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

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1. INTRODUCTION

Forecasts are issued with a 1-D version of the Advanced Research Weather Research and Forecasting (AR WRF) model to highlight differences between boundary layers (BLs) predicted using combinations of the BL schemes and land-surface models (LSMs). By comparing forecasts with observations we can acquire a broad view on biases in the BLs observed in 3-D WRF runs. The analysis of the simulations is valid for the summertime, over land and flat terrain.

The WRF model currently offers several options for parameterization of turbulence in the BL, among them: 1) Eta implementation of the 1.5-order closure by Janjić (2001) (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 LSMs: the NOAH (Ek et al. 2003), the RUCLSM (Smirnova et al. 2000), and our own force–restore/bucket model (FRB). Surface fluxes to the LSMs are supplied by MYJ's own scheme or a scheme based on Blackadar's approximation to similarity (SFCLAY), depending on the BL scheme used. It should also be noted that soil parameters assigned for soil categories vary in different LSMs.

The atmospheric 1-D WRF model consists of equations for momentum, thermodynamic and conservation of moisture which are solved implicitly. This model can be coupled with any of the LSMs. Further details are provided in Pagowski (2004).

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2. EXPERIMENT SETUP

To account for a variety of atmospheric and soil conditions, simulations with 1-D WRF are performed using a set of initial conditions derived from measurements at the Atmospheric Radiation Measurement Program (ARMP) site during the Bow Echo And Mesoscale Convective Vortex EXperiment (BAMEX) field experiment (from 03 May to 14 July, 2003). The measurements including atmospheric soundings and surface observations of wind, temperature, and mixing ratio are obtained twice daily at 1130 UTC (0530 LST) and 2330 UTC (1730LST). Soil temperature and moisture are measured at corresponding times. Forcings to the model are provided from measurements of downwelling shortwave and longwave radiation and precipitation (both at half-hourly interval) while geostrophic wind is obtained from hourly RUC model analyses. Currently, no account is taken for horizontal and vertical advection. The forcings are linearly interpolated in time at every model time step. 12-hourly 1-D WRF forecasts are issued to simulate diurnal and nocturnal BLs starting at 1130 UTC and 2330 UTC, respectively.

Following specifications of the site description record, USGS agriculture category (LU=2), "dry land, cropland and pasture" vegetation type (IVGTYP=2), and "silt loam" soil type are assigned. Vegetation fraction is set to 0.35. Physics packages from WRFV2.1.2 release are used.

Here, only simulations for the diurnal BLs (*i.e.* initialized at 1130 UTC) will be considered, and the analysis will be limited to potential temperature and moisture. A more complete presentation, including surface forcings of the atmospheric model through the observed fluxes will be given at the conference.

3. RESULTS AND ANALYSIS

Mean vertical profiles of potential temperature at 0530, 0830, 1130, 1430, and 1730 LST, which were obtained by averaging all the 1-D forecasts issued over the period of the field experiment are shown in Fig. 1. Potential temperature profiles indicate that results from the YSU and MRF with any of the LSMs are, in general, similar for these two schemes. When coupled with NOAH, all the BL schemes (YSU, MRF, and MYJ) display very similar positive biases and BLs that are too deep compared to the soundings. When coupled with the RUCLSM, the YSU and MRF are close to the observations in the middle of the day and the BLs are slightly too warm and too deep in the late afternoon. Forecasts issued using the MYJ coupled with the RUCLSM have a negative temperature bias throughout the day and BLs that are too shallow. Simulations with the FRB, despite its simplicity, are very close to the RUCLSM. Cooling above the BL in YSU and MRF which can be attributed to the parameterized turbulent transport across the inversion distinguishes these schemes from the MYJ where turbulence only occurs downgradient. Good agreement of the MYJ with observations above the BL as opposed to the divergence between the YSU and MRF simulations and reality is somewhat surprising. It is not clear whether this positive aspect of the MYJ forecasts is a result of the canceling effects of radiative heating/cooling, advection, and turbulent transport or their small magnitudes.

