Meeting Notes
Project 2023-07 Transmission System Planning Performance Requirements for Extreme Weather

November 6, 2023 | 1:00 – 4:00 p.m. Eastern

Review NERC Antitrust Compliance Guidelines and Public Announcement
Jordan Mallory, NERC staff, called attention to the NERC Antitrust Compliance Guidelines and the public meeting notice.

Roll Call and Determination of Quorum
J. Mallory completed the team roll call and quorum was determined. The member attendance sheet is attached as attachment 1.

Benchmarking Presentation
EPRI's Sr. Principal Technical Leader, Eknath Vittal and Climate Science Expert, Laura Fischer presented a presentation on FERC Order 896 for the NERC Project 2023-07 drafting team. The presentation is attached as attachment 2.

Defining benchmark event
The DT held discussion around what needs to be considered for extreme heat and extreme cold weather benchmark. Below lists out some of those items for consideration:

- Extreme Heat
  - Air temperature
  - Heat index
- Extreme Cold
  - Wind chill
  - Wind speeds

The DT discussed forward looking and two challenges will be hourly data and near term/long term data. In addition, consideration will need to be given to the length of climate model data, of which at this time 20 years was mentioned. A question came up from the team about how long the climate type data will be readily available to industry. It was mentioned that FERC Order 896 speaks to long-term transmission planning and NERC has defined this as 6-10 years and beyond.

Future Meeting(s)

a. November 9, 2023 | 12:00-3:00 p.m. Eastern
b. November 16, 2023 | 12:00-3:00 p.m. Eastern

c. November 17, 2023 | 1:00-3:00 p.m. Eastern

Adjourn

The meeting adjourned at 4:00 p.m. eastern.

Attachment 1

	Name	Entity	Attendance
Chair	Evan Wilcox	American Electric Power	Y
Vice Chair	Jared Shaw	Entergy Services	Y
Members	Josie Daggett	Western Area Power Administration	Y
	David Duhart	Southwest Power Pool	Y
	Michael Herman	PJM Interconnection	Y
	Tracy Judson	Florida Power & Light	Y
	Sun Wook Kang	ERCOT	Y
	Andrew Kniska	ISO New England	Y
	Dmitry Kosterev	Bonneville Power Administration	Y
	David Le	California ISO	Y
	Karl Perman	CIP CORPS	N
	Meenakshi Saravanan	ISO New England	Y
	Kurtis Toews	Manitoba Hydro	Y
	Hayk Zargaryan	Southern California Edison	Y
PMOS Liaison	Jason Chandler	Con Edison	Y
	Donovan Crane	WECC	Y
NERC Staff	Jordan Mallory – Standards Developer	North American Electric Reliability Corporation	Y

	Name	Entity	Attendance
	Lauren Perotti – Assistant General Counsel	North American Electric Reliability Corporation	Y

Transmission System Planning Performance Requirements for Extreme Weather

FERC Final Ruling:
Order No. 896

Eknath Vittal, Sr. Principal Tech Lead
Laura Fischer, Sr. Tech Lead

Project 2023-07 Kick-off Meeting
November 6, 2023

CLIMATE READi
RESILIENCE AND ADAPTATION INITIATIVE

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EPRI Climate Resilience and Adaptation Initiative (READi)

- **COMPREHENSIVE:** Develop a *Common Framework* addressing the entirety of the power system, planning through operations
- **CONSISTENT:** Provide an informed approach to climate risk assessment and strategic resilience planning that can be replicated
- **COLLABORATIVE:** Drive stakeholder alignment on adaptation strategies for efficient and effective investment

Workstream 1

- Identify climate hazards and data required for different applications
- Evaluate data availability, suitability, and methods for downscaling & localizing climate information
- Address data gaps

Workstream 2

- Evaluate vulnerability at the component, system, and market levels from planning to operations
- Identify mitigation options from system to customer level
- Enhance criteria for planning and operations to account for event probability and uncertainty

Workstream 3

- Assess power system and societal impacts: resilience metrics and value measures
- Create guidance for optimal investment priorities
- Develop cost-benefit analysis, risk mitigation, and adaptation strategies

Deliverables: Common Framework "Guidebooks"

- Climate data assessment and application guidance
- Vulnerability assessment
- Risk mitigation investment
- Recovery planning
- Hardening technologies
- Adaptation strategies
- Research priorities

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Climate READi Members

UNITED KINGDOM

FRANCE

Member Headquarters Member Operating States/Provinces ISO Service Territories *(only HQ location shown for IPPs)*

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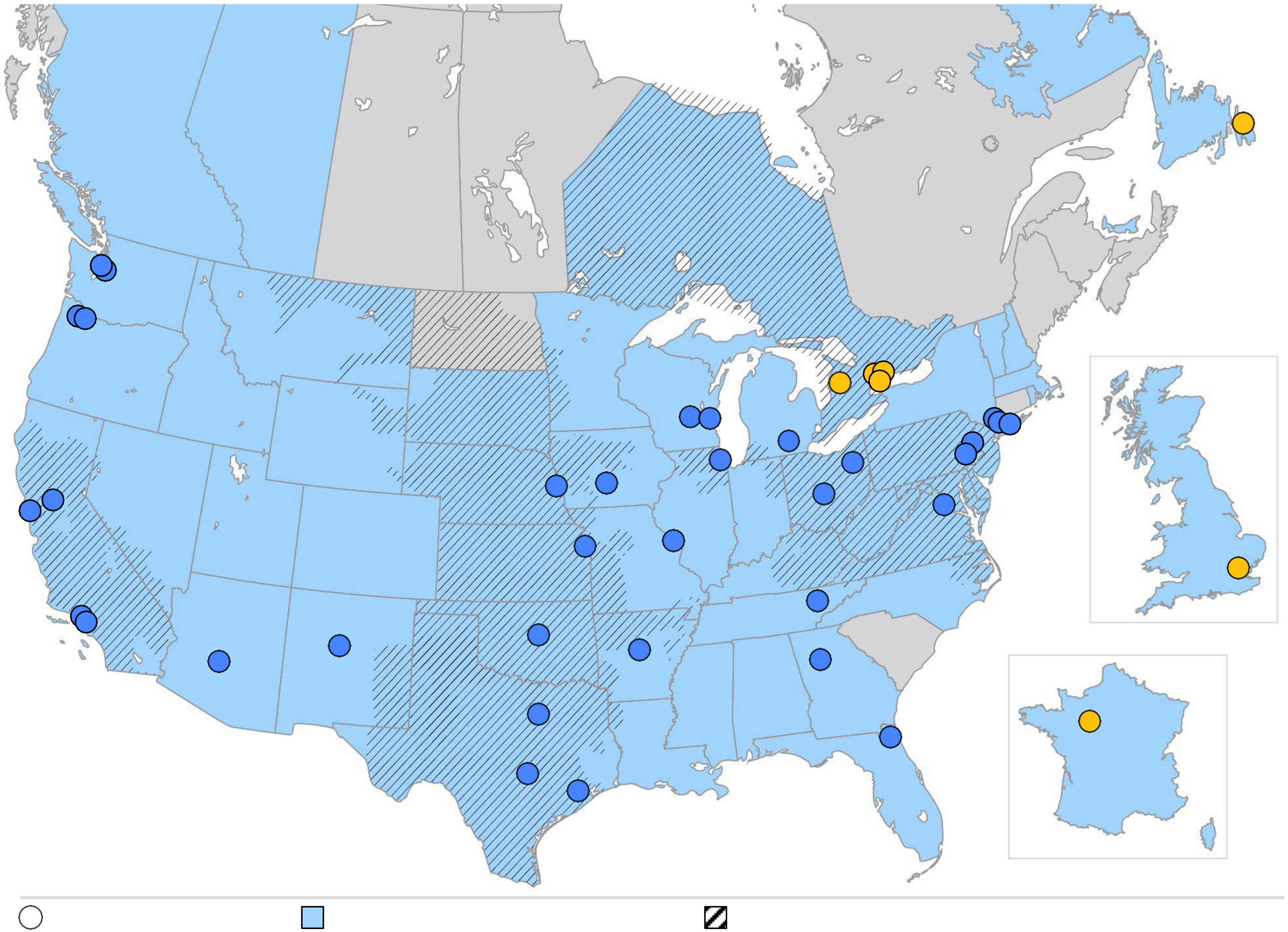
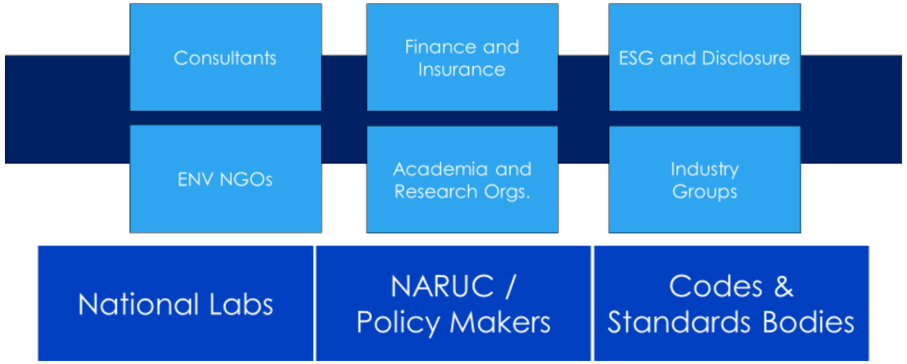
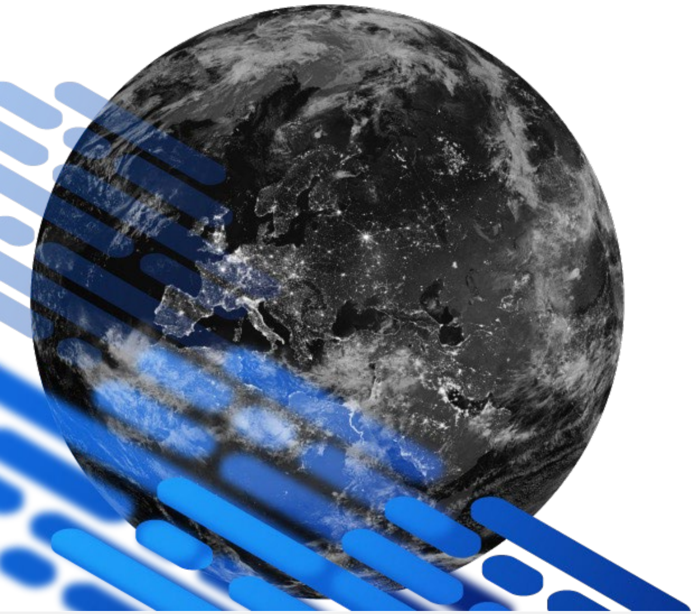


