Evaluation of coupling the Noah-MP land surface model with urban canopy models in WRF for a semiarid urban environment

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Overview:

- Introduction
- Application area
- WRF-simulations
- Results
- Conclusions

Introduction

• To address environmental issues NCAR (in collaboration with research groups) has developed the WRF/Urban modeling system to parameterize urban surface processes (they worked with the Noah land surface model):

1) **Bulk approach** (sf_urban_physics=0). It represents zero-order effects of urban surfaces.

2) **Single-layer urban canopy model** (SUCM, sf_urban_physics=1). It recognizes three different urban surfaces (roofs, roads, and vertical walls) and shadowing, reflections, and radiation trapping are solved in the urban canyon.

3) **Multilayer urban canopy model** (BEP, sf_urban_physcis=2). It recognizes three different urban surfaces and allows a direct interaction with the atmosphere. Buildings (vertically distributed) are considered sources/sinks of heat and momentum through the whole urban canopy layer.

4) **Multilayer building energy model** (MBEM, sf_urban_physics=3). A simple BEM integrated in the multilayer urban canopy model (BEP, sf_urban_physics=2).

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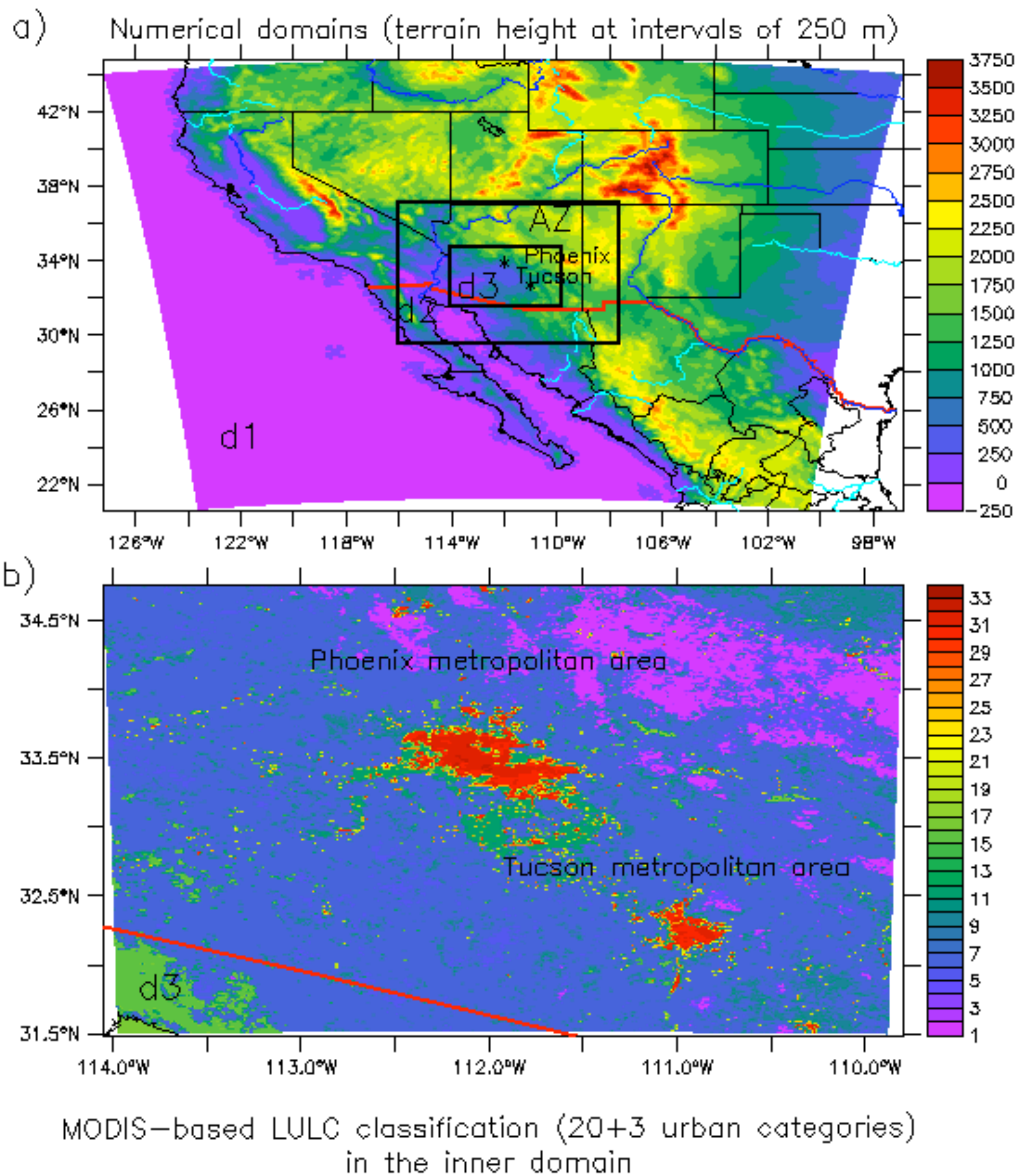
We have augmented the capabilities of the WRF/Urban modeling system by coupling the three urban canopy models (sf_urban_physics=1, 2, 3) with the Noah-MP land surface model.

Application area

- We focus on the rapidly expanding Phoenix and Tucson metropolitan areas in Arizona (USA).
- Our emphasis on a semiarid urban environment is justified because anticipated greater urban growth rates are expected in future decades relative to other ecological zones.
- Development of reliable physics-based predictive modeling tools that are able to quantify co-benefits and reveal tradeoffs associated with the conversion of natural to agricultural and urban landscapes is needed to address challenges associated with a continuously growing urban population.

