Evaluating Irradiance Accuracy Using California ISO Data: Lessons Learned

Tom Hoff, UVIG, February 9, 2012

California ISO
Shaping a Renewed Future

The California ENERGY COMMISSION

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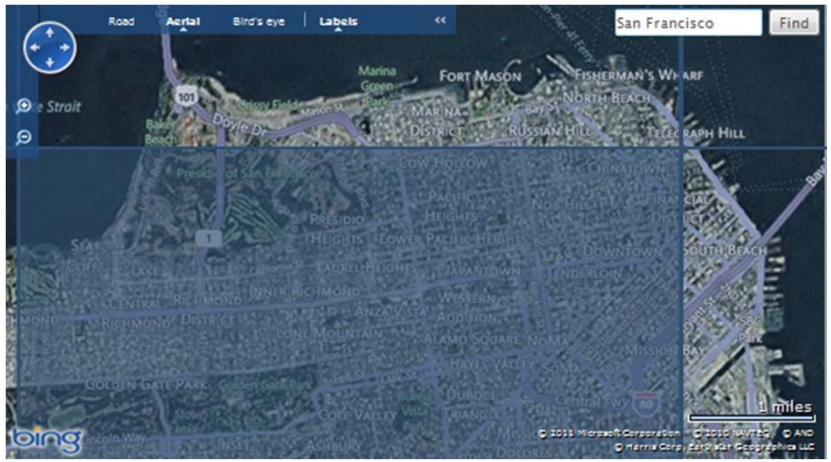
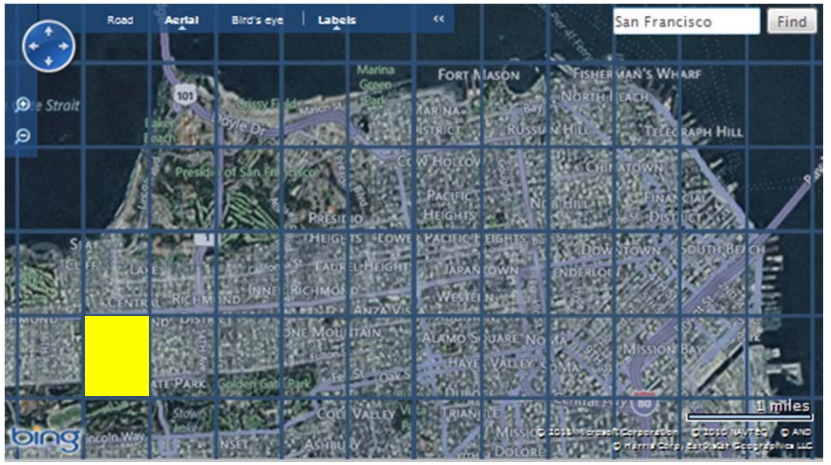
CSI R&D Phase I Grant

SOLARanywhere STANDARD RESOLUTION

SOLARanywhere ENHANCED RESOLUTION





Example: San Francisco, CA

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CEC PIER Grant

- *Goal: Validate existing research and tools in partnership with the California ISO, and to integrate the methodologies into the California ISO planning process in order to address existing and future variability from PV generation*

- *Acknowledgements*
  - Funding support from the CEC PIER program
  - Data and direction support provided by Jim Blatchford and others at California ISO

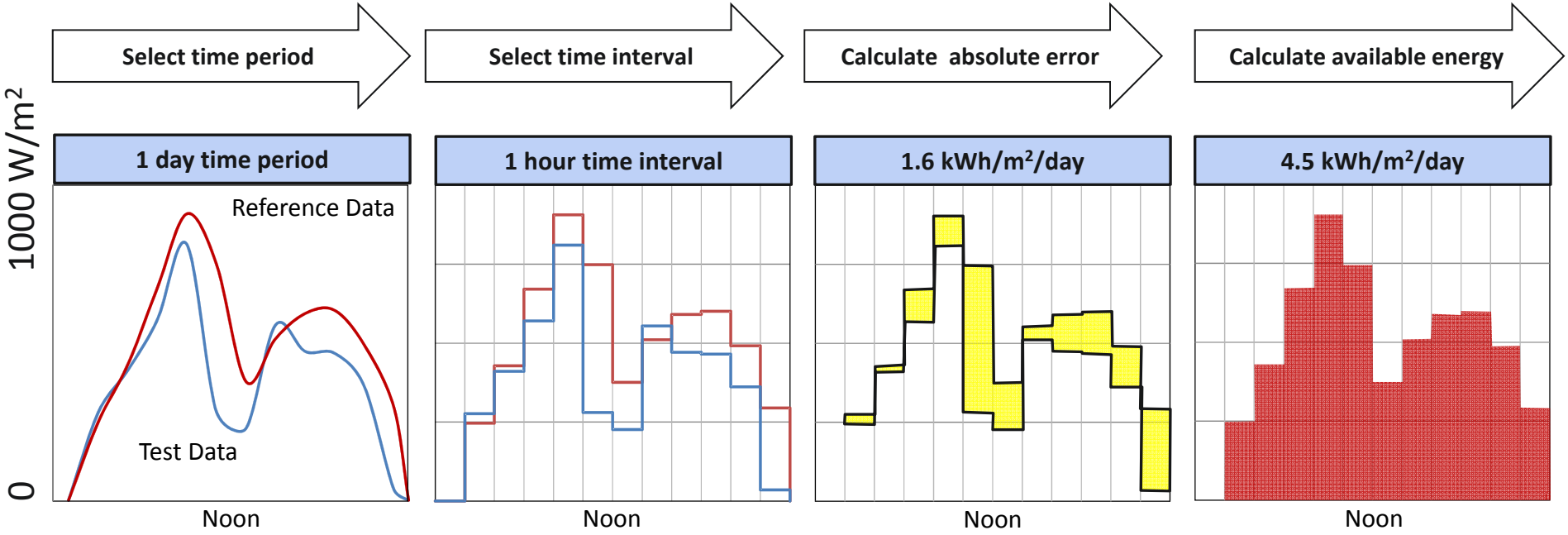
Quantify Accuracy Using Measured Data

- *Irradiance and simulated PV output*
- *Multiple time intervals*
  - *Long (year, month, day)*
  - *Medium (1 hour, ½ hour)*
  - *Short (minute, seconds)*
- *Individual locations and fleets*
- *Historical and forecasted*

Approach

- Obtain ½ hour GHI data for 2011 for 6 locations
  - Ground data from two separate sensors from California ISO
  - SolarAnywhere Enhanced Resolution data
  - SolarAnywhere Standard Resolution data (1 hour data)
- Evaluate every data point for data quality
- Calculate Mean Absolute Error relative to energy (***not capacity***)
- Extend results to fleets

Mean Absolute Error Calculation Example



Result: MAE relative to energy = **36%** (1.6/4.5)

Note: MAE relative to daytime capacity = **14%** (1.6/12)

MAE relative to daily capacity = **7%** (1.6/24)

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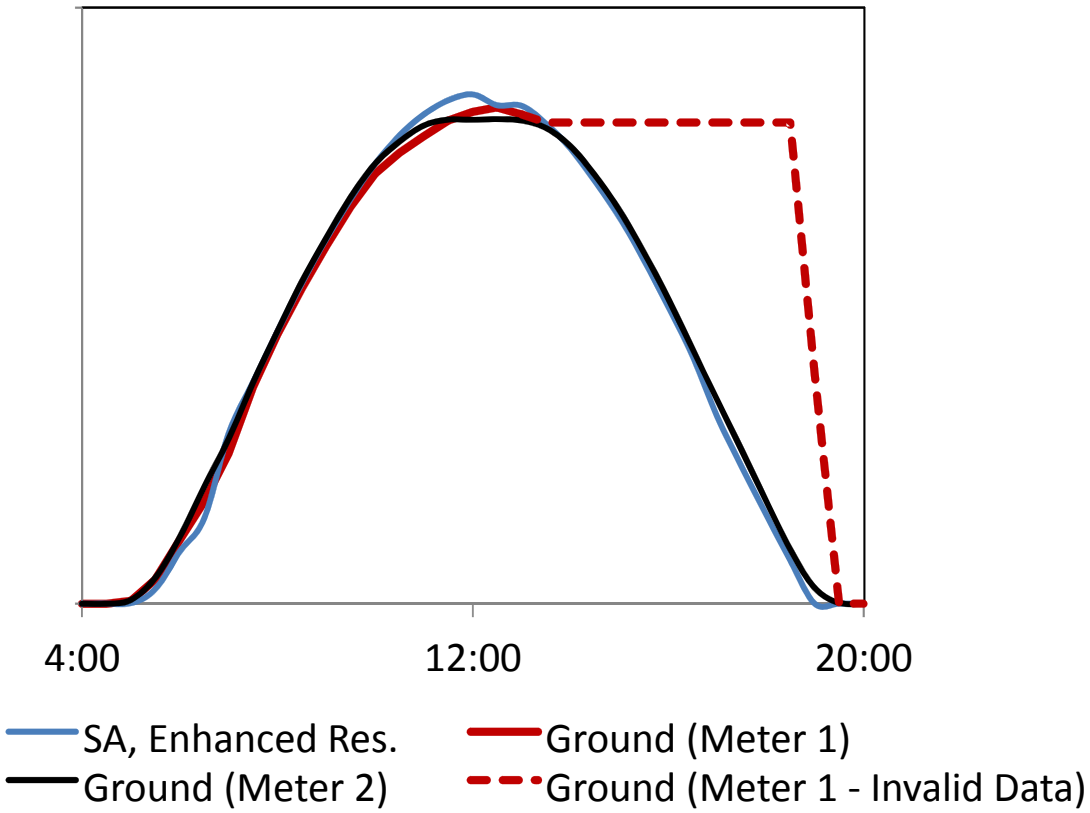
Example of Invalid Ground Sensor Data (Site A, June 22, 2011)



