Effects of future changes in urban areas on urban climate

Keith Oleson
TSS, CGD, NCAR

Brian Kauffman, Johan Feddema, Trish Jackson, Peter Lawrence

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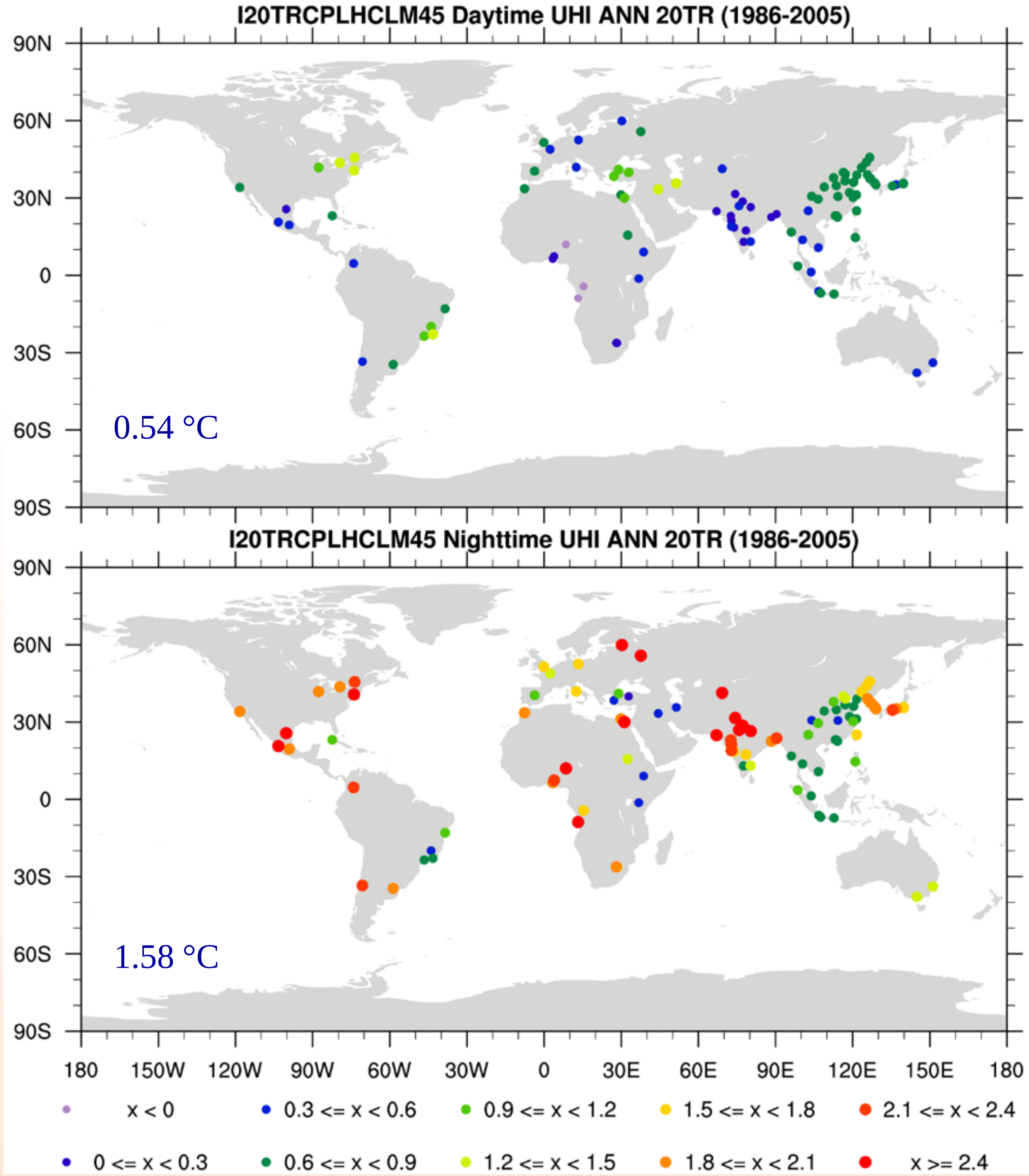
Annual average Urban Heat Island (1986-2005) (°C)

100 most populous settlements (GRUMP v1)



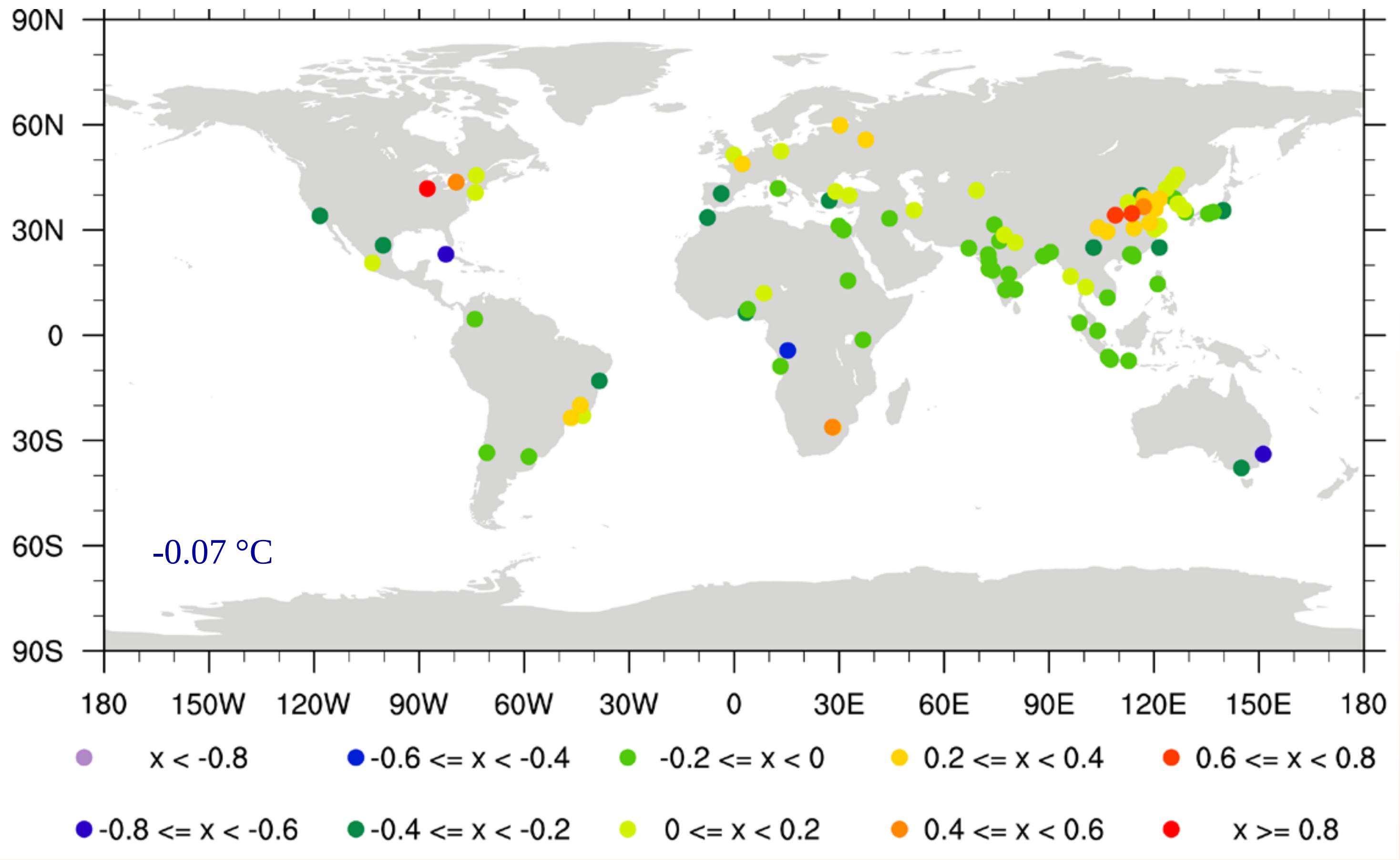
Spatial (and seasonal) variability controlled by urban properties (morphological, thermal, radiative), mix of density types (tall building district, high and medium density), rural landcover, and climate.

Model evaluated by comparing to observations at individual sites and with remote sensing.

Oleson et al. 2008, 2010, 2011, 2012, 2013, Zhao et al. 2014, Buzan et al. 2015, Demuzere et al. 2013, Fischer et al. 2012

Future changes in JJA nighttime UHI

CESM1 w BGC, RCP8.5, (2080-2099) – (1986-2005), °C



Oleson 2012

How will urban areas change in the future?

- In our modeling to date, urban areas are static in time; urban thermal, radiative, and morphological properties do not change in the future nor does urban extent.

- One goal of our EaSM2 project (Linking Human and Earth System Models to Assess Regional Impacts and Adaption in Urban Systems and their Hinterlands; B. O'Neill, PI) is to develop tools (THESIS) to allow us to project future changes in urban extent and properties.

- This will eventually allow us to examine the relative roles of urban development and climate change in determining future changes in urban climate, human heat stress, and building energy, and then link these to tools for impact assessment.

- Here, I will show a result from a future urban development scenario developed without the THESIS tool and one example generated from the tool.

Toolbox for Human-Earth System Integration & Scaling (THESIS)

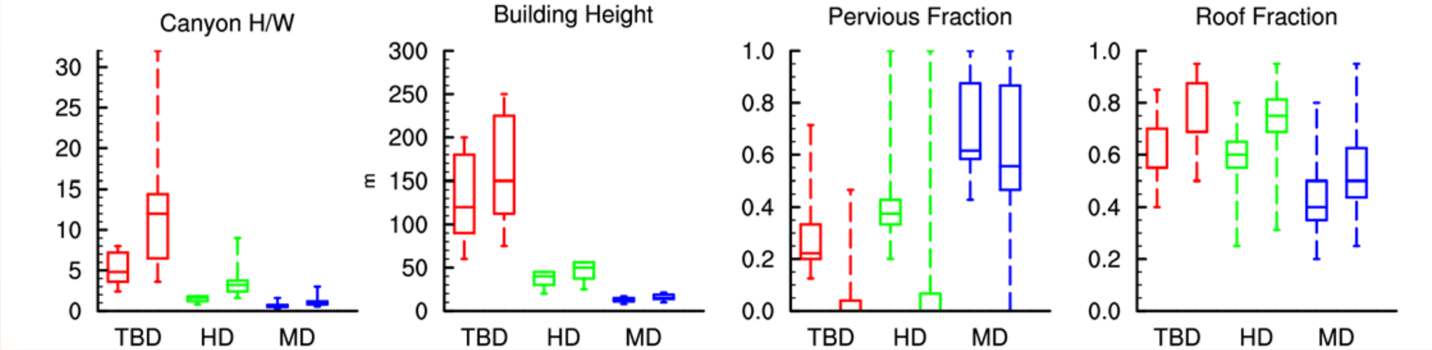
How will urban areas change in the future?

