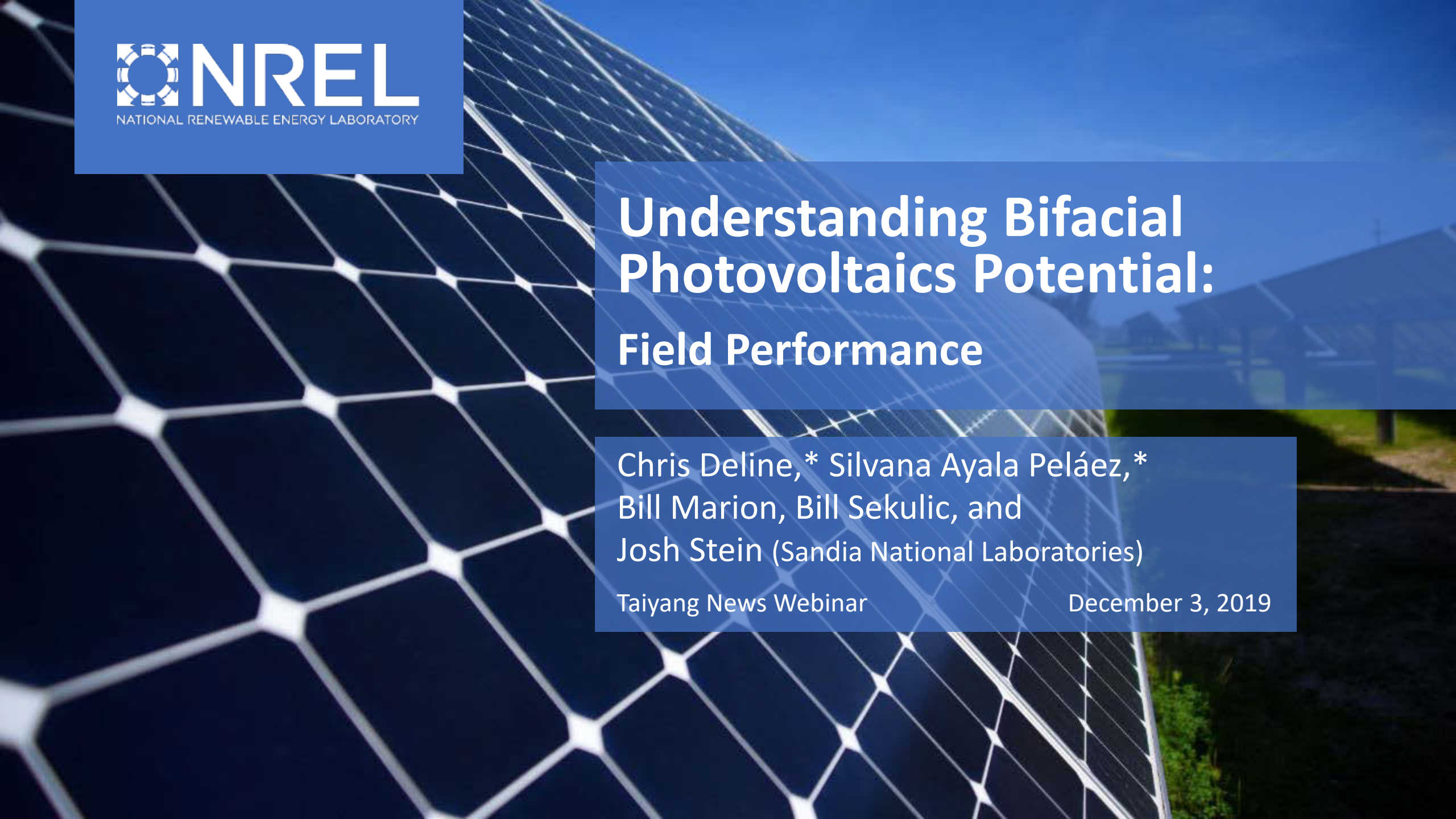


NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Understanding Bifacial Photovoltaics Potential:

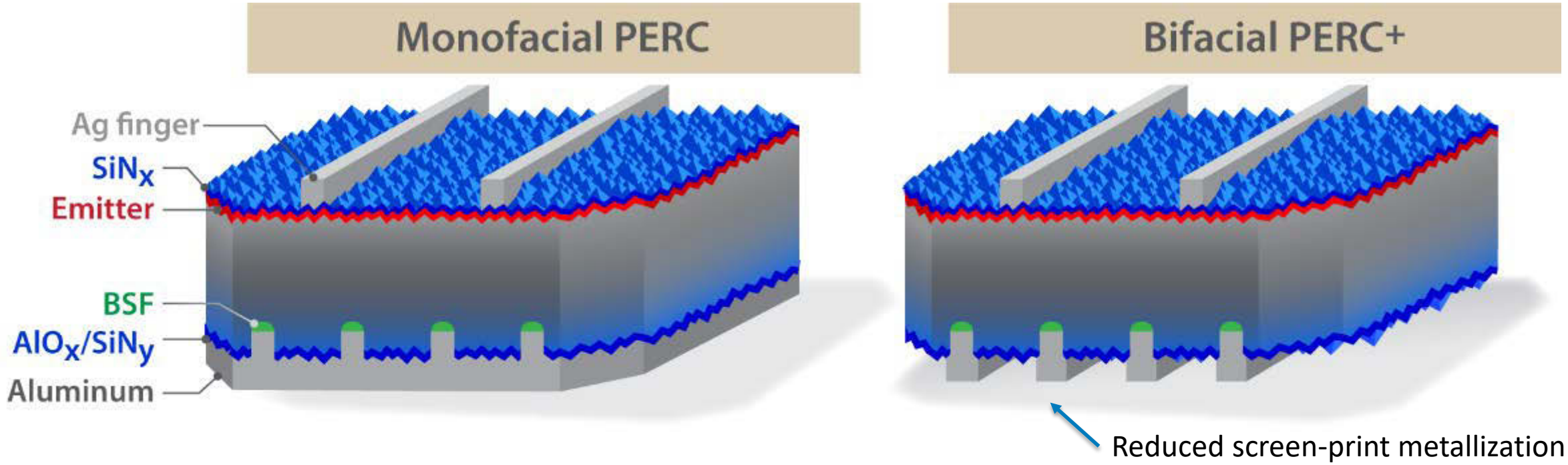
Field Performance

Chris Deline,* Silvana Ayala Peláez,*
Bill Marion, Bill Sekulic, and
Josh Stein (Sandia National Laboratories)

Taiyang News Webinar

December 3, 2019

PERC Cell Technology – Easily Bifacial



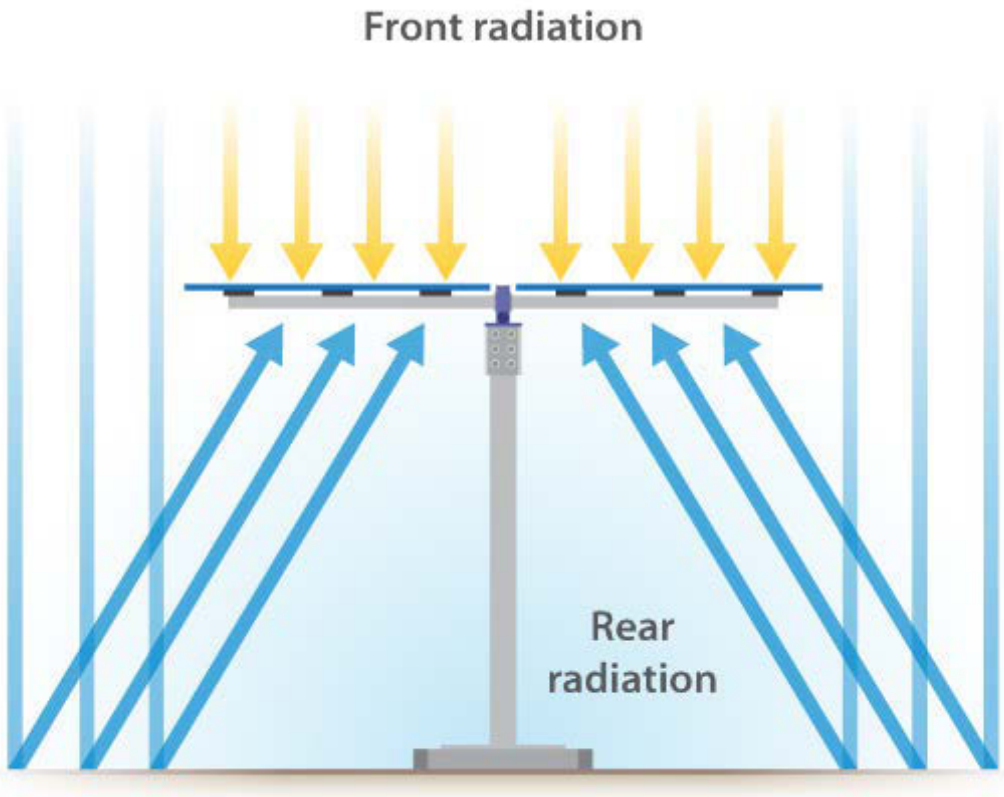
Module bifaciality $\phi = \frac{P_{Rear}}{P_{Front}} =$

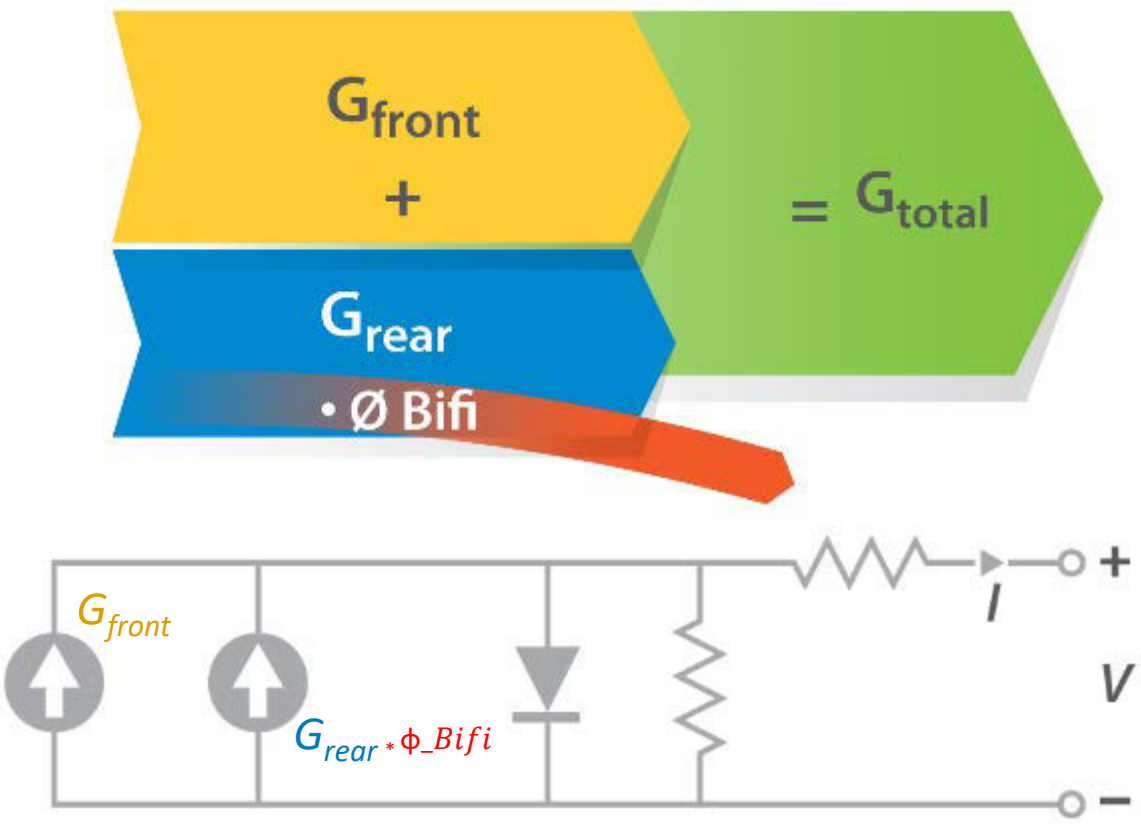
0.65–0.80 (p-PERC)	**0.75–0.90 (n-PERT)**	**0.85–0.95 (Si heterojunction)**

T. Dullweber et al., "PERC+: Industrial PERC solar cells with rear Al grid enabling bifaciality and reduced Al paste consumption," *Prog. Photovolt: Res. Appl.* (2015).

