Implementation of a Simple Actuator Disk for Large Eddy Simulation (SADLES) in the WRF Model

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Why do we simulate turbine wakes?

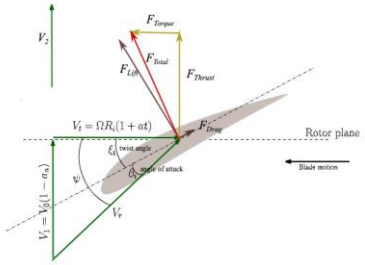
A good understanding of the interaction between wind turbines and the atmospheric boundary layer is critical for wind energy assessment and wind farm construction planning.

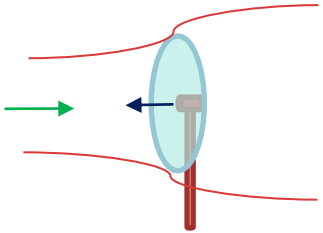
What do we need from a wind turbine simulation?

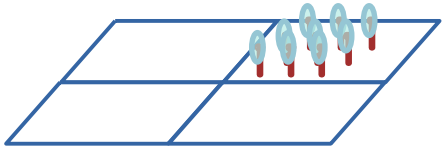
- Accurate wake presentation
- Realistic atmospheric conditions
- Turbine-turbine, Farm-farm interactions

Original Image: http://i.imgur.com/qruVcnu.jpg
Photo by Christian Steiness / Vattenfall (Horns Rev Offshore Wind Farm, Denmark)

Why yet another turbine model?







Actuator Surface/Line

Actuator Disk with Rotation
(i.e. Mirocha 2014)

Simple (no rotation) Actuator Disk

Wind farm parameterization
(i.e. Fitch et al 2012)

More Accurate

Less accurate

Requires lots of turbine information
Idealized atmospheric conditions
Costly to include multiple turbines
Not included in WRF

in-between compromise

Easy to implement
Realistic atmospheric conditions
Fast, multiple wind farms
Included in WRF

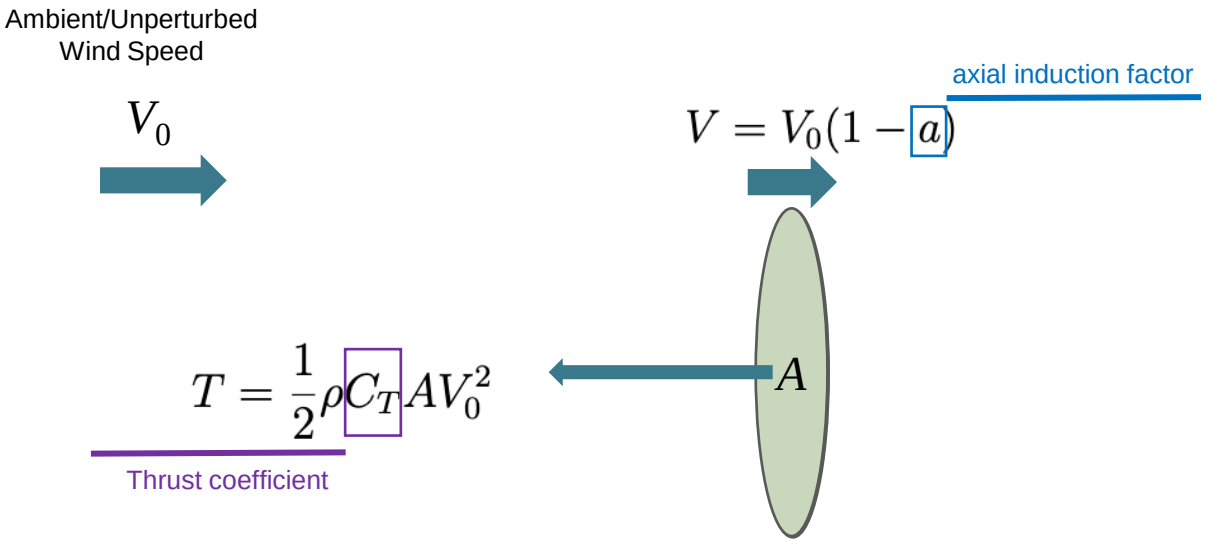
Target resolution 10-100 m
(also 100 m – 1 km?)

