



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

Forward Looking Extreme Weather Datasets

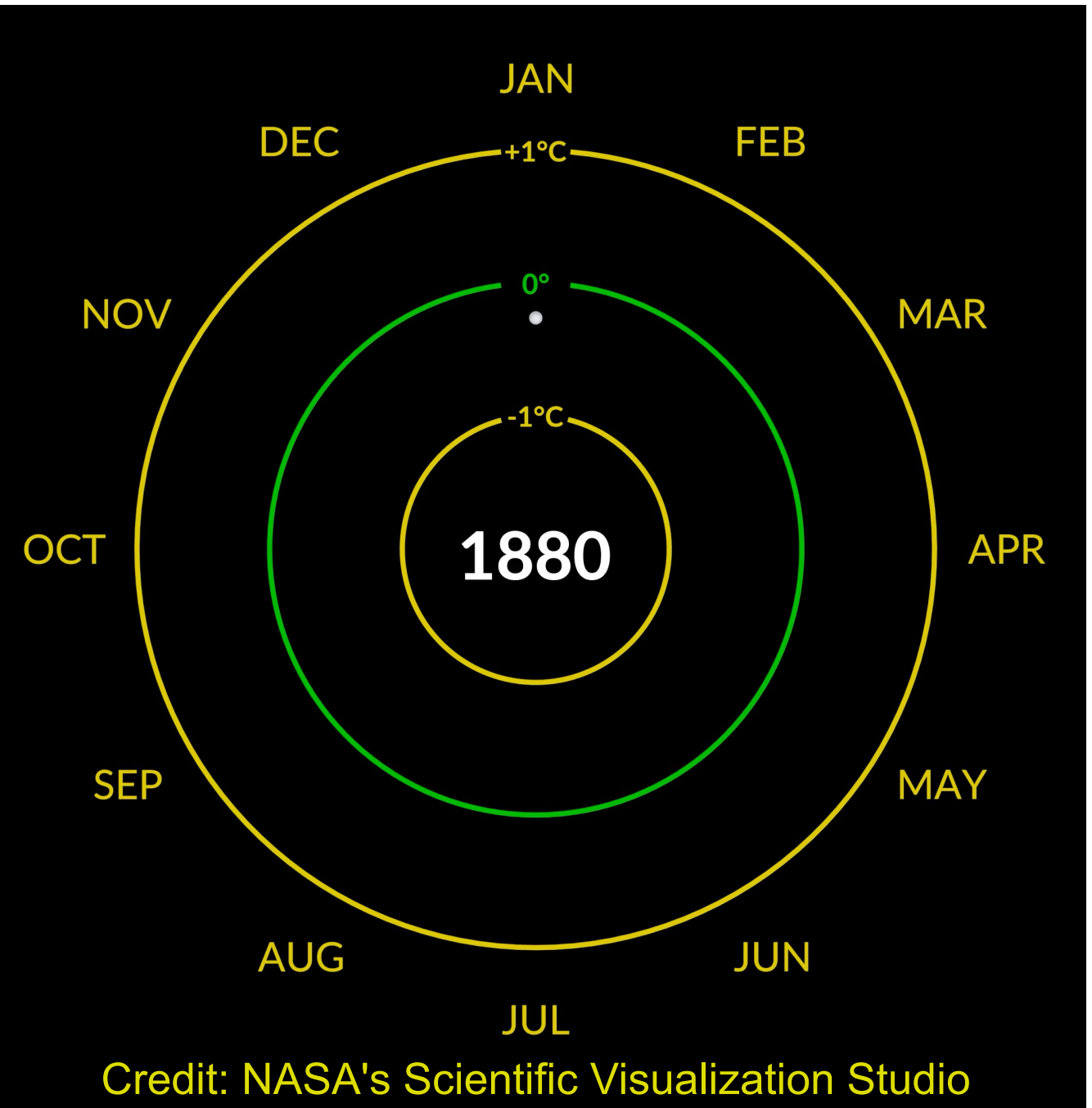
Casey Burleyson, Cameron
Bracken, Kostas Oikonomou, and
Nathalie Voisin



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



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.



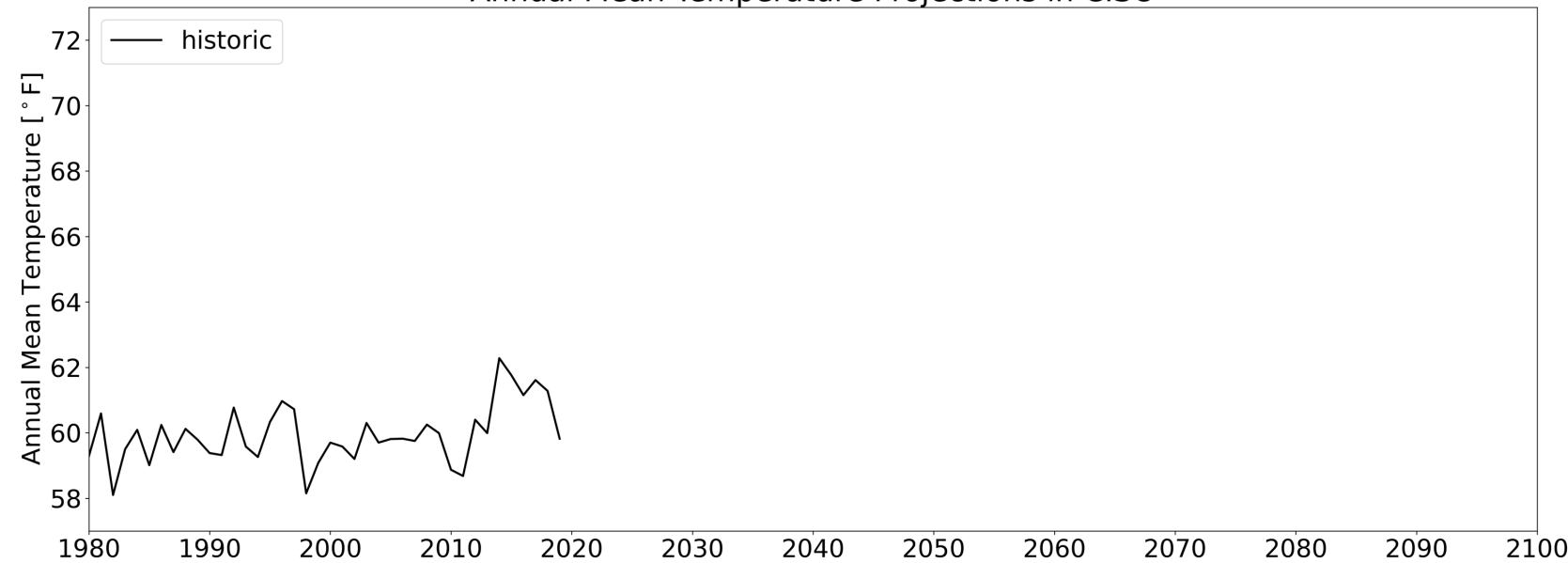
Key Messages

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

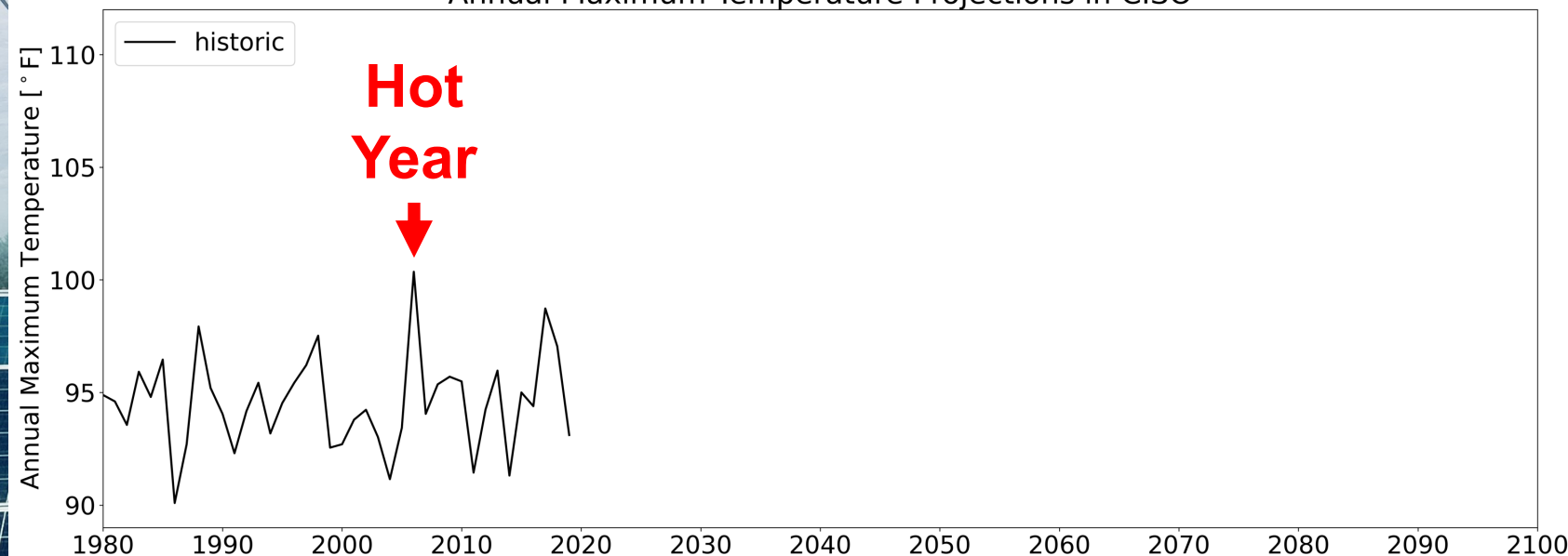
1. With coincident load-wind-solar-hydro conditions;
2. Across a wide range of historical and projected weather conditions.

