Developing a Framework for Forecasting the Top 100 Hours of Demand

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PA Act 129

- Pennsylvania Act 129, passed in 2008, sets various targets for energy reduction by the state's utilities:
  - Overall MWh reductions of 3% through energy efficiency and conservation programs.
  - Reduction in peak demand of 4.5% by May 2013, based on the average of the top 100 hours in the summer of 2007.

- There are potentially significant financial penalties if the targets are not met.

Peak Reduction Target

- For PPL, this results in the requirement to reduce demand by 300 MW on average for the top 100 load hours in the summer of 2012.
  - In implementing the programs, PPL has elected to double the load reduction for half the number of hours (i.e., 50 hours).
- This will be met through a combination of programs, including:
  - Direct Load Control
  - Load Curtailment
  - Appliance recycling
  - Efficient Equipment Incentive Program for I&C customers

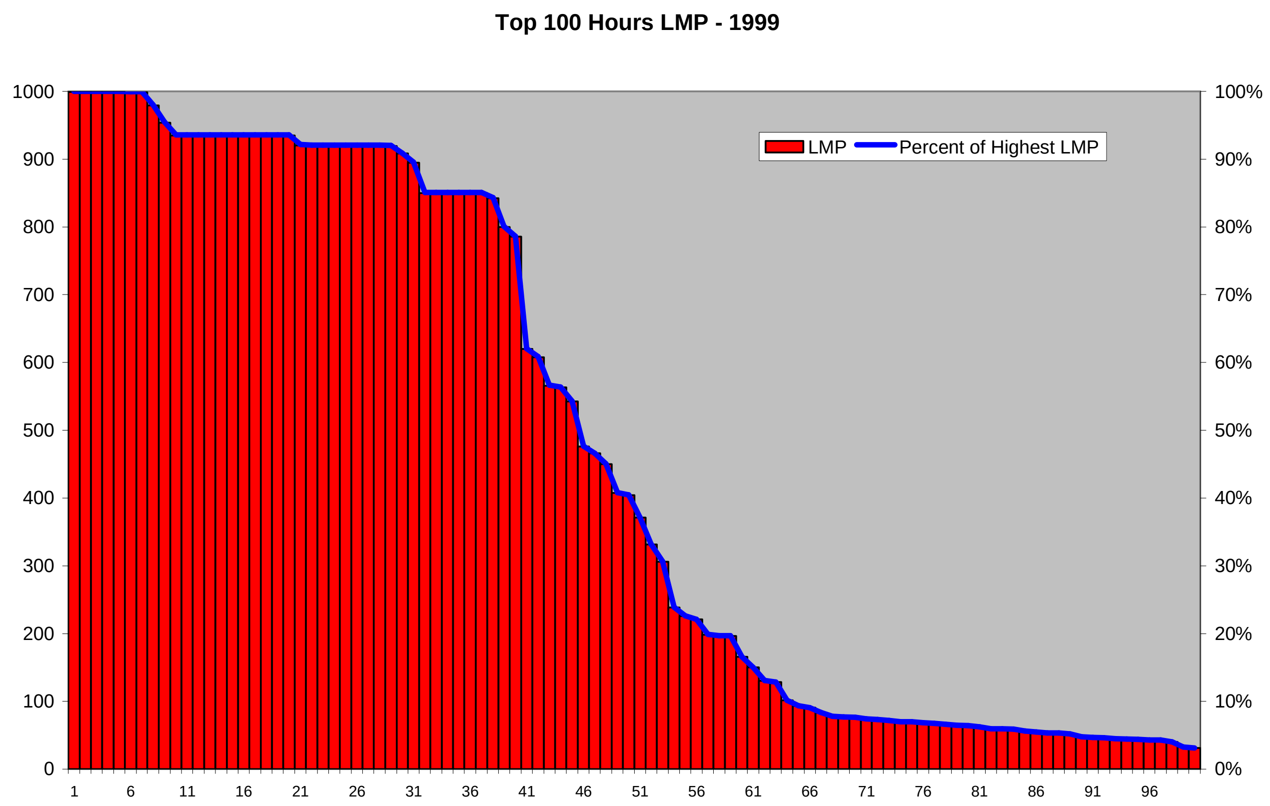
The Trick – How do you know if you have a top one-hundred load-day?

- Forecast next-day and near-term system hourly demand
  - Utilize a real-time neural network modeling framework
- Given forecast, determine if the day is likely to include some of the top one-hundred load hours
- Call an event and execute demand response strategy for selected hours

Why the Top 100 Hours?

Summer peak loads determine the Capacity Obligation for each EDC, so lower peaks should result in lower capacity costs.

Remember 1999? Just a few hours in the summer have significantly higher prices than all remaining hours. Today, even fewer hours have significantly higher prices.



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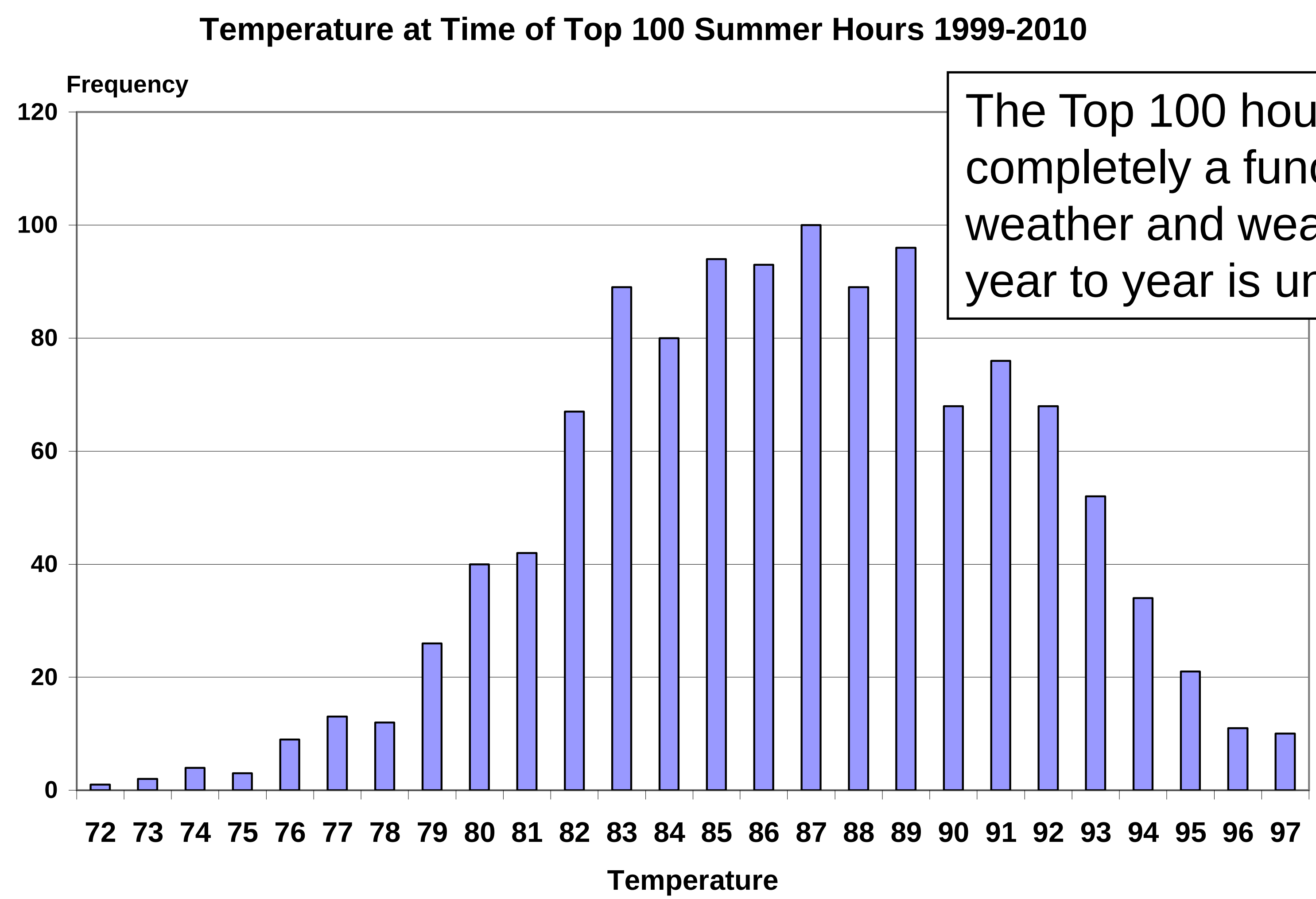
The Challenge



The Top 100 hours are completely a function of weather and weather from year to year is unpredictable.