AES Indiana
AES Ohio
Alliant Energy
Ameren
American Electric Power
Berkshire Hathaway Energy
Bonneville Power Administration
Bruce Power
California ISO
CenterPoint Energy
Consumers Energy
conEdison
ercot
evergy
exelon
FirstEnergy
FORTIS INC.
hydro one
ieso Connecting Today. Powering Tomorrow.
JEA
LADWP Los Angeles Department of Water & Power
LIPA Long Island Power Authority
nationalgrid
NY Power Authority
OG&E
OPPD Omaha Public Power District
Ontario Power Generation
PG&E
pjm
PNM
ppl
PSE Puget Sound Energy
Rte
SRP
Seattle City Light
Southern California Edison
Southern Company
SPP Southwest Power Pool
TVA Tennessee Valley Authority
VISTRA
WEC Energy Group

Climate READi Affinity Group (CRAG)



Embracing a 'Big-Tent' Approach to Framework Development



- Accenture
- ADEX
- Alison Silverstein (Consultant)
- Andre Dessler (Consultant)
- Applied Weather Associates
- Argonne National Laboratory
- Baringa
- Battelle
- Black & Veatch
- Brookhaven National Laboratory
- CAMPUT
- Canadian Climate Institute
- CANDU Owners Group
- CarbonPlan
- CDP North America
- Center for Climate & Energy Solutions
- Chemonics
- Clark Miller (Consultant)
- Clean Air Task Force
- Climate Risk Institute
- Columbia University
- Copperleaf Technologies
- CSA Group
- Desert Research Institute
- Disaster Tech
- Eagle Rock Analytics
- Eaton
- Electricity Canada
- Energy Systems Integration Group
- Energy Networks Association
- Enline Transmission
- Exponent
- Grid Lab
- Grid2.0
- Guidehouse
- Houston Advanced Research Center
- ICF
- IEEE
- Imperial College London
- King Abdullah Petroleum Studies and Research Center
- Institute of Nuclear Power Operations
- Jacobs Engineering
- Khalifa University
- King Abdullah University of Science and Technology
- King's College London
- Lawrence Berkeley National Laboratory
- Lawrence Livermore National Laboratory
- McCormick Taylor
- Midwest Climate Collaborative
- Model World Consulting
- National Association of Regulatory Utility Commissioners
- National Association of State Energy Officials
- National Center for Atmospheric Research
- National Oceanic and Atmospheric Administration
- National Renewable Energy Laboratory
- North American Electric Reliability Corporation
- North American Transmission Forum
- Nuclear Energy Institute
- Nuclear Electric Insurance Limited
- National Renewable Energy Laboratory
- Oak Ridge National Laboratory
- Oregon State University
- Pacific Northwest National Laboratory
- Pacific Northwest Utilities Conference Committee
- Power Systems Engineering Research Center
- Quanta Services
- RAND Corporation
- Resources for the Future
- RS Poles
- RUNWITHIT Synthetics
- Sharply Focused
- SLR Consulting
- Storm Impact
- Sunairio
- Union of Concerned Scientists
- Universidad Pontificia
- University of Albany
- University of Illinois
- University of Michigan
- University of Nottingham
- University of Reading
- University of Saskatchewan
- Verdantas

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Transmission System Planning Performance Requirements for Extreme Weather: Final Rule

Docket No. RM22-10-000, Order No. 896

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Ruling issued June 23, 2023

Looks at required planning actions for the next 6-10 years and establishes an update of the NERC TPL-001-5.1. Requires NERC to consider three primary aspects with respect to extreme heat and extreme cold

1

Development of benchmark cases for extreme heat and extreme cold events

2

Planning for extreme weather using steady-state and transient stability analysis for scenarios that include the expected resource mix's availability

3

Develop corrective action plans that mitigate the impacts of extreme weather

Determining Benchmark Events

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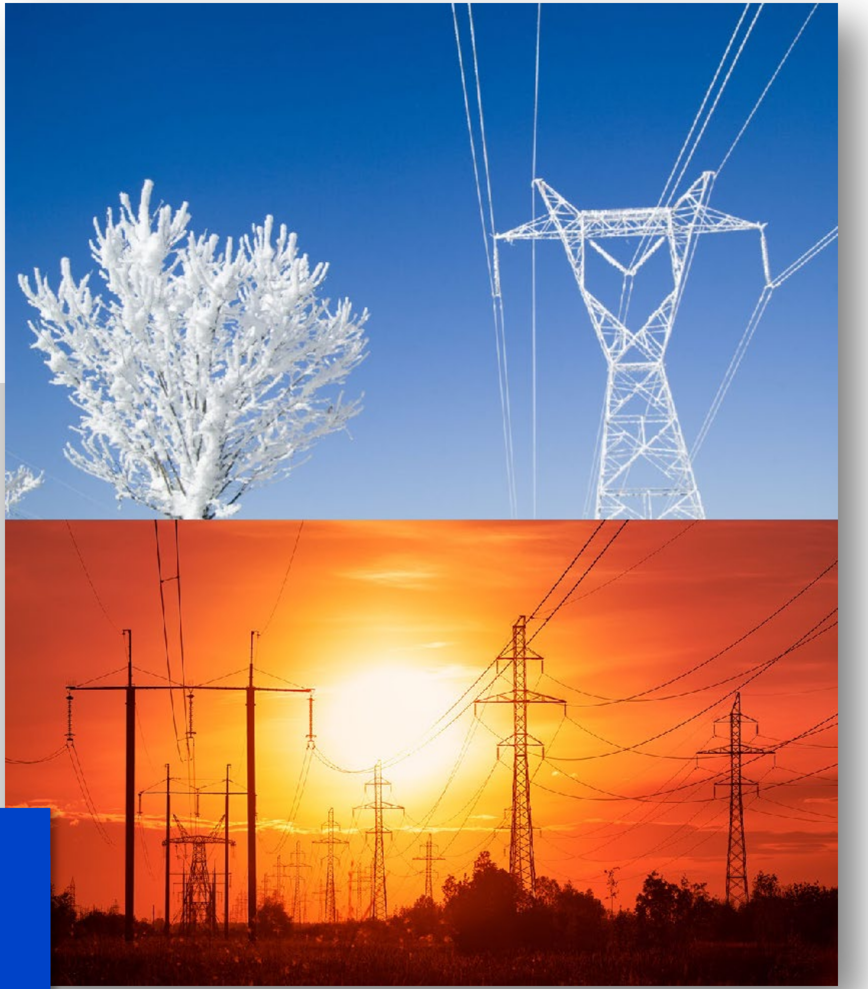
Weather and power system interactions are complex, we need to pass weather data through asset vulnerability models to fully understand impacts

- Additionally, there is a data gap that captures climate informed weather data for the next 5-10 years
- Need to understand and develop process that capture how the short-term variability of weather is impacted by the rapidly changing climate



Objective will be to leverage the READi framework to connect this data to the system analysis process

