Pacific Northwest
NATIONAL LABORATORY

Applications of GCAM-USA in the Integrated Multi-sector Multi-scale Modeling (IM3) Project

Casey Burleyson and Many Others

U.S. DEPARTMENT OF ENERGY BATTELLE

PNNL is operated by Battelle for the U.S. Department of Energy

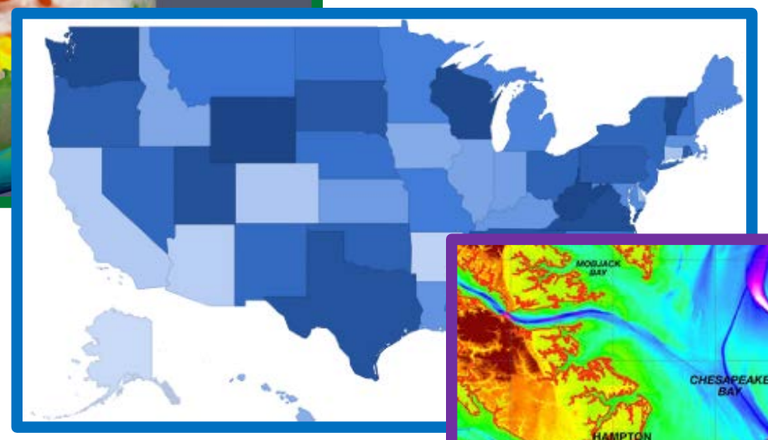
The Integrated Multi-sector, Multi-scale Modeling (IM3) Project

- Improve understanding of how the complex human-earth system responds to different stresses
- Coupling best-in-class, open source, physics- and process-based models in order to study complex system dynamics and the impacts of short-term shocks and long-term stressors on the vulnerability and resilience of co-evolving systems and associated infrastructure
- Supported by the U.S. Department of Energy, Office of Science, as part of research in the MultiSector Dynamics, Earth and Environmental System Modeling Program

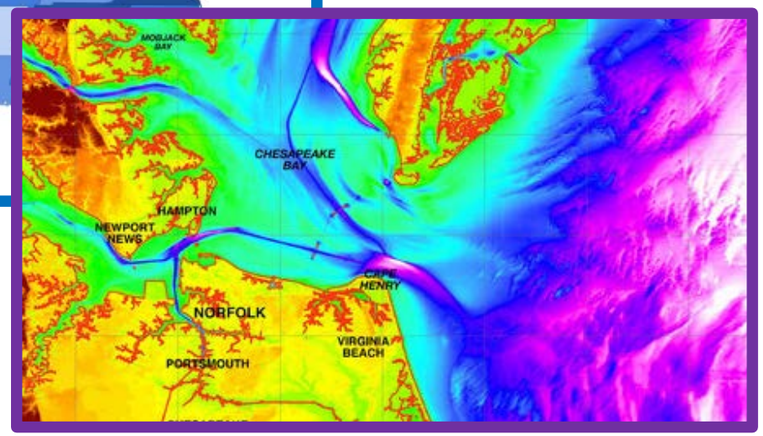
The Role of GCAM-USA in IM3

Metaphorical challenge: Understand changes in the probability of nuisance flooding

Start with global scale forcing to get the big picture

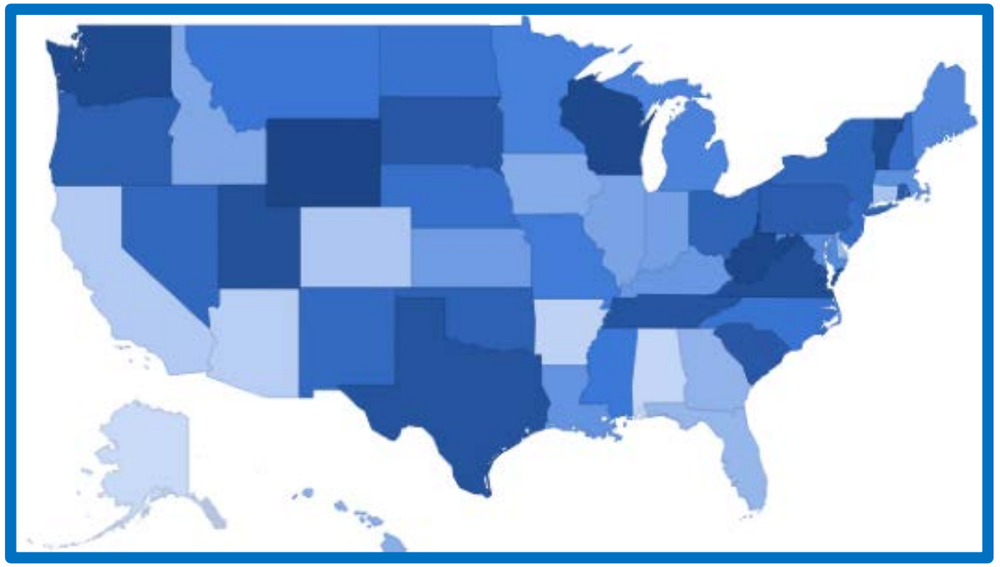


Narrow focus to resolve regional details



Add processes and resolution to capture local variability

The Role of GCAM-USA in IM3

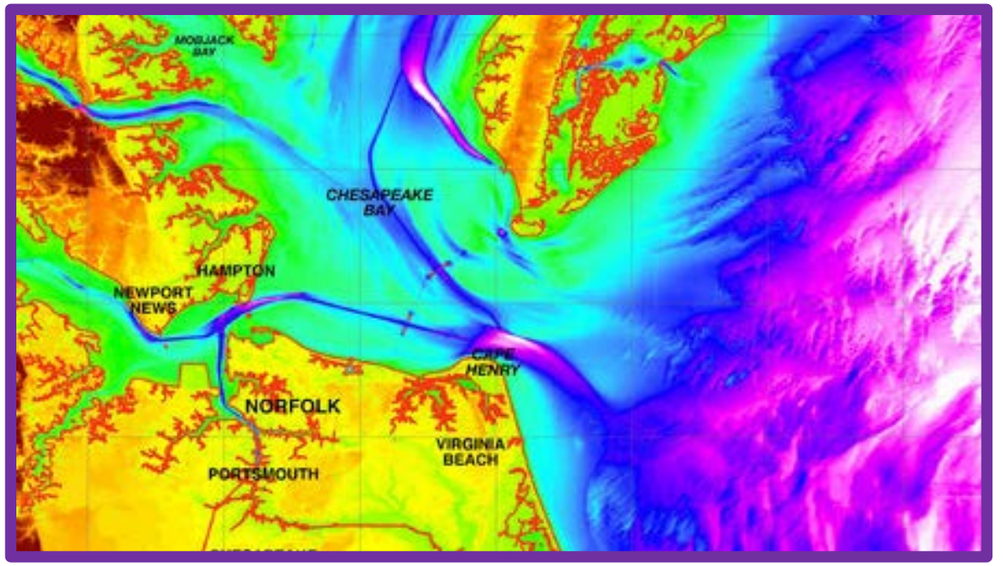


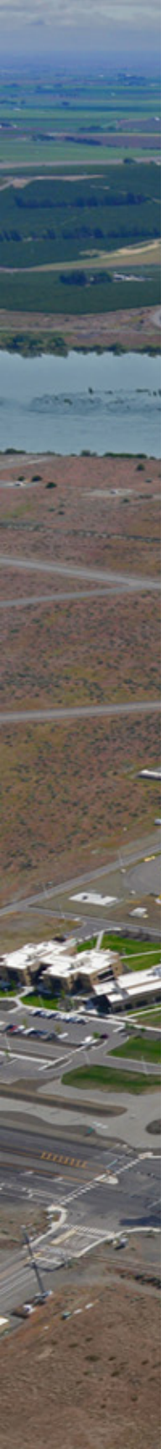
GCAM-USA

- Resolves global and national trends that may impact IM3 experiments
- Provides boundary or external forcing conditions for finer resolution models
- Captures multisector interactions using a unified economic framework

IM3 Sectoral Models

- Finer spatial resolution and regional domains
- Resolve processes and interactions that cannot be captured at larger scales
- Coupled to explore multisector interactions





Pacific Northwest NATIONAL LABORATORY

The Role of GCAM-USA in IM3

Current Experiments and Applications

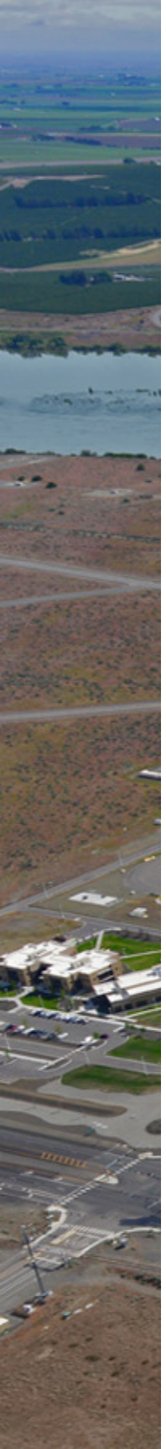
1) Using water demand from GCAM-USA as input to WM-PLEXOS simulations of power grid operations under historical and future water availability conditions and using historical water demands from GCAM-USA in agent-based simulations of interannual variability in water demand. Leads: Nathalie Voisin and Ning Sun

2) Studying the combined effects of climate and population change on building electricity consumption in GCAM-USA and BEND. Leads: Casey Burleyson, Gokul Iyer, Sonny Kim, and Page Kyle

3) Doing an intercomparison and harmonization of electricity capacity expansion scenarios from GCAM-USA and ReEDS. Leads: Gokul Iyer and Stuart Cohen

