High Penetration Solar Forum

CSI RD&D Project: Advanced Modeling and Verification for High Penetration PV

Clean Power Research
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What's the big picture?

For…

any PV deployment configuration

on any geographical and time scale

…predict

output variability without using

ground-based measurements

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CSI RD&D Project summary

Project participants including…

- Companies/Agencies/Organizations
  - CPR
  - SUNY
  - NREL
  - NYSERDA
  - SEPA
- Utilities
  - SMUD
  - LIPA
  - SRP
  - NYPA

…will complete four deliverables

- **Enhance spatial and temporal resolution of SolarAnywhere® for selected CA locations**
- **Develop output variability algorithms and validate**
- Integrate PV modeling capabilities into a distribution system engineering and analysis tool
- Create tool to calculate economic value of a specific PV fleet configuration

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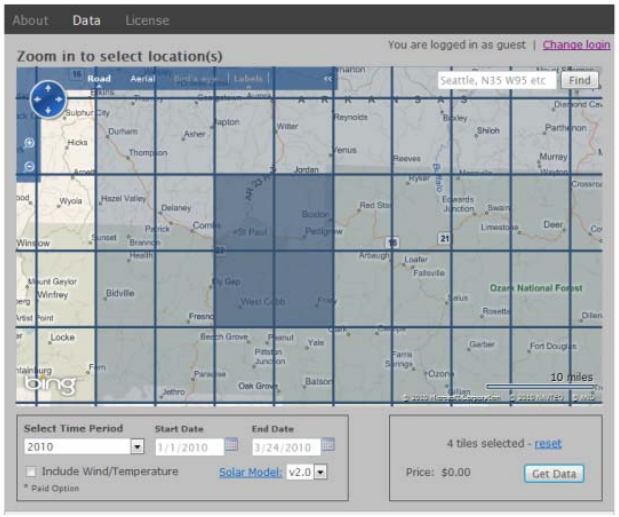
What is SolarAnywhere?

Web-accessible solar irradiance data service

- Innovative
  - Historical values from 1998 through latest hour
  - Hour by hour forecasts up to a week in advance

- Accessible
  - Select locations via web-based map
  - Programmatically accessible web service
  - Integrate with system operation tools

SolarAnywhere®



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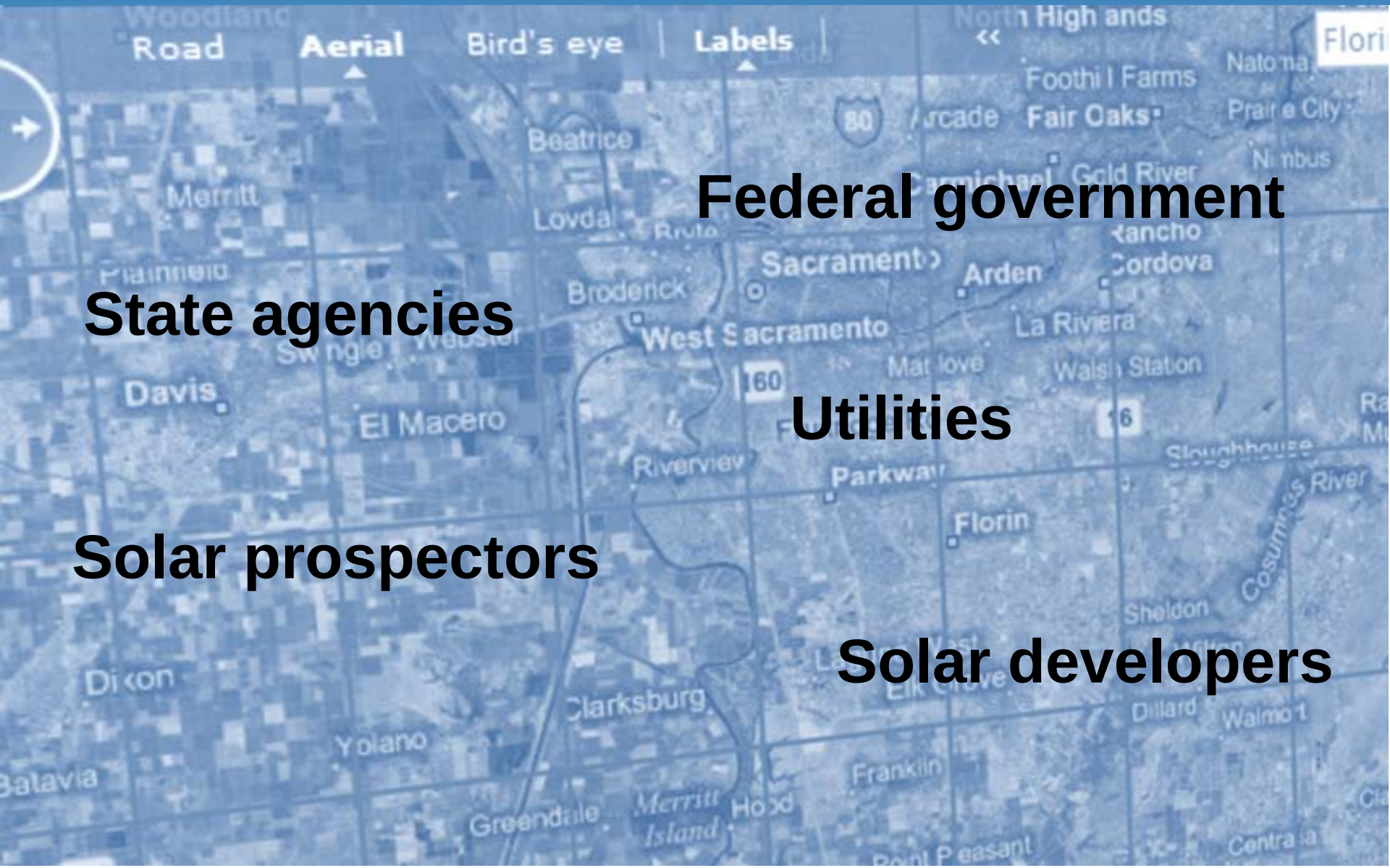
Who's using SolarAnywhere?



Federal government

State agencies

Utilities

Solar prospectors

Solar developers

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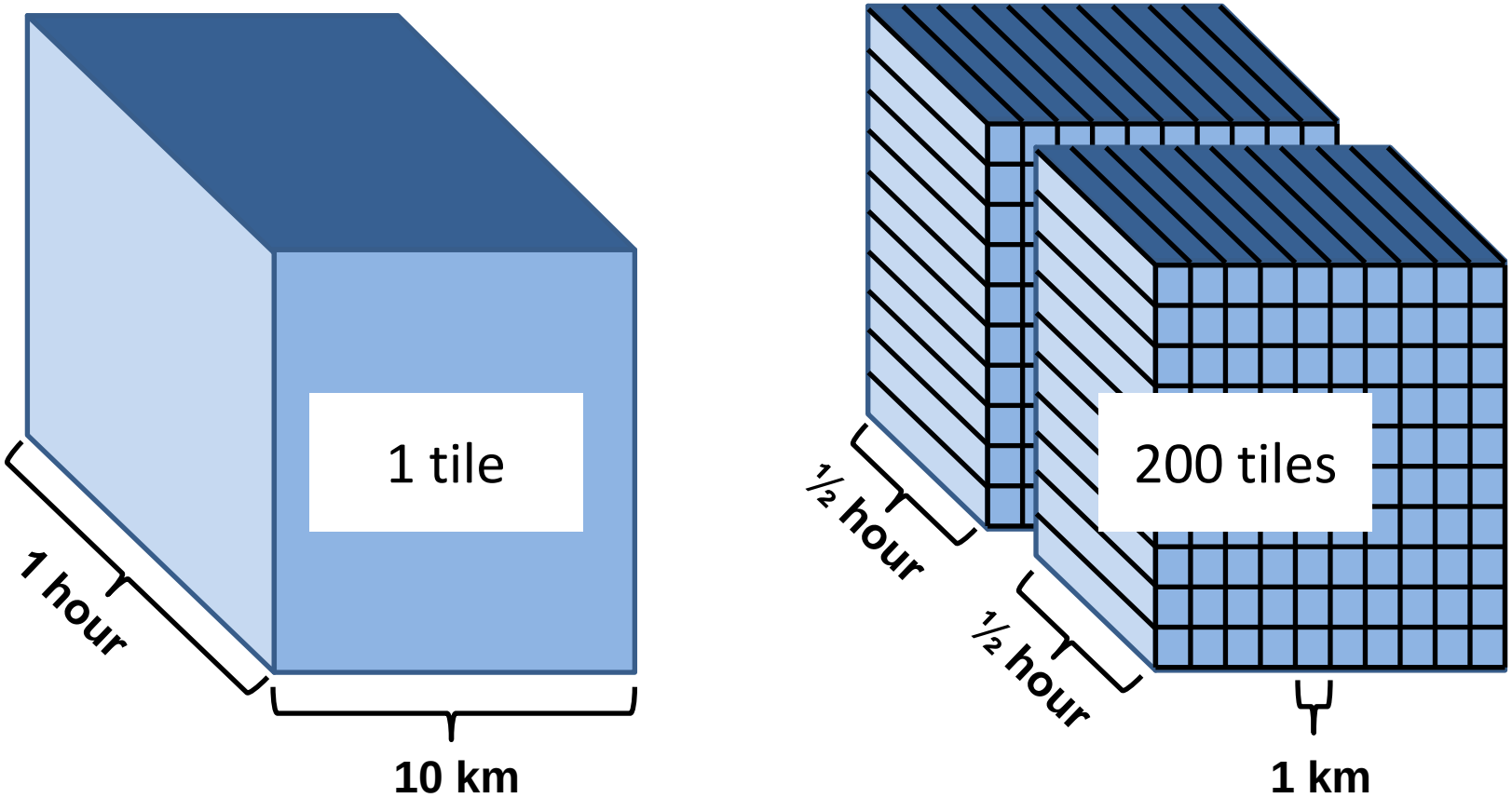
Create SolarAnywhere Enhanced Resolution

