Coordinated Ramping Product and Regulation Reserve Procurements Using Probabilistic Solar Power Forecasts

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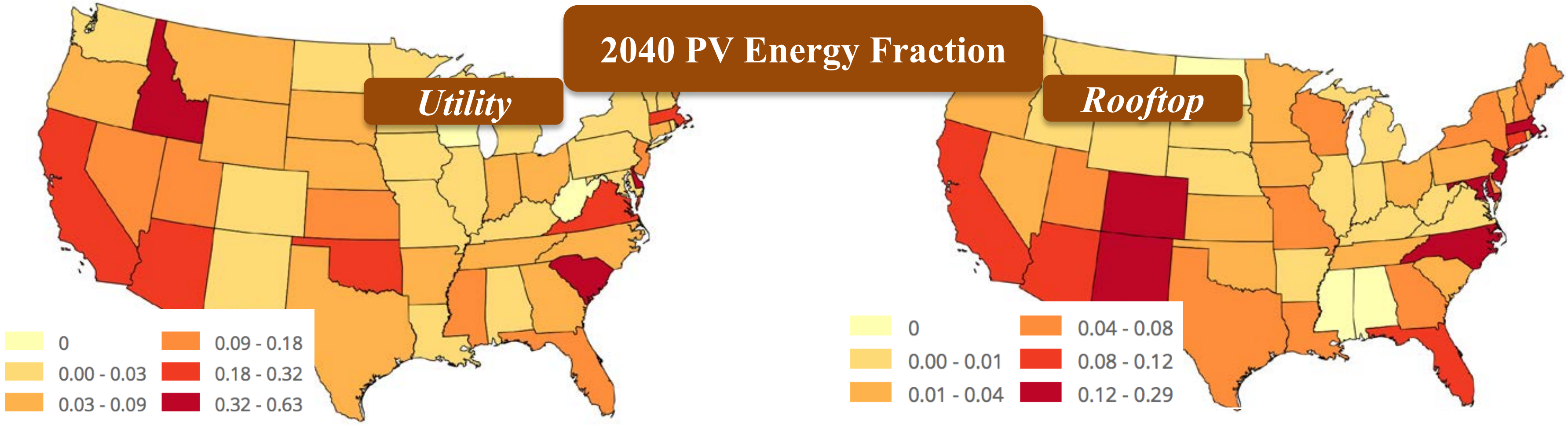
Project Motivation: Efficient System Operations



Source: NREL's 2016 Standard Scenarios from ReEDS model

- Increasing variable renewable penetration → Ramping and regulation issues →
- **Current reserve procurement practice:** based on historical data and offline analysis

  → Requirements that are ***too conservative*** for most conditions but ***inadequate*** or risky for other conditions.

Ramp Events Analysis[1]

#	Load	Net Load
Up	313	731
Down	245	622

Procurement needs up-to-date information on energy forecasts and their uncertainties to result in appropriate reserves that reflect the risks of imbalances.

[1] B. Huang, V. Krishnan, and B.-M. Hodge, "Analyzing the Impacts of Variable Renewable Resources on California Net-Load Ramp Events," presented at the IEEE PES General Meeting, Portland, Oregon, August 6–9, 2018.

Project Summary

Objective: Integrate probabilistic short-term (0–6 hours ahead) and midterm (day-ahead) solar power forecasts into operations of two ISOs:

- CAISO
- MISO.

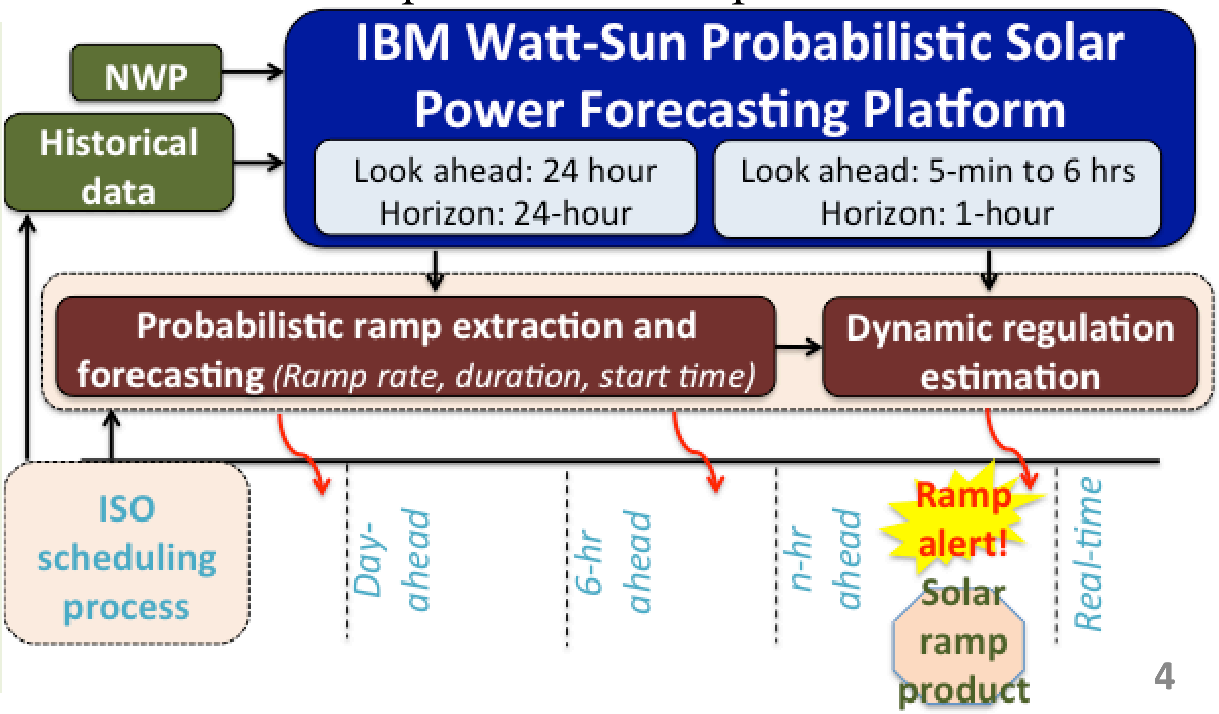
Approach:

1. Advanced big data-driven "probabilistic" solar power forecasting technology

- IBM Watt-Sun and PAIRS: **Big data** information processing
- **Machine learning approaches** to blend outputs from multiple models.

