Evaluating the Potential of Irrigation for Mitigating Urban Heat: Trade-off between Water Use and Heat Mitigation Capacity

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Background and Motivation

Urban irrigation: a climate adaptation and mitigation strategy

- Effective in cooling the built environment
- Large uncertainties in the trade-off between water use and heat mitigation capacity
- Dependence on irrigation scheduling, watering amount, and geographical and climatic backgrounds

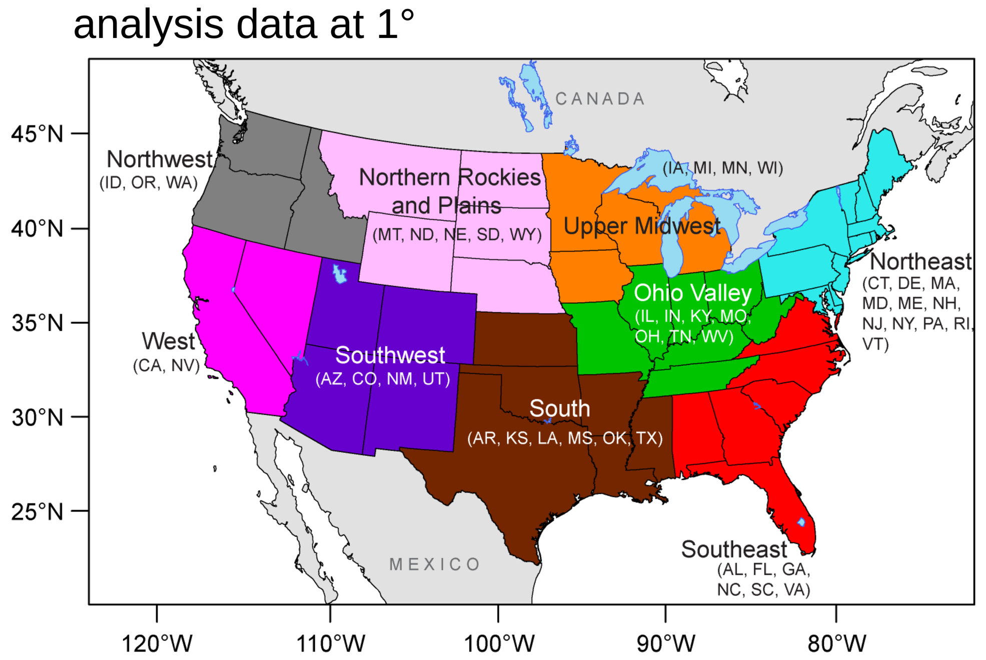
Research objective: quantify the trade-off between irrigation water use and the cooling effect it can provide in various climate regions

Urban water capacity: average irrigation depth per degree of urban temperature reduction (analogous to heat capacity) [mm day^{-1} °C^{-1}]

Methodology

Coupled WRF-LSM-urban modeling system:

- WRF-ARW version 4.0
- Simulation domain: contiguous U.S. (CONUS) – 8 climate regions
- Resolution: 5-km, 32 model eta levels, 3-hr outputs
- Initial and boundary conditions: 6-h NCEP FNL operational global analysis data at 1°



- NLCD 2011 + MODIS + NUDAPT (major cities)
- Unified Noah land surface model + single layer urban canopy model

Urban irrigation simulation and scenario design:

- Three summers in 2012–2014
- Five scenarios (control case 0 and irrigation scenarios 1–4)

	Daily irrigation duration	Local time	Threshold
0	No irrigation		
1	1 h nighttime	2100-2200	Field capacity
2	2 h daytime, 2 h nighttime	0900-1100, 2100-2300	Field capacity
3	2 h nighttime	2100-2300	Porosity
4	2 h daytime, 2 h nighttime	0900-1100, 2100-2300	Porosity

- Irrigation depth of urban grid = Irrigation volume / grid spacing^2
- Cooling effect: surface / 2-m air temperature reduction

