WHEN TRUST MATTERS

Mesoscale-to-microscale flow modelling in cold climate (WRF-to-CFD)

Narges Tabatabaei (DNV, SE), Leonardo Barriatto (DNV, BR), Christiane Montavon (DNV, NL)

James Bleeg (DNV, GB)

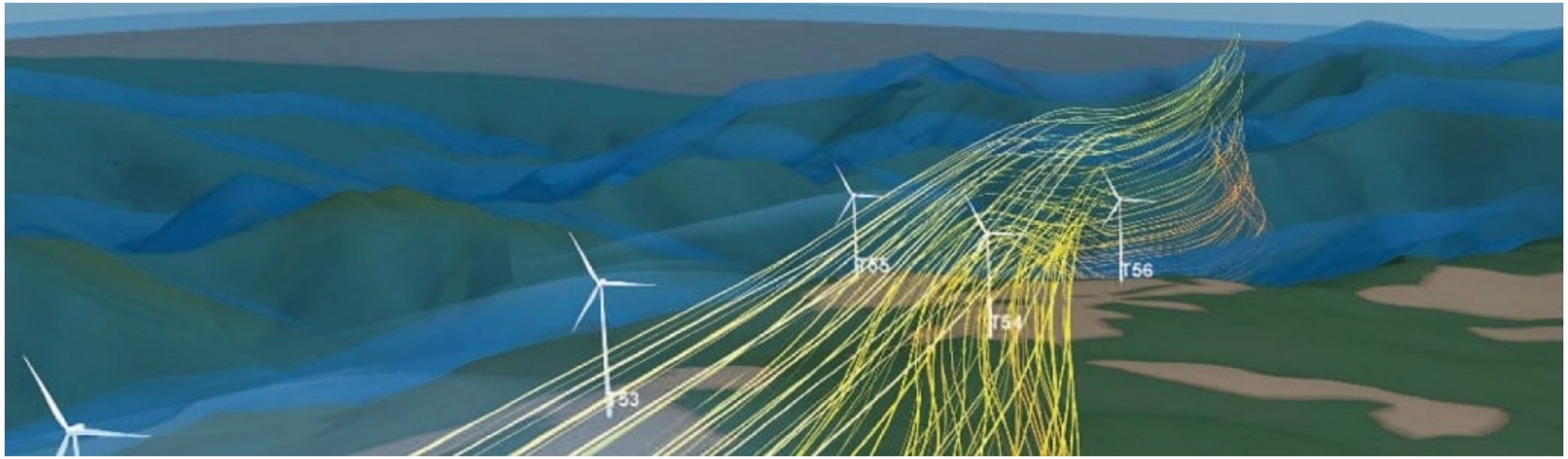
WRF to CFD

19 March 2024

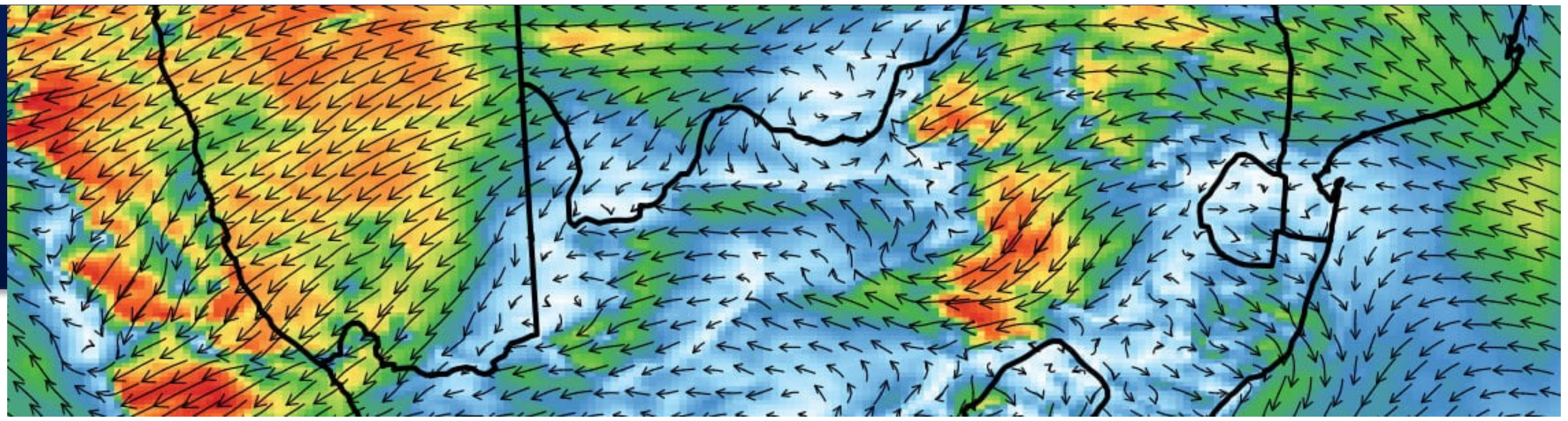
CFD flow modelling for wind farm sites

Accurate wind flow modelling is a key step in

- optimizing wind farm design,
- reducing uncertainty in energy production forecasts,
- maximizing returns.



Mesoscale vs Microscale



Flow modelling options roughly breakdown into two options: mesoscale and microscale.

