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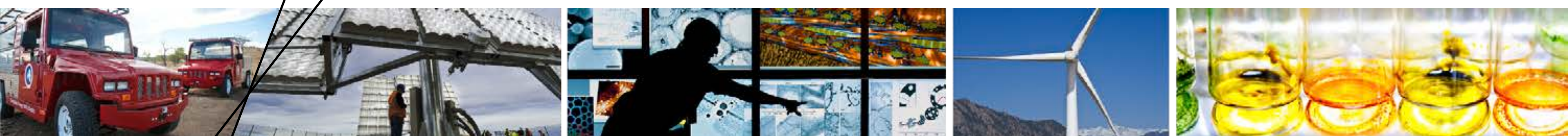
Using Mesoscale Weather Model Output as Boundary Conditions for Atmospheric Large-Eddy Simulations and Wind-Plant Aerodynamics Simulations



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Subject and Motivation

- ***The Subject:*** **Mesoscale-microscale one-way coupled simulation of atmospheric flow with focus on turbulence evolution**

- ***The Motivation:*** **Real wind plants are subject to microscale weather that is driven by mesoscale weather. Canonical microscale simulations do not capture:**
  - Frontal passages
  - Large-scale mean wind direction/speed changes
  - Significant wind direction/speed variation across the plant

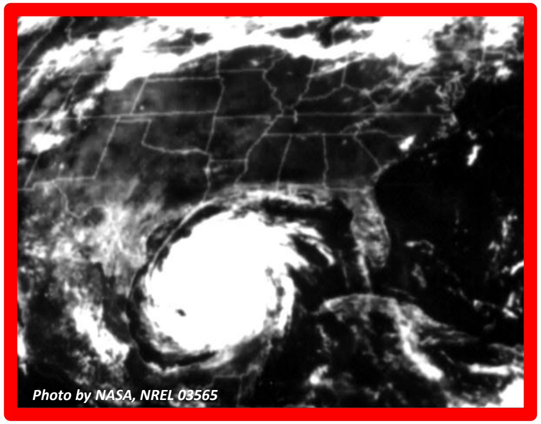
Simulation Tools

- **Mesoscale – WRF**
  - Nested Weather Research and Forecasting (WRF) model
  - Compressible, structured, higher-order finite-difference spatial scheme
- **Intermediary – WRF-LES**
  - Large-eddy simulation (LES) mode WRF (WRF-LES)
  - 1.5 equation turbulent-kinetic-energy (TKE) subgrid-scale (SGS) model
- **Microscale – OpenFOAM**
  - Created from Open-source Field Operations and Manipulations (OpenFOAM) computational fluid dynamics toolbox
  - Incompressible atmospheric LES solver with buoyancy forcing and shear stress lower boundaries
  - Unstructured, second-order finite-volume solver
  - Standard Smagorinksy model, C_s=0.135 (dynamic models available)
- **Turbine Model – FAST**
  - NREL's Fatigue, Aerodynamics, Structures, and Turbulence (FAST) tool
  - Blade element actuator line rotor with turbine system dynamics and control response model

Simulation Tools

NREL's Multiscale Coupling Effort:

The Simulator for On/Offshore Wind Farm Applications (SOWFA)



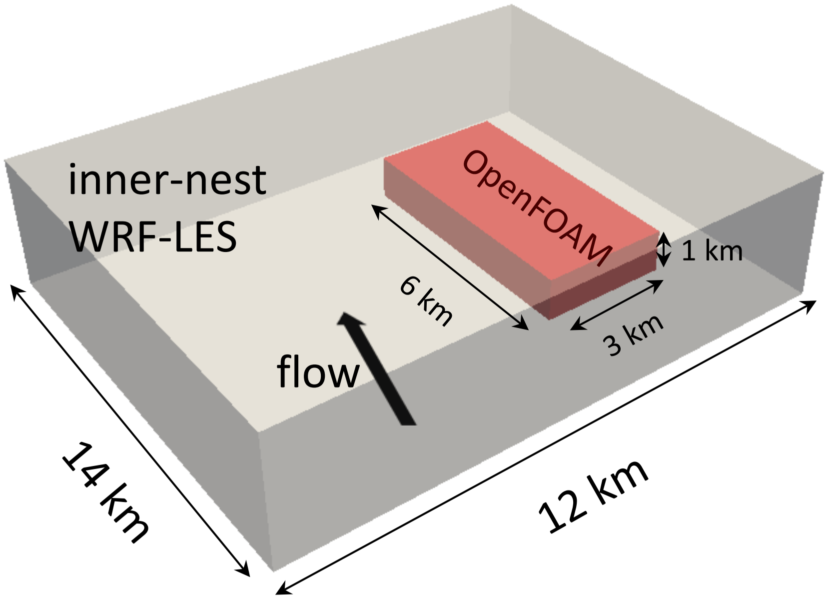
Mesoscale weather modeling (WRF)

