Analyzing and Improving Turbulence Characterization in a Multiscale Atmospheric Model of Transport and Dispersion Through an Urban Area

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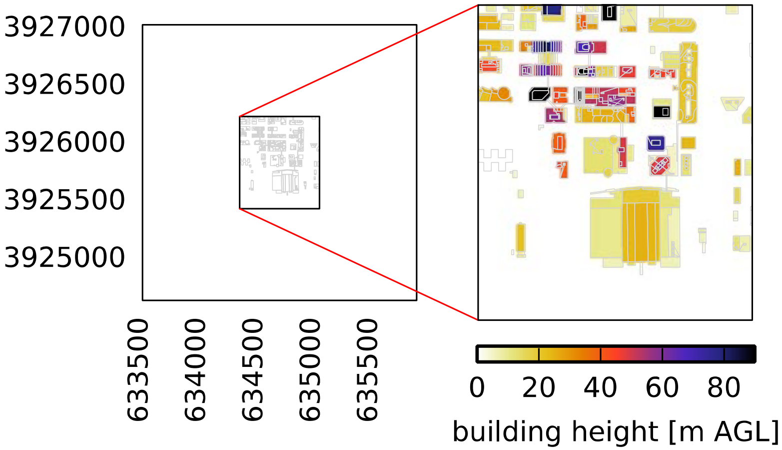
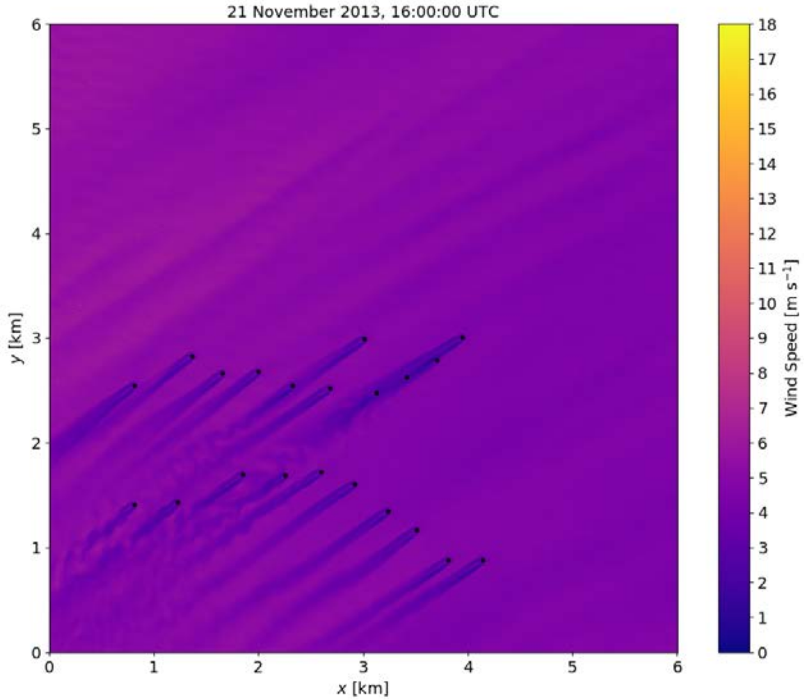
Multiscale Modeling Over Complex Terrain



Microscale-only approach:

- Periodic boundary conditions
- Initialized from a static vertical profile

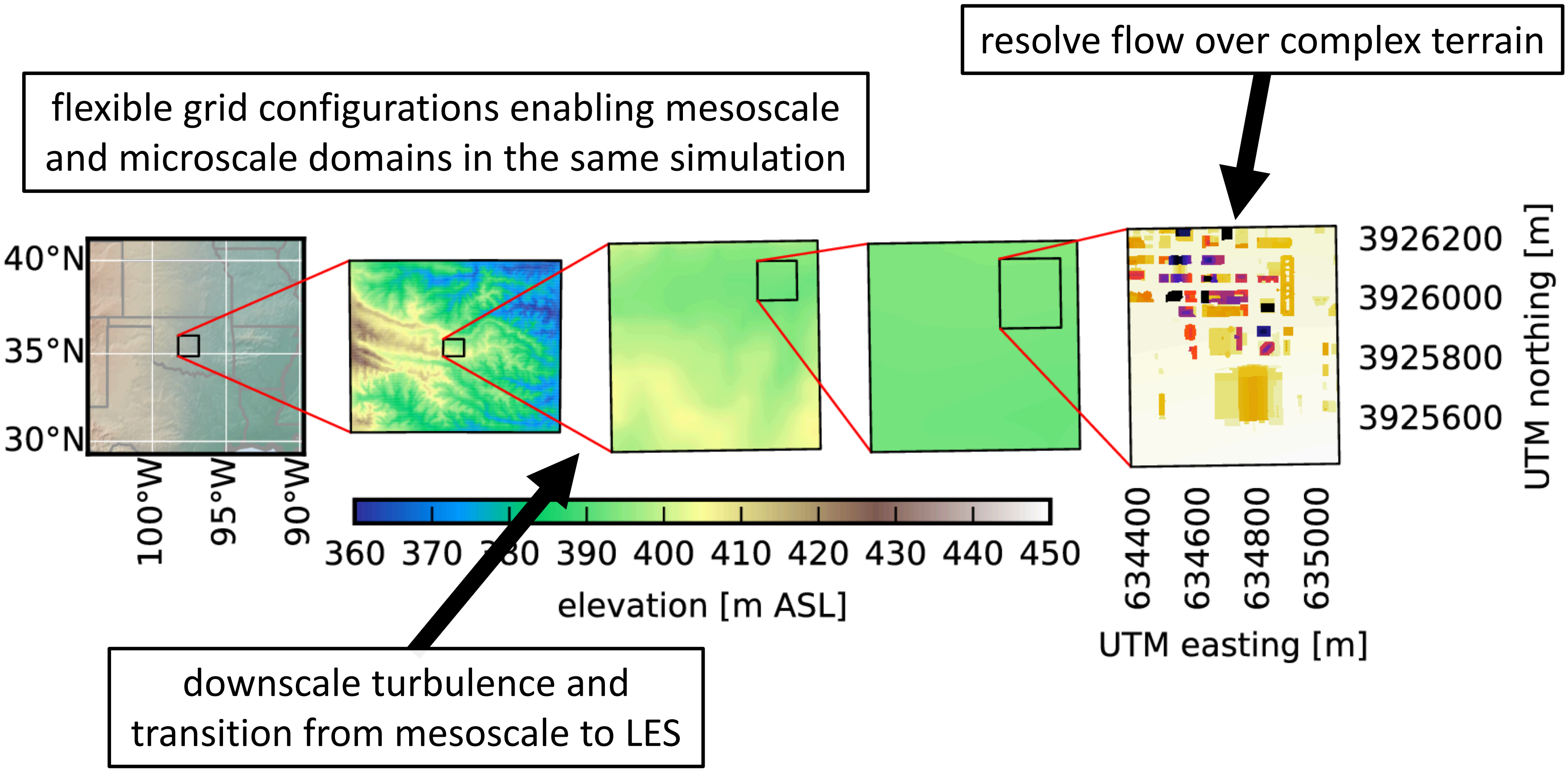
Goal: dynamically downscale from the mesoscale (Δ=10's of km) to the microscale (Δ=10's of m) within a single numerical weather prediction (NWP) model.



animation credit: Jeff Mirocha

Multiscale Modeling Over Complex Terrain

- D. Wiersema, K. Lundquist, and F. K. Chow, 2019: "Mesoscale to microscale simulations over complex terrain with the immersed boundary method in the Weather Research and Forecasting model", *Mon. Wea. Rev.*, in press.