Increase urban density to accommodate growth in urban dwellers and population

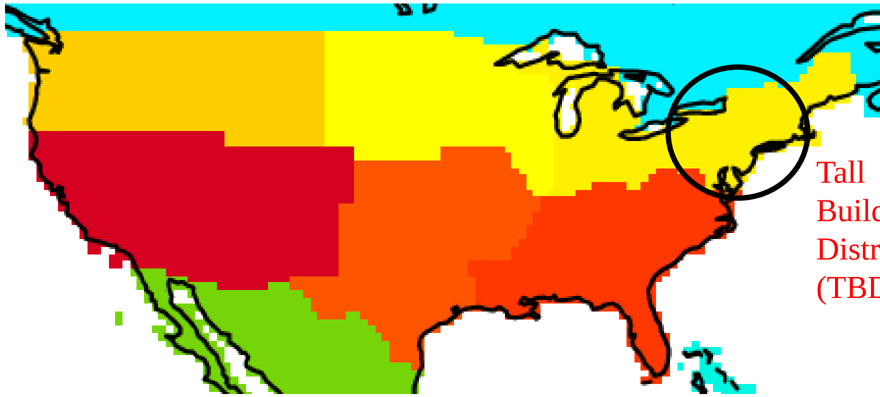
To represent an increase in urban density, we arbitrarily increase roof (building) fraction by 25% for all density types and assume this is preferentially accommodated by a decrease in the fraction of pervious canyon floor. Building height is increased by 25%.

Changes in Global Urban Properties

Morphological – Urban Density

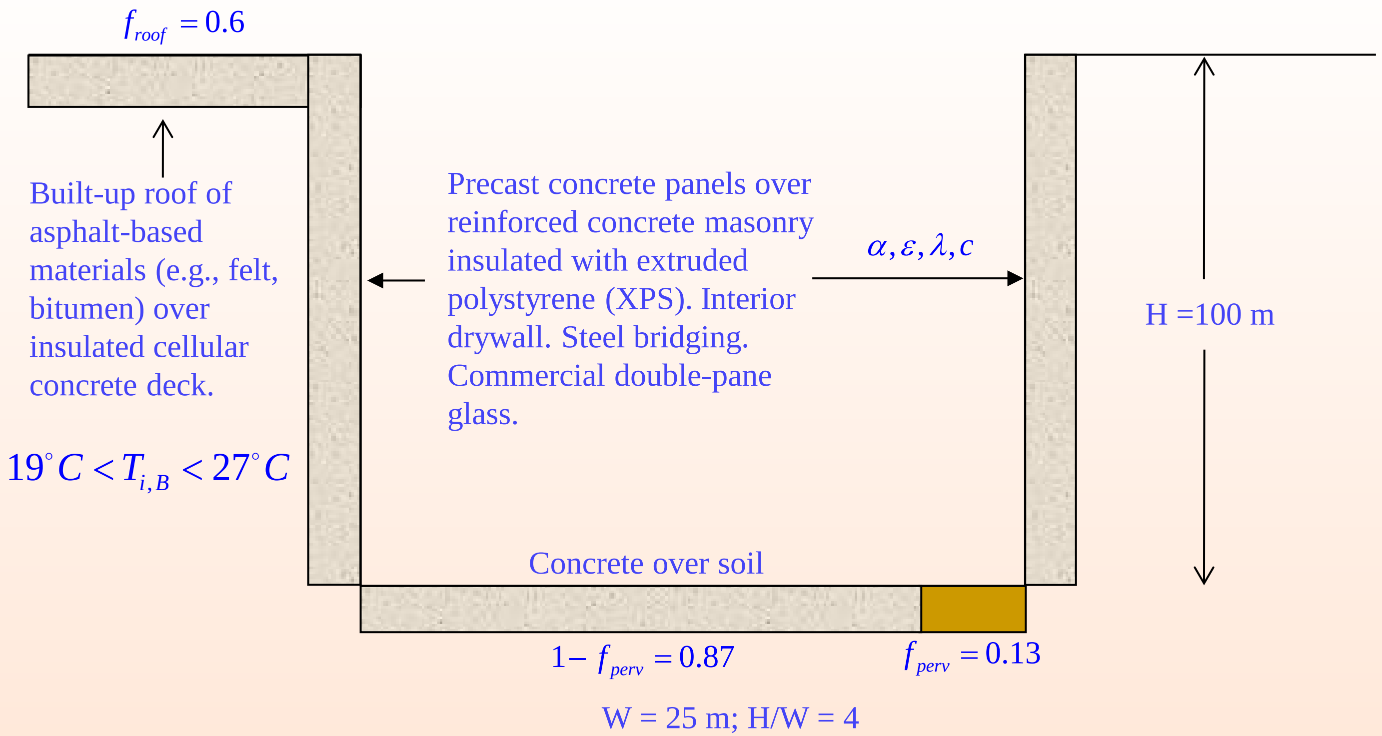


Typical Tall Building District



Tall Building District (TBD)

TBD –Building Type 1



EaSM2 - THESIS - Urban Properties Tool

Developed by Brian Kauffman, NCAR; based on Jackson, Feddema dataset

urban_properties.csh

↓

MATERIALS: mat_prop.csv

↓

WALLS, ROOFS, FRAMES & WINDOWS: lam_spec.csv

↓

FRAMES+WINDOWS: surf_spec_fw.csv

↓

WALL+WINDOW: surf_spec_ww.csv

↓

CITY: city_spec.csv

↓

REGION PROPERTIES: region_prop.csv

↓

CLM mksurfdata_map

↓

fsurdat = ‘surfdata_0.9x1.25_simyr2000_….nc

EaSM2 - THESIS - Urban Properties Tool

Developed by Brian Kauffman, NCAR

- Consider wall construction

mat_prop.csv

```
shortname        , therm_cond, density, spec_heat, vol_heat_cap,  emiss,  albedo
"window_pane",         0.74,    2480,        670,  1.6616E+06,    0.91,    0.08
"conc_panel"   ,       1.28,    2100,       1010,  2.1210E+06,    0.90,    0.23
"conc_block"   ,       0.86,     930,        840,  7.8120E+05,    0.94,    0.23
"XPS"          ,      0.029,    28.3,       1470,  4.1601E+04,    0.91,    0.62
"drywall_int"  ,       0.16,     700,        870,  6.0900E+05,    -999,    -999
"steel"        ,      45.00,    7800,        480,  3.7440E+06,    0.80,    0.18
```

WALL: lam_spec.csv

```
short_name      , conc panel/conc masonry
long_name       , "concrete panel with concrete masonry"
comment         ,
main_thickness,        0.089, 0.025,        0.200, 0.025,        0.012
main_material   , conc_panel,     air, conc_block,   XPS, drywall_int
bridge_material, conc_panel,   steel, conc_block,  steel, drywall_int
bridge_fraction, 0.025
```

EaSM2 - THESIS - Urban Properties Tool

Developed by Brian Kauffman, NCAR

WINDOW: lam_spec.csv

```
short_name      , glass_2c no frame
long_name       , "glass_2c, commercial no frame"
main_thickness,                0.007, 0.010,            0.007
main_material   , window_pane ,      air, window_pane
bridge_material, window_pane ,       air, window_pane
bridge_fraction , 0.0
EOD
short_name      , glass_2c frame
long_name       , "glass_2c, commercial frame"
main_thickness, 0.015,          0.001, 0.015
main_material   ,  steel, build_paper,   steel
bridge_material,  steel, build_paper,   steel
bridge_fraction, 0.0
```

FRAME+WINDOW: surf_spec_fw.csv

```
new surface  ,             surface #1,        surface #2, frac #2, comment
glass_2c +f   , glass_2c no frame, glass_2c frame,     0.05, with frame
```

EaSM2 - THESIS - Urban Properties Tool

Developed by Brian Kauffman, NCAR

WALL+WINDOW: surf_spec_ww.csv

```
new surface                  ,         surface #1,  surface #2,  frac #2,          comment
conc panel/conc masonry +w, conc panel/conc masonry, glass_2c +f,    0.1, conc_panel/conc_masonry + glass_2c
```

CITY: city_spec.csv

```
Region          , Bld%, Ht(m),  H:W,  % Per,  %Rf,                 Wall type,
NE-USA_TBD_1,  0.60,    160,    6.4,    0.05,   0.75,  conc panel/conc masonry +w,…
```

REGION PROPERTIES: region_prop.csv

```
Region,     Cat, ..., Wall_Albedo, Wall_e, Tot_Wall_Thickness, Wall_tk,    Wall_Cv, …
NE_USA,TBD, ...,        0.2155,  0.9004,                 0.3183,  0.4027, 1020991.0, ...
```

CLM mksurfdata_map

```
fsurdat = 'surfdata_0.9x1.25_simyr2000_....nc
```

EaSM2 - THESIS - Urban Properties Tool

Developed by Brian Kauffman, NCAR

Illustration of tool functionality: Replace all windows with triple-pane windows

Modify: lam_spec.csv
surf_spec_fw.csv
surf_spec_ww.csv
city_spec.csv

WINDOW: lam_spec.csv

```
short_name       , glass_3c no frame
long_name        , "glass_3c, commercial no frame"
main_thickness ,              0.007, 0.013,              0.004, 0.013,              0.007
main_material   , window_pane ,      air, window_pane ,      air, window_pane
bridge_material , window_pane ,      air, window_pane ,      air, window_pane
bridge_fraction  , 0.0
EOD
short_name       , glass_3c frame
long_name        , "glass_3c, commercial frame"
main_thickness , 0.010, 0.025, 0.010
main_material   ,  steel,   XPS,   steel
bridge_material ,  steel,   XPS,   steel
bridge_fraction  , 0.0
```

Global Offline CLM4.5SP Simulations

CONTROL: Control simulation is run from 1850-2100 using 20th century and Representative Concentration Pathway 8.5 (RCP8.5) atmospheric forcing from CESM MOAR. Base case building stock.

