Revision 1

Operational Impact of Extreme Weather Events

Energy Adequacy Study Performed in Collaboration with EPRI

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Operational Impact of Extreme Weather Events – Energy Adequacy Study

- ISO is working with EPRI to conduct a probabilistic energy adequacy study for the New England region in the operational time frame under extreme weather events
- ***Why***: Improve the ISO's and stakeholders' understanding of operational risks under future weather extremes
  - This work is intended to segue into the Energy Adequacy anchor project in Q2 2023: Study results will be used to educate the region on risks so that the region can have informed discussions on risk tolerance, develop a problem statement on energy adequacy, and begin to assess a range of possible solutions
- ***How***: Understand stressors and the related failure mechanisms during extreme weather events and then perform risk analysis across multiple scenarios
  - Establish a framework for analysis of risk under extreme weather events
  - The framework should prove useful as climate projections are refined as the resource mix evolves in the future; it will only get better over time as inputs become better defined

Operational Impact of Extreme Weather Events – Energy Adequacy Study, cont'd

- There are three major steps to this effort
  - Step 1: Weather Modeling (performed by EPRI)
  - Step 2: Risk Screening Model Development and Scenario Generation (performed by EPRI)
  - Step 3: Energy Adequacy Assessments (performed by the ISO)
- This presentation will highlight a preliminary set of extreme events (21-day periods) that the risk screening model has generated as candidates for further study; this set of events provides useful illustrative examples for discussion
  - Further study entails the application of categorical branching methods and scenario generation prior to the performance of energy adequacy assessments in Step 3
- This risk screening model is a coarse measure of system (supply and demand) risk; this model is intended to identify events for further study, not to determine system energy adequacy under specific conditions
  - Energy adequacy assessments in Step 3 will help to quantify system energy adequacy risks under extreme weather events using the outcomes of the Risk Screening Model and Scenario Generation process in Step 2
- *Note: This revision includes updated average load and average max load values on slides 25 and 26. Peak load and total energy demand values on slides 35, 37, 39, 41, 43, 46, 48, 50, 52, and 54 have also been updated. Slide 15 is a new addition.*

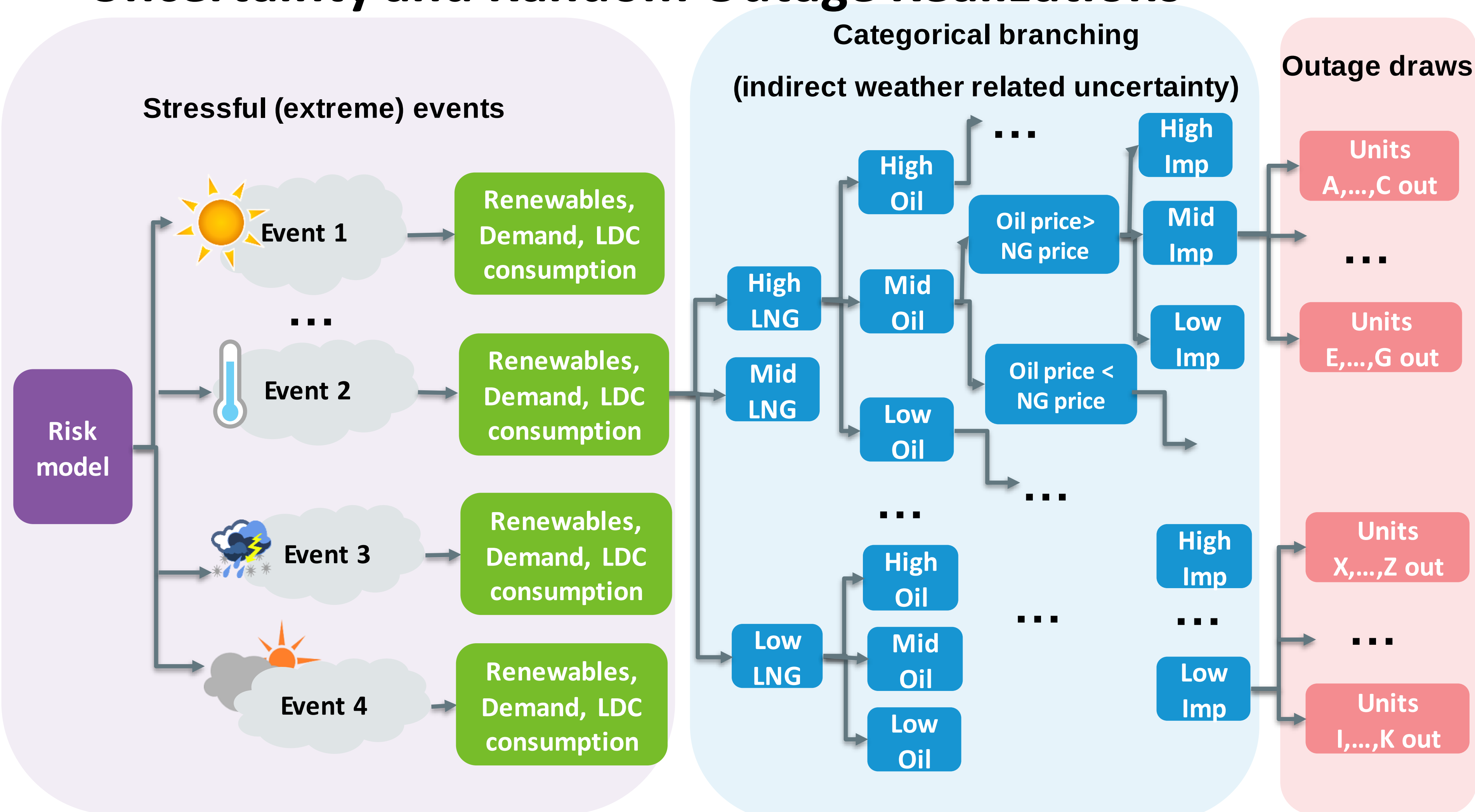
EVENT SELECTION METHODOLOGY

Overview of Event Selection Methodology

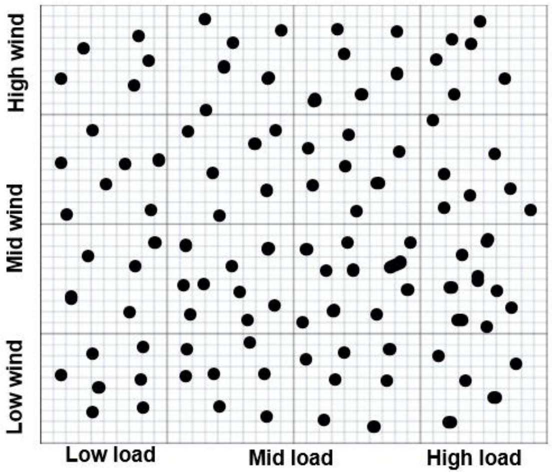
- Objective: Select a set of 21-day periods (events) that appear most stressful (extreme) to the future New England power system in terms of energy availability
  - The initial set of events is based on the output of the risk screening model which determines system risk as aggregated unavailable supply plus exceptional demand (*see* slides no. 10-12)
- Considerations in selecting events
  - Seek a representative set of 21-day events per target year (2027, 2032)
  - Events should include a diverse set of risks; however, diversity is a secondary consideration to vulnerability
  - Select extreme cases representative of similar risks

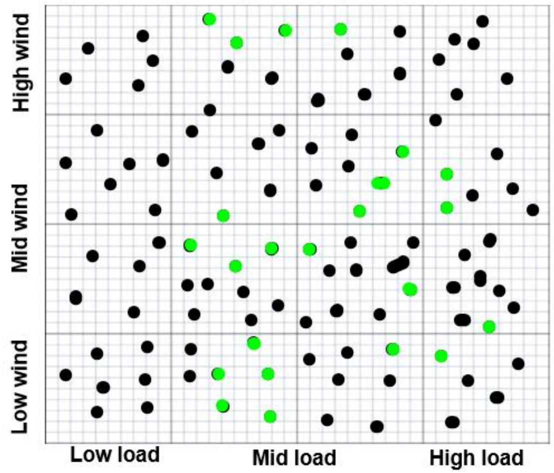
Following Event Selection, Scenario Trees Will Enable Incorporation of Indirect-Weather Related Uncertainty and Random Outage Realizations

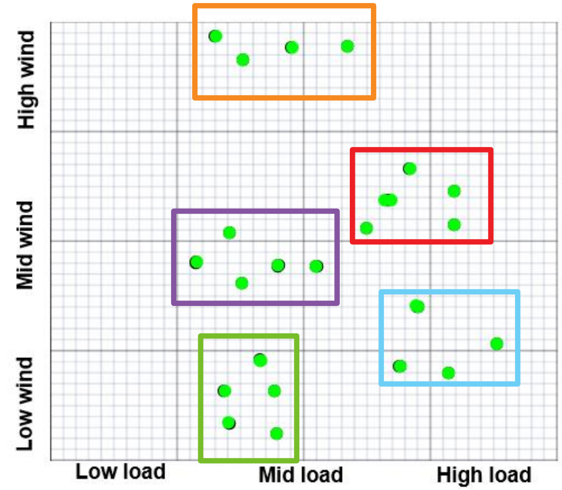
Introduced November RC Meeting



Visual Depiction of Event Selection Methods







Initial Set of Events

3,744* 21-day events per year of study *(as depicted by the* black dots *in figure above)*

52 21-day events/year x 72 versions of each study year = 3,744

*3,744 events is based on one climate model and one socio-economic pathway (*see* slide no. 13)

Risk Screening Model →

Select Highest Risk Events

147 events initially selected *(as depicted by the green dots in the figure above)*

(= top 21 events from each of 7 decades since 1950)

Clustering Algorithm →

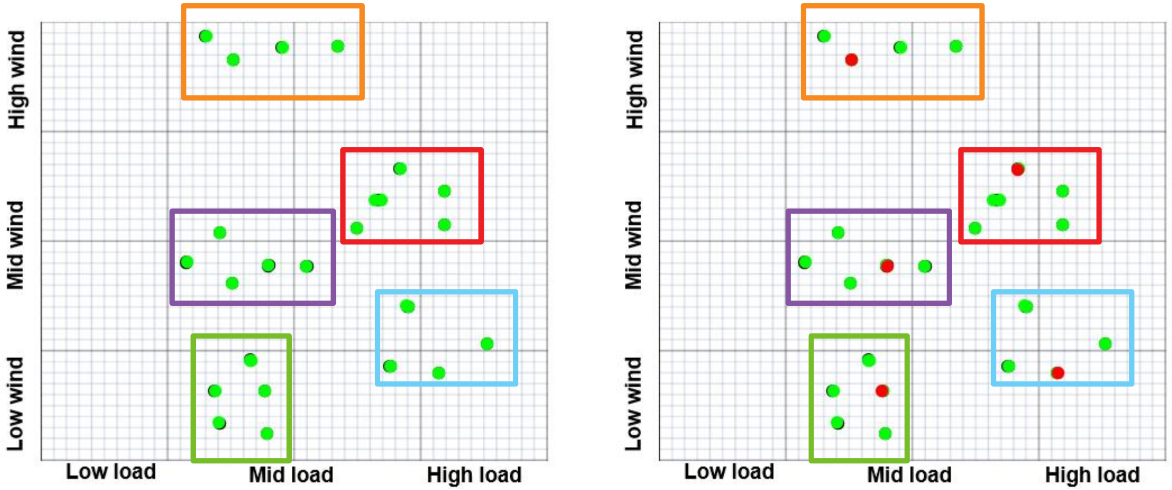
Group Similar Events

Use a clustering algorithm to group high risk events into multiple clusters

The clustering algorithm also determines the number of clusters

Note that these figures are intended only to represent event selection process and are not intended to convey actual results

Visual Depiction of Event Selection Methods, cont.



Group Similar Events

Use a clustering algorithm to group high risk events into multiple clusters

The clustering algorithm also determines the number of clusters

Select Representative Events

Select Events

From each group (or cluster), select one or more events (*as depicted by the red dots in the figure above)*

that represent the set of events within a cluster

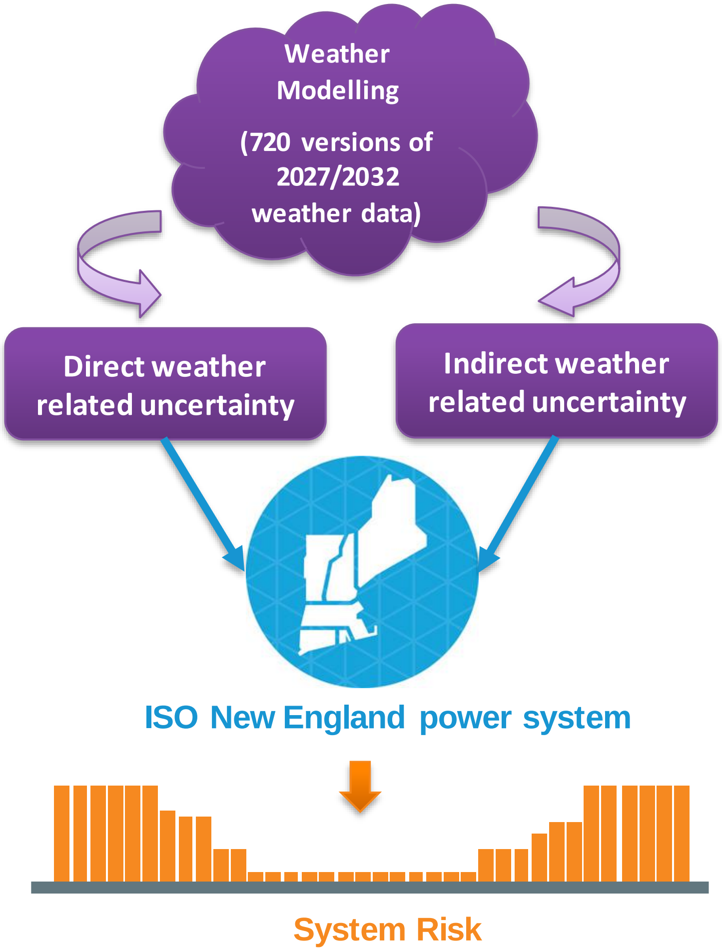
Note that these figures are intended only to represent event selection process and are not intended to convey actual results

BRIEF REVIEW OF RISK SCREENING MODEL

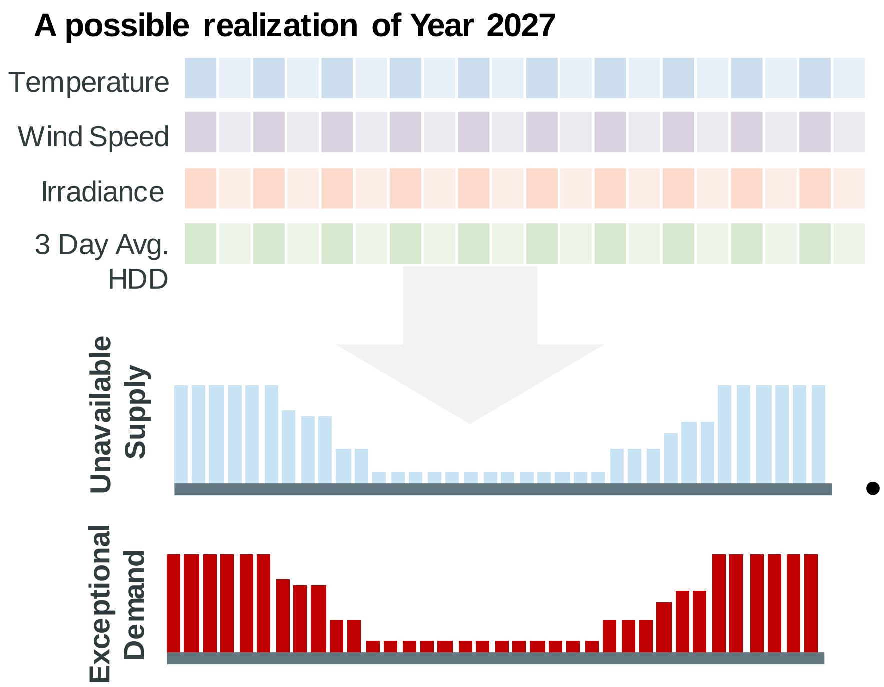
Introduced November RC Meeting

Goal of Risk Screening Model

- To search the weather data set and identify discrete (extreme) weather events that are potentially stressful to the New England power system from an availability of energy perspective
- Discrete events will be 21-day periods consisting of weather characteristics that place regional energy supplies at higher levels of risk
  - Multi-day weather events having weather characteristics similar to hurricanes or Nor'easters may be identified by the risk screening model to the extent that they are identified as being impactful to the region's energy supplies
- Risk screening model will quantify the relationship between weather and the power system
  - Direct weather related uncertainty – e.g., *wind output is a function of wind speed at the site*
  - Indirect weather related uncertainty – e.g., *gas plant fuel supply is a function of heating demand that is a function of weather*

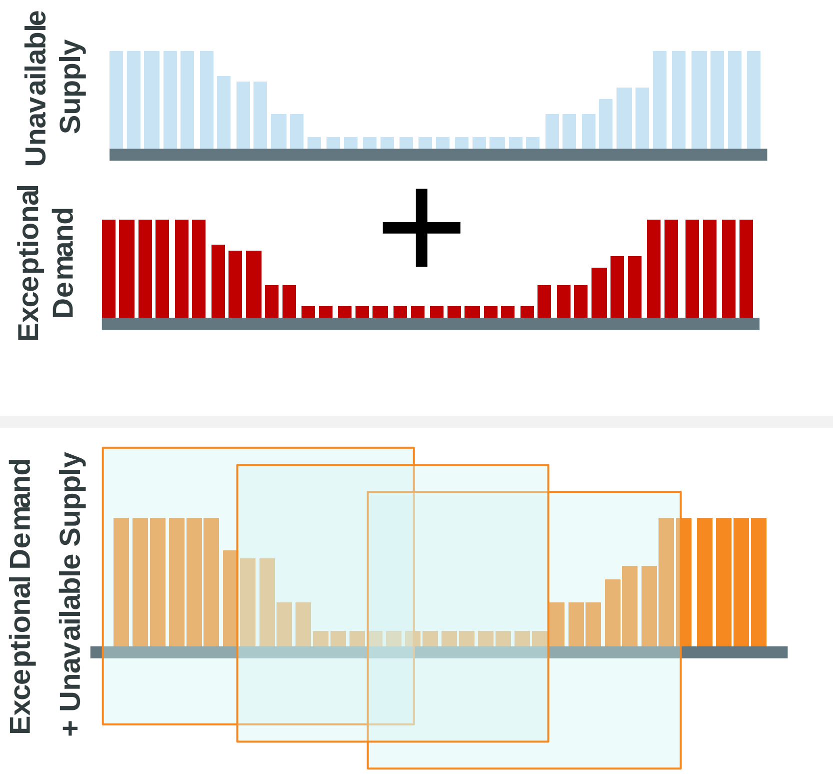


Risk Screening Model: Search Weather Data Set to Identify Potentially Stressful (Extreme) Events



- **Unavailable Supply**
  - Each resource-specific risk model is evaluated at each interval in the weather data provided and the unavailable capacity is estimated
  - Unavailable capacity is aggregated across all resource types in each interval
- **Exceptional Demand**
  - Exceptional demand represents demand above a fixed threshold
  - Example: demand above 23 GW

Risk Screening Model: Search Weather Data Set to Identify Potentially Stressful (Extreme) Events, cont.



