Simulating Intra-Farm Wind Variations with WRF-RTFDDA-LES Modeling System

Yubao Liu*, Yuewei Liu, *Will Cheng, Wanli Wu, and Thomas T. Warner

NCAR/Research Application Laboratory

Keith Parks

Xcel Energy

10th WRF Users Workshop, Boulder, CO
23 - 26 June 2009

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Outline

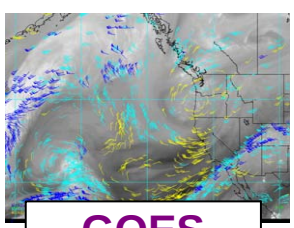
- Motivation
- WRF-RTFDDA modeling system
- RTFDDA-LES
- Case study
- Challenges
- Summary

Motivation

- ***Wind Energy forecasting:***
  NCAR and Xcel Energy
- ***Factors for wind power generation at wind farm:***
  → Overall farm-wide wind speed
  → Intra-farm wind variations
  → Vertical wind shear
  → Turbulence
- ***Wind forecasts: WRF-RTFDDA***
- ***Farm observation analyses and WRF-RTFDDA-LES:***
  → WRF LES modeling capability for real cases
  → Features of small-scale wind flow
  → Wind profiles within turbine height with PBL parameterization versus LES explicit mixing

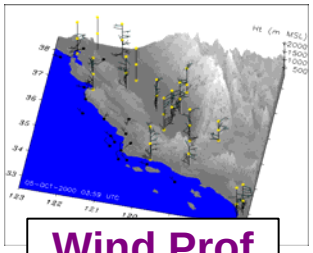
RTFDDA: Time-Continuous DA

All WMO/GTS

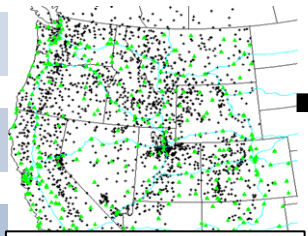


GOES

Radars



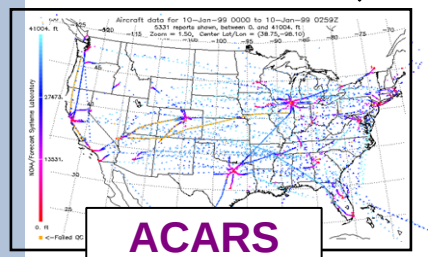
Wind Prof



MESONETs

RTFDDA

Regional-scale model, based on WRF

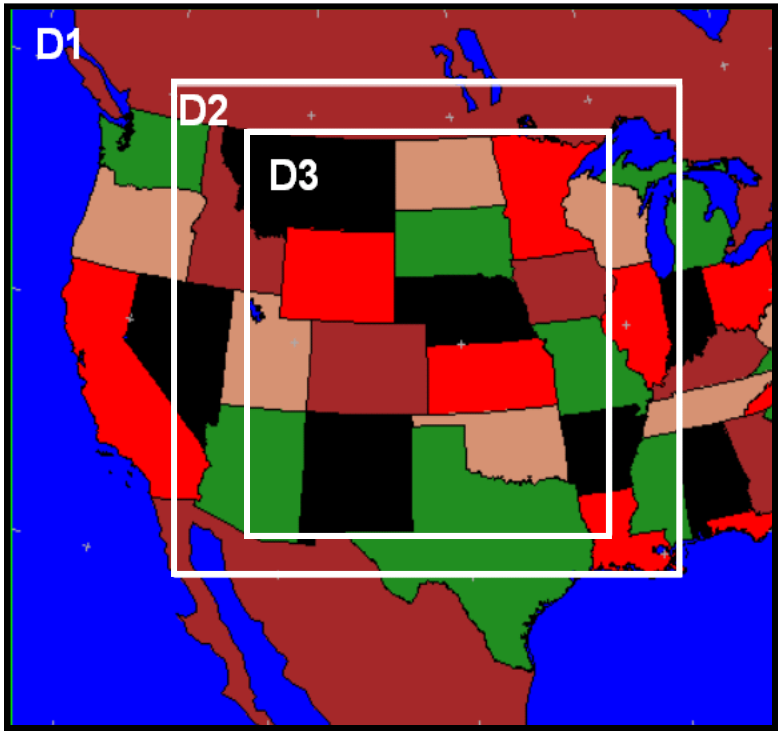


ACARS

Etc.

Met-Towers

Proposed Xcel domain map



DX = 30/10/3.3km

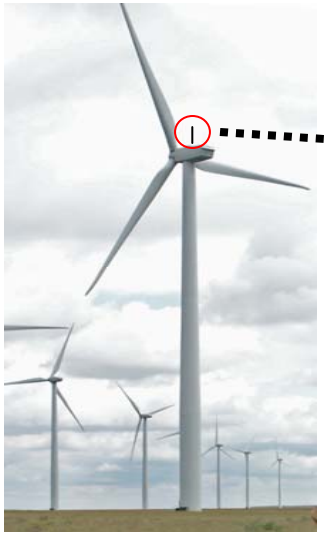
WRF-RTFDDA-LES

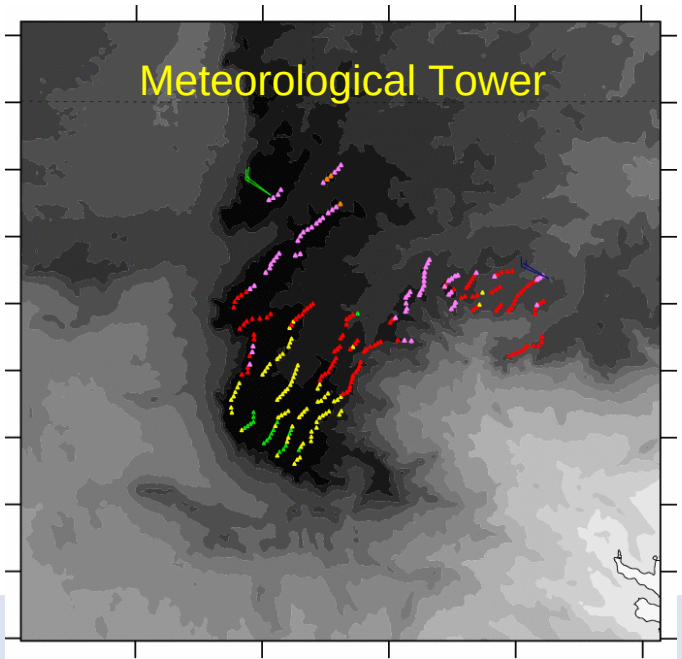
- **WRF-RTFDDA-LES downscaling capability (~100m):** adaptation of 3D TKE diffusion to interact with surface physics fluxes from V3

