Citywide impacts of cool roof and rooftop solar photovoltaic deployment on near-surface air temperature and cooling energy demand

F. Salamanca[1,4], M. Georgescu[2,4], A. Mahalov[1,3,4], M. Moustaoui[1,4], and A. Martilli[5]

[1]School of Mathematical and Statistical Sciences, [2]School of Geographical Sciences and Urban Planning, [3]School of Life Sciences, [4]Julie Ann Wrigley Global Institute of Sustainability, Arizona State University, Tempe, AZ, USA

[5]Research Center for Energy, Environment, and Technology, CIEMAT, Madrid, Spain

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- Introduction

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- Assessment of mitigation strategies that combat global warming, urban heat islands, and urban energy demands is crucial for urban planners and energy providers, specially for semiarid urban environments where summertime cooling demands are excessive.

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- Our emphasis on semiarid urban environments is further justified because anticipated greater urban growth rates are expected in future decades relative to other ecological zones.
- We focus on the rapidly expanding Phoenix (PHX) and Tucson (TUC) metropolitan areas in AZ.

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- Rooftop PV panels model in BEP+BEM

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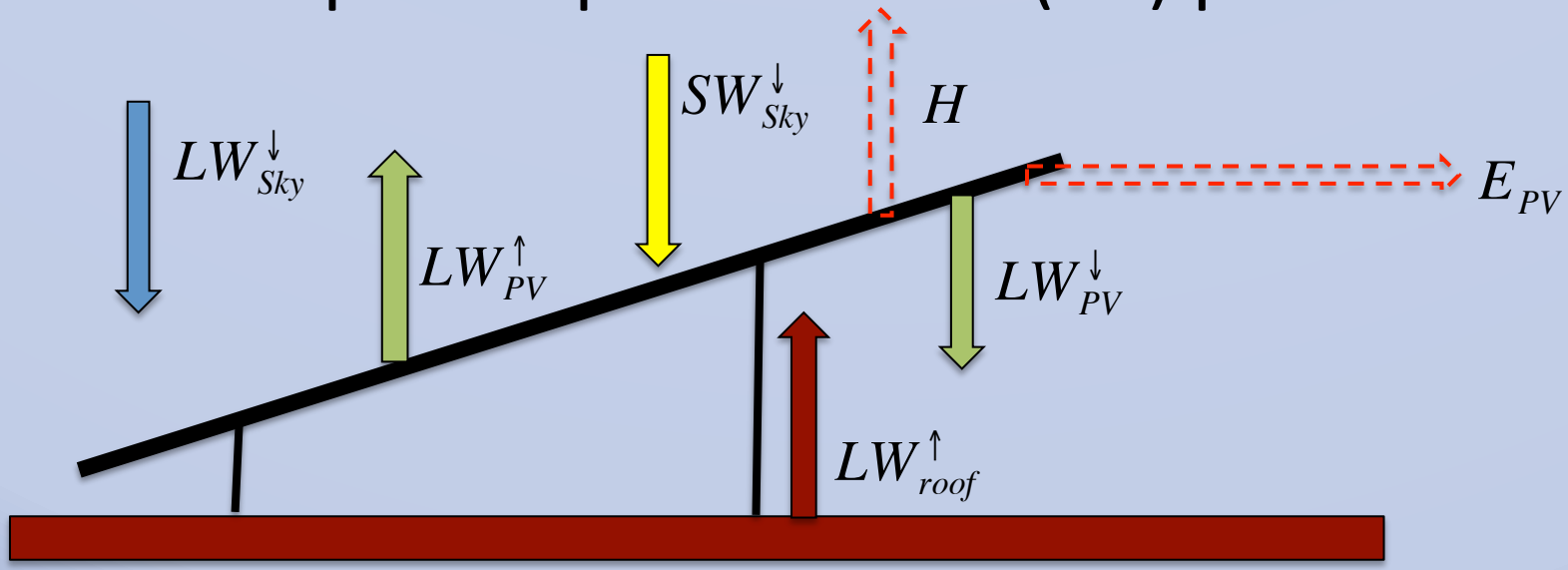
Rooftop solar photovoltaic (PV) panels model

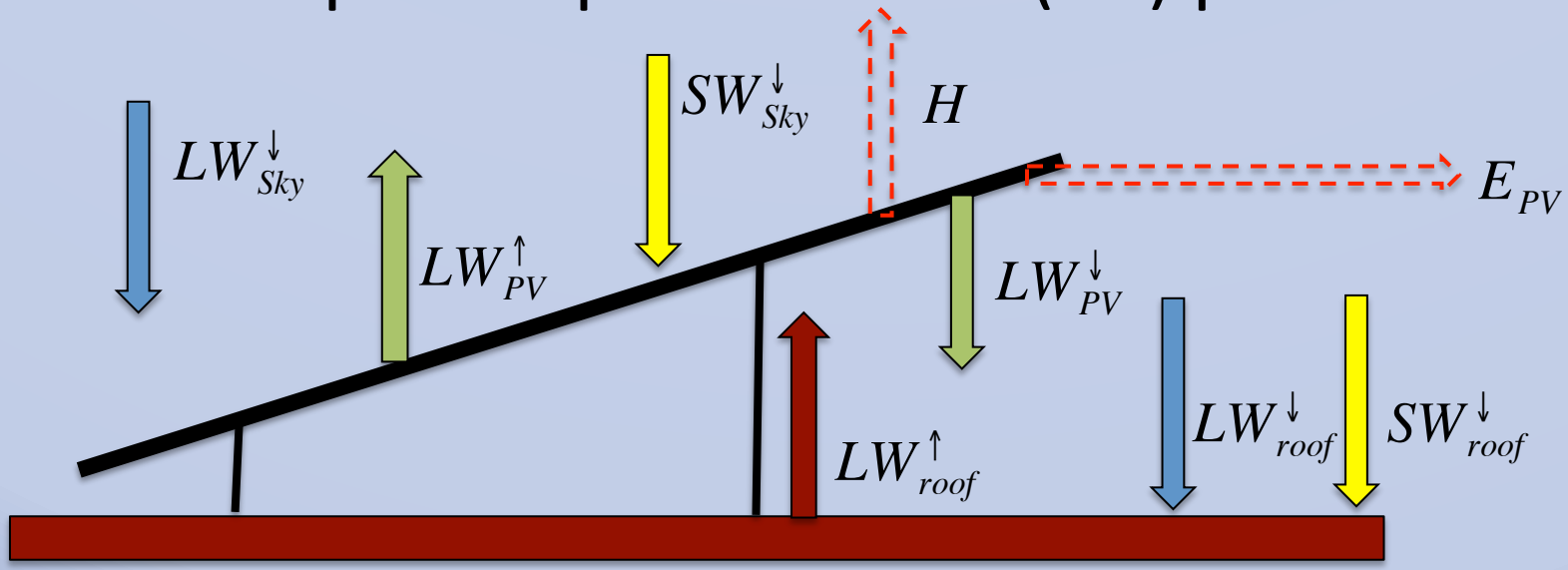


Energy balance equation solved to determine the sensible heat flux H from the rooftop PV panels to the atmosphere:

$$(1-\alpha_{PV})SW^{\downarrow}_{Sky} + LW^{\downarrow}_{Sky} - LW^{\uparrow}_{PV} + LW^{\uparrow}_{roof} - LW^{\downarrow}_{PV} = E_{PV} + H$$

(the parameterization adopted here to describe PV panels in BEP+BEM is based on the scheme proposed by Masson et al. [2014, Frontiers in Environmental Science]).

Rooftop solar photovoltaic (PV) panels model



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The radiative contributions to the surface energy balance of the roof are modified according to the following expressions:

$$SW^{\downarrow}_{roof} = (1-f_{PV})SW^{\downarrow}_{Sky}$$
$$LW^{\downarrow}_{roof} = (1-f_{PV})LW^{\downarrow}_{Sky} + f_{PV}LW^{\downarrow}_{PV}$$

In BEP+BEM a single temperature is still computed, and no distinction is made between the parts under or adjacent to the PV panels.

