Interaction between the boundary-Layer and precipitation processes in WRF

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1. Introduction

Recently the WRF model has been applied increasingly at grid sizes of 4 km or less in real-time cloud-resolving forecasts (http://wrf-model.org). For the Bow-Echo and Mesoscale Convective Vortex Experiment (BAMEX, Bull. Amer. Meteor. Soc., Davis et al. 2004), WRF was run daily over the central United States to evaluate its usefulness as a guidance tool for forecasters participating in the field program. With a 4 km grid size and no cumulus parameterization, it was found to have skill in predicting the occurrence and mode of precipitating systems in the spring of 2003. The PBL scheme chosen for BAMEX was the Yonsei University (YSU) PBL (Hong et al. 2005, manuscript in review in Mon. Wea. Rev.), and part of the success must be attributed to this scheme's capability because the forecasts were initialized at 00Z in the local evening and ran 36 hours, so that a complete diurnal cycle of PBL development was captured in the middle hours of the forecast.

Prior to BAMEX, the MRF PBL and YSU PBL were evaluated in several real-time and case studies. The most significant differences were in the developed PBL soundings in clear-sky conditions where the YSU PBL produced lower well-mixed layer depths, and cooler, moister PBL structures as was expected from the results in ideal case runs in the previous section. However, a few cases also showed distinct rainfall differences that can be understood in terms of the differences in these schemes. Here one such case that exhibited significant sensitivity to PBL treatment, will be presented.

2. Model setup

Convection triggered along a strong cold front and spawned 75 tornados in 13 states on the night of November 10th, 2002. Ohio, Tennessee, and Alabama all had numerous tornados as a 1000 km highly convective front produced a broad swath of damage resulting in 36 deaths. At 12Z 10 November 2002 (model initial time), a surface front was extended southwestward with a center in Wisconsin (not shown). A cold front had surged eastward extending from Louisiana to the northeastern United States at 00Z 11 (Fig.1a). Between 15Z and 18Z convection developed along the cold front in Illinois, and over the next 6 hours lengthened into a severe convective line ahead of the front from Ohio to Alabama (Fig. 1b).

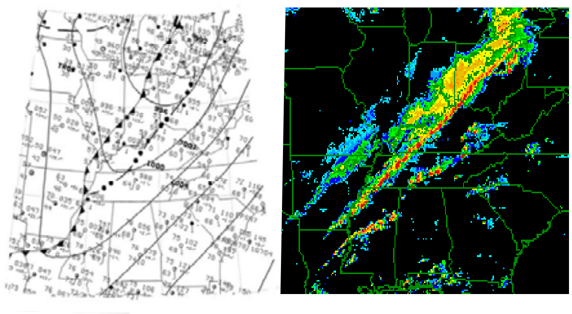

Figure 1. Surface analyses for (a) 00Z 11 November 2002, and (b) composite maximum reflectivity (dbZ) at 00Z 11 November 2002.

This case was simulated with the WRF model (Skamarock et al. 2005) on a large (380x380 x 34 levels) 4 km grid. The simulation was initialized at 12Z 10 November 2002, and was run for 24 hours driven by initial and three-hourly boundary conditions from the NCEP Eta model operational forecast grids. Here we will outline the differences between the simulations and explain them in terms of the differences between the MRF PBL and YSU PBL.

3. Results

It is apparent that the simulation with the YSU PBL scheme intensified the front more rapidly and lengthened the line of severe convection, in better agreement with observations, than the MRF PBL (see Fig. 2). Fig. 2a compared to Fig. 1b also shows that some characteristics, such as a double line of intense convection at 00Z were captured to some extent in the YSU PBL simulation, while comparing Figure 2b shows that the MRF PBL line extension to the south was weaker than observed at this time. On the other hand, it is distinct that the YSU PBL scheme reduces spurious widespread convection in front of intense convection regions that is seen in the simulation with the MRF scheme, in particular at 18Z (now shown).

