Are Climate Models Ready for the Urban Scale?

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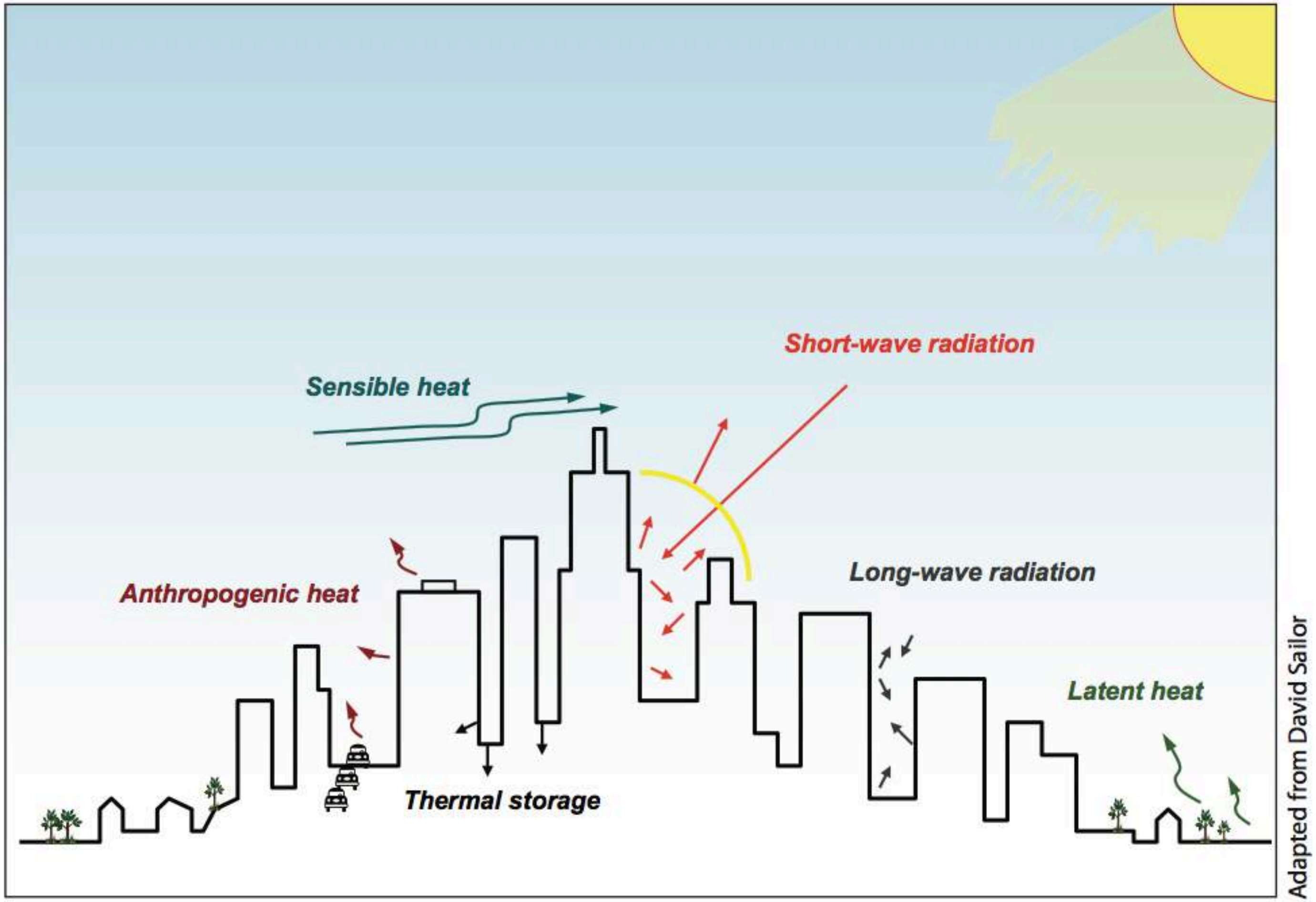
2014 NSF Urban Climate Institute (UCI)
Center for Quality Growth & Regional Development
Wednesday July 9, 2014

ARIZONA STATE UNIVERSITY

Our 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., anthropogenic heat).

Q: Are Climate Models Ready for the Urban Scale?

A: It depends on …

- Definition of 'urban' and 'scale':
  - According to UN (2012 – world population projections), there exist >70 definitions of urban, i.e., no consensus globally on what 'urban' means.
- Urban Priorities:
  - Urban Heat Island (UHI)
  - How about (i) hydroclimate, (ii) energy, (iii) air quality.
- Definition of "ready":
  - Utility, capability (and uncertainty) must be conveyed.

