Albedo, Climate, & Urban Heat Islands

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CSHub Webinar

February 15, 2018

(Slides revised February 21, 2018)

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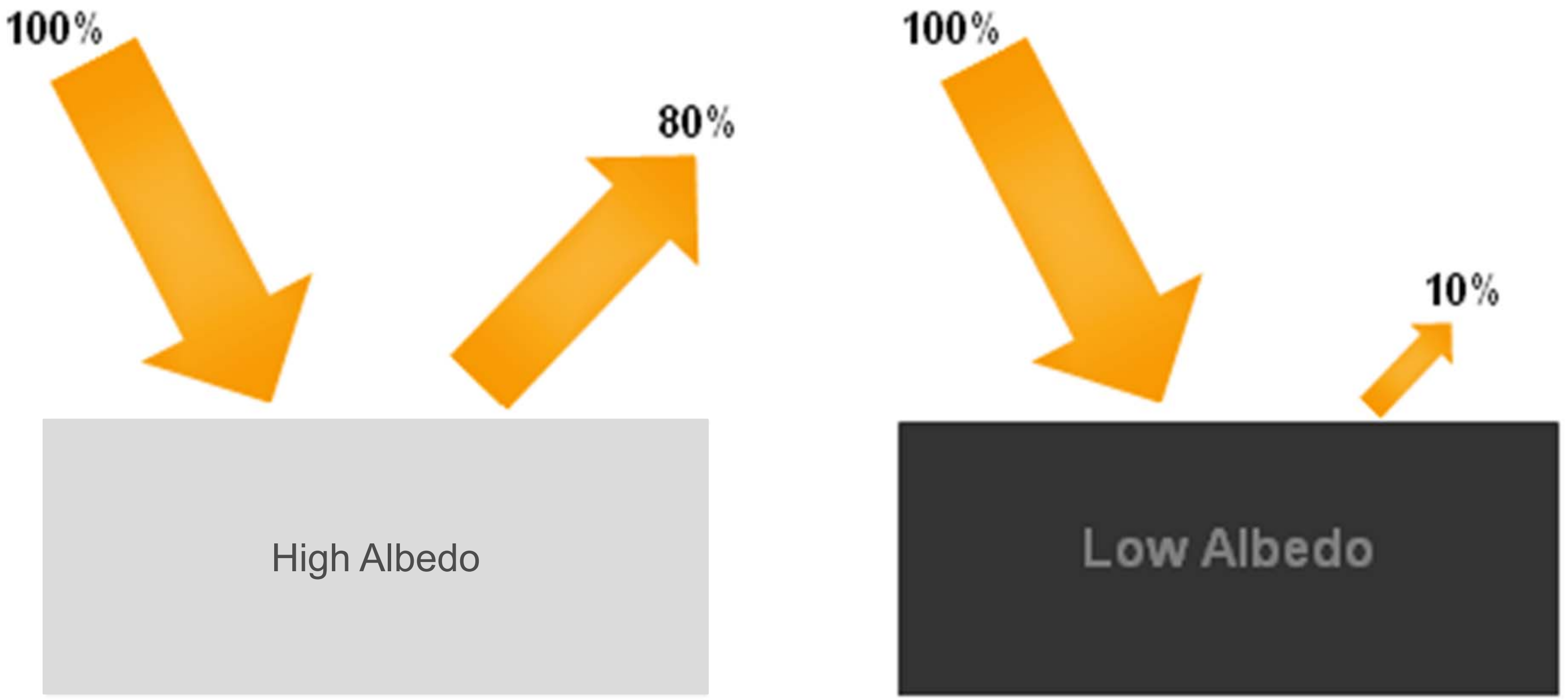
Albedo: fraction of solar radiation reflected from a surface

Measured on a scale from 0 to 1

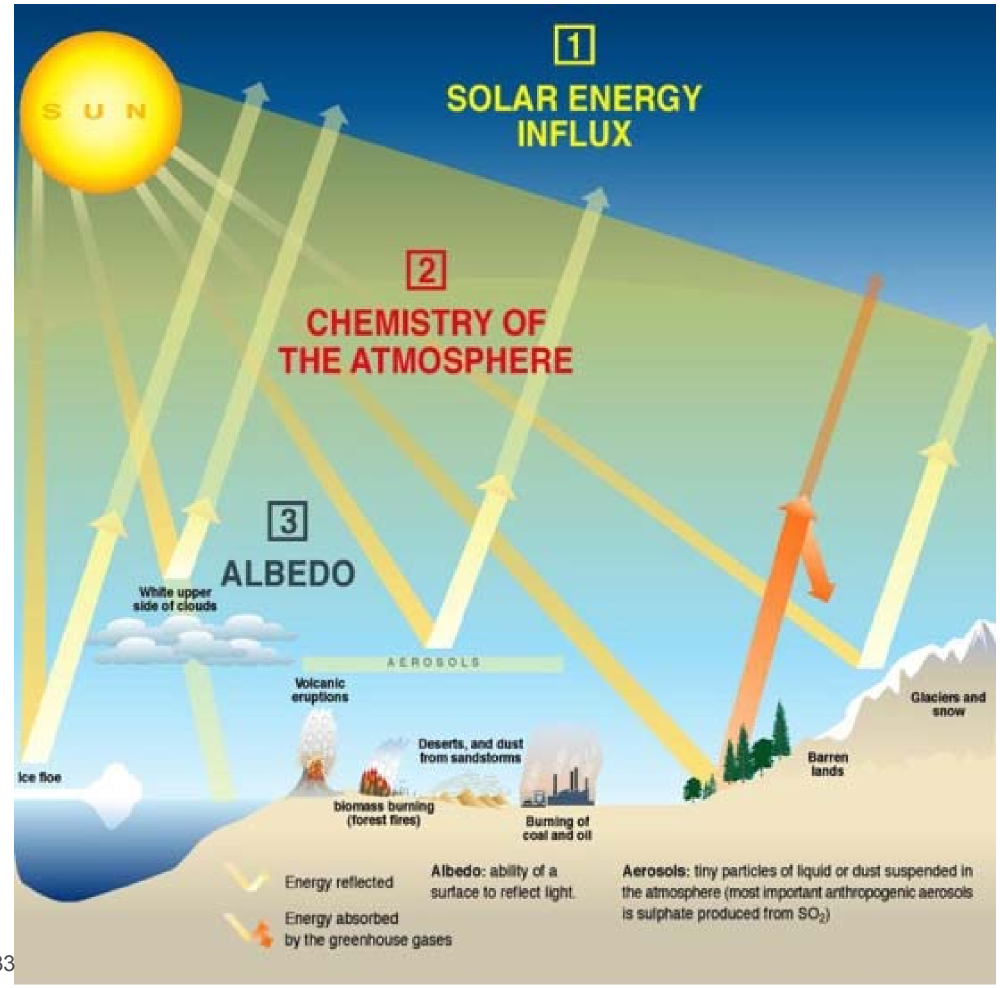


http://www.nc-climate.ncsu.edu/edu/Albedo

Earth's average albedo: ~0.3

Climate is affected by albedo

Three main factors affecting the climate of a planet:



Source: Grid Arendal, http://www.grida.no/resources/7033

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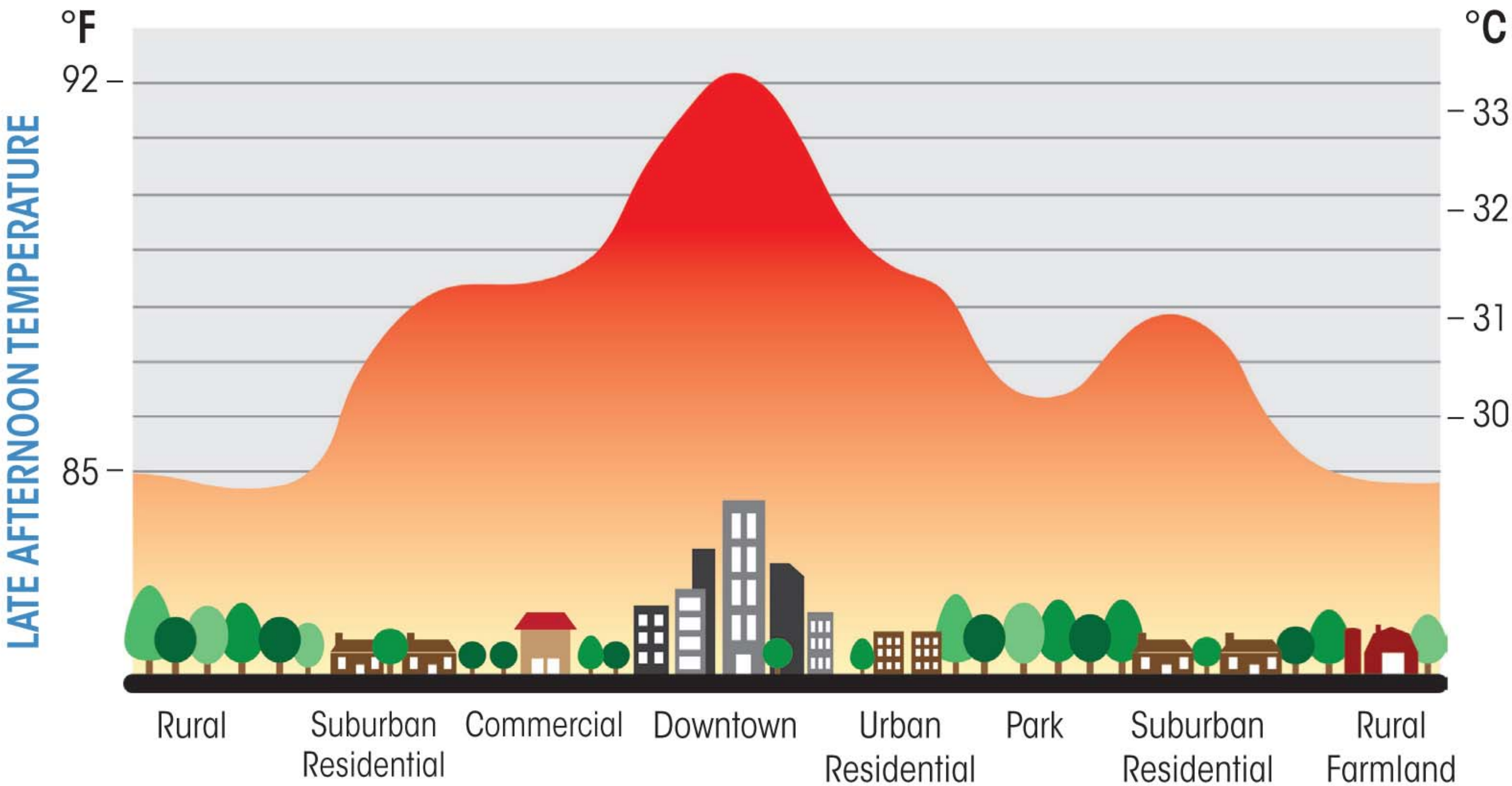
Urban heat islands are affected by albedo



Urban surface albedo is significant

In many urban areas, pavements and roofs constitute over 60% of urban surfaces

[redacted]				
[redacted]	33%	22%	36%	9%
[redacted]	20%	20%	45%	15%
[redacted]	27%	25%	37%	11%
[redacted]	37%	21%	29%	12%

Source: Rose et al. (2003)

20%~25% 30%~45%

Global change of urban surface albedo could reduce radiative forcing equivalent to **44 Gt of CO2** with **\$1 billion** in energy savings per year in US (Akbari et al. 2009)

