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Mesoscale to Microscale Coupling for Wind Energy Applications

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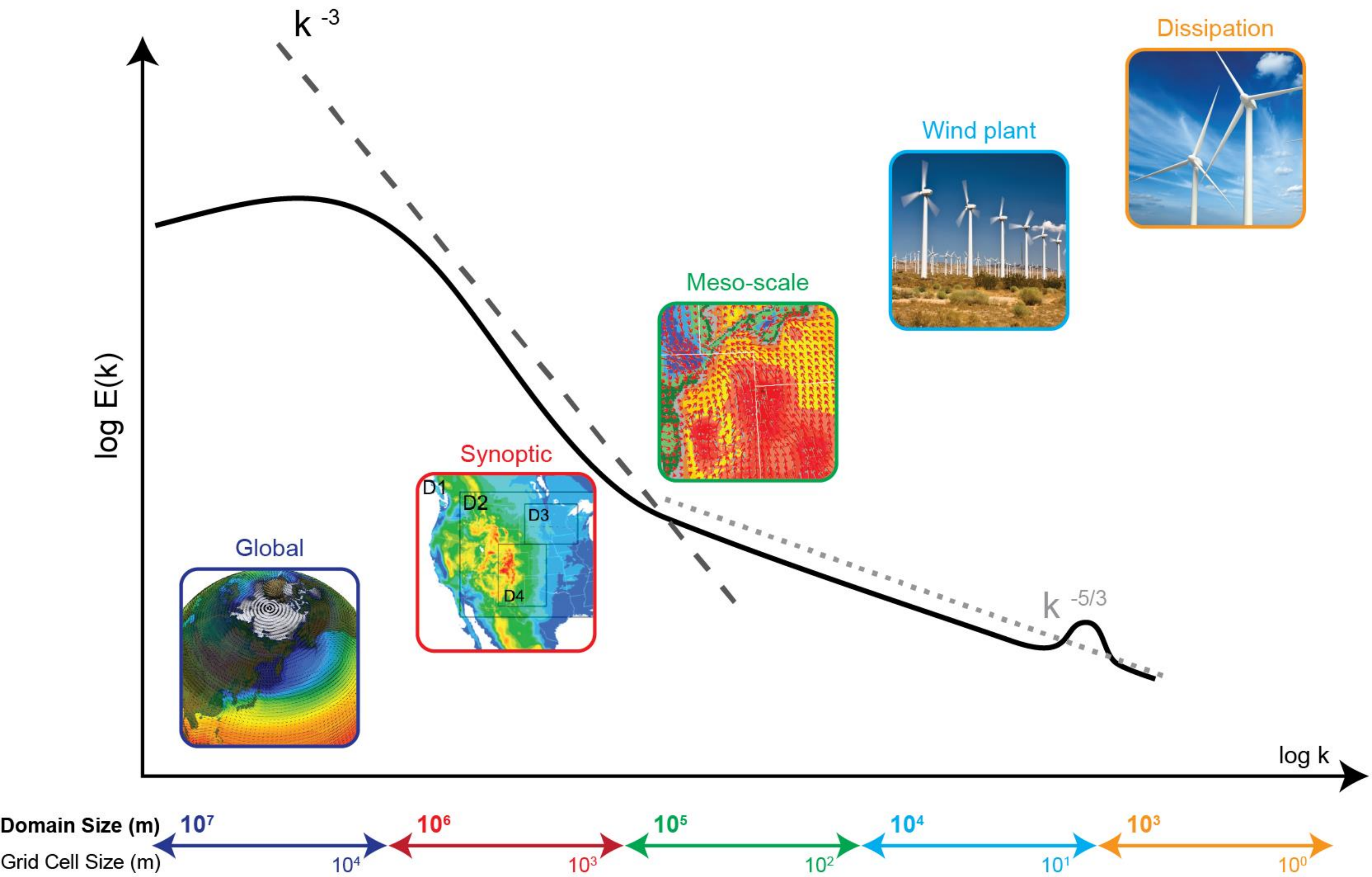
Atmosphere to Electrons

A2e Initiative

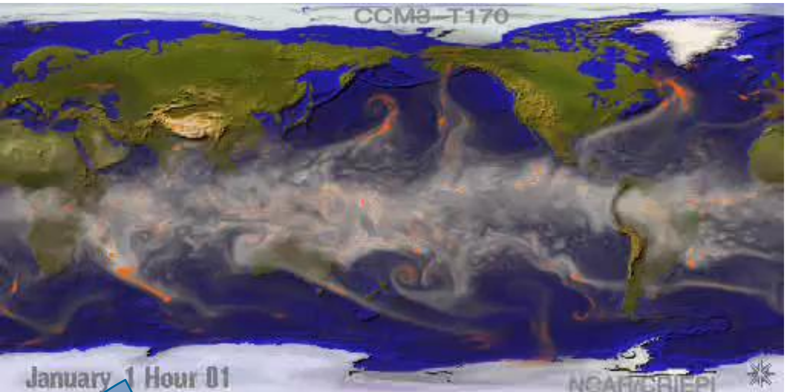
U.S. Department of Energy

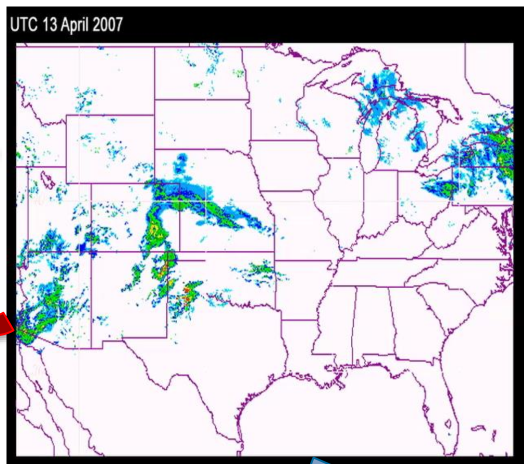
With Branko Kosovic, Will Shaw, Jeff Mirocha, Larry Berg, Matt Churchfield, Raj Rai, Caroline Draxl, Mike Robinson, Many Others

