Effect of Torque-Tube Parameters on Rear-Irradiance and Rear-Shading Loss for Bifacial PV Performance on 1-Axis Tracking Systems

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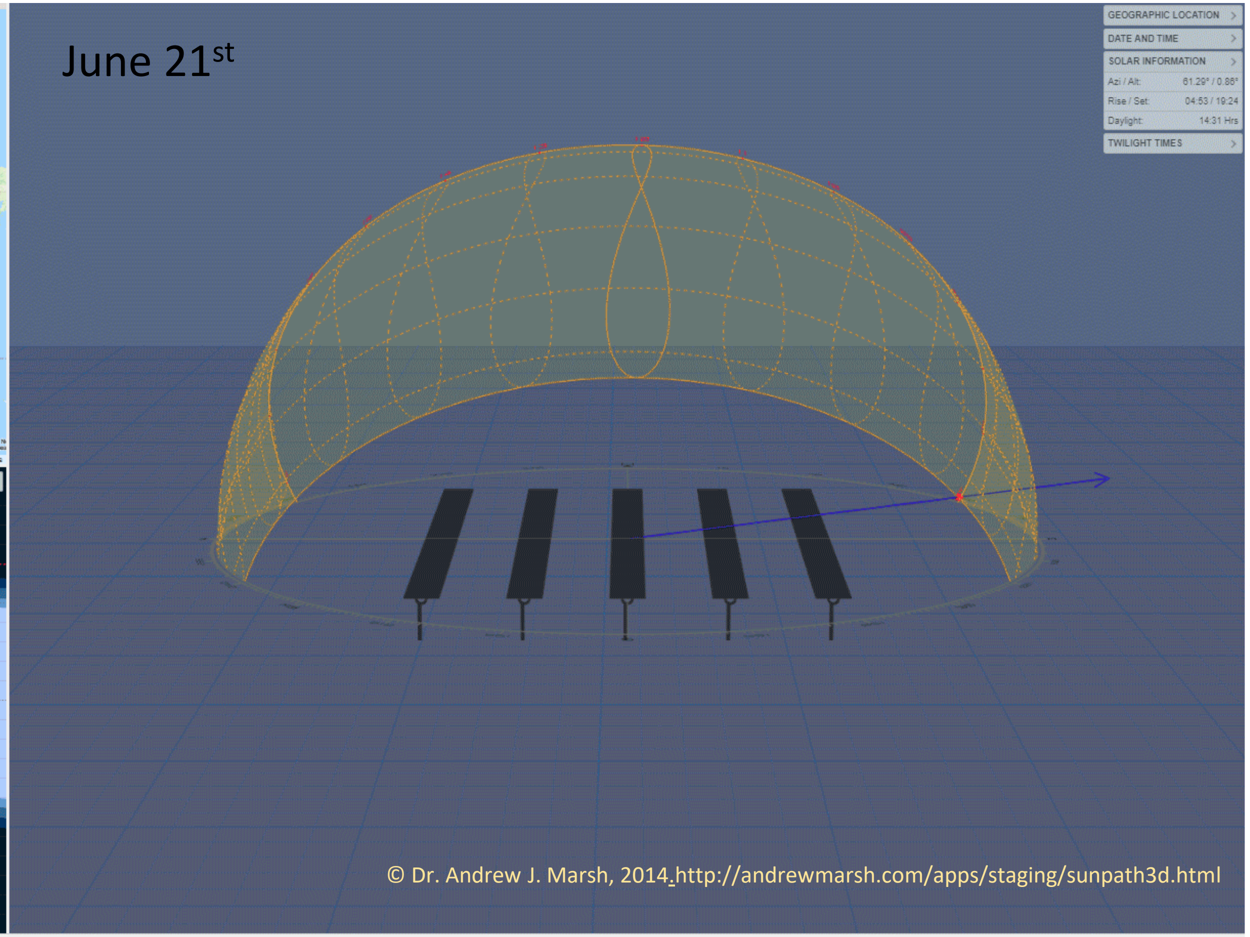
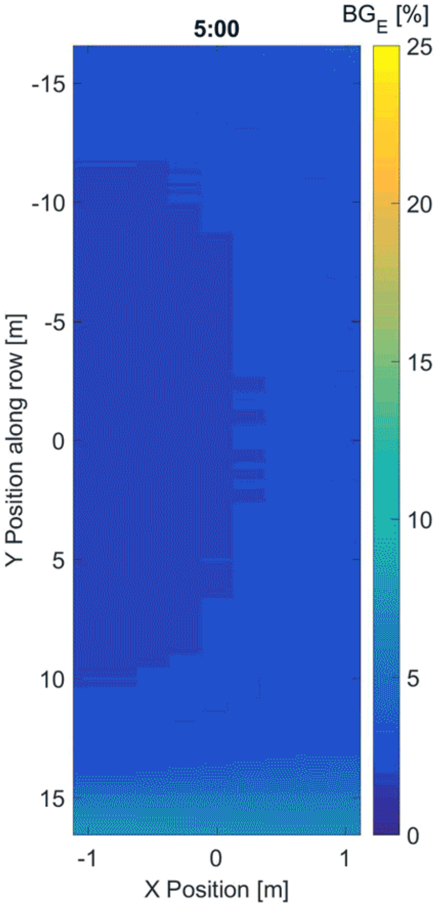
46th IEEE PVSC, June 16-21, 2019, Chicago, Illinois

