Characterization and Mitigation of Urban Heat: Meteorological and Air-Quality Modeling

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Haider Taha, PhD
Altostratus Inc.
haider@altostratus.com – www.altostratus.com

Sources and references for this presentation

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Taha, H., Wilkinson, J., Bornstein, R., Xiao, Q., McPherson, G., Simpson, J., Anderson, C., Lau, S., Lam, J., Blain, C. 2015. "An urban–forest control measure for ozone in the Sacramento, CA Federal Non-Attainment Area (SFNA)", *Sustainable Cities and Society*, 21, 51-65 doi: 10.1016/j.scs.2015.11.004

Taha, H., 2015. "Cool cities: counteracting potential climate change and its health impacts". Invited paper, *Current Climate Change Reports*, Vol. 1, No. 3, p. 163-175. doi: 10.1007/s40641-015-0019-1, http://link.springer.com/article/10.1007/s40641-015-0019-1

Taha, H., 2015. "Meteorological, air-quality, and emission-equivalence impacts of urban heat island control in California". Invited paper, *Sustainable Cities and Society*, Special Issue on Heat Island, doi:10.1016/j.scs.2015.03.009 http://www.sciencedirect.com/science/article/pii/S2210670715000372

Taha, H, Freed, T. 2015. "Creating and mapping an urban heat island index for California". http://www.calepa.ca.gov/UrbanHeat/Report/Report.pdf

Taha, H., 2013. "Meteorological, emissions, and air-quality modeling of heat-island mitigation: Recent findings for California, U.S.A.", *International Journal of Low Carbon Technologies*, doi: 10.1093/ijlct/ctt010

Taha, H. 2013. "Ranking and prioritizing the deployment of community-scale energy measures based on their indirect effects in California's climate zones". http://www.energy.ca.gov/2011publications/CEC-500-2011-FS/CEC-500-2011-FS-021.pdf

Taha, H. 2012. "Multi-episodic and seasonal meteorological, air-quality, and emission-equivalence impacts of heat island control and evaluation of the potential atmospheric effects of urban solar photovoltaic arrays". http://www.energy.ca.gov/2013publications/CEC-500-2013-061/CEC-500-2013-061.pdf

Taha, H., 2012. "The potential for air-temperature impact from large-scale deployment of solar photovoltaic arrays in urban areas". *Solar Energy*, Vol. 91, pp. 358–367 (May 2013) doi:10.1016/j.solener.2012.09.014

Taha, H., 2008. "Meso-urban meteorological and photochemical modeling of heat island mitigation". *Atmospheric Environment*, Vol. 42, No. 38 (December 2008), pp. 8795 – 8809 - doi:10.1016/j.atmosenv.2008.06.036

Taha, H. 2008. "Urban surface modification as a potential ozone air-quality improvement strategy in California: A mesoscale modeling study". *Boundary-Layer Meteorology* -- Volume 127, No. 2 (May 2008), pp. 219-239. doi:10.1007/s10546-007-9259-5

On-going projects:

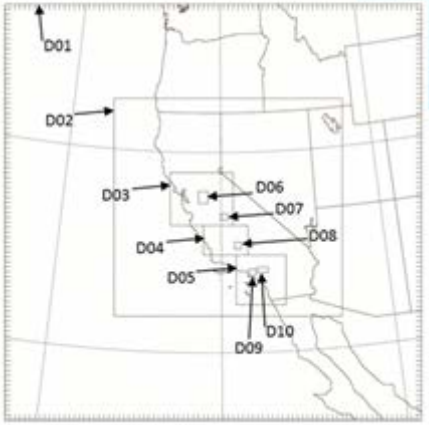
Intra-urban enhancement to probabilistic weather forecasts for the electric system, CEC, Altostratus Inc.

Real-world monitoring of the urban heat island and efficacy of future countermeasures, CEC, LBNL, Altostratus

1. Characterizing urban heat: The UHI Index

A UHI Index was computed for each census tract in 40 California urban areas:

- Developed for Cal/EPA per AB 296
- Advanced modeling systems
  - uWRF, uMM5 (+CMAQ, CAMx for AQ)
- Modified model and data ingestion
- Customized input data and parameterizations
  - AREAMOD, mod-UCM, mod-BEP
- Thorough systematic performance evaluation
  - Per modeling community benchmarks



WRF modeling domains / grids: 27, 9, 3, and 1 km resolution

UHII tiles configured relative to top 10% and 20% census tracts in CalEnviroScreen 2.0.

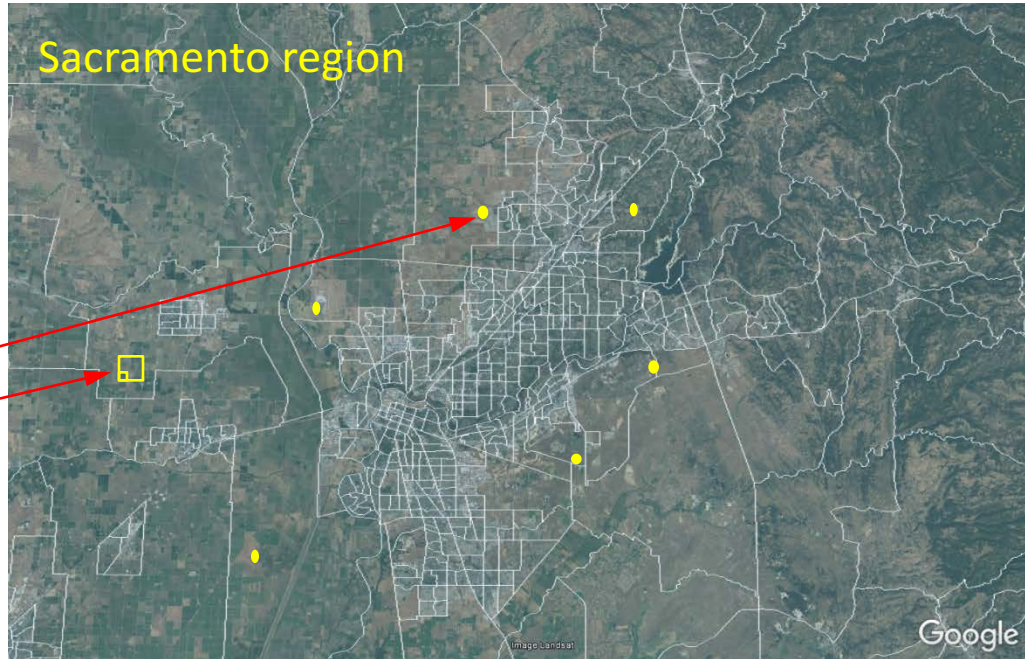
Urban Heat Island Index (UHII)

