BEHAVIOR OF WRF BL SCHEMES AND LAND-SURFACE MODELS IN 1D SIMULATIONS DURING BAMEX

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1. INTRODUCTION

The Weather Research and Forecasting (WRF) model currently offers three options for parameterization of turbulence in the boundary-layer (BL hereafter): 1) Eta implementation of the 1.5-order closure by Janjić (1994) (MYJ), 2) the Medium-Range Forecast (MRF) scheme based on Troen and Mahrt (1986), and Hong and Pan (1996) and 3) the Yonsei University (YSU) scheme (Hong and Dudhia 2003), which is a modification of the MRF scheme to include explicit entrainment fluxes of heat, moisture and momentum, counter-gradient transport of momentum, and different specification of the BL height. The above schemes can be coupled with any of the land-surface models (LSMs, hereafter): NOAH (Ek et al. 2003), RUCLSM (Smirnova et al. 2000), and the slab model (SLAB hereafter). Surface fluxes to RUCLSM and SLAB are supplied by MYJs own scheme or a scheme based on Blackadar's approximation to similarity (SFCCLAY), depending on BL scheme used, while NOAH fluxes are calculated inside the LSM. It should also be noted that soil parameters assigned for soil categories vary in different LSMs.

Simulations with a 1D version of WRF are performed to highlight differences between boundary layers predicted using combinations of the BL schemes and LSMs and possibly to provide a broad view on biases in the BL observed in 3D WRF runs. The analysis is valid for the summertime, and over land and flat terrain.

2. EXPERIMENT SETUP

For details on the 1D WRF model the reader is referred to Pagowski (2004).

To account for a variety of atmospheric and soil conditions, simulations are performed using a set of initial conditions and external forcings which are derived from WRF forecasts issued daily for the BAMEX field campaign. The WRF forecasts at 1200 UTC (12-hour forecasts, 0600 LST at BAMEX) and 0000 UTC (24-hour forecasts, 1800 LST at BAMEX) are used to derive initial conditions for the 12-hour 1D runs to simulate diurnal and nocturnal BLs, respectively. For the current experiment, a set consisting of a hundred profiles of wind, temperature, mixing ratio, soil moisture and soil temperature is obtained by randomly weighting two profiles so that

$$\varphi = \alpha\varphi_1 + (1-\alpha)\varphi_2 \,, \qquad (1)$$

where φ is the initial profile for a 1D simulation, φ_1 and φ_2 are profiles from 3D WRF forecasts at a certain BAMEX location, and α is a random weight.

Time-varying external forcings consisting of geostrophic wind and shortwave and longwave radiation are obtained similarly. Currently, no account is taken for precipitation or advection.

At the BAMEX location surface roughness is equal to 15 cm, vegetation fraction is about 60% and soil category is sandy clay. These are, we believe, typical conditions over the Central US.

Here, because of space limitations, only simulations for the diurnal BL will be considered. For the same reason, our analysis will be largely limited to potential temperature and moisture rather than wind. A more complete presentation, possibly including a comparison with observations, will be available during the workshop.

3. RESULTS AND ANALYSIS

Mean vertical profiles of potential temperature at 0600, 0900, 1200, 1500, and 1800 LST, which were obtained by averaging over the ensemble simulated with one hundred initial conditions, are shown in Fig. 1.

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Potential temperature profiles indicate that results from YSU and MRF are in general quite similar. With NOAH and RUCLSM differences between profiles of potential temperature for both schemes are practically indistinguishable. It can also be noted that YSU and MRF coupled with SLAB predict warmer and deeper BL in the late afternoon than when coupled with NOAH or RUCLSM. For both BL schemes rate of warming of the BL is faster with NOAH than with RUCLSM but in the late afternoon potential temperature profiles are very similar.