- **LES:** embedded in WRF-FDDA through downscaling nested grids

- **RTFDDA-LES:** simulate fine scale flows at wind farms and turbine sites (LES domain) with accurate mesoscale forcing

Wind Farm and Observation



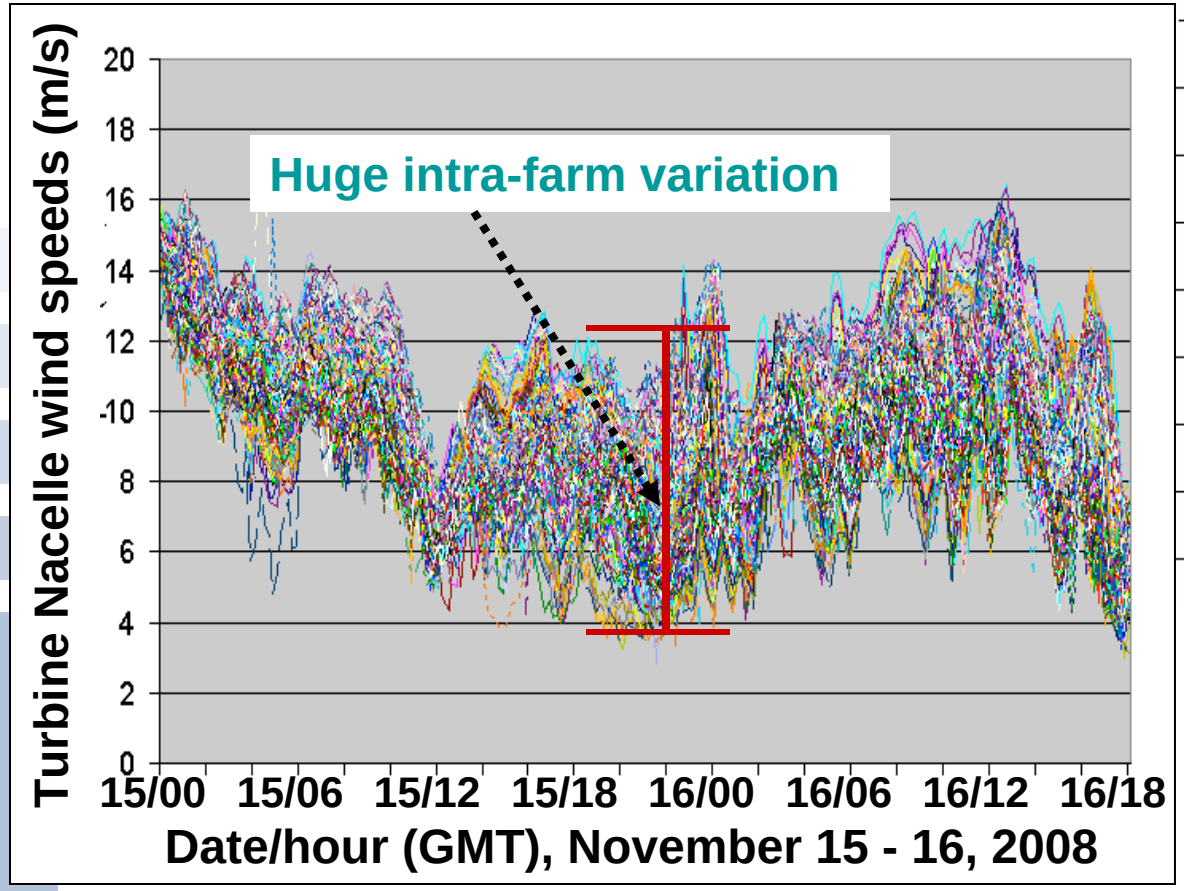


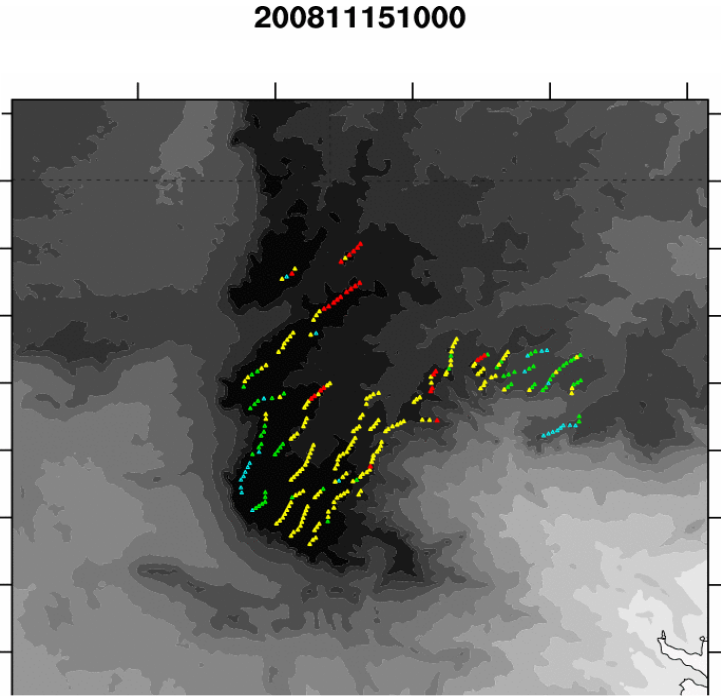
274 Turbines, 400-700m apart, Cedar Creek, CO

Case Study

(Nov. 15-16, 2008)

