

Integrated Multi-sector Modeling at City Scale

Oak Ridge National Laboratory

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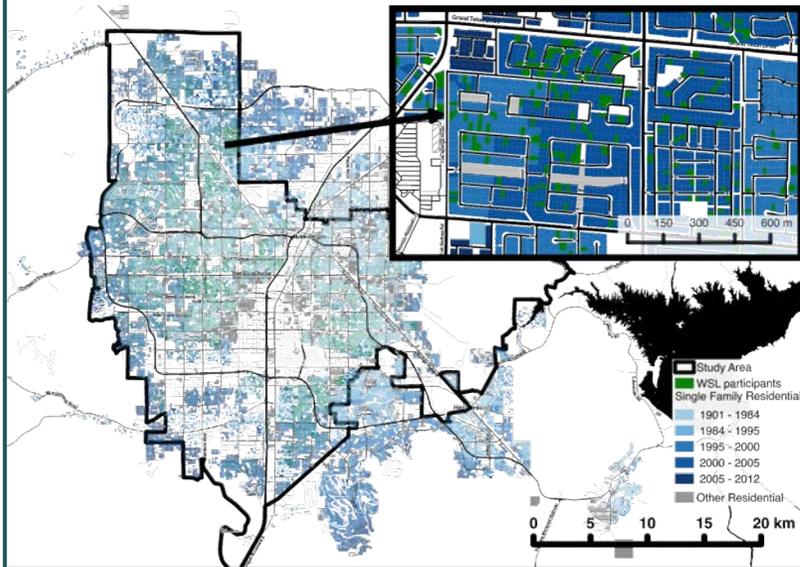
Activities Presented

- ORNL Urban Project Contributions to IM3 SFA led by Jennie Rice, PNNL
 - Urban Research Taxonomy Activity
 - Human Activity in and Between Cities
 - Sustainable Development in Cities
 - Urban Morphology and Urban Microclimate
- ORNL Urban Project Contributions to Urban Exascale project led by Charlie Catlett, ANL
 - Overview of coupled Socioeconomic and Transportation Modeling

Urban Research Taxonomy

Individuals

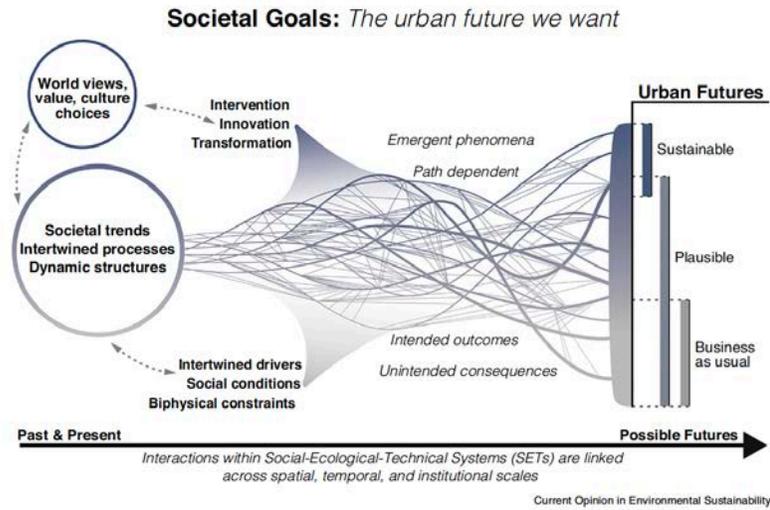
Probabilistic, Empirical or Agent Based Models



Brelsford & De Bacco. NETS (2018)

Cities

Urban Analysis and Stakeholder Engagement



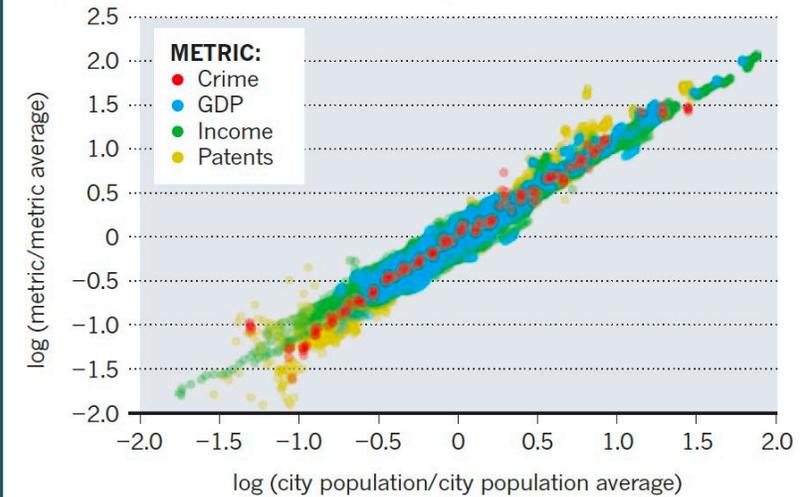
McPhearson, Iwaniec, & Bai.
Crnt. Opn. in Envi. Sust. (2016)

Nations

Urban Scaling Theory

PREDICTABLE CITIES

Data from 360 US metropolitan areas show that metrics such as wages and crime scale in the same way with population size.