Defining Urban (Scale)

Vancouver, Canada

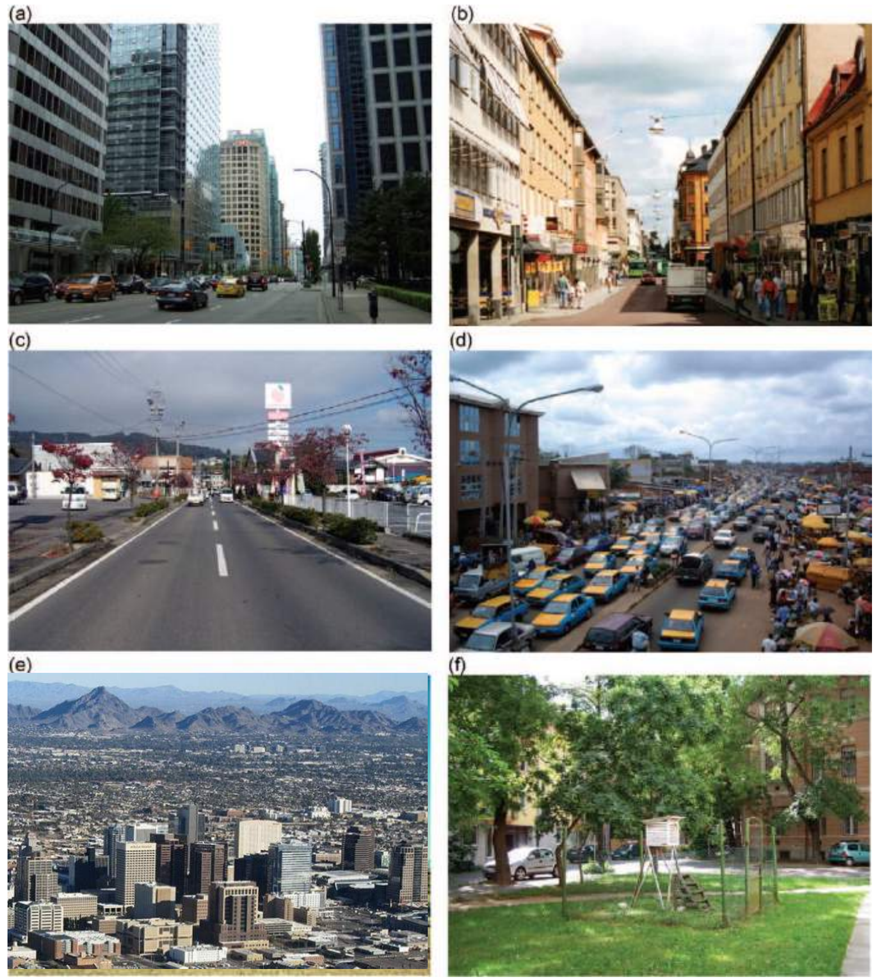
Uppsala, Sweden

Toyono, Japan

Akure, Nigeria

Phoenix, Arizona

University campus of Szeged, Hungary



- Adapted from: Stewart and Oke, (2012) Bull. Amer. Meteor. Soc., 93, 1879–1900.
- Additional Reading: Raciti et al., (2012) Ecological Applications, 22(3), 1015–1035.
- Voogt, J. A., and Oke, T. R. (2003), Thermal remote sensing of urban climates. Remote Sensing of Environment, 86(3), 370-384.

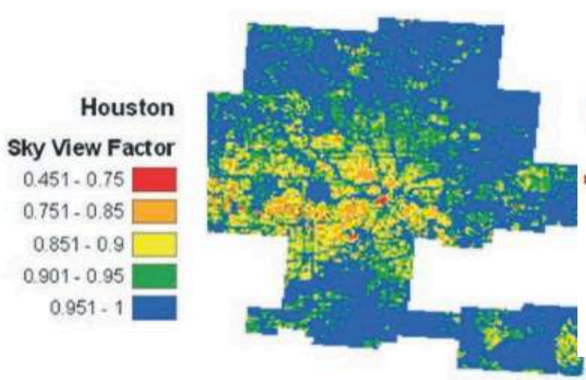
Defining Urban (Scale) in Models

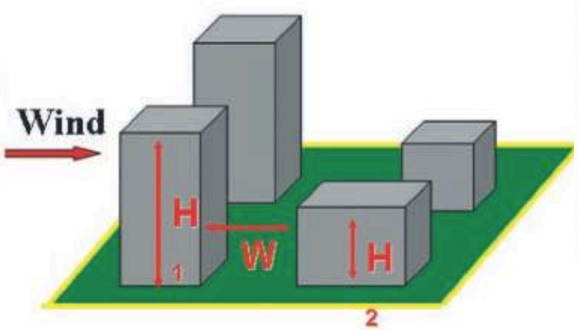
- 'Urban' in WRF model can be characterized as:
  - *A single class (i.e., bulk parameterization)*
  - MODIS LULC/Urban using SLUCM (or multi-layer model)
  - NLCD 3-class LULC/Urban using SLUCM (or multi-layer model)

- 'Urban' representation as city and/or metro specific morphological characteristics.