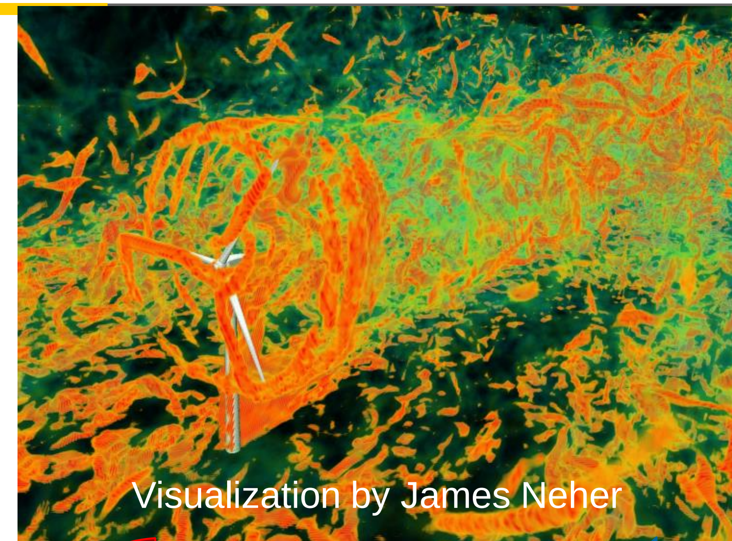
Energy Transfer in the Atmosphere

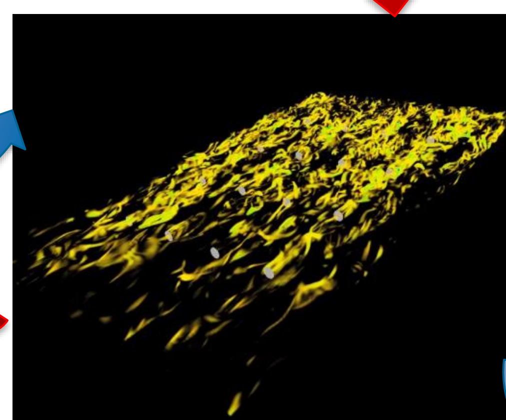


Forcing and Transfer of Energy Across Scales



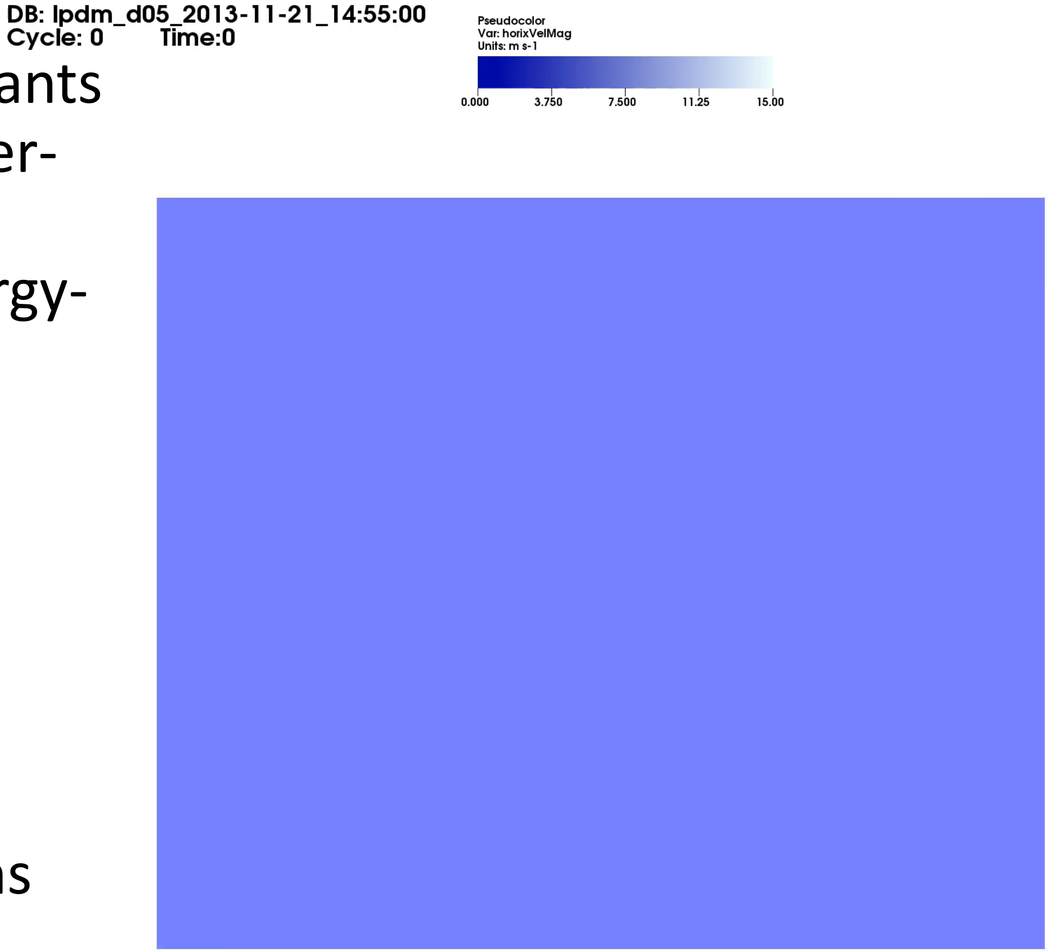






Relevance to Wind Energy

- Successful models of wind plants require forcing from the larger-scale atmospheric flow to capture the full range of energy-containing flow, including nonstationary motions.
- Integrating the full range of scales allows optimization of wind plant siting, design and operation.
- The resulting tools will be applicable to diverse locations and operating conditions, as required to support wind energy integration at future high penetration levels.



Animation courtesy of LLNL

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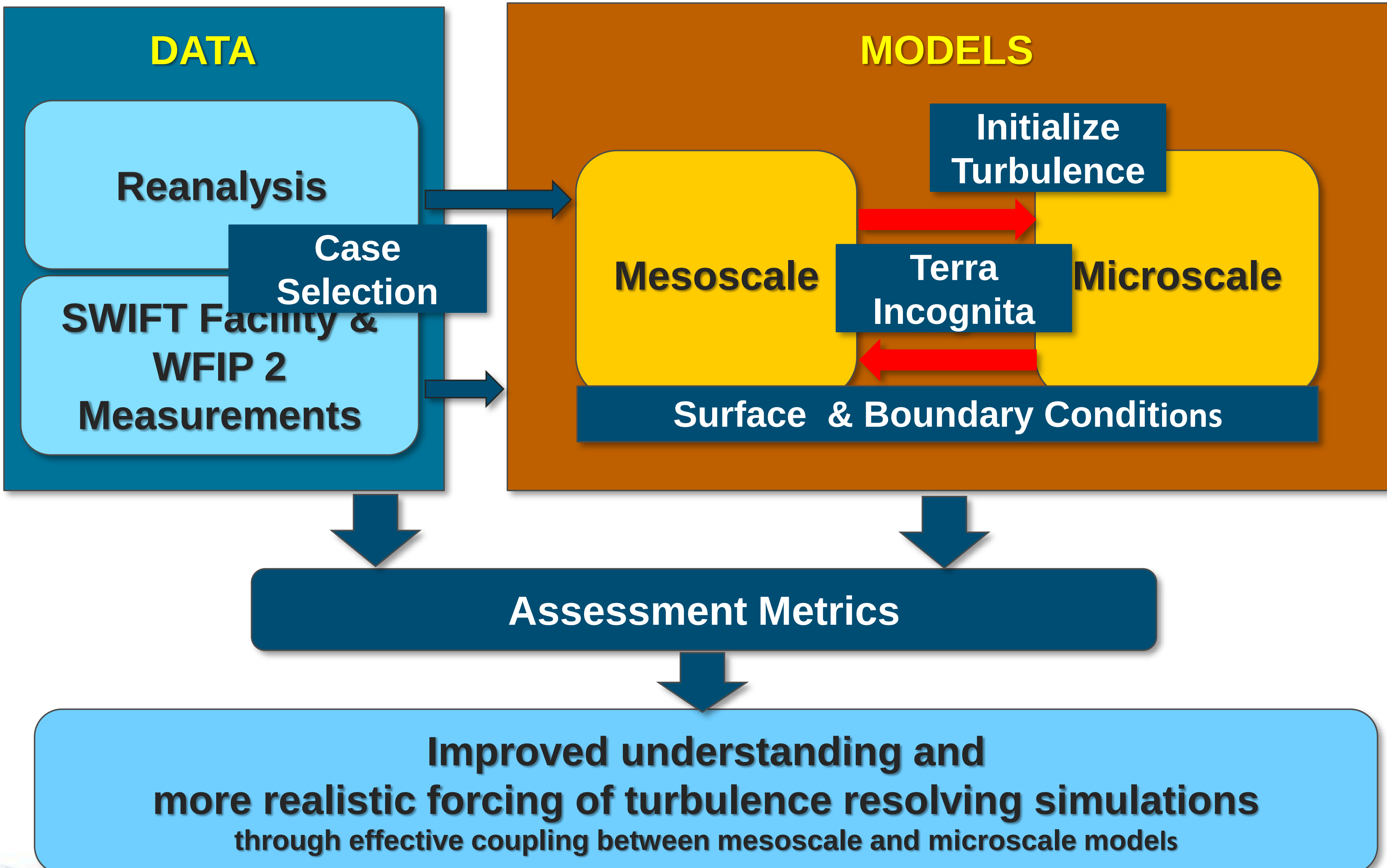
Mesoscale to Microscale Coupling (MMC) Approach