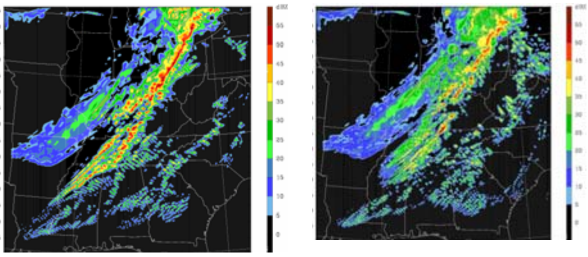

Fig. 2. Same as in Fig. 1b, but with the (left) YSUPBL and (right) MRFPBL.

The reason for the precipitation and reflectivity differences can be inferred from comparing the relative humidity and temperature profiles that are directly affected by the vertical turbulent mixing. Moistening within the PBL and drying above due to weaker mixing by the YSU PBL than the MRF PBL appear in both light and intense convection regions (not shown).

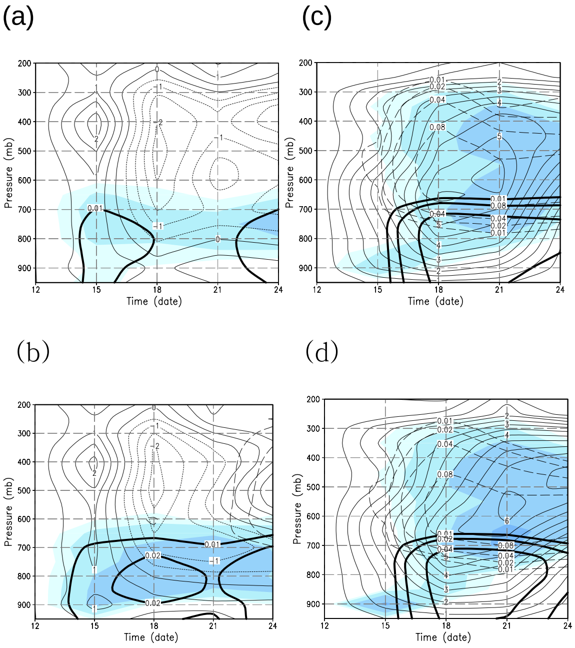

Figure 3. Time variation of the vertical velocity (cms^{-1}, upward with solid and downward with dotted lines), cloud and ice waters (shaded), rain water (gkg^{-1}, thick solid), snow and graupel (long dashed) from 12Z 10 to 00Z 11 November 2002, obtained from the (a) YSU PBL and (b) MRF PBL experiments, averaged over the light precipitation region, and (c) and (d), over the heavy precipitation region. Contour lines and shaded intensity are at 0.01, 0.02, 0.04, 0.08 gkg^{-1}.

In the pre-frontal region (Figs. 3ab), warm clouds are dominant. Downward motion is prevalent above the PBL in the daytime when the PBL develops, indicating the formation of the inversion layer at the PBL top. This inversion inhibits the initiation of convection. Both the YSU and MRF PBL schemes show the development of clouds in the morning hours, but more actively in case of the MRF PBL scheme. The reason for intense convection with the YSU can be attributed to the differences in synoptic environment associated with the formation of convection (Figs. 3cd). Upward motion prevails within the entire troposphere and cloud top reaches the tropopause, whereas the downward motion is dominant above the PBL ahead of a front. Ice-microphysics is the key mechanism, whereas the warm clouds are dominant in the pre-frontal region. This indicates that in contrast to the pre-frontal region, the PBL processes play a secondary role in the intense convection region. The enhanced convection in late afternoon in case of the YSU PBL is due to the moister boundary layer below clouds, which leads to a reduced evaporation of falling precipitation.

4. Concluding remarks

The results presented here serve to show that the new scheme is a promising option in mesoscale models alleviating several problems inherent in its predecessor, the MRF PBL. The enhancements to the YSU PBL scheme have little impact on its efficiency making it a viable option for real-time forecasting and computer-intensive regional climate runs. Since its addition in WRF, it has been used regularly in real-time forecasts at NCAR, including hurricane forecasts and has proved itself to be robust and realistic in its behavior in a wide variety of situations since its first inclusion in 2003.

Acknowledgements

This work was funded by the Korea Meteorological Administration Research and Development Program under Grant CATER_2006-2204.