

VIRTUAL

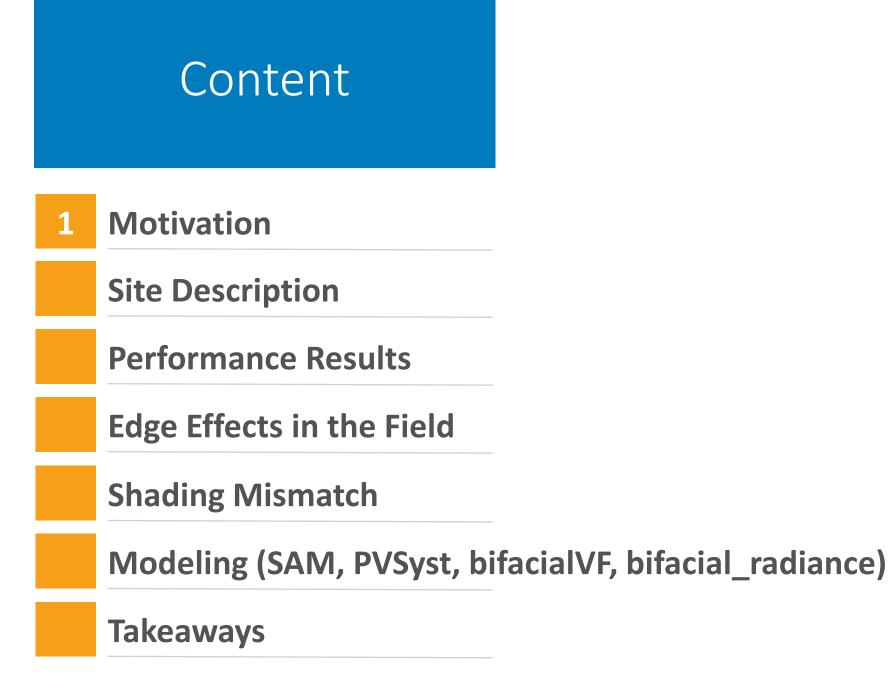


#### Ultimate Bifacial Showdown: 75kW Field Results

Silvana Ayala Peláez,\* Chris Deline, Bill Marion, Bill Sekulic, Byron McDanold, Joshua Parker, Mark Monarch, and Joshua S. Stein<sup>2</sup>

NREL <sup>2</sup>Sandia National Laboratories

July 29th, 2020



# Bifacial trackers, 75 kW 5 bifacial technologies

20 modules (7.5 kW) / row

4 PERC, 1 SHJ Bifacial strings

**3 PERC monofacial strings** 

Module electronics / monitoring

String kWh<sub>DC</sub> monitoring

Front, rear POA irradiance

20 modules (7.5 kW)

4 PERC, 1 SHJ Bifacia

#### **3 PERC monofacial strings**

Module electronics / monitoring

String kWh<sub>DC</sub> monito

Front, rear POA irradiance

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3 PERC monofacial strings

Module electronics / monitoring

String kWh<sub>DC</sub> monitoring

Front, rear POA irradiance

						V
solar	edge					
Dashboard	Layout	Charts	Reports	Alerts	Admin	
Daty	*					
			227.0 kW	31 1		1
	=5 88.98 kWh 2				88.63 kWh	
	89.79 kWh 2.0				88.38 kWh	
	2.29 kWh 2.0.1				2.25 kWh 4.0.1	
	2.31 kWh 2.0.2				2.27 kWh 4.0.2	
	2.32 kWh				2.16 kWh	

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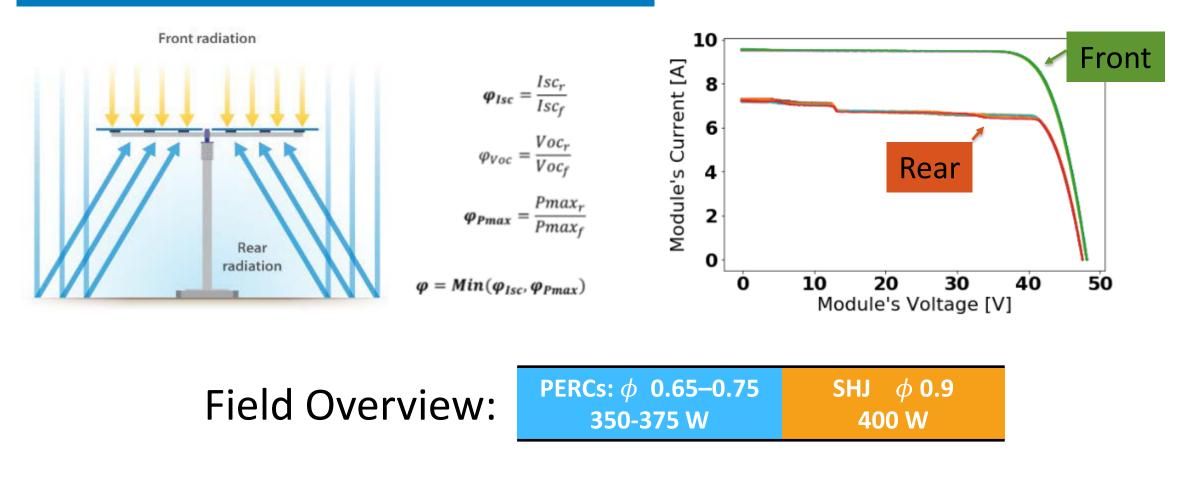
Front, rear POA irradiance