4) Studying how interconnection costs for different electricity capacity expansion scenarios from GCAM-USA are affected by local environmental and institutional factors regulating power plant siting in CERF. Leads: Chris Vernon, Matthew Binsted, and Jennie Rice

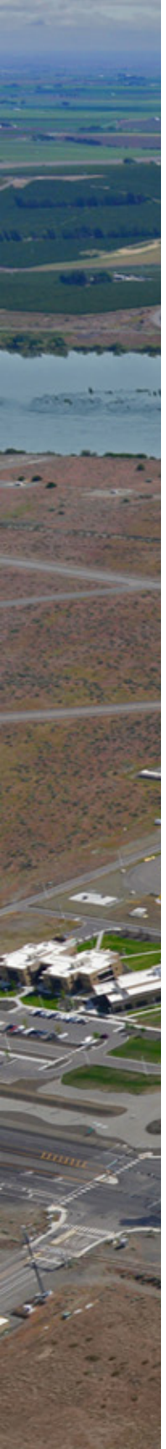
5) Creating GCAM-USA + Demeter downscaled land use and land cover change scenarios to drive CLM5 simulations over the continental U.S. Leads: Maoyi Huang and Chris Vernon



Climate and Population Impacts on Building Energy Demand

Casey Burleyson, Gokul Iyer, Mohamad Hejazi, Sonny Kim, Page Kyle, Jennie Rice, Todd Taylor, Nathalie Voisin and YuLong Xie

How and why does the impact of climate and population changes on building electricity consumption vary between GCAM-USA and BEND (the Building ENergy Demand model)?



Pacific Northwest NATIONAL LABORATORY

Climate and Population Impacts on Building Energy Demand

How and why does the impact of climate and population changes on building electricity consumption vary between GCAM-USA and BEND (the Building ENergy Demand model)?

GCAM-USA

Uses physically-meaningful empirical relationships between historical weather and building energy demand for each state.

$$Q^i_{heating} = k^i_{heating}(HDD^i \cdot Eff \cdot SR - G^i)\left[1 - \exp\left(-\frac{\ln 2}{\mu_j} \cdot \frac{Y^i}{P_j}\right)\right]$$

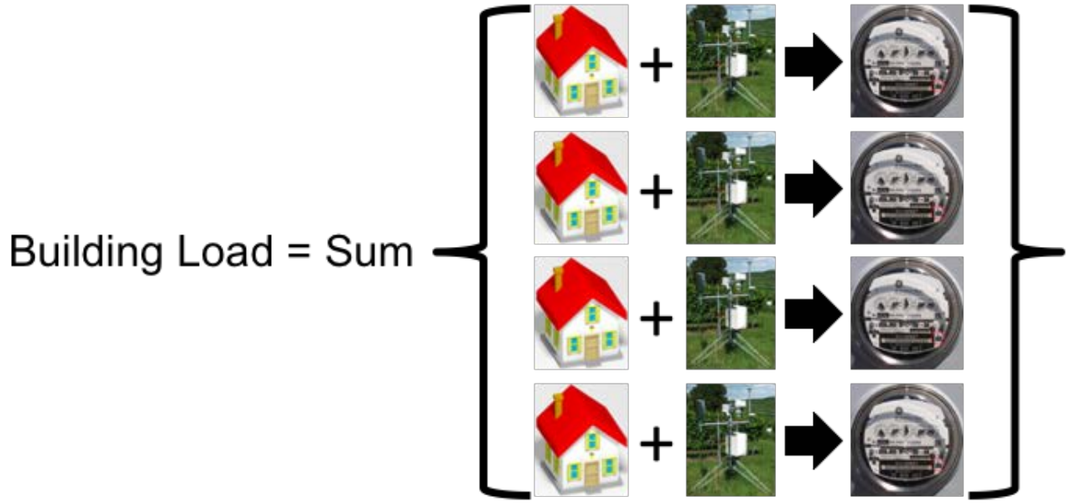
$$Q^i_{cooling} = k^i_{cooling}(CDD^i \cdot Eff \cdot SR + G^i)\left[1 - \exp\left(-\frac{\ln 2}{\mu_j} \cdot \frac{Y^i}{P_j}\right)\right]$$

$$Q^i_{others} = k^i_{others} q^i_{others}\left[1 - \exp\left(-\frac{\ln 2}{\mu_j} \cdot \frac{Y^i}{P_j}\right)\right]$$

Zhou et al. 2014 – *Applied Energy*

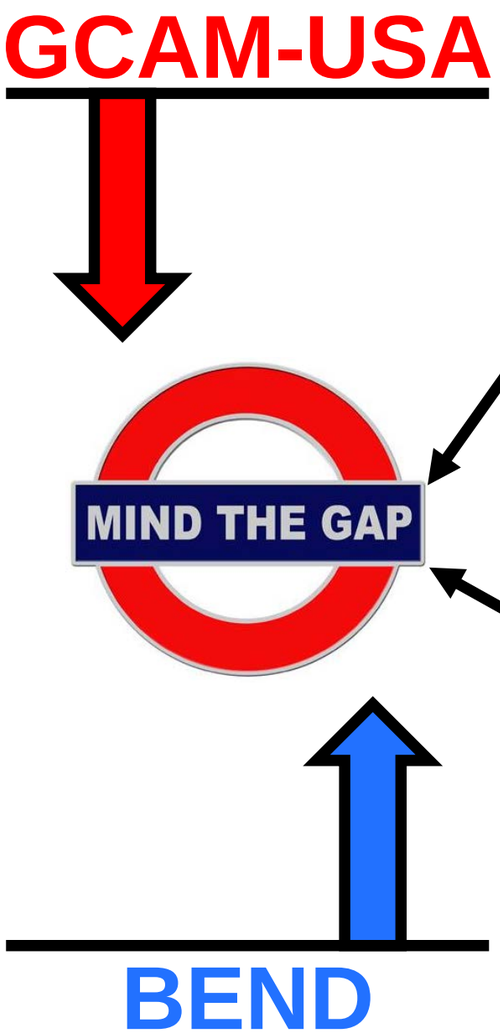
BEND

Uses EnergyPlus to simulate a (very) large representative sample of residential and commercial buildings over a distributed area.



N = 1:100,000

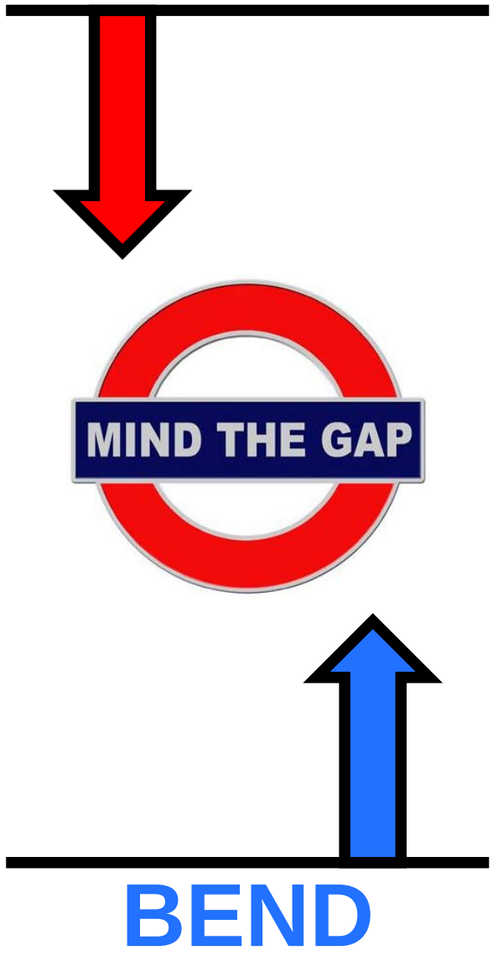
Climate and Population Impacts on Building Energy Demand



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	Endogenous and/or Exogenous Evolution of Technology
Single Spatial Scale (States)	Flexible Spatial Scales (Counties+)
Annual Time-Step	Hourly Time-Step

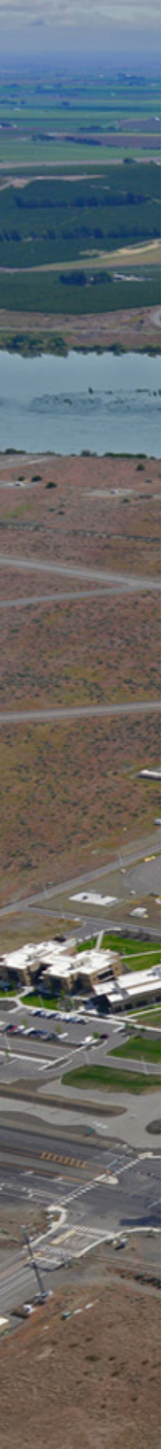
The overall strategy of the experiment is to reconcile as many variables as possible in order to understand how the model's different structures contribute to differences in their projections.

