2022 ESIG METEOROLOGY & MARKET DESIGN FOR GRID SERVICES WORKSHOP

Funded by: Solar Energy Technologies Office, U.S. Department Of Energy

Using Probabilistic Solar Forecasts for Operating Reserves Requirements




Benjamin Hobbs
(*Schad Chair of Environmental Management, Johns Hopkins University; Chair, CAISO Market Surveillance Committee*)
Hendrik Hamann, Carlo Siebenschuh, Rui Zhang (*IBM*)
Venkat Krishnan, Elina Spyrou, Ebrahim Kran, Xin Fang *(NREL)*
Jie Zhang, Binghui Li, Li He (*UT-Dallas*)   Josephine Wang, Shu Zhang (*JHU*)

Thanks to G. Bautista, A. Motley (CAISO) and S. Rose, B. Borrissov (MISO) for advice & data. Usual disclaimer applies.

AGENDA

1. Improved Probabilistic Solar Forecasts: Watt-Sun

→ *Probabilistic Solar Forecasts*

2. Link Prob. Solar Forecasts to NetLoad Ramp Uncertainty, & ACE*

→ *Ramp Product, regulation Requirements*

3. Western US Market Simulation: FESTIV

→ *Cost Savings & Reliability Improvements*

Funded by:

SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

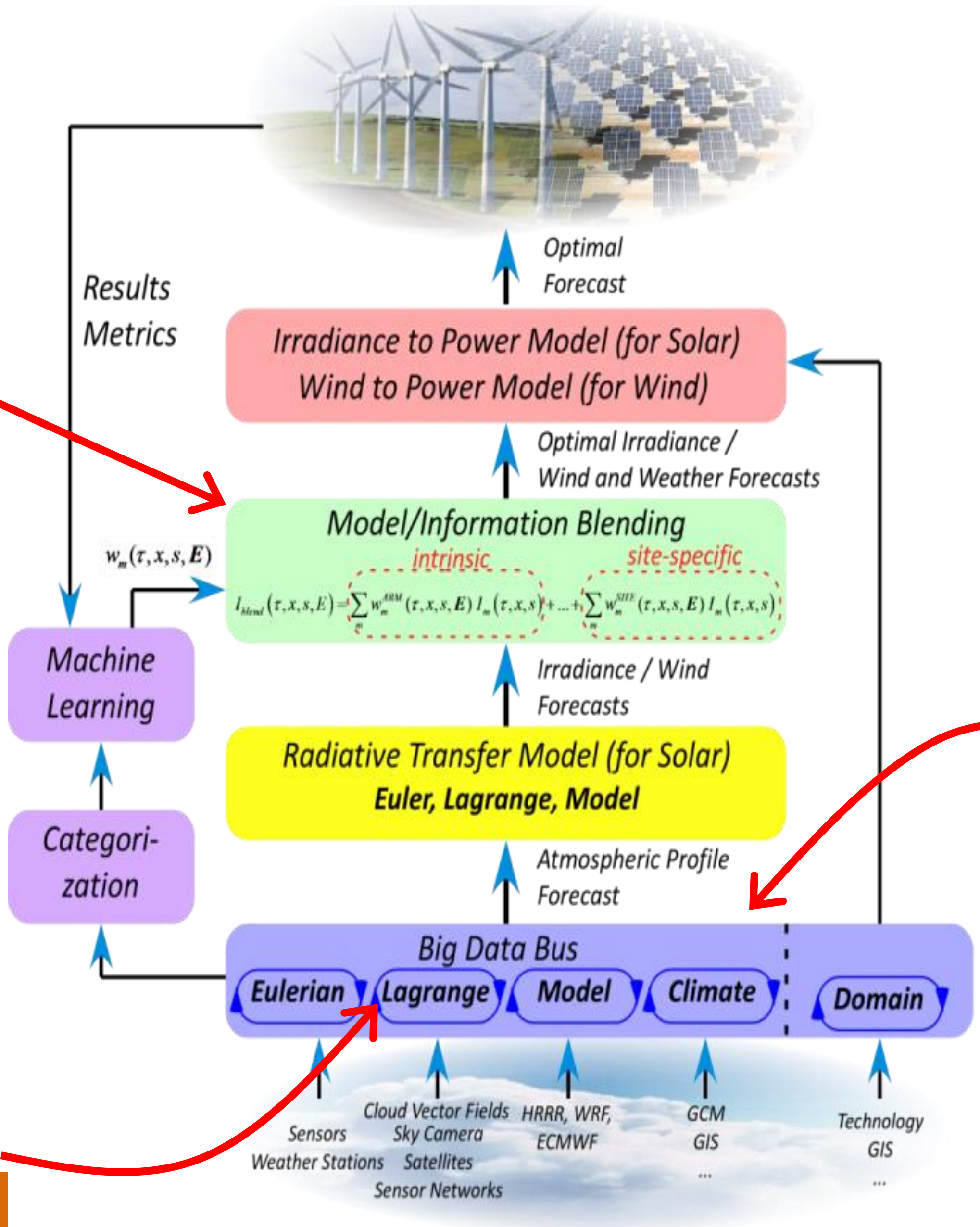
1. Improved Probabilistic Solar Forecasting: Probabilistic Watt-Sun

Watt-sun: Solar Forecasting I & II

Funded by:
SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

(Courtesy H. Hamann, IBM)

3. Probabilistic forecasts



2. Fully implemented Navier-Stokes enhanced optical flow-based cloud forecasts, using GOES data

se.

SF II enhancements:

1. **Replacement with PAIRS (<u>P</u>hysical <u>A</u>nalytics <u>I</u>ntegrated Data <u>R</u>epository and <u>S</u>ervices)**
   - Automatic data fusion
   - Non-relational/key-value store → Fully scalable
   - Supports tens of PBs
   - Improved curation speed (10’s TB/d)

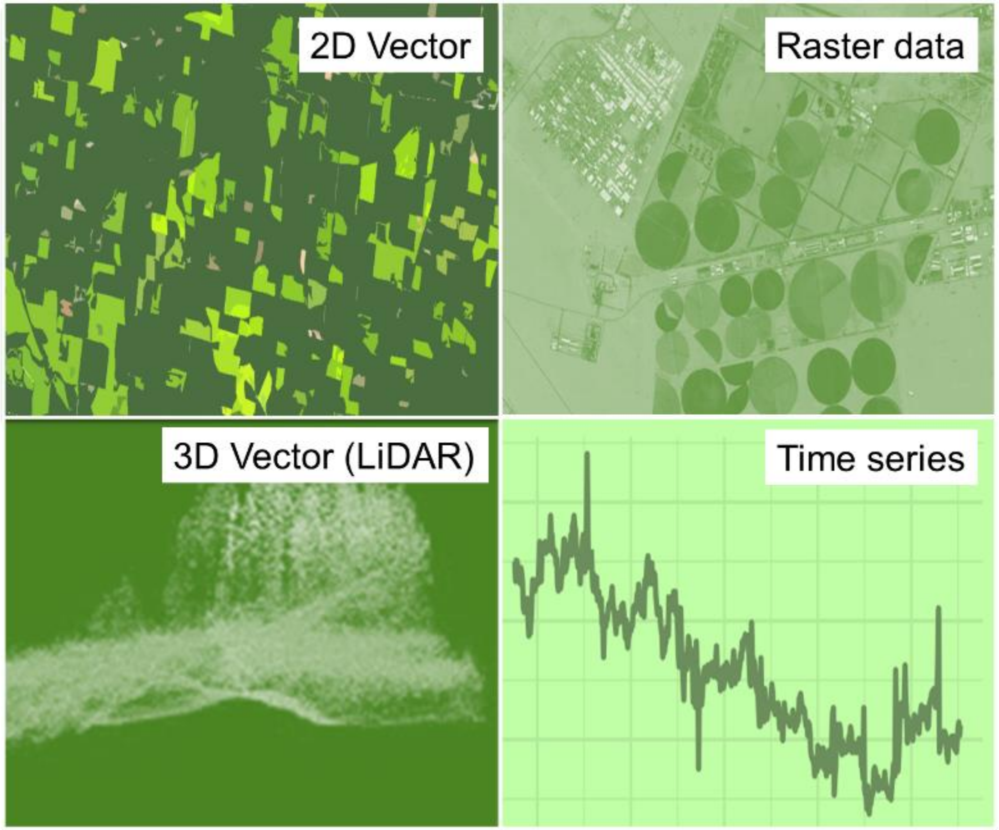
Watt-sun enhancement 1 of 3: Implementation of a big data platform for scalable processing

