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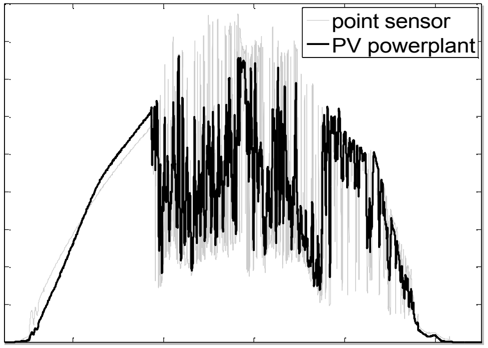

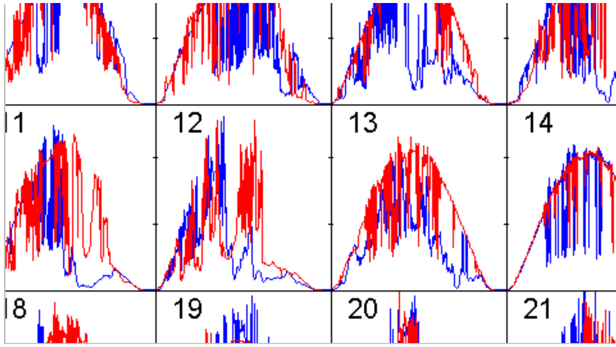

Simulated PV Power Plant RRs:

Implications for Ramp Limitations Imposed by Utilities

Matthew Lave[1], Jan Kleissl[2], Abraham Ellis[3], Felipe Mejia[2]

SPI 2013, Chicago, IL: October 22nd, 2013

[1]Sandia National Laboratories, Livermore, CA
[2]University of California, San Diego
[3]Sandia National Laboratories, Albuquerque, NM

mlave@sandia.gov

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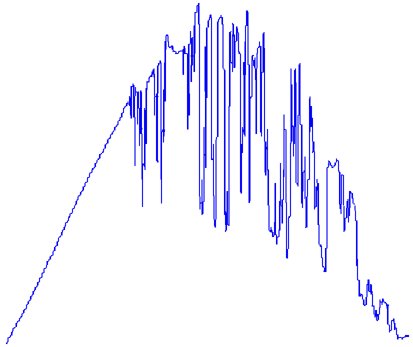
The Problem

- Solar PV power is variable
  - Passing cloud shadows
  - Movement of sun through sky
  - Other effects (shading, temperature, inverter behavior, soiling, etc.)



- Some utilities have imposed ramp rate (RR) restrictions:
  - The Puerto Rico Electric Power Authority (PREPA) :
    A 10 % per minute rate (based on nameplate capacity) limitation shall be enforced.[1]
- For PV plants in development, magnitude and occurrence of large RRs is not known
  - Impacts storage, sizing, siting, etc. decisions

[1]*Puerto Rico Electric Power Authority Minimum Technical Requirements for Photovoltaic Generation (PV) Projects* (2012)
http://www.fpsadvisorygroup.com/rso_request_for_quals/PREPA_Appendix_E_PV_Minimum_Technical_Requirements.pdf

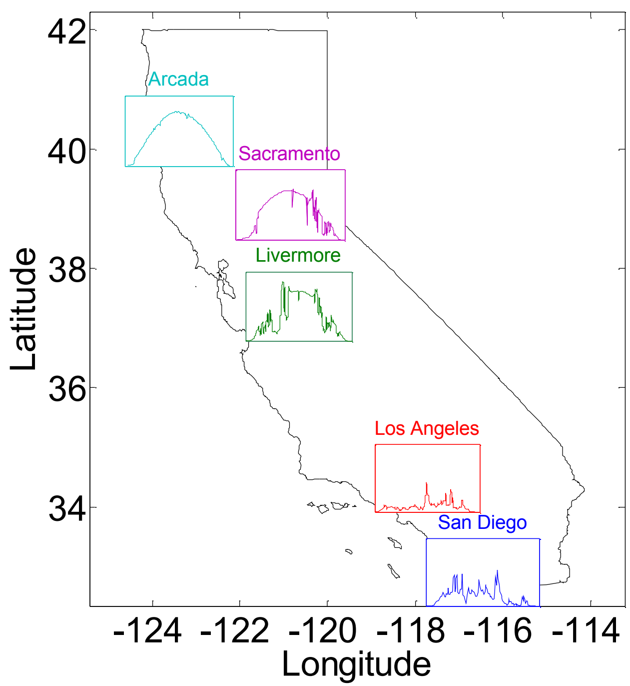
Irradiance Statistics

- To understand PV plant variability, we must understand the variability of incident irradiance.