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What are the best coupling strategies?

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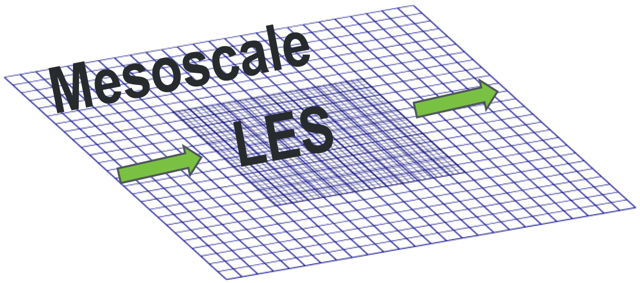
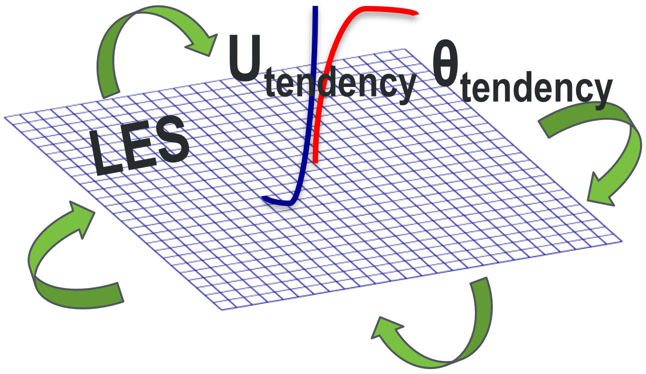
- Mesoscale models capture the full variability and physics derived from the larger scale flow
  - Compressible
  - Non-hydrostatic
  - Forcings from radiation, surface, boundary layer processes, etc.
- Microscale models capture flow details around objects – useful for
  - Controls
  - Details of Siting
- Want microscale model to dynamically follow the changes forced at the mesoscale

Approaches:

- Nesting
- Forcing





Modeling the Low Level Jet (LLJ)

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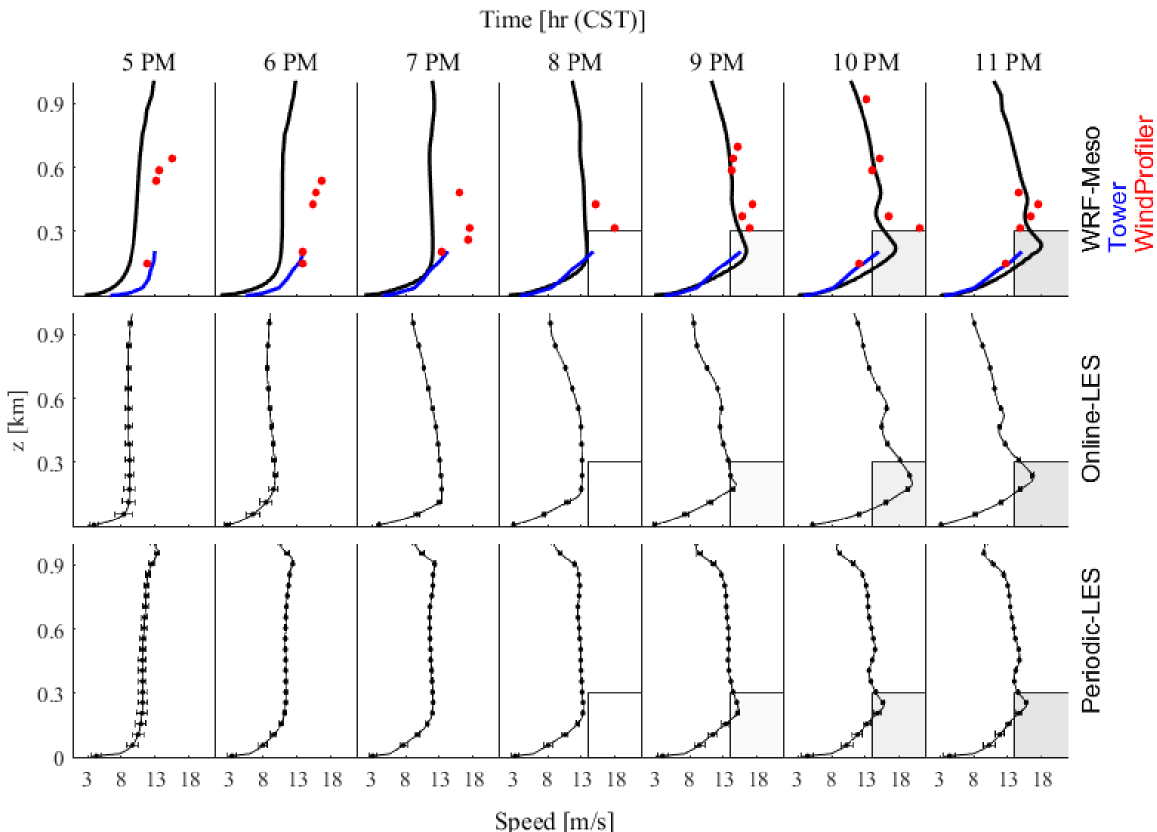
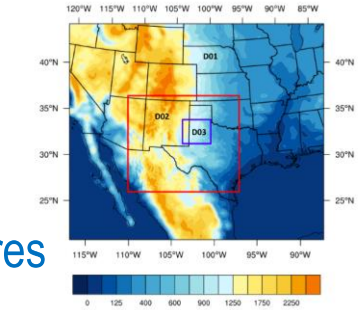
Inability to correctly capture low level jet (LLJ) without mesoscale nesting will compromise ability for industry to make use of high fidelity modeling capabilities.