Technical challenges include:

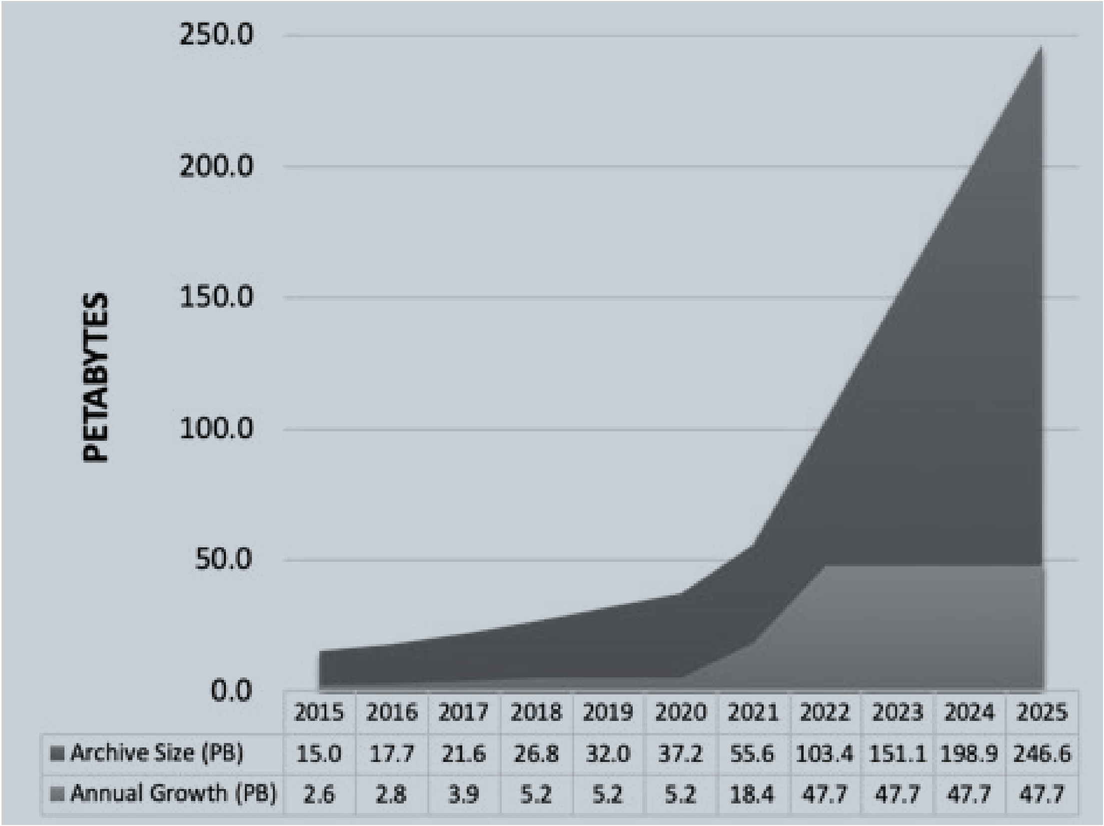
Funded by:
SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

(Courtesy H. Hamann, IBM)

1 Complexity



2 Data gravity

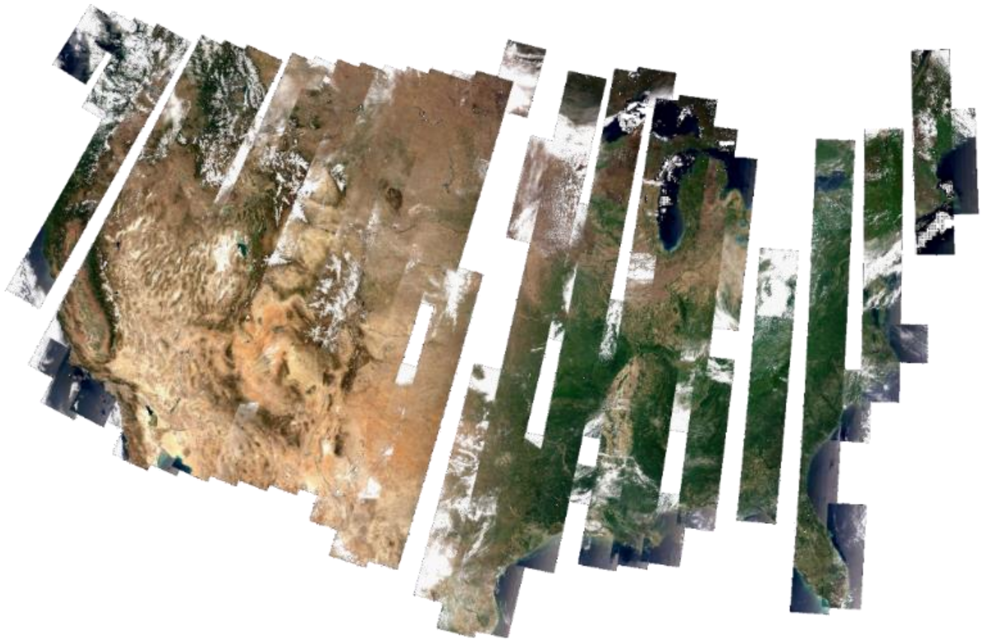


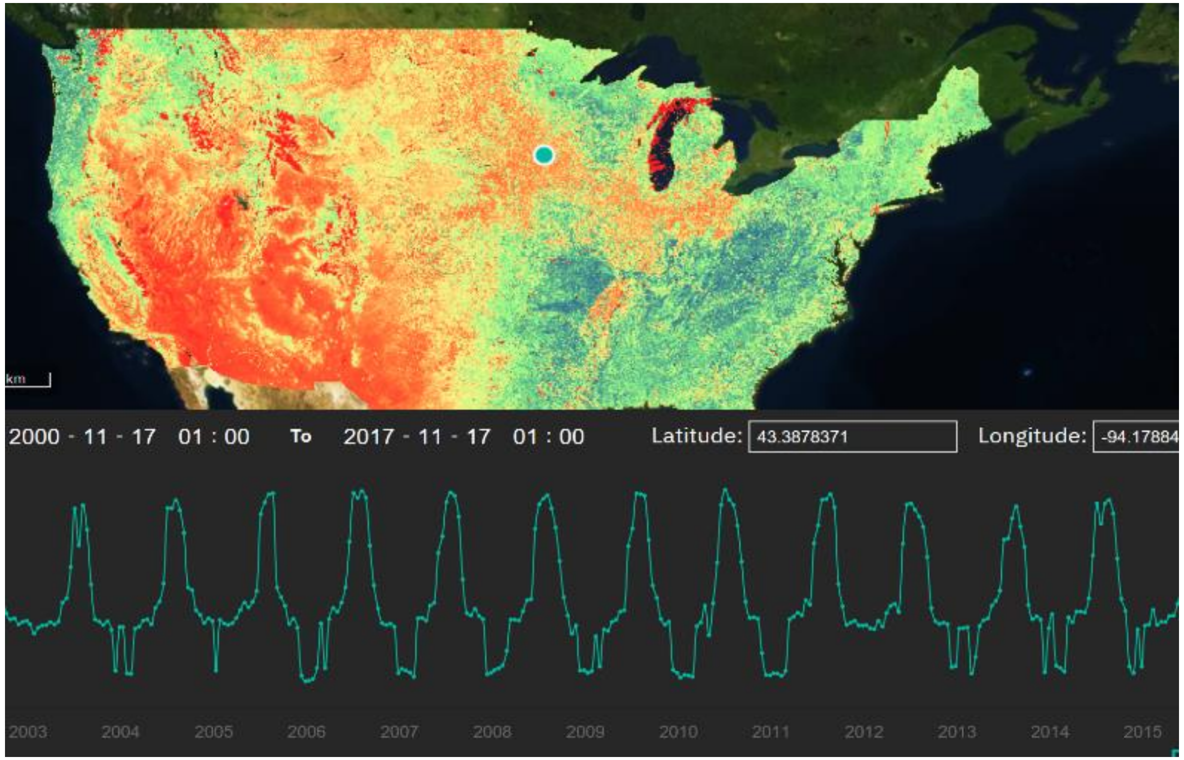
Funded by:
SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