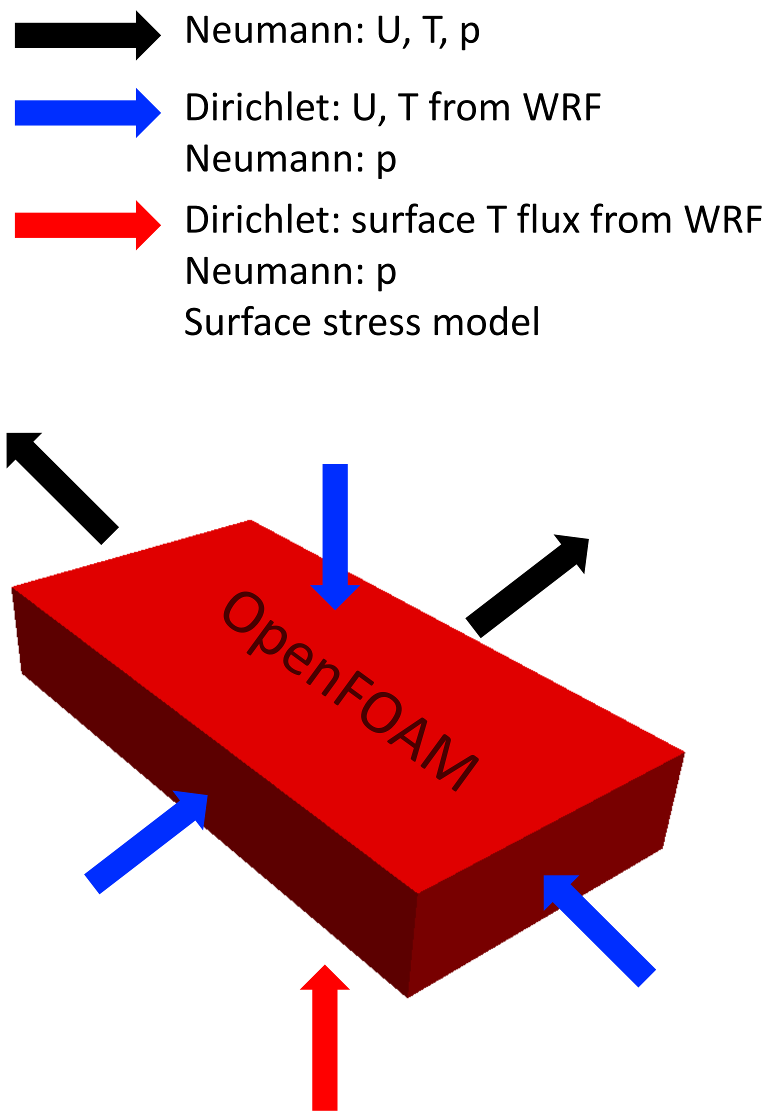
Microscale/wind-plant-scale large-eddy simulation (LES) (OpenFOAM)

Turbine system/structural dynamics (FAST)