2. Integrate probabilistic forecasts into ISO operations for *ramp product* and *regulation* requirements.

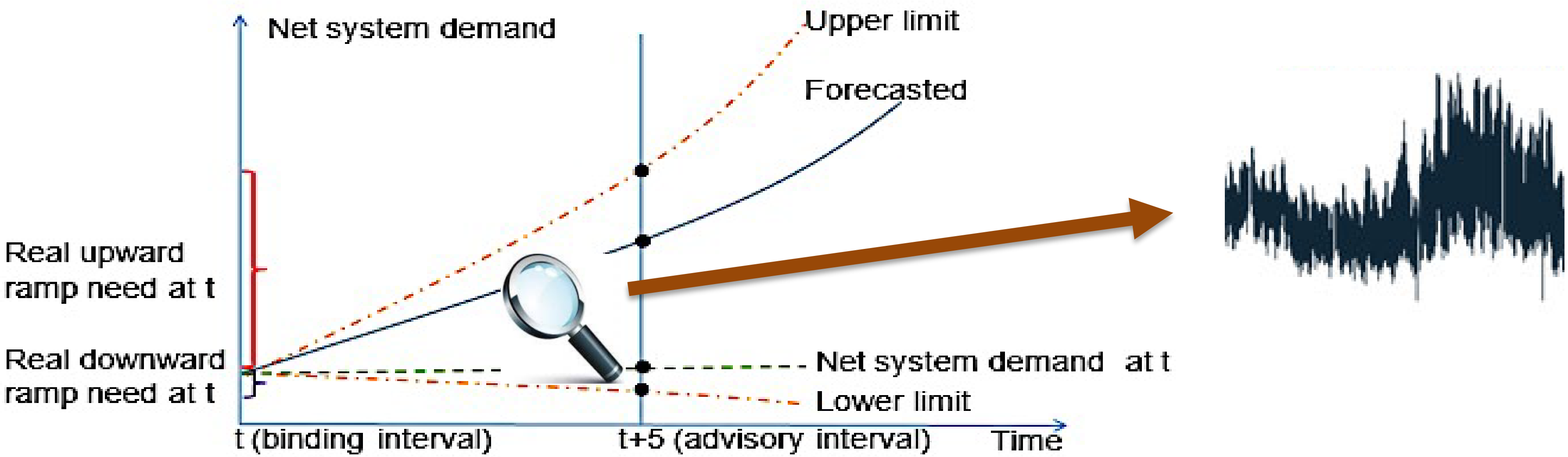
3. Provide **situational awareness via visualizations** of probabilistic ramp forecasts and alerts.



Flexible Ramping Product?

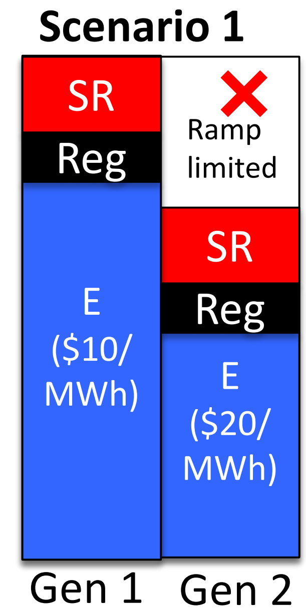
- Introduced to ensure load-following flexibility in market clearing
  - Ensure sufficient ramping capability in the current binding interval to meet the forecasted net load ramps (and their upward and downward uncertainties) in the future advisory intervals.
  - Insure against insufficient ramp capability in real-time markets that might result in extreme prices.

- *Not spinning reserves*, deployed after a contingency event.
- *Not regulation reserves,* used to meet fine-grained fluctuations.



[2] *Figure source: CAISO, "Flexible Ramping Product: Revised Draft Final Proposal," Dec. 17, 2015.*

Flexible Ramping Product for Market Efficiency



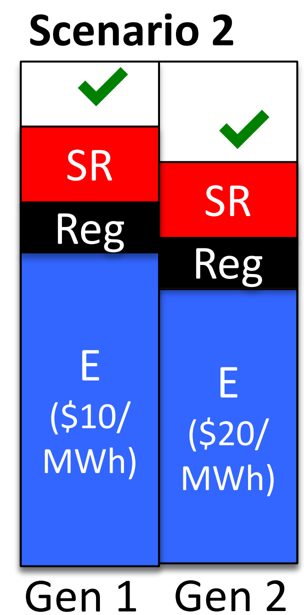
Scenario 1

Generation scarcity (ramp-limited) event → real-time price spikes → unplanned quick starts (+ regulation services to offset area control error)

Regulation and contingency reserves: "MW reserved" unavailable to the market when needed and results in real-time price spikes. (Make whole or uplift payments for unplanned starts.)

Scenario 2

Market efficiency improves if future flexibility/ramping needs explicitly modeled.



Gain in market efficiency and the consequent savings (reduced price spikes, unplanned quick starts, uplift payments)

much greater than

slight increase in energy market locational marginal price + ramp product payment.

Note: The cited examples in this slide assumes single-period dispatches without (Scenario 1) and with (Scenario 2) flexible ramping product (FRP). Multiperiod dispatches will help mitigate the ramping issues to a certain extent (as in NYISO and CAISO), but uncertainties in forecasted net-load ramps are still an issue that requires procuring FRP.

Flexible Ramping Product: Implementation

MISO: May 2016 in day-ahead market (24-h, foresight) and real-time economic dispatch (5-min)

CAISO[3]: Nov. 2016 in real-time market (unit commitment, 15-min, foresight) and economic dispatch (5-min)

(Latest developments, to be included in the day-ahead market at 15-min. intervals.)

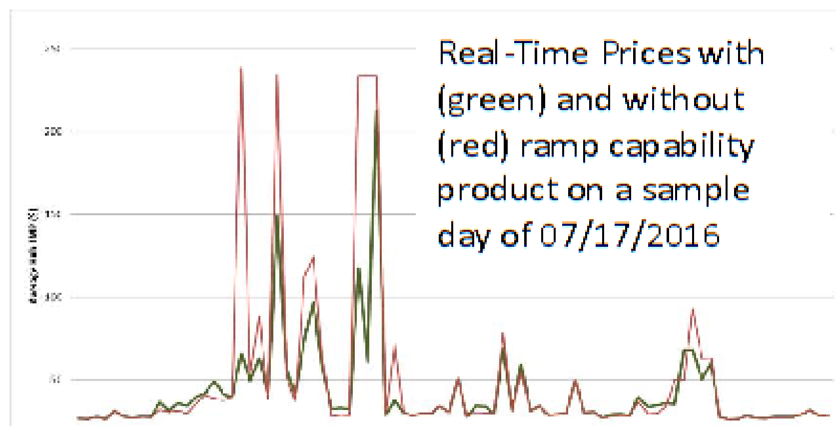
ISO-New England[4] and **Southwest Power Pool** are also looking to implement ramp products.

Note: Though the overarching objective of ramping product is the same, implementing entities have differences in the way ramping products are procured. Refer to the respective resources.

Source: MISO presentation at FERC technical conference, June '17

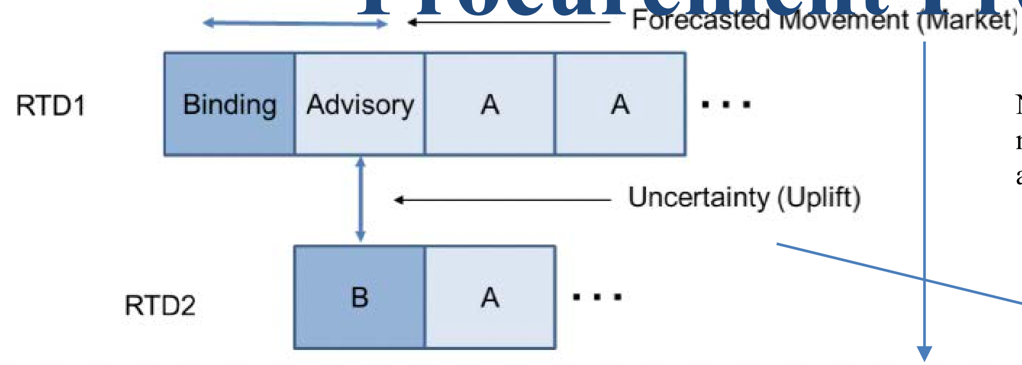
Expected Benefits obtained in Production