Technical challenges include:

(Courtesy H. Hamann, IBM)

3 Information indexing



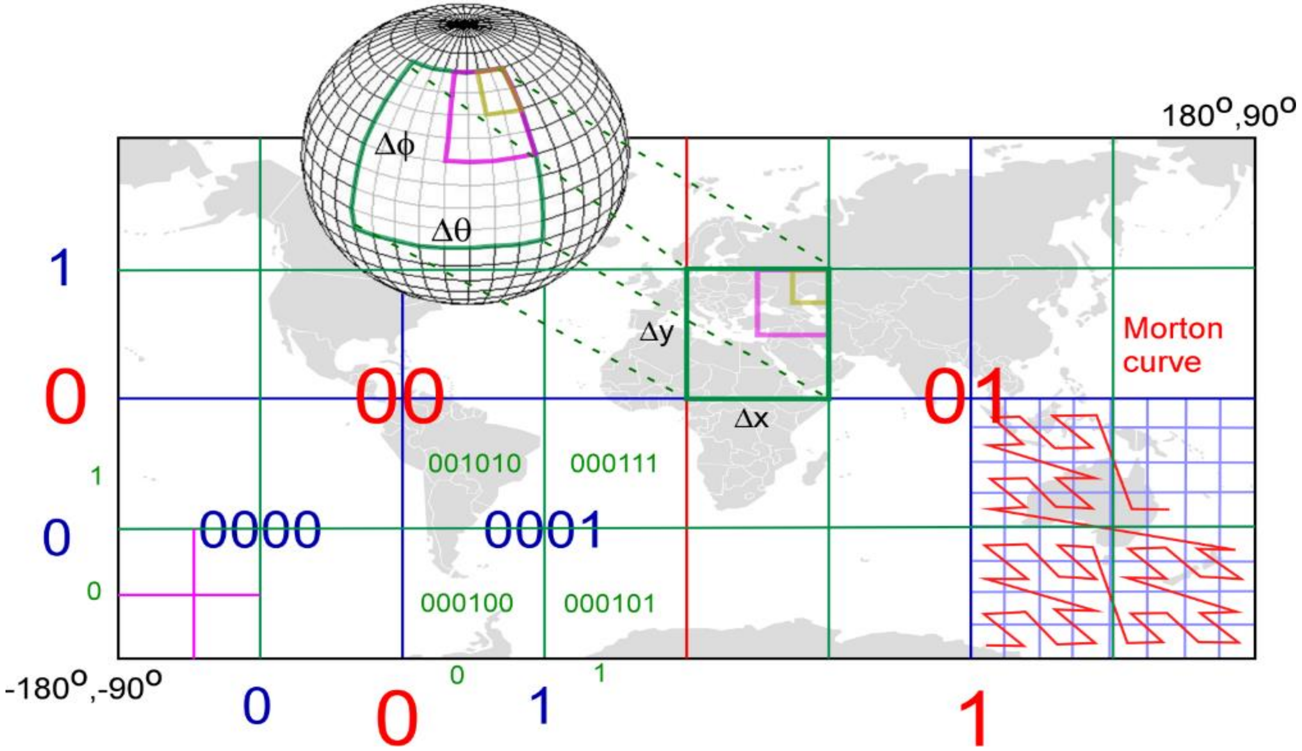


Many queries/workloads will require opening thousands of files

PAIRS: A scalable geospatial key-value store

(Courtesy H. Hamann, IBM)

A nested global spatial & temporal reference system



- All resolution layers are nested
  - Morton curves map 2D data to 1D while preserving locality of the data points
- Data at the same location and time "start" with the same key

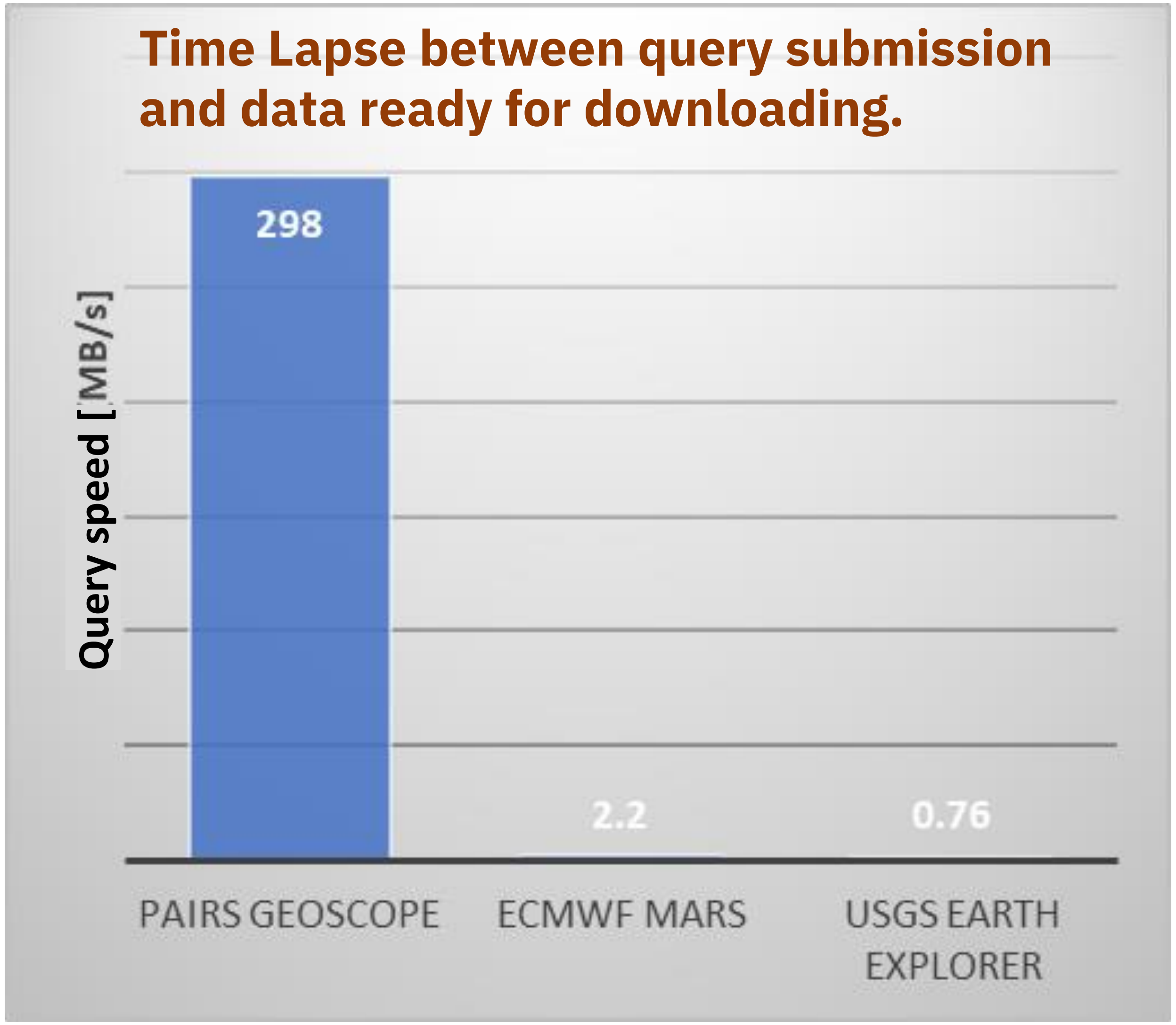
(S. Lu et al., IBM PAIRS: Curated big data service for accelerated geospatial data analytics and discovery, IEEE Intl. Conf. Big Data 2016).

