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Geographic Smoothing of Irradiance

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PV Performance Modeling Workshop

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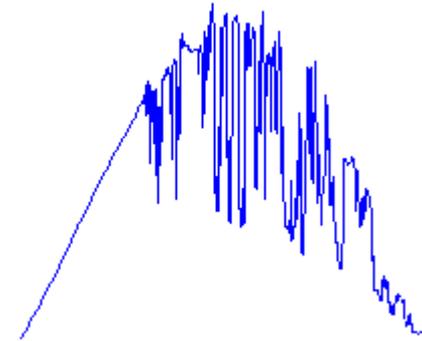


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Solar Variability and Smoothing

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:

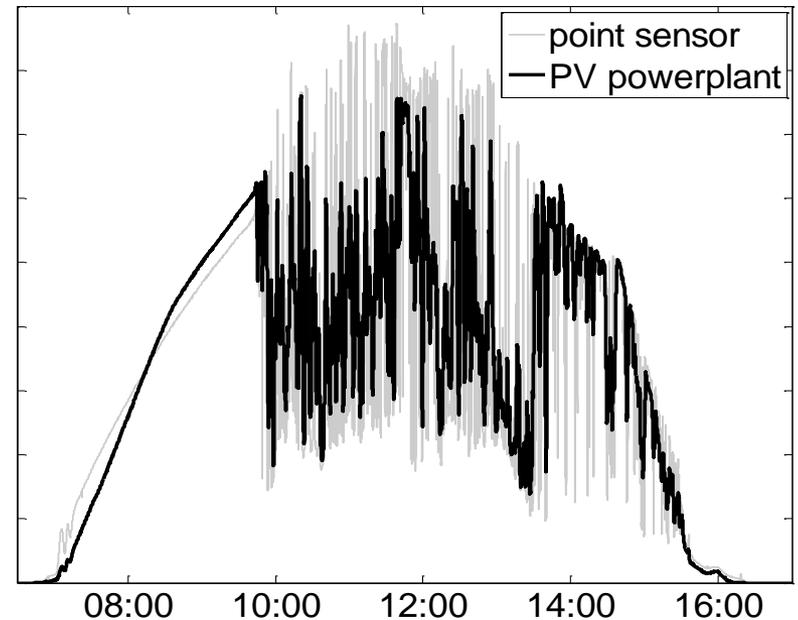
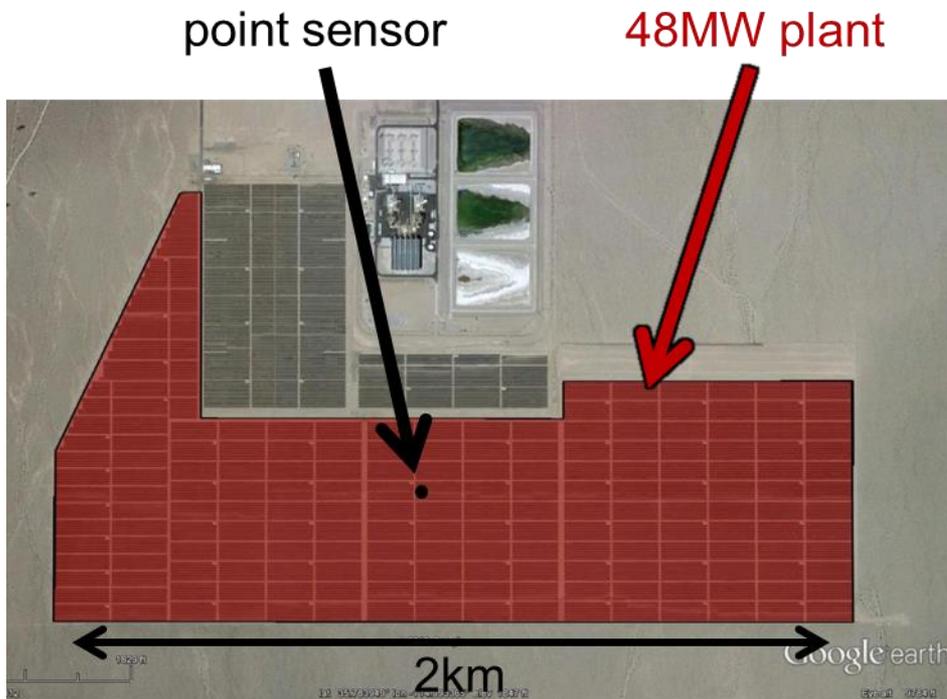
- For annual energy estimates, must accurately represent local variability
 - E.g., San Francisco and Santa Clara may have different cloud patterns (fog); must account for this in energy estimate.
- Large impact for transmission-level balancing.
 - Over long distances, PV fluctuations are typically uncorrelated,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

