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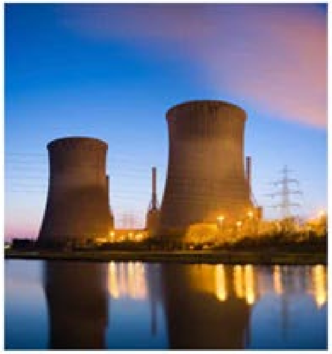
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

# 2024 NERC-NATF-EPRI Extreme Weather Transmission Planning and Modeling Workshop

**January 2024**

**RELIABILITY | RESILIENCE | SECURITY**



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# Agenda

- FERC Order 896 and TPL-008-1
  - Evan Wilcox
- Characterization of Climate Extreme Events and Data Needs
  - Delavane Diaz, EPRI
- Climate Data Panel Discussion
  - Tom Wall, ANL,
  - Grant Buster, NREL,
  - Nathalie Voisin, PNNL,
  - Delavane Diaz, EPRI
- Developing Benchmark Planning Cases for Extreme Heat and Extreme Cold Weather Events
  - Dmitry Kosterev (BPA)

# Agenda

- EPRI Framework Overview
  - Eknath Vittal
- ISO-NE Extreme Cold Study Experience
  - Stephen George (ISO-NE)
- Standard Drafting Team Next Steps
  - Jared Shaw (Entergy)

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# FERC Order 896 and TPL-008-1

Evan Wilcox, Drafting Team Chair

January 2024

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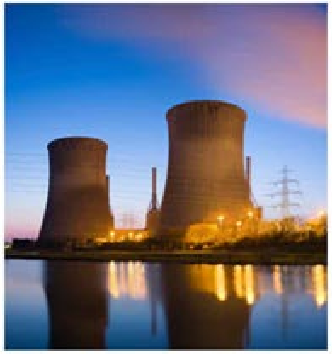


# FERC Order 896

- **NERC Project 2023-07 addressing FERC Order 896**
  - Regulatory deadline December 2024
  - Directives:
    - Develop New or Modified Standard
    - Develop Benchmark Events and Planning Cases Based on Major Prior Extreme Heat and Cold Weather Events and/or Meteorological Projects.
    - Define “wide-area”
    - Entities Responsible for Developing Benchmark Events and Planning Cases, and for Conducting Transmission Planning Studies of Wide-Area Events
      - Entity Responsible for Establishing Benchmark Events
      - Entities Responsible for Development of Planning Cases and Conducting Transmission Planning Studies of Wide-Area Events
    - Coordination Among Registered Entities and Sharing of Data and Study
    - Concurrent/Correlated Generator and Transmission Outages

# FERC Order 896

- Directives Continued:
  - Conduct Transmission System Planning Studies for Extreme Heat and Cold Weather Events
    - Steady State and Transient Stability Analyses
    - Sensitivity Analysis
    - Modifications to the Traditional Planning Approach
  - Implement a Corrective Action Plan if Performance Standards Are Not Met

# TPL-008-1

- **High-level Overview of TPL-008-1 Standard**
  - SDT is working with EPRI, NOAA and other DOE agencies with regards to statistical analysis needed to determine applicable benchmark events.
  - EPRI engaged to assist in developing the process to translate benchmark event data into benchmark planning cases used in TPL-008-1 studies.
  - New TPL-008-1 Standard will focus on the specific requirements and measures for PCs and TPs.
    - A framework process to select benchmark events, develop benchmark planning cases, and scope studies for impacted study areas drafted in Attachment 1 of TPL-008-1 standard.

# NERC Project 2023-07 Drafting Team

| Name | Entity |
|---|---|
| **Evan Wilcox (Chair)** | American Electric Power |
| **Jared Shaw (Vice Chair)** | Entergy Services |
| **Josie Daggett** | Western Area Power Administration |
| **David Duhart** | Southwest Power Pool |
| **Michael Herman** | PJM Interconnection |
| **Tracy Judson** | Florida Power & Light |
| **Sun Wook Kang** | ERCOT |
| **Andrew Kniska** | ISO New England |
| **Dmitry Kosterev** | Bonneville Power Administration |
| **David Le** | California ISO |
| **Karl Perman** | CIP CORPS |
| **Meenakshi Saravanan** | ISO New England |
| **Kurtis Toews** | Manitoba Hydro |
| **Hayk Zargaryan** | Southern California Edison |

# Questions and Answers

# Transmission System Planned Performance for Extreme Temperature: NERC TPL-008-1

## Process and Methods for Benchmark Event Identification and Case Creation

Eknath Vittal, PhD
Sr. Principal Technical Leader, EPRI

NERC-NATF-EPRI Virtual Workshop
January 17, 2024

# Developing a collaborative process…

As identified in FERC Order No. 896, TPL-008 needs to develop a consistent approach to define and study benchmark extreme events

- Convening national labs and industry to understand and distribute required data
- Supporting the standard drafting team
- Developing guidance for implementation

- Developing standard
- Providing reference information and process for selecting/approving benchmark events
- Developing framework for base case development

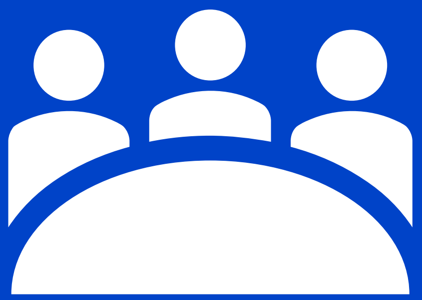
**Process and framework presented here is still developing as the SDT works to finalize the standard prior to the first balloting period at the start of March 2024**

# TPL-008 Process

## Step 1
## Benchmark Event Catalog

Potential events that will be considered for regional benchmark event

## Step 2
## Benchmark Event Selection



Coordinate selection of benchmark event for a region

## Step 3
## Benchmark Planning Case Development

Foundational and scenario (P0) cases developed and distributed to planning entities



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# Benchmark Event Selection

- BAL-003-2 establishes a process for the ERO to frequency response obligations
- TPL-008-1 intends to follow a similar approach
- Data needs to be aggregated, curated, and disseminated from the available sources
  - National Labs
  - Scientific Entities (NOAA, NSF NCAR, EPRI)
- EPRI will work to create the catalog of events
- PCs in coordination with regional entities and NERC will select benchmark events from the catalog of events

Standard BAL-003-1 — Frequency Response and Frequency Bias Setting

**Attachment A**

**BAL-003-1 Frequency Response & Frequency Bias Setting Standard**

**Supporting Document**

**Interconnection Frequency Response Obligation (IFRO)**

The ERO, in consultation with regional representatives, has established a target contingency protection criterion for each Interconnection called the Interconnection Frequency Response Obligation (IFRO). The default IFRO listed in Table 1 is based on the resource contingency criteria (RCC), which is the largest category C (N-2) event identified except for the Eastern Interconnection, which uses the largest event in the last 10 years. A maximum delta frequency (MDF) is calculated by adjusting a starting frequency for each Interconnection by the following:

- Prevailing UFLS first step
- $CC_{Adj}$ which is the adjustment for the differences between 1-second and sub-second Point C observations for frequency events. A positive value indicates that the sub-second C data is lower than the 1-second data
- $CB_R$ which is the statistically determined ratio of the Point C to Value B
- $BC'_{Adj}$ which is the statistically determined adjustment for the event nadir being below the Value B (Eastern Interconnection only) during primary frequency response withdrawal.

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**BAL-003-2 Frequency Response Obligation Allocation and Minimum Frequency Bias Settings for Operating Year 2023**

**Introduction**

Compliance with Requirement R1 on Frequency Response performance of NERC Standard BAL-003-2 – Frequency Response and Frequency Bias Setting went into effect on December 1, 2022. The official Frequency Response Obligations (FRO) and Minimum Frequency Bias Settings (FBS) for each Balancing Authority (BA) for Operating Year 2023 are attached.

This document outlines the procedure for setting FBS for 2023 and publishes the FRO and minimum FBS for BAL-003 operating year 2023 in accordance with BAL-003-2.

**Frequency Response Obligation Allocations**

Interconnection Frequency Response Obligations (IFROs) are annually calculated for each of the four Interconnections and published in the *Frequency Response Annual Analysis* (FRAA) report. Through annual endorsement of that report the NERC Reliability and Security Technical Committee sanctions the IFROs for allocation by the Electric Reliability Organization (ERO) through the methods put forth in Standard BAL-003-2.

In accordance with the recommendations from the *2022 FRAA* report that were approved by the NERC Resources Subcommittee and endorsed by the NERC Reliability and Security Technical Committee the IFRO values for the Eastern, Western, and Québec Interconnections for operating year 2023 (December 2022 through November 2023) shall not remain the same values as calculated in the *2016 FRAA* report for operating year 2017. The IFRO value for the each Interconnection shall increase or decrease slightly (in absolute terms) due to a change in the credit for load resources (CLR) and resource loss protection criteria as discussed in the *2021 FRAA*.

**Effective IFROs for Operating Year 2023**

| | Eastern (EI) | Western (WI) | Texas (TI) | Québec (QI) | Units |
|---|---|---|---|---|---|
| IFRO | -890 | -1096 | -463 | -211 | MW/0.1Hz |



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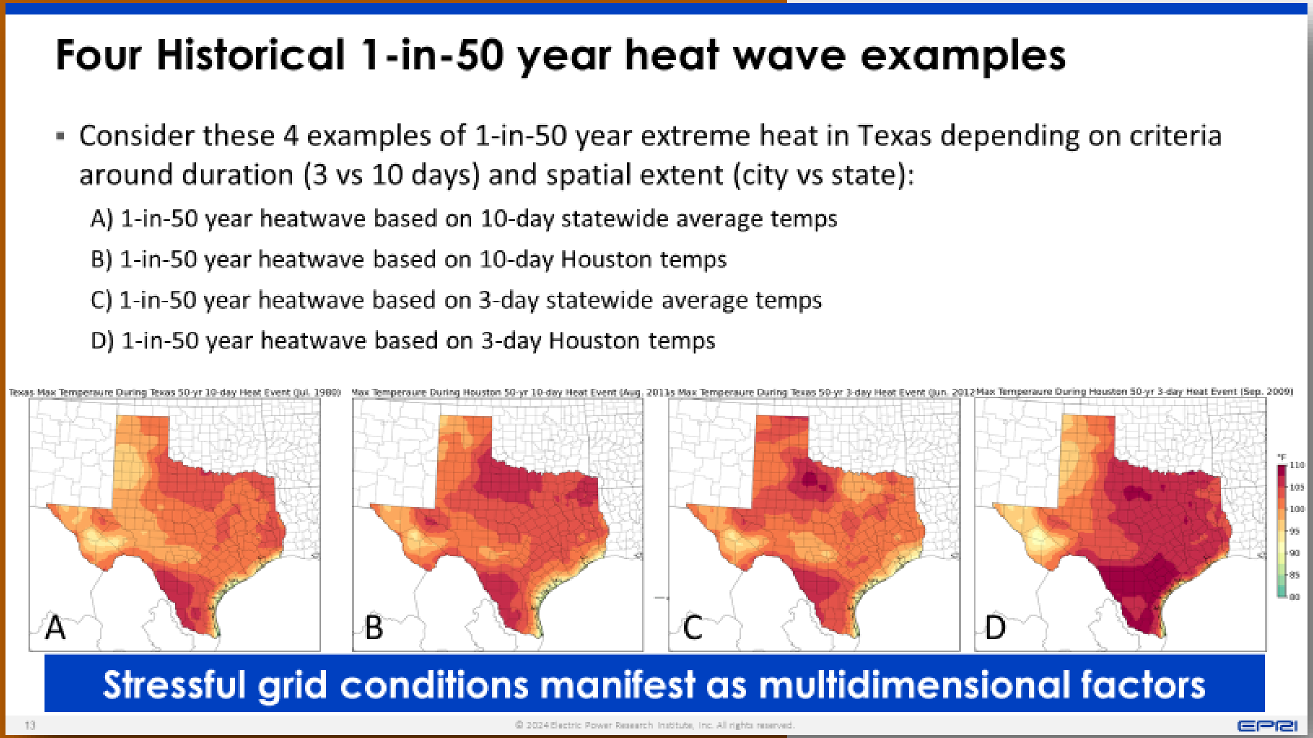
# Identifying Potential Benchmark Events




## Establish Criteria

Benchmark event criteria will vary across regions;

Criteria should consider multi-dimensional nature of both weather and grid impacts

## Wide-Area Coordination

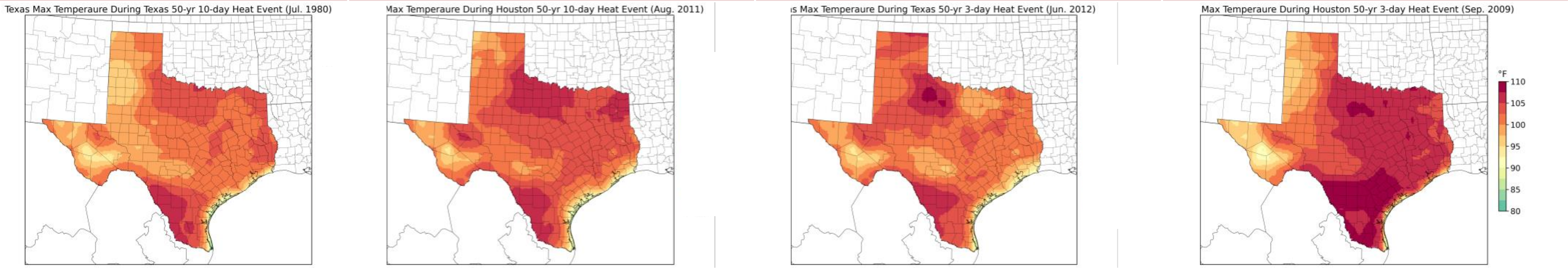
Extreme events may manifest across multiple PCs and regions

## Benchmark Event Selection

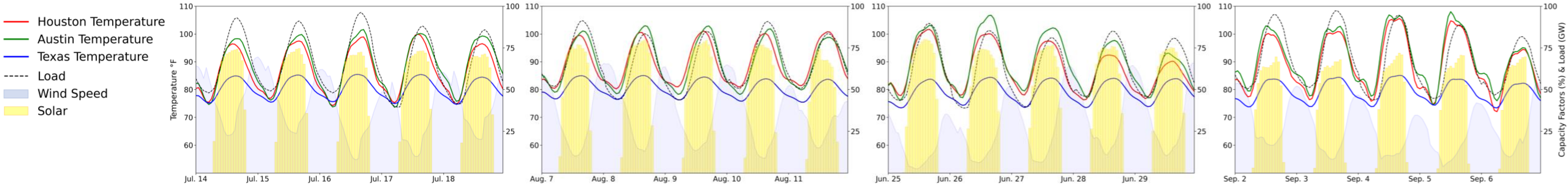
Benchmark events are selected from a catalog and rationale documented

# Four Historical 1-in-50 year heat wave examples

| | A) 10-day statewide | B) 10-day Houston | C) 3-day statewide | D) 3-day Houston |
|---|---|---|---|---|
| | July 16, 1980 | Aug 9, 2011 | June 26, 2012 | Sept 4, 2000 |




| | A) 10-day statewide | B) 10-day Houston | C) 3-day statewide | D) 3-day Houston |
|---|---|---|---|---|
| Austin 3-day high (°F) | 100.9 | 102.6 | 103.1 | 105.0 |
| Houston 3-day high (°F) | 99.6 | 101.7 | 101.2 | 104.3 |
| Texas 3-day high (°F) | 95.2 | 93.5 | 95.7 | 92.7 |
| Texas wind* (avg CF %) | 0.399 | 0.353 | 0.265 | 0.259 |
| Texas solar* (avg CF %) | 0.331 | 0.335 | 0.356 | 0.290 |
| Texas peak load* (GW) | 96 GW | 92 GW | 85 GW | 97 GW |




*Capacity factors based on current installed wind, XGW solar; load estimated based on 2020 residential/commercial/industrial technologies

# Considerations for Benchmark Event Selection for a Defined Likelihood

Multiple dimensions for consideration…

**1**

### Regionality

Each extreme event will have impacts across geographic and electrical boundaries

**2**

### Seasonality

Extreme events can extend into shoulder seasons when multiple generators may be unavailable due to scheduled maintenance

**3**

### Duration

The timeframe under which the extreme event impacts the system should also be considered and will have significant impacts on the subsequent sensitivity analysis

**4**

### Intensity

Intensity should considered alongside duration and regionality when determining benchmark events

**5**

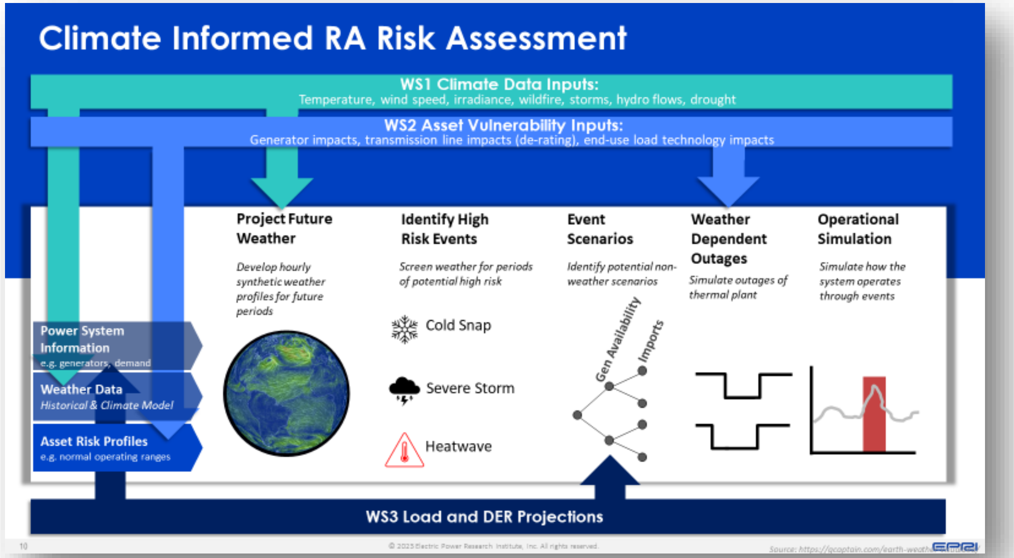
### Expected Demand

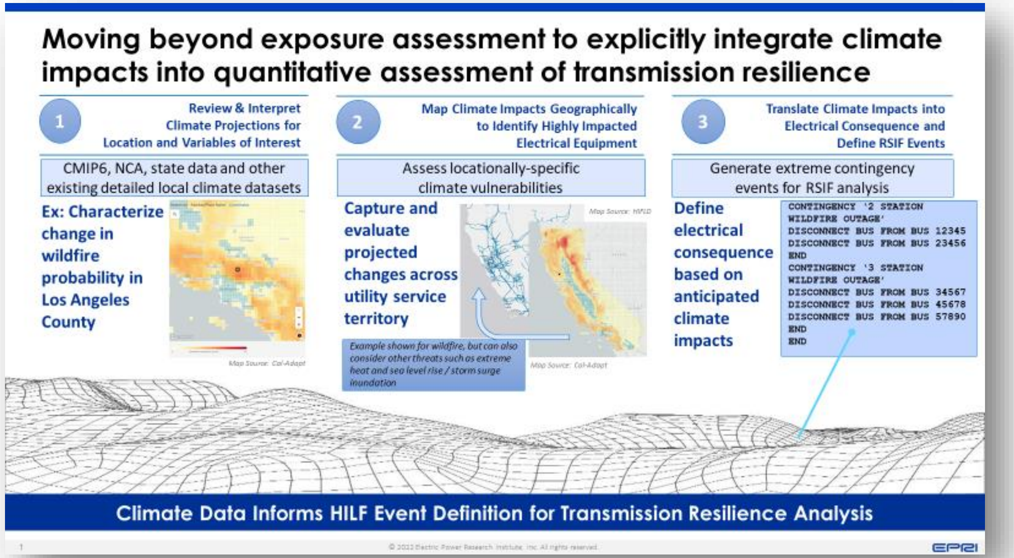
Demand levels experienced by a system will be impacted by the season of occurrence and the duration and intensity of the extreme event

# Wide-Area Event Definition

- FERC Order No. 896 does not prescribe how to define a “wide-area” event
- Can cross both geographic and electric boundaries
- NERC is directed to clarify definition of “wide-area” as part of the updated or new standard

EPRI has developed multiple approaches for wide-area event definition



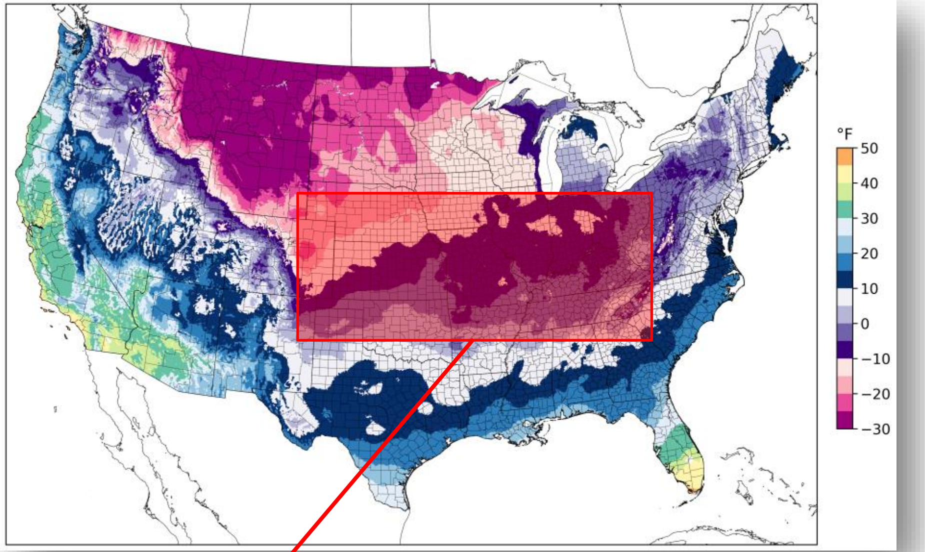



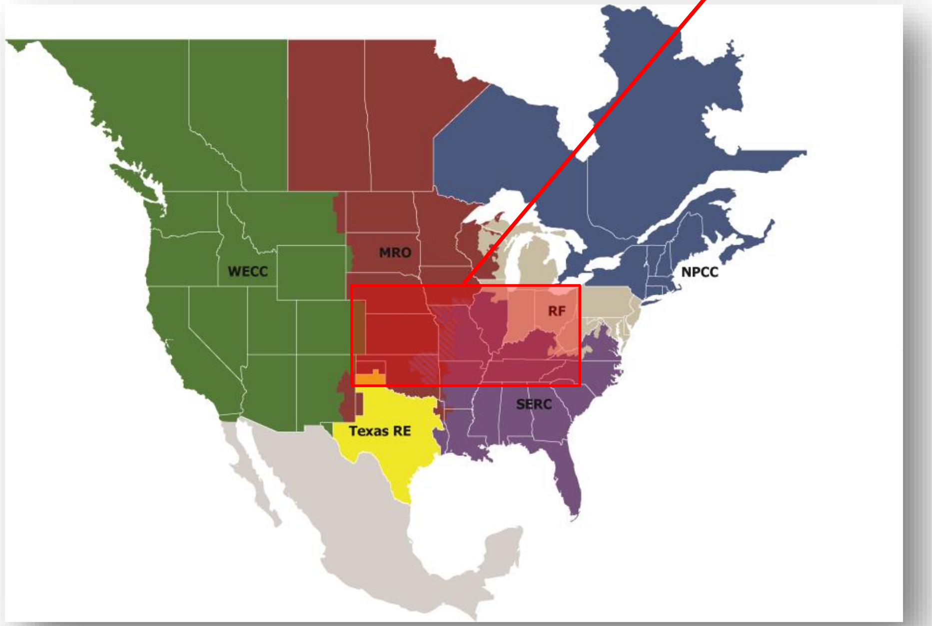

Can capture climate impacts on initial conditions and acute destructive events

# Wide-Area Coordination

- **Benchmark events can occur over multiple PCs and ISOs/RTOs**
- **Regional entities and PCs will need to coordinate on benchmark event selection**
- **The selection of the benchmark event should consider:**

1. Geographical boundaries of the benchmark for extreme heat and extreme cold temperature event.

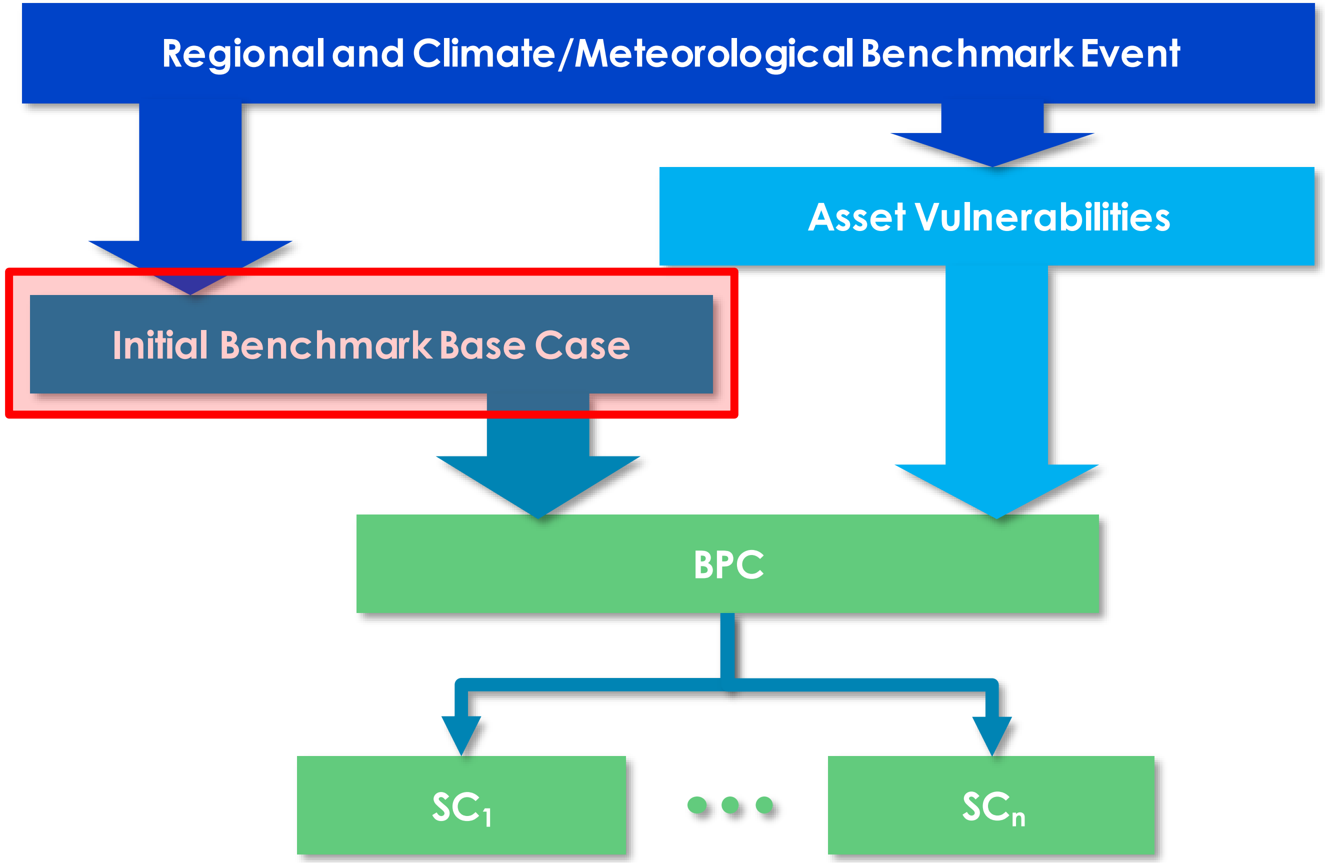



2. Electrical boundaries and applicable PCs. Electrical boundaries will be identified based on impacts to inter-tie across a region.

