Climate Change Implications for Resource Adequacy in the US Desert Southwest

Jon Cook, Salt River Project

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Introduction to SRP

Salt River Project Agricultural Improvement and Power District is a political subdivision of the State of Arizona

- Formed in 1937
- Operates SRP's vertically integrated power system
- Governed by publicly elected board and council
- Serves approximately one million power customers* in the Phoenix Metro area

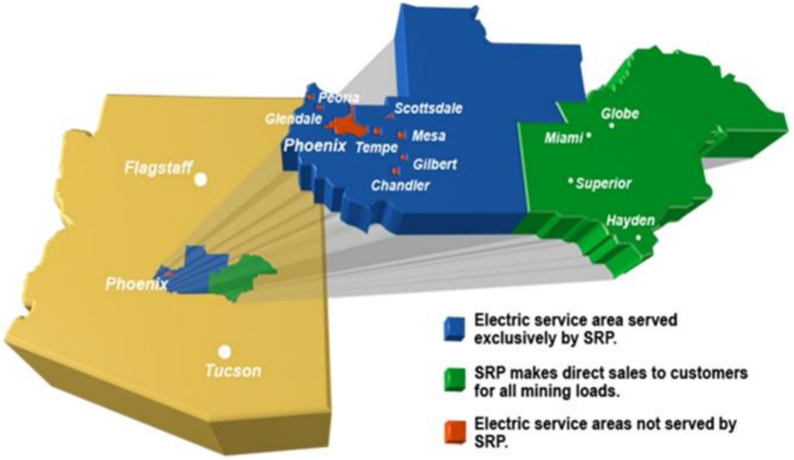
Extreme example of a summer-peaking system

- Multiple consecutive days with maximum temps >= 115°F produce highest-load conditions

Expecting 3.5% annual growth in peak MW and 5.9% annual growth in MWh for the next 10 years, driven by new large customers

*SRP is also a water provider (Salt River Valley Water Users' Association)

Electric Service Area



What are the hottest cities in the U.S.?

1. Phoenix, Arizona

Source: The 10 Hottest Cities in the U.S. | Redfin

Overview

Developing Future Hourly Weather Data with EPRI

- Methodology and climate scenarios overview
- Summary of final data

Climate Change Impacts on Adequacy Risk in the Desert SW

- Future load shapes
- Initial study results across climate scenarios

Consequences for Long-Term RA Studies and Resource Planning

- Important additional dimension of risk
- What to do with accreditation and capacity expansion?

Developing Future Weather Data with EPRI

1950-2023 hourly data based on ERA5-Land reanalysis

- Synchronous temperature, humidity, solar irradiance, wind speed for SRP service territory and resource locations
- Shifted to represent future climate scenarios based on ensemble results from 9 GCMs
- Corresponding TMY profiles for 2025-2054

An Approach to Synthetic Future Climate Hourly Profiles for Power System Modeling

Summary

Power system modeling tools typically rely on input data in the form of 8760 timeseries to capture the intra-annual conditions (including weather) that influence electricity supply and demand. However, nearly all global climate model (GCM) projections are limited to daily temporal resolution which presents a data challenge for incorporating their projections of future climate changes directly into power system modeling. This research presents an innovative approach developed by EPRI to create hourly weather timeseries for future climates at the local-level. A *monthly quantile anomaly* mapping technique is used to shift historical profiles according to the seasonal climatological shift being projected by an individual or ensemble of climate models. This method preserves important, real-world characteristics from the historical record that is otherwise missing from climate model output. Specifically, this approach captures important information from the historical record, such as locationally-specific extremes which can be missing from coarse climate projections, natural variability which isn't always well represented in the climate models, and important joint correlations among physically-linked variables such as wind, solar, and temperature. This method has many potential applications in the power sector, where 8760 timeseries are needed for simulation modeling, as well as for resource adequacy assessments that require many realizations (e.g., a sample of 100s or 1000s) to identify possible extremes for stress-testing a future year of interest.

Introduction

Many electricity system capacity planning and operational modeling tools are designed to use hourly timeseries, or profiles, as input data. These tools typically use 8760 timeseries of historical meteorological data or synthetic profiles (e.g., a typical meteorological year) to capture the intra-annual weather conditions that influence power supply and demand. Increasingly, power system planners are interested in accounting for climatic trends and potential extreme events in the meteorological inputs to their simulation models[1]. However, nearly all global climate model (GCM) projections are limited to daily temporal resolution which presents a data challenge for incorporating their projections of future changes directly into power system modeling.

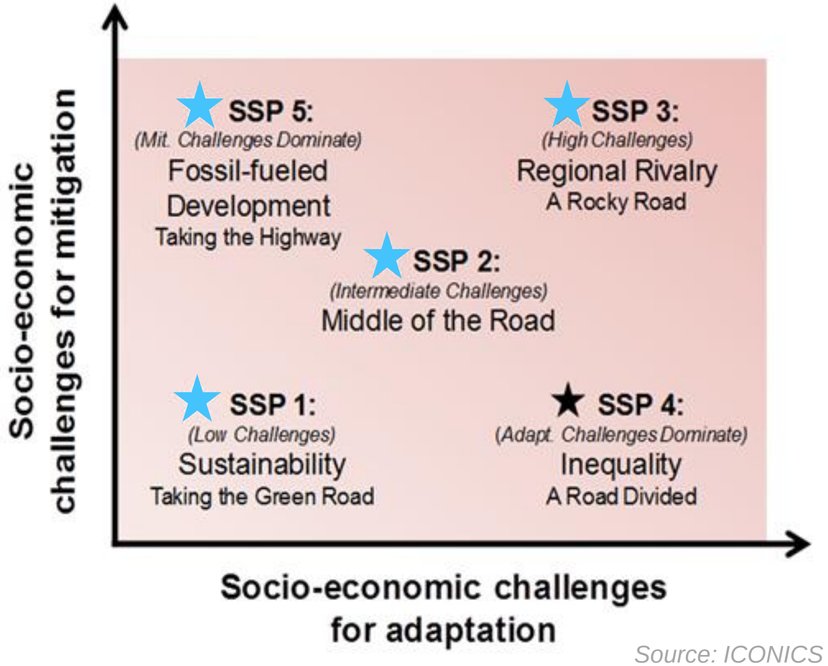
Because of this limitation, an approach that transforms daily climate model projections into hourly timeseries is needed. One such 'temporal downscaling' approach is to interpolate between the daily values to fill in the missing hours, but this simple method could miss important diurnal fluctuations that have material consequences on electricity demand or design thresholds. Figure 1 illustrates this interpolation approach for the temperature variable, which is typically

Figure 1: Hourly temperature vs daily max and min from Jan 1-20, 1950. For the winter season this illustration assumes the typical pattern of daily max temperature at 2 pm (19z) and daily min at 6 am (11z). Gray shading highlights differences between the daily and hourly lines.

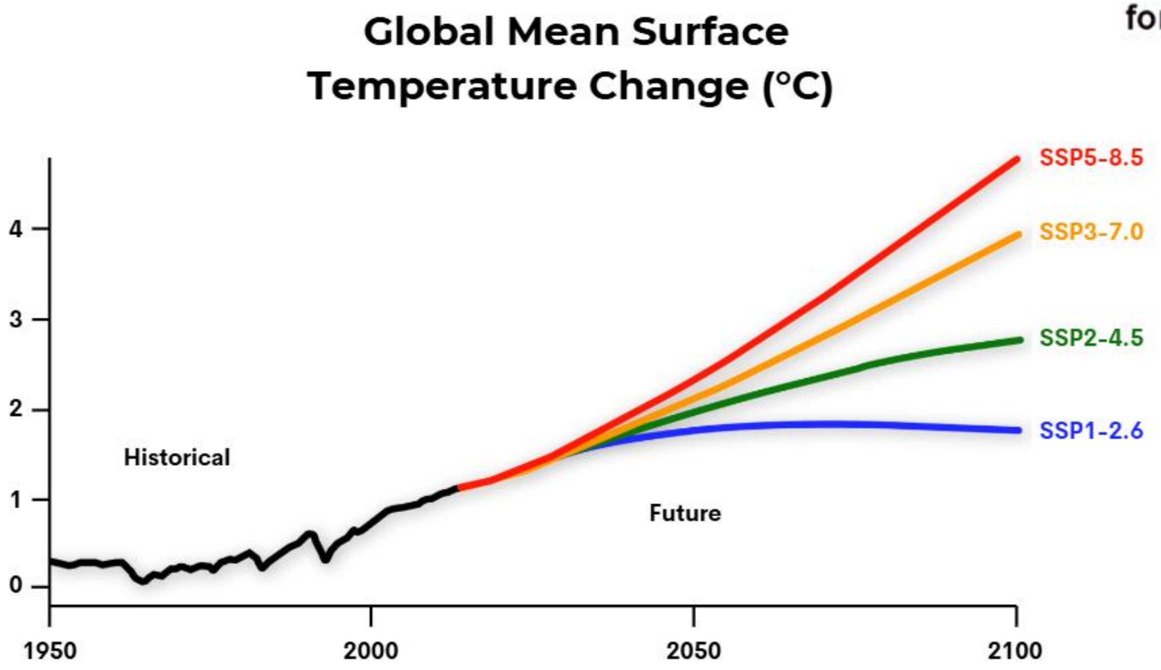
Source: https://esca.epri.com/pdf/EPRI-2022-Synthetic-Future-Climate-Hourly-Profiles-for-Power-System-Modeling.pdf