U.S. Climate Projection Dataset

Annual Mean Temperature Projections in CISO



Annual Maximum Temperature Projections in CISO

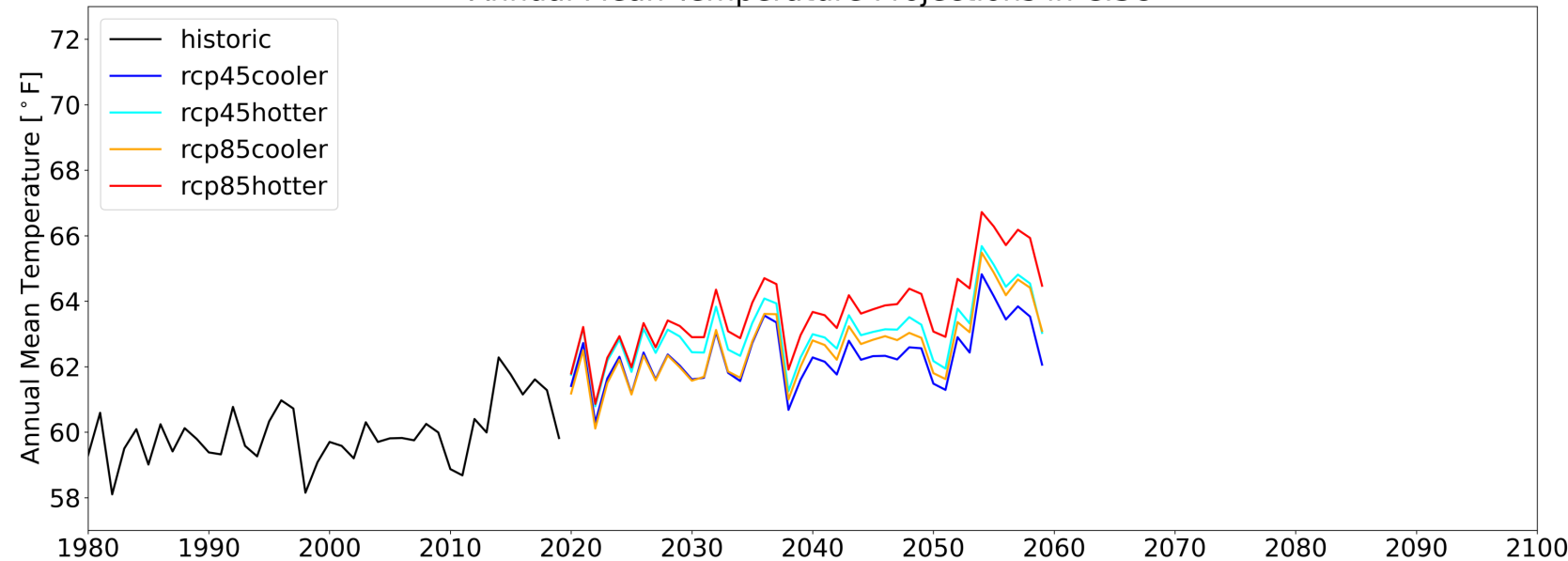


- Historic data reproduces observed sequence of past events (1980–2019)
- Sequence is repeated twice in the future (2020–2059 and 2060–2099) with additional warming gradually applied
- 1/8 deg (~12 km) resolution, U.S., hourly
- 25 hourly and 250+ three-hourly variables
- Output is first spatially-averaged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

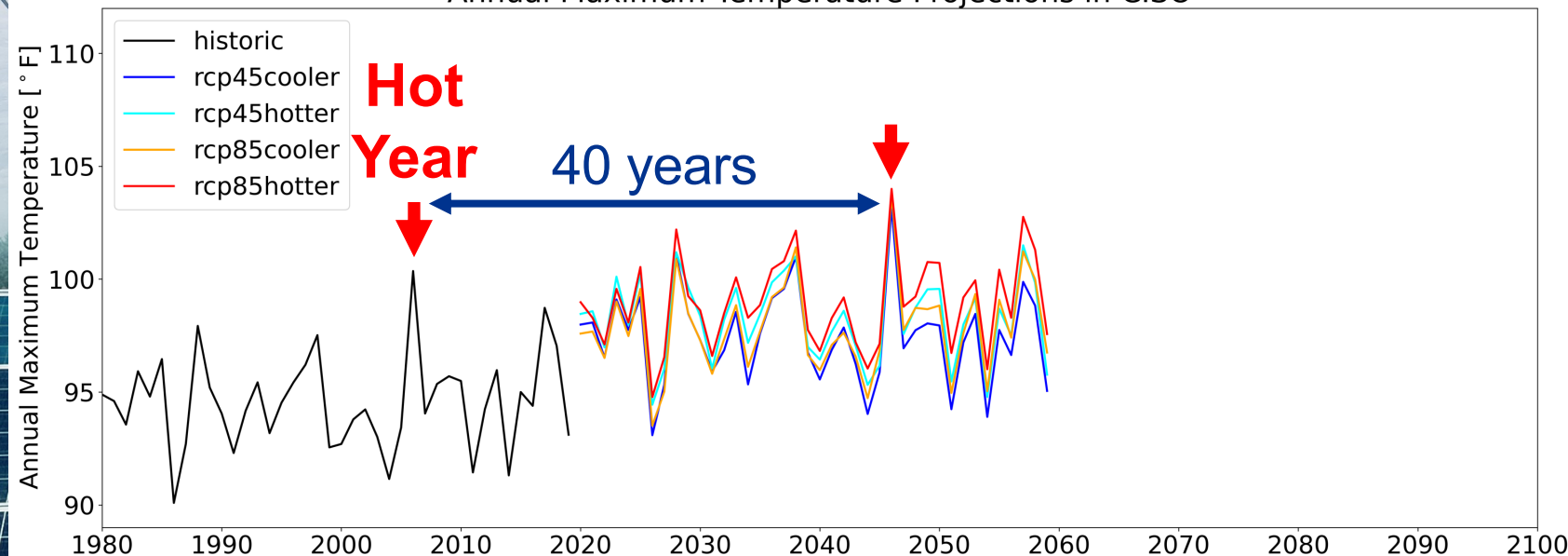
Climate data was developed with DOE Sc funding and is publicly available:
<https://data.msdlive.org/records/cnsy6-0y610>

U.S. Climate Projection Dataset

Annual Mean Temperature Projections in CISO



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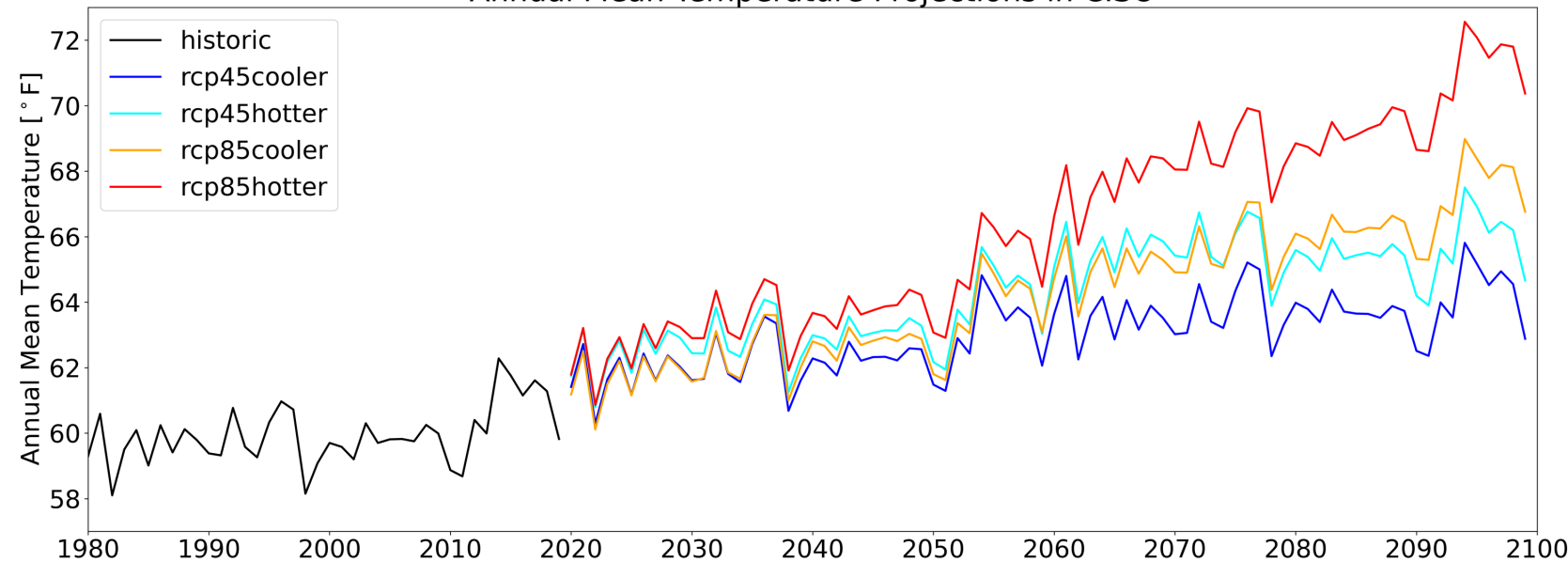


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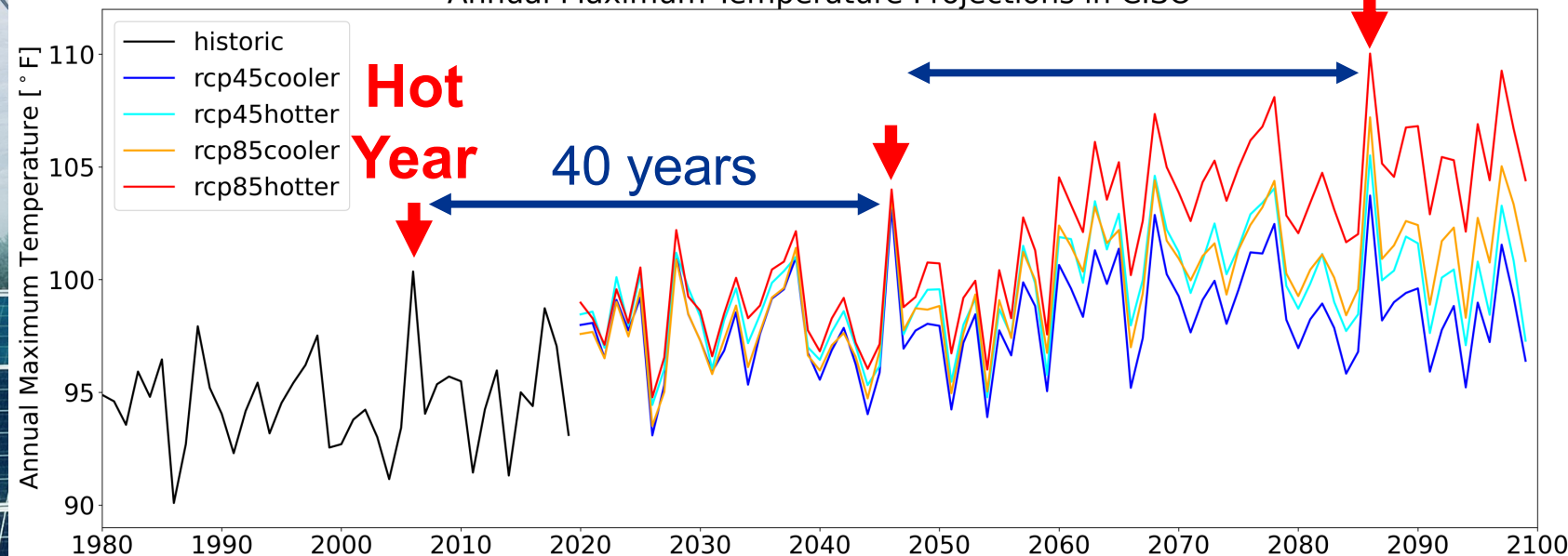
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U.S. Climate Projection Dataset