Figure 2 shows a comparison of mixing ratio profiles from model and soundings. As previously for the potential temperature, forecasts of the mixing ratio for both the YSU and MRF are very similar. When coupled with the NOAH, these schemes display the largest dry bias. The MYJ coupled with the NOAH ameliorates the dry bias in the middle of the day but equally fails to reproduce observed moistening of the BL in the late afternoon. Simulations using the YSU and MRF with RUCLSM are closer to reality in that they reproduce the moistening in the late afternoon but moist bias, albeit smaller in absolute value than the dry bias for NOAH, is present. Coupling the MYJ with the RUCLSM results in BLs which do not reflect observed surface drying in the middle of the day; though moistening in the late afternoon is reproduced but with large positive bias present. As for the potential temperature, the FRB results are similar to results obtained with the RUCLSM.

Figure 3, where fluxes of sensible heat and moisture are plotted, provides some explanations for Figs. 1 and 2. Sensible heat fluxes calculated with NOAH are systematically larger than observed while the opposite is true for the moisture fluxes. The RUCLSM provides sensible fluxes that on average compare favorably with measurements but display limited variance in combination with MYJ. Fluxes of moisture obtained with the RUCLSM are too large, especially in the afternoon, and apparently contribute to BLs that are too moist as seen in Fig. 2. Again, results with the FRB are similar to the RUCLSM.

4. CONCLUSIONS

The analysis of diurnal BL simulations with the 1-D WRF model leads us to the following conclusions. It appears that differences in the prediction of the evolution of the BL between YSU and MRF are small. Forecasts issued using these two schemes with the NOAH as well as the MYJ with the NOAH show warm and dry bias and too deep BL during the day. Better agreement with soundings, especially in the middle of the day, is achieved when the YSU and MRF are coupled with the RUCLSM. When the MYJ and RUCLSM are coupled, cold and moist bias is present throughout the day. Results obtained with the FRB are comparable to those obtained with the RUCLSM. Recent changes in the MYJ scheme and the NOAH LSM lead to their modified behavior compared to the versions in the previous releases of WRF. To confirm generality of the above findings over a broader range of atmospheric conditions, landuse categories and soil and vegetation types, it would be beneficial to evaluate the model against a more comprehensive data. Also, elucidation of the role of radiative heating/cooling of the atmosphere and advection would provide more confidence in these results. Nevertheless, we believe that even the current assessment provides guidance on a proper choice of BL schemes and LSMs combinations in the 3-D forecasts with WRF so that the observed model biases can be diminished.

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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.

Janjic, Z. I., 2001: Nonsingular Implementation of the Mellor-Yamada Level 2.5 Scheme in the NCEP Meso model. NOAA/NWS/NCEP Office Note #437, 61 pp.

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.