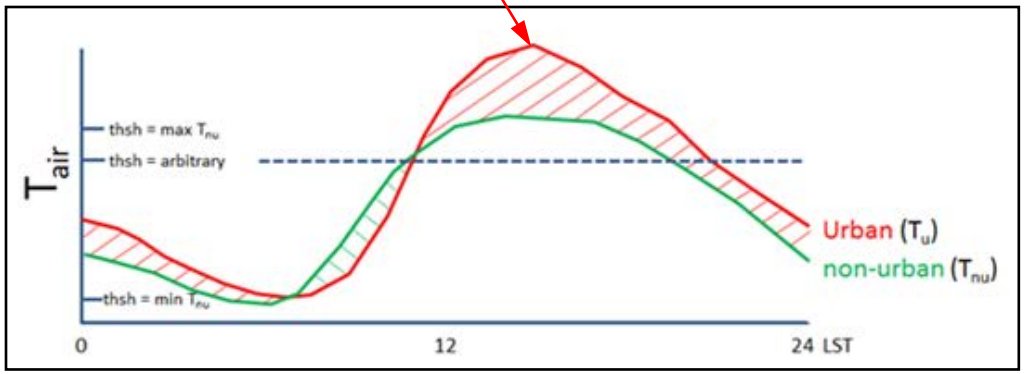
A cumulative temperature metric

Per AB 296: UHI Index must be defined to include both UHI severity (magnitude) and extent (duration), thus units are DH.

In this study:

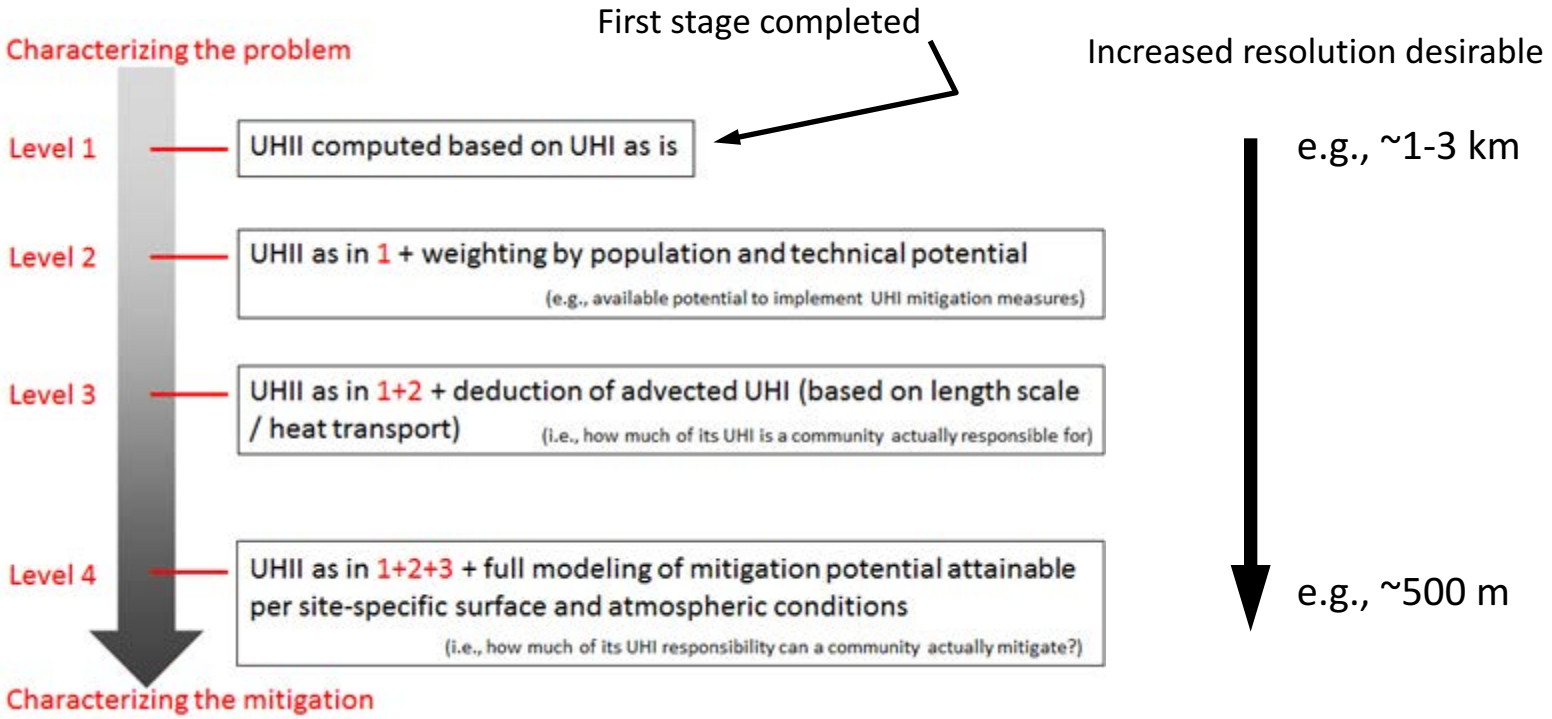
- Time-varying (hourly wind direction) upwind reference points
- Census-tract resolution (3 – 1 km)
- No temperature thresholds
- UHI Index is calculated only when urban temperature is higher than that at non-urban reference points





