Combining Satellite and Ground Data: What Works & What Doesn’t

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2015 NREL PV Solar Resource Workshop
Feb 27th, 2015

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Acknowledgements

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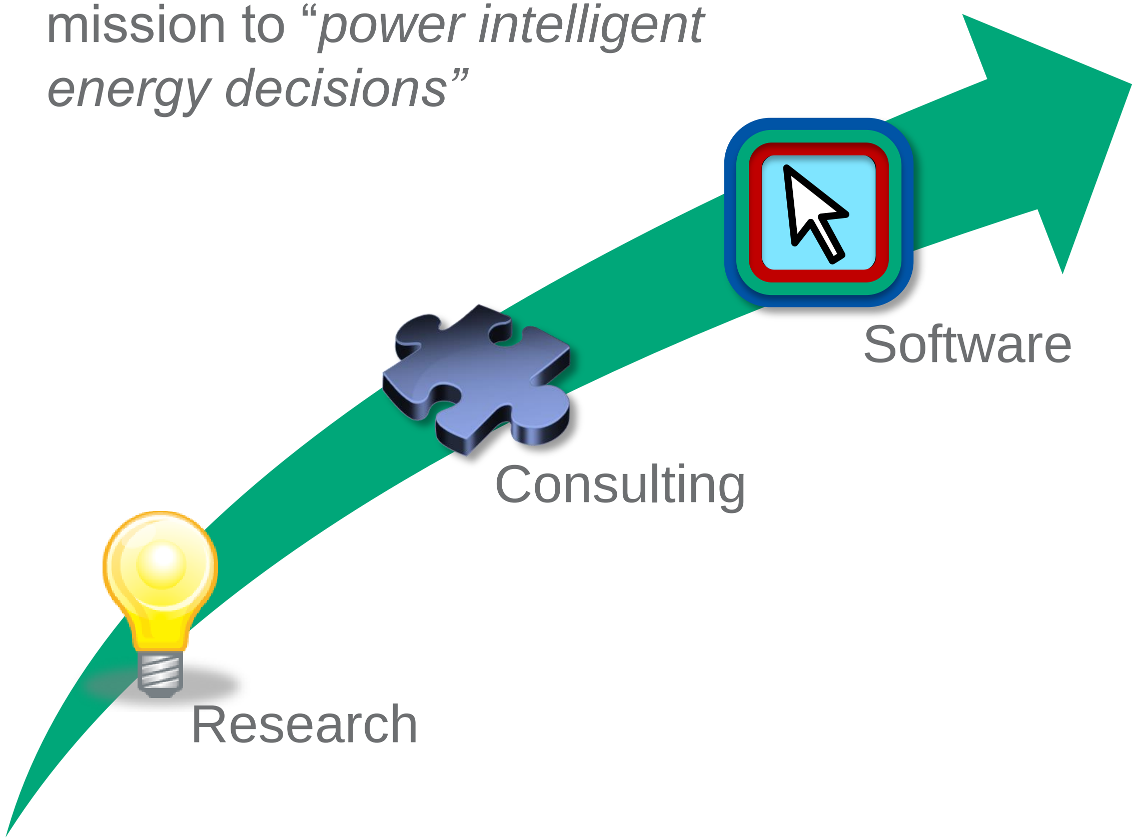
Founded in 1998 with the mission to "*power intelligent energy decisions*"



SOLAR PREDICTION

Most widely used solar resource database

PROGRAM OPTIMIZATION

~6.0 GW of renewable incentives processed

ENERGY VALUATION

>30 million solar estimations performed

Today’s Discussion

- What Data Should I Use?
- Ingredients Needed for High-Accuracy Solar Resource Assessment
- Optimizing Ground & Satellite Data
  - Case study
  - What works and what doesn’t
- Conclusions

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Which Dataset Should I Use?
Conclusions from 2014 Sandia Conference

Use Cases	TMY/ TGY	Ground	Satellite
Initial Estimates	✓		
Siting & Financing of Utility Scale PV Systems		✓	✓
Production Guarantees for DG Lease Funds			✓
Real-time Monitoring		✓	✓

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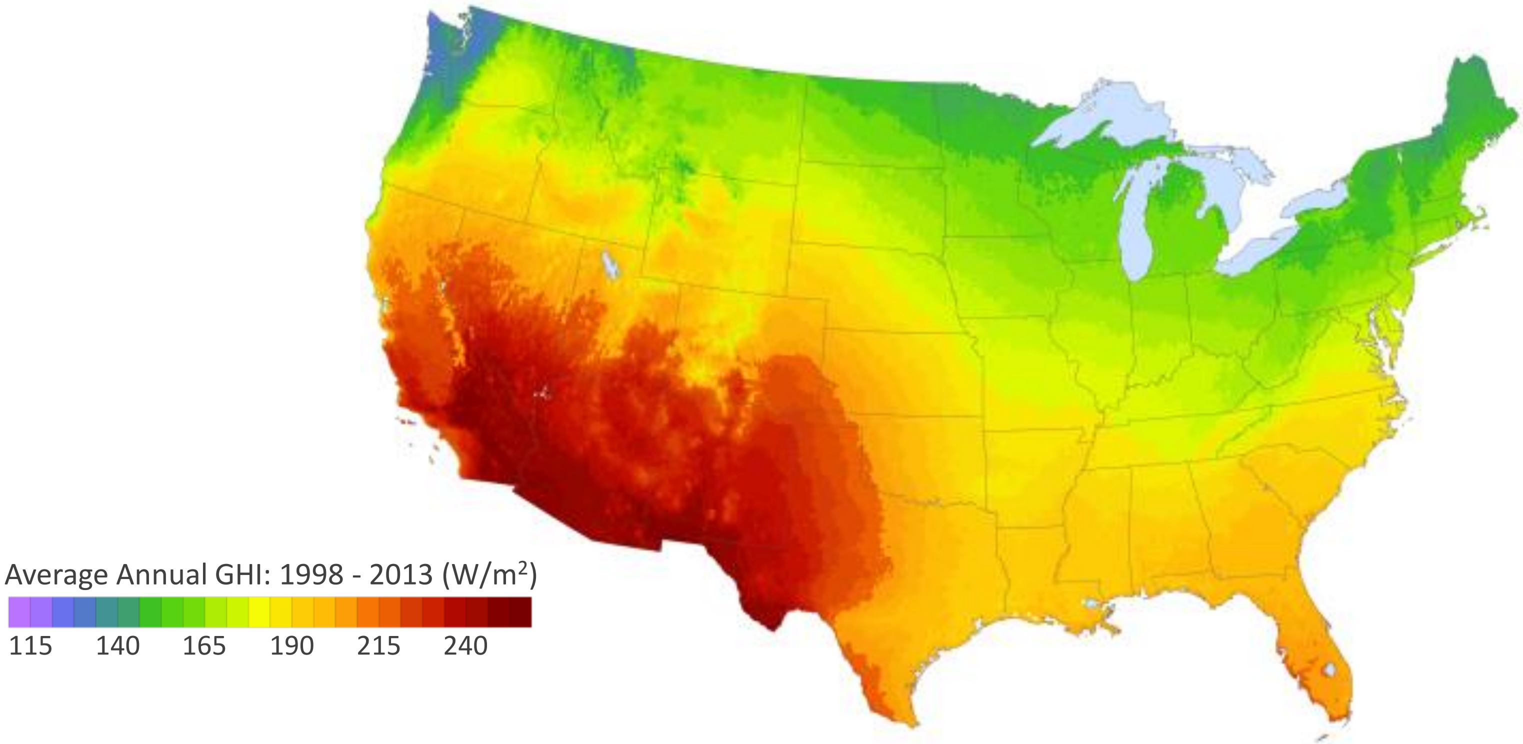
Ingredients Needed for a Dependable Solar Resource Assessment

- PV system details, near/far shading, soiling characteristics, etc. (site details)
- Solar resource (fuel)
- Ancillary inputs (air temperature, wind speed, precipitation (rain/snow), humidity, etc.)

Solar Resource: Foundation for All PV System Simulations



Satellite-based solar irradiance models

Advantages:

- Continuous geographical coverage (1 km resolution)
- Temporally solid and consistent (17+ years)
- Up to 15 minute frequency observations
- Site-specific historical weather observations

Limitations:

- Lower accuracy (than high quality ground observations)

Value of Ground-based Solar Resource Monitoring

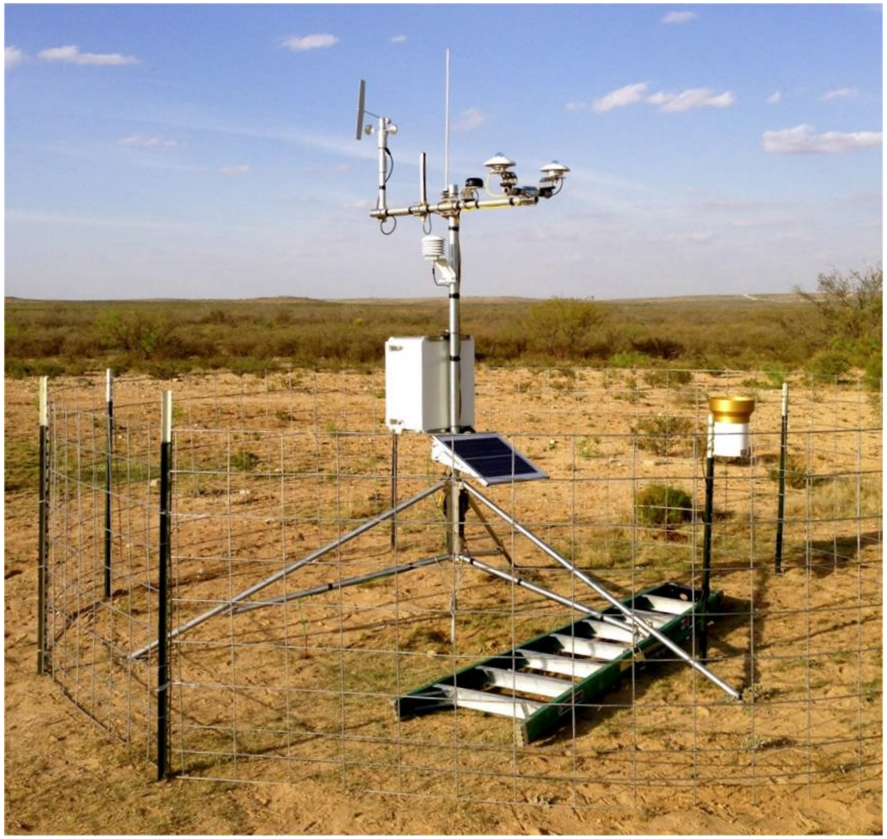


Image courtesy of GroundWork Renewables, Inc.

- High accuracy if properly maintained (dust, frost, snow, birds, event logging, etc.)
- Necessary to understand local variability effects
- Requires meticulous data QC
- Ground truth for tuning process
- Have to place into long term reference frame for proper resource context!

