Trees vs. Forests Views of Building Energy Demand Projections

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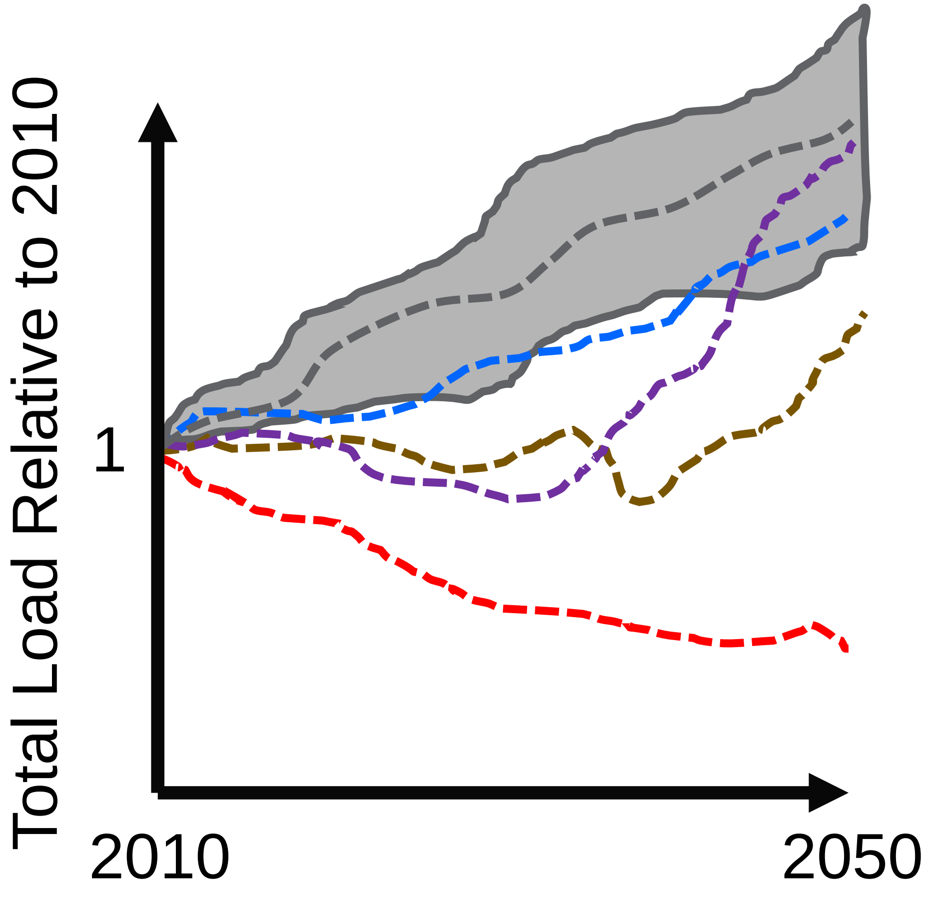
Understanding the Sensitivity of Building Energy Demand to Dynamic Stressors

Challenge: Researchers from a variety of communities are interested in understanding and projecting changes in building energy demand due to changes in weather/climate, population, policy, technology, and socioeconomics.



<u>Forcing Factors</u>

---- Technology
---- Population
---- Climate
---- Policy (e.g., building codes)

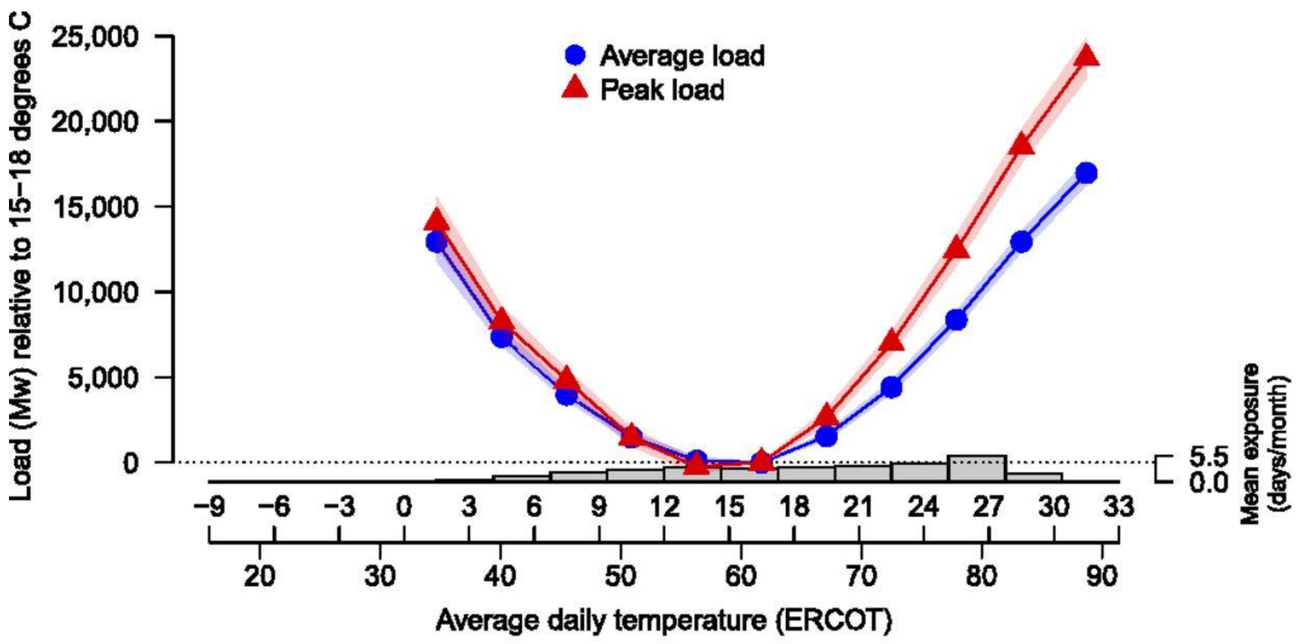
<u>Goal</u>

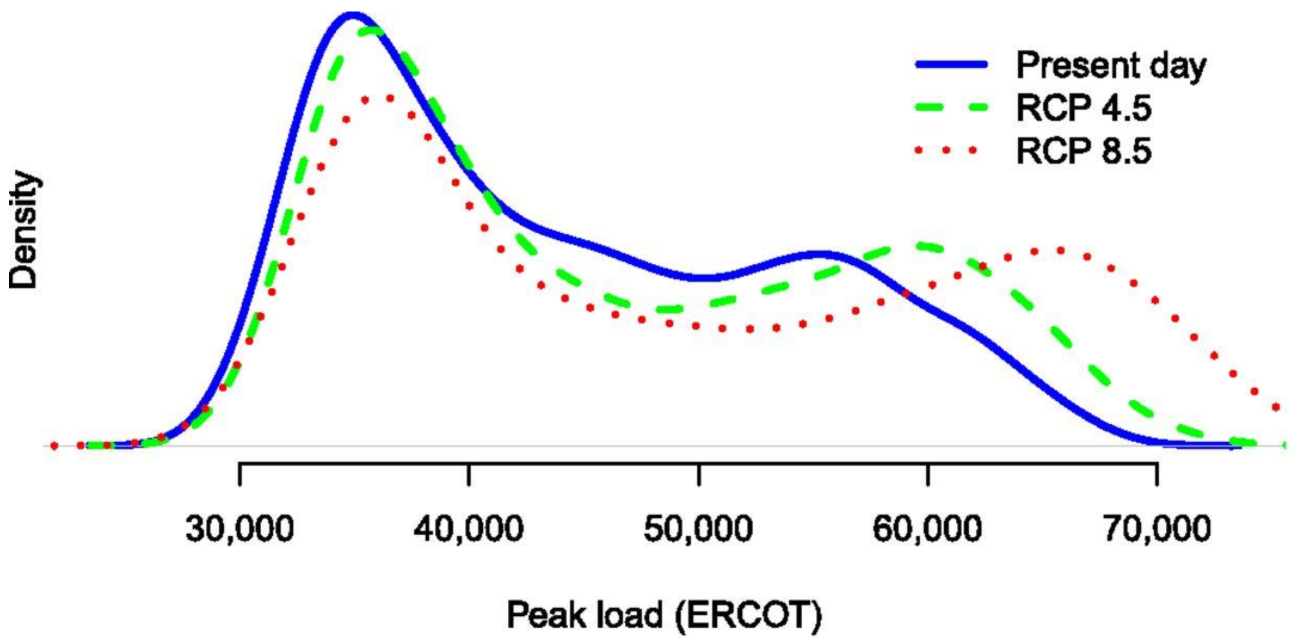
---- Climate + Population + Technology + Policy + Uncertainty