Annual Mean Temperature Projections in CISO



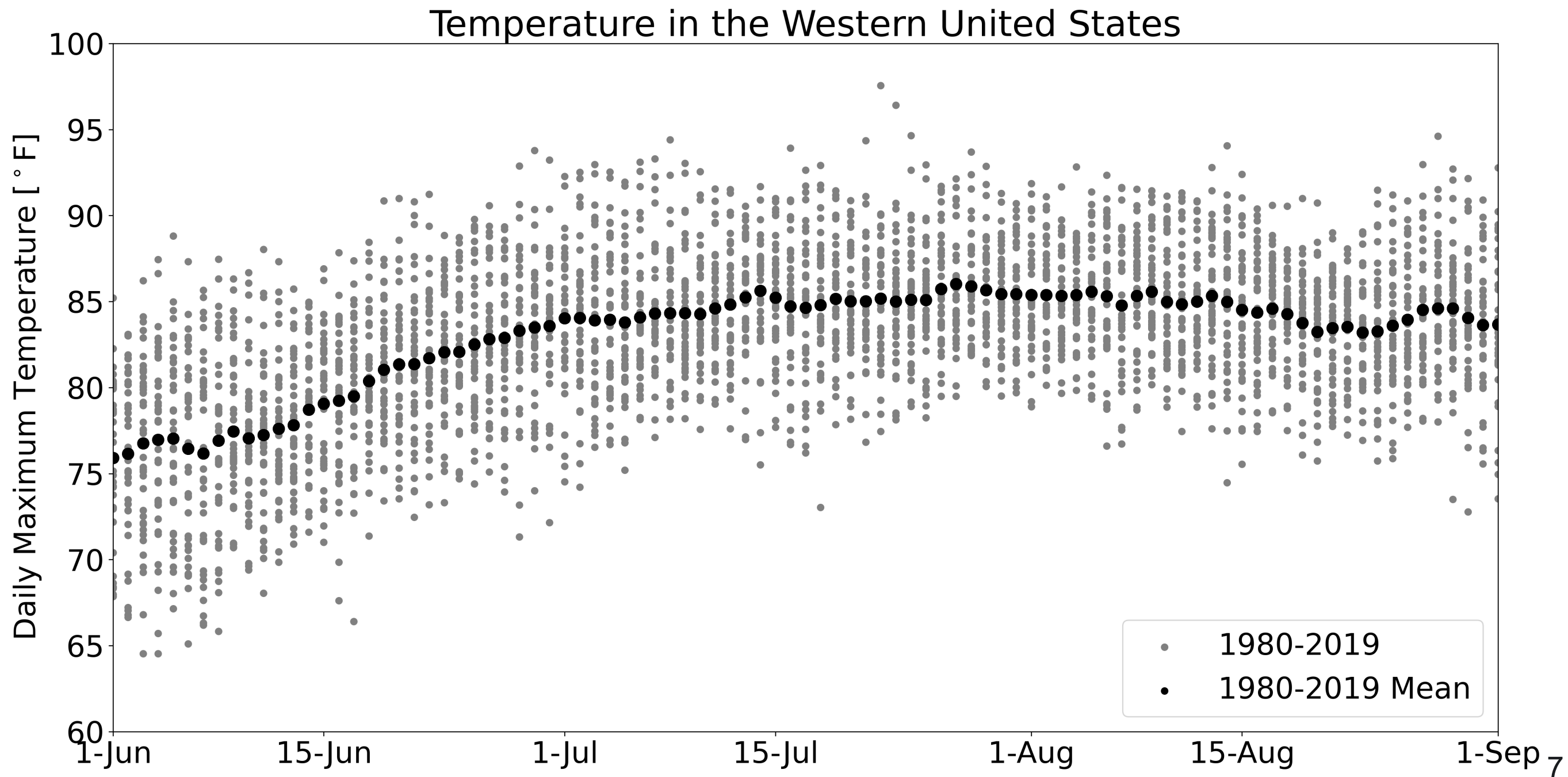
Annual Maximum Temperature Projections in CISO



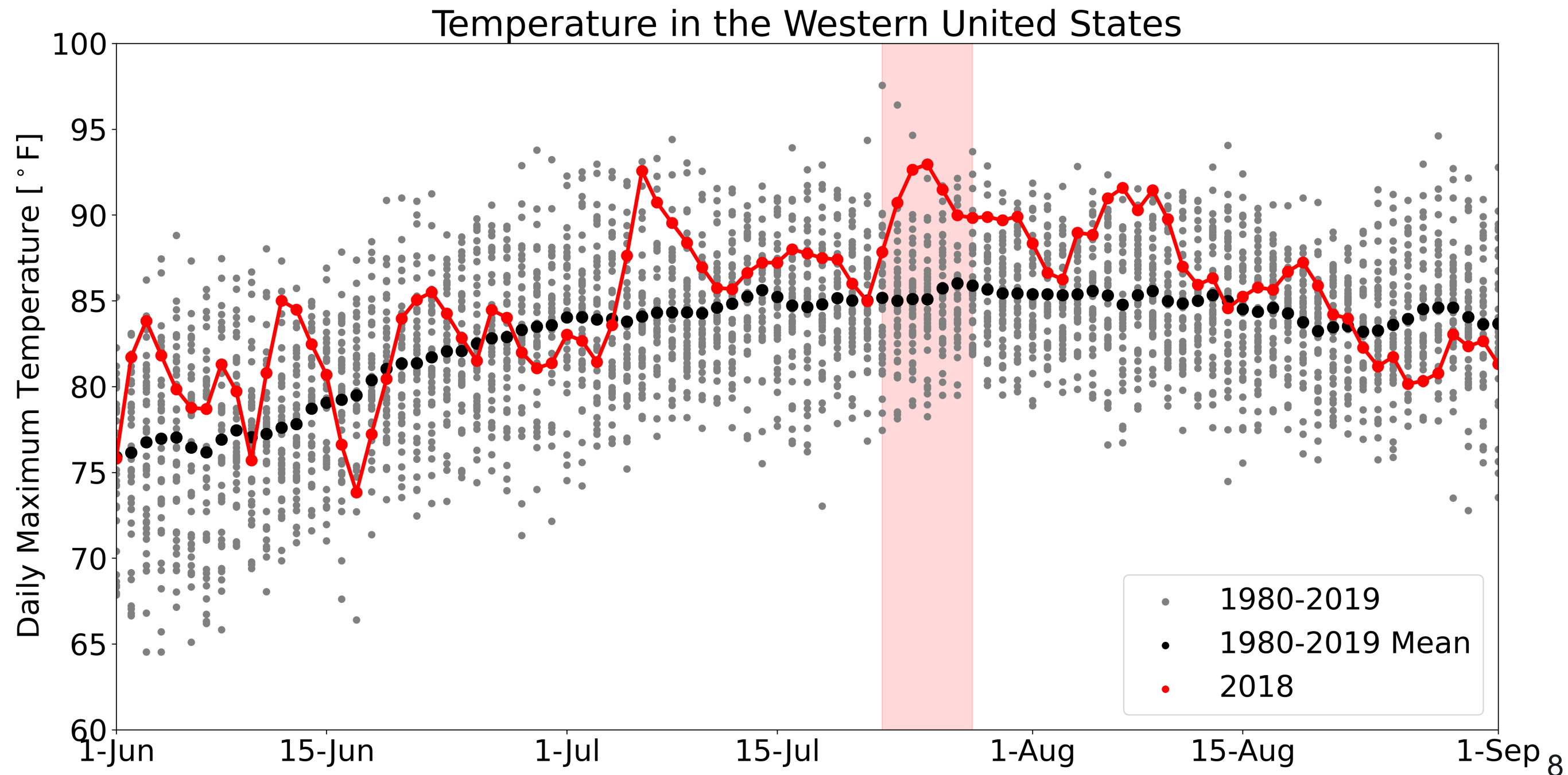
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Finding Heat Wave Events