SolarAnywhere → SolarAnywhere® ENHANCED RESOLUTION

10 km grid, 1 hour data

1 km grid, ½ hour data



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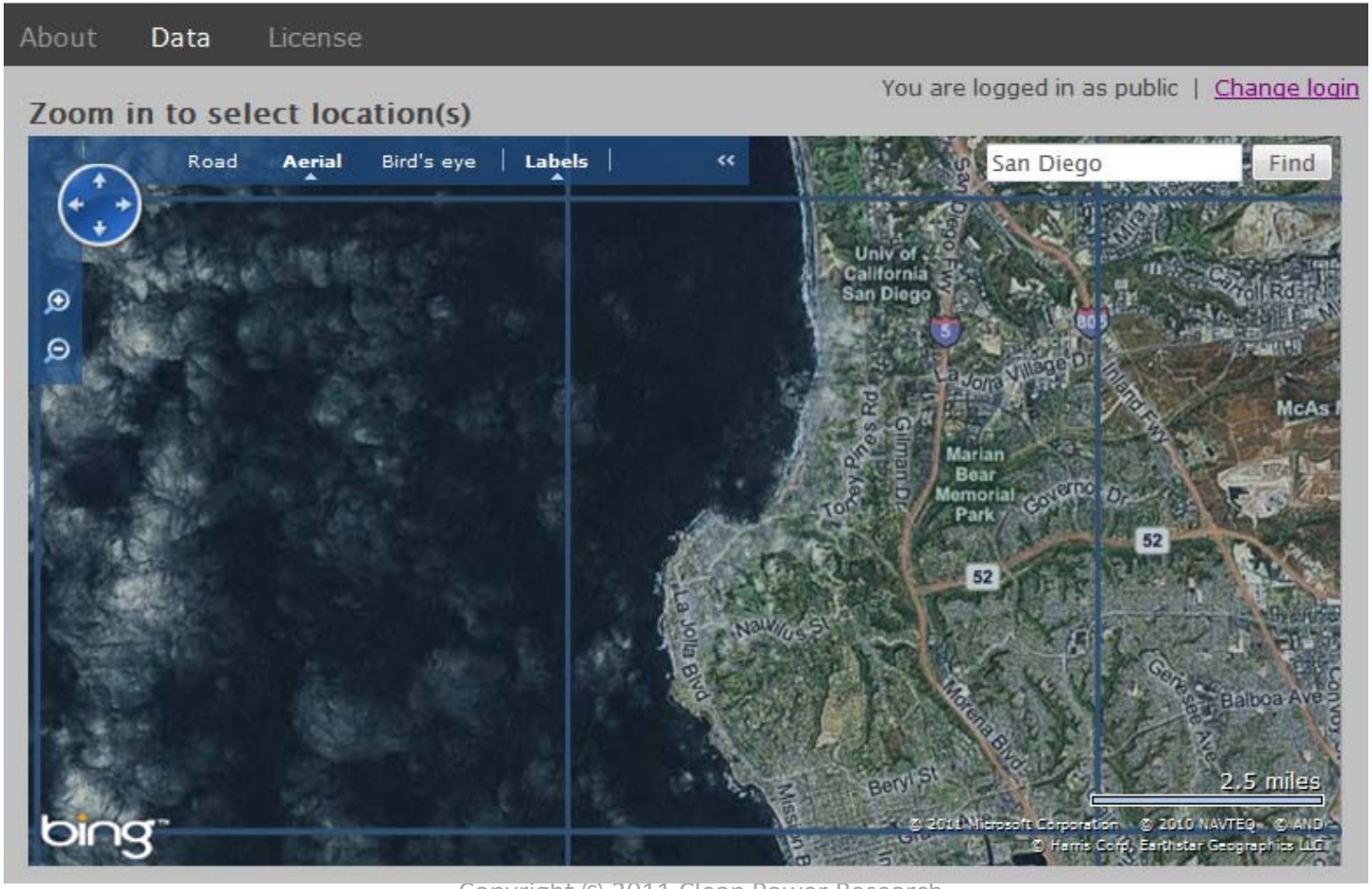
SolarAnywhere
(1 tile covers north San Diego)

SolarAnywhere®



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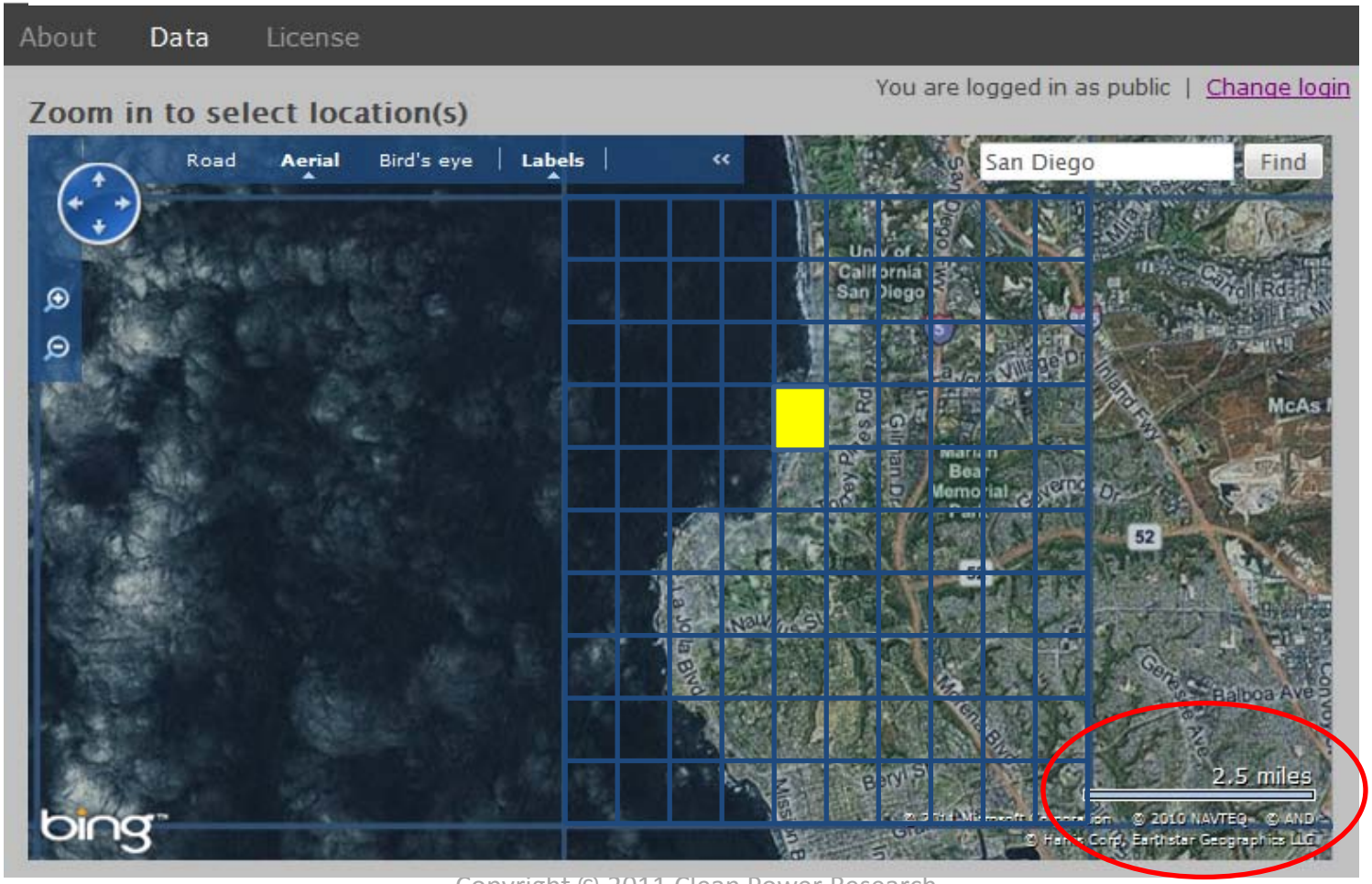
SolarAnywhere
(100 tiles cover north San Diego)