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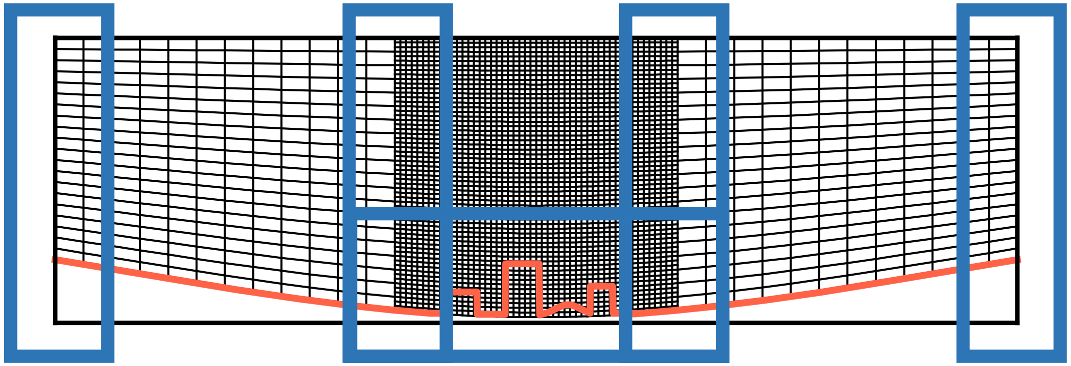
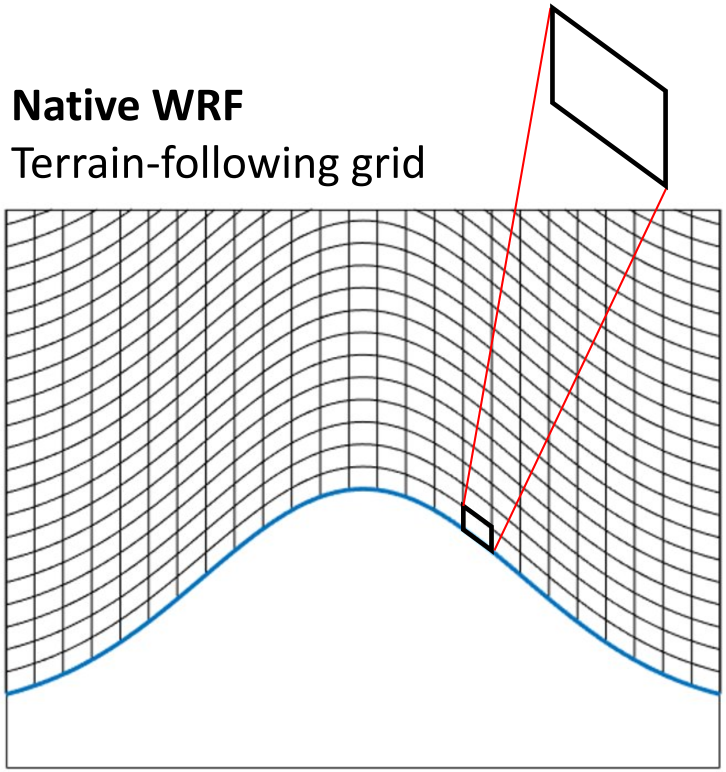


- Vertical grid nesting
  - M. Daniels, K. Lundquist, J. Mirocha, D. Wiersema, and F. K. Chow, 2016: "A new vertical grid nesting capability in the Weather Research and Forecasting (WRF) model", *Mon. Wea. Rev.*, **144**, 3725-3747.
- Immersed Boundary Method (IBM)
  - K. Lundquist, F. K. Chow, and J. Lundquist, 2010: "An immersed boundary method for the Weather Research and Forecasting model", *Mon. Wea. Rev.*, **138**, 796-817.
  - J. Bao, F. K. Chow, and K. Lundquist, 2018: "Large-eddy simulation over complex terrain using an improved immersed boundary method in the Weather Research and Forecasting model", *Mon. Wea. Rev.*, **146**, 2781-2797.
- Cell Perturbation Method (CPM)
  - D. Muñoz-Esparza, B. Kosovic, J. van Beeck, and J Mirocha, 2015: "A stochastic perturbation method to generate inflow turbulence in large-eddy simulation models: Application to neutrally stratified atmospheric boundary layers", *Phys. Fluids*, **27**, 35102.

The Immersed Boundary Method

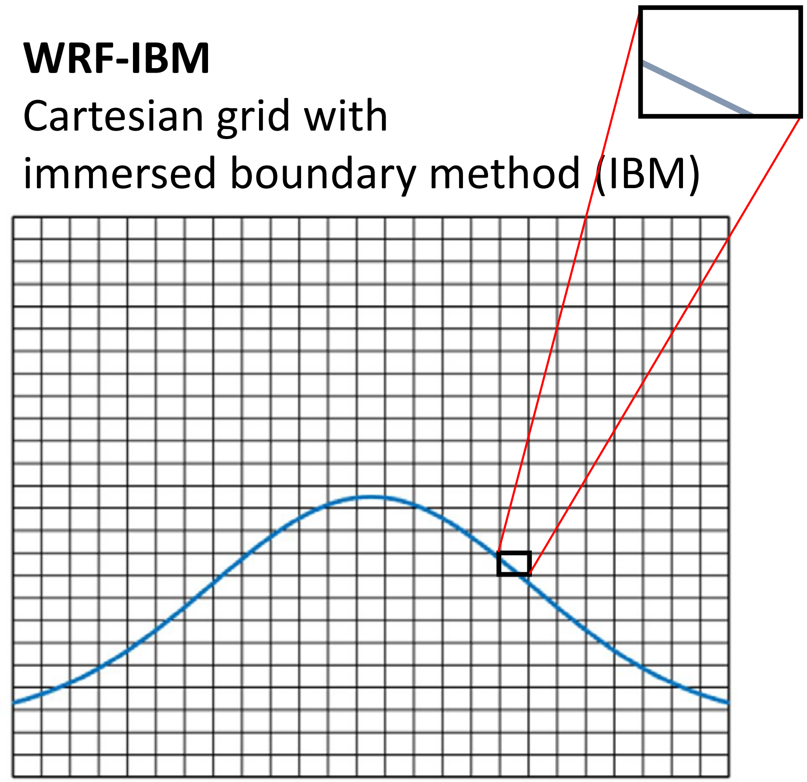
For more information, see Robert Arthur's poster "Ongoing improvements to surface-layer turbulence modeling in the Weather Research and Forecasting model"

Native WRF
Terrain-following grid



- Grids become skewed in regions of steep terrain, leading to errors and model failure.