# Conceptual Framework for Benchmark Planning Case Development

- TPL-008 establishes minimum requirements for Extreme Temperature Assessments
- Development of initial benchmark base case will be coordinated across entities impacted by the benchmark event

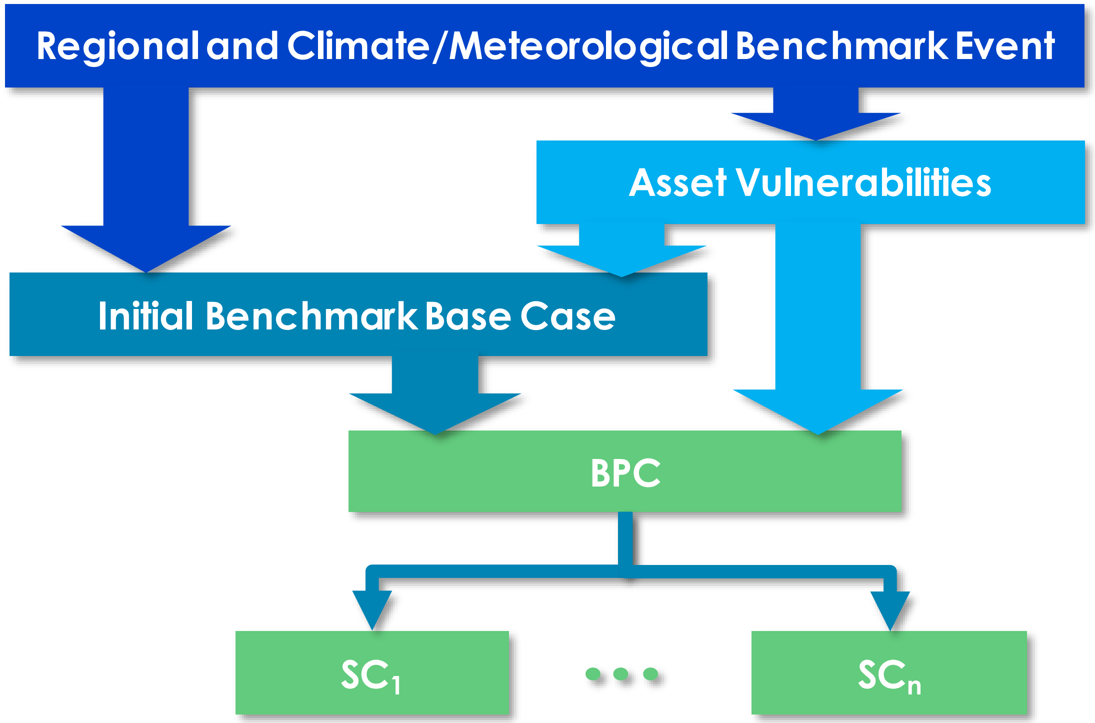



- Initial benchmark base case is the basis for case development
- Initial benchmark base case will be built using traditional transmission planning assumptions; 100 percent availability of generators (maintenance outages accounted for)
- Temperature dependent adjustments to load and generation should be accounted for selected extreme event condition



EPRI

# Conceptual Framework for Benchmark Planning Case Development



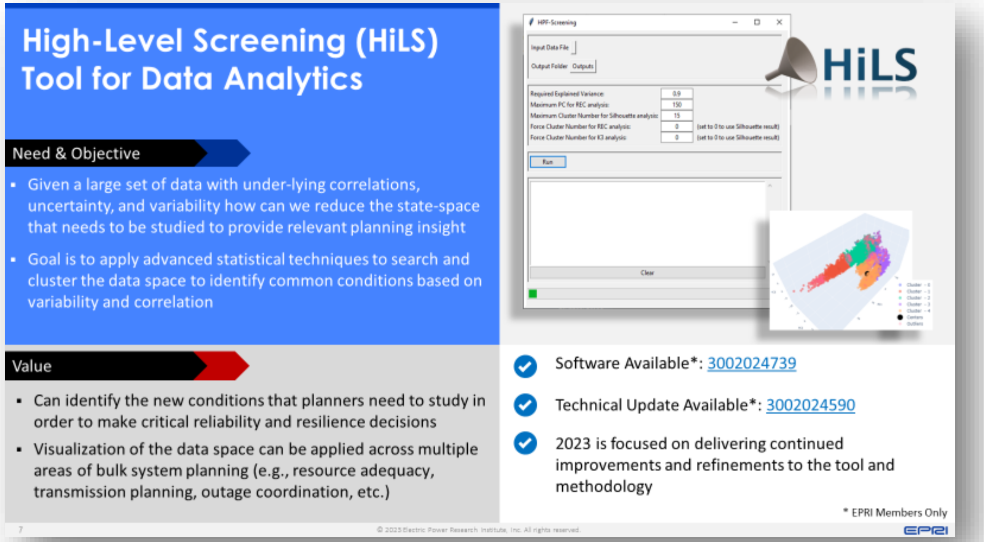

- Will need to account for temperature dependent generation capacity of thermal plants
- Set initial capacity factors for wind and solar plants that are coincident with the extreme event condition
- Modify generator availability based on the extreme temperature condition

- Initial benchmark base case will serve as the basis for the benchmark planning case used for contingency analysis
- Wind and solar capacity factors sensitivities and generator unavailabilities that could result from the benchmark extreme event condition are studied in subsequent sensitivity cases (SC)
- Since extreme event conditions occur over multiple days and generator unavailability is a probabilistic value, PCs likely need to develop multiple sensitivity conditions

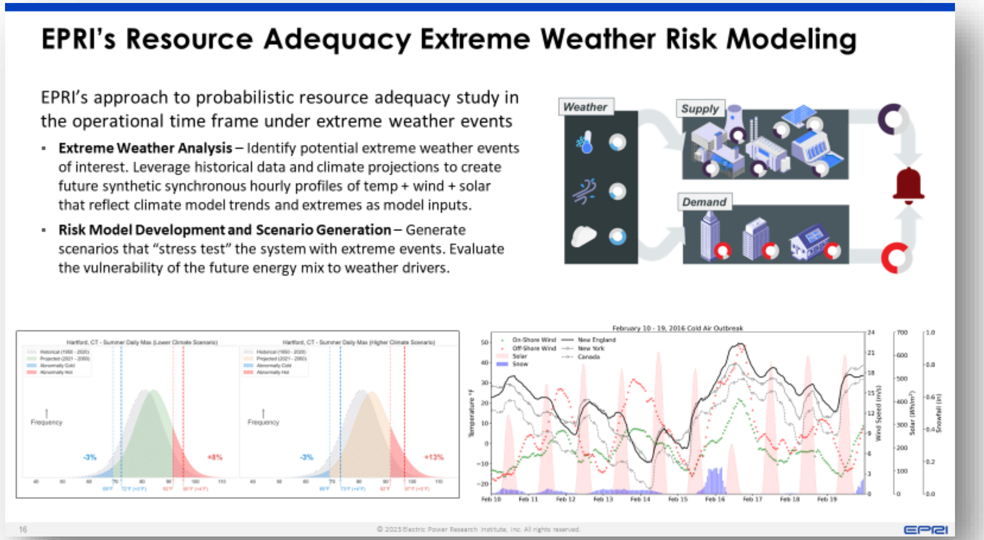
# Selecting and Building Benchmark Planning Cases

- Methodologies to select and build BPCs have to capture the statistical impacts of generator outages
- Commitments and dispatches within the windows of stressed operation would be identified and built as ac feasible power flow cases that capture redistributed flows
- Any process must robustly capture statistical impacts of outages

Statistical analysis of generation derates and outage risks




Resource adequacy and production cost models



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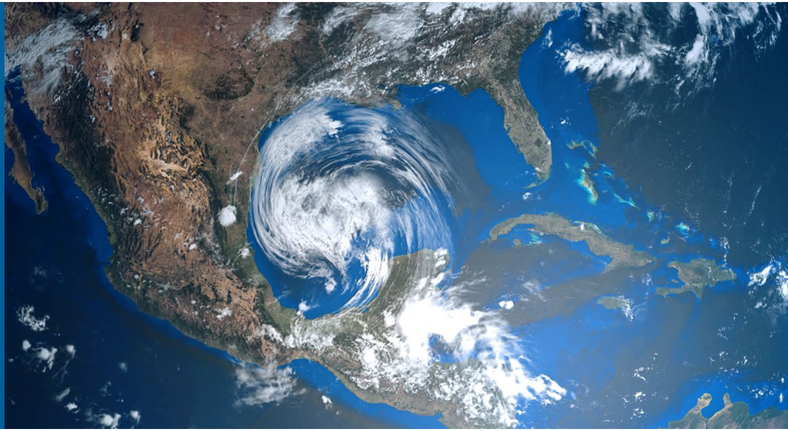
# CLIMATE & WEATHER PROJECTIONS WITH DYNAMICAL DOWNSCALING




**TOM WALL, PH.D.**
Director
Center for Climate Resilience and Decision Science

# LOCAL CLIMATE PROJECTIONS THROUGH DYNAMICAL DOWNSCALING

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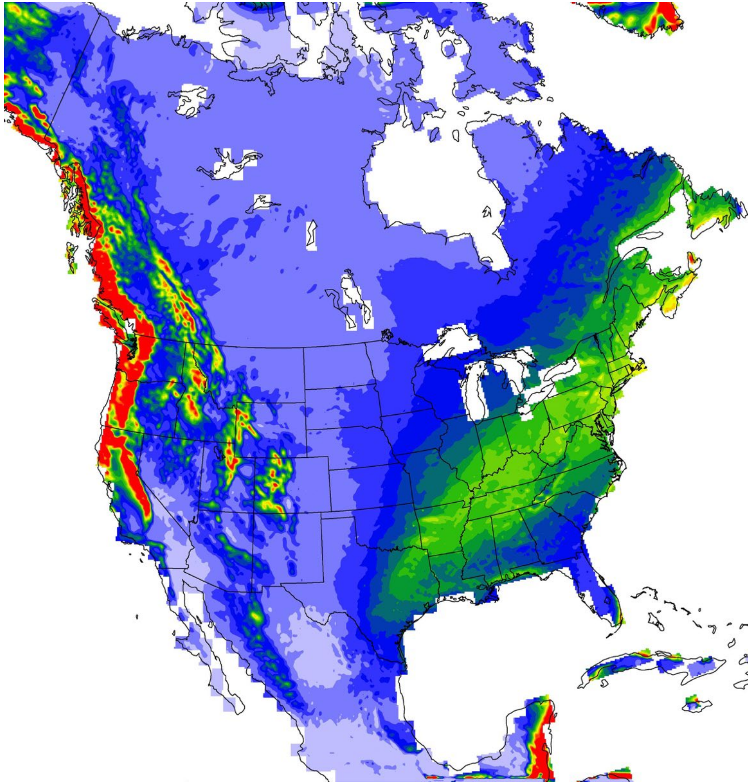
AND DECISION SCIENCE
Argonne National Laboratory

**Argonne's Dynamically Downscaled, Regional Climate Model Projects Climate Impacts Across North America**

- High resolution, neighborhood level (12km)
- Scientific transparency: widely published and scientifically peer reviewed modeling and outcomes
- Dynamical downscaling offers improvements over statistical downscaling
  - Physics-based, addresses non-stationarity
  - Produces 60+ unique climate variables
- RCP8.5 (upper limit) + RCP4.5 (mid-century peak)
- Three member ensemble of global climate models
- Three timeframes: historical, mid-century, end-of-century



# LOCAL CLIMATE PROJECTIONS THROUGH DYNAMICAL DOWNSCALING

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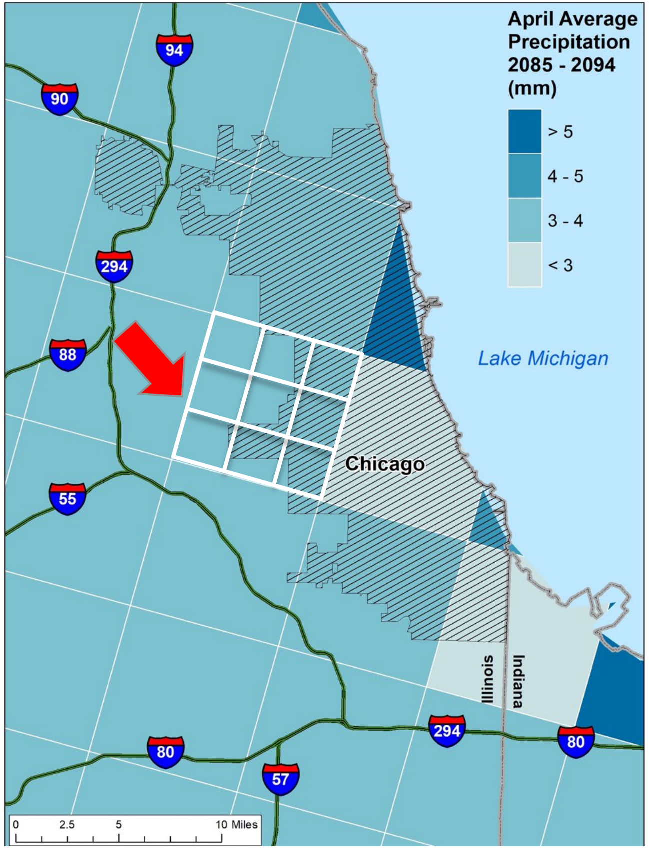
Argonne National Laboratory

**Argonne's Next-Gen Dynamically Downscaled Dataset: Convection Resolving 4-kilometer Data (ADDA.v2)**

| | ADDA.v1 | ADDA.v2 |
|---|---|---|
| Spatial Resolution | 12km | 4km |
| Temporal Resolution | 3-hourly | 1-hourly(selected)/3-hourly |
| Time Slices | 10-year | 20-year |
| Historical | 1995-2004 | 2000-2020 |
| Mid-Century | 2045-2055 | 2040-2060 |
| End-of-Century | 2085-2095 | 2080-2100 |
| GCMs | 3 | 3 |
| GHG Scenarios | CMIP5 | CMIP6 |
| | RCP4.5, RCP8.5 | SSP2-4.5, SSP5-8.5 (SSP3-7.0) |
| Coverage | CONUS + Alaska | CONUS + Alaska + Puerto Rico |



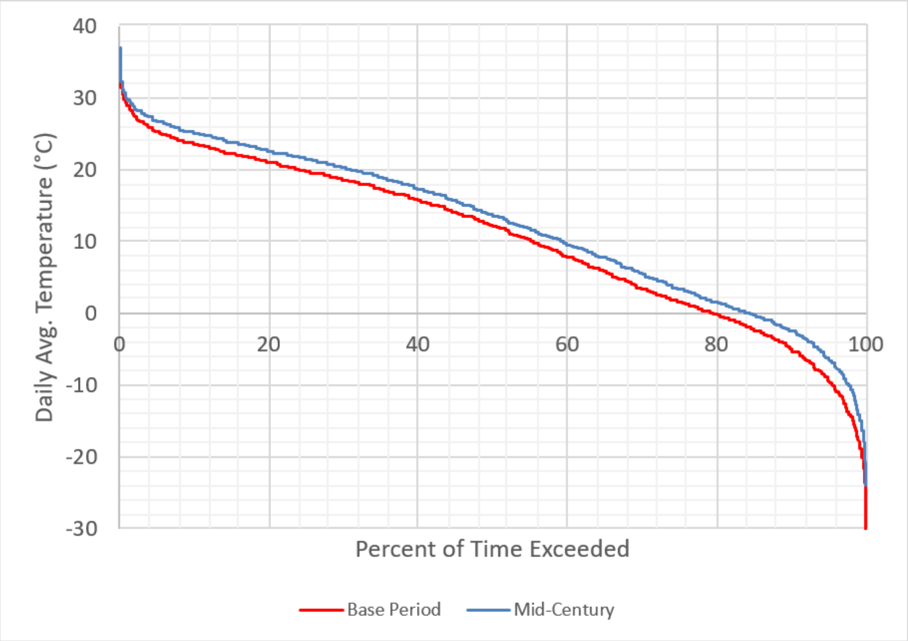
# EXAMPLE APPLICATION

## Argonne, ComEd assess future climate impacts in Northern Illinois

- Temperature extremes are critical for
  - Reliable operations of existing assets
  - Design and investment in future assets
  - Load forecasting

- Different **daily average** temperature thresholds are needed for different applications

- In northern Illinois:
  - Baseline: 35°C (95°F) exceeded ~1 days/decade
  - Mid-century: 35°C (95°F) exceeded ~4 days/decade




**Percentage of time (days/year) that daily average temperatures exceed a given threshold for the baseline and mid-century periods**

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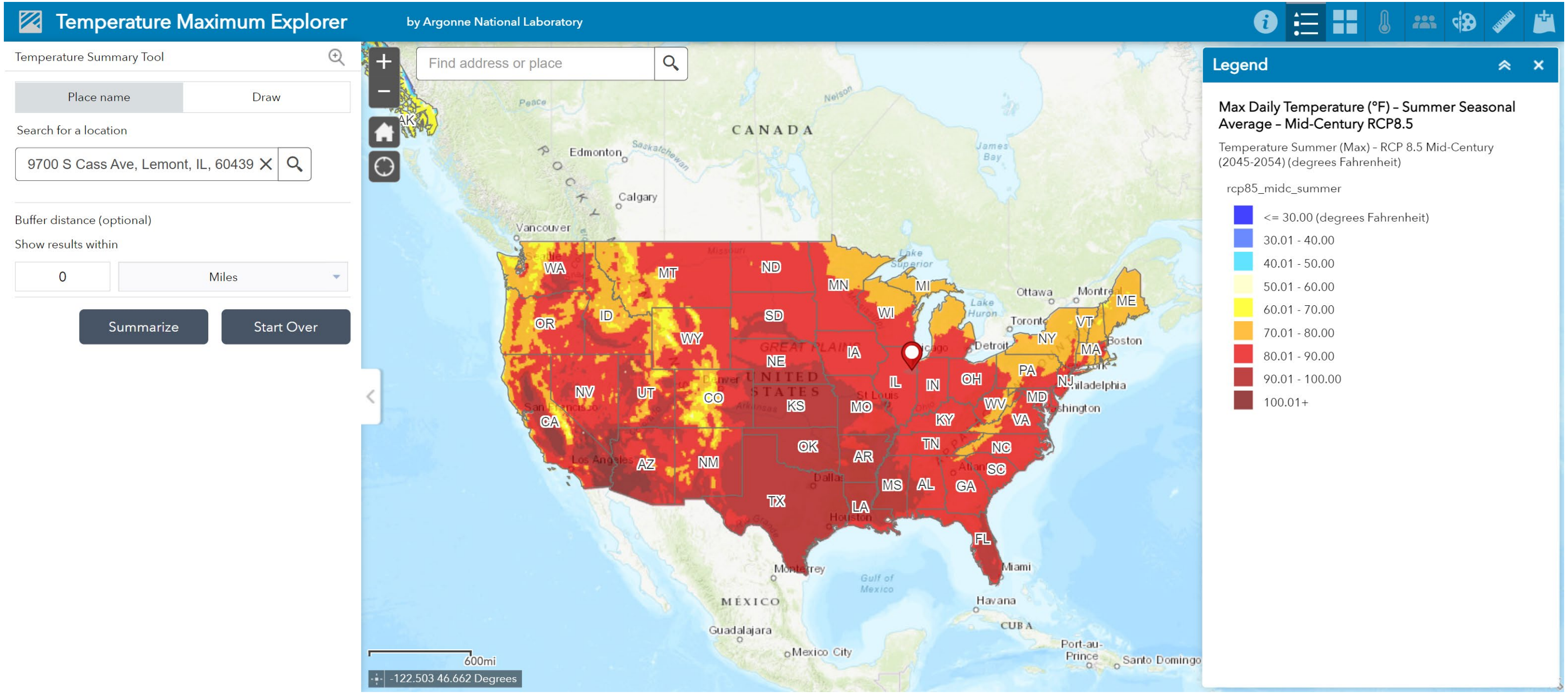
# INFORMING LOCAL DECISIONS

## Climate Risk and Resilience Portal (ClimRR)

http://climrr.anl.gov

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# ARTIFICIAL INTELLIGENCE & MACHINE LEARNING (AI/ML) DOWNSCALING



**AI / ML Climate Downscaling through Deep Learning**

- Relatively new field of science (~1-2 years) with no longstanding approaches or models **yet**
- Deep learning similar to how neurons function in the brain
  - Input taken from one layer, add weights and a 'change', and handed to next layer
  - Network output is evaluated for an optimization function, the error propagates backward up the network and used to improve the weights
  - Algorithm ***learns*** from this backward propagation to seek ***deeper*** connections in data that minimize error
- Requires a supercomputer to "train" AI/ML models on massive data, but once trained, can run on a laptop
- Seek to improve spatiotemporal resolution of existing datasets – global or regional climate models – but AI/ML-based climate models also possible

# THANK YOU

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NREL
Transforming ENERGY

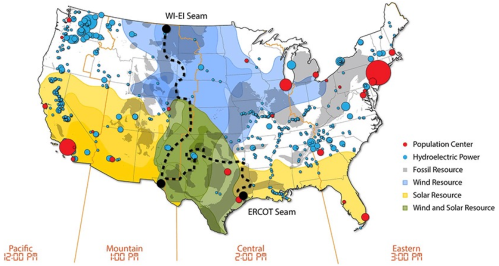
# Weather and Climate Data at NREL

Grant Buster, Data Scientist

Extreme Weather Transmission Planning and Modeling Workshop
January 17th, 2024

# Renewable Energy Integration Studies: Envisioning Future Energy Systems

The NREL Seams Study

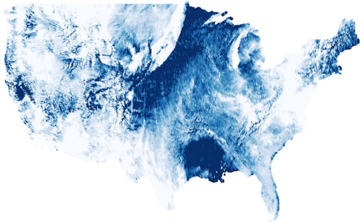



The North American Renewable Integration Study (NARIS)

LA100

The Los Angeles 100% Renewable Energy Study

PR100



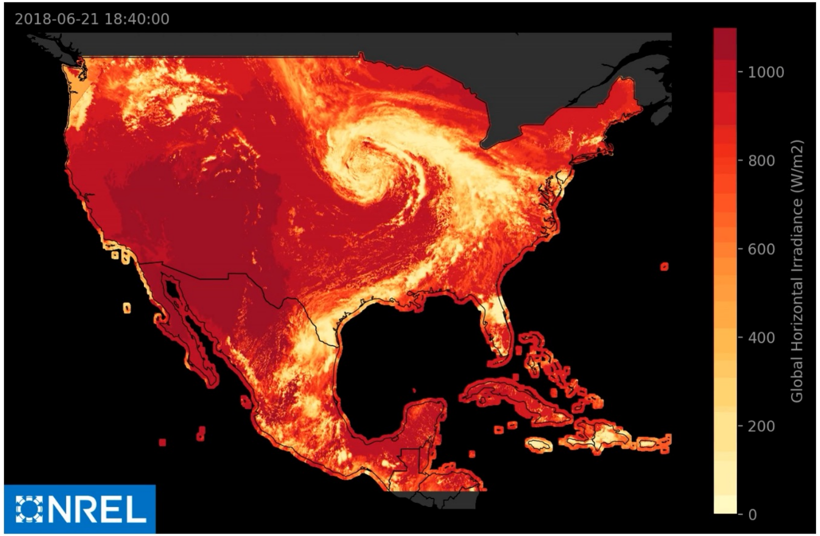
"The Evolving Role of Extreme Weather Events in the U.S. Power System with High Levels of Variable Renewable Energy"

