Recent Developments and Research with the Community Land Model Urban (CLMU)

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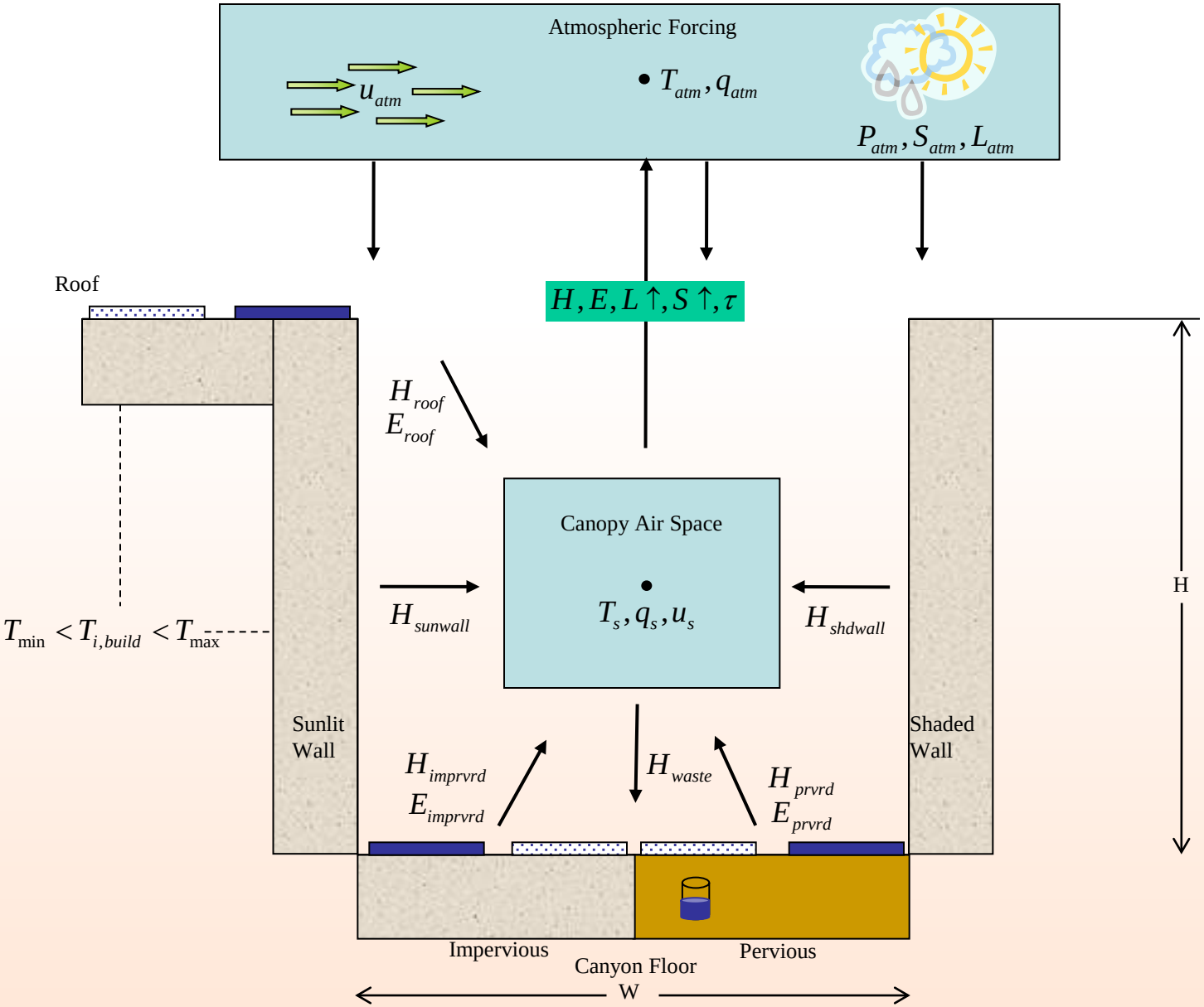
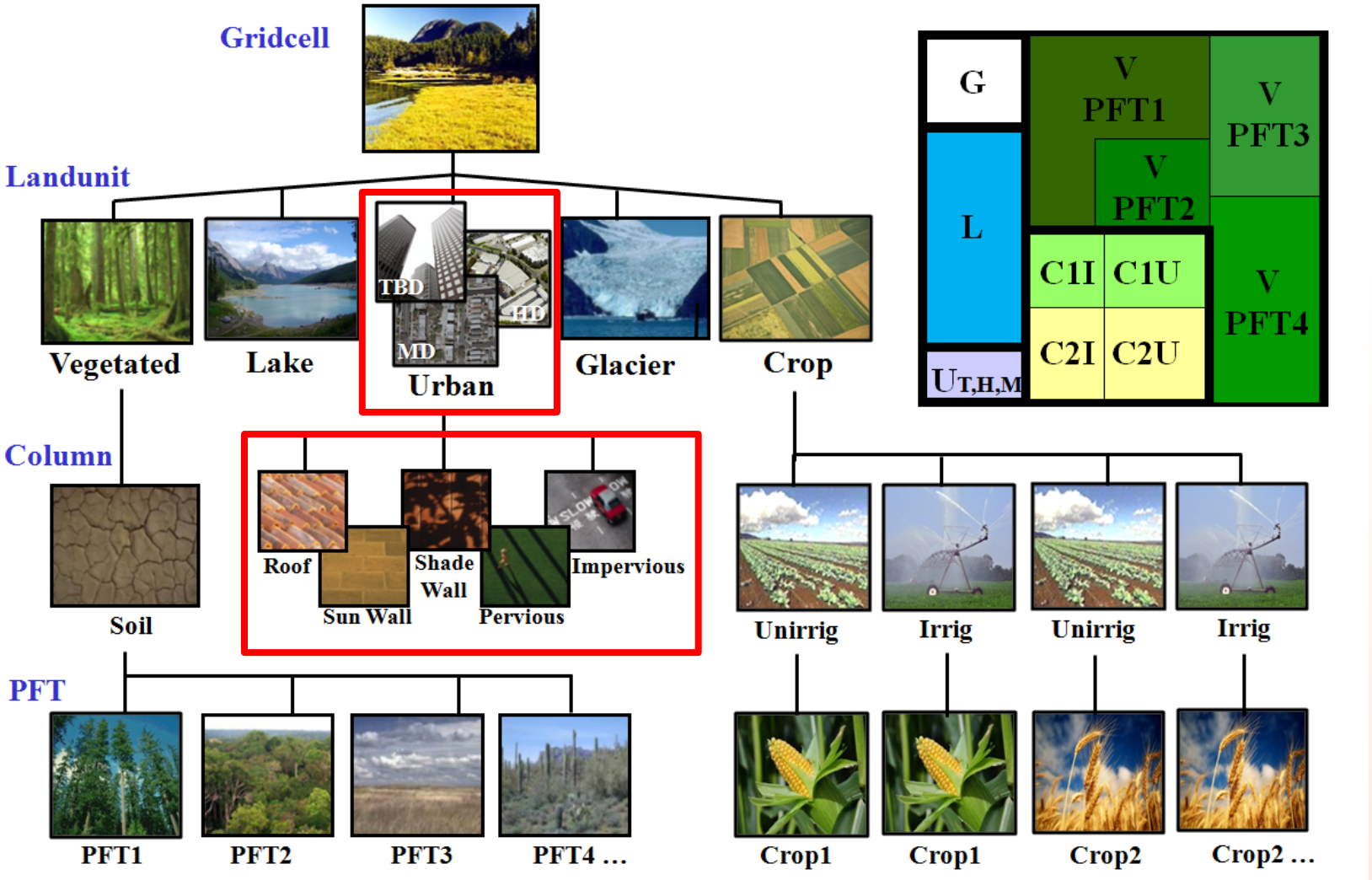
CLMU