- **System Risk** = aggregated unavailable supply + exceptional demand
- Sliding windows applied in order to define extreme events
  - Shift a 21-day window every 7 days
- Select tail risk events for each study year

Risk Screening Model Inputs and Outputs

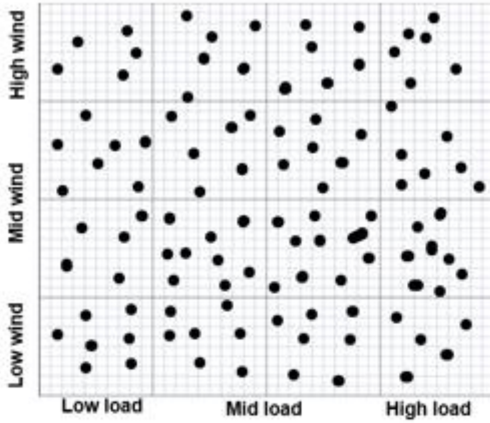
- 2 target years as part of the initial study (2027, 2032)
  - Generation fleet in each target year is based on the set of resources that cleared the most recent forward capacity market auction in addition to state-sponsored resources that are either under contract or have been selected under recent RFP's
  - Demand profiles incorporate ISO's most recent heating and transportation electrification forecasts
- Initial input to the risk screening model is 3,744 events, based on
  - 72 weather years (1950 – 2021), climate-adjusted according to **one climate model (NOAA Geophysical Fluid Dynamics Laboratory, GFDL) and one socio-economic pathway (SSP126)** – *see* appendix slides for more details
  - Each generator is mapped to one of 10 weather stations
- Weather is climate-adjusted according to the GFDL model and SSP126
  - The combination of the GFDL model and SSP126 provides an indicative (median) climate change signal for the near-term; no significant deviations between these models and other models are foreseen between now and target study years
  - Once all five climate models and two socio-economic pathway scenarios are used in the final risk screening model (in progress), there will be a total of 37,440 events screened
- Output of Risk Screening Model is 147 high risk events (top 4% of all events)
  - Model is run in 10-year batches (each batch is one decade since 1950)
  - Process screens top 21 risk periods per batch, ranked based on highest avg. system risk

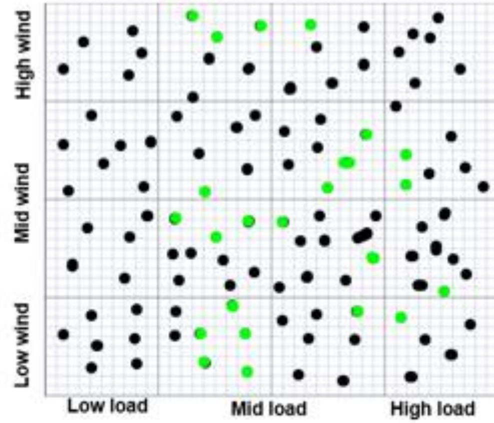
PRELIMINARY RISK SCREENING MODEL RESULTS

Risk Screening Model Results Are Preliminary, But Illustrative Examples Are Useful

- The objective of this presentation is to walk through the event selection methodology with illustrative examples
- The following slides indicate a preliminary set of potential high-risk events (and clusters of events) based on the modeling currently implemented
- The preliminary events and clusters reflect possible outcomes which may adjust as modeling is complete
  - For example, behind-the-meter PV is not yet fully incorporated into the risk screening model; once fully incorporated this may shift the selected set of events (particularly summer events) and the identified clusters
- Modeling efforts continue and progress will be shared at future meetings

Selection of Highest Risk Events





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Risk Screening Model

Select Highest Risk Events

147 events initially selected

(= top 21 events from each of 7 decades since 1950)

**Note that these figures are intended only to represent event selection process and are not intended to convey actual results*

Risk Screening Model Top 10 Events, Ranked by Highest Avg. System Risk, 2027 and 2032 Study Years

2027 (Top 10 of 147 events)		
Rank	21-Day Event Start Date	Avg. System Risk (MW)
1	Jan 22, 1961	9182
2	Jan 15, 1961	9000
3	Jan 01, 1981	8963
4	Jan 11, 1994	8937
5	Jan 07, 1982	8877
6	Jan 15, 1971	8826
7	Jan 05, 2004	8714
8	Jan 12, 2004	8555
9	Feb 02, 1979	8546
10	Jan 04, 1994	8444
14	1st Summer Event, Jul 05, 2010	8315

2032 (Top 10 of 147 events)		
Rank	21-Day Event Start Date	Avg. System Risk (MW)
1	Jan 22, 1961	9691
2	Jan 15, 1961	9636
3	Jan 07, 1982	9600
4	Jan 01, 1981	9577
5	Jan 11, 1994	9437
6	Jan 15, 1971	9405
7	Jan 05, 2004	9315
8	Jan 12, 2004	9162
9	Jan 04, 1994	8972
10	Feb 02, 1979	8959
19	1st Summer Event, Jul 28, 1988	8572

Analysis of Risk Screening Model Top 10 Events Indicates Some Similarities Between 2027 and 2032

2027 (Top 10 of 147 events)

Rank	21-Day Event Start Date	Avg. System Risk (MW)
1	Jan 22, 1961	9182
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Analysis of Top 10 Events

Based on the highest average system risk (MWs):

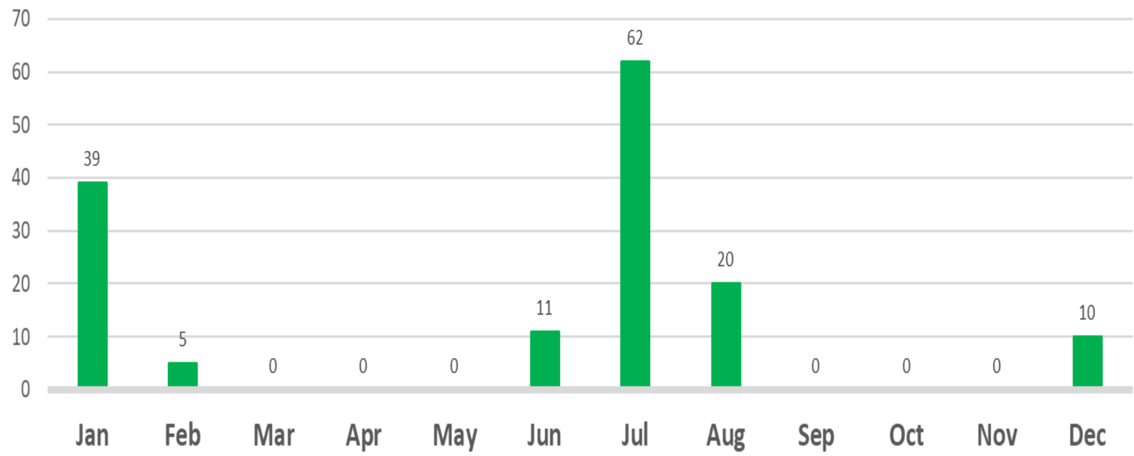
- Top 10 events in both study years consistently demonstrate system risks associated with winter cold weather
- System risk increases slightly from 2027 to 2032
- Significant overlap exists **within events** in target study years (***see color-shaded pairs in each table***)
- All of the Top 10 events overlap across target study years, though system risk varies

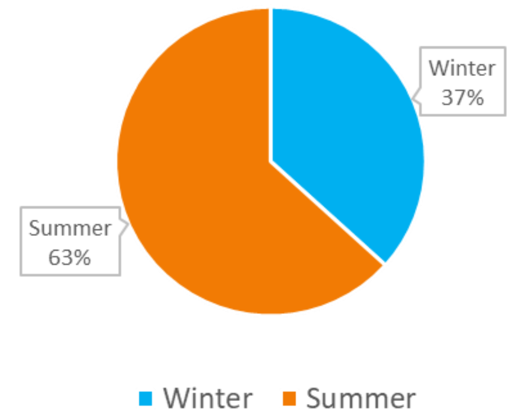
2032 (Top 10 of 147 events)

Rank	21-Day Event Start Date	Avg. System Risk (MW)
1	Jan 22, 1961	9691
2	Jan 15, 1961	9639
3	Jan 07, 1982	9600
4	Jan 01, 1981	9577
5	Jan 11, 1994	9437
6	Jan 15, 1971	9405
7	Jan 05, 2004	9315
8	Jan 12, 2004	9162
9	Jan 4, 1994	8972
10	Feb 02, 1979	8959
19	1st Summer Event, Jul 28, 1988	8572

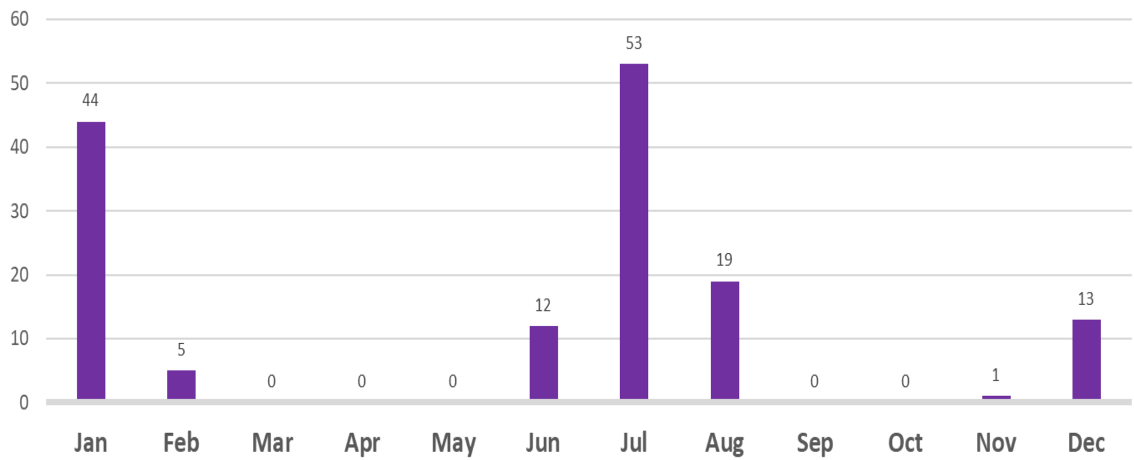
Top 10 Lists Highlight Winter Events, but Summer Events are Prevalent in Risk Screening Model Results

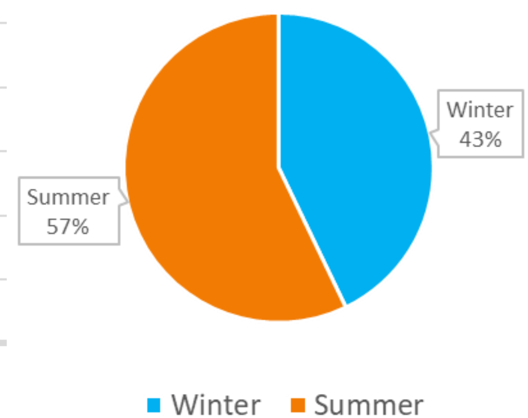
2027



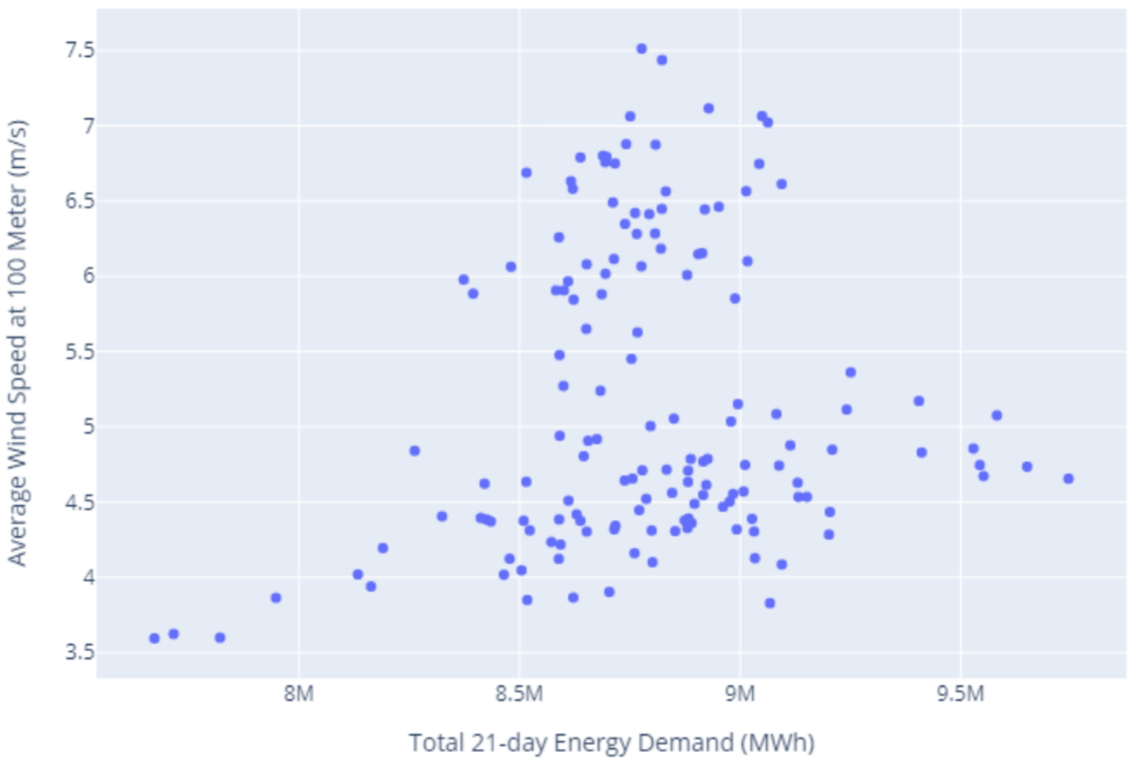


2032





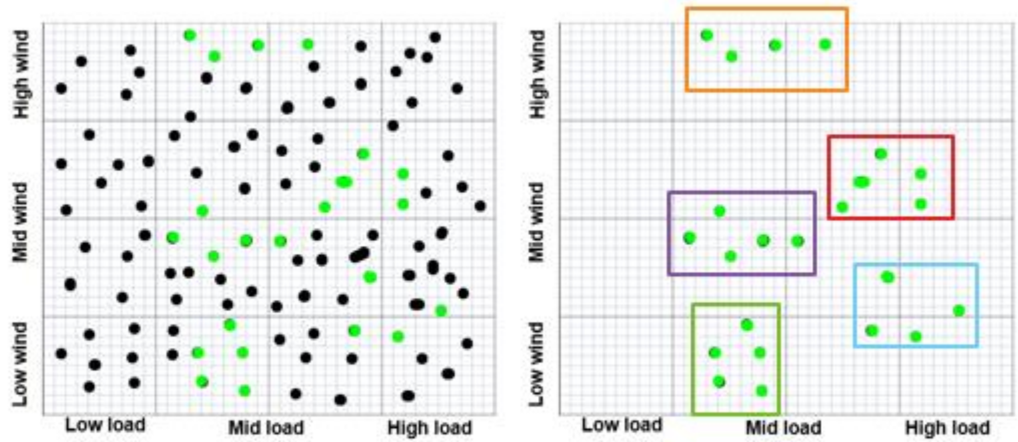
Risk Screening Model Results Do Not Directly Reveal Characteristics of Specific Events



- As an example, the figure on the left depicts 2027 Risk Screening Model results by mean 100 meter wind speed and total 21-day energy demand
- It is challenging to select representative 21-day events directly from raw risk screening results

GROUPING OF SIMILAR EVENTS

Reduction Techniques Facilitate Grouping of Events With Similar Characteristics



Select Highest Risk Events

147 events initially selected

(= top 21 events from each of 7 decades since 1950)

Clustering Algorithm

Group Similar Events

Use a clustering algorithm to group high risk events into multiple clusters

The clustering algorithm also determines the number of clusters

**Note that these figures are intended only to represent event selection process and are not intended to convey actual results*

Several Options For Grouping Similar Events Were Considered, Clustering Method Has Been Proposed

Approach	Scenario Selection Policy (e.g. Top 3 winter, Top 3 summer)	Clustering (K-means/ K-medoids)	OptEx D-Opt	OptEx S-Opt	Unsupervised Learning
Advantages	Simplified approach following pre-established rules	Commonly implemented approach, allows from selection from group	Ensures 'most diverse set' of scenarios across all dimensions	Ensures selection of 'least alike' scenarios across all dimensions	Not exposed to bias
Disadvantages	Rulemaking significantly exposed to confirmation bias risk	Dimension selection exposed to confirmation bias	Does not allow for grouping; Exposed to dimension selection conf. bias risk		Insufficient training data and low transparency

Description of Clustering Method

- Clustering by the K-means/K-medoids approach is a machine-learning technique that involves the grouping of data points
- A clustering algorithm is used to group similar 21-day events
- Factors used to differentiate events
  - System Factors
    - Average system risk across event
    - Maximum system risk
    - Total load
  - Common Mode Factors
    - Average temperature
    - Extreme temperature
  - Renewable Factors
    - Average irradiance
    - Number of dark days and/or calm days
    - Wind speed
  - Precipitation (including snow) were evaluated but later excluded as they reinforced load and temperature dimensions in Principal Component Analysis (PCA)
- The outcome of the clustering process is five “clusters” (or groups) of events for each study year, each with unique operational challenges

Summary of Clustering Outcomes, Study Year 2027

Cluster Name	# of Events in Cluster (of 147)	Brief Representative Description of Events in Cluster	Avg. Temp (F)	Avg. System Risk (MW)	% of Days with Extreme Cold/Hot Temps (<10 F, or >85 F)	% of Days with Low Wind (<4 m/s)	% of Days with Low Irr (<200 W/m²)	Avg. Load (GW)	Avg. Max Load (GW)
Winter 1 (W1)	16	Long-Duration Extreme Cold Wave(s), Low Winds and Very Low Solar	**17.3**	**8,623**	**30%**	61%	99%	**16.3**	**21.1**
Winter 2 (W2)	38	Short-Duration Extreme Cold Snap(s), Low Winds and Very Low Solar	20.6	7,717	16%	**66%**	**100%**	15.9	20.8
Summer 1 (S1)	35	Long-Duration Heat Wave, Highest Summer Loads, Very Low Winds	**76.4**	**7,894**	1%	96%	15%	**16.8**	**25.7**
Summer 2 (S2)	51	Sustained High Temps, High Summer Loads, Very Low Winds and Low Solar	74.8	7,554	1%	96%	15%	15.9	24.4
Summer 3 (S3)	7	Moderate Summer Temps, Avg. Summer Loads, Very Low Winds and Very Low Solar	71.3	7,477	0%	**99%**	**22%**	14.4	21.7

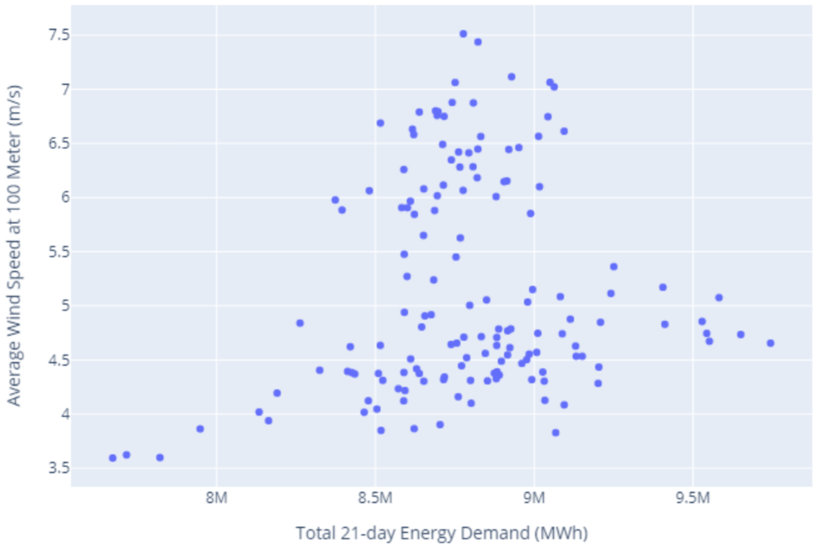
*Bold and colored (**blue** or **red**) text indicates the cluster in which each variable is the largest value within the same season (winter or summer)

