PO.ID 155

A fast reduced order method for assessment of wind farm layouts

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Abstract

There is a need for accurate and fast methods for assessing different wind farm layouts. To assess the expected performance of a layout, the method needs to be able to compute the flow field and the wake losses in a wind farm for a range of wind speeds and wind directions.

We adapt and assess model reduction methodology applied to wind farm flow. Model reduction has been successfully applied to other fields, but to our knowledge, this application to wind power is new.

By basing our method on Computational Fluid Dynamics (CFD) and the Reynolds Averaged Navier-Stokes (RANS) equations, we believe that we can offer a method that is more accurate than the current state of the art for fast flow field assessment.

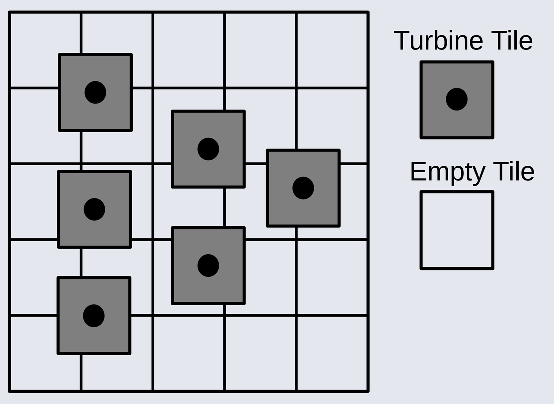
Objectives

Develop an *interactive* tool for wind farm layout assessment based on wake effects.

Asses the accuracy and speed of the tool for varying wind speeds, multiple wake effects, and turbine locations.

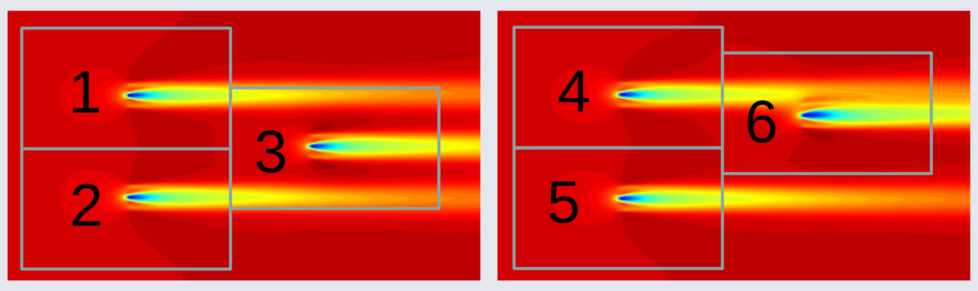
Methods

- ***Tile*** *– a subdomain of the wind farm*
- ***Snapshot*** *– the CFD solution within a tile for a given simulation.*
- ***Modes*** *– the set of orthogonal vectors/functions representing the reduced space*

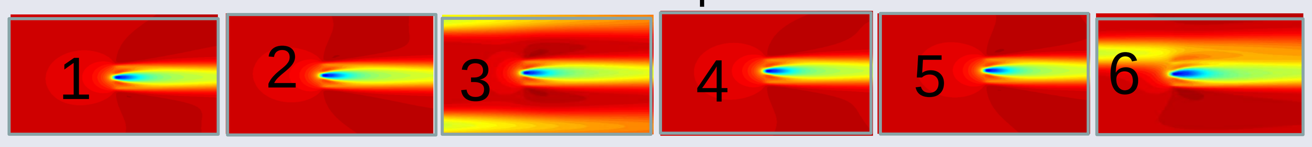


1. Run multiple CFD simulations using CMR-Wind [1] for varying setups (turbine positions, wind speeds). Extract snapshots for each simulation.