NREL/PR-5K00-74236

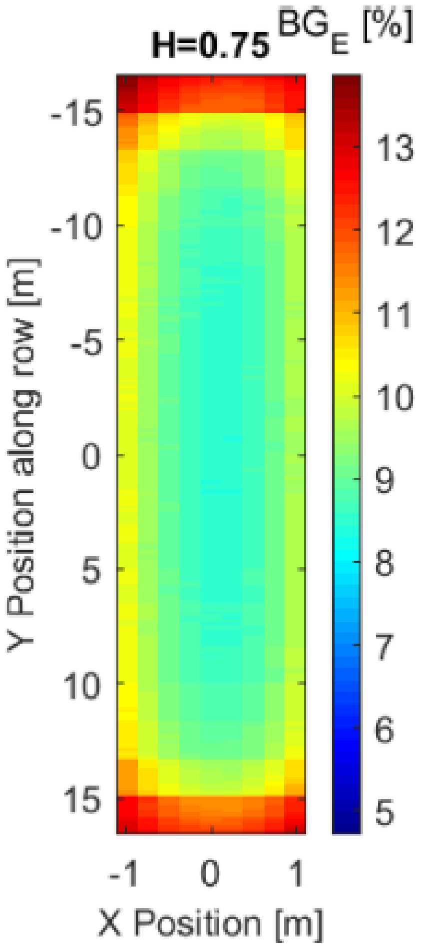
Bifacial modules boost energy yield by 4% to 15%

Hourly BG_E





Yearly BG_E



Ayala Pelaez, Silvana, et al. "Model and Validation of Single-Axis Tracking With Bifacial PV." *IEEE Journal of Photovoltaics*(2019).


Silfab bifacial panel

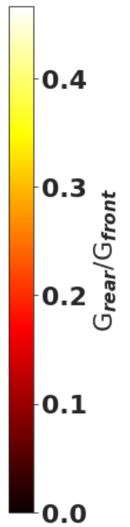
Effect of torque tube on rear-irradiance

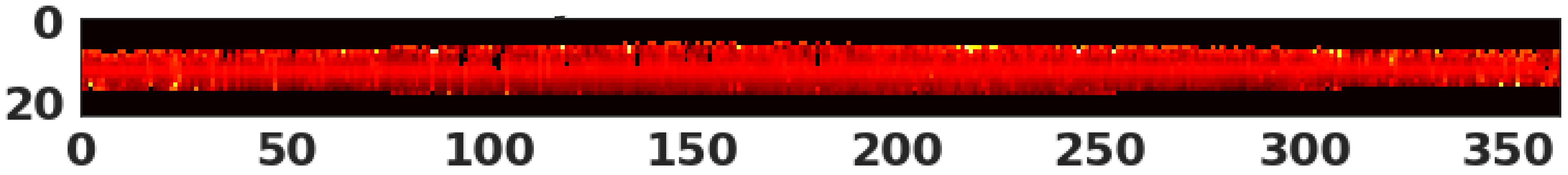
Repercussions on energy loss

Ideal location of sensors?