Turbine Nacelle Wind Speeds at Cedar Creek Wind Farm

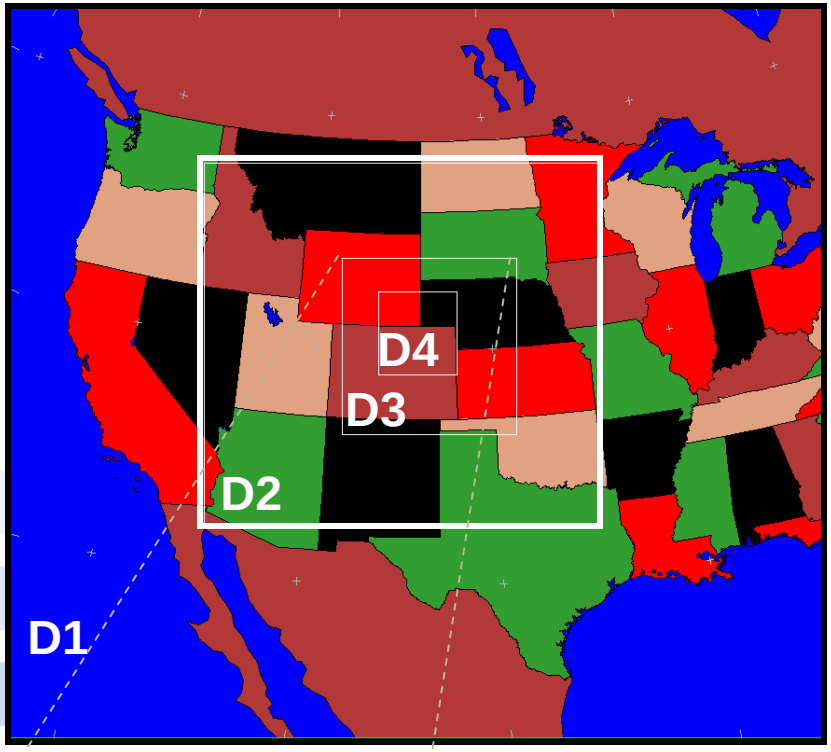




△ 0 – 2 m/s
▲ 2 – 4
▲ 4 – 6
▲ 6 – 8
▲ 8 – 10
▲ 10 – 12
▲ 12 – 14
▲ > 14 m/s

Six Nested-Grid WRF-RTFDDA-LES

NCAR



DA & MYJ PBL

D1: 30km 128x114

D2: 10km 184x169

D3: 3.3km 244x247

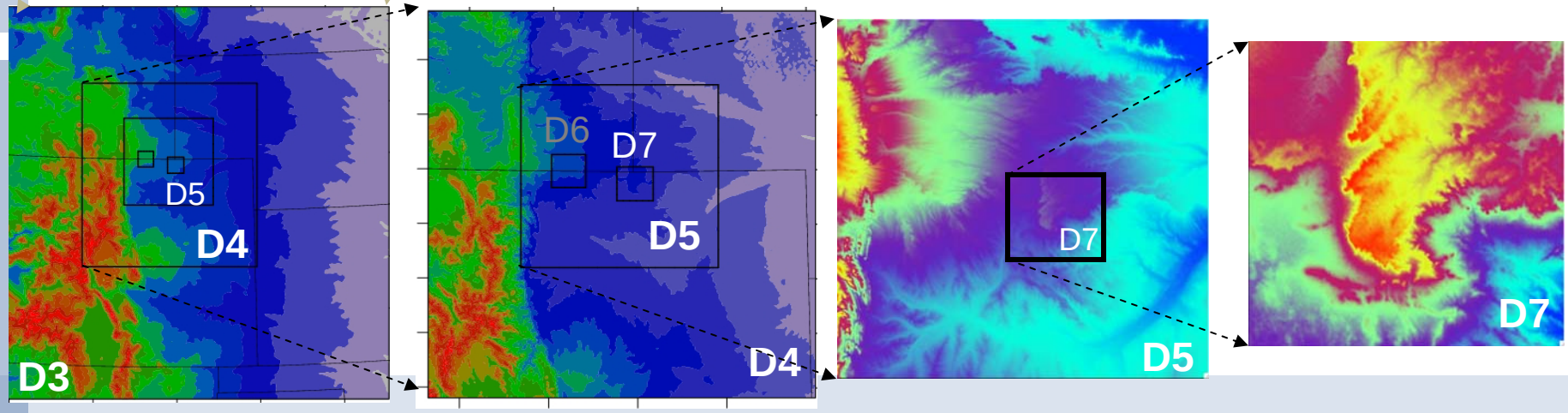
D4: 1.1km 331x346

LES: dynamical downscaling

