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

The dynamic nature of the atmosphere as captured by MMC:

Moving toward offshore, complex terrain, and integration with artificial intelligence

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Mesoscale-Microscale Coupling Project
Wind Energy Technologies Office (WETO)
U.S. Department of Energy

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On behalf of WETO, the four participating DOE national laboratories (LANL, LLNL, NREL, PNNL), and NCAR.

Why should the wind energy industry care about mesoscale-microscale coupling?

Classic interpretation: An engineering problem

Turbines are designed for this... **but operate in this...**

This is also an atmospheric science problem

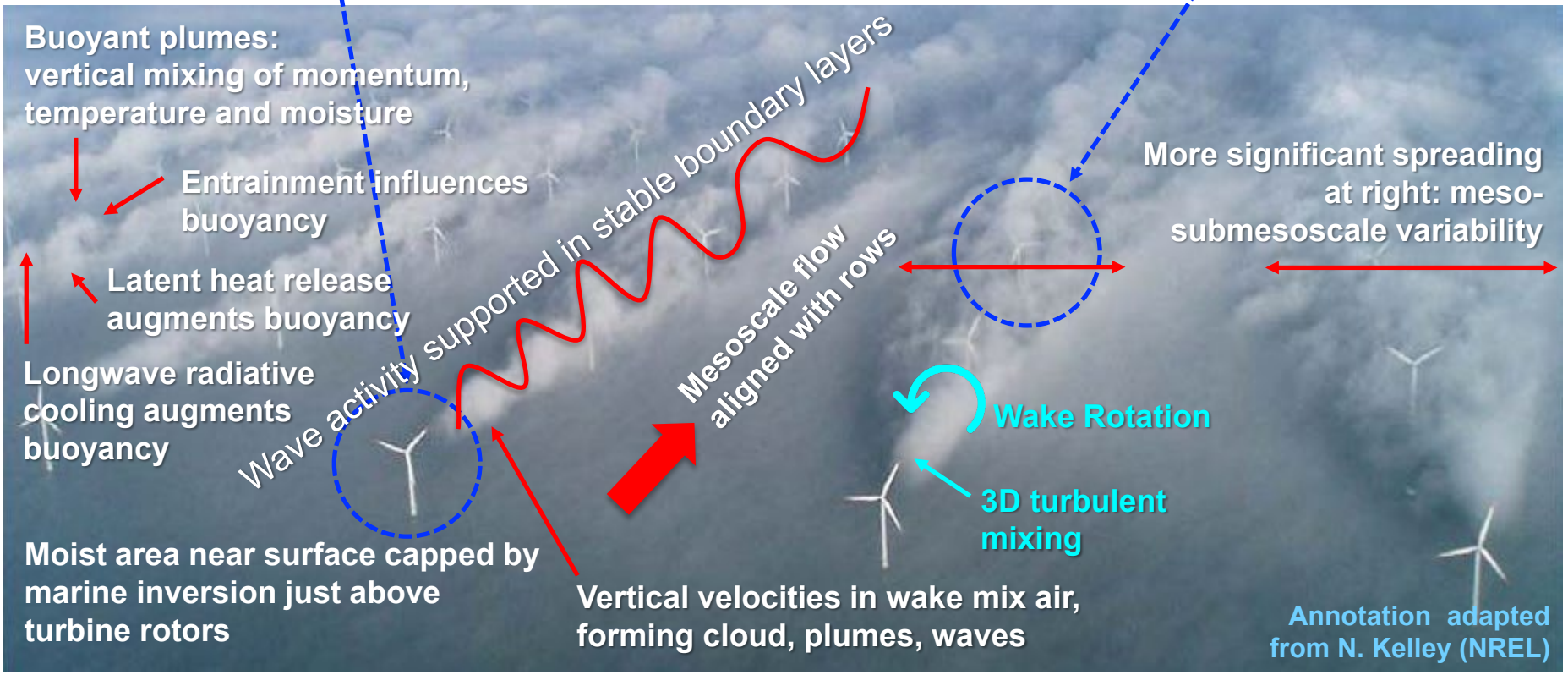

Image from Horns Rev Wind Farm in the North Sea showing turbine wakes.

Mesoscale and microscale processes interact. Mesoscale weather and environmental drivers are critical to a full understanding and control of wind plant phenomena.

