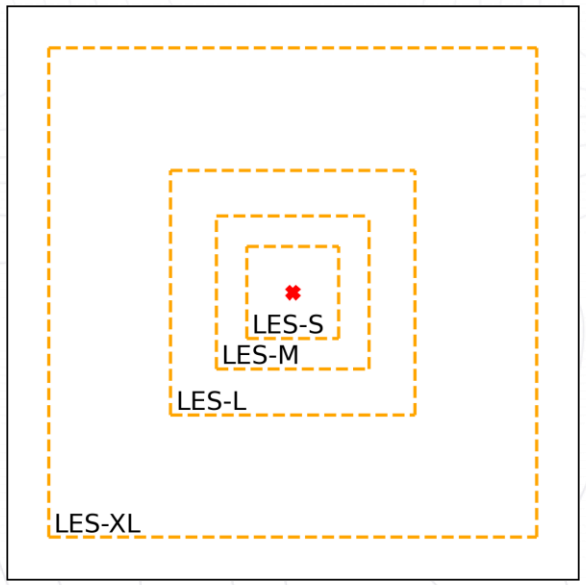
Aim: investigate sensitivity to LES domain size

- Take IJVer-IV site as a case study (67 turbines of 15 MW, ~1GW)
- Take 4 LES domain sizes at 100m resolution (LES-S 20km, LES-M 30km, LES-L 50km, LES-XL 100km)
- All nested in mesoscale simulation (500km, including all wind farms), which is nested in ERA5
- 100 days, selected from 2023 were simulated

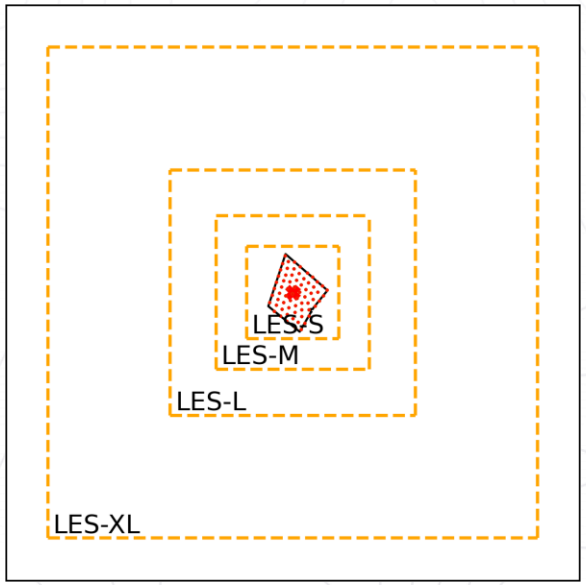


Setup of study (2 / 2)

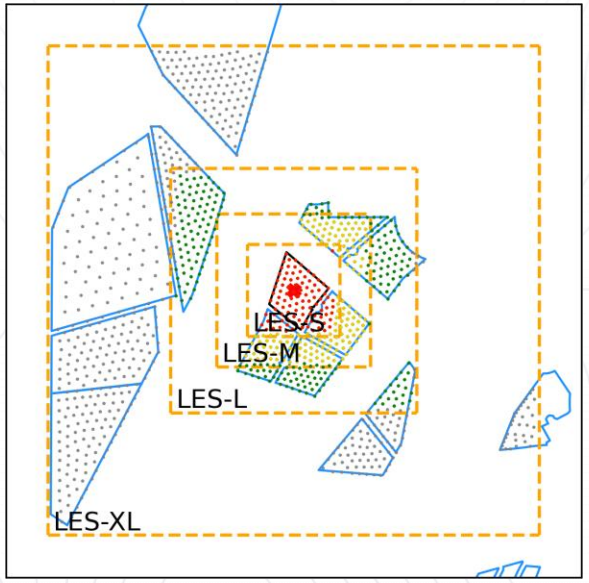
3 wind farm configurations were simulated



Free-stream / thrustless (A)



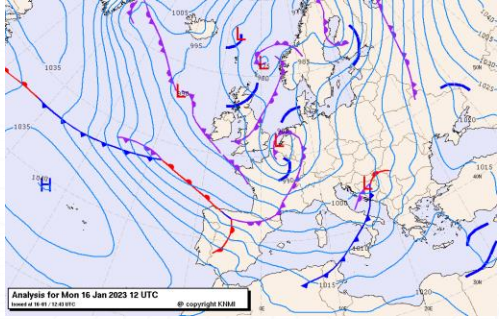
Isolated (B)

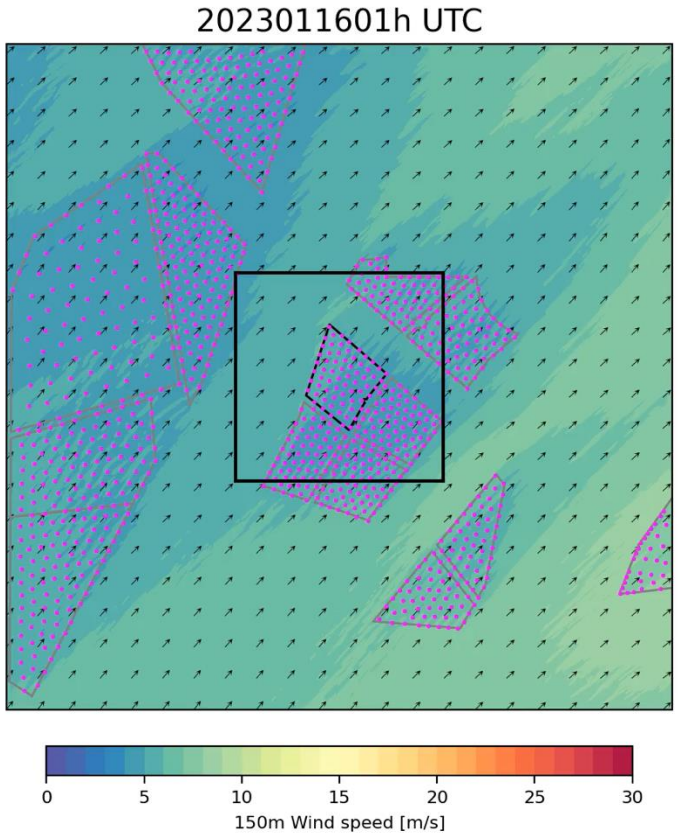


All wind farms (C)