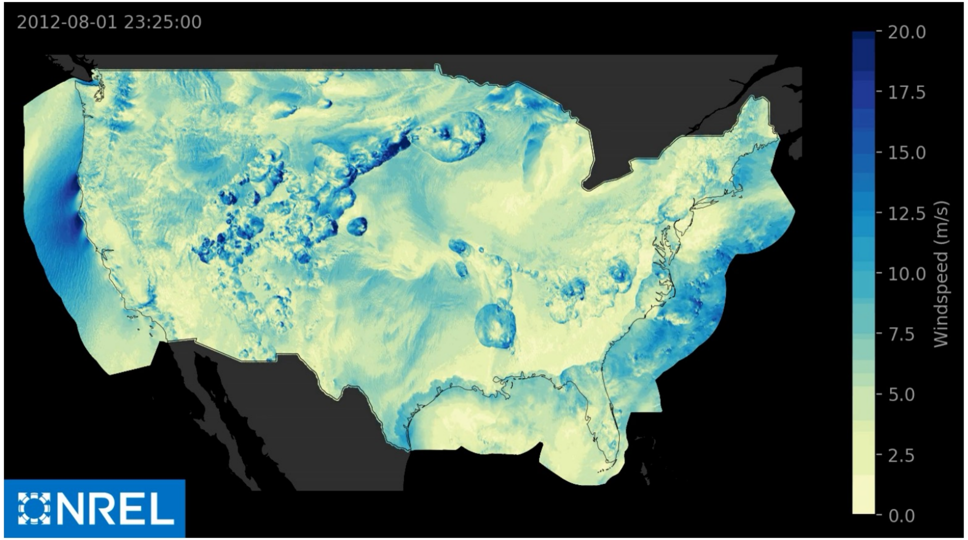
U.S. DEPARTMENT OF ENERGY

**Building a Better Grid**

*National Transmission Planning Study*

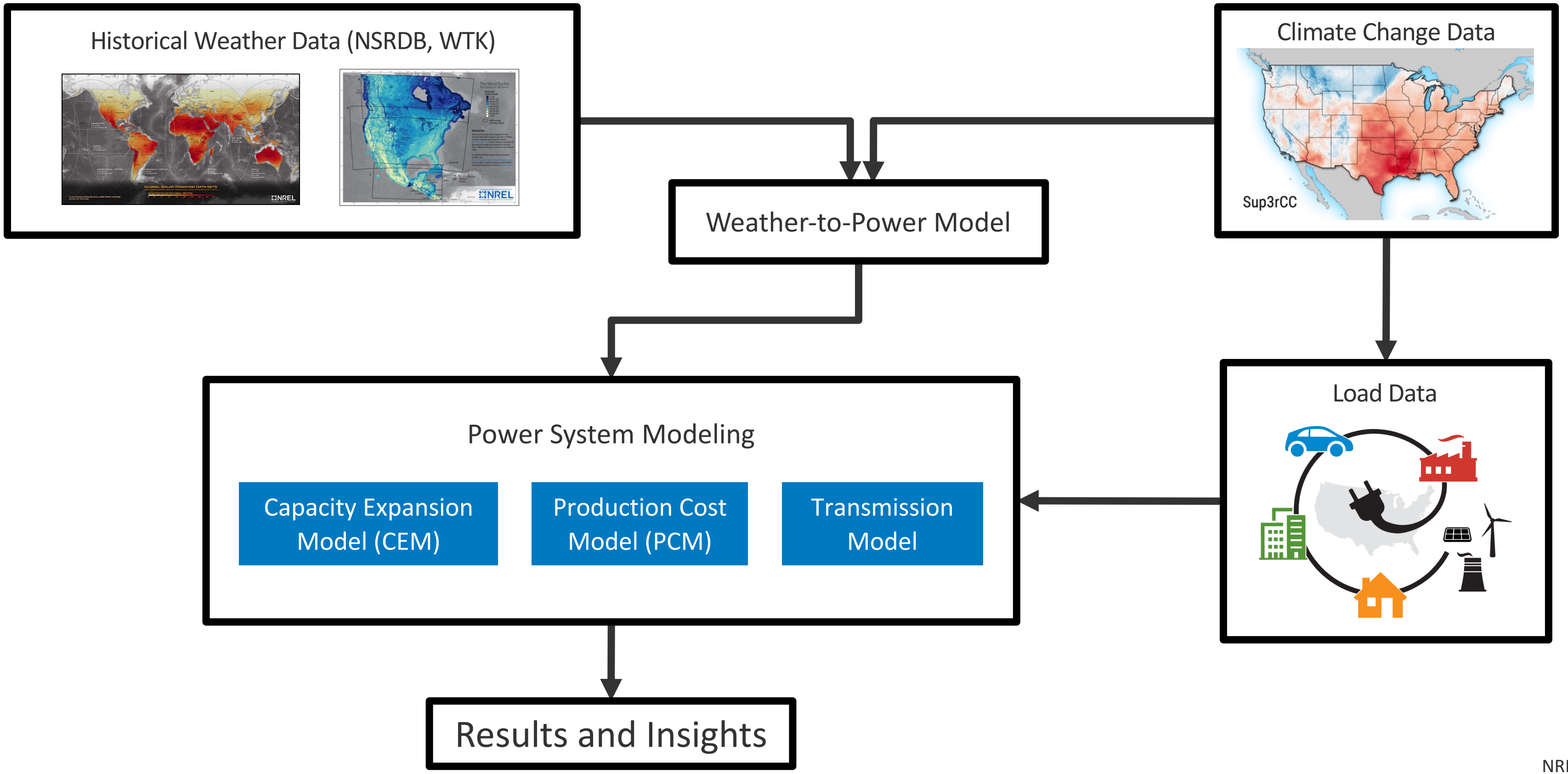
# Historical Weather Data: NSRDB and WIND Toolkit




- The National Solar Radiation Database (NSRDB) is a satellite-derived irradiance dataset
- The Wind Integration National Dataset (WIND) Toolkit is produced using numerical weather prediction
- Focused on the accurate reproduction of historical weather conditions and wind and solar variability
- Limited temporal scope, no uncertainty quantification

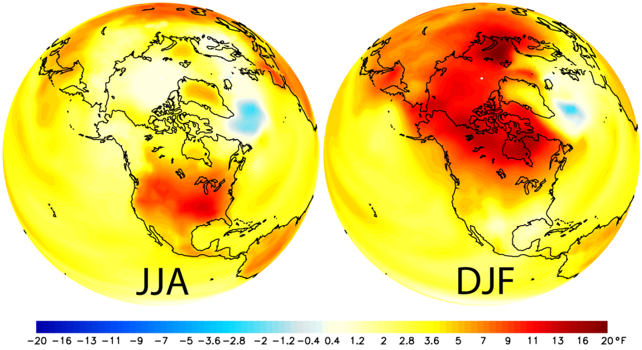
# How is this data used?



# Climate Data Downscaling: Mind the Gap

## Global Climate Models (GCMs)

NOAA GFDL CM2.1 Climate Model

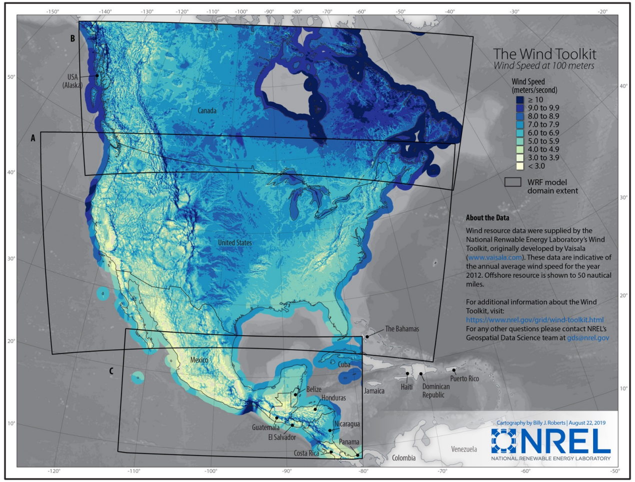



Surface Air Temperature Change [°F]

(2050s average minus modeled 1971-2000 average) SRES A1B scenario

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

## Mesoscale NREL Datasets (WTK, NSRDB)



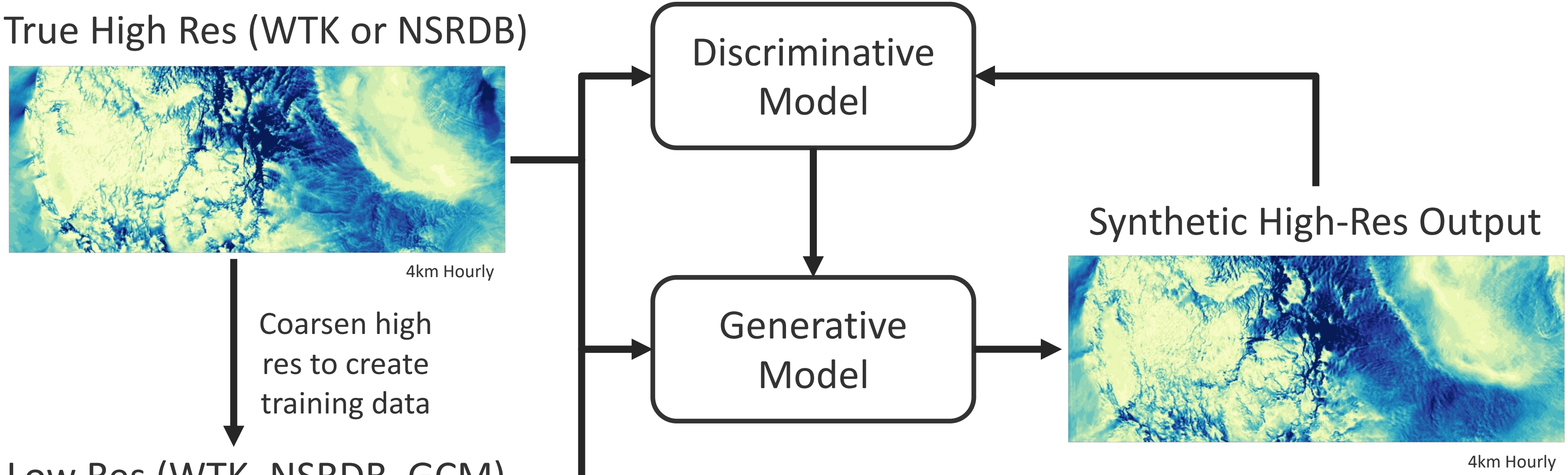

~100 km grid resolution
daily average data
2000-2100

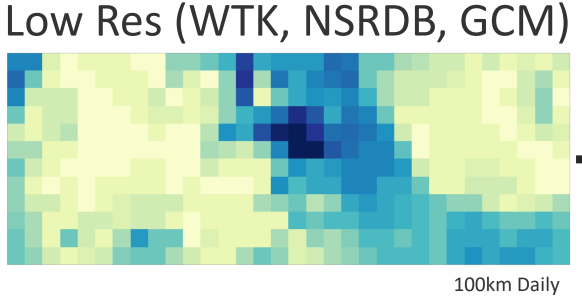
How do we bridge this gap?

~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)



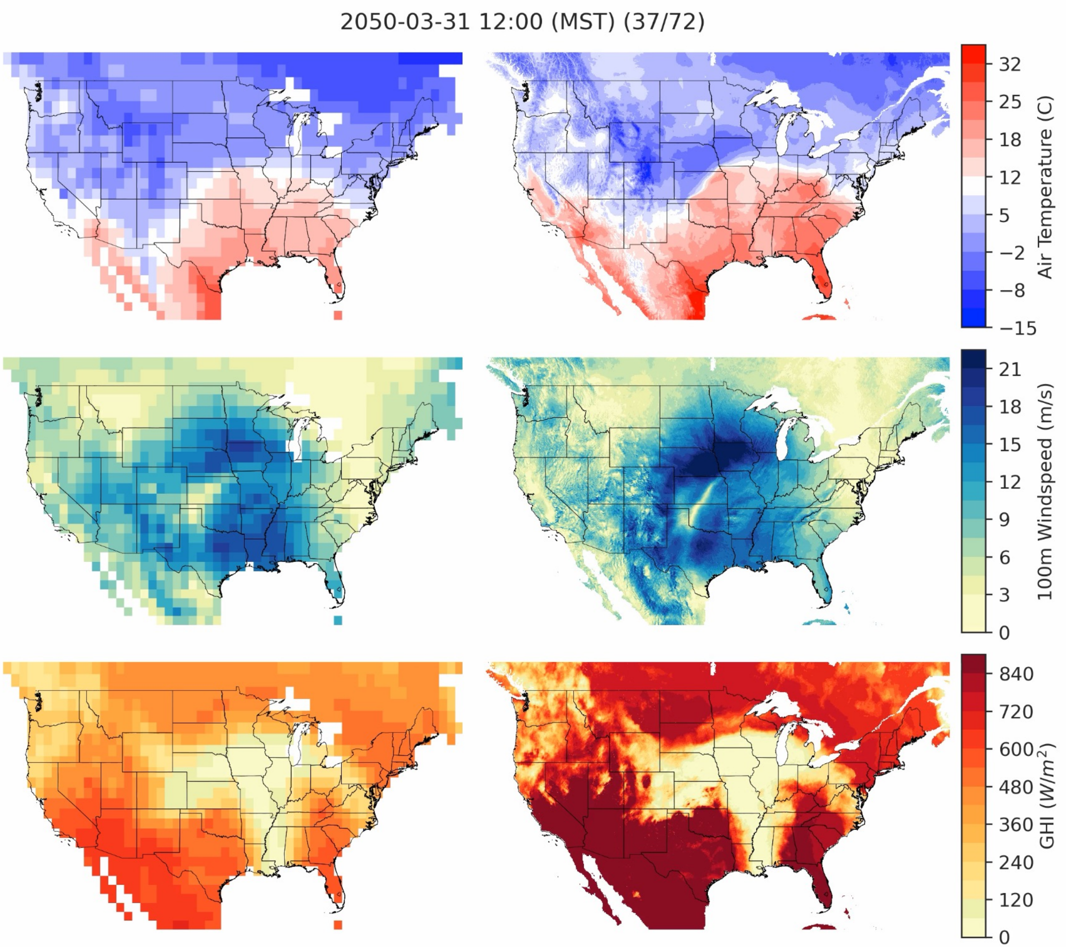




**Benefits of Downscaling with ML:**

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/

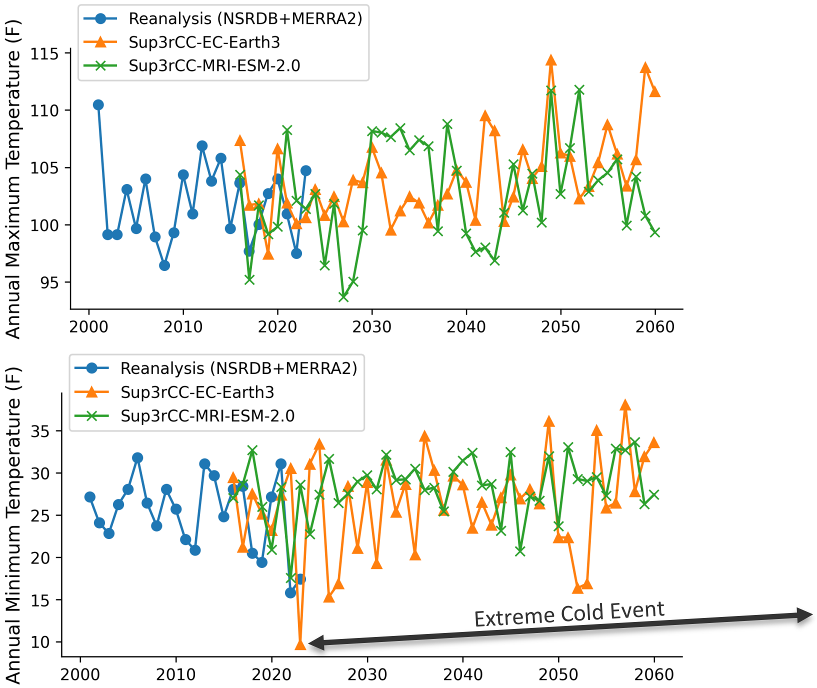
# Sup3rCC

- 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
- 90 year of data is available for two GCMs, SSP5-8.5, 2015-2059
- Hosted on AWS, integrated with cloud data streaming solutions:
  - [DOI 10.25984/1970814](https://doi.org/10.25984/1970814)



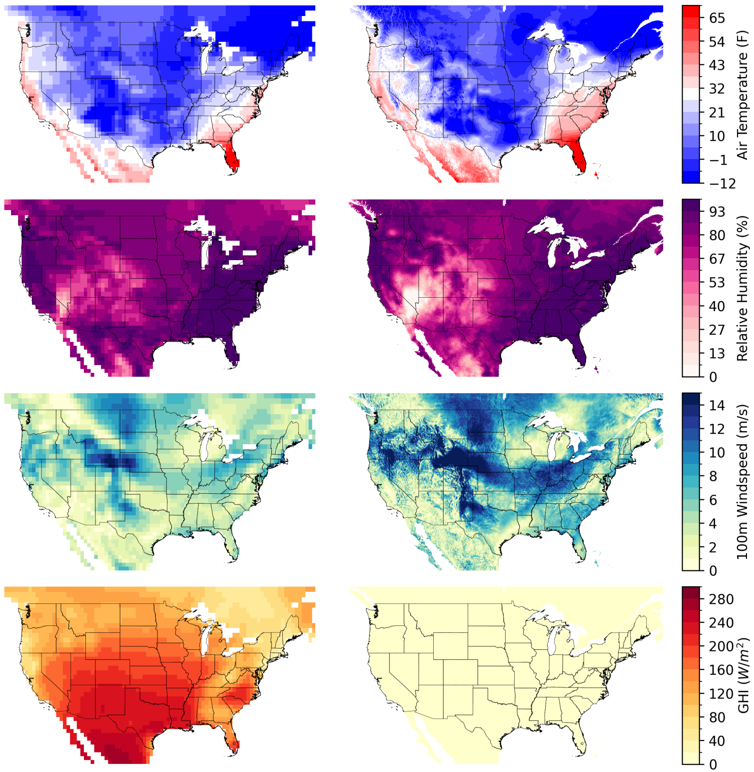

Buster et al., "Super-Resolution for Renewable Energy Resource Data with Climate Change Impacts using Generative Machine Learning", in review at *Nature Energy* (2024).

# Example Extreme Events in Houston, Texas




Sup3rCC can be used to study unprecedented hot and cold events but cannot be used to study historical events like the 2021 Texas cold wave

EC-Earth3 (left) and Sup3rCC-EC-Earth3 (right)




EC-Earth3 maps are daily values (e.g., daily minimum temperature), Sup3rCC is instantaneous at minimum nighttime temperature

# PACES: Power Planning for Alignment of Climate and Energy Systems

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

- 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

NREL Transforming ENERGY

Oak Ridge National Laboratory
Los Alamos National Laboratory
TVA Tennessee Valley Authority
Southern Company
EPRI Electric Power Research Institute
Evolved Energy Research
CUNY The City University of New York
UCONN School of Engineering
Colorado State University

# For Your Consideration…

- How is the data represented across **space, time, and multiple variables**?
  - Wind and solar resource variability, synchronicity across variables, etc…
- How is **meteorological uncertainty** represented in the data?
  - Uncertainty from inter-annual variability, different climate models, downscaling method(s), climate scenarios, etc…
- How can we handle this **uncertainty in decision making**?
  - Can we make good decisions now given that we cannot perfectly predict the future?
- **Pragmatic** considerations:
  - Data access and streaming, cloud deployment, software integration, etc…

**Shoutout to Colleagues**:

**Sup3rCC** – Brandon Benton, Andrew Glaws, Ryan King

**NSRDB** – Manajit Sengupta, Yu Xie, Aron Habte, Brandon Benton

**WTK** – Caroline Draxl, Michael Rossol, Ethan Young

Sup3rCC on OEDI

# Thank you

**www.nrel.gov**

Grant.Buster@nrel.gov

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

# Characterization of Climate Extreme Events and Integration in Power System Studies

## 2024 NERC-NATF-EPRI Extreme Weather Transmission Planning and Modeling Workshop

Jan 17, 2024

**Nathalie Voisin**, Casey Burleyson, Cameron Bracken

U.S. DEPARTMENT OF ENERGY BATTELLE

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

# Climate Dataset Features: Essential versus Desirable

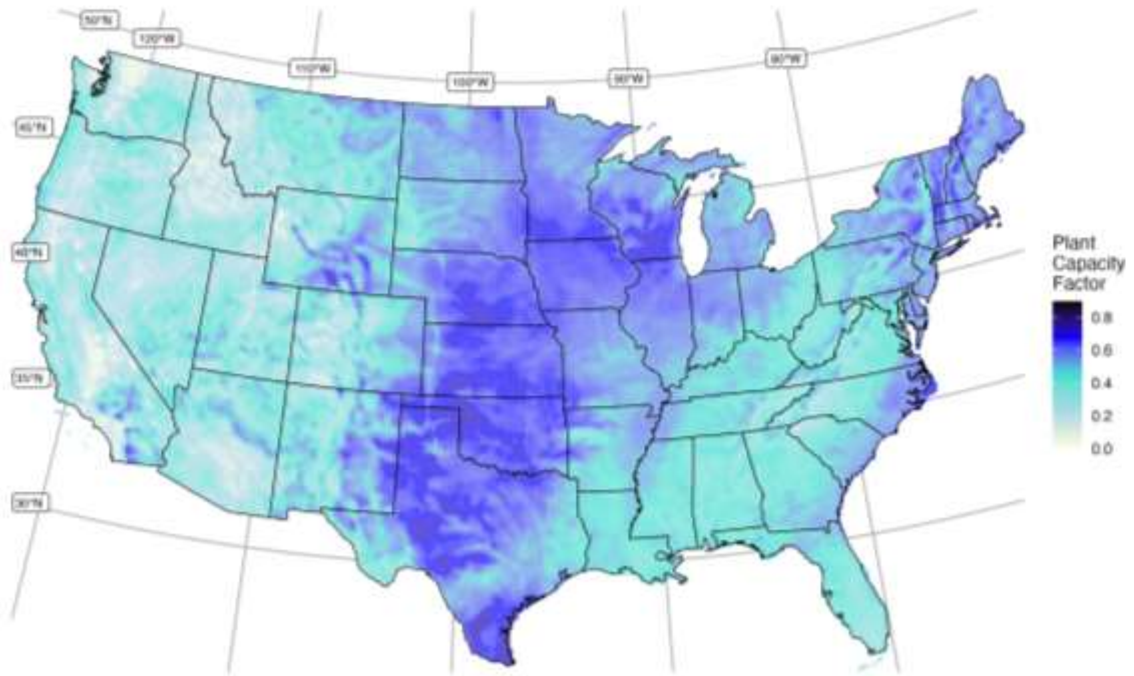
Desirable attributes of climate datasets to inform power system planning are getting consensus among the applied climate community.

Even if the datasets seem perfect, the collaboration between climate scientists and power engineers (guidance) is needed to use the datasets appropriately.

Climate “threats” reside in the dynamics between variables across scales and the interactions with and between human systems (energy generation, demand and delivery).