Expected results	Actual Results
Production cost savings	$4.2 million/year
Reduced Price volatility	~7%
Improved Day-Ahead /Real-Time convergence	~3%
Reduced short-term scarcities and price spikes	



[3] http://www.caiso.com/informed/Pages/StakeholderProcesses/CompletedClosedStakeholderInitiatives/FlexibleRampingProduct.aspx
[4] https://www.iso-ne.com/static-assets/documents/2017/09/20170920-procurement-pricing-of-ramping-capability.pdf
[5] https://www.spp.org/documents/29342/ramp%20product%20design.pdf

Current Practice: Flexible Ramping Product Procurement Process



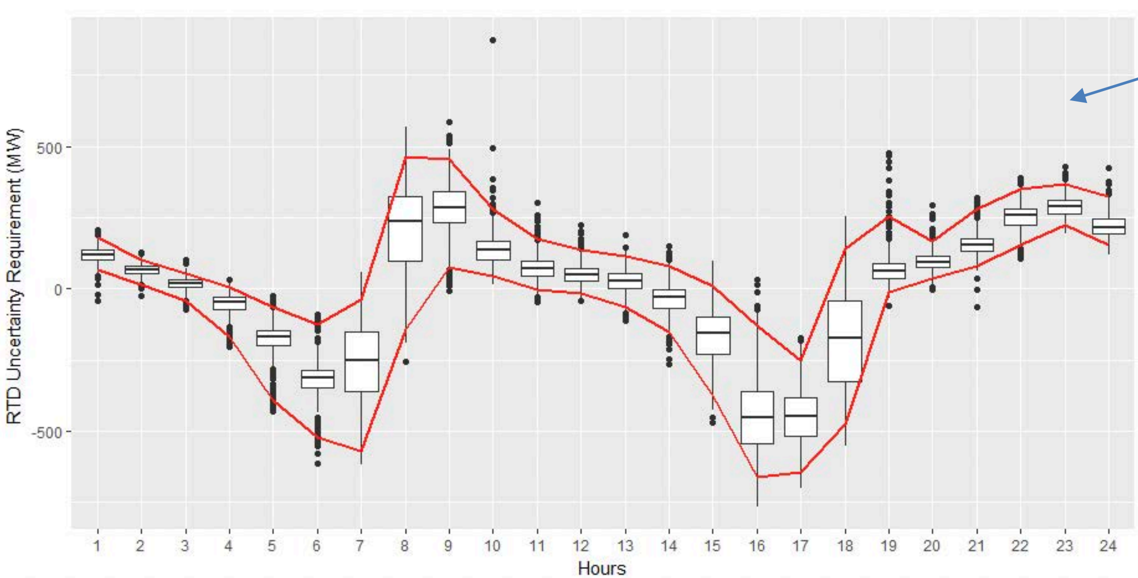
Step 1

Note: Refer to Footnote 3 in previous slide for details and nuances of each step in the ISO process. This slide shows a high-level summary only.

[6] *Figure source: CAISO, "Flexible Ramping Product: Revised Draft Final Proposal," Dec. 17, 2015.*

$$Ramp\ Up\ Req_t = \max\{0, \widehat{Netload\ forecast}_{t+5min} - Netload_t + up - forecast\ error\}$$

$$Ramp\ Down\ Req_t = \max\{0, Netload_t - \widehat{Netload\ forecast}_{t+5min} + downforecast\ error\}$$



Step 2

- For each hour, assess last 30–40 days of historical data for "advisory interval" forecast errors.
- Introduce bias for weather events based on forecasts.

[7] *Figure source: CAISO, "Market Performance and Planning Forum," presentation slides, Feb. 20, 2018.*

Probability of X MW forecast error * **Penalty** (price spike) = **$/MWh** price for procuring X MW flexibility (risk index)

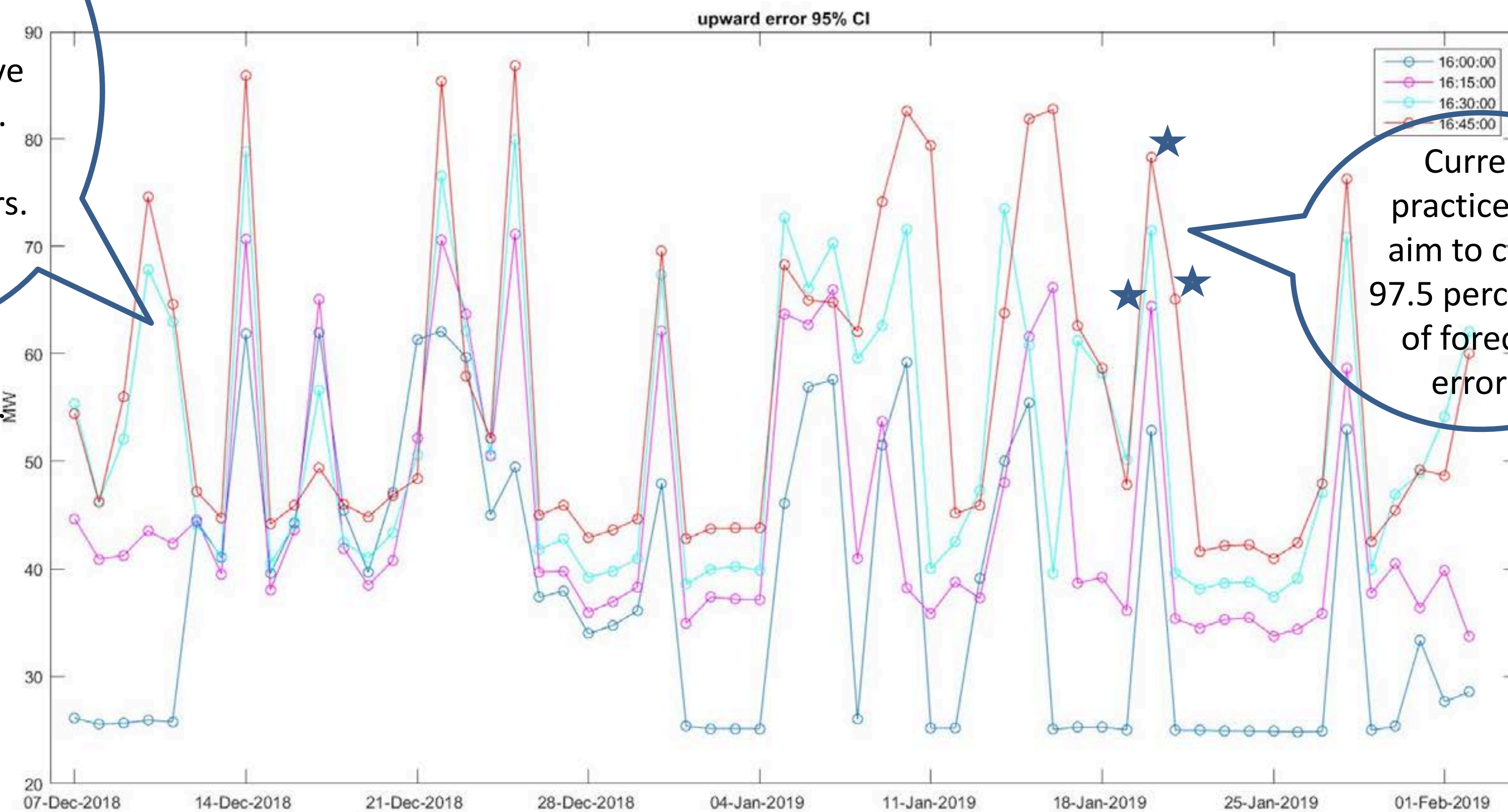
Step 3

(demand curve for uncertainty)

Use of Probabilistic Forecasts

For a selected hour (4–5 p.m.), we have four 15-min. upward forecast errors.