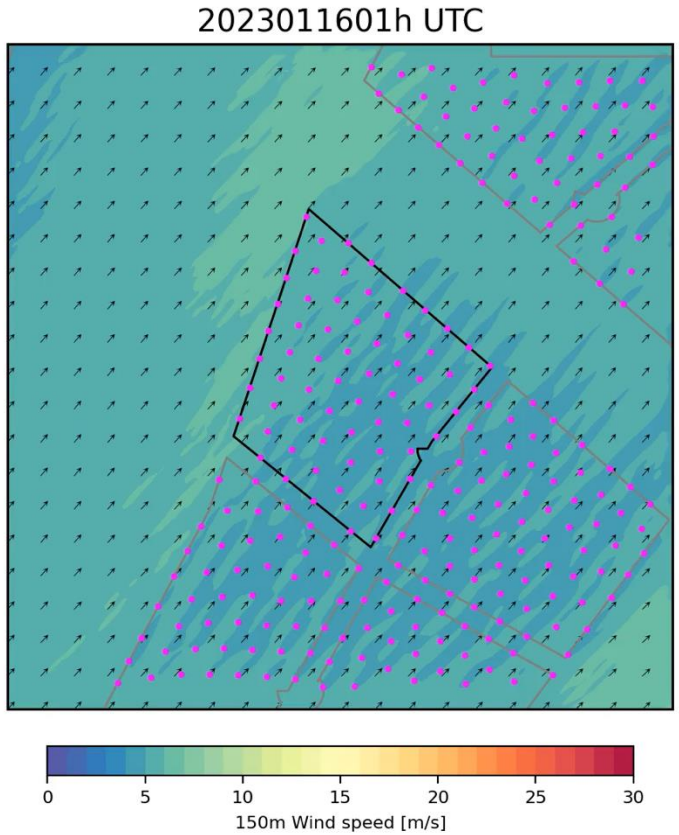
- Total aerodynamic losses : production C – A
- Internal losses : production B - A
- External losses : total aerodynamic losses – internal losses

LES model in action: 16 Jan 2023





LES-XL (100km)



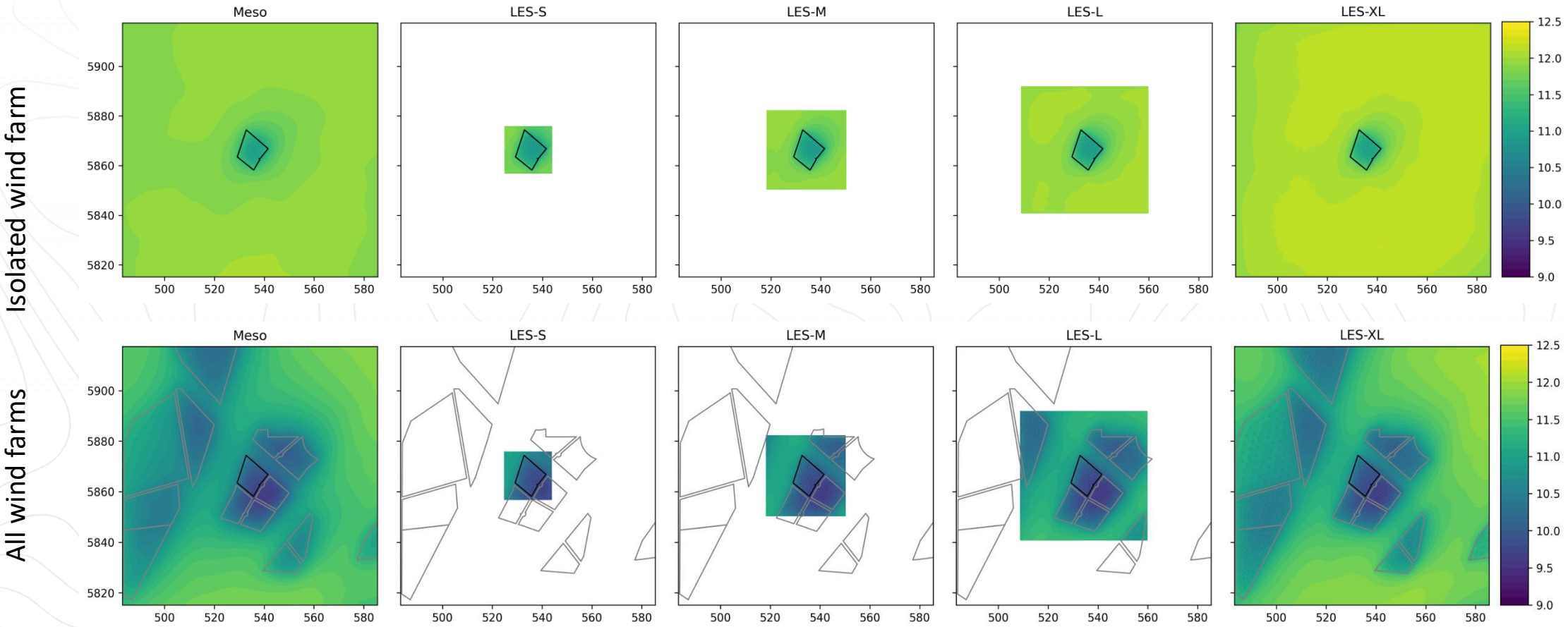
LES-M (30km)

- Example real-weather LES
- Passage of small-scale low- pressure area
- *LES-XL* and *LES-M* both (independently) nested in *Meso*