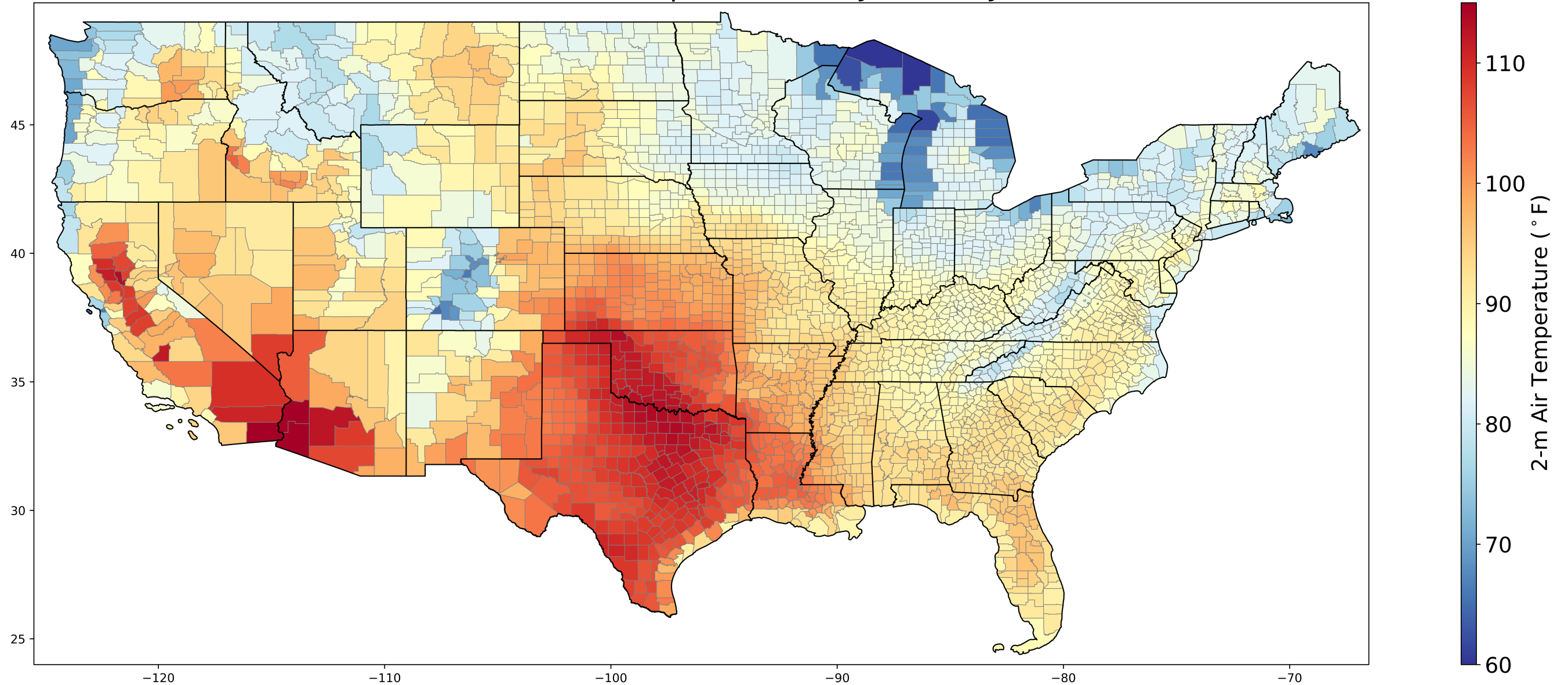


Finding Heat Wave Events



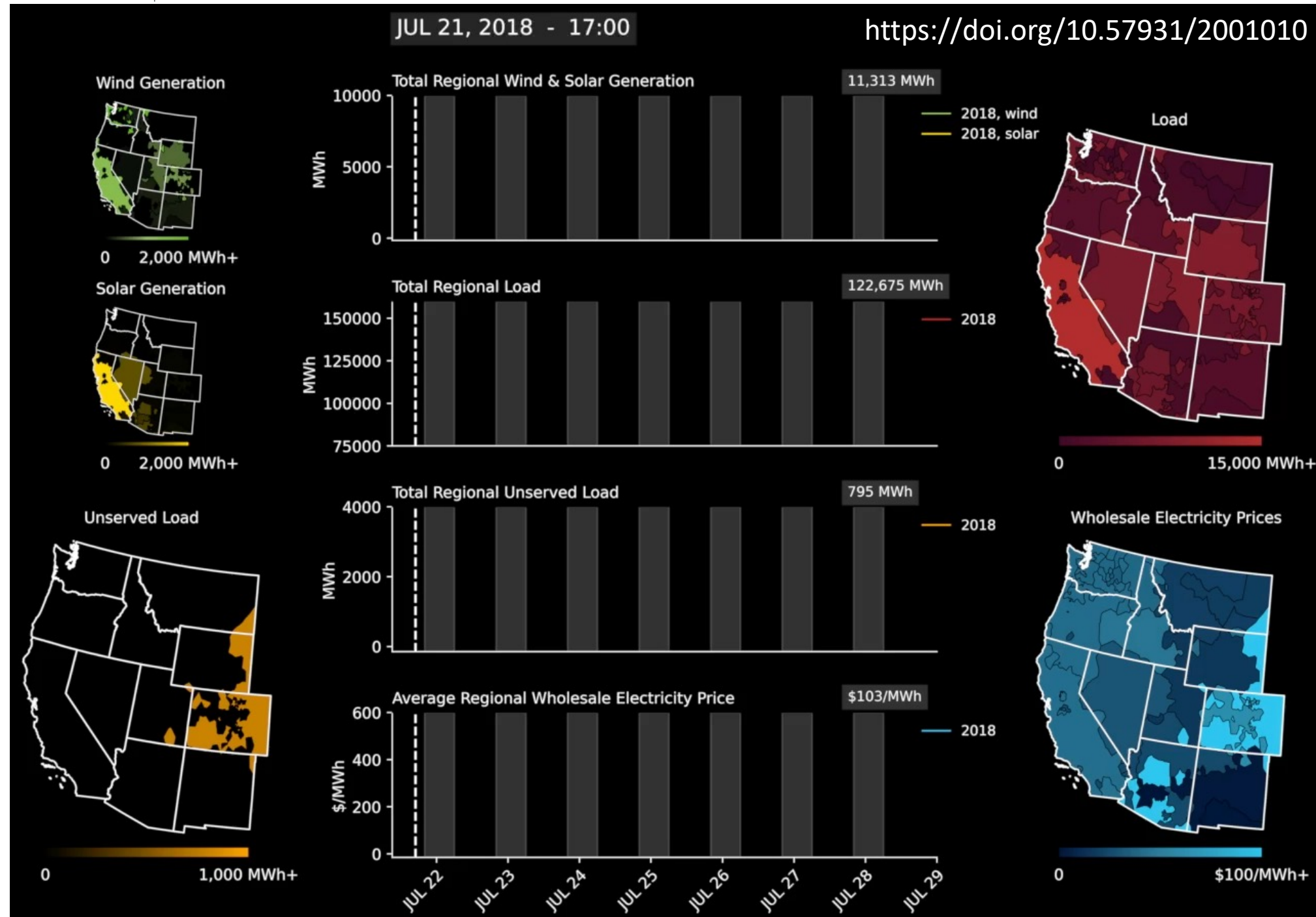
Finding Heat Wave Events

Maximum Heat Wave Temperature: 22-Jul to 28-Jul 2018



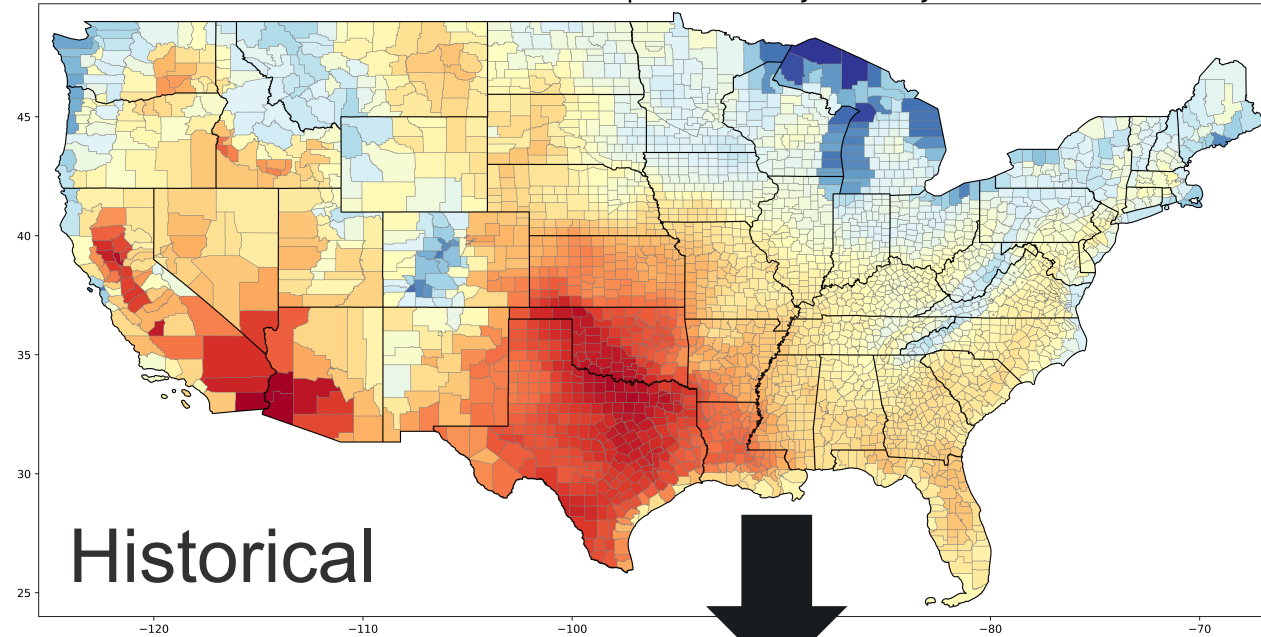


Exploring Historical Heat Wave Grid Stress