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

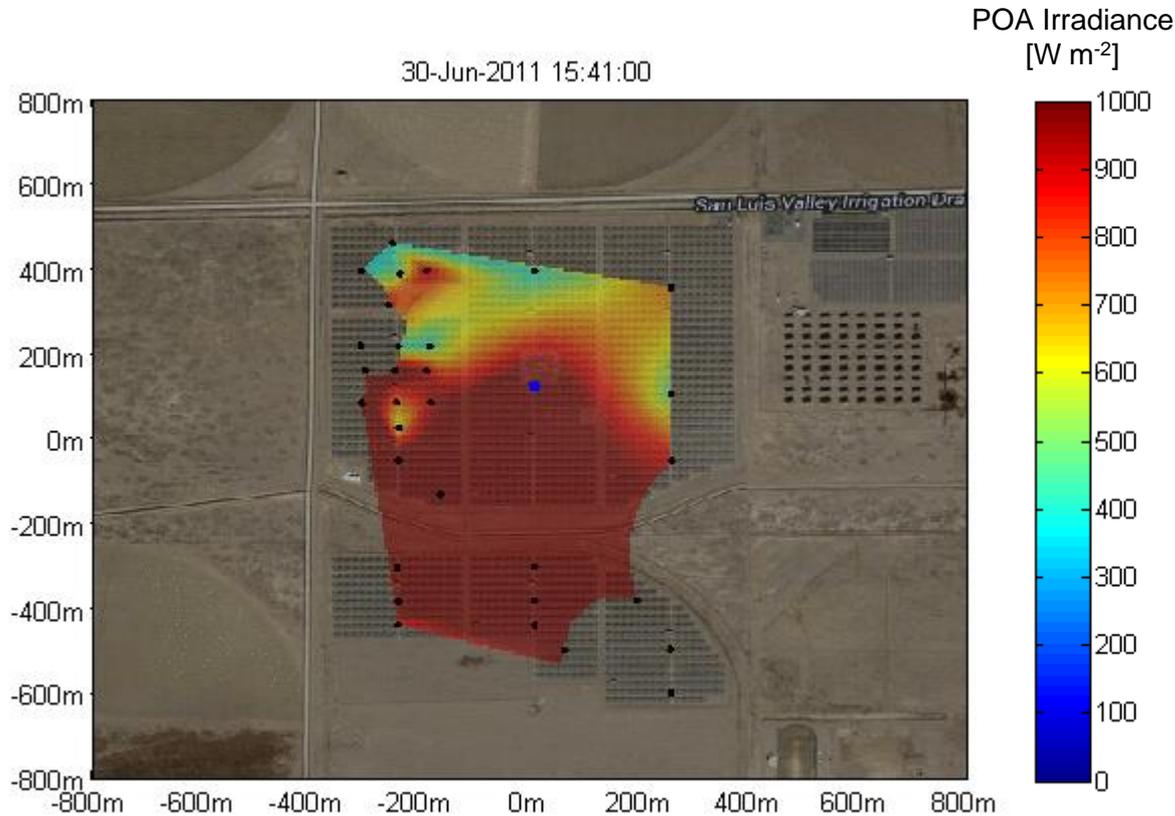
Spatial Variability: Point vs. Plant

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

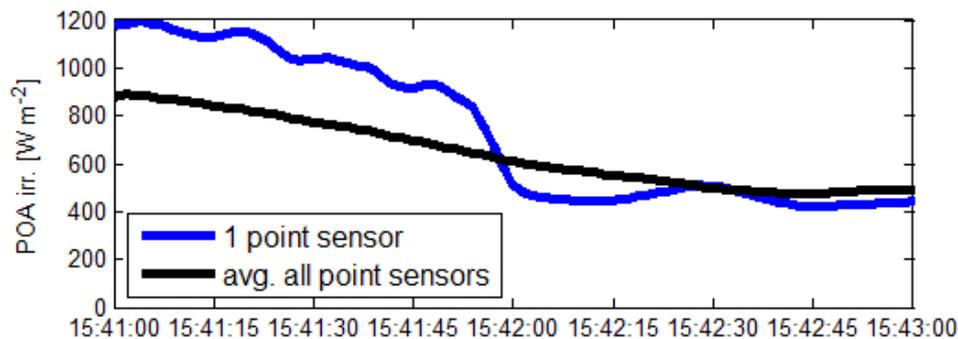
- At long timescales (e.g., > 1-hour), point sensor and PV plant produce similar relative power output profile.
- But, at short timescales **point sensor variability > PV plant variability.**



