A Planetary-Scale Data–Model Integration Framework to Resolve Urban Impacts Across Scales

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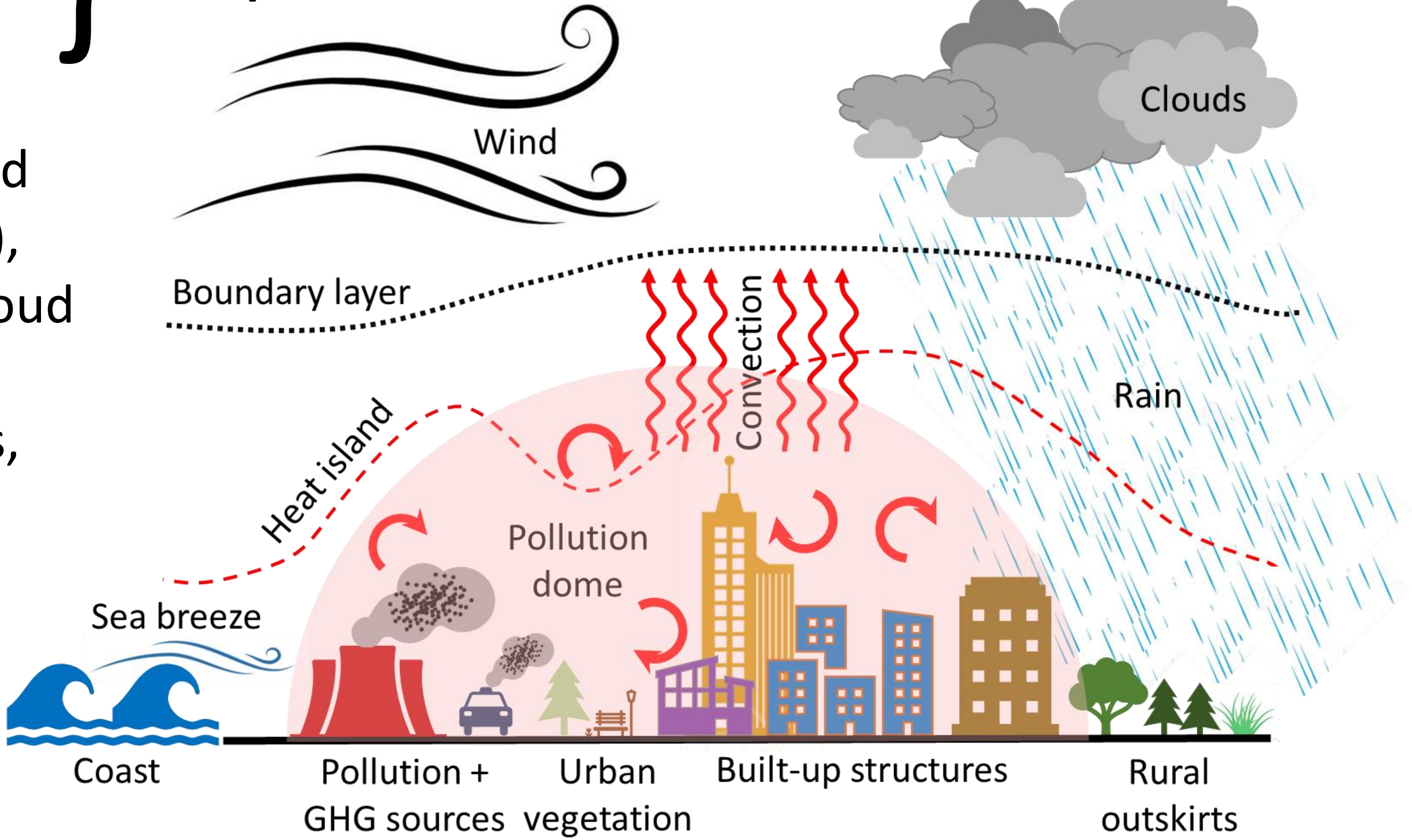
Urban impacts on weather and climate

Increase in urban extent + changes in surface properties + anthropogenic activities } = Impacts on weather and climate

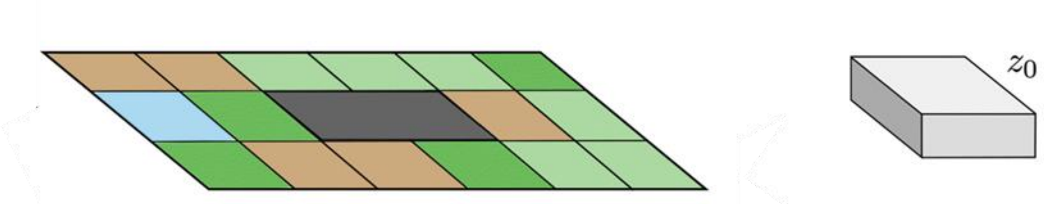
- Urbanization causes localized warming (urban heat island), drying (urban dry island), cloud formation and precipitation over and downwind of cities, enhanced air pollution, etc.
- Urban growth and densification may lead to further feedbacks to the atmosphere



Modified from Qian, Chakraborty *et al.*, 2022

Urban representation in Earth system models

Mostly slabs or no urban



- Urban areas are rarely represented in global models
- We assume that urban land fraction is small and won't impact broader climate
- The few global models with urban representation are too simple

Urban representation in Earth system models

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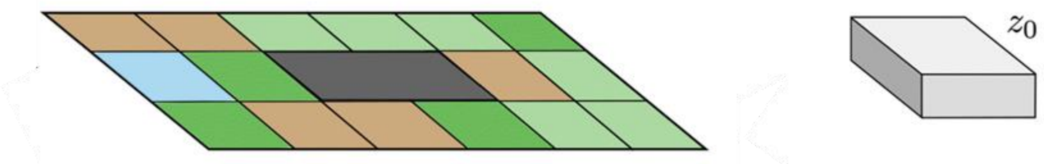