= Front POA= Rear POA

Albedometers

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## Technologies in the Field

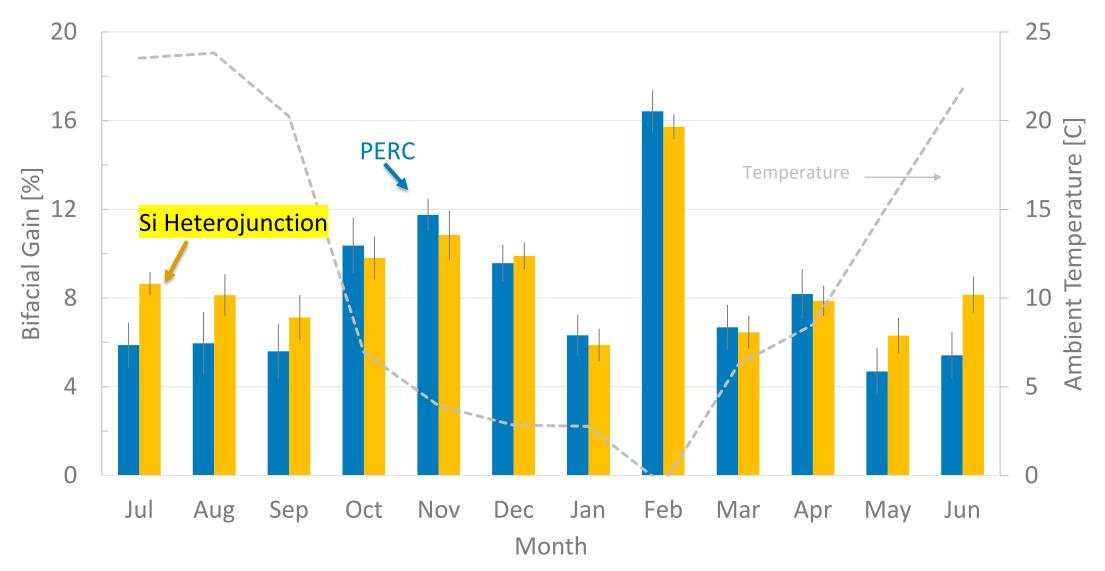


#### Row 2 – Poly p-ptype PERC Module

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

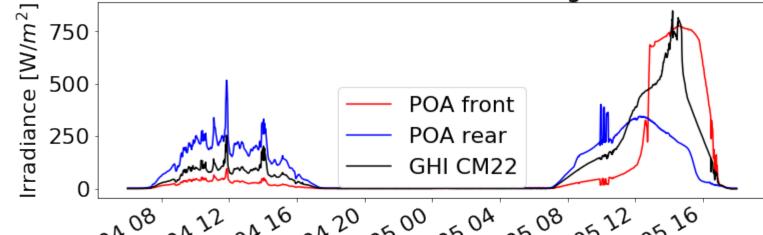