Urban Heat Island Index

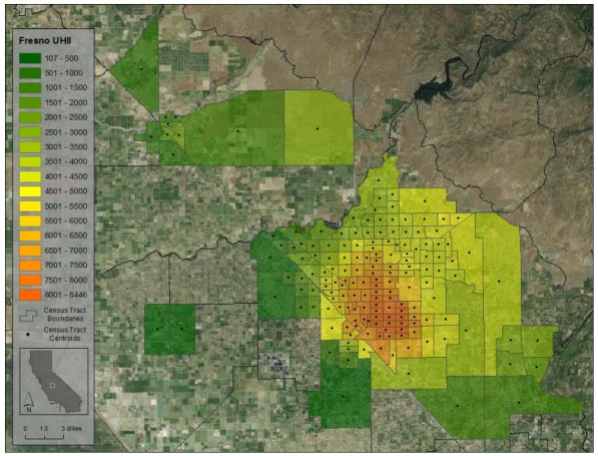
Modeling levels

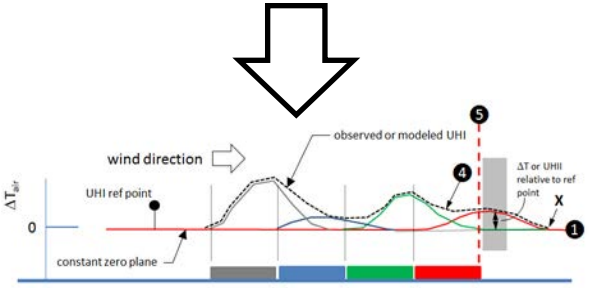


Each level produces a different spatial pattern (map) of the UHI

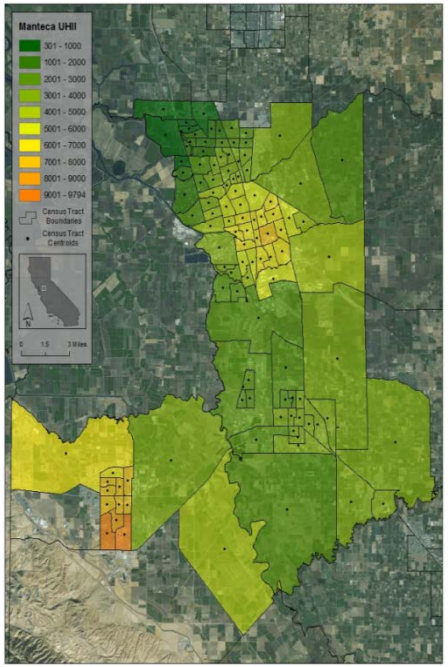
Types of UHI / UHII (examples)

Fresno
(single-core UHI)

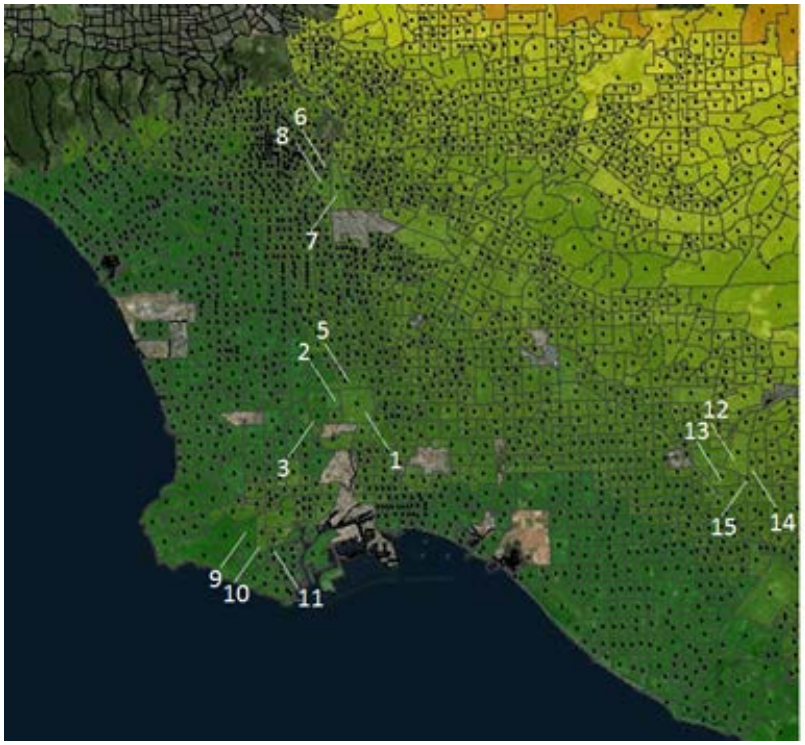


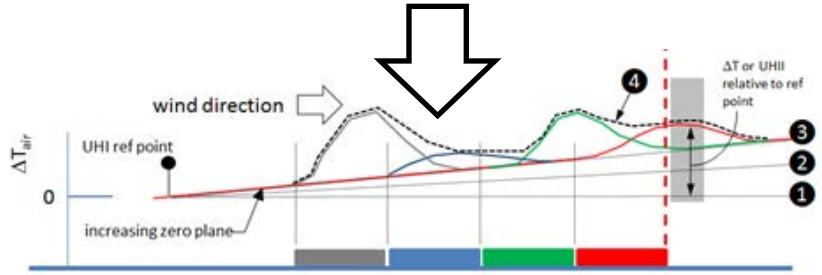


Stockton-Manteca-Tracy
(multi-core UHI)

