Impact of Shade Trees on Urban Hydroclimate for Phoenix and the Continental United States

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Background and Summary

The presence of built terrains modifies land surface energy and water transport, leading to adverse environment issues, e.g., the urban heat island effect. As an important urban mitigation strategy, trees in urban areas have shown as effective to alleviate excessive thermal stress in urban areas through radiative shading and evapotranspirative cooling.

How will the urban hydroclimate be impacted by shade trees?

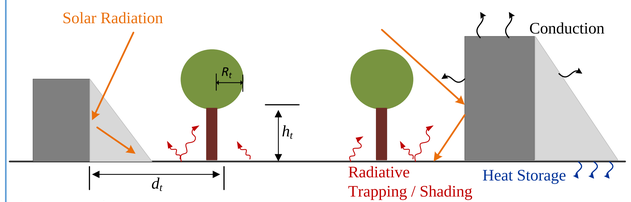
Most of the existing urban land surface models do not contain adequate representations of trees up to date. A **coupled Weather Research and Forecasting (WRF) Model and advanced urban canopy modeling (UCM) framework** is adopted in this study and applied to the **Phoenix metropolitan** as well as the **continental United States**.

Methodology

Representing urban trees in WRF

Trees: (1) interrupt the radiative rays transmitted between the canyon facets; (2) modify the view factors (VFs) between them.

Simulating VFs: stochastic ray-tracing method based on the Monte Carlo algorithm – to capture the radiative exchange processes inside the street canyon.



Assumptions:

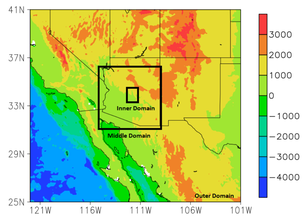
(1) Two symmetric rows of trees with cylindrical crown size of radius R_t

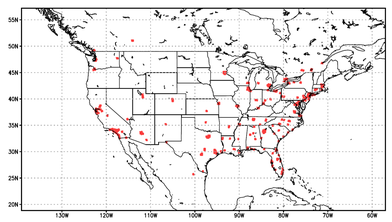
(2) The ray blocking effect of trunks is negligible

(3) All facets are Lambertain and gray

(4) Dimensions of tree and canyon – retrieved from CAP-LTER project and UBC

Study Areas





Meteorological conditions: National Centers for Environmental Prediction Final Operational Global Analysis data (1˚× 1˚, 6-h temporal frequency)

Land surface processes: Noah land surface model + single layer UCM

Phoenix Metropolitan Area

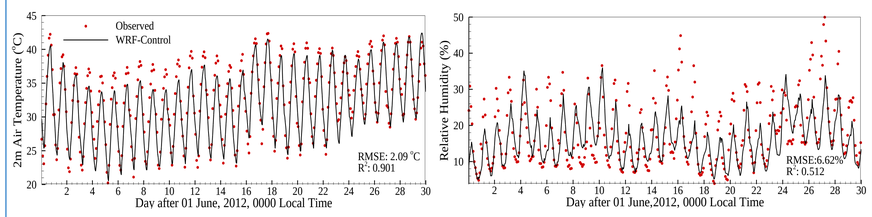
- Three domains (resolution: 32, 8, and 2 km)
- MODIS global land-cover data – outer and middle domains (Mexico)
- NLCD 2006 – inner domain (3 types of urban land)
- Three months (summer, June – August, 2012)

Continental US

- One domain (resolution: 20 km)
- MODIS global land-cover data (Mexico, Canada, etc.)
- One month (June, 2012 – initial results)

The impact of trees = modified single-layer UCM (with urban trees) – control run

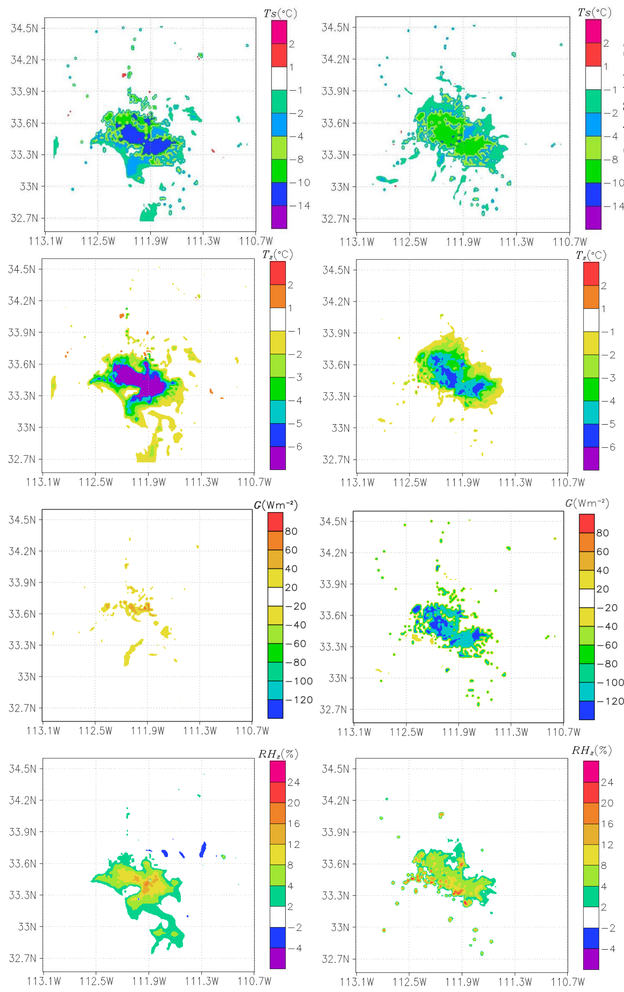
Model Evaluation



Comparison of time series of simulated and observed 2-m air temperature, and 2-m relative humidity averaged over 3 urban AZMET stations in Phoenix Metropolitan Area for June, 2012