Gradual Cloud Movement

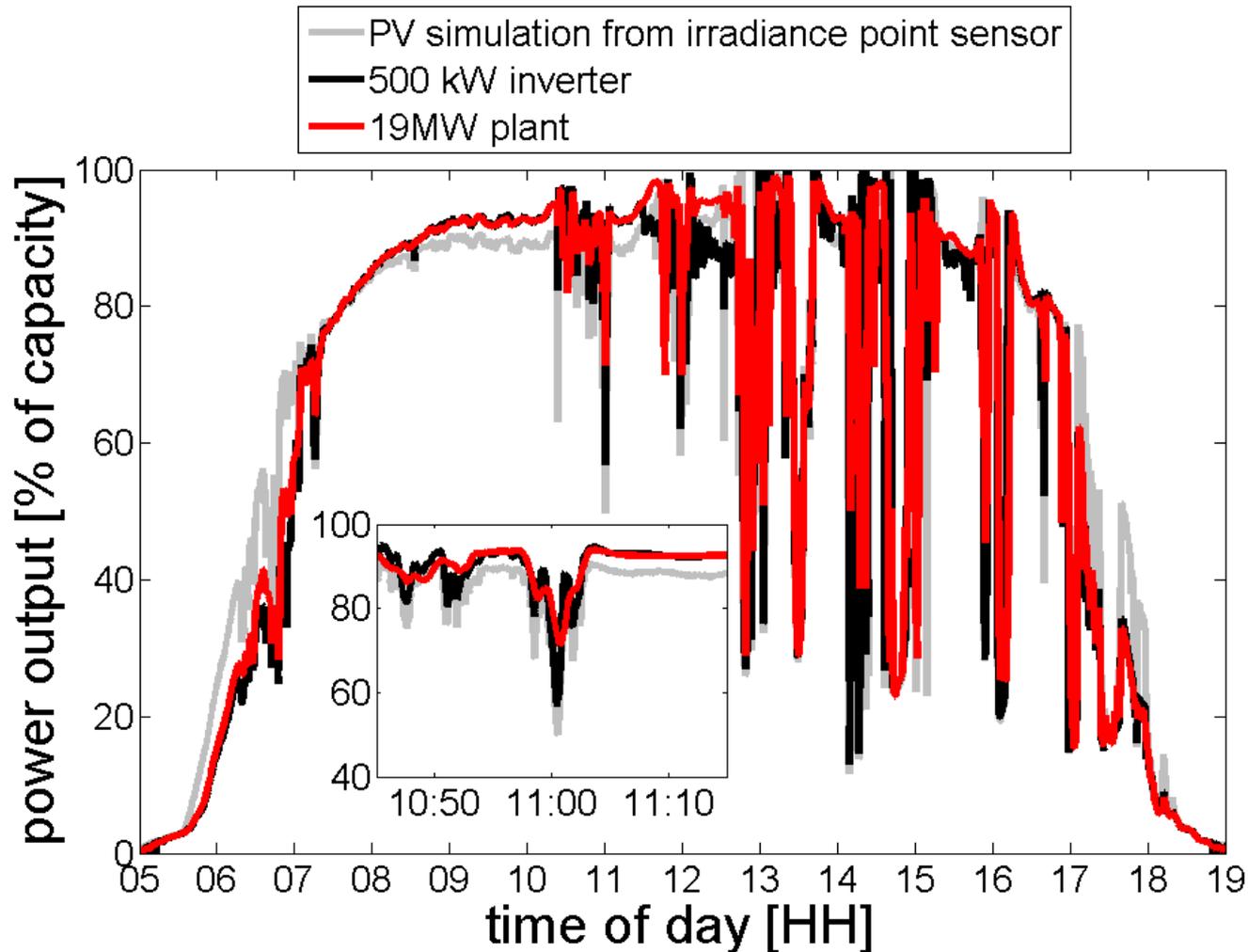


- Single point sensor has a sharp ramp down around 15:42.
- Aggregate of all point sensors ramp down at a much slower rate.