### Bifacial Gain by Technology

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

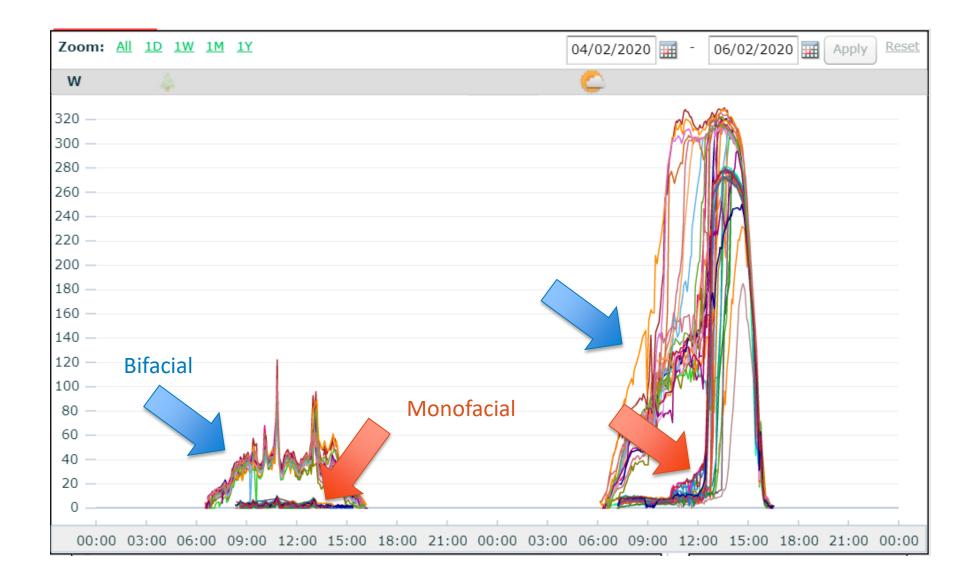




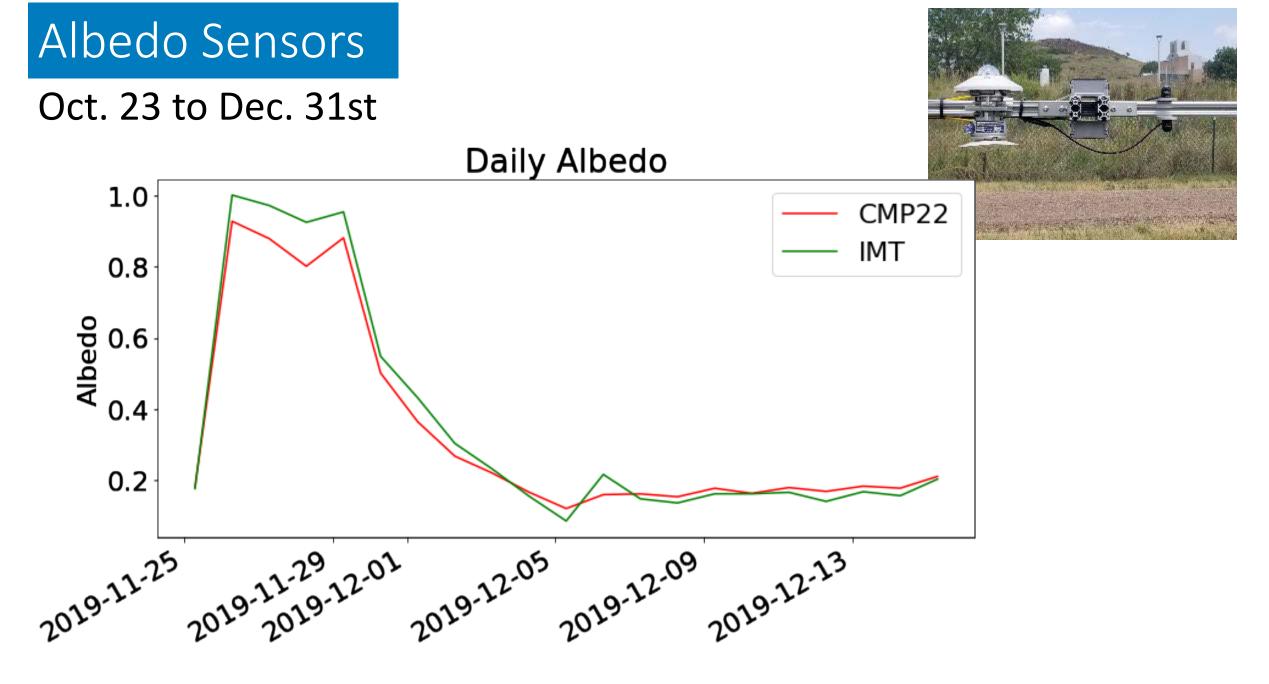




#### Snow



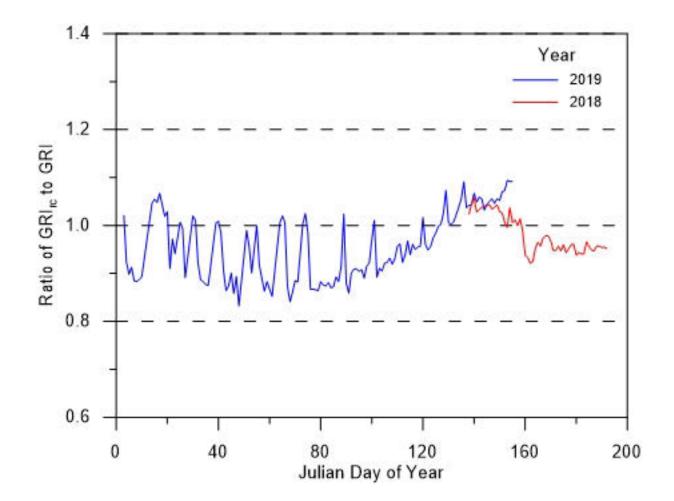




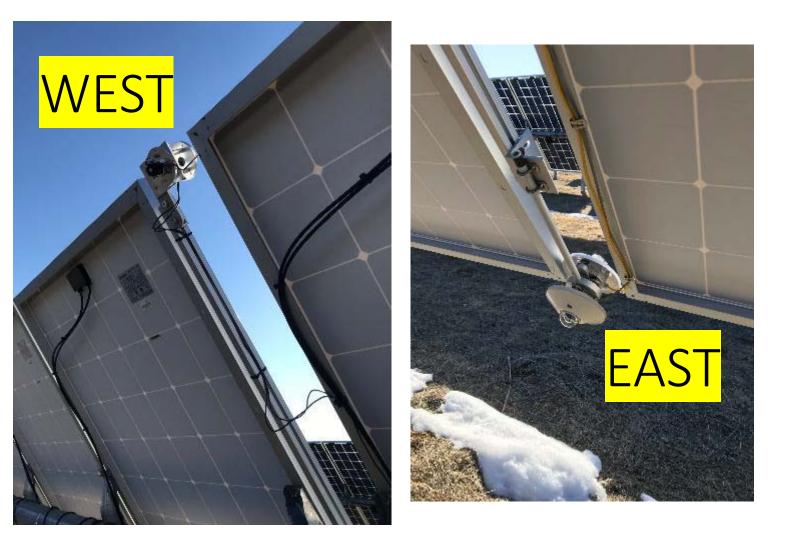
## Albedo Assessments for Bifacial PV Systems