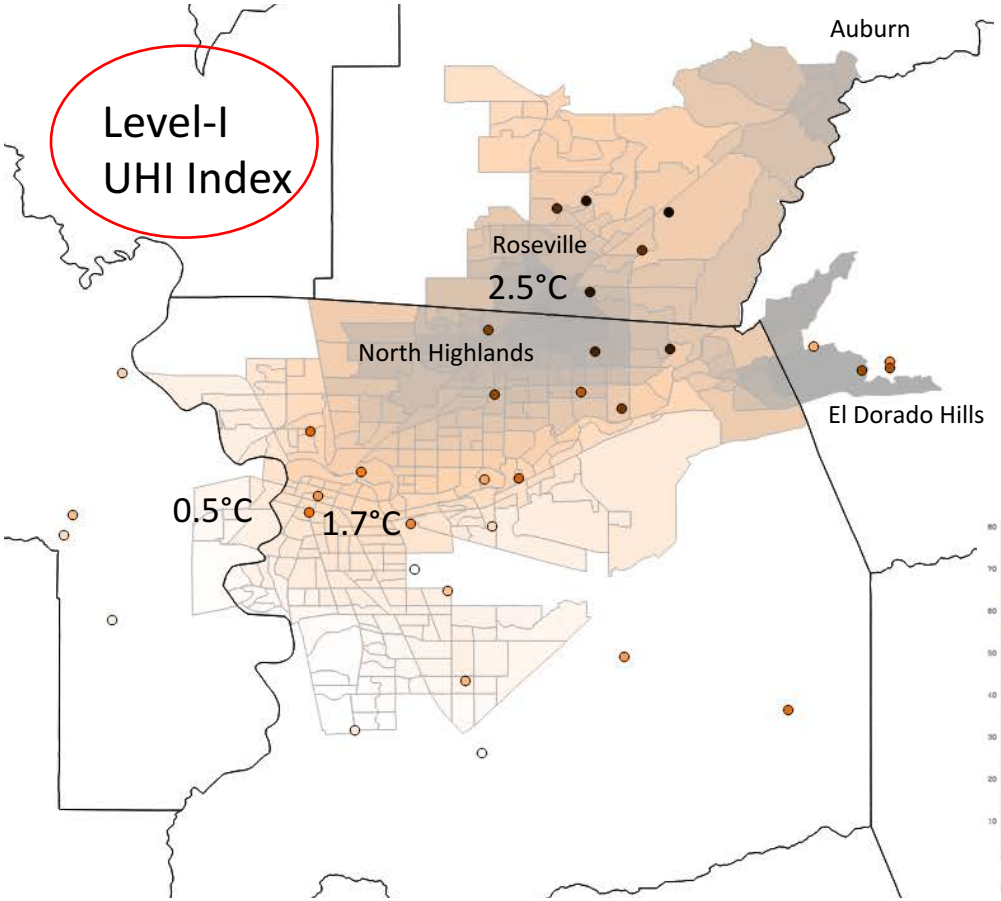


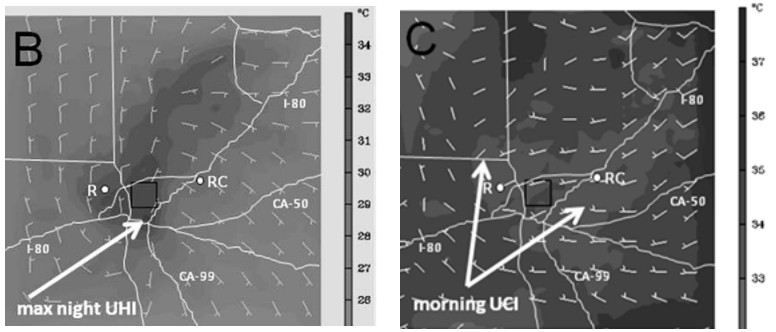
Los Angeles region
(urban climate archipelago: embedded UHI signals)



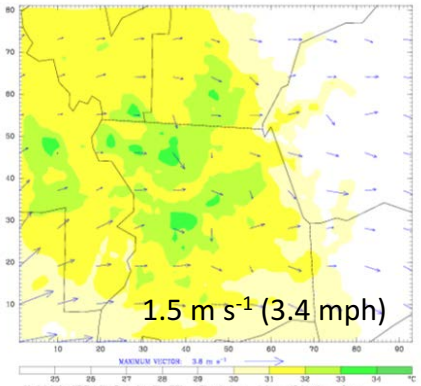


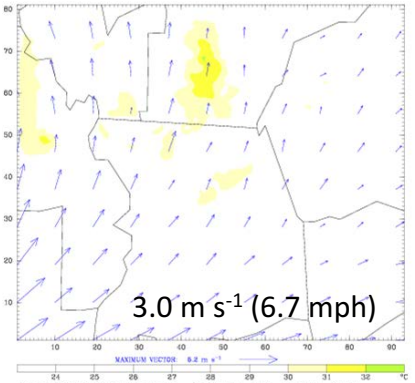
Sacramento region UHI / UHI Index





Inscribed square is downtown area; small arrows are wind vectors; white lines are major highways.