Impact on Power Output

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



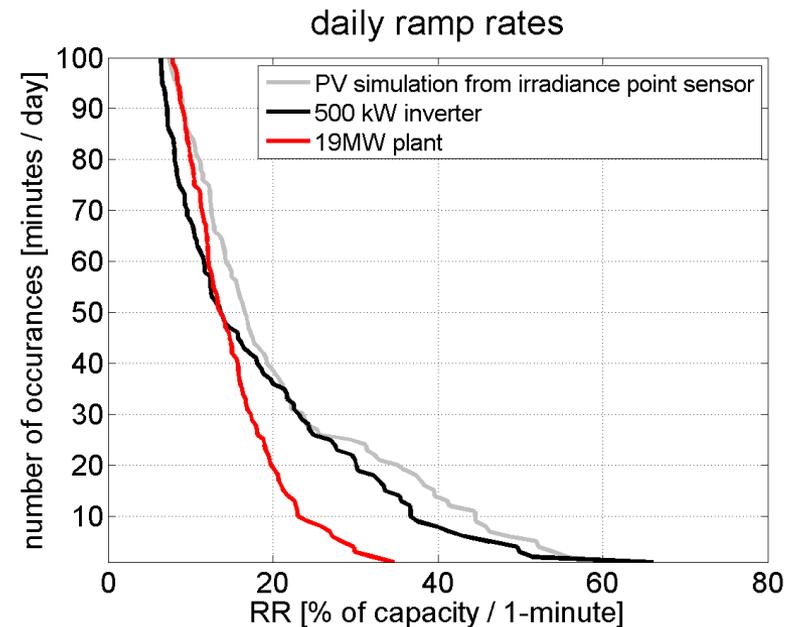
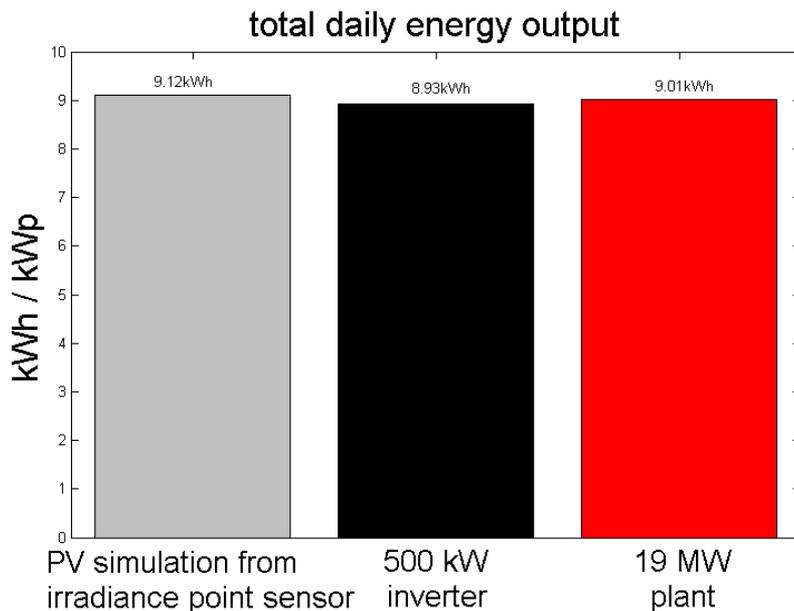
Impact on Energy and Ramp Rates

Daily/Annual Energy:

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

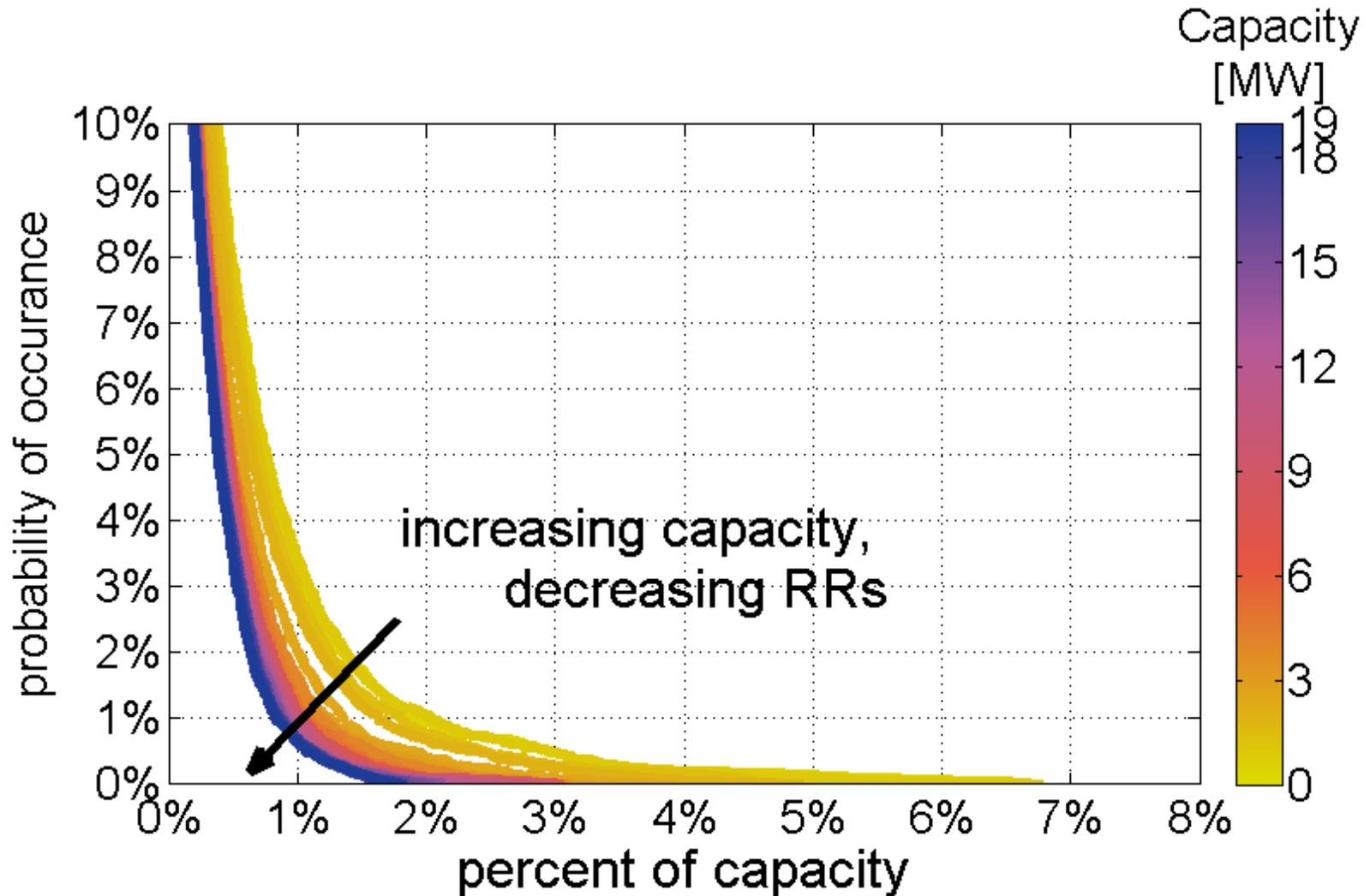
Short-timescale variability:

- 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):

$$VR(\bar{t}) = \frac{\text{variability}_{\text{point sensor}}}{\text{variability}_{\text{PV system}}}$$

$VR = 1$: no smoothing

larger VR \Rightarrow more smoothing

VR depends on:

Timescale

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

Average distance between PV modules

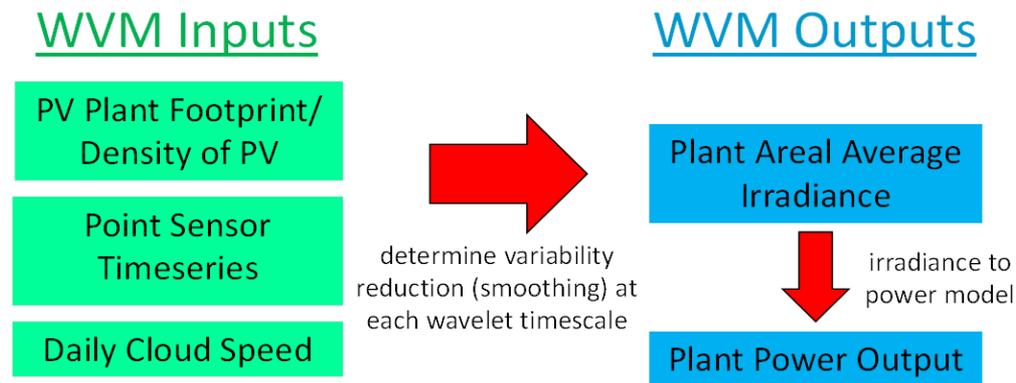
$$\bar{d} \uparrow, VR \uparrow$$

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"

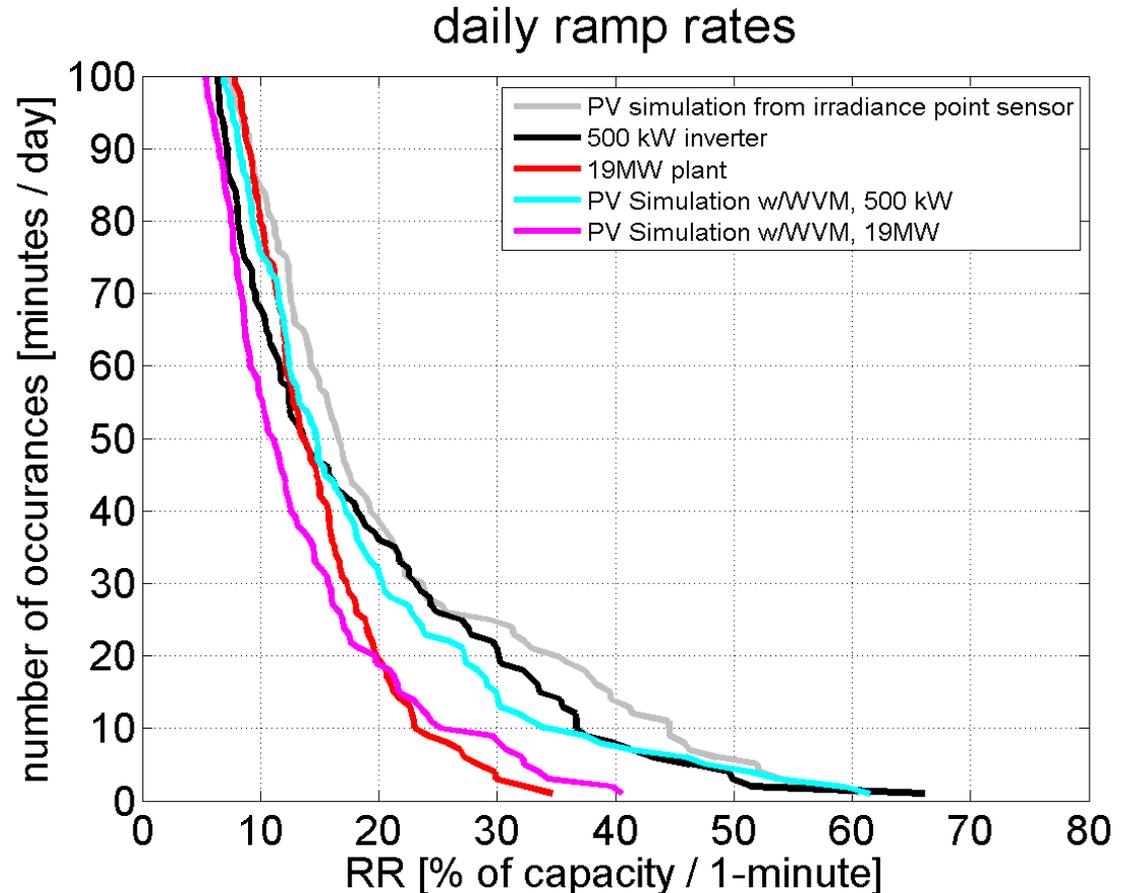
SANDIA REPORT
SAND2013-4757
Unlimited Release
June 2013