Empirical Modeling Approaches

Given enough data, one could formulate a statistical model relating the current state of the forcing factors to the total building load:

$$Building\ Load_{Aggregate} = x_1 * Tech. + x_2 * Pop. + x_3 * Climate + x_4 * \cdots$$



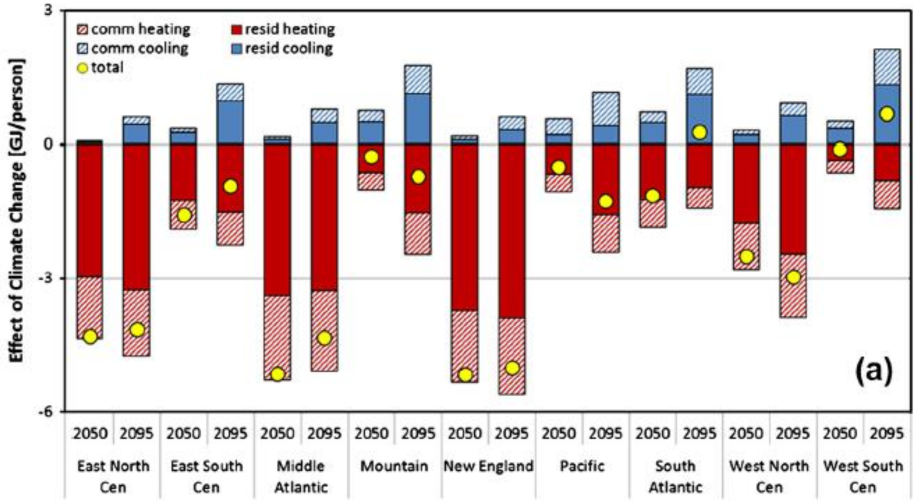


Auffhammer et al. 2017 – *PNAS* (Figs. 1 and 2)

Empirical Modeling Approaches

Given enough data, one could formulate a statistical model relating the current state of the forcing factors to the total building load:

$$
\begin{cases}
Q^i_{heating} = k^i_{heating}(HDD^i \cdot Eff \cdot SR - G^i)\left[1 - \exp\left(-\frac{\ln 2}{\mu_j} \cdot \frac{Y^i}{P_j}\right)\right] \\
Q^i_{cooling} = k^i_{cooling}(CDD^i \cdot Eff \cdot SR + G^i)\left[1 - \exp\left(-\frac{\ln 2}{\mu_j} \cdot \frac{Y^i}{P_j}\right)\right] \\
Q^i_{others} = k^i_{others} q^i_{others}\left[1 - \exp\left(-\frac{\ln 2}{\mu_j} \cdot \frac{Y^i}{P_j}\right)\right]
\end{cases}
$$



Zhou et al. 2014 – *Appl. Energy*
(Eq. 2 and Fig. 6a)

Challenges

1) Coefficients ($x_1, \ldots, x_n$) reflect physical relationships, but are inherently black boxes
2) "Past performance is no guarantee of future results"
3) Parameters cannot be easily separated:

Population Climate

Physical Modeling Approaches

Alternatively, one could simulate the energy usage of specific buildings using a physical model (e.g., EnergyPlus [*E*+]) and then force the physical model with an alternate set of future conditions.

<u>E+ Parameters</u>

HVAC type, wall type, roof type, insulation, windows, schedule, etc.

+

Weather data

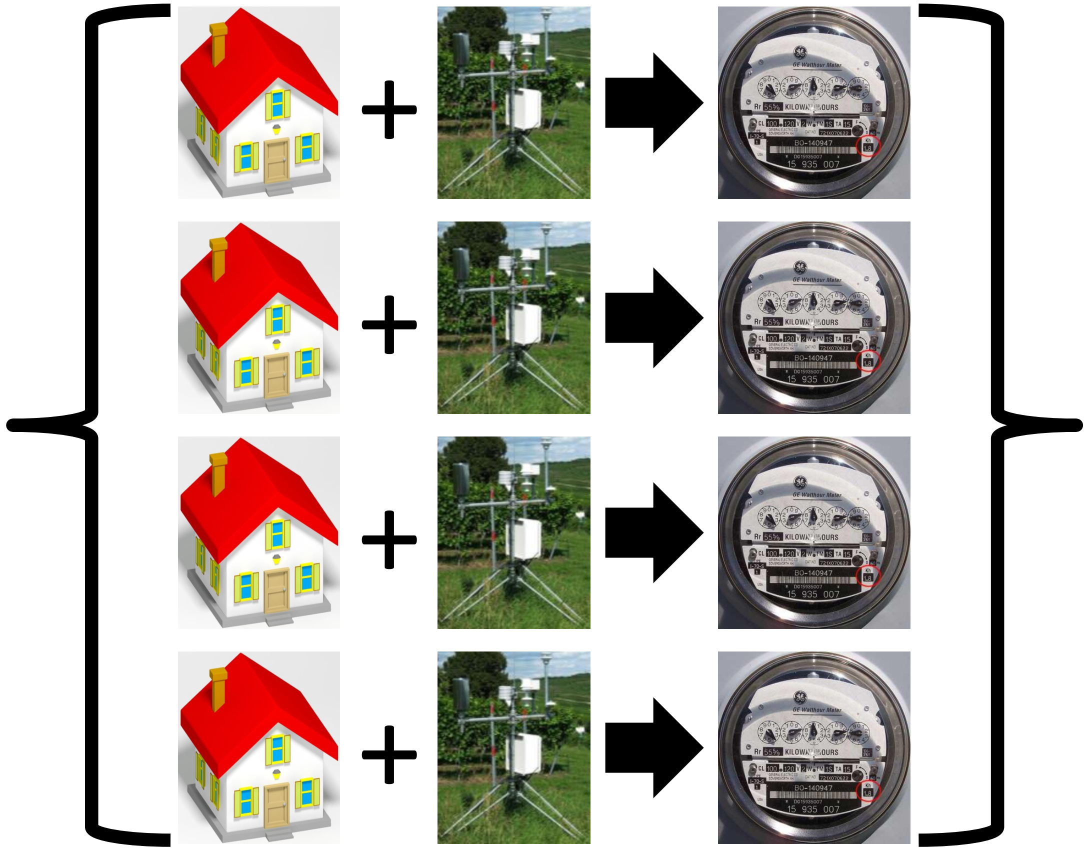
→

Hourly energy demand for 1 year

PNNL's Building ENergy Demand (BEND) Model

Novelty: Rather than simulating a single building in a single location and then extrapolating from the results, simulate a (very) large representative sample of residential and commercial buildings over a distributed area.

Building Load = Sum



N = 1:100,000

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Example: How much oxygen will trees in the Appalachian Mountains release in the future?

Top-Down
Aggregate empirical modeling of the total system

Bottom-Up
Detailed physical modeling of a subset of the total system

It is Not Uncommon for Top-Down and Bottom-Up Approaches to Yield Different Results. Why?