Available at http://wind.nrel.gov/designcodes/simulators/sowfa/

Mesoscale-Microscale Simulation Strategy

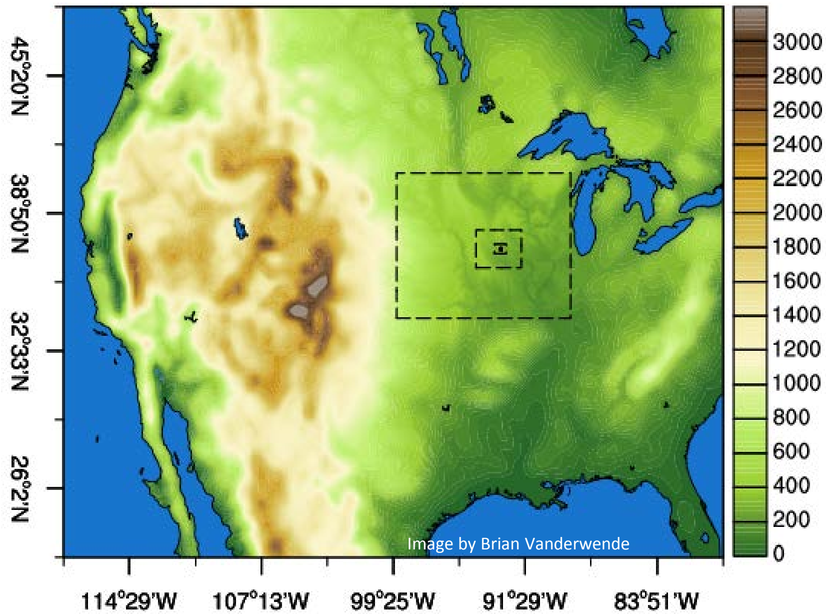




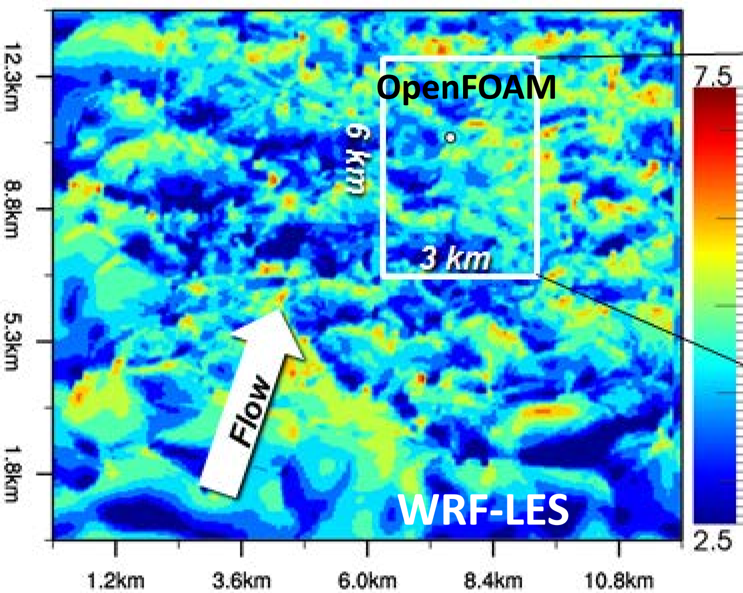
1. Run WRF and WRF-LES
2. Interpolate time history to OpenFOAM boundary locations and initial field to OpenFOAM interior
3. Run OpenFOAM using WRF-LES initialization and boundary conditions

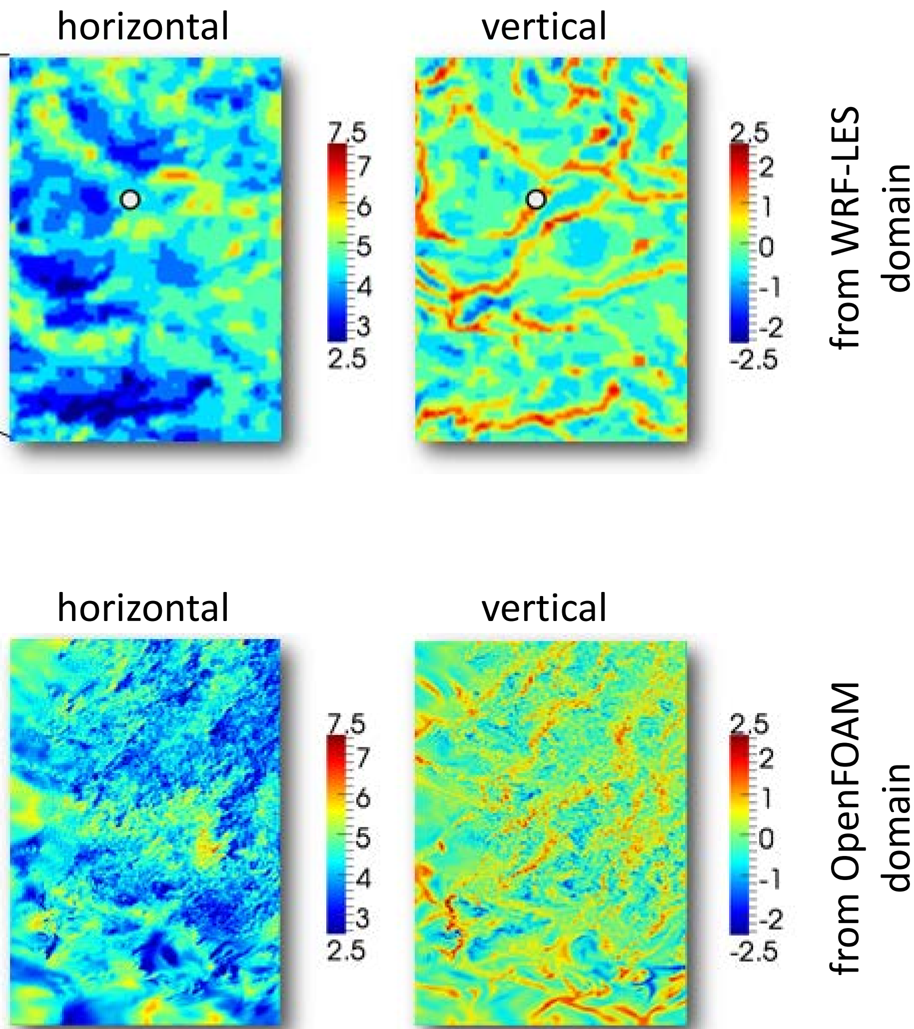
Case Simulated

- Crop and Wind Energy eXperiment (CWEX)
- Wind plant in Iowa over relatively flat farm land
- Summer, daytime case – moderately convective
- 1 hr of coupled simulation



