The Community Land Model Urban (CLMU): A Tool for Societal Dimensions Research

- CLMU Overview
- Application – Heat stress
- Next Generation

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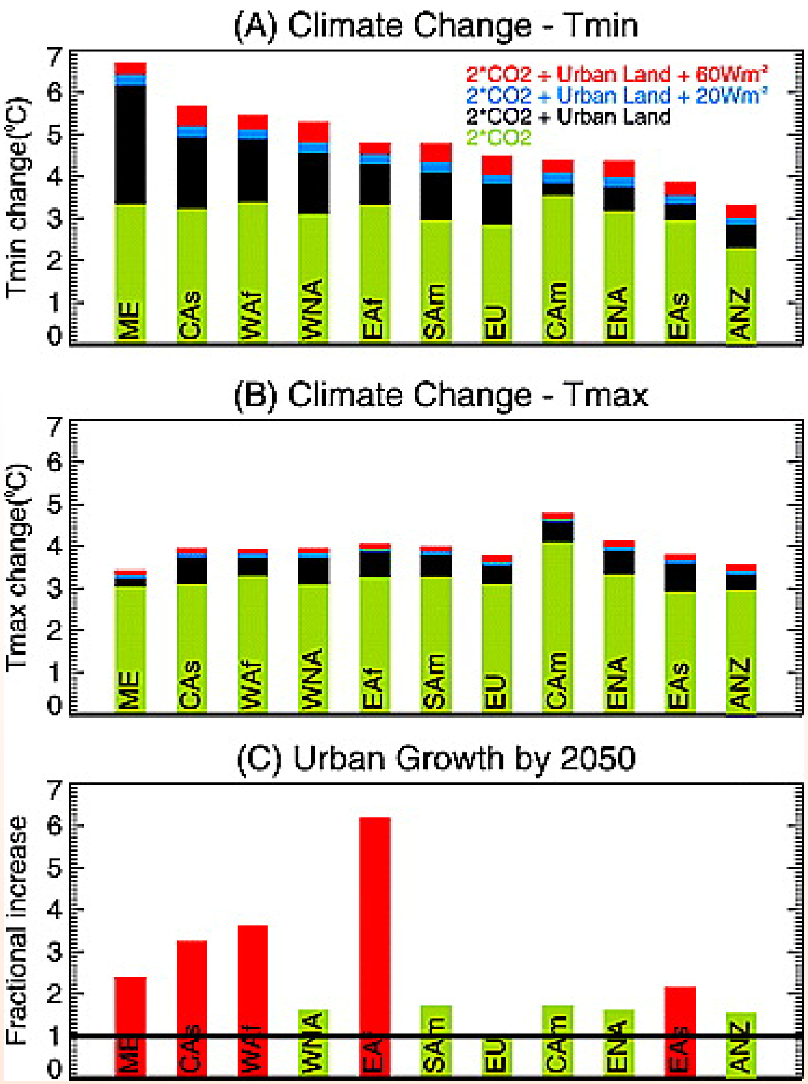
Why represent urban areas in a climate model?



McCarthy et al. 2010

- Global climate change simulations until recently have failed to account for urban areas, which is where the majority of people live and feel the effects of climate change.
- "Those regions with the higher cumulative impact of climate change and urban effects are…also projected to at least double their urban populations by 2050" (McCarthy et al. 2010)
- It is important to consider the additional urban warming as well as how climate change and urban areas might interact.

Processes contributing to the Urban Heat Island

- Increased shortwave absorption due to trapping inside urban canyon (lower albedo)
- Decreased surface longwave radiation loss due to reduction of sky view factor
- Reduction of ET due to replacement of vegetation with impervious surfaces
- Increased storage of heat due to larger heat capacity of urban materials
- Reduced turbulent transfer of heat due to reduced wind within canyon
- Anthropogenic sources of heat (heating, air conditioning, wasteheat, traffic, human metabolism)

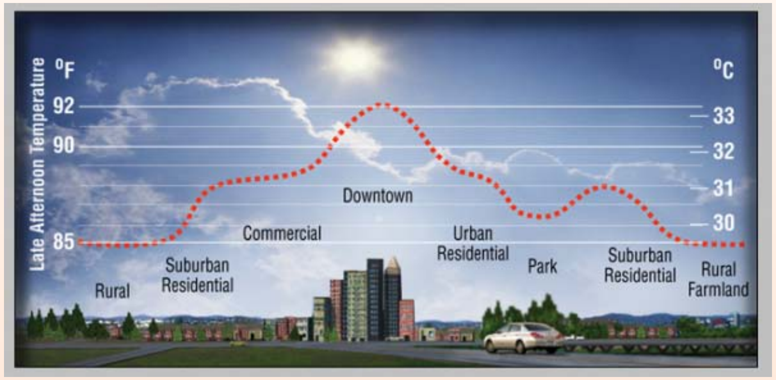
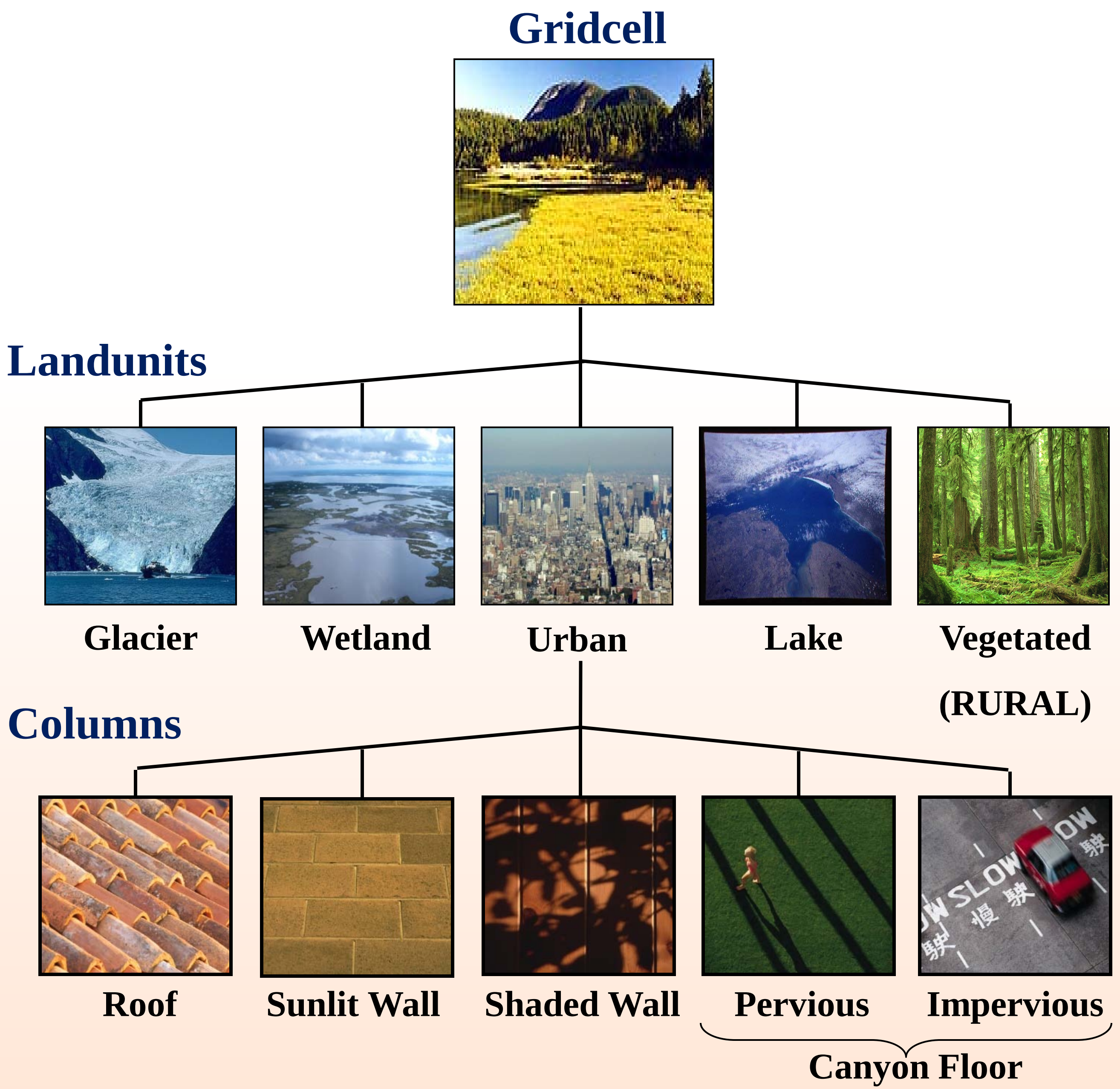


