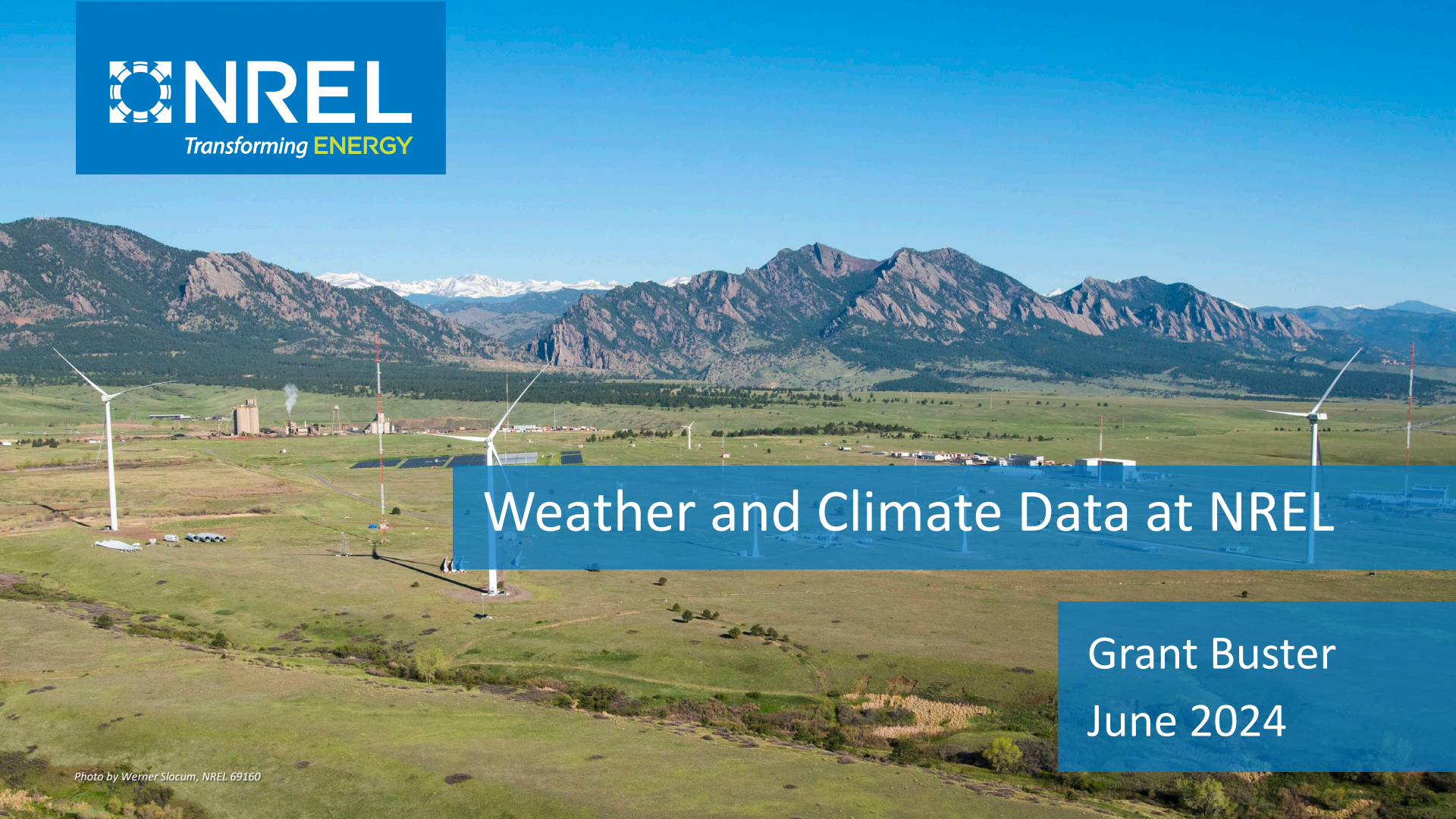
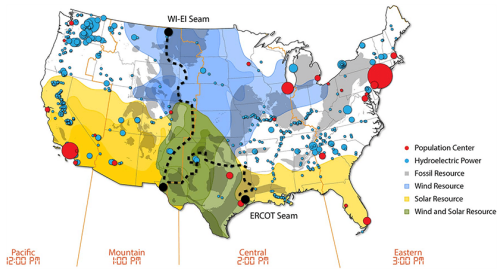

