Marine Boundary Layer Modeling

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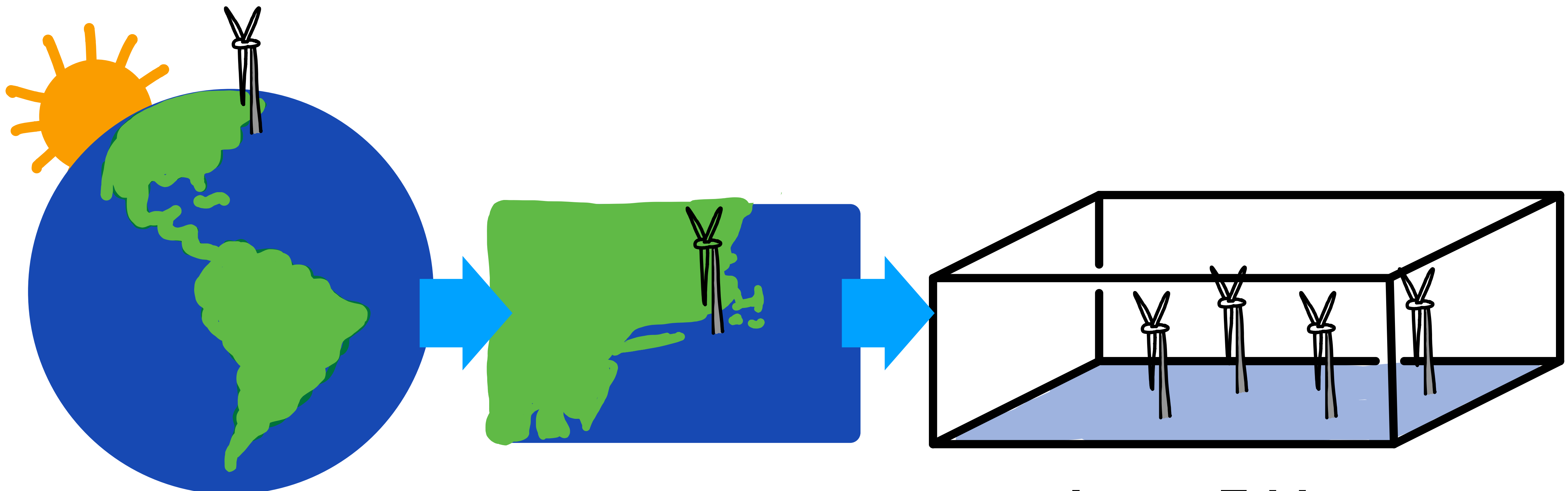
Motivation – Objectives

- Offshore wind is an abundant energy resource with significant environmental and economic benefits
- Overarching project goal is to improve the wind farm design and operation by better characterizing the meteorological conditions at the wind-farm scale
  - As a natural resource, wind is variable. Thus, energy extraction and wind farm operations can improve by better understanding the environmental conditions
- **Objective** is to develop a validated computational framework for high resolution (meter-scale) wind farm modeling
- **Deliverable** is UConn's Large-Eddy Simulation (LES) model with wind turbine modeling capability, a series of validation/assessment cases, and a framework to use a regional model to drive the LES model
- UConn's LES Model:
  - High-resolution (grid size: 0.1 – 200 m) time-variable simulations
  - High-fidelity numerical methods and physical models
  - Physics-based meteorological model
- Current status
  - New (?) project (started January 2020)
  - Most of the technical development has been completed
  - Validation and demonstration simulations are ongoing

Modeling from global to wind-turbine-blade scale



Global circulation

weather forecast
reanalysis

Where energy
enters the system

input

Regional weather model

WRF
(Dr. Astitha)

