Simulations Across Scales over Complex Terrain

Lessons Learned from a Perdigão Case Study

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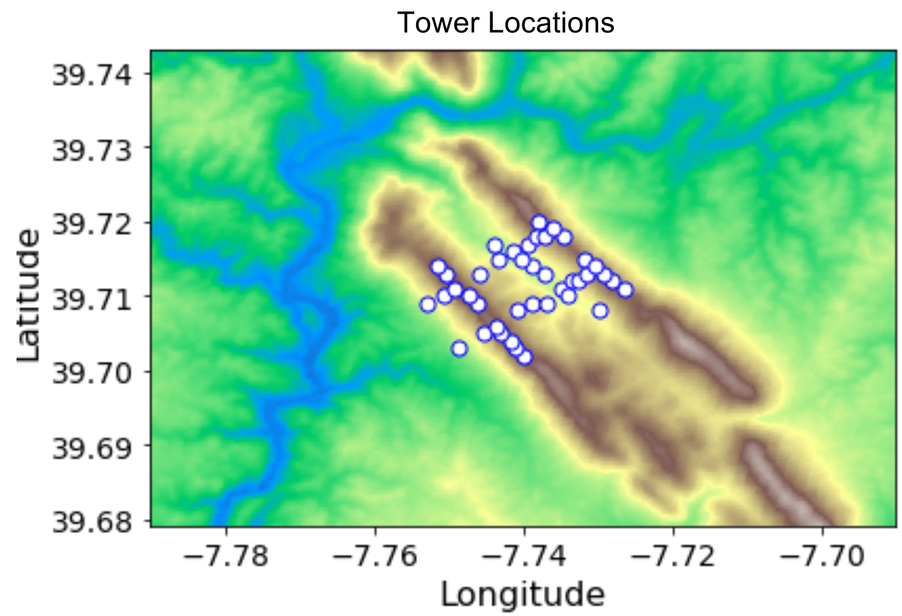
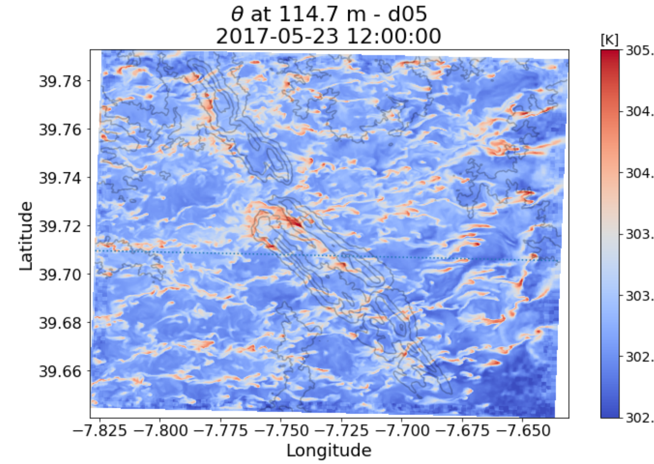
Background

- Perdigão Field Campaign
  - Perdigão, Portugal
  - Dec. 2016 – June 2017
  - **Objective**: collect observations in order to improve model performance simulating flow over complex terrain
  - **Impacts**: wind energy, physics parameterizations, flow and dispersion
- Instrumentation
  - Towers (measurement levels from 2 m to 100 m; white/blue dots to right)
  - Radiosondes
  - Profilers

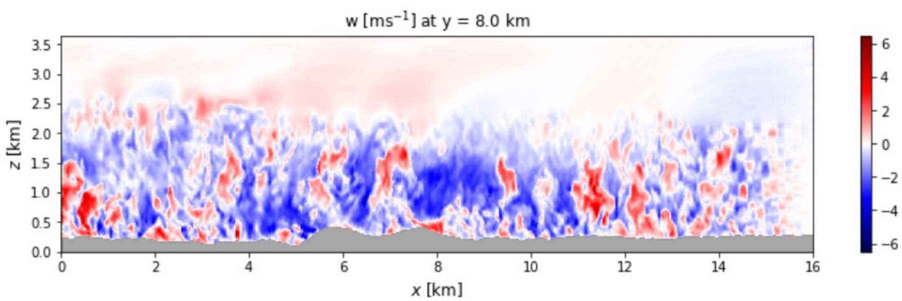


Overview of Modeling Efforts

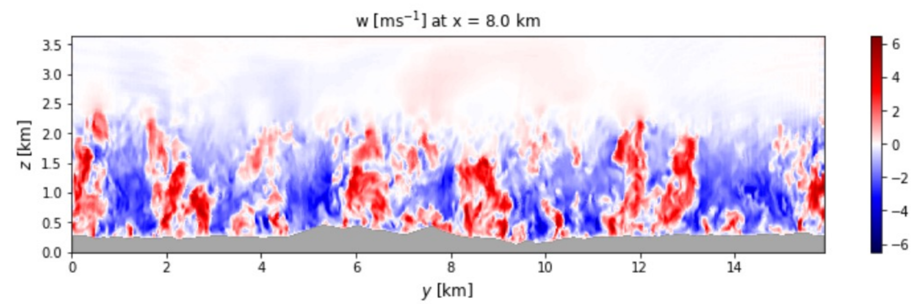
- Model intercomparison of the afternoon + evening transition on June 23rd 12Z – 00Z (24th)
  - WRF+WRF-LES
    - WRF mesoscale → microscale inline simulations
  - FastEddy
    - WRF mesoscale → offline FastEddy simulations
  - SCM
    - WRF mesoscale forcing → single column model conditions



WRF-LES output (to be discussed)



