



Going beyond the mean

Multi-year, time series-based validation of a real weather, meso-scale coupled large eddy simulation (LES) of wind farm power production for 10 operational wind farms

Pim van Dorp & The Whiffle Team

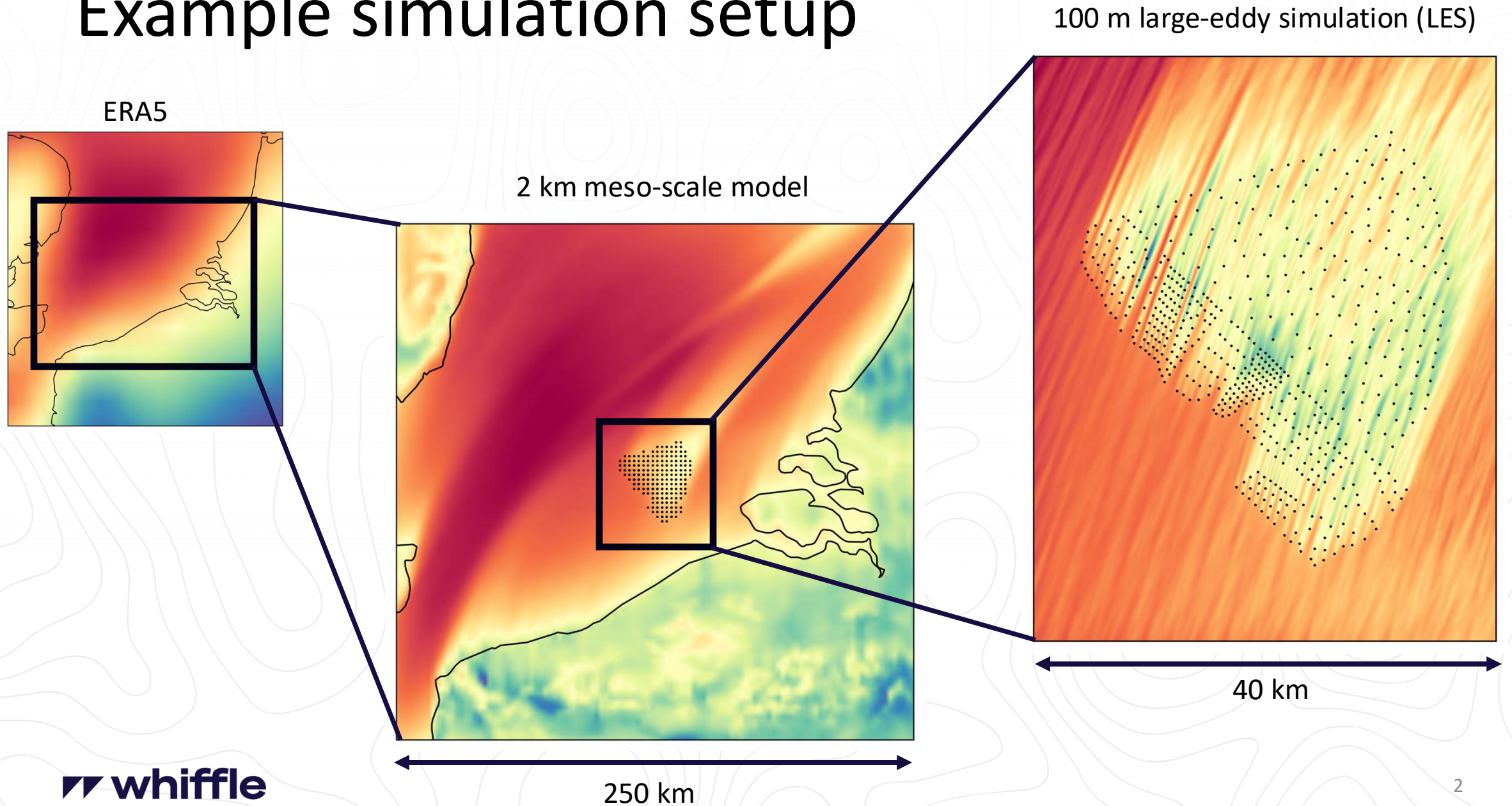
Why real weather meso-scale coupled LES?

Real weather represents the full spectrum of site-specific conditions.

