Understanding the Relationships among City Microclimate, Morphology and Energy Use

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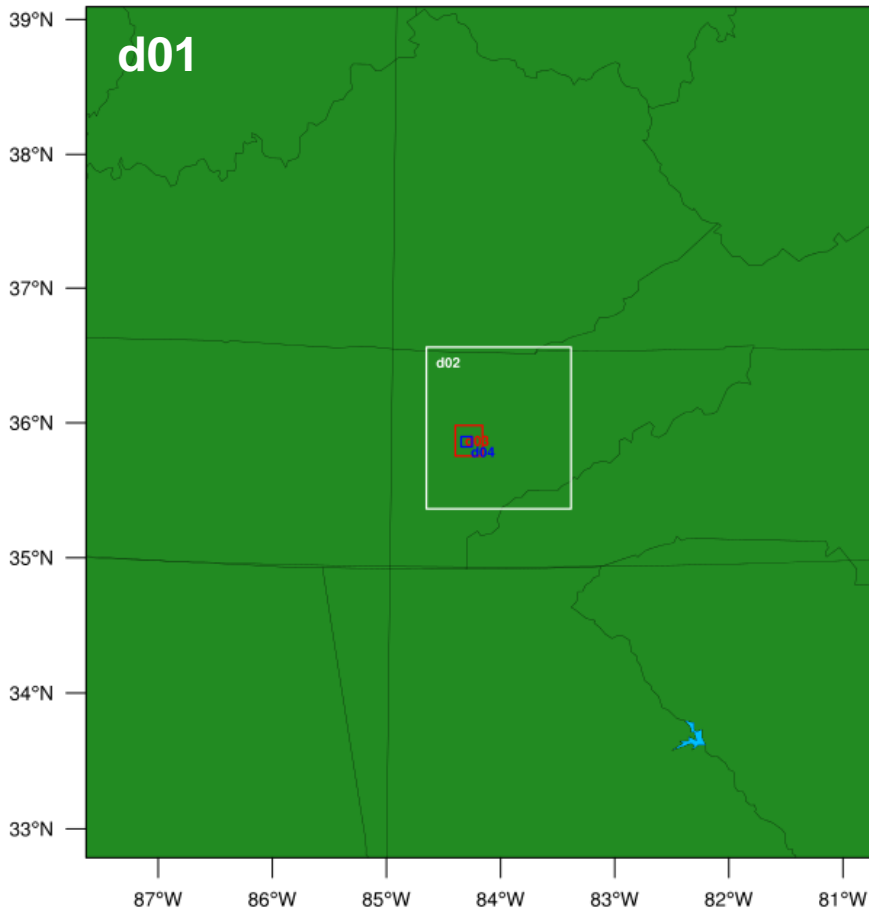April 7, 2017

Urban-MET

- **Integrate approaches across three research areas: earth system and climate modeling; energy modeling; and population/urban planning; to:**

  - Model urban micrometeorological processes and effects on and from regional climate and building energy use at neighborhood resolution

  - Integrate climate, population, and land use projections in order to determine the most energy-efficient urban configurations for the mid-21st century

  - Provide analysis and visualization tools to help planners optimally use these results
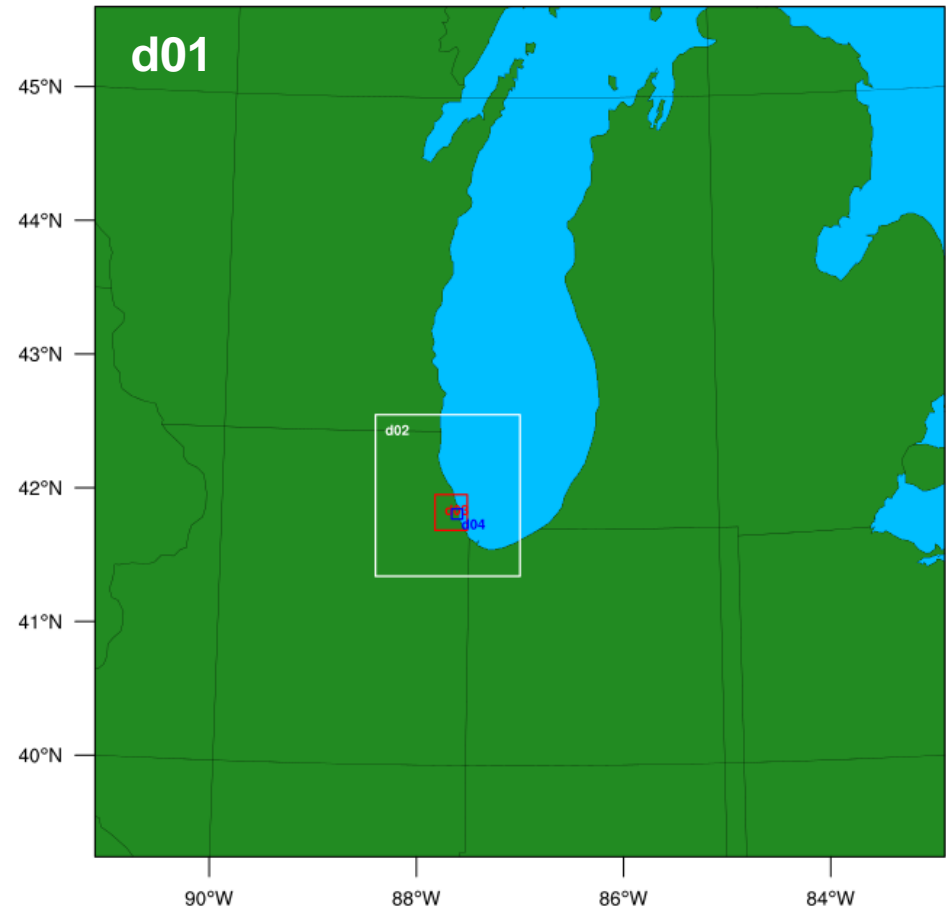
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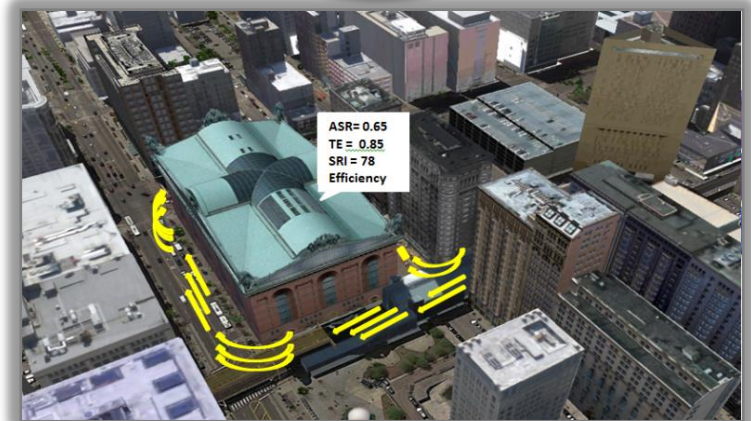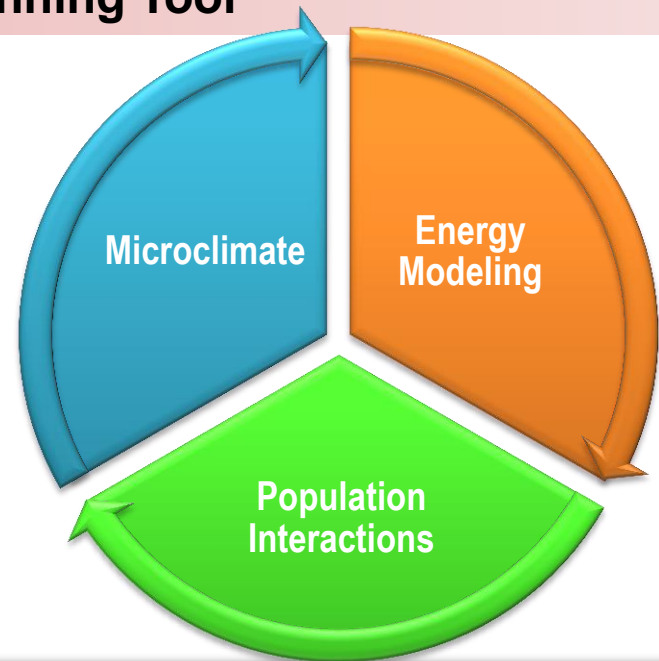
Microclimate Modeling (Domains: 6km, 1km, 270m, 90m)