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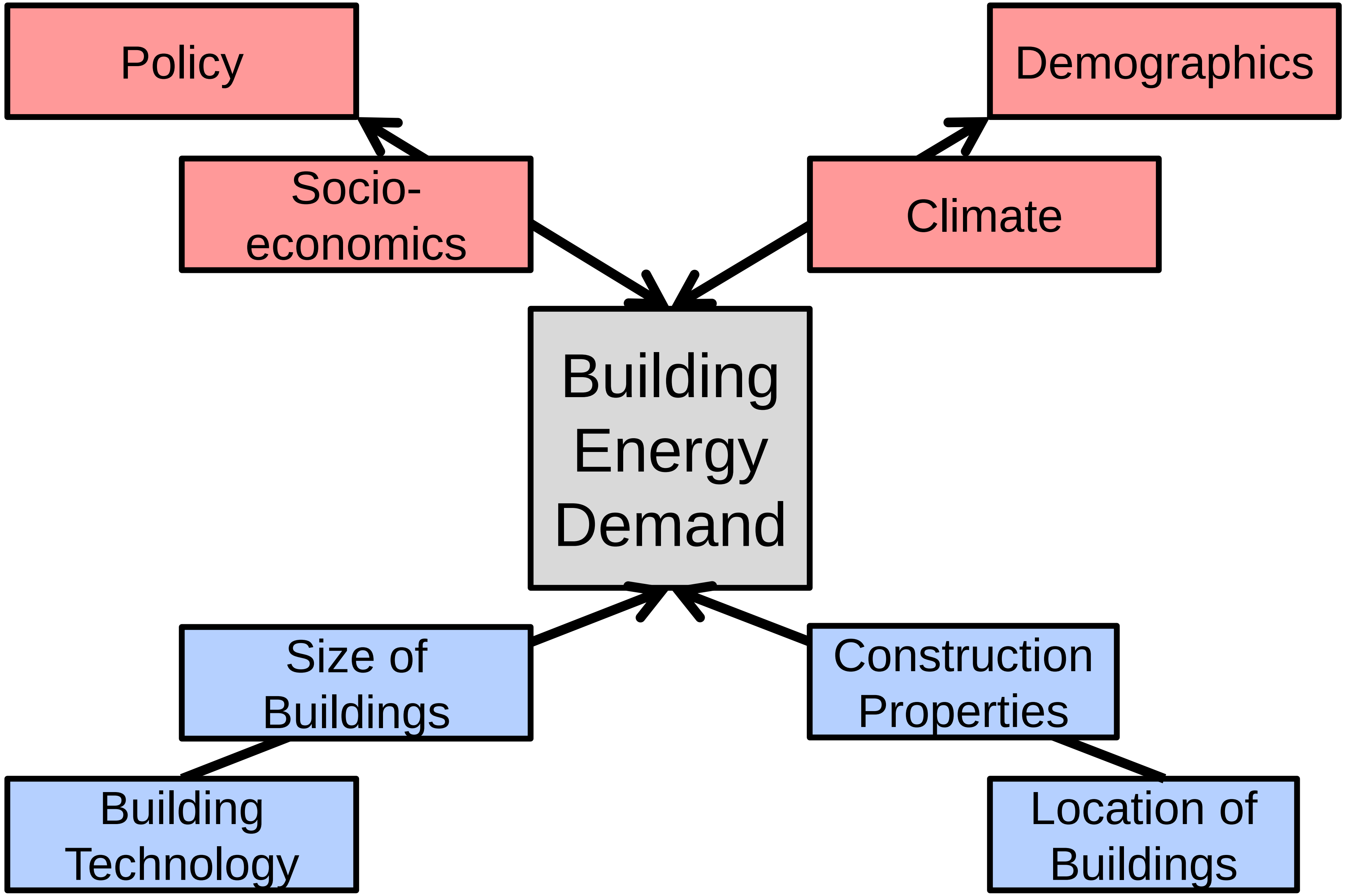
Aggregate empirical modeling of the total system



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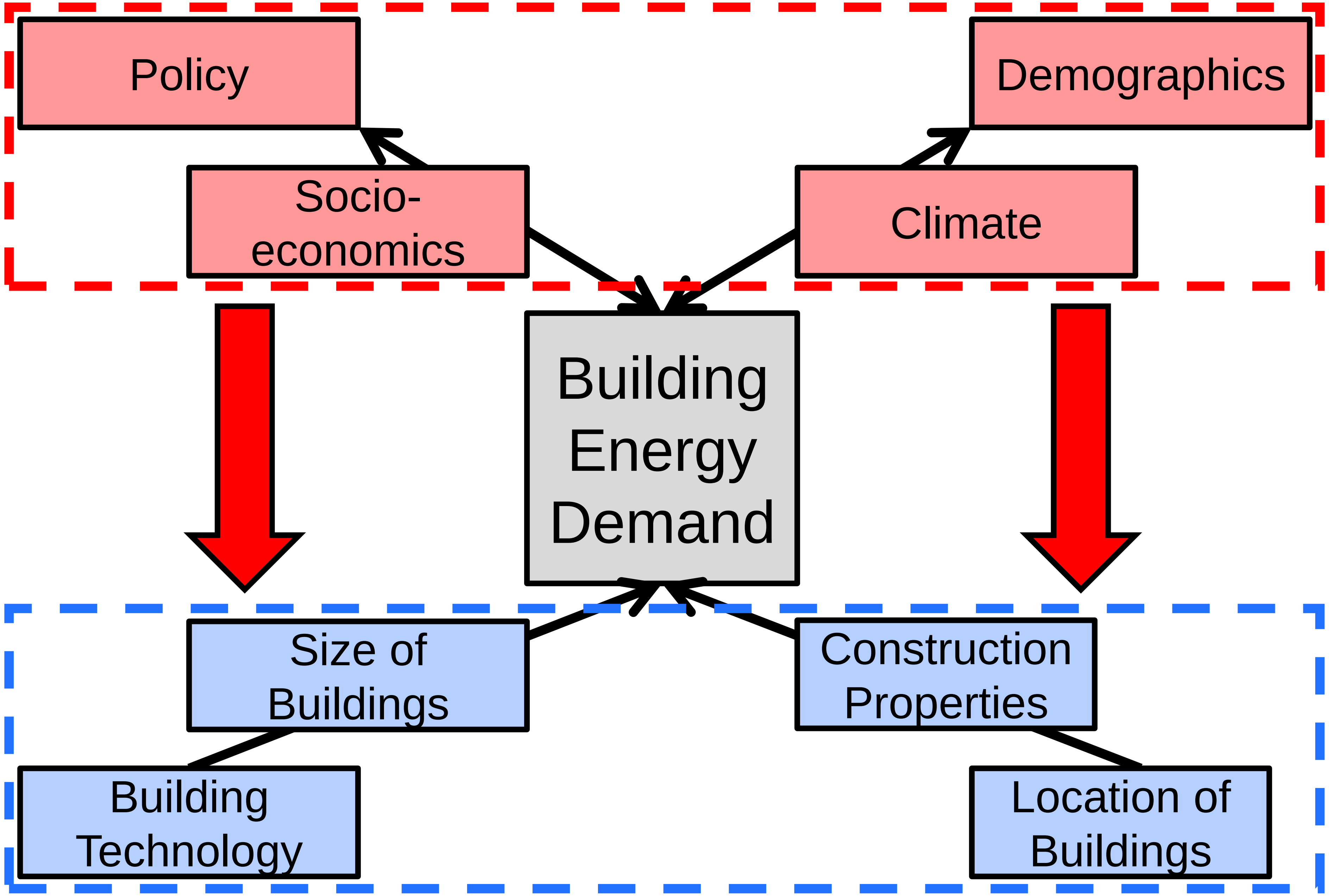