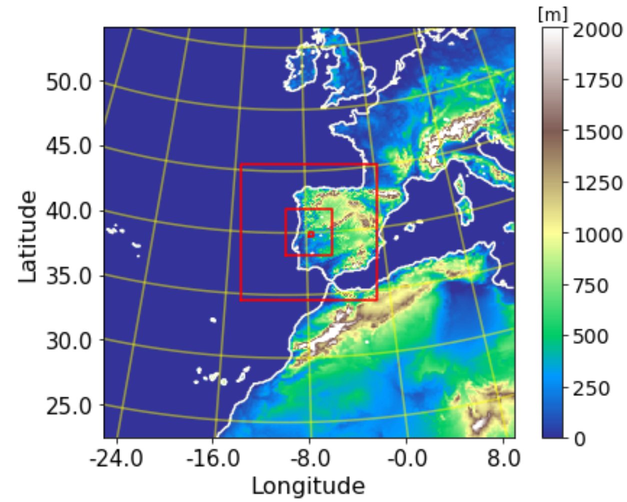
FastEddy output from coupled simulations courtesy of Jeremy Sauer

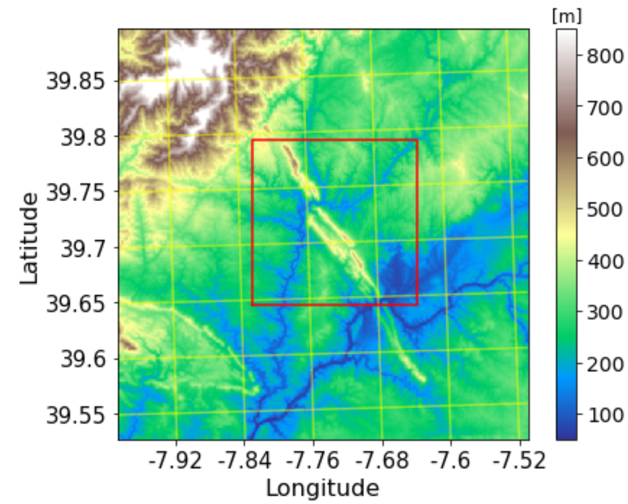


Model Setup

Domain	Δx,y [km]	Nx,Ny	Nz	Δt [s]
1	9000	400	60	45
2	3000	400	60	15
3	1000	400	60	5
4	100	401	95	0.2
5	20	801	188	0.05

- 5 domains
  - 3 Mesoscale
  - 2 LES
- Kain-Fritsch on d01 **only**
- Turbulence closure
  - MYNN 2.5 on mesoscale domains
  - 1.5 order TKE on LES
- Vertical refinement between d03 and d04, then again between d04 and d05
- Revised M-O surface layer
- Unified Noah land surface model
- RRTMG short- and longwave on all domains
- WSM 6-class graupel scheme