Results: Coupling with No Turbines





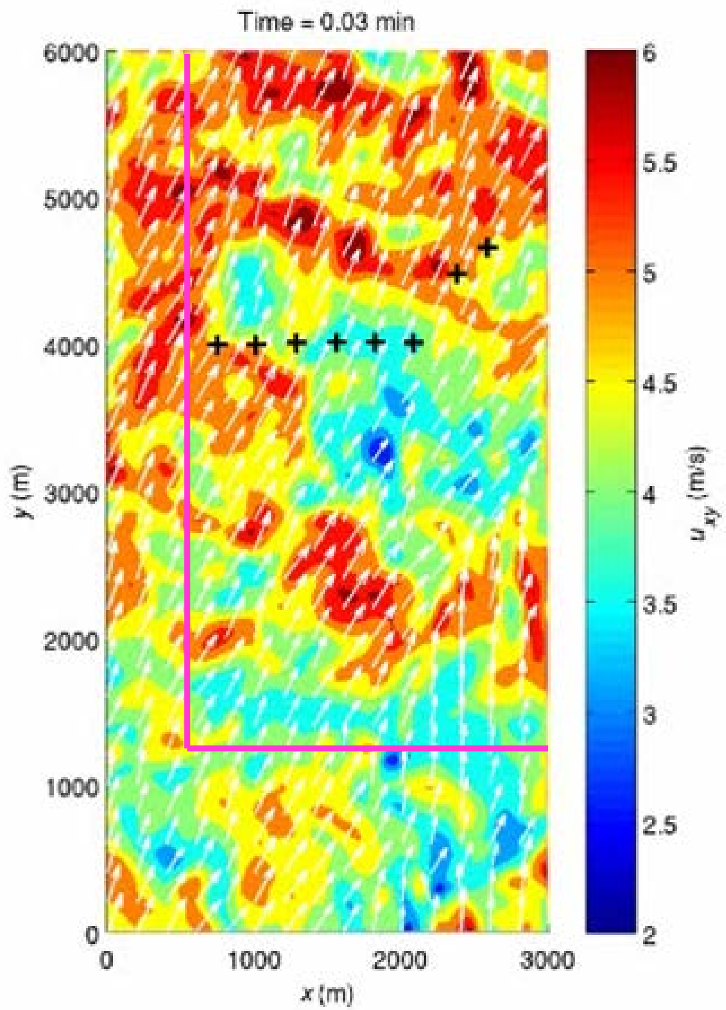
Instantaneous velocity at 85 m above surface

Results: Coupling with No Turbines

WRF-LES initialized flow field

Finer-scale flow features begin to develop

Region in which finer scales visually appear fully developed



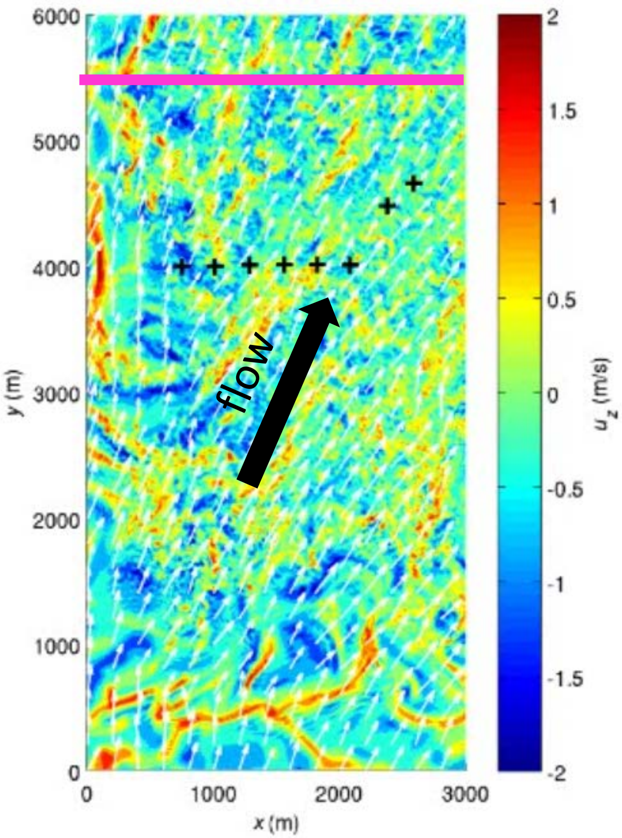
Black crosses denote actual turbine locations **(turbines not included in this simulation)**