- **Necessary variables**
- Multiple Decades
- Coincident and physically consistent
- Validated
- Documented
- Regularly refreshed
- Available and accessible

Energy Systems Integration Group. 2023. Weather Dataset Needs for Planning and Analyzing Modern Power Systems (Full Report). A Report of the Weather Datasets Project Team. Reston, VA. https://www.esig.energy/weather-data-for-power-system-planning



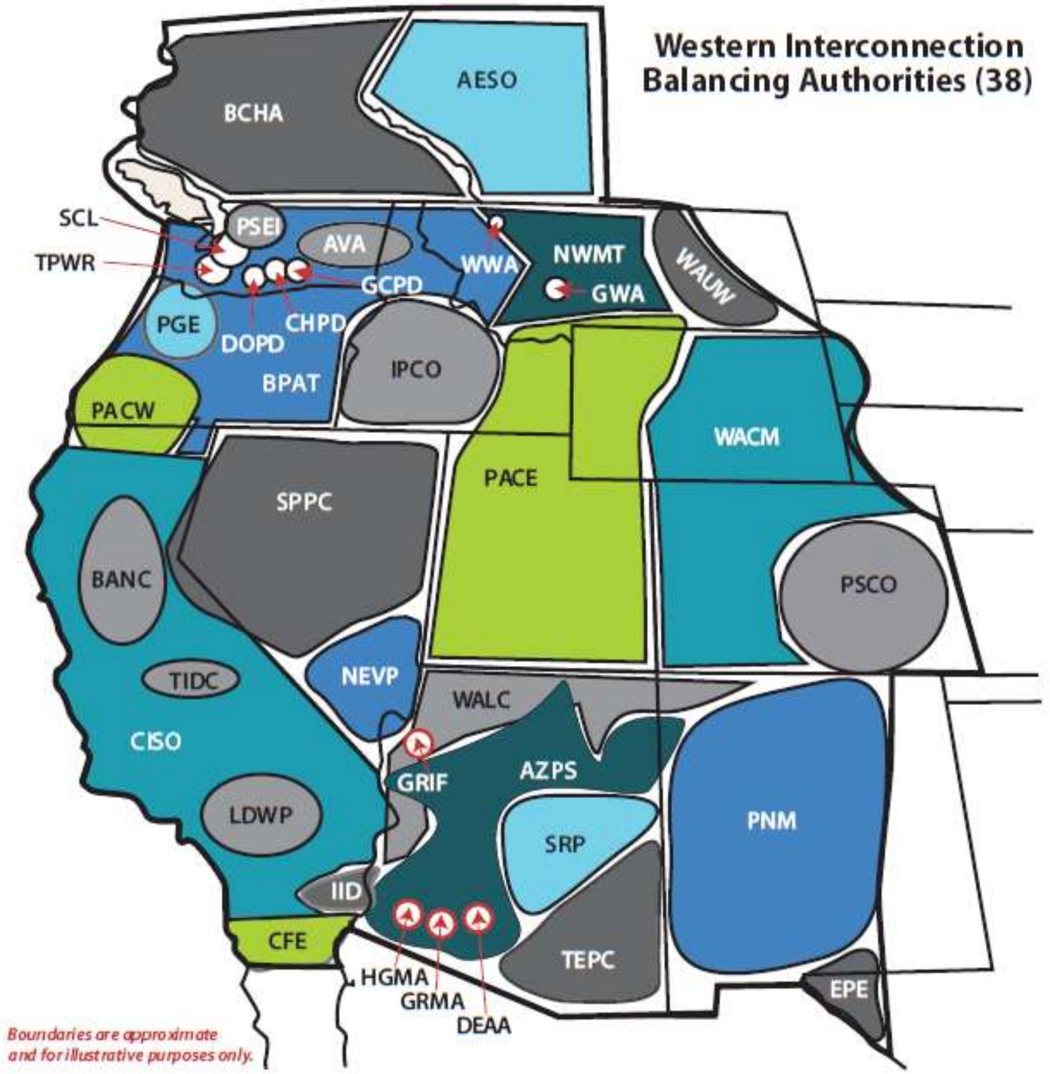

Bracken, C., Thurber, T., & Voisin, N. (2023). Hourly Wind and Solar Generation Profiles at 1/8th Degree Resolution (v1.0.0) [Data set]. https://doi.org/10.5281/zenodo.10214348

# Ideal datasets might differ for asset and system dynamics specifics reliability standards, for now…

Recent advances in understanding and quantifying the impact of climate on energy generation, demand and delivery:

- From a single technology to a set of technologies:
  - Trends : availability of fuels
  - Extreme events : operational availability (outage) and efficiency (deratings)

- From asset scale to power grid dynamics
  - Regional coordination: short term, seasonal and annual imports/exports
  - Regional propagation: compound extreme event –initial conditions - storyline approach

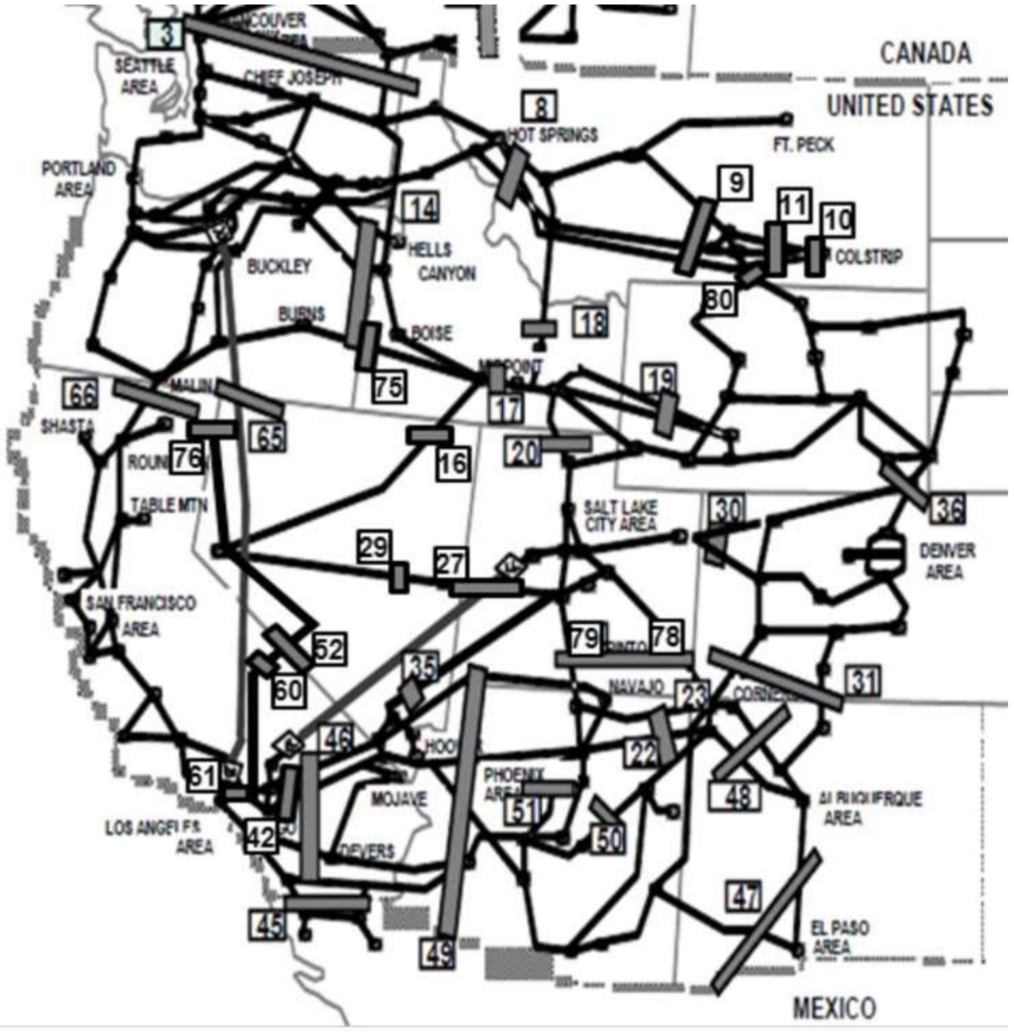



WECC 2013. Balancing Authority Cooperation Concepts to Reduce Variable Generation Integration Costs in the Western Interconnection: Intra-Hour Scheduling. https://www.osti.gov/servlets/purl/1073496

# Climate Dataset Features Specific To Transmission Studies

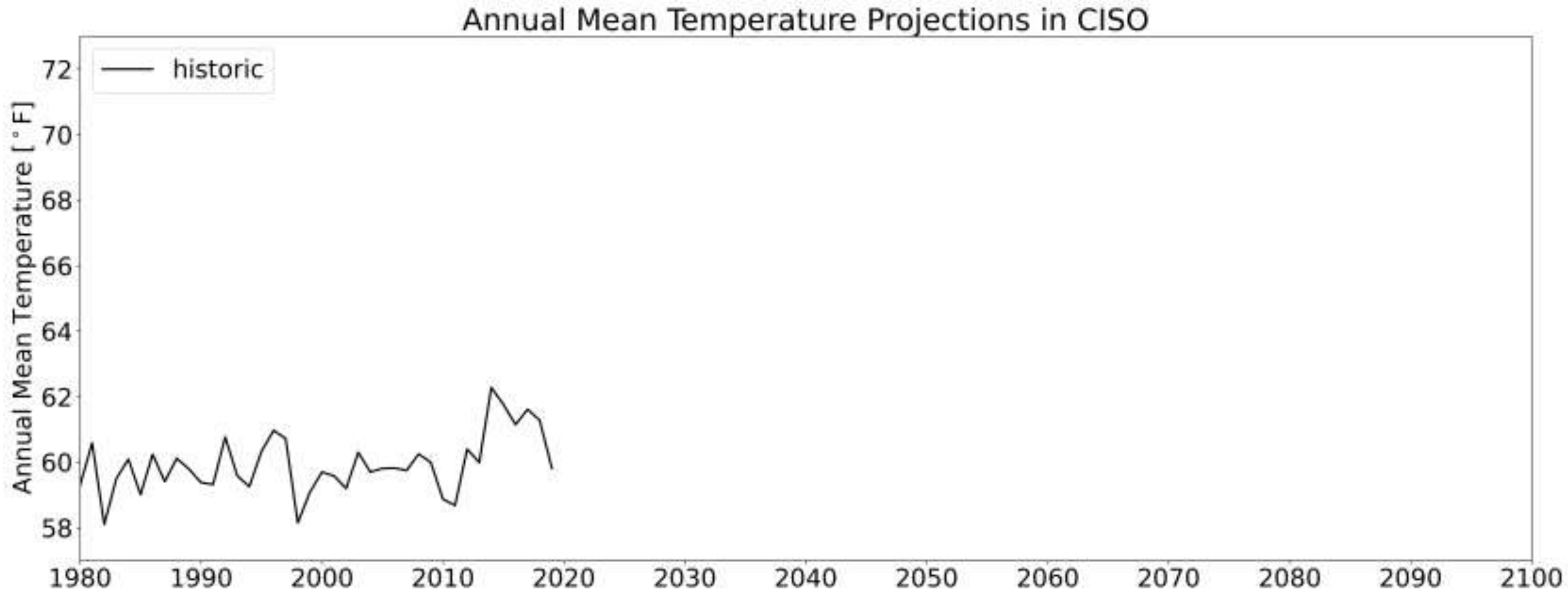
To assess the resilience and reliability of the bulk power system, it is critical to evaluate system performance:

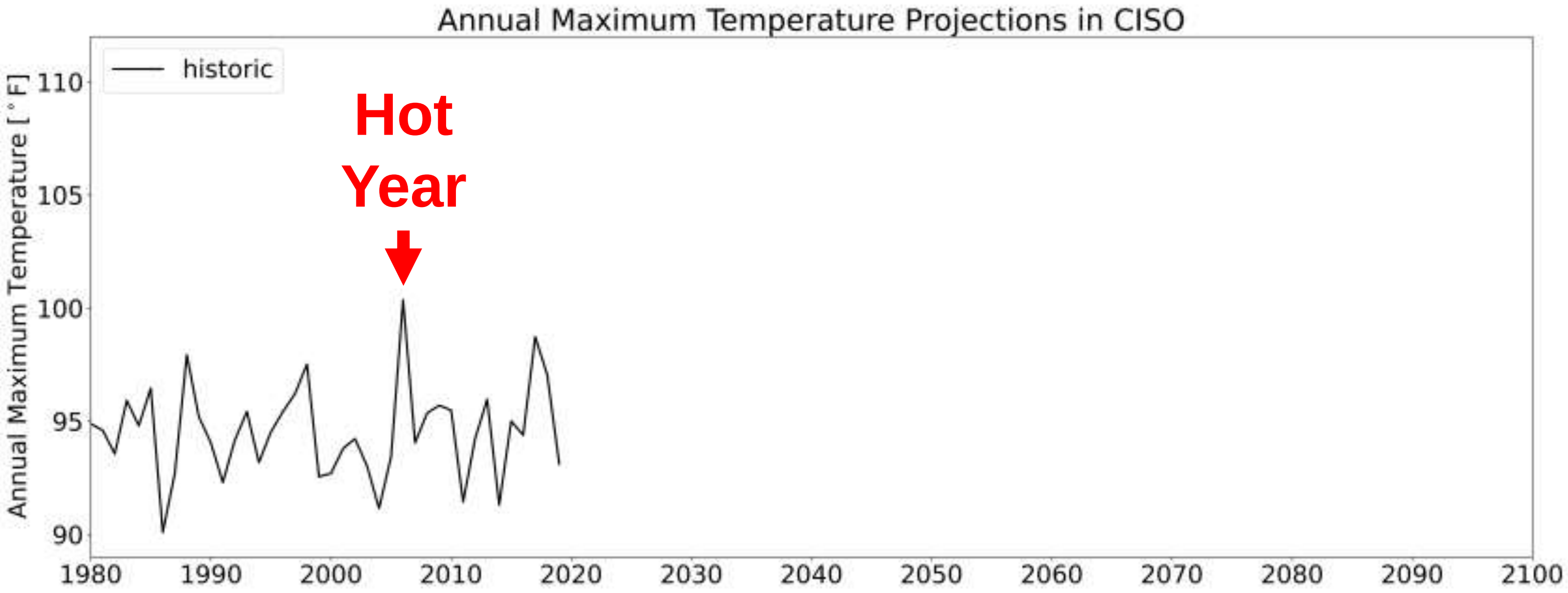
1. With coincident load-wind-solar-hydro conditions;
2. Across a wide range of historical and projected weather conditions.




WECC 2013. WECC Path Reports.
https://www.wecc.org/Reliability/TAS_PathReports_Combined_FINAL.pdf

# 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
- RCP4.5 and RCP8.5 hot/cold
- 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 : Burleyson, C., Thurber, T., & Vernon, C. (2023). Projections of Hourly Meteorology by Balancing Authority Based on the IM3/HyperFACETS Thermodynamic Global Warming (TGW) Simulations (v1.0.0) [Data set]. MSD-LIVE Data Repository. https://doi.org/10.57931/1960530

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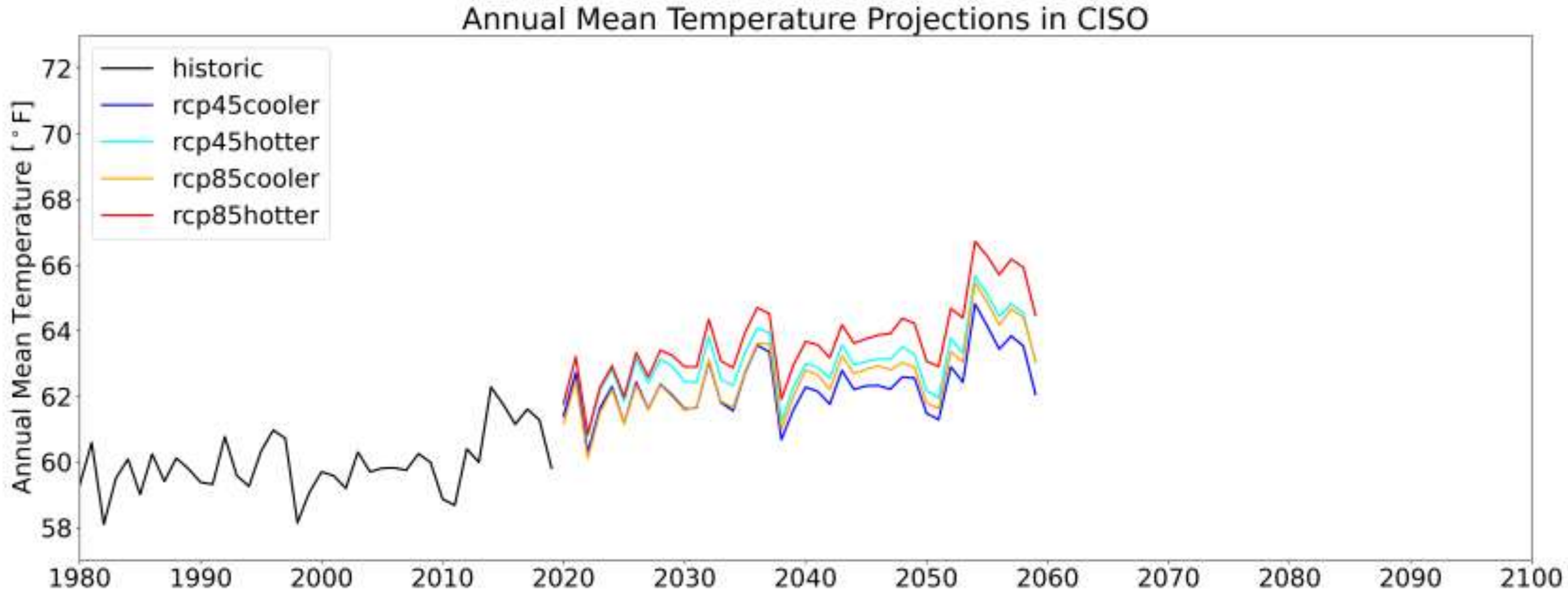


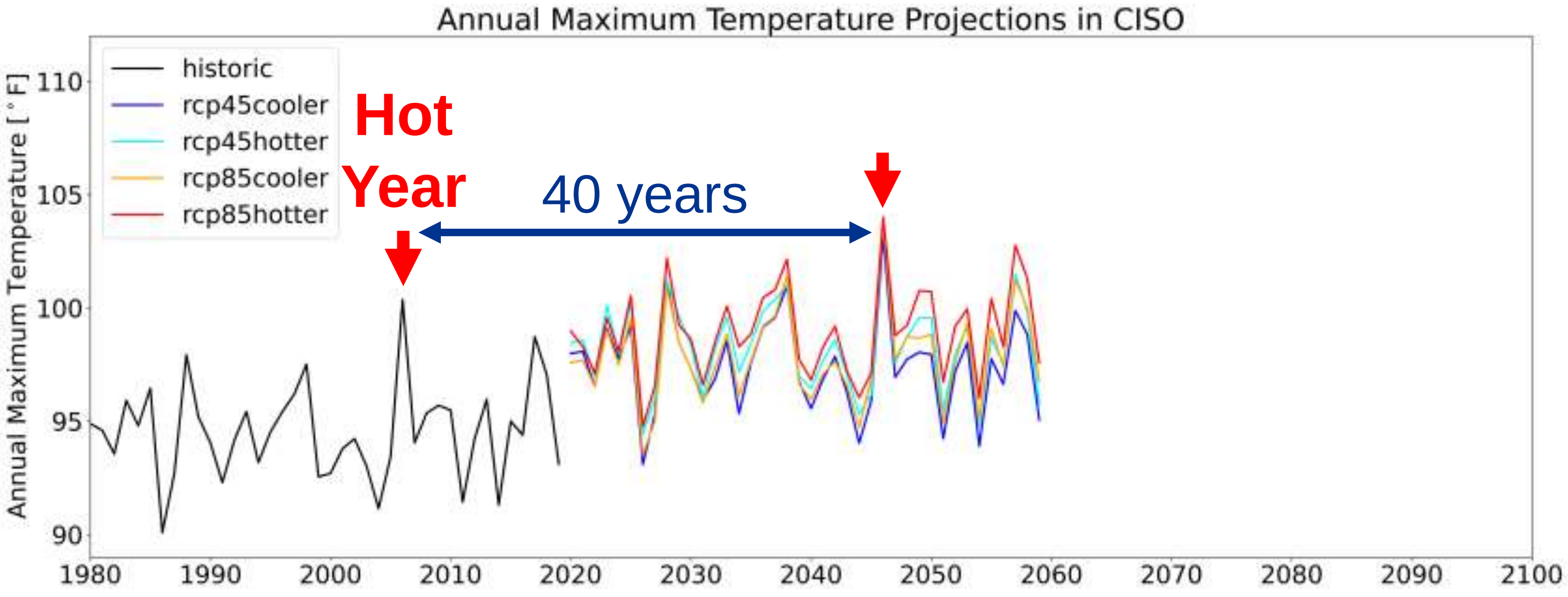


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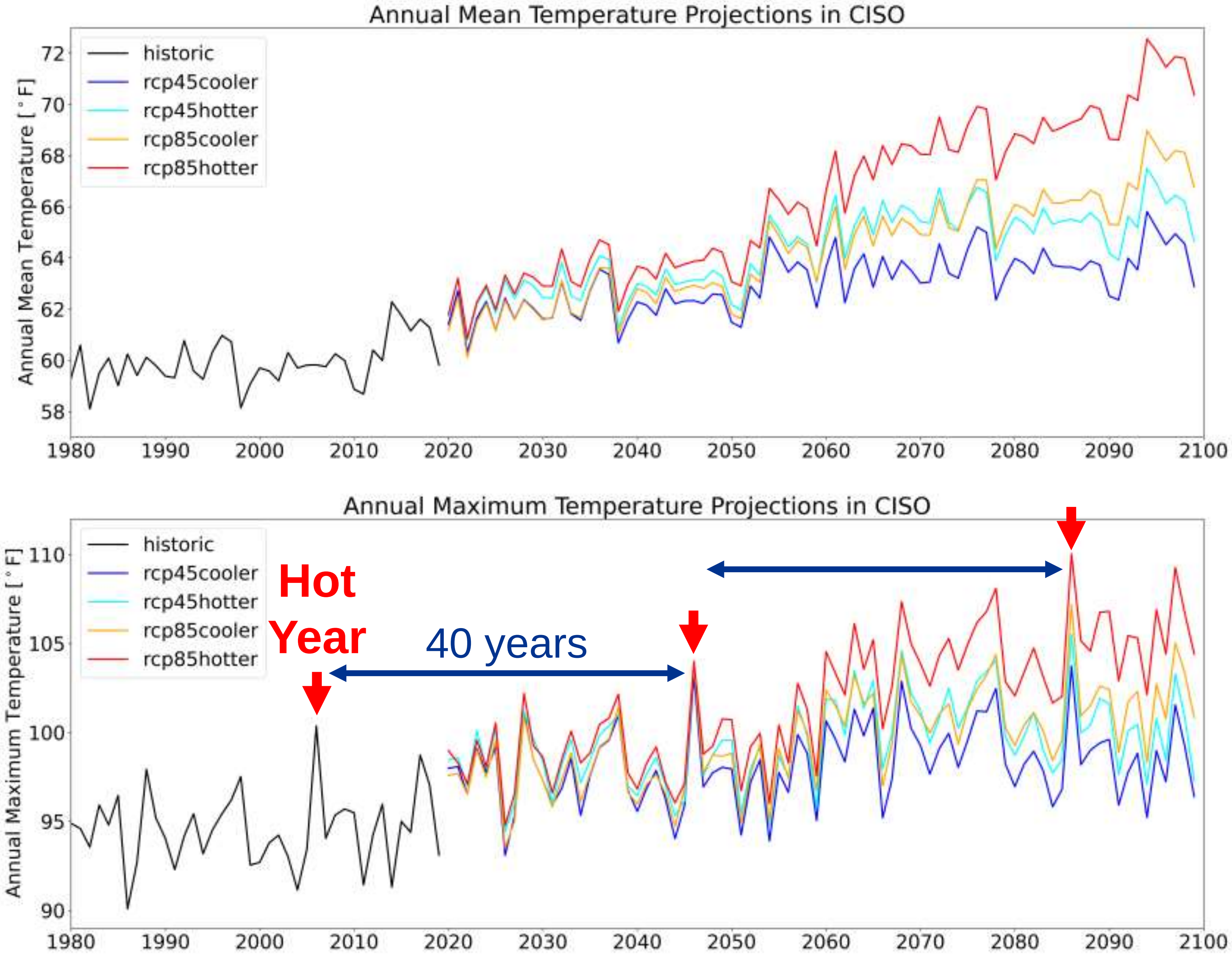


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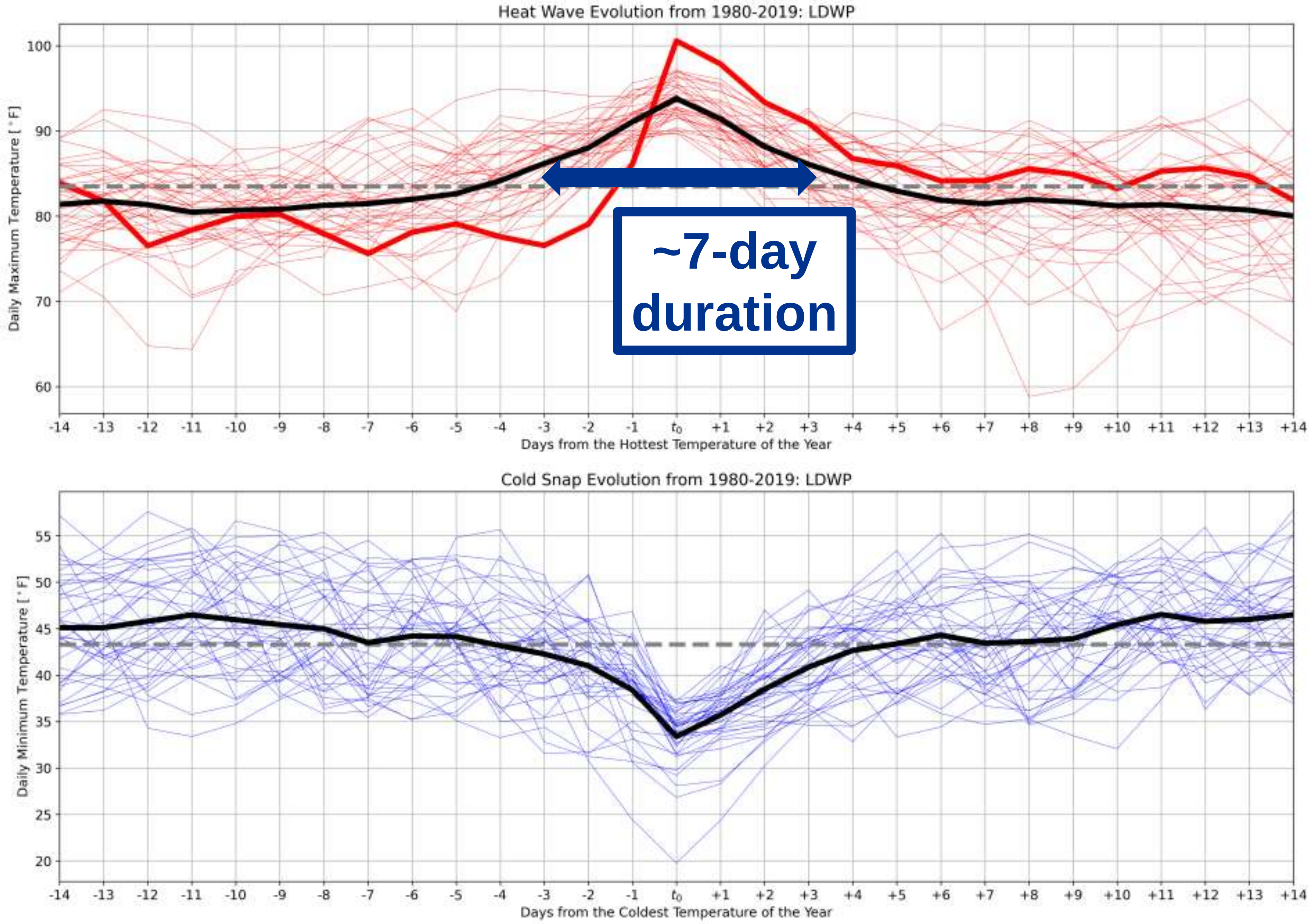
# Designing Stress Tests Based on Heat Waves and Cold Snaps Dynamics

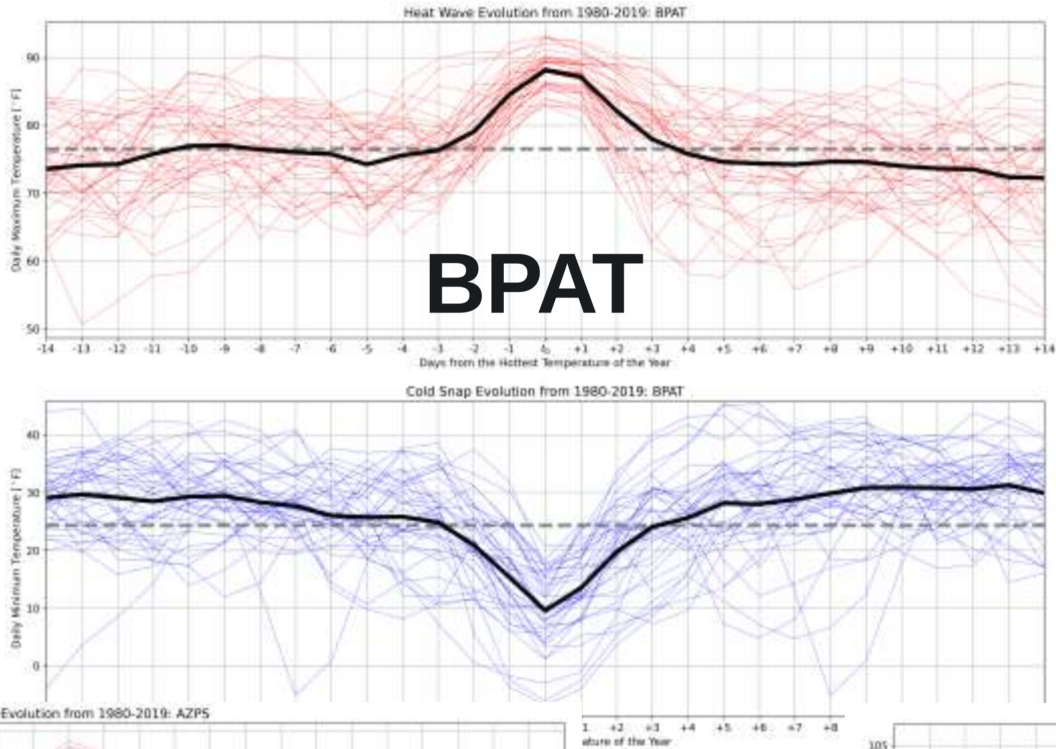


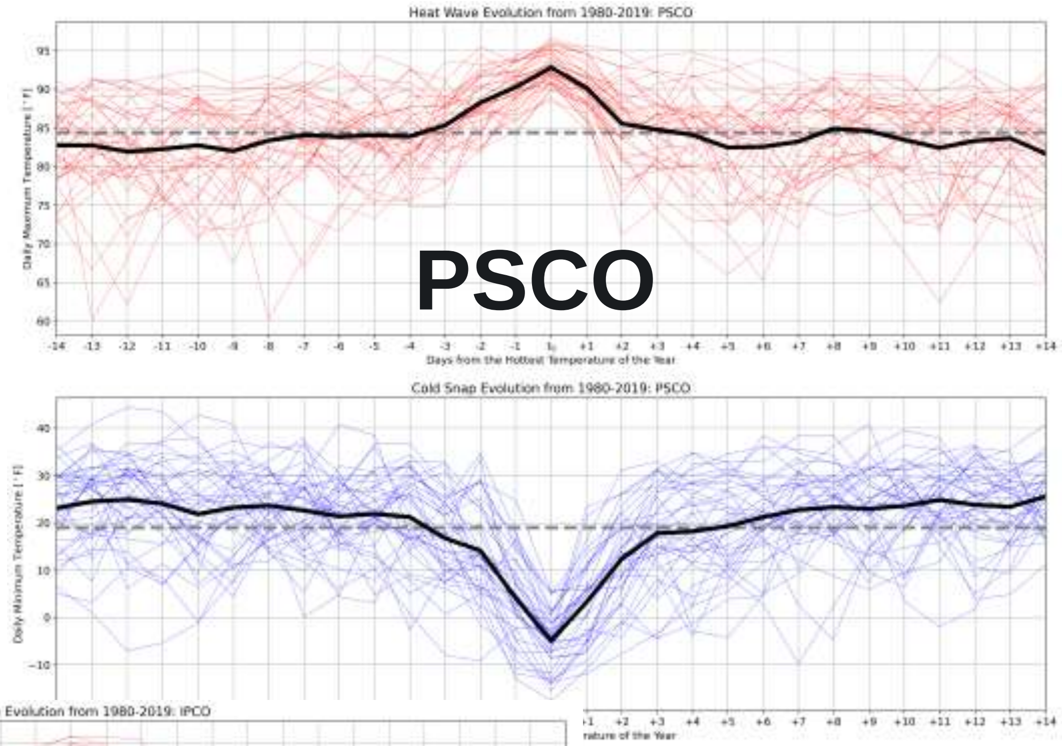

Typical heat waves and cold snaps last ~6-7 days and are, on average, symmetric about the maximum temperature day.