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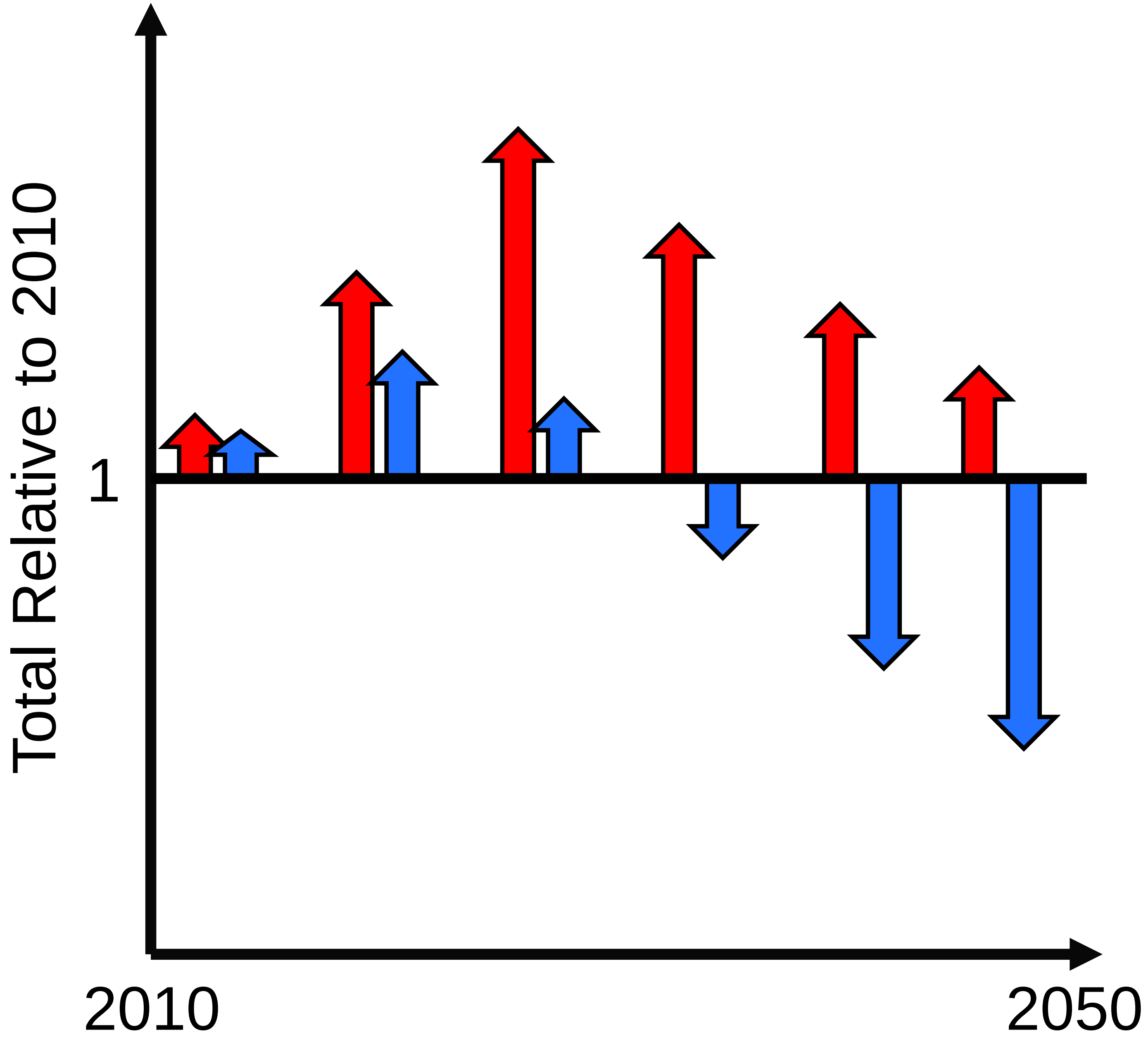

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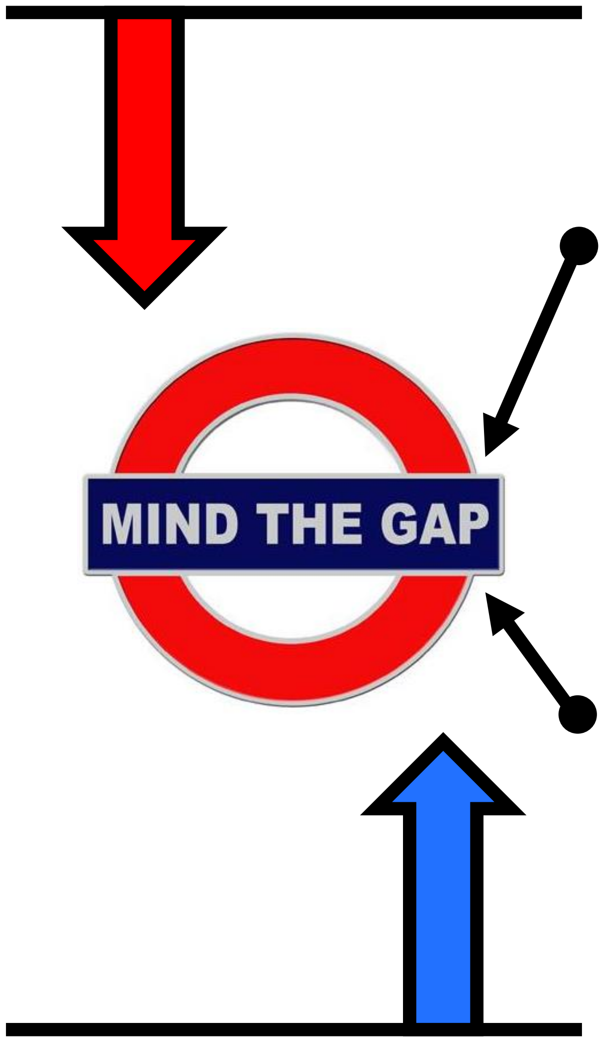
Reconciling Top-Down and Bottom-Up Approaches to Building Energy Modeling



GCAM-USA	BEND
Sensitive to Population	Sensitive to Population via Floor Space
Cross-Sectoral Impacts	Single Sector
Economic Model	Physical Model
Sensitive to Climate	Sensitive to Climate via Weather
Endogenous and/or Exogenous Evolution of Technology	Exogenous Evolution of Technology
Single Spatial Scale (States)	Flexible Spatial Scales (Counties+)
Annual Time-Step	Hourly Time-Step

The overall strategy of the experiment is to reconcile as many variables as possible in order to understand how the model’s different structures contribute to differing projections.

Upcoming Numerical Experiments

We are conducting a numerical experiment using BEND and GCAM-USA to explore the impact of climate and population changes on building energy demand in the western U.S.

Science Questions

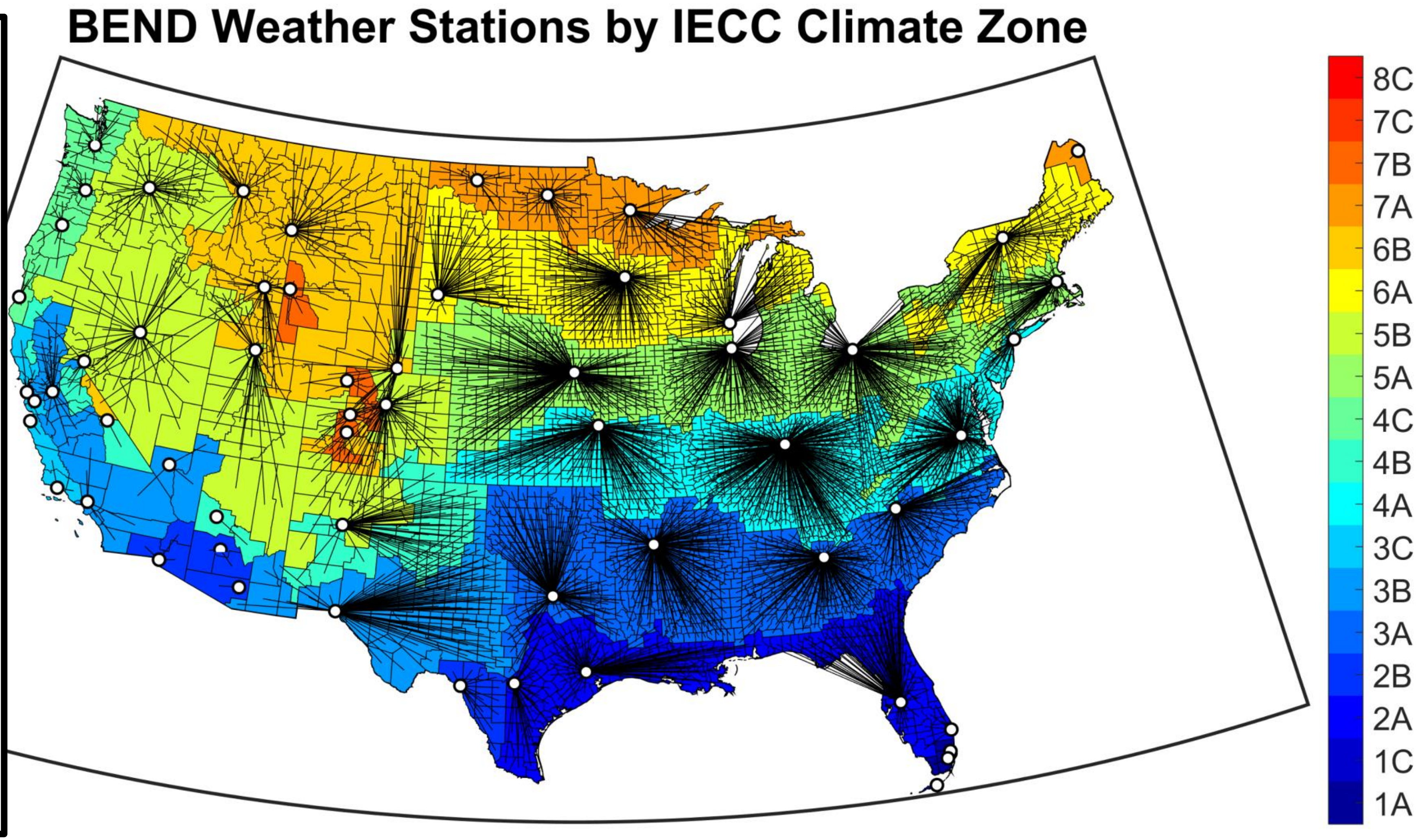
1. How does the impact of climate and population changes vary between the two models? How do the structural differences contribute to disagreements in the projections?