Results. Mean 150 m (hub height) wind speed

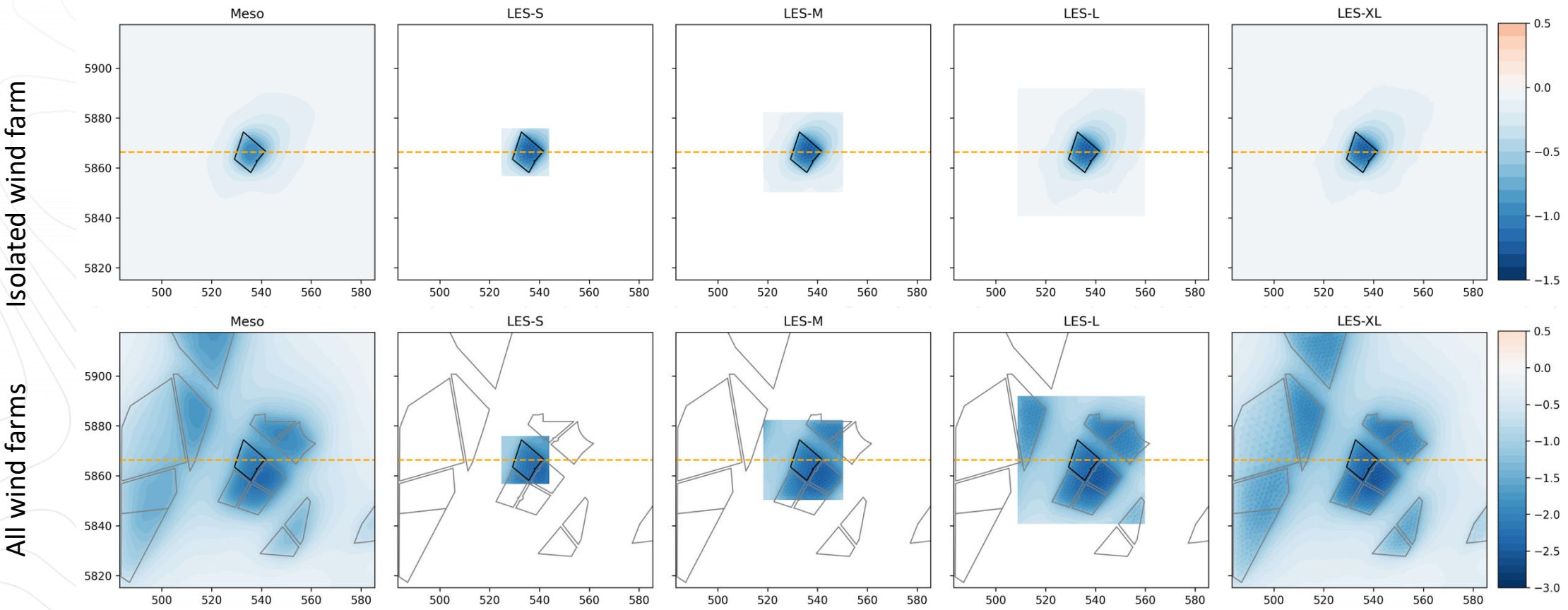
For *Meso*, *LES-S*, *LES-M*, *LES-L*, and *LES-XL*

All LES domains are directly nested in *Meso*



Wake effect w.r.t. free-stream wind
(zoom on *LES-XL*)

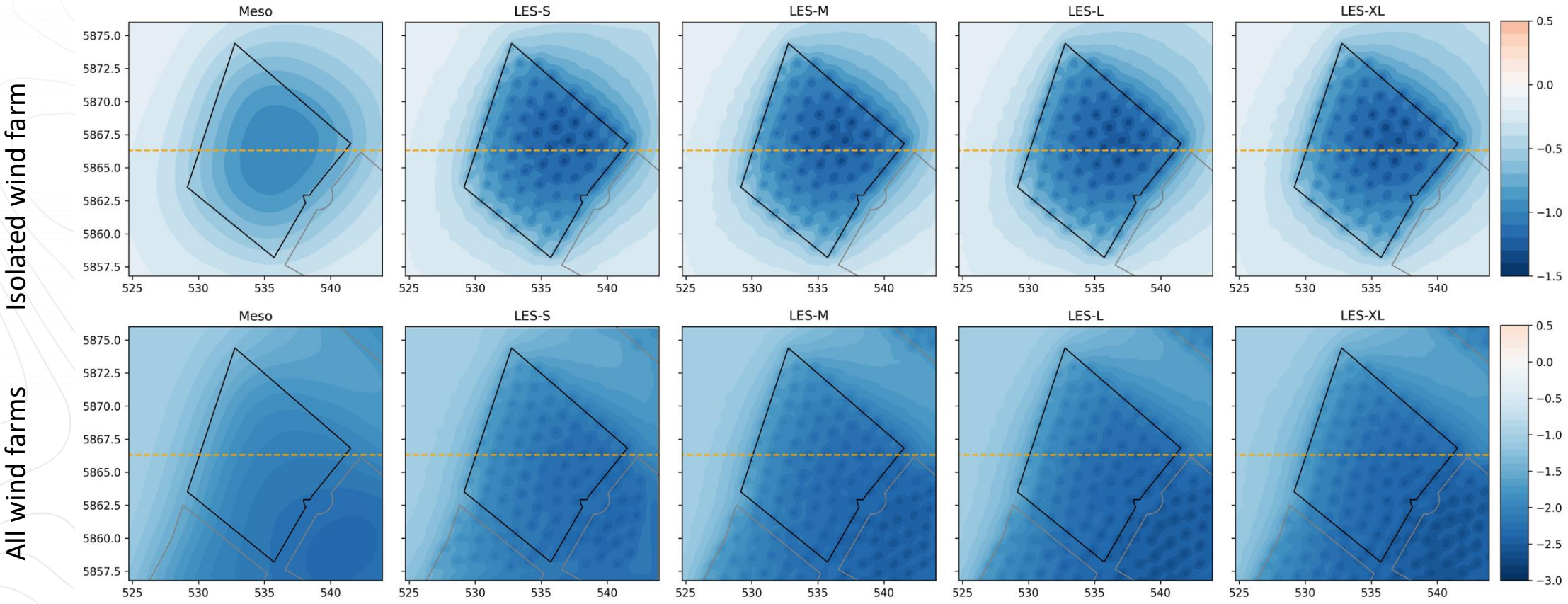
Qualitatively, the difference in velocity deficits is small