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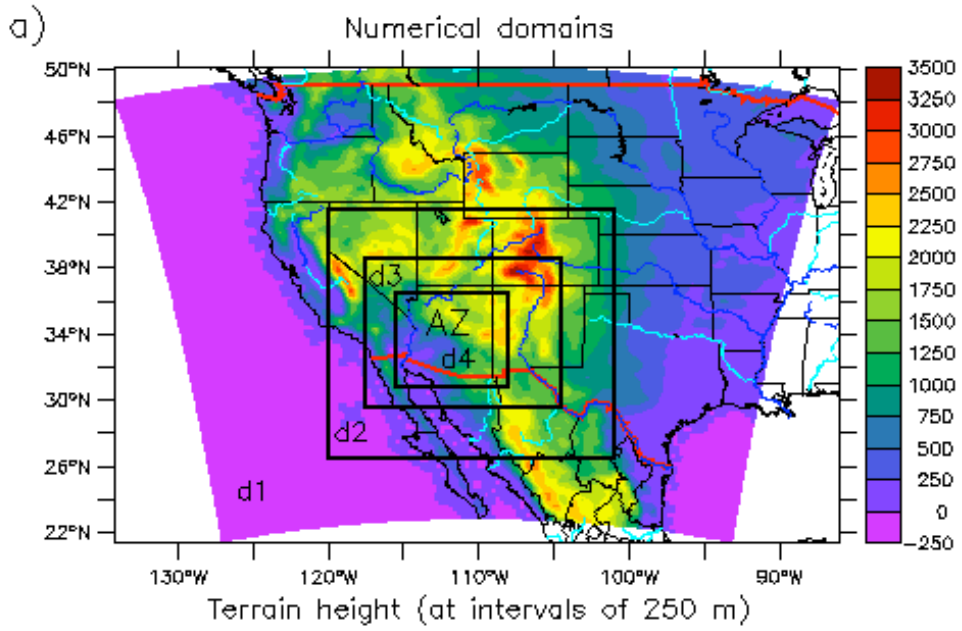
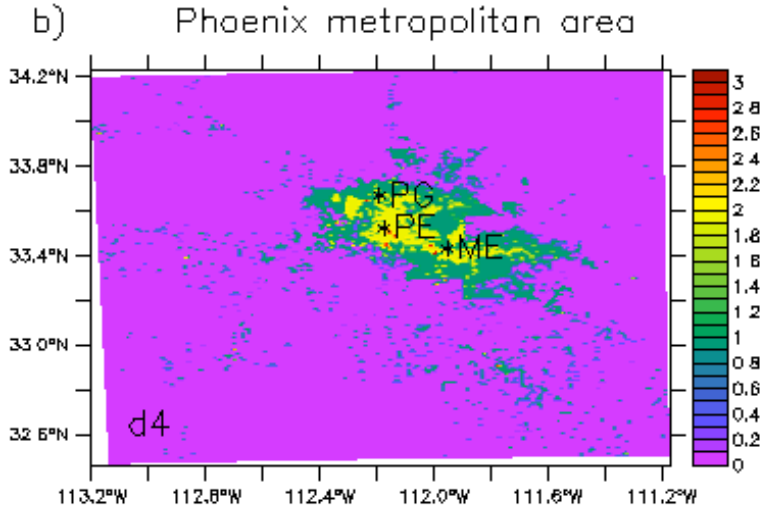
WRF-simulations

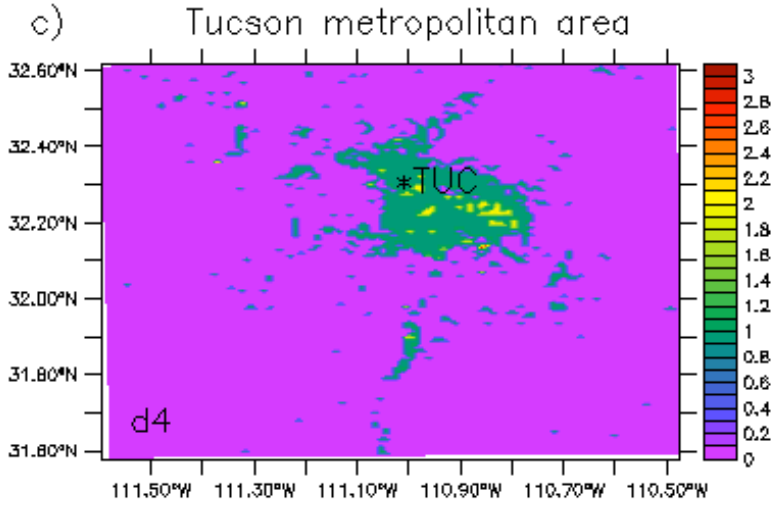
- The twelve WRF (V3.4.1) simulations were performed with four two-way nested domains with a grid spacing of **27, 9, 3, and 1 km** respectively. The number of vertical sigma pressure levels was **40 (14 levels in the lowest ~1.5 km).**
- The simulations were conducted with the NCEP Final Analyses data (number **ds083.2**) covering a **10-day EHD period** from 00 LT July 10 to 23 LT July 19, 2009.
- The US Geological Survey 30m 2006 **NLCD** set was used to represent modern-day LULC within the **Noah-LSM** for the urban domain. Three different urban classes describes the morphology of the cities: **COI, HIR, and LIR**.
- The multilayer building energy parameterization (**BEP+BEM**) was applied to the fraction of grid cells with built cover (sf_urban_physics=3).

135 x 115 domain 1 (27 km)
201 x 183 domain 2 (9 km)
390 x 321 domain 3 (3 km)
615 x 555 domain 4 (1 km)



Urban stations for WRF-model evaluation





1: Low Intensity Residential (Green)
2: High Intensity Residential (Yellow)
3: Commercial or Industrial (Red)

WRF-simulations

WRF-simulations	% of the roof covered with highly reflective membranes	% of the roof covered with PV panels
CTRL_AC	0	0
CTRL_AC_ALB0.25	25	0
CTRL_AC_ALB0.5	50	0
CTRL_AC_ALB0.75	75	0
CTRL_AC_ALB1.0	100	0
CTRL_AC_FPV0.25	0	25
CTRL_AC_FPV0.5	0	50
CTRL_AC_FPV0.75	0	75
CTRL_AC_FPV1.0	0	100
CTRL_AC_FPV0.25_ALB0.75	75 (hybrid scenario)	25
CTRL_AC_FPV0.5_ALB0.5	50 (hybrid scenario)	50
CTRL_AC_FPV0.75_ALB0.25	25 (hybrid scenario)	75

