Ultimate Bifacial Showdown: 75kW Field Results

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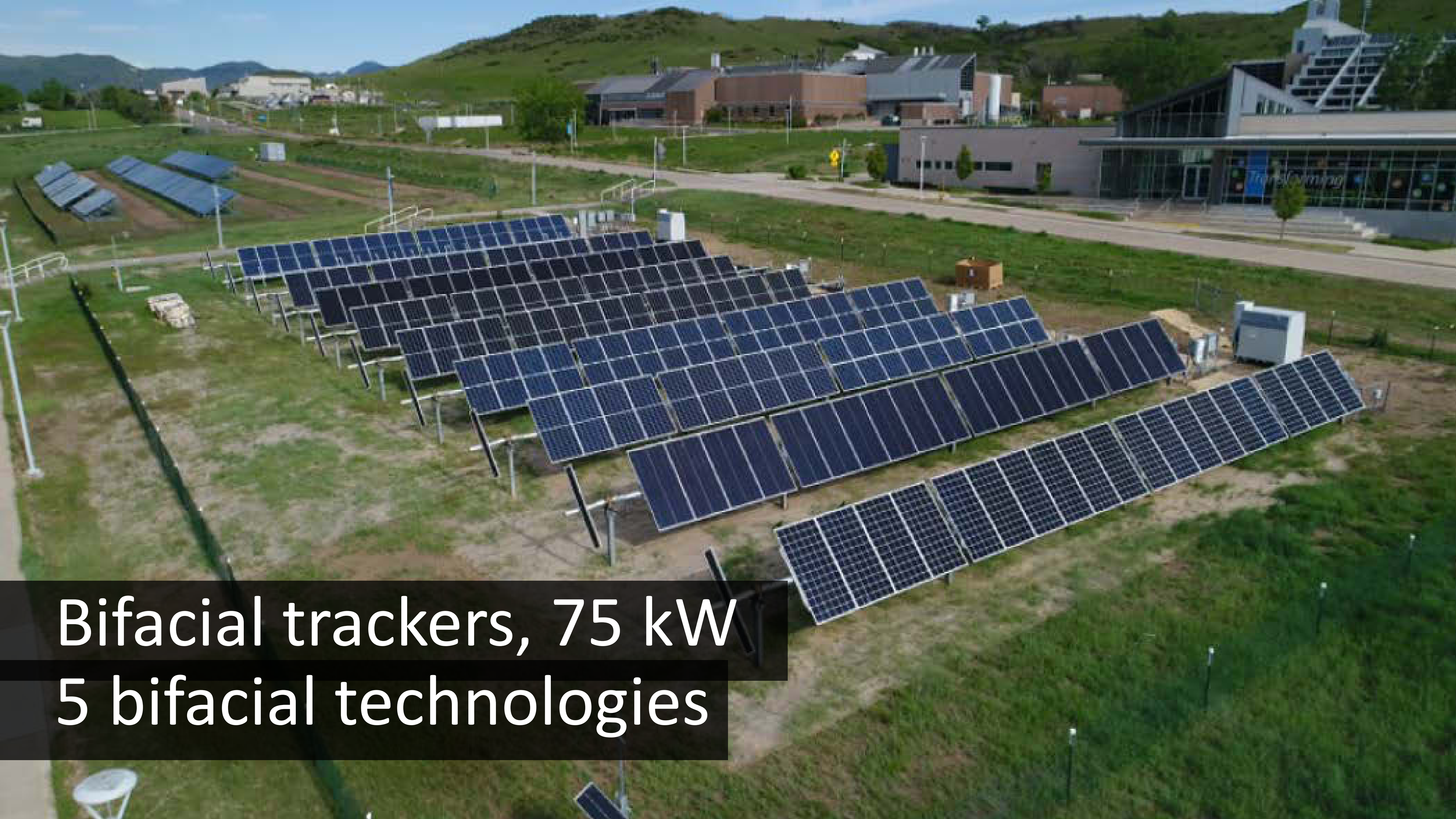
Content


Bifacial trackers, 75 kW
5 bifacial technologies

Bifacial system configuration

- 20 modules (7.5 kW) / row
- **4 PERC, 1 SHJ Bifacial strings**
- 3 PERC monofacial strings
- Module electronics / monitoring
- String kWh_{DC} monitoring
- Front, rear POA irradiance

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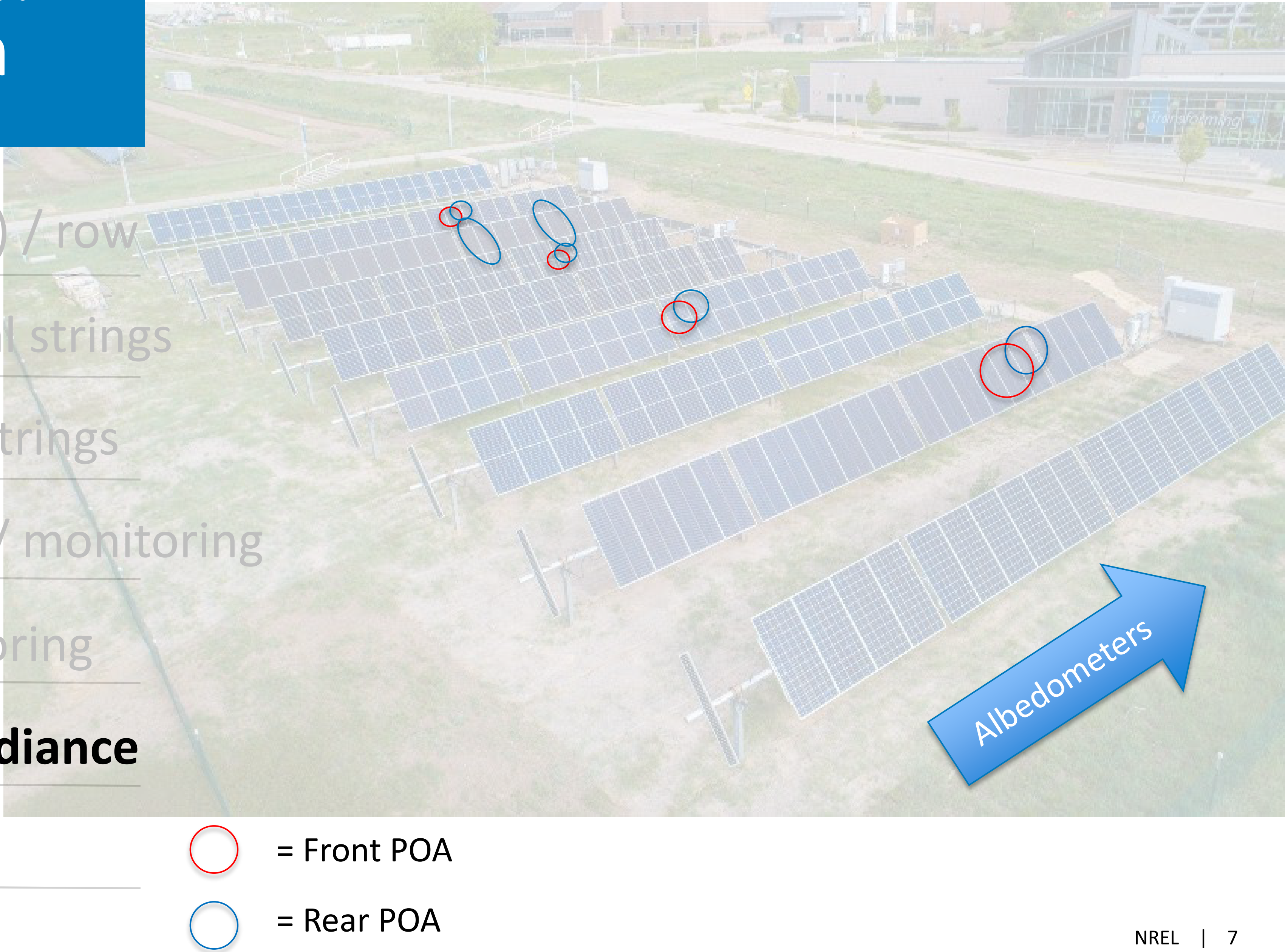
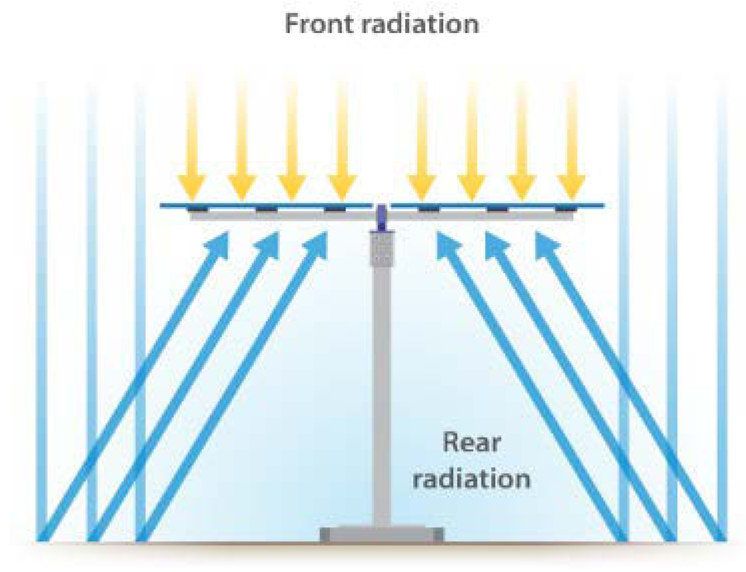


Technologies in the Field

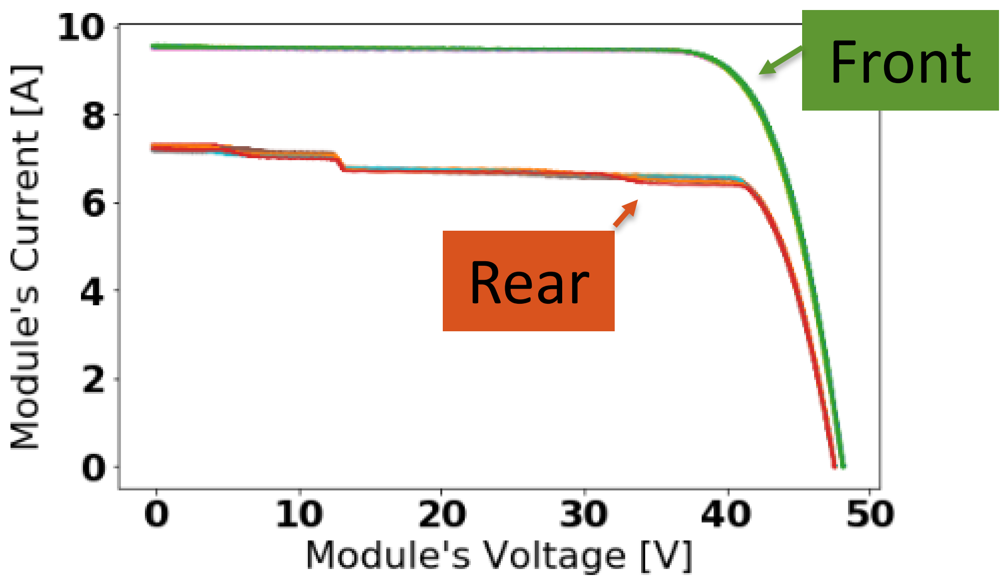


$$\varphi_{Isc} = \frac{Isc_r}{Isc_f}$$

$$\varphi_{Voc} = \frac{Voc_r}{Voc_f}$$

$$\varphi_{Pmax} = \frac{Pmax_r}{Pmax_f}$$

$$\varphi = Min(\varphi_{Isc}, \varphi_{Pmax})$$



Field Overview:

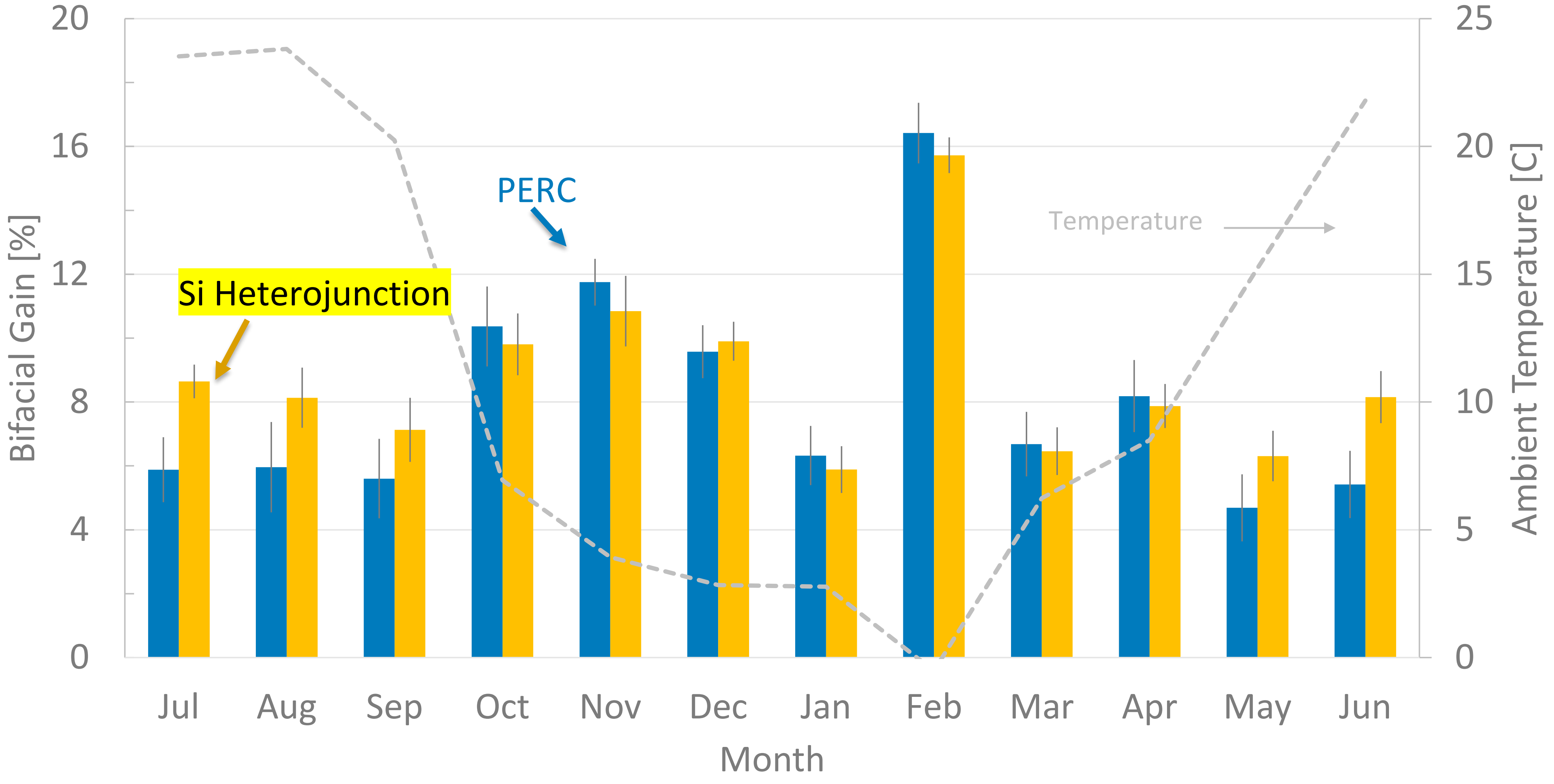
PERCs: ϕ 0.65–0.75 350-375 W	SHJ ϕ 0.9 400 W

Row 2 – Poly p-ptype PERC Module

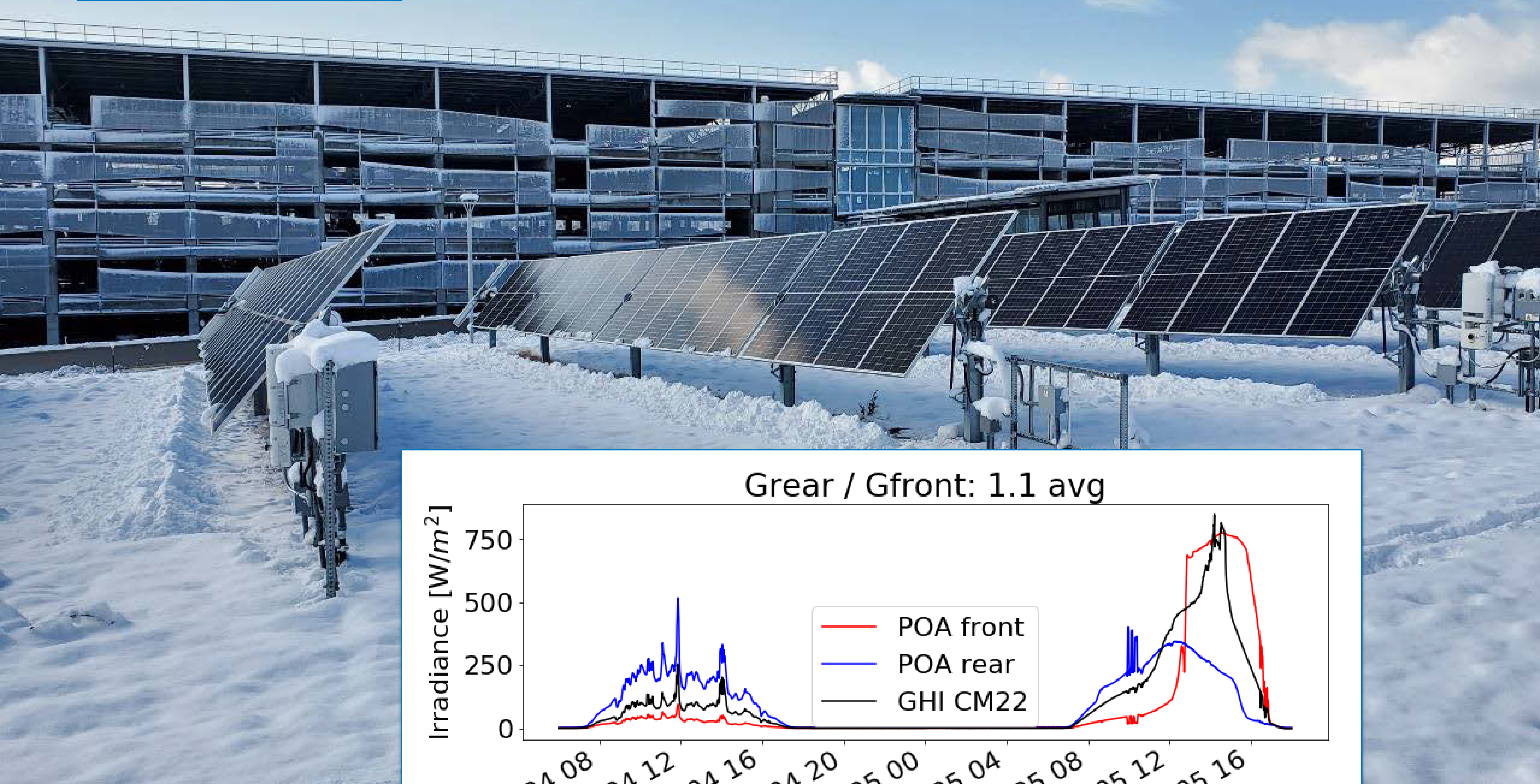
	Measurement Front Avg	std	Measurement Back	std
Pmp [W]	361.69	0.95	361.69	1.57

Bifacial Gain by Technology

$$\text{Bifacial Gain} = \frac{P_{dc_{bifacial}}}{P_{dc_{monofacial}}}$$

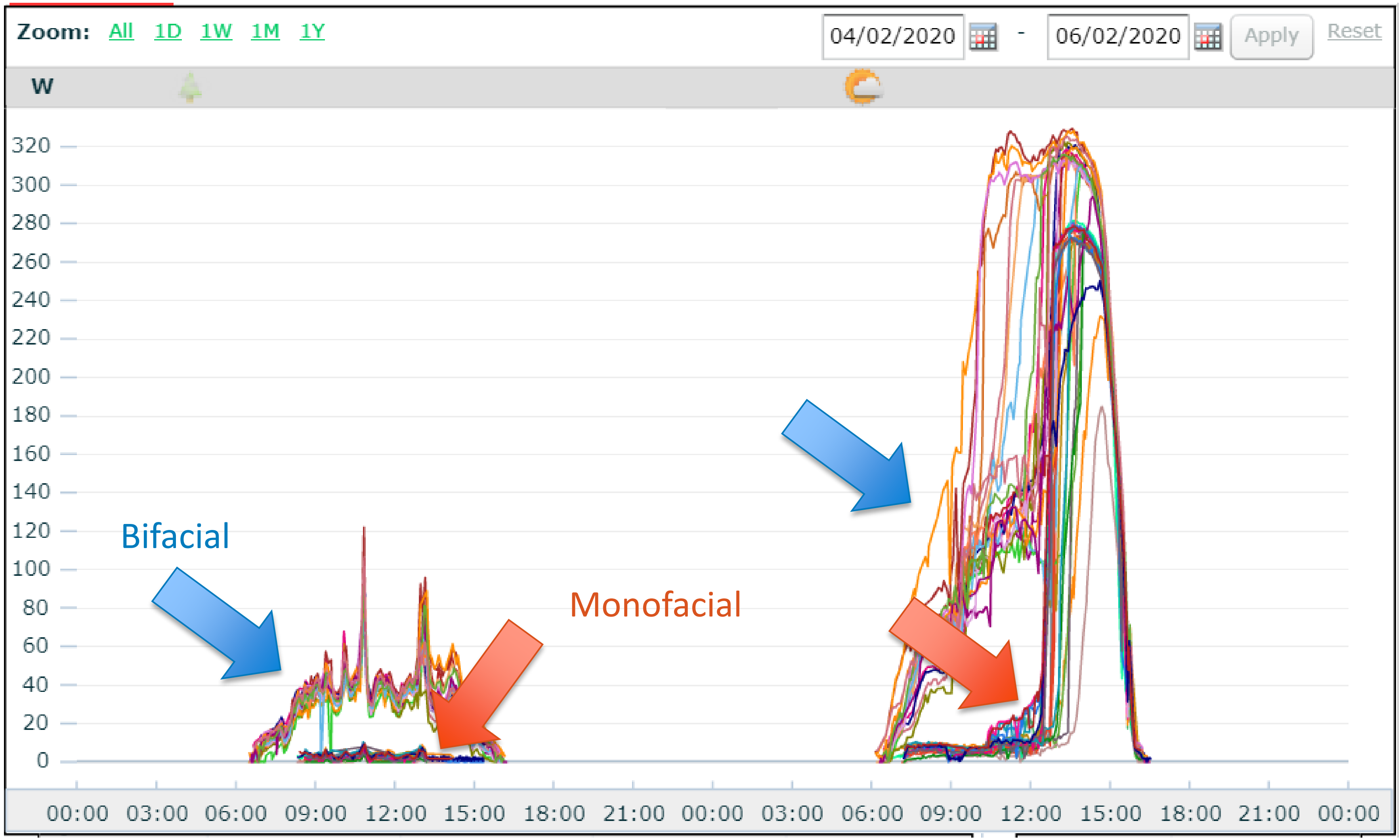


Snow



Grear / Gfront: 1.1 avg
Irradiance [W/m^2]
750
500
250
0
POA front
POA rear
GHI CM22

Snow

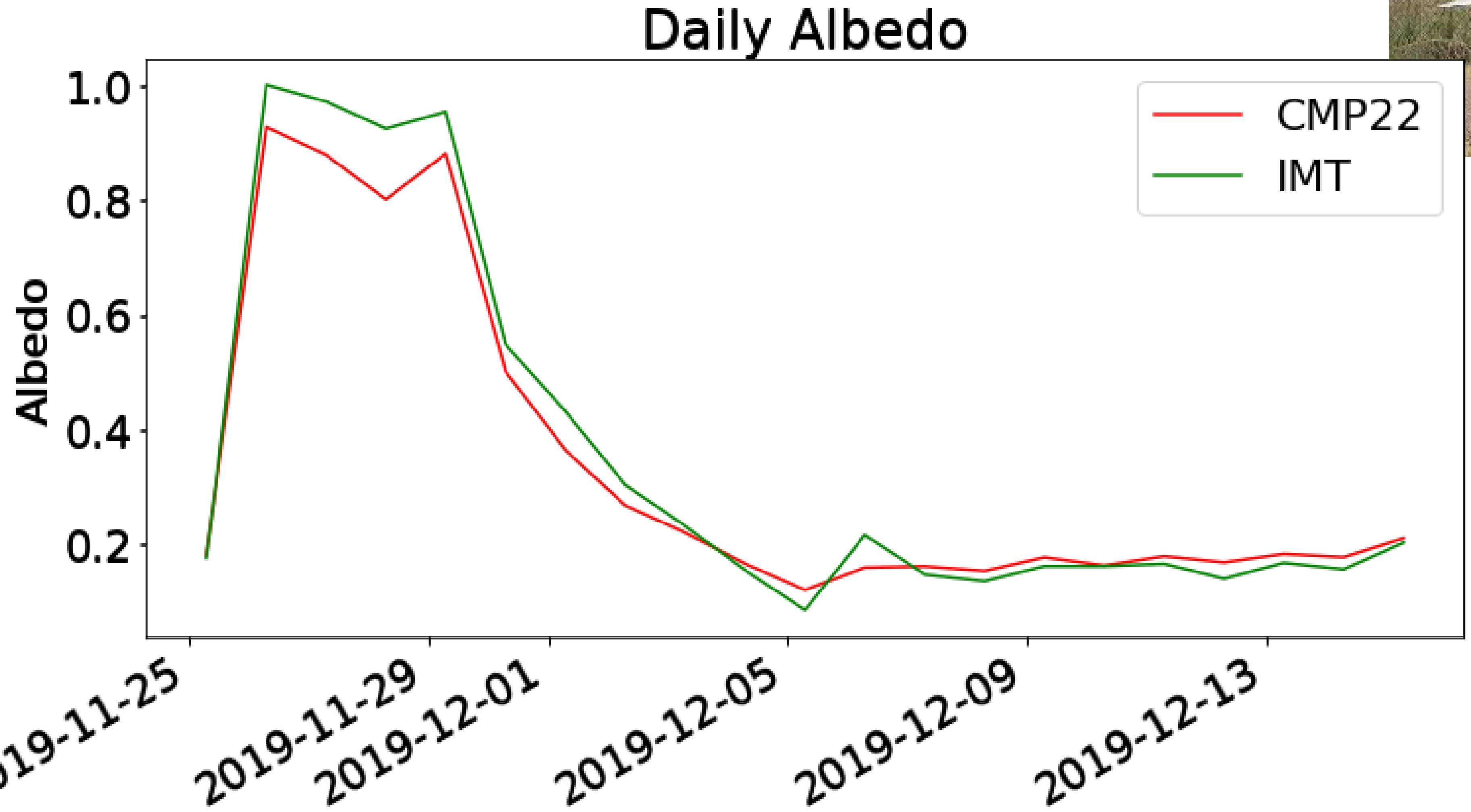


Zoom: All 1D 1W 1M 1Y
04/02/2020 - 06/02/2020 Apply Reset
W
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
00:00 03:00 06:00 09:00 12:00 15:00 18:00 21:00 00:00 03:00 06:00 09:00 12:00 15:00 18:00 21:00 00:00
Bifacial
Monofacial