Tracking and Torque tube

Hourly annual simulations



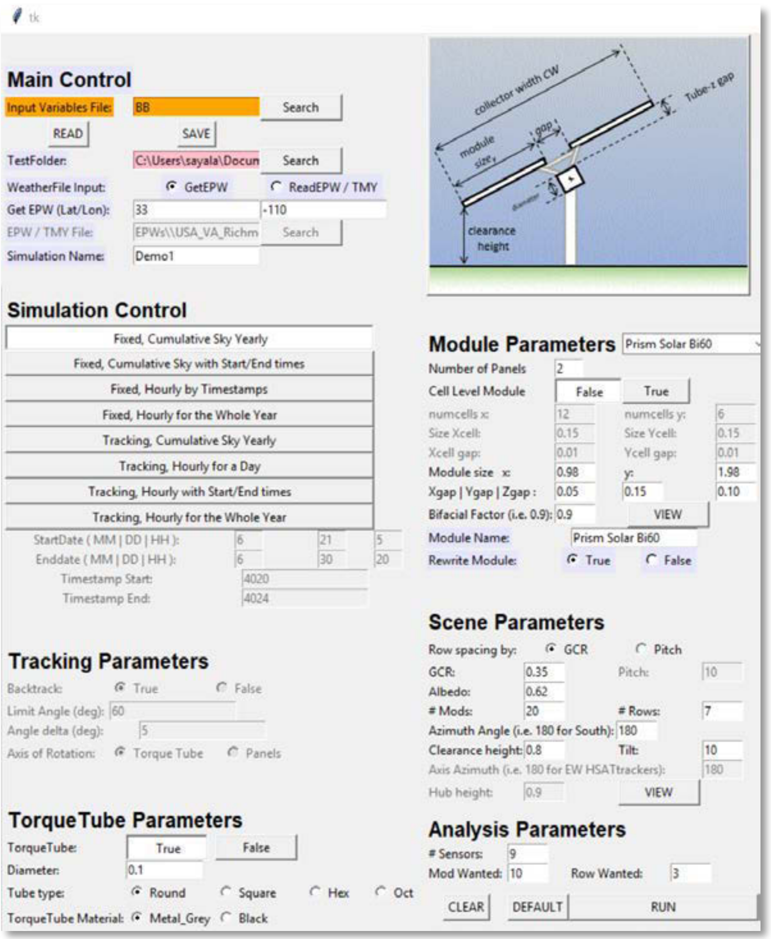


bifacial_radiance program (raytrace)

Cairo, Egypt. 20 modules per row, 7 rows.