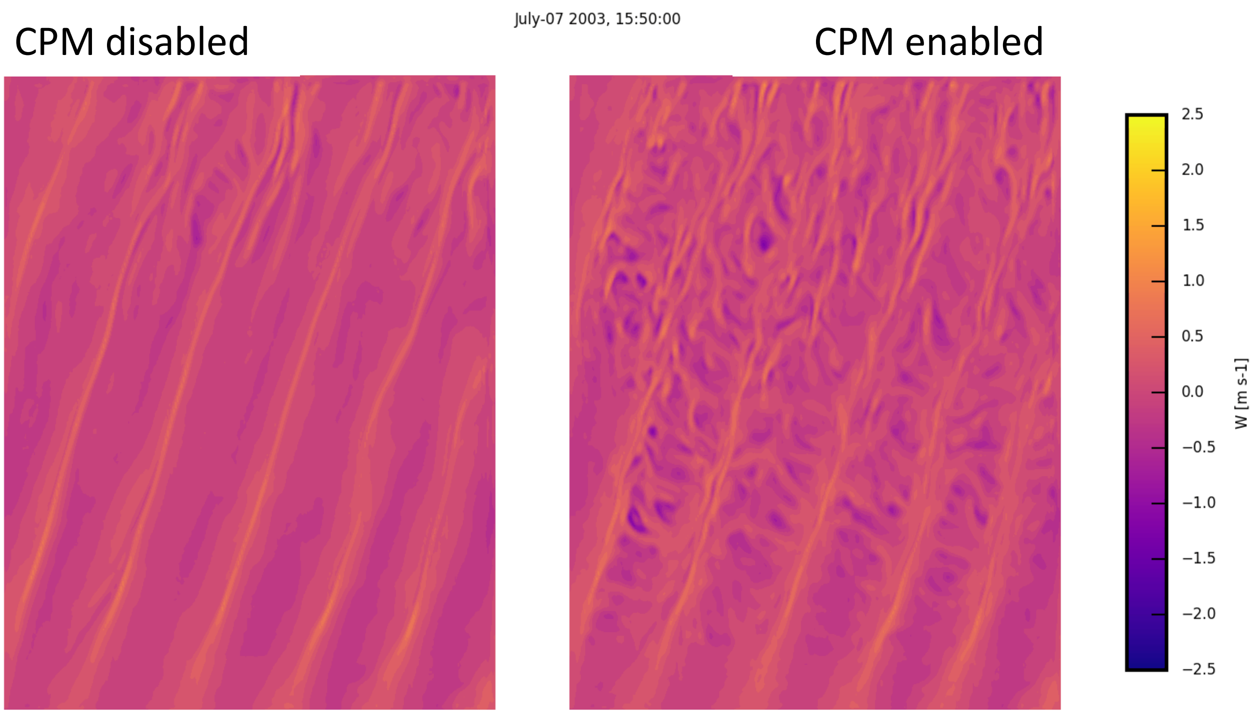
WRF-IBM
Cartesian grid with immersed boundary method (IBM)



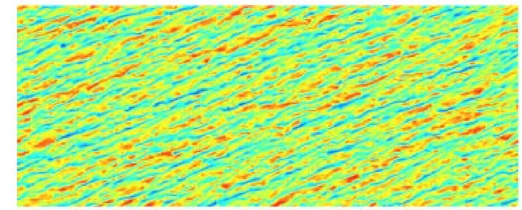
- Reduces grid-related errors; boundary conditions are applied by interpolation to the "immersed boundary."

The Cell Perturbation Method

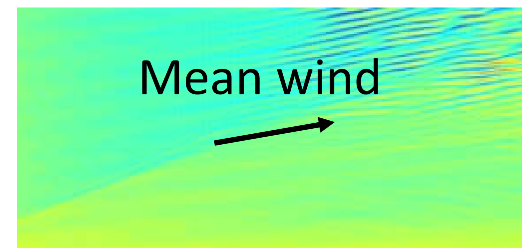
- Development continues through DOE's Mesoscale-Microscale Coupling project (Jeff Mirocha's presentation from yesterday)
- Adds temperature perturbations along inflow boundaries
- Speeds the development of turbulence after grid refinement
- Especially useful between a mesoscale parent → LES nest

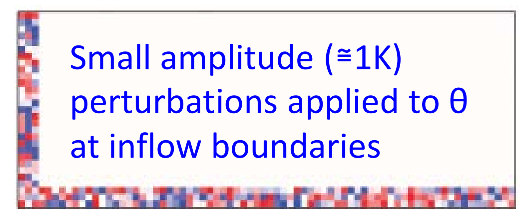


periodic LES

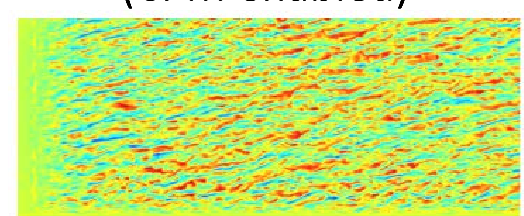


LES nested in mesoscale





LES nested in mesoscale (CPM enabled)