Bettencourt & West. Nature (2010)

Individual

Neighborhood

City

Region

Nation

Social Scale

Relevant Research Sectors from Earth Systems Research

Relevant Research Sectors from Urban Systems Research

Effect of Earth Systems on Cities

Carbon
Water
Land

Coastal processes
Changes in Water Risks

Urban Vulnerability and Resilience

Effect of Cities on Earth Systems

Carbon
Water
Land

**EARLY SKETCH OF A FRAMEWORK:
NOT COMPLETE!**

Urban Teleconnections

Inter-city Dynamics

Water
Energy
Land Use
Socio-Economics
Infrastructure
Population

Energy-Water Nexus
Urban Morphology
Urban Metabolism

Urban Scaling
Urban Vulnerability and Resilience

Focal Spatial Scale

Degree of coupling

Loosely coupled

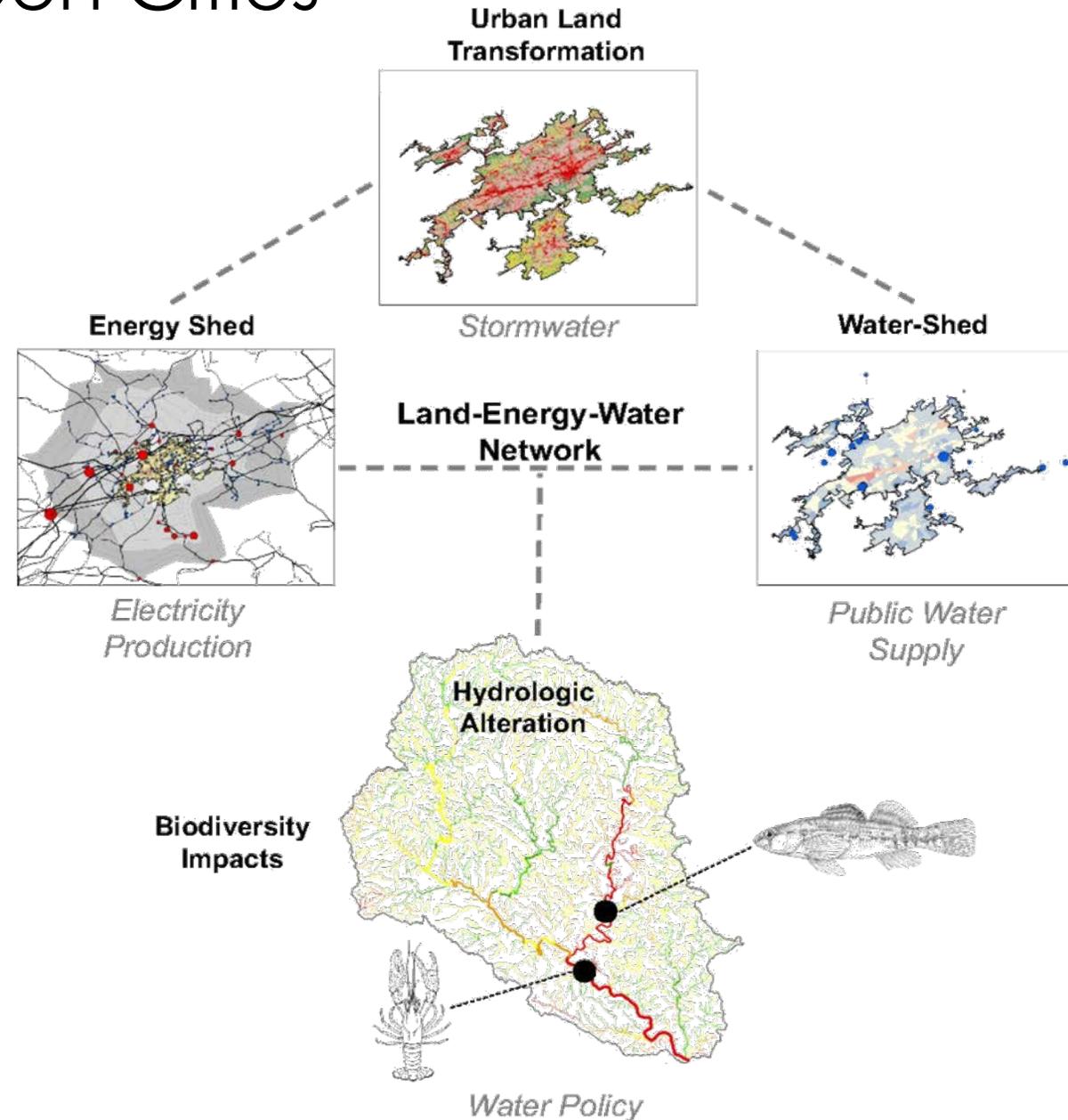
Tightly coupled

Co-evolving

Human Activity in and between Cities

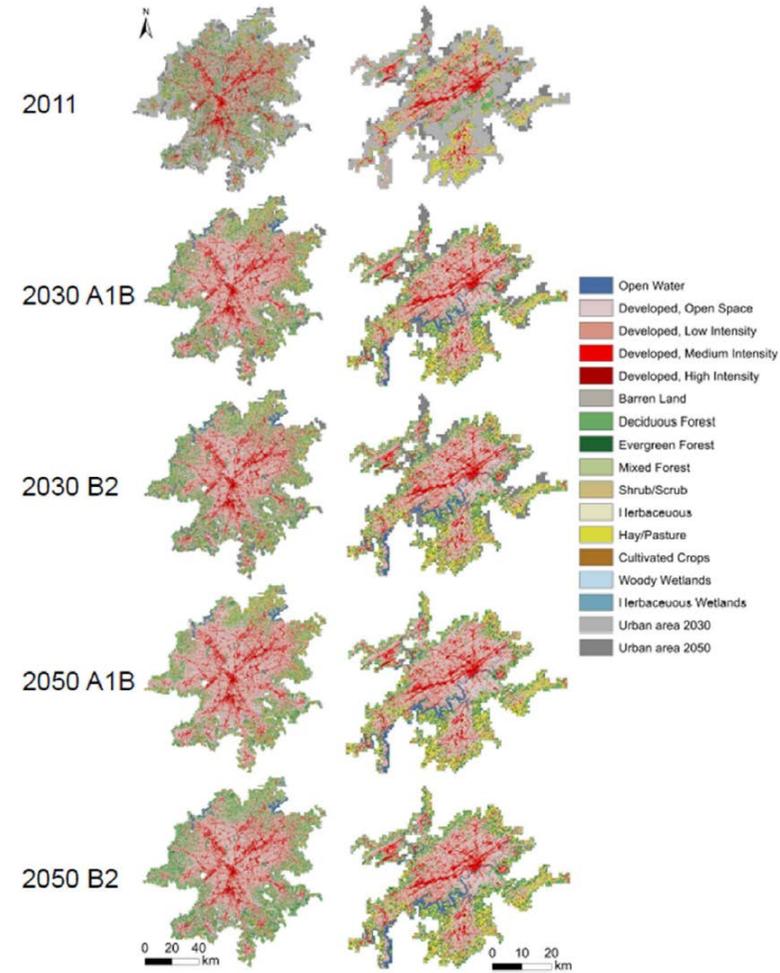