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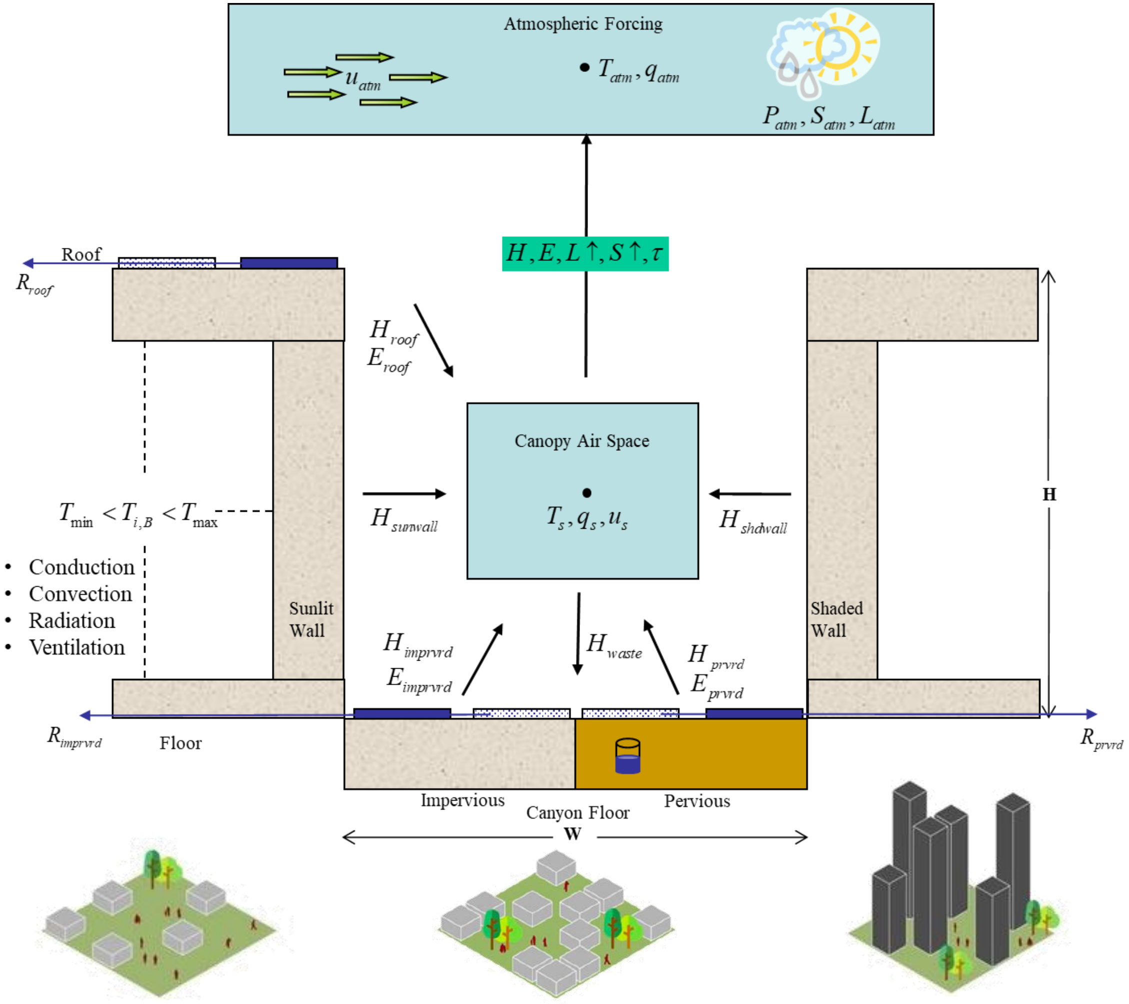
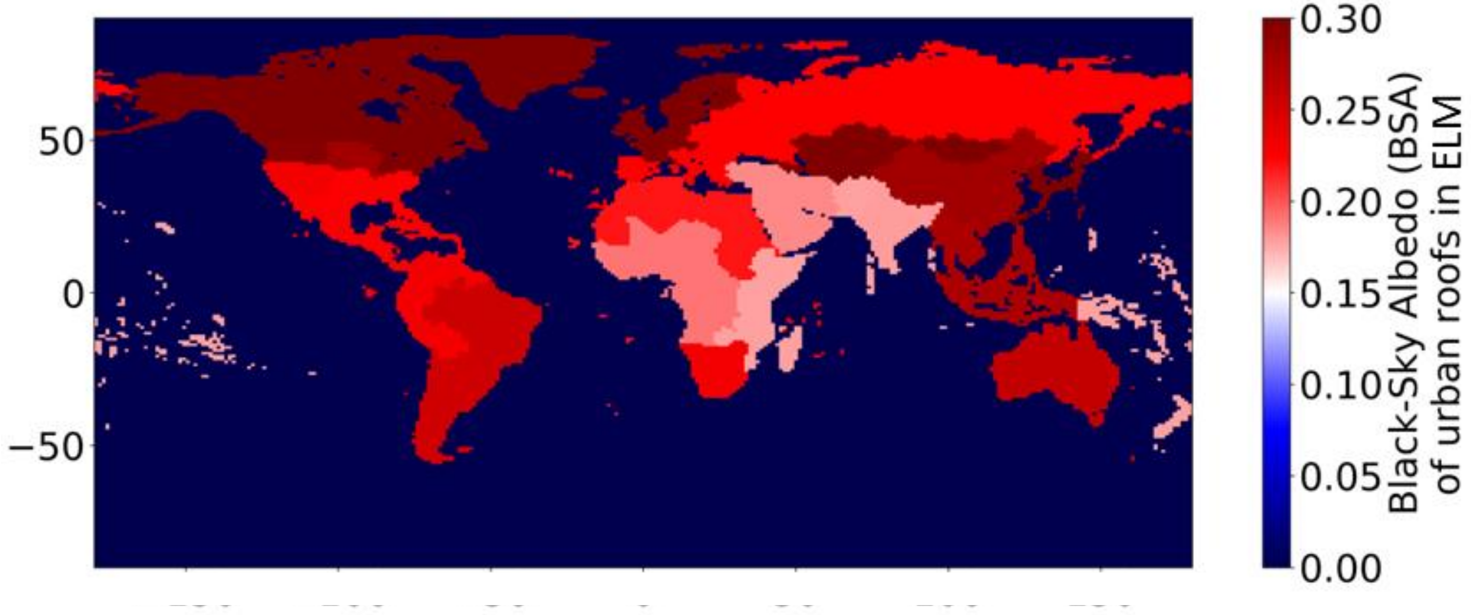
E3SM: DOE's Energy Exascale Earth System Model