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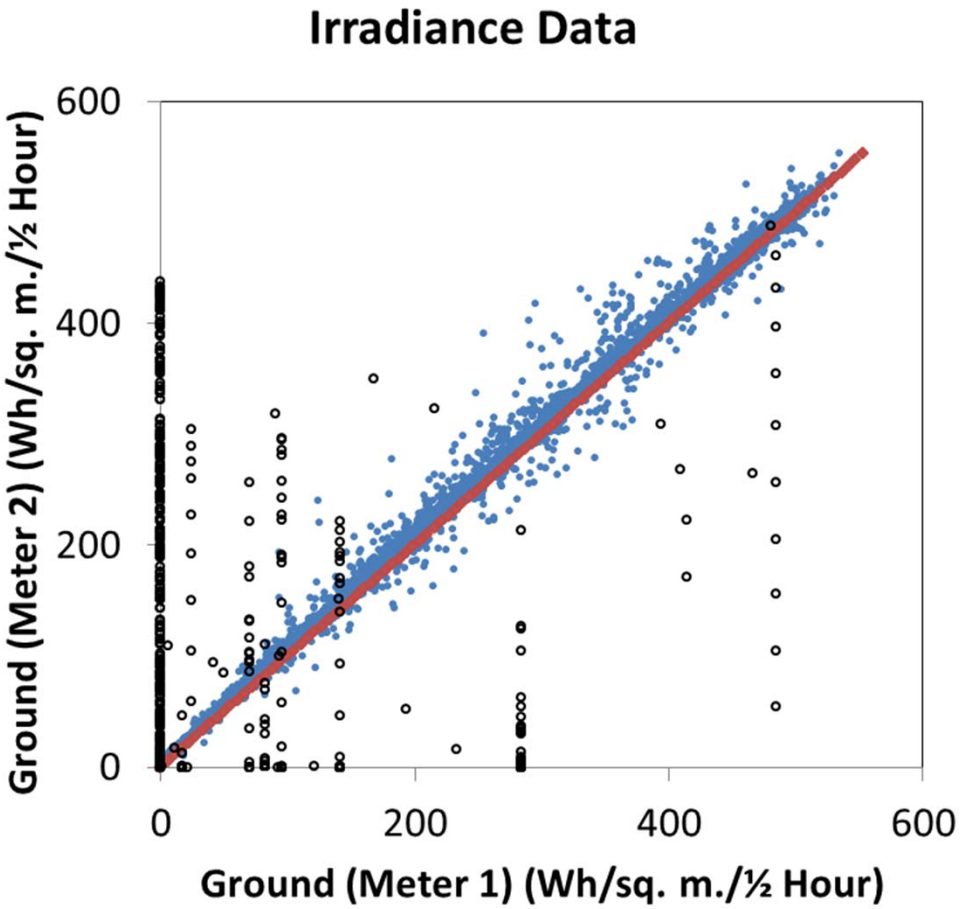
Screen Invalid Data Using 2nd Ground Sensor and SA Enhanced Resolution (Site A)



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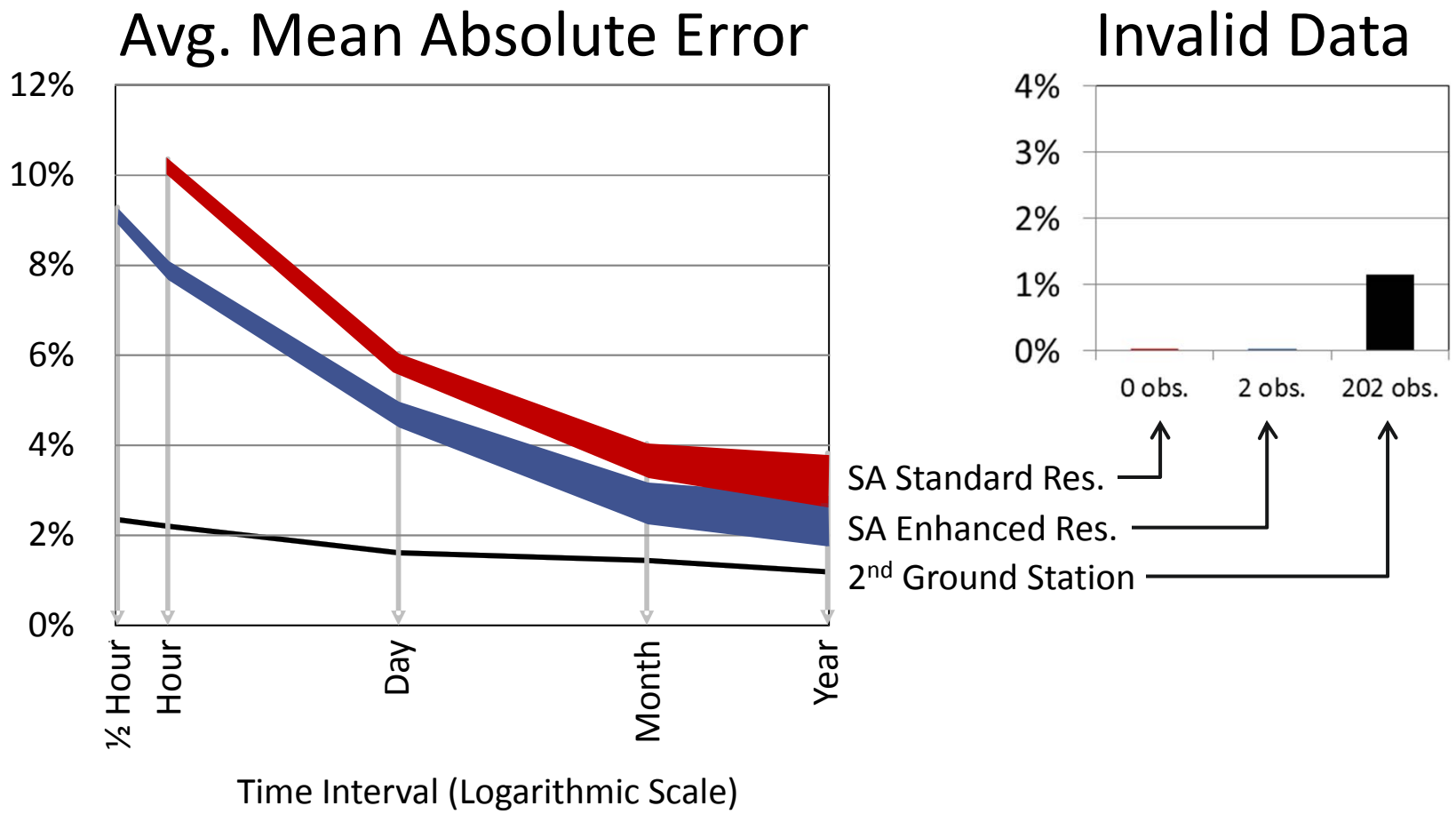
Summary: Average of 4 Individual Locations



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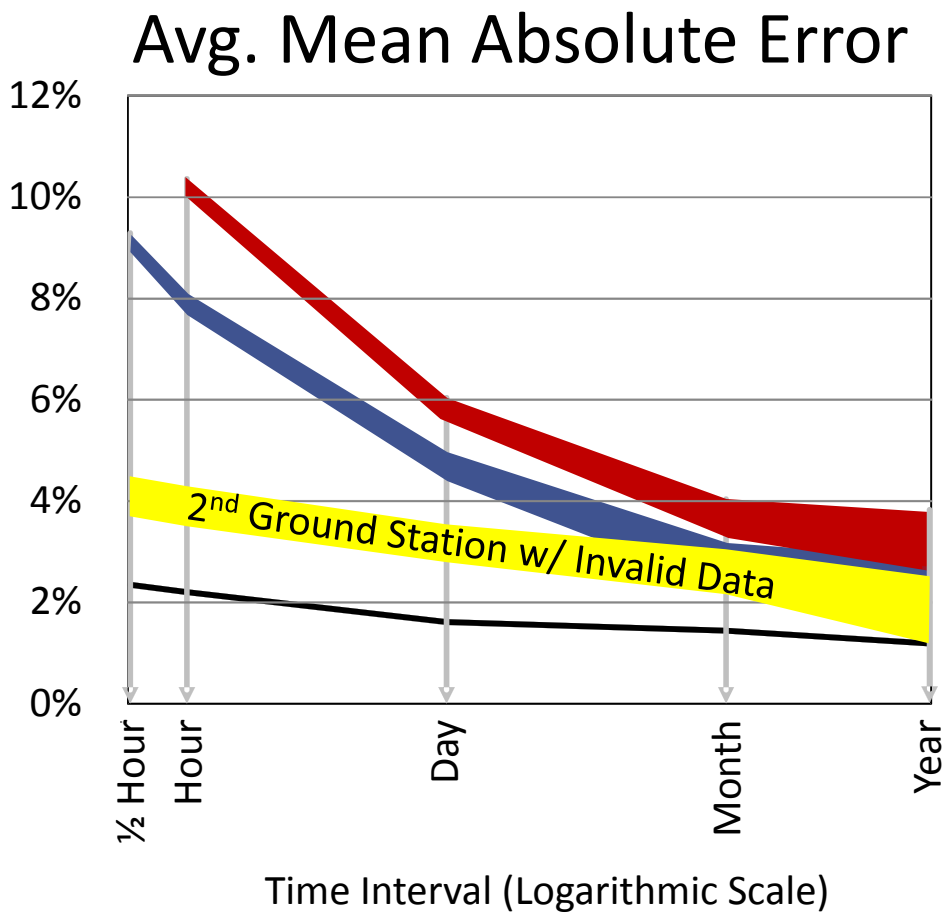
Effect of Data Quality Issues?