Atmospheric Forcing
u_{atm}
T_{atm}, q_{atm}
$P_{atm}, S_{atm}, L_{atm}$
$H, E, L\uparrow, S\uparrow, \tau$
Roof
H_{roof}
E_{roof}
Canopy Air Space
T_s, q_s, u_s
$H_{sunwall}$
$H_{shdwall}$
$T_{min} < T_{i,build} < T_{max}$
Sunlit Wall
Shaded Wall
H
$H_{imprvrd}$
$E_{imprvrd}$
H_{waste}
H_{prvrd}
E_{prvrd}
Impervious
Pervious
Canyon Floor
W

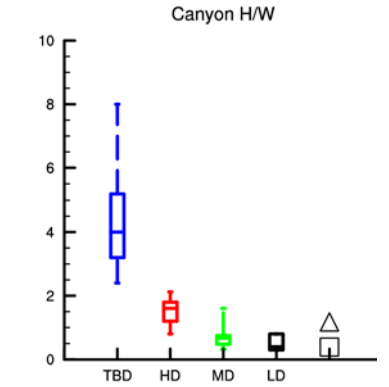
Outline

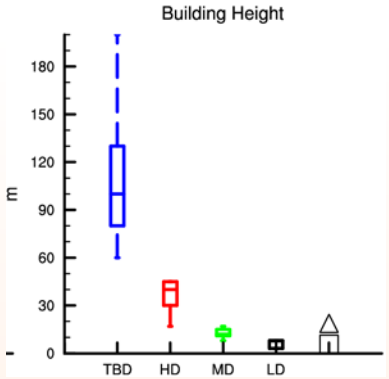
- Developments
  - Multiple urban landunits within each gridcell
  - Improved modeling of anthropogenic heat due to space heating and air conditioning processes
  - New diagnostic module of heat/cold stress indices
- Research
  - Exploring representations of heat/cold stress in CLM

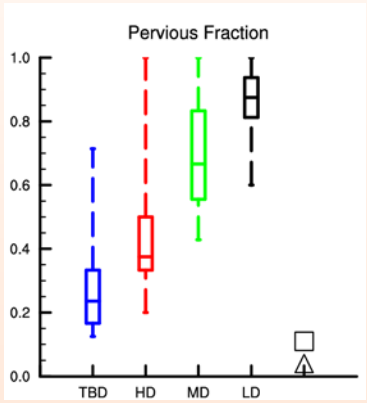
Dominant Urban Landunit Expanded to TBD, HD, MD