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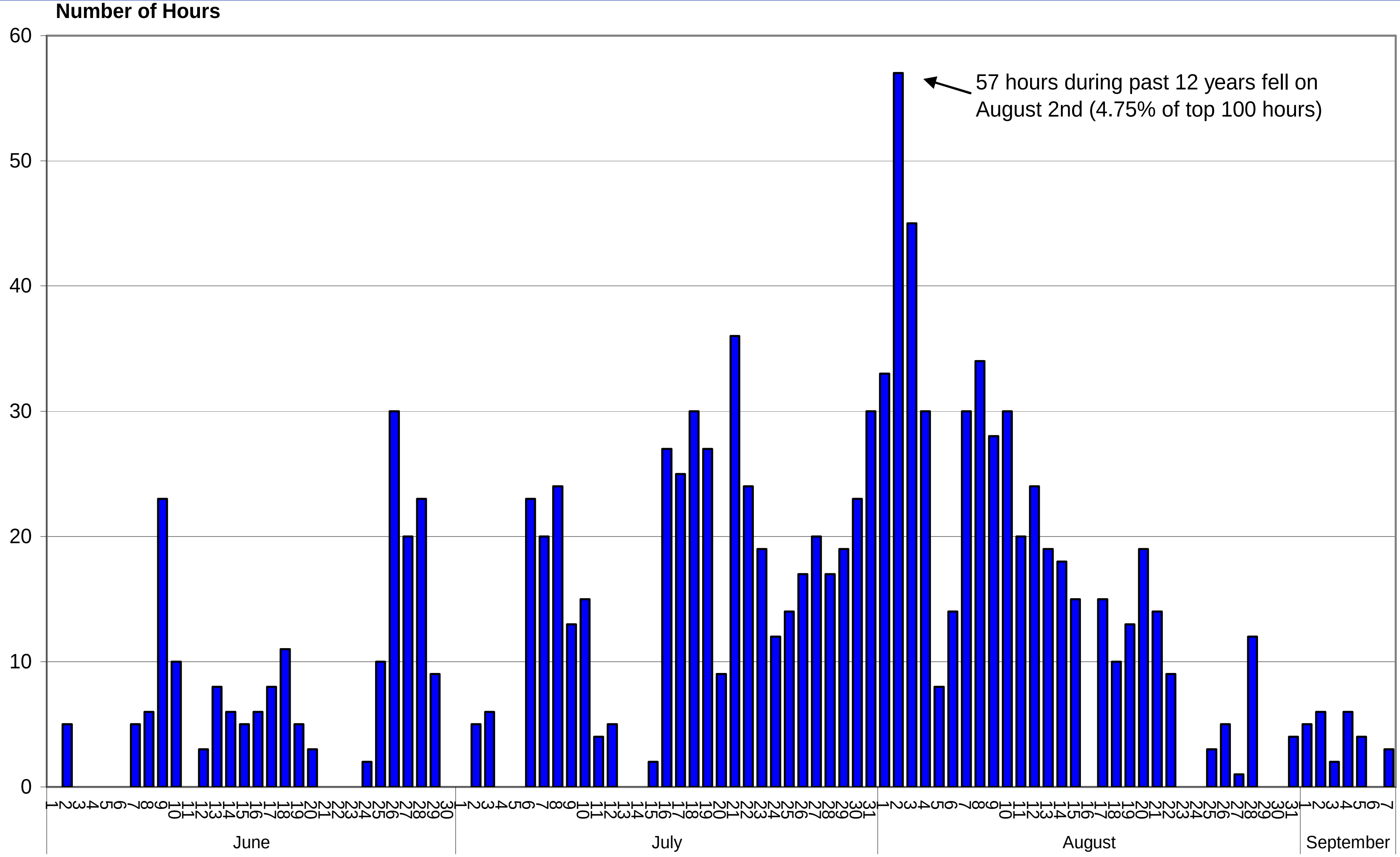
Top 100 Summer Hours by Date 1999-2010



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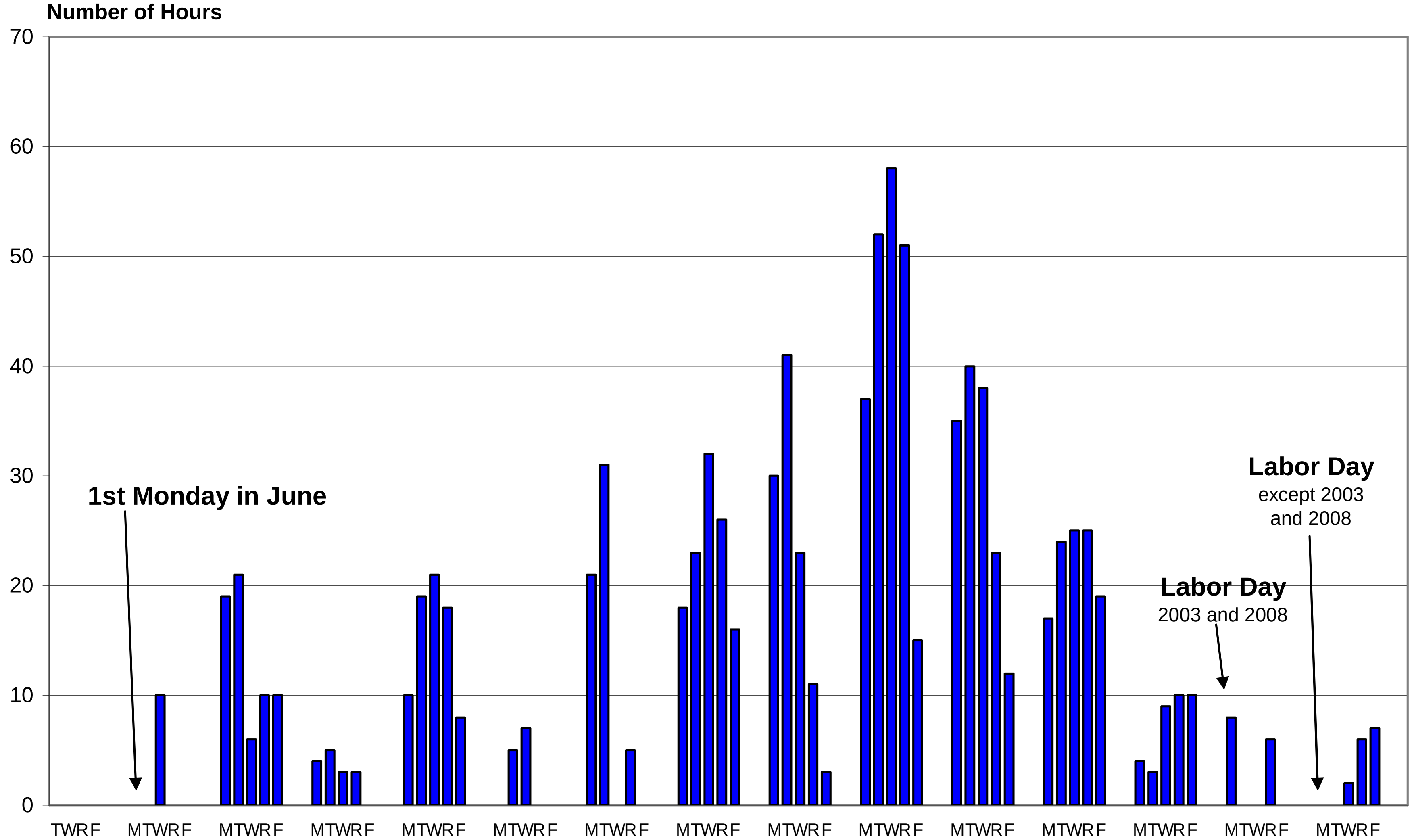
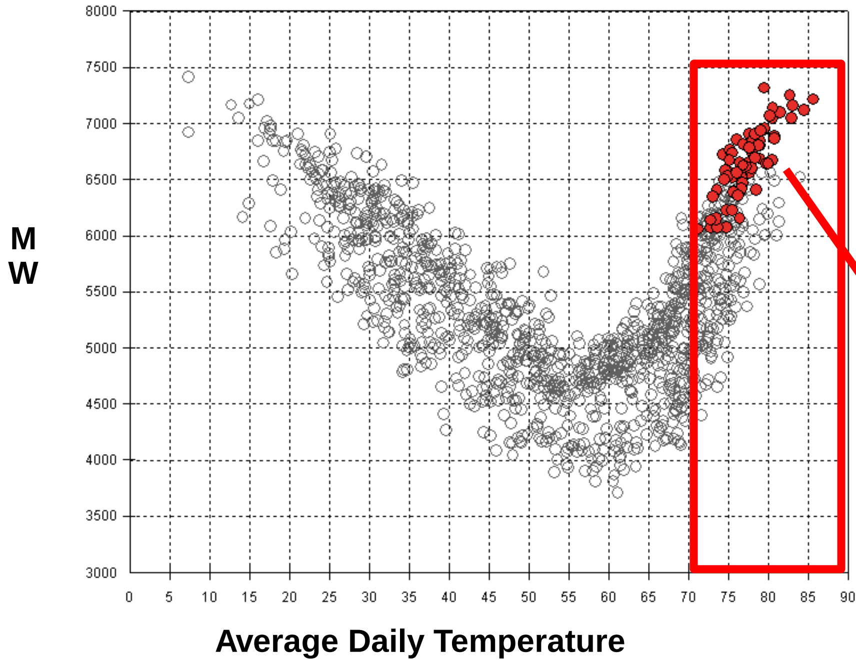
Top 100 Hours Normalized for Day of Week

