Sustainable Urban Systems – A Climatic Perspective

Matei Georgescu
School of Geographical Sciences and Urban Planning
Urban Climate Research Center
Arizona State University

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National Academies Workshop
Advancing Urban Sustainability in China and the US
Panel II: Architecture, Urban Design, and Sustainable Cities in China and the US

Matei.Georgescu@asu.edu

Road Map

1. Introduction –

- Urban Climate System
  - ➢ Drivers
- Twin Forcing Agents
  - ➢ GHGs and Built Environment

2. Continental US Perspective –

- Individual and Total Impacts of GHGs and Urbanization
- Heat-health outcomes and heat exposure

3. Local Perspective –

- Phoenix, AZ; Atlanta, GA; Detroit, MI

4. Concluding Remarks

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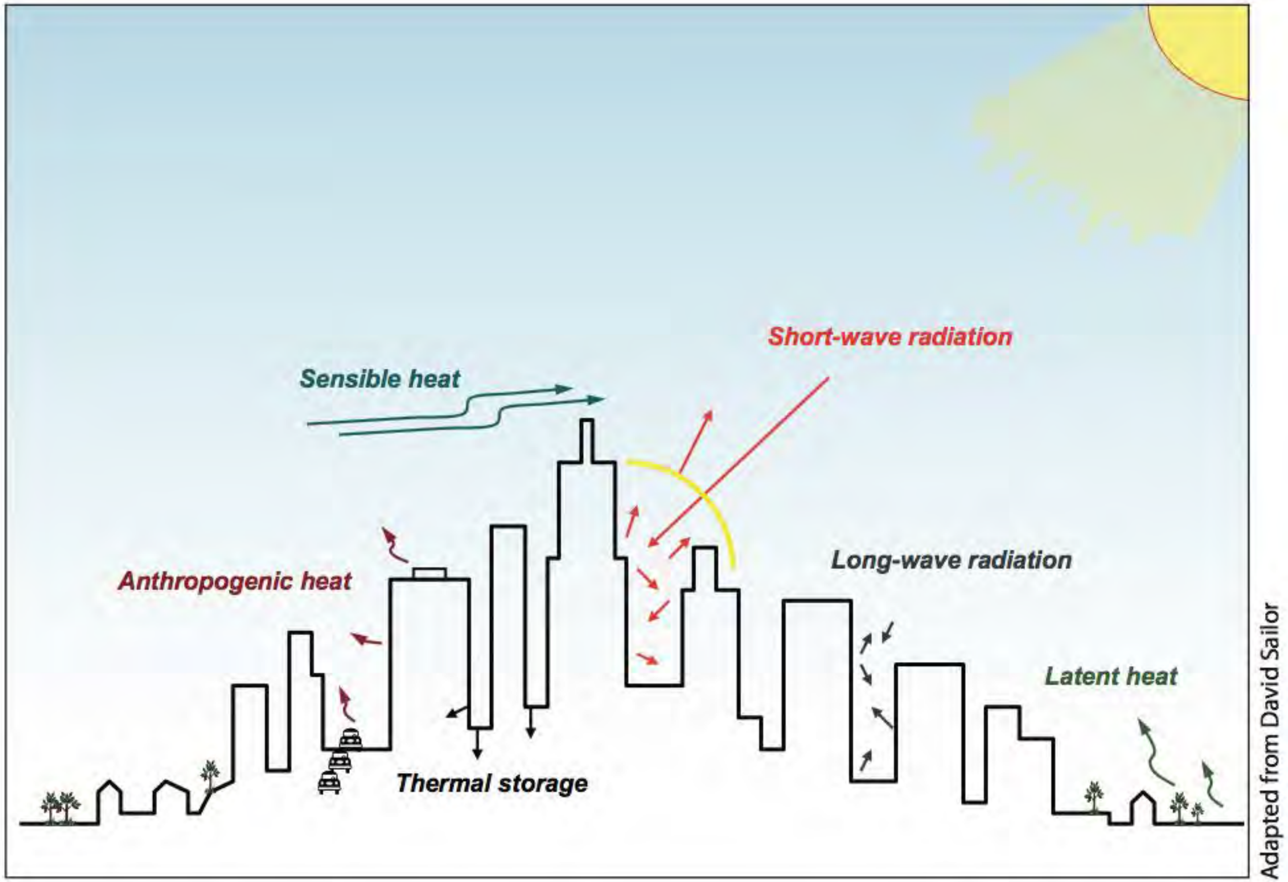
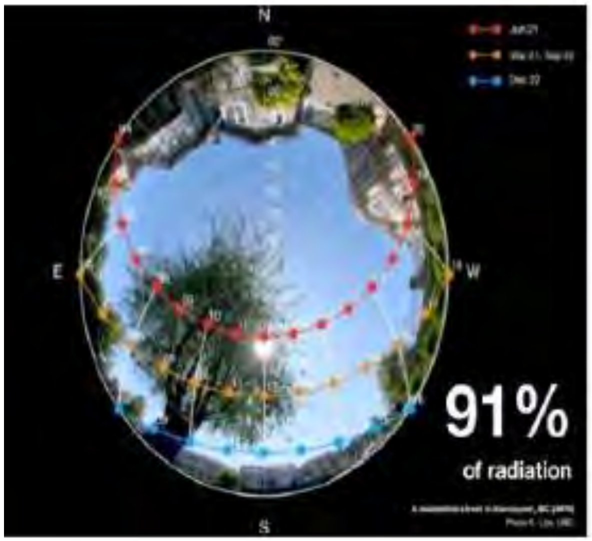
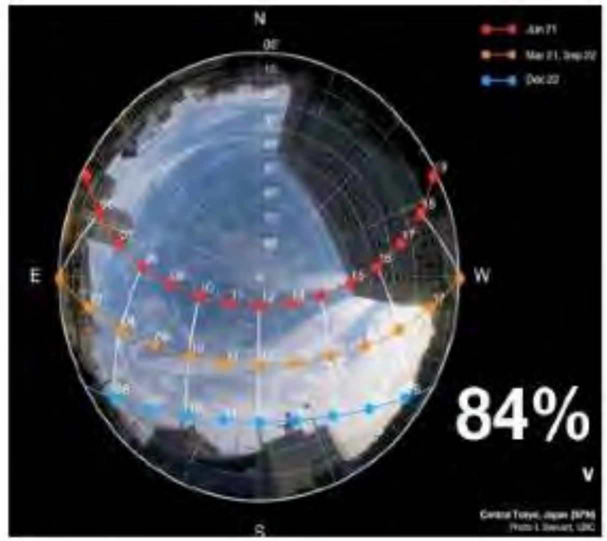
Urban Climate System

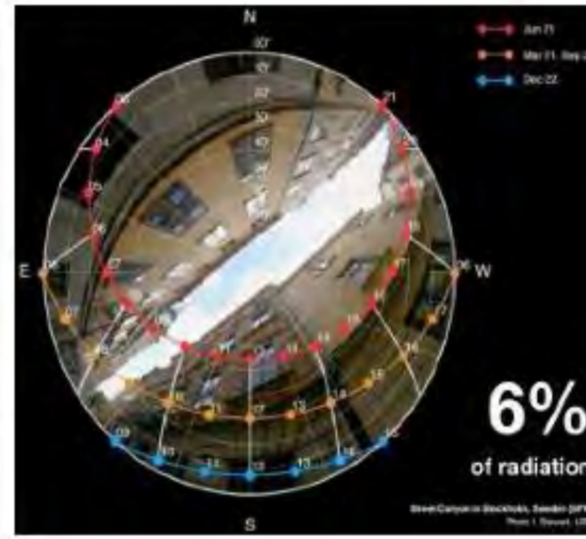


Balance of incoming and outgoing energy fluxes: Surface energy budgets of urban areas and their more rural surroundings differ because of variability in **(1)** *land cover and surface characteristics*, and **(2)** *level of human activity* (e.g., how we use energy).