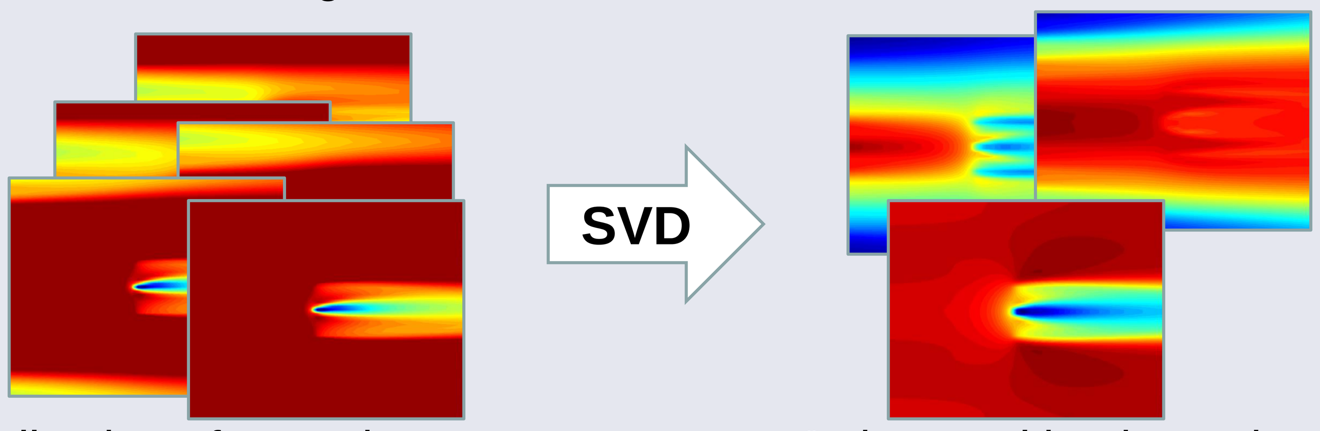
Example with two CFD simulations. Three tiles per Simulation.



Extract six snapshots



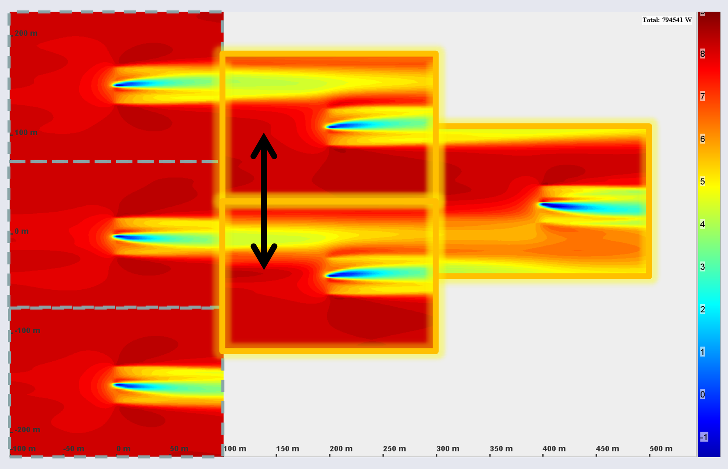
2. Apply Singular Value Decomposition (SVD) to produce a reduced space solution basis of orthogonal modes.



Collection of snapshots — Orthogonal basis modes

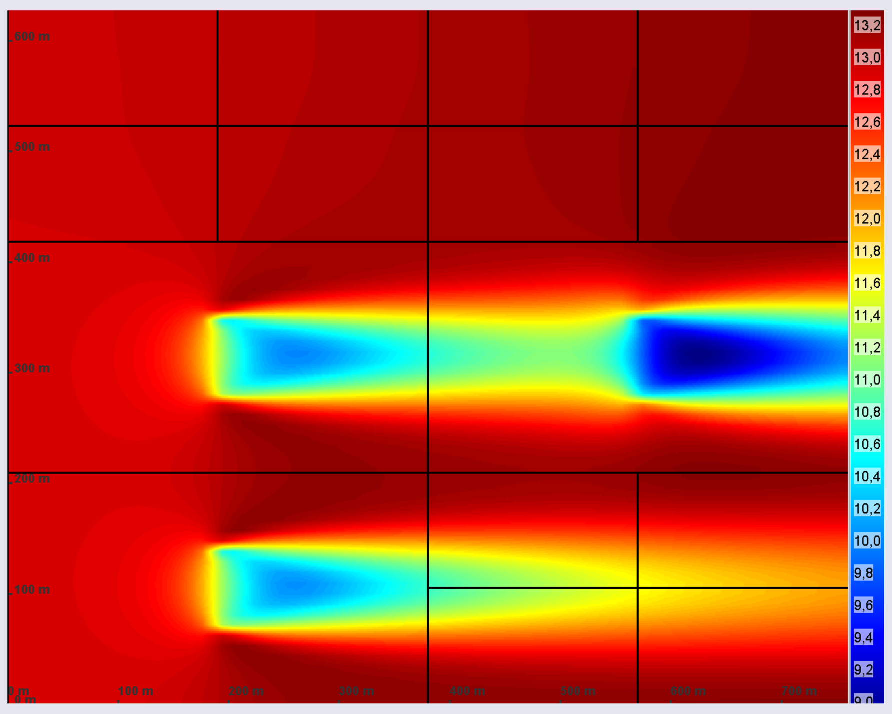
3. Interactively change wind conditions and/or turbine positions. Construct a new solution that weights between tile coupling and RANS equations.

