



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

# Forward Looking Extreme Weather Datasets

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

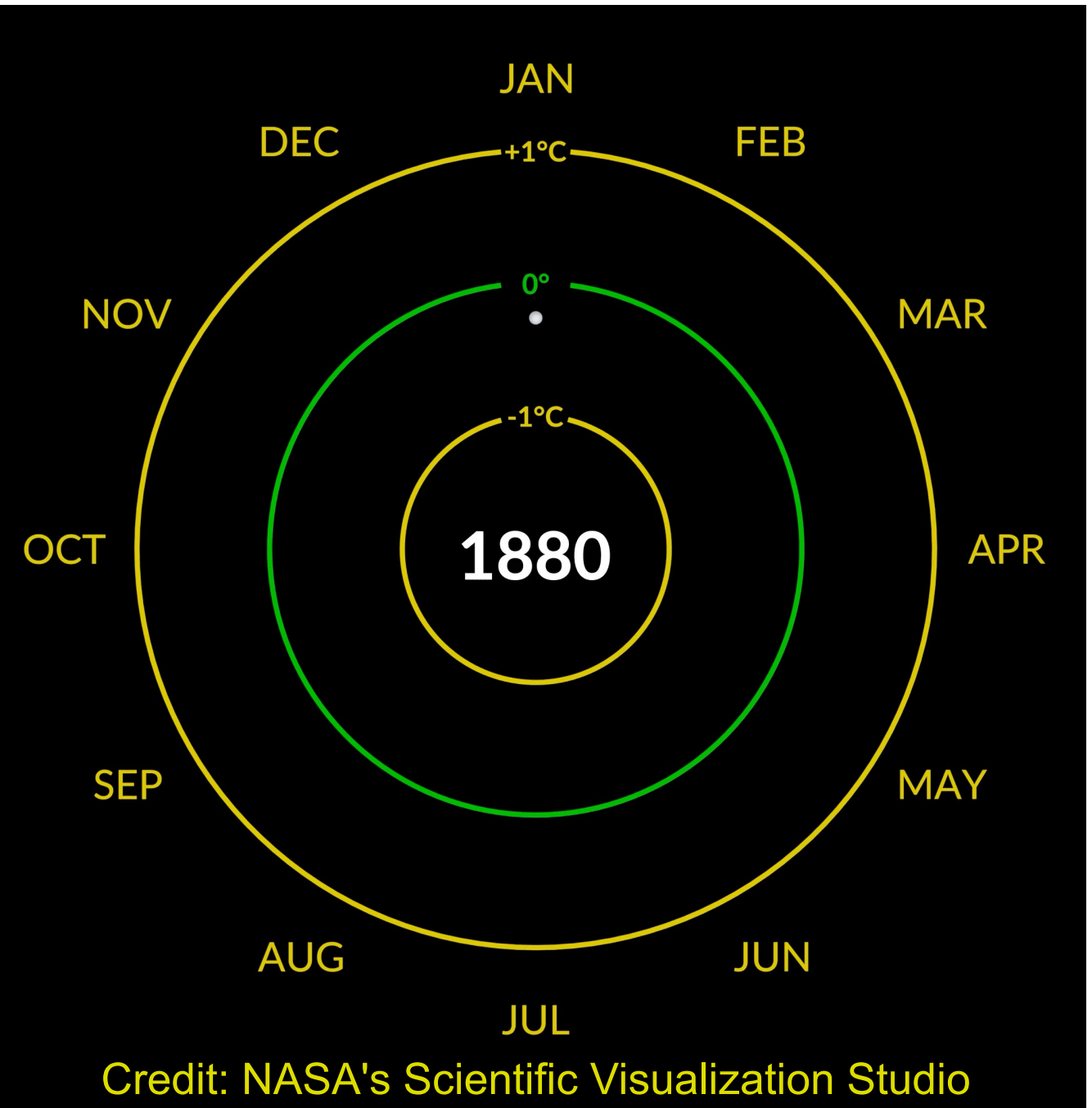


PNNL is operated by Battelle for the U.S. Department of Energy





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.



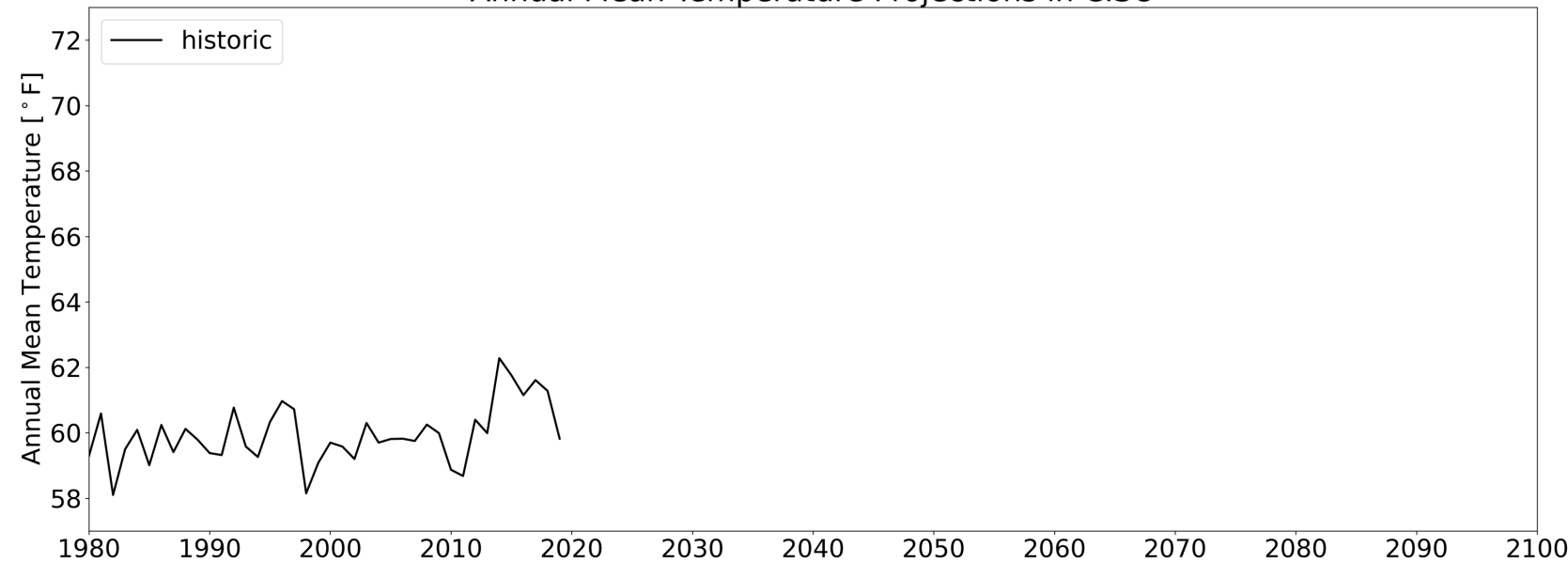
# Key Messages

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

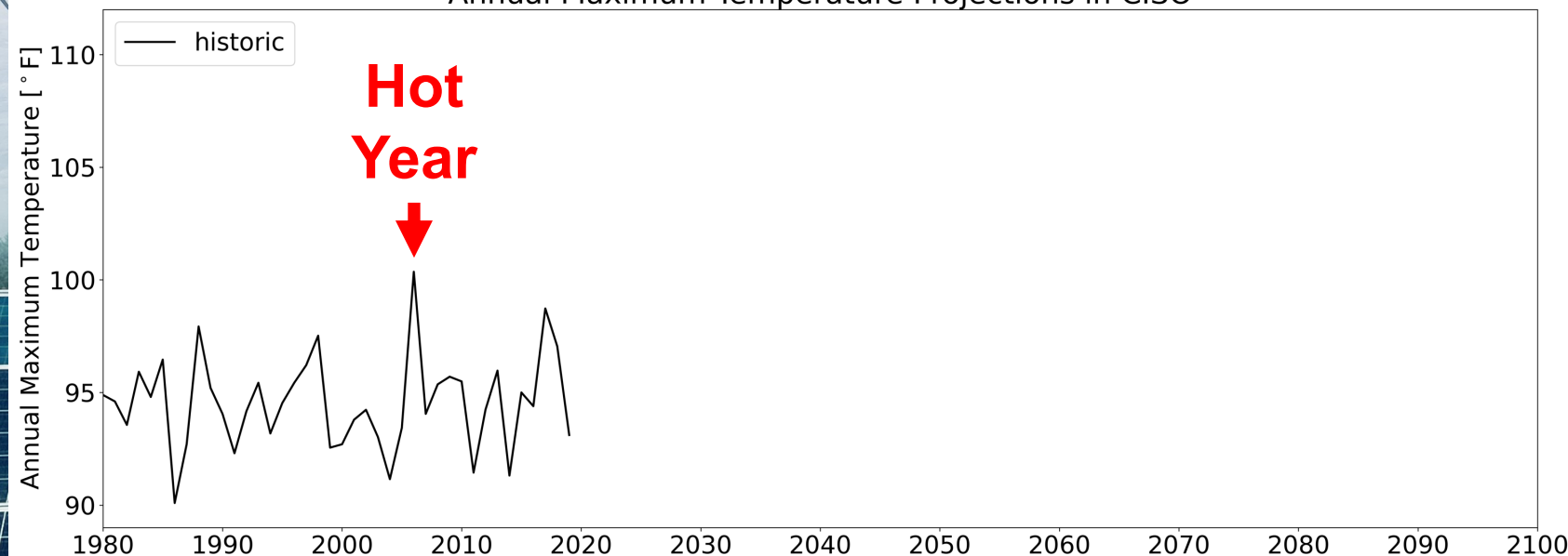
1. With coincident load-wind-solar-hydro conditions;
2. Across a wide range of historical and projected weather conditions.