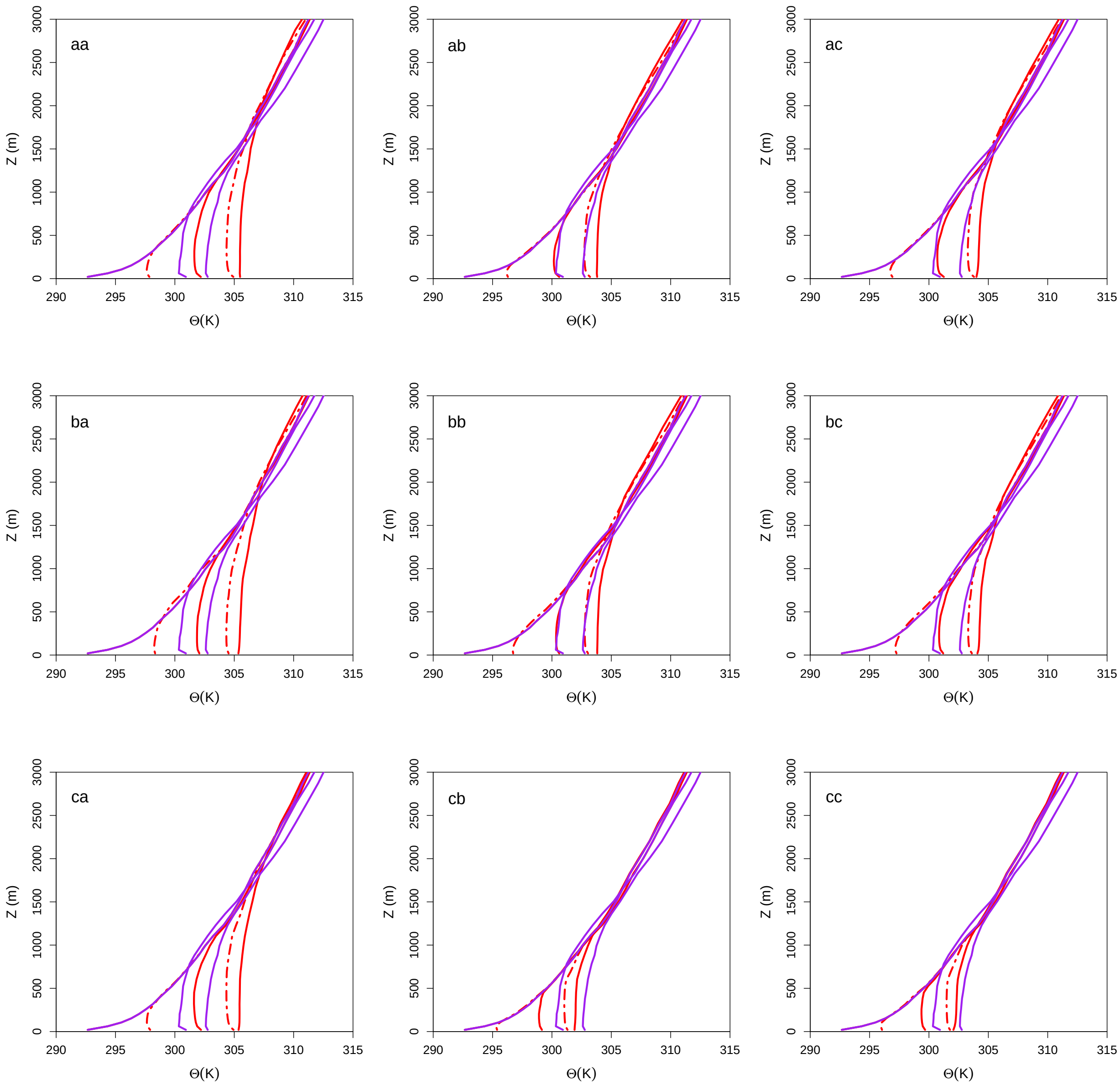

Figure 1: Mean vertical profiles of potential temperature at 0530(solid), 0830(dot-dashed, model only), 1130(solid), 1430(dot-dashed, model only), and 1730(solid) LST for different boundary layer schemes (first label letter): a – YSU, b – MRF, c – MYJ and land-surface schemes (second label letter): a – NOAH, b – RUCLSM, c – FRB. Red – model, purple – observations.