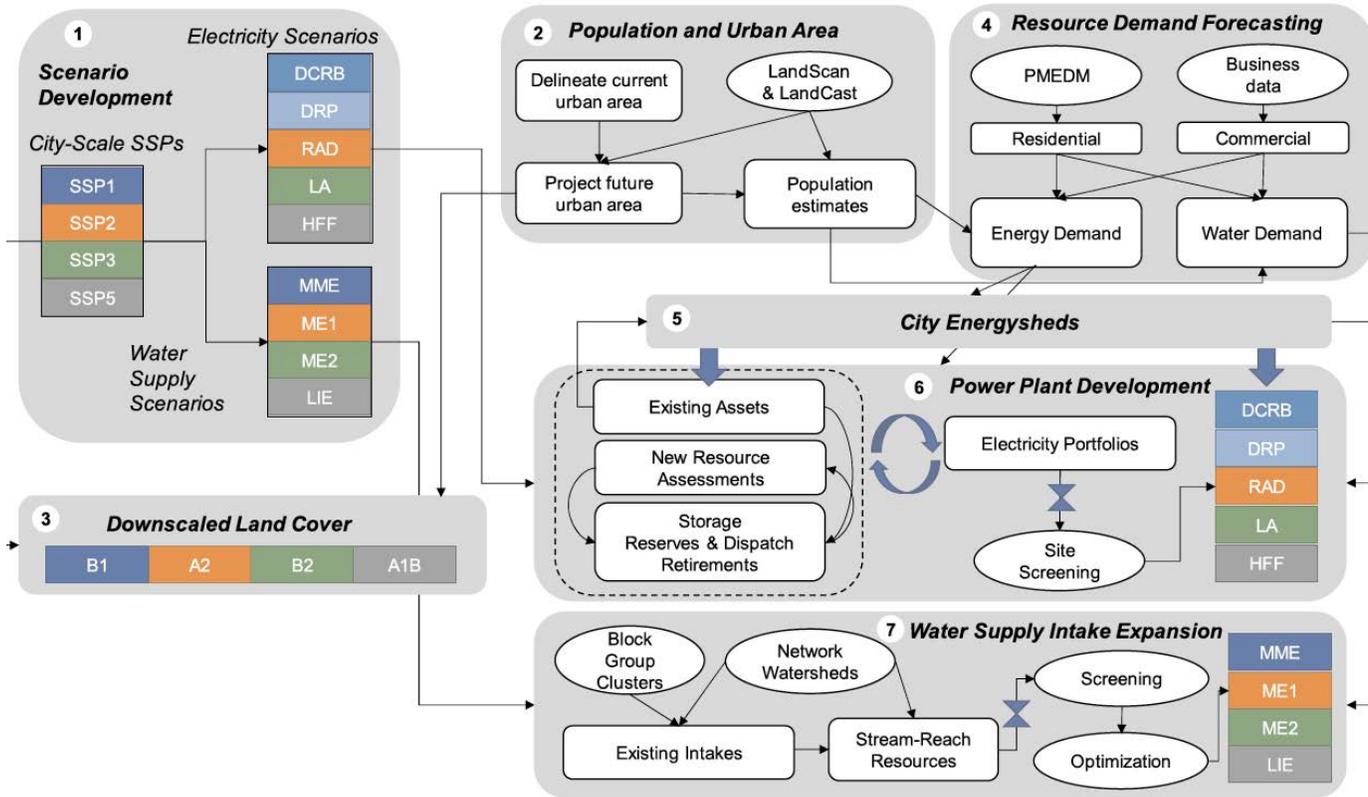
City land-energy-water networks

- Use urban signatures and their non-urban counterparts to determine the implications of
 - population growth
 - past climate regimes
 - land cover
 - water availability
- Assess levels of resource stress and potential adaptation strategies using
 - Dynamic Time Warping: clustering cities based on land-energy-water usage time series trends
 - Random Forests: characterize energy, water and land trends based on changes in population, past climate regimes, and water availability



Spatially explicit land-energy-water future scenarios for cities: Guiding infrastructure transitions for urban sustainability

Spatially explicit future infrastructure scenarios are needed to help cities set attainable goals for efficient management of regional resources.