SolarAnywhere®
ENHANCED RESOLUTION



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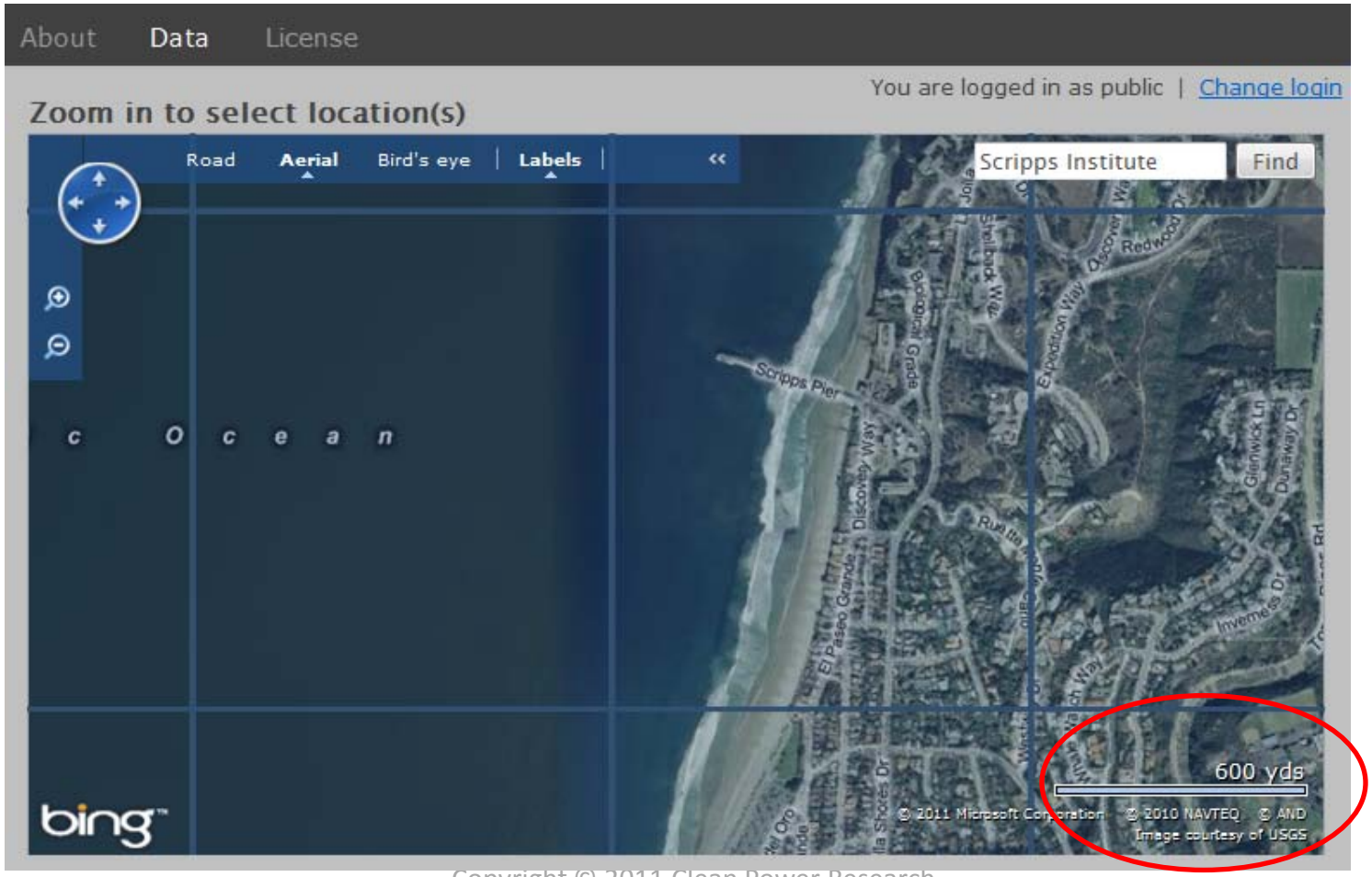
SolarAnywhere Enhanced Resolution (1 tile covers part of UCSD)

SolarAnywhere®
ENHANCED RESOLUTION



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Key SolarAnywhere accomplishments

SolarAnywhere Enhanced Resolution

- Free, high resolution (1 km grid) data from 2003 through 2009 for EVERY location in California (http://ca.SolarAnywhere.com)
- Provide data to perform high penetration renewables studies (e.g., CAISO high penetration study)

SolarAnywhere

- Free, low resolution (10 km grid) data through 2008 anywhere in the U.S. (http://www.SolarAnywhere.com)

Real-time and forecast data are available for license and platform is prepared to generate high resolution data in other states

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Enhance output variability algorithms

Develop output variability algorithms and test and validate implementation to perform PV simulations on a sub-hourly time scale

- Previous approach modeled **relative** output variability for a **simplistic** PV fleet configuration over any time interval
- Enhanced approach models **absolute** output variability for **any** PV fleet configuration over any time interval

	Output Variability	PV Fleet Configuration
Previous Model	**Relative**	**Simplistic**
Enhanced Model	**Absolute**	**Any**

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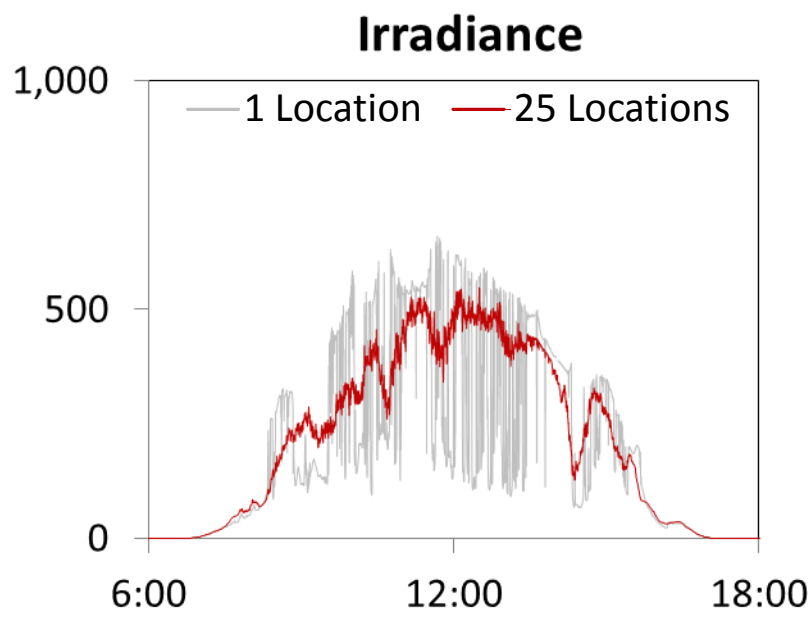
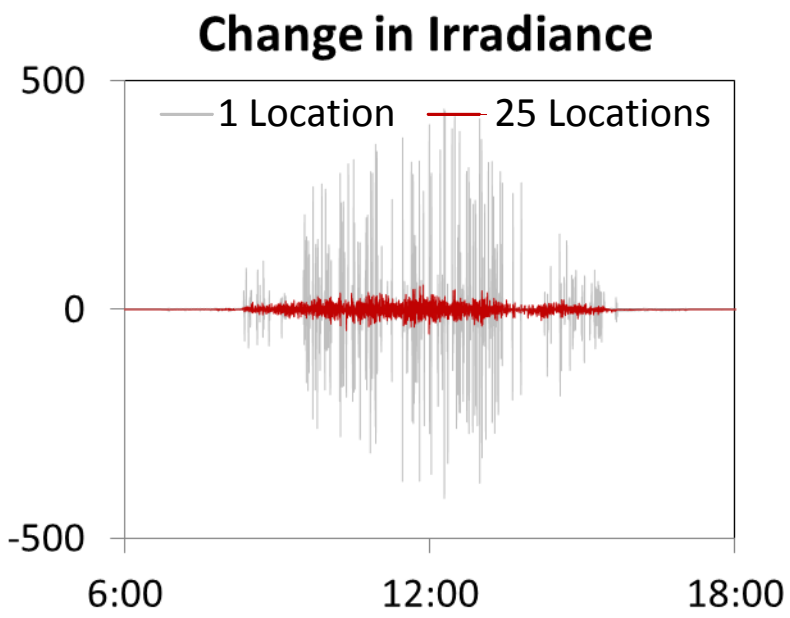
What is output variability?





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Power output variability is driven by a few factors

For a small, ***single*** PV system, changes in short-term output (several minutes to several hours) are primarily driven by:

1. Clearness of the sky as characterized by the clearness index – i.e., the level of cloudiness

2. Sun position

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Power output variability for a fleet of PV systems

For a ***fleet*** of PV systems, changes in output are driven by the same forces as those of a small, single system…

+

Fleet orientation (i.e., dimensions, plant spacing, etc.) whether this is across one multi-MW system or across an entire state

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Quantify correlation between “two-location” fleets

Approach

- Calculate correlation coefficient of *change in clearness index*
- Use 12 years of hourly SolarAnywhere irradiance data
- Apply to Southwest, Southern Great Plains, and Hawaii
- Calculate for thousands of “two-location” fleets

PV Power Output Variability: Correlation Coefficients paper is available at http://www.cleanpower.com/Research

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Use SolarAnywhere to assess variability

