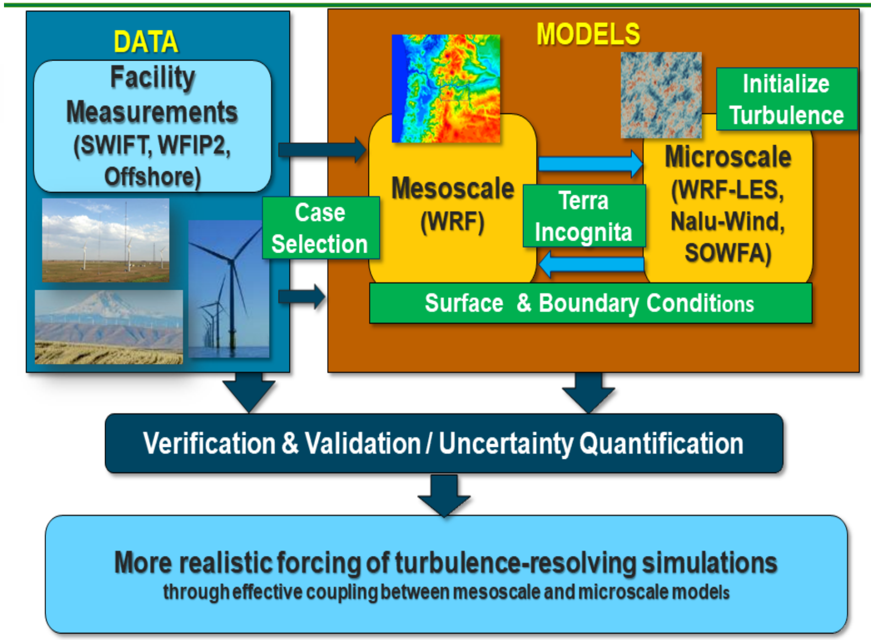
T16 – MMC - Model Development & Validation

Tech R&D – Atmosphere to electrons
Sue Ellen Haupt
National Center for Atmospheric Research

4 August 2021

Mesoscale to Microscale Coupling (MMC) Overview



FY21 Peer Review – MMC Project Overview

Project Summary:

- The MMC project seeks to improve coupling between mesoscale and microscale simulations via enhanced guidance and new strategies for setting up simulations and for the development of new tools that can be used across the community. Including the mesoscale forcing is critical to modeling the full energy transfer across scales in the atmosphere.
- Collaborative work between LANL, LLNL, NCAR, NREL, and PNNL.

Project Objective(s) 2019-2020:

- Apply verification and validation (V&V) techniques to the new modeling tools and develop estimates of the uncertainty;
- Reduce turbulence spin-up time in microscale simulations and hence decrease their computational cost;
- Improve the surface layer treatment in microscale models to more accurately simulate wind speed and shear over the rotor diameter;
- Develop best practice guidance for the community;
- Prepare and document a suite of software tools that can be used across the community; and
- Transition MMC research to the offshore environment.

Overall Project Objectives (life of project):

- As above.
- Engage stakeholders through workshops, webinars, panels.

Project Start Year: [FY19]
Expected Completion Year: [FY 22]
Total expected duration: [4] years

FY19 - FY20 Budget: X

Key Project Personnel: Sue Ellen Haupt (NCAR); Colleen Kaul, Larry Berg (PNNL), Jeff Mirocha (LLNL), Matt Churchfield (NREL), Rod Linn (LANL)

Key DOE Personnel: Shannon Davis

MMC Project Impact

- Enables simulation of mesoscale and microscale flow characteristics affecting turbine and wind plant performance and uncertainties, allowing improvements in
  - wind plant design,
  - operation, including forecasting needs, and
  - performance projections.
- Enables detailed guidance for developing wind plants.
- Supplies high-performance-computing-based multiscale wind plant simulation tools that couple a broad range of scales.
- Supports better understanding and modeling non-stationary meteorological conditions (such as diurnal cycles, frontal passages, thunderstorm outflows, baroclinic systems, and low-level jets).
- Informs tool development under High Fidelity Modeling activities and are synergistic with efforts such the Wind Forecast Improvement Project 3 (WFIP3).
- Culminates in guidelines for best-practice modeling, software tools, datasets for testing, and full documentation.
- Archives data and model output on the A2e Data Archive and Portal (DAP) and analysis tools and model codes on the project GitHub. The tools have been evaluated via observation-based case studies.

