Turbulent Transport and Surface Interactions within the Convective Boundary Layer: An Evaluation of WRF Parameterization Schemes

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INTRODUCTION

The Weather Research and Forecasting (WRF) model (Skamarock et al. 2008) is rapidly becoming a popular tool in the field of numerical weather prediction. One reason for this popularity lies in the model's ability to simulate atmospheric phenomena at fine horizontal grid spacing. The growing trend is to utilize a grid spacing in the general range of 1 to 4km. Unfortunately, this has led to an increase in "black box" users who are simply content to obtain results without regard for the underlying physics schemes. At such fine spacing, these schemes play an especially vital role in atmospheric simulations. Physics schemes in WRF include microphysics, cumulus convection, atmospheric radiation, land surface model (LSM), surface layer (SL), planetary boundary layer (PBL), and turbulent mixing parameterizations. In this study, WRF simulations incorporating these sensible options are compared to results from a University of Oklahoma large eddy simulation (OU-LES) model following Fedorovich et al. 2001a,b, 2004. Such comparisons describe the proficiency of WRF parameterization schemes in representing atmospheric features that are resolvable in scale by LES. Additionally, internal variations in WRF simulations amongst disparate grid spacing is investigated.

MODEL SPECIFICATIONS

OU LES

The OU-LES model employed a simulation domain of 50x50x4km^3 centered over Lamont, Oklahoma. Finite-difference atmospheric equations were solved on a 512x512x80 staggered grid with horizontal spacing of $\Delta x = \Delta y = 100$m and vertical spacing of $\Delta z = 50$m. Knowing that such grid specifications represent the coarse end of LES capabilities, they were nonetheless implemented due to computational restrictions. However, even at such grid spacing, OU-LES is assumed as "truth" since it directly computes atmospheric quantities at scales considered subgrid in WRF. The OU LES simulation spanned twelve hours, from June 08, 2007 12Z to June 09, 2007 00Z. The model was initialized and nudged with 12Z, 18Z, and 00Z atmospheric soundings taken from the Lamont Atmospheric Radiation Measurements (ARM) profiler, with geostrophic adjustment calculated from Rapid Update Cycle (RUC) analyses. Initial fields were taken from the 12Z Lamont sounding and taken as horizontally uniform across the entire simulation domain.

WRF

WRF version 3 was implemented for this study. Three domain configurations were used:

1) **WRF10** – Simulation domain of 1000x1000km^2 in the horizontal, extending to 100mb in the vertical. Equations were solved on a 101x101x41 staggered grid with spacing of of $\Delta x = \Delta y = 10$km and first model level located at approximately 8m.
2) **WRF04** – Simulation domain of 400x400km^2 in the horizontal, extending to 100mb in the vertical. Equations were solved on a 101x101x41 staggered grid with spacing of of $\Delta x = \Delta y = 4$km and first model level located at approximately 8m.
3) **WRF01** – Simulation domain of 400x400km^2 in the horizontal, extending to 100mb in the vertical. Equations were solved on a 241x241x41 staggered grid with spacing of of $\Delta x = \Delta y = 1$km and first model level located at approximately 8m.

All WRF configurations were initialized with the 32km North American Regional Reanalysis (NARR) dataset. Each simulation spanned 24 hours, from June 08, 2007 00Z to June 09, 2007 00Z. The twelve hour head start versus the OU-LES simulation was coupled with a cycling technique to force a stable diurnal solution, thus eliminating the so-called model spin-up problem. Table 1 enumerates the sensible combinations of turbulent transport and surface interaction schemes implemented. The other physics schemes were set constant for all configurations.

Comparison Exercises

Three comparison exercises were carried out. The first comparison was between OU-LES, WRF04, and WRF10 across the entire LES domain, hereafter the global comparison. The second was between LES and WRF01 over a centrally spaced sub-domain, hereafter the local comparison. Lastly, WRF01 and WRF10 were compared across the entire LES domain, hereafter the internal comparison. Meteorological fields included in the comparisons were TKE, horizontal velocity components, potential temperature, and water vapor mixing ratio.