# U.S. Climate Projection Dataset

Annual Mean Temperature Projections in CISO



Annual Maximum Temperature Projections in CISO



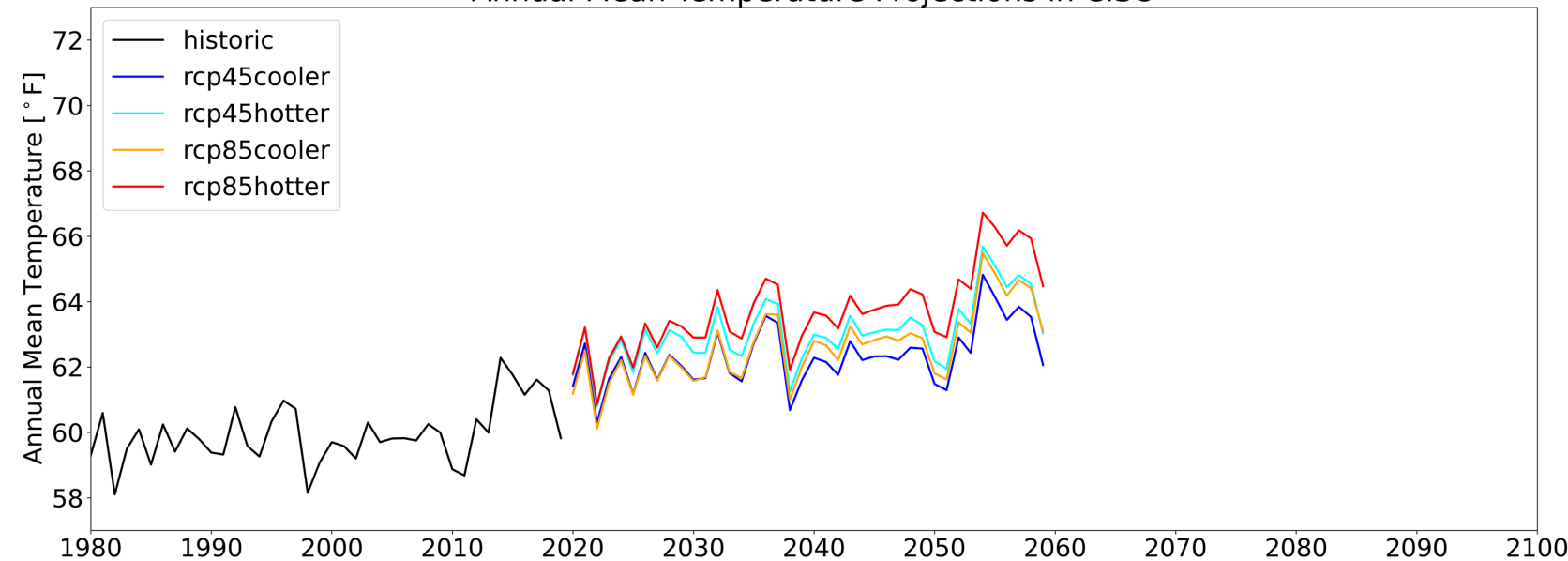
- Historic data reproduces observed sequence of past events (1980–2019)
- Sequence is repeated twice in the future (2020–2059 and 2060–2099) with additional warming gradually applied
- 1/8 deg (~12 km) resolution, U.S., hourly
- 25 hourly and 250+ three-hourly variables
- Output is first spatially-averaged 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>

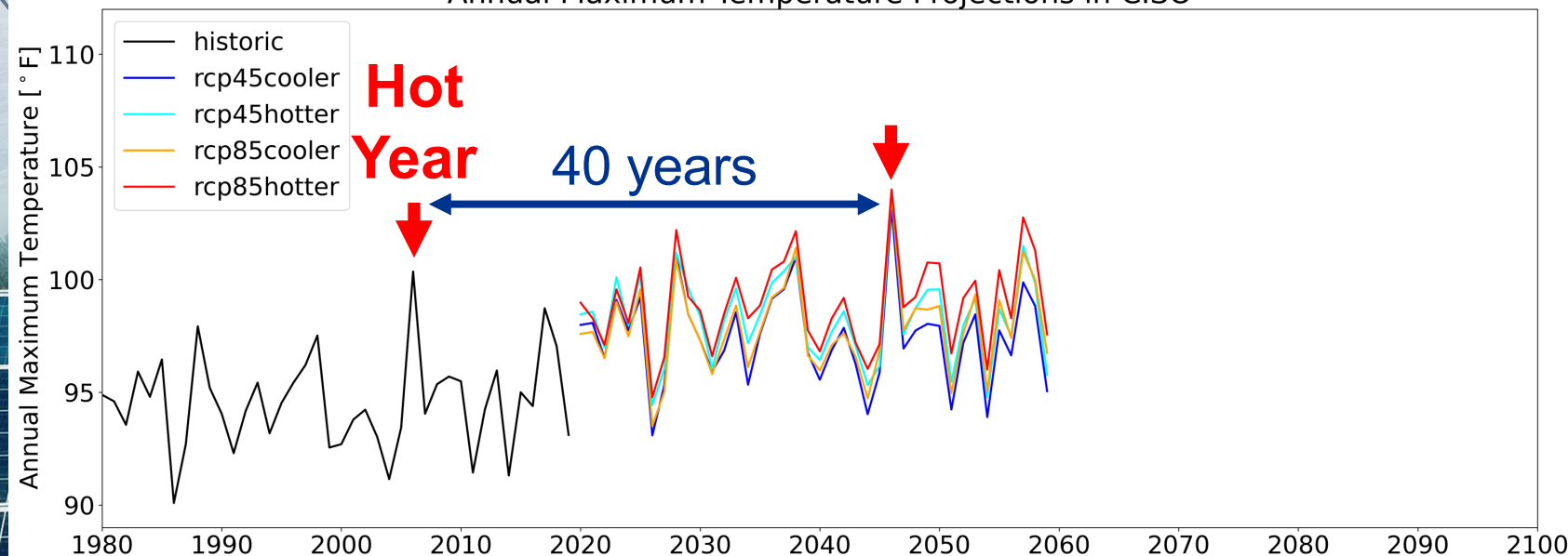


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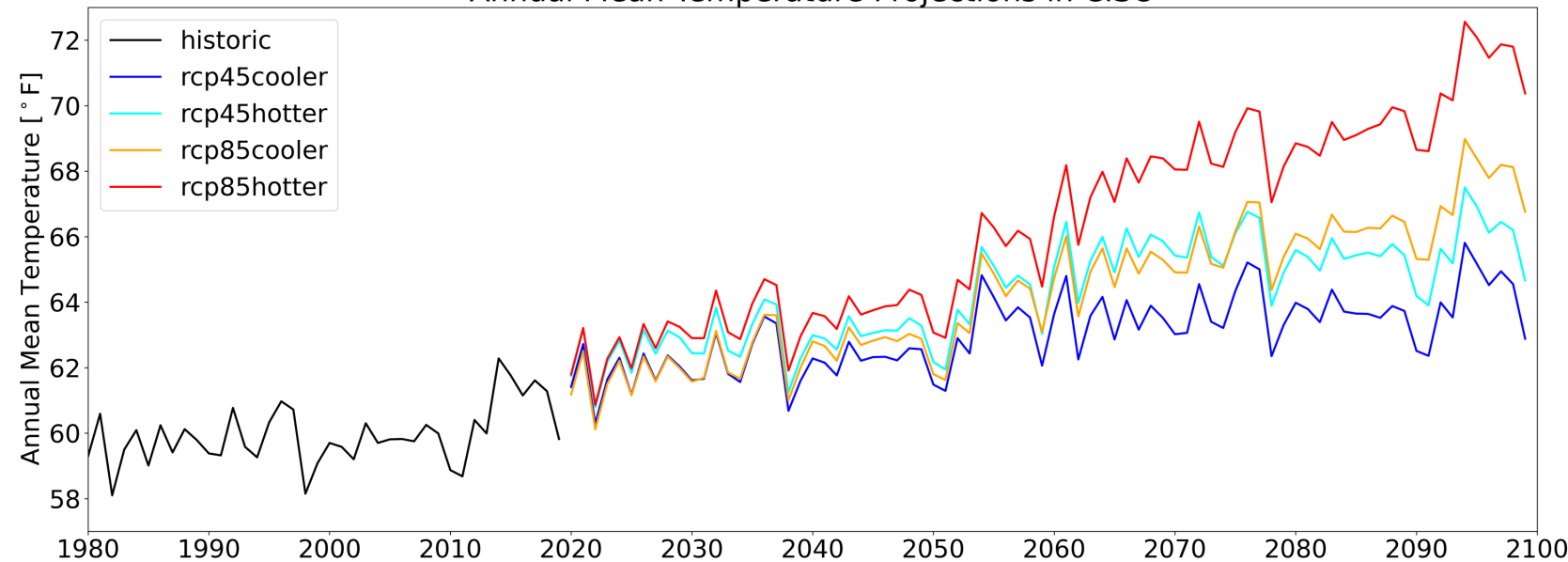


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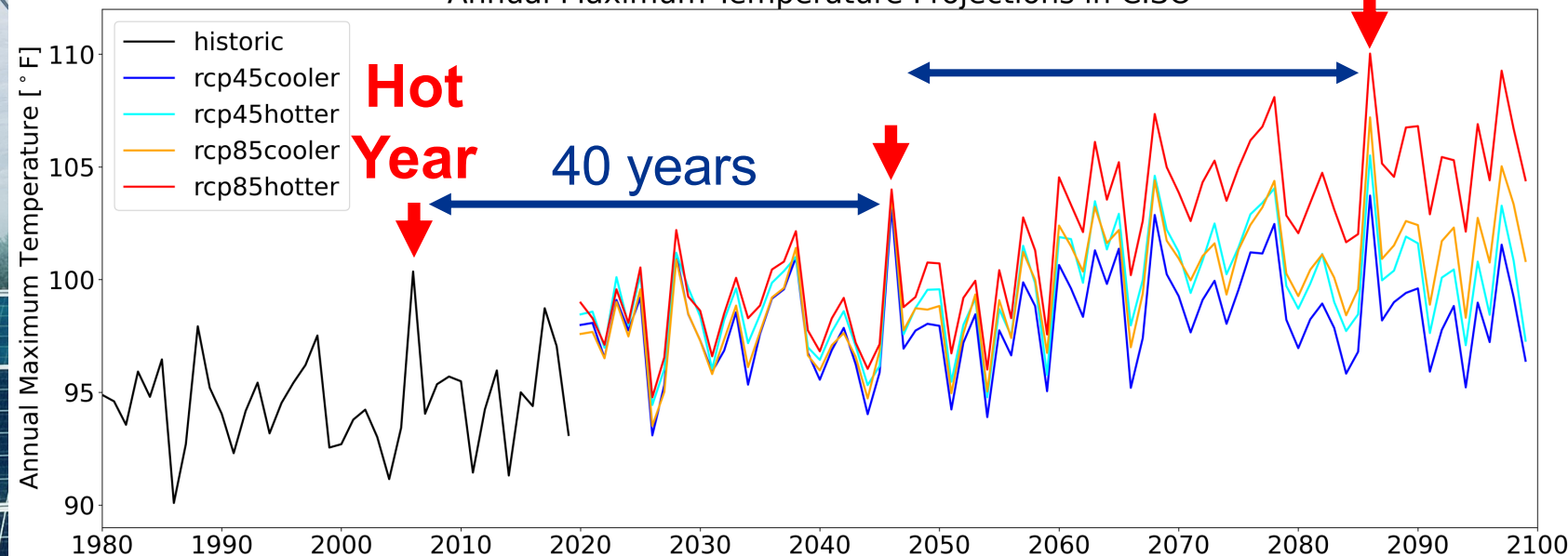
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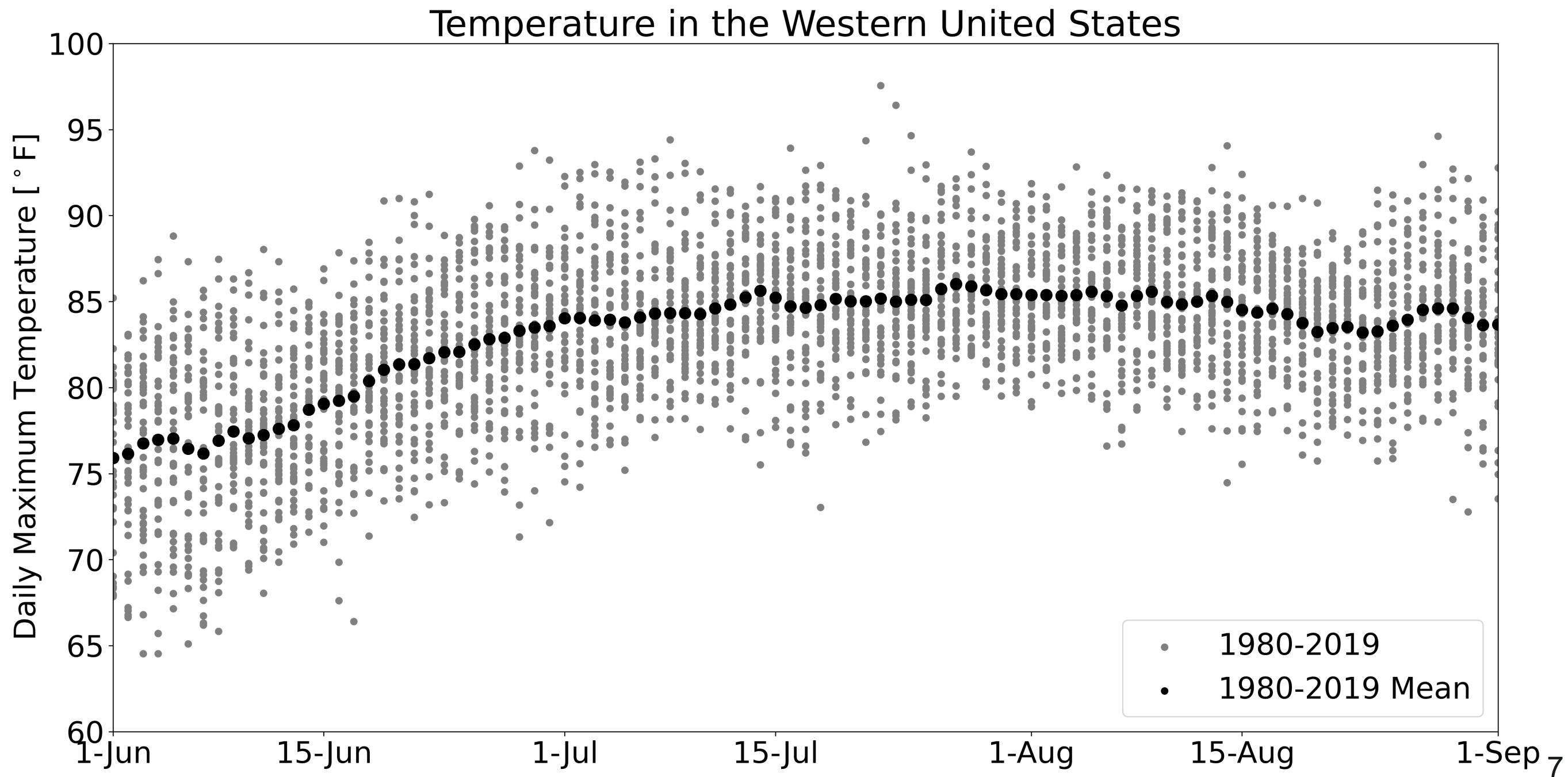