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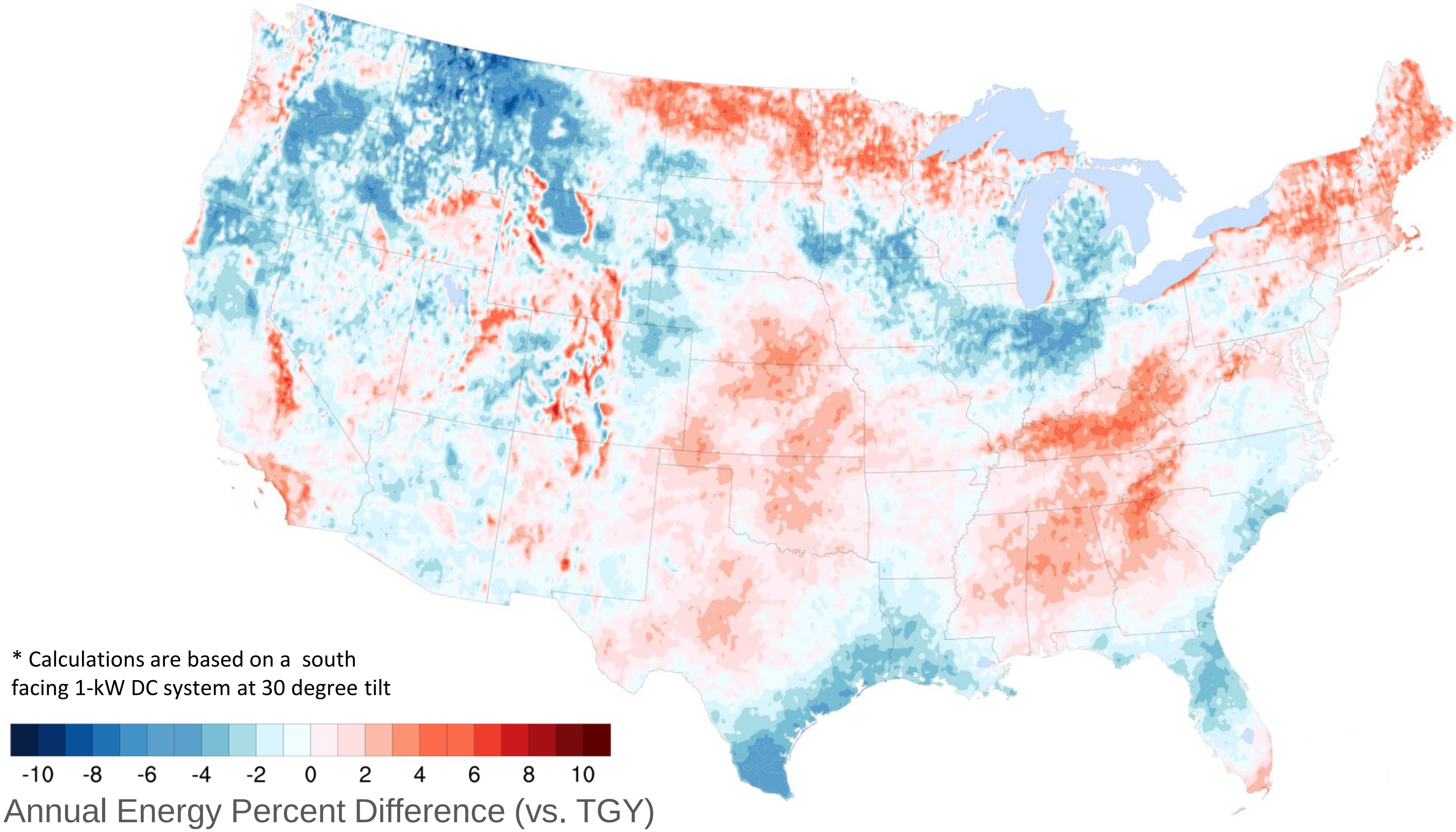
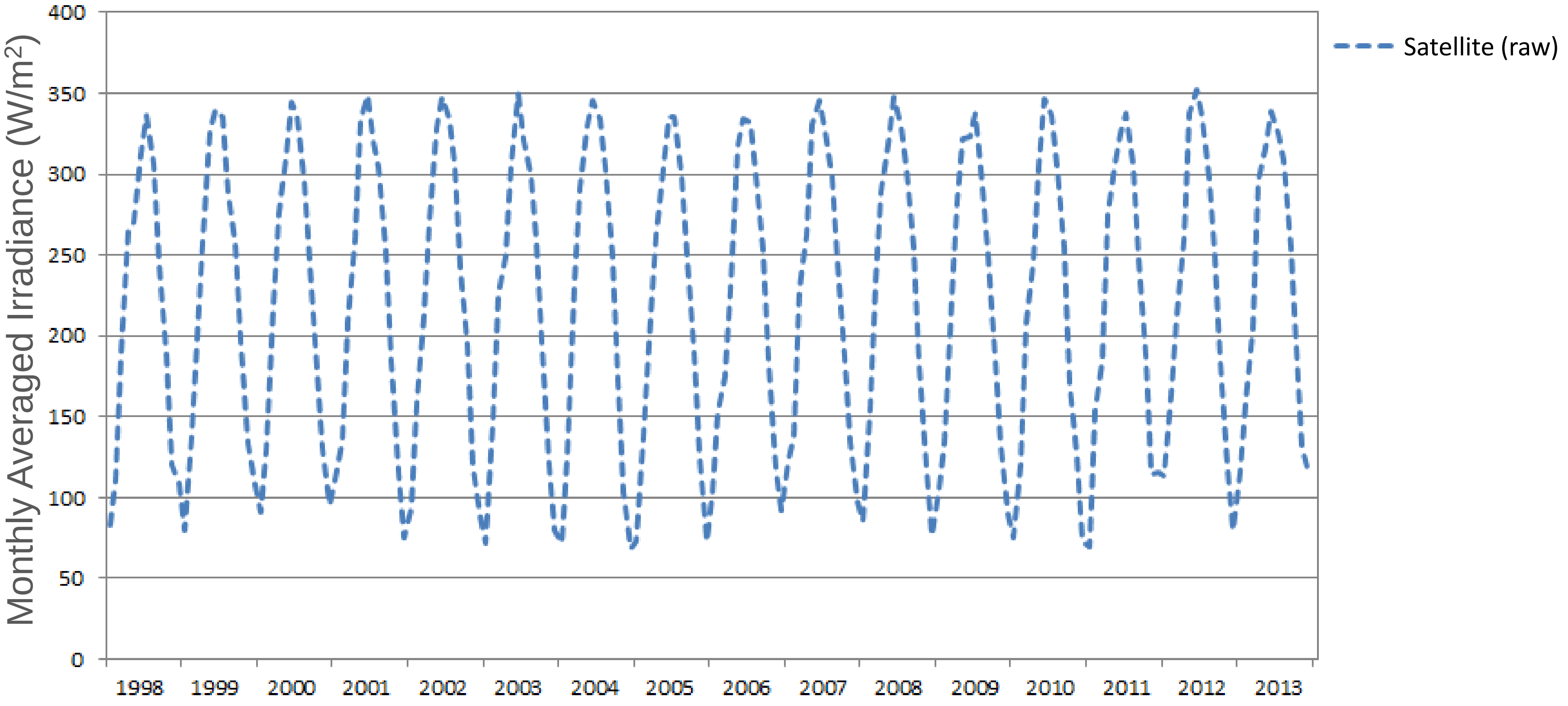
2014 Annual PV Production Variance*



* Calculations are based on a south facing 1-kW DC system at 30 degree tilt

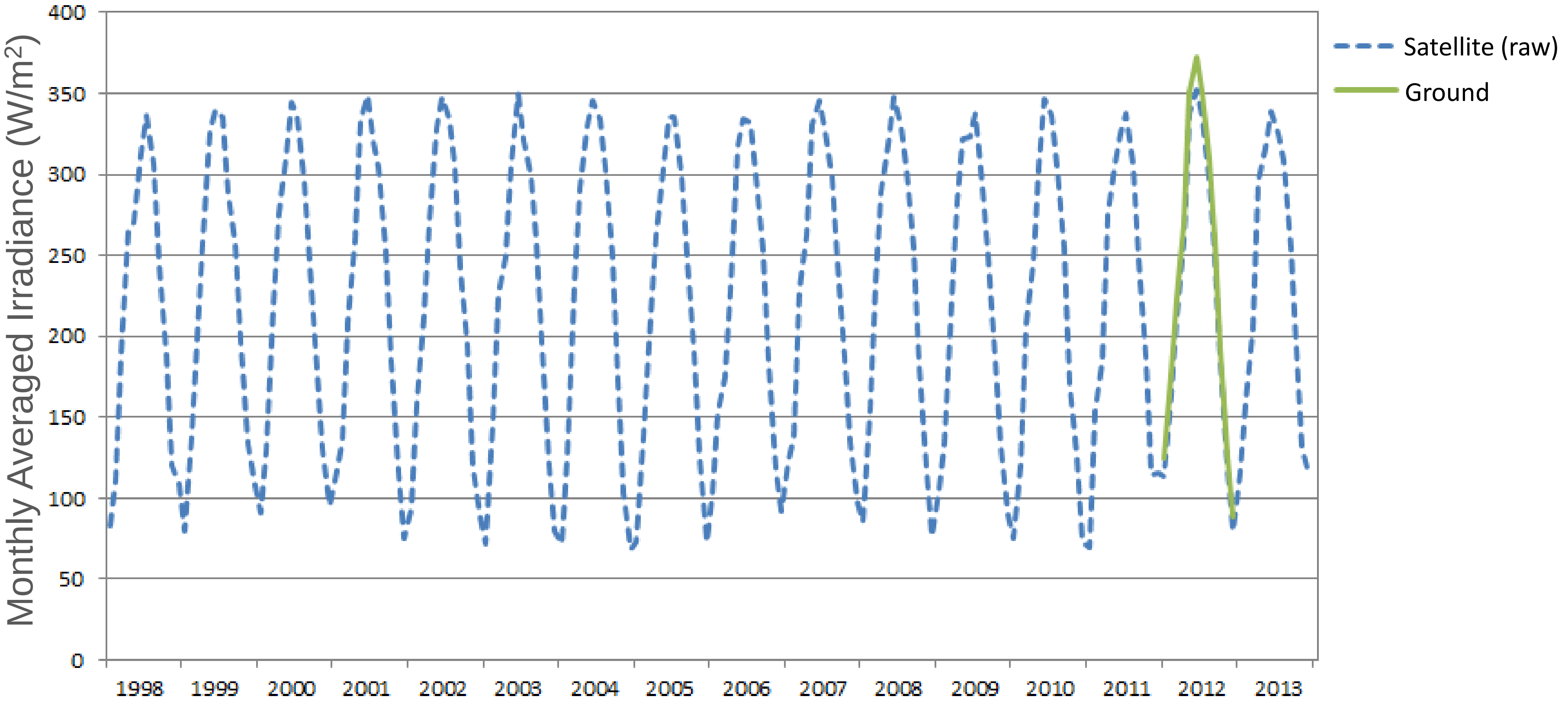
Need to place on-site measurements into long term reference frame due to year-to-year variability