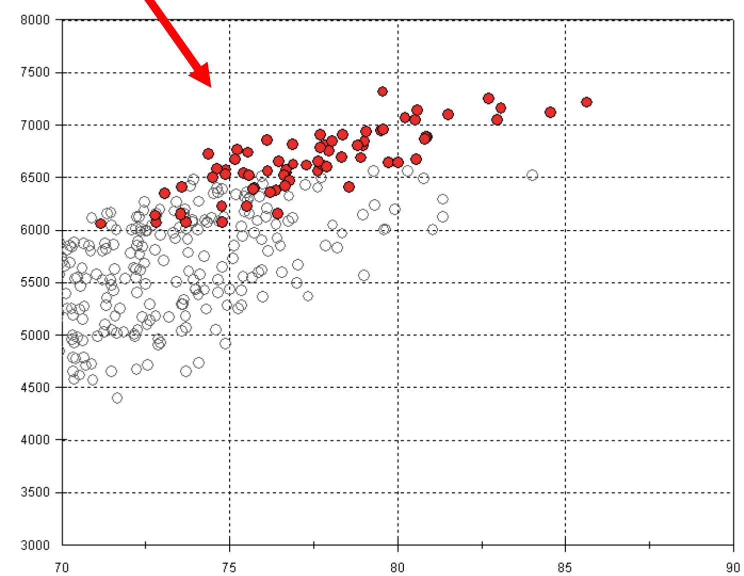


Top One Hundred Load Hour Days (June 2007 to September 2010)



•Top 100 Hour Days
•Other Days

Need to focus on a relatively few days



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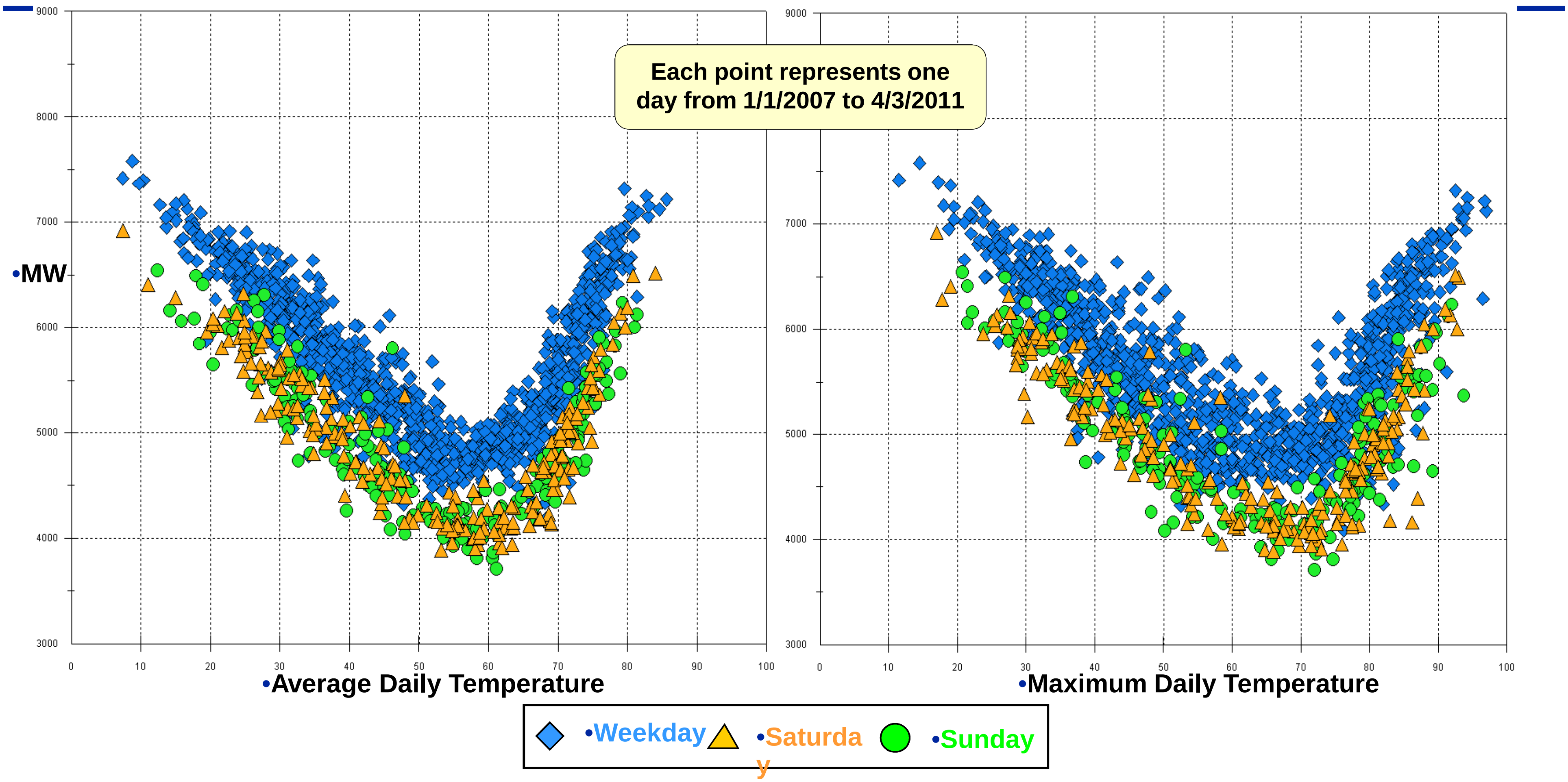
Daily Peak Load vs. Maximum Daily Temperature