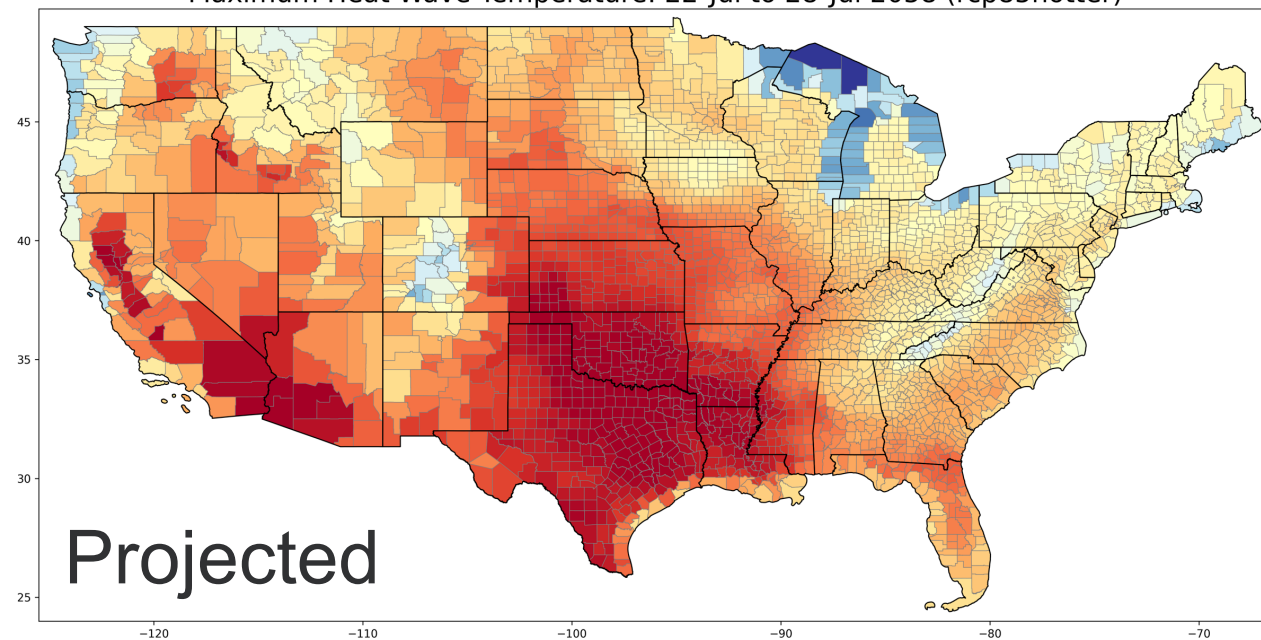


Exploring Future Heat Wave Grid Stress

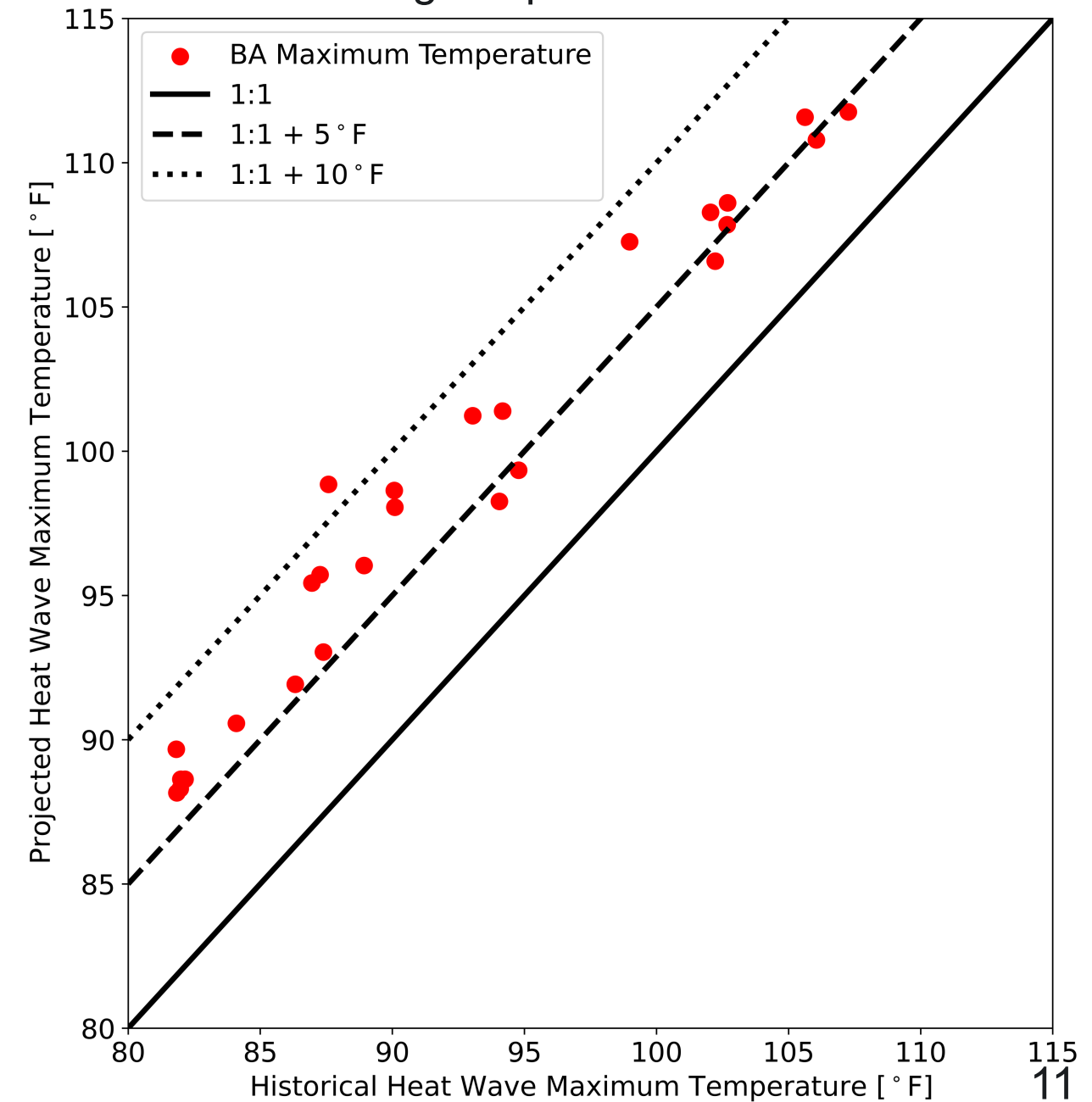
Maximum Heat Wave Temperature: 22-Jul to 28-Jul 2018



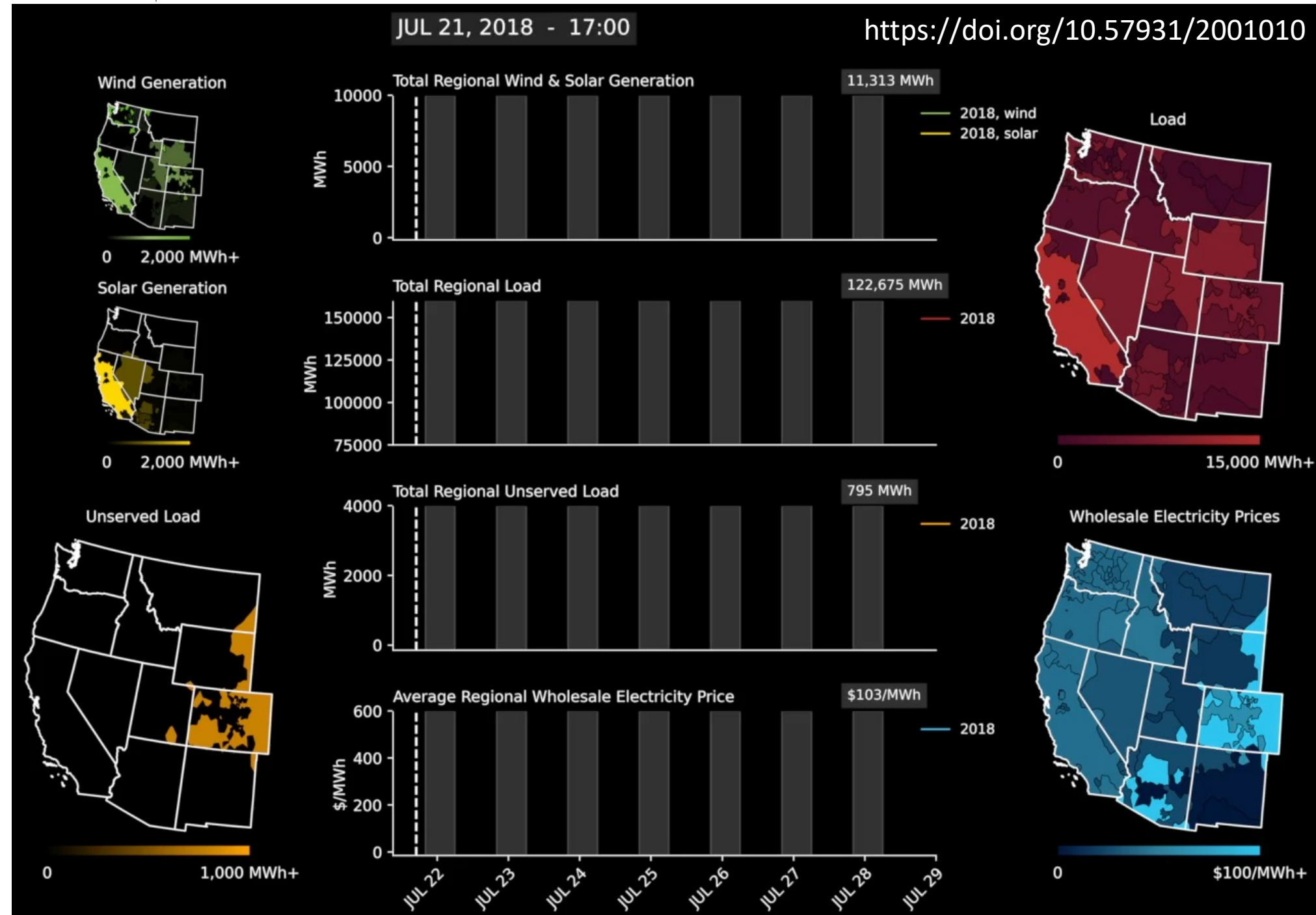
Maximum Heat Wave Temperature: 22-Jul to 28-Jul 2058 (rcp85hotter)