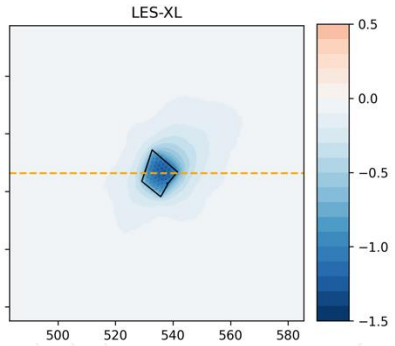
Wake effect w.r.t. free-stream wind

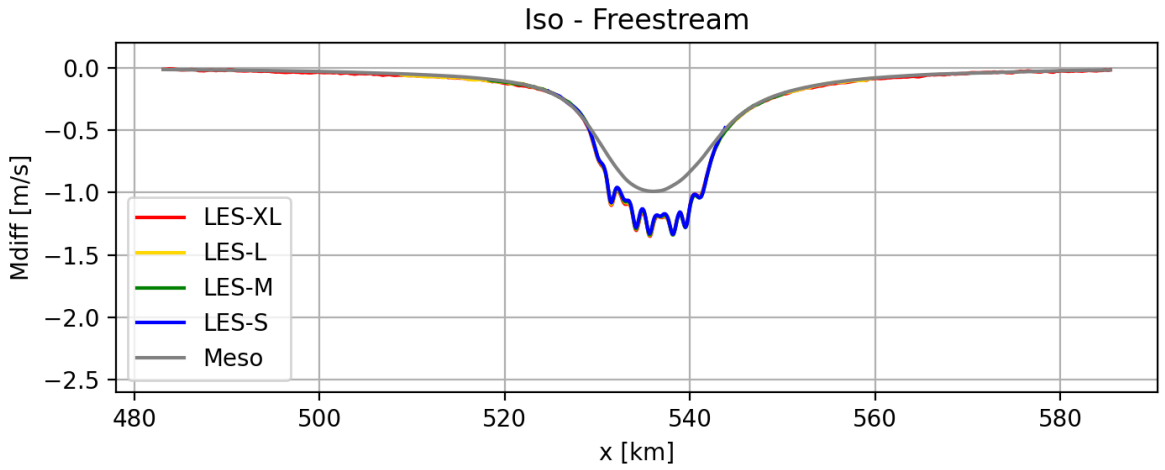
(zoom on *LES-S*)

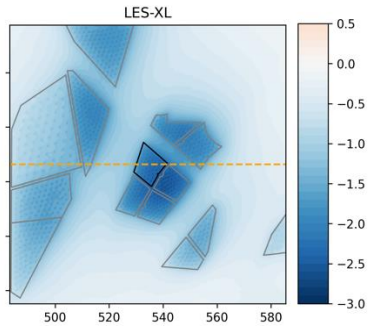
Zooming-in to the *LES-S* domain illustrates the difference between 2 km *Meso* grid and the 100 m *LES* grid