15-min. solar forecast errors (historical data analysis of upward errors)



Current practice will aim to cover 97.5 percentile of forecast errors.

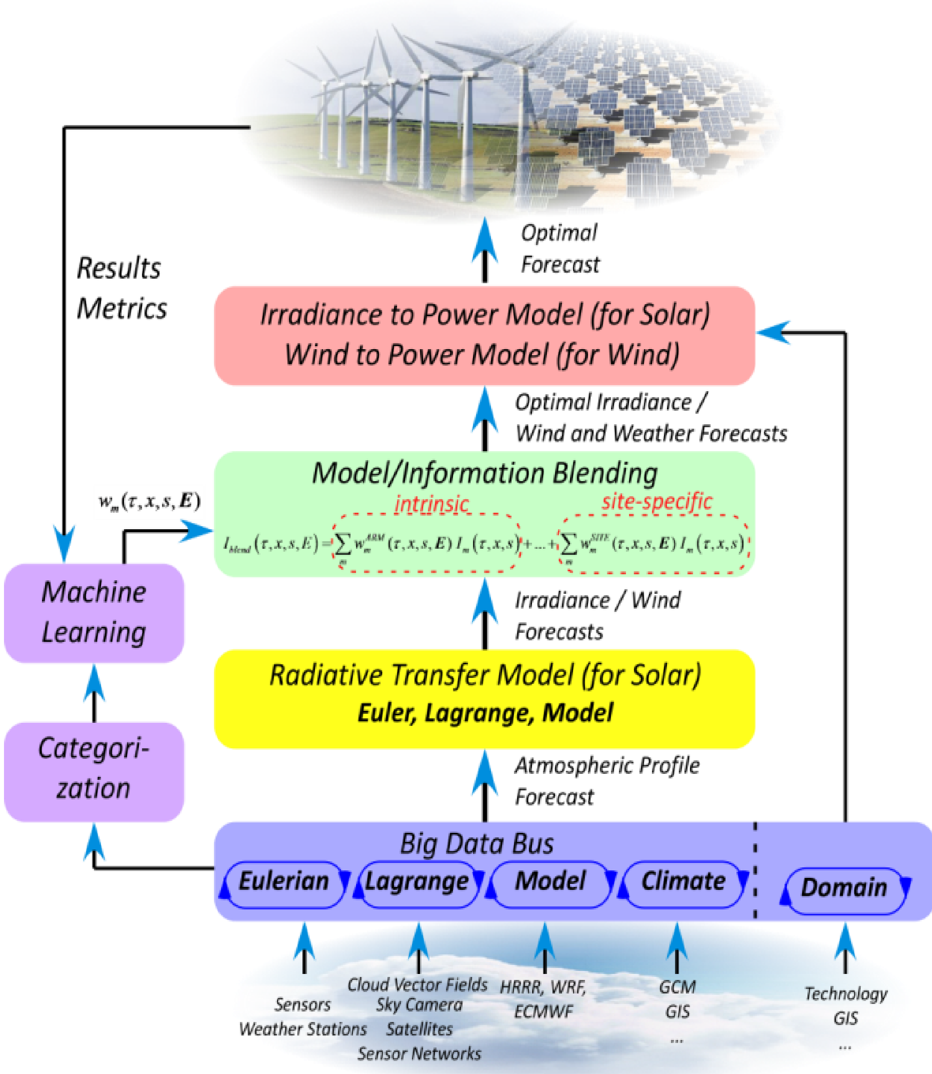
$$Ramp\ Up\ Req_t = \max\{0, \widehat{Netload\ forecast}_{t+5min} - Netload_t + \alpha\sigma_{t,5min}\}$$

$$Ramp\ Down\ Req_t = \max\{0, Netload_t - \widehat{Netload\ forecast}_{t+5min} + \beta\sigma_{t,5min}\}$$

Probabilistic forecasts

Improvement over current practice: Robust, dynamic FRP procurements using latest probabilistic forecasts → avoid costly over-procurement and risky under-procurement.

Big Data-Driven Probabilistic Forecasting System



Situation-dependent blending of forecast models:

- Apply multi-expert deep machine learning with historical forecasts and weather data.
- Learn which model is better, when and where.

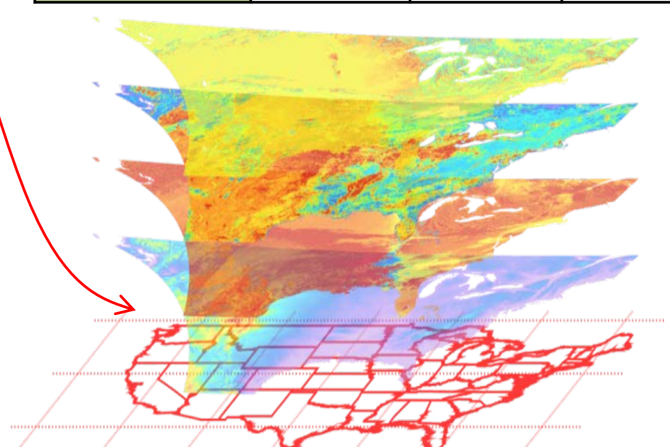
Leverage *"big" data platform* and *advanced machine learning-based analytics* to complement NWP models → high-fidelity probabilistic forecasts and adaptive and more accurate forecasts

PAIRS Big Data Platform

Physical Analytics Integrated Data Repository and Services (PAIRS)