Snow

Albedo Sensors

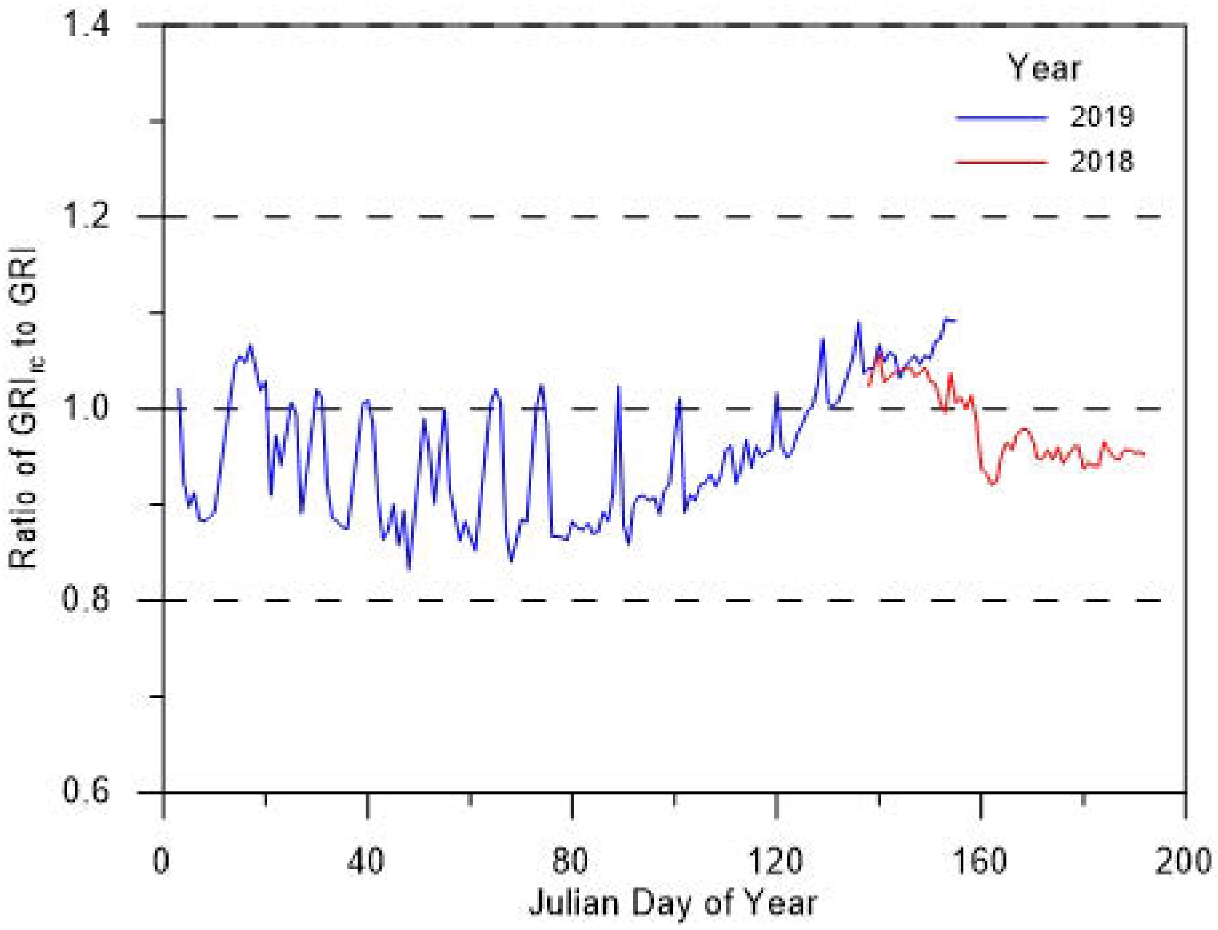
Oct. 23 to Dec. 31st



Albedo Assessments for Bifacial PV Systems

Measured Spectral Effect

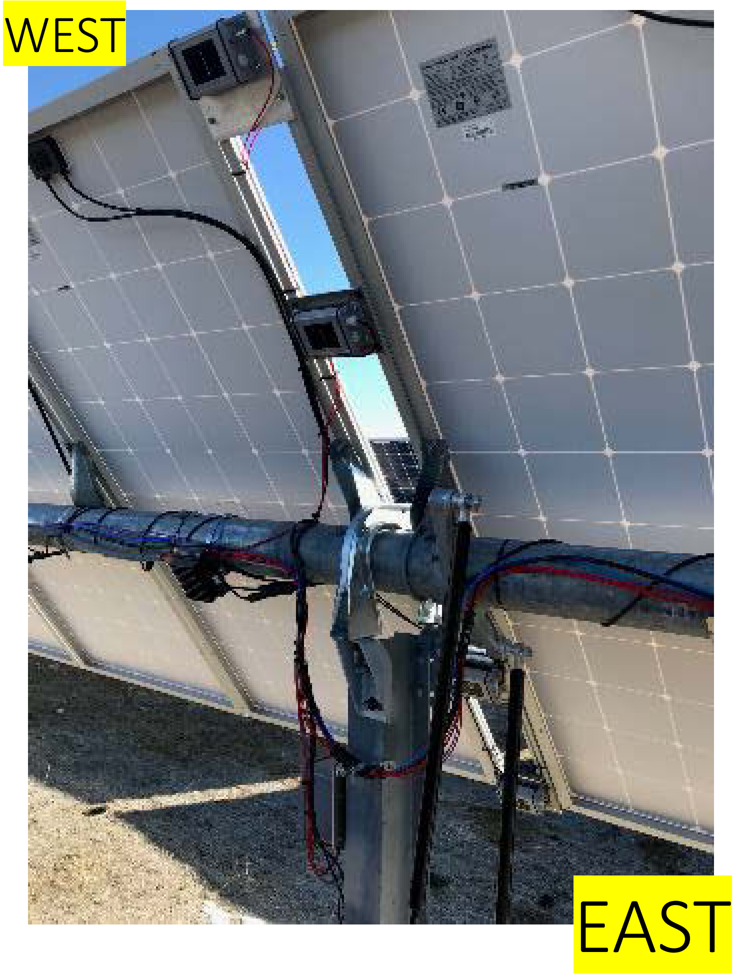
- Evaluated with the ratio of the daily GRI of the reference cell to that of the CMP22 pyranometer
- Spectral effect of snow was +15% relative to brown winter grass
- Spectral effect of green grass was greater than snow and +10% relative to drier summer grass