Low-Uncertainty, Long-term Solar Resource Dataset



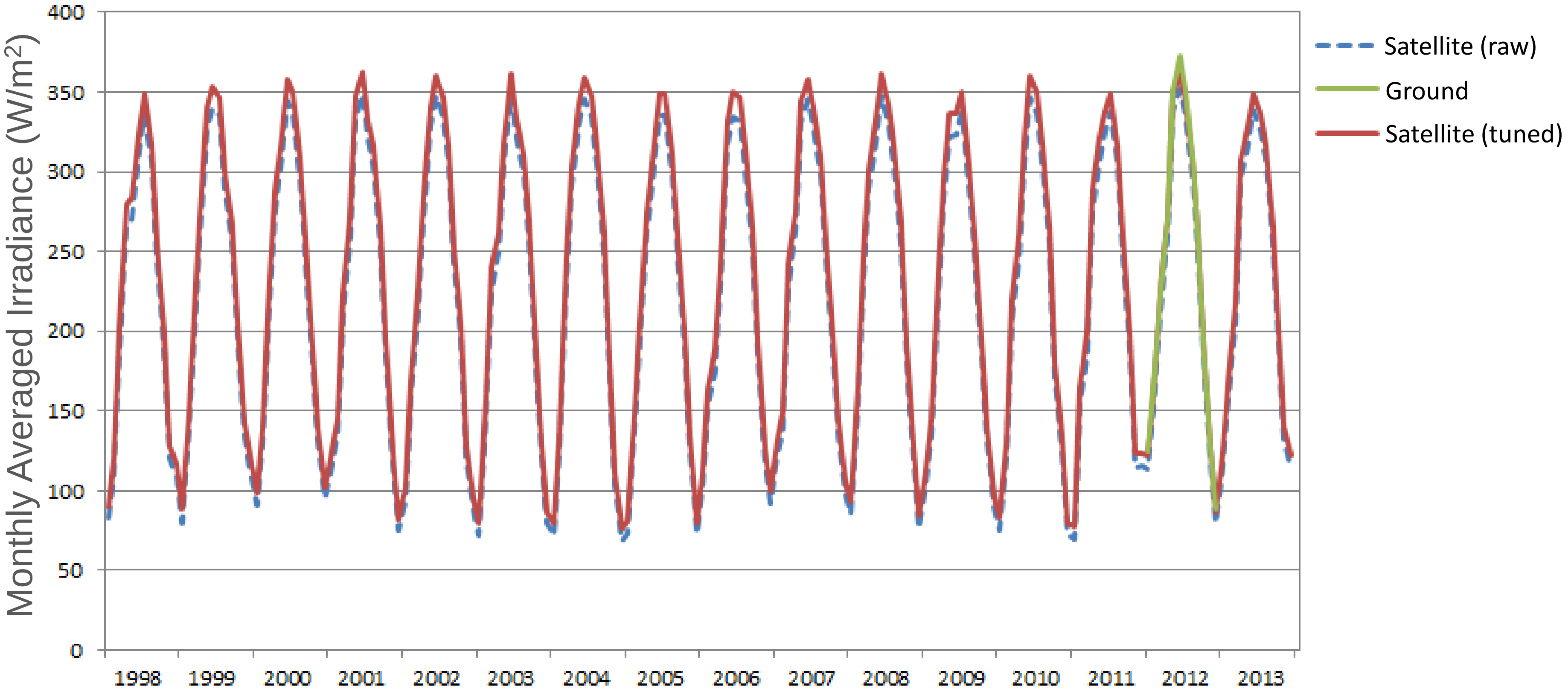
Satellite data

Low-Uncertainty, Long-term Solar Resource Dataset



Satellite data + quality ground data

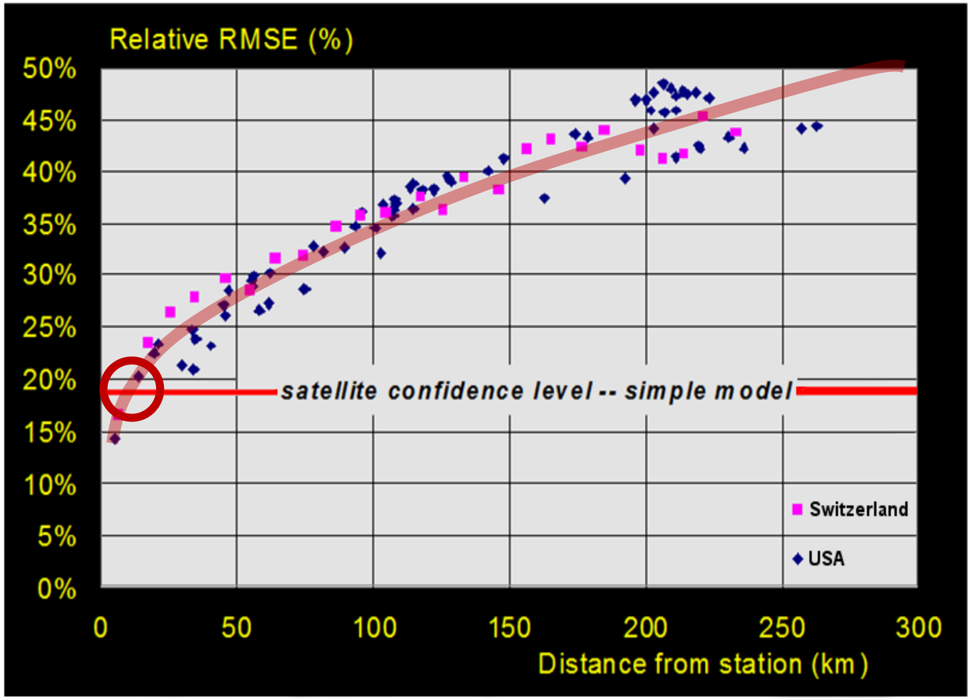
Low-Uncertainty, Long-term Solar Resource Dataset



Satellite data + quality ground data + intelligent tuning methodology
= most reliable long term solar resource

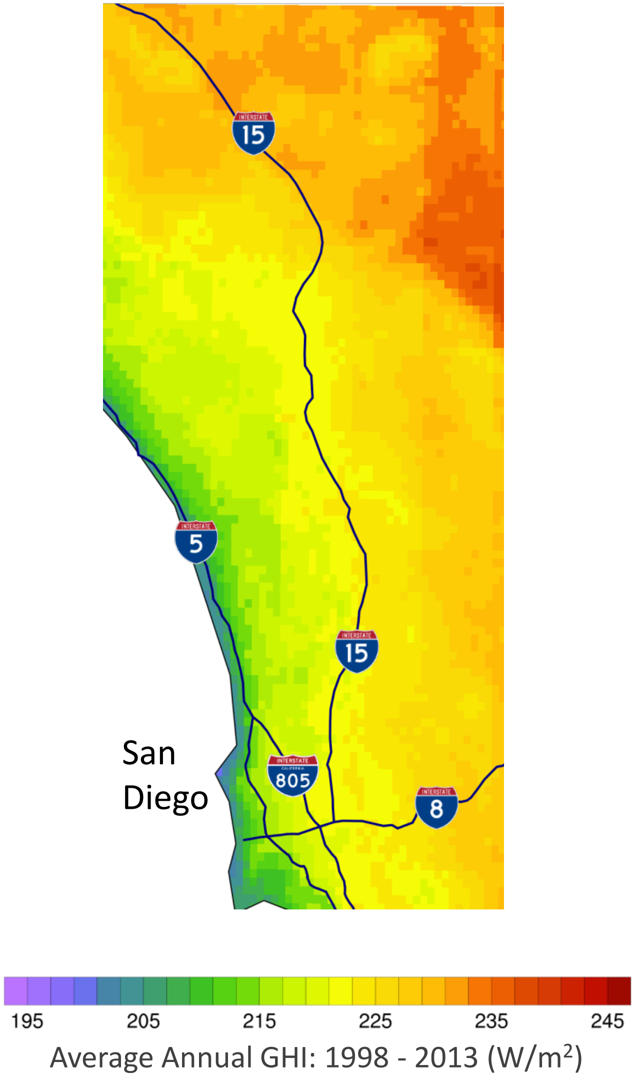
(P50, P90, inter-annual variability, etc.)

Ground Data Usefulness Degrades with Distance



Ground data are suitable at distances up to 10-25 km from project site (can be <5 km in regions with variable topography)

1 km SA TGY data



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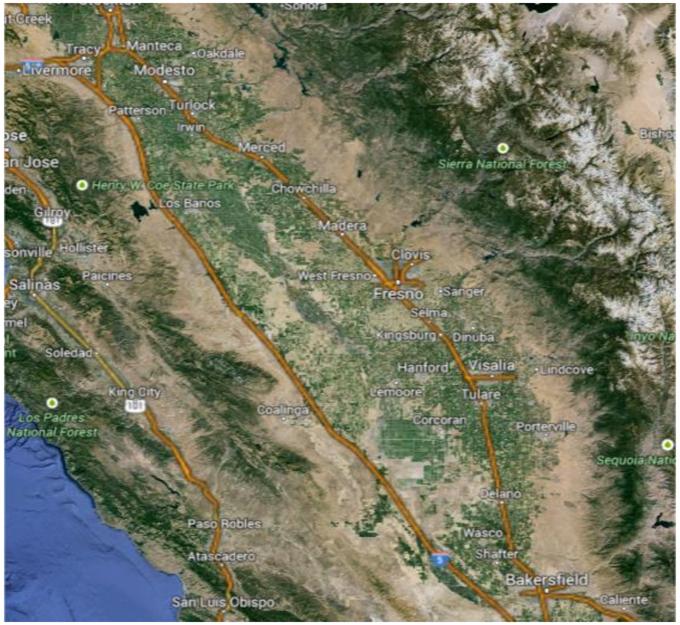
Case Study: PV Prospecting Site

Arid Desert Climate Site



High-Quality Ground Data (12 months)

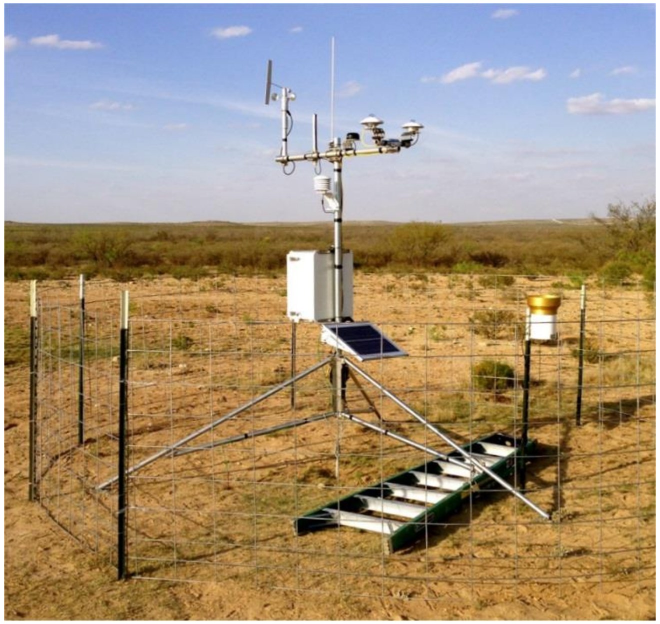


Image courtesy of GroundWork Renewables, Inc.