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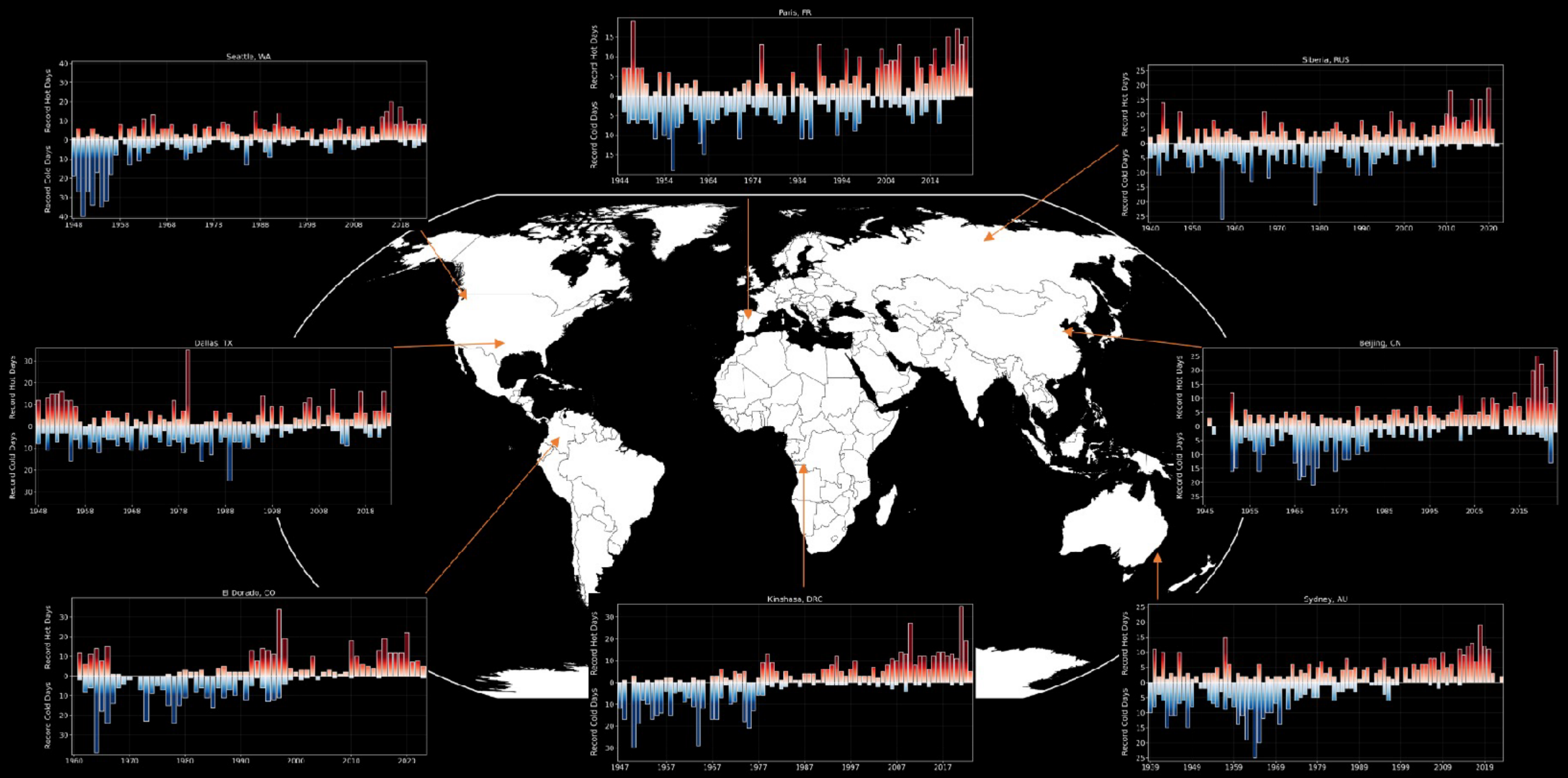
Historical and Projected Changes in Extreme Weather

Extreme heat has increased in frequency and intensity in recent decades and is projected to continue going forward

Extreme cold has decreased in frequency and intensity in recent decades and is projected to continue going forward



Annual Hot and Cold Temperature Records Across the Globe

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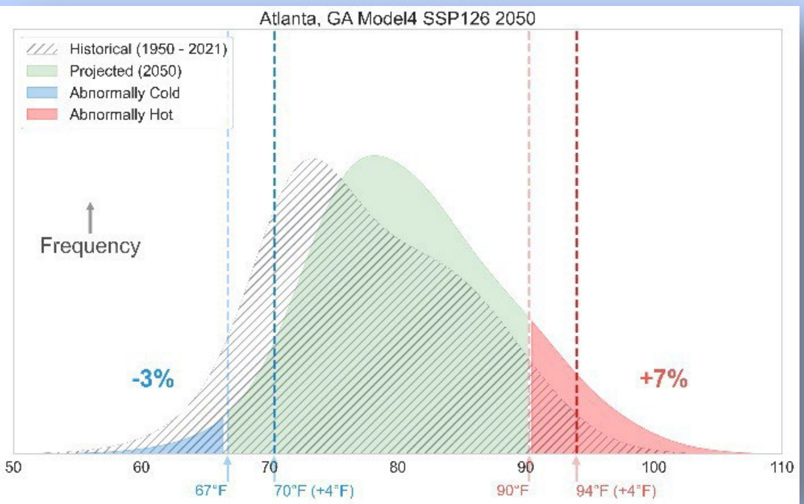
Benchmark Events: Extreme Heat

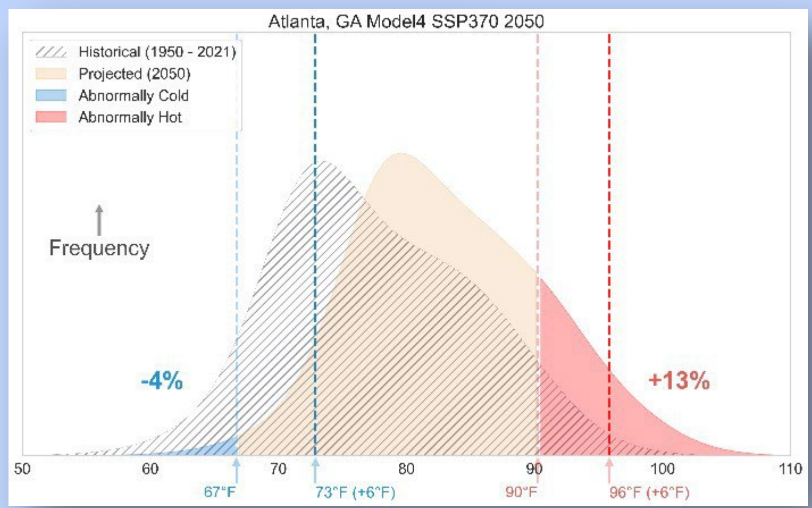
- Important variables: dry-bulb (air temperature) or heat index (considers moisture)
- Common metrics
  - ***Frequency***: annual number of days exceeding percentile or set threshold
  - ***Duration:*** consecutive days exceeding percentile or set threshold
  - ***Intensity:*** annual/seasonal maximum temperatures

Extreme Heat Projections: Assessing Future Risk

- Because extreme heat is increasing in frequency and intensity, the historical record underrepresents the likelihood of events
- Warming has accelerated in the past 2 decades, meaning projections are more critical than ever in assessing changing likelihoods of extreme heat
- As with the PNW heatwave, record shattering heatwaves are becoming increasingly common across the globe

Climate models show an increase in heat events across emission pathway scenarios





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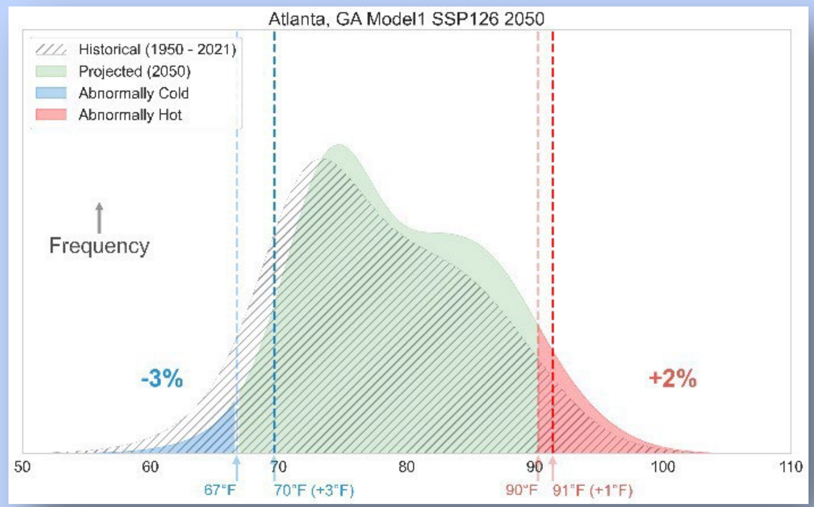
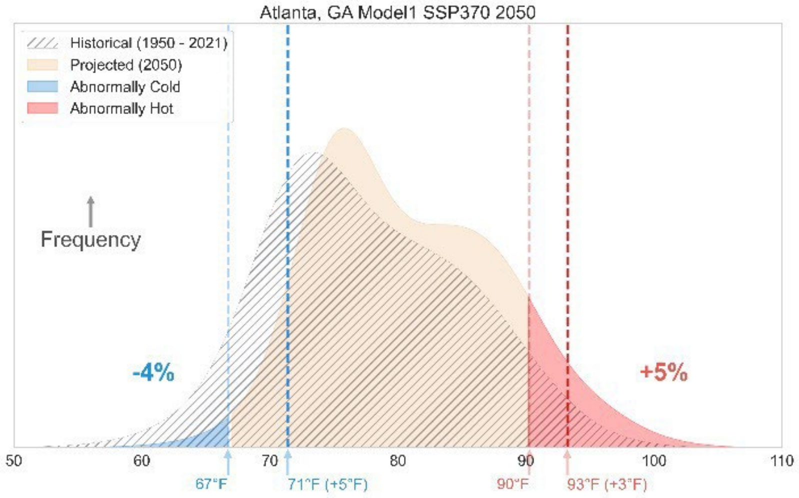
Benchmark Events: Extreme Cold