DENSITY: increase in urban density (RCP8.5 2081-2100)

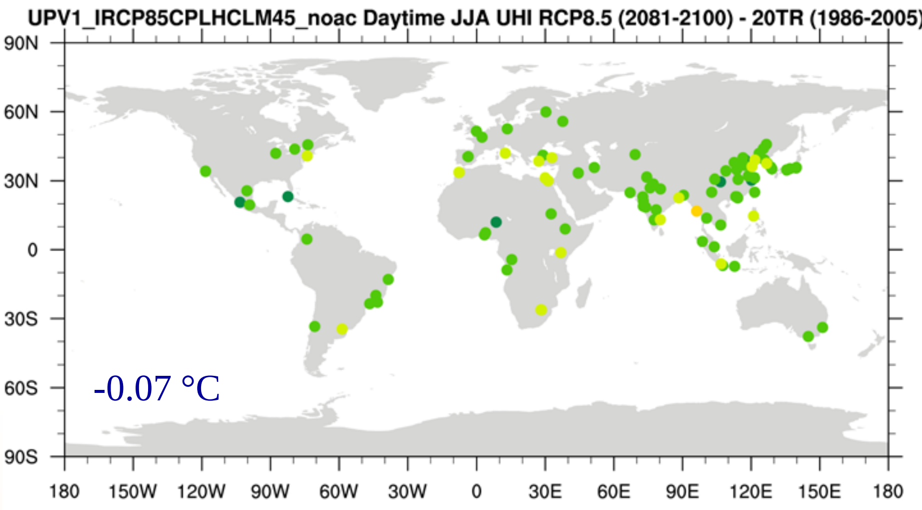
DENSITY+3P WINDOWS: DENSITY + triple-pane windows

What are the effects on the UHI?

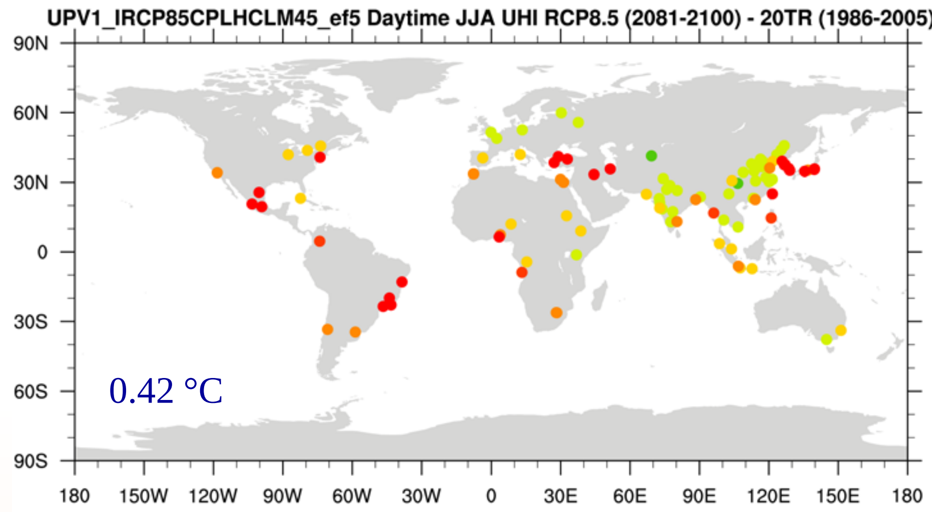
Changes in JJA Daytime Urban Heat Island: (2081-2100) – (1986-2005)

PD: 0.73 °C

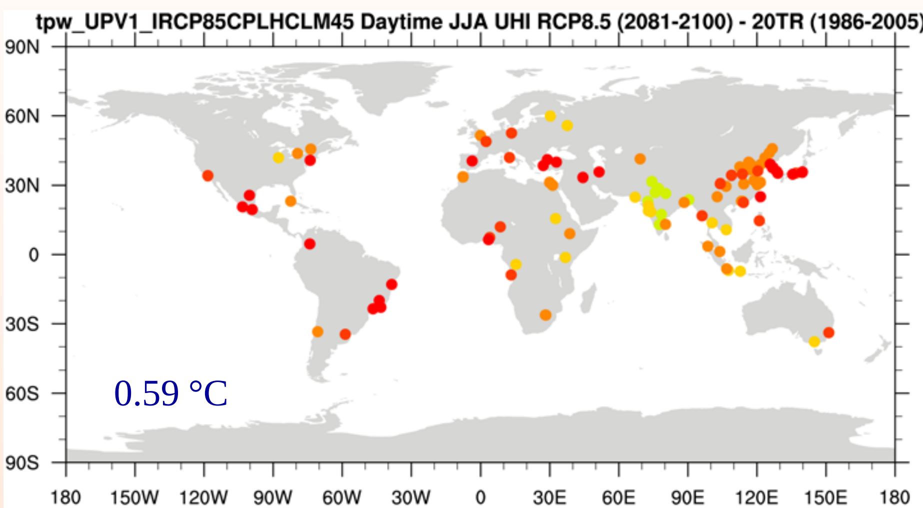
CONTROL



DENSITY



DENSITY + 3P WINDOWS

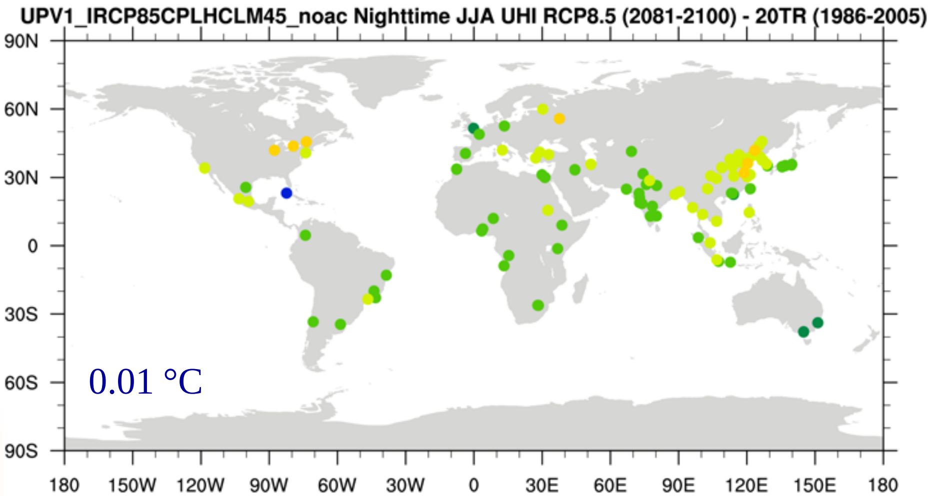


x < -0.8	-0.6 <= x < -0.4	-0.2 <= x < 0	0.2 <= x < 0.4	0.6 <= x < 0.8
-0.8 <= x < -0.6	-0.4 <= x < -0.2	0 <= x < 0.2	0.4 <= x < 0.6	x >= 0.8

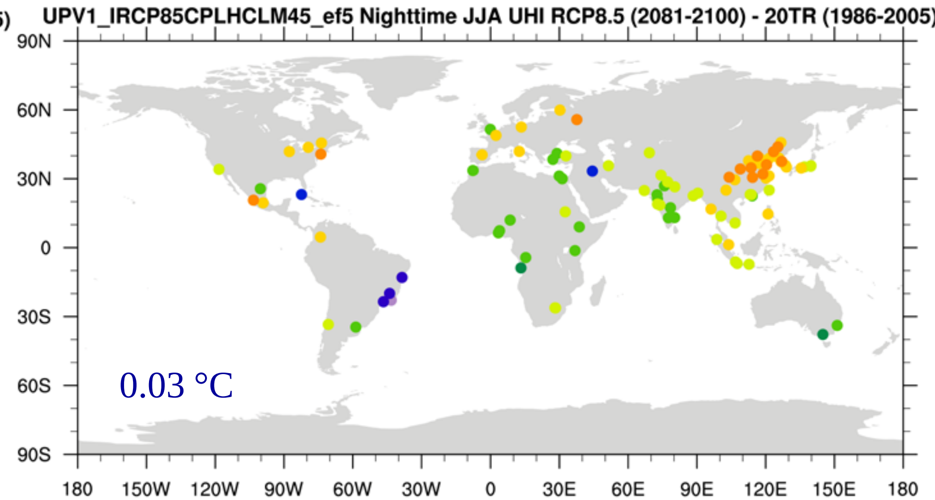
Changes in JJA Nighttime Urban Heat Island: (2081-2100) – (1986-2005)

