Evaluation of updated urban land-use and geographical data on WRF simulations for the Utah Northern Wasatch Front

UTAH DEPARTMENT of ENVIRONMENTAL QUALITY
AIR QUALITY

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Introduction

The Utah Division of Air Quality (UDAQ) runs the Weather Research and Forecasting (WRF) model over the Northern Wasatch Front of Utah (Figure 1) to provide inputs for the Comprehensive Air Quality Model with Extensions (CAMx) across the same domain. There is an ongoing effort to improve the accuracy of the WRF inputs to CAMx, but this is challenging for many reasons. The Wasatch Front is characterized by complex topography, with a variety of land surface types, multiple mountain ranges, valleys, basins, and the large terminal saline lake - the Great Salt Lake (GSL) - composing the landscape. At the heart of the Wasatch Front lies a narrow and densely populated urban corridor, filling in valley areas bounded by Wasatch Mountains to the east, Oquirrhs to the west, and GSL to the north and west. The variable topography and sharp gradient between urban and natural land surfaces creates a variety of interactions between mountain/diurnal winds systems, including canyon winds, and lake breezes, and the urban environment. Previous WRF simulations poorly captured nighttime low temperatures, were significantly drier than observations, and underestimated wind speed at some monitors.

This study aims to improve the accuracy of modeled meteorological fields across the Northern Wasatch Front by using updated urban land use data, incorporating the use of two Urban Canopy Models (UCMs), and including a more accurate GSL extent (Figure 4). We ran WRFv4.5 with urban land use from the merged Copernicus Global Land Service Land Cover (CGLC), MODIS, and global LCZ dataset (CGLC-MODIS-LCZ) implemented directly into WRF Preprocessing System (WPS) (Deumuzere et al., 2023). We tested two urban physics schemes, the Multi-layer, Building Environment Parameterization (BEP) and Multi-layer, Building Environment Model (BEM). We assessed model performance at meteorological stations in a variety of land use areas. These include the Salt Lake City airport (KSLC), which is located in a large low rise/paved area; Gateway, a meteorological station within the compact high rise urban area, and Hawthorne, a Utah Division of Air Quality station within the sparsely built area that experiences high summertime ozone.