Climate and Population Impacts on Building Energy Demand



	GCAM-USA		BEND	
Scenario	**Population and GDP**	**HDD/CDD**	**Floor Space**	**Weather Station Forcing**
SSP 5, RCP 8.5, *Static Climate*	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, *Changing Climate*	SSP5			RCP 8.5 GCM Run
SSP 5, RCP 4.5, *Changing Climate*	SSP5			RCP 4.5 GCM Run
SSP 3, RCP 4.5, *Changing Climate*	SSP3			RCP 4.5 GCM Run

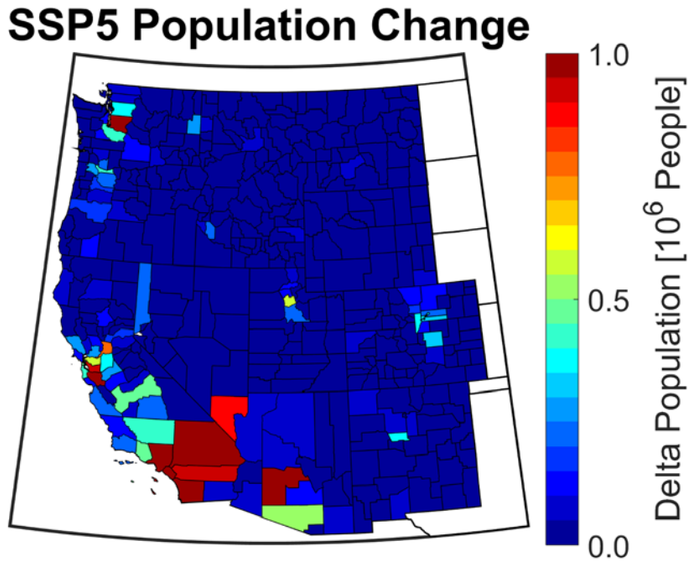
We ran 4 experiments using different combinations of climate (RCP 4.5 and RCP 8.5) and population (SSP 3 and SSP 5) scenarios.

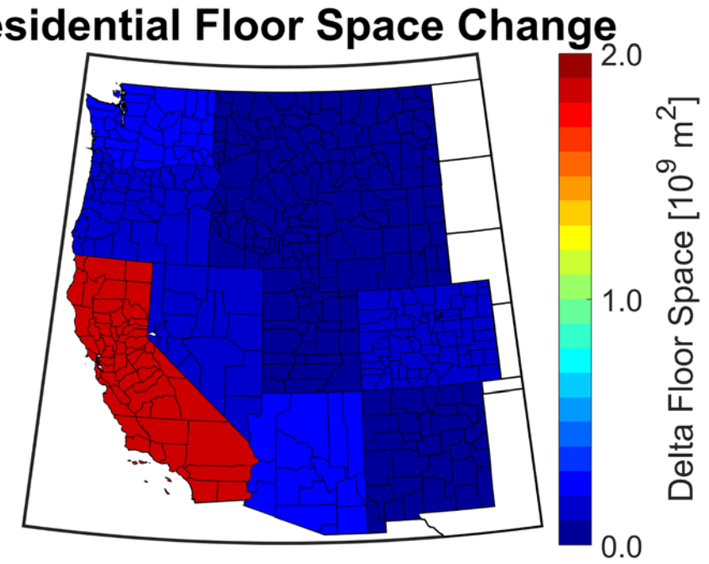


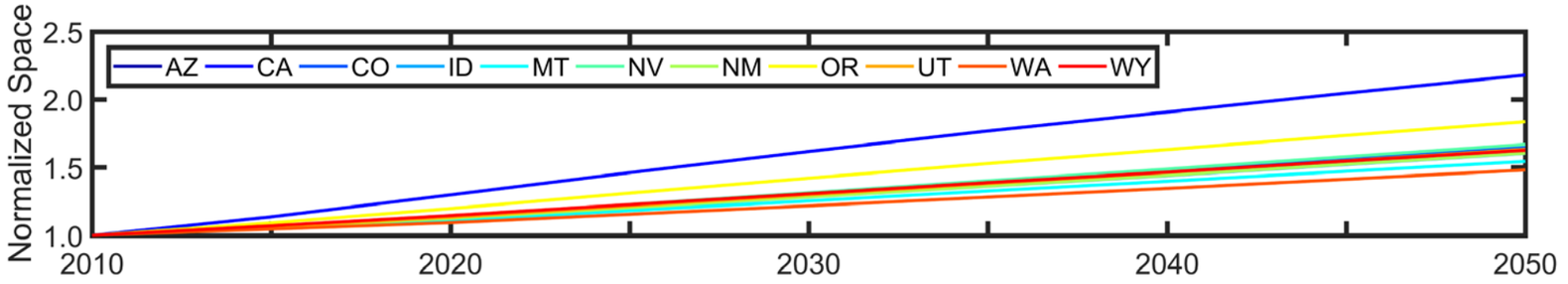
Pacific Northwest
NATIONAL LABORATORY

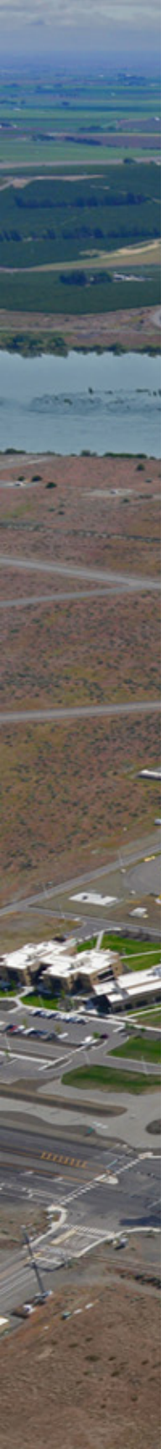
Climate and Population Impacts on Building Energy Demand