Michael Gostein, Bill Marion, Bill Stueve, PVSC 2020

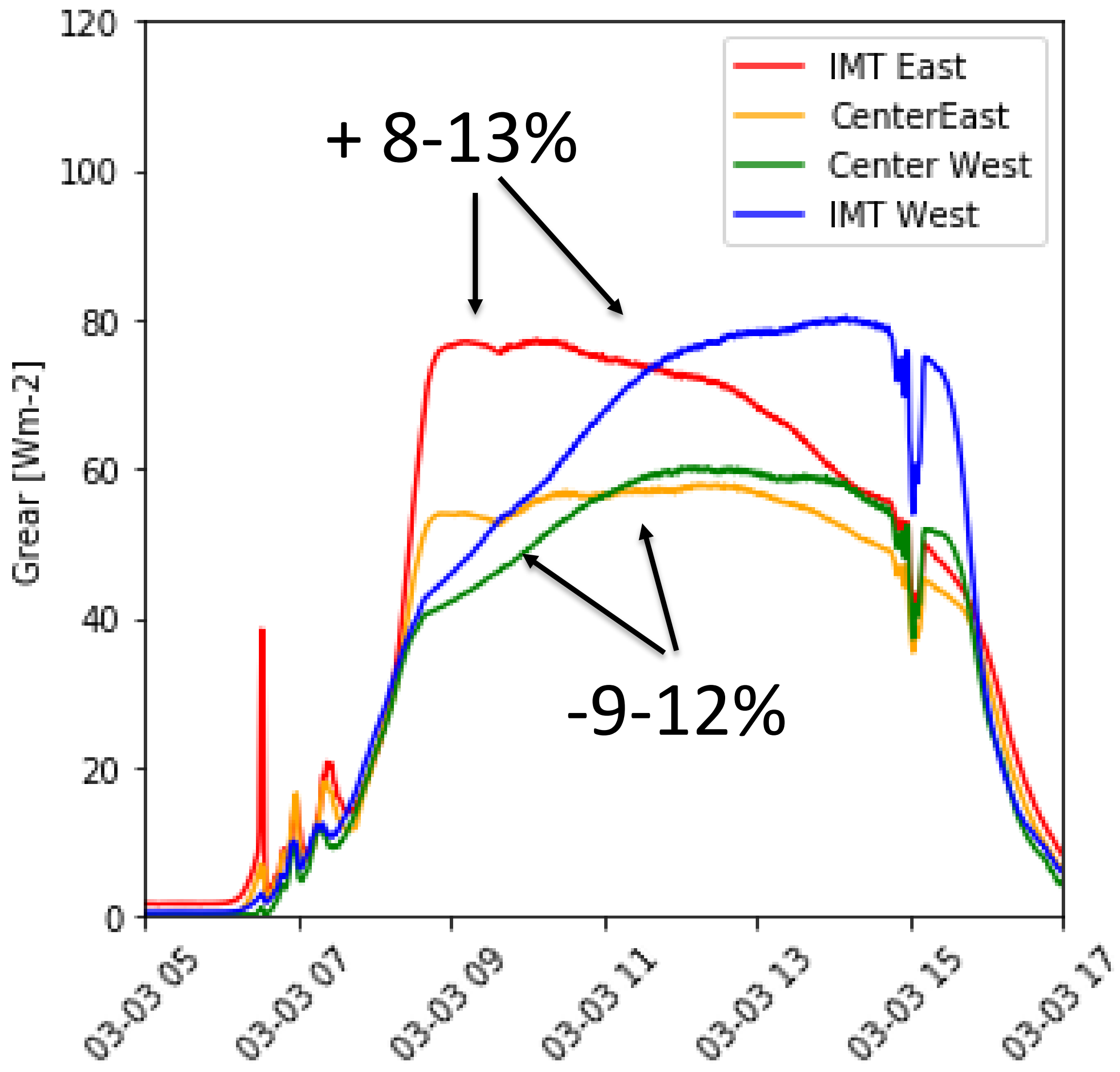
Rear POA Measurements

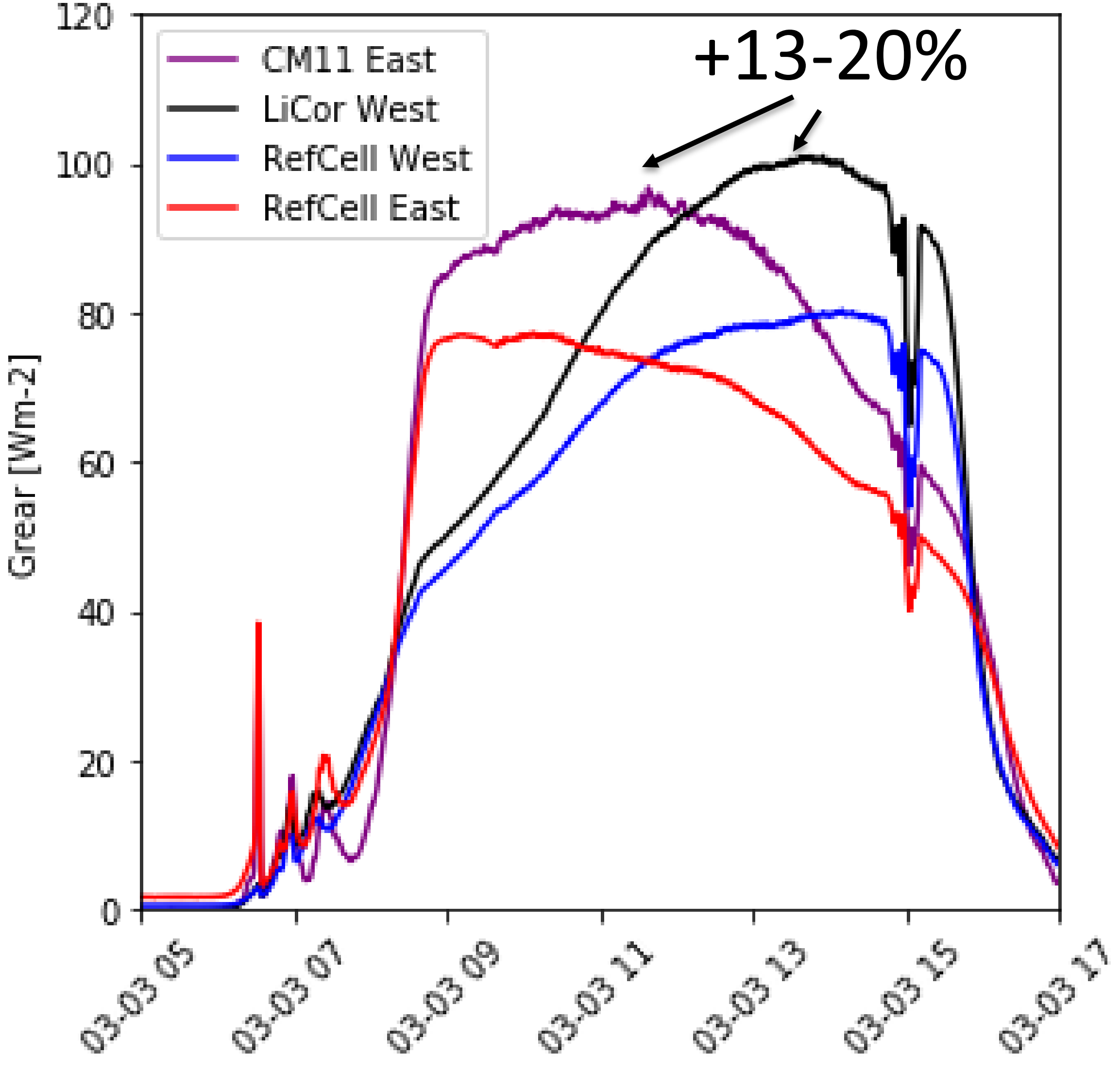
2 Broadband irradiance sensors



4 Reference Cells

Rear POA Variability

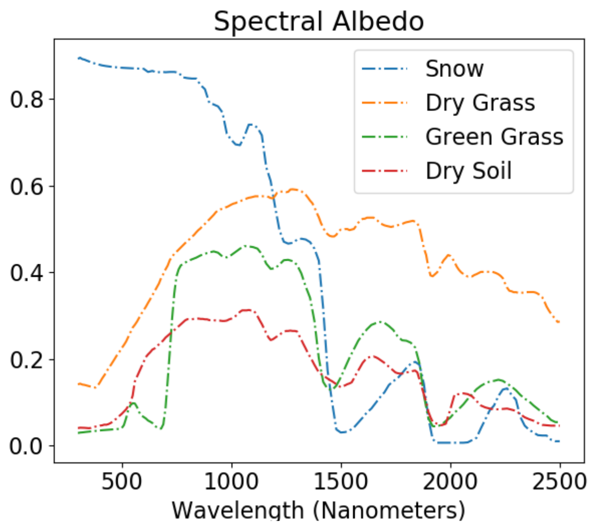


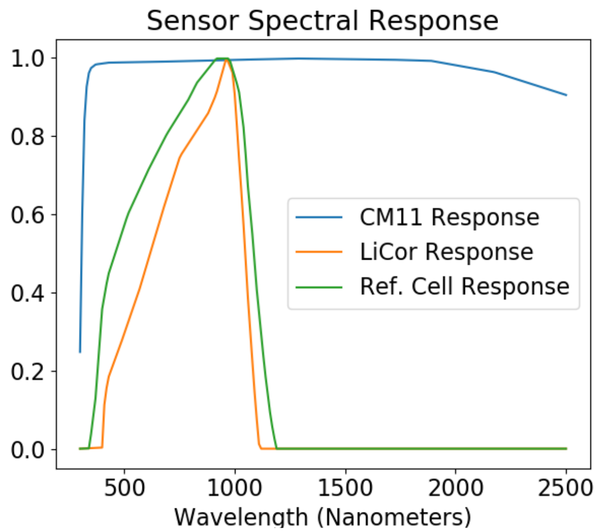


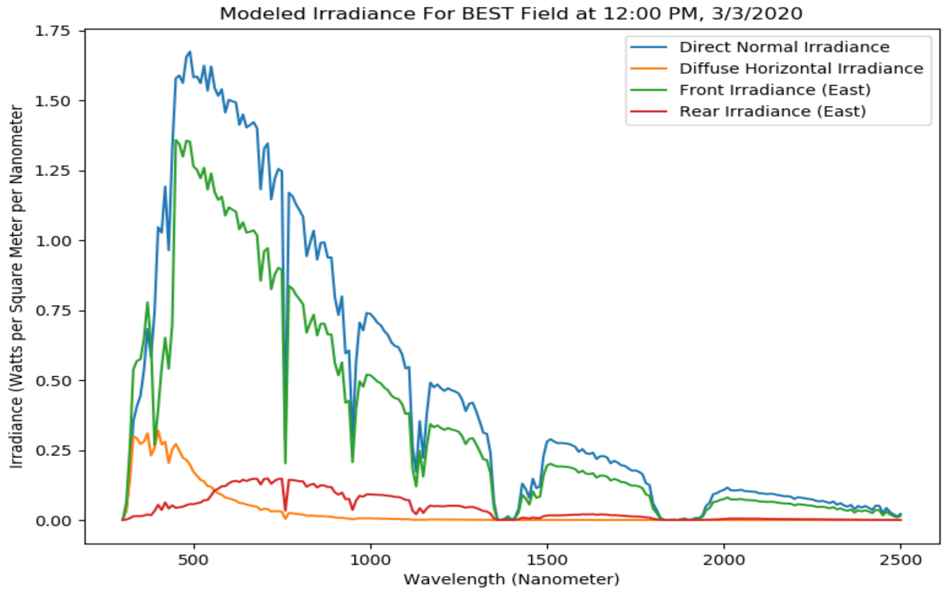
*Cumulative variability 06/19 to 03/20

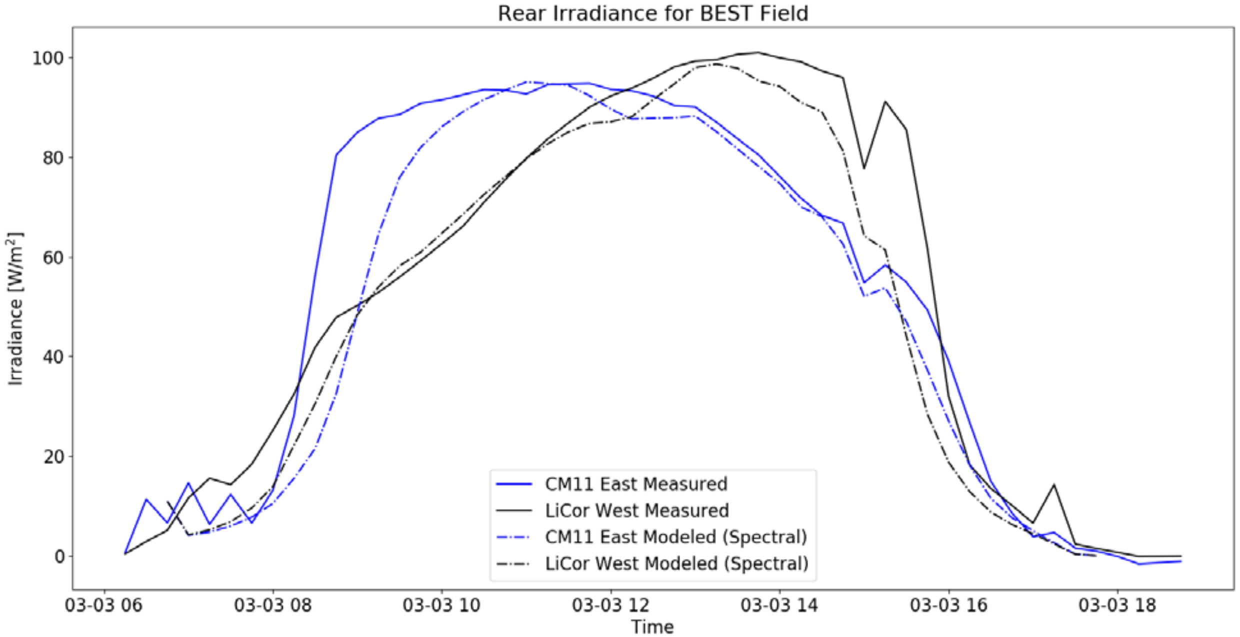
Rear POA Spectral Effects

https://nrel.heysummit.com/ August 5th, 1-3 PM MDT







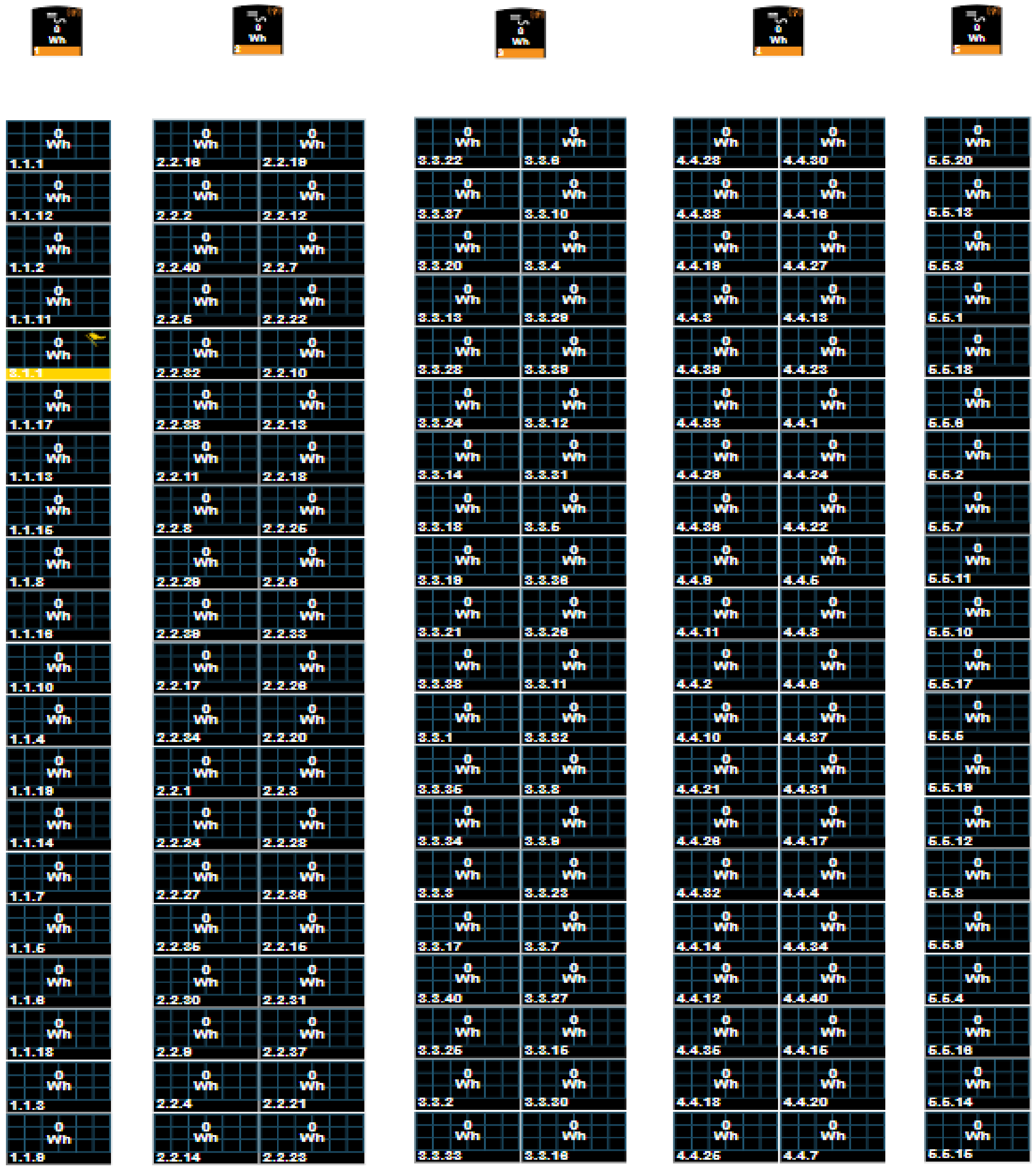


- Modeling full spectrum of light incident on modules using bifacial_radiance
- Analyze impacts of albedo, scene objects spectral reflectivity and spectral DNI + DHI on system performance
- Considering spectral response of modules and sensors. Validating with bifacial field data.
- Investigating simpler methods of approximating incident rear spectra