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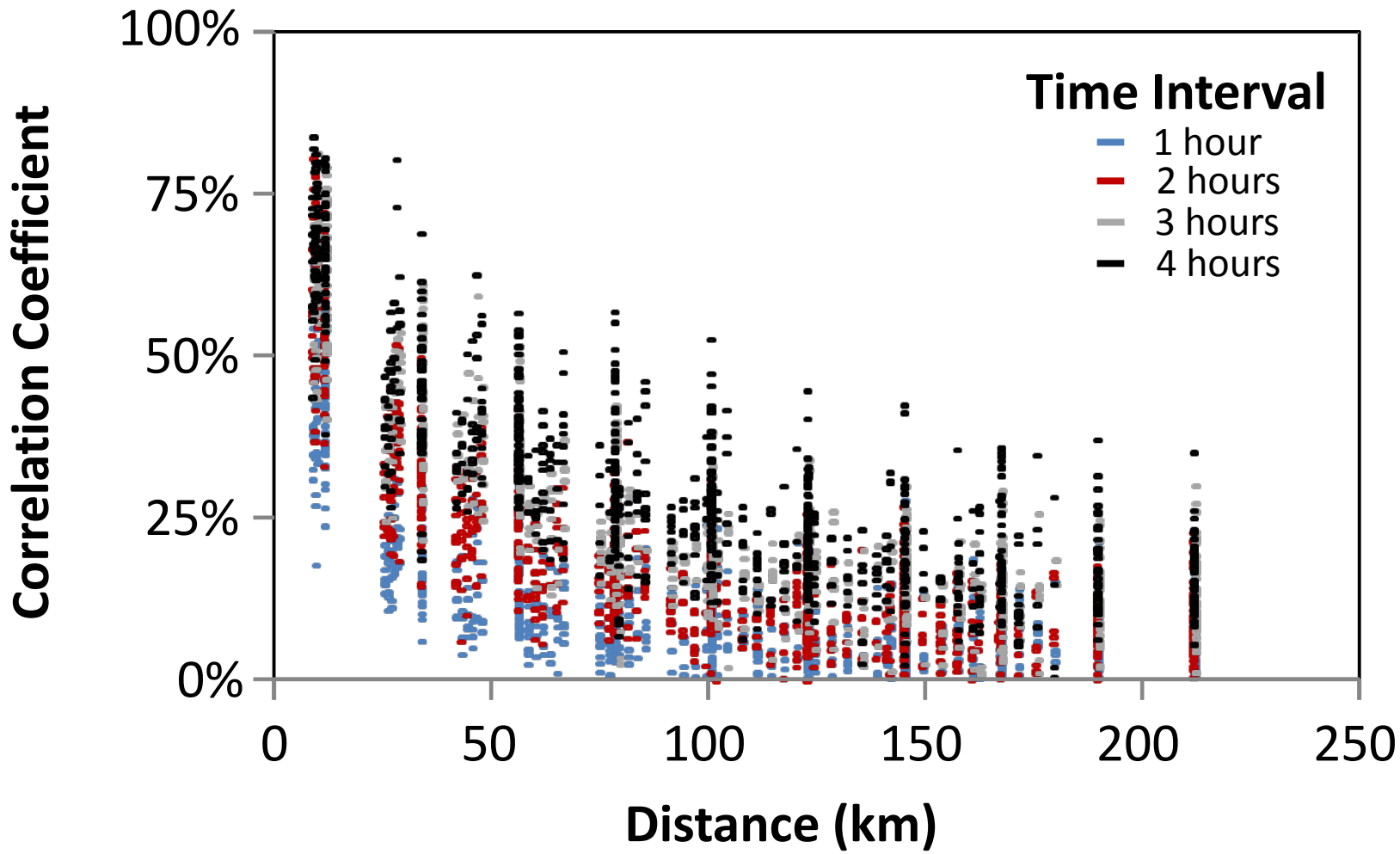
Correlation decreases with distance



Results for Southwest U.S.

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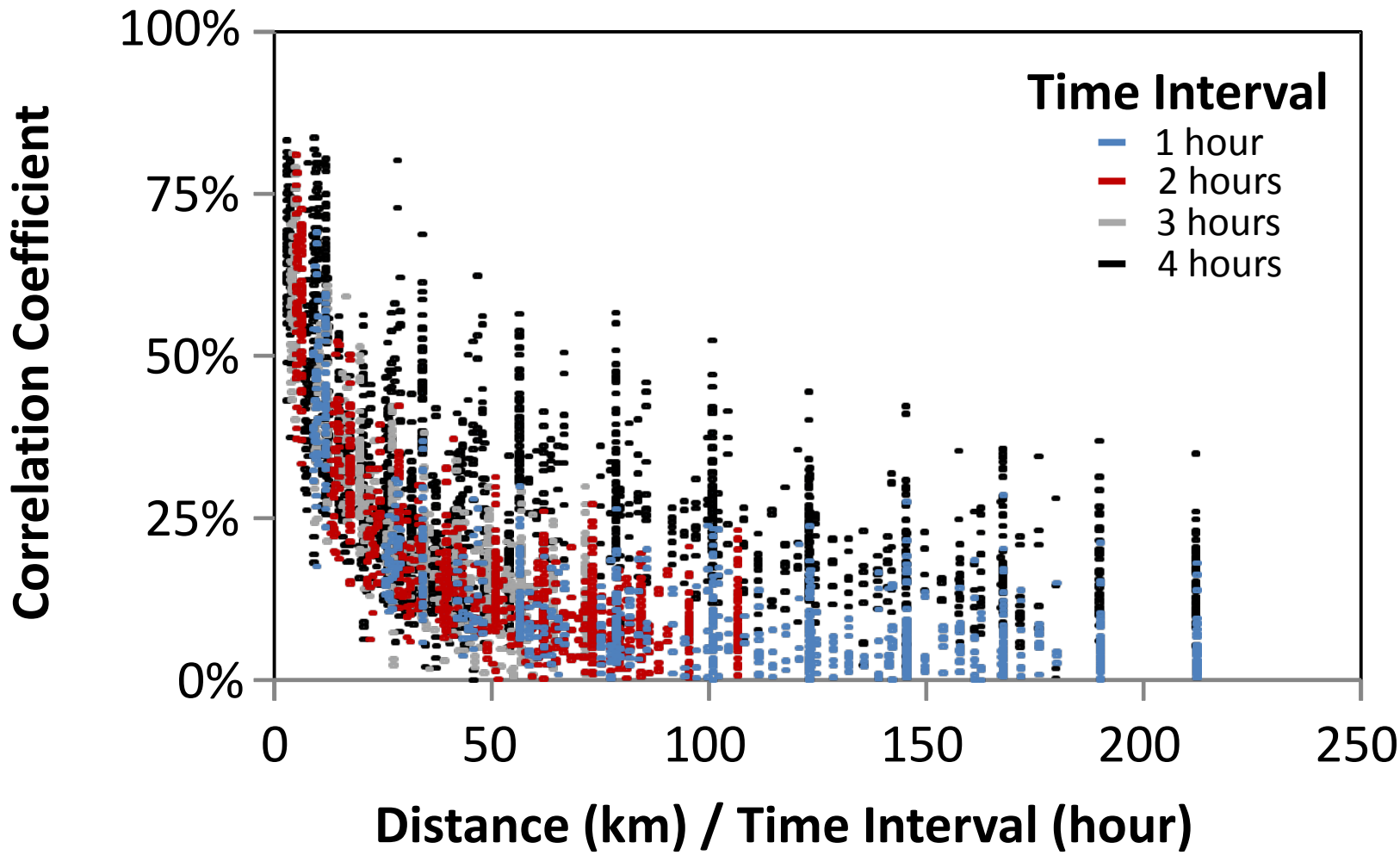
… results also scale with time interval



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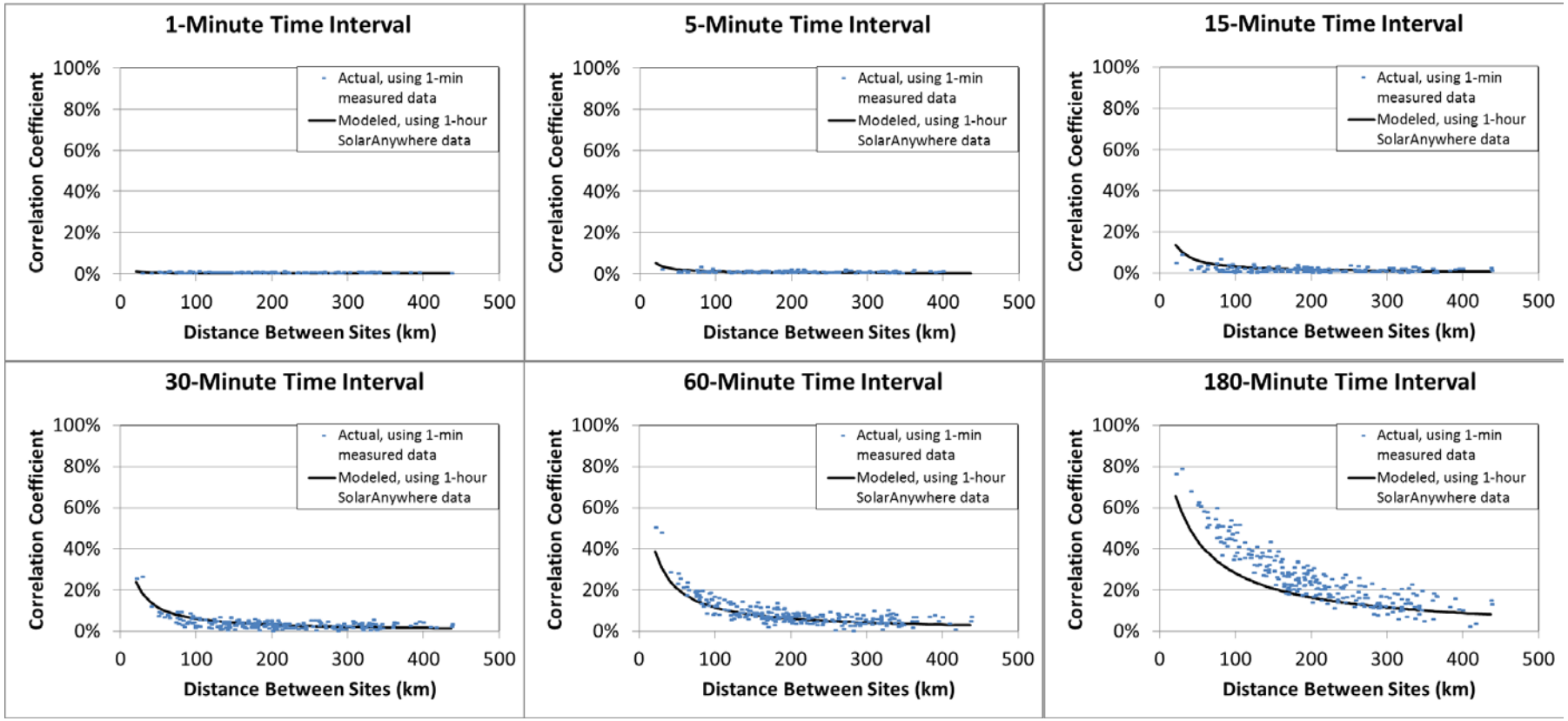
Results validate against LBL study