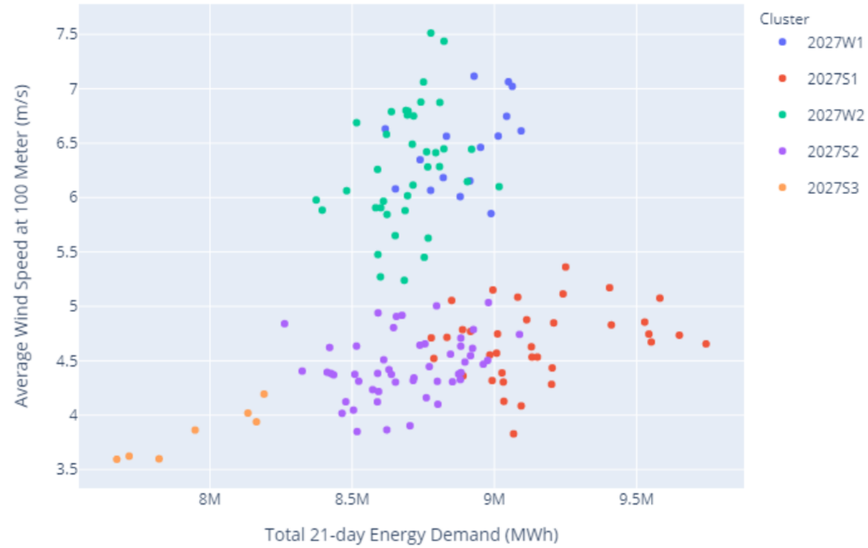
Summary of Clustering Outcomes, Study Year 2032

Cluster Name	# of Events in Cluster (of 147)	Brief Representative Description of Events in Cluster	Avg. Temp (F)	Avg. System Risk (MW)	% of Days with Extreme Cold/Hot Temps (<10 F, or >85 F)	% of Days with Low Wind (<4 m/s)	% of Days with Low Irr (<200 W/m²)	Avg. Load (GW)	Avg. Max Load (GW)
Winter 1 (W1)	10	Long-Duration Extreme Cold Wave(s), Low Winds and Very Low Solar	**16.6**	**9,376**	**32%**	60%	100%	**18.0**	**23.64**
Winter 2 (W2)	27	Short-Duration Extreme Cold Snap(s), Low Winds and Very Low Solar	20.2	8,365	22%	62%	100%	17.5	23.56
Winter 3 (W3)	26	Consistently Low Winter Temps, Low Winds and Very Low Solar	21.7	7,893	7%	**68%**	100%	17.2	22.9
Summer 1 (S1)	47	Long-Duration Heat Wave, Highest Summer Loads, Very Low Winds	**76.5**	**7,952**	**2%**	95%	16%	**17.1**	**26.1**
Summer 2 (S2)	37	Consistently High Summer Temps, Very Low Wind and Low Solar	74.7	7,684	0%	**98%**	**27%**	16.2	24.7

*Bold and colored (**blue** or **red**) text indicates the cluster in which each variable is the largest value within the same season (winter or summer)

Visual Depiction of 2027 Clustering Outcomes





Select Highest Risk Events

147 events initially selected

(= top 21 events from each of 7 decades since 1950)

Clustering Algorithm

Group Similar Events

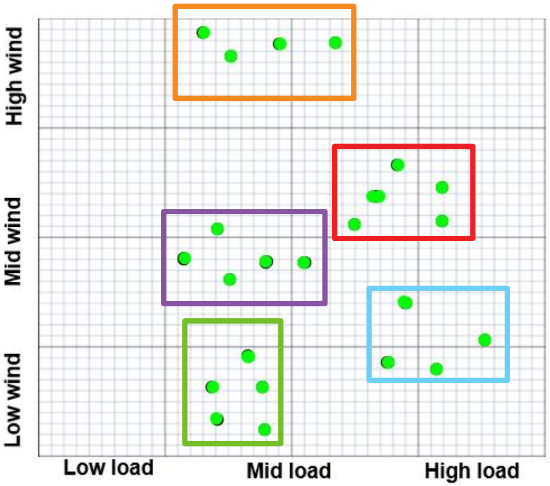
Use a clustering algorithm to group high risk events into multiple clusters

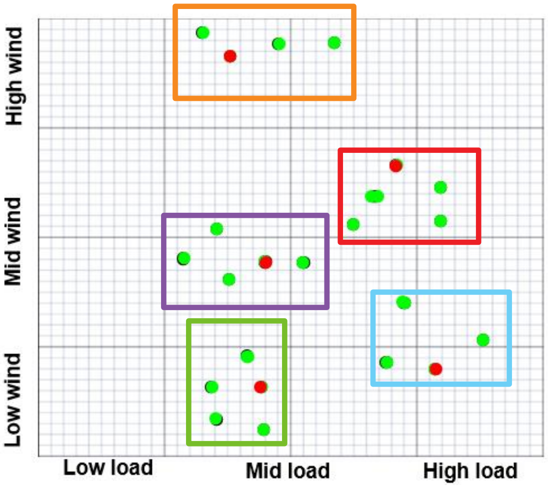
The clustering algorithm also determines the number of clusters

*The visual depiction on this slide includes only two variables, total 21-day energy demand (MWh) and average wind speed at 100 meters (m/s). Notably, the clustering algorithm takes many additional variables into consideration.
This exhibit is intended only to visually reinforce the clustering methodology.

SELECTION OF EVENTS FROM CLUSTERS

Following Clustering of Events, Representative Events Must Be Selected for Further Study





Group Similar Events

Use a clustering algorithm to group high risk events into multiple clusters

The clustering algorithm also determines the number of clusters

Select Representative Events

Select Events

From each group (or cluster), select one or more events that represent the set of events within a cluster

Note that these figures are intended only to represent event selection process and are not intended to convey actual results

Several Options for Selecting Events From a Cluster Have Been Considered

- Options to select an event included
  - Most representative event (at the medoid of each cluster)
  - Events with most system risk (average, maximums, etc.)
- The table below displays results of preliminary event selection based on **highest avg. system risk**

2027 Target Year				2032 Target Year			
Cluster	**Selected 21-Day Event Start Date**	**Avg. System Risk (MW)**	**Event Rank** (of 147)	**Cluster**	**Selected 21-Day Event Start Date**	**Avg. System Risk (MW)**	**Event Rank** (of 147)
W1*	1/22/1961	9,182	1	**W1***	1/22/1961	9,691	1
W2	1/12/2009	8,161	21	**W2**	1/8/1971	8,834	9
S1	7/5/2010	8,314	14	**W3**	1/15/2011	8,389	27
S2*	8/17/1973	7,916	41	**S1**	7/28/1988	8,572	19
S3	7/28/2008	7,598	88	**S2***	8/17/1973	8,332	53

* Two Instances of Overlap Between Target Years (1/22/1961 and 8/17/1973)

Clustering Approach Appears Valid Based on Review of Historical Periods

- As depicted on the following slides, reasonable coverage of historical events has resulted from the clustering methodology that has been employed
- ISO and EPRI continue to evaluate the selection of additional events within each cluster (i.e., top 2 highest average system risks events) and/or the utilization of other methods (i.e., other than highest average system risk) for the selection of events
  - Any suggested modifications to the current approach will be discussed at future meetings

Comparison of Selected Events to Top 10 Coldest Historical Periods – New England Weighted (HDDs)

NE Weighted Avg.	Coldest Day	Coldest 3-Day	Coldest 5-Day	Coldest 10-Day	Coldest 21-Day
1	70.6 (1957-01-15)	63.7 (1968-01-09)	62.2 (1979-02-12)	59.5 (1979-02-15)	52.3 (1961-01-29)
2	66.8 (1968-01-08)	62.9 (1957-01-15)	61.7 (1968-01-10)	55.6 (1961-01-24)	52.2 (1982-01-18)
3	65.4 (2016-02-14)	62.5 (1979-02-11)	60.9 (1957-01-16)	55.6 (2018-01-03)	51.7 (1979-02-10)
4	65.4 (1981-01-04)	62.5 (2004-01-15)	59.4 (1971-01-18)	55.6 (1981-01-09)	51.6 (1981-01-04)
5	65.2 (1968-01-09)	61.1 (1955-12-21)	58.7 (2017-12-30)	55.1 (1968-01-07)	51.4 (2004-01-17)
6	65.2 (1962-12-31)	60.8 (1981-01-04)	57.4 (1981-01-11)	54.8 (1982-01-15)	50.1 (1968-01-08)
7	64.4 (1994-01-16)	60.7 (1971-01-19)	57.2 (1965-01-17)	54.5 (2004-01-12)	49.8 (1957-01-09)
8	64.1 (1982-01-18)	60.3 (1965-01-16)	57.2 (1961-01-23)	54.4 (1957-01-16)	49.8 (1970-01-14)
9	63.9 (1968-12-26)	60.1 (1979-02-14)	56.7 (1979-02-17)	53.9 (1971-01-17)	49.7 (2015-02-10)
10	63.7 (1965-01-15)	59.7 (1994-01-20)	56.7 (1961-02-01)	53.4 (2000-01-19)	49.4 (1994-01-17)

Selected as a Representative Event for 2032 (purple) | **Selected as a Representative Event for 2027 & 2032** (orange)

Description: Values are based on daily mean temperatures. 3, 5, 10, and 21-days are means for the period. Dates are mid-points of events.

Comparison of Selected Events to Top 10 Hottest Historical Periods – New England Weighted (CDDs)

NE Weighted Avg.	Hottest Day	Hottest 3-Day	Hottest 5-Day	Hottest 10-Day	Hottest 21-Day
1	23.3 (2011-07-22)	19.9 (1991-07-20)	18.3 (2013-07-18)	16.1 (1988-08-11)	14.5 (1988-08-06)
2	22.2 (1975-08-02)	19.7 (2011-07-22)	18.1 (1991-07-20)	15.4 (2020-07-24)	13.7 (2013-07-13)
3	21.8 (2010-07-06)	19.0 (2013-07-19)	17.7 (1988-08-13)	15.3 (2013-07-19)	13.6 (2020-07-28)
4	21.2 (2001-08-09)	18.9 (2001-08-08)	17.5 (2001-08-08)	15.2 (2010-07-09)	13.3 (2010-07-14)
5	21.1 (1999-07-05)	18.9 (1975-08-02)	17.2 (2002-08-16)	14.9 (1991-07-21)	12.6 (2002-08-08)
6	21.0 (2006-08-02)	18.7 (2002-07-03)	17.1 (2010-07-07)	14.9 (2002-08-15)	12.4 (2016-07-22)
7	20.8 (2019-07-21)	18.7 (2010-07-06)	17.0 (2011-07-21)	14.4 (1953-09-02)	12.2 (2006-07-24)
8	20.7 (2013-07-19)	18.6 (2006-08-02)	16.6 (2016-08-13)	14.3 (1952-07-19)	12.1 (2011-07-14)
9	20.5 (1991-07-21)	18.3 (1982-07-18)	16.6 (1977-07-19)	14.1 (2016-07-26)	11.9 (2019-07-12)
10	20.1 (1991-07-20)	18.0 (1988-08-13)	16.6 (1993-07-09)	14.0 (2006-07-30)	11.8 (2018-08-02)

Selected as a Representative Event for 2032 (purple): 1988 events. Selected as a Representative Event for 2027 (green): 2010 events.

Description: Values are based on daily mean temperatures. 3, 5, 10, and 21-days are means for the period. Dates are mid-points of events.

REVIEW OF SELECTED EVENTS, 2027

Events selected based on highest average system risk in each cluster

Representative Event, Winter Cluster 1, 2027

Long-Duration Cold Wave Coincident With Low Avg. Winds and Solar

Event Description

Cluster: Winter 1 (includes 16 of 147 events)

Event Ranking: 1 (of 147 events)

Date: Jan 22 – Feb 12, 1961

Avg. System Risk: 9,182 MW

Max System Risk: 19,276 MW

Peak Load: 20,601 MW

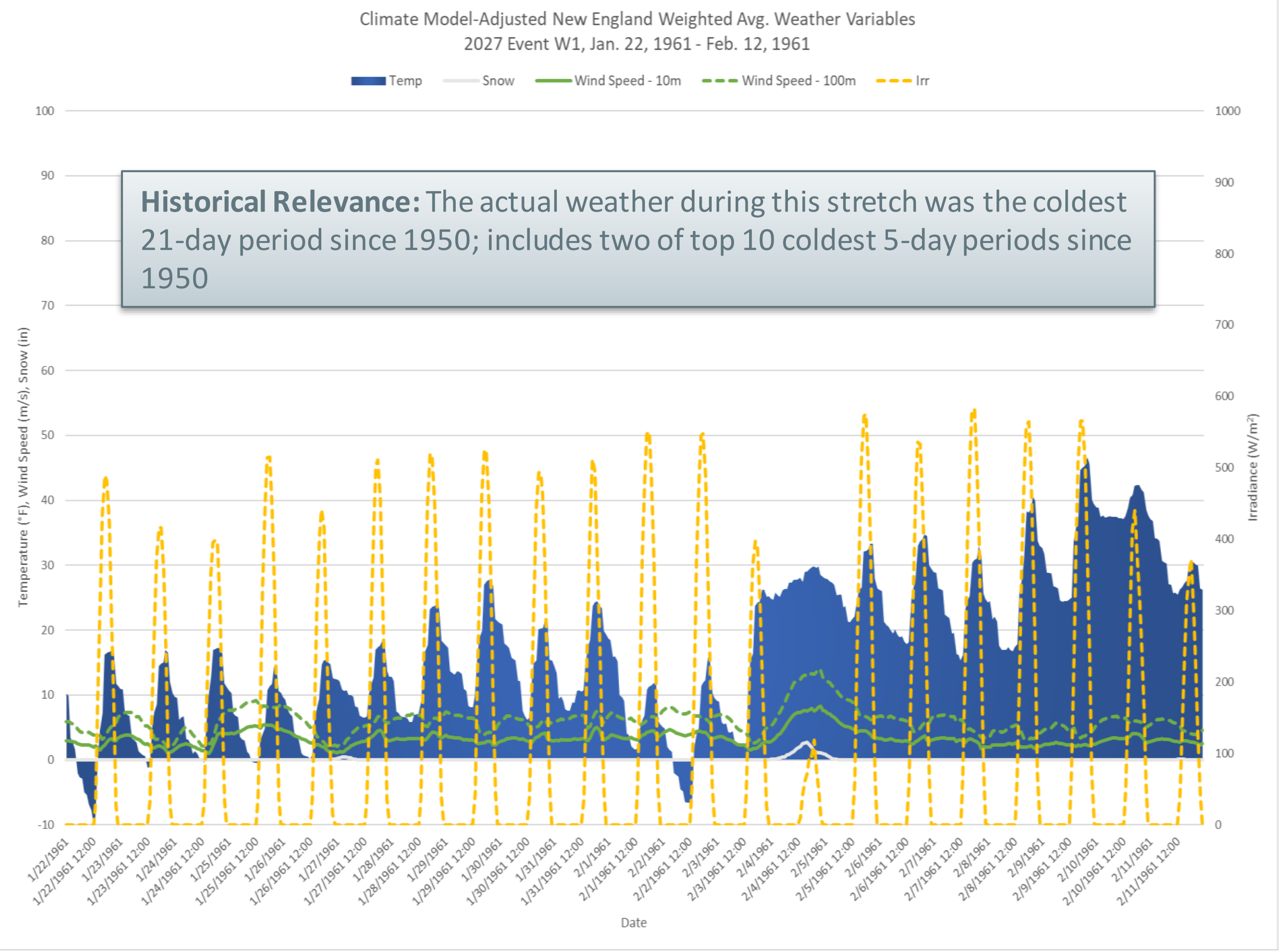
Total Energy Demand: 8.18 TWh

Min/Mean/Max (°F): -9.6/17.1/46.4

Mean 100m Wind Speed (m/s): 6.0

Mean Irradiance (W/m²): 118.8

Key Weather Variables



Representative Event, Winter Cluster 1, 2027

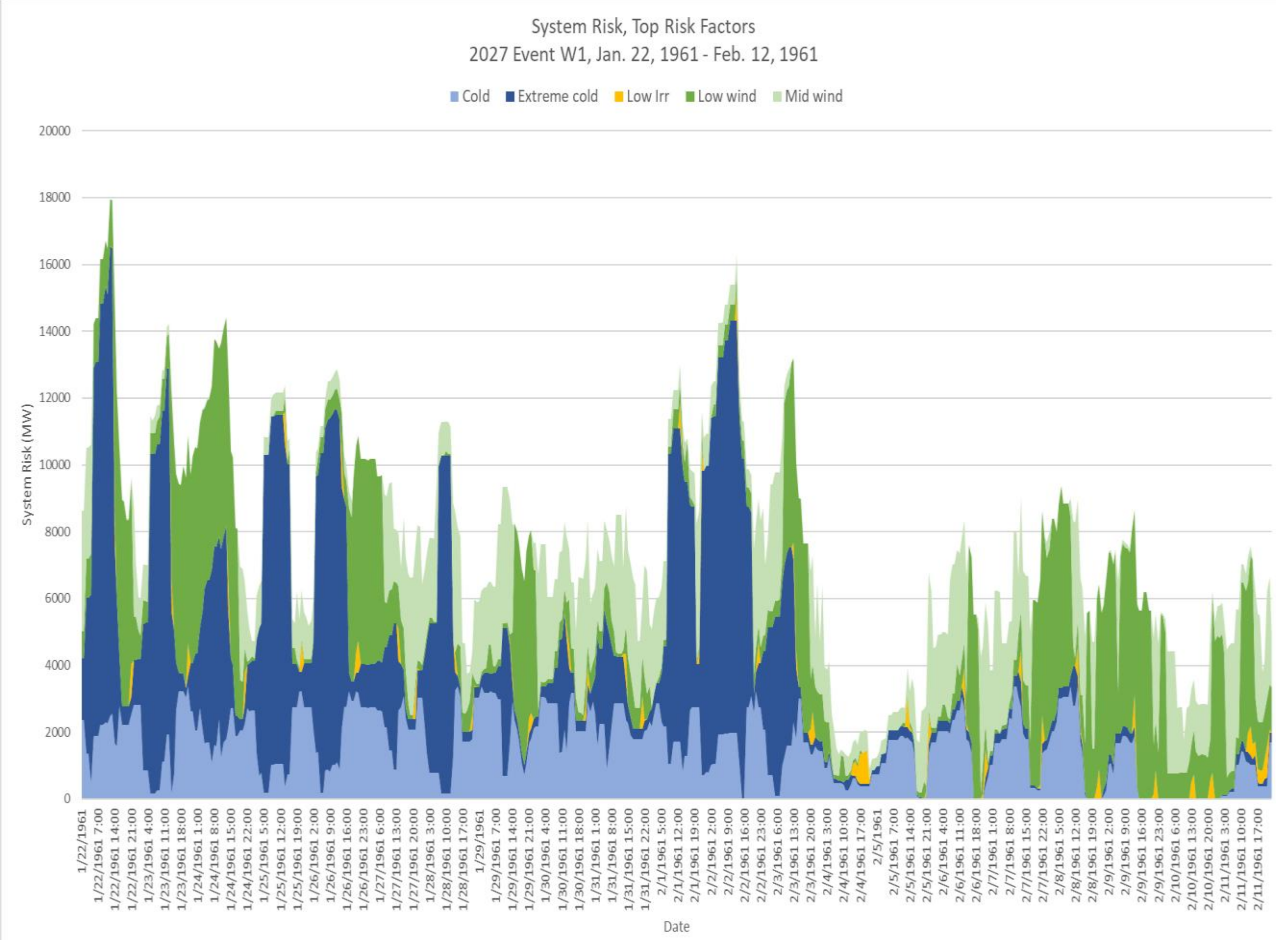
Long-Duration Cold Wave Coincident With Low Avg. Winds and Solar