Mesoscale ->WRF

- The Weather Research and Forecasting model (WRF) is a mesoscale numerical weather prediction system (NWP)
- Solve the governing equations of atmospheric flow over a large horizontal scale.
- The horizontal extent of the major outer domain is typically more than 1000 km .
- Suitable for running high-resolution simulations with horizontal grid spacing down to 1-2 km.
- Horizontal grid sizes are too coarse to resolve flow features below the kilometres scale.

Microscale ->DNV CFD :

- Simulates atmospheric flows over terrain and through wind farms using a general-purpose physics simulation software package best known for CFD modelling.
- The horizontal extent of the major outer domain is typically 35-95 km.
- DNV CFD, on the other hand, uses horizontal grid spacings in the meters scale (order of 10m).

Microscale

Microscale

Microscale computational fluid dynamics (CFD) models are capable of resolving the key physics down to turbine scale.

A big uncertainty:
uncertainty in the inflow boundary conditions

This shortcoming is an issue in most regions where wind farms are developed, including those in **cold climates**

Uncertainty in their representativeness of the actual atmospheric conditions at the site being simulate → Uncertainty in the results of the CFD analysis.

Boundary layers are frequently thinner + Larger modern turbines → Extra important to simulate atmospheric conditions within and above the boundary layer that are consistent with the actual local conditions.

Coupling Mesoscale & microscale

Microscale

Microscale computational fluid dynamics (CFD) models are capable of resolving the key physics down to turbine scale.

A big uncertainty:
uncertainty in the inflow boundary conditions

This shortcoming is an issue in most regions where wind farms are developed, including those in **cold climates**

Mesoscale

WRF models have historically been used to predict flow over terrain. In the last ten years, however, the capability to represent wind farms has been added.

The main disadvantage of WRF : It is unable to reliably resolve the flow down to many of the scales that are important in wind farm flow.

To address these issues, mesoscale models are sometimes coupled with reduced-order microscale models

WRF-to-CFD

After months of tests and validations, these attempts have successfully converged into a new modelling methodology that consists of a

one-way coupling between WRF and DNV-CFD

(WRF-to-CFD).

using WRF to inform CFD boundary conditions → more representative of the actual atmospheric conditions at the site → more accurate wind flow predictions

Validation-onshore: Østerild

Measurements at 7, 37, 103, 175, 241 m

Filtered by stability (z_{ref} = 37 m)

Obukhov length range	Atmospheric stability class
-0.5 <= zref/L <= -0.2	Unstable
0.2 <= zref/L <= 0.5	Stable
|zref/L| <= 0.05	Neutral

- WRF simulations were run over the measurement period and classified/filtered according to above.
- A representative potential temperature profile for each stability condition was derived from the WRF results, along with a mean heat flux.
- SCM* RANS simulations were run using the WRF- derived inputs

* (Single Column Model)→ The processes for taking potential temperature profiles from WRF and converting them to boundary conditions that can be used in 3D steady-state RANS simulations.

Ref: Peña A; Kosovic B; Mirocha J. "Evaluation of idealized large-eddy simulations performed with the Weather Research and Forecasting model using turbulence measurements from a 250 m meteorological mast." *Wind Energy Science* 2021