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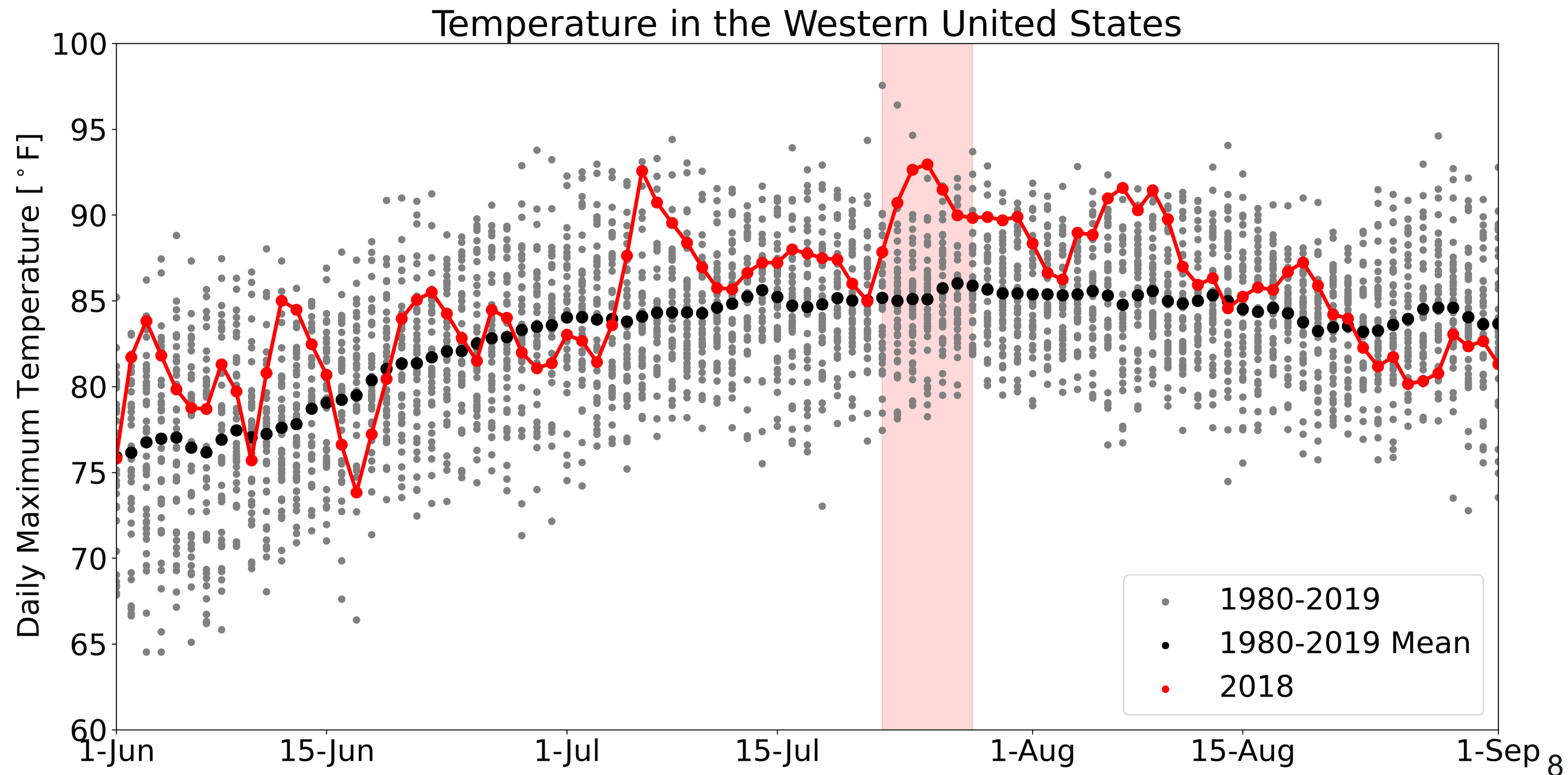
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# Finding Heat Wave Events