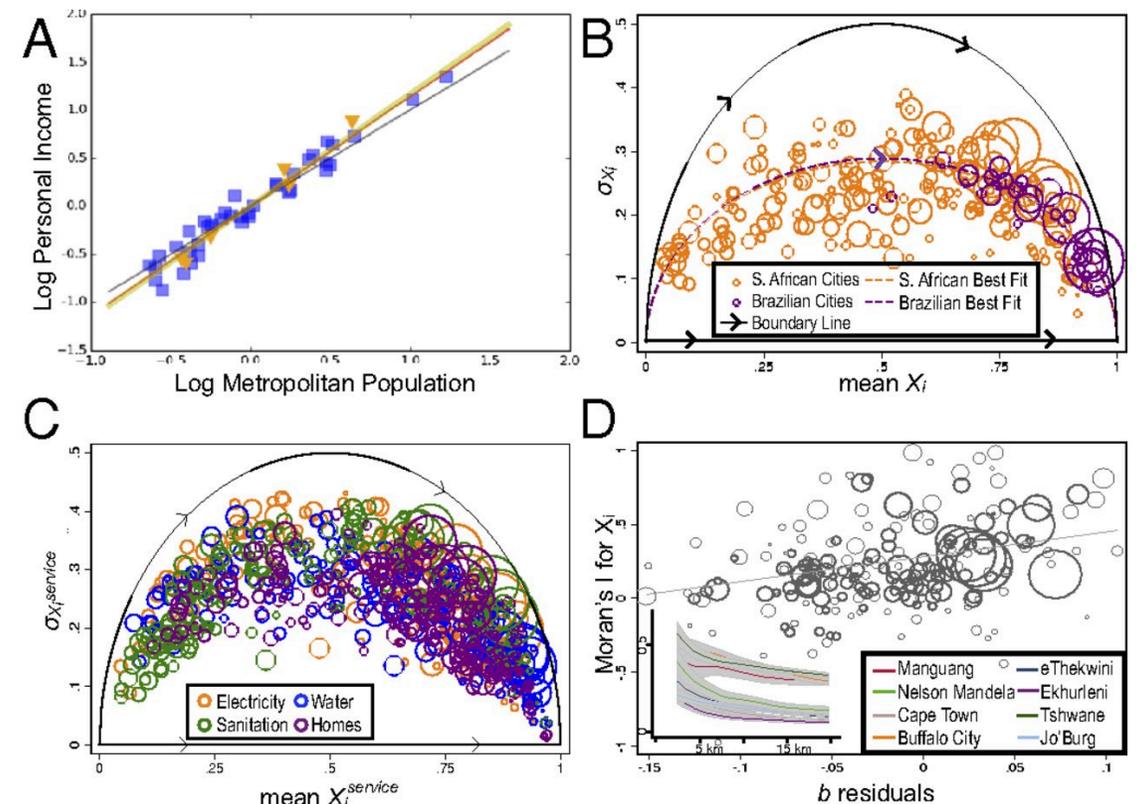


Downscaled (30-m) land cover scenarios for Atlanta and Knoxville in 2011, 2030, and 2050

Sustainable Development in Cities

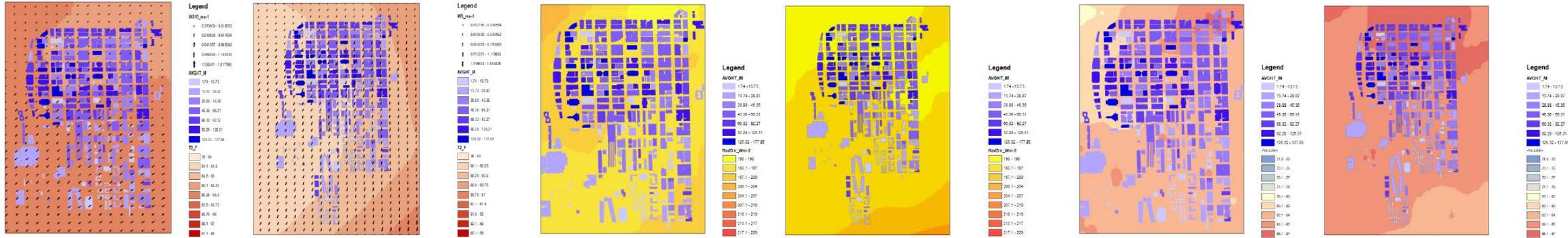
Urban Scaling and Residuals

- Analyze proportionate saving in costs gained by an increased level of production for urban infrastructure
 - land use and land cover change (non-urban to urban)
 - water and wastewater system development
 - transportation volume and road lane mile increases/decreases
 - changes in electricity demand and distribution
- Residuals from these baseline estimates help determine which characteristics of which cities scale differently from the norm.



Can Urban Morphology affect Neighborhood Resilience to Microclimate Extremes?

Building Density of New Addition Correlated with Temperature Changes in the Loop



(a) Present Day Chicago Loop

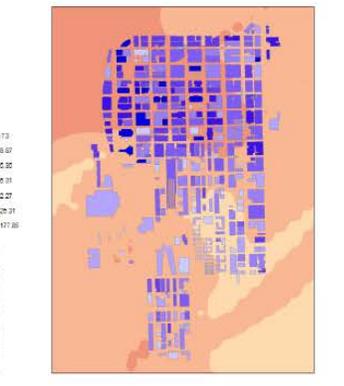
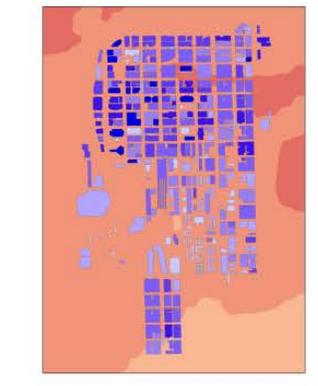
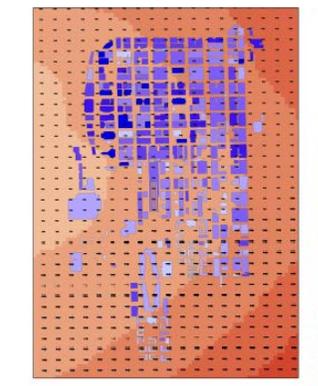
(b) Chicago Loop with Added New Development, Morphology 1

