Improved representation of small-scale turbulence and intra-hour variability in the stable boundary layer by coupling mesoscale and large-eddy simulation models

Domingo Muñoz-Esparza*, Branko Kosović*, Jeremy A. Sauer*, Julie K. Lundquist,*** and Rodman R. Linn******

*National Center for Atmospheric Research, Boulder, Colorado, USA, domingom@ucar.edu

**Department of Atmospheric and Oceanic Sciences, University of Colorado Boulder, Boulder, Colorado, USA

***National Renewable Energy Laboratory, Golden, Colorado, USA

****Los Alamos National Laboratory, Los Alamos, New Mexico, USA

Keywords: *multiscale modeling, stably-stratified boundary layers, large-eddy simulation, WRF.*

Abstract

The stable boundary layer (SBL) is a challenging scenario for numerical weather prediction (NWP) models due to the complex dynamics involved including Kelvin–Helmholtz instabilities, turbulent intermittency, low-level jets and gravity waves, among others. Therefore, SBLs remain the most difficult atmospheric boundary layer regime to forecast, and where the largest NWP model errors occur. This deficient representation of the SBL hinders our ability to properly forecast wind farm dynamics under these conditions, typically resulting in large errors in wind power prediction.

In this talk, we will present coupled mesoscale-LES simulations of the SBL during one of the nights of the CWEX-13 field experiment using the Weather Research and Forecasting model [1]. Dynamical downscaling from synoptic-scale down to resolved three-dimensional eddies in the SBL was performed, spanning four orders of magnitude in horizontal grid resolution: from 111 km down to 8.2 m. Turbulence generation at the mesoscale-LES transition was enabled by the cell perturbation method [2,3]. By comparing to wind profiler and sonic anemometer observations at the CWEX-13 site, we show that multi-scale modeling is capable of improving vertical wind speed shear, turbulent kinetic energy and surface temperature predictions in the SBL. Remarkably, the multiscale WRF simulation improved not only the turbulence fluctuations but also variability at scales from 1-min to 1-h, not captured by the mesoscale model with a PBL parameterization, as shown in Figure 1. These improvements result from resolving part of the turbulent and sub-meso spectra, which in turn allows for explicit representation of SBL phenomena such as global intermittency in our finest LES domain. This work demonstrates the great potential of multi-scale modeling to improve prediction of real-world stable boundary layers and therefore power prediction by providing more realistic inflow conditions for wind farm models.

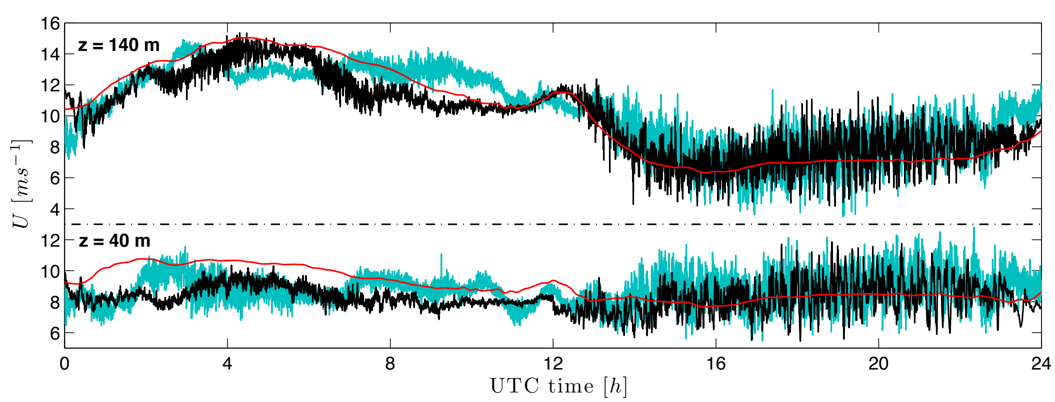

Figure 1: Time evolution of horizontal wind speed at $z = 40$, 140 m during the 26 August 2013. Lidar measurements (light blue), coupled mesoscale-LES WRF (black), and mesoscale WRF (red).

References

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

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

3. D. Muñoz-Esparza, B. Kosović, J. van Beeck, J.D. Mirocha, 2015: A stochastic perturbation method to generate inflow turbulence in large-eddy simulation models: Application to neutrally stratified atmospheric boundary layers, Physics of Fluids, (27) 035102.