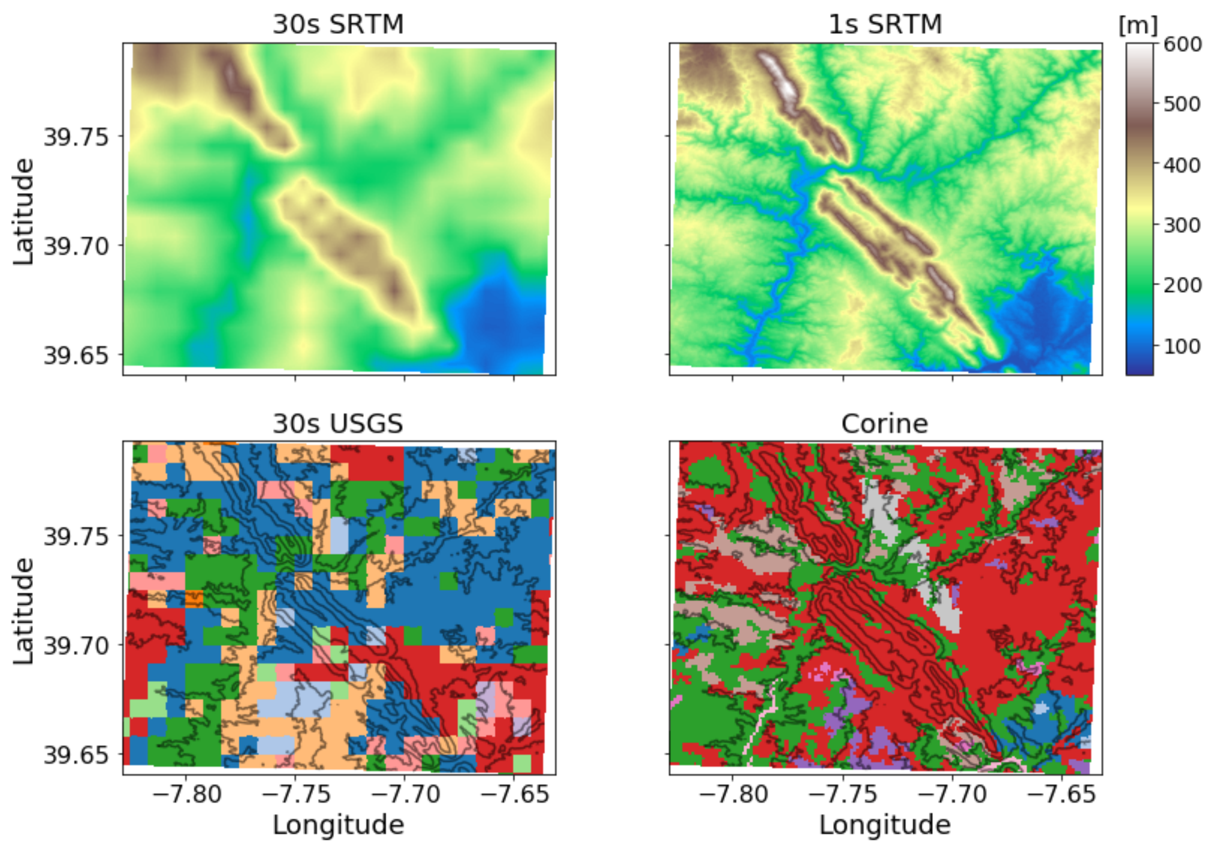
Computational Power

- Domain size:
  - 400x400x60 (x3) – mesoscale domains
  - 401x401x95 – coarse LES domain (domain 4)
  - 801x801x188 – 20 m LES domain (domain 5)
  - Total = ~165 million cells
- HPC Information
  - Cheyenne
  - 40 nodes w/ 36 CPUs = 1,440 CPUs
  - 12 hours wall time = 30 min model time
    - 24 restarts + 4 for model spinup
    - Roughly 500k core hours for 1 simulation

Source: https://www2.cisl.ucar.edu/resources/computational-systems/cheyenne

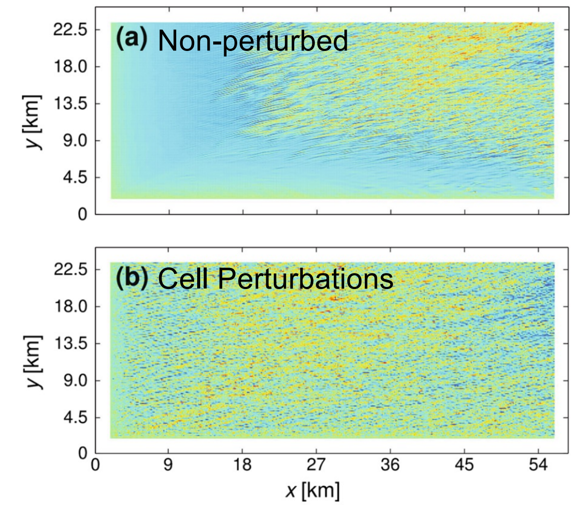
Auxiliary Data Used

- SRTM 1s Topography
  - Perdigão hills under-resolved with standard 30s topography data
- Corine Land use
  - Converted to be the same LU values as USGS before processing
  - Much higher resolution
  - 30s USGS showing mostly dryland and grassland
  - Corine showing mostly shrubland and woodland

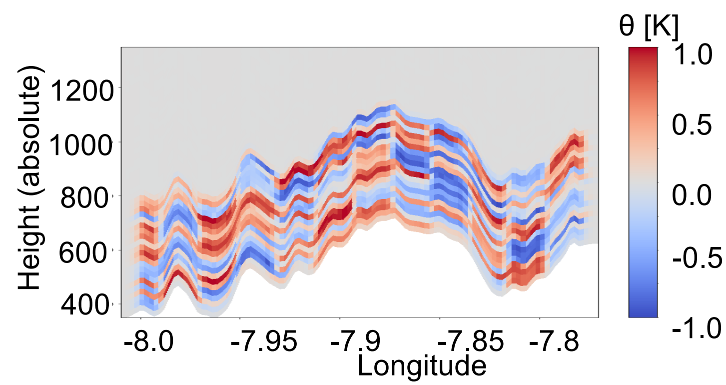


Auxiliary Physics Used

- Cell Perturbation Method on both LES domains
  - Stochastic potential temperature perturbations within a region near all domain boundaries to decrease turbulent fetch regions on inflow
  - Maximum height of perturbations depends on boundary layerheight (determined fromd03 PBL_H before running the LES domains)
  - Amplitude of perturbations also varies in time
  - An input NetCDF file is used to inform the model of these values over time
- Flow becomes turbulent at heights within the boundary layer faster
- Helpful even in complex terrain!



Comparison of quasi-steady state flow without (top) and with (bottom) cell perturbations from [1]



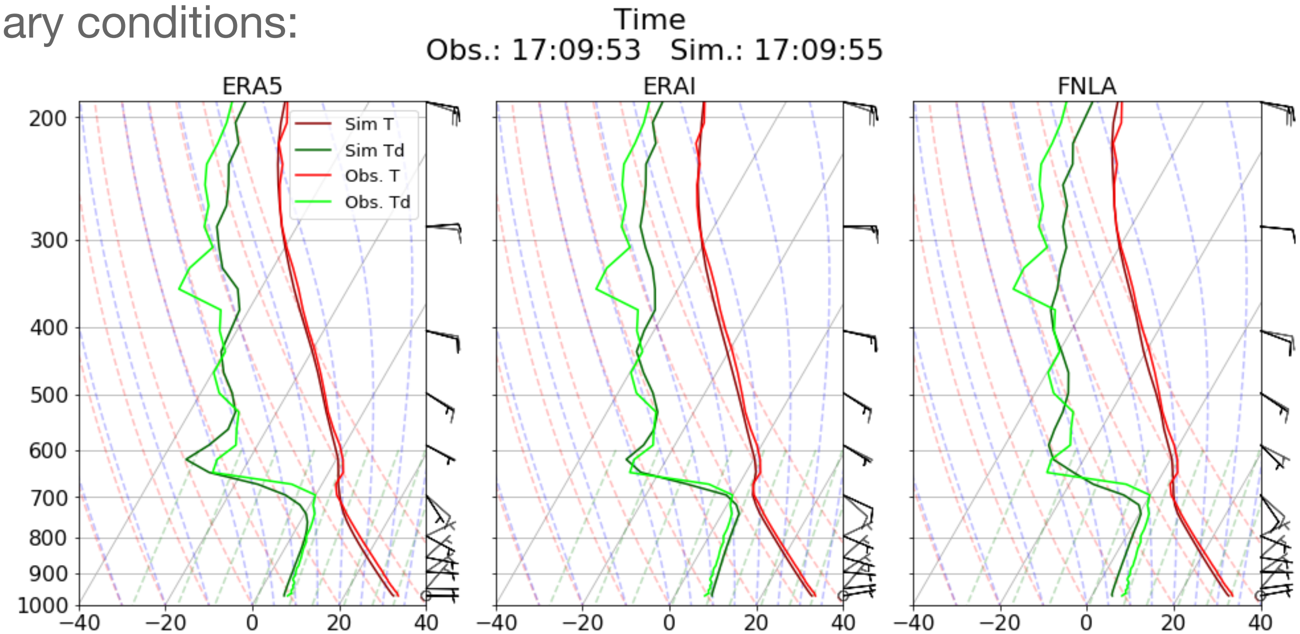
[1] D. Muñoz-Esparza, B. Kosović, J.D. Mirocha, J. van Beeck. "Bridging the transition from mesoscale to microscale turbulence in numerical weather prediction models". *Boundary-Layer Meteorology*, vol. 153 (2014) 409–440.

