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Geographic Smoothing of Irradiance

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PV Performance Modeling Workshop

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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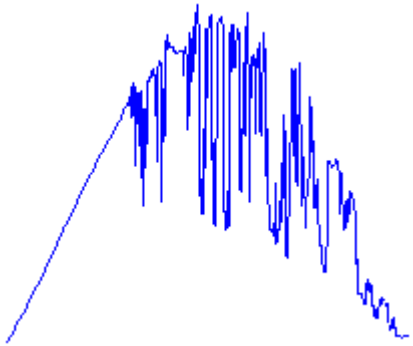
Solar Variability and Smoothing

Solar irradiance is variable due to:

- Long-timescale
  - Movement of sun through the sky
  - Seasonal changes: length of day, composition of clear atmosphere, etc.
- Short-timescale
  - Cloud shadows passing over PV modules



Two types of variability smoothing:

- Smoothing due to spatial diversity
  - Short-distance (< a few kms), short timescale smoothing due to different incidence times of cloud shadows.
  - E.g., smoothing within a PV plant.
- Smoothing due to geographic diversity
  - Long-distance (10s to 100s of km), all timescale smoothing due to different cloud patterns at different locations.
  - E.g. smoothing when aggregating multiple PV plants many miles apart.

Impact of Solar Variability

Spatial Diversity:

- Small impact on annual energy estimates for PV plants.
  - When averaged over 1-year, little spatial variation in energy.
- Large impact on short-timescale (e.g., <1-hour) ramp rate estimates.
  - Affect interconnection decisions such as storage sizing, especially in locations with utility imposed RR restrictions such as Puerto Rico [1].

Geographic Diversity:

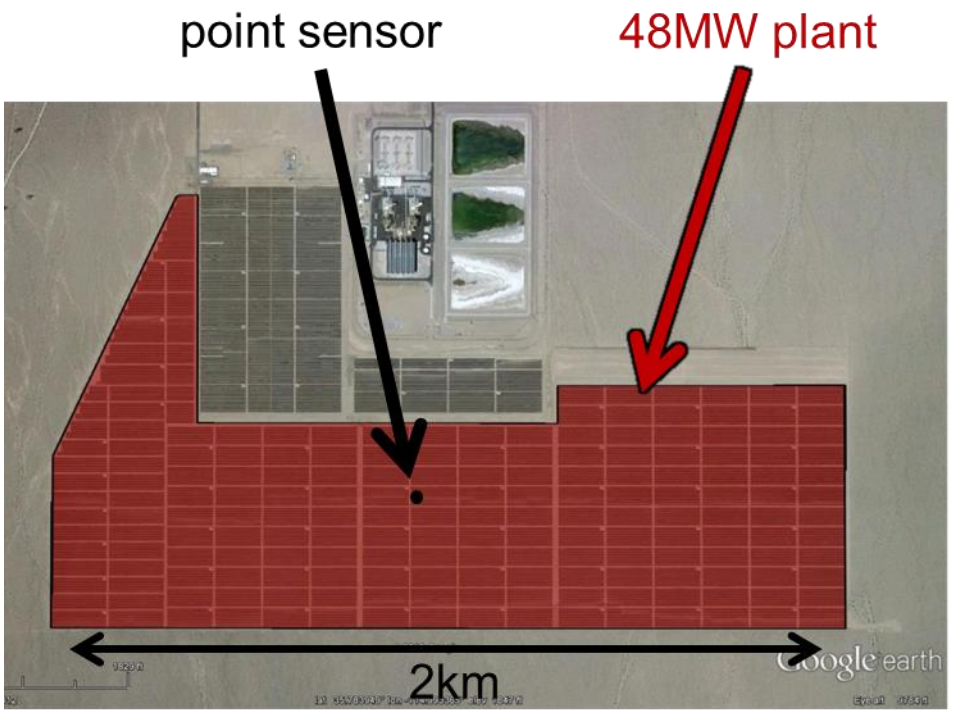
- For annual energy estimates, must accurately represent local variability
  - E.g., San Francisco and Santa Clara may have different cloud patterns (fog); must account for this in energy estimate.
- Large impact for transmission-level balancing.
  - Over long distances, PV fluctuations are typically uncorrelated, reducing variability and uncertainty in load balancing.

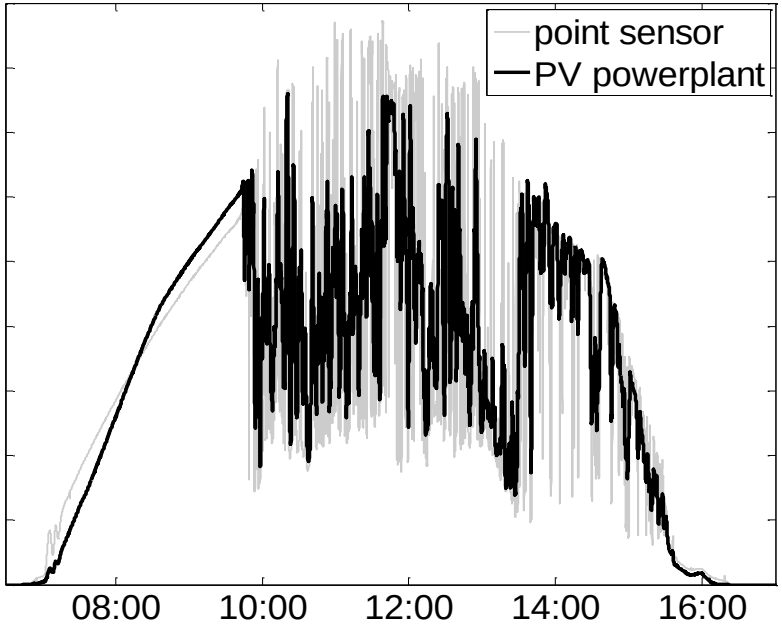
[1] *Puerto Rico Electric Power Authority Minimum Technical Requirements for Photovoltaic Generation (PV) Projects* (2012)
http://www.fpsadvisorygroup.com/rso_request_for_quals/PREPA_Appendix_E_PV_Minimum_Technical_Requirements.pdf