Urban Climate System







Sky View Factor – dimensionless parameter that represents the fraction of visible sky for some reference location relative to sky fraction over a flat horizontal surface with no obstructions.

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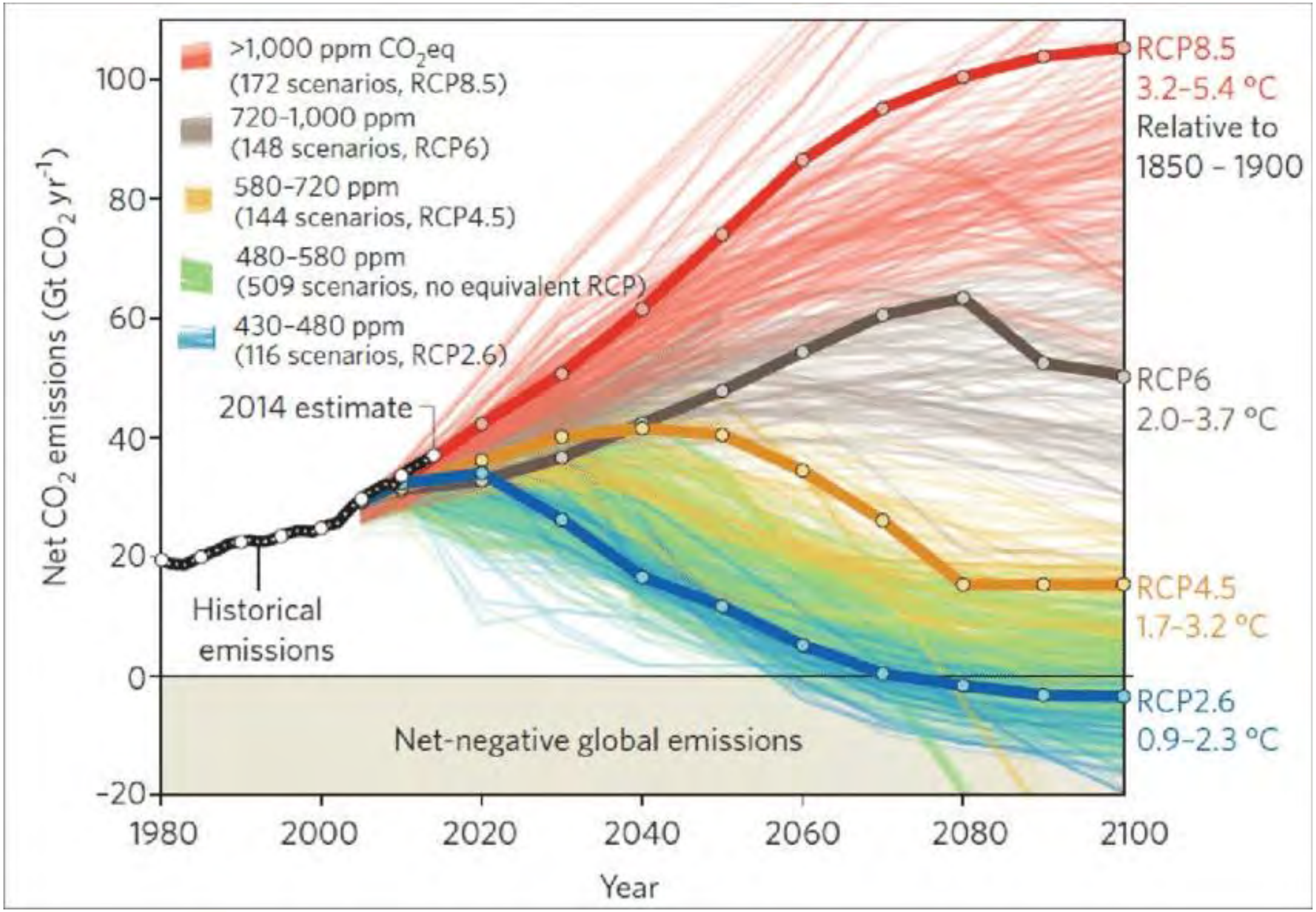
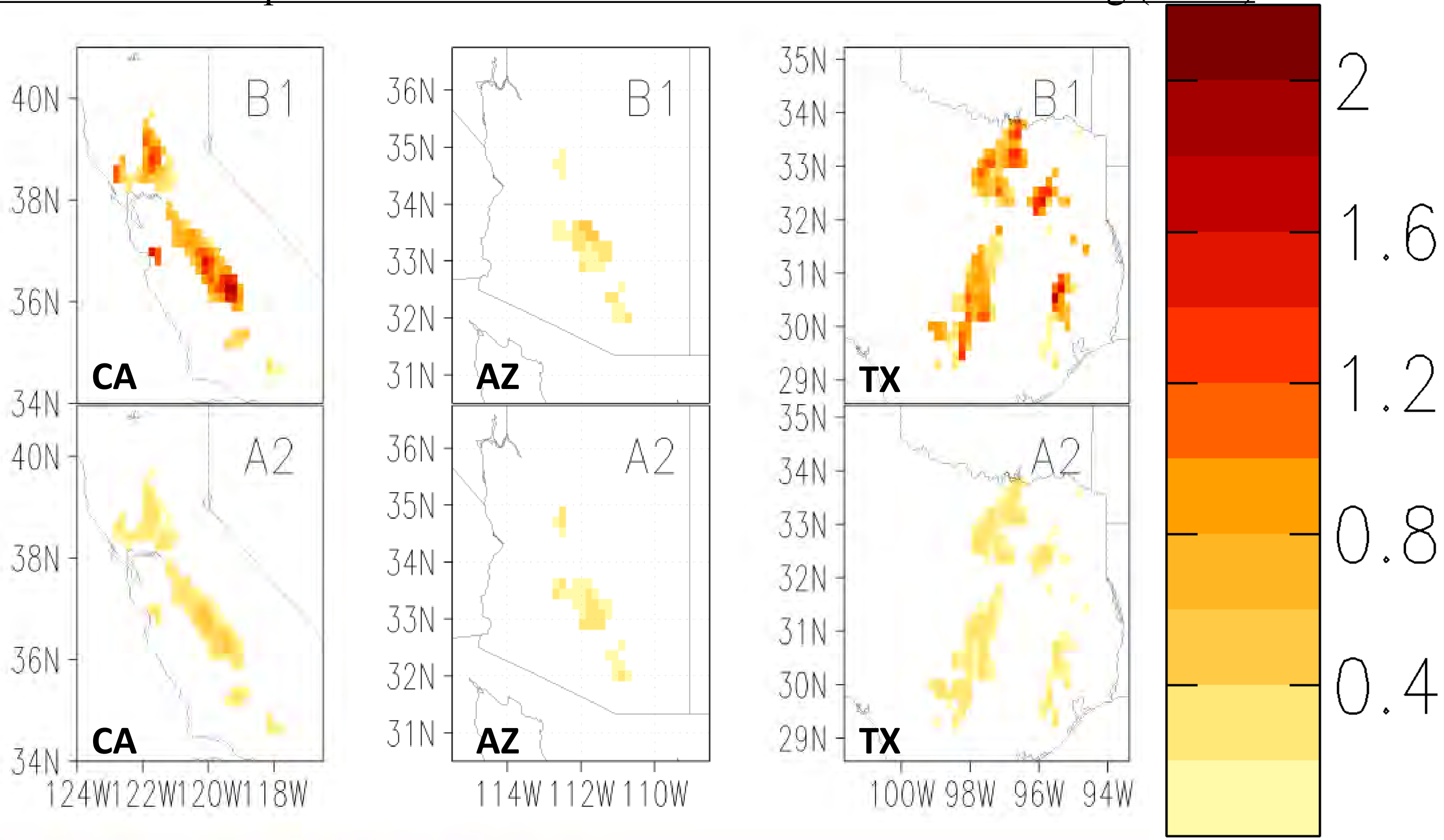
Twin Forcing Agents