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.

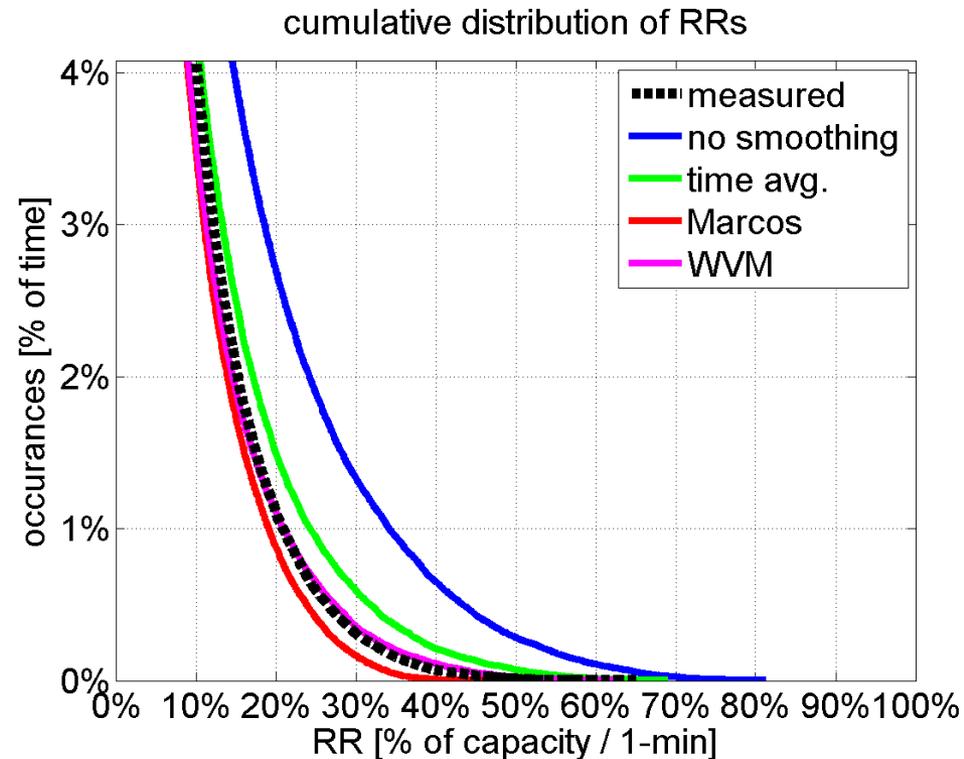


WVM Results: 1-year

On an annual basis, WVM simulations are very accurate.

