Pacific Northwest
NATIONAL LABORATORY

GODEEEP
Grid Operations, Decarbonization, Environmental and Energy Equity Platform
@PNNL

Forward Looking Extreme Weather Datasets

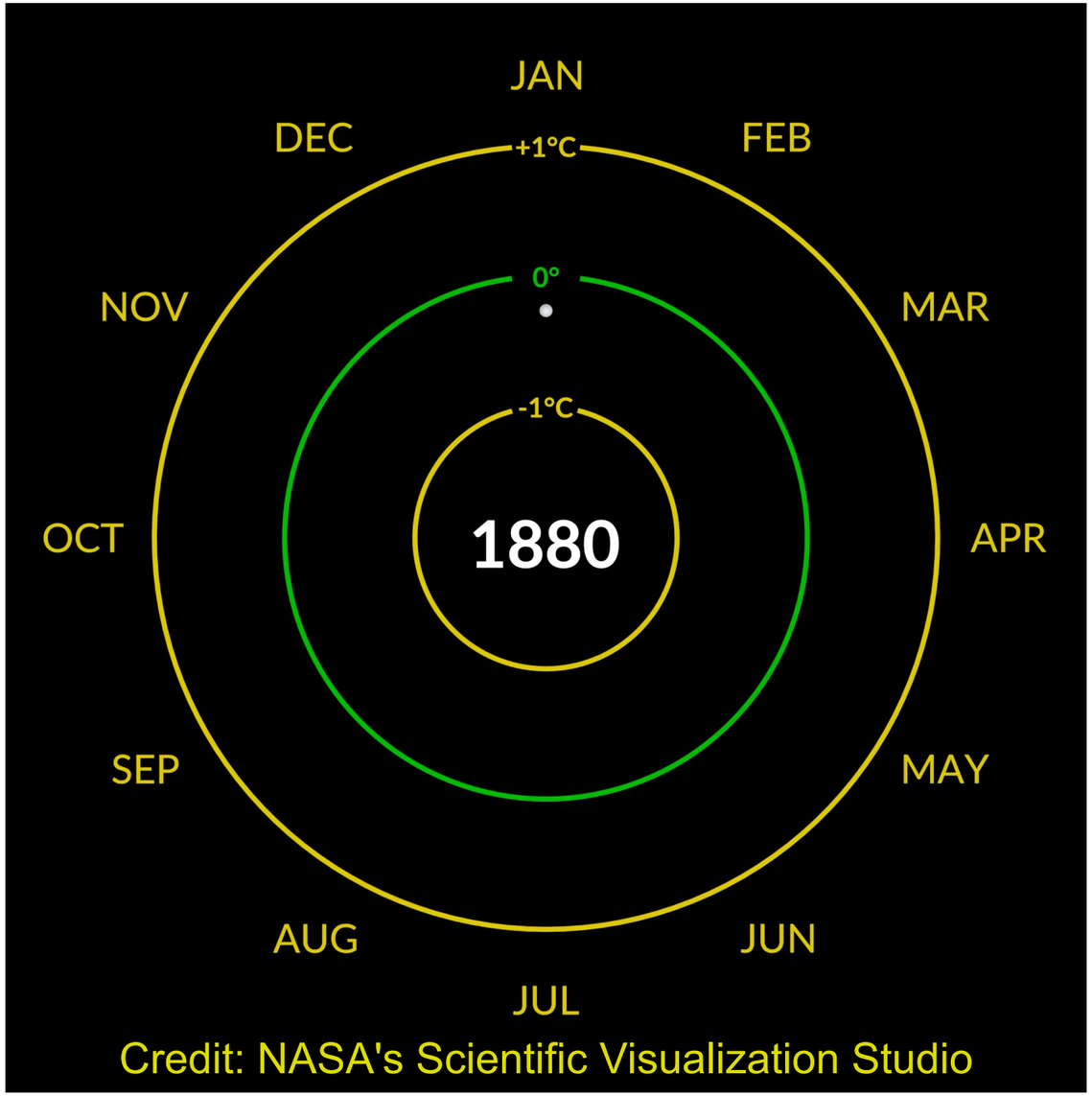
Casey Burleyson, Cameron Bracken, Kostas Oikonomou, and Nathalie Voisin

U.S. DEPARTMENT OF ENERGY
BATTELLE

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

Assertions

1. The existing grid is weather sensitive.
2. Weather characteristics (e.g., extremes) are changing rapidly.
3. The grid is also changing rapidly.
4. A high renewables grid will be even more weather sensitive.



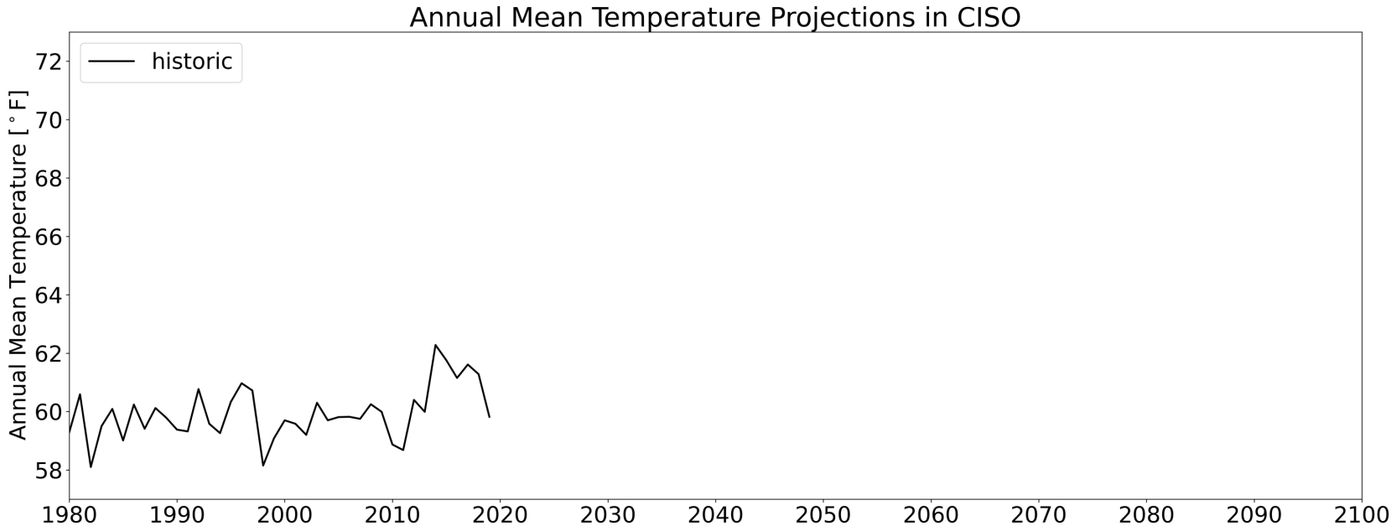
Credit: NASA's Scientific Visualization Studio

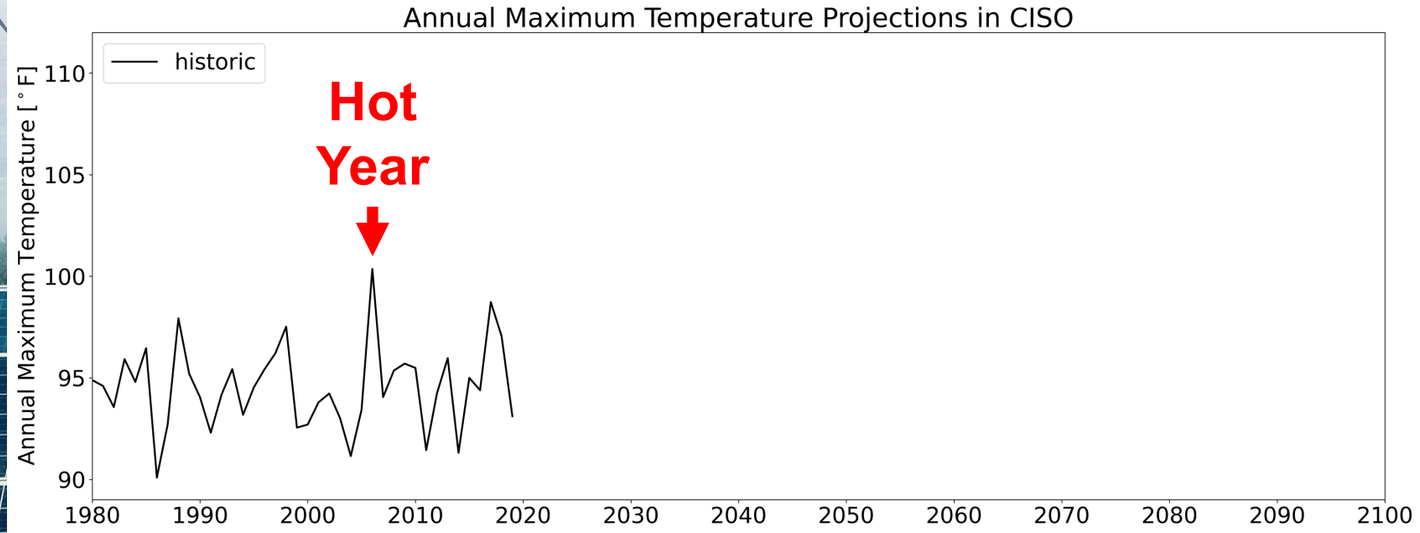
Key Messages

To assess the resilience and reliability of the bulk power system, it is critical to evaluate system performance:

1. With coincident load-wind-solar-hydro conditions;
2. Across a wide range of historical and projected weather conditions.