above figures credit: Jeff Mirocha

Joint Urban 2003 Field Campaign, Oklahoma City

Campbell Scientific
https://www.campbellsci.ca/

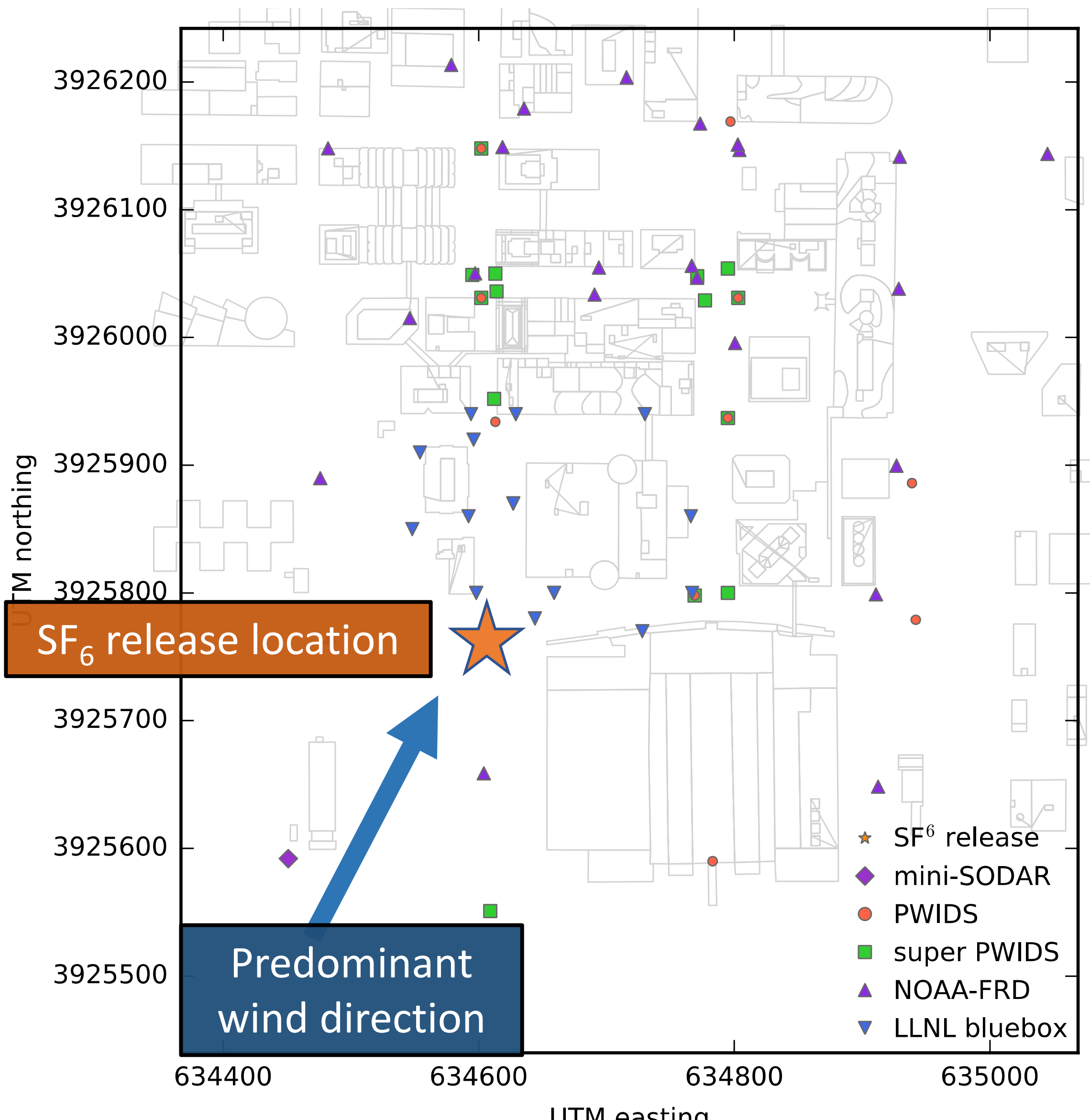
image credit: Katherine Lundquist

image credit: David Wiersema

- Intensive Observational Period 3
- July 7th 2003, 16:00 – 16:30 UTC
- Continuous release of SF_6 at 5 g s^{-1}

- 1 SODAR
  - Argonne National Laboratory
- 11 propeller/vane anemometers
  - Dugway Proving Ground (DPG) portable weather information display systems (PWIDS)
- 16 sonic anemometers
  - 15 DPG super PWIDS
  - 1 NOAA Air Resources Laboratory Field Research Division (ARL FRD)
- 44 integrated gas samplers
  - 19 LLNL “bluebox” samplers
  - 25 NOAA ARL FRD programmable integrating gas samplers (PIGS)

Joint Urban 2003 Field Campaign, Oklahoma City



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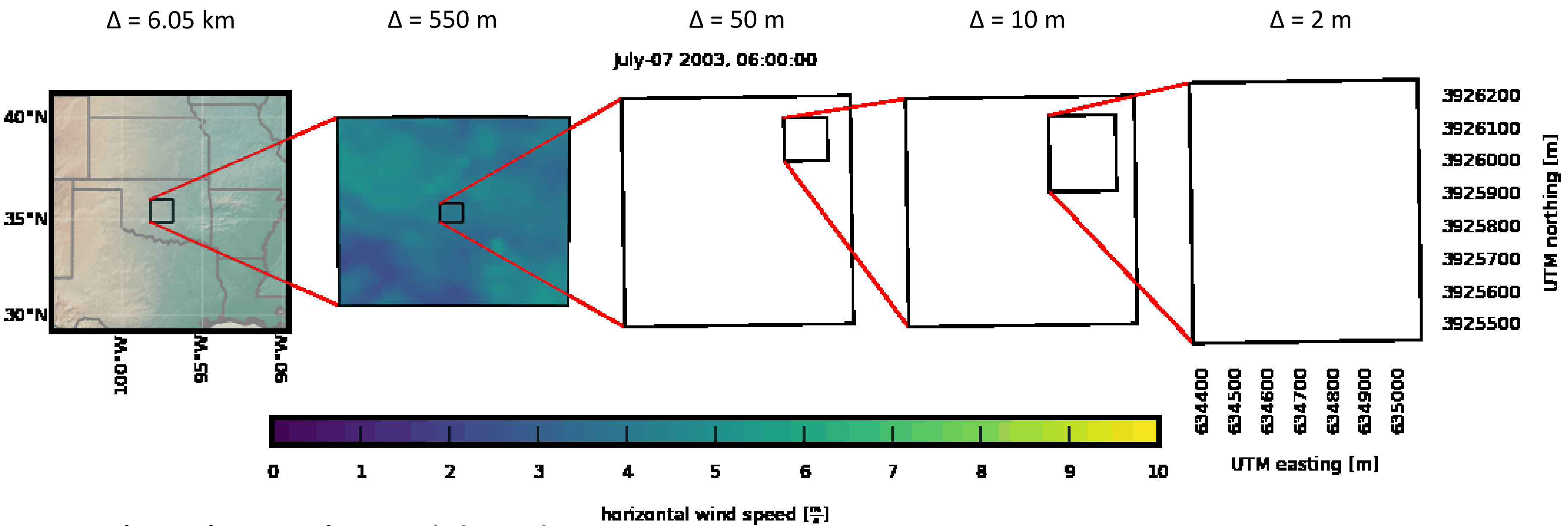
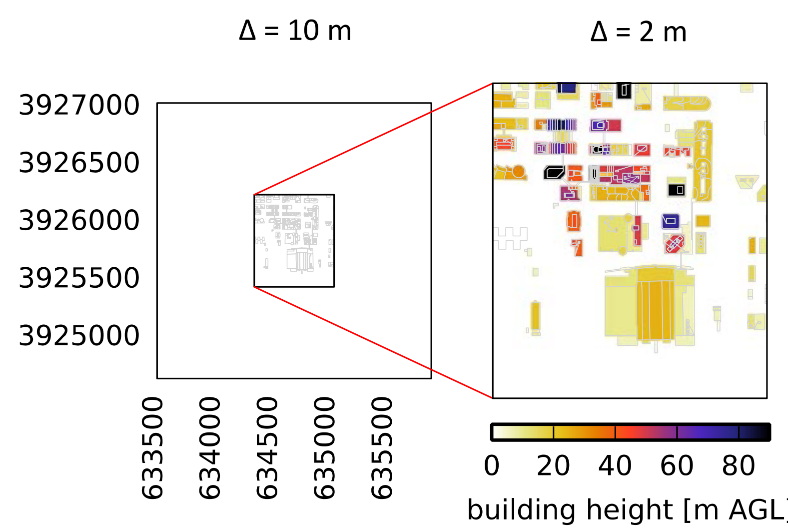


