

# Extreme Weather and the Grid of the Future

**Justin Sharp, Ph.D.**

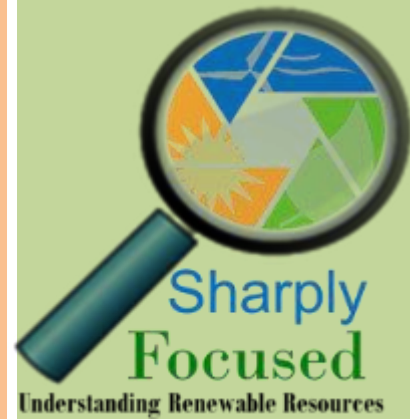
**Collaborators:**

**Josh Novacheck, Marty Schwarz, Zack Tzavelis,  
Grant Buster, Michael Rossol (NREL)**

*Your assumptions are your windows on the world. Scrub them off every once in a while, or the light won't come in.*

*Alan Alda, actor, writer and director*

Klondike Wind Farm. Photo © Justin Sharp



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**Meteorology and Market Design  
For Grid Services Workshop  
Online COVID Edition, June 18, 2020**



# Disclaimer

- Purpose of Presentation
  - To obtain external technical review on methods and analysis and promote robust technical discussion within ESIG community
  - Not to convey findings or conclusions to take away or inform activities
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  - Data, results, conclusions, and interpretations presented have received limited review by technical experts outside NREL
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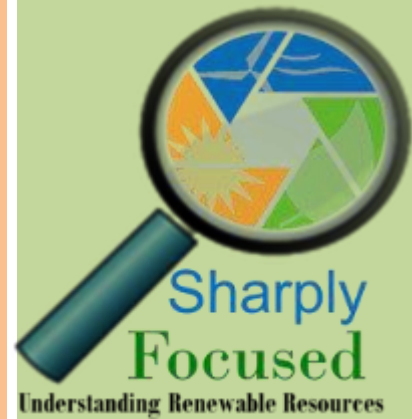
**Material includes unpublished preliminary data and analysis that is subject to change**





# Objectives

- Context: Meteorology and the energy transition
- Provide guidance on important ways the impact of meteorology will change for the grid of the future through referencing a subset of preliminary results from the NREL Tail Events project.

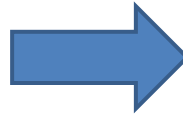
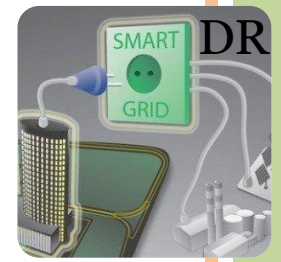


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# The Renewable Energy Transition



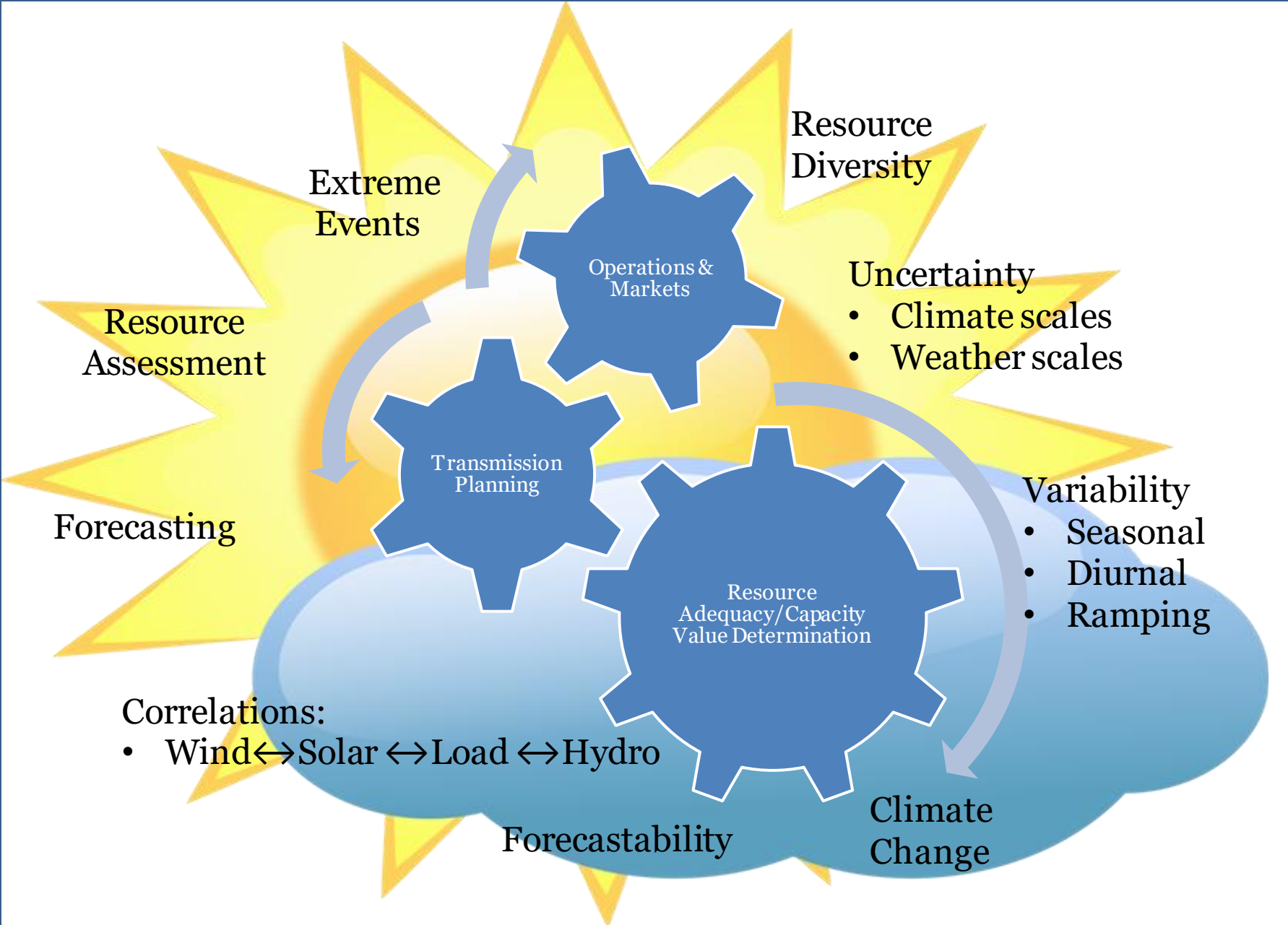
Weather modulated load and generation  
Largely thermal  
Dispatchable  
Centralized  
N-1 contingency  
Lots of inertia but little storage  
Slow to moderate ramping rates



Strong correlation between weather generation  
Weather modulated load and Wx driven response  
Mostly weather driven generation  
More storage but less inertia  
Fast ramping rates  
More distributed  
RE penetration and thus gas use ultimately depends on generation planning.



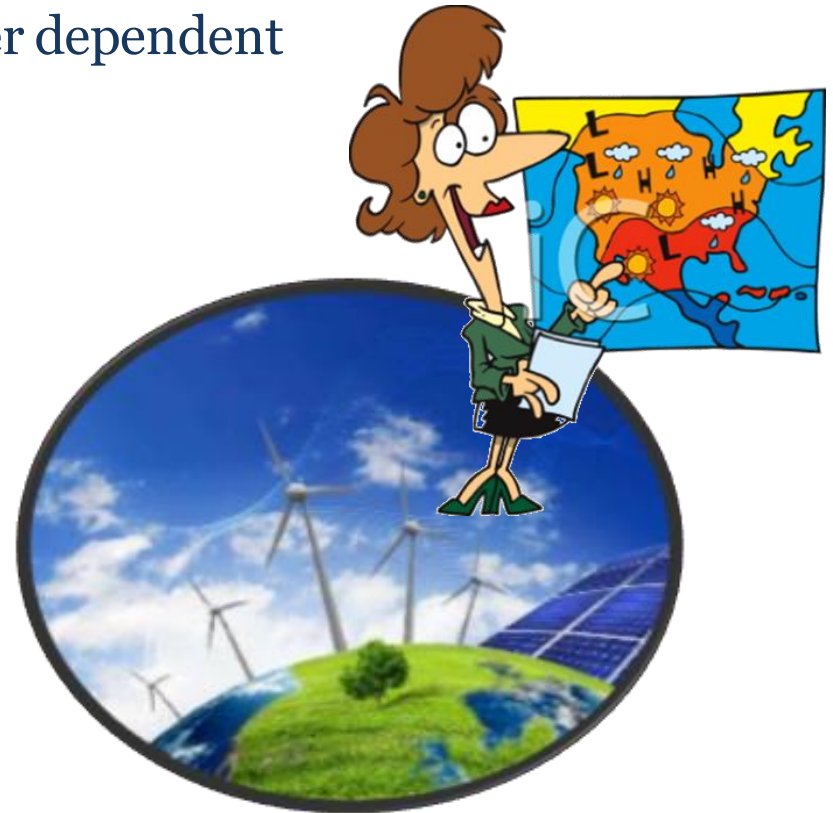






# Geologist is to Oil and Gas as...?

- Uncertainty and variability are a function of footprint and weather
- Wind, solar, load and to some extent hydro are all interdependent
- Even imports and exports are weather dependent



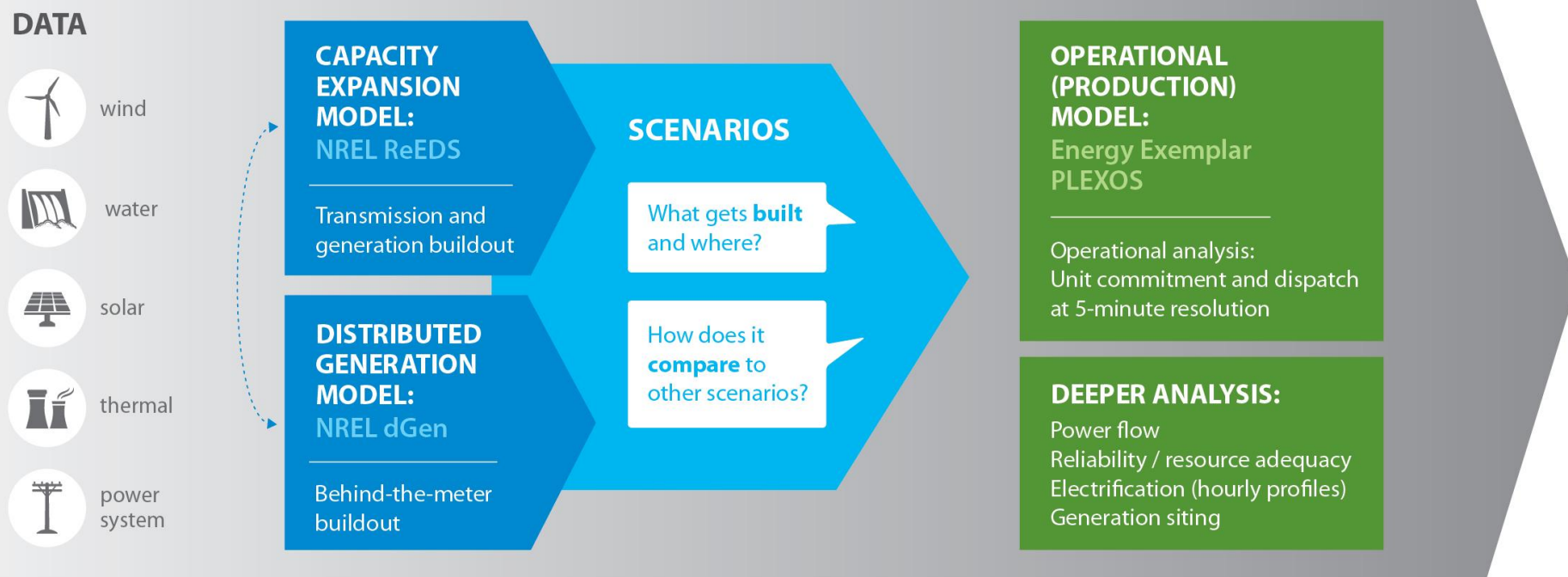


# Impact of Weather Tails on High-Penetration Renewables

- Identify days where weather events occurred throughout the US that had a major impact on load, system operation, and VER generation
- Objectively analyze the impact of tail weather events on future scenarios of renewable energy build out.
- Funded by DOE

