Summer cooling efficiency of landscapes in Phoenix, AZ

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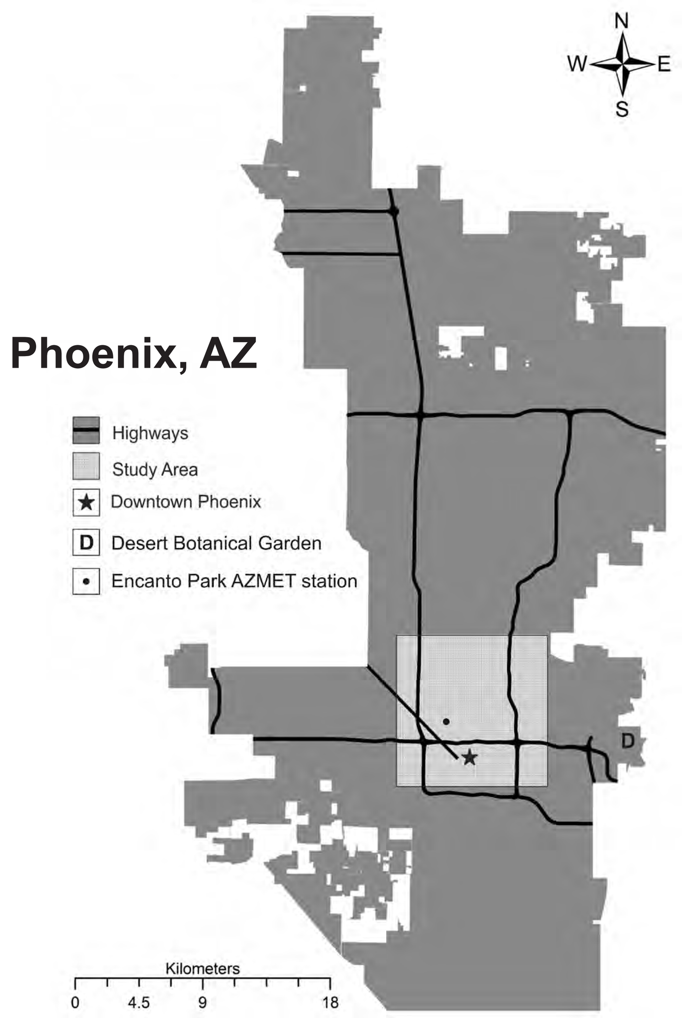
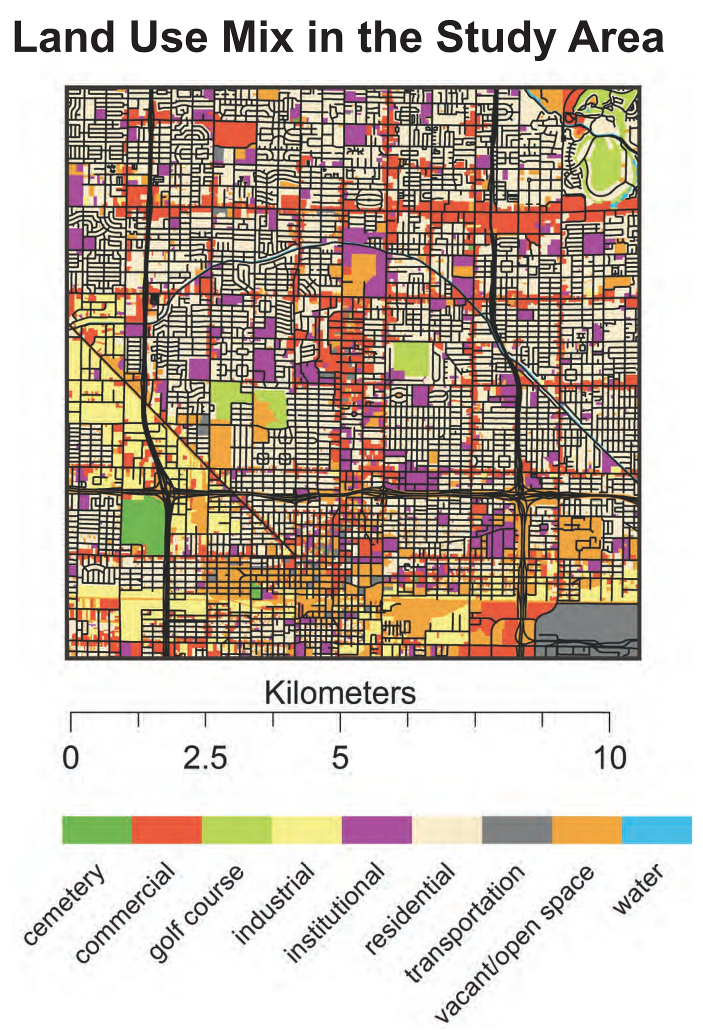
Introduction

