P83 Nested Realistic Daily WRF-LES Simulations Using Eddy-Seeded Lateral Boundary Conditions

Brian J. Gaudet, Aijun Deng, David R. Stauffer, Nelson L. Seaman, and Astrid Suarez
Pennsylvania State University, University Park, PA 16802

1. INTRODUCTION

For grid spacing on scales smaller than those of the energy-containing turbulent eddies in the planetary boundary layer (PBL), it becomes appropriate to model turbulent structure with the large eddy simulation (LES) method. WRF has the capability of being run in LES mode as a nest within a coarser domain that uses Reynolds-averaged PBL parameterizations, while at the same time containing realistic topography and heterogeneous atmospheric features. Time is required for realistic eddy structures to develop in an LES after initialization. These populate the LES domain when periodic lateral boundary conditions (LBCs) are used. However, for realistic topography, nonperiodic LBCs are needed, and if there is a mean horizontal flow, eddy-deficient regions will tend to develop near the inflow boundaries.

Here we present examples of the WRF-LES model (Δx = 333m, 111 m) recently running as nests within one of our high-resolution WRF configurations that run on a daily basis over central PA. We show how the use of an eddy seeding relaxation method, previously applied to single-domain idealized LES, can also produce more realistic eddy structures in a realistically heterogeneous LES nest. Different methods of treating the LBCs on the innermost domain will be contrasted and evaluated.

2. MODEL SETUP

In this study we apply the WRF-ARW model to the ridge-and-valley topography of central Pennsylvania. The domain configuration is similar to one of those described in Deng et al. (2012). Three mesoscale nested grids (9 km, 3 km, 1 km) were run on a daily basis over the northeastern United States (Figure 1), using the GFS model for initial and lateral boundary conditions. There are 51 vertical levels, with the lowest half-level about 25 m above the surface.

The simulations used the RUC land surface model, the Thompson microphysics scheme, the RRTMG longwave / shortwave radiation package, and the Mellor-Yamada-Janjic PBL scheme to parameterize the effects of turbulence. These simulations begin at 1200 UTC after the three-hour pre-forecast period that uses data assimilation to help 'spin-up' the model.

At 1200 UTC, two additional simultaneous LES nested domains were spawned, with 333-m and 111-m horizontal grid spacing. These domains, like the coarser domains, contain fully heterogeneous surface characteristics and make use of a full land surface model, but are run using an LES subgrid turbulence closure rather than a PBL scheme that functions as a one-dimensional column parameterization within the WRF-ARW framework. The lateral boundary conditions for the 333-m domain are provided by the 1-hr frequency output from the 1-km domain, while the boundary conditions for the 111-m domain are provided every timestep by the 333-m domain.

