909: Modeling the Climate and Land Cover Change Effects on Urban Water and Energy Dynamics in the Phoenix Metropolitan Area

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I. Introduction

Rapid urbanization in Phoenix Metropolitan Area (PMA) is known to impact water and energy dynamics due to changes in impervious cover, stormwater infrastructure and landscaping. Meanwhile, increasing extreme events such as heat waves and floods interact with land use and land cover (LULC) change, highlighting the importance of city planning, infrastructure development and mitigation actions.

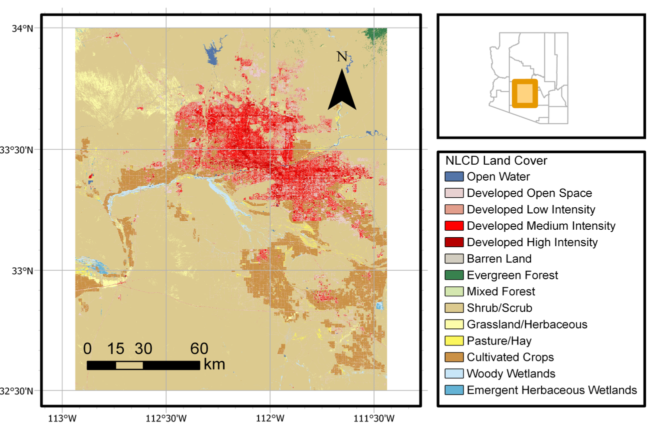

Figure 1. Phoenix study domain and the NLCD land Cover .

In this work, we use the Variable Infiltration Capacity (VIC) land surface hydrologic model to investigate the effects of LULC and climate change on the hydroclimatic dynamics in the PMA. We use the Land Surface Temperature (LST) as our model calibration target due to its association with Urban Heat Island (UHI) and the availability of remote sensing products. Results from the comparisons are discussed in light of the utility of remotely-sensed LST for testing distributed hydrologic models in capturing the LST over different land cover types.

II. Methodology

Hydrologic Model setup:

The distributed hydrologic model used in this study, Variable Infiltration Capacity (VIC) model release 5.1 (Liang et al., 1994; Hamman et al., 2018) (Fig. 2, up) has been modified to a "clumped" scheme (Figure 2, bottom) to more properly account for bare soil in arid and semiarid ecosystems.

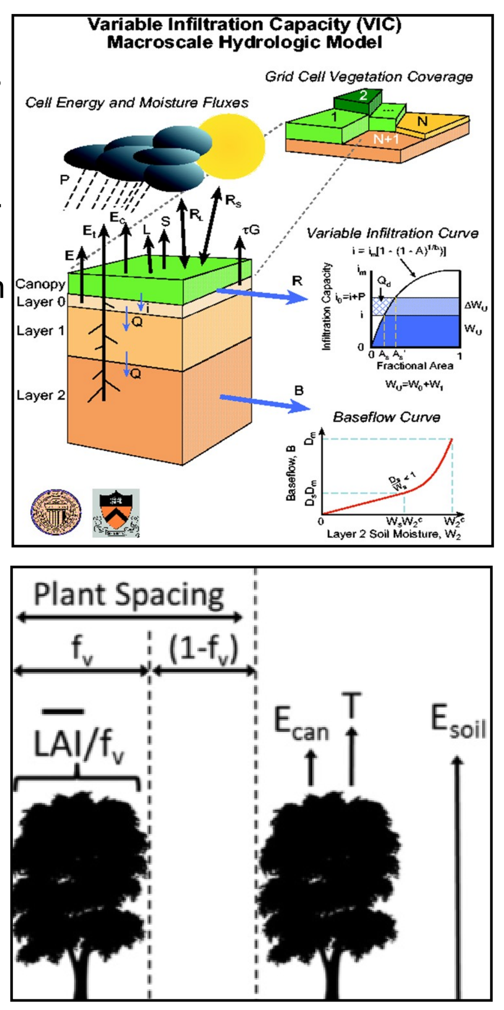

Figure 2. VIC hydrology model (up) and the schematic of clumped vegetation scheme (bottom)

Forcing Datasets:

- Historical simulations

Daily precipitation, temperature and wind speed from Livneh et al., 2015 product.