U.S. Climate Projection Dataset

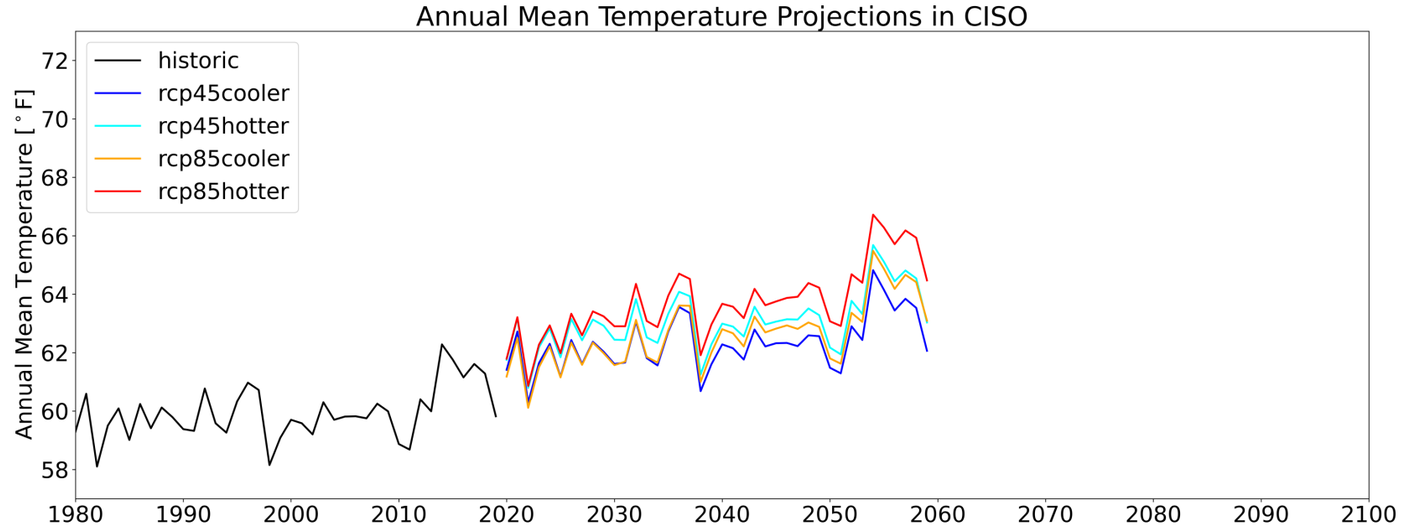


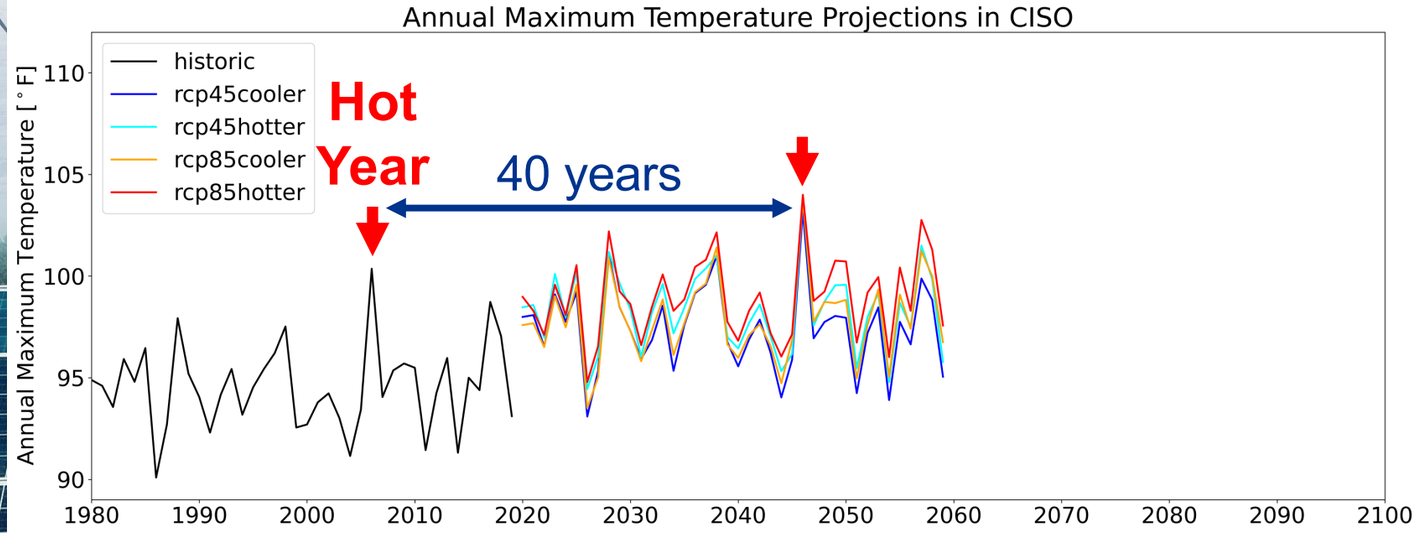


- Historic data reproduces observed sequence of past events (1980–2019)
- Sequence is repeated twice in the future (2020–2059 and 2060–2099) with additional warming gradually applied
- 1/8 deg (~12 km) resolution, U.S., hourly
- 25 hourly and 250+ three-hourly variables
- Output is first spatially-averaged by county then population-weighted to create annual 8,760-hr meteorology time series for 54 BAs across the U.S.

Climate data was developed with DOE Sc funding and is publicly available:
https://data.msdlive.org/records/cnsy6-0y610

U.S. Climate Projection Dataset

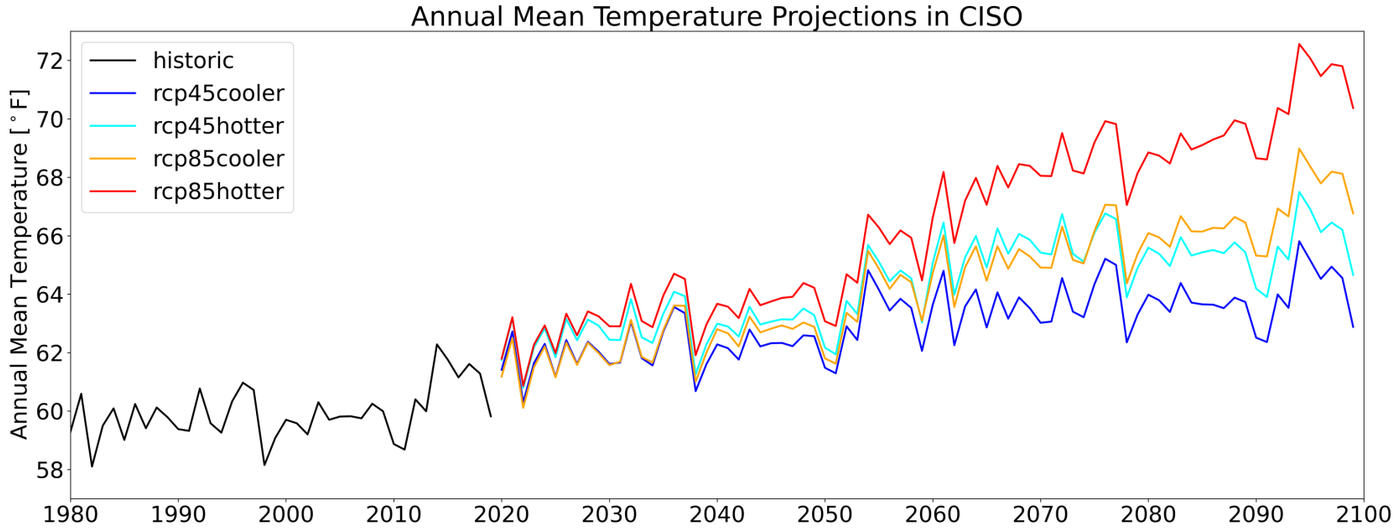


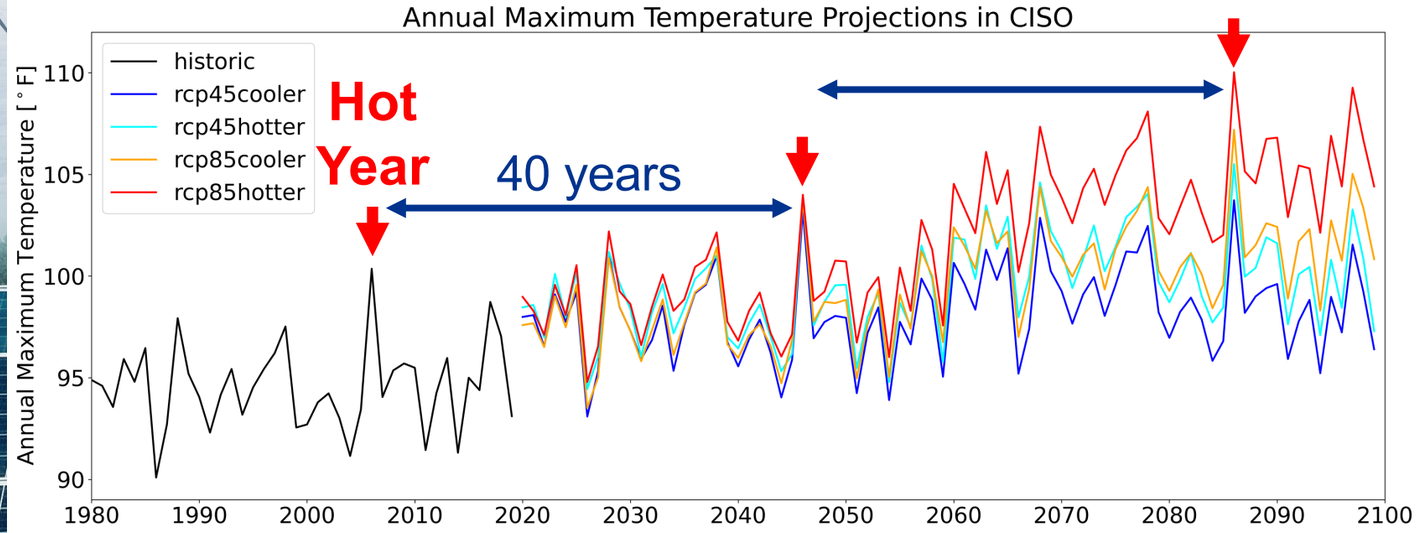


- Historic data reproduces observed sequence of past events (1980–2019)
- Sequence is repeated twice in the future (2020–2059 and 2060–2099) with additional warming gradually applied
- 1/8 deg (~12 km) resolution, U.S., hourly
- 25 hourly and 250+ three-hourly variables
- Output is first spatially-averaged by county then population-weighted to create annual 8,760-hr meteorology time series for 54 BAs across the U.S.

Climate data was developed with DOE Sc funding and is publicly available:
https://data.msdlive.org/records/cnsy6-0y610