Risk Summary

Top 3 Risks	Total Risk	Impacted Resources
Extreme Cold (<10F)	29%	CC (13%) GT (4%) Wind Offshore (9%) Misc. (3%)
Cold (10-30F)	18%	CC (13%) GT (3%) ST (2%)
Low Wind (<6 m/s)	22%	Wind Offshore (14%) Wind Onshore (8%)

System Risk – Top Risk Factors*

*(*not all risk factors are included in plot below, only most significant risks)*



Representative Event, Winter Cluster 2, 2027

Short-Duration Cold Snaps With Low Avg. Winds and Very Low Avg. Solar

Event Description

Cluster: Winter 2 (38 of 147 events)

Event Ranking: 21 (of 147)

Date: Jan 12 – Feb 2, 2009

Avg. System Risk: 8,161 MW

Max System Risk: 18,552 MW

Peak Load: 20,585 MW

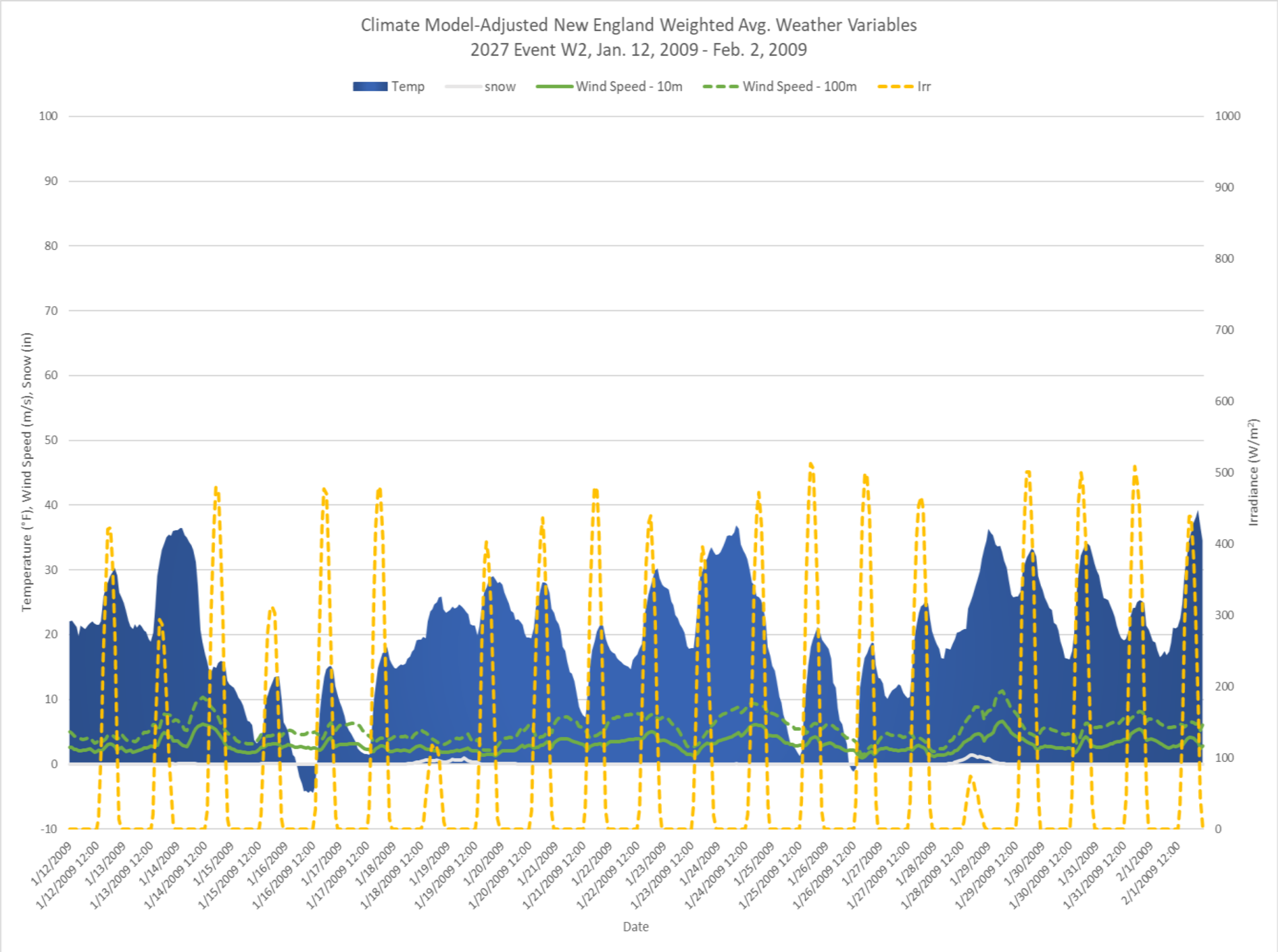
Total Energy Demand: 8.08 TWh

Min/Mean/Max(°F): -4.4/20.0/39.3

Mean 100m Wind Speed (m/s): 5.5

Mean Irradiance (W/m²): 99.6

Weather Conditions



Representative Event, Winter Cluster 2, 2027

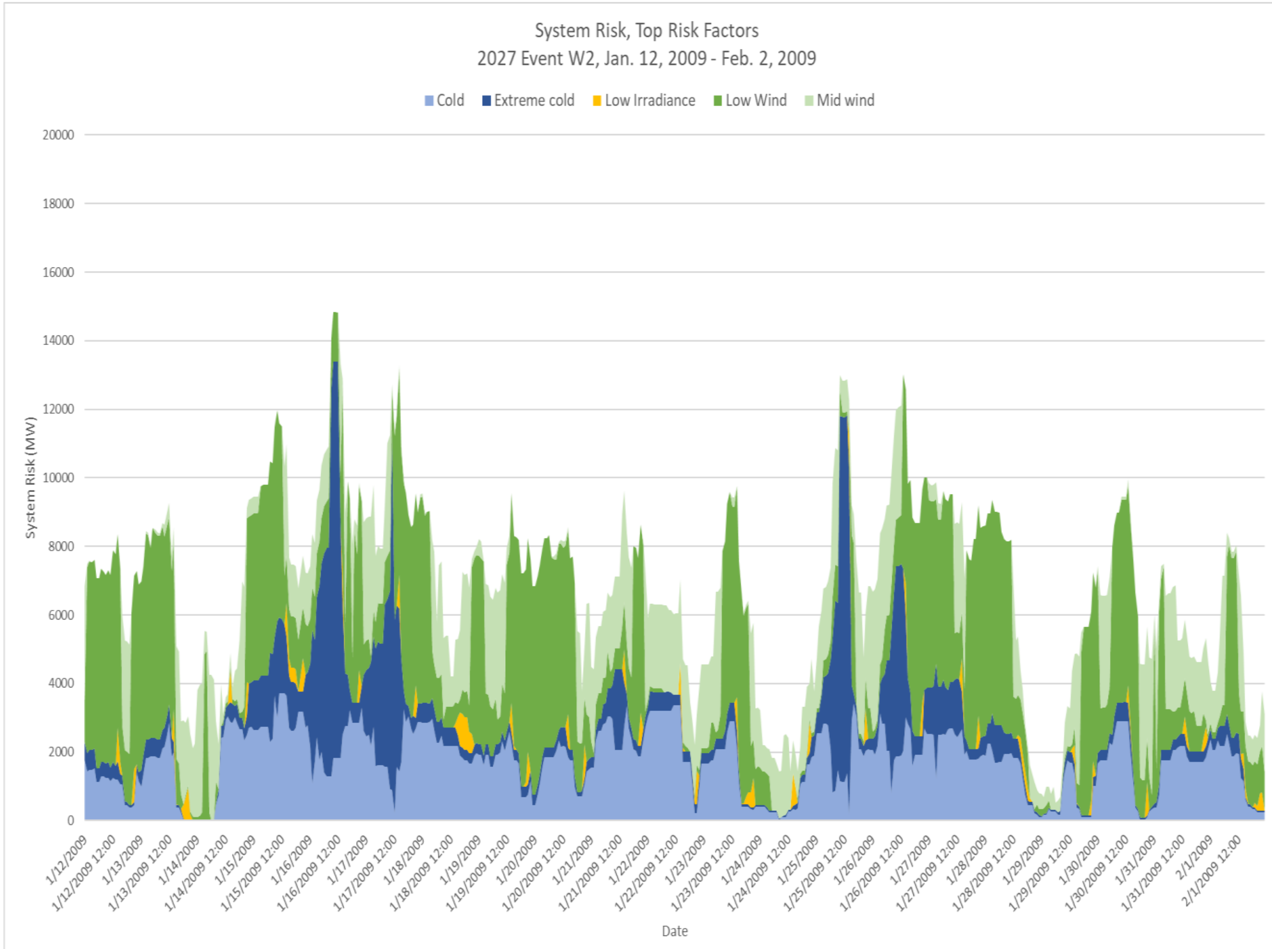
Short-Duration Cold Snaps With Low Avg. Winds and Very Low Avg. Solar

Risk Summary

Top 3 Risks	Total Risk	Impacted Resources
Low Wind (<6 m/s)	34%	Wind Offshore (23%) Wind Onshore (11%)
Mid Wind (6-12 m/s)	17%	Wind Offshore (13%) Wind Onshore (4%)
Cold Temp (10-30F)	22%	CC (17%) GT (4%) ST (1%)

System Risk – Top Risk Factors*

*(*not all risk factors are included in plot below, only most significant risks)*



Representative Event, Summer Cluster 1, 2027

Long Duration Heat Wave Coincident with Very Low Avg. Winds

Event Description

Cluster: Summer 1 (35 of 147 events)

Event Ranking: 14 (of 147)

Date: Jul 5 – Jul 26, 2010

Avg. System Risk: 8,314 MW

Max System Risk: 19,342 MW

Peak Load: 27,350 MW

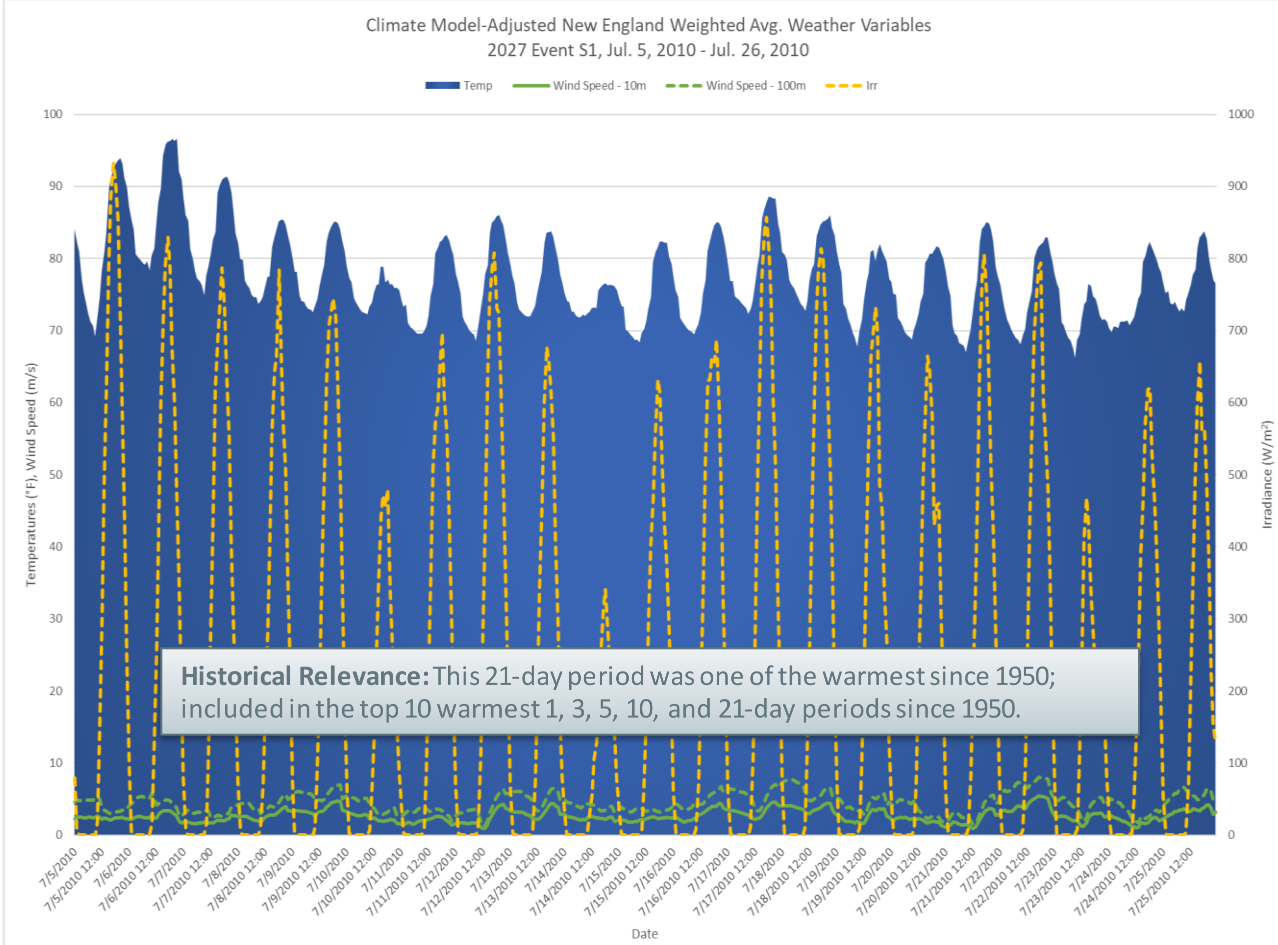
Total Energy Demand: 8.55 TWh

Min/Mean/Max (°F): 66.2/77.5/96.6

Mean 100m Wind Speed (m/s): 4.4

Mean Irradiance (W/m²): 239.9

Weather Conditions



Historical Relevance: This 21-day period was one of the warmest since 1950; included in the top 10 warmest 1, 3, 5, 10, and 21-day periods since 1950.

Representative Event, Summer Cluster 1, 2027

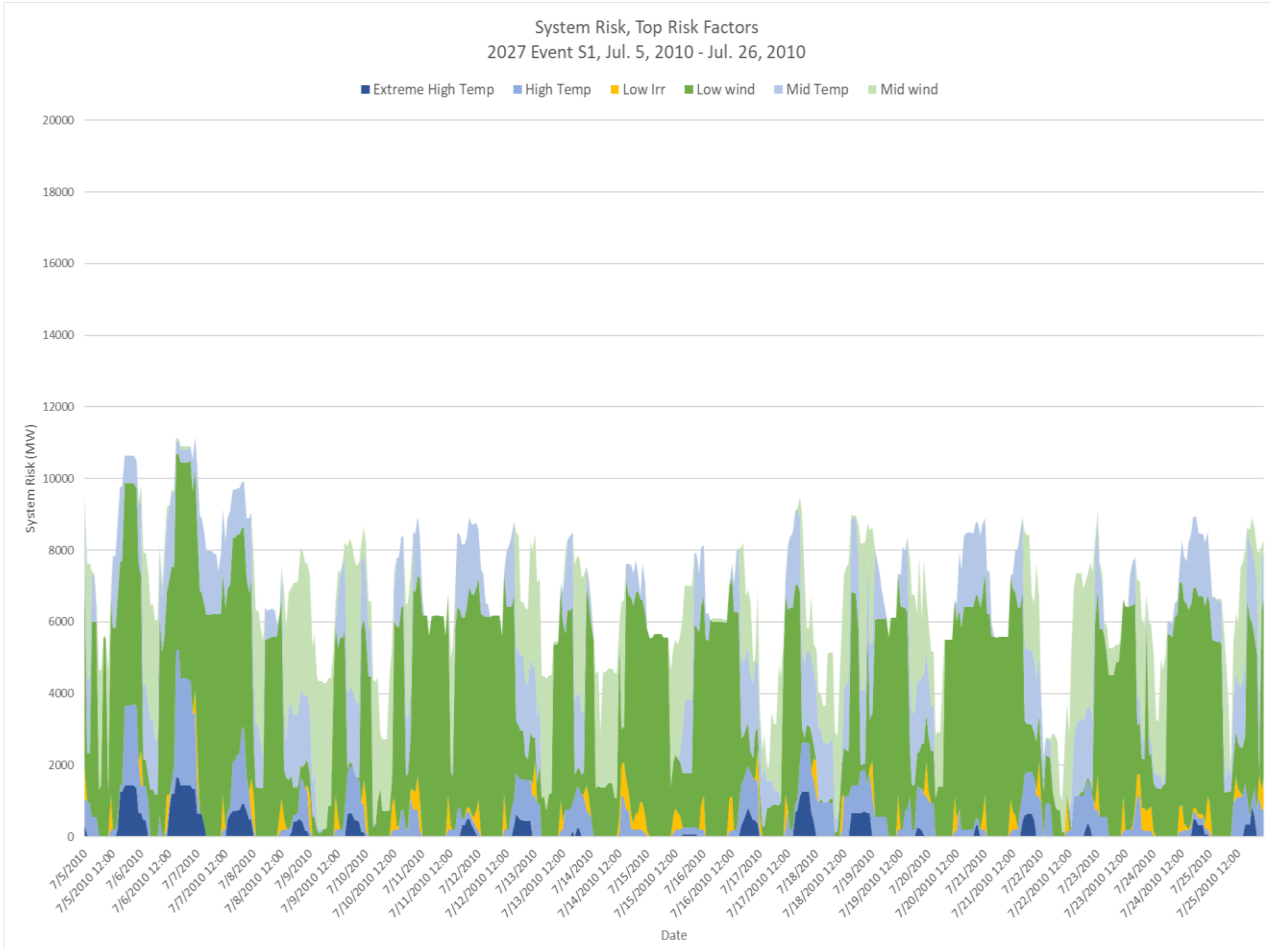
Long Duration Heat Wave Coincident with Very Low Avg. Winds

Risk Summary

Top 3 Risks	Total Risk	Impacted Resources
Low Wind (<6 m/s)	47%	Wind Offshore (33%) Wind Onshore (14%)
Mid Wind (6-12 m/s)	16%	Wind Offshore (16%) Wind Onshore (3%)
Mid Temp (up to ~95F)	14%	CC (11%) GT (3%)

System Risk – Top Risk Factors*

*(*not all risk factors are included in plot below, only most significant risks)*



Representative Event, Summer Cluster 2, 2027

Sustained High Temps Coincident with Very Low Avg. Winds and Solar

Event Description

Cluster: Summer 2 (51 of 147 events)

Event Ranking: 41 (of 147)