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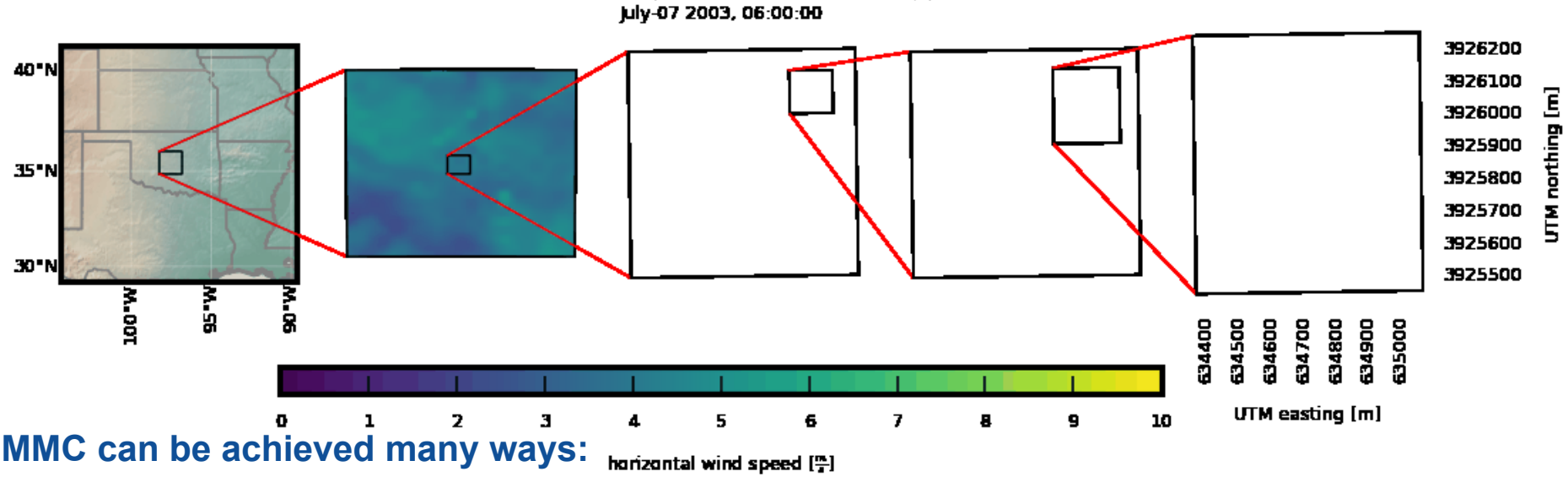
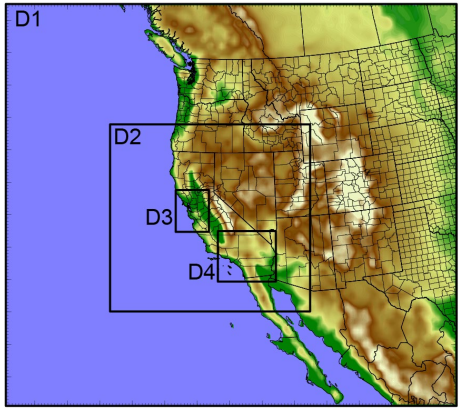
Most general MMC approach: online via successive mesh refinement

Multiscale WRF simulation, DJ Wiersema et al (LLNL, UC Berkeley)

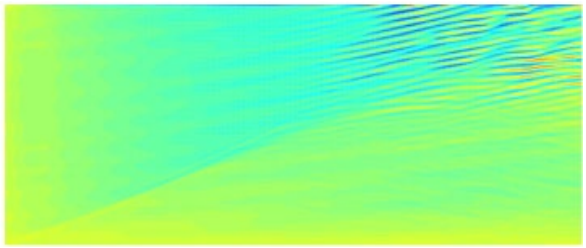


MMC can be achieved many ways:

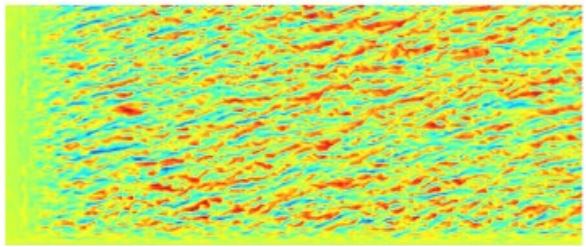
1) **Online Coupling: Grid nesting within one model, as shown above**
2) **Offline Coupling: Use of separate mesoscale and microscale simulation codes**
   - **a) Mesoscale data used at CFD model lateral boundaries**
   - **b) Mesoscale information used internally within LES/CFD codes (idealized setups)**