PD: 1.26 °C

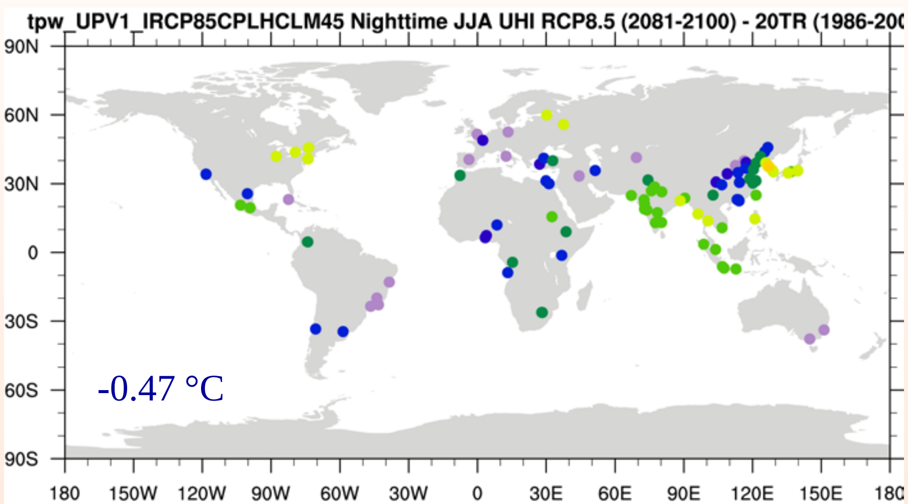
CONTROL



DENSITY

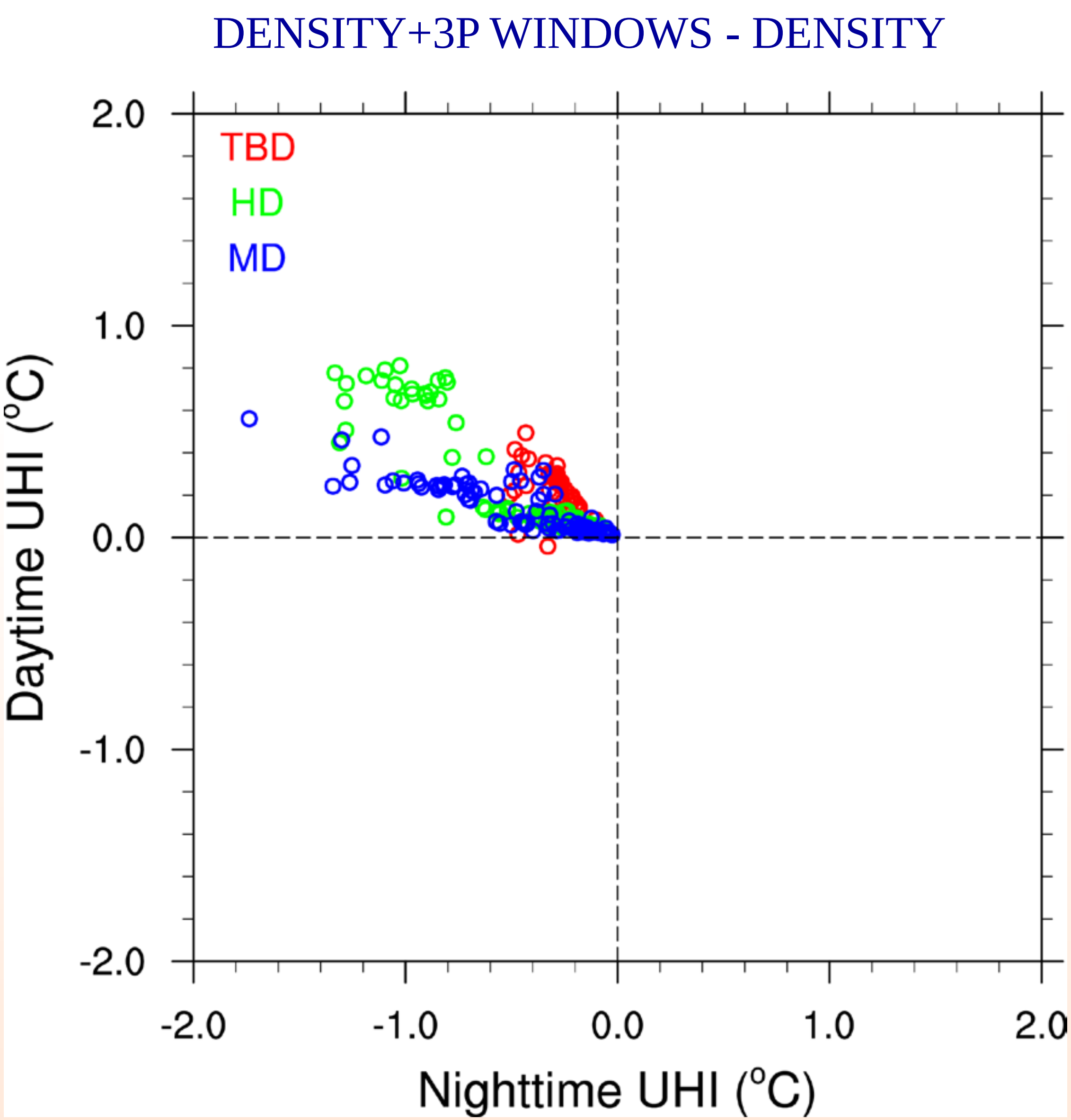


DENSITY + 3P WINDOWS



x < -0.8	-0.6 <= x < -0.4	-0.2 <= x < 0	0.2 <= x < 0.4	0.6 <= x < 0.8
-0.8 <= x < -0.6	-0.4 <= x < -0.2	0 <= x < 0.2	0.4 <= x < 0.6	x >= 0.8

Changes in JJA Daytime and Nighttime UHI by density class: (2081-2100)

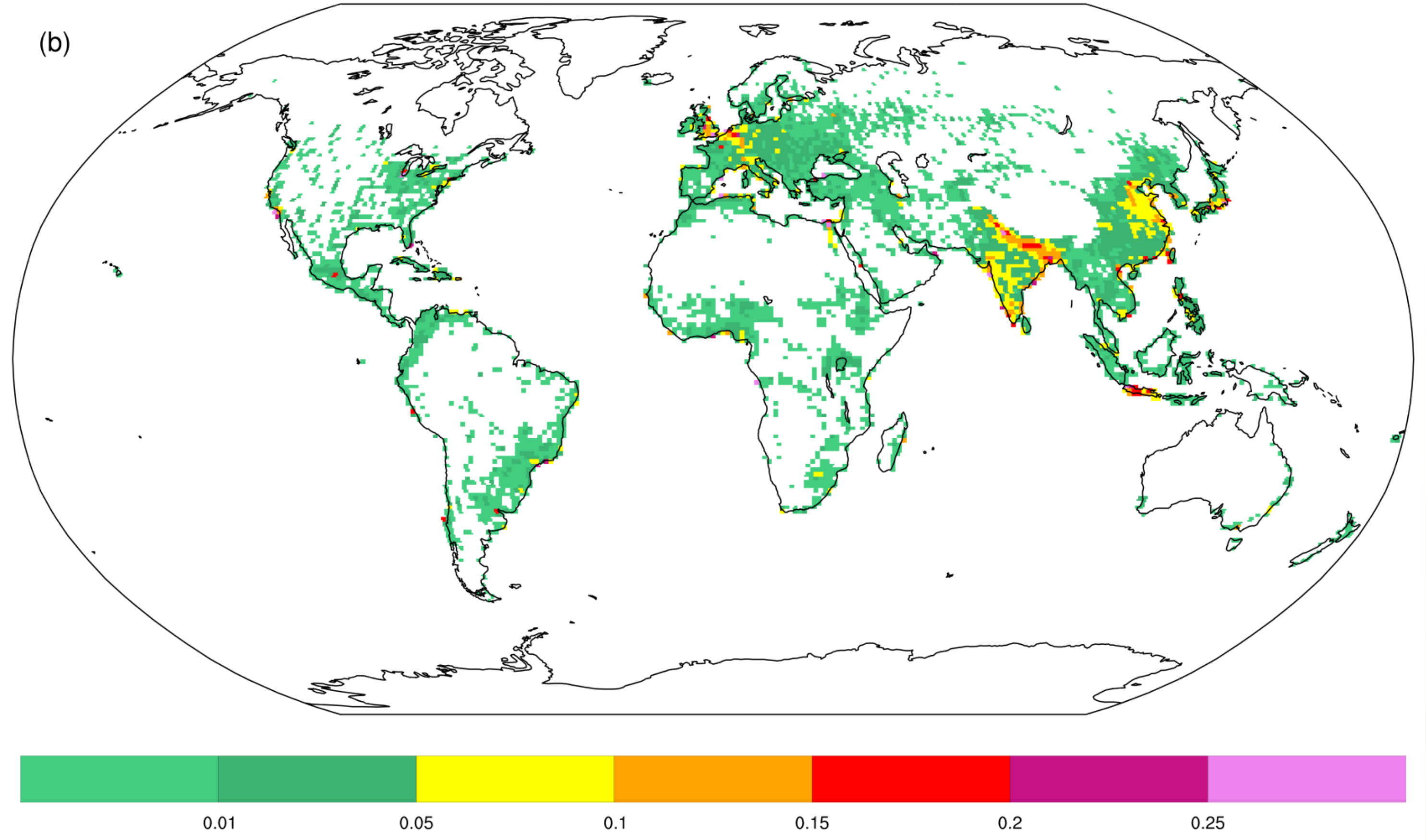


Summary and Next Steps

- An increase in global urban living space (through an increase in density) of 50% at 2081-2100 results in increases of 57% and 7% in daytime and nighttime global average UHI compared to present day, respectively.
- Triple pane windows further increase the daytime UHI by 23%. The increase in nighttime UHI due to density is more than offset and is reduced by 37% compared to present day.
- Results vary spatially/temporally and depend on the same factors that determine the heat island in the first place (urban properties, mix of density types, rural landcover, and climate).
- Next steps are to add more capability to the urban properties tool and develop and test a comprehensive set of global and region-specific future urban scenarios

Thank You

Urban fraction at CESM 1deg resolution



How will urban areas change in the future?

Mitigation policies targeted at reducing the UHI

To mitigate, we implement two policies to reduce the UHI: 1) increase the reflectivity of roofs, 2) decrease thermal conductivity (Tk) of roofs and walls thereby reducing the UHI and energy consumption by space heating and cooling

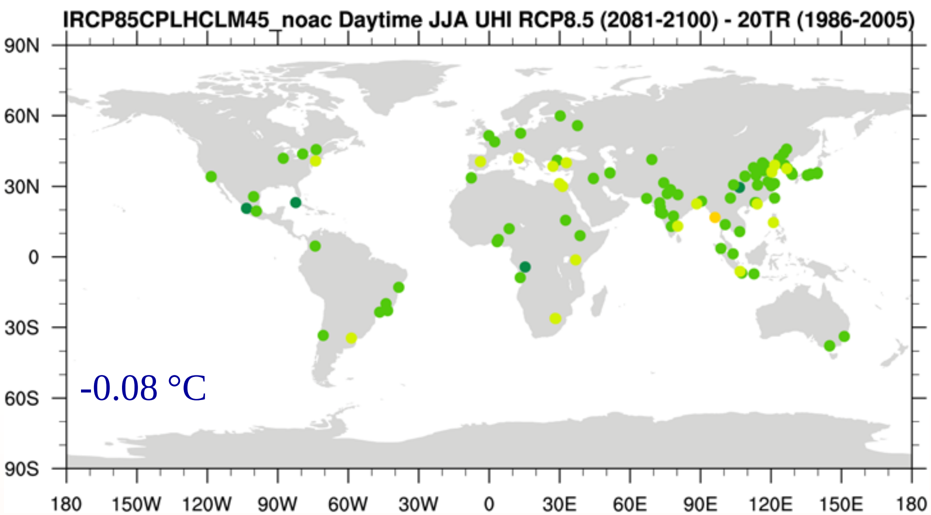
For guidance on 1) we use the EPA Energy Star® Reflective Roof program. To qualify for the Energy Star® rating, a cool roof must have an initial solar reflectance greater than or equal to 0.65 and a three-year reflectance greater than or equal to 0.50. Here we use an albedo of 0.50 and assume 100% implementation between 45N and 45S by end of century.

For guidance on 2) we use the LEED™ standard for new construction and major renovations. Assuming proportional point awards in other LEED™ categories (sustainability, water efficiency, indoor air quality), new buildings and renovations of existing buildings would need a 34-38% increase in energy efficiency to achieve platinum status (14 out of 19 points), respectively. We find that a factor of six reduction in Tk combined with reflective roofs results in a decrease of 35% in global building energy consumption for year 2005. This does not mean that we've achieved LEED™ platinum status for energy efficiency for all buildings in our model because our changes are relative to our base case building stock. And heating/cooling is only one aspect of a building's energy performance.