Climate Scenarios

- Raw History – Estimate of observed 1950-2023 weather conditions
- Base Climate – Detrended 1950-2023 data to represent 1991-2020 climate
- SSP Narratives
  - SSP1 - 2.6
  - SSP2 - 4.5
  - SSP3 - 7.0
  - SSP5 - 8.5



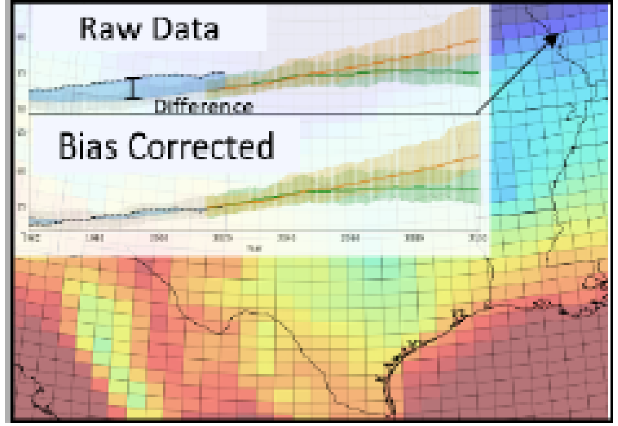
Source: ICONICS



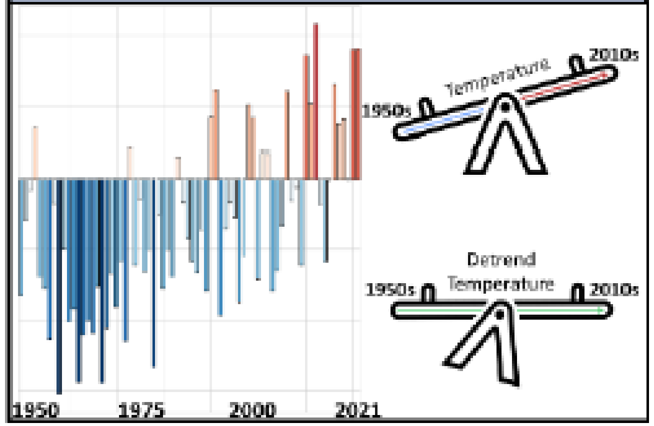
Source: https://climatedata.ca

QDM Method for Creating Synthetic Hourly Timeseries

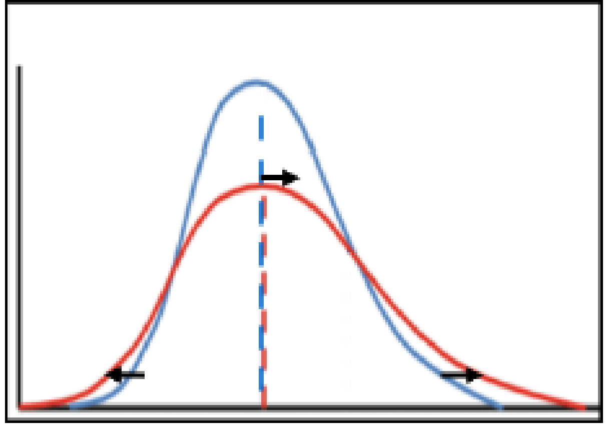
Step 1: Spatial bias-correction to localize climate projections (standard practice)



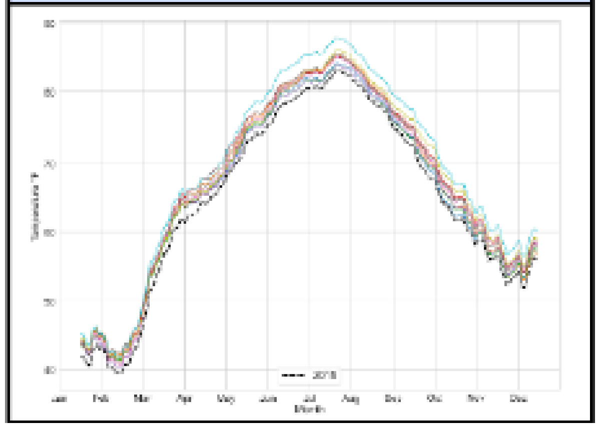
Step 2: Detrend historical data using representative years with natural variability