While current study used 1-hour data set to construct model parameters, results are comparable to LBL study even down to 1-minute time intervals.



Source: Correlation coefficients provided Andrew Mills. Data used to create Figure 5 in report "Implications of Wide-Area Geographic Diversity for Short-Term Variability of Solar Power, LBNL-3884E"

Note: Minor difference in 180 minute time interval is due to methodological differences using in averaging interval.

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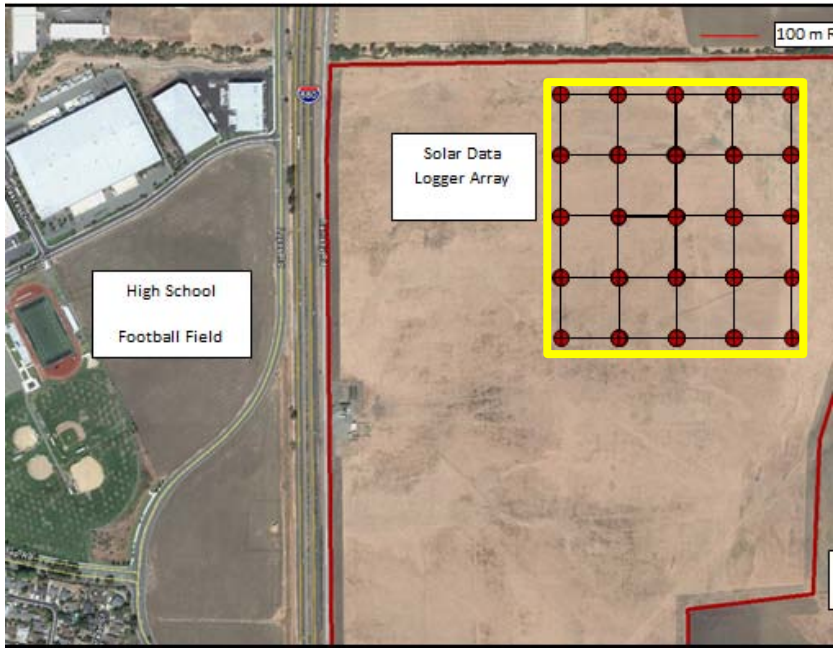
Validate using measured data at two high-density networks

Location	Cordelia Junction, CA	Napa, CA
Grid Size	400 m x 400 m	4 km x 4 km
Representative Capacity	4 MW	400 MW
Data collection rate	10 seconds	10 seconds
Data collection period	11/6/10 to 11/12/10	11/19/10 to 11/23/10



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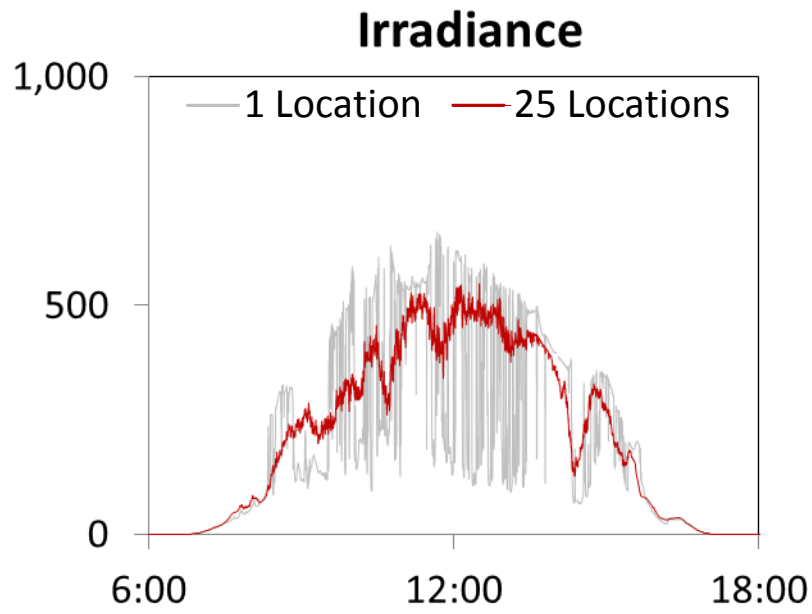
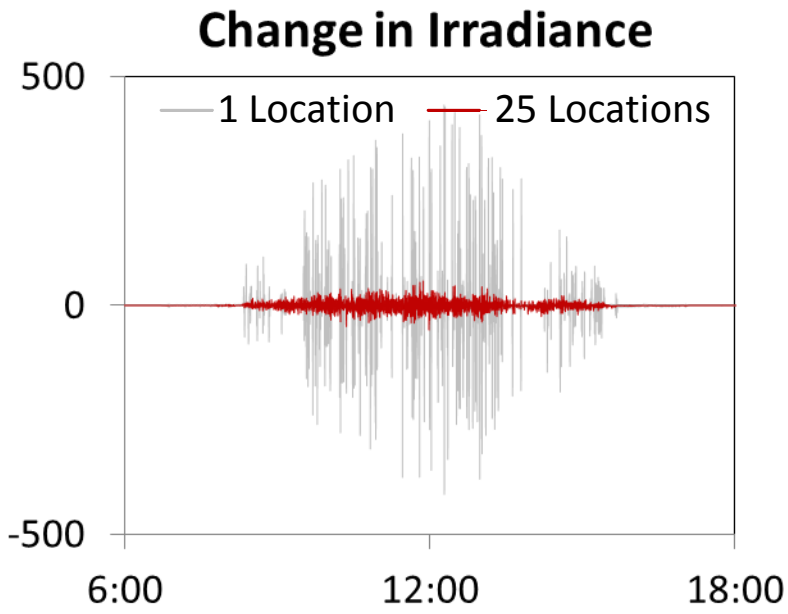
10-second data in 4 km grid (11/21/10)

Combining output from multiple locations in a large grid reduces both uncertainty in irradiance and change in irradiance





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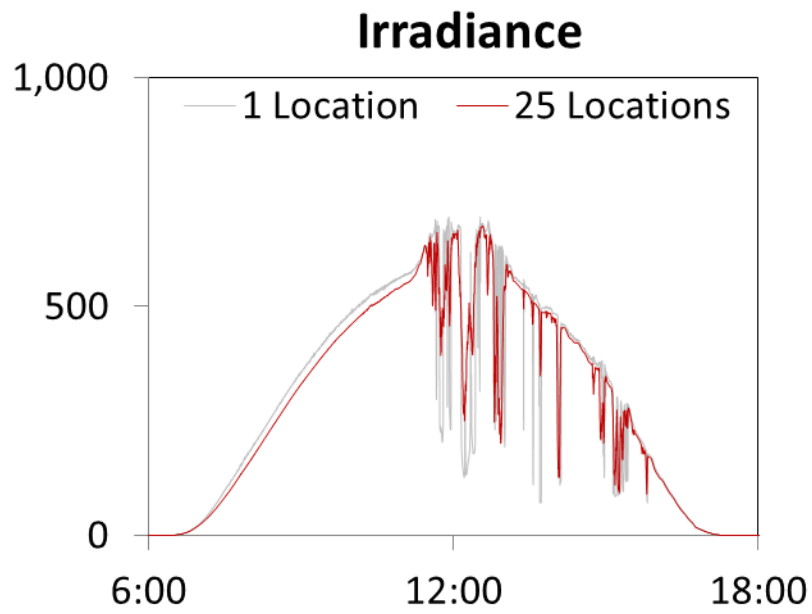
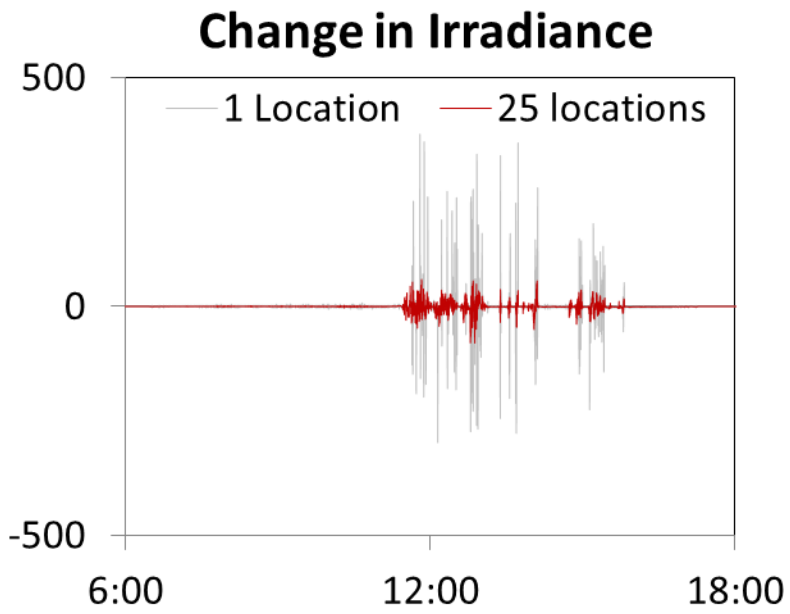
10-second data in 400 meter grid (11/10/10)