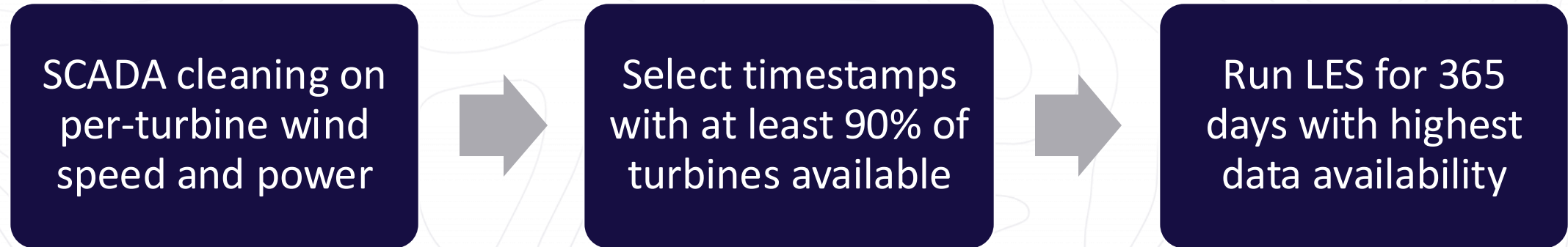
Capturing **meso-scale** effects is essential for wind farm in heterogenous surroundings.

Turbine-scale large-eddy simulation (**LES**) provides an accurate physics-based description of the atmospheric flow in and around wind farms.

Example simulation setup



Validation methodology



Internal wake losses

$$\text{Internal wake losses} = 1 - \frac{P_{\text{mean}}}{P_{\text{ref}}}$$

P_{mean}

Average power of all turbines in wind farm (at each time instance).

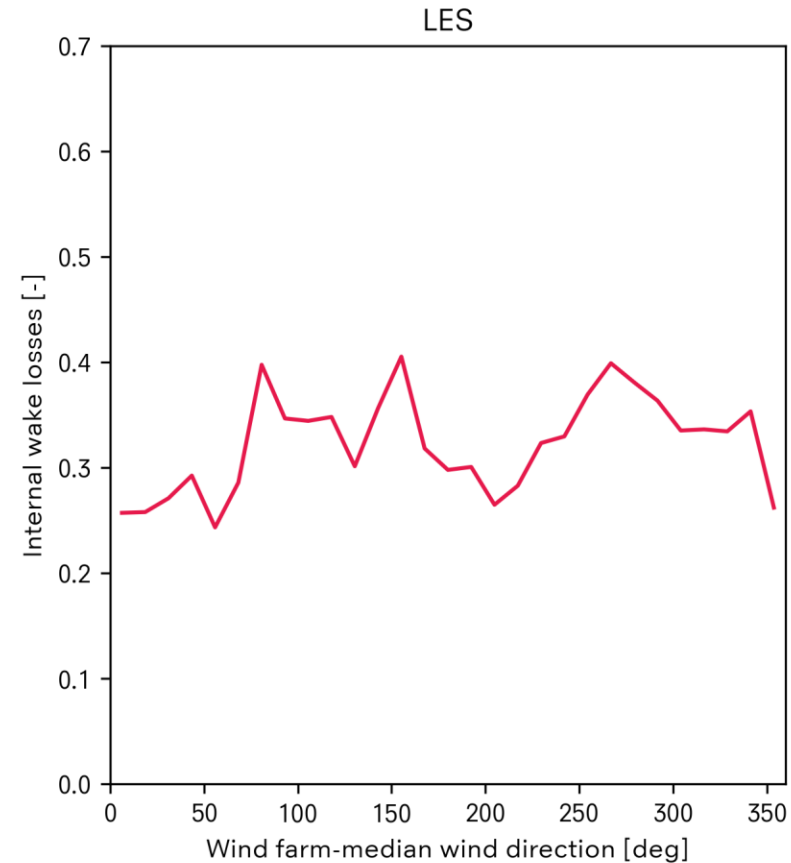
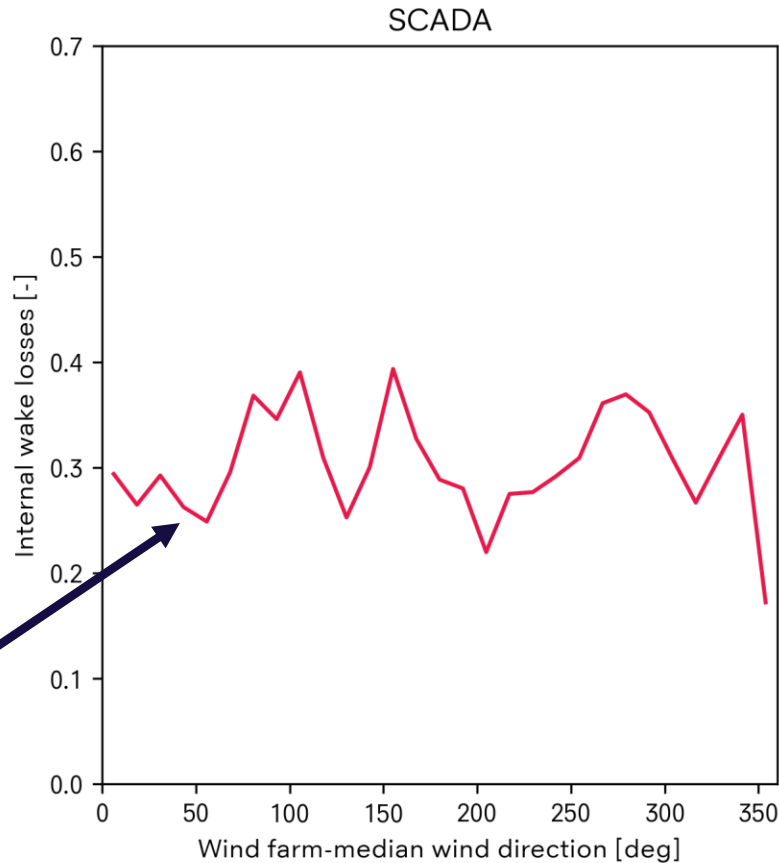
P_{ref}