Oak Ridge Domain Configuration

Chicago Domain Configuration

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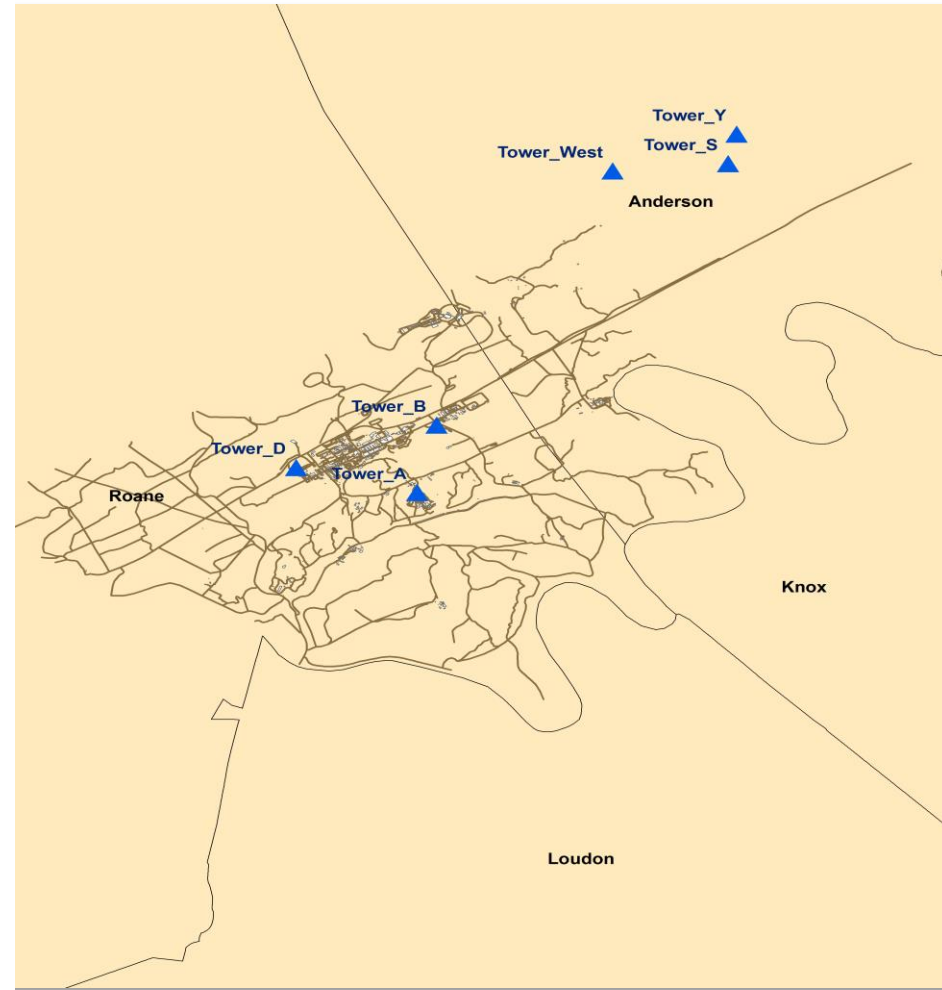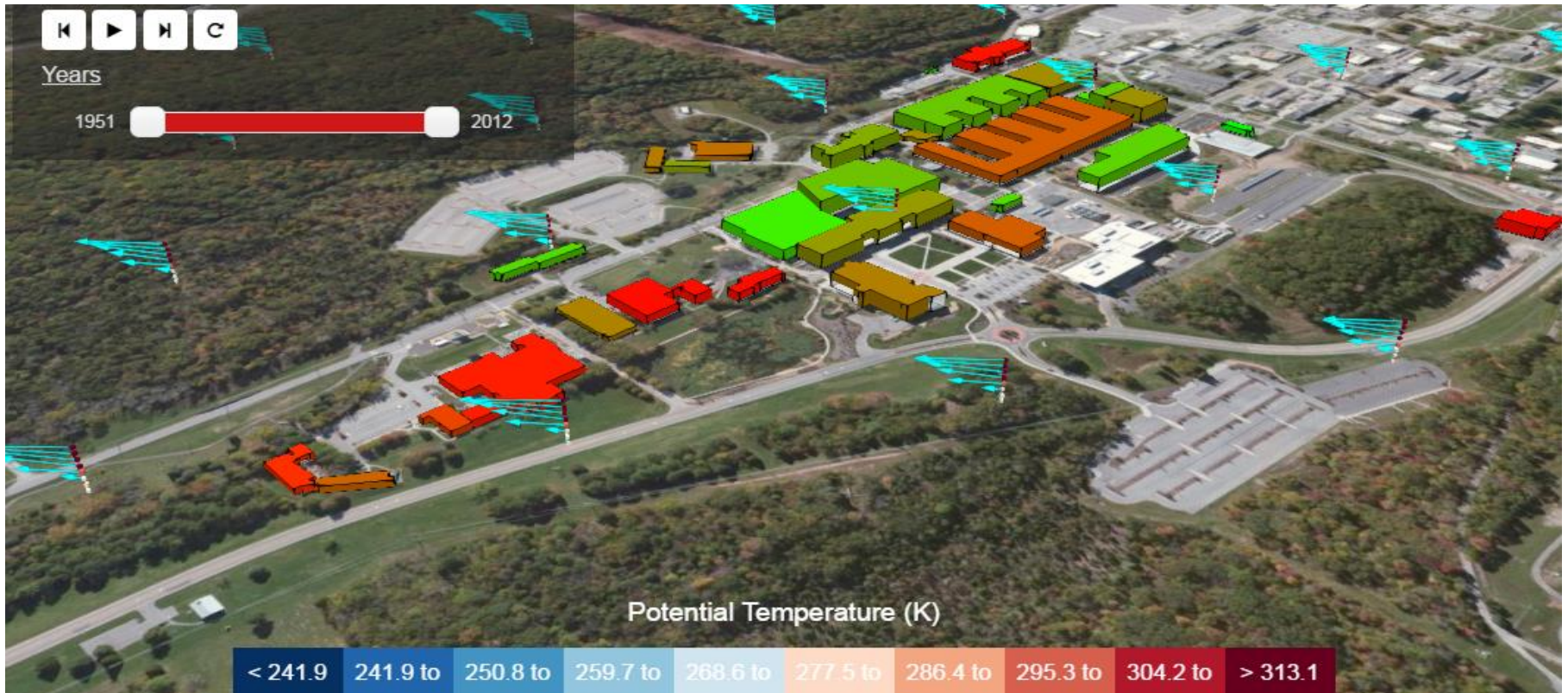
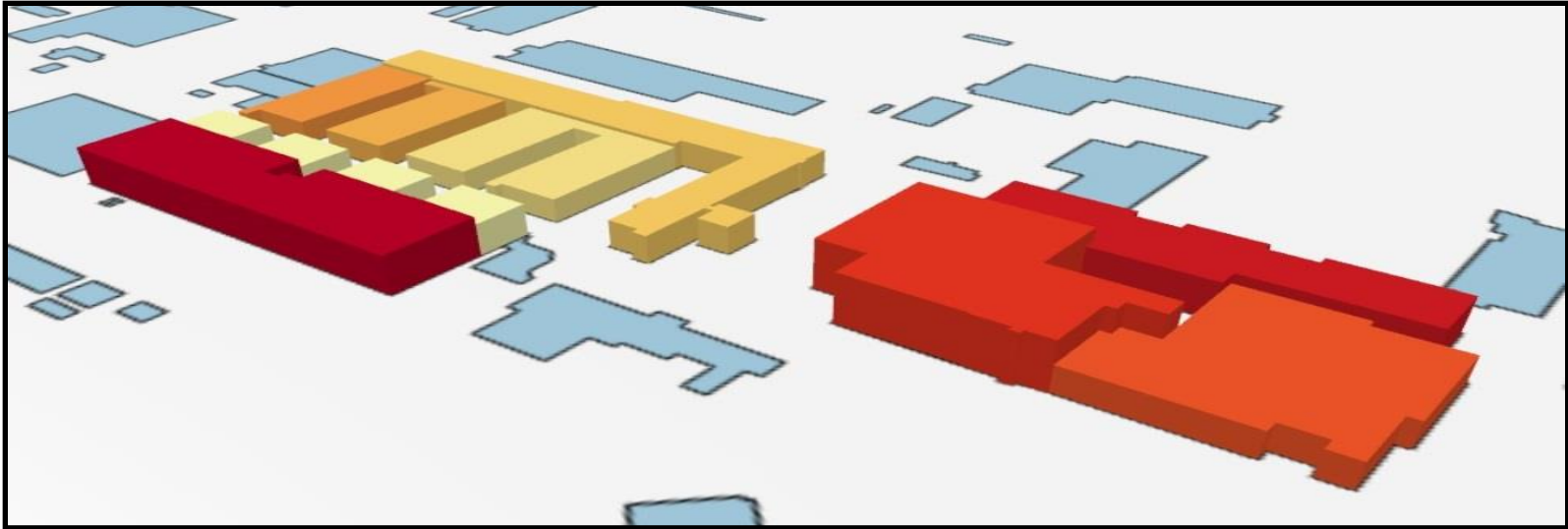# Data Collection/Parameters for ORNL Campus Benchmark Study

- Hourly building energy use data for 2013-2015 for over 40 ORNL campus buildings

- Metasys hourly indoor/outdoor temperature/humidity/wind data for years 2014, 2015 for ORNL building 4500N

- Hourly meteorological station data for 2009-2015 from Towers A, B, D, K, L, M, Y, S, West

- Building shape files (Building height, height to width ratio, the building fraction, and the road fraction parameters at the individual building level computed)

ORNL Campus Morphology

Potential Temperature (K)

| < 241.9 | 241.9 to | 250.8 to | 259.7 to | 268.6 to | 277.5 to | 286.4 to | 295.3 to | 304.2 to | > 313.1 |