U.S. Climate Projection Dataset

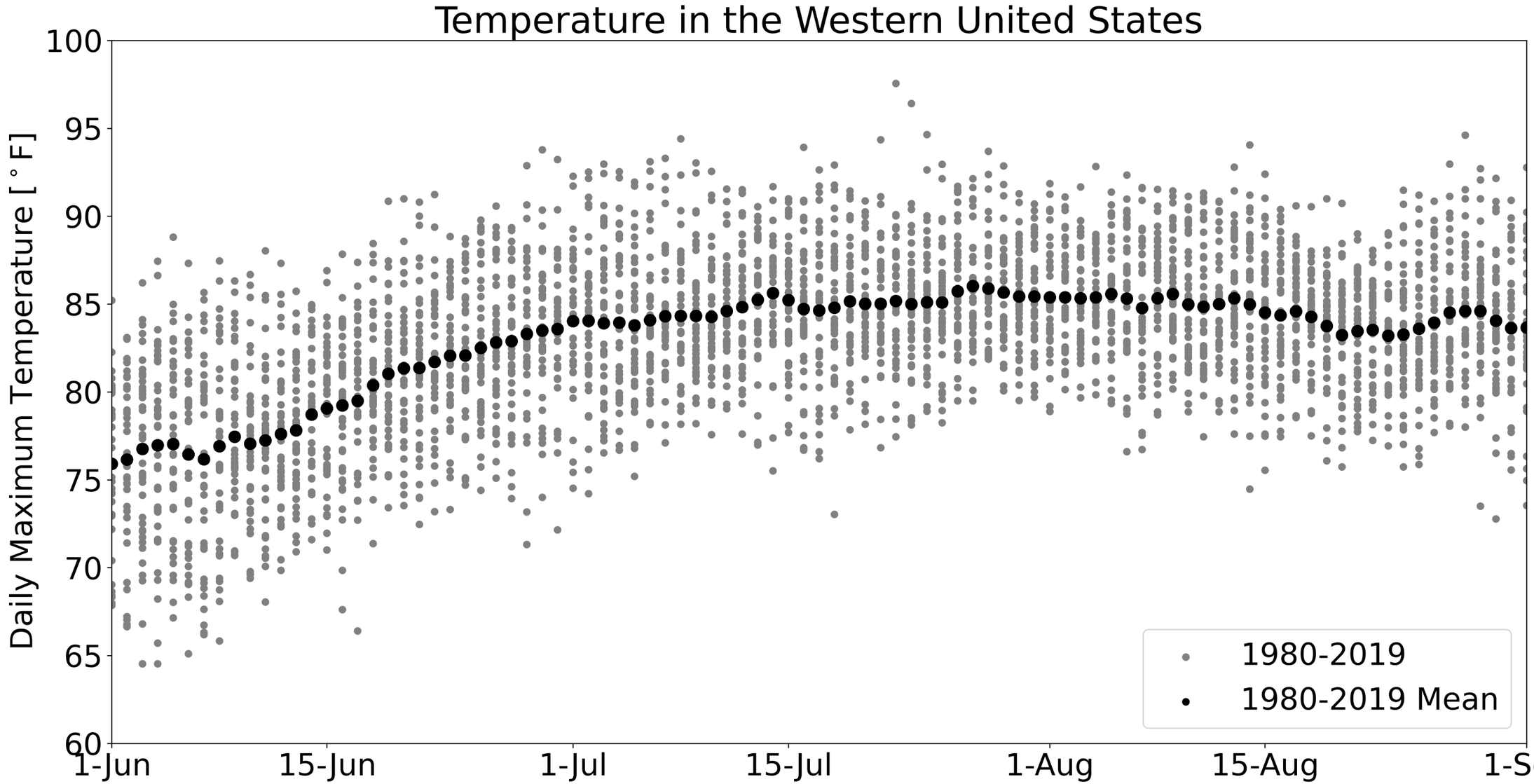




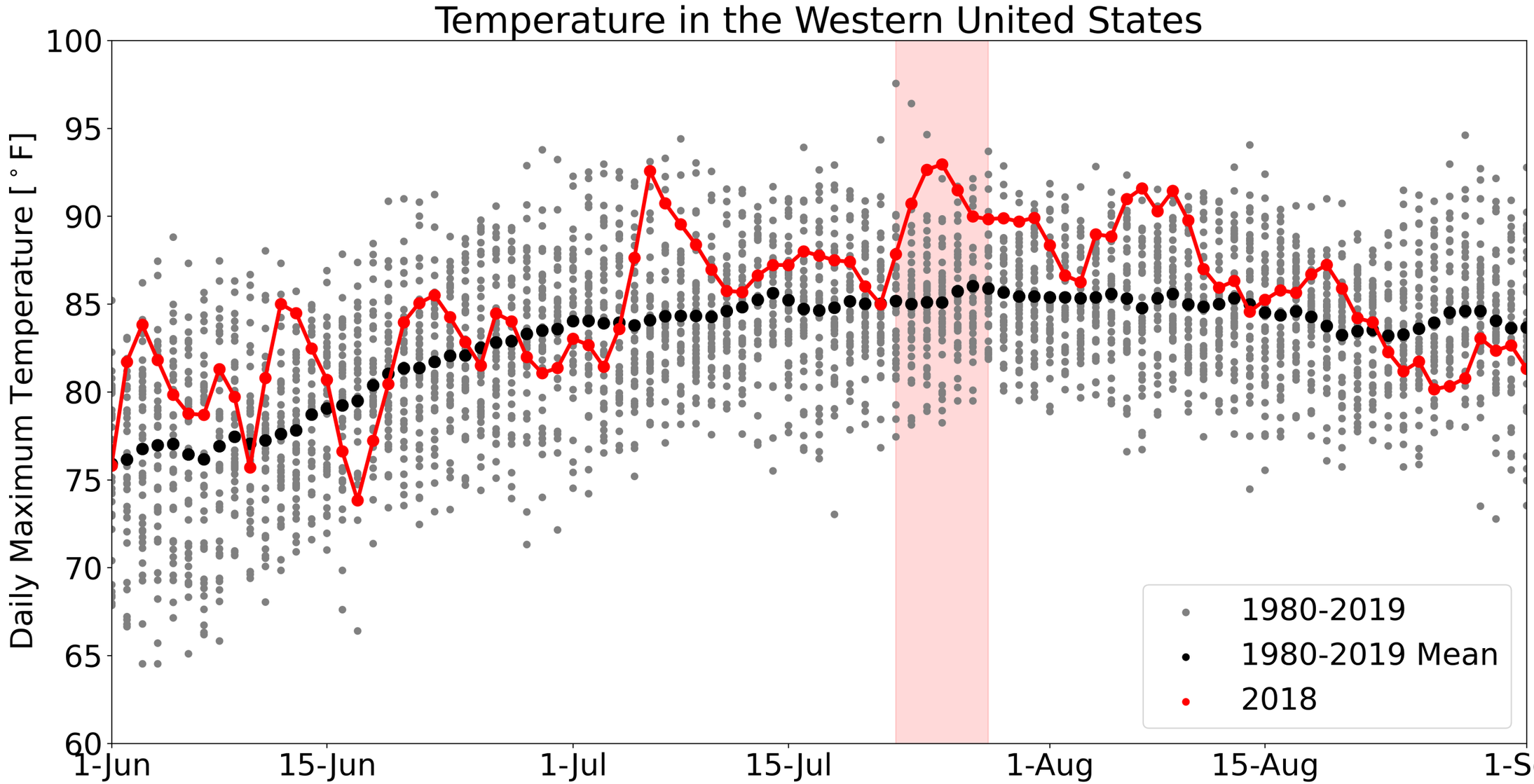
- Historic data reproduces observed sequence of past events (1980–2019)
- Sequence is repeated twice in the future (2020–2059 and 2060–2099) with additional warming gradually applied
- 1/8 deg (~12 km) resolution, U.S., hourly
- 25 hourly and 250+ three-hourly variables
- Output is first spatially-averaged by county then population-weighted to create annual 8,760-hr meteorology time series for 54 BAs across the U.S.

Climate data was developed with DOE Sc funding and is publicly available:
https://data.msdlive.org/records/cnsy6-0y610

Finding Heat Wave Events



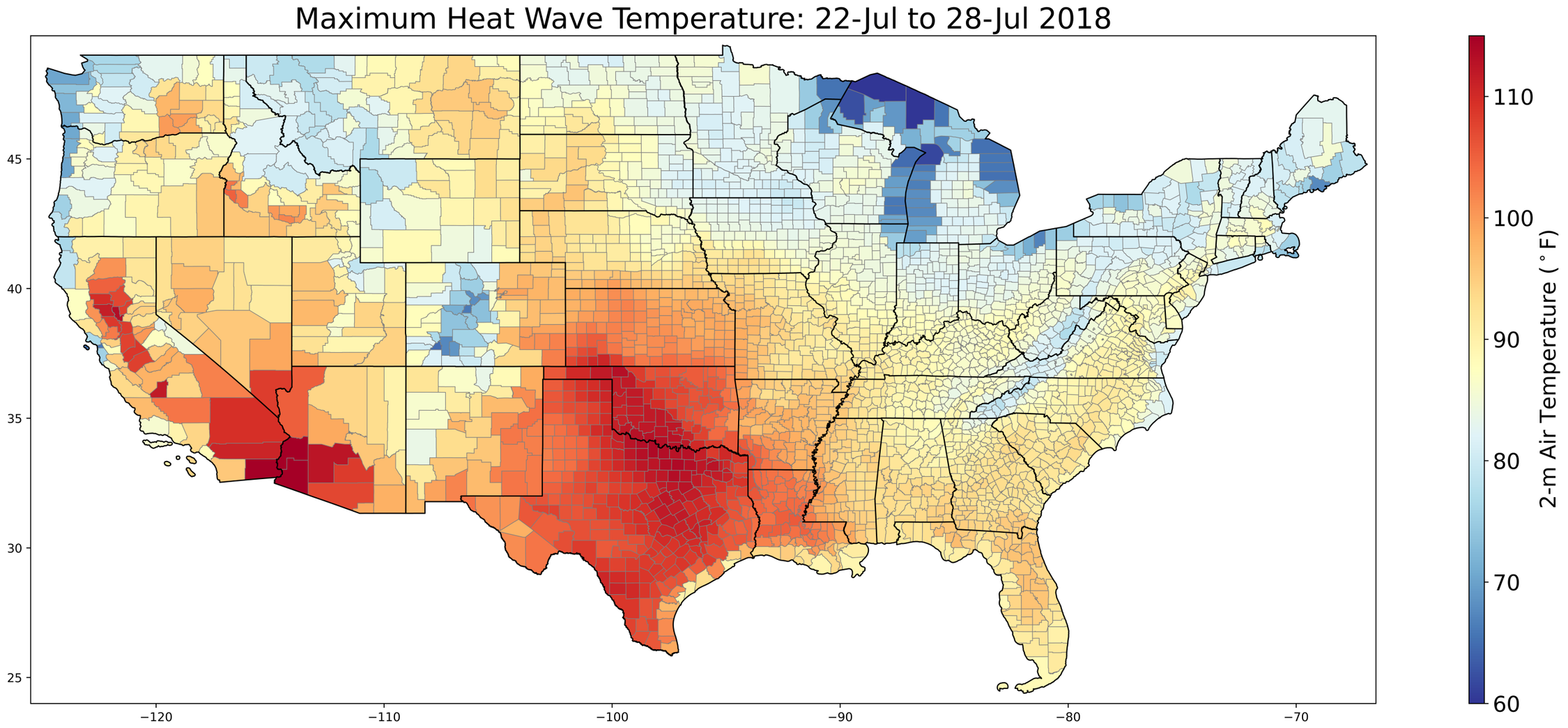
Finding Heat Wave Events



Pacific Northwest NATIONAL LABORATORY

GODEEEP
Grid Operations, Decarbonization, Environmental and Energy Equity Platform
@PNNL