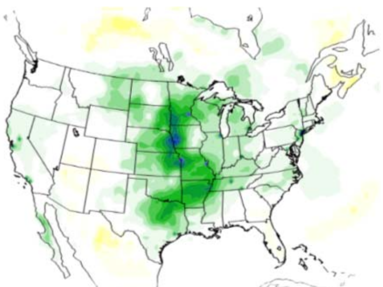
Cool pavements are a potential mitigation mechanism for climate change and UHI

heatisland.lbl.gov

https://www.nytimes.com/2017/07/07/us/california-today-cool-pavements-la.html

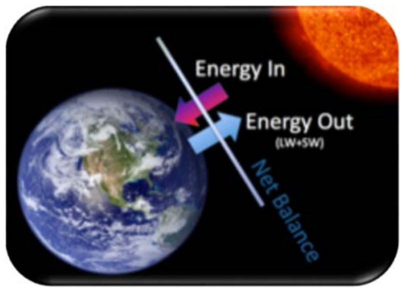
Evaluating the impacts of pavement albedo is complicated

Regional Climate



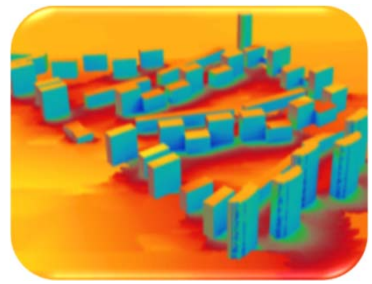
Climate feedback

Radiative forcing



Earth's Energy Balance

Urban Buildings Energy Demand



Incident radiation

Ambient Temperature

Pavement life cycle environmental impacts

Materials Production

Design & Construction

Use

End-of-Life

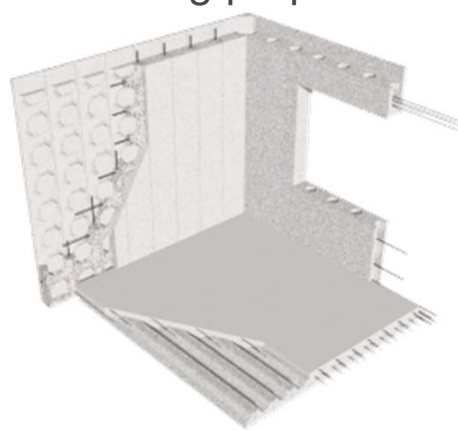
Contexts vary significantly

Location

Urban morphology

Climate

Building properties

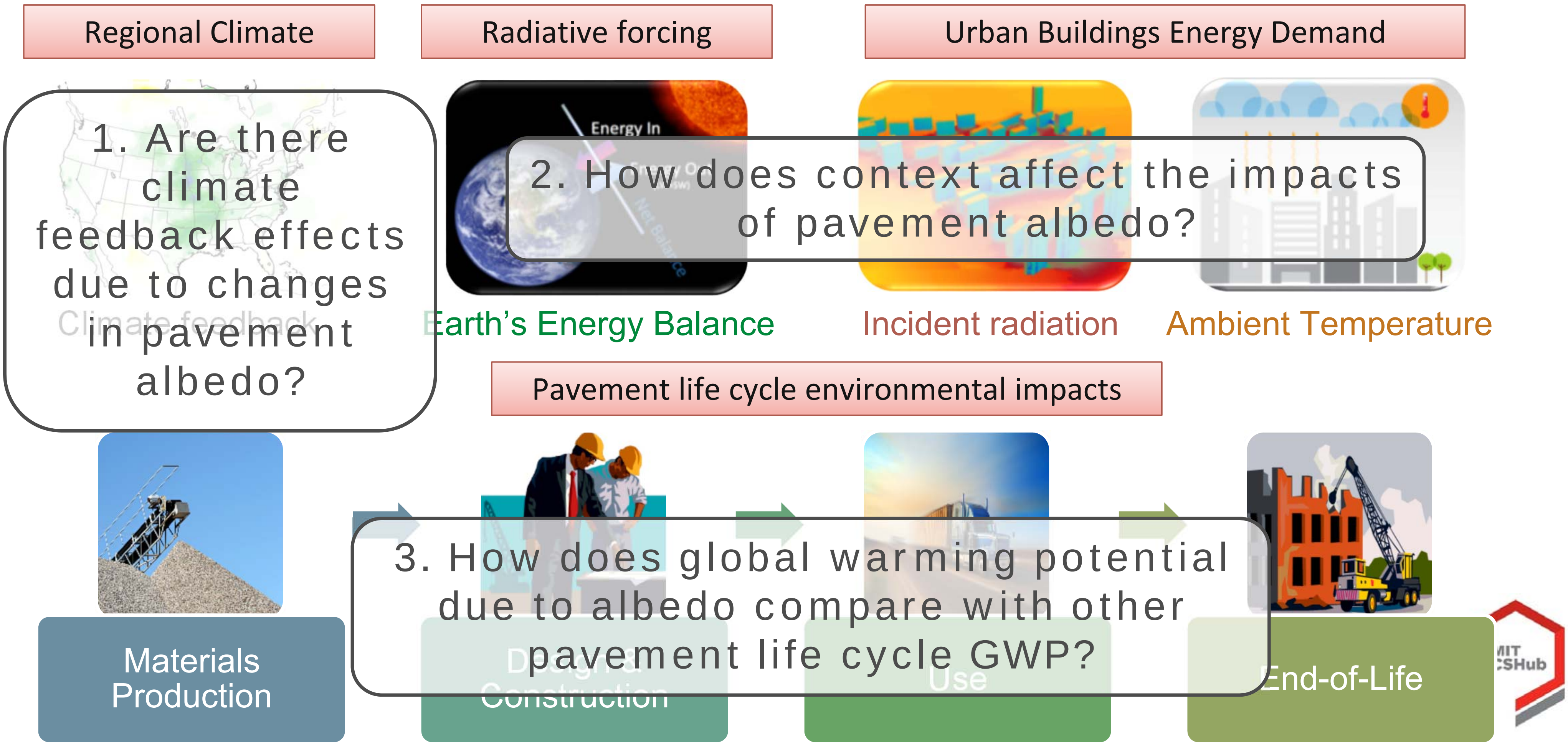


Electricity grid

Key research questions

1. Are there climate feedback effects due to changes in pavement albedo?
2. How does context affect the impacts of pavement albedo?
   a) Is radiative forcing or building energy demand more significant?
3. How does global warming potential due to albedo compare with other pavement life cycle GWP?
   a) Which climate change and UHI mitigation strategies are the most promising?

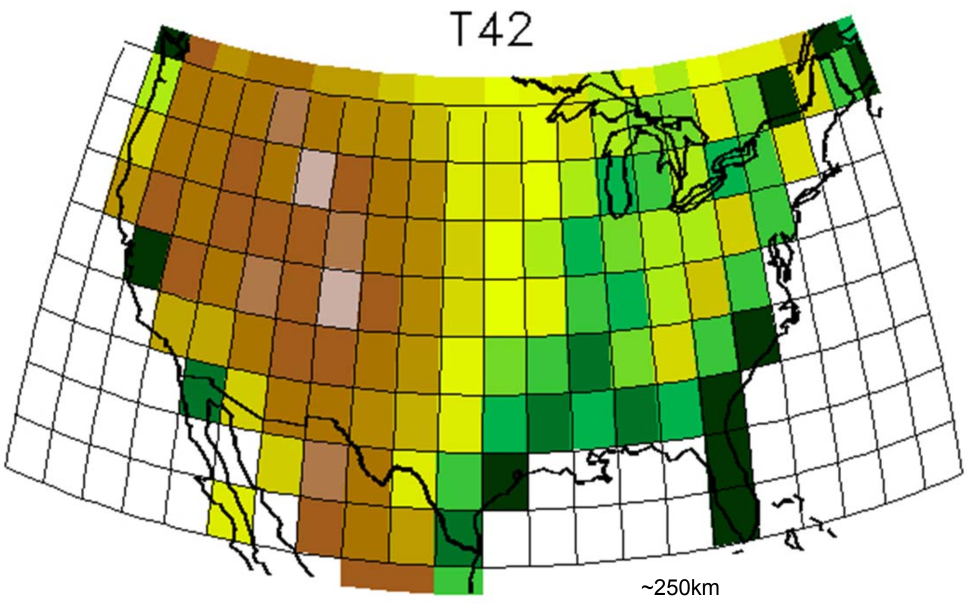
Research questions and approach



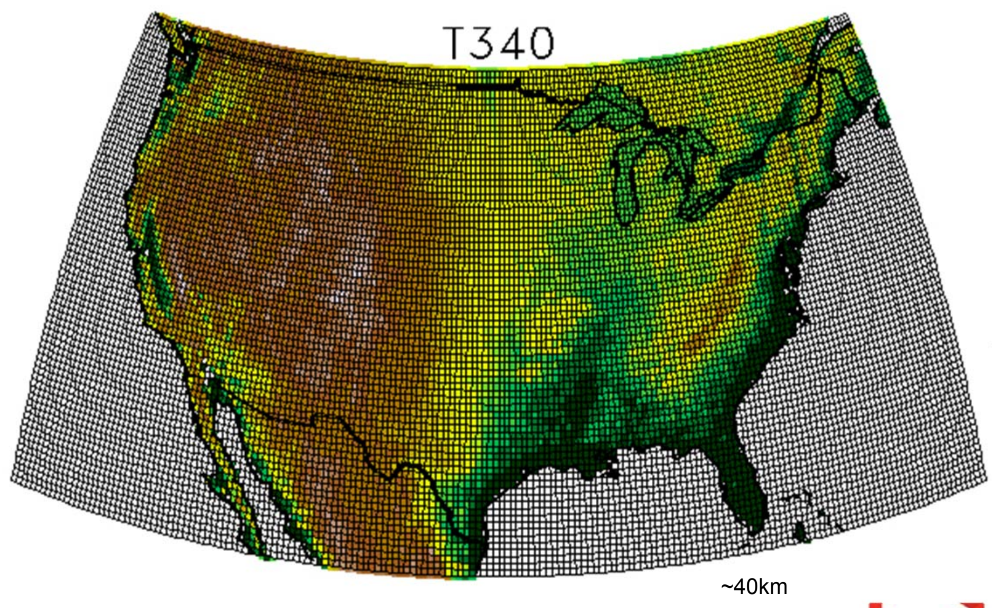
Weather Research & Forecasting (WRF) Model

Model regional climate using large scale simulations to identify possible feedback