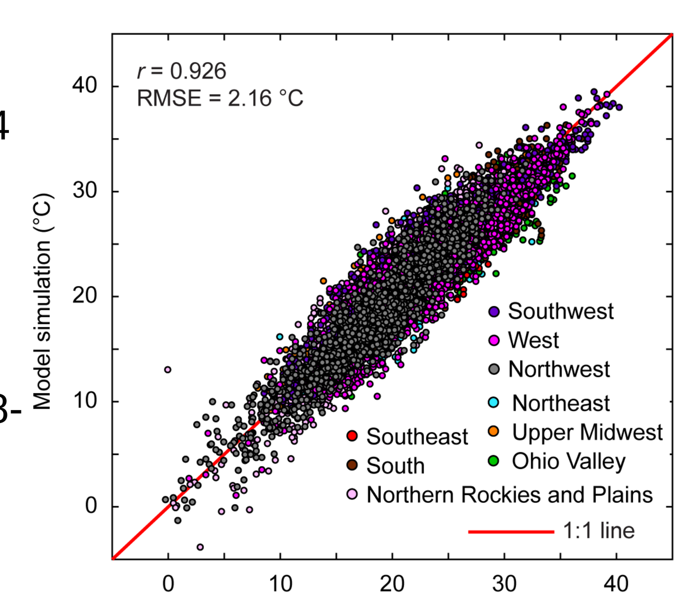
Model Evaluation

Station measurement (air):

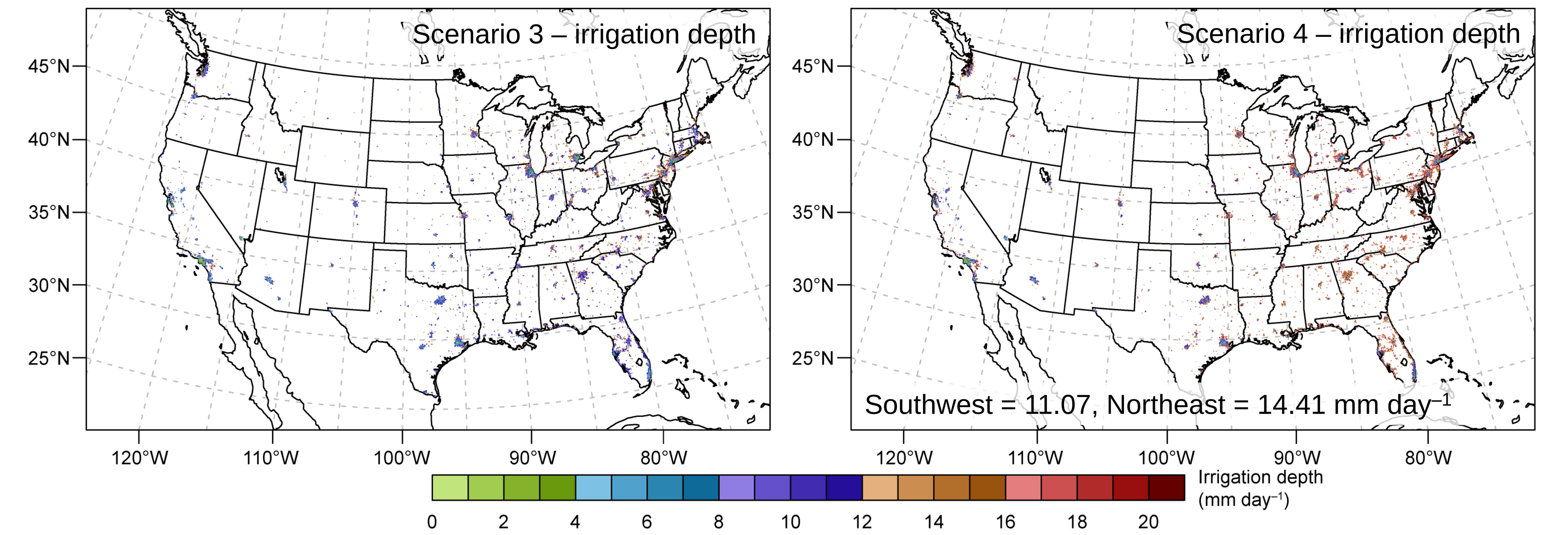
- 135 stations from Global Historical Climate Network-Daily database (64 urban, 71 non-urban)
- r = 0.926, RMSE = 2.16 °C