Urban canopy structure in E3SM



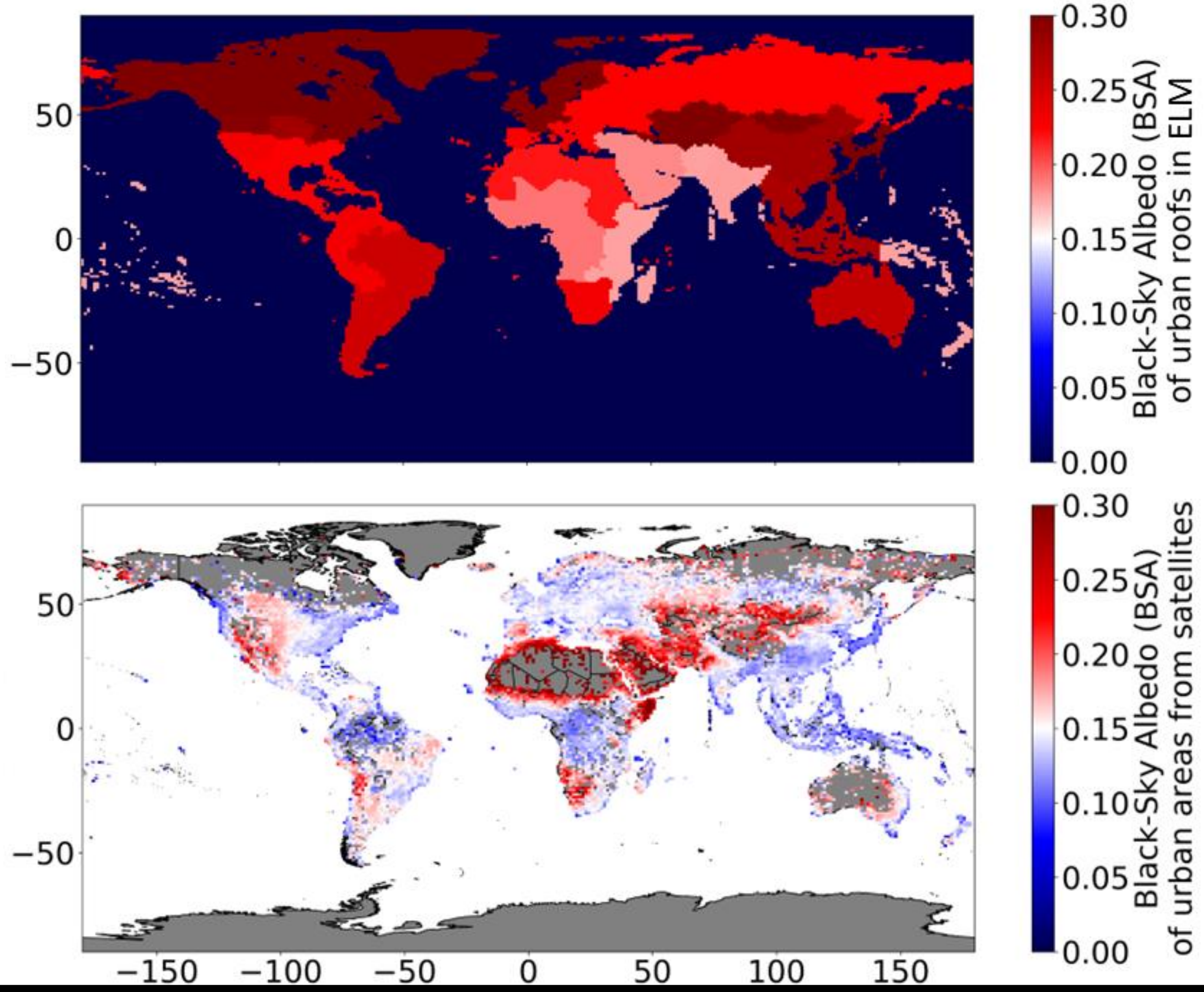
Medium Density **High Density** **Tall Building District**

Poor surface constraints for urban areas



- In E3SM, the world is divided into 33 regions, each with unique values for urban radiative, thermal, and morphological parameters

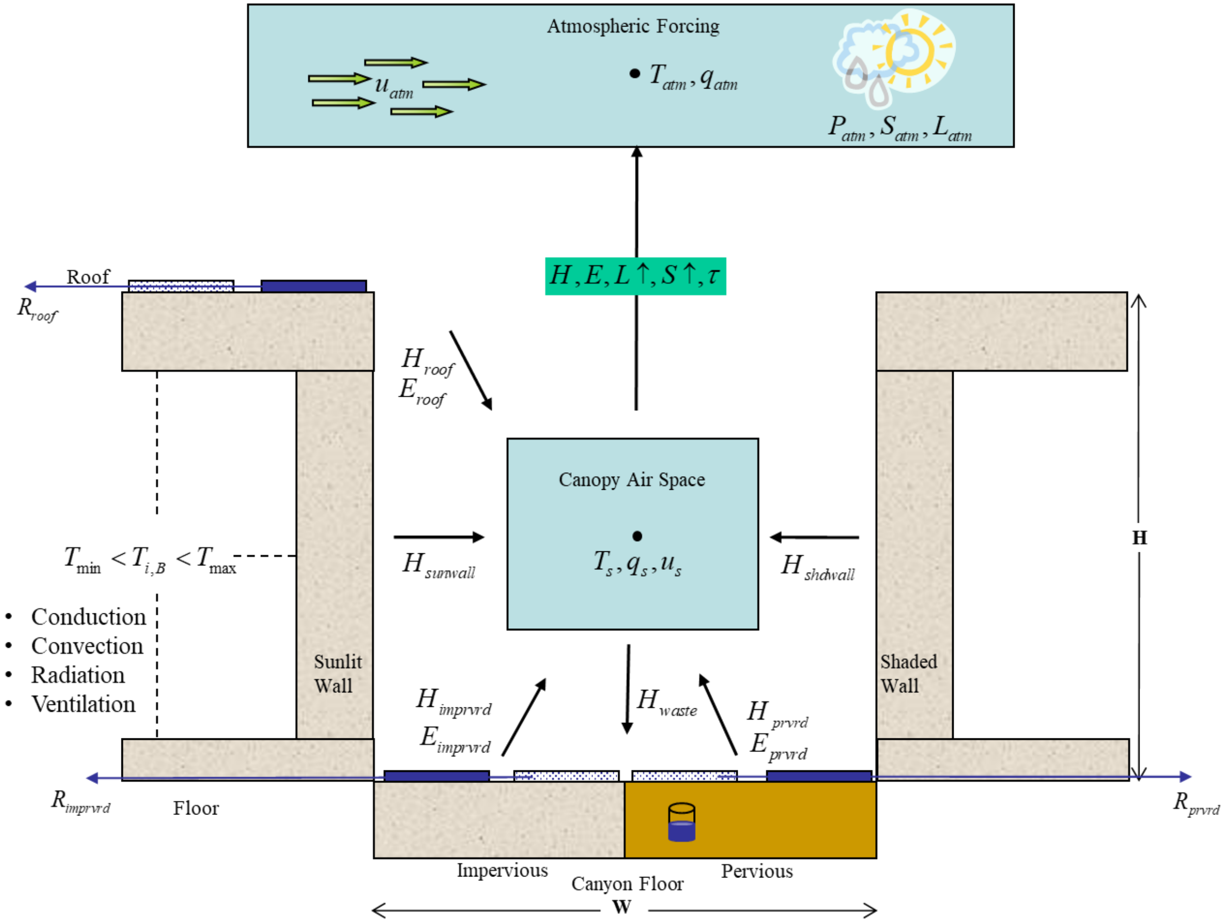
Poor surface constraints for urban areas