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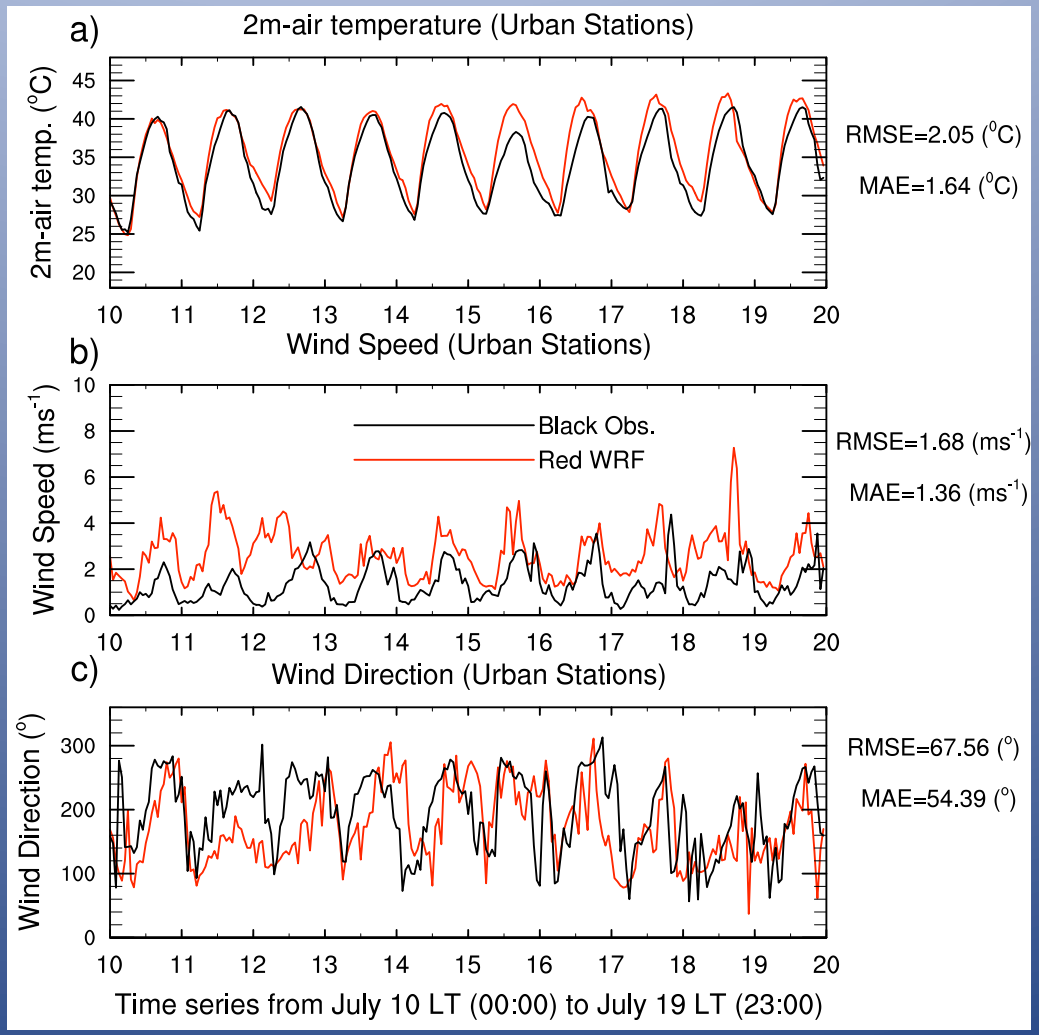
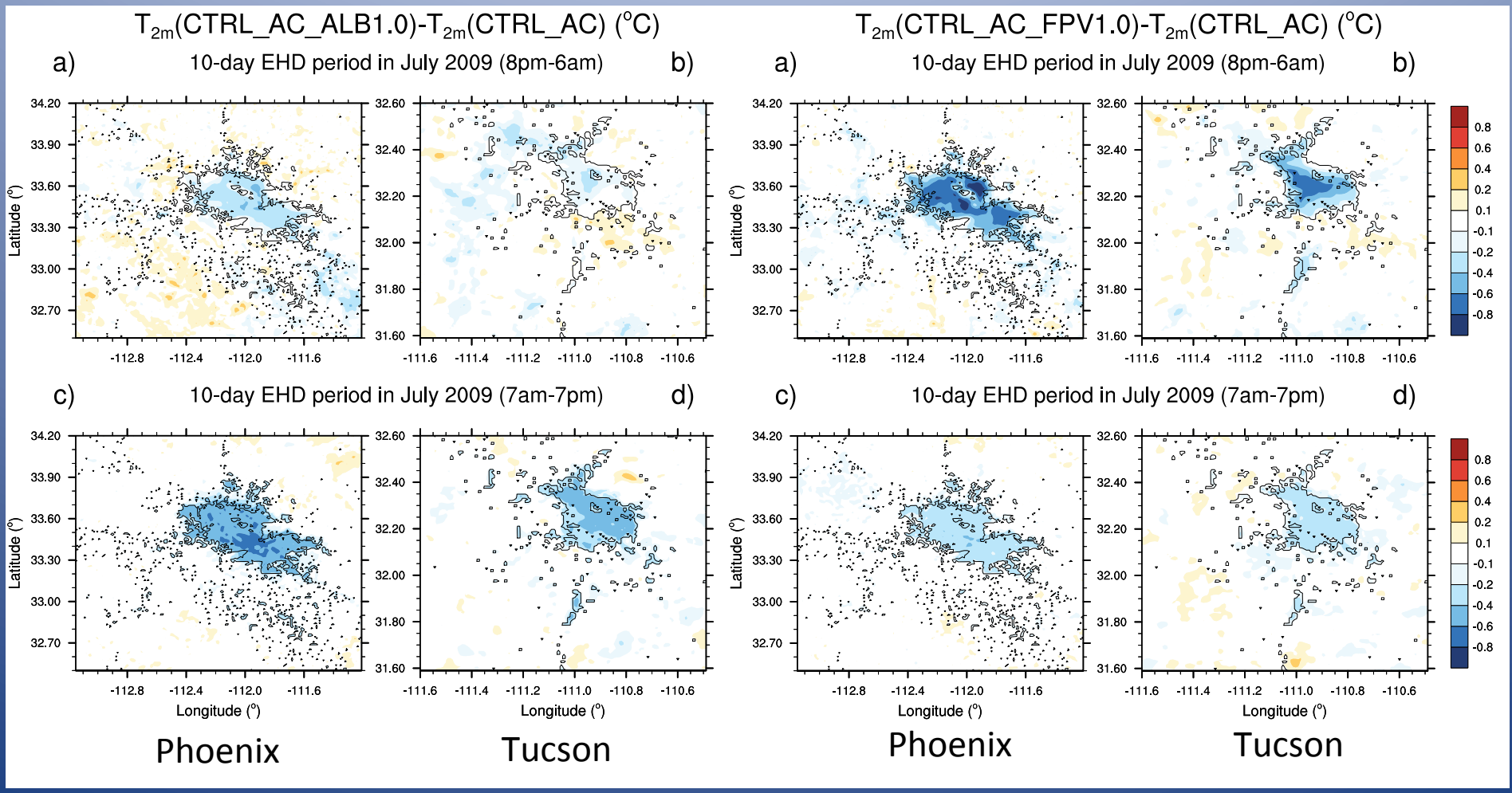
CTRL_AC-simulation

WRF-mod.

Observed



Modeled mean 2m-air temperature differences (°C) averaged for the entire 10-day EHD period



Daytime cooling for PVs was roughly half of the daytime cooling associated with cool roofs. Nighttime cooling for PVs was roughly twice as large as the nighttime cooling associated with cool roofs.