Morphology Creation Tool

Key Parameters:
- Plan Area Density – Ratio of the plan area to the dilated area
  - Plan area - sum of the building surface areas within the dilated area

- Frontal Area Index – Ratio of the wall area to the average distance between the building centroids from North to South multiplied by the average from East to West

- Height to Width Ratio – ratio of the building height to the average distance between each building
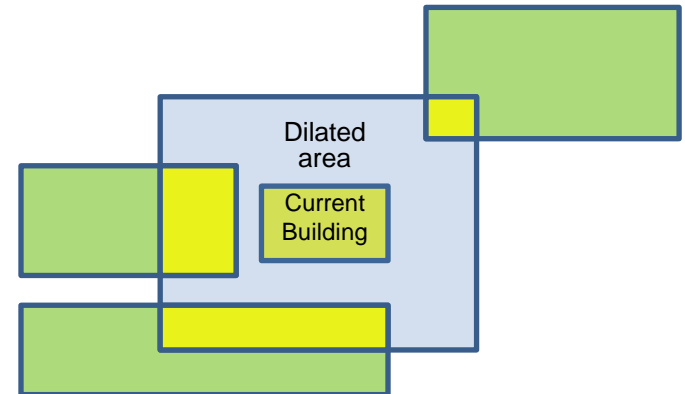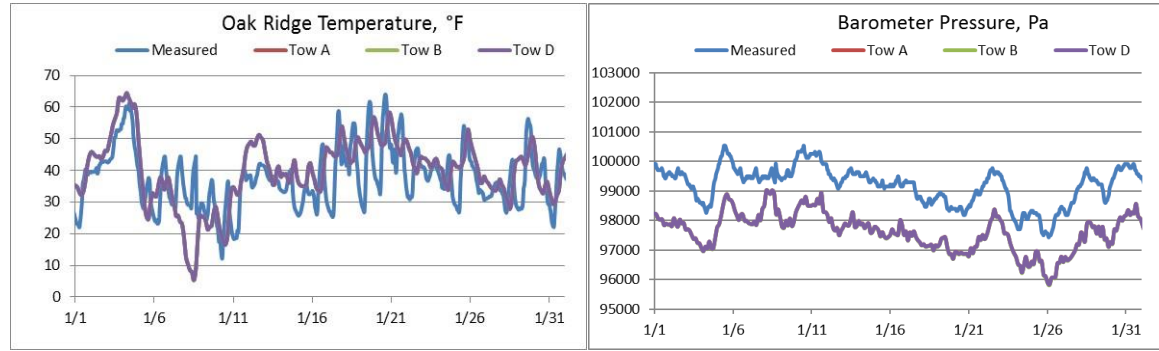

Plan area is highlighted in yellow

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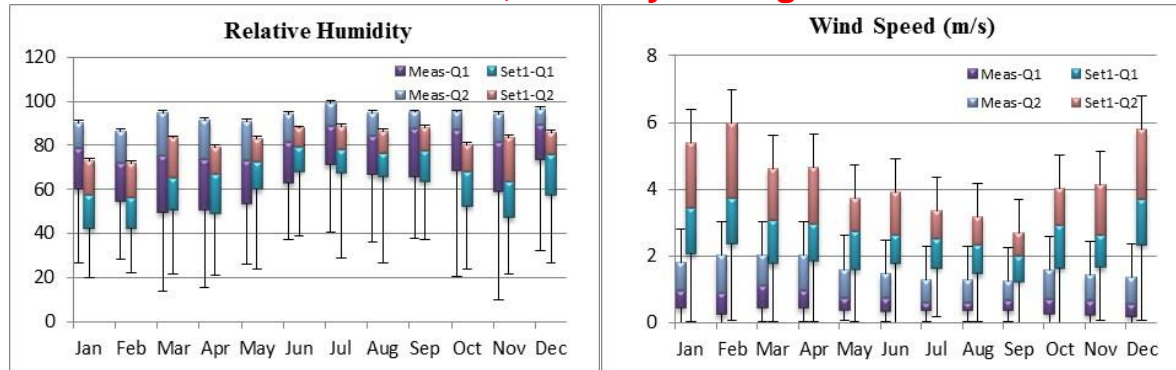MANAGED BY UT-BATTELLE FOR THE U.S. DEPARTMENT OF ENERGY

Uncertainty Quantification: Observations and Model Results

- Bias Corrections
- Daily, monthly, annual statistical characterization (frequency distribution, linear regression, TMY, whole building energy analysis), summary and comparison
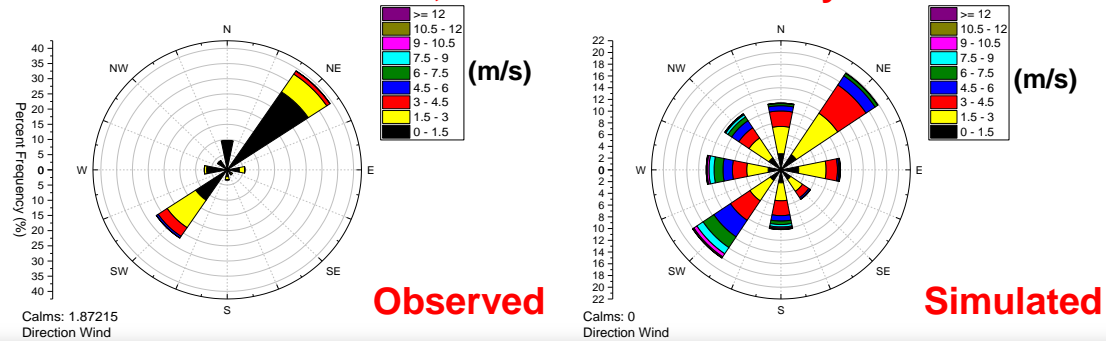- Wind rose analysis

90m horizontal resolution, hourly output

**270m horizontal resolution, monthly averages**

**270m horizontal resolution, 2015 annual summary**

Observed

Simulated

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Communication between models

- Conversion of potential temperature at each vertical level to actual temperature

- Conversion of U,V,W at each vertical level to wind speed and direction at each level

- Conversion of Water Vapor to Relative Humidity and to Dew Point temperature at each vertical level

- Placing above variables plus relevant native output onto 2d grids for each vertical level and then converting each variable set at each vertical level to per-building values and translating to epw-type csv files for reading into E+.

