PJM Short-Term Load Forecasting Overview

October 5, 2023

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Topics

- Why is Short-Term Forecasting Important?
- Inputs to the Forecast
- How Forecast is Developed
- Forecast Timeline
- Forecast Error Monitoring and Reporting
- Solar Growth including Behind the Meter
- Five-minute Forecast

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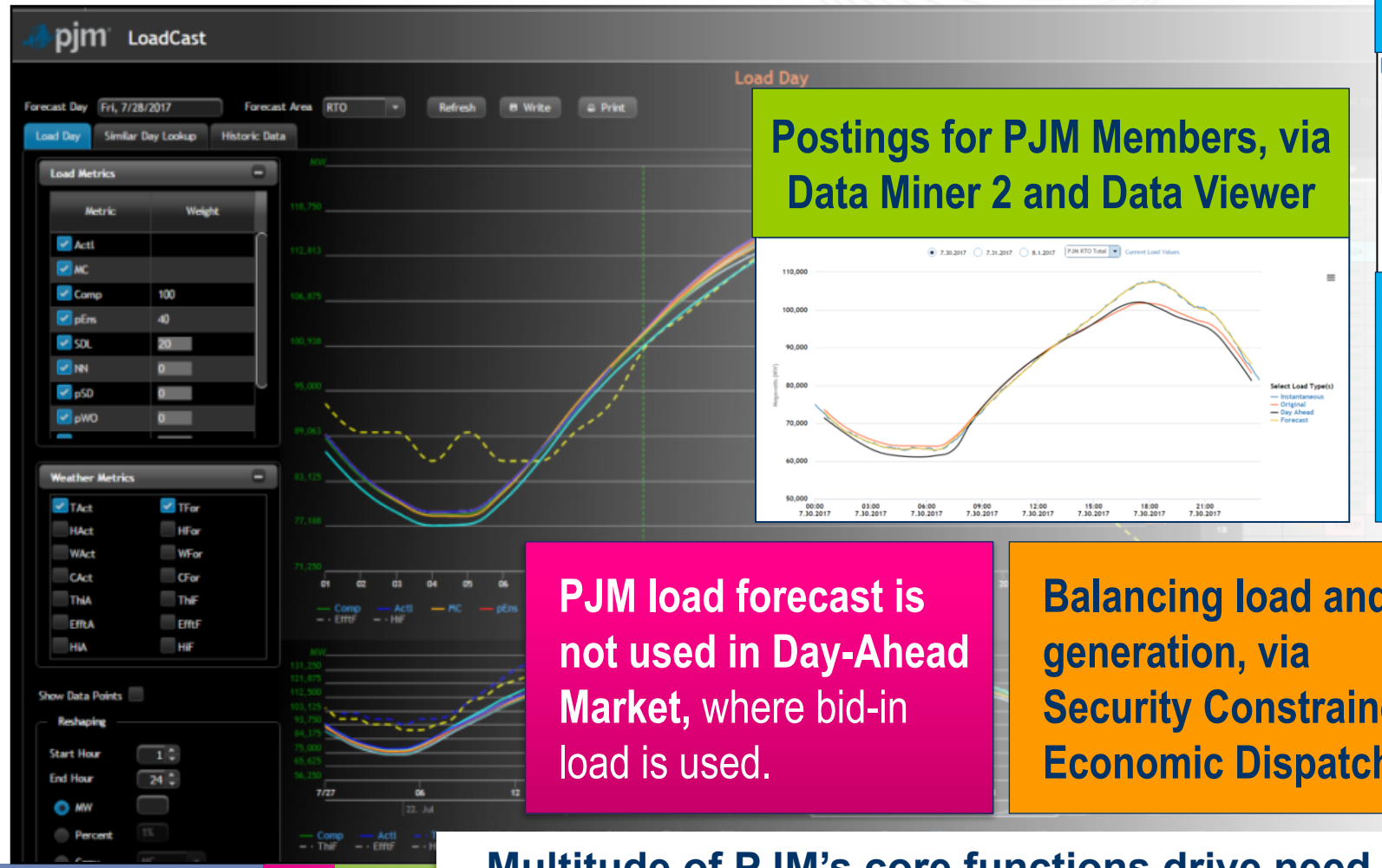
Why Is Short-Term Load Forecasting Important?

From Dispatch LoadCast tool, load forecast is used for…



Postings for PJM Members, via Data Miner 2 and Data Viewer

PJM Operations and Markets functions, via in-house tools

- Day-ahead unit commitment
- Maintenance margin calculations
- Approving generation and transmission equipment outage requests

PJM load forecast is not used in Day-Ahead Market, where bid-in load is used.

Balancing load and generation, via Security Constrained Economic Dispatch

Multitude of PJM's core functions drive need for accurate short-term load forecast.

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Load Forecast Inputs

Weather Forecast

- Weighted average of three vendors
- Adjusted based on performance

Load Forecast Model

- Historical load and weather actuals
- Day of week/ holiday flag
- 15 models

Manual Adjustment

- Dispatch modifies forecasts throughout shift.
- Forecast team provides support.

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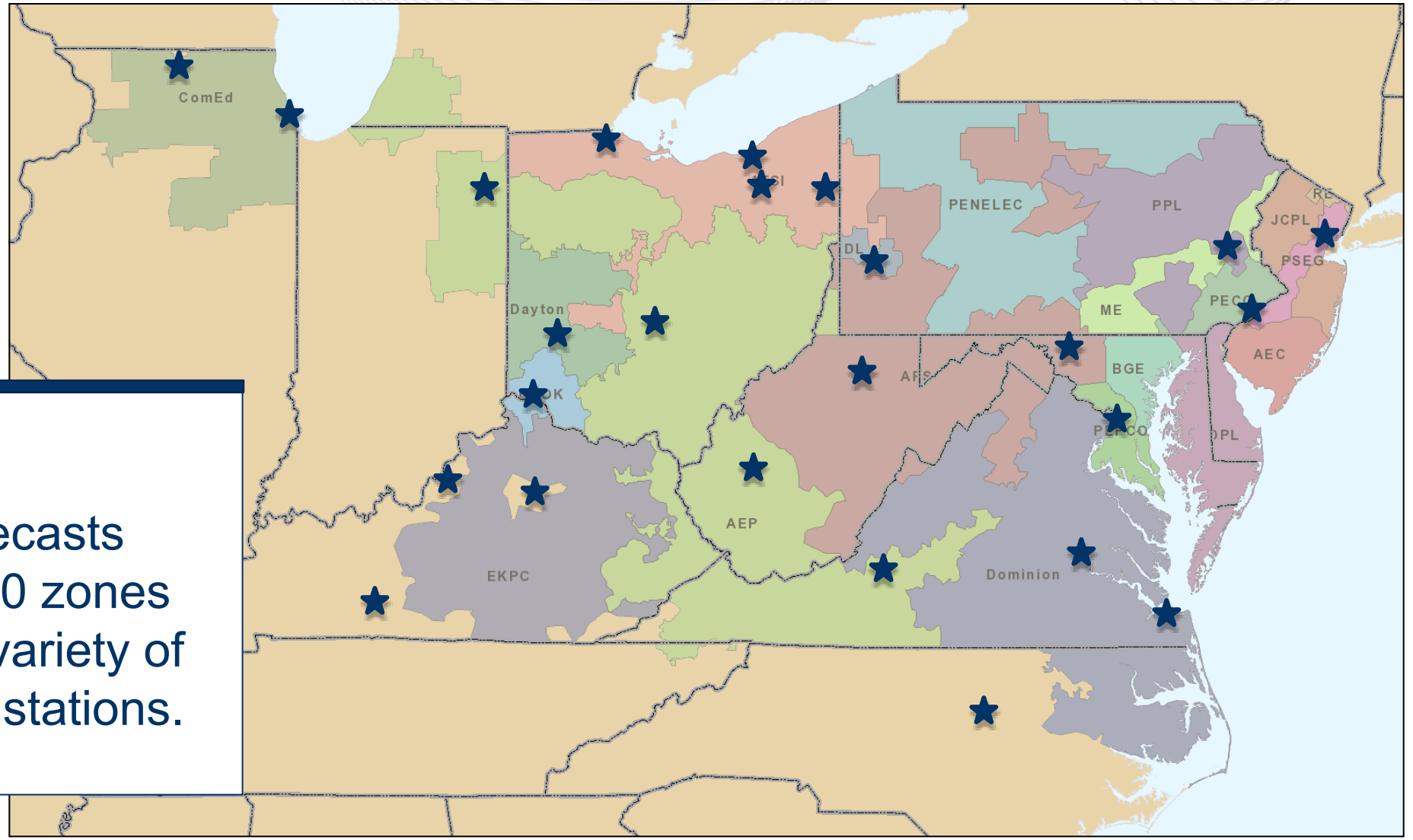
Forecasting Zones



PJM forecasts load in 10 zones using a variety of weather stations.