IPCC, AR5

Twin Forcing Agents

Relative thermal impact of Urban to GHG-induced near-surface warming ($^0C/^0C$)



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Georgescu et al.. (2014), *PNAS.*

Twin Forcing Agents

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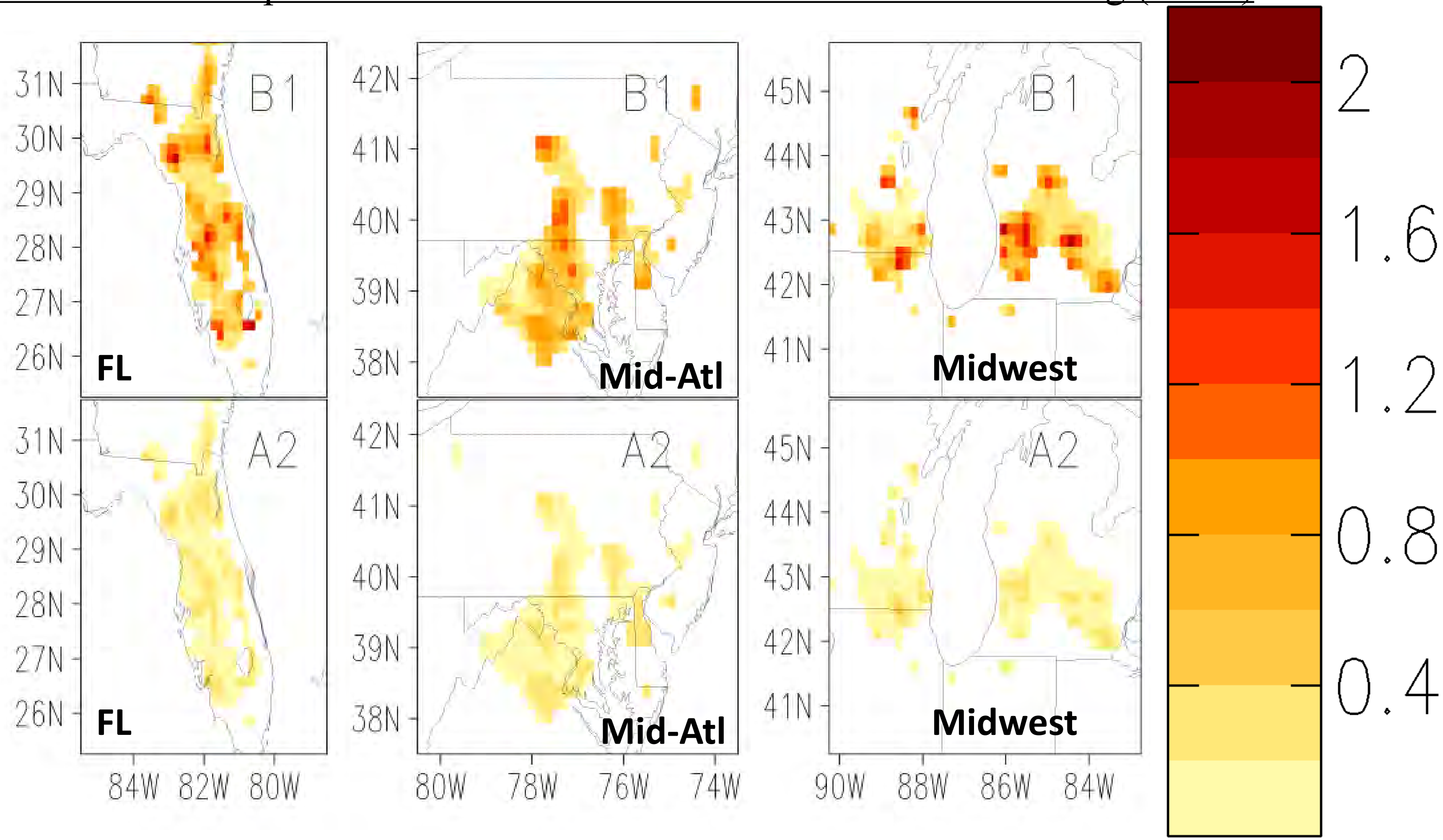

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Twin Forcing Agents

Key Limitations

1. Assumed linear sum of urban + GHGs (i.e., not interactive)
    - ➢ Quantify non-linear interaction

2. Impacts are diurnally averaged
    - ➢ Examine impacts across diurnal cycle

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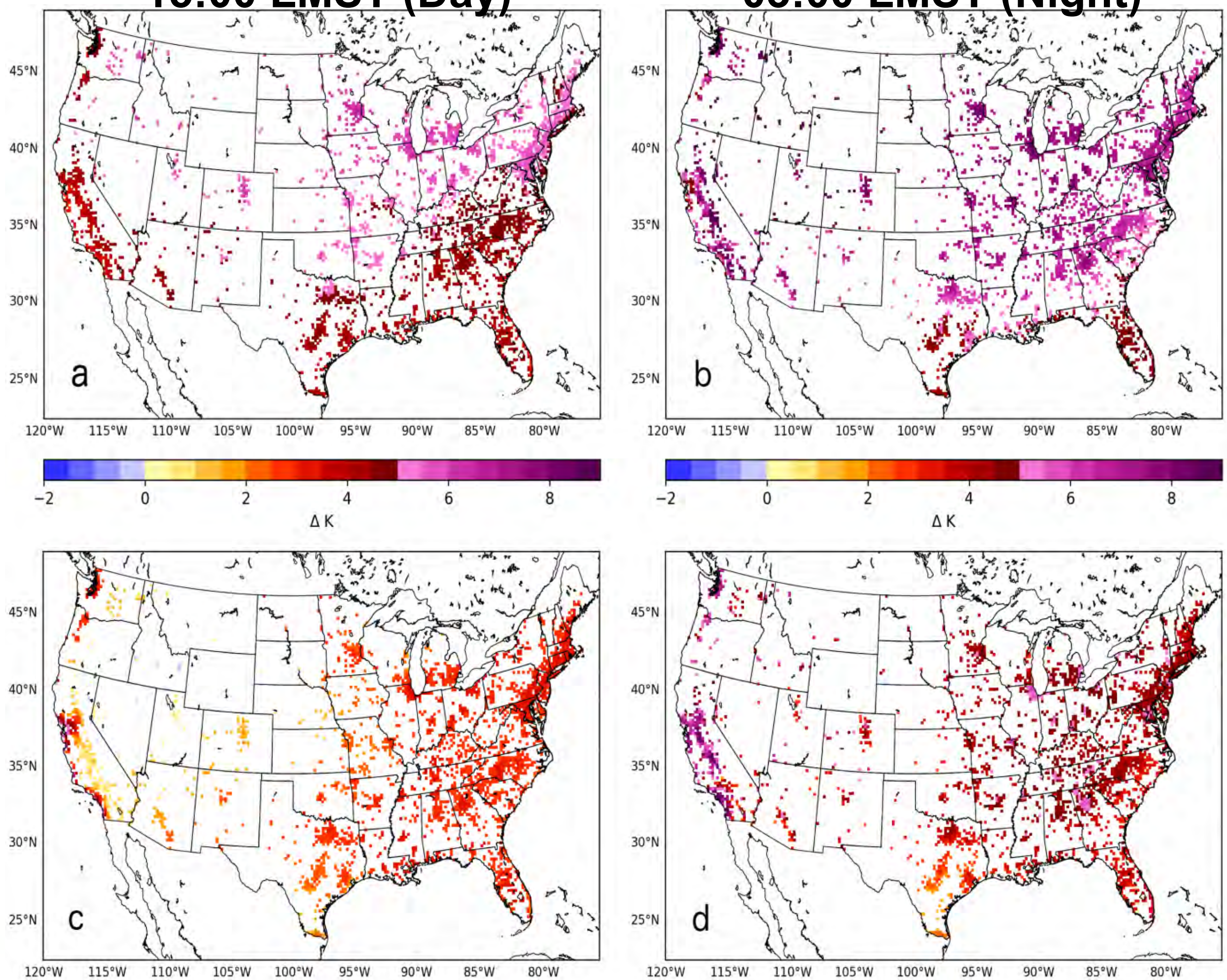
Individual and Total Impacts of GHGs and Urbanization