2. What information is gained by having higher spatial-resolution weather and building output in BEND compared to state-level values in GCAM-USA?

Homogenizing Climate Projections

To minimize the differences in climate, we adapted the weather forcing of BEND into the standard HDD/CDD approach for GCAM-USA.

1. BEND uses 4 weather stations per IECC climate zone.



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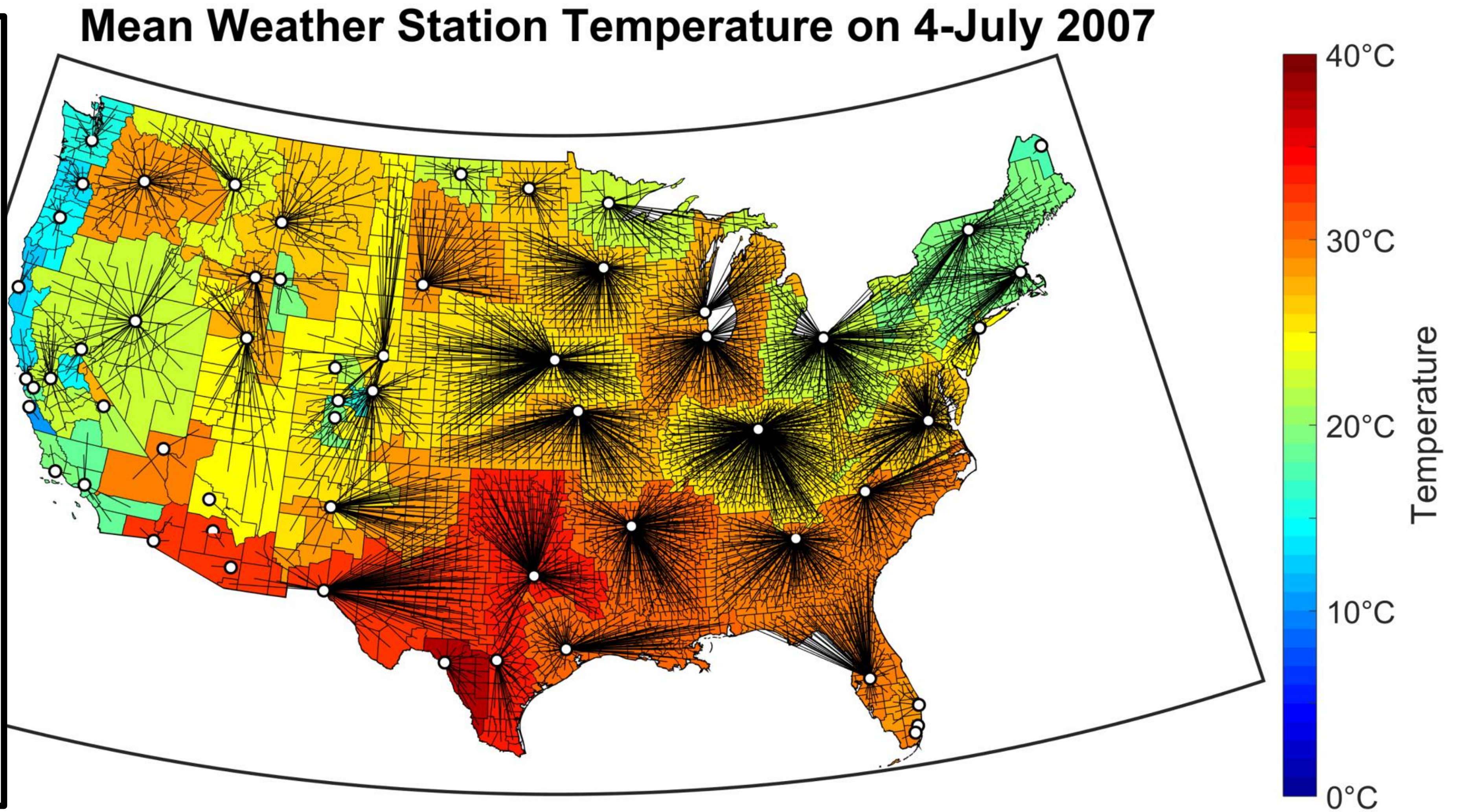

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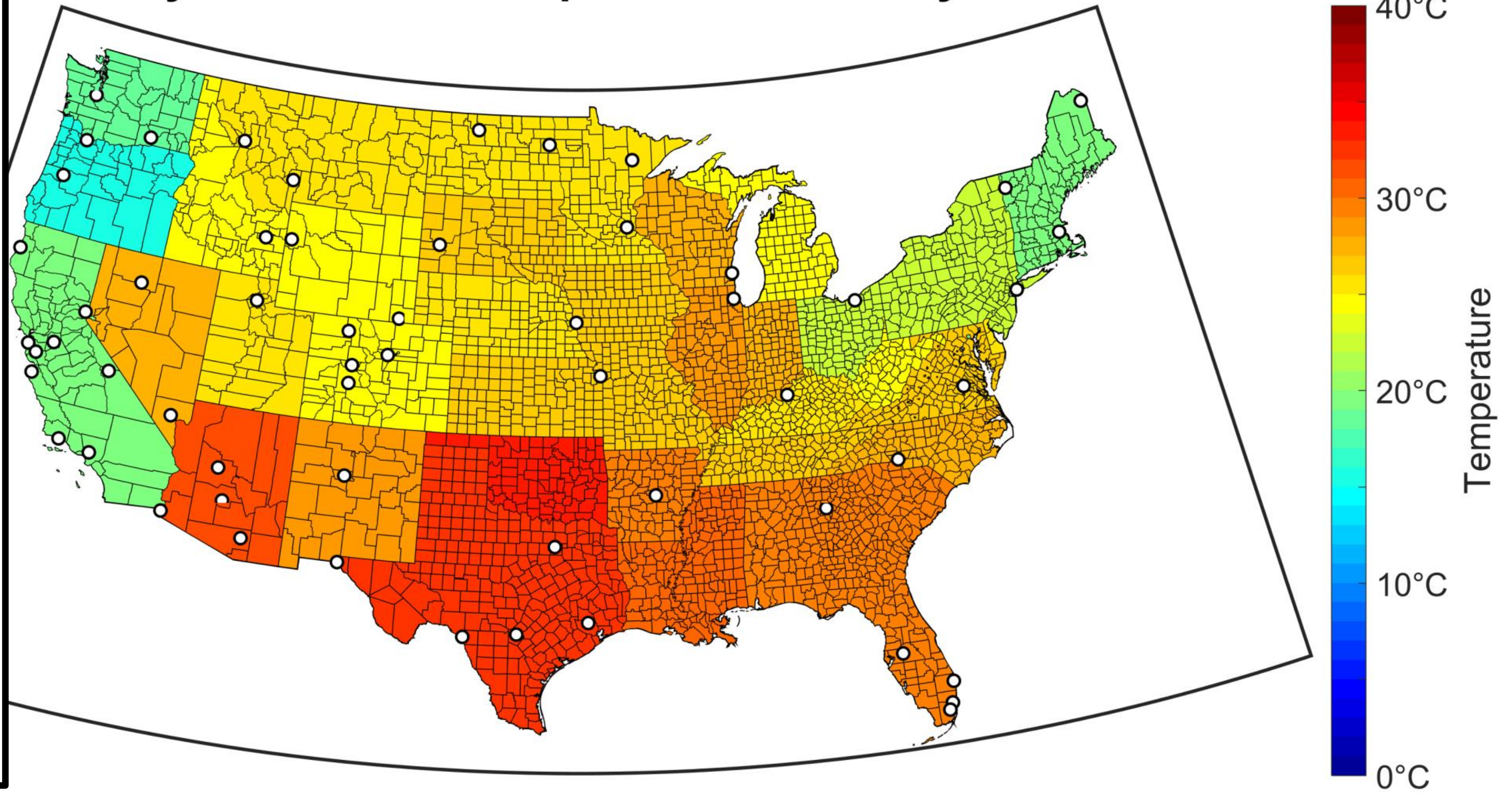
3. We population-weight those means into daily mean state temperatures.