- Future simulations:

LOCA downscaled climate projections (Pierce et al., 2014)

- Forcing disaggregation:

Meteorology Simulator (Metsim), release 1.1 (Bennett et al., 2018; Bohn et al., 2013)

Estimates hourly inputs (short- and long-wave radiation, vapor pressure).

Remote-sensed LST products:

- MODIS (4 times a day, 1 km resolution)

Processed through the R package MODIStsp Version 1.3.2 (L. Busetto and L. Ranghetti, 2016).

- GOES (hourly, 5 km resolution)

Downloaded from the Copernicus Global Land Service of the European Space Agency (https://land.copernicus.eu/global/).

Numerical Simulations:

- Run and calibrate the VIC model with remote-sensed LST in year 2012.
- Investigate the effects of historical land cover change.
- Evaluate future climate change impacts on LST, each simulation has 1-year spin-up period.

Experiment	Land Cover Inputs	Forcing
Exp2001	NLCD 2001, MODIS 2001	2001-2011
Exp2011	NLCD 2011, MODIS 2011	
Current	NLCD 2011, MODIS 2011	2004-2013
Future		2051-2060

Table 1. Experiment design of land cover and climate change impact study.

III. Remotely Sensed Parameters

A set of remote-sensing-based surface parameters is retrieved from MODIS (Figure 3), including:

- Albedo: MODIS, MCD43A3, 16 day, 500 m;
- LAI: MODIS, MOD15A2, 8 day, 1 km;
- NDVI: MODIS, MOD13A1, 16 day, 1km.

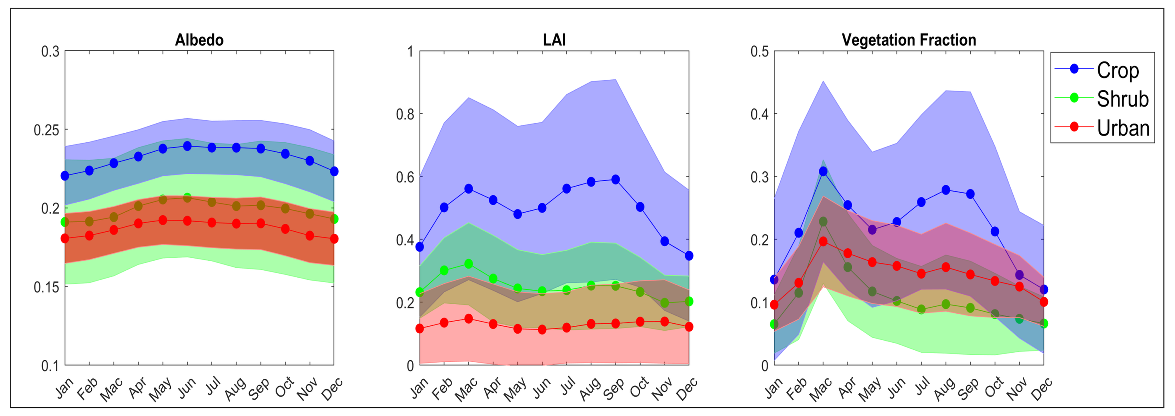

Figure 3. Time series of remote-sensing based parameters over different land cover types. Shaded areas denote spatial variability (one standard deviation).