Image courtesy of Heat Island Group, Lawrence Berkeley National Laboratory

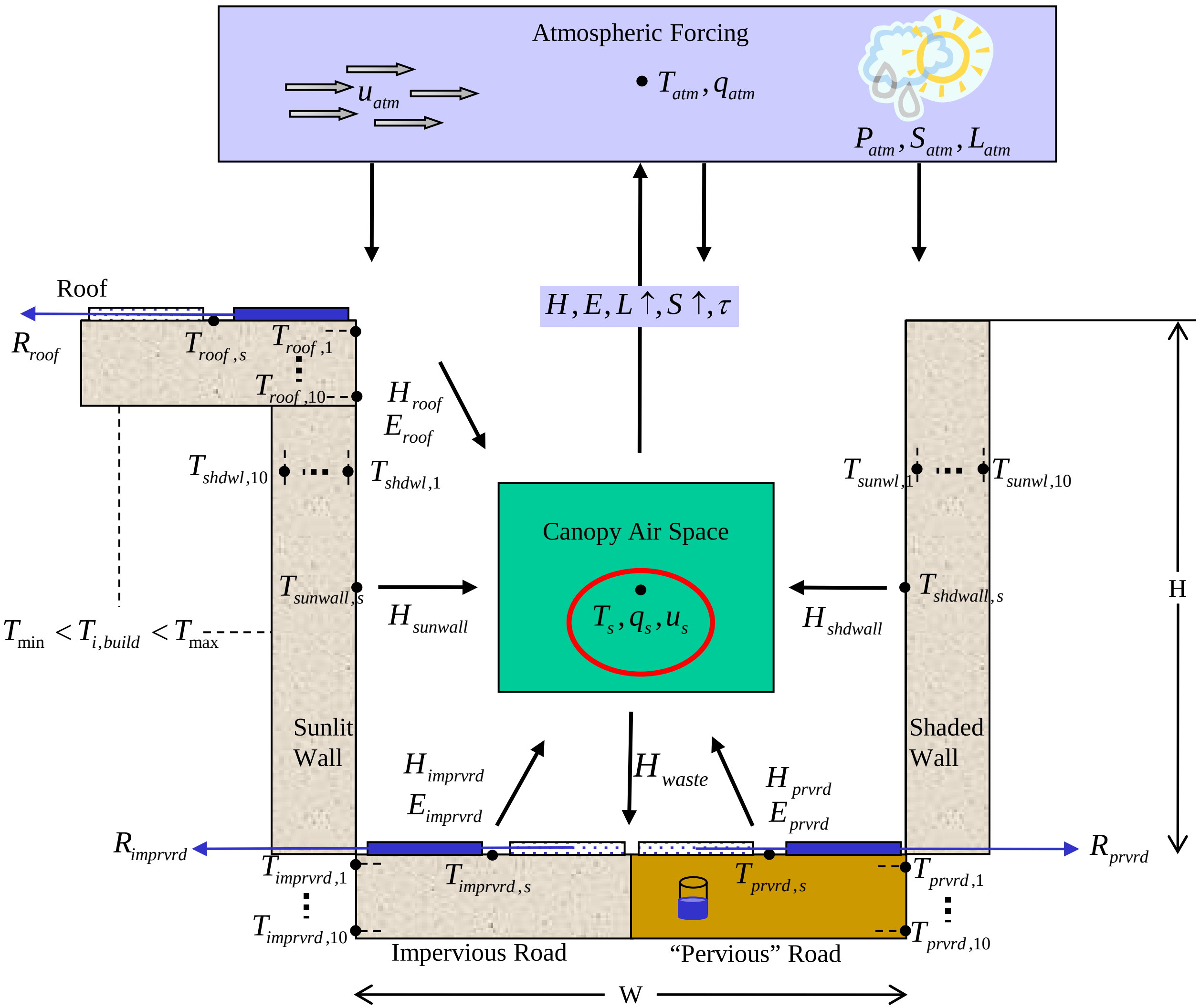
For more information see papers by Tim Oke and colleagues

Incorporating Urban Areas into CESM



Community Land Model – Urban (CLMU)