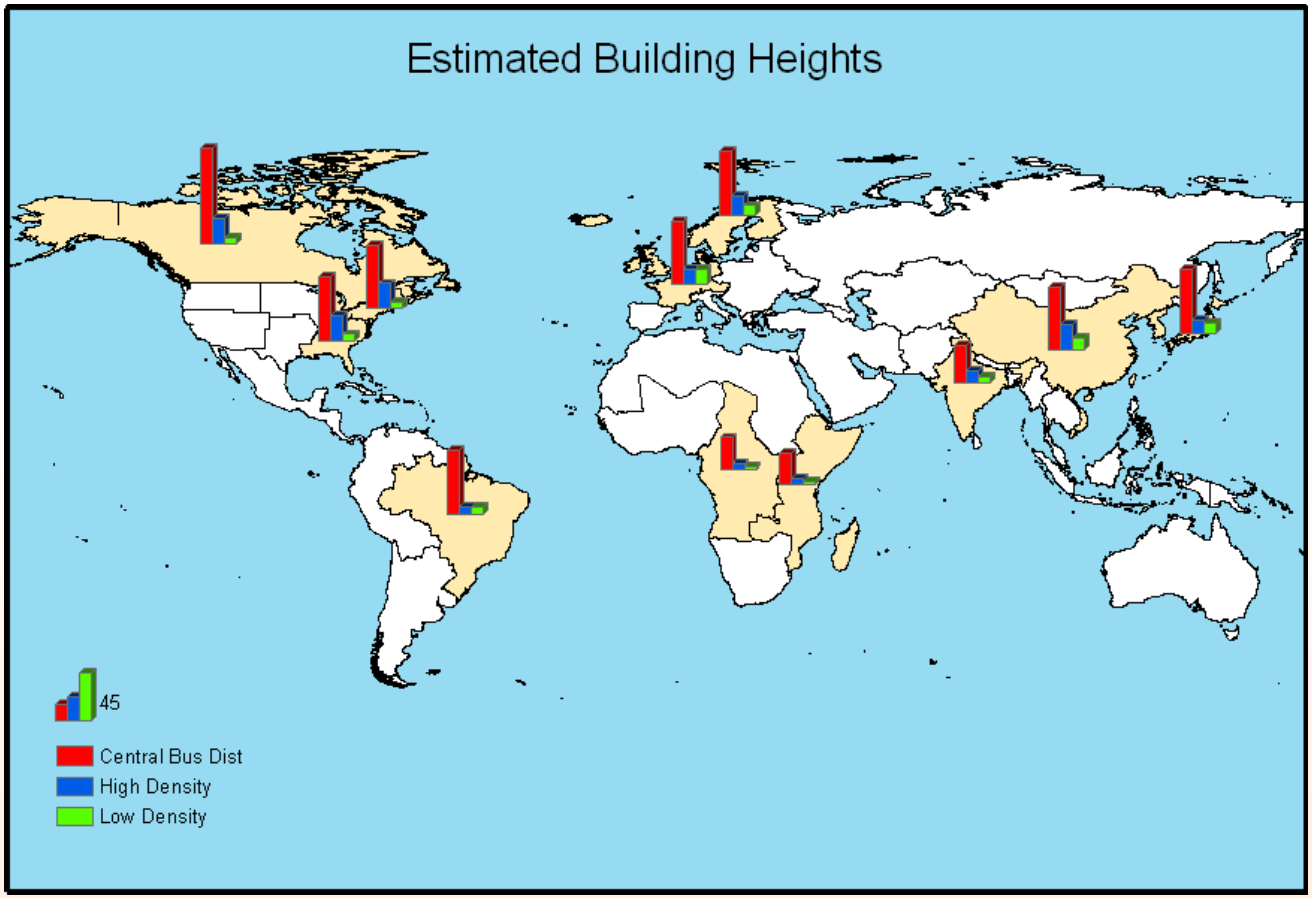


TBD, HD, MD Properties





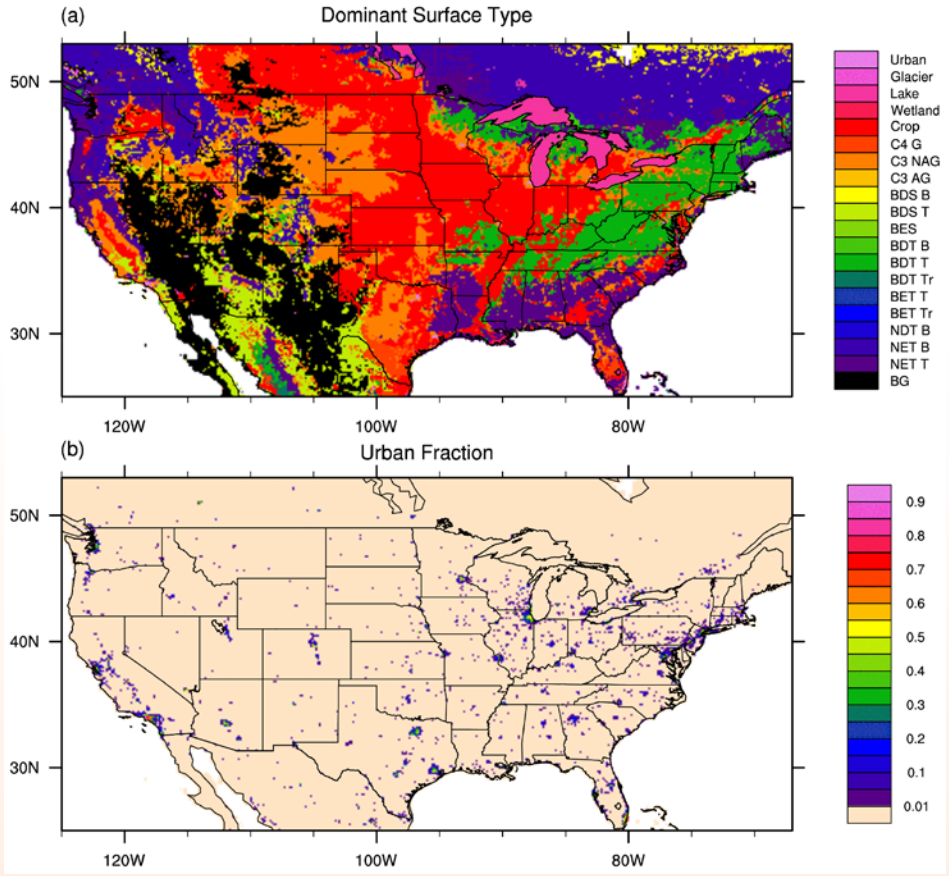




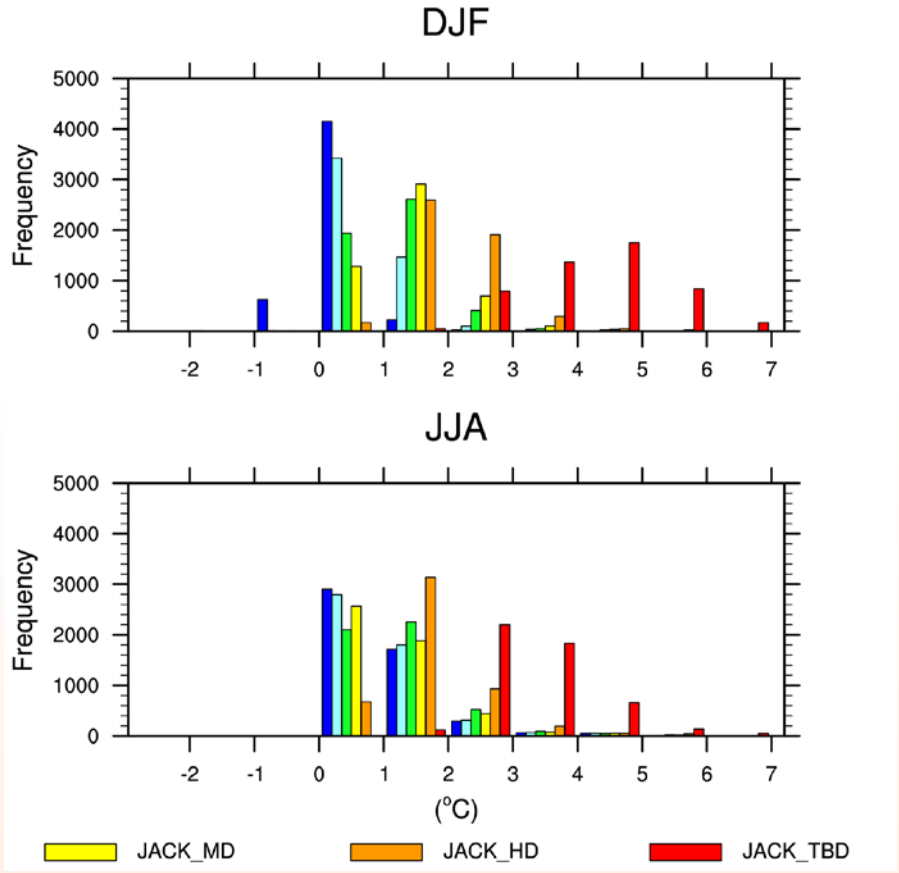
Jackson et al. (2010)

Effects of Urban Density on Urban Heat Island

CLM forced by NLDAS (1990-2009)