# Finding Heat Wave Events

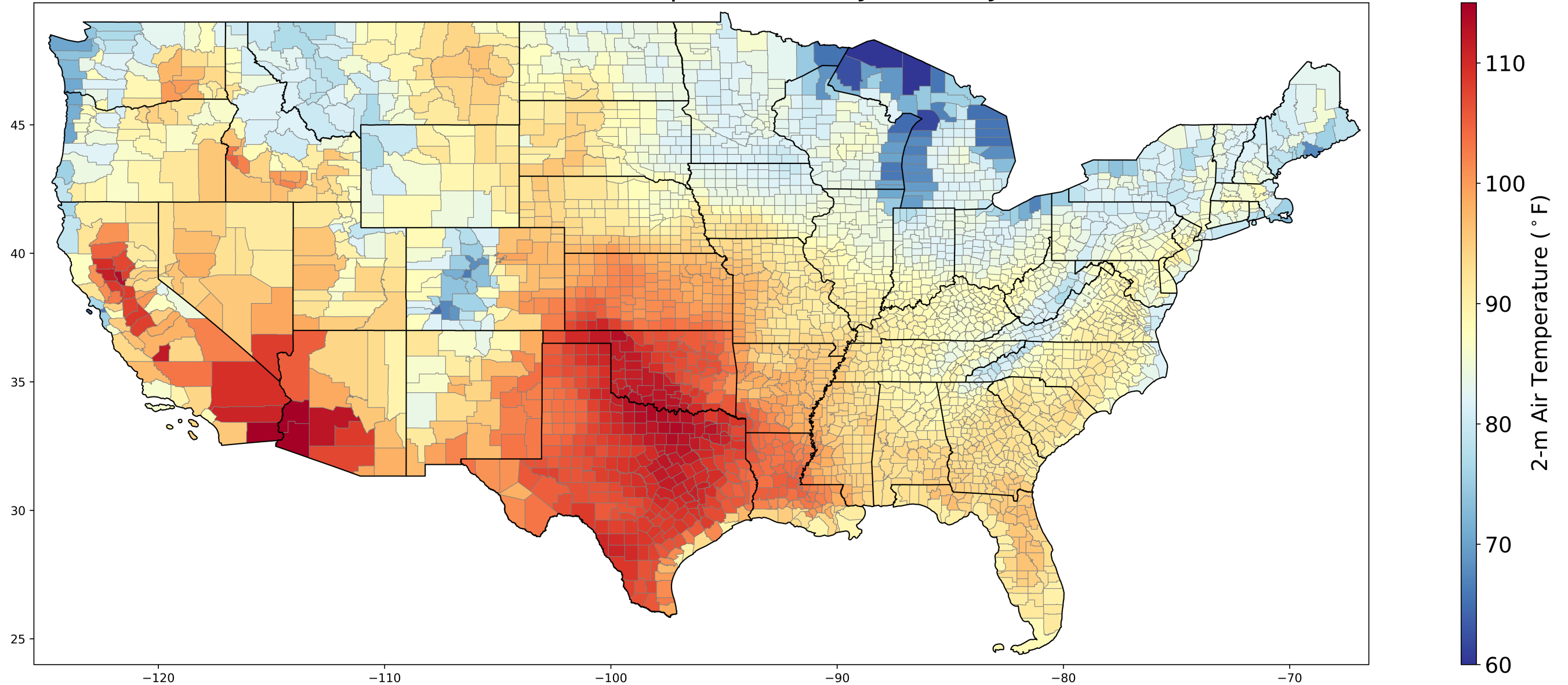






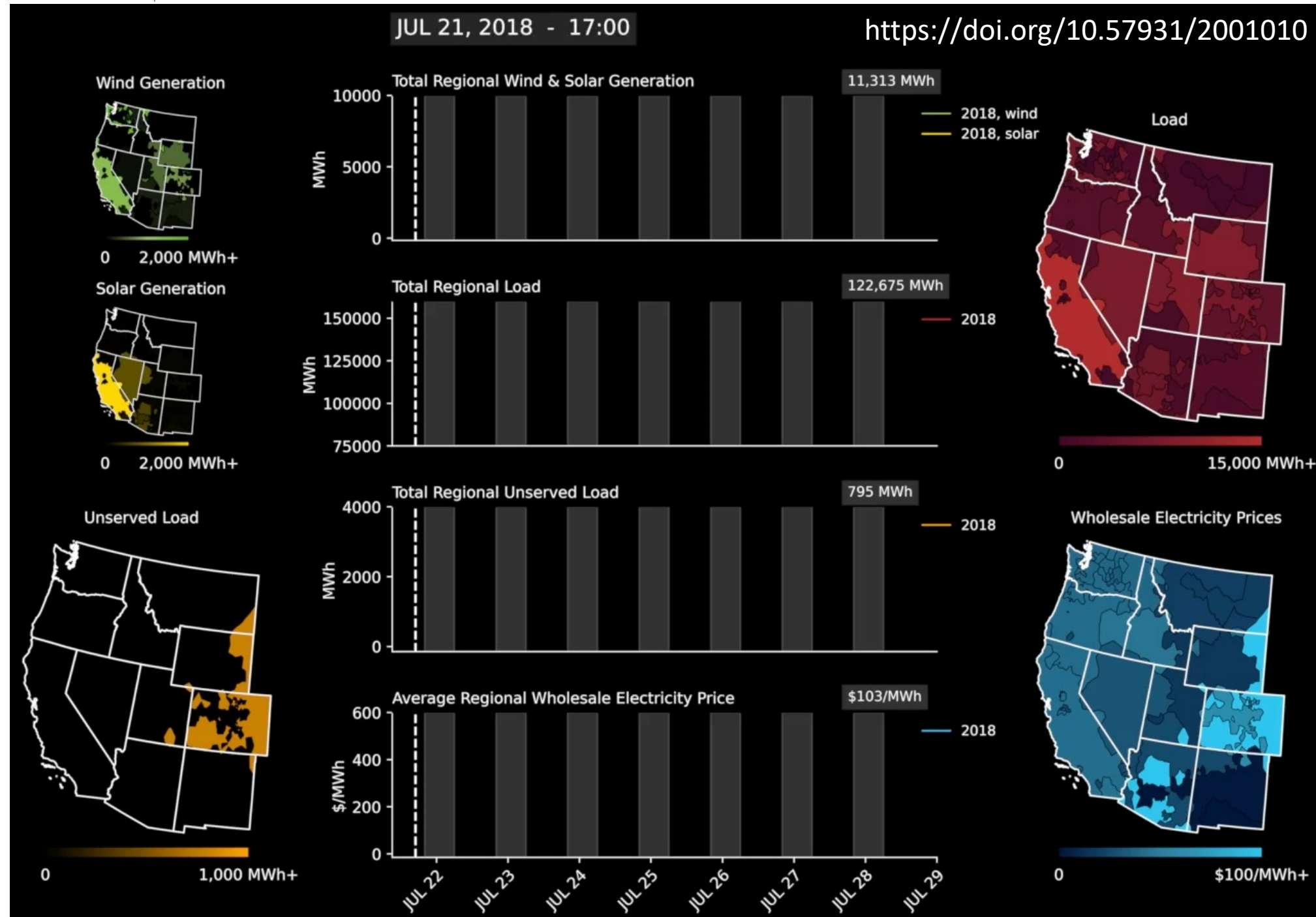
# Finding Heat Wave Events

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





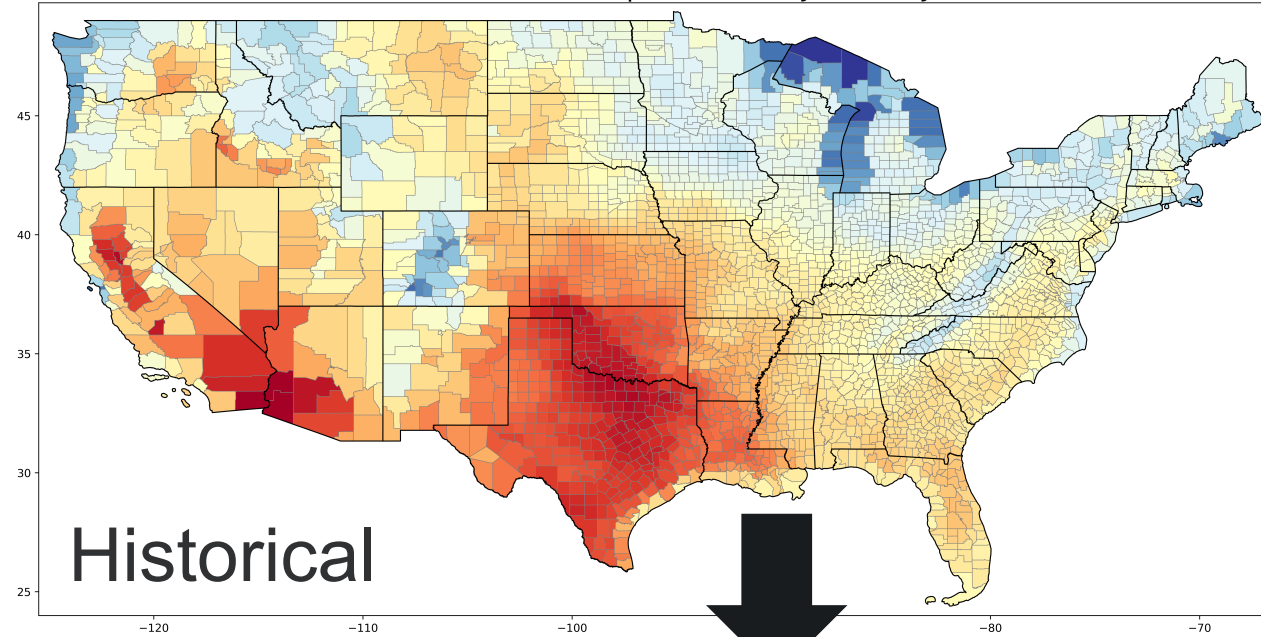
# Exploring Historical Heat Wave Grid Stress



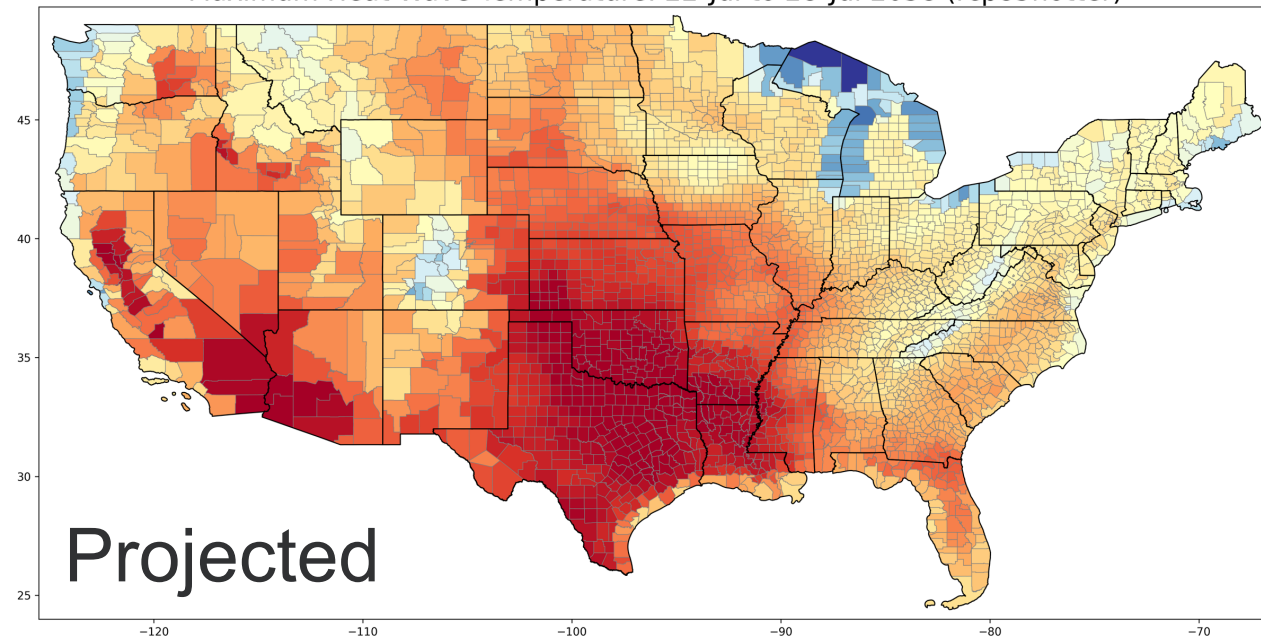


# Exploring Future Heat Wave Grid Stress

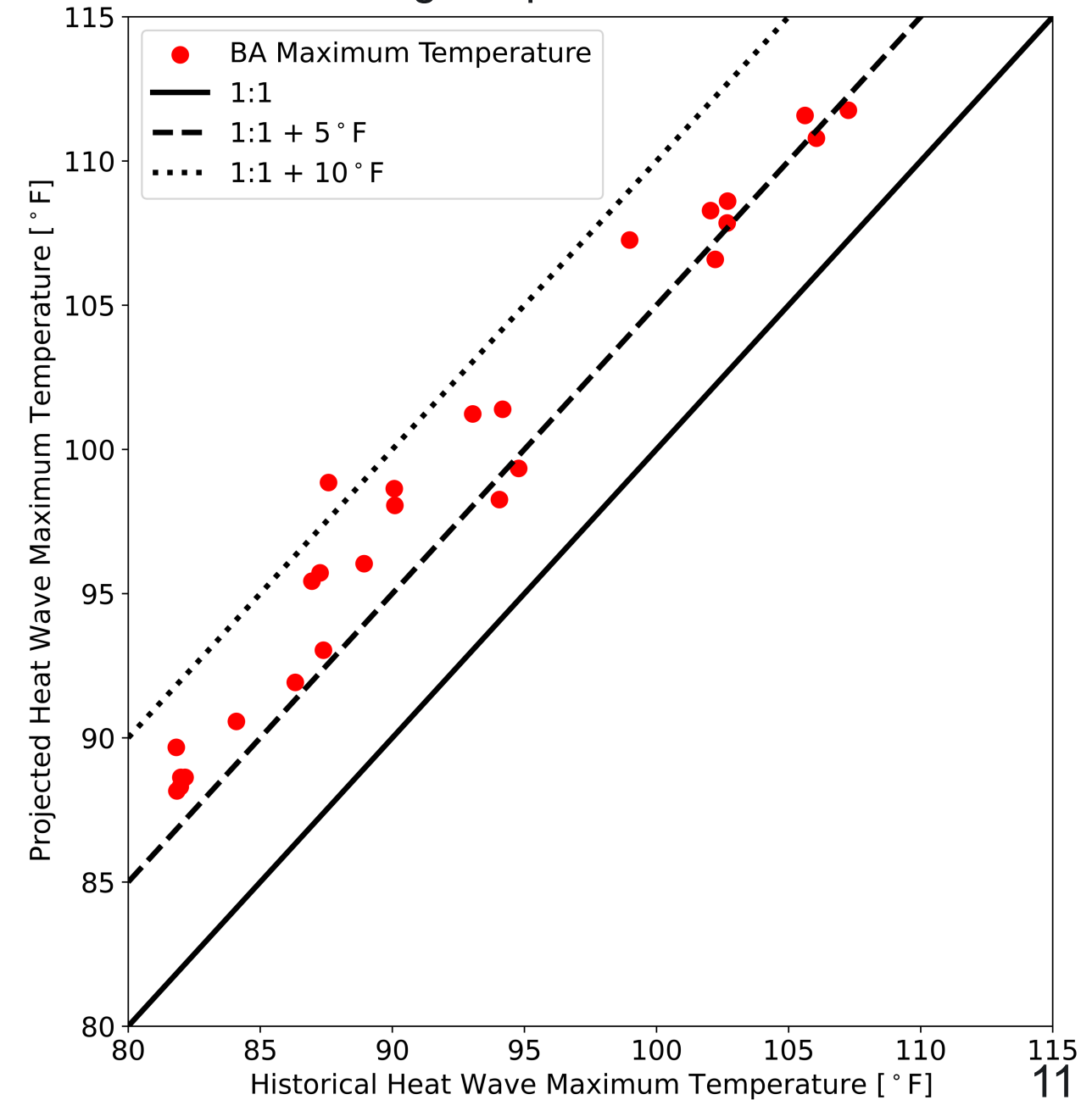
Maximum Heat Wave Temperature: 22-Jul to 28-Jul 2018