Climate Change Impact on 2018 Heat Wave

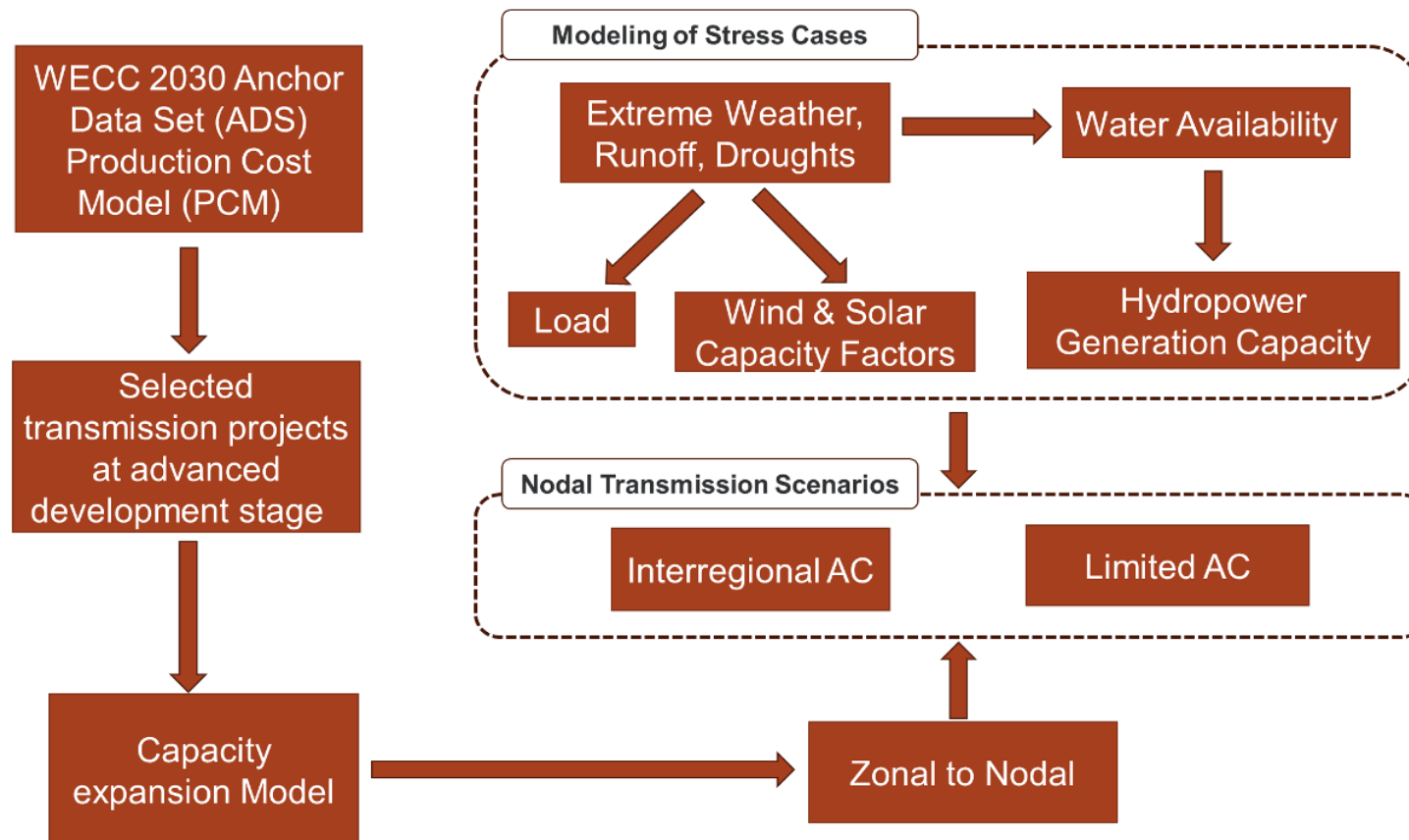


Exploring Future Heat Wave Grid Stress



Stress Tests for Understanding Resilience of System Projections

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

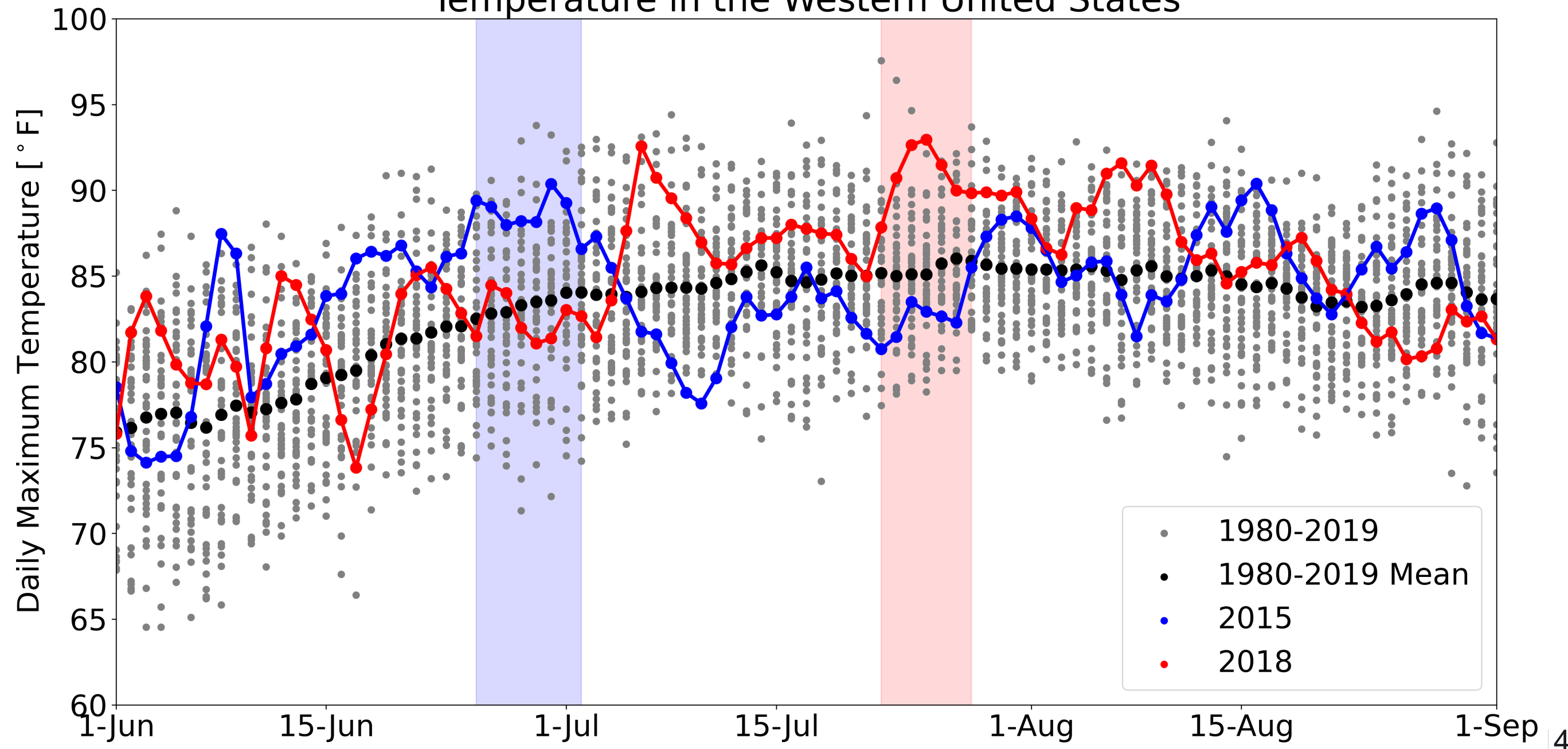
COMING SOON

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: TF00000000-05300-3123796
DOE Program Manager: Kelly Kozdras, Adria Brooks

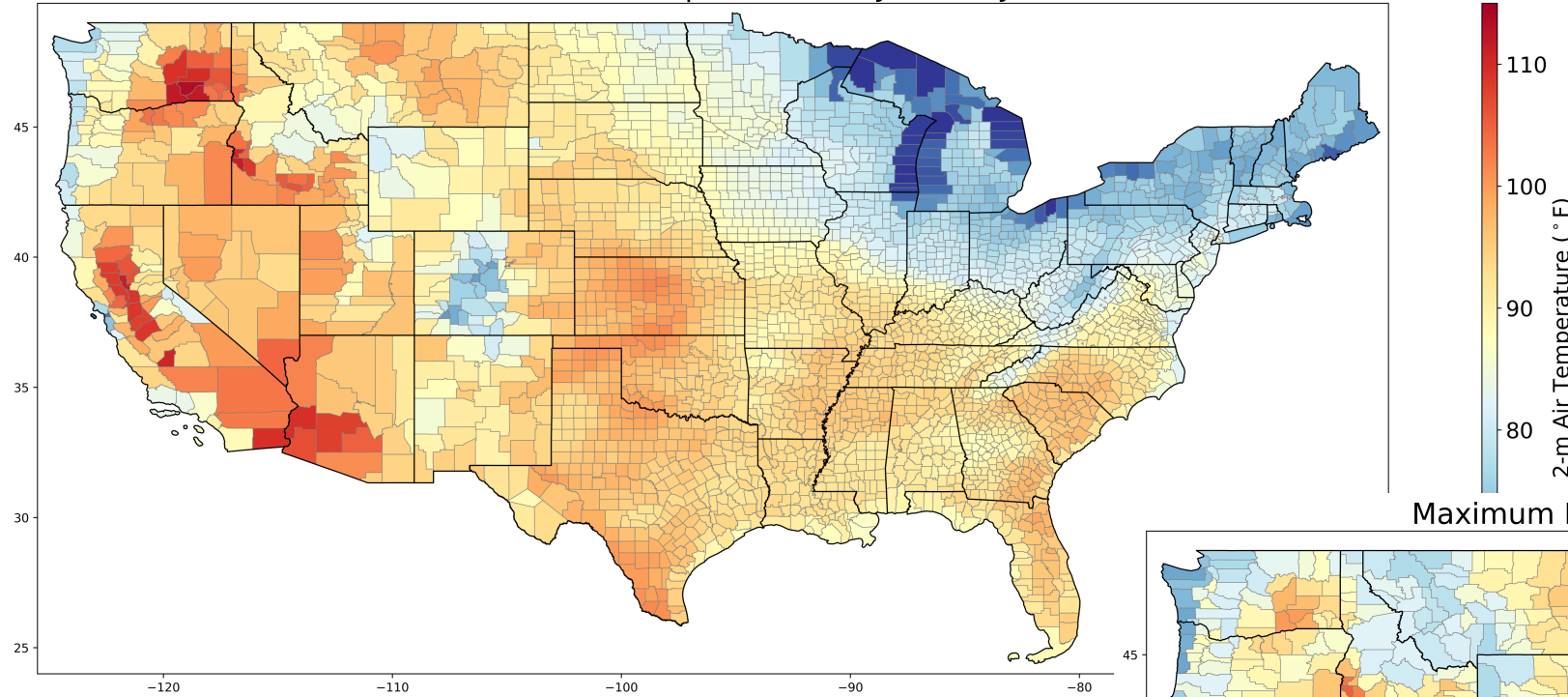
Exploring Resilience Across a Range of Contrasting Events

Temperature in the Western United States

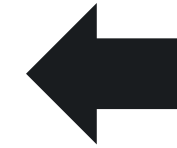


Exploring Resilience Across a Range of Contrasting Events

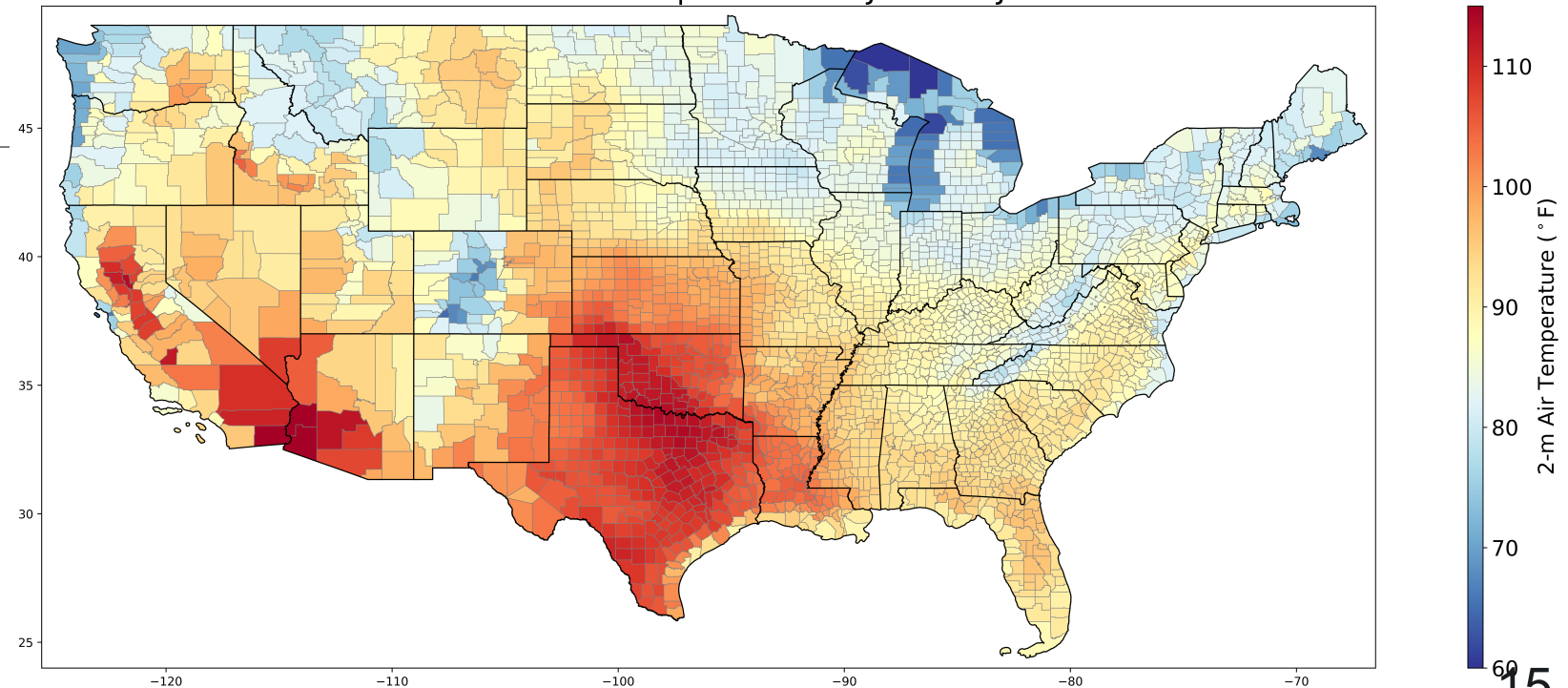
Maximum Heat Wave Temperature: 25-Jun to 2-Jul 2015



