



Trees vs. Forests Views of Building Energy Demand Projections

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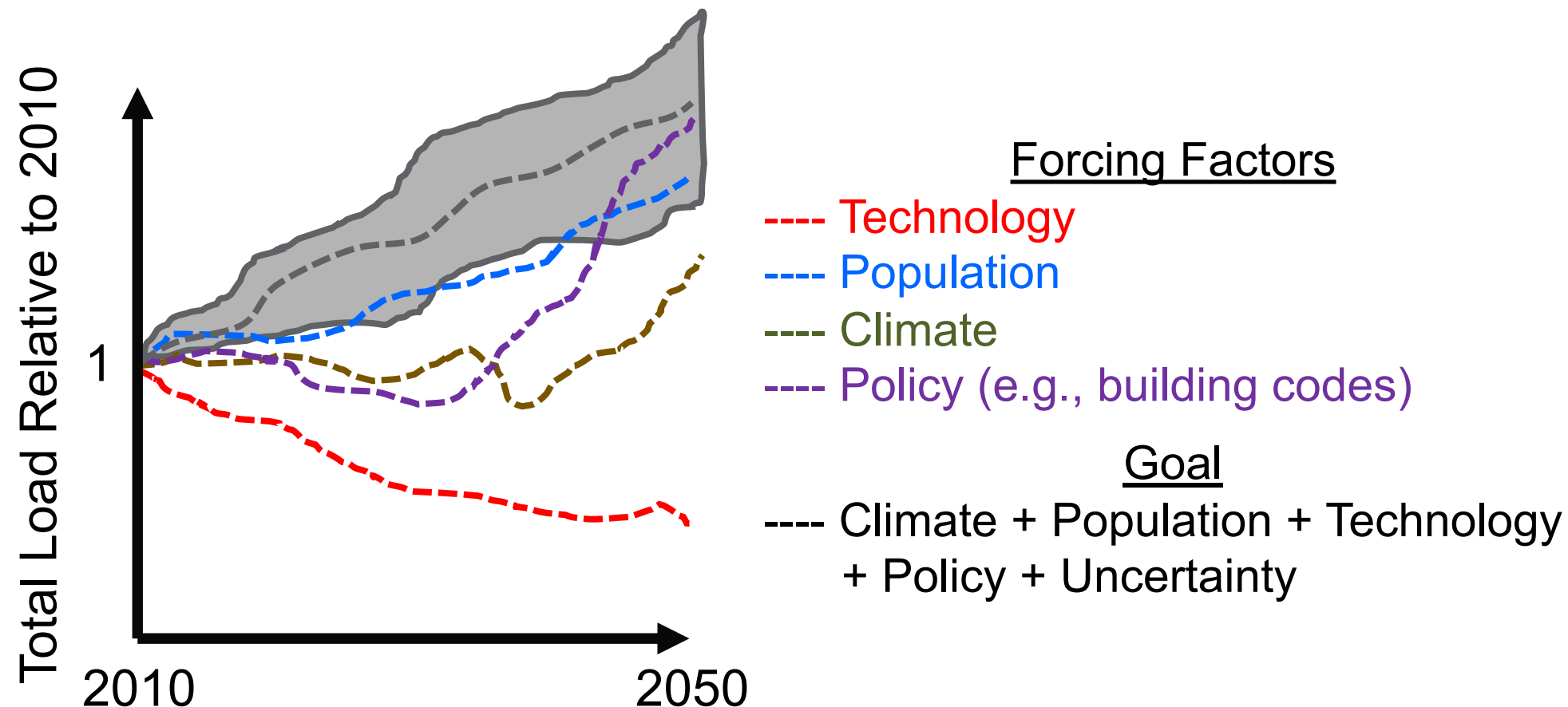


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Understanding the Sensitivity of Building Energy Demand to Dynamic Stressors

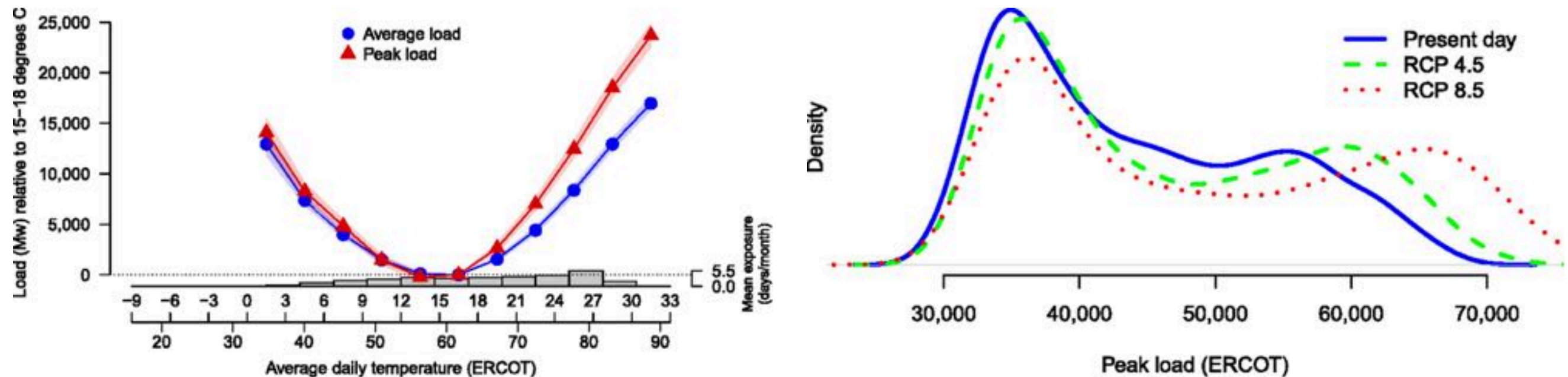
Challenge: Researchers from a variety of communities are interested in understanding and projecting changes in building energy demand due to changes in weather/climate, population, policy, technology, and socioeconomics.



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:

$$\text{Building Load}_{\text{Aggregate}} = x_1 * \text{Tech.} + x_2 * \text{Pop.} + x_3 * \text{Climate} + x_4 * \dots$$

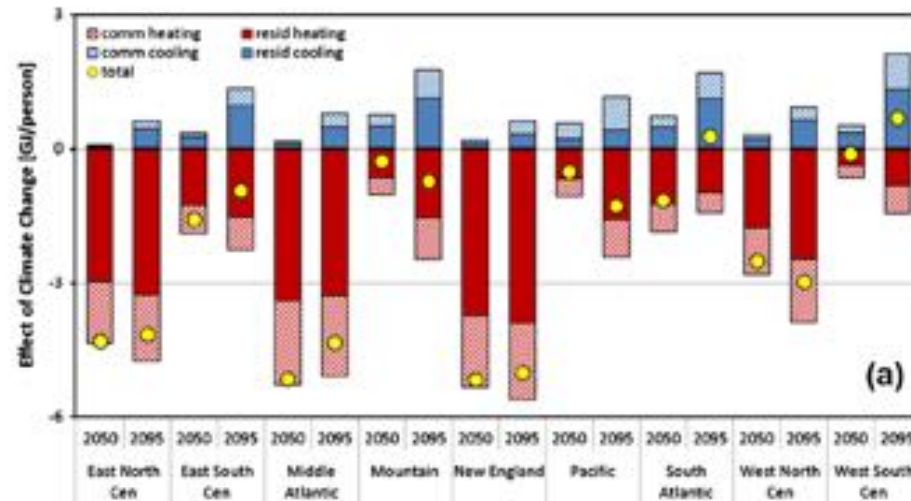


Auffhammer et al. 2017 – *PNAS* (Figs. 1 and 2)