Power of the reference turbine, we use the front row turbine which on average has the highest power [1].

[1] Nygaard, N. G., et al. "Large-scale benchmarking of wake models for offshore wind farms." *Journal of Physics: Conference Series*. Vol. 2265. No. 2. IOP Publishing, 2022.

Internal wake losses by wind direction

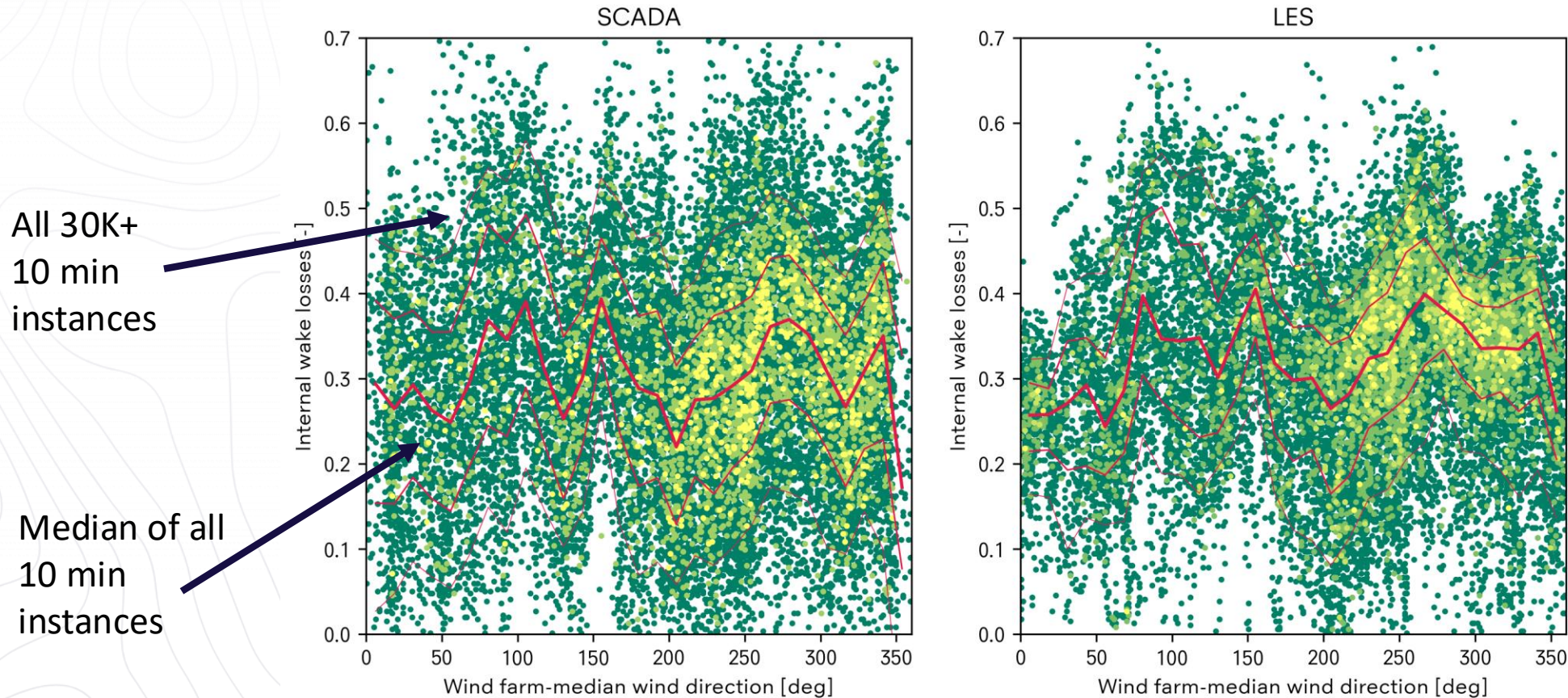
Single wind farm, wind speed < 12 m/s



Median of all
10 min
instances

Internal wake losses by wind direction

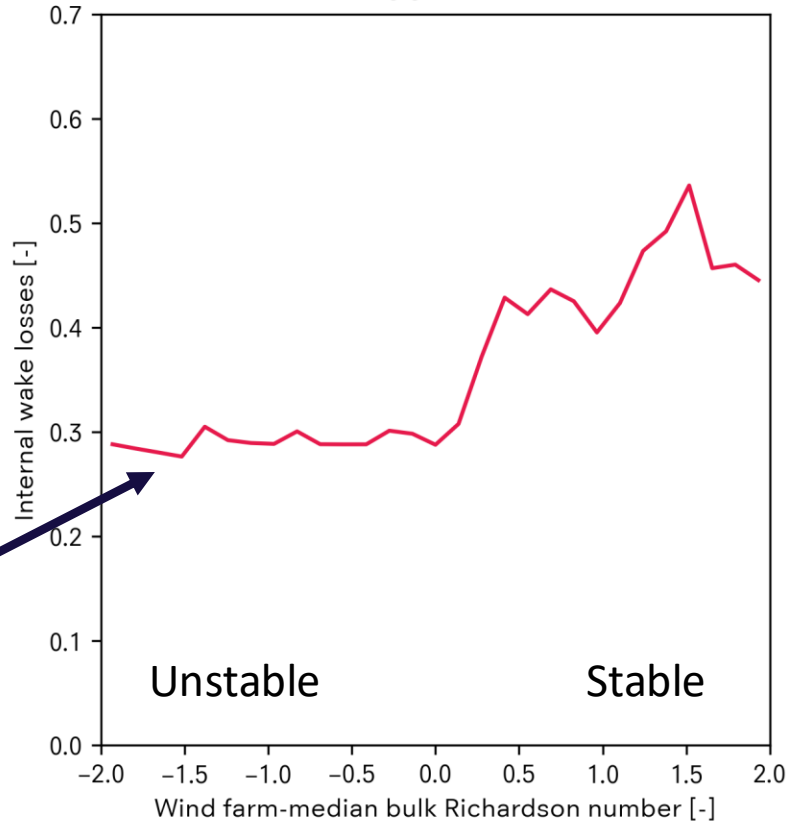
Single wind farm, wind speed < 12 m/s



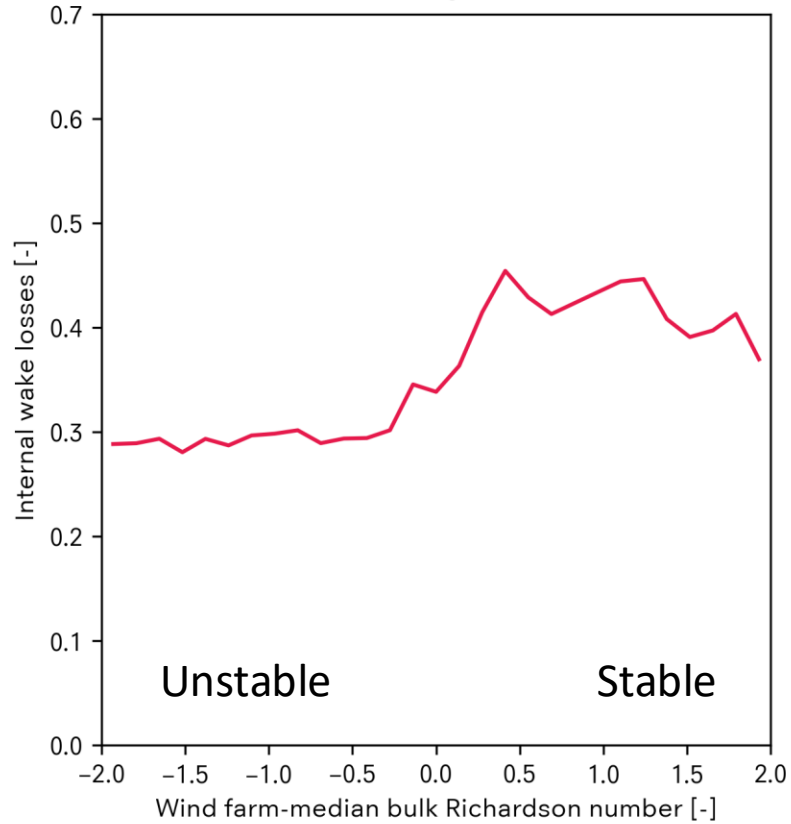