2015 heat wave event used in NTPS was WECC-wide



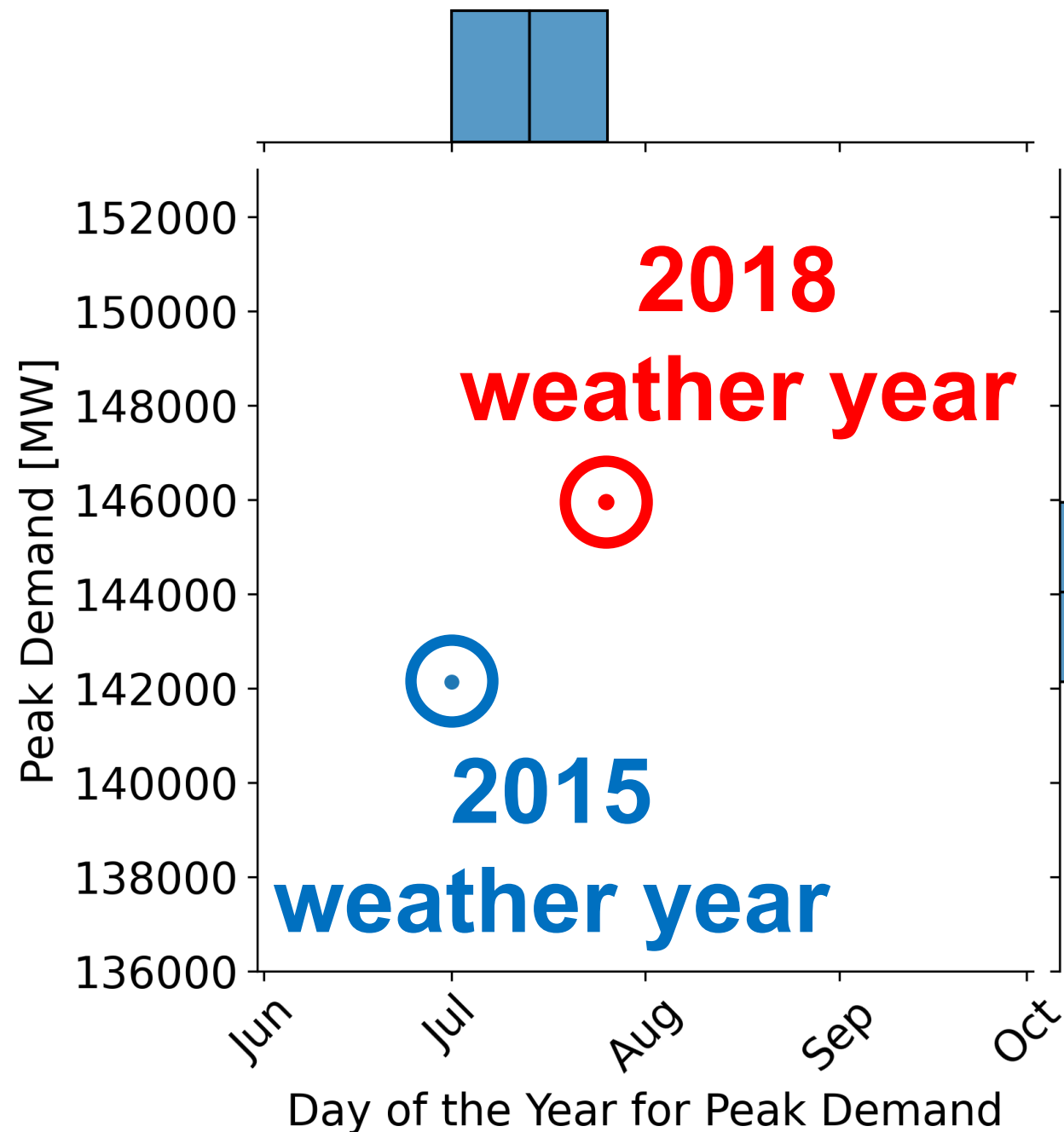
Maximum Heat Wave Temperature: 22-Jul to 28-Jul 2018



2018 event was more concentrated in California and the desert southwest



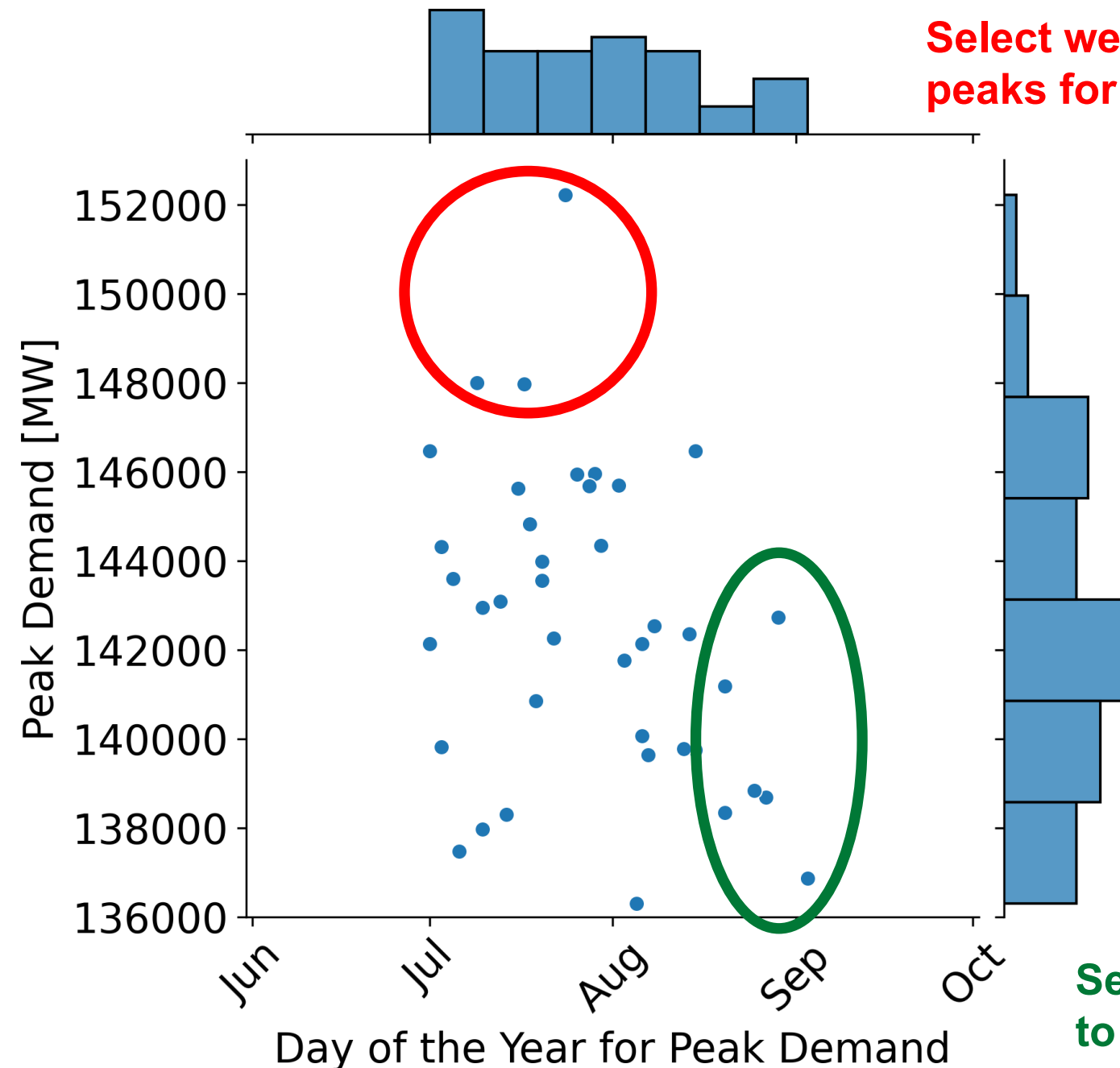
Simulating Multiple Weather Years to Explore Uncertainty



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...

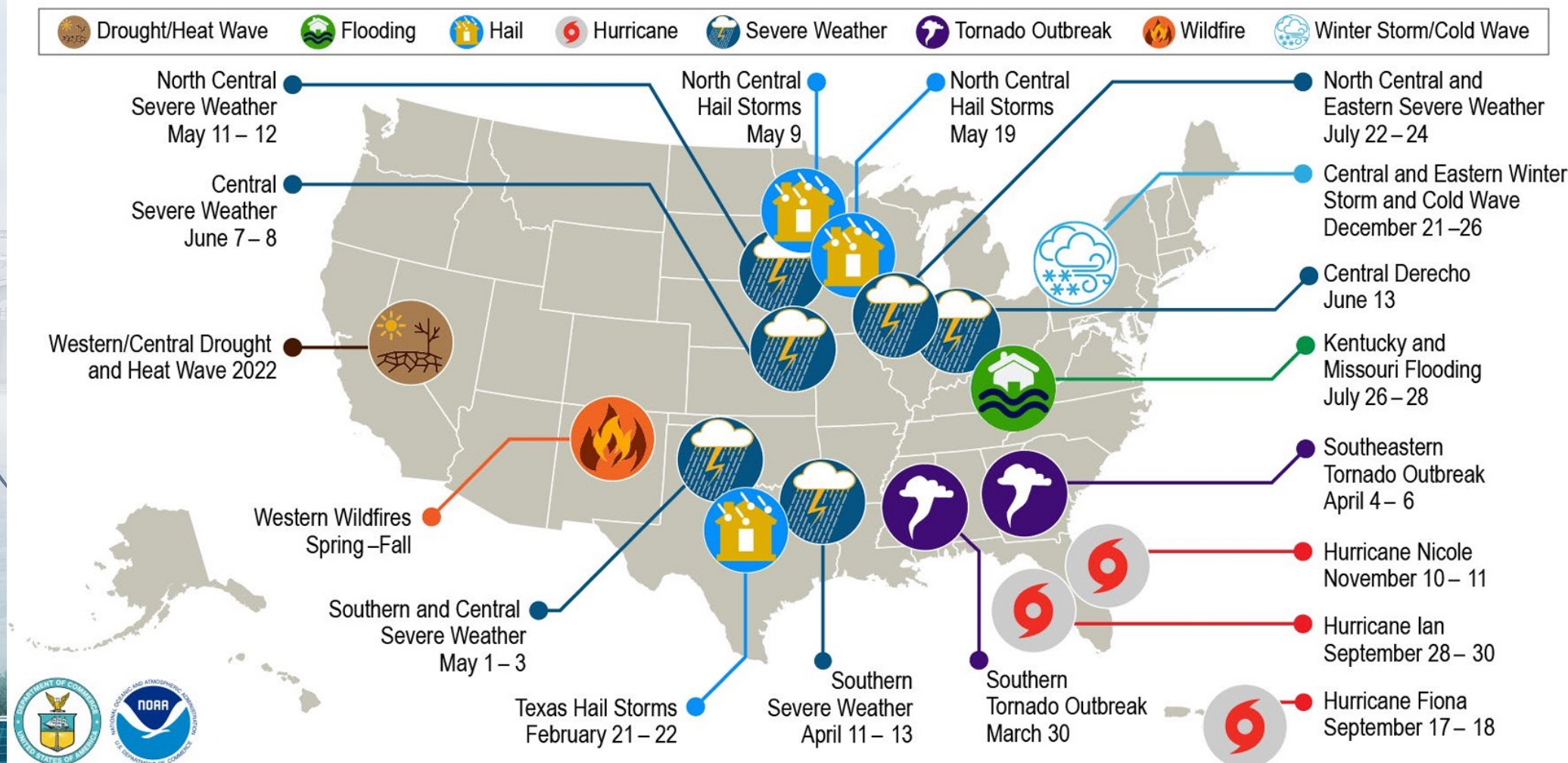
We can run many unique weather years through PNNL's wind, load, and solar models:

- 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

U.S. 2022 Billion-Dollar Weather and Climate Disasters



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, Elliott 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 

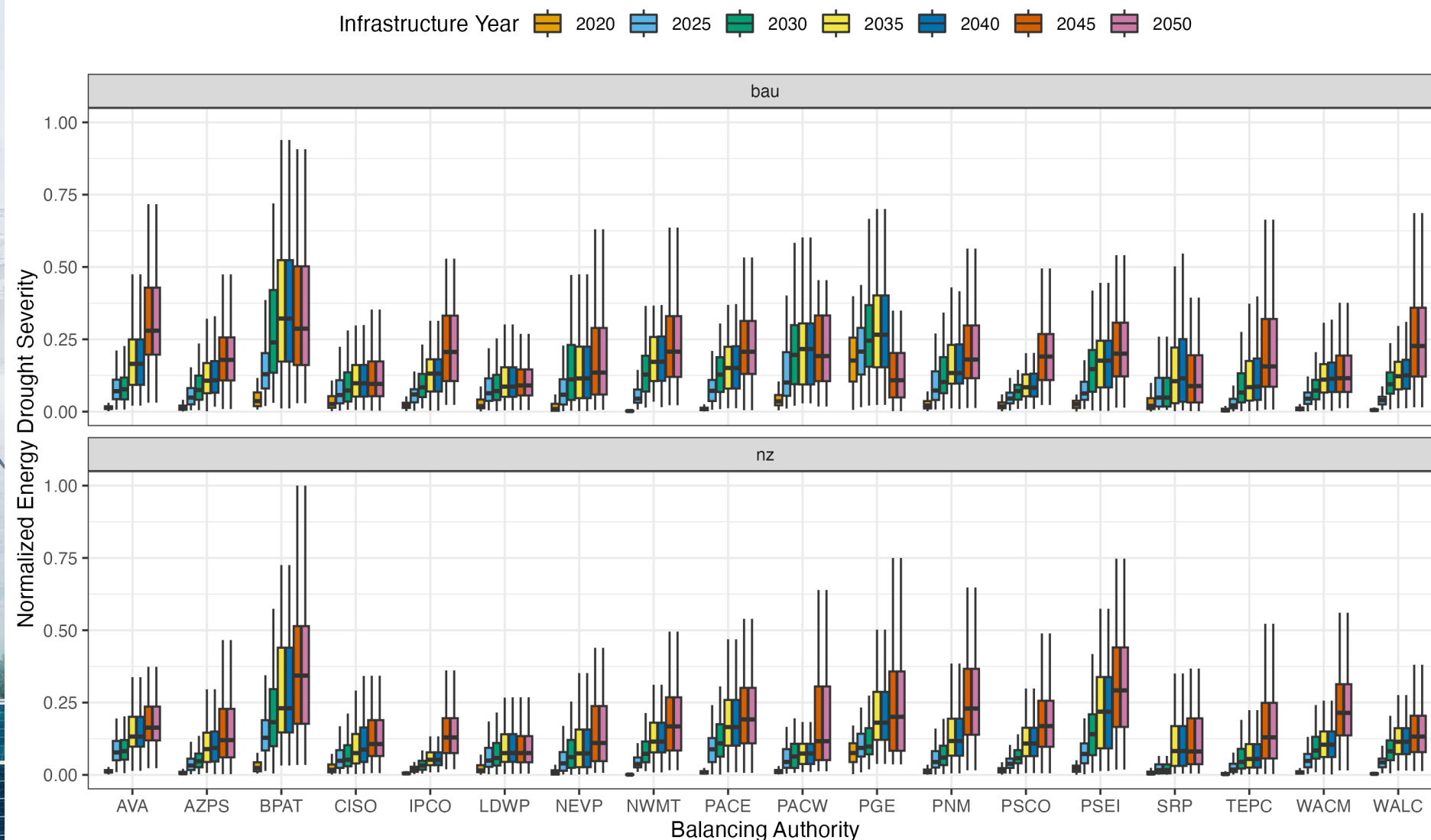
Coincident Datasets Help Identify Periods of Potential Stress



- 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

- Testing using historical load-wind-solar-hydro data for a limited number of specific historical events

Better

- Testing using data for a wide range of historical events

Best

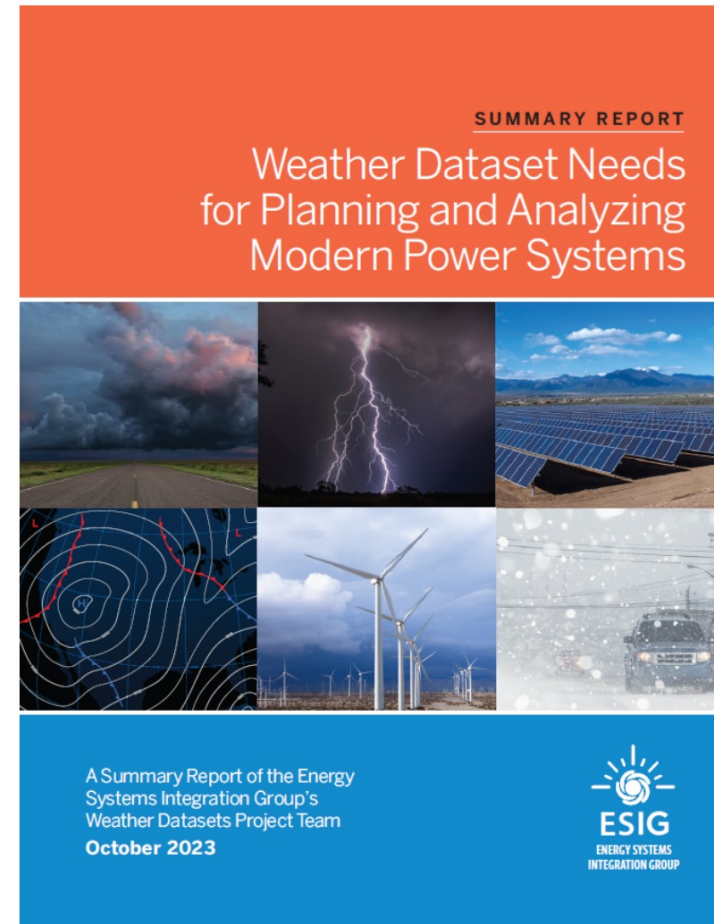
- Testing using data based on forcing from a single climate dataset
- Testing using data based on forcing from multiple climate datasets

Continuum of Stress Testing Approaches

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

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

Choose a Scenario Comparison

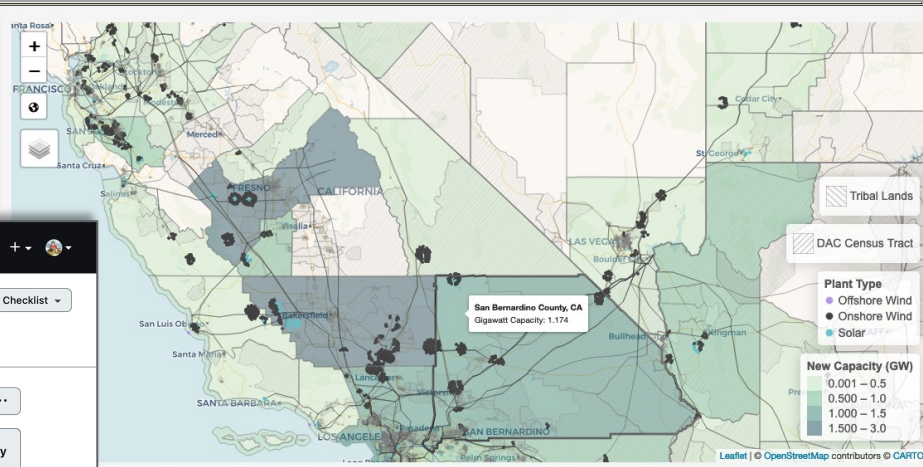
Compare 2035 Clean Grid scenario to 2020 conditions

Choose Aggregation Scale for Map

County

Choose U.S. State(s)

Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico



Tribal Lands

DAC Census Tract

Plant Type

- Offshore Wind
- Onshore Wind
- Solar

New Capacity (GW)

- 0.001 – 0.5
- 0.500 – 1.0
- 1.000 – 1.5
- 1.500 – 3.0

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thurber updated transportation workflow and notebook; updated readme styles (#19 ... 5d5a8d4 18 days ago History

CERF_testrun.ipynb Updates (#16)

28 days ago

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Open-Source Datasets

Topic: All Resolution: All

Block-level Income Projections for WA Wan 2023b DOI 10.5281/zenodo.7869437

Block-level Population Projections for WA Wan 2023a DOI 10.5281/zenodo.7402538

GCAM-USA Decarbonization Pathways Ou et al 2023 DOI 10.5281/zenodo.7838871

Population scenarios for U.S. states consistent with shared socioeconomic... Zoragheini et al 2020 DOI 10.5281/zenodo.3796178

Projecting Residential Energy Consumption across Multiple Income... Zhang et al 2023 DOI 10.5281/zenodo.7988037

RectifHyd Turner et al 2023 DOI 10.5281/zenodo.6607824

Solar and Wind Energy Drought Data for 15 BAs in the CONUS Brackeen et al 2023b DOI 10.5281/zenodo.8008033

State-level Income Decile Projections Narayan et al 2023 DOI 10.5281/zenodo.6902357

Thermodynamic Global Warming Simulations Jones et al 2022 DOI 10.57931/1885796

Total Load Profiles by BA Narayson et al 2023c DOI 10.5281/zenodo.8067471

Transportation Electrification Load Profiles Acharya et al 2023 DOI 10.5281/zenodo.7888568

U.S. Balancing Authority Projections of Hourly Meteorology under Climate Change Burleyson et al 2023a DOI 10.57931/1960530

U.S. County Projections of Hourly Meteorology under Climate Change Burleyson et al 2023b DOI 10.57931/1960548

Wind and Solar Capacity Factor Profiles Brackeen et al 2023a DOI 10.5281/zenodo.7901614

Wind and Solar Generation by BA Campbell et al 2023 DOI 10.5281/zenodo.7991870

update_grid_view_database.py GridView Database

Legend dataset interface

I data provided from gcamextractor, the substation energy

e file

operating and maintenance costs, offshore wind, and

it file and the GridView_mdb database to update

6.1 15.1 9.1 12.5

Outside DAC Generator Location Inside DAC

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