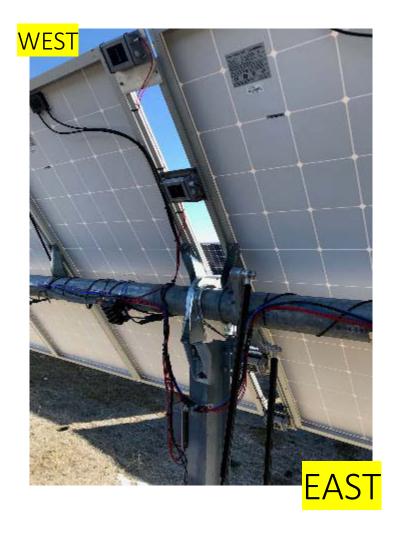
#### **Measured Spectral Effect**

- 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



#### Rear POA Measurements

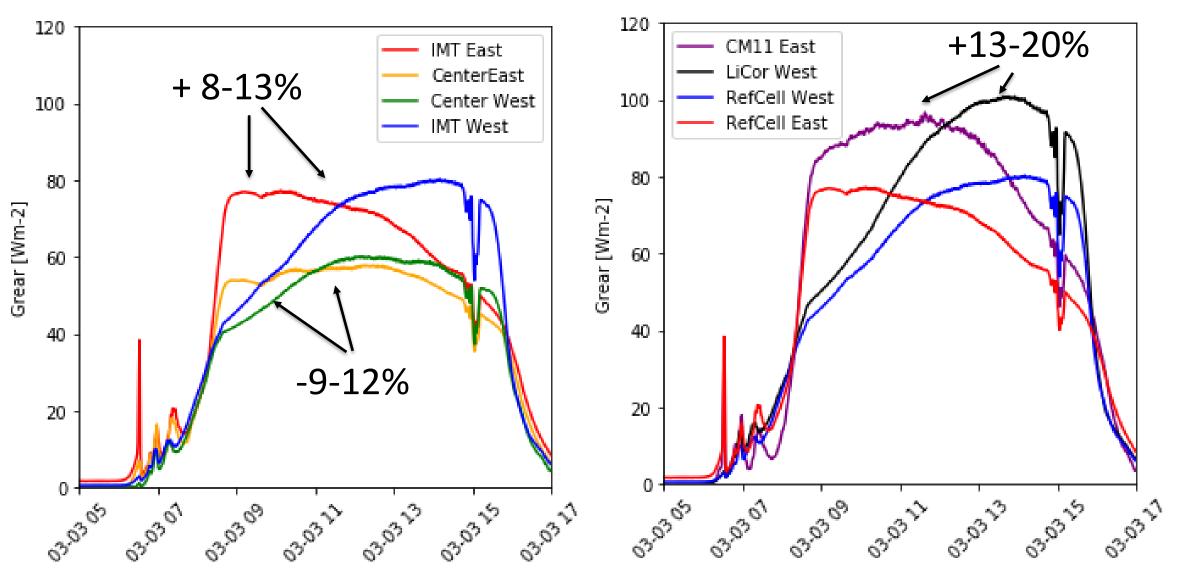




#### 2 Broadband irradiance sensors

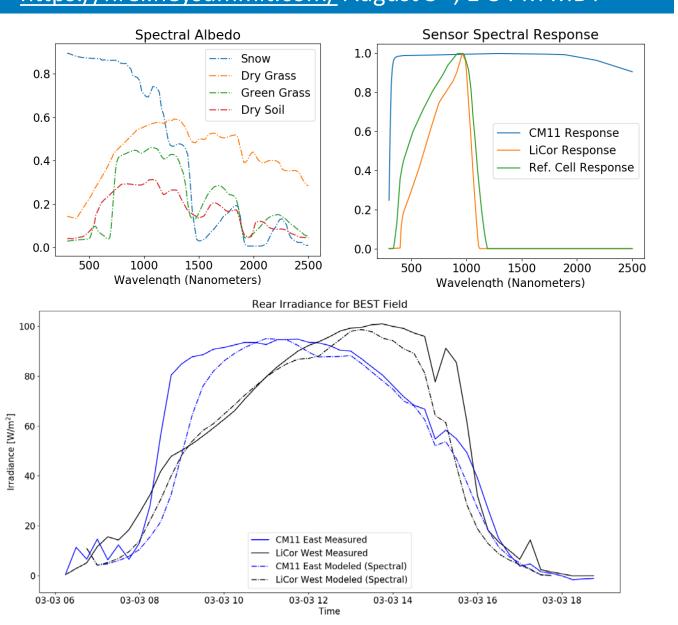
**4** Reference Cells

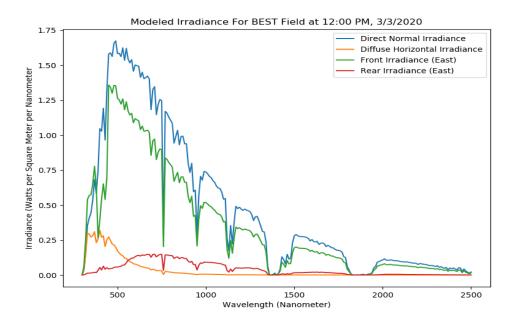
#### Rear POA Variability



\*Cumulative variability 06/19 to 03/20

#### Rear POA Spectral Effects https://nrel.heysummit.com/ August 5<sup>th</sup>, 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