Spatial Variability: Point vs. Plant

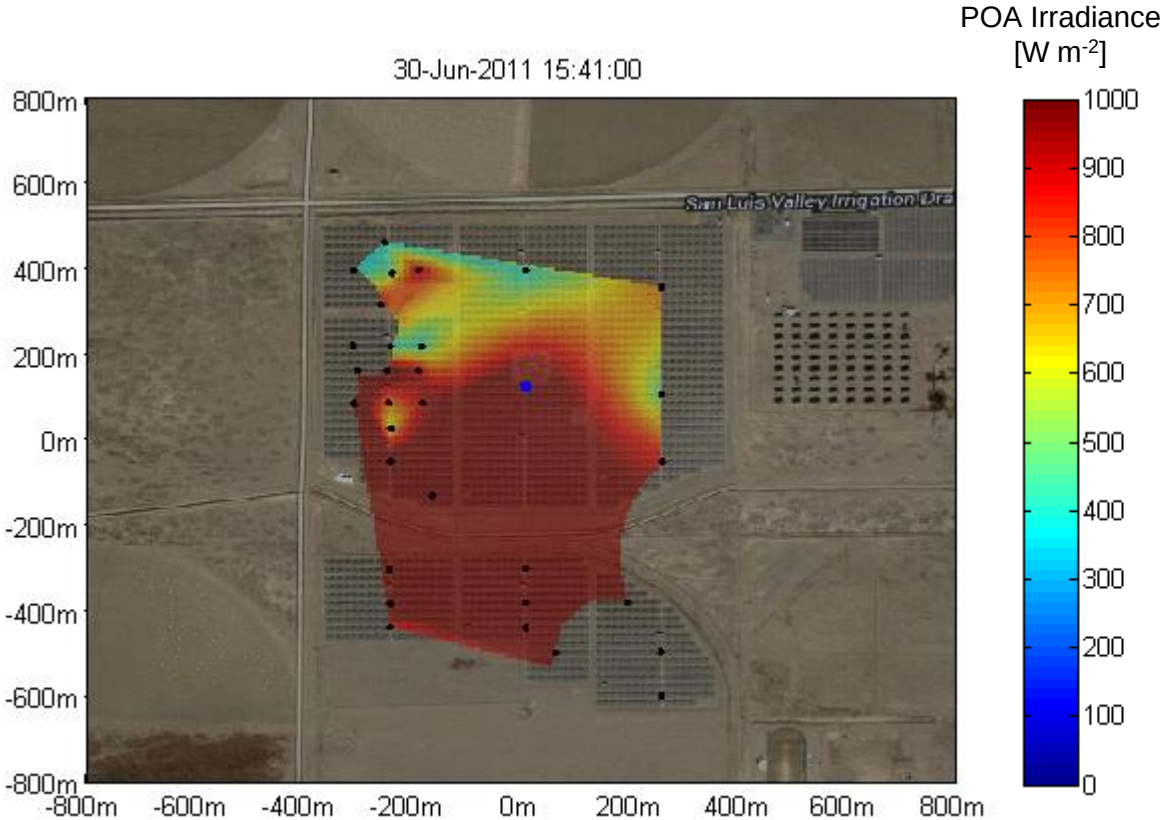
To simulate the power output of a PV plant, we often start with an irradiance point sensor.

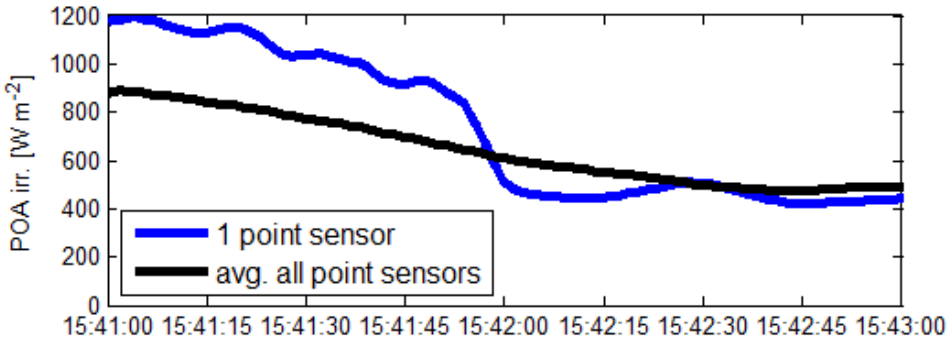
- At long timescales (e.g., > 1-hour), point sensor and PV plant produce similar relative power output profile.
- But, at short timescales **point sensor variability** > **PV plant variability**.