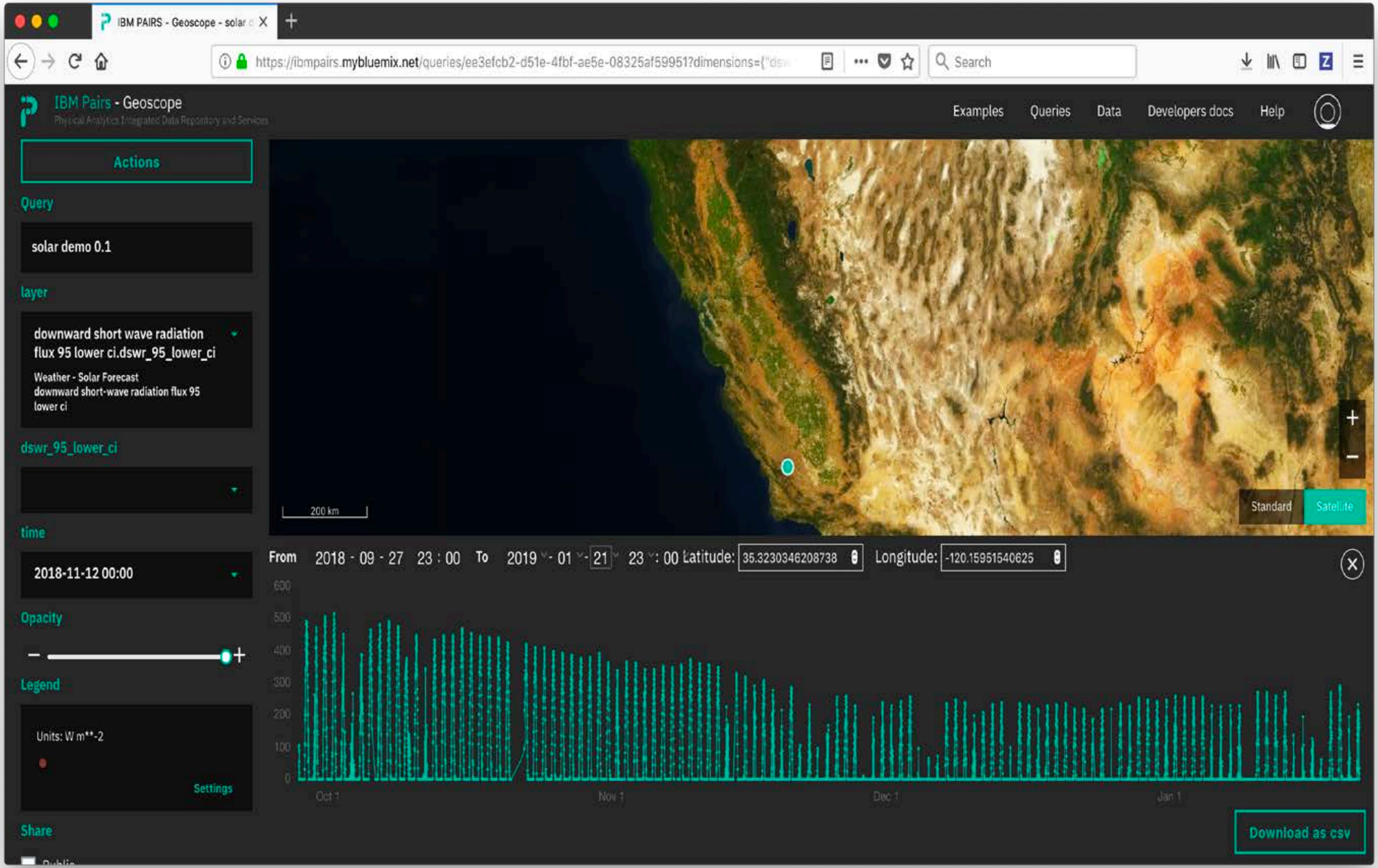
Harmonized data curation: aligned to a global spatio-temporal reference and indexing system

	Lagrangian		*Weather Forecast Models*						*Climate*
Models	**Sky Cam**	**GOES-R**	**RAP**	**HRRR**	**SREF**	**NAM**	**GFS**	**ECMWF**	**CFS**
Spatial Res. & Coverage	Local 10 m	Global 0.5~ 1 km	U.S. 13 km	U.S. 3 km	U.S. 16 km/40 km	U.S. 5 km	Global 0.5 deg	Global 0.1 deg	Global 0.5 deg
Temporal Resolution	1 min	15 min	15 min 2D, 1 h 3D	15 min 2D, 1h 3D	1 h (40 km); 3 h (16 km)	1 h	3 h	1 h	6 h
Forecasting Horizon	10 min	4 h	18 h	15 h	0–87 h	0–60 h	6–192 h	0–60 h	6 mo
Ensemble Forecast	No	No	No	No	CTL, P1, P2, P3, N1, N2, N3	No	No	N.A.	4 members



- **GOES-R/16 satellite** can generate up to 16 GB/d.
- GOES-R will be used with deep convolutional neural network for next-generation solar forecast models.

IBM Watt-Sun Output via IBM PAIRS Geoscope

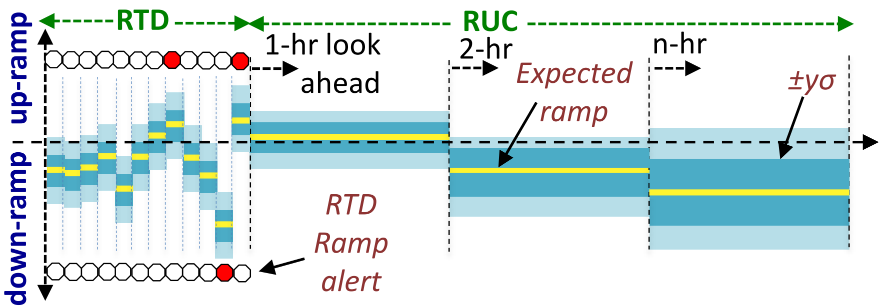


Contact: hendrikh@us.ibm.com or Rui.Zhang@ibm.com

Market Impact Assessment

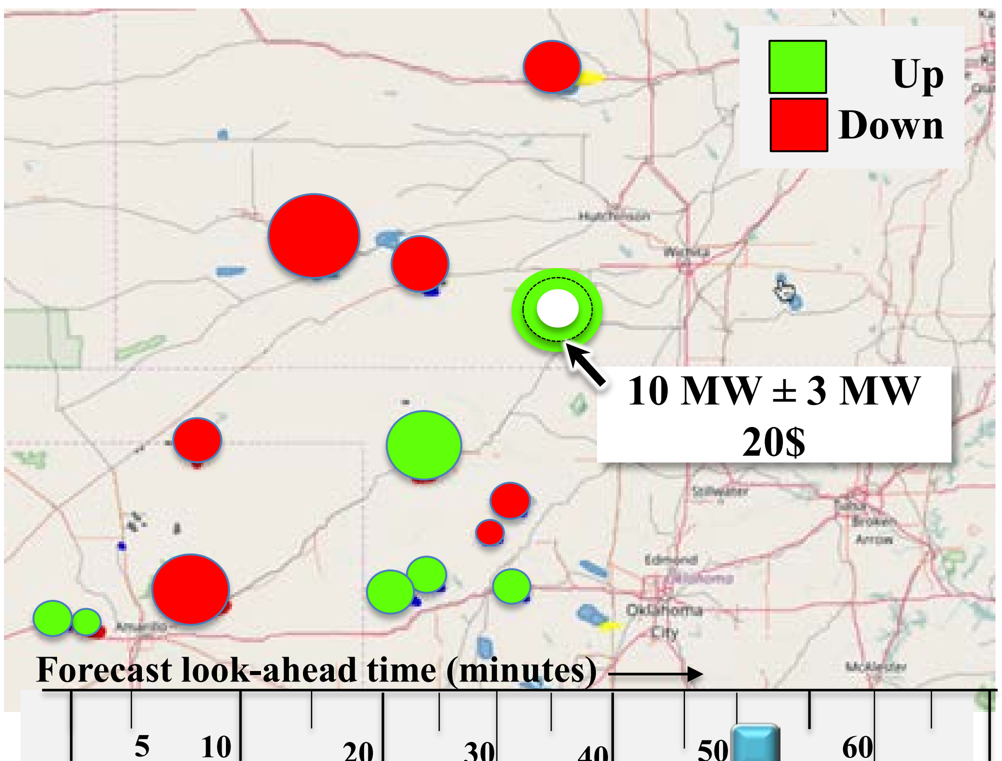
- Ramping procurement passed on to ISO scheduling procedures
  - Align process with well-documented ISO procedures.
- **~July 2019:** **Test 1** on modified IEEE 118-bus test system with high solar penetration
  - Resource mix, load, and solar profiles that mimic ISOs.
- **~April/July 2020:** Test 2 on Western Electricity Coordinating Council system, with CAISO as focus area.
- Metrics:
  - *Economic:* Production costs, prices (average and real-time spikes), make-whole payments, procurement vs. actual deployment
  - *Reliability:* Quick starts, area control error, and Control Performance Standard 2.