Geospatial-temporal data access (150x faster)

Funded by: SOLAR ENERGY TECHNOLOGIES OFFICE U.S. Department Of Energy

(Courtesy H. Hamann, IBM)

- Test: Access 1.6 GB of geopotential data (6 pressure levels, 4 forecast times)
- Also: 1-3 Orders of magnitude speed up in regression & time series analyses

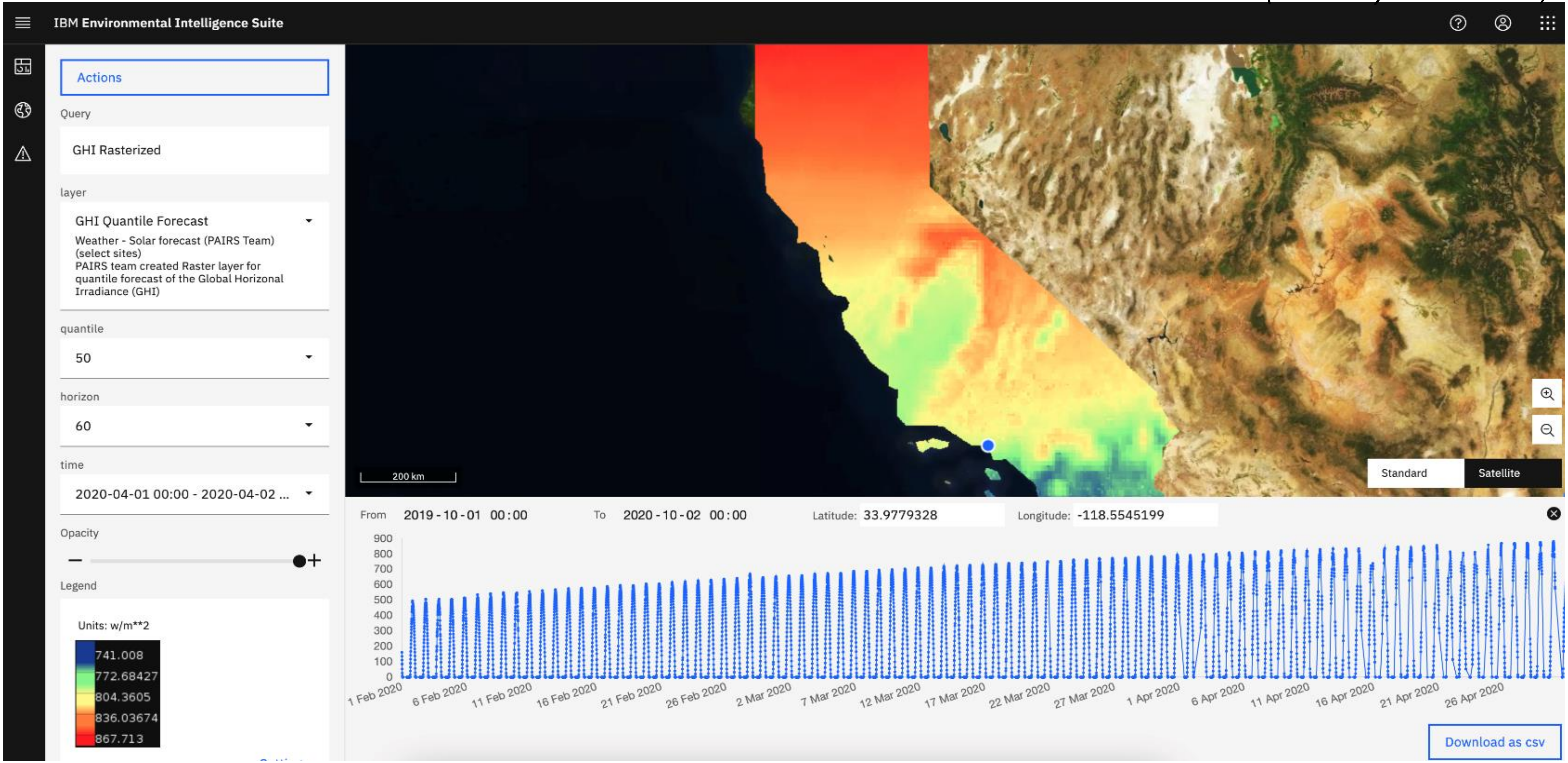


Watt-sun enhancement 2 (of 3):
Rasterized gridded probabilistic forecasts

Sample Outputs of Rasterized Probabilistic Forecasts

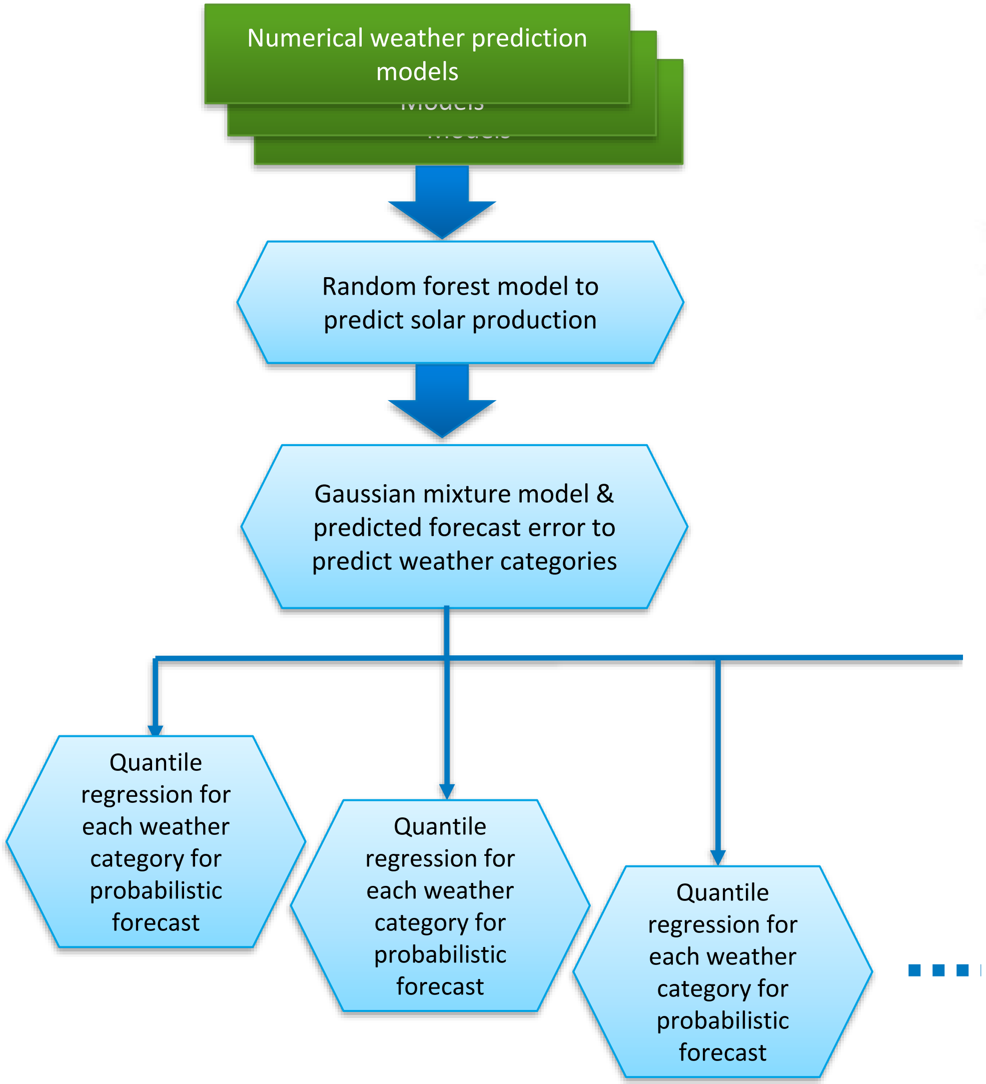
Funded by: SOLAR ENERGY TECHNOLOGIES OFFICE U.S. Department Of Energy