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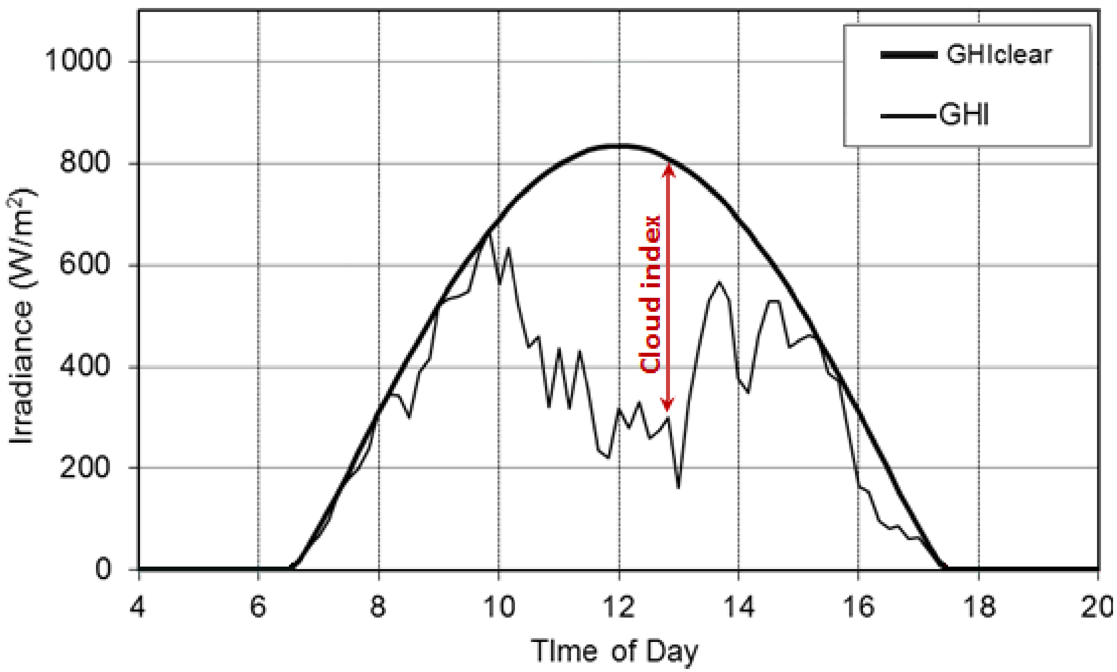
Understanding Differences: Satellite and Ground Datasets

Sources of satellite-model and ground irradiance differences:

- Clear sky bias (AOD, etc.)
- Seasonal (winter v. spring, etc.)
- Cloudy sky measurement error (satellite/ground mismatch, etc.)

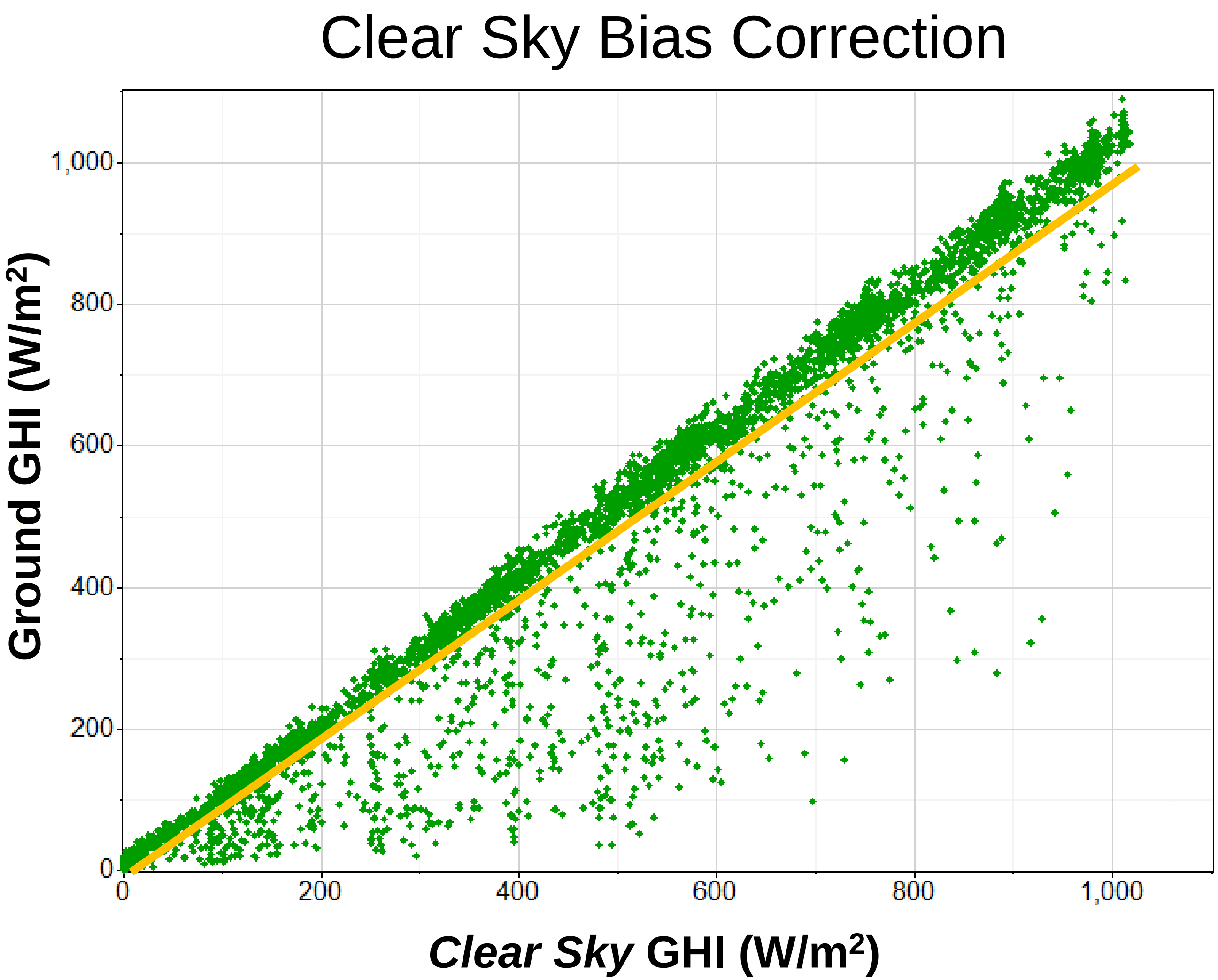
Other considerations:

- Irradiance rebalancing
- Ancillary data



<u>Differences need to be targeted individually during the tuning process</u>

Tuning Satellite Data with Ground Observations: Clear Sky Corrections



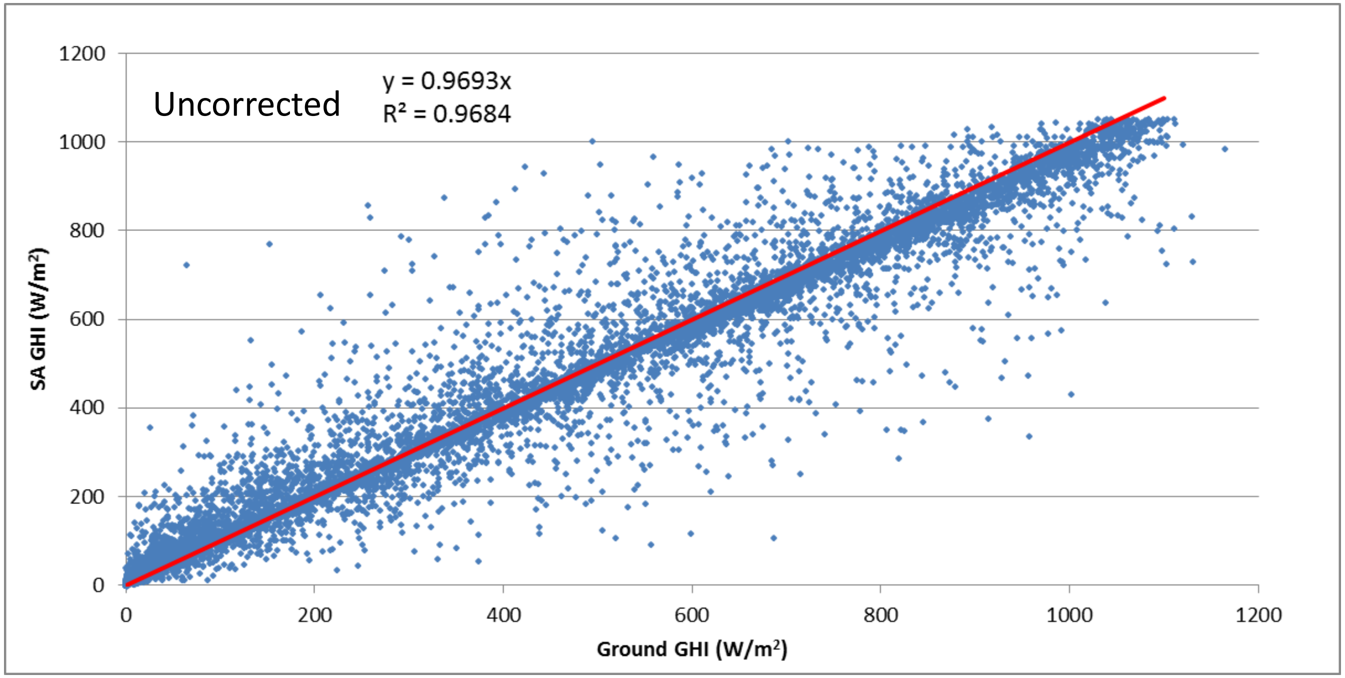
Overall Bias: 4.6%
Clear Sky Bias: 4.1%

Non targeted bias corrections would over correct in this situation

Addressing Clear Sky Bias Only

High quality ground data versus SolarAnywhere ("SA") satellite data

	rMBE
Overall	-0.59%
Clear Sky	-2.71%



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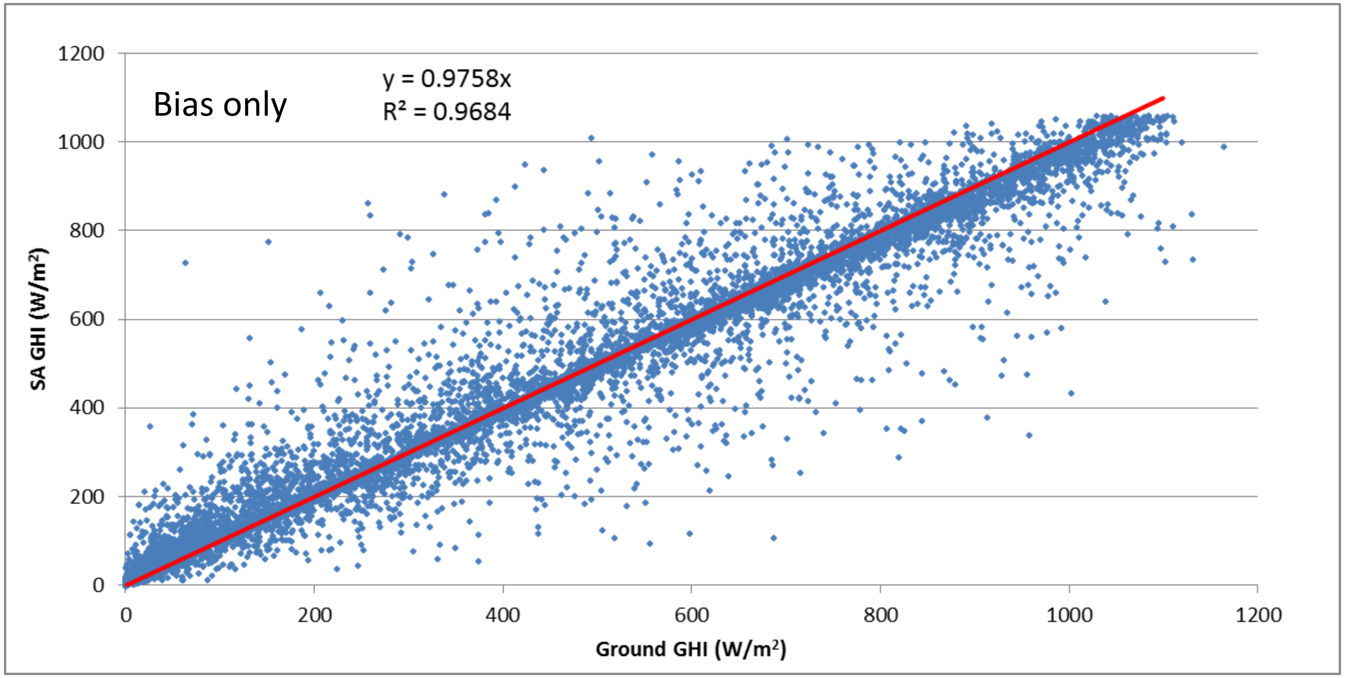