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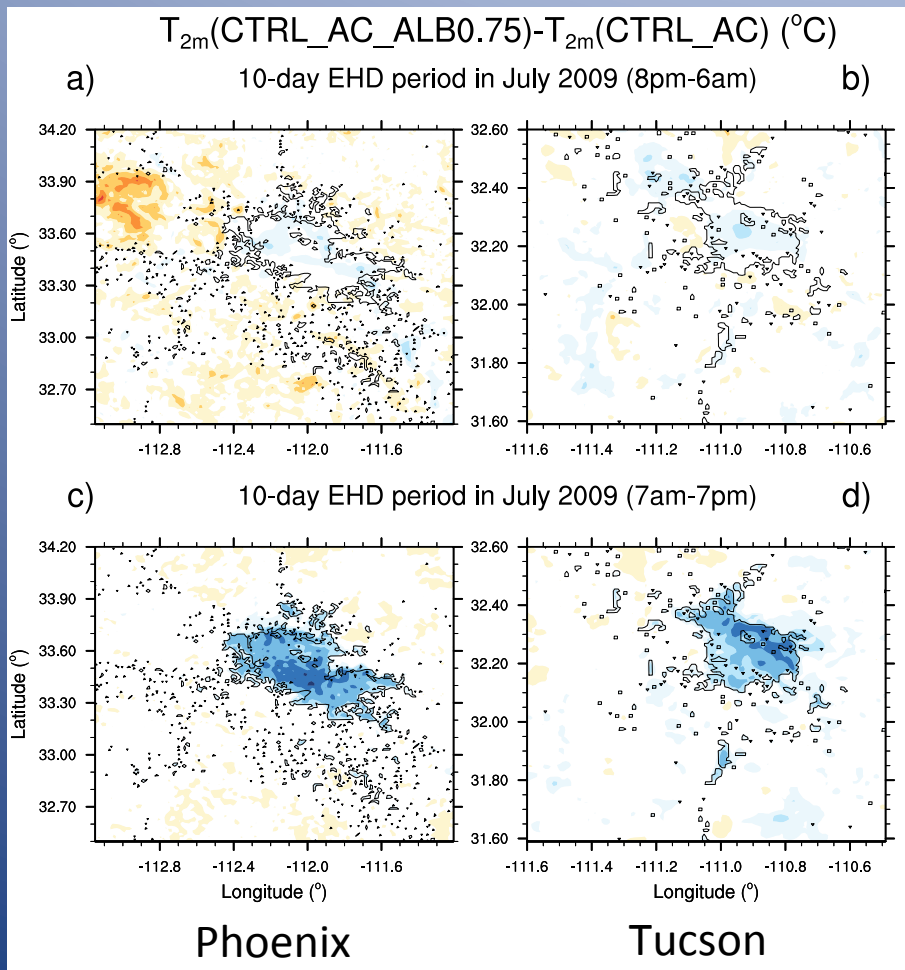
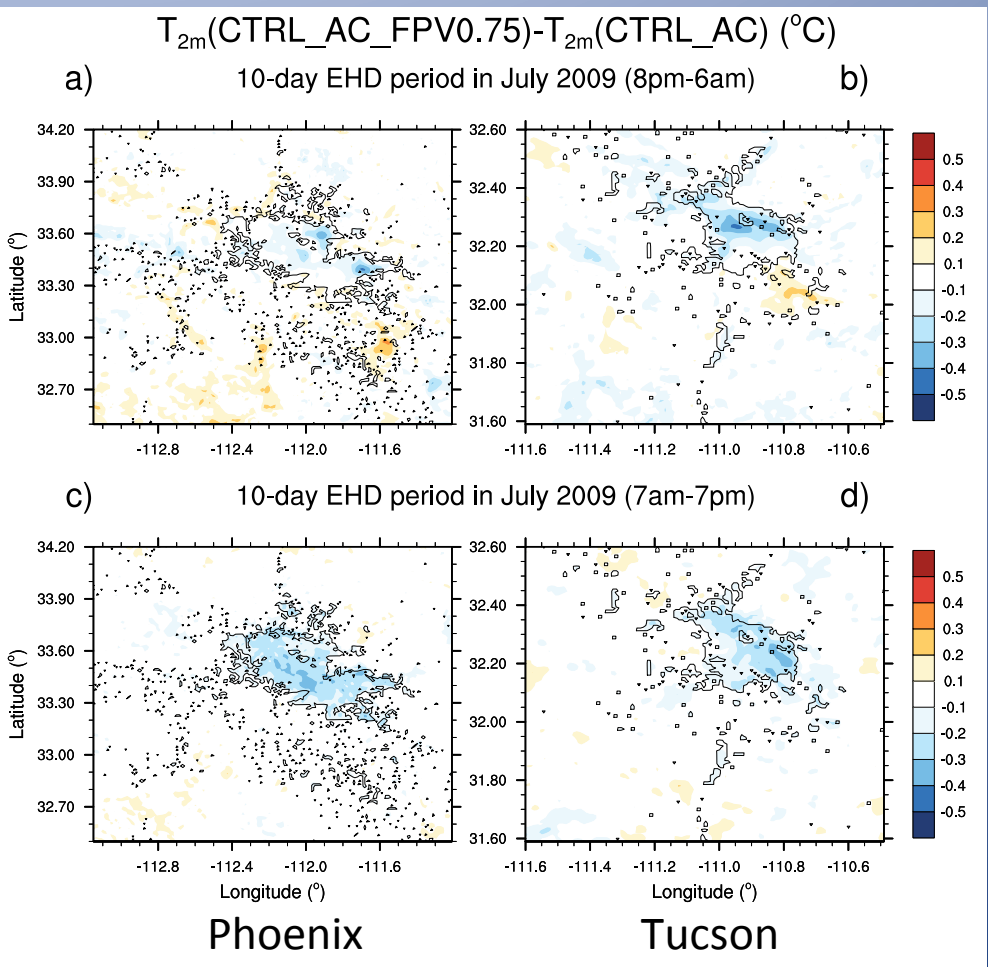
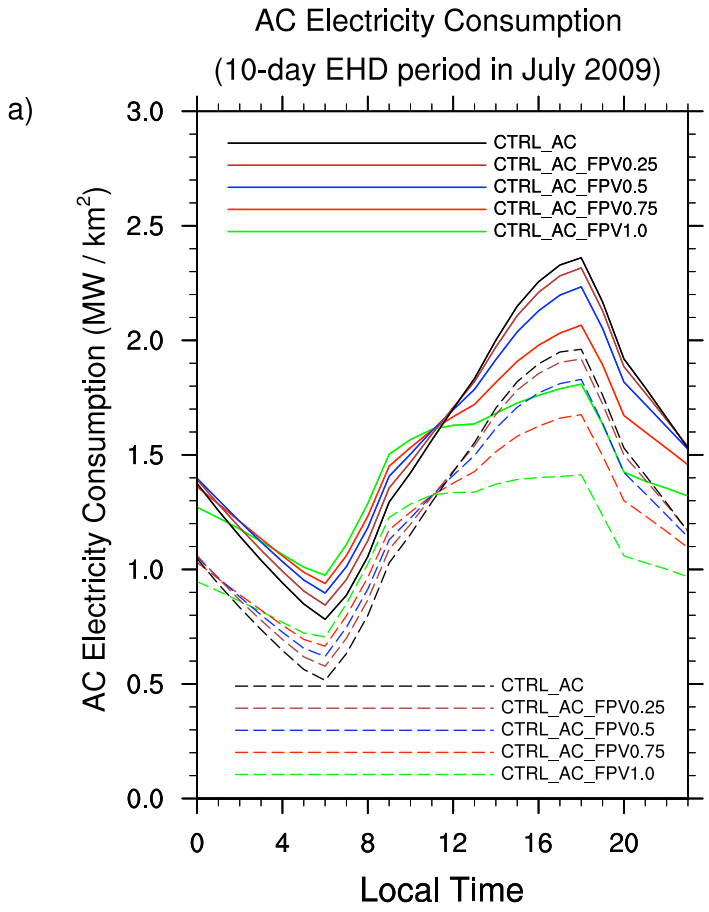
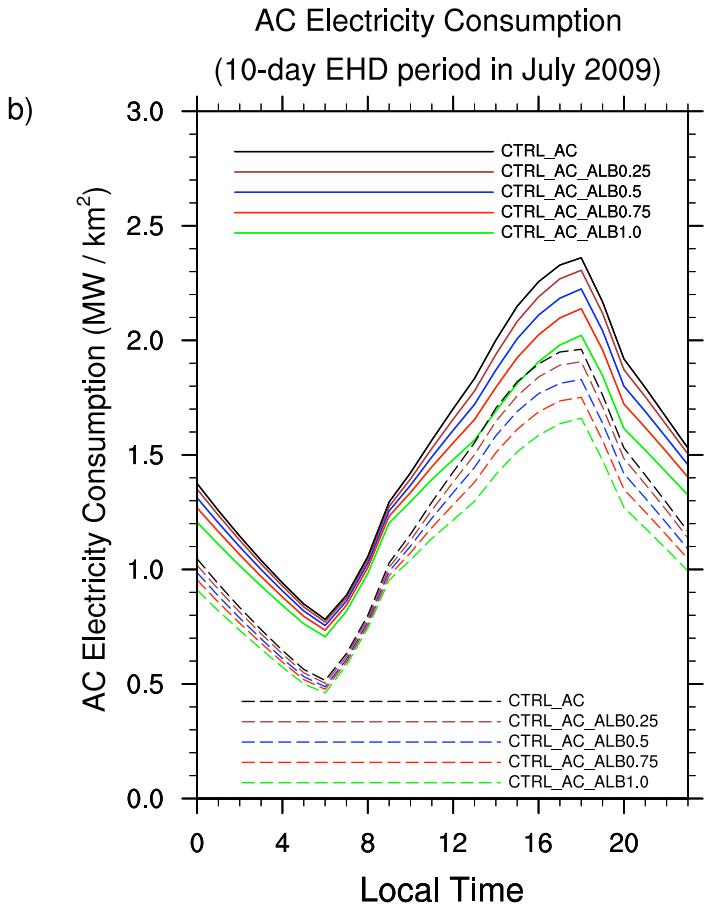




The behavior just described previously is evident for less than maximum penetration rates.