- Background (map): Model UHI Index
- Dots: Mesonet observed averaged temperatures

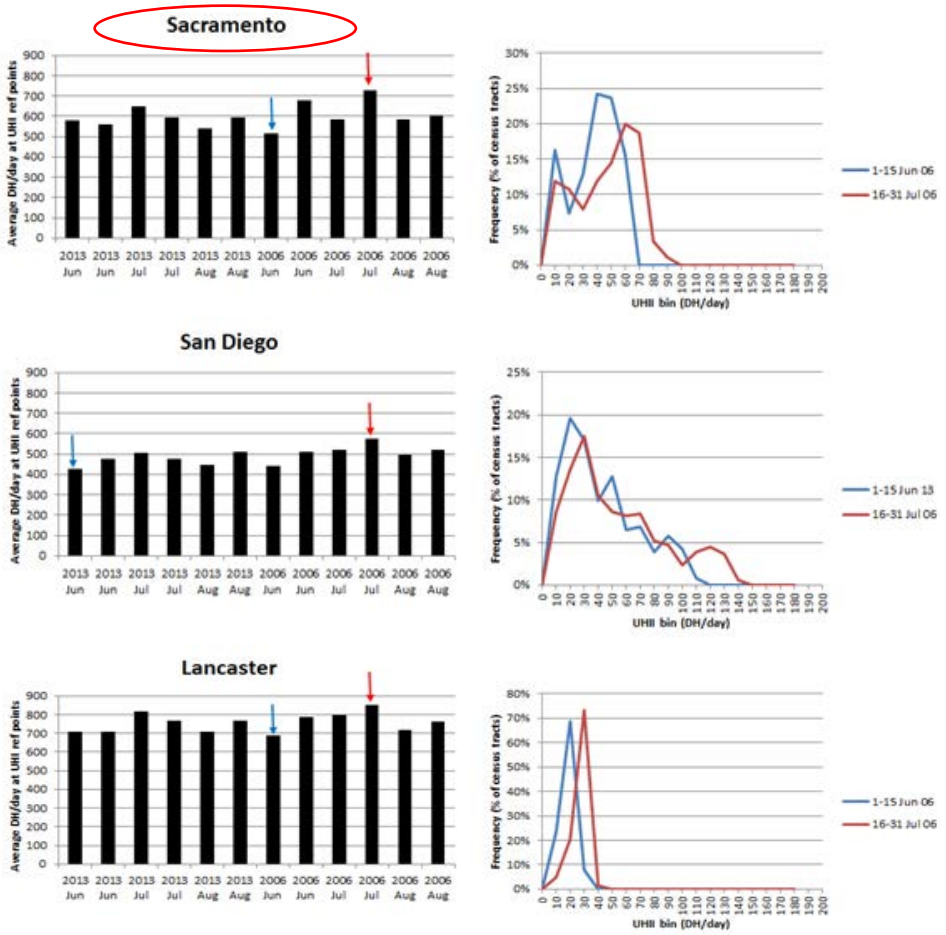
Levels 2-4 UHII modeling needed to asses local generation versus transport, optimal deployment (up/downwind), and mitigation of UHI Index

Effects of warmer weather

- Warmer weather (in the short term, e.g., a heat event, or in the long term, e.g., because of potential climate change) exacerbates urban heat.
- Warmer weather shifts the UHI Index from lower to higher temperature bins.

For example, in the Sacramento region:

Bins of 70, 80, and 90 DHPD have zero census tracts in them in CP, but 19%, 3%, and 1% of the tracts, respectively, in the HW period



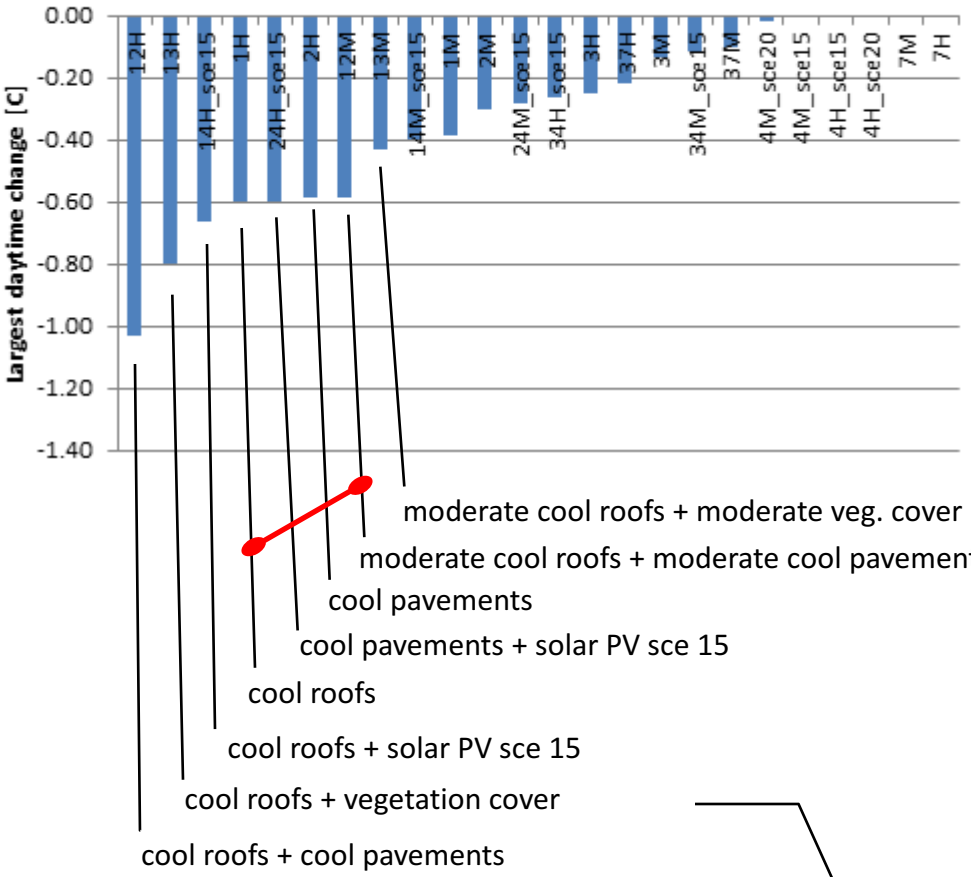
- DHPD: Degree-hours per day / UHII bin
- Blue lines and arrows : Cooler period
- Red lines and arrows: California heat wave (July-August 2006)

