Impacts of Urban Tree Canopy and Water Features on a Semi-Arid Thermal Environment

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Abstract

Added heat due to the urban heat island (UHI) can negatively impact air quality, thermal comfort, and heat-related outcomes. Concerns associated with these compounding factors are of great importance in an expanding hot desert city like Tempe, Arizona. Strategically introducing trees and water features in urban settings moderates thermal stress by intercepting incoming solar radiation and repartitioning available energy to latent heat. The objective of this study is to assess the impacts of urban trees and the presence of water features on the urban micro-climate and human thermal comfort (HTC) in and around Rio Salado Park (Tempe). Five 90-minute transects using a mobile human-biometeorological platform (MaRTy) were completed on June 22nd, 2018 between 10:00 and 20:00 MST to gather meteorological variables to quantify the thermal environment and HTC. Mean radiant temperature (sum of longwave and shortwave radiation) contributes largely to HTC. Findings indicate that provision of tree shade decreases mean radiant temperatures (MRT) by ~20ºC when placed over concrete and grass surfaces. Although open water surfaces provide a cooling effect, urban tree canopy better improves HTC. Our results demonstrate the relative thermal and radiative impacts associated with tree coverage and water features in a semi-arid environment and provide useful guidelines for improving the thermal environment for urban inhabitants.

Introduction

- Impacts of heat stress within an expanding hot desert city include: increased heat-related illnesses and mortality, increased water and energy use, and decreased use of outdoor spaces for activity.
- Blue and green infrastructure can cool down urban temperatures and increase thermal comfort through the conversion of solar energy into latent heat.
- Human thermal comfort encompasses meteorological variables such as MRT, relative humidity, wind speed, and temperature. MRT is the driving force of thermal comfort in semi-arid urban environments.
- **The aim of the study is to monitor microclimate variability at Rio Salado Park, Tempe. Our focus is the impacts of trees and water bodies (Tempe Town lake) on HTC and MRT during hot summer conditions.**

Methods and Material

- We conducted five 90-minute transects at 2 hour intervals around Rio Salado Park (***Figure 1***) using a mobile human biometeorological platform (***Figure 2-MaRTy***). Weather conditions included sunny clear skies, a maximum air temperature of 43.3ºC at 14:51, and an average humidity of 6.5% and windspeed of 4.4m/s.
- MaRTy contains the following instruments:
  - **(1)** Temperature and Relative Humidity Probe
  - **(2)** Omega Type T Thermocouple
  - **(3)** 2D Wind Sensor
  - **(4)** GPS
  - **(5)** Three Hukseflux 4-Component Net Radiometers

Figure 1- *Rio Salado Park Transect Routes*

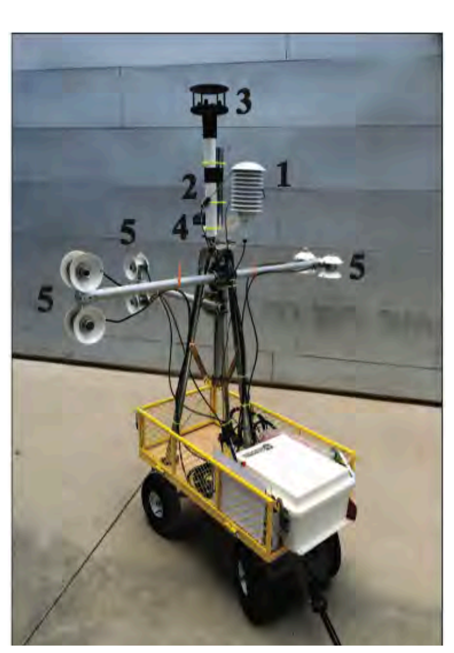

Figure 2 *(left) - Human Biometeorological Platform (MaRTy[1]) used to complete transects.*

Figure 3 *(above) - Infrared Camera used for thermal imaging of surface temperatures.*

- Measurements were conducted at 27 transect stops for 45+ seconds. Stop locations were characterized as sun-exposed concrete or grass, and shaded concrete or grass.
- Data were time-detrended to compensate for ambient changes in temperature and humidity during the transect.
- Infrared camera (***Figure 3***) was used to capture surface temperatures images.
- We calculated the Physiologically Equivalent Temperature (PET)[2], a measure of HTC, using RayMan software.