Variability changes:

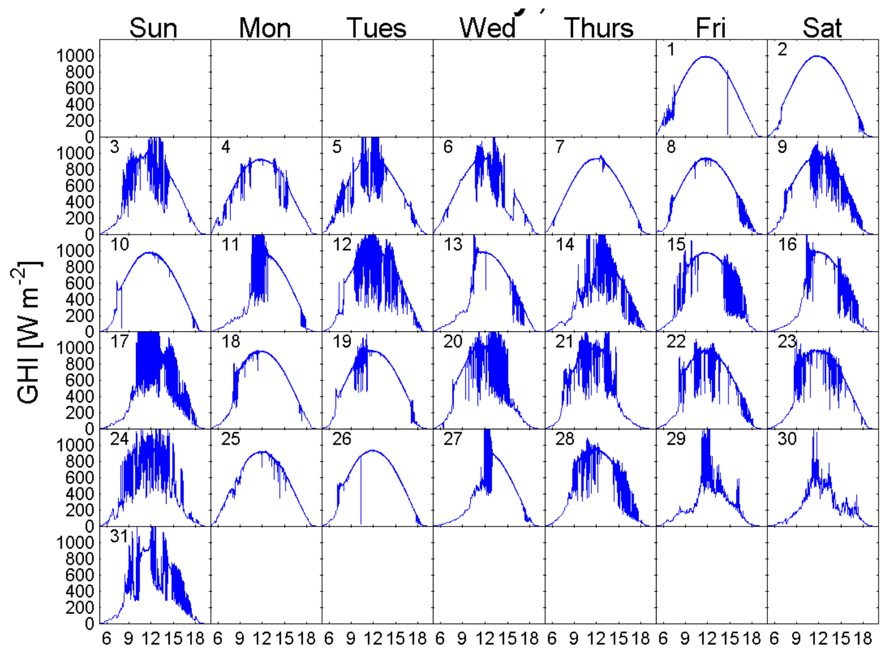
by location

October 9, 2013



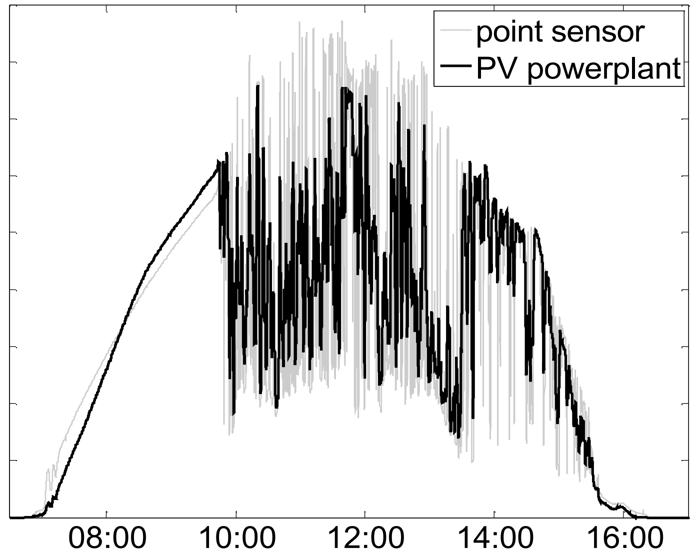
and by day

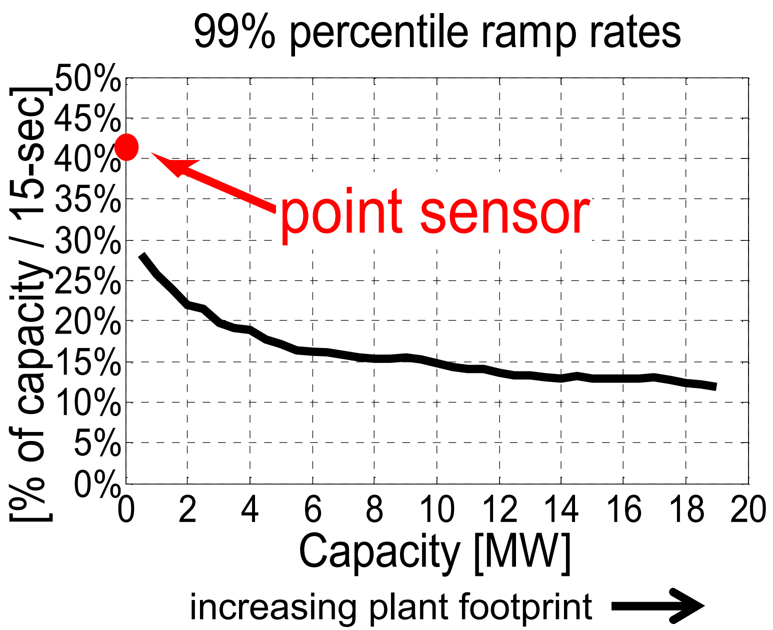
San Diego, July, 2011



Spatial Smoothing

- Plant output is smoothed due to spatial diversity of PV modules.





