Understanding the Physical Dynamics of Microclimate: Ongoing Research Projects

Ariane Middel[1], Kathrin Häb[2], Benjamin L. Ruddell[3], Anthony J. Brazel[4], Chris A. Martin[5]

[1]Center for Integrated Solutions to Climate Challenges, Arizona State University, PO Box 878009, Tempe AZ 85287-8009
[2]Department of Computer Science, University of Kaiserslautern, PO Box 3049, 67653 Kaiserslautern, Germany
[3]College of Technology and Innovation, Arizona State University Polytechnic, 7231 E. Sonoran Arroyo Mall, Mesa AZ 85212
[4]School of Geographical Sciences and Urban Planning, Arizona State University, PO Box 875302, Tempe AZ 85287-5302
[5]School of Letters and Sciences, Arizona State University Polytechnic, 6073 South Backus Mall, Mesa AZ 85212

ASU CENTER FOR INTEGRATED SOLUTIONS TO Climate Challenges
ARIZONA STATE UNIVERSITY

NSF

Central Arizona-Phoenix Long-Term Ecological Research
CAP LTER

Research Goals

- Understand the physical dynamics of microclimate in desert environments through meteorological observations, thermography, and modeling
- Explain microclimatic patterns at various spatial and temporal scales
- Investigate how microclimate dynamics affect thermal perceptions and comfort

Research Questions

- How does microclimate vary with land cover, upwind fetch, and shade at different times of day and seasonally in an urban desert environment?
- Which land cover and shade combinations (trees and engineered canopies) are most beneficial for thermal comfort and why?
- How does land cover patch size and composition impact the spatial and temporal distribution of microclimates under various upwind speeds at different times of day and year?

Merit

A comprehensive understanding of microclimate dynamics:

- will inform public policy decision-making to design more comfortable and sustainable urban environments
- will foster the development of science-based adaptation solutions to urban climate challenges in desert cities

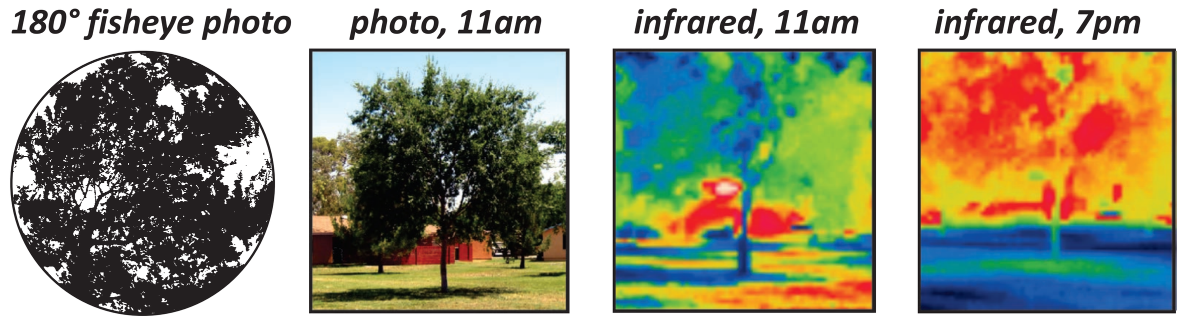
North Desert Village: Trees, Shade, and Comfort [1]

Assessment of diurnal microclimate and thermal benefits of tree canopy shade based on hourly meteorological observations, thermographic images, and fisheye photography