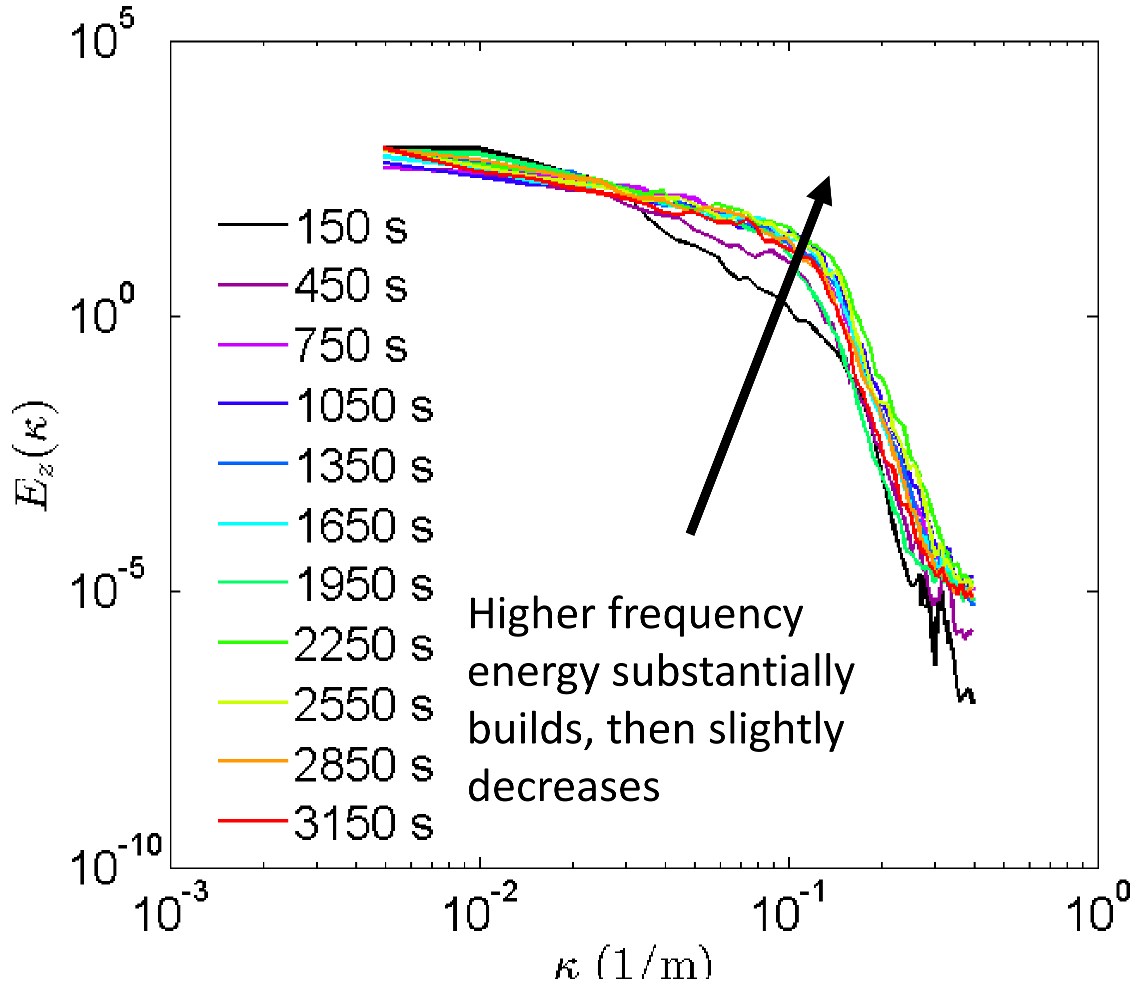
Horizontal velocity time history at 80 m above surface from OpenFOAM microscale calculation