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Weather Is Crucial

Thu, 8/12/2021

Area	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
ORD	83	80	79	79	78	77	75	75	75	77	79	81	83	85	87	89	89	87	87	86	84	82	81	79
MDW	82	82	82	81	80	79	79	77	78	79	80	82	85	87	88	89	88	88	87	86	84	83	82	81
RFD	80	79	79	77	75	71	68	67	68	72	77	81	84	86	88	90	91	90	89	87	85	82	79	76
DPA	78	79	78	77	76	75	73	72	73	75	78	80	83	85	85	88	87	87	87	84	82	80	78	77
CMH	78	79	78	77	77	77	77	75	76	79	82	85	87	89	90	92	91	91	89	87	86	82	81	79
FWA	78	77	77	77	77	77	77	76	77	78	80	80	82	83	85	85	84	84	83	82	81	78	77	75
CRW	76	75	75	73	73	73	72	72	74	77	81	85	87	90	92	93	94	92	91	88	85	82	80	78
ROA	76	75	74	73	73	73	74	74	76	80	84	88	91	93	93	94	91	92	91	90	88	85	83	82
CAK	73	74	73	73	74	75	75	75	76	79	82	85	87	89	89	88	88	86	83	82	80	78	77	76
CLE	76	76	74	75	77	77	77	76	77	80	82	85	86	86	84	84	85	84	83	81	79	78	77	76
TOL	77	77	77	77	79	79	79	78	78	80	81	83	85	85	85	87	89	87	85	84	81	79	77	77
YNG	72	73	70	71	73	74	74	75	76	78	81	83	86	87	88	86	84	83	82	81	79	76	74	73
CVG	80	80	79	78	78	77	76	77	77	80	83	85	87	89	90	91	92	93	92	90	87	85	83	82
BWG	83	82	81	80	78	77	76	77	79	82	85	88	91	93	94	95	95	94	94	92	89	87	85	83
SDF	85	84	84	83	82	82	81	79	81	83	85	88	91	93	94	95	96	97	95	93	91	89	88	87
LEX	79	77	77	76	76	75	74	74	75	78	81	84	86	87	89	90	90	90	89	87	84	82	80	79
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HGR	74	75	74	72	72	73	73	72	74	78	82	86	90	93	95	97	98	99	97	96	92	89	87	85
CKB	73	72	72	71	70	69	69	71	74	77	81	84	87	89	90	91	93	91	90	88	85	82	79	78
PHL	78	76	75	75	75	76	76	77	78	81	84	87	90	93	94	95	97	96	95	93	91	89	87	86
ABE	73	72	72	72	71	71	70	71	74	78	81	85	88	91	93	94	95	94	92	91	88	86	83	81
DCA	79	77	75	76	76	76	76	75	77	81	84	88	92	94	96	98	99	98	96	94	91	89	87	86
ORF	81	80	79	79	78	78	78	78	80	82	85	88	90	92	93	94	95	94	93	91	89	87	85	84
RIC	75	76	75	73	72	74	74	76	77	81	85	88	90	93	94	95	96	96	93	90	88	85	84	83
IAD	75	75	73	73	72	72	71	71	75	79	83	88	92	95	96	98	98	96	95	93	90	87	85	83
RDU	80	80	78	77	77	76	75	75	78	81	85	88	91	93	95	97	95	94	93	91	88	85	83	83
EWR	78	79	76	75	76	76	76	76	78	82	85	89	92	94	96	97	98	98	97	95	92	90	89	86

Area	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23

Thu, 8/12/2021

Thu, 1/31/2019

Area	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
ORD	-21	-22	-22	-22	-22	-22	-21	-21	-21	-20	-18	-15	-12	-10	-8	-6	-5	-5	-5	-5	-5	-4	-3	-3
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MDW	-18	-19	-19	-19	-19	-19	-19	-18	-18	-17	-15	-13	-10	-7	-5	-3	-2	-2	-2	-2	-2	-1	-1	0	1
	12	12	11	11	10	10	10	10	10	10	10	10	10	10	9	9	9	8	7	7	7	7	6	6
RFD	-22	-23	-23	-24	-25	-26	-26	-25	-25	-23	-21	-18	-15	-12	-10	-8	-7	-7	-6	-6	-6	-5	-5	-5
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FWA	-11	-12	-12	-12	-13	-13	-13	-13	-12	-10	-8	-6	-3	-1	1	2	3	3	2	2	1	2	2	3
	13	13	12	12	12	11	11	11	11	11	11	11	11	11	10	9	8	7	7	5	5	4	4	5
CRW	8	8	7	6	6	5	5	4	5	6	8	10	13	15	17	18	19	18	17	16	16	15	15	15
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ROA	15	14	13	12	11	11	11	11	12	14	16	19	21	24	28	28	27	26	24	23	22	22	21	20
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CAK	-6	-6	-6	-7	-8	-8	-9	-7	-7	-6	-4	-2	0	2	3	4	5	5	3	3	3	3	3	3
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CLE	-5	-6	-7	-7	-7	-8	-8	-7	-6	-5	-4	-2	0	2	3	4	5	4	3	3	2	2	2	1
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YNG	-5	-5	-6	-7	-8	-8	-8	-9	-8	-7	-5	-3	0	2	3	4	4	4	3	2	2	2	2	1
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CVG	0	0	-1	-2	-3	-4	-4	-4	-3	-1	2	4	7	10	12	13	13	14	13	13	13	13	13	14
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BWG	13	14	14	14	14	14	14	14	16	17	19	20	23	25	27	29	30	30	28	27	26	26	26	26
	3	3	3	2	2	2	2	2	2	3	3	3	4	4	3	4	4	4	4	5	5	5	5	5
SDF	5	5	5	6	6	6	5	5	5	7	10	12	15	17	19	22	22	22	21	21	21	21	21	21
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LEX	6	5	5	6	5	5	5	5	6	7	10	11	14	16	19	20	21	20	20	19	19	19	19	19
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DAY	-3	-3	-4	-4	-6	-6	-6	-6	-5	-3	-1	2	4	7	8	10	11	10	10	9	9	9	10	10
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PHL	12	12	11	10	10	10	10	9	8	10	11	12	13	14	15	18	16	16	16	16	16	15	15	14
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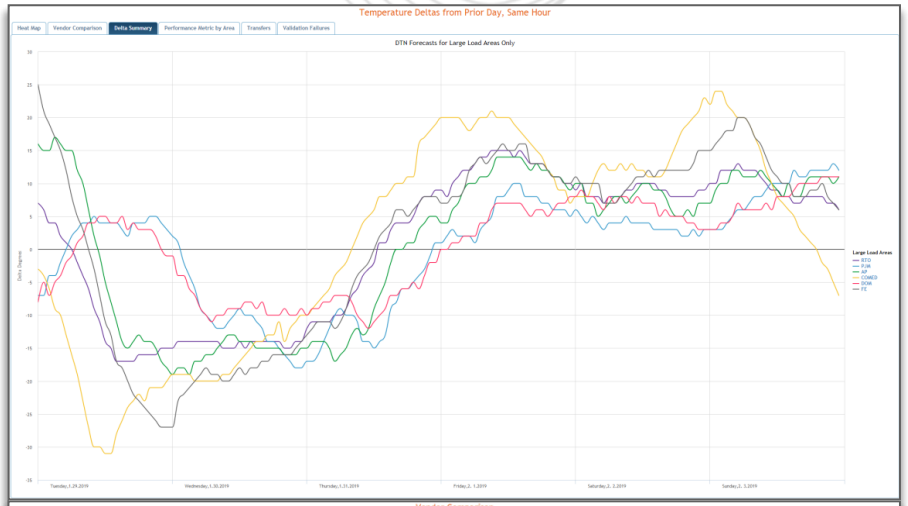
ABE	5	4	3	3	3	3	2	3	3	4	5	7	8	10	12	13	14	12	11	10	10	10	9	9
	8	8	8	8	8	9	9	10	10	11	12	12	12	12	12	11	10	9	8	7	7	7	7	7
DCA	16	16	15	14	14	14	14	14	15	16	17	18	19	20	21	22	24	23	22	21	20	19	18	18
	8	8	8	8	8	7	8	8	9	9	9	10	10	10	9	9	8	6	5	4	3	3	2	2
ORF	28	27	26	25	25	24	23	23	23	24	25	27	29	30	32	33	33	32	31	29	29	28	28	28
	11	11	10	11	11	11	11	11	11	11	11	11	10	9	9	9	9	8	8	7	6	6	6	6



- PJM uses forecasts from three weather vendors.
- Several tools help visualize data, identify trends and highlight anomalies.

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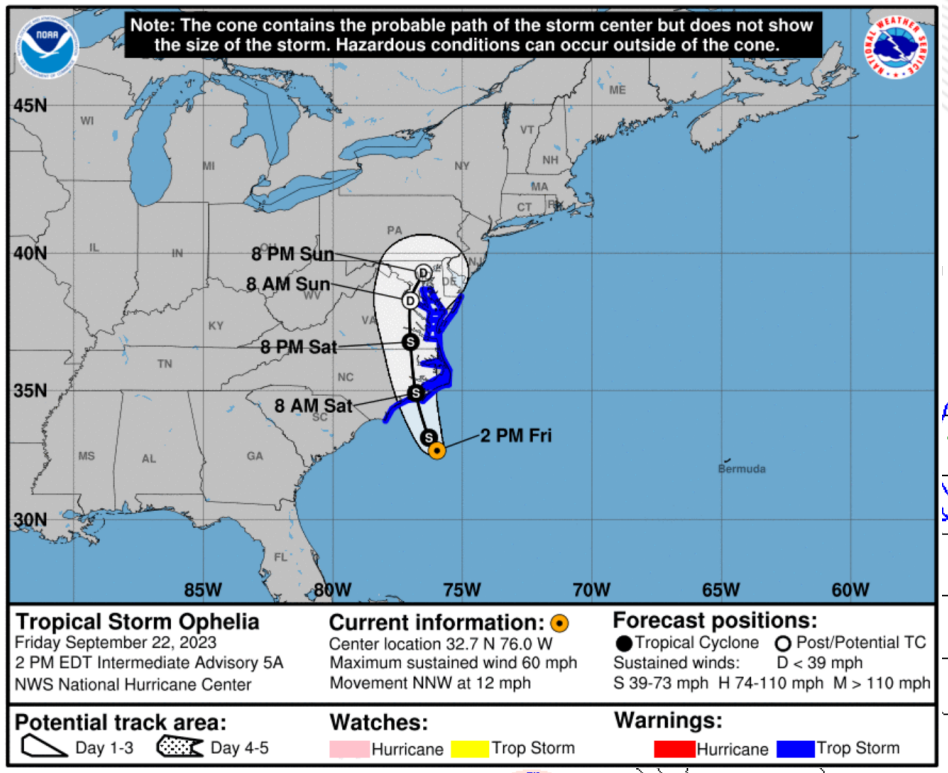
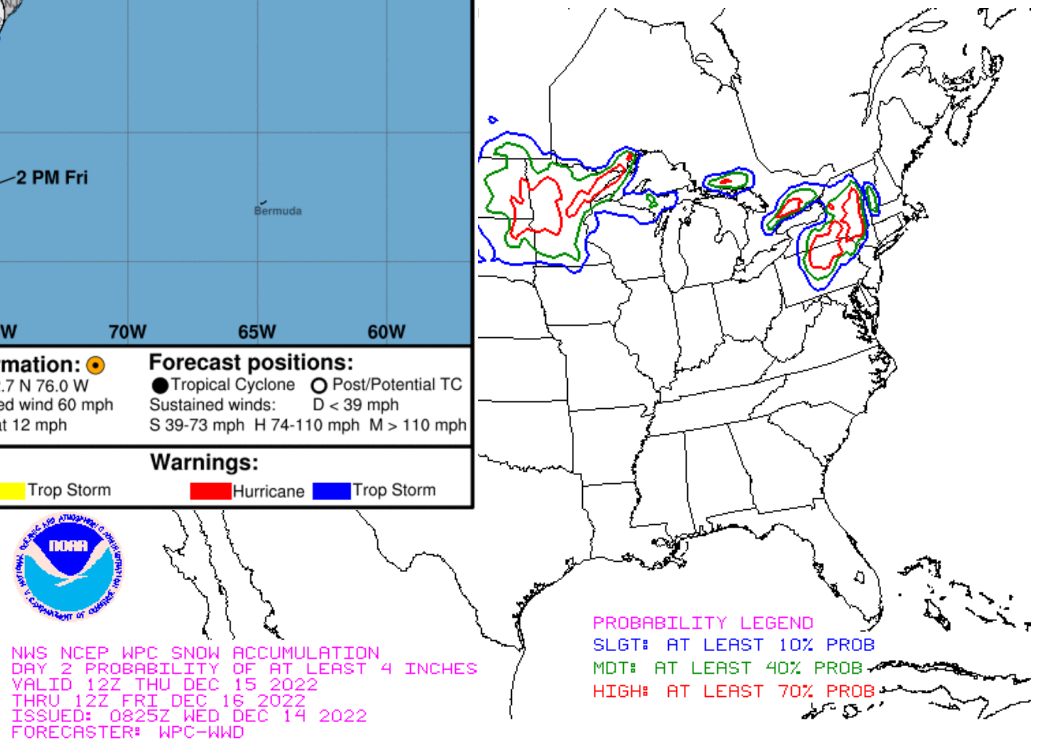
Preparing for Severe Weather





