NATIONAL RENEWABLE ENERGY LABORATORY

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Coupling a Mesoscale Numerical Weather Prediction Model with Large-Eddy Simulation for Realistic Wind Plant Aerodynamics Simulations

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MOTIVATION

A major hurdle to reducing the cost of wind energy is limited understanding of wind plant flow physics and variability. Using Large-Eddy Simulations (LES) coupled with numerical weather prediction (NWP) models for wind plant simulations can overcome that hurdle.

Wind plant aerodynamics are influenced by a combination of microscale and mesoscale phenomena. Incorporating mesoscale atmospheric forcing (e.g., diurnal cycles and frontal passages) into wind plant simulations can lead to a more accurate representation of microscale flows, aerodynamics, and wind turbine/plant performance.

Our goal is to couple a NWP model that can represent mesoscale flow [specifically the Weather Research and Forecasting (WRF) model] with a microscale large-eddy simulation (LES) model (OpenFOAM) that can predict microscale turbulence and wake losses. Our specific requirements are:

- Because wake losses depend on atmospheric stability, test coupling methods in different atmospheric stability conditions.
- Implement a computationally efficient coupling method.
- Use mesoscale forcing of wind speed, temperature, and surface heating.

METHOD

Mesoscale/NWP: WRF

WRF in NWP/mesoscale mode offers realistic time-varying forcing, but turbulence not resolved

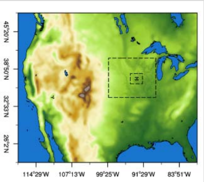


Figure 1. (left) WRF modeling domains – 4 mesoscale nests (31.2 km, 6.2 km, 1.2 km, 250 m) and 1 LES nest (50 m)

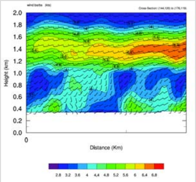


Figure 2. (right) horizontal wind speeds modeled by WRF

Microscale: WRF LES

Seamless integration with mesoscale solution, atmospheric physics represented, however for many forcing scenarios long upstream fetches are needed to transition from the mesoscale flow to turbulent LES;

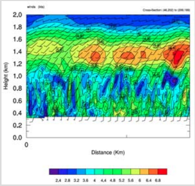


Figure 3. (left) Horizontal wind speeds modeled by WRF LES

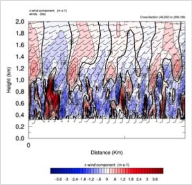


Figure 4. (right) Vertical wind speeds modeled by WRF LES

Microscale LES/CFD: OpenFOAM

Model microscale flow features of atmospheric boundary layer and turbine interactions. Advantages include:

- Flexible unstructured mesh used to increase resolution around turbines and in wakes; closely follow terrain
- Can be coupled with mesoscale model to include mesoscale forcing

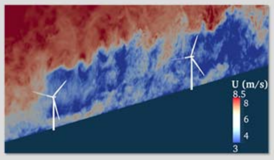


Figure 5. (left) Modeling of wakes in OpenFoam

Figure 6. (right) Wakes observed at the Horns Rev wind farm

CHALLENGES | SOLUTIONS

CHALLENGES	SOLUTIONS
Slow turbulence spin up in stable/weakly convective cases; important for wind energy production.	**Add perturbations to stimulate turbulence production.** **Perturbations must be** **➢ Adaptable to different inflow conditions** **➢ Optimized for rapid turbulence development** **➢ Extended to general atmospheric forcing** Perturbation approaches: e.g., Mirocha et al, 2013, doi: 10.1175/MWR-D-13-00064.1; Muñoz-Esparza et al. BLM (in review), Talk 9B.2.
Significant computation expended spinning up turbulence	**Use idealized cases (e.g., periodic boundary conditions for stable/weakly convective cases)**

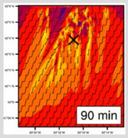


Figure 7. WRF LES simulation of the horizontal wind speed on a 50-m grid during weakly convective conditions over flat, homogeneous terrain after 90 min of simulation time

RESULTS

WRF LES simulations with realistic boundary conditions using different subgrid-scale models

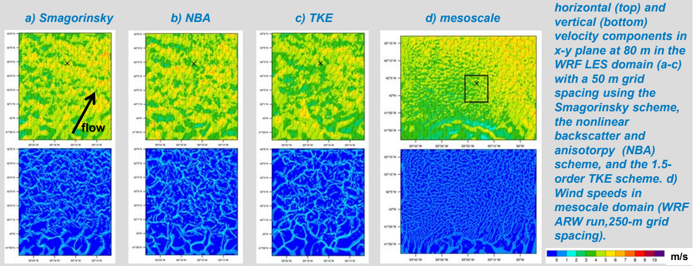
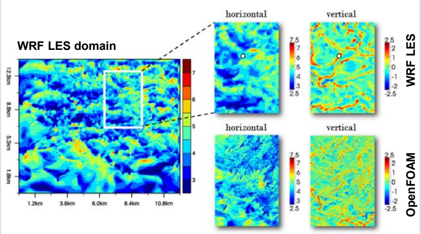


Figure 8. Left to right: horizontal (top) and vertical (bottom) velocity components in x-y plane at 80 m in the WRF LES domain (a-c) with a 50 m grid spacing using the Smagorinsky scheme, the nonlinear backscatter and anisotorpy (NBA) scheme, and the 1.5-order TKE scheme. d) Wind speeds in mesocale domain (WRF ARW run,250-m grid spacing).

Coupling WRF – WRF LES – OpenFOAM

Finer scales are resolved in OpenFOAM.



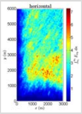


Figure 9. Integrated spectral energy of horizontal motions at 80 m in the OpenFOAM domain.

Figure 10. Instantaneous horizontal and vertical velocity contours during convective conditions showing the location of the OpenFOAM nest relative to the innermost WRF-LES nest. Grid spacing in LES domain is 50 m, in OpenFOAM 10 m.

FUTURE WORK

- Experiment with coarsest WRF resolution that still allows for reasonably fast development of small scale turbulence in OpenFOAM
- Add perturbations to microscale inflow boundary conditions to accelerate development of small-scale turbulence
- Compare perturbations in WRF-LES vs. OpenFOAM
- Investigate one-way vs. two-way coupling
- Investigate the need for consistent SGS modeling between WRF LES and OpenFOAM

SUMMARY

Using realistic atmospheric forcing for wind-plant aero-dynamics simulations requires innovative solutions (perturbations) to spin up turbulence in stable and weakly unstable atmospheric conditions. Initial coupling results in convective conditions and idealized simulations show expected atmospheric response. Developing robust capability for arbitrary atmospheric conditions is critical for wind energy.

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