Gradual Cloud Movement

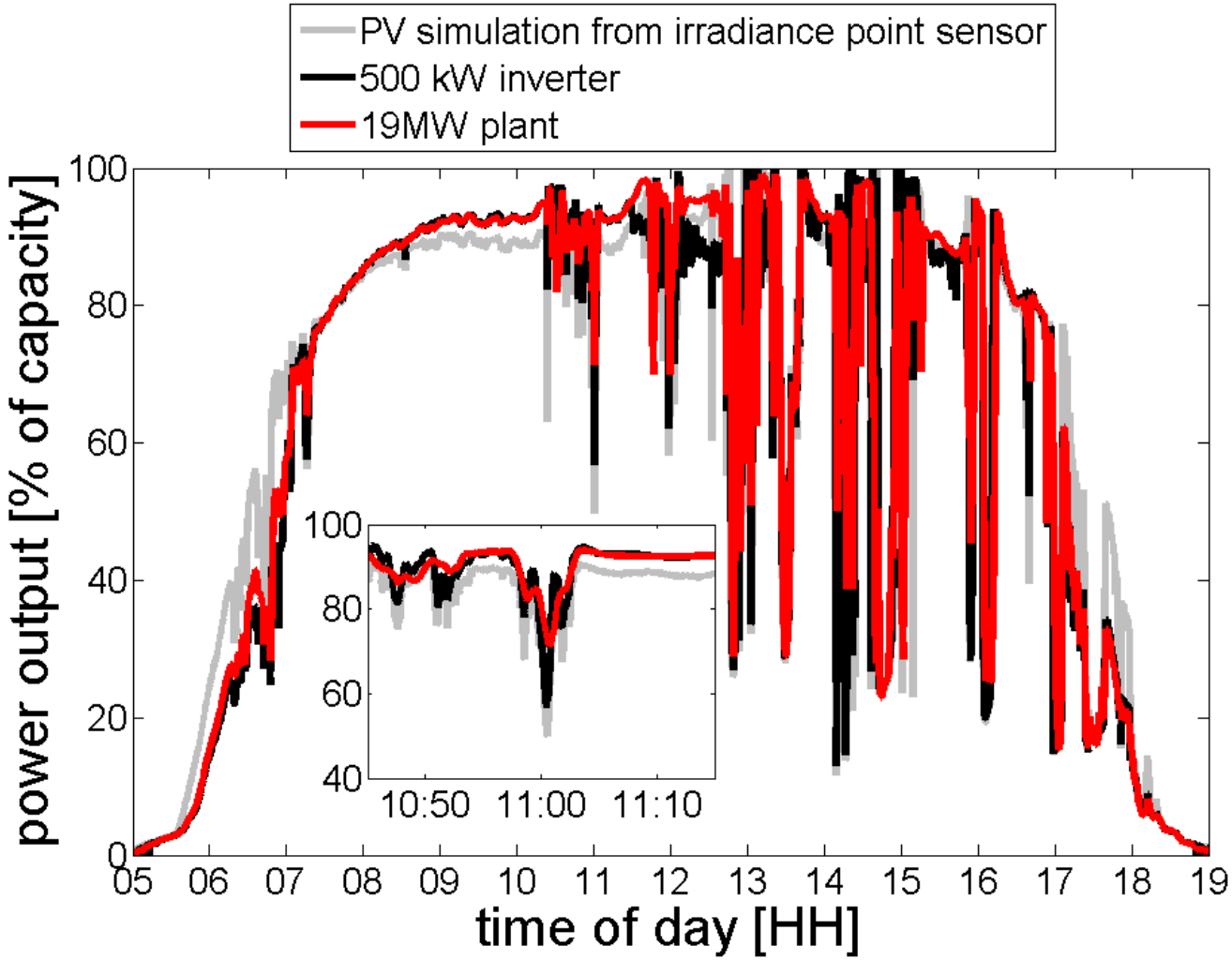




- Single point sensor has a sharp ramp down around 15:42.
- Aggregate of all point sensors ramp down at a much slower rate.

Impact on Power Output

Different amount of spatial smoothing for 1 inverter vs. whole plant.