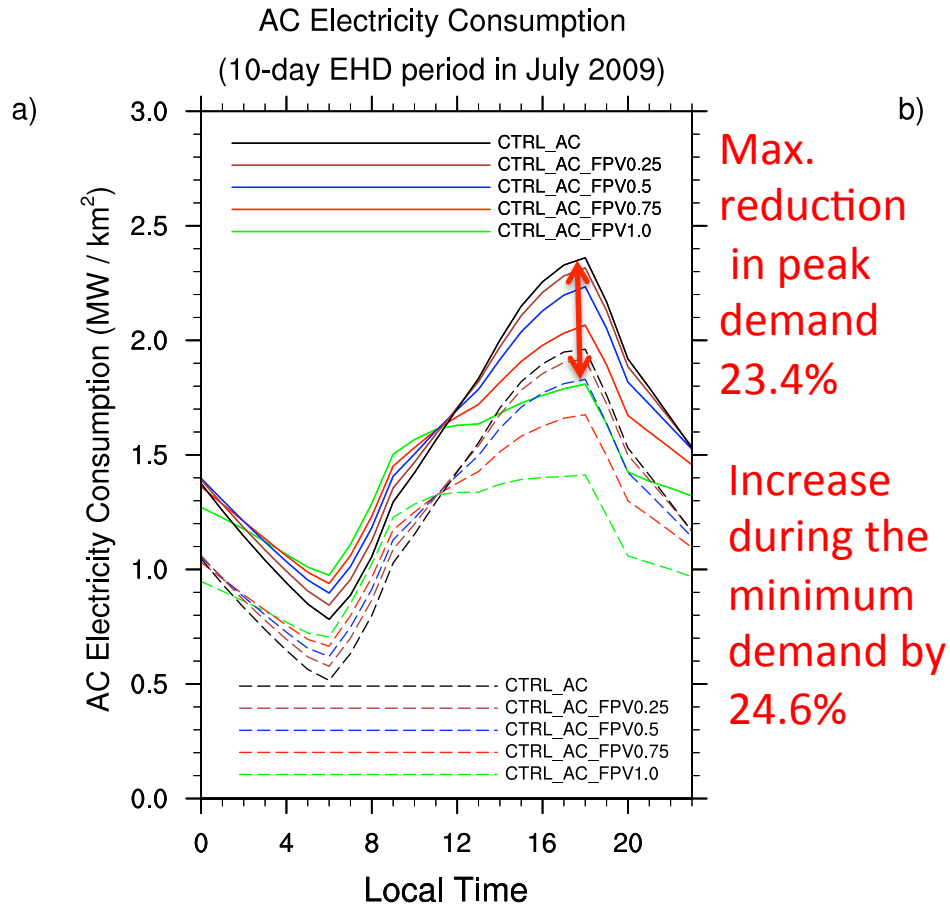
Diurnal cycle of modeled AC (MW/km^2 of urban land) electricity consumption averaged for the entire 10-day EHD period and across the Phoenix (continuous curves) and Tucson (dashed curves) metropolitan areas





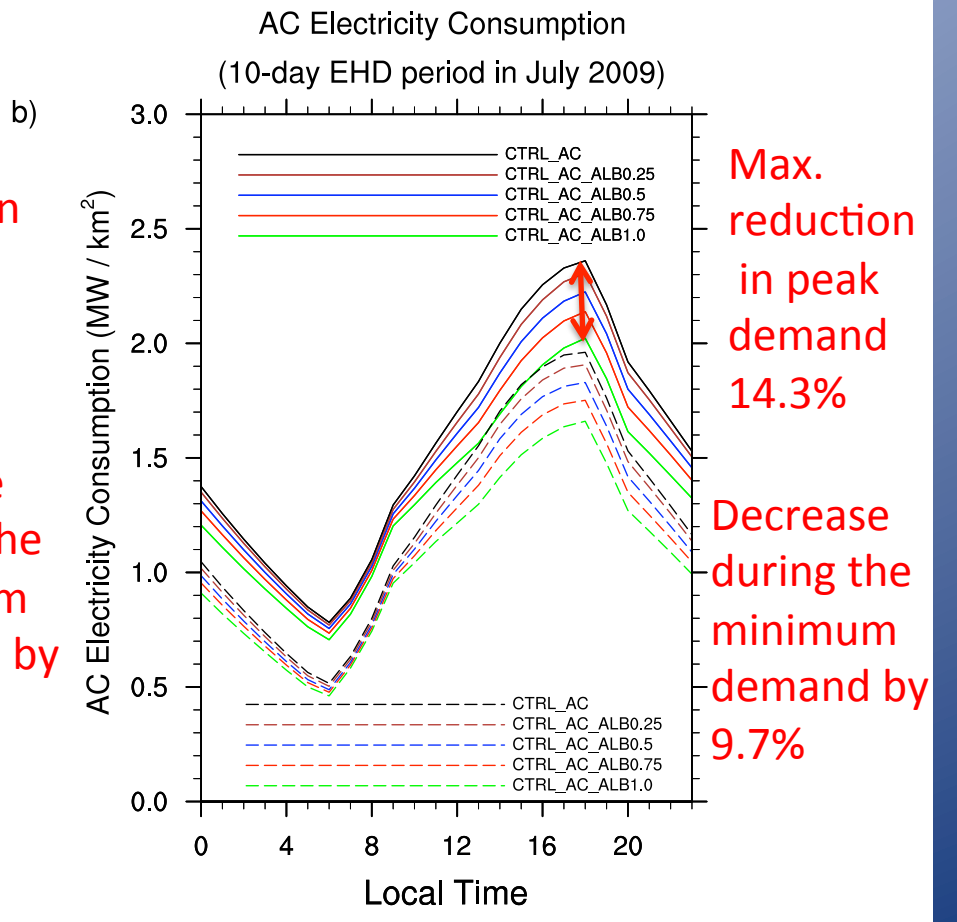
These computed savings do not account for the additional savings derived from electricity production from PVs

Diurnal cycle of modeled AC (MW/km^2 of urban land) electricity consumption averaged for the entire 10-day EHD period and across the Phoenix (continuous curves) and Tucson (dashed curves) metropolitan areas