A number of tools help us monitor upcoming weather situations:

- Publicly available data
- PJM-developed applications
- Vendor tools and data
  - Weather forecasts
  - Wind turbine icing and high-speed cutoff

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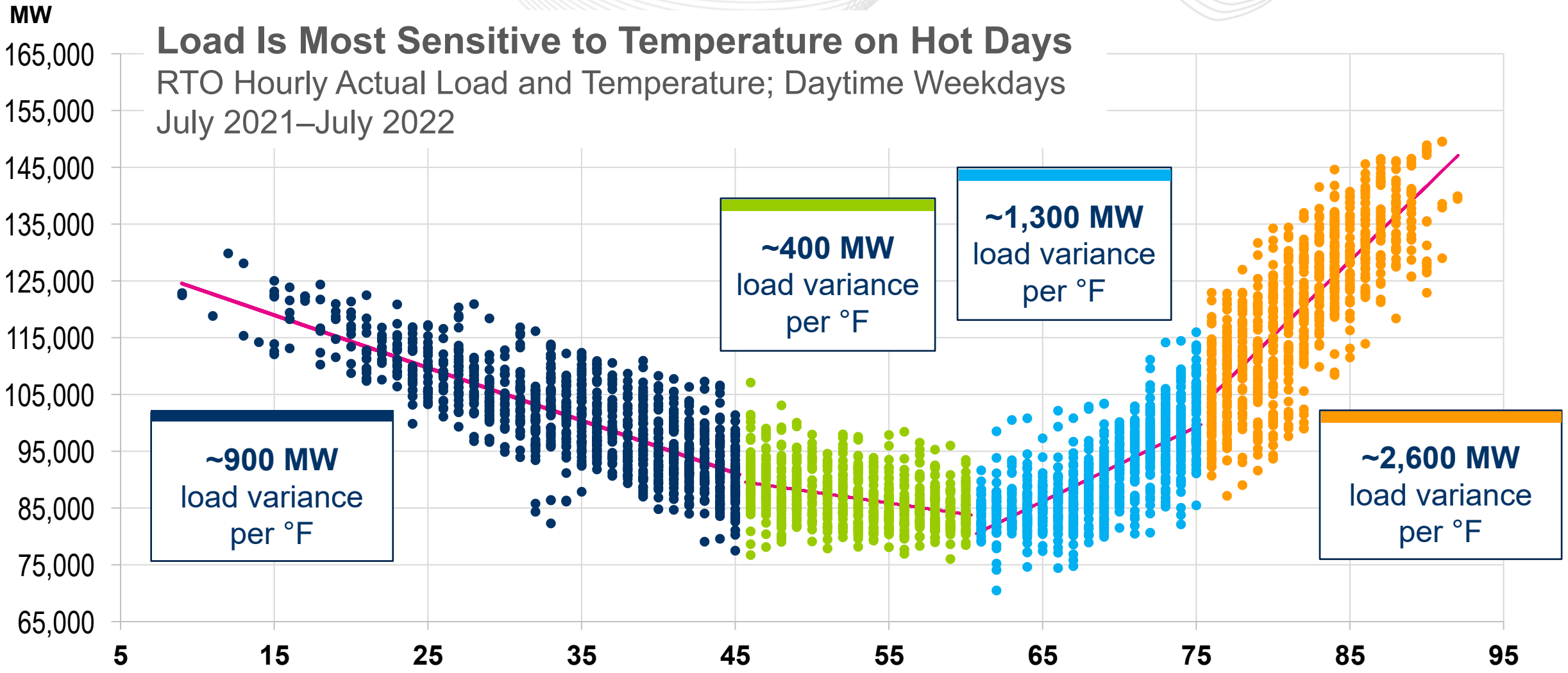
Load Sensitivity to Temperature



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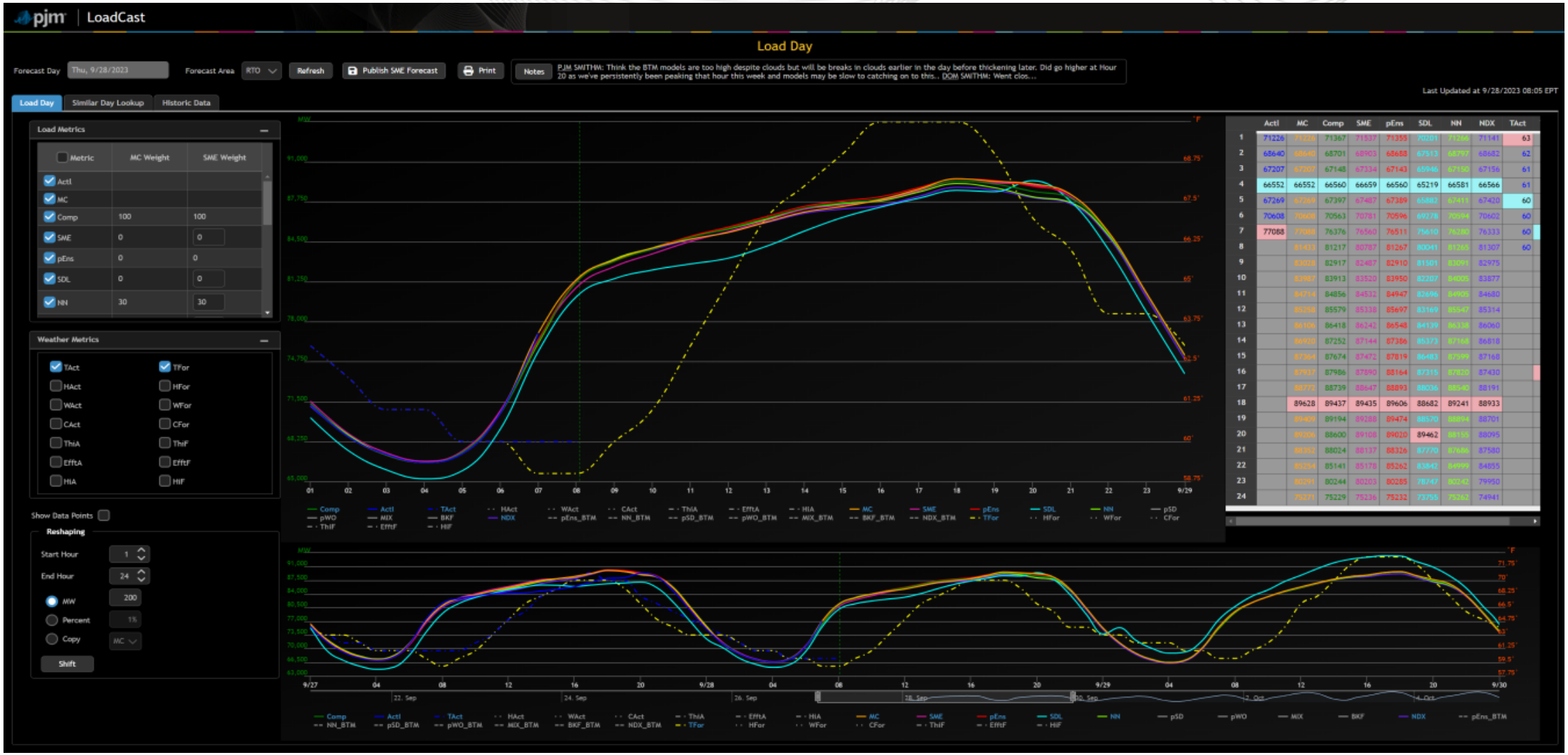
Hourly Load Forecast