Global Climate Model

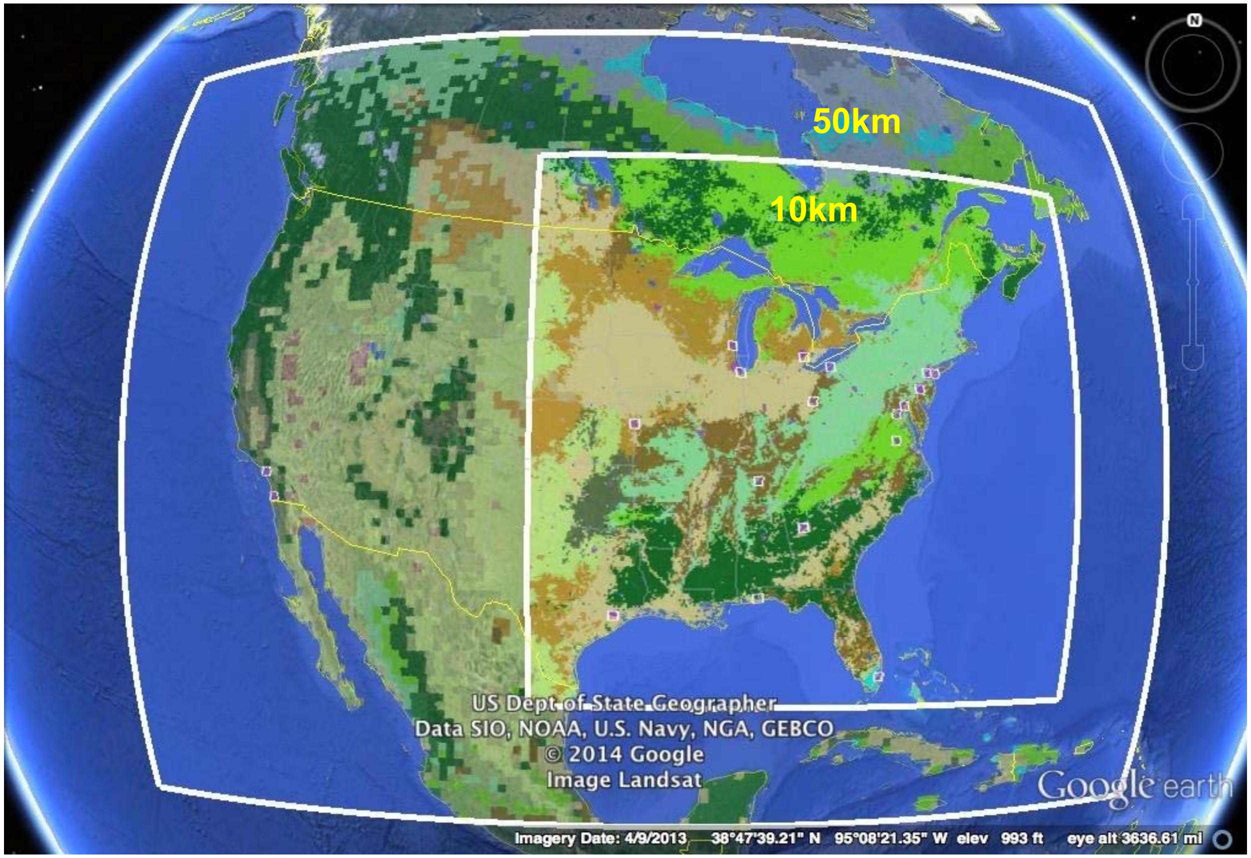


Regional Climate Model



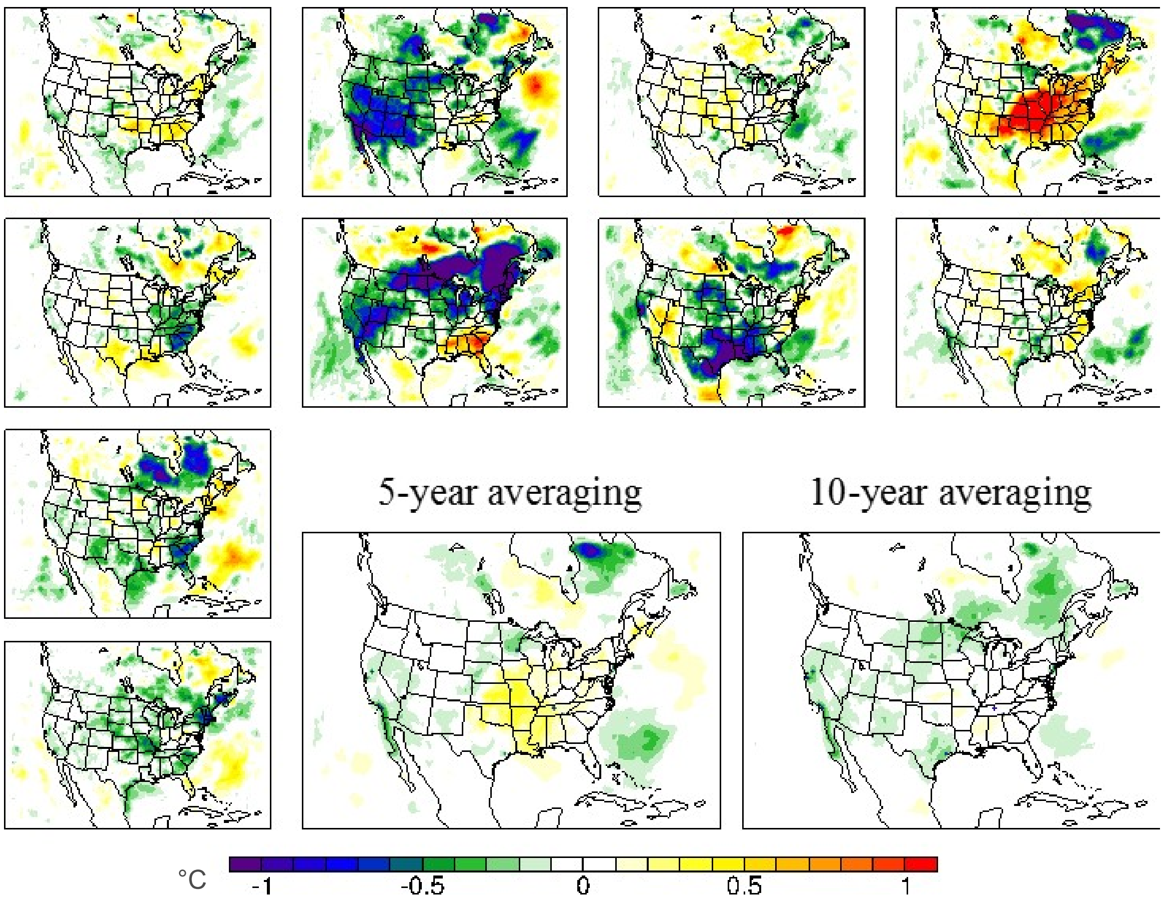
WRF Land Cover Map

Analyze regional climate effects of increasing *urban* albedo from 0.2 (control) to 0.4 over *10 years*



Year-to-year results are highly variable

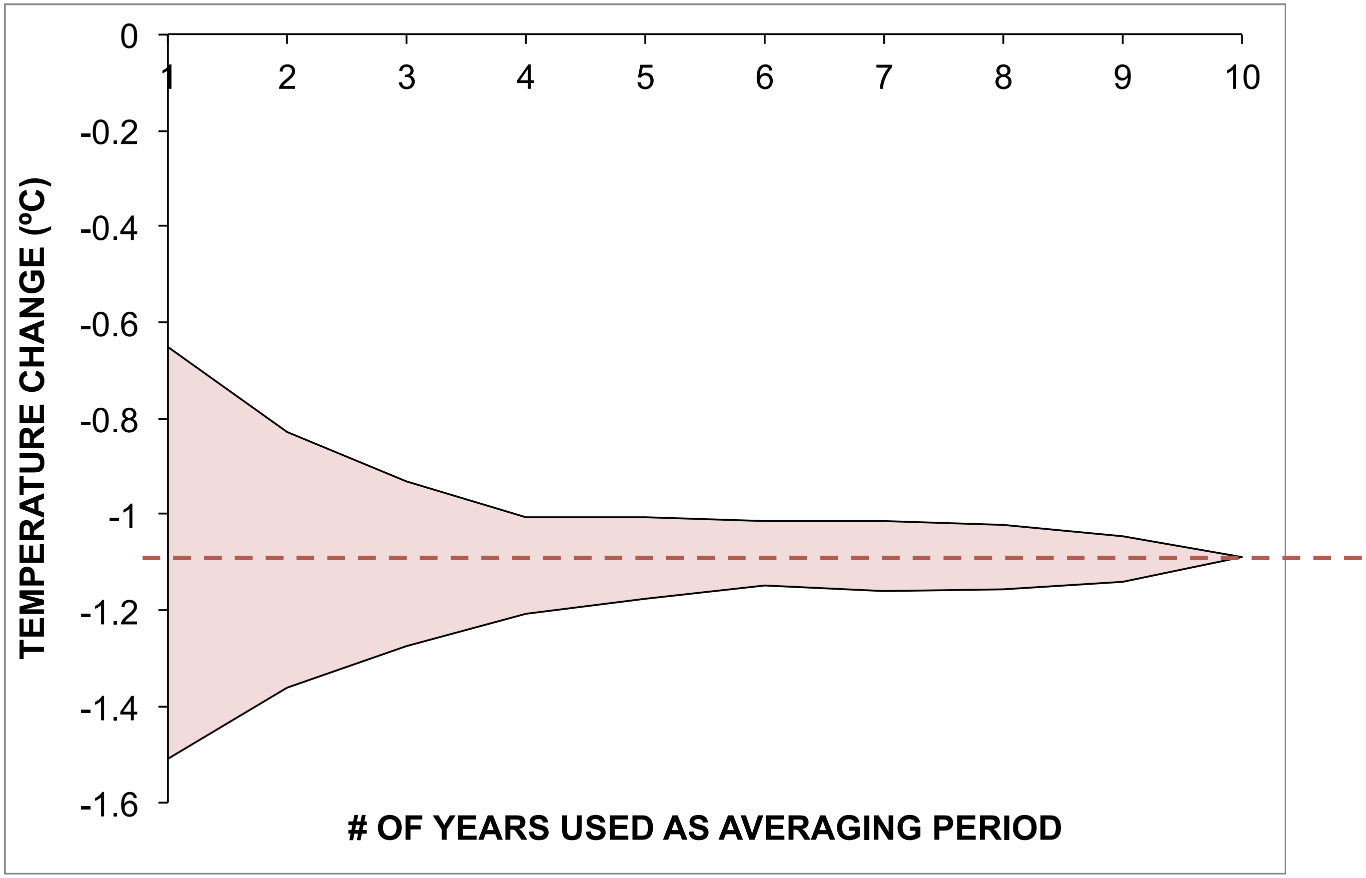
$$\Delta T_{surface} = T_{surface(alb0.40)} - T_{surface(control)}$$



Urban areas cooler on average due to albedo change

Once we consider at least 5 years of temperature data

Important to consider multiple years of climate data

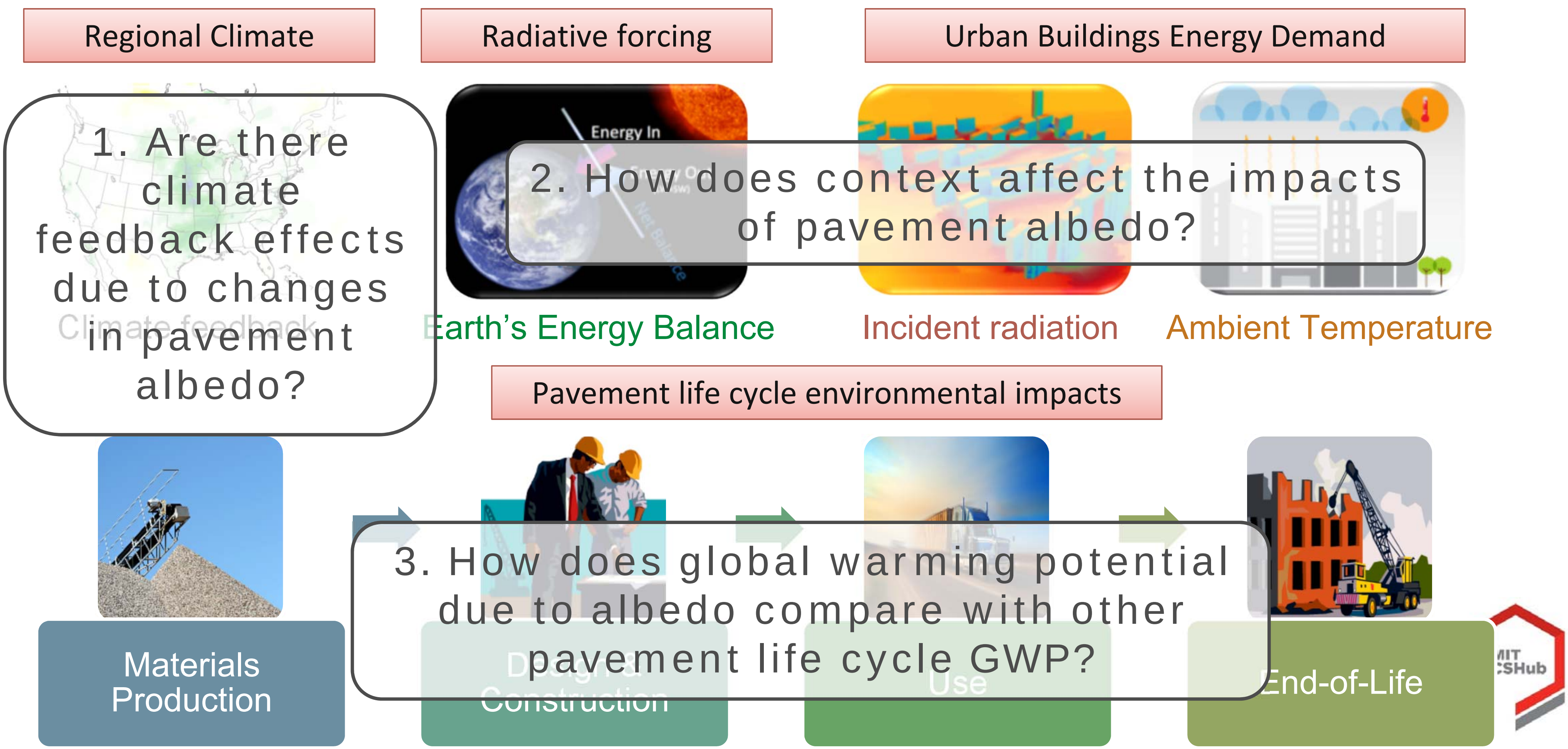


Are there climate feedback effects due to changes in pavement albedo?