Effects of Urban Trees on Hydroclimate for Phoenix

Simulated impact of trees during June-August, 2012 at 0200 LT (left), and 1400 LT (night)



Surface Temperature

Maximum reduction of surface temperature: ~ 10 ˚C (0200 LT) > ~ 8 ˚C (1400 LT)

2-m air temperature

Cooling effect: ~ 6 ˚C at the urban core, 1-4 ˚C for the rest of Phoenix metropolitan area (0200 LT) > ~ 1-5 ˚C (1400 LT)

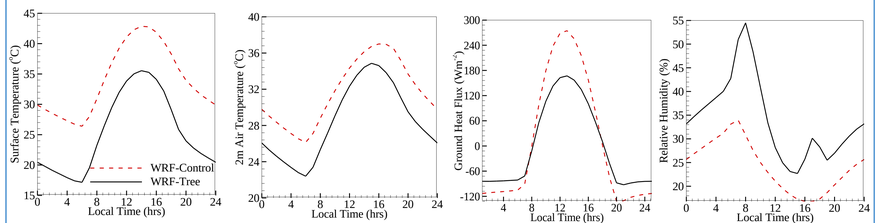
Ground heat flux

* Positive downward Reduction: maximum ~ 120 W m^{-2} (1400 LT), the upwelling flux decreased for ~ 40 W m^{-2} (0200 LT)

Relative humidity

Increase: Up to ~ 16% (0200 LT) > ~ 12% (1400 LT)

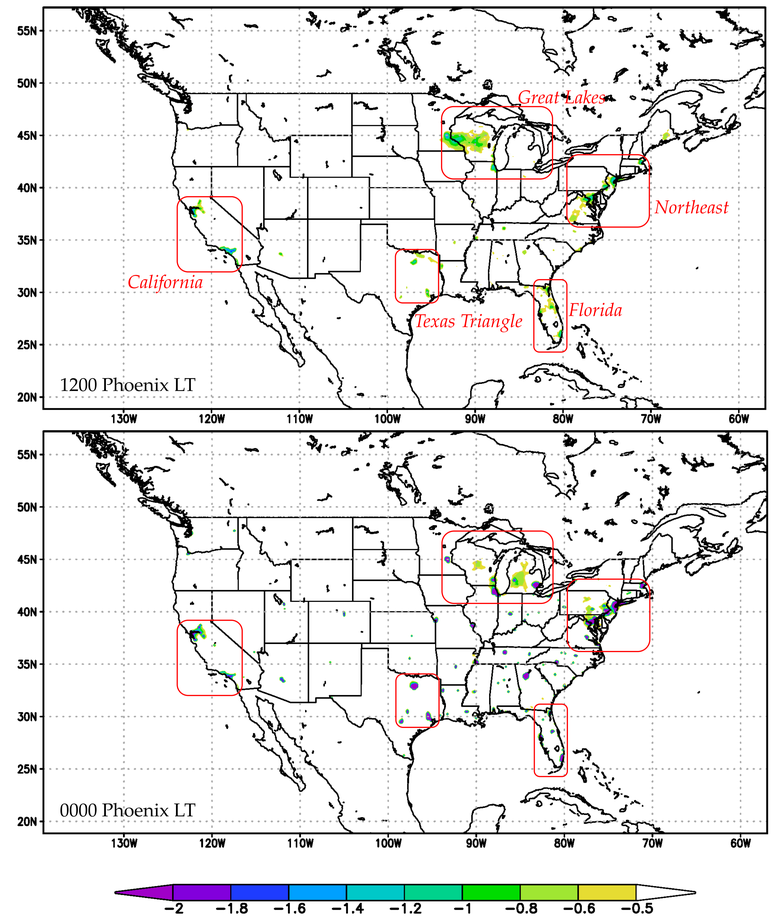
Diurnal variation of the average impact of trees during June-August, 2012



– 9.98 ˚C (at night) – 4.17 ˚C (at night) – 107 W m^{-2} (daytime) + 23% (morning)

* Maximum decrease (–) or increase (+)

Effects of Urban Trees on Air Temperature for the Continental United States



Conclusion and Perspective

- Urban trees were implemented into the single-layer UCM coupled with the WRF modeling system.
- Urban trees reduced 2-m air temperature, surface temperature, and ground heat flux, but increased relative humidity for the Phoenix metropolitan area.
- The cooling effect of trees is greater in nighttime than in daytime, primarily due to the reduced heat storage in engineering materials resulted from the blockage of incoming solar radiation by trees in daytime.
- Other ecohydrological processes (e.g. ET) remain open for future research.
- We are applying this modeling system to the continental US with one year meteorological data and assessing seasonal and geographical effects.

Acknowledgement

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