Visualization of Probabilistic Ramp Forecasts for Situational Awareness



Will provide:

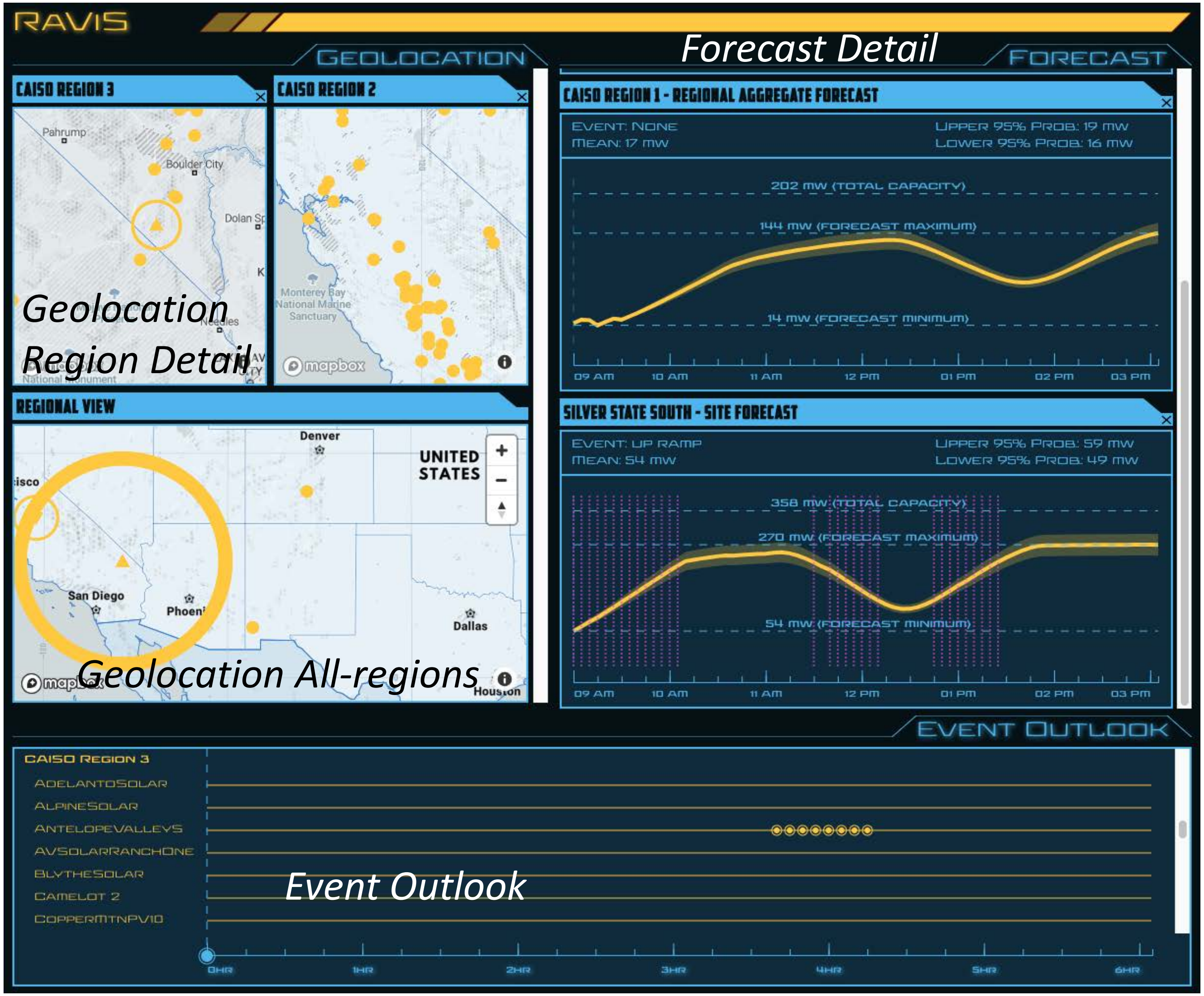
1) **Forecasted net-load ramps and their uncertainties**
2) **"Ramp alerts"** at shorter timescales, *when ramp forecast > available capability.*



Site-specific solar ramp visualization

Regional solar power ramp forecasts: may identify economic output control options in event of ramping alerts.

Ramp Visualization for Situational Awareness (RaViS): User Interface



Features:

- Forecast data from IBM integrated
- Probabilistic and deterministic values
- RaViS refresh rate of 60 s
- User interface is implemented as a single-page Web application
- Open-source libraries
- Shows site-specific metadata via hover
- Highly flexible and easily configurable
- Adaptable to other kinds of events: outage/trip, cyber threats.

Contact: Venkat.Krishnan@nrel.gov or Paul.Edwards@nrel.gov, or Haiku.Sky@nrel.gov

Summary: Impact and Significance

- Probabilistic forecasting approach will **significantly transform the forecasting software** (for solar power, load, and wind).

- Enhance existing ISO optimizations by supplying probabilistic forecasts in the form of reserve procurement targets and visualization aids.

  - ❑ **Has the ability to create a better way for markets to optimize the uncertainty embedded with renewable resources into market products.**

- Future work:

  - ❑ Data-driven dynamic regulation requirements, a) finer resolution forecasts and error characterization, b) using deployed regulation and area control error historical data.

Thank You

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NREL/PR-5D00-73568

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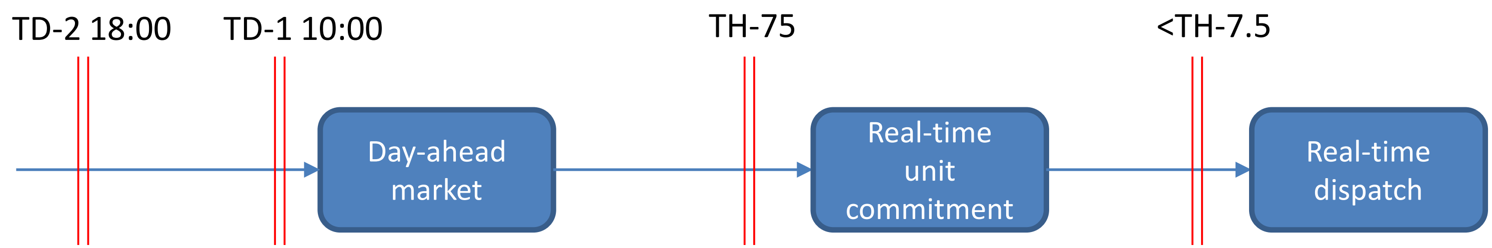
EXTRA SLIDES

CAISO Baseline Market Simulation

Flexible Energy Scheduling Tool for Integrating Variable Generation (FESTIV)