No – based on multiple years of climate simulations

Urban areas cooler on average

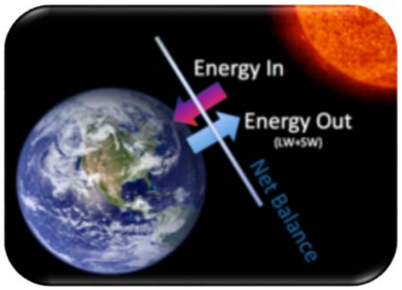
Research questions and approach



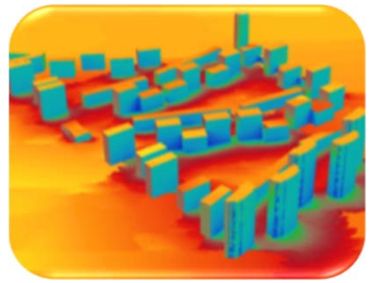
Albedo Impacts Radiative Balance & Urban Energy Demand

Radiative Forcing

Urban Buildings Energy Balance



Earth's Energy Balance



Incident radiation

Ambient Temperature

Increasing pavement albedo

- Negative RF
- Cooling benefits

- Increased cooling
- Reduced heating

- Reduced cooling
- Increased heating

NET EFFECT?

Depends on location, climate, urban geometry, building properties, energy grid and efficiency, etc.

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Approach: calculate NET effects of RF & BED

Radiative forcing

- Develop analytical model accounting for
  - Solar radiation intensity
  - Solar zenith angle
  - Cloudiness
- Case study of 14 representative locations
- Nationwide analysis

Building energy demand

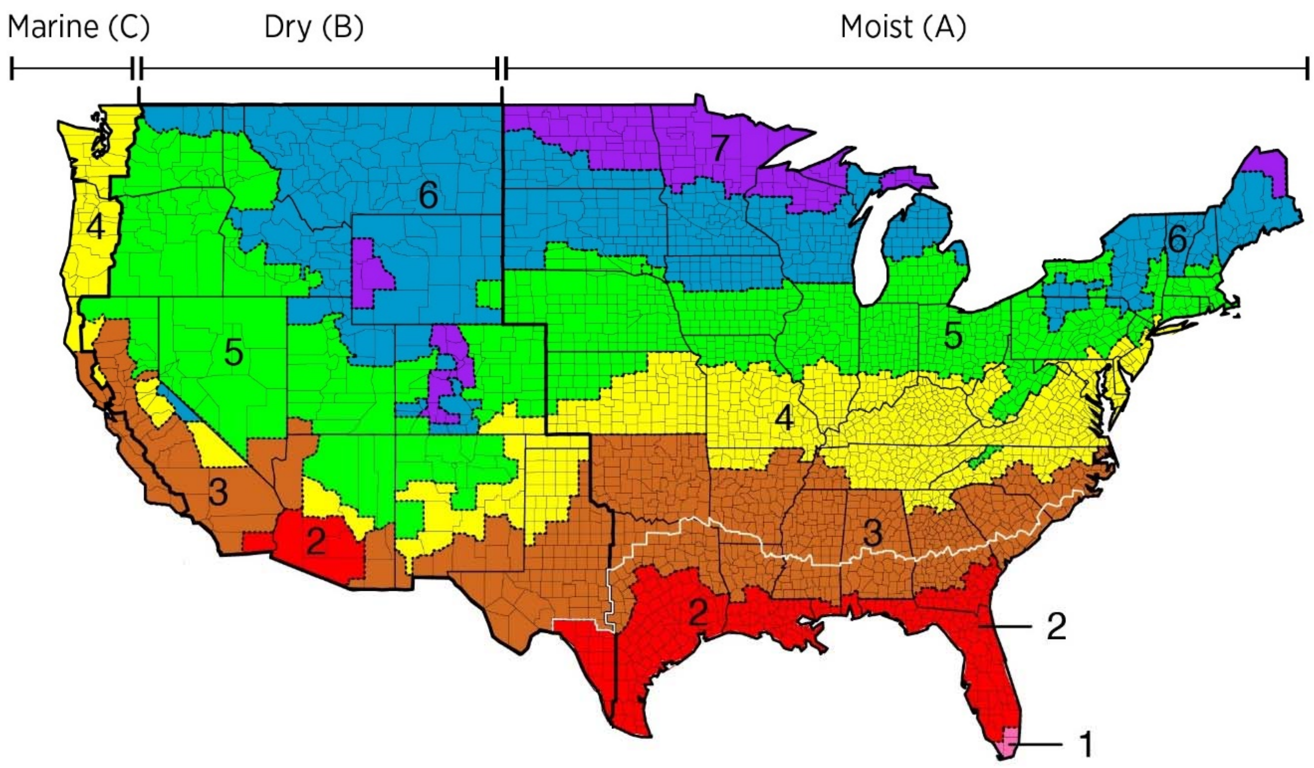
- Parametric analysis on impact of urban morphology
- Develop context-specific BED model
  - Microclimate
  - Urban morphology
- Case study of Boston using GIS data

Quantifying location-specific impacts of pavement albedo on radiative forcing using an analytical approach

- Model-based parameterization considering solar intensity, cloud transmittance and solar angle
- Location-specific data from climate simulations
- Incorporating urban transmittance to account for shading effect in urban areas
- Change of pavement albedo decay linearly over time

Explore climate change mitigation potential of pavement albedo via radiative forcing

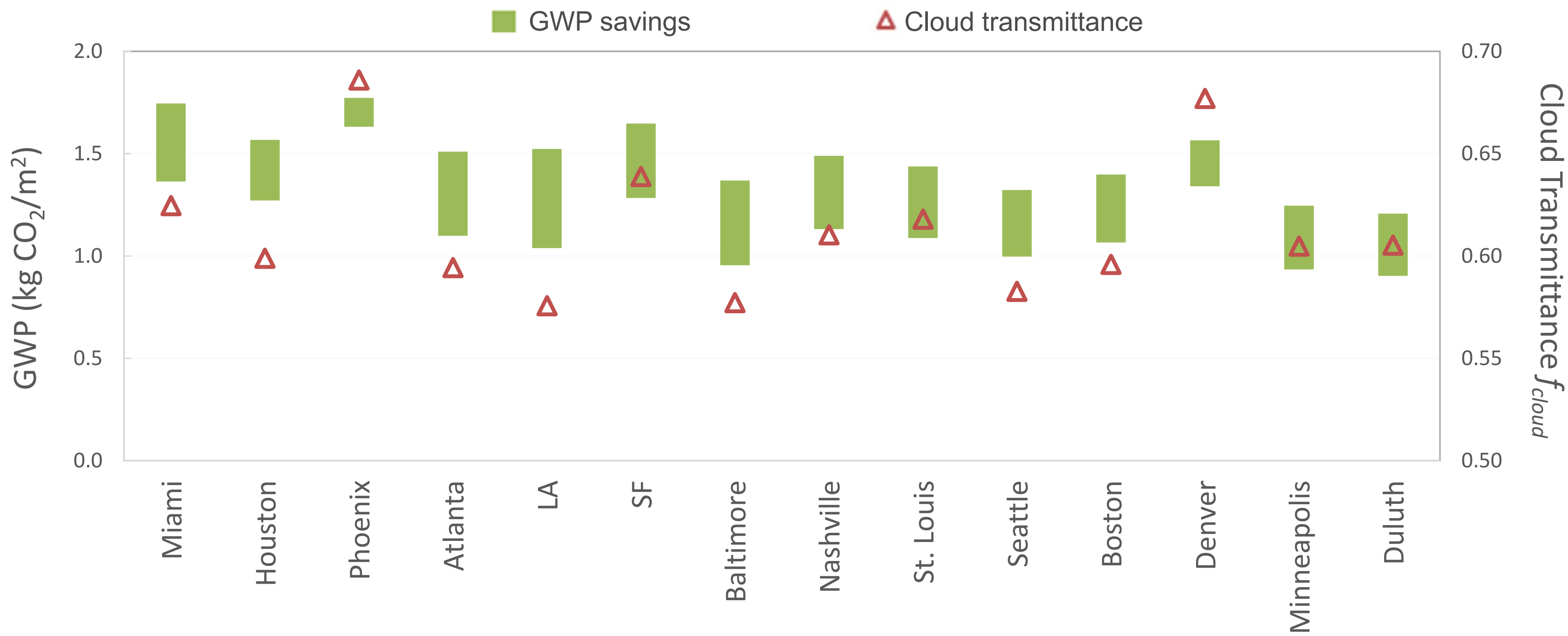
14 cities chosen representative of 7 different climate zones



Climate zone 1 – Very hot-humid – Miami FL
Climate zone 2A – Hot-humid – Houston, TX
Climate zone 2B – Hot-dry – Phoenix, AZ
Climate zone 3A – Warm-humid – Atlanta, GA
Climate zone 3B – Warm-dry – Los Angeles, CA
Climate zone 3C – Warm-marine – San Francisco, CA
Climate zone 4A – Mixed-humid – Baltimore, MD
Climate zone 4A – Mixed-humid – Nashville, TN
Climate zone 4A – Mixed-humid – St. Louis, MO
Climate zone 4C – Mixed-marine – Seattle, WA
Climate zone 5A – Cool-humid – Boston, MA
Climate zone 5B – Cool-dry – Denver, CO
Climate zone 6 – Cold-humid – Minneapolis, MN
Climate zone 7 – Very cold – Duluth, MN

Location-specific RF estimate of higher-albedo pavements

GWP savings from RF due to 0.01 increase in pavement albedo for the selected 14 locations over 50 years