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

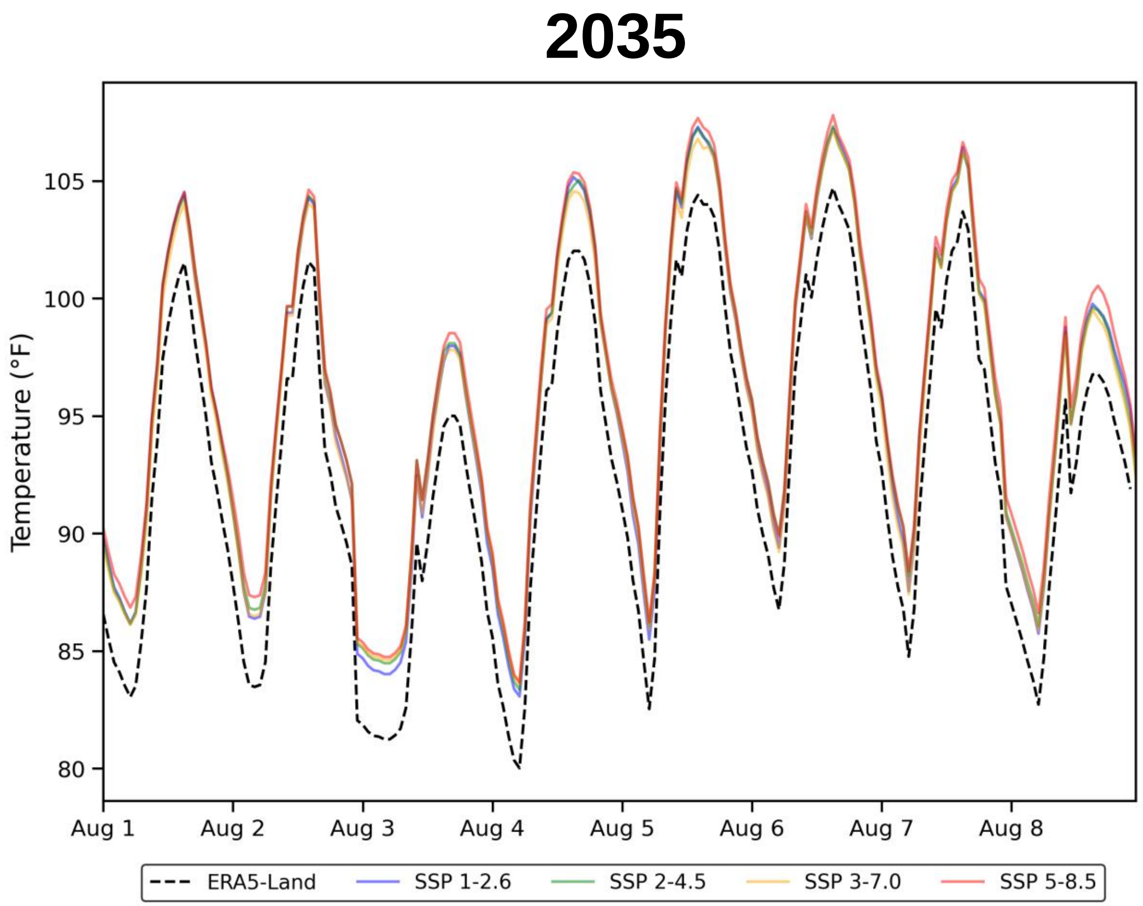


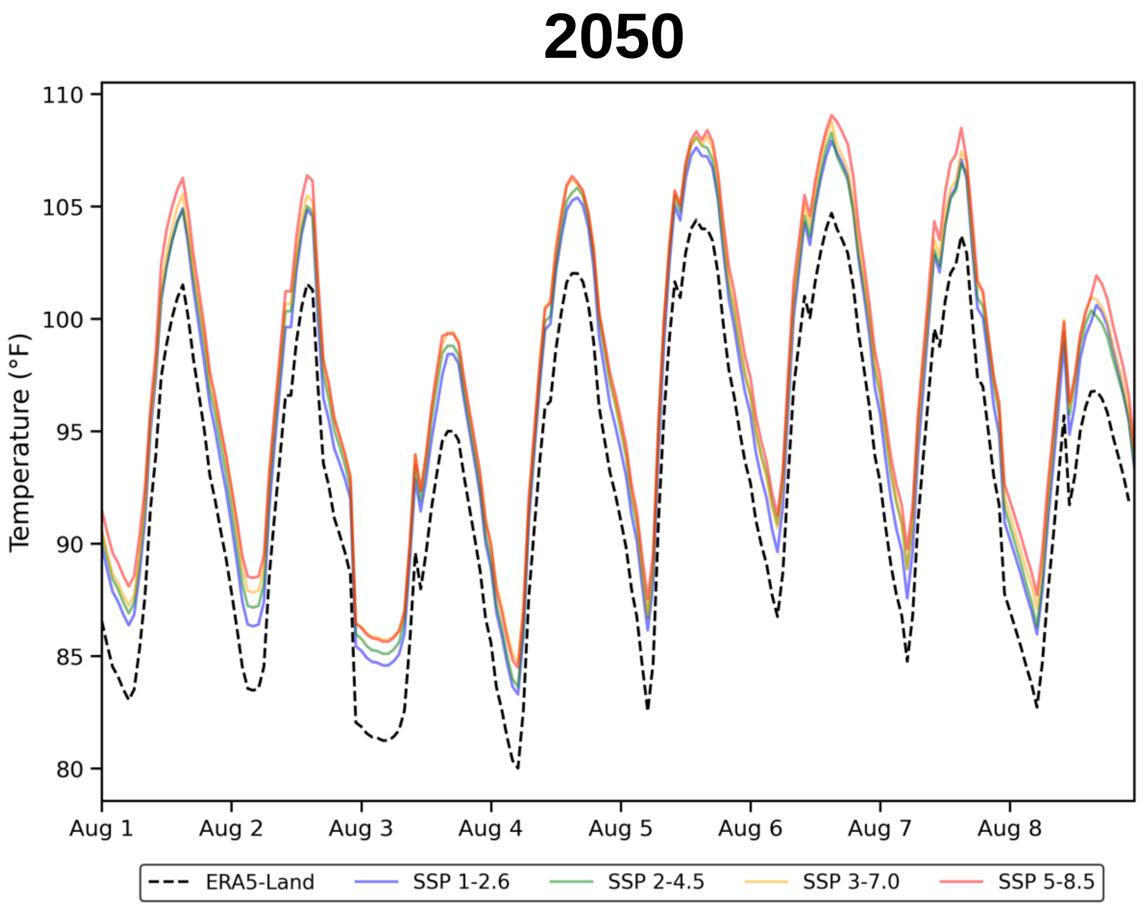
Step 4: Apply temperature delta for monthly quantile to historical data