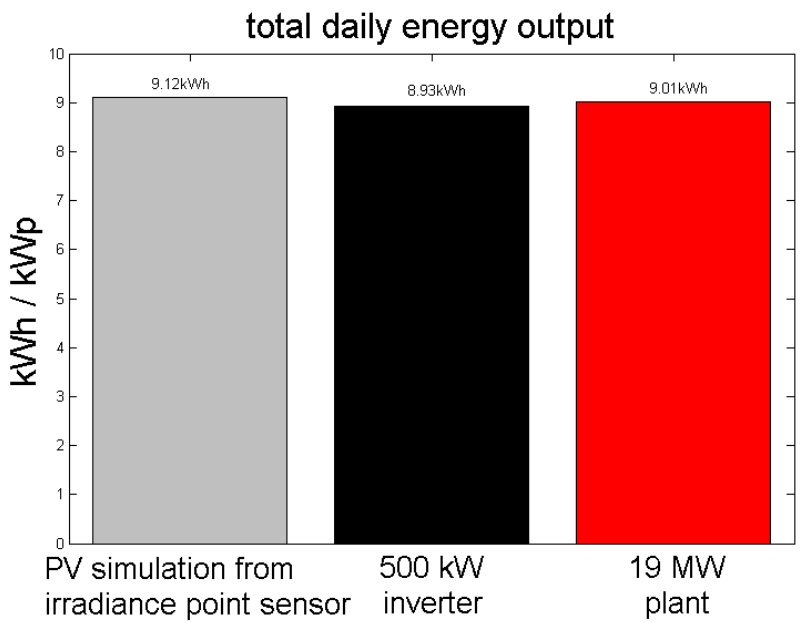
Impact on Energy and Ramp Rates

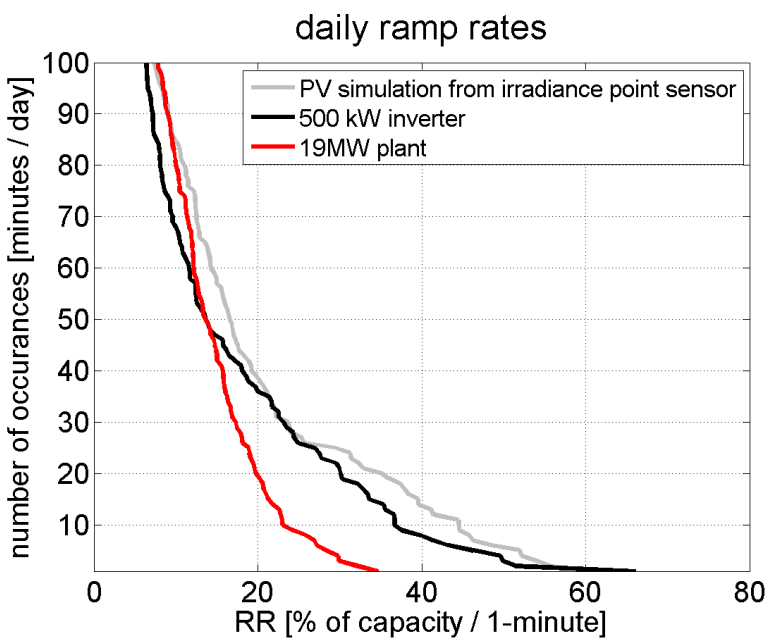
Daily/Annual Energy:

- Very small differences between point sensor, 1 inverter, and whole PV plant.

Short-timescale variability:

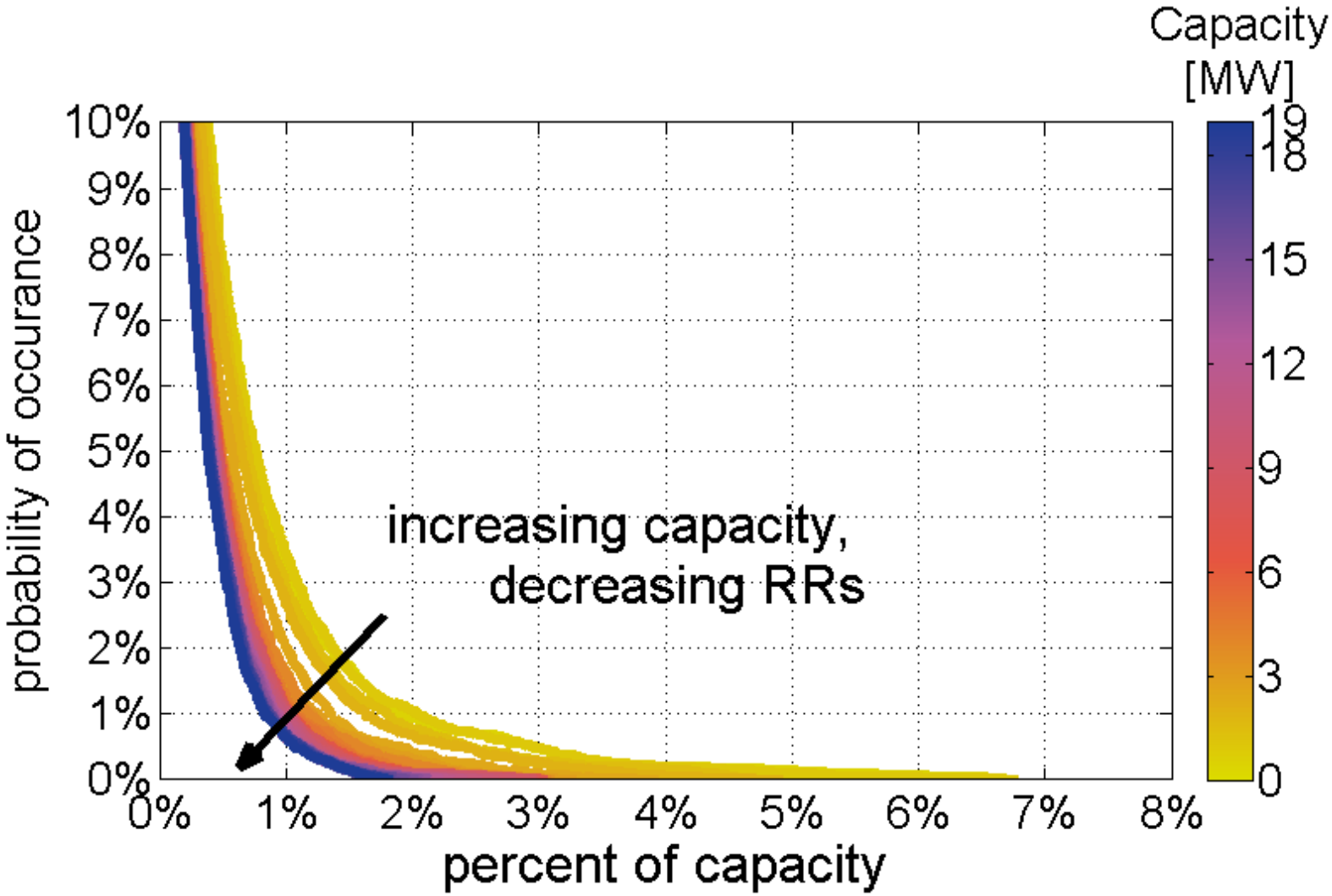
- Very large differences between point sensor and 19MW PV plant.
- Moderate differences between point sensor and one 500kW inverter.





Variability Scaling

Spatial smoothing depends on area aggregated.