Typical resolution < 10 m

Typical resolution > 1 Km

A Simple Actuator Disk for Large Eddy Simulation (SADLES)
within the Weather Research and Forecast
Will be published as open source.

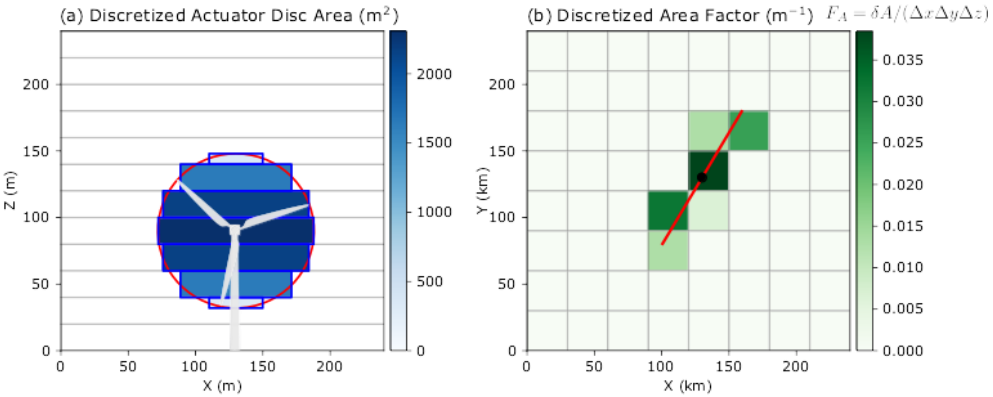
A Simple Actuator Disk model for Large Eddy Simulation (SADLES)



The thrust coefficent C_T is assumed to depend on V_0 only, and can be derived from a more complicated model or turbine manufactures

Implementation of SADLES within the WRF model

The actuator disc is discretized into WRF grids vertically and horizontally.



Two options of SADLES

Option 1

Direct evaluation of the axial induction factor
$\mathbf{V}_0$ is measure at 2 diameter ahead

$$a = \frac{|\mathbf{V}_0|}{|\mathbf{V}|},$$

Option 2

Infered evaluation of the axial induction factor
(From the 1-D momentum theory)

$$a = \frac{1}{2}(1 - \sqrt{1 - C_T(|\mathbf{V}|)})$$

Add tendencies to WRF model

zonal wind

$$\left.\frac{\partial U}{\partial t}\right|_T = -\frac{1}{2(1-a)^2}\mu_d C_T |\mathbf{V}| u F_A$$

medional wind

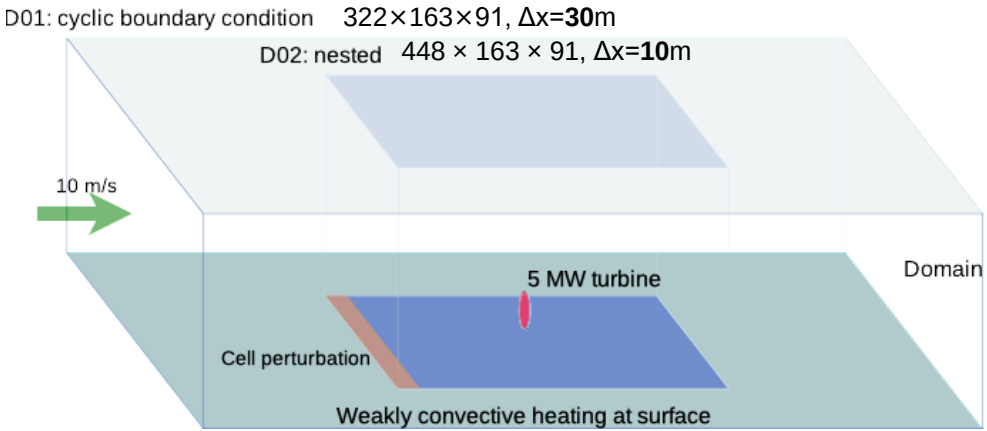
$$\left.\frac{\partial V}{\partial t}\right|_T = -\frac{1}{2(1-a)^2}\mu_d C_T |\mathbf{V}| v F_A$$