Bifacial Total Irradiance

$$G_{Total} = G_{Front} + (G_{Rear}) \times (\boldsymbol{bifaciality}) \times (1 - \eta_{Loss})$$





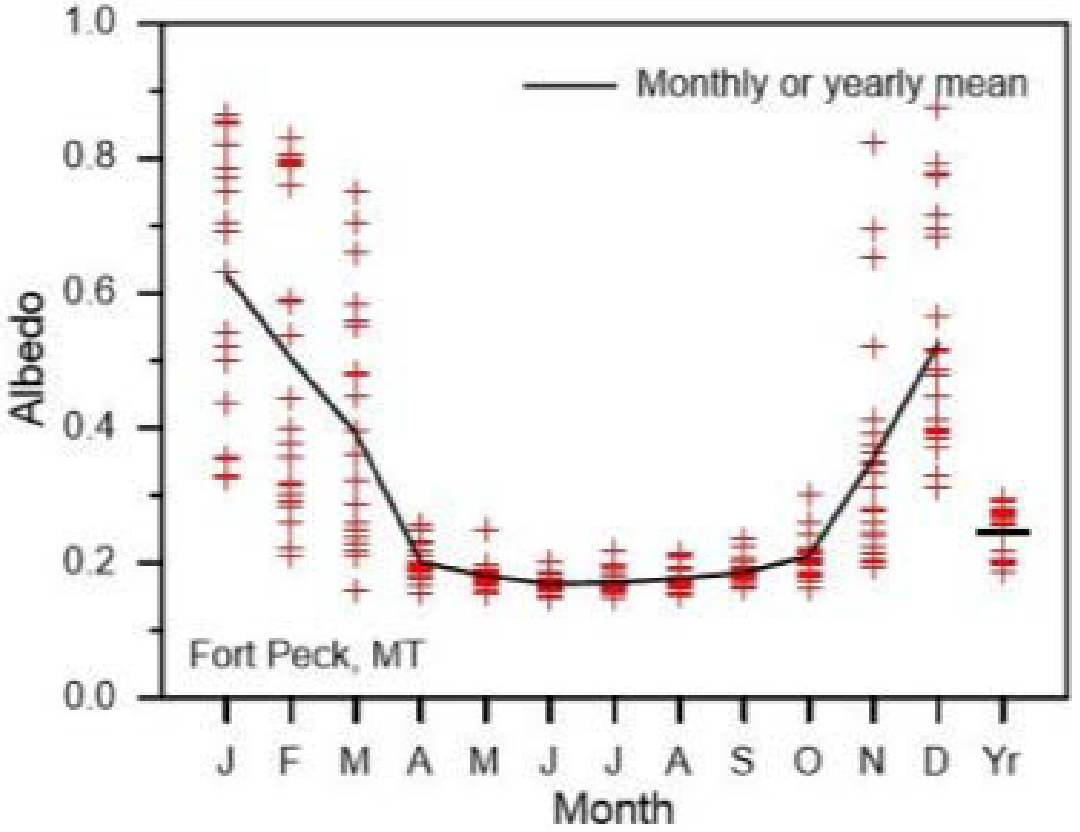
Module bifaciality $\boldsymbol{\phi_{Bifi}} = \dfrac{Pmp_0\ rear}{Pmp_0\ front}$

Albedo Variability

- Albedo is an essential parameter for determining the Earth's energy balance and climate change
- Monthly and year-to-year variability depends on location and ground surface, especially snow
- Site-measured albedo has best accuracy, but satellite data has better coverage.

- *Ground data for 37 stations available from the DuraMAT website*:

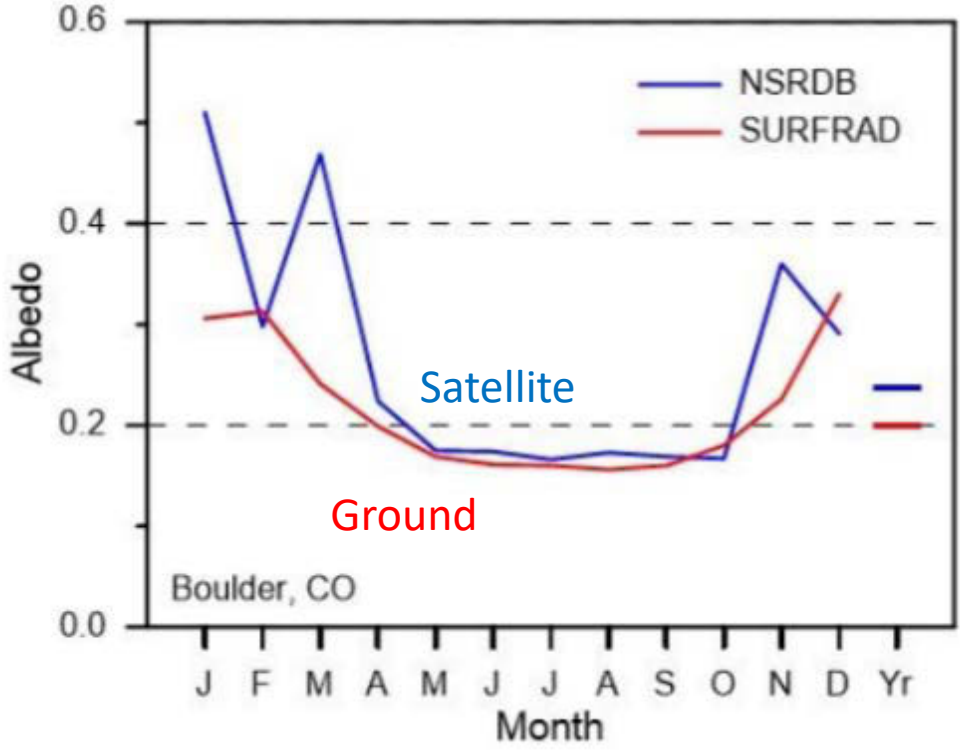
  https://datahub.duramat.org/project/albedo-study

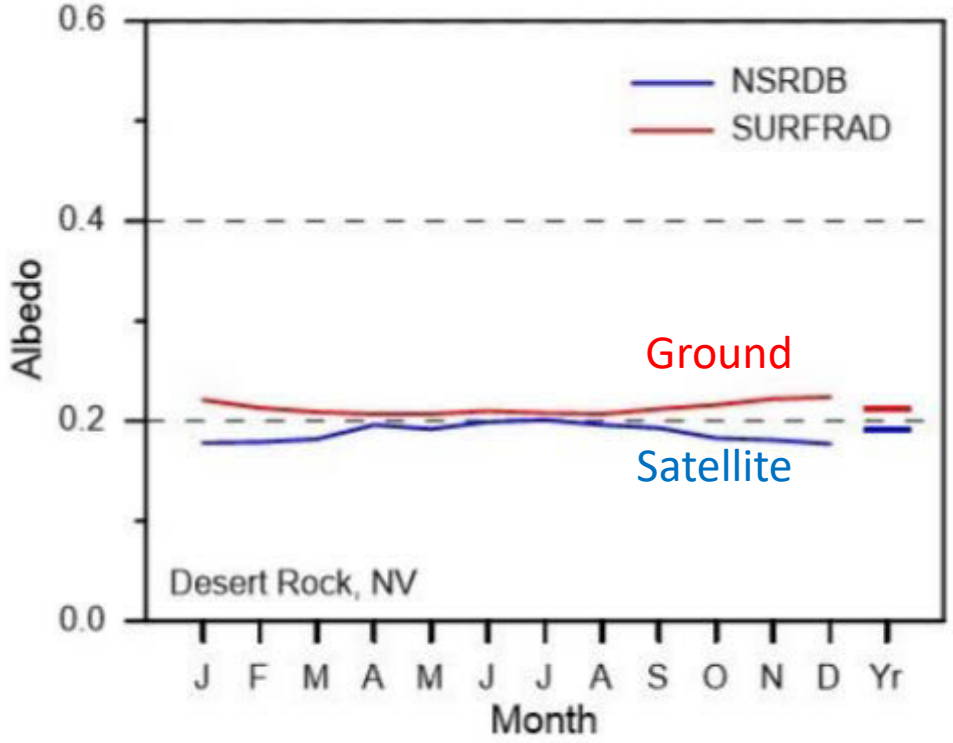


http://bifipv-workshop.com/fileadmin/layout/images/bifiPV/presentations2019/bifdiPV2019-NREL_Marion.pdf

Surface vs. Satellite Albedo

Satellite albedos can be close to measured values,
but snow may be problematic for the satellite data.

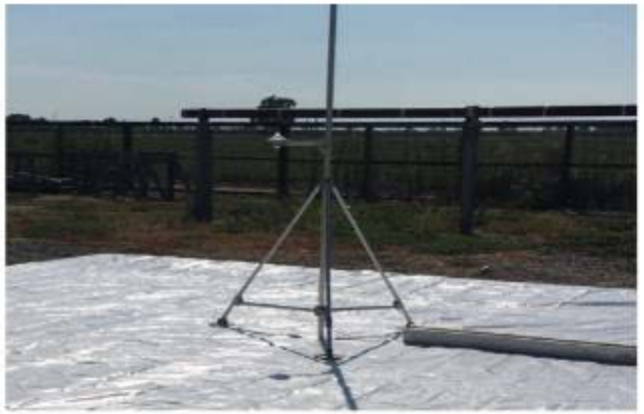




http://bifipv-workshop.com/fileadmin/layout/images/bifiPV/presentations2019/bifdiPV2019-NREL_Marion.pdf

Site Measurements – Albedo

http://bifipv-workshop.com/fileadmin/images/bifi/denver/presentations/5__Bourne-_Albedo_measurements_bifiPV2018.pdf