km-scale

input

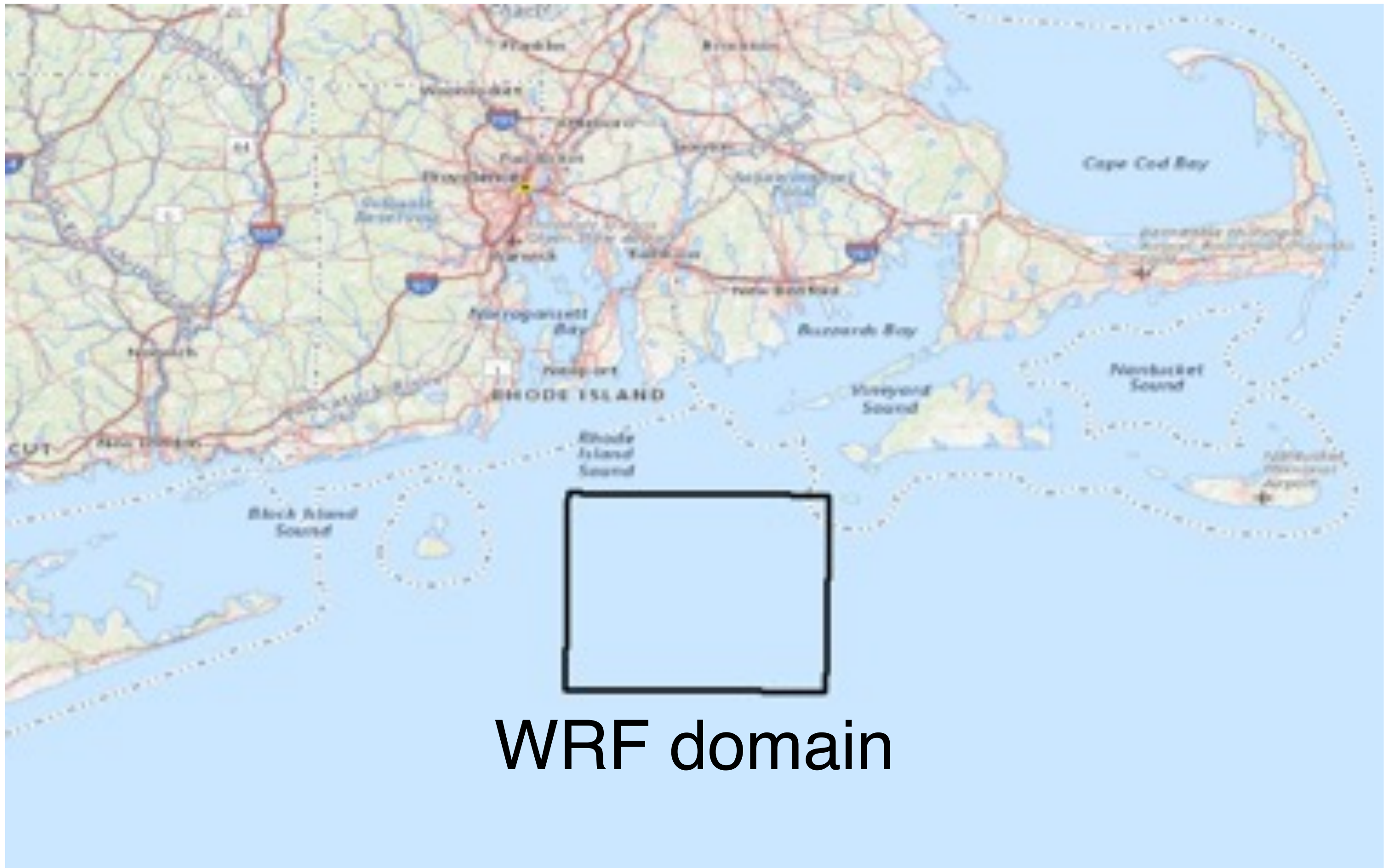
Large-Eddy Simulation (LES) model

(this project)

m-scale
representation
of turbine-atmosphere
interactions

LES model setup based on WRF model

- WRF model output data provided by Prof. Astitha's group
- Fair-weather marine boundary layer at (–71º, 40º)
- Initial and boundary conditions to LES from horizontal averages of WRF output on a 20 × 20 km subdomain
- Two LES runs carried out to date
  - LES with constant (not time-dependent) boundary conditions
  - LES run for one hour at different instances of the time-evolving WRF run
  - Currently working on using more sophisticated time-dependent conditions