NREL
Transforming ENERGY
Weather and Climate Data at NREL
Grant Buster
June 2024
Photo by Werner Slocum, NREL 69160

Renewable Energy Integration Studies: Envisioning the Future of Energy Systems

The NREL Seams Study

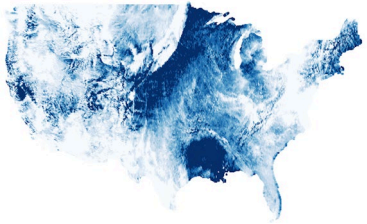


The North American Renewable Integration Study (NARIS)

LA100

The Los Angeles 100% Renewable Energy Study

PR100



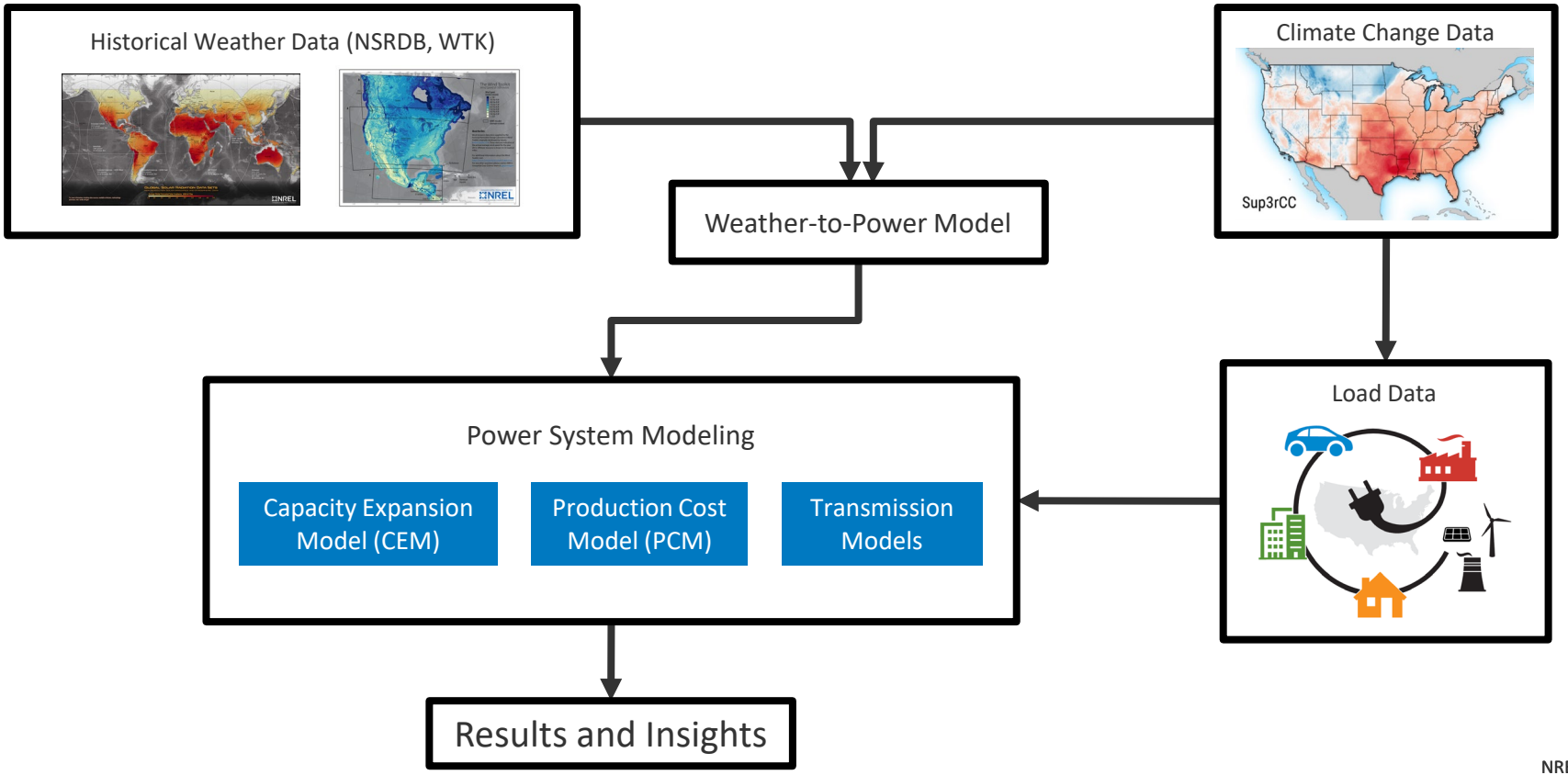
"The Evolving Role of Extreme Weather Events in the U.S. Power System with High Levels of Variable Renewable Energy"