WRF-simulations

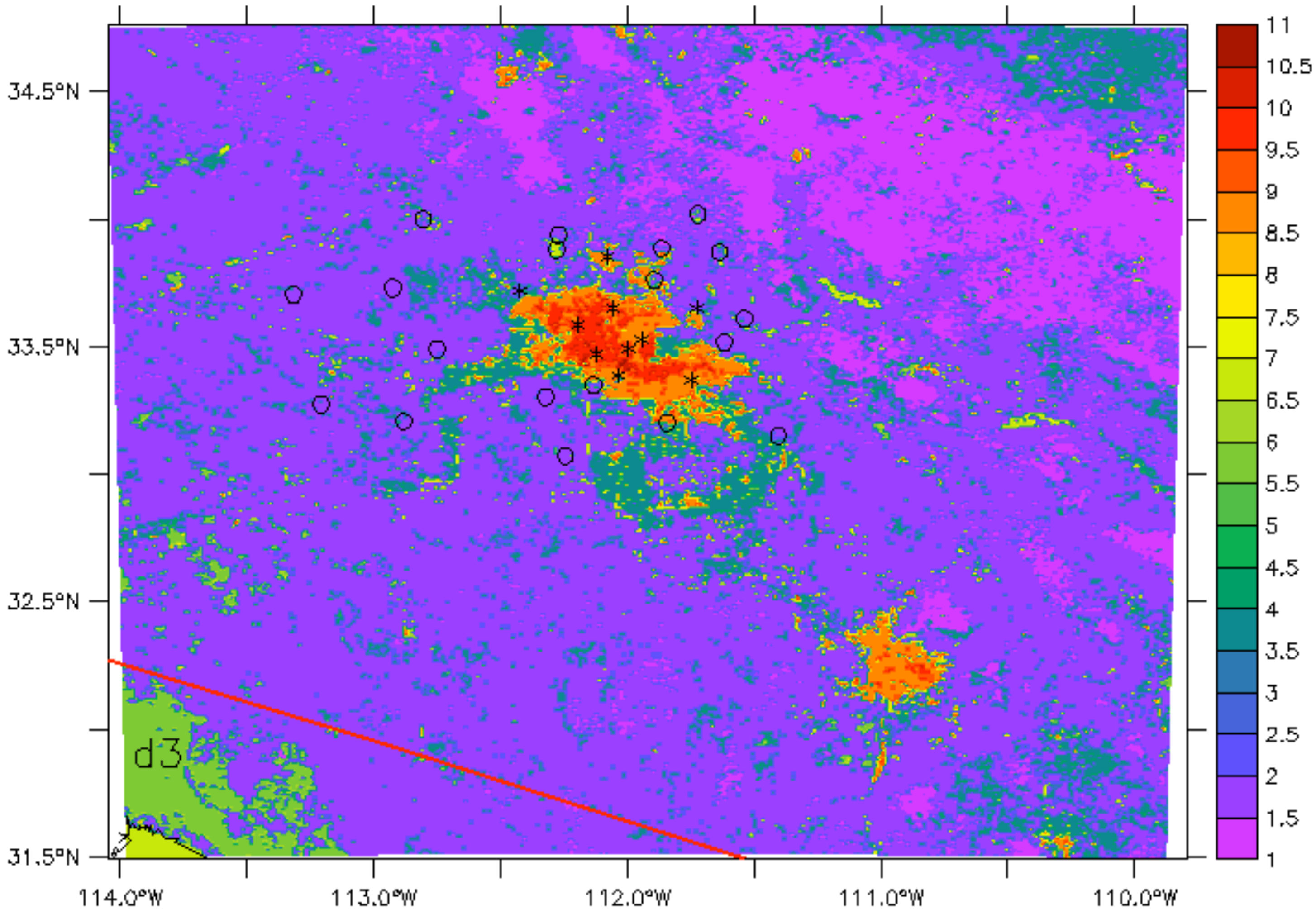
WRF-model (V3.7.1) experiment	Land surface model	Urban physics parameterization
NH_BULK	Noah	Bulk (sf_urban_physics=0)
NH_SUCM	Noah	Single layer urban canopy model (sf_urban_physics=1)
NH_MBEM	Noah	Multilayer building energy model (sf_urban_physics=3)
NHMP_BULK	Noah-MP	Bulk
NHMP_SUCM	Noah-MP	Single layer urban canopy model
NHMP_MBEM	Noah-MP	Multilayer building energy model



- Six WRF-model (V3.7.1) simulations were performed with three two-way nested domains with a grid spacing of 9, 3, and 1 km respectively (the number of vertical sigma pressure levels was 40).
- The simulations were conducted with the NCEP North American Regional Reanalysis data (number ds608.0) covering a 5-day extreme heat period from 00 LT June 26 to 23 LT June 30, 2013.
- The US Geological Survey 30m 2006 National Land Cover Data set was used to represent modern-day LULC within the Noah and Noah-MP land surface models for the urban domain. Three different urban classes describe the morphology of the cities: COI, HIR and LIR.

MODIS-based LULC and urban classification (shaded based on Fry et al., 2011)
Weather stations deployed within the Flood Control District of Maricopa County (FCDMC)
(o=rural, *=urban) for model evaluation

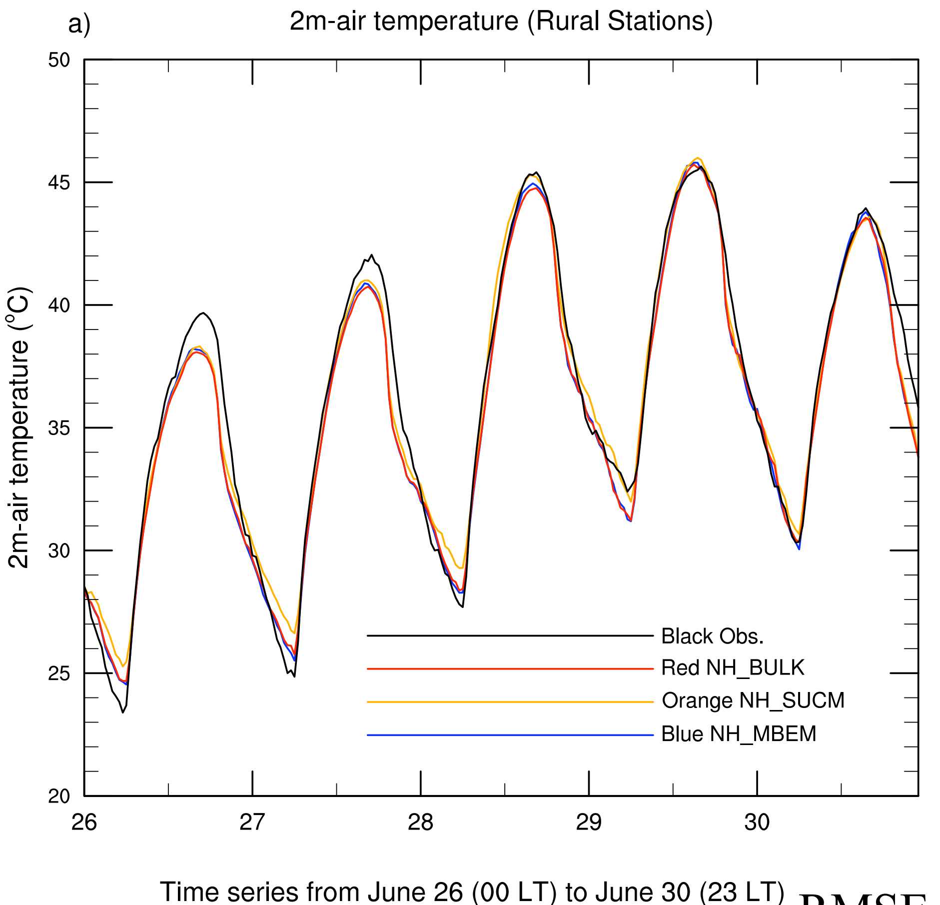
19 rural and 10 urban weather stations were considered for WRF model evaluation