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



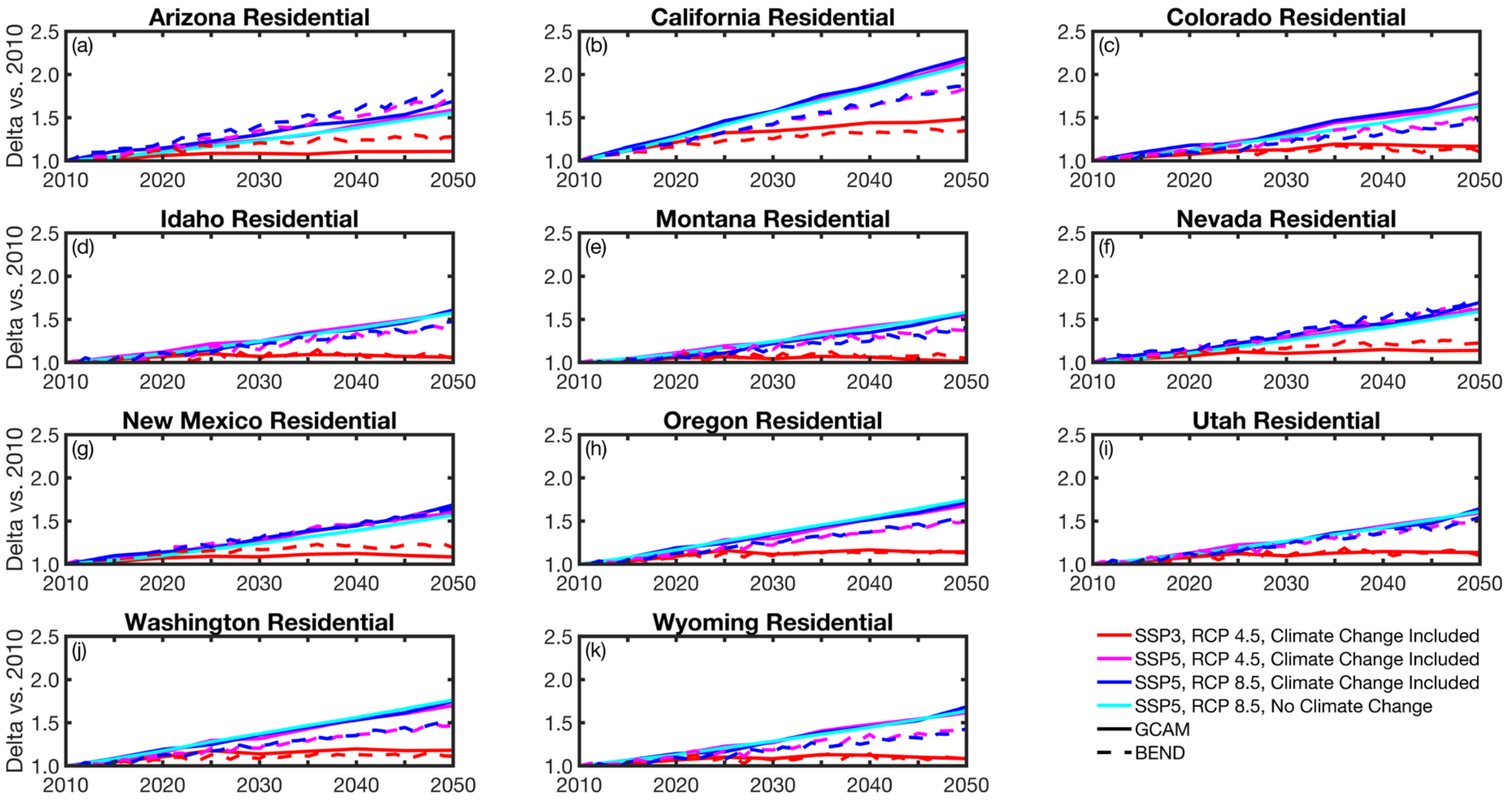


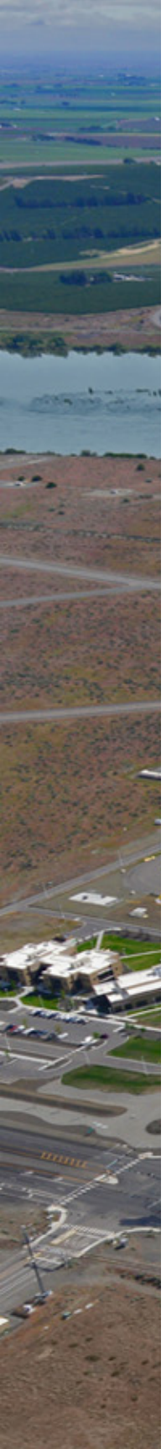




Pacific Northwest
NATIONAL LABORATORY

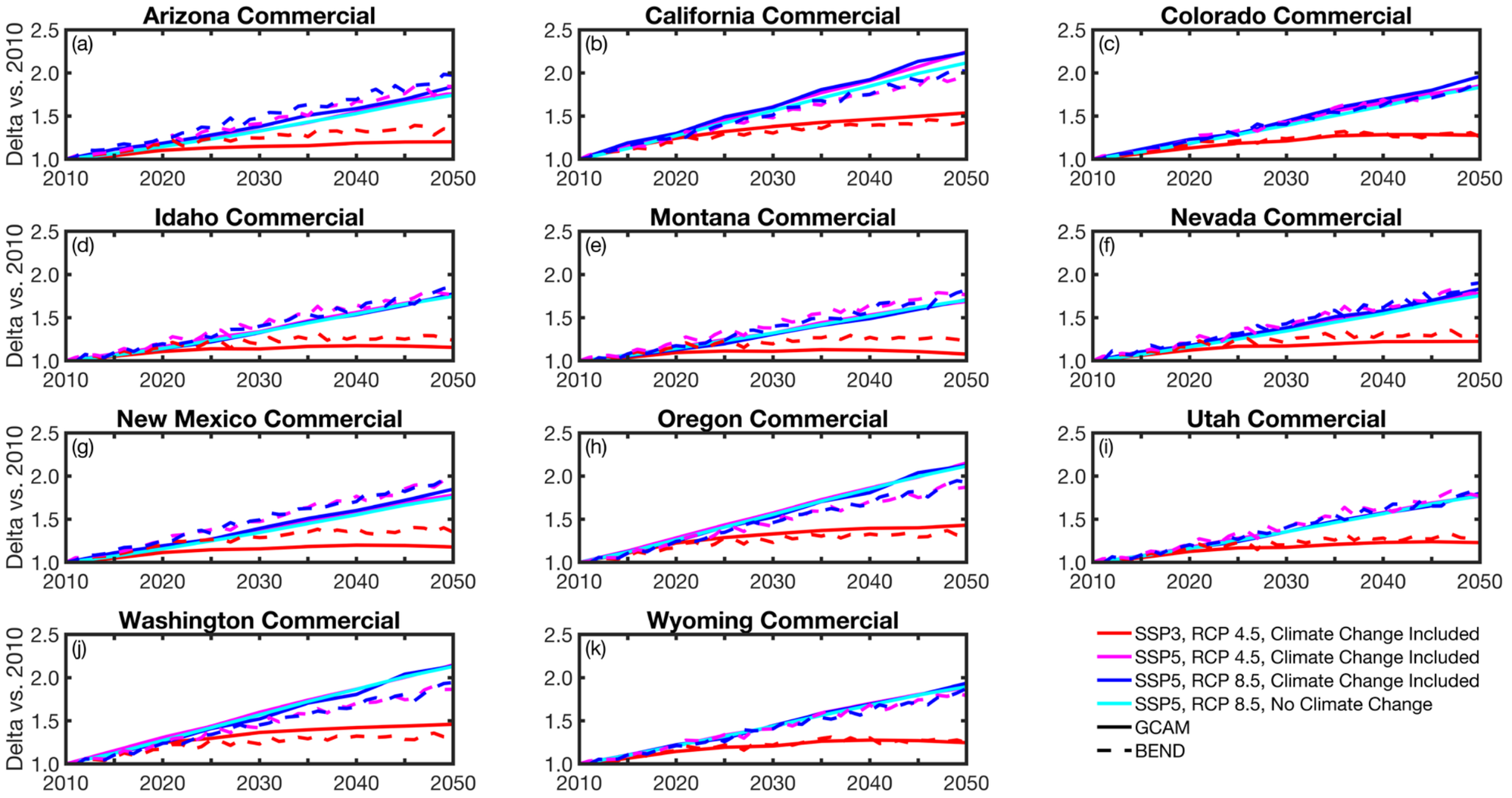
Climate and Population Impacts on Building Energy Demand

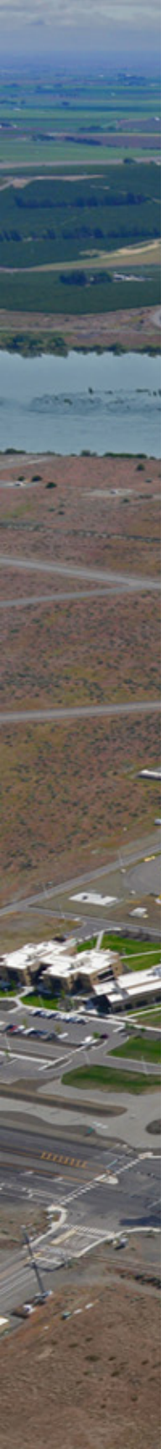




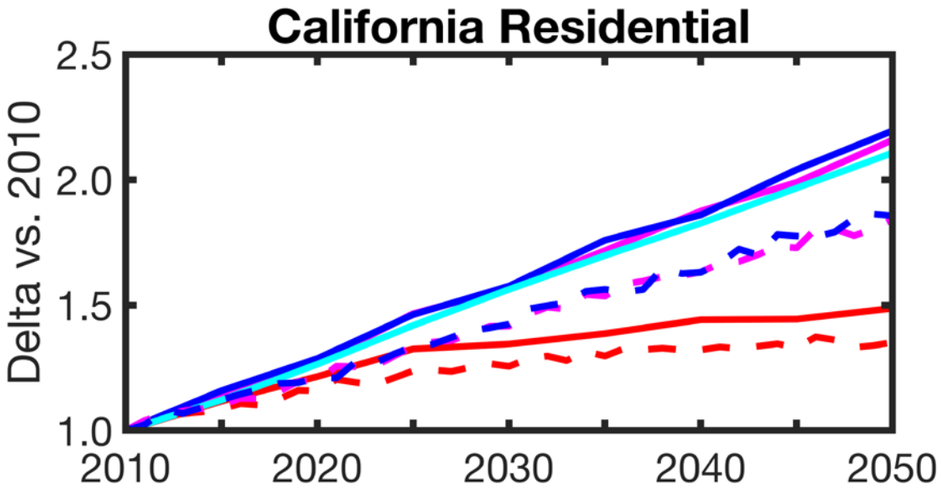
Pacific Northwest
NATIONAL LABORATORY

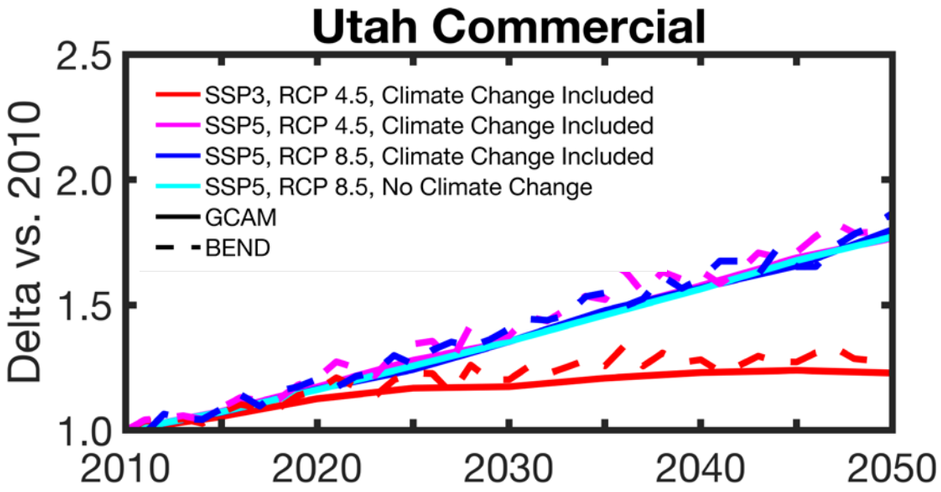
Climate and Population Impacts on Building Energy Demand





Climate and Population Impacts on Building Energy Demand

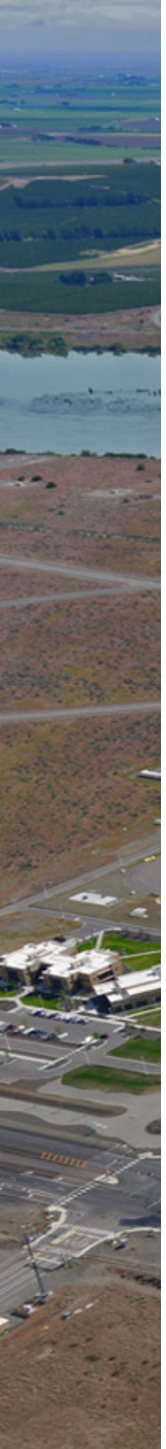




Key Results

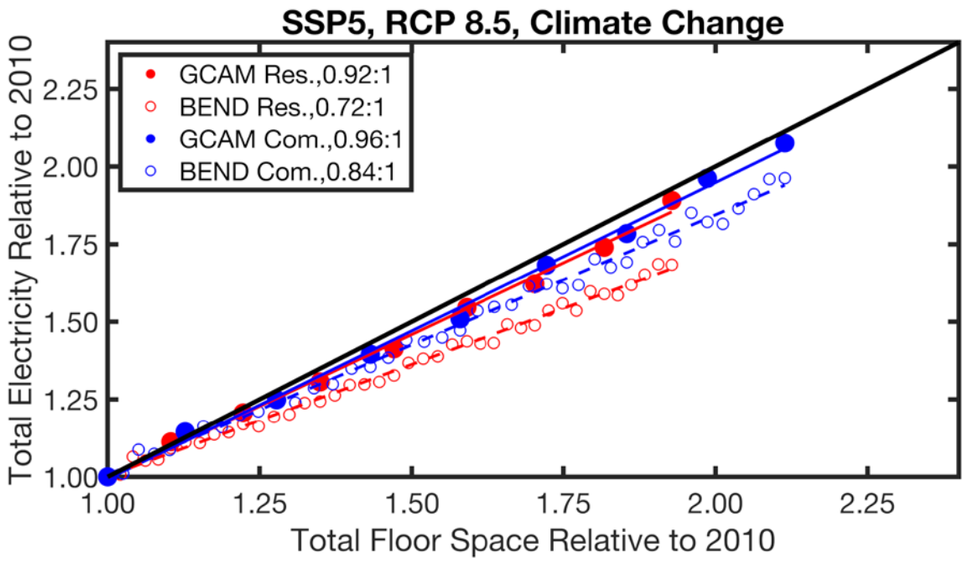
1) Residential building electricity consumption increases in both models by 1-49% under SSP3 and by 37-119% under SSP5.