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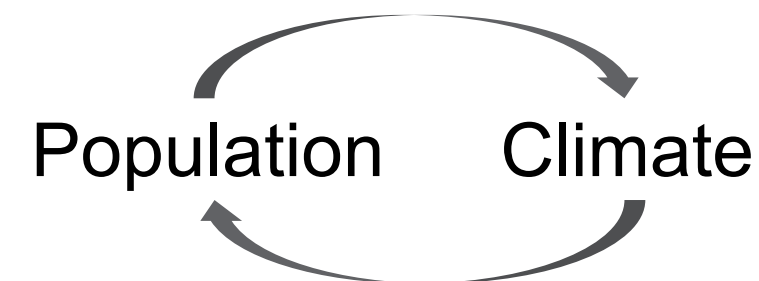
$$\begin{cases} Q_{heating}^i = k_{heating}^i (HDD^i \cdot Eff \cdot SR - G^i) \left[1 - \exp \left(-\frac{\ln 2}{\mu_j} \cdot \frac{Y^i}{P_j} \right) \right] \\ Q_{cooling}^i = k_{cooling}^i (CDD^i \cdot Eff \cdot SR + G^i) \left[1 - \exp \left(-\frac{\ln 2}{\mu_j} \cdot \frac{Y^i}{P_j} \right) \right]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



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

Challenges

- 1) Coefficients (x_1, \dots, 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:



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.



E+ Parameters

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

+



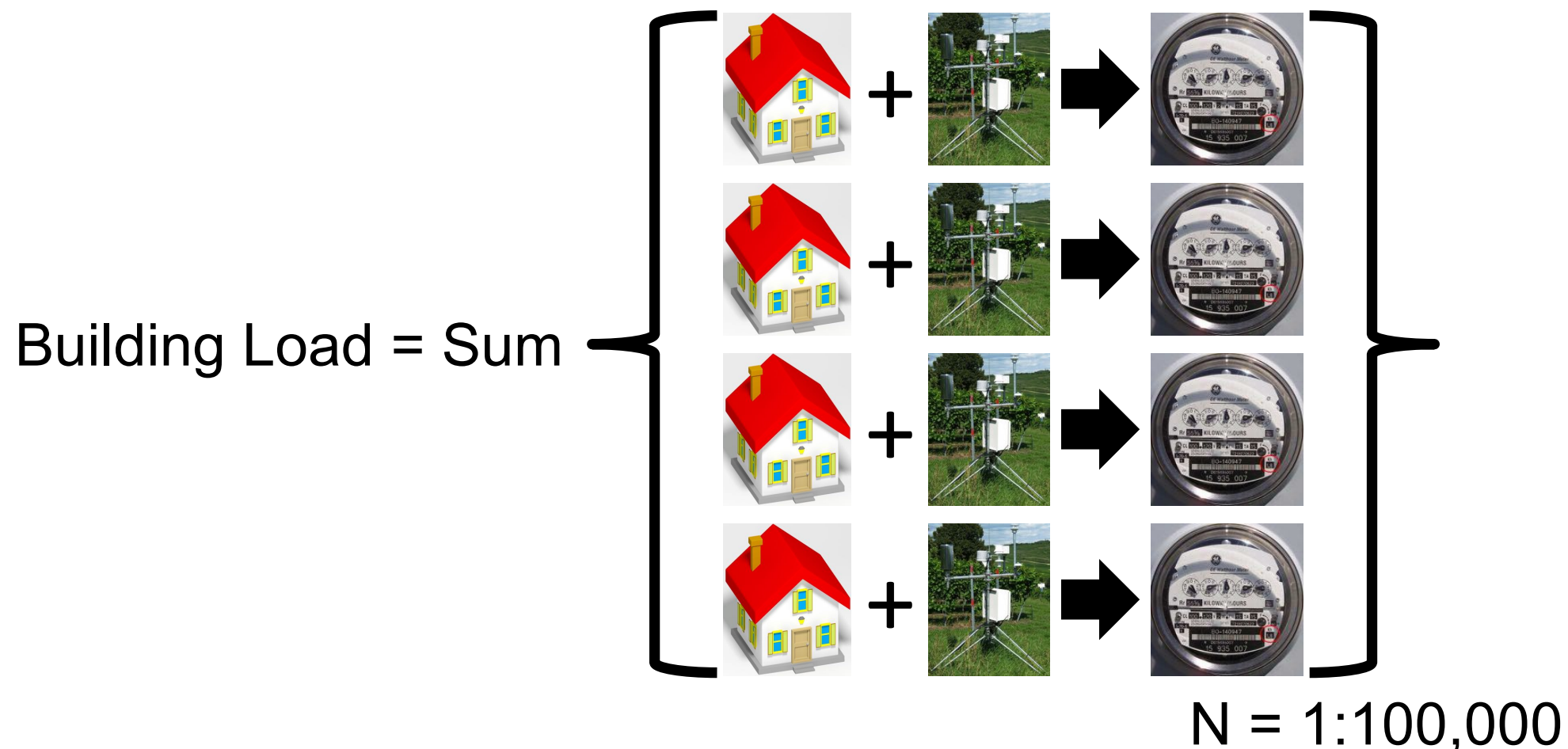
Weather data



Hourly energy
demand for 1 year

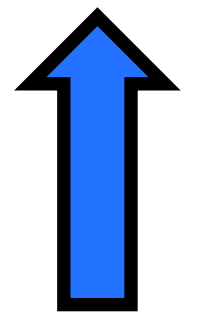
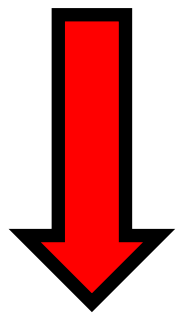
PNNL's Building ENergy Demand (BEND) Model

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.