## SCENARIO CREATION MODELS

## DETAILED SCENARIO ANALYSIS TOOLS

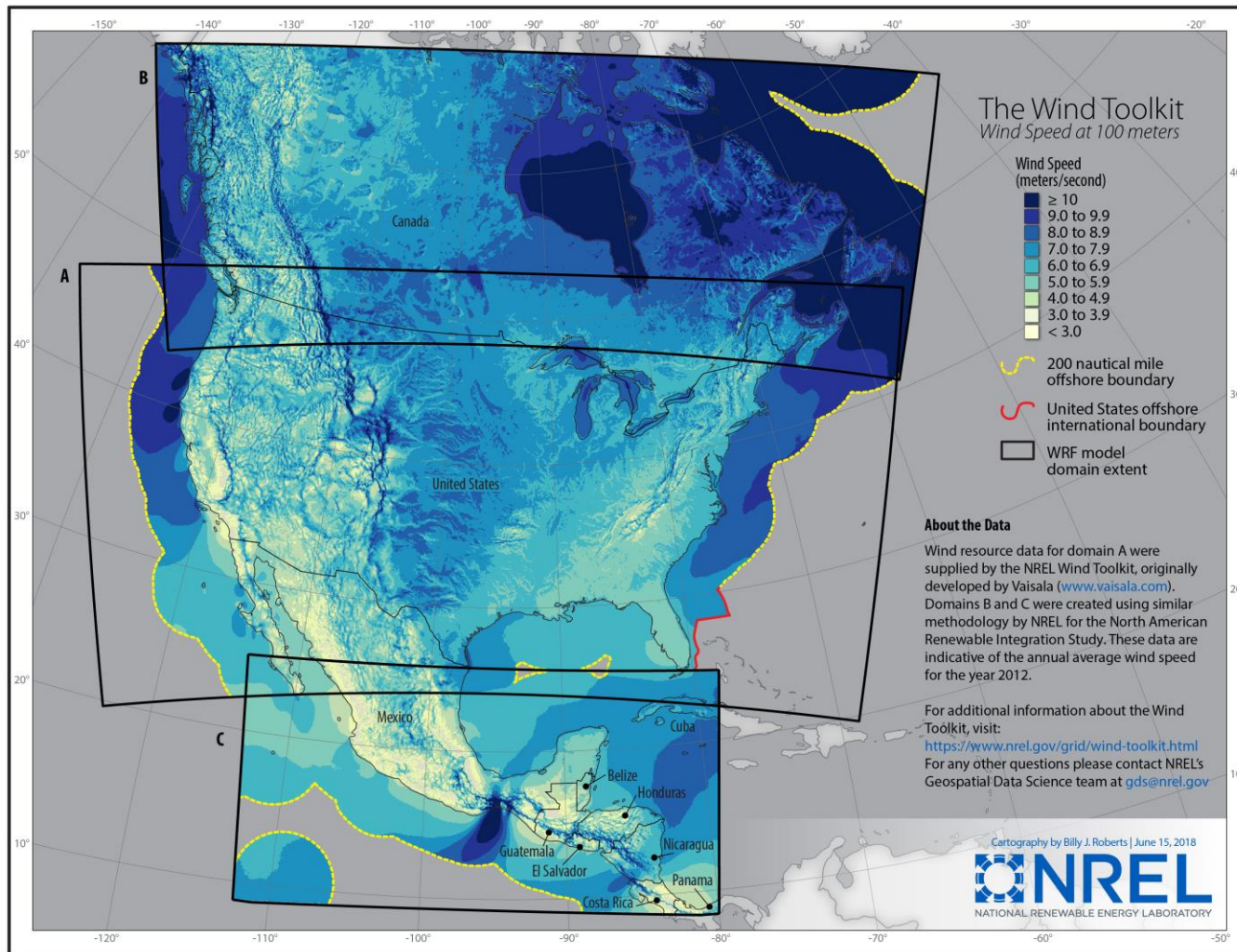




A photograph of a white wind turbine in a mountainous region. Two technicians in blue work clothes and white hard hats are on the nacelle, working on the tower. The background features rugged, snow-capped mountains under a clear blue sky. The text 'Concurrent Wind, Solar, and Weather Datasets (2007-2013)' is overlaid in white on a dark horizontal band across the middle of the image.

# Concurrent Wind, Solar, and Weather Datasets (2007-2013)





## WIND Toolkit

### Domain A

- Vaisala Wind Toolkit
- 2007-2013
- Continuous United States

### Domain B

- NREL created using similar method
- 2010-2013
- Canada

### Domain C

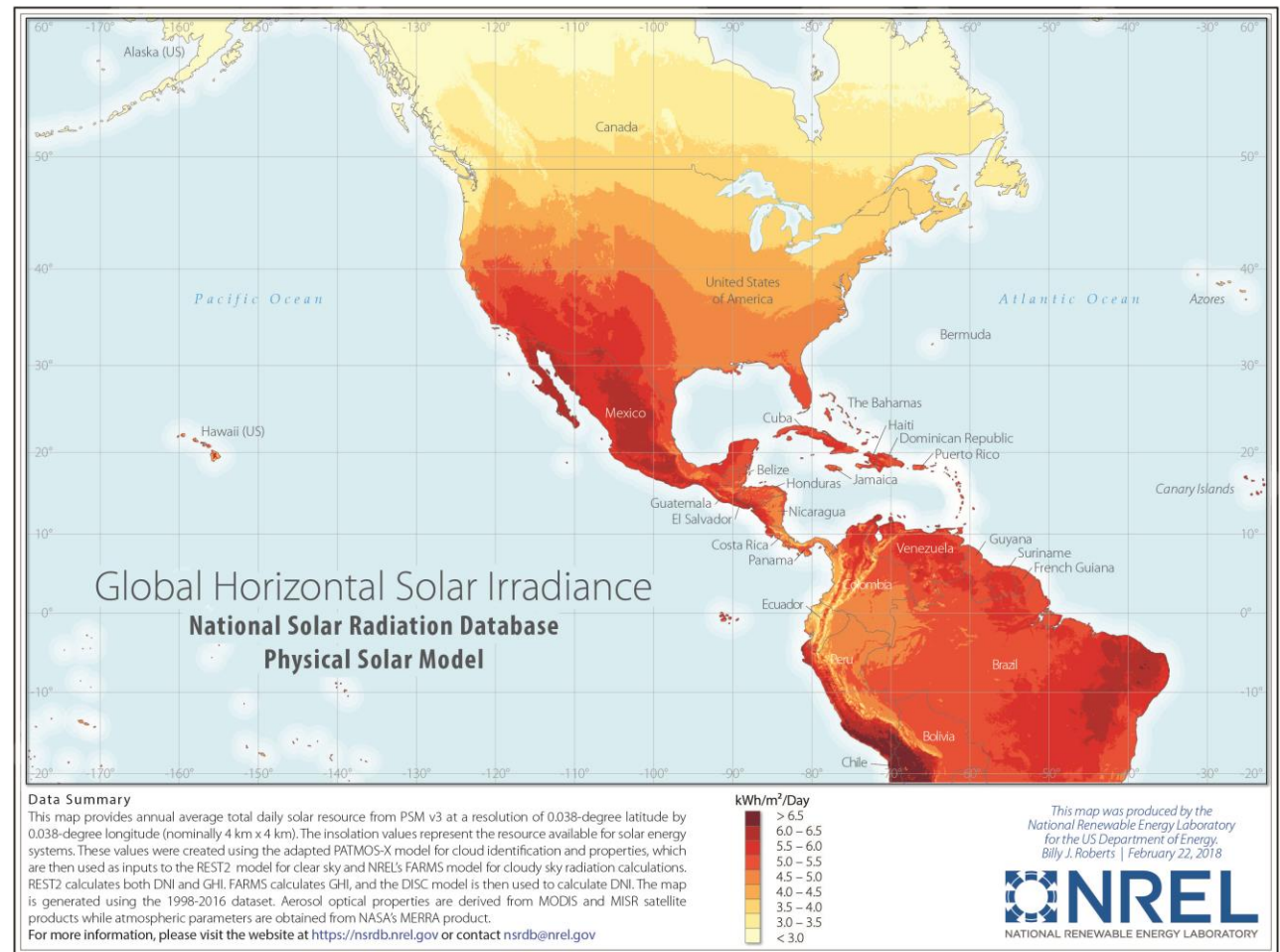
- NREL created using similar method
- 2009-2013
- Southern Mexico

5-minute resolution  
2km x 2km spatial  
resolution



## National Solar Radiation Database (NSRDB)

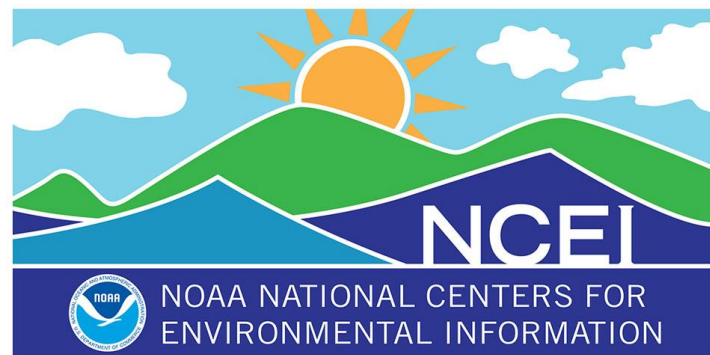
- 1998 – 2017
- 30-minute resolution
- 4km x 4km spatial resolution





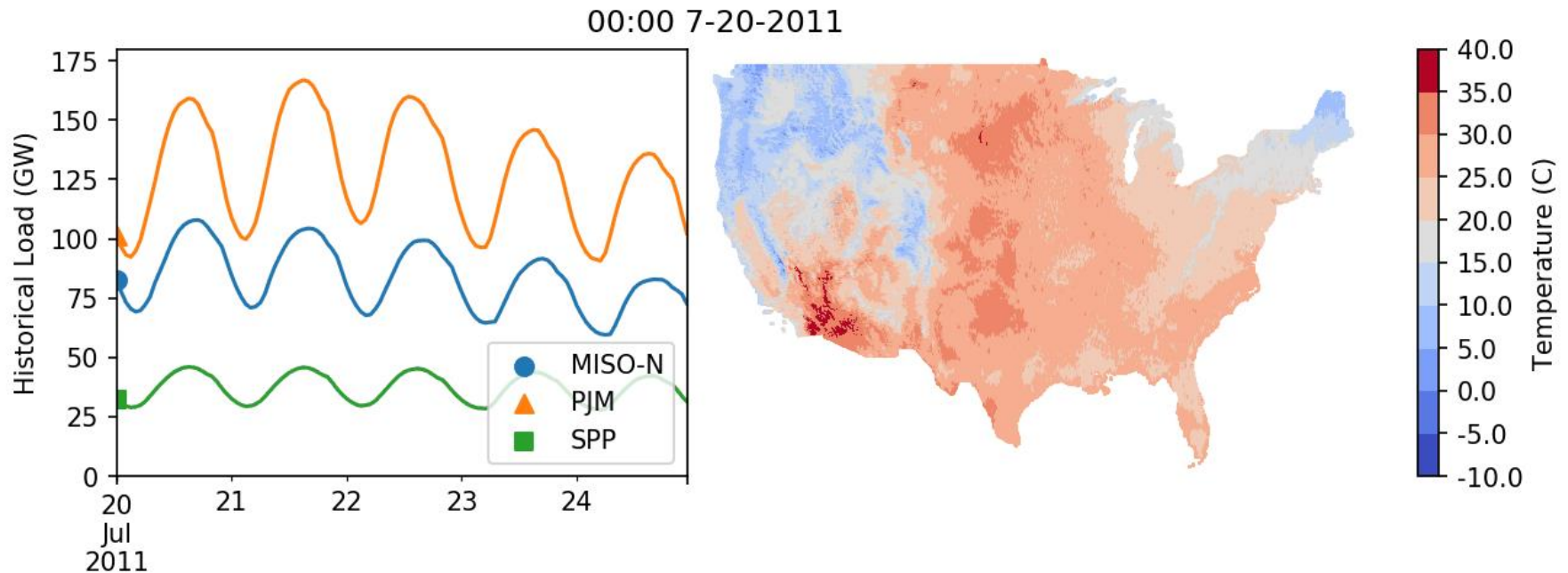
# Local Climatological Data (LCD)

- Local Climatological Data (LCD) consist of hourly, daily, and monthly summaries for approximately 1,600 U.S. locations.
- Hourly data includes major meteorological fields:
  - present weather
  - sky cover
  - precipitation amount and type
  - wind direction, sustained speed and gust
- Summary of the day:
  - Max/min temperature
  - Deviations from normal
  - Heating/Cooling Degree Days
- Best set for providing ground truth of fields impacting load and renewable resources





# Operators Need To Plan For Extreme Loads, Right?

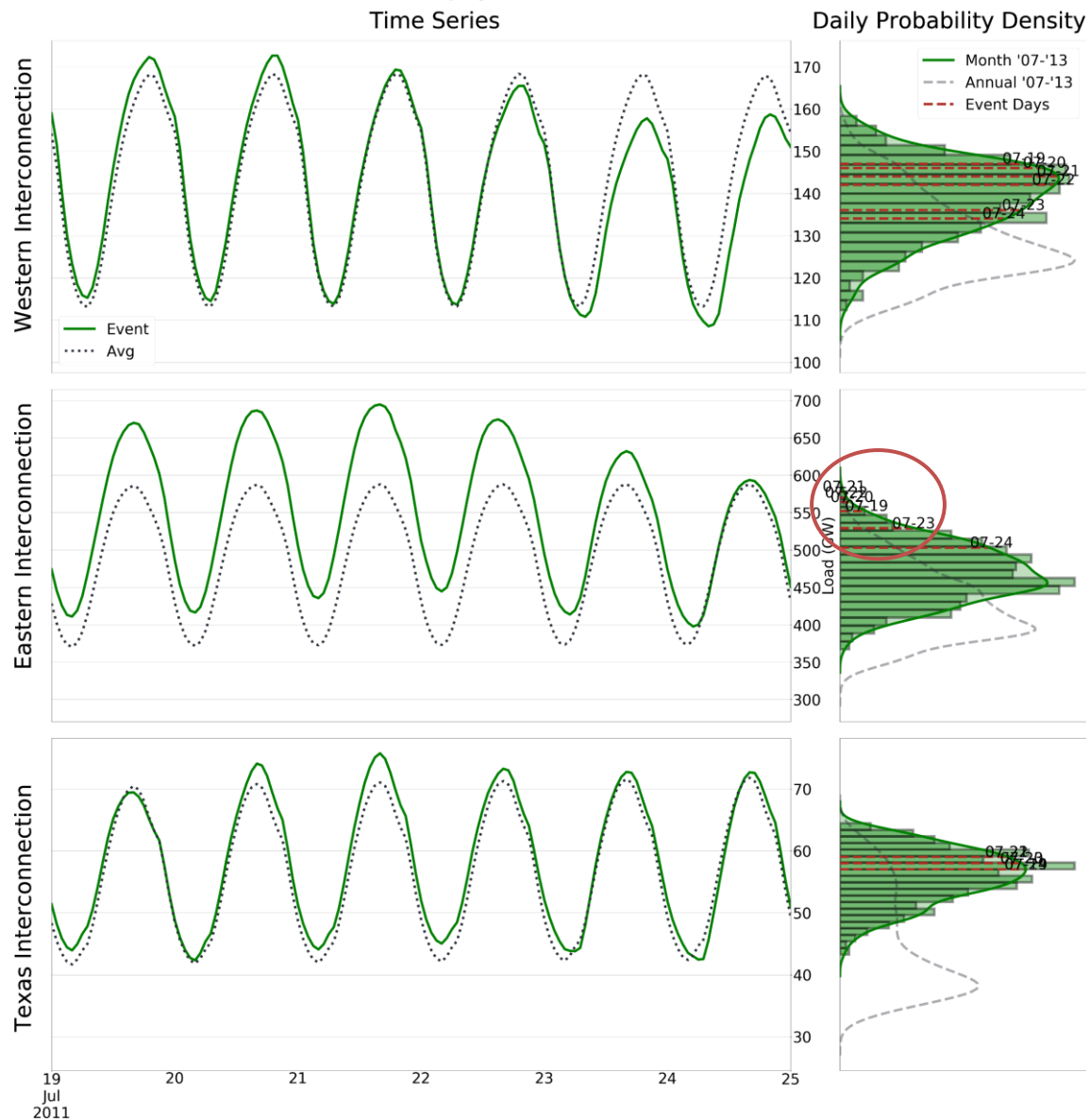




## Hottest Period in the 7-year Record

This plot shows the hourly load time series for a period that, with the average for the same period (dashed). On the right is the distribution for the 29 days centered around the middle of the event for each of the 7-years in the dataset. The actual event days are labelled, and the dashed line is the annual distribution.

