# Assessment of large-eddy simulations of the atmospheric boundary layer for wind energy applications

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## Abstract

Assessed was the ability of three codes used for wind energy applications to simulate atmospheric boundary layer flows observed at the SWiFT facility in Lubbock, Texas. Large-eddy simulations (LES) of canonical boundary layers were first carried out by imposing constant large scale forcing. These simulations were followed by LES of a full diurnal cycle and a frontal passage at the SWiFT site. For this purpose two approaches to coupling LES and mesoscale simulations were implemented and tested. Assessed was the ability to reproduce flow parameters relevant for wind power production including wind speed, shear, turbulence spectra and cospectra, etc.

**Keywords:** *Mesoscale-Microscale, Large-Eddy Simulations, Turbulence Spectra*

## Introduction

Accurate representation of atmospheric flows in numerical simulations is essential for a range of wind energy applications including wind resource assessment, wind plant siting and layout, and determining turbine design characteristics for a specific location. High-resolution, turbine-resolving, computational fluid dynamics (CFD) simulations of operating wind farms can be used to optimize wind plant design and assess wind plant performance. However, to achieve high-fidelity wind plant simulations in a realistic operational environment it is necessary to couple atmospheric flow, mesoscale simulations with turbine-resolving, microscale simulations.

The Department of Energy (DOE) Atmosphere to Electrons (A2e) program supports the Mesoscale to Microscale Coupling (MMC) project with a goal to develop and assess high-fidelity numerical simulation tools and methodologies for wind plant scale simulations driven by realistic atmospheric motions. This project is a collaborative effort among several DOE laboratories and the National Center for Atmospheric Research (NCAR). To achieve this goal it is necessary to numerically resolve all the relevant scales of atmospheric motion, from synoptic scale weather patterns through mesoscale circulations affected by surface characteristics down to the coherent flow structure affecting performance of individual turbines.

## Methodology

We report on the progress and achievements toward development of an effective coupling methodology. While the MMC project includes also assessment of mesoscale modeling capabilities here we focus on the assessment of large-eddy simulation (LES) capabilities for atmospheric boundary layers (ABLs) (Haupt et al., 2015, 2016). We first assessed LES capabilities for simulation of canonical ABLs. The model validation study included an extensive sensitivity study including three codes used for wind energy applications: HIGRAD (Sauer, 2013), Simulator for Wind Farm Applications (SOWFA, e.g. Churchfield et al., 2012), and the Weather Research and Forecasting model (WRF, Skamarock et al., 2008). These codes were used in LES mode to simulate convective and neutrally stratified atmospheric boundary layers observed at the DOE's SWiFT facility near Lubbock, Texas consisting of a 200 m tower with ten measurement levels. (Kelly and Ennis, 2016). SOWFA and WRF were also used to simulate diurnal cycle of an ABL and a frontal passage observed at the same site.

**Results**
Assessed was the ability to reproduce flow parameters of interest for wind energy applications including wind profiles, shear, turbulence spectra, etc. An example of agreement between observed wind speed profiles and streamwise velocity frequency spectra and those simulated by WRF are shown in Figure 1. While canonical ABL flows represent useful idealization of real atmospheric flows simulations of neutral boundary layer demonstrated the need for capturing diurnal cycle of an ABL. Furthermore, to simulate atmospheric flow variability affecting wind plant performance associated with frontal passages, storm outflows, etc., it is necessary provide time varying forcing for LES of ABLs. We therefore assessed two approaches to coupling mesoscale and microscale simulations. The first approach consists of imposing large scale forcing derived from mesoscale simulations on periodic LES while the second approach consists of nesting an LES within a mesoscale simulation. A detailed analysis of simulations carried out with WRF and SOWFA will be presented.

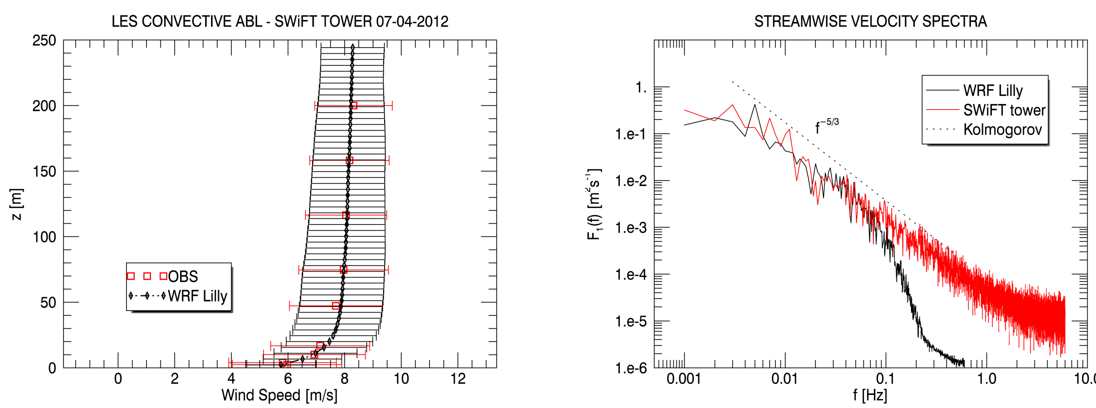


Figure 1. Comparison of observed (red) and simulated (black) convective boundary layer wind speed profile (left panel) and streamwise velocity frequency spectra (right panel).

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