MYJ systematically predicts a shallower and cooler BL than YSU and MRF. For MYJ evolution of BL stratification is different from YSU or MRF in that the rate of warming is fastest when it is coupled with NOAH, followed by SLAB and RUCLSM. Also, MYJ coupled with RUCLSM predicts BL which is cooler and shallower than when it is coupled with NOAH or SLAB.

We believe that some of the differences in BLs simulated by the different BL schemes can be explained, in addition to very different parameterizations of turbulence in the mixed layer, by the analysis of mixing ratio profiles and latent heat fluxes shown in Figs. 2 and 3, respectively.

It can be seen in Fig. 2 that BLs simulated with SLAB are driest of all LSMs possibly because of the lack of moisture transport in soil and/or canopy. It would be interesting to reassess SLAB after adding a simple bucket model to handle surface moisture. However, most striking in this figure is the difference in behavior between MYJ and YSU or MRF. While for MYJ lower BL moistens during the day, for YSU and MRF lower BL is becoming drier. This behavior is most apparent when MYJ is coupled with RUCLSM.

Analysis of Fig. 3 reveals that, indeed, latent heat fluxes simulated with MYJ are larger than with YSU (and also MRF, not shown). Since differences in mean friction velocities and stratification (not shown) are small between the schemes and skin temperatures (not shown) for MYJ are lower, larger latent heat fluxes can only be a result of higher skin moisture for this BL scheme. Also, in this figure the largest latent heat fluxes occur when MYJ is coupled with RUCLSM. Characteristically, the largest spread in simulations with different initial conditions and forcings occurs for RUCLSM, followed by SLAB (not shown) and NOAH.

Finally, in Fig. 4 a 10-m wind speed for individual ensemble members and ensemble mean using the three BL schemes coupled with NOAH LSM is shown. (Similar results for other LSMs.) As both spread and mean remain very similar for all the schemes significant differences can be noted in response of the schemes to the synoptic forcings.

4. CONCLUSIONS

The analysis of BL simulations with the 1D WRF model leads us to the following conclusions. It appears that differences in the prediction of the diurnal evolution of the BL and soil between YSU and MRF are rather small. BLs simulated with MYJ are shallower by several hundred meters, depending on the LSM, when compared to the other BL schemes. Interestingly. for this scheme BL moistens during the day while opposite is true for YSU or MRF.

Coupling of BL schemes with SLAB leads to the driest BLs possibly because of the lack of parameterizations of surface moisture transport. On average, BL simulations with YSU(MRF) coupled with NOAH and RUCLSM are similar. However, coupling MYJ with RUCLSM results in shallower, cooler and more moist BLs than when it is coupled with other LSMs.

To confirm the above findings it would be beneficial to perform simulations over broader range of landuse categories and soil and vegetation types. To assess benefits of the available BL schemes and LSMs, comprehensive verification with observations is needed.

5. REFERENCES

Ek, M.B., K.E. Mitchell, Y. Lin, E. Rogers, P. Grunmann, V. Koren, G. Gayno, and J.D. Tarpley, 2003: Implementation of Noah land surface model advances in the National Centers for Environmental Prediction operational mesoscale Eta model, *J. Geophys. Res.*, **108(D22)**, 8851.

Hong, S.-Y., and J. Dudhia, 2003: Testing of a new non-local boundary layer vertical diffusion scheme in numerical weather prediction applications, 16th Conference on Numerical Weather Prediction, Seattle, WA.

Hong, S.-Y, and H.-L. Pan, 1996: Non-local boundary layer vertical diffusion in Medium-Range Forecast model, *Mon. Wea. Rev.*, **124**, 1215–1238.

Janjić, Z.I., 1994: The step-mountain eta coordinate model: further developments of the convection, viscous layer, and turbulence closure schemes, *Mon. Wea. Rev.*, **122**, 927–945.

Pagowski, M., 2004: Some comments on PBL parameterizations in WRF, *The Joint WRF/MM5 Users' Workshop*, Boulder, CO.