Quantifying Spatial Smoothing

To quantify spatial smoothing, define the variability reduction (VR):

$$VR(\bar{t}) = \frac{variability_{point\ sensor}}{variability_{PV\ system}}$$

$VR = 1$: no smoothing

larger VR => more smoothing

VR depends on:

Timescale

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

Average distance between PV modules

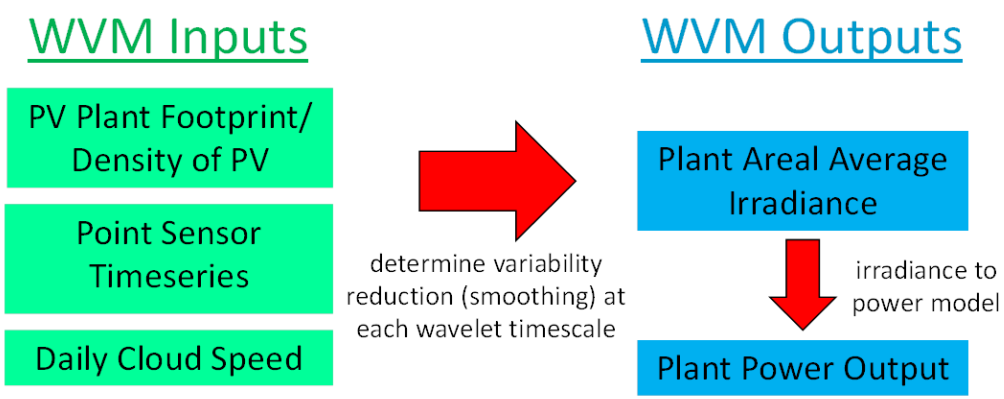
$$\bar{d} \uparrow, VR \uparrow$$

Daily cloud speed

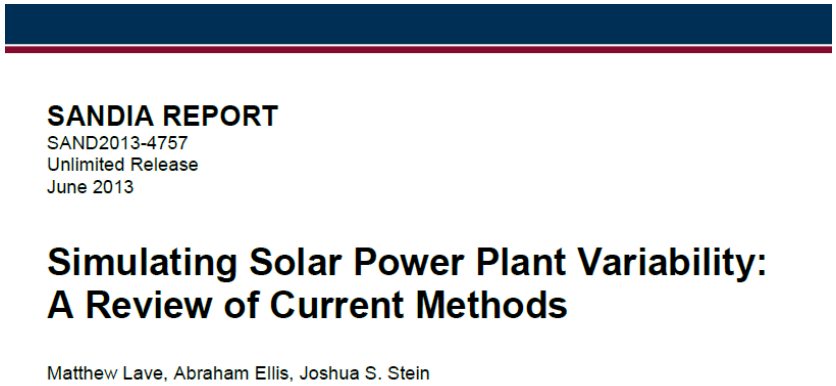
$$CS \uparrow, VR \downarrow$$

PV Plant Variability Simulation

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



- Other methods exist:
  - pv.sandia.gov
    ↳ "PV Publications"



SANDIA REPORT
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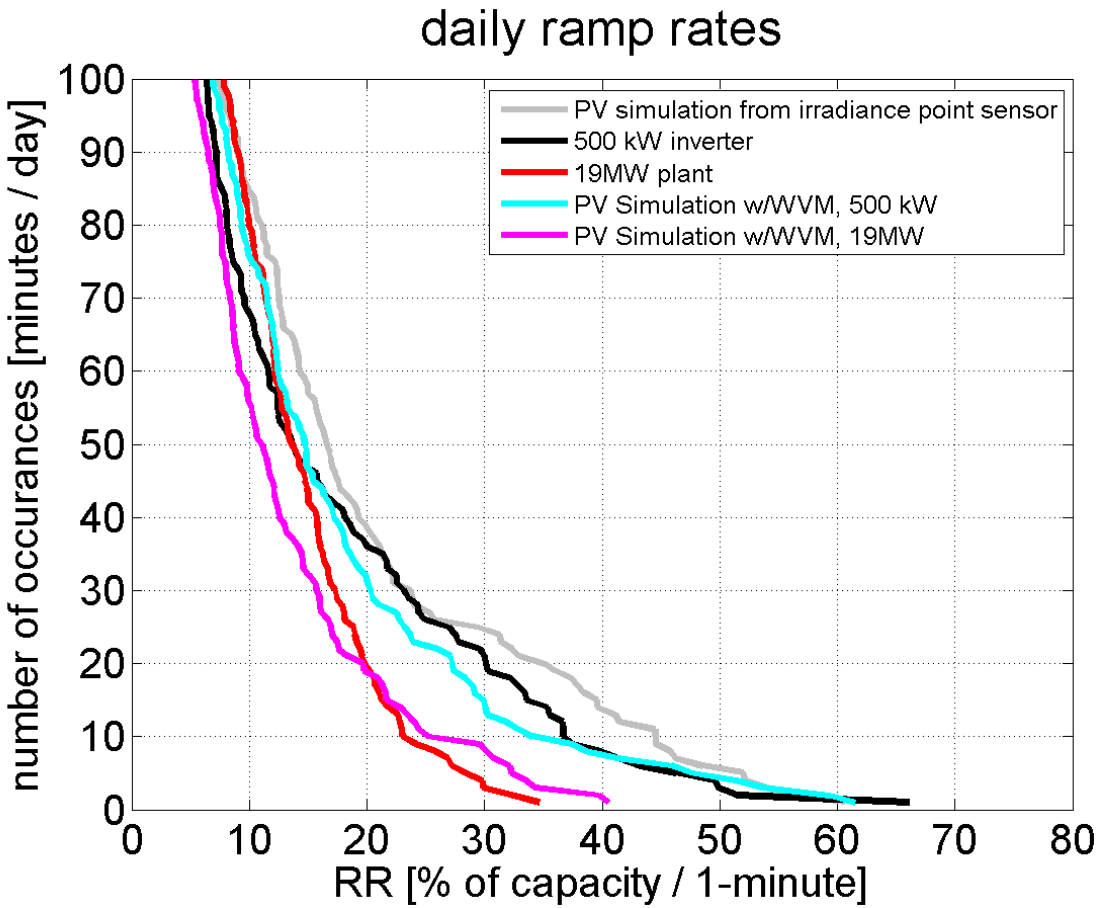
June 2013