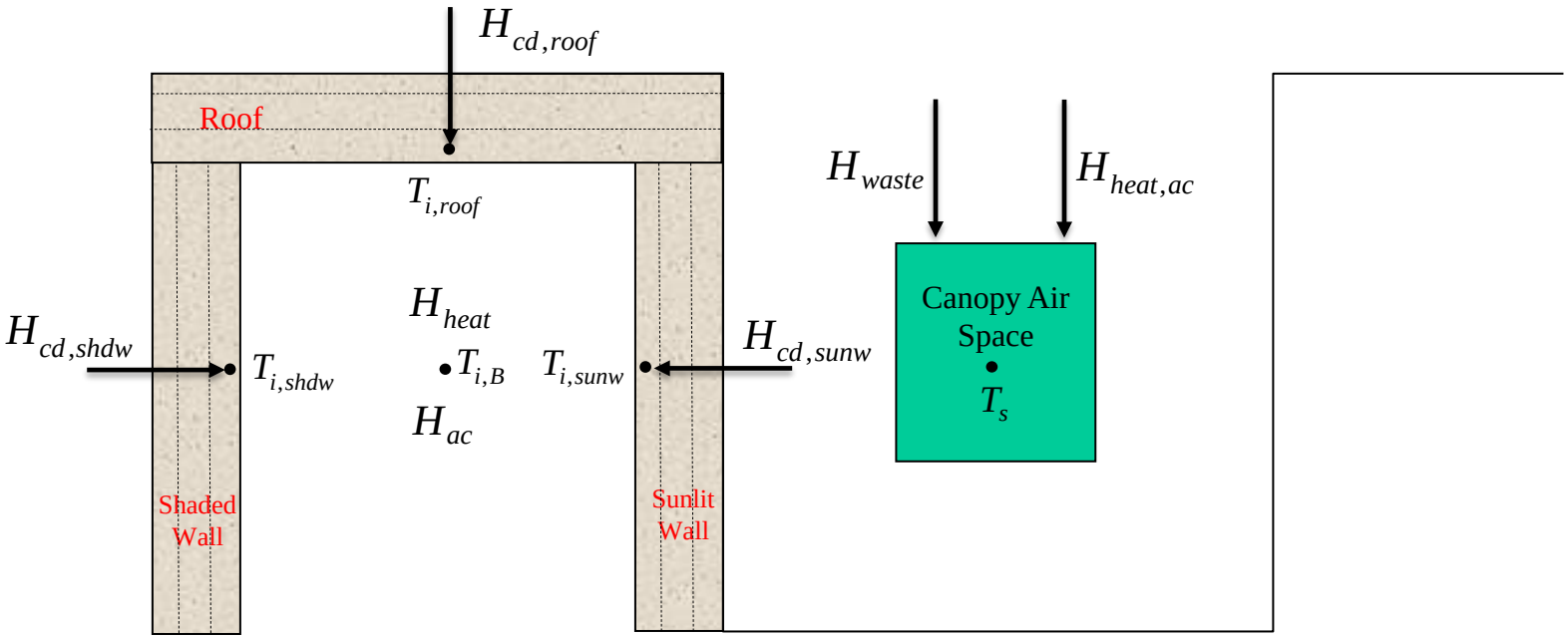
Urban – Rural MIN Air Temp



Average Urban – Rural MIN Air Temp (°C)

	JACK_MD	JACK_HD	JACK_TBD
DJF	1.4	2.0	4.1
JJA	1.2	1.7	3.3

Old Building Energy Parameterization in CLMU



$$T_{i,B} = f\left(T_{i,shdw}, T_{i,sunw}, T_{i,roof}\right)$$

$$T_{\min} < T_{i,B} < T_{\max}$$

$$H_{waste} = f\left(H_{heat}, H_{ac}\right)$$

$$H_{heat,ac} = H_{ac}$$

$$H_{heat} = \sum_{sfc} \frac{\lambda}{\Delta z}\left(T_{i,sfc} - T_{i,B}\right) \qquad T_{i,B} < T_{\min}$$

$$H_{ac} = \sum_{sfc} \frac{\lambda}{\Delta z}\left(T_{i,sfc} - T_{i,B}\right) \qquad T_{i,B} > T_{\max}$$

Year 2005 global building heating/cooling energy demand (TW)

Estimated (IEA and UNEP)	3.1
CLMU	9.0

Objectives

- Develop a more realistic building energy parameterization to yield a "true" internal building air temperature suitable for assessing indoor thermal comfort.

- Get closer to the global number (tuning but guided by observational data and common sense)

Factors influencing space heating/air conditioning

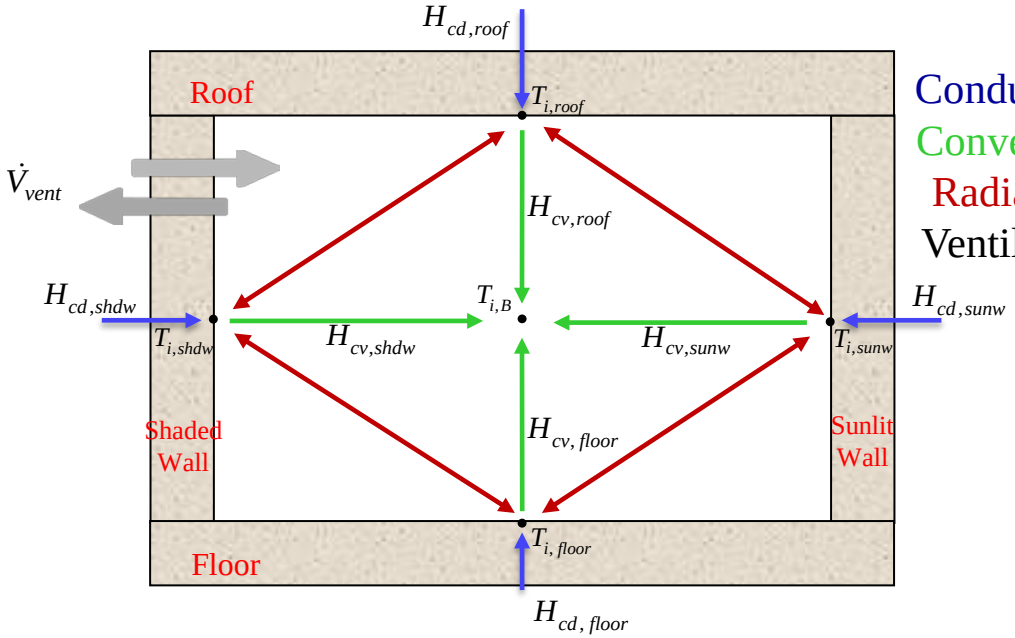
- New building energy parameterization

- Heat transfer through roofs/walls (thermal properties) – Feddema V2 urban surface dataset

- Refined building thermostat settings

- More realistic wasteheat factors (Sivak 2013, ERL)

CLMU Building Energy Model



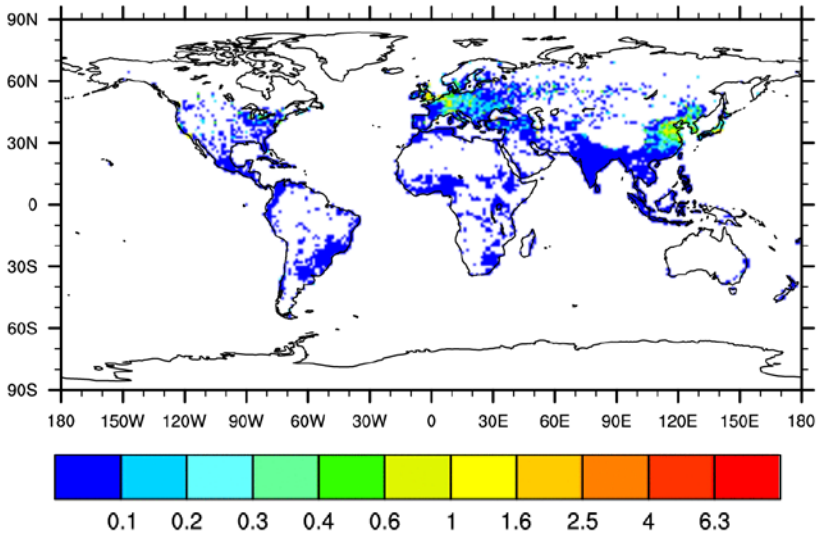
Conduction
Convection
Radiation
Ventilation

Year 2005 global building heating/cooling energy demand (TW)