200 points per hour modeled across center module's collector width

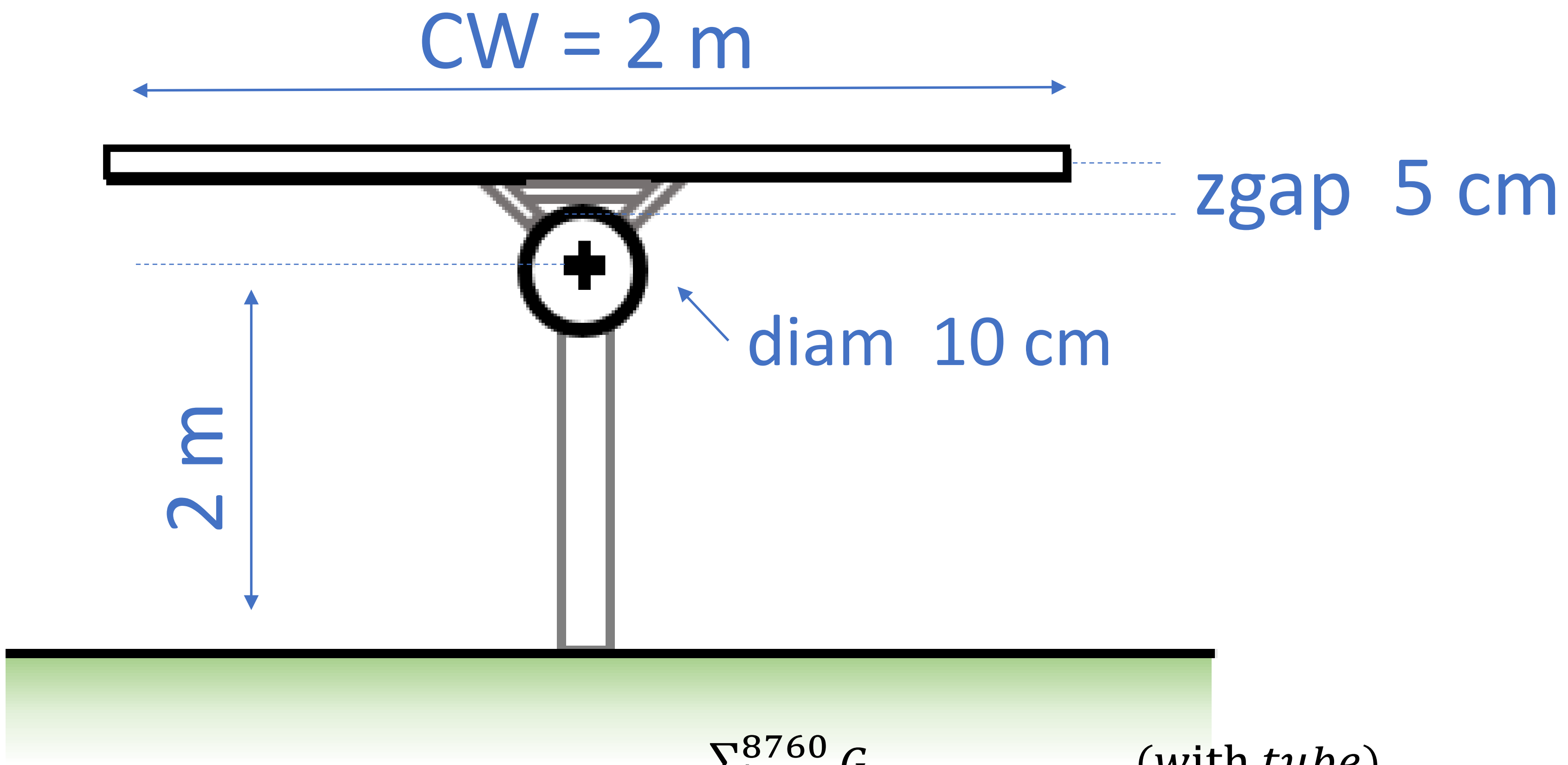
Albedo of 0.28, GCR of 0.25



https://github.com/NREL/bifacial_radiance/

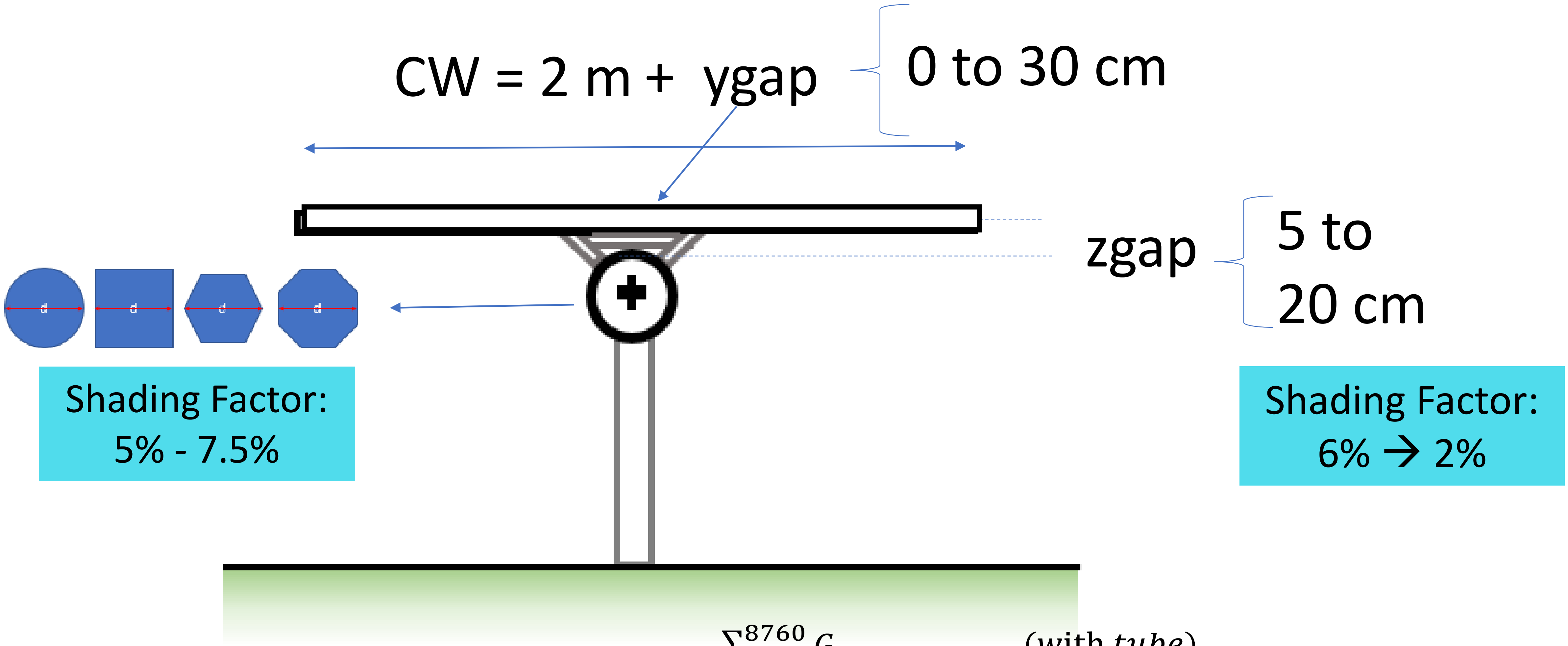
Open Source! (a.k.a. free!)

Comparing to a case with no torquetube, This base case has a 5.7% Shading Factor



$$G_{rear}\text{ Shading Factor} = 1 - \frac{\sum_{t=0}^{8760} G_{rear\ average}\,(\text{with } tube)}{\sum_{t=0}^{8760} G_{rear\ average}\,(\text{no } tube)}$$