Remotely sensed data (surface):

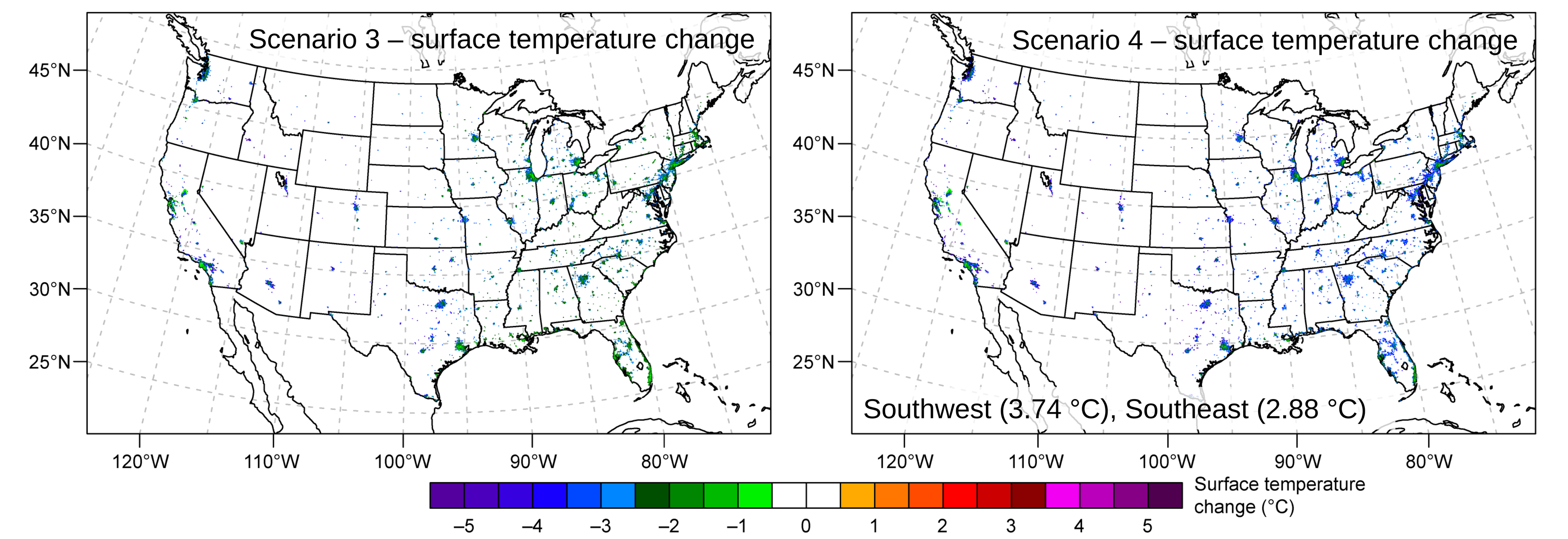
- MOD11B2 and MYD11B2 (5.6 km, 8-day composites)
- June 25–July 2, 2012 (min cloud)
- r = 0.970, RMSE = 3.35 °C



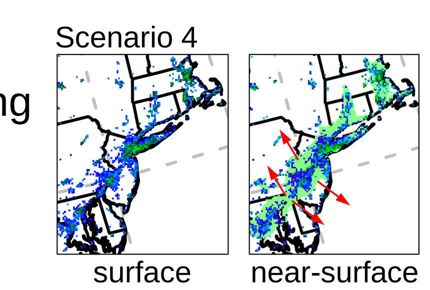
Urban Irrigation Water Use and Cooling Effect