(a) Present Day Chicago Loop

(b) Chicago Loop with Added New Development, Morphology 1

(a) Present Day Chicago Loop

(b) Chicago Loop with Added New Development, Morphology 1



(c) Chicago Loop with Added New Development, Morphology 2

(d) Chicago Loop with Added New Development, Morphology 3

(c) Chicago Loop with Added New Development, Morphology 2

(d) Chicago Loop with Added New Development, Morphology 3

(c) Chicago Loop with Added New Development, Morphology 2

(d) Chicago Loop with Added New Development, Morphology 3

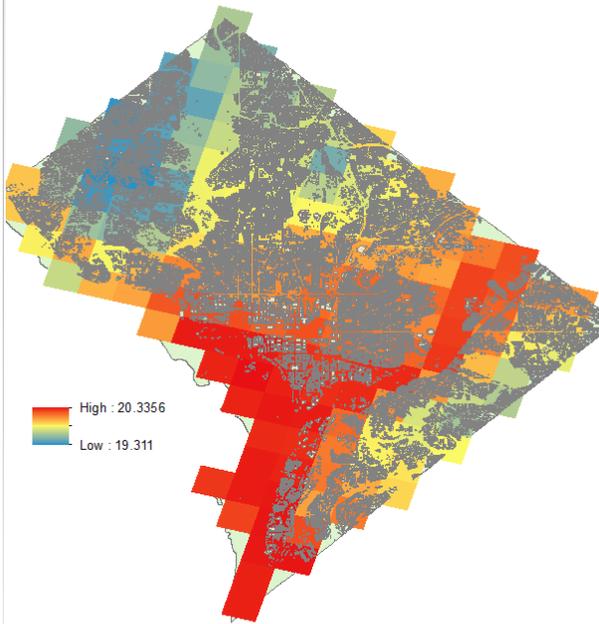
Temperature and Wind

Direct Normal Radiation

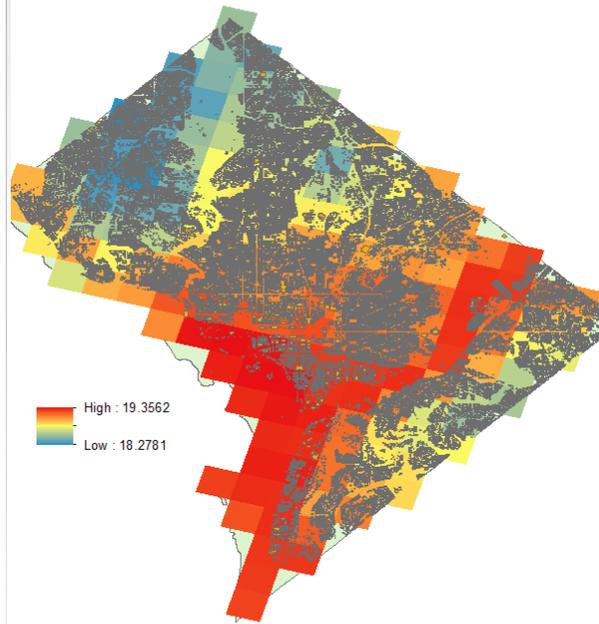
Diffuse Radiation