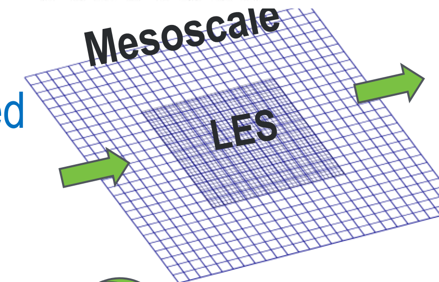
Mesoscale forcing provided by Weather Research and Forecasting (WRF) model. Large Eddy Simulation (LES) embedded.

Nov. 8, 2013 Diurnal Case

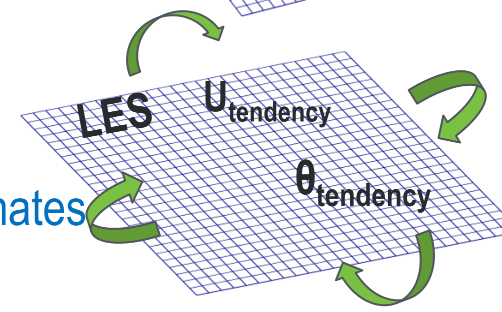




Mesoscale WRF captures LLJ



LES embedded in WRF captures LLJ

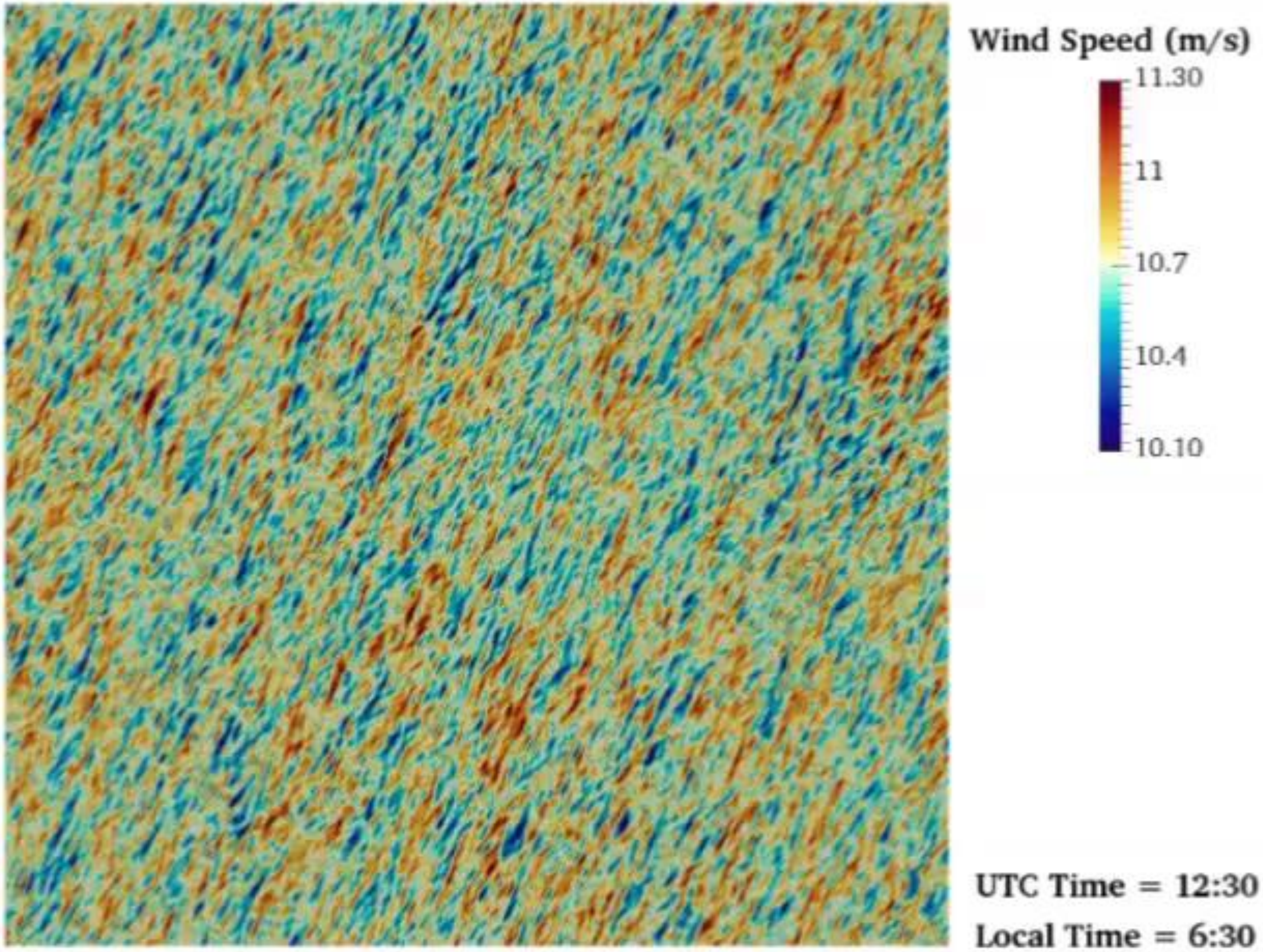


LES w/o mesoscale greatly underestimates LLJ

Need mesoscale to capture important features like LLJ

Raj Rai & Larry Berg, PNNL

Diurnal Case – SOFWA - Nov 8, 2014



Matt Churchfield, NREL

How to initialize turbulence at the microscale?

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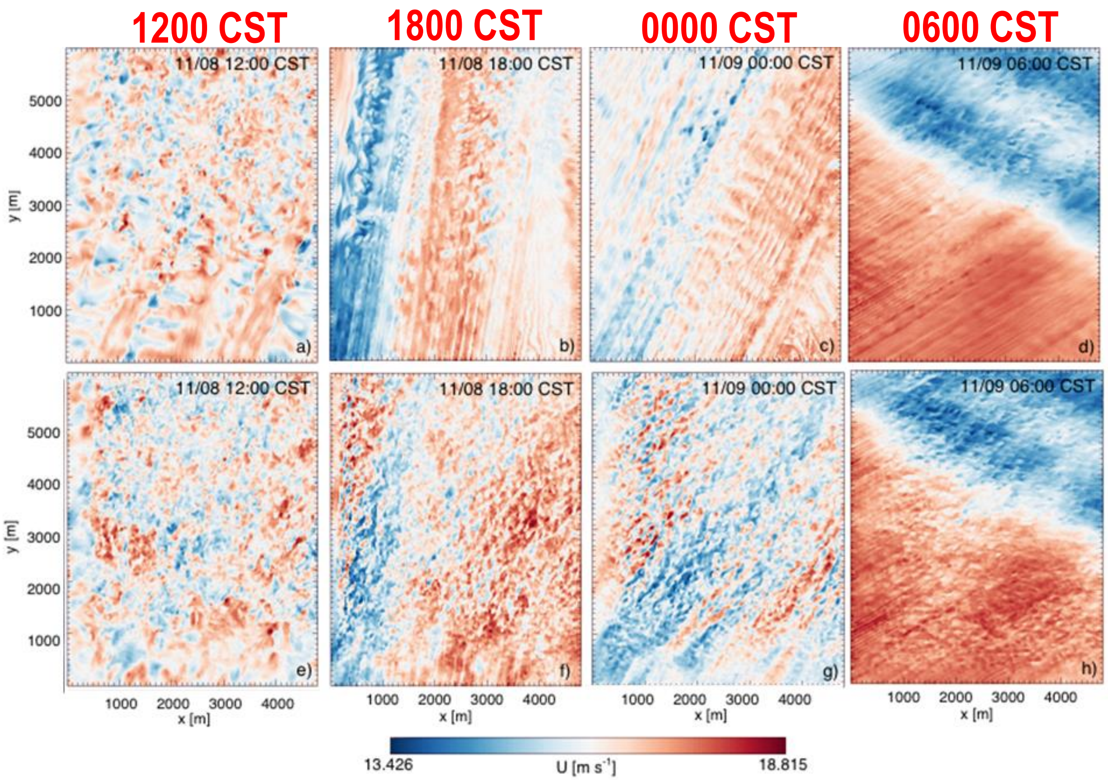
Stochastic Cell Perturbation Method (SCPM)