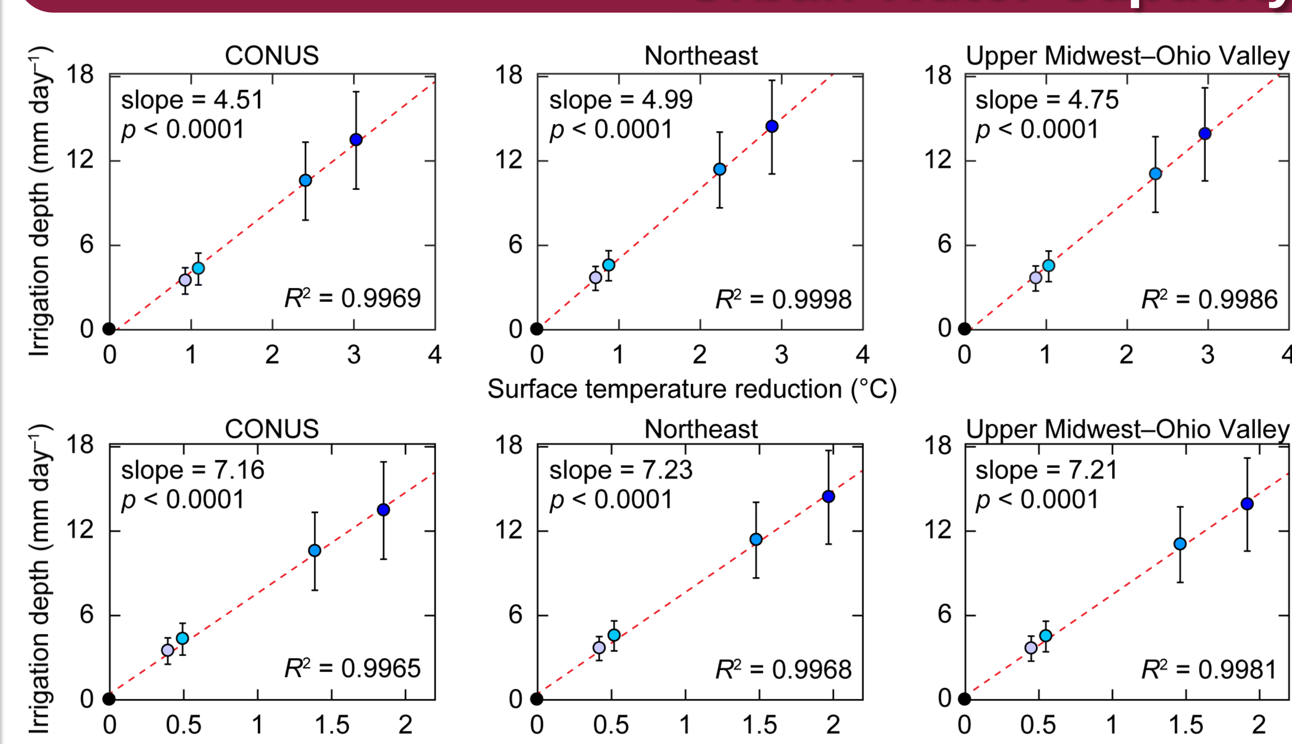
- Daily mean irrigation depth: 3.47 – 13.46 mm day^{-1} (four scenarios)
- Spatial variability: difference in urban fractions, evapotranspiration, and groundwater recharge