2. Mitigation of urban heat

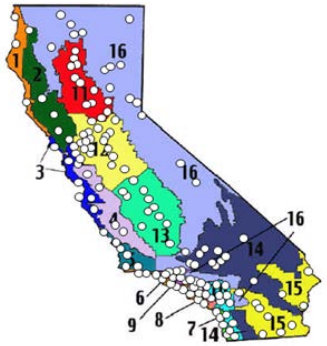
Measure	Health-relevant pathways (Heat and Air Quality)
Cool roofs	• Decreased surface, air, and apparent temperatures • Decreased anthropogenic and biogenic emissions • Reduced photochemical reaction rates
Cool pavements	• Decreased surface [1], air, and apparent temperatures • Decreased anthropogenic and biogenic emissions • Reduced photochemical reaction rates
Urban forests	• Increased deposition of pollutants • Increased cooling (evapotranspiration [2]) and shading • Decreased anthropogenic and biogenic emissions • Reduced photochemical reaction rates [3]
Solar photovoltaics	• Increased effective albedo [4] • Decreased surface, air, and apparent temperatures
Green roofs / walls	• Decreased surface, air, and radiant temperatures
Anthropogenic-heating control	• Decreased air and apparent temperatures • Decreased anthropogenic emission rates • Reduced photochemical reaction rates
Runoff / surface-water control	• Decreased air temperature [2] • Decreased anthropogenic and biogenic emissions • Reduced photochemical reaction rates

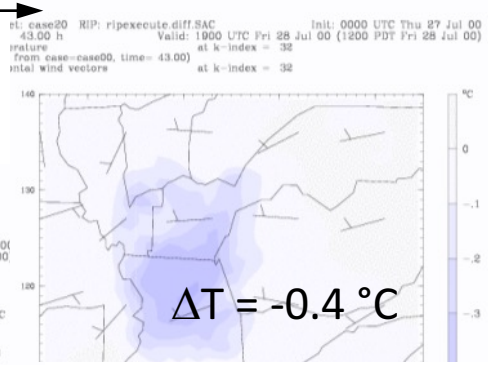
[1] Can increase radiant heat if not implemented properly
[2] Increases atmospheric moisture to some extent
[3] Low-emitting species assumed
[4] Unless implemented on highly-reflective roofs or surfaces

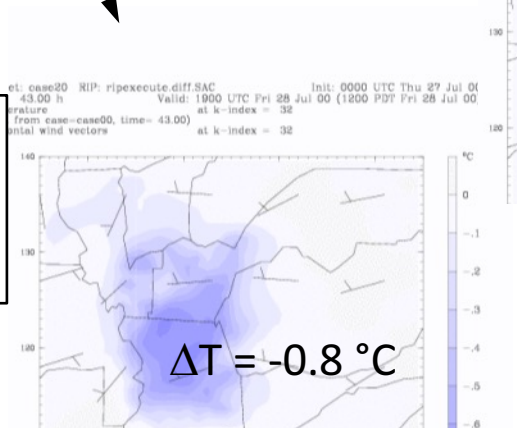
Sacramento region



Reasonable high- and moderate-control regional simulations (4 km): Coarse-level assessment of uniform deployment.







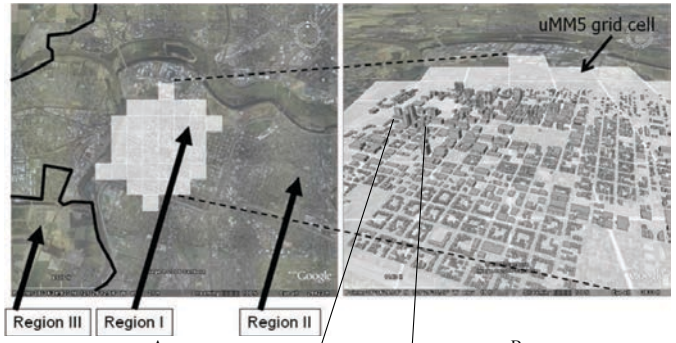
Levels 2 – 4 UHI Index modeling needed to:

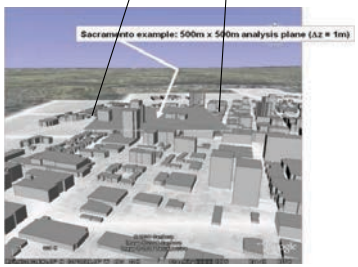
- identify optimal start locations
- distribution (uniform vs. targeted)
- up/downwind and transboundary effects

