Earth & Environmental Systems Modeling

Urban Breakout Report
Research Gaps, Barriers, Opportunities

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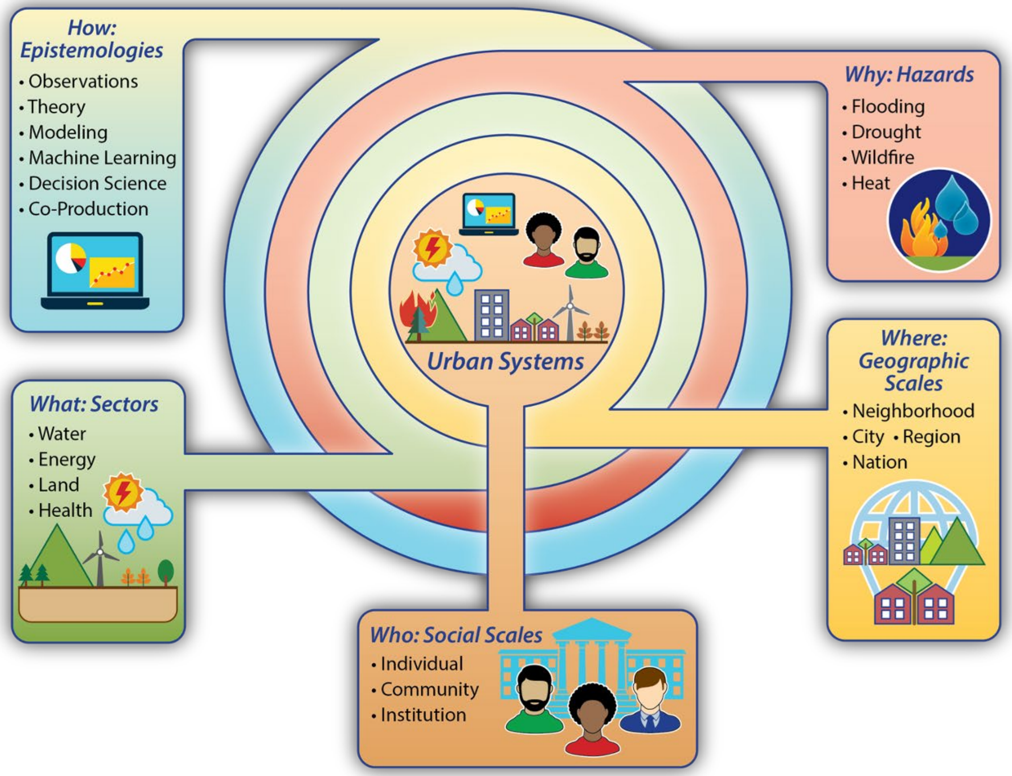
There are many ways to organize urban research



Structural, Parameter, and Process Uncertainties/Biases in Urban Modeling

Research gaps:

- Urban structure, parameters, and processes simplified in models (like in E3SM and WRF)
- Not always appropriate for conducting science at decision-relevant scales
- Biases our understanding of response of human systems to climate change and extreme events (including to compound extremes)

Barriers:

- Traditional dearth of observational data in urban environments
- Poorly accounting for critical urban processes and parameters in models (urban vegetation, morphology, anthropogenic heat, & their changes)
- Lack of concentrated effort in developing urban-resolving models

Opportunities:

- Leverage recent DOE investments in urban IFLs and CRCs to gather more decision-relevant and urban microclimate data
- Take advantage of modeling and model development efforts through multiple DOE-funded projects (IM3, ICoM, HyperFACETS, Early Career Projects, etc.)

Cross-Scale Interactions for Urban Modeling

Gaps:

- Bridging scales from large scale climate down to native resolution that gives rise to decision-relevant outcomes and variability
  - Urban influences on larger scale climates/links to regional infrastructure and vulnerabilities
  - Role of sea breeze / regional air flow dynamics in defining microclimates, especially extremes
- Capturing the right process interactions at fine-scale
  - Fine-scale coupling of natural and human processes that give rise to time and space varying dynamics
  - Indoor environments/Human mobility within urban areas/Storm infrastructure status

Barriers:

- High resolution data; disaggregation of what processes matter at what scale using model experiments.

Opportunities:

- E3SM:
  - Incorporation of structures and processes at sub-kilometer scale that can interact with local and global climate. Possible use of AI/ML surrogates here.
- Urban IFLs/ARM:
  - High resolution measurements from field campaigns can be compared to those taken at fixed tower locations.
  - The four urban areas represent different sized cities in different climatic locations.