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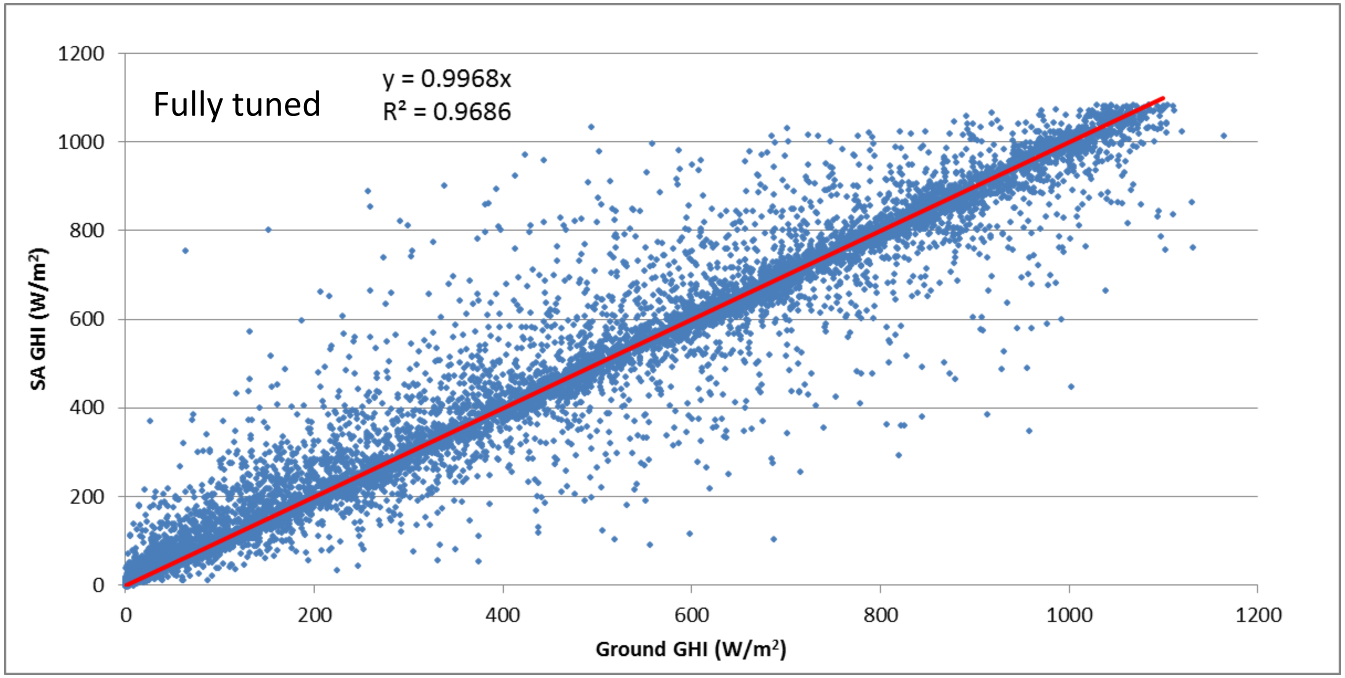
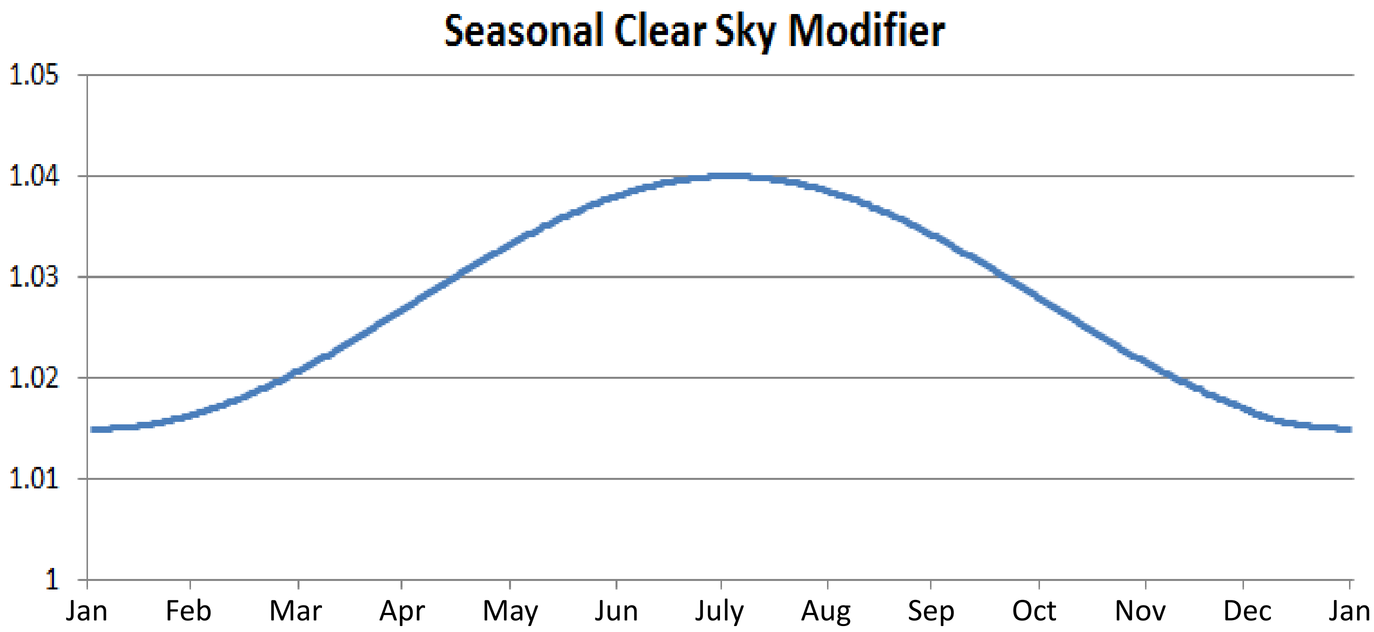


Targeting clear sky conditions addresses intrinsic measurement source errors

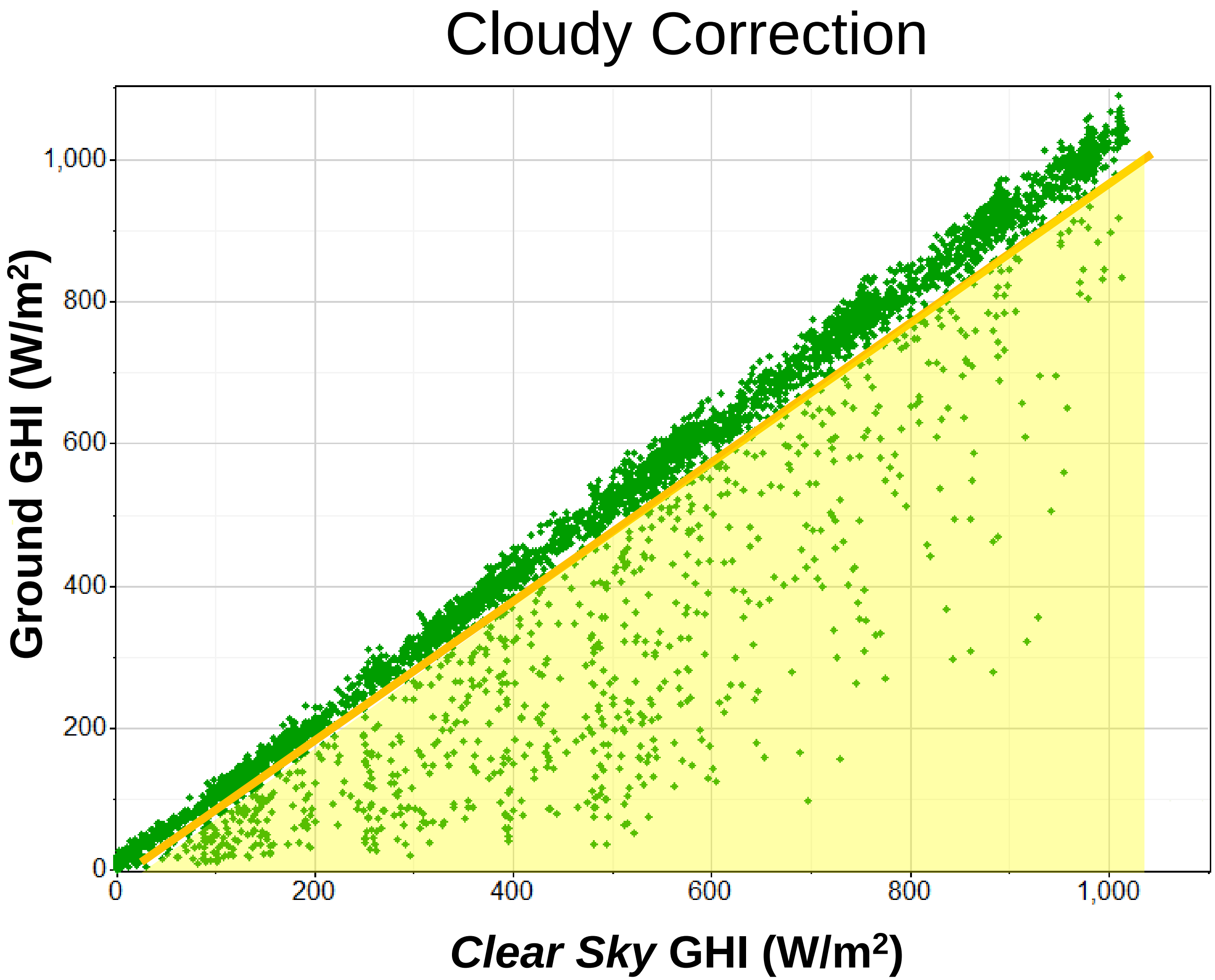
Tuning Satellite Data with Ground Observations: Seasonal Clear Sky Corrections