Turbulent kinetic energy

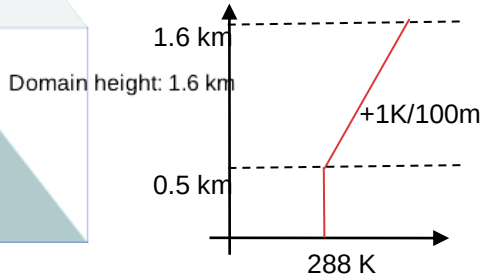
$$\left.\frac{\partial \mathrm{TKE}}{\partial t}\right|_T = \frac{1}{2(1-a)^3}\mu_d C_{TKE} |\mathbf{V}|^3 F_A$$

with $C_{TKE} = f_{TKE}(C_T - C_P)$
$f_{TKE} =$ 0.5 in this study

Example 1: Idealized experiments with a 5-MW turbine

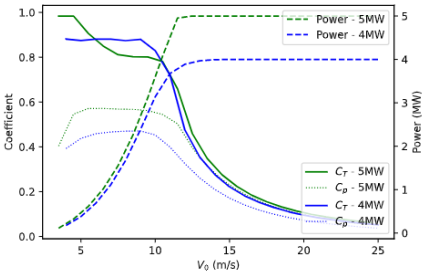


Nested domains



Surface turbulent heat flux: 0.02

Initial pot. temperature



Turbine curves

Spin up time: 24h, Simulation time: 5h

PALM

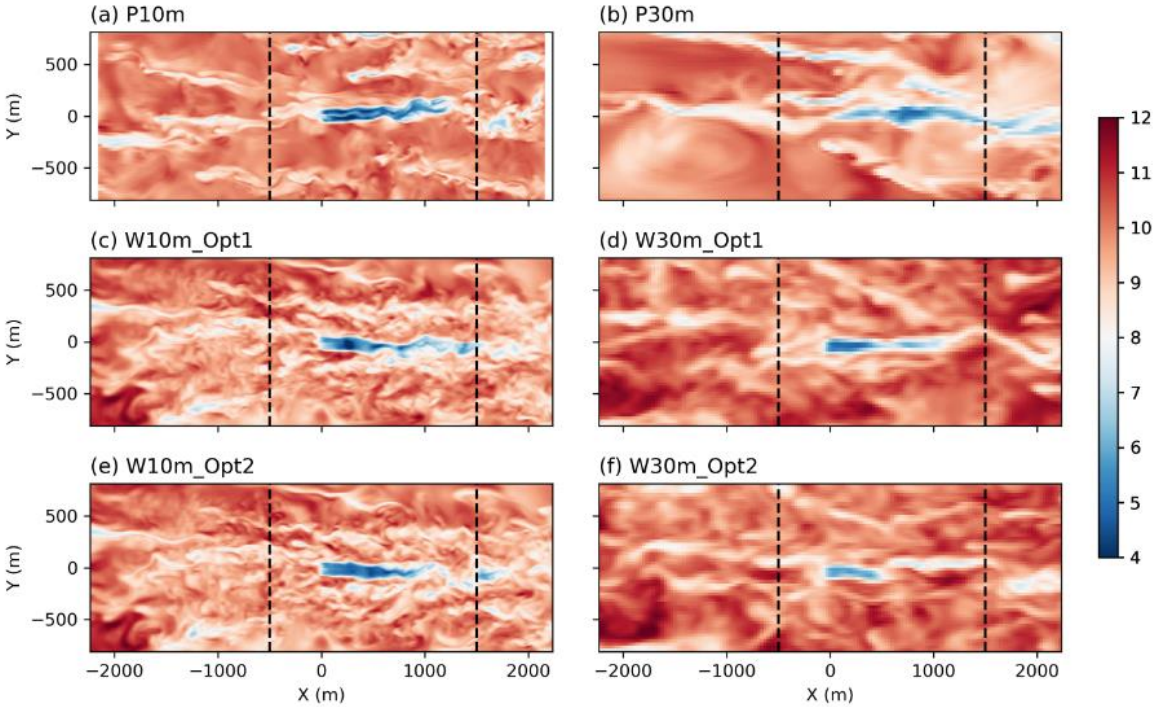
(https://palm.muk.uni-hannover.de/trac)
Using an actuator disk with rotation, based on BEM theory