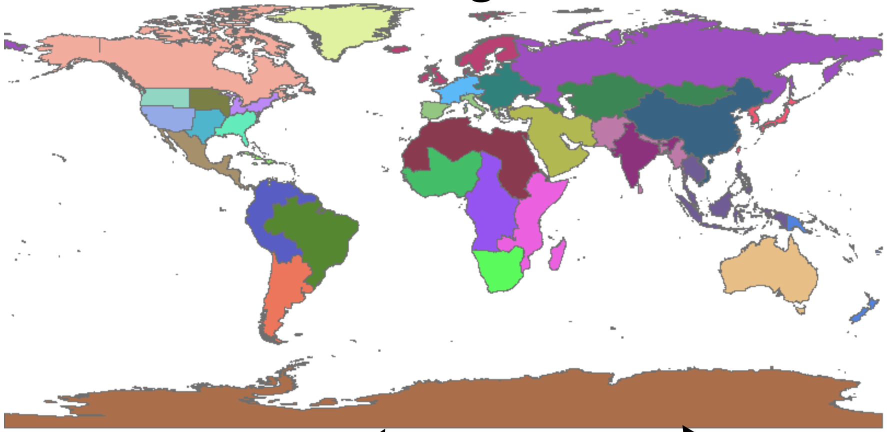
Oleson et al. 2008



Global Urban Characteristics Dataset

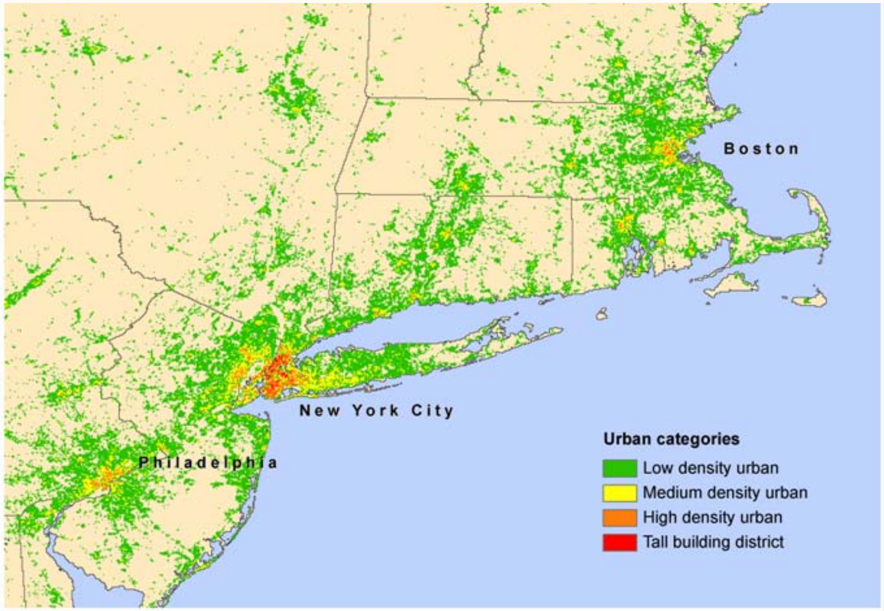
Jackson et al. 2010

Global Regions



To CLMU

Urban Extent - Landscan 2004



Urban Properties – Compilation of building databases

Morphological

- ***Building Height***
- ***H/W ratio***
- ***Pervious fraction***
- ***Roof fraction***

Radiative – Roof/Wall/Road

- ***Albedo***
- ***Emissivity***

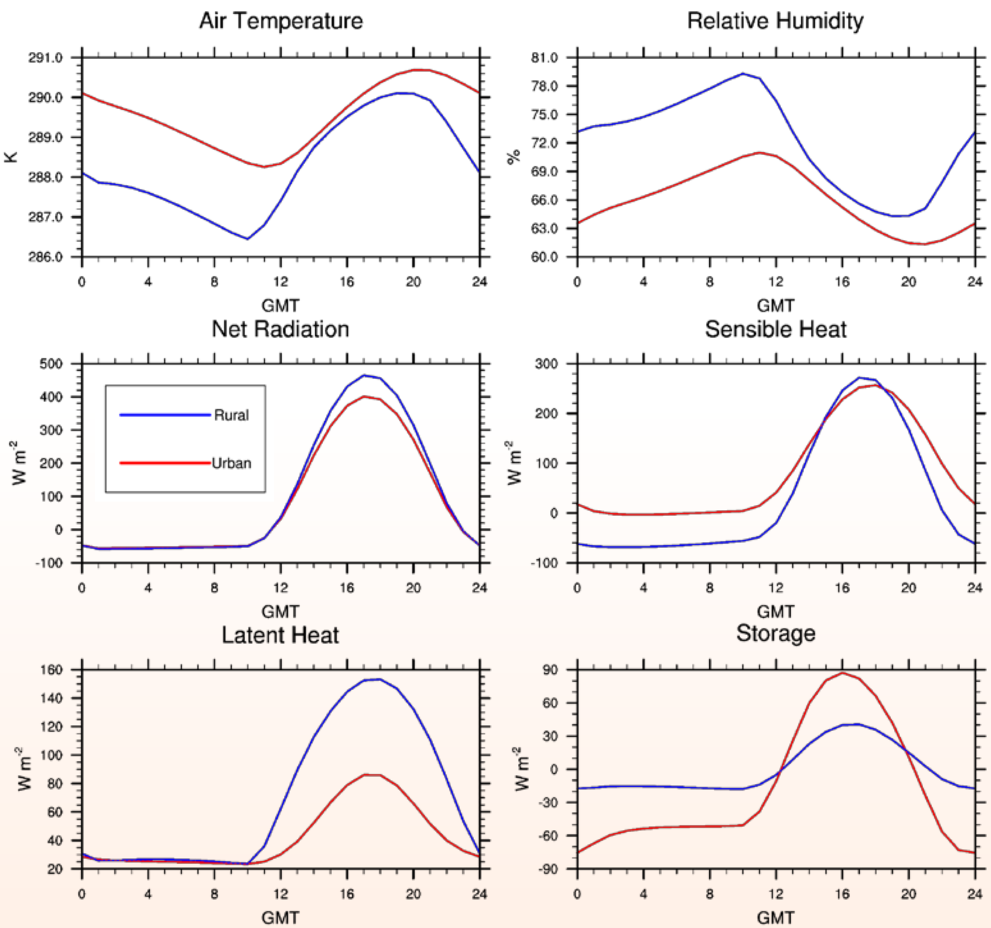
Thermal – Roof/Wall/Road

- ***Conductivity***
- ***Heat Capacity***

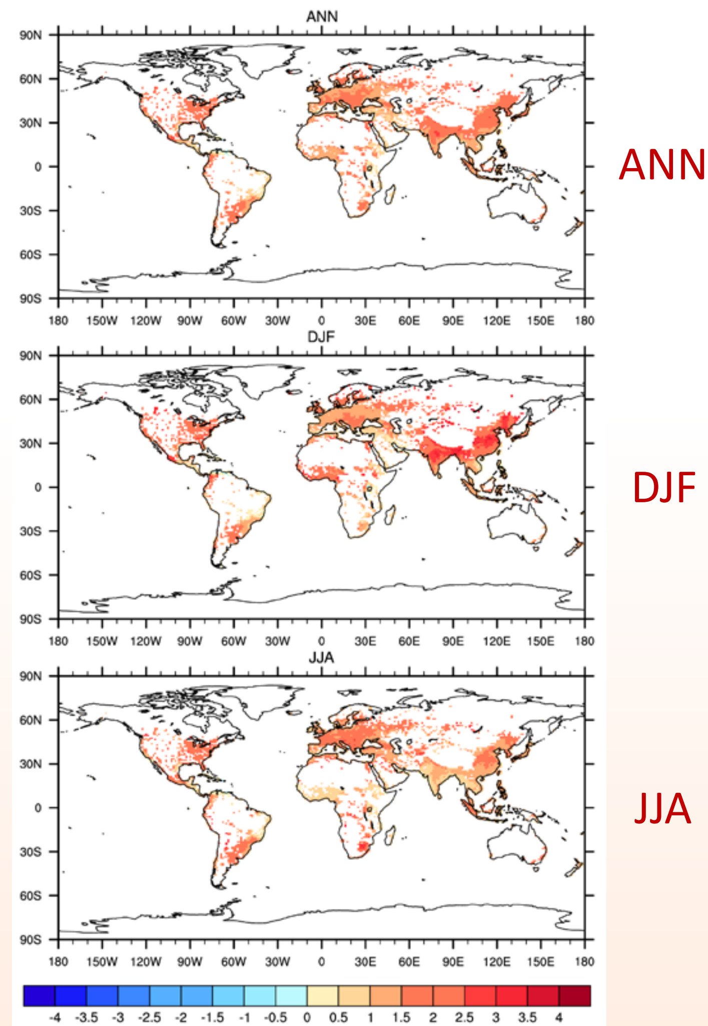
Interior temperature settings (HAC)

Present Day Urban Energy Balance and Heat Island

Annual Average Diurnal Cycle



Average Heat Island (°C)



•Urban area stores more heat during daytime and releases heat at night resulting in nighttime heat island