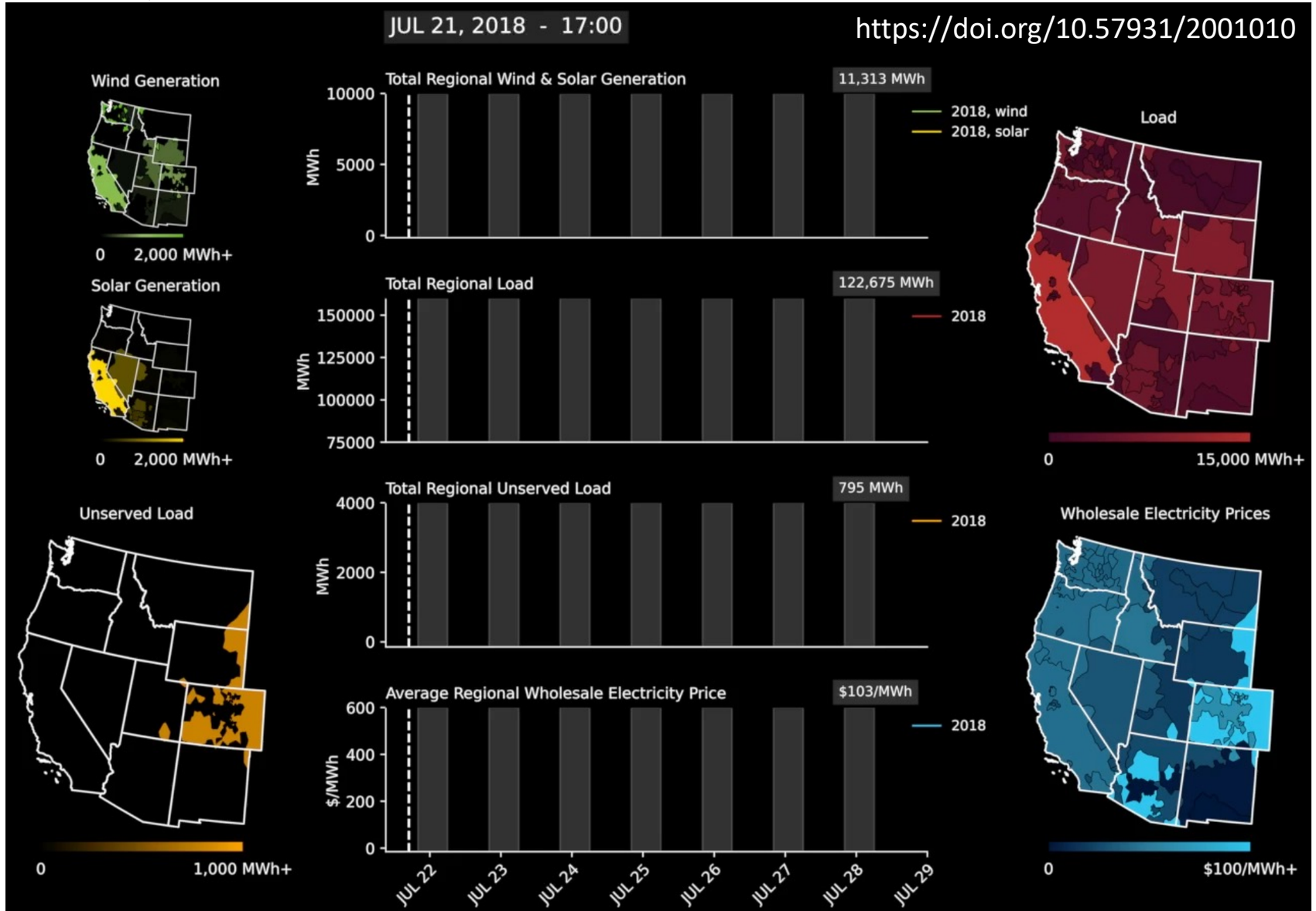
Finding Heat Wave Events



Pacific Northwest NATIONAL LABORATORY

GODEEEP
Grid Operations, Decarbonization, Environmental and Energy Equity Platform
@PNNL

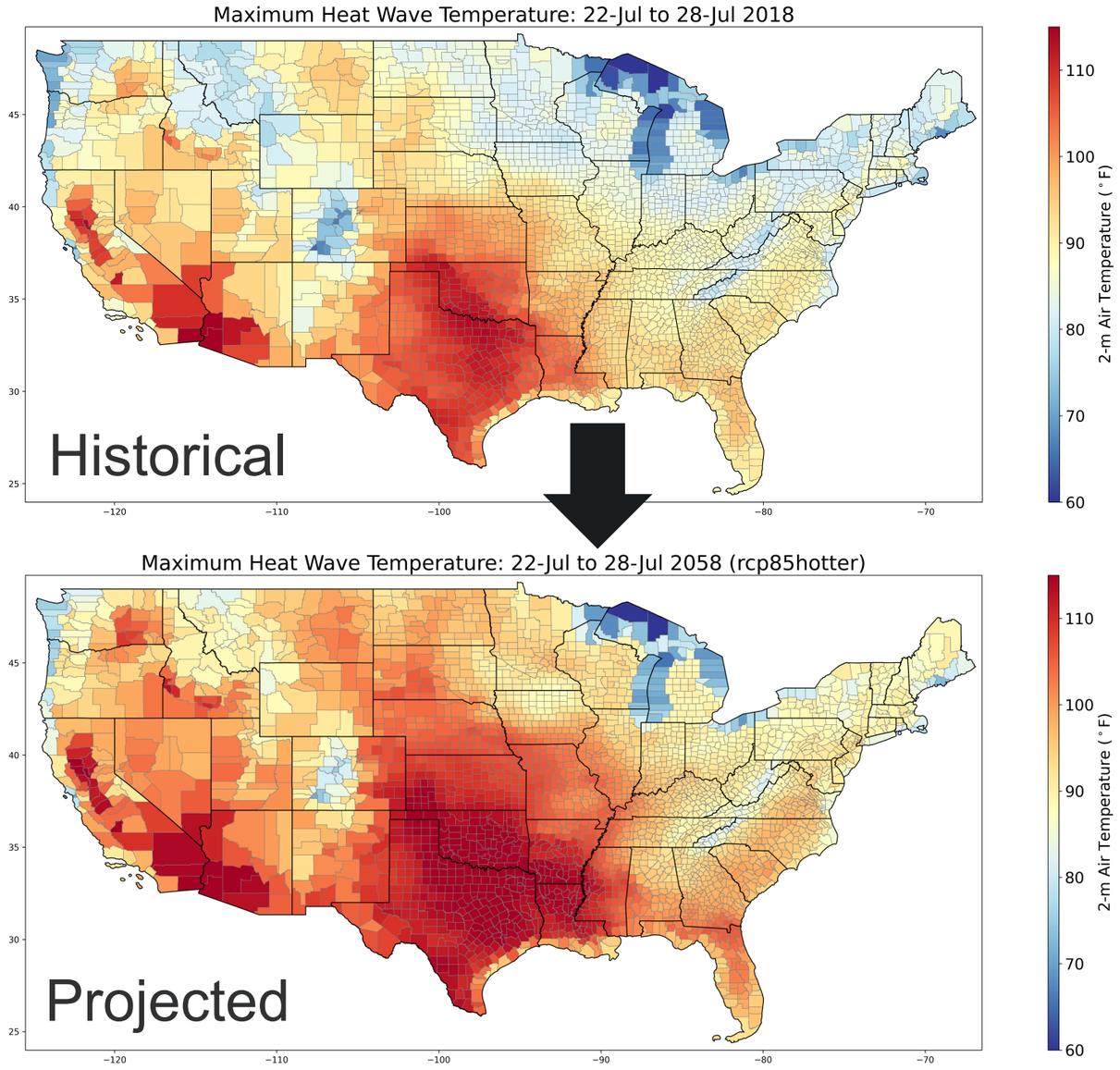
Exploring Historical Heat Wave Grid Stress

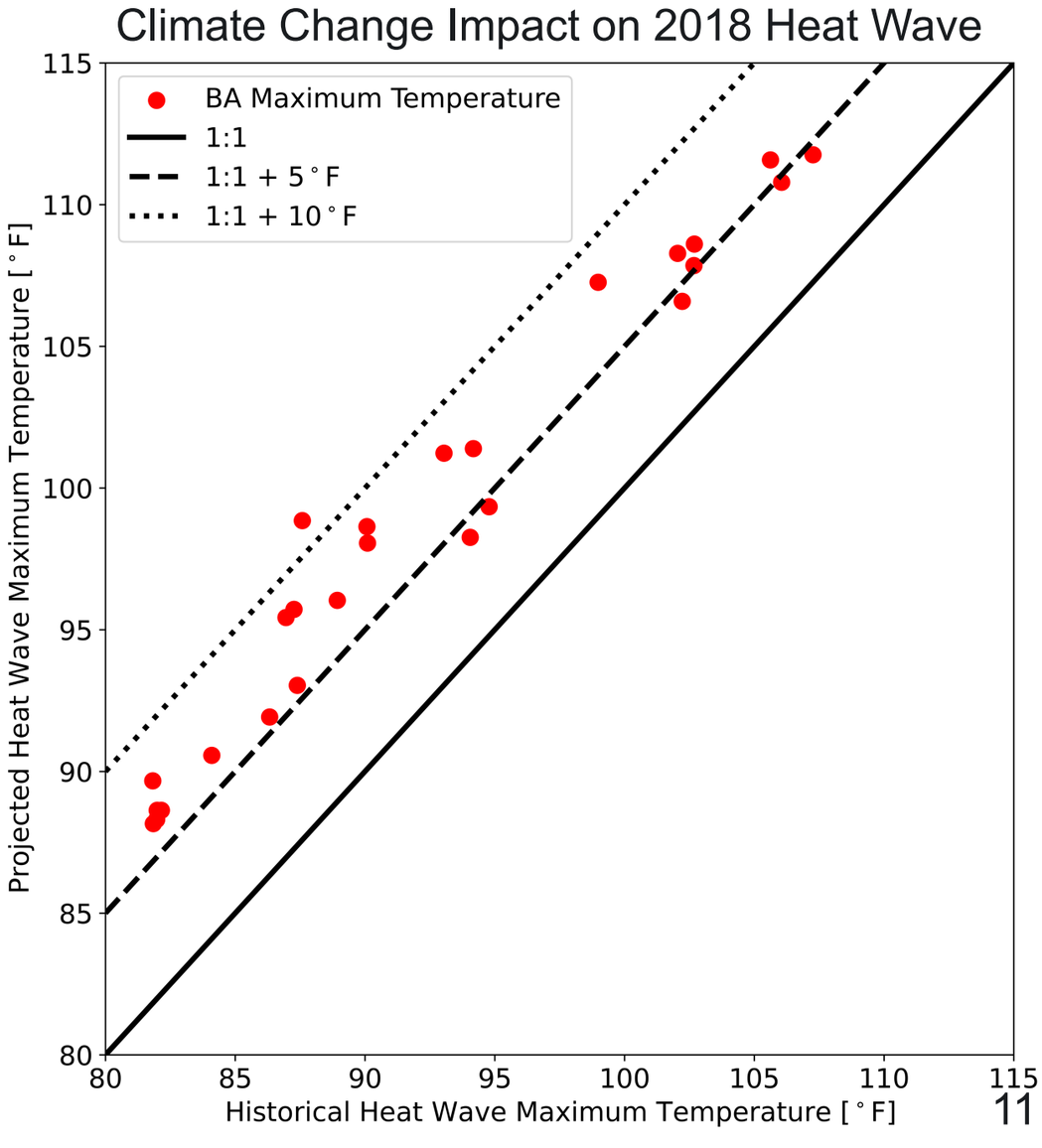


Exploring Future Heat Wave Grid Stress

Pacific Northwest NATIONAL LABORATORY

GODEEEP
Grid Operations, Decarbonization, Environmental and Energy Equity Platform
@PNNL