The July 2011 heatwave saw the 1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup>, 4<sup>th</sup>, 8<sup>th</sup> and 9<sup>th</sup> highest number of cooling degree days across 31 large load centers.



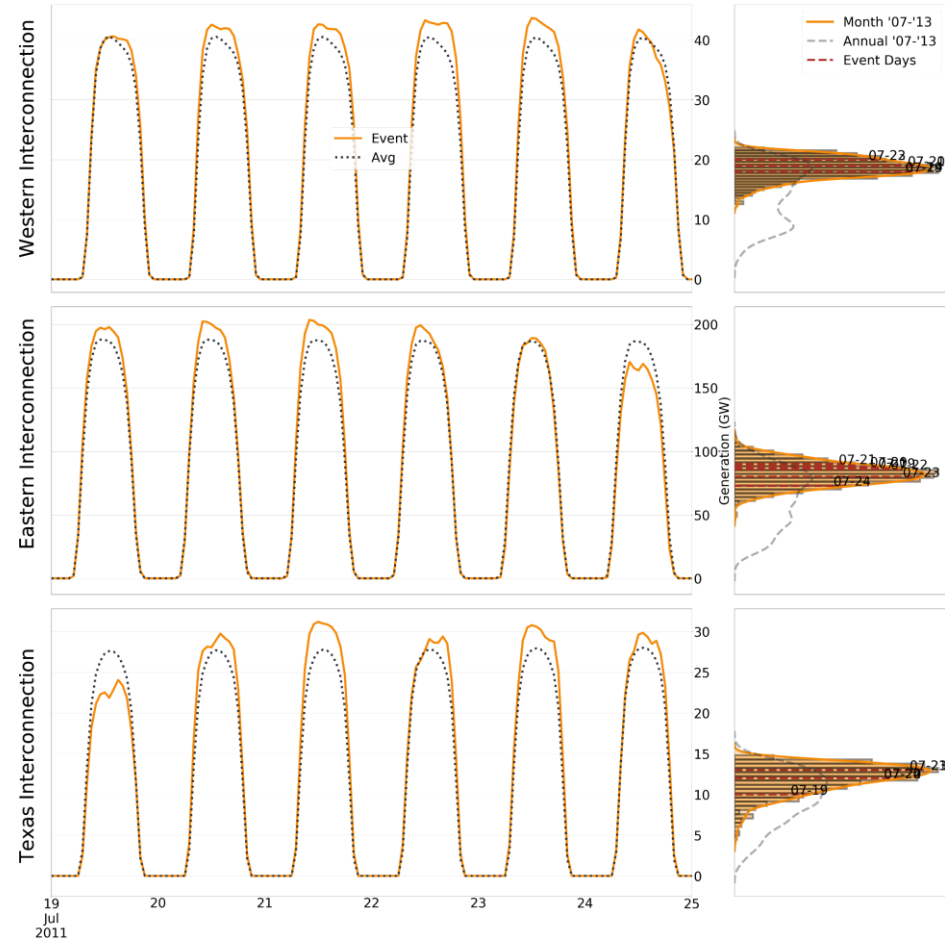


# Wind and Solar Resource

Heat Wave (July 19th - 24th, 2011) TB 2036 PV

Time Series

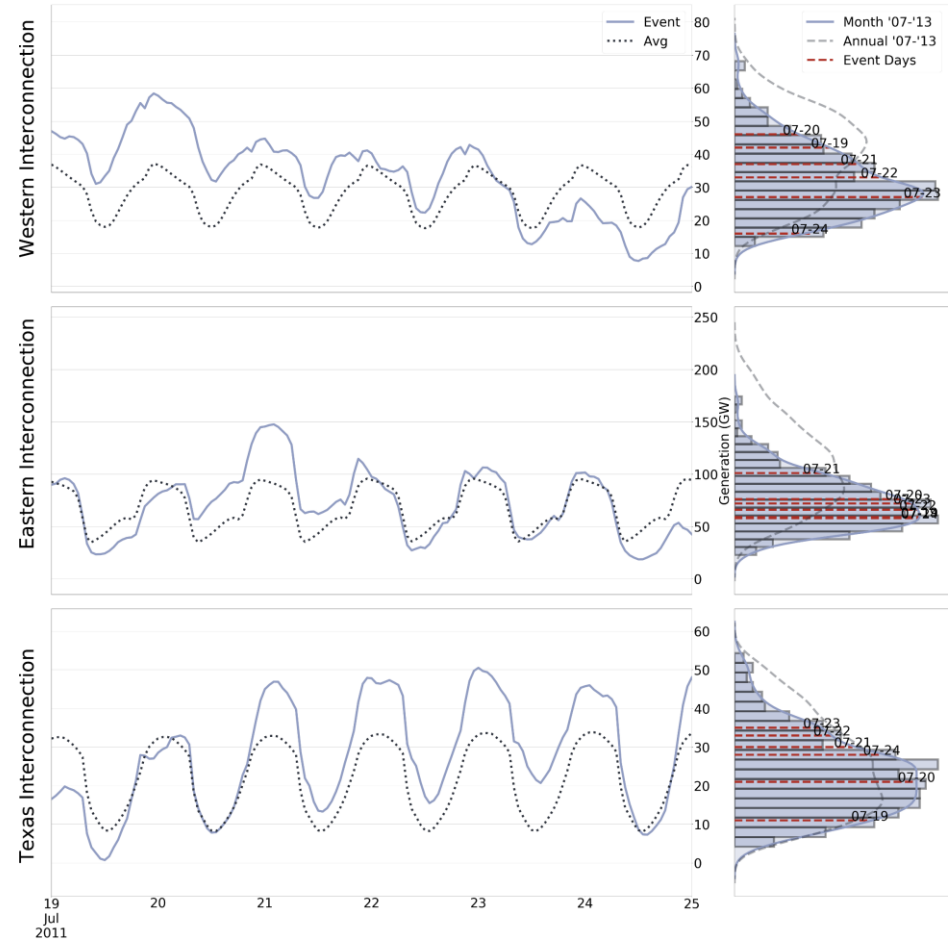
Daily Probability Density



Heat Wave (July 19th - 24th, 2011) TB 2036 Wind

Time Series

Daily Probability Density

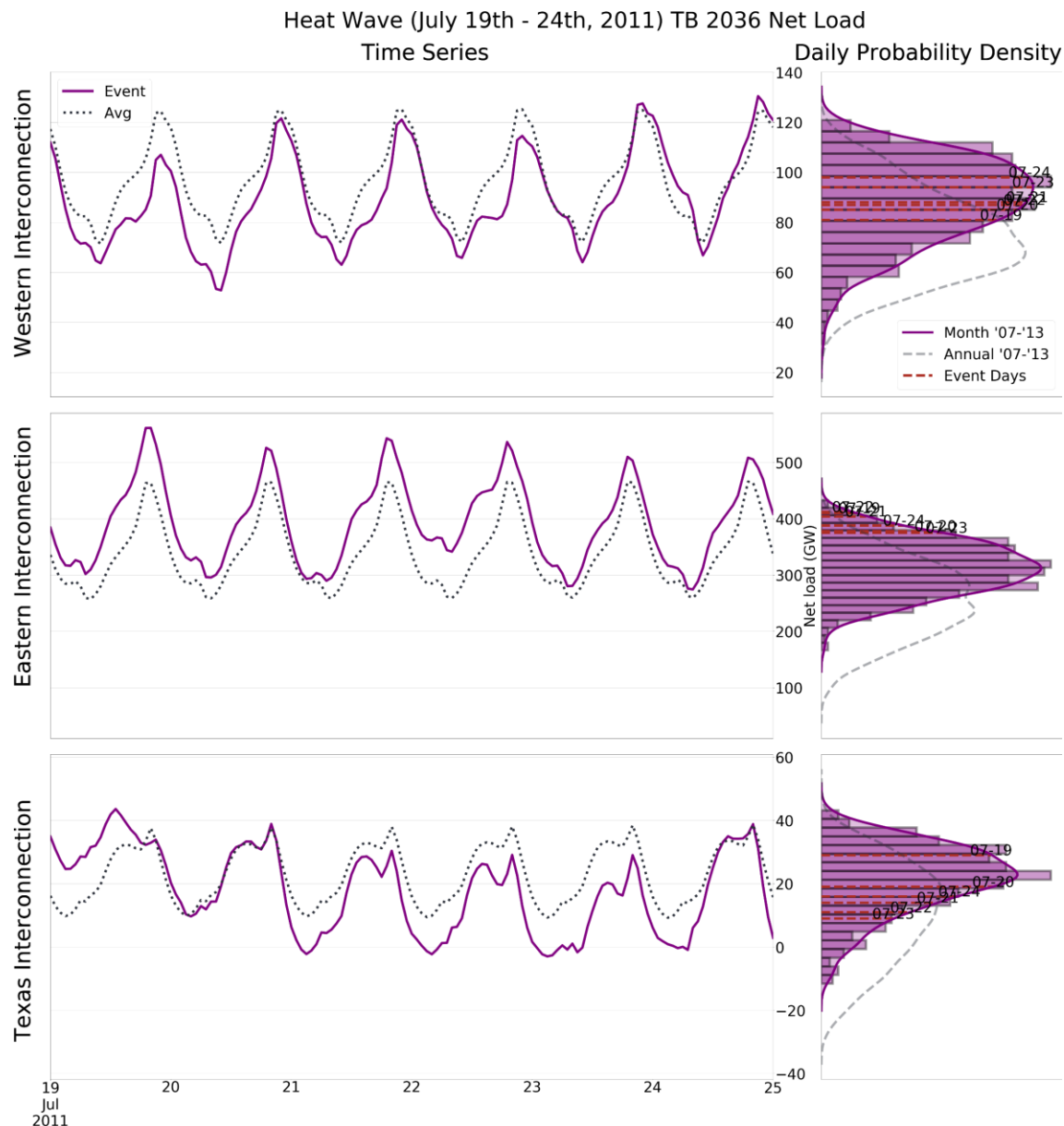




# Residual Load Net Renewables

Data is for 2036 Tech-break Scenario

Note how the time series is closer to average for the EI and below average for Texas. The distribution shift downwards and for the EI, out of the far tail.