Results & Discussion

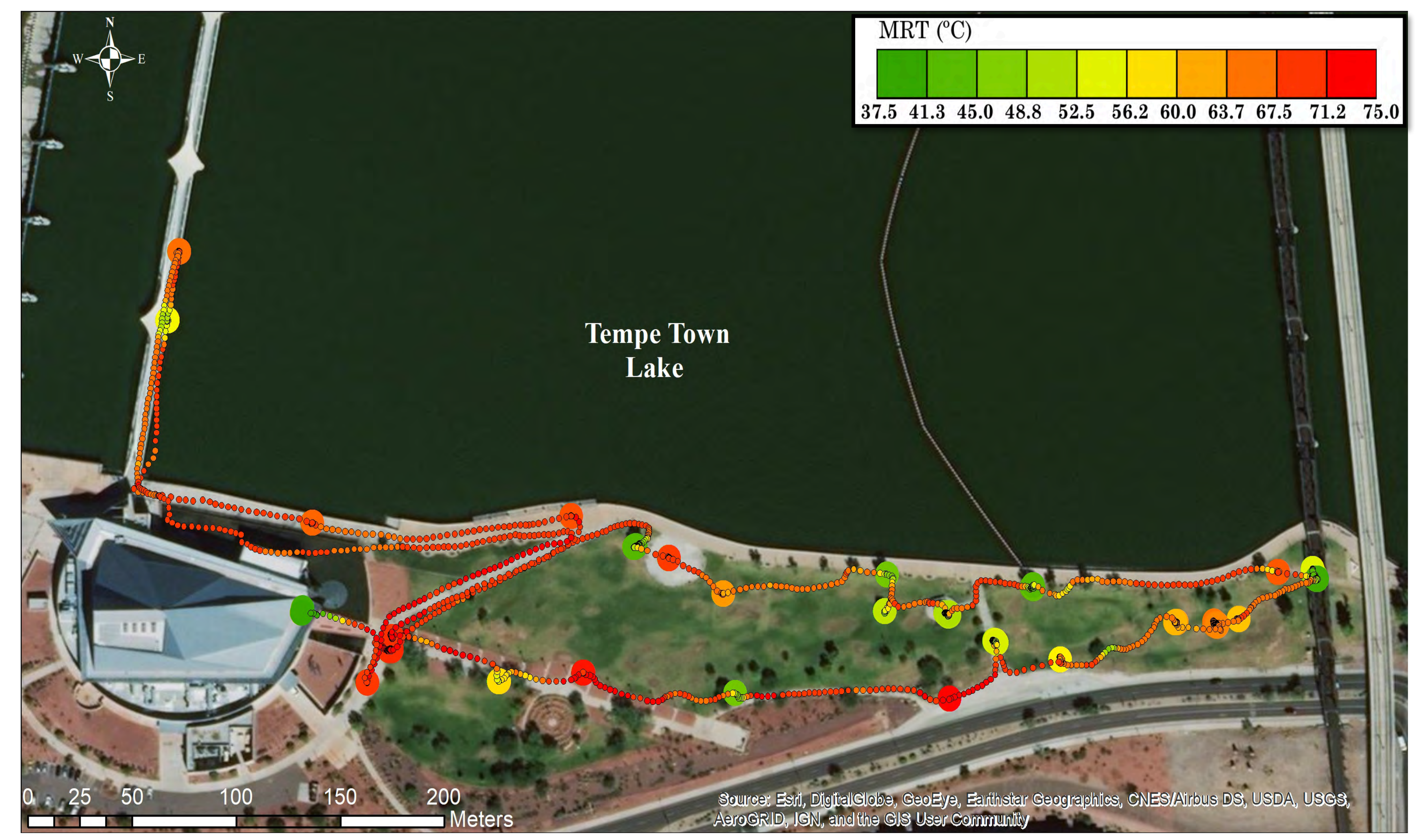

Figure 4- *MRT variables at Rio Salado Park at 1400 MST (Basemap source: Esri)*

- At exposed sites, maximum recorded MRT on the Water Transect route (blue pins in ***Figure 1***) was 67.5ºC, under shade maximum MRT is 60ºC. By contrast, the highest MRT recorded at concrete sites furthest away from the lake and water feature was 75.0ºC.
- Shade provided by tree canopy over concrete resulted in significantly lower MRT values than the sun-exposed sites by the water features, an approximate 7.5ºC difference. The ranges of MRTs on sun-exposed concrete are similar near green and blue infrastructure, respectively.
- ***Figure 5 (IR thermal images),*** shows the lower surface temperatures of water (32ºC), trees, (~28ºC) and shaded grass (~26ºC) as compared to concrete, asphalt, and soil (~50ºC+).