SA Standard Res.
SA Enhanced Res.
2nd Ground Station

Two types of errors

- Measurement error
- Invalid data

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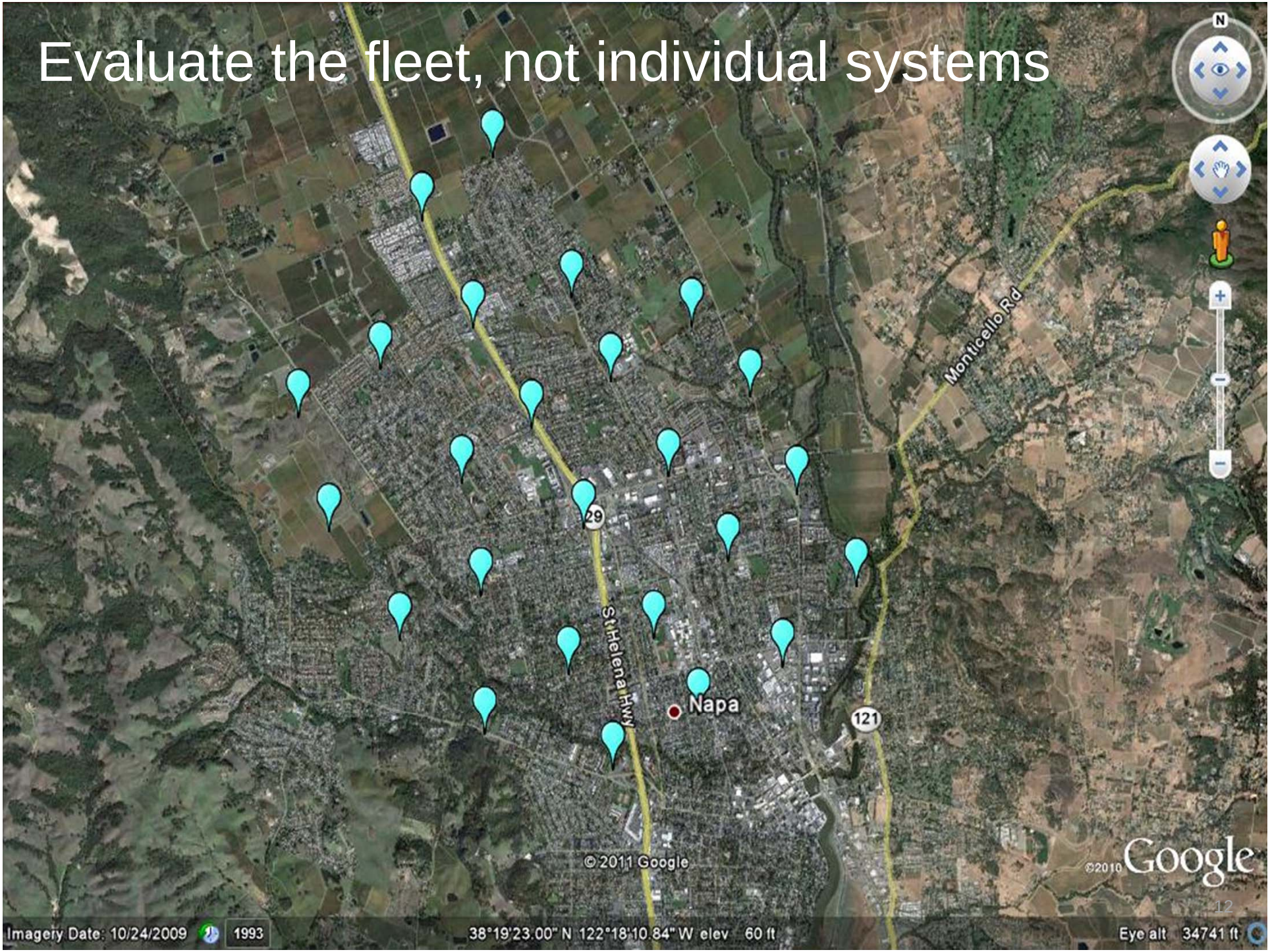
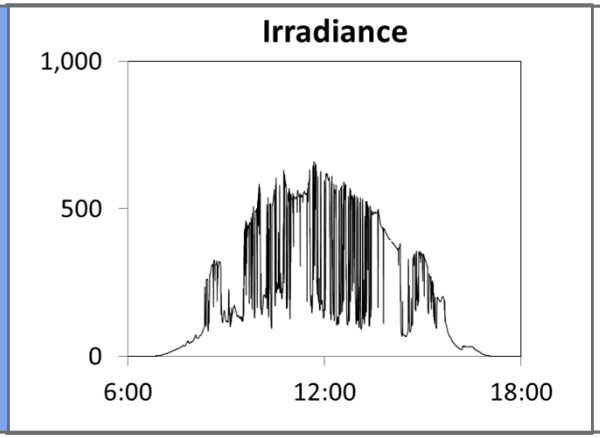
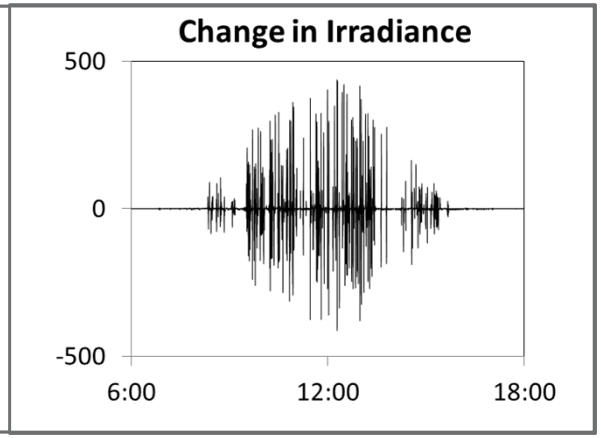
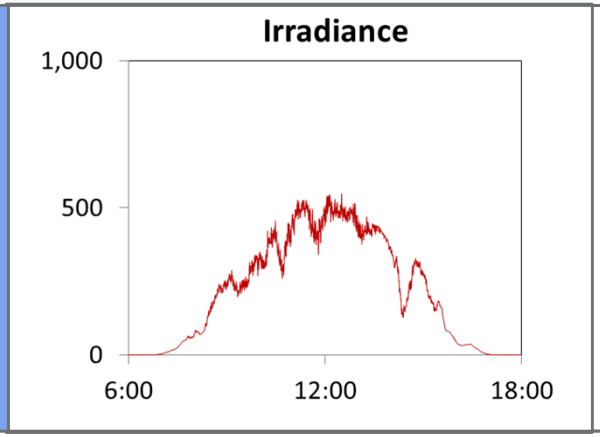
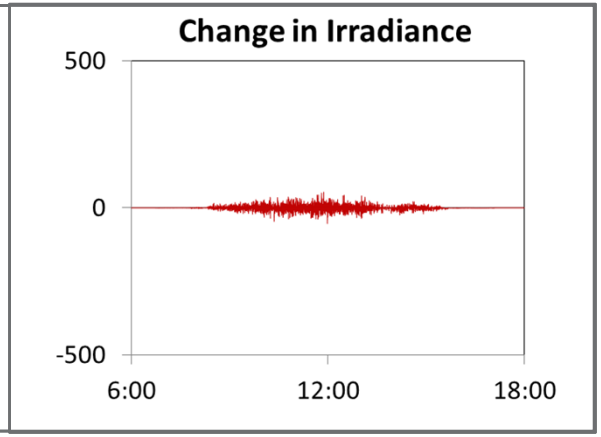
Evaluate the fleet, not individual systems



Output Variability Reduces with Geographic Diversity

10 second irradiance data from 4 x 4 km grid in Napa on Nov. 21, 2010

1 Location Measured		
25 Locations Measured		

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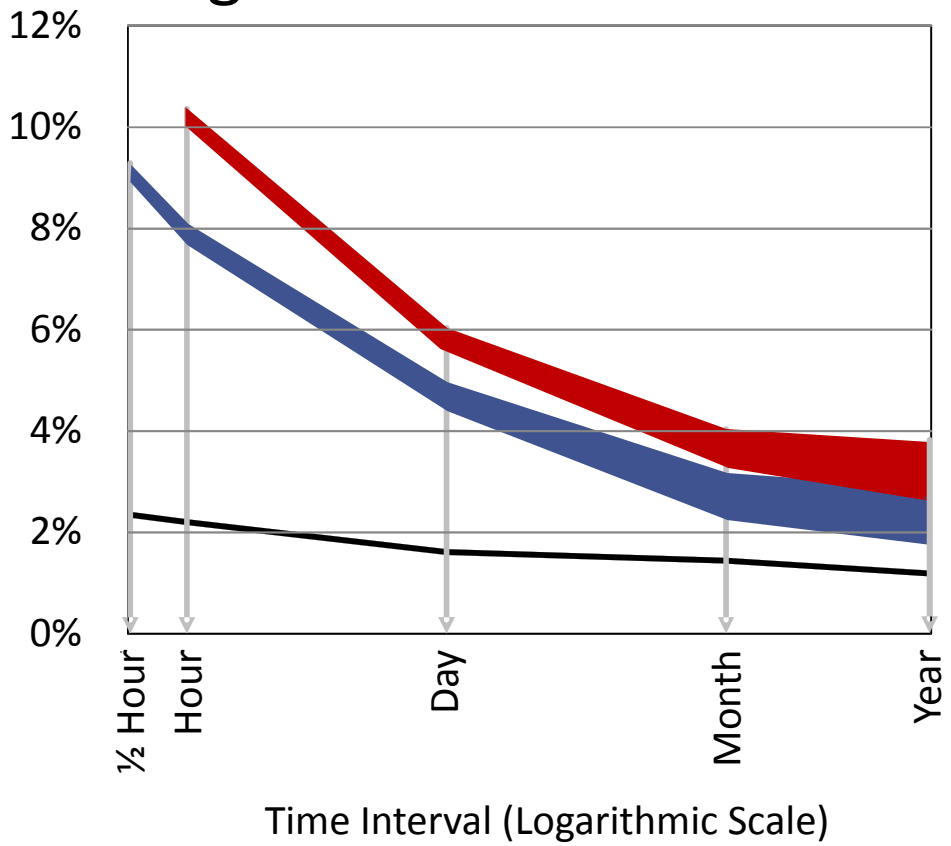
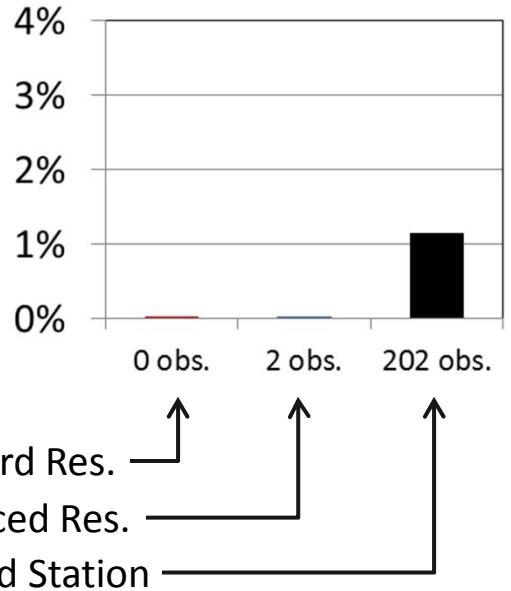
Summary: Average of 4 Individual Locations