MMC can capture downscaling of a frontal passage to the wind plant environment



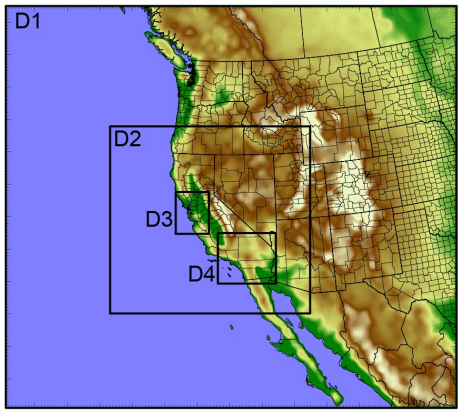
LES nested within mesoscale. Turbulence develops slowly



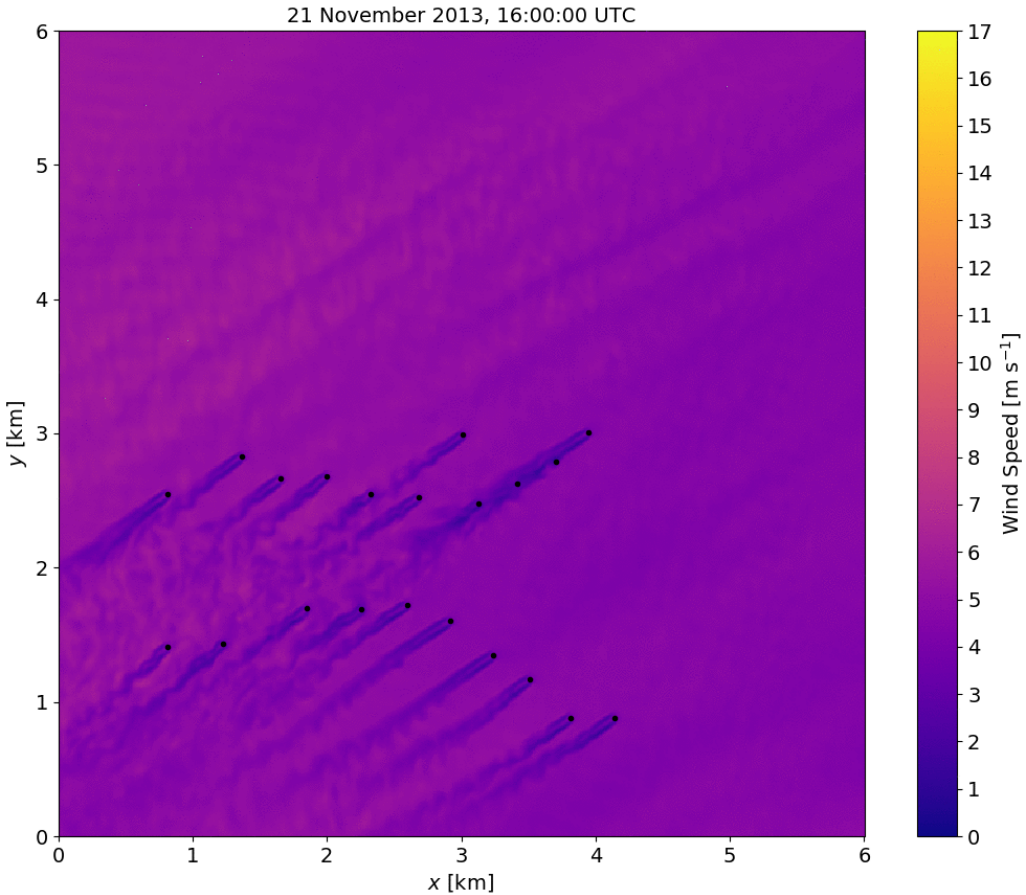
Turbulence can be accelerated by modifying the inflow

Stochastic Cell Perturbation Method, D Munoz-Esparza et al (NCAR, LANL, LLNL ...)