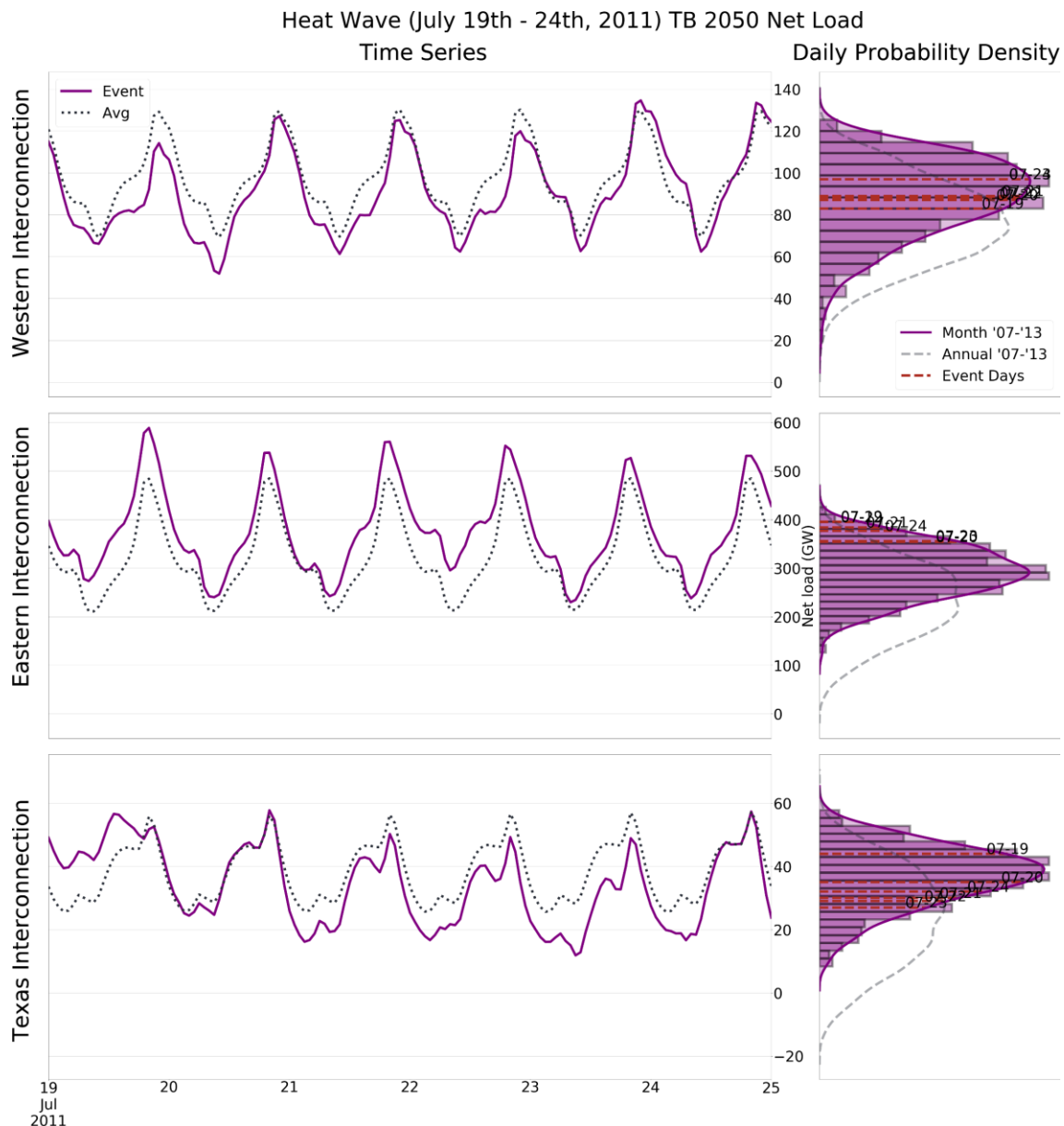




# Residual Load Net Renewables

Compare to 2050 Tech-break where lots more renewables have been added.

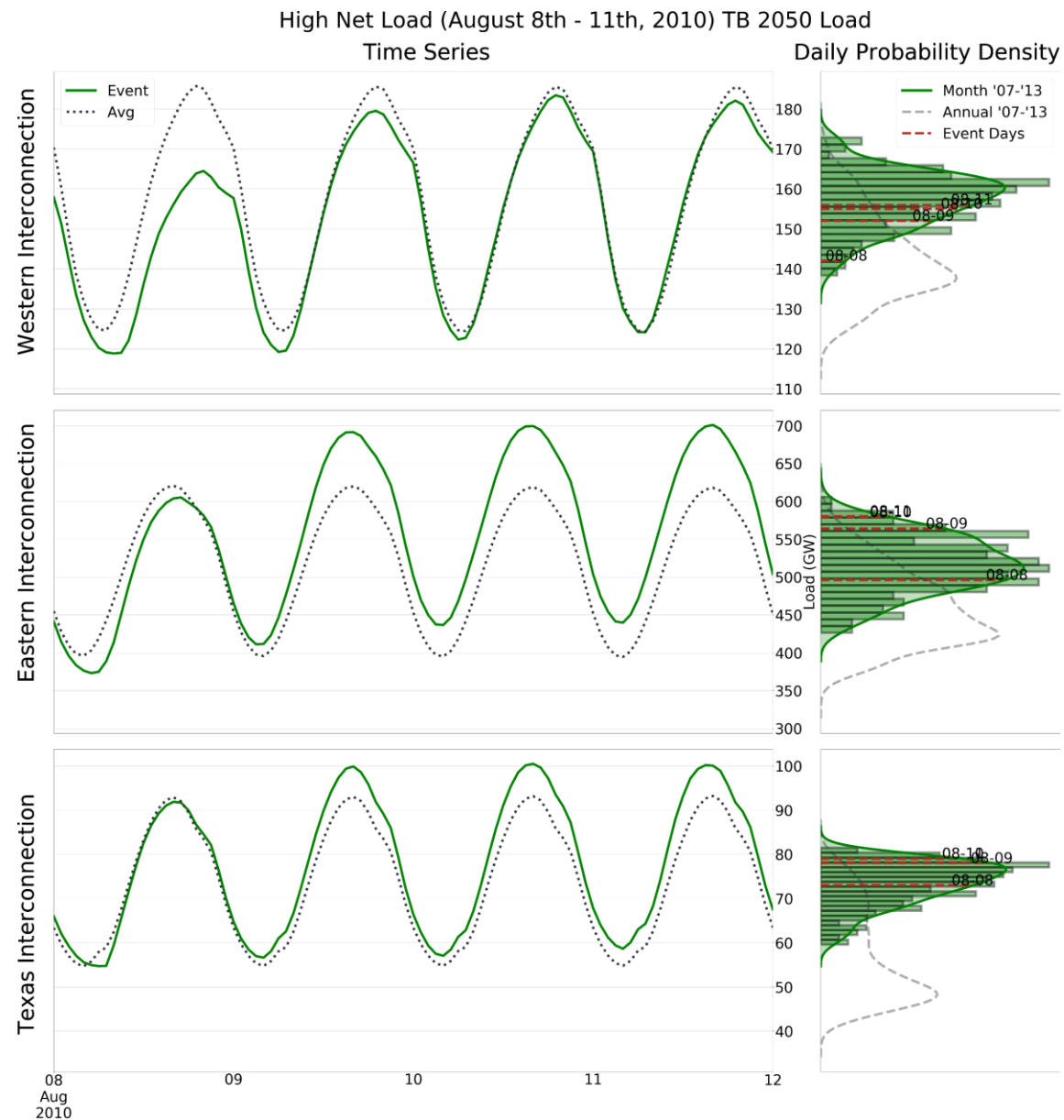
Note the significant shift out of the tail in the EI. This was a characteristic result for extreme load excursions. Typically, extreme heat does not correlate with poor wind and solar resource over the study area. A definitive analysis of this impact is still needed in future work.





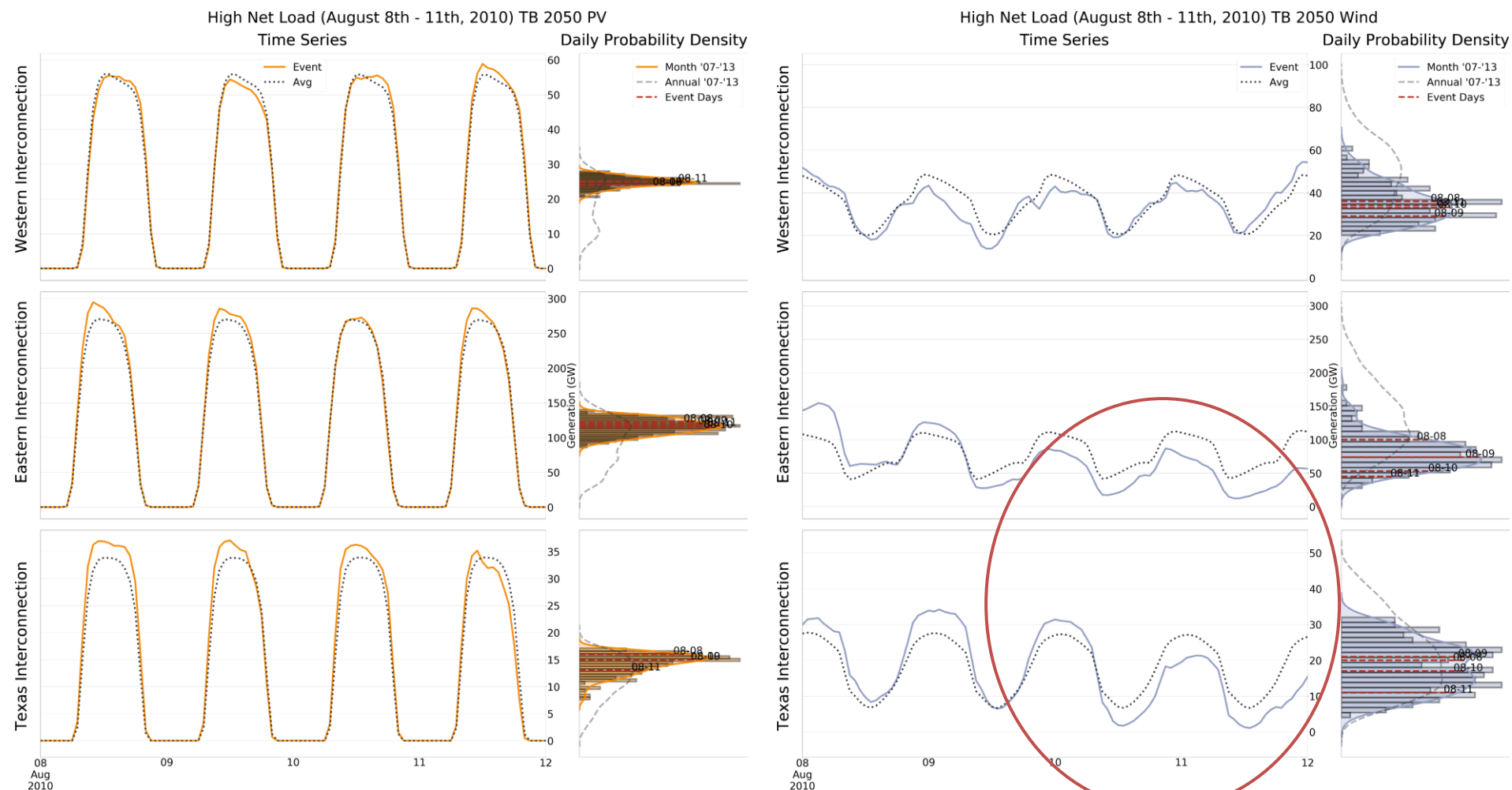
## August 8-11, 2010 Warm Period

This period experienced moderately above normal temperatures. August 11 was 14<sup>th</sup> in the record for CDD, mainly driven by Texas. Other days were not noteworthy. somewhat above normal temperatures. As a result the daily averages fall closer to the middle of the distribution as expected. (Note, this plot shows 2050 load which is scaled higher than 2036 for load growth)





# Wind and Solar Resource below average in EI/TX



Note the wind/solar synergy and anti-correlation



# Residual Load Net Renewables

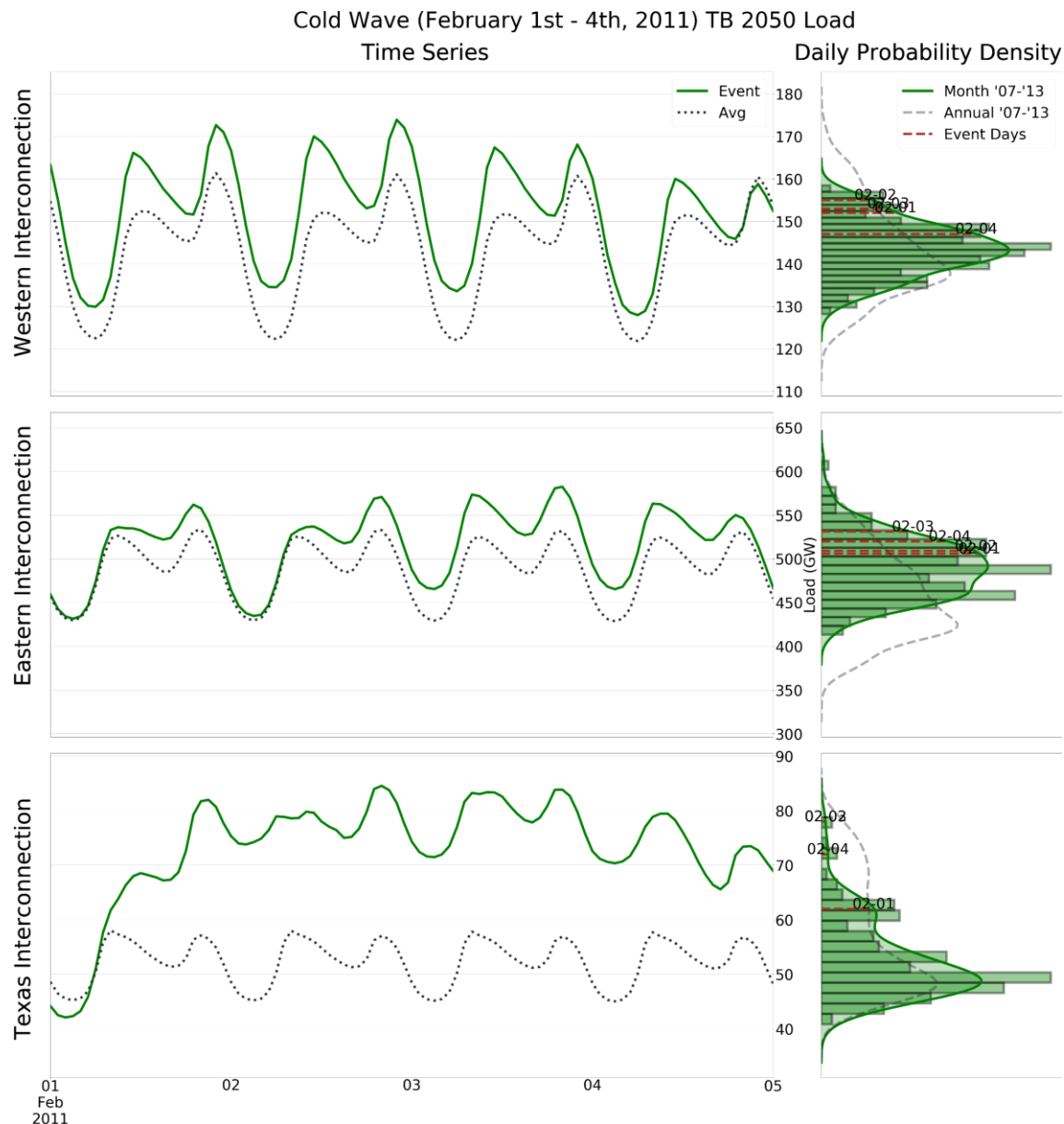
Lower resource pushes the netload curve up, forcing some days into the tails despite this not being an exceptionally warm period.