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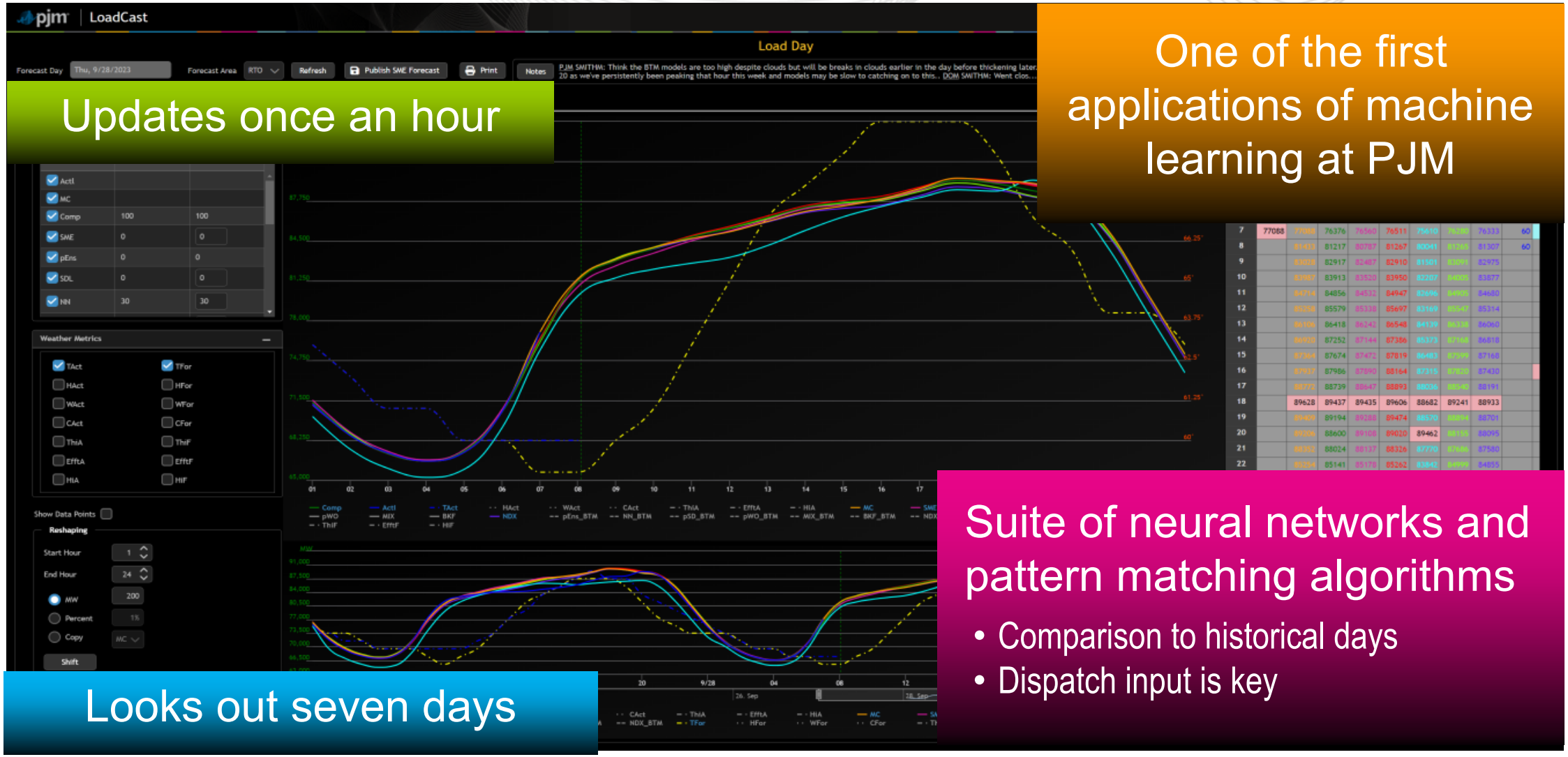
Hourly Load Forecast



Updates once an hour

One of the first applications of machine learning at PJM

Suite of neural networks and pattern matching algorithms

- Comparison to historical days
- Dispatch input is key

Looks out seven days

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Eight Load Forecast Models

Neural Networks Progressively learning system	**Temperature Based:** Uses historical load and forecasted and historical temps	**Weather Indexed:** Uses historical THI/effective temp. instead of temperature
	Weather Optimized: Optimized for sudden changes in weather patterns	**Backfill:** Configuration to handle sudden changes in weather patterns
Pattern Matching Algorithms Looks for similar historical days	**Similar Day:** Uses weather pattern matching	**Similar Day Lookup:** Suggests a number of similar days from which operator can choose
Blended Models "Best weighted most" average	**Ensemble:** Uses ***vendor-provided forecasts***	**Mix:** Uses ***PJM forecasts***

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Models Optimize for Various Factors

	Normal	Holiday	Drastic weather change	Extreme temps.	High humidity or wind
Temperature Based	✓				
Weather Indexed					✓
Weather Optimized			✓	✓	
Backfill			✓	✓	
Similar Day Lookup	✓	✓			
Ensemble	✓				
Mix	✓				

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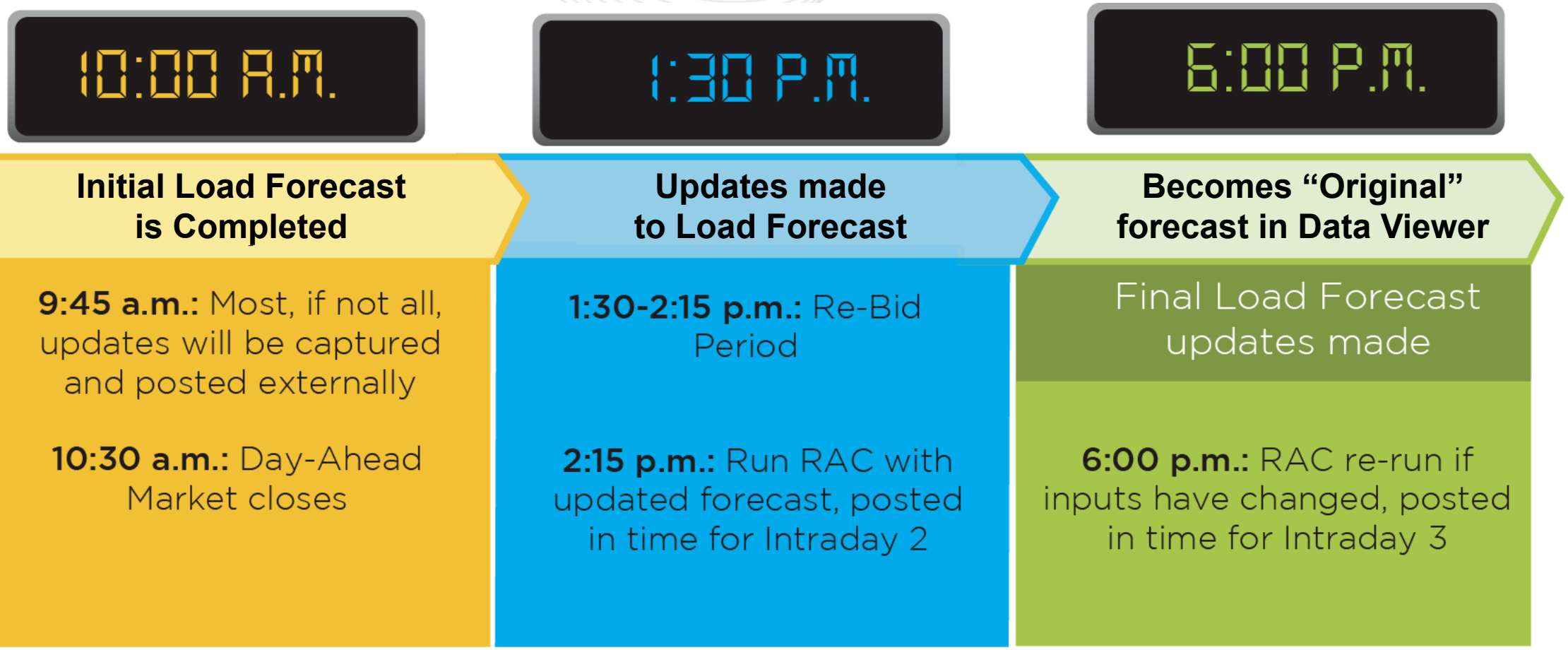
Day-Ahead Forecast Timeline



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What Causes Load Forecast Error?