The overall warming trend indicates extreme cold events is decreasing in frequency and intensity across climate models and emission scenarios





- Variables: dry-bulb (air temperature) or wind chill (considers wind speeds)
- Common metrics
  - ***Frequency:*** annual number of days below percentile or set threshold
  - ***Duration:*** consecutive days below percentile or set threshold
  - ***Intensity:*** annual/seasonal minimum temperatures

Extreme Cold Projections: Assessing Future Risk

- Because extreme cold is decreasing in frequency and intensity, the historical record likely represents a higher risk of extreme cold than shown by most climate models
- The historical record would be a conservative scenario when planning for extreme cold as warmer scenarios like SSP585/RCP8.5 likely underrepresent the risk of extreme cold in the future
- Should use historical data back through 1980 at least, though back to 1950 is best

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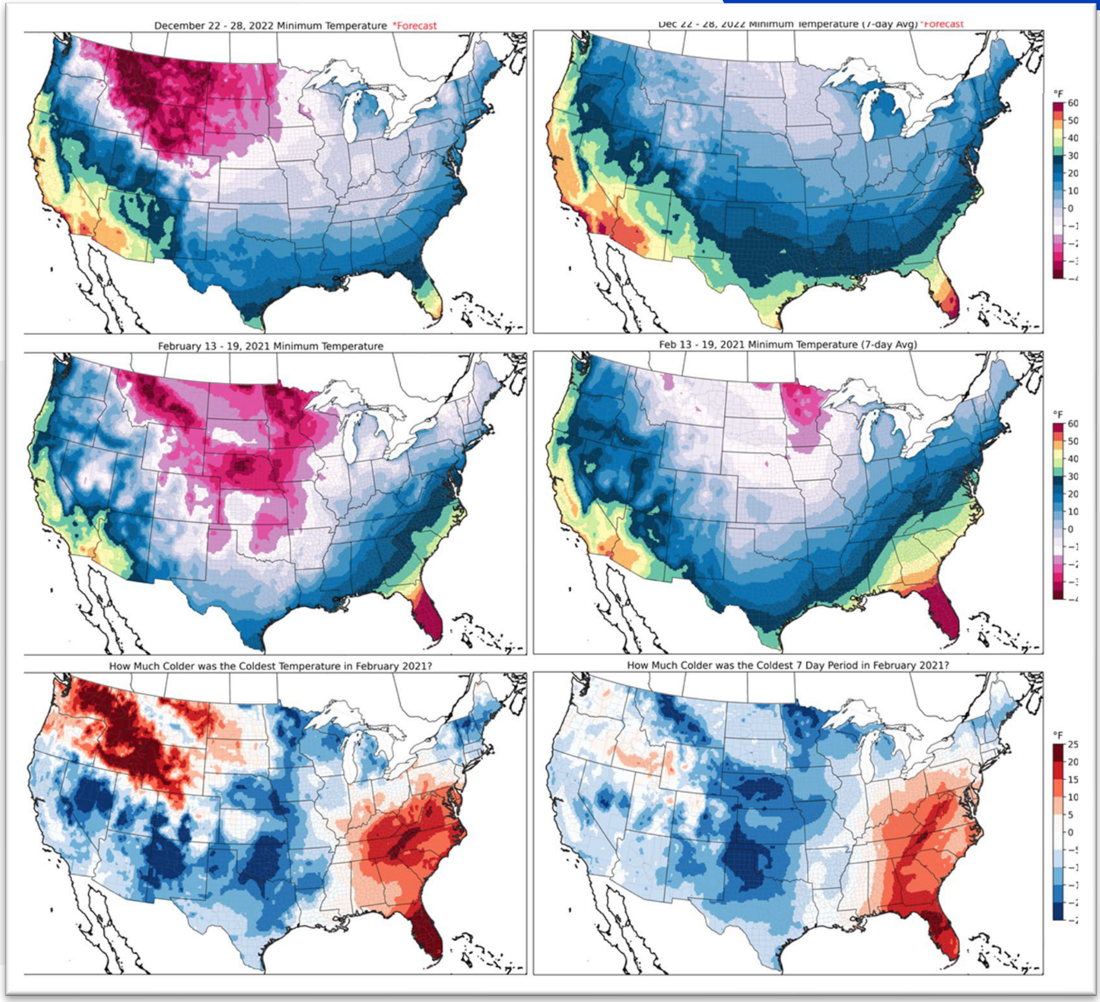
Challenges in Identifying Benchmark Events

Winter Storm Elliot Example: Focusing exclusively on historical temperatures can miss events

- 2 to 3 days of extreme cold in most locations
- Lasted for only a couple of days, and no low temperature records broken
- The December 2022 cold air outbreak was very cold across the Eastern US
- Colder in the east than the Feb 2021 cold air outbreak, but not record breaking by any means



Focusing exclusively on extreme temperatures is insufficient to capture winter

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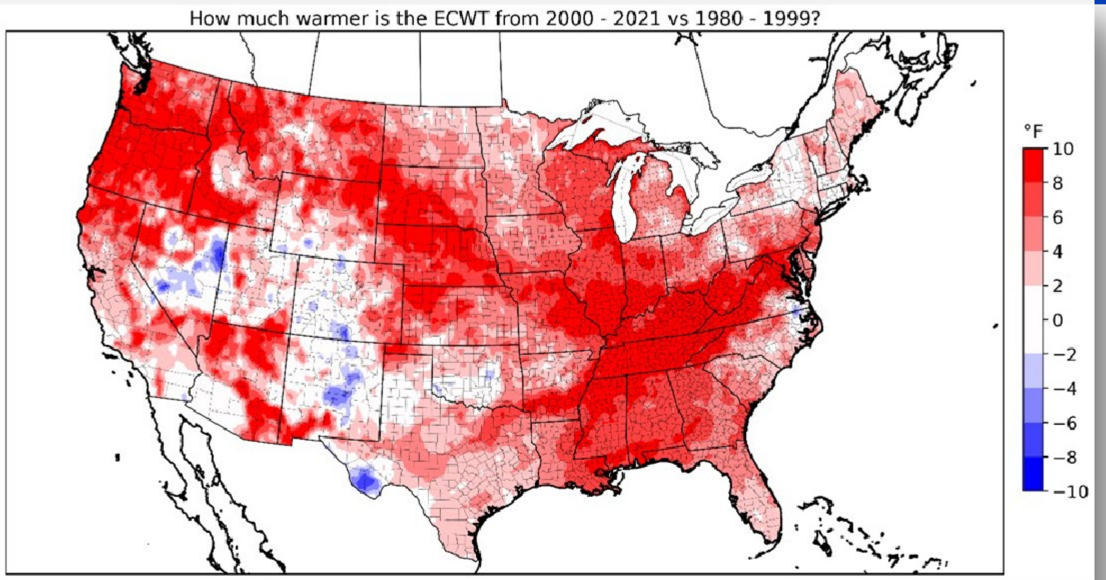
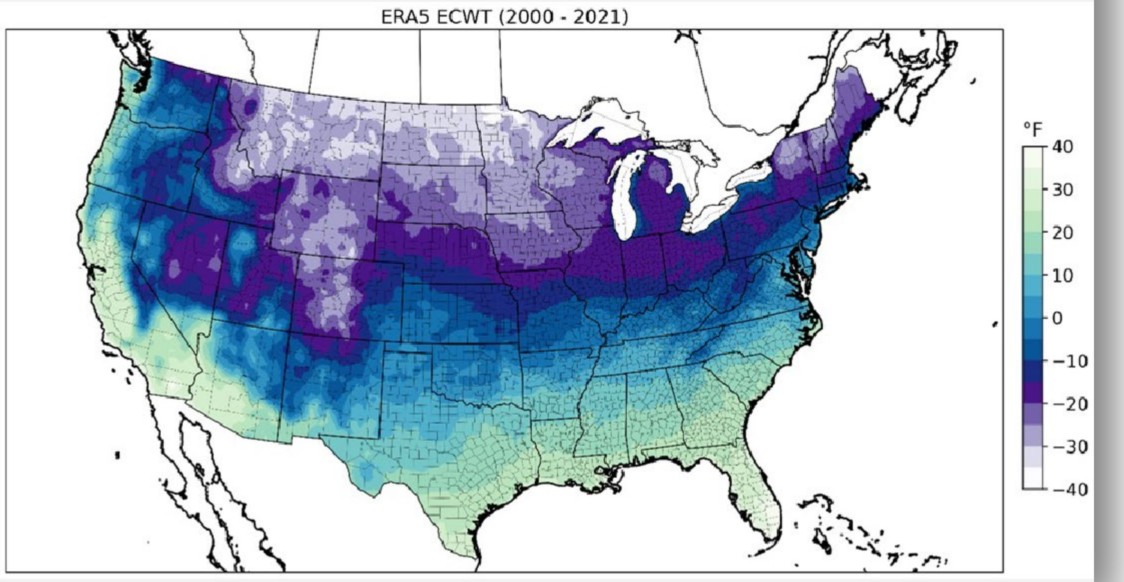
Challenges in Identifying Benchmark Events