U.S. DEPARTMENT OF ENERGY

Building a Better Grid

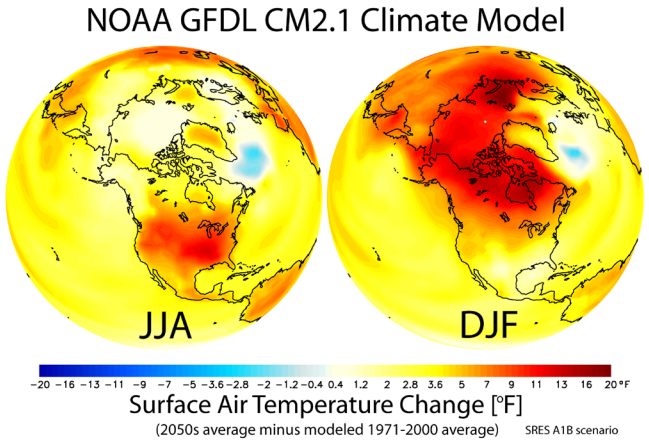
National Transmission Planning Study

How Is Weather Data Used In Analysis?



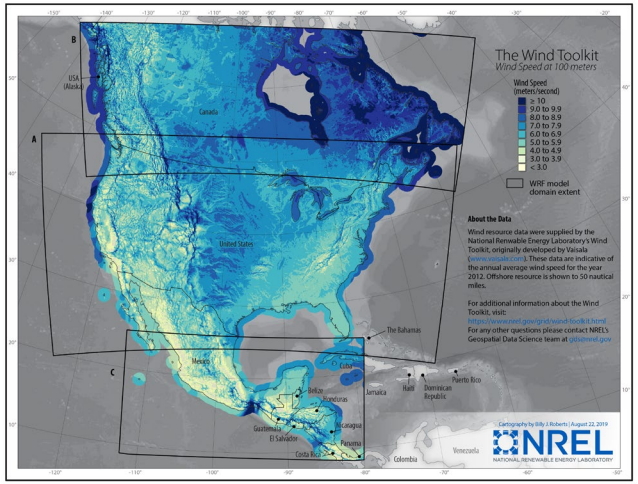
Integration of Climate Data: Mind the Gap

Global Climate Models (GCMs)



https://www.gfdl.noaa.gov/visualizations-climate-prediction/

Mesoscale NREL Datasets (WTK, NSRDB)



~100 km grid resolution
daily average data
2000-2100

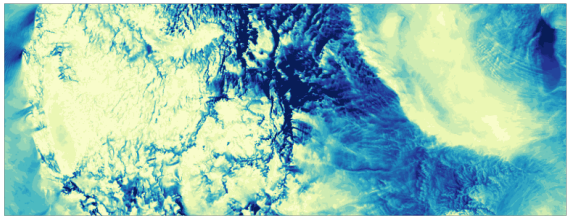
How do we bridge this gap?

~2-4 km grid resolution
5 min-hourly data
Historical

Our solution needs to be flexible enough to enable researchers to study any climate model or climate change scenario and to stay current with new climate research.