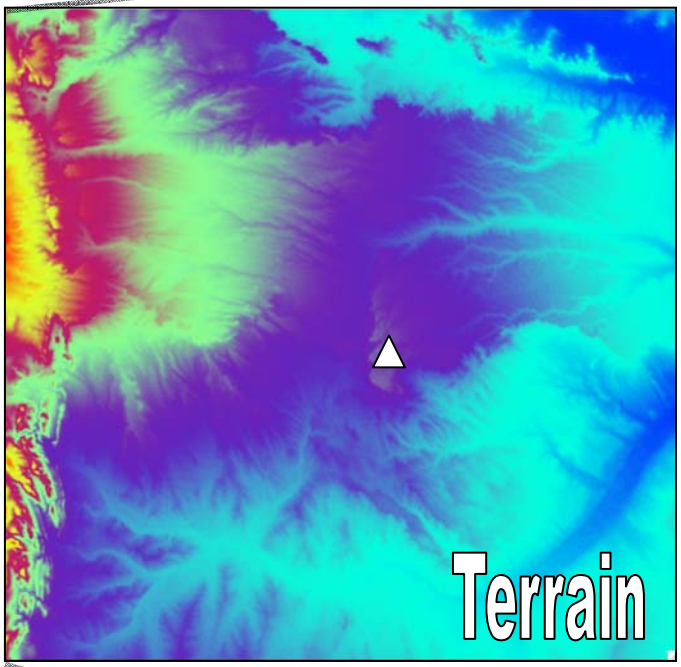
D5: 370m 505x490

D6: 123m 262x268

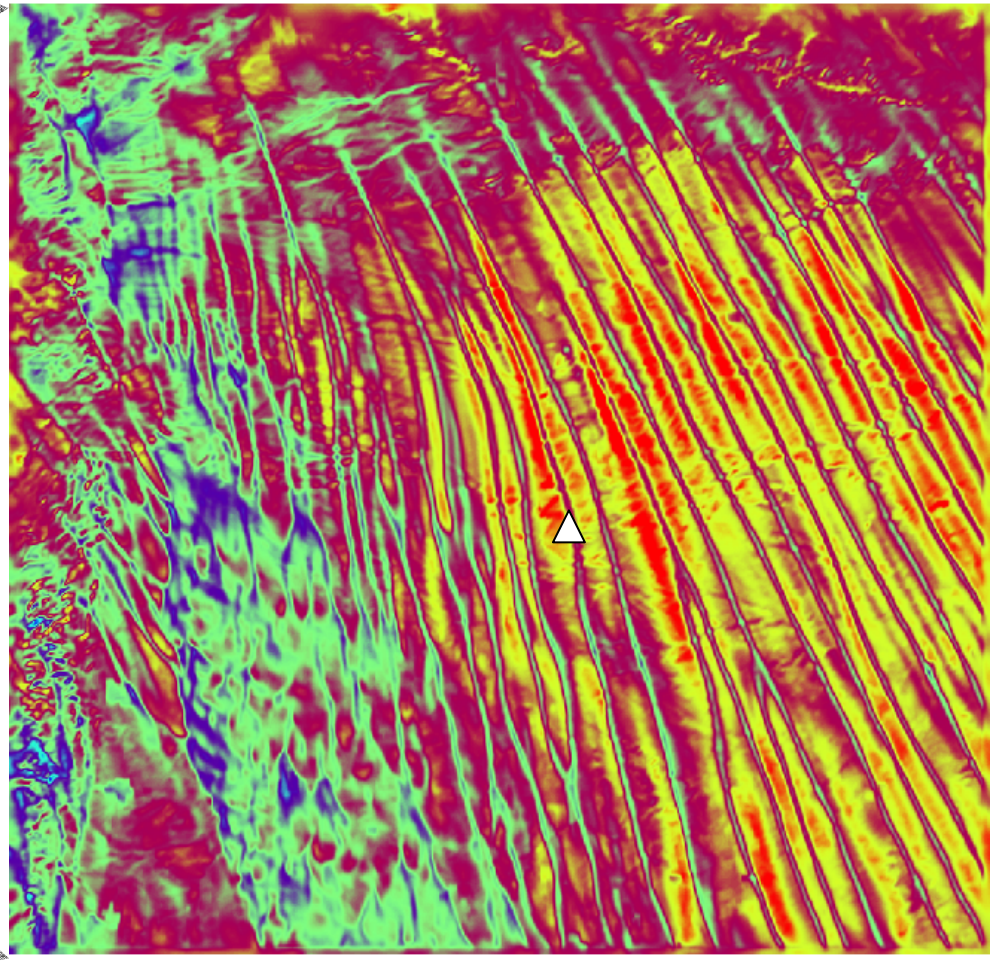
D7: 123m 280x271



D5 Wind Speed Animation at 15m AGL (LES)



187 x 181 km^2



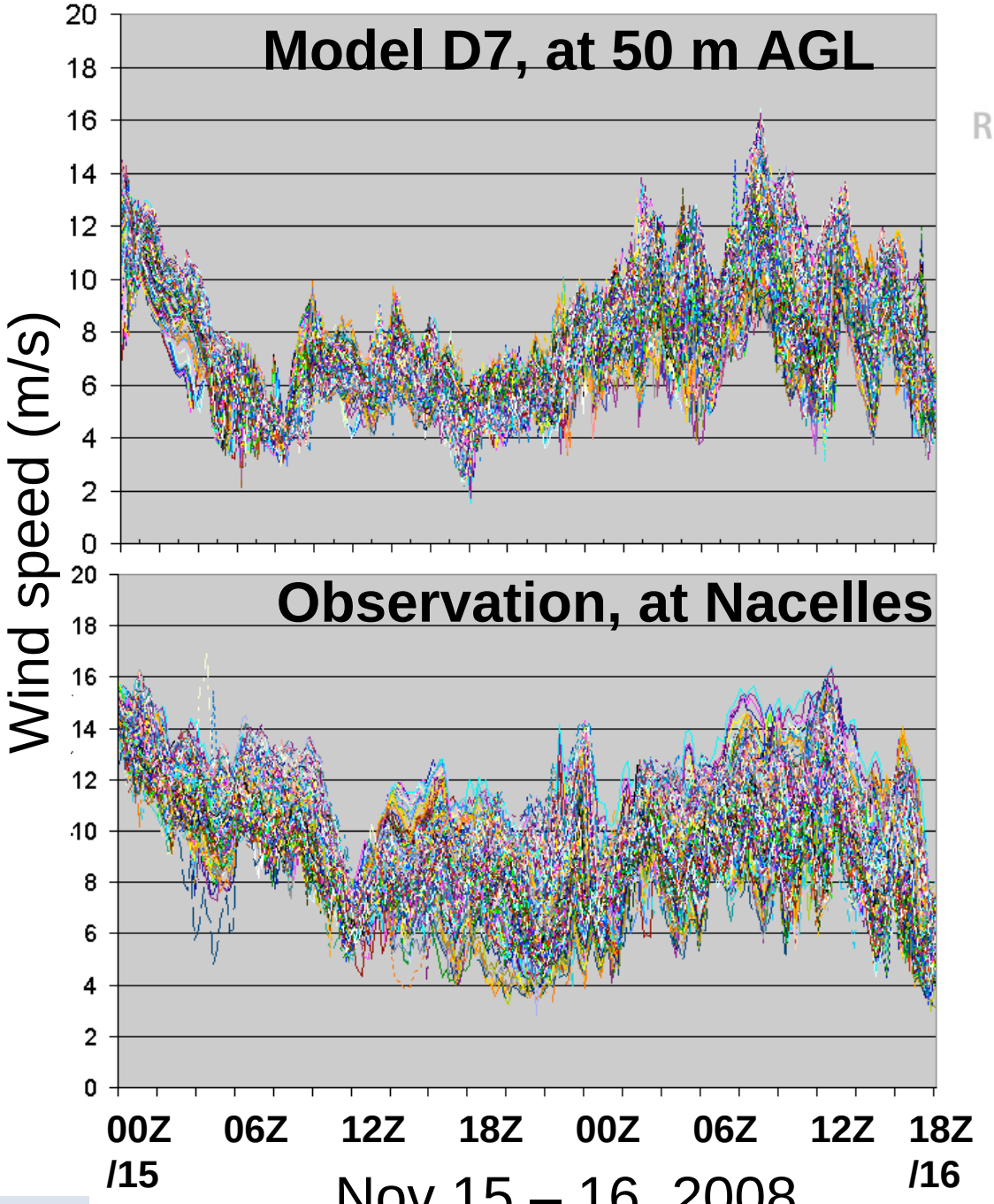
m/s

Range of west_east: 0 to 503
Range of south_north: 0 to 488
Current Time: 66
Current bottom_top: 0
Frame 1 in File yspd_wrfout_d05_2008-11-14_23:00:00