Internal wake losses by stability

Single wind farm, wind speed < 12 m/s

SCADA



LES

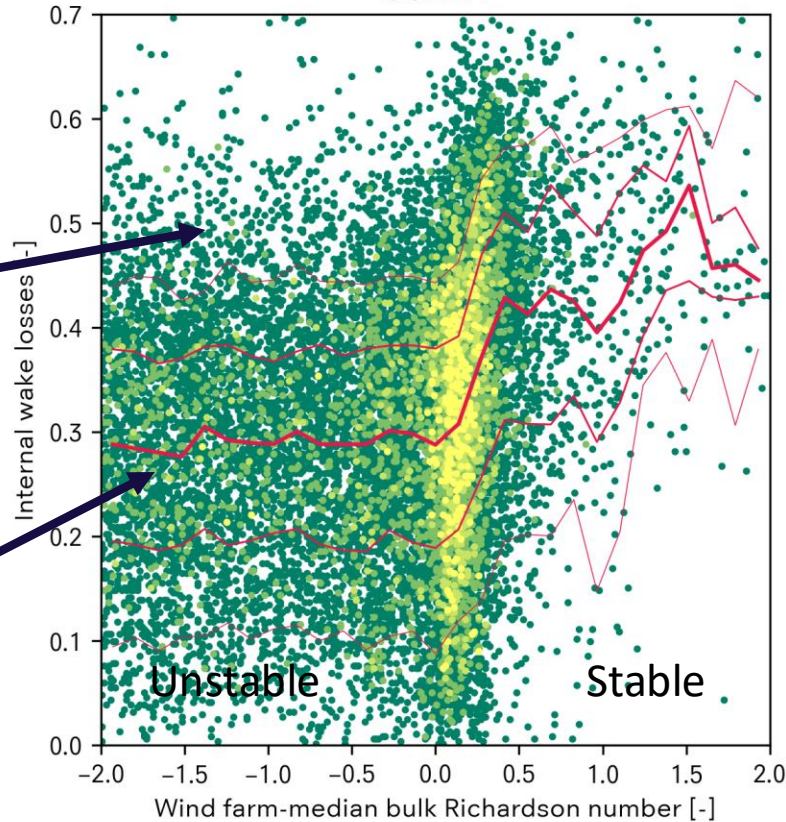


Median of all 10 min instances

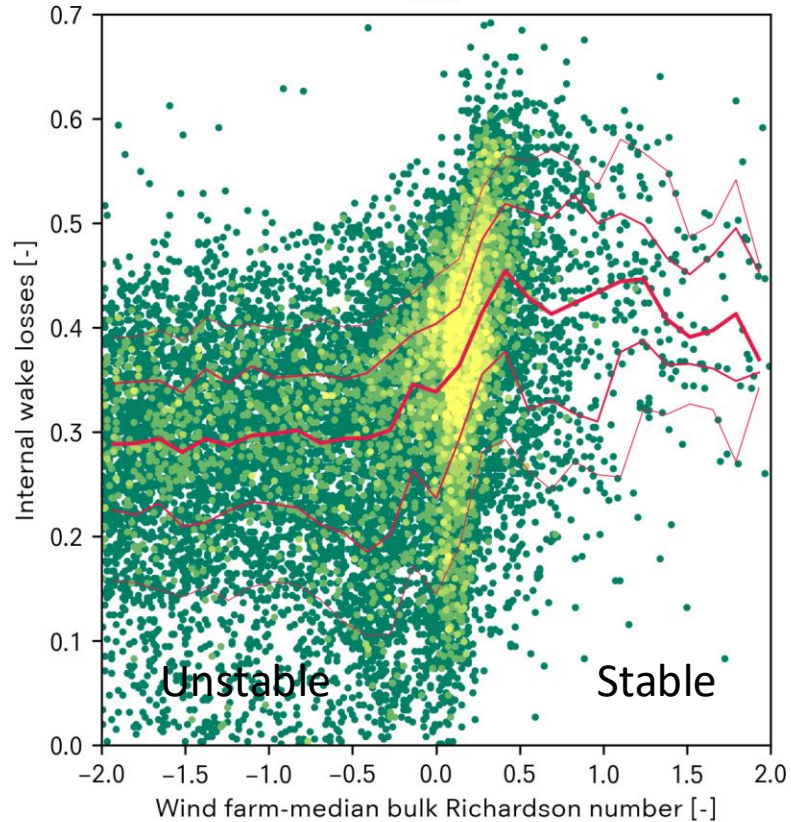
Internal wake losses by stability

Single wind farm, wind speed < 12 m/s