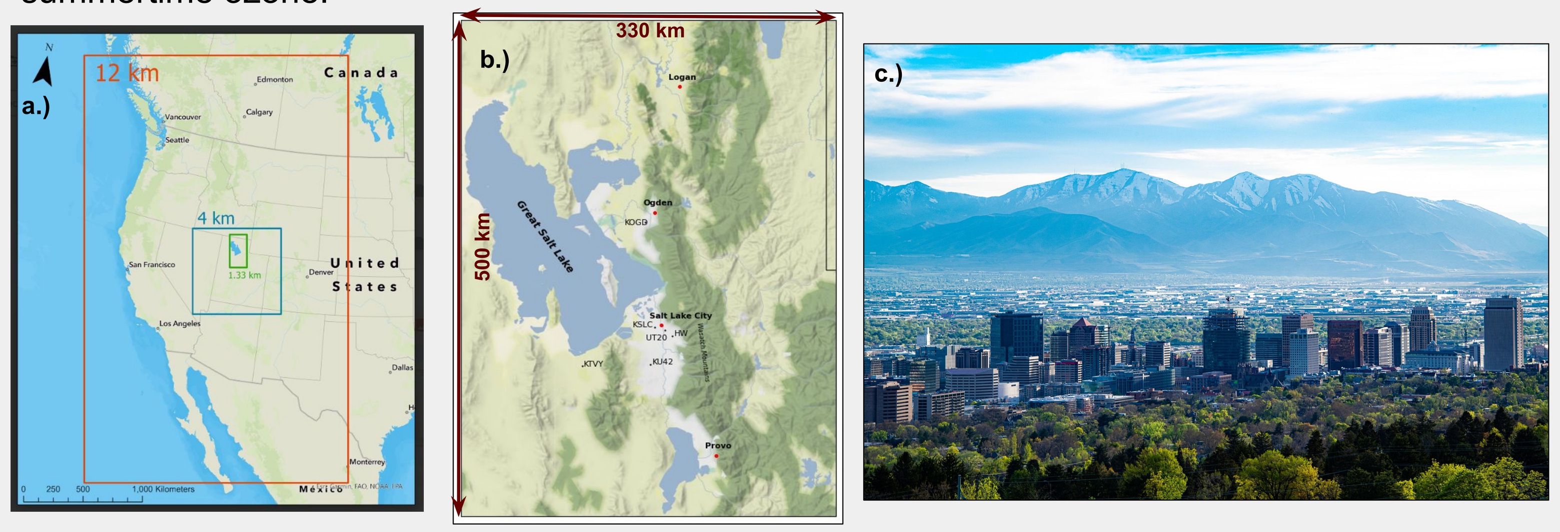


Figure 1. a.) WRF 12km (D01), 4km (D02), and 1.33km (D03) domains (left), **b.)** Northern Wasatch Front (1.33km domain) (middle), and **c.)** Westward looking view across SLC and the SL Valley towards the Oquirrh Mtns (right).

Background

Incorporating LCZ data into WRF

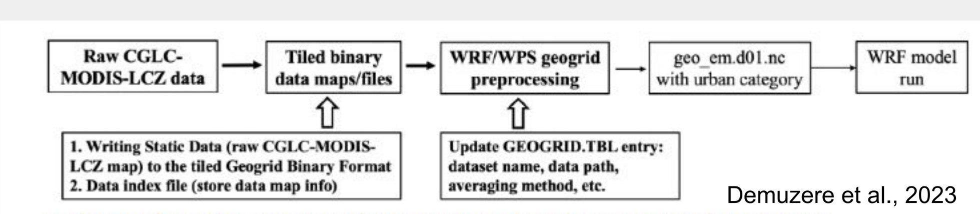


Figure 2. Direct implementation of Local Climate Zone (LCZ) data into WRF was developed by Demuzere et al., 2023. The LCZ geographical data is integrated directly into WRFv4.5 without having to use intermediary tools such as WUDAPT to WRF (https://www.wudapt.org/wudapt-to-wrf/).

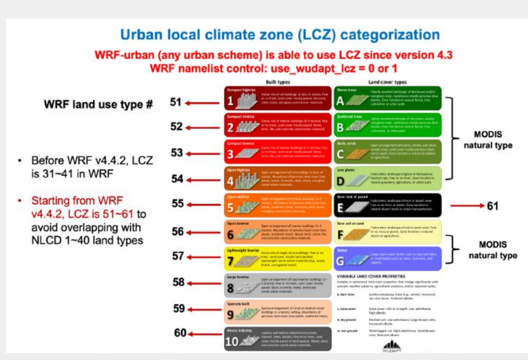


Figure 3. CGLC-MODIS-LCZ urban land use categories compared to the original WUDAPT LCZ (Stewart and Oke, 2012; Demuzere et al., 2020)