Simulating Solar Power Plant Variability: A Review of Current Methods

Matthew Lave, Abraham Ellis, Joshua S. Stein

WVM Results: 1-day

- PV simulations w/WVM match the RR distributions much better than the simulation from the un-smoothed point sensor.

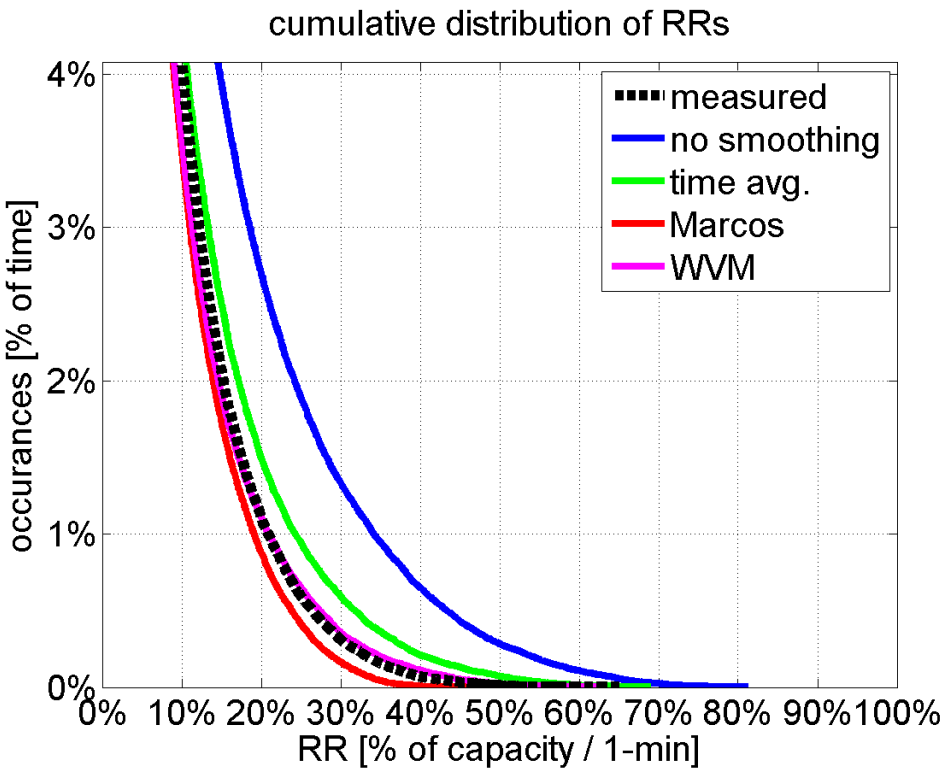


WVM Results: 1-year

On an annual basis, WVM simulations are very accurate.