2) Both models show the impacts of climate change are substantially smaller than population changes. RCP 8.5 increases total building electricity consumption by 4-6% in southern states.



Pacific Northwest
NATIONAL LABORATORY

Climate and Population Impacts on Building Energy Demand



Key Results

1) Residential building electricity consumption increases in both models by 1-49% under SSP3 and by 37-119% under SSP5.

2) Both models show the impacts of climate change are substantially smaller than population changes. RCP 8.5 increases total building electricity consumption by 4-6% in southern states.

3) Differences between the two projections are largely due to subtle differences in how each model improves the efficiency of the building stock over time.

Publications

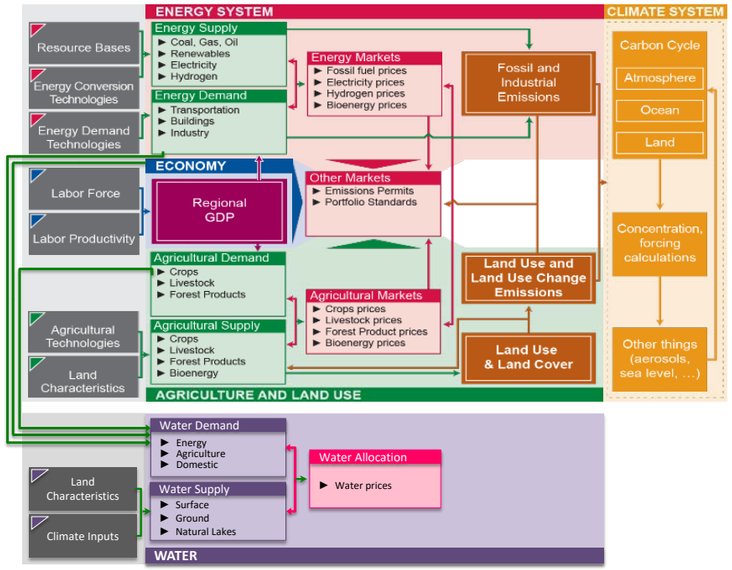
- Burleyson et al., in prep. “Reconciling Climate and Population Impacts on Building Energy Demand from Top-Down and Bottom-Up Modeling Perspectives.”

Understanding Tradeoffs Between Consistency and Structural Uncertainty in Electricity Capacity Expansion Scenarios

Gokul Iyer, Maxwell Brown, Stuart Cohen, Jordan Macknick, Pralit Patel, Marshall Wise, Matthew Binsted, and Nathalie Voisin

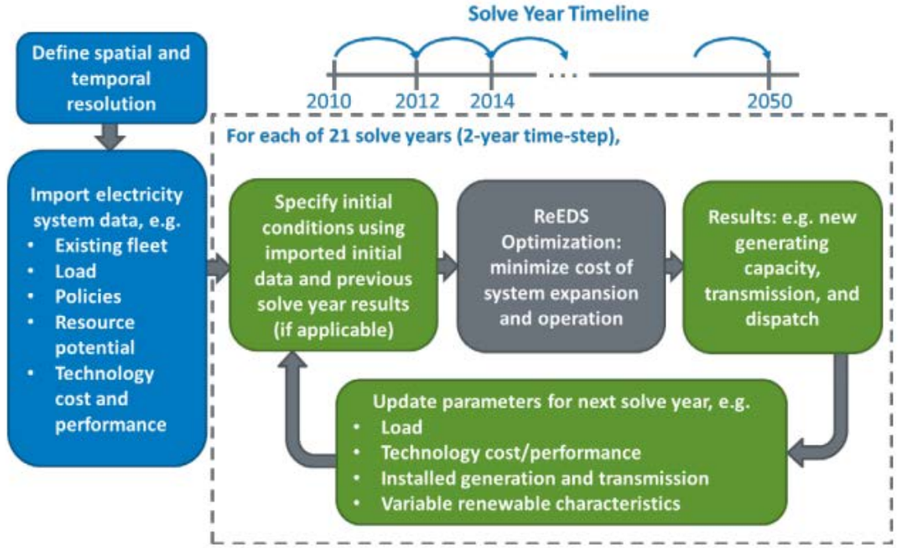
What does it take to make projections from two electricity capacity expansion models with different structures consistent?

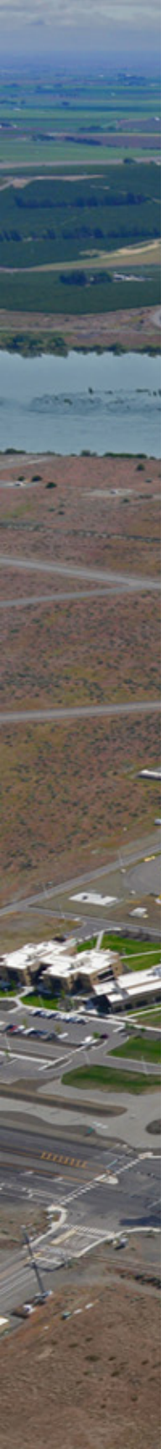
GCAM-USA (multisector)



ReEDS (power sector only)

Regional Energy Deployment System



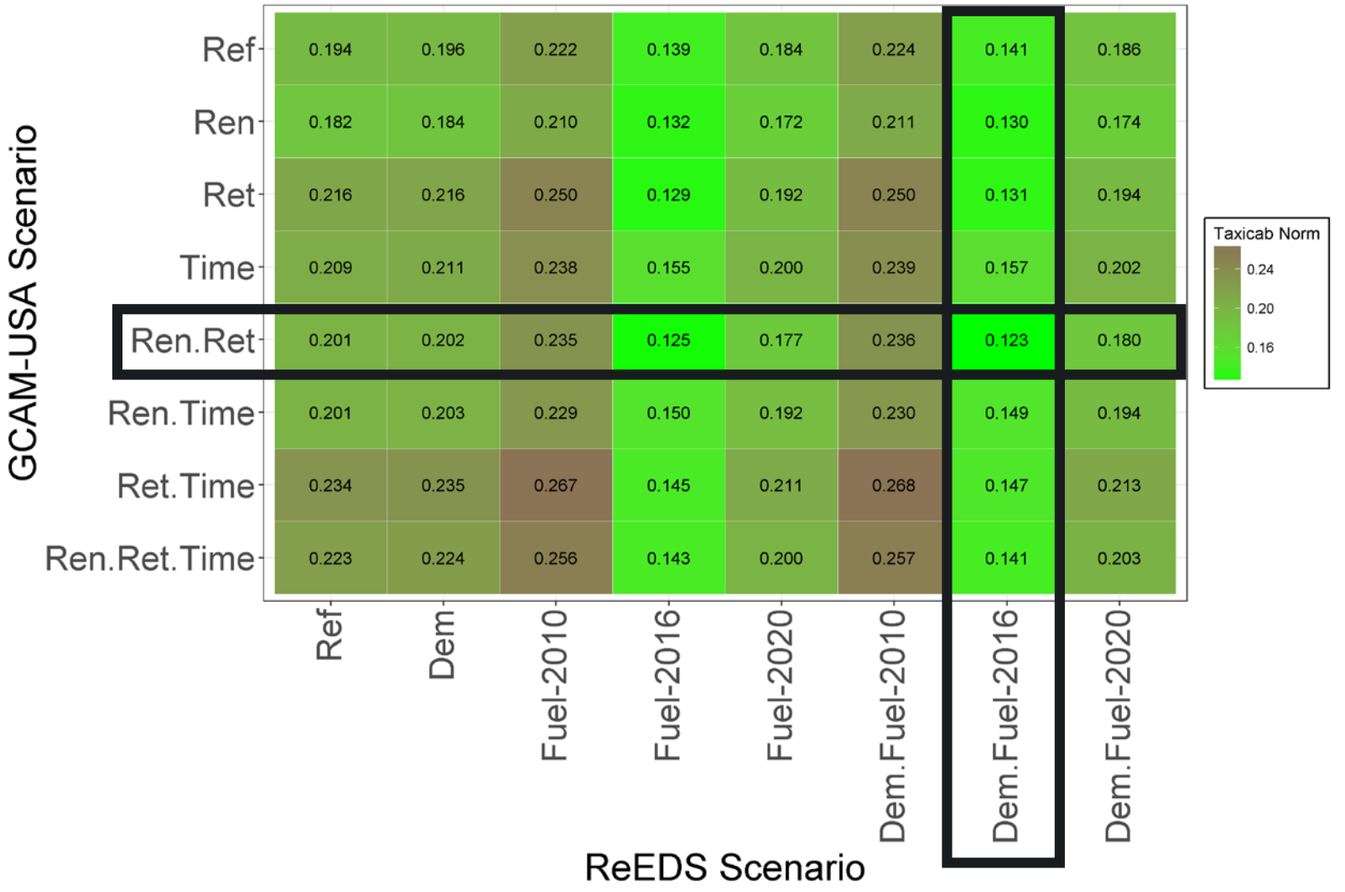


Understanding Tradeoffs Between Consistency and Structural Uncertainty in Electricity Capacity Expansion Scenarios

Key Results

1) Harmonizing fuel prices, renewable resources, retirements, and demand could improve consistency significantly.