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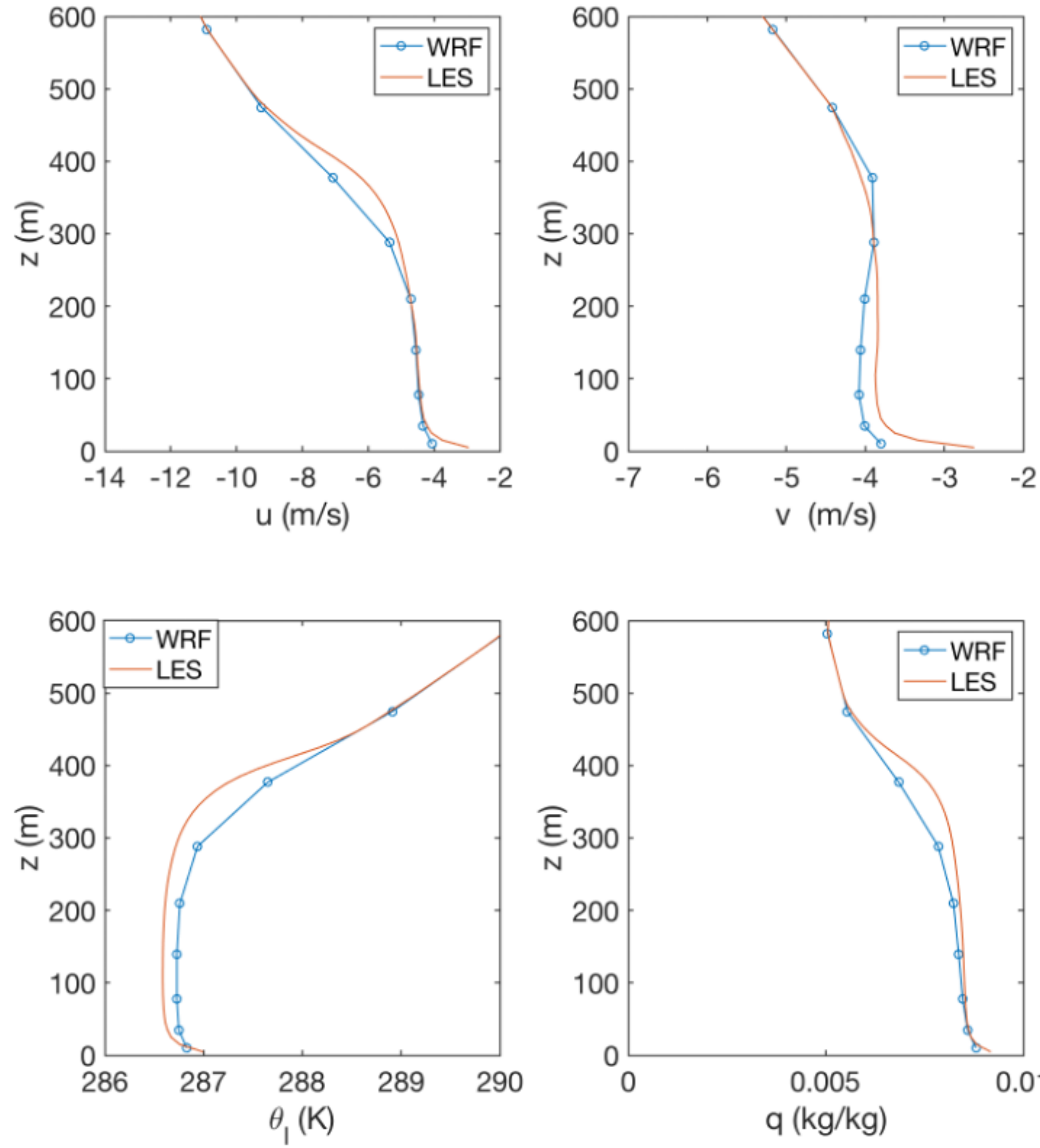
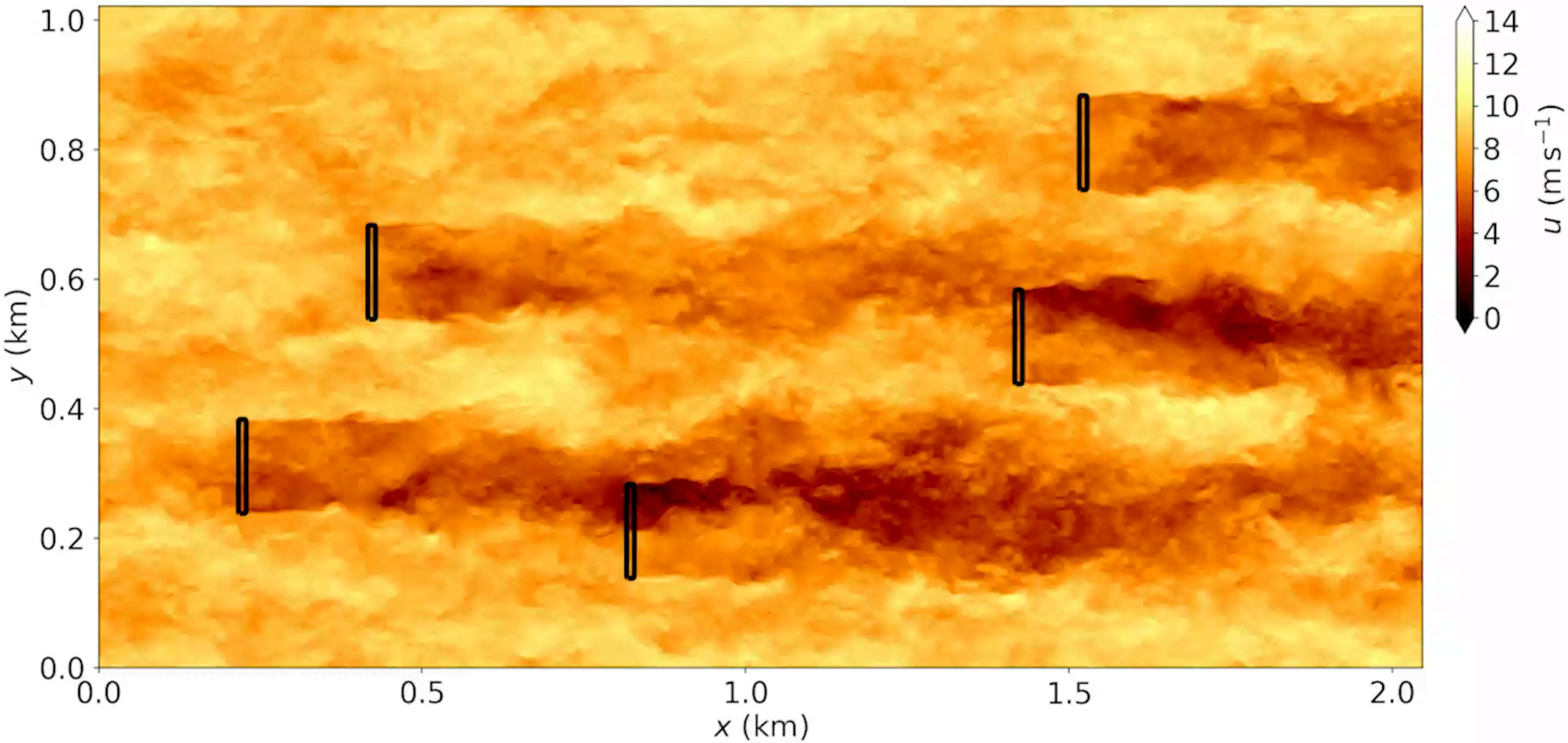
WRF–LES comparison