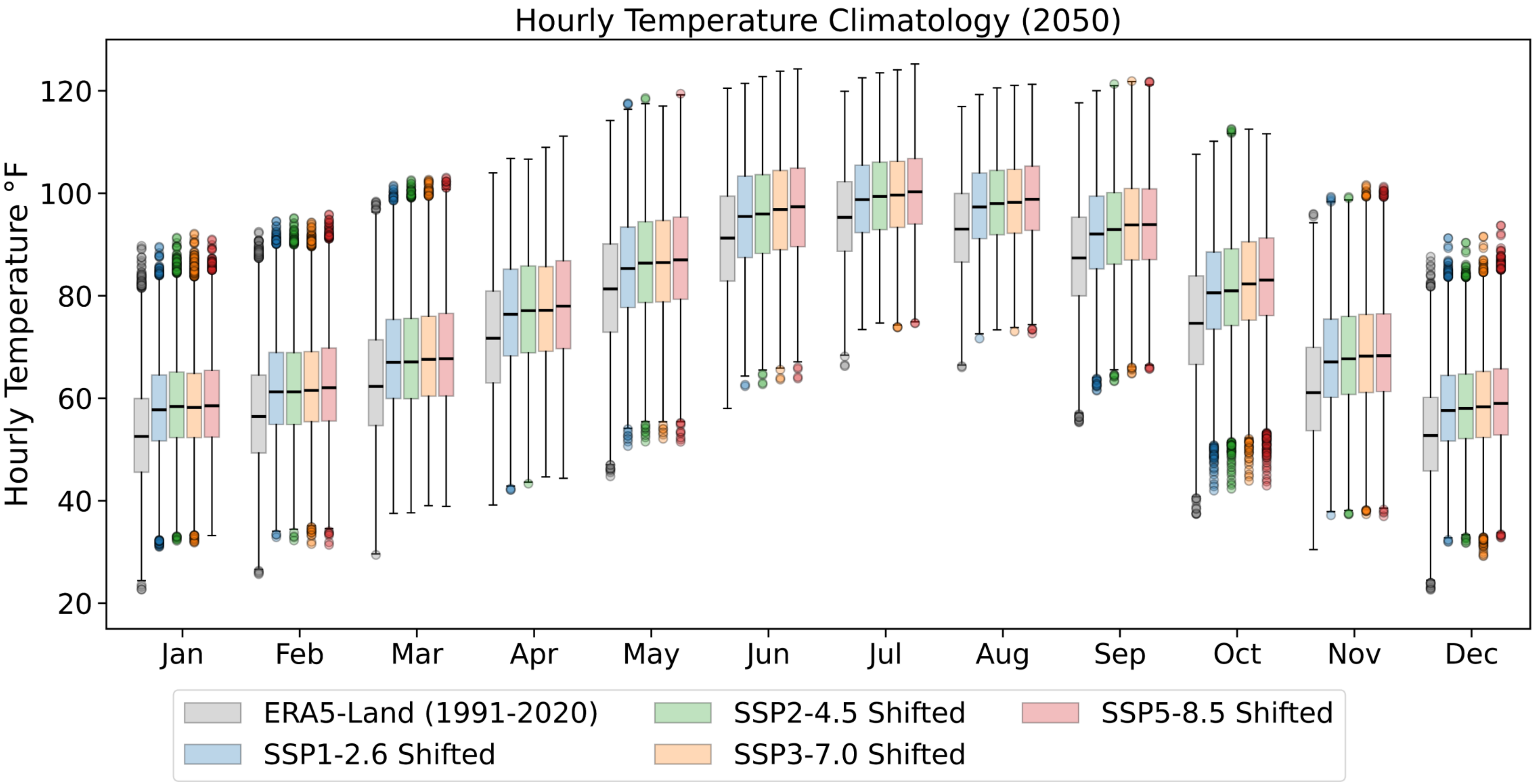
Source: EPRI

Examples of Shifted Weather Timeseries

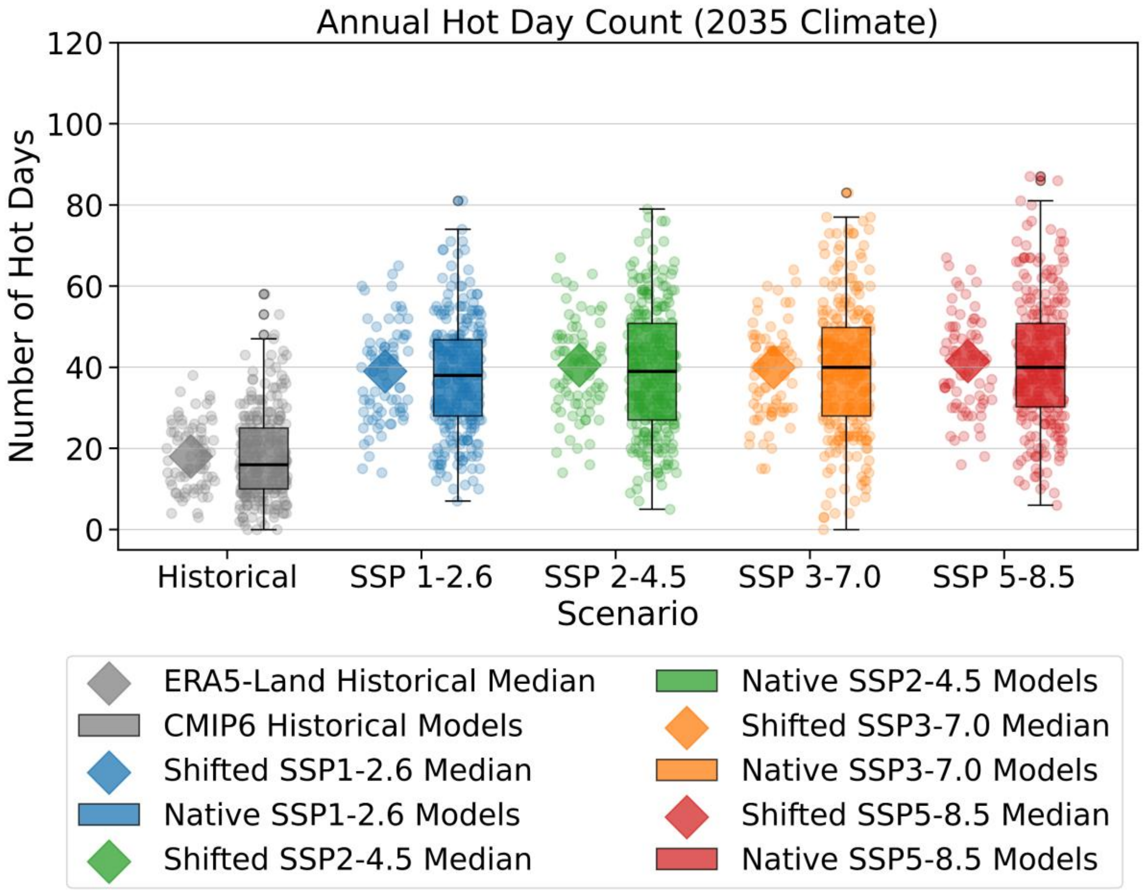


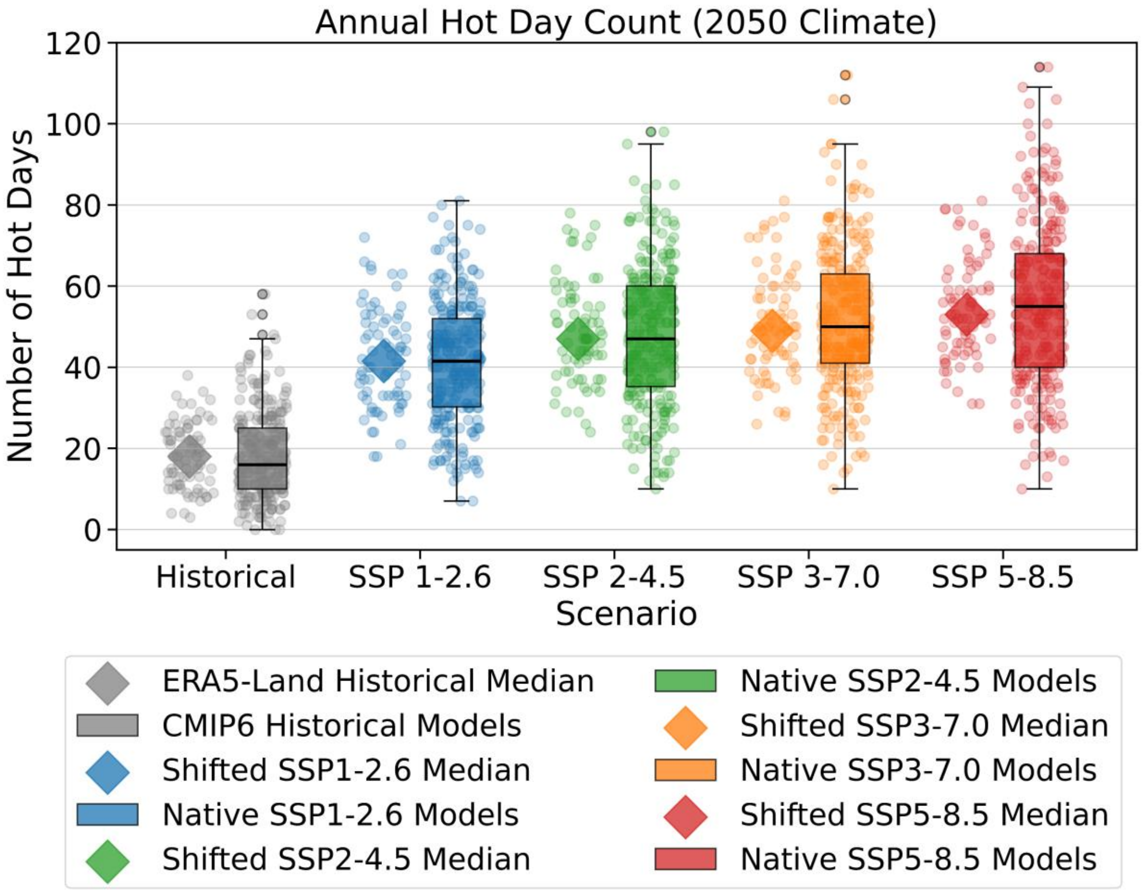


Climate-Induced Shifts in Temperature Distributions

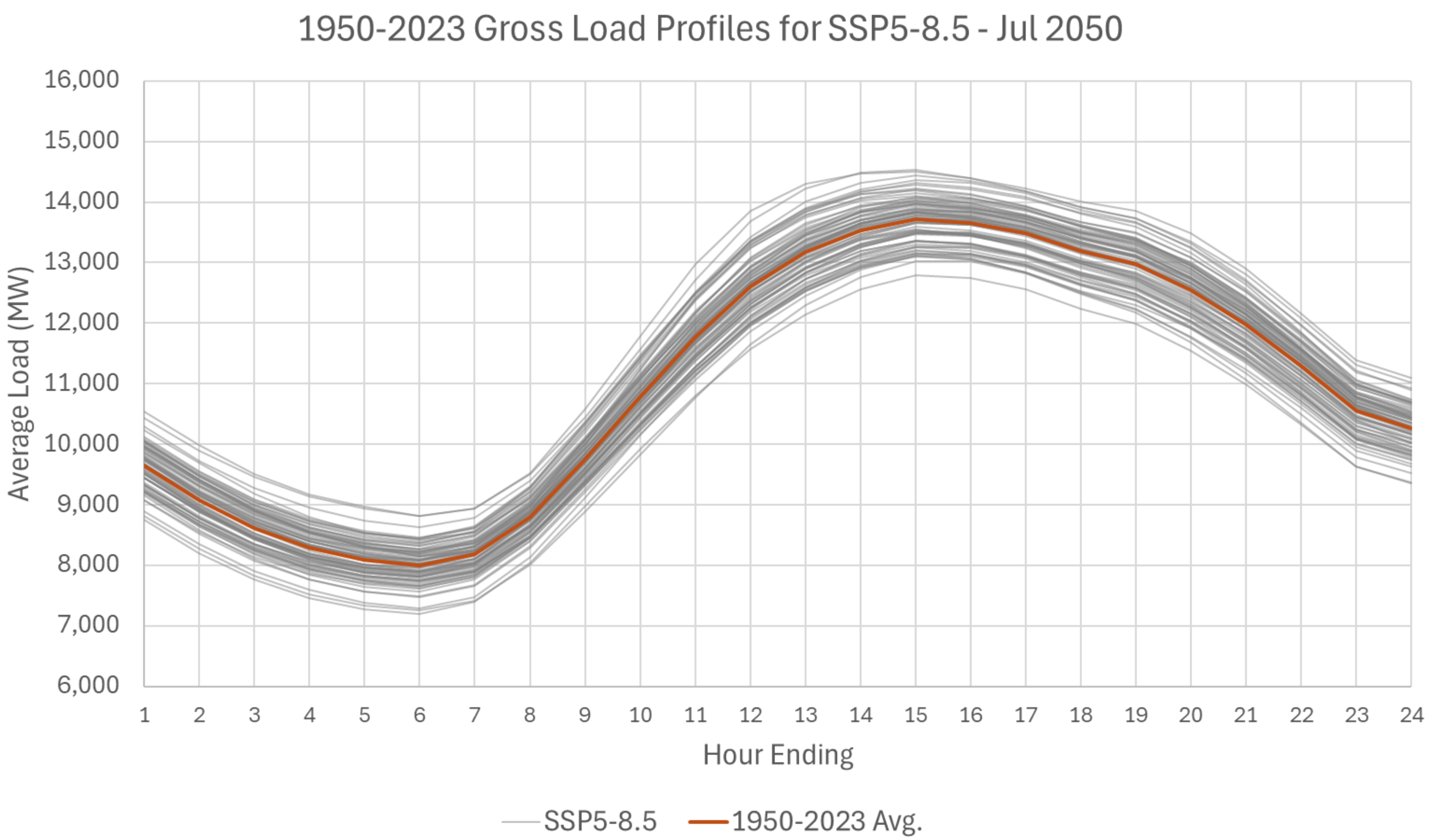


More Days of Extreme Heat Coming



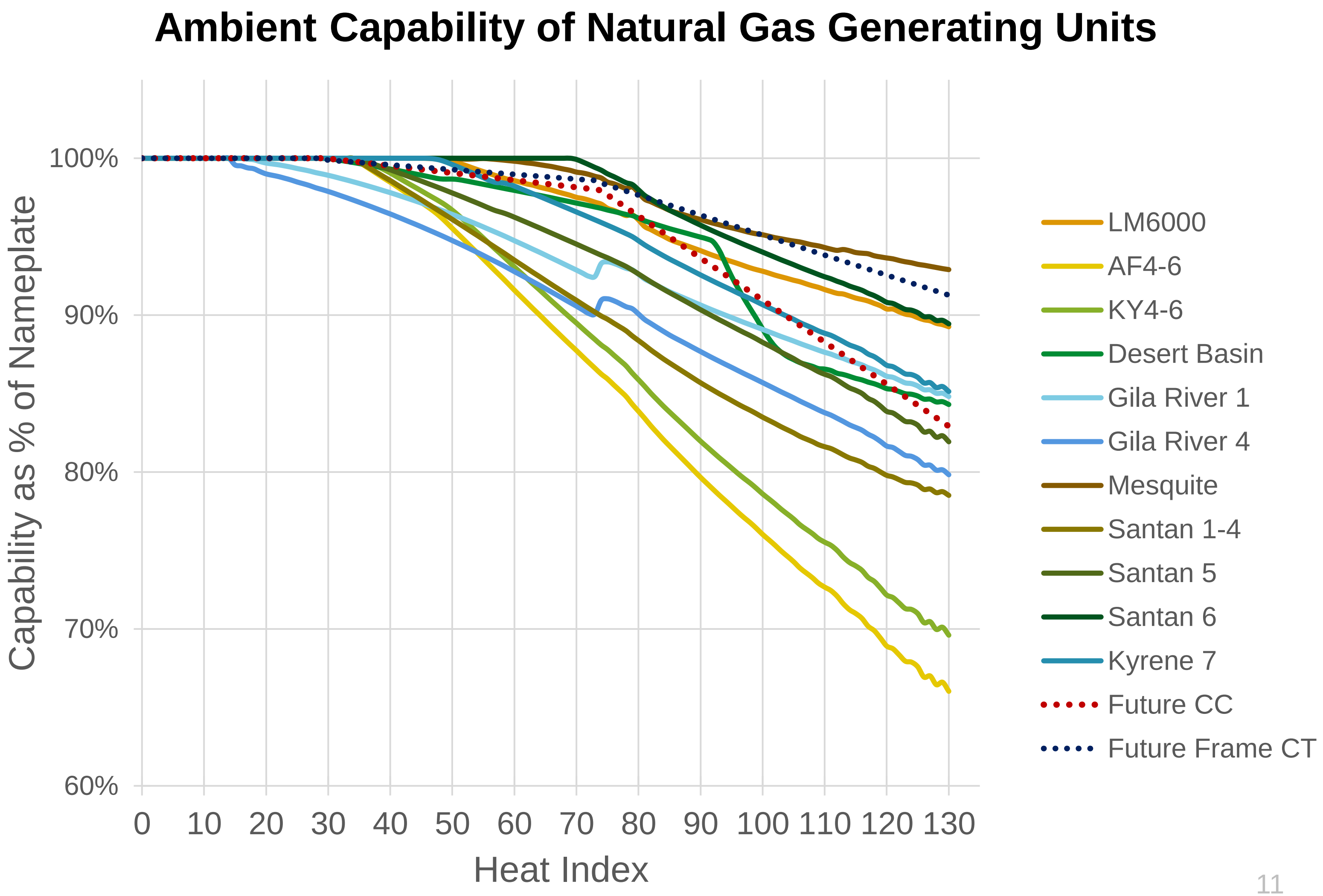


Climate-Adjusted SRP Load Profiles for July 2050



Hotter Temps Also Reduce Generation Capacity

- Ambient capability of natural gas generating units is a function of temperature and humidity
- Unit-specific ambient derate curves developed for SRP fleet
  - Oldest units most affected
  - Combined cycles affected more than combustion turbines

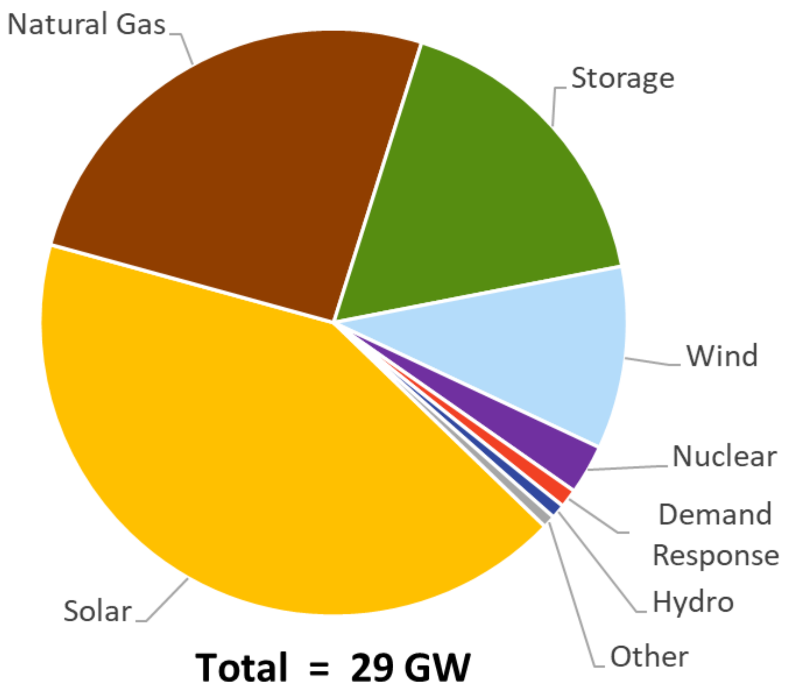


2035 Results

Annual Metrics

Climate scenario	LOLE (days/yr)	LOLEV (events/yr)	LOLH (hours/yr)	LOLP	EUE (MWh/yr)
Raw History	0.08	0.09	0.15	0.1%	80
Base Climate	0.09	0.10	0.18	0.2%	97
SSP1-2.6	0.33	0.41	0.85	0.9%	501
SSP2-4.5	0.41	0.51	1.07	1.1%	605
SSP3-7.0	0.38	0.47	0.95	1.1%	523
SSP5-8.5	0.57	0.73	1.58	1.7%	974

2035 Capacity Mix



Total = 29 GW

Monthly LOLE

Climate Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Raw History	0.01	0.00	0.00	0.00	0.00	0.00	0.03	0.04	0.01	0.00	0.00	0.00
Base Climate	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.01	0.00	0.00	0.00
SSP1-2.6	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.19	0.05	0.00	0.00	0.00
SSP2-4.5	0.02	0.00	0.00	0.00	0.00	0.00	0.08	0.22	0.10	0.00	0.00	0.00
SSP3-7.0	0.00	0.00	0.00	0.00	0.00	0.01	0.09	0.19	0.09	0.00	0.00	0.00
SSP5-8.5	0.00	0.00	0.00	0.00	0.00	0.01	0.09	0.33	0.13	0.00	0.00	0.00

Note: Analysis based on a generic resource portfolio developed to achieve 0.1 LOLE in Base Climate and does not represent SRP's official resource plan.