Smirnova, T.G., J.M. Brown, S.G. Benjamin, and K. Dongsoo, 2000: Parameterization of cold-season processes in the MAPS land-surface scheme, *J. Geophys. Res.*, **105(D3)**, 4077–4086.

Troen, I., and L. Mahrt, 1986: Simple model of the atmospheric boundary layer; sensitivity to surface evaporation, *Boundary-Layer Meteorol.*, **37**, 129–148.

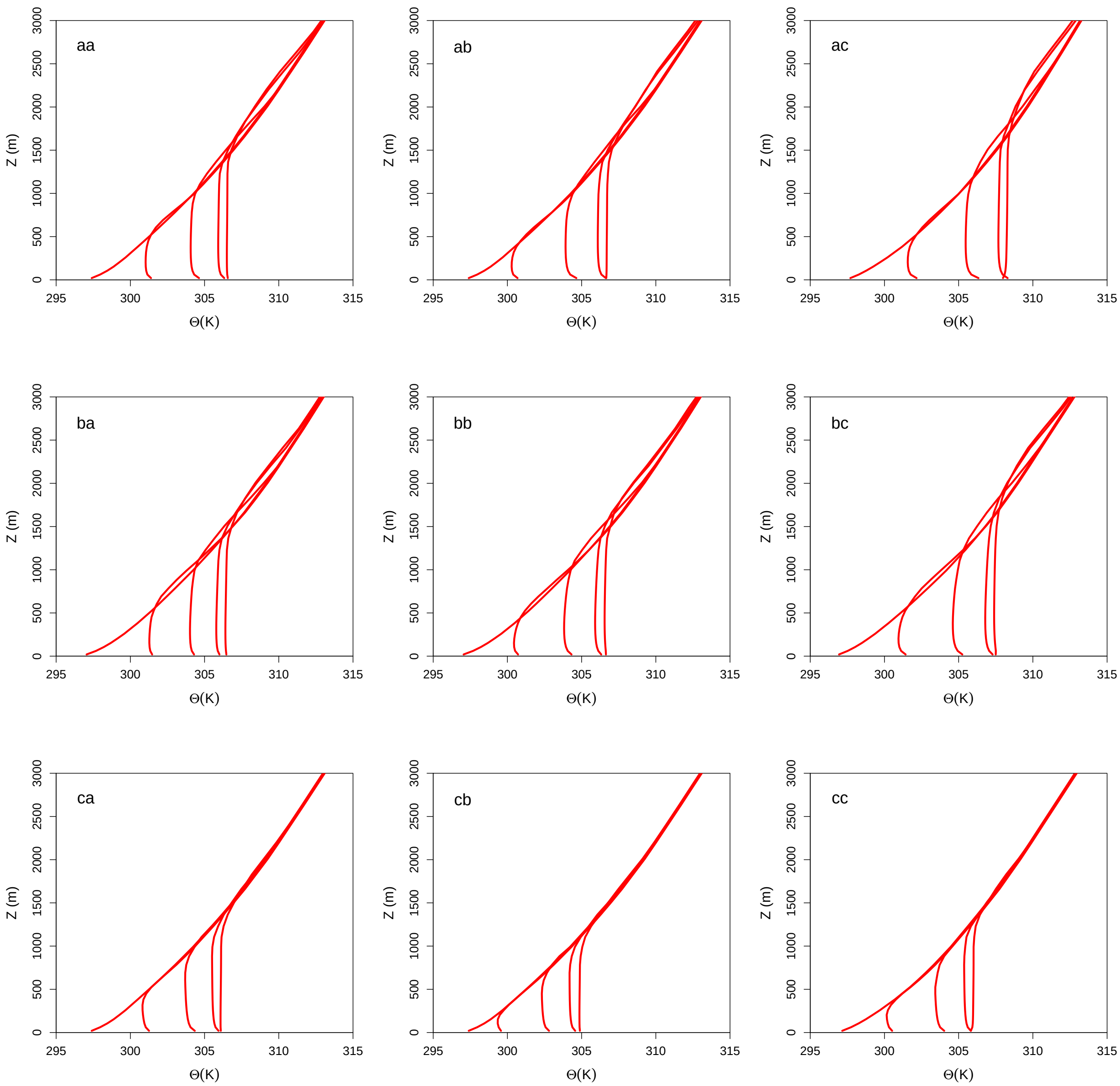

Figure 1: Mean vertical profiles of potential temperature at 06, 09, 12, 15, and 18 LST for different boundary layer schemes (first label letter): a – YSU, b – MRF, c – MYJ and land-surface schemes (second label letter): a – NOAH, b – RUCLSM, c – SLAB.