IV. Remote-sensed LST Analysis

(A) LST Spatial Pattern from MODIS

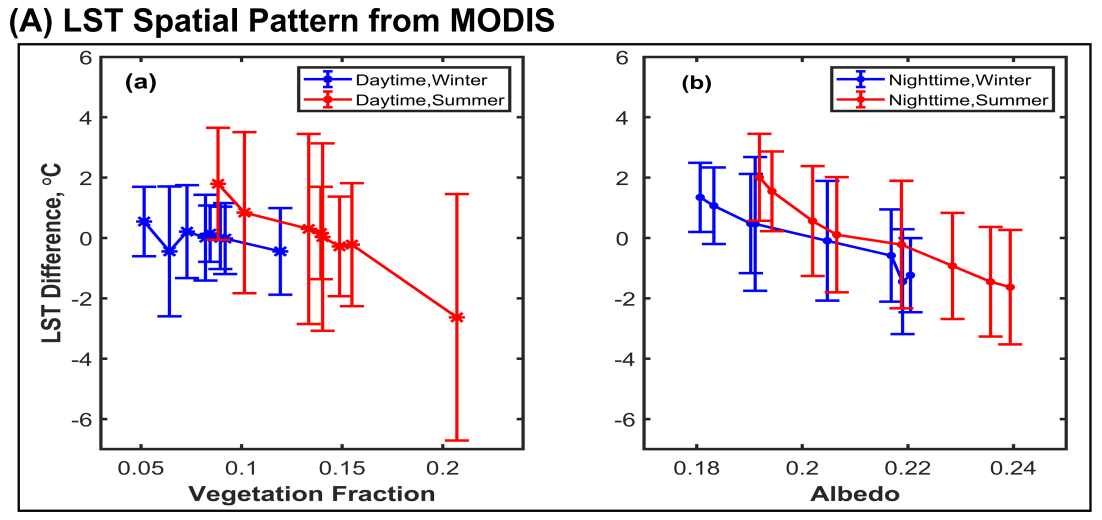

Figure 4. The variations of MODIS LST departure from domain mean on each land cover, versus (a) vegetation fraction in the daytime and (b) albedo in the night time, for summer and winter season.

- Daytime LST difference between different land covers is correlated with vegetation fraction.
- Nighttime LST difference is more controlled by the albedo.

(B) Diurnal Cycle of LST from GOES

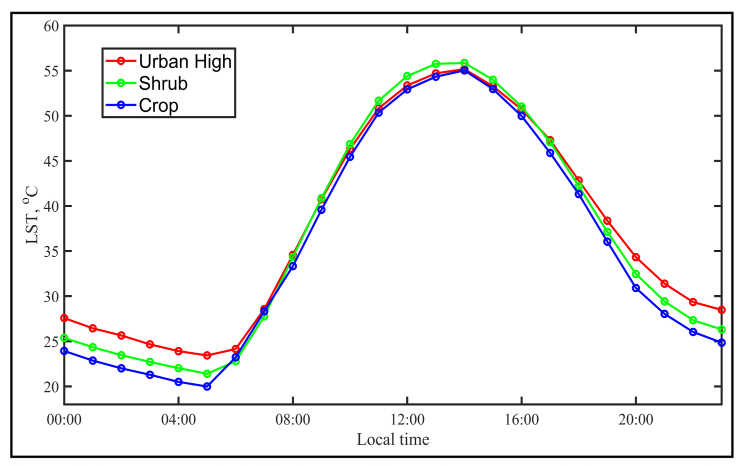

Figure 5. Average hourly LST of three different land covers during summer, 2012.

- Lower daytime LST over urban areas.
- Warmer Nighttime in urban areas, suggesting a nocturnal UHI.
- Different warming and cooling rates between urban and non-urban areas.