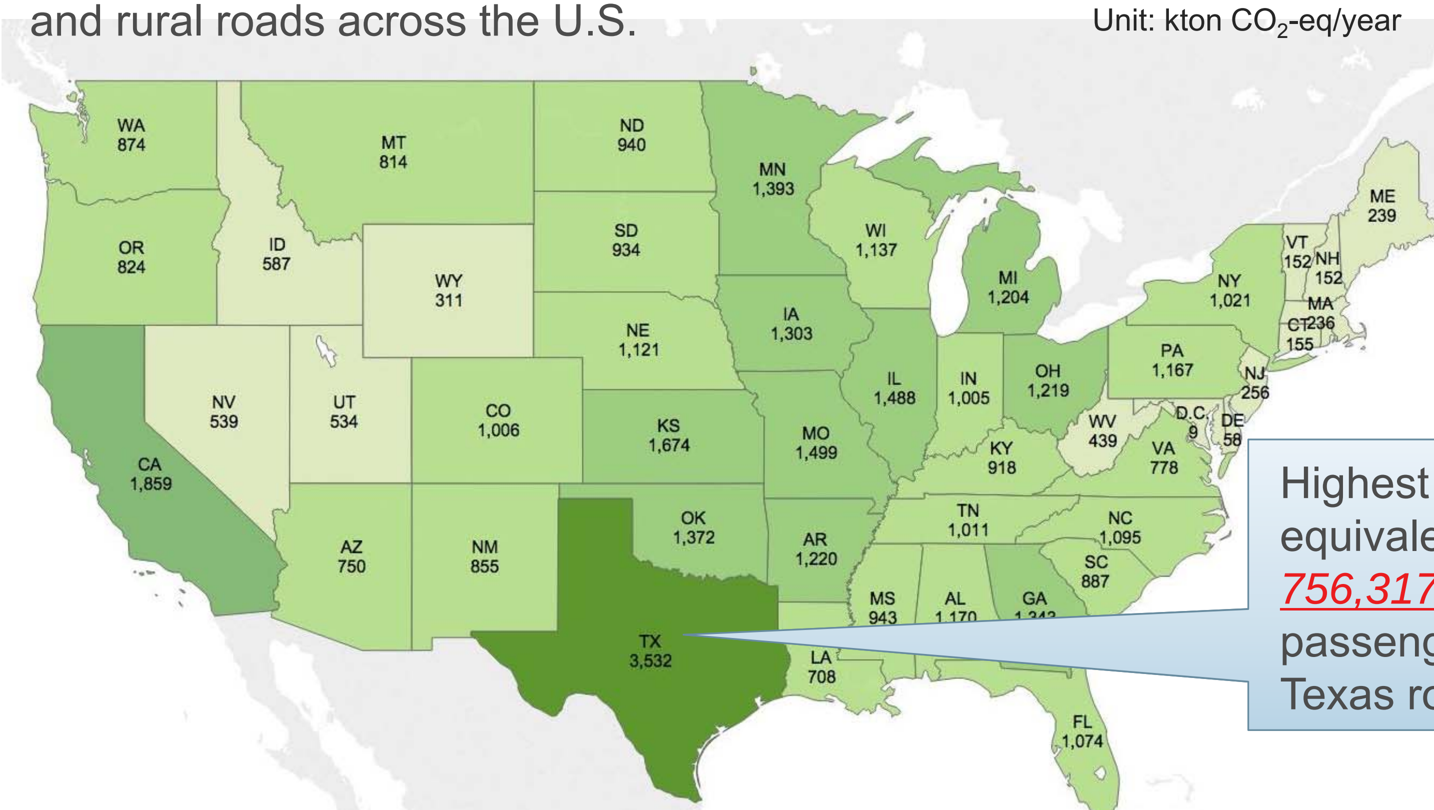


GWP savings highly correlate with cloud transmittance f_{cloud}

Nationwide analysis of pavement albedo impact on RF

Annual GWP savings from RF due to 0.2 albedo increase in all urban and rural roads across the U.S.

Unit: kton CO_2-eq/year



Highest GWP savings: equivalent to removing *756,317* or *9%*, of passenger vehicles from Texas roads for one year.

Nationwide, savings would be equivalent to removing nearly *9.4 million*, or roughly *8%,* of passenger vehicles

Approach: calculate NET effects of RF & BED

Radiative forcing

- Develop analytical model accounting for
  - Solar radiation intensity
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Building energy demand

- Parametric analysis on impact of urban morphology
- Develop context-specific BED model
  - Microclimate
  - Urban morphology
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Building energy modeling at urban scale

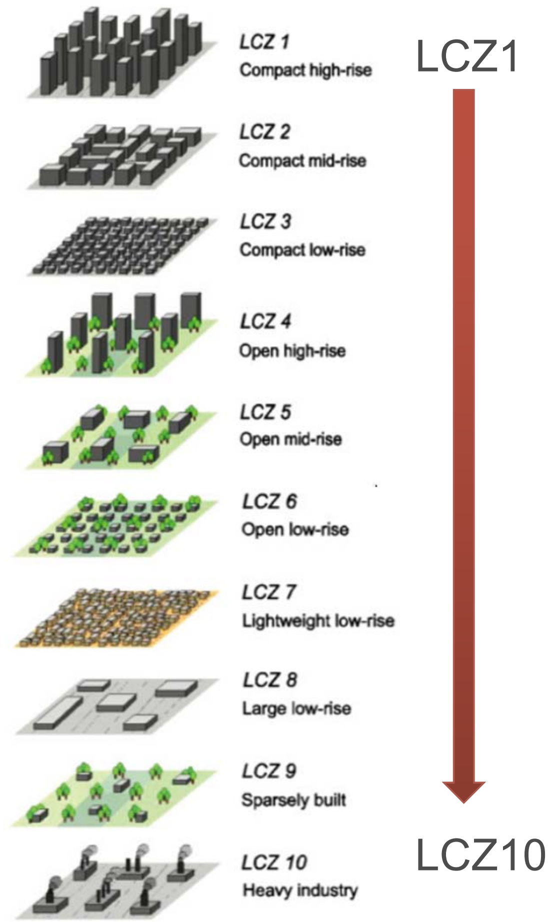
Goal: To estimate albedo-induced BED at urban scale for any given context

Modeling approaches:

- **Top-down**: Doesn't allow for investigation of urban context
- **Bottom-up**: Computationally prohibitive

→ **Combined approach**

Categorizing urban neighborhoods using local climate zones



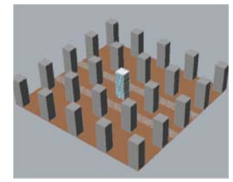
I. D. Stewart, and T. R. Oke. 2012. "Local Climate Zones for Urban Temperature Studies." Bulletin of the American Meteorological Society 93(12): 1879–1900.

Integrated tools for quantifying context-specific BED at neighborhood scale

STEPS | TOOLS | OUTPUTS

Step 1:
Urban geometry generation for LCZs

Rhinoceros NURBS modeling for Windows
grasshopper

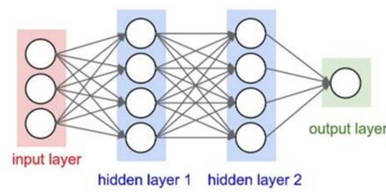


Step 2:
Parametric design of experiment
for energy consumption for LCZs

Urban Weather Generator (UWG)

ΔE_R & ΔE_T for LCZs

Step 3:
Energy metamodel development

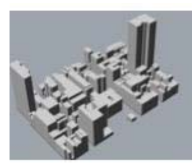


$\Delta\alpha$
ρ_b
H/W
S/V
⋮

Metamodels

ΔE

Step 4:
Application of metamodel with GIS data



GIS Data

Morphological parameters & ΔE

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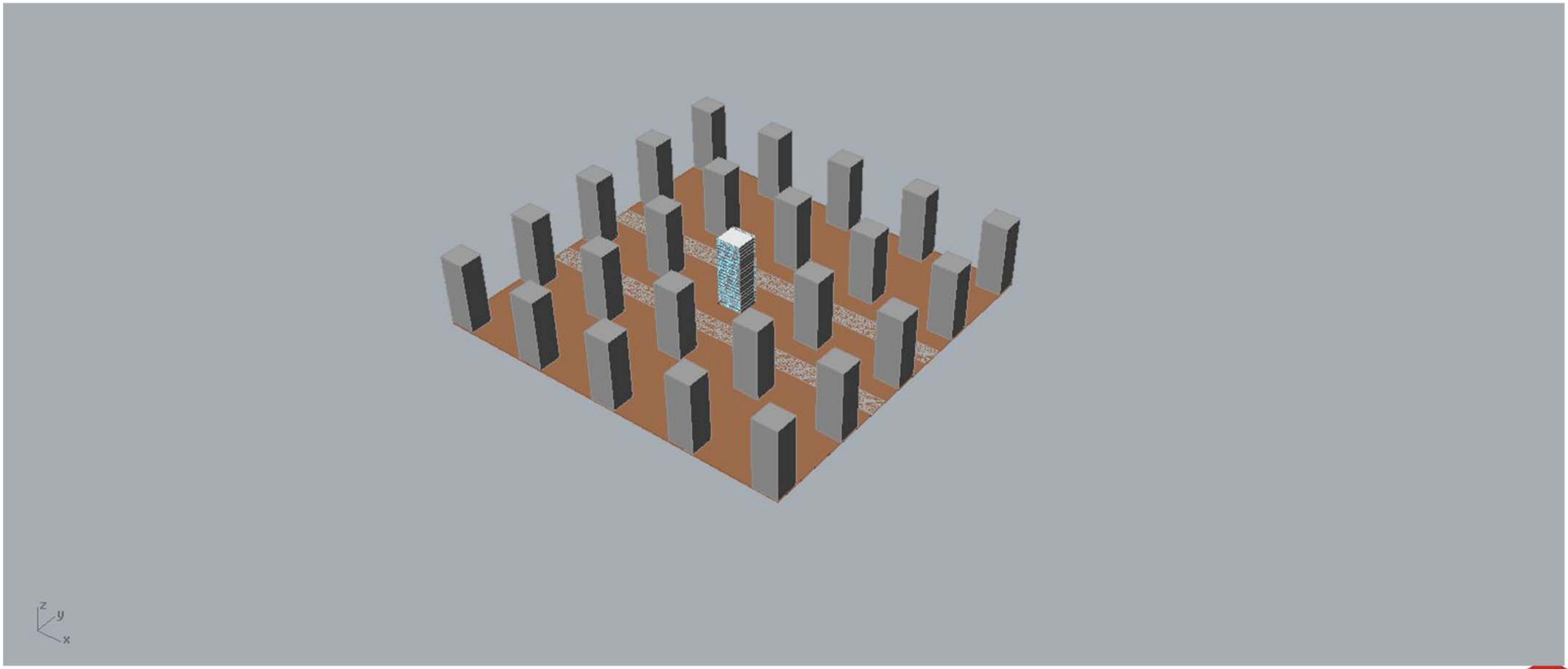
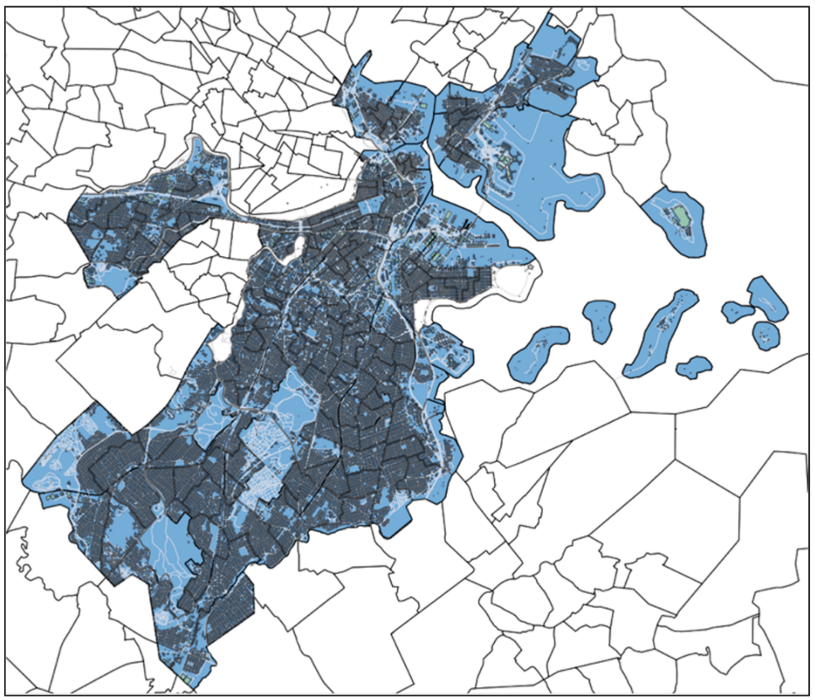
Urban geometry generation for parametric analysis