[2] D. Muñoz-Esparza, B. Kosovic, J. van Beeck, J. Mirocha. "A stochastic perturbation method to generate inflow turbulence in large-eddy simulation models: application to neutrally stratified atmospheric boundary layers". *Physics of Fluids*, vol. 27 (2015) 035102.

[3] D. Muñoz-Esparza, J.K. Lundquist, J.A. Sauer, B. Kosović, R.R. Linn. "Coupled mesoscale-LES modeling of a diurnal cycle during the CWEX-13 field campaign: From weather to boundary-layer eddies". *Journal of Advances in Modeling Earth Systems,* vol. 9 (2017) 1572–1594

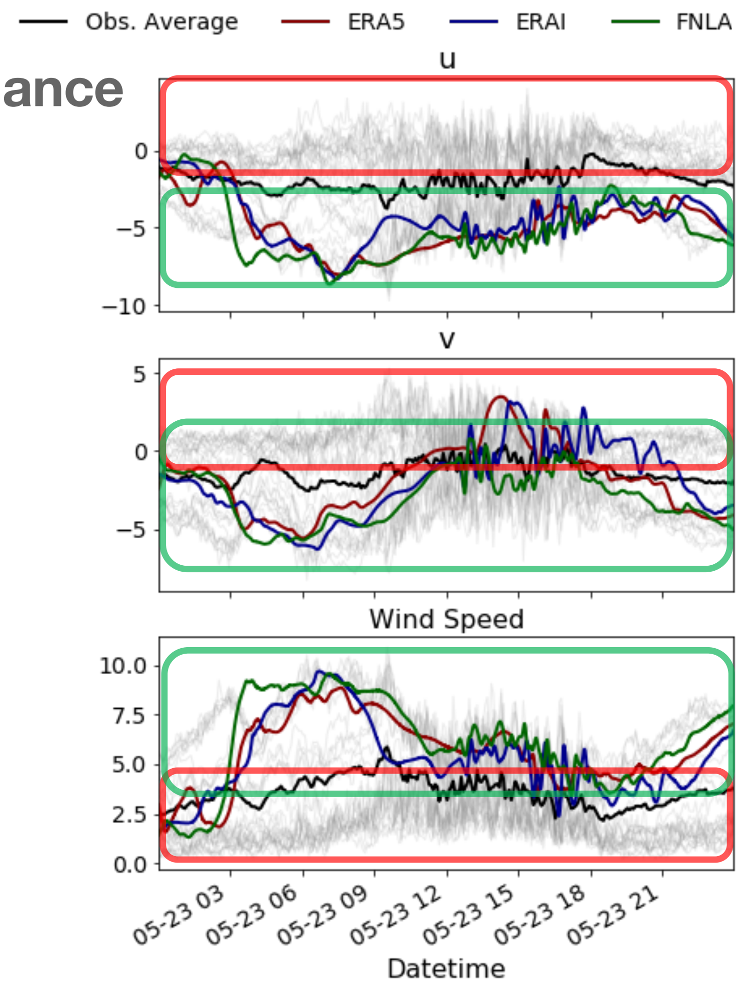
Mesoscale Runs

- Ran with 3 initial/boundary conditions:
  - ERA5
  - ERA-Interim
  - GFS Final Analysis
- Assess performance based on available observations
  - **Sondes**
  - Towers
  - Lidars