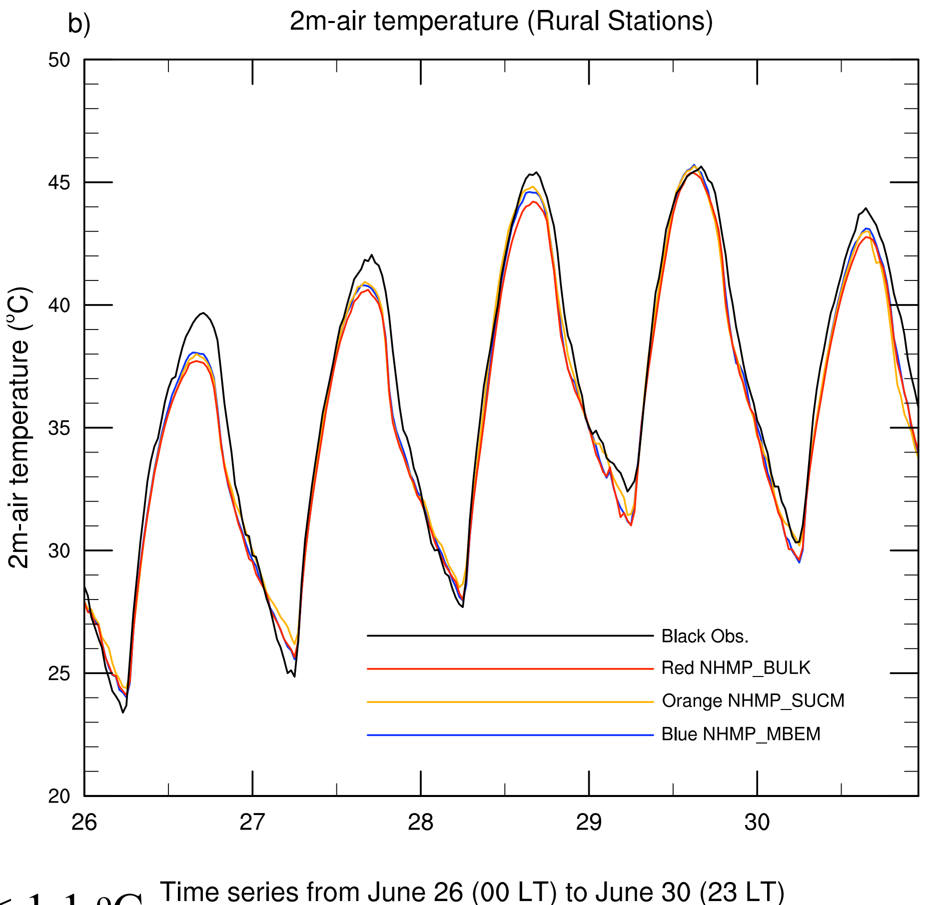
1: Forests, 2: Shrublands, 3: Savannas, 4: Wetlands/Croplands/Grasslands
5: Snow/Ice, 6: Barren/Sparsely vegetated, 7: Water, 8: Tundra
9: Urban (LIR), 10: Urban (HIR), 11: Urban (COI)

Results (2-m air temperature)

(a) Time series of observed and WRF-Noah modeled 2-m air temperature (^{o}C) averaged over all rural stations during the 5-day extreme heat period in June 2013. (b) Same as in (a) but using the Noah-MP land surface model.



WRF-Noah LSM



WRF-NoahMP LSM

RMSE < 1.1 ^{o}C
MAE < 1.0 ^{o}C

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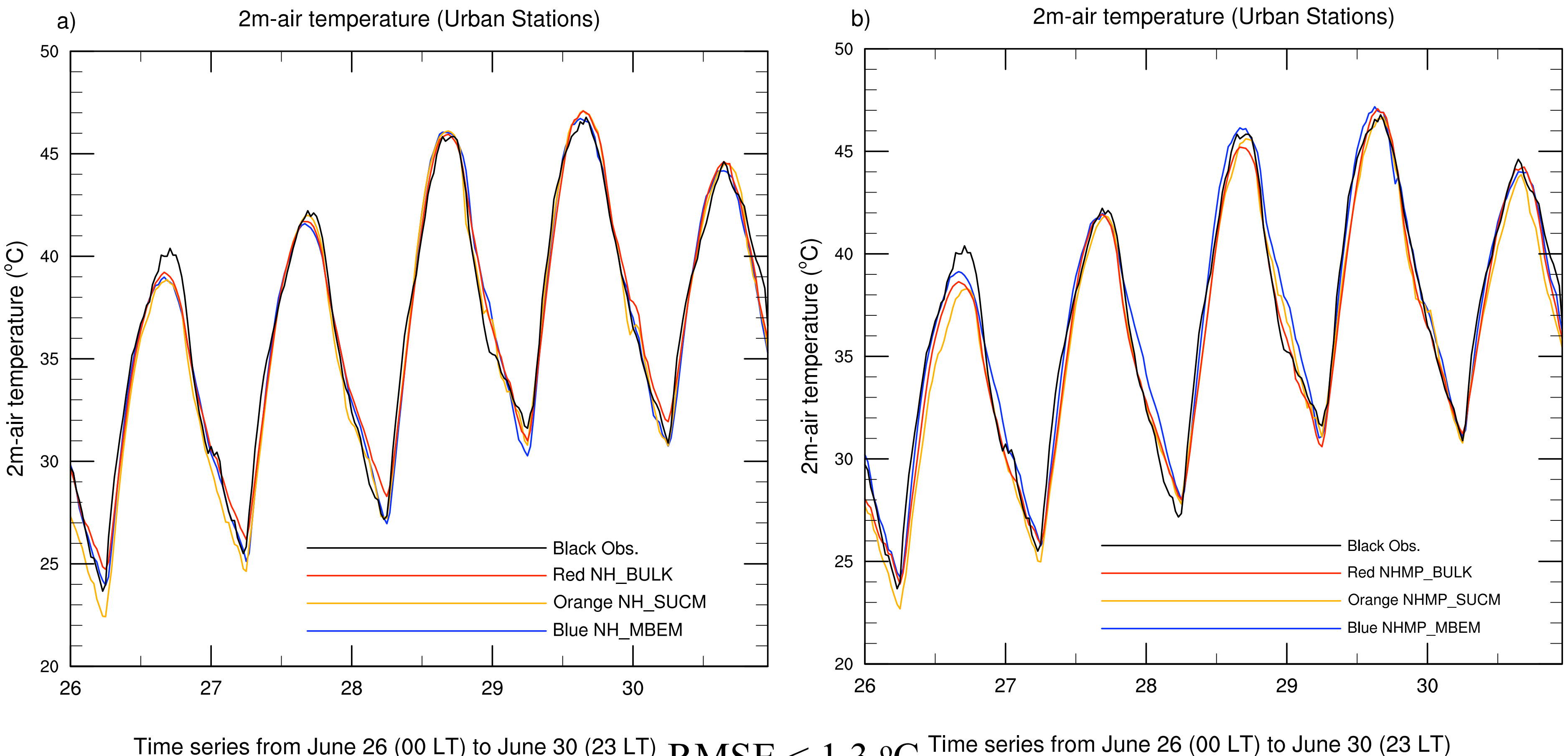