(Courtesy H. Hamann, IBM)

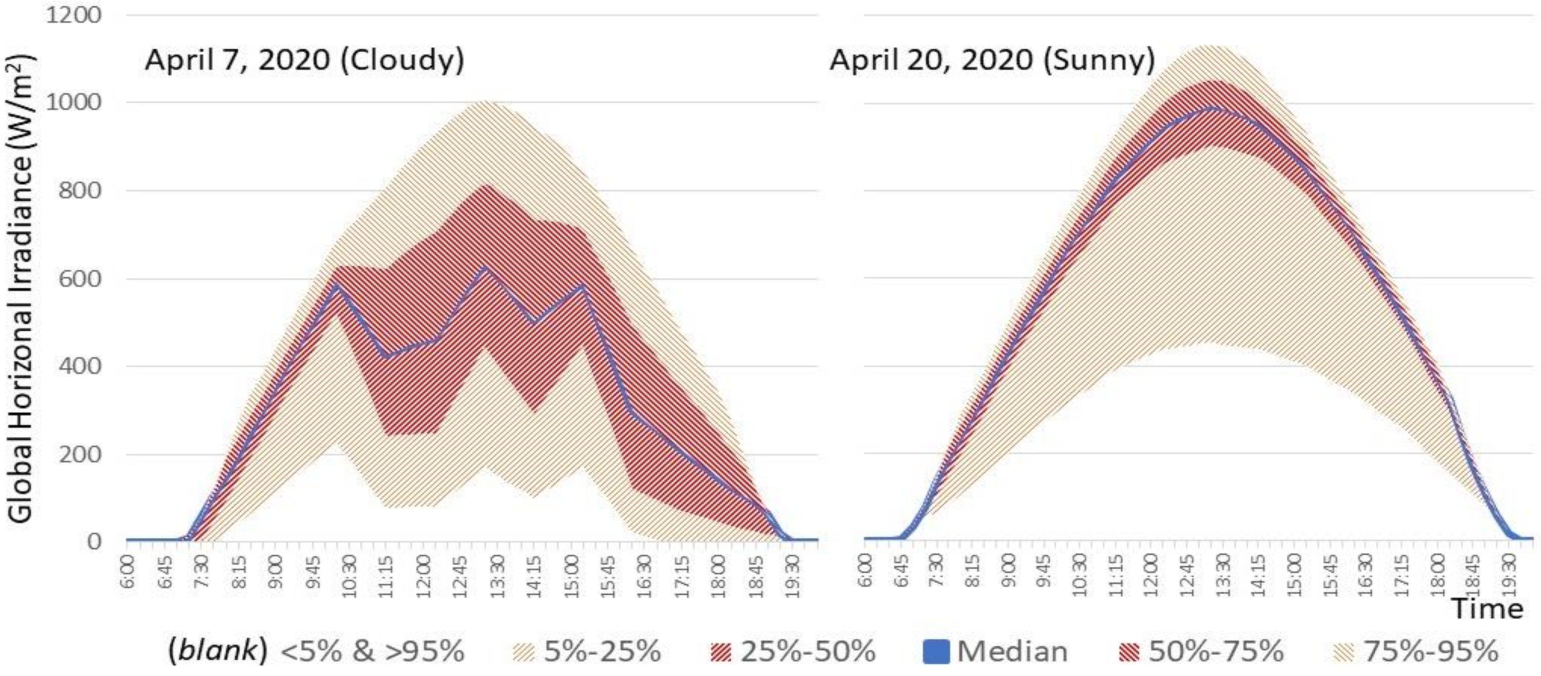


Watt-sun enhancement 3 (of 3): Watt-sun evolution

Probabilistic Watt-Sun Flowchart (IBM)



- Quantiles of solar as function of independent variables
- Example results for 2-hr-ahead forecasts



P-P metric found better calibration performance than baseline at 79% of 24 MISO & CAISO sites tested

- *Compared to persistence estimator augmented with empirical error distribution*

Funded by: SOLAR ENERGY TECHNOLOGIES OFFICE U.S. Department Of Energy

Future of renewable energy forecasting from IBM's point of view

(Courtesy H. Hamann, IBM)

- Technology
  - More data, new data
  - New architectures, forms of indexing
  - Special purpose AI
- Business
  - Vendor consolidation
  - Cross-industry for cost-effectiveness
- Decision support
  - Much closer integration with Decisions
  - Especially, alignment with needed:
    - spatial scales, and
    - update rates/lead times/horizons

} Next generation information architectures for future energy systems

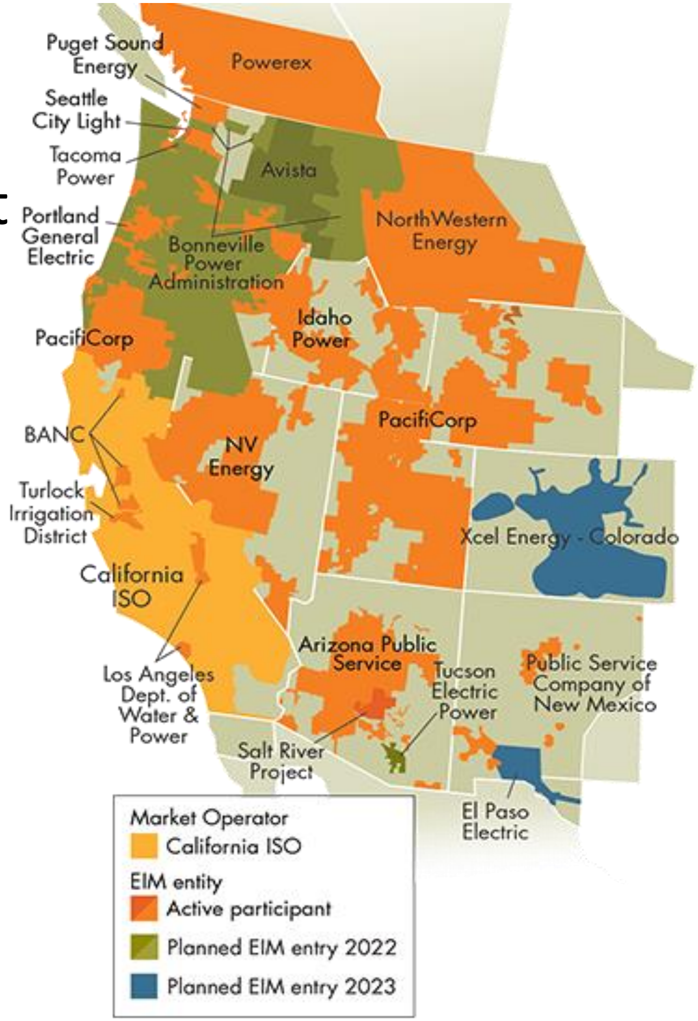
Funded by:
SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

2. Linking Reserve Requirements to Probabilistic Solar Forecasts

2.1 Weather-Aware Flexible Ramping Product Procurement

- Main goal of Flexible Ramp Product (FRP) (CAISO, MISO, SPP):
  - To pre-position resources to meet unexpected net load ramps up or down

- CAISO implemented in 2016, throughout "EIM" real-time market
  - Cover ramp uncertainty in:
    - up direction (97.5th percentile)
    - down direction (2.5th percentile)
  - CAISO:
    - Interested in making it conditional on weather
    - Plans to extend to day-ahead: "Imbalance reserve"