Northern Wasatch Front - WRF LCZ Land use

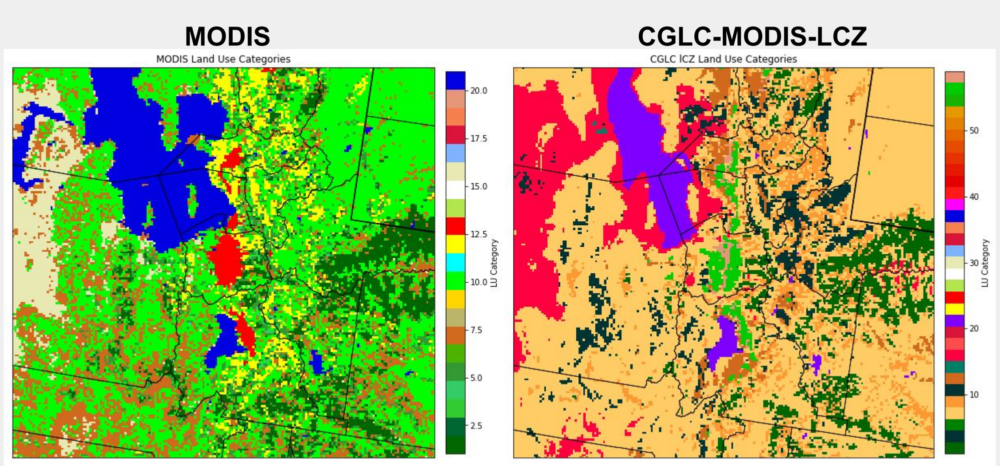


Figure 4. WRF 1.33km domain; Left: MODIS land use categories and unedited GSL extent and **Right:** CGLC LCZ land use and edited GSL extent. Note the more detailed representation of LU categories for the urban areas.

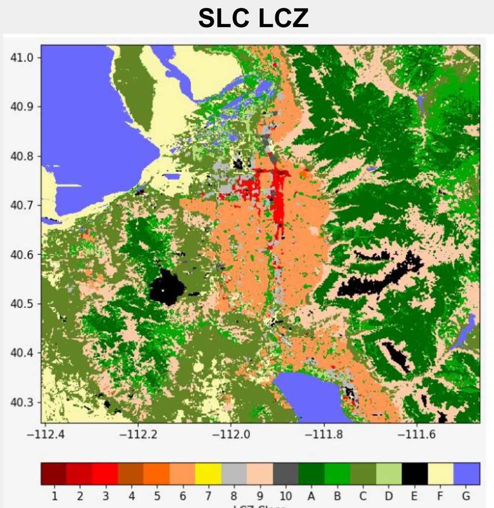


Figure 5. LCZ map with land use categories for the Salt Lake Valley and surrounding area (White, Natalie, 2022).

Background

Urban Canopy Model

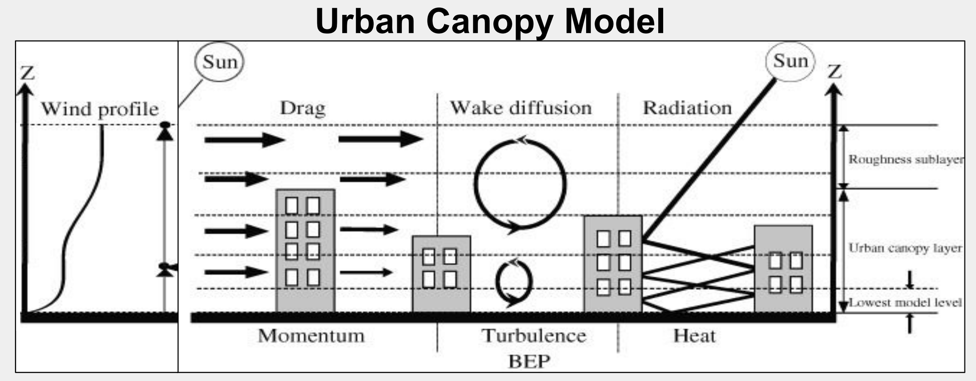


Figure 6. WRF urban physics allows the direct interaction of the urban canopy and Planetary Boundary Layer (PBL) through a more detailed representation of city morphology and surface characteristics (e.g. albedo, heat capacity, emissivity, urban/vegetation fraction) (Ribeiro et al., 2020).