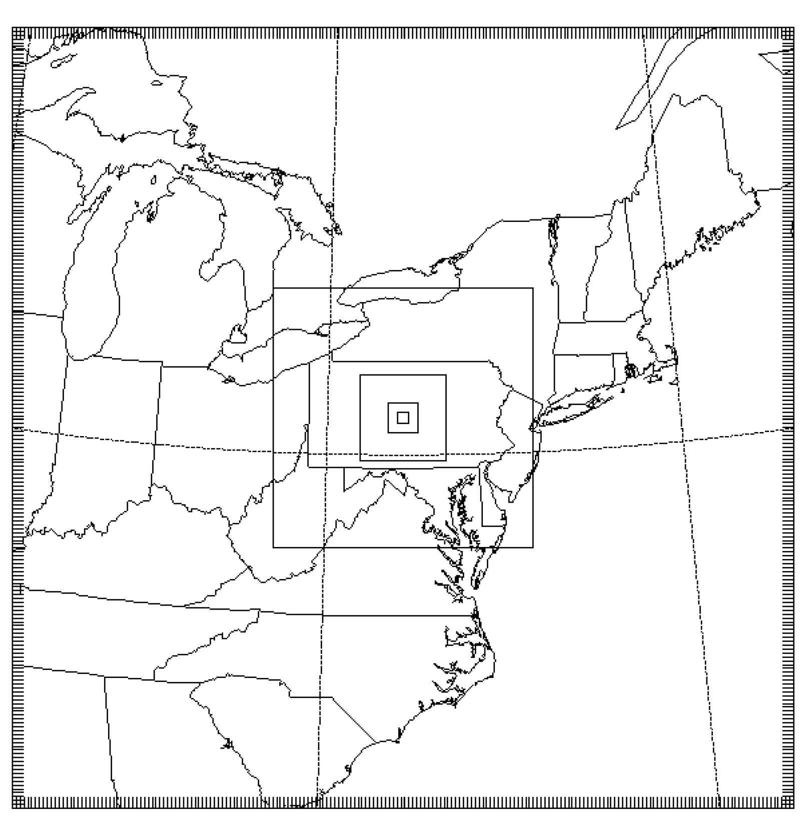

Figure 1: Grid configuration showing Δx = 9-km, 3-km, and 1-km outer mesoscale domains, and 0.33 km and 0.11-km domains for daily nested LES model runs.

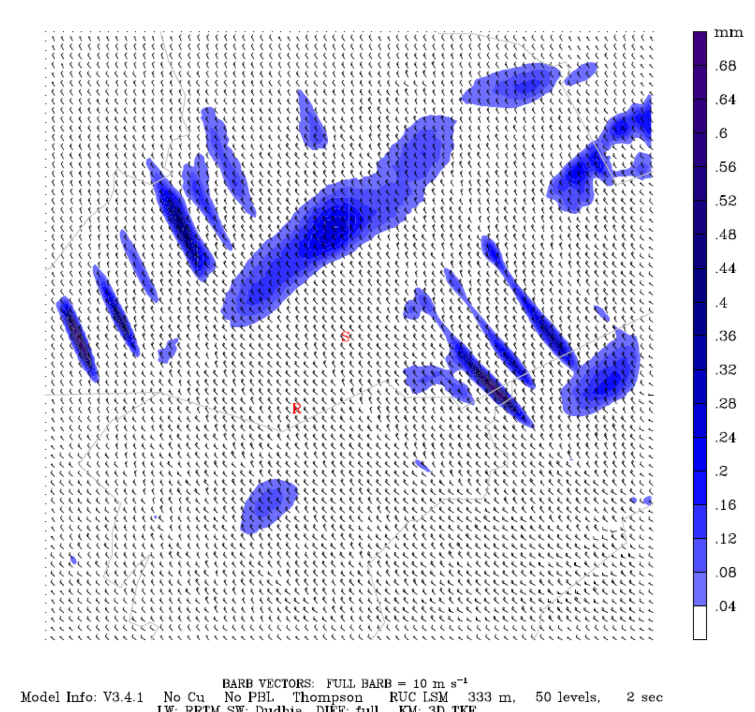

Figure 2: Example of delayed spinup of eddy structures (here, in vertically integrated cloud water) near the inflow boundary in a northwest flow case of 13 Jun 2013, for a 333-m LES domain nested from a 1-km mesoscale domain.

*Corresponding author address: Brian J. Gaudet, Penn State University, Dept. of Meteorology, University Park, PA 16802; e-mail: bjg20@met.psu.edu

3. EDDY SEEDING METHODOLOGY

Since the lateral boundary conditions of the 333-m LES domain are derived from those of the non-LES 1-km domain, and because only hourly 1-km output are used to provide those conditions, the lateral boundaries of the 333-m domain will be eddy-deficient in regions of sustained inflow (e.g., Figure 2). It has been shown in idealized situations that turbulent statistics can be adversely affected by eddy-deficient inflow even well within the center of an LES model domain (Gaudet et al. 2012).

For the case described below, we use the eddy seeding method described in Gaudet et al. (2012) to improve the eddy structure near the lateral boundaries of the 333-m domain, with some modifications. An offline 'canned LES' simulation was performed using periodic lateral boundary conditions, which ensures that turbulent eddies uniformly fill the horizontal extent of the domain after an initial spinup period of tens of minutes (Figure 3). The canned LES used for this application possessed the same grid spacing as the 333-m domain of the daily forecast model, but with flat model terrain and horizontally homogeneous surface properties and initial atmospheric profiles (single sounding). The surface heat flux (0.20 K m s^{-1}) and sounding mixed-layer depth (z_i approximately 1100 m AGL) of the canned LES were selected to be characteristic of the center of the domain near 1800 UTC).