Super-Resolution for Renewable Energy Resource Data with Climate Change Impacts (Sup3rCC)

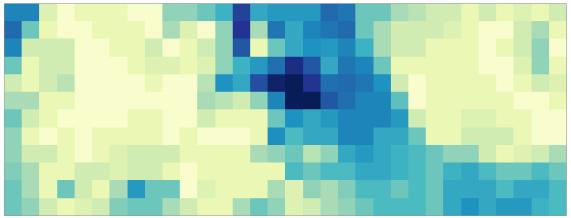
True High Res (WTK or NSRDB)



4km Hourly

Coarsen to create training data

Low Res (WTK, NSRDB, GCM)

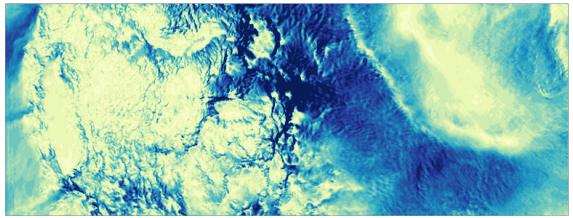


100km Daily

Discriminative Model

Generative Model

Synthetic High-Res Output



4km Hourly

Benefits of Downscaling with ML:

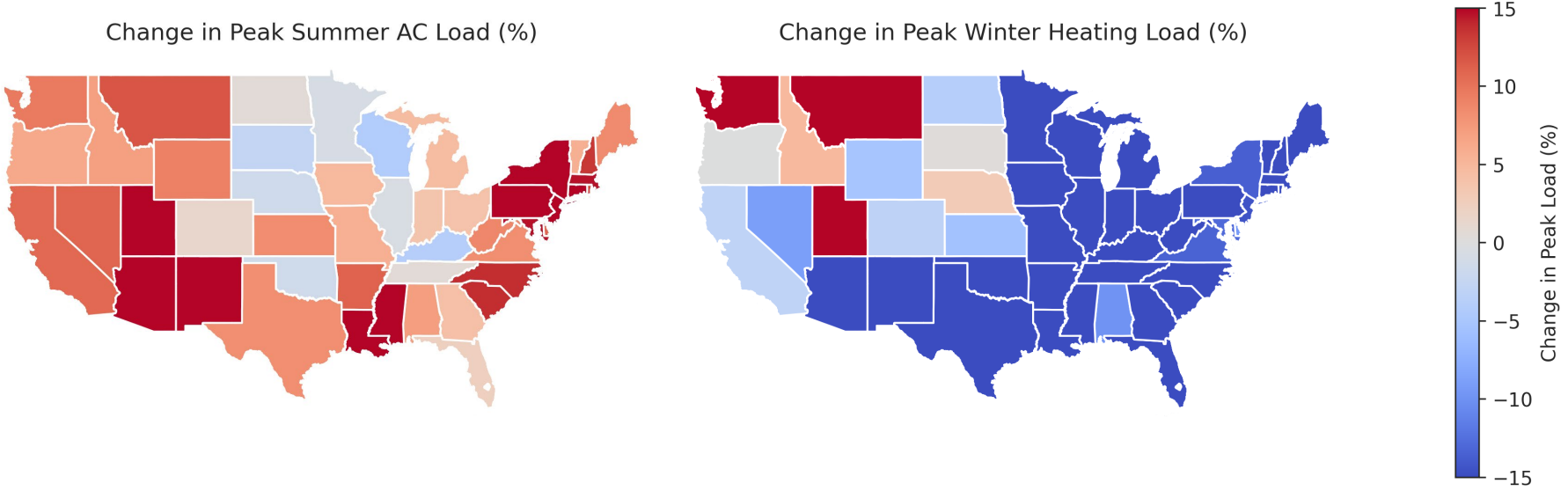
1. Computational efficiency (40x-200x faster than WRF)
2. Designed for renewables (wind, solar, temp, humidity)
3. Fully integrated into energy analysis software
4. Open-source: https://nrel.github.io/sup3r/

Sup3rCC

- The Sup3rCC 4km hourly outputs (right) add **high-resolution spatial features and temporal dynamics** conditioned on the low-res GCM input (left)
- Includes **wind speed, solar irradiance, temperature, and humidity**, all spatiotemporally coincident
- Initial data is available for two GCMs, SSP5-8.5, 2015-2059
- Data on NREL-HPC and OEDI:
  - /datasets/sup3rcc/
  - DOI 10.25984/1970814

Buster et al., "High-resolution meteorology with climate change impacts from global climate model data using generative machine learning", *Nature Energy* (2024). https://doi.org/10.1038/s41560-024-01507-9