- Relationship between peak-day and temperature are non-linear
- Much stronger correlation with average temperature than maximum temperature

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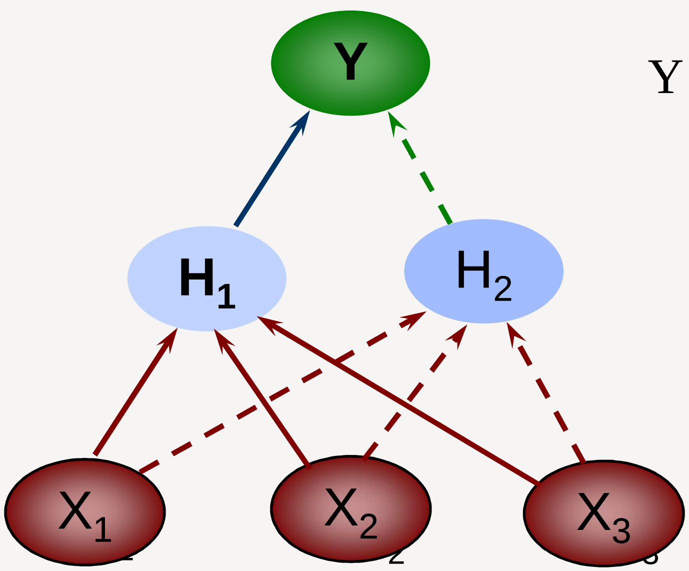
Forecast Day-Ahead and Near-Term Hourly Demand
Daily Energy and Demand Forecasted using ANN Models

- Feed forward Neural Net with a Single Output
- One Hidden Layer with Two Nodes
- Logistic Activation Function in the Hidden Layer
- Linear Activation Function in the Output Layer



$$Y^t = B_0 + B_1 \times H_1^t + B_2 \times H_2^t + u^t$$

$$H_1^t = \frac{1}{1 + e^{-\left(a_0 + a_1 X_1^t + a_2 X_2^t + a_3 X_3^t\right)}}$$

$$H_2^t = \frac{1}{1 + e^{-\left(b_0 + b_1 X_1^t + b_2 X_2^t + b_3 X_3^t\right)}}$$

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Why Neural Network Models Fit Load Data So Well

Highly Interactive

$$\frac{1}{1+e^{-(a_0+a_1X_1+a_2X_2)}} = \frac{e^{a_0+a_1X_1+a_2X_2}}{1+e^{(a_0+a_1X_1+a_2X_2)}}$$

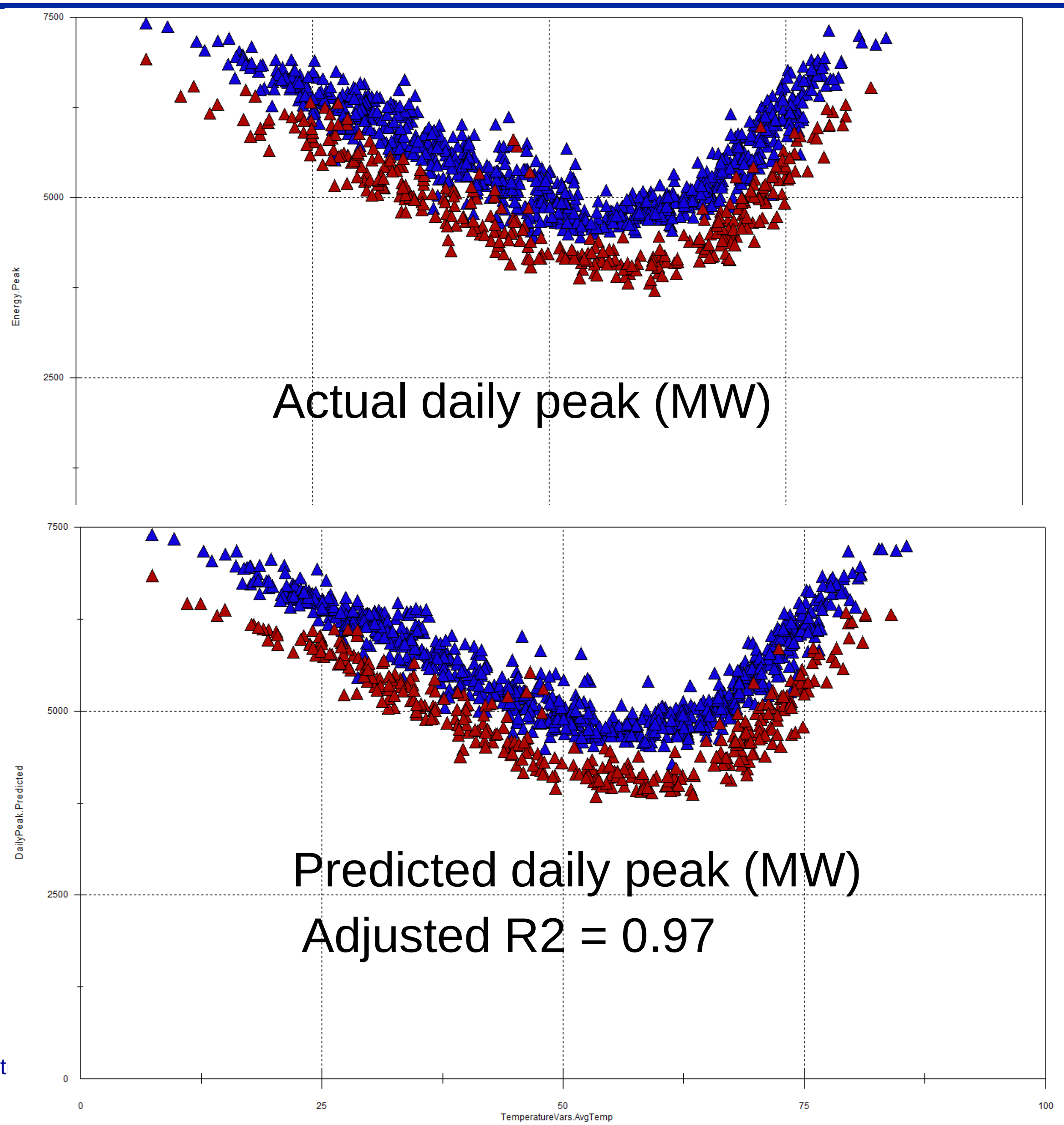
$$= \frac{e^{a_0}e^{a_1X_1}e^{a_2X_2}}{1+e^{a_0}e^{a_1X_1}e^{a_2X_2}}$$

$$= \text{Interactive if } \ a_1 \neq 0, a_2 \neq 0$$

Model Variables (The Xs)

- Interactive Nodes
  - Maximum daily temperature
  - Minimum daily temperature
  - Dew point
  - Lag temperatures
  - Season, Day of the week, Hours of light
- Linear Nodes
  - Month
  - Day of the Week
  - Holidays
  - Daylight Savings

Daily Peak Demand Vs. Daily Average Temperature (Jan 2008 to May 2011)



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Forecast Framework

- We can forecast near-term energy, demand, and hourly loads relatively well – given a reasonable weather forecast
  - But it doesn't tell us if we should call an event day or not
- Can we define the problem in terms of a probabilistic framework?
  - Probability that the next day will include the top 100 load hours
  - Given expected load values and standard errors we should be able to construct a probability distribution and use this information to determine whether to call an event-day or not.