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1.1.11

1.1.17

1.1.13

1.1.16

1.1.8

1.1.18

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1.1.18

1.1.14

1.1.7

1.1.6

1.1.8

1.1.18

1.1.3

wh a

Module
electronic
monitoring

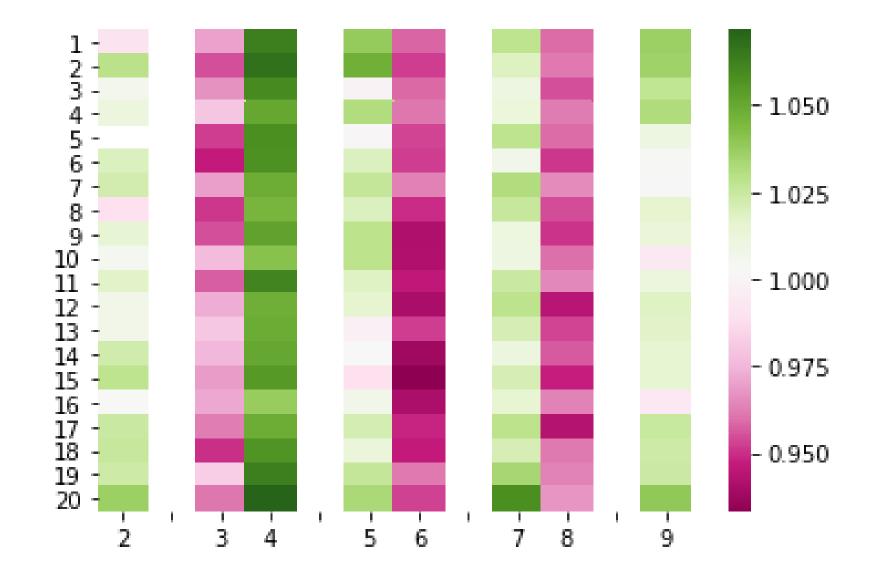
String
kWh<sub>DC</sub>
monitoring

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Wh Wh

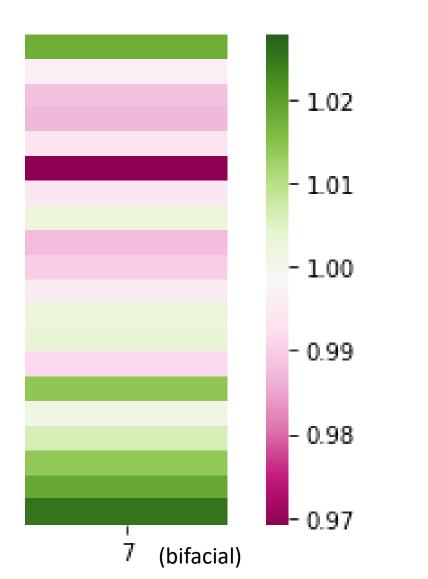
### Field normalized Production



\*Cumulative January-May 2020 Pmp

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#### January-May Edge Effects



\*Cumulative January-May 2020 Pmp

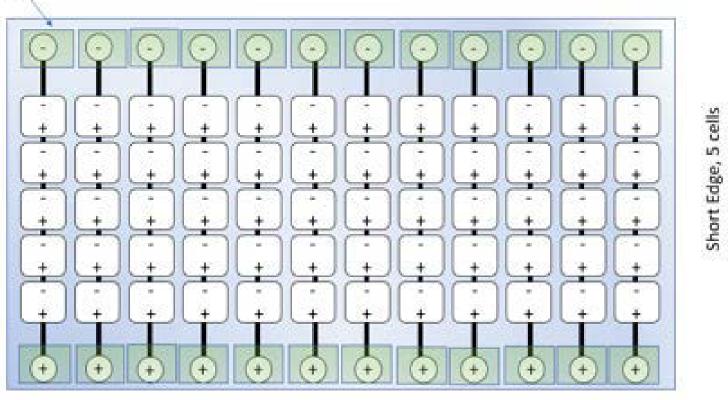
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## Shading Effects