Date: Aug. 17 – Sep. 7, 1973

Avg. System Risk: 7,916 MW

Max System Risk: 16,919 MW

Peak Load: 24,865 MW

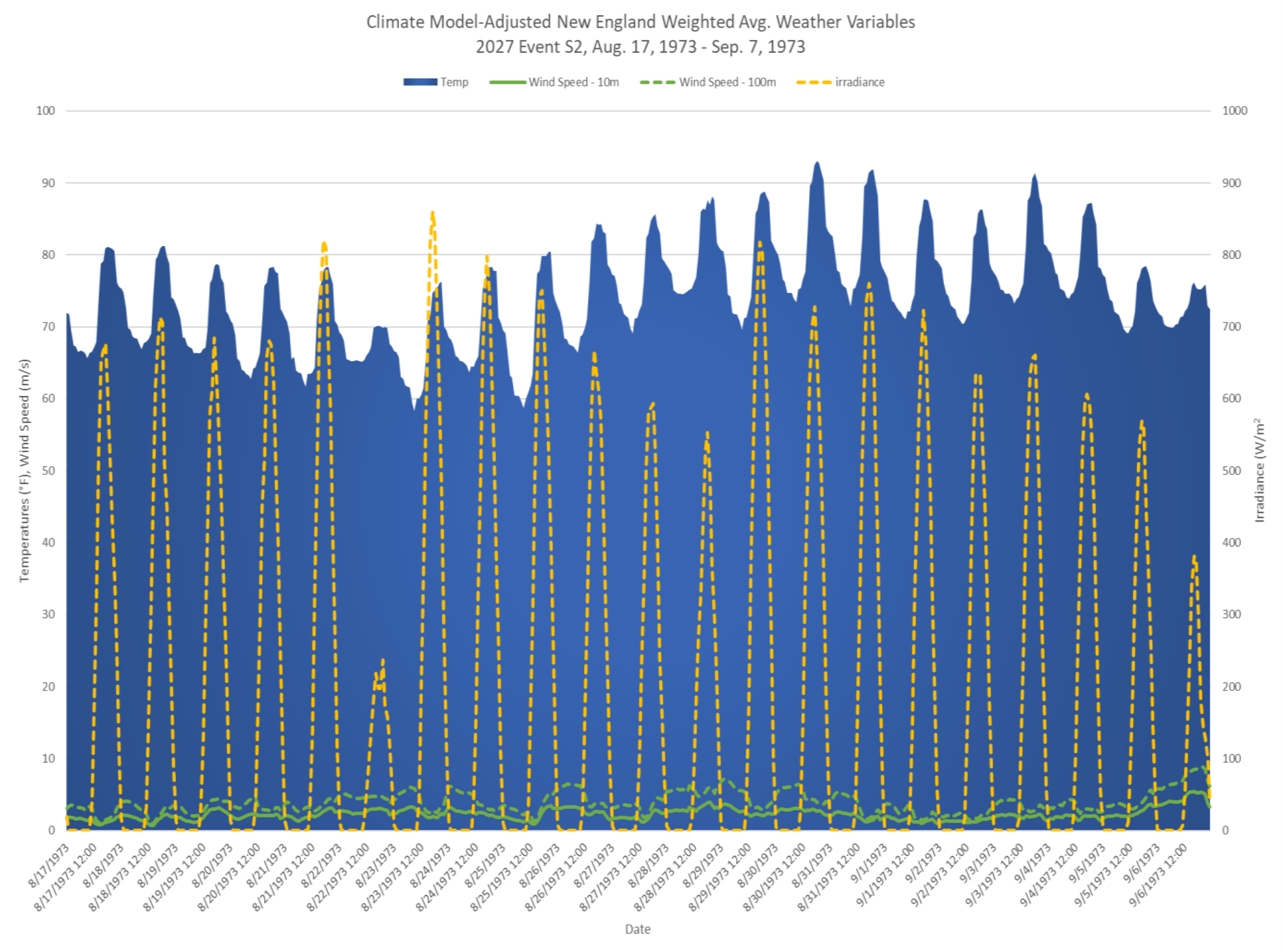
Total Energy Demand: 8.02 TWh

Min/Mean/Max (°F): 58.3/74.4/93.0

Mean 100m Wind Speed (m/s): 3.9

Mean Irradiance (W/m²): 206.5

Weather Conditions



Representative Event, Summer Cluster 2, 2027

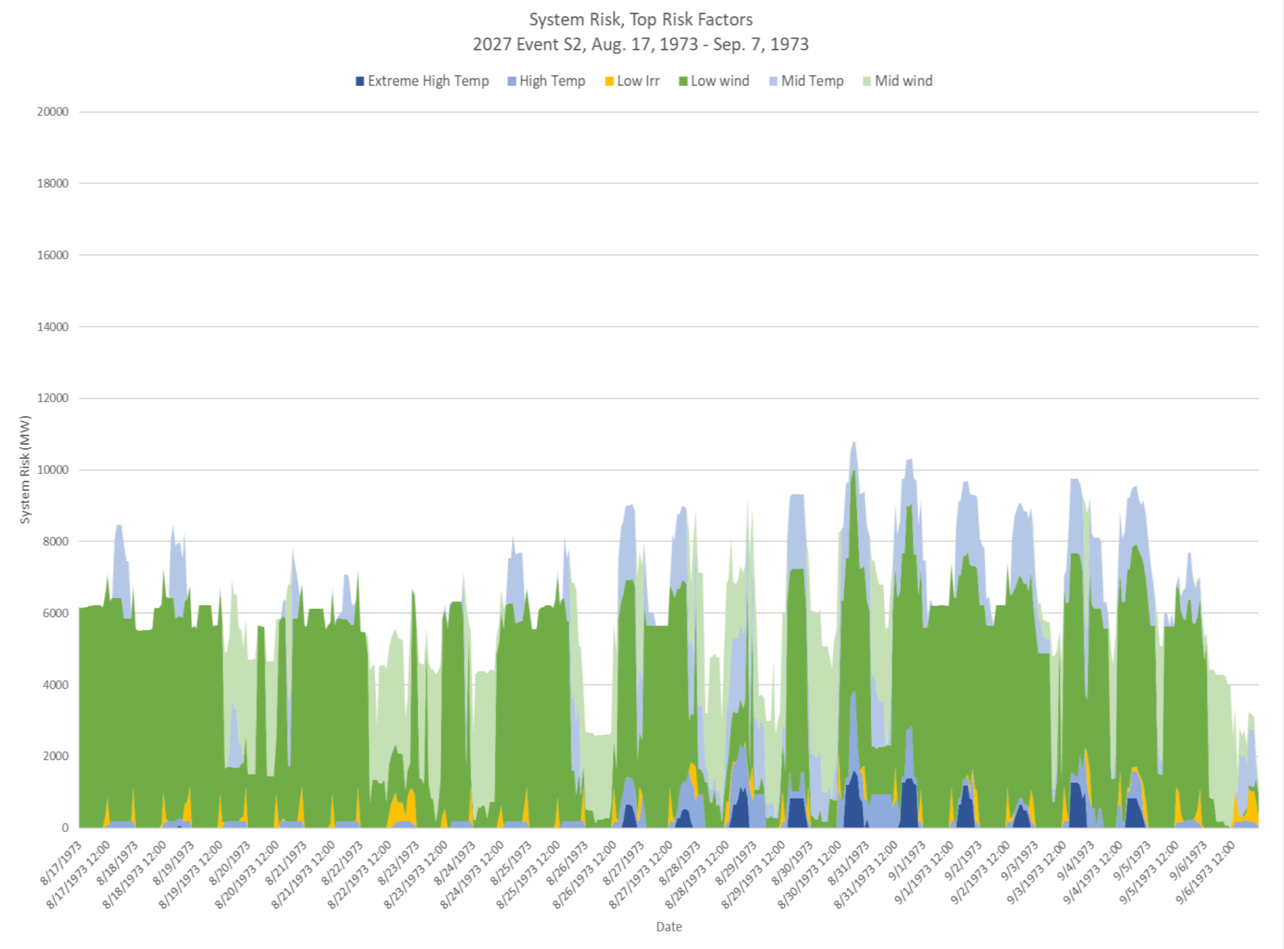
Sustained High Temps Coincident with Very Low Avg. Winds and Solar

Risk Summary

Top 3 Risks	Total Risk	Impacted Resources
Low Wind (<6 m/s)	53%	Wind Offshore (37%) Wind Onshore (16%)
Mid Wind (6-12 m/s)	14%	Wind Offshore (12%) Wind Onshore (2%)
Mid Temp (up to ~95F)	10%	CC (8%) GT (2%)

System Risk – Top Risk Factors*

*(*not all risk factors are included in plot below, only most significant risks)*



Representative Event, Summer Cluster 3, 2027

Moderate Summer Temps Coincident with Very Low Avg. Solar and Wind Drought

Event Description

Cluster: Summer 3 (7 of 147 events)

Event Ranking: 88 (of 147)

Date: Jul. 28 – Aug. 18, 2008

Avg. System Risk: 7,598 MW

Max System Risk: 10,544 MW

Peak Load: 20,135 MW

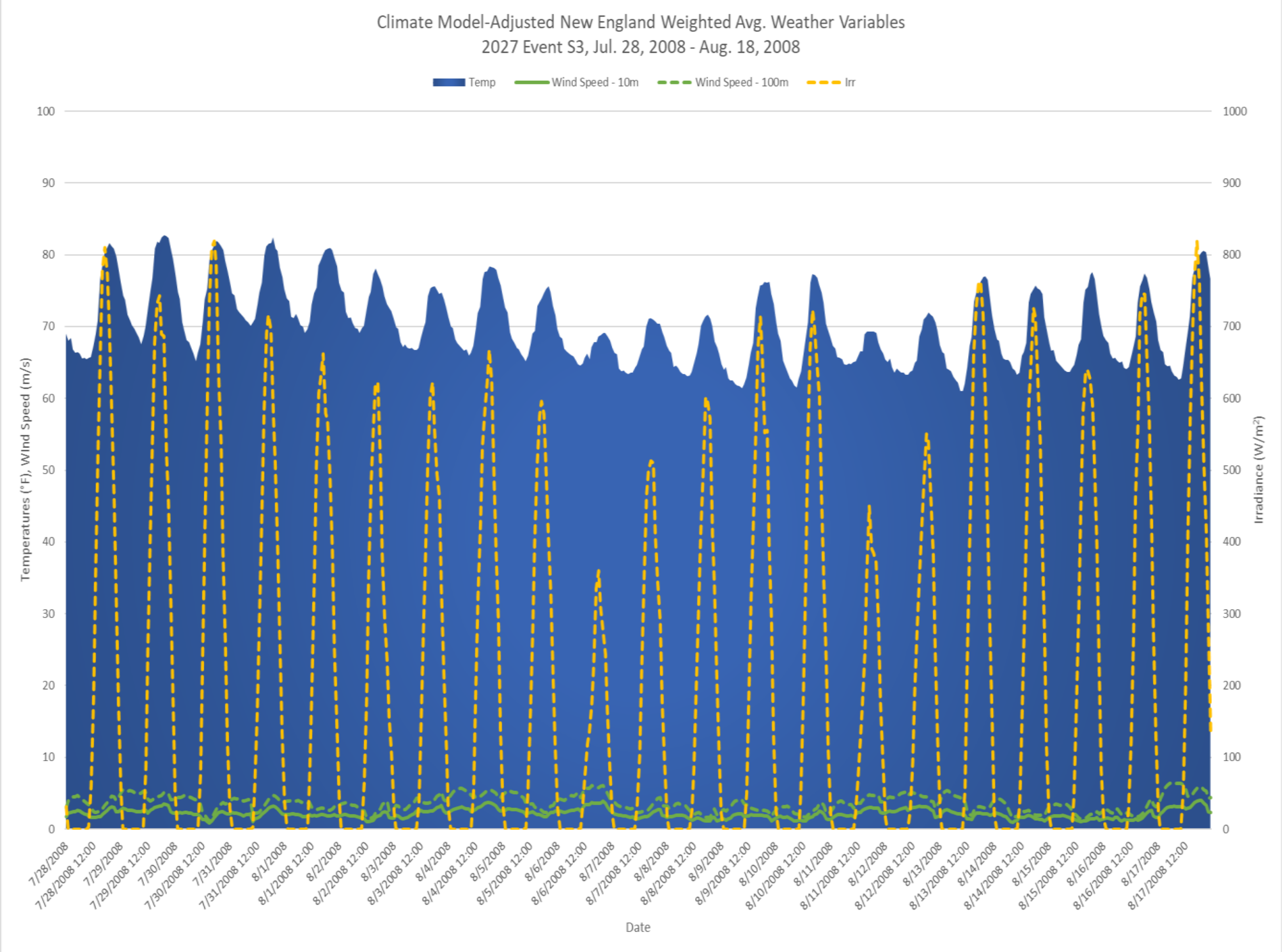
Total Energy Demand: 7.02 TWh

Min/Mean/Max(°F): 61.0/70.2/82.7

Mean 100m Wind Speed (m/s): 3.6

Mean Irradiance (W/m²): 214.7

Weather Conditions



Representative Event, Summer Cluster 3, 2027

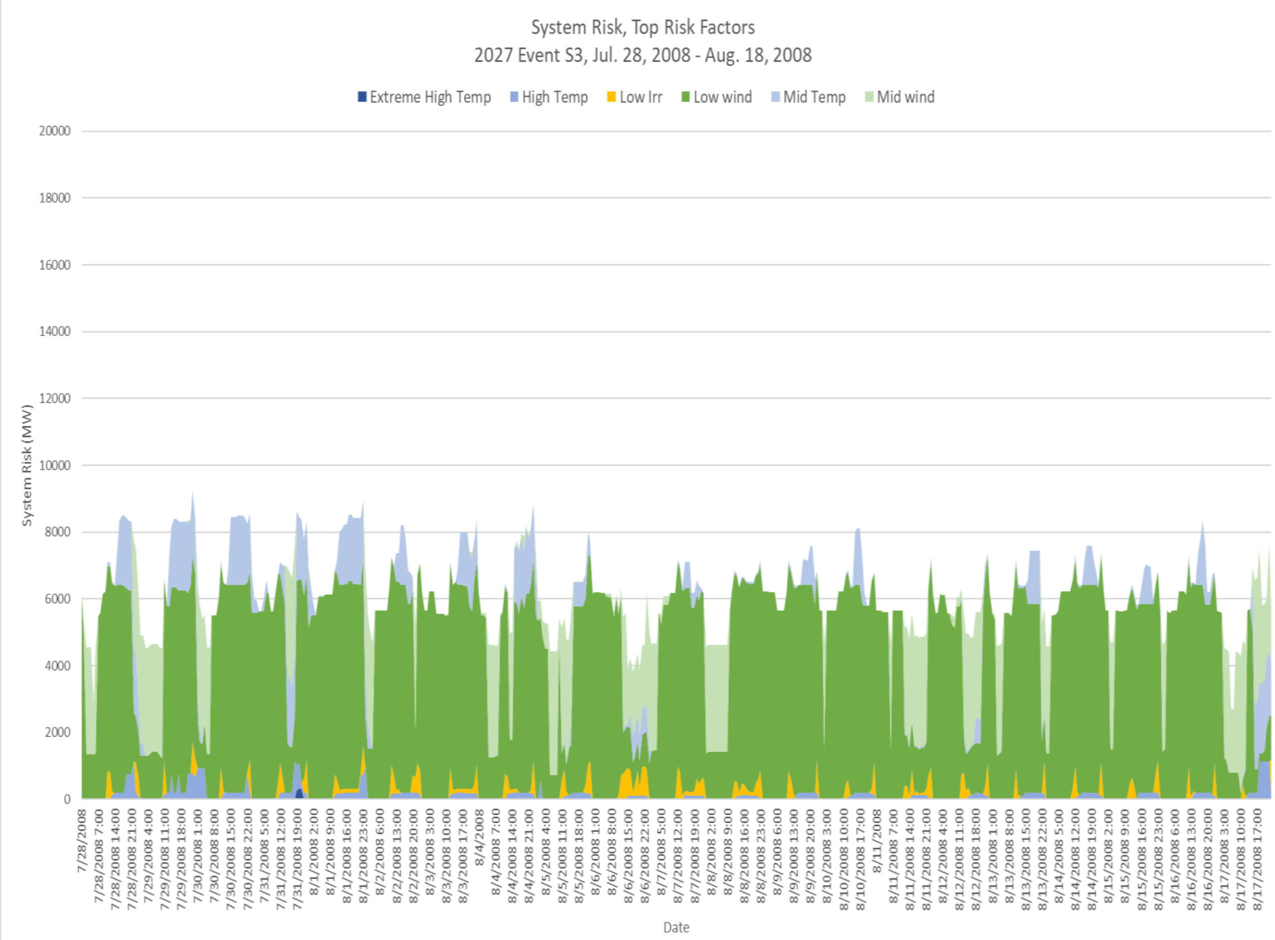
Moderate Summer Temps Coincident with Very Low Avg. Solar and Wind Drought

Risk Summary

Top 3 Risks	Total Risk	Impacted Resources
Low Wind (<6 m/s)	62%	Wind Offshore (44%) Wind Onshore (18%)
Mid Wind (6-12 m/s)	10%	Wind Offshore (9%) Wind Onshore (1%)
Low Temp (up to ~77F)	7%	CC (6%) GT (1%)

System Risk – Top Risk Factors*

*(*not all risk factors are included in plot below, only most significant risks)*



REVIEW OF SELECTED EVENTS, 2032

Events selected based on highest average system risk in each cluster

Representative Event, Winter Cluster 1, 2032

Long-Duration Cold Wave Coincident With Low Avg. Winds and Solar

Event Description

Cluster: Winter 1 (includes 10 of 147 events)

Event Ranking: 1 (of 147 events)