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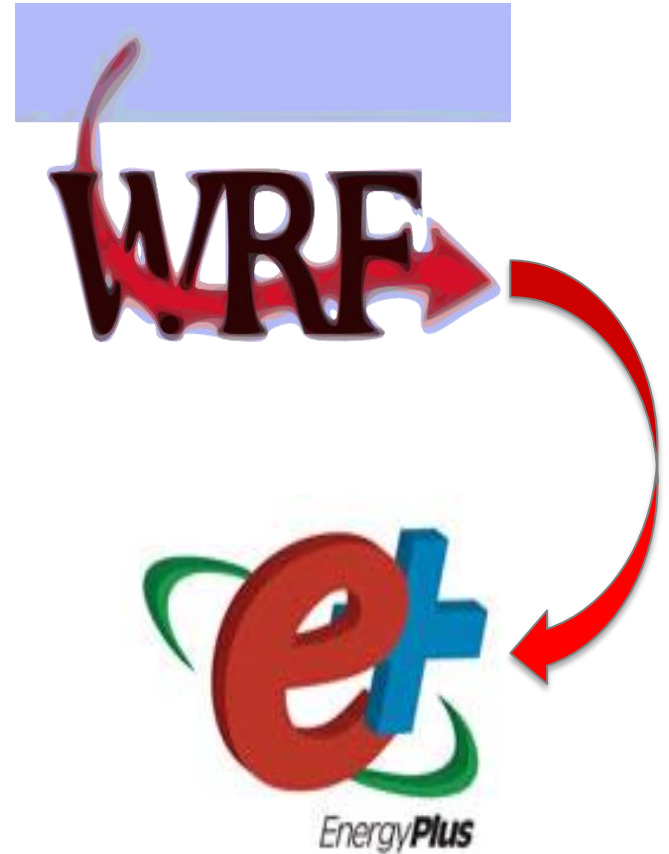
Whole Building Energy Analysis

EnergyPlus models of three buildings used to compare energy consumption differences based on measured versus simulated weather

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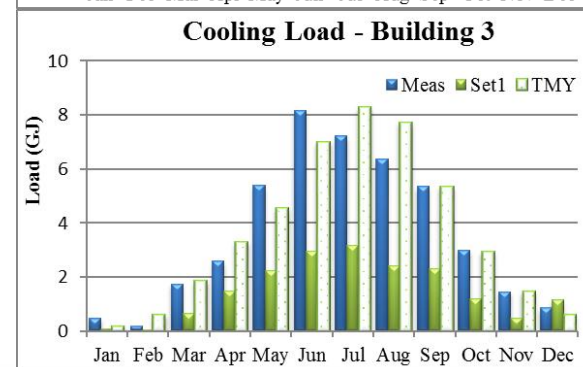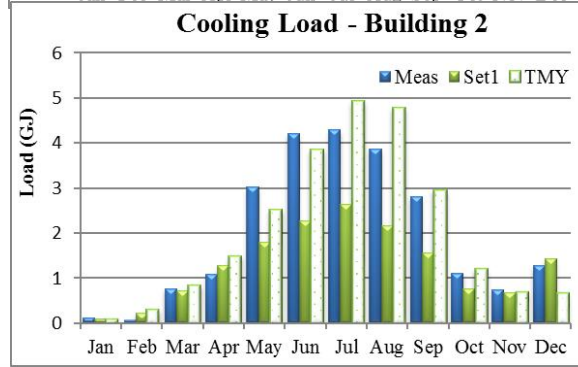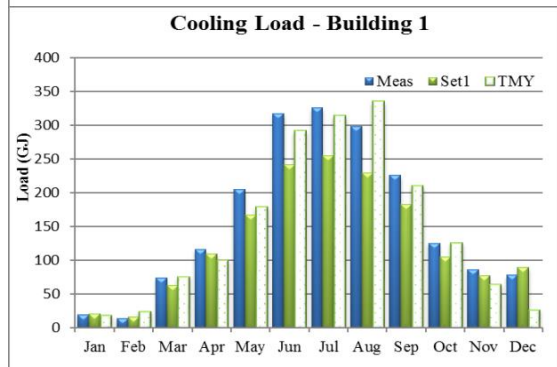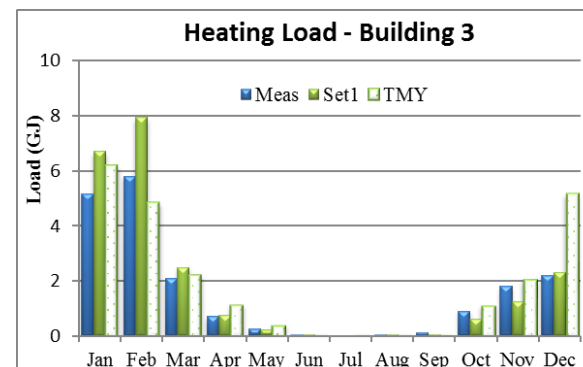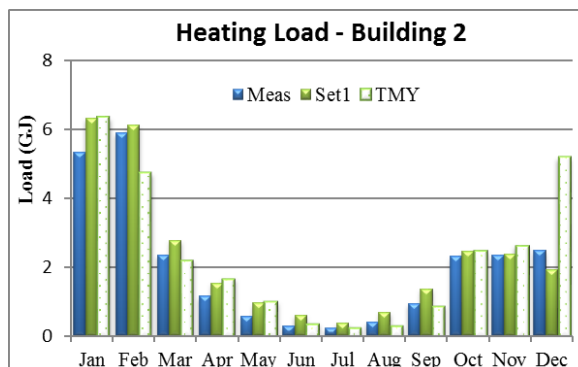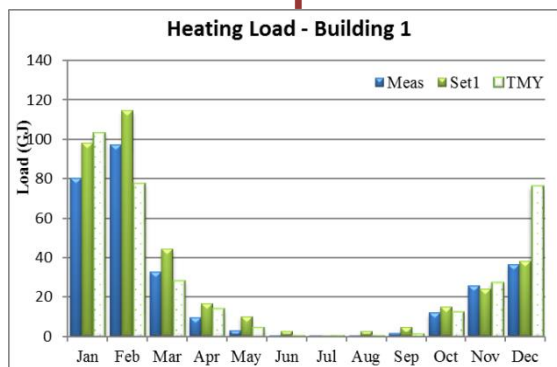
Proposed Morphologies for New Development in Chicago Loop