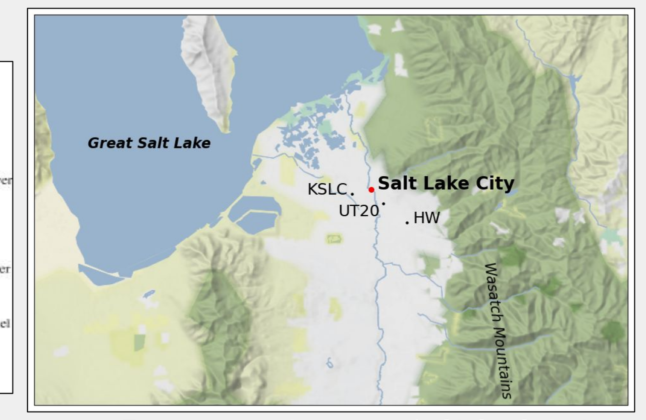


Figure 7. MET site locations (**KSLC: Salt Lake International Airport; UT20: Gateway; HW: Hawthorne**) used in observation to model comparison.

WRF urban physics schemes

Urban 0: No urban physics

Urban 2: Building Effect Parameterization (BEP); parameterizes a 3D urban morphology in a multi-layer model grid

Urban 3: Building Energy Model (BEM); considers energy consumption in buildings (heating/cooling) for a more accurate effect on urban heat budget

Incorporation of LCZ data enables the use of different urban canopy models (UCMs) within WRF. We test out three UCMs/urban physics options: 1.) No urban physics, 2.) BEP, and 3.) BEM.

WRF Base Configuration

Parameter	Baseline
Resolution (D01, D02, D03)	12, 4, 1.33 km
Grid size (x,y) (D01; D02; D03)	(287, 299); (291, 291); (249, 381)
Vertical levels	44
Vertical coordinates	Hybrid vertical
IC/BC	NAM 12 km; D01; D02
Land Use Dataset	CGLC-MODIS-LCZ+default
Microphysics	Thompson graupel scheme (2-moment)
Randiation	RRTMG
Land Surface Model	Noah LSM
PBL Scheme	YSU
Cumulus Parameterization	Mulit-scale Kain-Fritsch (D01-D03)

Results

Basecase WRF ("No urban physics") vs. WRF urban physics

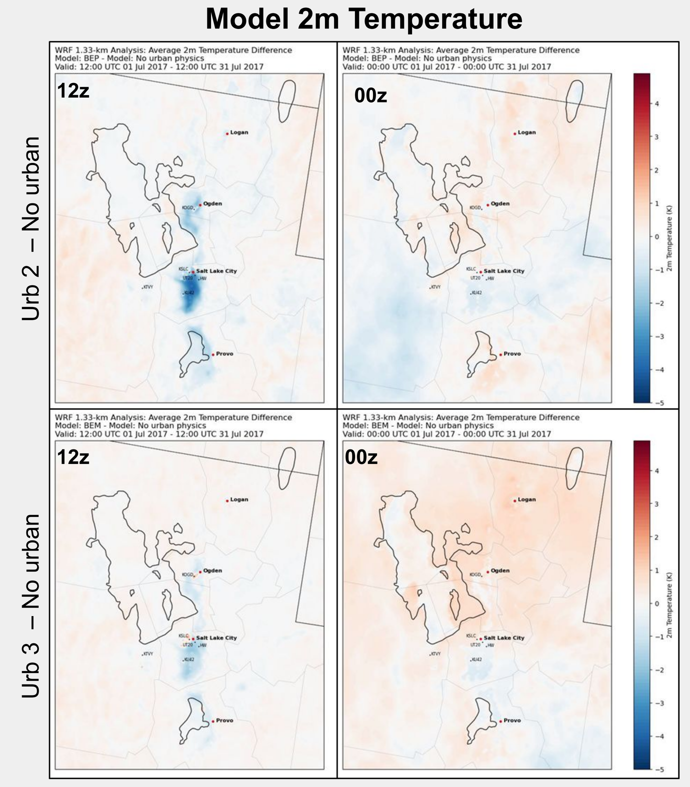


Figure 8. 2m Temperature difference between WRF No urban physics and Urban 2 (BEP) (**top**) and Urban 3 (BEM) (**bottom**) urban schemes at 12z (**left**) and 00Z (**right**)