Climate Change Impact on 2035 LOLP Profile

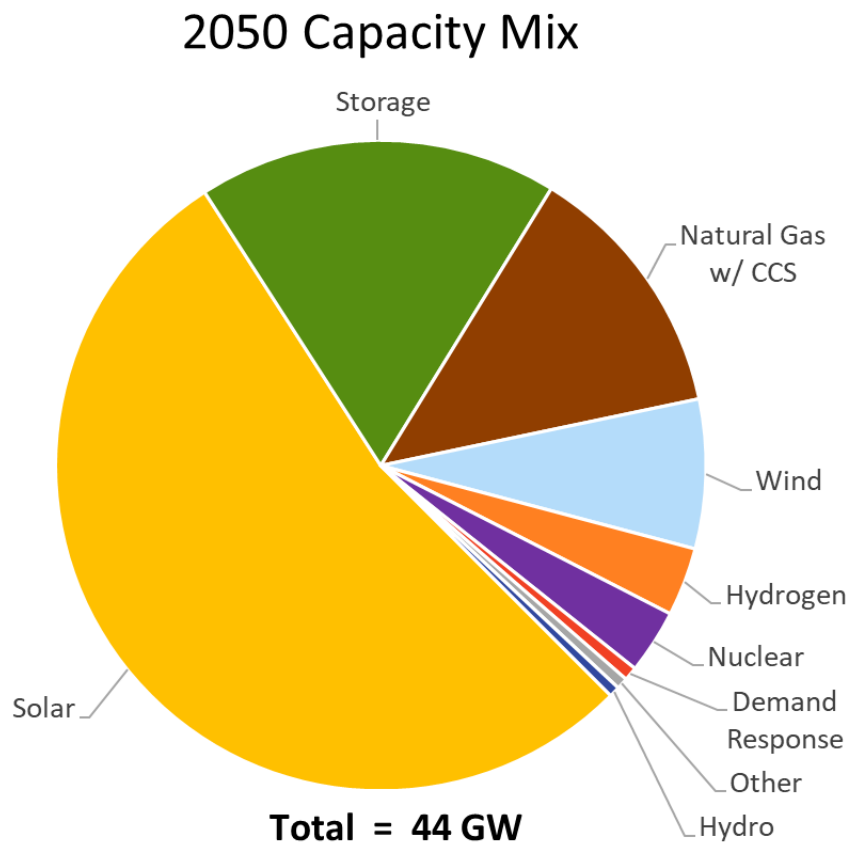
2035 LOLP Heat Map - SSP5-8.5

LOLP	Month											
Hour Ending	1	2	3	4	5	6	7	8	9	10	11	12
1						0.007%	0.040%	0.323%	0.121%			
2						0.005%	0.046%	0.303%	0.092%			
3						0.004%	0.036%	0.235%	0.058%			
4						0.003%	0.031%	0.205%	0.058%			
5						0.003%	0.030%	0.189%	0.067%			
6	0.001%					0.007%	0.042%	0.207%	0.081%			0.002%
7	0.002%							0.185%	0.102%			0.004%
8	0.011%	0.001%							0.006%			0.007%
9									0.001%			
10									0.002%			
11									0.001%			
12												
13												
14												
15												
16												
17												
18								0.002%	0.002%			
19							0.001%	0.112%	0.147%			
20						0.010%	0.213%	0.680%	0.194%			
21						0.004%	0.102%	0.276%	0.062%			
22							0.013%	0.112%	0.037%			
23							0.008%	0.154%	0.050%			
24						0.005%	0.029%	0.286%	0.099%			

2050 Results

Annual Metrics

Climate scenario	LOLE (days/yr)	LOLEV (events/yr)	LOLH (hours/yr)	LOLP	EUE (MWh/yr)
Raw History	0.04	0.04	0.07	0.1%	42
Base Climate	0.08	0.09	0.13	0.1%	83
SSP1-2.6	0.31	0.33	0.64	0.7%	478
SSP2-4.5	0.65	0.71	1.51	1.7%	1,205
SSP3-7.0	0.75	0.82	1.71	1.9%	1,299
SSP5-8.5	1.23	1.34	2.99	3.4%	2,468



Monthly LOLE

Climate Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Raw History	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.00
Base Climate	0.03	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.01	0.00	0.00	0.00
SSP1-2.6	0.01	0.00	0.00	0.00	0.00	0.00	0.03	0.18	0.08	0.00	0.00	0.00
SSP2-4.5	0.02	0.00	0.00	0.00	0.00	0.00	0.04	0.38	0.21	0.00	0.00	0.00
SSP3-7.0	0.01	0.00	0.00	0.00	0.00	0.00	0.06	0.40	0.28	0.00	0.00	0.00
SSP5-8.5	0.02	0.00	0.00	0.00	0.00	0.01	0.11	0.65	0.44	0.00	0.00	0.00

Note: Analysis based on a generic resource portfolio developed to achieve 0.1 LOLE in Base Climate and does not represent SRP's official resource plan.

Climate Change Impact on 2050 LOLP Profile

2050 LOLP Heat Map - SSP5-8.5

LOLP	Month											
Hour Ending	1	2	3	4	5	6	7	8	9	10	11	12
1							0.005%	0.125%	0.121%			
2							0.006%	0.214%	0.149%			
3							0.011%	0.352%	0.177%			
4						0.004%	0.021%	0.638%	0.282%			
5						0.009%	0.089%	1.015%	0.468%			
6	0.003%					0.022%	0.268%	1.595%	0.831%			
7	0.012%							1.379%	1.112%			
8	0.059%							0.016%	0.049%			
9							0.003%	0.008%	0.014%			
10									0.005%			
11												
12												
13												
14												
15								0.004%				
16								0.007%				
17								0.009%				
18								0.004%	0.006%			
19									0.013%			
20							0.055%	0.068%	0.022%			
21							0.045%	0.057%	0.031%			
22							0.003%	0.032%	0.050%			
23								0.024%	0.062%			
24							0.006%	0.088%	0.099%			

Takeaways and Implications for Resource Planning

Using historical or detrended weather data for forward-looking RA studies underestimates system risk

- Late summer months most prone to increased risk, impacts grow over time
- Some additional capacity risk, but additional energy risk is bigger concern for SRP’s future low-carbon system

What does this mean for accreditation and capacity expansion modeling?

- Static accreditation based on today’s system will be vulnerable to future climate risk
- Iterating between capacity expansion and RA models is time consuming and computationally expensive

Adequacy-Aware Capacity Expansion Modeling

SRP working with Tennessee Valley Authority and NREL to develop and demonstrate new capacity expansion approach with embedded RA model

- Robust loss-of-load modeling and metrics
- Automated iteration between existing commercial-grade capacity expansion (Sienna/Invest) and RA (PRAS) tools
- Testing performance on TVA and SRP systems relative to current methods

Potential Benefits

- Fully automated RA analysis of candidate resource portfolios
- Direct inclusion of RA metric eliminates need for capacity accreditation
- “Smart sampling” of stress periods to greatly improve runtime and guarantee capacity expansion results achieve target criteria

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

TVA

SRP®

Heat Index

SRP uses heat index for modeling in SERVM because humidity is relevant for load and ambient capability of thermal generators

Relative Humidity (%)

Temperature (F)

%	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	%
126	113	116	119	123	126	130	134	138	142	147	151	156	161	166	171	177	182																																	126
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%	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92	94	96	98	100	%

www.weather.gov/jetstream/hi

Relative Humidity (%)

Temperature (F)

The Heat Index Equation

The computation of the heat index is a refinement of a result obtained by multiple regression analysis carried out by Lans P. Rothfusz and described in a 1990 National Weather Service (NWS) Technical Attachment (SR 90-23). The regression equation of Rothfusz is

$$HI = -42.379 + 2.04901523*T + 10.14333127*RH - .22475541*T*RH - .00683783*T*T - .05481717*RH*RH + .00122874*T*T*RH + .00085282*T*RH*RH - .00000199*T*T*RH*RH$$

where **T** is temperature in degrees F and **RH** is relative humidity in percent. **HI** is the heat index expressed as an apparent temperature in degrees F. If the **RH** is less than 13% and the temperature is between 80 and 112 degrees F, then the following adjustment is subtracted from **HI**:

$$ADJUSTMENT = [(13-RH)/4]*SQRT\{[17-ABS(T-95.)]/17\}$$

where **ABS** and **SQRT** are the absolute value and square root functions, respectively. On the other hand, if the **RH** is greater than 85% and the temperature is between 80 and 87 degrees F, then the following adjustment is added to **HI**:

$$ADJUSTMENT = [(RH-85)/10] * [(87-T)/5]$$

The Rothfusz regression is not appropriate when conditions of temperature and humidity warrant a heat index value below about 80 degrees F. In those cases, a simpler formula is applied to calculate values consistent with Steadman's results:

$$HI = 0.5 * \{T + 61.0 + [(T-68.0)*1.2] + (RH*0.094)\}$$

In practice, the simple formula is computed first and the result averaged with the temperature. If this heat index value is 80 degrees F or higher, the full regression equation along with any adjustment as described above is applied.