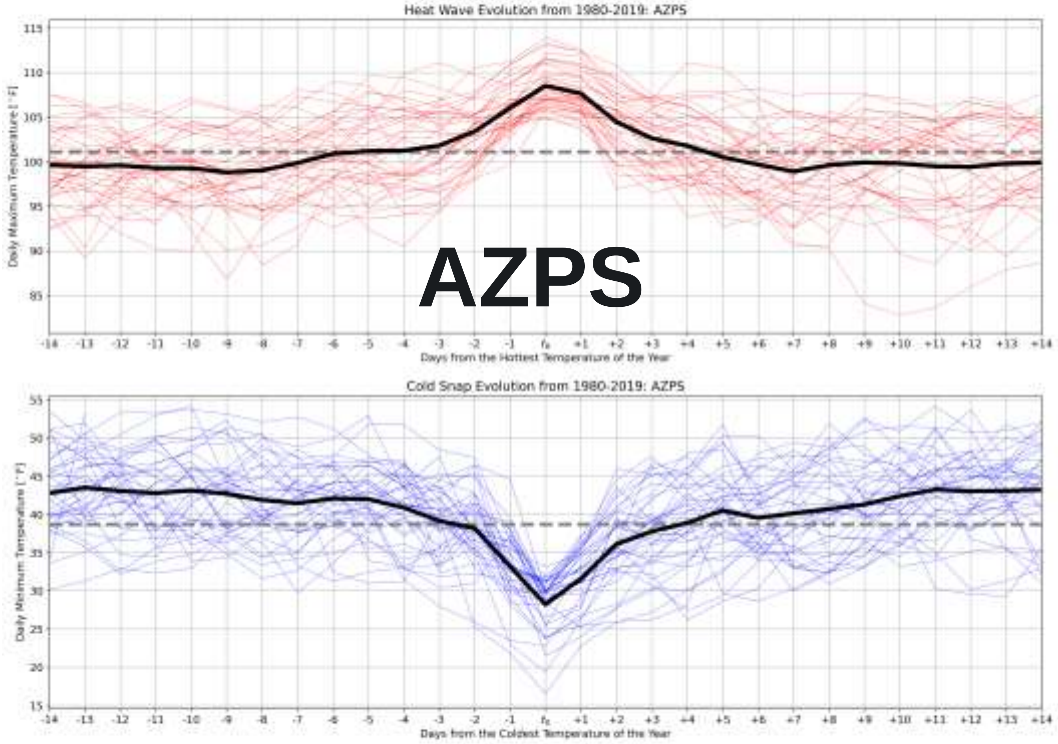
Burleyson, C., Thurber, T., & Vernon, C. (2023). Projections of Hourly Meteorology by Balancing Authority Based on the IM3/HyperFACETS Thermodynamic Global Warming (TGW) Simulations (v1.0.0) [Data set]. MSD-LIVE Data Repository. https://doi.org/10.57931/1960530

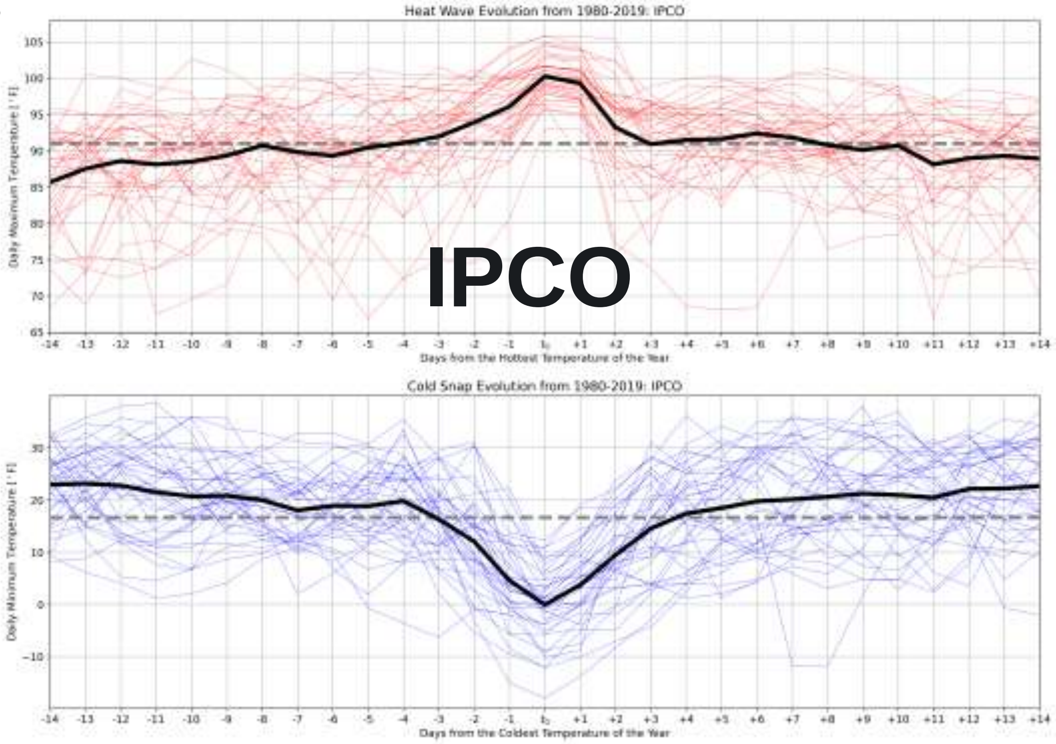
# Heat Wave and Cold Snap Duration

**Patterns are consistent across BAs in the Western US**

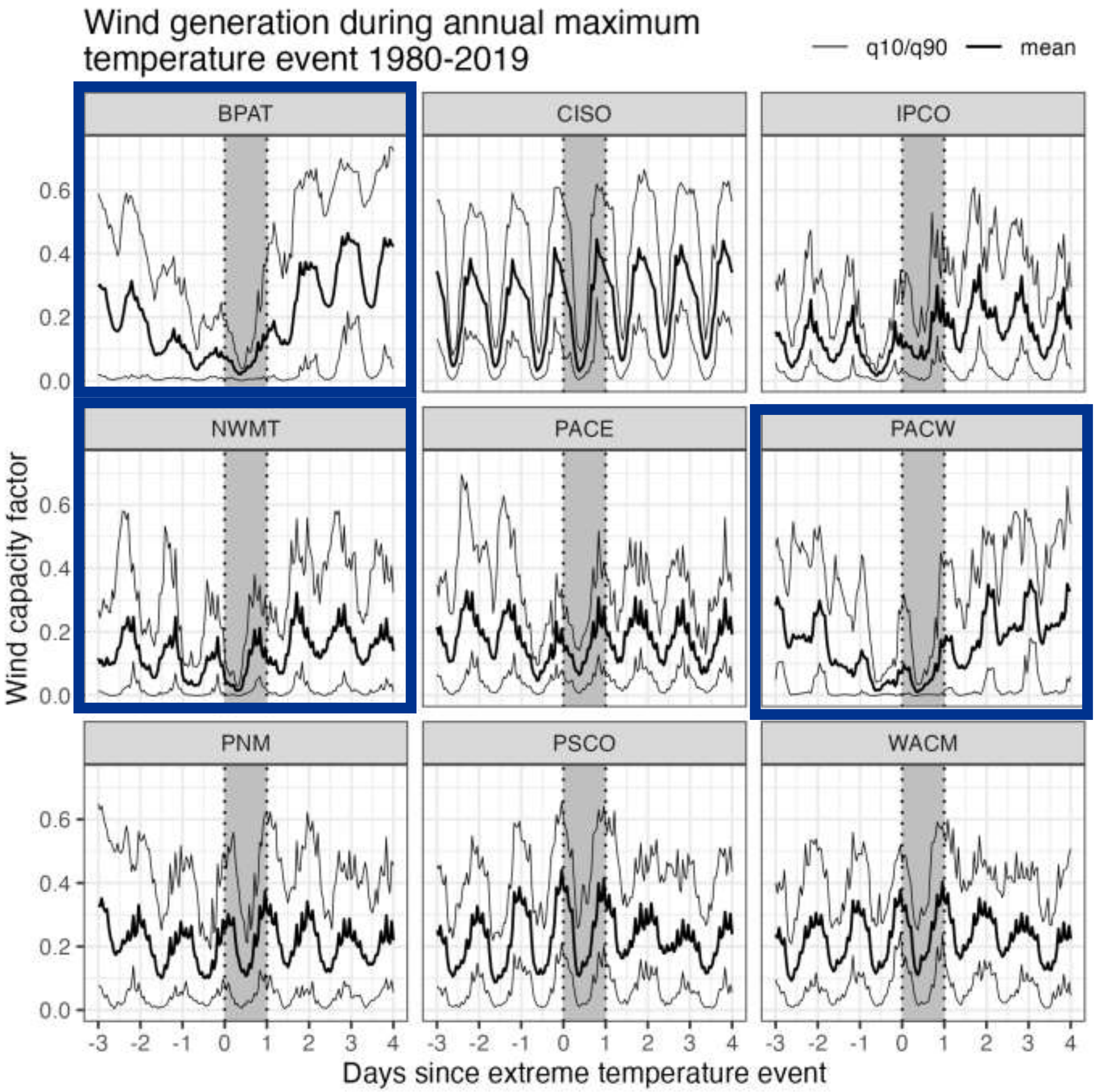


# Notable Suppression of Wind Generation During Heat Waves

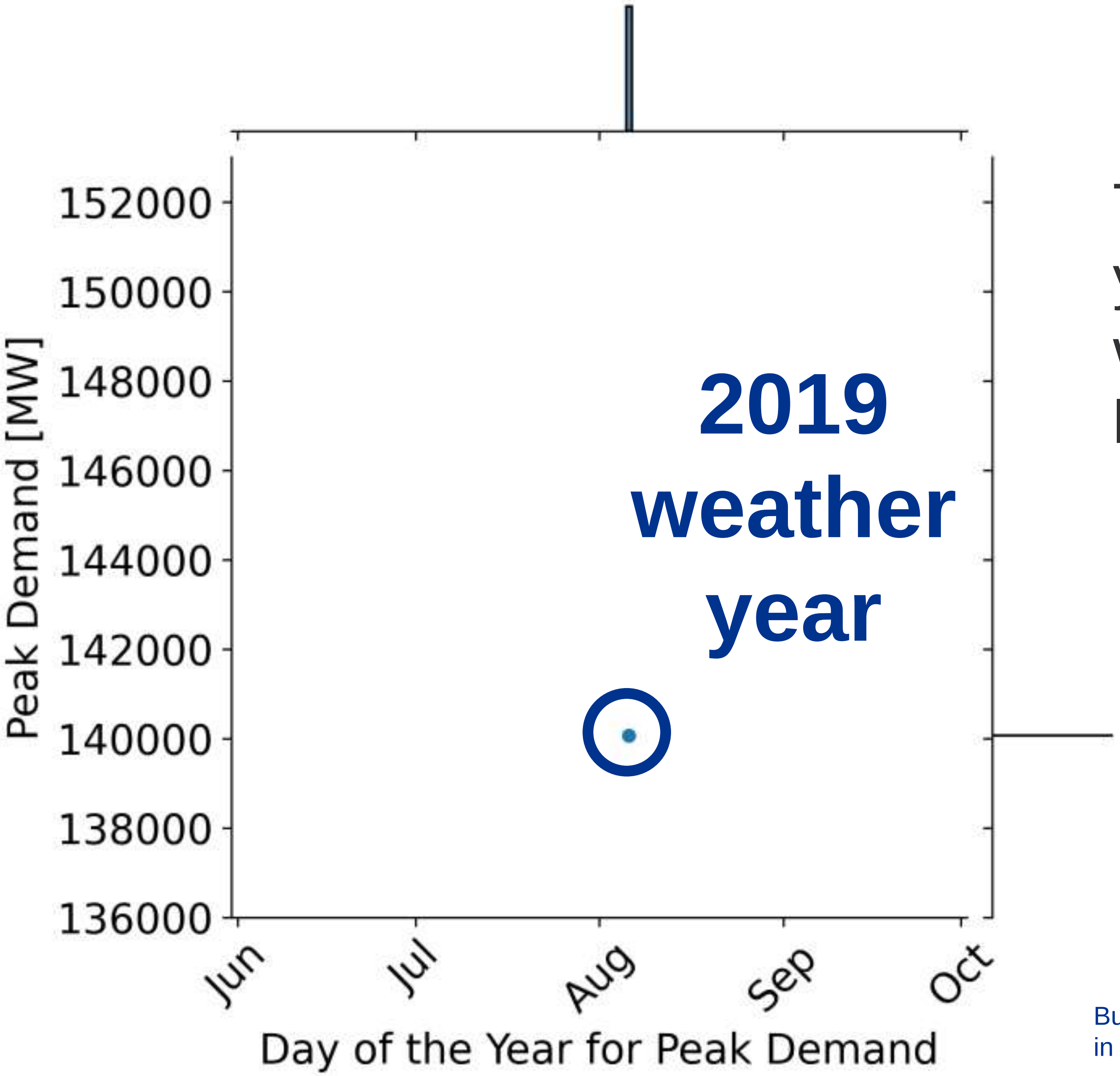



BAs in the Pacific Northwest (e.g., BPAT, PACW, and NWMT) show notable suppression of wind generation during heat waves.


Bracken, C., Voisin, N., Burleyson, C.D., Campbell, A.M., Hou, Z.J. and Broman, D. 2024. Standardized benchmark of historical compound wind and solar energy droughts across the Continental United States. Renewable Energy 220, 119550.

Bracken, C., Underwood, S., Campbell, A., Thurber, T. B., & Voisin, N. (2023). Hourly wind and solar generation profiles for every EIA 2020 plant in the CONUS (v1.1.1) [Data set]. https://doi.org/10.5281/zenodo.7901614

# Simulating Multiple Weather Years to Explore Uncertainty




The prior example used a single weather year, but 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

Burleyson C.D., N. Voisin, and C.W. Bracken. 10/26/2023. "Integration of Climate Forecasts in Bulk Power System Studies." Online Conference, Washington. PNNL-SA-191582.

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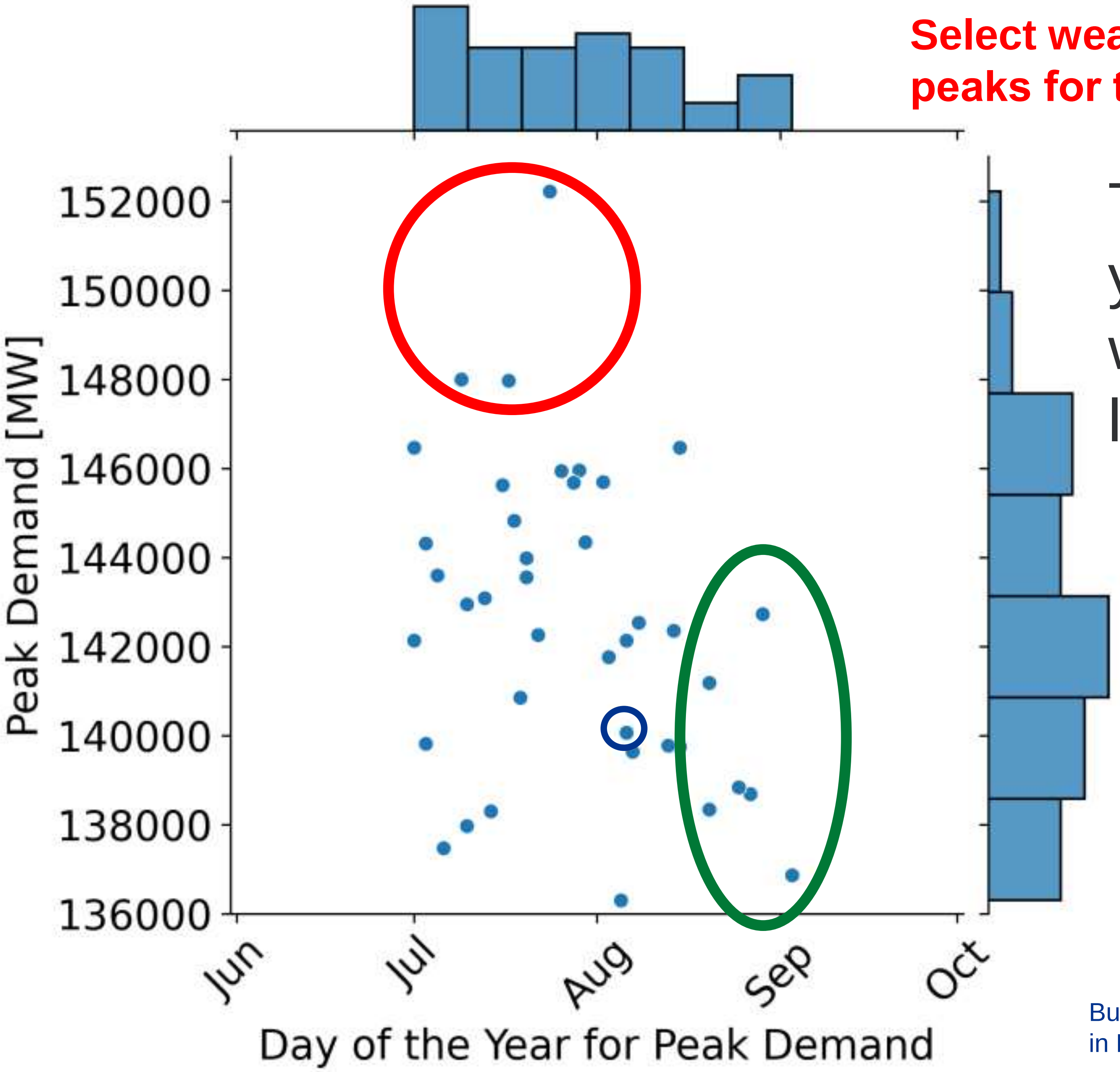



**Select weather years with extreme peaks for testing resilience…**

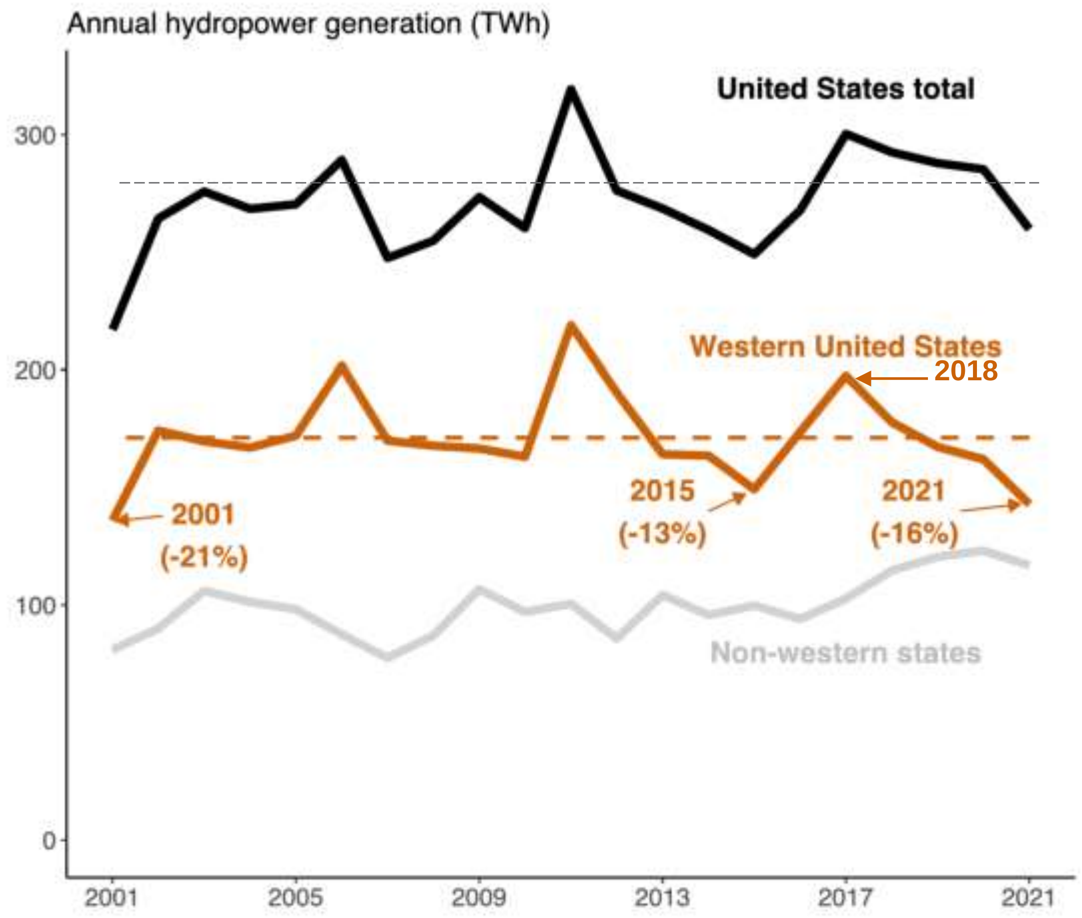
The prior example used a single weather year, but we can run many unique weather years through PNNL's wind, load, and solar models:

- 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…**

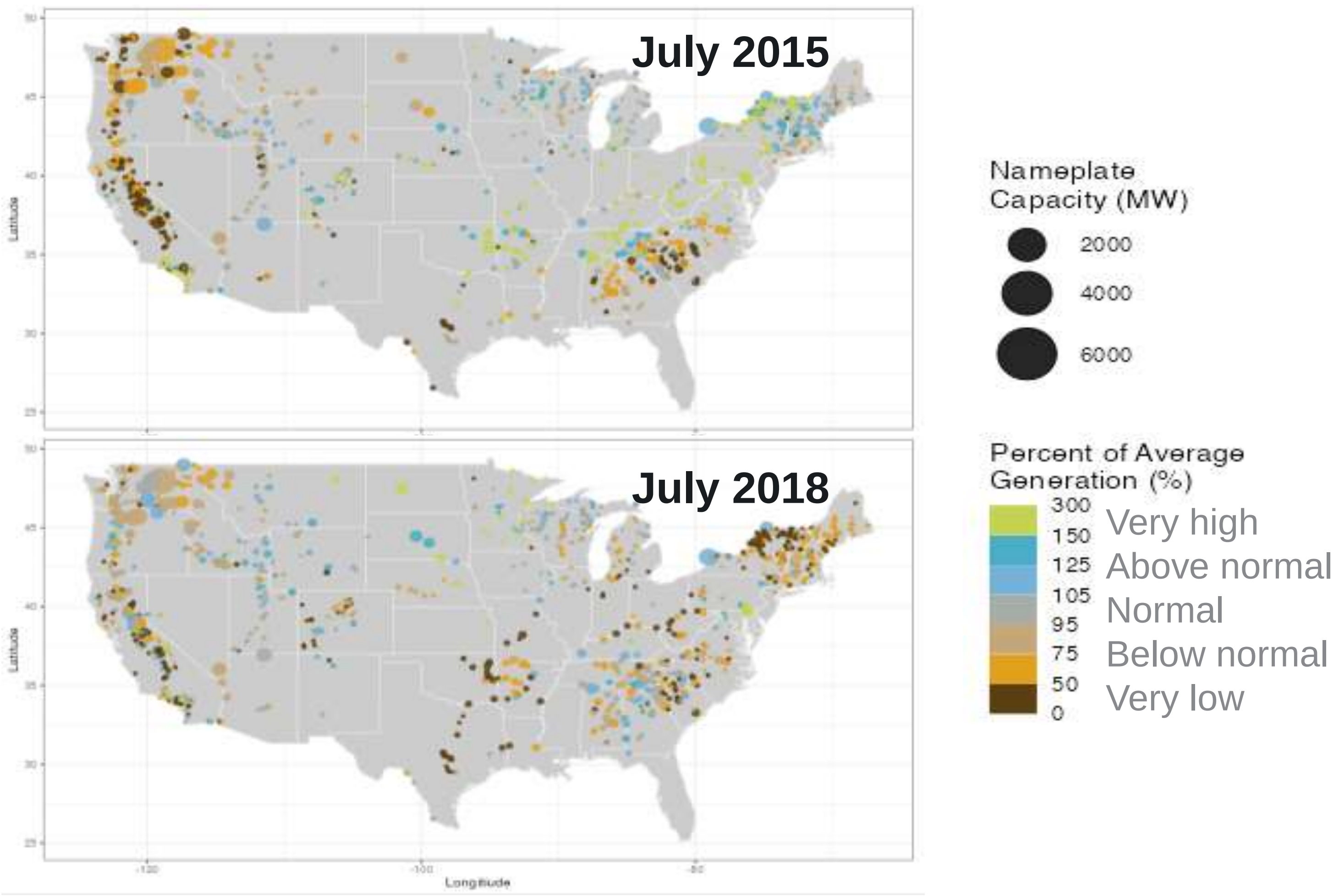
Burleyson C.D., N. Voisin, and C.W. Bracken. 10/26/2023. "Integration of Climate Forecasts in Bulk Power System Studies." Online Conference, Washington. PNNL-SA-191582.