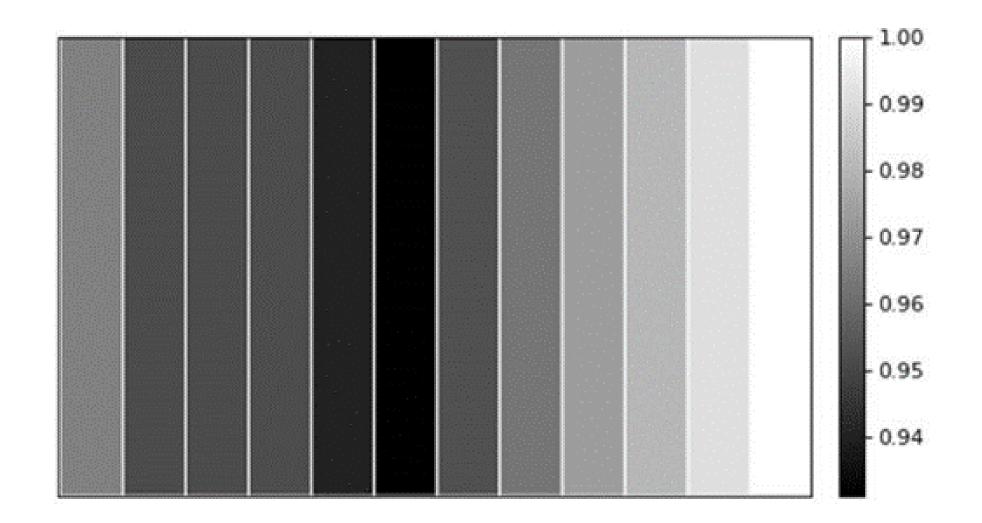
## Shading Effects

Junction boxes



Long Edge, 12 cells

## 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

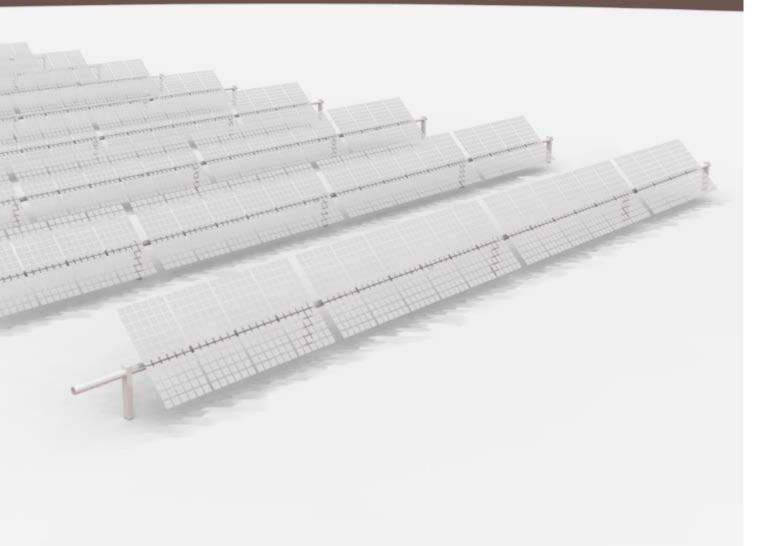
- User Manual: site description and column headers
  - Row 2, Row 9 string performance and module level performance
  - Comparison monofacial string performance
  - Front and rear irradiance sensors
  - Weather data
  - Albedo data

#### <u>https://datahub.duramat.org/dataset/best-field-data</u>

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	А	Row Current
row2tmod	Bifacial Row	С	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	А	Row Current
row9tmod	Bifacial Row	С	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	11/112	Albedo measured by Sunkitty CM22
	Albedo Albedo	W/m2	
sunkitty_albedo_1		,	Albedo measured by Sunkitty CM22
sunkitty_albedo_1 sunkitty_GRI_CM22	Albedo	W/m2	Albedo measured by Sunkitty CM22 Ground Reflected Irradiance measured by CM22
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# Model vs Measured