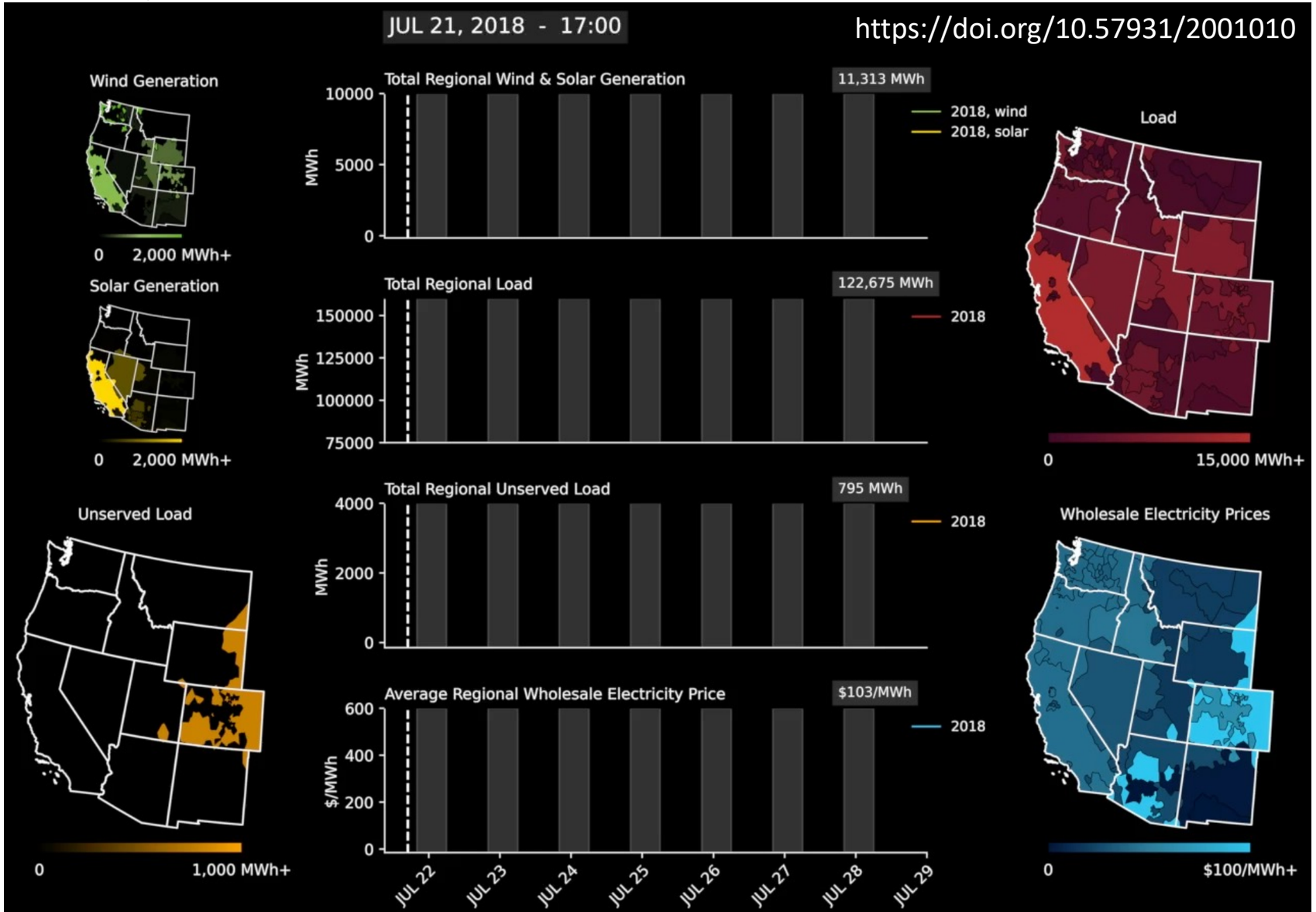




Pacific Northwest NATIONAL LABORATORY

GODEEEP
Grid Operations, Decarbonization, Environmental and Energy Equity Platform
@PNNL

Exploring Future Heat Wave Grid Stress

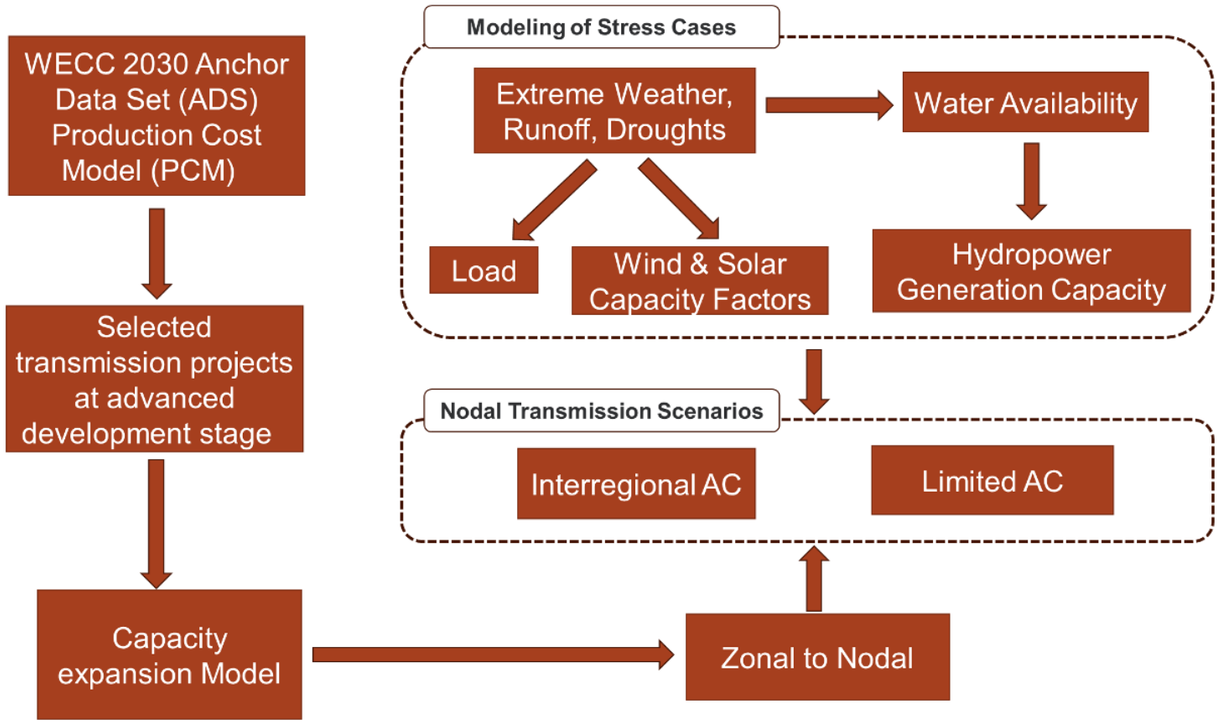


Stress Tests for Understanding Resilience of System Projections

Pacific Northwest NATIONAL LABORATORY

GODEEEP
Grid Operations, Decarbonization, Environmental and Energy Equity Platform
@PNNL

Projects like the National Transmission Planning Study (NTPS) are using the historical and future meteorology to test the resilience of their projected system to extreme weather events.



National Transmission Planning Study: Stress Analysis

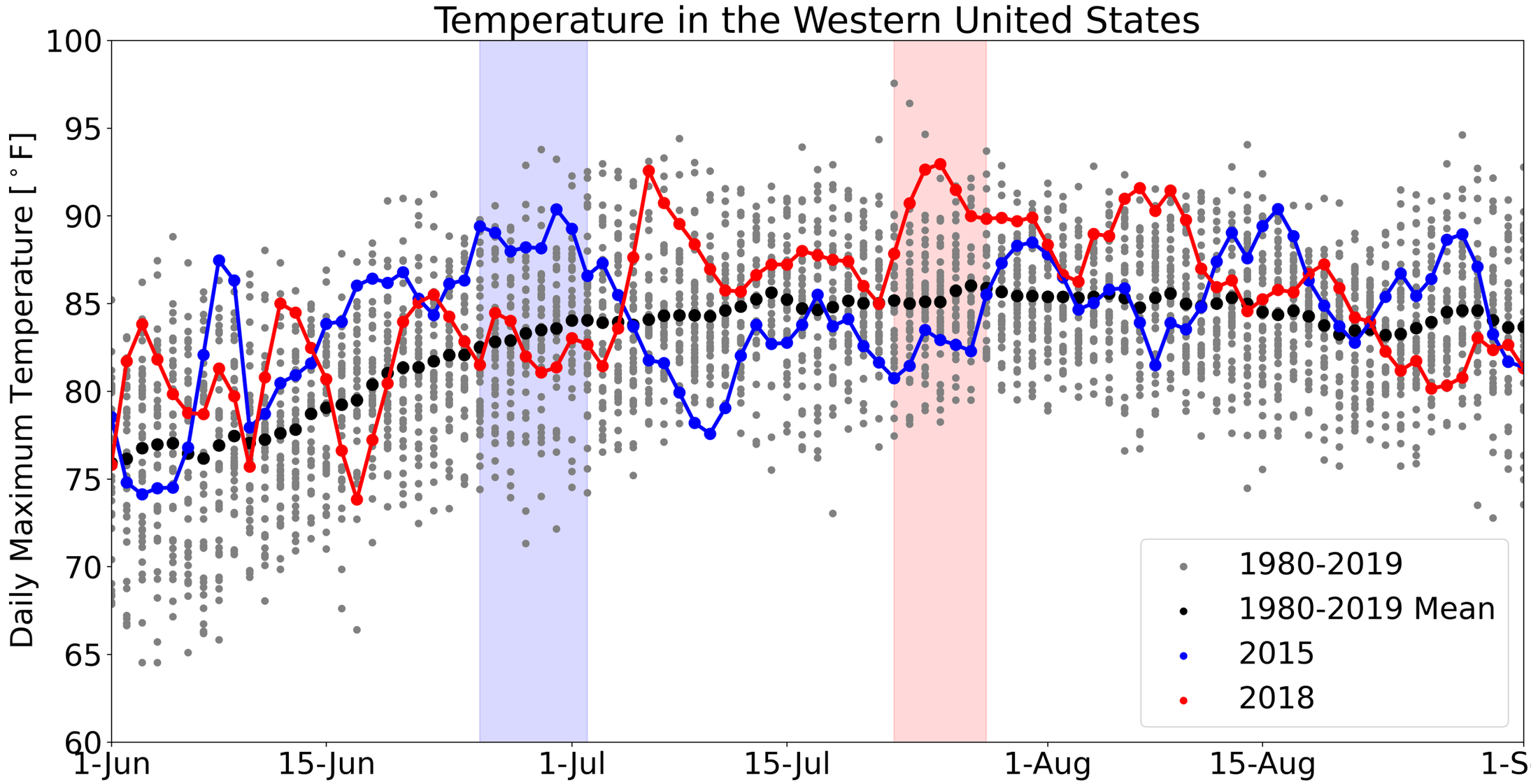
COMING SOON

Konstantinos Oikonomou, Kyle Wilson, Mark Weimar, Abhishek Somani, Casey D. Burleyson, Cameron W. Bracken, Fernando Bereta dos Reis, Nathalie Voisin
Pacific Northwest National Laboratory

B&R Code: TF0000000-05300-3123796
DOE Program Manager: Kelly Kozdras, Adria Brooks

U.S. DEPARTMENT OF ENERGY | Prepared for the U.S. Department of Energy under Contract DE-AC05-76RL01830

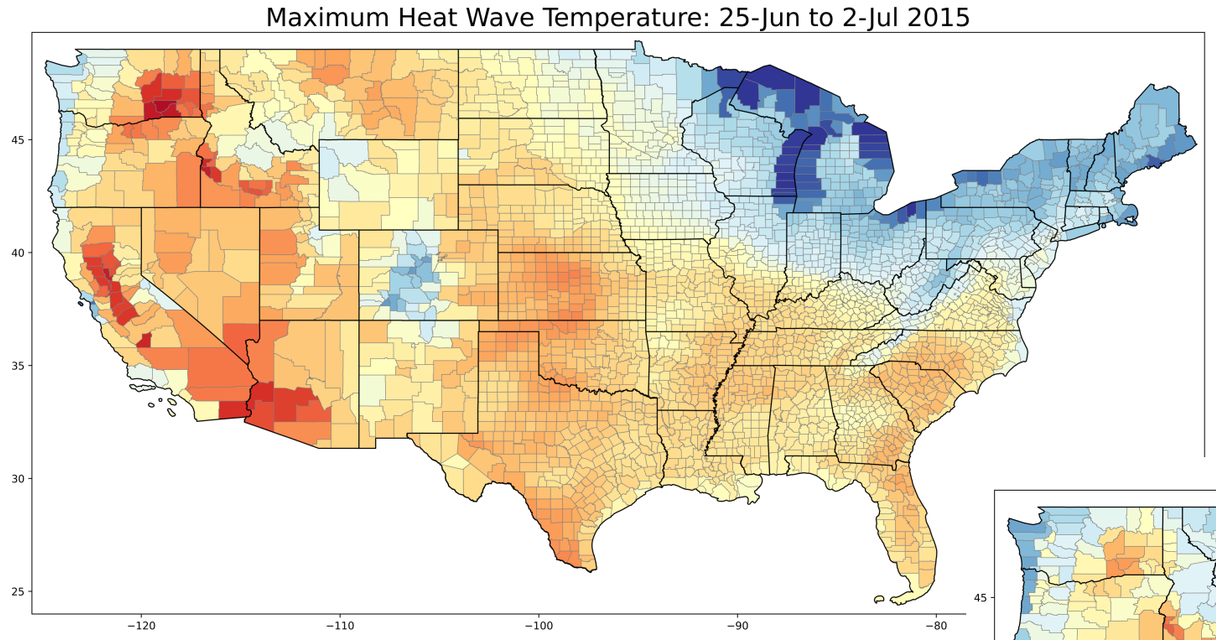
Exploring Resilience Across a Range of Contrasting Events