15:00 LMST (Day) | 03:00 LMST (Night)

CESM RCP 8.5

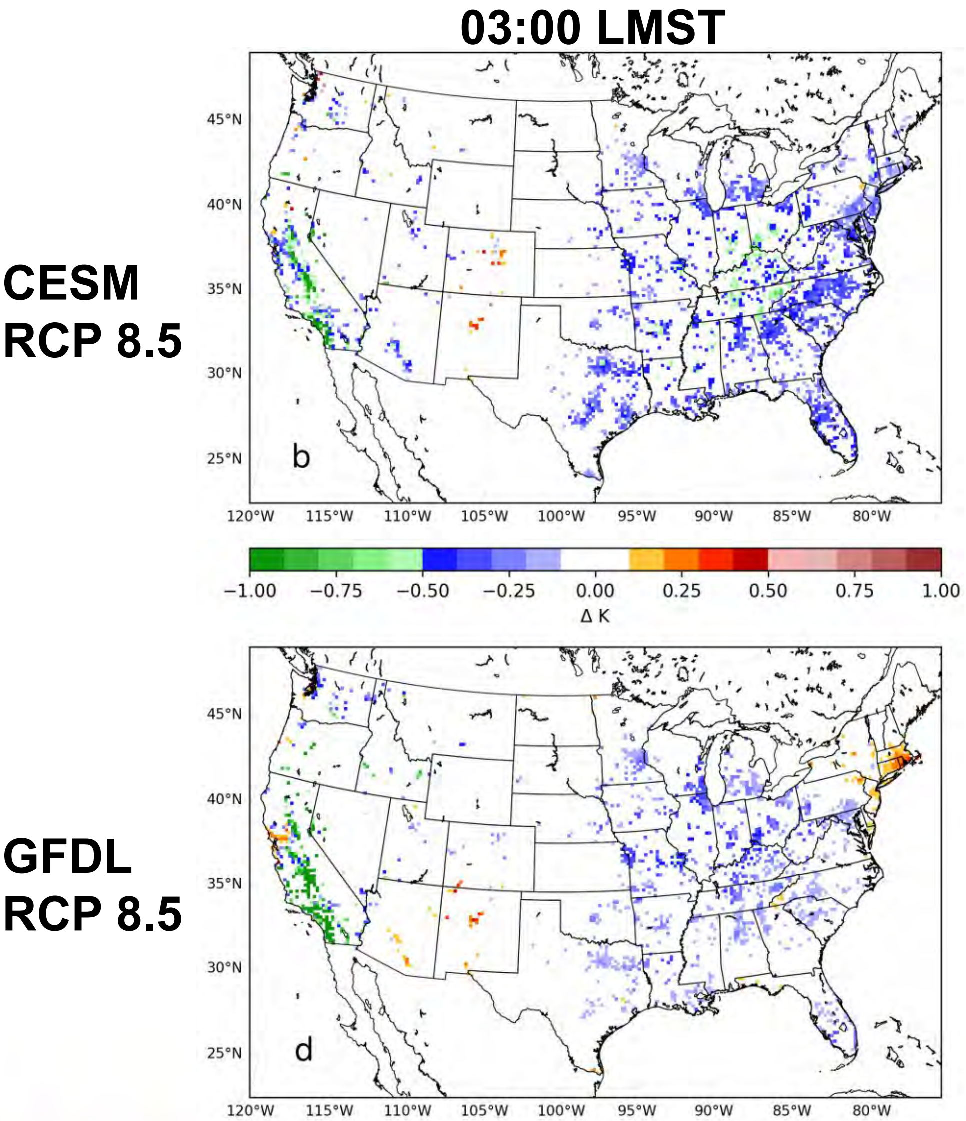
GFDL RCP 8.5



The sum of the effects of climate change, urban expansion *and* their interaction.

Krayenhoff, E. S., et al. (2018), *Nature Climate Change.*

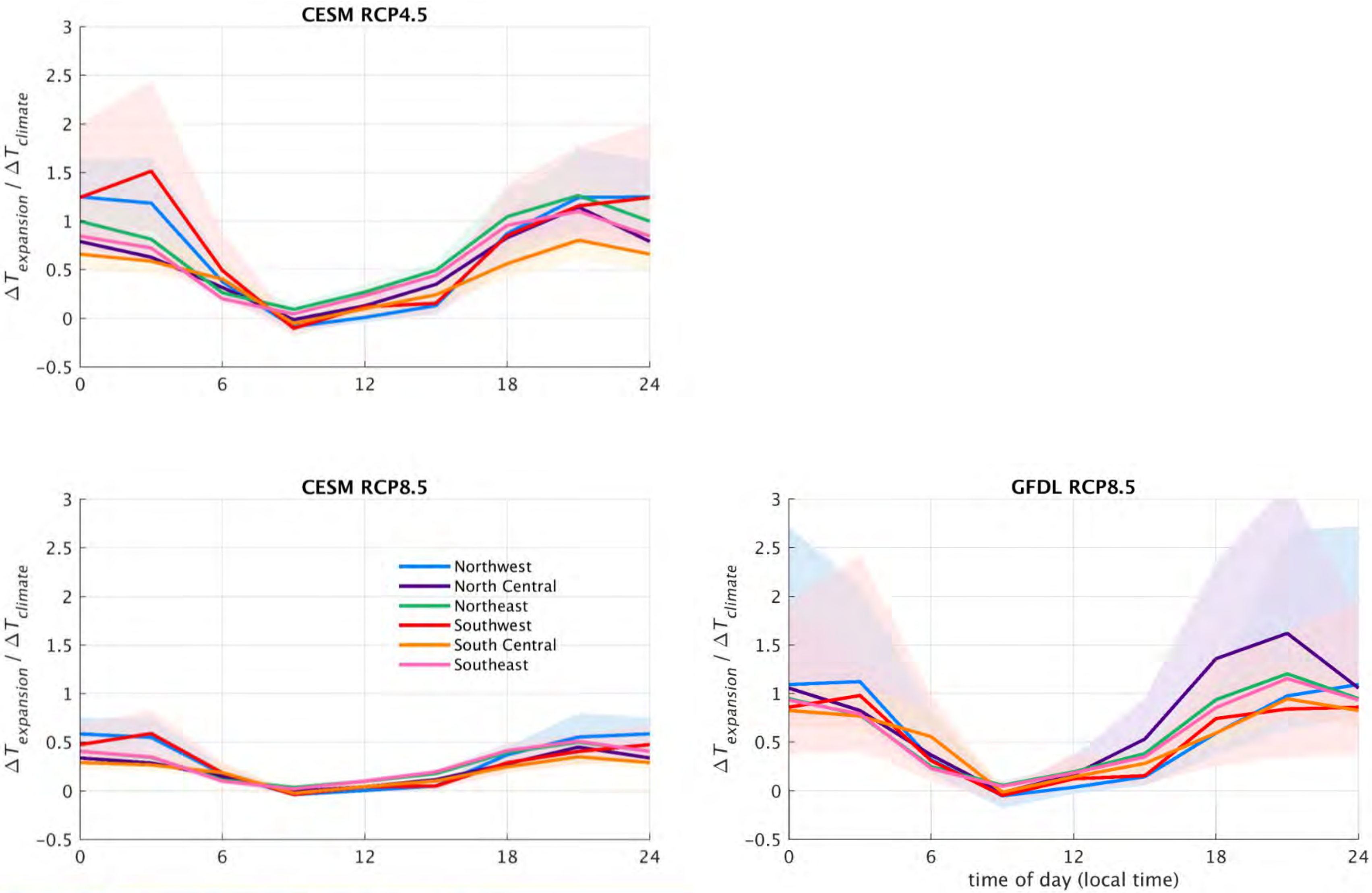
Individual and Total Impacts of GHGs and Urbanization