SCADA



LES

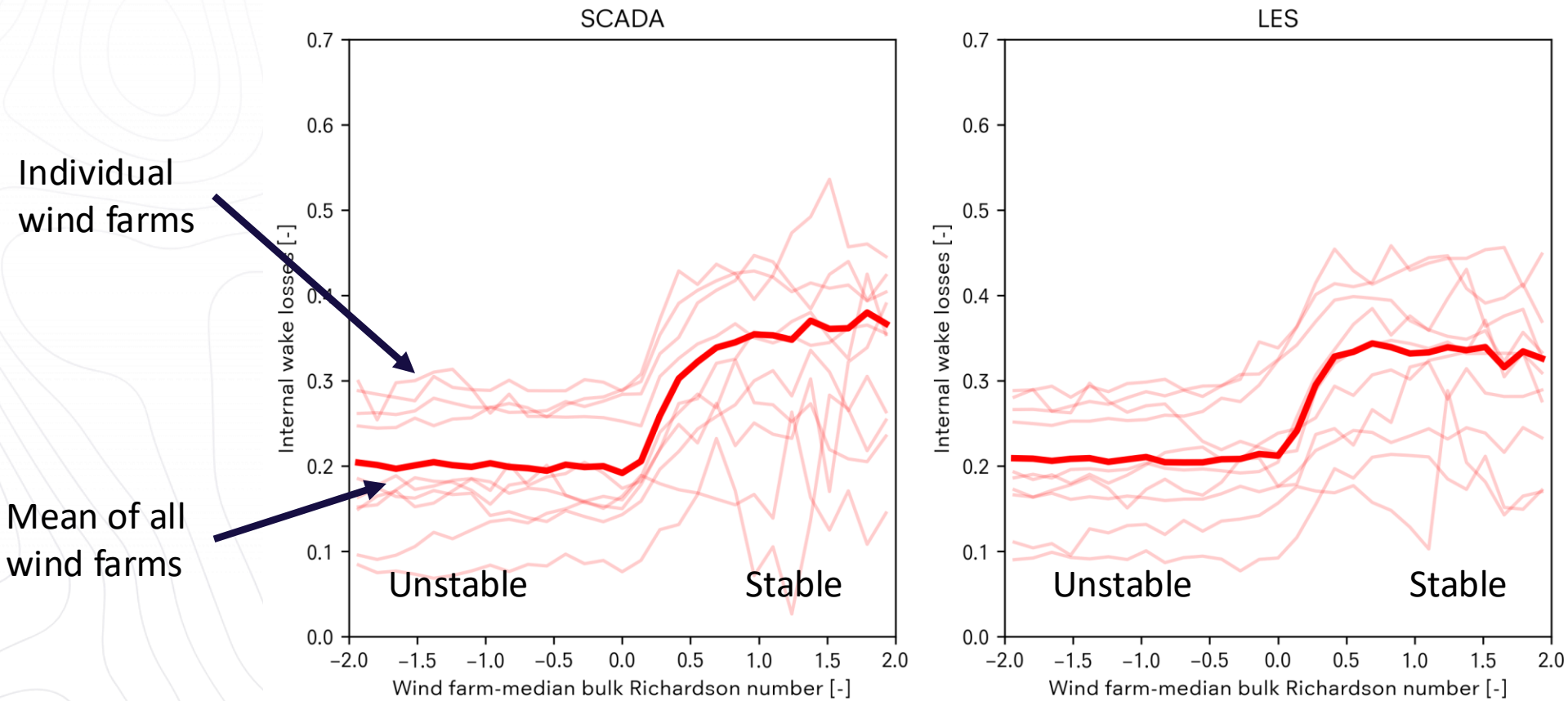


All 30K+
10 min
instances

Median of all 10
min instances

Internal wake losses by stability

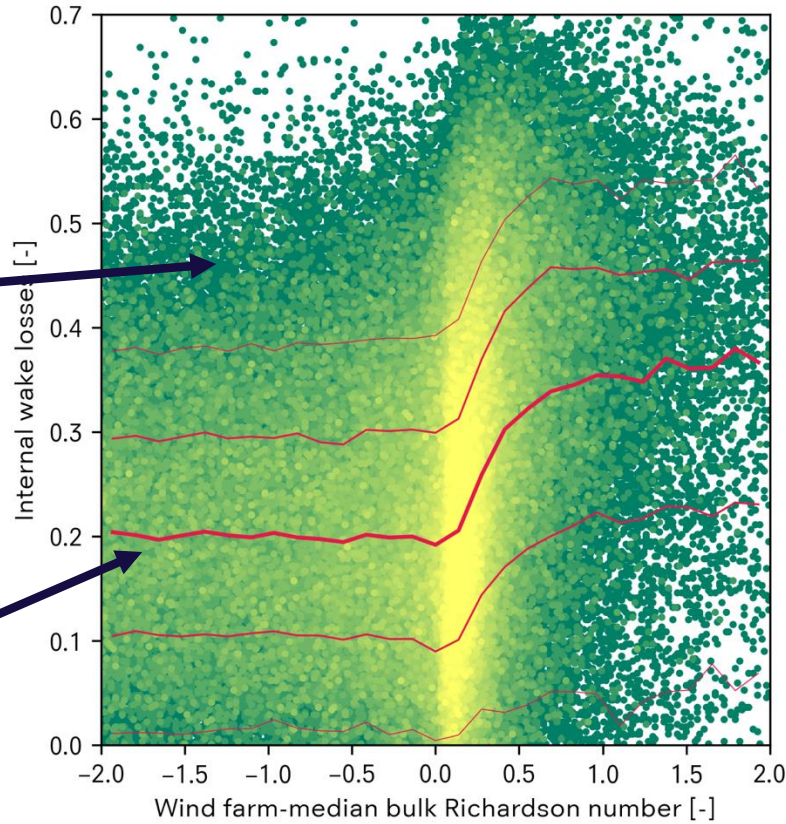
All 10 wind farms, wind speed < 12 m/s



Internal wake losses by stability

All 10 wind farms, wind speed < 12 m/s