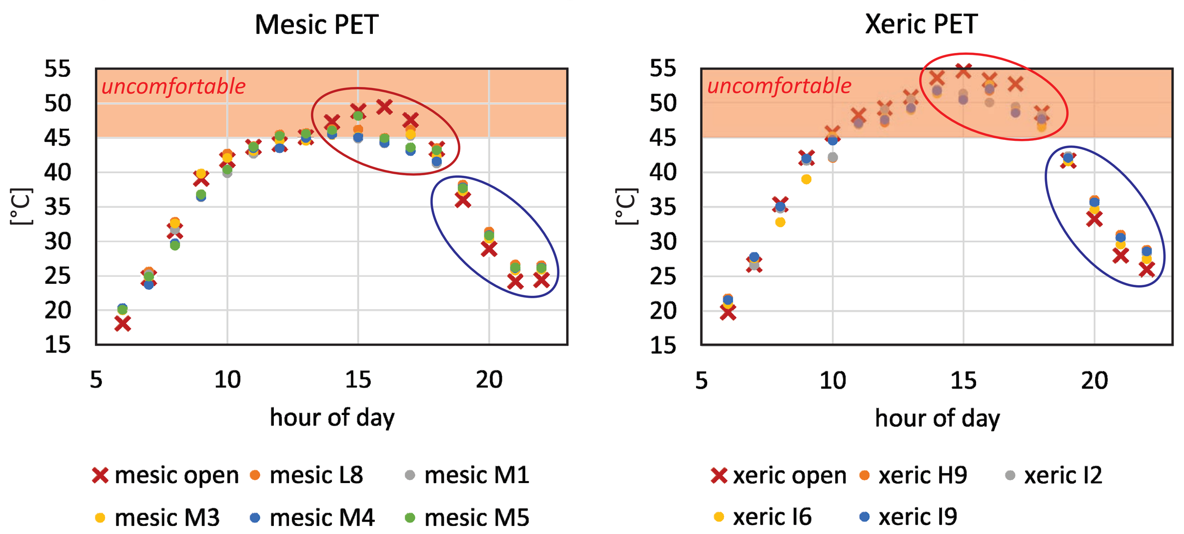
- Hourly surface temperature observations under selected trees in NDV using a FLIR i3 infrared camera
- 1s microclimate observations (mobile weather station)
- Observation periods:
  - 06:00am to 10:00pm on June 21, 2012
  - 07:00am to 08:00pm on October 24, 2013
- Average shaded and non-shaded surface temperatures were extracted from the infrared images using a region growing algorithm
- Calculated Mean Radiant Temperature (MRT), Predicted Mean Vote (PMV), Standard Equivalent Temperature (SET), Physiological Equivalent Temperature (PET), and Universal Thermal Comfort Index (UTCI) with Rayman, using 180° fisheye photos and microclimate observations

Chinese Elm, NDV mesic neighborhood, June 21, 2012

180° fisheye photo | *photo, 11am* | *infrared, 11am* | *infrared, 7pm*



Physiologically Equivalent Temperature (PET) for a woman (65kg, 1.60m, 35 years, t-shirt and skirt, standing) under a tree [•] and in the open [x]



Power Ranch: Tree and Shade Transect

Analysis of microclimate under trees and engineered canopy in comparison to non-shaded land covers using a matrix of select surface types and tree species