Average of Mean Absolute Error



Invalid Data



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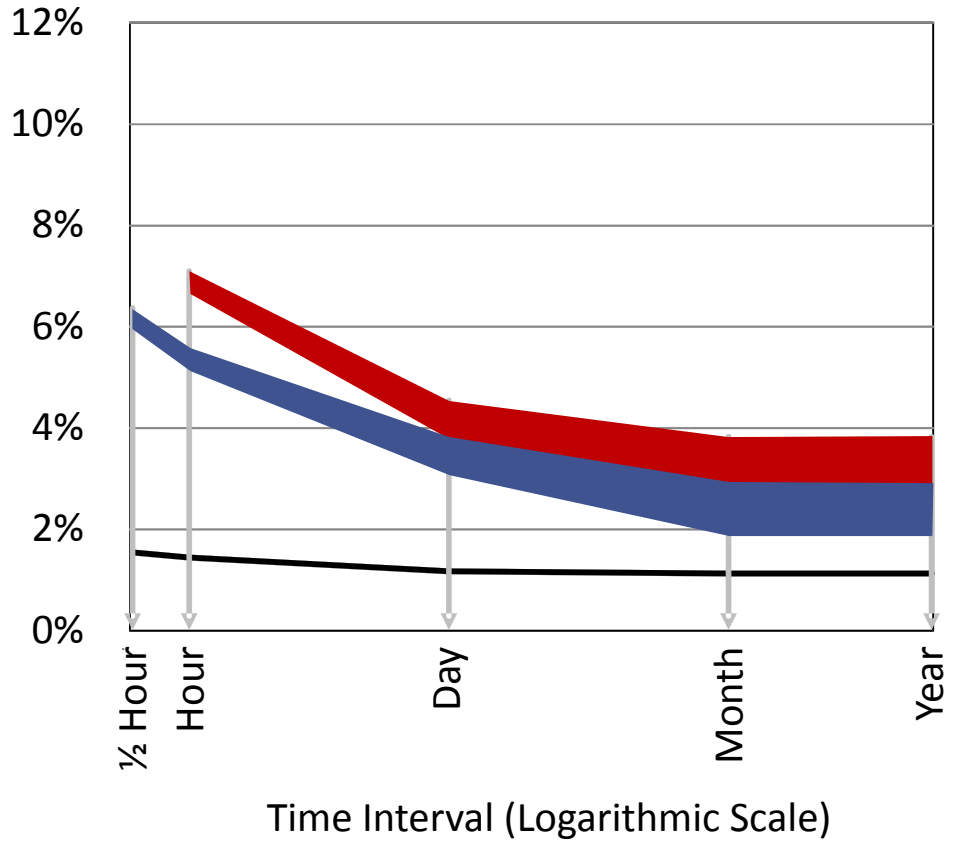
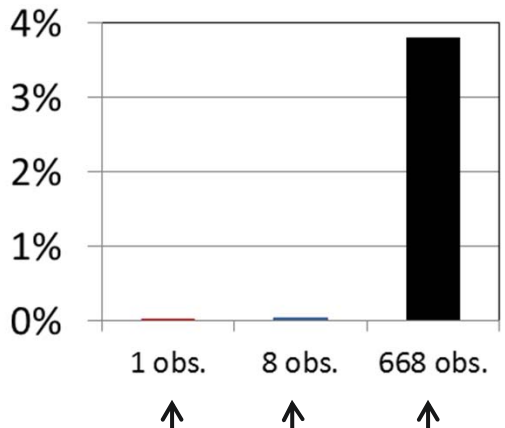
Geographic Diversity Reduces Prediction Error

Mean Absolute Error of 4-Location Average



Invalid Data



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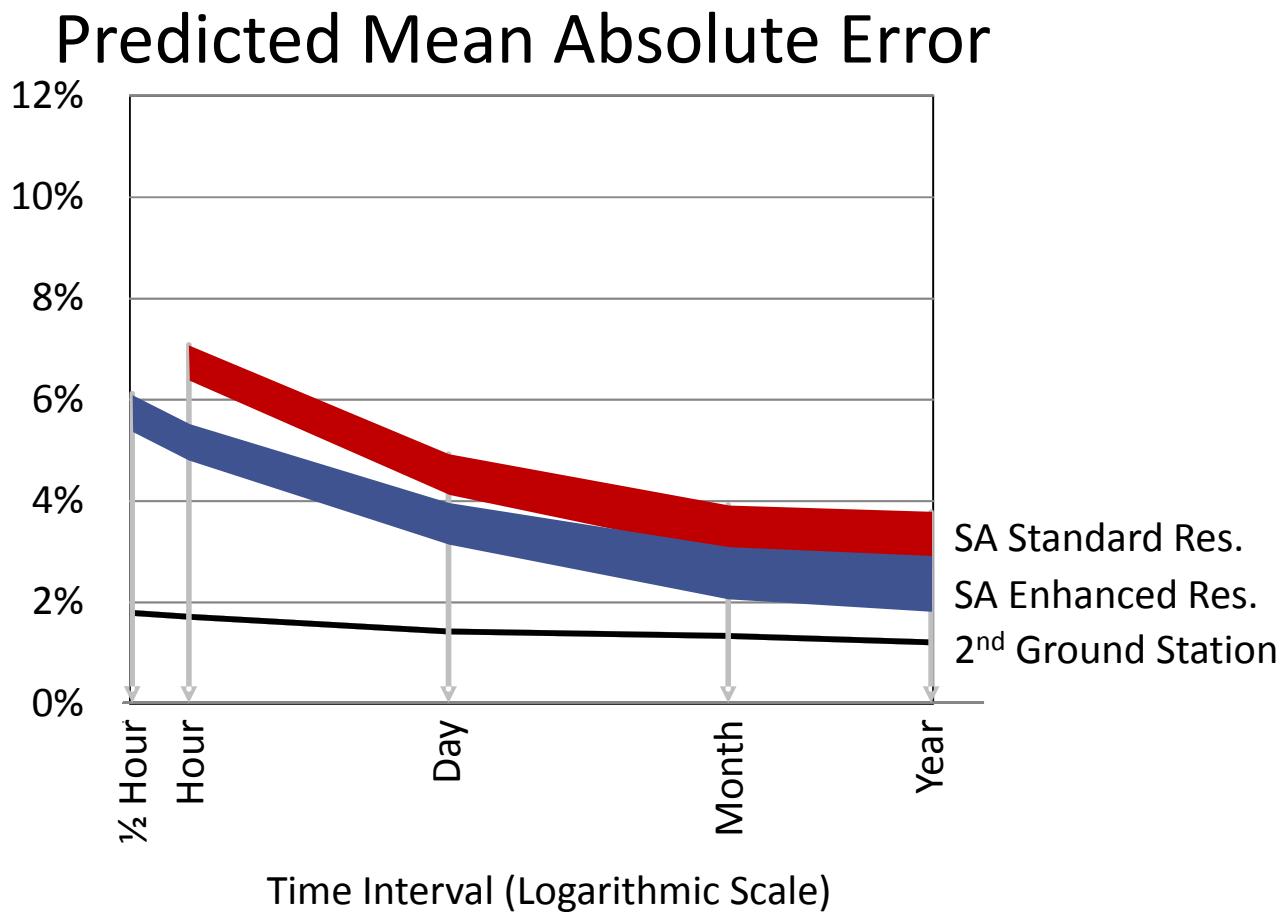
Combined Error is Predictable



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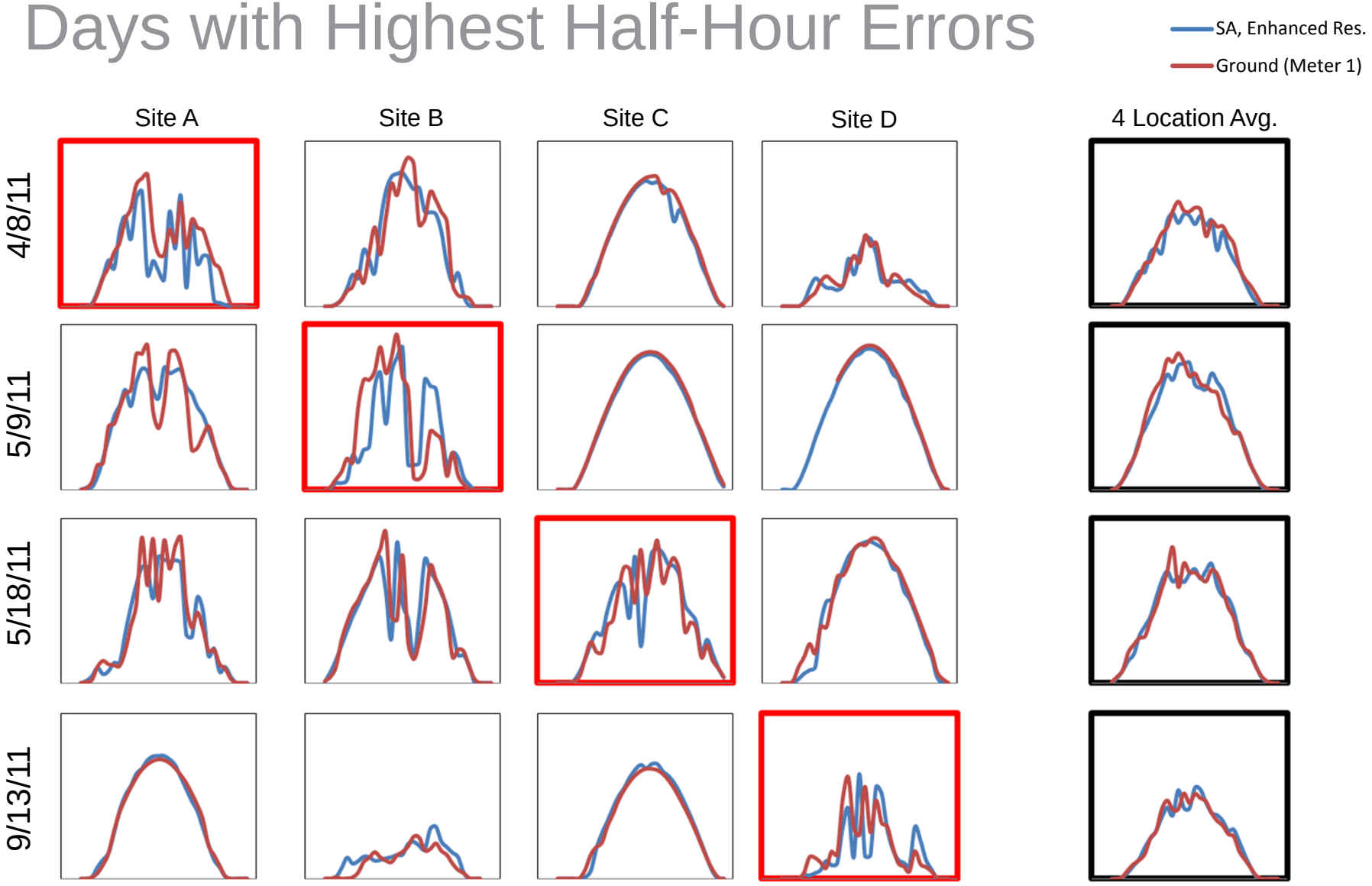
Days with Highest Half-Hour Errors



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Conclusions

- Satellite-based irradiance data have essentially no invalid data; ground sensors have 1 percent invalid data
- SA Enhanced Resolution has annual error comparable to ground sensors and twice the hourly error when invalid data is included
- Accuracy improves (predictably) due to benefit of geographic dispersion