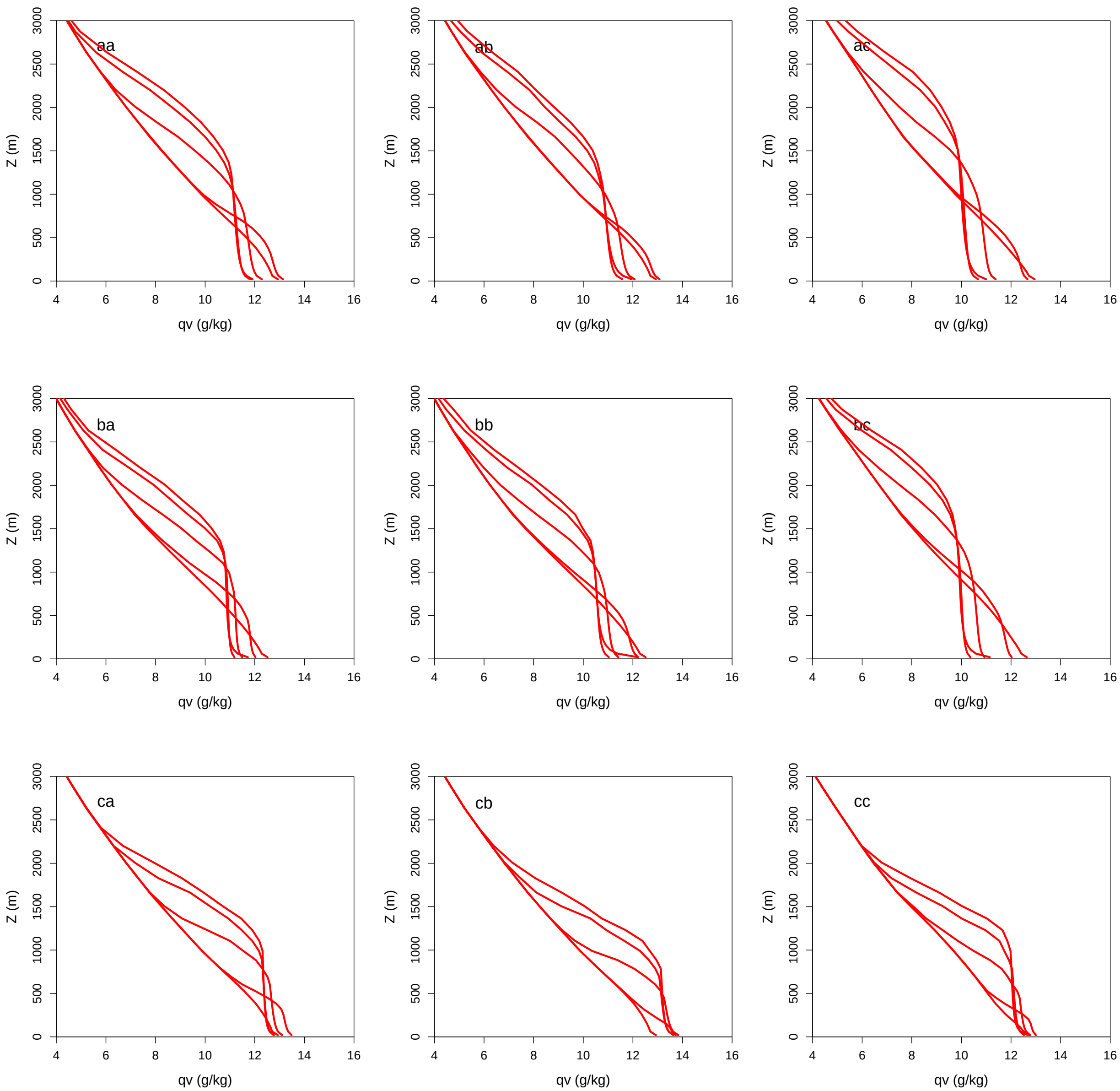

Figure 2: Mean vertical profiles of mixing ratio at 06, 09, 12, 15, and 18 LST for different boundary layer schemes (first label letter): a – YSU, b – MRF, c – MYJ and land-surface schemes (second label letter): a – NOAH, b – RUCLSM, c – SLAB.

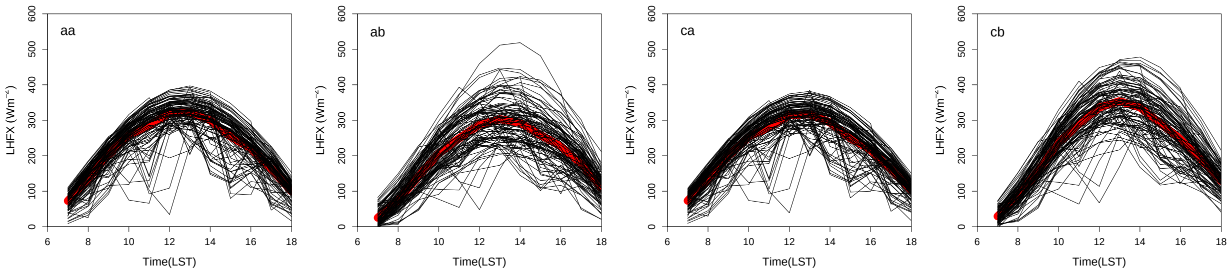

Figure 3: Daytime individual ensemble members (black) and ensemble mean (read) latent