Can correct for seasonal clear sky biases with year+ of ground data observations



Seasonal impacts occur over the full year

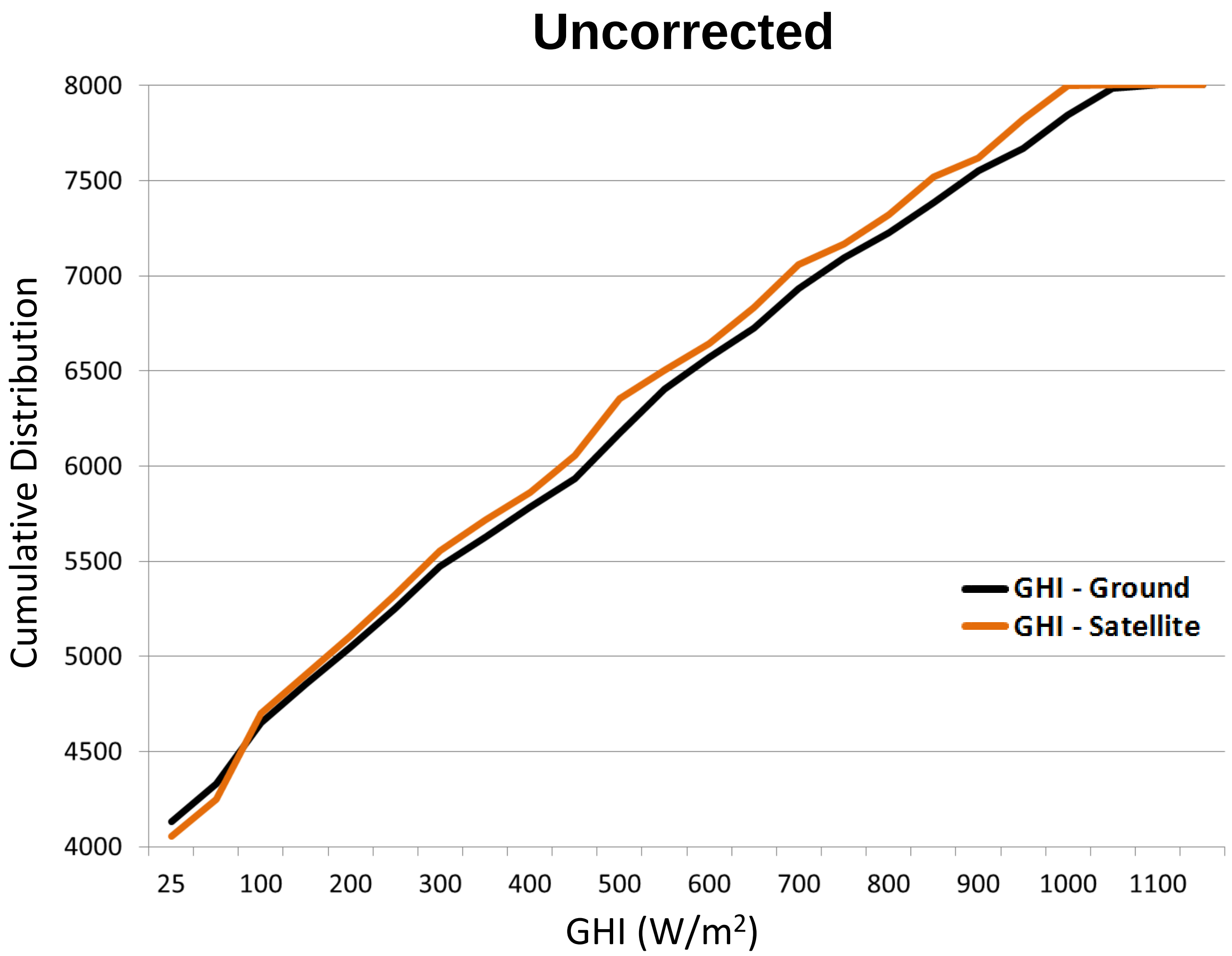
Tuning Satellite Data with Ground Observations: Cloud Measurement Error



Overall Bias: 4.6%
Clear Sky Bias: 4.1%

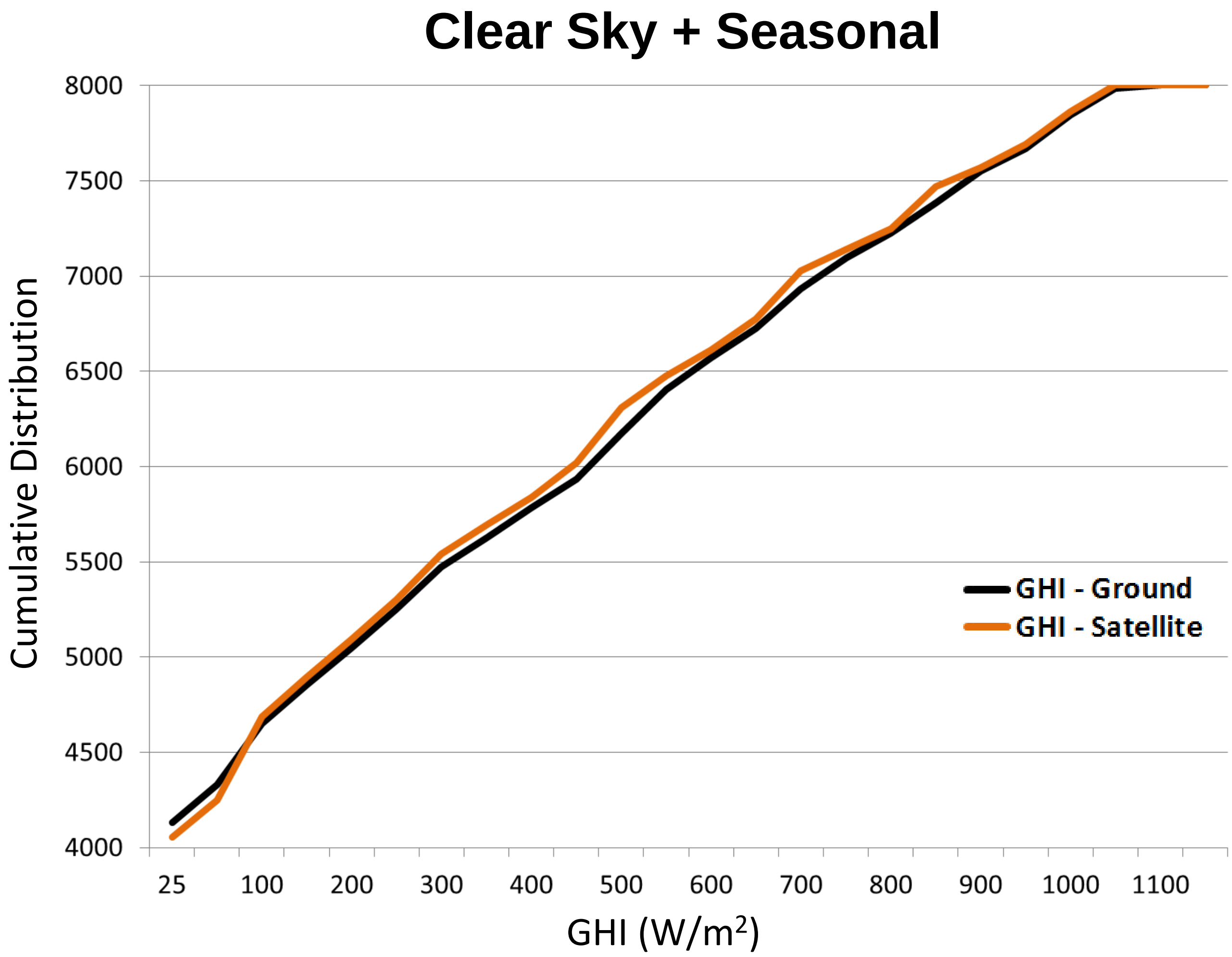
How do we target bias in the cloud measurements?

Tuning Satellite Data with Ground Observations: Cloud Measurement Error



Overall Goal: Minimize error (RMSE and KSI)

Tuning Satellite Data with Ground Observations: Cloud Measurement Error



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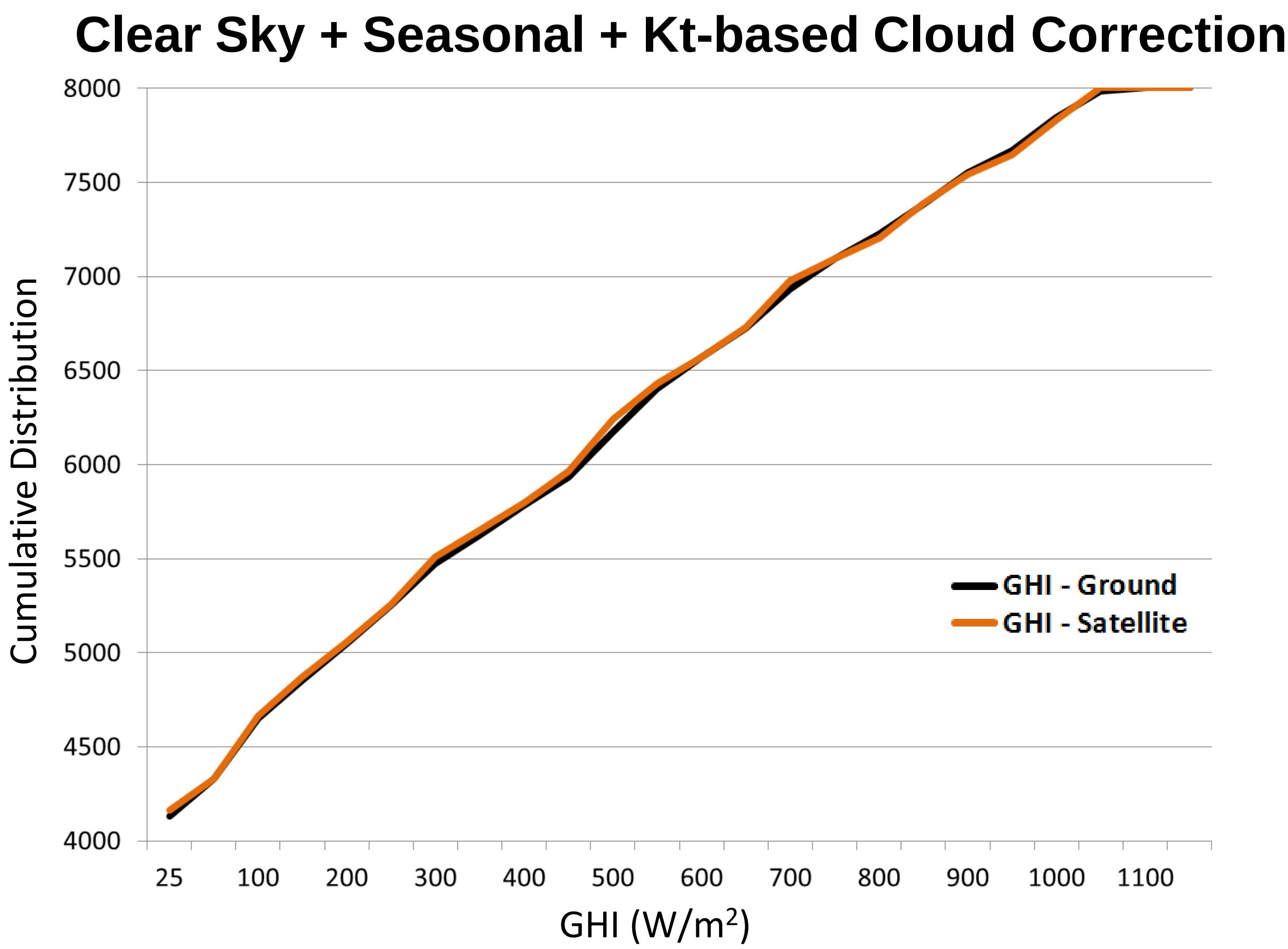
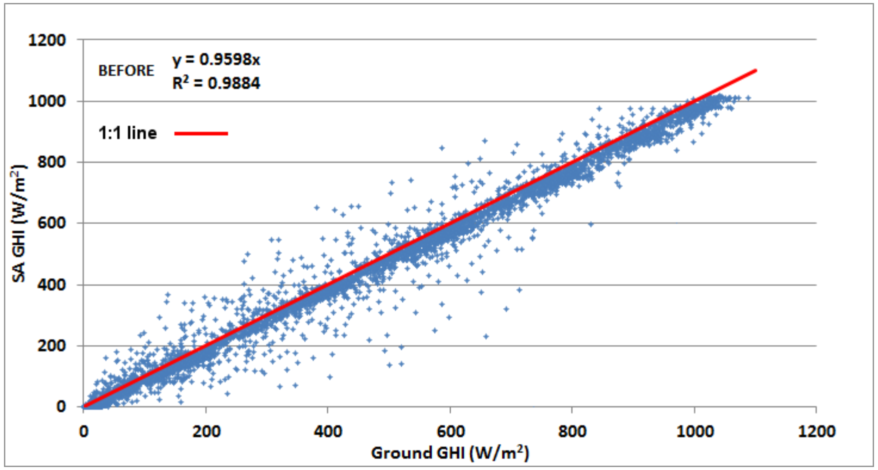
Tuning Satellite Data with Ground Observations: Cloud Measurement Error