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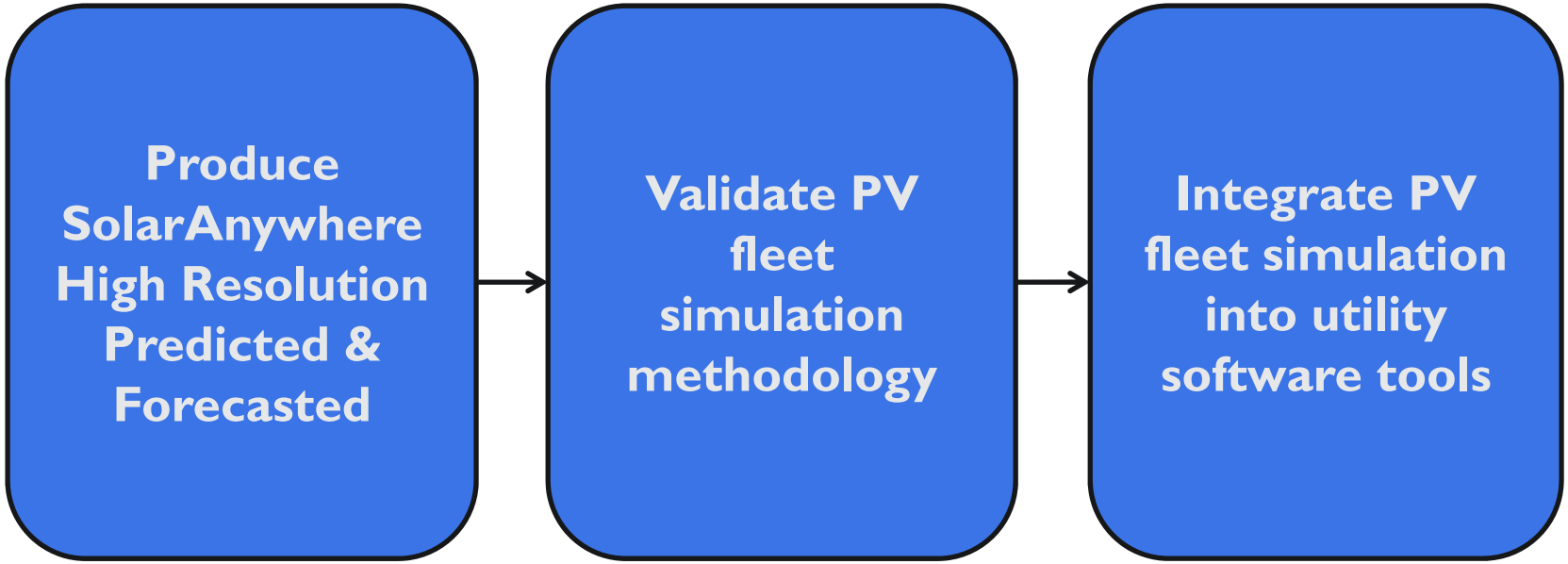

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Thank you

Questions?
Contact Tom Hoff
tomhoff@cleanpower.com
cleanpower.com

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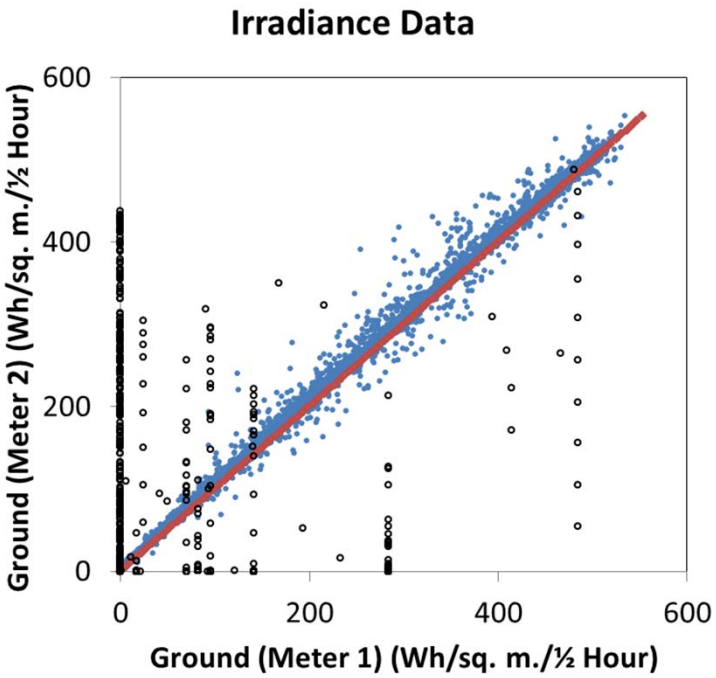
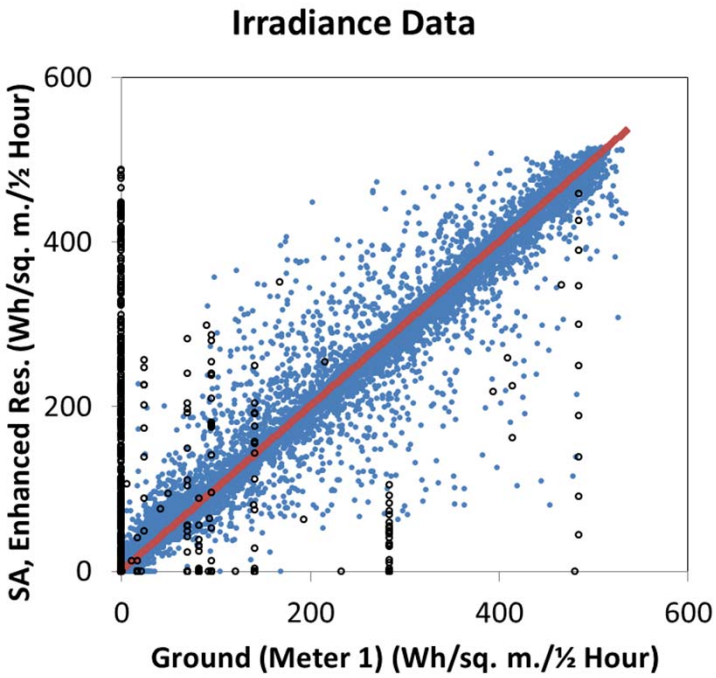
Appendices

Screen Invalid Data Using 2nd Ground Sensor and SA Enhanced Resolution – Site A





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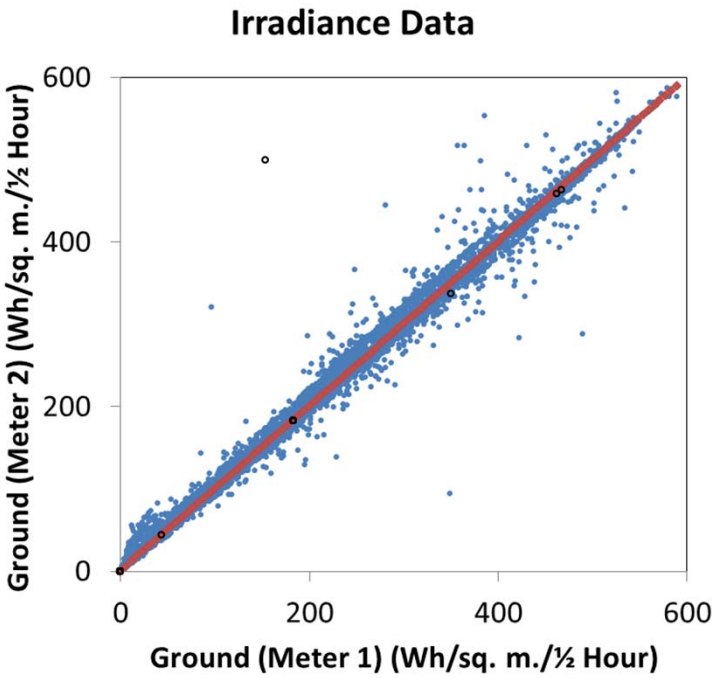
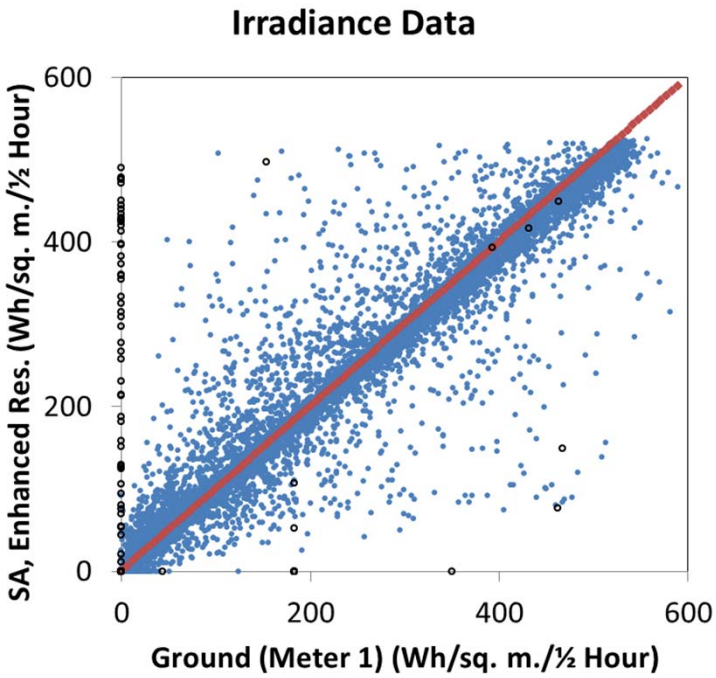
Screen Invalid Data Using 2nd Ground Sensor and SA Enhanced Resolution – Site B