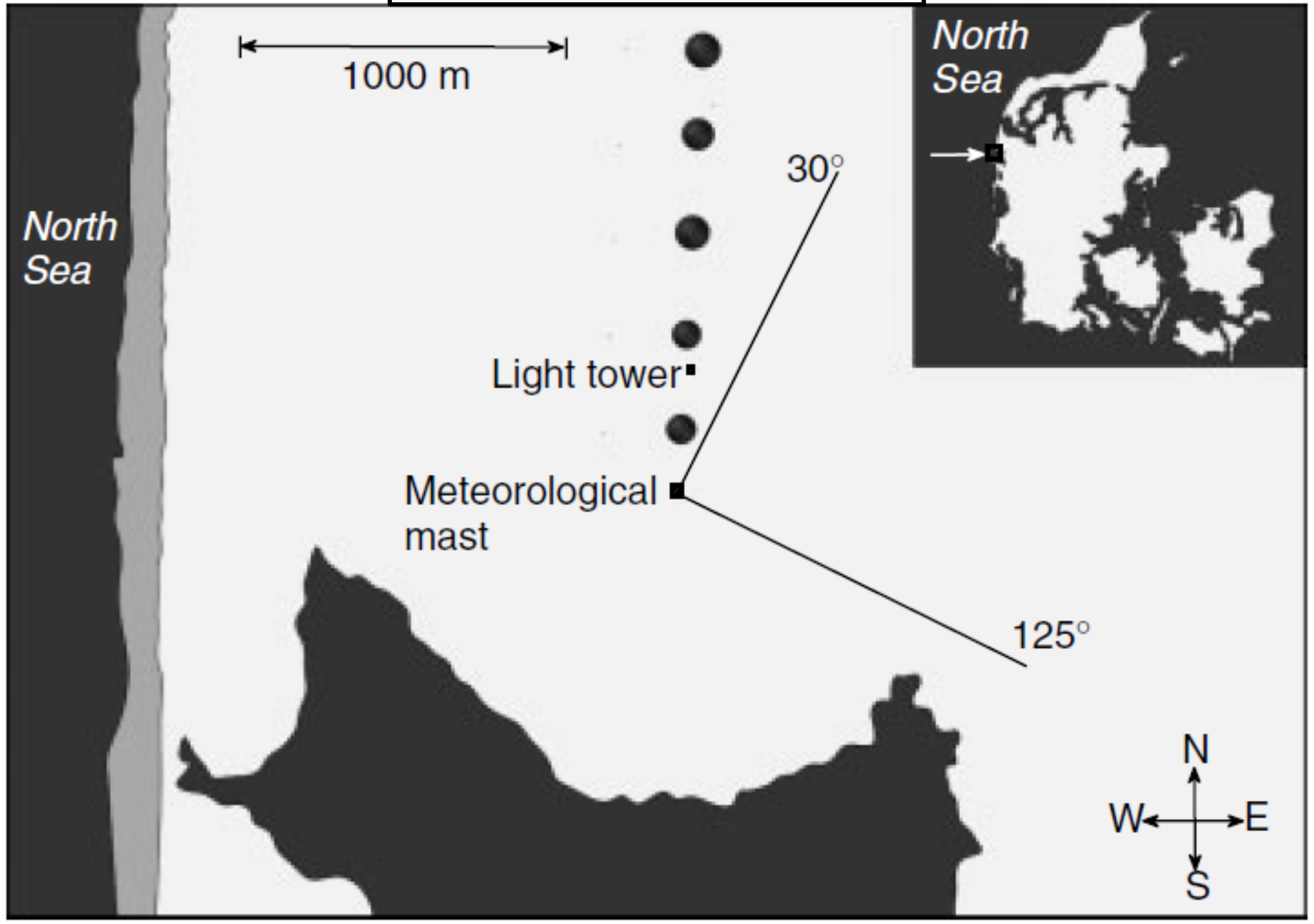
Validation-onshore: Høvsøre

Measurements up to 160 m

Filtered by stability

Obukhov length range (m)	Atmospheric stability class
$-100 \le L \le -50$	Very unstable (vu)
$-200 \le L \le -100$	Unstable (u)
$-500 \le L \le -200$	Slightly unstable (su)
$\|L\| \ge 500$	Neutral (n)

Location of Høvsøre mast



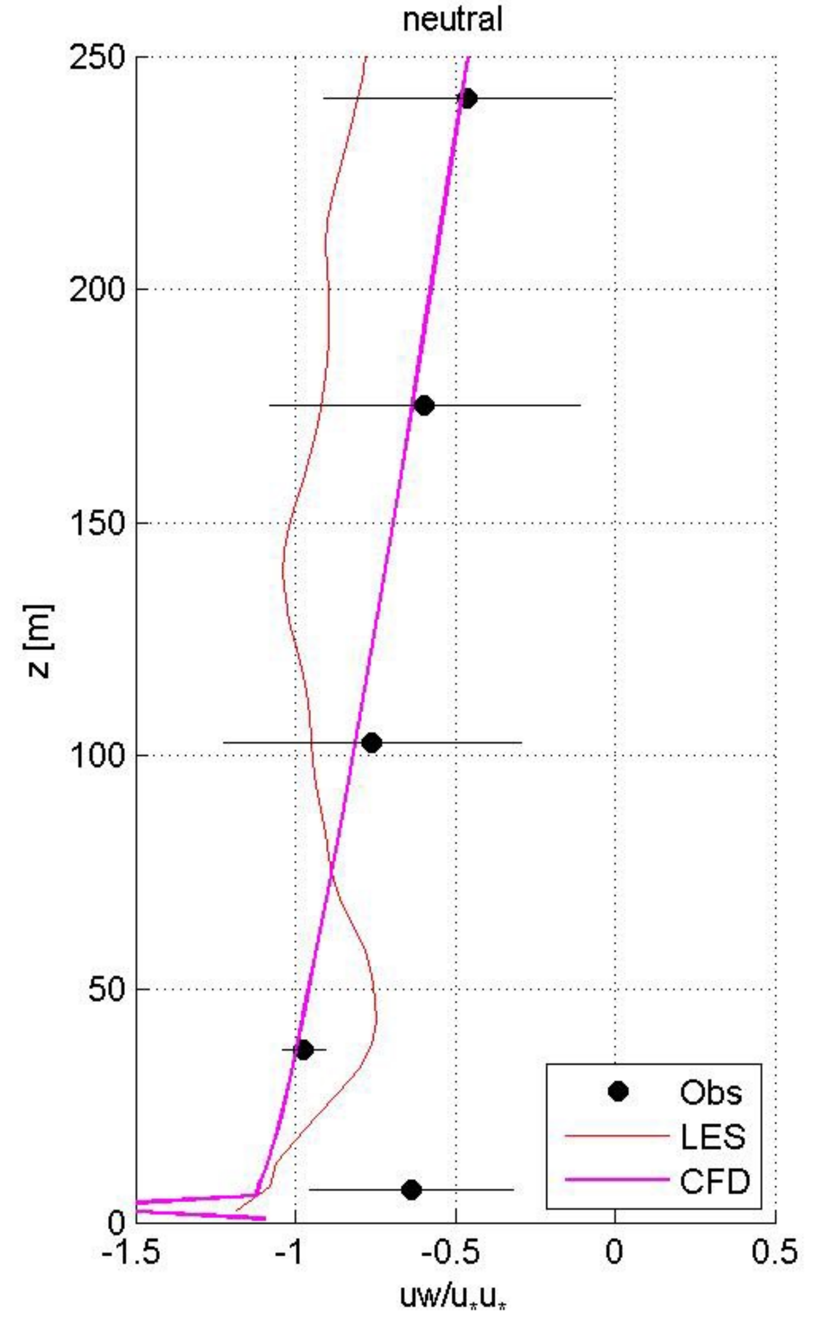
- WRF simulations were run over the measurement period and classified/filtered according to the above. No WRF records found for "very unstable".
- A representative potential temperature profile for each stability condition was derived from the WRF results, along with a mean heat flux.
- SCM RANS simulations were run using the WRF- derived inputs