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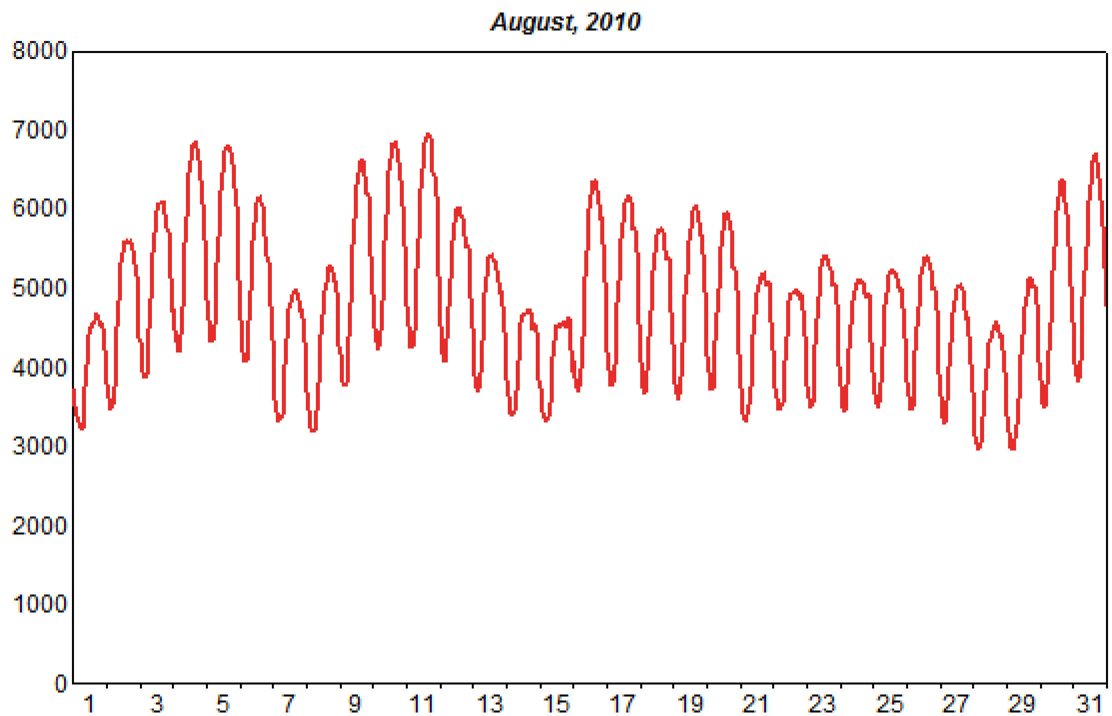
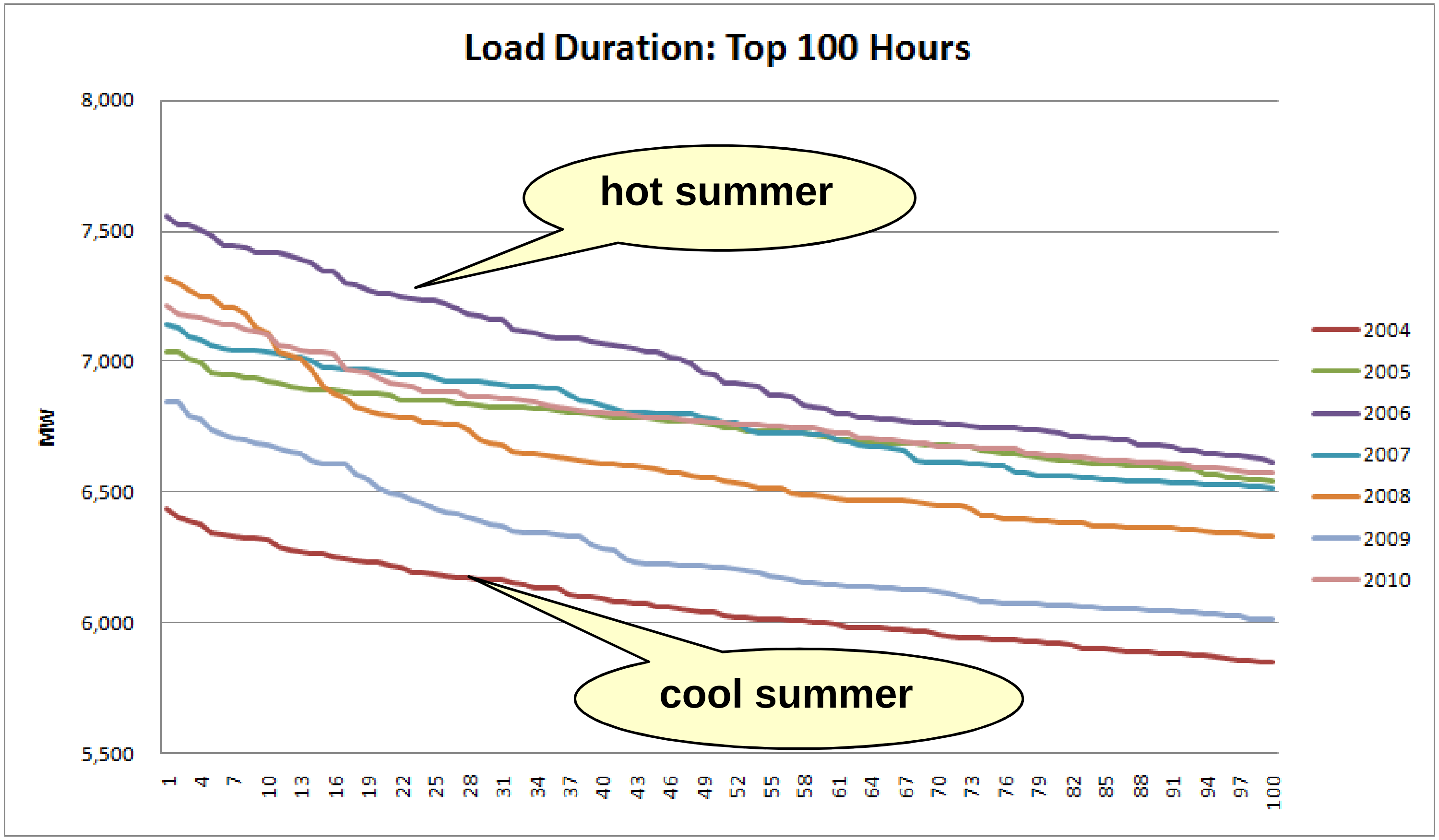
Analysis

- Execute hourly load model with historical weather data
  - Simulate 2010 hourly demand using weather data from 1995 to 2010
  - Sixteen hourly load simulations (one for each year)
  - Derive expected peaks and standard errors for probability model



Hourly Load Simulation Results (2004 – 2010)

- Problem – weather patterns are not random
  - Expected load/weather conditions not much help in a specific year