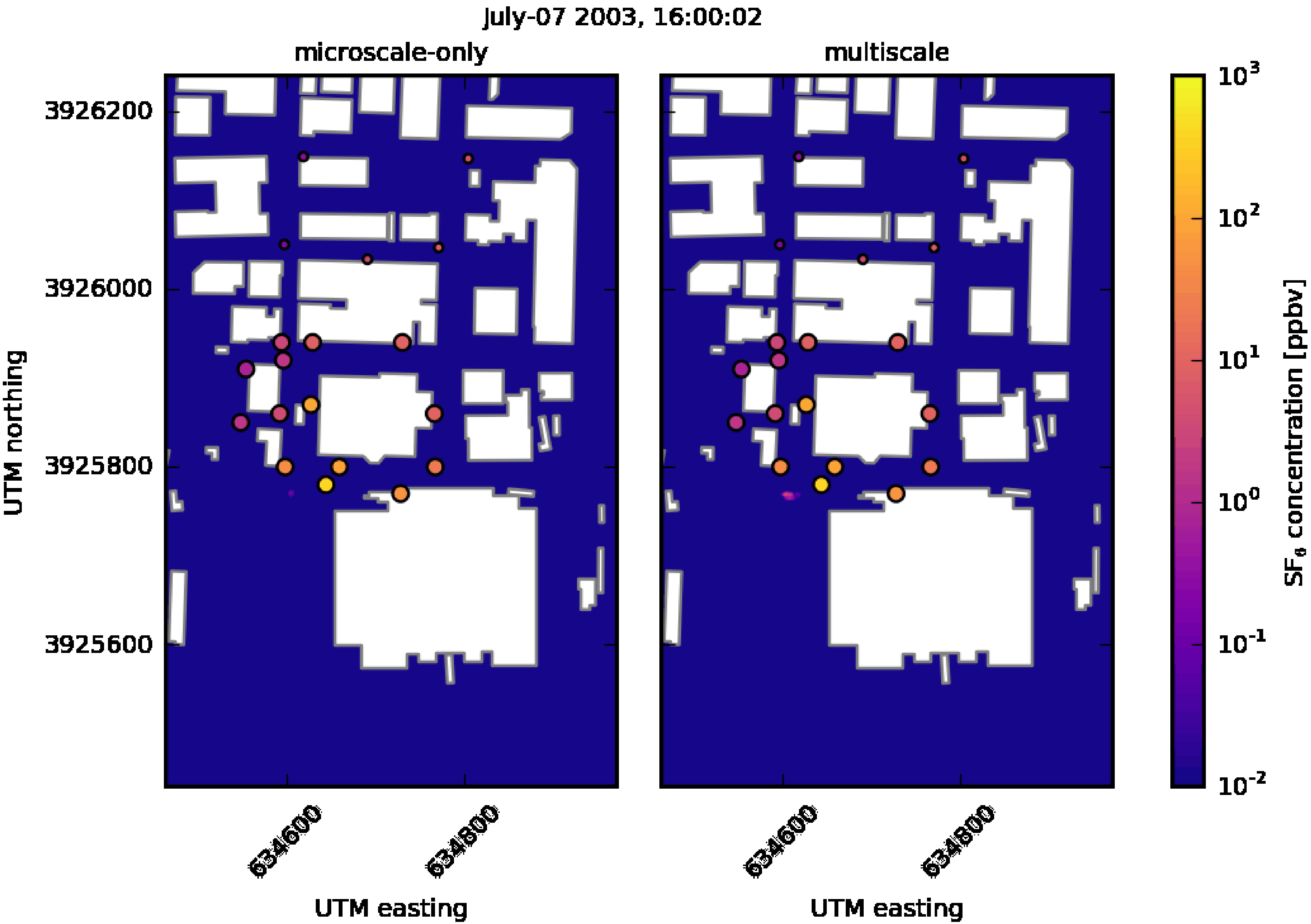
Multiscale simulation (above)

- 5-domain nested configuration
- Forced using NARR (no tuning)
- WRF-IBM (Δ = 10 m & 2 m)

Microscale-only simulations (right)

- 2-domain nested configuration
- Periodic lateral boundary conditions (Δ = 10 m)
- Forced by the addition of a pressure gradient
    - Tuned to match observations
- Immersed boundary method (WRF-IBM)





July-07 2003, 16:00:02
microscale-only
multiscale
3926200
3926000
3925800
3925600
UTM northing
634600
634800
UTM easting
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
SF_6 concentration [ppbv]

Model Skill Compared to Observations

$$\text{FAC}x = \text{fraction satisfying} \ldots$$
$$\ldots \frac{1}{x} \leq \frac{X_p}{X_o} \leq x$$

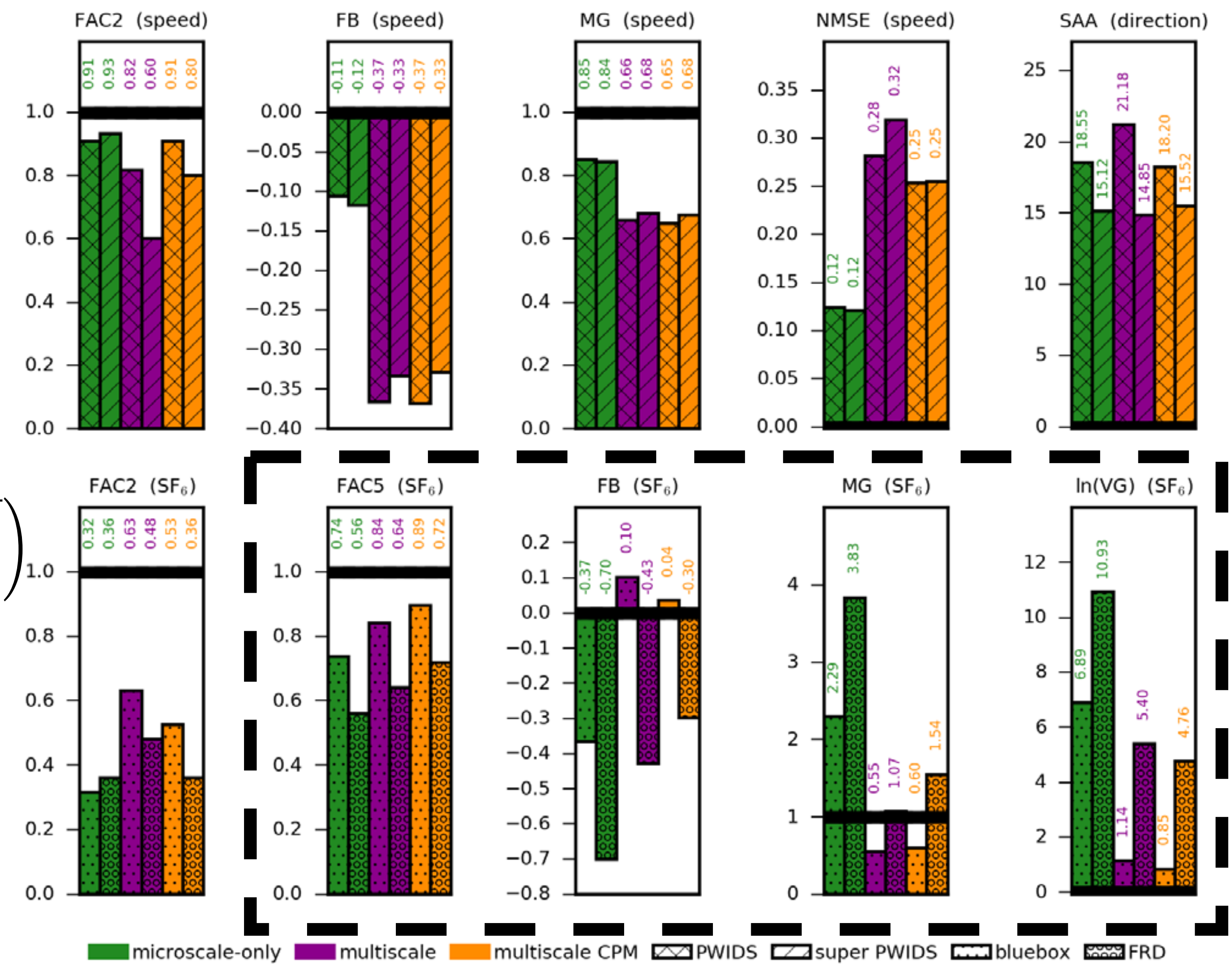
$$\text{FB} = 2\,\frac{\left(\overline{X_o} - \overline{X_p}\right)}{\left(\overline{X_o} + \overline{X_p}\right)}$$