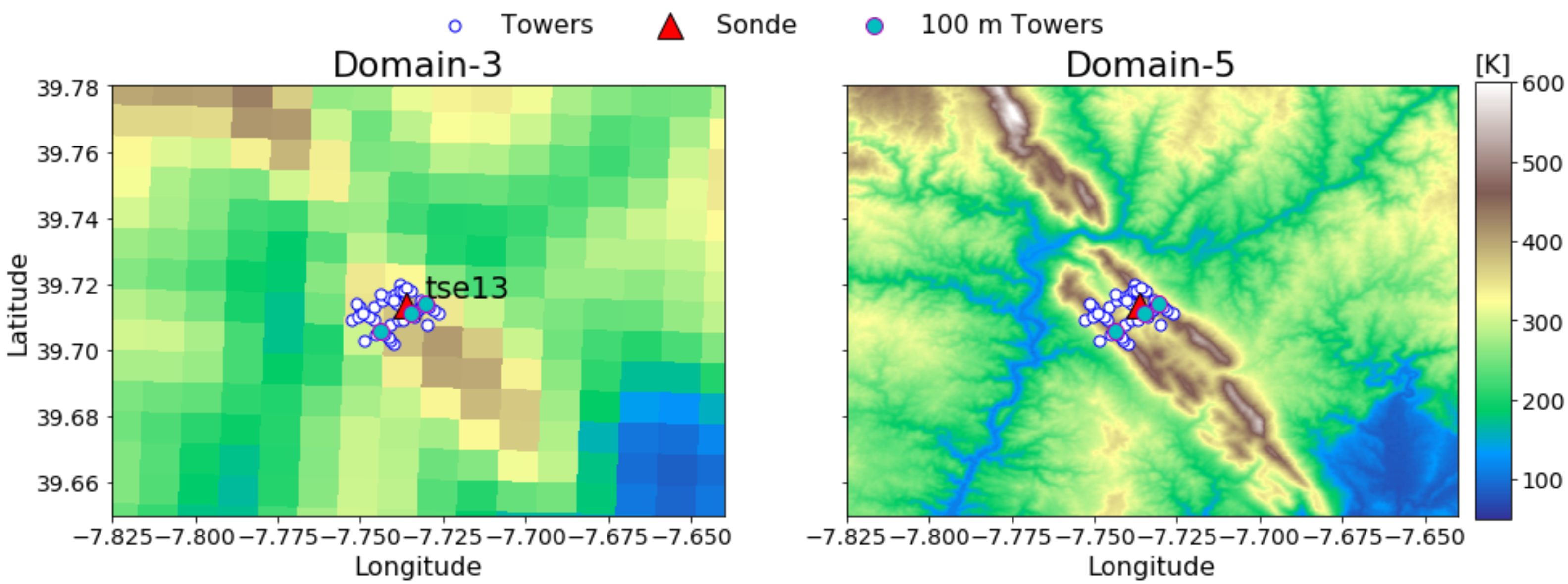


Mesoscale Tower Performance

- 20 m wind speed results from all towers:
  - Mesoscale results seem reasonable compared to *some* of the towers
  - Results from other towers seem to be **way** off
    - Very low wind speeds
  - Observed mean does not compare favorably with mesoscale output…
  - **Why?**



Terrain on Mesoscale vs. Microscale



- Perdigão terrain is relatively small compared to mesoscale Δx,y
- Seen as single hill on Domain 3

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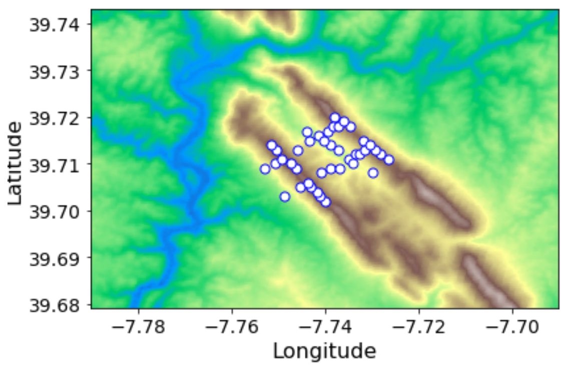
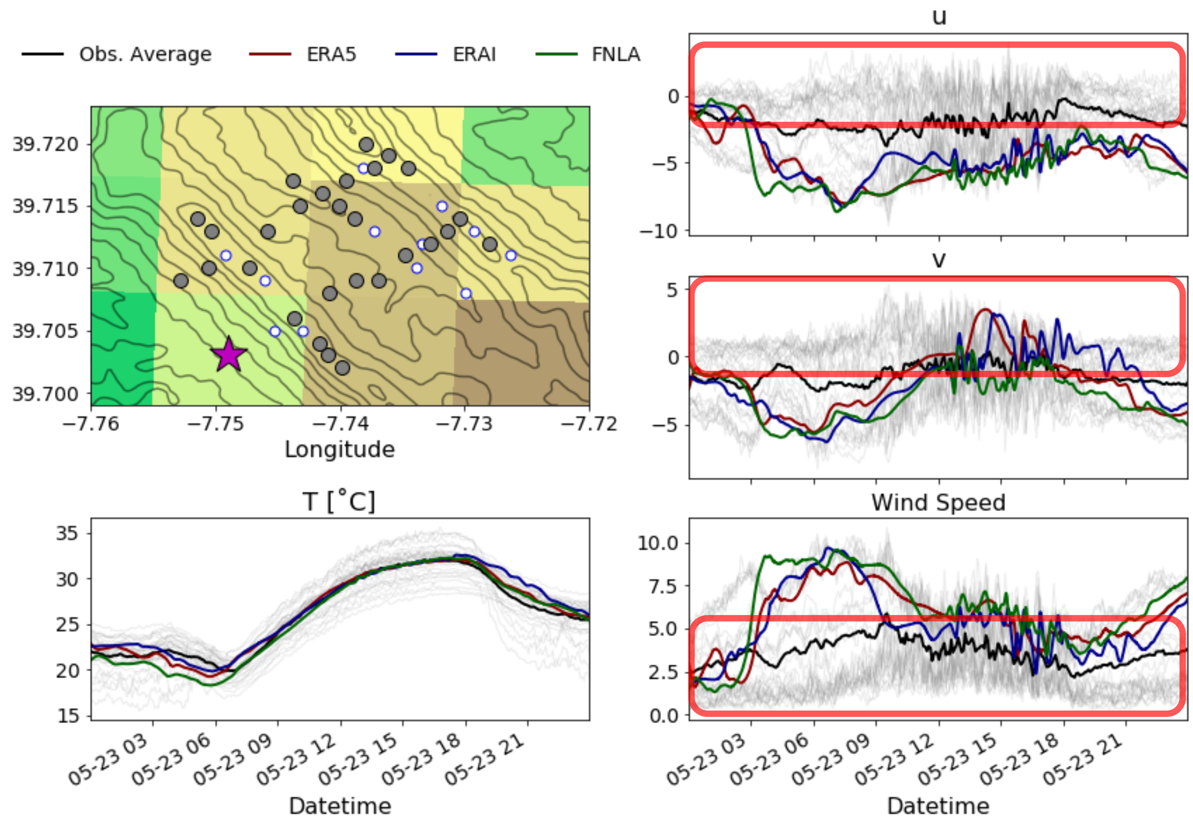
Mesoscale Performance (Towers)