Exploring Resilience Across a Range of Contrasting Events

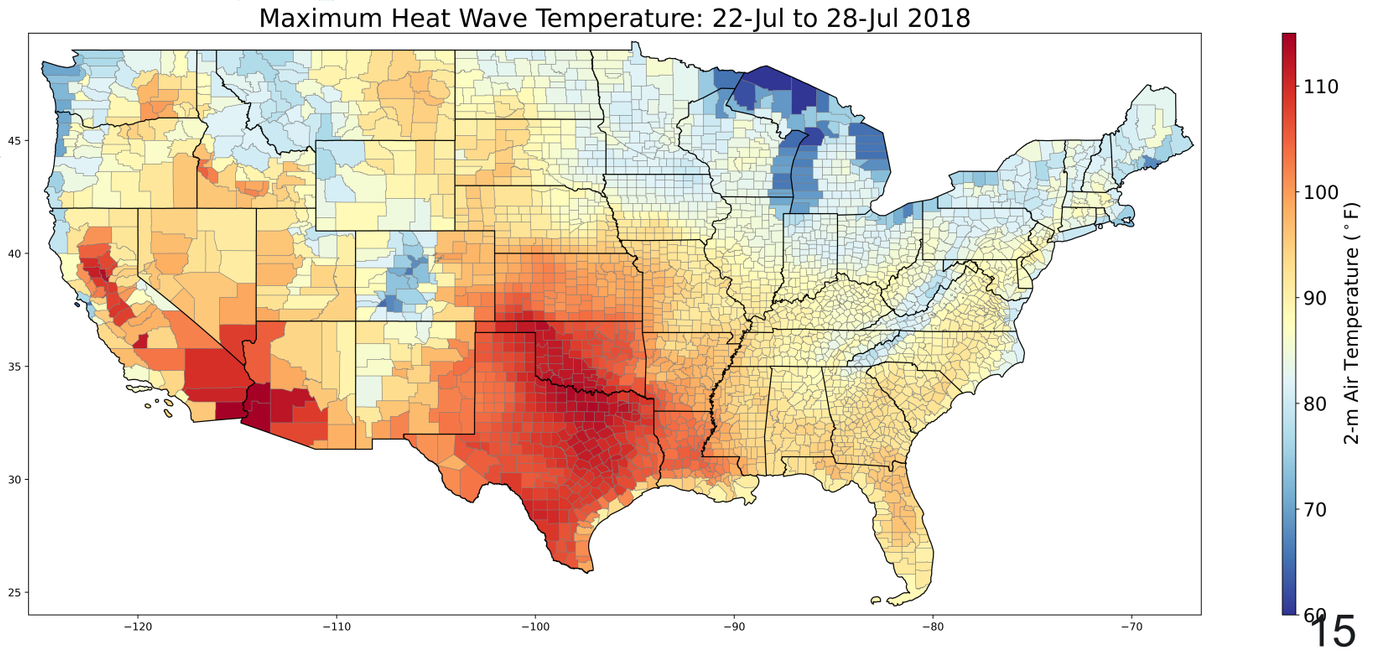
Pacific Northwest NATIONAL LABORATORY

GODEEEP
Grid Operations, Decarbonization, Environmental and Energy Equity Platform
@PNNL

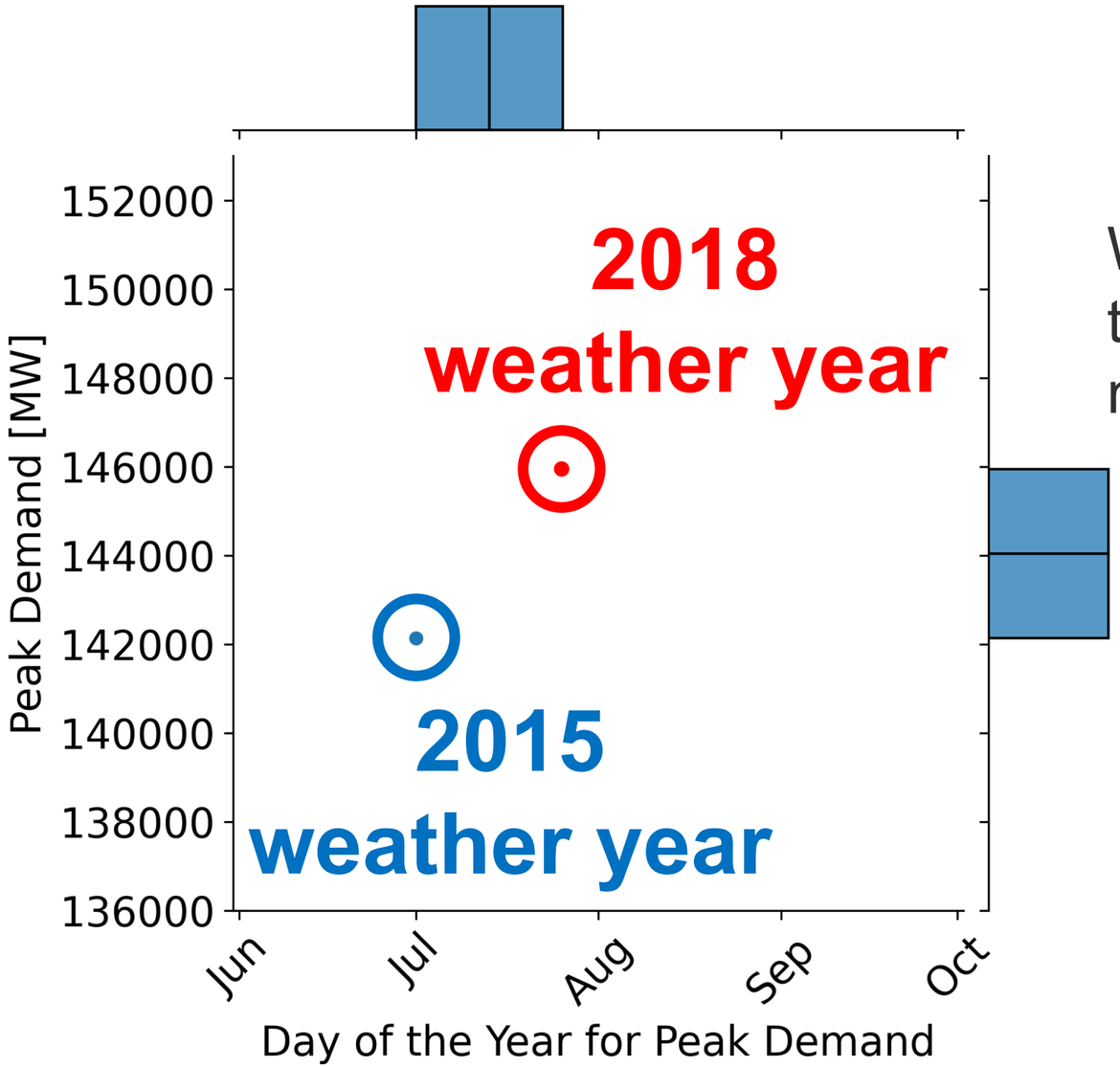


2015 heat wave event used in NTPS was WECC-wide

2018 event was more concentrated in California and the desert southwest



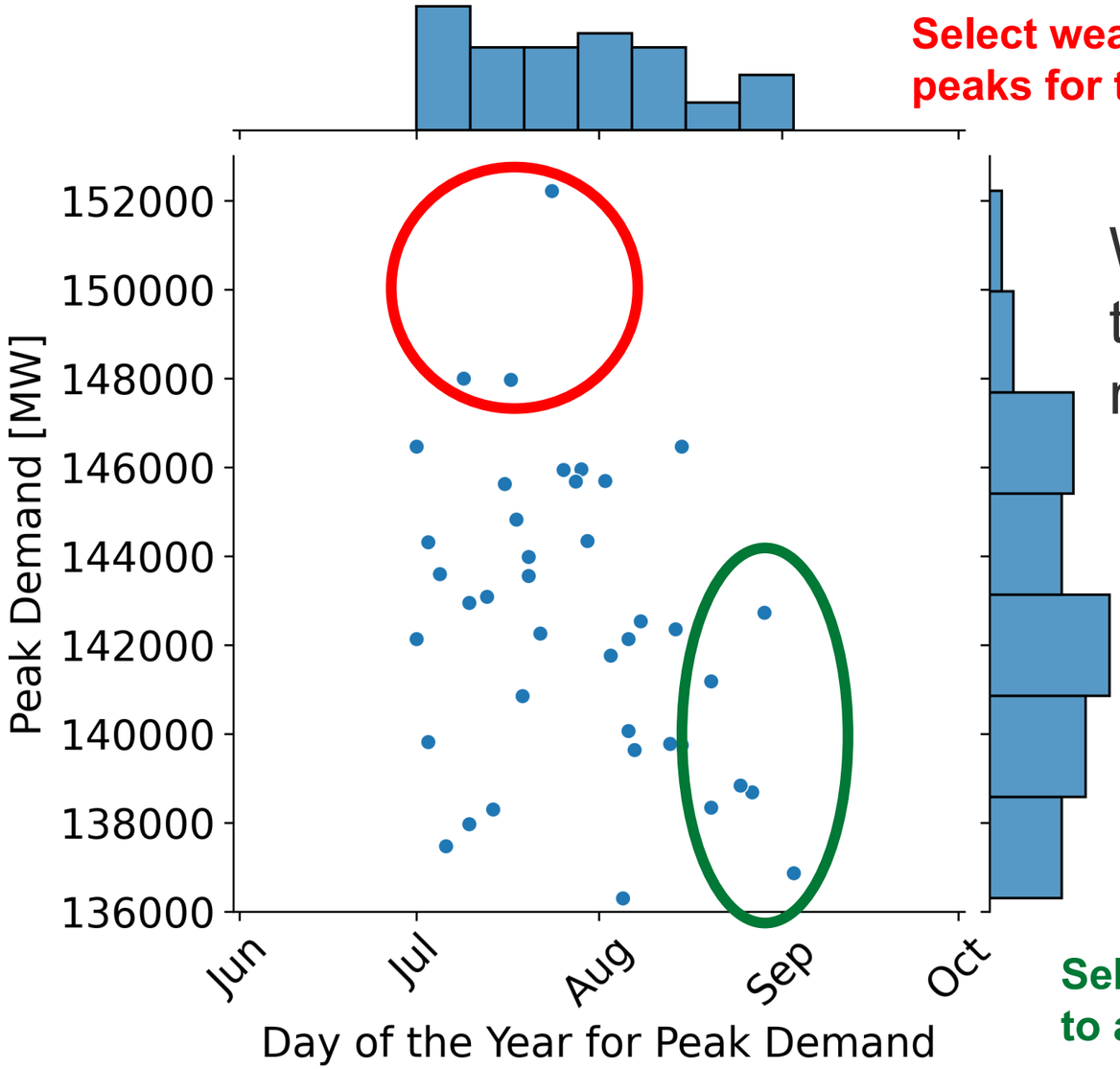
Simulating Multiple Weather Years to Explore Uncertainty