Combining output from multiple locations in a small grid reduces change in irradiance





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1 minute interval

Do these results hold true for a longer time interval?

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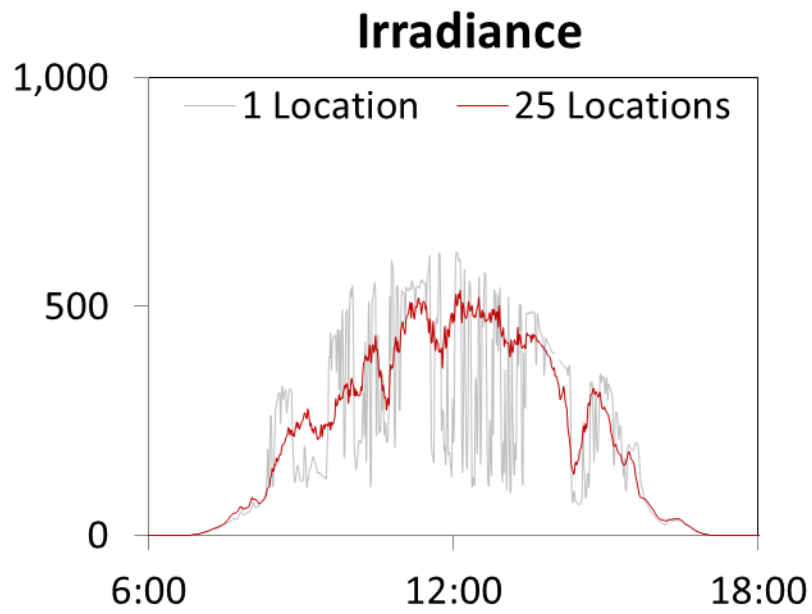
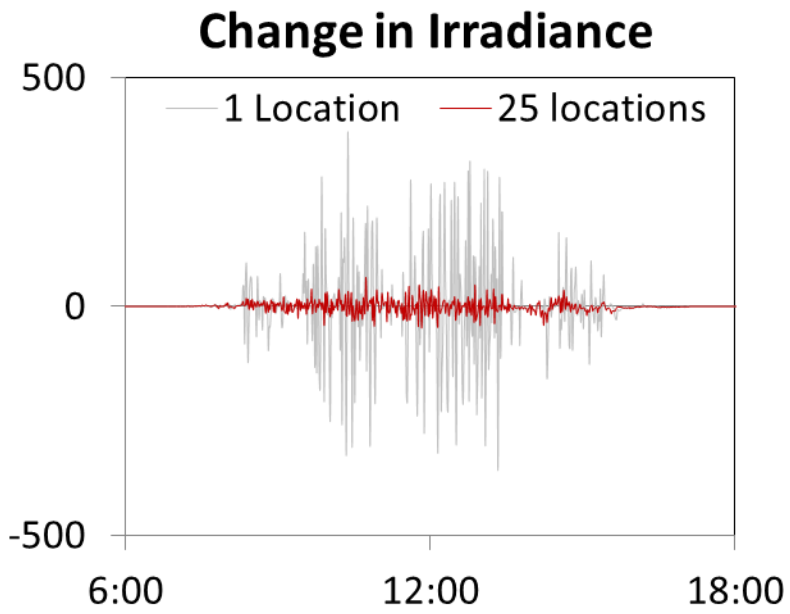
1-minute data in 4 km grid (11/21/10)

Combining output from multiple locations in a large grid reduces both uncertainty in irradiance and change in irradiance





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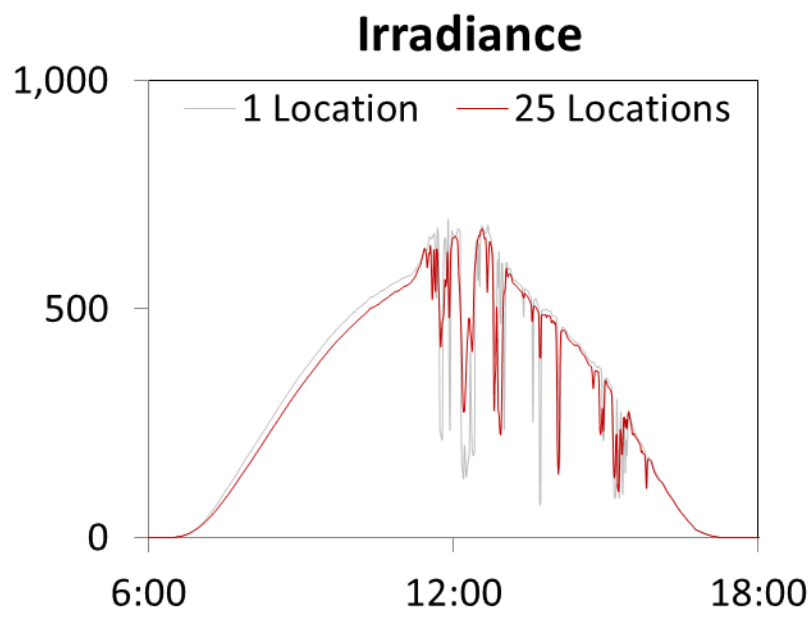
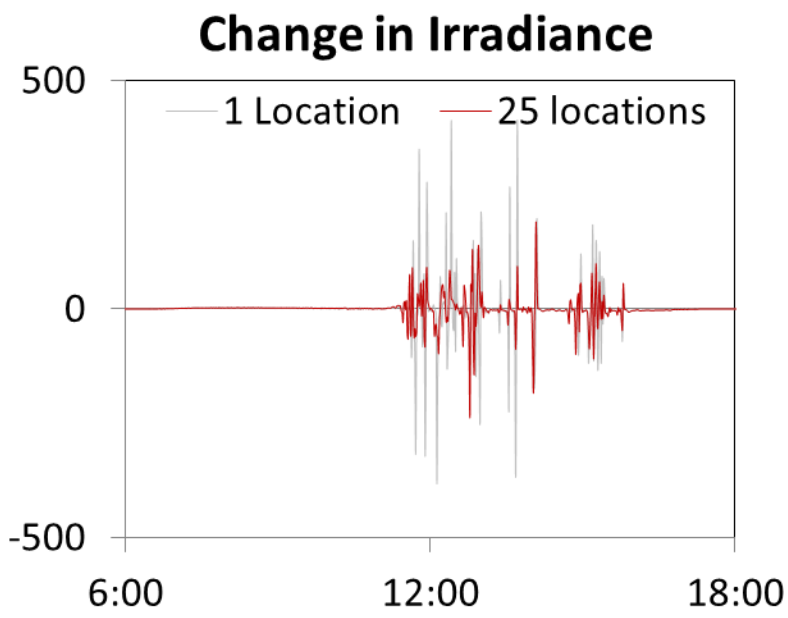
1-minute data in 400 meter grid (11/10/10)

Combining output from multiple locations in a small grid only somewhat reduces change in irradiance





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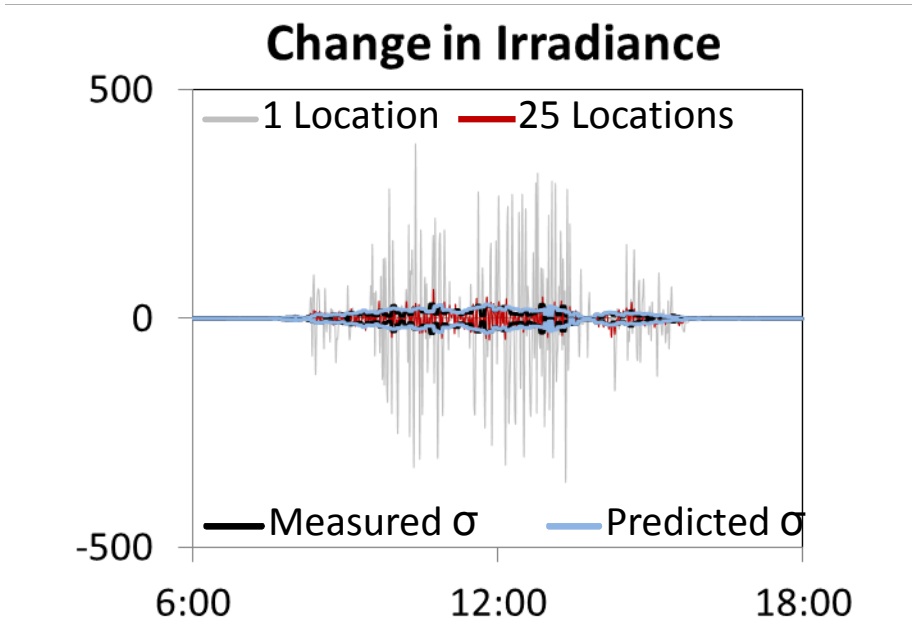
Is output variability predictable from single location?