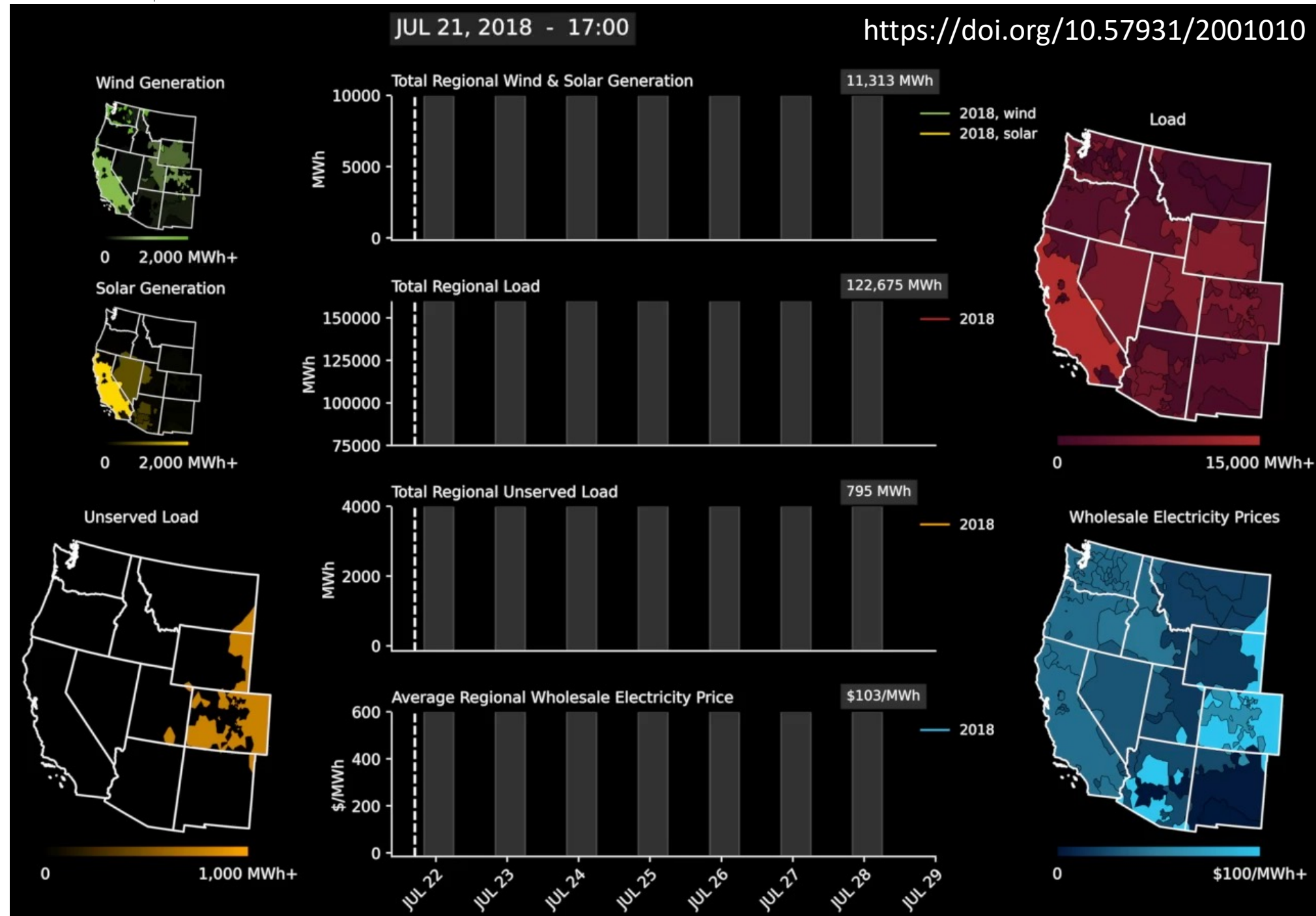
Maximum Heat Wave Temperature: 22-Jul to 28-Jul 2058 (rcp85hotter)



Climate Change Impact on 2018 Heat Wave



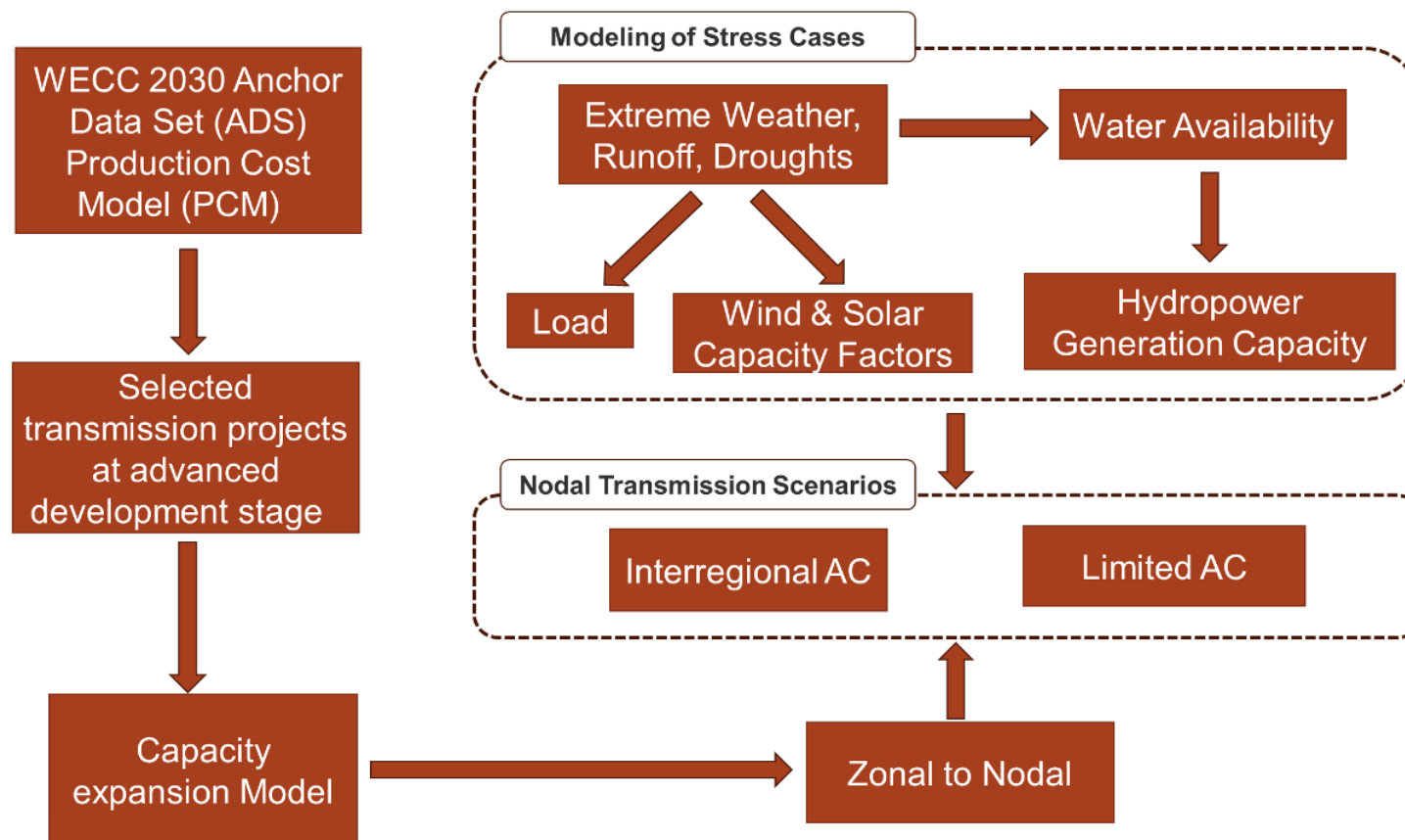
# Exploring Future Heat Wave Grid Stress





# 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.



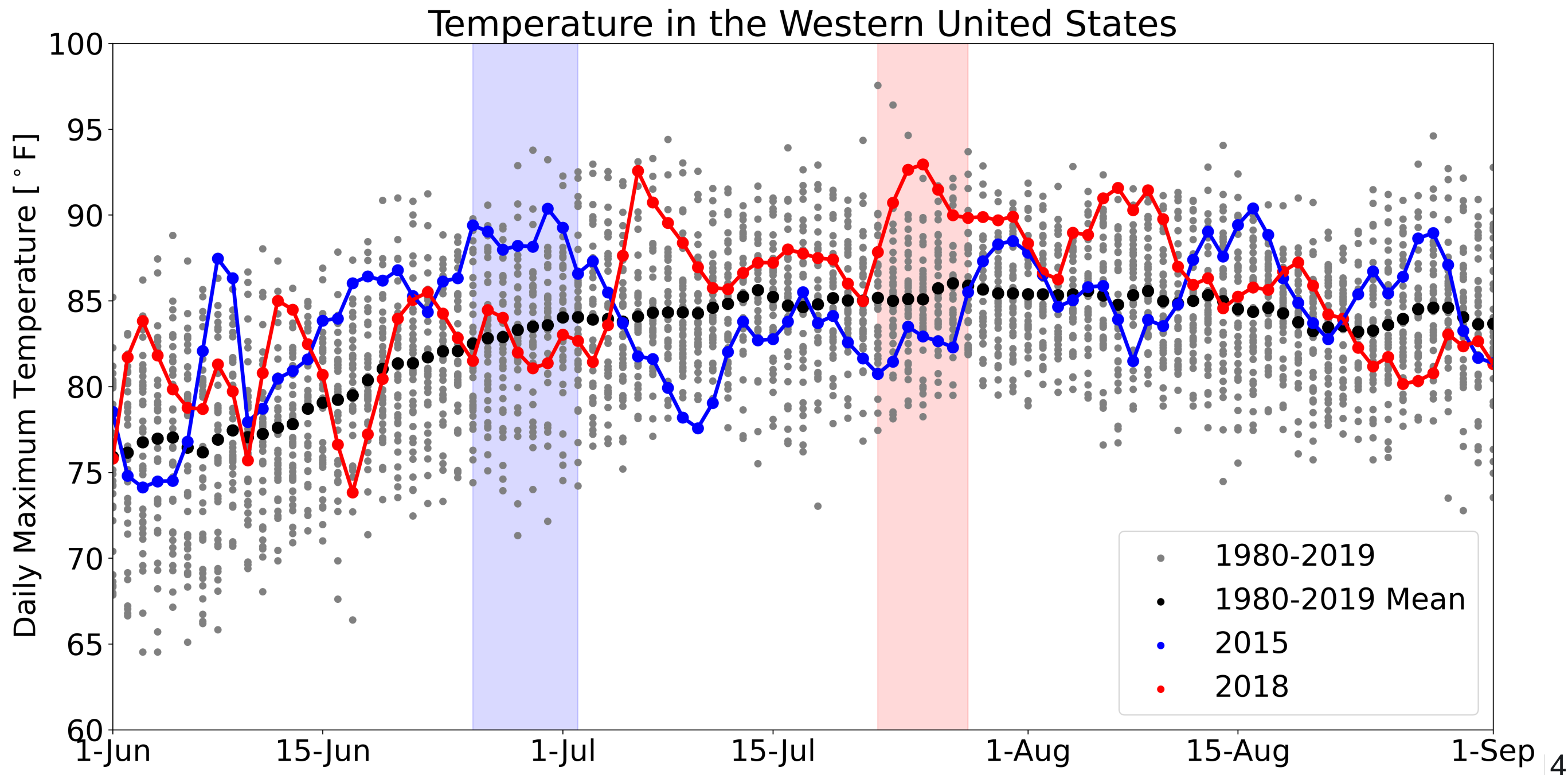
## National Transmission Planning Study: Stress Analysis