- In E3SM, the world is divided into 33 regions, each with unique values for urban radiative, thermal, and morphological parameters
- Actual variability, as seen from satellites, is much higher than what is represented in the model.
- Would strongly impact simulations of cross-sample variability in urban climate

No vegetation within urban areas

Urban canopy structure in E3SM



Modified from *Ching et al.*, 2014

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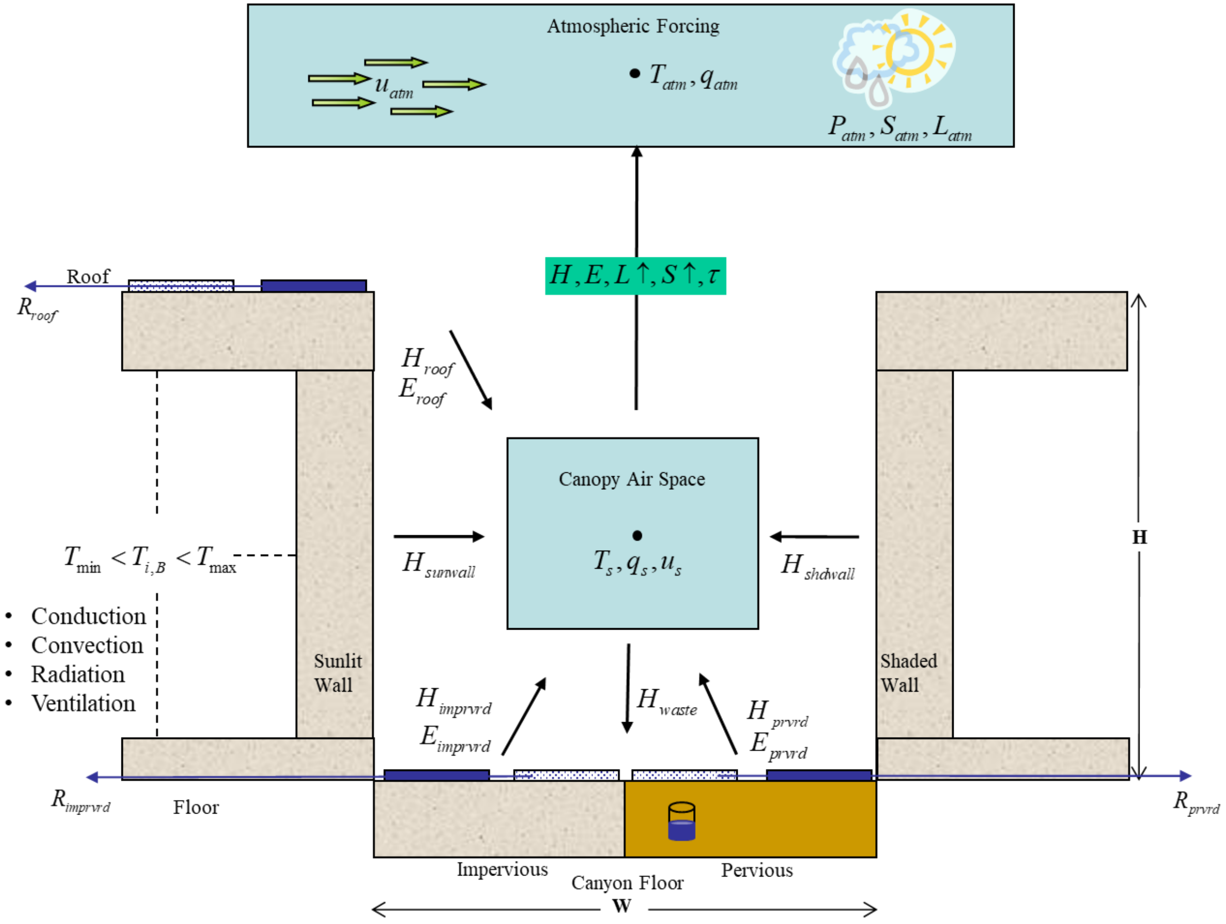
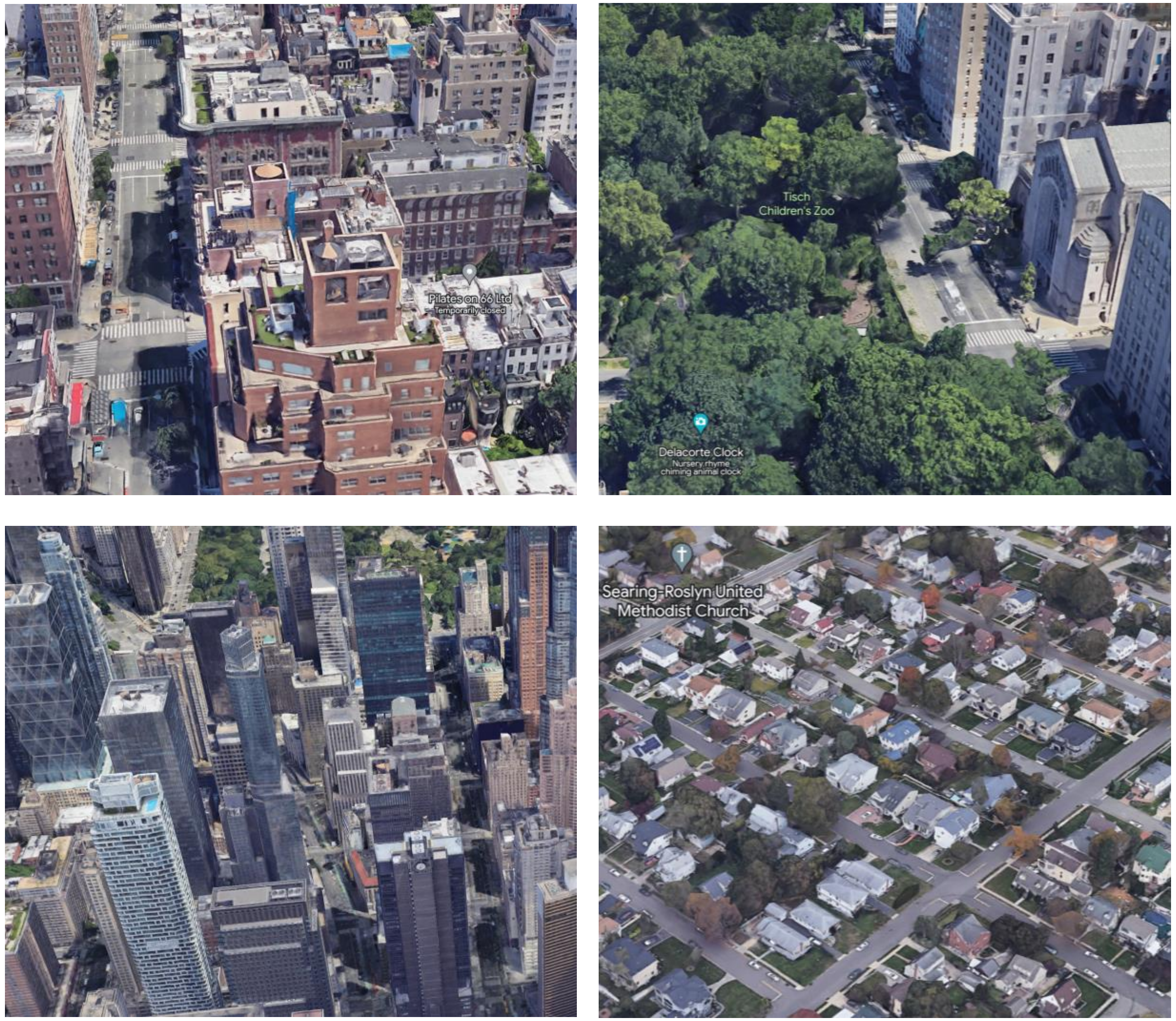
Urban canopy structure in E3SM