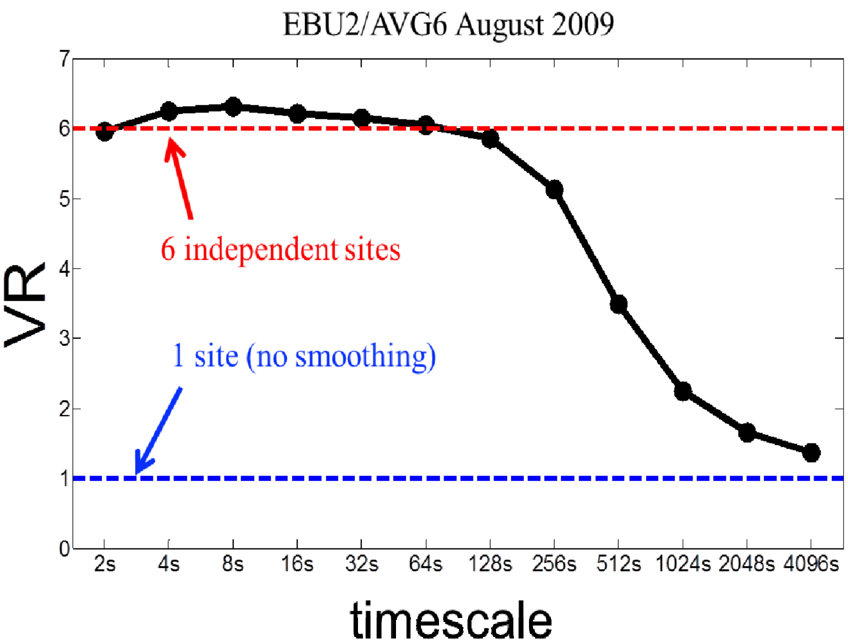
Reduction in variability depends on cloud speed and plant layout (dimensions and density of PV).

Timescale Impact on Smoothing

- Spatial smoothing varies by timescale.

$$VR = \frac{point\ sensor\ variability}{power\ plant\ variability}$$

Larger VR indicates more smoothing.



The shorter the timescale, the more smoothed PV plant output will be compared to a point sensor.

Take Home Message #1

- **The variability of a point sensor is not the same as the variability of a PV power plant.**
  - In many cases, a point sensor will significantly over-predict ramps
  - Variability reduction $VR(\bar{t}) = \frac{point\ sensor\ variability}{power\ plant\ variability}$
  - Spatial smoothing within a PV plant depends on:
    - Average distance between sites:

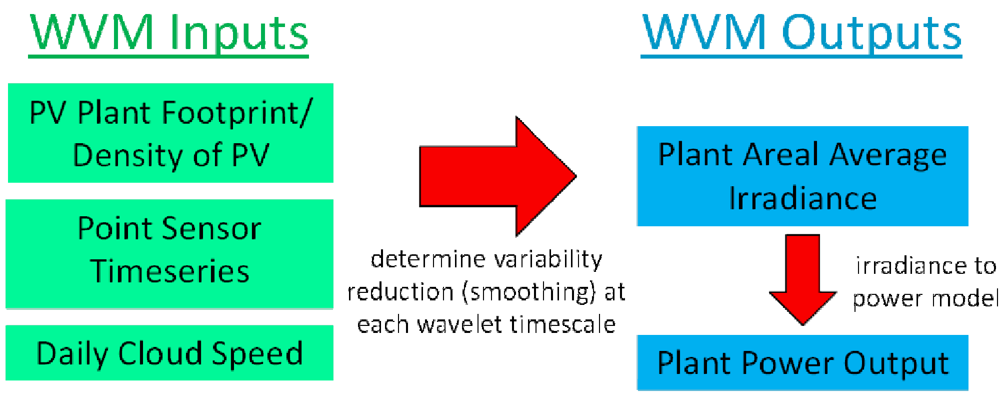
      $$\bar{d} \uparrow, VR \uparrow$$
    - Cloud speed

      $$CS \uparrow, VR \downarrow$$
    - Timescale

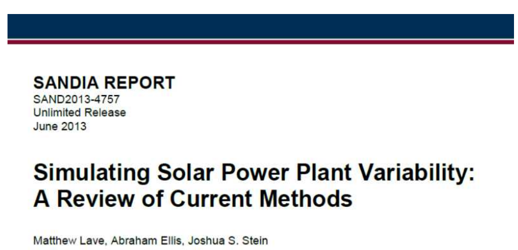
      $$\bar{t} \uparrow, VR \downarrow$$

PV Plant Variability Simulation

- To appropriately simulate PV plant variability, need a method that upscales point sensor irradiance
  - One method: Wavelet Variability Model (WVM)



- Other methods exist:


SANDIA REPORT
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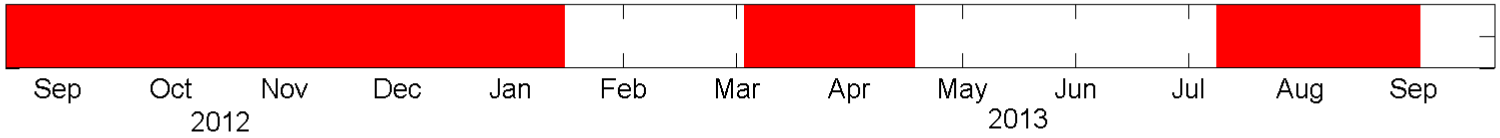
Simulating Solar Power Plant Variability:
A Review of Current Methods