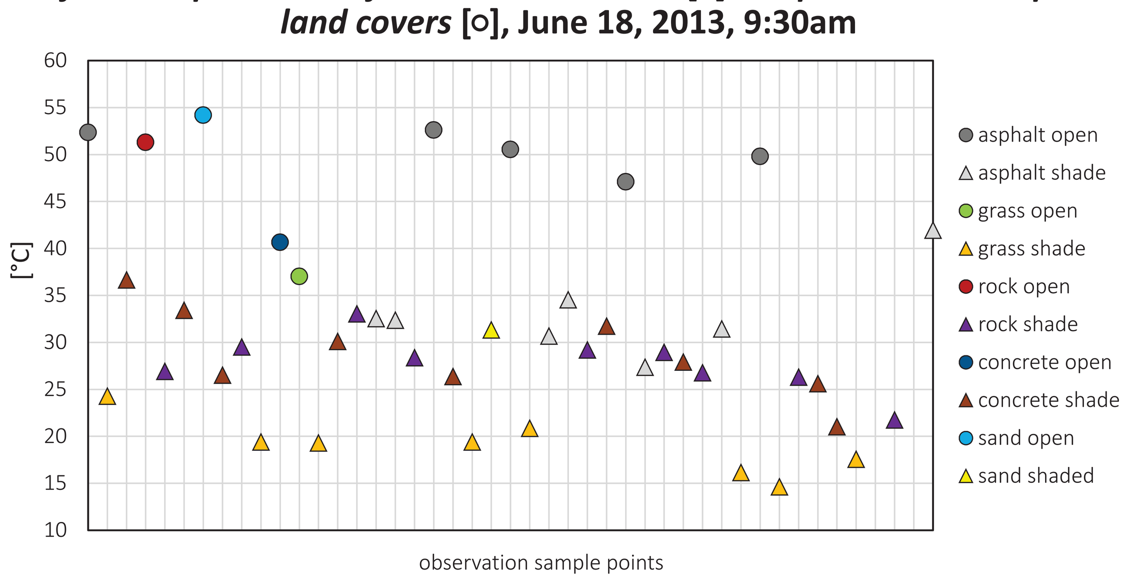
- Neighborhood transects with 42 observational stops at various tree species and surface type combinations
- Summer and fall transect runs:
  - June 18, 2013, every 3 hours, 07:00am to 10:00pm
  - June 20, 2013 at 03:00am
  - October 30, 2013, every 3 hours, 08:00am to 08:00pm
- 1s microclimate observations: surface temperature, air temperature (1m/2m), relative humidity (1m/2m), incoming solar radiation, infrared cone (up/down); measurements at each stop: shade width & length, Wet Bulb Globe Temperature (WBGT)
- Post-processing includes time-detrending, aggregation of 1s observations for each stop, and time transformation (times relative to sunrise and sunset)

Tree and land cover matrix

	asphalt	concrete	grass	rock	sand
fan palm	-	x	x	x	-
palo verde	x	x	x	x	-
mesquite	x	x	x	x	-
willow acacia	x	x	x	x	-
cottonwood	x	x	x	x	-
oak	x	x	x	x	-
ash	x	x	x	x	-
cedar	x	x	x	x	-
artificial shade	-	x	-	-	-
roof	-	-	-	-	x
full sun	x	x	x	x	x

Transect route and observational locations

Surface temperatures of shaded land covers [Δ] compared to sun-exposed land covers [○], June 18, 2013, 9:30am

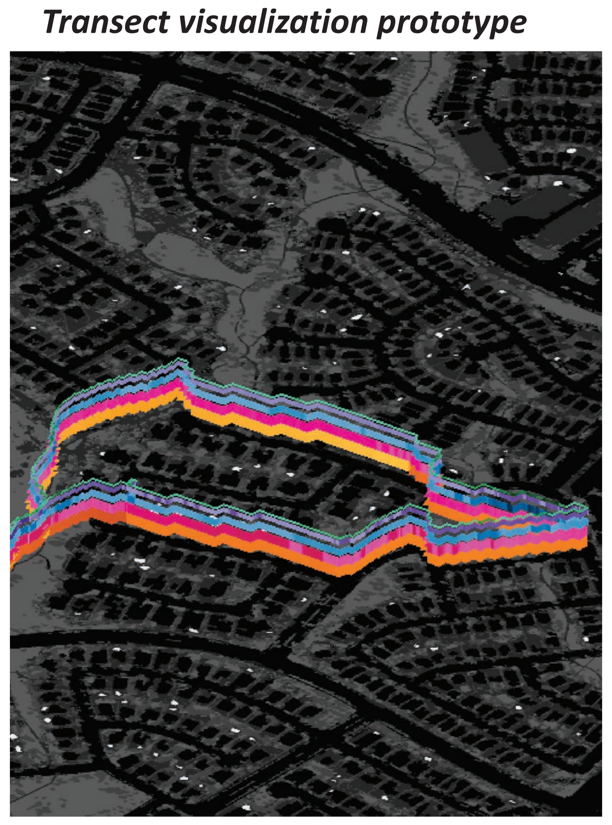


Power Ranch: Transect Visualization [2,3]