Estimated (IEA and UNEP)	3.1
CLMU Version 1	9.0
CLMU Version 2	3.0

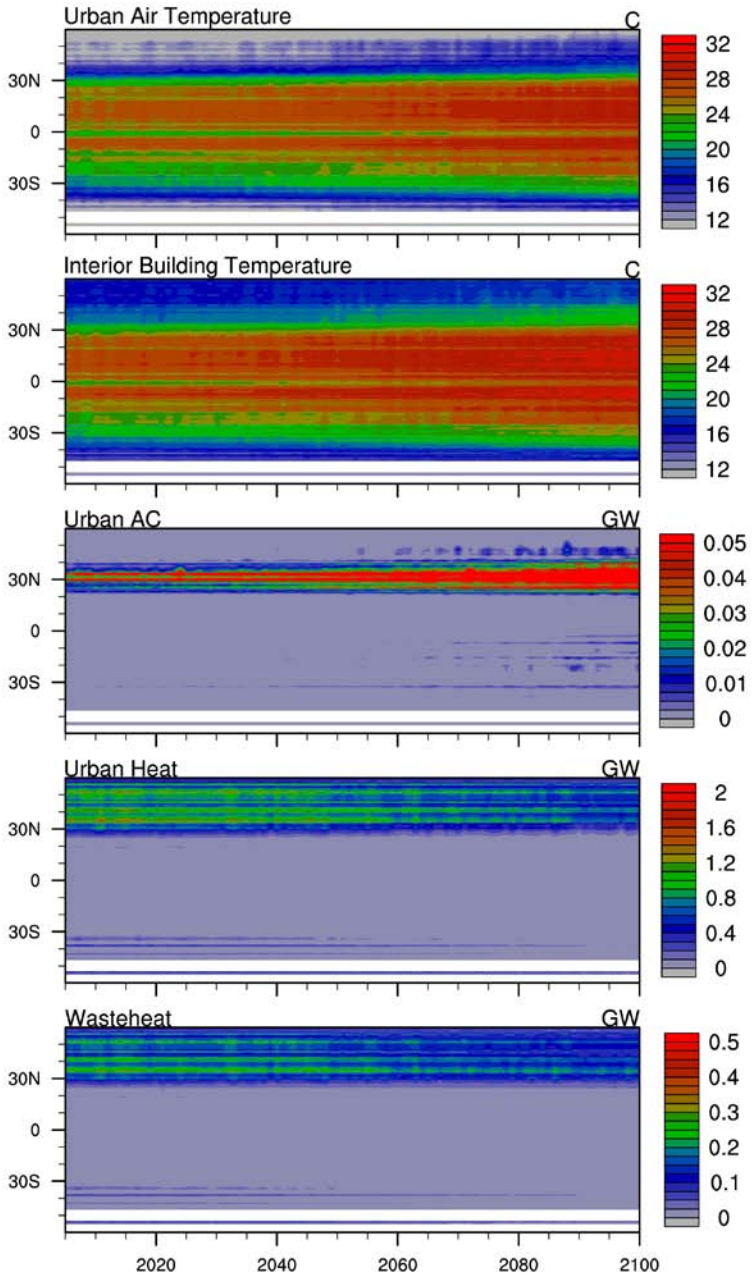
Year 2005 Anthropogenic Heat Flux (W m^{-2})

CLMU V2

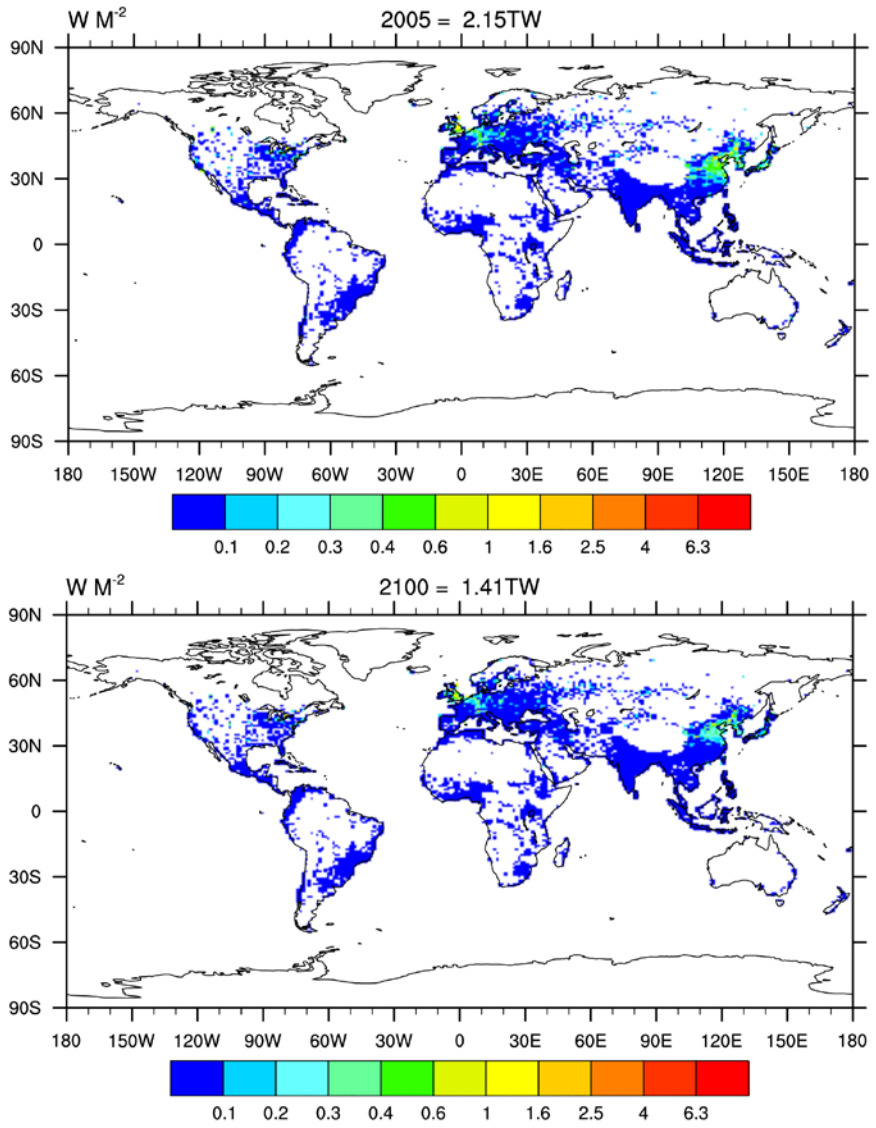


CLM Forced by CCSM4 RCP8.5 Atmosphere

Zonal Annual Mean Time Series



Total Anthropogenic Heat Flux (W m^{-2})