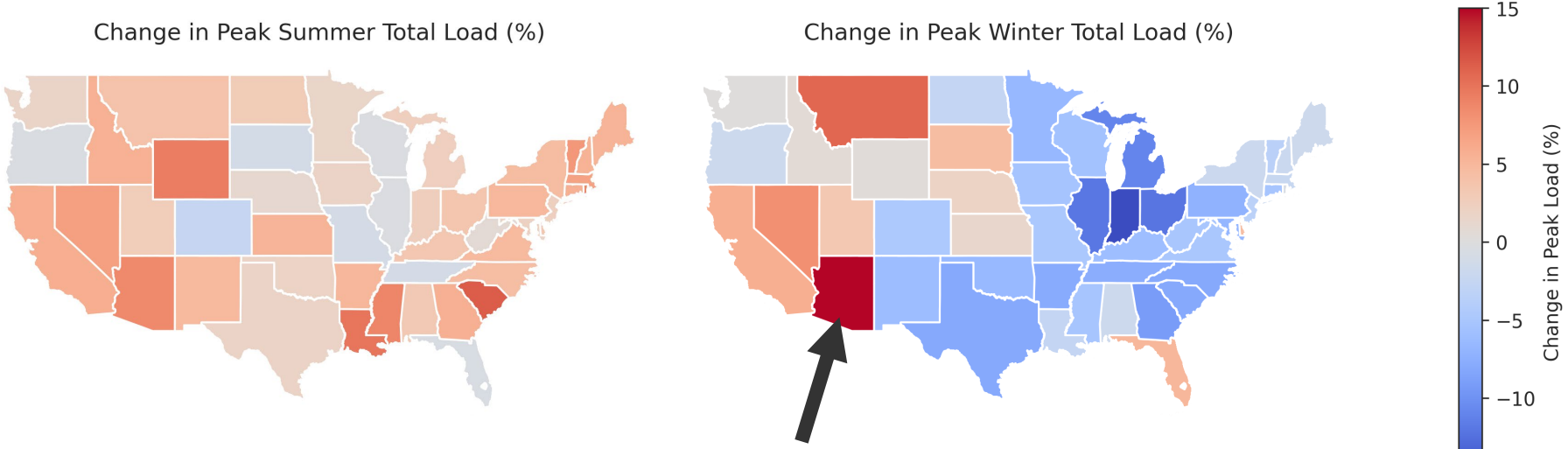
Impacts of Climate Change on Heat and Cooling Peak Energy Demand



Widespread increases in summer peak AC load and decreases in winter heating load

this only compares historical load to mid-century weather for a single possible climate scenario

Impacts of Climate Change on All-Sector Peak Energy Demand



40% increase in peak winter load

Less pronounced changes for all-sector peak loads, but some dramatic local changes

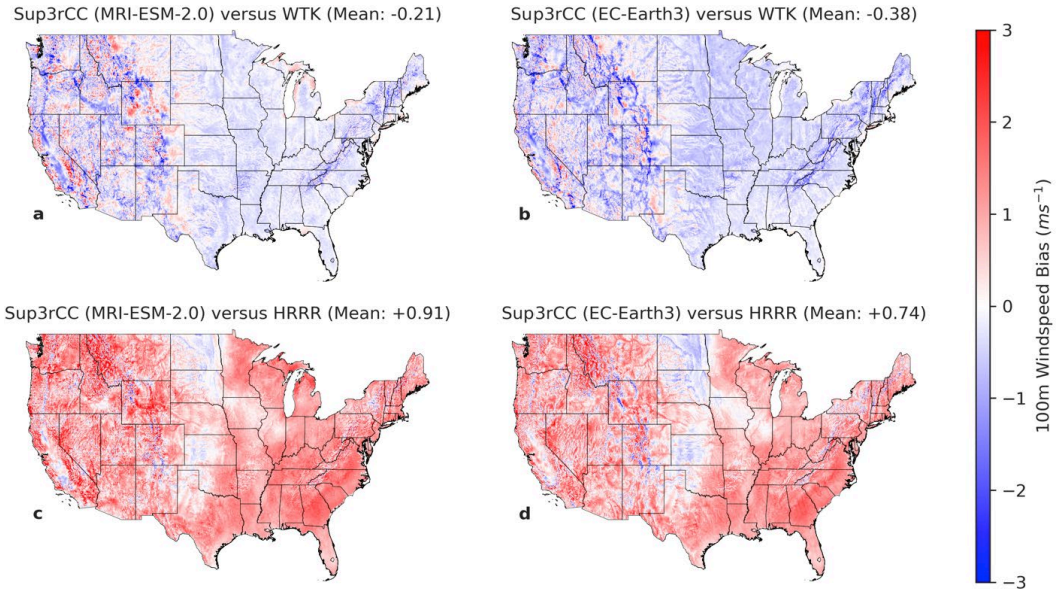
this only compares historical load to mid-century weather for a single possible climate scenario