**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

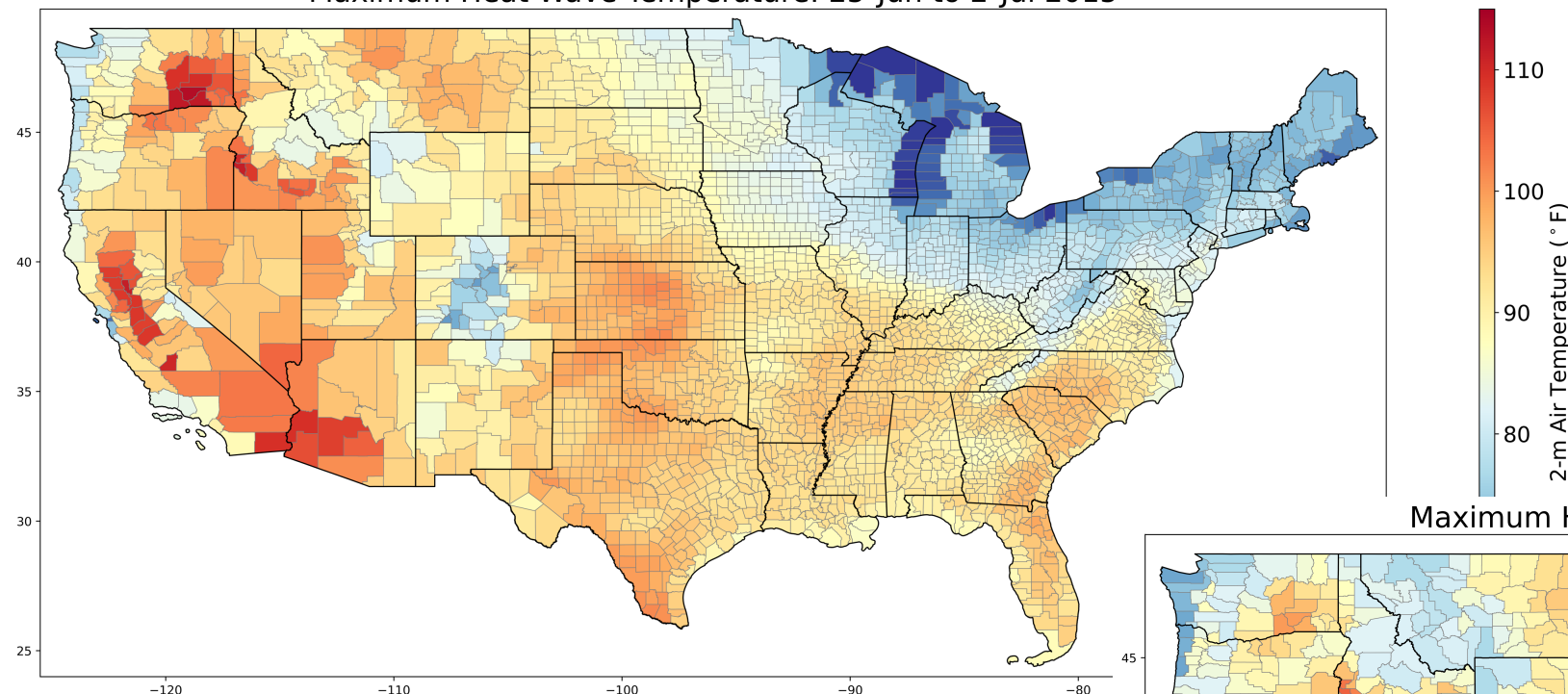
# Exploring Resilience Across a Range of Contrasting Events



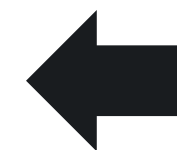


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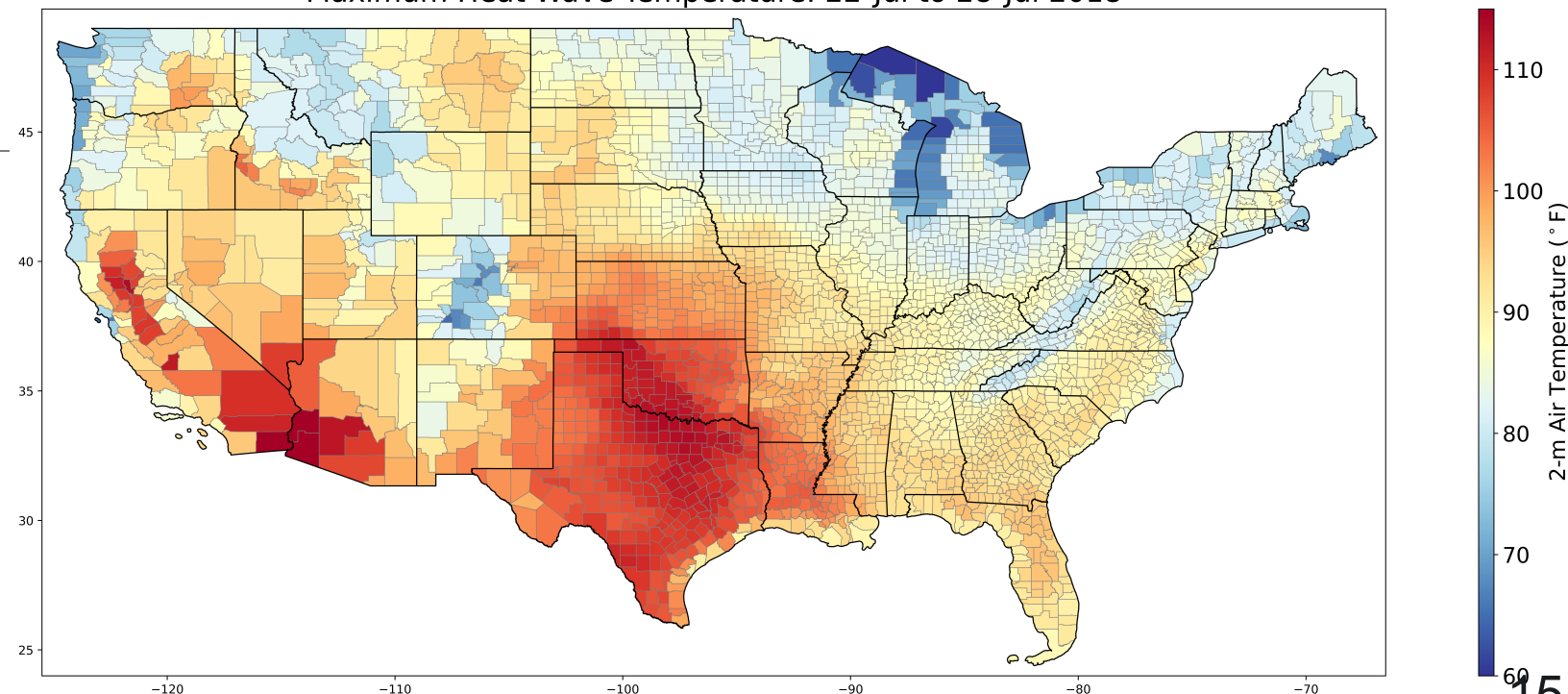
Maximum Heat Wave Temperature: 25-Jun to 2-Jul 2015



2015 heat wave event used in NTPS was WECC-wide



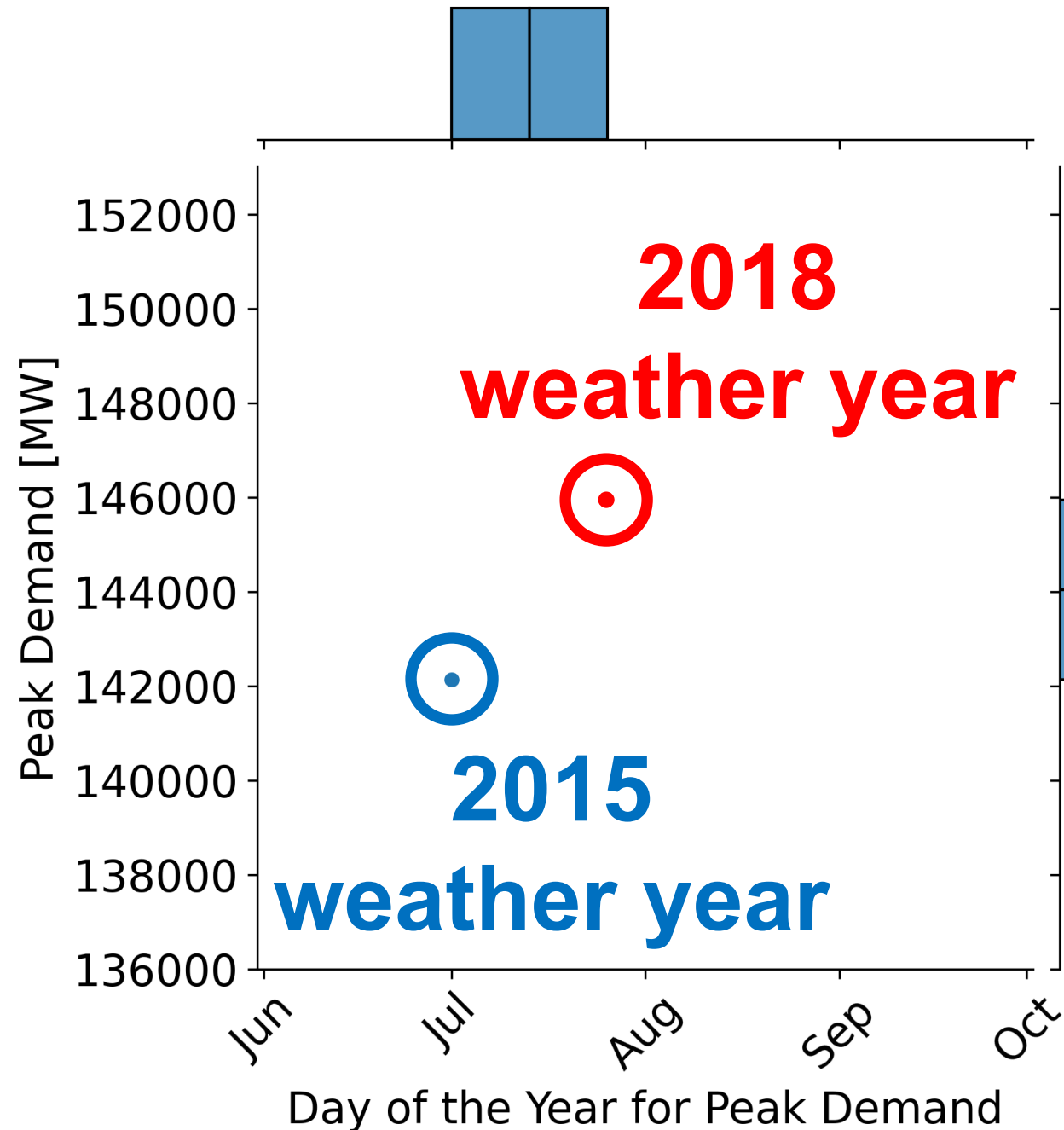
Maximum Heat Wave Temperature: 22-Jul to 28-Jul 2018