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

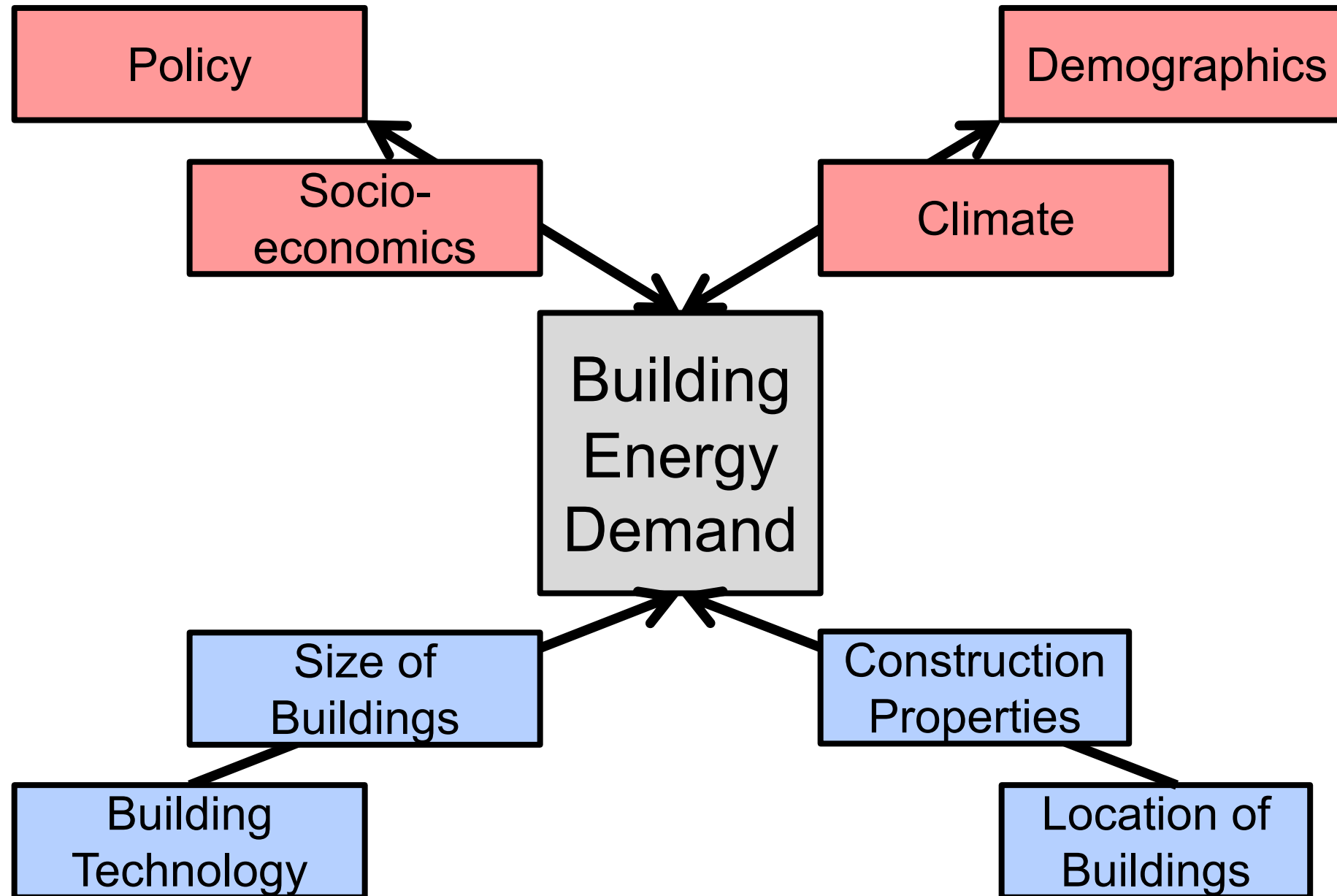
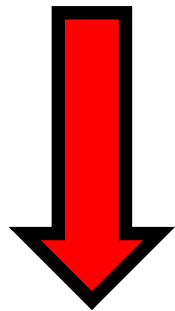
Top-Down
Aggregate
empirical
modeling of
the total
system



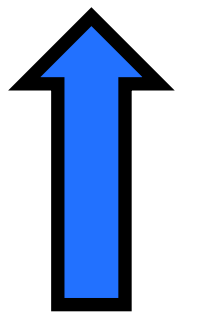
Bottom-Up
Detailed
physical
modeling of a
subset of the
total system

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

Top-Down
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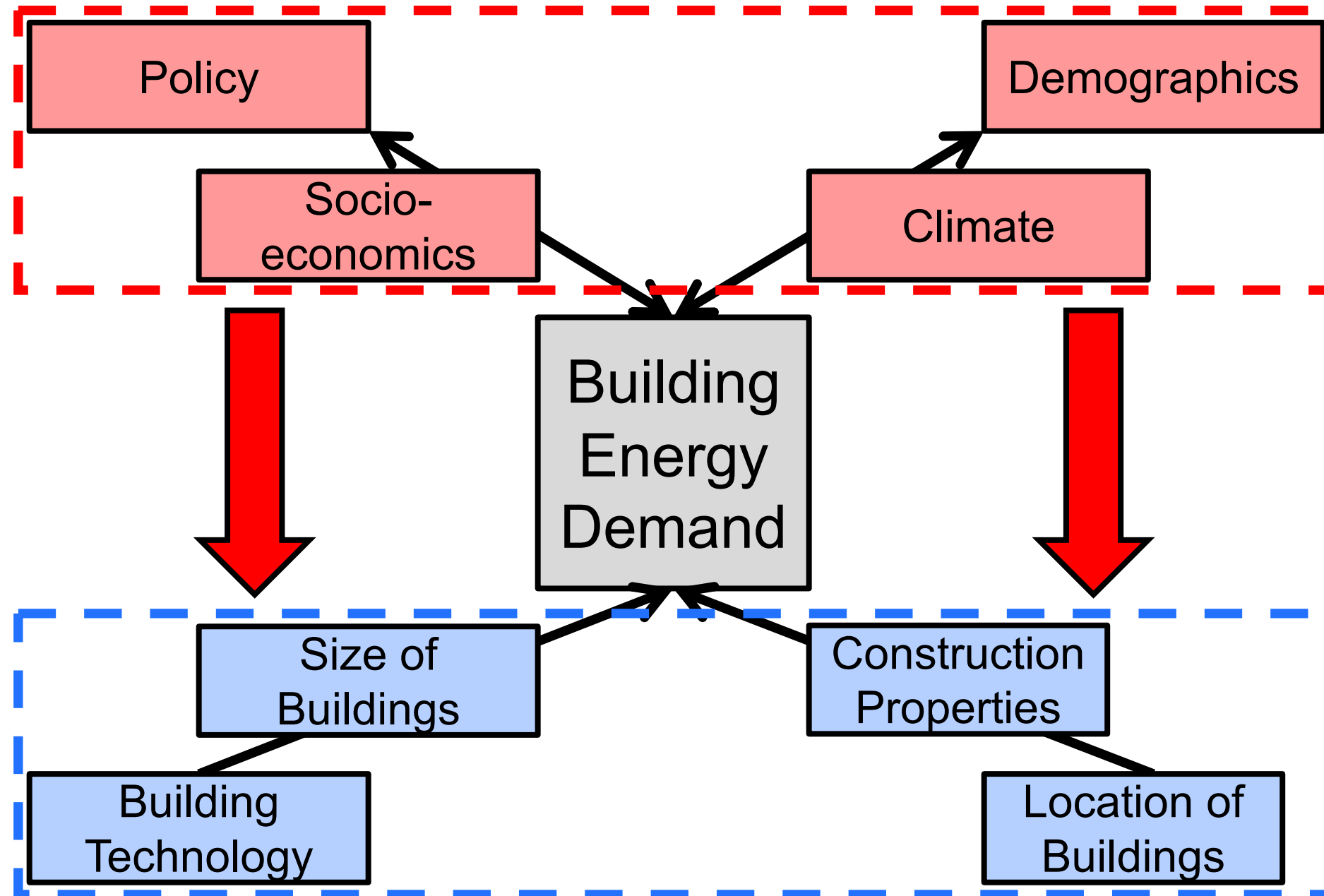
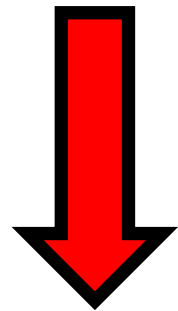