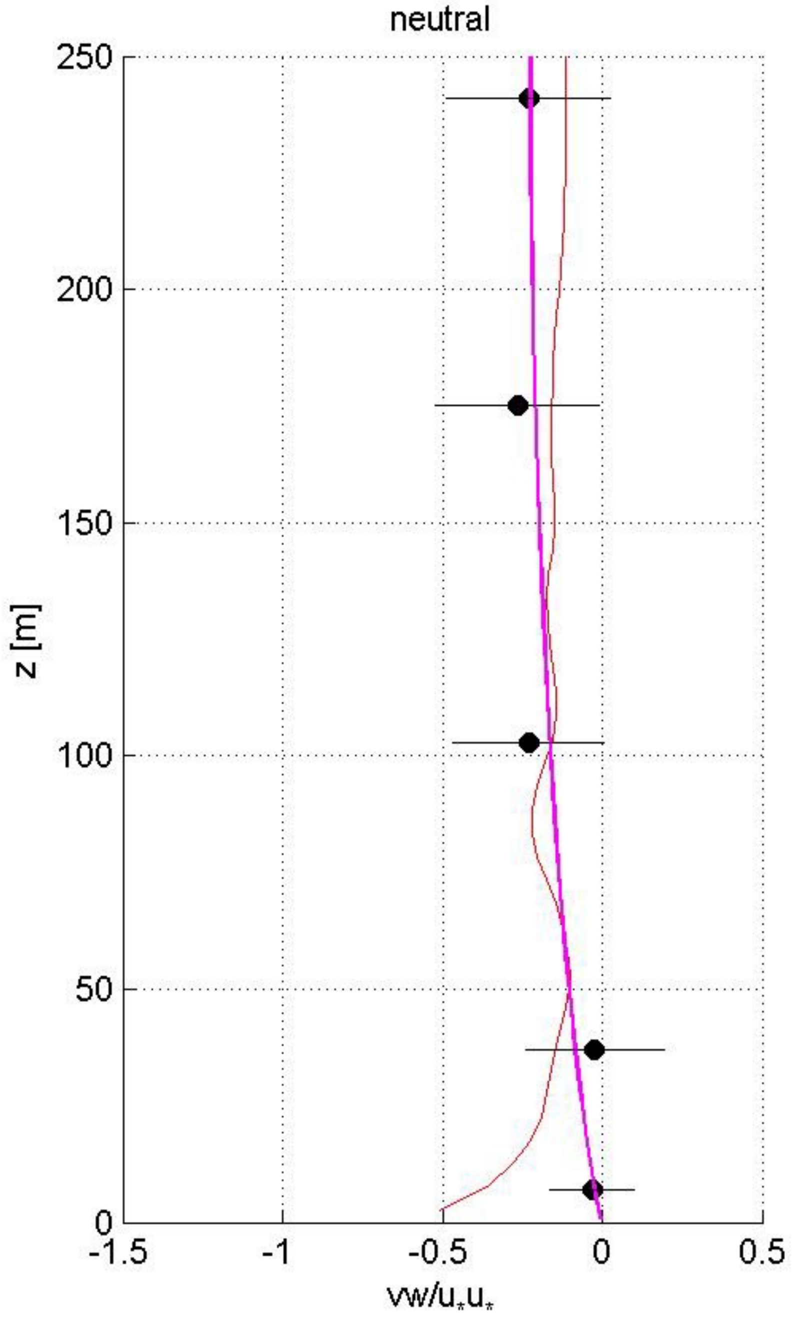
Ref: Peña A; Gryning SE; Mann J. "On the length-scale of the wind profile." *Q. J. R. Meteorol. Soc.* 2010