Weather forecast error

Sudden changes in weather

Holidays

Daylight saving time transition

Low visibility into sources of load/human behavior

Behind-the-meter solar

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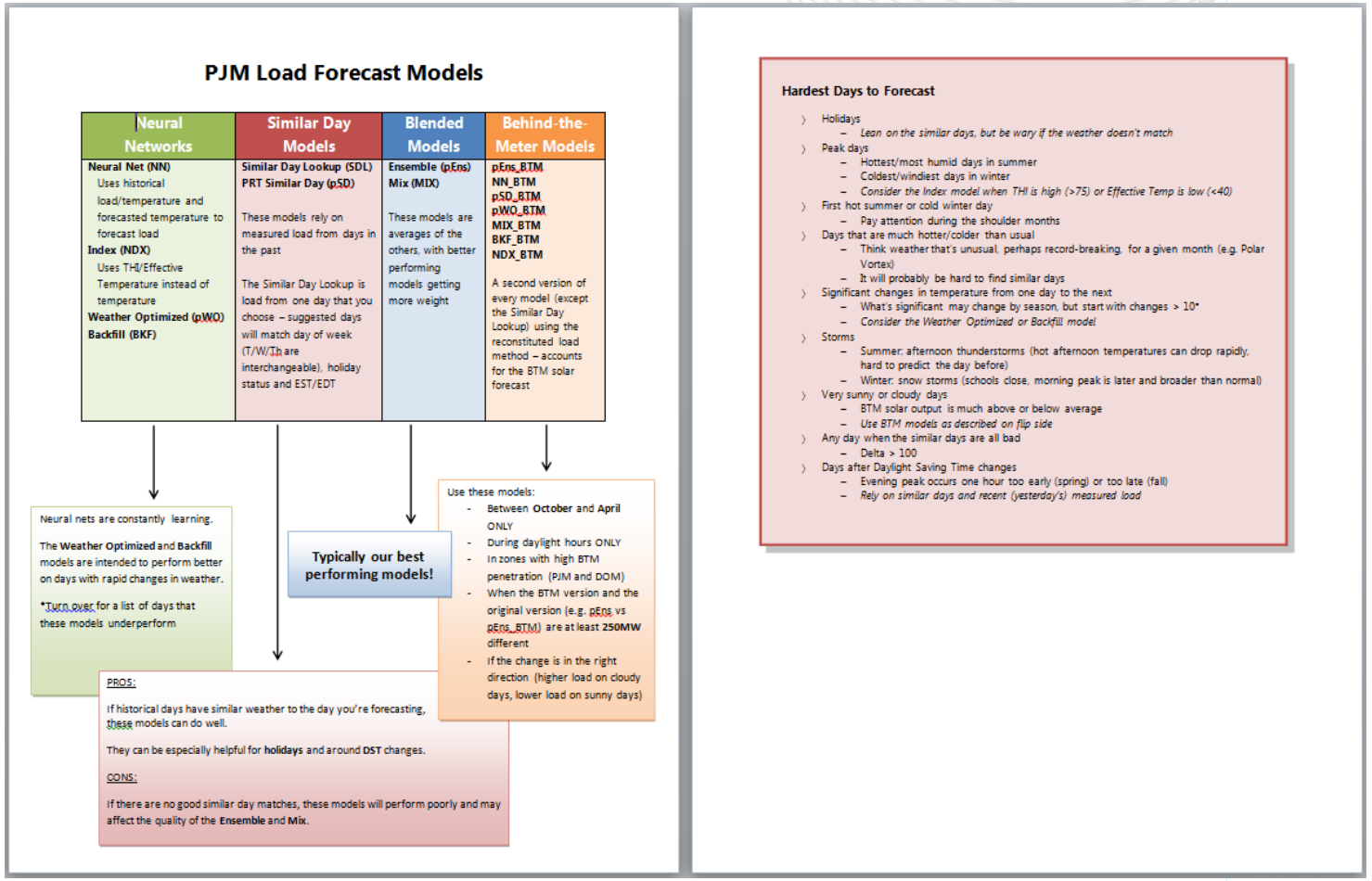
How Do We Minimize These Errors?



PJM Load Forecast Models

Neural Networks	Similar Day Models	Blended Models	Behind-the-Meter Models
Neural Net (NN) Uses historical load/temperature and forecasted temperature to forecast load **Index (NDX)** Uses THI/Effective Temperature instead of temperature **Weather Optimized (pWO)** **Backfill (BKF)**	**Similar Day Lookup (SDL)** **PRT Similar Day (pSD)** These models rely on measured load from days in the past The Similar Day Lookup is load from one day that you choose – suggested days will match day of week (T/W/Th are interchangeable), holiday status and EST/EDT	**Ensemble (pEns)** **Mix (MIX)** These models are averages of the others, with better performing models getting more weight	**pEns_BTM** **NN_BTM** **pSD_BTM** **pWO_BTM** **MIX_BTM** **BKF_BTM** **NDX_BTM** A second version of every model (except the Similar Day Lookup) using the reconstituted load method – accounts for the BTM solar forecast

Neural nets are constantly learning.

The **Weather Optimized** and **Backfill** models are intended to perform better on days with rapid changes in weather.

*Turn over for a list of days that these models underperform

Typically our best performing models!

Use these models:

- Between **October** and **April** ONLY
- During daylight hours ONLY
- In zones with high BTM penetration (PJM and DOM)
- When the BTM version and the original version (e.g. pEns vs pEns_BTM) are at least **250MW** different
- If the change is in the right direction (higher load on cloudy days, lower load on sunny days)

PROS:

If historical days have similar weather to the day you're forecasting, these models can do well.

They can be especially helpful for **holidays** and around **DST** changes.

CONS:

If there are no good similar day matches, these models will perform poorly and may affect the quality of the **Ensemble** and **Mix**.

Hardest Days to Forecast

- Holidays
  - *Lean on the similar days, but be wary if the weather doesn't match*
- Peak days
  - Hottest/most humid days in summer
  - Coldest/windiest days in winter
  - *Consider the Index model when THI is high (>75) or Effective Temp is low (<40)*
- First hot summer or cold winter day
  - Pay attention during the shoulder months
- Days that are much hotter/colder than usual
  - Think weather that's unusual, perhaps record-breaking, for a given month (e.g. Polar Vortex)
  - It will probably be hard to find similar days
- Significant changes in temperature from one day to the next
  - What's significant may change by season, but start with changes > 10°
  - *Consider the Weather Optimized or Backfill model*
- Storms
  - Summer: afternoon thunderstorms (hot afternoon temperatures can drop rapidly, hard to predict the day before)
  - Winter: snow storms (schools close, morning peak is later and broader than normal)
- Very sunny or cloudy days
  - BTM solar output is much above or below average
  - *Use BTM models as described on flip side*
- Any day when the similar days are all bad
  - Delta > 100
- Days after Daylight Saving Time changes
  - Evening peak occurs one hour too early (spring) or too late (fall)
  - *Rely on similar days and recent (yesterday's) measured load*

- Dispatcher training
- Analysis of load forecast model and weather forecast performance
- Routine neural net training
- Backcasts
- Weather alerting and weekly outlooks

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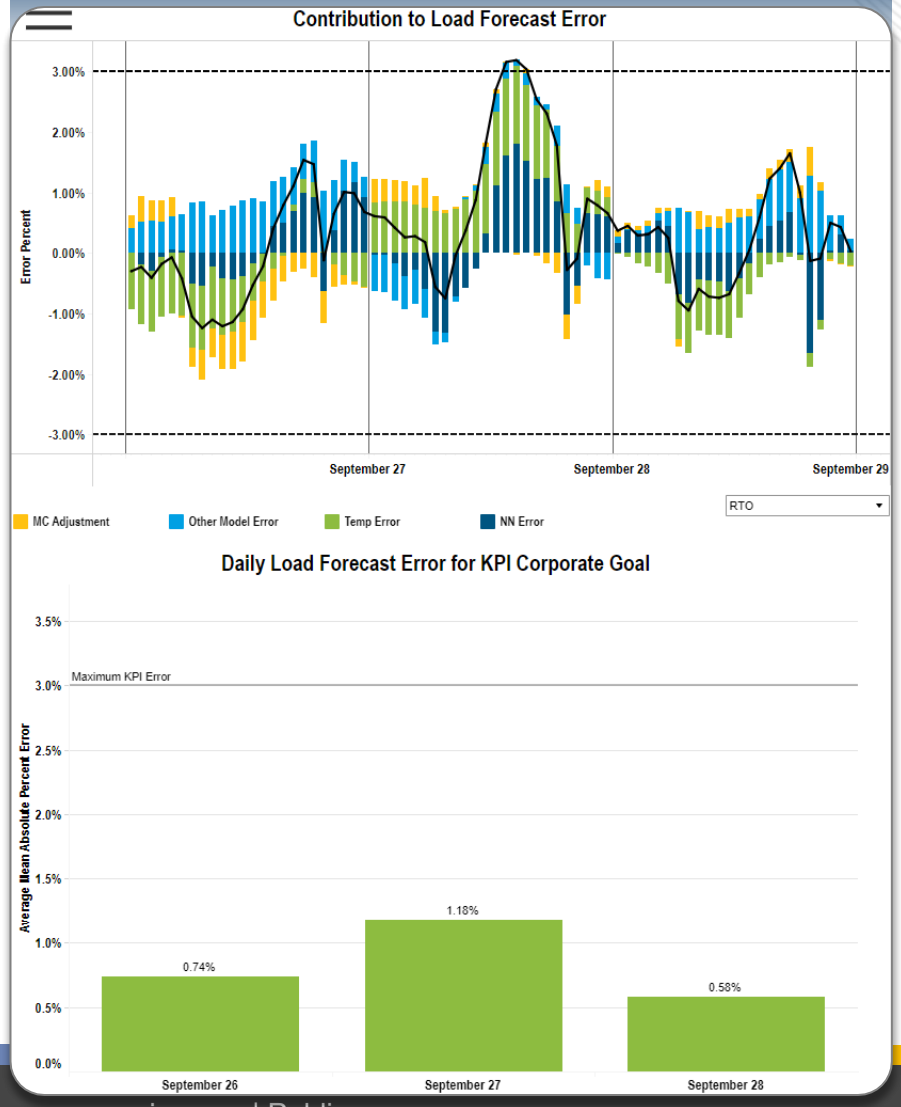
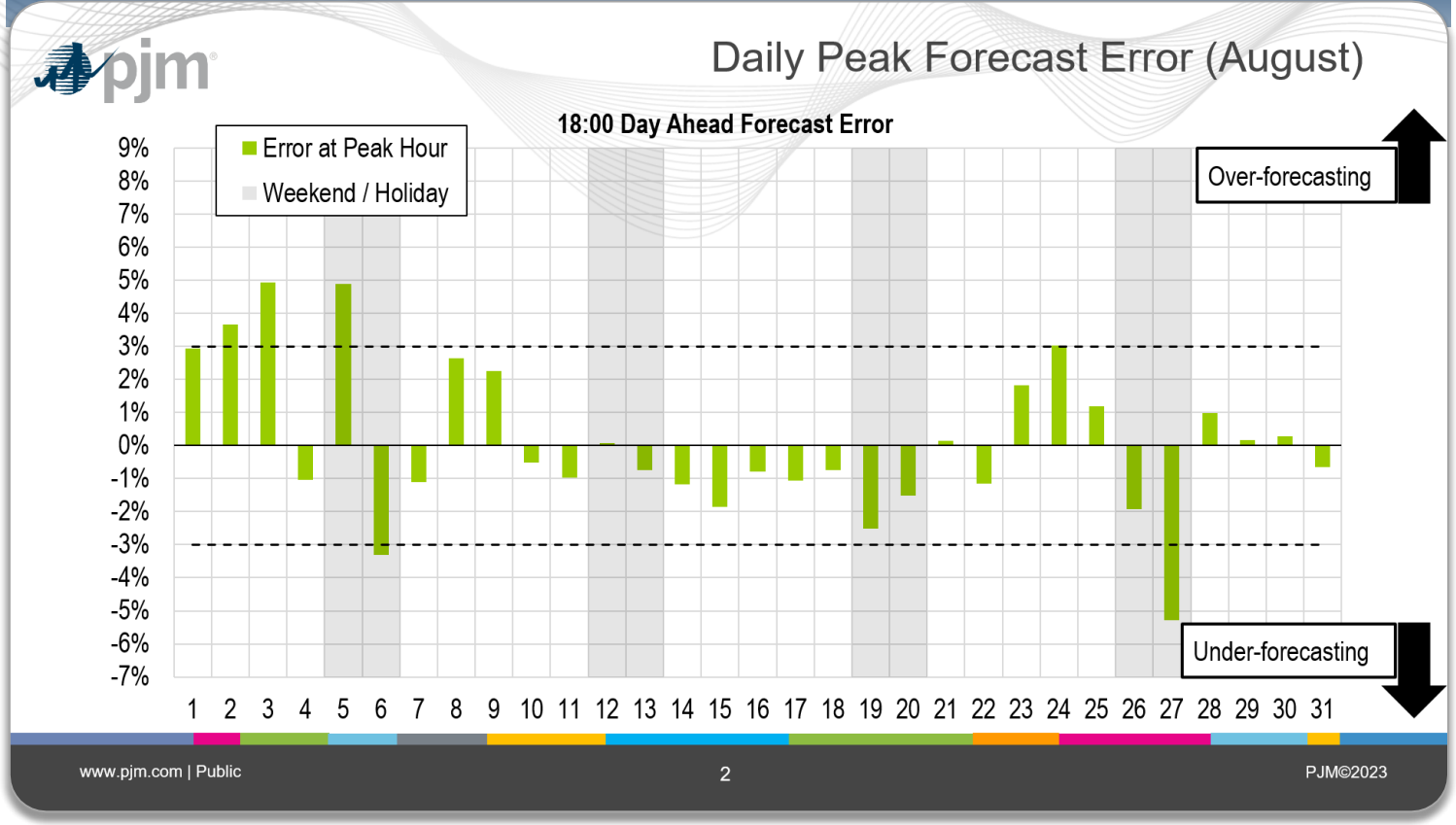
Error Reporting and After-the-Fact Analysis