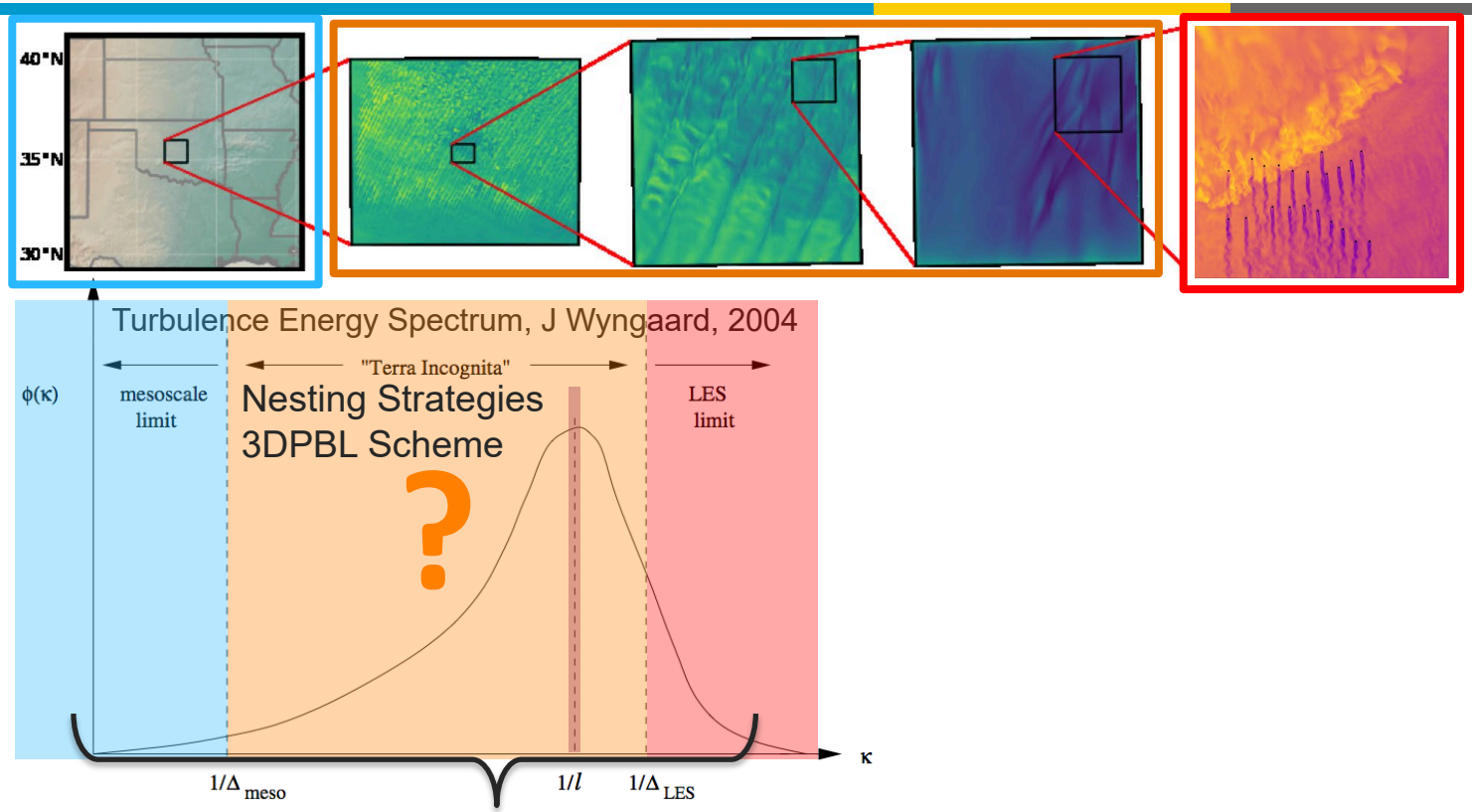
Online coupled multiscale WRF simulation using actuator disks in nested LES domain, RS Arthur et al (LLNL, NCAR, ...)

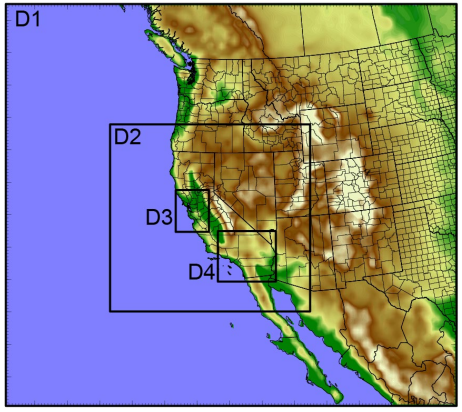


What is required to Make MMC accurate, robust and efficient?