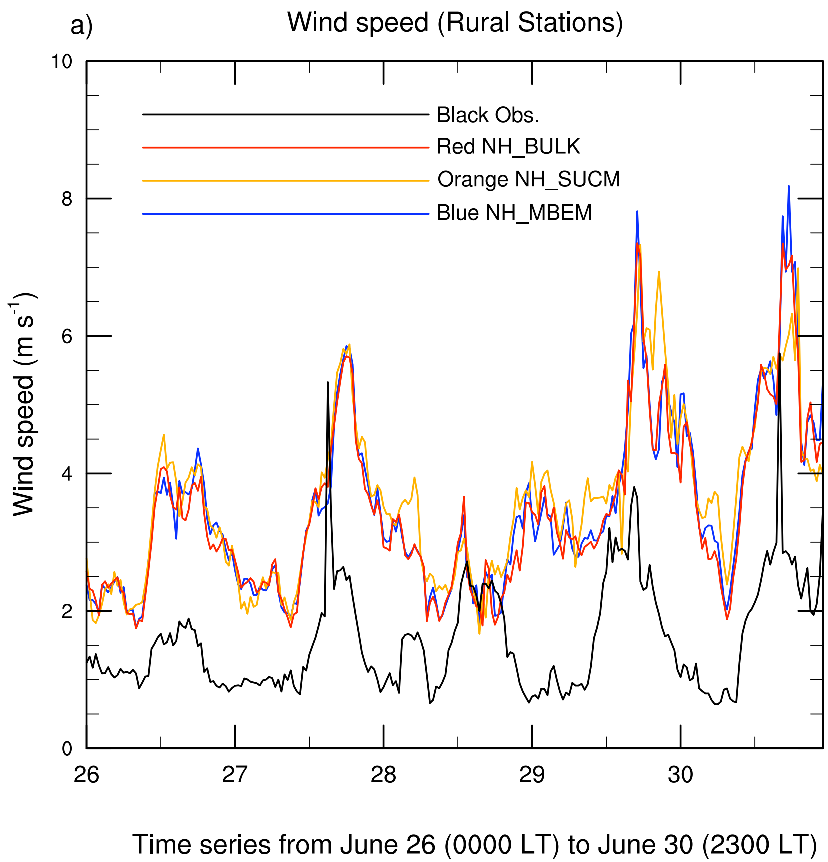
WRF-Noah LSM

RMSE < 1.3 °C
MAE < 1.0 °C

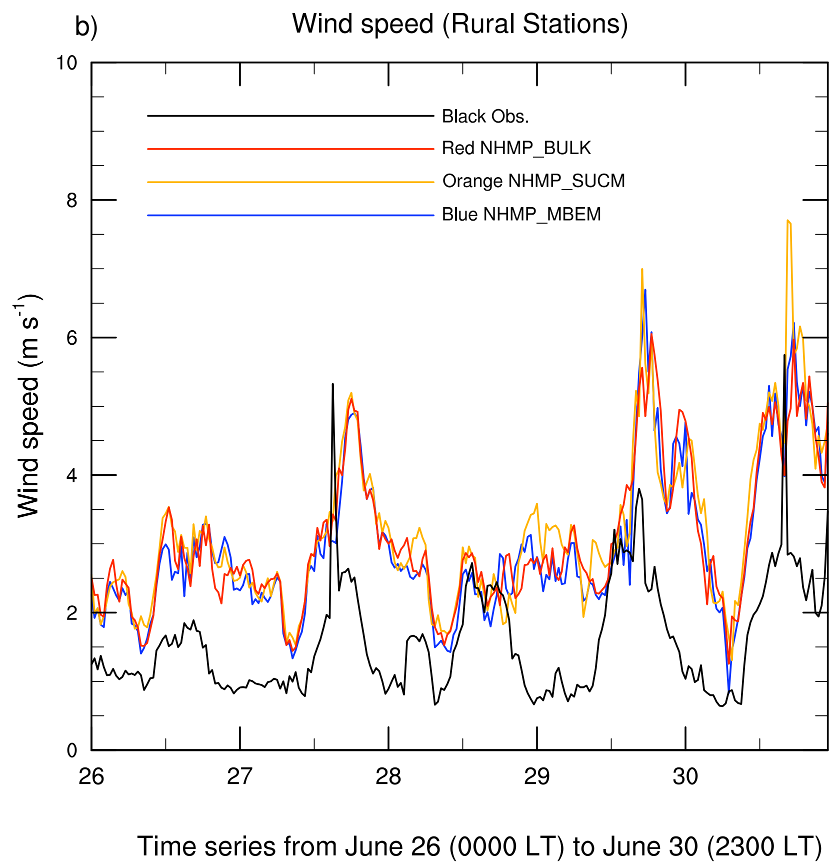
WRF-NoahMP LSM

Results (10-m wind speed)

(a) Time series of observed and WRF-Noah modeled 10-m wind speed (m s^{-1}) averaged over all rural stations during the 5-day extreme heat period in June 2013. (b) Same as in (a) but using the Noah-MP land surface model.