(C) Comparison of MODIS and GOES Product

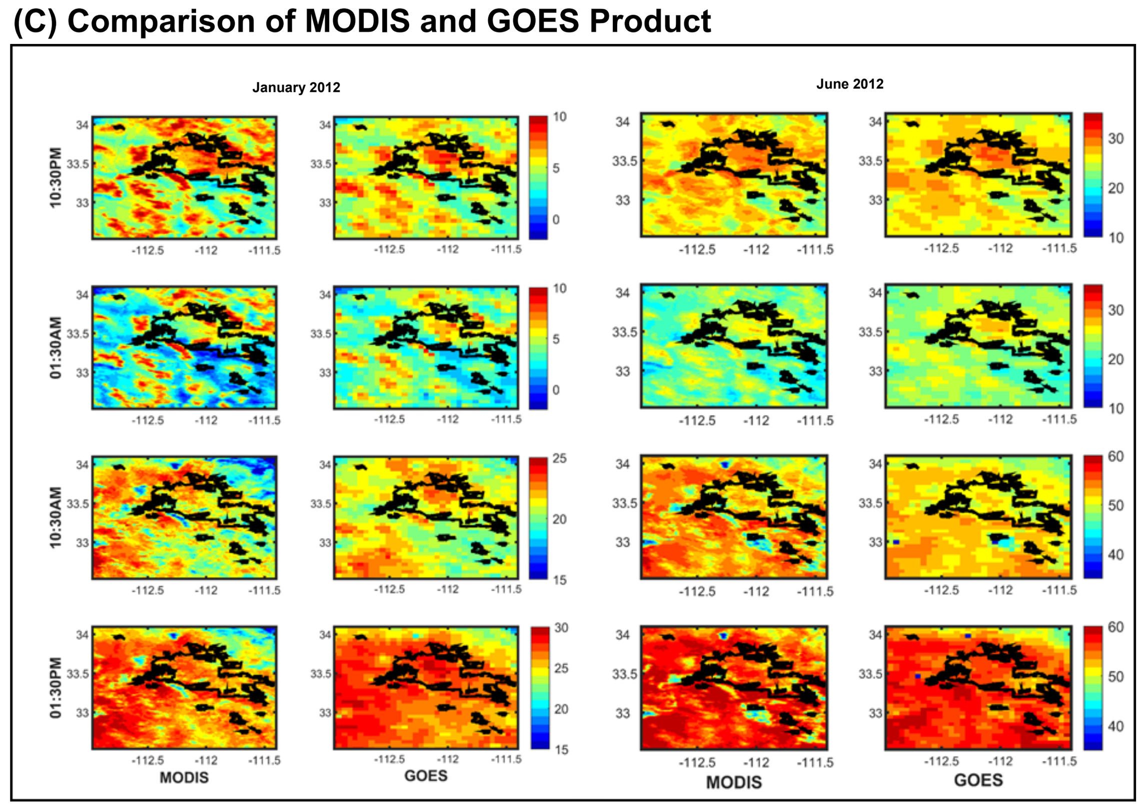

Figure 6. Comparison of MODIS and GOES LST (°C) averaged for January and June, at MODIS over-passing time (10.30 PM, 01:30 AM, 10:30 AM, and 01:30 PM)

- MODIS and GOES product have similar spatial pattern (Figure 6).
- GOES slightly overestimates nighttime LST than MODIS.

V. Results Validation

We combine MODIS and GOES LST product to validate the VIC simulation and find a good match in the year 2012.