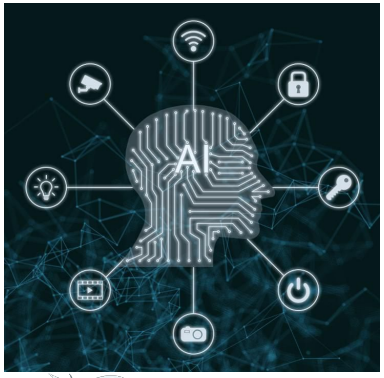
MMC challenges: Turbulence generation and the “Terra Incognita”





Artificial Intelligence (AI) approaches to improving MMC:

- Surface Layer modeling (D Gagne et al, NCAR)
- Atmospheric downscaling (R King, NREL)



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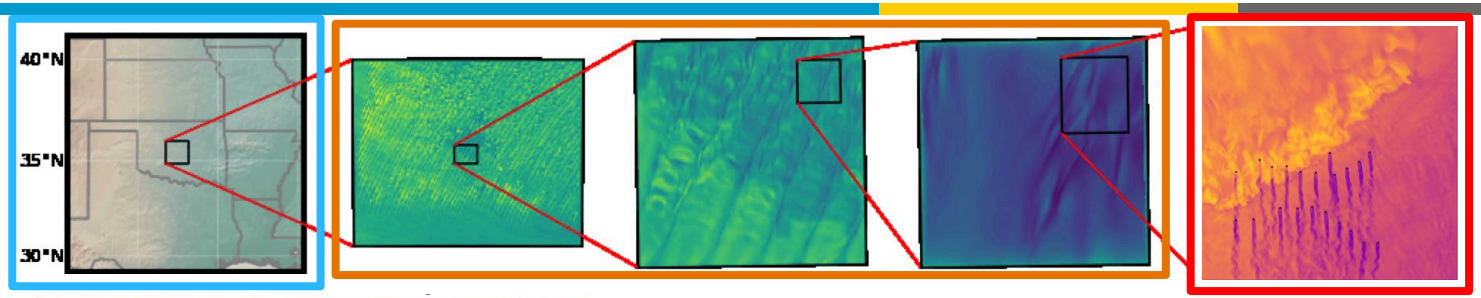
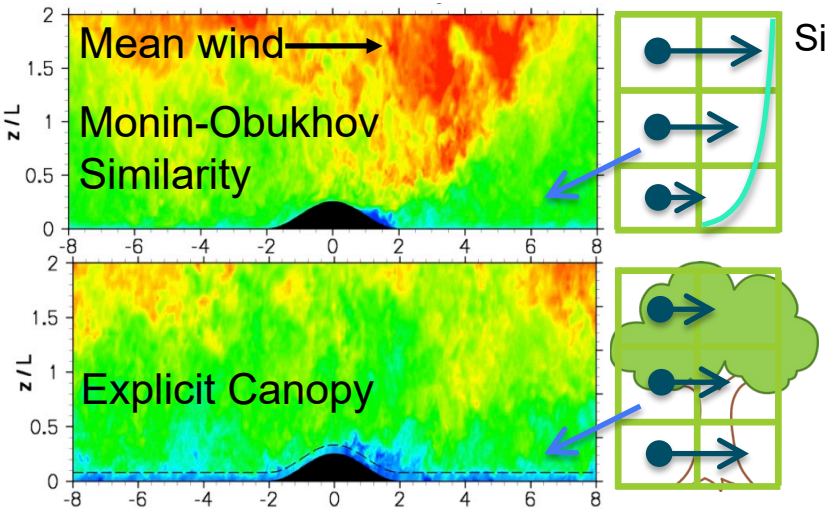
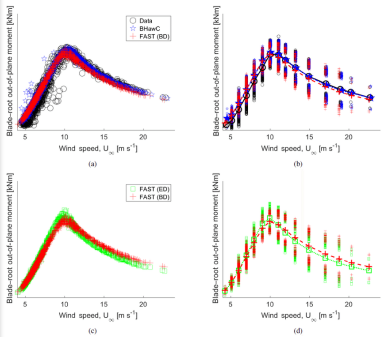
MMC challenge: Improved surface layer models and integration with AI

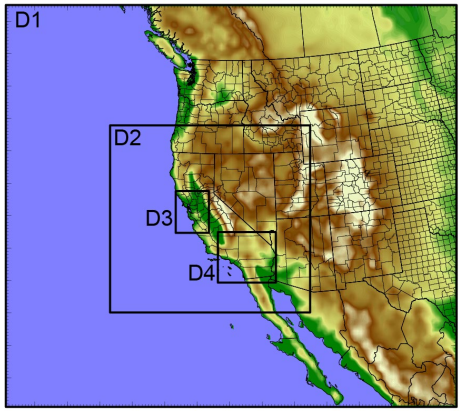




Simulations by N Patton (NCAR)

Atmospheric Characteristics for Design Criteria (AC⚡DC):
Combine high-fidelity models (MMC, Turbine, ...) with AI to a) discover relationships between environmental (atmosphere, terrain, wave) inputs and machine response (power, loads), and b) improve lower-fidelity design codes.