Daily Mean State Temperature on 4-July 2007



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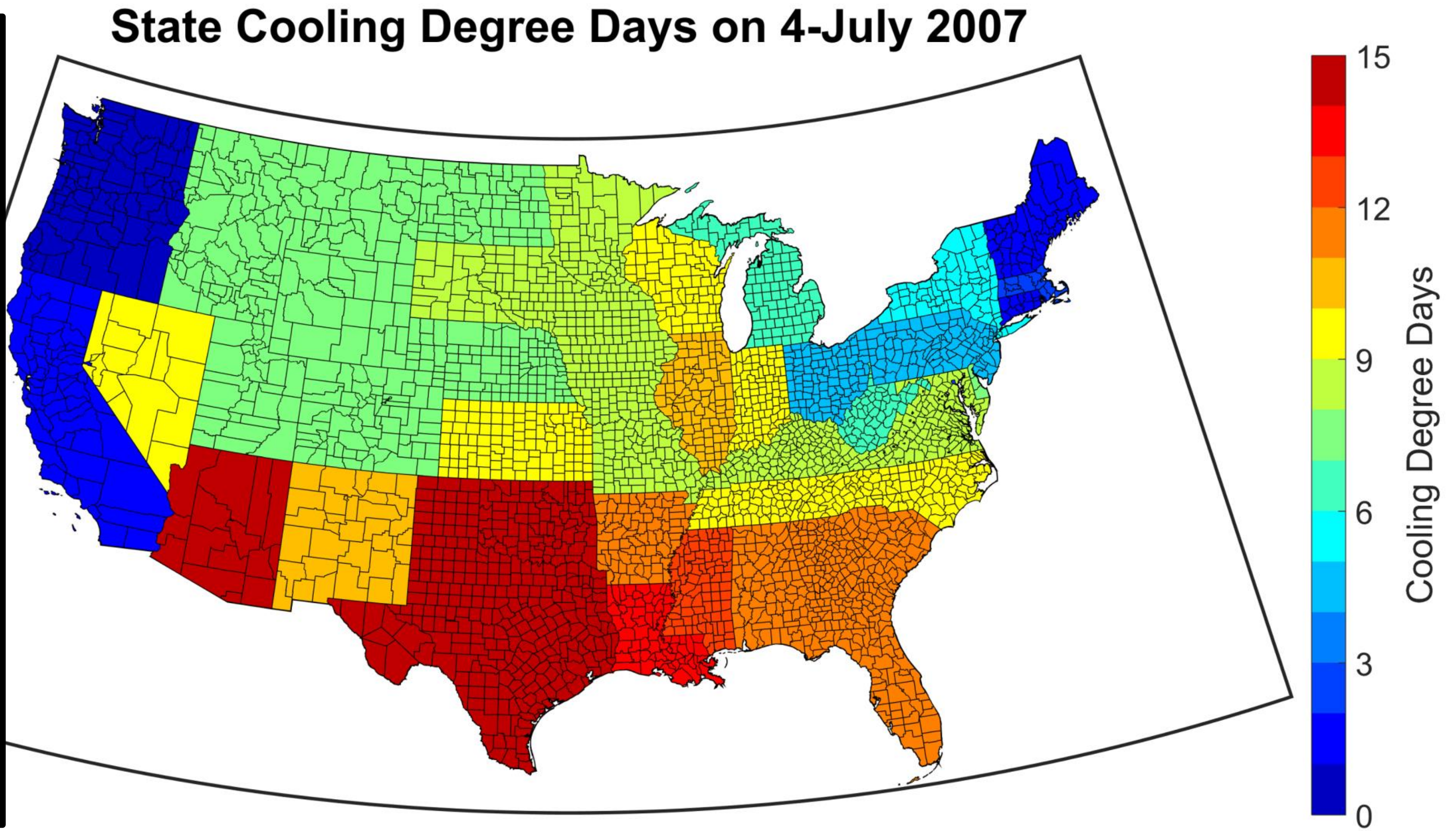
3. We population-weight those means into daily mean state temperatures.
4. We use the state temperatures to compute HDD/CDD.