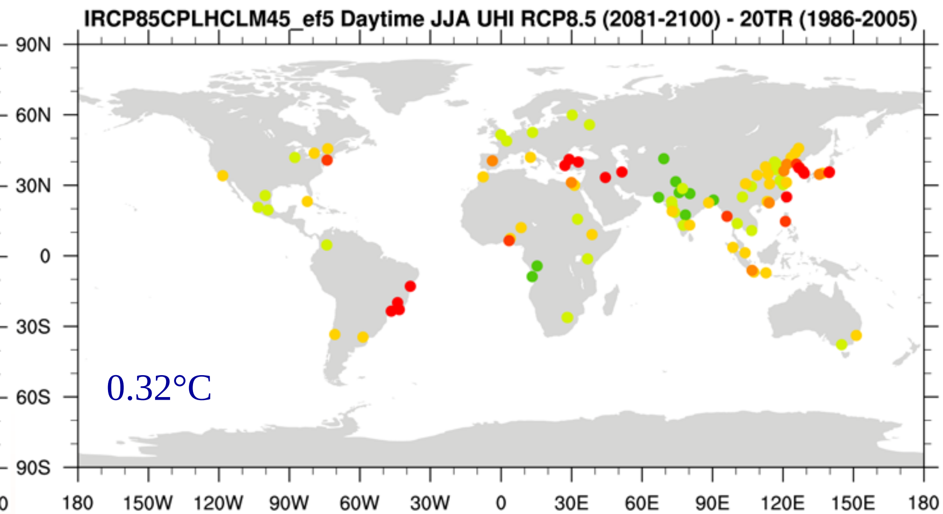
Changes in JJA Daytime Urban Heat Island: (2081-2100) – (1986-2005)

PD: 0.56 °C

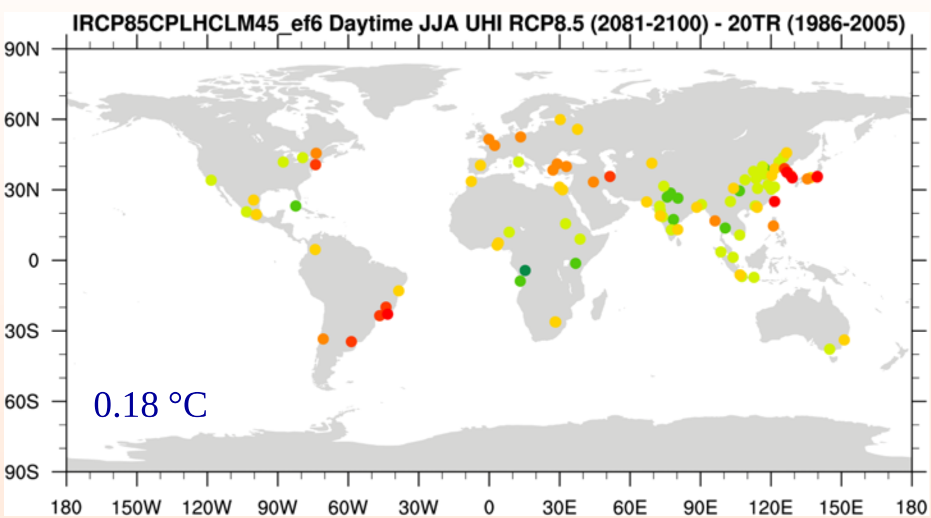
CONTROL



DENSITY



DENSITY + MITIGATION

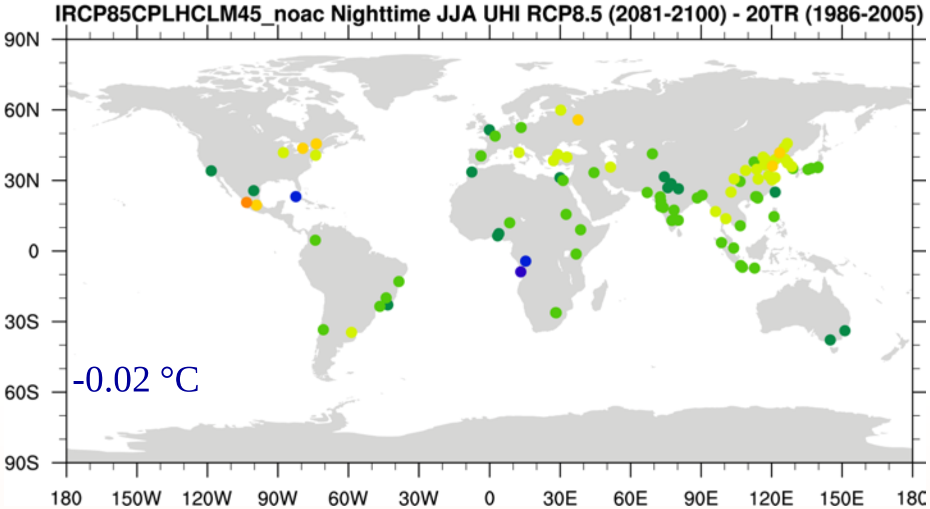


x < -0.8	-0.6 <= x < -0.4	-0.2 <= x < 0	0.2 <= x < 0.4	0.6 <= x < 0.8
-0.8 <= x < -0.6	-0.4 <= x < -0.2	0 <= x < 0.2	0.4 <= x < 0.6	x >= 0.8

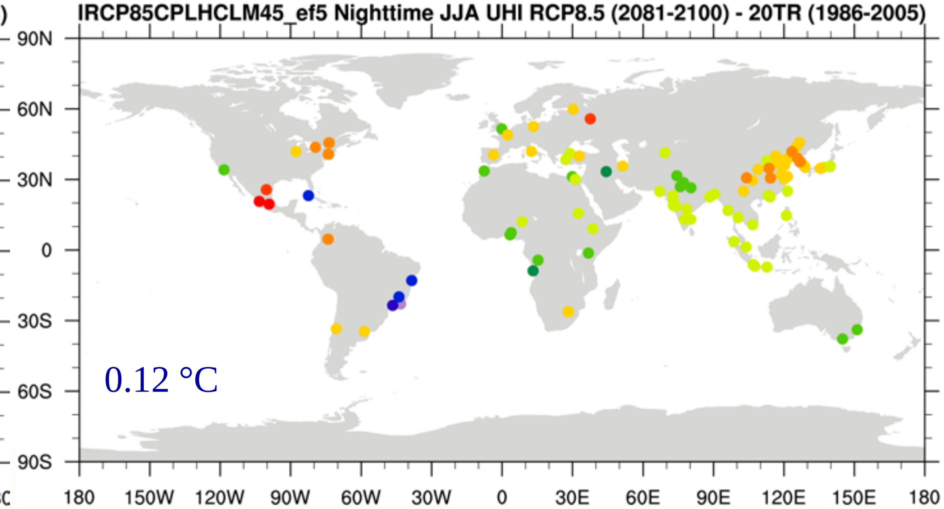
Changes in JJA Nighttime Urban Heat Island: (2081-2100) – (1986-2005)

PD: 1.72 °C

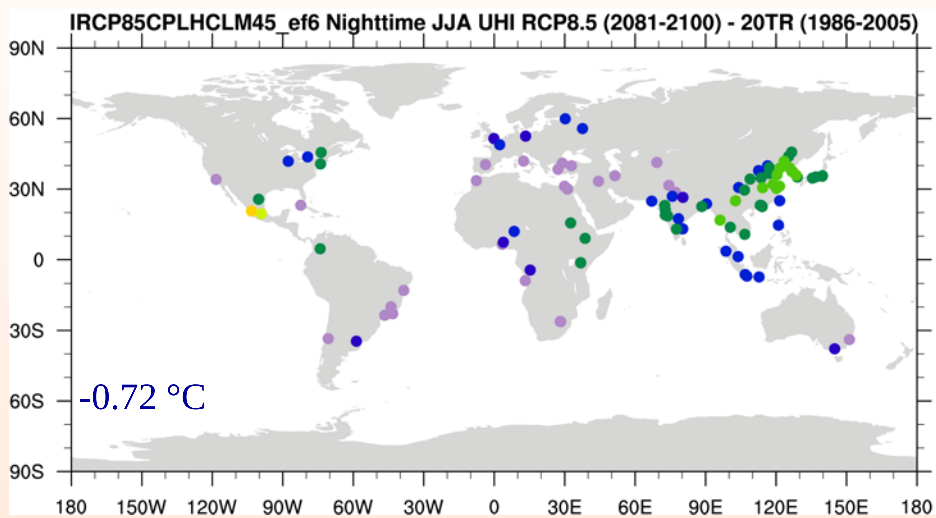
CONTROL



DENSITY



DENSITY + MITIGATION

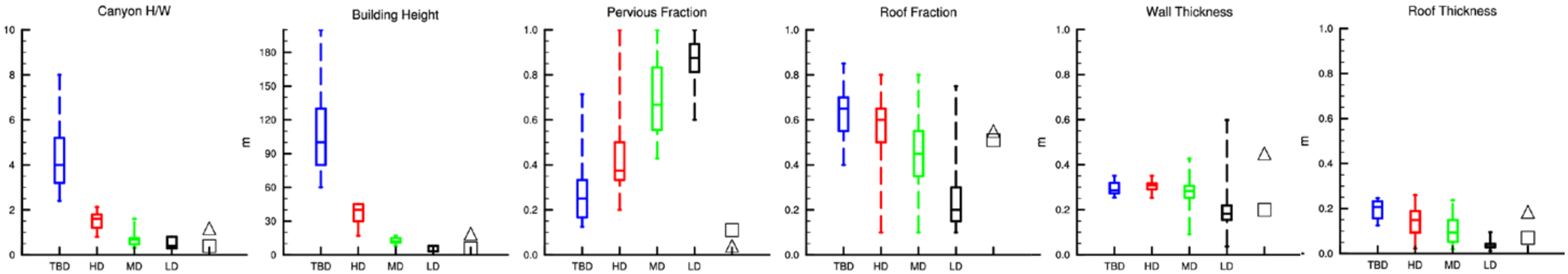


x < -0.8 | -0.6 <= x < -0.4 | -0.2 <= x < 0 | 0.2 <= x < 0.4 | 0.6 <= x < 0.8

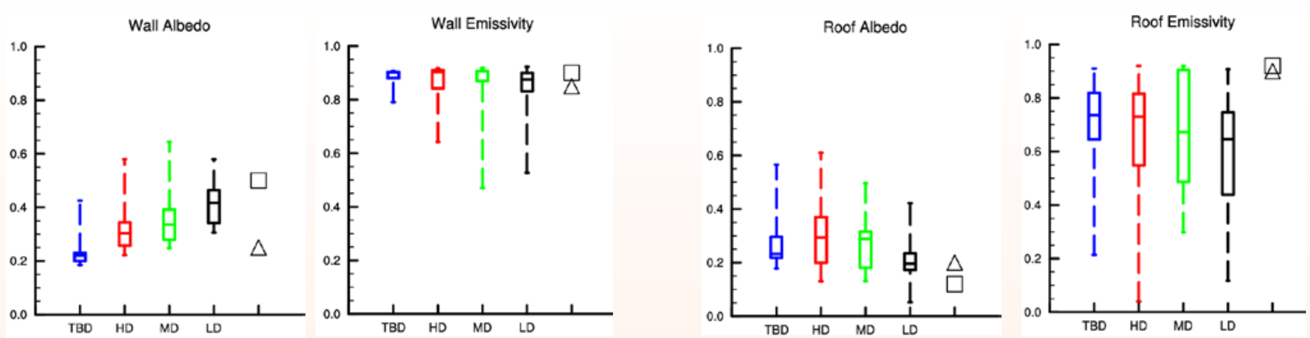
-0.8 <= x < -0.6 | -0.4 <= x < -0.2 | 0 <= x < 0.2 | 0.4 <= x < 0.6 | x >= 0.8