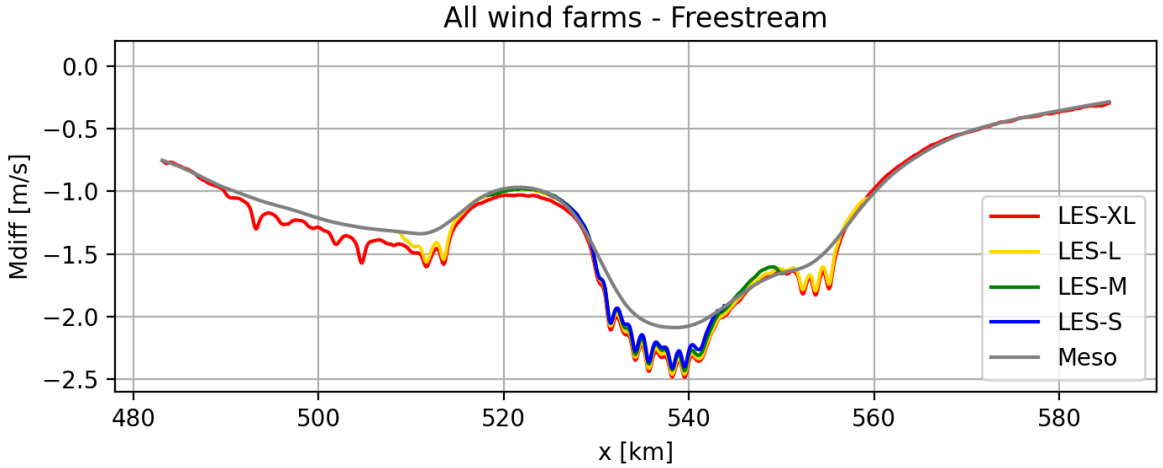


West-east cross-section half-way the domain



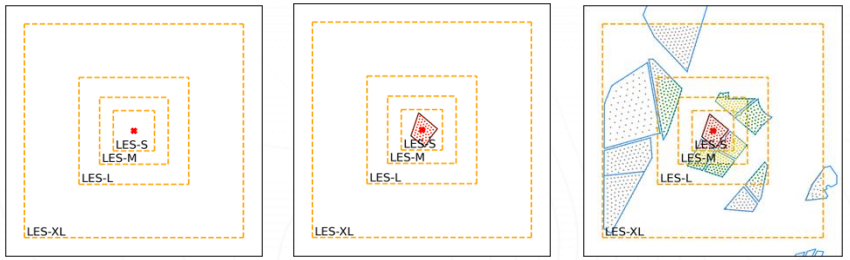


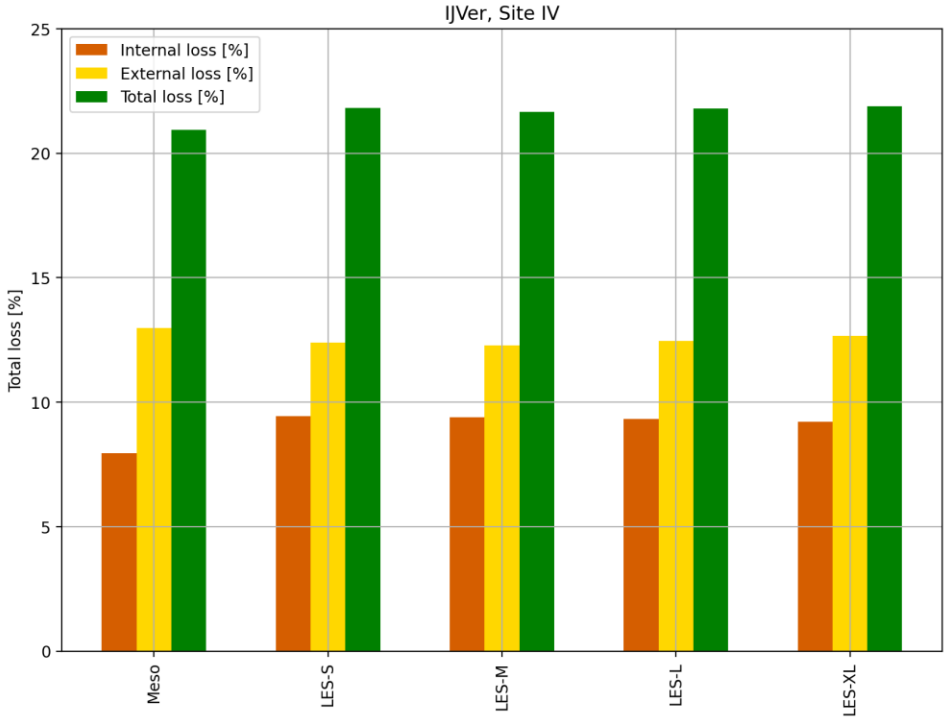


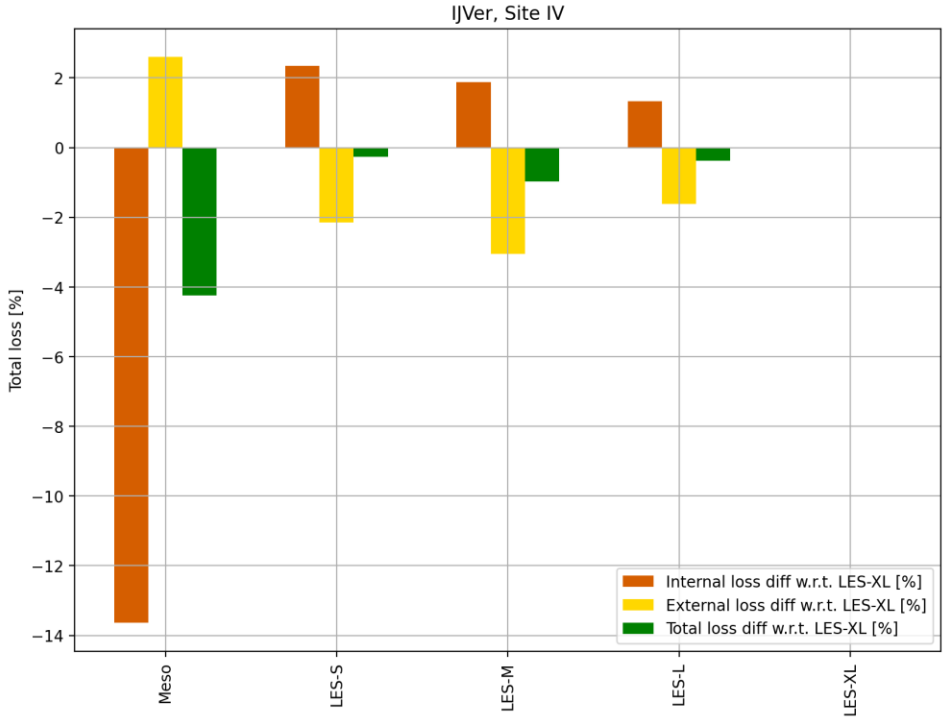


- Wakes in *Meso* are too shallow
- Wakes in the different LES domains are close together