Validation summary for onshore

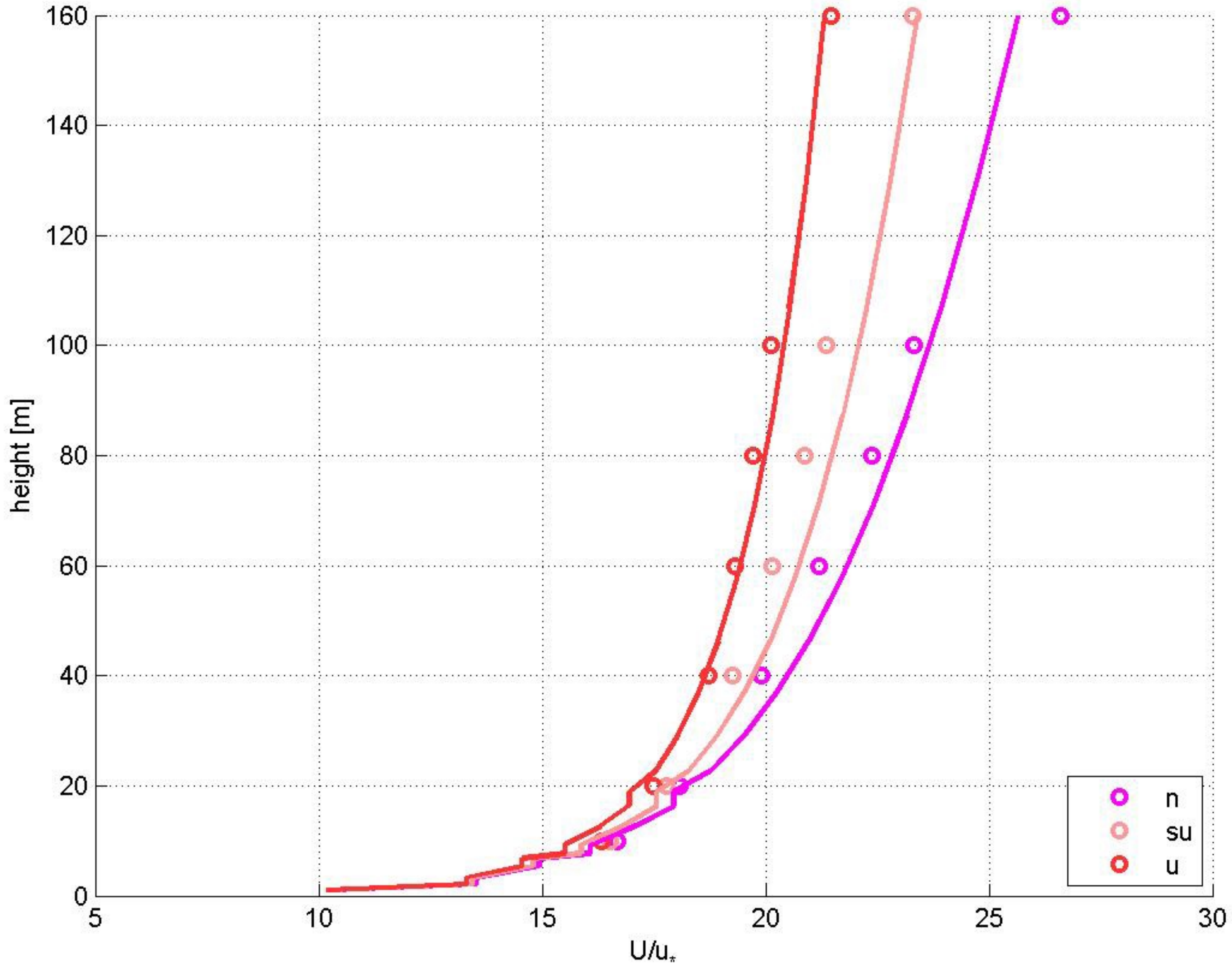
Østerild	Høvsøre

WRF-CFD **Measurements** **LES**





WRF-CFD (curves) **Measurements (dots)**



Validation-offshore: Hohe See and Albatros Blockage/wakes

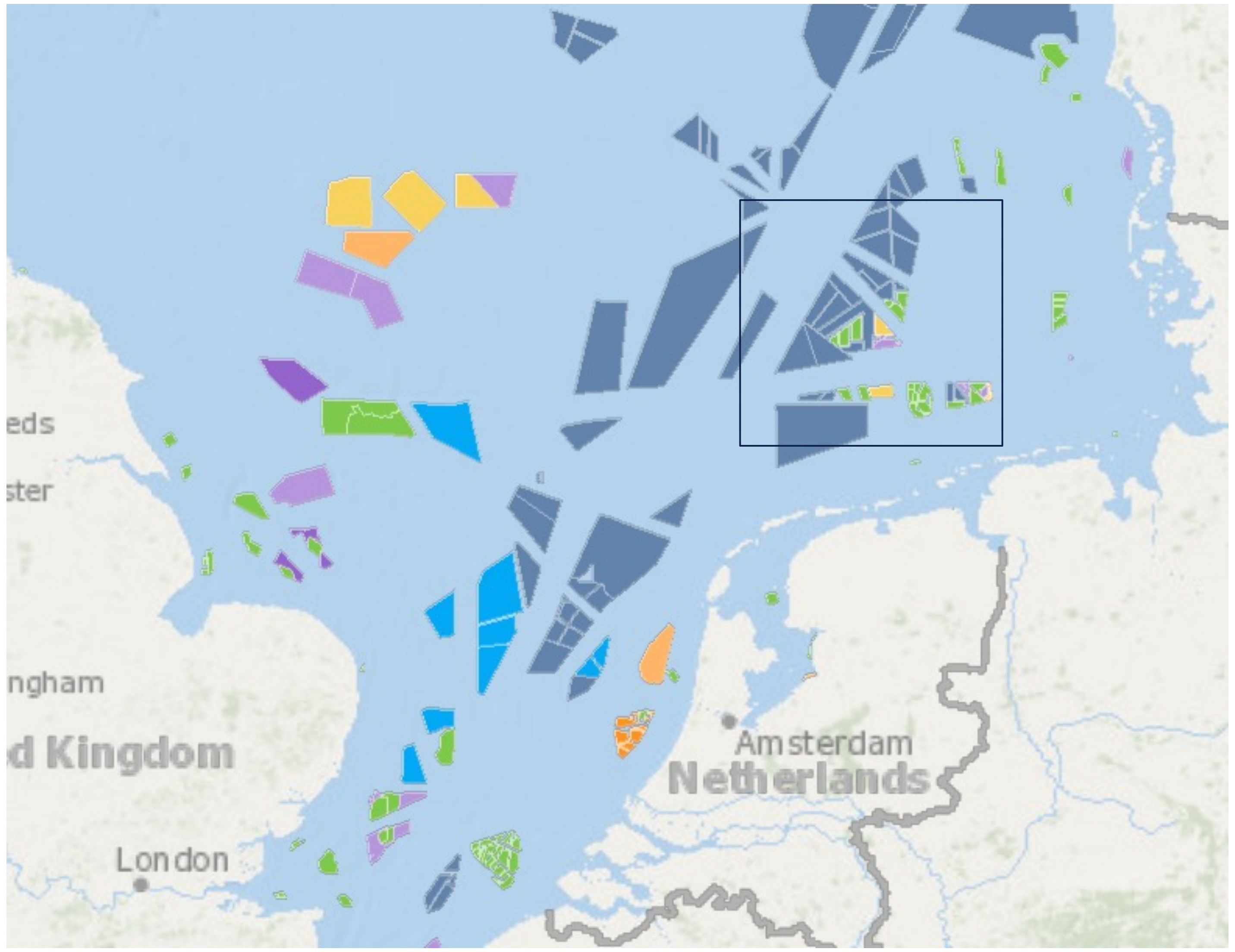
WRF – informed CFD captures the magnitude of the blockage and of the cluster wakes