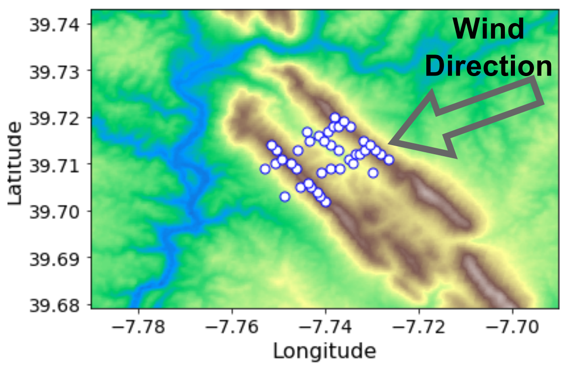


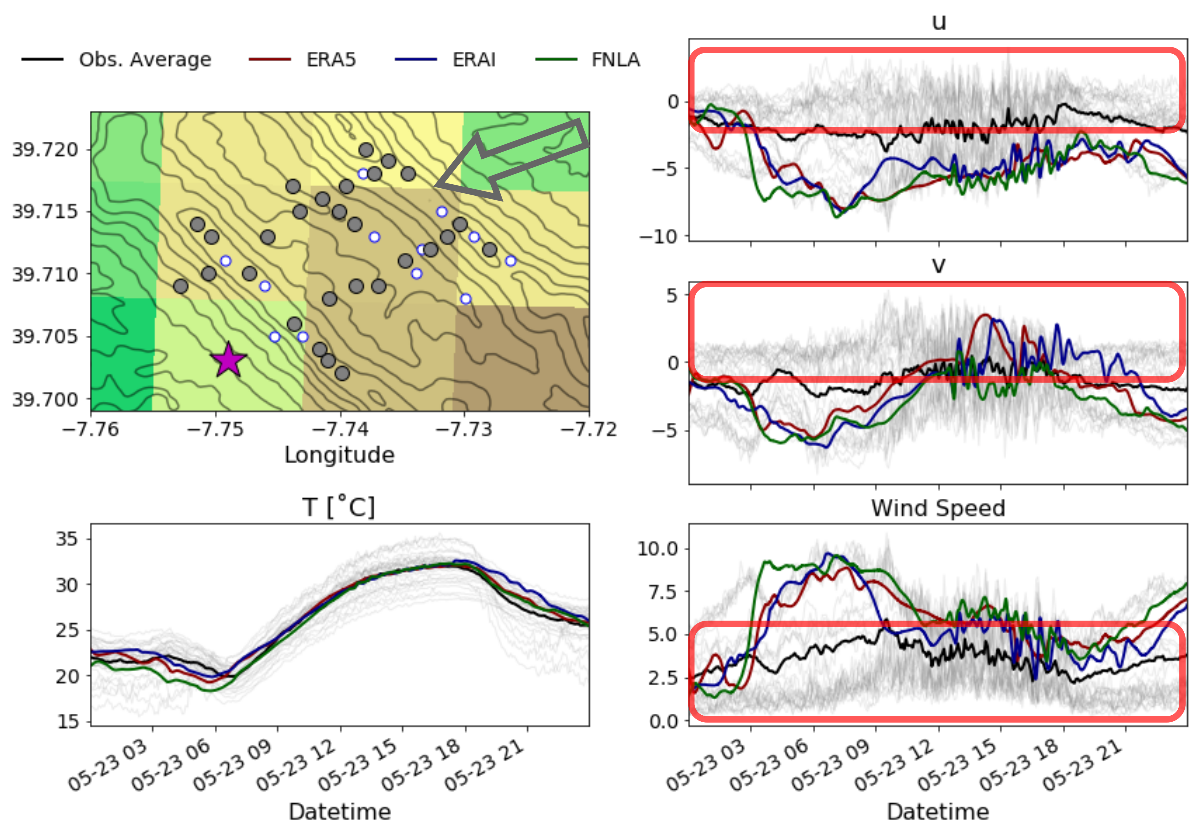


- Seems to be 2-3 “groups” of tower results
  - 1 group matches the model well
  - The others do not

Mesoscale Performance (Towers)

Guess which stations these low value winds are from...