Internal, external, and total losses



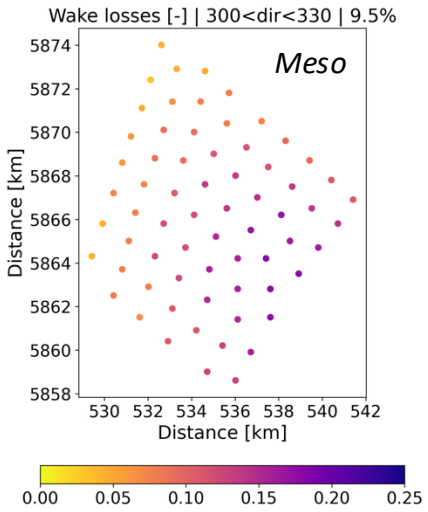


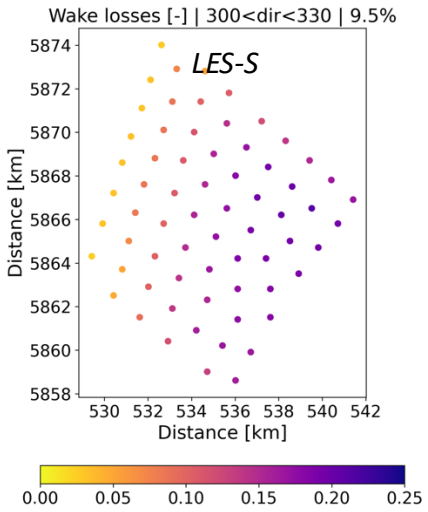


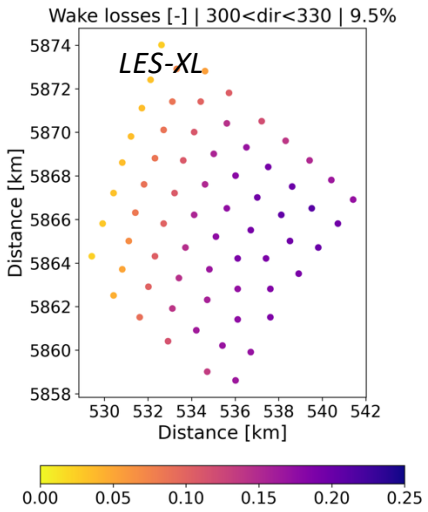
- Production losses from *Meso* are too low (consistent with wind patterns)
- Differences between LES domain sizes are small, especially when considering total losses

Spatial gradients of internal losses for the isolated case

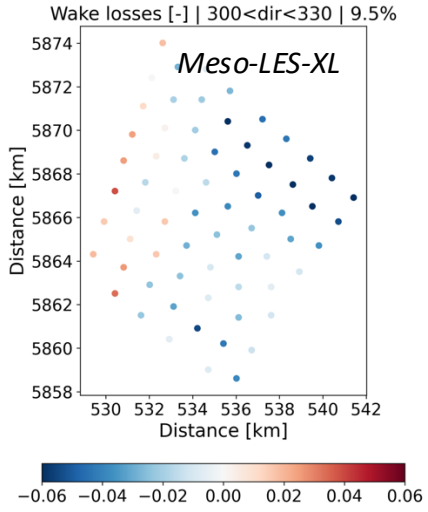
Internal losses

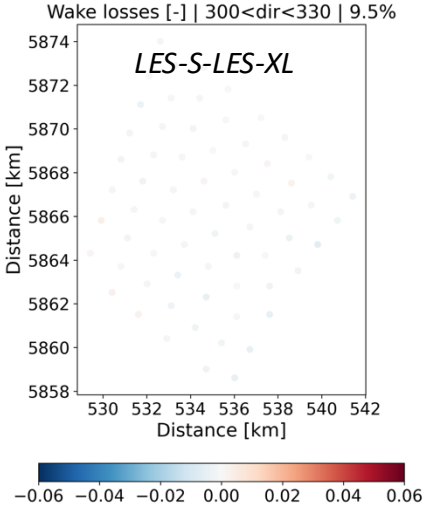






Difference w.r.t. *LES-XL*

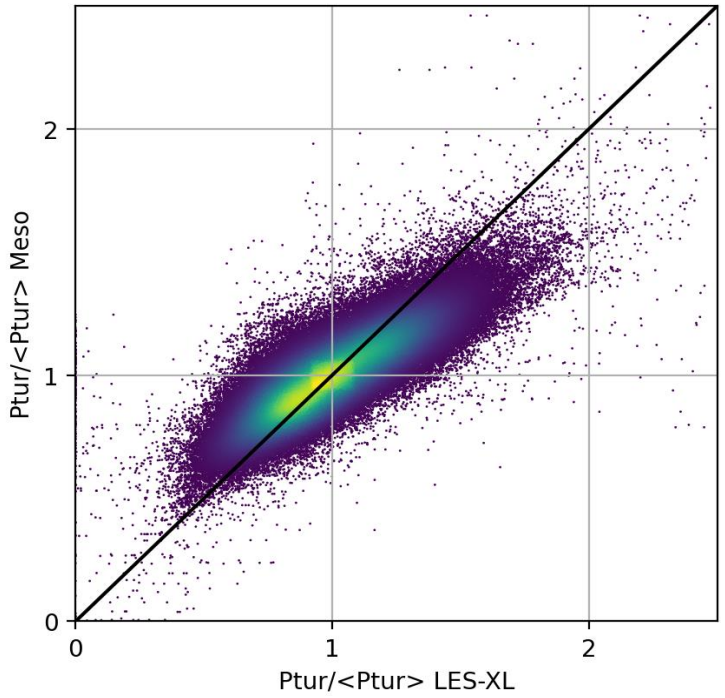


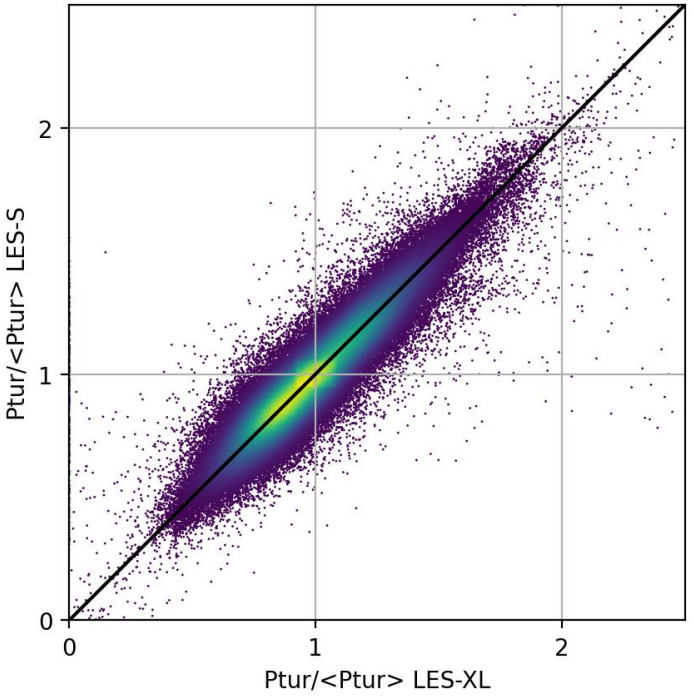


- For NW winds (300 < dir < 330)
- Losses per wind turbine
- Spatial gradient in Meso too small
- LES-S captures gradient already well