•Urban has lower latent heat due to impervious surfaces which contributes to heat island

•Spatial/temporal variability in the heat island caused by urban to rural contrasts in energy balance and response of these surfaces to seasonal cycle of climate

SIMMER (System for Integrated Modeling of Metropolitan Extreme Heat Risk) – NASA, Olga Wilhelmi, PI

Research Components

•Determining the combined impact of extreme heat and the characteristics of urban environmental and social systems on human health ("health")

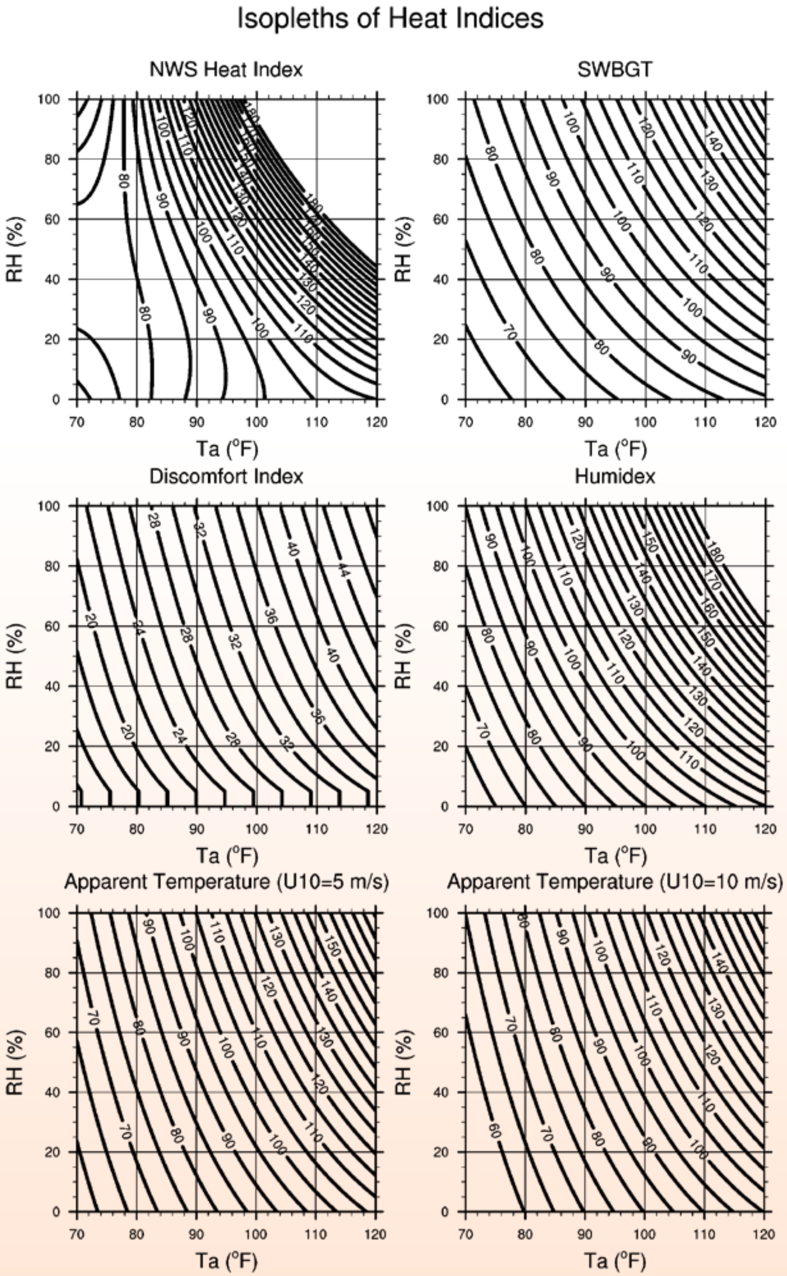
•Characterizing societal vulnerability and the responses (i.e., mitigation and adaptation strategies) ("vulnerability")

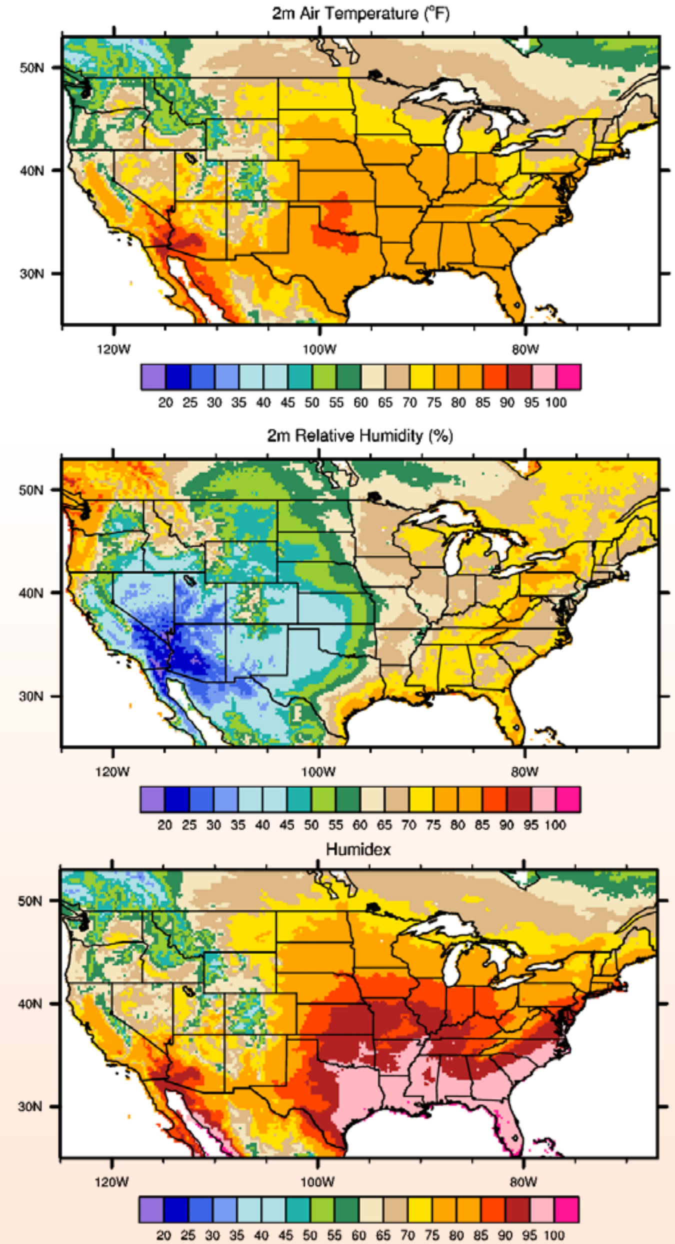
•Improving representation of urban land cover and its accompanying radiative and thermal characteristics at local and regional scales ("land use")

•Characterizing and modeling present and future extreme heat events at local and regional scales ("atmospheric modeling")