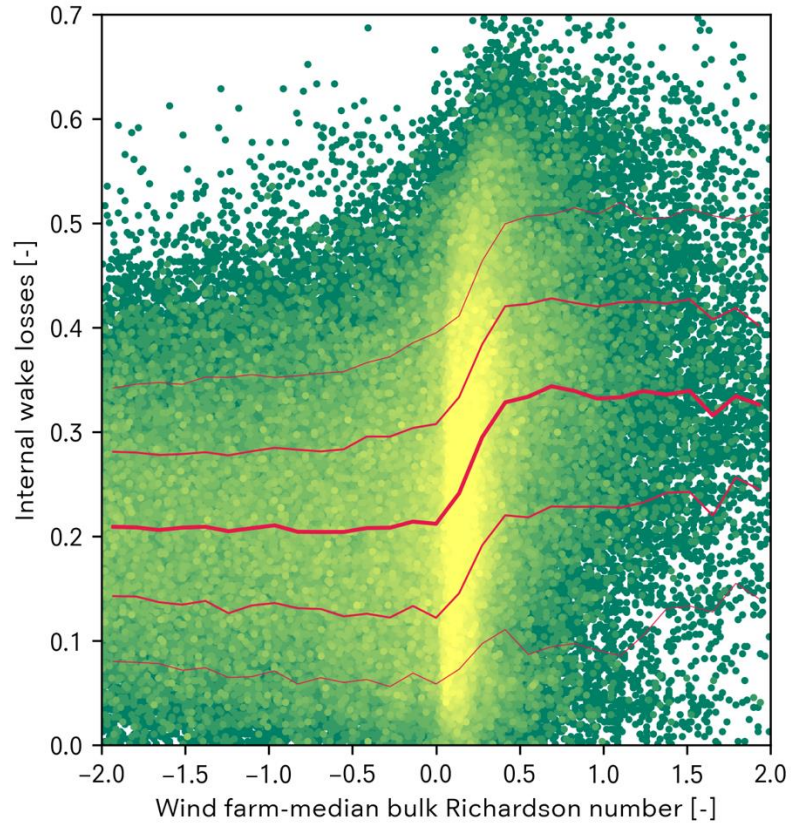
SCADA



All 300K+
10 min
instances
of all wind
farms

Median of all 10
min instances

LES



Conclusions

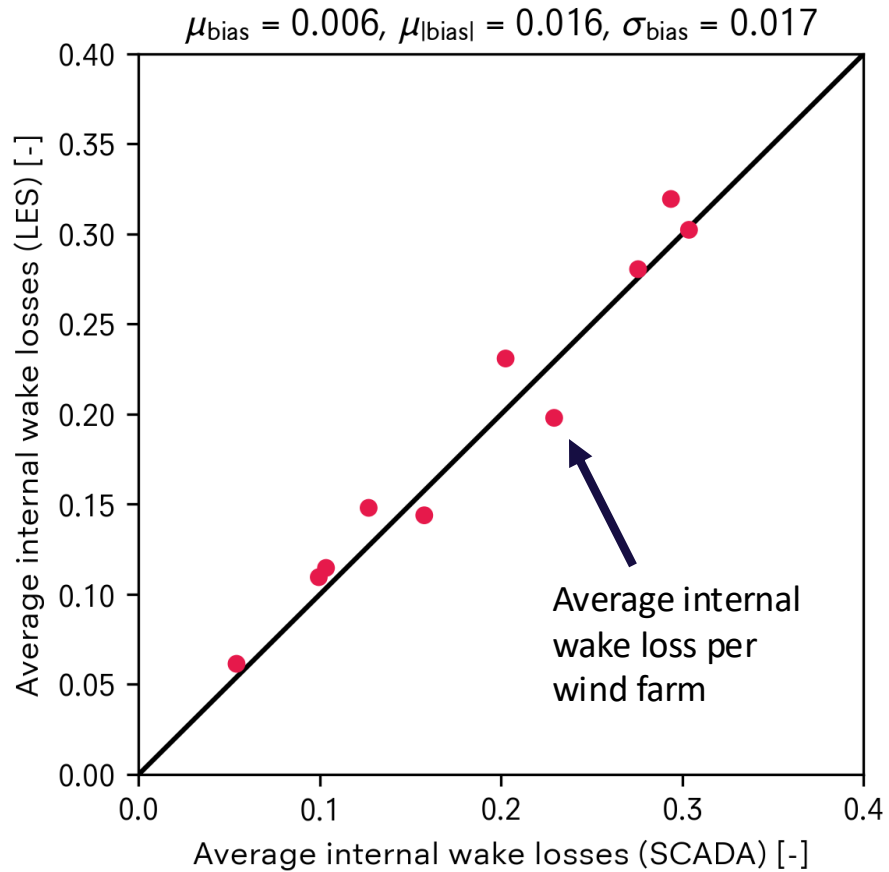
On average internal wake losses vary between ~20-40% depending on atmospheric conditions, with extremes up to ~60%.

Impact of atmospheric stability at least as significant as wind direction.

LES with real weather inputs accurately captures the full distribution of internal wake losses.

Why going beyond the mean matters

Average internal wake losses



Average power production