WRF-SADLES-Opt1

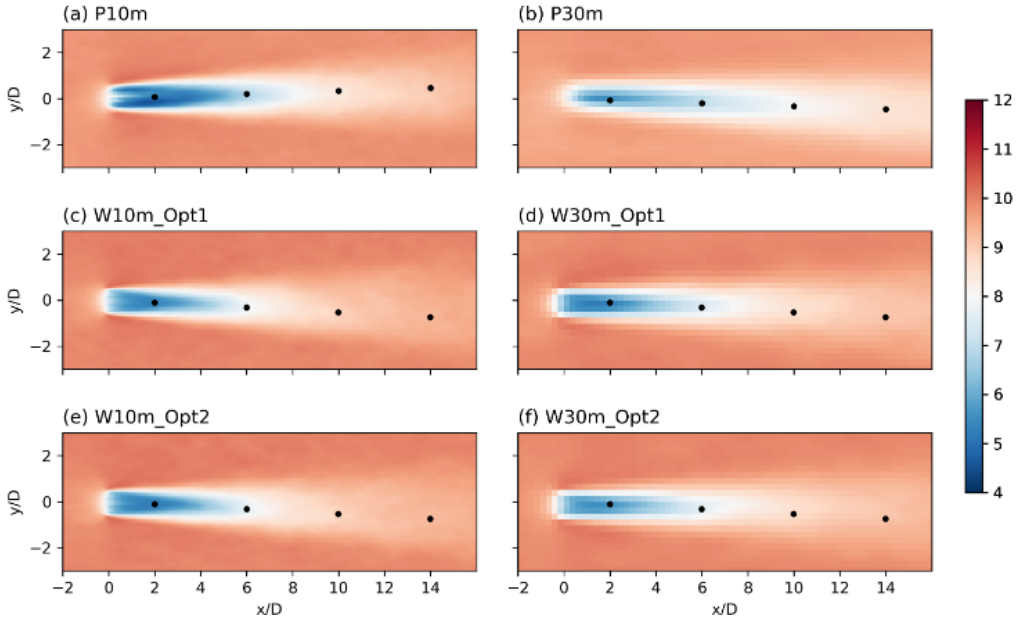
Direct evaluation $a = \frac{|\mathbf{V}_0|}{|\mathbf{V}|}$

WRF-SADLES-Opt2

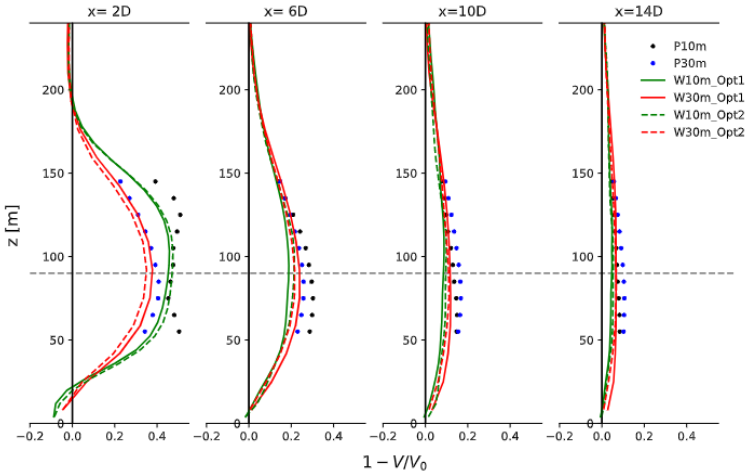
Using1-D momentum theory $a = \frac{1}{2}(1 - \sqrt{1 - C_T}).$