Deterministic criteria is likely not sufficient to capture impacts of future events

NERC Extreme Cold Weather Temperature (ECWT)

- The NERC ECWT is based on the 0.2 percentile for 2000 – present, however, limiting the calculation to this time period omits some of the coldest events in the US during the 1980s
- The ECWT, when calculated for the years of 2000 – present, is 6° F to 10° F warmer than if calculated with the years of 1980 – 1999
- ***Key takeaway: period of record is critical when assessing a hazard!***





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Hourly Forward-Looking (near-term) Climate Data

QDM methodology developed by Delavane Diaz and Erik Smith, EPRI

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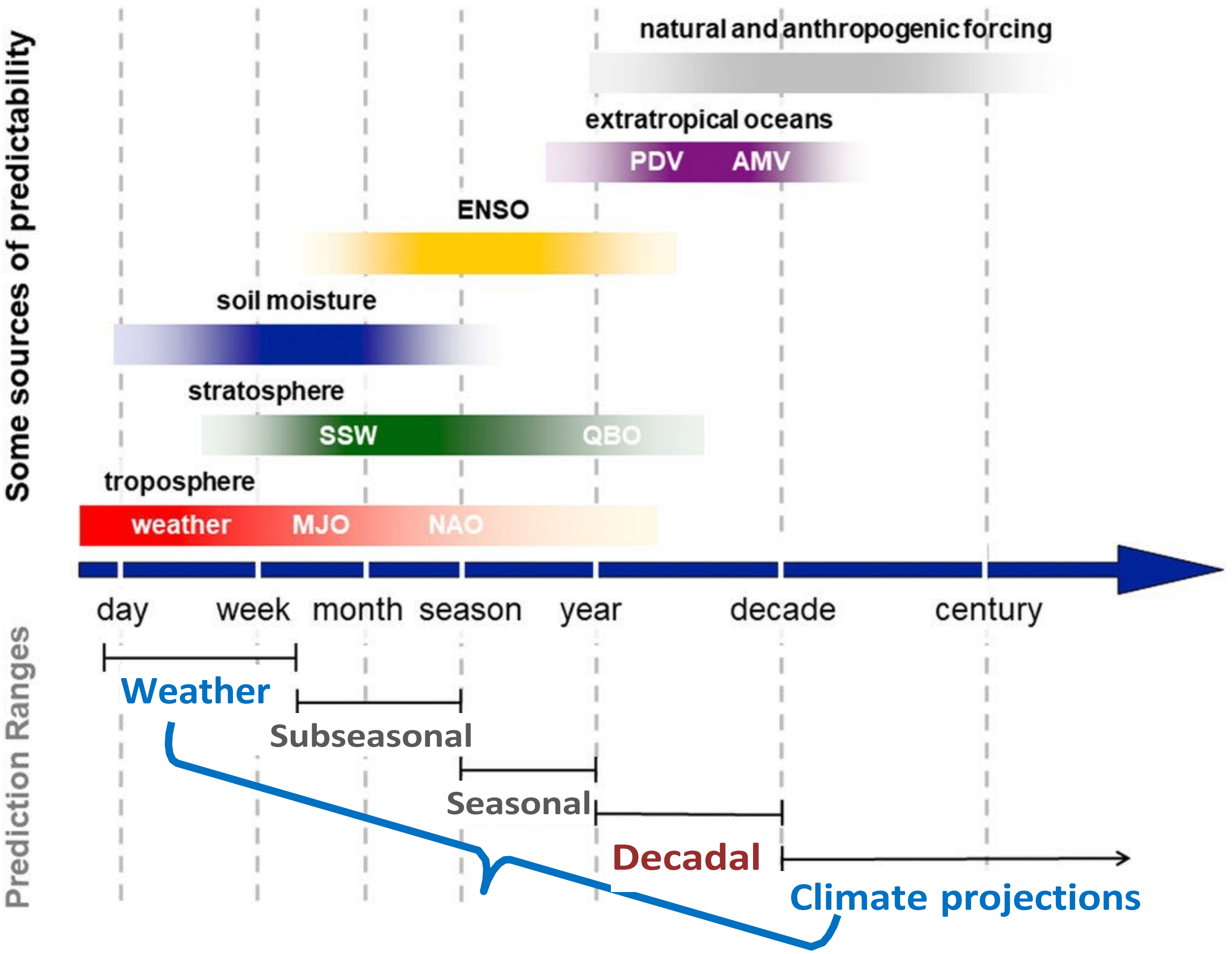
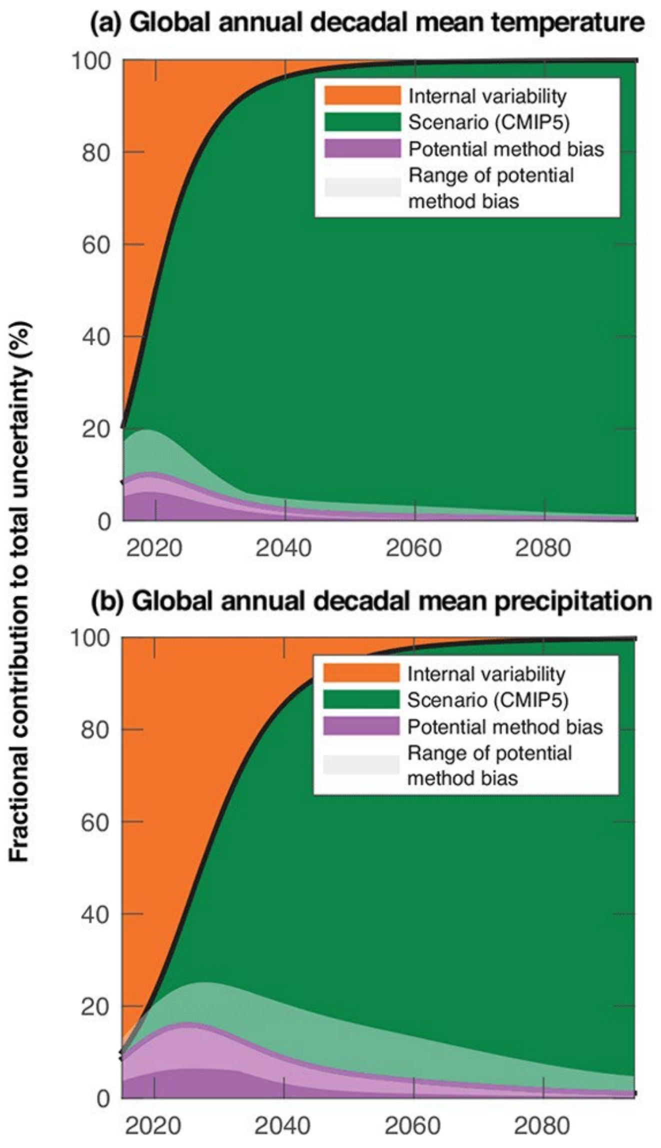
Challenge of Near-Term Climate Projections





Bridging the Weather to Climate Continuum (W2CC) gap

Source: Merryfield et al 2020; Lehner et al 2020

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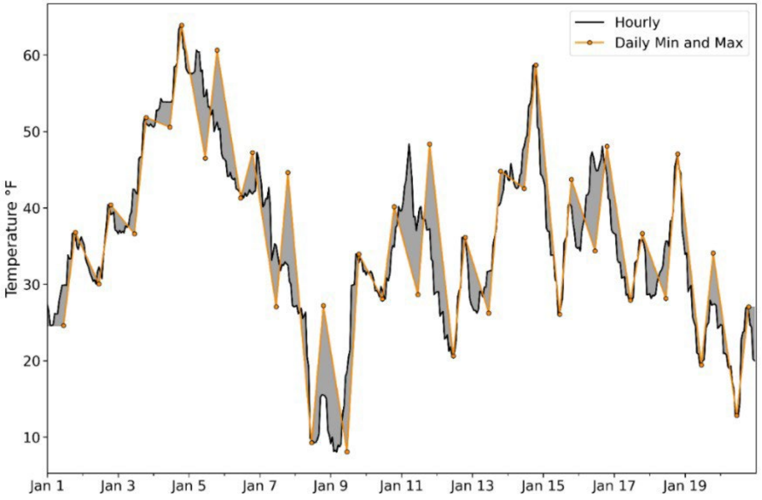
Background on future synthetic hourly profiles

Motivation: Global climate model (GCM) projections typically have daily resolution, whereas most power system applications require hourly data



Example: Hourly vs Daily Temperature

- Interpolating between daily values can miss important patterns (see figure)
- Customized dynamical downscaling can offer hourly resolution (but expensive, computationally and $$)
- Historical weather records capture real-world variability and preserve physical link between meteorological variables
- We present an innovative approach that leverages “best” of both historical and projection datasets to create 720 realistic synthetic hourly weather profiles

Relevance: Various utility functions could utilize this type of future hourly data, such as resource adequacy or other risk analysis, system planning, load projections, line ratings, asset/engineering design standards, among others