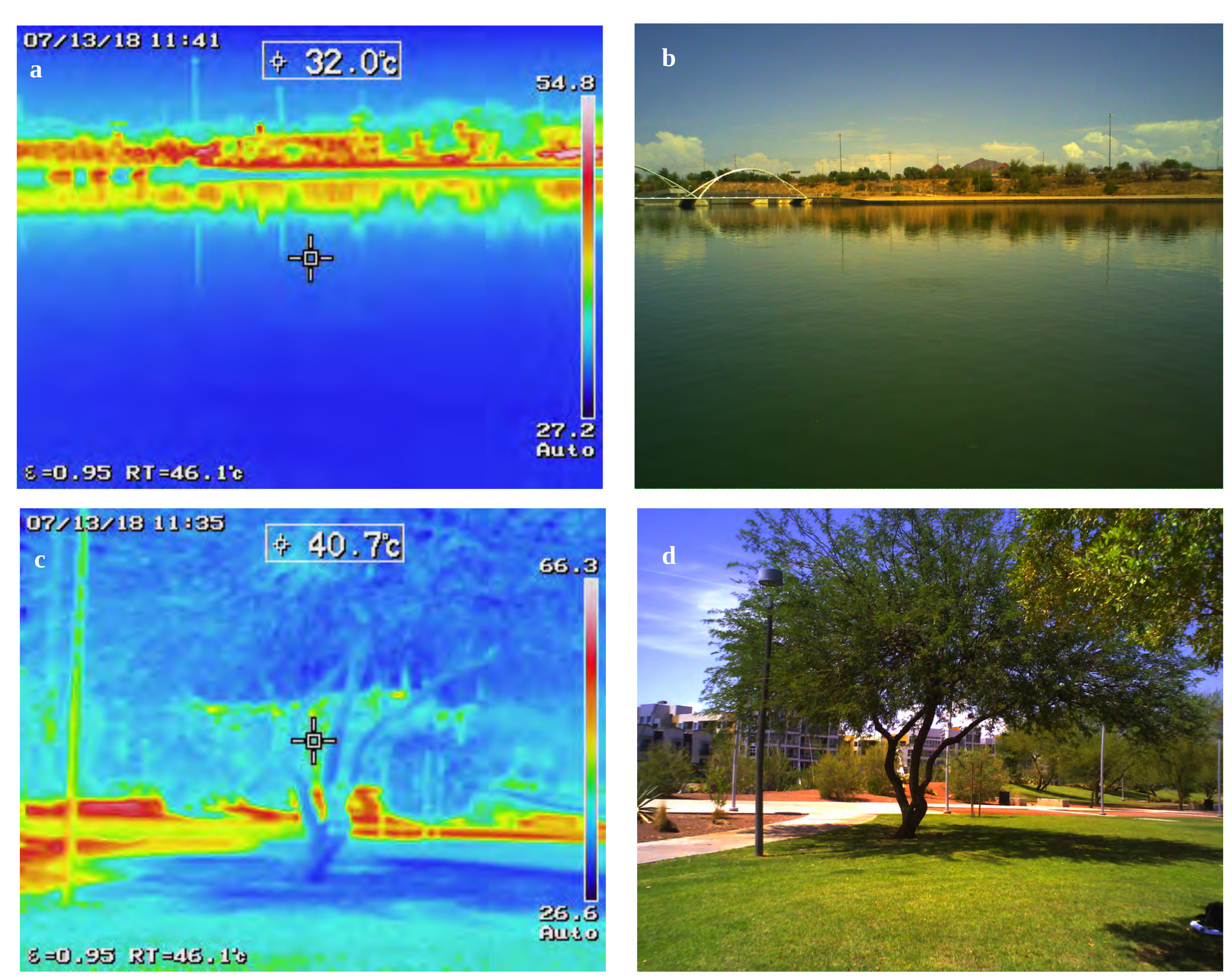

Figure 5- *a) Infrared Image of Tempe Town Lake. b) Visible image of Tempe Town Lake. c) Infrared Image of a Velvet Mesquite tree in Rio Salado Park. d) Visible image of a Velvet Mesquite tree in Rio Salado Park.*

Results & Discussion (continued)

- There are no significant differences between air temperatures among the heterogenous locations except at 10:00 where the air temperature above exposed grass surfaces is ~1.5º warmer than exposed concrete (***Figure 6A***).
- We observe a large differences in MRT (***Figure 6B***) between fully shaded and non-shaded areas. At 14:00, the difference in **MRT over sun-exposed concrete is ~20ºC higher than shaded concrete and ~25ºC higher than shaded grass surfaces.**
- Surface temperatures of exposed concrete (***Figure 6C***) are highest throughout the day compared to exposed grass, shaded concrete, and shaded grass. From 10h00 to 14:00, surface temperatures of exposed concrete are a minimum of 10ºC hotter than the remaining surfaces.
- During this extreme heat day, most PET values (***Figure 6D)*** ranged in the "Extreme Heat Stress" category (PET > 41ºC). Our results show that **thermal stress on the average human is lessened directly under canopy coverage.**