4-h average wind speed



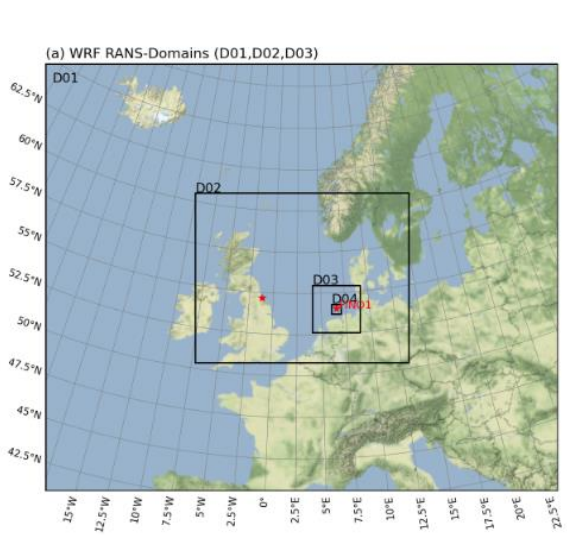
Wake deficit

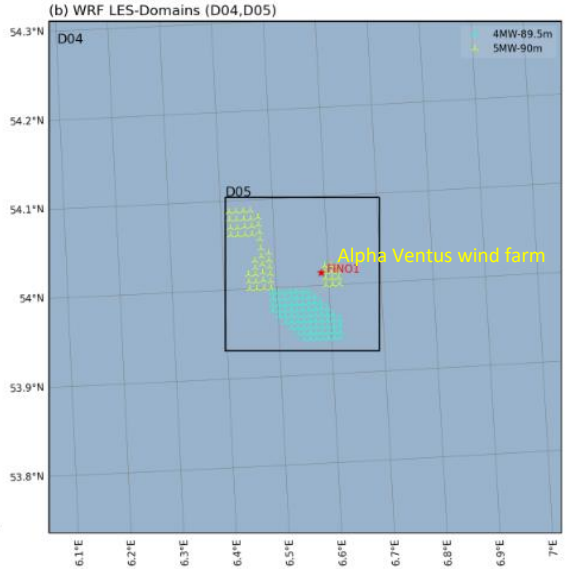


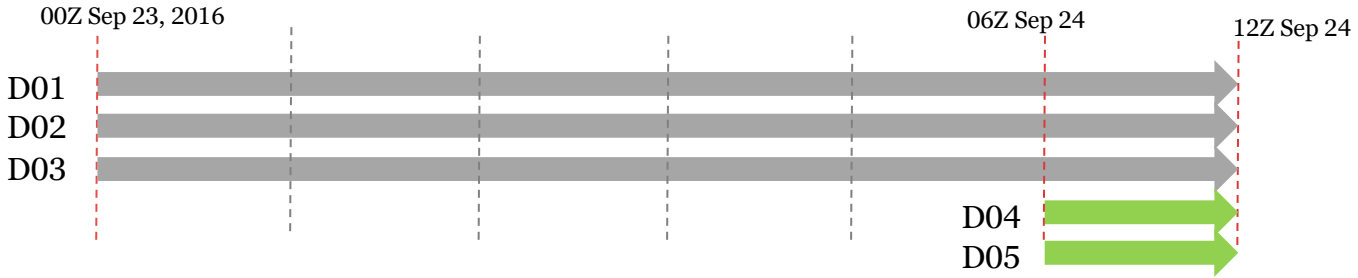
Example 2: Realistic wind farms simulations