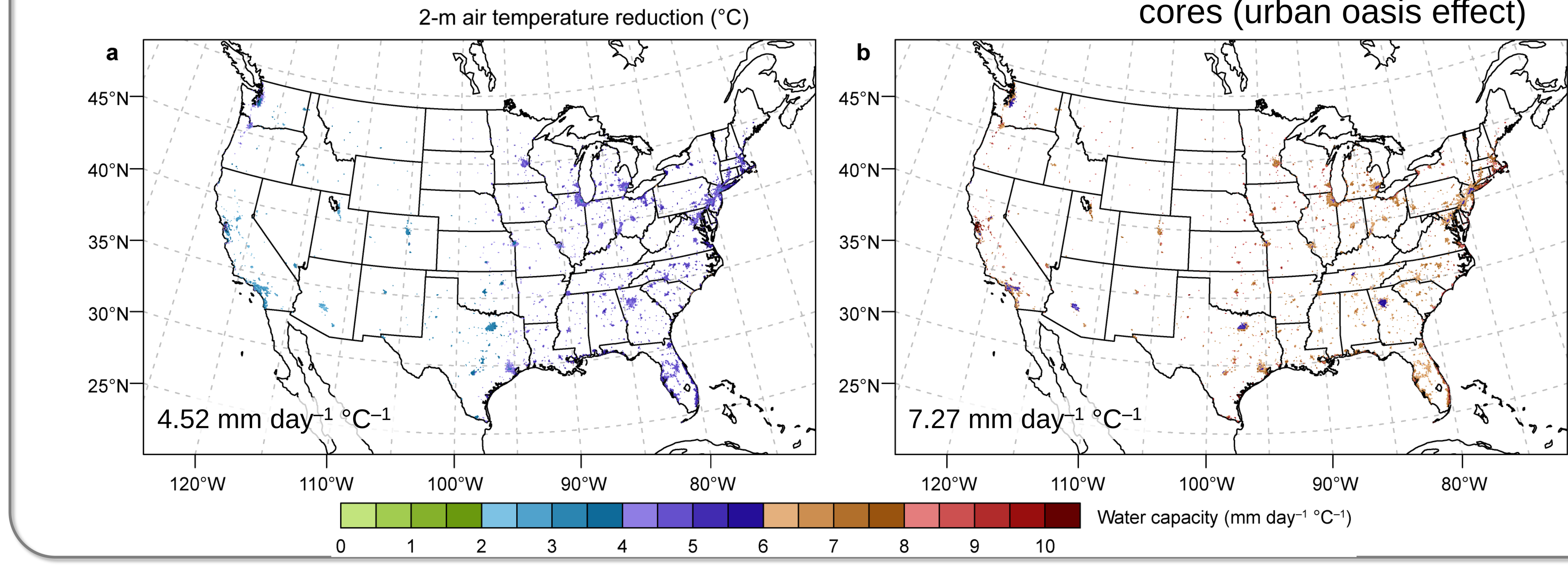
- Greater amount of irrigation → higher temperature reduction
- Intra-city variability: less cooling in urban cores, smaller area of surface cooling
- Scenario 4: surface cooling = 3.04 °C, near-surface cooling = 1.86 °C
- Cooling due to: increased soil moisture, decreased sensible heat, changed latent heat, increased ground heat (higher thermal conductivity)