The weighting between tile coupling and fitting to the RANS equations is controlled through a parameter alpha. Alpha = 0 gives all the weight to the tile coupling. Alpha = 1 gives all the weight to the RANS equations.

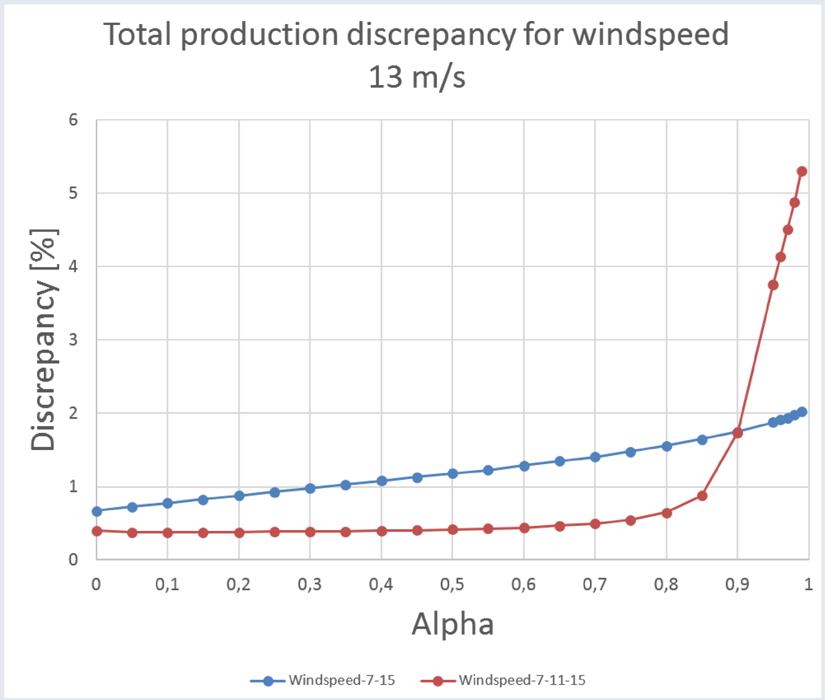


4. Compare solutions to RANS CFD solutions. If necessary improve the solution basis by running more CFD simulations and repeating steps 1-4.

Results



The setup of three turbines in the wind speed study. The black lines indicate the tile boundaries. This is the u-velocity at hub height for 13 m/s wind speed using the basis 7-15 with alpha = 0.5



The total production discrepancy compared to CFD for different values of alpha.