Thermal eddy structures from the canned LES are stored in a reference file, for subsequent use in seeding the lateral boundaries of the realistic non-periodic 333-m LES domains from the daily runs. The magnitude of the eddy perturbations are first scaled using the properties of mixed layer similarity theory, according to which the characteristic scale of the thermal perturbations is proportional to ($H^{2/3} / z_i^{1/3}$), where H is the magnitude of the surface heat flux, while z_i is the height of the top of the mixed layer (e.g., Young 1988). The surface heat flux is provided by the land surface model of the 333-m LES domain, while the top of the mixed layer is found by finding the maximum value of the vertical Laplacian of potential temperature. Furthermore the top of the mixed layer relative to that in the canned LES is used to scale the vertical positioning of an eddy structure. Once a properly scaled eddy structure is obtained, a relaxation technique is used within a zone along the lateral boundaries to spin up the structure gradually, similar to the method described in Stauffer and Seaman (1994) and Deng et al. (2009).

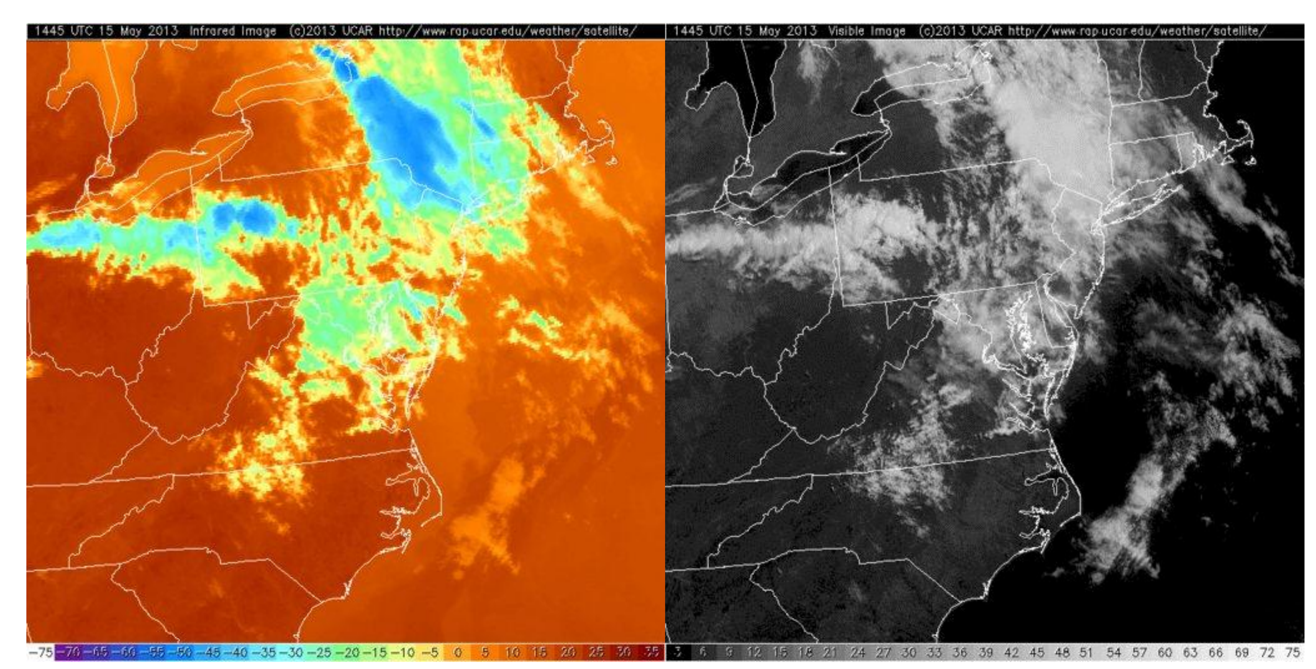

Figure 4: GOES Infrared and visible satellite images at 1445 UTC 15 May 2013. courtesy UCAR/RAL website.