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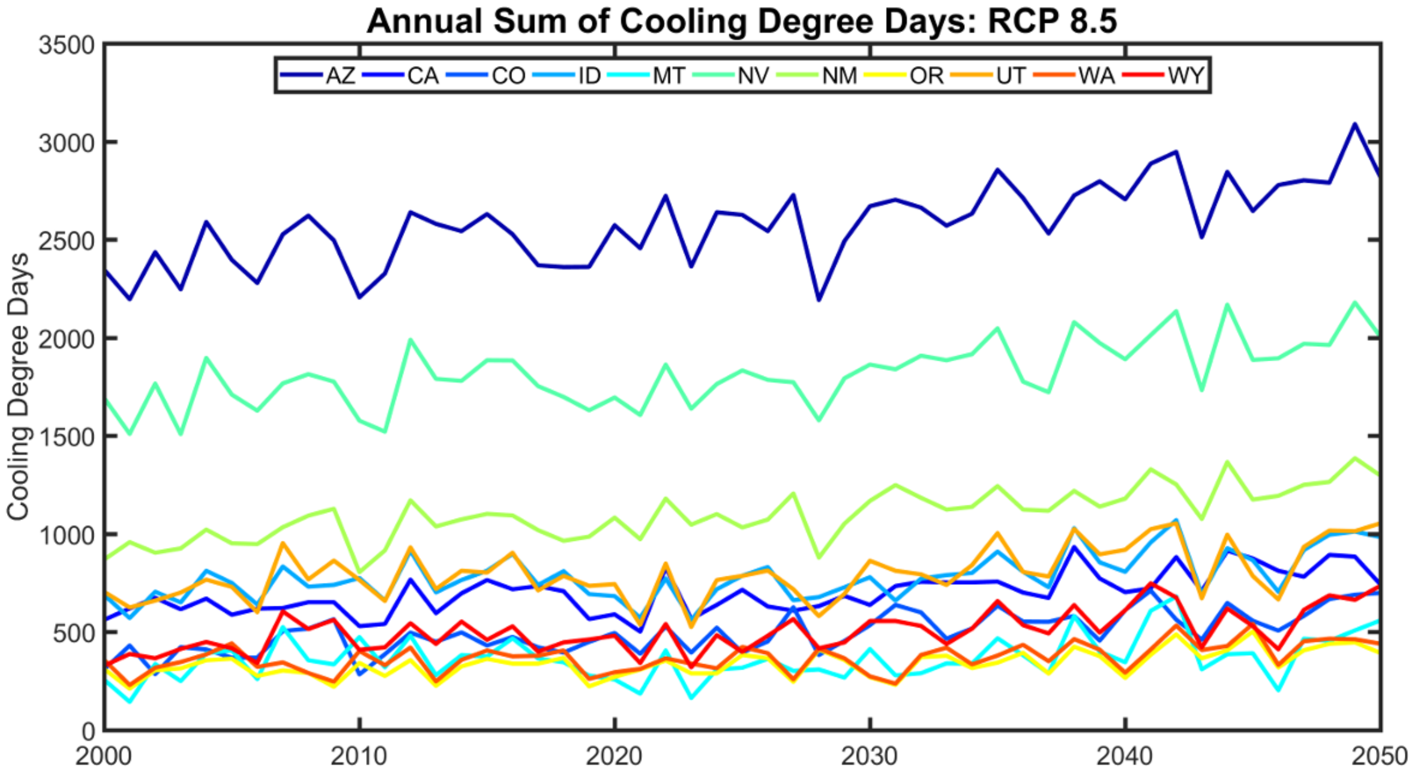
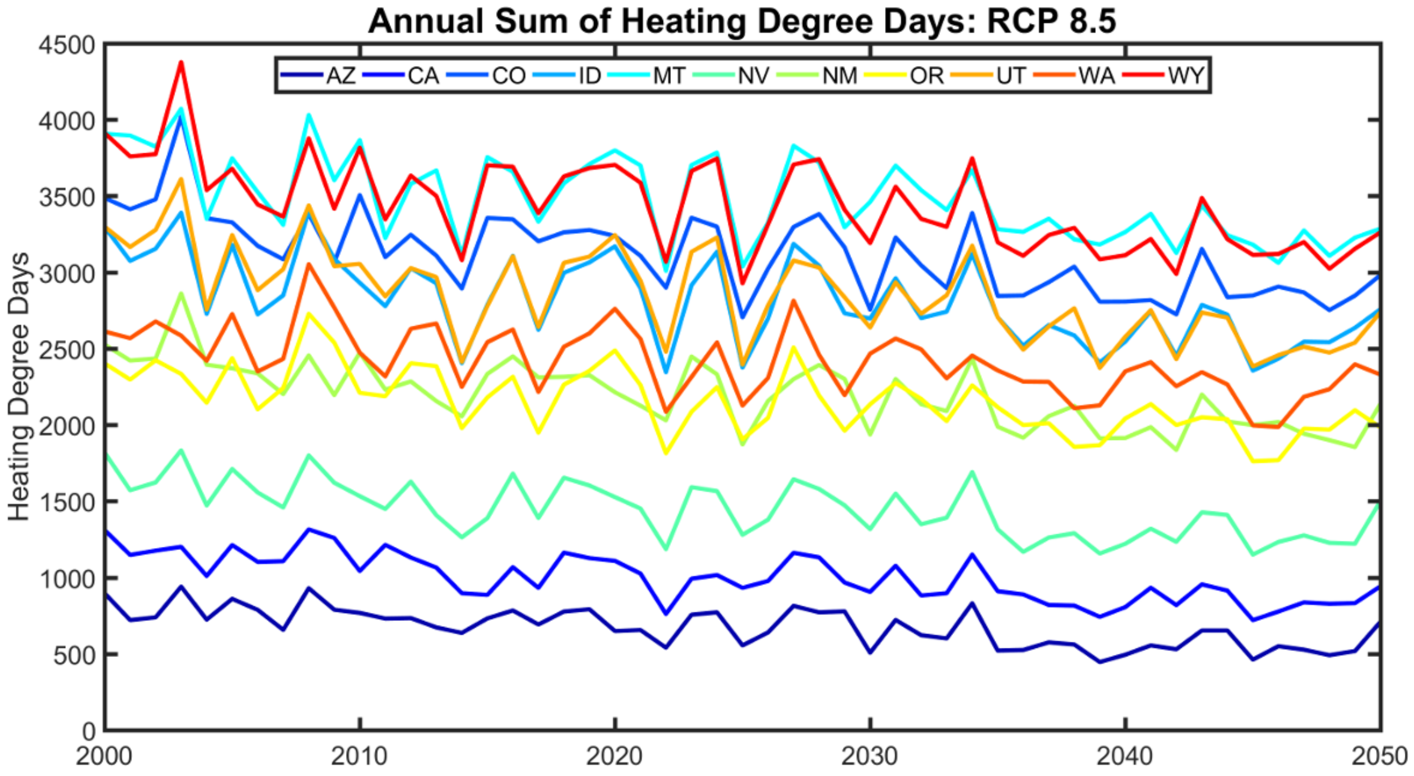
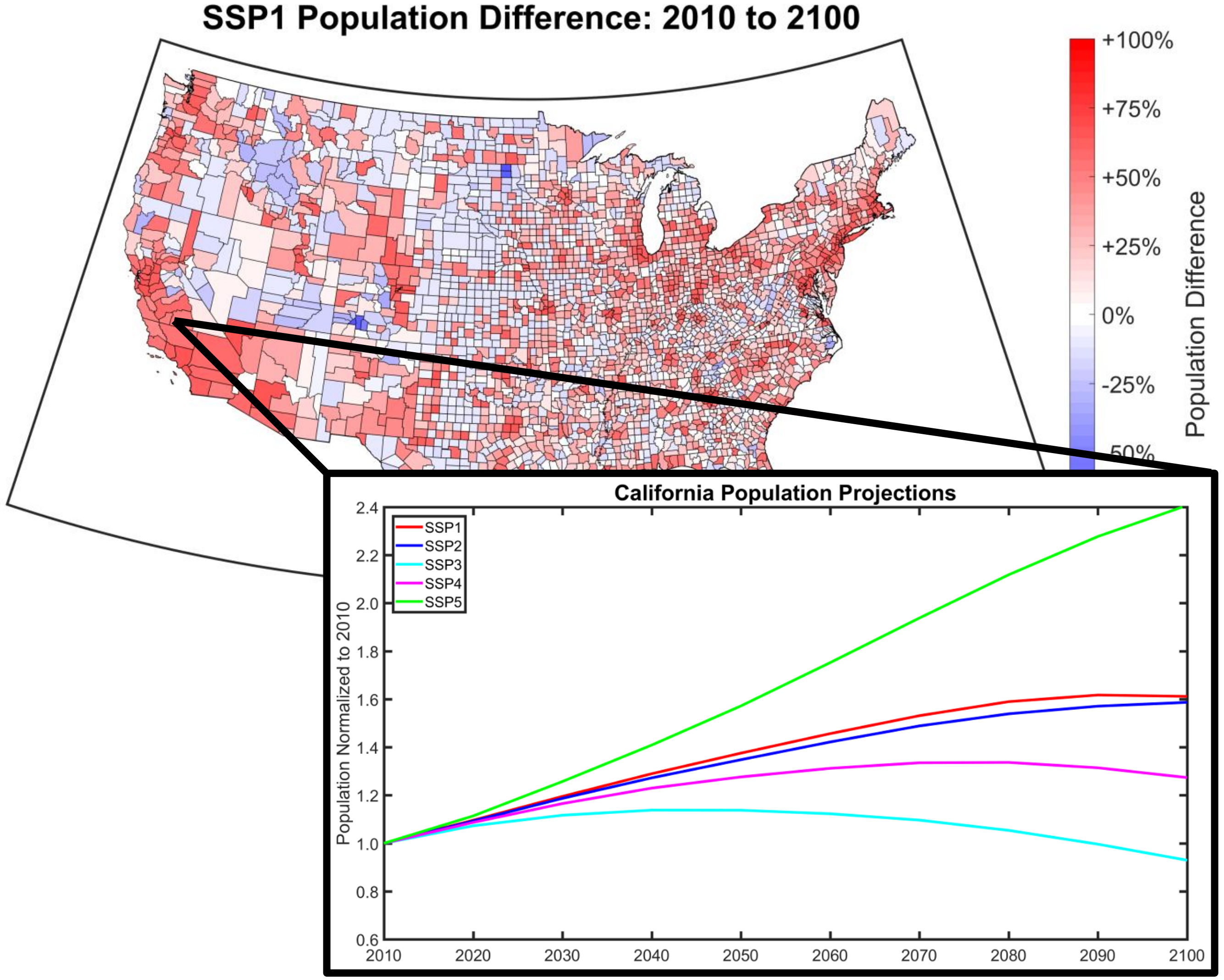
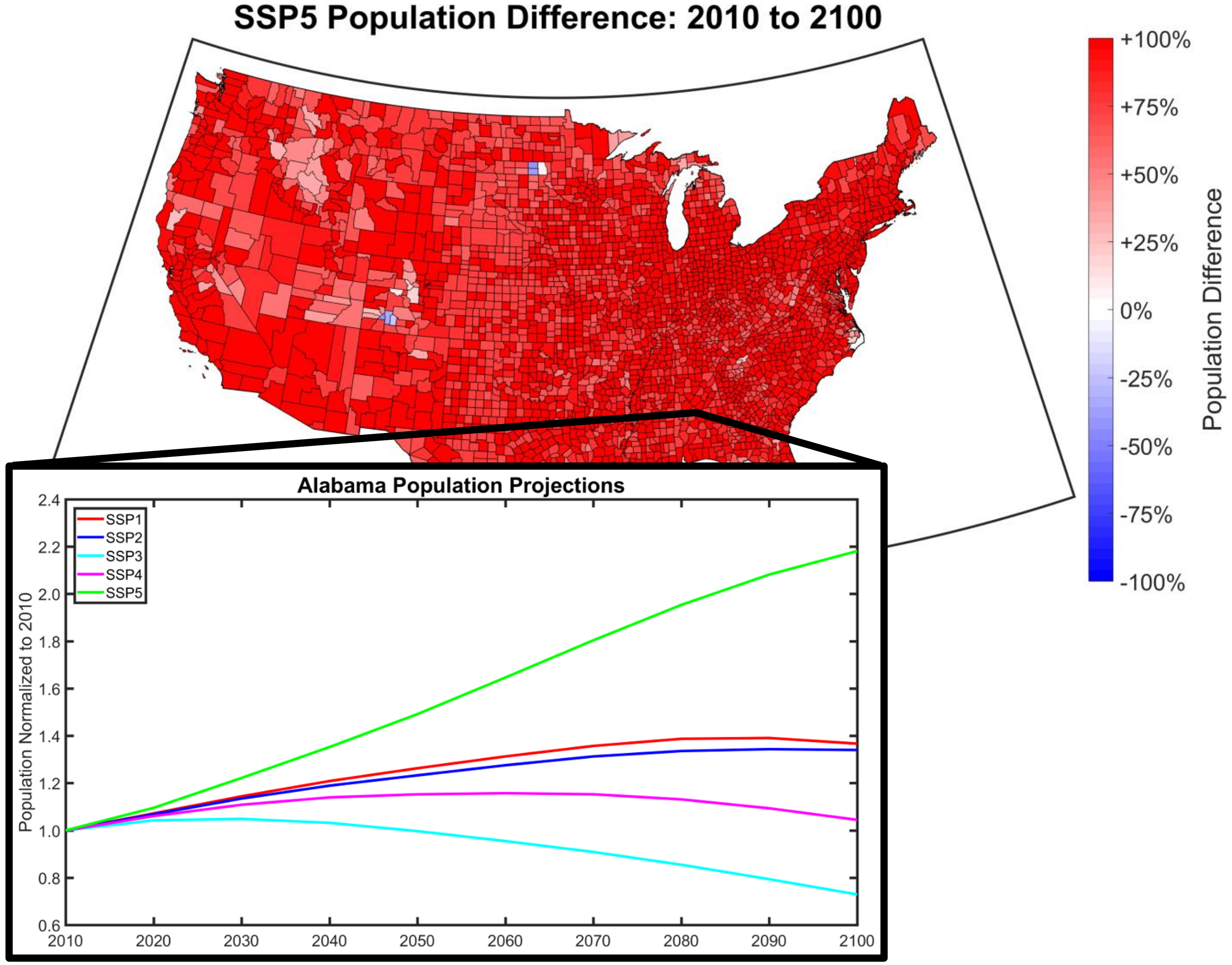