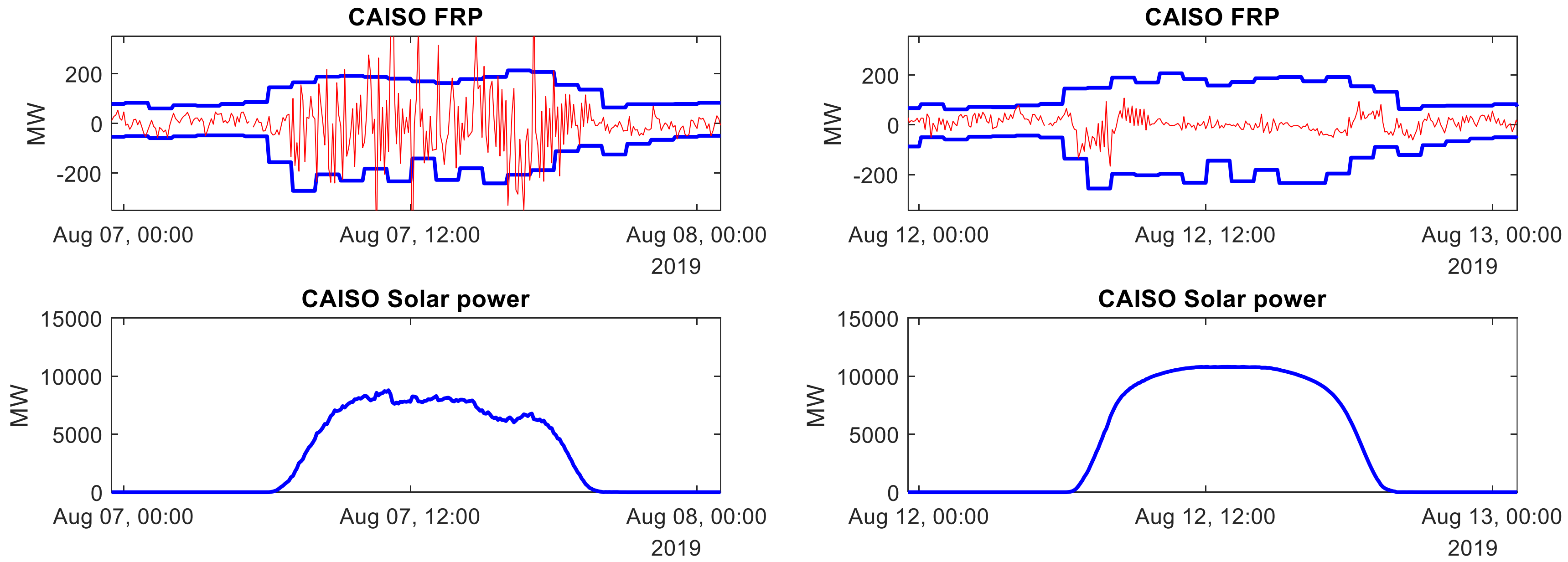
Funded by:
SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

Day Type Categorization

(Courtesy B. Li, UT-D)

- Type of days *vs.* uncertainties

Day Type	Cloudy day	Sunny day
Net load forecast uncertainty	**More**	**Less**
Solar power profile	**Jagged**	**Smooth**
Problems with non-weather conditioned baseline FRP	**Under** procurement →risk of reserve shortage	**Over** procurement →reduced market efficiency



Funded by: SOLAR ENERGY TECHNOLOGIES OFFICE U.S. Department Of Energy

The kNN-based Method: Procedures

(Courtesy B. Li, UT-D)

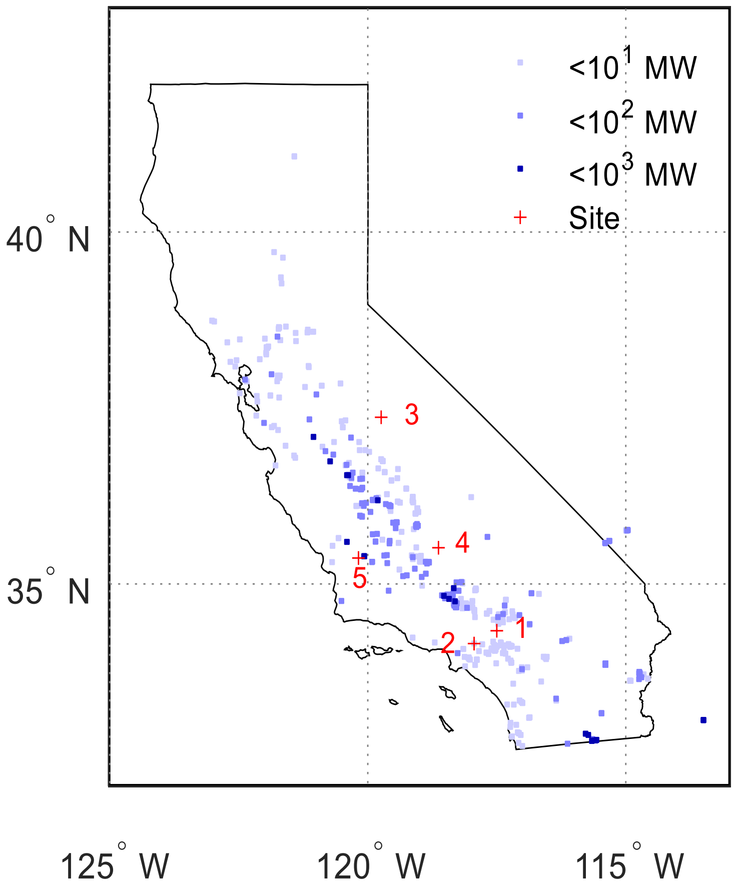
Weather characterization
- Characterize weather conditions using forecasts

→

Distance calculation
- Quantify similarity in terms of weather conditions
- ℓ_2 norm is used to measure distances

→

FRP determination
- Collect samples
- Build histograms
- Determine FRP requirements



Locations of CAISO solar PV plants and IBM sites

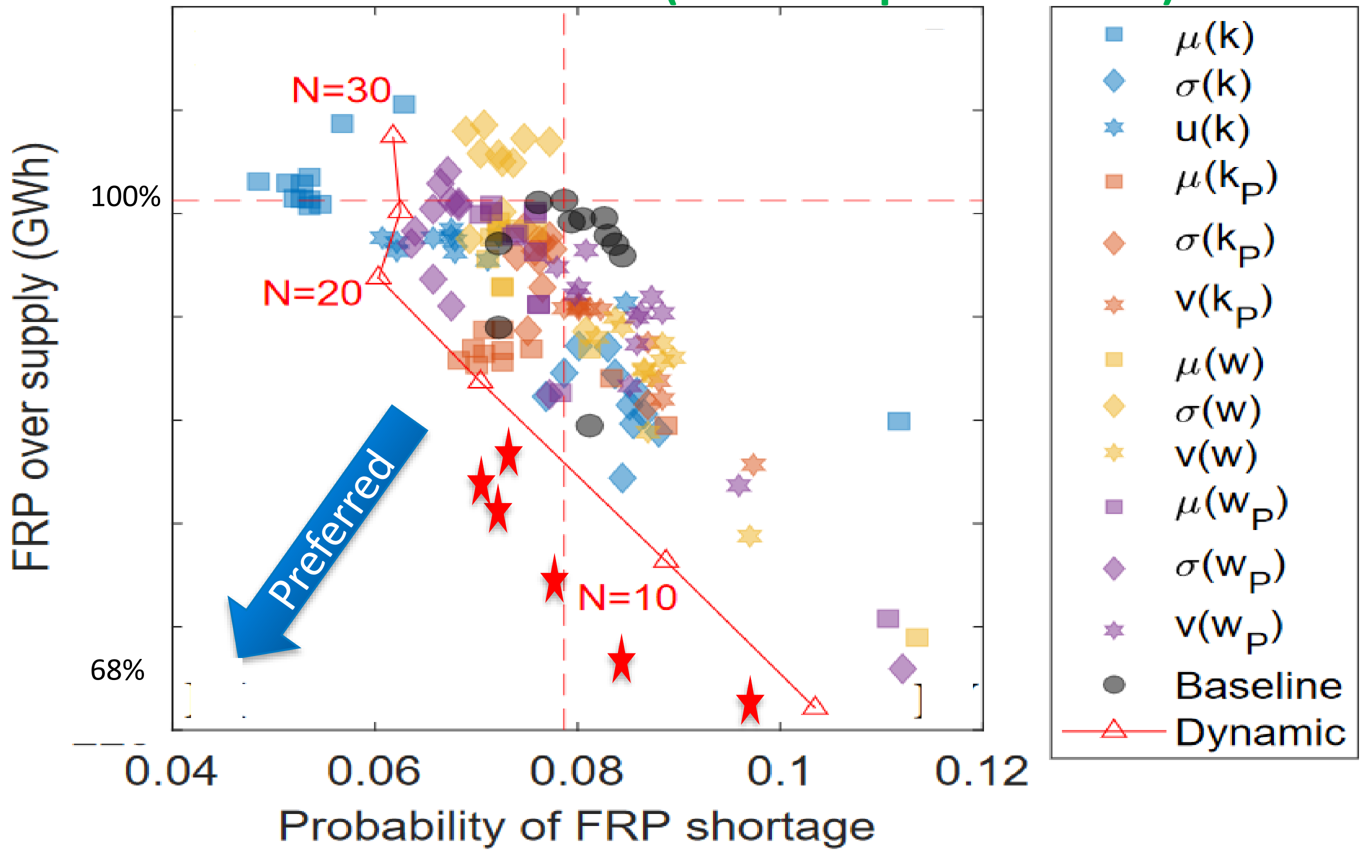
- IBM provides 5th, 25th, 50th, 75th, and 95th percentiles of GHI **every 15 min**
  - **Cloudiness conditions**: k -- Clear-sky index, k^{PV} -- clear-sky power index
  - **Uncertainty**: w -- Width of k, w^{PV} -- width of k^{PV}
- Mean (μ), standard deviation (σ) , volatility (v) of each
  → 12 potential independent variables