Measured standard deviation is calculated based on 1 minute change in output for the 25 locations over each 5-minute period on Nov. 21, 2010

Predicted standard deviation is calculated based on average variability for a single location combined with the geographical footprint of the 25 locations

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Illustration of application to LTPP: assumptions

- 5,434 MW of PV
- Installed at 471 locations
- Horizontal systems
- Locations have uncorrelated changes in output
- Highly variable weather conditions

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Example of how to use results

November 10, 2010, 12:00

Time Interval (minute)	1
Clear Sky Irradiance (Watts/sq. meter)	580
Std. Dev. Of Change in Clearness Index at 1 Location	0.17

Number of Plants	Plant Capacity (MW)	Plant Output (MW)	Variability (Std.Dev.) of Output (MW/min)
450	5	3	0.3
2	10	6	0.5
3	52	30	1.5
1	62	36	1.6
5	63	37	1.7
2	100	58	2.2
2	131	76	2.6
1	156	90	2.9
2	250	145	3.8
3	500	290	5.7
471	**5,434**	**3,151**	**15**

Variability is estimated to be 0.28% of fleet capacity

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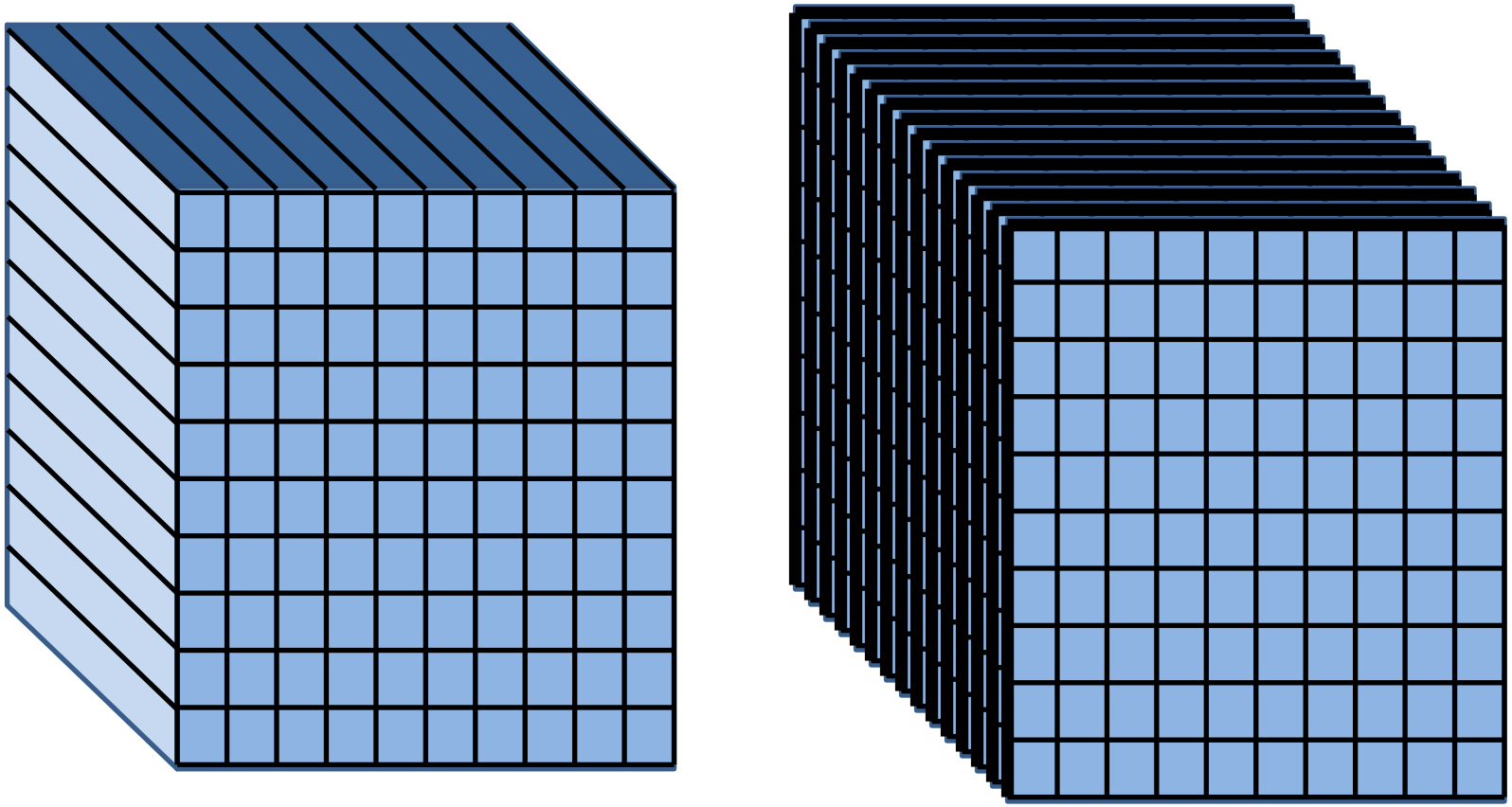
Use SolarAnywhere Enhanced Resolution to generate 1 minute data

1 km grid
½ hour data

→

1 km grid
1 minute data



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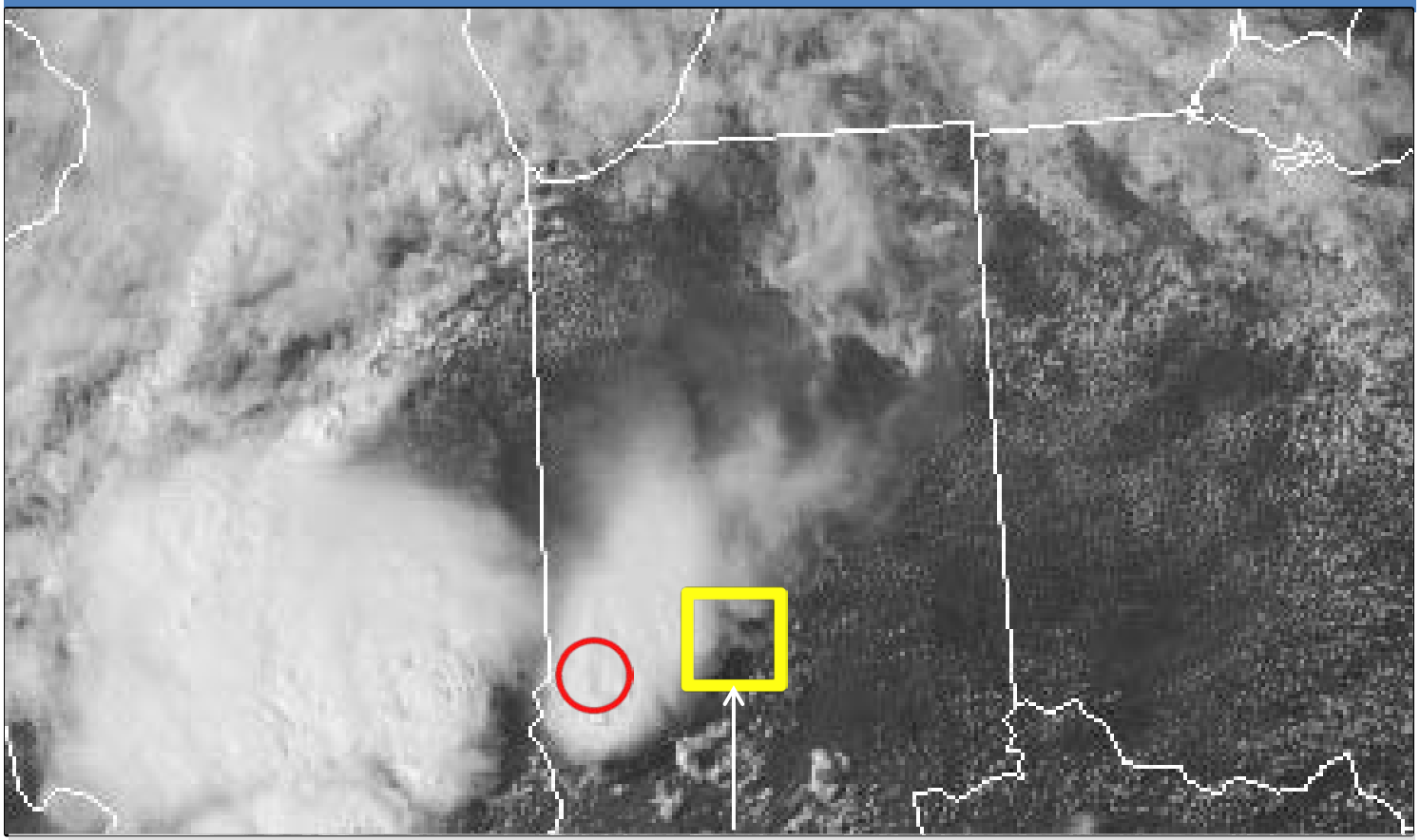
How? Use cloud motion forecasting method