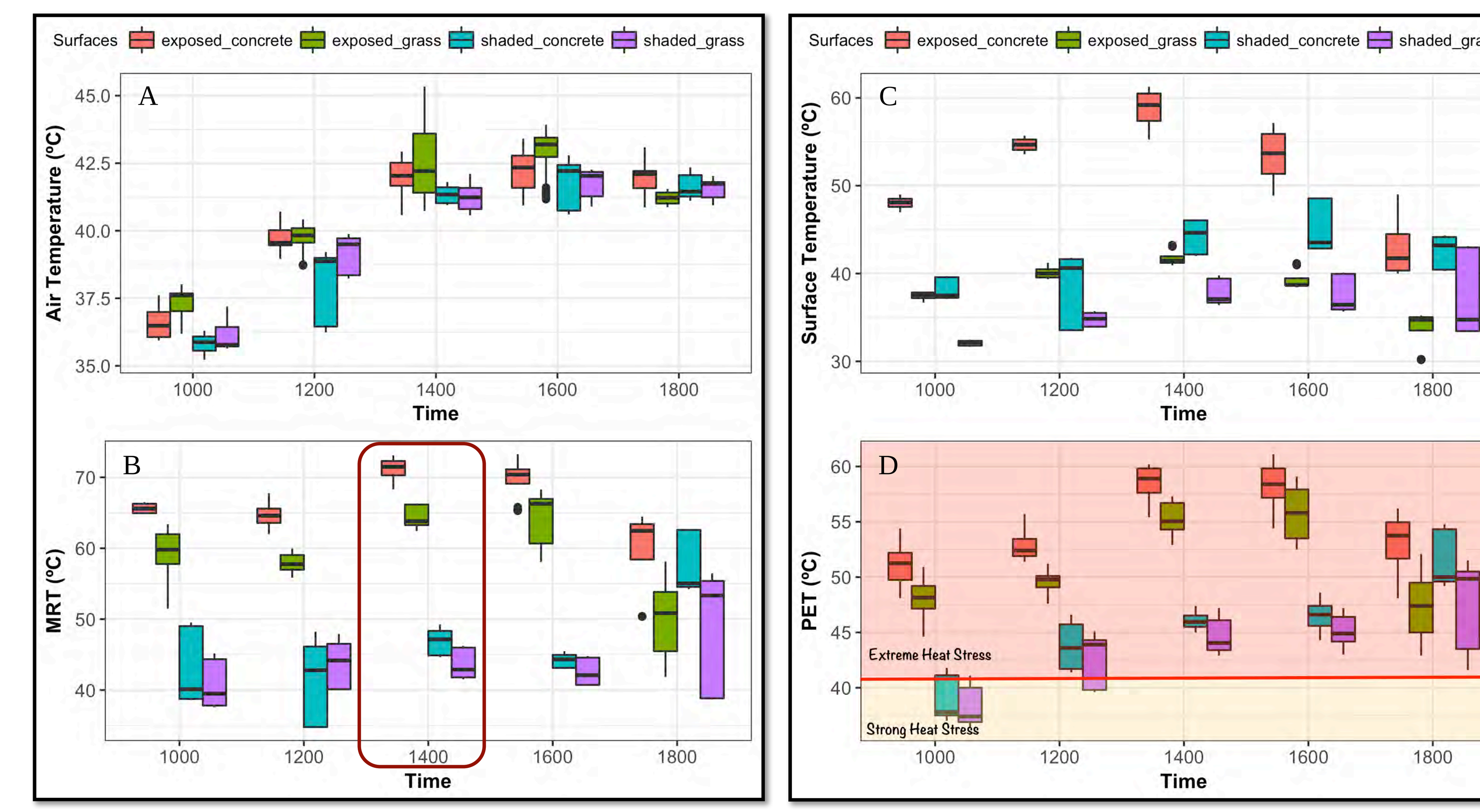

Figure 6 *– Box and Whisker Plot of A) MRT, B) Air Temperature and C) Surface Temperature D)PET. Exposed concrete (n=300), Exposed Grass (n=300), Shaded Concrete (n=300) Shaded Grass (n=300)*

Conclusions

- Urban tree canopy intercepts incoming solar radiation and therefore decreases surface temperature (and hence outgoing longwave radiation) and shortwave radiation, on both grass and concrete surfaces. Therefore, implementing urban trees will provide a beneficial cooling effect and increase human thermal comfort.
- Although water is lower in temperature than the surrounding environment, it is less effective than tree canopy at reducing mean radiant temperatures and ambient temperatures. The cooling properties of a still, open water body depend on wind direction and speed.
- Increasing urban canopy in the Valley of Sun will require a copious amount of water. Therefore, it would be in our best interest to introduce drought resistant trees.

References

1. Middel, A and Krayenhoff , S (in preparation), Micrometeorological Factors Determining the Outdoor Thermal Environment During Record-Breaking Extreme Heat in Tempe, Arizona: Design for Optimal Microscale Heat Mitigation, *Building and Environment*.
2. Matzarakis, A., & Amelung, B. (2008). Physiological Equivalent Temperature as Indicator for Impacts of Climate Change on Thermal Comfort of Humans.

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