Exploring Human Heat Stress in Climate Models

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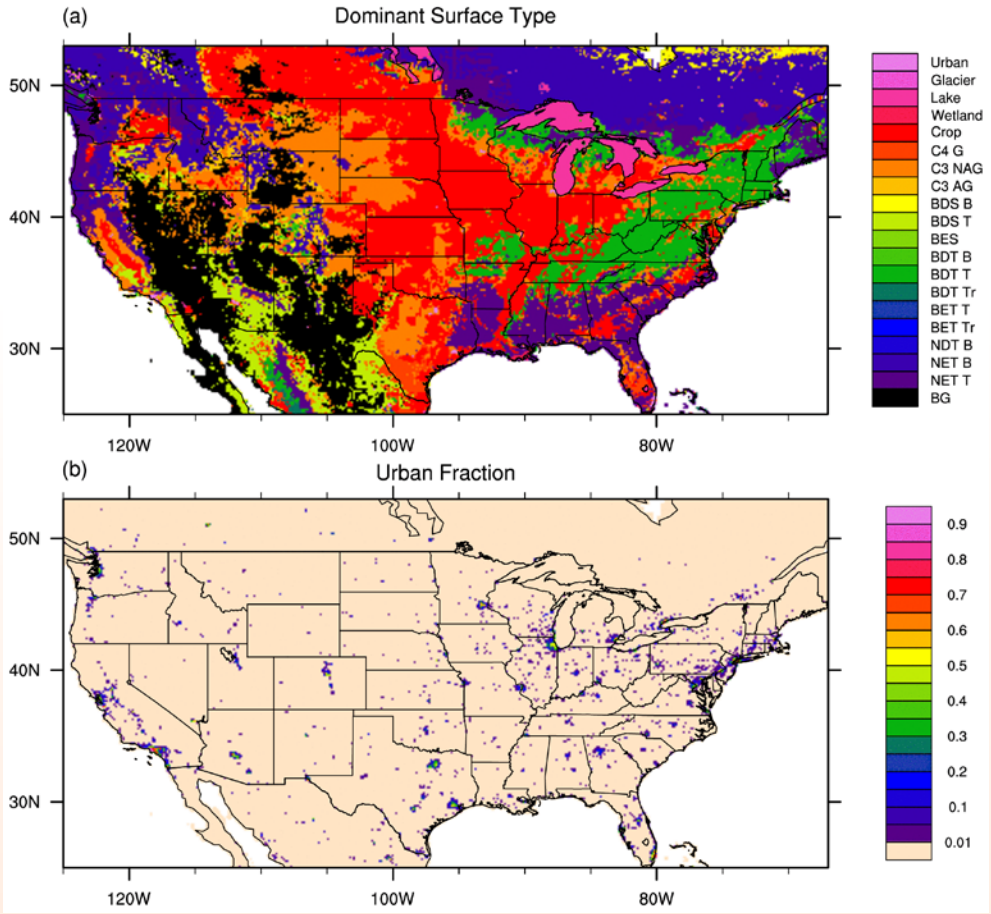
[1]NESL, Climate and Global Dynamics Division
[2]RAL, Climate Science & Applications Program
[3]RAL, Hydrometerological Applications Program
[4]University of Kansas, Department of Geography
[5]University of New Hampshire

Simulations of heat stress with CLM



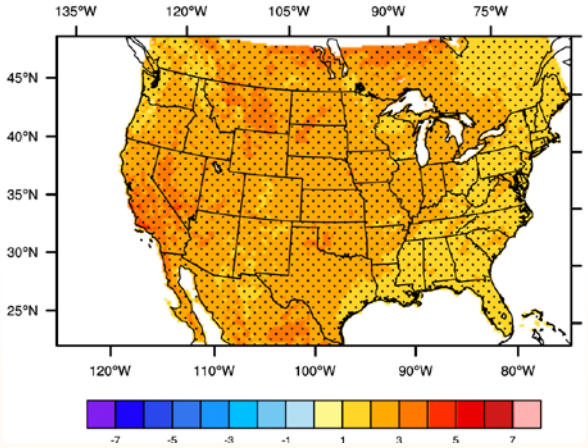
- WRF used to downscale a CCSM4 20th century and a RCP8.5 ensemble member to provide a consistent set of atmospheric forcing variables
- 1/8th degree simulations for 1986-2005 and 2046-2065
- Diagnostic heat stress indices:
  - NWS Heat Index
  - Apparent Temperature
  - Simplified Wet Bulb Globe Temperature
  - Humidex
  - Discomfort Index

Oleson et al. 2013, Climatic Change

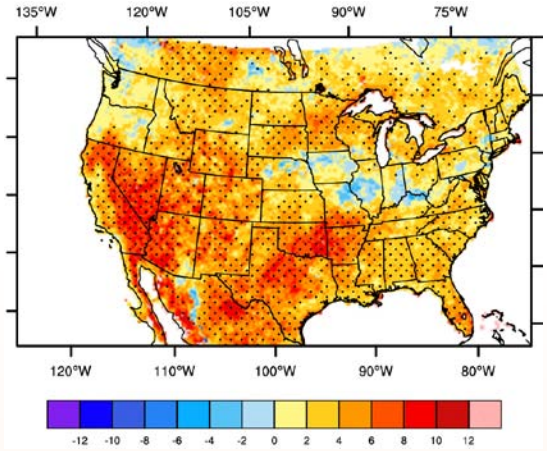
2046-2065 – 1986-2005 JJA Heatwaves

Air Temperature

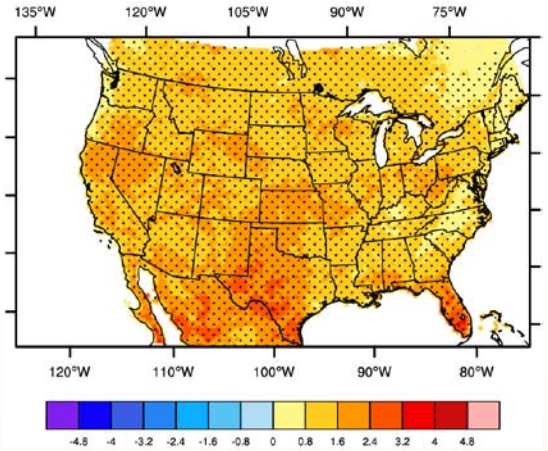
Intensity (°C)



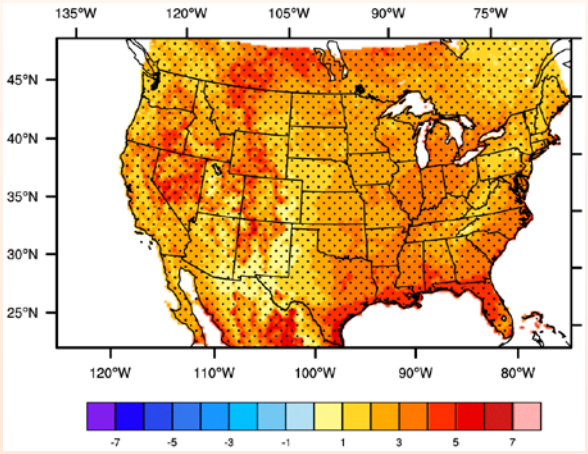
Duration (days/event)