Realistic neighborhoods in Boston using GIS data

Data sources: City of Boston and State of Massachusetts

Data processed and visualized with *QGIS* and *Tableau*



Boston

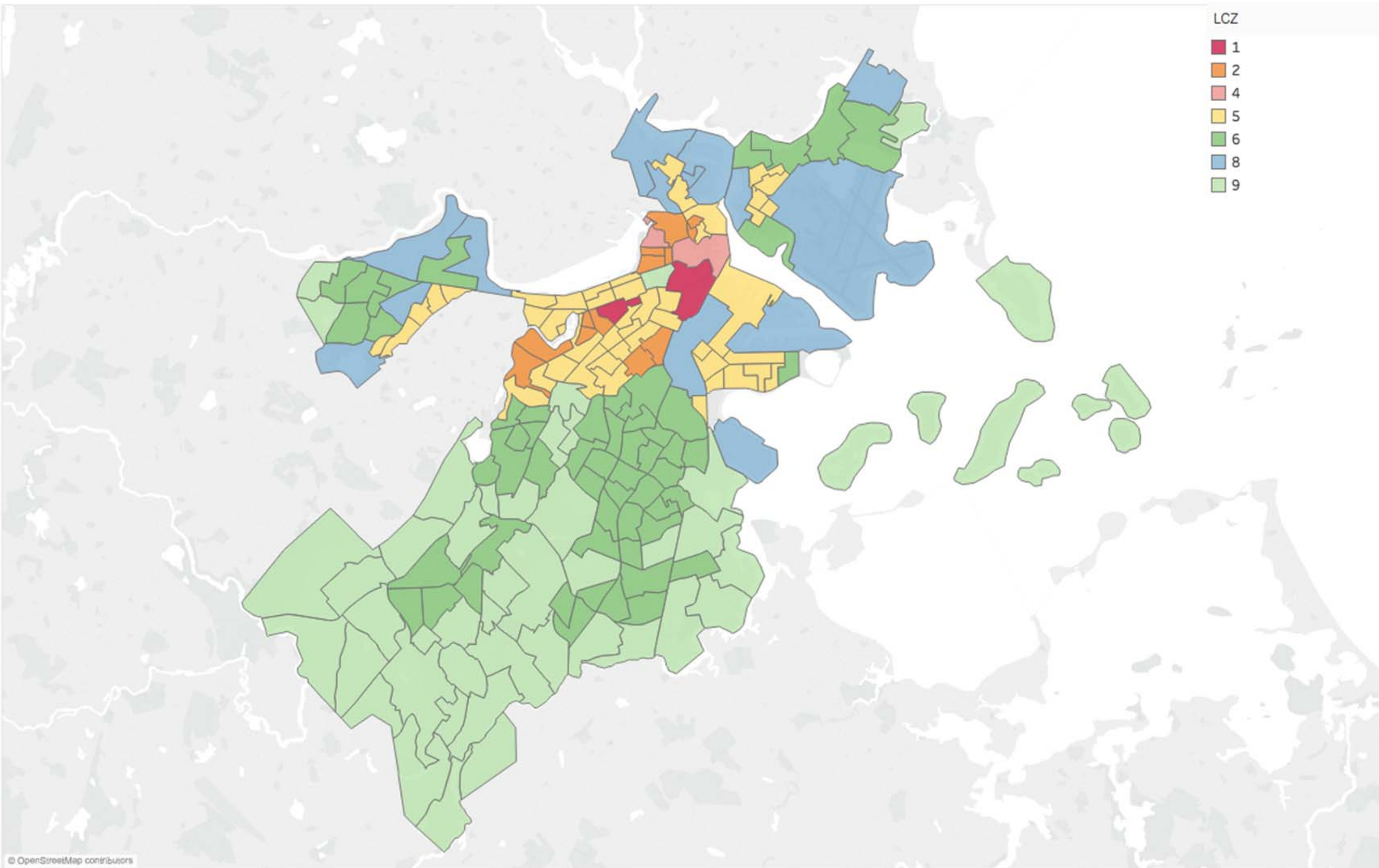
- 177 census tracts
- 129,370 buildings
- 20,224 road sections

Parameter to extract:

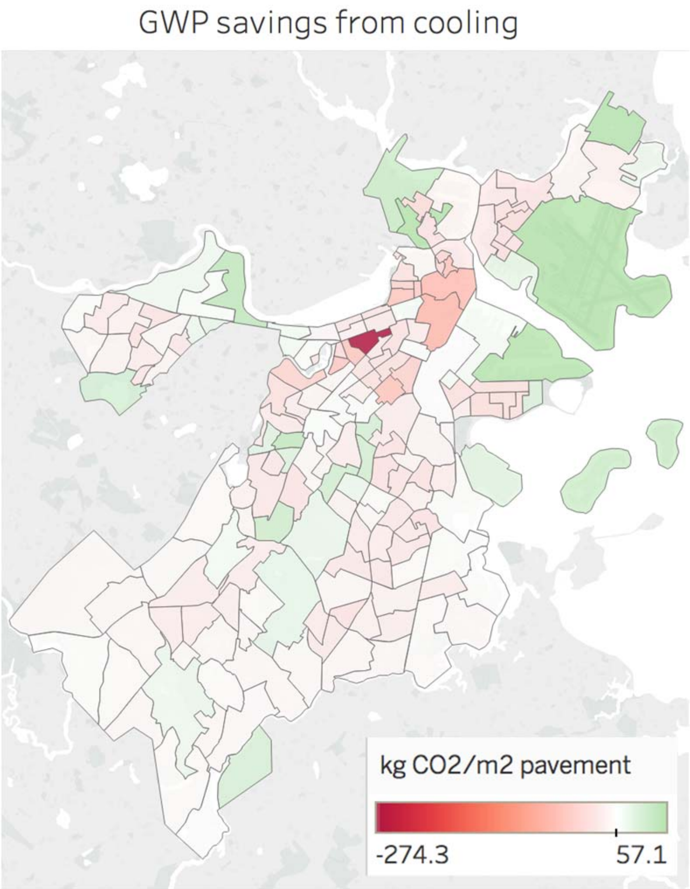
- Avg. building height
- Avg. building length
- Canyon aspect ratio
- Building density