Finer-scale modeling of urban heat mitigation

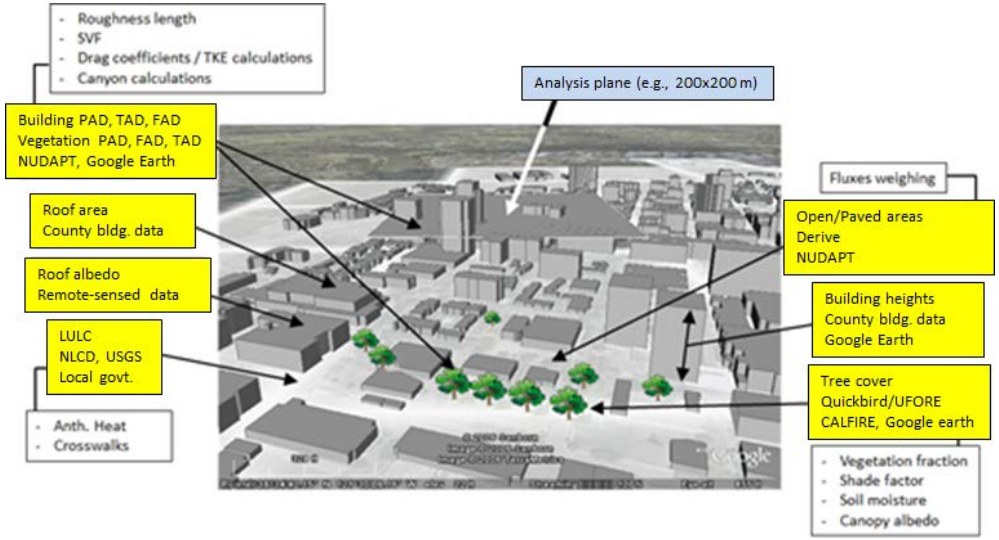
Land-use / land-cover analysis and development of cell-specific surface input to meteorological model

Depending on modeling approach, some 60% - 70% of data is available for modeling the Sacramento region (in future efforts). The remaining 40% - 30% must be derived indirectly or acquired anew.





Sacramento

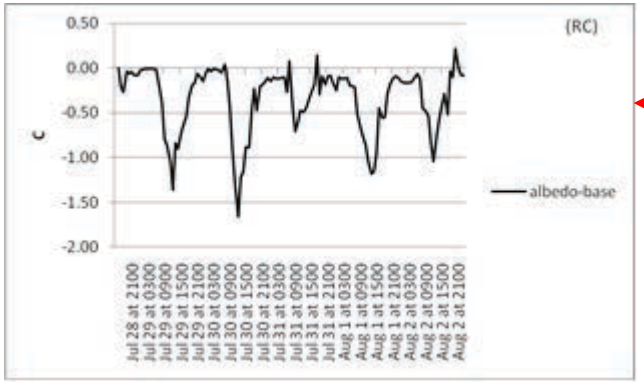


Development of highly cell-specific input to fine-resolution meteorological models (500 m or better) based on fine-resolution urban morphology and surface characterization datasets.

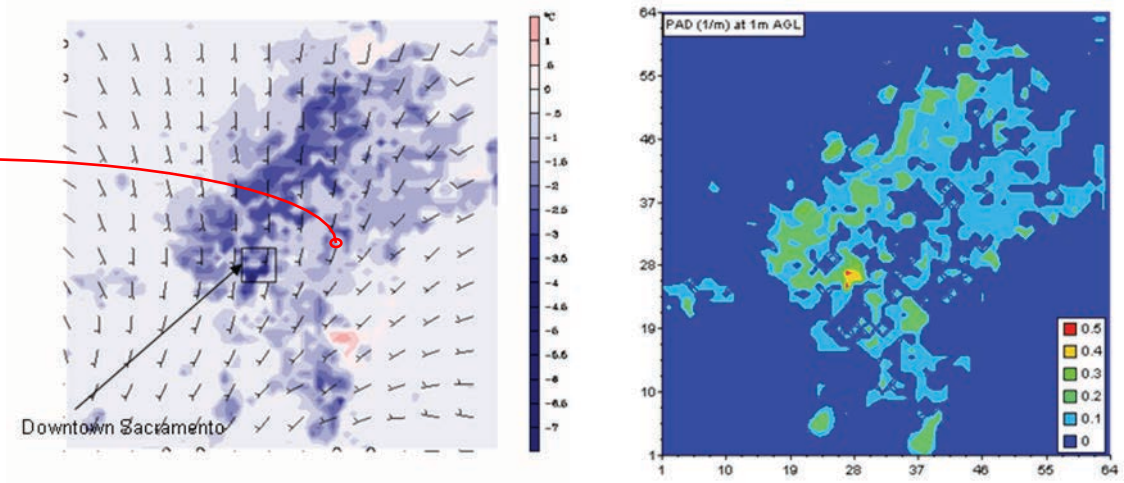
Example: urban albedo increase

Sacramento region; 1-km resolution

Upper-bound scenario modifications in albedo**: Surface temperature reduction up to 7 °C and air temperature reduction up 2-3 °C.



Air-temperature change resulting from increased albedo (location RC, moderate impacts on temperature)

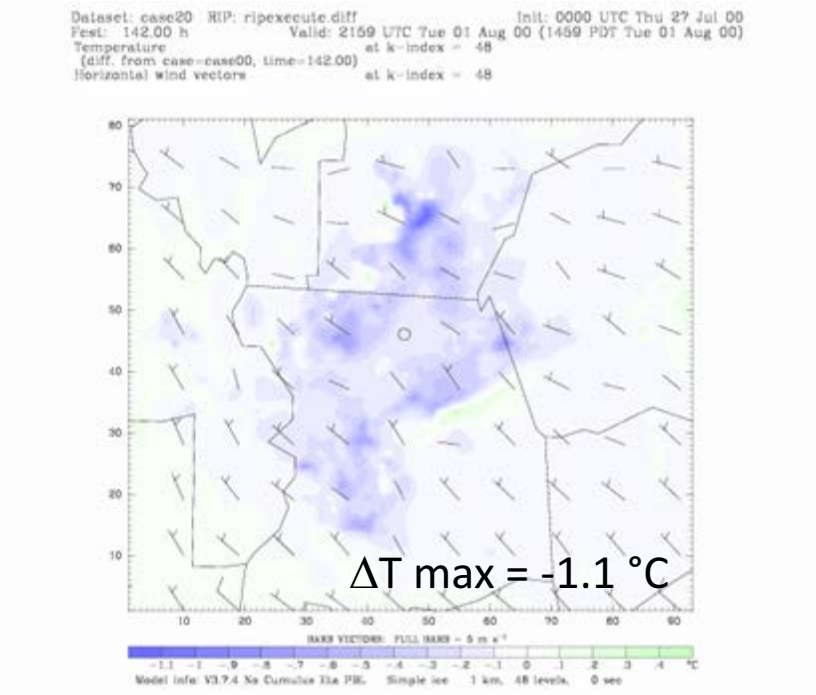


Left: Surface-temperature change resulting from increased albedo. Right: building plan-area density at 1 m AGL.