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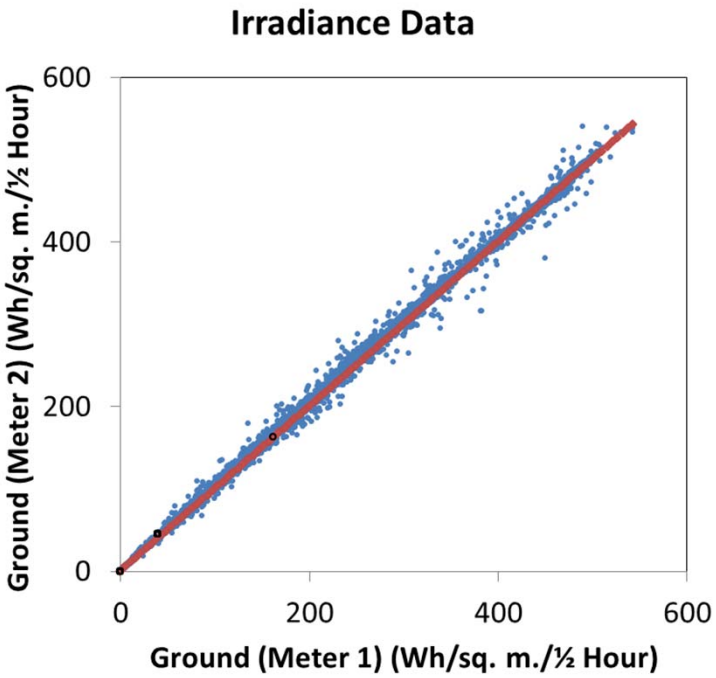
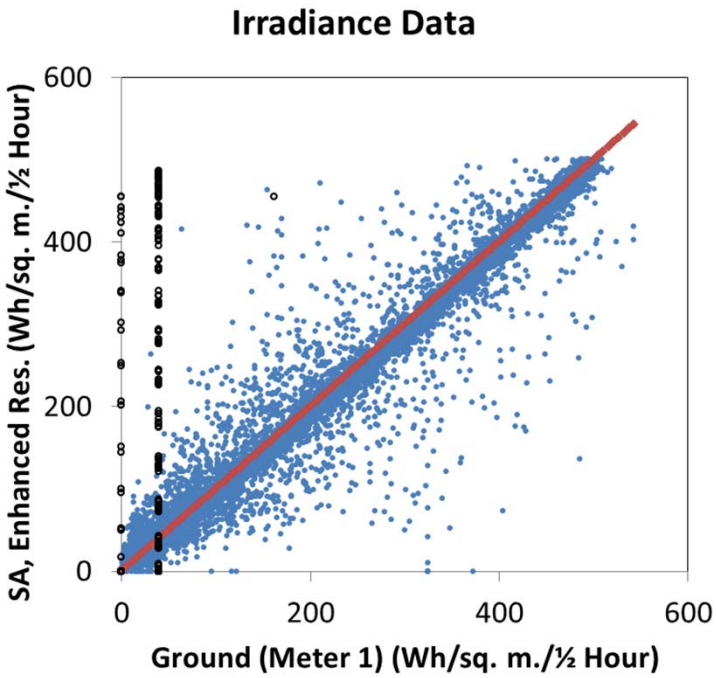
Screen Invalid Data Using 2nd Ground Sensor and SA Enhanced Resolution – Site C





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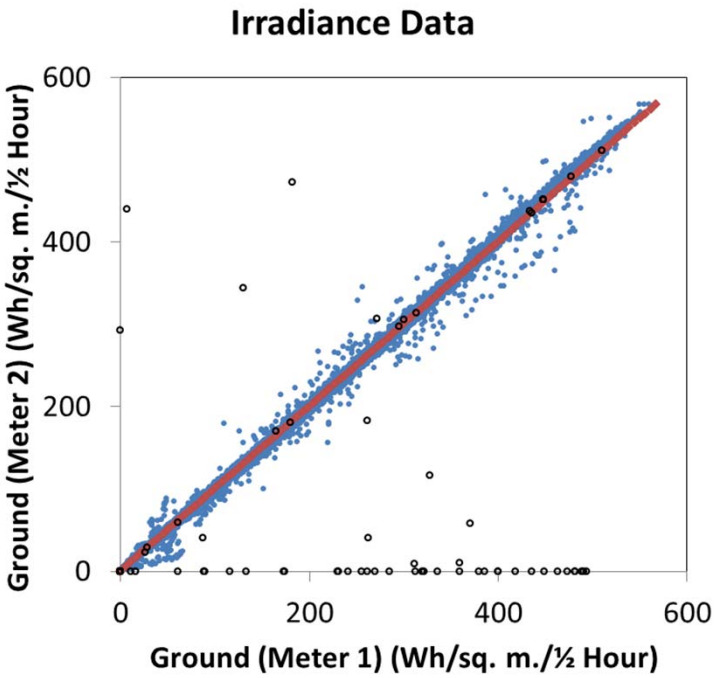
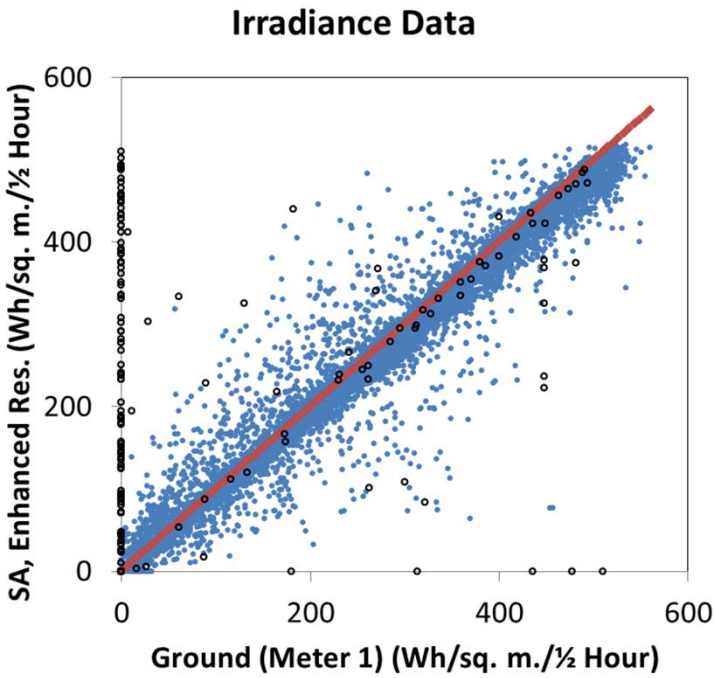
Screen Invalid Data Using 2nd Ground Sensor and SA Enhanced Resolution – Site D





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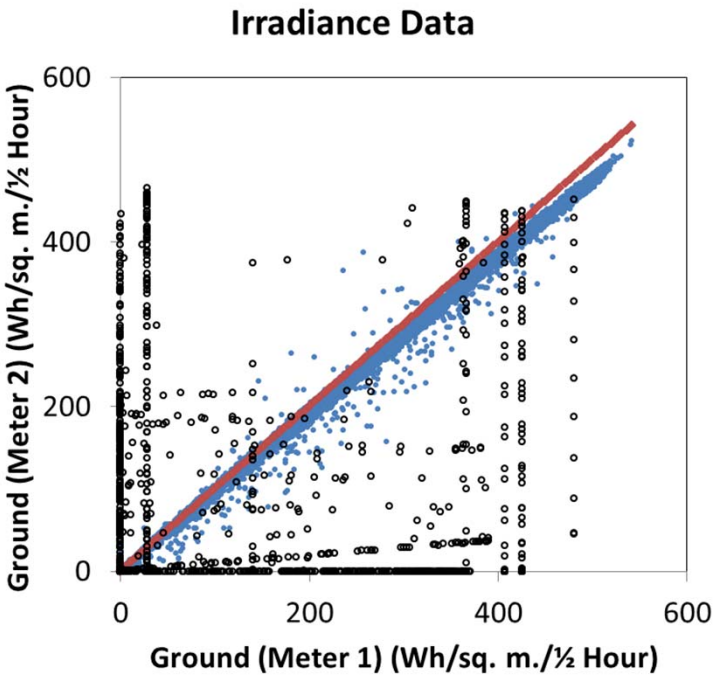
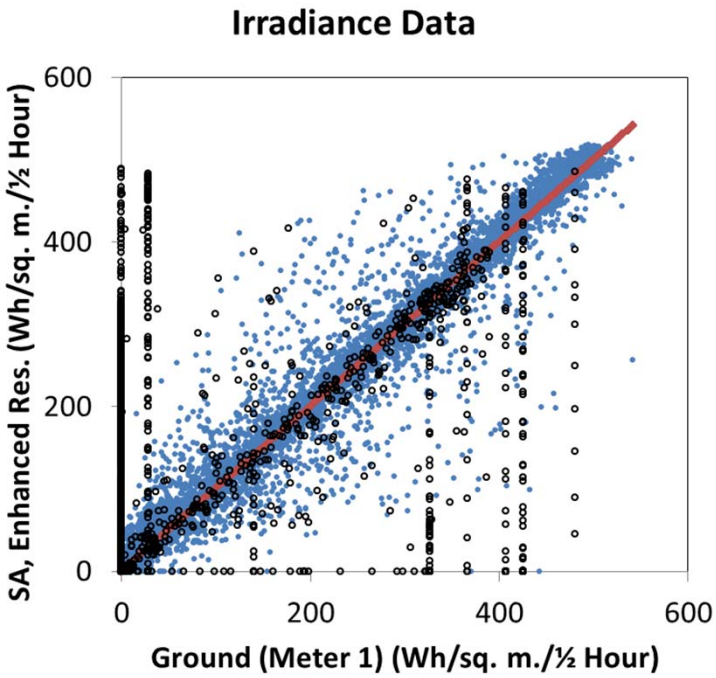
Screen Invalid Data Using 2nd Ground Sensor and SA Enhanced Resolution – Site E





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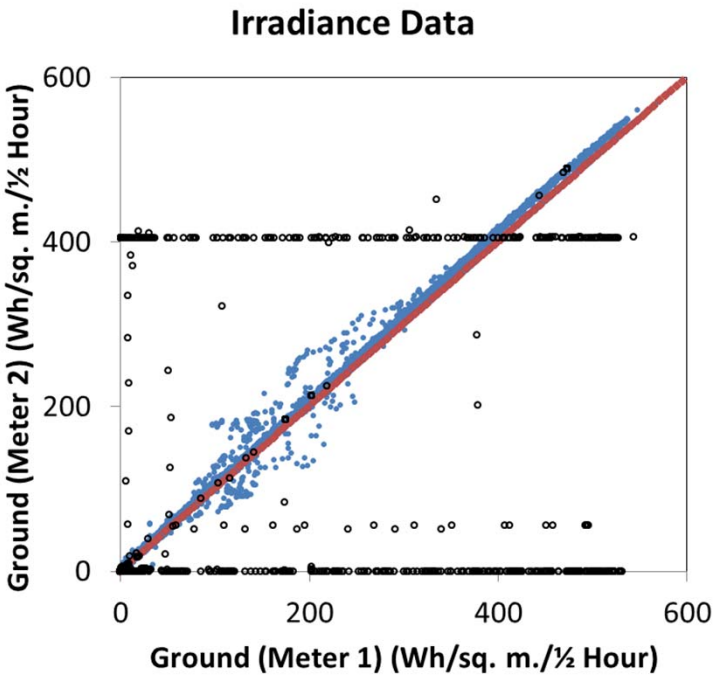
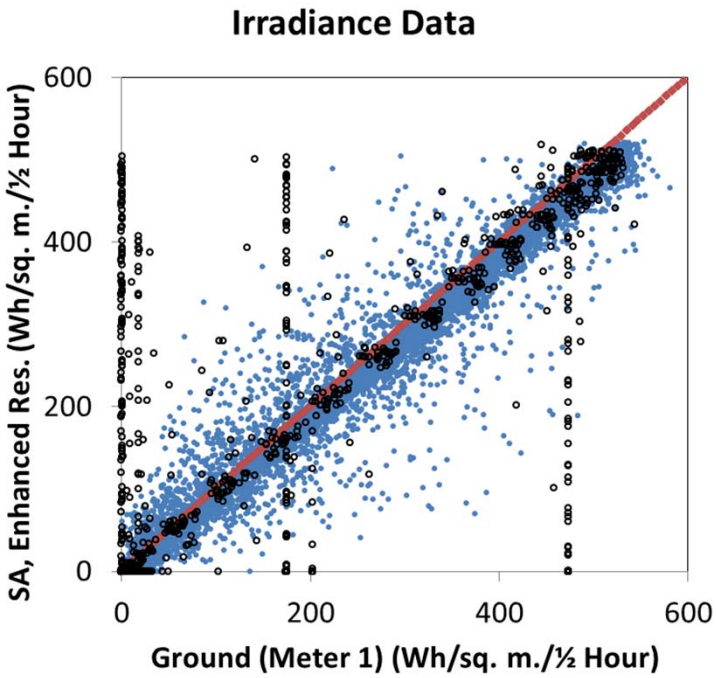
Screen Invalid Data Using 2nd Ground Sensor and SA Enhanced Resolution – Site F