The PCA/kNN-based Method for FRP Estimation

Funded by: SOLAR ENERGY TECHNOLOGIES OFFICE U.S. Department Of Energy

(Courtesy B. Li, UT-D)

- Shown: kNN-based FRP requirements: Reliability-oversupply trade-offs Feb. 2020.
  - 1-D classifiers from solar site 2 using various predictors.
- Multisite/PCA classifiers perform even better
- Used in FESTIV Benefits Assessment (Part 3 of presentation)



B. Li, C. Feng et al., Sizing ramping reserve using probabilistic solar forecasts: A data-driven method, Applied Energy 313 (2022).

2.2 Weather-Aware Regulation Requirements Estimation

Funded by:
SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

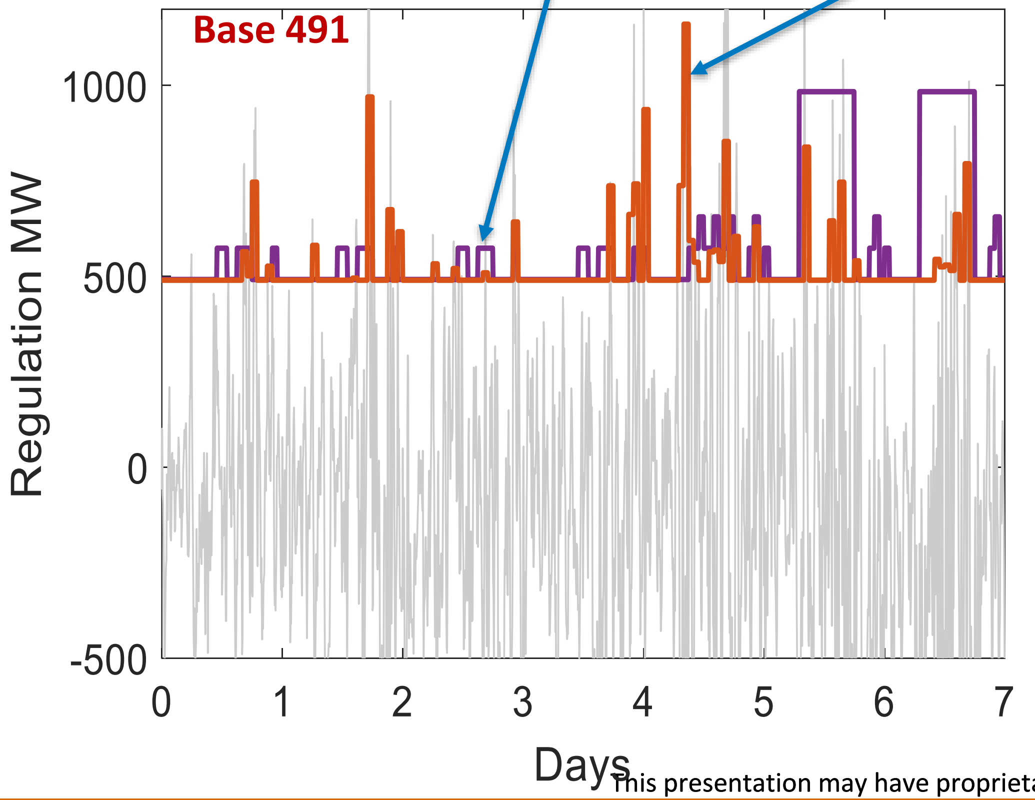
(Courtesy L. He, UT-D)

Real-time Reg procurement: Base X = *max* (Forecasted ACE*, X)

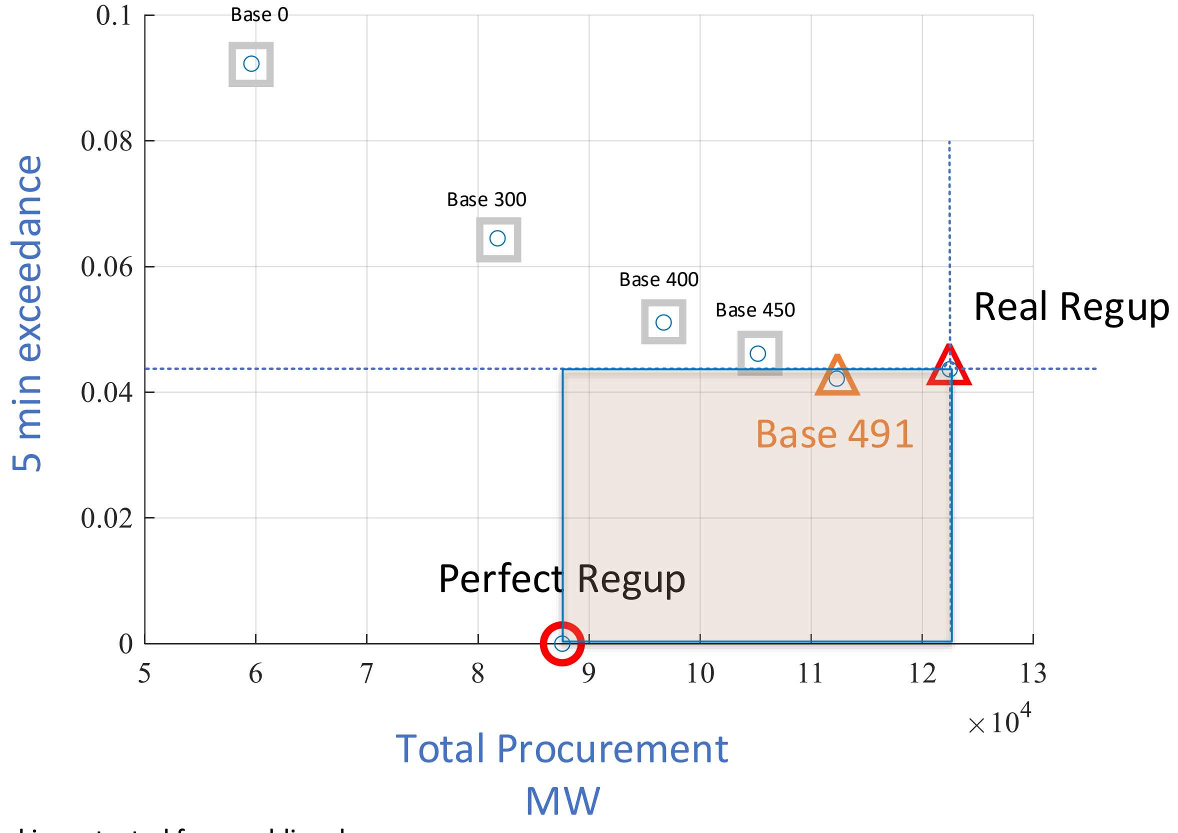
E.g., Base 491 = max (Forecasted ACE*, 491 MW)

CAISO reg-up: comparison of two methods

Real-time CAISO reg-up:
(1) Current CAISO day-head baseline (purple); (2) Base 491 MW real-time (orange), based on previous ACE* & solar forecasts



Reg-up requirements in last 7 days, May 2020 (compared to 5 min averages of ACE*)



Funded by: SOLAR ENERGY TECHNOLOGIES OFFICE U.S. Department Of Energy

3. Benefit Estimation for California Market using FESTIV

Summary: Experimental Setup

Question addressed:

What is the benefit of improved flexible ramp product requirements (FRP) on large systems operation with full network constraints?