Program Performance – Scope, Schedule, Execution

Completed Task

Completion Expected

Original 3-year Plan

Title	Description	Responsible Partner	Date	Deliverable and Milestone Verification Method
Kickoff meetin	Kickoff meeting for the project team, including review of existing PIRT (Quarterly Progress Measure)	NCAR	12/31/18	Delivery of meeting summary to DOE
Workshop	Host workshop with industry and academia to share results, solicit input, and review PIRT (Quarterly Progress Measure)	NCAR	3/31/19	Delivery of meeting summary to DOE
Revised PIRT	Prepare revised PIRT (Annual)	NREL	6/30/19	Delivery of revised PIRT to DOE
3D PBL tests	Complete MMC simulations over complex terrain with 3D PBL parameterization (Quarterly Progress Measure)	NCAR	9/30/19	Deliver summary description of simulation results to DOE
Perturbation recommendatic	Provide preliminary recommendations of optimal perturbation techniques (Quarterly Progress Measure)	LLNL	12/31/19	Deliver summary recommendations to DOE
PBL recommendatic	Provide preliminary recommendations of optimal PBL parameterizations (Quarterly Progress Measure)	PNNL	3/31/20	Deliver summary recommendations to DOE
Surface layer	Deliver revised surface layer parameterization for MMC (Quarterly Progress Measure)	LLNL	6/30/20	Deliver summary report description new parameterization to DOE
V&V	Document and archive V&V benchmarks and provide recommend metrics (Annual)	NREL	9/30/20	Deliver summary report of V&V benchmarks to DOE
Recommendations	Provide recommendations for metrics, perturbation techniques, PBL parameterizations, and optimal MMC coupling strategies (Quarterly Progress Measure)	PNNL	12/31/20	Deliver summary report to recommendations to DOE
Workshop	Host industry workshop to report on project results (Quarterly Progress Measure)	NCAR	3/31/21	Delivery of meeting summary to DOE
New system	Delivery of a validated MMC system, and recommendations for an optimal model configuration (Quarterly Progress Measure)	PNNL	6/30/21	Deliver report summarizing new system to DOE
Final report	Comprehensive report detailing project accomplishments of the science in MMC for wind energy (Annual)	NCAR	9/30/21	Deliver final report to DOE

Added Tasks – Evolving DOE Priorities

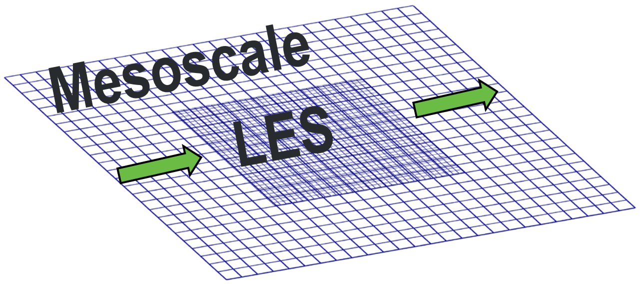
Title	Description
Offshore Test Case	Test MMC methods for offshore environment
NE US Test Case	Test MMC methods for difficult NE US Case
3DPBL Coastal Case	Test new 3DPBL for coastal environment
ML Downscaling	Test Deep Learning methods to downscale from the mesoscale to microscale

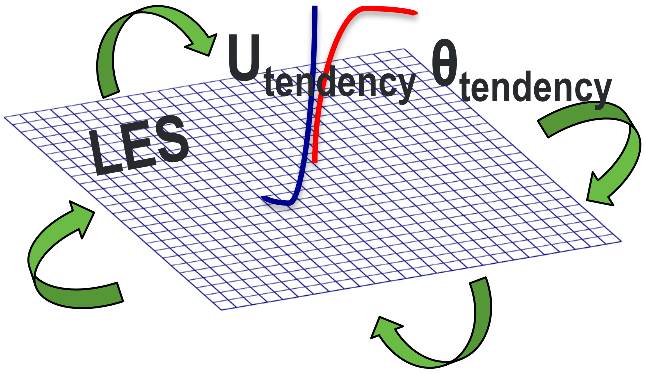
MMC Progress: Testing Coupling Strategies

- Mesoscale models capture the full variability of the large scale flow
  - Full physics: radiation, surface, boundary layer processes, etc.
- Microscale models capture flow details around objects – useful for
  - Controls
  - Loads
  - Details of Siting
- Want microscale model to dynamically follow the changes forced at the mesoscale
- No single best strategy meets all situational requirements

Approaches:

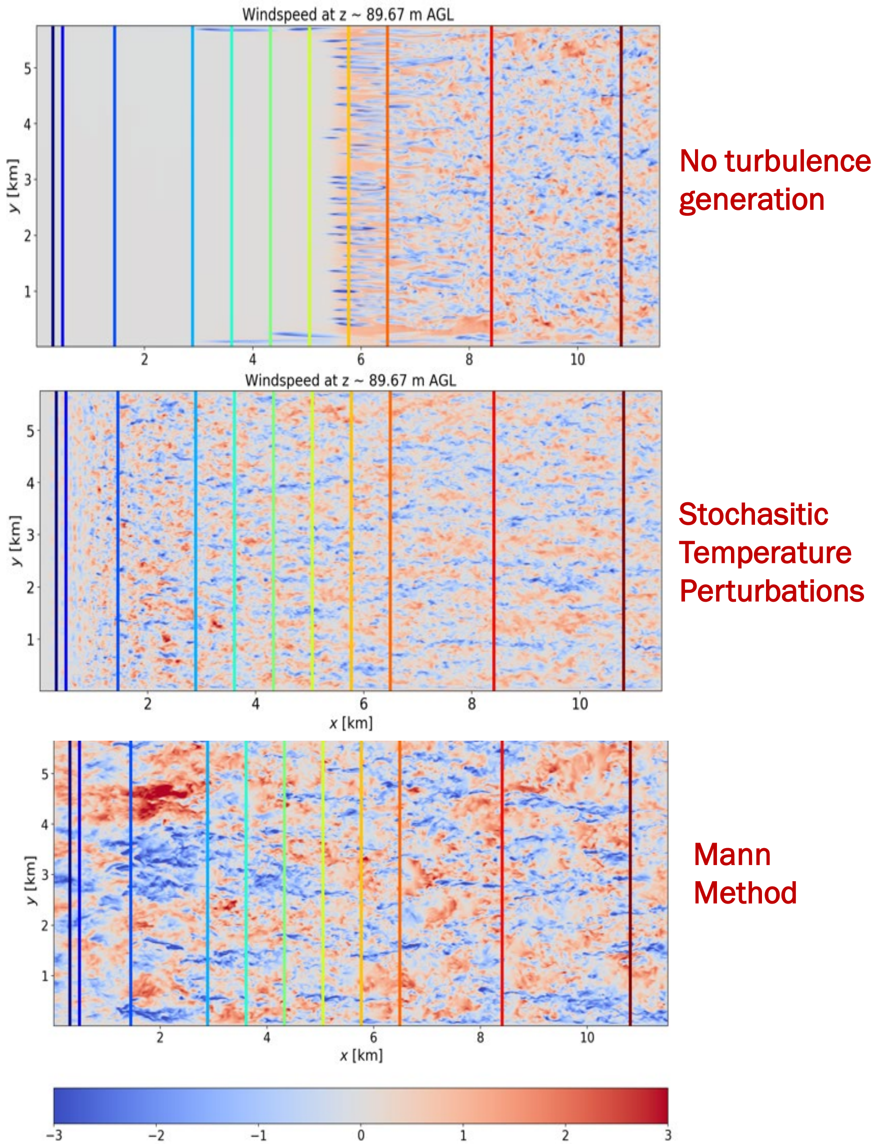
- Nesting
- Forcing





Accomplishments: Generating Turbulence at the Microscale

- Microscale models must “spin-up” turbulence that is not explicitly simulated by mesoscale models
- Methods to enhance turbulence generation at the microscale are needed to avoid long fetch and limit computational expense
- Several methods have been tested, although character of turbulence is a bit different for each.
- The team has been systematically investigating which method is best ~~each~~ under different stability conditions



Convective Conditions

Improving Model Physics Parameterizations

Build new Surface Layer Model with Machine Learning (ML)

- Replaces empirically fit Monin-Obukhov (MO) Theory model
- Uses flux and met measurements
  - Onshore: Towers in Netherlands and Idaho
  - Offshore: FINO1 tower in North Sea: wind, wave, & fluxes
- Tested Random Forest (RF) and Artificial Neural Networks
- ML models outperform prior model, even at sites where not trained.

3D Boundary Layer Parameterization improves Simulations

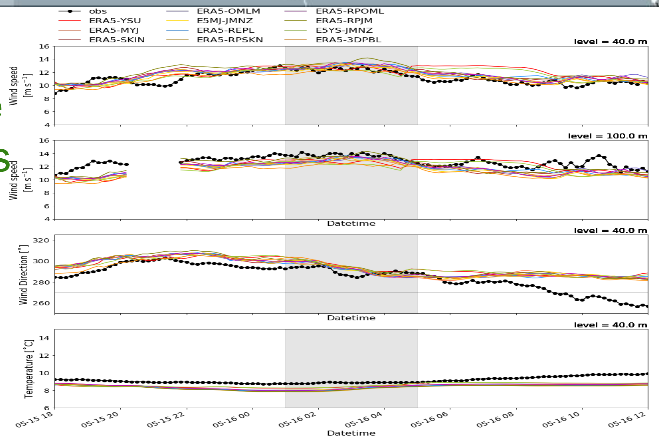
Current 1D Planetary Boundary schemes not appropriate for grid sizes < 2 km