- LES setup:
  - 10 m grid resolution
  - $\Delta x = \Delta y = \Delta z$ (uniform)
  - 5 km horizontal domain
  - Horizontally periodic domain
  - Good agreement of wind profiles between LES and WRF
  - Most differences between LES and WRF are in the thermodynamic structure of the boundary layer
    - Improvements in thermodynamic forcing will be part of future simulations

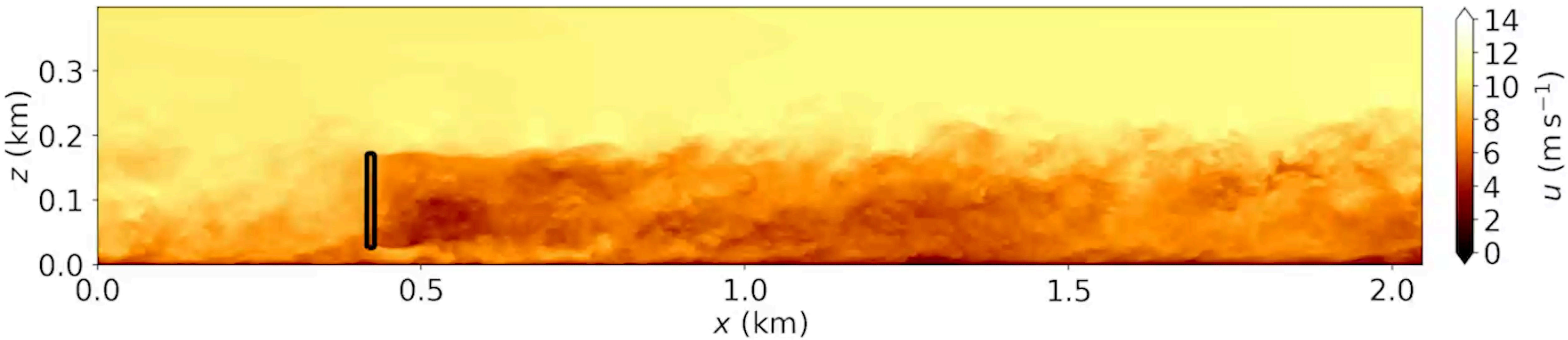


Turbine model in LES

- Actuator disc model: captures volume-mean momentum extraction from turbines
- Regions of low wind speed downstream of turbines show reduction of remaining kinetic energy in the atmosphere