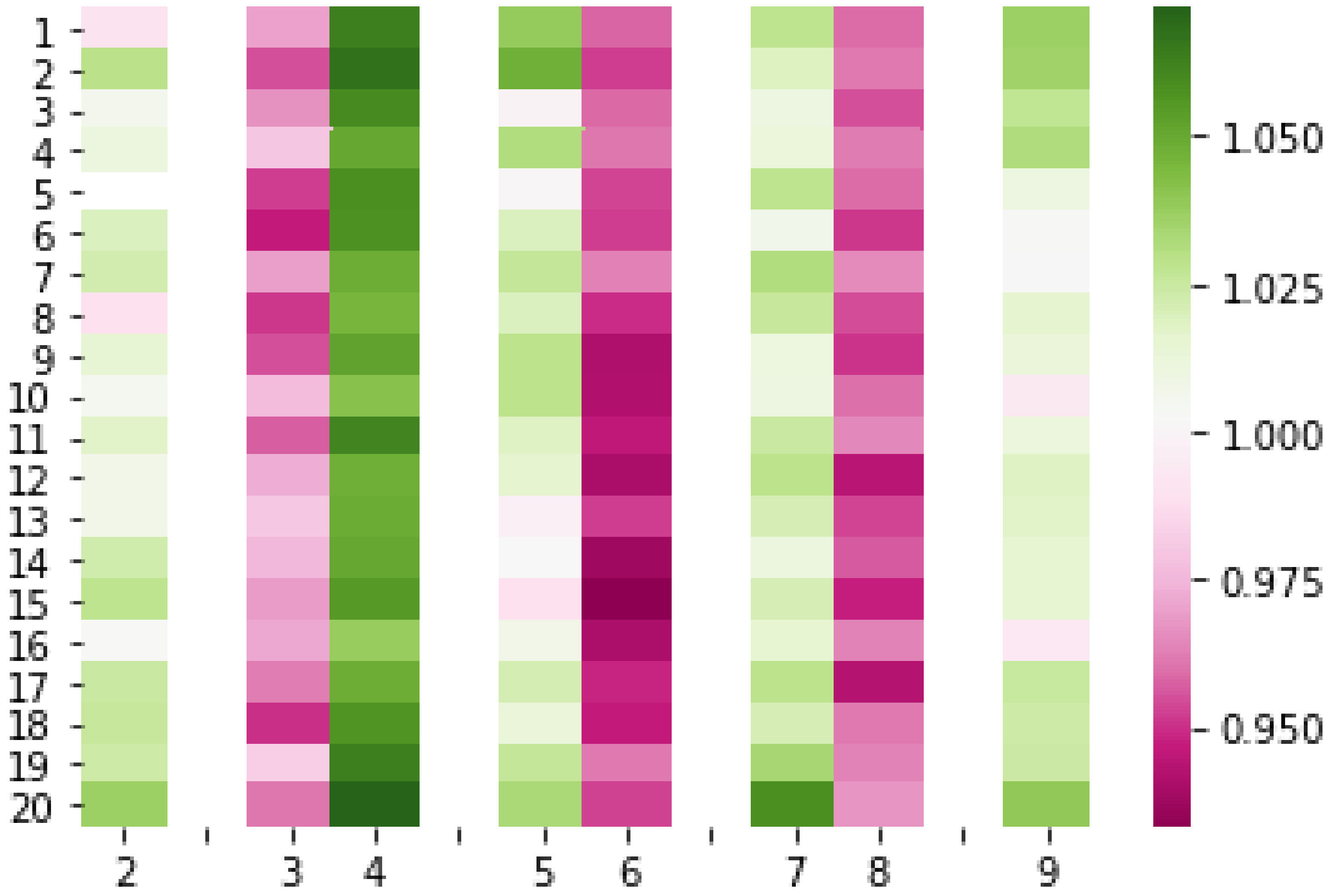
Research by Mark Monarch, NREL SULI
https://www.linkedin.com/in/mark-monarch/

Edge Effects

- **Module electronic monitoring**
- **String kWh_{DC} monitoring**

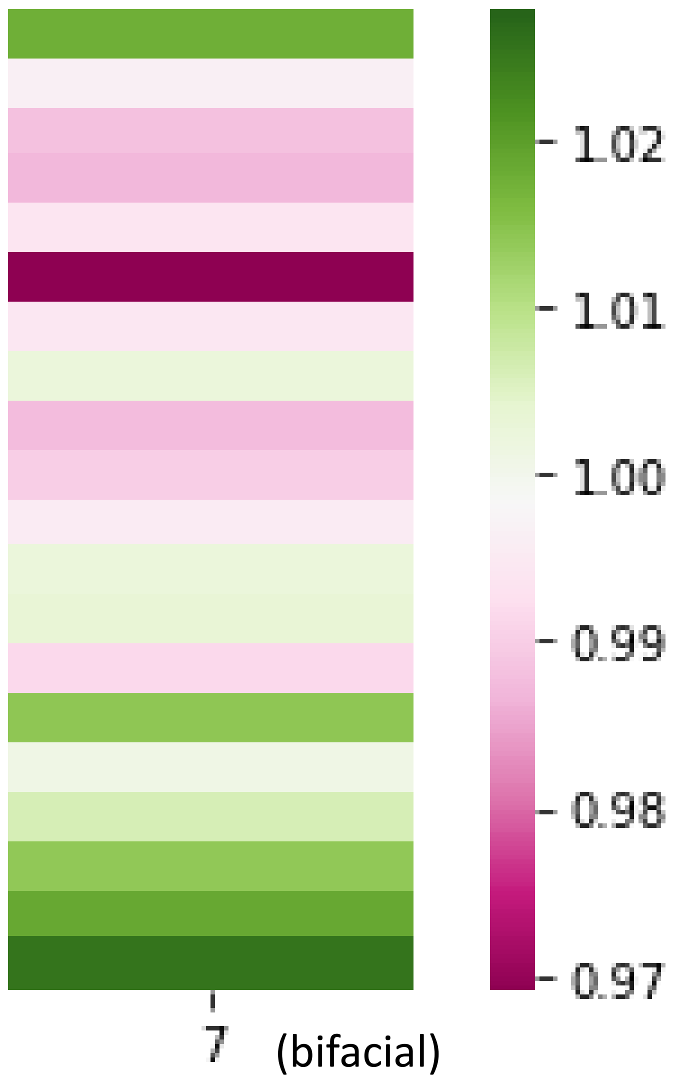


Field normalized Production



*Cumulative January-May 2020 Pmp

January-May Edge Effects



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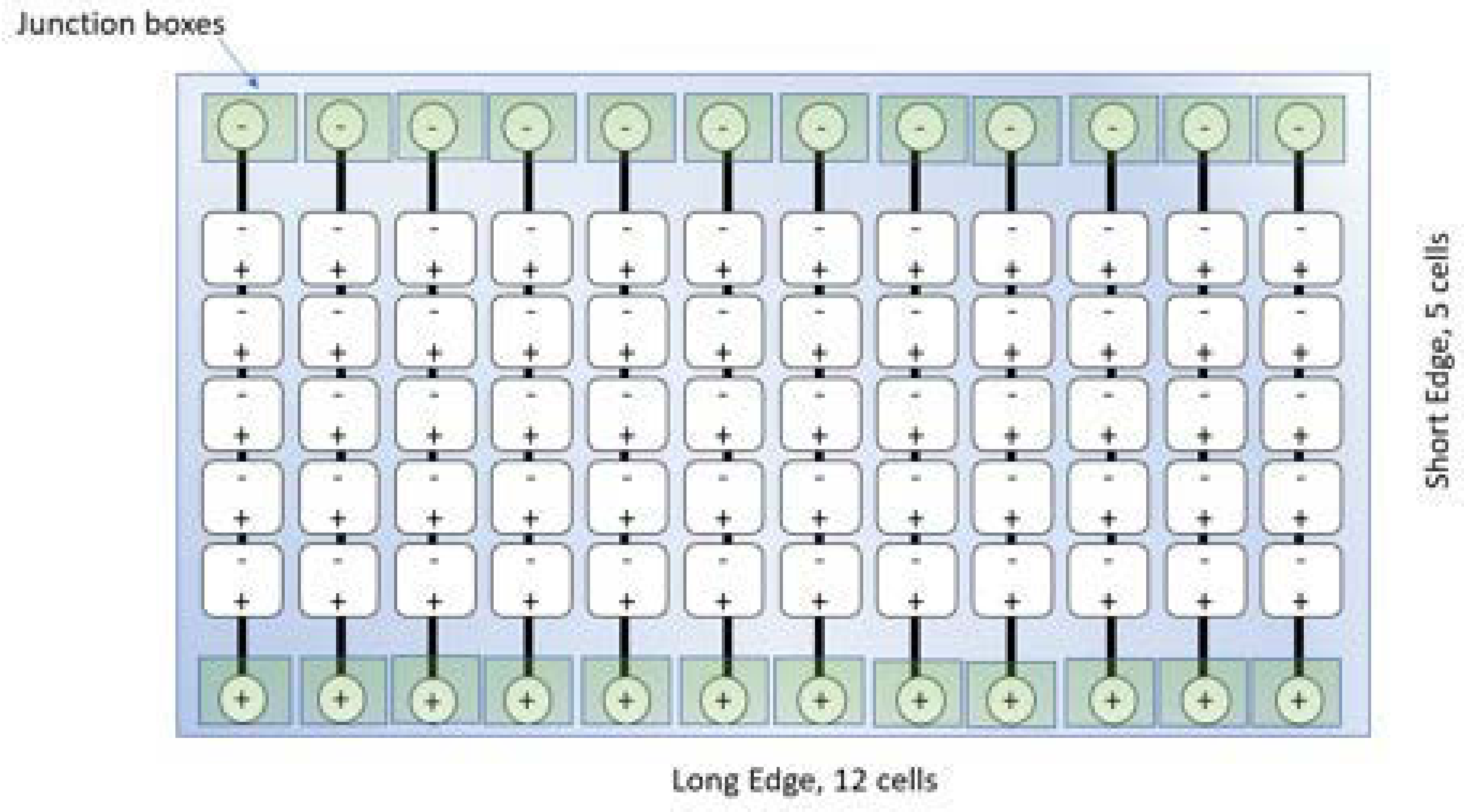
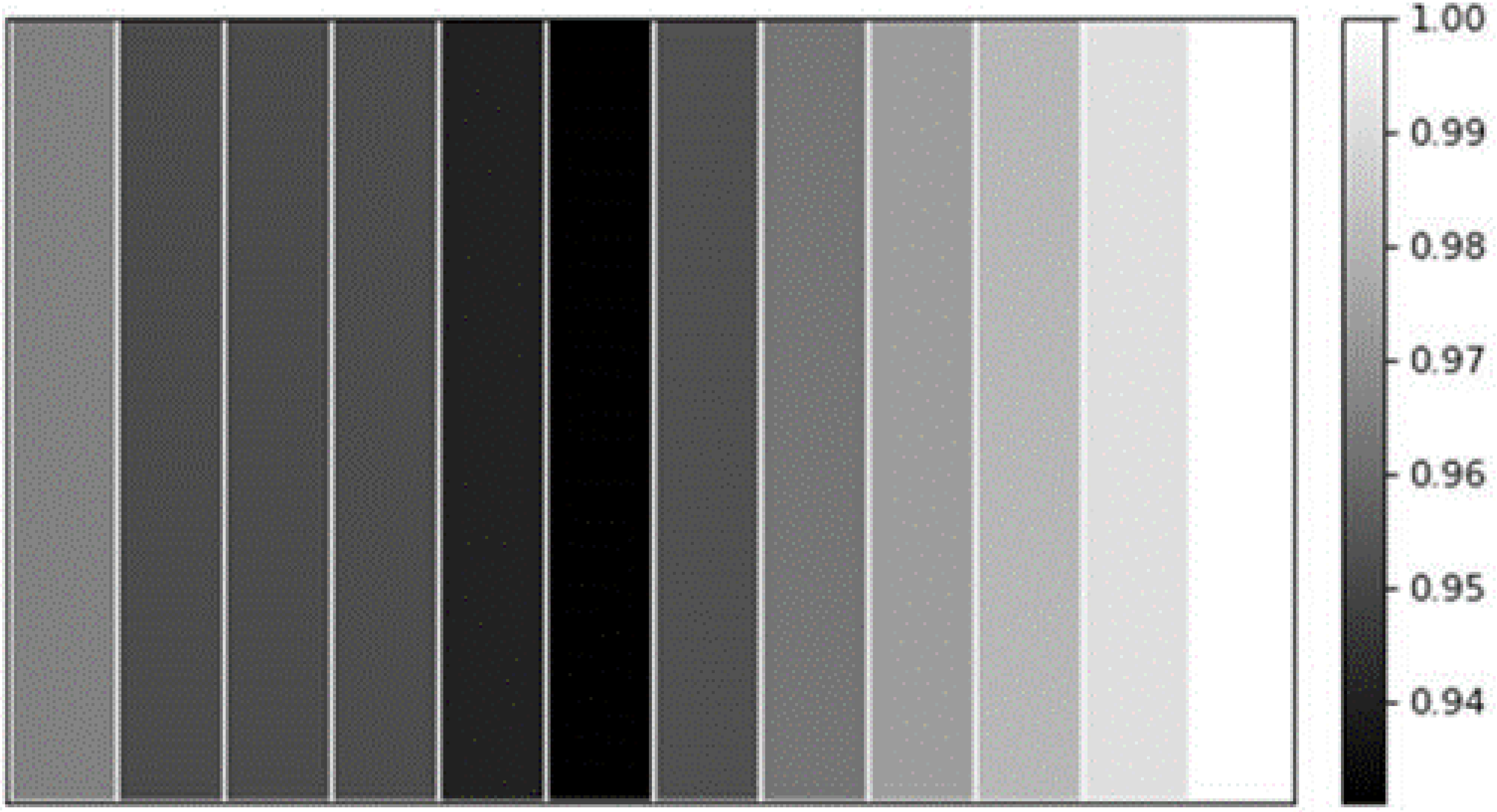
Shading Effects