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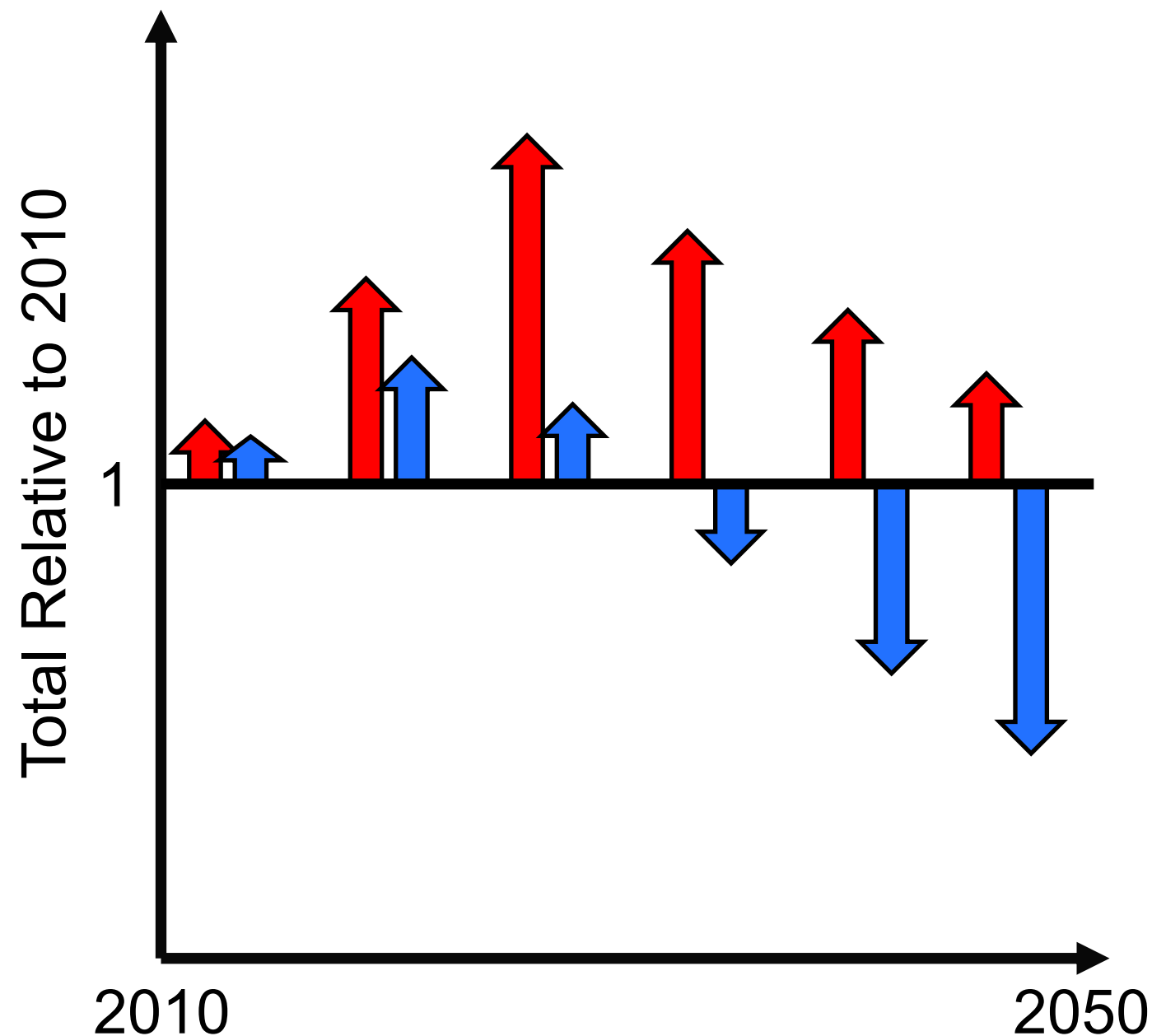
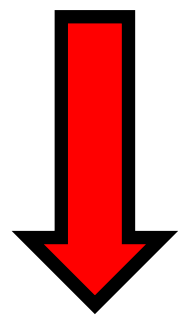
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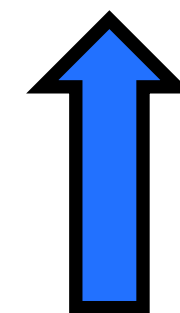
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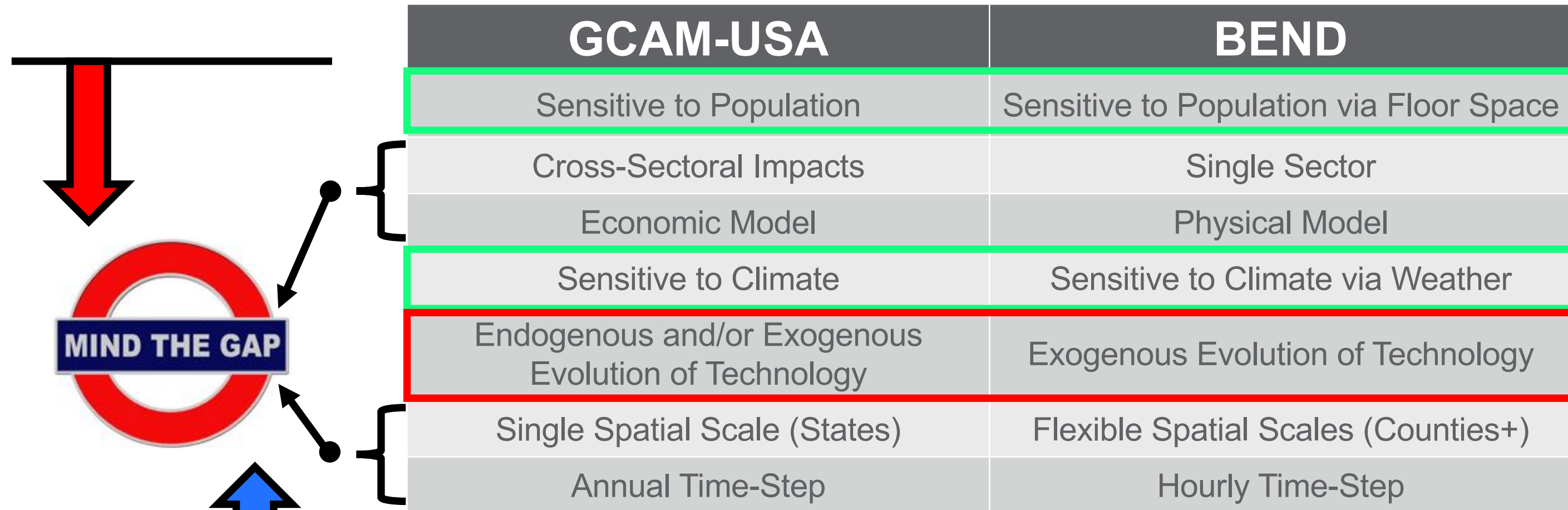
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Reconciling Top-Down and Bottom-Up Approaches to Building Energy Modeling



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.