WRF

- MYJ PBL scheme
- driven by ERA-5 reanalysis, ERA-5 SST
- period concurrent with the measurement campaign (Nov 2021 – Feb 2023)
- processed to derive boundary conditions for CFD model (particularly potential temperature profile)
- Per groups of directions, two sets of profiles for
  - Stable
  - Unstable conditions

CFD

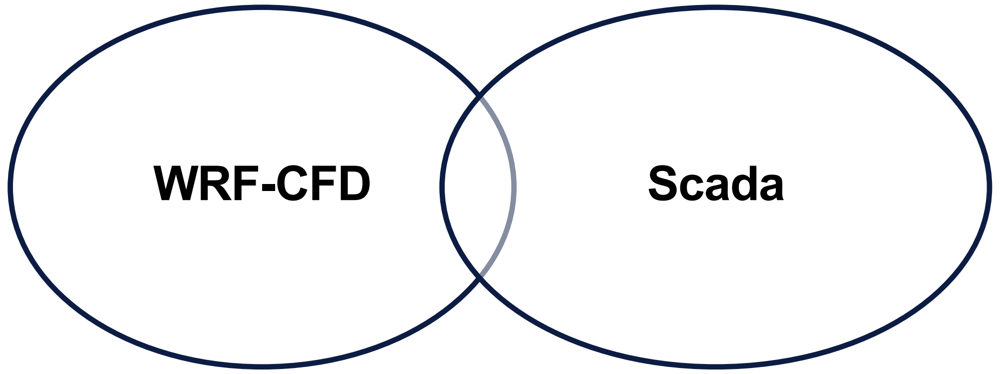
- Steady state RANS (k-e, modified turbulence constants)
- Transport equation for potential temperature
- Buoyancy in momentum and turbulence equations
- Coriolis
- Turbines via actuator disk
- WRF – informed boundary conditions
- CFD.ML
  - Machine learning model to interpolate pattern of production to a fine direction resolution, between directions solved by CFD