Shading Effects



Shading Effects



*cumulative irradiance, normalized, December 2019 to January 2020

Data Available on DURAMAT

- 15min data, June 19 – May 2020, in excel and pickle data
- User Manual: site description and column headers
  - Row 2, Row 9 string performance and module level performance
  - Comparison monofacial string performance
  - Front and rear irradiance sensors
  - Weather data
  - Albedo data

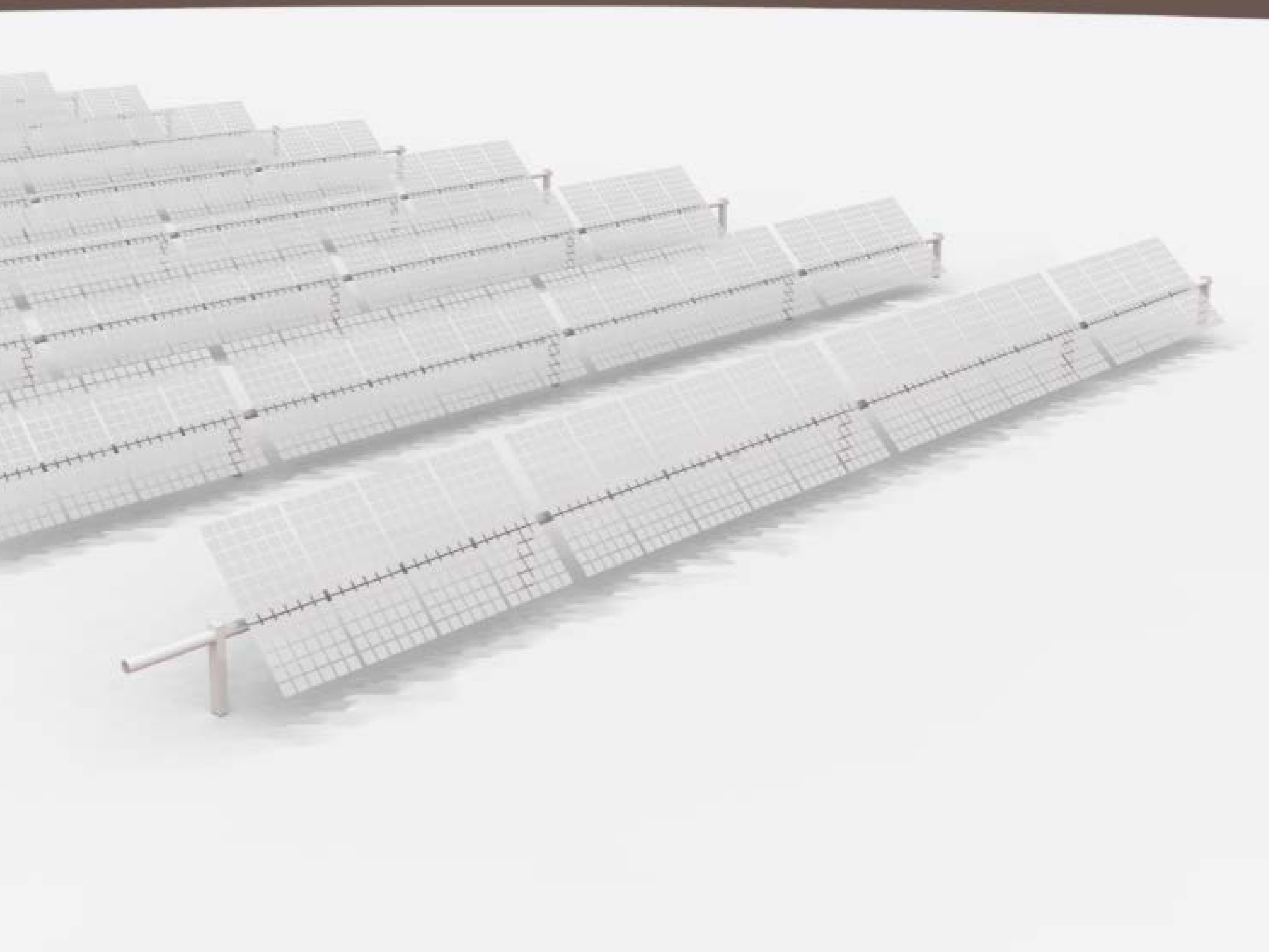
Variable	Category	Units	Description
row2dcp	Bifacial Row	W	Row DC-Power
row2Gpoa_front	Bifacial Row	W/m2	Plane of array irradiance, front-facing
row2kWh	Bifacial Row	kWh	Row Energy
row2dcv	Bifacial Row	V	Row Voltage
row2dci	Bifacial Row	A	Row Current
row2tmod	Bifacial Row	C	Row module temperature
Yf2	Bifacial Row		Row DC-power normalized by row nameplate capacity measured on Spire
PR2	Bifacial Row		Row Performance Ratio, calculated with row 9 front POA irradiance
row9dcp	Bifacial Row	W	Row DC-Power
row9Gpoa_front	Bifacial Row	W/m2	Plane of array irradiance, front-facing
row9Gpoa_rear	Bifacial Row	W/m2	Plane of array irradiance, rear-facing
row9kWh	Bifacial Row	kWh	Row Energy
row9dcv	Bifacial Row	V	Row Voltage
row9dci	Bifacial Row	A	Row Current
row9tmod	Bifacial Row	C	Row module temperature
Yf9	Bifacial Row		Row DC-power normalized by row nameplate capacity measured on Spire
PR9	Bifacial Row		Row Performance Ratio, calculated with row 9 front POA irradiance
poa_irradiance_front_IMT	POA Irradiances	W/m2	Row 3 Module 5 from North, front facing IMT reference cell
poa_irradiance_rear_IMT_West	POA Irradiances	W/m2	Row 3 Module 5 from North, rear facing IMT reference cell
poa_irradiance_rear_IMT_CenterWest	POA Irradiances	W/m2	Row 3 Module 5 from North, rear facing IMT reference cell
poa_irradiance_rear_IMT_CenterEast	POA Irradiances	W/m2	Row 3 Module 5 from North, rear facing IMT reference cell
poa_irradiance_rear_IMT_East	POA Irradiances	W/m2	Row 3 Module 5 from North, rear facing IMT reference cell
poa_irradiance_front_licor	POA Irradiances	W/m2	Row 3 Module 10 from North, front facing licor sensor
poa_irradiance_rear_licor	POA Irradiances	W/m2	Row 3 Module 10 from North, rear facing licor sensor
poa_irradiance_front_cm11	POA Irradiances	W/m2	Row 3 Module 10 from North, front facing CM11 sensor
poa_irradiance_rear_cm11	POA Irradiances	W/m2	Row 3 Module 10 from North, rear facing CM11 sensor
sunkitty_albedo_1	Albedo		Albedo measured by Sunkitty CM22
sunkitty_GRI_CM22	Albedo	W/m2	Ground Reflected Irradiance measured by CM22
sunkitty_GHI_CM22	Albedo	W/m2	Ground Horizontal Irradiance measured by CM22
sunkitty_albedo_2	Albedo		Albedo measured by Sunkitty IMT reference cell
sunkitty_GRI_IMT	Albedo	W/m2	Ground Reflected Irradiance measured by IMT reference cell
sunkitty_GHI_IMT	Albedo	W/m2	Ground Horizontal Irradiance measured by IMT reference cell
sunkitty_albedo_3	Albedo		Albedo measured by Sunkitty Apogee Licor pyranometer
sunkitty_GRI_AP	Albedo	W/m2	Ground Reflected Irradiance measured by Apogee Licor pyranometer
sunkitty_GHI_AP	Albedo	W/m2	Ground Horizontal Irradiance measured by Apogee Licor pyranometer
Hydra_current_1	Hydra	A	Custom Module measured short-circuit current
Hydra_current_2	Hydra	A	Custom Module measured short-circuit current
Hydra_current_3	Hydra	A	Custom Module measured short-circuit current
Hydra_current_4	Hydra	A	Custom Module measured short-circuit current
Hydra_current_5	Hydra	A	Custom Module measured short-circuit current
Hydra_current_6	Hydra	A	Custom Module measured short-circuit current
Hydra_current_7	Hydra	A	Custom Module measured short-circuit current
Hydra_current_8	Hydra	A	Custom Module measured short-circuit current
Hydra_current_9	Hydra	A	Custom Module measured short-circuit current
Hydra_current_10	Hydra	A	Custom Module measured short-circuit current
Hydra_current_11	Hydra	A	Custom Module measured short-circuit current
Hydra_current_12	Hydra	A	Custom Module measured short-circuit current
temp_ambient	Weather	C	Ambient tempterature
wind_direction	Weather		Wind direction
wind_speed	Weather	m/s	Wind speed
SRRL Tower Dry Bulb Temp [deg C]	SRRL	C	SRRL ambient temperature
SRRL Avg Wind Speed @ 6ft [m/s]	SRRL	m/s	SRRL wind speed
SRRL Direct CHP1-1 [W/m^2]	SRRL	W/m2	SRRL DNI
SRRL Diffuse 8-48 (vent) [W/m^2]	SRRL	W/m2	SRRL DHI
SRRL Global CMP22 (vent/cor) [W/m^2]	SRRL	W/m2	SRRL GHI
SRRL Albedo (CMP11)]	SRRL		SRRL Albedo