Annual Average Daily Maximum Temperature (Daymet, 1km): 1999 – 2015

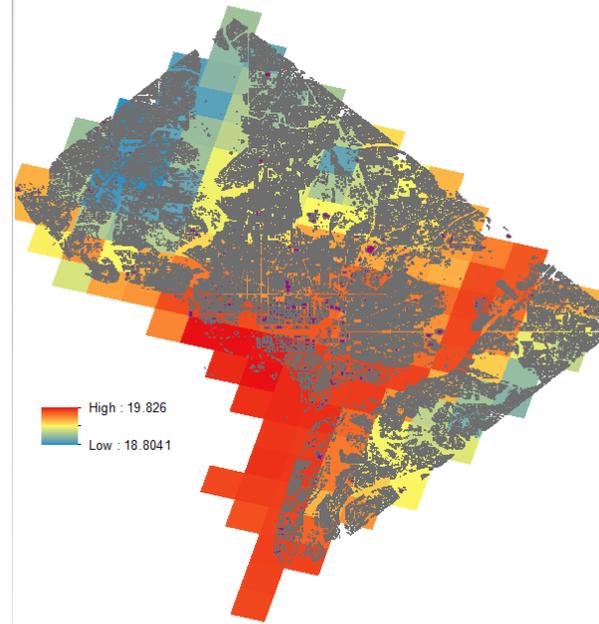
1999



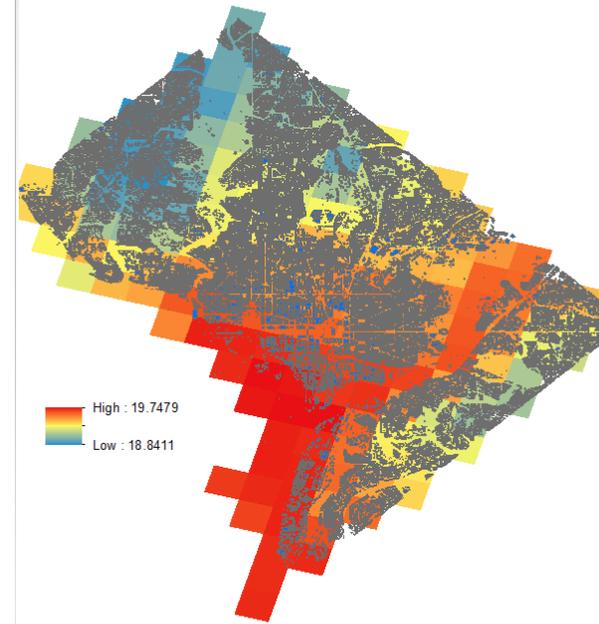
2005



2010

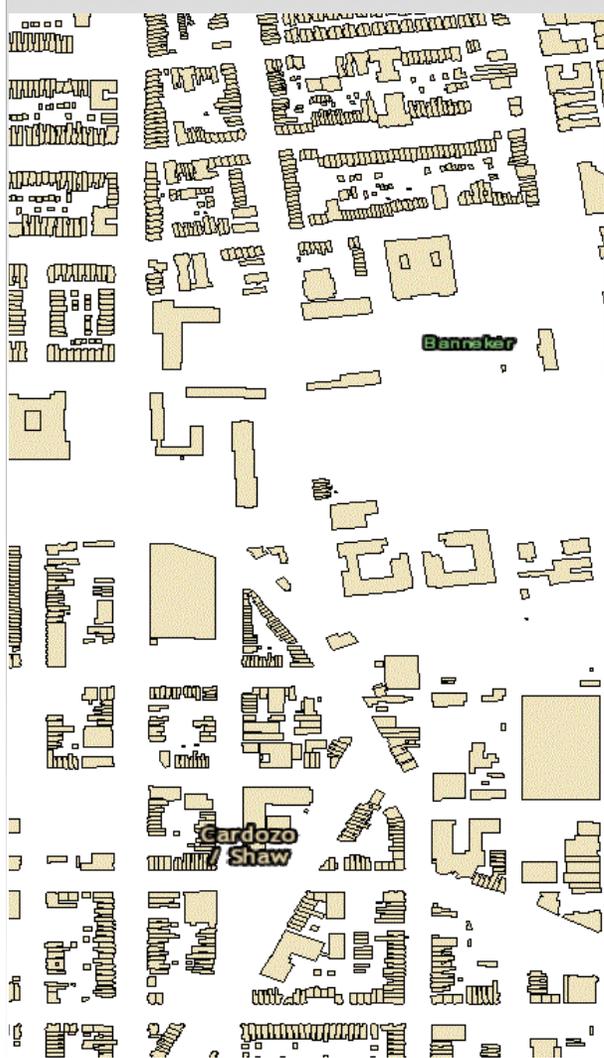


2015

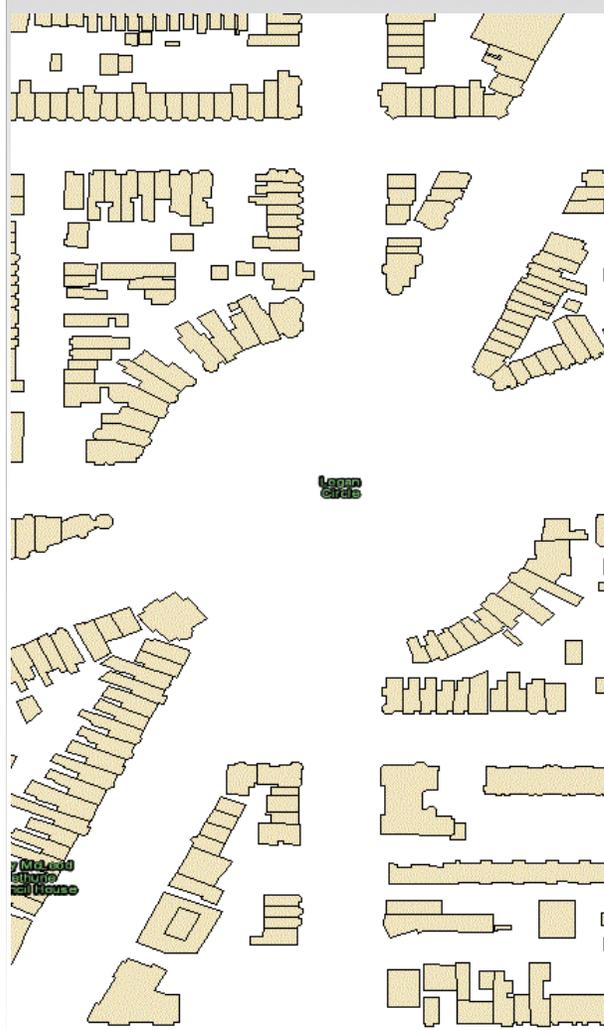




Columbia Heights



Logan Circle



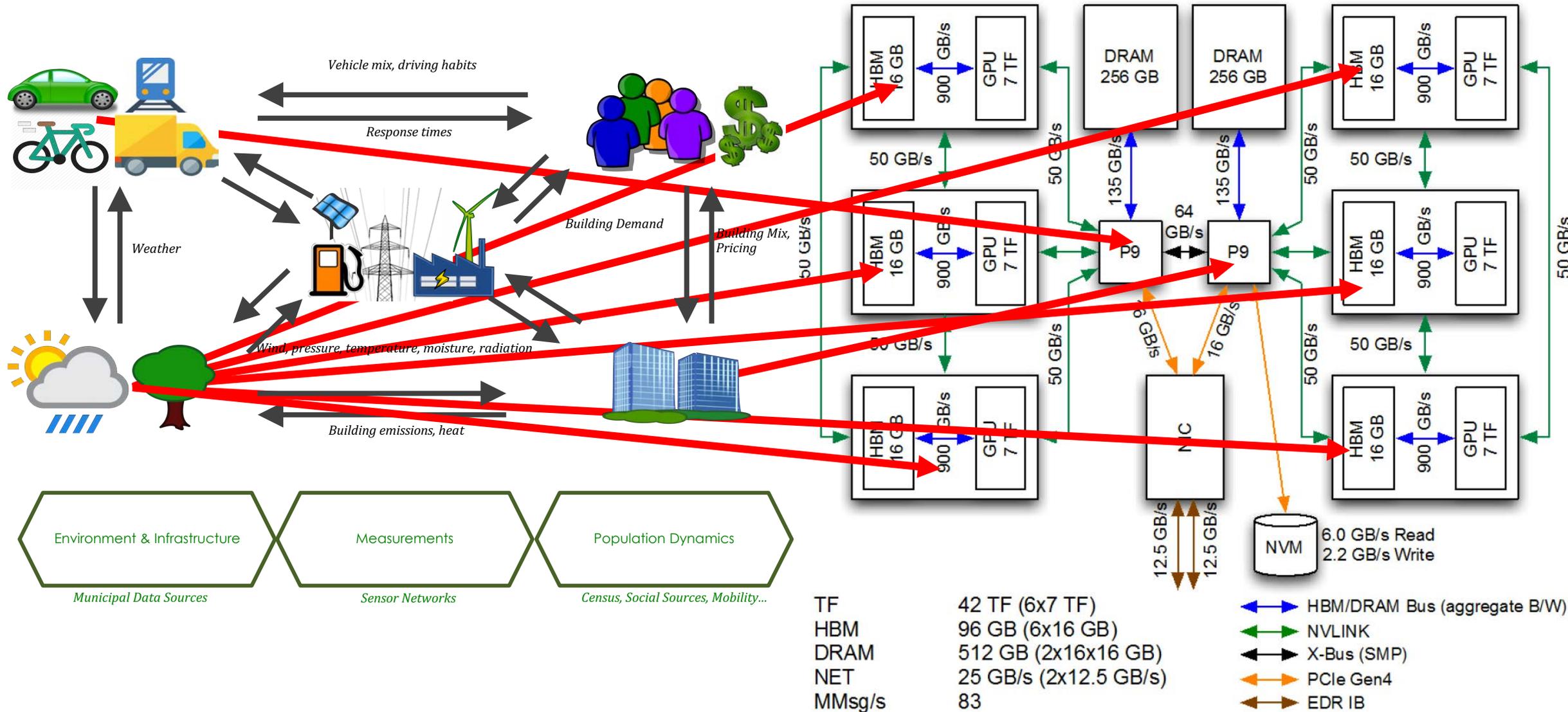
Mall Area



Waterfront

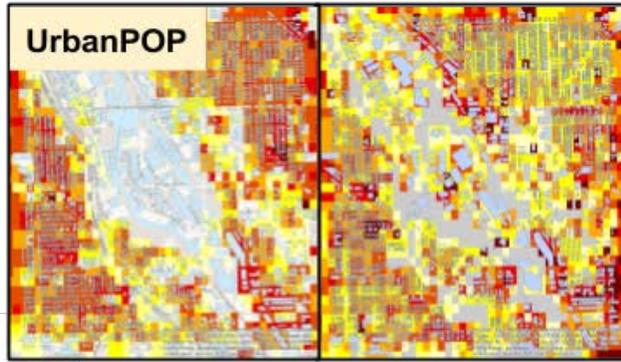


Exascale Urban Project: A Framework for the City Scale

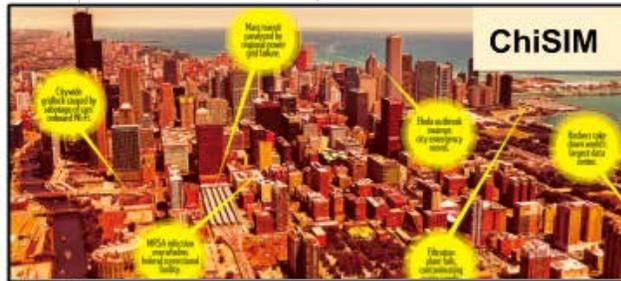


HBM & DRAM speeds are aggregate (Read+Write).
All other speeds (X-Bus, NVLink, PCIe, IB) are bi-directional.

Coupled Socio-economic and Transportation Modeling