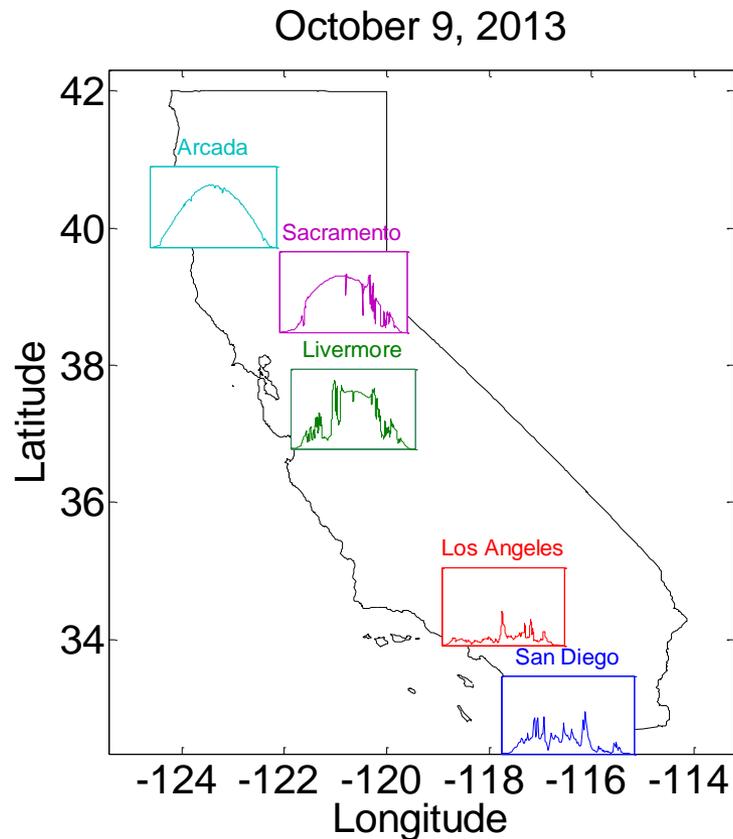
Ex: for RRs > 10% of capacity

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

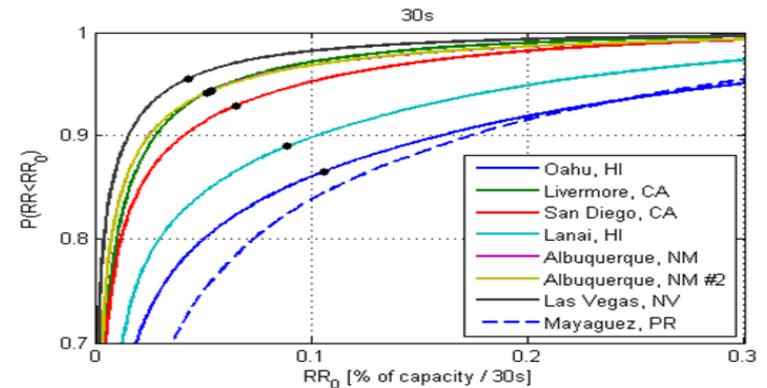


Geographic Differences

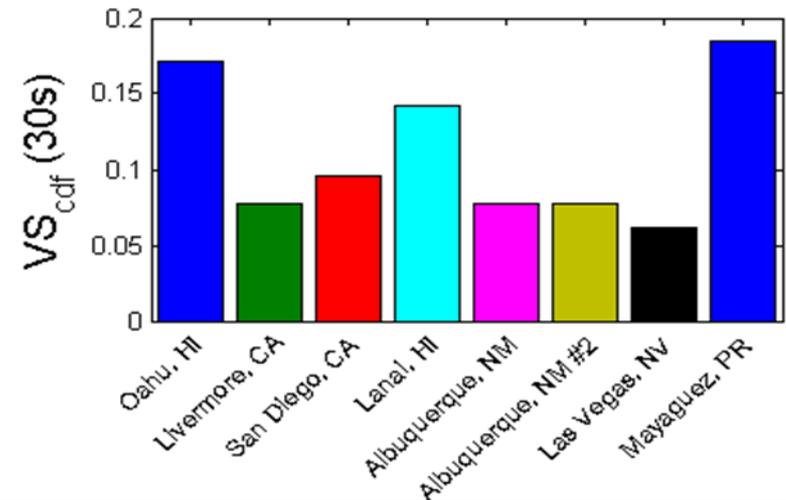
Variability statistics can vary significantly across different locations.