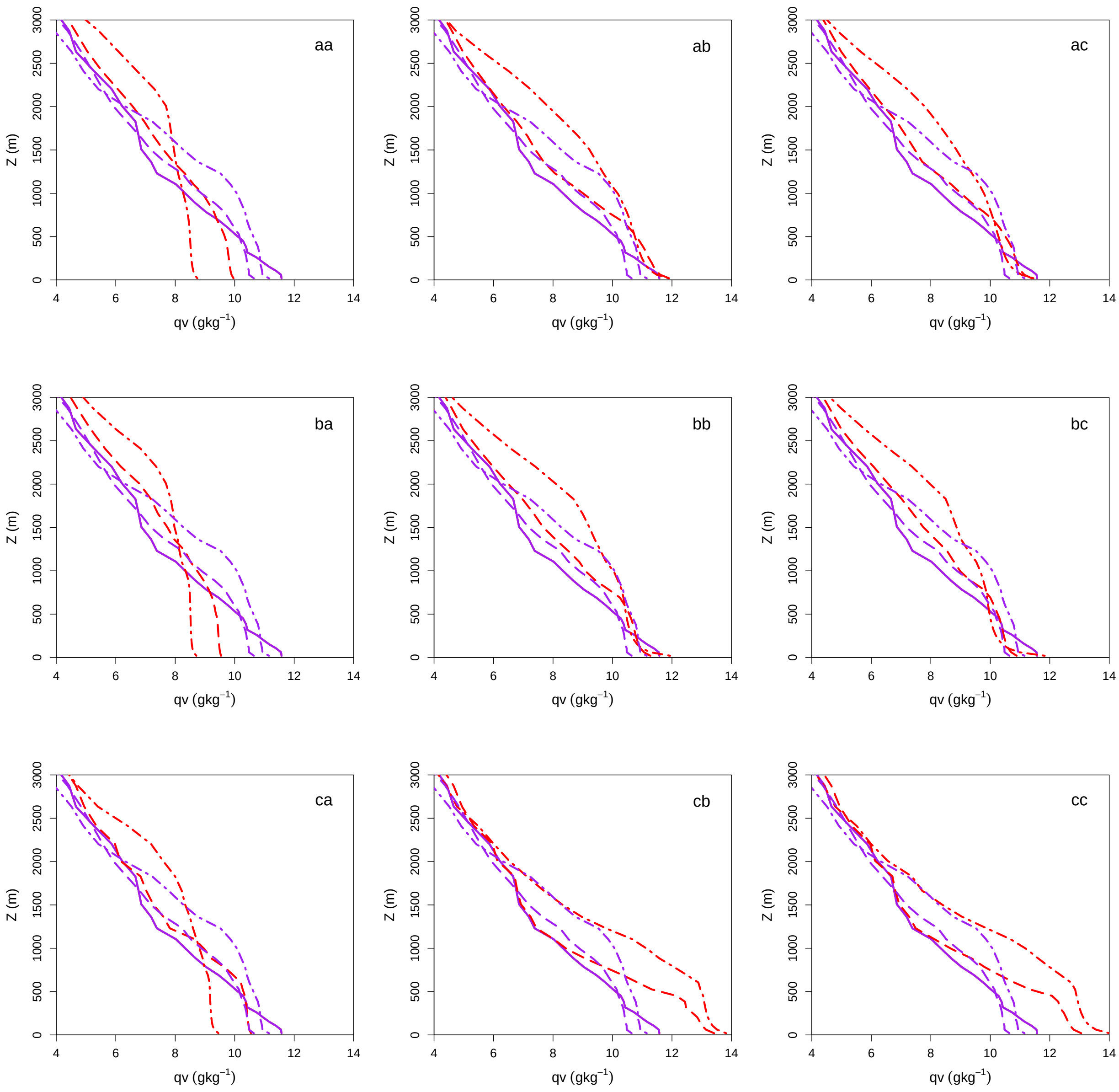

Figure 2: Mean vertical profiles of mixing ratio at 0530(solid), 1130(dashed), and 1730(dot-dashed) LST for different boundary layer schemes (first label letter): a – YSU, b – MRF, c – MYJ and land-surface schemes (second label letter): a – NOAH, b – RUCLSM, c – FRB. Red – model, purple – observations.