WRF

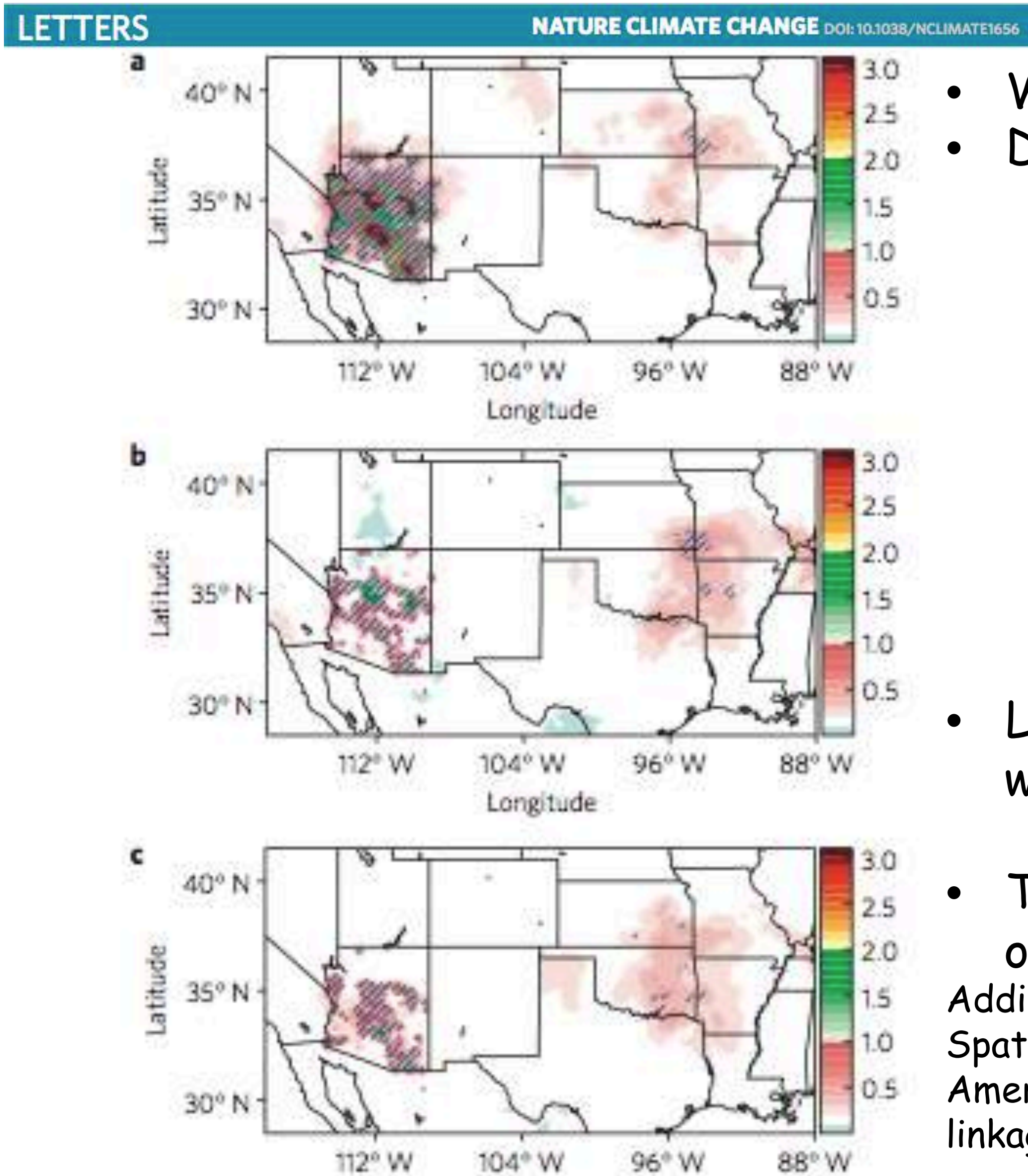
- Urban fraction
- Building height, *ZR*
- Roughness for momentum above the urban canopy layer, Z_0, C
- Roughness for heat above the urban canopy layer Z_0, HC
- Zero-displacement height above the urban canopy layer, ZDC
- Percentage of urban canopy (PUC)
- Sky-view factor (SVF)
- Building coverage ratio (roof area ratio), R
- Normalized building height, HGT
- Drag coefficient by buildings, CDS
- Buildings volumetric parameter, AS
- Anthropogenic heat, AH





Ching, J., and Coauthors (2009) National Urban Database and Access Portal Tool. *Bull. Amer. Meteor. Soc.*, **90**, 1157–1168.

Megapolitan expansion: Arizona's Sun Corridor



- WRF simulations: 2006-2008
- Domain: CONUS (20-km Δx, Δy)
  - 4 scenarios
    - Control
    - SunCorrHi
    - SunCorrAdapt
    - SunCorrLo
  - 4 members for each scenario = 12 simulation years per scenario
- Local (scenario dependent) JJA warming 1-3°C
- Teleconnection pathway *suggestive* of remote impacts.