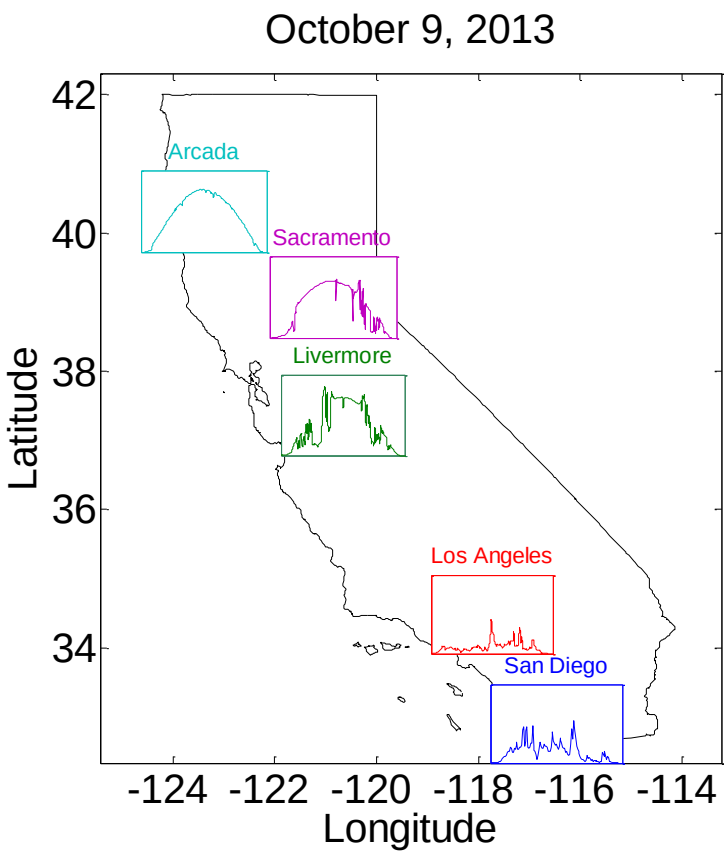
Ex: for RRs > 10% of capacity

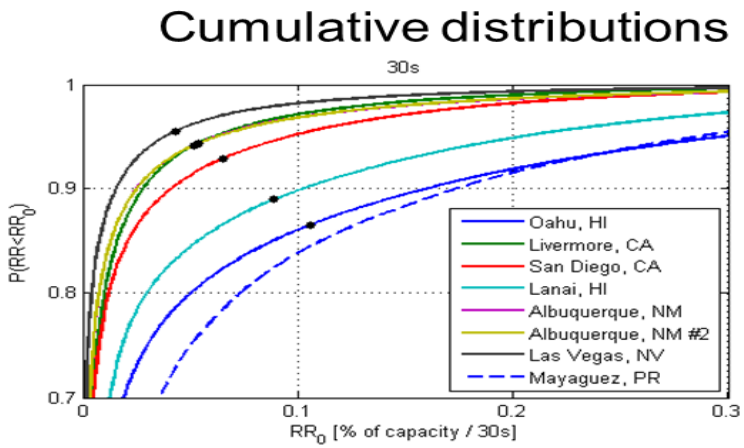
	P(RR > 10% of capacity)
measured	4.13%
no smoothing	7.30%
time avg.	5.06%
Marcos	3.47%
WVM	4.08%

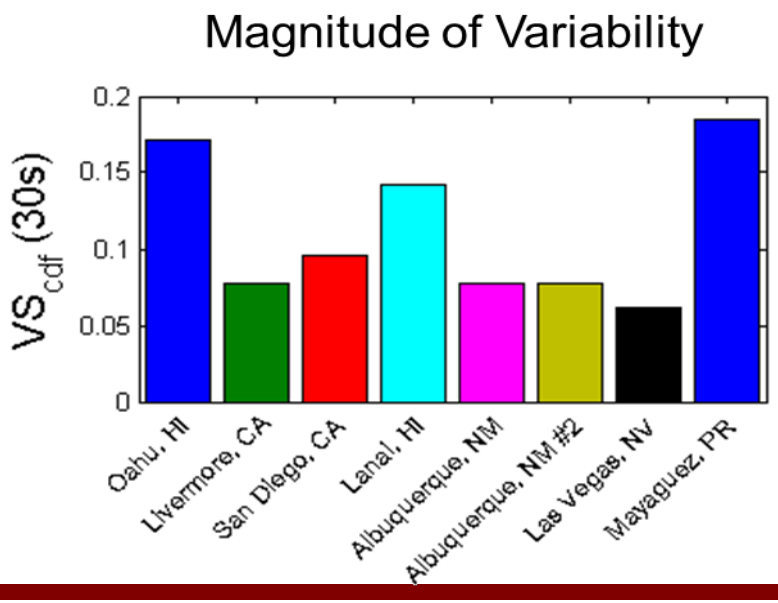


Geographic Differences

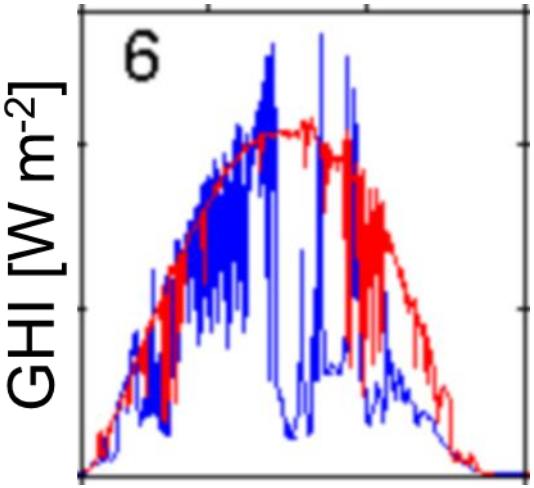
Variability statistics can vary significantly across different locations.