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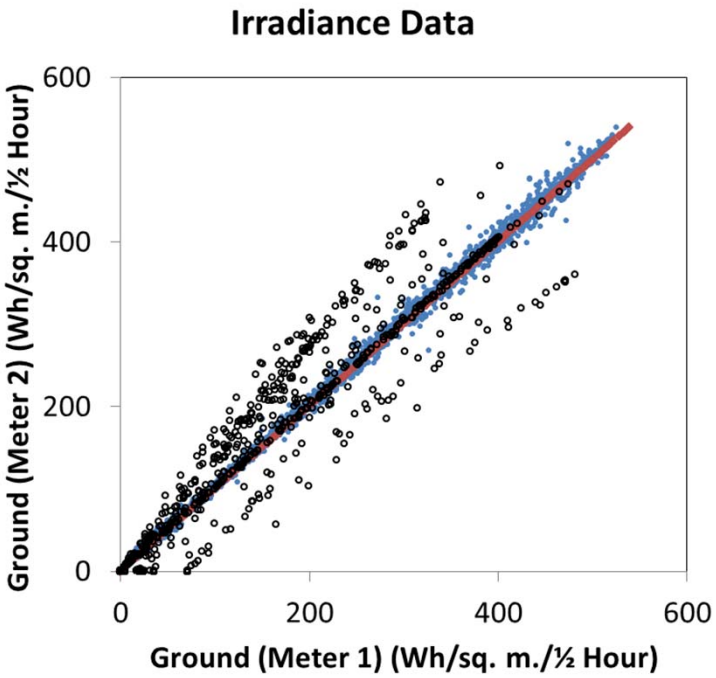
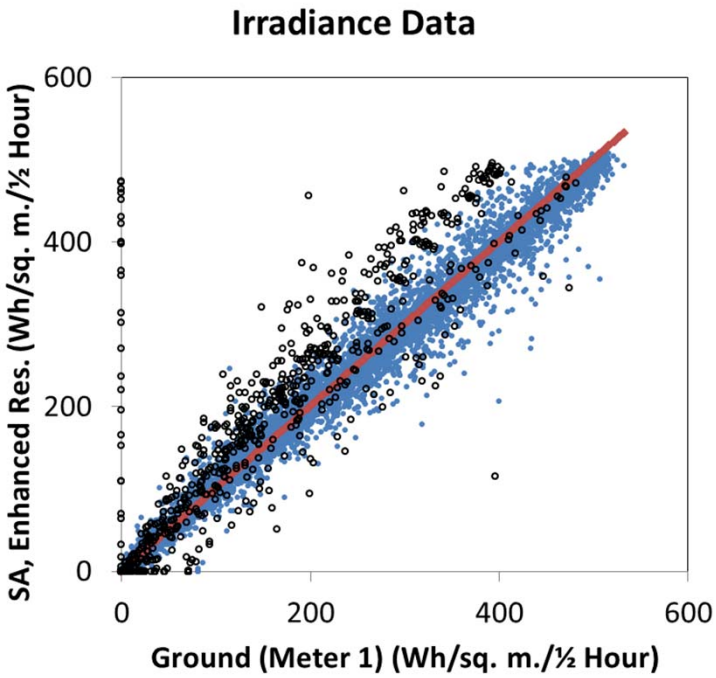
4 Sites Combined





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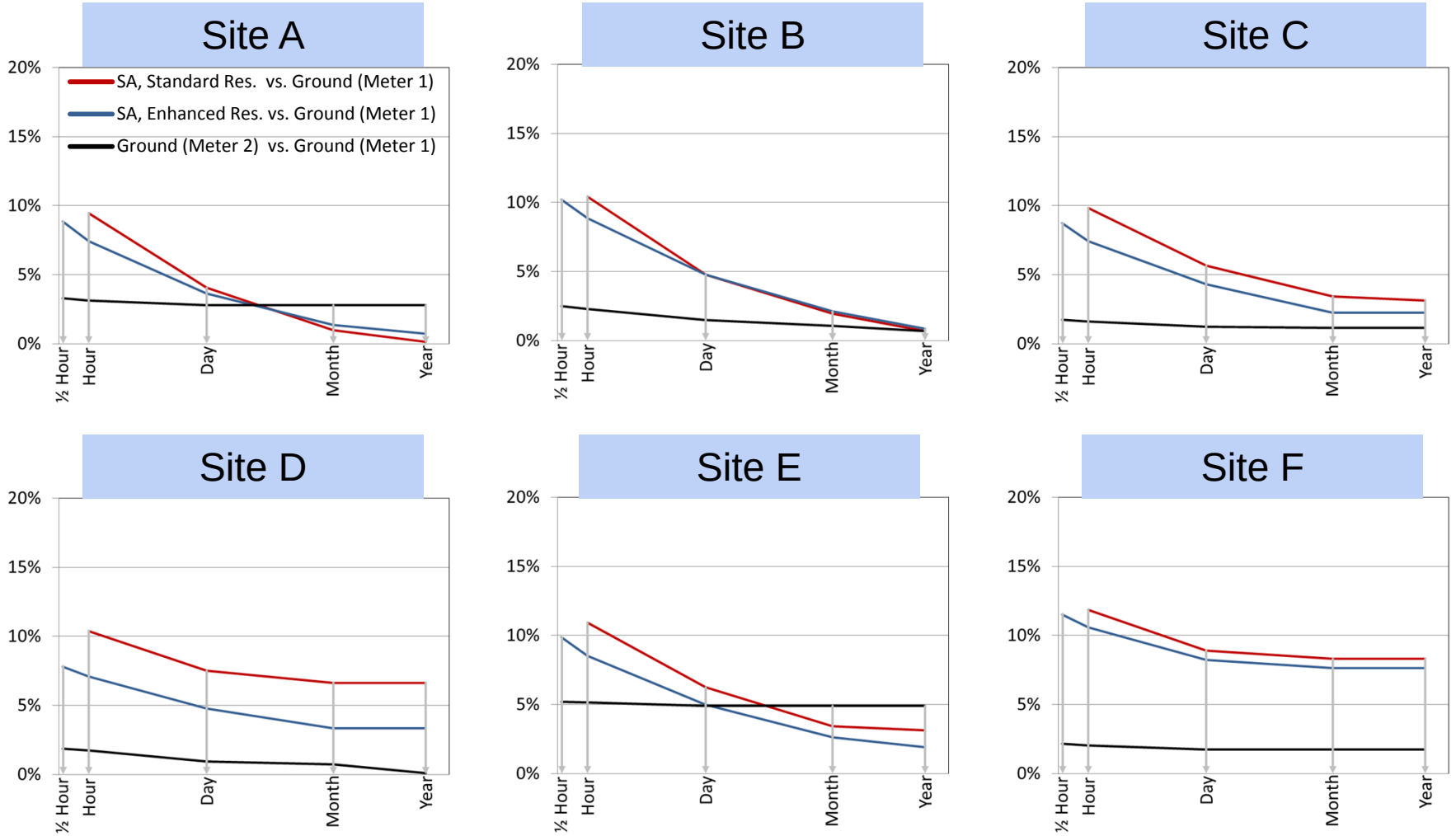
MAE vs. Time Interval (Logarithmic Scale)



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Number of Invalid Data Observations

	Site A	Site B	Site C	Site D	Site E	Site F
SA, Enhanced Res.	1	3	0	5	0	0
SA, Standard Res.	0	0	0	1	0	0
Ground (Meter 1)	513	88	249	175	700	590
Ground (Meter 2)	49	86	249	209	1,099	1,387

17,520 observations available for Ground and SA Enhanced Res.
8,760 observations available for SA Standard Res.

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Results

Mean Absolute Error

		Reference Device: Meter 1					Reference Device: Meter 2				
		½ Hour	Hour	Day	Month	Year	½ Hour	Hour	Day	Month	Year
Site A	SA, Enhanced Res.	8.9%	7.4%	3.6%	1.3%	0.7%	9.5%	8.2%	4.7%	3.4%	3.4%
	SA, Standard Res.		9.4%	4.0%	1.0%	0.1%		9.9%	4.9%	2.9%	2.9%
	Ground (Meter 1 or 2)	3.3%	3.1%	2.8%	2.8%	2.8%	3.2%	3.0%	2.7%	2.7%	2.7%
	Ground (w/ Invalid Data)	3.9%	3.6%	3.2%	2.6%	2.5%	7.0%	6.9%	6.1%	5.4%	4.1%
Site B	SA, Enhanced Res.	10.2%	8.8%	4.8%	2.1%	0.8%	10.3%	8.9%	5.1%	2.5%	1.5%
	SA, Standard Res.		10.4%	4.8%	2.0%	0.7%		10.5%	5.1%	2.3%	1.4%
	Ground (Meter 1 or 2)	2.5%	2.3%	1.5%	1.1%	0.7%	2.5%	2.3%	1.5%	1.1%	0.7%
	Ground (w/ Invalid Data)	3.3%	3.1%	2.3%	1.6%	0.1%	3.3%	3.1%	2.3%	1.7%	1.4%
Site C	SA, Enhanced Res.	8.9%	7.6%	4.5%	2.3%	2.3%	9.5%	8.2%	5.2%	3.4%	3.4%
	SA, Standard Res.		10.0%	5.8%	3.5%	3.2%		10.6%	6.6%	4.4%	4.3%
	Ground (Meter 1 or 2)	1.7%	1.6%	1.2%	1.2%	1.2%	1.7%	1.6%	1.2%	1.1%	1.1%
	Ground (w/ Invalid Data)	4.1%	3.9%	3.1%	2.5%	0.5%	4.0%	3.9%	3.1%	3.0%	2.8%
Site D	SA, Enhanced Res.	7.8%	7.0%	4.8%	3.3%	3.3%	7.8%	7.1%	4.8%	3.4%	3.3%
	SA, Standard Res.		10.3%	7.5%	6.6%	6.6%		10.4%	7.6%	6.6%	6.5%
	Ground (Meter 1 or 2)	1.9%	1.8%	0.9%	0.7%	0.1%	1.9%	1.8%	0.9%	0.7%	0.1%
	Ground (w/ Invalid Data)	3.5%	3.4%	2.6%	1.9%	1.7%	3.6%	3.5%	2.6%	2.0%	1.7%
Site E	SA, Enhanced Res.	9.6%	8.4%	5.0%	2.8%	2.2%	12.3%	11.1%	8.3%	7.4%	7.4%
	SA, Standard Res.		10.7%	6.1%	3.7%	3.4%		13.8%	9.5%	8.7%	8.7%
	Ground (Meter 1 or 2)	5.2%	5.1%	4.9%	4.9%	4.9%	5.5%	5.4%	5.2%	5.1%	5.1%
Site F	SA, Enhanced Res.	11.8%	10.9%	8.5%	7.9%	7.9%	12.8%	11.9%	9.8%	9.5%	9.5%
	SA, Standard Res.		12.2%	9.3%	8.6%	8.6%		13.2%	10.6%	10.2%	10.2%
	Ground (Meter 1 or 2)	2.2%	2.0%	1.7%	1.7%	1.7%	2.1%	2.0%	1.7%	1.7%	1.7%