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We can leverage the important characteristics from both the historical and climate projection datasets

Historical Data	Climate Projections
Hourly data	Daily data
Realistic variability - Scales of weeks, months, & years from 72 years of historical weather (1950-2021)	Limited variability - Variability is constrained to the underlying physical model; typically not well-captured
Historical years only - Can't represent weather extremes that haven't happened	**Future years + historical simulations** - Can capture how the climate will change - Can represent weather that has never happened
Preserves physical link between variables - Variables are dynamically consistent since they come from the same dataset (ERA5)	Projection data lacks variables at hourly resolution - Physical link is absent when interpolating daily data or using variables from different sources
All variables available - i.e., 10 m & 100 m wind speeds	Limited number of variables - i.e., 10 m wind speeds only

Important or desired characteristic

*Currently we only shift temperature profiles (and precipitation where relevant), maintaining historical hourly correlation with wind and solar (which haven't been shown by GCMs to shift distribution)

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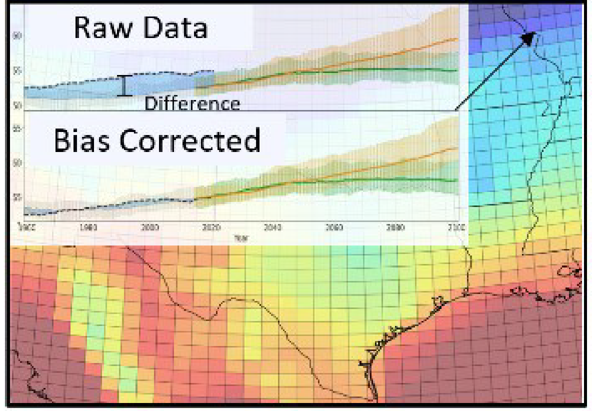
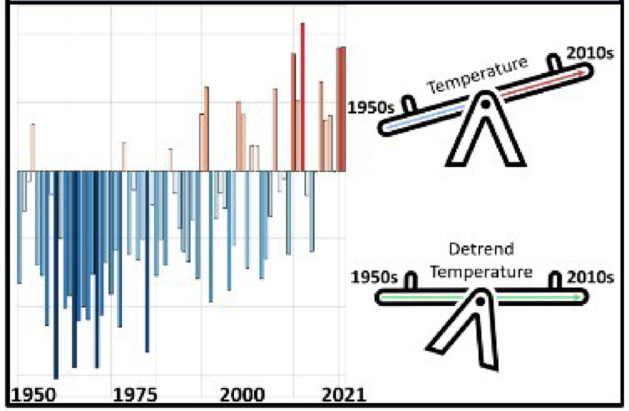
Overview of Data & Methods

- Historical data: ERA5
  - 1950 – 2021 (72 years)
- Projected Data: 5 CMIP6 models from Inter-Sectoral Impact Model Intercomparison Project (ISI–MIP)
  - SP1-2.6 (lower emission scenario) and SSP3-7.0 (higher emission scenario)
  - 5 models x 2 scenarios x 72 years of historical data = 720 synthetic profiles

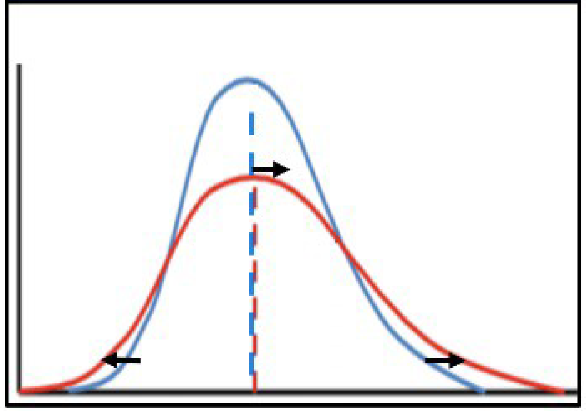
Step 1: Spatial bias-correction to localize climate projections (standard practice)



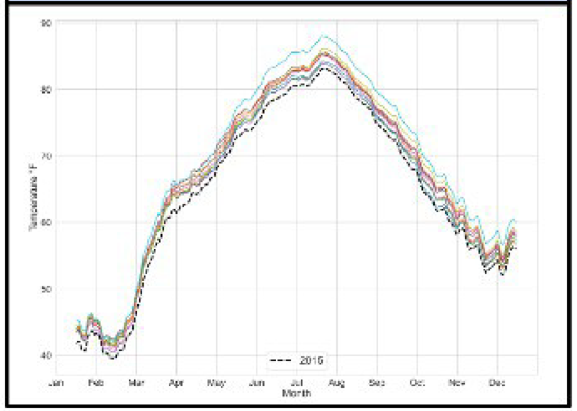
Step 2: Detrend historical data using representative years with natural variability



Step 3: Calculate **distributional shift** from GCM historical simulation to projection period



Step 4: Apply temperature delta for monthly quantile to historical data



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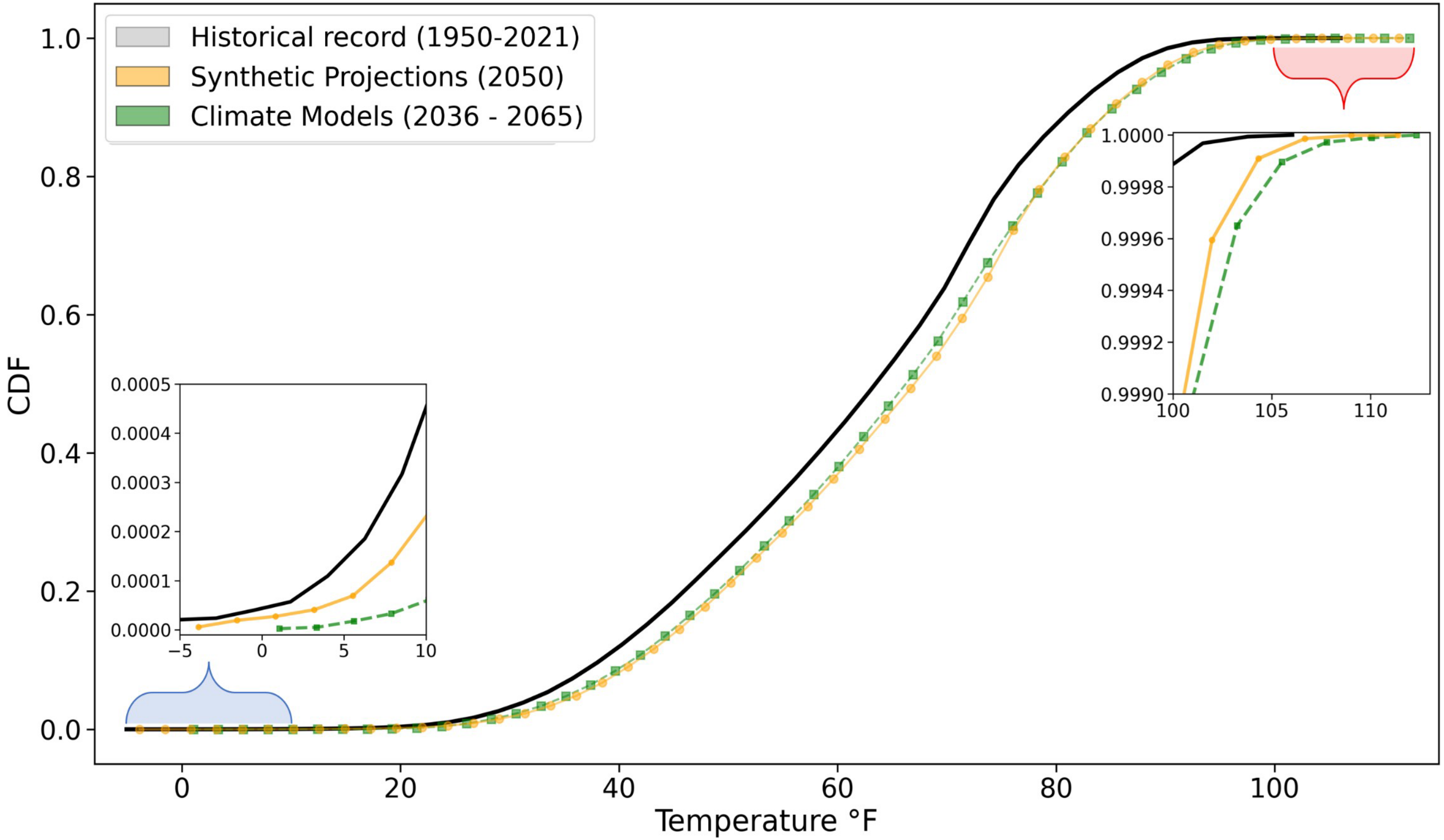
Validation of Synthetic Profiles
Atlanta, GA

Key Takeaways

- Synthetic profiles align with the climate model distribution well
- Synthetic data has more cold extremes



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Summary

GCM projections lack hourly resolution for company planning but can be leveraged to create realistic synthetic future scenarios