Global Urban Properties V1

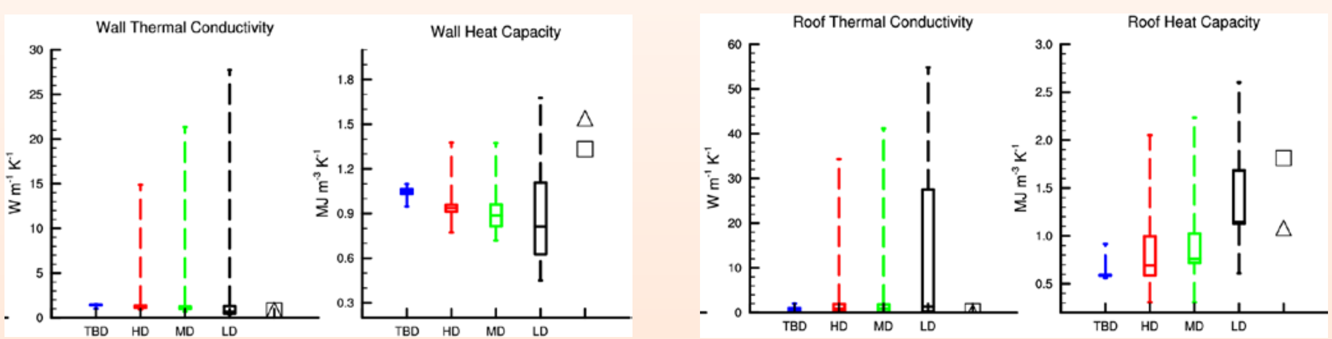
Morphological



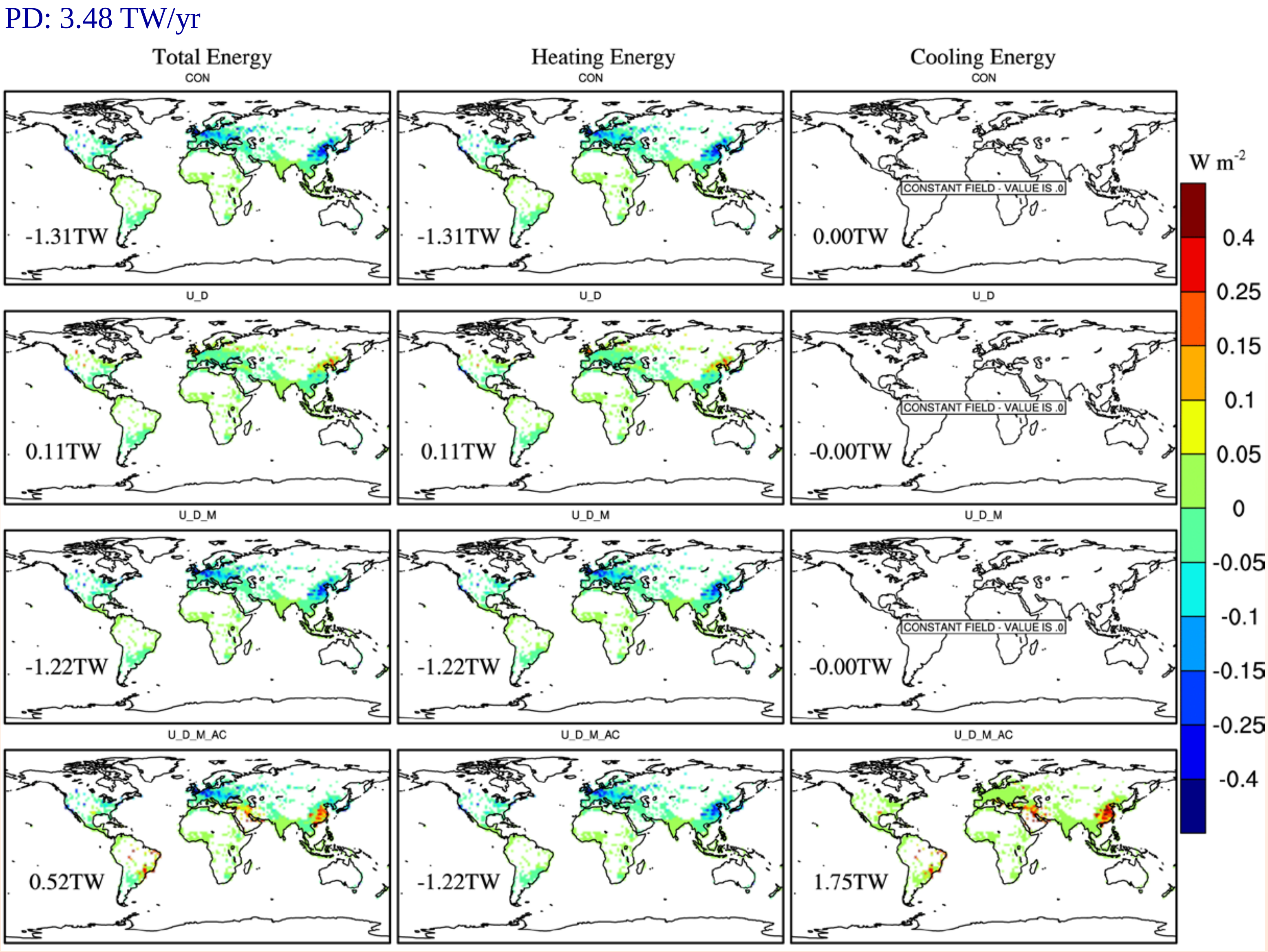
Radiative



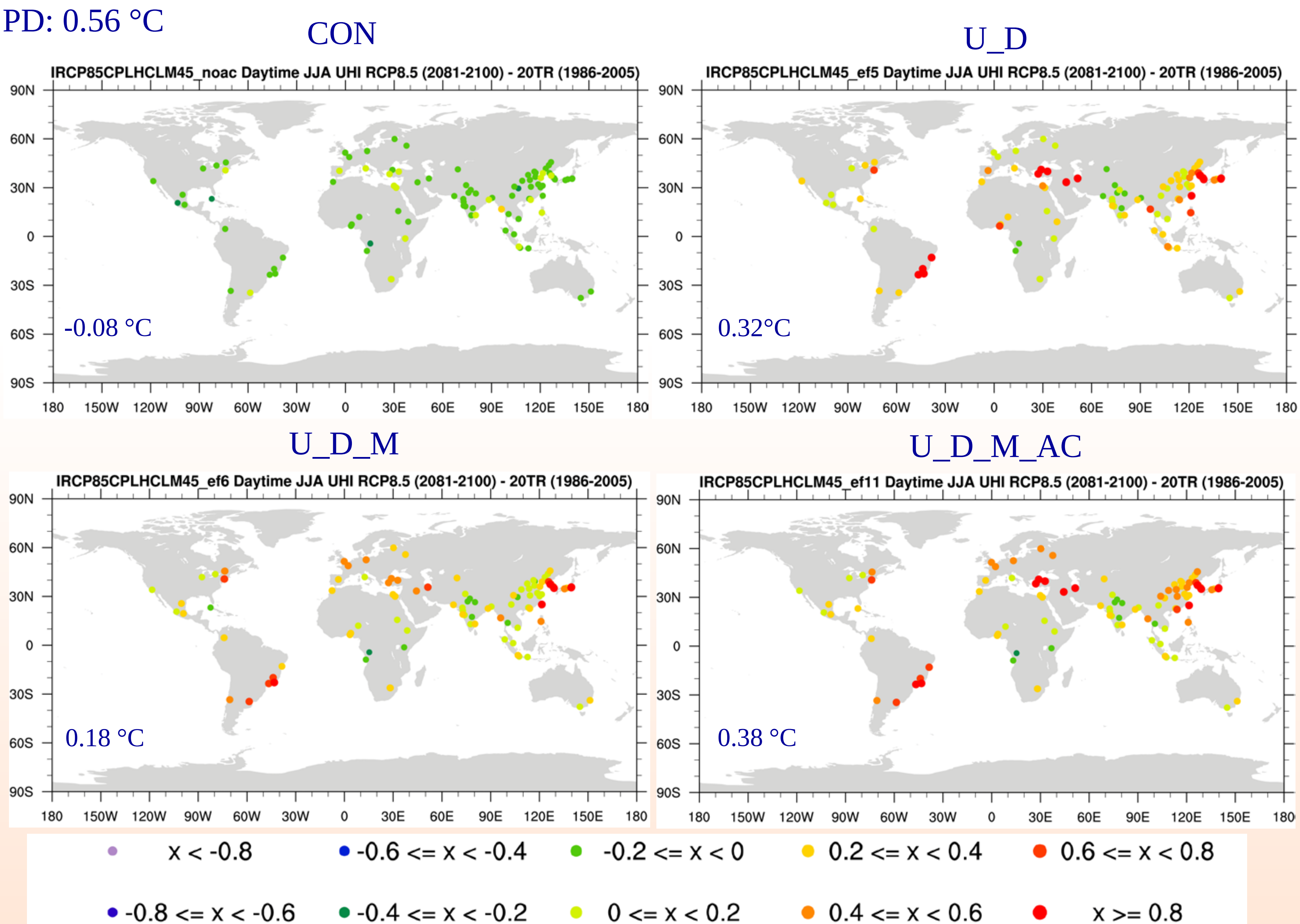
Thermal



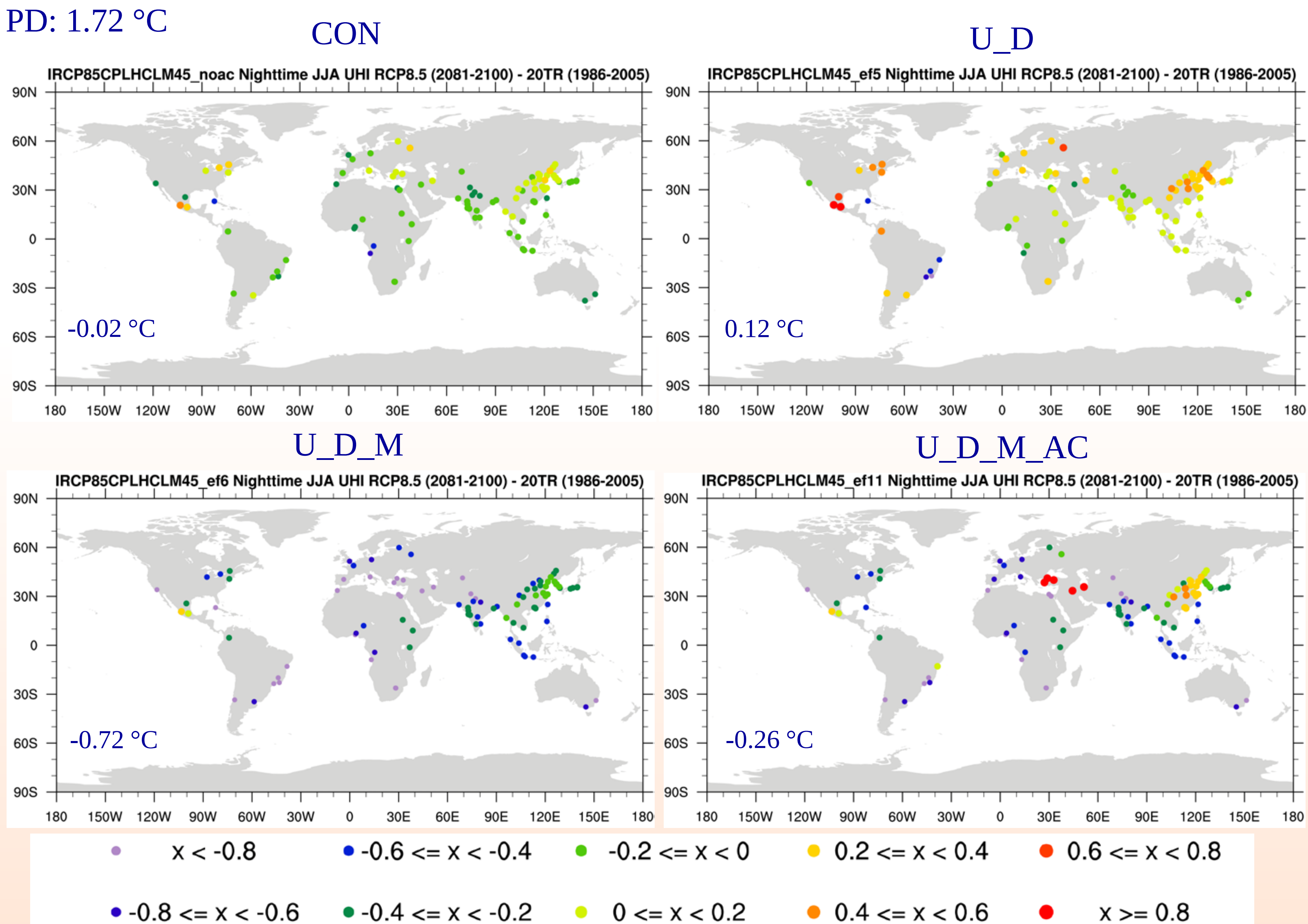
Changes in Annual Mean Total and Space Heating and Cooling Energy : (2081-2100) – (1986-2005)



Changes in JJA Daytime Urban Heat Island: (2081-2100) – (1986-2005)

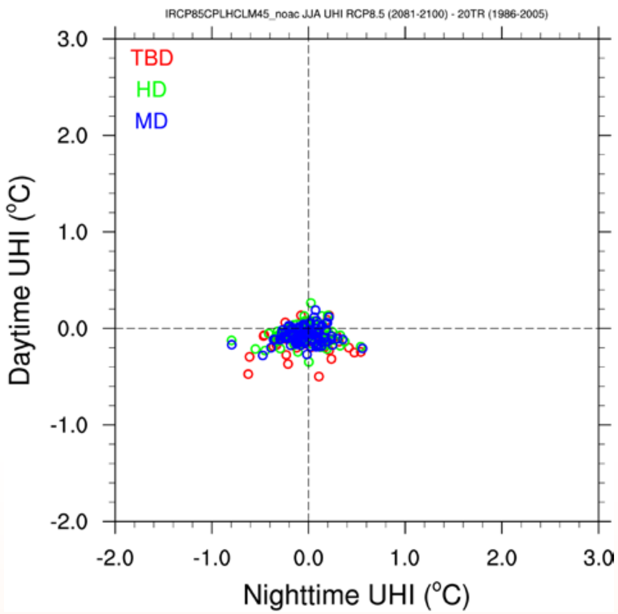


Changes in JJA Nighttime Urban Heat Island: (2081-2100) – (1986-2005)

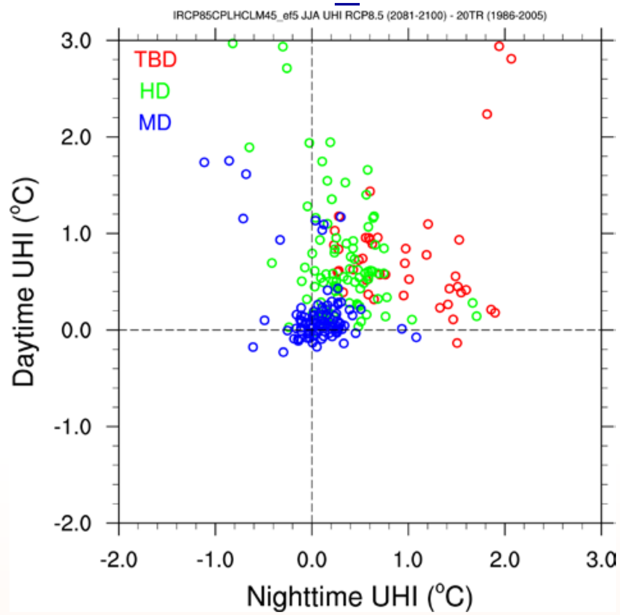


Changes in JJA Daytime and Nighttime UHI by density class: (2081-2100) – (1986-2005)