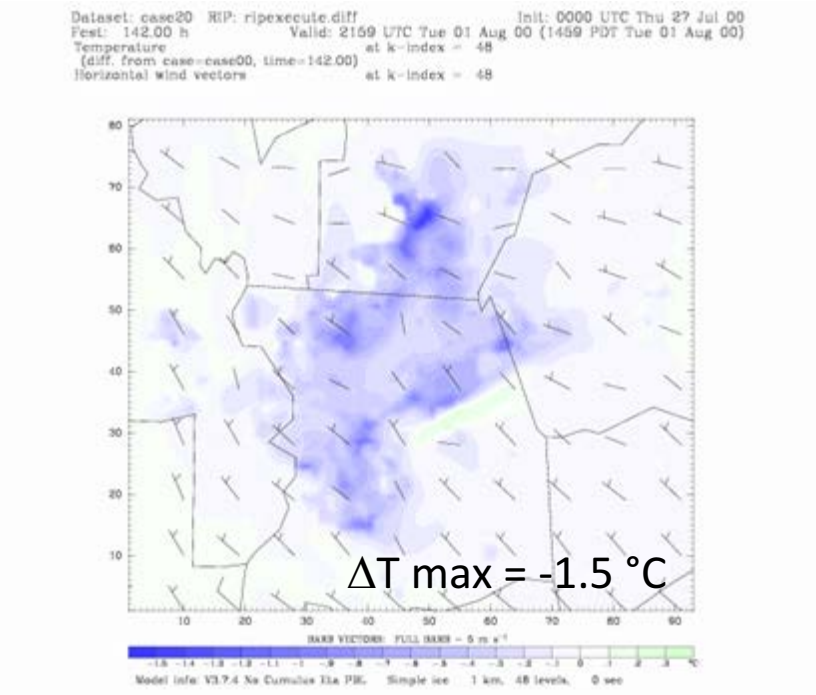
** 0.4 avg. increase in roof albedo
0.2 avg. increase in paved albedo
0.1 avg. increase in wall albedo

Example: urban vegetation-cover increase

Sacramento region; 1-km resolution



Temperature difference (°C) at 1500 PDT on 1 August for cover 17.9% -> 20.6%



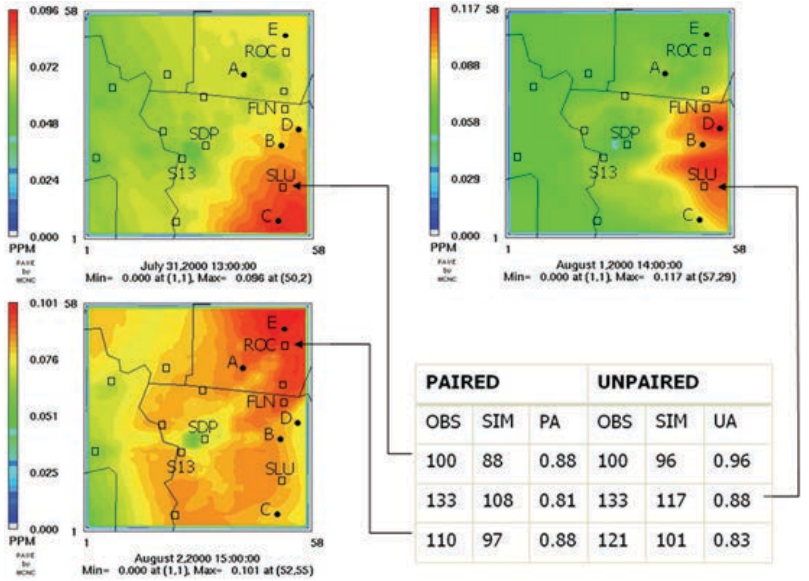
Temperature difference (°C) at 1500 PDT on 1 August for cover 17.9% -> 23.5%

Example: albedo increase and O_3 air quality

Sacramento region; 1-km resolution

Albedo increases by up to 0.4 on roofs and 0.15 on pavements (cool roofs and cool pavements)

- Decrease ozone by up to 5 – 11 ppb (1-hr average, fine-resolution, localized) during the daytime (note: historical emission inventories)
- Most of the decreases occur during times of 1-hr peaks, thus most beneficial (between 1200 and 1600 LST)
- Some small increases occur mostly earlier in the morning because of reduced mixing
- Equivalent to 2 – 4.5 ppb $°C^{-1}$ (non-linear; older, historical emission inventories)
- Produce a relative reduction factor (daily maximum 8-hour average) of 4% to 9% (historical emission inventories)



PAIRED			UNPAIRED		
OBS	SIM	PA	OBS	SIM	UA
100	88	0.88	100	96	0.96
133	108	0.81	133	117	0.88
110	97	0.88	121	101	0.83

Suggestions for future modeling of the Capital Region

- Levels 3,4 UHI Index modeling and development of mitigation indicators
- Fine-resolutions modeling and advanced urban parameterizations
- More recent LULC, urban morphology, vegetation cover, and albedo
- Revised / recent emission inventories
- State-of-the science local climate change scenarios
- Revised, plan-specific albedo / vegetation control scenarios

These steps can assist the Capital Region in establishing a target urban heat reduction, e.g., a target temperature threshold and related spatial attributes based on the region's climate, land use, technical potential, UHI Index, and other factors.

Thank you!