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

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Outline

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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

RTFDDA
Regional-scale model, based on WRF

All WMO/GTS
GOES
Radars
Mesonet
ACARS
Wind Prof
Proposed Xcel domain map

DX = 30/10/3.3km
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

Anemometer
Meteorological Tower
Terrain height
Case Study

(Nov. 15-16, 2008)
Turbine Nacelle Wind Speeds at Cedar Creek Wind Farm

Huge intra-farm variation

Date/hour (GMT), November 15 - 16, 2008

- 0 – 2 m/s
- 2 – 4
- 4 – 6
- 6 – 8
- 8 – 10
- 10 – 12
- > 14 m/s
Six Nested-Grid WRF-RTFDDA-LES

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)

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

187 x 181 km²

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
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)

Observed Nacelle Wind Speed
Model D7, Speed+2, 53m AGL
Wind Speed: LES vs. OBS
(Valid at 15:30Z Nov. 15, 2008)

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
Comparison of intra-farm wind variations simulated by different model grid resolutions.
Statistical Property: Median Wind Speed of 274 CC Turbines

November 2008 (dd/hh, UTC)
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