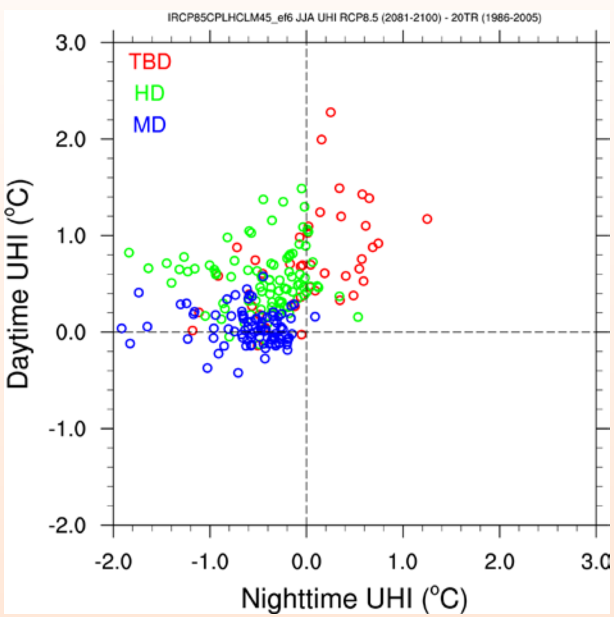
CON



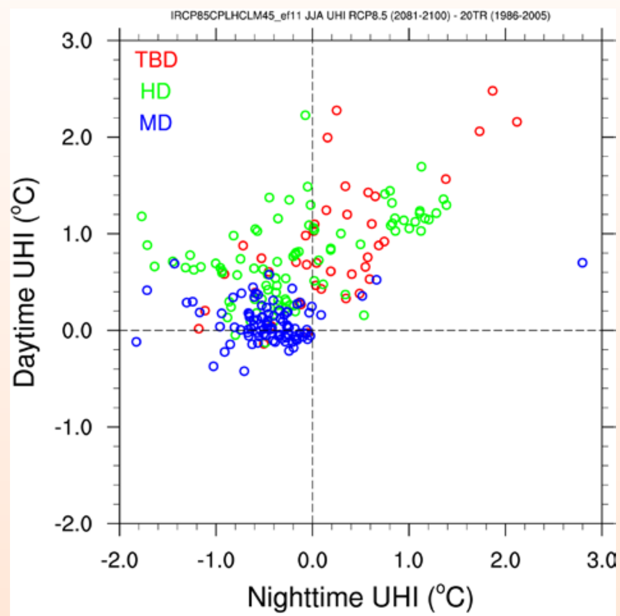
U_D



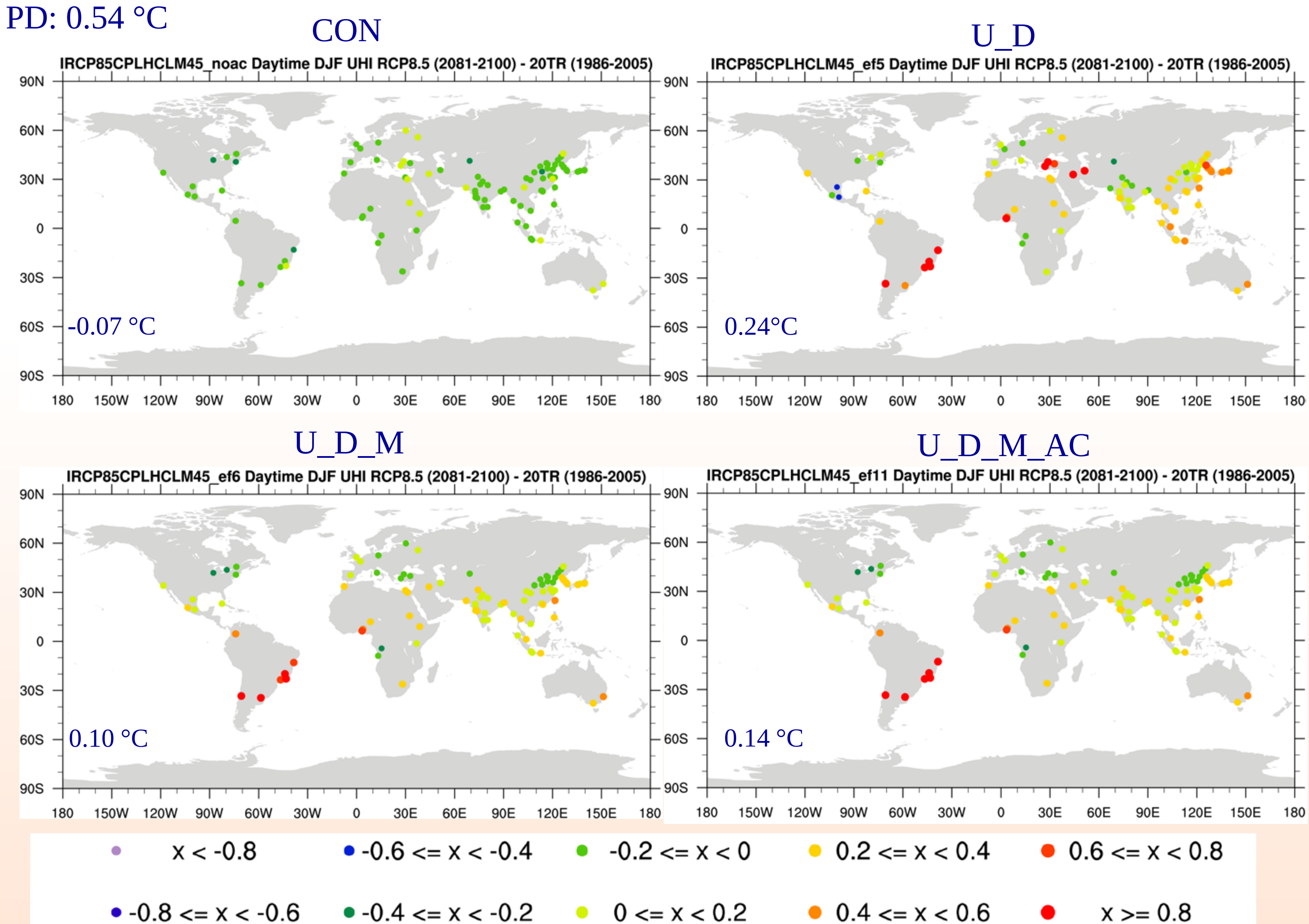
U_D_M



U_D_M_AC

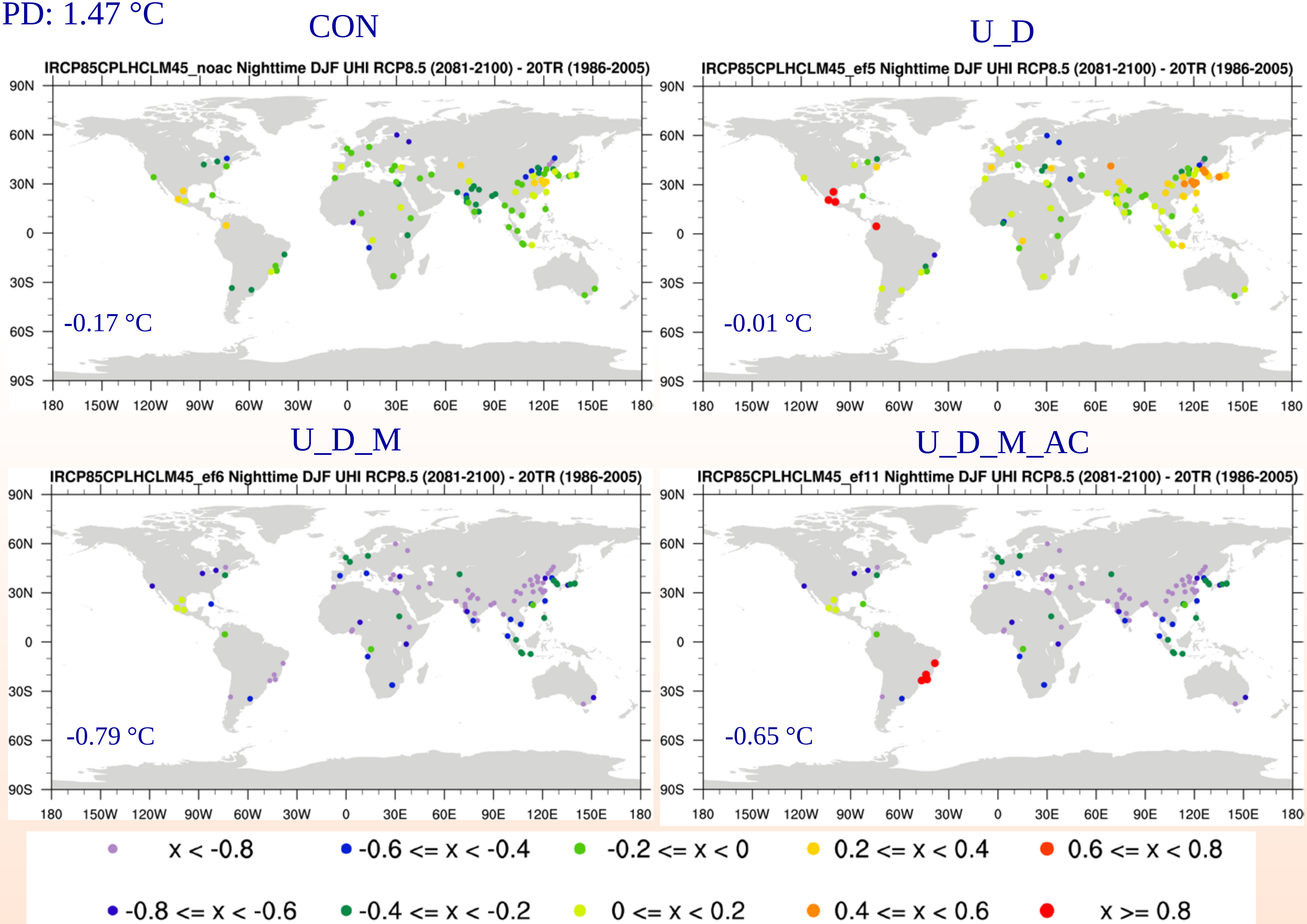


Changes in DJF Daytime Urban Heat Island: (2081-2100) – (1986-2005)



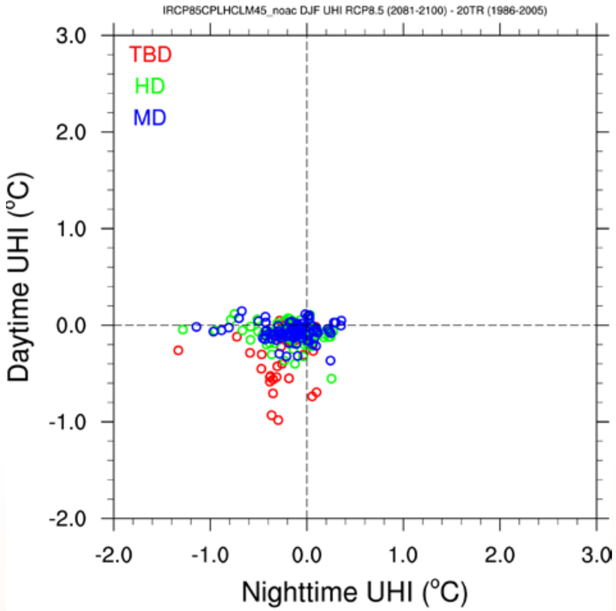
Changes in DJF Nighttime Urban Heat Island: (2081-2100) – (1986-2005)

PD: 1.47 °C

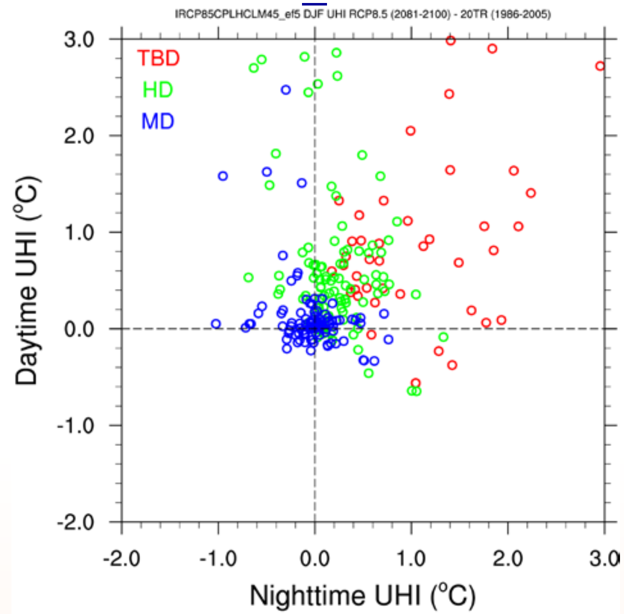


Changes in DJF Daytime and Nighttime UHI by density class: (2081-2100) – (1986-2005)

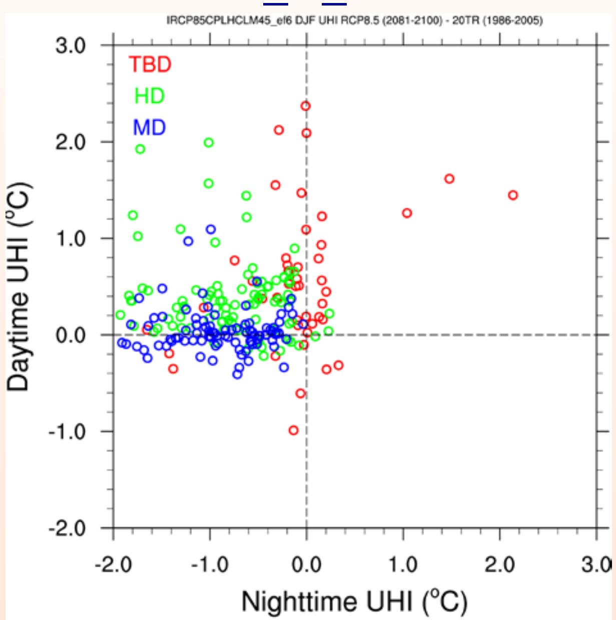
CON



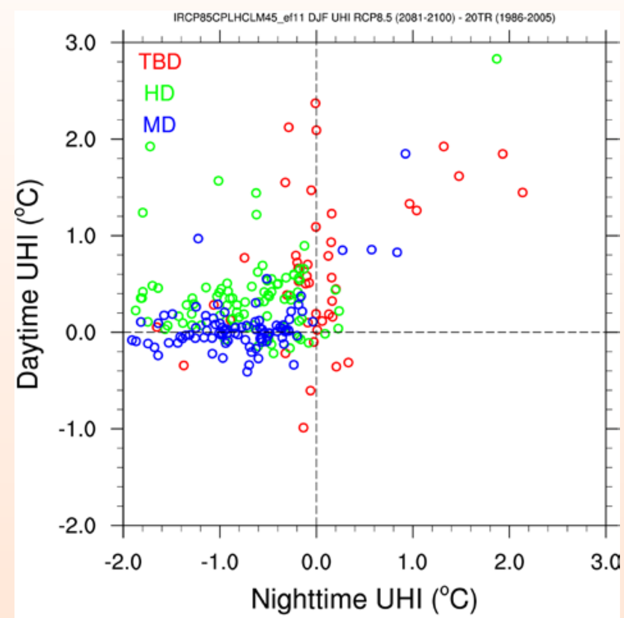
U_D



U_D_M



U_D_M_AC



Summary

- An increase in global urban living space of 50% by 2081 results in increases of 57% and 7% in daytime and nighttime global average UHI compared to present day, respectively.
- Mitigation policies (reflective roofs and larger whole-roof/wall R-values) are effective at reducing the UHI. These policies offset about 44% of the increase in the daytime UHI due to density. The increase in nighttime UHI due to density is more than offset and is reduced by 58% compared to present day.
- Adding AC where appropriate increases daytime and nighttime UHI. Net global effect of density, mitigation, and AC is that daytime UHI increases by 68% and nighttime UHI decreases by 15% compared to present day.
- Heating energy decreases by 1/3 from present day due to climate change, increases to near present day levels due to density, and decreases again by 1/3 in response to increase in building efficiency.
- Results vary spatially/temporally and depend on the same factors that determine the heat island in the first place (urban properties, mix of density types, rural landcover, and climate).