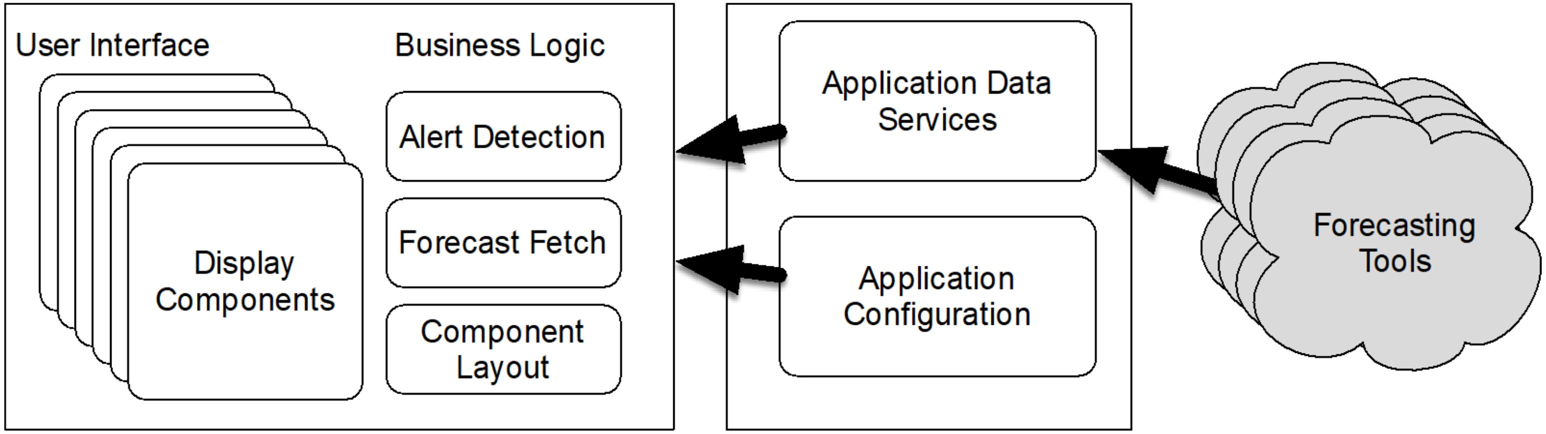
	Regulation requirements posted	Bids submitted (incl. renewables)	• Bids submitted • Demand frequency update: 30 min.	• Renewable forecast frequency update: 5 min. (private)

	Day-ahead market	Real-time unit commitment	Real-time dispatch
Resolution	Hourly ✓	15-min. ✓	5-min. ✓
Horizon	24 hours ✓	1–3 h Fixed: 3 h	65-min. ✓
Commit	Fast- to long-start units ✓	Fast- and short-cycle time if <3 h + medium start	N/A ✓

Market power mitigation and reliability runs not included.
(No virtual bids, single forecast across market participants, no reliability must-run units.)

Ramp Visualization for Situational Awareness (RaViS): Design

The user interface is implemented as a single page Web application in which all user interaction takes place within a customizable dashboard. This is achieved via a modular architecture (using open-source libraries) in which each functional aspect is contained in a set of files constituting a single component.

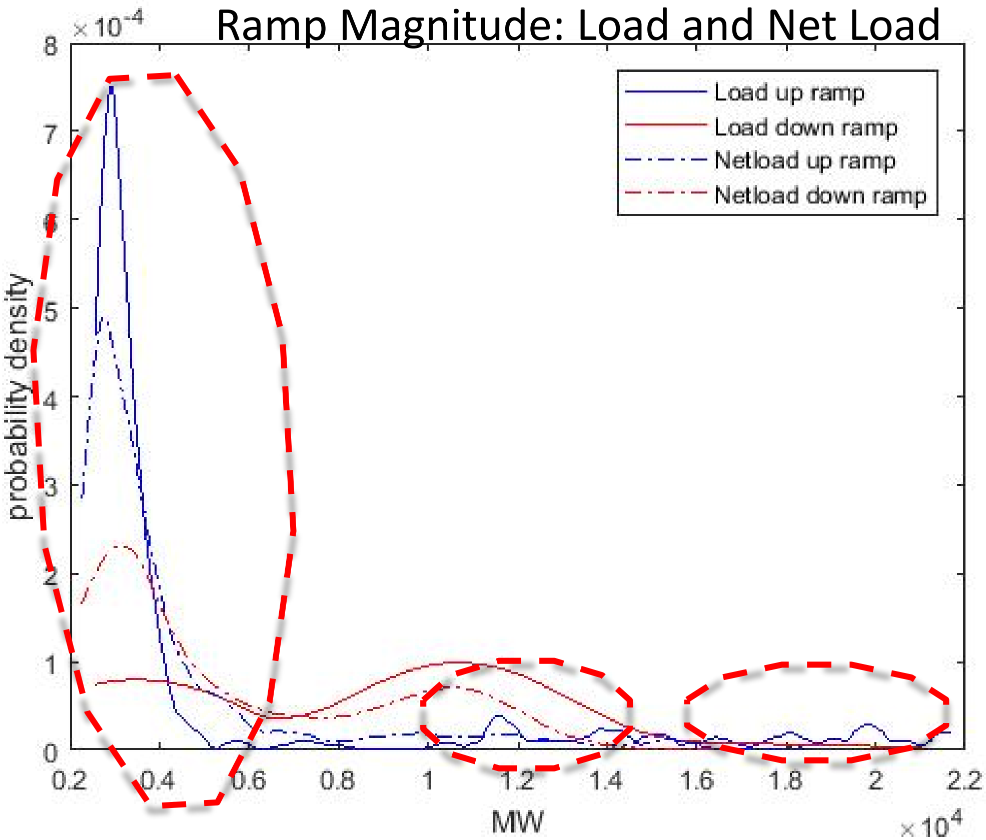


Can Solar Resources Provide Flexible Ramping Product?

California load and net load ramp event characterization

Solar (other renewable energy) resources contribute to increase in the frequency of ramp events …