Unshaded sensor for expected energy modeling

- Avoid obstructions & self-shading
- Deploy over representative ground cover

Site Measurements – Rear Irradiance

Rear POA for energy yield / capacity testing

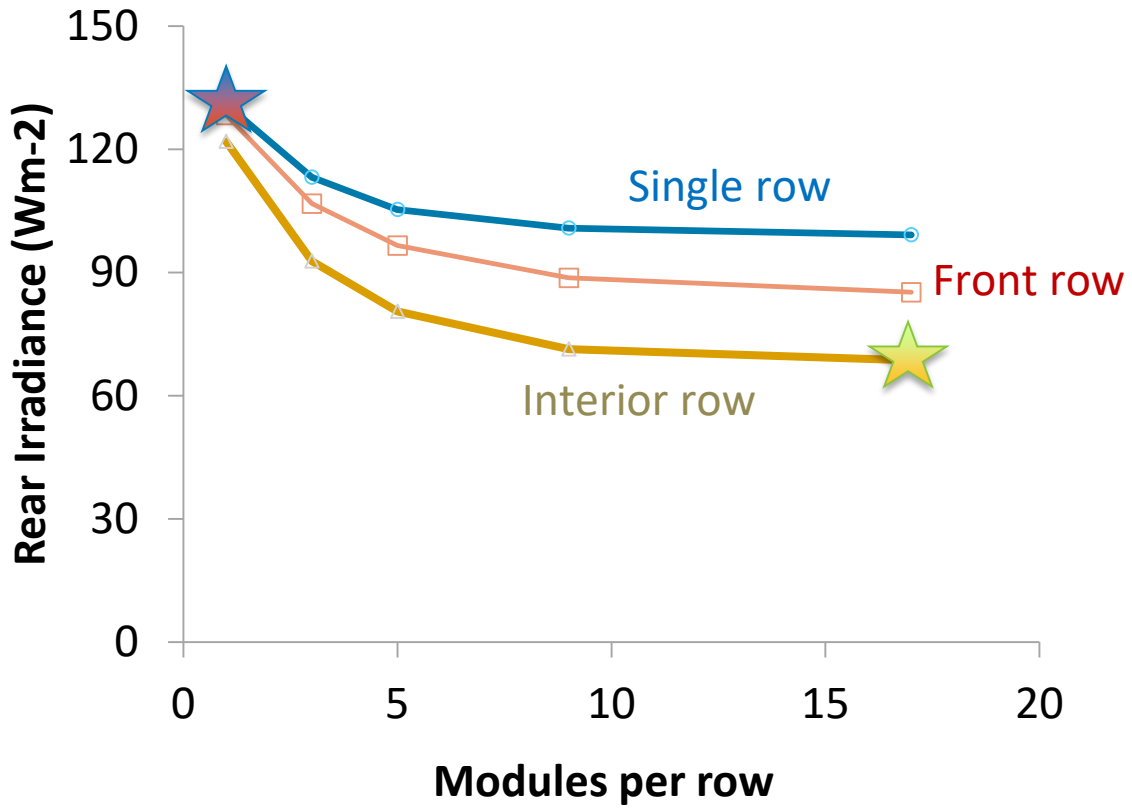
- Deploy within the array (shaded)
- Multiple sensors to capture ground / albedo variability

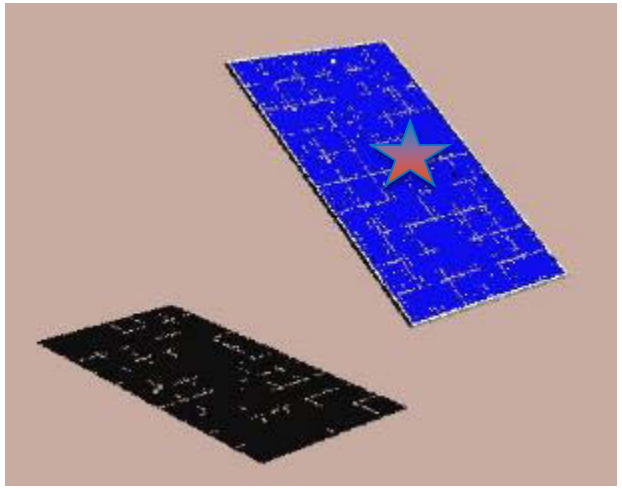
$E_{monofacial} \approx f(G_{Front}, T_{mod})$ $E_{bifacial} \approx f(G_{Total}, T_{mod})$

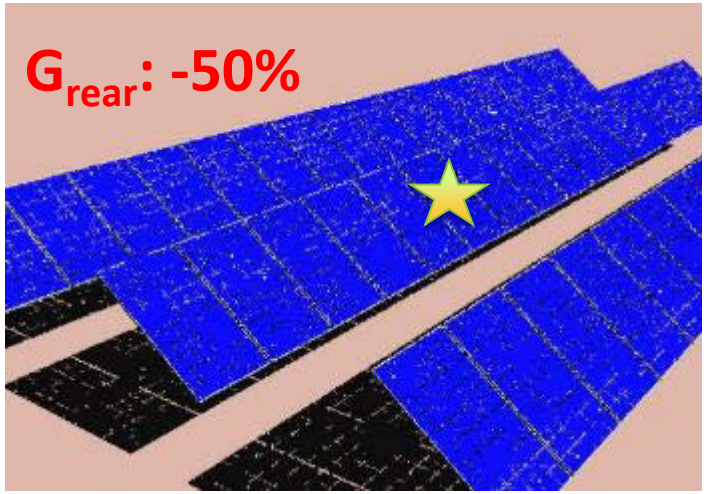
$$G_{Total} = G_{Front} + (G_{Rear}) \times (\varphi_{bifi})$$

M. Waters, C. Deline, J. Kemnitz, J. Webber, "Suggested modifications for bifacial capacity testing," https://www.nrel.gov/docs/fy20osti/73982.pdf

System Experiences Self-Shading



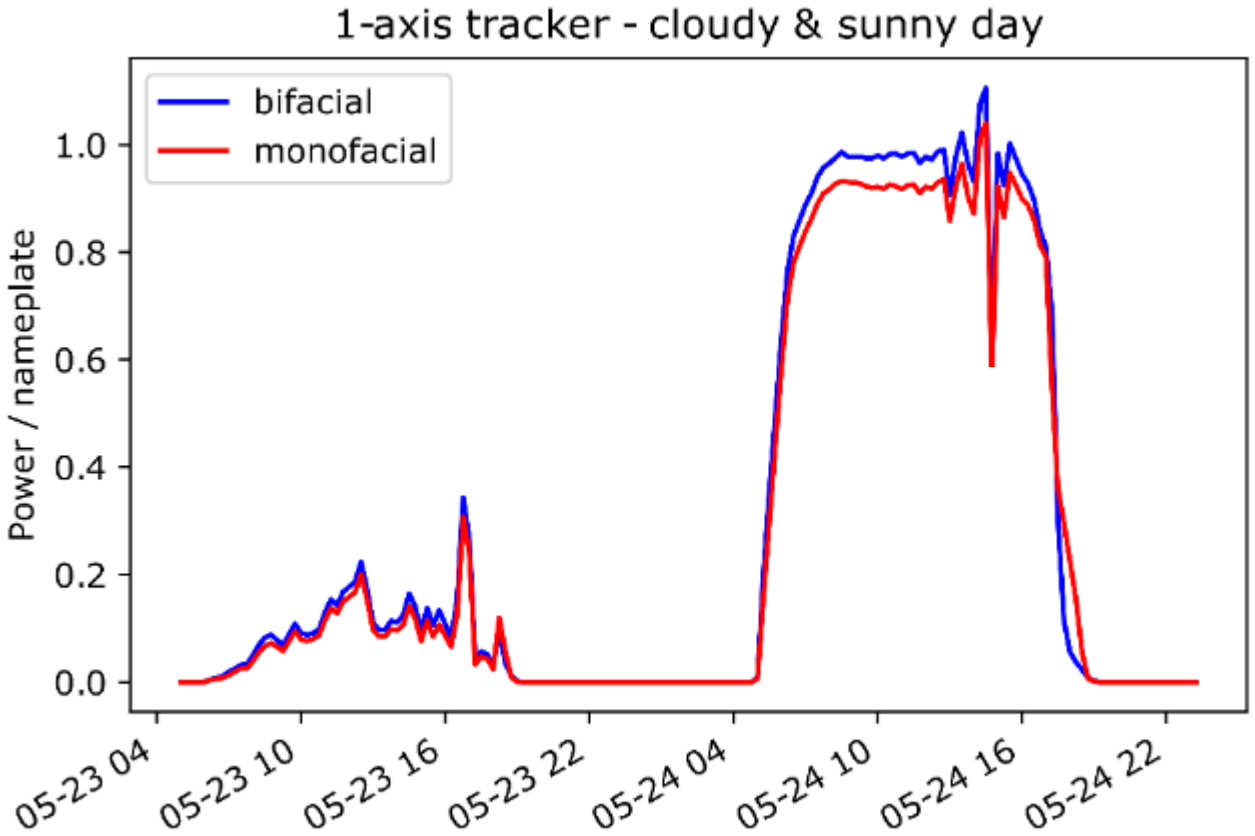




C. Deline et al., "Assessment of bifacial photovoltaic module power rating methodologies – Inside and out," *J. Photovoltaics* **7** (2017).