Without perturbations

With perturbations



LES of a diurnal cycle, from late morning through the evening transition and into the nocturnal period, observed on November 08-09 2013 at the SWiFT site.

SCPM considerably improved the representation of turbulence for all time periods.

Spatial/Temporal Inhomogeneity – Frontal Passage

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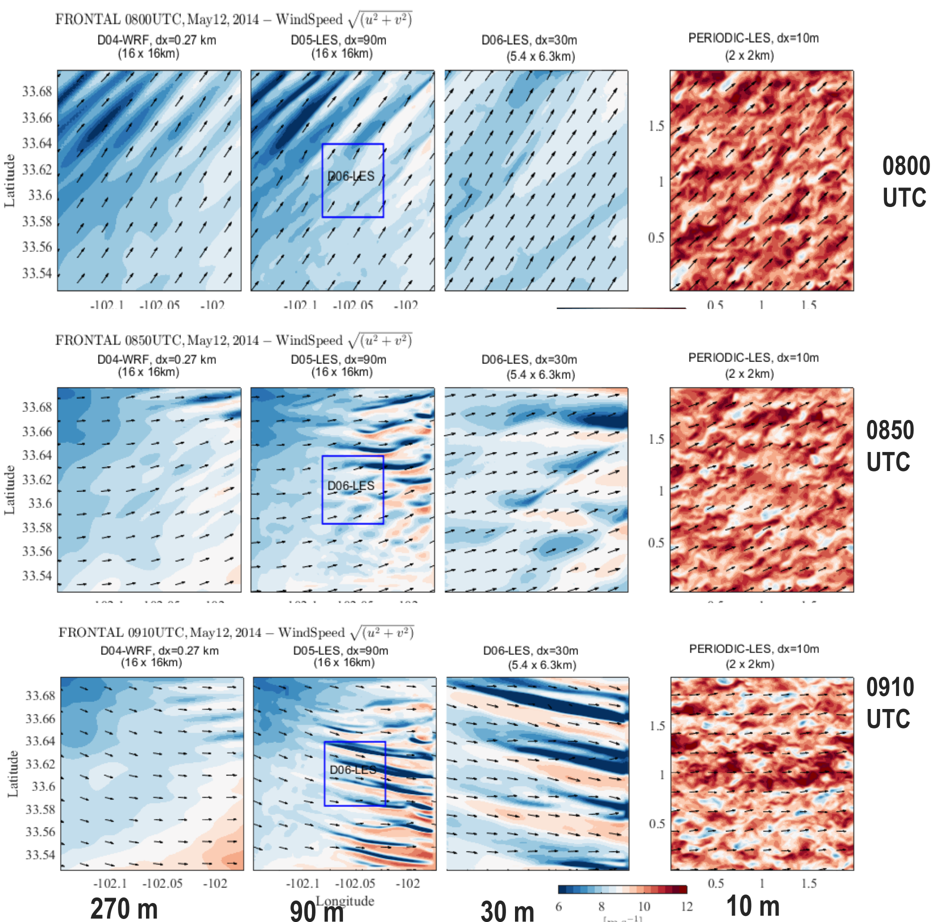
Frontal case: May 12, 2014 ONLINE nesting simulation. LES Domains D04-D06 forced by mesoscale WRF D03. Blue box in D05 shows area of D06.

Periodic forcing from WRF tendencies and heat flux



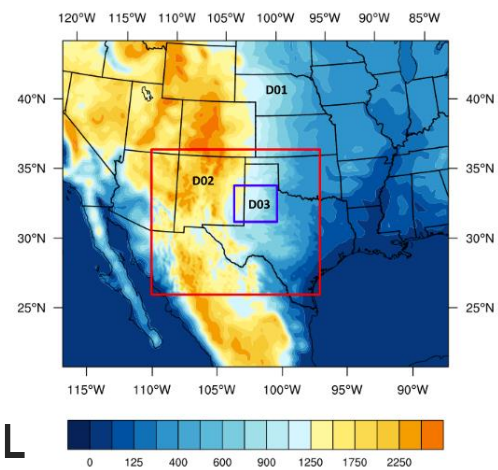
270 m
16x16 km
D04

90 m
16x16 km
D05

30 m
5.4x6.3 km
D06

10 m
2x2 km
Pdic

- See change in flow through all scales during frontal passage
- Forced by mesoscale
- Microscale follows mesoscale via forcing
- Turbulence obvious at finest scale



Raj Rai & Larry Berg, PNNL

How to best bridge the *terra incognita*?

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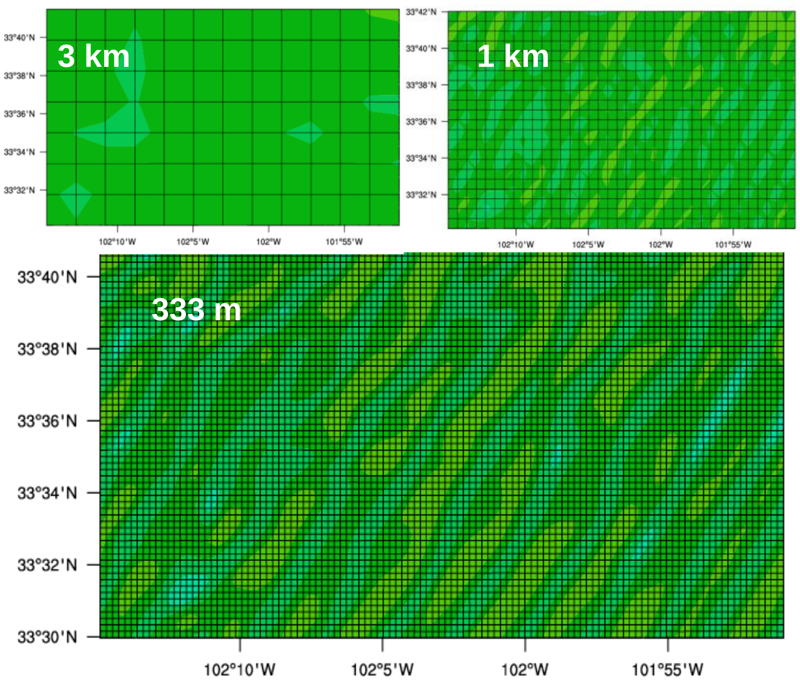
- Mesoscale models can display numerical artifacts (spurious rolls) when horizontal resolutions are in the so-called *terra incognita*.
- Terra incognita traditionally defined as range between 100 m and 1000 m where neither weather prediction Reynolds Average Navier-Stokes (RANS) nor Large Eddy Simulation (LES) models are appropriate.
- Wind plant modeling requires resolving this issue.