## Coldest Period in the 7-year Record

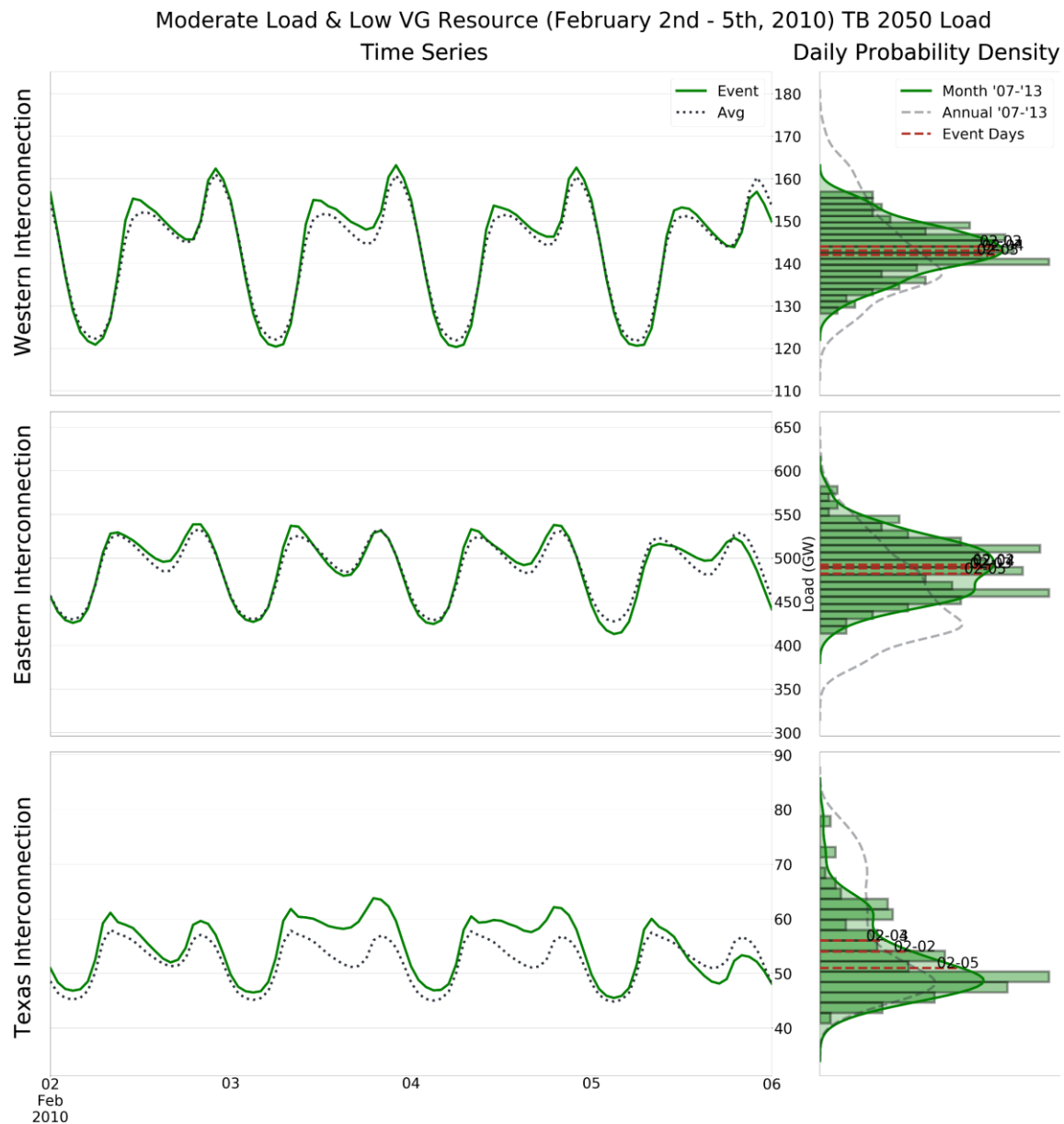
February 3, 2011 has the most HDD in the record, 2/2 is 6<sup>th</sup> and the other days are in the top 40. The cold reached far south setting many records in Texas which saw extreme load excursions as a result.





## Compare to a more typical period

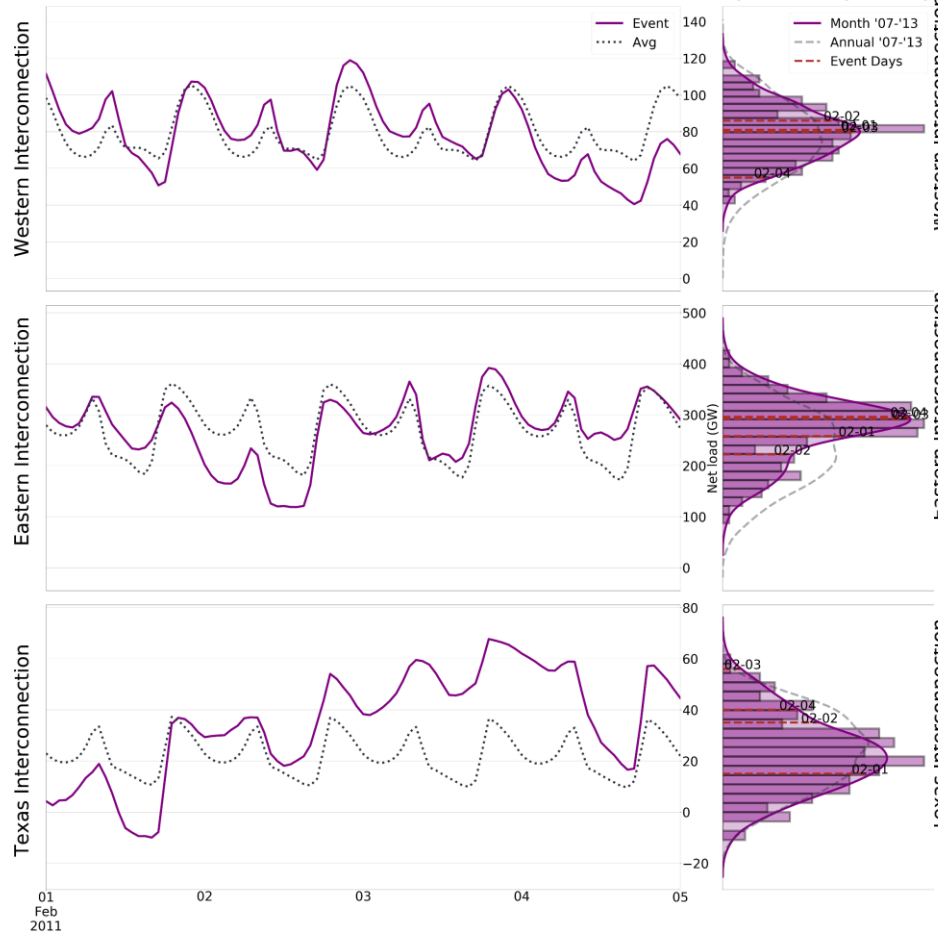
February 2 – Feb 5, 2010 was a fairly typical period as can be clearly seen here.



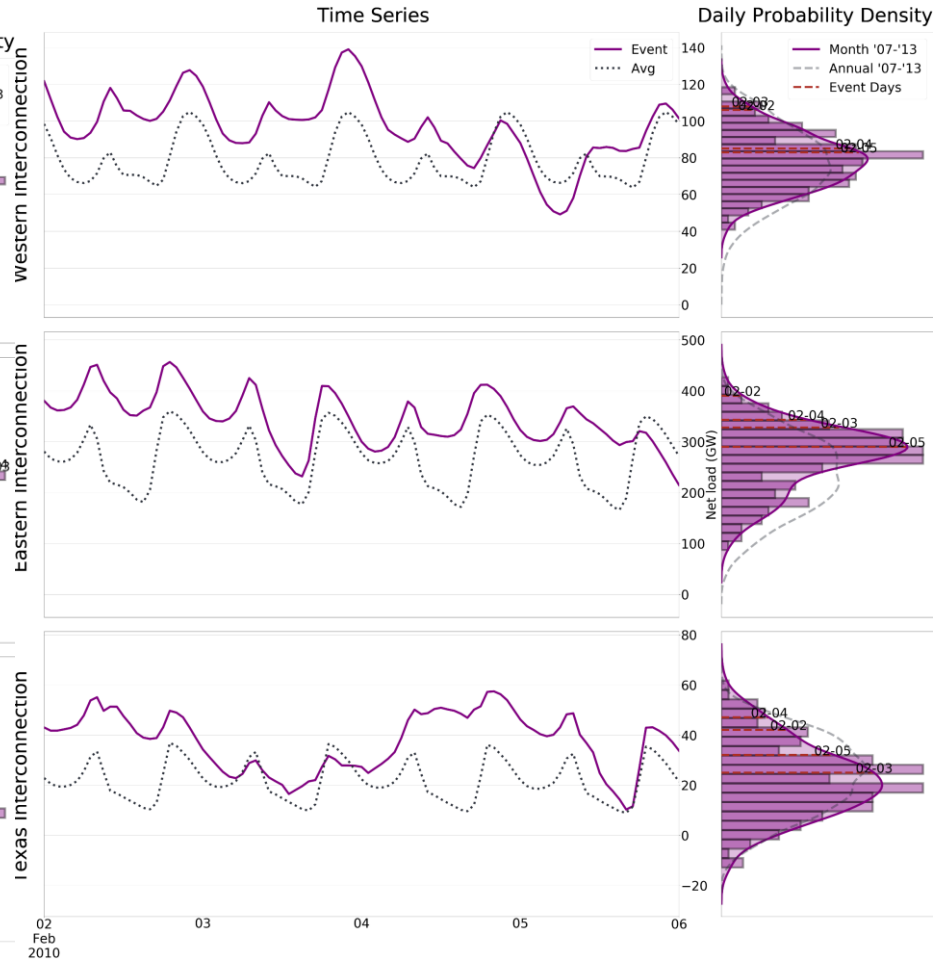


Above average renewables mitigate load excursion during the cold wave. Compare to the more typical period where low renewable resource drives net-load higher.