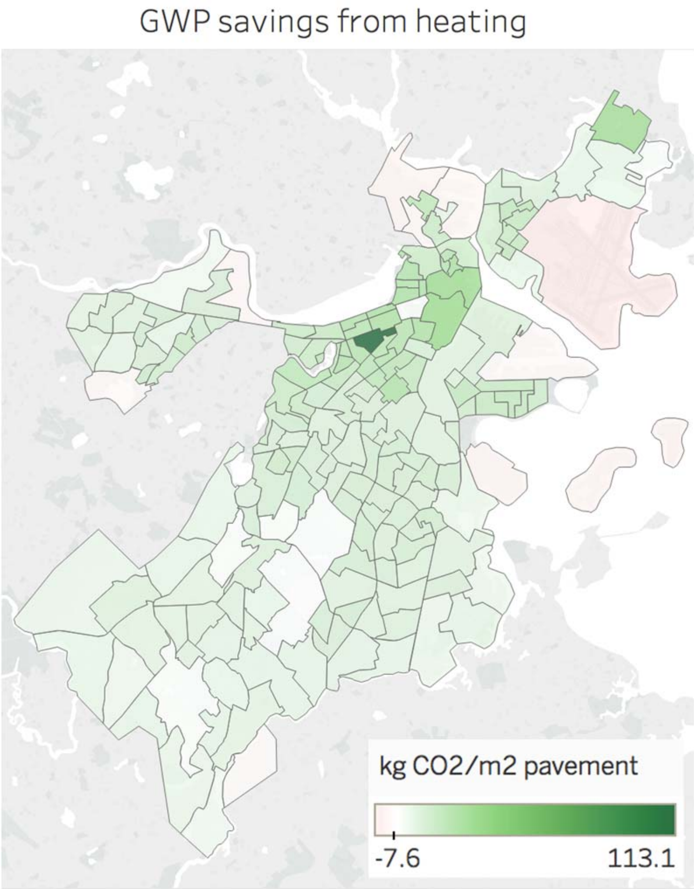
Results for Boston: Local Climate Zones

Boston Local Climate Zones

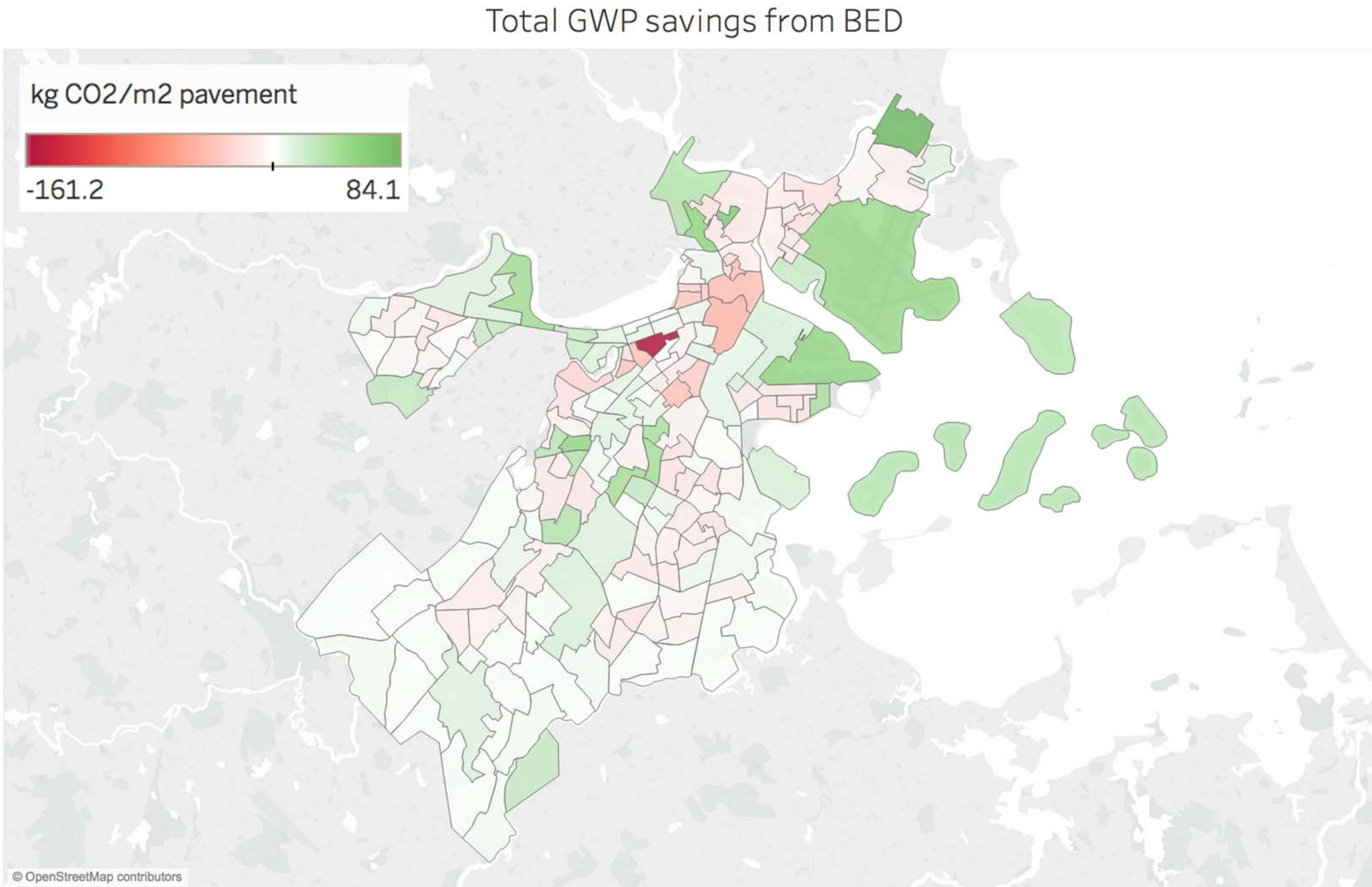


GWP savings from BED
due to 0.2 increase in pavement albedo for 50 years

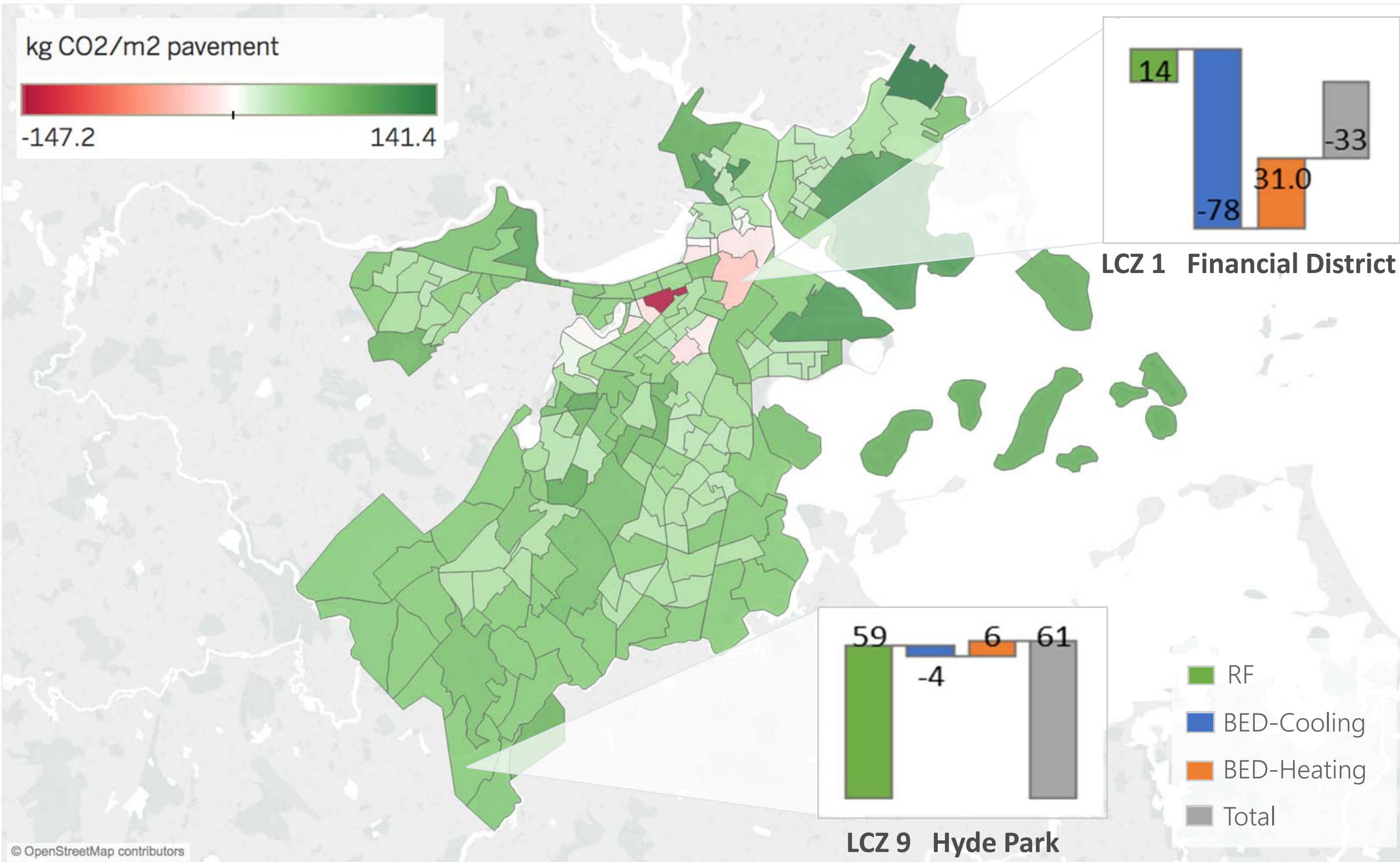




Total GWP savings from BED
due to 0.2 increase in pavement albedo for 50 years



Net GWP savings from BED and RF
due to 0.2 increase in pavement albedo for 50 years



GIS data enables highly localized analyses

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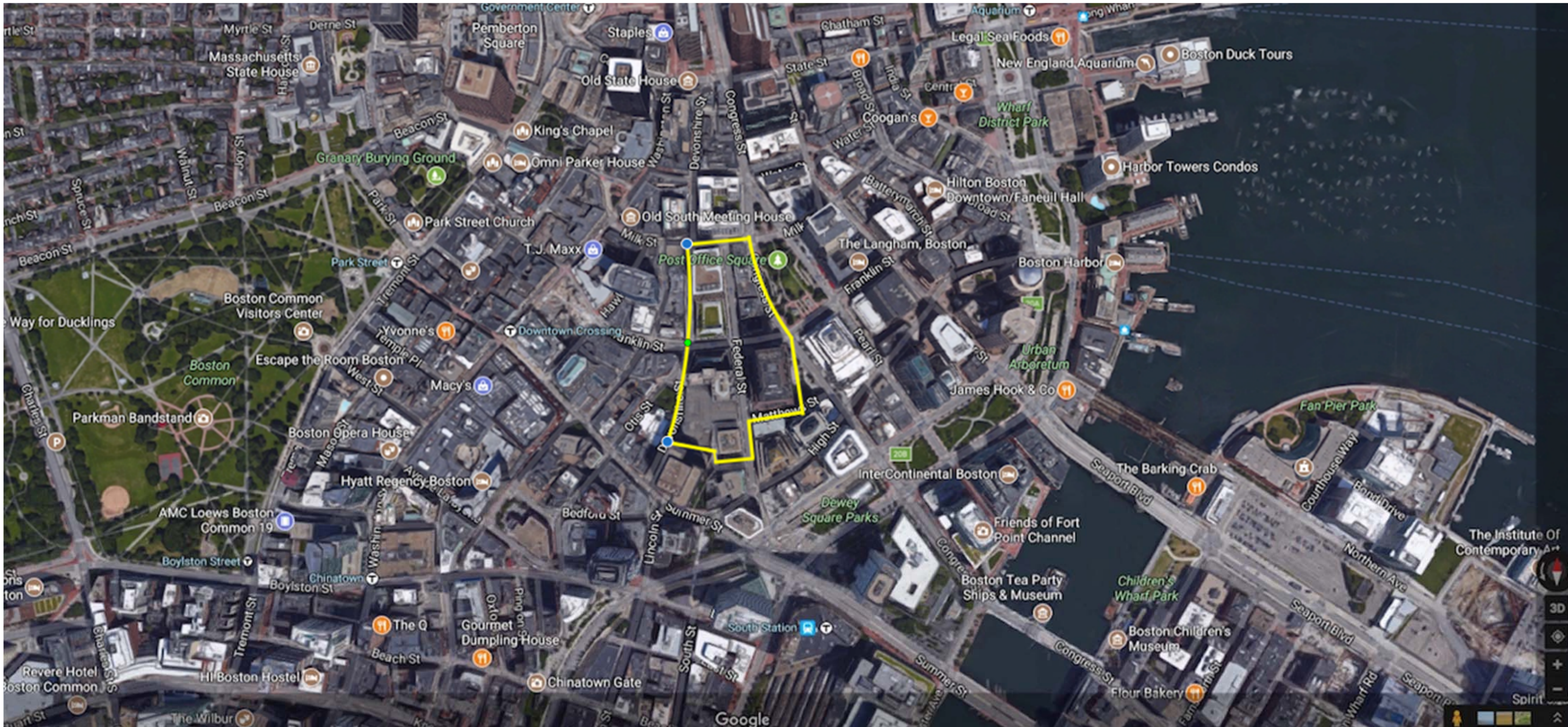
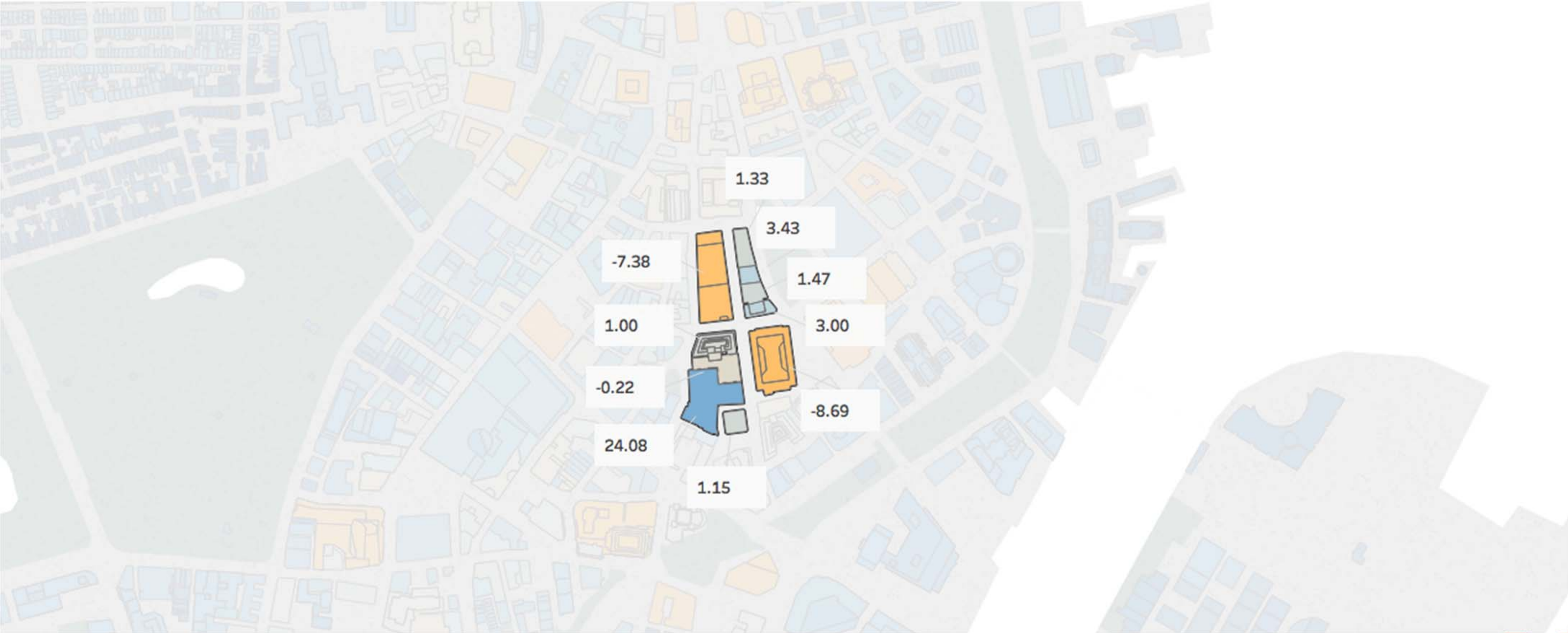


GIS data enables highly localized analyses



How does context affect the impacts of pavement albedo?