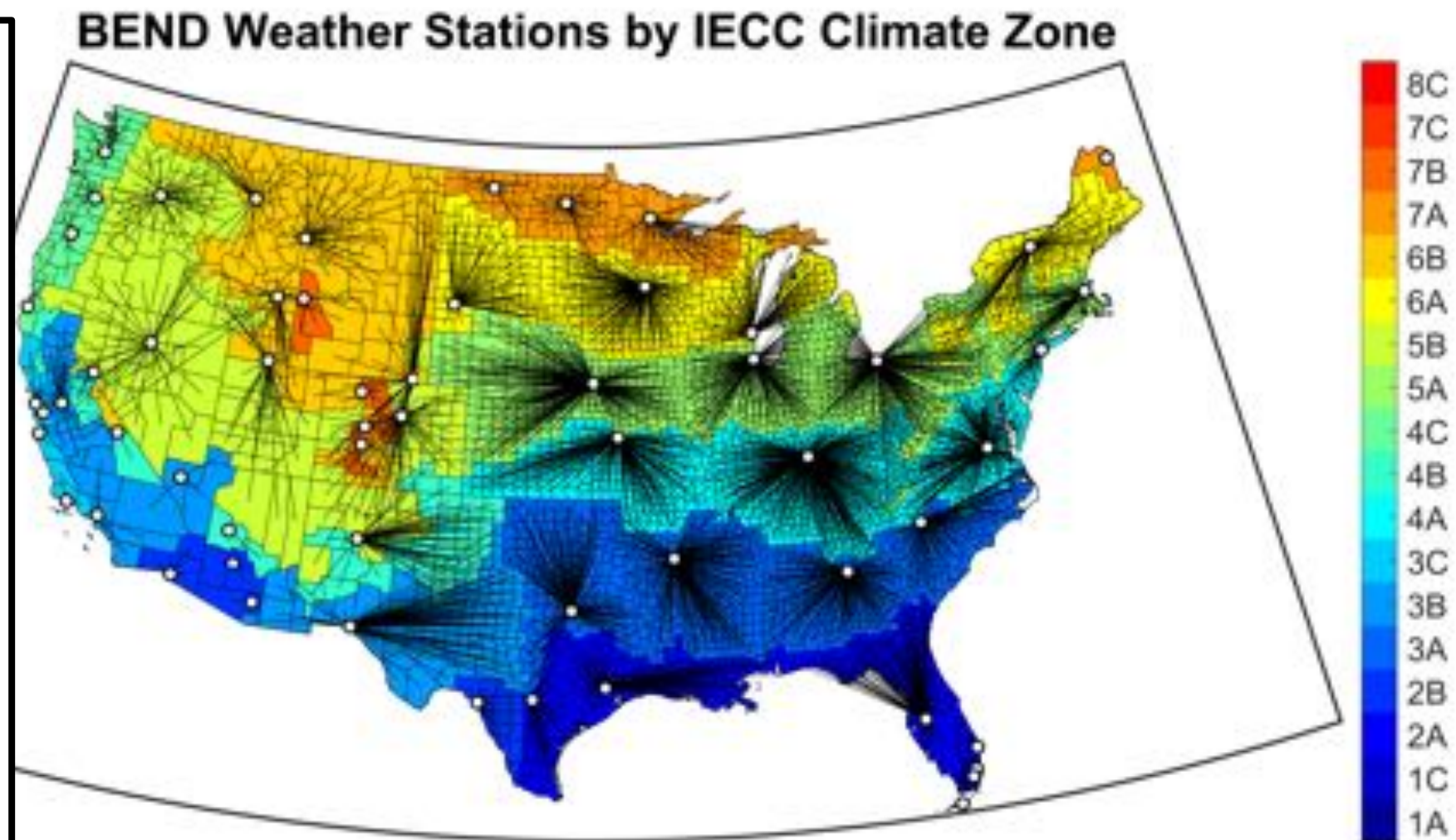
Science Questions

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.