Benefits of Synthetic Profiles for Future Climates

- Provides hourly projection data when critical for the application
- Captures real-world variability from 72 years of historical data
- Potential to create 1000s of realistic climate-adjusted profiles
- Preserves the physical link between synchronous meteorological variables (temp / wind / solar / precipitation)
  - Not all variables need to be adjusted
- Can include historical years in future scenarios as a lower bound for risk assessments particularly concerned with extreme cold

Next Steps

- Additional validation
  - More detailed comparisons of the statistical properties (e.g., variability and extreme event characteristics) of these synthetic profiles vs native GCM projections
- Exploration of alternatives

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Project Future Weather

Develop hourly synthetic weather profiles for future periods

Identify High Risk Events

Screen weather for periods of potential high risk

Cold Snap

Severe Storm

Heatwave

Event Scenarios

Identify potential non-weather scenarios

Gen Availability

Imports

Weather Dependent Outages

Simulate outages of thermal plant

Operational Simulation

Simulate how the system operates through events

 Source: https://gcaptain.com/earth-weather-visualized/

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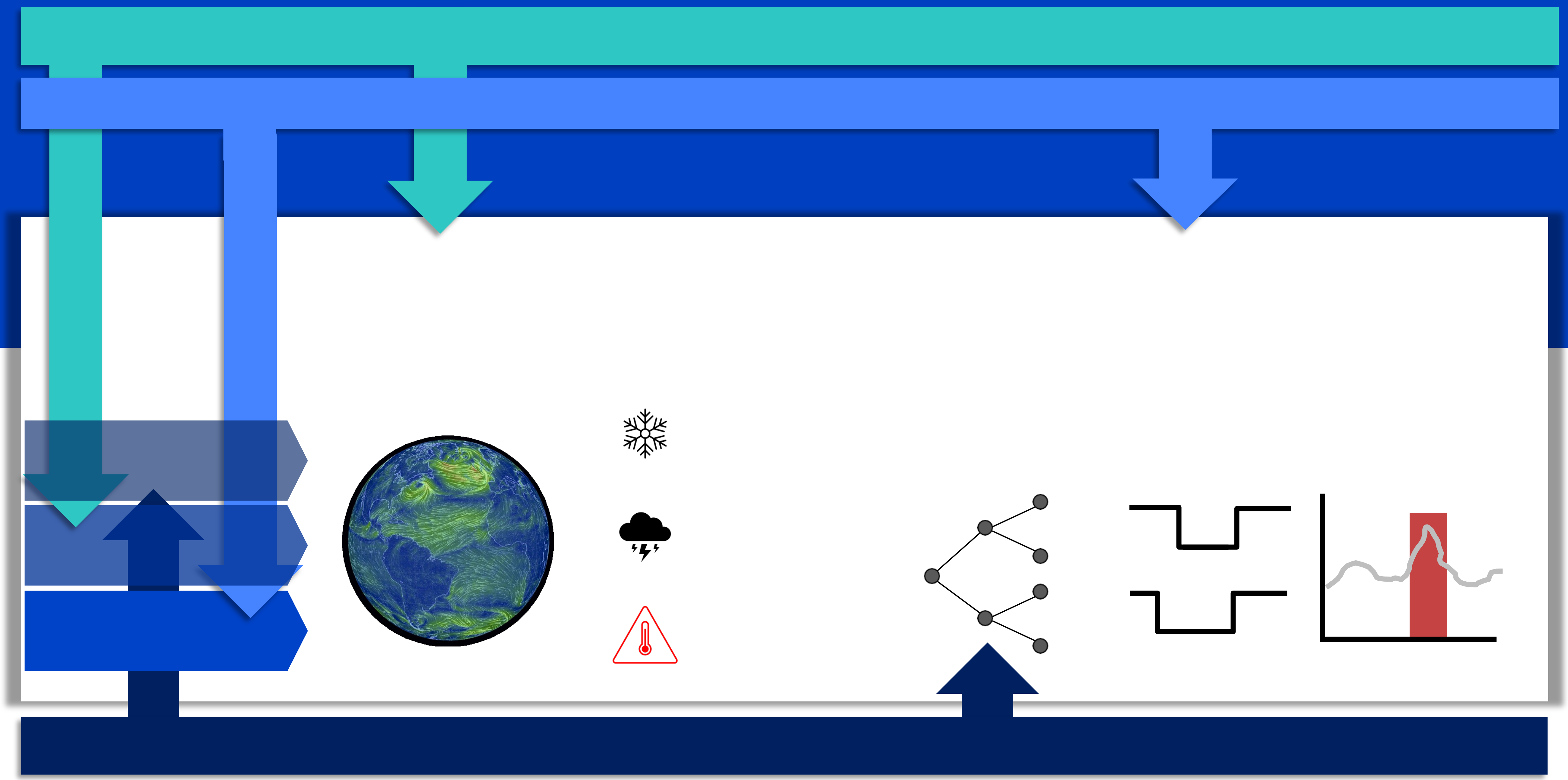
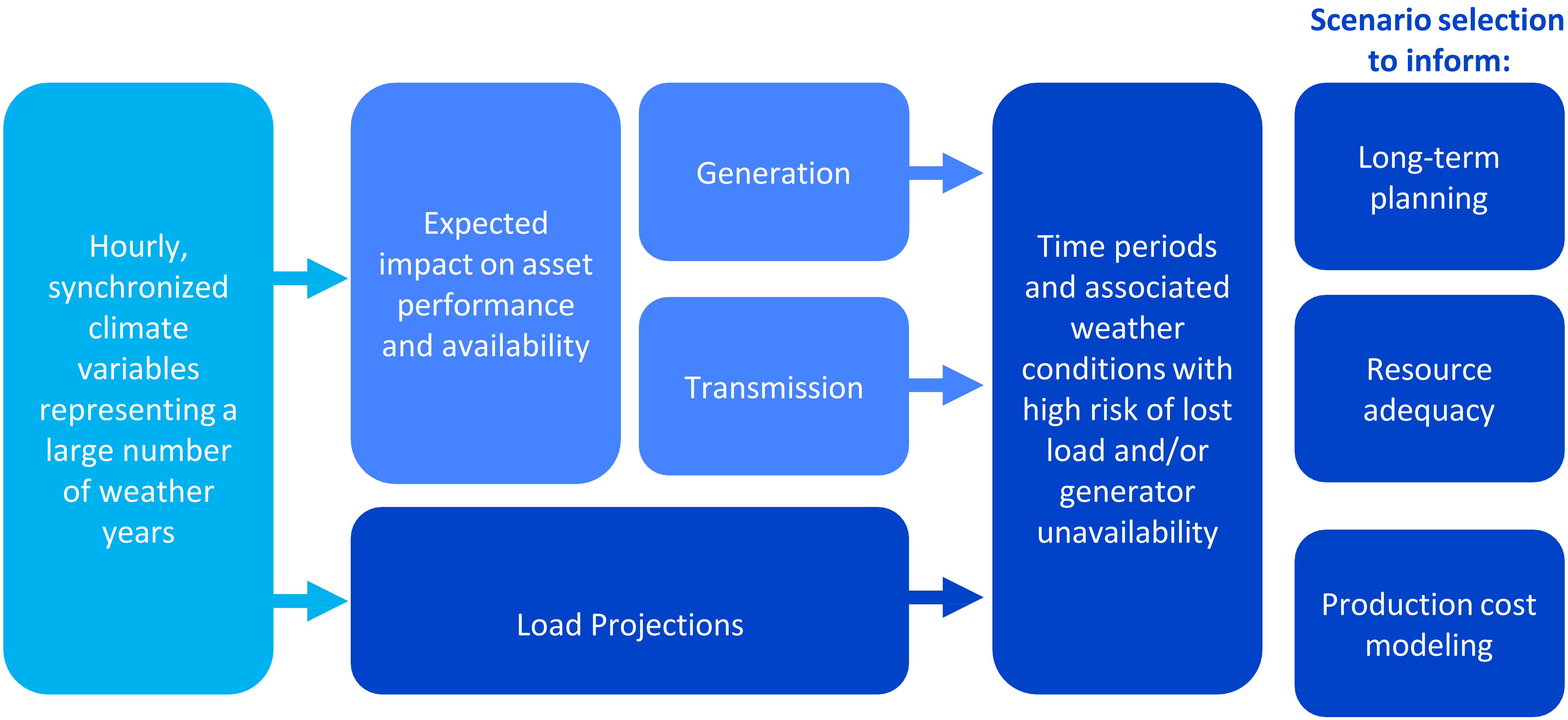


Risk Screening Tool – fast, *approximate* method for identifying time periods of interest