Dynamic interaction **(cooling up to 1K) between effects of climate change and urban expansion.**

Krayenhoff, E. S., et al. (2018), *Nature Climate Change.*

Individual and Total Impacts of GHGs and Urbanization



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Krayenhoff, E. S., et al. (2018), *Nature Climate Change.*

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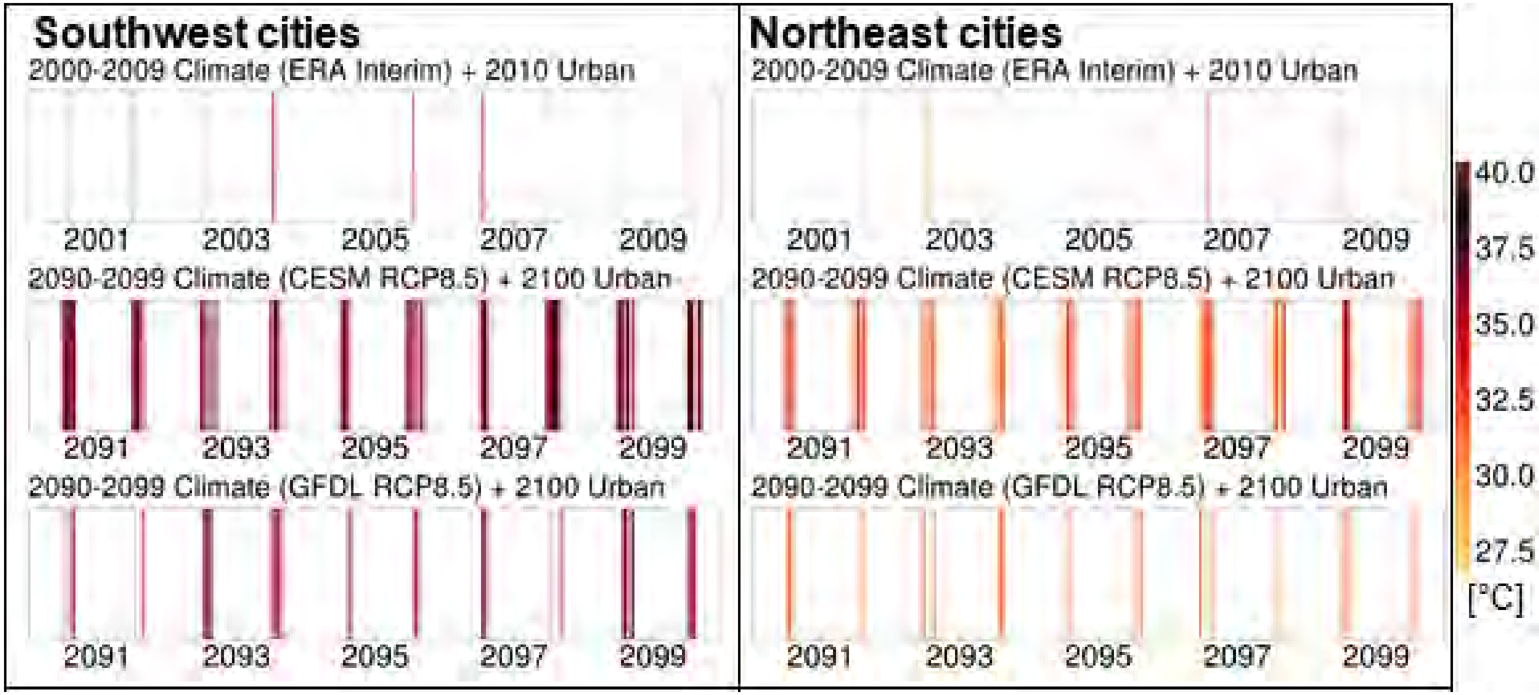
Extending to Health Outcomes

Occurrence and magnitude of hot days that exceed the National Climate Assessment (NCA) region average contemporary (2000–2009) 95th percentile 1500 LMST temp.

Contemporary (WRF driven w/Reanalysis)

Future (WRF driven w/CESM RCP8.5 + Urban)

Future (WRF driven w/GFDL RCP8.5 + Urban)



Note:

- Widening and "reddening" indicated broadening of regionally heat waves.
- Sensitivity to GCM forcing.

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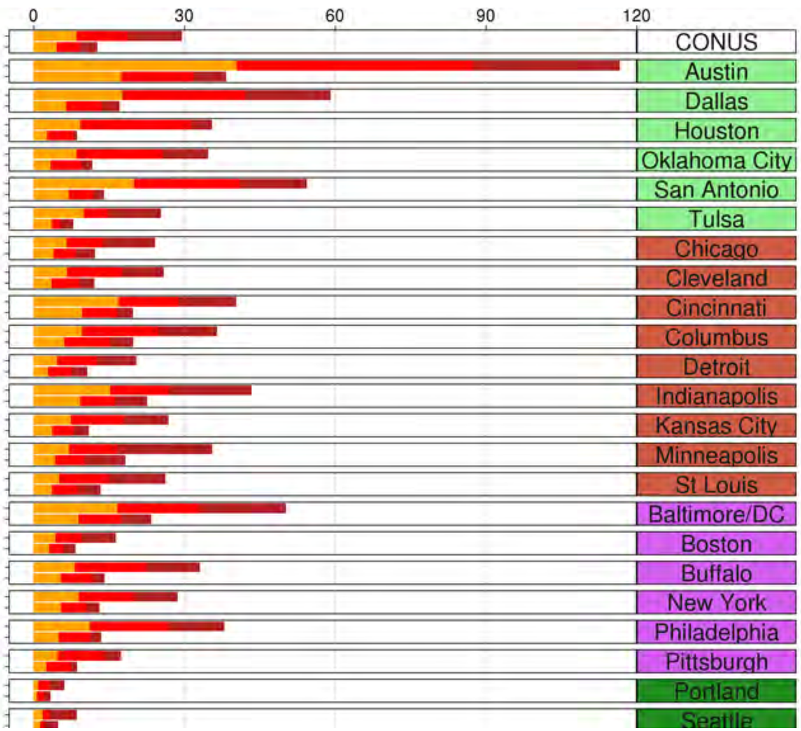
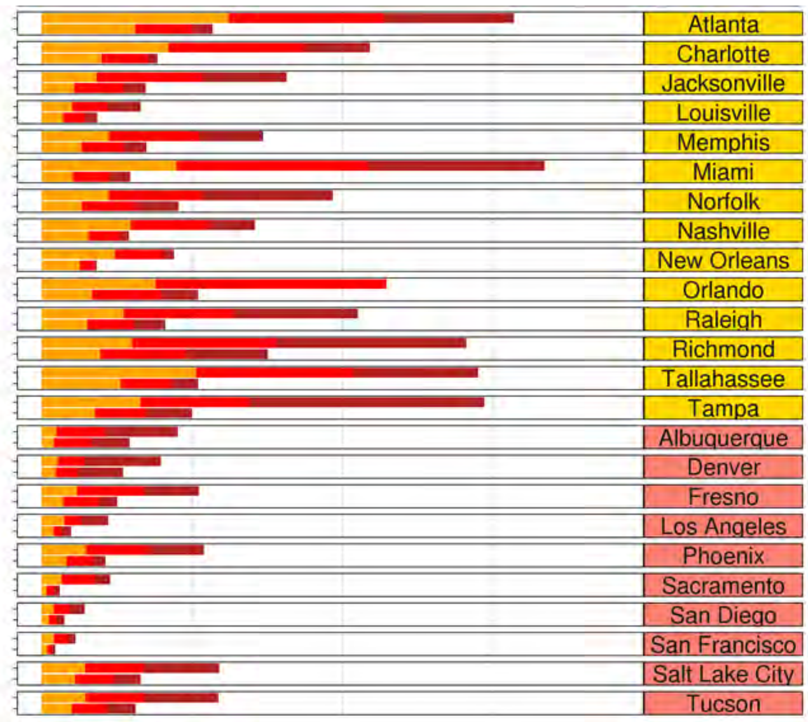
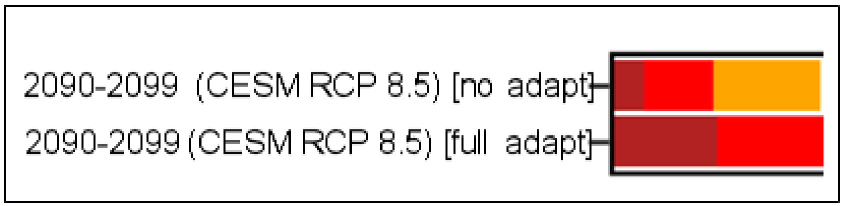
Broadbent et al. (2019), *to be submitted.*
Not for public dissemination.