Slide courtesy Olga Wilhelmi

Heat Stress Indices

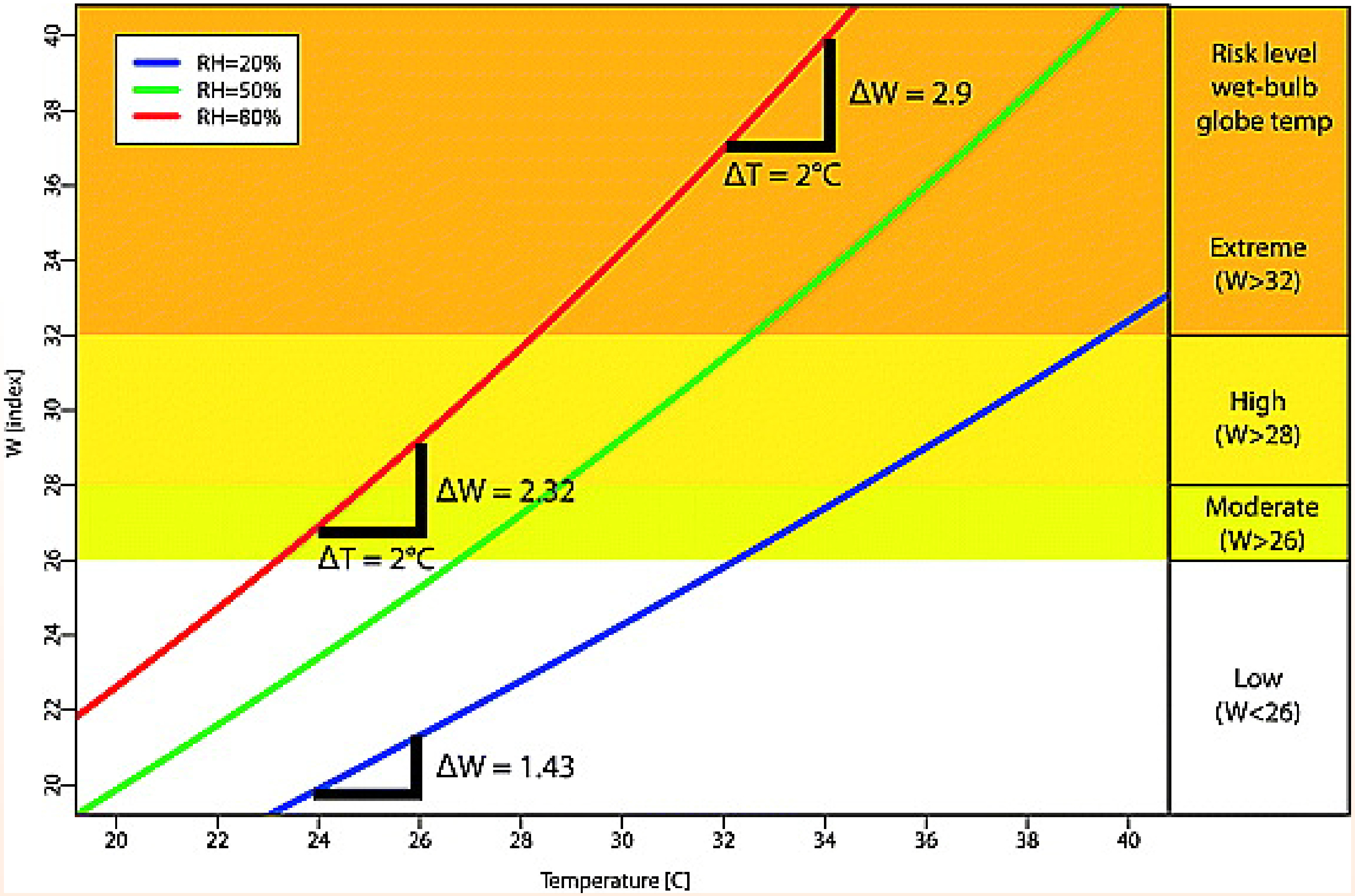




JJA
1986-
2005

Urban and rural heat stress response to climate change

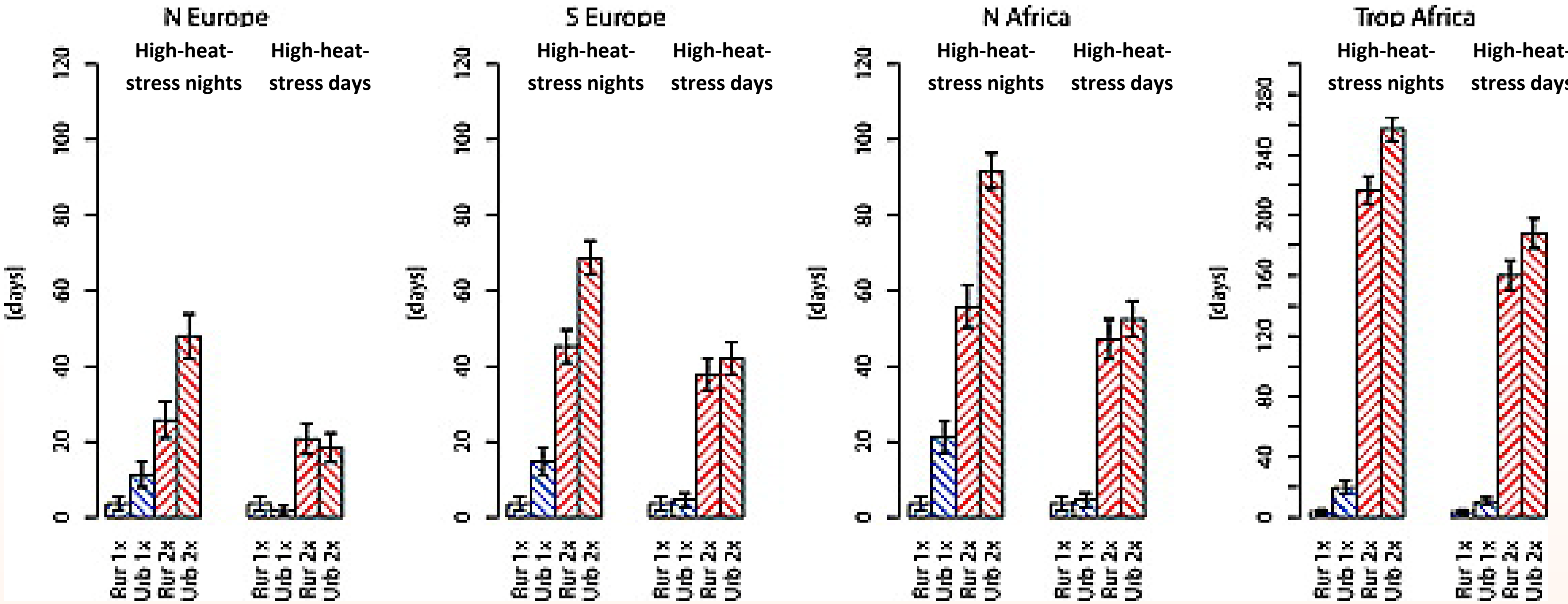
Simplified Wet-bulb Globe Temperature : W = 0.567T+0.393e+3.94
(Willett and Sherwood 2011)



A 2°C warming yields larger W increases if humidity is high and/or temperature is high

Fischer, E.M., K.W. Oleson, and D.M. Lawrence, 2012: Contrasting urban and rural heat stress responses to climate change. GRL, 39, doi10.1029/2011GL050576.