Real cities?



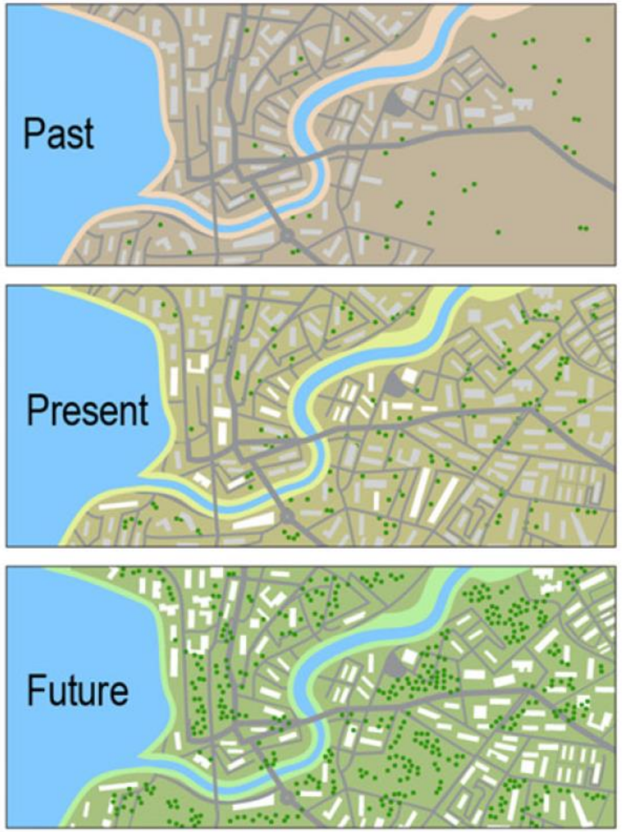
Modified from *Ching et al.*, 2014

Source: Google

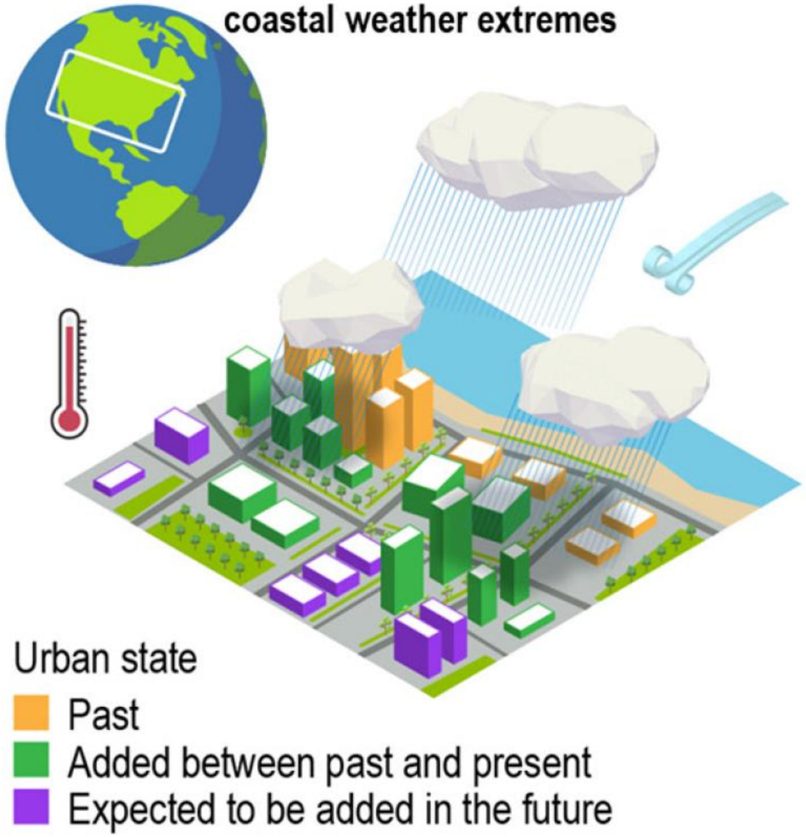
Overview of DOE Early Career Project

Objective 1: Develop a new urban parameterization for E3SM

Objective 2: Isolate the role of urban evolution on surface climate from continental to coastal scales



Objective 3: Examine urban feedbacks to the atmosphere and their impacts on U.S. coastal weather extremes



- **Explicitly represent urban vegetation and its interactions with climate**
- **Global spatially continuous urban surface dataset**

- **Spatiotemporally varying estimates of urbanization**
- **Examine urban impacts on surface climate across scales**

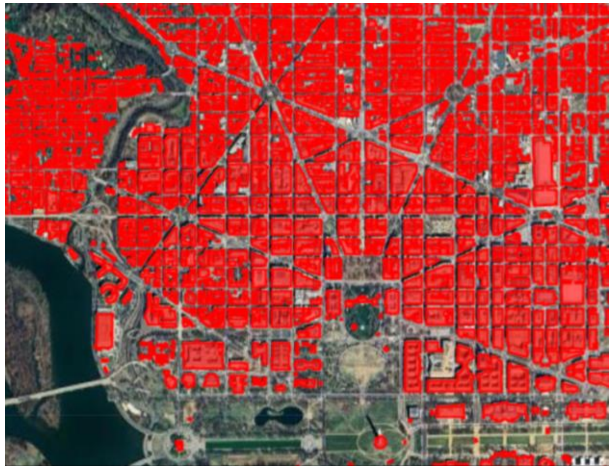
- **Isolate feedback from CONUS to e urban coastal scales**
- **Urban impacts on coastal weather extremes**