Results: Coupling with No Turbine

Spectra evolution in time

Spectrum of different segments of time history averaged over y constant line

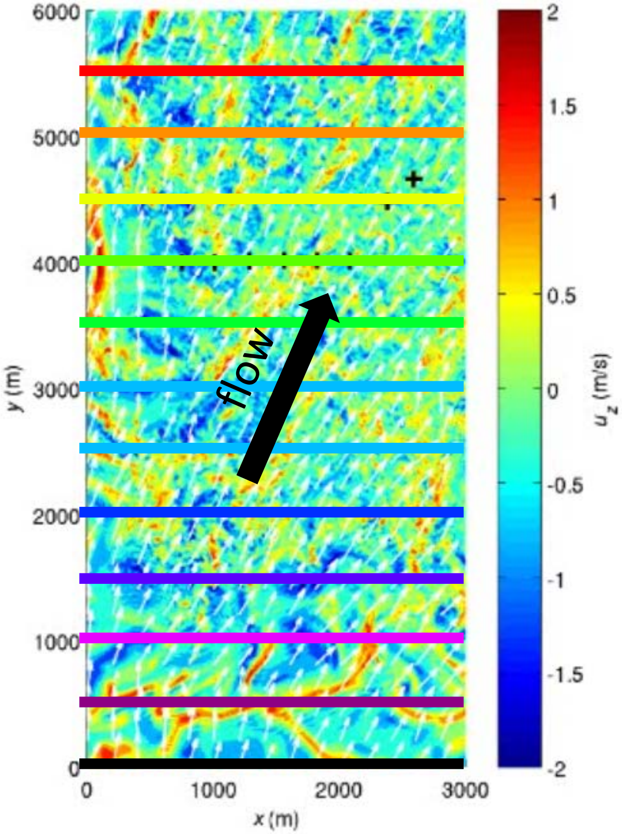


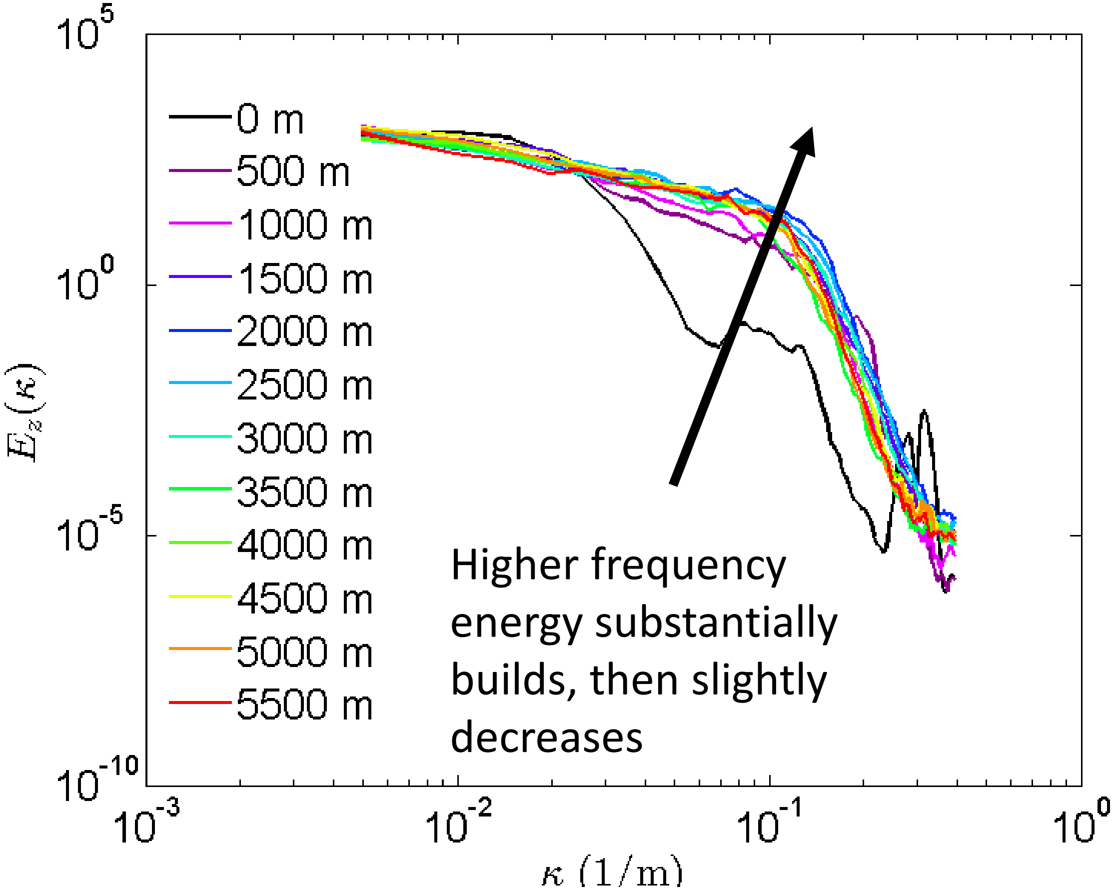


Results: Coupling with No Turbines

Spectra evolution in space

Spectrum of segments of time history averaged over time and y-constant lines

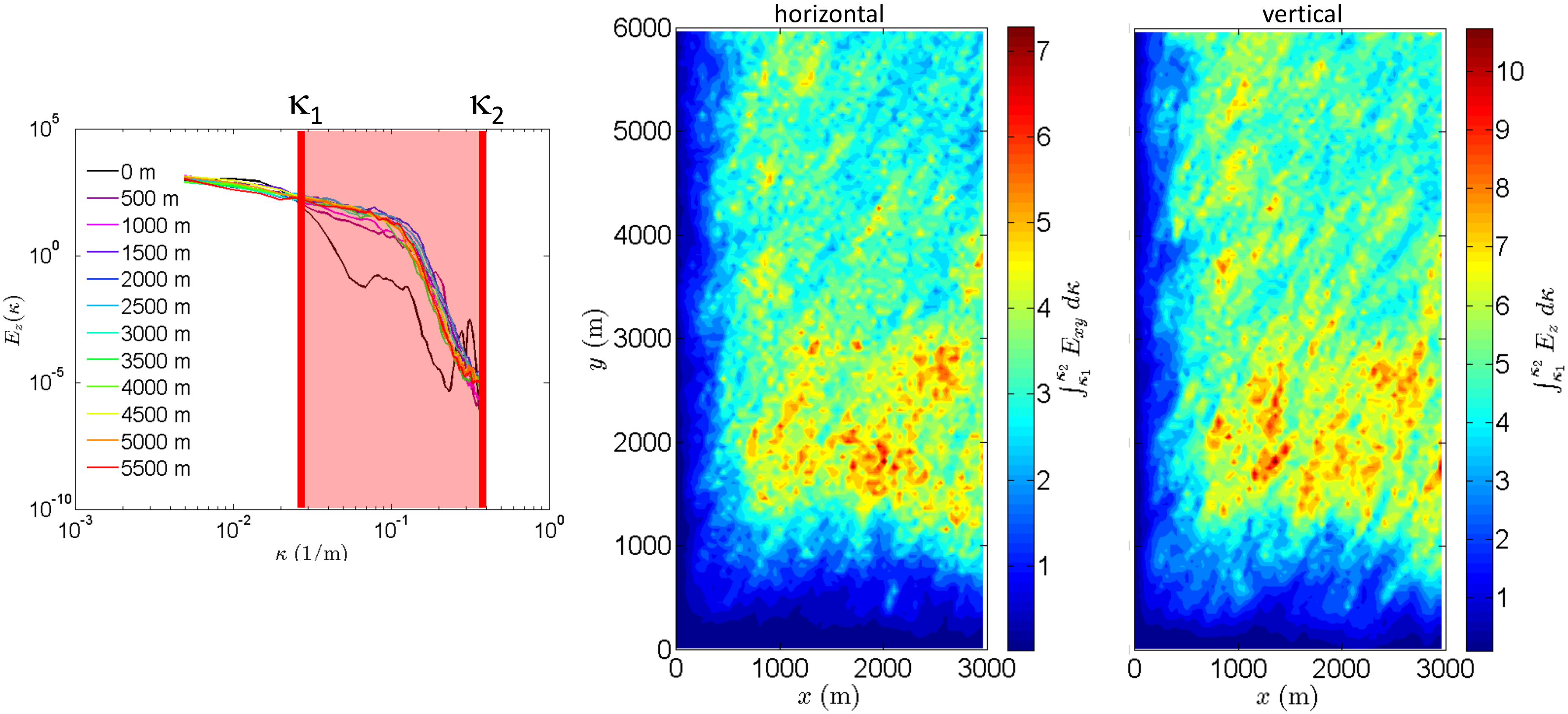




Results: Coupling with No Turbines

Spectra evolution in space

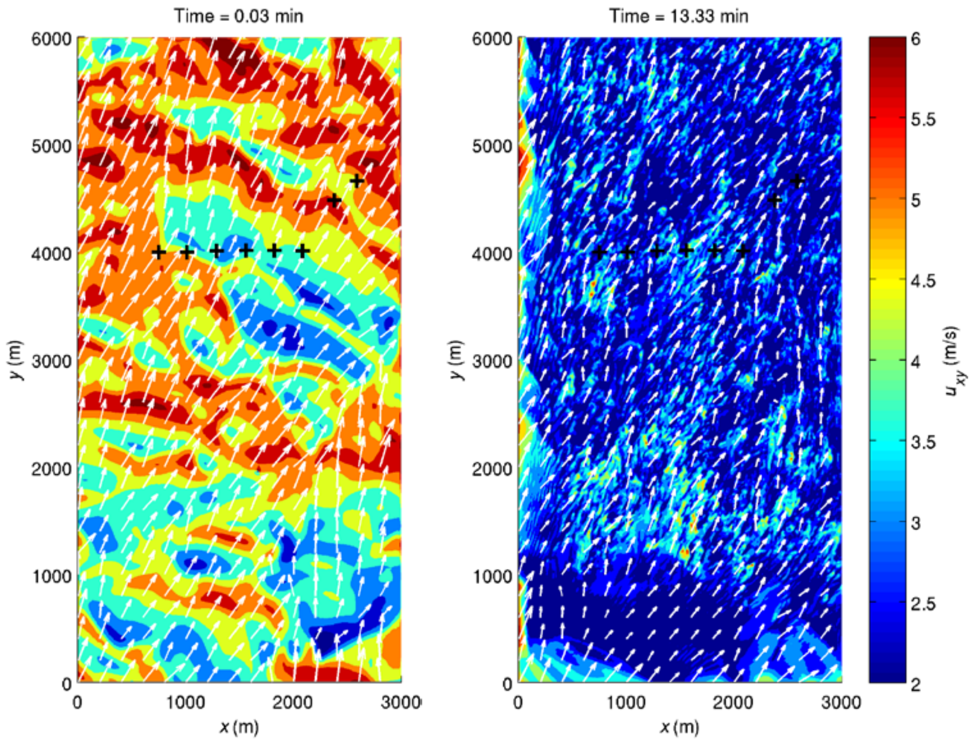