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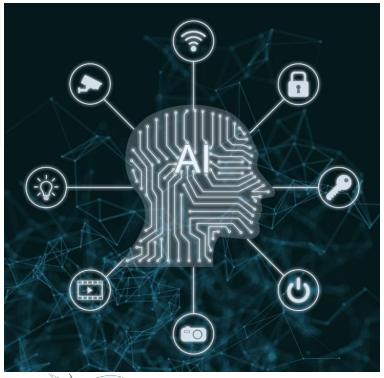

Complex Terrain and Offshore

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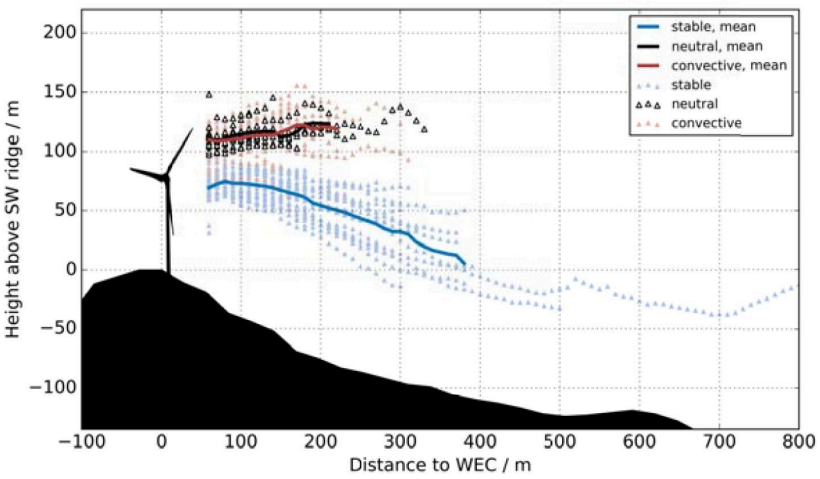
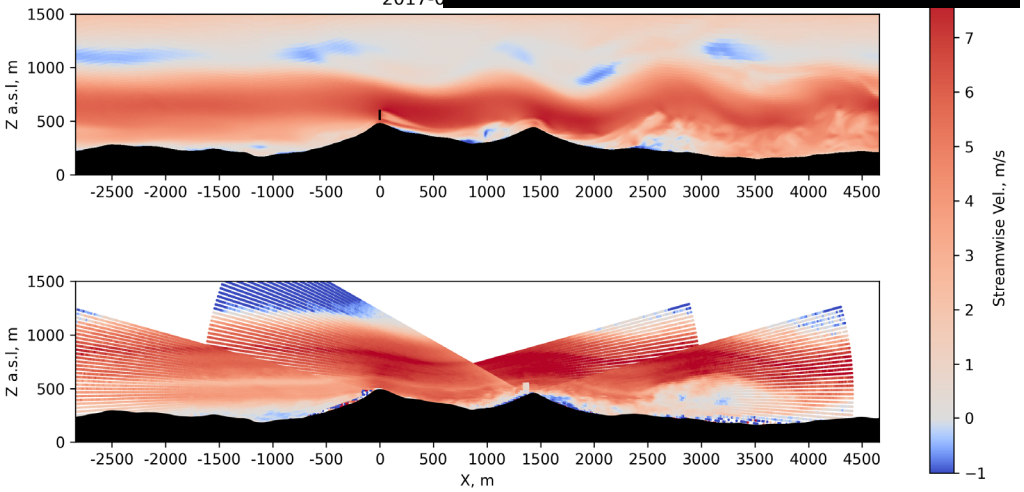
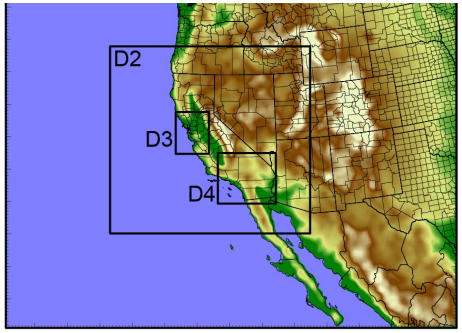
MMC Challenge: Complex terrain