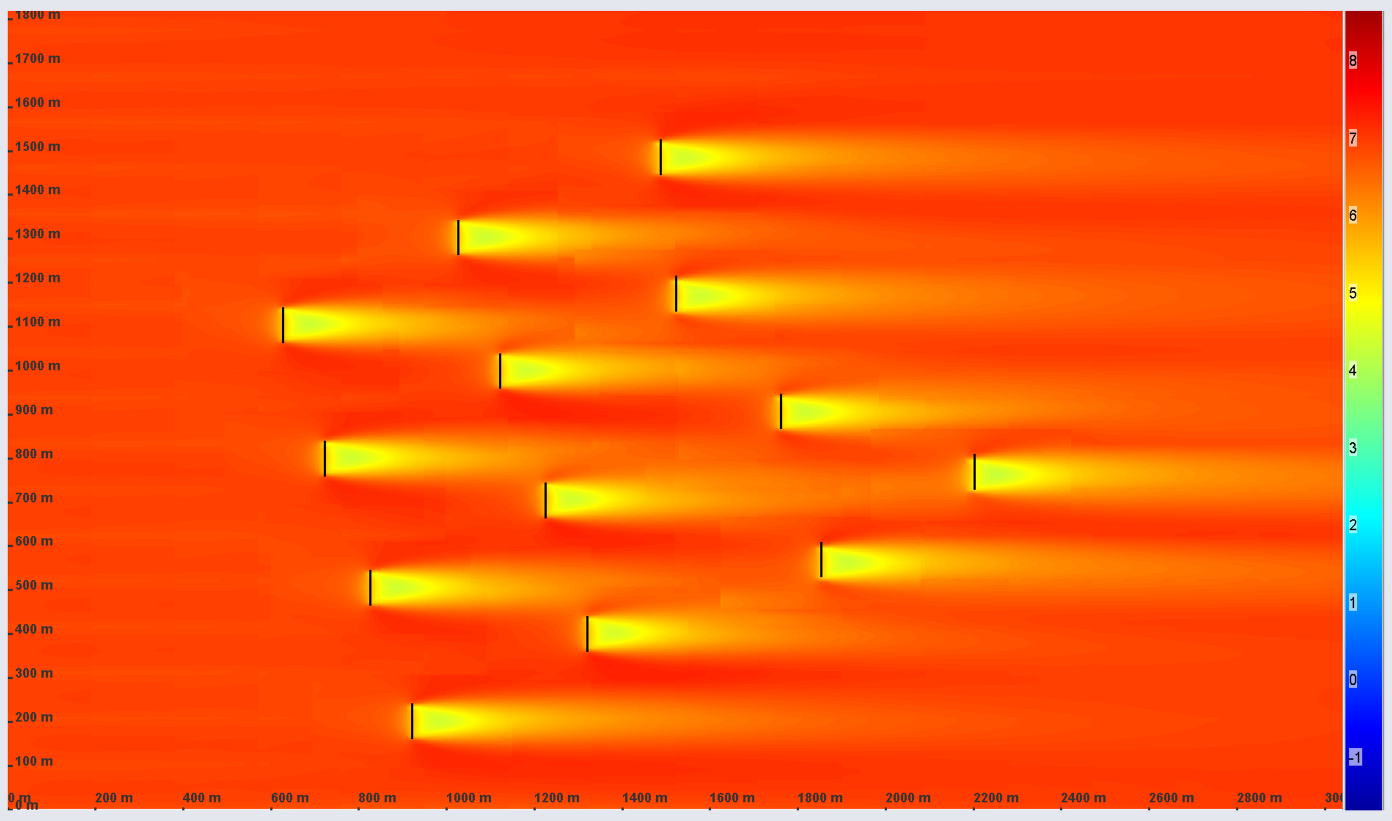
We have previous verified our model with CFD on a setup of six turbines by changing the position of downstream turbines as well as with multiple wake interactions in a line of ten turbines [2]. In 2014 we studied varying the wind speeds [3]. A basis with speeds of 7 m/s, 11 m/s, and 15 m/s was constructed and verified with wind speeds of 9 m/s and 13 m/s.

Total production discrepancy compared to CFD with alpha = 0.5

Basis Name		Verification Case	
	9 m/s	11 m/s	13 m/s
7-15	2.3%	2.4%	1.2%
7-11-15	0.9%	0.3%	0.4%

Conclusions

A model reduction technique based on CFD has been presented. In addition to arbitrary turbine position and multiple wake interactions the model reduction technique is able to simulate varying wind speeds from a relatively small set of underlying CFD simulations. For the test cases presented, the model reduction technique provides accurate approximations of the CFD results in **seconds rather than hours**.



An example of a virtual wind farm from our tool.

Future plans:

- Verify the tool to a moderate sized wind farm.
- Assess the wake induced fatigue loading on turbines by coupling the flow field and turbulent kinetic energy field to an external tool.
- Include the effects of different atmospheric stabilities.

References

1.Khalil M. and Sælen, L. 2013 . Near and far wake validation study for two turbines in line using two sub-grid turbine models. EWEA conference, Vienna, Austria, 4-7 February 2013.

2.Heggelund Y., Khalil M., Jarvis C., Interactive design of wind farm layouts using CFD and model reduction, EWEA 2014, Barcelona, Spain, 10-13 March 2014.

3.Heggelund, Y., Jarvis, C., Khalil, M., 2015, A fast reduced order method for assessment of wind farm layouts, Energy Procedia (submitted)