DAILY

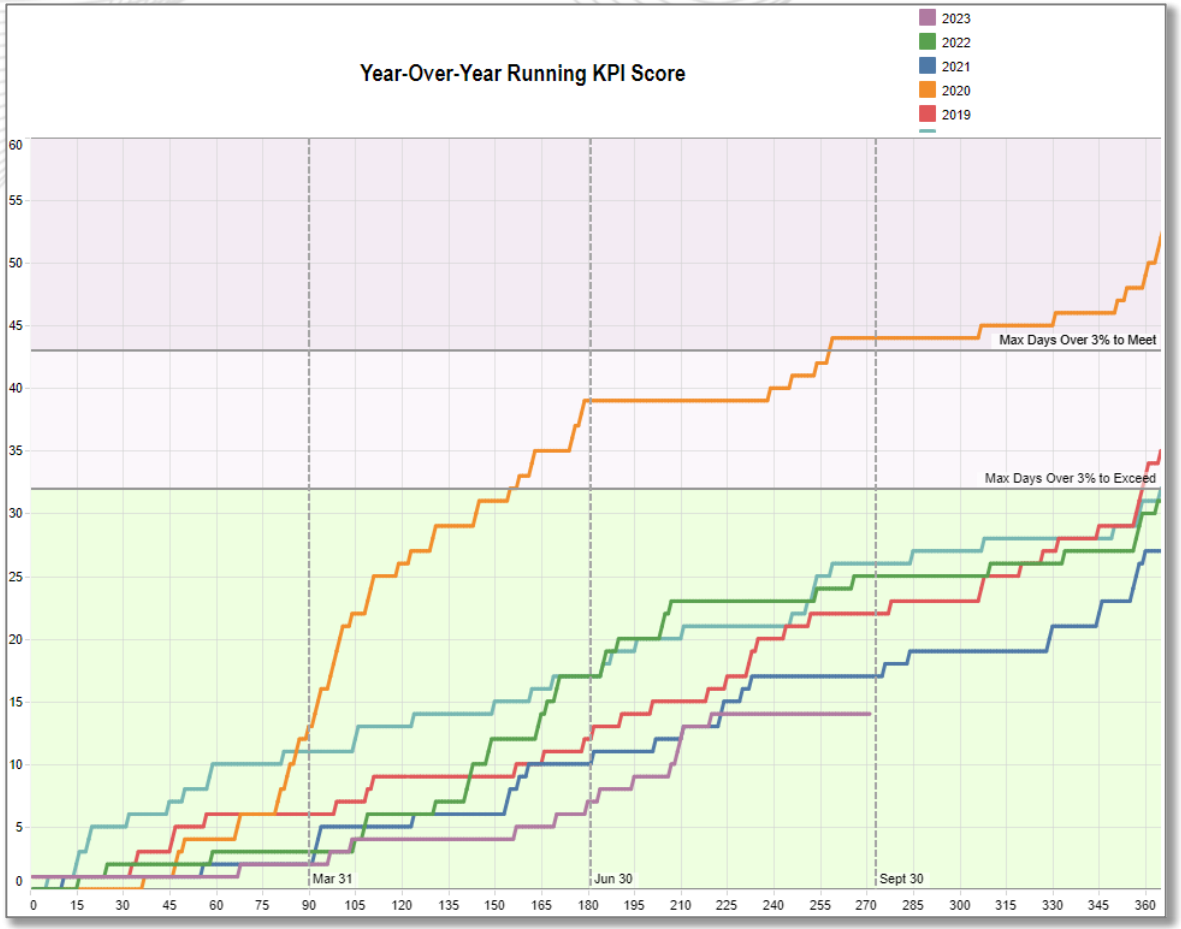


MONTHLY



Load Forecast Team reviews metrics daily and provides written explanation of performance each month.

2023 Load Forecast Performance (All Hours)



Year-to-Date KPI Corporate Goal Score

Date		2023	2022	2021	2020
Sept..	27	94.81%	90.74%	93.70%	83.76%

Visualization allows for progress tracking and trend spotting.

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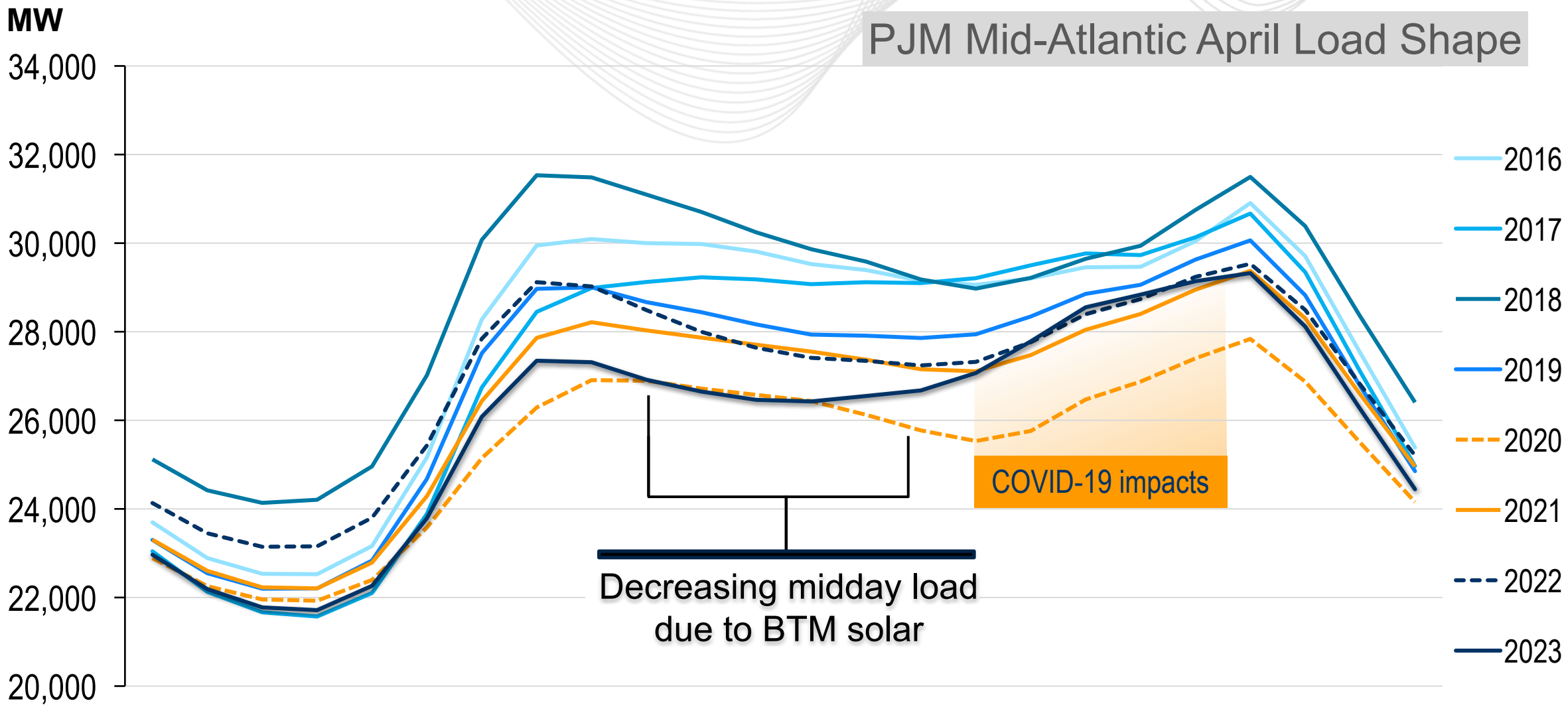
Behind-the-Meter Solar Impacts on PJM Load