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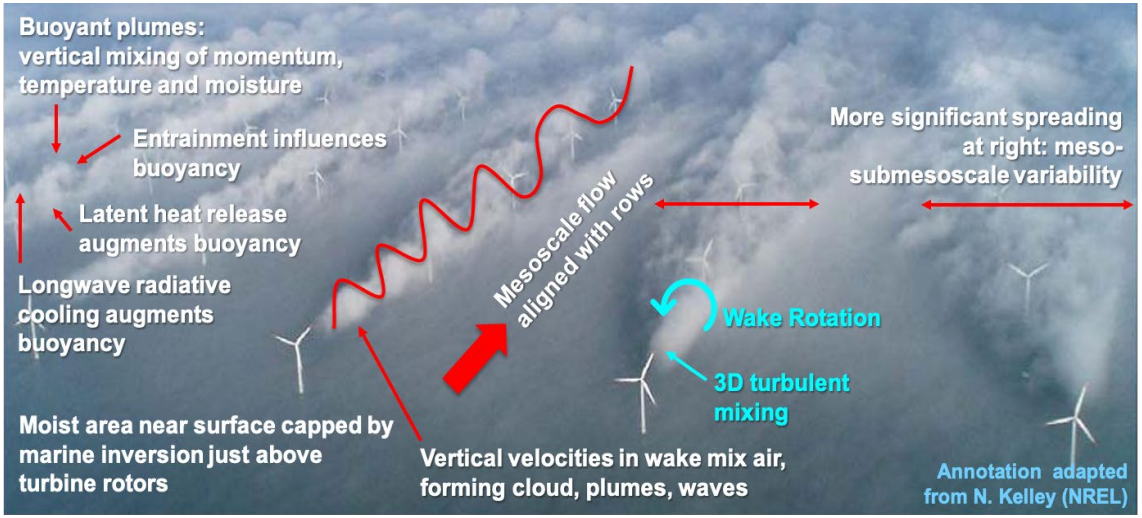
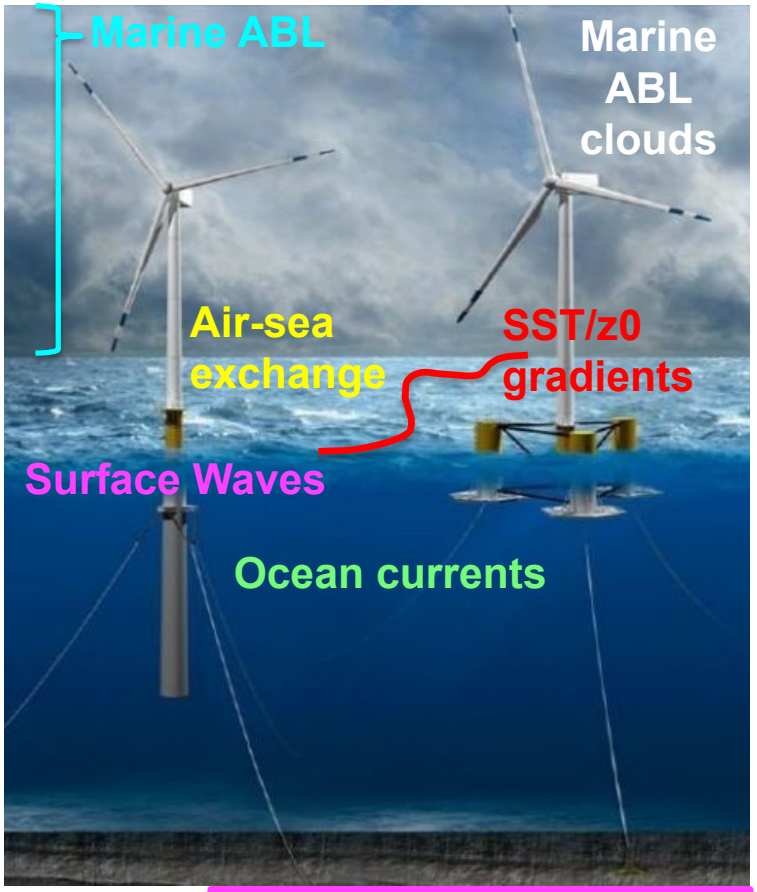
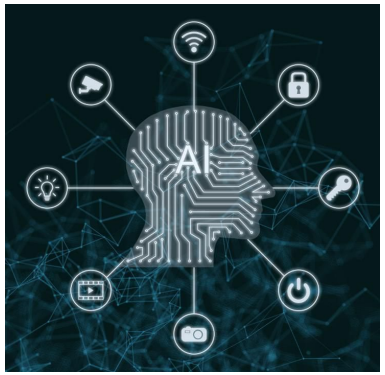
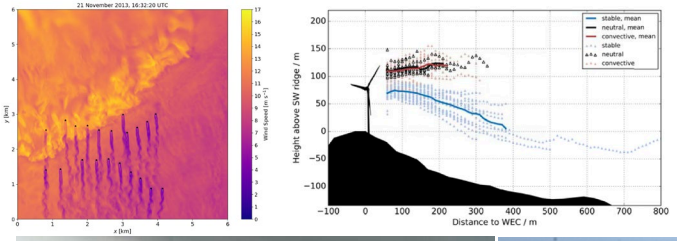
MMC Challenge: Offshore