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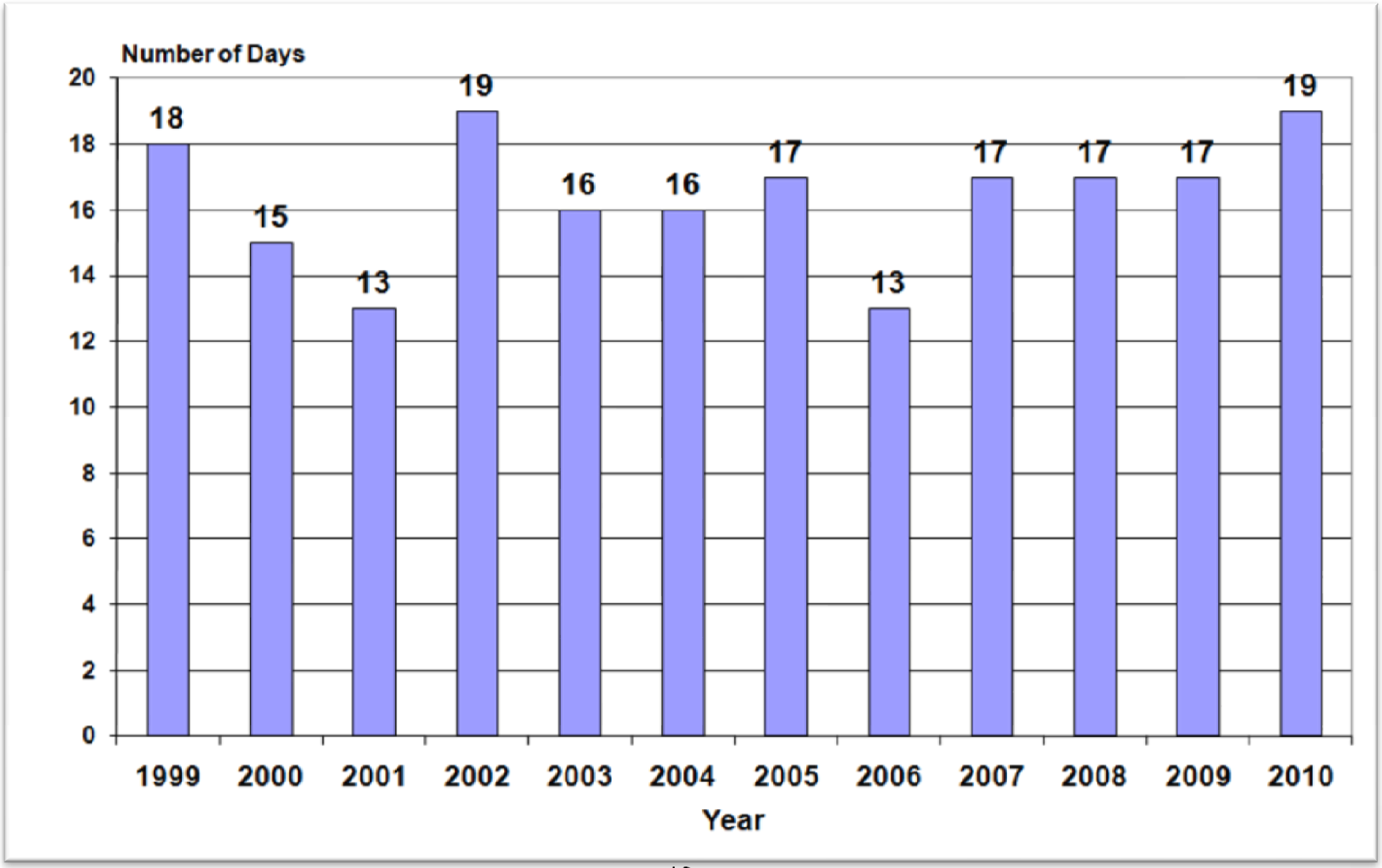
Top 100 Load Days

- Number of days you would have to call an event to catch all 100 top load hours. Average = 17.



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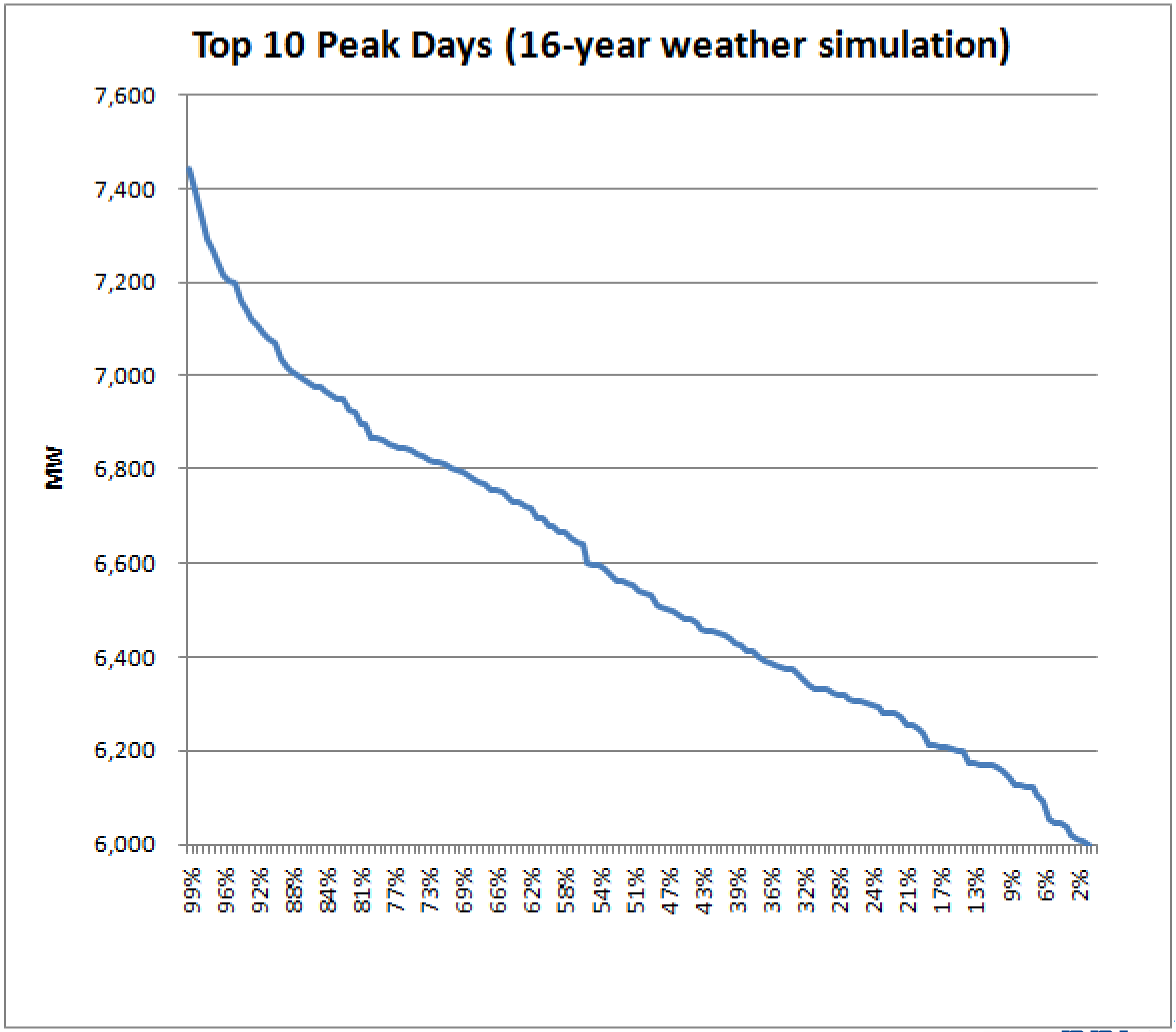
Top 100 Load Days

- The ten highest summer peak days include on average 76% of the top 100 load-hours
- For a “normal” weather pattern, the ten highest summer peak days include 80% of the top 100 load-hours
- Focus on hitting the top-ten summer peak days

Year	Pct of Top 100 Hours In Top-10 Peak Days
1995	81%
1996	66%
1997	76%
1998	63%
1999	74%
2000	75%
2001	79%
2002	71%
2003	80%
2004	78%
2005	74%
2006	82%
2007	80%
2008	80%
2009	82%
2010	76%
Norm	80%
Average	76%