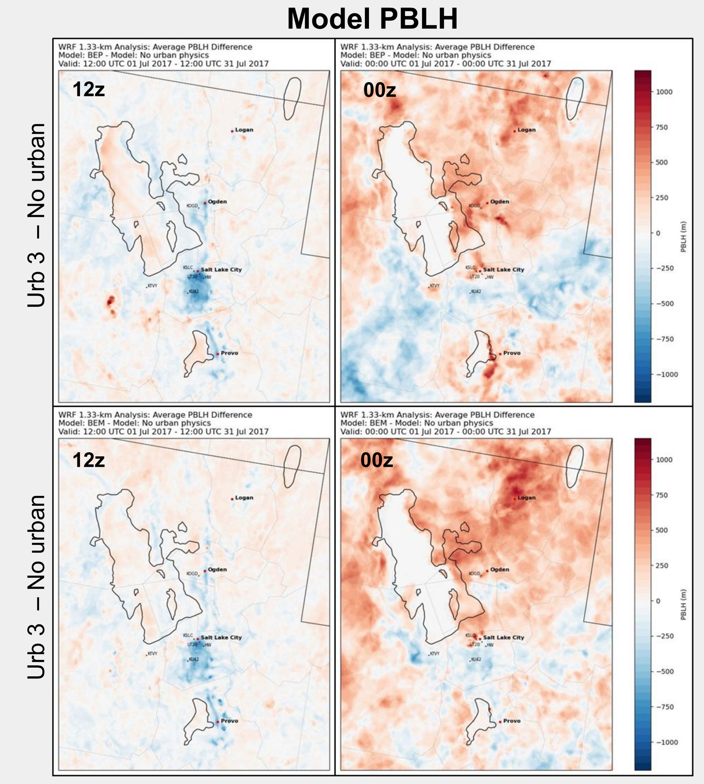
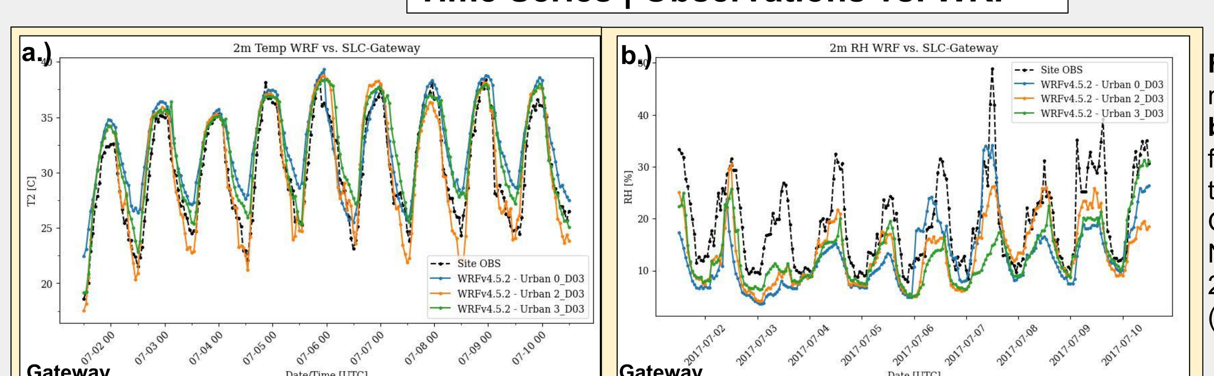


Figure 9. Planetary Boundary Layer height (PBLH) difference between WRF No urban physics and Urban 2 (BEP) (**top**) and Urban 3 (BEM) (**bottom**) urban schemes at 12z (**left**) and 00Z (**right**)