### Software Comparisons

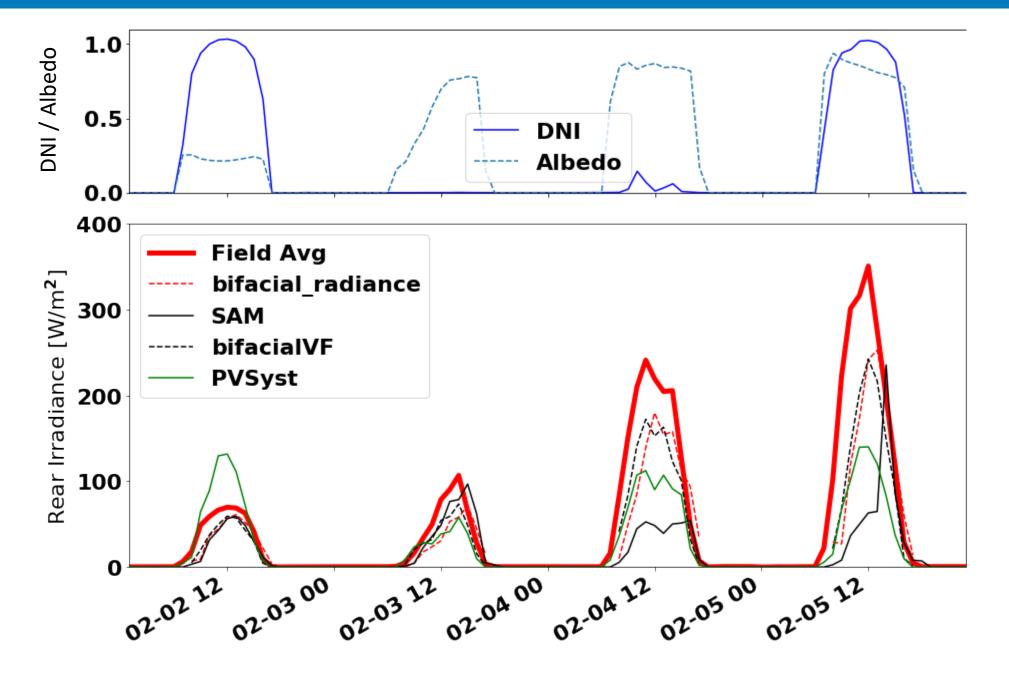


- SAM
- PVSyst

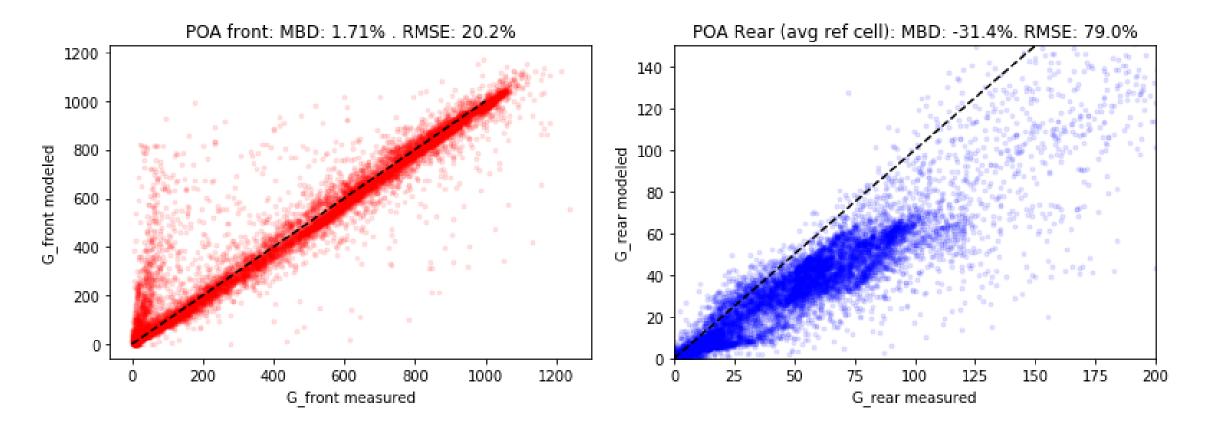
#### Irradiance Modeling Only

- bifacialVF
- bifacial\_radiance

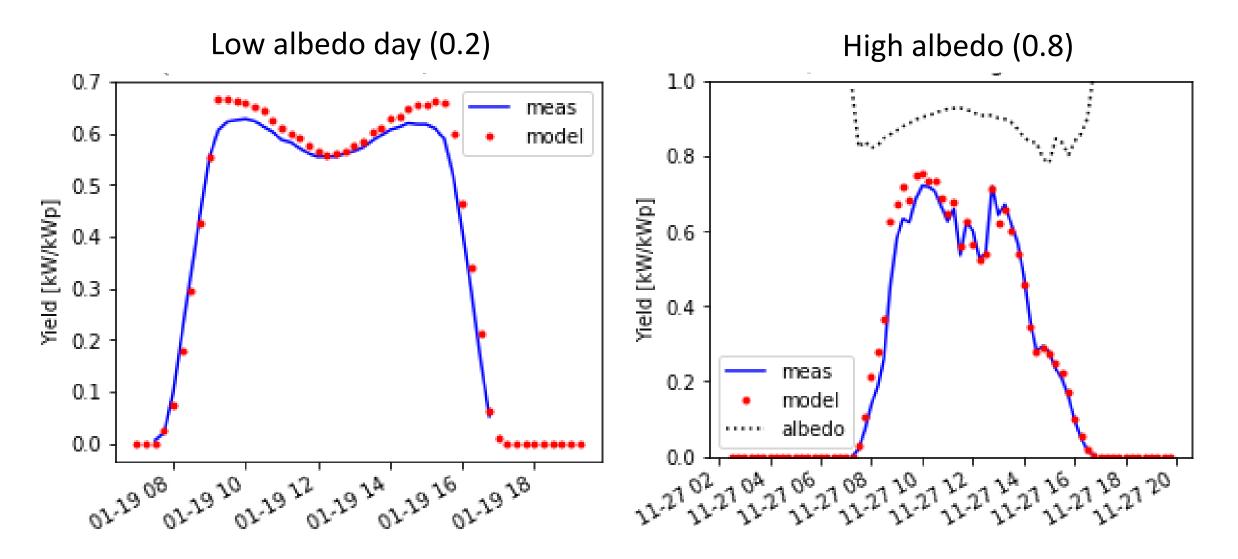
Models under-prediction is more pronounced under high albedo and high DNI conditions