Matthew Lave, Abraham Ellis, Joshua S. Stein

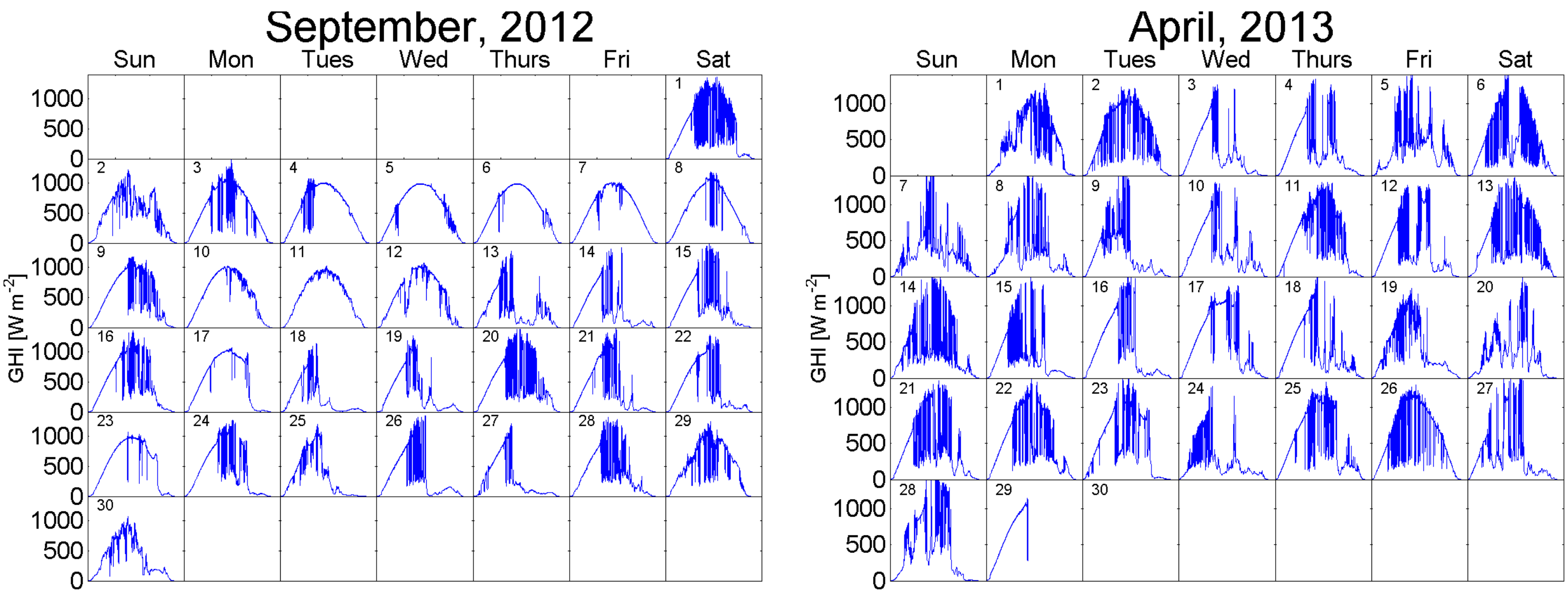
Case Study: Puerto Rico

- Kleissl Lab Group at the University of California, San Diego has been collecting 1-second irradiance measurements at the University of Puerto Rico, Mayaguez since September 2012.

- Data available Aug. 28, 2012 – Sept. 10, 2013
  - Due to data outages, only 252 days with saved data



Mayaguez Solar Resource



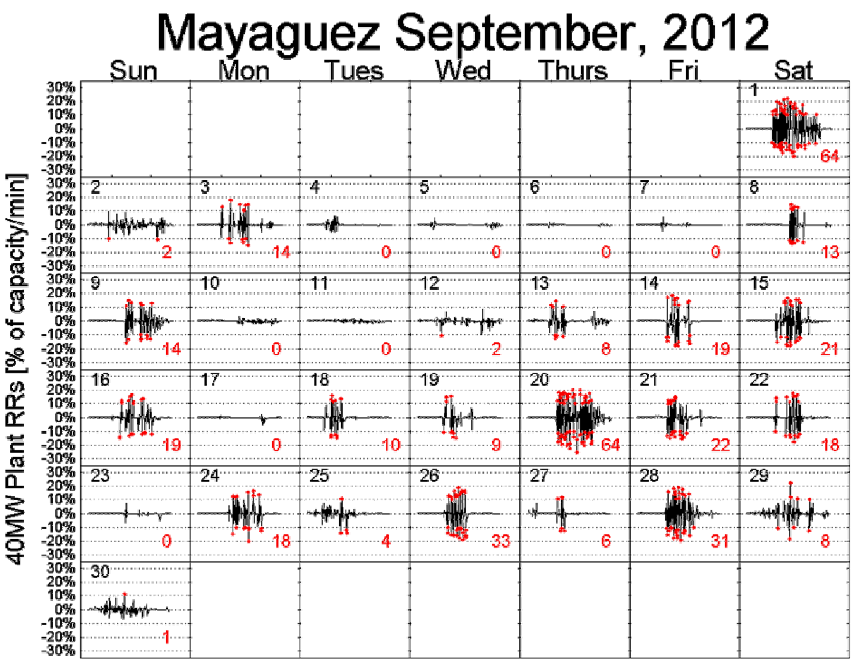
- Often clear in mornings, highly variable by midday.
- Seasonal variation: September less variable than April.