Time-averaged integral of high wavenumber part of spectrum at every location



- Roughly 1.5 km required for high wave number energy to “fill in”
- High wave number content “overshoots” then decays

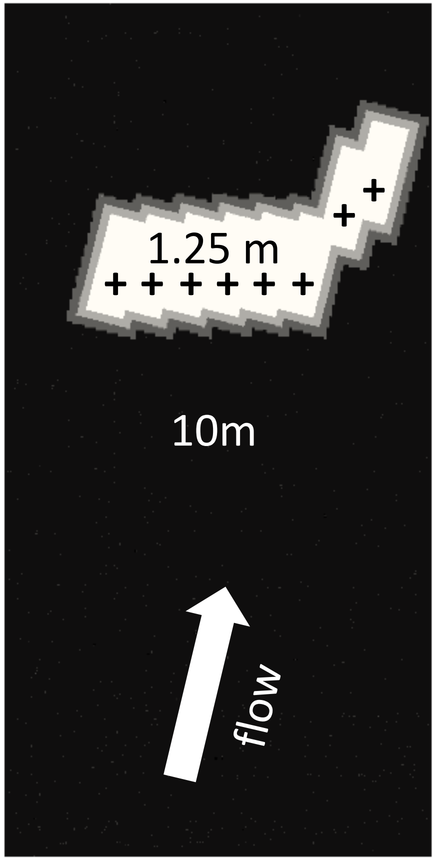
Results: Coupling with No Turbines

- **Near the surface, the horizontal velocity predicted in OpenFOAM domain rapidly decreases with distance from the inflow boundaries**
- **Unclear why this mismatch between WRF-LES and OpenFOAM LES occurs**