$$\text{MG} = \exp\left(\overline{\ln(X_o)} - \overline{\ln(X_p)}\right)$$

$$\text{VG} = \exp\left(\overline{\left(\ln(X_o) - \ln(X_p)\right)^2}\right)$$

$$\text{NMSE} = \frac{\overline{\left(X_o - X_p\right)^2}}{\overline{X_o}\;\overline{X_p}}$$

$$\text{SAA} = \frac{\sum |U_i||\phi_i|}{N|\overline{U_i}|}$$



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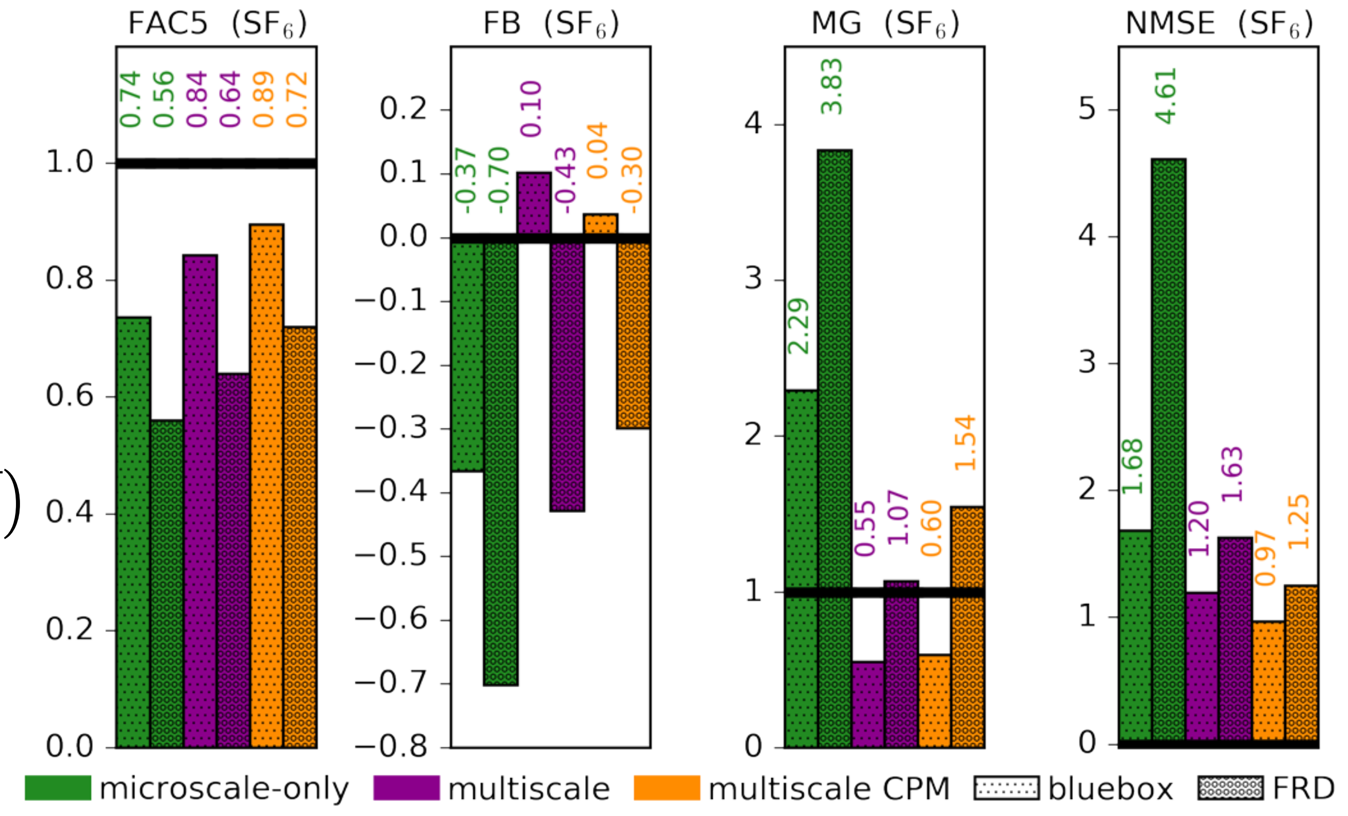
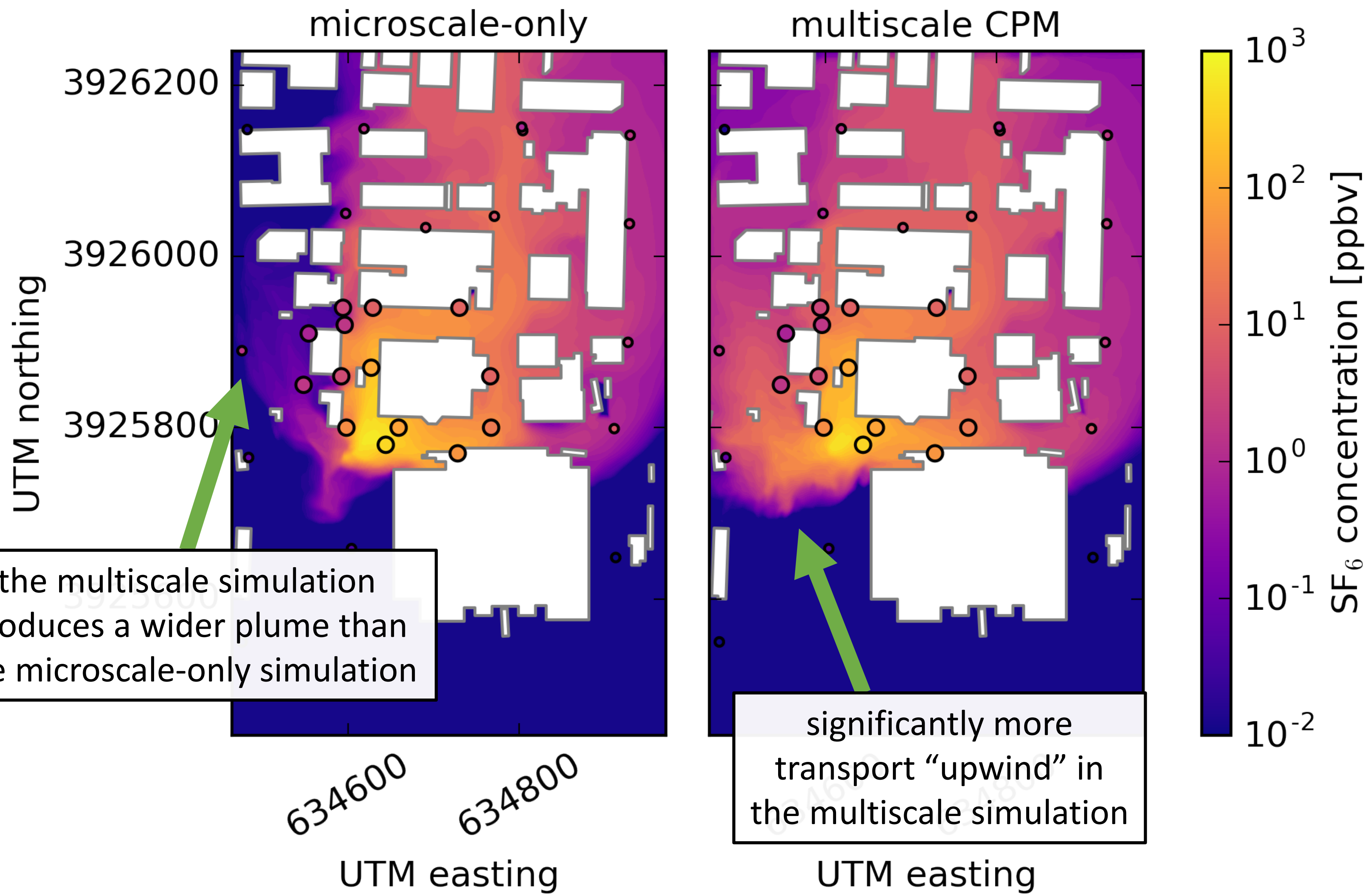
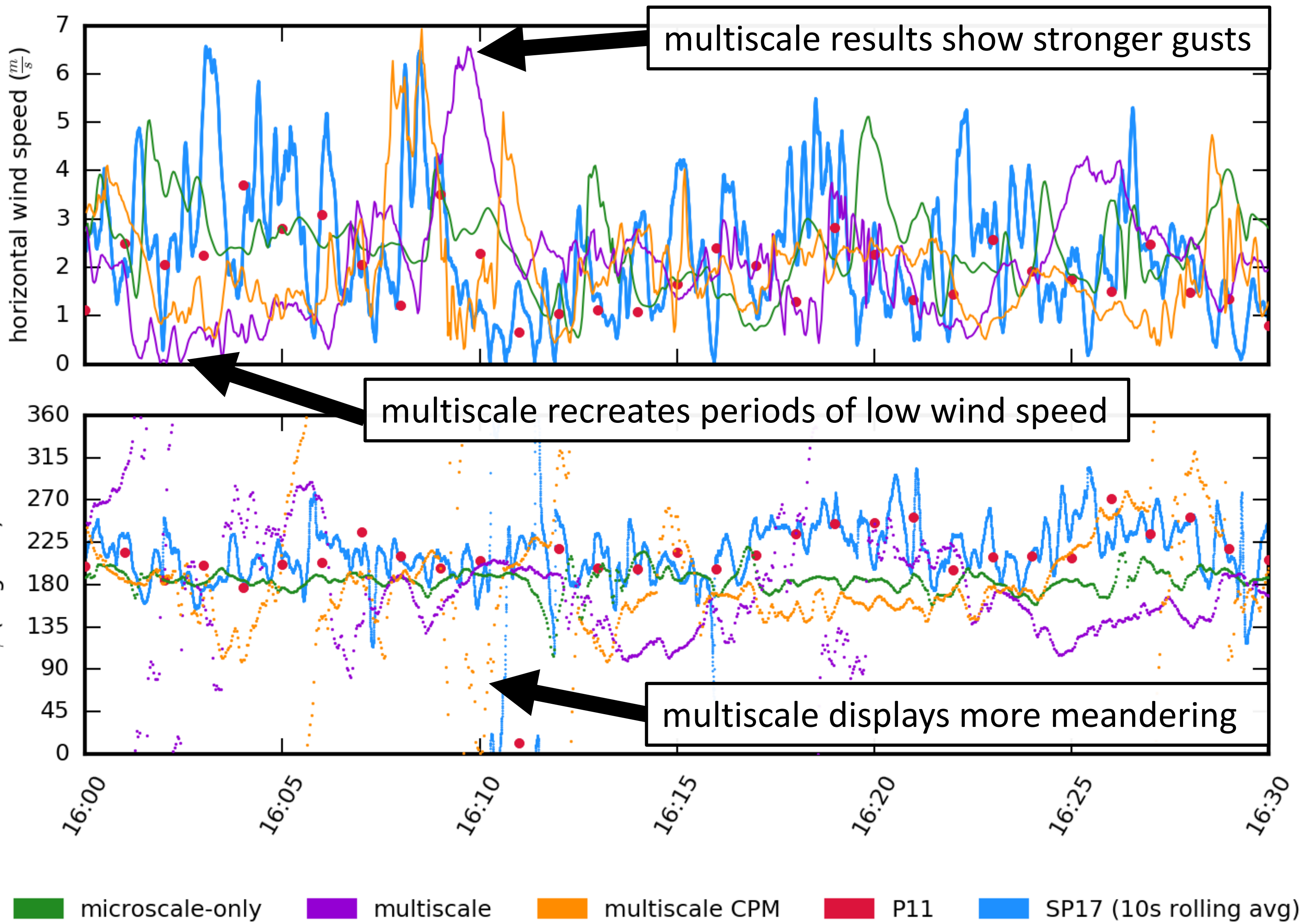