Frequency of rural and urban high-heat-stress nights and days at 1xCO2 and 2xCO2: Number of days per year with Wmin and Wmax exceeding the present-day rural $Wmin99_{1xCO2}$ and $Wmax99_{1xCO2}$



- At 1xCO2, high-heat-stress nights are substantially higher in urban areas
- 2xCO2 leads to substantially more high-heat-stress nights and days
- Despite similar urban-rural response of W to 2xCO2, the frequency increase of urban high-heat-stress nights can substantially exceed that in rural areas, a consequence of the non-linearity in the exceedance frequency.
- Despite weaker overall warming in tropical Africa, occurrence of high-heat-stress nights and days increases strongly, a consequence of small temperature seasonal cycle and low synoptic variability.

Next Generation CLMU

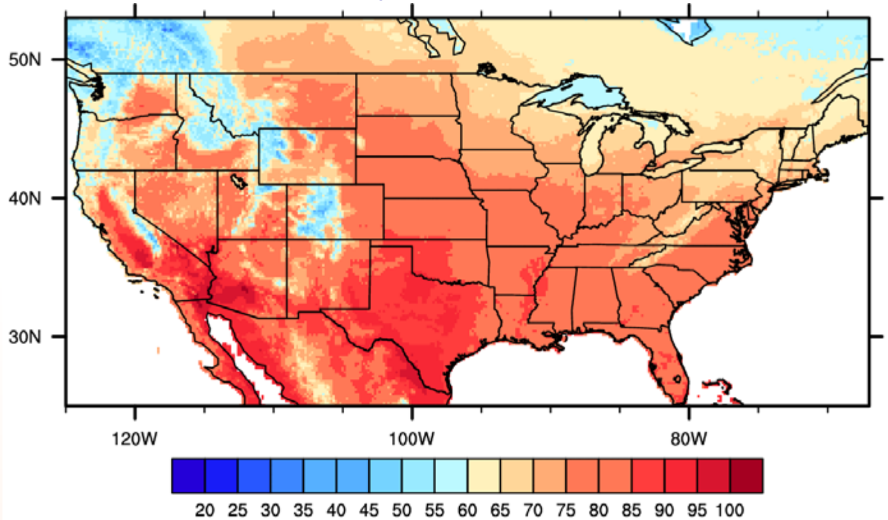
- Improved current day datasets
- Future scenario datasets (transient or time-slice)
- Improved anthropogenic heat fluxes
- Multiple urban density classes

Urban Density Classes

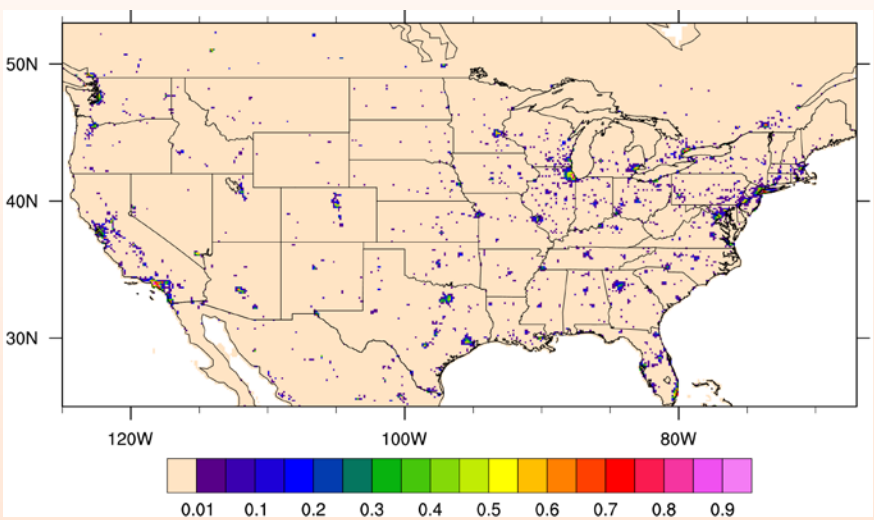
Urban Class	H/W	Building Heights (m)	Pervious Fraction (%)	Population Density (km2)	Typical Building Types
Tall Building District (TBD)	4.6	40-200+	5-15	14,000 – 134,000+	Skyscrapers
High Density (HD) Residential/ Commercial/ Industrial	1.6	17-45	15-30	5,000 – 80,000+	Tall apartments, office bldgs, industry
Medium Density (MD) Residential	1.0	8-17	20-60	1,000 – 7,000	1-3 story apartment bldgs, row houses

Effects of Urban Density on the UHI

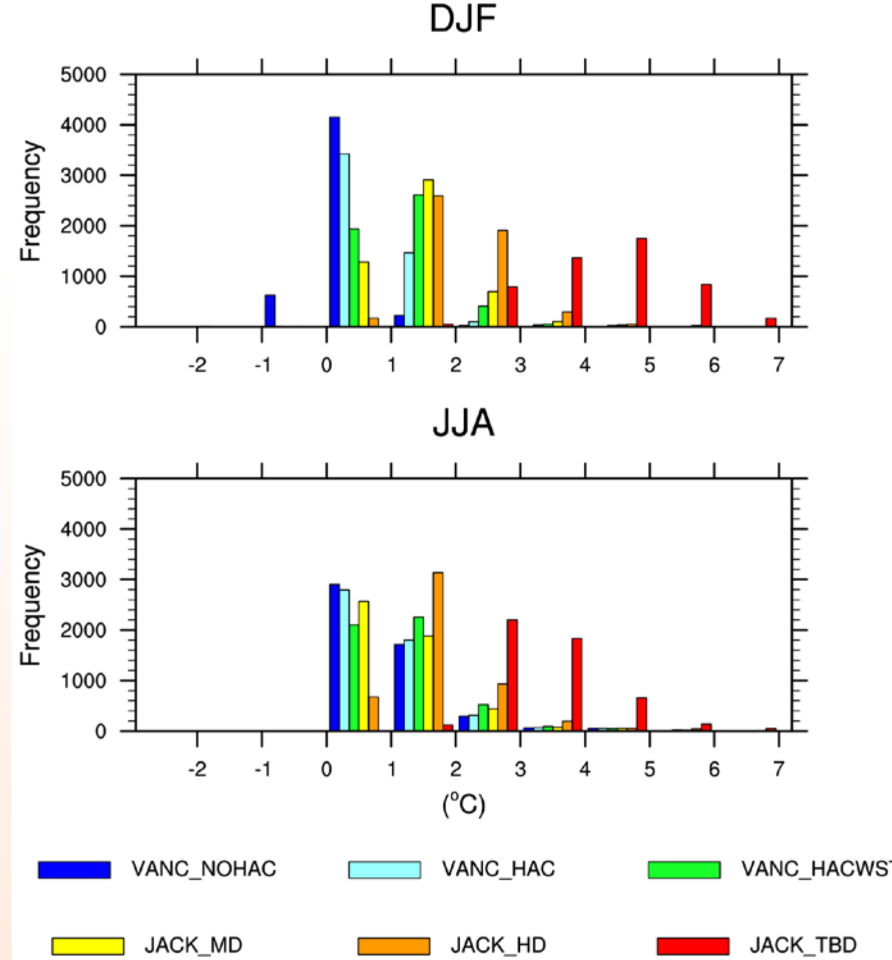
JJA Surface Temperature (°F) 1990-2009



Urban Fraction



Urban – Rural MIN Air Temp



Summary

- Urban climate effects are significant both in terms of means and extremes
- Heat stress indices are one way of making the urban model more useful for urban dwelling populations
- Model improvements are being implemented to make the model more versatile

Thank You

The NESL Mission is:
To advance understanding of weather, climate, atmospheric composition and processes;
To provide facility support to the wider community; and,
To apply the results to benefit society.