# Hydropower Datasets Are Available for Input Into Power System Models




*Interannual variations in hydropower generation are expected and need to be considered in power system studies.*


Turner, S.W.D., Voisin, N., Nelson, K.D. and Tidwell, V.C. 2022 Drought Impacts on Hydroelectric Power Generation in the Western United States, p. Medium: ED; Size: 56 p., United States. https://www.osti.gov/biblio/1887470


*July hydropower generation by power plant. Hydropower datasets include weekly potential generation and flexibility.*


Voisin N., K.M. Harris, K. Oikonomou, S. Turner, A. Johnson, S. Wallace, and P. Racht, et al. 2022. "WECC ADS 2032 Hydropower Dataset." PNNL-SA-172734.
Turner, S. W. D., Bracken, C., Voisin, N., & Oikonomou, K. (2024). HydroWIRES B1: Monthly and Weekly Hydropower Constraints Based on Disaggregated EIA-923 Data (v1.2.0) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.10574003

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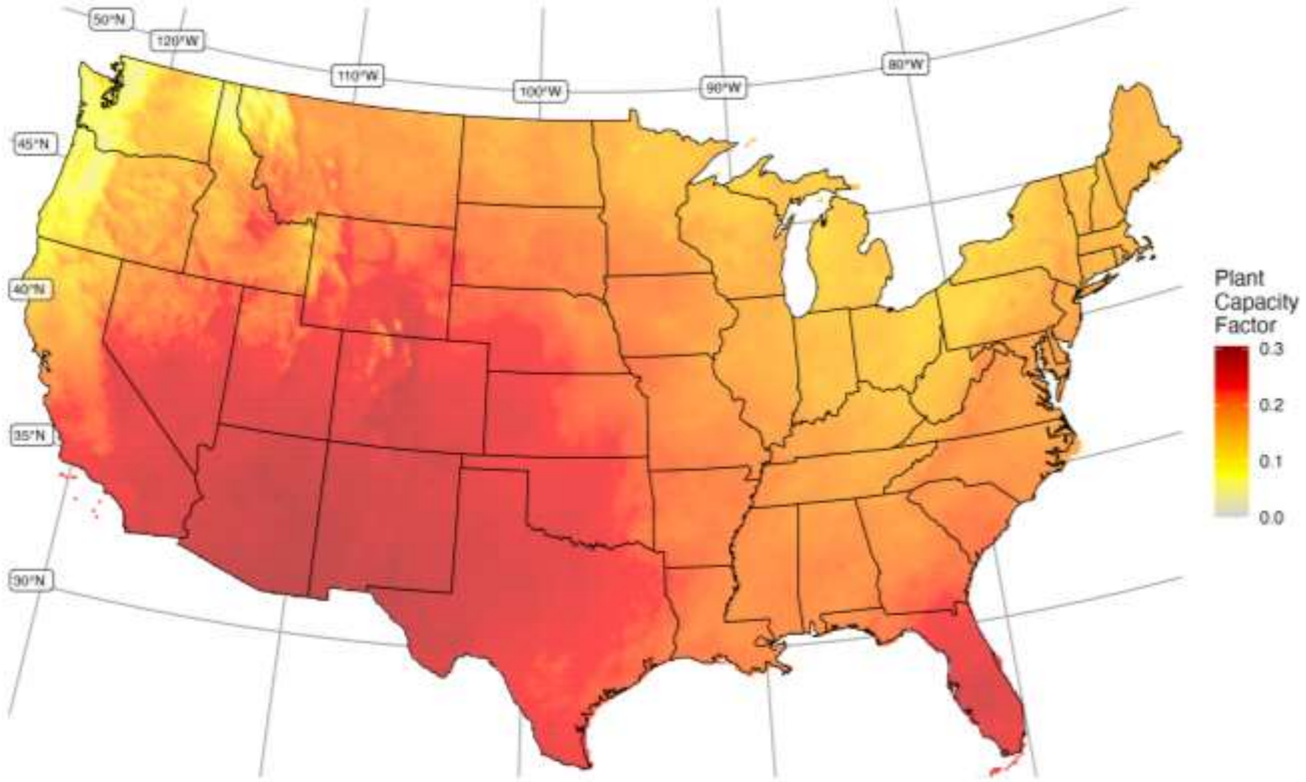
# Reliability to climate extremes: needs for datasets and guidance

Need to work with Earth system scientists (climate, hydrology, etc)!

Recent studies (WECC reliability studies, NTPS) demonstrate that we can move forward with designing reliability standards for transmission planning using climate datasets that may not have all the “ideal features” for asset-scale reliability standards. Those, however, need the physical consistence and coincidence features.

The science and collaboration between climate scientists and power system engineers are critical. Efforts will lead to:

- New power system relevant climate datasets,
- Climate benchmark and extreme scenarios co-produced with power sector energy
- Novel representations of climate sensitive resources in power system models.

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Pacific Northwest NATIONAL LABORATORY

# Thank you

Nathalie.Voisin@pnnl.gov

https://climate.pnnl.gov/
https://godeeep.pnnl.gov/

# Developing Benchmark Planning Cases for Extreme Heat and Extreme Cold Weather Events

NERC-NATF-EPRI Technical Conference

January 17, 2024

Presented by Dmitry Kosterev

Bonneville Power Administration

# Outline

This presentation will cover:

a. Proposed process for selecting extreme heat and extreme cold benchmark events

b. Developing **initial benchmark powerflow** base cases

c. Developing **benchmark planning cases** and sensitivity cases for contingency analysis

# Historic Events – Extreme Cold

| Event | Region | Unavailable Generation* | MW of Load Lost | Reference |
|---|---|---|---|---|
| **February 1-5, 2011** | Southwest | 14,702 MW | 5,412 (7.5 hours) | https://www.nerc.com/pa/rrm/ea/Pages/February-2011-Southwest-Cold-Weather-Event.aspx |
| **January 6 – 8, 2014 Polar Vortex** | Midwest, South Central and East Coast | 9,860 MW | 300 MW (3 hours) | https://www.nerc.com/pa/rrm/January%202014%20Polar%20Vortex%20Review/Polar_Vortex_Review_29_Sept_2014_Final.pdf |
| **January 15-19, 2018** | South Central | 15,600 MW | 900 MW | https://www.ferc.gov/sites/default/files/legal/staff-reports/2019/07-18-19-ferc-nerc-report.pdf |
| **February 13-17, 2021 Winter Storm Uri** | Southwest and South Central | 65,622 MW | Total: 23,418 MW<br>ERCOT: 20,000 MW (70 hours)<br>SPP 2,718 MW (4 hours)<br>MISO South 700 MW (2 hours) | https://www.ferc.gov/media/february-2021-cold-weather-outages-texas-and-south-central-united-states-ferc-nerc-and |
| **December 21-26, 2022 Winter Storm Elliott** | Central, Midwest, Southeast and Northeast | 90,500 MW, or 13% of EI generation capacity | Total: 5,400 MW<br>Including:<br>TVA: 3,000 MW (7 hours)<br>DEC:1,000 MW (3 hours)<br>DEP: 961 MW (4 hours) | https://www.ferc.gov/media/winter-storm-elliott-report-inquiry-bulk-power-system-operations-during-december-2022 |

*Total MW capacity unavailable due to freezing issues, natural gas supply issues

# Historic Events – Extreme Heat

| Event | Region | Unavailable Generation | MW of Load Lost | Reference |
|---|---|---|---|---|
| **September 9-11, 2013** | Midwest, mid-Atlantic | | None reported | |
| **August 14-19, 2020** | California, Desert Southwest | 475 MW trip | 1,000 MW (1.5 hours) | http://www.caiso.com/Documents/Final-Root-Cause-Analysis-Mid-August-2020-Extreme-Heat-Wave.pdf |
| **June 26-30, 2021** | Pacific Northwest | 250 MW trip | None reported | https://www.oregonencyclopedia.org/articles/heat-dome-2021/ |

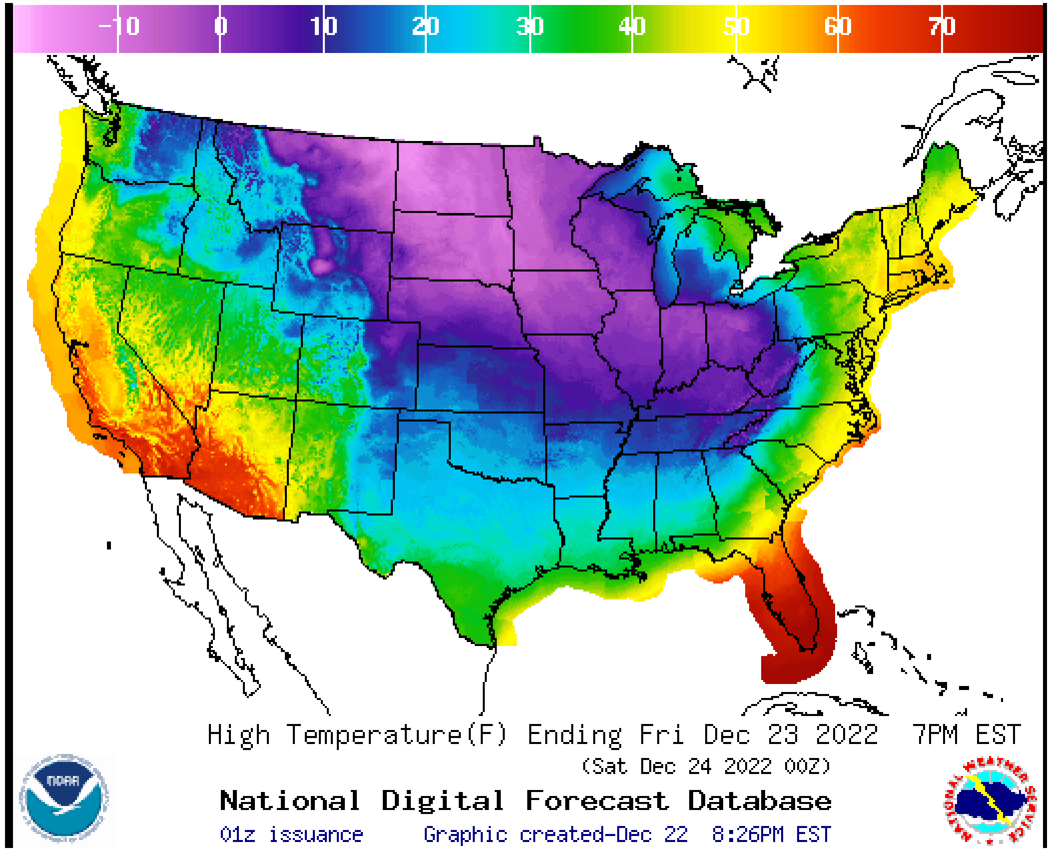
# Key Variables Defining Benchmark Weather Events

- **Ambient Temperature, Event Duration, and Frequency** are the key variables defining extreme heat and extreme cold events
  - Extreme weather reports cited other secondary factors that played role in the events, such as humidity, precipitation, wind speed, wildfires.

- The criterion for extreme heat and extreme cold benchmark events will be established:
  - E.g. 3-day heatwaves, that exceed the 95$^{th}$ percentile of climate normal temperature during daytime hours

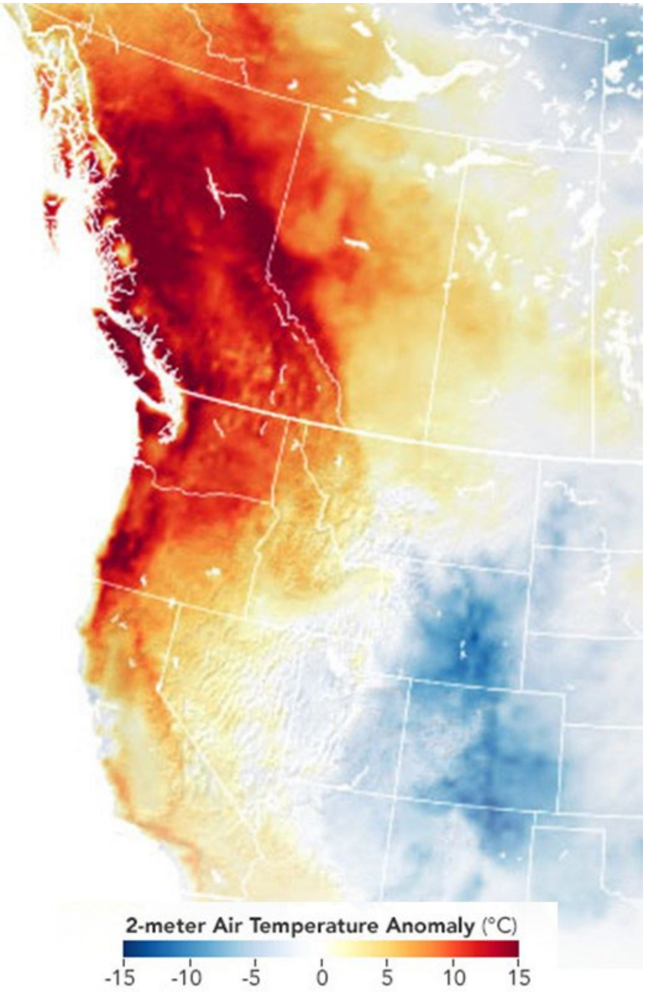
# Selecting Benchmark Weather Events

- A team of climate experts including National Labs and EPRI will compile a collection of extreme cold and extreme heat wide-area events that meet the NERC-specified target criterion
  - The data set will include temperature data as well as secondary variables like wind speeds and solar irradiance
  - The data set is projected 10-years out
- PC or a group of PCs, in consultation with NERC and Regional Entities (TRE, MRO, NPCC, WECC, SERC, RF), will select benchmark weather events to be studied




Source: NOAA

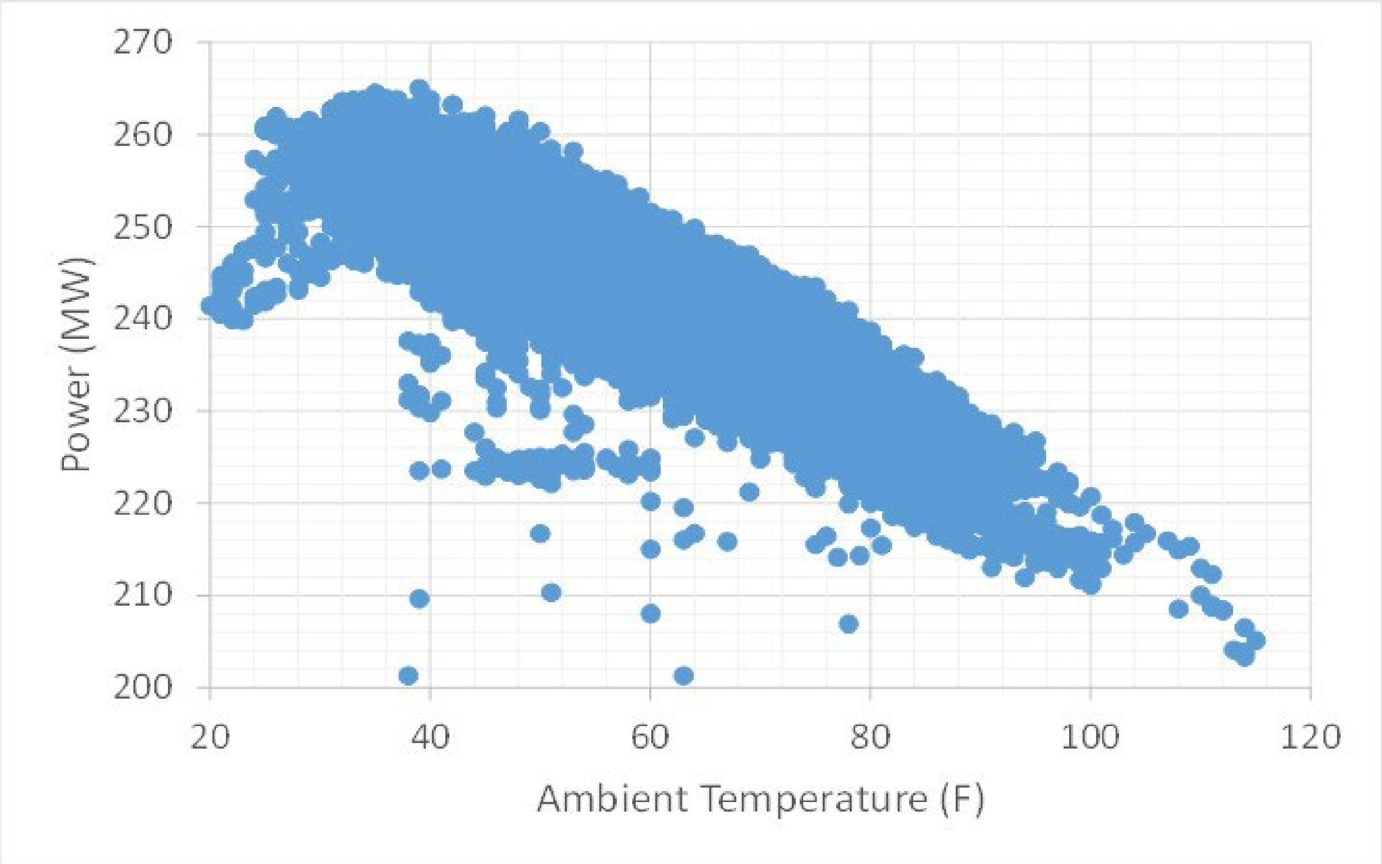
# Developing Initial Benchmark Powerflow Base Case




- **Initial benchmark powerflow** base cases are developed for the selected extreme heat and extreme cold events
  - Adjust load MWs and MVArs anticipated for extreme temperatures
  - Use applicable transmission Facility Ratings for the modeled ambient temperature conditions
  - Represent temperature-dependency of generating resources (see next slide)

- The **initial** cases do not account for concurrent generation and/or transmission outages that may occur due to the extreme heat and cold (e.g., freezing issue, fuel supply issue)

# Temperature-Dependent Gas Power Plant Capacity

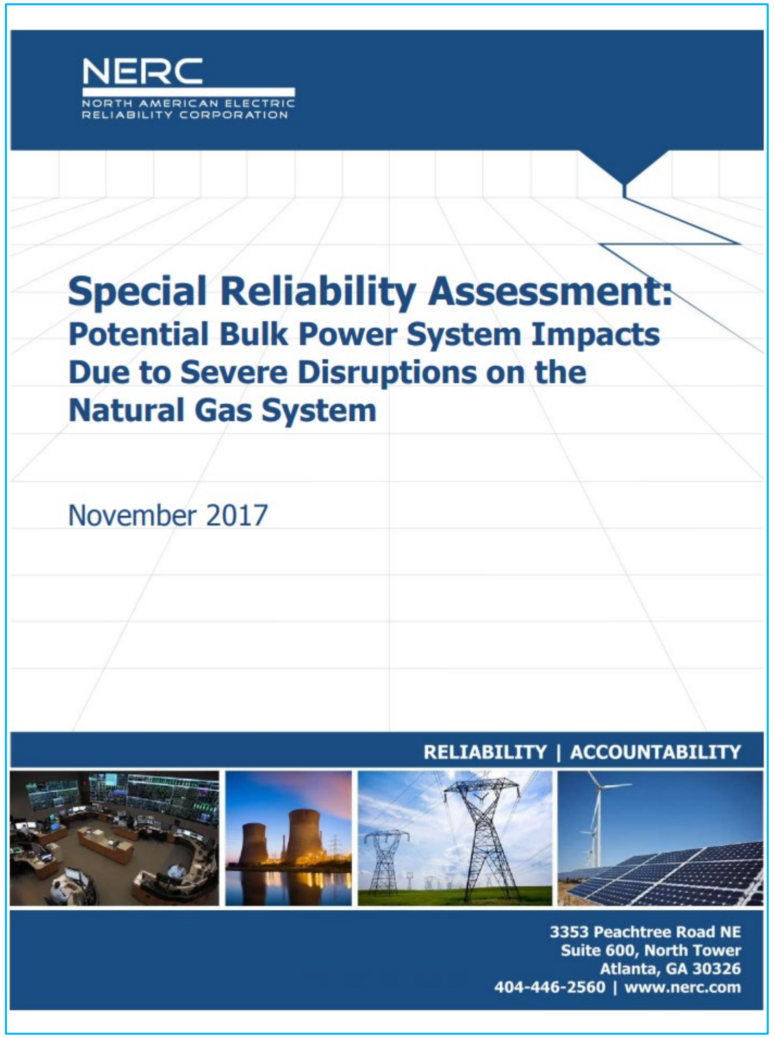



Example: power output of a 250-MW gas-powered combined cycle plant as a function of ambient temperature

- Gas-powered plants experience reduction in power output at extreme temperatures
  - Combustion engine efficiency decreases at warmer ambient temperatures
  - Gas plant auxiliary loads usually increase at extreme cold temperatures

# Developing benchmark planning cases

- **Benchmark planning cases** are developed from the initial benchmark base case
- **Benchmark planning cases** will consider concurrent / correlated generation and transmission outages during extreme heat and extreme cold conditions, e.g.:
  - Thermal plant outages or generation de-rates due to constraints in natural gas availability
    - See NERC report on the topic
  - Plant failures during extreme temperatures
  - Reduced generation from Variable Energy Resources due to:
    - Land-based wind suppression during extreme temperatures
    - Wind turbine safety shutdown due to ice loading
    - Reduction of solar panel power due to snow and ice cover
    - Reduce output of solar generation during wildfires due to air pollution
    - Reduced battery's ability to hold charge during extreme cold



# Winter storm landing at the Pacific Coast

# FERC O896 Benchmark Event Definition and Meteorological Data Needs

## Considerations and Challenges

Delavane Diaz, PhD
Principal Team Lead, Climate Resilience Analysis

NERC-NATF-EPRI Meeting
January 17, 2024

# FERC O896 Transmission System Planning Performance Requirements for Extreme Weather

**Order No. 896**

183 FERC ¶ 61,191
DEPARTMENT OF ENERGY
FEDERAL ENERGY REGULATORY COMMISSION

18 CFR Part 40

[Docket No. RM22-10-000; Order No. 896]

Transmission System Planning Performance Requirements for Extreme Weather

(Issued June 15, 2023)

**AGENCY**: Federal Energy Regulatory Commission.

**ACTION**: Final rule

**SUMMARY**: The Federal Energy Regulatory Commission directs the North American Electric Reliability Corporation, the Commission-certified Electric Reliability Organization, to develop a new or modified Reliability Standard no later than 18 months of the date of publication of this final rule in the Federal Register to address reliability concerns pertaining to transmission system planning for extreme heat and cold weather events that impact the Reliable Operation of the Bulk-Power System. Specifically, we direct the North American Electric Reliability Corporation to develop a new or modified Reliability Standard that requires the following: development of benchmark planning cases based on prior extreme heat and cold weather events and/or future meteorological projections; planning for extreme heat and cold events using steady state and transient stability analyses that cover a range of extreme weather scenarios, including the expected resource mix's availability during extreme weather conditions and the broad area impacts of extreme weather; and corrective action plans that include mitigation activities for

- Directs NERC to develop a new or modified Reliability Standard (i.e., **TPL-008**) for 6-10 year planning timeframe
- **Three primary requirements** for NERC to consider with respect to extreme heat and extreme cold:

**1**

**Develop benchmark cases for extreme heat and extreme cold based on prior events or future projections**

**2**

**Plan for extreme events using steady state and transient stability analysis for scenarios that include expected resource mix availability**

**3**

**Corrective action plans that mitigate the impacts of extreme weather**

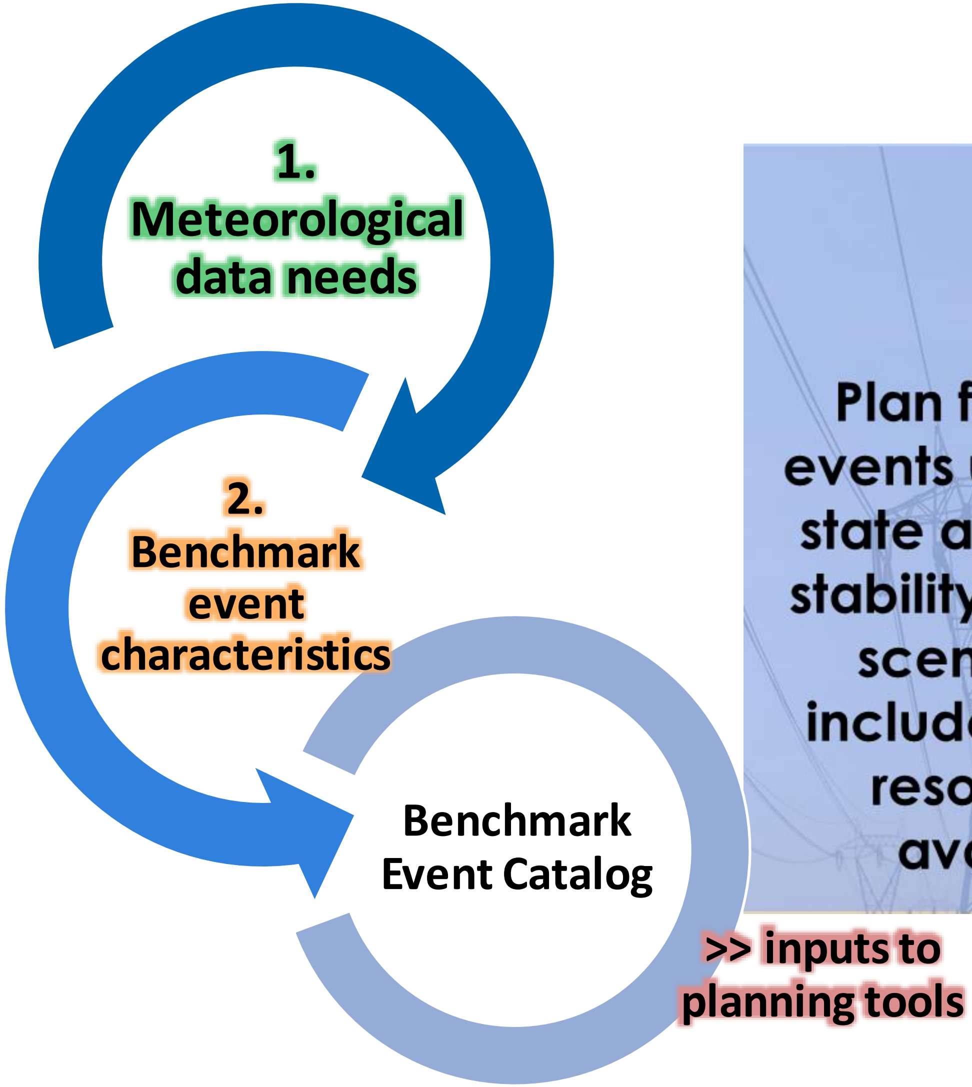


EPRI

# Two key aspects of requirement 1 *Develop benchmark cases for extreme heat and extreme cold*

**1**

Develop benchmark cases for extreme heat and extreme cold based on prior events or future projections




**2**

Plan for extreme events using steady state and transient stability analysis for scenarios that include expected resource mix availability

**3**

Corrective action plans that mitigate the impacts of extreme weather

# FERC O896 IV.B. Develop Benchmark Heat and Cold Events

§30 NERC to include in the new/modified Reliability Standard: **benchmark events** that responsible entities must study… NOPR proposed basing such benchmark events on **prior events** (e.g., Feb 2011 SW Cold Weather Event, Jan 2014 Polar Vortex Cold Weather Event) and/or **meteorological projections**… NERC to consider a **uniform framework** for developing benchmark events while still recognizing **regional differences**; for example, NERC could define benchmark events around a projected **frequency** (e.g., 1-in-50-year event) or **probability distribution** (95th percentile event).