Agent Hourly Locations

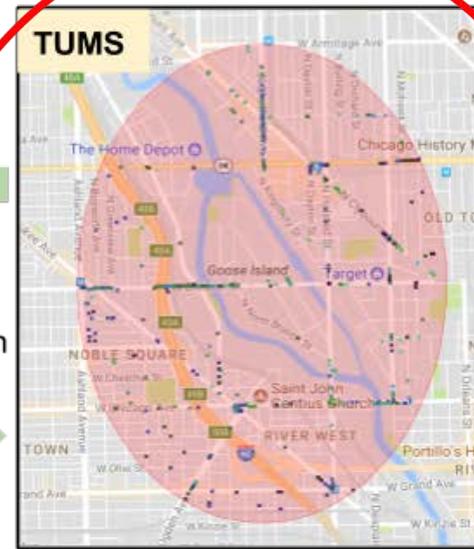


Close Coupling in Repast HPC

Agent Travel Mode Decision

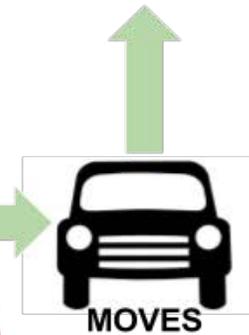


Agent Arrival Time



Vehicles Deployed on Road Network

Heat Exhaust to Nek5000



Impacts of Inclement Weather on Transportation

Objectives

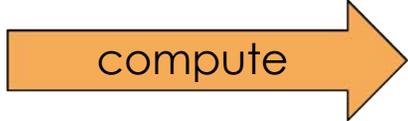
- Understand inclement weather impact on transportation
- Understand the challenges and performance bottlenecks in porting transportation simulation to emerging HPC architectures.
- Develop a large-scale transportation simulation capability, which will enable users to perform thousands of simulations in a reasonable time.