Summary: Benefits Assessment By Simulations of Western US Markets

(Courtesy V. Krishnan, E. Spyrou, NREL)

- ***F**lexible **E**nergy **S**cheduling **T**ool for **I**ntegrating **V**ariable generation (FESTIV) tool, modified with CAISO operating rules*

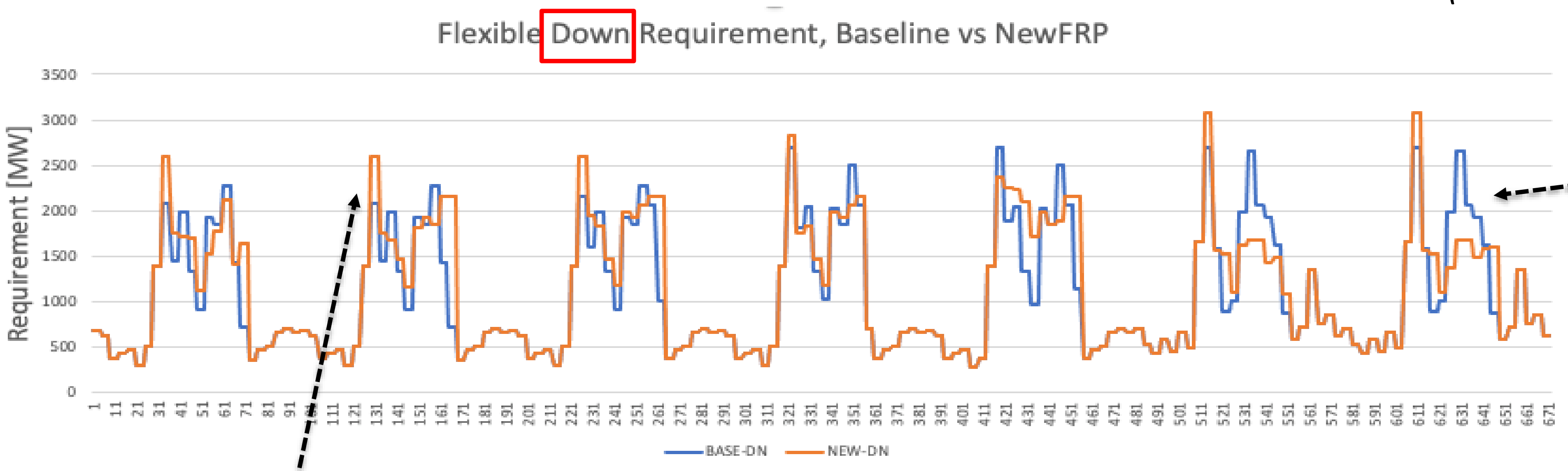
- **Two scenarios compared here…**
  1. ***Baseline*—**used historical FRP requirements obtained from OASIS
  2. ***New FRP*—**used new kNN-based FRP requirements

- **… in terms of two metrics of FRP performance:**
  1. **System production cost** (CAISO 2019 cost ~ $8B)
  2. **Total FRP procurement cost** (CAISO 2020 ~ $10M; 2018 ~$25M)

Summary: Example of Improved FRP Requirements & Results: March 9-15, 2020: Baseline vs. New FRP (kNN method)

Funded by: SOLAR ENERGY TECHNOLOGIES OFFICE U.S. Department Of Energy

(Courtesy V. Krishnan, I. Kran, NREL)

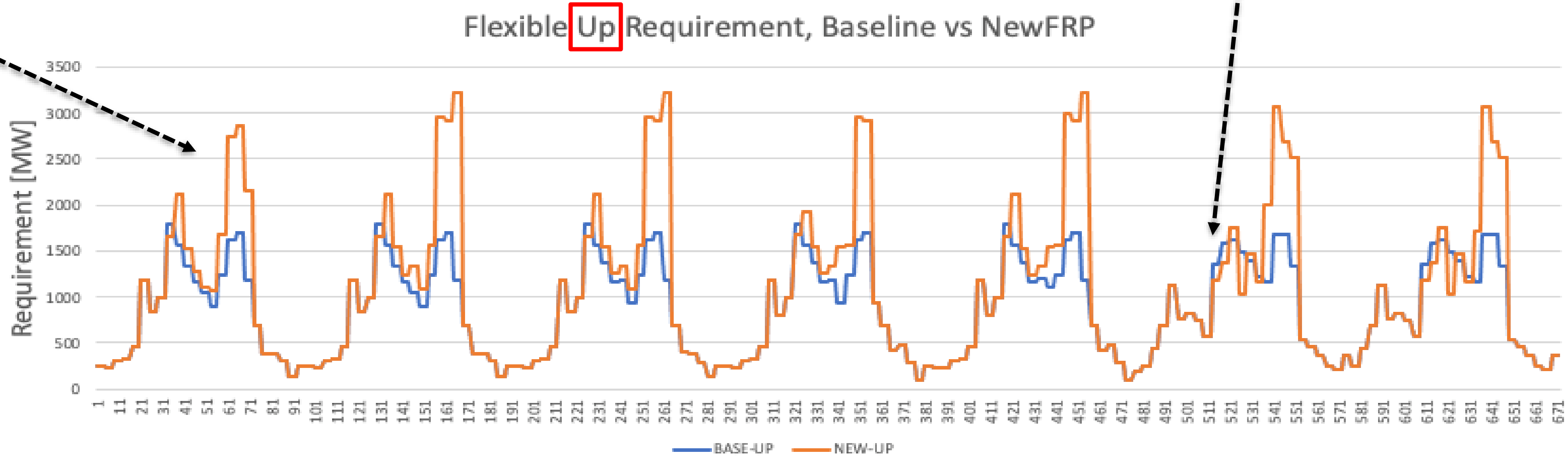


When ***decrease*** requirement:

- Reduce peaker unit scheduling
- Reduce production costs

When ***increase*** requirement:

- Improve reliability
- Reduce generation scarcity & price spikes
- Reduce renewable curtailment



Production Cost and FRP Procurement Cost Comparison: Baseline vs Solar-Informed FRP, March 16-20, 23-25, 2020

Funded by:
SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

(Courtesy V. Krishnan, I. Kran, X. Fang, NREL)

	Baseline (Current CAISO Method)
Production Cost $	$106.6M
(Savings $, Percent)	
FRP Procurement Cost (Price*Quantity) $	$136.5K
(Savings $,Percent)	

Funded by: SOLAR ENERGY TECHNOLOGIES OFFICE U.S. Department Of Energy

Conclusion

1. Improved Probabilistic Solar Forecasts: Watt-Sun

→ *Probabilistic Solar Forecasts*

2. Link Prob. Solar Forecasts to NetLoad Ramp Uncertainty, & ACE*

→ *Ramp Product, regulation Requirements*

3. Western US Market Simulation: FESTIV

→ *Cost Savings & Reliability Improvements*

- We conclude that probabilistic solar forecasts are a highly promising way to condition ancillary service requirements on up-to-date weather forecasts.

Funded by:
SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

Questions?