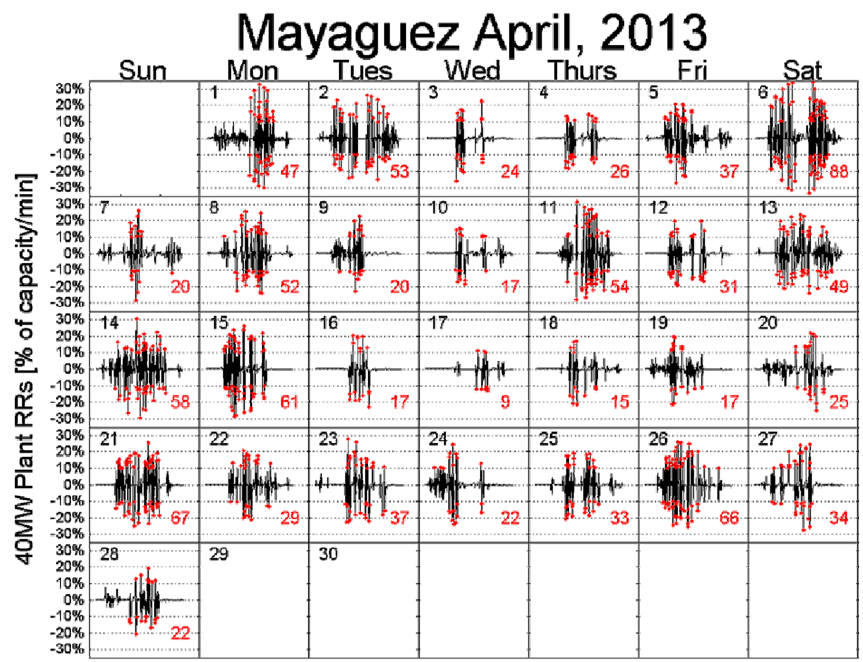
PR Plant RRs

- Used WVM to upscale irradiance measurements to represent various sized PV plants in Mayaguez.

Example: Simulated RRs for a 40MW plant.

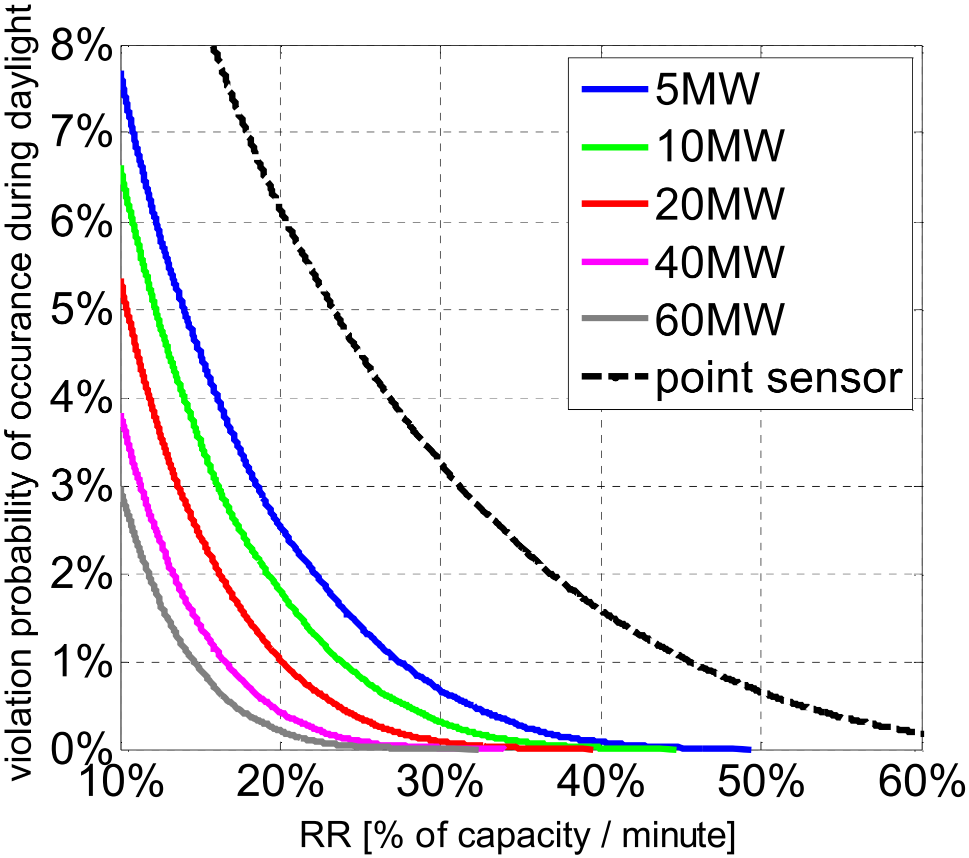
- Red dots indicate RRs larger than 10% of capacity per minute