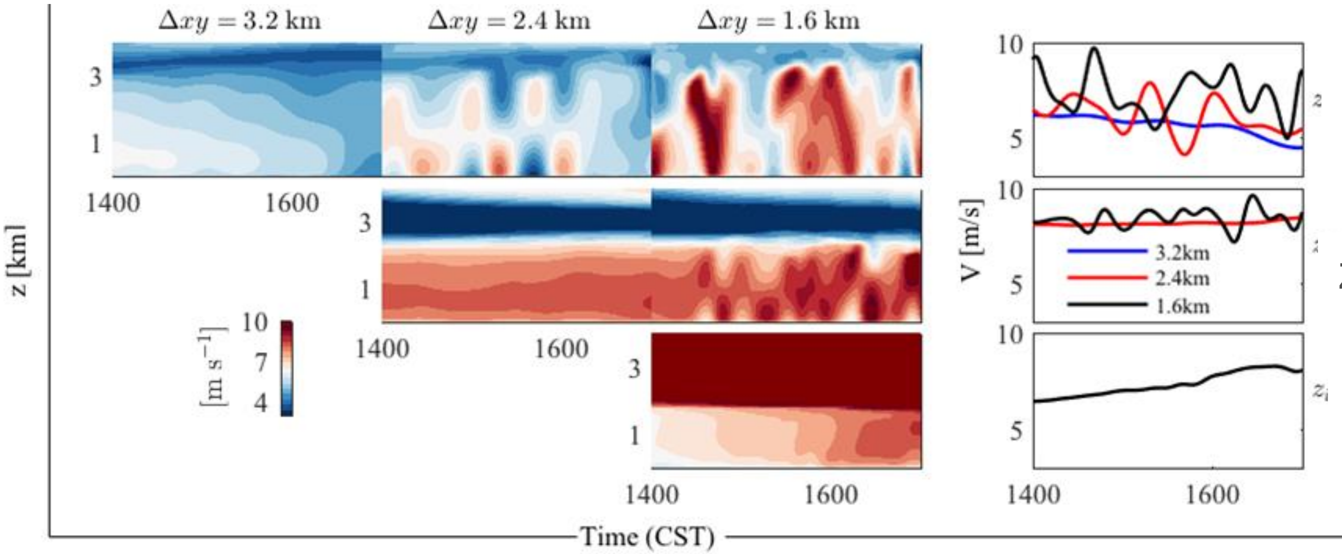


Contours of instantaneous horizontal velocity in a horizontal plane 117 m above the surface during the peak of convective activity in the SWiFT November 8 case study.

Caroline Draxl, NREL

How to best bridge the *terra incognita*?

Carefully constructed experiments



z_i = 3.2 km

z_i = 2.4 km

z_i = 1.6 km

Suite of WRF simulations designed to look at impact of grid spacing and refinement ratio for a site with simple terrain.

- *Terra incognita* defined as height of boundary layer – **new result in the literature**.
- More energy observed at microscale when coupled to mesoscale nest.
- Impact of *terra incognita* on mesoscale simulations is more important as grid spacing shrinks.
- Flow structures change with closure model used on finest resolution (mesoscale or LES).
- LES results are insensitive to mesoscale or terra incognita parent grid for certain conditions, but more research is needed to be definitive.

Rai et al. 2018

Nested Mesoscale to Microscale Simulation Over Complex Terrain

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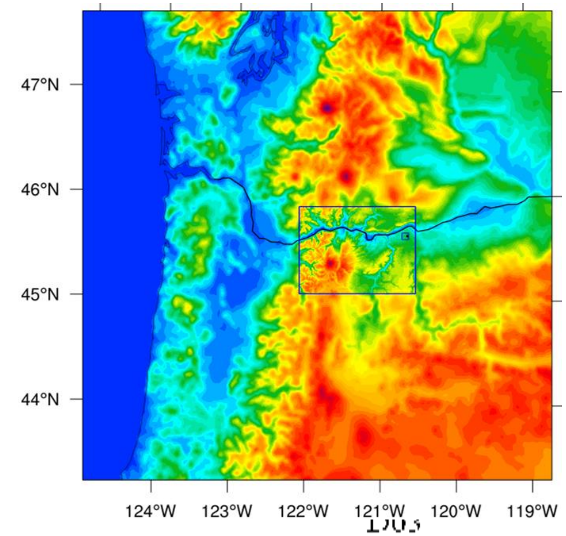
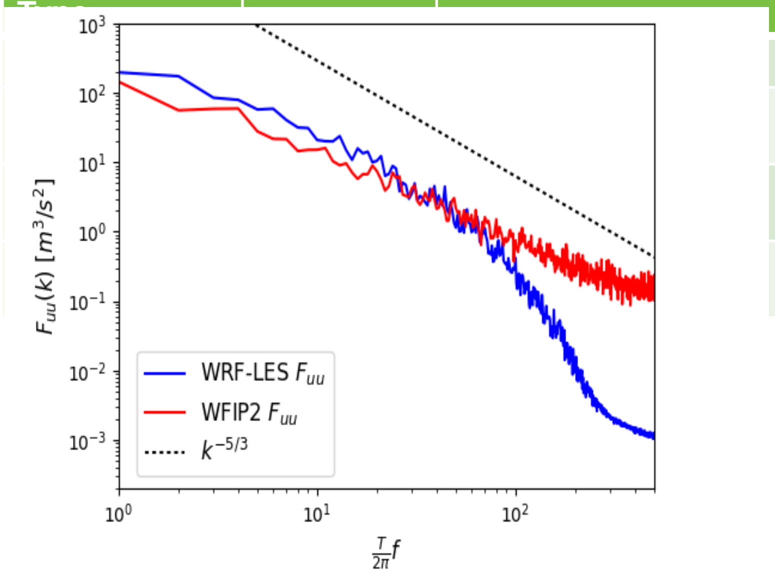
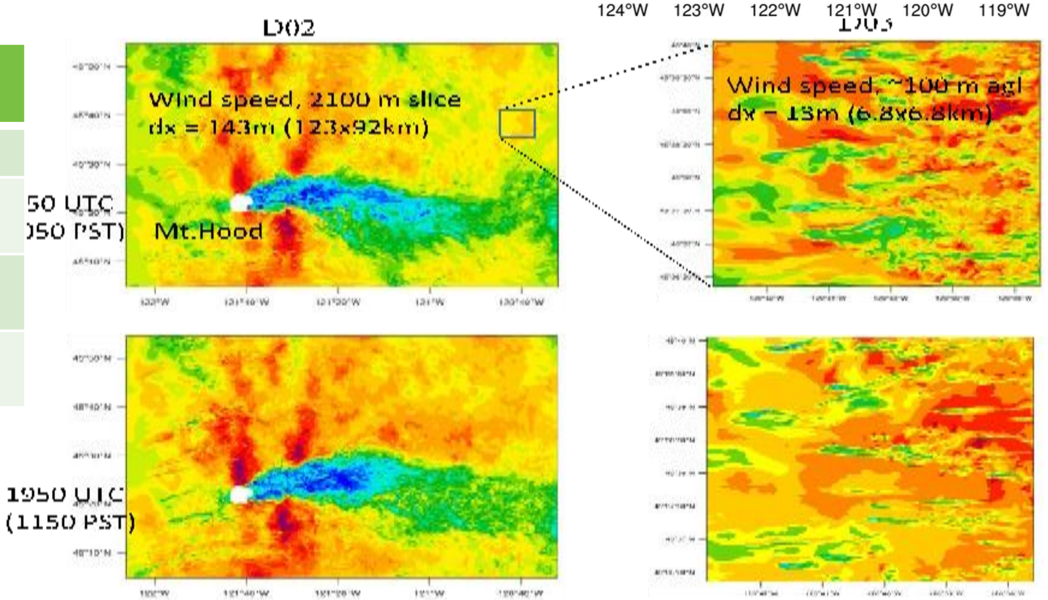
- November 21, 2016 case was selected for assessment of mesoscale to microscale coupling due to relatively good mesoscale forecast.
- During the night between November 20 and 21 the measured wind speed at the Physics Site was relatively low, 4 – 5 m s^{-1}, after 19 UTC (11 AM local time) the wind speed increased to 10 m s^{-1}.