Pattern of Production (isolated case)

- For each turbine & time step calculate the power (Ptur) divided by mean power of all turbines for that timestep (<Ptur>)
- Indicates how spatial patterns are represented
- Here: comparison of Meso and LES-S versus LES-XL



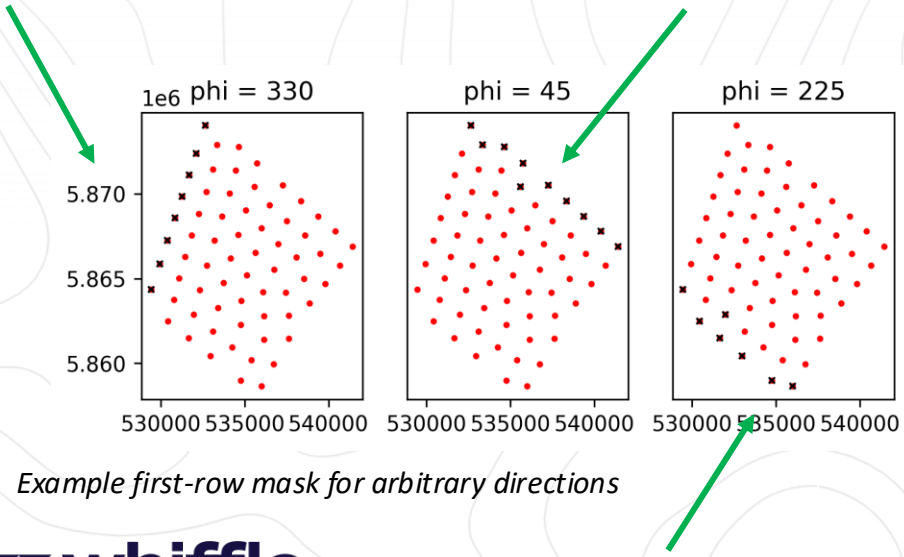


First-row losses (blockage) of the isolated case

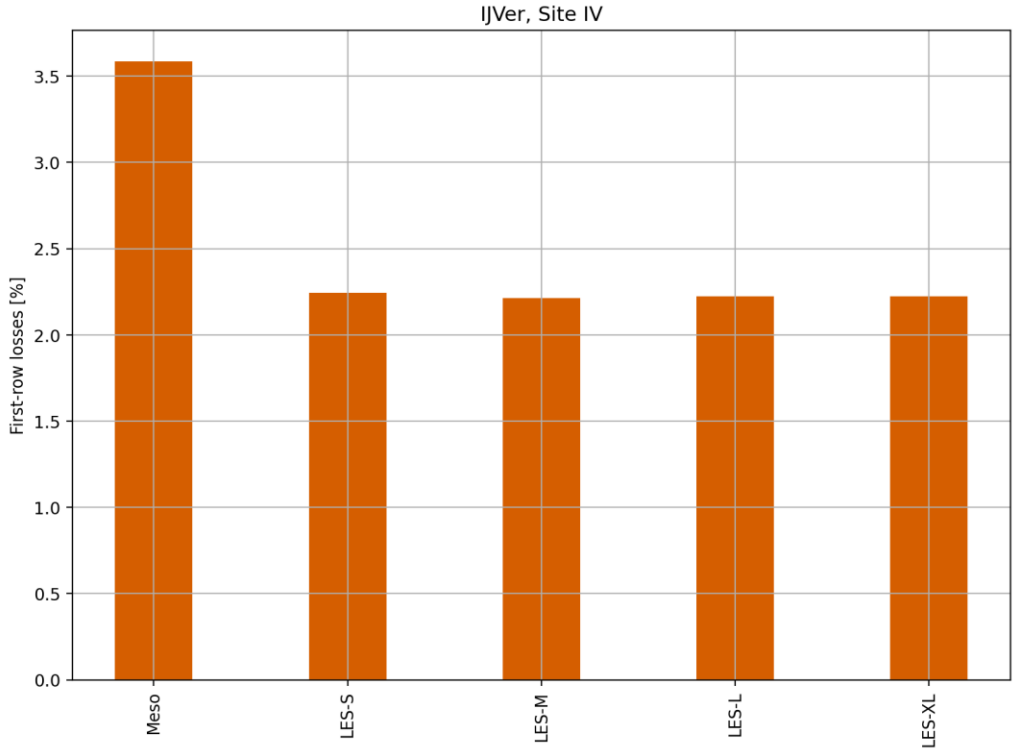
- First-row losses as proxy for global blockage

Recipe

- Define direction dependent mask of first-row turbines from wind farm layout
- Determine first-row turbines per time record
- Accumulate first-row losses w.r.t. freestream over time



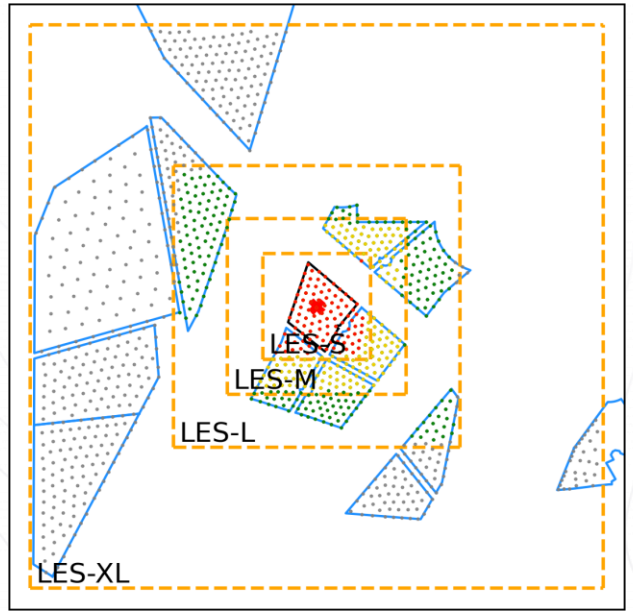
Example first-row mask for arbitrary directions