WRF-Noah LSM



WRF-NoahMP LSM

WRF-NoahMP LSM reduced considerably the RMSE and MAE compared to WRF-Noah

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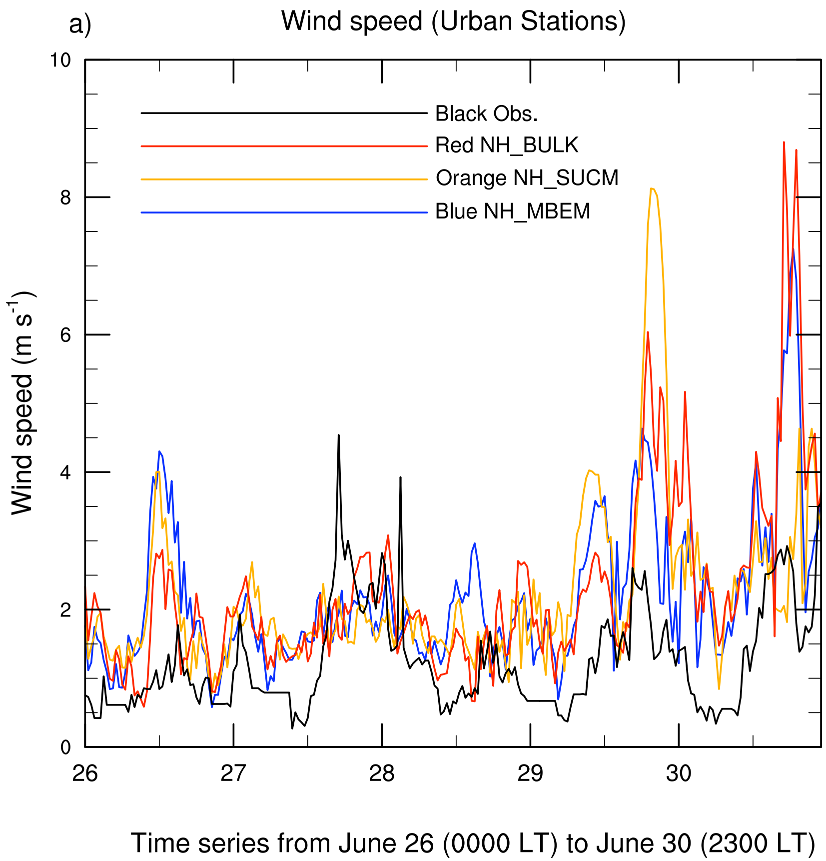
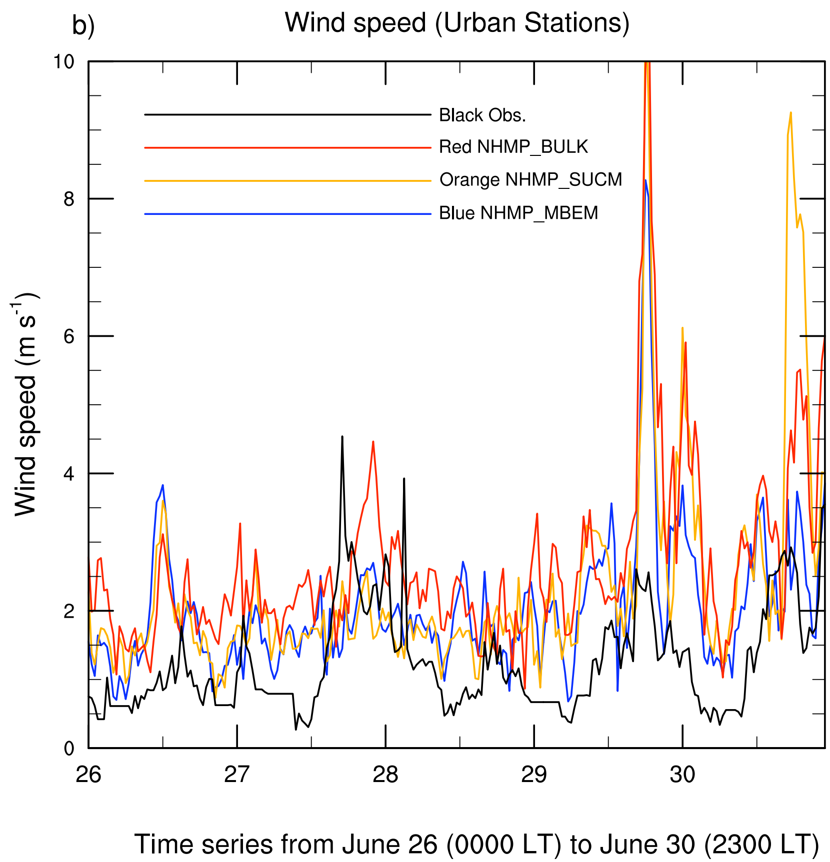