Urban Water Capacity

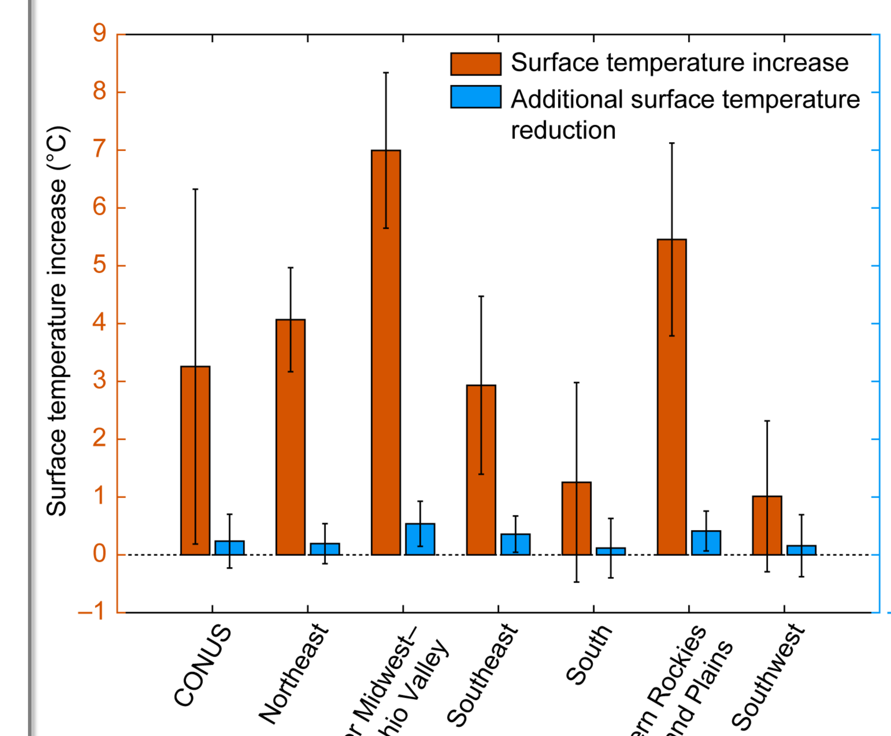


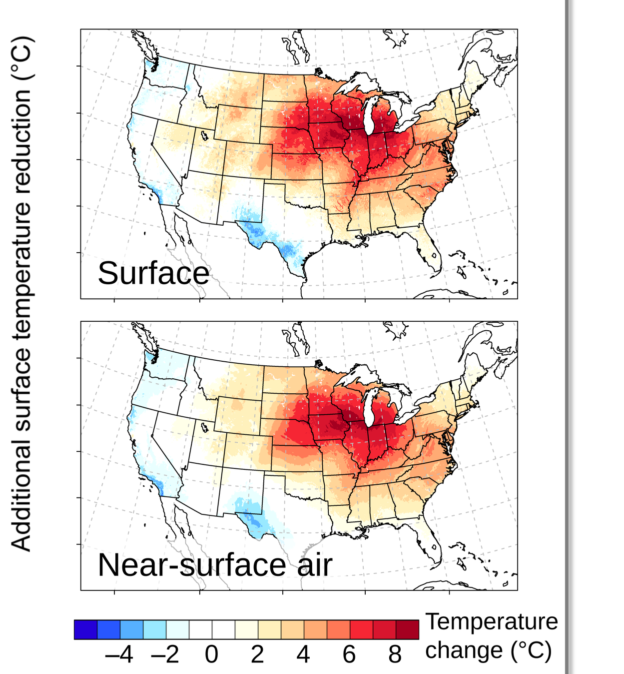
- R^2 > 0.96 for all climate regions [linear regression]
- Urban water capacity for surface < near surface cooling
- For surface cooling: lowest water capacity in Southwest, but highest in Northeast and Southeast
- Higher water capacity in urban cores (urban oasis effect)



Efficacy of Urban Irrigation in Extreme Heat

- Extreme heat: a climate analogue (future climate),
- The most extreme heat wave: 1200 UTC, July 1–0900 UTC, July 8, 2012 (based on 7-day moving windows, exceeds 99th percentile)
- Surface temperature increase: positive anomaly = $T_{HW,0} - T_{norm,0}$
- Additional cooling = $(T_{HW,0} - T_{HW,4}) - (T_{norm,0} - T_{norm,4})$ (for scenario 4)





- Intensification of irrigation-induced cooling is in line with positive temperature anomalies (greater reduction)
- Potential of urban irrigation in combating elevated thermal stress under future climate
- Relatively consistent urban water capacity under both normal and heat wave conditions (proportional)

Conclusion and Perspective

- We proposed the use of *urban water capacity* to ease the comparison of the trade-off between water use and cooling effect among cities and regions on the same ground
- Effectiveness of urban irrigation in alleviating thermal stress
- Urban water capacity is a convenient measure for urban planners to assess environmental and economic co-benefits
- Operational uses under current and future climate (e.g., irrigation–cooling conversion)
- Caution needs to be taken for arid or semi-arid regions
- Future improvement of the numerical simulation

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