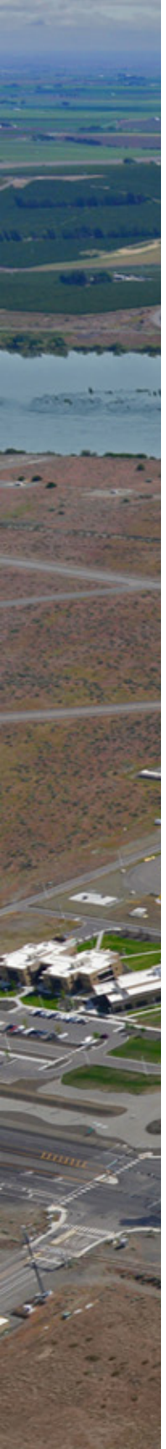
2) The degree to which consistency can improve is likely scenario dependent, as will be shown in a subsequent paper.



Distance metric by combining annual electricity generation outputs across all states, technologies and 5-year time periods between 2010 and 2050. Lower values (lighter colors) = better consistency.

Publications

- Iyer, G. C., et al., 2019. "Improving Consistency among Models of Overlapping Scope in Multi-Sector Studies: The Case of Electricity Capacity Expansion Scenarios." *Renewable and Sustainable Energy Reviews,* 116:109416.
- Cohen, S. M., et al., in prep. "The effect of scenario choice on multi-model agreement: Harmonization versus consistency for two electricity capacity expansion models."



The Role of GCAM-USA in IM3

IM3 Sectoral Models

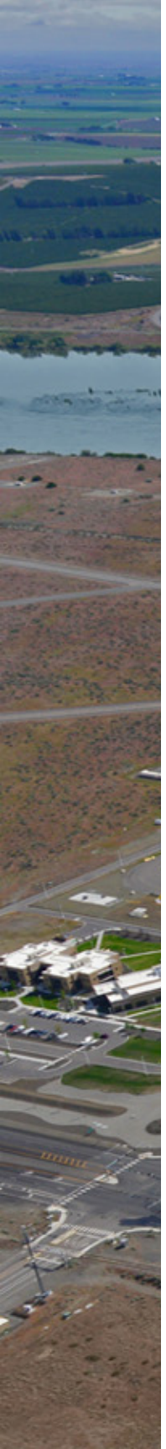
- Finer spatial resolution and regional domains
- Resolve processes and interactions that cannot be captured at larger scales
- Coupled to explore multisector interactions

GCAM-USA

- Resolves global and national trends that may impact IM3 experiments
- Provides boundary or external forcing conditions for finer resolution models
- Captures multisector interactions using a unified economic framework

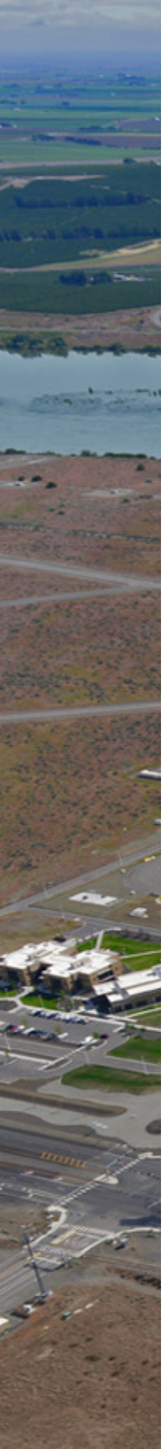
Current Experiments and Applications

1) Using water demand from GCAM-USA as input to WM-PLEXOS simulations of power grid operations under historical and future water availability conditions and using historical water demands from GCAM-USA in agent-based simulations of interannual variability in water demand.
2) Studying the combined effects of climate and population change on building electricity consumption in GCAM-USA and BEND.
3) Doing an intercomparison and harmonization of electricity capacity expansion scenarios from GCAM-USA and ReEDS.
4) Studying how interconnection costs for different electricity capacity expansion scenarios from GCAM-USA are affected by local environmental and institutional factors regulating power plant siting in CERF.
5) Creating GCAM-USA + Demeter downscaled land use and land cover change scenarios to drive CLM5 simulations over the continental U.S.



Pacific Northwest
NATIONAL LABORATORY

Backup Slides



Pacific Northwest
NATIONAL LABORATORY

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.

Group

Bulk Characteristics
Size [N = 6]
Vintage [N = 7]
Type [N = 16]
Location [N = 15]
+
Each building is given a weight that reflects how many other buildings it represents

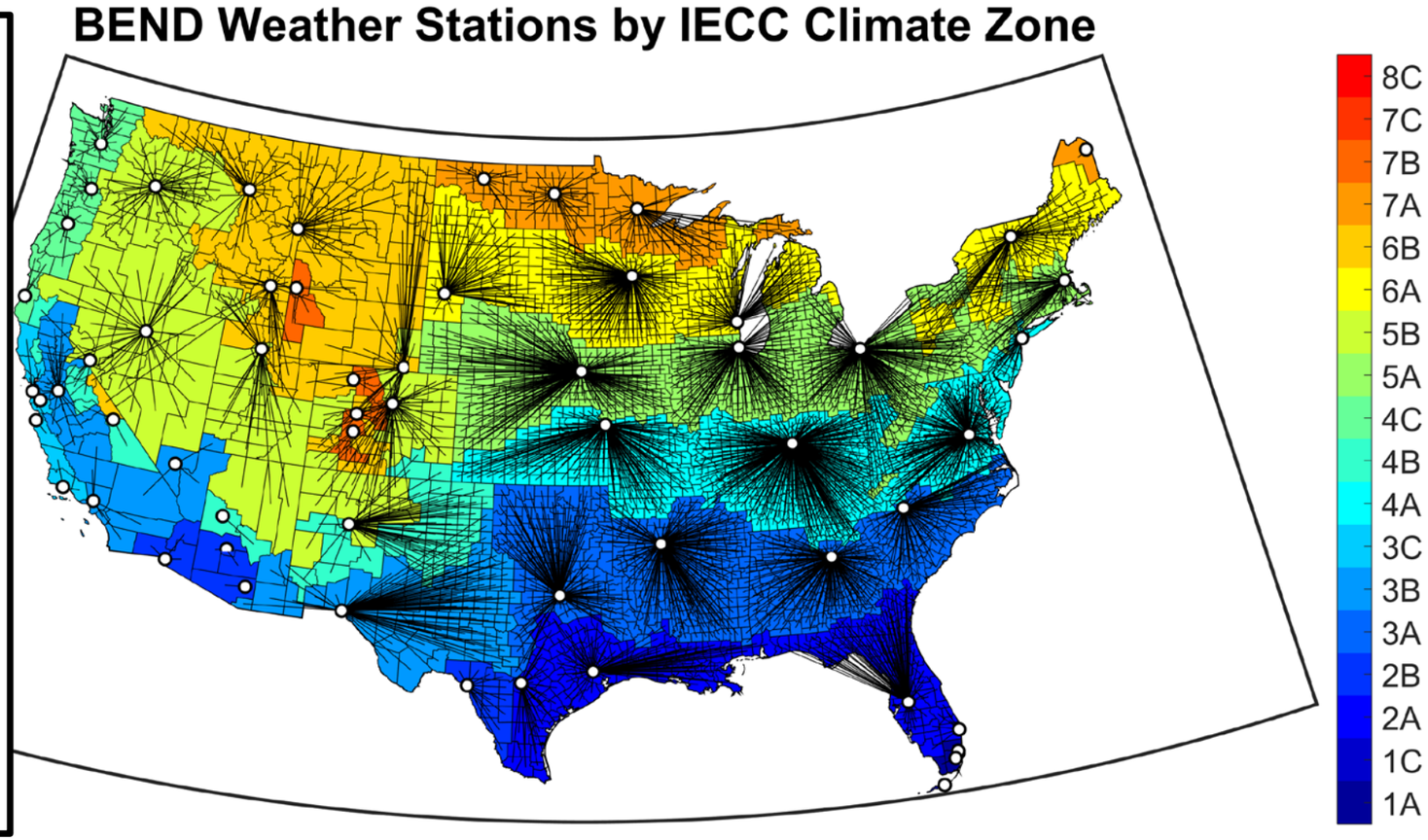
Infer

E+ Parameters
HVAC type
Wall type
Roof type
Insulation
Windows
Schedule
Etc.

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.