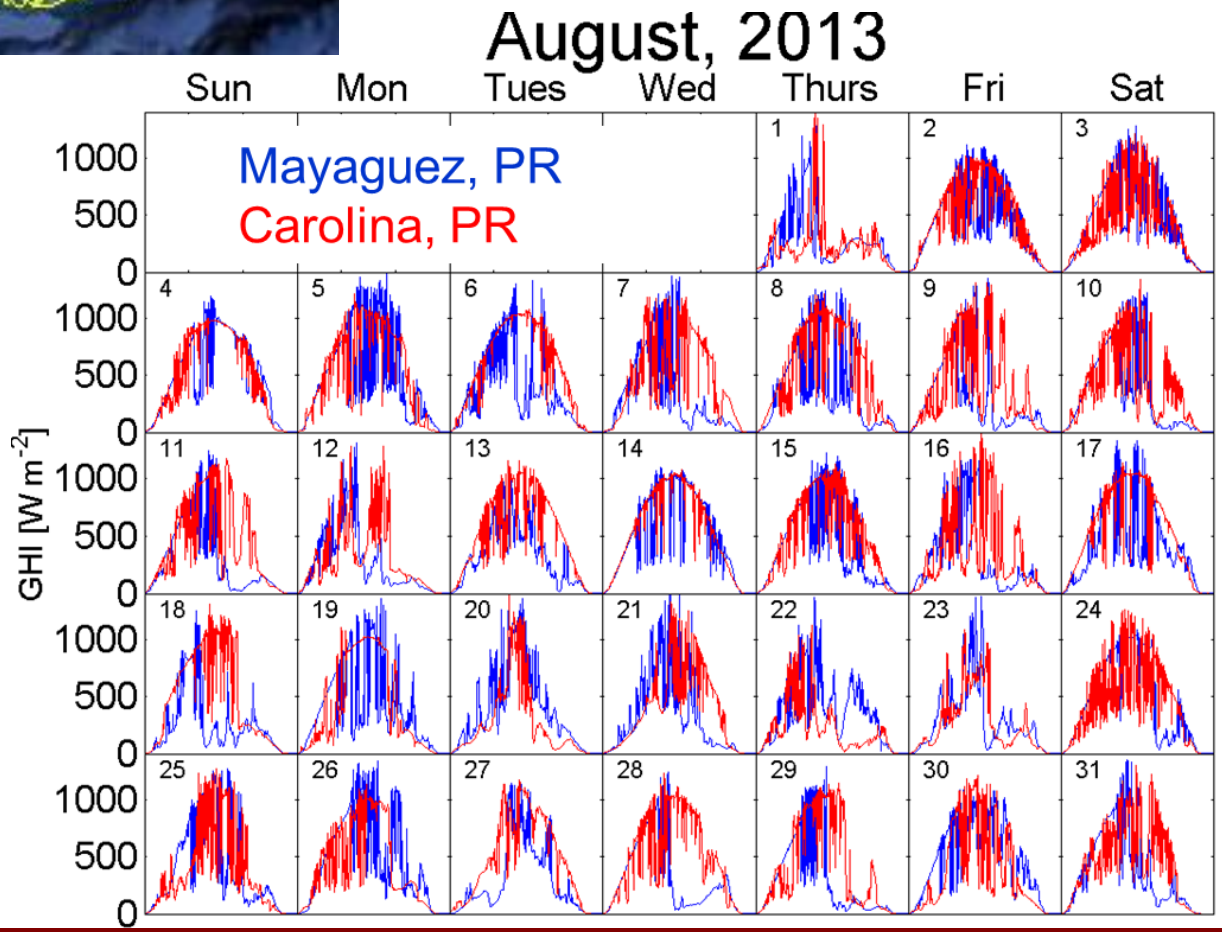






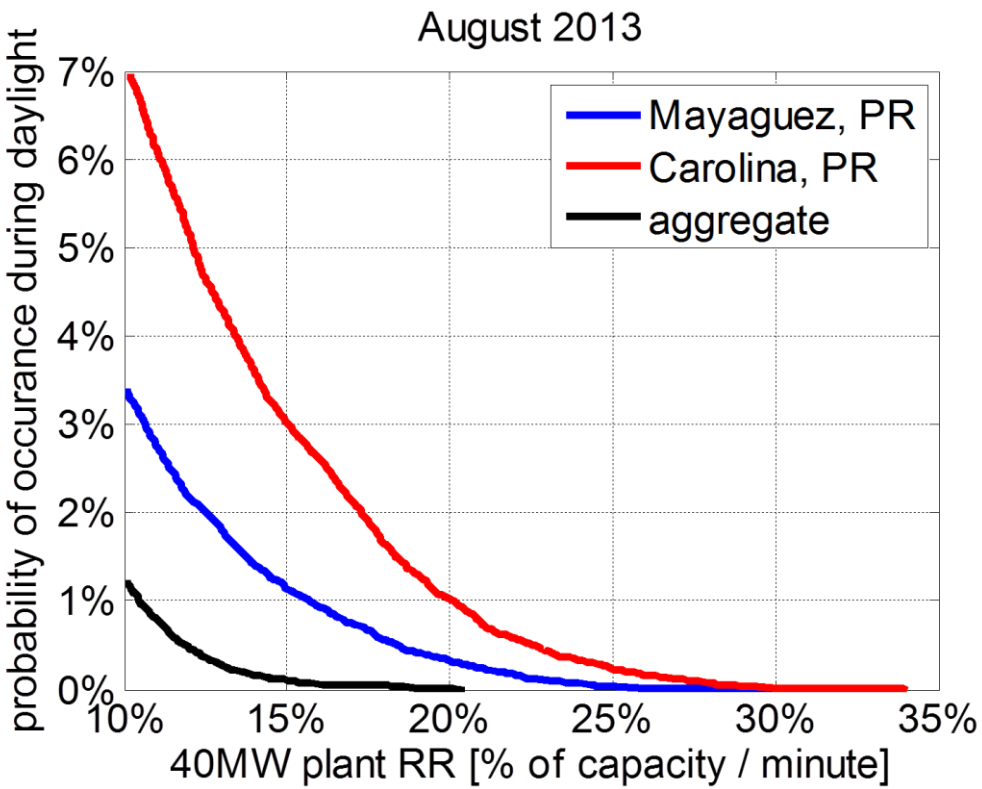
Geographic Variation in Puerto Rico





Geographic Smoothing Within Puerto Rico

WVM simulated RRs for 40MW plants in August 2013



	$P(\lvert \boldsymbol{RR} \rvert > 10\%)$	$\max(\lvert \boldsymbol{RR} \rvert)$
Mayaguez	3.4%	31% of capacity
Carolina	7.2%	34% of capacity
aggregate of both plants	**1.3%**	**20% of capacity**

Summary

- Smoothing depends on timescale and geographic separation.
- Spatial smoothing: short timescales (< 1-hr), short distances (< a few km)
  - Clouds edges cross PV modules at different times, lead to smoothed aggregate output.
  - Point sensor relative variability > PV plant relative variability.

- Long timescales (>1-hr), short distances (< a few km)
  - All PV modules see similar cloud patterns, little smoothing.
  - Annual energy of a PV plant can be well approximated from a point sensor

- Geographic smoothing: long distances, all timescales
  - PV modules see different cloud patterns, fluctuations uncorrelated.
  - Aggregate variability reduced significantly.
  - Annual energy estimates should be performed separately for each location.

Thank You!

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