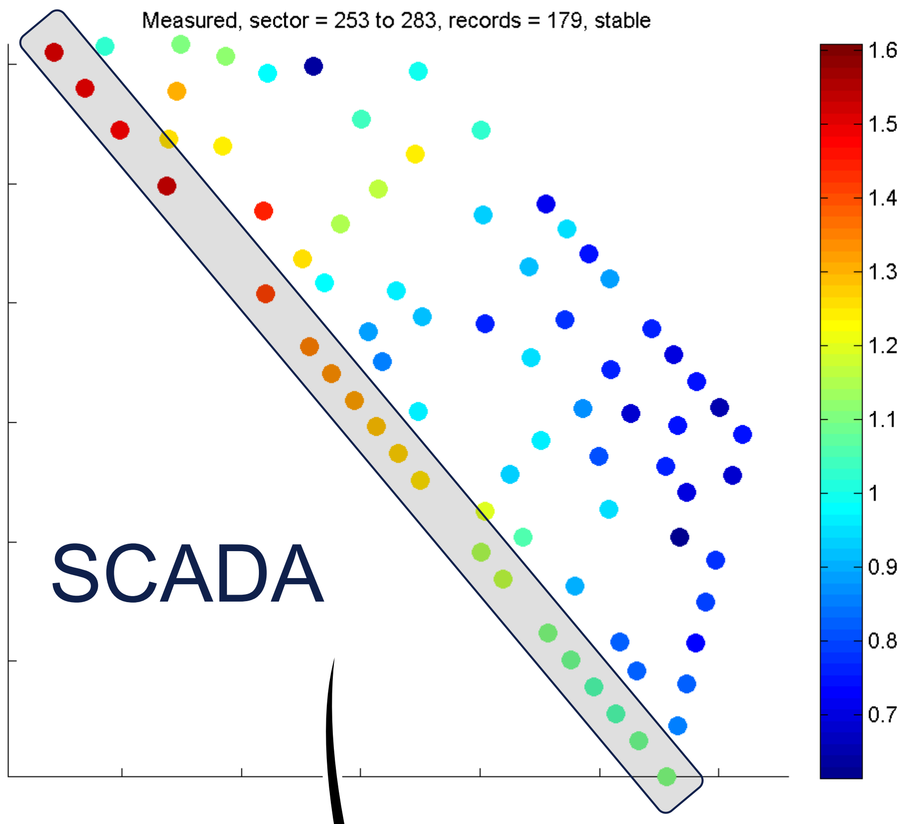


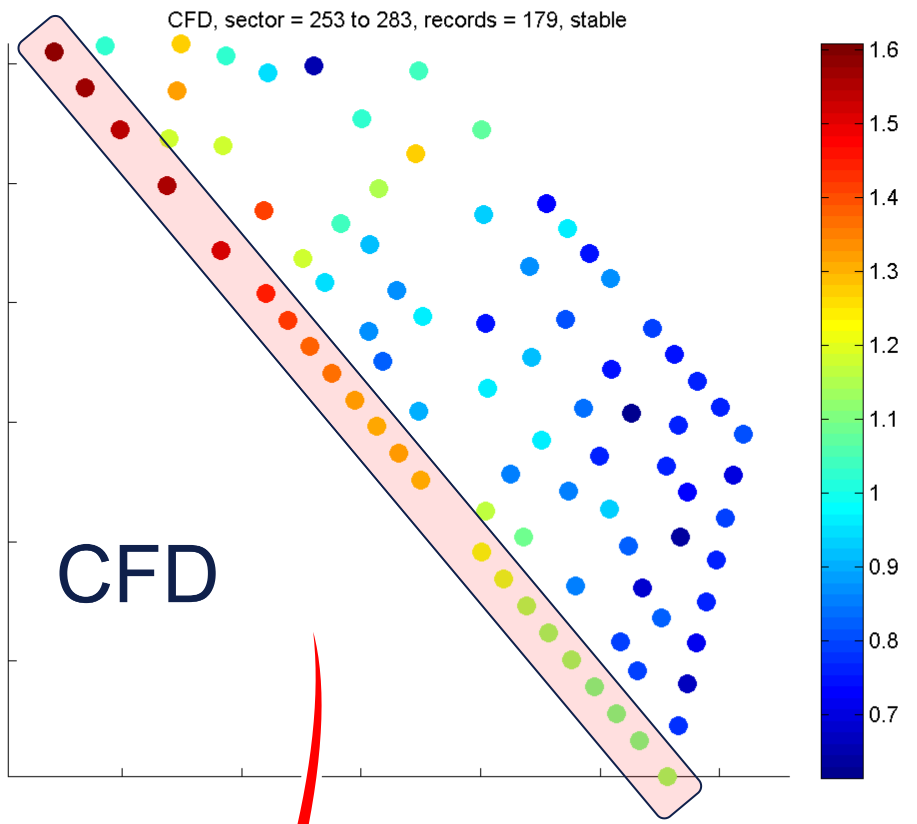
Purpose : cluster-to-cluster interactions

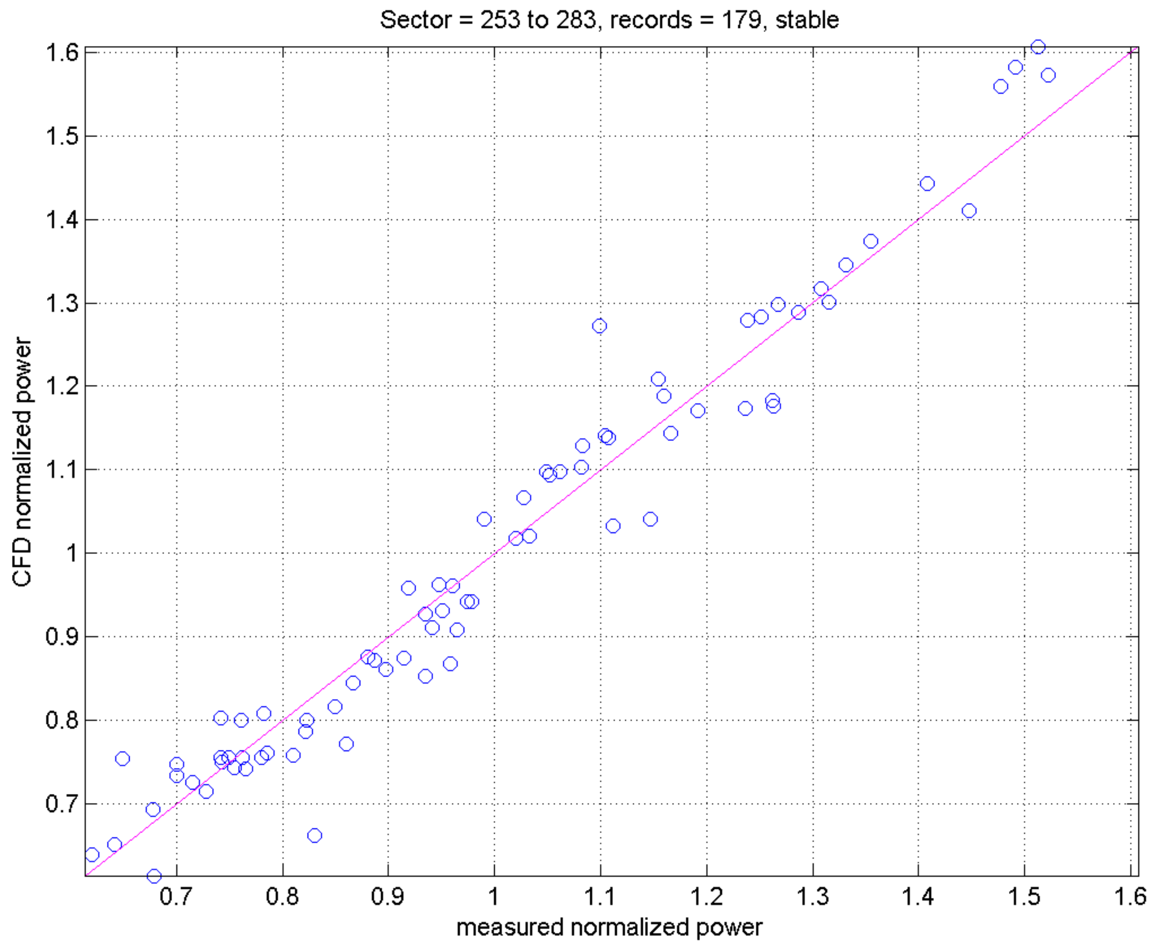
We acknowledge the project sponsors, EnBW and Enbridge, who not only funded the work, but also allowed this material to be made public.
DNV