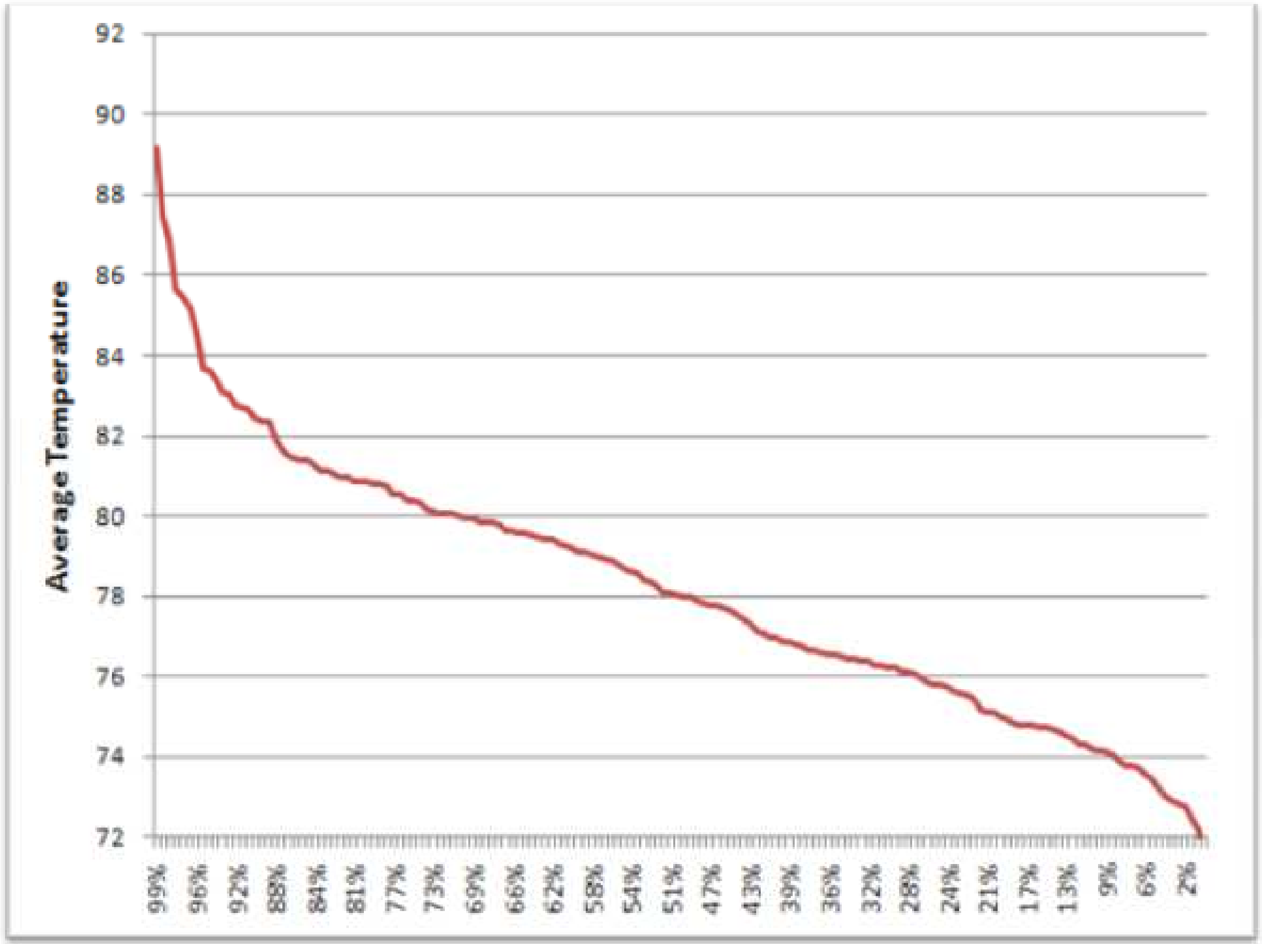
Top 10 Peak-Day Load Distribution

- 50% of the peaks are above 6,500 MW
- 30% of the peaks are above 6,800 MW
- There is a wide distribution even across the top-ten peak days which account for roughly 15% of all summer peak days



Peak-Day Average Temperature Distribution

- 6,500 MW is at approximately 78 degrees
- 6,800 MW is at approximately 80 degrees



Number of Top Ten Days Above 78 and 80 Degrees

- There are years in which all the top-ten load days are above 78 degrees (6,500 MW)
- There are also years in which none or very few days are above 78 degrees

Year	78 Degrees And Above	80 Degrees And Above
1995	10	10
1996	-	-
1997	7	4
1998	1	1
1999	8	6
2000	3	-
2001	7	3
2002	9	5
2003	2	1
2004	-	-
2005	10	9
2006	8	2
2007	5	4
2008	7	4
2009	2	-
2010	10	8
Average	5.6	3.6

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Percent of Peak Days between July 15 and August 15

- Most of the top-ten load days are likely to fall between the middle of July and middle of August

- Certainly means that at the beginning of the summer season you do not want to call too many events unless it is unusually hot

Year	Share
1995	60%
1996	20%
1997	40%
1998	90%
1999	70%
2000	40%
2001	80%
2002	80%
2003	60%
2004	50%
2005	80%
2006	90%
2007	50%
2008	30%
2009	60%
2010	50%
Average	59%

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So What Do We Know

- Most of the top-ten load days are likely to come between the middle of July and the middle of August
- Top-ten load day is not likely to occur on Friday or Weekends (unless it does – like this year)
- In most years an event-day should be called if the load forecasts is 6,800 MW or higher (average temperature 80 degrees or higher)
- Days with projected loads of 6,500 MW or higher are strong candidates for an event-day
- If loads are less than 6,500 MW through the first half of July, may indicate a cool summer and that the load threshold for calling an event should be lower

Rules Based Model

- Factors to consider
  - Seasonal timing
    - Early vs. late in the summer
  - Temperature or load trigger
  - Number of previous alerts called
    - If several alerts have been called early in the year than raise the temperature/load threshold for future alerts

Dt	IsPeakDt	WkDay	DBTrigger	DBAdj	DBTriggerAdj	Alert	AlertCount	AlertCorrect
7/12/2010	0	2	76.5	0	77	0	0	0
7/13/2010	0	3	76.5	0	77	1	1	0
7/14/2010	1	4	76.5	0	77	1	2	1
7/15/2010	1	5	76.5	0	77	1	3	1
7/16/2010	1	6	76.5	0	77	1	4	1
7/17/2010	0	7	0	0	0	0	4	0
7/18/2010	0	1	0	0	0	0	4	0
7/19/2010	0	[illegible]	[illegible]	[illegible]	77	0	4	0
7/20/2010	0	[illegible]	[illegible]	[illegible]	77	0	4	0
7/21/2010	0	[illegible]	[illegible]	[illegible]	77	0	4	0
7/22/2010	0	[illegible]	[illegible]	[illegible]	77	0	4	0
7/23/2010	0	6	[illegible]	0	77	1	5	0
7/24/2010	0	[illegible]	0	0	0	0	5	0
7/25/2010	0	[illegible]	0	0	0	0	5	0
7/26/2010	0	2	76.5	0	77	1	6	0
7/27/2010	1	3	76.5	0	77	1	7	1
7/28/2010	0	4	76.5	0	77	1	8	0
7/29/2010	0	5	76.5	[illegible]	77	1	9	0
7/30/2010	0	[illegible]	[illegible]	[illegible]	77	1	10	0
7/31/2010	0	[illegible]	[illegible]	[illegible]	0	0	10	0
8/1/2010	0	[illegible]	[illegible]	[illegible]	0	0	10	0
8/2/2010	1	[illegible]	[illegible]	[illegible]	77	1	11	1
8/3/2010	1	[illegible]	[illegible]	[illegible]	77	1	12	1
8/4/2010	1	4	76.5	0	77	1	13	1
8/5/2010	0	5	76.5	0	77	1	14	0
8/6/2010	0	6	76.5	0	77	0	14	0
8/7/2010	0	7	0	0	0	0	14	0
8/8/2010	0	1	0	0	0	0	14	0
8/9/2010	0	[illegible]	[illegible]	[illegible]	77	0	14	0
8/10/2010	0	[illegible]	[illegible]	[illegible]	77	0	14	0
8/11/2010	0	[illegible]	[illegible]	[illegible]	77	0	14	0
8/12/2010	0	[illegible]	[illegible]	[illegible]	77	1	15	0
8/13/2010	0	[illegible]	[illegible]	[illegible]	77	1	16	0
8/14/2010	0	[illegible]	[illegible]	[illegible]	[illegible]	0	16	0
8/15/2010	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16	0
8/16/2010	1	[illegible]	[illegible]	[illegible]	77	1	17	1
8/17/2010	1	3	76.5	0	77	1	18	1
8/18/2010	1	4	76.5	0	77	1	19	1