2018 event was more concentrated in California and the desert southwest



# Simulating Multiple Weather Years to Explore Uncertainty

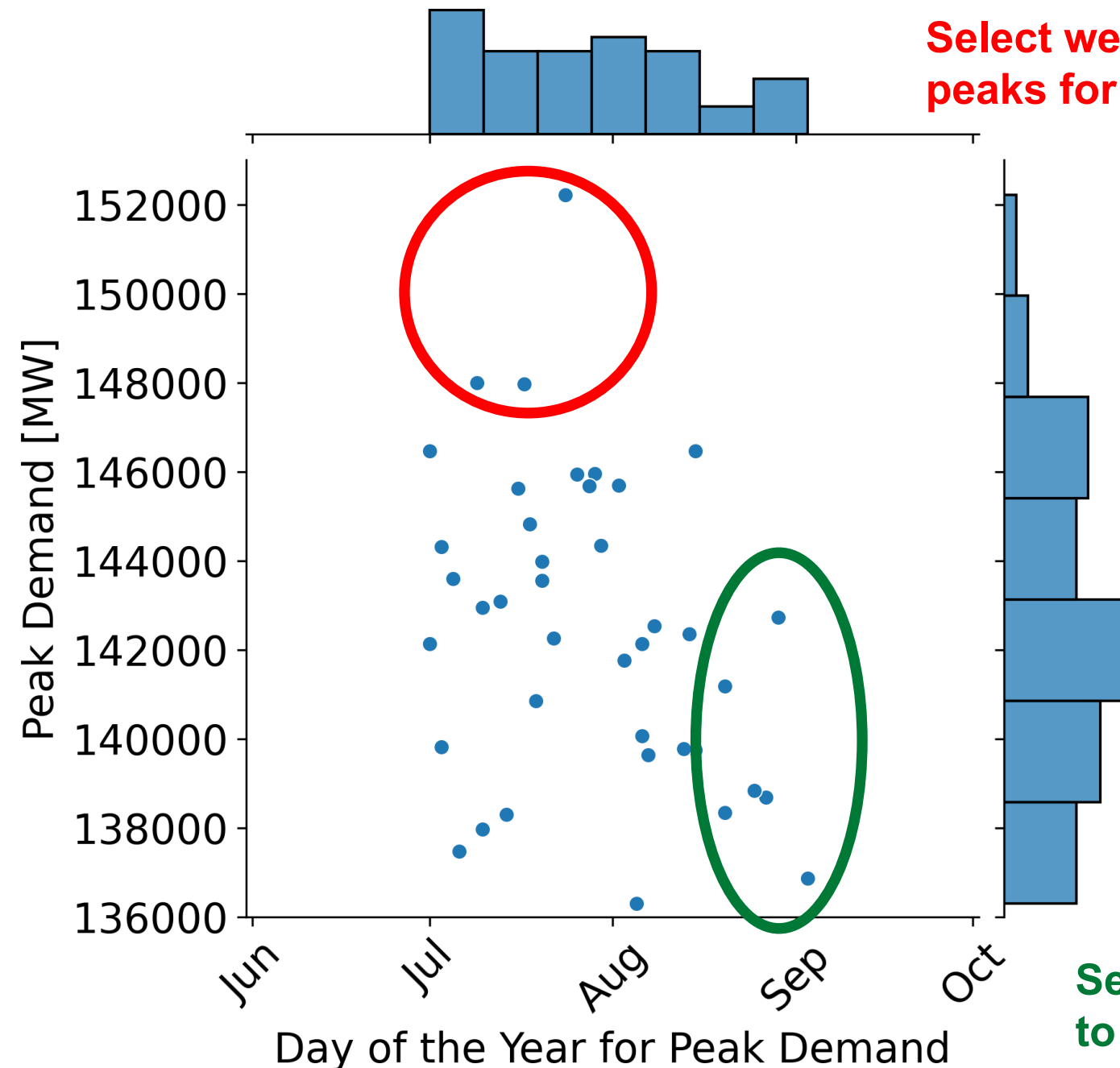


We can run many unique weather years through PNNL's wind, load, and solar models:

- 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

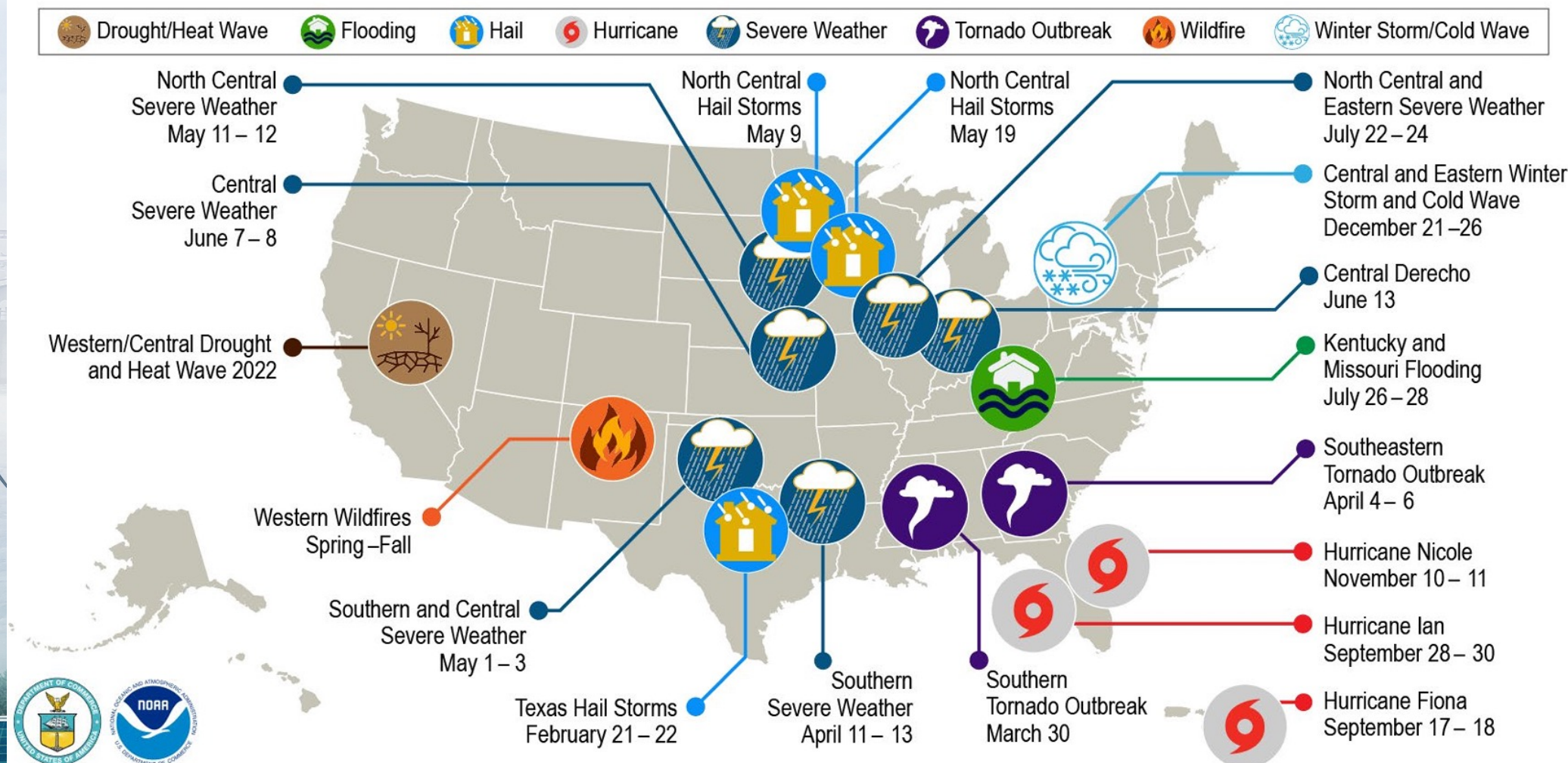


# Simulating Multiple Weather Years to Explore Uncertainty



# 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](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

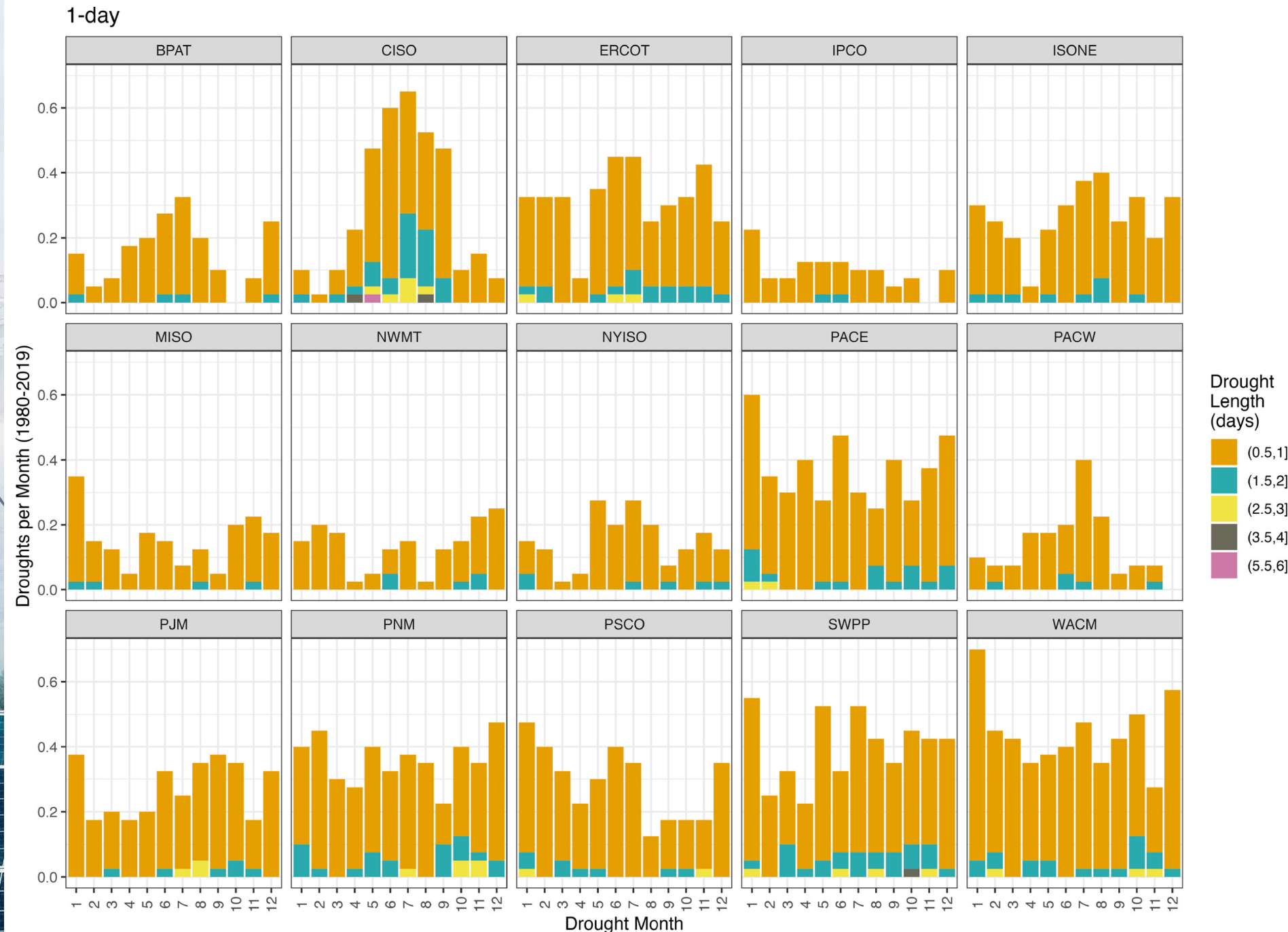
Jacek Kapica , Jakub Jurasz , Fausto A. Canales , Hannah Bloomfield , Mohammed Guezgouz , Matteo De Felice , Zbigniew Kobus 

### Future regional increases in simultaneous large Western USA wildfires

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



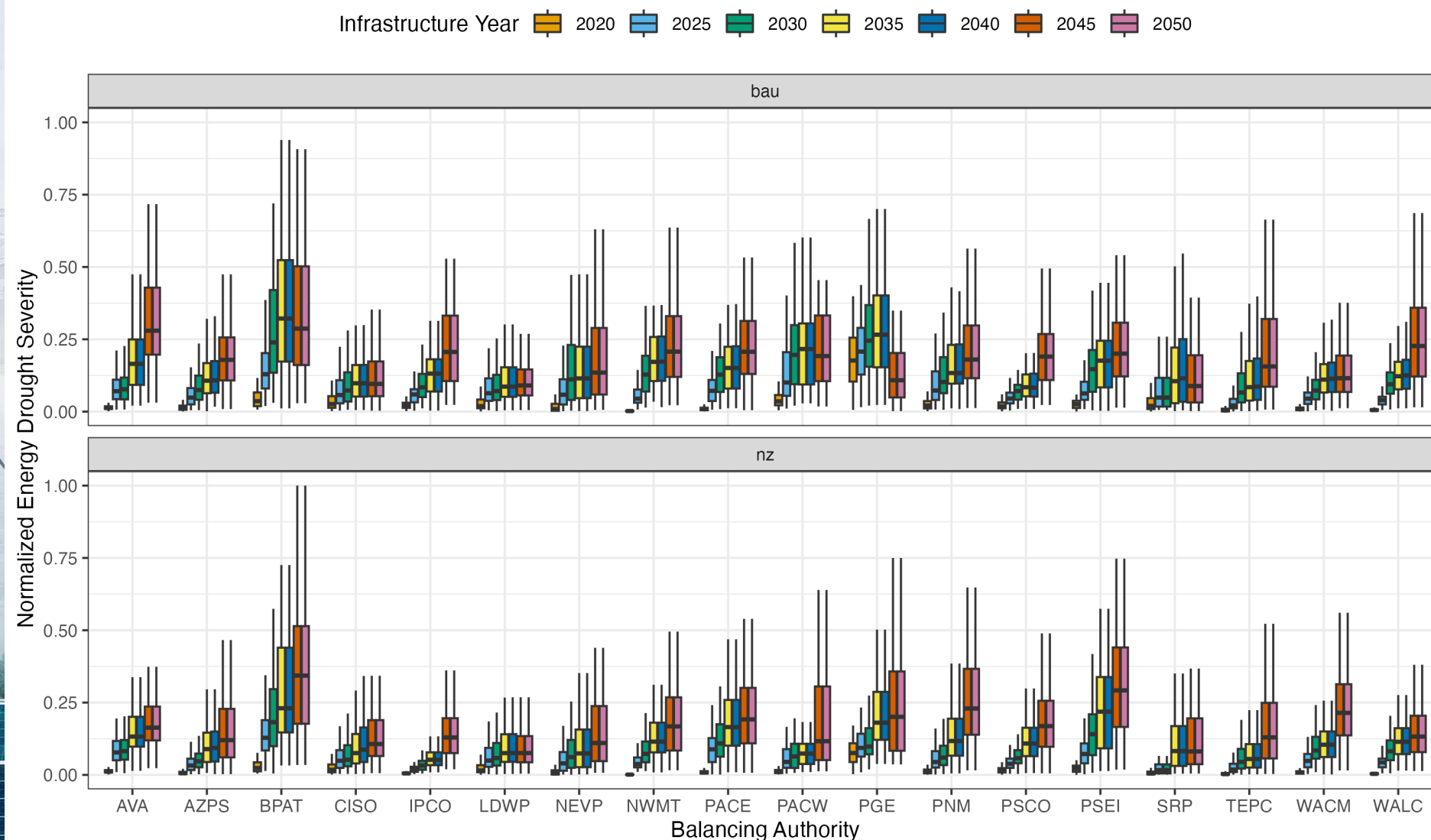
# Coincident Datasets Help Identify Periods of Potential Stress



- 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**

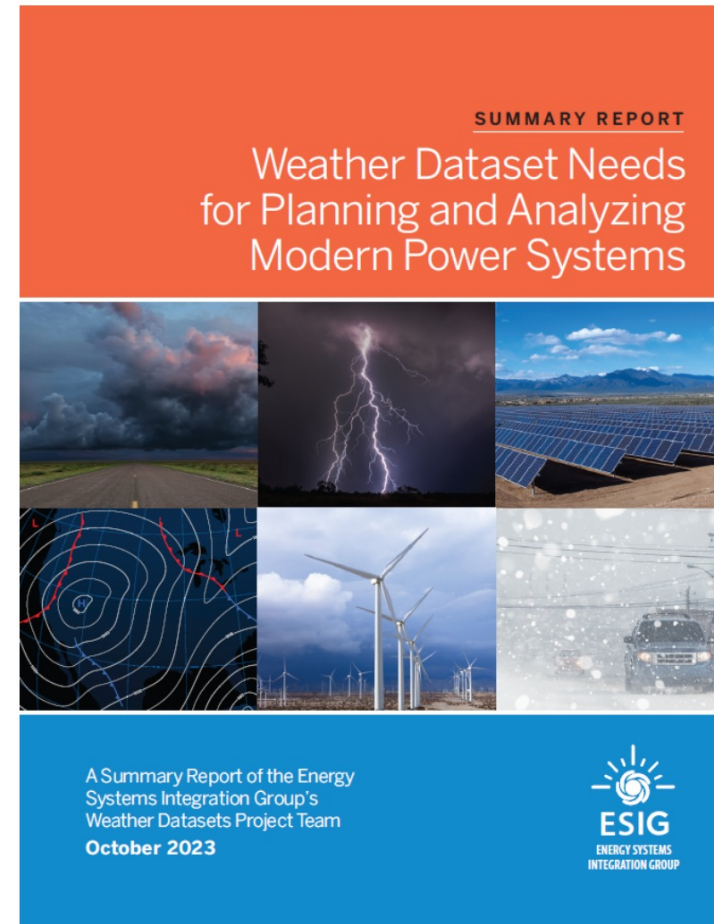
- Testing using data based on forcing from a single climate dataset
- Testing using data based on forcing from multiple climate datasets

# Continuum of Stress Testing Approaches

Good

Better

Best



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

<b>Including the necessary variables</b>	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
<b>Covering multiple decades with ongoing extension</b>	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
<b>Coincident and physically consistent</b>	Are coincident and physically consistent, in space and time, across weather variables
<b>Validated</b>	Are validated against real conditions with uncertainty quantified
<b>Documented</b>	Are documented transparently and in detail, including limitations and a guide for usage
<b>Periodically refreshed</b>	Are periodically refreshed to account for scientific and technological advancements
<b>Available and accessible</b>	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

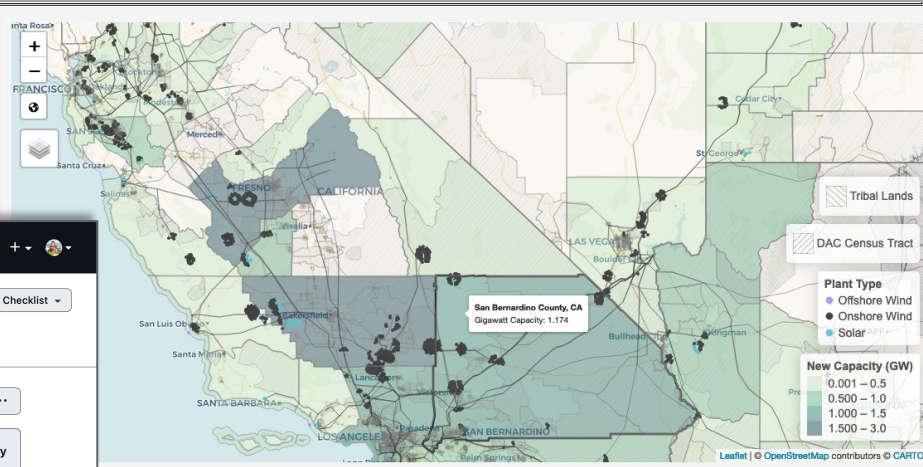
Compare 2035 Clean Grid scenario to 2020 conditions

Choose Aggregation Scale for Map

County

Choose U.S. State(s)

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



San Bernardino County, CA  
Gigawatt Capacity: 1,174

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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GODEEEP / godeeep Private

Code Issues (4) Pull requests Actions Projects (1) Wiki Security Insights Settings

main godeeep / CERF-to-GridView /


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

CERF\_testrun.ipynb Updates (#16)


Decarbonization Pathways Resilience & Reliability Justice & Equity **Datasets** Webinars Framework About Us

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



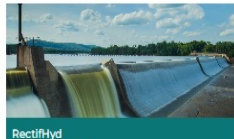
GCAM-USA Decarbonization Pathways  
Ou et al 2023  
DOI 10.5281/zenodo.7838871




Population scenarios for U.S. states  
consistent with shared socioeconomic...  
Zoraghein 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  
Narayanan 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

[godeeep.pnnl.gov](https://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](mailto:casey.burleyson@pnnl.gov)