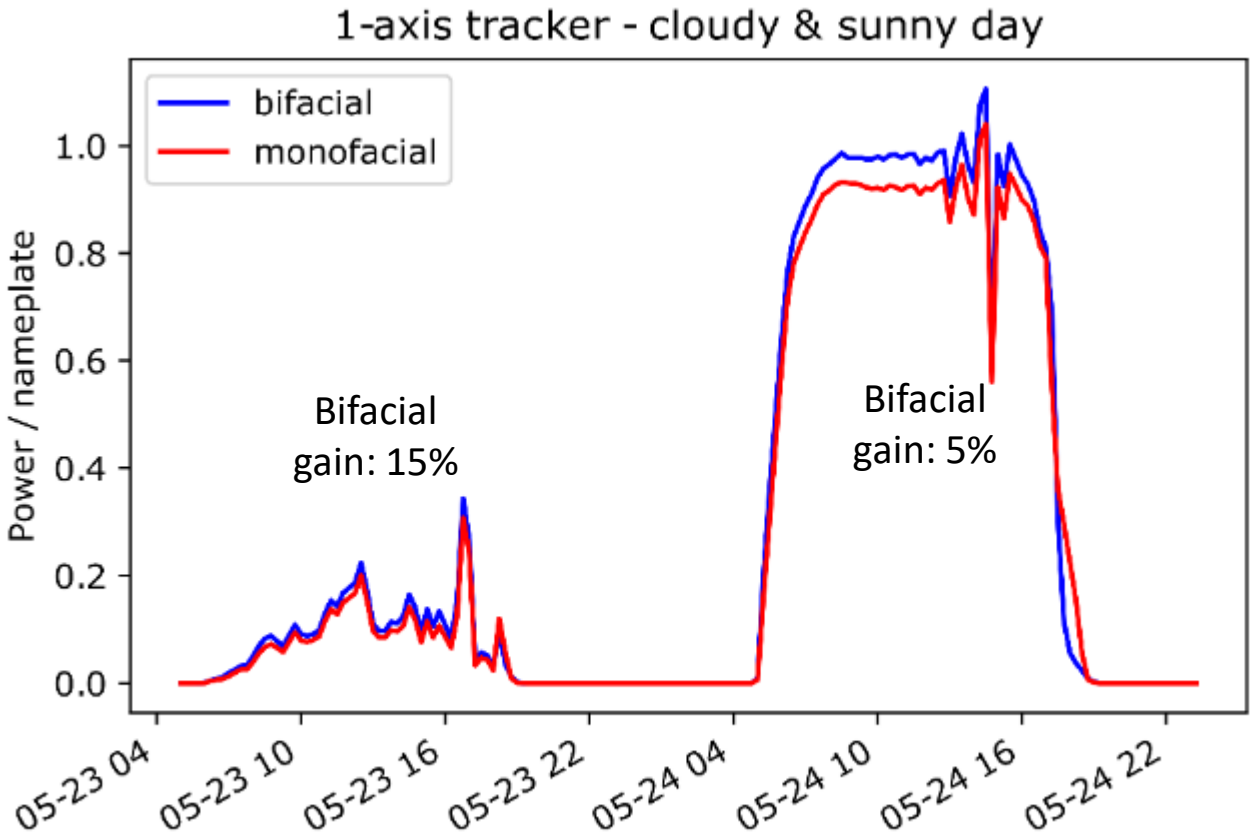

Bifacial trackers, 75 kW
Five bifacial technologies

Initial Field Results – Bifacial Trackers



$$BG_E = \frac{E_{bifacial}}{E_{mono}} - 1$$

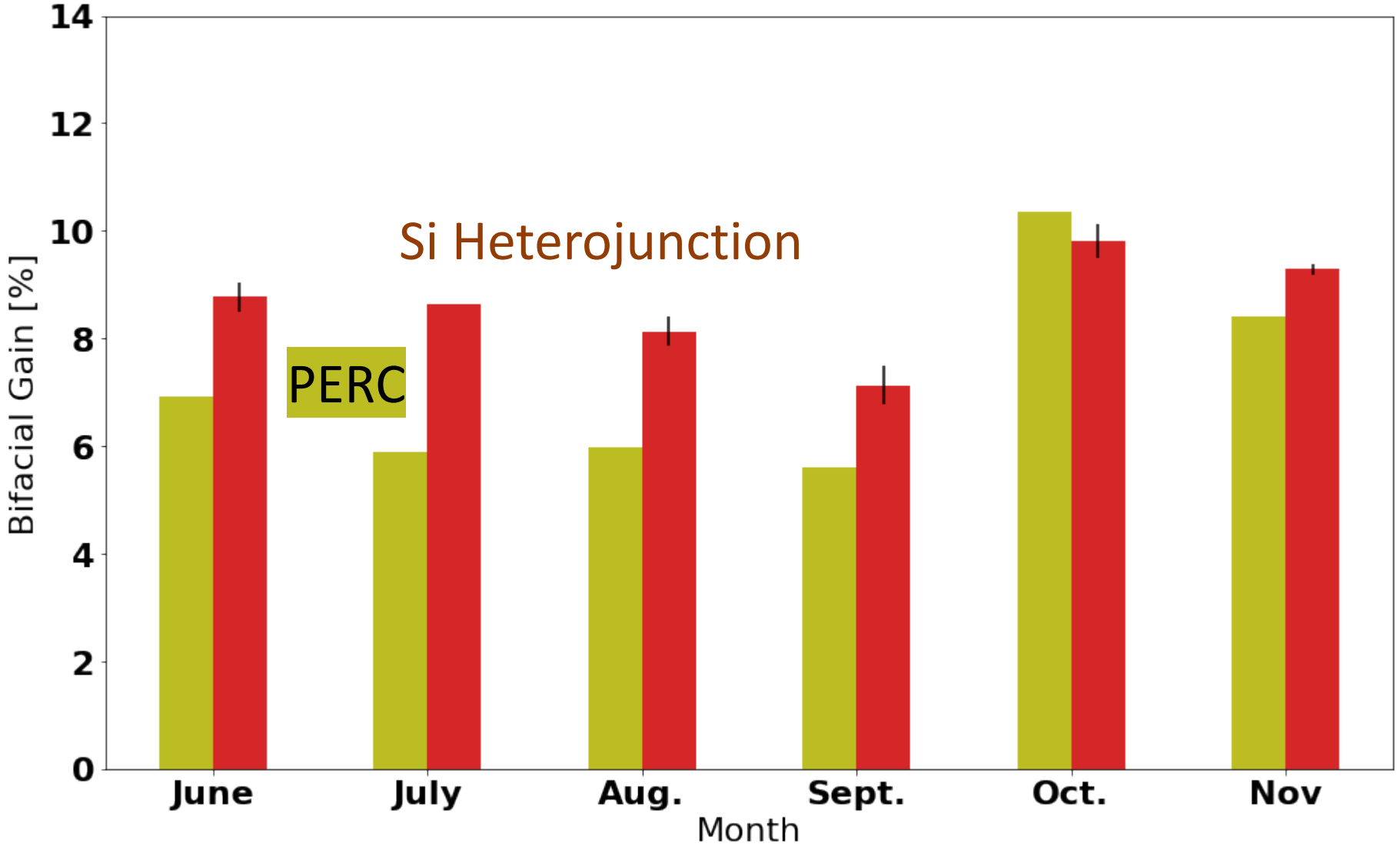
Initial Field Results – Bifacial Trackers