Conservative Driving Behavior

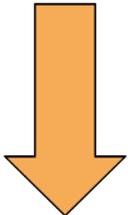


Creating Building Occupancy from Transportation

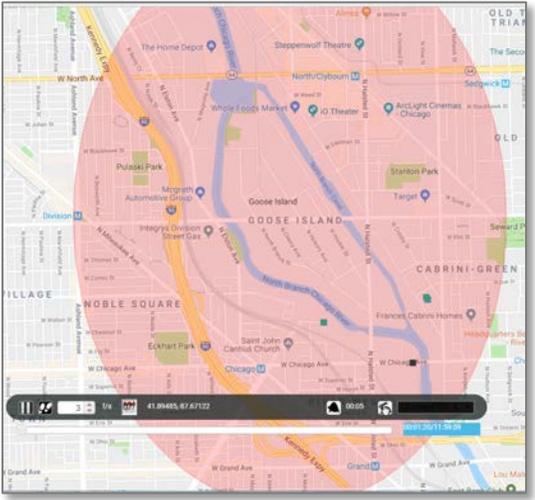


Each agent location for each time step

DRIVER	TIME	LAT	LOX
268701	0:01:17	42.1740653	-89.757311
1278201	0:01:17	42.1751715	-89.785531
1489401	0:01:17	42.3064353	-89.709907
3938501	0:01:17	42.233066	-89.619333
4348501	0:01:17	42.232068	-89.636112
5561101	0:01:17	42.2004822	-89.716741



Last observed location for each agent in the simulation

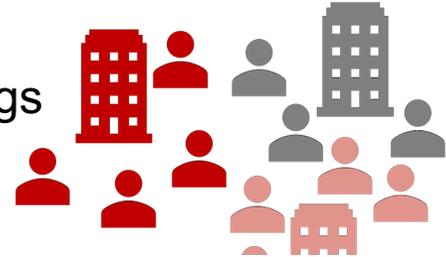


Building footprints for areas of interest

- Goose Island
- Chicago Loop

Driver	Building
268701	58
1278201	946
1489401	234
3938501	234
4348501	82
5561101	736

Map agents to nearest buildings



Hourly occupancy schedule for each building for each day of the week.

Building	Day	Hour	Occupancy
1	Mon	1am	0.05
...
1	Mon	7am	0.10
1	Mon	8am	0.35
1	Mon	9am	0.80



Discussion

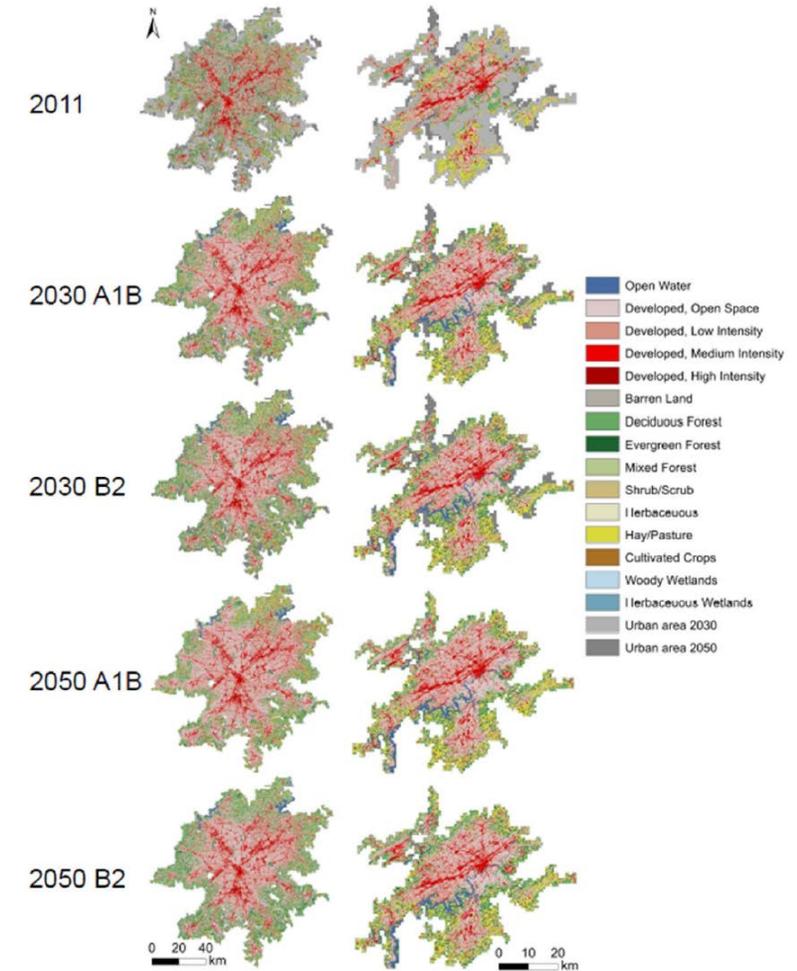


Spatially explicit land-energy-water future scenarios for cities: Guiding infrastructure transitions for urban sustainability

Spatially explicit future infrastructure scenarios are needed to help cities set attainable goals for efficient management of regional resources.

<p>Objectives</p>	<p>Development of tangible city-scale alternative future scenarios informed by neighborhood level data and land-energy-water resource characterization.</p>
<p>New science</p>	<p>New data and methodology for developing plausible spatially explicit alternative futures for city infrastructures with respect to tradeoffs in land, energy, carbon, and water resources and among alternative future pathways.</p>
<p>Significance</p>	<p>Translation of land-energy-water tradeoff scenarios into physical decision-level relevant information in order to ensure transparent communication among city- and utility-level governance.</p>

Ryan A. McManamay, Christopher R. DeRolph, Sujithkumar Surendran-Nair, Melissa Allen-Dumas (2019). *Renewable and Sustainable Energy Reviews*, 112, 880-900.



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