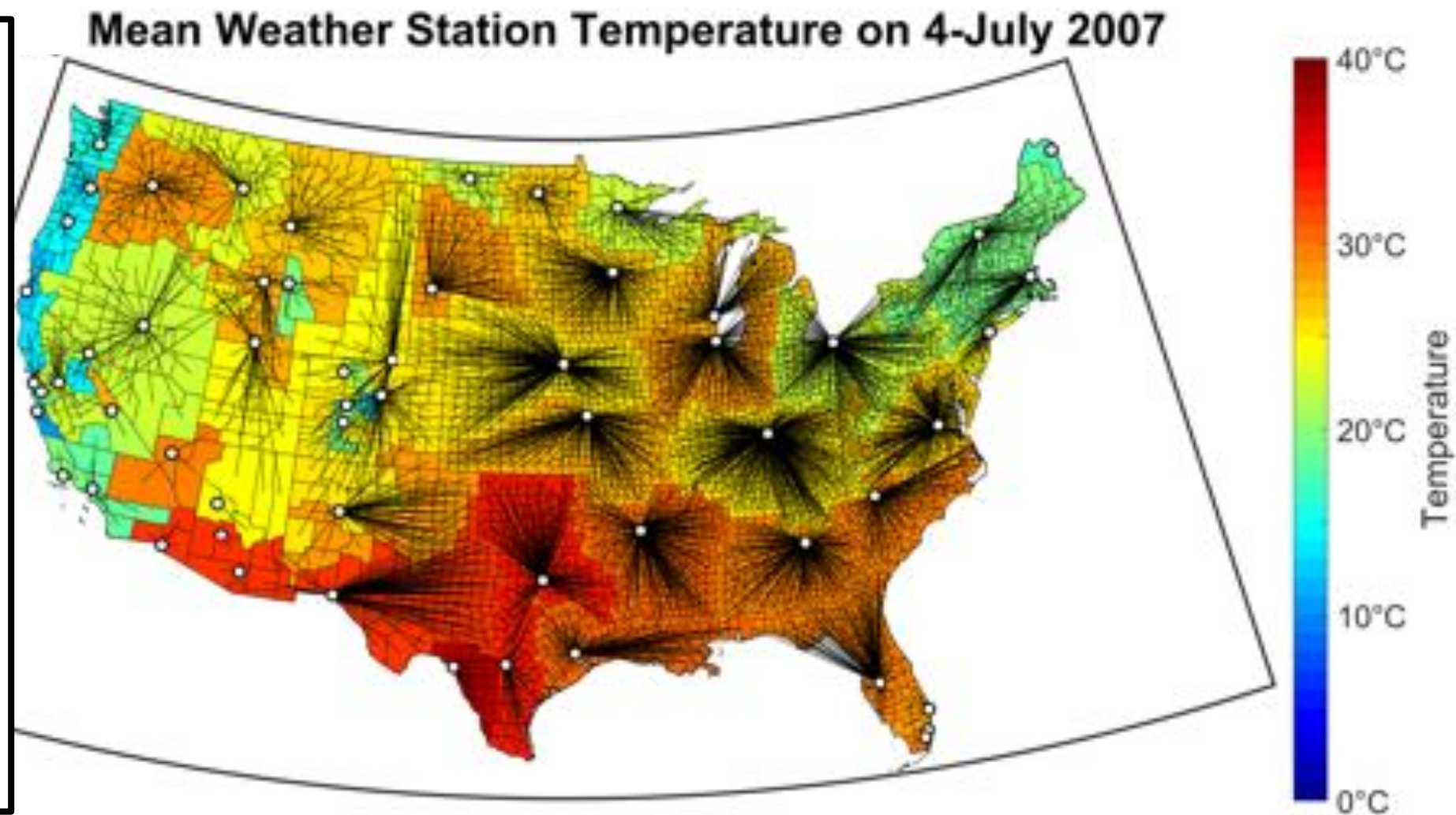
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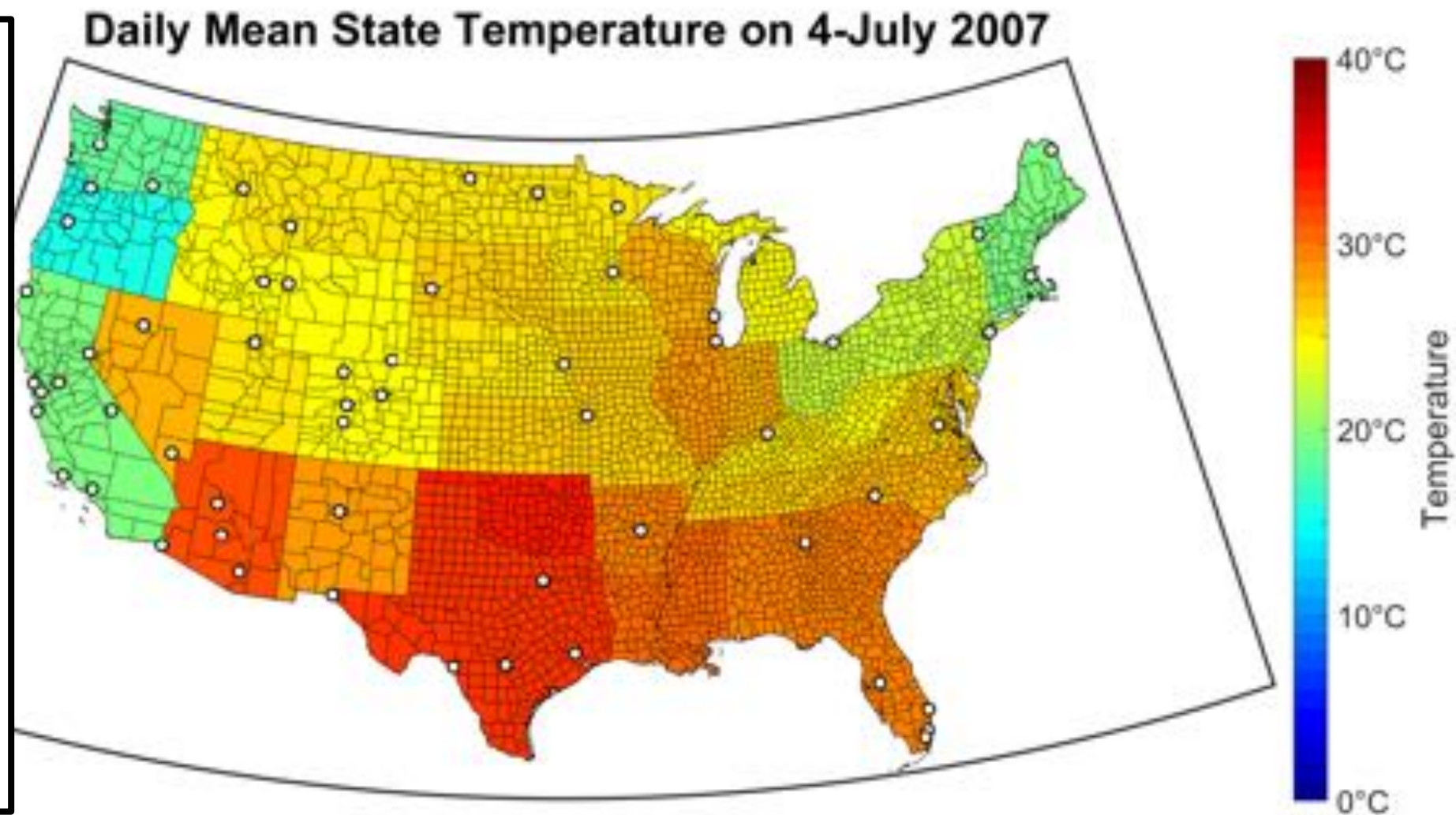
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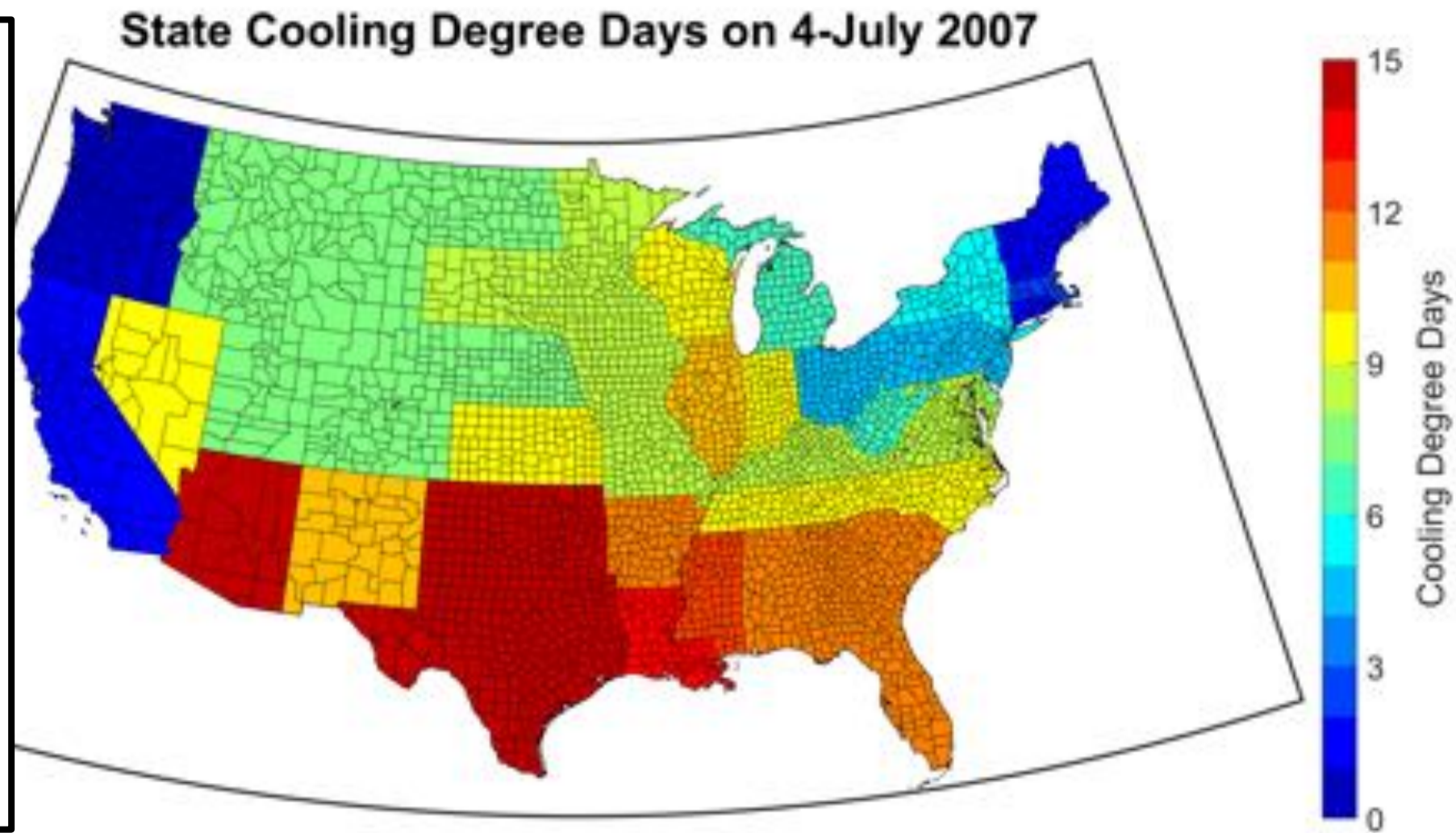
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3. We population-weight those means into daily mean state temperatures.