Ramp Magnitudes/Probabilities

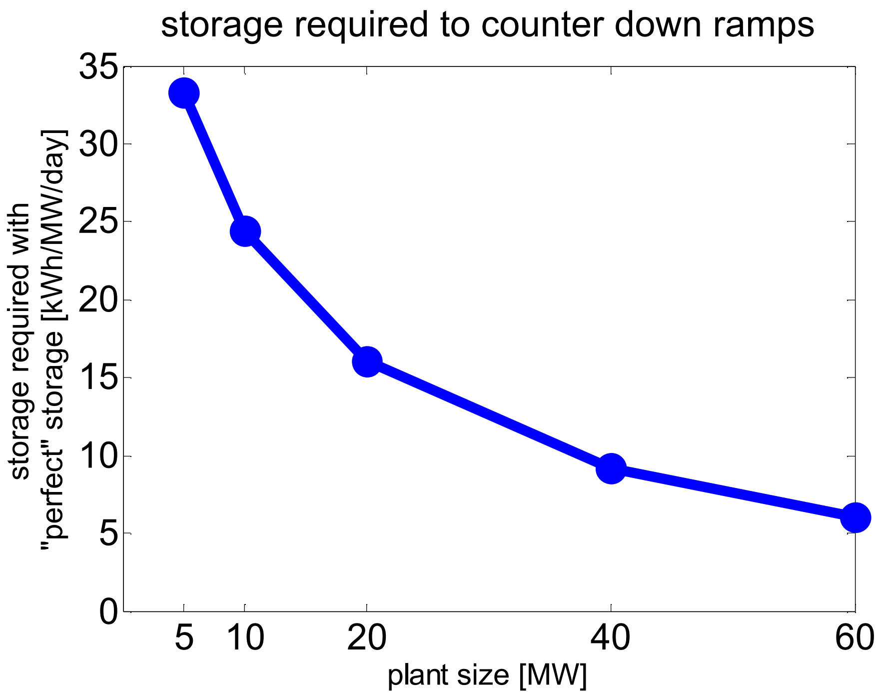
- Results for all 252 days with collected data
  - Plants assumed to be fixed latitude tilt



	$P(\lvert \boldsymbol{RR} \rvert > 10\%)$	$max(\lvert \boldsymbol{RR} \rvert)$
point sensor	11.59%	82.63% of capacity
5MW	7.70%	49.42% of capacity
10MW	6.63%	44.75% of capacity
20MW	5.35%	39.54% of capacity
40MW	3.82%	34.06% of capacity
60MW	2.99%	32.31% of capacity

Storage Req. to Counter >10% Ramps

- Amount of storage required depends PV ramp rates, but also control algorithm, storage ramp ability, capacity, etc.
- Eliminating all these variables and assuming "perfect" storage