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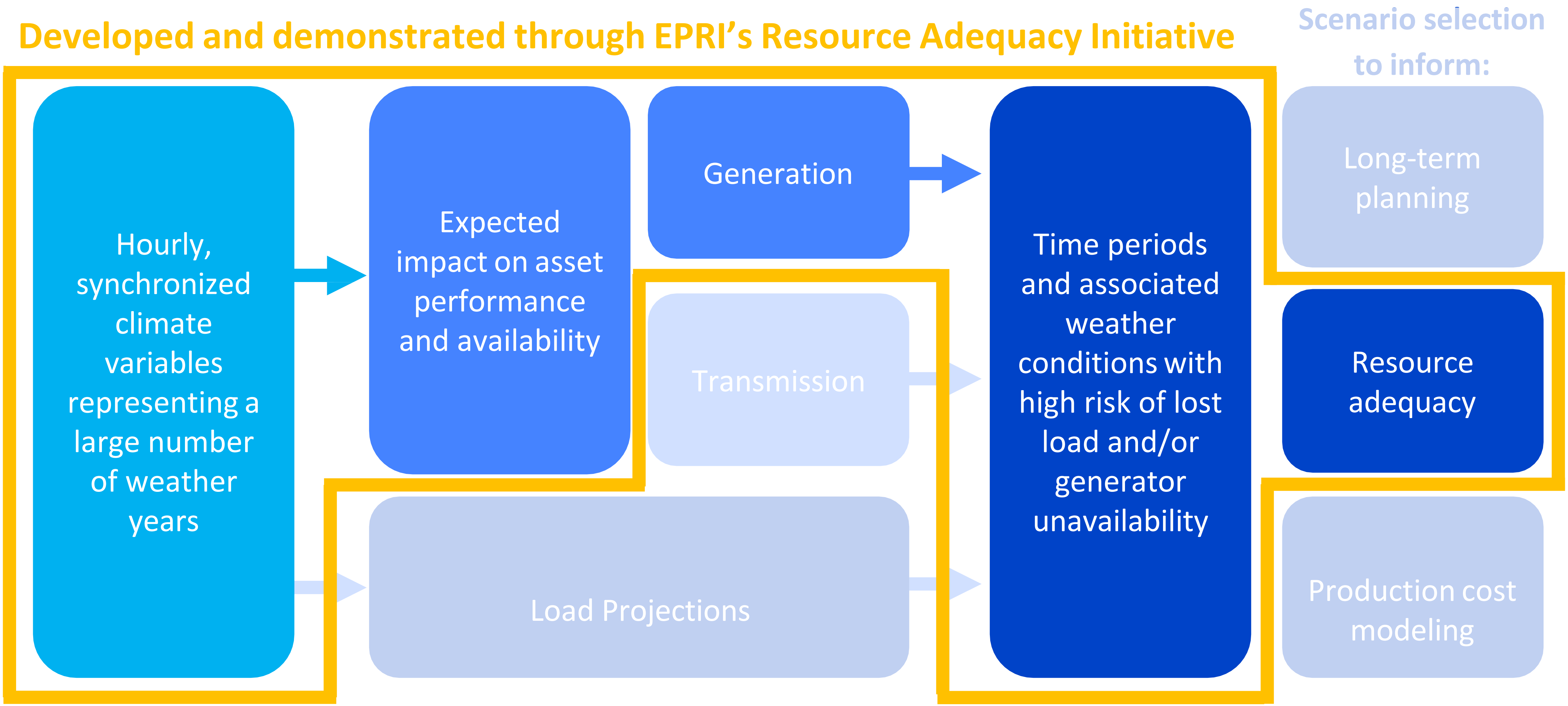
Risk Screening Tool – fast, *approximate* method for identifying time periods of interest

Developed and demonstrated through EPRI's Resource Adequacy Initiative



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Risk Screening Tool – fast, *approximate* method for identifying time periods of interest

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Likely necessary to capture extreme impacts for transmission planning cases

Hourly, synchronized climate variables representing a large number of weather years

Expected impact on asset performance and availability

Generation

Transmission

Load Projections

Time periods and associated weather conditions with high risk of lost load and/or generator unavailability

Scenario selection to inform:

Long-term planning

Resource adequacy

Production cost modeling

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Screen for Potential Scarcity Events: Asset vulnerabilities

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Define asset vulnerability matrix and derating factors that include supply and demand risks

Technology	Weather variable 1	Operator 1	Threshold 1	Weather variable 2	Operator 2	Threshold 2	Derating	Asset vulnerability label
PV	temperature	<=	32F	Snow	>=	1inch	90%	Snowstorm
PV	Irradiance	<	200 W/m2	Irradiance	>=	80 W/m2		Low sun
PV	Irradiance	>	200W/m2	Irradiance	<=	600 W/m2		Mid sun
CCGT	Temperature	<	10F				50%	Cold exposure
Wind On/offshore	Wind speed	>=	60m/s				100%	Hurricane/Tornado
Wind On/offshore	Wind speed	<	3m/s				100%	No wind
Wind Onshore	Wind speed	>	25m/s				100%	Cut-off wind speed
Wind Offshore	Wind speed	>	30m/s				100%	Cut-off wind speed
….	…	…	….	…	…	…	…	…

Note: The values in this table might vary significantly depending on the study region.

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Summary Event: illustrative output

Screen for Potential Scarcity Events

Event Ranking: 1

Date: Jul 5-Jul 26

Max 3-day risk date: Jul 5-Jul 8

Weather year: 2010

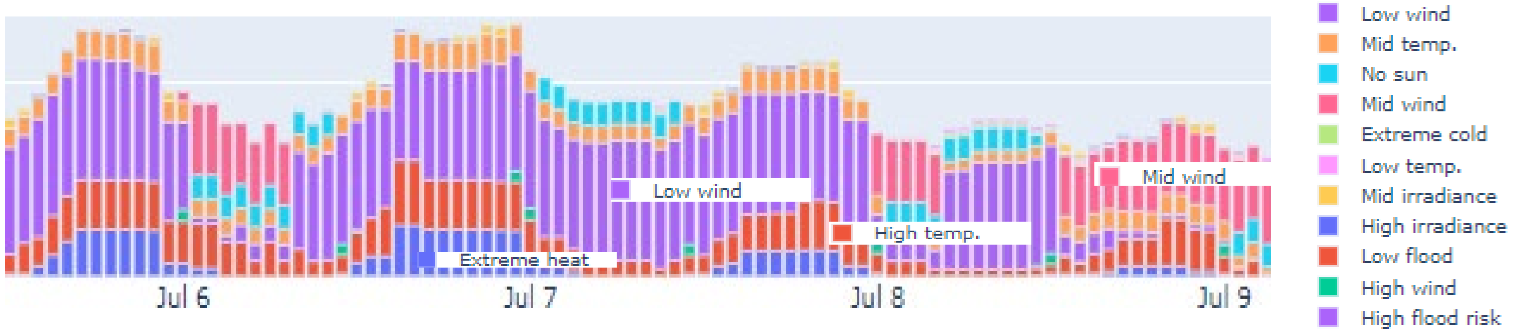
Events in group: 20

Avg Capacity at Risk: 15% total capacity

Max Capacity at Risk: 30% total capacity

Description: Heat wave + low wind

Capacity at risk (MW)
(3-day zoom in)



Top 3 high level risks	Total risk contribution	Top 3 technologies affected
Low Wind	45%	Wind Offshore Wind Onshore PV
Mid Wind	15%	Wind Offshore Wind Onshore
High temp.	13%	CC GT Wind Offshore

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Winter Event: illustrative output

Screen for Potential Scarcity Events

Event Ranking: 7

Date: Jan 14-Feb 4

Max 3-day risk date: Jan 17-Jan 21

Weather year: 1957

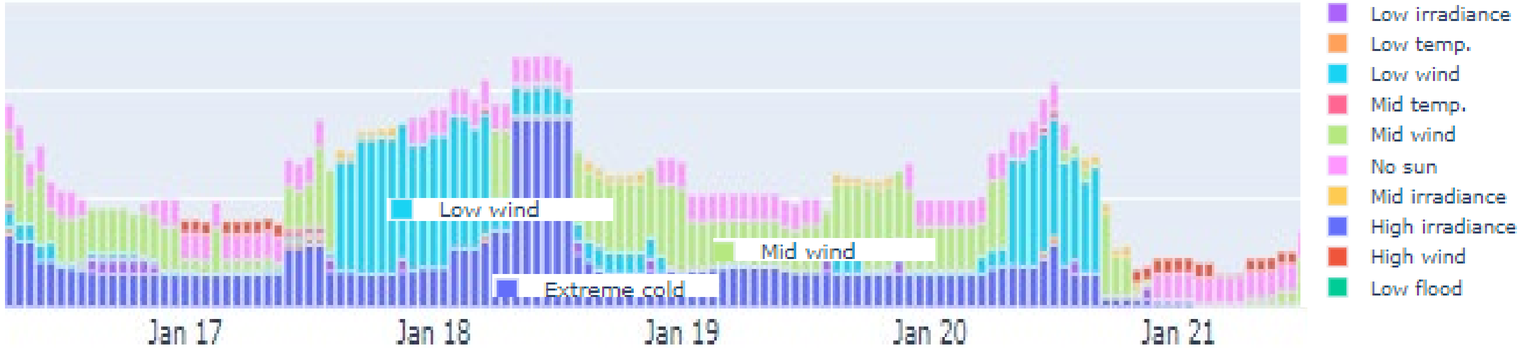
Events in group: 20

Avg Capacity at Risk: 14% total capacity

Max Capacity at Risk: 32% total capacity

Description: Cold snap + low wind

Capacity at risk (MW)
(3-day zoom in)



Top 3 high level risks	Total risk contribution	Top 3 technologies affected
Low Wind	37%	Wind Offshore Wind Onshore
Extreme cold	25%	CC Batteries Wind Offshore
Mid Wind	17%	Wind Offshore Wind Onshore

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