Time Series | Observations vs. WRF



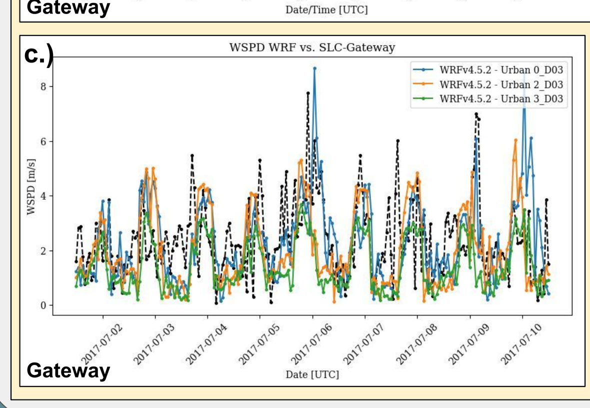


Figure 10. Observed vs. modeled **a.)** 2m Temperature, **b.)** RH, and **c.)** 10m wind speed for the period 7/1/- 7/10/2017 at the Gateway (UT20) site. Observations (black dashed), No urban physics (blue), Urban 2 (BEP) (orange), and Urban 3 (BEM) (green).

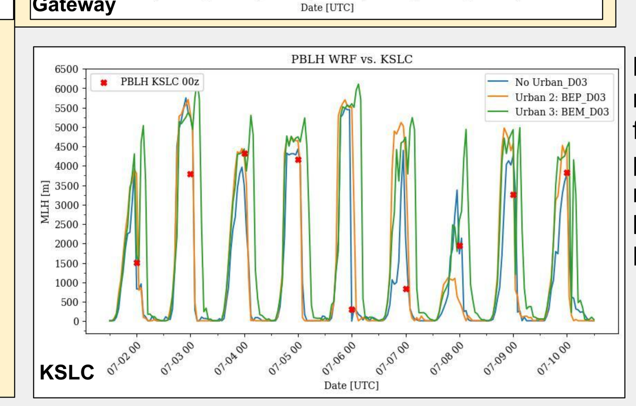


Figure 11. Observed vs. modeled PBLH at KSLC. PBLH from was estimated using the potential temperature gradient method (PTG) from soundings launched KSLC at 00Z (1800 LST) (red x's).

Results

Average Diurnal Plots | Observations vs. WRF

2m Temperature

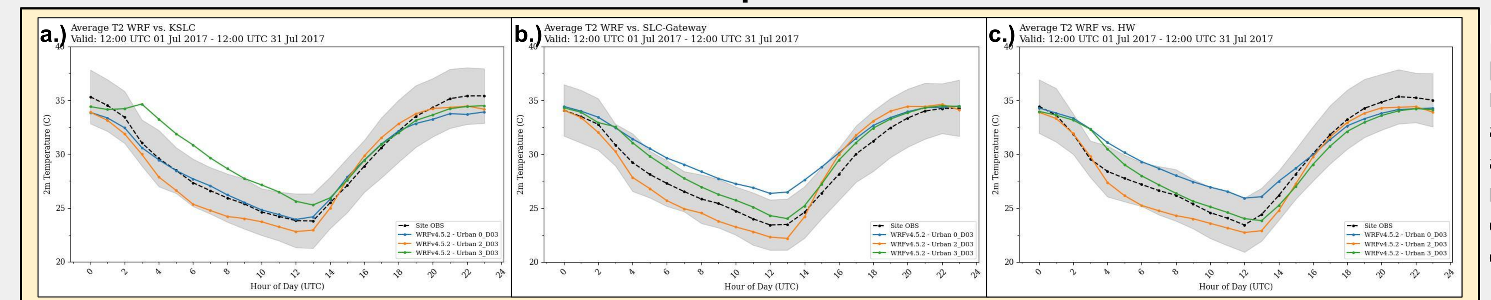


Figure 12. Average diurnal plots of observations vs. model 2m Temperature at **a.)** KSLC, **b.)** Gateway, and **c.)** HW. Shaded area represents one standard deviation from the observed hourly mean.