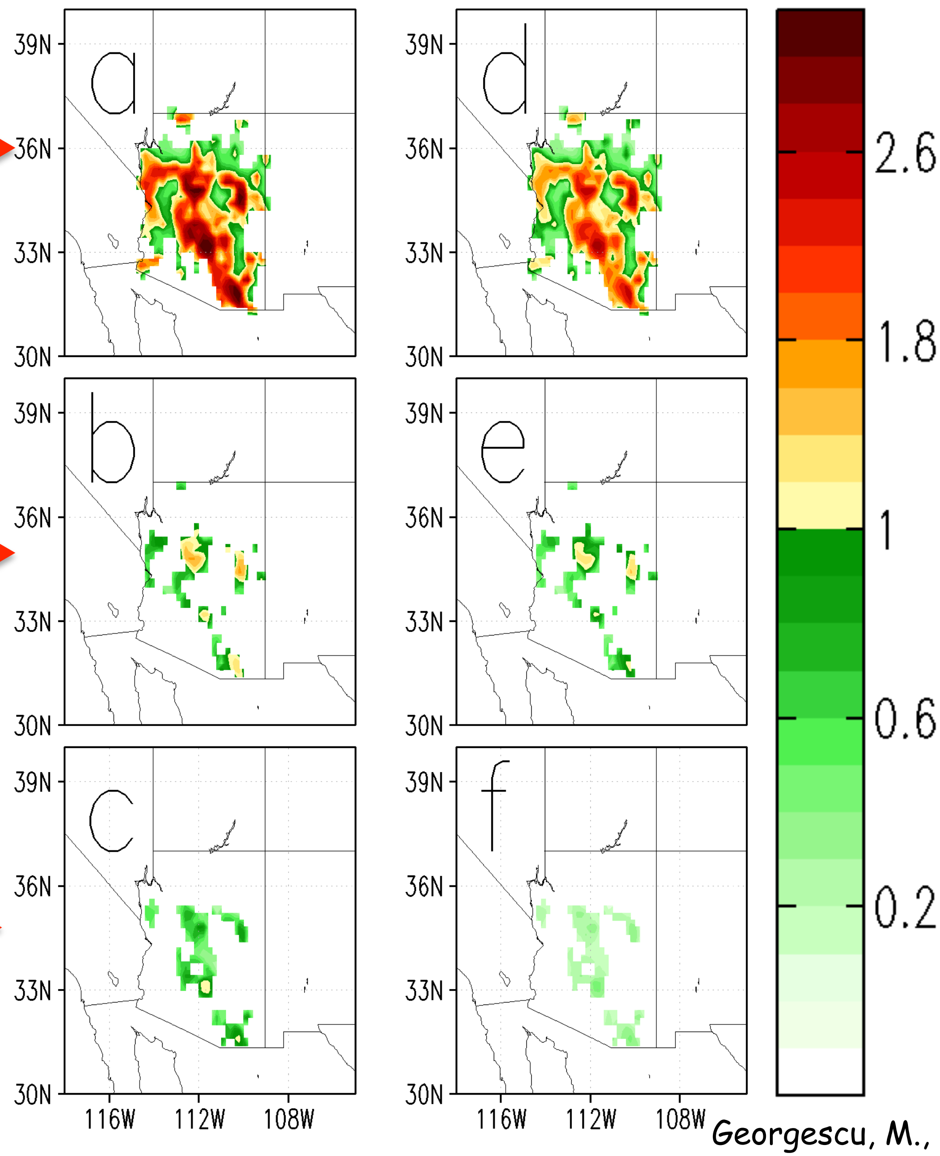
Additional reading: Dominguez, F. et al. (2009), Spatial extent of the North American Monsoon: Increased cross-regional linkages via atmospheric pathways. GRL 36, L07401.