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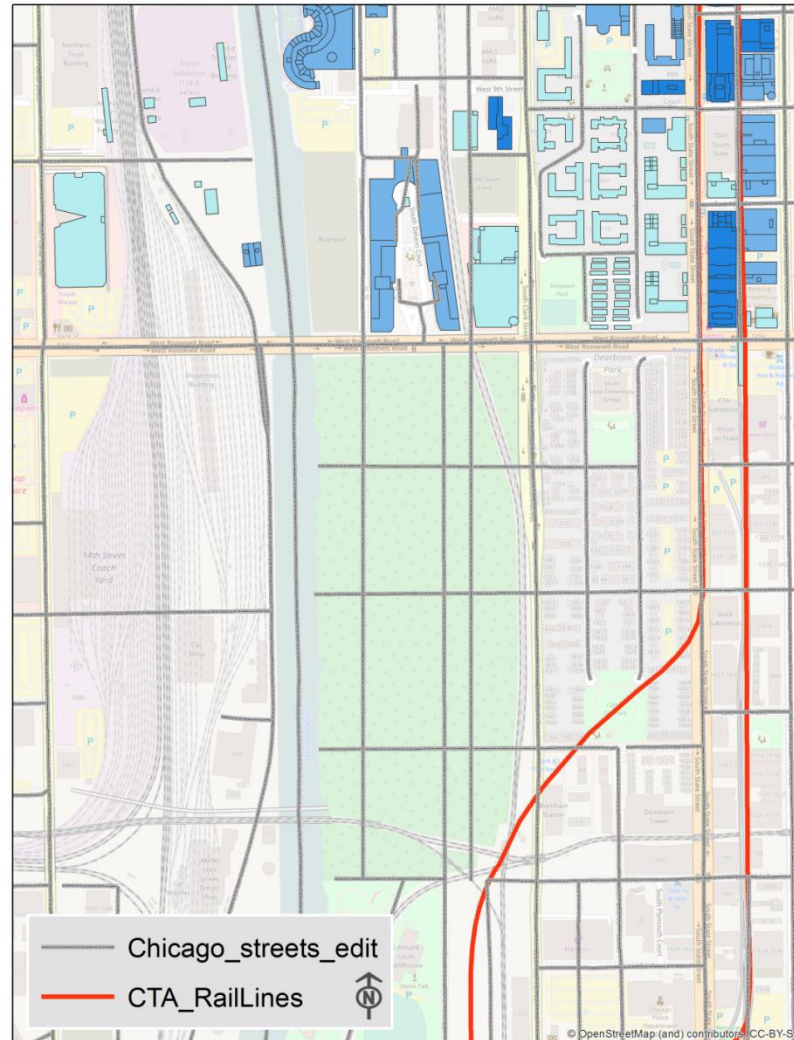
Morph 1: Supposed Development Plans

Office Building

Commercial Real Estate

Related Midwest Building (OneEleven luxury apts, Hotel Chicago)

Columbia College, Sage Medical Group, Car share, Parking garage, Dry Cleaner, Small Businesses, lofts