$$BG_E = \frac{E_{bifacial}}{E_{mono}} - 1$$

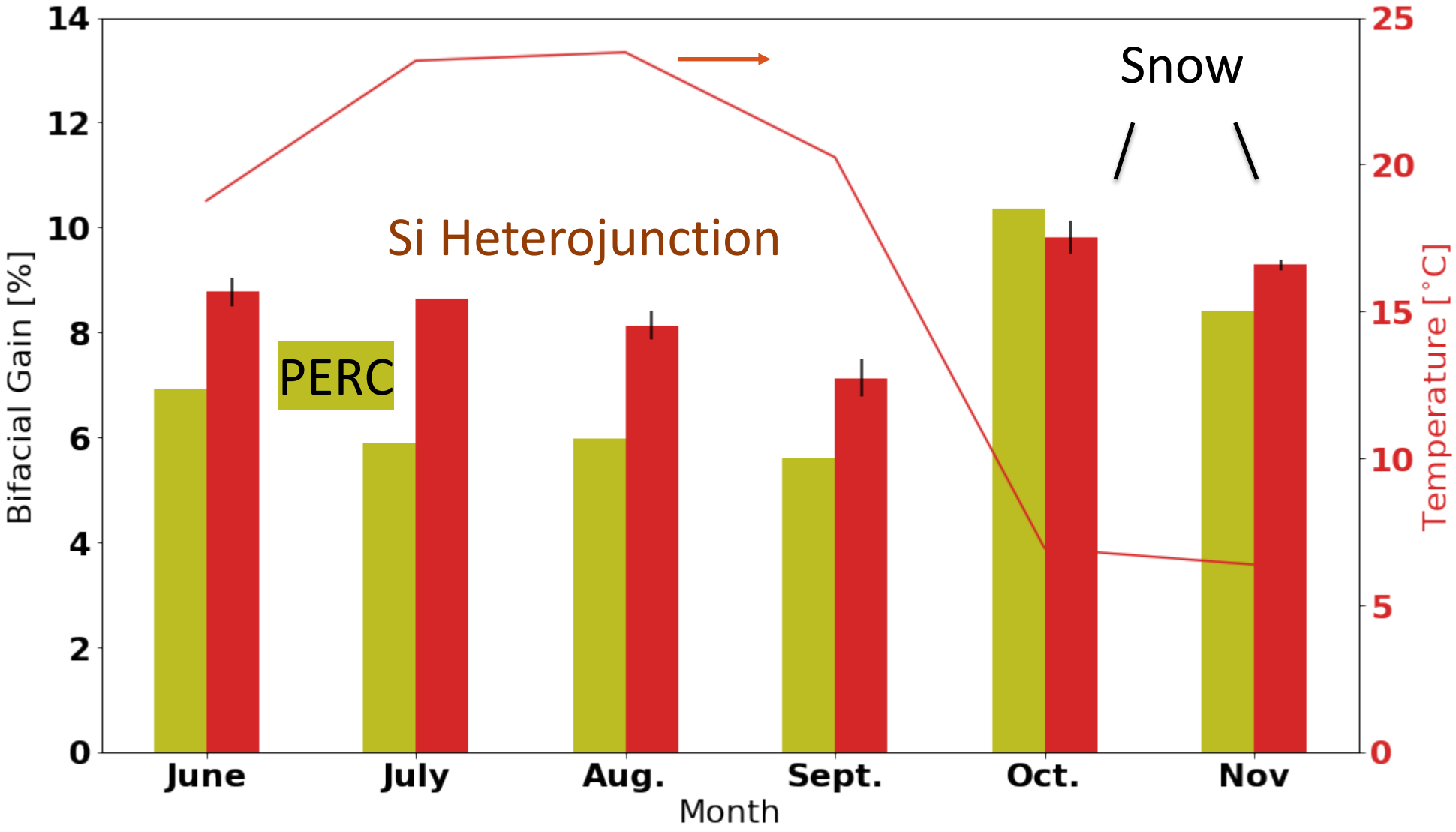
Monthly Bifacial Energy Gain

$$BG_E = \frac{E_{bifacial}}{E_{mono}} - 1$$



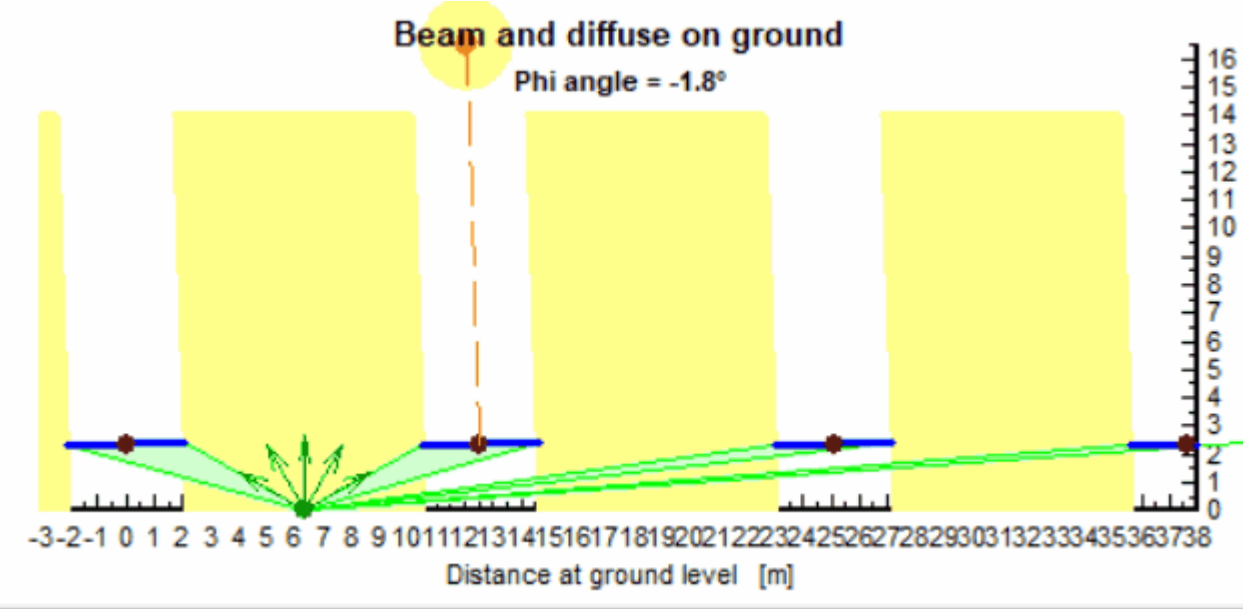
Monthly Bifacial Energy Gain

$$BG_E = \frac{E_{bifacial}}{E_{mono}} - 1$$



Modeled Bifacial Performance

View Factor Models for Rear Irradiance



PVSyst v6.8.4

SAM 2018.11.11

Simple

Basic
Geometry

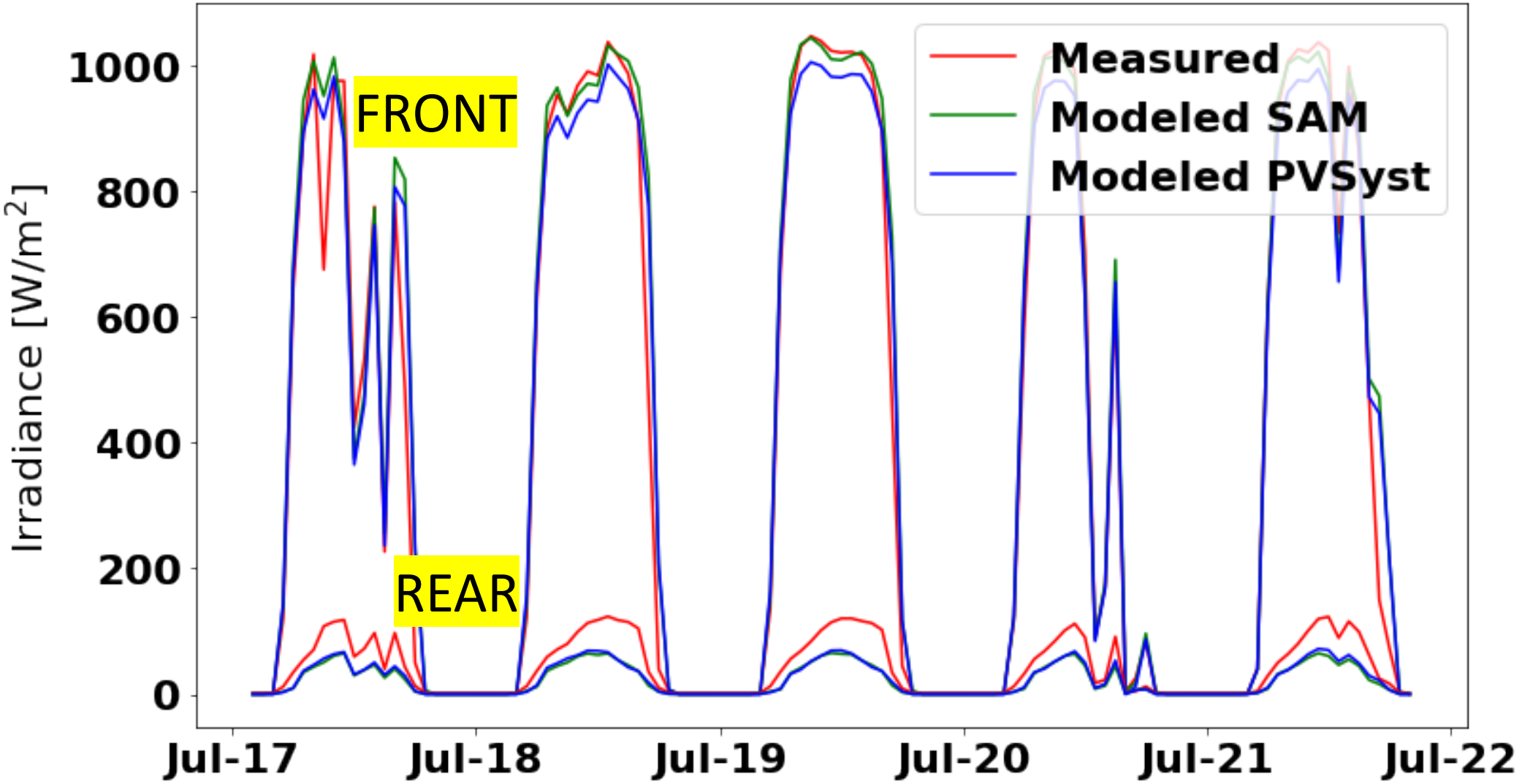