Downscaling of ERA5 data using 5 nested domains

Domain	$N_x \times N_y \times N_z$	Δx (m)	Δt [s]	L_x [km]	L_y [km]
D01	$385 \times 321 \times 60$	9000	45	3456	2880
D02	$481 \times 382 \times 60$	3000	15	1440	1143
D03	$322 \times 322 \times 60$	1000	5	321	321
D04	$321 \times 321 \times 60$	200	1	64	64
D05	$481 \times 481 \times 60$	40	1/5	19.2	19.2







It took about 20 hours using 1028 CPU cores.

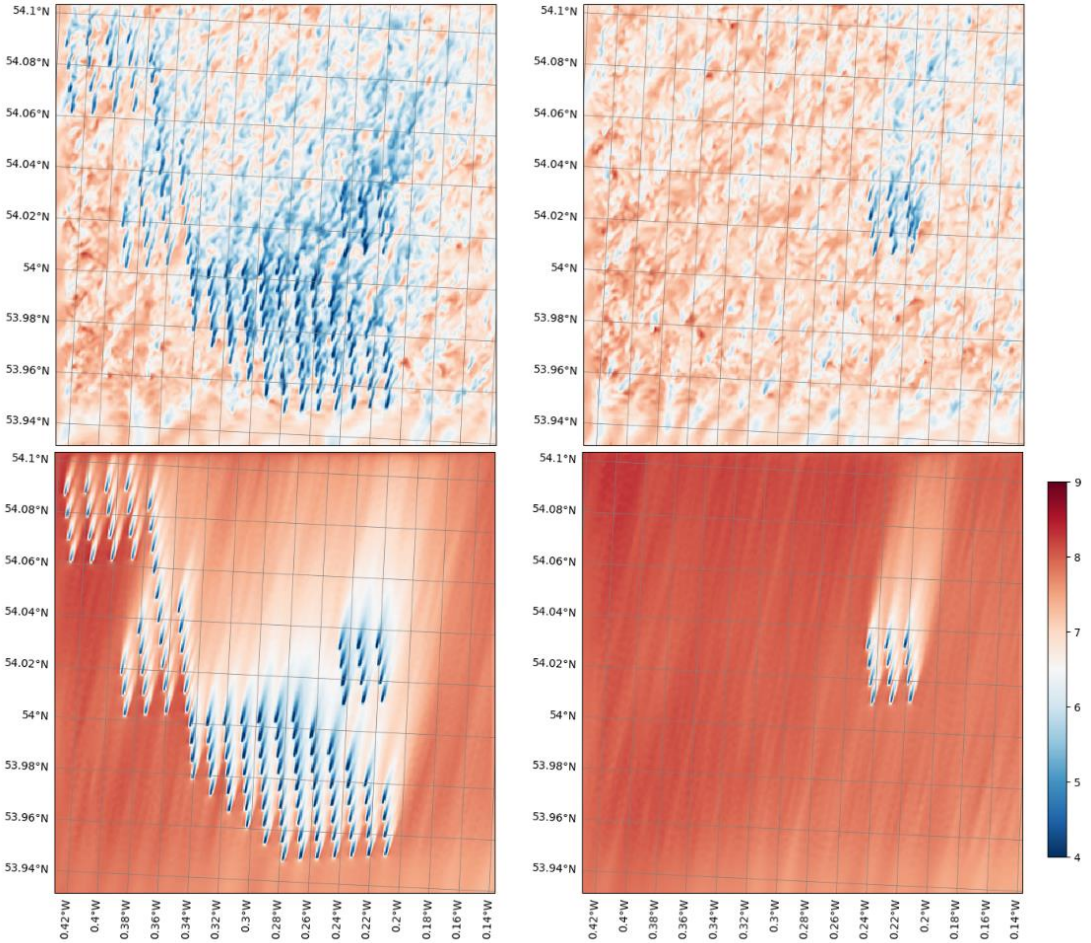
90-m wind speed

4-farms

1-farm

at 08Z Sep 24, 2016

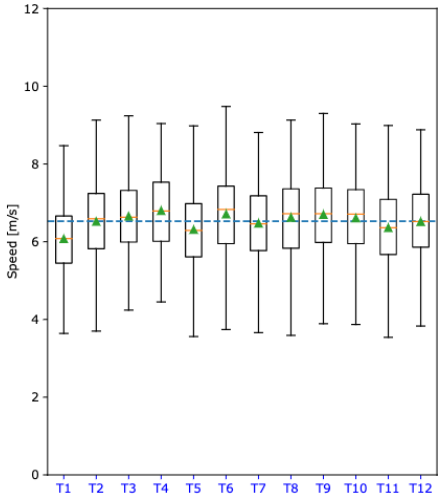
5-h average



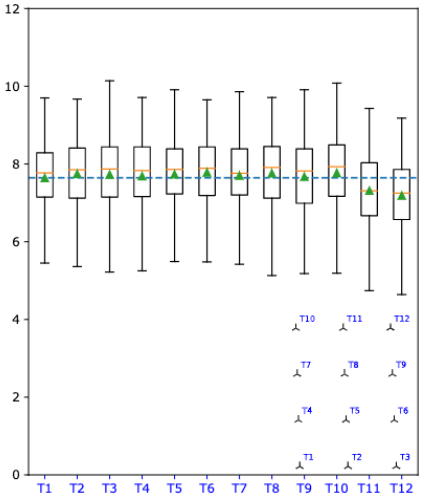
Alpha Ventus turbines

5-h ambient wind speed

4-farms



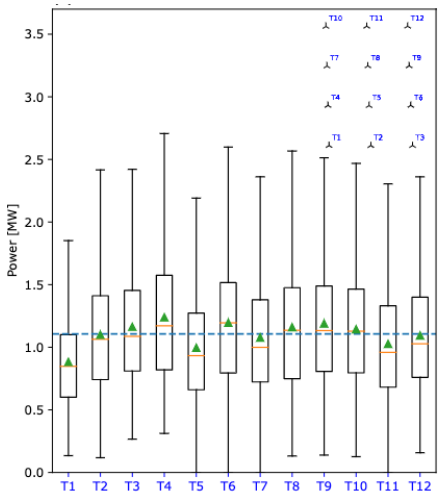
1-farm



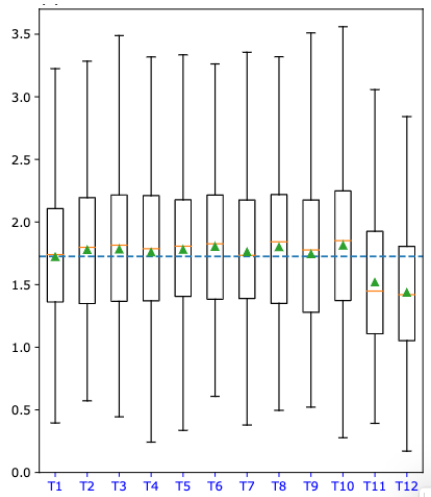
About 14% speed reduction

5-h turbine powers

4-farms



1-farm



About 35% power reduction

Summary

- We have implemented a Simple Actuator Disk model for Large Eddy Simulation (SADLES) within the Weather Research and Forecasting (WRF) system.
- WRF-SADLES is comparable to the PALM-WTM (using Actuator Disk with Rotation) model in simulating turbine far wakes at 10-meter resolution.
- WRF-SADLES has better agreement between the resolutions of 30 meters and 10 meters, making it suitable for LES studies with a coarser resolution and less computing power.
- We demonstrated a realistic downscaling simulation of multiple wind farms.
- SADLES will be released as open-source software for open research purposes.