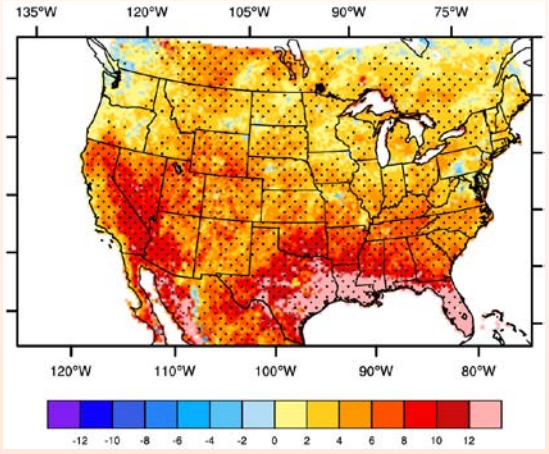


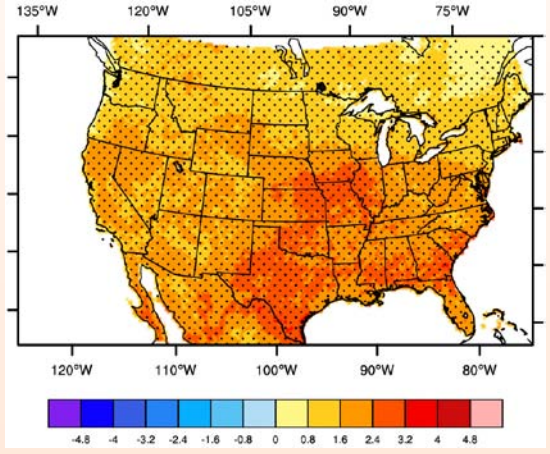
Frequency (events/JJA)



NWS Heat Index







Heatwaves defined following Meehl and Tebaldi (2004) and Gao et al. (2012).

HumanIndexMod.F90
Developed by Jonathan Buzan, UNH

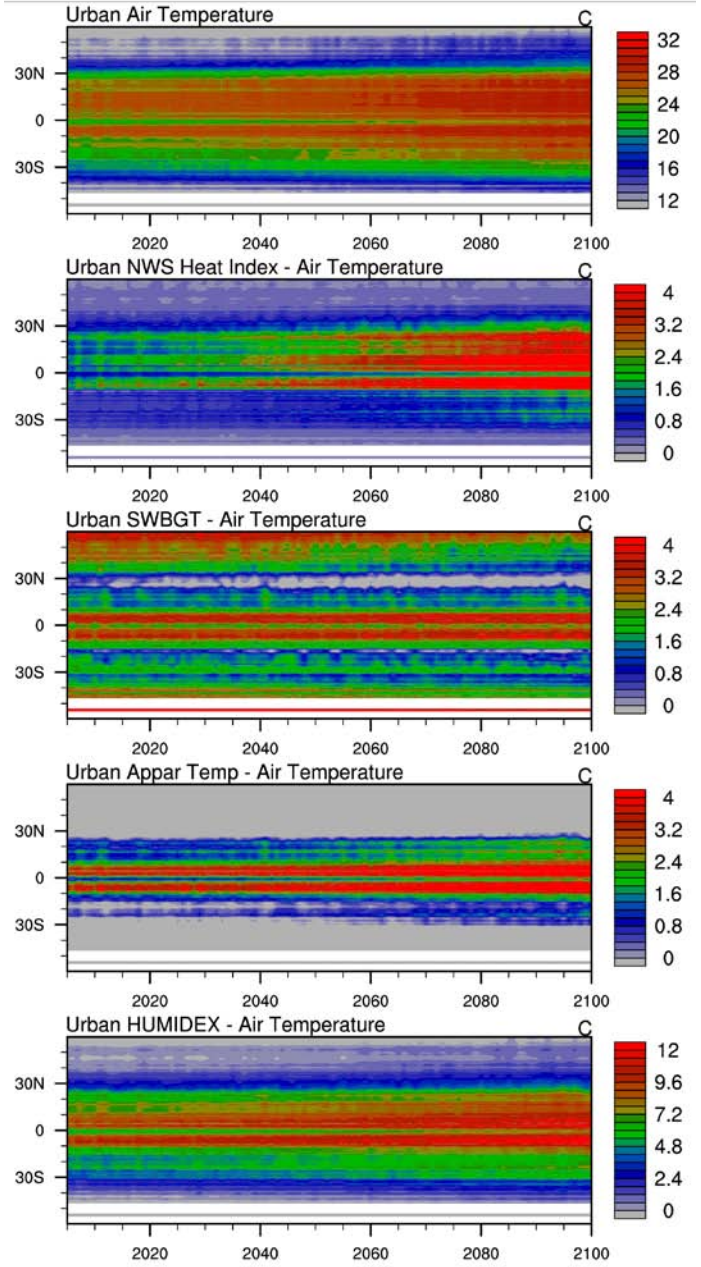
Single Module with 11 Subroutines
Calculates 12 Metrics
Requires: T, P, Q

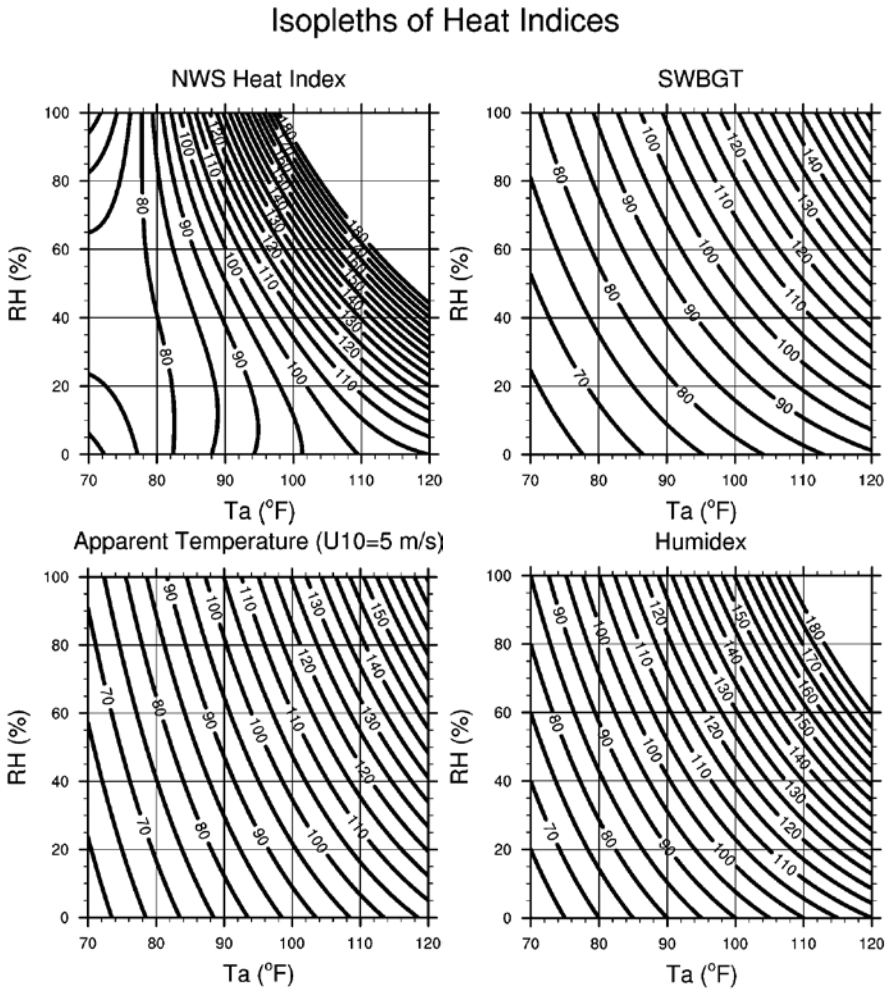
- NWS Heat Index
- Apparent Temperature
- Simplified WBGT
- Humidex
- Discomfort Index