Developing a global urban surface dataset for E3SM

E3SM urban surface constraints

Radiative	Roof | Impervious Road | Pervious Road | Wall Emissivity
	Roof | Impervious Road | Pervious Road | Wall Albedo
Morphological	Roof Height
	Canyon Height-to-width Ratio
	Roof Fraction | Pervious Road Fraction
	Urban Percentage
Thermal	Numbers of impervious road layers
	Roof | Wall Thickness
	Minimum | Maximum Interior Building Temperature
	Roof | Impervious Road | Wall Thermal Conductivity
	Roof | Impervious Road | Wall Volumetric Heat Capacity

Combine high-resolution satellite-derived products with global segmentation results for buildings and roads



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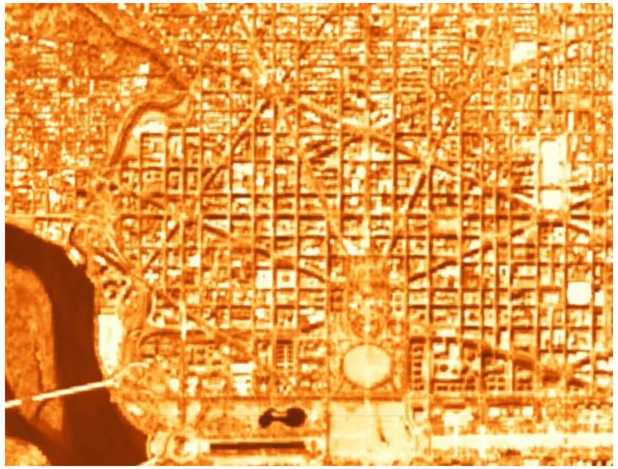
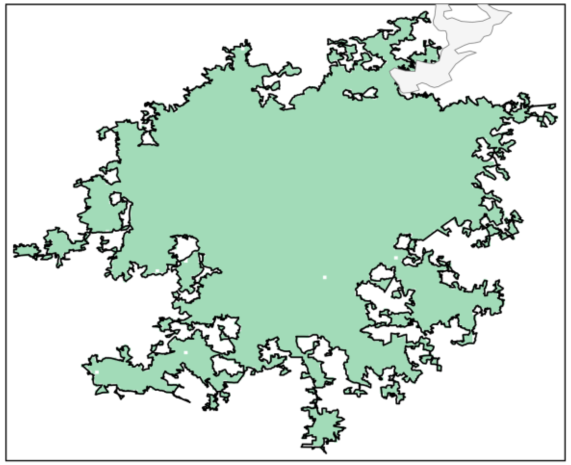
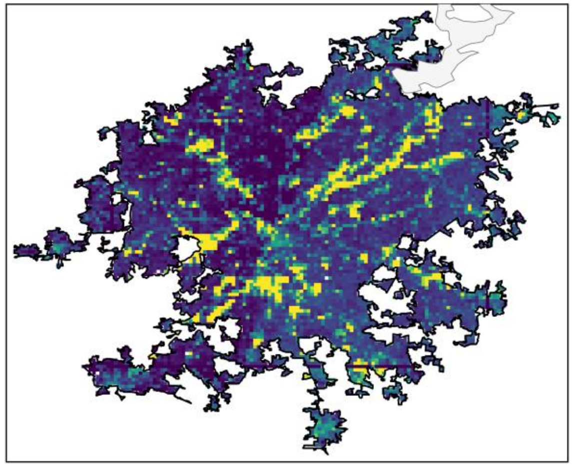