We can run many unique weather years through PNNL's wind, load, and solar models:

- All years have the same total annual energy consumption by design
- Absolute magnitude and timing of peak demand varies significantly depending on the weather each year

Simulating Multiple Weather Years to Explore Uncertainty



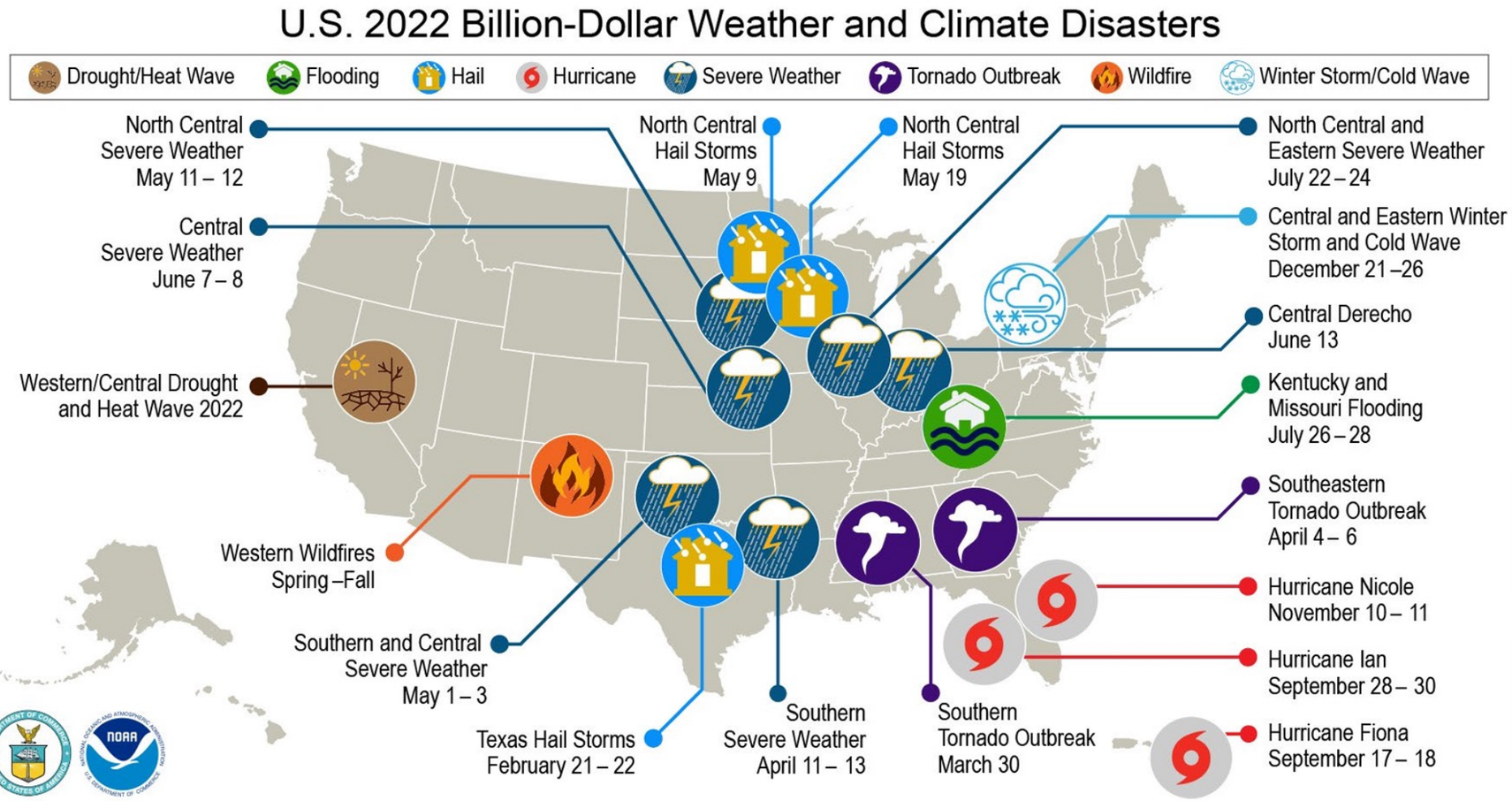
Select weather years with extreme peaks for testing resilience…

We can run many unique weather years through PNNL's wind, load, and solar models:

- All years have the same total annual energy consumption by design
- Absolute magnitude and timing of peak demand varies significantly depending on the weather each year

Select weather years with late season peaks to assess reliability with low hydro…

Isolated, Compounding, and Sequential Extreme Events



*This map denotes the approximate location for each of the **18 separate billion-dollar weather and climate disasters that impacted the United States in 2022.***

Bissolli, P., C. Ganter, A. Mekonnen, A. Sánchez-Lugo, and Z. Zhu, Eds., 2023: Regional Climates [in "State of the Climate in 2022"]. Bull. Amer. Meteor. Soc., 104 (9), S366–S473, https://doi.org/10.1175/2023BAMSStateoftheClimate_Chapter7.1.

The unprecedented Pacific Northwest heatwave of June 2021

Rachel H. White, Sam Anderson, James F. Booth, Ginni Braich, Christina Draeger, Cuiyi Fei, Christopher D. G. Harley, Sarah B. Henderson, Matthias Jakob, Carie-Ann Lau, Lualawi Mareshet Admasu, Veeshan Narinesingh, Christopher Rodell, Eliott Roocroft, Kate R. Weinberger & Greg West

Nature Communications **14**, Article number: 727 (2023) | Cite this article

ENVIRONMENTAL RESEARCH
LETTERS

LETTER

How unprecedented was the February 2021 Texas cold snap?

James Doss-Gollin, David J Farnham, Upmanu Lall and Vijay Modi

Past and Projected Future Droughts in the Upper Colorado River Basin

Gregory J. McCabe, David M. Wolock, Subhrendu Gangopadhyay

First published: 29 February 2024 | https://doi.org/10.1029/2023GL107978

The potential impact of climate change on European renewable energy droughts

Jacek Kapica, Jakub Jurasz, Fausto A. Canales, Hannah Bloomfield, Mohammed Guezgouz, Matteo De Felice, Zbigniew Kobus

Future regional increases in simultaneous large Western USA wildfires

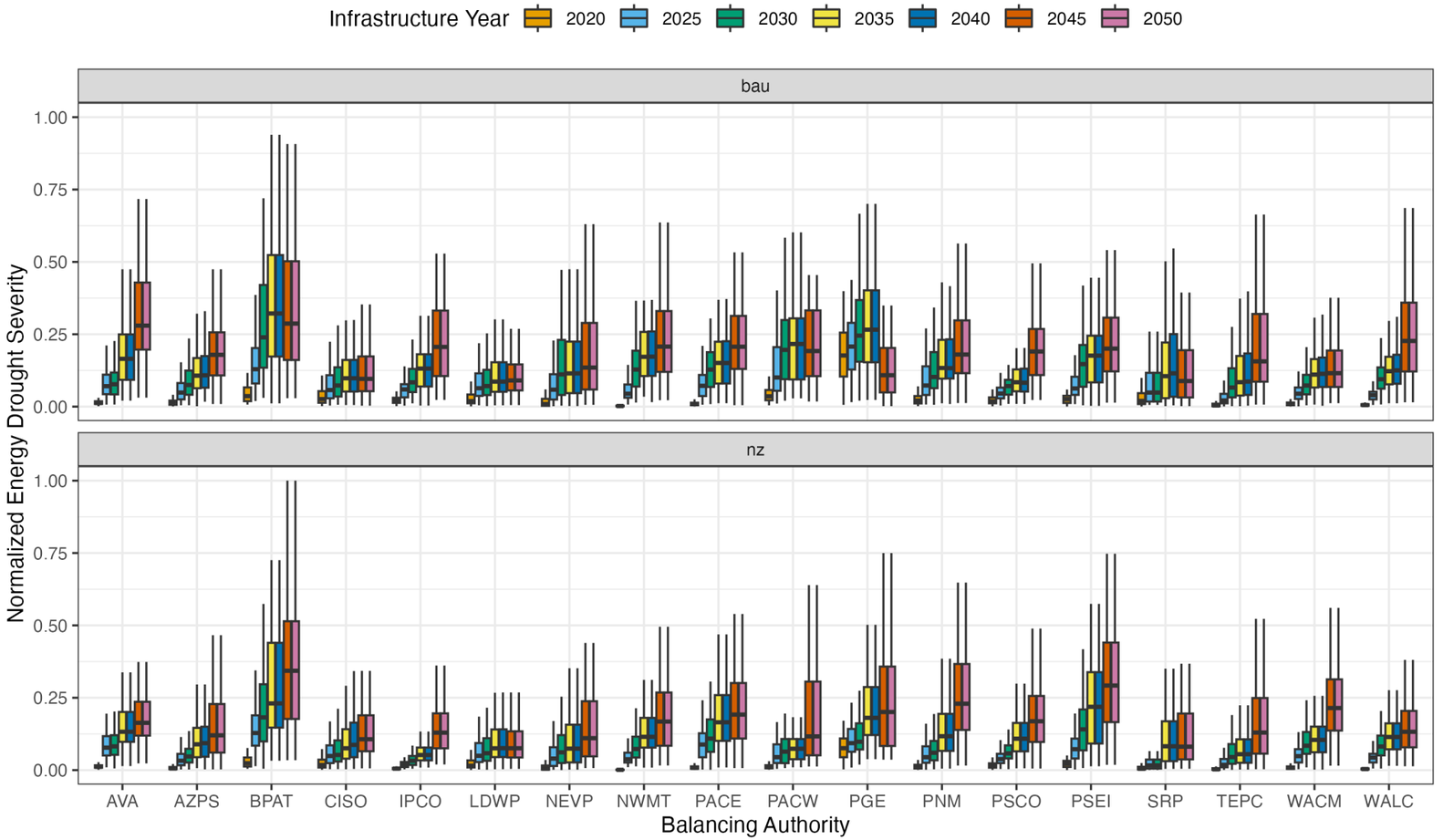
Seth McGinnis, Lee Kessenich, Linda Mearns, Alison Cullen, Harry Podschwit and Melissa Bukovsky

Coincident Datasets Help Identify Periods of Potential Stress

- Energy droughts are periods of simultaneously suppressed wind and solar potential.
- Characterizing energy droughts helps to understand storage and regional transmission needs.

Bracken, C. W., et al., 2023: Standardized benchmark of historical compound wind and solar energy droughts across the continental United States. Renewable Energy, 220, doi:10.1016/j.renene.2023.119550.

Energy Droughts Matter More in a Decarbonized System



- The relative severity of energy droughts is expected to increase due to increased capacity of renewables.
- The amount of increase depends on the potential for buildout within a particular BA.