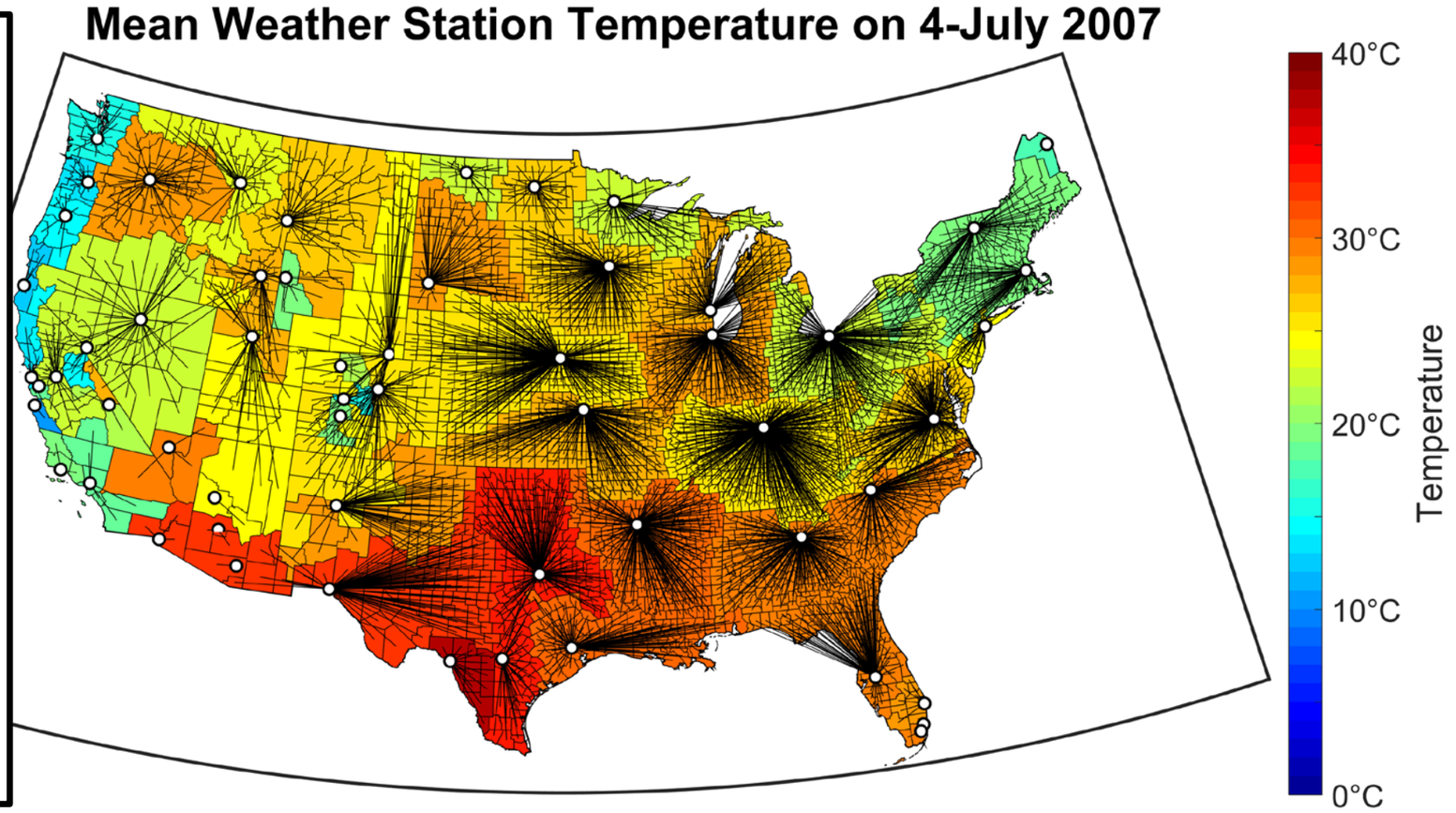


Homogenizing Climate Projections

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.

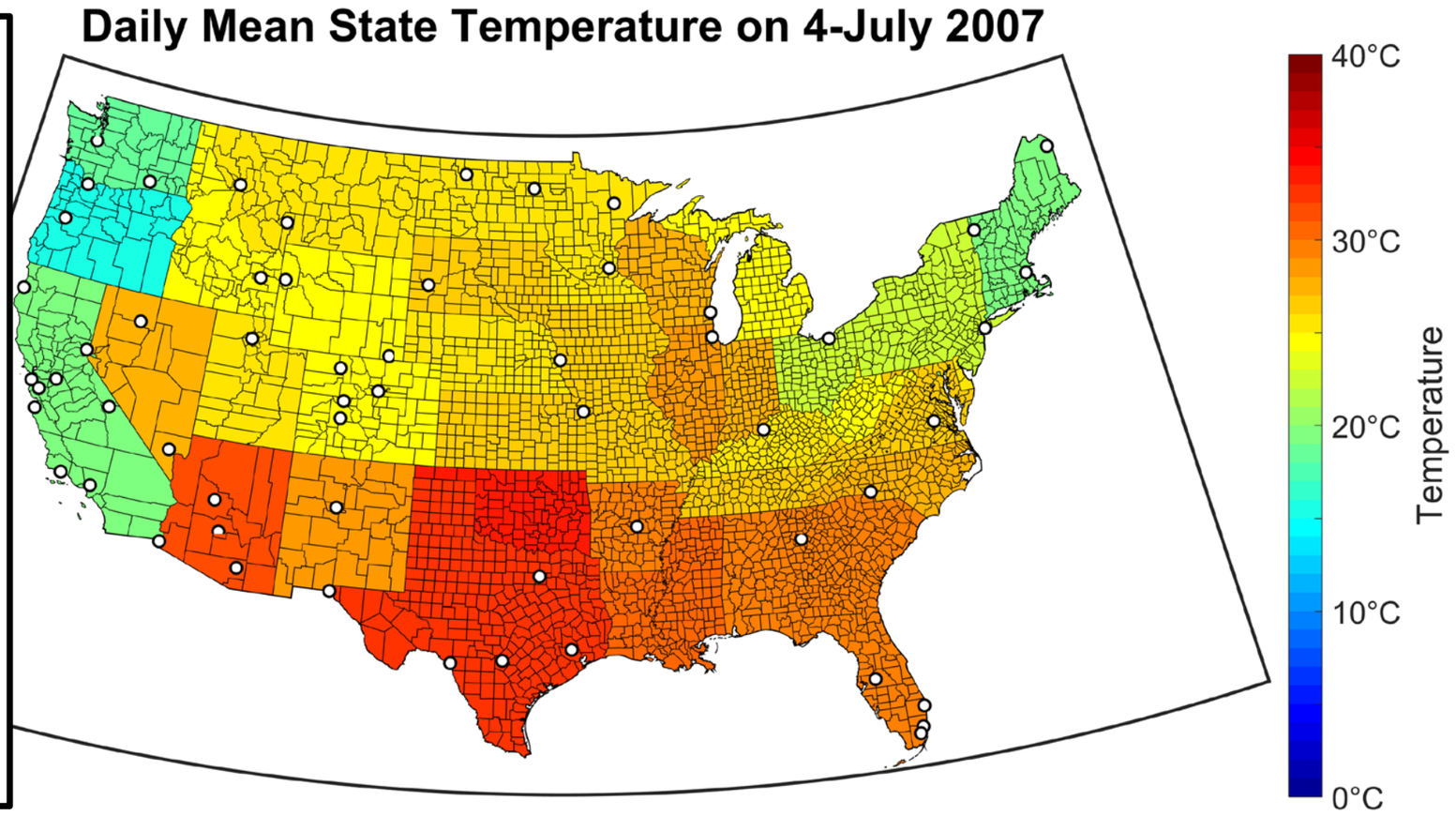
2. We take a daily mean temperature for each weather station.

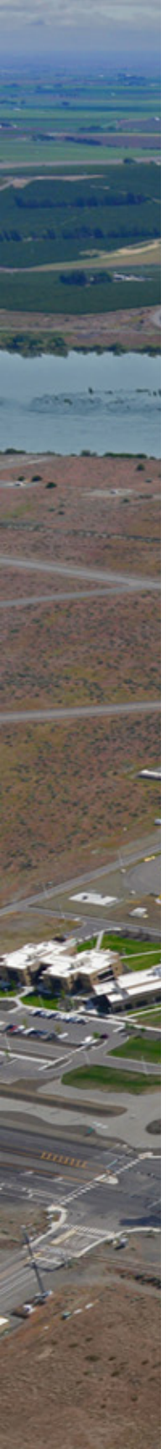


Homogenizing Climate Projections

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.
2. We take a daily mean temperature for each weather station.
3. We population-weight those means into daily mean state temperatures.