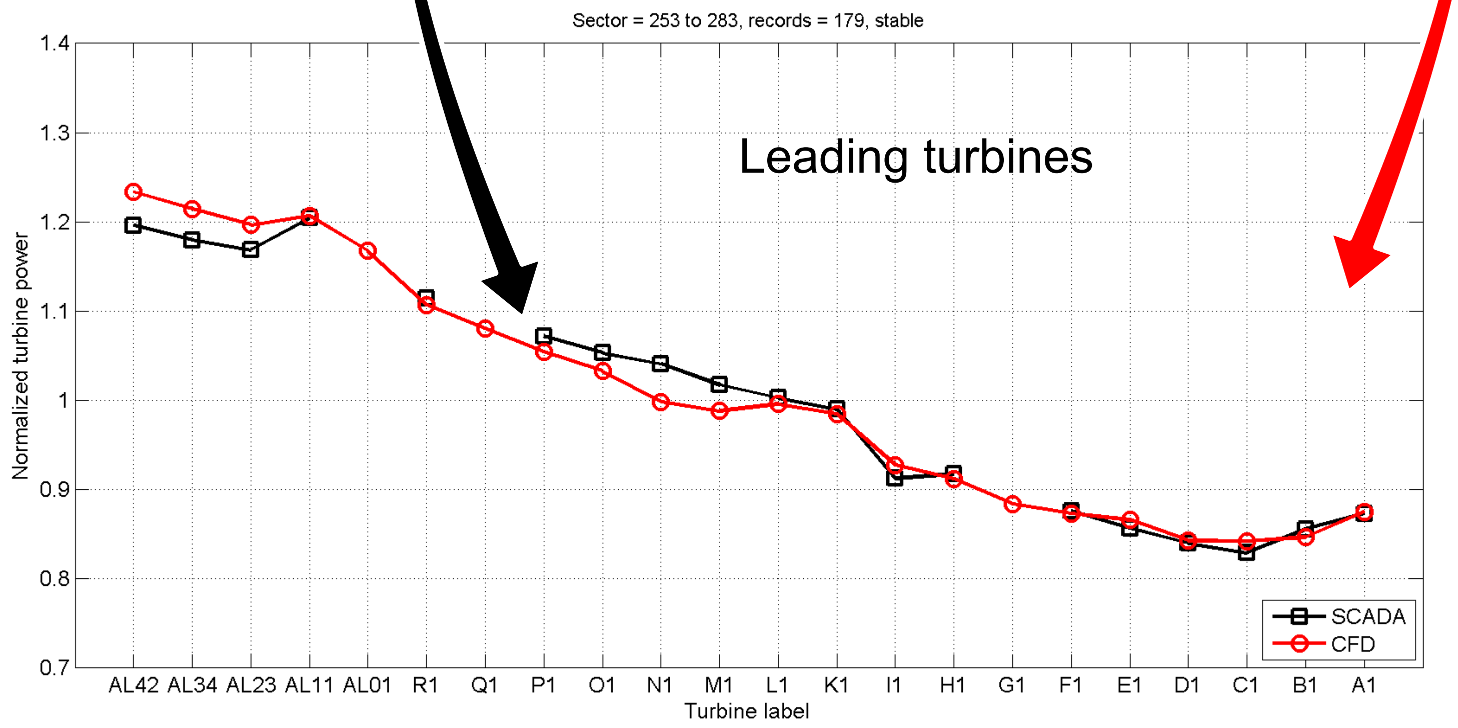
Pattern of production (253° -283°), stable











Whole array normalised power well captured by CFD

Conclusion

The presentation describes an effort to improve the representativeness of CFD inflow boundary conditions by deriving them from WRF output.

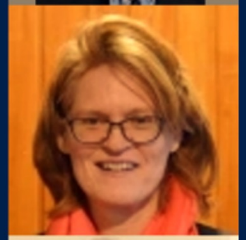
- Using WRF to inform CFD boundary conditions should lead to the simulation of conditions that are more representative of the actual atmospheric conditions at the site.
- Results from the proposed approach are validated against observations related to wakes, blockage, and flow over terrain at four wind farms, offshore and onshore.
- While obtained results show promise, we are also working to improve the WRF-to-CFD approach.

This research marks a significant stride towards bridging the gap between mesoscale and microscale CFD simulations, contributing to more accurate wind flow predictions, and bolstering confidence among stakeholders in the planning and execution of wind farm projects

WRF to CFD

Thanks for listening!

James Bleeg
James.Bleeg@dnv.com
+44 7860 181323



Christiane Montavon
Christiane.Montavon@dnv.com
+31 614651514

Narges Tabatabaei
Narges.tabatabaei@dnv.com
+46 735298419

DNV Sweden AB,
Elektrogatan 10,171 54 Solna,Sverige

www.dnv.com

DNV