Dynamic Evolution of Cities

Research Gap

- Urban extent, morphology, infrastructure, institutions are evolving in consequential ways in tandem with population, technology, economy etc., (e.g. energy transition, adaptation)
- Need internally consistent scenarios across these drivers (e.g., urban people vs urban land)
- Need to understand range of possible futures and their implications

Barriers

- Conceptual challenges - prediction vs. design
- Data challenges - relationship among high-level drivers and fine-scale outcomes difficult
- Coordination challenges - disciplinary stovepipes

Opportunities

- Stakeholders can inform key questions, scenarios, outcomes of interest
- AI approaches for generating fine-scale scenarios from high level drivers and constraints

What are the current and unique strengths and foundational capabilities of DOE for this topic?

- IM3 coupling between WRF and Energy+ enables feedbacks between buildings, energy sytems, urban microclimates and indoor environment
- Strong expertise in extremes writ large
- Remote sensing -based analysis
  - E.g. TC use of land surface temperature to characterize urban contribution at larger scale
- Urban IFLs offer rich set of observations
- ARM campaigns

What are the grand challenges in advancing the research on this topic?

- Bridging scales from large scale climate down to native resolution that gives rise to decision-relevant outcomes and variability
  - Urban influences on larger scale climates
  - Role of sea breeze / regional air flow dynamics in defining microclimates, especially extremes
  - Links to regional infrastructure and vulnerabilities (electricity system vulnerabilities to heat and energy droughts).
  - Influence of urban dynamics on larger scale sectors (commodity prices, resource demands)
    - E.g. , Mediated through competition for land
    - E.g. water demand at regional level as a function of urban morphology
- Capturing the right process interactions at fine-scale
  - Fine-scale coupling of natural and human processes that give rise to time and space varying dynamics
  - Indoor environments
  - Human mobility within urban areas
  - E.g. storm infrastrsucture status can matter more than precip characteristics for floods
  - Wildland Urban Interface / fire risk / urban growth / insurance dynamics

What are the grand challenges in advancing the research on this topic?

- Model strategy, biases, structural uncertainties
  - What are advantages or disadvantages of AI/ML vs. physic based models
  - How to characterize Structural uncertainty in physics-based models
    - E.g. anthropogenic heat in urban canopy models
    - E.g. microphysics scheme affects sign of urban impact on regional deep convection
- Decomposing influences
  - How much is a a given outcome (e.g. precipitation intensity) a function of urban characteristics vs. physical processes (e.g. urban extent / form vs. microphysical processes) vs. internal variability / noise

What are the grand challenges in advancing the research on this topic?

- Dynamic changes on decadal scenario timescales
  - Characeterizing range of urban scenarios – extent, morphology, population density, energy / water infrastrutcture
  - E.g. energy transition affects AH, indoor exposures, air quality emissions
  - Adaptation scenarios
  - Downscaling of coarser scale scenarios to smaller scale
    - Stable patterns of association between scenario factors such as population, urban morphology etc.
  - Conceptual issues – which scenario factors are predictions vs. choices vs. projections that follow from higher level scenario factors
    - For any given study, must sort out XLRM (
- Linking with decision-makers
  - How to identify the events / conditions that matter (beyond heat, also stable air days that have implications for air quality
  - Characterizing and communicating confidence from existing data
  - New ways of deriving insght that might not be about resolving everything
  - Transferability of knowledge from one geographic context to another

What are the gaps in research / infrastructure / coordination that prevent advances?

- Observations systematically disregard urban areas
- Global models rarely represent or focus on urban dynamics
- Fine scale boundary conditions are critical (land use / morphology) but hard to chartacterize
    - Large uncertainties across datasets in terms of what is characterized as “urban”
- Standardized metrics packages would be helpful for consistency across
- Computational limits
- Many EESM urban researchers have no formal or funded connection to the urban IFLs
- Consistent global and local scenarios (e.g., downscaling of SSPs to urban land use)
    - Population and urban morphology projections not necessarily consistent with one another
- Navigating programmatic constraints related to fundamental vs. applied research can be especially challenging for urban research

What opportunities exist to overcome each of those gaps?

- Systematic ways of exploring model structural uncertainty
- More fine-scaled resolution of key processes, hierarchical
  - LES scale modeling
  - 3d radiative coupling among buildings, vegetation, other built structures
- Greater collaboration between EESM PIs and Urban IFLs
- Leverage in-situ observational data, e.g. from ARM
- For Co-production of Actionable Research
  - Mindset shift
  - Resources for engagement
  - Learn from existing literature on coproduction
  - Address stakeholder fatigue