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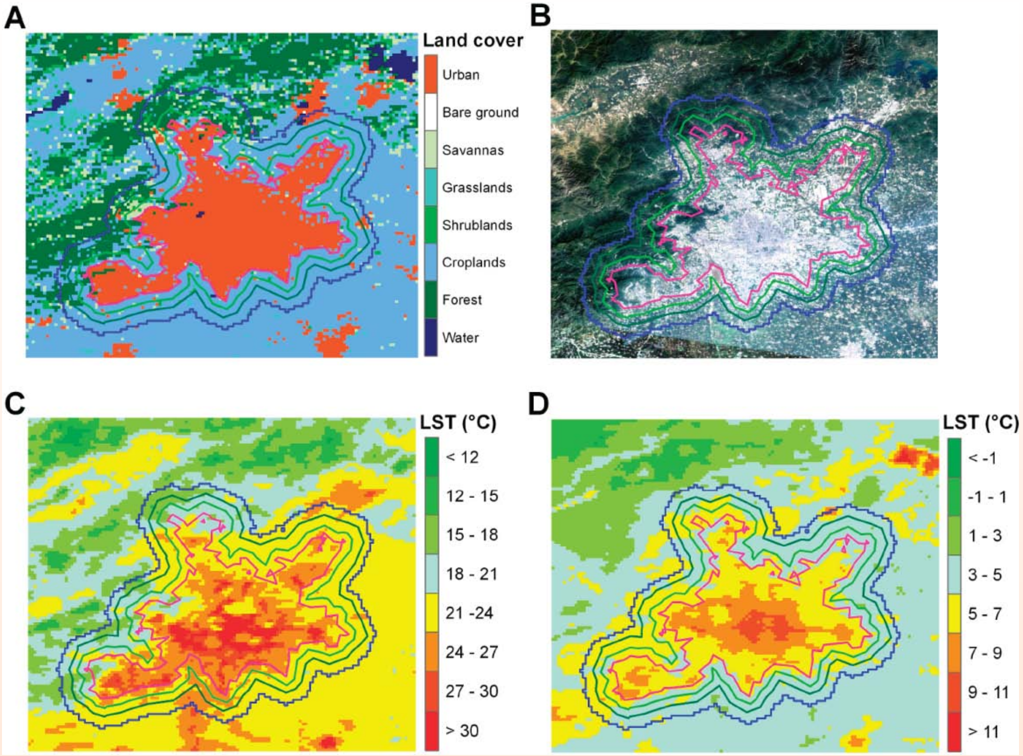
The Urban Heat Island (UHI)

- The UHI is defined as the relative warmth of a city compared to the surrounding "rural" areas.
- Typically quantified as the urban air or surface temperature minus the rural air/surface temperature.
- Average air UHI for a mid-latitude city is 1°-3°C but may reach up to 12°C at night under optimal conditions.



Beijing
(A) MODIS data derived land cover/use
(B) Landsat ETM+ true color image with spatial resolution 30 m × 30 m in August, 2005
(C) annual mean daytime land surface temperature (LST) (°C)
(D) annual mean nighttime LST (°C).

Source: Peng et al, 2012, EST

Model Evaluation

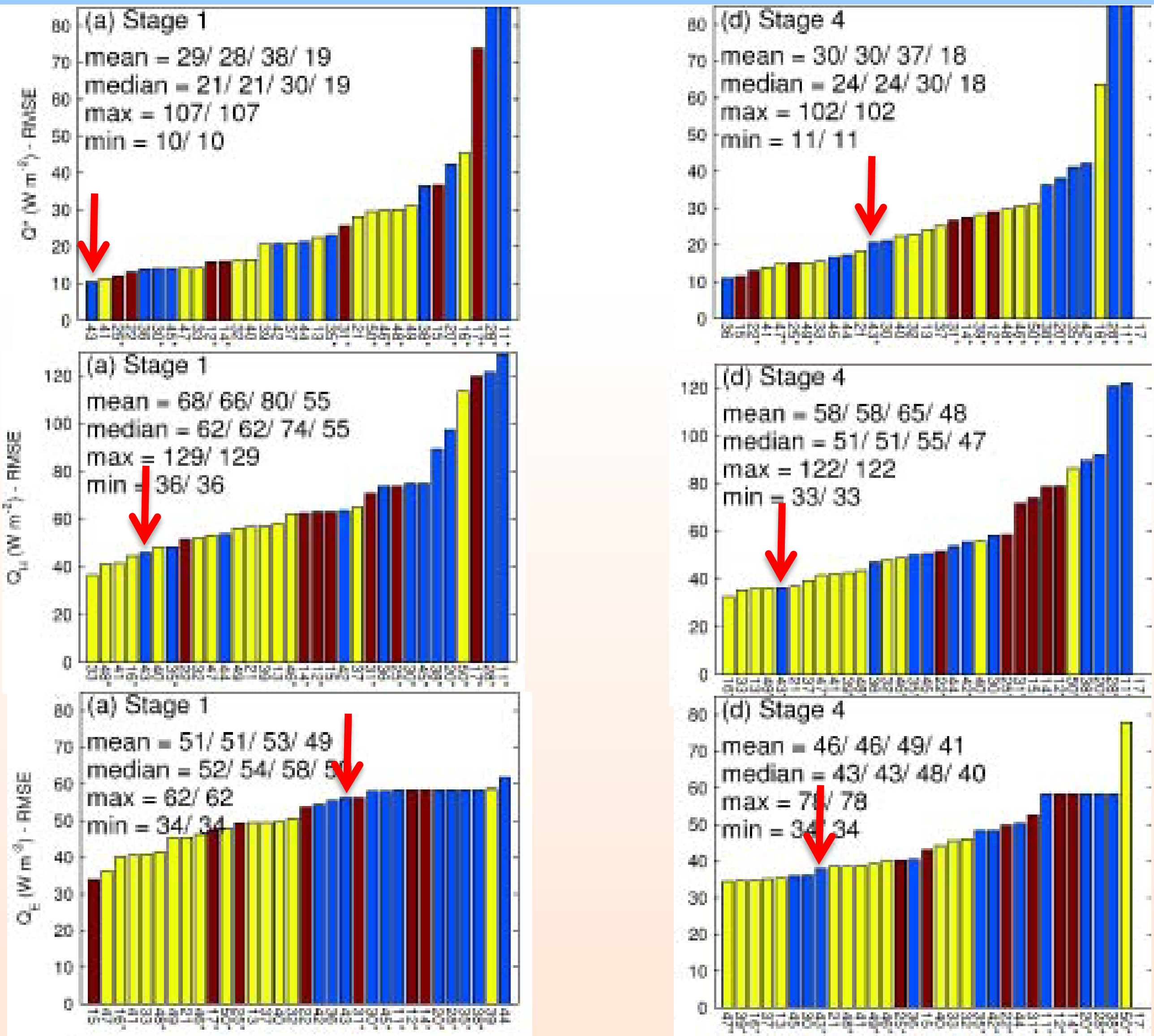
International Urban Energy Balance Model Comparison (Grimmond et al. 2010);