Bracken, C. W., et al., 2024: Future energy droughts. In preparation for *Renewable Energy*.

Continuum of Stress Testing Approaches

Good

Better

Best

- Testing using historical load-wind-solar-hydro data for a limited number of specific historical events
- Testing using data for a wide range of historical events
- Testing using data based on forcing from a single climate dataset
- Testing using data based on forcing from multiple climate datasets

Continuum of Stress Testing Approaches

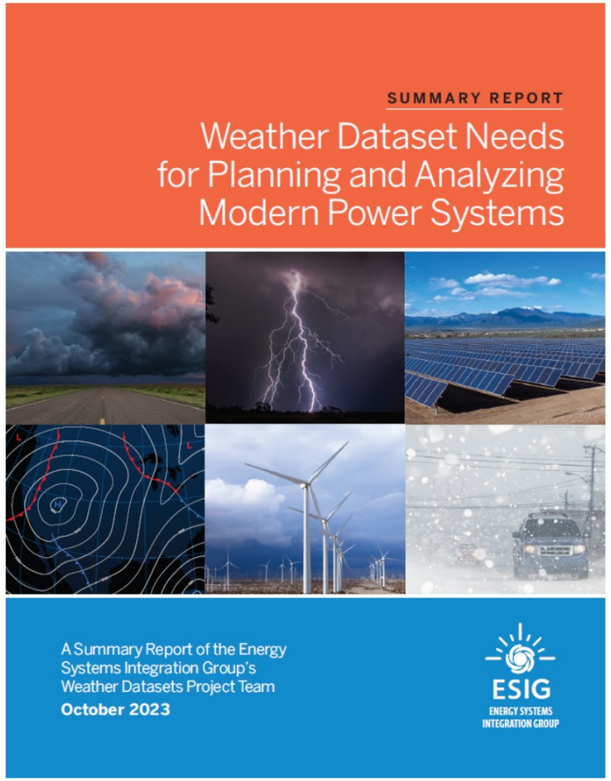
Pacific Northwest NATIONAL LABORATORY

GODEEEP
Grid Operations, Decarbonization, Environmental and Energy Equity Platform
@PNNL

Good

Better

Best



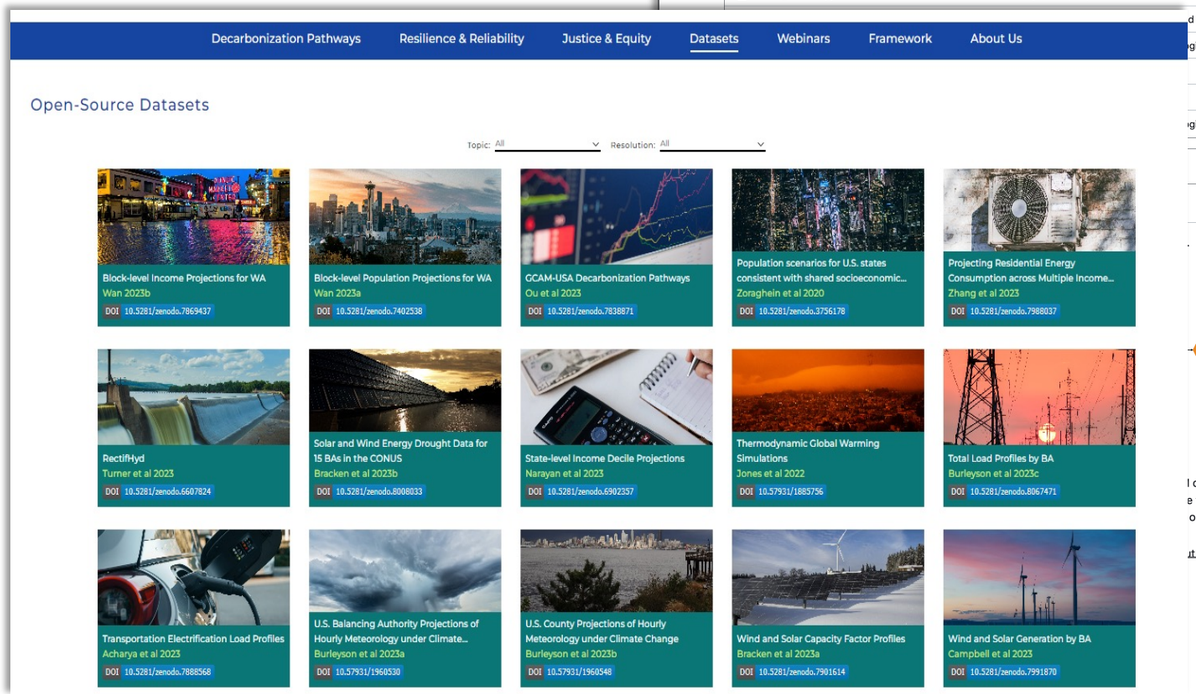
The Main Attributes of Time Series Data Necessary to Meet General Power System Modeling Needs

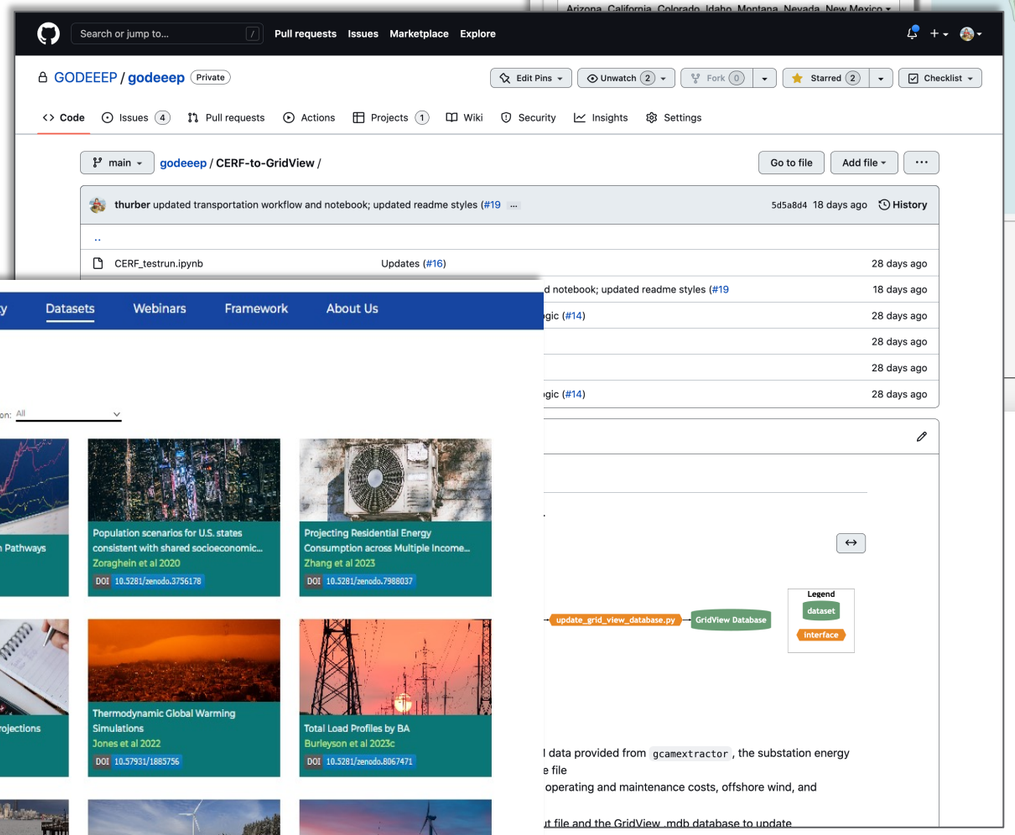
Including the necessary variables	Include the necessary variables at sufficient spatio-temporal resolution and accuracy to reflect actual conditions that define the generation potential at current and future wind/solar sites and temperature at load centers
Covering multiple decades with ongoing extension	Cover multiple decades with consistent methodology and be extended on an ongoing basis to capture the most recent conditions and allow climate trends to be identified
Coincident and physically consistent	Are coincident and physically consistent, in space and time, across weather variables
Validated	Are validated against real conditions with uncertainty quantified
Documented	Are documented transparently and in detail, including limitations and a guide for usage
Periodically refreshed	Are periodically refreshed to account for scientific and technological advancements
Available and accessible	Publicly available, expertly curated, and easily accessible

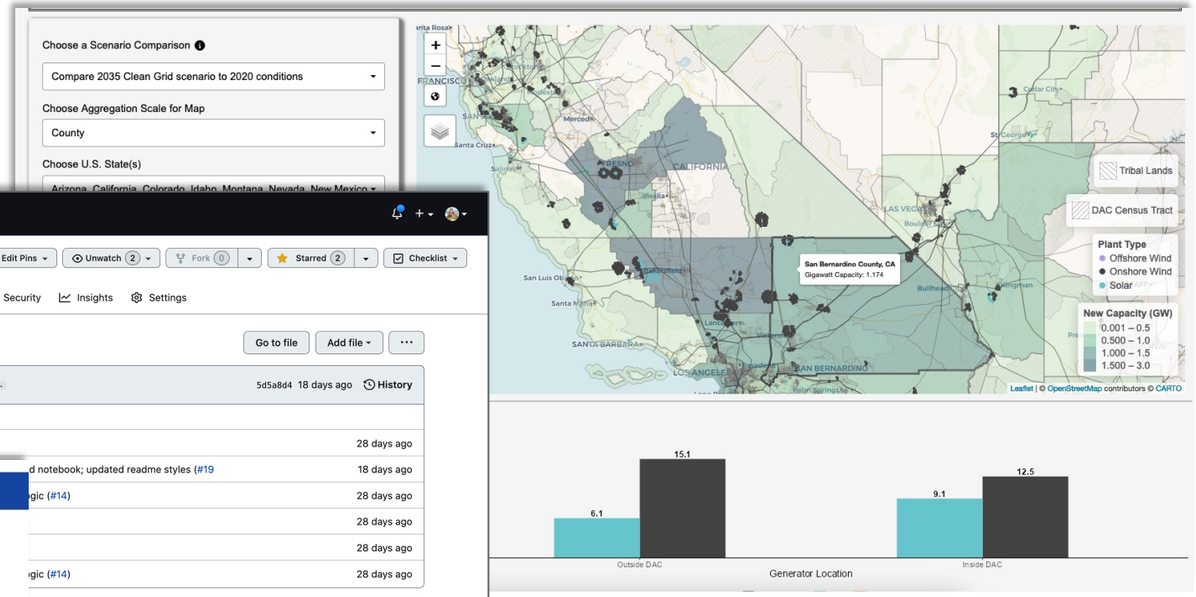
- Testing using data based on forcing from multiple climate datasets

Sharing Data and Models

Open-source, vetted datasets are available in multiple formats in support of targeted questions by industry.







godeeep.pnnl.gov

Key Messages and Results

- To assess the resilience and reliability of the bulk power system, it is critical to evaluate system performance with coincident load-wind-solar-hydro conditions and across a wide range of historical and projected weather conditions.
- The conditions that stressed your system in the past may not be the ones that stress your system in the future. It is important to consider isolated, compounding, and sequential extreme events.
- PNNL Innovations:
  - Open source spatially- and temporally-coincident load, wind, and solar data
  - Capture consistent and realistic impacts on electricity supply and demand for use in stress testing projected infrastructure
  - Quantitative characterization of wind and solar droughts
- Contact: https://godeeep.pnnl.gov and casey.burleyson@pnnl.gov