Fast

Computationally
Inexpensive

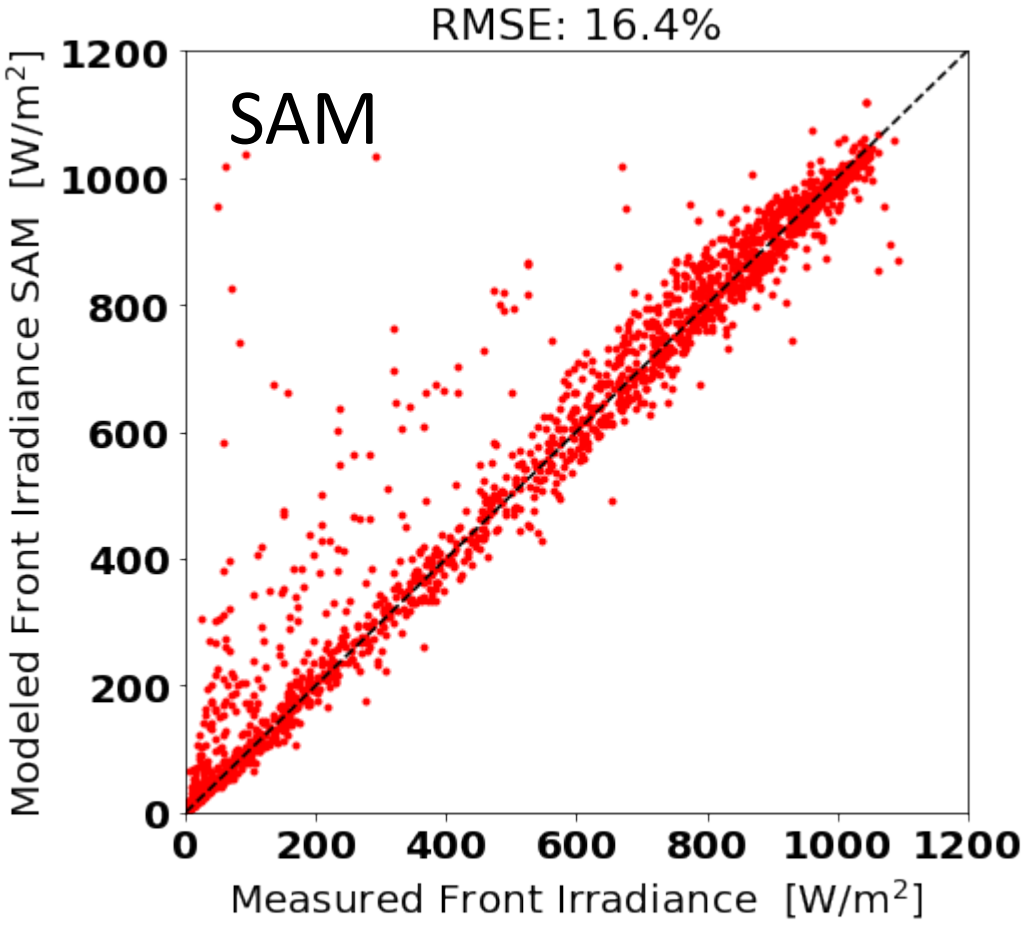
Common

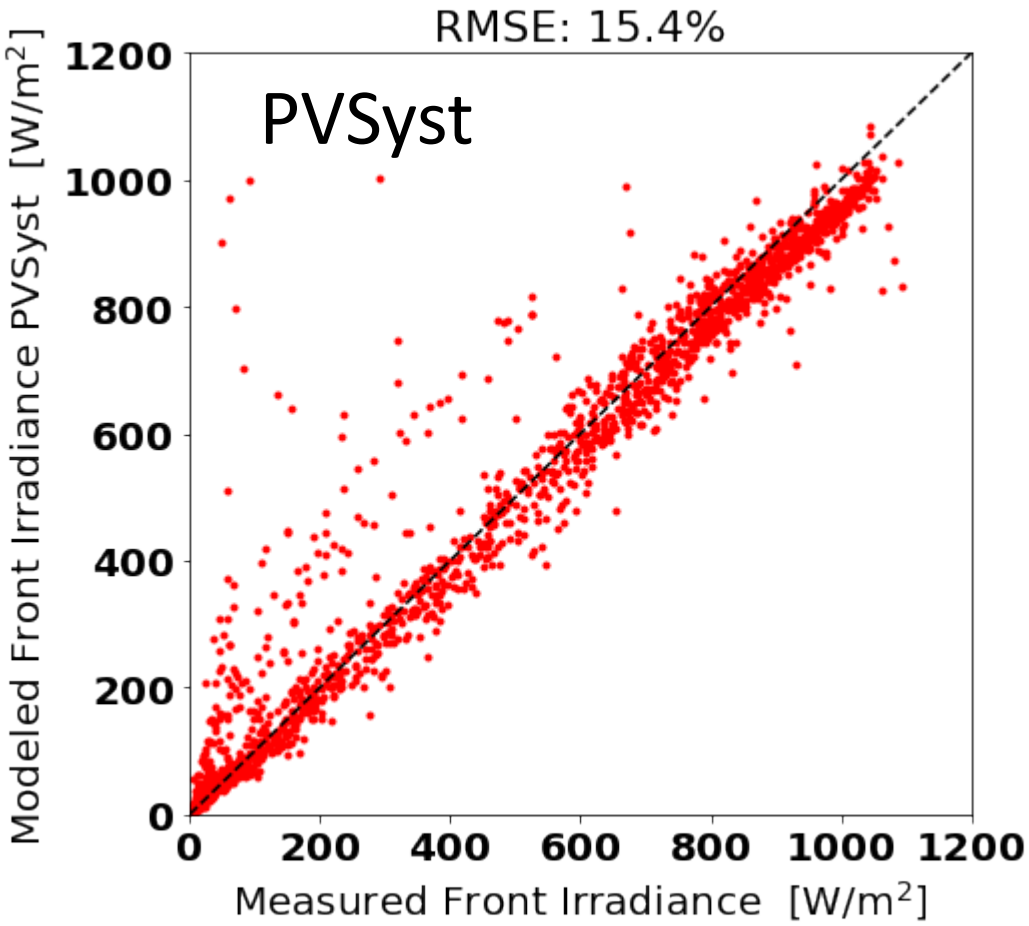
Behind
SAM, PVSyst, and others

Measured vs Modeled Irradiances



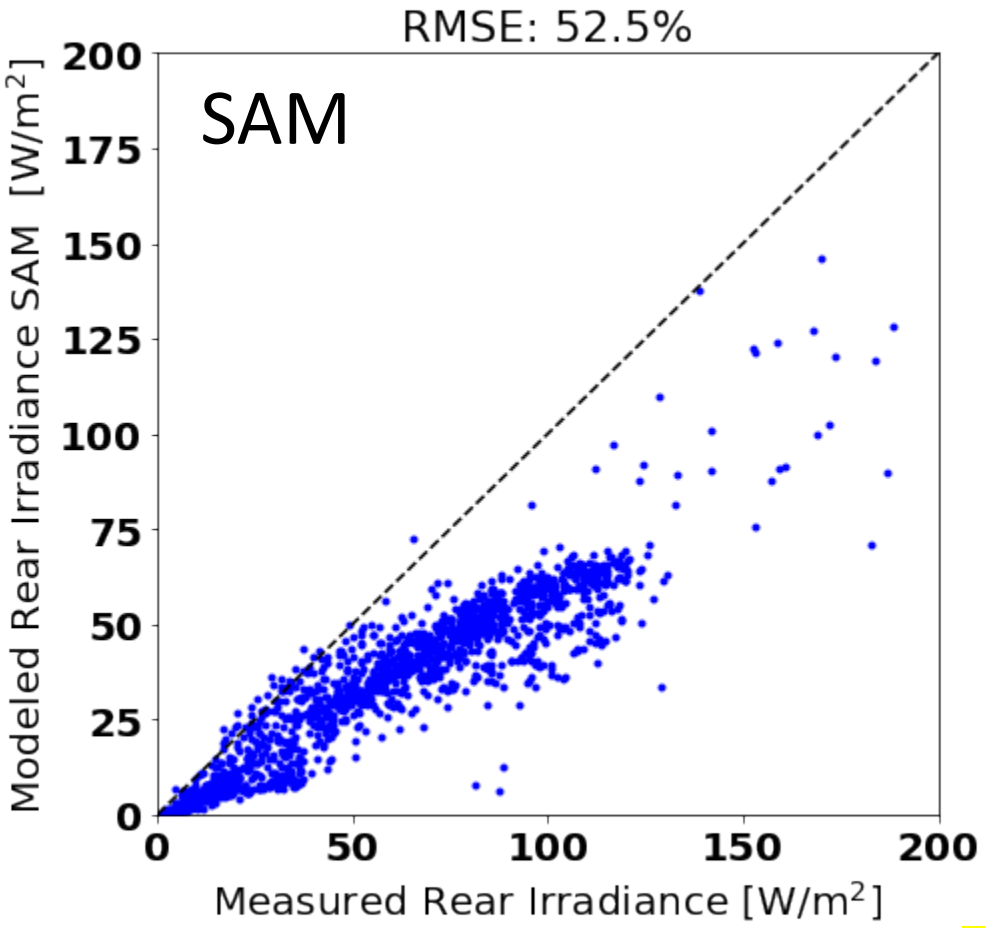
Measured vs Modeled Irradiance July to November 21st

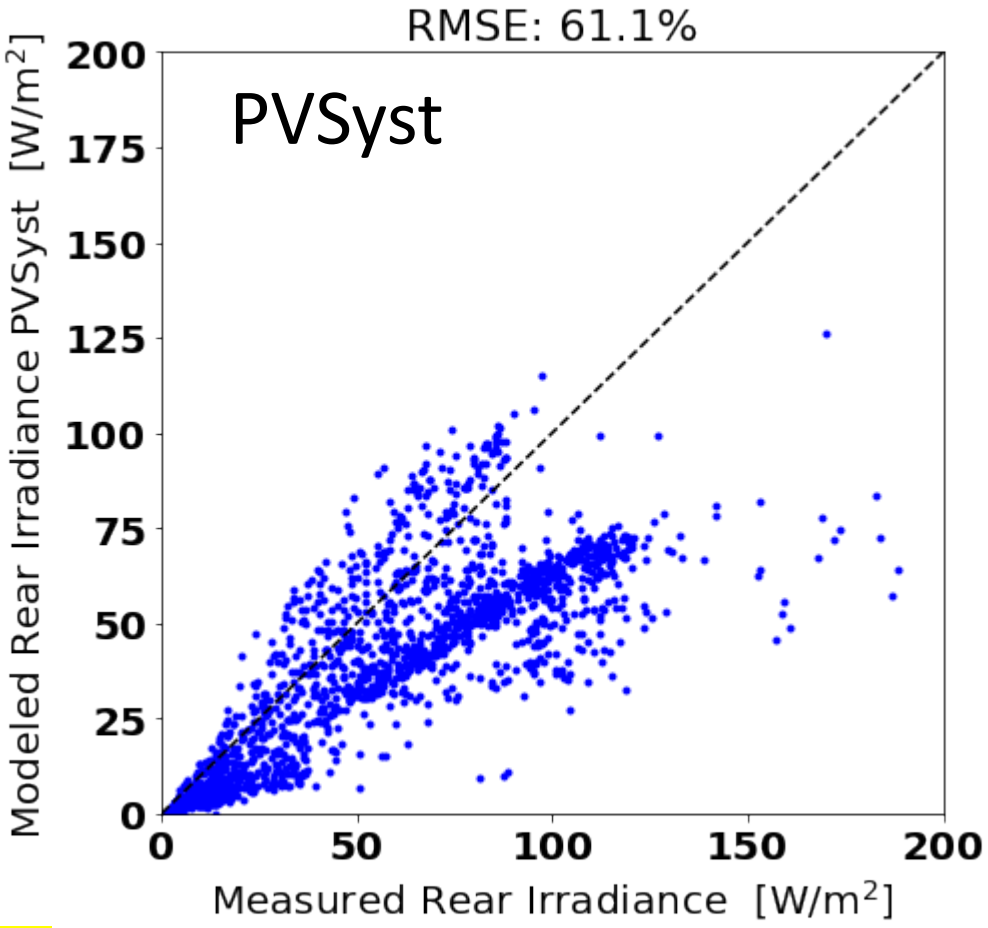




FRONT

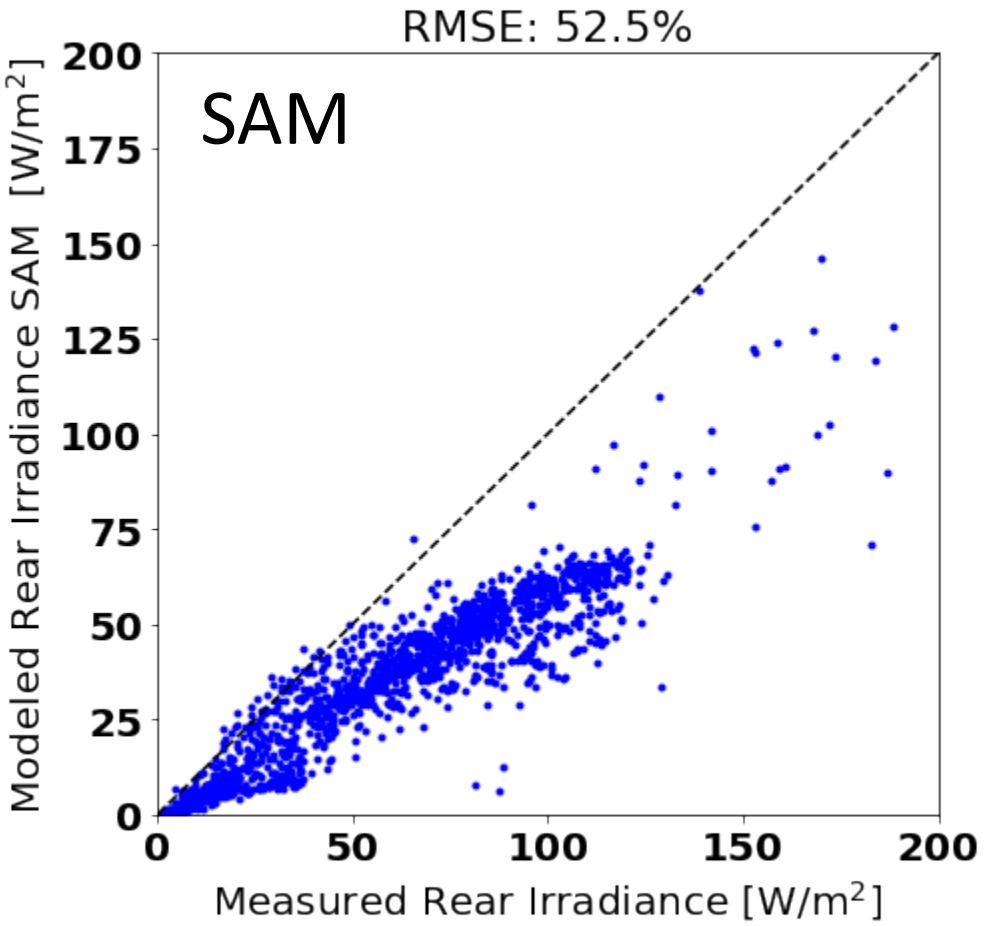
Measured vs Modeled Irradiance July to November 21st