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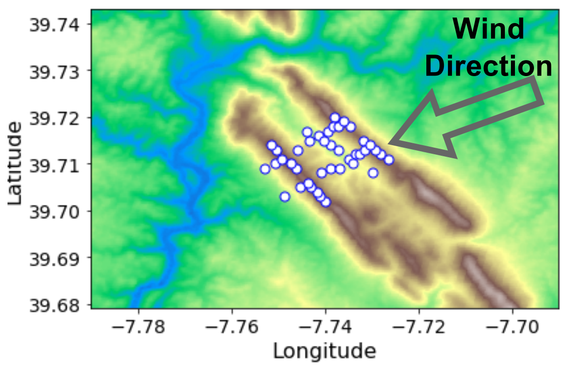

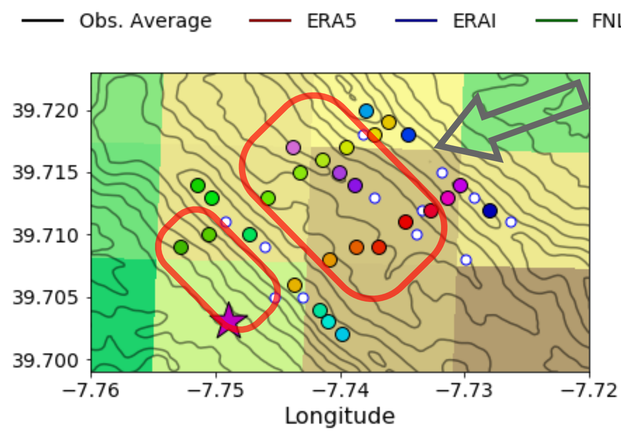

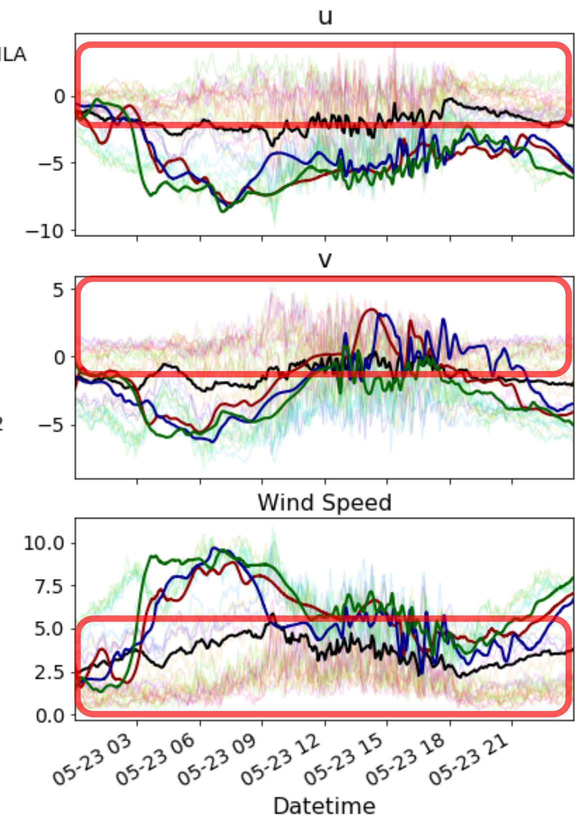

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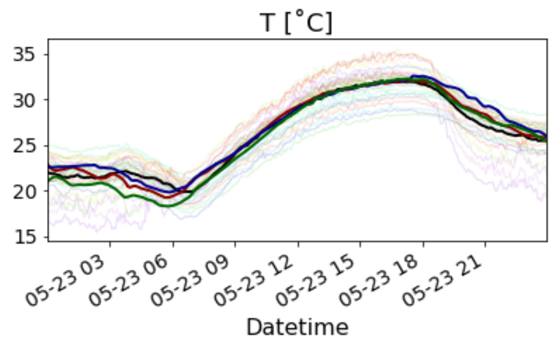
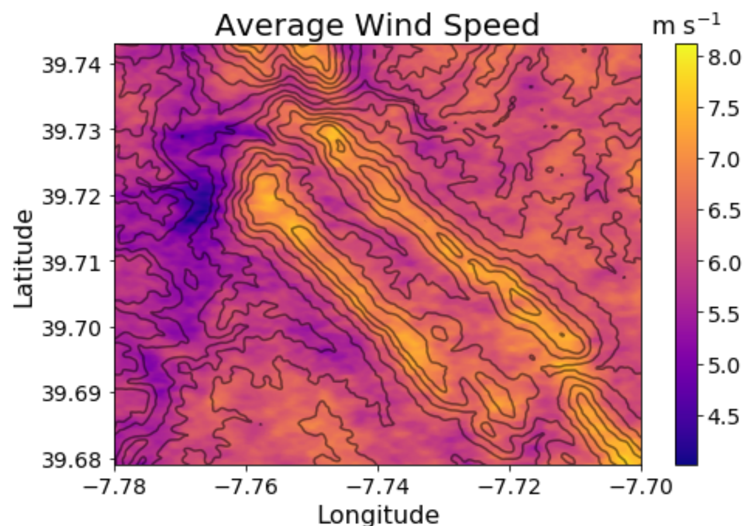
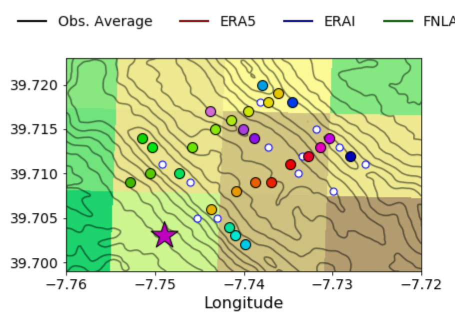
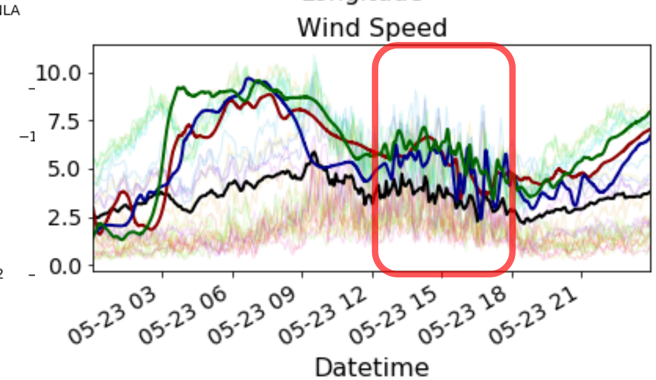