Condos, businesses

Low-rise residential

MAXHT_M

■	235 - 489
■	132 - 234
■	75 - 131
■	36 - 74
■	3 - 35

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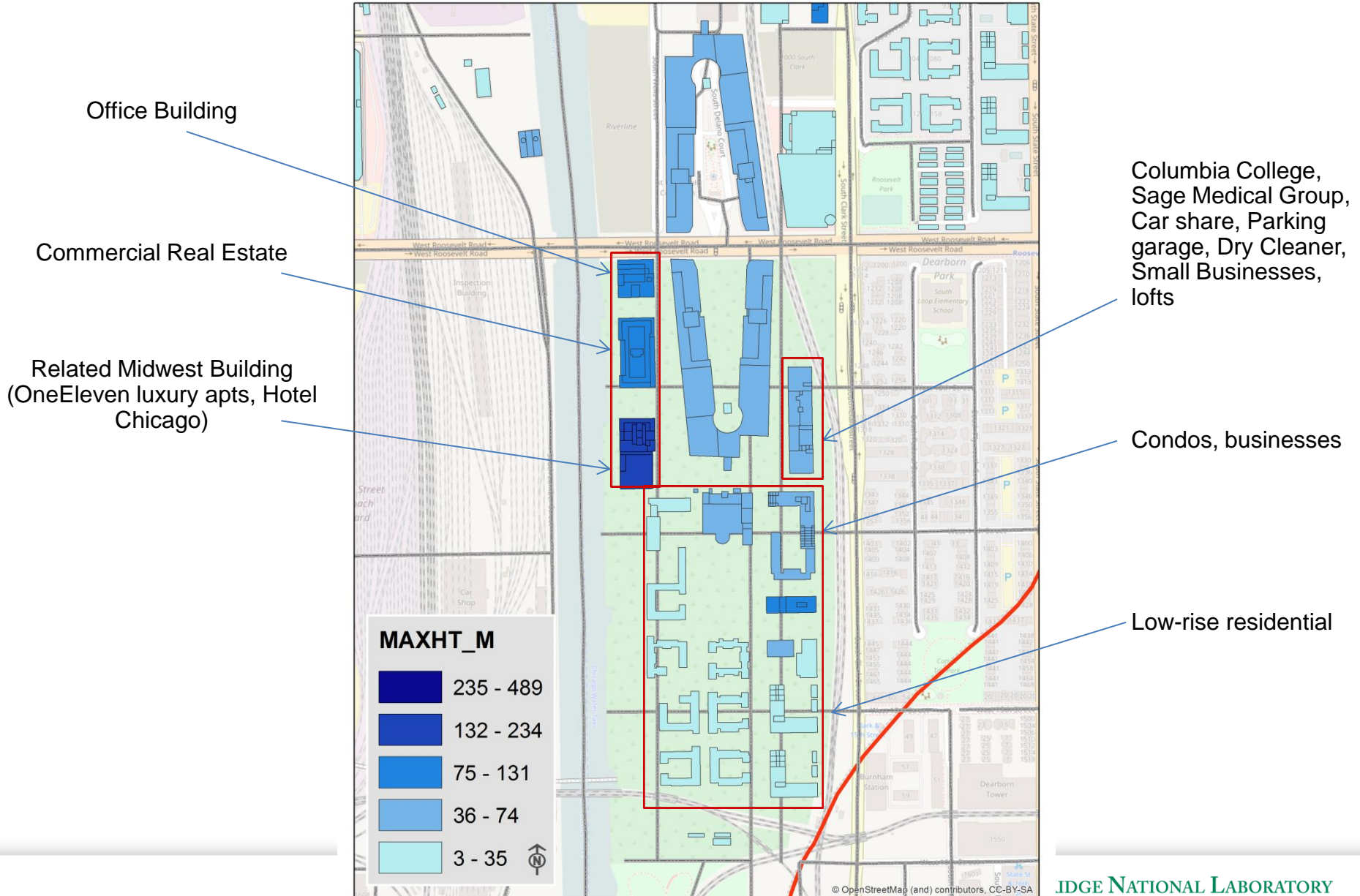
Microclimate Projections for Future Energy Use
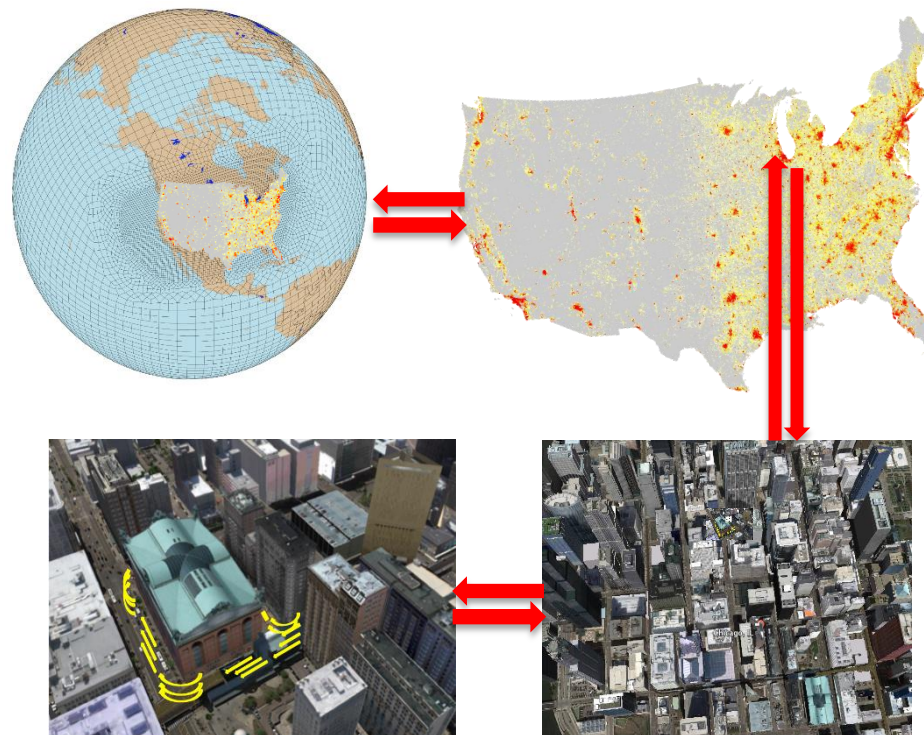
- Global Climate Models as boundary conditions
  - CMIP5 Ensemble Members

- Regional model with embedded CFD
  - Downscale to meso and micro

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Urbanization projections: evaluating future per capita energy use
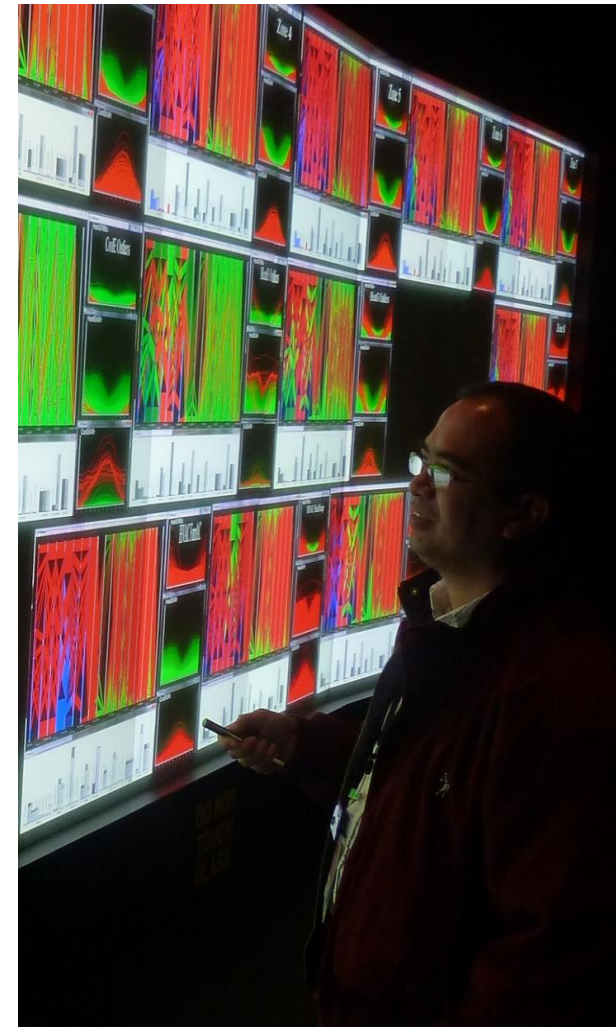
- LandCast
  - Locally adaptive, spatially explicit population predictions
  - Business as usual growth rate, land use, land cover change
  - Shows changes from 2010 to predicted urbanization for 2050
  - Dense settlement can afford energy efficiencies by encouraging multi-dwelling living
  - Average carbon footprint per capita is smaller for cities in which individuals live in multi-dwelling buildings