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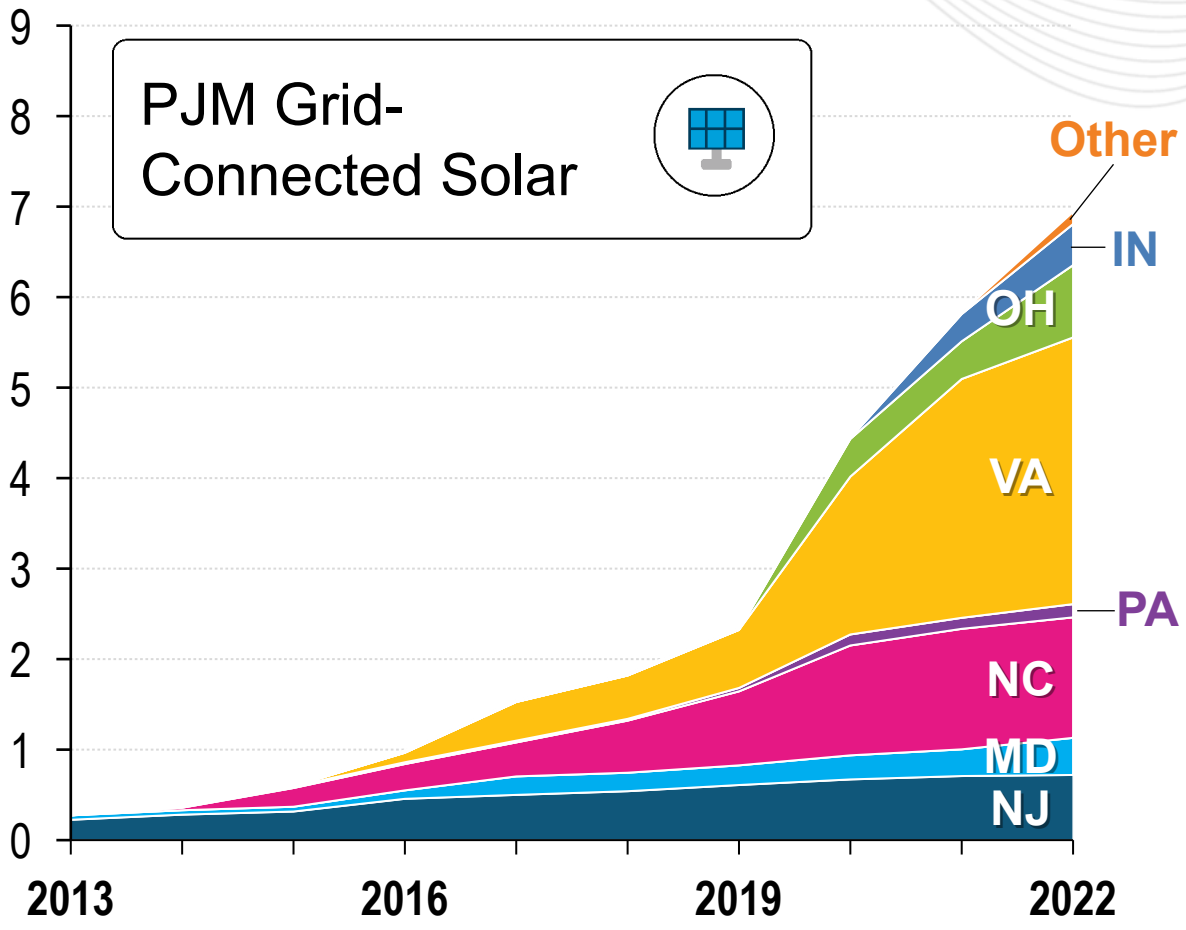
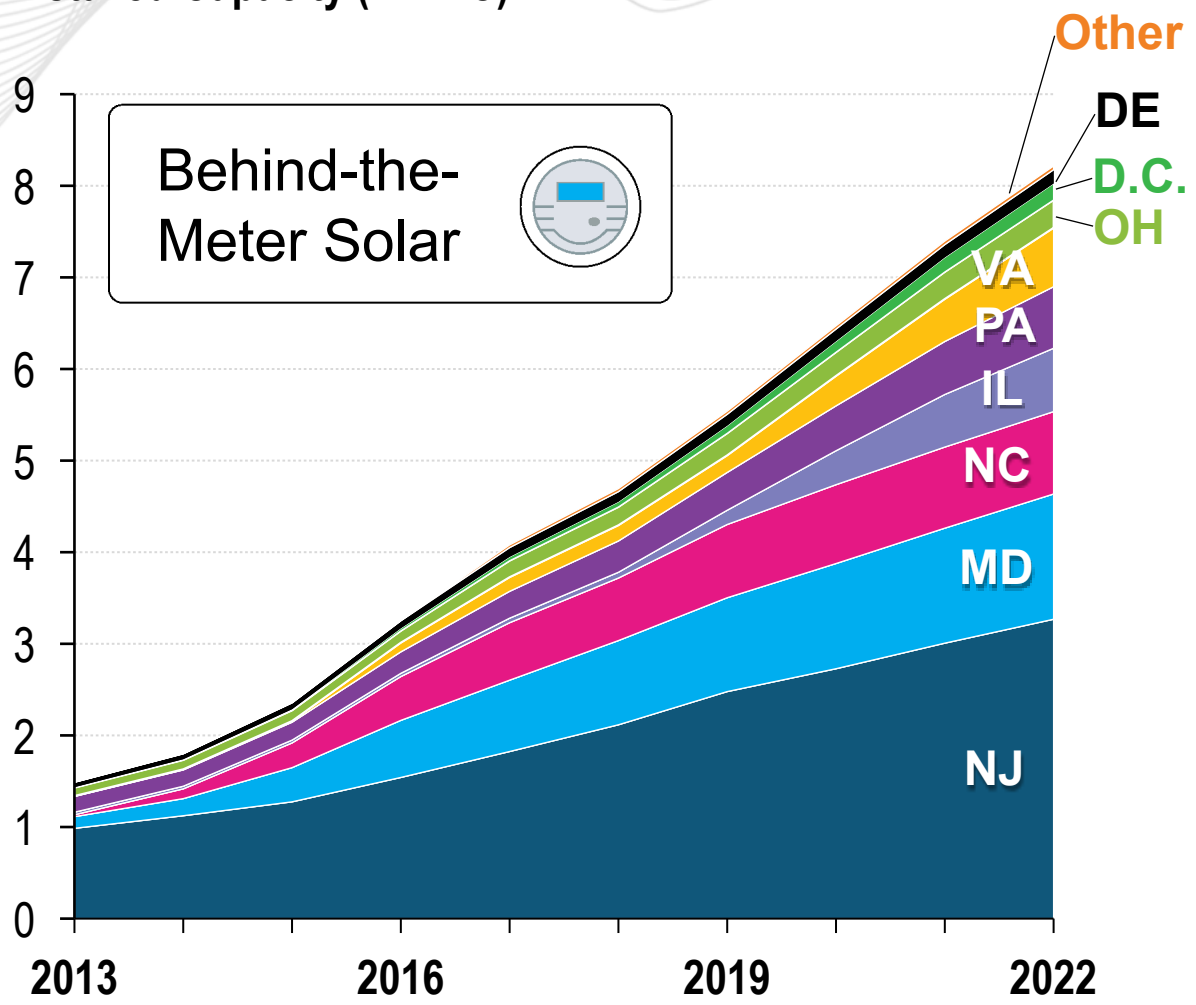
Solar Growth in PJM

Installed Capacity (MWDC)

Thousands



Installed Capacity (MWDC)



As of April 2023 | Source: GATS

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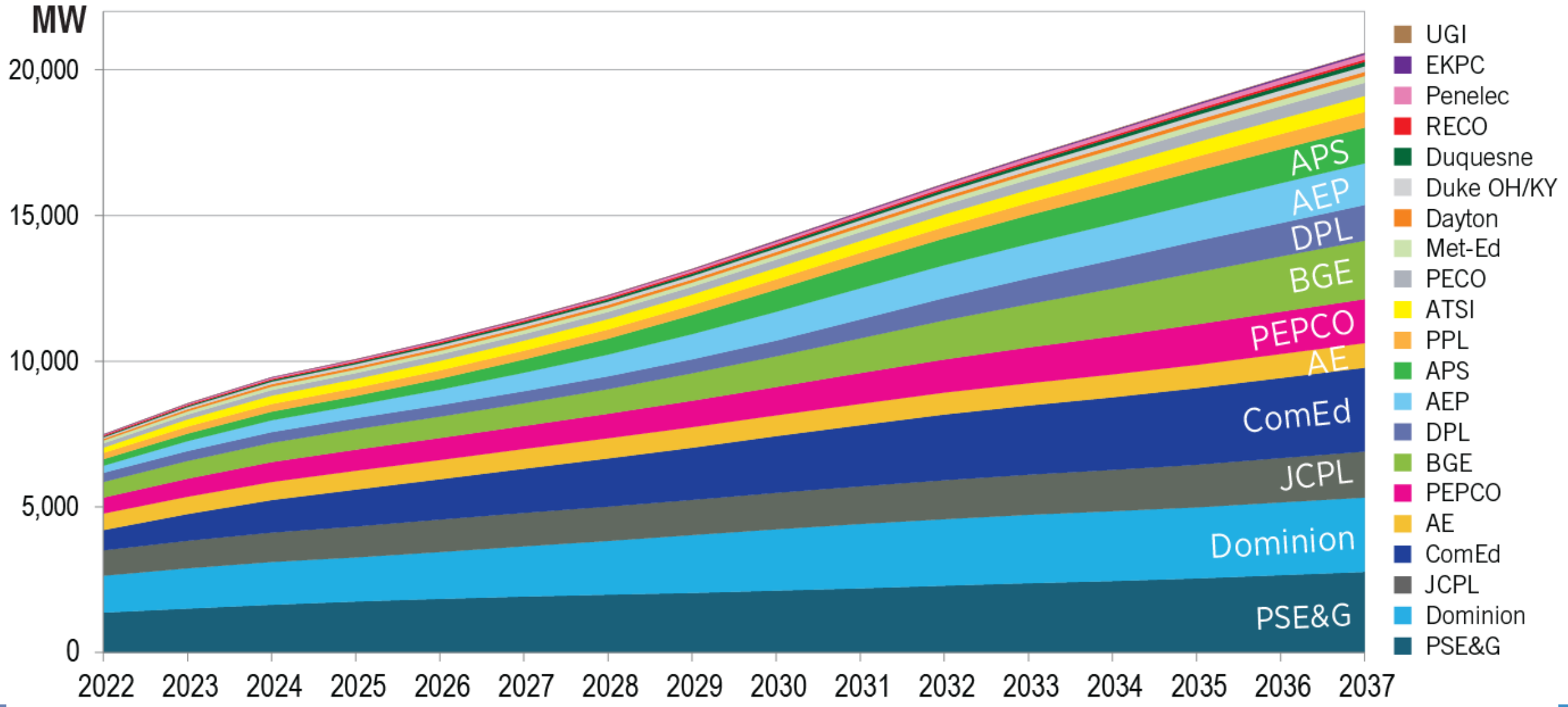
Forecasted Behind-the-Meter Solar