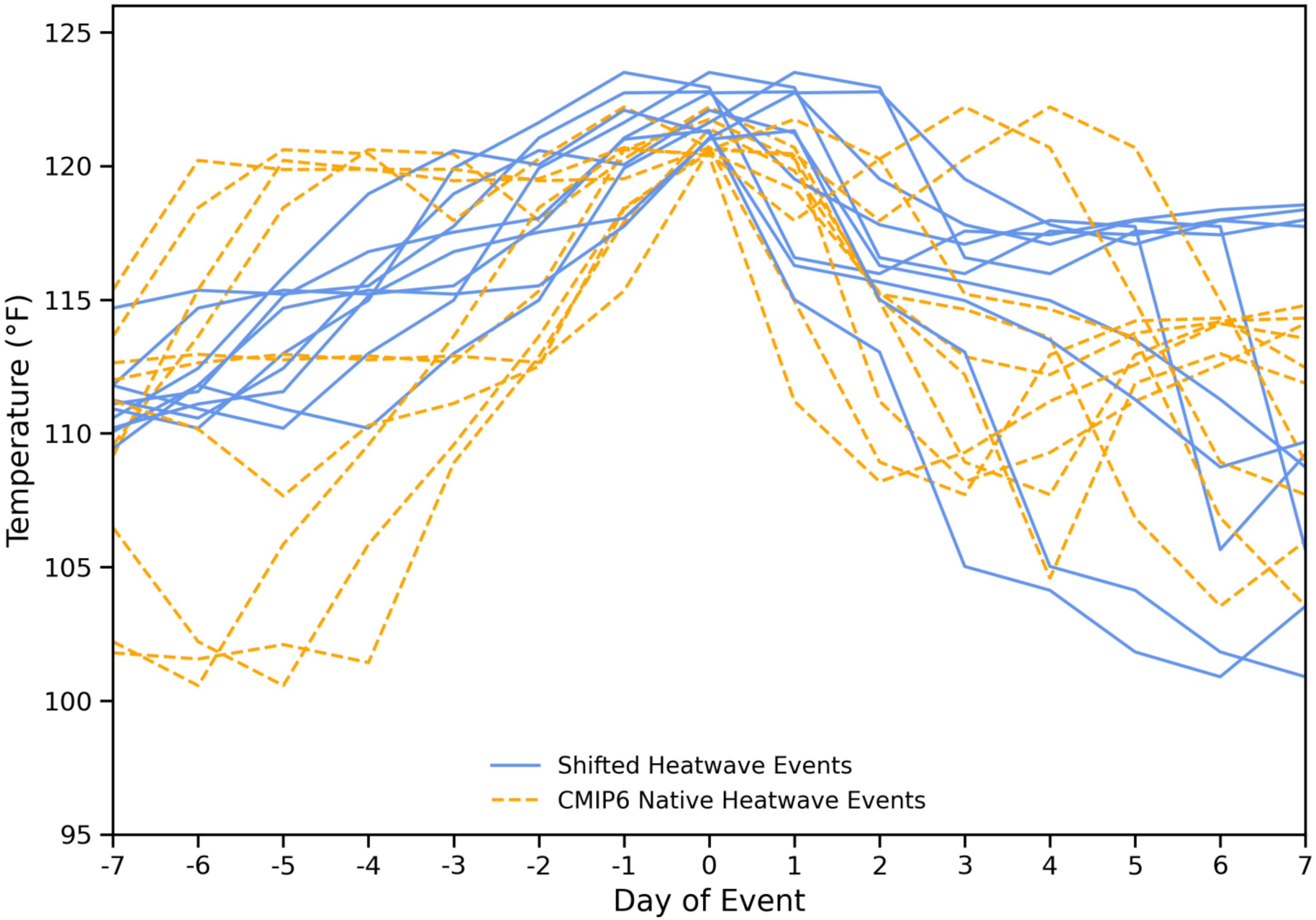
The Rothfusz regression is not valid for extreme temperature and relative humidity conditions beyond the range of data considered by Steadman.

Shifted Historical Data vs. Synthetic Climate Projections

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

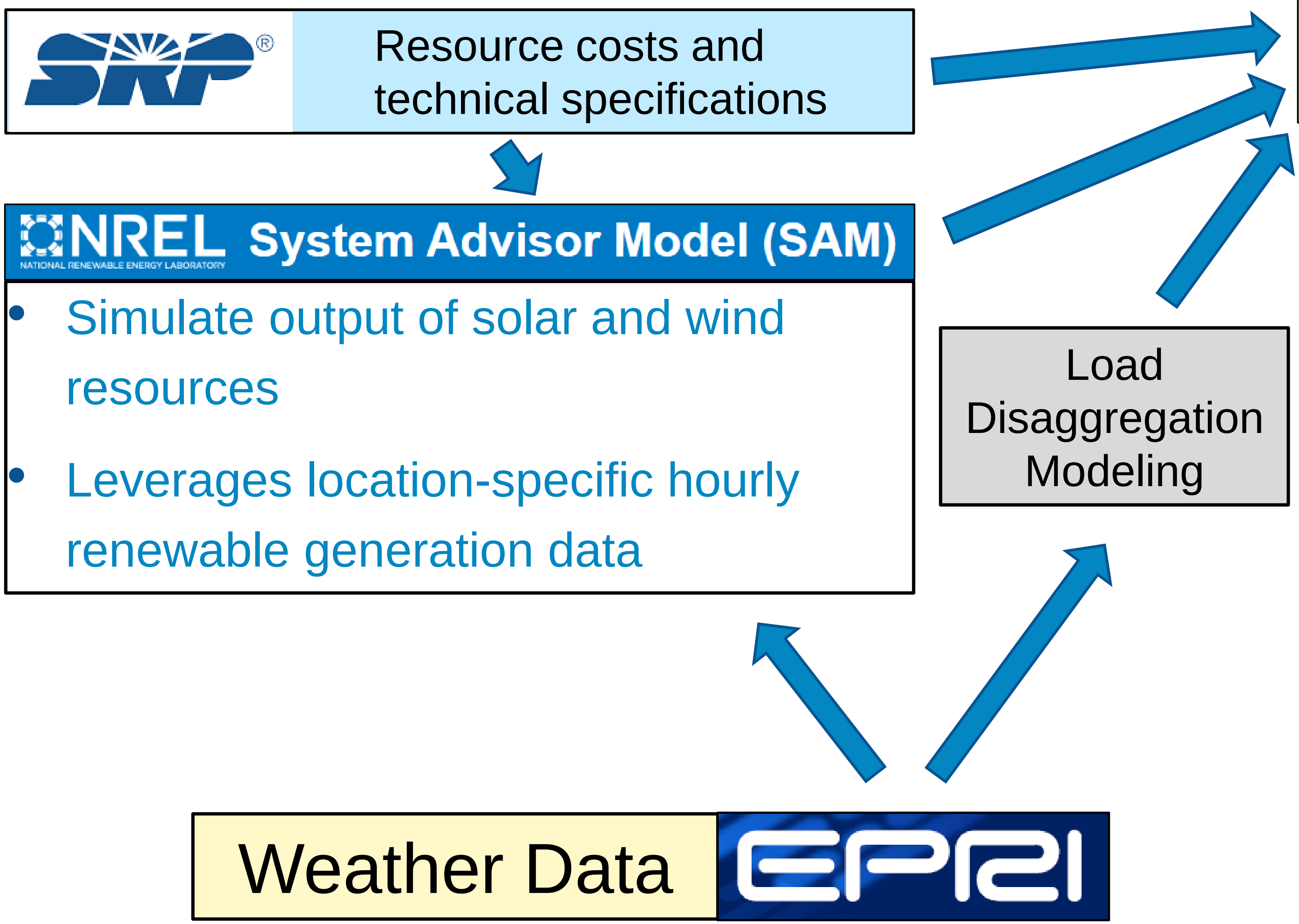
Important or desired characteristic (shaded cells)

2050 Heatwave Events



- Shifted historical timeseries can capture extreme weather events in the tail of the temperature distribution
- Heatwave events in shifted timeseries are well-aligned with events from native CMIP6 output in terms of magnitude and evolution

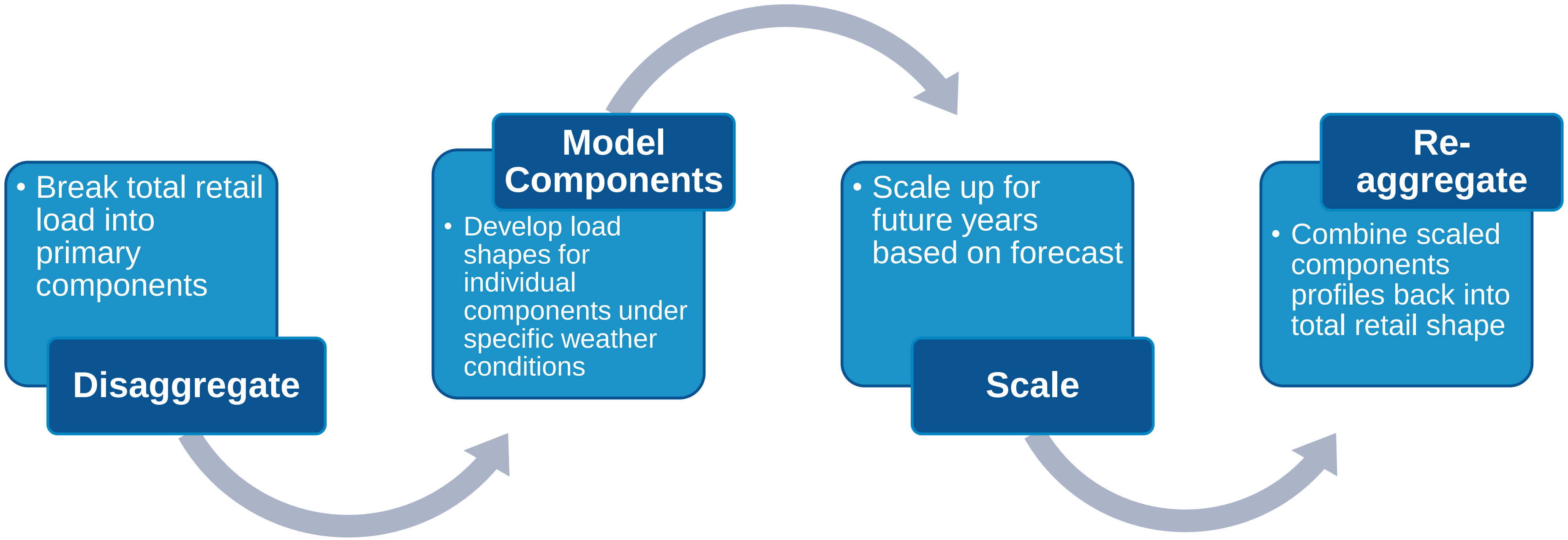
Modeling Setup



SERVM

- Simulate commitment and dispatch of SRP system over a wide range of potential weather conditions and outages
- Calculate RA metrics and SRP risk profile
- Identify capacity required to hit reliability target (1-in-10)
- Calculate capacity values for existing resources