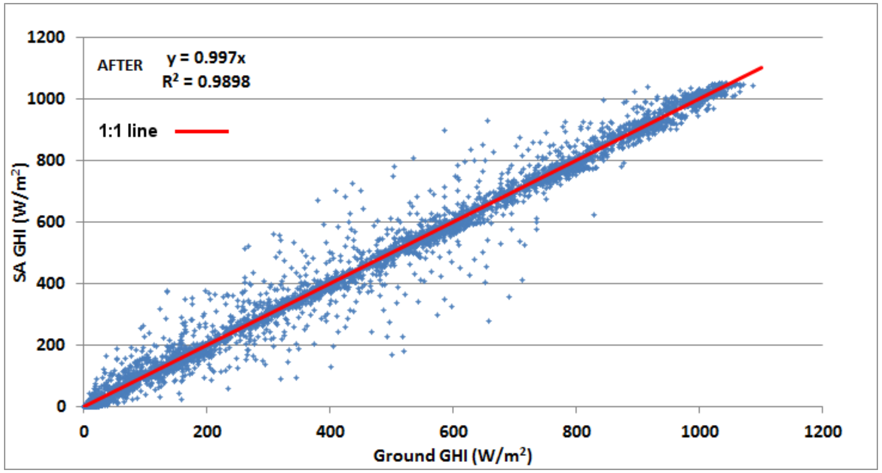
Overall Goal: Minimize error (RMSE and KSI)

Tuning Satellite Data with Ground Observations: Case Study Results

Ground/Satellite Tuning Results



Original Data

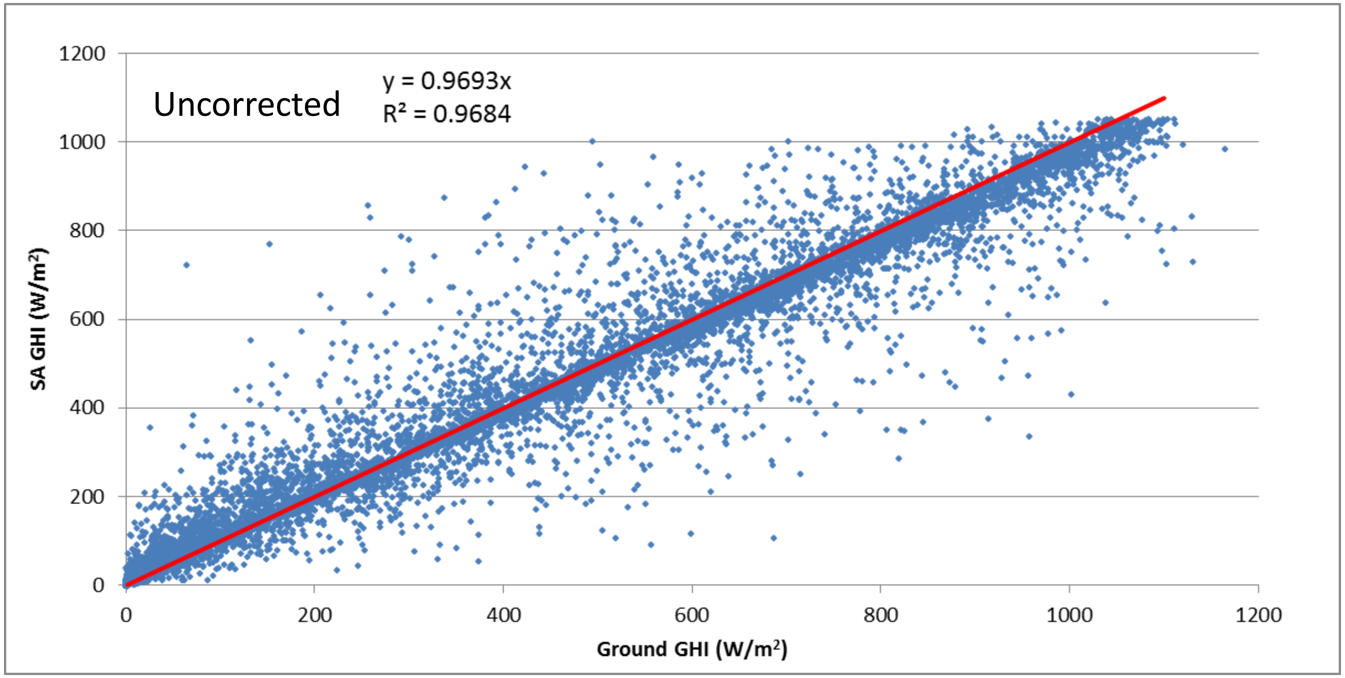


Final Tuned Data

Tuning Satellite Data with Ground Observations: Multi-year Validation

Two years of high quality ground data combined with SolarAnywhere ("SA") satellite data

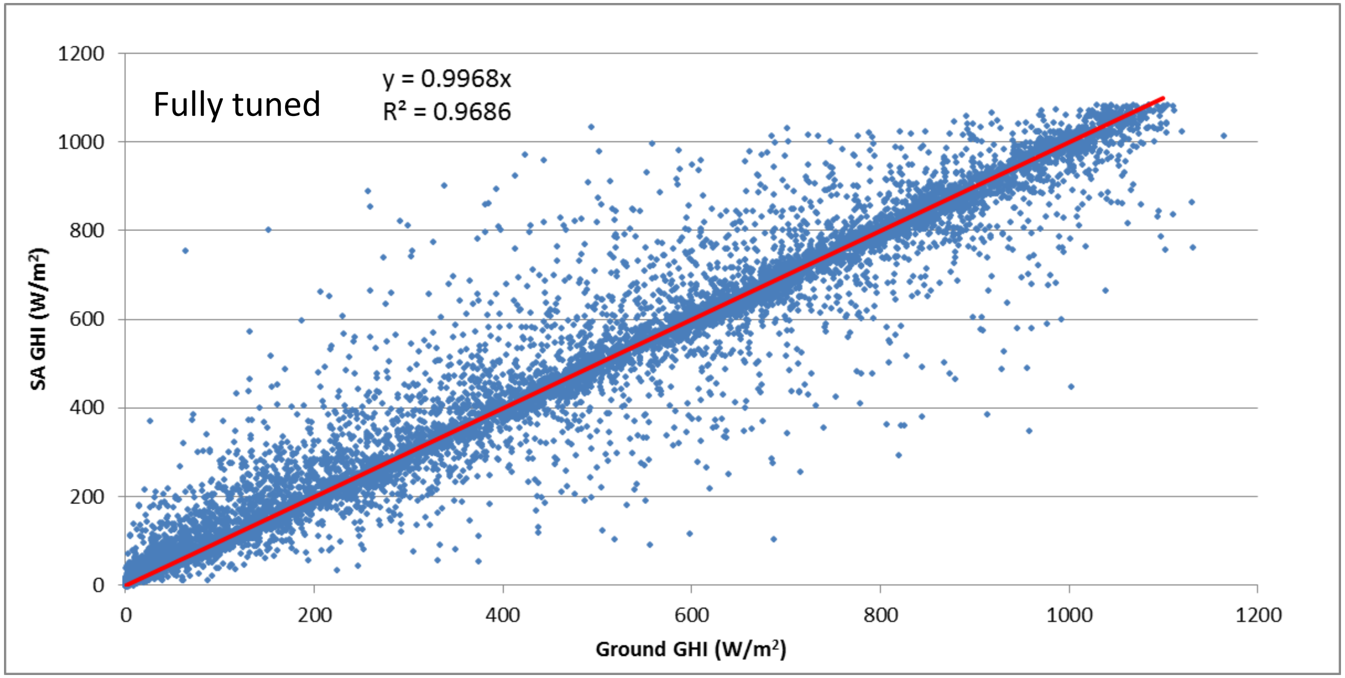
	Year 1 rMBE
Overall	-0.59%
Clear Sky	-2.71%



Tuning Satellite Data with Ground Observations: Multi-year Validation

Two years of high quality ground data combined with SolarAnywhere ("SA") satellite data