- Potential WB Temperature
- Equivalent Pot. Temperature
- Wet Bulb Temperature
- Temp. Hum. Index Comfort
- Temp. Hum. Index Physiology
- Swamp Cooler Efficiency 80%
- Swamp Cooler Efficiency 65%

CLM Forced by CCSM4 RCP8.5 Atmosphere

Zonal Annual Mean Time Series





Average number of summer days in each heat stress index category
Daily Maximum
Houston - Medium Density Urban

NWS Heat Index (Smith et al. 2013)

Category	Caution	Extreme Caution	Danger	Extreme Danger
Threshold	> 80°F (26.7°C)	>90°F (32.2°C)	>105°F (40.6°C)	>130°F (54.4°C)
Present-day Urban	4.8	81.6	5.3	0.0
Mid-century Urban	1.2	38.4	52.1	1 day/4 years

Humidex (Masterson and Richardson 1979)

Category	Some Discomfort	Great Discomfort	Dangerous	Imminent Heat Stroke
Threshold	≥30°C	≥40°C	≥46°C	≥54°C
Present-day Urban	15.8	73.2	2.5	0.0
Mid-century Urban	4.0	60.3	27.4	1 day/5 years

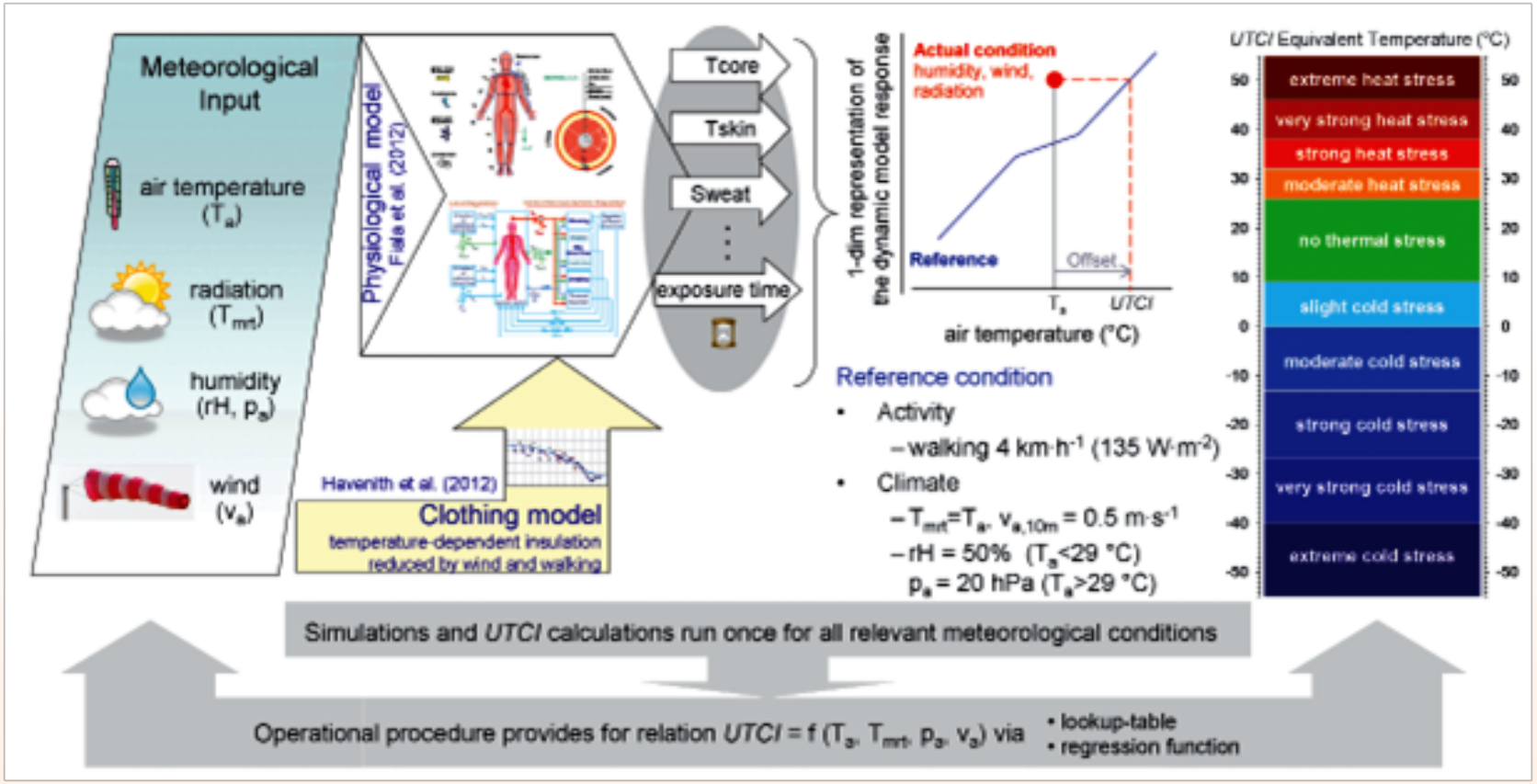
Discomfort Index (Epstein and Moran 2006)

Category	No Heat Stress	Mild Sensation of Heat	Moderately Heavy Heat Load	Severe Heat Load
Threshold	< 22 units	≥22 units	>24 units	> 28 units
Present-day Urban	0.2	1.1	10.1	80.5
Mid-century Urban	0.0	0.1	2.8	89.0

Oleson et al. 2013, Climatic Change

Humans in CESM/CLM

Universal Thermal Climate Index (UTCI; utci.org)



Bröde et al. 2012

Thermal strain index calculated by PCA as a single dimensional representation of the multidimensional dynamic response of the physiological model.
UTCI equivalent temperature for given combination of wind, radiation, humidity and air temperature is defined as the air temperature in the reference environment, which produces the same strain index value.

CLMU Future Work

- Future urban – dynamic urban landunits – transitions between urban density types; how will cities change – more energy efficient buildings and urban sprawl versus densification
- Incorporation of UTCI
- Building energy – NREL Collaboration: EnergyPlus/BeOpt -> Reduced-Order Model -> CLMU
- Suburban model (low density (LD) urban)
- Integrated urban vegetation model (transpiration, shading of building by trees)
- Irrigation for pervious fraction

Thank You

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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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