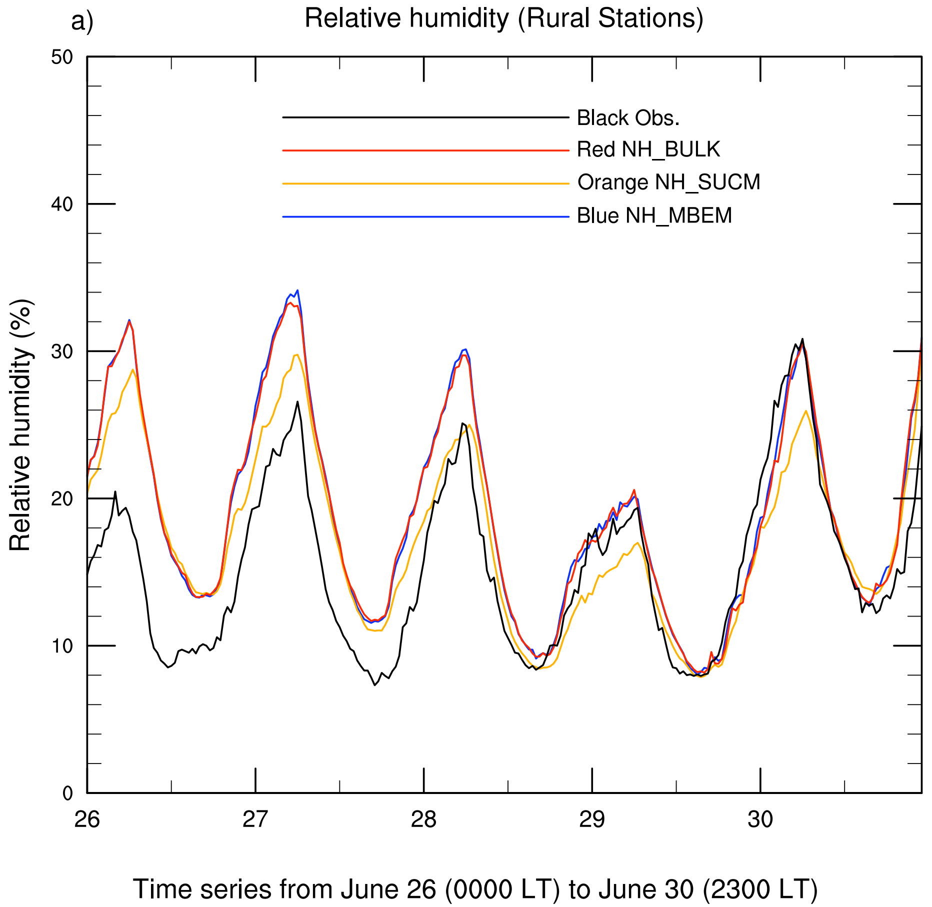
WRF-Noah LSM

WRF-NoahMP LSM

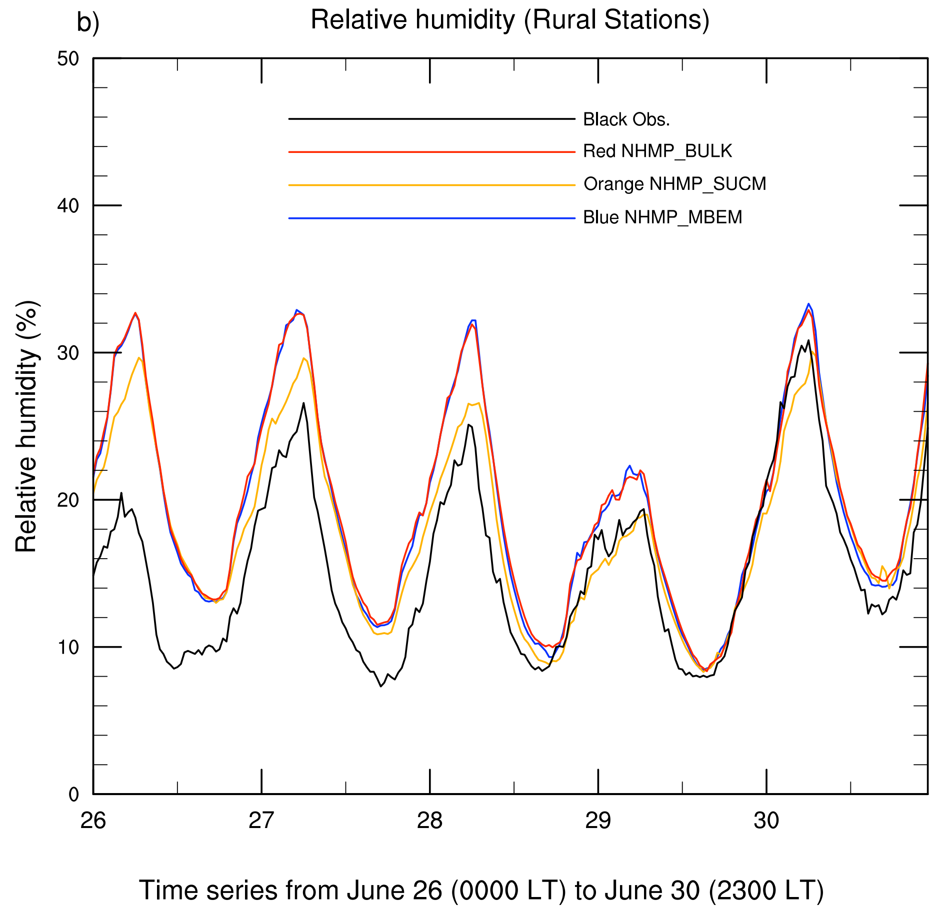
The MBEM reduced both the RMSE and MAE compared to BULK and SUCM

Results (near-surface relative humidity)

(a) Time series of observed and WRF-Noah modeled near-surface relative humidity (%) averaged over all rural stations during the 5-day extreme heat period in June 2013. (b) Same as in (a) but using the Noah-MP land surface model.



WRF-Noah LSM

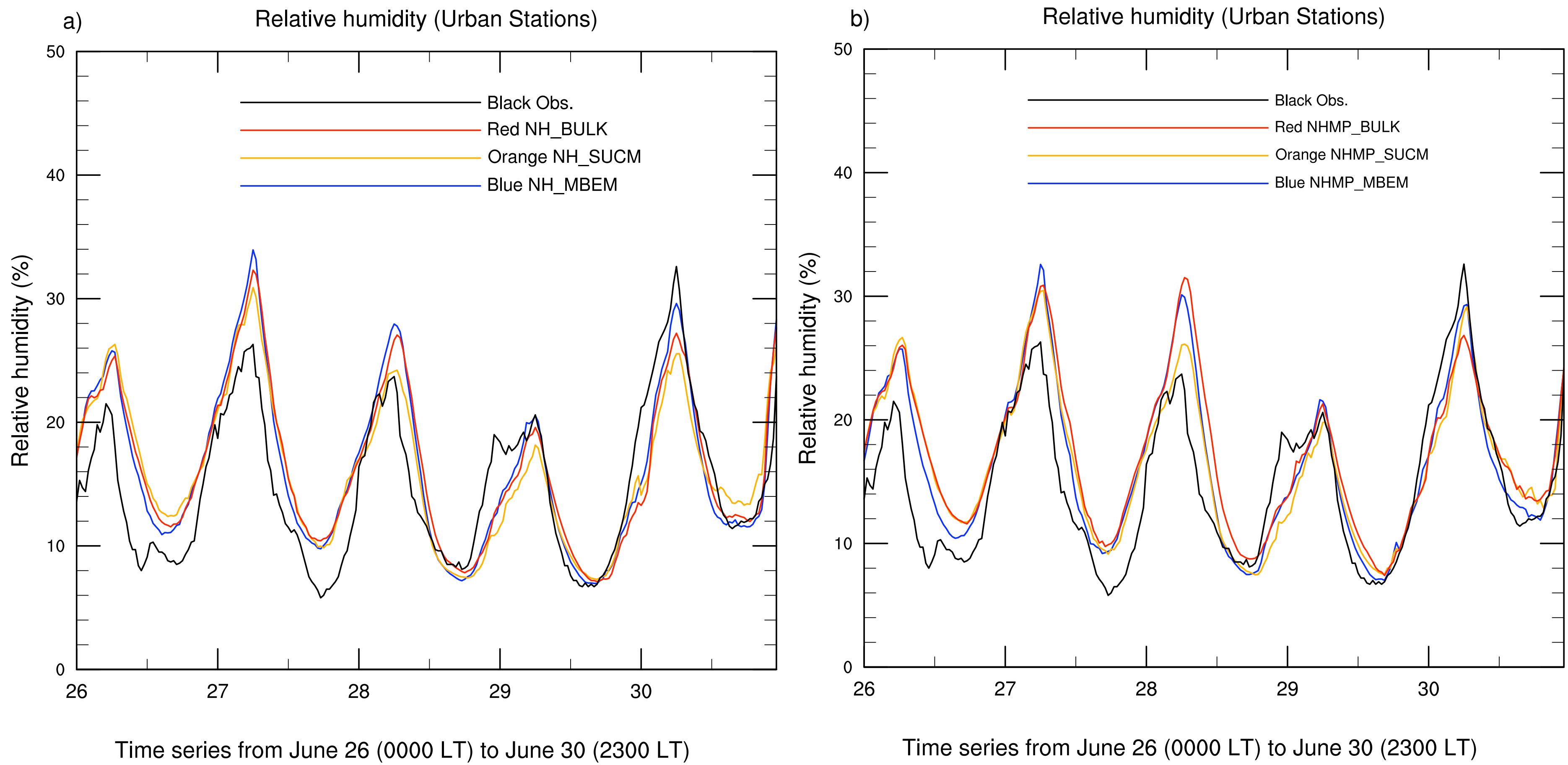


WRF-NoahMP LSM

Both WRF-Noah and WRF-NoahMP experiments produced similar RMSE and MAE

Results (near-surface relative humidity)

(a) Time series of observed and WRF-Noah modeled near-surface relative humidity (%) averaged over all urban stations during the 5-day extreme heat period in June 2013. (b) Same as in (a) but using the Noah-MP land surface model.