heat fluxes for different boundary layer schemes (first label letter): a – YSU, c – MYJ and land-surface schemes (second label letter): a – NOAH, b – RUCLSM.

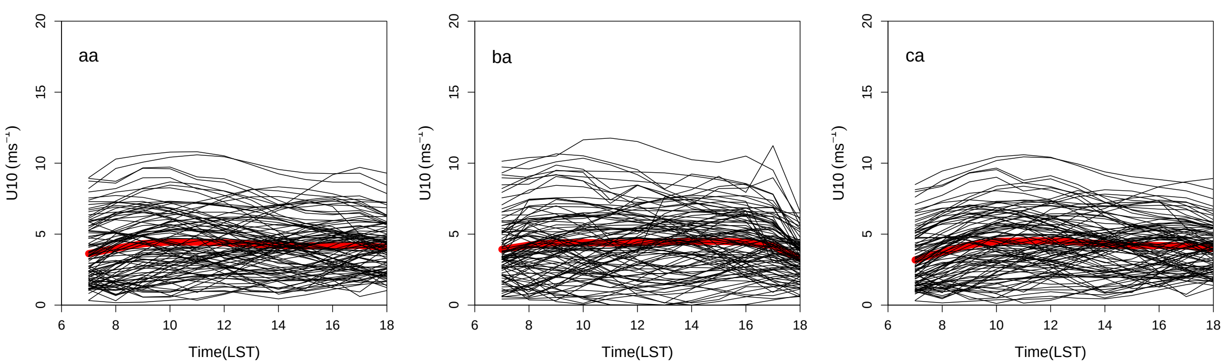

Figure 4: Daytime individual ensemble members (black) and ensemble mean (red) 10-m wind speed for different boundary layer schemes (first label letter): a – YSU, b – MRF c – MYJ with a – NOAH LSM (second label letter).