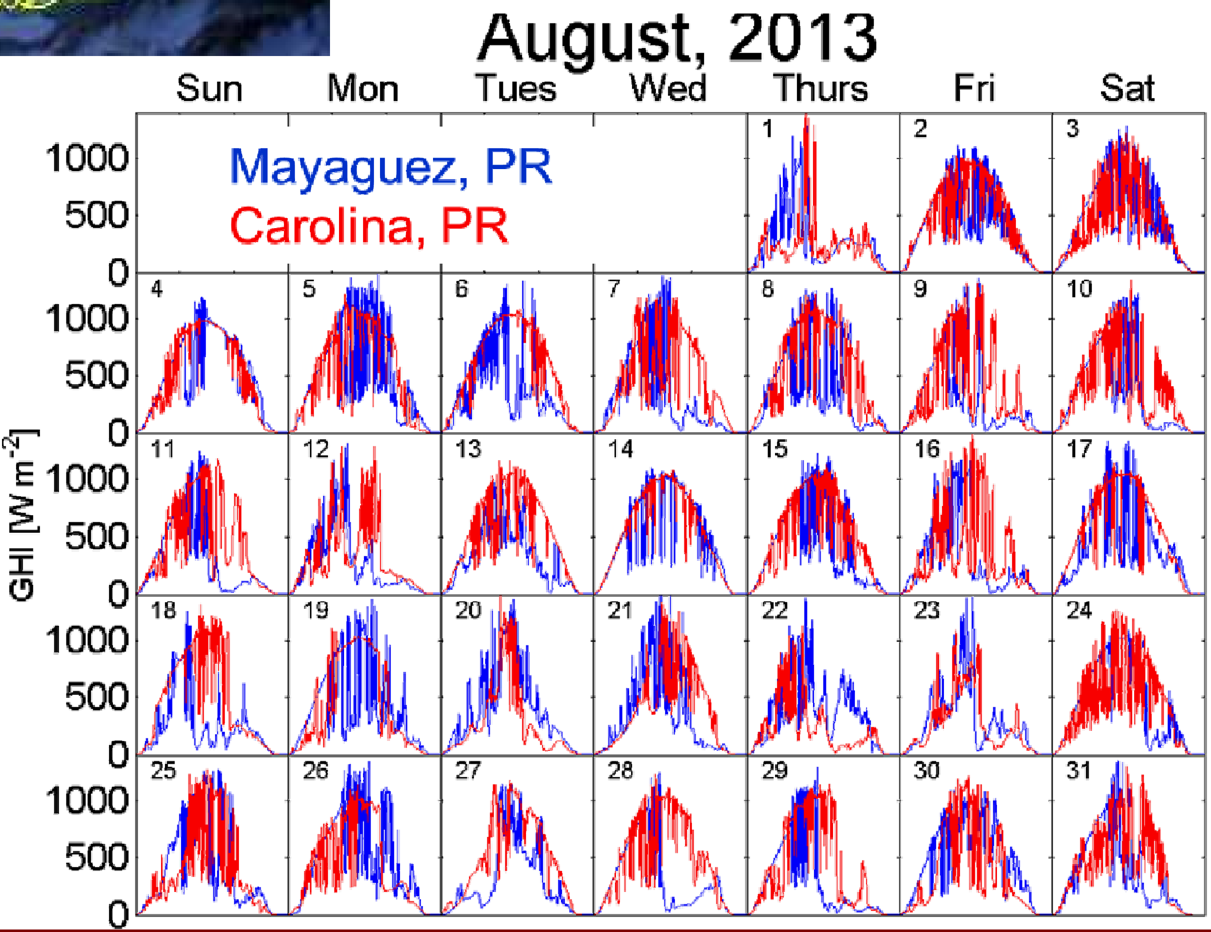


***WARNING: Do not use this plot to make storage sizing decisions! The assumption of "perfect" storage is a gross oversimplification. This plot is only meant to illustrate that relative storage requirements decrease with increasing capacity.

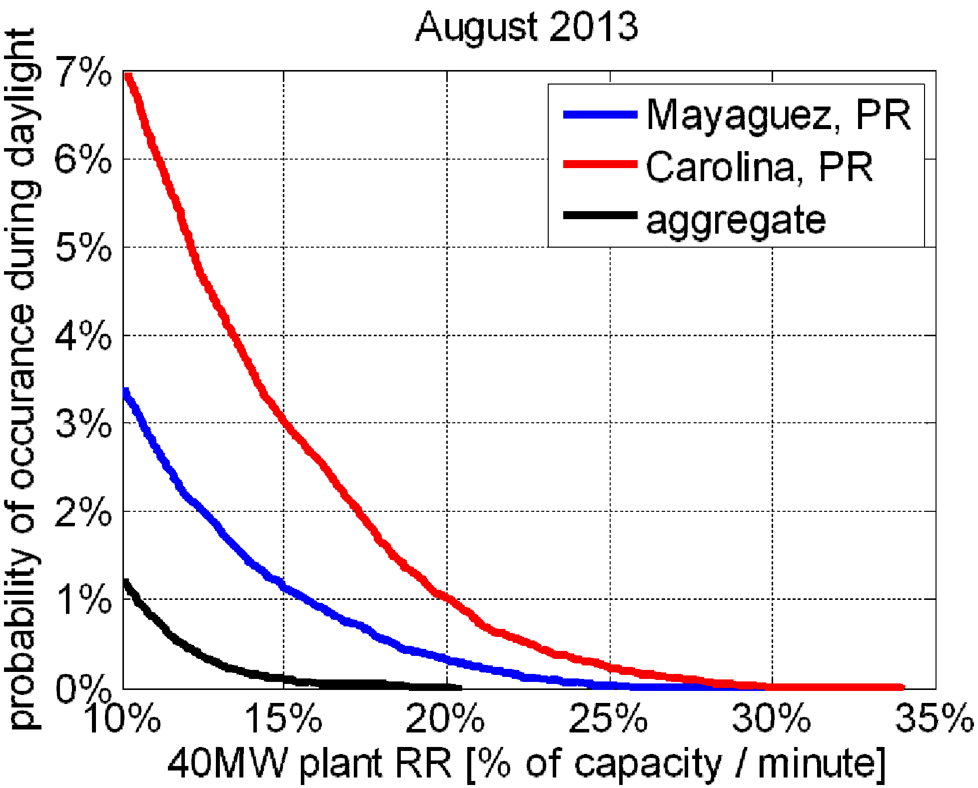
Take Home Message #2

- **The amount of storage required to reduce ramps into compliance with the utility 10% ramp limitation depends on both the frequency of occurrence and on the magnitude of ramps.**
  - The question is not simply “how often would I be in violation of the 10% rule?” but also, “by how much?”.
  - Larger plants have smaller maximum RRs (as a % of capacity), so require less storage relative to capacity.