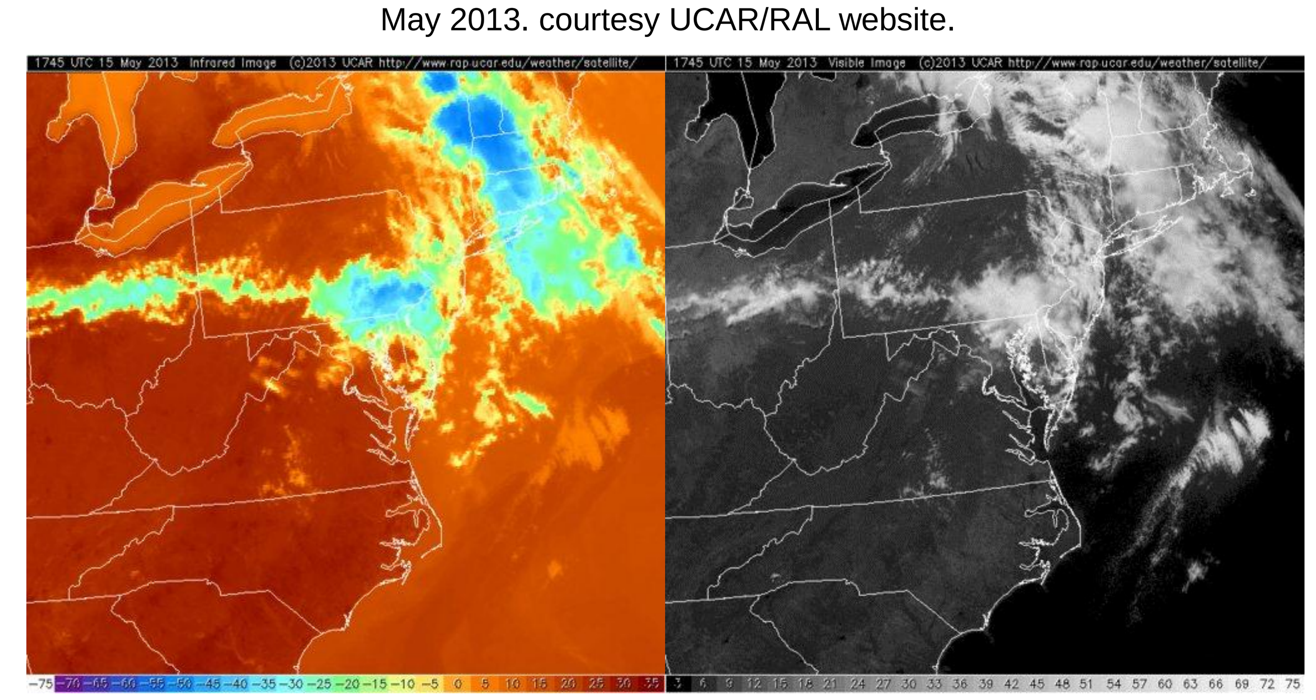

Figure 5: GOES Infrared and visible satellite images at 1745 UTC 15 May 2013. courtesy UCAR/RAL website.

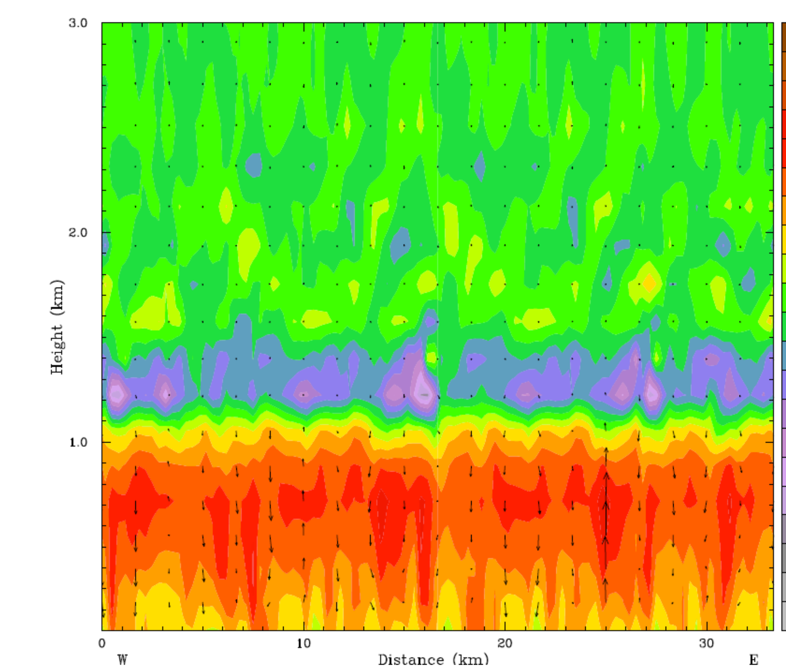

Figure 3: Example of eddy structures within canned LES, at 60 minutes simulation time. Shading is temperature perturbation from value at initial time.