Climate Change through:
2040-2060 2080-2099

SunCorr_Hi
B1 Scenario

SunCorr_Adapt
B1 Scenario

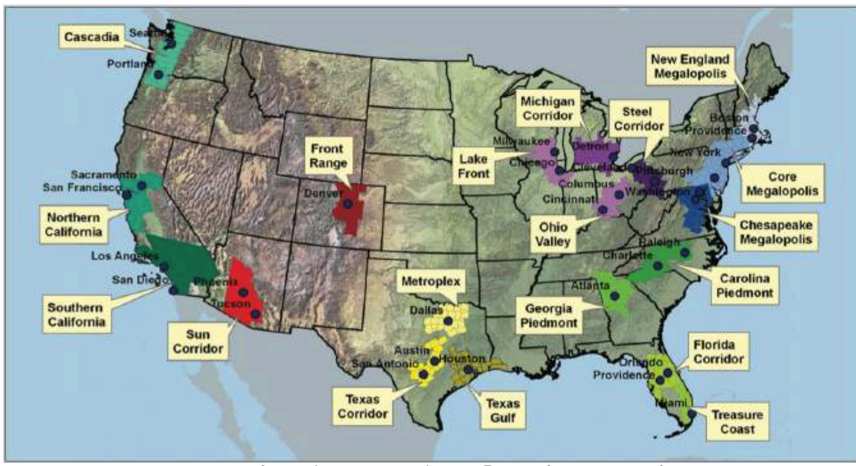
SunCorr_Lo
A2 Scenario



Georgescu, M., et al. (2013), *Nature Climate Change*, **3**(1) 37-41

Concurrent Megapolitan Expansion

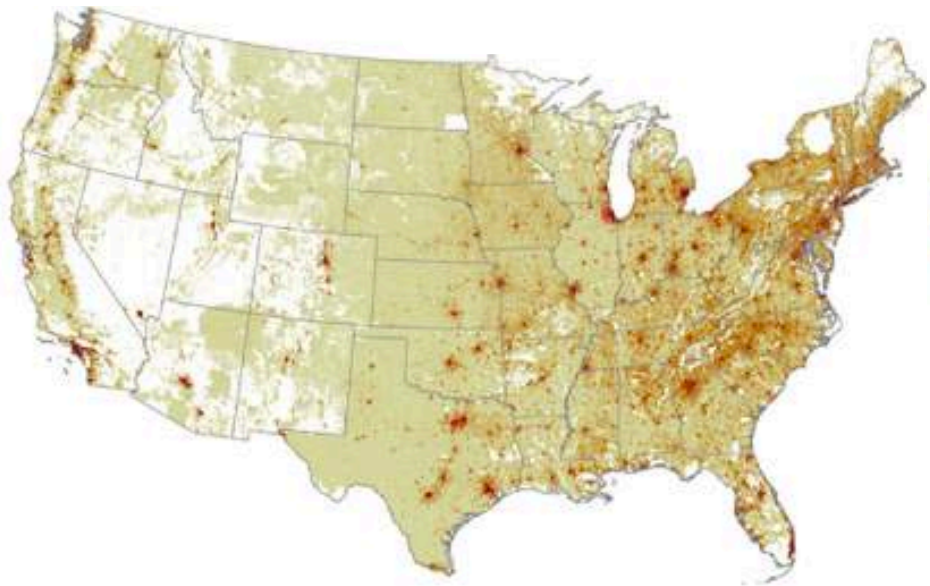
- What about other geographic/climatic regions?
  - Do hydroclimatic impacts due to urban expansion vary with place and time (i.e., season)?
  - Are urban adaptation strategies equally impactful across climatic and geographic gradients?



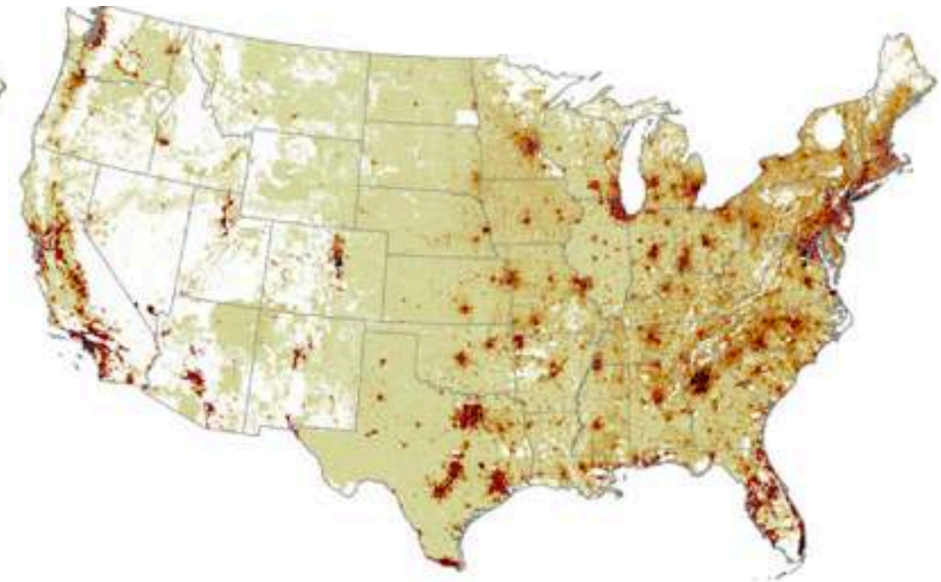
Grimm et al., (2008), *Ecological Applications*.

National Scale Assessment Necessary: ICLUS

Urban: 2000



ICLUS_A2: 2100



Bierwagen et al., (2010), ***Proc. Natl. Acad. Sci., 107*****(49), 20887-20892**

Expansion is consistent with SRES GHG emissions storylines rather than independent, locally generated projections, that may be in conflict with adjacent socioeconomic development (and may therefore be unrealistic).