https://datahub.duramat.org/dataset/best-field-data

Model vs Measured

Photo credit: C. Deline

Software Comparisons

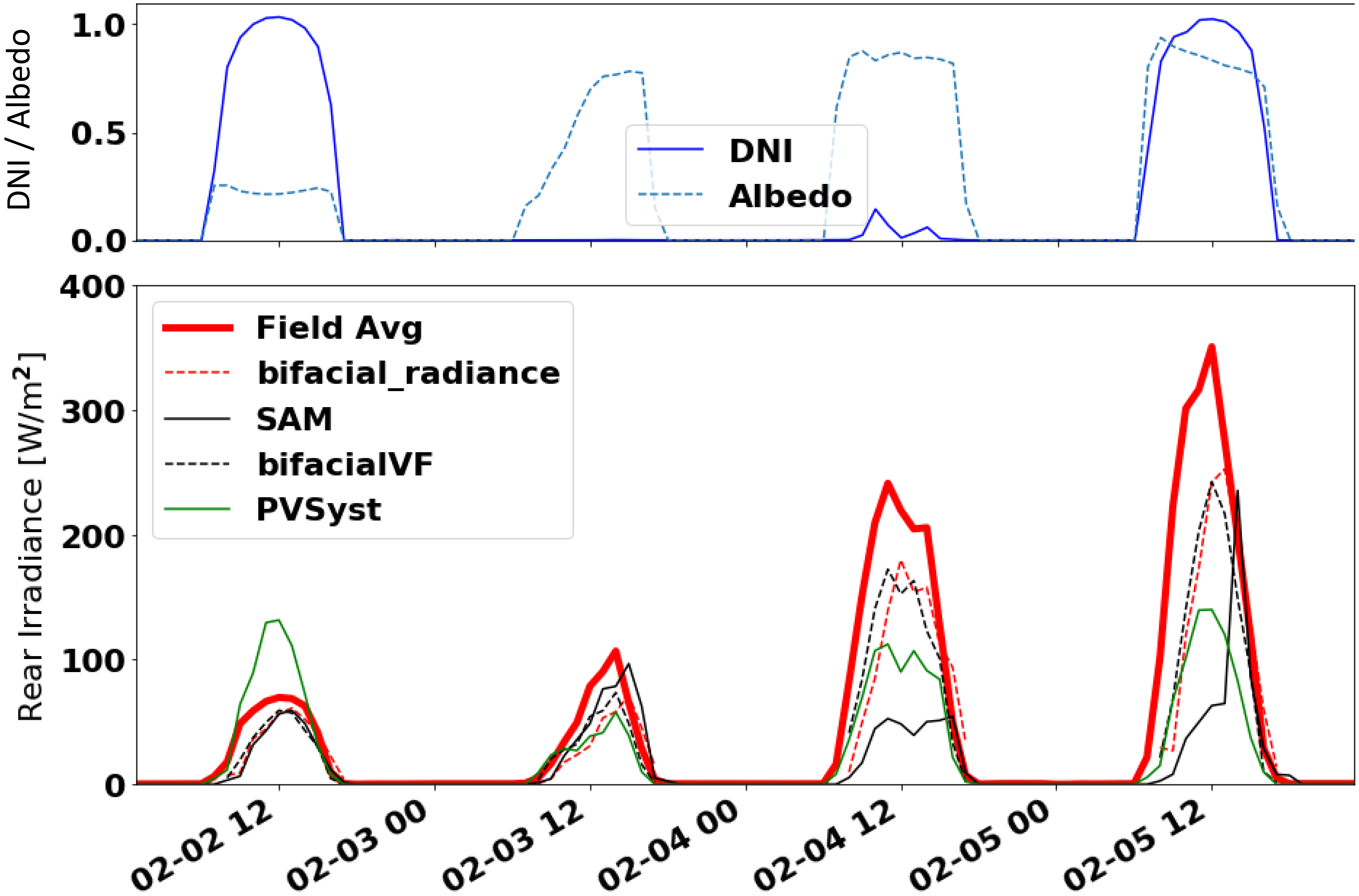


- SAM
- PVSyst

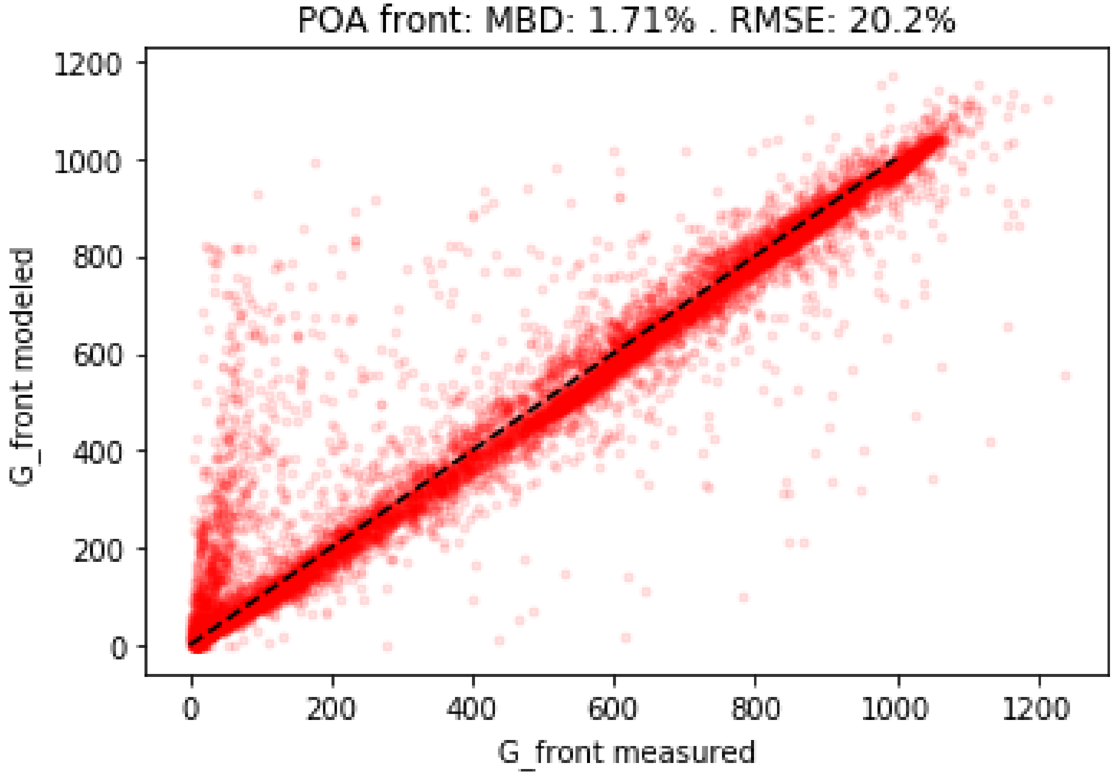
Irradiance Modeling Only

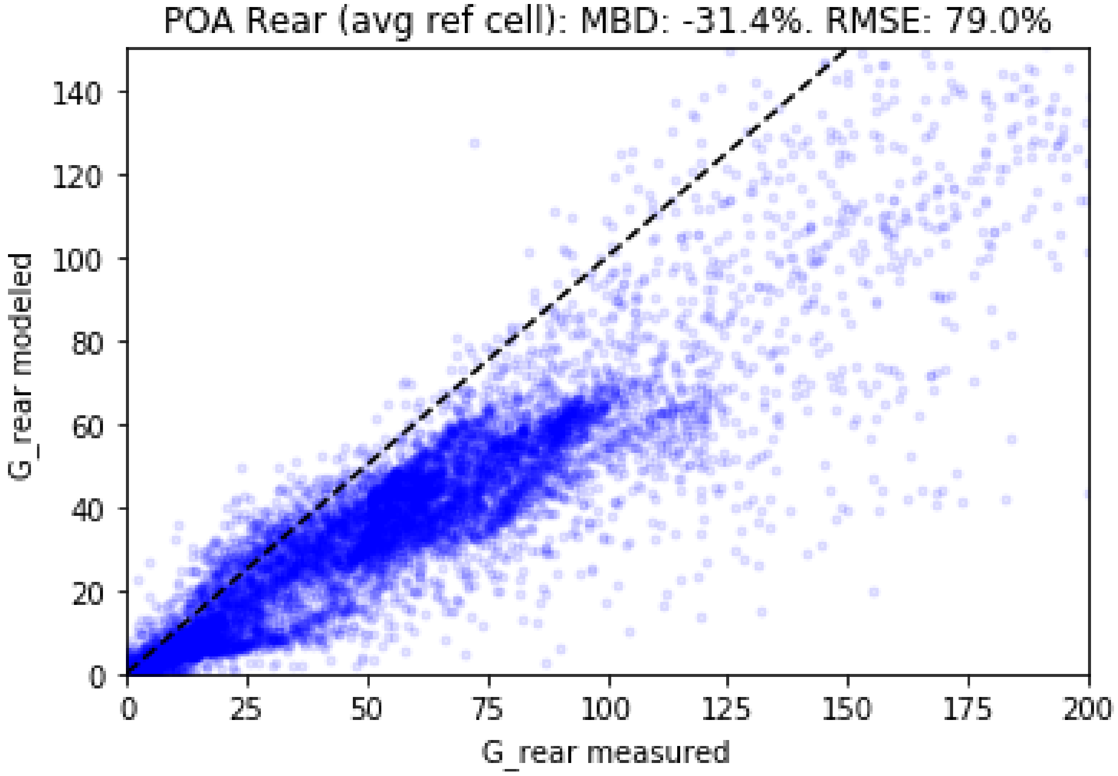
- bifacialVF
- bifacial_radiance

Models under-prediction is more pronounced under high albedo and high DNI conditions



Modeled Irradiance

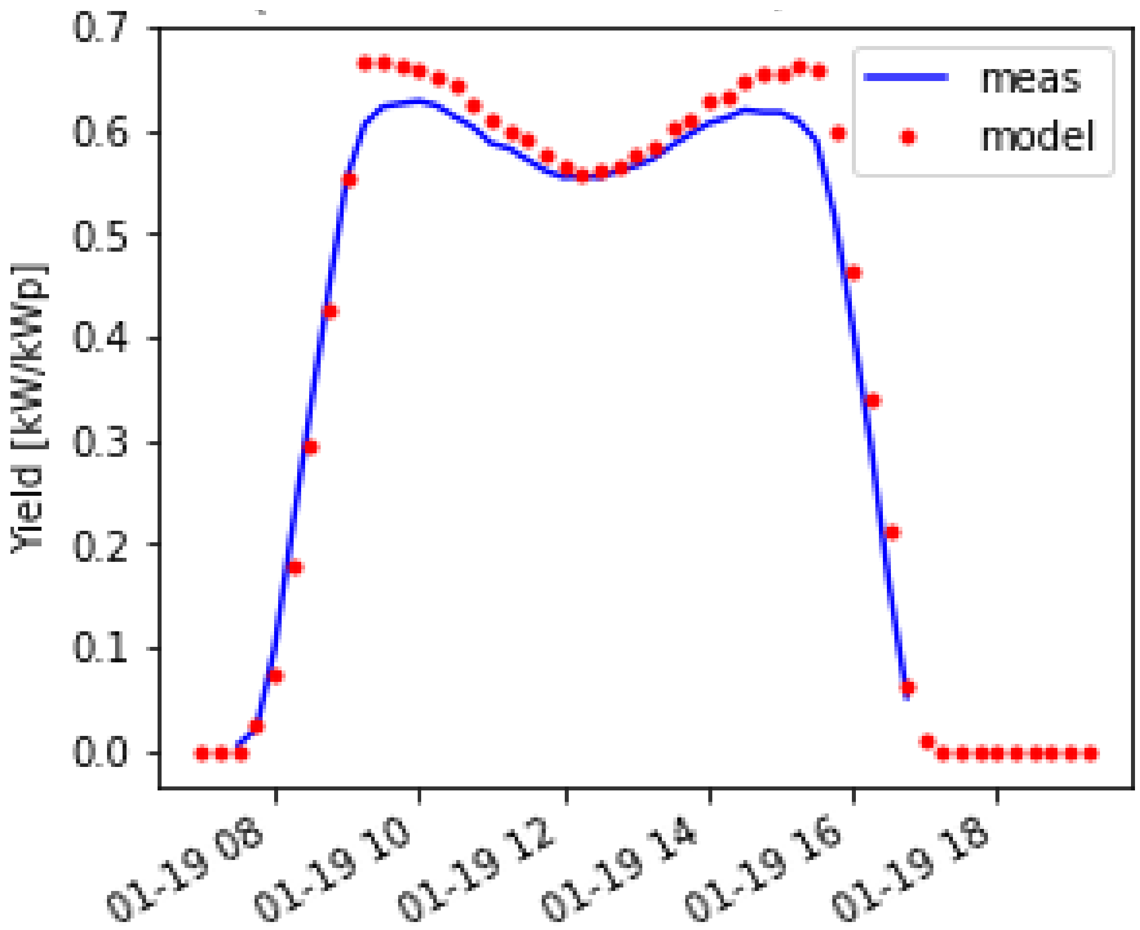




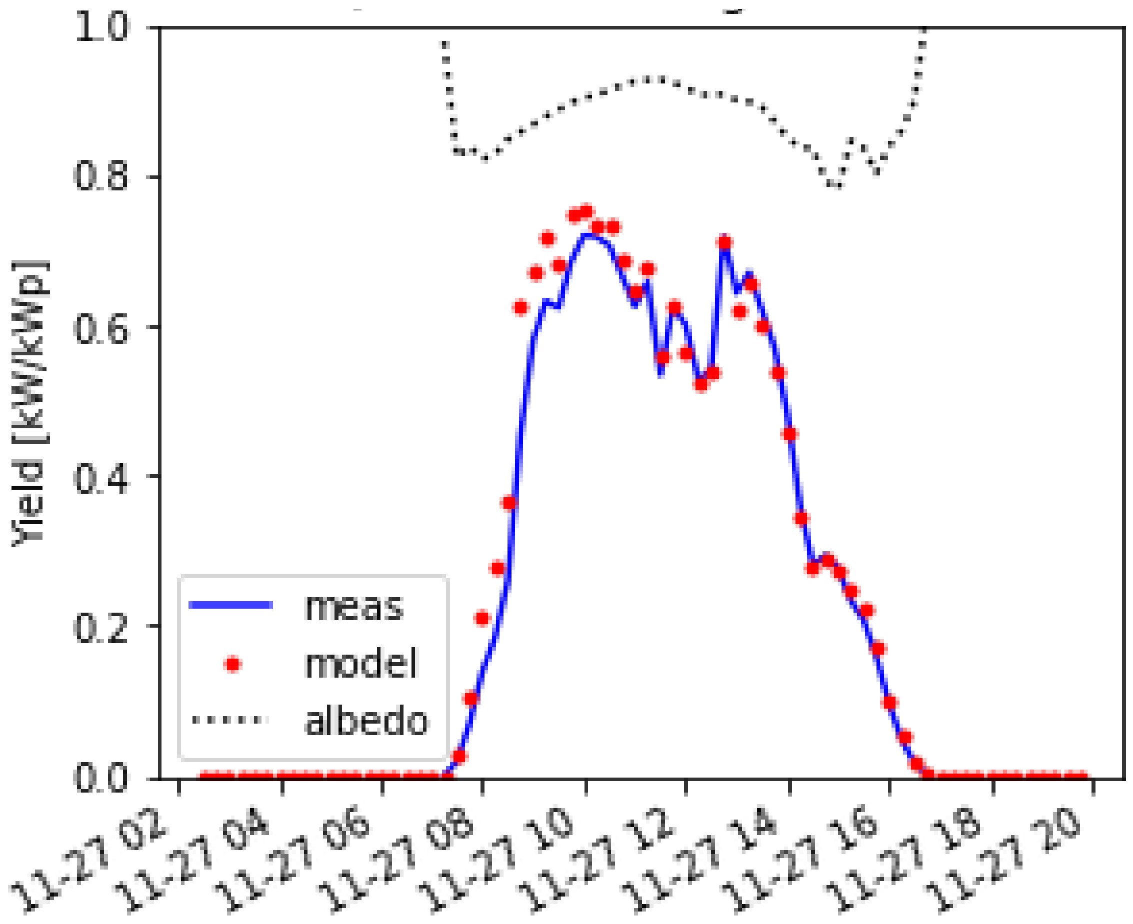
SAM, July 2019 – March 2020

Modeled Power Results

Low albedo day (0.2)