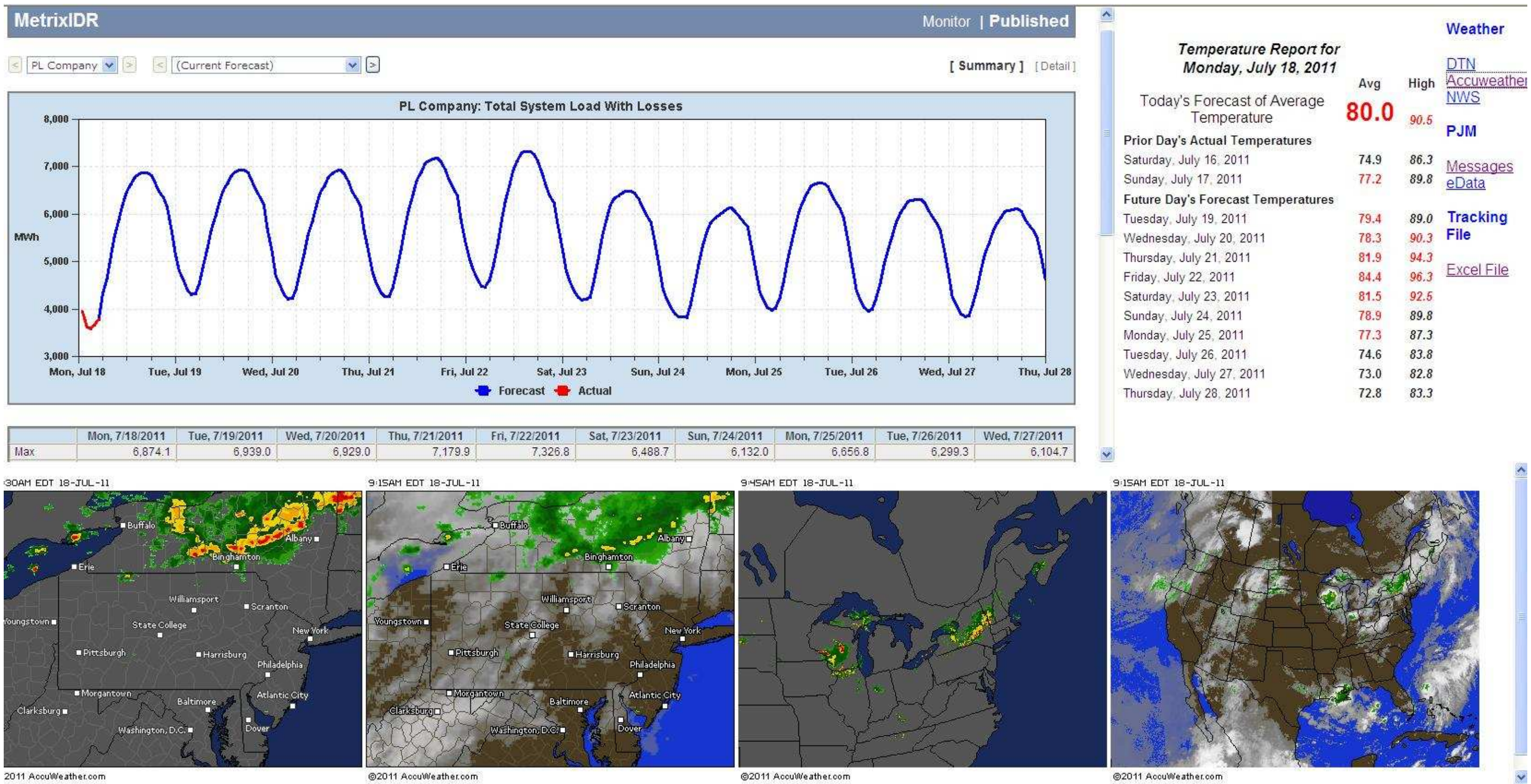
Indicates one of the top-10 peak days

Indicates that we would issue an alert based on the rules.

Indicates that we would have correctly called an alert on one of the top 10-days.

Daily Operations

PPL created a web interface for daily monitoring of the forecasted load, forecast of temperatures, and current weather patterns. Itron's Metrix IDR is used for the hourly load forecast model.



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Daily Operations – Typical Problem

On July 18th, forecasting temperatures near 100 degrees by the end of the week with five days where peak loads exceeded 6,800 MW.

At this point we had already called events for 6 days (32 hours).

Given we still have the peak summer period ahead, what should we do?

	Mon, 7/18/2011	Tue, 7/19/2011	Wed, 7/20/2011	Thu, 7/21/2011	Fri, 7/22/2011
Max	6,848.7	6,940.6	6,911.1	7,215.4	7,377.4
Min	3,586.1	4,346.6	4,184.0	4,265.1	4,487.1
Avg	5,569.1	5,823.6	5,711.3	5,937.1	6,057.8
Total	133,659.6	139,766.4	137,071.1	142,490.5	145,387.3
10:00	5,916.6	6,005.4	5,840.9	6,088.0	6,312.9
11:00	6,234.4	6,299.9	6,154.4	6,459.8	6,679.4
12:00	6,474.8	6,540.2	6,412.7	6,751.8	6,993.2
13:00	6,633.4	6,681.6	6,570.7	6,928.3	7,176.2
14:00	6,756.5	6,835.0	6,748.9	7,100.9	7,343.7
15:00	6,820.0	6,895.6	6,834.6	7,165.8	7,377.4
16:00	6,835.4	6,931.6	6,893.4	7,199.0	7,361.2
17:00	6,848.7	6,940.6	6,911.1	7,215.4	7,301.3
18:00	6,808.5	6,865.8	6,834.0	7,147.6	7,157.7
19:00	6,672.5	6,694.3	6,645.4	6,970.8	6,896.7
20:00	6,497.5	6,506.4	6,438.4	6,750.6	6,621.7
21:00	6,362.4	6,346.3	6,288.2	6,581.0	6,420.7
22:00	6,193.5	6,174.3	6,118.5	6,416.4	6,252.8
23:00	5,674.9	5,664.4	5,608.1	5,882.6	5,780.9
24:00	5,194.5	5,183.1	5,128.2	5,386.7	5,278.1

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Performance to Date

- What we did for that week (July 18th to July 22)
  - Called an alert every day (5 alerts, 28 hours)
  - Captured the system peak-day to date: 7,537 MW
    - Friday, July 22, max temp103 degrees, average temp 89.5 degrees

- To Date Results
  - Called 11 event days for 60 hours
  - Captured 56% of the top 100 hours to date
  - If no additional events are called, we would still have captured 50% of the top 100-hours even if 35 hours exceed 6,651 MW
    - Hopefully we are done for the summer

Conclusions

- Given the nature of the problem can't really address it using a meaningful probabilistic framework
  - Can't use an expected load forecast to evaluate probability of next-day and near-term load forecast including top 100 hours.
    - Weather patterns are not random – we seem to get cool summer or hot summer weather patterns with not much in-between.
- Can assess qualitative information to help make reasonable decision
  - Decision to call an alert based on load and weather forecasts, number of alerts already called, day of the week, where we are in the summer period, and gut feeling.
- Best strategy is to take next summer off