Simulation Type	Mesoscale	Microscale





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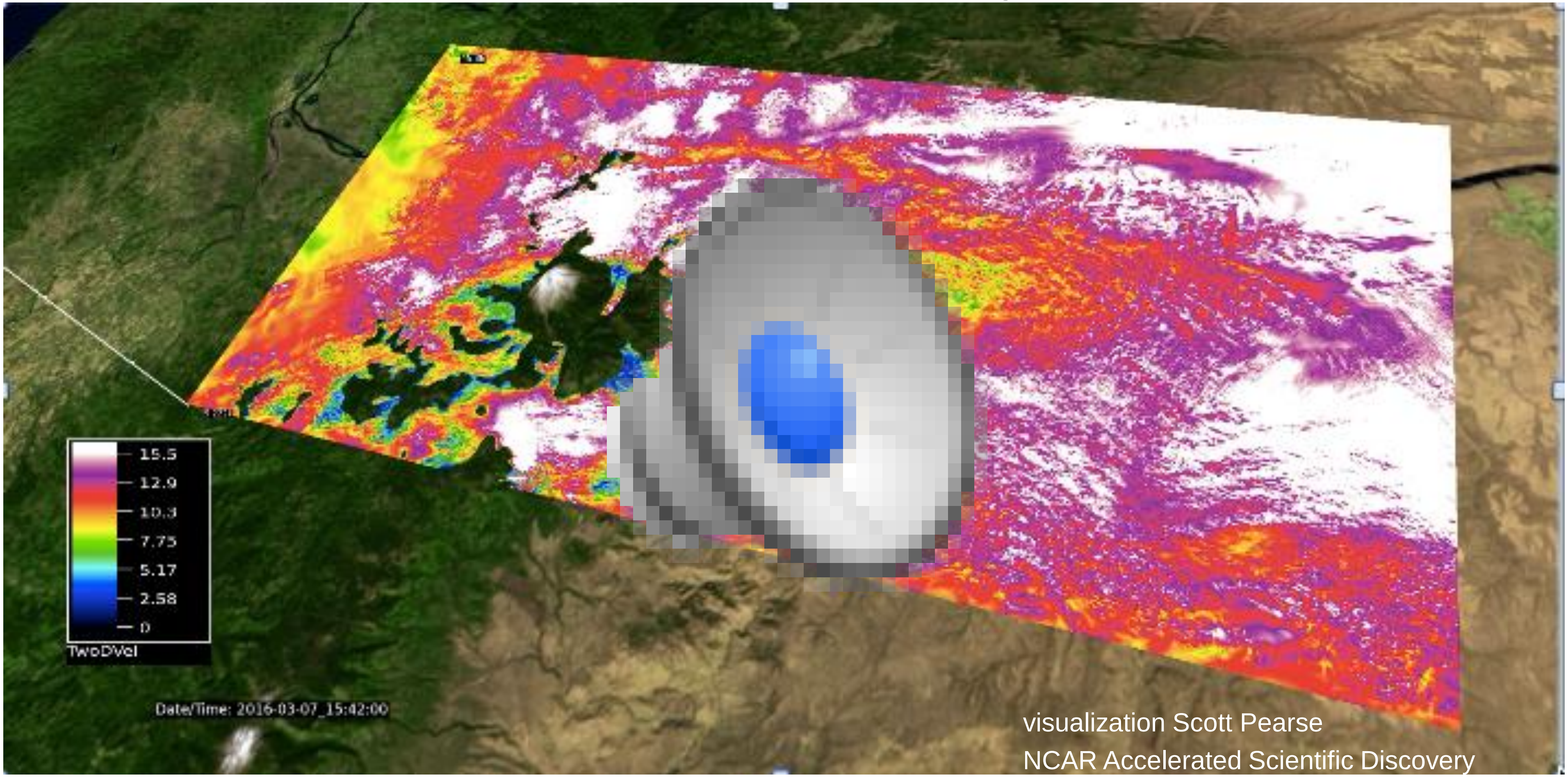
High-Resolution Modeling with 3D PBL Scheme