A substantial body of literature has focused on urban heat island mitigation strategies over the past decade with urban design being proposed as an effective measure by various studies (Baker et al. 2002, Coutts et al. 2007, Middel et al. 2011). An important design strategy to improve local climate in places with dry hot summers is cooling through vegetation, because evapotranspiration (ET) is an important cooling agent in arid environments (Bonan 2000). However, adding vegetation in arid regions increases irrigation requirements and raises concerns about water scarcity and conservation. Finding a balance between temperature amelioration and water conservation in mitigating heat islands is crucial to developing more sustainable landscape practices.Therefore, this research systematically investigates the cooling-water use trade-off for different landscapes in Phoenix.

Study Site





- Area covers approximately 51 census tracts in and around downtown Phoenix
- Diverse land use and land cover classes, including urban and suburban neighborhoods (commercial, industrial, and residential segments with different densities) as well as desert landscape, unmanaged soil, and undeveloped areas
- Representative cross-section of typical neighborhoods in Phoenix

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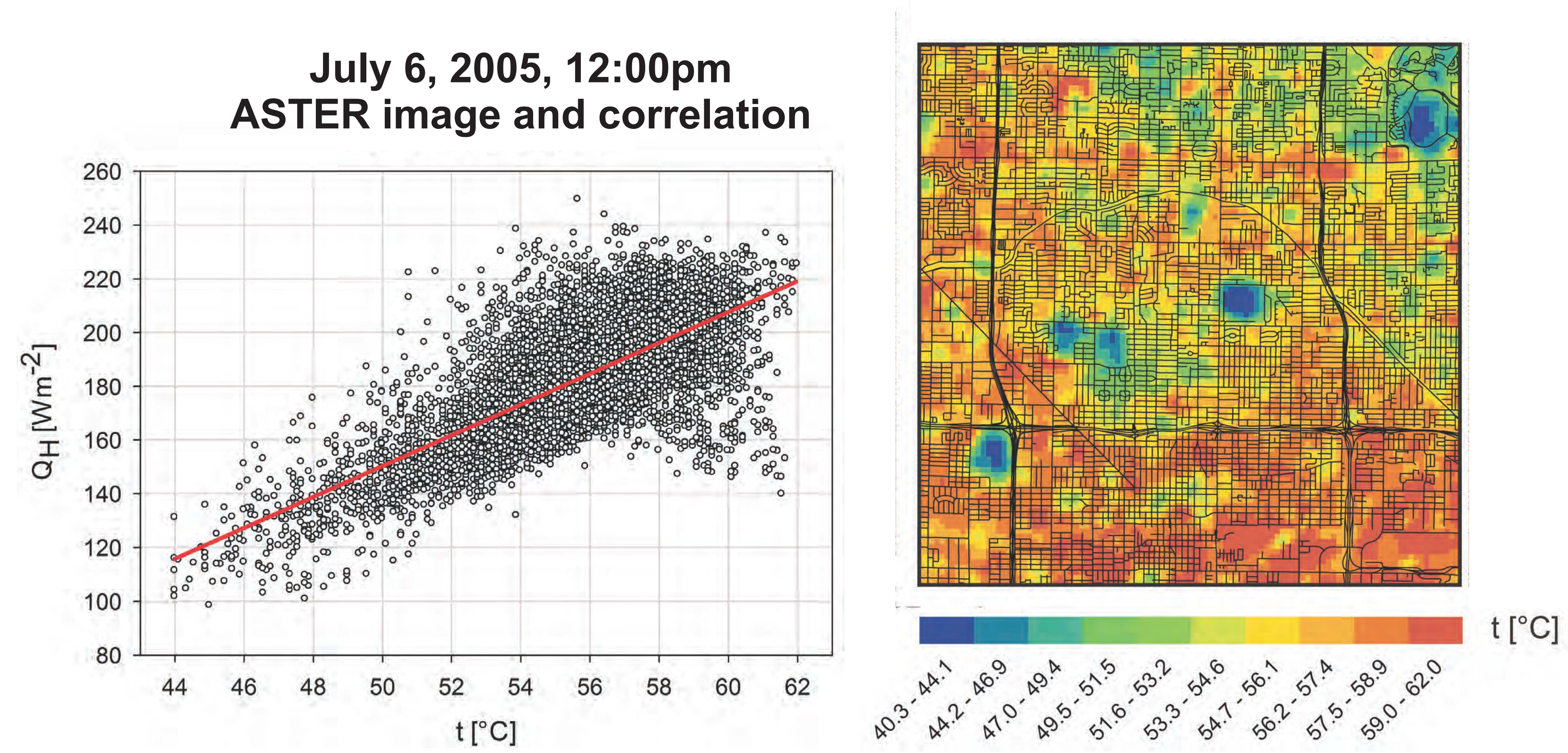
Methodology