SRP’s Load Disaggregation Approach

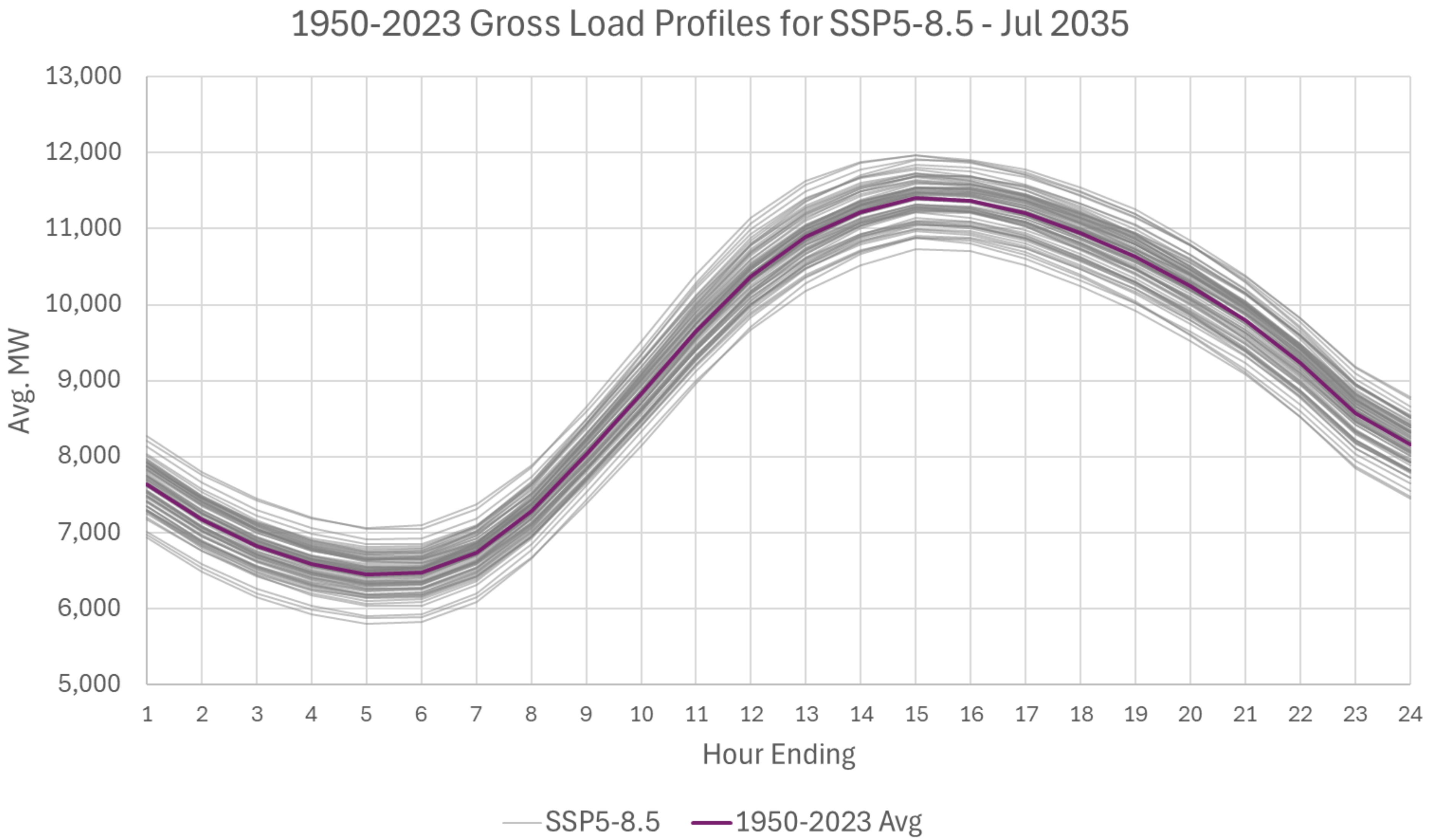


Calculate gross load, i.e., treat BTM solar generation as a resource and not a load modifier

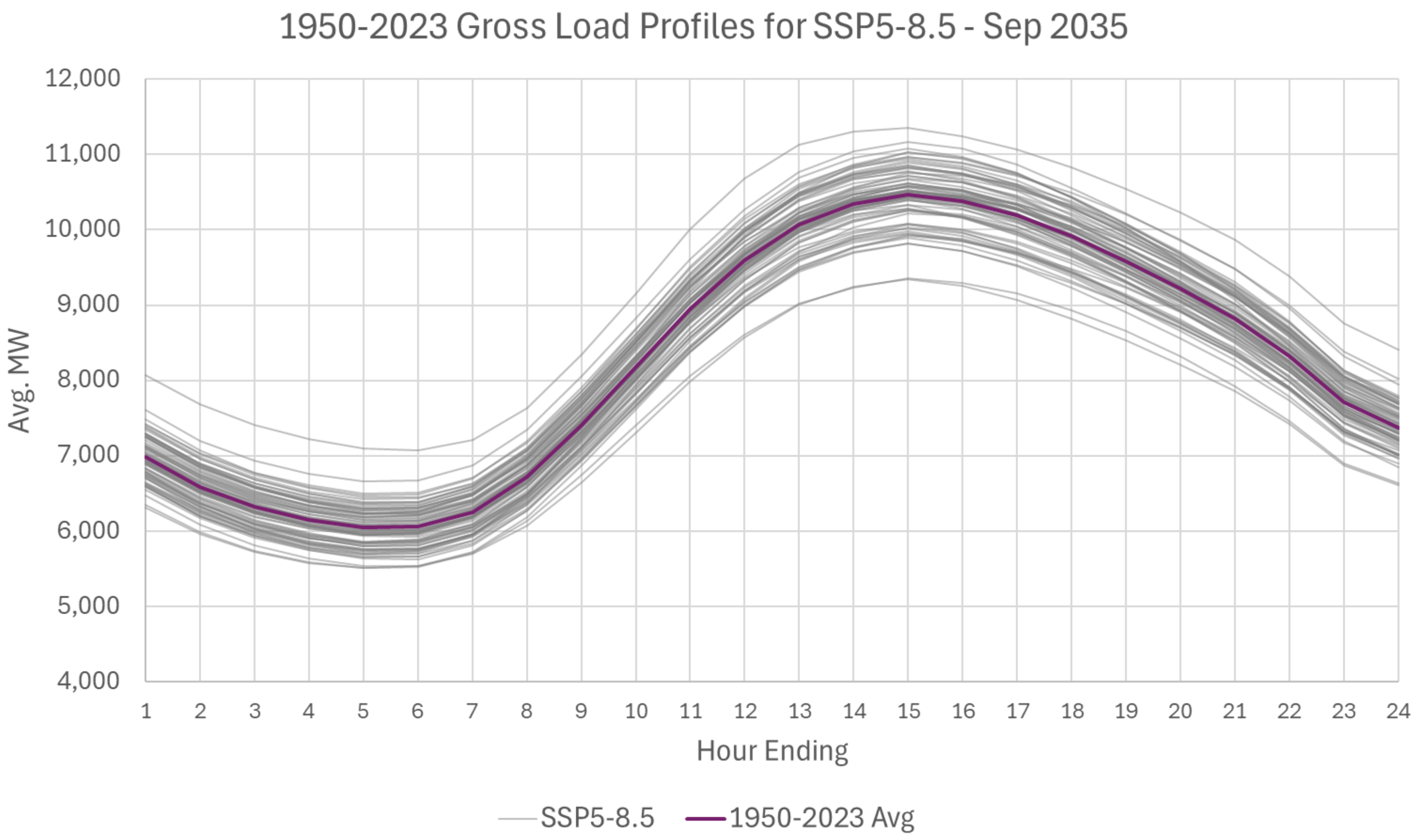
Total Retail Load made up of three primary components

- Large Customer – Lumpy, highly uncertain, minimal weather dependence
- Gross Residential + Small/Medium Business (Gross Res+SMB) – strong weather dependence
- EV – Highly dependent on rate structure, day-to-day uncertainty, mild weather dependence

Climate-Adjusted SRP Load Profiles for July 2035



Climate-Adjusted SRP Load Profiles for September 2035



Climate Adjusted SRP Load Profiles for September 2050