Date: Jan 22 – Feb 12, 1961

Avg. System Risk: 9,691 MW

Max System Risk: 23,215 MW

Peak Load: 22,959 MW

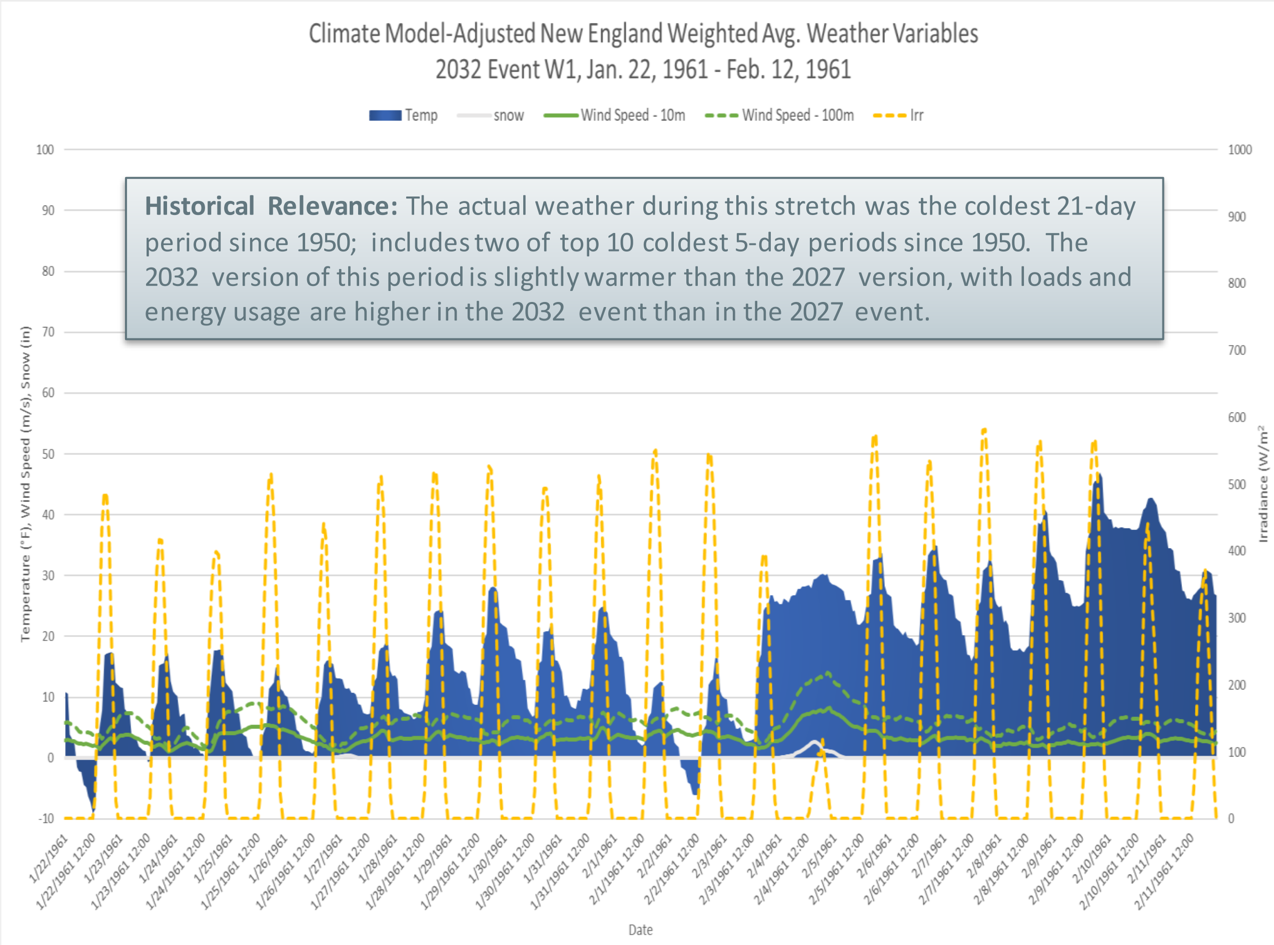
Total Energy Demand: 8.93 TWh

Min/Mean/Max (°F): -9.2/17.6/47.0

Mean 100m Wind Speed (m/s): 6.0

Mean Irradiance (W/m²): 118.8

Key Weather Variables



Representative Event, Winter Cluster 1, 2032

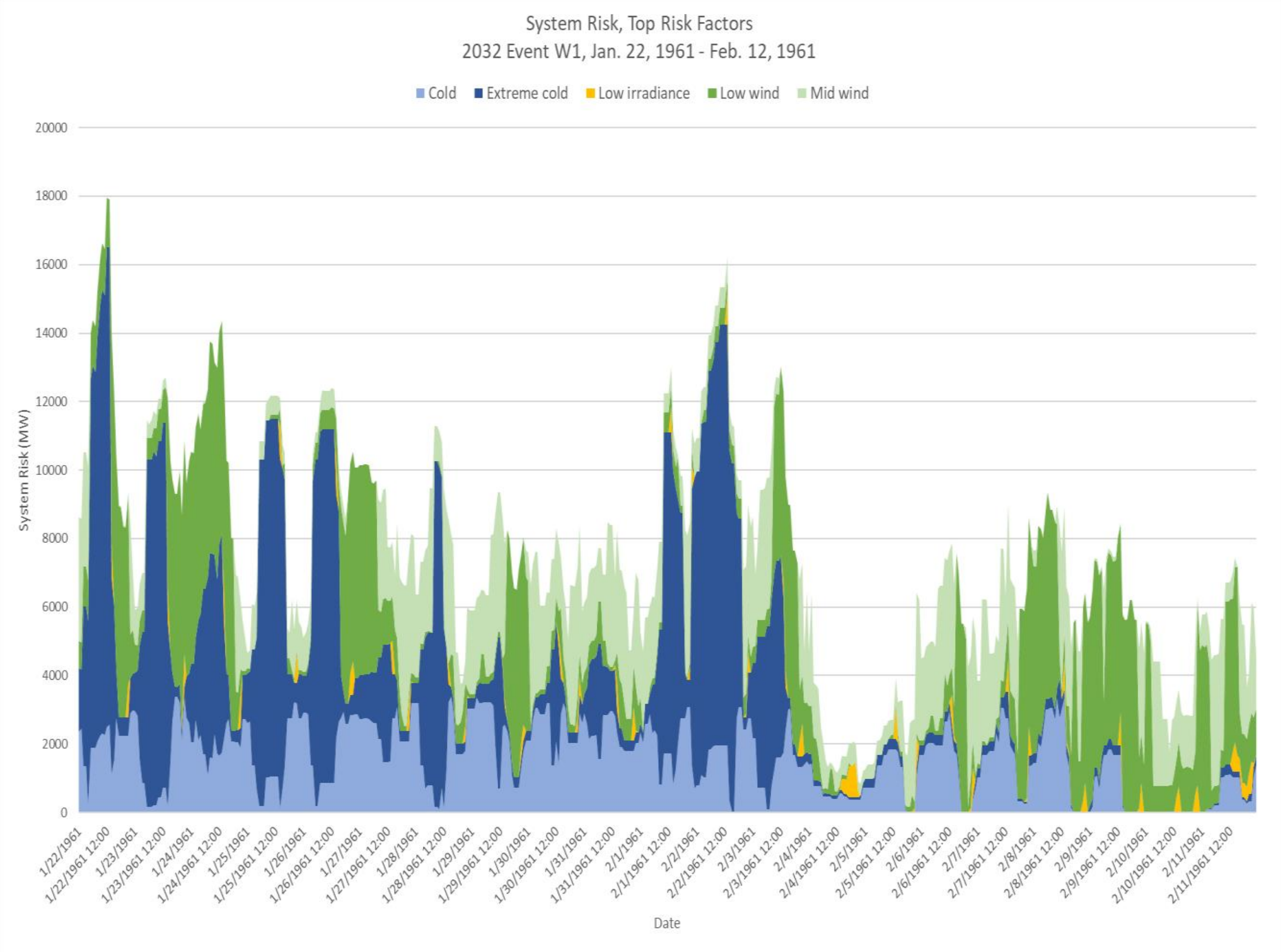
Long-Duration Cold Wave Coincident With Low Avg. Winds and Solar

Risk Summary

Top 3 Risks	Total Risk	Impacted Resources
Extreme Cold (<10F)	28%	CC (13%) GT (4%) Wind Offshore (8%) Misc. (3%)
Cold (10-30F)	18%	CC (13%) GT (3%) ST (2%)
Low Wind (<6 m/s)	23%	Wind Offshore (14%) Wind Onshore (9%)

System Risk – Top Risk Factors*

*(*not all risk factors are included in plot below, only most significant risks)*



Representative Event, Winter Cluster 2, 2032

Short Duration Cold Snap Coincident with Low Avg. Winds and Very Low Avg. Solar

Event Description

Cluster: Winter 2 (27 of 147 events)

Event Ranking: 11 (of 147)

Date: Jan 8 – Jan 29, 1971

Avg. System Risk: 8,834 MW

Max System Risk: 19,985 MW

Peak Load: 23,793 MW

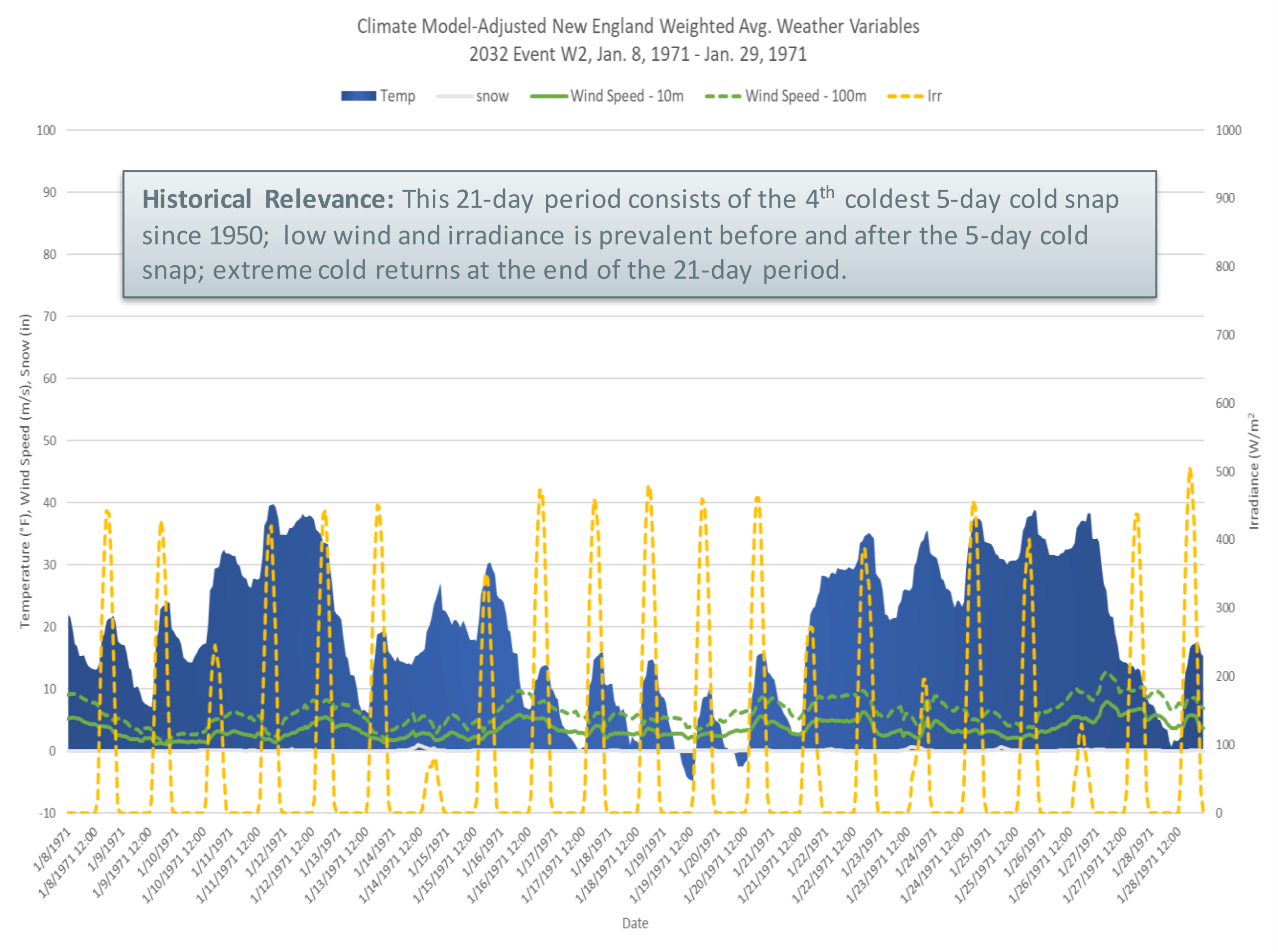
Total Energy Demand: 8.88 TWh

Min/Mean/Max(°F): -4.9/19.3/39.8

Mean 100m Wind Speed (m/s): 6.2

Mean Irradiance (W/m²): 89.8

Weather Conditions



Representative Event, Winter Cluster 2, 2032

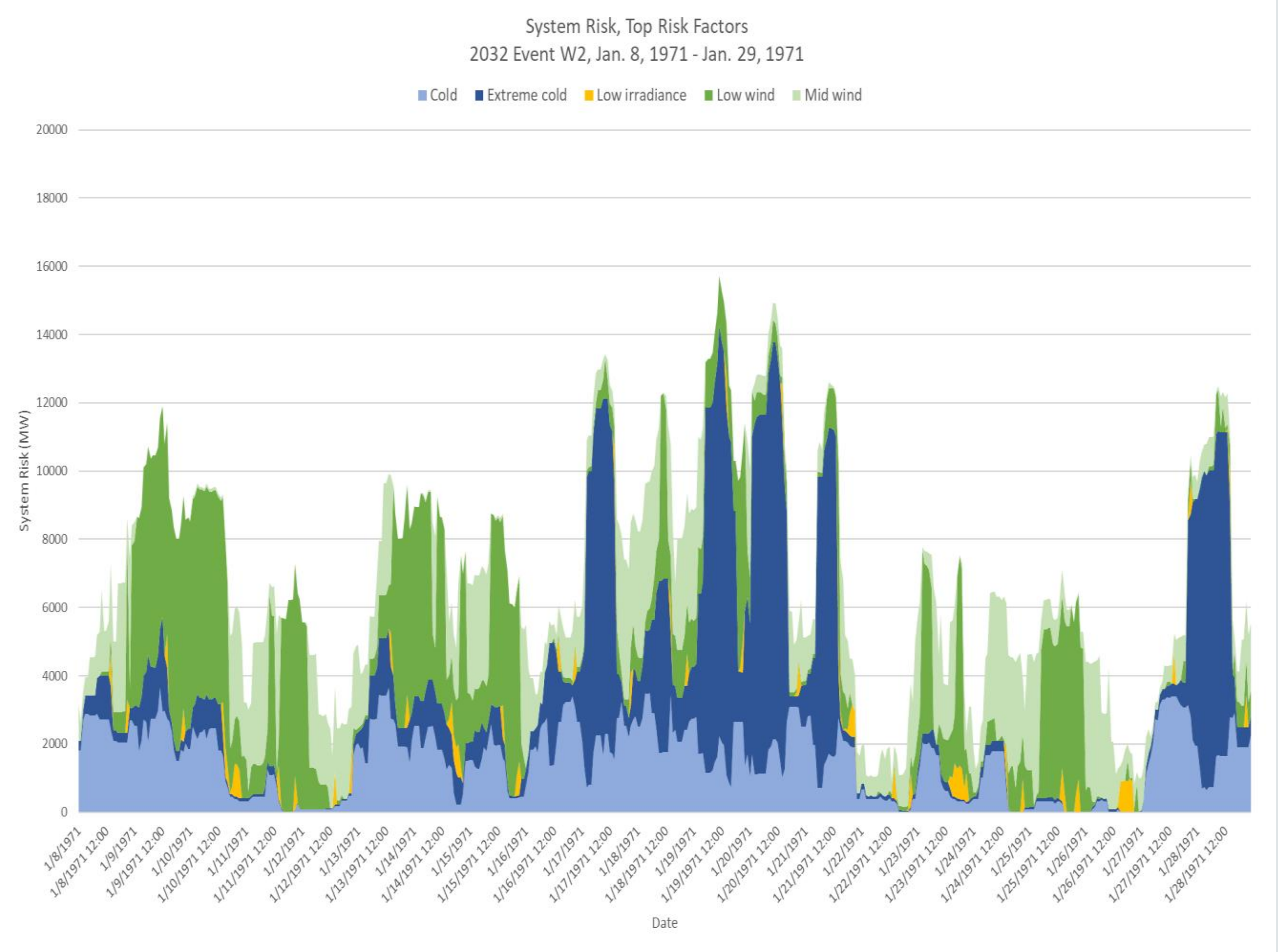
Short Duration Cold Snap Coincident with Low Avg. Winds and Very Low Avg. Solar

Risk Summary

Top 3 Risks	Total Risk	Impacted Resources
Low Wind (<6 m/s)	34%	Wind Offshore (23%) Wind Onshore (11%)
Mid Wind (6-12 m/s)	17%	Wind Offshore (13%) Wind Onshore (4%)
Cold Temp (10-30F)	22%	CC (17%) GT (4%) ST (1%)

System Risk – Top Risk Factors*

*(*not all risk factors are included in plot below, only most significant risks)*



Representative Event, Winter Cluster 3, 2032

Consistently Low Winter Temps Coincident With Low Avg. Winds and Very Low Avg. Solar

Event Description

Cluster: Winter 3 (26 of 147 events)

Event Ranking: 27 (of 147)