PACES: Power Planning for Alignment of Climate and Energy Systems

- Downscaling climate projections for power system analysis with multiple methods
  - Generative Machine Learning (Sup3rCC)
  - Numerical Weather Prediction (WRF)
- Exploration of planning strategies under climate change uncertainty
  - Decision making with deep uncertainty (DMDU)
  - Stochastic capacity expansion
- Application to utilities
  - Tennessee Valley Authority
  - Southern Company

Sup3rCC Known Issues

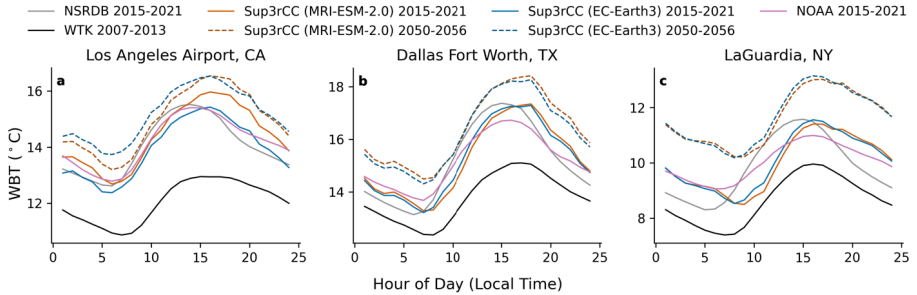
- **Simplistic bias correction**
  - **Linear scalar/adder factors**
  - **7-year comparison**
- Imperfect diurnal cycles
  - Mean wind diurnal cycles are “noisy”
  - Timing of peak temperature can be off



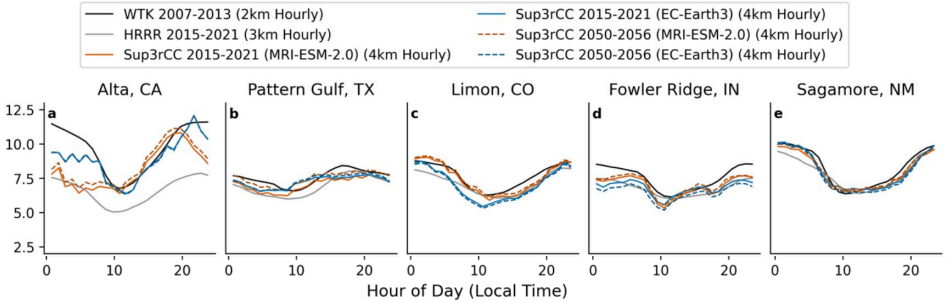
Supplementary Figure 4. a-d, Maps of mean bias for wind speed. a, Comparison of Sup3rCC based on MRI-ESM-2.0 to the WTK. b, Comparison of Sup3rCC based on EC-Earth3 to the WTK. c, Comparison of Sup3rCC based on MRI-ESM-2.0 to HRRR. d, Comparison of Sup3rCC based on EC-Earth3 to HRRR. Sup3rCC and HRRR data is from 2015-2021 while WTK is from 2007-2013. Positive bias values indicate Sup3rCC has wind speed greater than the reference dataset.

Sup3rCC Known Issues

- Simplistic bias correction
  - Linear scalar/adder factors
  - 7-year comparison
- **Imperfect diurnal cycles**
  - **Mean wind diurnal cycles are “noisy”**
  - **Timing of peak temperature can be off**



Supplementary Figure 17. a-c, Mean diurnal cycles for modeled versus observed temperature. Plots compare gridded datasets (e.g., NSRDB, WTK, and Sup3rCC) to historical observation from NOAA at three large airports.



Supplementary Figure 14. a-y, Mean diurnal cycles for wind speed. Data is included for 25 large wind energy facilities in the contiguous United States comparing the WTK, HRRR, and Sup3rCC.