	-50,000 - -5,000
	-5000 - -500
	-500 - -1
	-1 - 1
	1 - 500
	500 - 1,000
	1,000 - 120,000
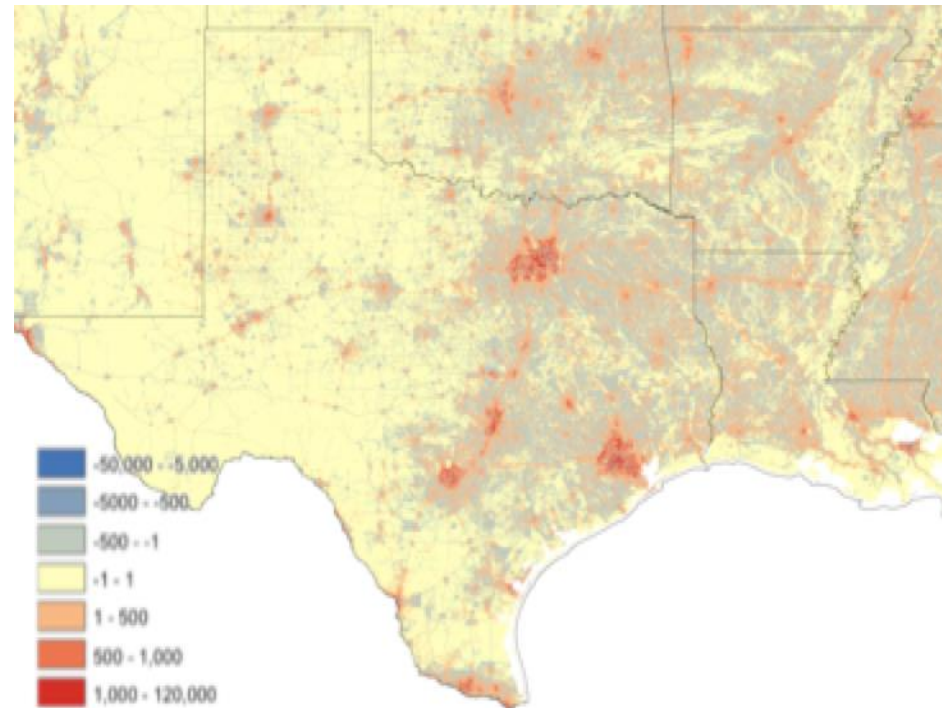
**Change in population per 1km cell from 2010 to 2050**

Fractional Factorial Design: Sensitivity Analysis for Test Morphologies

- **Developed the world's fastest building energy model creator**
  - Capable of creating 155,793 unique buildings (35.58GB of storage) on a laptop in 2.6 minutes

- **Advanced fractional-factorial designs were extended to allow sensitivity analysis in a way that maximizes the statistical resolution for a given number of simulations**
  - ~150k buildings were simulated and verified for this project
  - Covers all 16x DOE reference buildings (representing over 70% of the U.S. commercial building stock)
  - 16x climate zones
  - 3x vintages (based on building codes active at the time: pre-1980, 1980-1990, post-1990)

Project Urban Morphological Changes for Future Years

- Site for residential and commercial growth using LandCast methodology

- Determine neighborhood by neighborhood the best morphology to accommodate that new growth

- Evaluate greenspace options using unique ORNL capabilities

- Analysis is high resolution and spatially explicit

- Interactive visualization for planning and development professionals
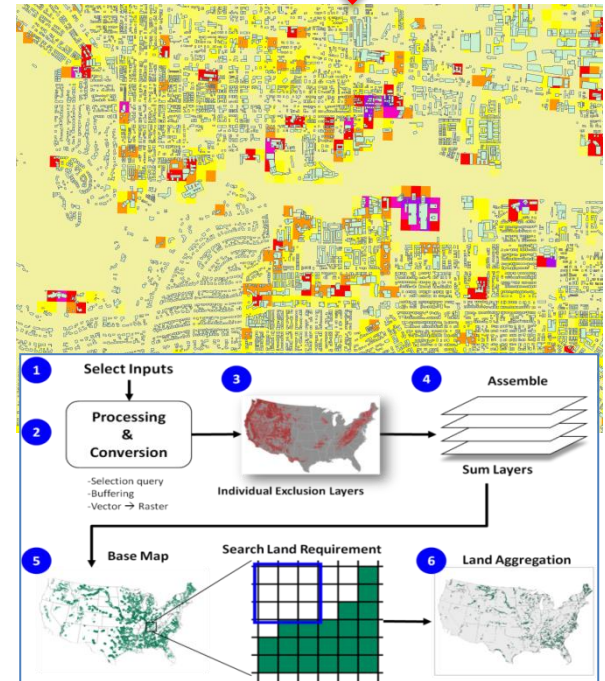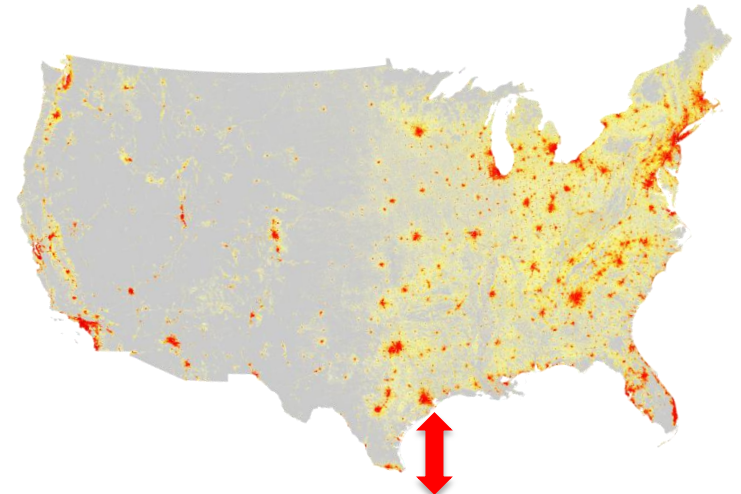
Acknowledgements

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