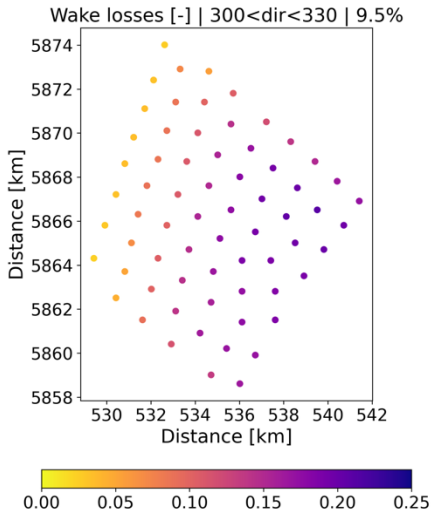


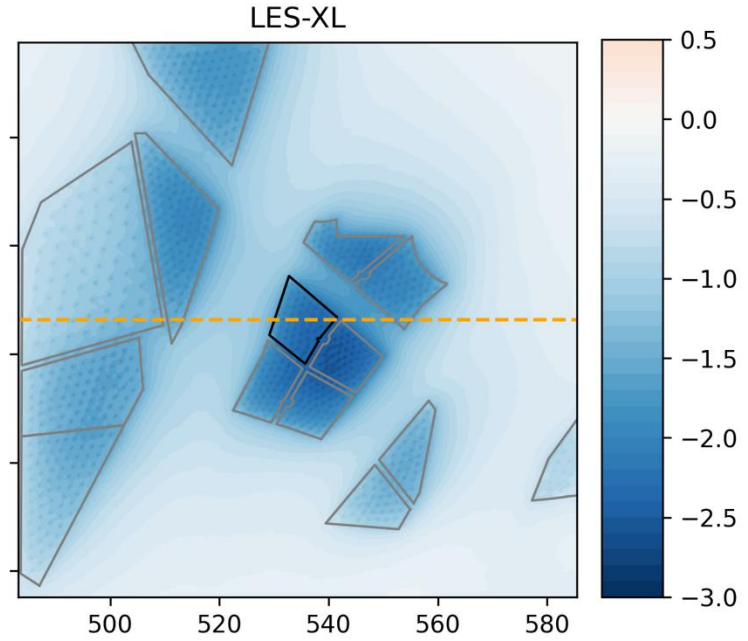
LES first-row losses do not depend on domain size. *Meso* has larger value.

Conclusions

- Mesoscale simulation captures cumulative wake effects well, provides accurate boundary conditions for the LES. Internal wake effects are underestimated and smeared-out.
- LES offers accurate representation of wind farm dynamics. Small to moderate domain sizes suffice.
- LES provides
  - Accurate internal wakes / wake losses
  - First-row (or blockage) losses
  - Spatial gradients in production
  - (Turbulence intensity)



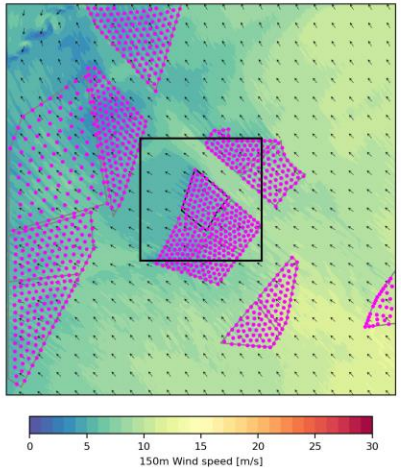


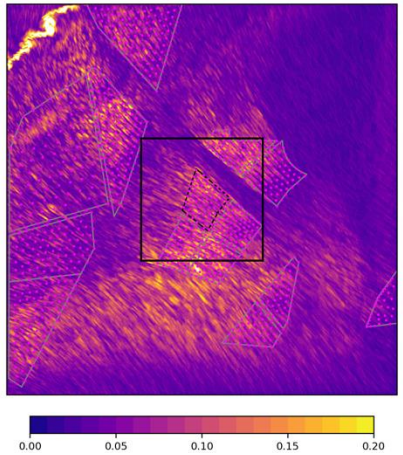


Example: Turbulence Intensity

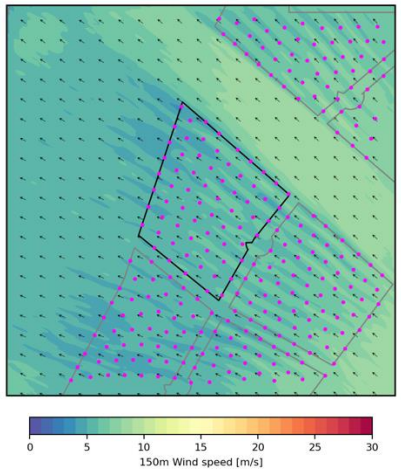
Wind field | Turbulence Intensity

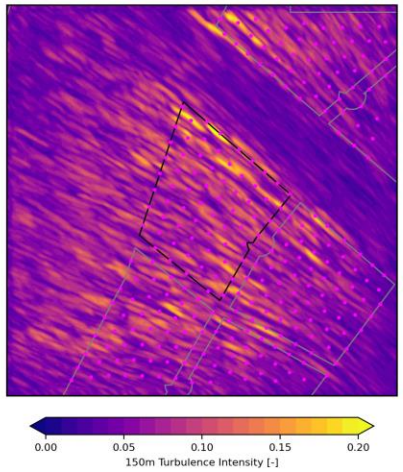
LES-XL





LES-M





- Snapshots 150m wind fields and turbulence intensity (10 min mean values) from 16 Jan 2023
- For *LES-M* and *LES-XL*