Horizontal velocity



Topographic wake and gap flow observed on March 07 – 08, 2016

Branko Kosovic and Pedro Jimenez, NCAR

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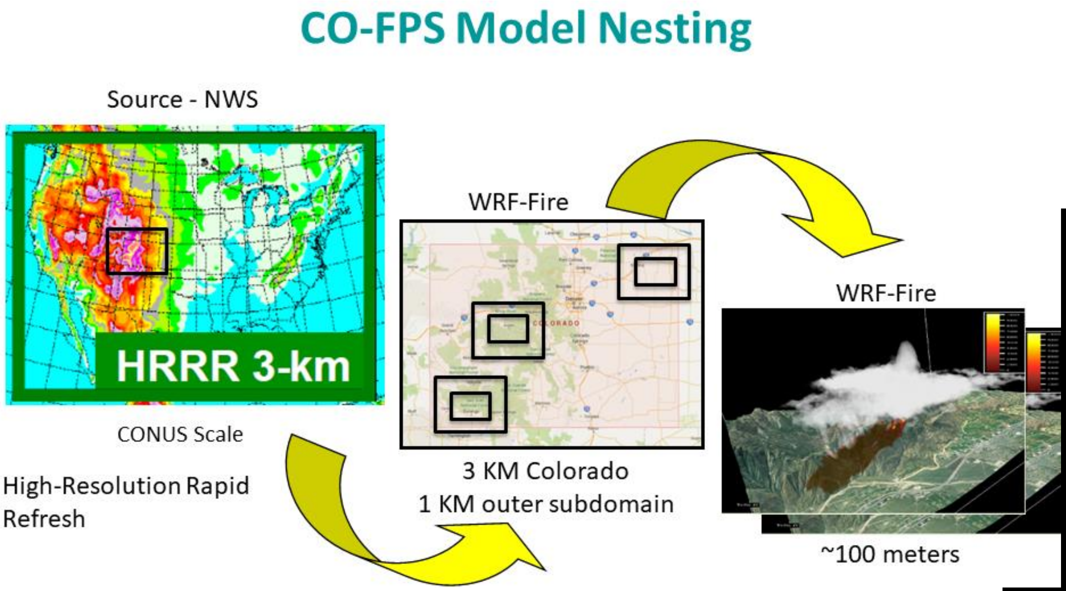
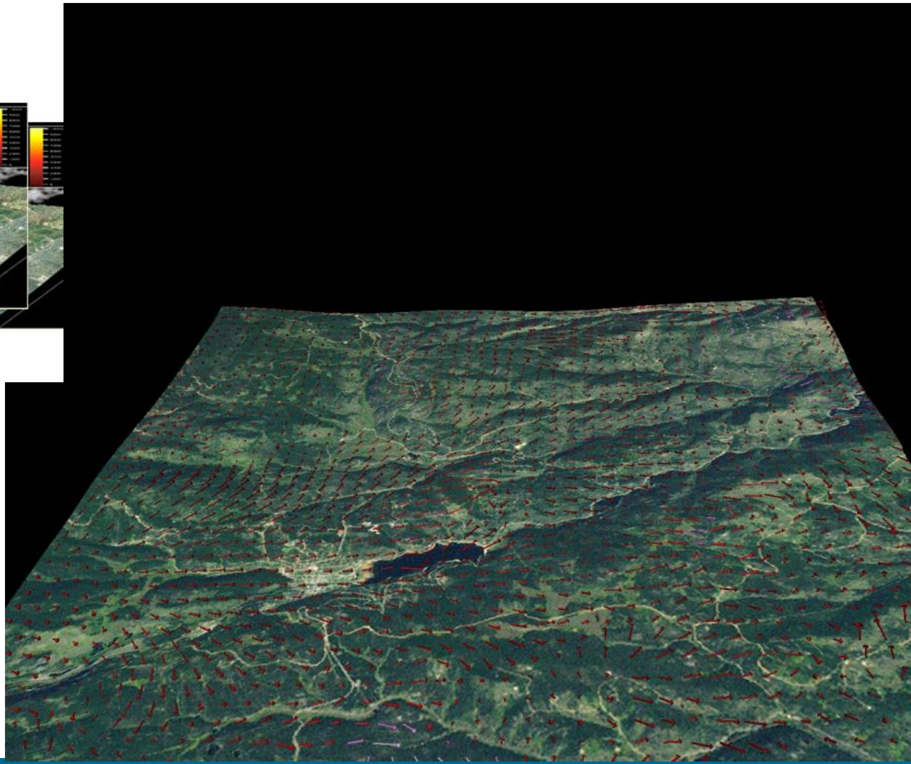
Not Yet, but perhaps in the not too distant future

For example, NCAR is currently modeling Wildland Fire Progression at 100 m resolution.





Branko Kosovic, Pedro Jimenez, Domingo Munoz-Esparza

Can we use this for Forecasting?

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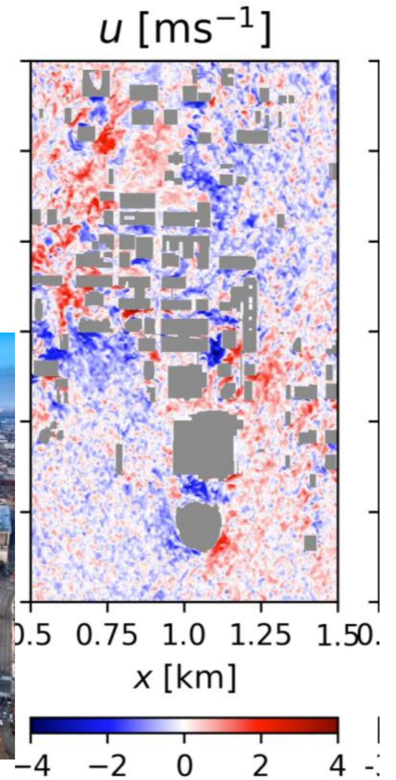
Not Yet, but perhaps in the not too distant future

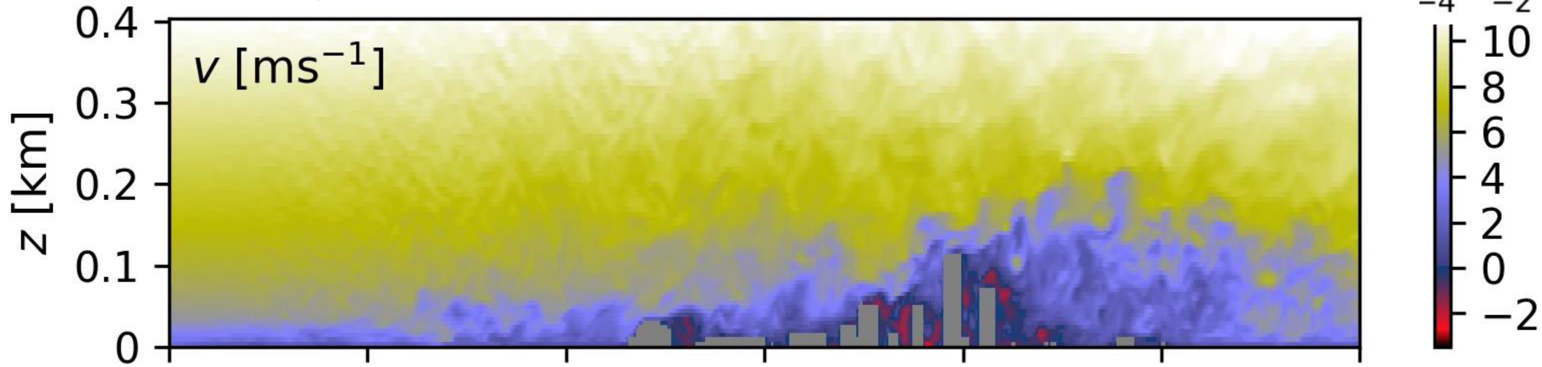
FastEddy™ : **Promising Performance**

- Native GPU-enabled LES code
- FastEddy execution time on Nvidia Pascal GP100 is **0.023 s per timestep**
- Explicit CFL constrained dt = 0.05 s (fully compressible)
- **~2x faster than real time!!!**
- Time-splitting methods may further speed

L_x, Ly, L_z = (2.0,3.0,1.2) km
Δx = Δy = 2 m
Δz = 2 – 12 m (stretched)



Jeremy Sauer, Branko Kosovic
Domingo Munoz-Esparza



Summary

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- Coupling mesoscale to microscale is necessary to capture energy transfer
- Tendency coupling is effective
- Stochastic perturbations are effective
- *Terra incognita* bounded by PBL depth
- 3D PBL scheme alleviates problems
- Using LES for forecasting may be in sight

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energy.gov/eere/wind/atmosphere-electrons

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