Gaps!

Hurricanes

How does climate change affect hurricanes? How can we simulate hurricanes for power system impacts?

Wildfires

How does climate change affect wildfires? How can we simulate wildfires for power system impacts?

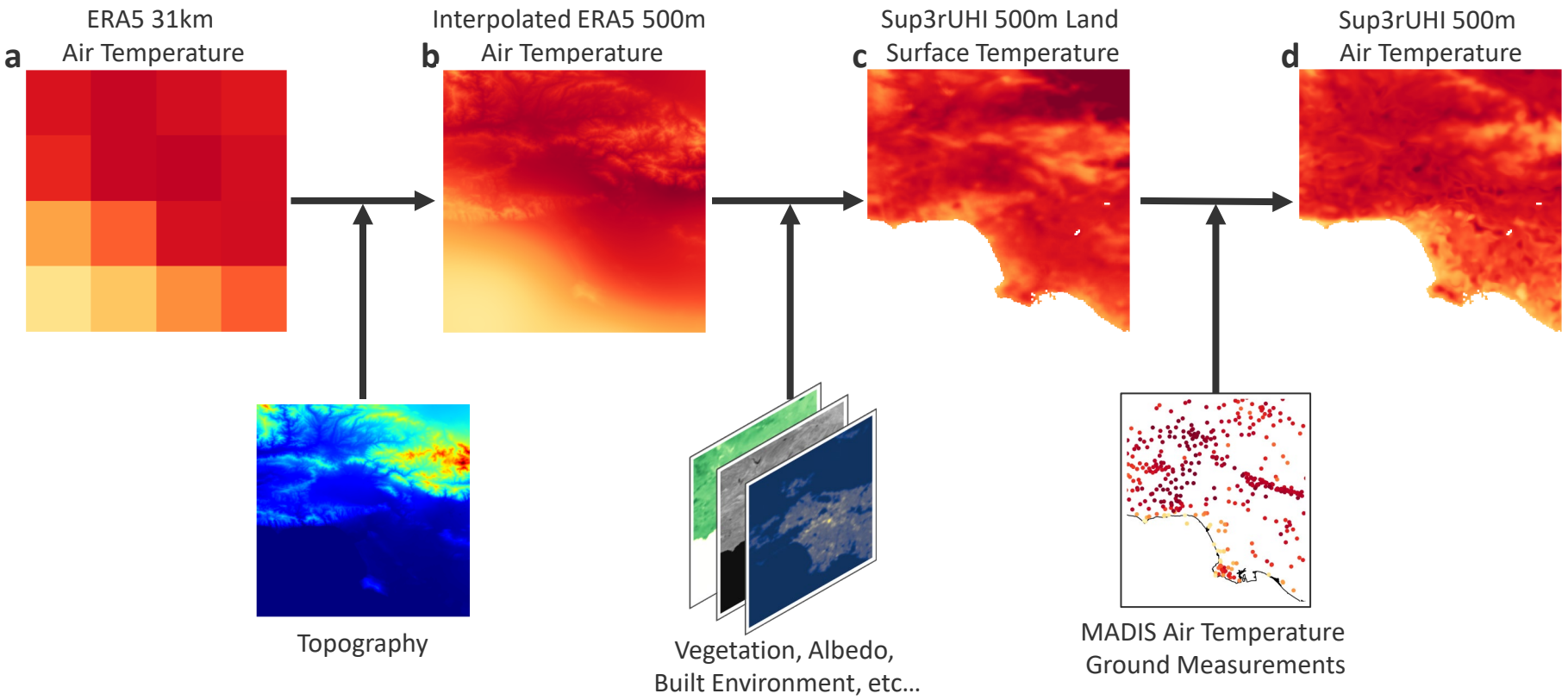
Migration

How might climate change drive human migration? How does this stress energy infrastructure and energy demand?

Urban Effects

How does the urban microclimate exacerbate impacts from climate change?