Variation Within Puerto Rico



Smoothing Within Puerto Rico



	$P(\|\boldsymbol{RR}\| > 10\%)$	$max(\|\boldsymbol{RR}\|)$
Mayaguez	3.43%	31.04% of capacity
Carolina	7.21%	34.03% of capacity
aggregate of both plants	**1.25%**	**20.48% of capacity**

***These results are likely not representative of annual trends at Carolina or Mayaguez. On an annual basis, it is possible that Carolina is less variable than Mayaguez. This plot is meant to show the benefit of aggregating geographically diverse PV power plants.

How does PR Compare to other Locations?

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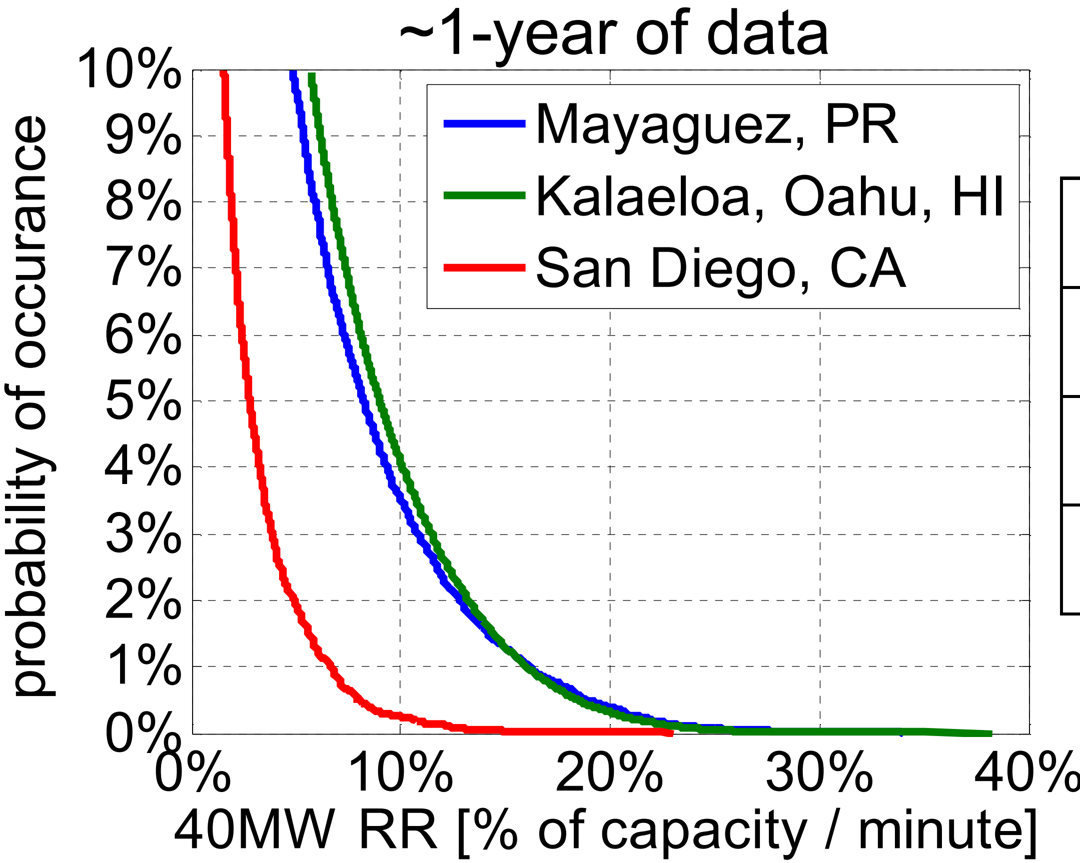

	$P(\lvert \boldsymbol{RR} \rvert > 10\%)$	$max(\lvert \boldsymbol{RR} \rvert)$
Mayaguez	3.82%	34.06% of capacity
Kalaeloa	4.09%	38.29% of capacity
San Diego	0.25%	23.06% of capacity

- Mayaguez and Kalaeloa have similar variability statistics.
- San Diego is much less variable.

Take Home Message #3

- **PV plants located in different climates can have significantly different variability statistics. Aggregating plants from different climates can significantly reduce the relative variability.**
  - Important to understand local variability, especially when choosing proxy data.
  - Strong reductions in variability at all timescales (not just short time scales) are achieved when combining plants in different climates.

Conclusions

- Take Home Messages:
  - Point sensor variability ≠ PV plant variability
  - Storage scales with both magnitude and frequency of RRs.
  - Variability statistics can vary significantly by climate; can be used to achieve significant smoothing.

- Outlook for Utility-Imposed RR restrictions:
  - Compliance plant-by-plant, or based on aggregate output of multiple plants?
    - Can make a significant difference for number of violations.
  - Same rules for small vs. large plants?
    - Even though relative (% of capacity) variability is reduced for larger plants, absolute variability (MWs) increases.

Thank You!

Questions/Comments?

Contact: mlave@sandia.gov