LES Performance

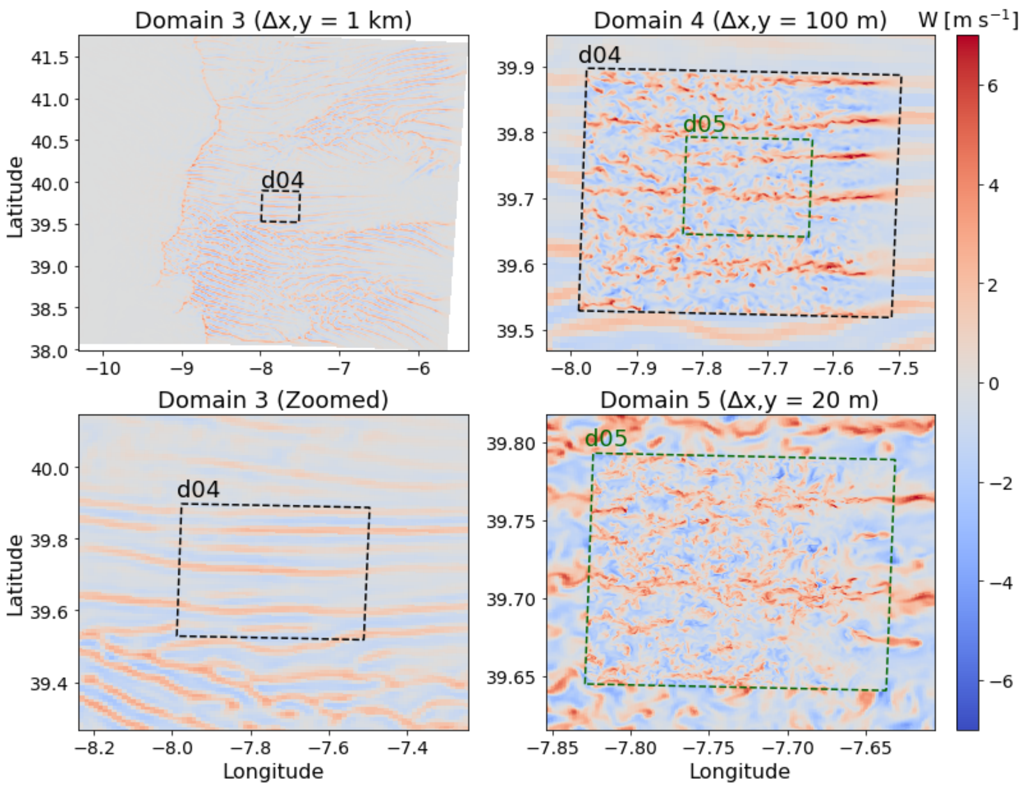
- **<u>Note</u>**: we do not have tslist data for these runs and only have model output between 12 and 18 UTC… will discuss on next slide
- During this period, the ridge and saddle velocities are similar, but still slightly weaker in saddle
  - LES captures this, but potentially overpredicts velocities in saddle
  - Will run LES again – found an issue when running the first time…







Issue Going From Meso- to Microscale



- Erroneous convective rolls feed from mesoscale (Domain 3) to microscale (Domains 4 and 5)
  - *Terra incognita*
  - Discussed in Rai et al. (2019)
- Rolls can be mitigated via:
  - Use of different PBL schemes
  - Increase Smagorinsky coefficient
- Work in progress – no LES results for mesoscale without rolls

D. Muñoz-Esparza, J.K. Lundquist, J.A. Sauer, B. Kosović, R.R. Linn. "Coupled mesoscale-LES modeling of a diurnal cycle during the CWEX-13 field campaign: From weather to boundary-layer eddies". *Journal of Advances in Modeling Earth Systems,* vol. 9 (2017) 1572–1594

Rai, R. K., Berg, L. K., Kosović, B., Haupt, S. E., Mirocha, J. D., Ennis, B. L., & Draxl, C. (2019). Evaluation of the impact of horizontal grid spacing in terra incognita on coupled mesoscale–microscale simulations using the WRF framework. *Monthly Weather Review*, *147*(3), 1007-1027.

Lessons Learned

- Size of mesoscale domains must be sufficiently large to allow for scaling on LES domains
- Develop grid spacing from smallest Δx,y to largest → Nice grid ratios
- Mesoscale roll issues
  - Increase c_s to dissipate the structures
  - Different PBL schemes
- Get it right *the first time* ☺
  - LES is **expensive**!
  - Analyze / adjust the mesoscale as needed then (hopefully) run the LES domains only once
  - We have been using FastEddy to test the microscale performance with different WRF mesoscale setups before running the WRF-LES simulation to try to ensure good performance

References

- D. Muñoz-Esparza, B. Kosović, J.D. Mirocha, J. van Beeck. "Bridging the transition from mesoscale to microscale turbulence in numerical weather prediction models". *Boundary-Layer Meteorology*, vol. 153 (2014) 409–440.
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Questions?

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Supplementary Information

To compare: FastEddy runs the 12 hour simulation on a similar size domain in x and y, with 128 vertical levels on 32 GPUs in 14 wall hours. Though the land surface model and microphysics package in FastEddy is less sophisticated and computationally intensive that WRF's, and it does not include a radiation scheme