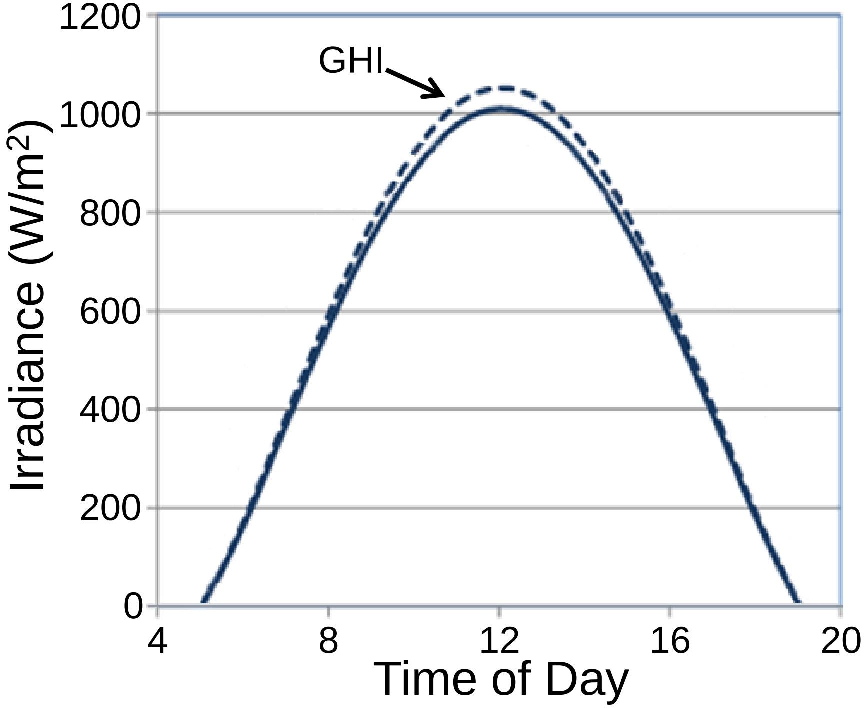
	Year 1 rMBE	Year 2 rMBE	Combined rMBE
Overall	-0.59%	-0.75%	-0.67%
Clear Sky	-2.71%	-3.16%	-2.93%



Targeted satellite tuning is reasonably consistent on a year-to-year basis

Other Considerations: Satellite DNI/DHI Rebalancing

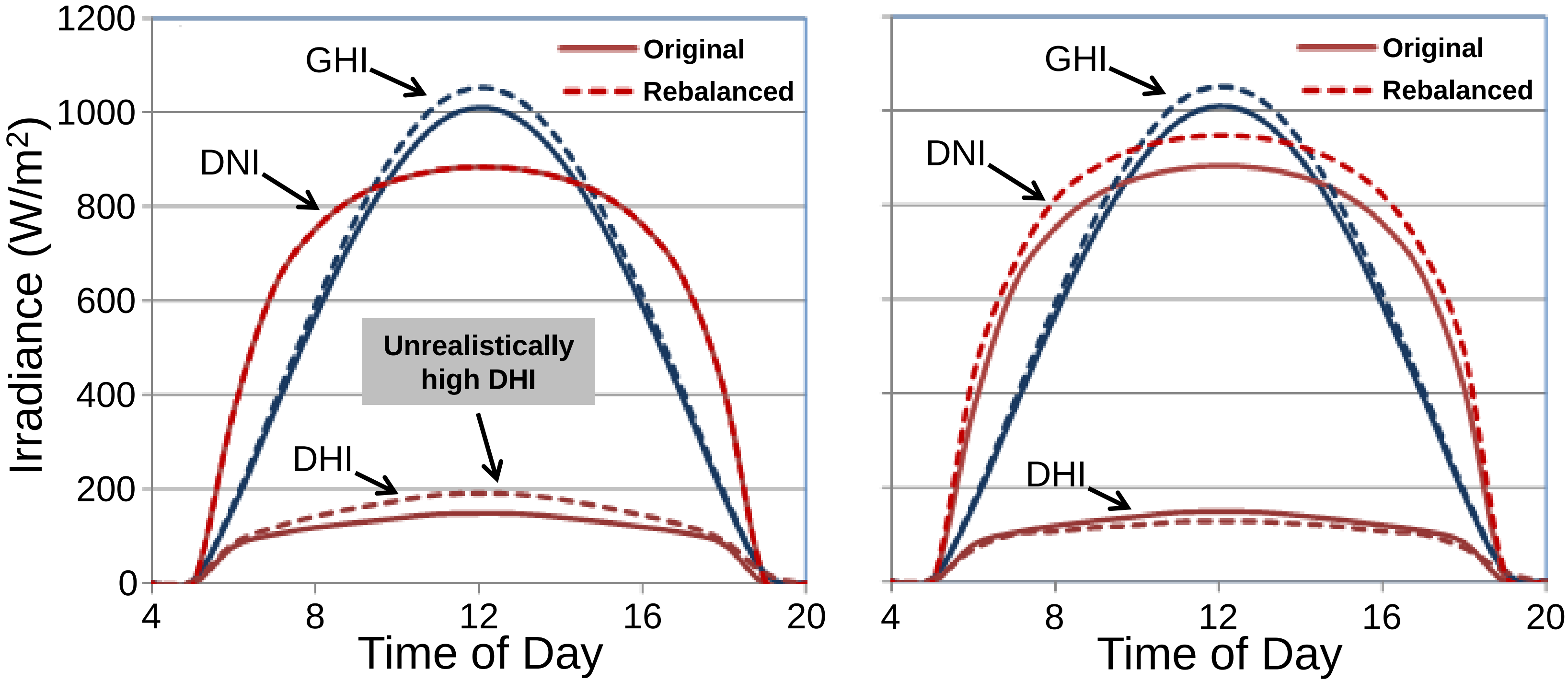
GHI = COS(Z)*DNI + DHI



Correction up in GHI needed due to modeled AOD inputs. What about DNI and DHI?

Other Considerations: Satellite DNI/DHI Rebalancing

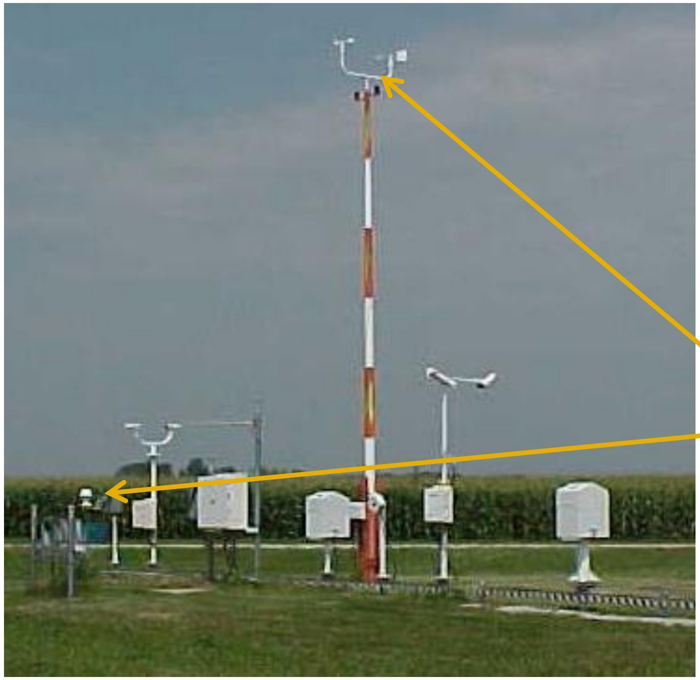
GHI = COS(Z)*DNI + DHI



Improper rebalancing can skew PV energy simulations (PVsyst & SAM)

Simple corrections do not address clear/cloudy sky biases and DNI rebalancing needs

Other Considerations: Ancillary Meteorological Data Collection

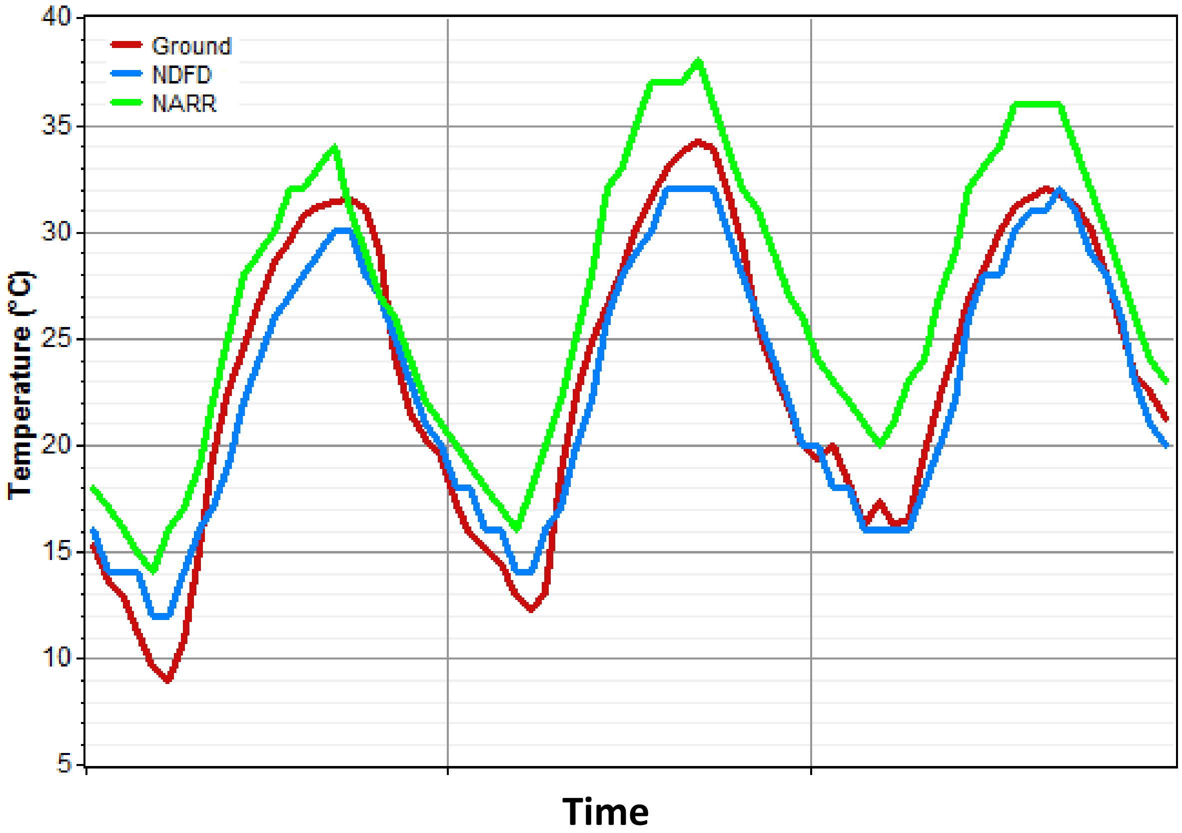


NWS ASOS weather station (image credit: NOAA)

Standard surface observations are taken at 2 meters for dry bulb temperature and 10 meters for wind speed and direction.

Long term reference datasets (both observed and modeled) report 2 meter dry bulb temperature and 10 meter wind speed and direction data. <u>PV site met observations taken at different levels will need to be reconciled with long term reference met sources</u>

Other Considerations: Ancillary Meteorological Data Biases



Site Air Temperature Biases

NDFD (all)	NDFD (day)	NARR (all)	NARR (day)
0^oC	-0.8^oC	$+2.9^oC$	$+2.6^oC$

Need to correct for daytime-only biases in long term ancillary datasets

A $+2^oC$ swing in temperature results in a -1% swing in energy output in PVsyst for most PV modules

Conclusion: Ground + Satellite Data
"Better together when properly combined"

Run a well maintained and monitored ground campaign and collect 1+ year of high-quality ground data

+

Combine intelligently with
long-term reference satellite and ancillary met data

=

Results in lowest uncertainty and most reliable solar resource available for a solar project site

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Thank you

Please feel free to contact us for any details or clarification related to presentation

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