Δ (km)	PBL	Cumulus	Diffusion	Turbulence
1	MYJ	None	Coordinate	2D Smagorinsky
1	MYJ	None	Physical	2D Smagorinsky
1	None	None	Physical	1.5 3D TKE
4	MYJ	None	Coordinate	2D Smagorinsky
4	MYJ	KF	Coordinate	2D Smagorinsky
4	MYJ	None	Physical	2D Smagorinsky
4	MYJ	KF	Physical	2D Smagorinsky
10	MYJ	KF	Coordinate	2D Smagorinsky
10	MYJ	KF	Physical	2D Smagorinsky

Table 1: Sensible configurations of different turbulent transport and surface interaction schemes

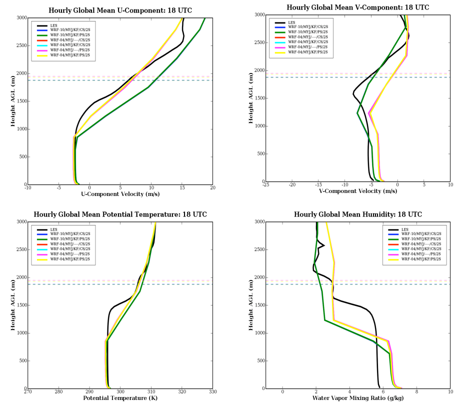

Figure 1: Global comparison at 18Z on June 8, 2007 (OU-LES vs. WRF04, WRF10).

DISCUSSION

In the global comparison, both WRF10 and WRF04 closely represented the CBL structure described by OU-LES. Profiles of potential temperature and velocity indicated that WRF10 exaggerated the entrainment layer, and thus the PBL depth. In the local comparison, atmospheric flow feature reproduced by WRF01 were nearly equivalent in nature to that of OU-LES. In fact, for the majority of cases, differing turbulence parameterizations resulted in few differences. The lone exception was specification of the 1.5-order TKE closure scheme with no PBL parameterization. This configuration underrepresented vertical mixing as evident from the lack of a well-mixed layer. The internal comparison confirmed resolution dependence in estimating the PBL depth. These comparisons demonstrate the overall ability of WRF to reproduce CBL structures of atmospheric phenomena. It is important to note that these comparisons were strictly statistical in nature and not a means to evaluate forecasting proficiency. Future work will include a higher resolution OU-LES grid and evaluation of the two other PBL parameterization schemes included in WRF version 3.

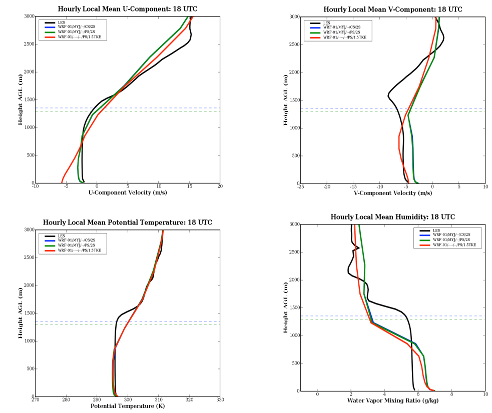

Figure 2: Local comparison at 18Z on June 8, 2007 (OU-LES vs. WRF01).

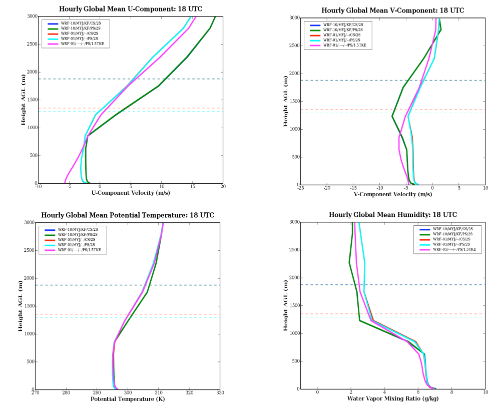

Figure 3: Internal comparison at 18Z on June 8, 2007 (WRF01 vs. WRF10).

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