Multiple atmospheric science challenges in marine environments. Then there is the actual water ...
and giant, floating turbines ...





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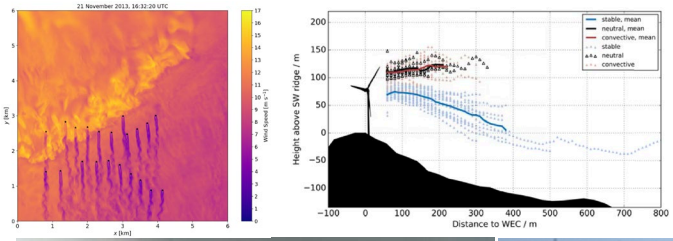
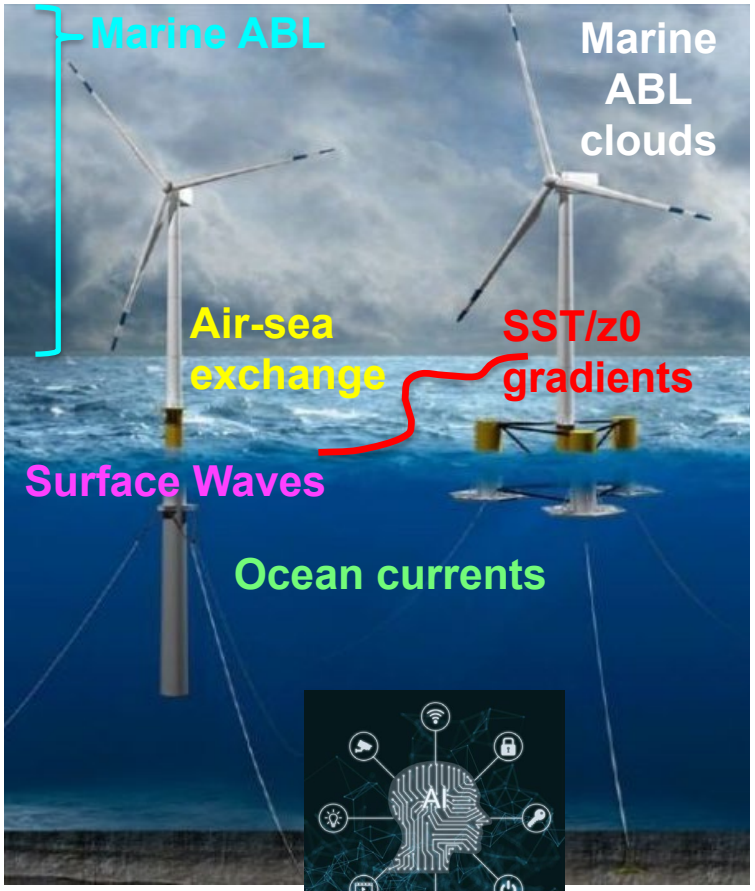
MMC Goal: Accurate multiscale simulations/optimization in complex environments

Wake Steering, M Churchfield (NREL)





1. What are we overlooking?

2. What are your highest priorities?

Breakout Sessions

1. Details of downscaling

2. Modeling for turbines

3. Using AI in atmospheric modeling