D5: DX= ~370 m
Every 10 minutes
From Nov.14, 23:00
To Nov.15, 19:00

Wind Speed Comparison of LES and Nacelle OBS at Cedar Creek Turbine Sites

D07 Wind Speed (DX=123 m) interpolated to turbine sites



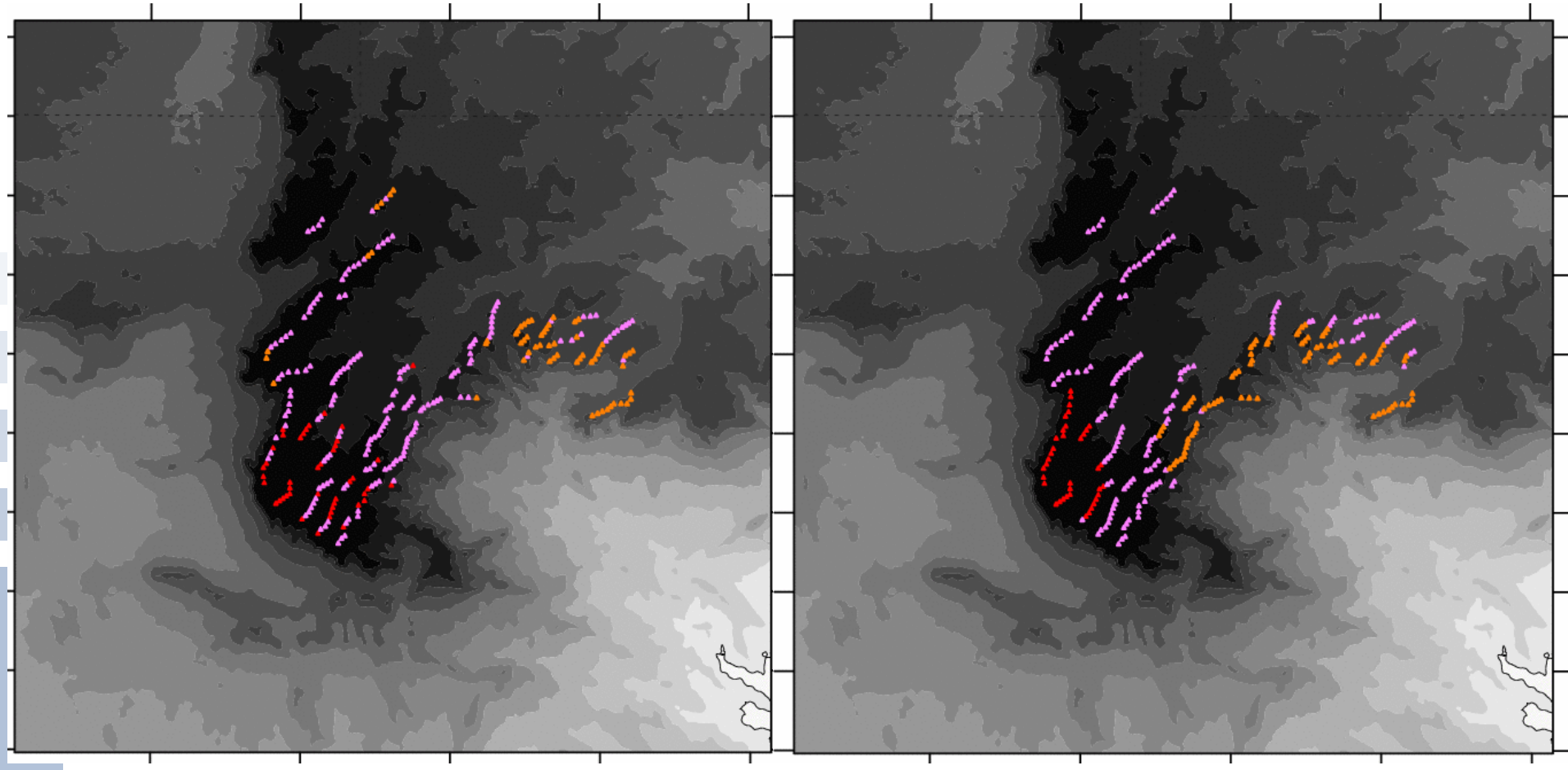
Wind Speed: LES vs. OBS

(Valid at 01:40Z Nov. 15, 2008)

NCAR

Observed Nacelle Wind Speed

Model D7, Speed+2, 53m AGL



△ 0 – 2 m/s ▲ 2 – 4 m/s ▲ 4 – 6 m/s ▲ 6 – 8 m/s ▲ 8 – 10 m/s ▲ 10 – 12 m/s ▲ 12 – 14 m/s ▲ > 14 m/s