Max. reduction in peak demand 23.4%

Increase during the minimum demand by 24.6%

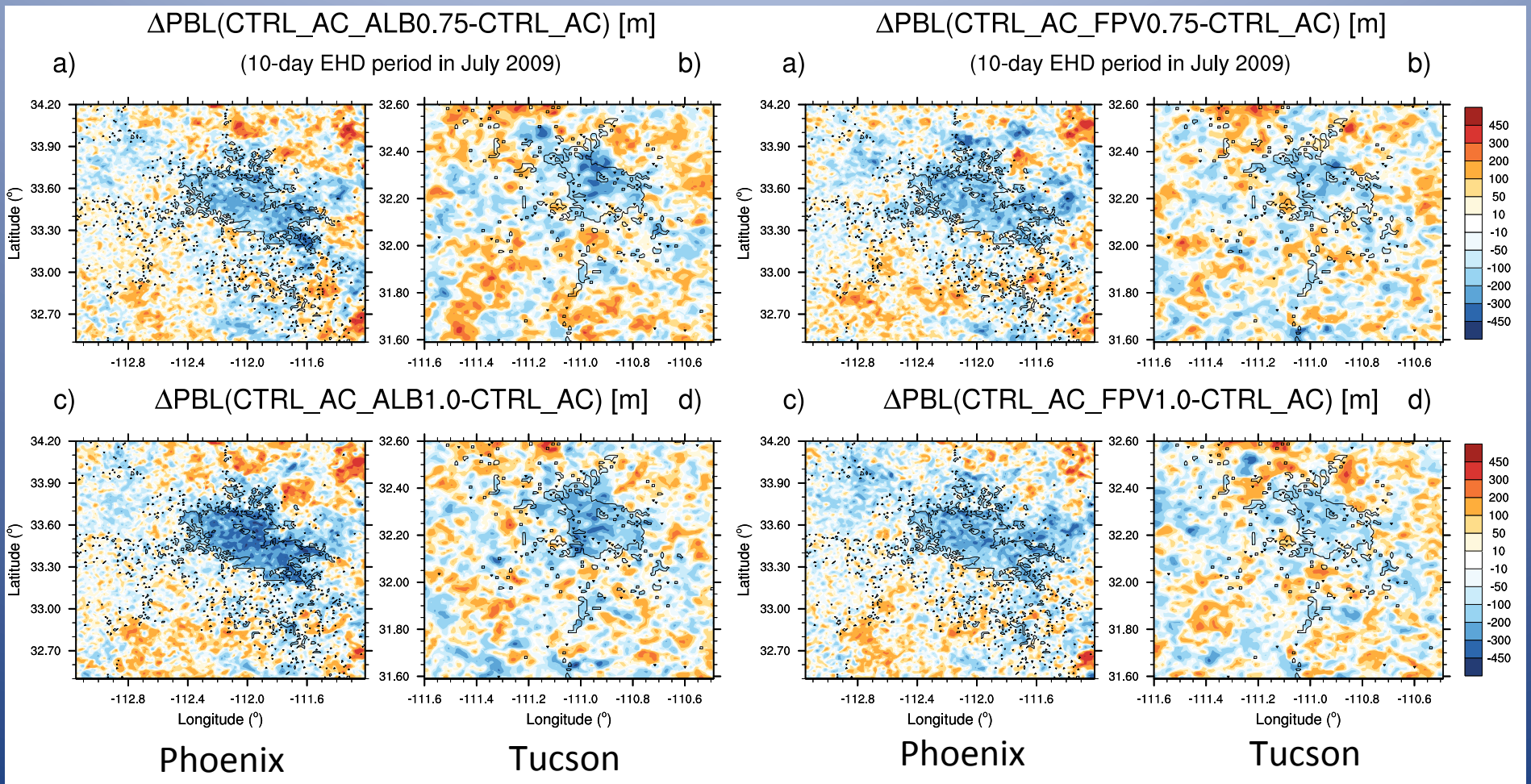


Max. reduction in peak demand 14.3%

Decrease during the minimum demand by 9.7%

AC electricity demand for CTRL_AC run was validated against observations (see *Salamanca et al., ERL 2013*)

Modeled Planetary Boundary Layer height reduction [m] averaged for the entire 10-day EHD



Any penetration rate of large-scale cool roof and rooftop PV deployment reduced the convective PBL height over the metropolitan areas

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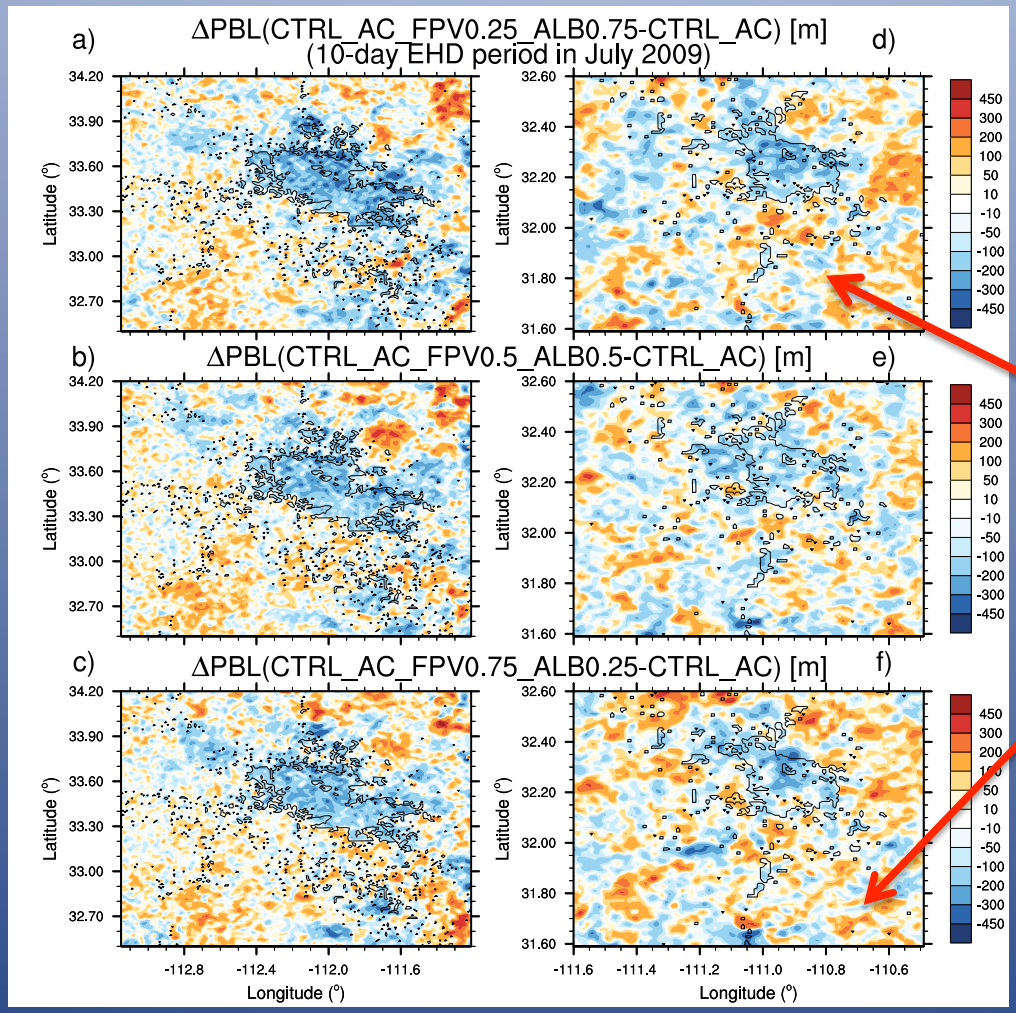
Modeled Planetary Boundary Layer height reduction [m] averaged for the entire 10-day EHD (hybrid scenarios)



Unexpected random effects outside the urban areas

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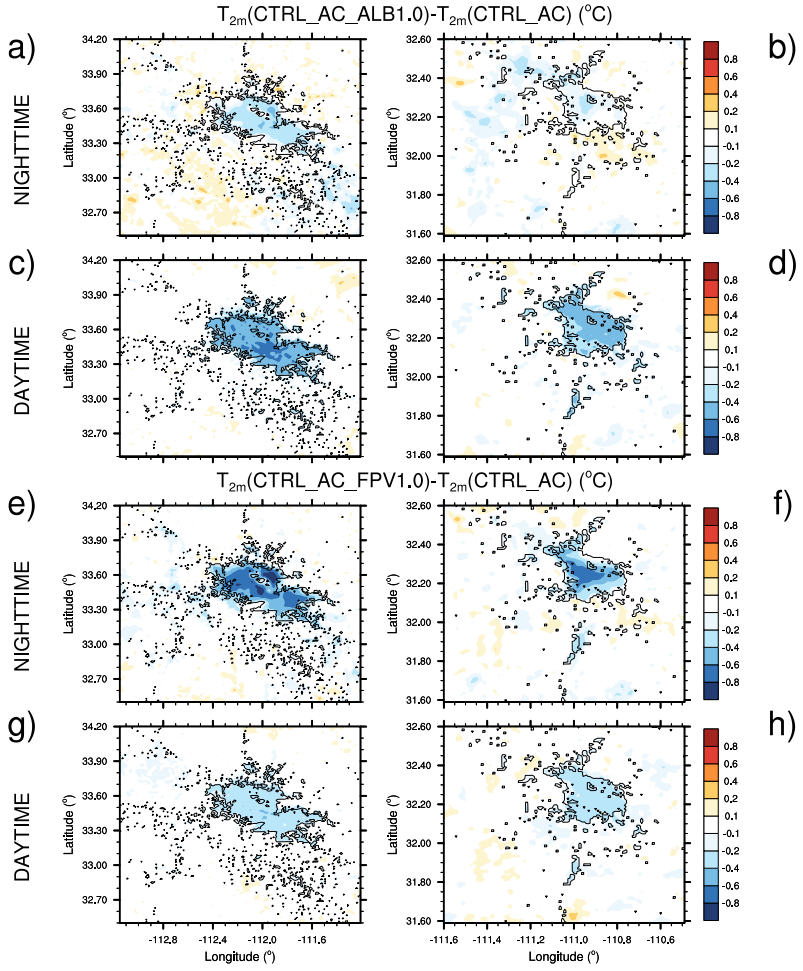
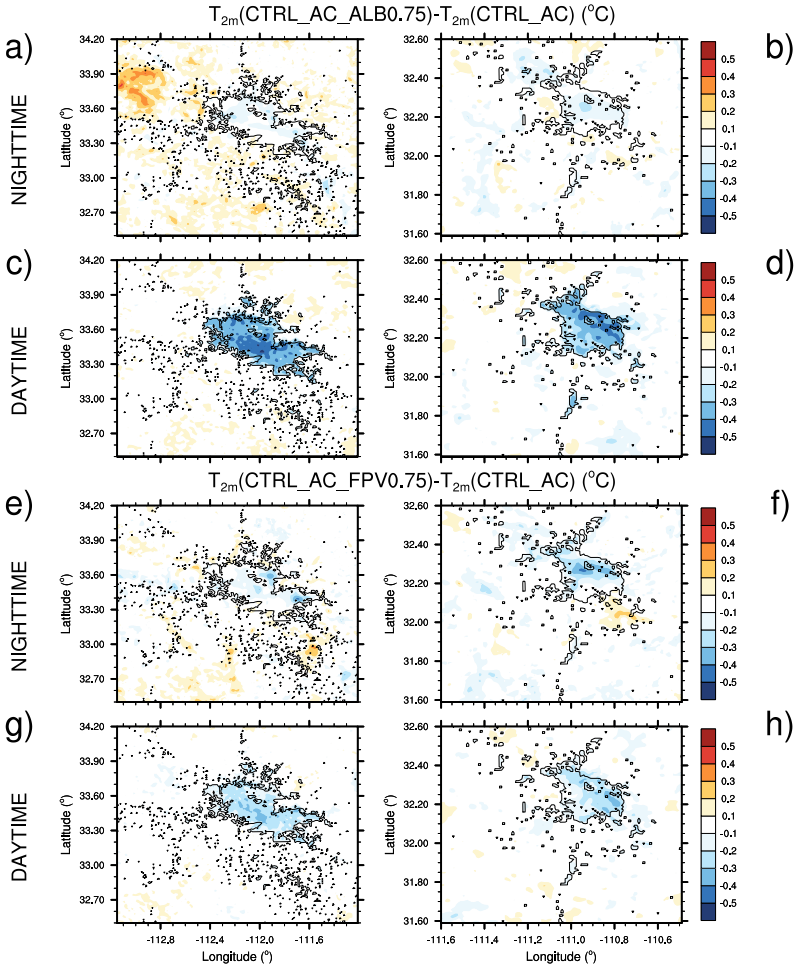
Conclusions