Real time



Location of Interest

Source:Perez

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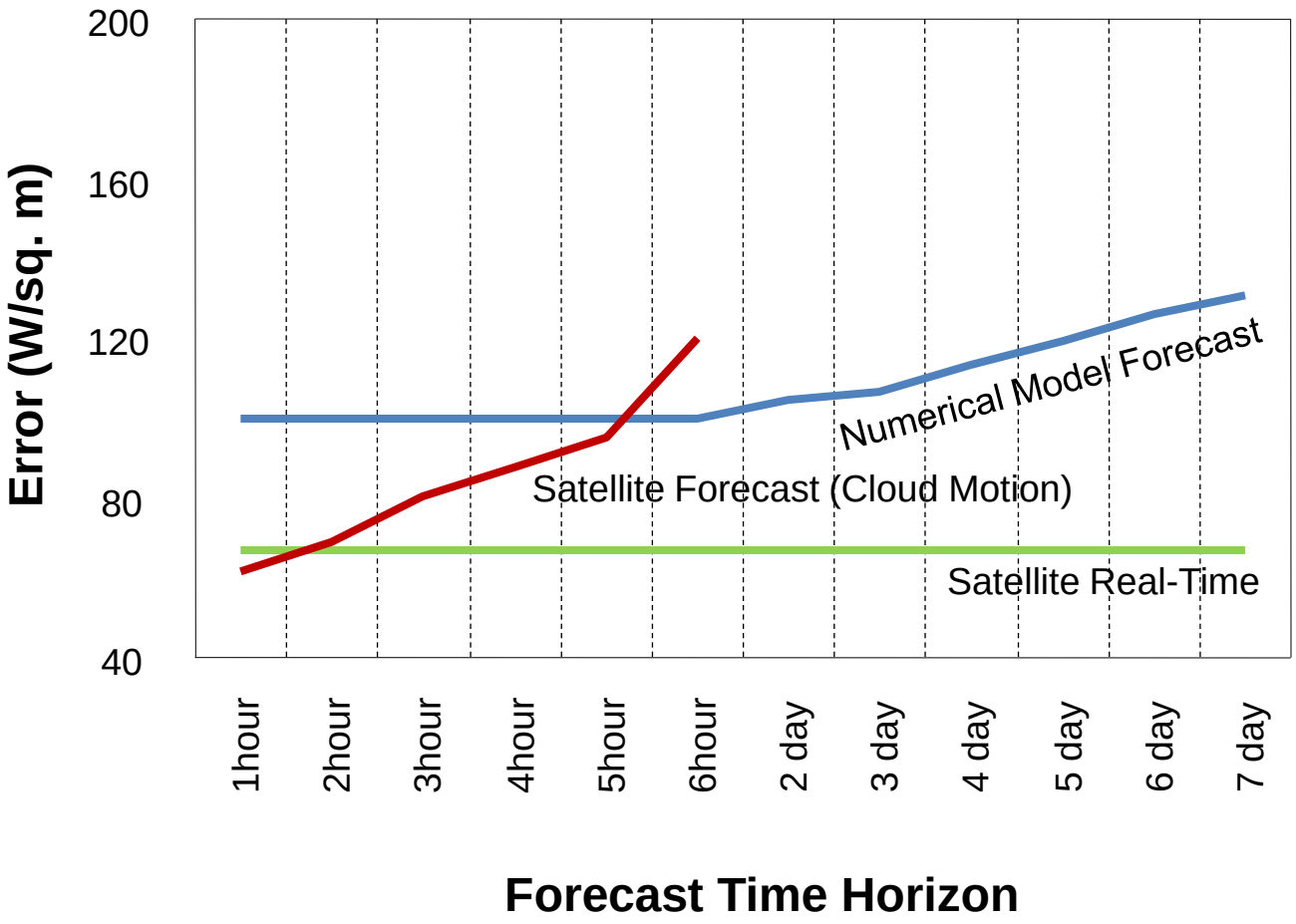
Cloud motion forecast has good accuracy



*Results for a seven site index
Source: Perez analysis

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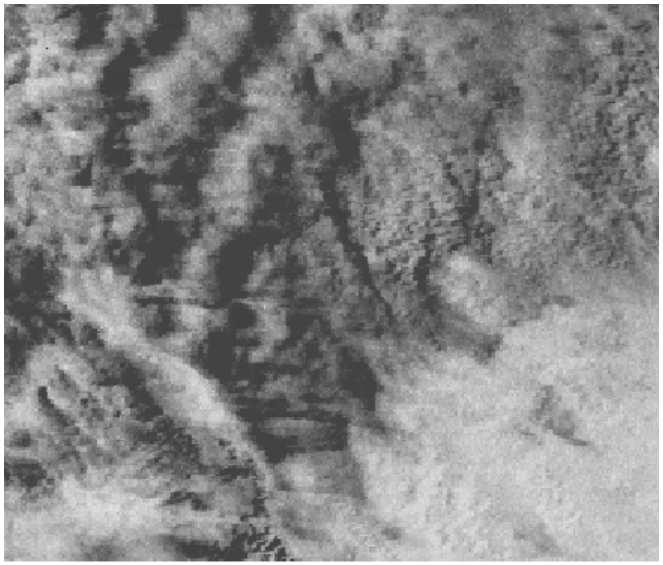
Combine Solar Anywhere Enhanced Resolution with cloud motion vector approach to get 1 minute data

Satellite image (16:00)



Satellite image (16:30)

Each image is composed of 90,000 1 km x 1 km tiles

Source:Perez. 90,000 tiles

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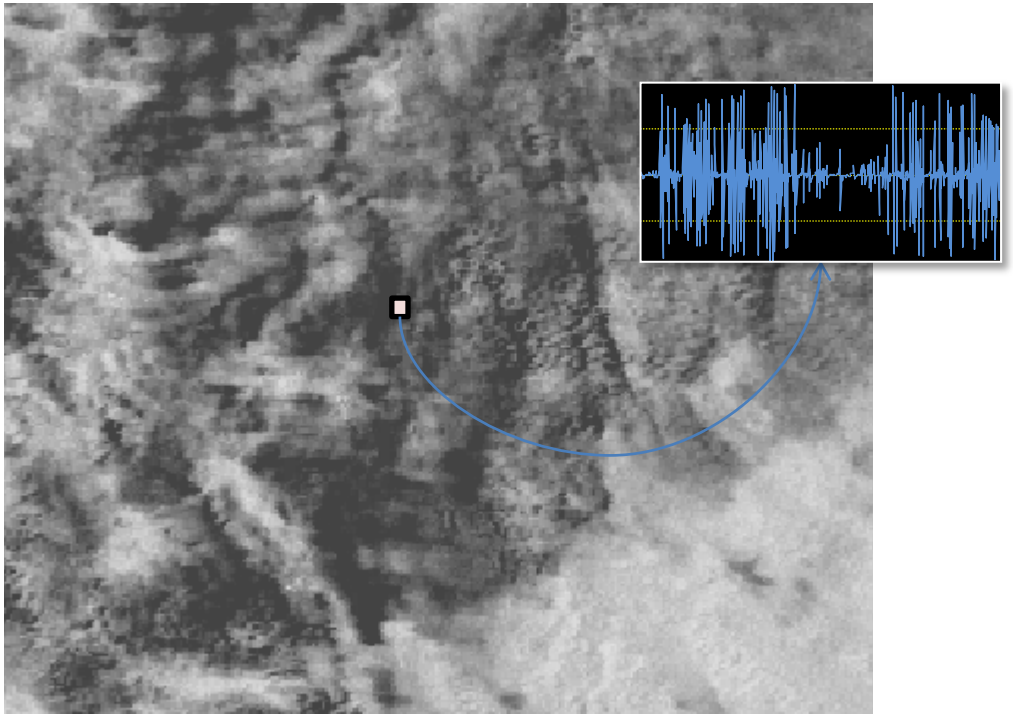
Detailed 1-minute data generation

16:30



Each image is composed of 90,000 1 km x 1 km tiles

Source:Perez

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Putting the pieces together

For any PV deployment configuration on any geographical and time scale, predict output variability without using ground-based measurements

	SolarAnywhere Enhanced Resolution data
Apply cloud motion vector translation	1 minute (or faster), 1 km data
Calculate output variability	Output variability for 1 km^2 of solar
Apply output var. algorithms for 1 km^2 solar footprint	Average output variability for single point
Apply output var. algorithms for actual PV deployment	**Output variability for ANY PV fleet configuration**

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Key next steps

- Extend SolarAnywhere Enhanced Resolution to real time and forecasting (as is currently available with SolarAnywhere)
- Expand SolarAnywhere Enhanced Resolution data to other locations outside of California
- Implement cloud motion data translation to generate high speed data
- Perform further validation of entire process against measured ground data and fleets of PV systems

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- Opinions expressed herein are those of the authors only

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Funding Distributor	California IOUs

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