§33 to develop **extreme weather "design threshold" metrics**, as well as investigate targeted **planning thresholds** (e.g., 1-in-50-year events)

2. Commission Determination

§35. Pursuant to section 215(d)(5) of the FPA, we adopt the NOPR proposal and direct NERC to: **(1) develop extreme heat and cold weather benchmark events**, and (2) require the development of benchmark planning cases based on identified benchmark events.

§ 36. NOPR outlined some of FERC's expectations, including that benchmark events be based on **prior extreme heat and cold events and/or meteorological projections**, there is currently **no established guidance or set of tools** in place to facilitate the development of extreme heat and cold benchmark events for the purpose of informing transmission system planning. For defining benchmark NERC should consider: examples in NOPR (e.g., the use of projected **frequency** or **probability distribution**); other approaches that achieve the objectives.

We encourage NERC to **engage with national labs**, RTOs, NOAA, and other agencies and organizations as needed. To that end, we have modified the NOPR proposal to allow more time for NERC to consider these complex issues and engage additional expertise where necessary.

# FERC O896 IV.C–I: Additional Technical Considerations

C.2. §50 Definition of "Wide-Area". NERC to consider the **wide-area impacts** of extreme heat and cold weather. NERC to describe the process to define the wide-area boundaries. [Regarding] a **geographical approach [vs] electrical approach** to defining wide-area boundaries, we do not adopt any one approach in this final rule…this technical matter deserves a more fulsome vetting in the Reliability Standards development process.

F. §80 Modeling **derating** and possible **loss of wind, solar, natural gas** will help better assess the probability of potential occurrences of cascading outages, uncontrolled separation, or instability

§88 Benchmark events to study **concurrent/correlated generator and transmission outages** [for the expected resource mix's availability]

G.2. §119, §124 **Sensitivity Analysis**: NERC should consider including conditions that vary with temperature such as 1) demand probability scenario cases, 2) generators that are affected by these events (i.e., wind tripping off, solar dropping off, gas plants not being operational due to gas restrictions/freeze-offs, etc.) and 3) system transfer levels.

§135 Planning Approach Modifications: Including **probabilistic scenarios** and elements where possible

I. §177 We **decline** to specifically require assessment of **drought conditions** [but] the type of long-term meteorological study…**necessarily includes** examining base climate conditions… that would have to include anticipated drought conditions in relevant planning areas.

# Summary of FERC O896 language on developing benchmark cases for extreme heat and extreme cold

- Explicit
- Implicit

## Data needs

- Prior events and/or meteorological projections
- Regional differences
- Engage with national labs and expert organizations
- Wind, solar
- Drought conditions (?)
- Hourly or subhourly data
- Synchronous meteorology of wind/solar/temperature
- Sufficient sample size to determine extremes of weather distribution

## Benchmark events

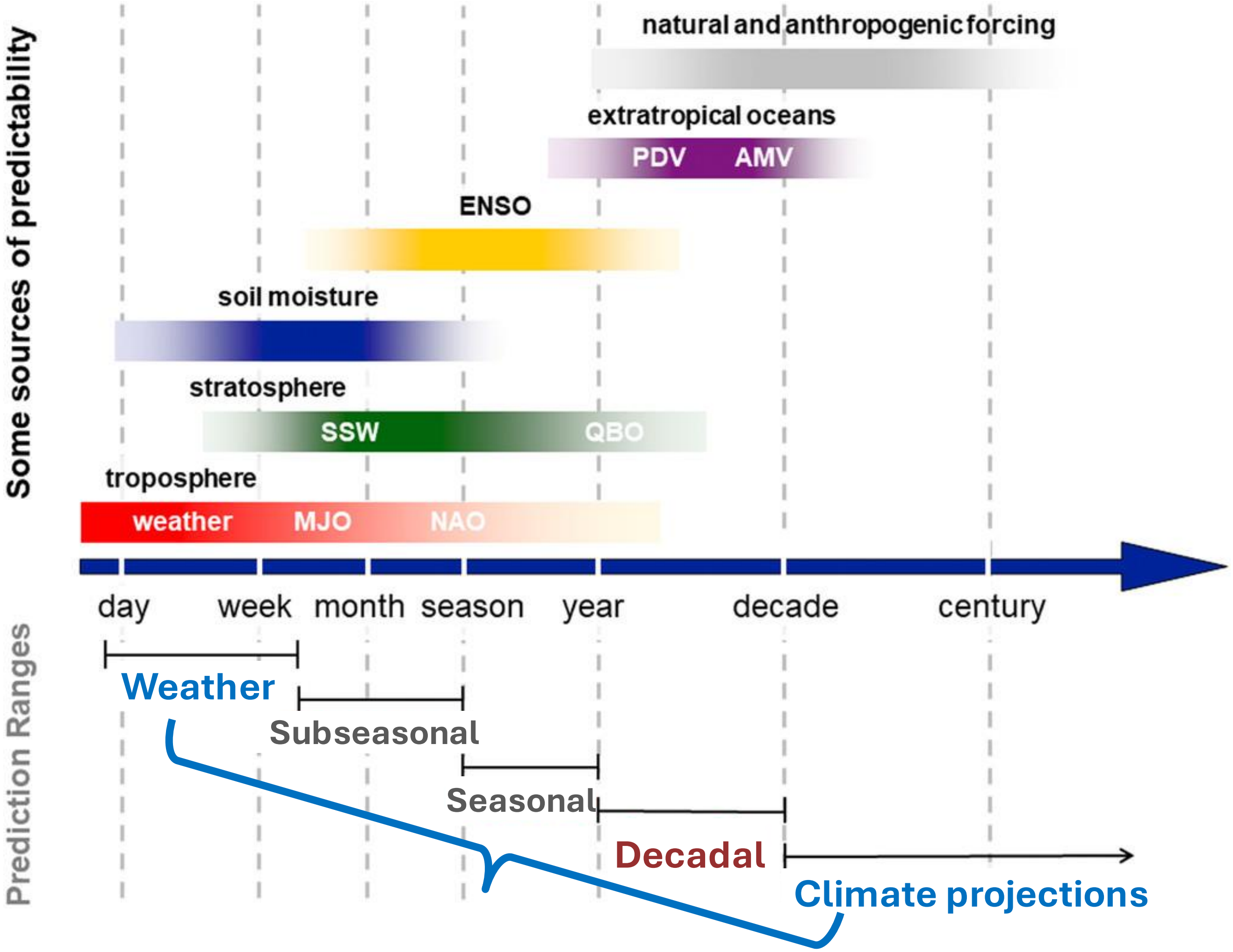
- Uniform framework
- Regional differences
- Frequency or probability distribution
- "Design threshold" metrics and targeted planning thresholds
- No established guidance or set of tools for benchmark events
- Definition of "wide-area" geographical approach [vs] electrical approach

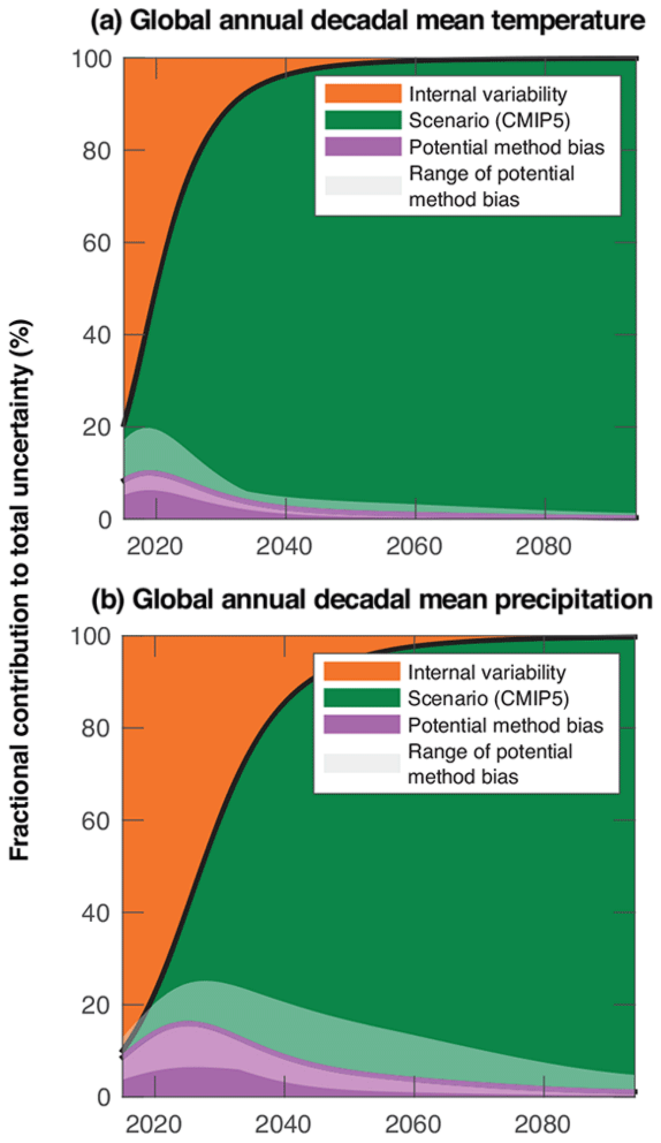
## >> Planning tools

- Derating and possible loss of wind, solar, natural gas
- Expected resource mix's availability
- Concurrent/correlated generator and transmission outages
- Natural gas fuel
- Sensitivity analyses: demand cases, affected generators, system transfer levels

# Meteorological data needs

# W2CC data needs: Challenge of forward-looking meteorology and near-term projections



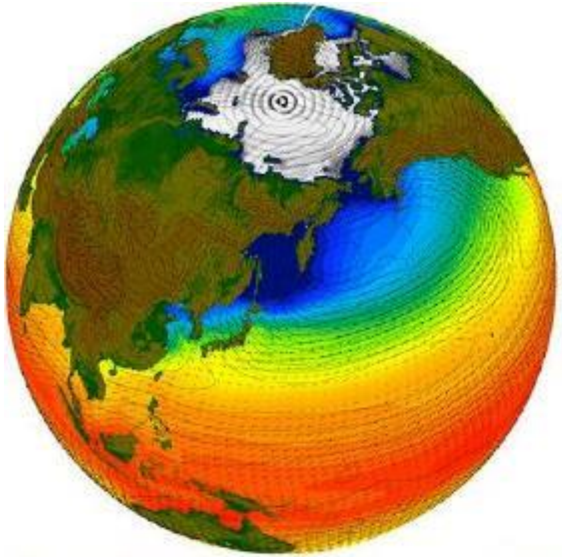




**Bridging the Weather to Climate Continuum (W2CC) gap**

Source: Merryfield et al 2020; Lehner et al 2020

# Frontier methods and datasets are underway in W2CC

- Current approaches to forward-looking meteorological data
  - Statistical inference: projections of the next few years of climate variability based on historical records and current observations
  - Dynamical modeling: decadal climate projections using Earth System Models that include explicit physics-based representation of the land surface and biosphere, the atmosphere, ocean and large ice sheets
  - Machine Learning (ML): using machine-learning methods trained on historical simulations of dynamical models and the actual observed conditions to post-process dynamical model projections



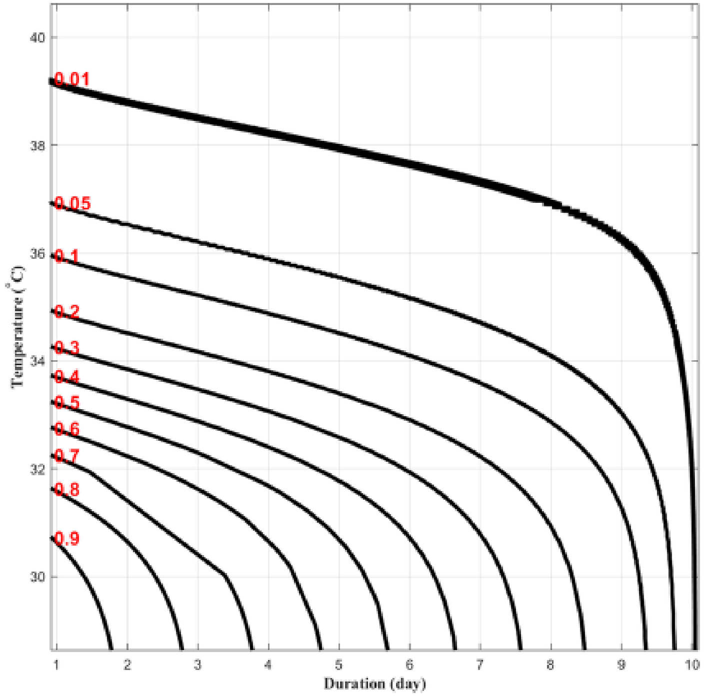
# Some considerations for target attributes of meteorological datasets used in TPL-008 Benchmark Event definition

- Timescale: historical period to future climate projections (e.g., 2050)
- Temporal resolution: hourly or subhourly
- Spatial extent: capture regional differences across CONUS and Canada
- Variables included: wind, solar, temperature at minimum, and synchronous
- Drought conditions(?)
- Sufficient spatial resolution
- Sufficient sample size to determine extremes of weather distribution
- Open-source and peer-reviewed

# Benchmark events

# Extreme event characteristics vary across dimensions

- Primary characteristics: intensity (magnitude), duration, frequency (e.g., IDF curves)
  - + spatial extent
  - + compound / multi-variate hazards
  - + consequence or impact

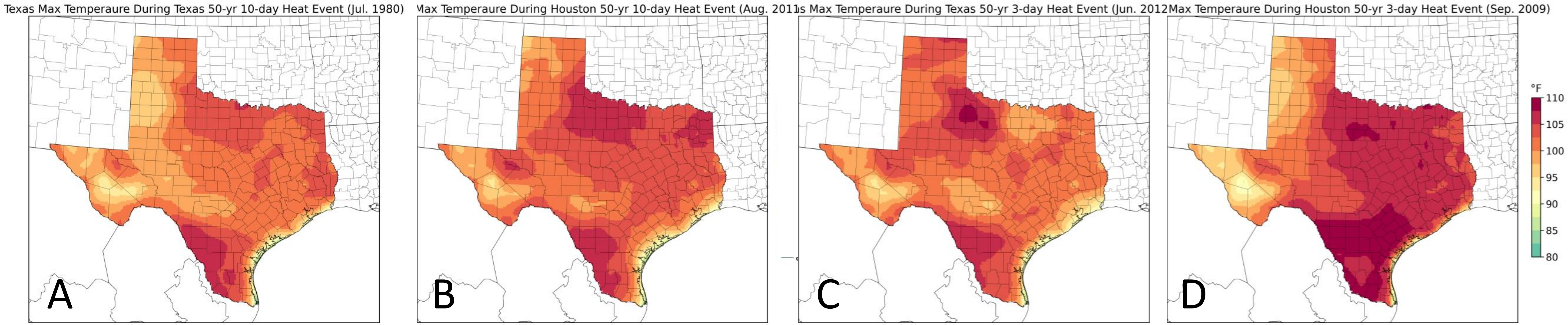



**Heat wave intensity-duration-frequency (HIDF) curves for Chicago** using exceedance probabilities (red values).

Mazdiyasni, O., et al (2019)

# Four Historical 1-in-50 year heat wave examples

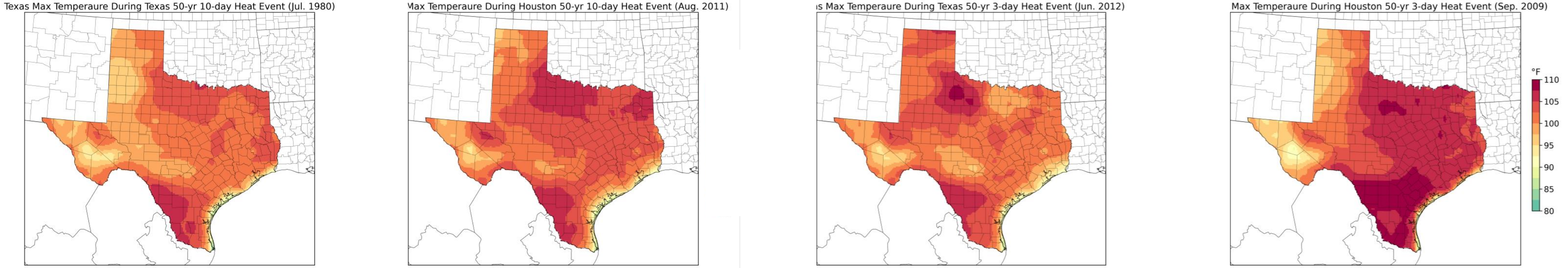
- Consider these 4 examples of 1-in-50 year extreme heat in Texas depending on criteria around duration (3 vs 10 days) and spatial extent (city vs state):
  A) 1-in-50 year heatwave based on 10-day statewide average temps
  B) 1-in-50 year heatwave based on 10-day Houston temps
  C) 1-in-50 year heatwave based on 3-day statewide average temps
  D) 1-in-50 year heatwave based on 3-day Houston temps

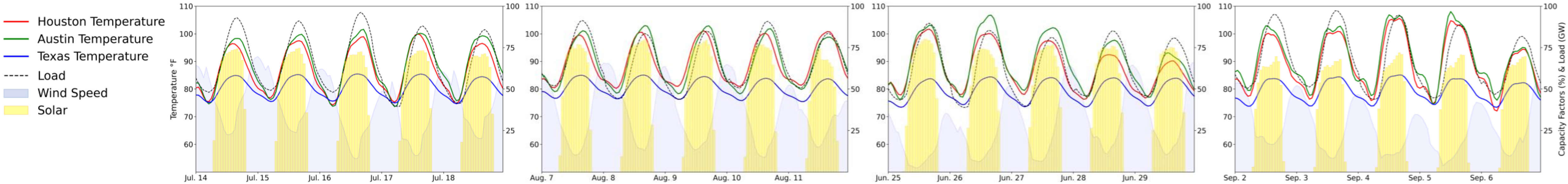



**Stressful grid conditions manifest as multidimensional factors**

# Four Historical 1-in-50 year heat wave examples

| | A) 10-day statewide | B) 10-day Houston | C) 3-day statewide | D) 3-day Houston |
|---|---|---|---|---|
| | July 16, 1980 | Aug 9, 2011 | June 26, 2012 | Sept 4, 2000 |
| Austin 3-day high (°F) | 100.9 | 102.6 | 103.1 | 105.0 |
| Houston 3-day high (°F) | 99.6 | 101.7 | 101.2 | 104.3 |
| Texas 3-day high (°F) | 95.2 | 93.5 | 95.7 | 92.7 |
| Texas wind* (avg CF %) | 0.399 | 0.353 | 0.265 | 0.259 |
| Texas solar* (avg CF %) | 0.331 | 0.335 | 0.356 | 0.290 |
| Texas peak load* (GW) | 96 GW | 92 GW | 85 GW | 97 GW |




*Capacity factors based on current installed wind, 20 GW solar; EPRI estimated Texas load based on 2020 residential/commercial/industrial technologies

# Criteria for Benchmark Event Selection

Multiple dimensions for consideration…

**1 Regionality**

Each extreme event will have impacts across geographic and electrical boundaries

**2 Seasonality**

Extreme events can extend into shoulder seasons when multiple generators may be unavailable due to scheduled maintenance

**3 Duration**

The timeframe under which the extreme event impacts the system should also be considered and will have significant impacts on the subsequent sensitivity analysis

**4 Intensity**

Intensity should considered alongside duration and regionality when determining benchmark events

**5 Expected Demand**

Demand levels experienced by a system will be impacted by the season of occurrence and the duration and intensity of the extreme event

# Extreme Events Panel Discussion

# Extreme Event and Climate Data Panel

Moderator

**Delavane Diaz**

Principal Project Manager,
Climate Resilience Analysis

EPRI

**Thomas Wall**

Director, Center for Climate
Resilience & Decision Science

Argonne National Laboratory

**Nathalie Voisin**

Chief Scientist

Pacific Northwest
National Laboratory

**Grant Buster**

Data Engineer

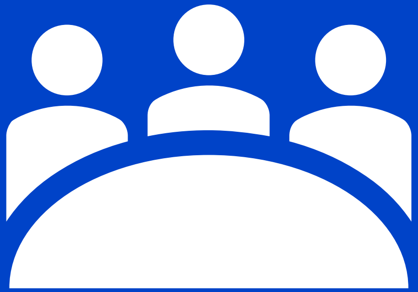
National Renewable
Energy Laboratory

# TPL-008 Process

## Step 1
## Benchmark Event Catalog

Potential events that will be considered for regional benchmark event

## Step 2
## Benchmark Event Selection



Coordinate selection of benchmark event for a region

## Step 3
## Benchmark Planning Case Development

Foundational and scenario (P0) cases developed and distributed to planning entities

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JANUARY 17, 2024

# Probabilistic Energy Adequacy Tool (PEAT) – Operational Impact of Extreme Weather Events

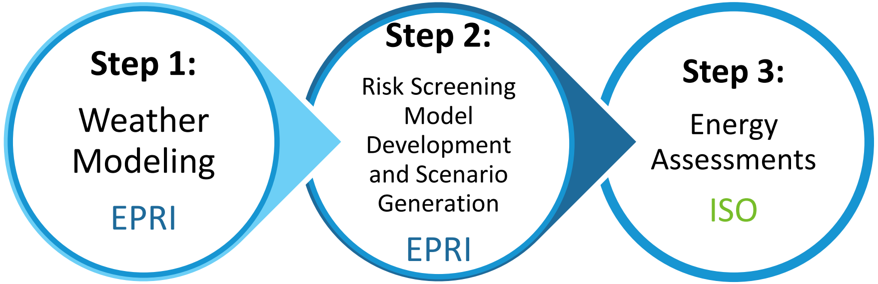
*2024 NERC-NATF-EPRI Extreme Weather Transmission Planning and Modeling Workshop*