Homogenizing Climate Projections

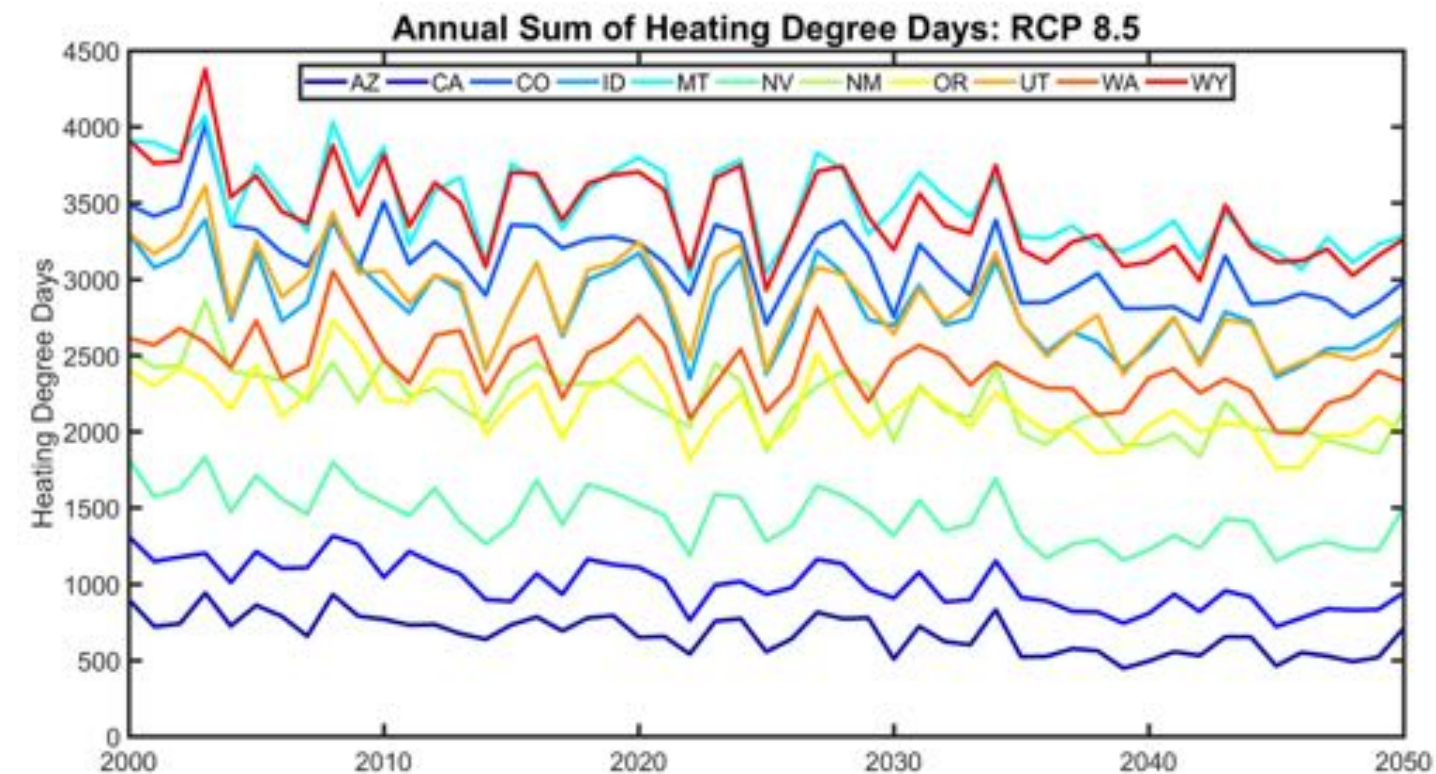
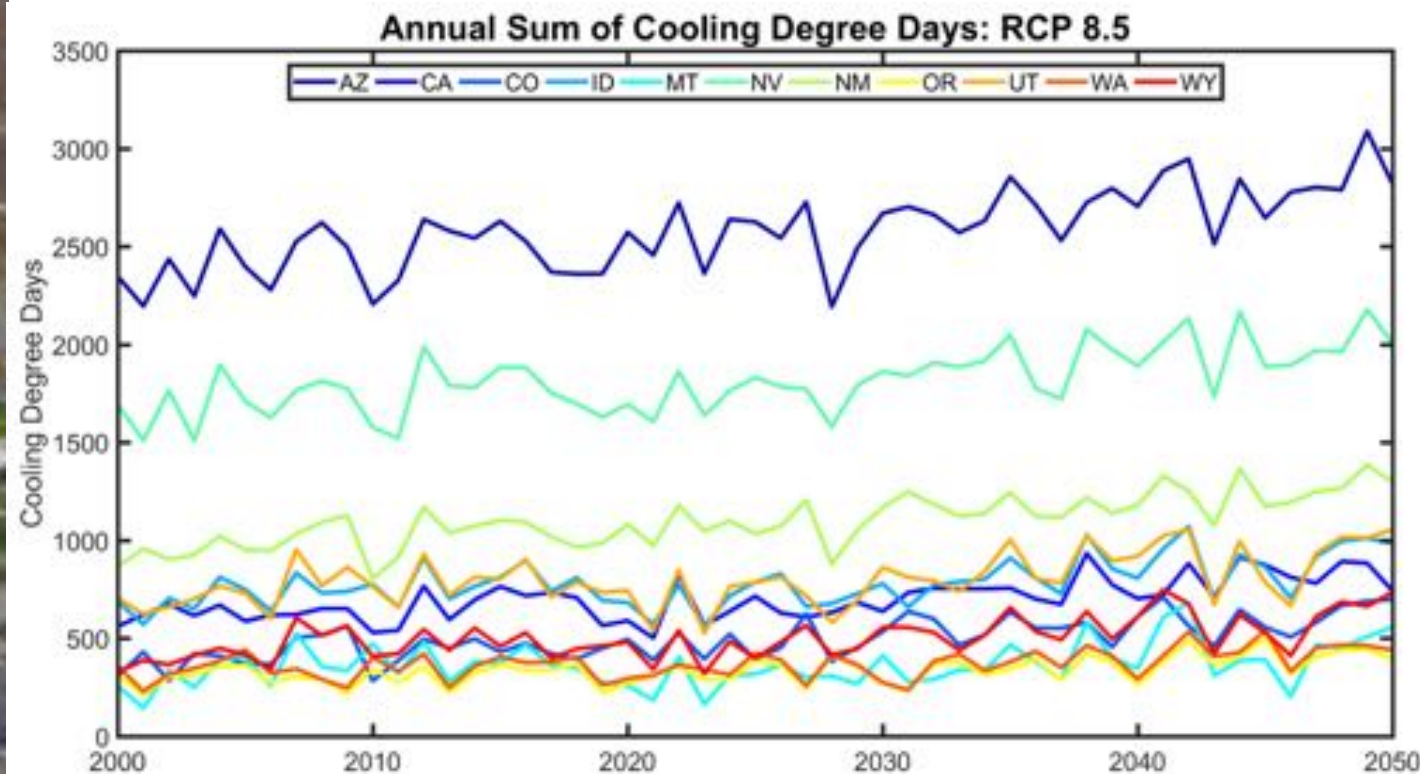
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1. BEND uses 4 weather stations per IECC climate zone.
2. We take a daily mean temperature for each weather station.
3. We population-weight those means into daily mean state temperatures.
4. We use the state temperatures to compute HDD/CDD.