Date: Jan. 15 – Feb. 5, 2011

Avg. System Risk: 8,389 MW

Max System Risk: 20,513 MW

Peak Load: 23,816 MW

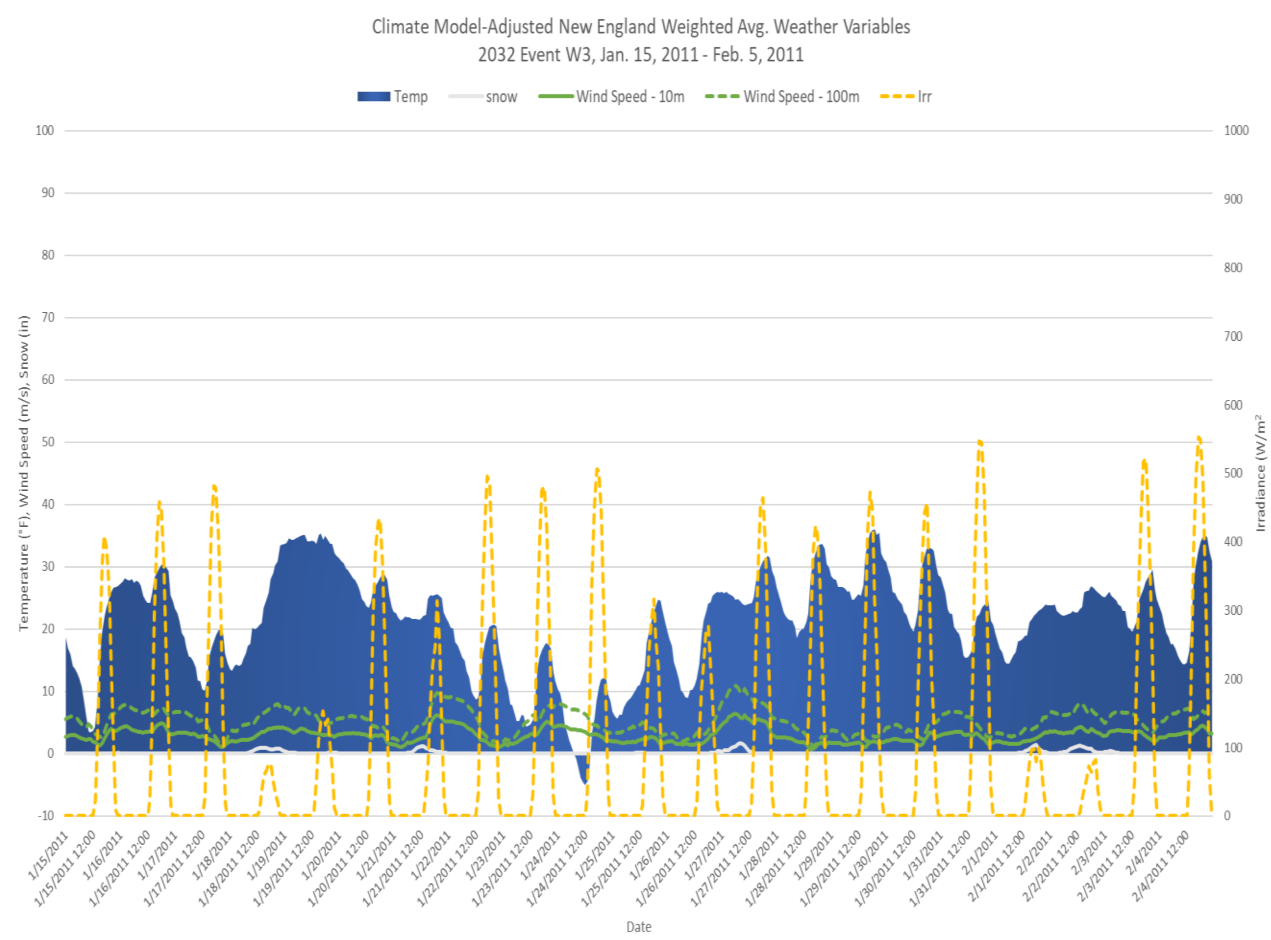
Total Energy Demand: 8.71 TWh

Min/Mean/Max(°F): -5/21.2/36.0

Mean 100m Wind Speed (m/s): 5.2

Mean Irradiance (W/m²): 90.7

Weather Conditions



Representative Event, Winter Cluster 3, 2032

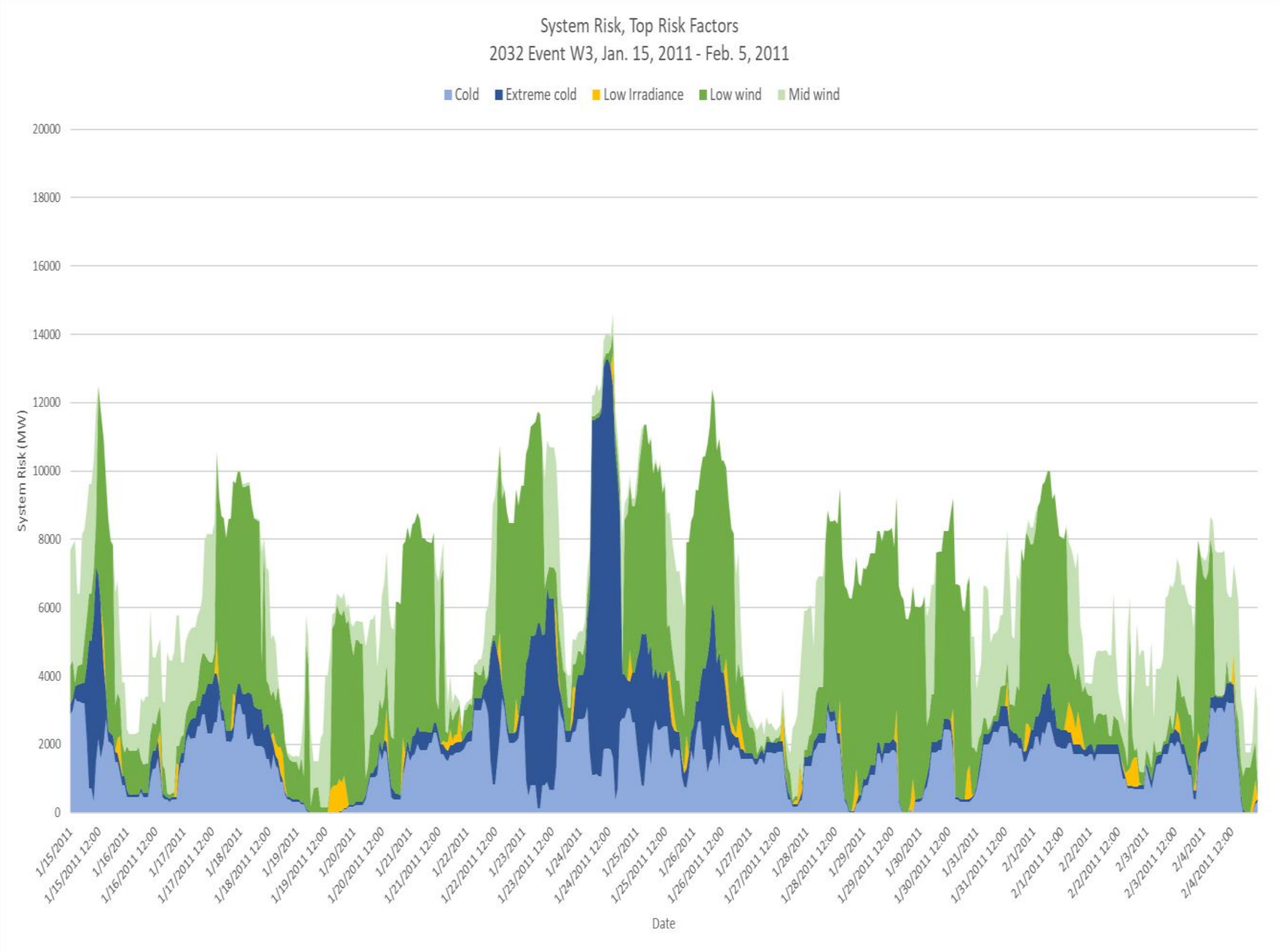
Consistently Low Winter Temps Coincident With Low Avg. Winds and Very Low Avg. Solar

Risk Summary

Top 3 Risks	Total Risk	Impacted Resources
Cold Temp (10-30F)	20%	CC (15%) GT (4%) ST (1%)
Low Wind (<6 m/s)	36%	Wind Offshore (24%) Wind Onshore (12%)
Mid Wind (6-12 m/s)	17%	Wind Offshore (13%) Wind Onshore (4%)

System Risk – Top Risk Factors*

*(*not all risk factors are included in plot below, only most significant risks)*



Representative Event, Summer Cluster 1, 2032

Long Duration Heat Wave Coincident with Very Low Avg. Winds

Event Description

Cluster: Summer 1 (46 of 147 events)

Event Ranking: 19 (of 147)

Date: Jul 28 – Aug 18, 1988

Avg. System Risk: 8,572 MW

Max System Risk: 16,755 MW

Peak Load: 25,493 MW

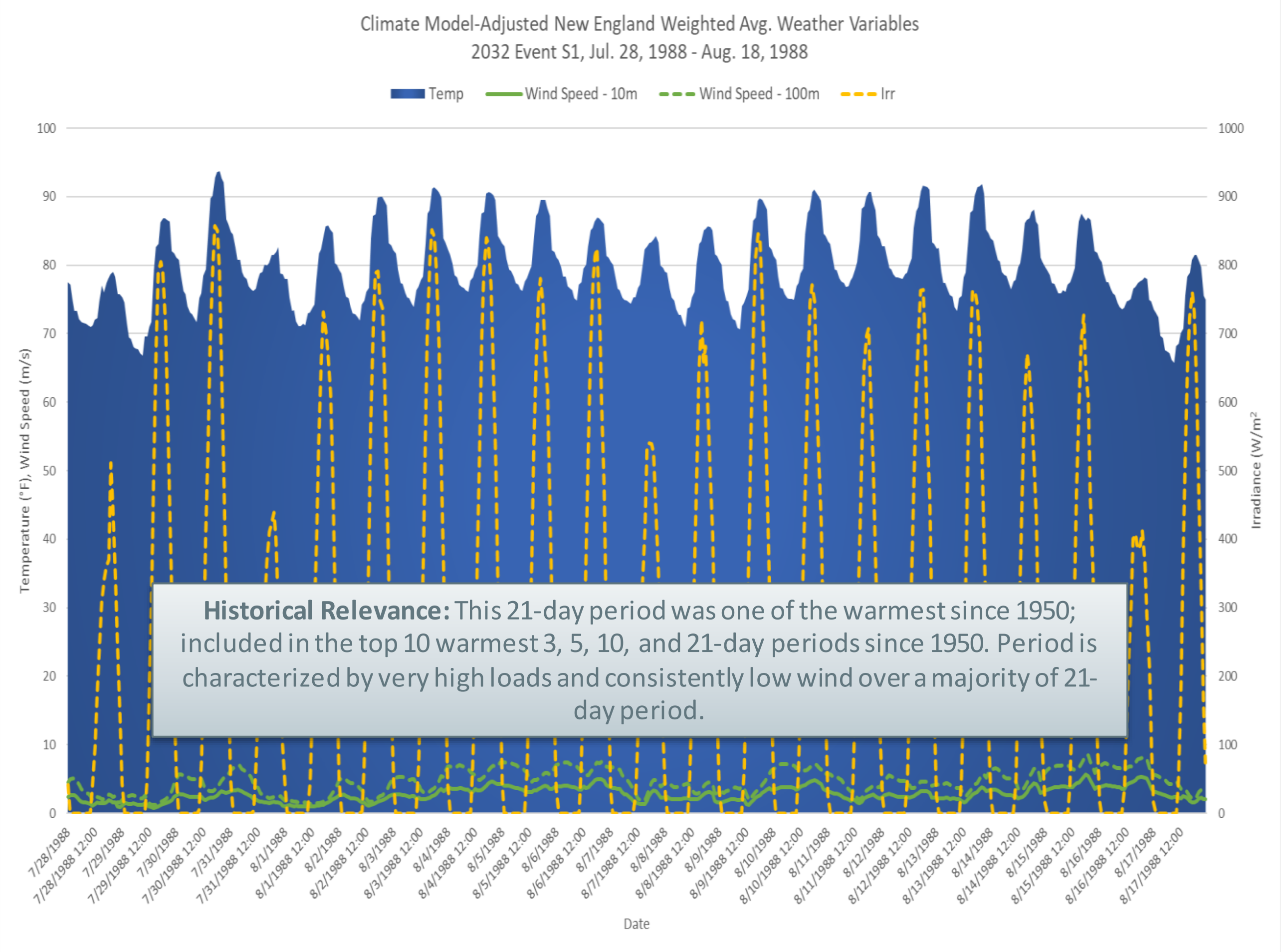
Total Energy Demand: 9.29 TWh

Min/Mean/Max (°F): 65.7/79.8/93.7

Mean 100m Wind Speed (m/s): 4.7

Mean Irradiance (W/m²): 238.7

Weather Conditions



Representative Event, Summer Cluster 1, 2032

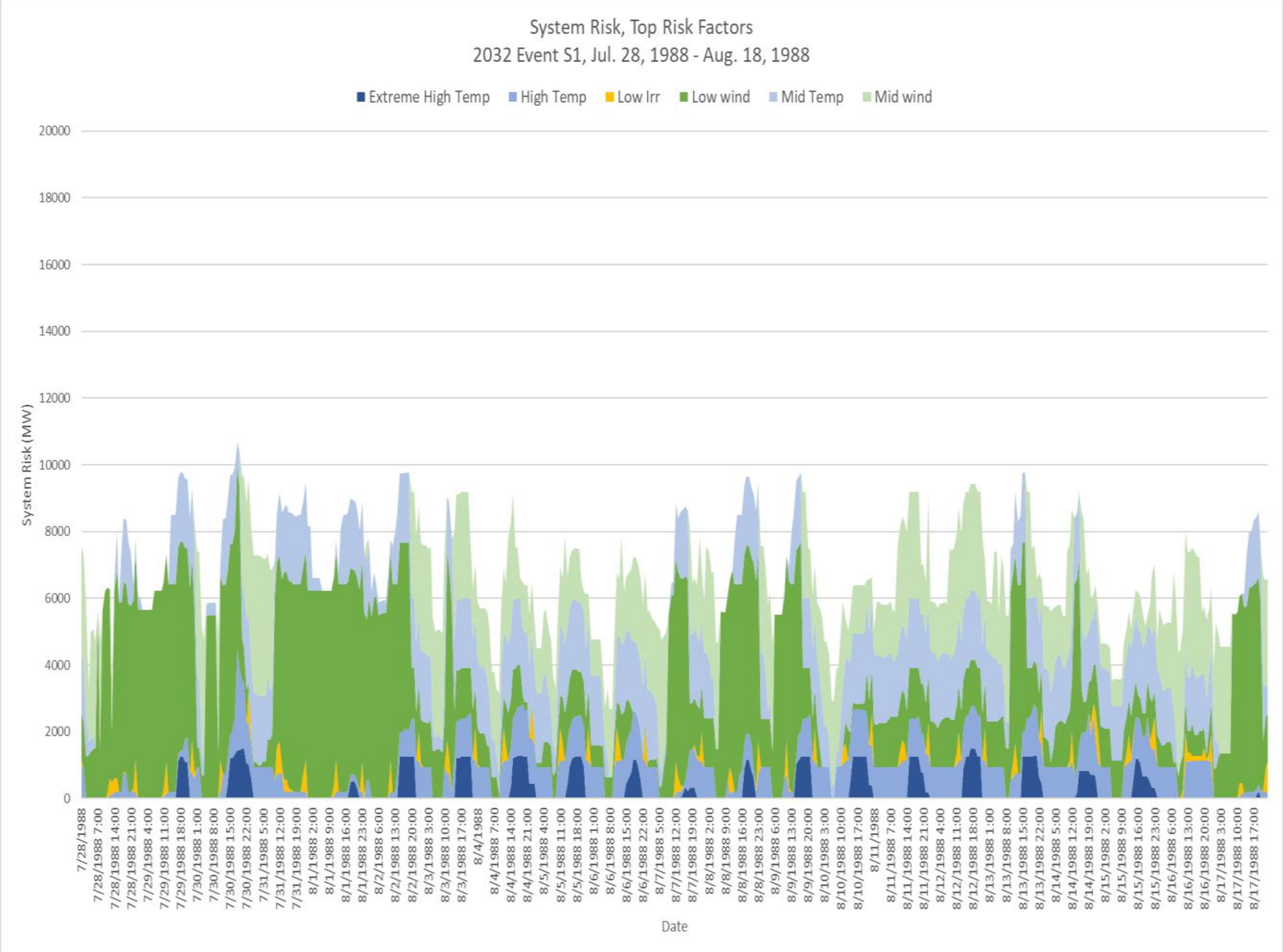
Long Duration Heat Wave Coincident with Very Low Avg. Winds

Risk Summary

Top 3 Risks	Total Risk	Impacted Resources
Low Wind (<6 m/s)	36%	Wind Offshore (21%) Wind Onshore (15%)
Mid Wind (6-12 m/s)	18%	Wind Offshore (16%) Wind Onshore (2%)
Mid Temp (up to ~95F)	20%	CC (16%) GT (4%)

System Risk – Top Risk Factors*

*(*not all risk factors are included in plot below, only most significant risks)*



Representative Event, Summer Cluster 2, 2032

Sustained High Temps Coincident with Very Low Avg. Winds and Solar

Event Description

Cluster: Summer 2 (38 of 147 events)

Event Ranking: 53 (of 147)

Date: Aug. 17 – Sep. 7, 1973

Avg. System Risk: 8,082 MW

Max System Risk: 16,881 MW

Peak Load: 25,266 MW

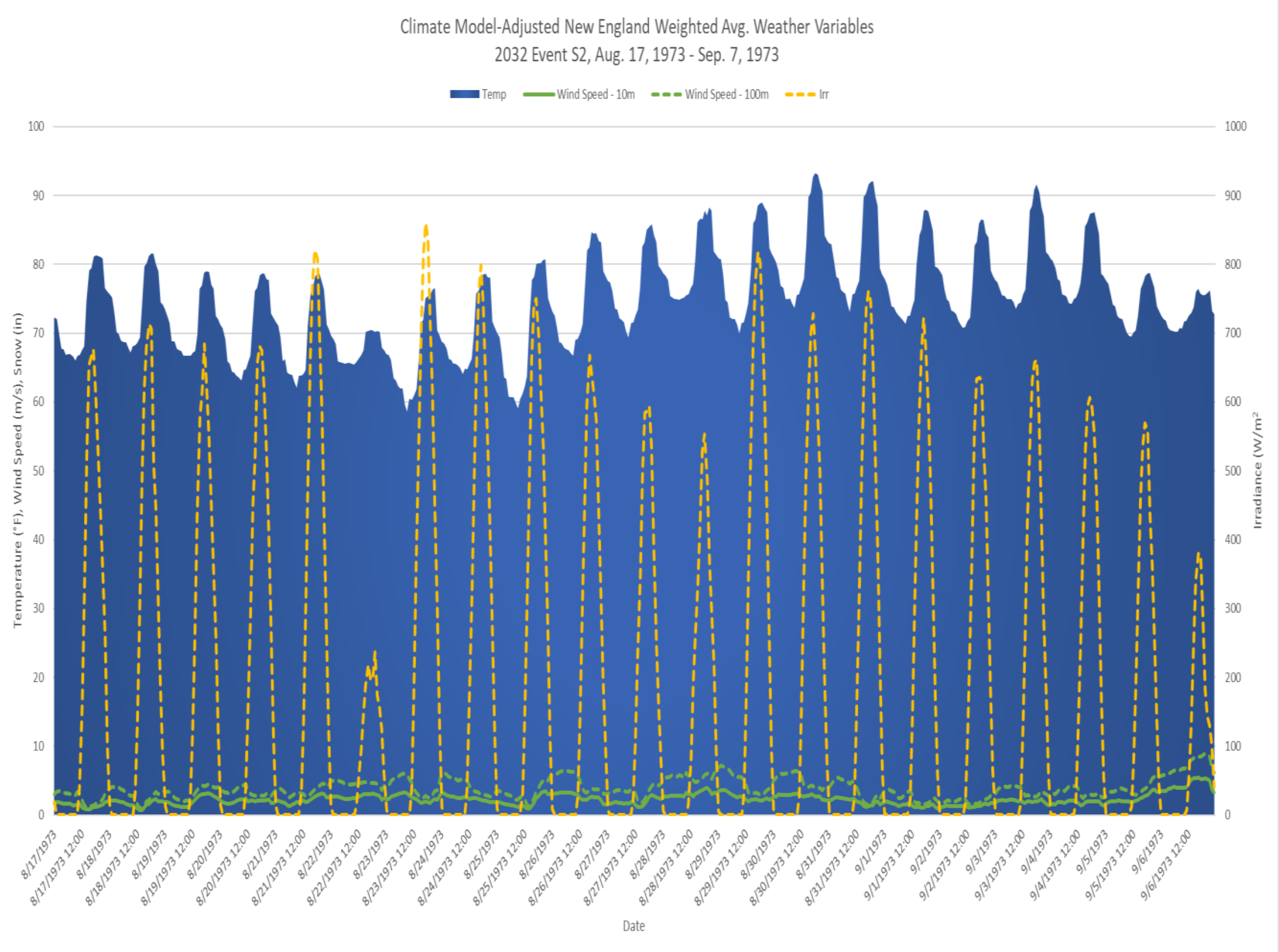
Total Energy Demand: 8.23 TWh

Min/Mean/Max (°F): 58.7/74.7/93.3

Mean 100m Wind Speed (m/s): 3.9

Mean Irradiance (W/m²): 206.5

Weather Conditions



Representative Event, Summer Cluster 2, 2032

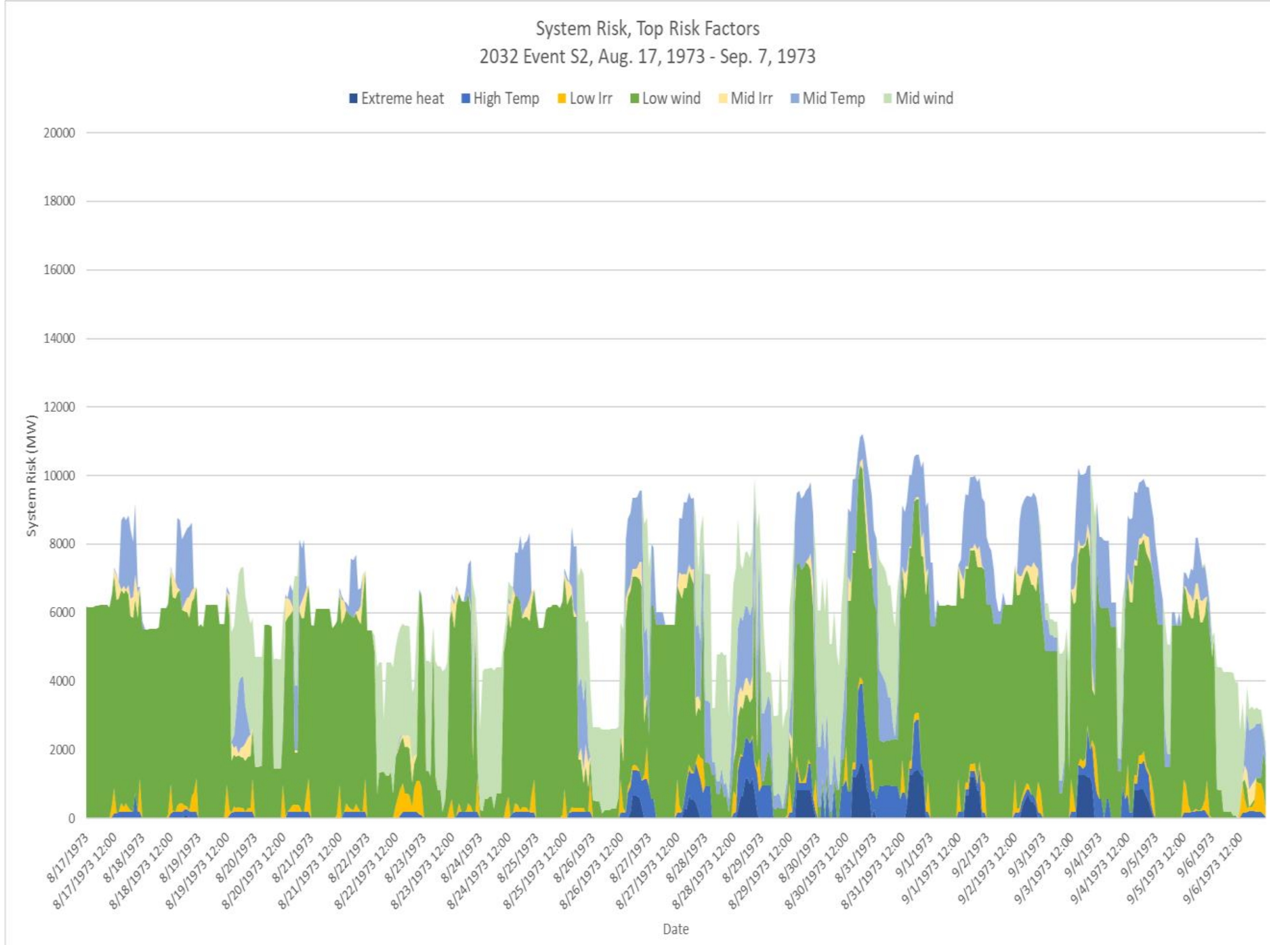
Sustained High Temps Coincident with Very Low Avg. Winds and Solar