Cold Wave (February 1st - 4th, 2011) TB 2050 Net Load  
Time Series



Moderate Load & Low VG Resource (February 2nd - 5th, 2010) TB 2050 Net Load



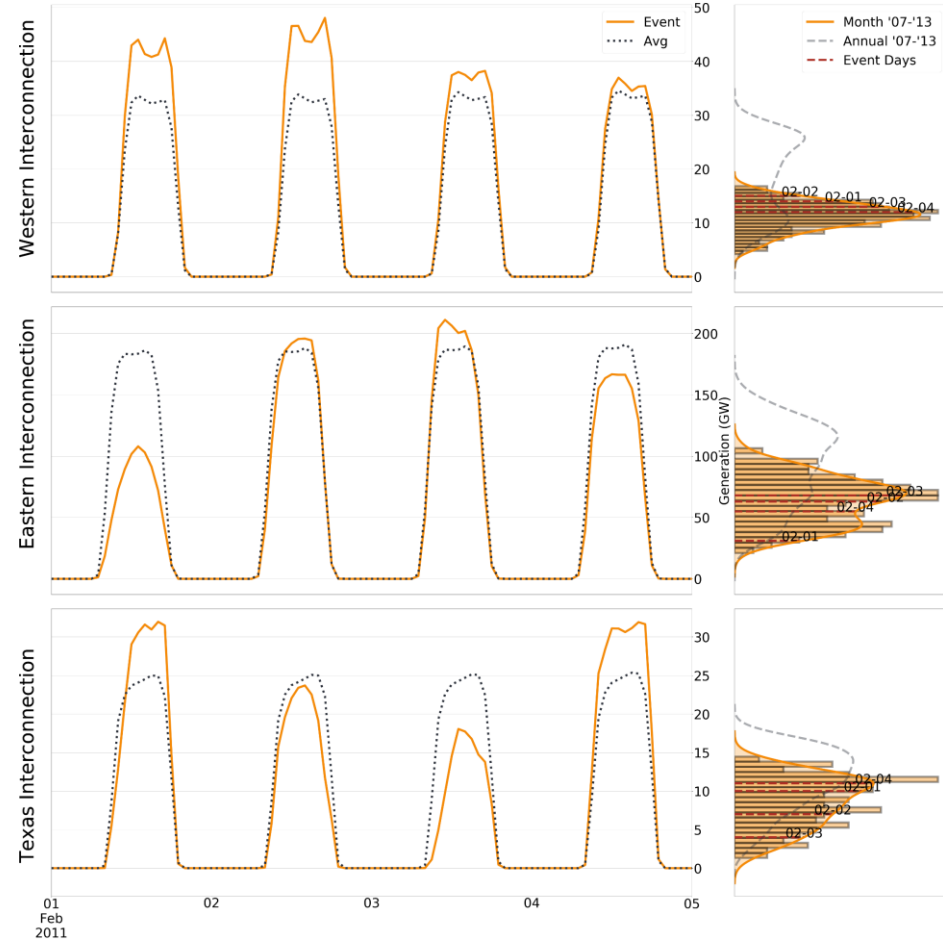


# 2011 Wind and Solar Resource above average

Cold Wave (February 1st - 4th, 2011) TB 2050 PV

Time Series

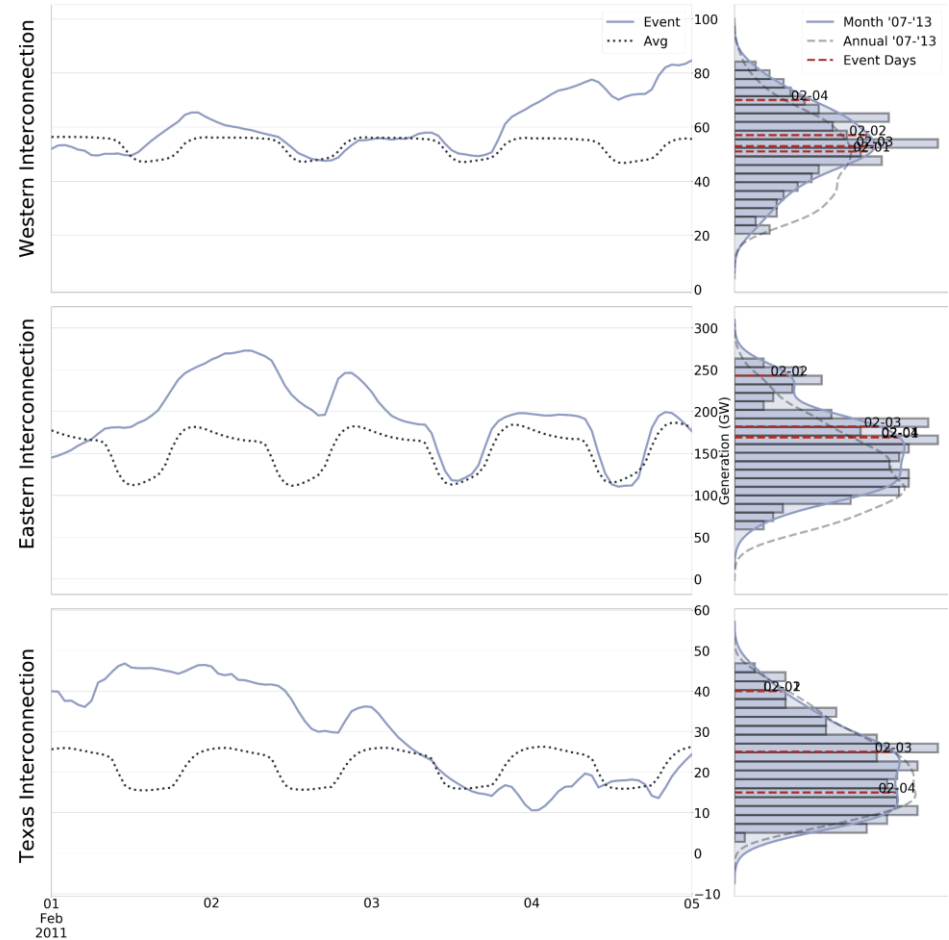
Daily Probability Density



Cold Wave (February 1st - 4th, 2011) TB 2050 Wind

Time Series

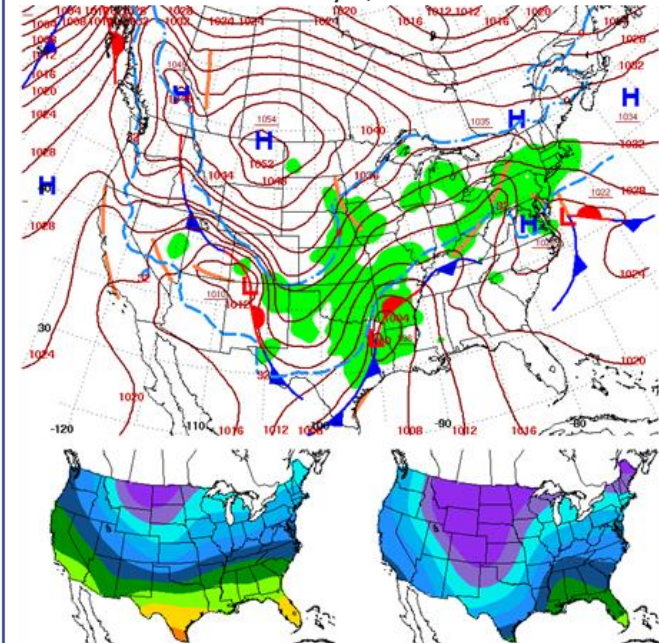
Daily Probability Density



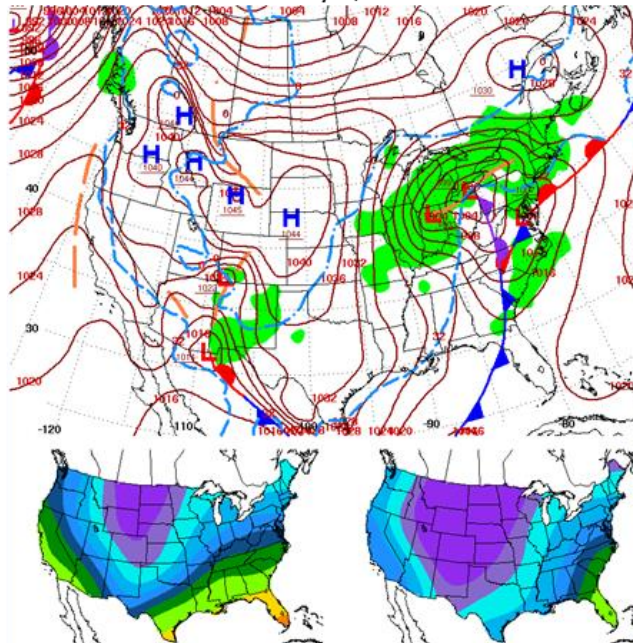
Note the wind/solar synergy and anti-correlation