(A) Spatial Pattern Comparison with MODIS

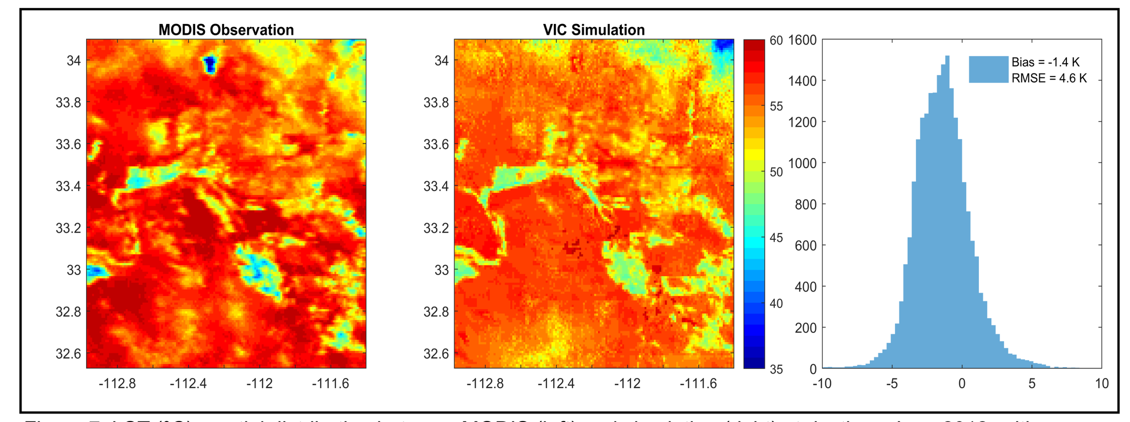

Figure 7. LST (°C) spatial distribution between MODIS (left) and simulation (right) at daytime, June 2012, with error histogram (right) at MODIS Terra over-passing time.

- VIC captures the urban-shrub-crop contrasts of LST.
- In average, VIC underestimates the LST by –1.4 K during the June.
- Underestimate LST over sparsely vegetated shrubland.

The bias of the LST differences between VIC simulations and MODIS observations over major land use categories is further examined.

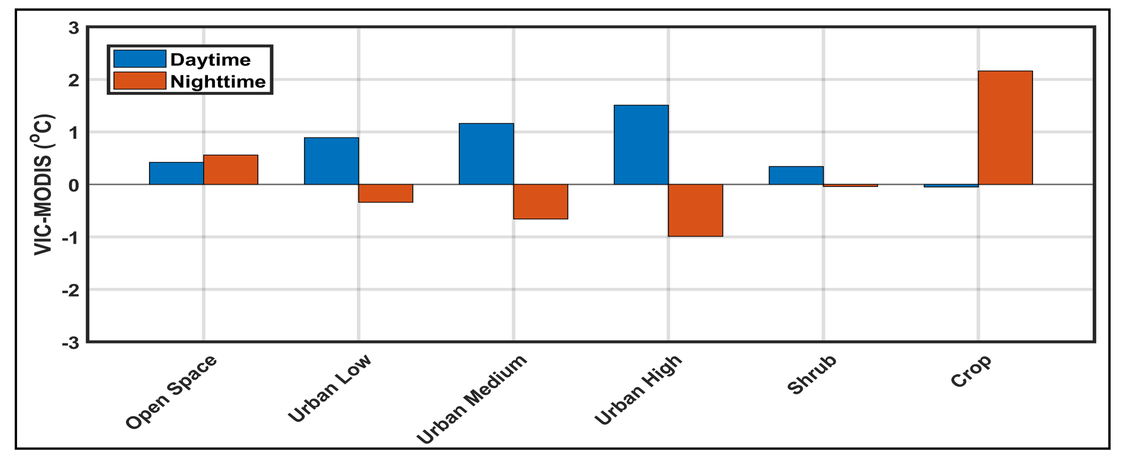

Table 2. LST biases at Aqua overpassing time (01:30 AM and 01:30 PM) between VIC simulation and MODIS observations over major land cover categories in the year 2012.