Effects on heat exposure

Projected (2090 – 2100) change in person-hours relative to 2000-2010)







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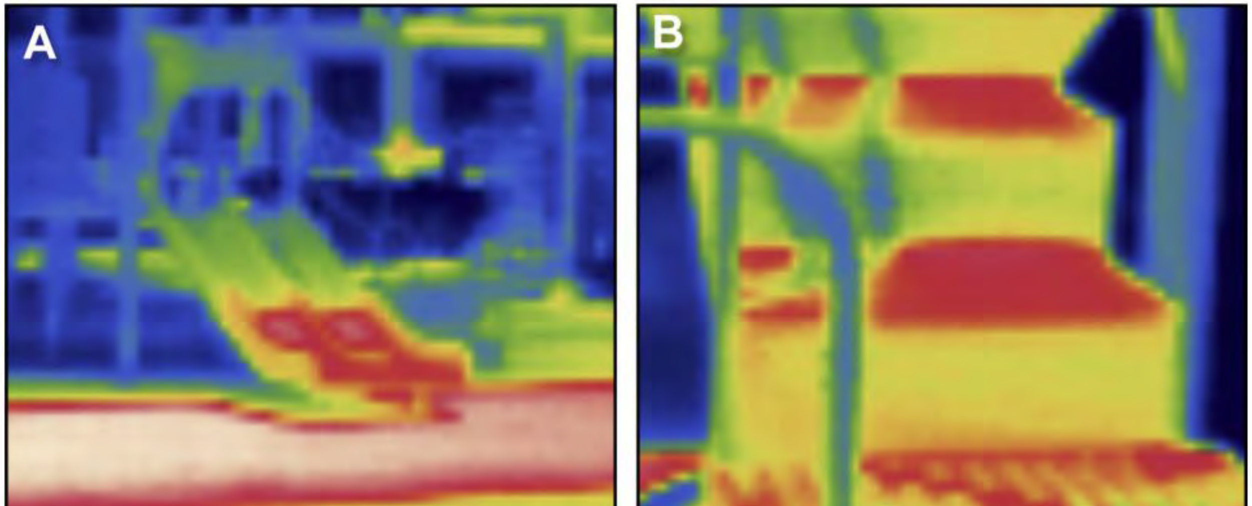
Effects on heat exposure

Design of urban spaces



Surface temperature images photographed in study playgrounds using Infrared Thermography:

(A) Slide and black/green rubber ground surface in sun (71^{0}C on slide; 82^{0}C on rubber) and under sail (blue/green);

(B) playground steps in sun. Photos taken at 1045 h LST (*Vanos et al., 2016, Land. Urban Planning*)

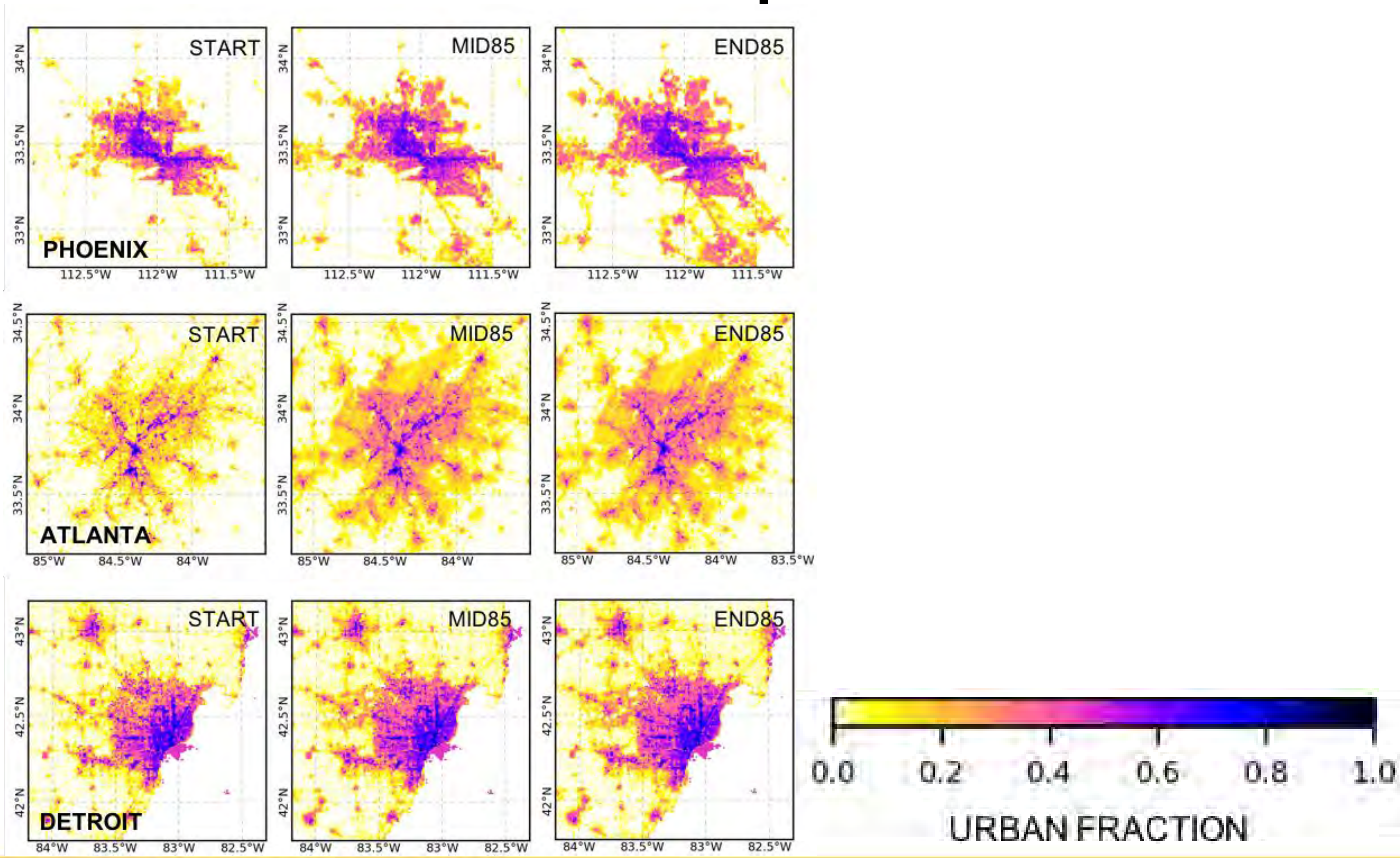
J.K. Vanos et al. / Landscape and Urban Planning 146 (2016) 29–42 31

Table 1
Burn thresholds when skin is in contact for short periods of time (3 s, 5 s, 1 min) with hot surfaces made of materials commonly found within playgrounds. Thresholds of materials with similar heat conductivity are combined to represent one value.