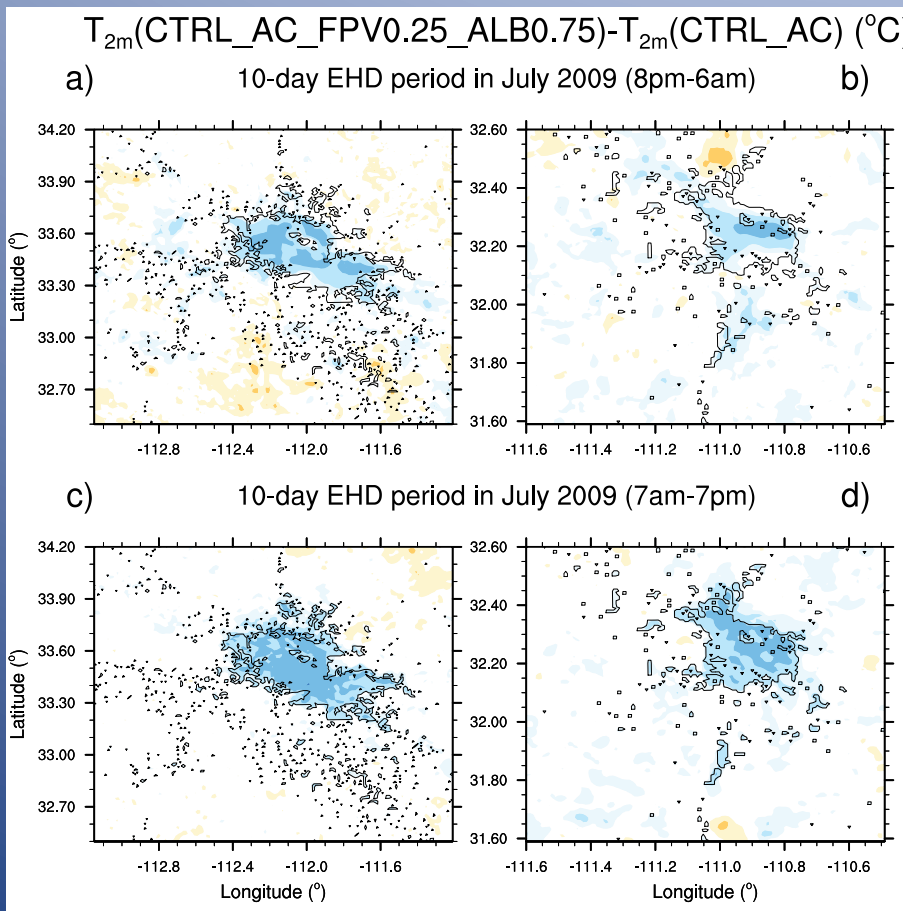
- Large-scale deployment of cool roofs and rooftop PV panels reduce near-surface air temperature and cooling energy demand on a city scale.
- During the day, cool roofs are more effective at cooling than rooftop PV panels, but PV panels are more efficient at reducing nocturnal urban heat island.
- Potential implications for air quality associated with the reduction of both air temperature and PBL height requires additional investigation.

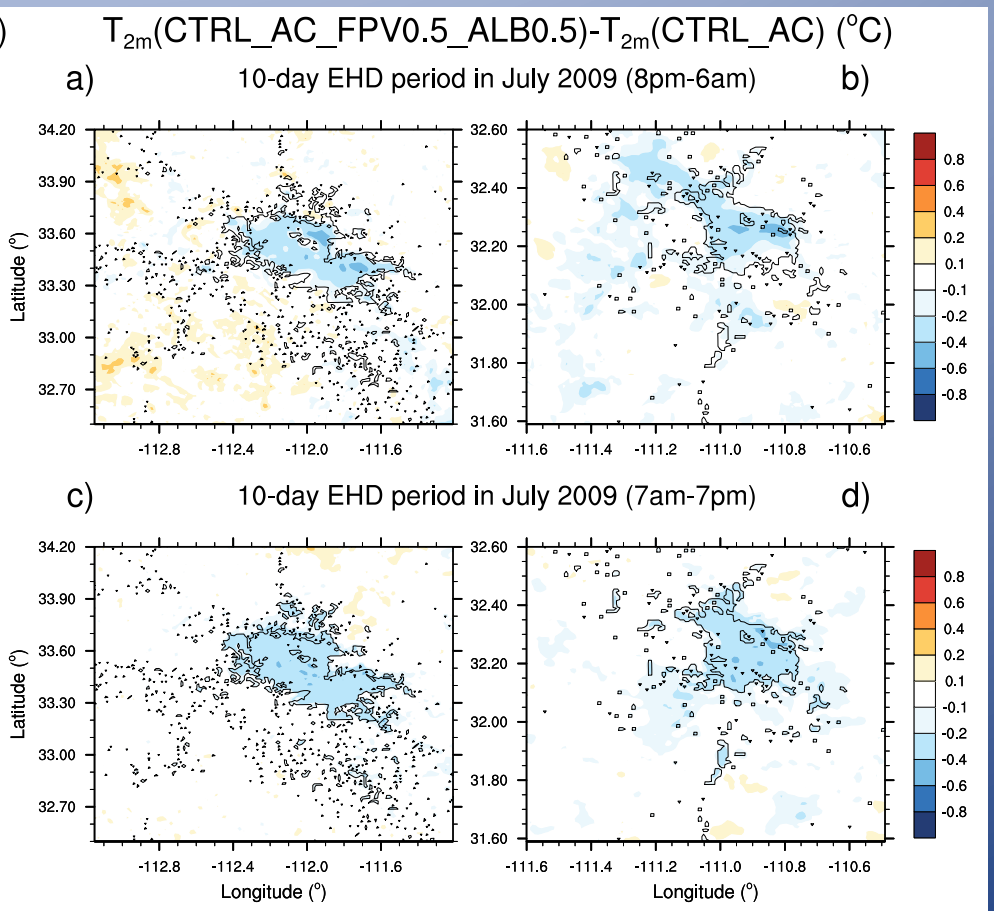
Modeled mean 2m-air temperature differences (°C) averaged for the entire 10-day EHD period