(B) Diurnal Cycle Comparison with GOES

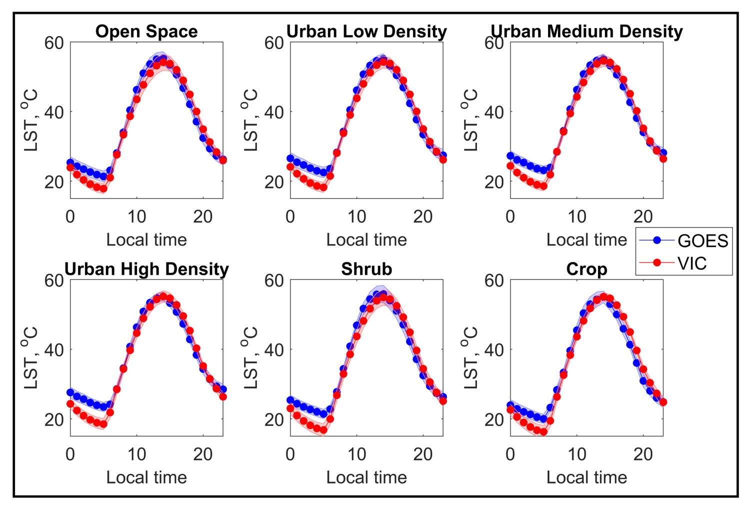

Figure 8. Diurnal cycle of LST over different land cover types between VIC simulation and GOES observation, averaged over Summer, 2012. Shaded area denotes one standard deviation.

- VIC captures the timing of minimum and maximum temperature.
- The simulated daily maximum temperature matches well with GOES.

VI. Historical Land Cover Change Impacts

- Extensive urbanization (more than 565 km^2) from 2001-2011.
- Significant changes in land surface biophysical properties (Figure 11).
- Captures the LST change over induced by land cover change (Figure 12).

Categories	Total Areas (km^2)	Percentage
Open Space	114.18	14.5%
Developed Low	231.47	29.5%
Developed Medium	257.35	32.8%
Developed High	77.33	9.9%
Shrub	32.67	4.2%
Crop	28.64	3.6%

Table 3. New land use categories during 2001-2011.

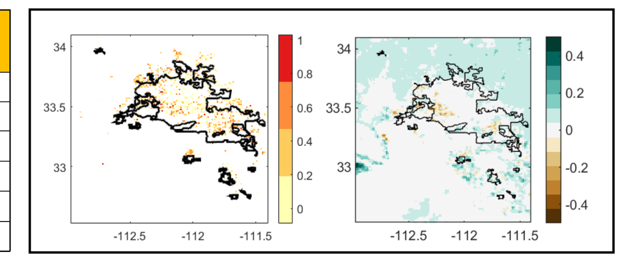

Figure 11. Change of impervious surface (left) and vegetation fraction (right) from the year 2001 to 2011.

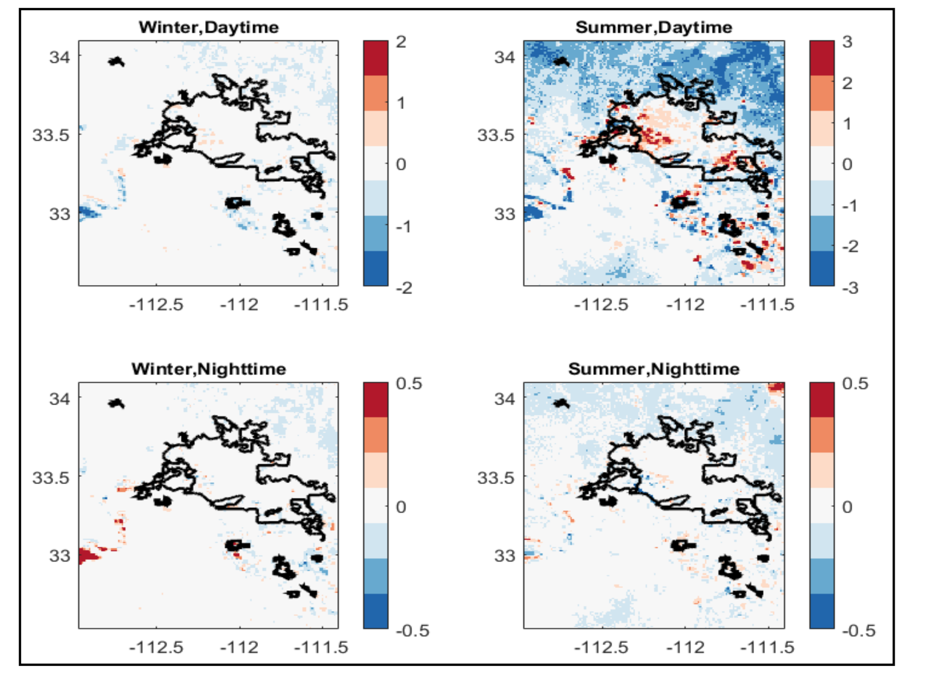

Figure 12. LST differences (°C) between two experiments (Exp2011-Exp2001) during winter (left) and summer (right) season, averaged over daytime and nighttime.