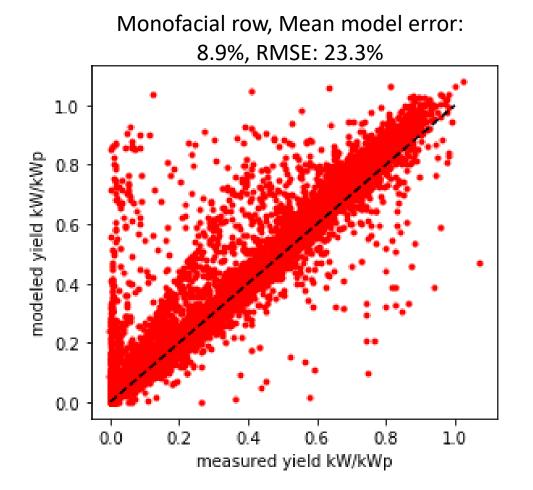
#### Modeled Irradiance



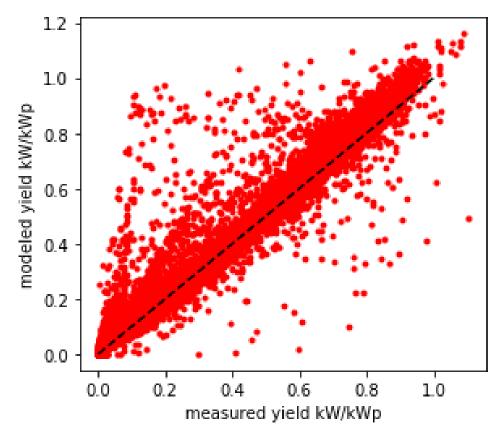
#### Modeled Power Results



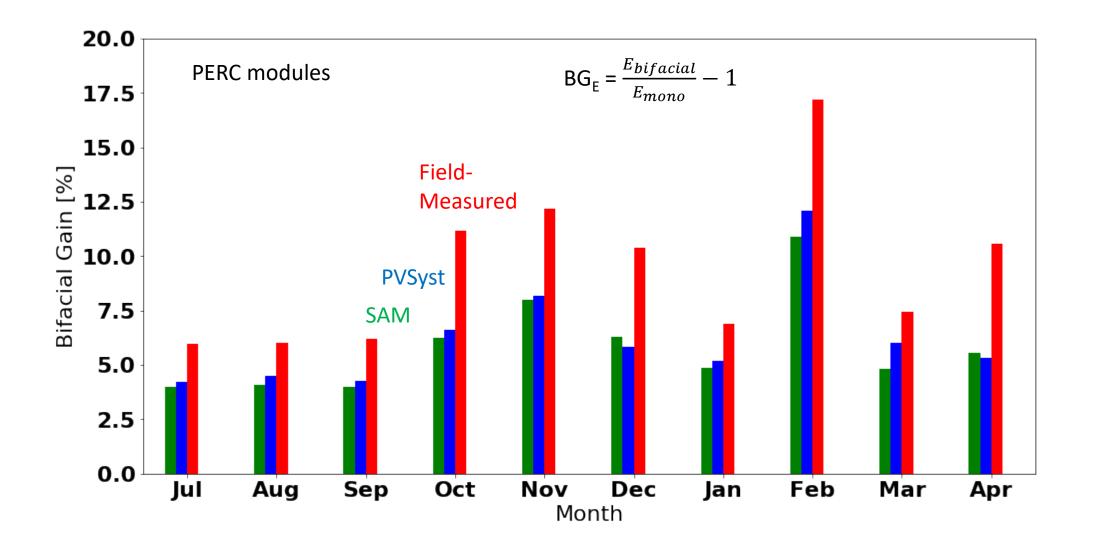
#### Modeled Power Results



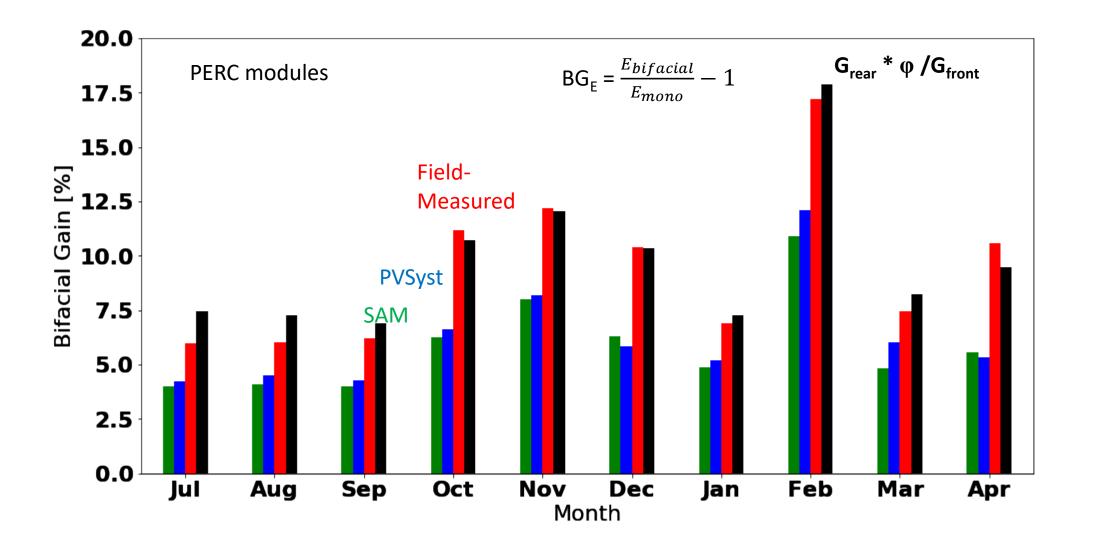
Bifacial row, Mean model error: 7.5%, RMSE: 19.7%



#### Monthly Bifacial Gain Measured vs. Modeled



#### Monthly Bifacial Gain Measured vs. Modeled



## 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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