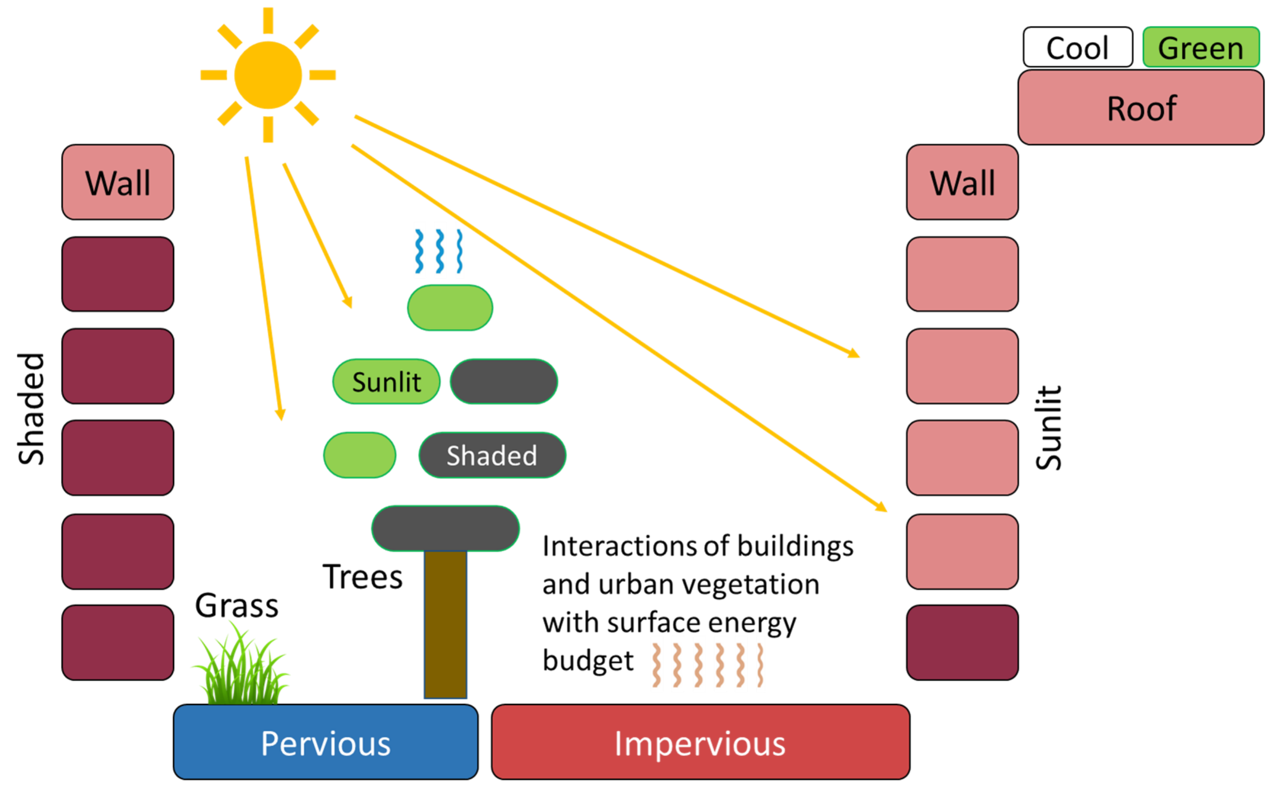
Default roof albedo



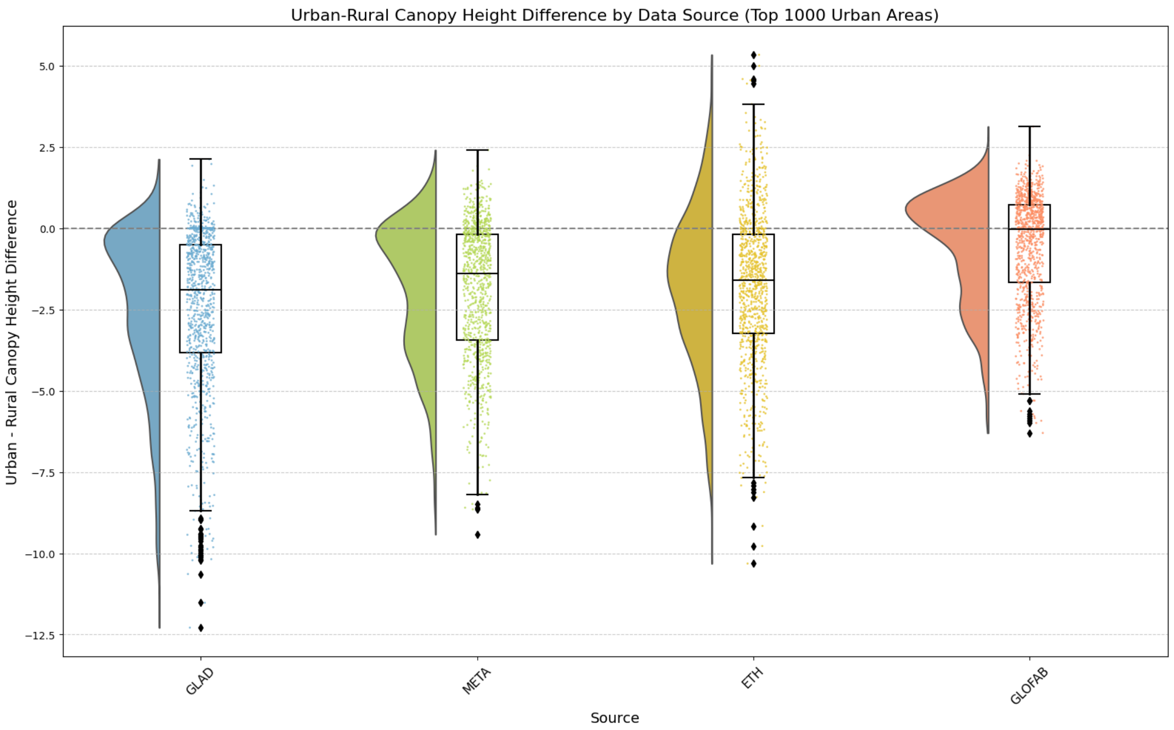
Updated roof albedo



Representing urban vegetation in E3SM



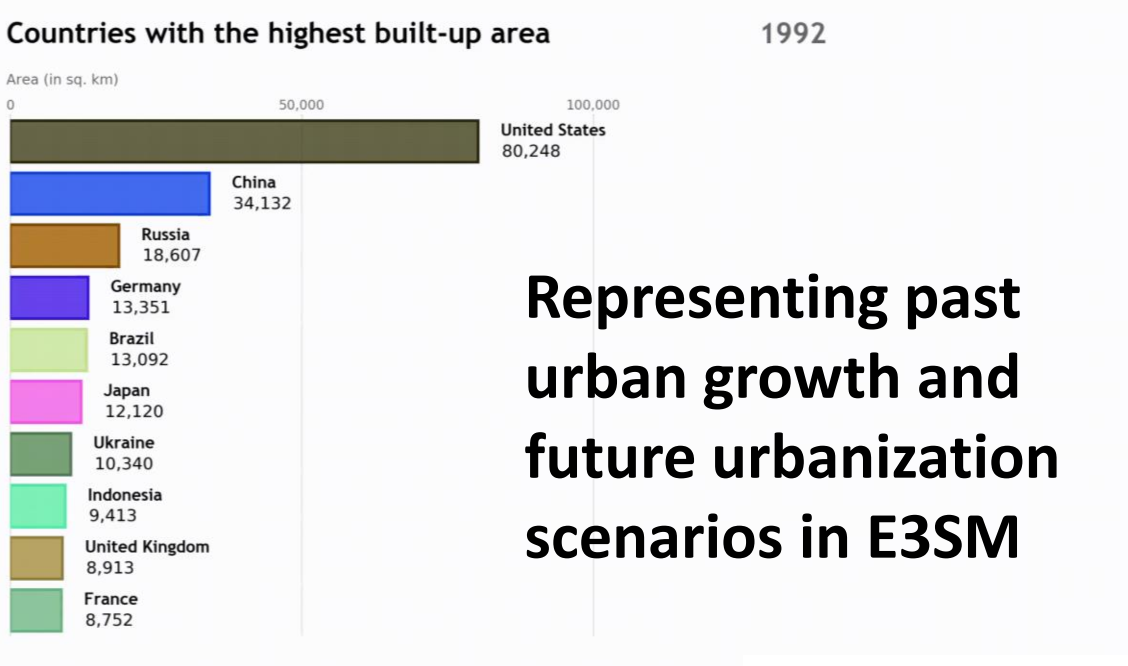
	Source	Number of Samples	Mean Canopy Height Difference	Percentage Urban > Rural
0	GLAD	935	-2.466280	8.449198
1	META	1000	-1.882331	18.500000
2	ETH	999	-1.807205	20.720721
3	GLOFAB	996	-0.538920	49.497992



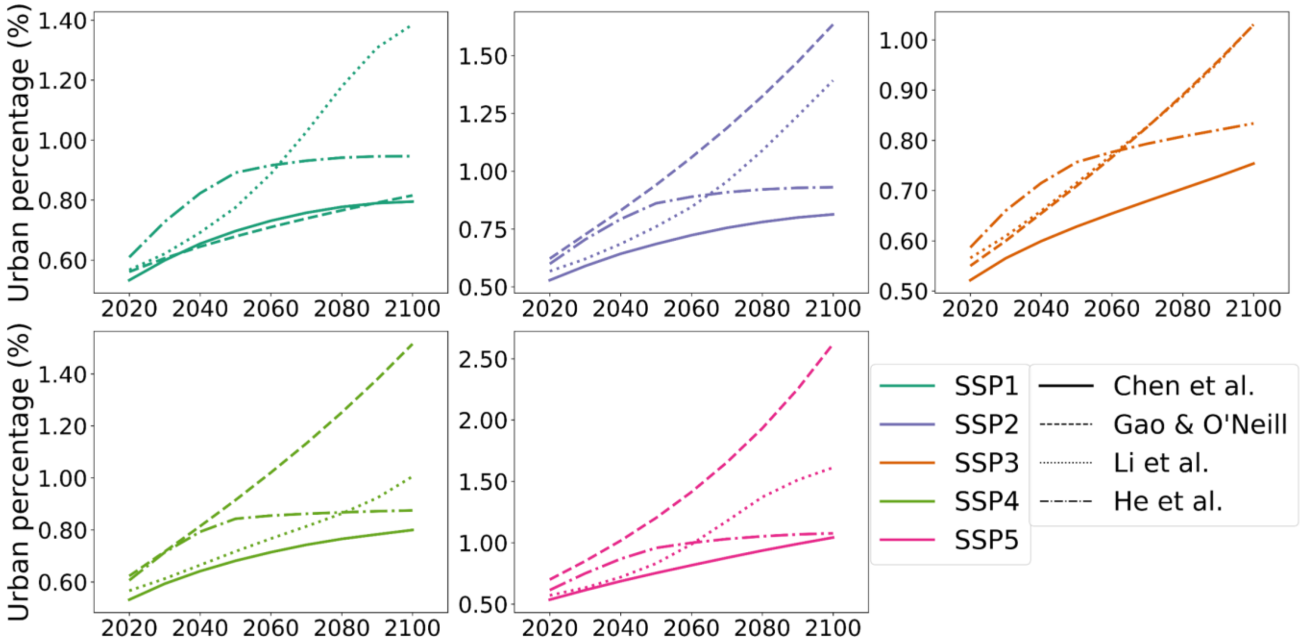
- Incorporating urban vegetation and its interactions into E3SM
- Associated development of global 1 km urban vegetation properties

Mukherjee and Chakraborty, *In Prep*

Ongoing and Future Work



Representing past urban growth and future urbanization scenarios in E3SM



Multiple critical collaborations across labs, other institutions, and countries

Integration with ongoing DOE-funded projects

Data sharing & model benchmarking

CROCUS Community Research on Climate & Urban Science

BSEC

Co-developing future urban evolution scenarios

IM3

Calibrating model improvements to isolate coastal-urban interactions

COMPASS | GREAT LAKES MODELING
Coastal Observations, Mechanisms, and Predictions Across Systems and Scales

ICOM

Thank you!

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- Sue Grimmond, University of Reading, United Kingdom

U.S. DEPARTMENT OF ENERGY | Office of Science

E3SM

Pacific Northwest NATIONAL LABORATORY

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Questions?