Risk Summary

Top 3 Risks	Total Risk	Impacted Resources
Low Wind (<6 m/s)	53%	Wind Offshore (37%) Wind Onshore (16%)
Mid Wind (6-12 m/s)	14%	Wind Offshore (12%) Wind Onshore (2%)
Mid Temp (up to ~95F)	11%	CC (9%) GT (2%)

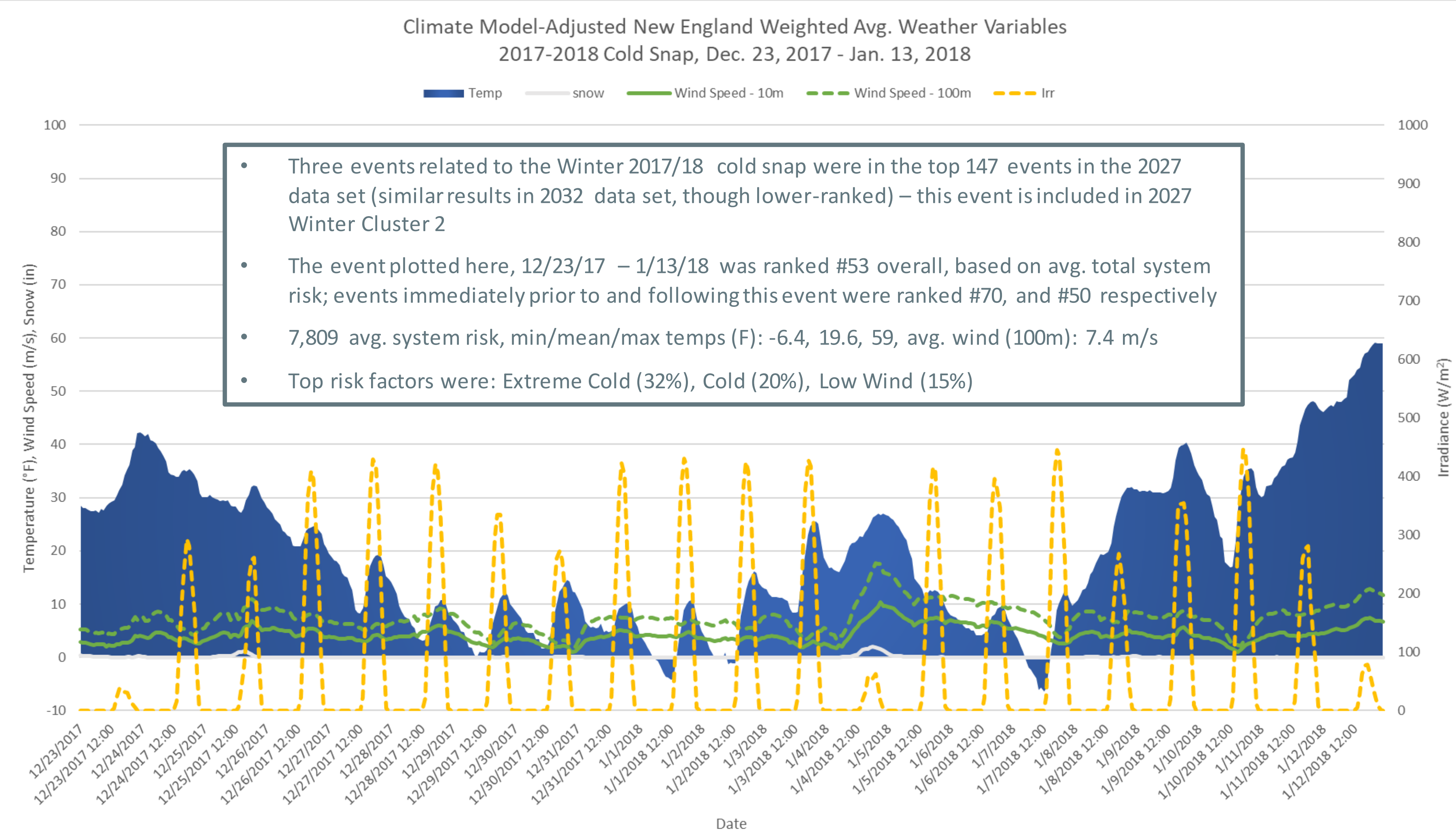
System Risk – Top Risk Factors*

*(*not all risk factors are included in plot below, only most significant risks)*



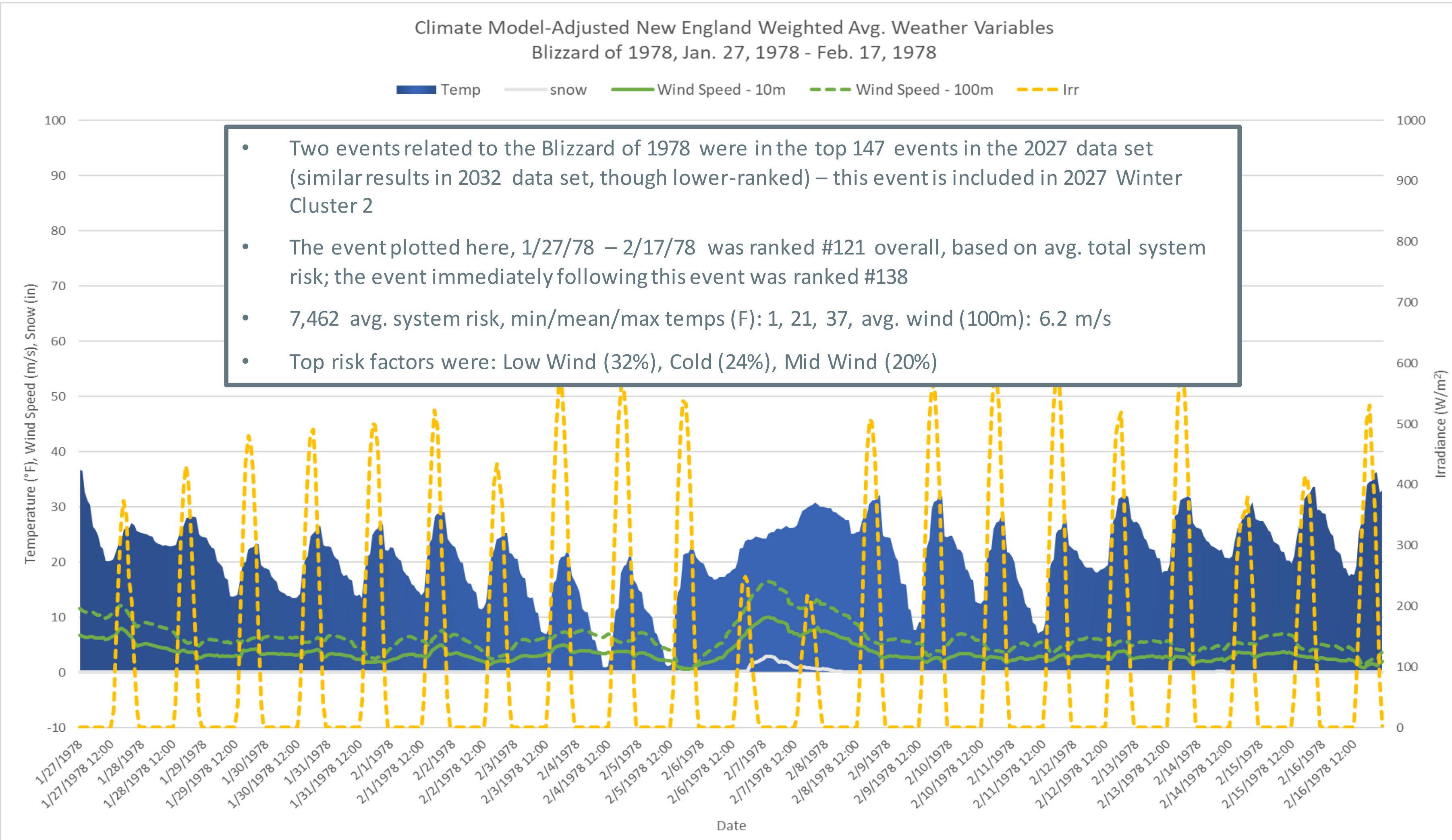
HISTORICAL EVENTS OF INTEREST

Winter 2017/18 Cold Snap – Summary of Conditions and Risks



- Three events related to the Winter 2017/18 cold snap were in the top 147 events in the 2027 data set (similar results in 2032 data set, though lower-ranked) – this event is included in 2027 Winter Cluster 2
- The event plotted here, 12/23/17 – 1/13/18 was ranked #53 overall, based on avg. total system risk; events immediately prior to and following this event were ranked #70, and #50 respectively
- 7,809 avg. system risk, min/mean/max temps (F): -6.4, 19.6, 59, avg. wind (100m): 7.4 m/s
- Top risk factors were: Extreme Cold (32%), Cold (20%), Low Wind (15%)

Blizzard of 1978 – Summary of Conditions and Risks



- Two events related to the Blizzard of 1978 were in the top 147 events in the 2027 data set (similar results in 2032 data set, though lower-ranked) – this event is included in 2027 Winter Cluster 2
- The event plotted here, 1/27/78 – 2/17/78 was ranked #121 overall, based on avg. total system risk; the event immediately following this event was ranked #138
- 7,462 avg. system risk, min/mean/max temps (F): 1, 21, 37, avg. wind (100m): 6.2 m/s
- Top risk factors were: Low Wind (32%), Cold (24%), Mid Wind (20%)

Next Steps

- Incorporate feedback into final selection of events for further study
- Perform categorical branching to selected events (Part of Step 2)
  - Add scenarios to events – LNG, fuel inventory, imports, etc.
- Perform outage draw (Part of Step 2)
  - To incorporate random forced and maintenance outages
- Perform energy adequacy assessment (Step 3) using 21-day energy assessment tool

Preliminary Stakeholder Schedule

**Schedule is subject to change based on modeling progress*

Stakeholder Committee and Date	Scheduled Project Milestone
Reliability Committee February 15, 2022	Initial presentation
Reliability Committee March 15, 2022	Summary of EPRI's historical weather analysis deliverables and discussion of macro assumptions
Reliability Committee May 17, 2022	Share results of Step 1 (Extreme Weather Modeling) report. Review and discuss Step 2 (Risk Model Development and Scenario Generation) activities
Reliability Committee July 19, 2022	Review progress on Step 2 activities
Reliability Committee September 20, 2022	Continue to gather feedback with respect to Step 2 activities
Reliability Committee November 16, 2022	Continue to gather feedback with respect to Step 2 activities
Reliability Committee January 18, 2023	Discuss preliminary results of Step 2 Risk Screening Model
Reliability Committee February 14, 2023	Continued discussion of Step 2 Risk Screening Model results; review categorical branching methodology
Reliability Committee March 14, 2023	Discuss preliminary results of Step 3 (pending modeling progress)

Questions

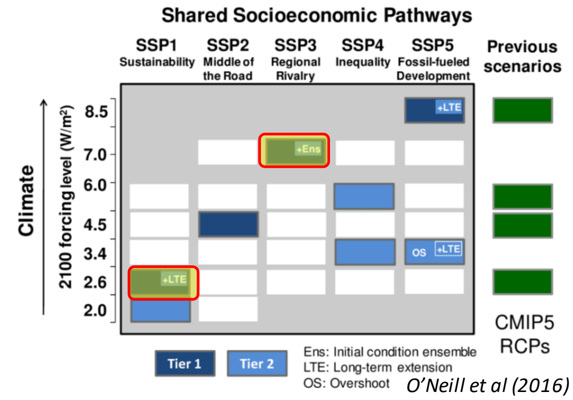
APPENDIX

Additional Reference Slides

Latest Generation CMIP6 Scenario Results Are Used in this Study

New scenarios: updated emission pathways explore a wider range of possible future outcomes than CMIP5

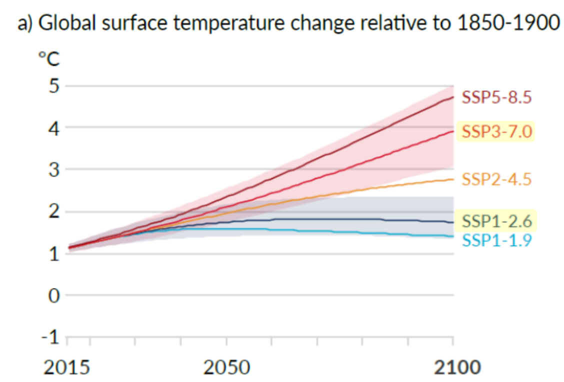
- For this study, EPRI is using two Intergovernmental Panel of Climate Change (IPCC)-selected scenarios
  - SSP1-1.9 compatible with 1.5°C warming
  - **SSP1-2.6** ambitious policy (global CO2 negative by 2075) – “**lower warming scenario**”
  - SSP2-4.5 moderate policy pathway
  - **SSP3-7.0** *NEW* no-policy baseline – **“higher warming scenario”**
  - SSP5-8.5 even higher emissions than CMIP5 RCP8.5



O’Neill et al (2016)

New models: 103 distinct climate models from 49 institutions (vs 59 CMIP5 models)

- EPRI has selected five reputable GCMs that span a range of climate sensitivities*
  - NOAA Geophysical Fluid Dynamics Laboratory: GFDL-ESM4 2.7°C
  - Max Planck Institute (Germany): MPI-ESM1 3.0°C
  - Meteorological Research Institute (Japan): MRI-ESM2 3.1°C
  - Institut Pierre-Simon Laplace (France): IPSL-CM6A 4.6°C
  - UK Met Office: UKESM1 5.4°C

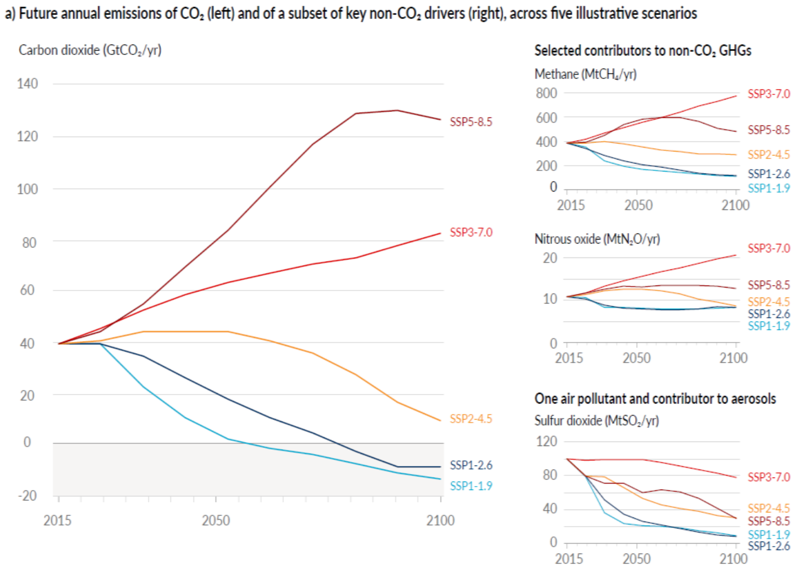


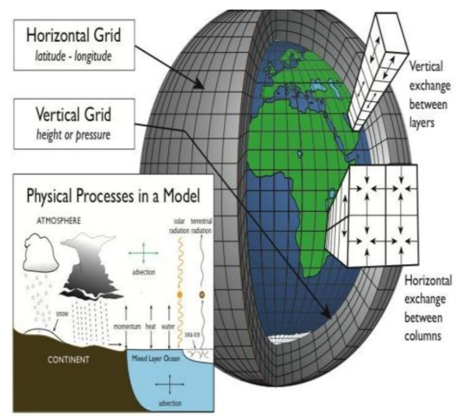
*Equilibrium Climate Sensitivity value (shown for each model above) summarizes a model’s warming response; it reports the total amount of warming from a doubling of preindustrial CO2 concentrations. The 2021 IPCC WGI AR6 best estimate is 3°C, with a very likely range of 2 to 5°C (5-95% range). CMIP6 multimodel mean is 3.7°C (SD 1.1).

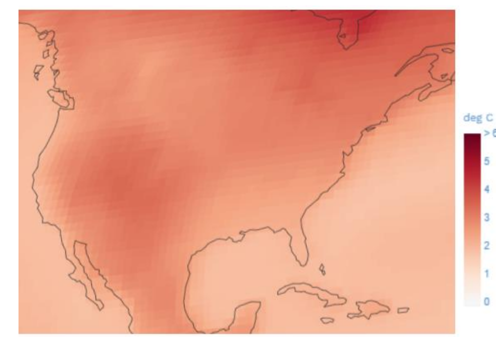
Global Climate Models Translate Greenhouse Gas Scenarios To Climate Outcomes

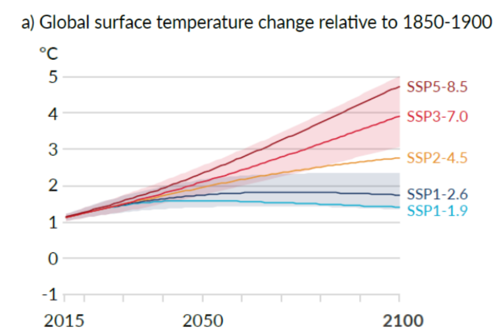
Introduced May 2022 RC Meeting

Standardized Climate "Forcing" Scenarios ⇨ Global Climate Model (GCM) ⇨ Gridded Projection Data









Figures: IPCC WGI AR6 Report (2021) SPM.4 (left) and SPM.8 (bottom right),
GCM schematic by Jablonowski & Limon (2020),
North America CMIP6 ensemble for 2C average warming (IPCC 2021)