Stephen George

DIRECTOR | OPERATIONAL PERFORMANCE, TRAINING, & INTEGRATION | ISO NEW ENGLAND

# Operational Impact of Extreme Weather Events – Energy Adequacy Study

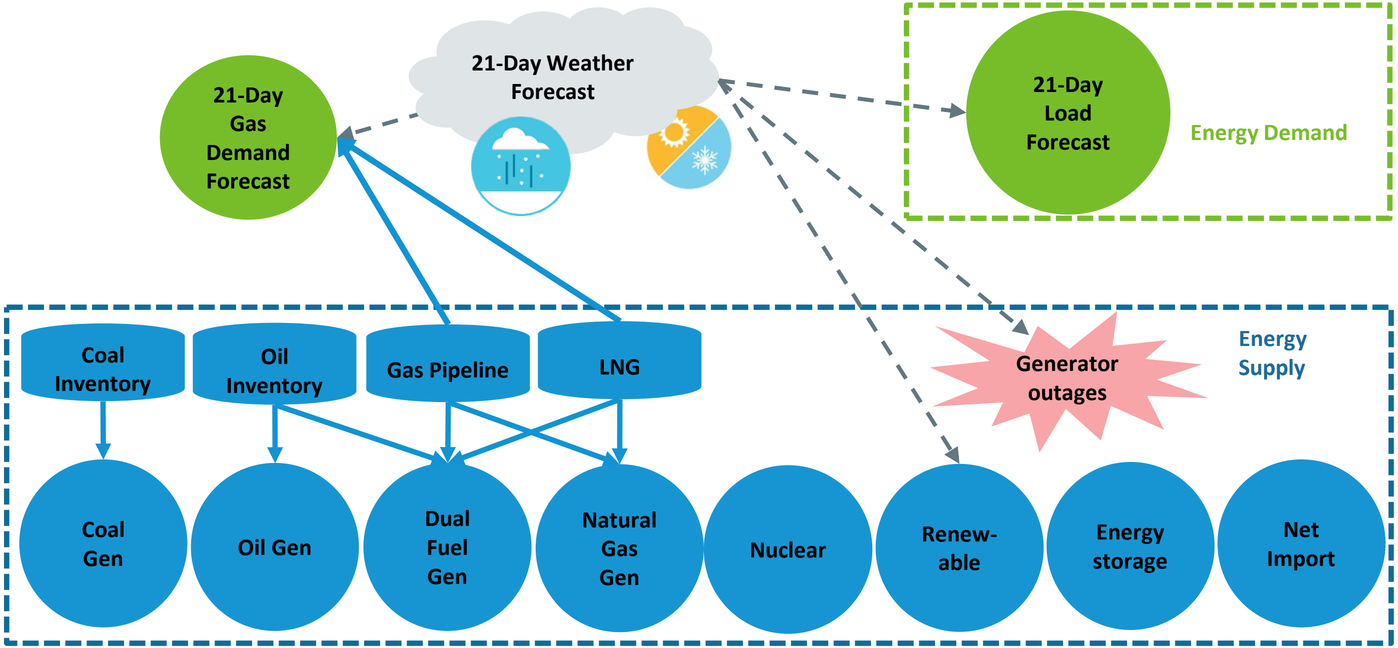
- ISO collaborated with EPRI to conduct a probabilistic energy adequacy study for the New England region in the operational time frame under extreme weather events; initial studies were focused on 2027 and 2032
- Study results have informed the region on energy shortfall risks over the next decade
  - These results will inform the development of a regional energy shortfall threshold (REST) in 2024
- This study has established the Probabilistic Energy Adequacy Tool (PEAT) framework for risk analysis under extreme weather events; ISO expects this framework will be essential as climate projections are refined and the resource mix evolves



# Objectives of the PEAT Framework

- Stress test the New England power system's energy shortfall risk under extreme weather conditions in the future
  - Evaluating the power system's capability to handle disruptions in energy demand and supply over a 21-day period
- This framework establishes an innovative approach to quantitatively and probabilistically assess the operational impact of climate change on power systems
- Study results can inform the region on energy shortfall risks and help the region to adapt to a changing climate and meet its clean energy goals

# Energy Surplus = Energy Supply – Energy Demand




- Energy adequacy is measured by energy surplus; energy surplus indicates whether the available energy supply is sufficient to satisfy energy demand within a 21-day duration under extreme weather conditions

# Overview of the PEAT Framework

**Step 1.**
**Weather Modeling**
(EPRI)

Utilize climate models to project hourly weather variable profiles in the New England region

**Step 2.**
**Risk Screening Model Development and Scenario Generation**
(EPRI)

Select extreme events, and generate a range of possible scenarios incorporating various uncertainties and their likelihoods

**Step 3.**
**Energy Assessments**
(ISO)

Perform probabilistic analysis of energy assessment outcomes

# Overview of Step 1 - Weather Modeling

- The objectives of this step were to identify 21-day weather events of interest using statistical analysis and to develop hourly profiles of weather variables for future periods of study
- This analysis includes the acquisition and interpretation of locationally-specific climate data
  - This data was used to characterize trends, including uncertainty, in the mean and extremes for different weather variables of interest
- As part of Step 1, EPRI performed a historical weather (1950 – 2021) review of the New England region which provided context to ISO and stakeholders related to historical extremes and trends
- EPRI used five global climate models spanning a range of climate sensitivities and two climate scenarios to project changes to historical weather
- Hourly profiles of weather variables produced via the climate modeling techniques were then used to develop hourly demand forecasts and energy output profiles for wind and solar resources for the periods being studied

# Step 1 - Hourly Profiles of Weather Variables

- Each future weather realization is a single year of synthetic hourly data
- There are 720 realizations for each projected year
  - 72 historical weather years (1950-2021)
  - 5 climate models & 2 climate scenarios each model (10 total)
  - 72 historical weather years x 10 model and scenario combinations = 720 realizations for each year of study
- Hourly weather variable profiles are high-dimensional
  - Dimension 1: Time series of data for each weather variable (temperature, wind speed, dew point, etc.)
  - Dimension 2: locations (10 weather stations)
  - Dimension 3: 2 climate scenarios (lower scenario & higher scenario)
  - Dimension 4: 5 climate models
  - Dimension 5: Year in which the synthetic profiles are valid (2027 & 2032)

# Overview of Step 2 - Risk Screening Model and Scenario Generation

- The objective of Step 2 is to identify 21-day weather events of interest and develop the inputs to the 21-day energy assessment in Step 3

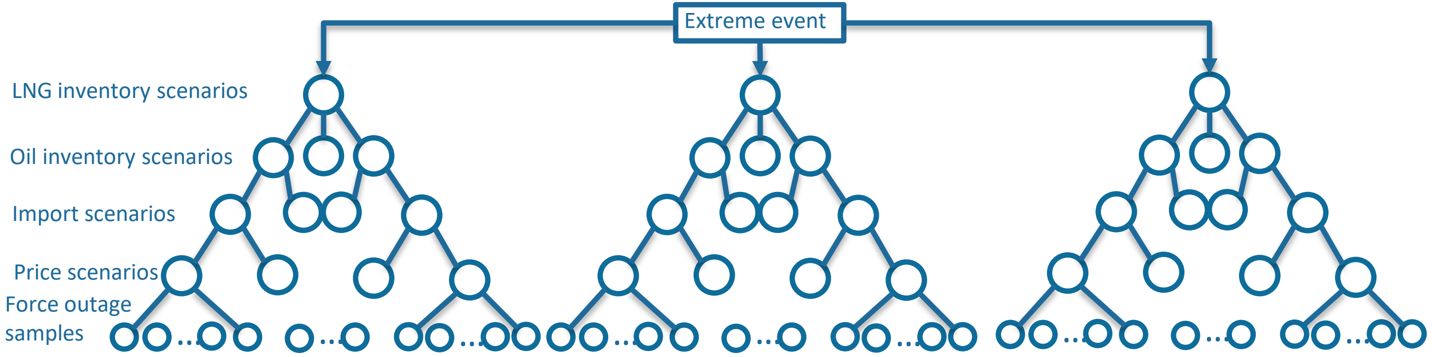
- Key activities in this step include:
  - Risk Screening Model, which is used to facilitate selection of extreme events by searching the weather data obtained in Step 1
  - Event selection, which identifies events of interest from the results of the Risk Screening Model
  - Scenario generation, which develops the input to the 21-day energy assessment in Step 3

# Step 2 – Risk Screening Model Facilitates Selection of Extreme Events For Study

- The Risk Screening Model assigned each 21-day event with a system risk score, and identified the extreme events based on system risk scores
- The system risk score was a coarse measure of system (supply and demand) risk
  - Supply risk estimates unavailable capacity of each type of supply resource under different weather conditions
  - Demand risk estimates exceptional demand above a fixed threshold
  - The scope of the current framework did not include weather related disruptions in transmission and distribution systems

# Step 2 - Power System Scenario Generation

- Following the identification of events for study, a full set of scenarios andtheir probabilities are generated as an input to the 21-day energy assessments in Step 3
  - LNG inventory scenarios: high, medium, low
  - Oil inventory scenarios: high, medium, low
  - Import scenarios: high, low
  - Fuel price: natural gas price > oil price, natural gas price ≤ oil price
  - Forced outages: Temperature-dependent forced outage rate model developed for each unit type by size (MW), physical location (state), and age (years)



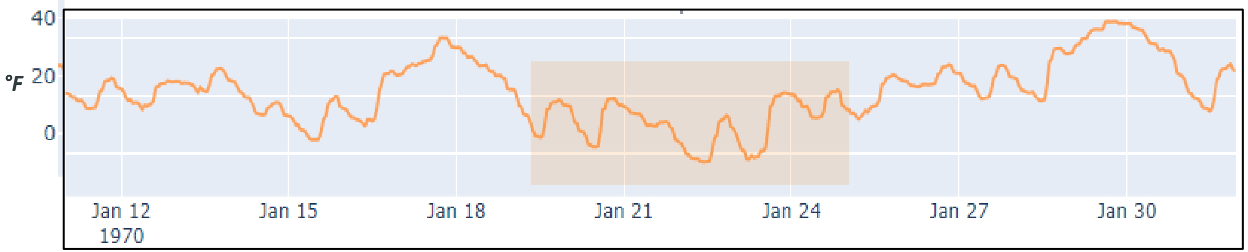

A scenario tree is generated for each extreme event

# Example Forced Outage Profiles for Event

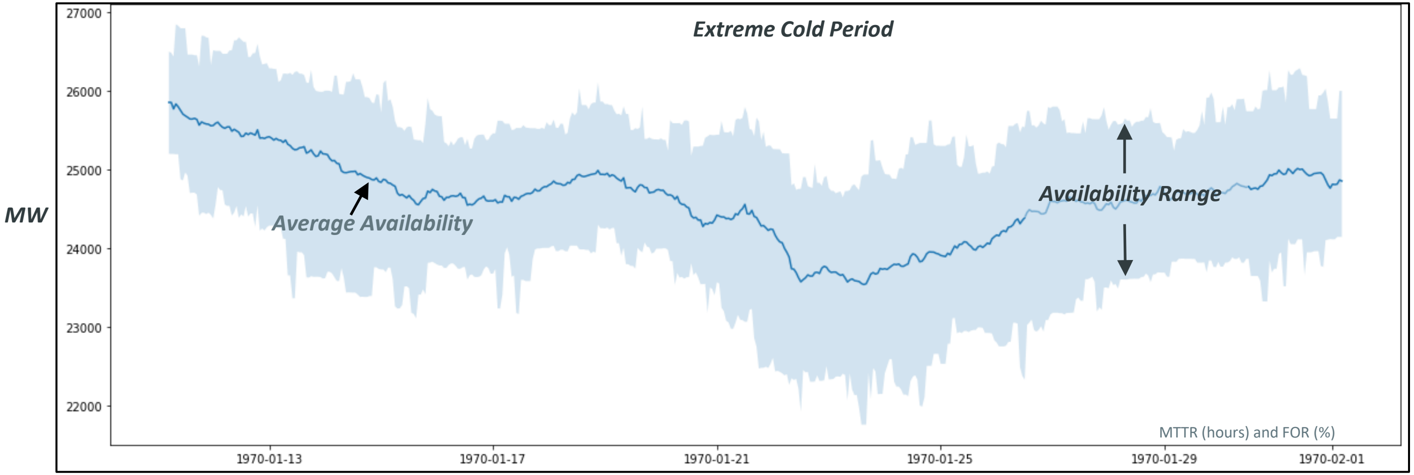
January 1971

| Event | W1 |
| --- | --- |
| Study year | 2032 |
| Climate Model | GFDL |
| Emission scenario | Low |

## Regional Average Temperature




## Available Capacity

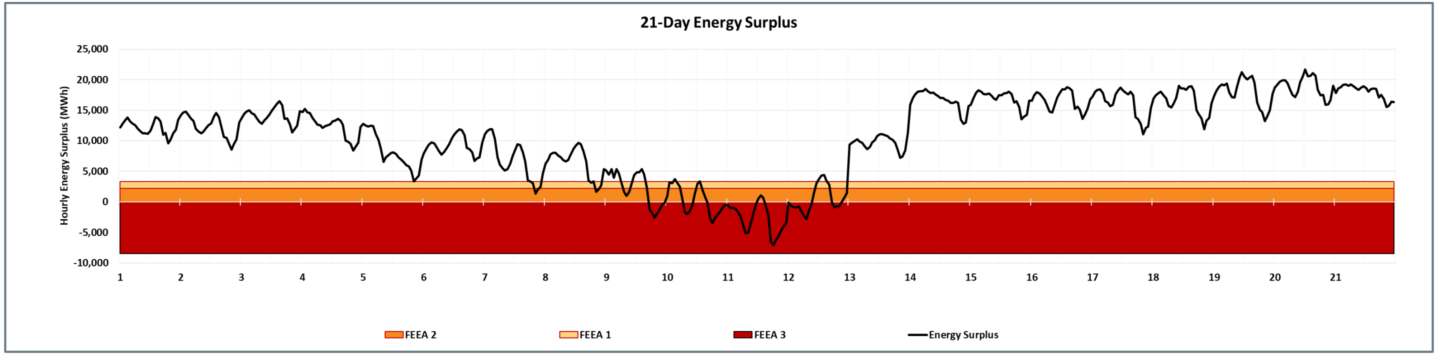


# Overview of Step 3 - Energy Assessments

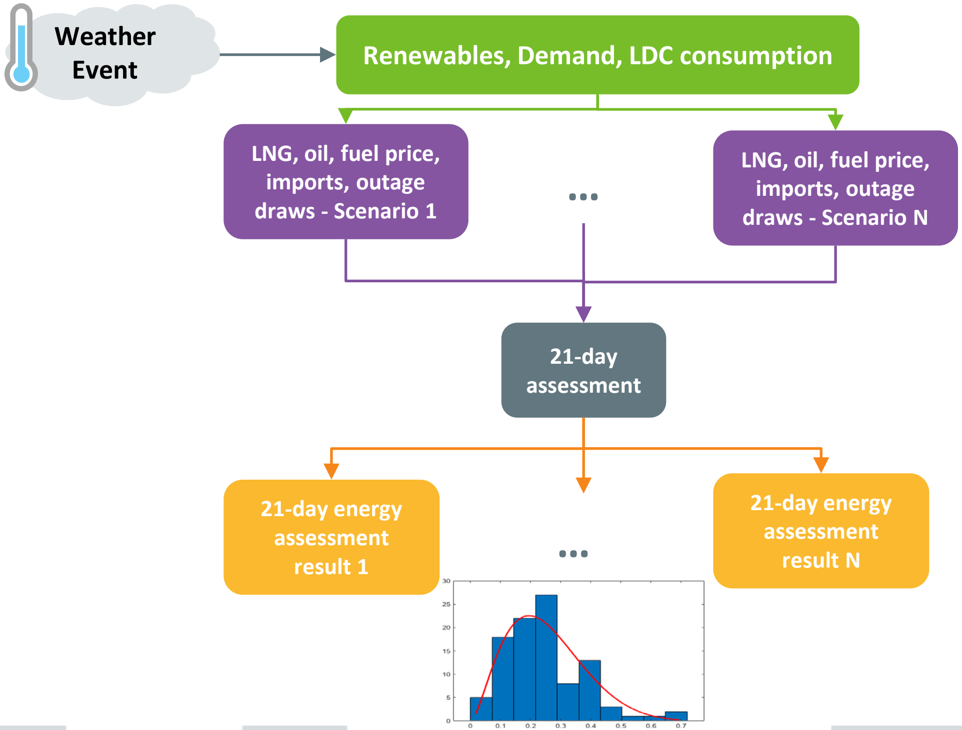
- ISO-NE utilizes the 21-Day Energy Assessment to forecast potential energy shortfalls across a 21-day period
  - Since Winter 2018/19, this analysis has been performed on a weekly basis during the winter months, bi-weekly otherwise
  - Results of the analysis are made publicly available on ISO-NE website, including the declaration of Energy Alerts and Energy Emergencies
  - Situational awareness provided by the analysis allows ISO-NE and stakeholders to make informed decisions in advance of any forecasted energy shortfalls
- The 21-Day Energy Assessment is the workhorse of Step 3

# Step 3 – Performance of Energy Assessments

- The 21-Day Energy Assessment Tool is an application developed by ISO-NE that calculates hourly energy surplus over a 21-day study period
  - Dispatches generators to meet demand based on economic merit order during the 21-day period
  - Dispatch capability of fossil fuel units is constrained by physical fuel storage
  - Coal, oil, pipeline gas, and LNG inventory is tracked hour-by-hour
- For each scenario, the 21-Day Energy Assessment Tool evaluates energy shortfall, quantity (MW) and duration *(as depicted by periods where the energy surplus curve dips into the red shaded area)*



# The Connection Between Selected Events (Step 2) and Probabilistic Energy Assessments (Step 3)

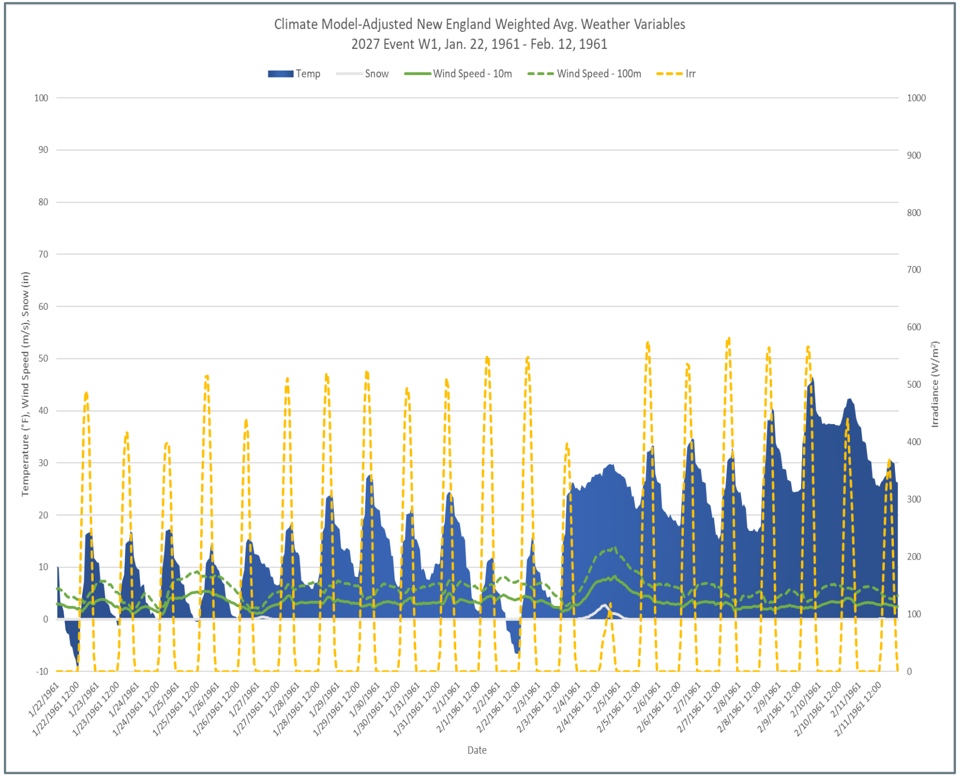


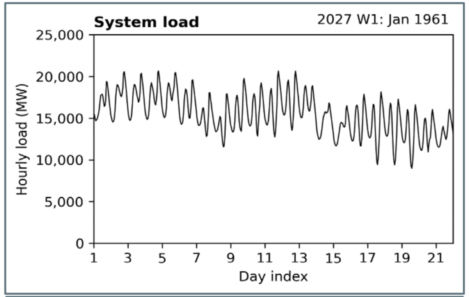

- In Step 2, a scenario tree is generated for each selected event, representing LNG, oil, fuel price, import, and outage uncertainties

- In Step 3, ISO performs analysis of 21-day energy assessment outcomes

# Jan 22, 1961 Winter Event (2027 Projection) Overview

## ~12-Day Cold Wave Coincident With Low Wind and Very Low Solar



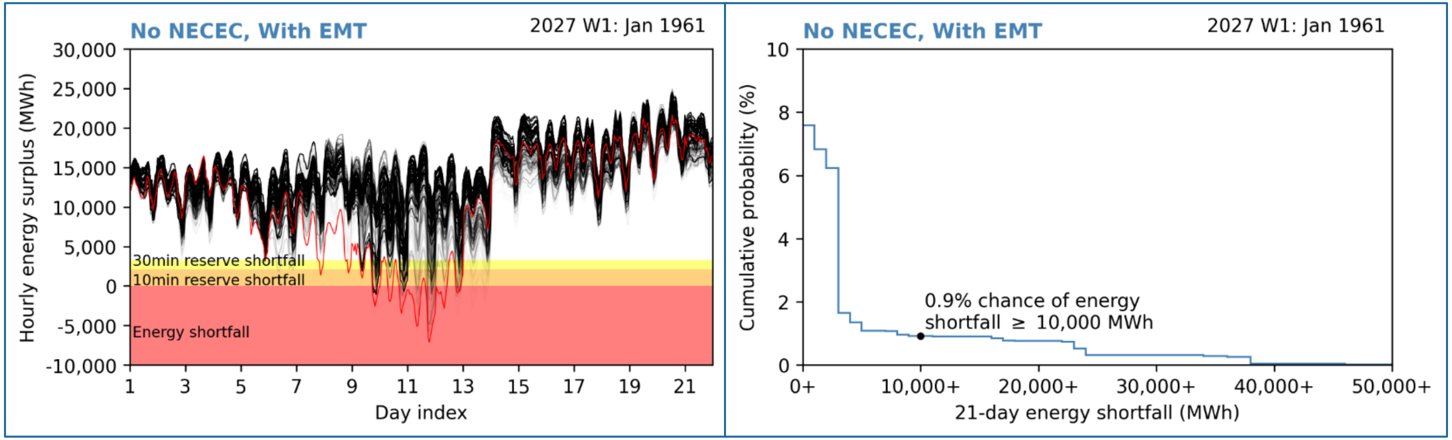

- **Min/Mean/Max (°F):** -9.8/15.8/45.7
- **Mean 100m Wind Speed (m/s):** 6.0
  - Offshore Wind avg. 800 MW/hr
  - Onshore Wind avg. 370 MW/hr
- **Mean Irradiance (W/m²):** 118.8
  - Utility Scale PV avg. 230 MW/hr
  - BTM PV avg. ~800 MW/hr
- **Avg. Energy From Renewables:** ~2,200 MW/hr
- **Peak Load:** 20,655 MW (day 4)
- **Peak Energy Demand:** ~424,000 MWh (day 5)
- **Total 21-Day Energy Demand:** 7.82 TWh
- **Historical Relevance:** Coldest 21-day period since 1950; includes two of the top 10 coldest 5-day periods since 1950



*temperatures, wind speeds, and irradiance are based on a New England eight-city weighted average

# Summary of 21-Day Energy Analysis Results

## Example Results from Jan 22, 1961 Event Studies




*in the energy surplus chart above (upper-left), the red highlighted trace represents the case that has the highest energy shortfall amount (MWhs); otherwise, the lower the probability of a case, the lighter its corresponding trace

| # of cases having energy shortfall (of 720) | Max 21-day total energy shortfall in a case (MWh) | Min 21-day total energy shortfall in a case with energy shortfall (MWh) | Probability weighted avg. 21-day total energy shortfall per case with energy shortfall (MWh) | Weighted probability of energy shortfall occurring in a case | Probability of the case with max 21-day total energy shortfall |
|---|---|---|---|---|---|
| 233 | 111,353 | 36 | 421 | 7.6% | 0.0006% |

# Key Takeaways of 2027 and 2032 Studies

- The region's energy shortfall risk is dynamic and will be a function of the evolution of the supply and demand profiles
  - Various assumptions inform the analysis and significant deviation from any of these assumptions may result in an increasingly risky profile; assumptions include that the market will respond with new renewables to meet the increased demand caused by electrification and that transmission will be built to interconnect offshore wind resources and increase import capabilities from Canada
  - The studies also anticipate a reliable gas system, a responsive oil supply chain, and no significant disruptions in energy production due to emissions limitations

- Results of the energy adequacy studies reveal a range of energy shortfall risk and associated probabilities
  - In the near-term, the winter energy shortfall risk appears manageable over a 21-day period
  - Results are consistent with expectations for load growth and significant quantities of solar, offshore wind, battery storage resources, and additional imports

- Sensitivity analysis of 2032 worst-case scenarios indicates an increasing energy shortfall risk profile between 2027 and 2032

- The PEAT framework provides a much needed foundation to study energy shortfall risk as the system evolves

# Questions

# For More Information

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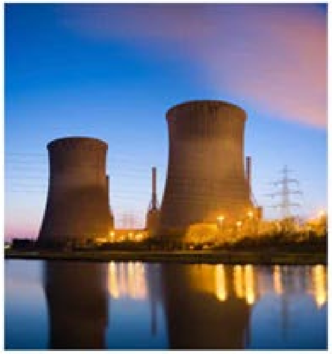
# Next Steps

## NERC Project 2023-07

Jared Shaw, Drafting Team Vice Chair
January 2024

RELIABILITY | RESILIENCE | SECURITY

# Timeline

- Initial Posting:
  - March 20 – April 29, 2024 (45-day comment and ballot period)
- Additional Postings:
  - July 9 – August 6, 2024 (35-day comment and ballot period)
  - September 17 – October 15, 2024 (35-day comment and ballot period)
- Final Ballot period:
  - November 5 – 15, 2024
- NERC Board Adoption:
  - December 13, 2024
- File with Regulatory Authorities:
  - December 2024 (Regulatory Deadline – FERC Order 896)

# Questions

- Questions throughout the standards development process or want to have a call with some drafting team members to discuss the standard.

Contact:

Jordan Mallory, Standards Developer
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770.686.4171 (cell)

# Questions and Answers