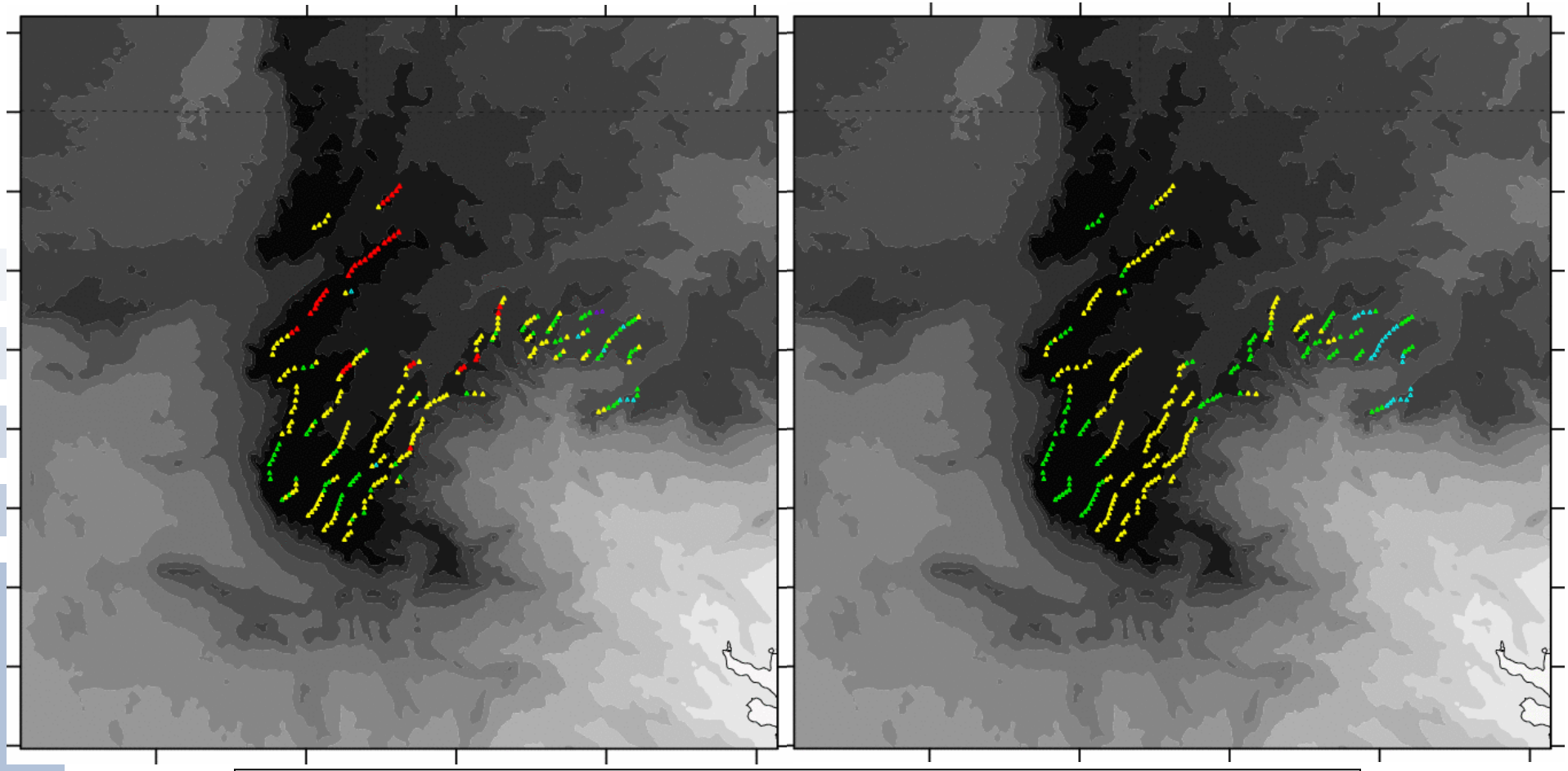
Wind Speed: LES vs. OBS

(Valid at 15:30Z Nov. 15, 2008)