Material	Material characteristics		Burn threshold (°C)	
	Contact time	3 s	5 s	1 min
Metal	Uncoated	60 °C	57 °C	51 °C
Coated metal[a]	Lacquer coat: 100 µm	68 °C	61 °C	51 °C
	Powder: 90 µm	65 °C	60 °C	51 °C
	Enamel: 160 µm	63 °C	59 °C	51 °C
	Polyamid 11 or 12: 400 µm	77 °C	70 °C	51 °C
Stone material	Concrete, granite, asphalt	73 °C	60 °C	56 °C
Plastic[b]	Polyamide, acrylglass, polytetrafluorethylene, duroplastic	77 °C	74 °C	60 °C
Wood	Bare, low moisture	99 °C	93 °C	60 °C

Source: ISO 13732 (2010).
[a] Polyurethane enamel-coated steel is used predominantly in the study site playgrounds for hold/touch surfaces, and powder coated steel for walking surfaces.
[b] UV stabilized high-density polyethylene (HDPE) used in playgrounds is similar in material properties to polyamide.

Local Perspective



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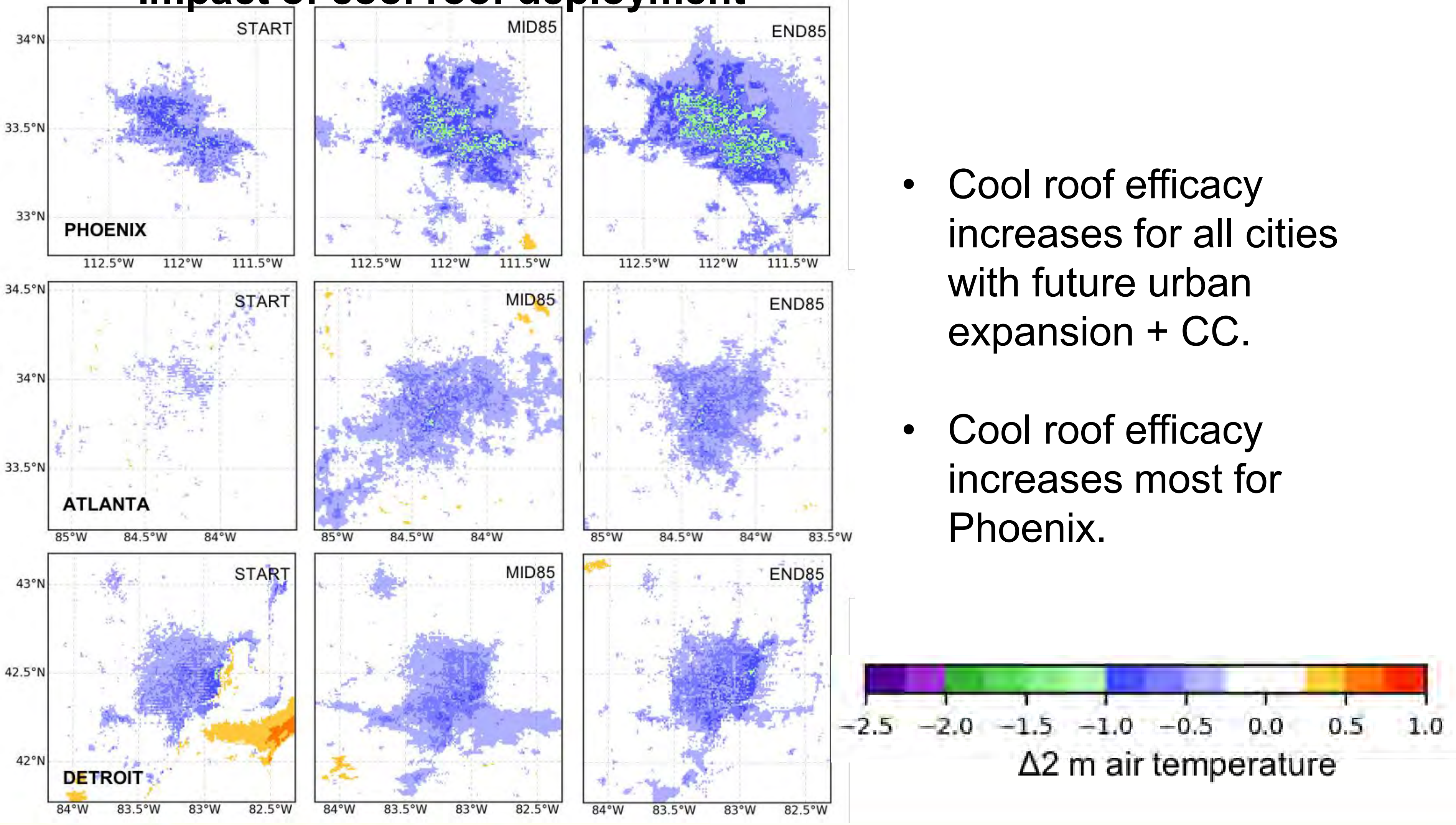
Broadbent, A., et al. (2019), *In Revision, ERL.*
Not for public dissemination.

Local Perspective

Impact of cool roof deployment



- Cool roof efficacy increases for all cities with future urban expansion + CC.
- Cool roof efficacy increases most for Phoenix.

Broadbent, A., et al. (2019), *In Revision, ERL.*

Not for public dissemination.

Concluding Remarks

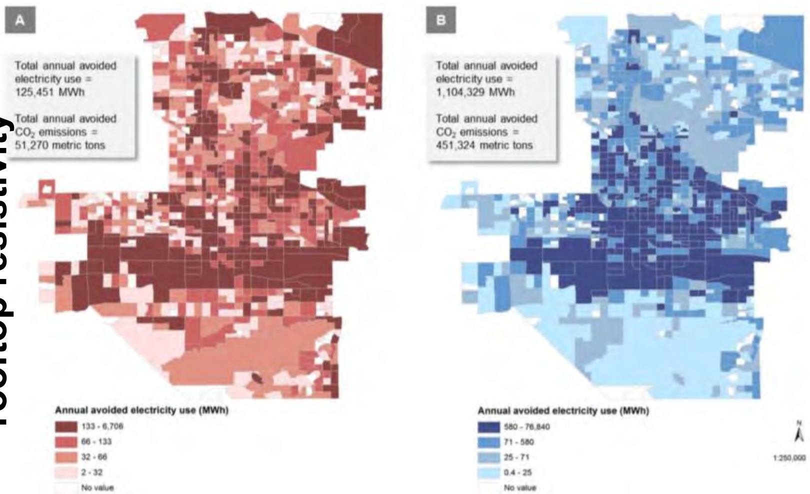
 What are the key knowledge gaps and critical research needs toward sustainable urban settlements, from the physical and social sciences and arts, including architecture and urban design?