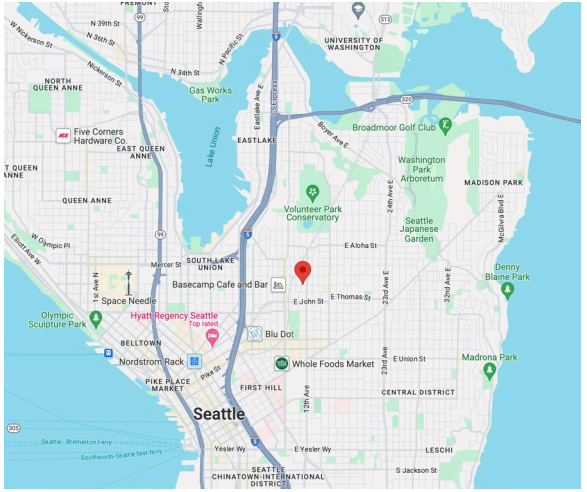
Sup3r Resolution for Urban Heat Island (Sup3rUHI)

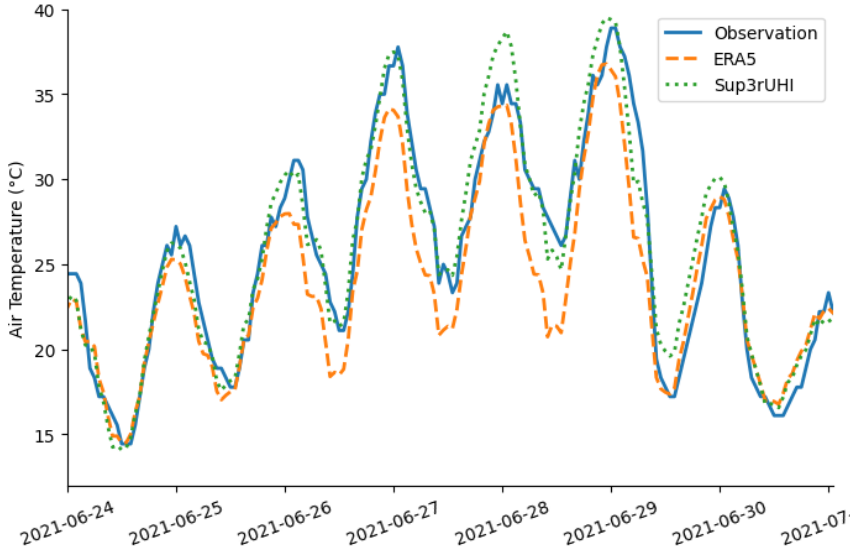


Los Angeles shown here for example

Validation – Seattle

- Sup3rUHI yields much better data on 2021 Seattle heatwave in the urban core than reanalysis, as measured in Capitol Hill
- ERA5 underestimates the heat wave's peak temperature by more than 2°C
- Sup3rUHI overestimates by 0.6°C
- **Supports the use of this model to study unprecedented heat waves in urban microclimates**





Validation – LA Albedo

- Applying the albedo changes reported in Taha 2024 to Pacoima, CA we see an average change of -0.13°C with a maximum change of -0.75°C
  - This corresponds to a T_{air} reduction of 0.08°C per 0.1 increase in albedo
    - Comparable to previous cooling estimates previously reported in the literature
- **Supports the use of this model to estimate effects of albedo manipulation**

Table 2. Comparison of reported T_{air} reductions per 0.1 increase in albedo from previous modeling studies.

Study	Spatial scale	T_{air} reduction per 0.1 increase in albedo (°C)	T_{air} height (m)
This study	Neighborhood-scale	0.11, 0.10 [a]	1.6, 3 [a]
Taleghani *et al* [33]	Neighborhood-scale	0.09	1.5
Taha [31, 87]	City-scale	0.17–0.2	2
Mohegh *et al* [24]	City-scale	0.05–0.22	2
Millstein and Levinson, [88]	Hypothetical hotplate (~200 m)	0.05	2

Ko et al., 2022

Efficacy of Albedo Modification on Residential Cooling Demand in Los Angeles

- Increase in cooling demand through midcentury: +23%
- Road albedo modifications: -2%
- Large-scale neighborhood albedo modifications: -6%
- Cool roof modification: -11%
- Cool roof + large scale neighborhood albedo modifications: -17%

- Based on Sup3rCC data from 2015-2024 versus 2050-2059
- Los Angeles residential building stock represented using ResStock

NREL Contributors to Climate Change Data and Climate Impacts Analysis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Thank you

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https://www.nature.com/articles/s41560-024-01507-9
https://data.openei.org/submissions/5839

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