WRF-Noah LSM

WRF-NoahMP LSM

Results

Root-mean-square (RMSE) and mean absolute (MAE) errors for 2-m air temperature (^{o}C), 10-m wind speed (m s^{-1}), and near-surface relative humidity (%) for all WRF experiments and rural weather stations

	NH_BULK	NHMP_BULK	NH_SUCM	NHMP_SUCM	NH_MBEM	NHMP_MBEM
RMSE (^{o}C)	0.99	1.14	0.96	1.09	0.97	1.00
MAE (^{o}C)	0.76	0.96	0.73	0.85	0.72	0.81
RMSE (ms^{-1})	2.07	1.69	2.27	1.82	2.15	1.64
MAE (ms^{-1})	1.87	1.51	2.05	1.61	1.93	1.43
RMSE (%)	5.17	5.42	4.21	4.13	5.16	5.29
MAE (%)	4.08	4.45	3.31	3.18	4.03	4.27

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Root-mean-square (RMSE) and mean absolute (MAE) errors for 2-m air temperature (°C), 10-m wind speed (m s^{-1}), and near-surface relative humidity (%) for all WRF experiments and rural weather stations

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RMSE (°C)	0.99	1.14	0.96	1.09	0.97	1.00
MAE (°C)	0.76	0.96	0.73	0.85	0.72	0.81
RMSE (ms^{-1})	2.07	1.69	2.27	1.82	2.15	1.64
MAE (ms^{-1})	1.87	1.51	2.05	1.61	1.93	1.43
RMSE (%)	5.17	5.42	4.21	4.13	5.16	5.29
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	NH_BULK	NHMP_BULK	NH_SUCM	NHMP_SUCM	NH_MBEM	NHMP_MBEM
RMSE (°C)	0.86	1.02	1.02	1.33	0.91	0.95
MAE (°C)	0.72	0.80	0.81	1.05	0.70	0.76
RMSE (ms^{-1})	1.56	1.87	1.60	1.77	1.38	1.25
MAE (ms^{-1})	1.16	1.52	1.18	1.25	1.09	0.98
RMSE (%)	3.97	4.38	4.06	3.80	3.69	3.49
MAE (%)	3.15	3.41	3.32	2.96	2.93	2.67

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Root-mean-square (RMSE) and mean absolute (MAE) errors for 2-m air temperature (^{o}C), 10-m wind speed (m s^{-1}), and near-surface relative humidity (%) for all WRF experiments and urban weather stations

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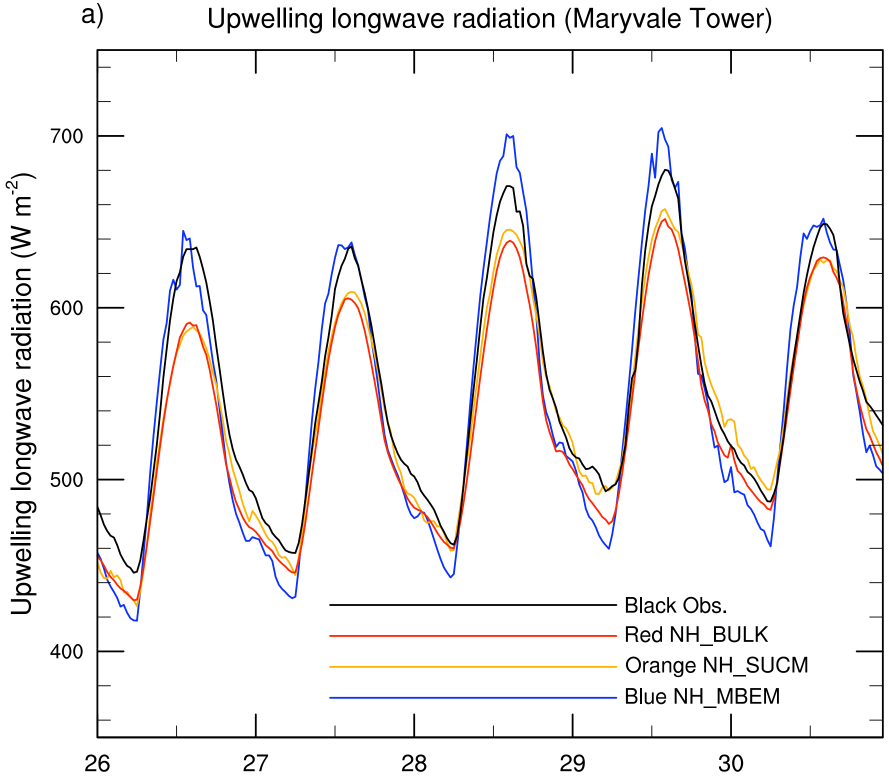
MAE (^{o}C)	0.72	0.80	0.81	1.05	0.70	0.76
RMSE (ms^{-1})	1.56	1.87	1.60	1.77	1.38	1.25
MAE (ms^{-1})	1.16	1.52	1.18	1.25	1.09	0.98
RMSE (%)	3.97	4.38	4.06	3.80	3.69	3.49
MAE (%)	3.15	3.41	3.32	2.96	2.93	2.67

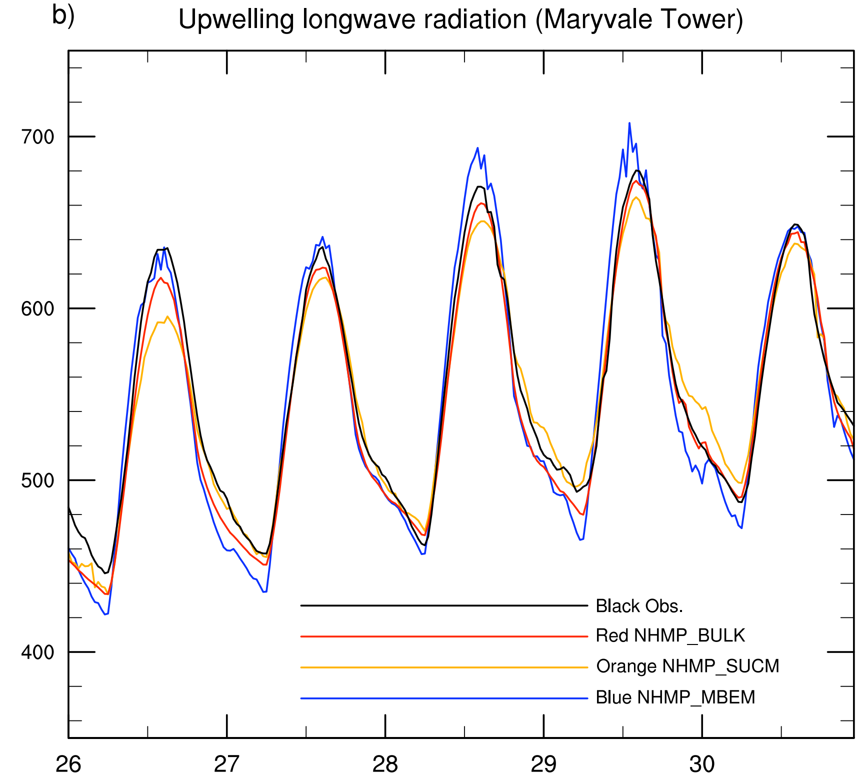
Results (Upwelling LW radiation)