Visualization tool to explore the multivariate relationship between microclimate, land cover, and upwind fetch, using mobile seasonal microclimate transects of a residential neighborhood

- Transect data are multivariate, time-varying, spatially dependent, and can be affected by sensor lags
- Anticipated features of the visualization tool *TraVis*:
  (1) Transect data post-processing, including sensor lag correction and time-detrending
  (2) Display of microclimate observations in spatial context for interactive exploration
  (3) Fetch area calculation for each observation based on wind speed, direction, and sensor height
  (4) Multivariate statistics for transect data analysis in relation to land cover
  (5) Data clustering and 3D visualization using glyphs
- A first prototype shows microclimate variables as color-coded wall, following the transect route on a land cover map; descriptive statistics of select variables can be displayed
- Dataset for visualization prototype: Power Ranch neighborhood transects from 2011 to 2012 at various times of day and year

Transect visualization prototype



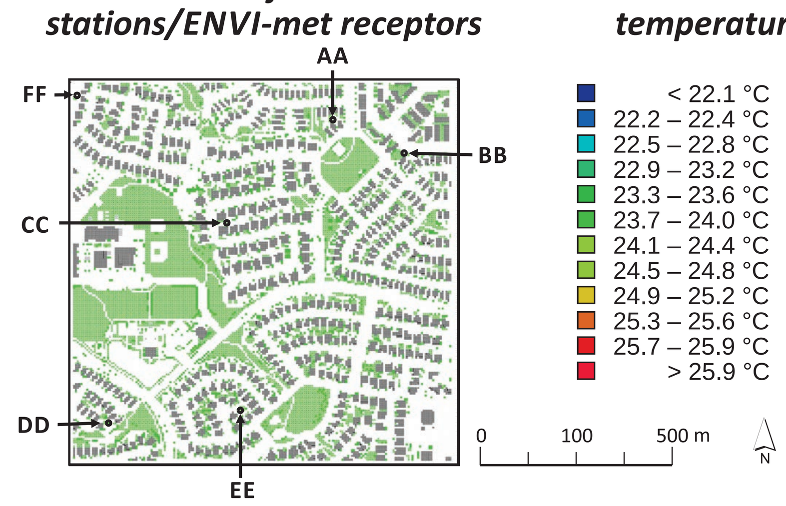
Mobile weather station

Power Ranch: ENVI-met Patch Shuffle

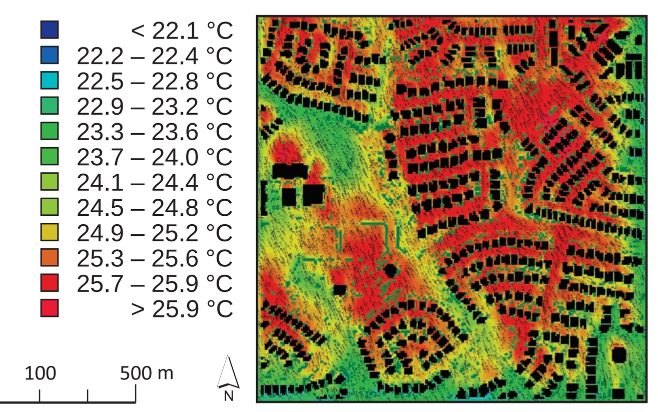
Analysis of microclimate variability at various upwind speeds, times of day and year for different land cover compositions and patch sizes

- ENVI-met microclimate simulations for 10 scenarios of randomly shuffled land cover patches at 5 different patch sizes each
- Patch sizes:
  4 patches at 510m, 16 patches at 255m, 64 patches at 125m, 256 patches at 60m, 1024 patches at 30m
- Meteorological scenarios:
  June 18, 2012 and December 24, 2011
  - 05:00am to 07:00am (easterly wind)
  - 11:00am to 01:00pm (midday, includes solar noon)
  - 05:00pm to 09:00pm (westerly wind)
- ENVI-met is parameterized using 333m resolution WRF output data; results are validated using observations from mobile weather stations in Power Ranch backyards