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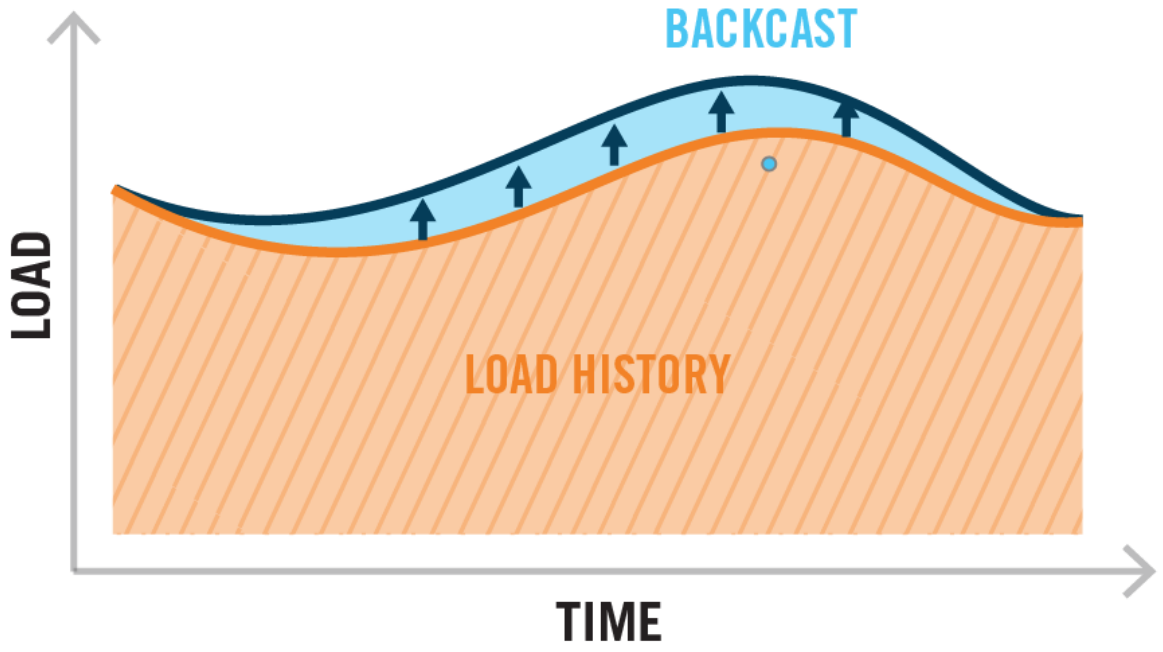
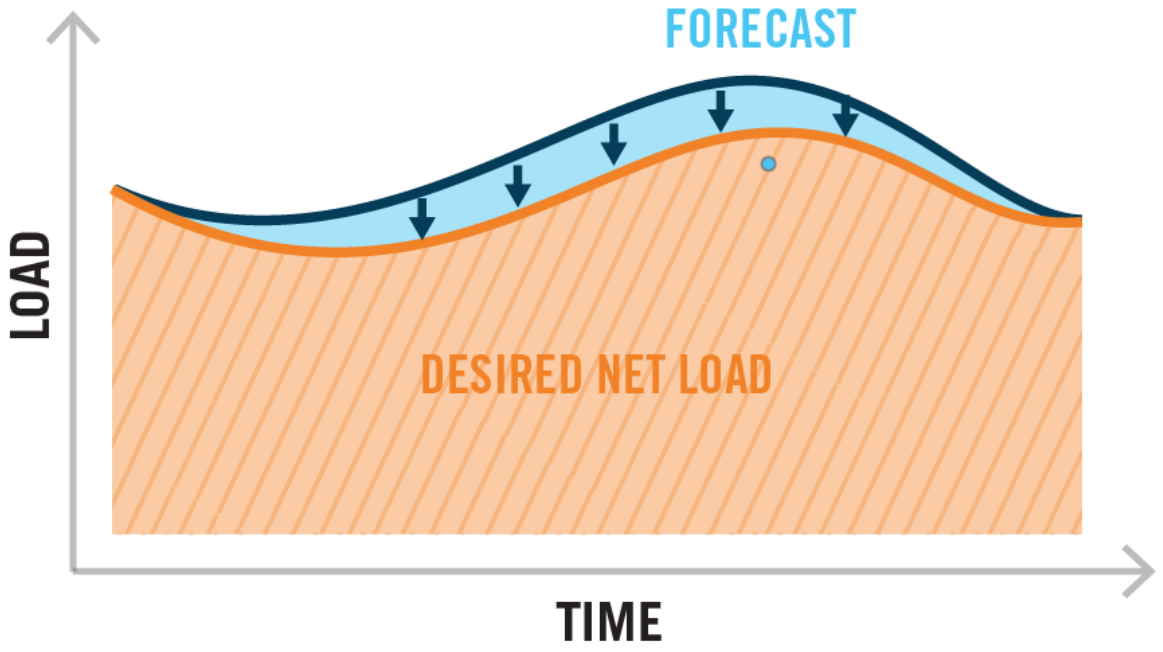
BTM Consideration in the Hourly Load Forecast

RECONSTITUTED LOAD METHOD

Load History + BTM Solar Backcast = Load History w/ BTM Solar

Load History w/ BTM Solar − BTM Solar Forecast = Desired Net Load





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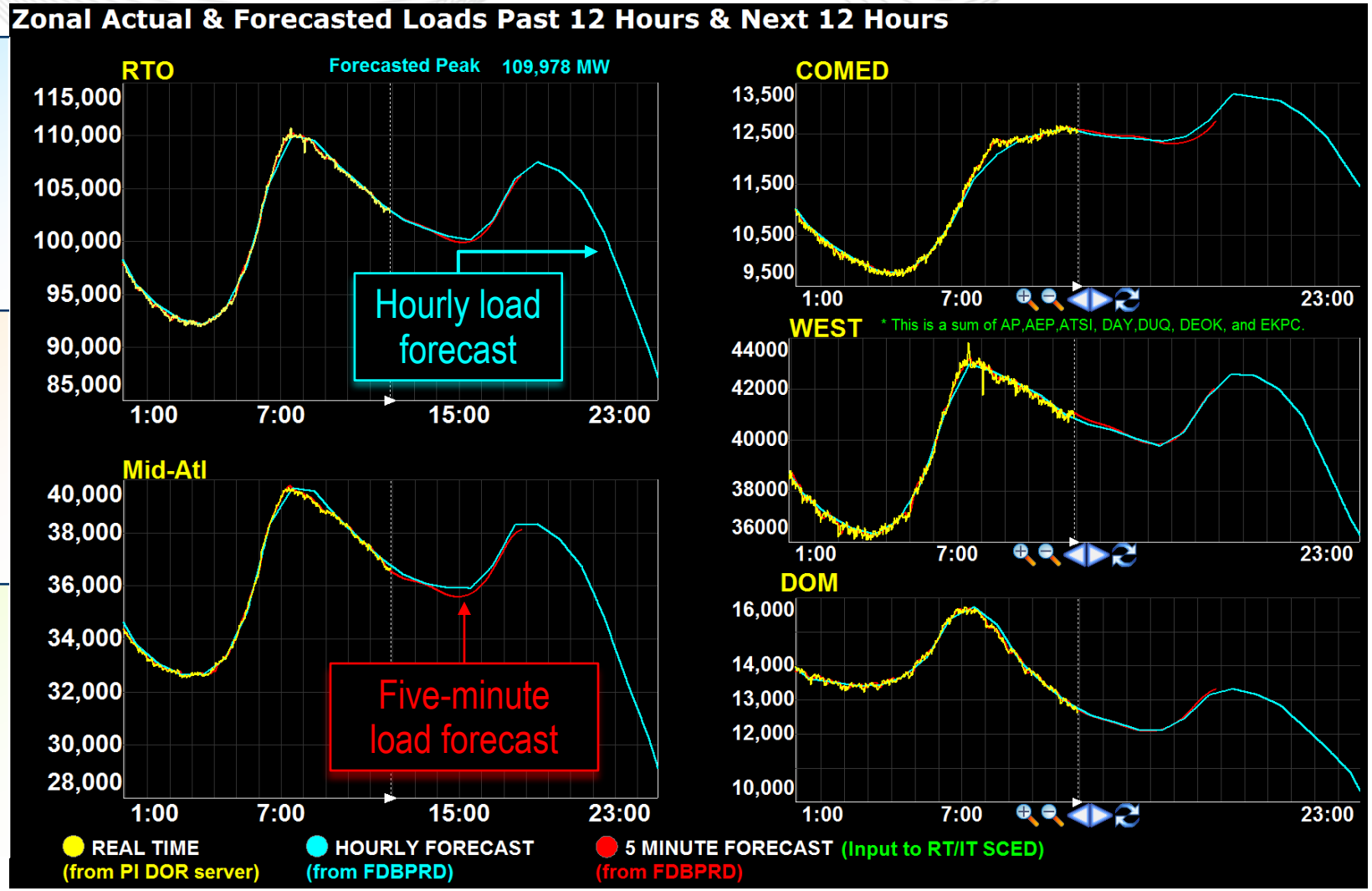
Five-Minute Load Forecast

Produces a forecast every five minutes for next six hours

Forecast is a cubic spline of recent measured loads into hourly forecast.

Primary consumer is Security Constrained Economic Dispatch.



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