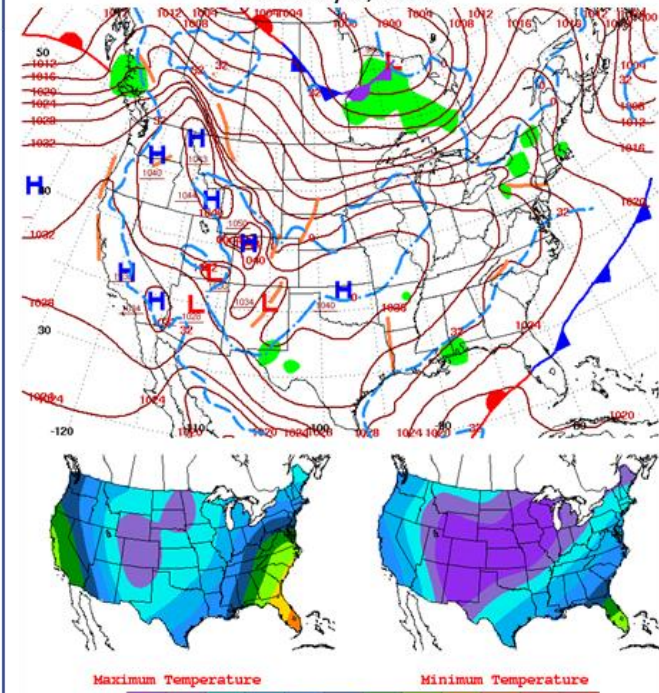
February 1, 2011



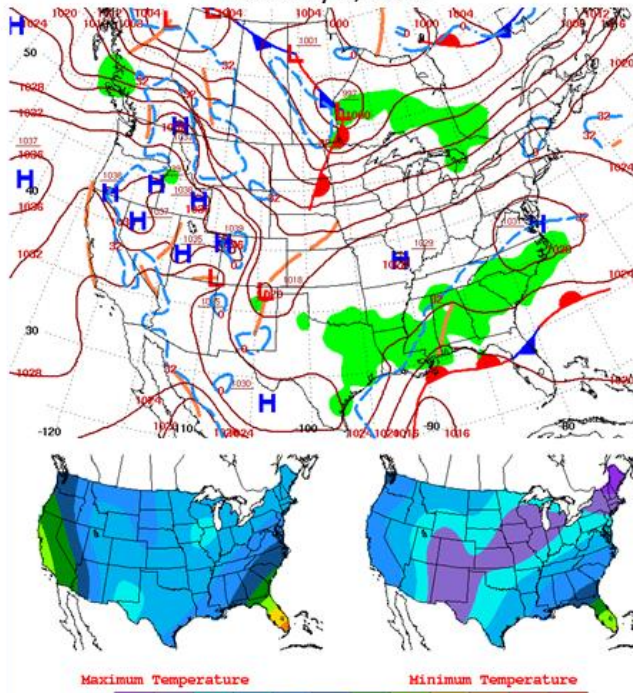
February 2, 2011



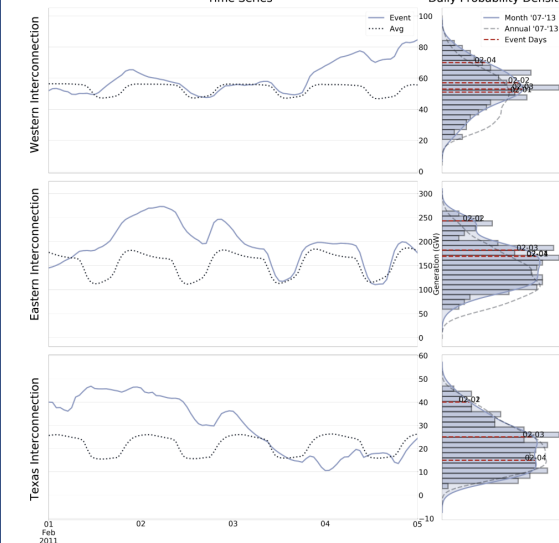
February 3, 2011



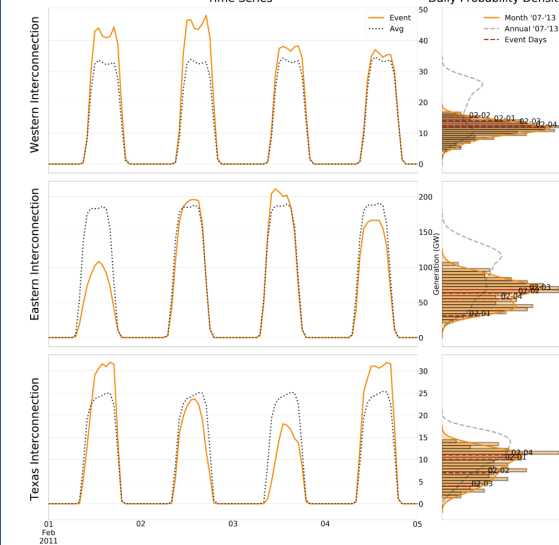
February 4, 2011



Cold Wave (February 1st - 4th, 2011) TB 2050 Wind



Cold Wave (February 1st - 4th, 2011) TB 2050 PV



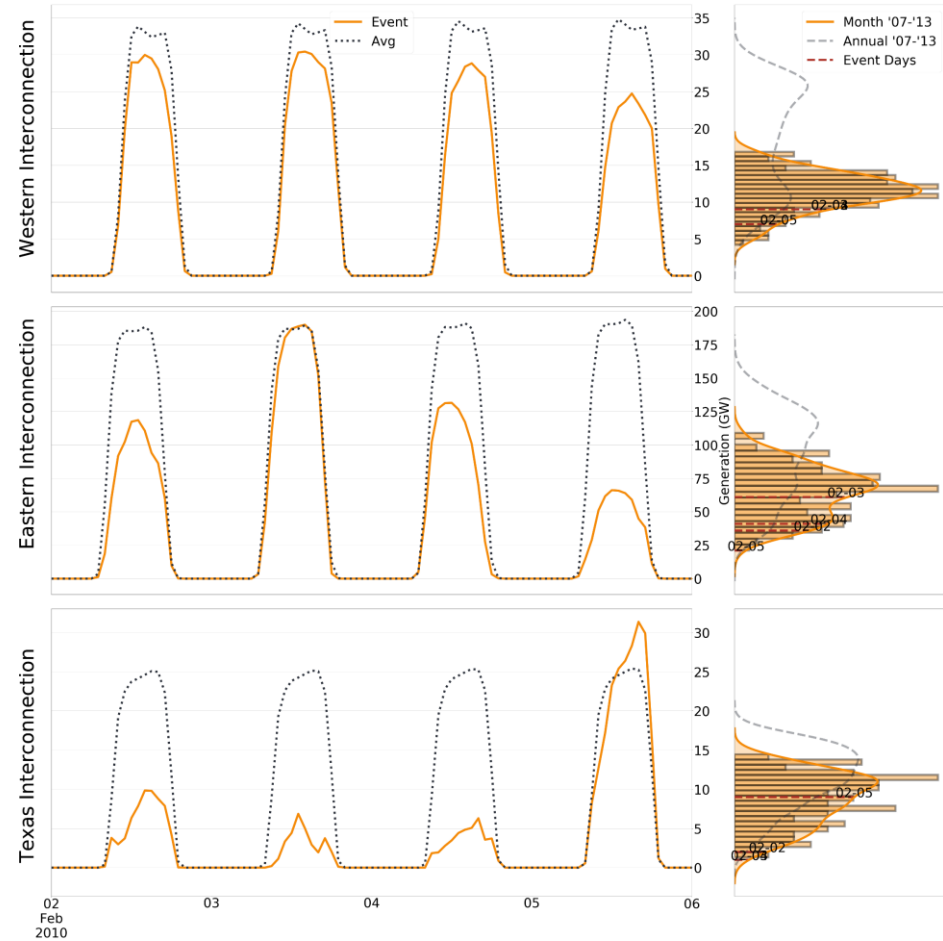


# 2010 Wind and Solar Resource well below average

Moderate Load & Low VG Resource (February 2nd - 5th, 2010) TB 2050 PV

Time Series

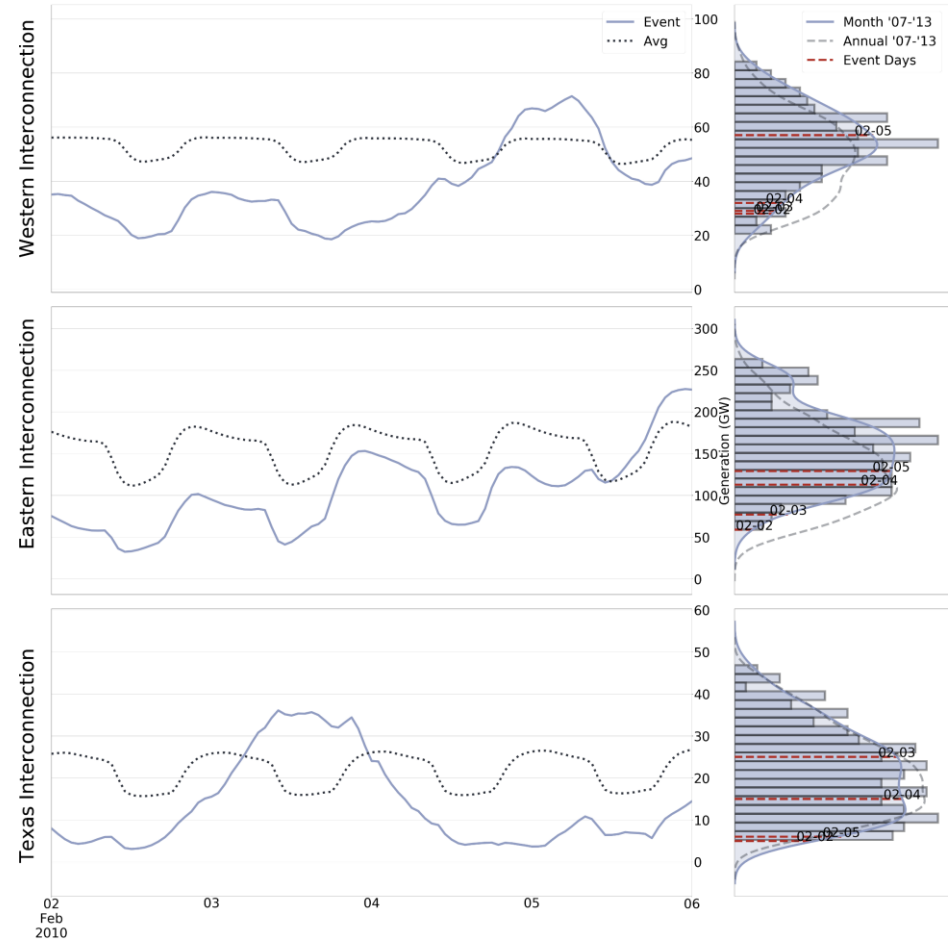
Daily Probability Density



Moderate Load & Low VG Resource (February 2nd - 5th, 2010) TB 2050 Wind

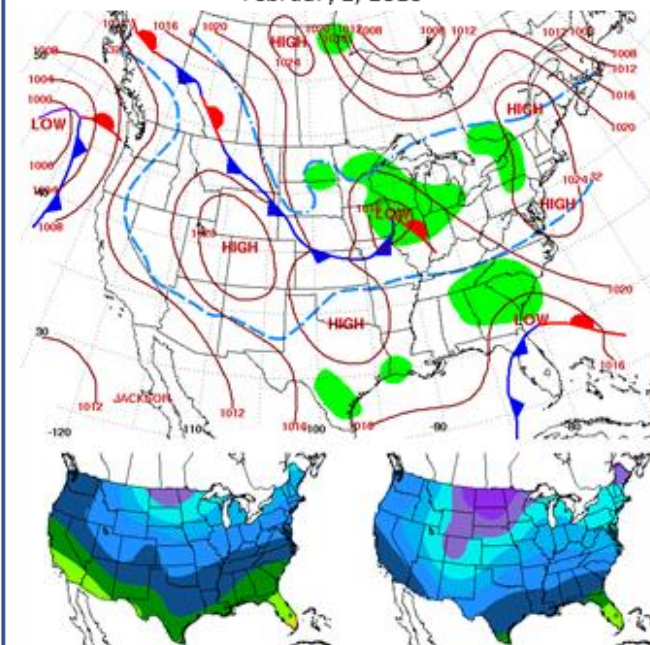
Time Series

Daily Probability Density

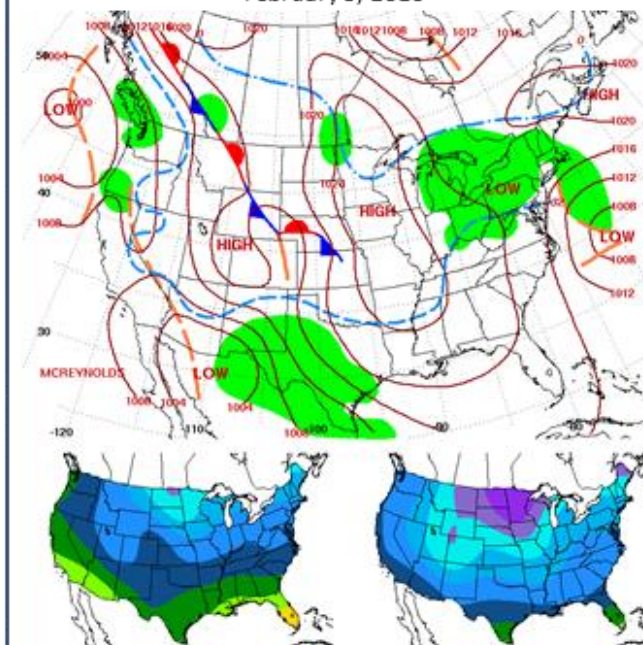




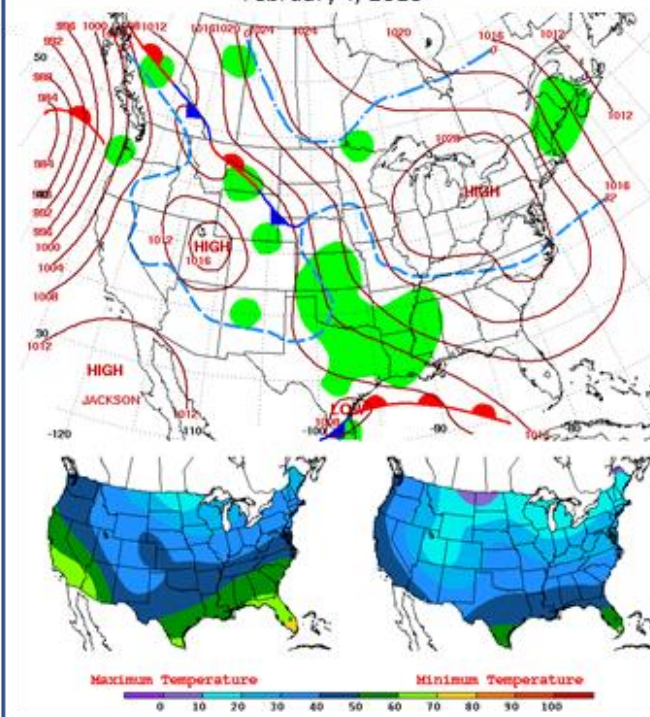
February 2, 2010



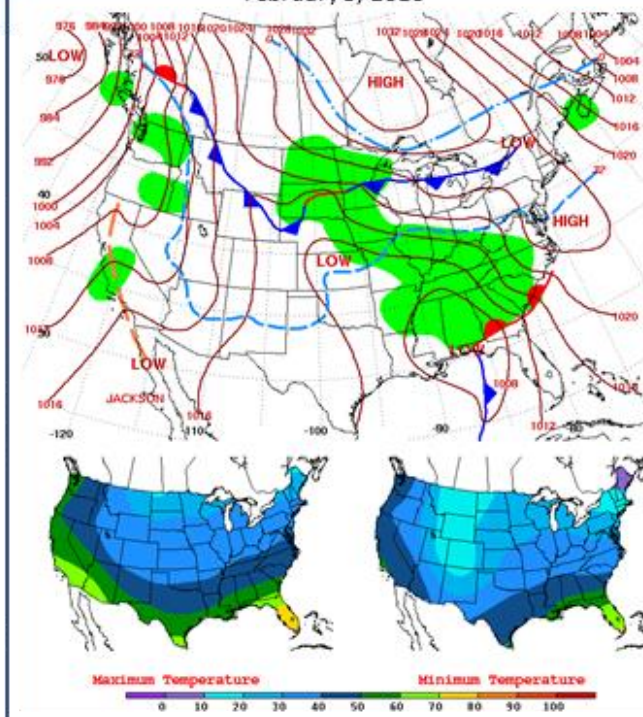
February 3, 2010



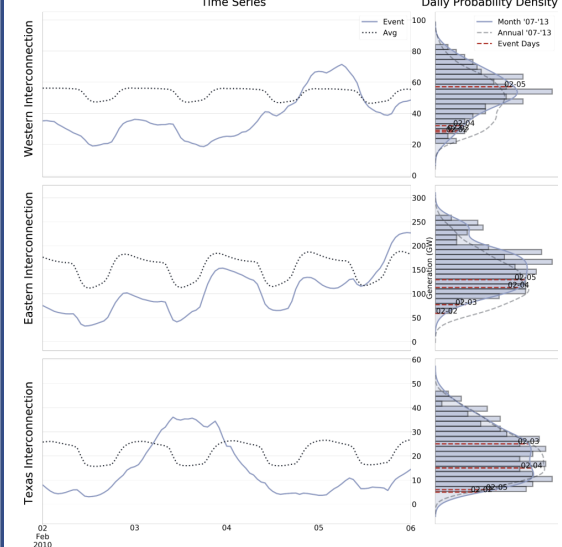
February 4, 2010



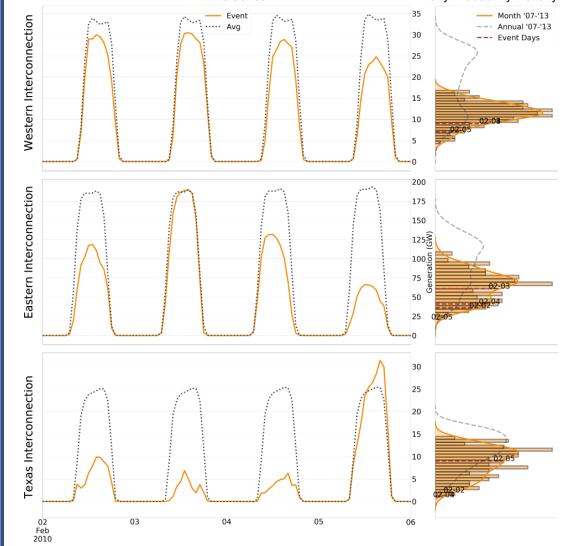
February 5, 2010



Moderate Load &amp; Low VG Resource (February 2nd - 5th, 2010) TB 2050 Wind



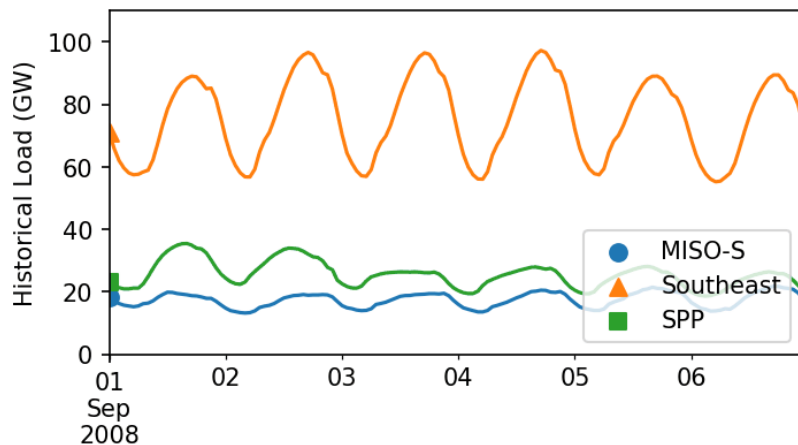
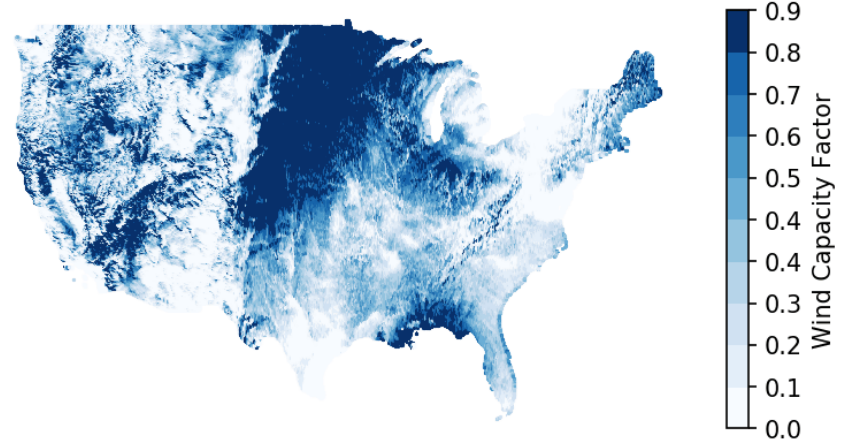
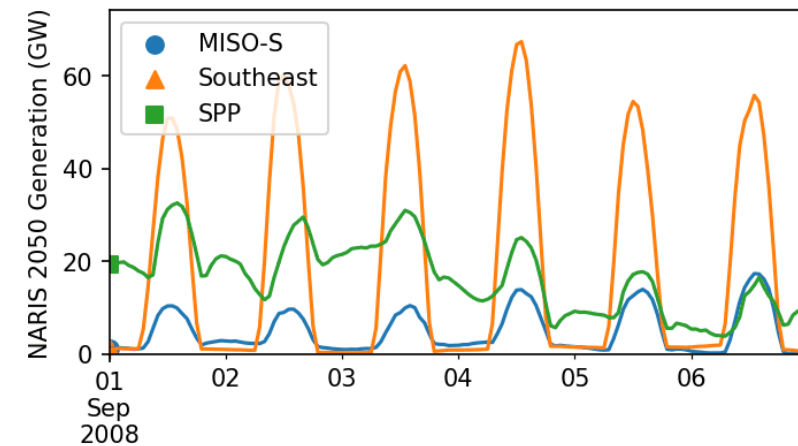
Moderate Load &amp; Low VG Resource (February 2nd - 5th, 2010) TB 2050 PV





# Tropical Storms and Hurricanes - Gustav

00:00 9-1-2008



Scale of the storm is smaller than typical mid-latitude storms, so impact is minimal except locally. Wind and solar impact tend to cancel to some extent too.