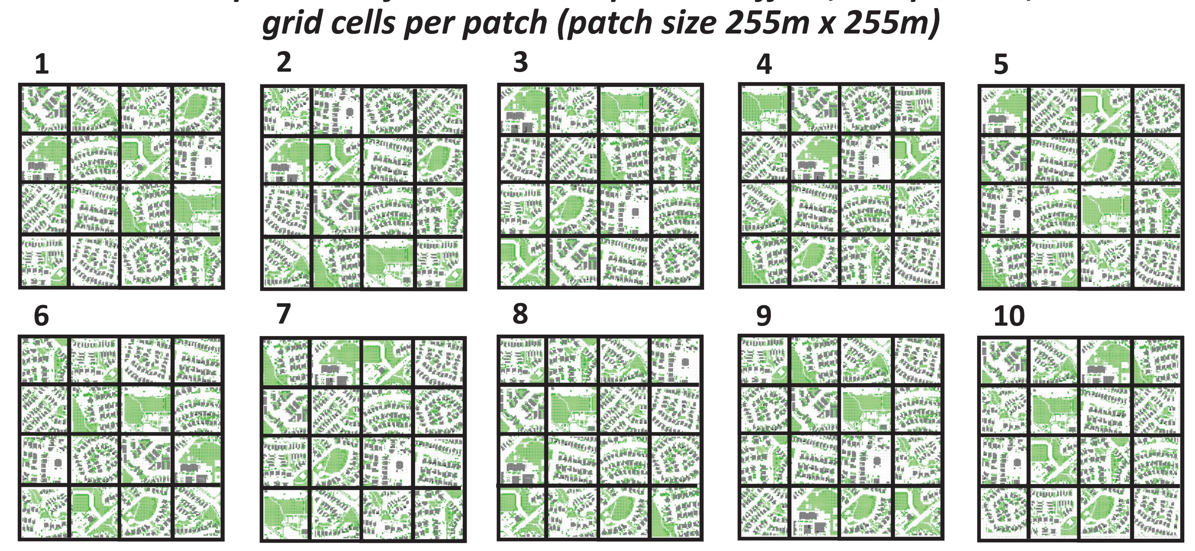
Location of weather stations/ENVI-met receptors



ENVI-met simulation of 2m air temperatures, June 18, 2012, 6am



ENVI-met input areas for 10 random patch shuffles, 4x4 patches, 51 x 51 grid cells per patch (patch size 255m x 255m)



References

[1] Ariane Middel, Kathrin Häb, Anthony J. Brazel, Chris A. Martin, and Benjamin L. Ruddell, 2014, Linking shading patterns of trees in Phoenix, AZ to thermal comfort. Poster to be presented at the *11th Symposium on the Urban Environment, AMS conference*, Atlanta, Georgia, February 2014.

[2] Kathrin Häb, Ariane Middel, Benjamin L. Ruddell, 2014, Source area computation for microclimate measurements within the urban canopy layer. Abstract submitted to the *AAG Annual Meeting*, Tampa, Florida, April 8-12, 2014.

[3] Kathrin Häb, Ariane Middel, Benjamin L. Ruddell, 2014, Visualizing urban transect data. *16th Annual CAP LTER Poster Symposium*, Tempe, AZ, January 17, 2014.

Acknowledgements

This research was supported by the National Science Foundation (Grant BCS-1026865, Central Arizona-Phoenix Long-Term Ecological Research, CAP-LTER; Grant SES-0951366, Decision Center for a Desert City II: Urban Climate Adaptation) and the German Science Foundation (DFG, Grant 1131) as part of the International Graduate School (IRTG 1131) at University of Kaiserslautern, Germany. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the sponsoring agencies.