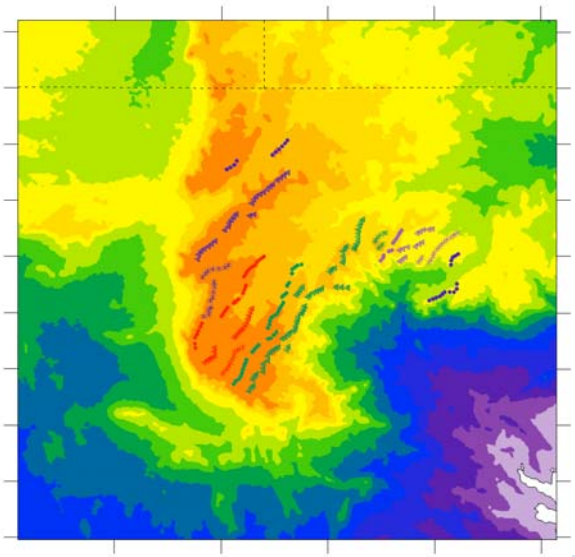
NCAR

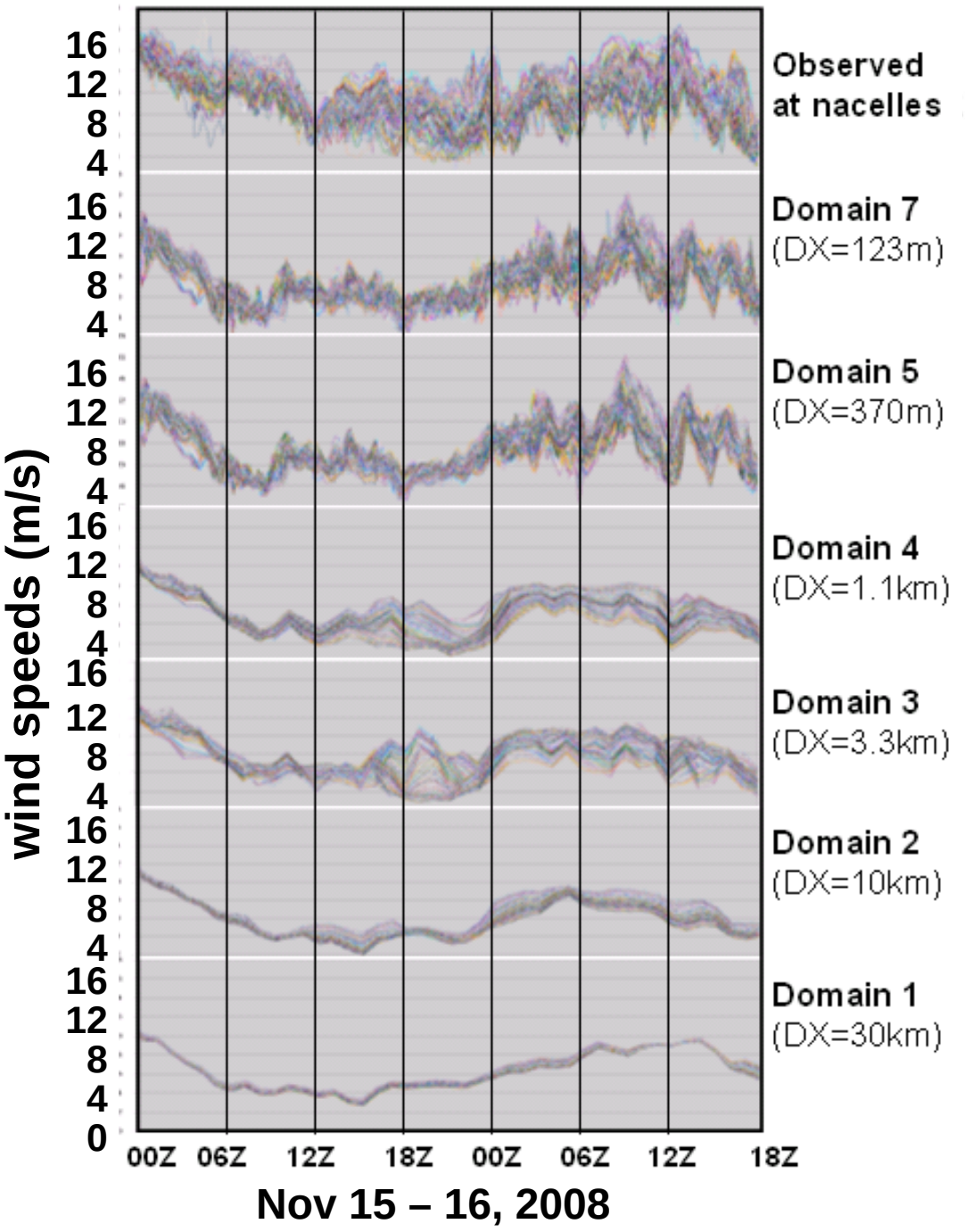
Observed Nacelle Wind Speed

Model D7, Speed+2, 53m AGL

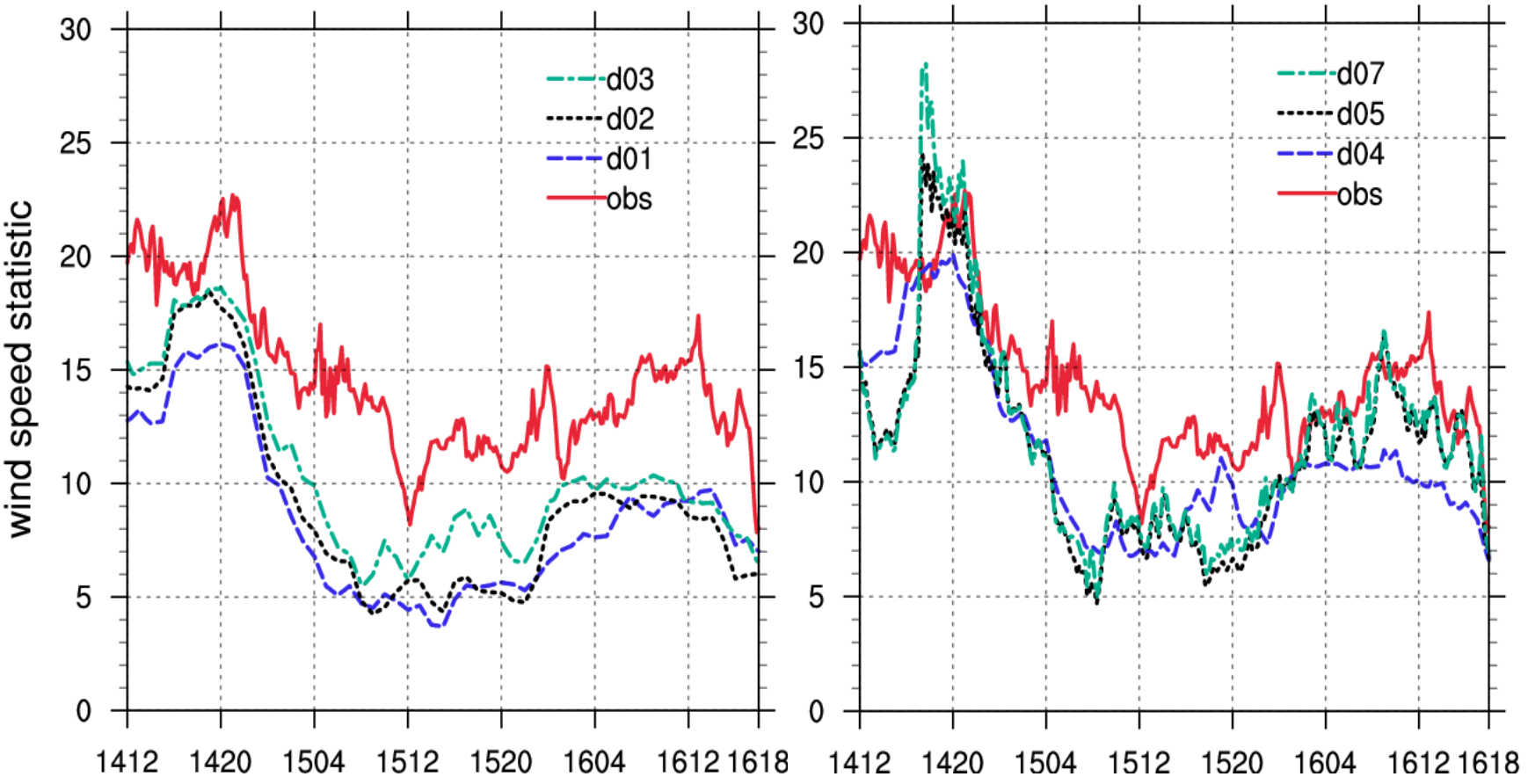


Comparison of intra-farm wind variations simulated by different model grid resolutions