Scenario-based U.S. Megapolitan Expansion

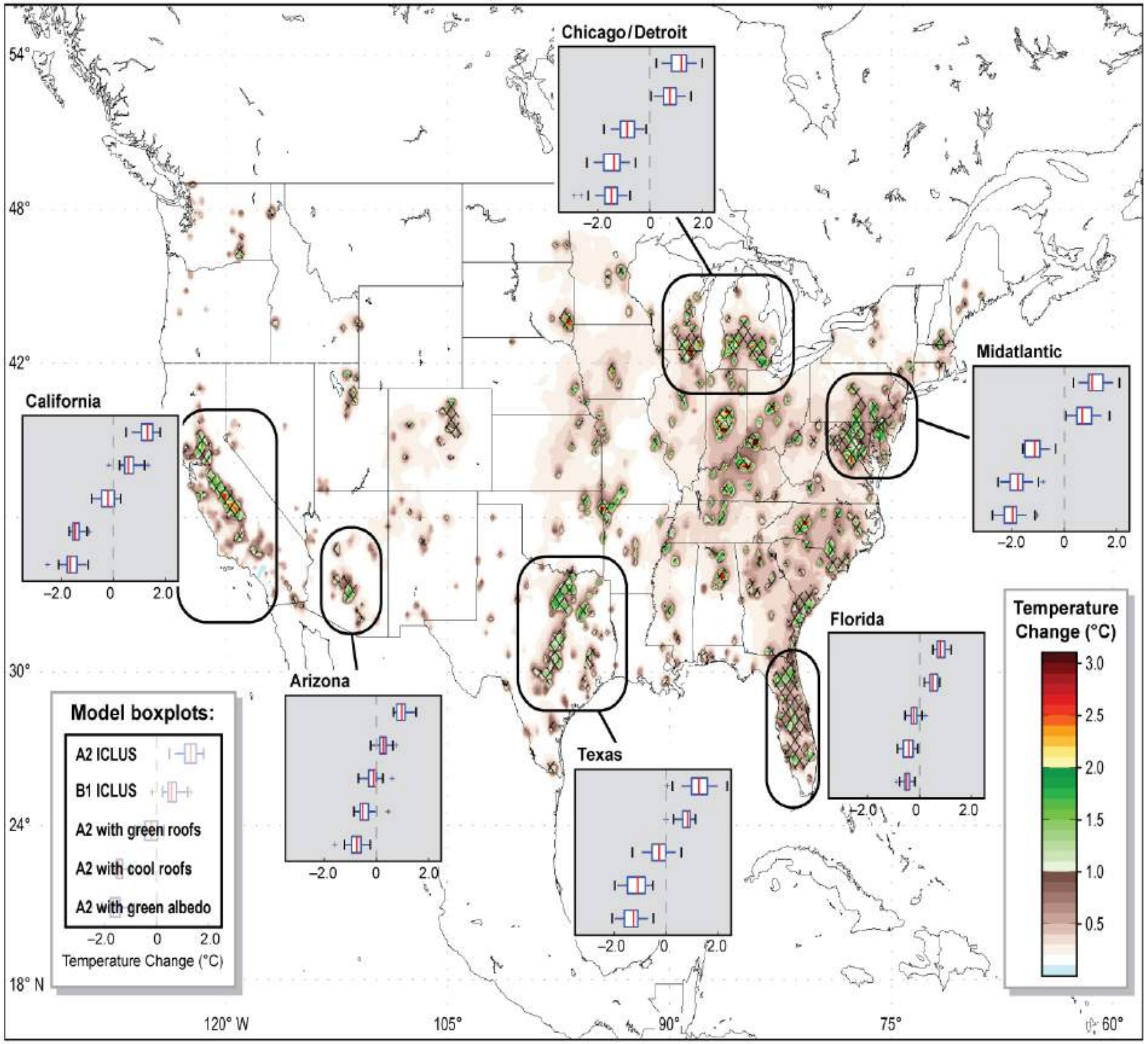
Naming Convention (CONUS simulations)

Experiments: 2001-2008 Climate (3 ensemble members)
Horizontal Resolution: 20-km Δx, Δy

1. **Control**: Baseline urban (2000)
2. **A2_ICLUS**: Maximum urban expansion for 2100
3. **B1_ICLUS**: Minimum urban expansion for 2100
4. **A2_GreenRoofs**: *As A2* with green roofs deployment
5. **A2_CoolRoofs**: *As A2* with cool roofs deployment
6. **A2_GreenAlbedo**: *As A2* with hybrid reflective and evapotranspiring properties.

- Each scenario represents 24 years of simulations (8 years X 3 ensemble members)
- In total: **144 years** of CONUS simulations (~2 million grid cells)