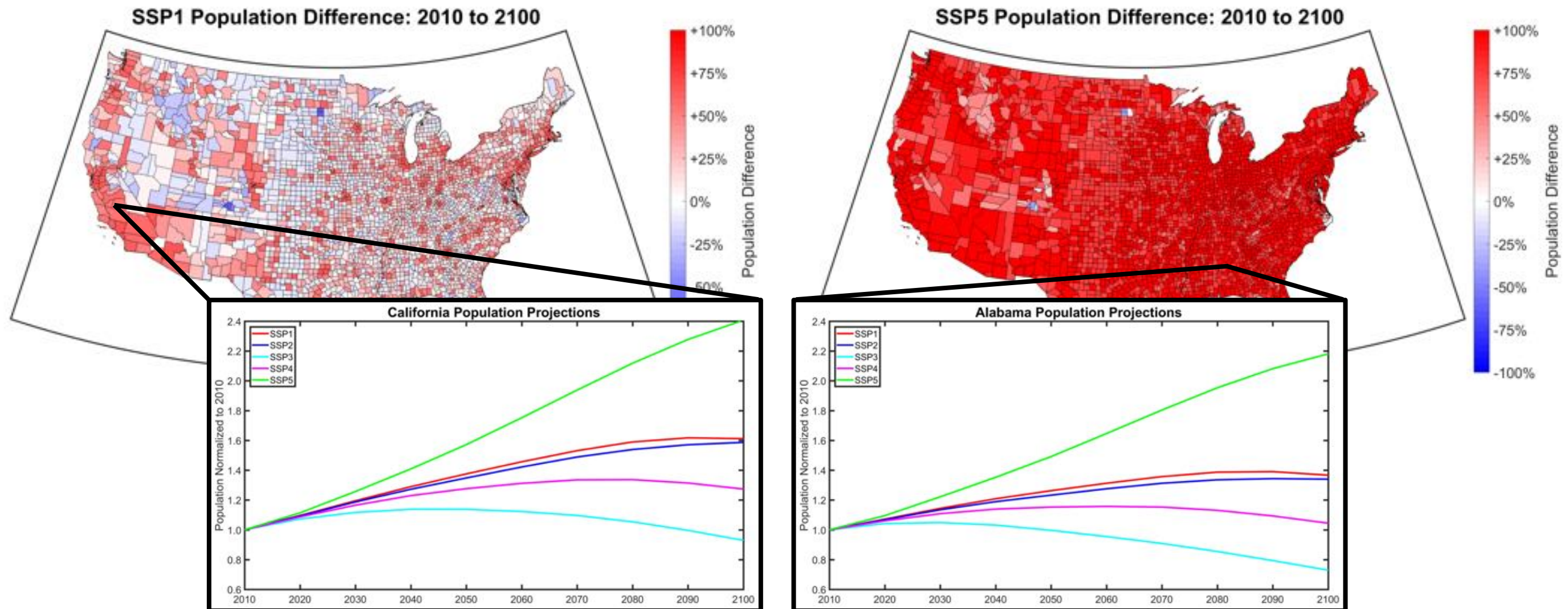
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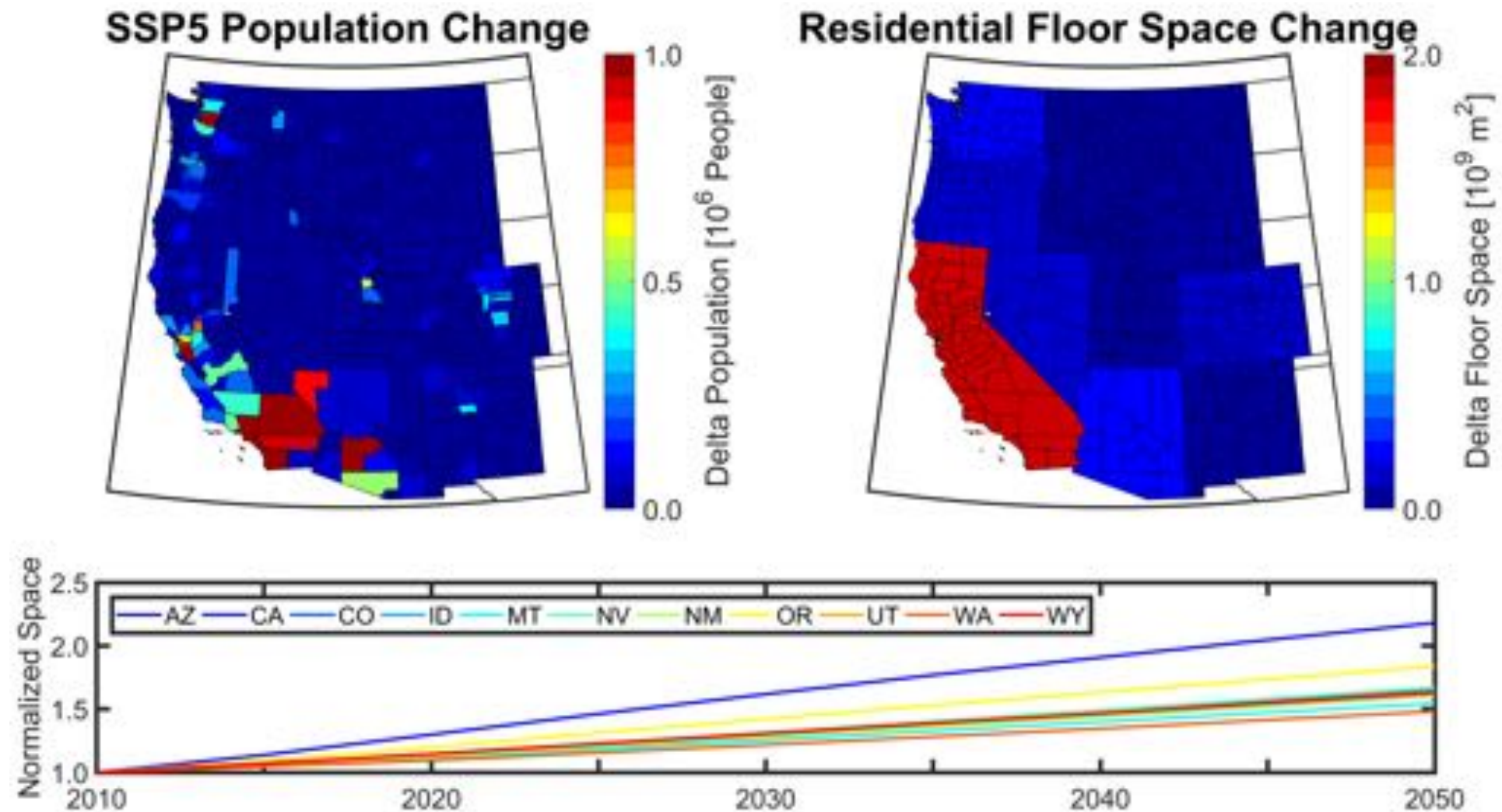
Homogenizing Population and Floor Space Projections

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.



Upcoming Numerical Experiments

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

	GCAM-USA		BEND	
Scenario	Population and GDP	HDD/CDD	Floor Space	Weather Station Forcing
SSP 5, RCP 8.5, <i>Static Climate</i>	SSP5	HDD/CDD from BEND Weather Station Forcing	Floor Space from GCAM-USA Population and GDP	Fixed at 2010 Values
SSP 5, RCP 8.5, <i>Changing Climate</i>	SSP5			RCP 8.5 GCM Run
SSP 5, RCP 4.5, <i>Changing Climate</i>	SSP5			RCP 4.5 GCM Run
SSP 3, RCP 4.5, <i>Changing Climate</i>	SSP3			RCP 4.5 GCM Run

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.

Backup Slides

PNNL's Building ENergy Demand (BEND) Model

We use the CBECS and RECS building surveys to construct a representative population of building models in the western U.S.