- We used the Local-scale Urban Meteorological Parameterization Scheme (LUMPS) (Grimmond & Oke 2002, Loridan et al. 2011) to model the surface energy balance above canopy for July 6, 2005
- To investigate the trade-off between water demand of irrigated landscape and the amount of cooling achieved, we adopted the cooling efficiency index by Shashua-Bar et al. (2009). Cooling efficiency was estimated from differences in daytime sensible (Q_H) and latent (Q_E) heat fluxes of the LUMPS output fluxes between urban surfaces and the desert:

$$f = \frac{\Delta Q_H}{\Delta Q_E} \cdot (-100)$$

Validation

- LUMPS sensible heat fluxes were correlated to surface temperatures from ASTER imagery and yielded R^2 values of 0.53



- LUMPS latent heat fluxes were validated using reference ET values from a nearby agricultural meteorological weather station. The model appears to perform well for areas of high vegetation fraction, capturing the magnitude and temporal variability in these cases within 1-4% of the station's estimates

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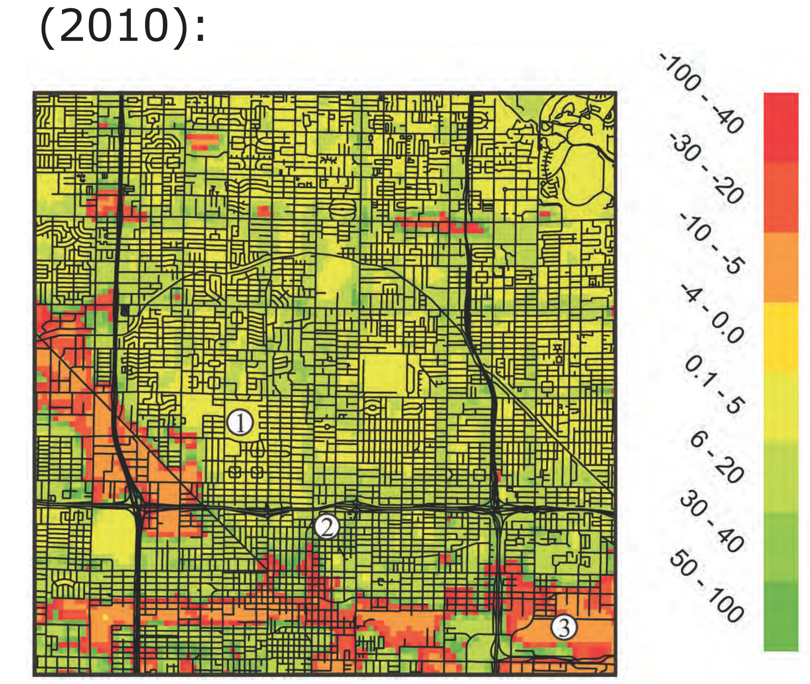
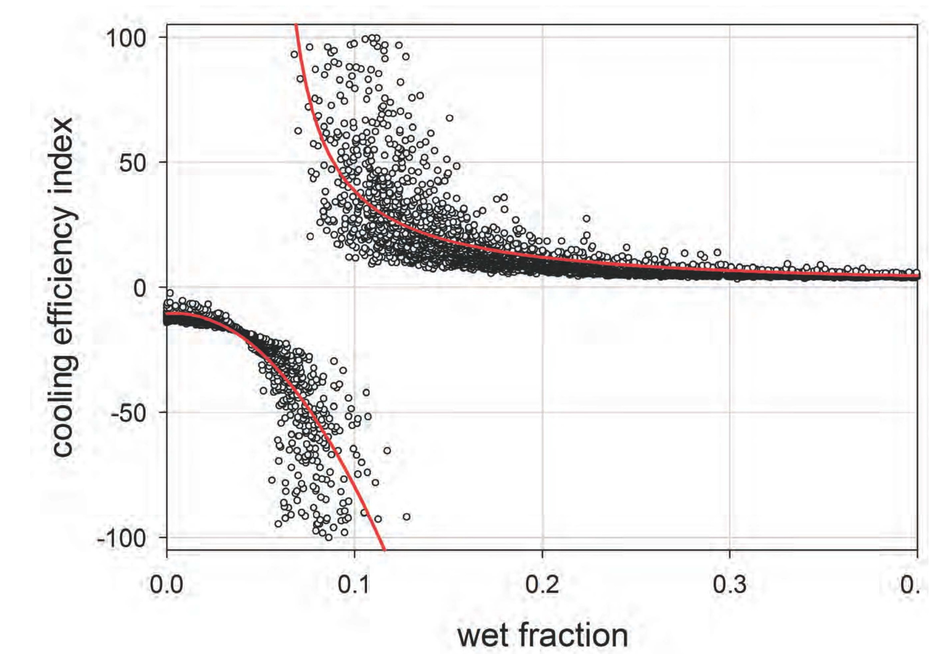
Results

- Spatial distribution of cooling efficiency indices and three sample sites, classified into local climate zones (LCZ) according to Stewart and Oke (2010):



(1) mesic open-set lowrise LCZ, residential location with flood irrigation, adjacent to golf course
(2) dry open-set lowrise LCZ, resembles many sites of urban, dry residential areas near commercial-transportation and downtown locations
(3) bare concrete LCZ, Sky Harbor Airport

- Efficiency index graph (cooling efficiencies of urban areas compared to the desert):



  - Cluster of points with negative cooling efficiencies consists of study sites with high impervious surface cover (> 60%) and low wet fraction. These sites are mainly located in the industrial zones of the study area and at Skyharbor airport (sample site 3).
  - Most parts of the study area have a positive efficiency index, but cooling efficiencies do not increase with wet fractions higher than 20%.
  - Overall, the Phoenix urban core is slightly more cooling efficient than the desert, but adding vegetation to already mesic neighborhoods does not increase efficiency. In fact, the most efficient cooling with minimal water consumption occurs in dry areas such as sample site 2. These sites are mainly located in areas of high land use mix.

Conclusions

Findings indicate that arid to moderately dry neighborhoods with heterogeneous land uses are the most efficient landscapes in balancing cooling and water use in Phoenix. However, further factors such as energy use and human vulnerability to extreme heat waves have to be considered in the cooling-water use tradeoff, especially under the uncertainties of future warming of the climate. Multiple, perhaps contrasting policies may be proposed for these scenarios and decision-makers will have to determine optimal approaches for the future of the Phoenix metropolitan area, assessing the tradeoff of cooling-water use while considering vulnerability.