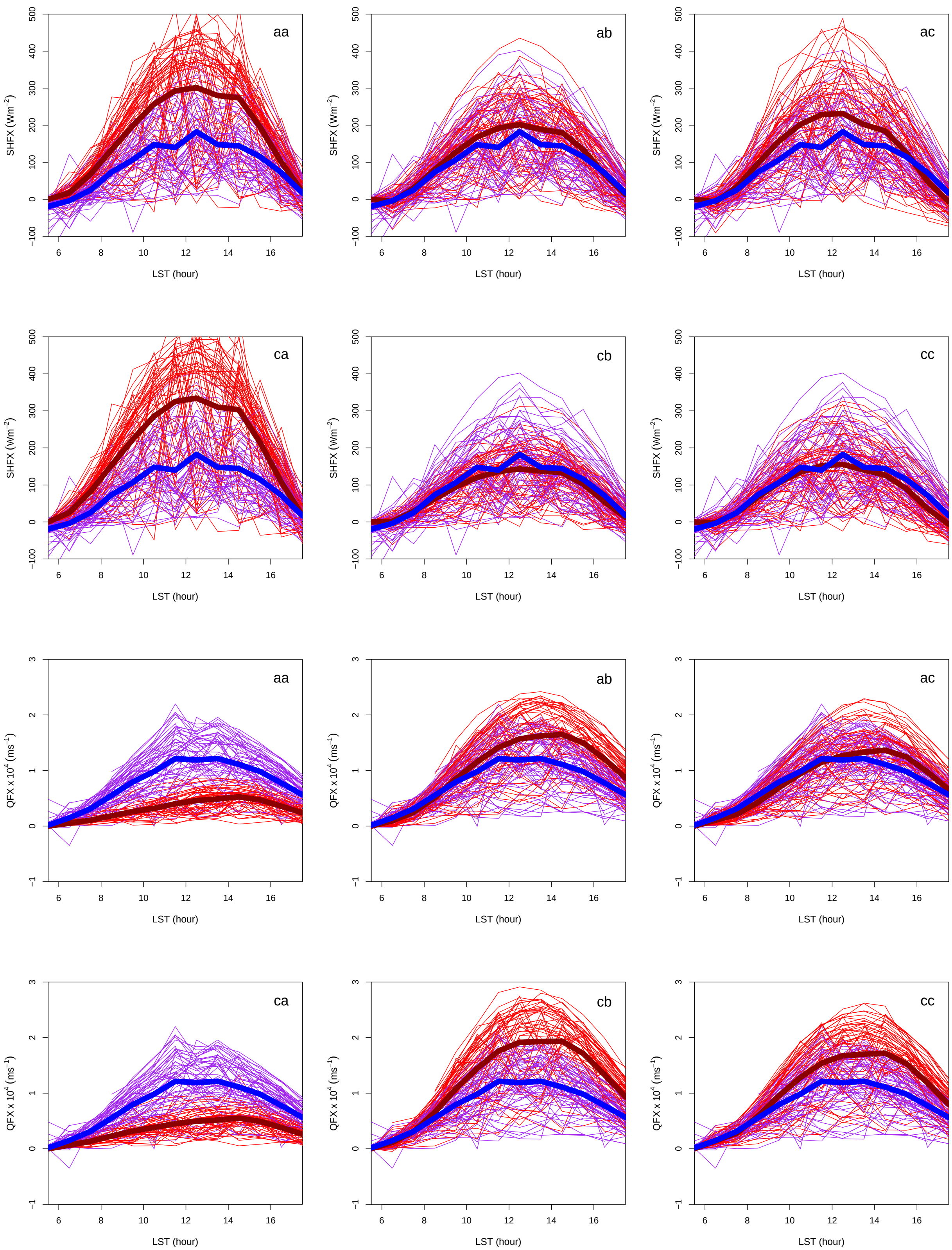

Figure 3: Time series of daytime sensible heat fluxes (top two panels) and moisure fluxes (bottom two panels) for different boundary layer schemes (first label letter): a – YSU, c – MYJ and land-surface schemes (second label letter): a – NOAH, b – RUCLSM, c – FRB; model (red) and observations (purple); mean fluxes plotted with heavy solid lines, model – dark red, observations – blue.