(a) Time series of observed and WRF-Noah modeled upwelling long-wave radiation (W m^{-2}) for the Maryvale urban weather station during the 5-day extreme heat period in June 2013. (b) Same as in (a) but using the Noah-MP land surface model.



Time series from June 26 (0000 LT) to June 30 (2300 LT)

WRF-Noah LSM



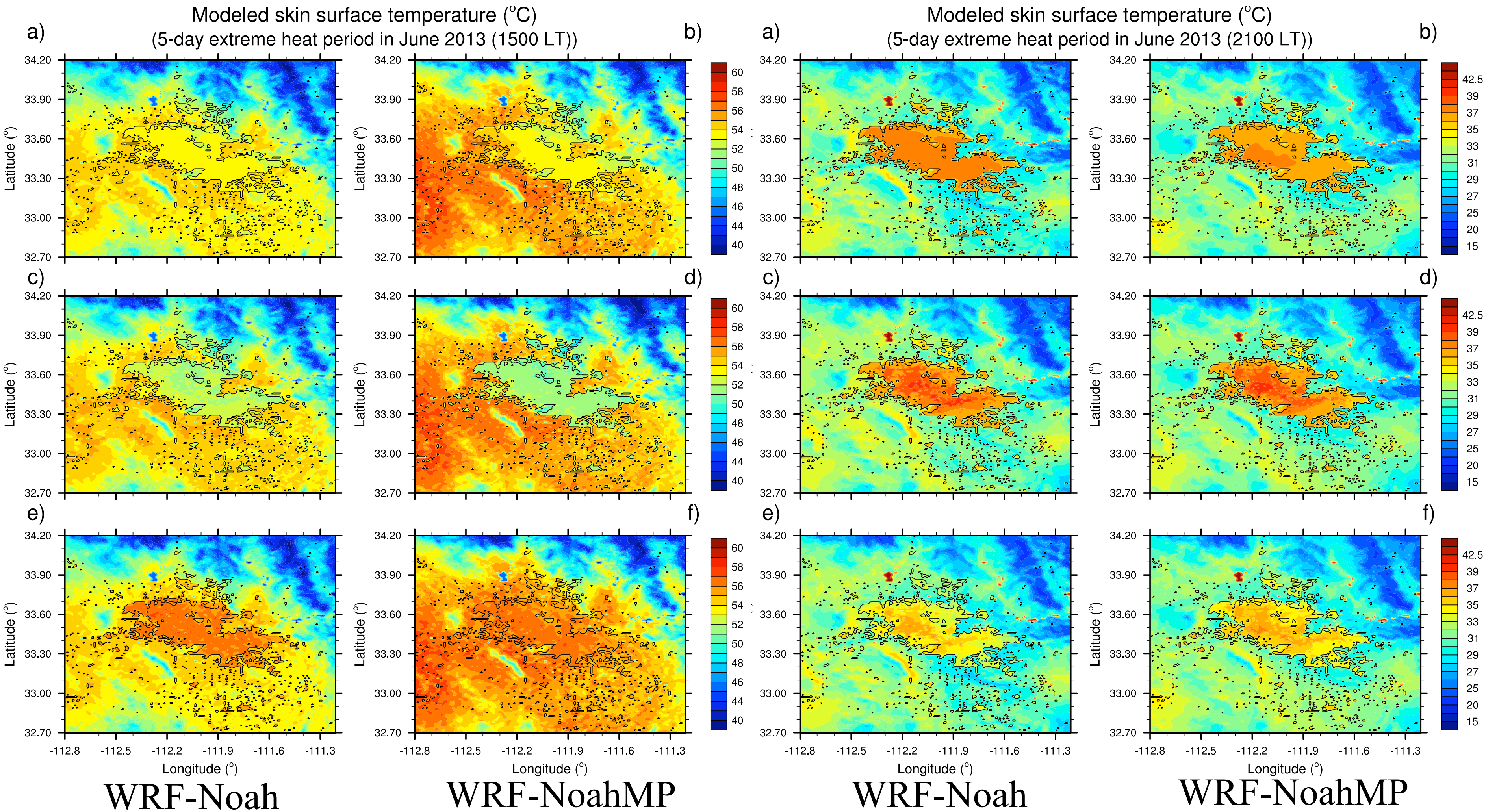
Time series from June 26 (0000 LT) to June 30 (2300 LT)

WRF-NoahMP LSM

$$LW\uparrow = emiss \times \sigma \times (TSK)^4 + (1 - emiss) \times GLW\downarrow$$

Results (Skin-surface temperature)

(a-b) WRF-modeled mean skin surface temperature (^oC) averaged for the entire 5-day extreme heat period in June 2013 at 1500 LT (left) and at 2100 LT (right) for the Phoenix metropolitan area using the BULK scheme. (c-d) Same as in (a-b) but using the SUCM. (e-f) Same as in (a-b) but using the MBEM.



Results

Root-mean-square (RMSE) and mean absolute (MAE) errors for WRF-modeled upwelling long-wave radiation (W m^{-2}) at Maryvale urban weather station

	NH_BULK	NHMP_BULK	NH_SUCM	NHMP_SUCM	NH_MBEM	NHMP_MBEM
RMSE (W m^{-2})	20.82	11.00	16.55	13.91	20.44	17.08
MAE (W m^{-2})	18.19	9.28	13.01	10.60	18.22	14.76

Conclusions

- Noah-MP LSM performed better than Noah LSM for near-surface wind speed.
- Similar errors for near-surface air temperature and relative humidity were computed with both Noah and Noah-MP LSMs compared to observations.
- Concerning built-up areas, all urban schemes produced almost the same errors for near-surface air temperature and relative humidity, but for wind speed the MBEM clearly reduced the bias compared to BULK and SUCM.

Conclusions

Thank you for your attention