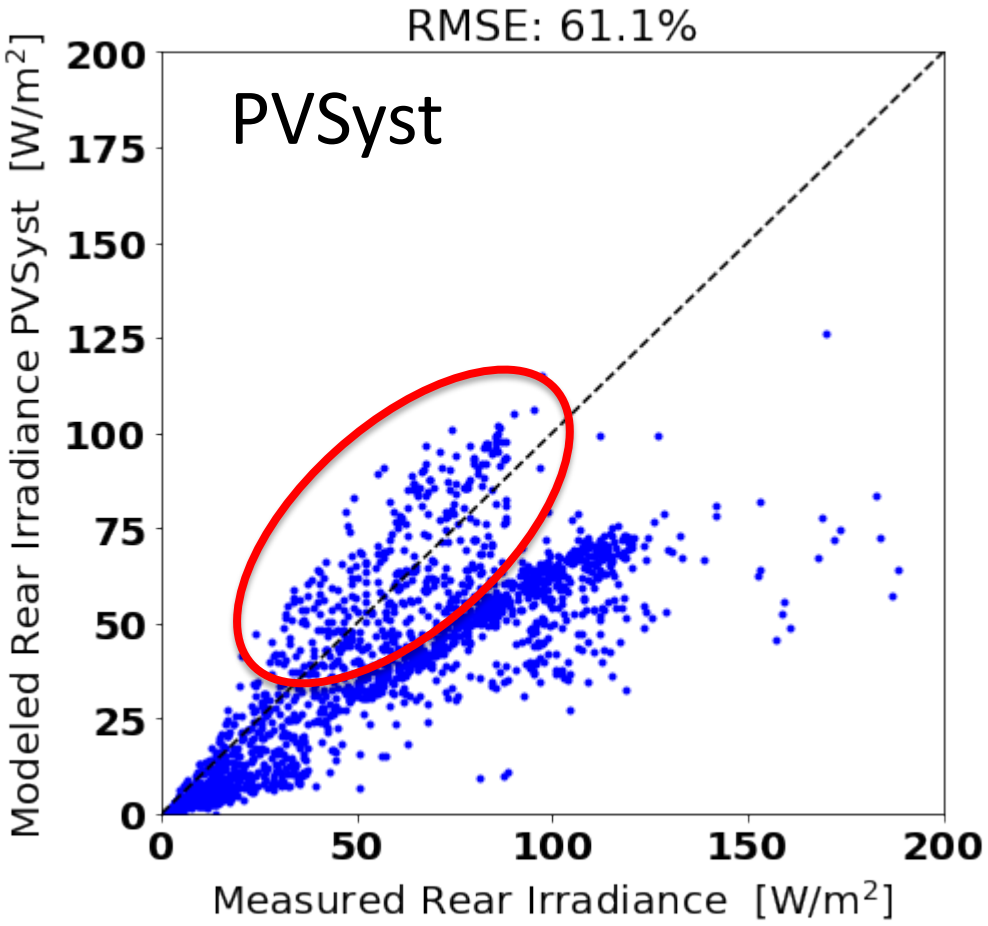




REAR

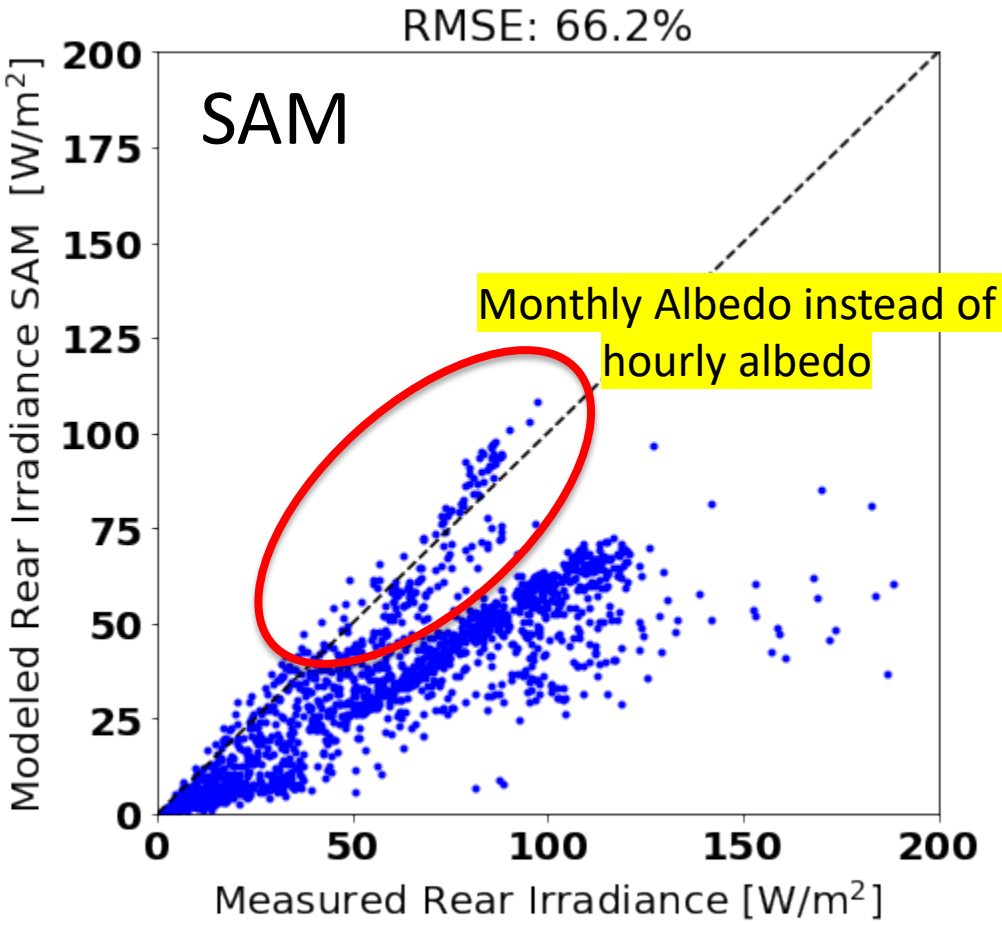
Measured vs Modeled Irradiance July to November 21st

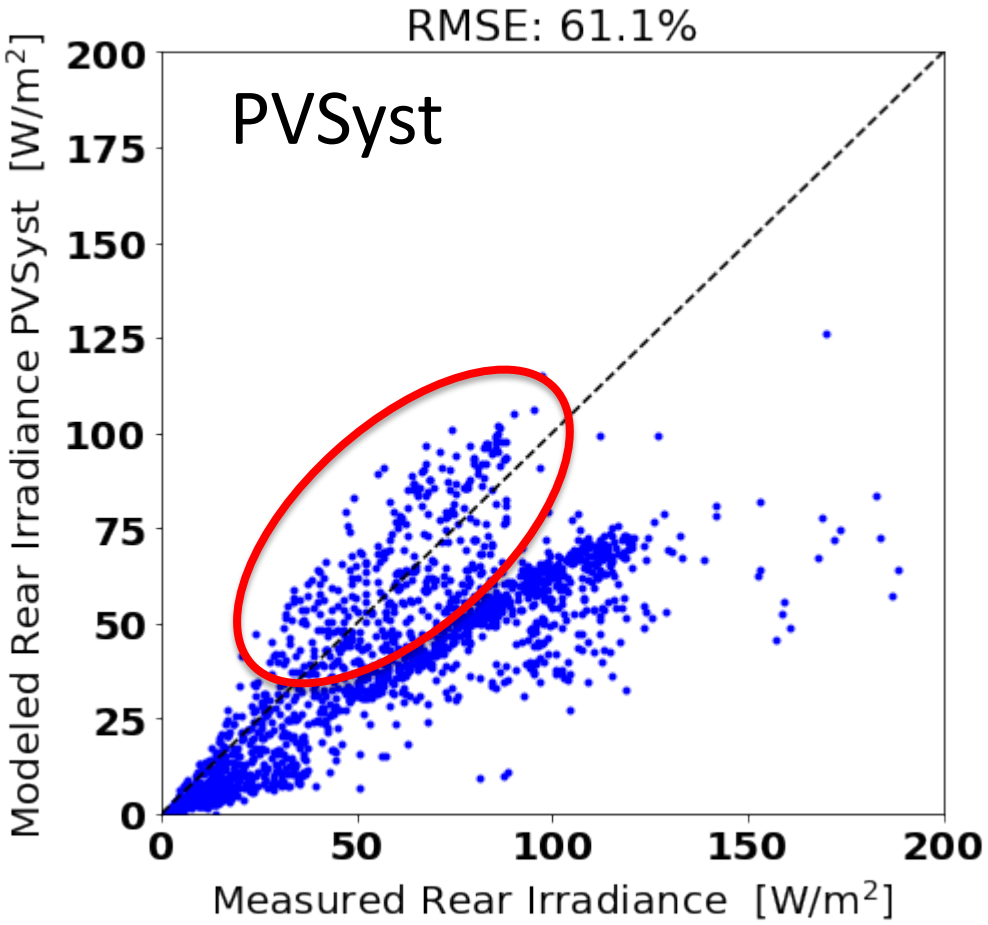




REAR

Measured vs Modeled Irradiance July to November 21st

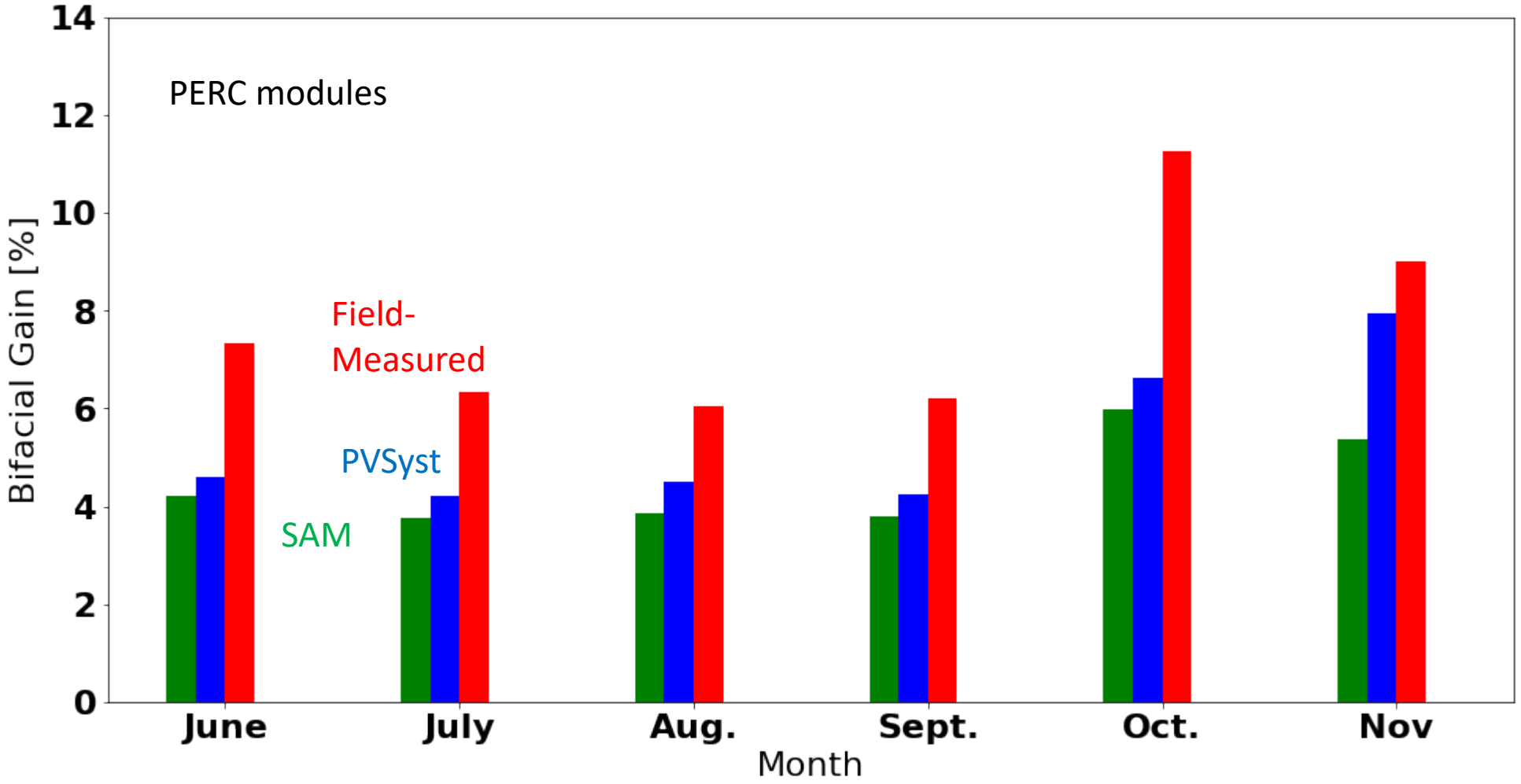




REAR

Monthly Bifacial Gain
Measured vs. Modeled

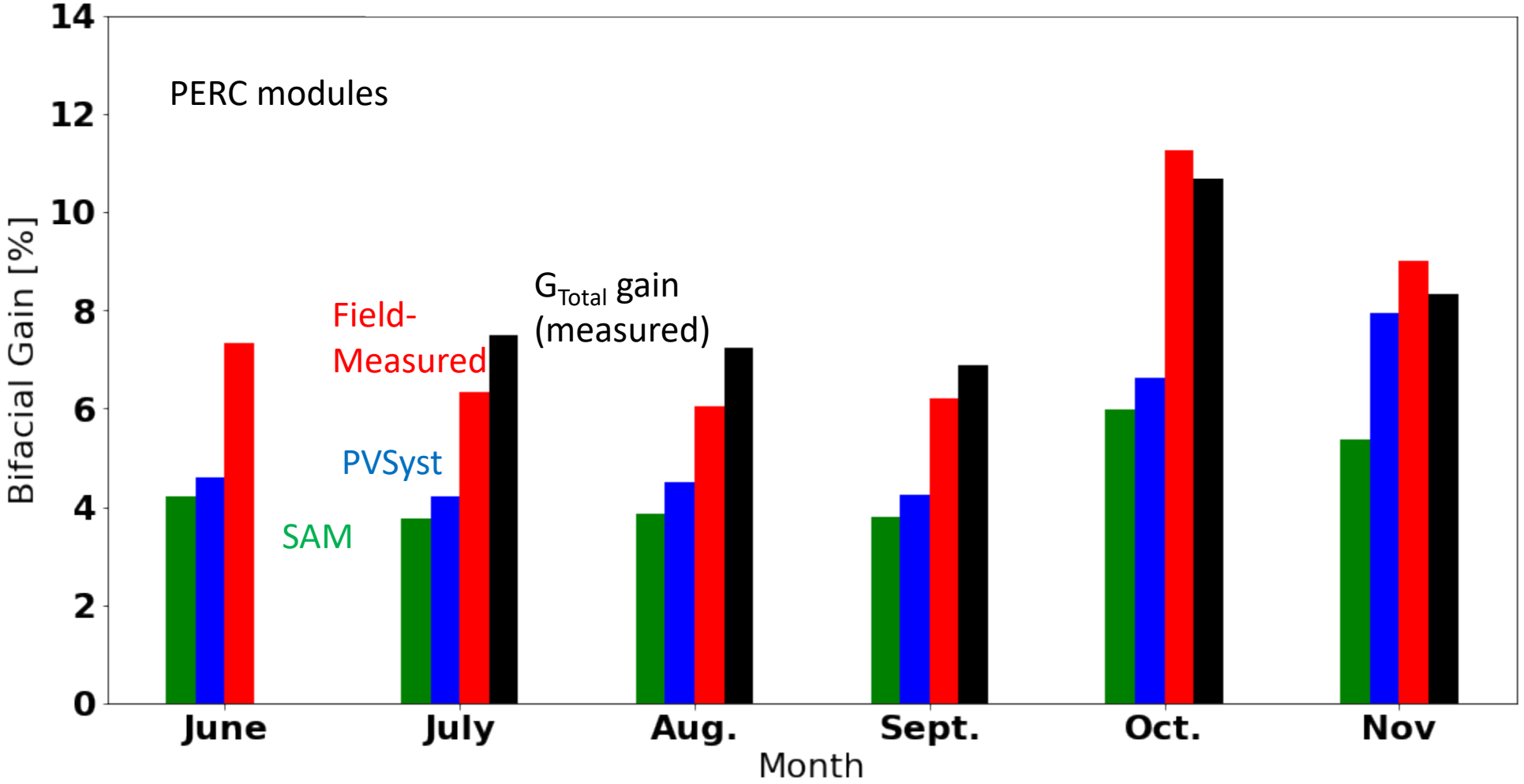
$$BG_E = \frac{E_{bifacial}}{E_{mono}} - 1$$