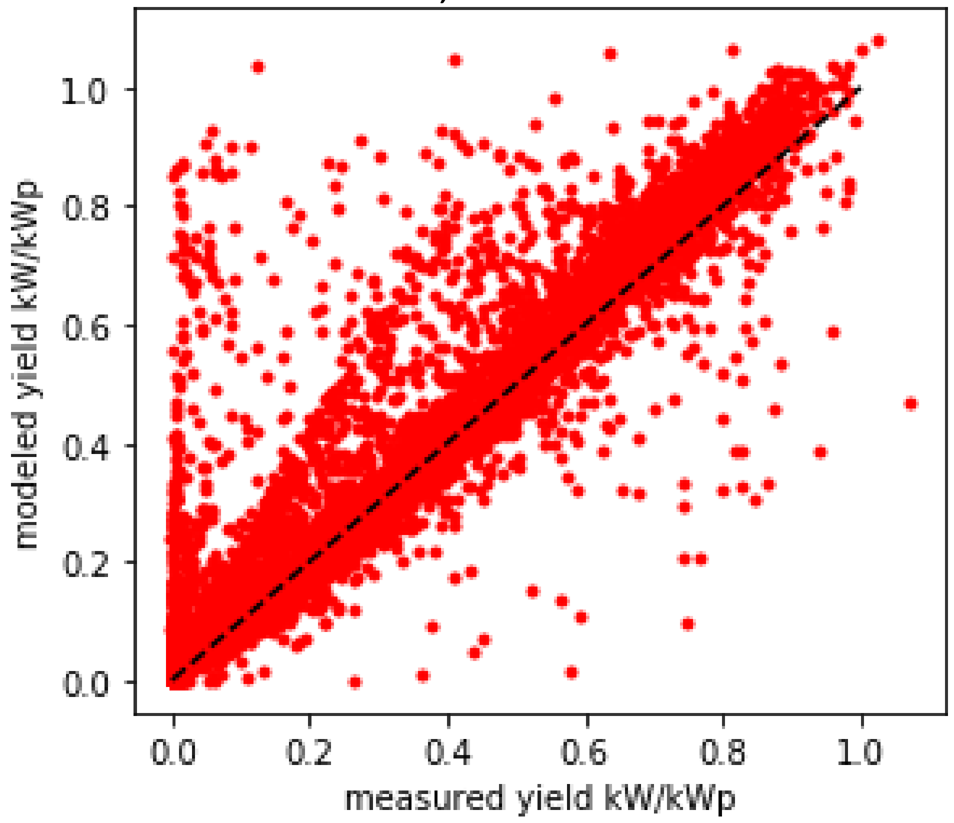


High albedo (0.8)

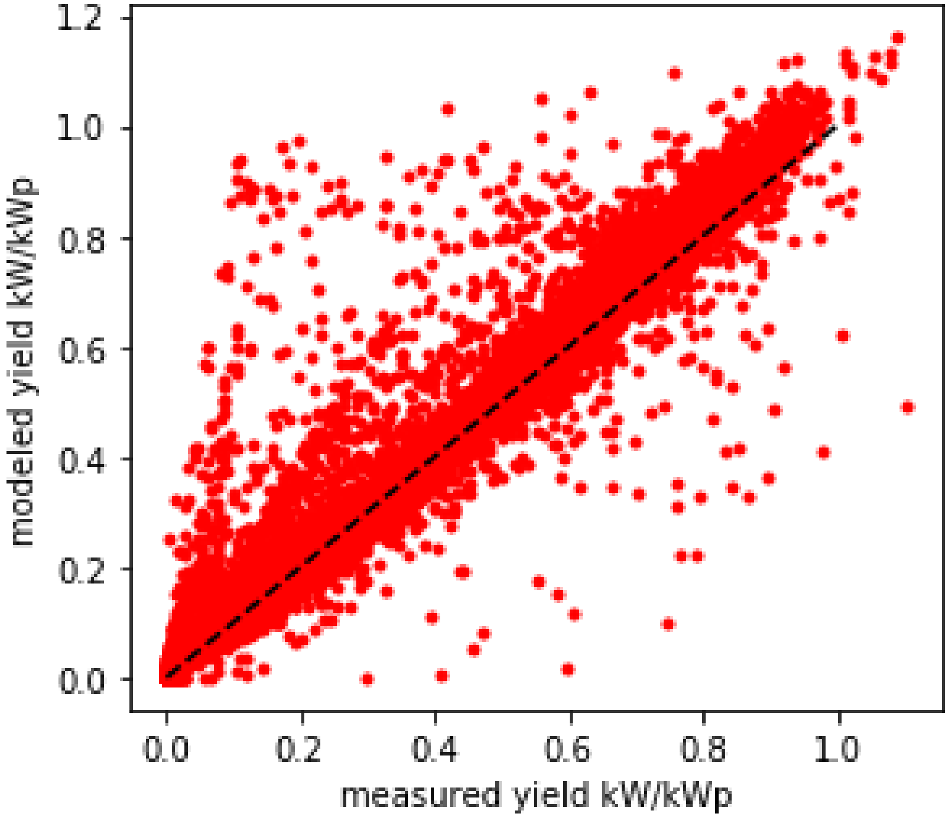


Modeled Power Results

Monofacial row, Mean model error: 8.9%, RMSE: 23.3%

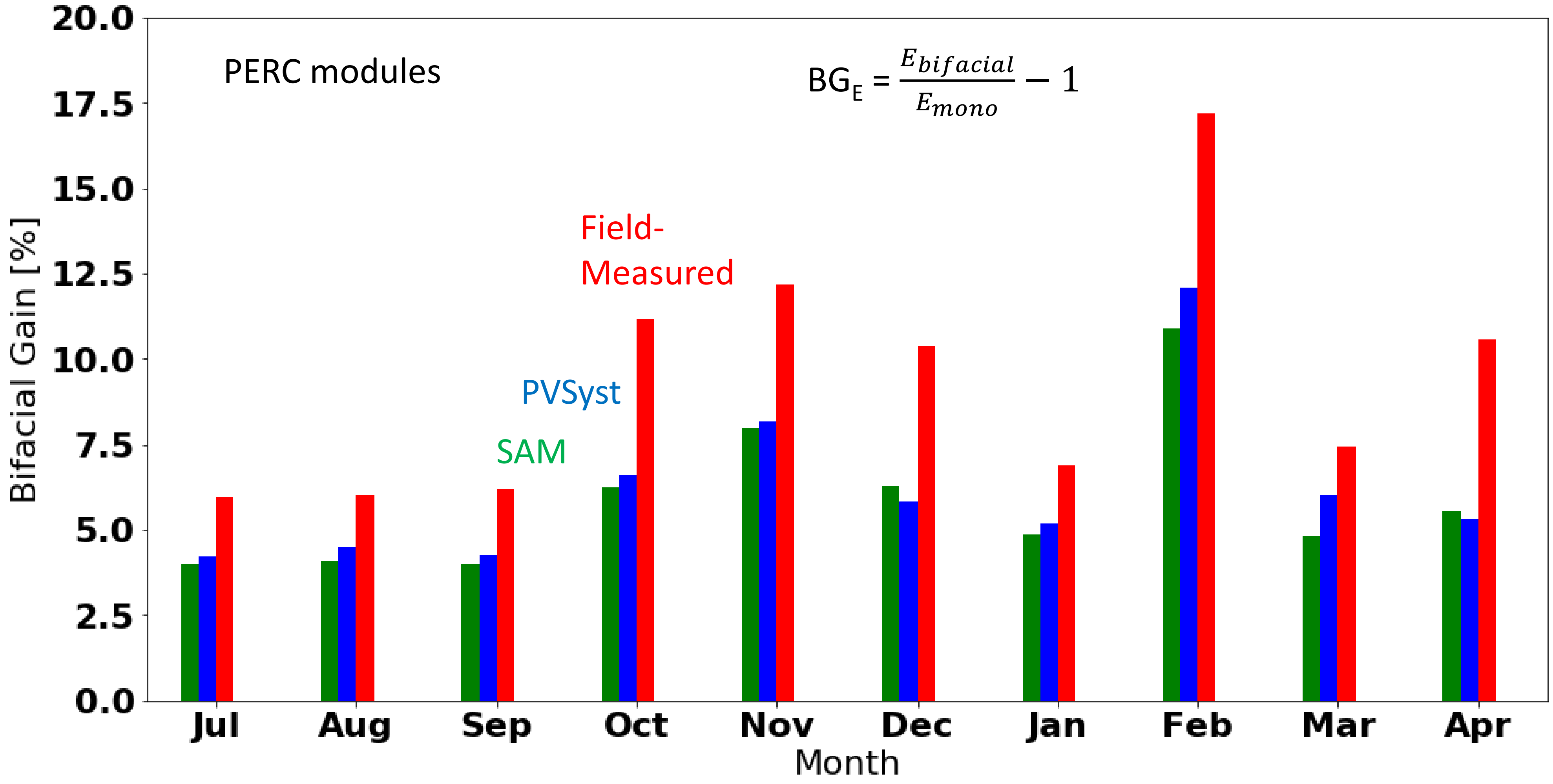


Bifacial row, Mean model error: 7.5%, RMSE: 19.7%



Monthly Bifacial Gain

Measured vs. Modeled



Monthly Bifacial Gain

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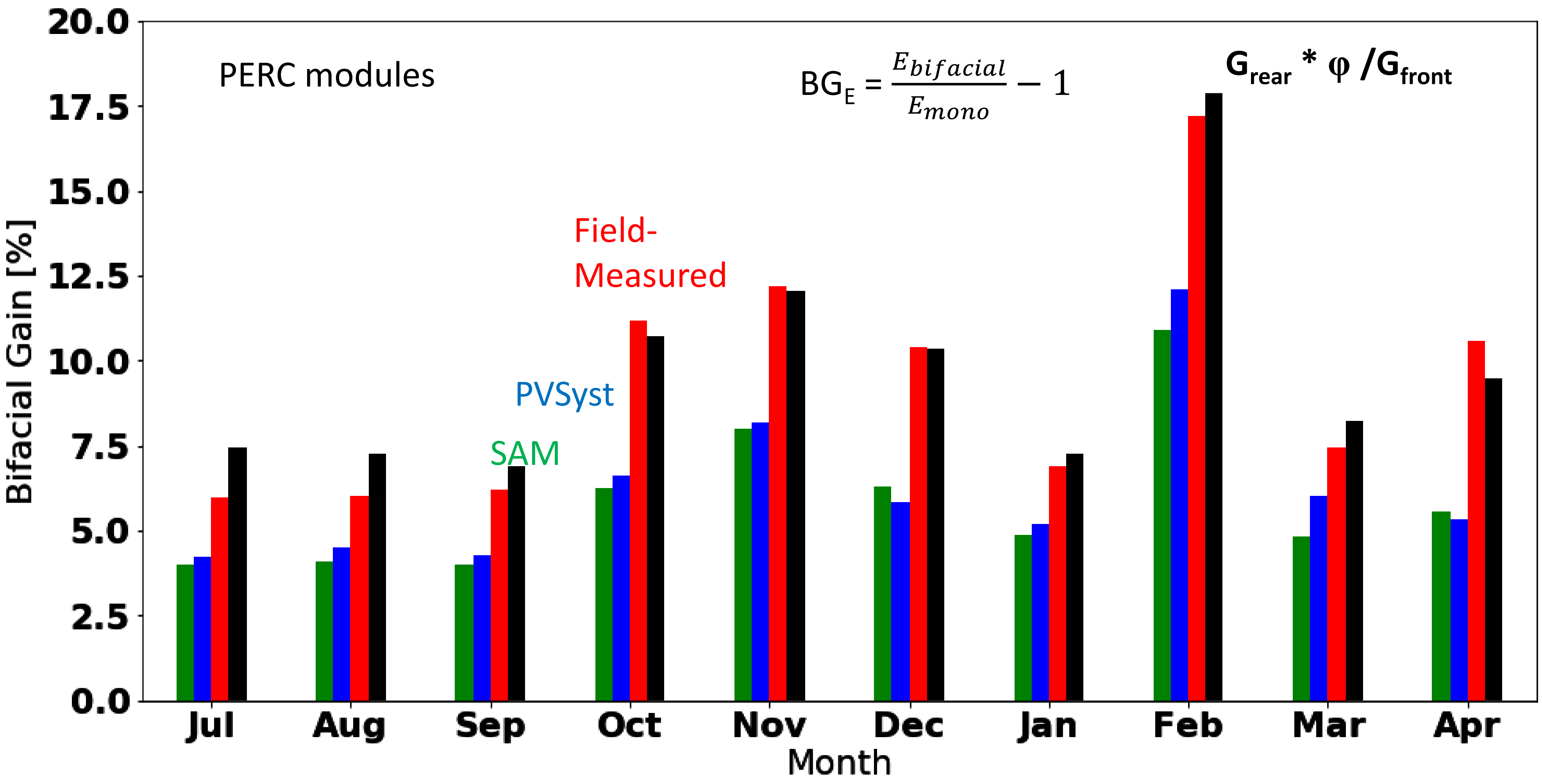

Takeaways

- Sensors:
  - Various rear irradiance sensors throughout the field; at different positions in the slope of the module. Avoid edges.
  - Keep calibrated, and clean (dirt & snow)
  - Measure albedo on site.
  - Compare various types to see spectral effects.
- Data
  - Down sampling, left averaged or right averaged according to software
  - Keep maintenance records. Clean (remove) data for maintenance periods.
  - Check data quality often
- Power:
  - Test IV curve of modules before and after (degradation). Keep control modules.
  - Consider only same hours of production
  - Try to compare equivalent monofacial to bifacial technology
- Others:
  - Edge effects and shading: can place dummies on first and last rows. Also on edge of rows.
  - If varying albedo conditions, take photos and ad a ruler next to a post to gauge snow or grass depth.

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.
- Current VF software (SAM, PVSyst) appears to be conservative relative to measured rear irradiance.

Thank you

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