Modeled mean 2m-air temperature differences (°C) averaged for the entire 10-day EHD period (hybrid scenarios)





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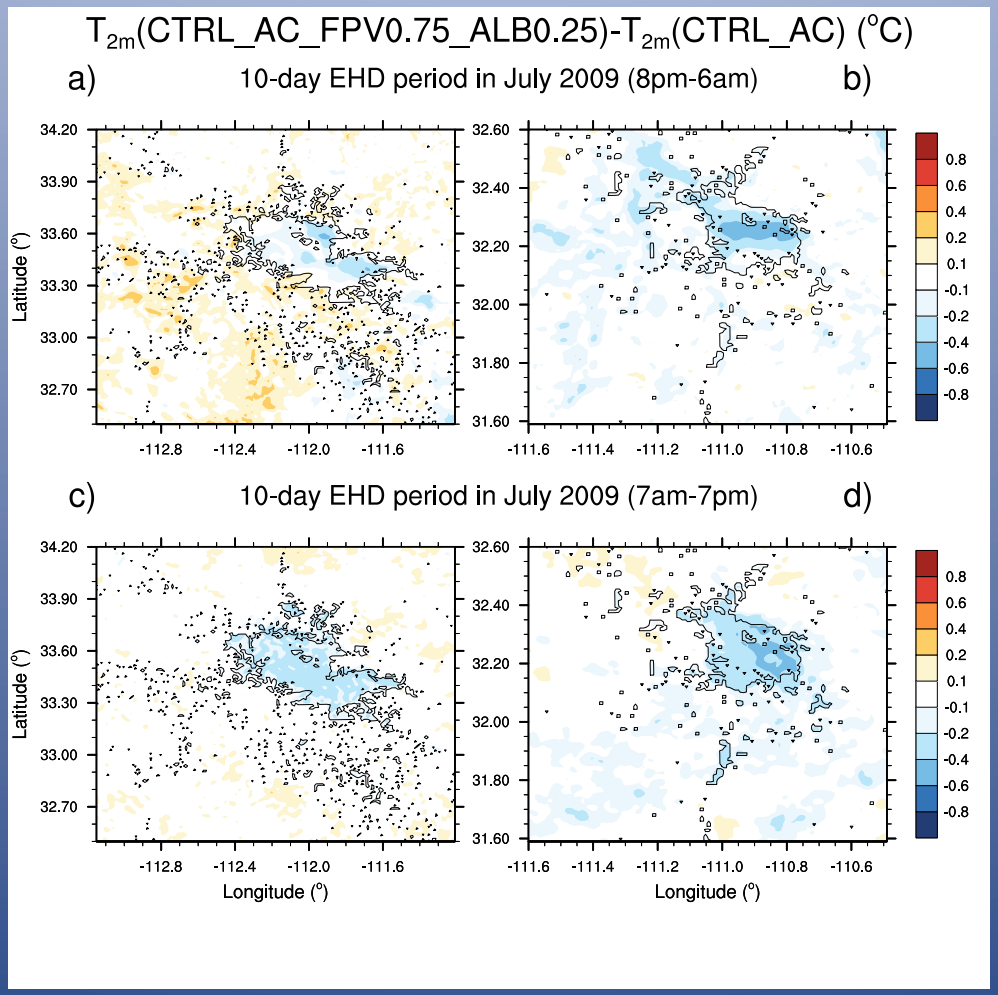

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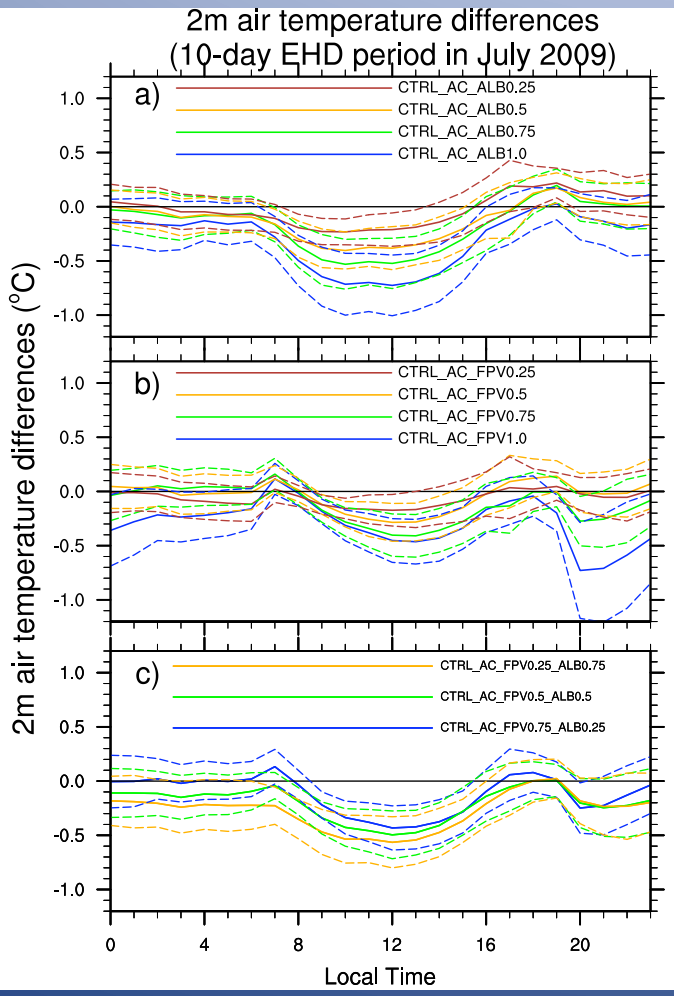
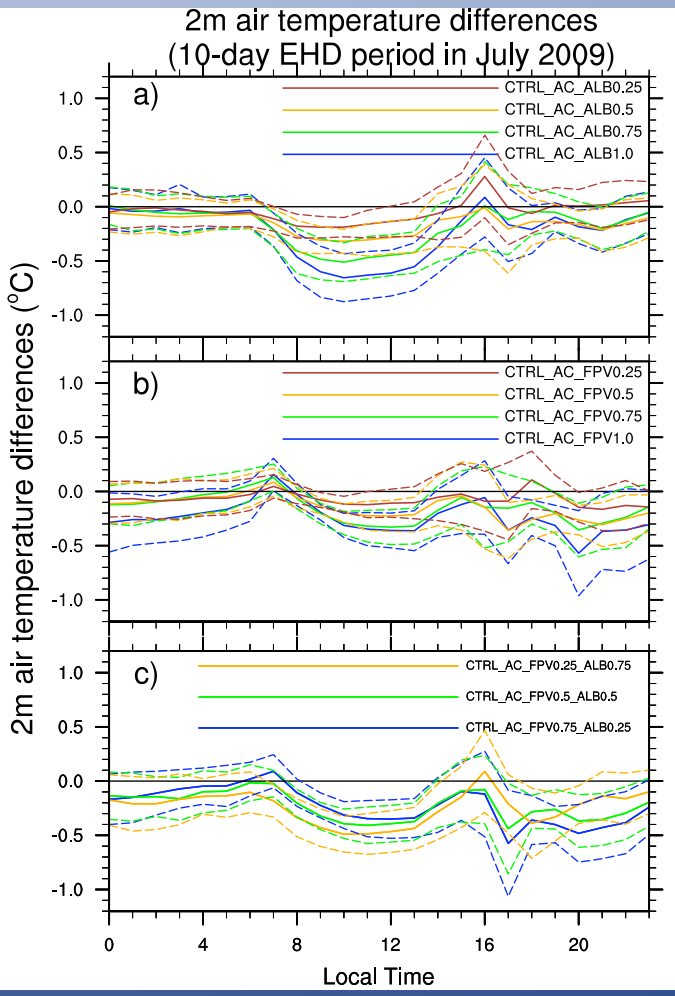
Diurnal cycle of modeled 2m-air temperature (°C) differences averaged for the entire 10-day EHD period



Phoenix metropolitan area



Tucson metropolitan area

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