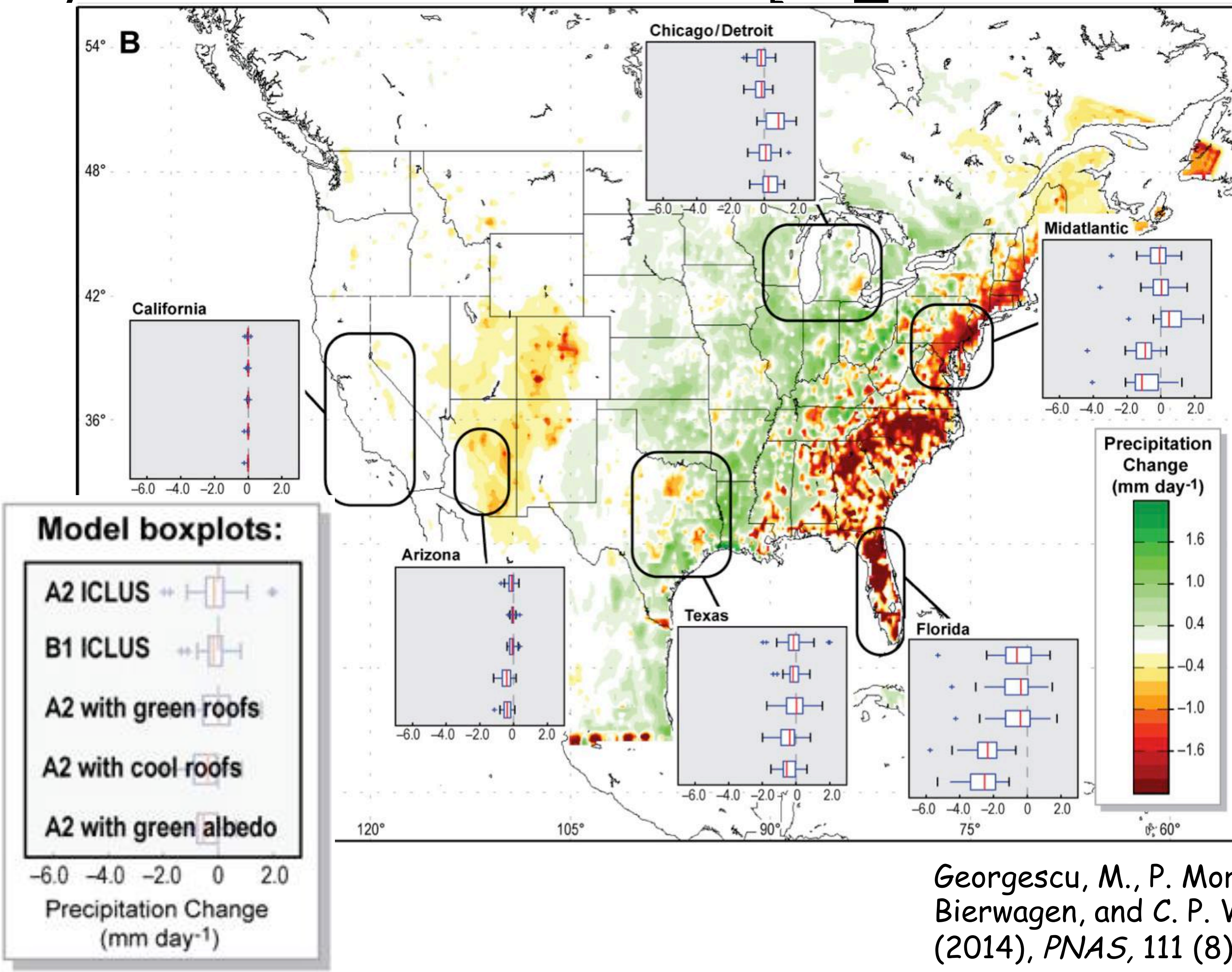
2m Temp difference (°C): JJA [A2– Control]



- For all regions, each urban adaptation strategy completely offsets urban-induced warming.
- Cool roofs are more effective at cooling than green roofs, but geography matters (e.g., Florida relative to California).
- Hybrid strategies reveal an urban adaptation saturation effect.