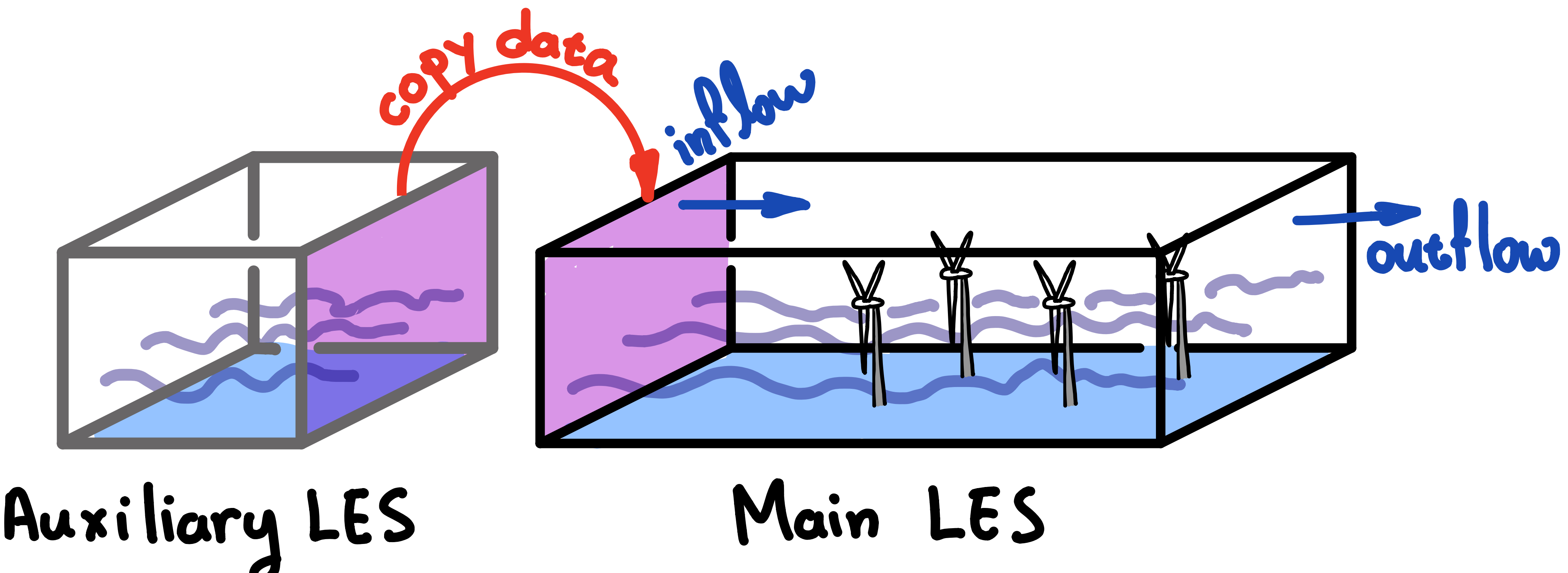


Turbine model in LES



Generating turbulent inflow data

- Turbulent inflow condition is generated by running two separate concurrent simulations
- Auxiliary simulation is used to generate the turbulent inflow data
- Data from the auxiliary LES are used to enforce the turbulent inflow condition in the main LES
  - No feedback from main LES to auxiliary
- Method is very computationally efficient because turbulence is realistic at the inflow of the main LES
  - No buffer zones, entrance regions, etc. required



Summary

- The project leverages the **unique** multi-scale modeling capabilities at the EEC
  - LES model is full-fledged meteorological model (other groups use engineering-flow prediction tools which are not suitable for environmental flows)
- A combination of models is used to predict meteorology and atmospheric turbulence from the regional scale (about 300 km domains) to wind-turbine scale, i.e., model resolution of a few meters
- Wind power extraction and equipment maintenance operations are directly affected by atmospheric turbulence
  - The interaction of the atmosphere with the surface, including wind shear and temperature difference effects between the atmosphere and the ocean, result in a rich spectrum of atmospheric motions
  - The LES model accurately represents the atmospheric turbulence near the surface
- Please contact Dr. Matheou for further questions

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