Homogenizing Population and Floor Space Projections

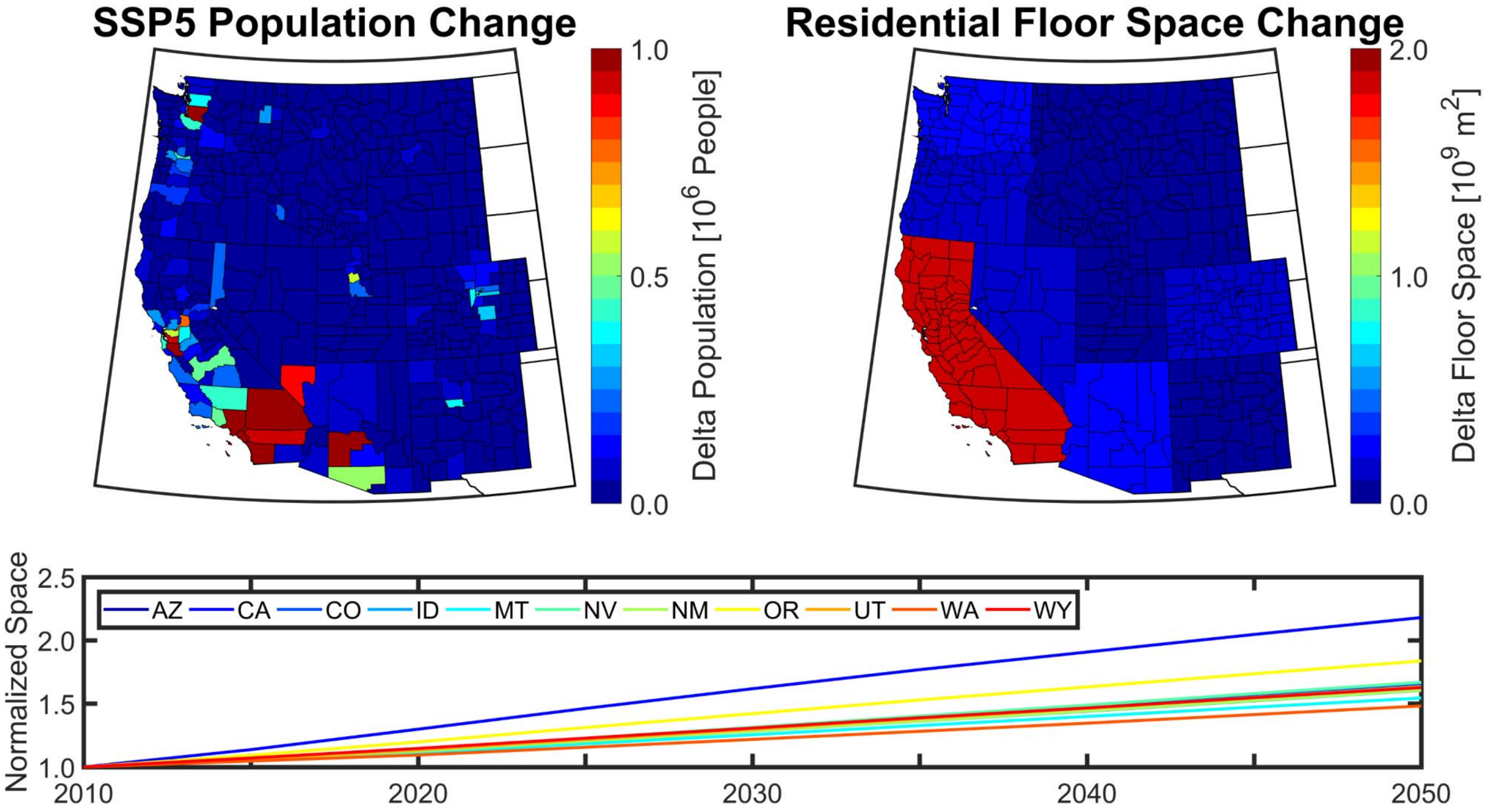
Population projections following the Shared Socioeconomic Pathways (SSPs) are converted into floor space projections at the state level.





Homogenizing Population and Floor Space Projections

GCAM-USA calculates changes in residential and commercial floor space as a function of population and GDP.



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<table>
<tr><th></th><th colspan="2">GCAM-USA</th><th colspan="2">BEND</th></tr>
<tr><th>Scenario</th><th>Population and GDP</th><th>HDD/CDD</th><th>Floor Space</th><th>Weather Station Forcing</th></tr>
<tr><td>SSP 5, RCP 8.5, Static Climate</td><td>SSP5</td><td rowspan="4">HDD/CDD from BEND Weather Station Forcing</td><td rowspan="4">Floor Space from GCAM-USA Population and GDP</td><td>Fixed at 2010 Values</td></tr>
<tr><td>SSP 5, RCP 8.5, Changing Climate</td><td>SSP5</td><td>RCP 8.5 GCM Run</td></tr>
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<tr><td>SSP 3, RCP 4.5, Changing Climate</td><td>SSP3</td><td>RCP 4.5 GCM Run</td></tr>
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Take Home Points

1. Many people are interested in understanding the sensitivity of building energy demand to changes in weather/climate, population, policy, technology, and socioeconomics.

2. Many top-down and bottom-up studies are difficult to reconcile given the plethora of experimental designs.

3. We are conducting simulations using GCAM-USA and BEND to explore the impact of climate and population on building energy demand.

4. The goal is to homogenize as many variables as possible in order to understand how the model’s different structures contribute to differing projections.