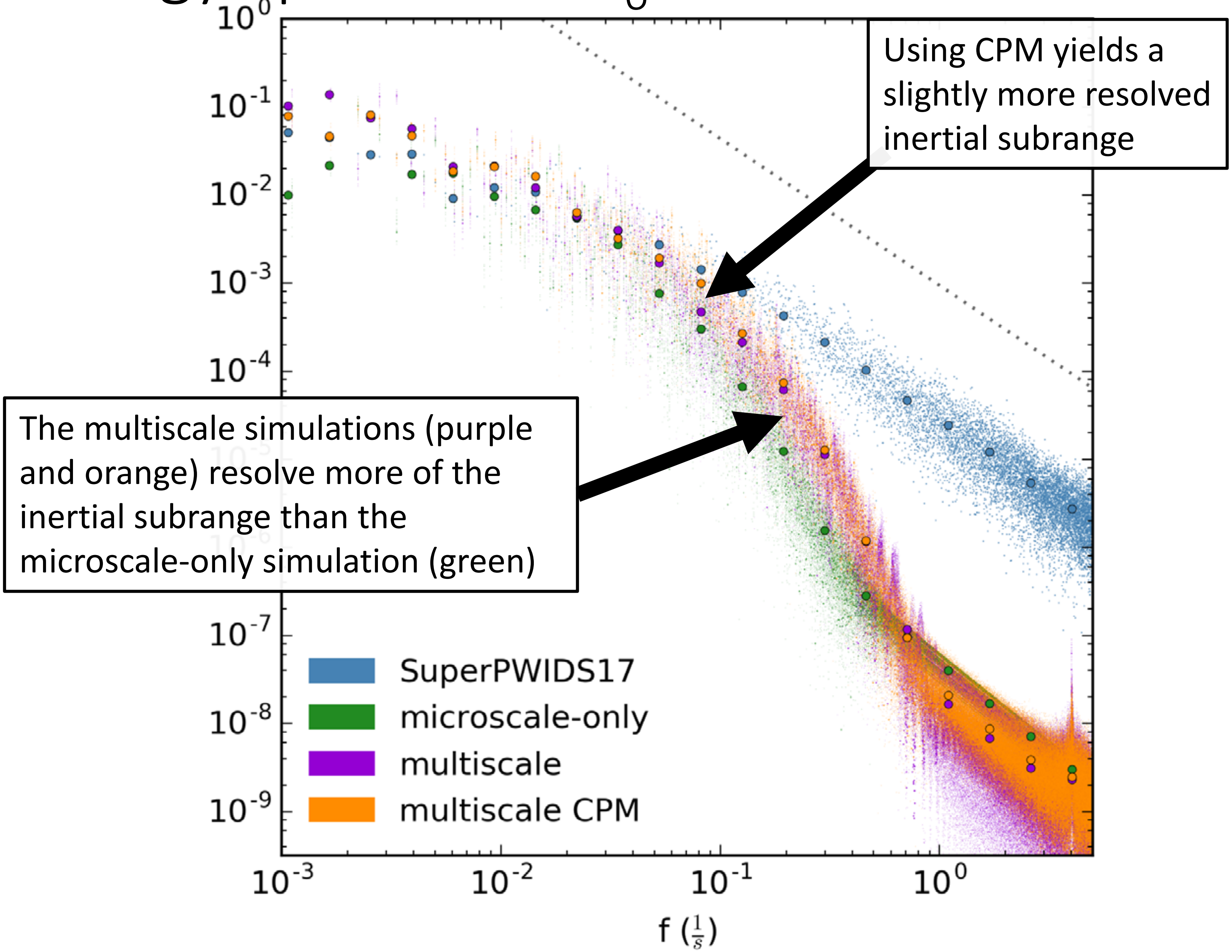
Time-Averaged SF_6 Plumes

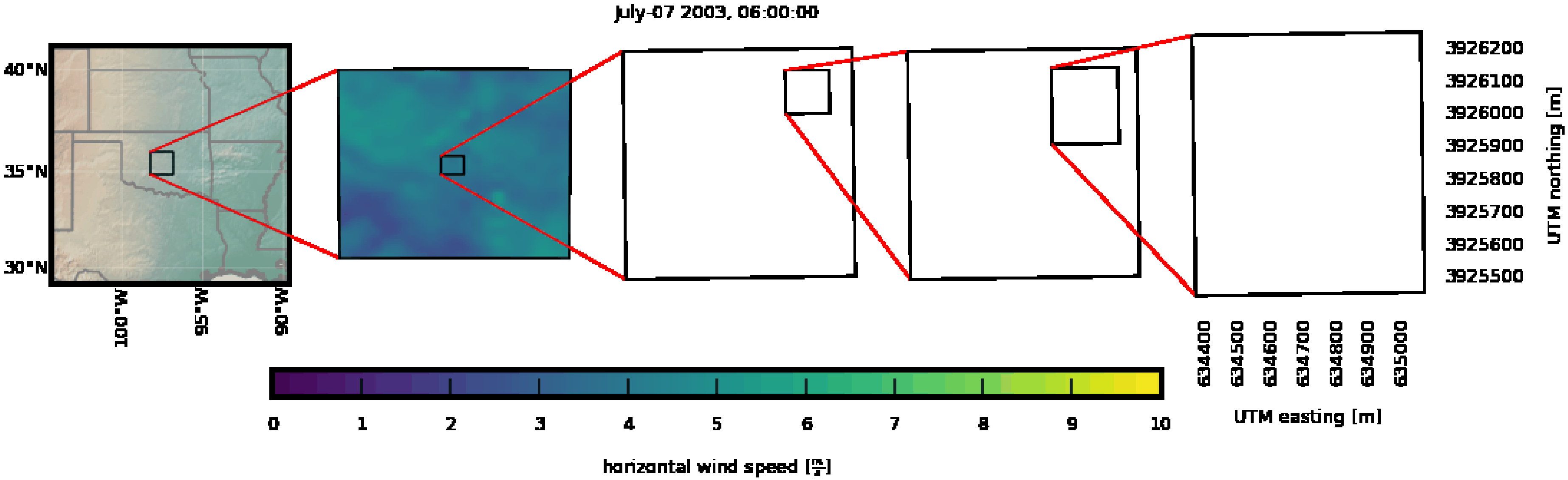


Wind Speed / Direction Timeseries



Energy Spectra at SF_6 Release Location



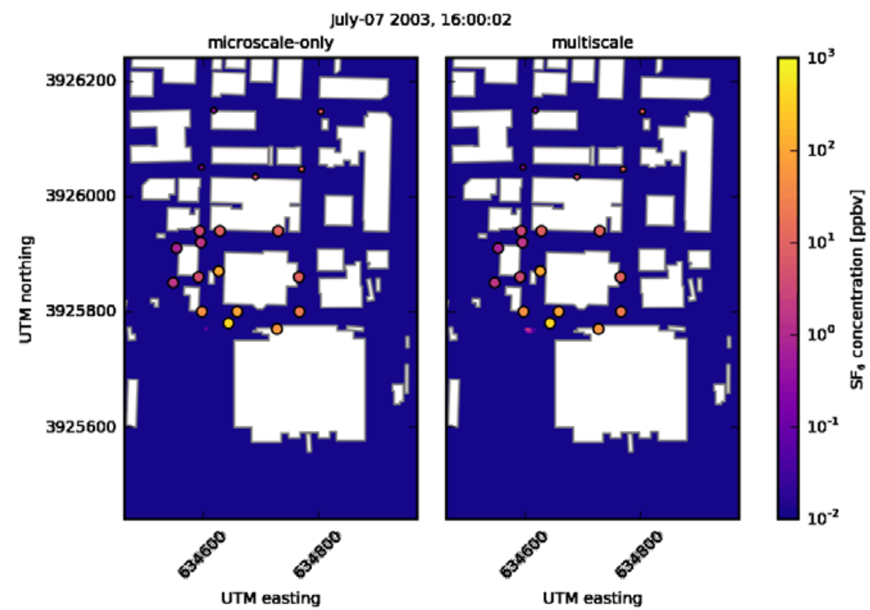


- Vertical grid nesting
- Immersed Boundary Method
- Cell Perturbation Method

→ Intelligent downscaling & multiscale modeling

→ Improved predictions for transport & dispersion

- Katherine A. Lundquist
- Jeffrey D. Mirocha
- Robert Arthur
- Tina Katopodes Chow
- Lawrence Graduate Scholars Program



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