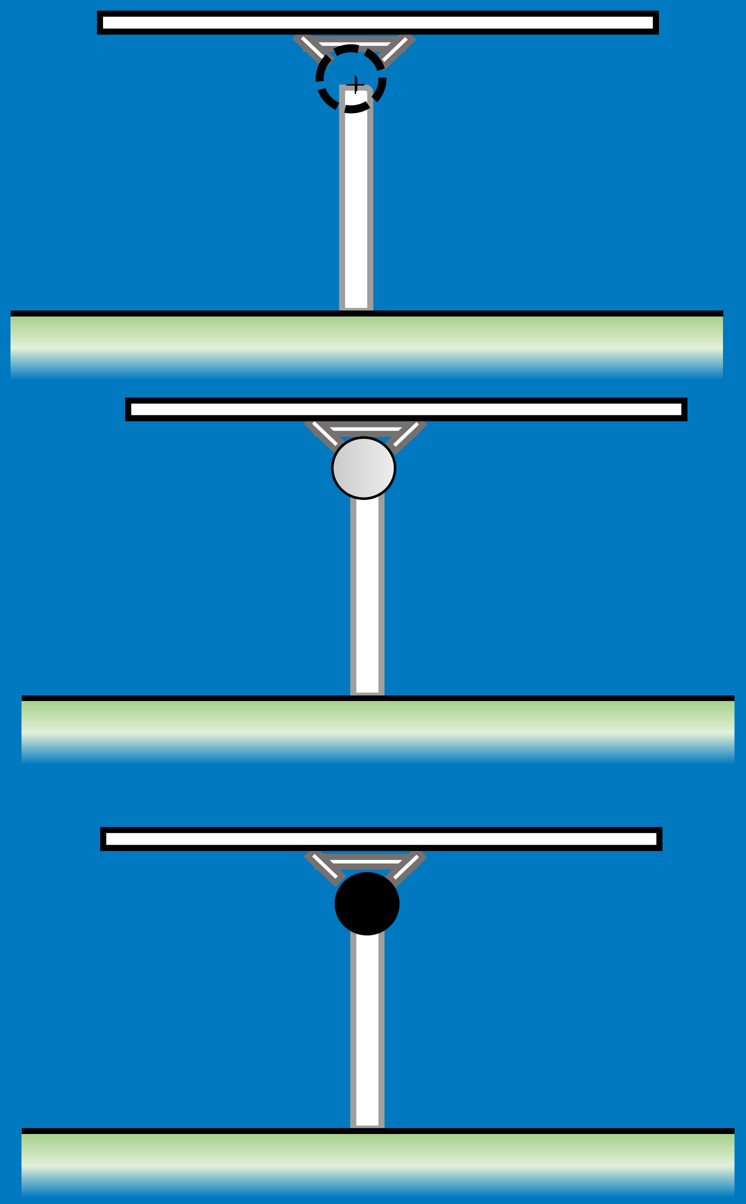
Compared to various scenarios



$$G_{rear} \text{ Shading Factor} = 1 - \frac{\sum_{t=0}^{8760} G_{rear\ average}\,(\text{with } tube)}{\sum_{t=0}^{8760} G_{rear\ average}\,(\text{no } tube)}$$