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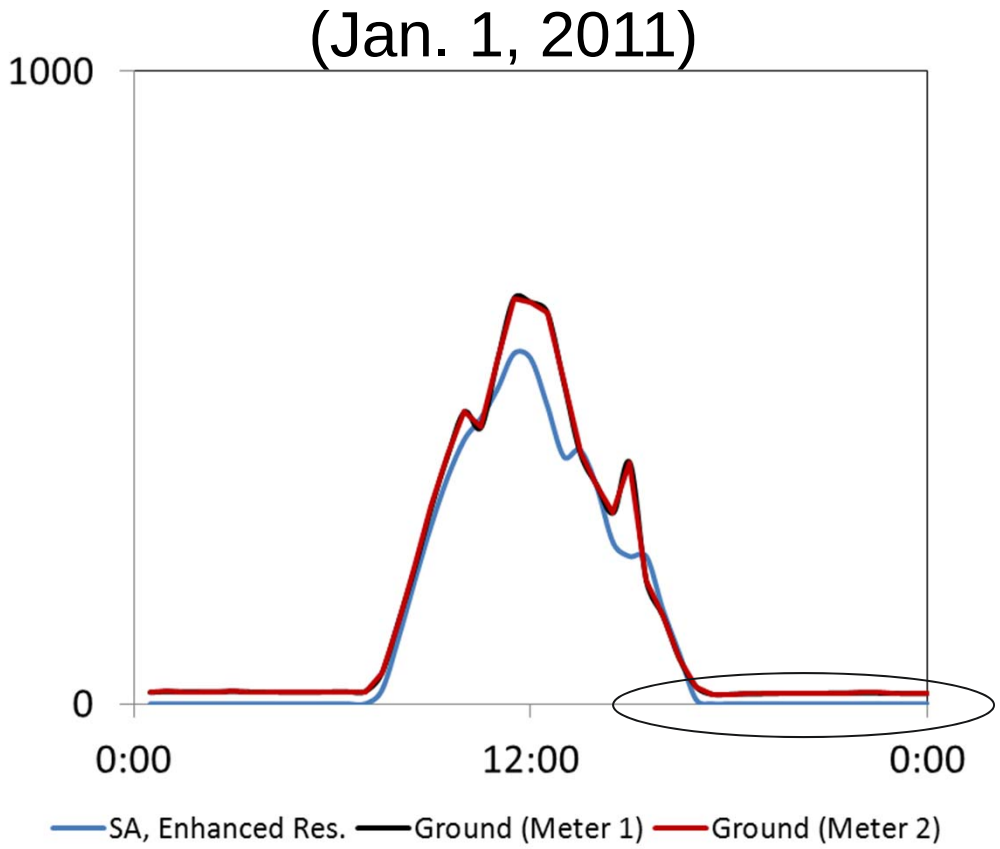
Site F – Calibration Error Across All Hours



Could be a night time diffuse offset error (unique to specific pyranometers – artifact of way instrument is designed).

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Eliminate 2 locations

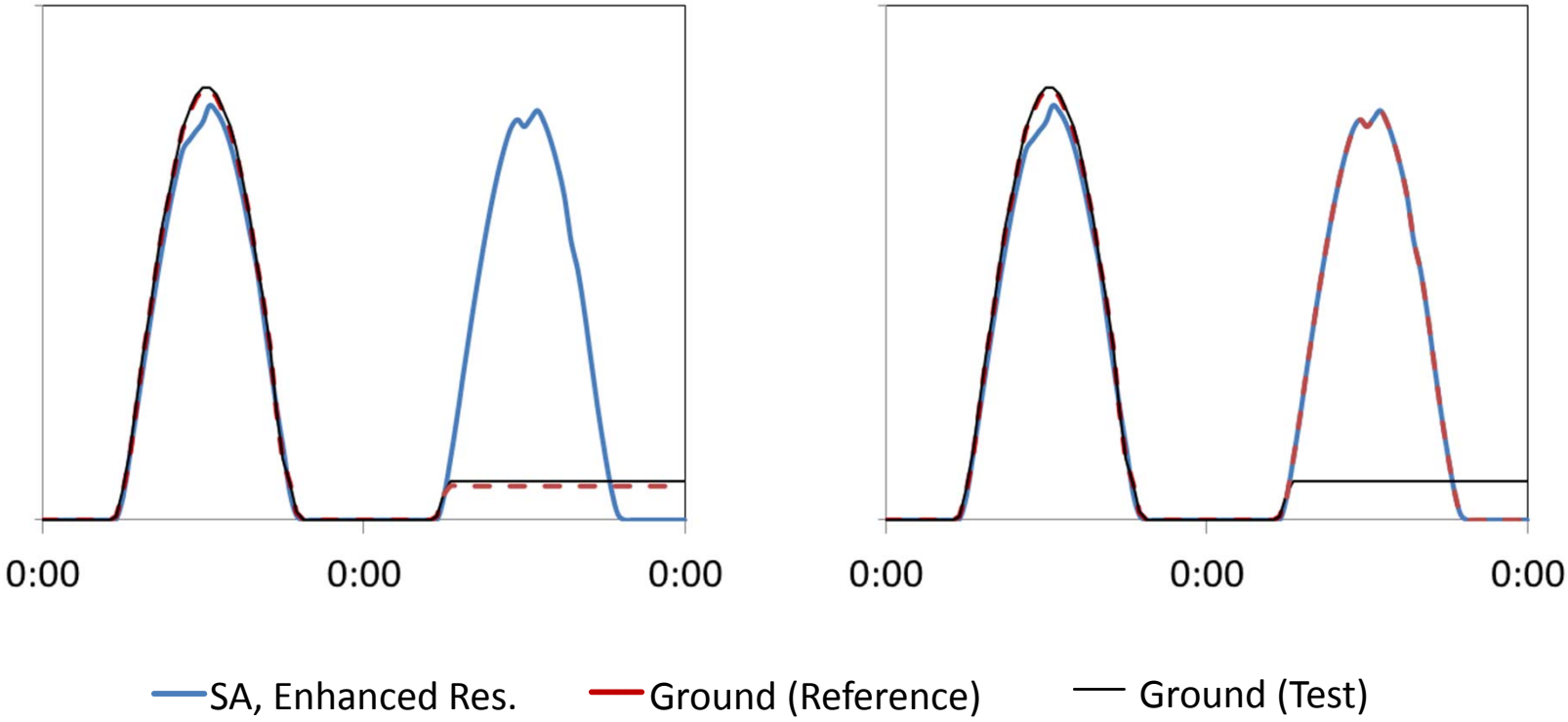
- Site E is missing more than a month of data during the first part of the year. More important, there is a 5% difference between the two sensors. Site E is eliminated.
- The two sensors at Site F calibrate well with each other well but record positive irradiance values at night throughout the year (average of 11 W/sq. m. at night). Site F is eliminated.

But There are 2 Types of Errors

- Two types of errors
  - Measurement error
  - Invalid data

- Approach to quantify invalid data errors
  - Fill in invalid ground reference data with SA Enhanced Resolution data to approximate complete, accurate data set
  - Include all data in error analysis of 2nd ground sensor

Method Example (Site C, May 1, 2011)



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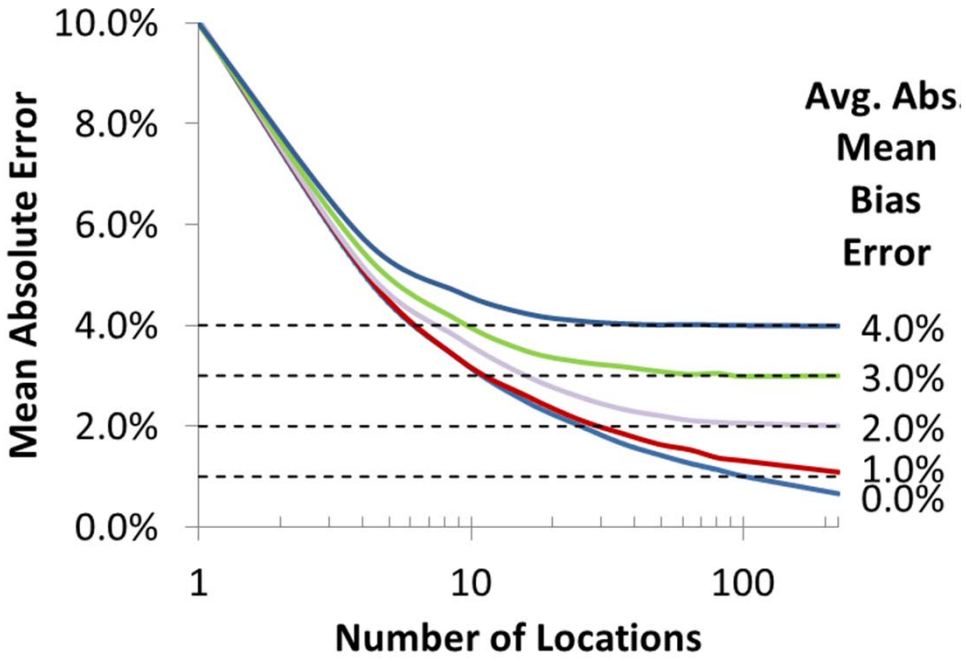
Fleet Prediction Model Based on Random Normal Variables w/ Bias Error



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