VII. Future Climate Change Impacts

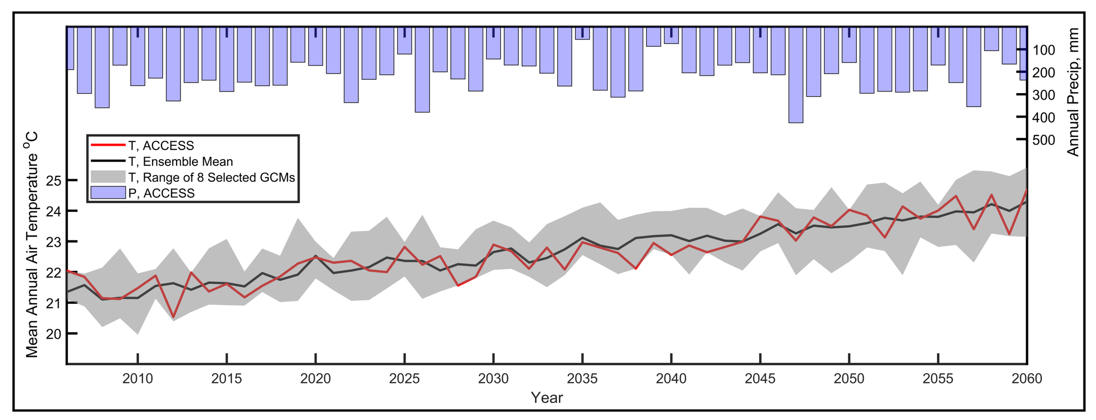

Figure 9. Projections of future climate from ACCESS-1 model averaged over the study domain.

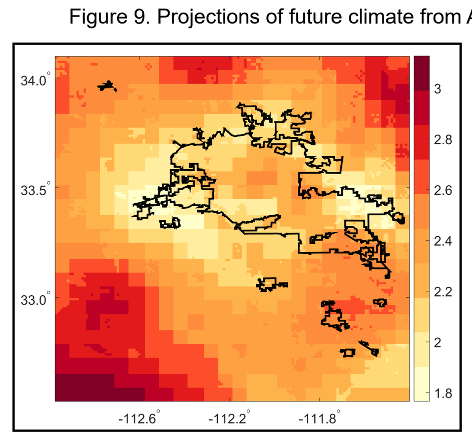

Figure 10. Mean annual LST change (°C) between two experiments (Future - Current).

- ACCESS-1 model (Bi et al., 2013).
- RCP 8.5 scenario, air temperature increases 2.42 °C (Future - Current).
- Simulated LST increases from 1.8-3 (°C) across the domain (Figure 10).
- 'Cooler' urban core than surrounding shrubland.
- Suburban areas might have greater vulnerability to excessive heat in future urban expansion scenarios.

VIII. Findings and Future Work

- Combining LST products from MODIS and GOES is a useful approach to understand the spatio-temporal variations of the LST and UHI.
- The spatial distribution of LST over the study domain is strongly controlled by vegetation fraction during daytime, suggesting the effectiveness of vegetation cover on mitigating excessive heat in urban.
- The validation of VIC simulation shows that the model could capture the spatiotemporal variability of LST on different land cover types.
- The accuracy of simulated LST can be further improved by introducing higher resolution remote-sensed products (e.g. Landsat) to derive land surface biophysical parameters, especially in urban regions.
- With better confidence built in historical modeling performance, the **combined effects of land cover and climate change** will be evaluated using future climate and land cover change scenarios.

IX. Acknowledgements

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