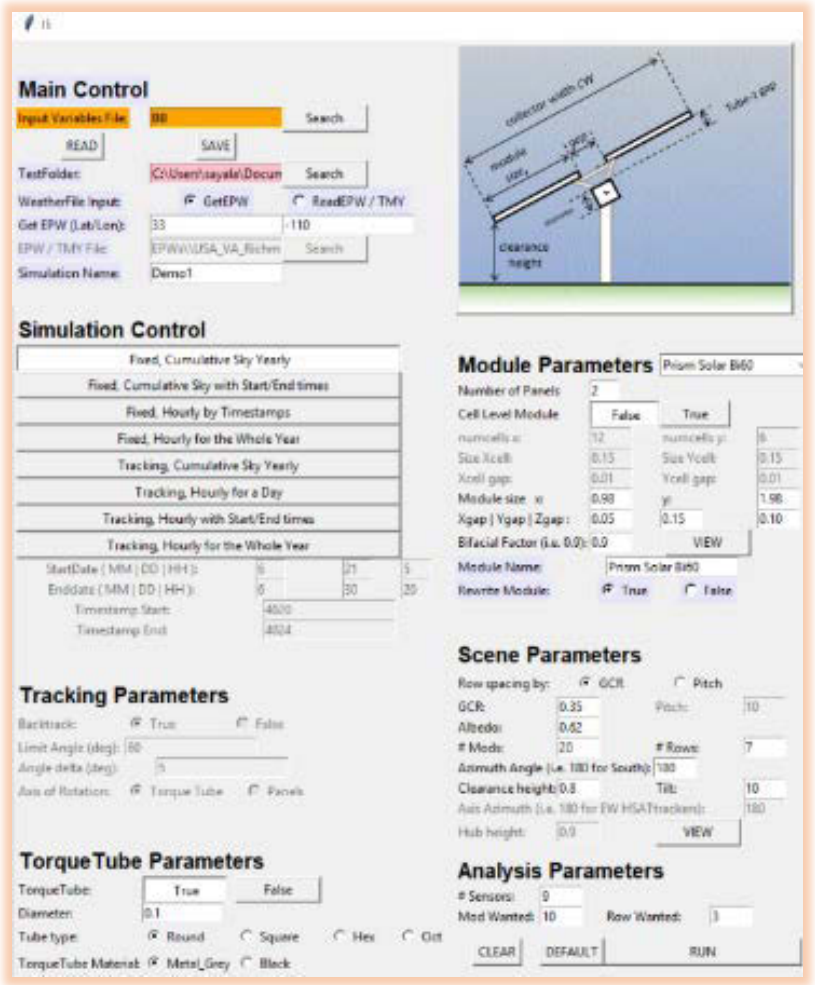
Monthly Bifacial Gain
Measured vs. Modeled

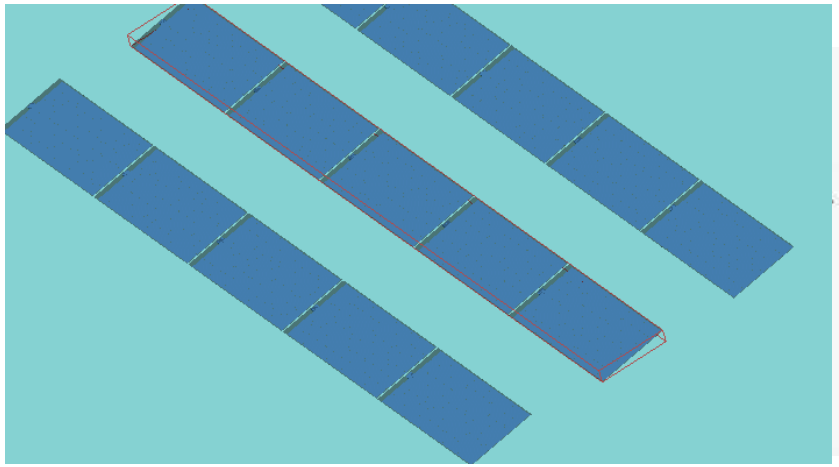
$$BG_E = \frac{E_{bifacial}}{E_{mono}} - 1$$

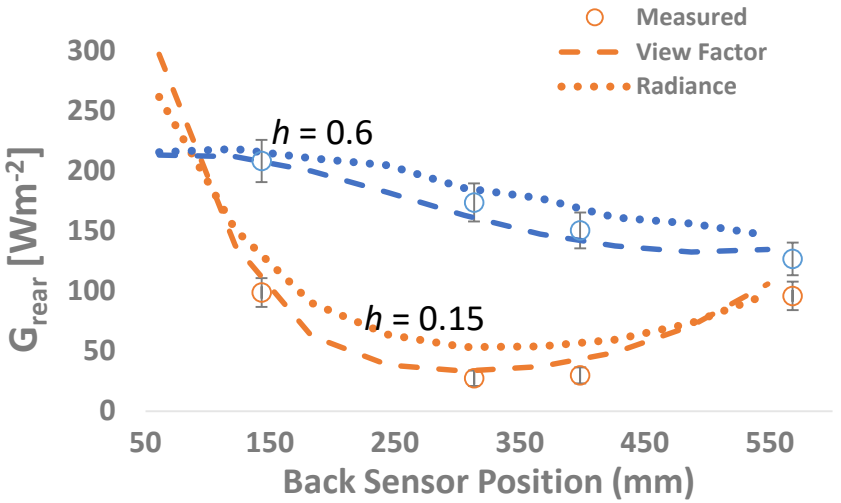
$$BG_{Irradiance} = \frac{G_{Total}}{G_{Front}} - 1$$



Bifacial_Radiance Model for Rear Irradiance







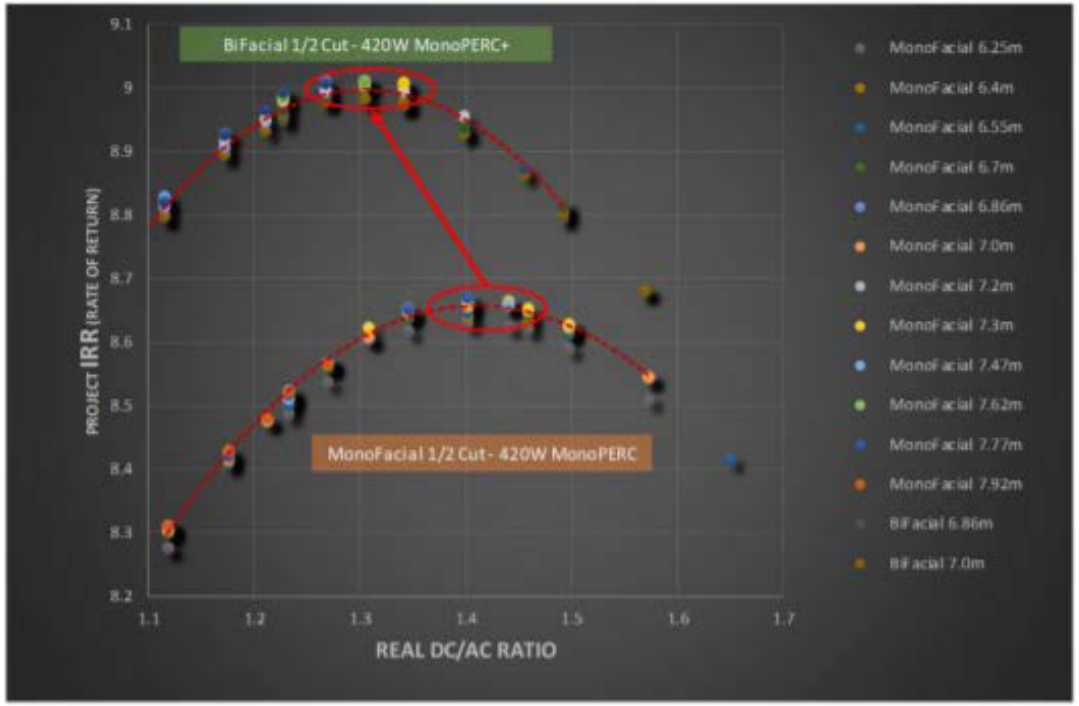
Open-source software freely available at
http://www.github.com/NREL/bifacial_radiance

Field validation shows good agreement with close-mount rooftop mockup

S. Ayala Pelaez, C. Deline, S. MacAlpine, B. Marion, J. Stein, R. Kostuk, "Comparison of bifacial solar irradiance model predictions with field validation," *IEEE Journal of Photovoltaics* **9**(1), 82–88 (2019).

BIFACIAL VS. MONOFACIAL SYSTEM DESIGN OPTIMIZATIONS

Project site in California (lower DHI/GHI)



Bifacial field optimizations:

GCR <<

DC/AC ratio <<

Itai Suez, 2019 BifiPV Workshop (Amsterdam)
http://bifipv-workshop.com/fileadmin/layout/images/bifiPV/presentations2019/bifiPV2019-Silfab_Suez.pdf

Conclusions

- Bifacial PV is becoming mainstream with gigawatts of installed projects.
- Energy gain depends on the site configuration and surface albedo. Models like SAM, PVSyst, and bifacial_radiance can assist with system design and power estimation.
- 1-axis tracker validation is underway at NREL and is showing good bifacial annual energy gain of 6.5% and 9% for PERC and Si-HJT, respectively.
- Model validation is underway, and current VF software (SAM, PVSyst) appears to be conservative relative to measured rear irradiance.

Thank you

www.nrel.gov

chris.deline@nrel.gov
silvana.ayala@nrel.gov

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