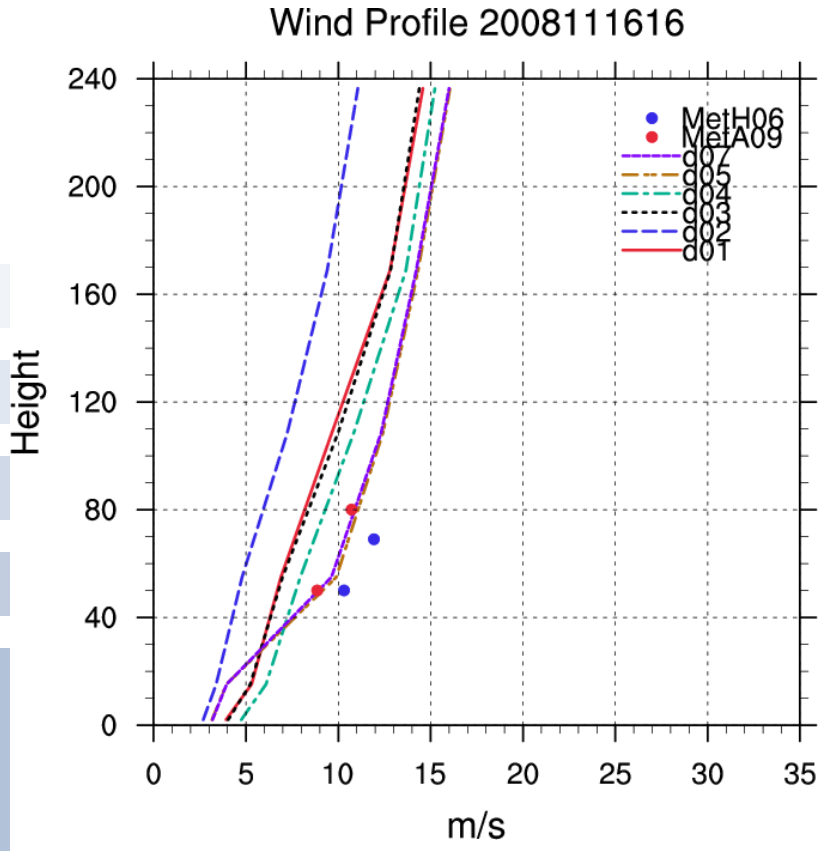


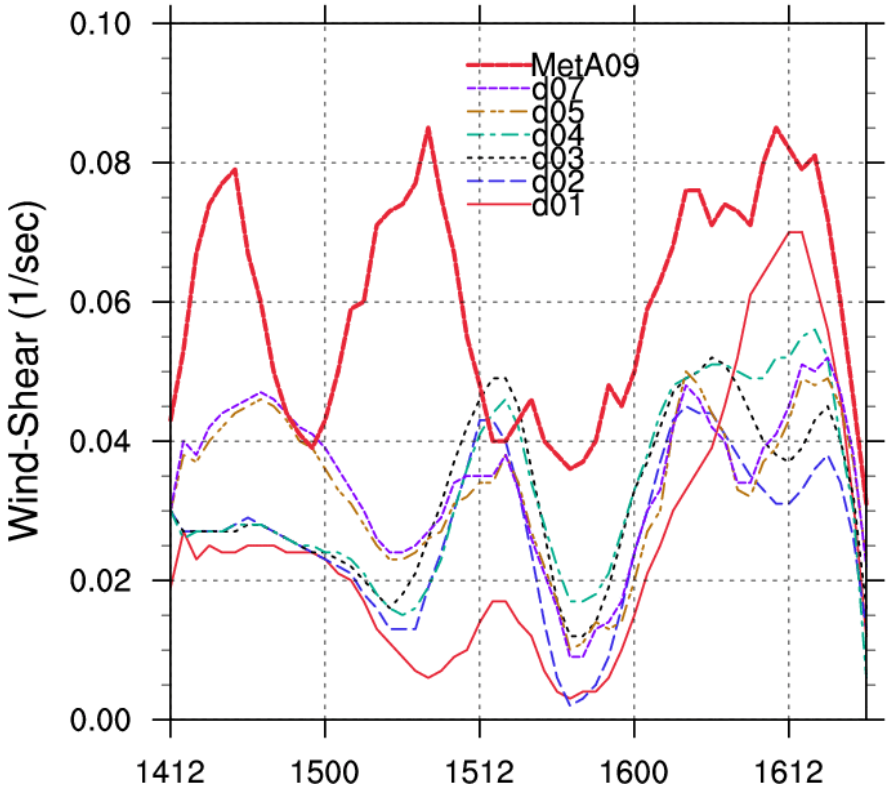


Statistical Property: Median Wind Speed
of 274 CC Turbines



Comparison of Wind Shear

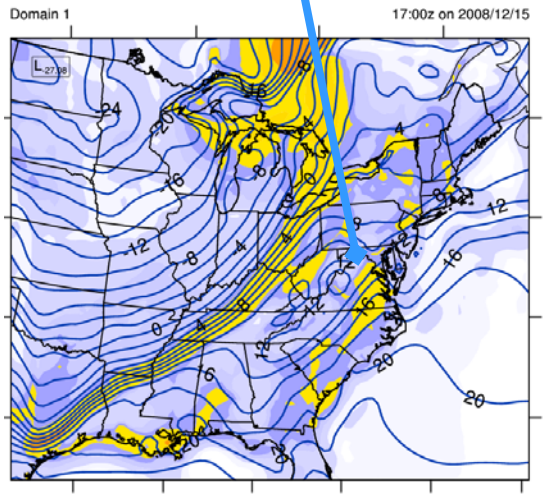




November 2008 (dd/hh, UTC)

Challenges

- **From mesoscale to LES modeling**
  - → Subgrid eddy parameterizations
    - → Partially-eddy-resolved grids
      - → Fully eddy-resolved grids
- **Is simultaneously downscaling with refined nested-grids a viable way?**
- **Cope with the real weather regimes**
  - → Forcing of microscale terrain and land surface heterogeneities
  - → Big eddies versus small eddies
  - → Eddy-forcing interactions



Summary

- WRF-RTFDDA-LES supports multi-scale weather modeling with FDDA on mesoscale nests and LES scale fine meshes.
- WRF-RTFDDA-LES is tested with six simultaneous downscaling grids from 30km to 123m for 42 hours for one wind farm in CO, and verified against unique observations on wind turbines and two tall-tower obs.
- The results suggest an **encouraging** **downscaling capability** of the WRF-RTFDDA-LES model for simulation of **fine scale flows** in the wind farms and also expose **challenges**.
- Lower level **wind shear** is sensitive to model **grid size** with the YMJ scheme, which questions the usage of PBL scheme with different resolutions. LES model produces better wind profiles at near surface level.


The End