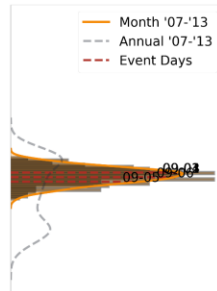
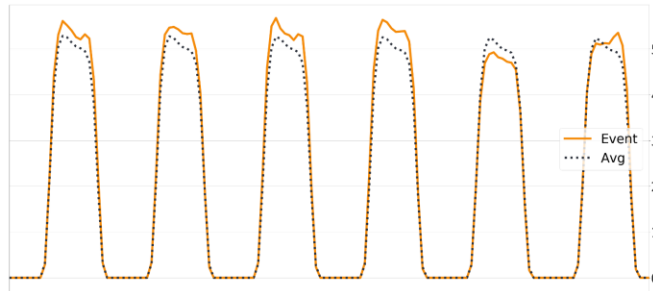
# Wind/Solar During Gustav

Hurricane Gustav (September 1st - 6th, 2008) TB 2050 PV

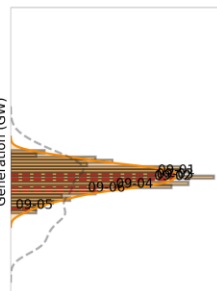
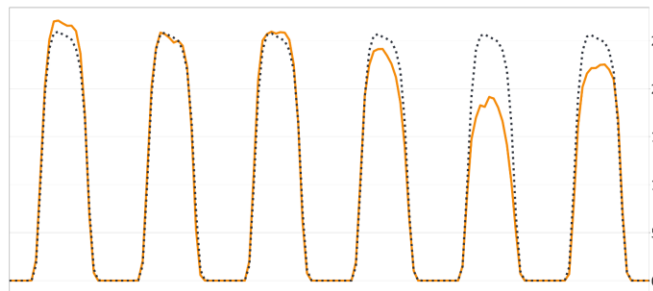
Time Series

Daily Probability Density

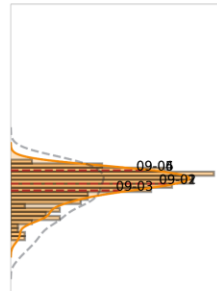
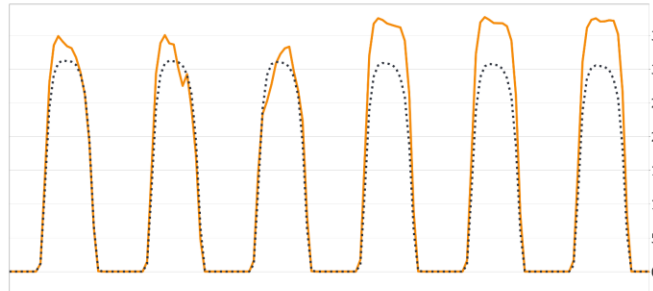
Western Interconnection



Eastern Interconnection



Texas Interconnection

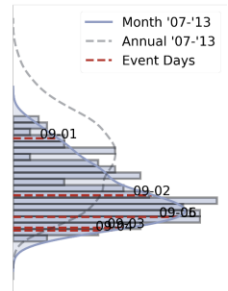
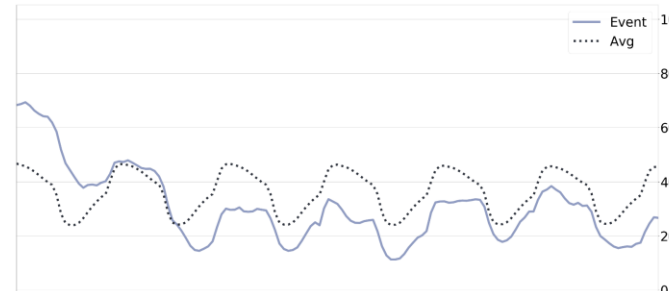


Hurricane Gustav (September 1st - 6th, 2008) TB 2050 Wind

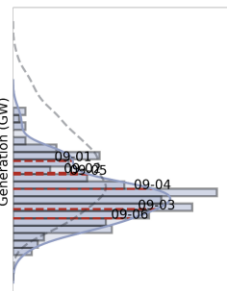
Time Series

Daily Probability Density

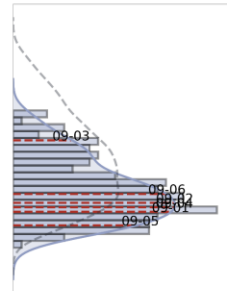
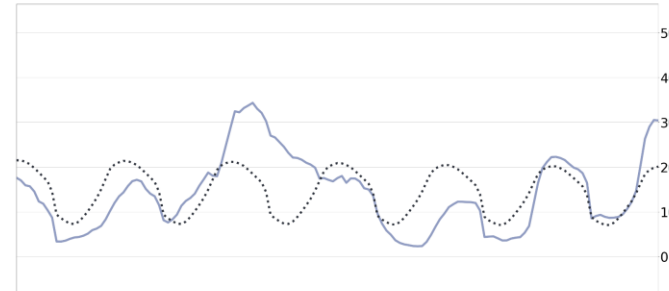
Western Interconnection



Eastern Interconnection



Texas Interconnection



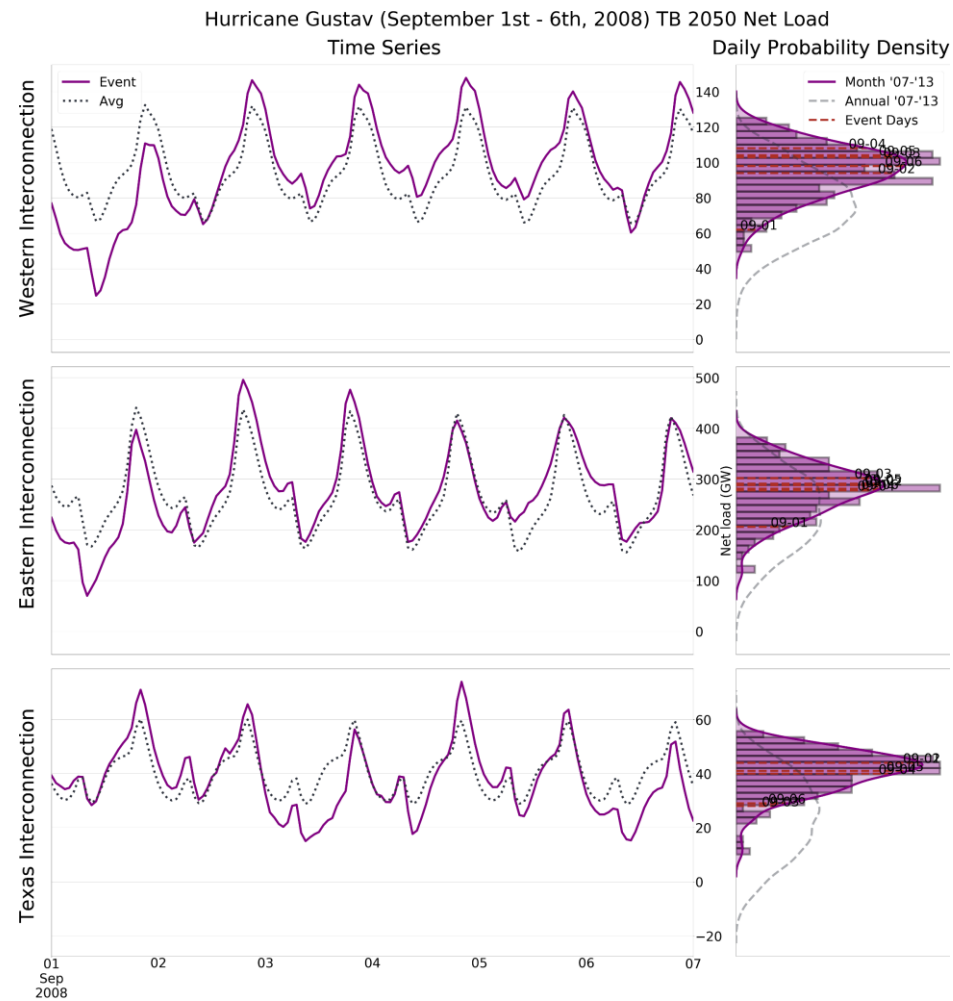
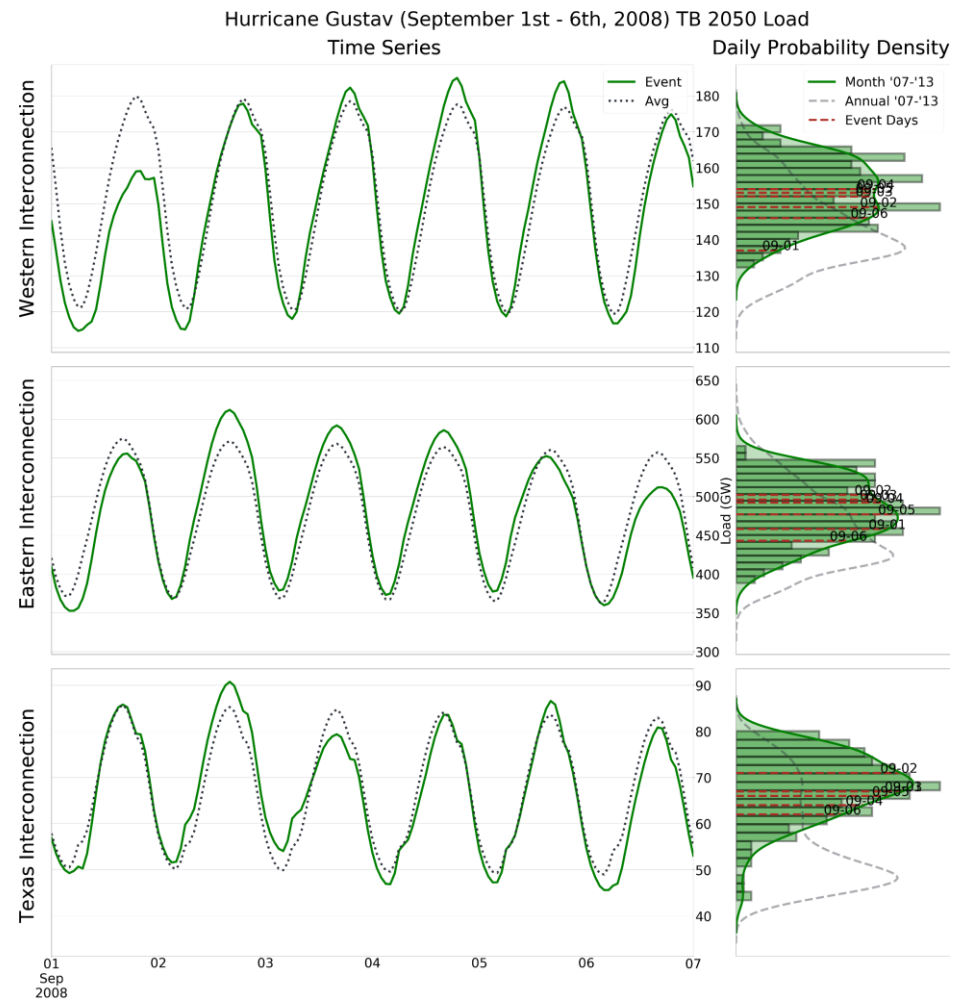
Significant impact is not detectable on a system wide scale

Meteorology and Market Design For Grid Services Workshop  
Online COVID Edition, June 18, 2020





# Load and Net-load During Gustav



## Significant impact is not detectable on a system wide scale

# Meteorology and Market Design For Grid Services Workshop

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# Summary

- Temperature stops being the primary modulator of supply/demand balance
- Weather driving generation becomes the primary modulator
- Wind/Solar are synergistic most of the time
- Supply constraints no longer typically coincides with record warmth/cold
- Concurrent weakness of wind and solar resource is a bigger driver than temperature excursions. The weather causing this is often boring!
- Net load distributions tighten as penetration increases and the tails narrow!
- Should season high wind and solar combos will lead to over supply. Hydro will exacerbate this in the spring (not shown)
- Cut out due to T, ice and snow now matters (not discussed)
- Hurricanes and other “severe” weather have only local negative impact; severe weather is a developer concern but is typically less so a grid operator concern with respect to generation (existing T&D impacts remain).





## The Takeaway:

**Grid planning needs to consider ALL the attributes of weather driven supply and demand, especially the correlations in the net-load tails!**

**Thank You**

“Like a prairie, savannah or rain forest, the new and renewable energy industry must also evolve to form a complete, stable and complex ecosystem... the global shift to clean energy is all about systems.

*Michael Liebreich, Founder, Bloomberg New Energy Finance*

Mount Hood Wake. Photo © Keith Barr