- Scaling from local to regional;
- Integrating impacts under a <u>*desired*</u> outcomes framework, which is locally defined?

City of Phoenix 2050 Sustainability Goals Category*	Desired Outcomes*	UA Delivery Mechanisms	Metrics
Local Food Systems	"Eliminating food deserts" (p.13)	Help reduce food deserts via local production of food	- Local food supply from UA - Total tons - Tons/census block - Tons/person
			- In block groups overlapping known food deserts (½ mile LILA tracts) - Total tons - Tons per food desert - Tons/person
Parks, Preserves and Open Spaces	"Having all residents within a five-minute walk of a park or open space by adding new parks or open space in underserved areas." (p.10)	Create green open spaces by repurposing vacant lands as urban farms or community gardens	- Increase in green space area (%)
			- Number of census blocks with public green space that formerly had none (#)
			- Increase in the 5-minute green open space access zones (% area and population served)
Energy: Buildings and Land Use	"Reduce carbon pollution from vehicles, buildings, and waste by 80%-90%" (p.3)	Create rooftop gardens that insulate buildings	- Avoided electricity use in buildings from added insulation provided by rooftop deployment of UA (MWh)
			- Avoided CO_2 emissions as a result of reduced building electricity use (metric tons)

<u>Avoided building electricity use</u>

Average and consistent thermal rooftop resistivity



 Discuss effective mechanisms for strengthening the science-policy interface and adopting best practice to address current and future urban sustainability challenges in both countries.

- Are city-level climate adaptation plans research dependent?

Uludere et al. (2019), *Env. Res. Lett.*

References

1. Georgescu, M., Morefield, P. E., Bierwagen, B. G., & Weaver, C. P. (2014). Urban adaptation can roll back warming of emerging megapolitan regions. *Proceedings of the National Academy of Sciences*, *111*(8), 2909-2914.

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3. Vanos, J. K., Middel, A., McKercher, G. R., Kuras, E. R., & Ruddell, B. L. (2016). Hot playgrounds and children's health: a multiscale analysis of surface temperatures in Arizona, USA. *Landscape and Urban Planning*, *146*, 29-42.

4. Uludere, N.A., Stuhlmacher, M., Smith, J., Clinton, N., & Georgescu, M. (2019), Urban Agriculture's Bounty: Contributions to Phoenix's Sustainability Goals. *Environmental Research Letters – Special Issue on Sustainable Cities*, 14(10).

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Additional Slides

Four 10-year regional climate model (WRF) simulations

Code	Name	Climate scenario	Urban development scenario
b	Base case	2000-2009	2000
bc	Climate change	2090-2099	2000
bu	Urban development	2000-2009	2100
bcu	Climate change + Urban development	2090-2099	2100

Temperature (T), as an example:

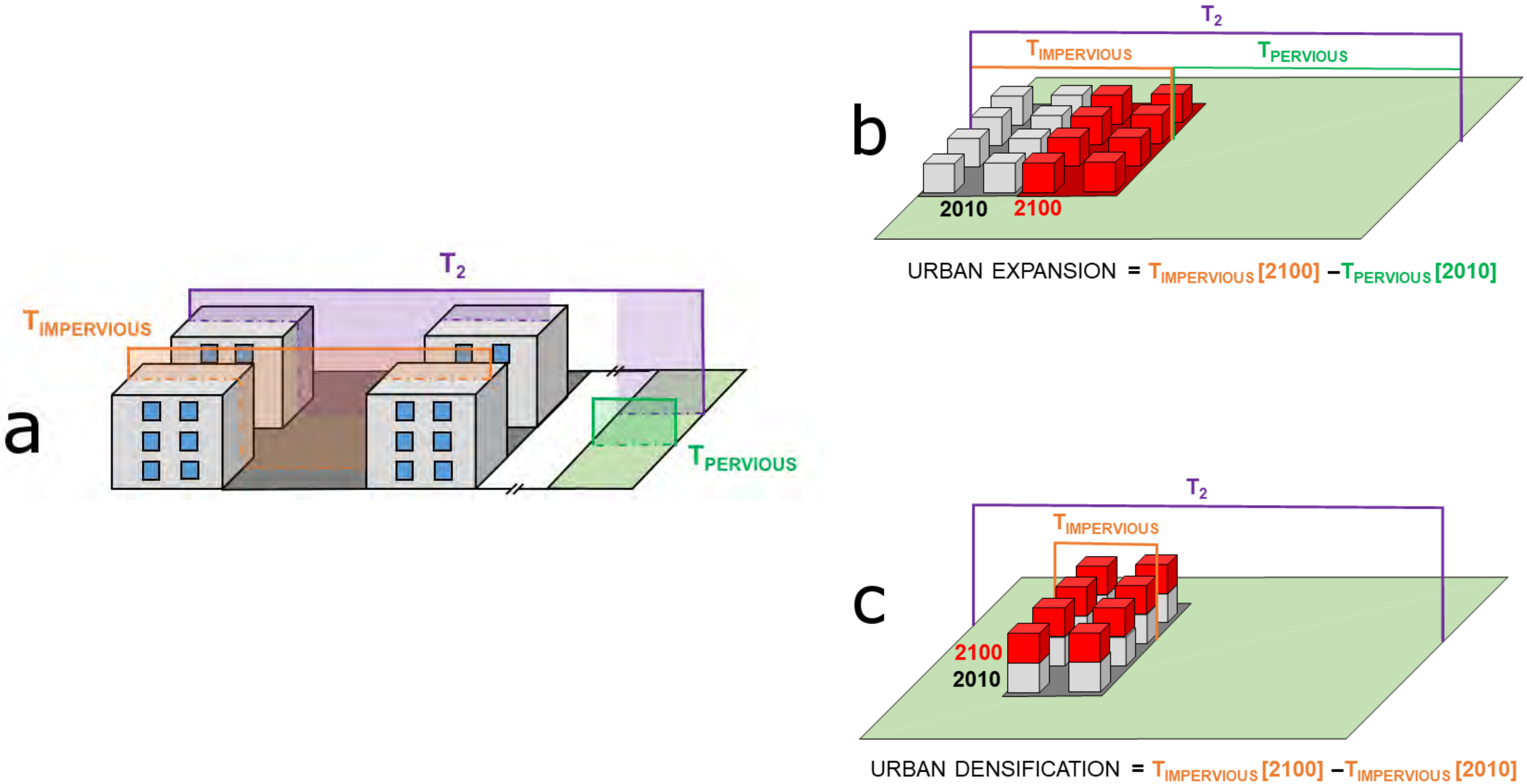
T (bcu) = Base case + Effect of Climate Change + Effect of Urban development + Effect of interactions

T (bcu) = ~~T(b)~~ + T(bc) – ~~T(b)~~ + T(bu) – T(b) + Effect of interactions

Rearranging:

Effect of interactions = [T(bcu) – T(bc)] – [T(bu) – T(b)]

$$\text{Effect of interactions} = \underbrace{[T(bcu) - T(bc)]}_{\text{Urban effect (2090-2099)}} - \underbrace{[T(bu) - T(b)]}_{\text{Urban effect (2000-2009)}}$$


a
T2
TIMPERVIOUS
TPERVIOUS
b
T2
TIMPERVIOUS
TPERVIOUS
2010
2100
URBAN EXPANSION = TIMPERVIOUS [2100] – TPERVIOUS [2010]
c
T2
TIMPERVIOUS
2100
2010
URBAN DENSIFICATION = TIMPERVIOUS [2100] – TIMPERVIOUS [2010]