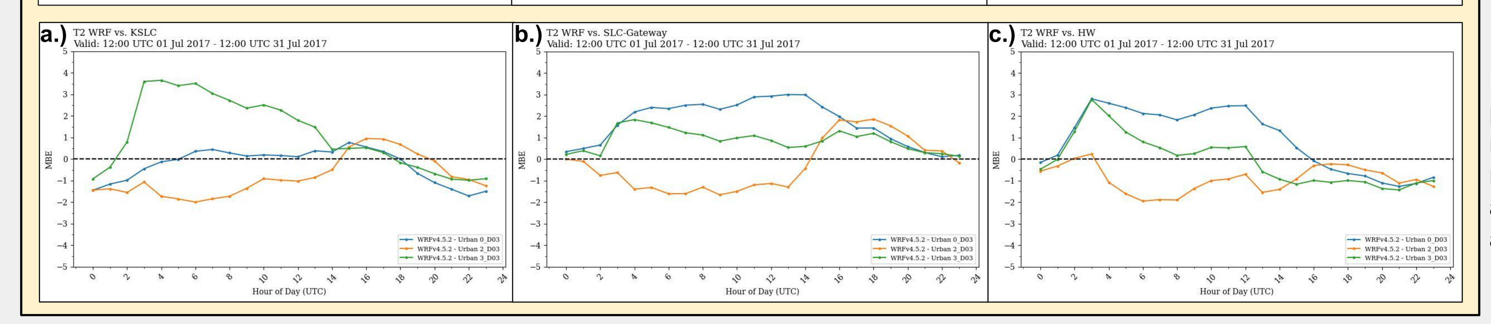


Figure 13. Average diurnal plots of observations vs. model 2m Temperature mean bias error (MBE) at **a.)** KSLC, **b.)** Gateway, and **c.)** HW.

Wind speed

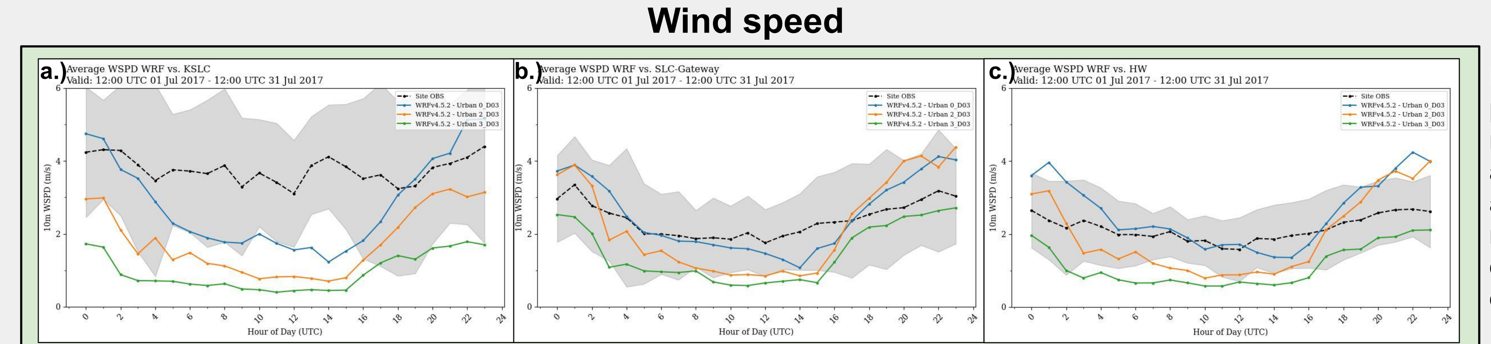


Figure 14. Average diurnal plots of observations vs. model 10m wind speed at **a.)** KSLC, **b.)** Gateway, and **c.)** HW. Shaded area represents one standard deviation from the observed hourly mean.