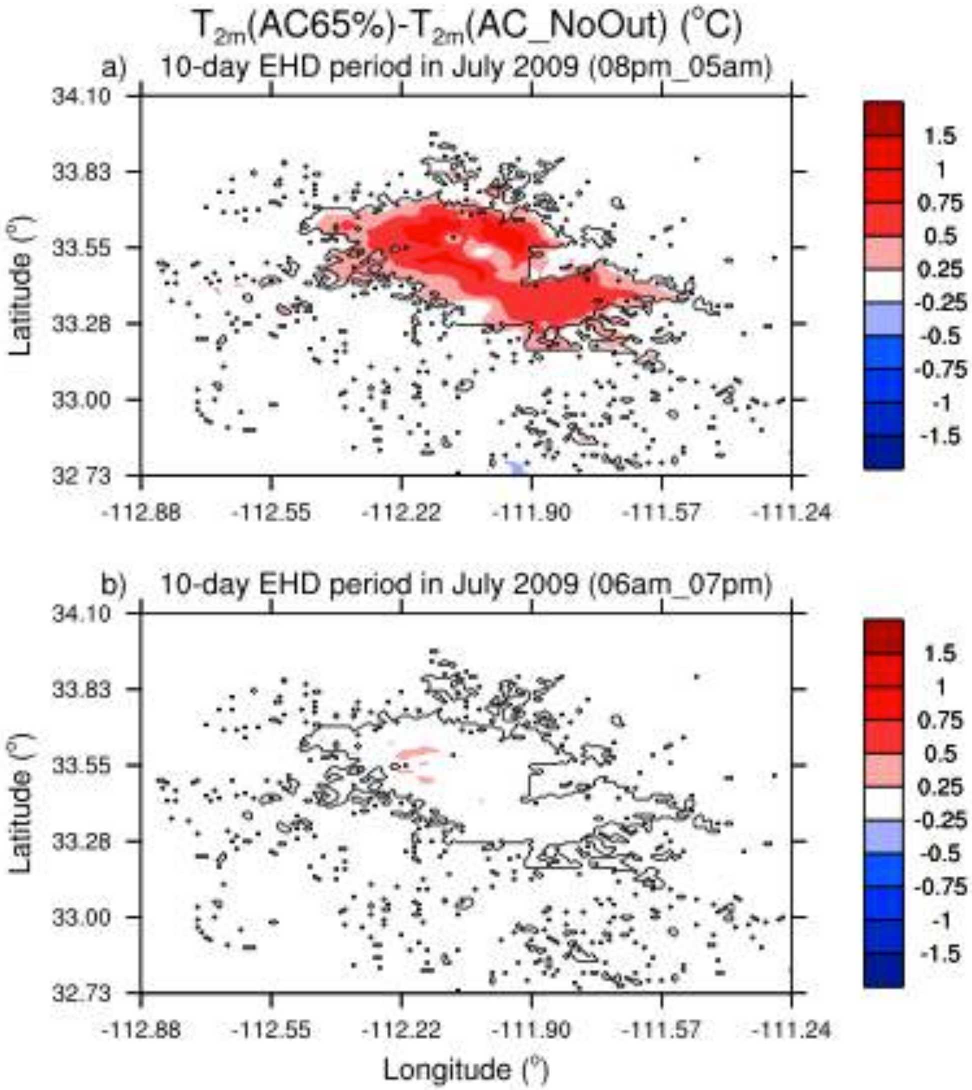
Georgescu, M., P. Morefield, B. G. Bierwagen, and C. P. Weaver (2014), *PNAS,* 111 (8), 2909-2914.

Hydroclimatic tradeoffs: JJA [A2_CoolRoofs – Control]



Georgescu, M., P. Morefield, B. G. Bierwagen, and C. P. Weaver (2014), *PNAS,* 111 (8), 2909-2914.

Coupled Atmospheric-Energy Demand Calculations



- 2km grid spacing covering Phoenix metro area (4 nested grids).
- Simulation time: 10 day Extreme Heat Event
- 2 sets of experiments:
  - With AC
  - Without AC

Salamanca, F., M. Georgescu, A. Mahalov, M. Moustaoui, and M. Wang (2014), Anthropogenic heating of the urban environment due to air conditioning, J. Geophys. Res. Atmos., 119, 5949–5965, doi:10.1002/2013JD021225.

Q: Are Climate Models Ready for the Urban Scale?

[mgeorge7@saguaro3 Control]$ tail rsl.error.0000
Timing for main: time 2008-06-24_11:40:30 on domain 4: 0.07896 elapsed seconds
Timing for main: time 2008-06-24_11:40:35 on domain 4: 0.07951 elapsed seconds
Timing for main: time 2008-06-24_11:40:40 on domain 4: 0.08043 elapsed seconds
Timing for main: time 2008-06-24_11:40:40 on domain 3: 0.47632 elapsed seconds
Timing for main: time 2008-06-24_11:40:45 on domain 4: 0.08336 elapsed seconds
Timing for main: time 2008-06-24_11:40:50 on domain 4: 0.07905 elapsed seconds
Timing for main: time 2008-06-24_11:40:55 on domain 4: 0.07966 elapsed seconds
Timing for main: time 2008-06-24_11:41:00 on domain 4: 0.07818 elapsed seconds
Timing for main: time 2008-06-24_11:41:00 on domain 3: 0.47869 elapsed seconds
Timing for main: time 2008-06-24_11:41:00 on domain 2: 1.56438 elapsed seconds

4 Nested Domains (finest 1km) for Mexico City:

- 145 points X 141 points (finest mesh) ~0.08 seconds per (180 second) timestep
- 6 month simulations ~ 10-12 days using 80-120 processors (SandyBridge, Westmere, Nehalem) w/OpenMPI using Intel Compilers

Answer depends on prioritizing fine scale physical representation relative to temporal scale. Ultimately "It's the question that drives us".

Some Concluding Remarks

Urban Climate Modeling

- Urbanization induced hydroclimatic, energy, and health impacts require consideration in addition to similar effects owing to GHGs.

- Prioritizing urban adaptation strategies requires tradeoff assessment (e.g., extension to air quality impacts), rather than exclusive focus on near-surface temperatures – no silver bullet solutions.

- Uncertainty quantification is necessary. These are process-based models that permit for informed decision-making based on what-if scenarios.

THANK YOU!