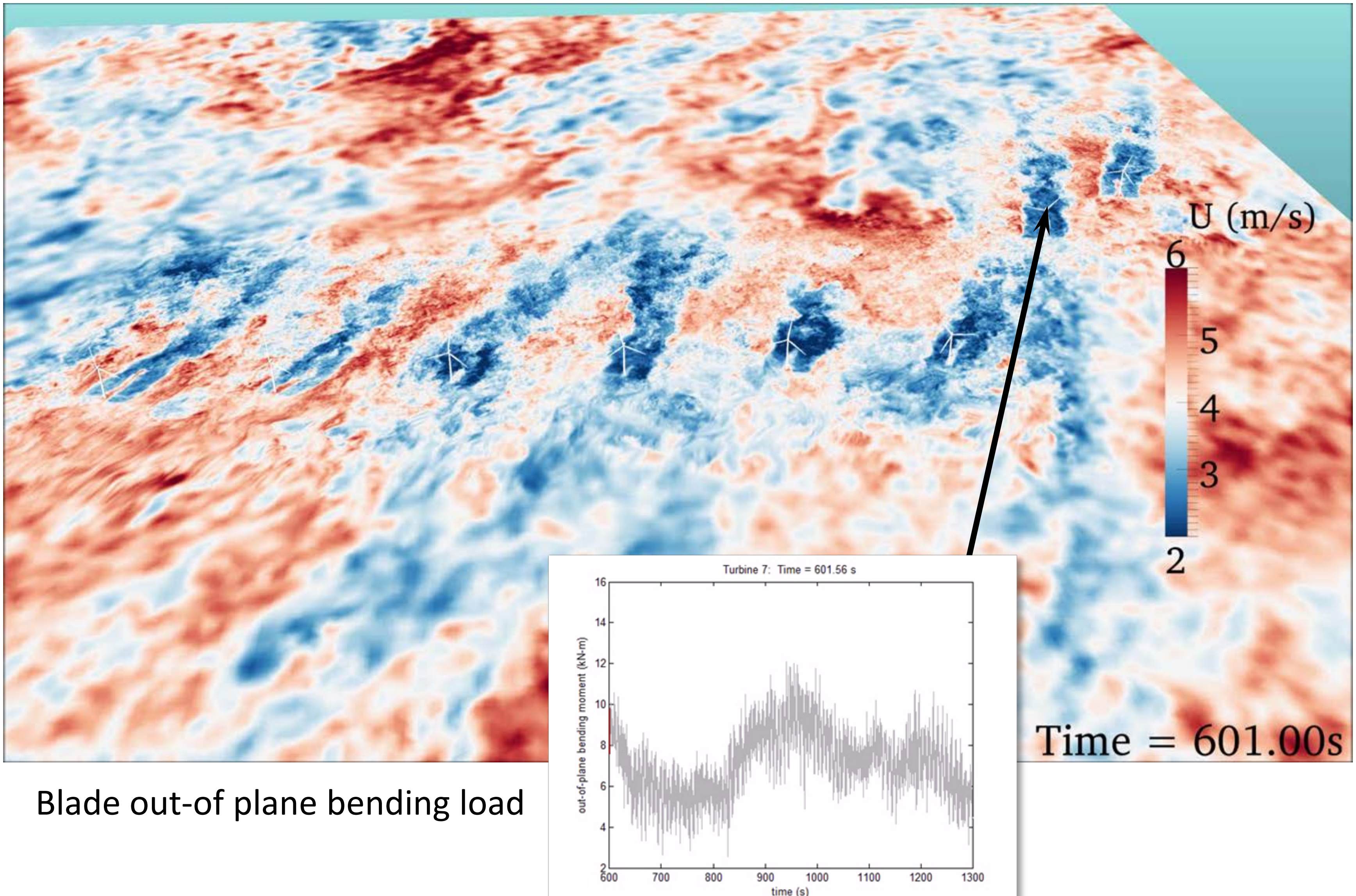
Coupling with Turbines

- **Eight 1.5-MW turbines modeled using rotating actuator lines**
- **Turbine model includes control so rotor speed reacts to flow**
- **Multi-resolution unstructured mesh**
  - 10 m background
  - 1.25 m around turbine and in wake



Horizontal slice through microscale mesh with region of refinement around turbines and wakes

Results: Coupling with Turbines



Blade out-of plane bending load

Conclusions

- **One-way mesoscale-microscale coupling allows for non-canonical conditions**
  - Extreme events
  - Nonhomogeneous flow across farm
  - Ramp events
- **Extension to two-way coupling will facilitate wind plant parameterization for mesoscale models**
  - Plant-to-plant interaction
  - Environmental effects
- **Significant distance necessary for microscale high wavenumber content to develop (1.5 km in this case)**
- **Some time also required for high wavenumber development**
- **Following the flow direction or progressing in time, an overshoot in high wavenumber energy is observed, followed by decay**

Future Work

- **Examine effect of mesoscale inner nest resolution**
  - Does coarser resolution require more distance in microscale domain for high wave number turbulence development?
- **Examine effect of atmospheric stability**
  - Do neutral conditions require more distance in microscale domain for high wave number turbulence development?
- **Examine inflow perturbation methods**
  - i.e., Muñoz-Esparza and Kosović
- **Would a dynamic SGS model avoid overshoot of high wavenumber energy content?**

Questions

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