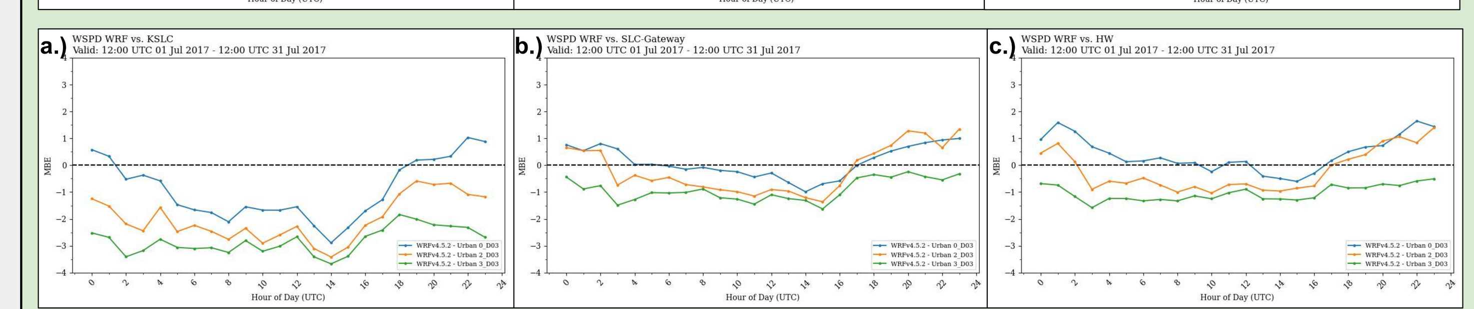


Figure 15. Average diurnal plots of observations vs. model 10m wind speed mean bias error (MBE) at **a.)** KSLC, **b.)** Gateway, and **c.)** HW.

Conclusions

Including more sophisticated land use categories and urban physics parameterizations resulted in complex and inconsistent modeling outcomes.

- Inclusion of more "open" city land use areas instead of a continuous "built up" area (Figures 4 & 5), decreases modeled temperature (Figure 8).
- At our selected meteorological stations, including urban physics results in higher maximum daytime temperatures and variable nighttime temperature biases (Figures 12 & 13).
- Overall, including urban physics tends to decrease nighttime temperatures, likely due to surfaces with higher albedo, solar shading, and increased radiative cooling at night.
- Excluding urban physics results in higher nighttime temperatures at Gateway and HW sites, except at KSLC which has artificial heat maximum at night.
- Urban 2 has the lowest nighttime, and the highest daily maximum temperature at all sites, but the afternoon maximum doesn't correspond temporally with observed maximum temperature.
- Including urban physics options generally improves model performance for relative humidity (Figure 10). However, all models are drier than observations.
- Including urban physics results in lower nighttime PBLH but generally similar daytime PBLH in the metro area (Figure 9).
- PBLH estimated from soundings at KSLC compared favorably with Urban 0 and Urban 2, but the delayed onset of peak heating in Urban 3 overestimates PBLH at 00z (Figure 11).
- Modeled winds generally track diurnal trends, but are lower on average than observations, especially at night (Figures 14 & 15).
- Urban 0 has the most favorable comparison to observed wind speeds, though Urban 0 and Urban 2 have stronger than observed winds in the afternoon/early evening.

Future work:

Representativeness of meteorological sites is potentially a major contributor to observed errors in model wind speed and temperature. Future work may include a larger ensemble of met stations to try and gauge model performance over more of the metro area. Model simulations targeting moisture variables or using different PBL schemes will be investigated. Adjustments to urban characteristics may also be tested. The ultimate goal of the UDAQ WRF platform is improved CAMx performance, and we will continue to focus on model variables most critical to ozone.

Additional information and acknowledgements

Referenced works:

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Stewart, I. D., & Oke, T. R. (2012). Local climate zones for urban temperature studies. Bulletin of the American Meteorological Society, 93(12), 1879-1900.

White, Natalie (2022). WUDAPT Level 0 training data for Salt Lake City (United States of America), submitted to the LCZ Generator. This dataset is licensed under CC BY-SA, and more information is available at https://lcz-generator.rub.de/factsheets/ d36c0e70fc19db43036890de4f1f55cb1f907f67/d36c0e70fc19db43036890de4f1f55cb1f907f67_factsheet.html

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