#	Load	Net Load
Up	313	731
Down	245	622



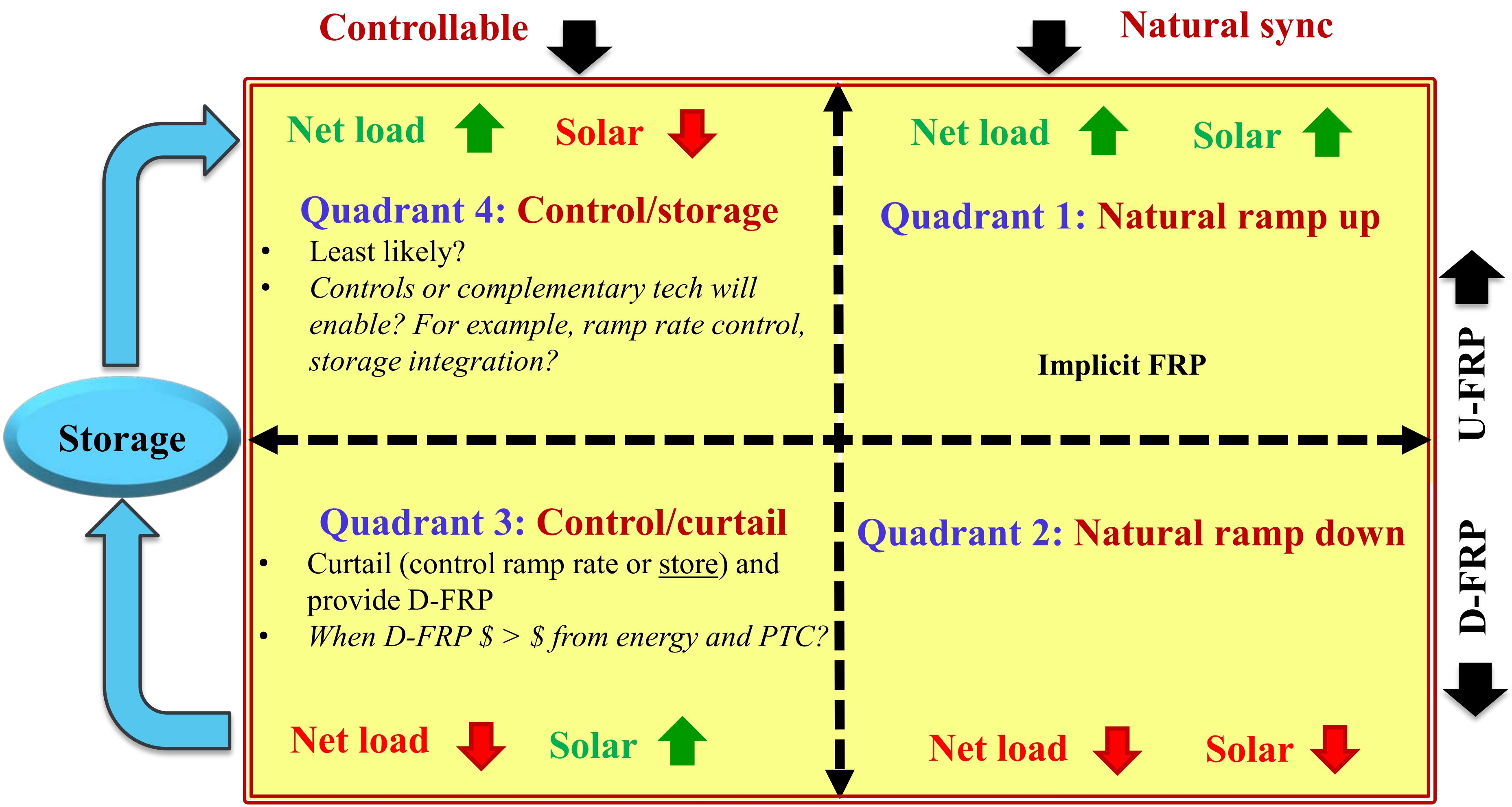
… but also decrease large ramp magnitudes in some hours.

	Load (MW)		Net Load (MW)	
	Up	Down	Up	Down
Max	21,704	21,058	18,400	16,594
Min	2,566	2,561	2,270	2,271
Mean	5,406	8,075	4,317	5,694
Std	5,077	4,227	2,894	3,349

"Implicit ramp product" from renewable energy resources?
Solar explicit ramp product?

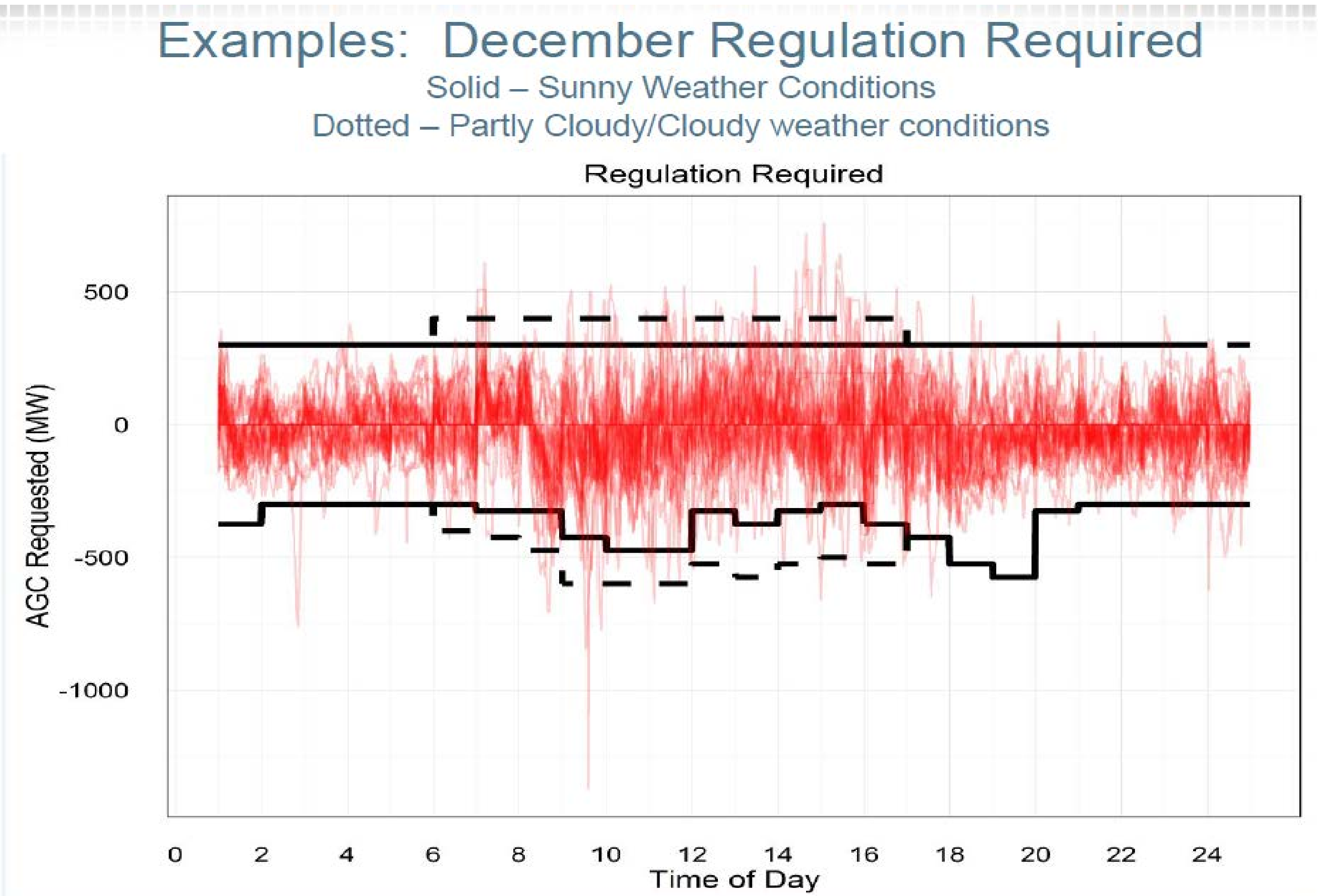
[1] B. Huang, V. Krishnan, and B.-M. Hodge, "Analyzing the Impacts of Variable Renewable Resources on California Net-Load Ramp Events," presented at the IEEE PES General Meeting, Portland, Oregon, August 6–9, 2018.

Solar Ramping Product Taxonomy



- ❑ Ways solar resources can provide FRP and regulation, possible coordination with storage technologies
- ❑ Impact of solar FRP on total FRP procurements (i.e., net load estimations), use of site-specific solar forecasts.

Example of Evolving CAISO Regulation Requirements



- Use of historical data to set regulation requirements based on probabilistic criterion (automatic generation control needs)
- *Opportunity to condition forecast of distribution on most recent weather.*

Source: Amber Motley, CAISO Market Performance and Planning Forum, presented on Jan. 18, 2017, Slide 1 7, www.caiso.com/Pages/DocumentsByGroup.aspx?GroupID=04839625-a0b1-4a88-825c-d7fe028481e5.