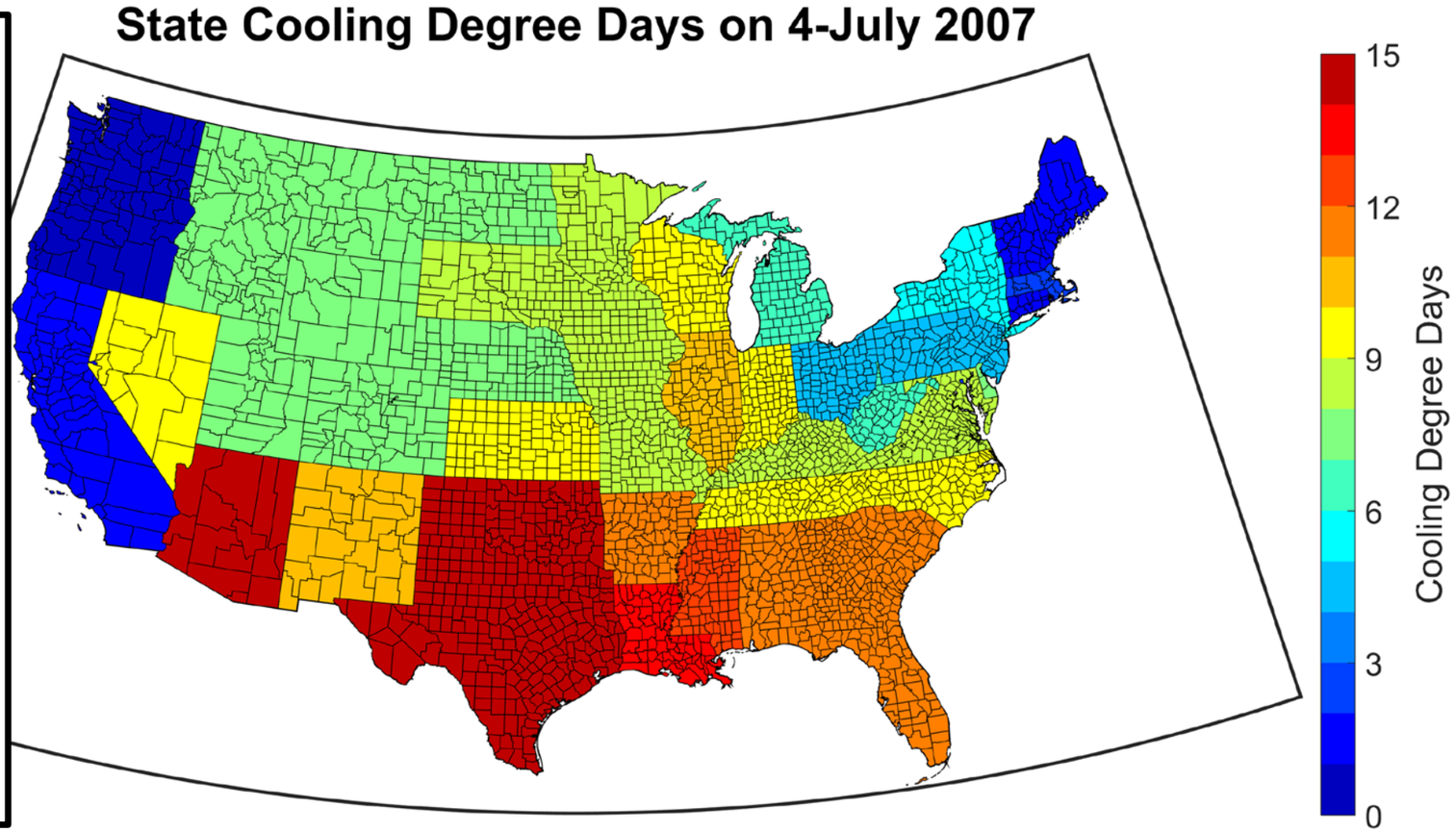


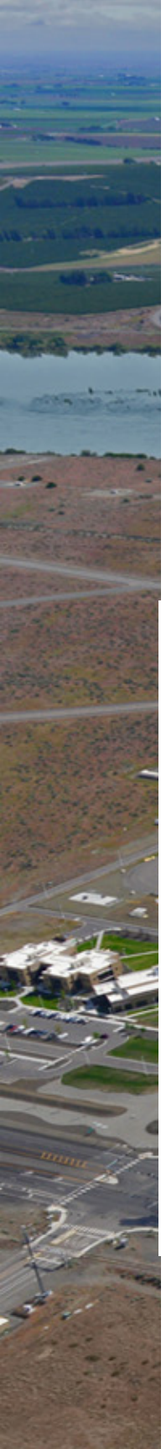


Homogenizing Climate Projections

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

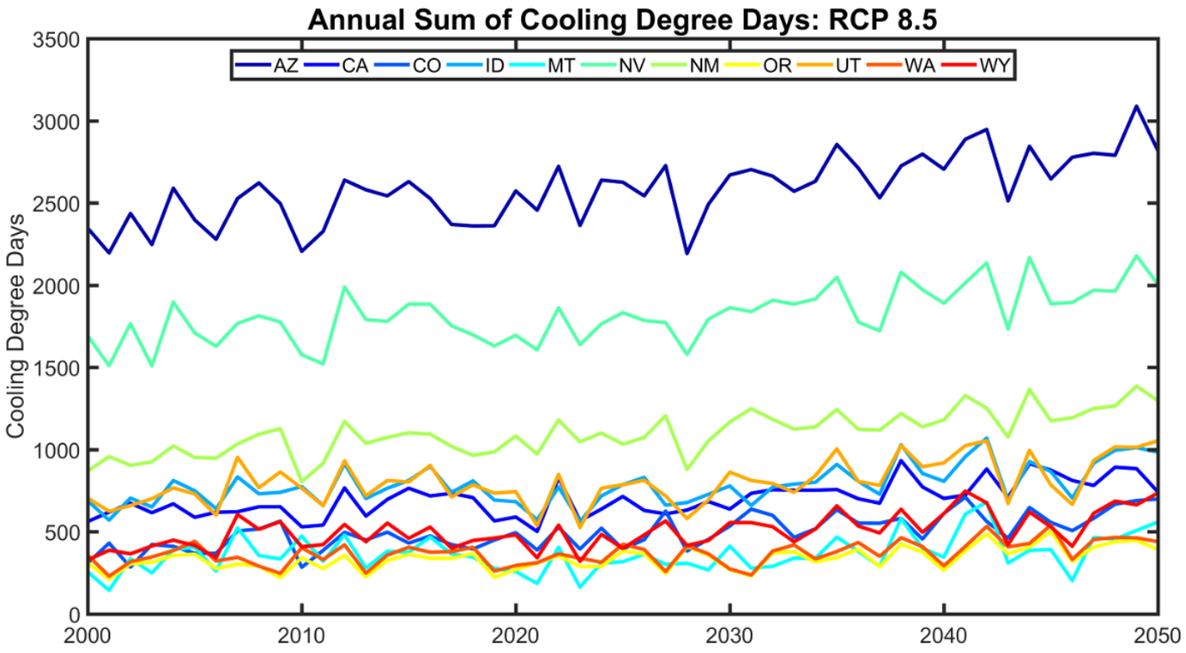
1. BEND uses 4 weather stations per IECC climate zone.
2. We take a daily mean temperature for each weather station.
3. We population-weight those means into daily mean state temperatures.
4. We use the state temperatures to compute HDD/CDD.

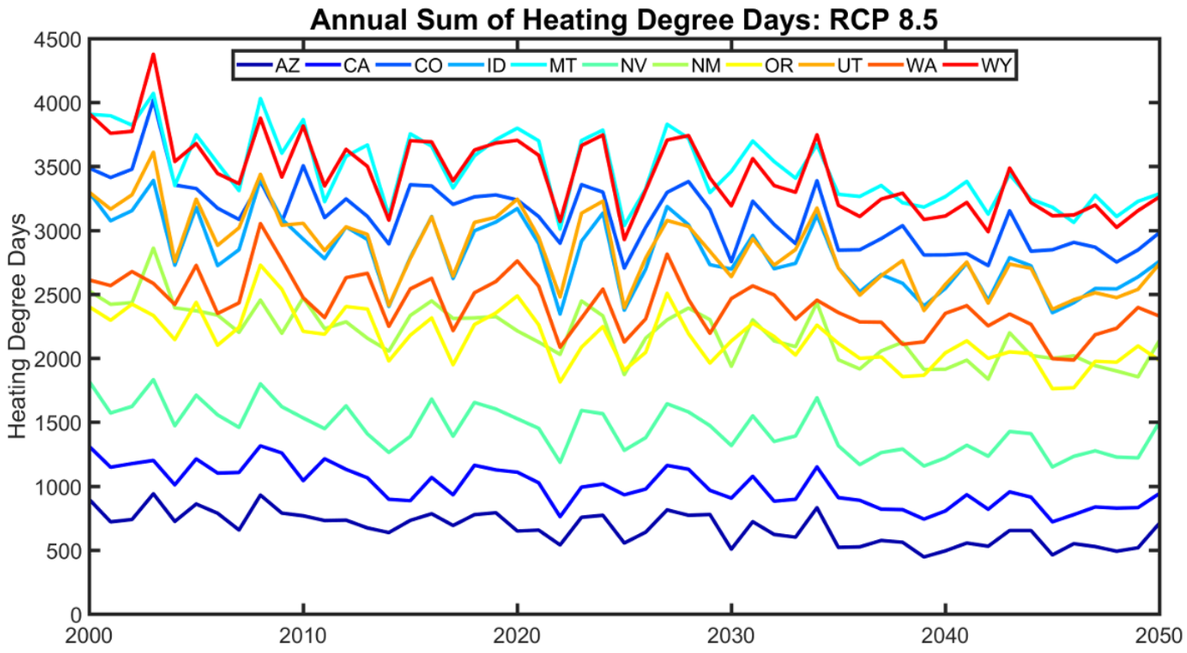


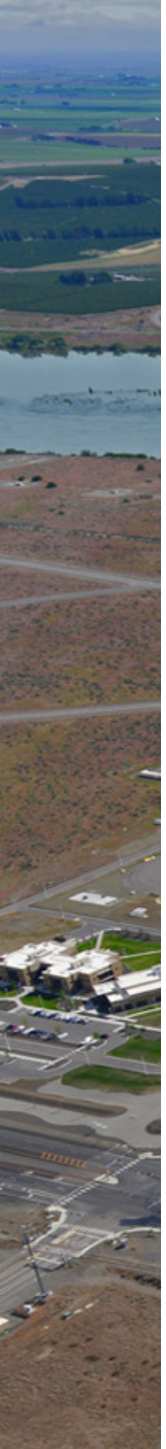


Homogenizing Climate Projections

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







Pacific Northwest NATIONAL LABORATORY

Homogenizing Population and Floor Space Projections

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