Cumulative distributions



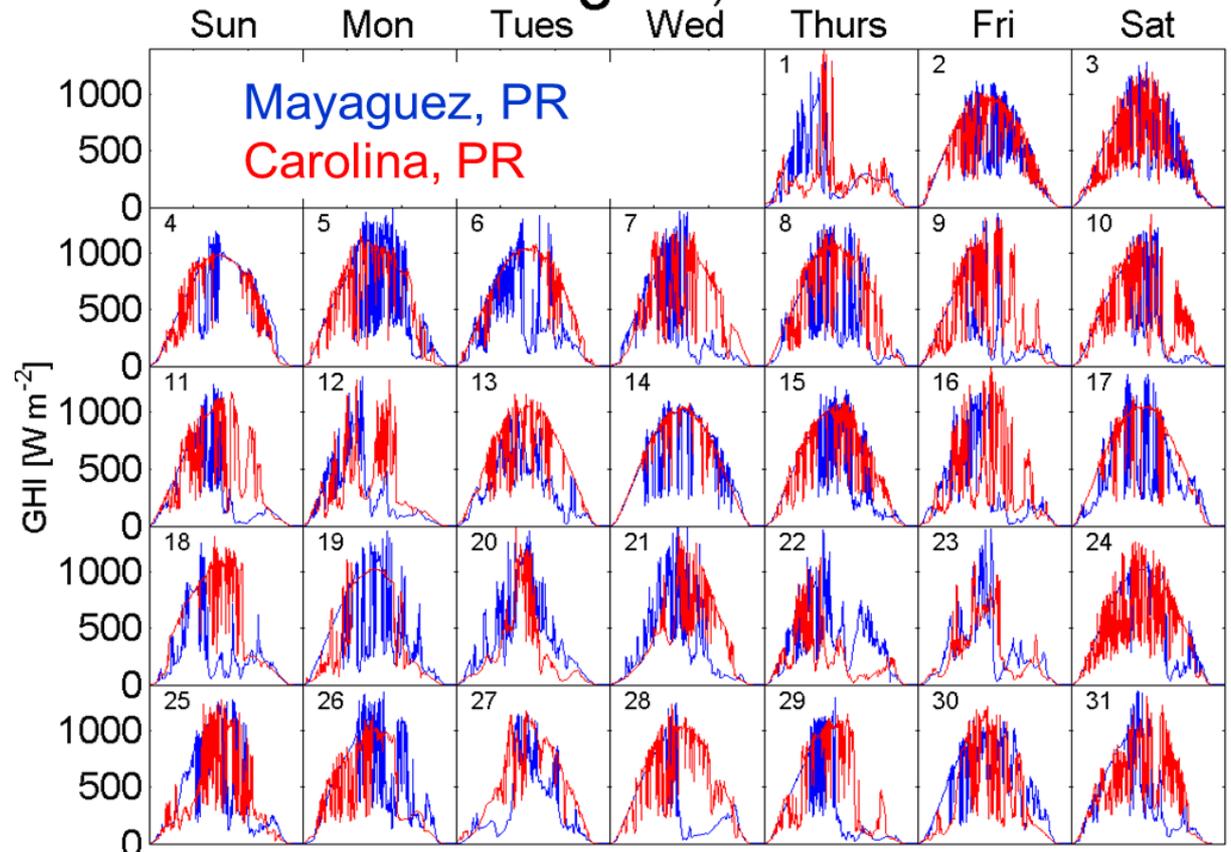
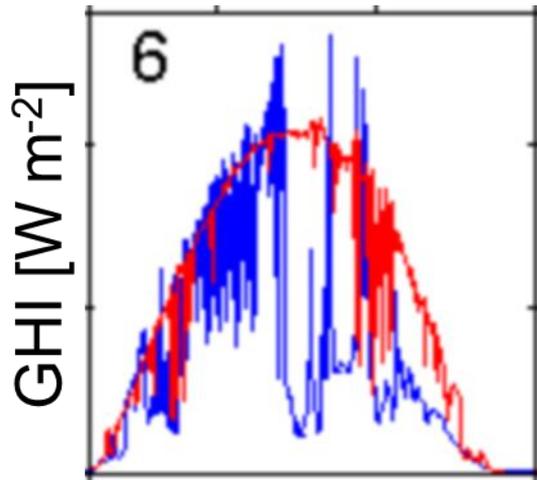
Magnitude of Variability



Geographic Variation in Puerto Rico

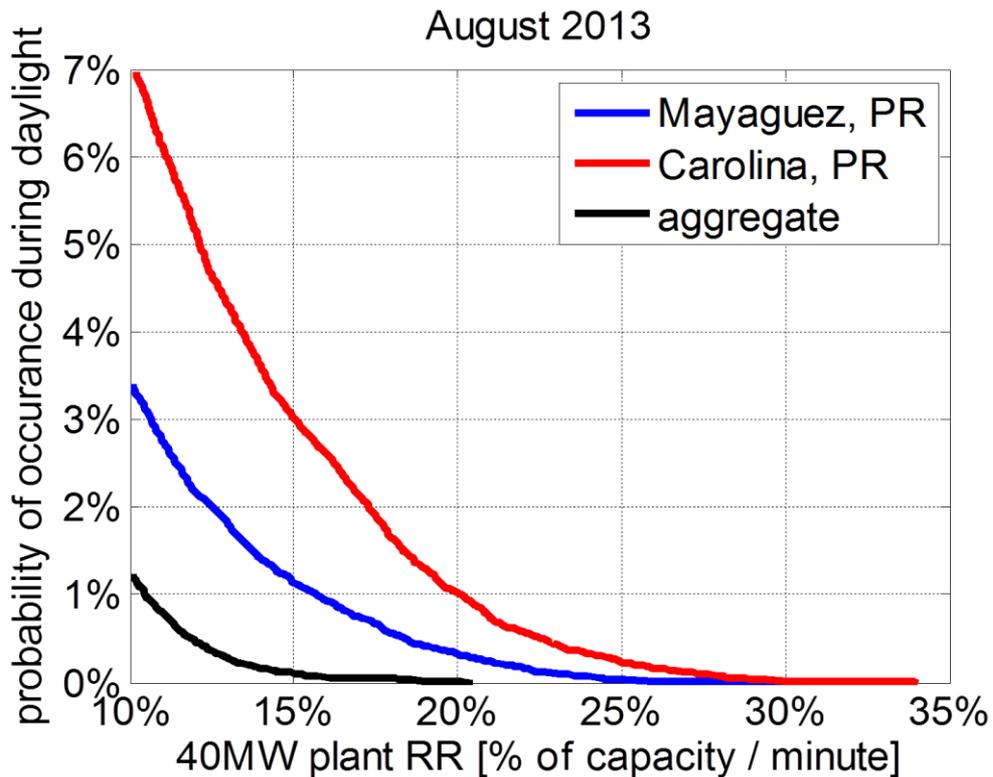


August, 2013



Geographic Smoothing Within Puerto Rico

WVM simulated RRs for 40MW plants in August 2013



	$P(RR > 10\%)$	$\max(RR)$
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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