Aug 2003 – Nov 2004 Suburban (Preston) Melbourne, Australia

Net Radiation

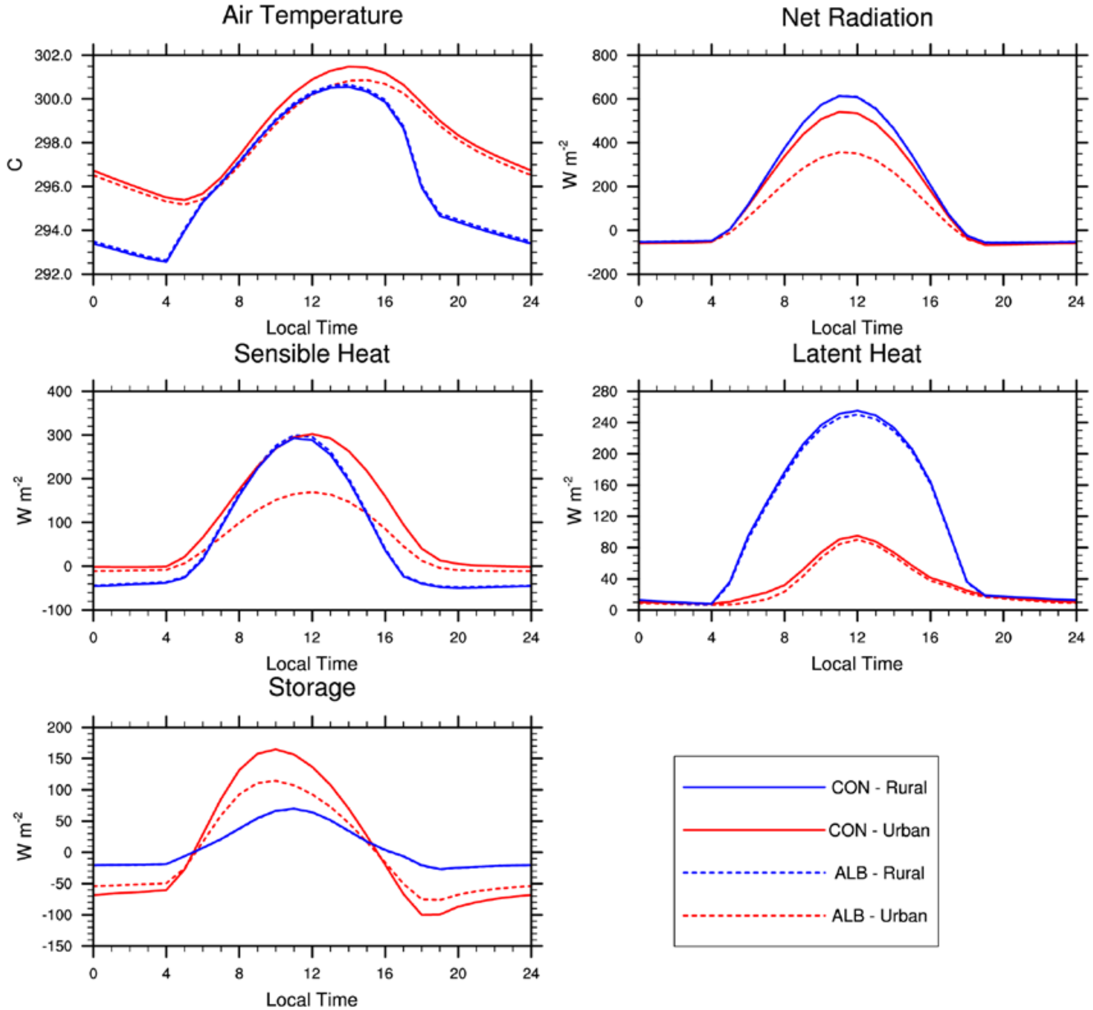
Sensible Heat

Latent Heat



Experiment Results

JJA average diurnal cycle
40.7N, 287.5E



Urban compared to Rural in the control simulation (CON: solid red/blue lines):

- Available energy partitioned into more storage and less latent heat
- Stored heat released at night
- Warmer urban temperatures, particularly at night

Effects of white roofs (ALB-CON: red lines):

- CON Albedo = 0.32
- Reduce daytime available energy, storage, and sensible heat
- Cools daytime temperatures more than nighttime temperatures
- Cooler daily mean temperature (-0.5°C)

Caveats

- Complexity of cities reduced to a single urban landunit
  – Dominant type by area (medium density: 1-3 story apartment buildings, row houses, i.e., 1 to 3 stories, H/W-0.5 to 2.0, significant pervious fraction of canyon floor)
- Coarse spatial resolution
  – Mesoscale features not captured (heat island circulation)
  – Urban and rural areas forced by same climate (no boundary layer heat island or pollution, or precipitation differences)
  – Individual cities generally not resolved, urban areas are highly averaged representation of individual cities
  – Urban fluxes affect only local, not regional/global climate (minimal feedbacks)
- Energy Demand
  – The heating, air conditioning, and wasteheat fluxes in the model are highly simplified representations of these processes (ignore windows, building ventilation, diversity of HAC systems). We also ignore other sources of anthropogenic heat such as those due to internal heat gains (e.g., lighting, appliances, people), traffic, human metabolism, as well as anthropogenic latent heat.

CLMU Publications

- Oleson, K.W., 2012: Contrasts between urban and rural climate in CCSM4 CMIP5 climate change scenarios, *J. Climate*, 25, 1390-1412, doi: 10.1175/JCLI-D-11-00098.1.
- Fischer, E.M., K.W. Oleson, and D.M. Lawrence, 2012: Contrasting urban and rural heat stress responses to climate change, Geophys. Res. Lett., 39, L03705, DOI:10.1029/2011GL050576.
- Grimmond, C.S.B, et al., 2011: Initial results from phase 2 of the international urban energy balance model comparison, *Int. J. Clim.*, 31, 244-272, doi:10.1002/joc.2227.
- Oleson, K.W., G.B. Bonan, J. Feddema, and T. Jackson, 2011: An examination of urban heat island characteristics in a global climate model, *Int. J. Clim.*, 31, 1848-1865, DOI:10.1002/joc.2201.
- Oleson, K.W., G.B. Bonan, and J. Feddema, 2010: The effects of white roofs on urban temperature in a global climate model, *Geophys. Res. Lett.*, 37, L03701, doi:10.1029/2009GL042194.
- Jackson, T.L., J.J. Feddema, K.W. Oleson, G.B. Bonan, and J.T. Bauer, 2010: Parameterization of urban characteristics for global climate modeling, *A. Assoc. Am. Geog.*, 100:4, 848-865, doi:10.1080/00045608.2010.497328.
- Grimmond, C.S.B., et al., 2010: The International Urban Energy Balance Models Comparison Project: first results from phase I, *J. Appl. Meteorol. Clim.*, 49, 1268-1292, doi: 10.1175/2010JAMC2354.1.
- Oleson, K.W., G.B. Bonan, J. Feddema, M. Vertenstein, and C.S.B. Grimmond, 2008a: An urban parameterization for a global climate model. 1. Formulation and evaluation for two cities, *J. Appl. Meteorol. Clim.*, 47, 1038-1060.
- Oleson, K.W., G.B. Bonan, J. Feddema, and M. Vertenstein, 2008b: An urban parameterization for a global climate model. 2. Sensitivity to input parameters and the simulated urban heat island in offline simulations, *J. Appl. Meteorol. Clim.*, 47, 1061-1076.