Progress: Testing Coupling Methods in Offshore Environment

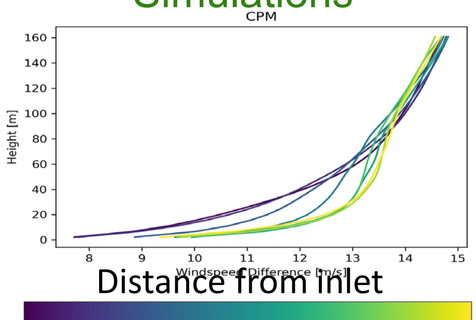
- Obtained Data
  - FINO – 3 towers
  - Alpha Ventus Wind Farm
- Reviewed data and selected case
  - 2-week period in 2010 (turbulence data)
- Modifications to the mesoscale model
  - Added algorithm for offshore surface roughness
  - Ran 2-week period – compared setups
  - Compared to towers
- Microscale Coupled Runs
- Trained ML Surface Layer
- Planned turbine simulations

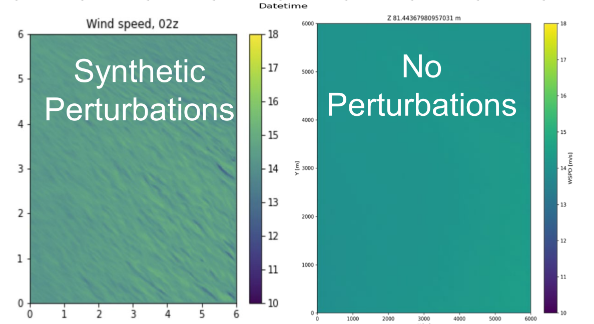
Tower Locations

Compare Mesoscale Simulations to Data



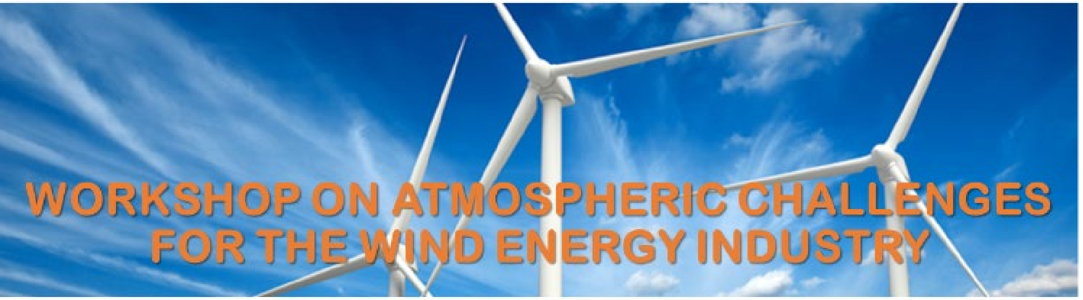
Test Microscale Simulations





Test Turbulence Generation

Stakeholder Engagement & Information Sharing



Purpose: Discuss the Future of Atmospheric Modeling Research for Wind Energy

Sponsored by: DOE Mesoscale to Microscale Coupling Team

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

October 19-20, 2020
Virtual

- 200 registrants
- Typically 120 online for sessions

https://ral.ucar.edu/events/2020/atmospheric-challenges-for-the-wind-energy-industry-workshop

Goal: Promote conversation between the research community and industry regarding wind energy modeling research needs

- Heard from industry regarding their current modeling, plans for the future, and perception of research needs
- Presented current state of atmospheric modeling research
- Forged a dialog to inform future research in atmospheric / oceanic modeling for wind energy

Key Takeaways and Closing Remarks

Project Impact:

Understanding and Modeling the Full Range of Atmospheric Phenomena will Enable Best Use of the Wind Resource

Project Performance:

- Demonstrated multiple coupling techniques
- Tested several methods to generate turbulence at the microscale
- Integrated modeling with measurements
- Developed MMC Phenomena Identification and Ranking Table (PIRT)
- Built new model physics parameterizations – 3DPBL, ML surface layer scheme
- Studied gravity waves in microscale models
- Tested coupled models in offshore environment
- Created assessment tools for testing models
- Made models and tools widely available

Stakeholder Engagement:

- Formed Industry Advisory Panel
- 2-day Industry Workshop
- Several Industry Webinars
- Frequent Publication of Results in Peer Reviewed Journals

ON BRIDGING A MODELING SCALE GAP

Mesoscale to Microscale Coupling for Wind Energy

Sue Ellen Haupt, Branko Kosovic, William Shaw, Larry K. Berg, Matthew Churchfield, Joel Cline, Caroline Draxl, Brandon Ennis, Eunmo Koo, Rao Kotamarthi, Laura Mazzaro, Jeffrey Mirocha, Patrick Moriarty, Domingo Muñoz-Esparza, Eliot Quon, Raj K. Rai, Michael Robinson, and Gokhan Sever

This work has advanced coupled mesoscale to microscale modeling through the terra incognita, generating turbulence at the microscale, testing coupling techniques, and assessing results relevant for wind energy applications.