For Boston location and climate:

- Dense, urban neighborhoods:
  - BED larger than RF due to shading
  - GWP is a net burden
- Most other neighborhoods:
  - RF larger than BED
  - GWP is a net savings

Next: evaluate other locations and climates and impacts of aggregation

Research questions and approach

Regional Climate

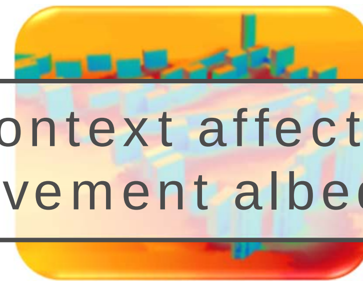
Radiative forcing

Urban Buildings Energy Demand

1. Are there climate feedback effects due to changes in pavement albedo?

Climate feedback

Earth's Energy Balance



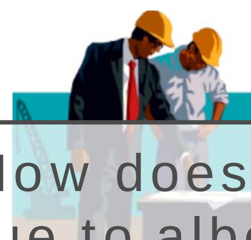
Incident radiation

Ambient Temperature

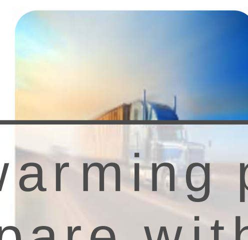
2. How does context affect the impacts of pavement albedo?

Pavement life cycle environmental impacts

Materials Production



Design & Construction



Use

End-of-Life

3. How does global warming potential due to albedo compare with other pavement life cycle GWP?

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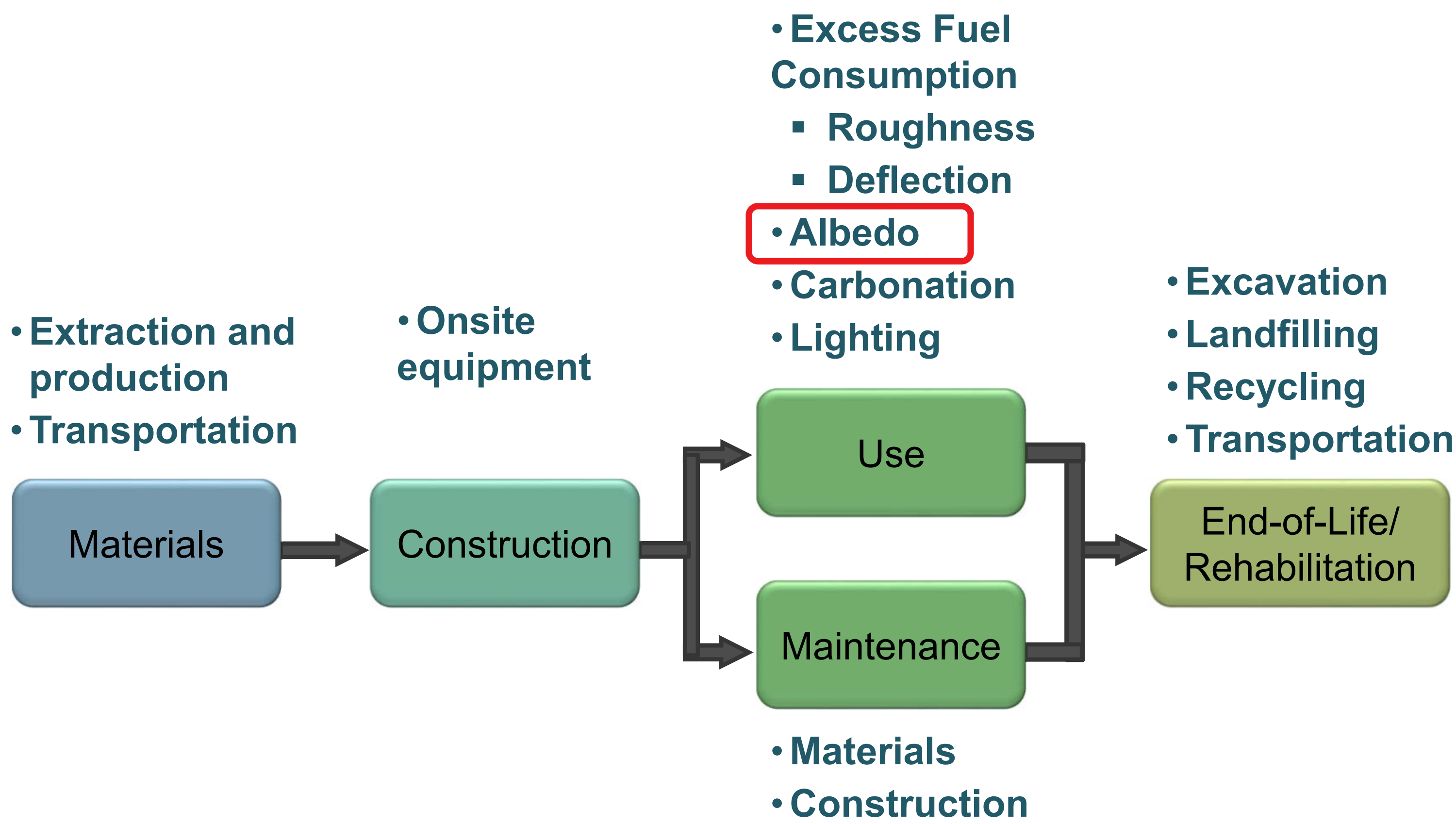
Sustainable pavement design decisions

- Pavement life cycle: Should one use materials with recycled content, or increase surface albedos?
- What are life cycle environmental impacts of cool pavements?

Pavement life cycle assessment model



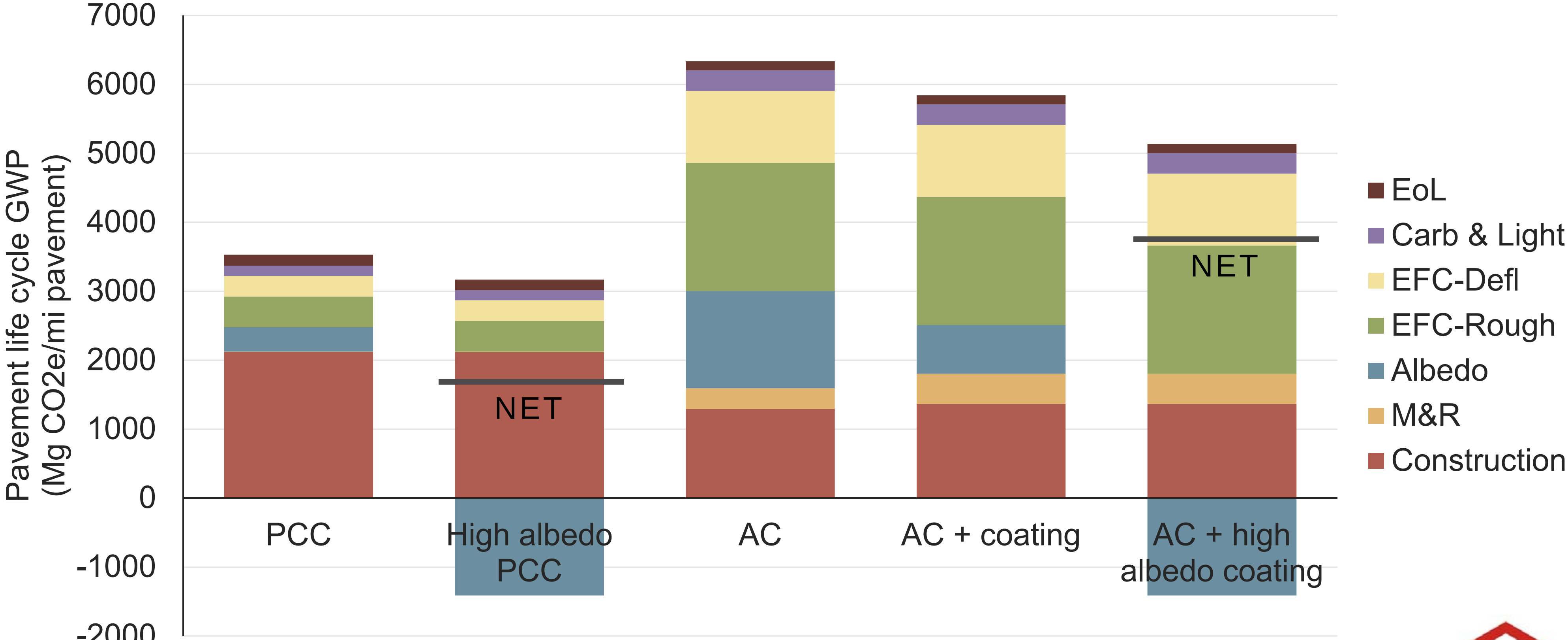
Pavement scenarios for Boston LCZ9 Census Tract

Key question: is climate change and/or UHI mitigation explicitly part of pavement design goal?

New construction	Rehabilitation	Aged Albedo
PCC	Full depth repair	0.25
High albedo PCC	Full depth repair	0.5
AC	Mill & fill AC overlay	0.1
AC + coating	Mill & fill AC overlay + reflective coating	0.25
AC + high albedo coating	Mill & fill AC overlay + high albedo reflective coating	0.5

Pavement designs and maintenance scenarios created by a pavement engineer for urban traffic loads
Aged albedo values from UCPRC and LBNL, except *AC+ high albedo coating*

Pavement life cycle GWP breakdown for Boston LCZ9



Albedo impacts relative to baseline of average earth albedo (0.3)

M&R=maintenance & rehabilitation; EFC= excess fuel consumption; Defl=deflection; Rough=roughness; Carb&Light= carbonation & lighting; EoL= end-of-life

How does global warming potential due to albedo compare with other pavement life cycle GWP?

Preliminary results:

- Comparison of scenarios depends on goal: include climate change and/or UHI mitigation?
- Albedo can be significant portion of pavement life cycle GWP

Next:

- Evaluate relative impacts of albedo for range of scenarios: location, climate, LCZs, materials, M&R, albedos
- Analyze impacts of uncertainty

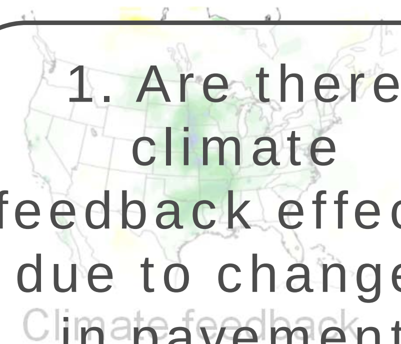
Research questions and approach

Regional Climate

Radiative forcing

Urban Buildings Energy Demand

1. Are there climate feedback effects due to changes in pavement albedo?



Climate feedback

Earth's Energy Balance

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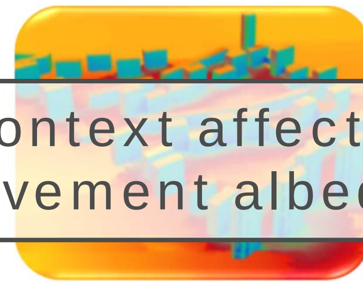
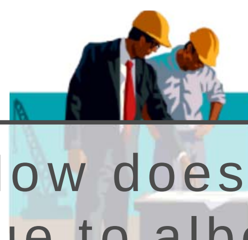


Incident radiation

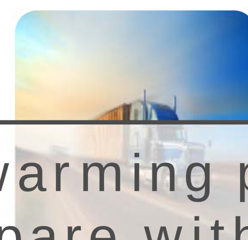
Ambient Temperature

Pavement life cycle environmental impacts

Materials Production



Design & Construction



Use

End-of-Life

3. How does global warming potential due to albedo compare with other pavement life cycle GWP?

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Overall Conclusions

- Increasing pavement albedo has significant potential to mitigate impacts of climate change and UHI effects
- Climate simulation models should be run for several years
- Significant opportunity for RF benefits at the national level
- BED impacts depend on urban morphology and favor less dense neighborhoods
- RF is more significant in most neighborhoods
- Albedo can be a significant portion of pavement life cycle environmental impacts, but is context sensitive

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Thank You!

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