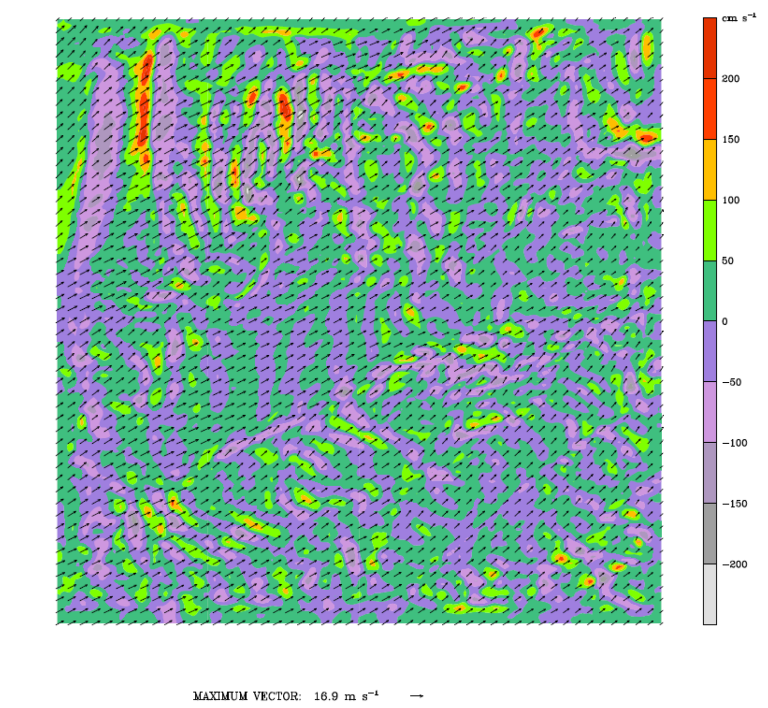

Figure 6: Vertical velocity at 1 km height on 333-m domain for LES simulation with eddy simulation, at 1500 UTC 15 May 2013.

4. IMPLEMENTATION OF METHOD

An example of the implementation of the method is shown below, for May 15, 2013. The morning began with much of Pennsylvania enveloped in patchy cloudiness (Figure 3), but by 1800 UTC this had largely dissipated over central Pennsylvania (Figure 4). The canned LES used for this application possessed the same grid spacing as the 333-m domain of the daily forecast model, but with flat model terrain and horizontally homogeneous surface properties and initial atmospheric profiles (single sounding). The surface heat flux (0.20 K m s^{-1}) and sounding mixed-layer depth (z_i approximately 1100 m AGL) of the canned LES were selected to be characteristic of the center of the domain near 1800 UTC. The canned eddies were then introduced into the lateral boundary region (20 points) of the 333-m LES domain. It can be seen that a realistic pattern of turbulent eddies fills the domain once solar heating has caused a substantial surface heat flux in the model domain (Figure 5). More development and evaluation still needs to be done on more shear-driven, stable cases, however.

5. SUMMARY

We have implemented the eddy seeding method into WRF using a canned LES simulation and mixed layer scaling of thermal eddy structures, and successfully applied the method to a realistic case study with fully heterogeneous atmospheric and surface properties. The method is adapted from existing WRF data assimilation procedure. Once fully evaluated, the method should allow for the performance of more realistic LES model runs as a nest within a region of heterogeneous atmospheric or surface properties, without the need for periodic boundary conditions.

It needs to be determined if one set of canned eddy structures can be sufficient for generating turbulence along the lateral boundaries even in cases where the turbulence is largely driven by wind shear, or if multiple eddy structures and scaling methods would need to be applied to generate realistic flow fields. Future work will also determine if eddy structures of momentum, in addition to thermal eddy structures, should be stored.

6. REFERENCES

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7. ACKNOWLEDGMENTS

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