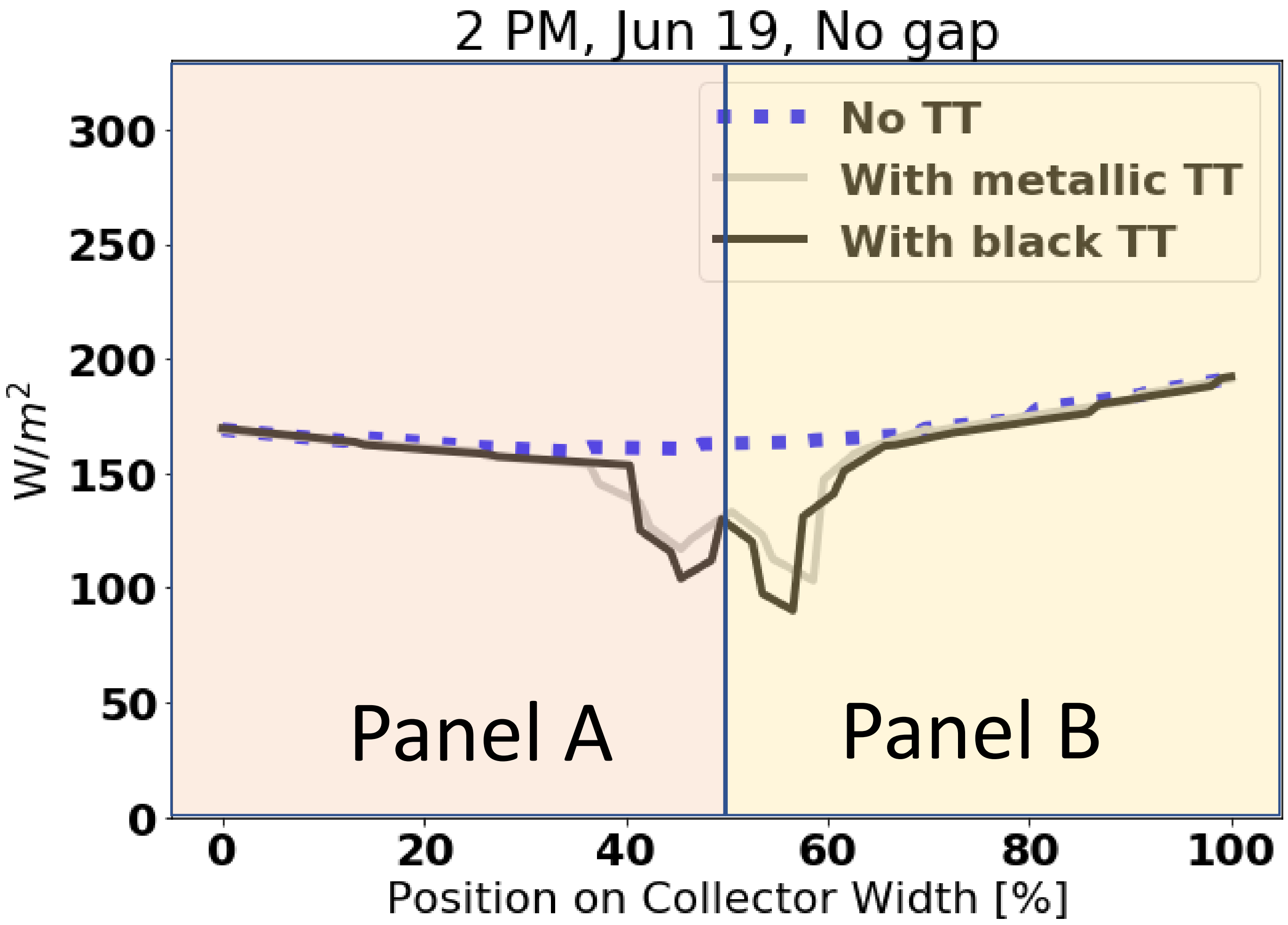
Varying torquetube reflectivity

$$G_{rear}\text{ Shading Factor} = 1 - \frac{\sum_{t=0}^{8760} G_{rear\ average}\ (\text{with tube})}{\sum_{t=0}^{8760} G_{rear\ average}\ (\text{no tube})}$$

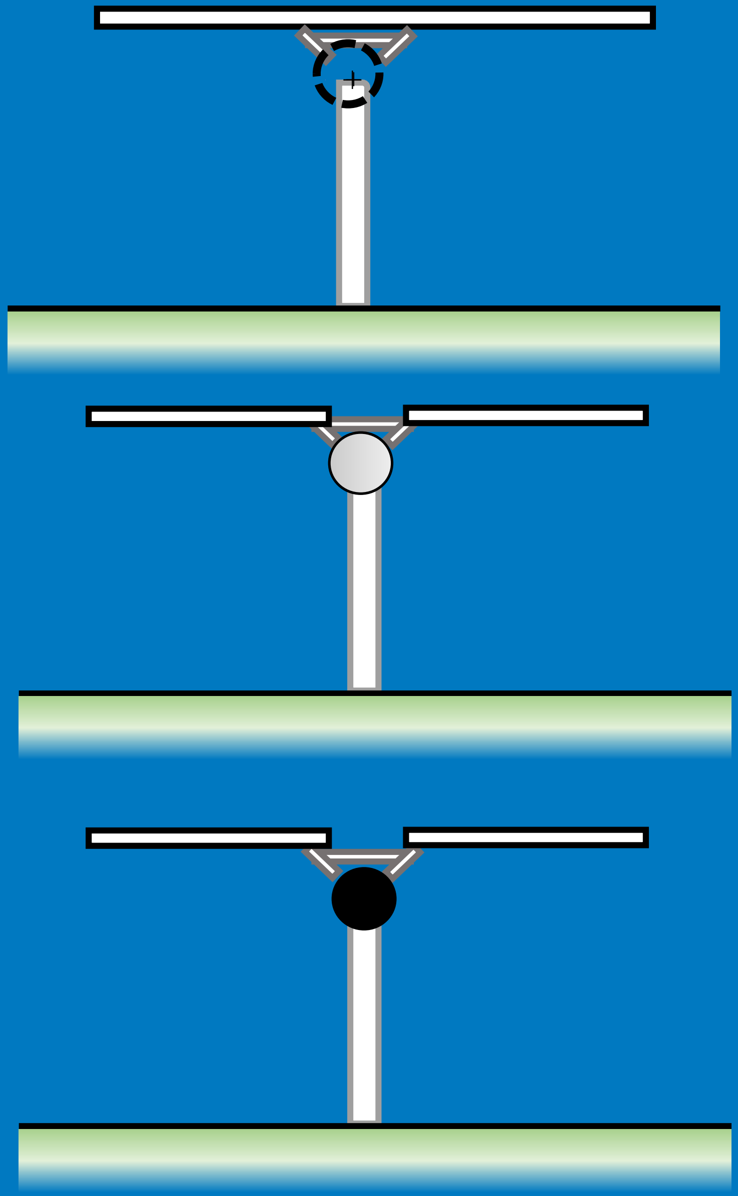


5.7% Shading Factor

7.8% Shading Factor

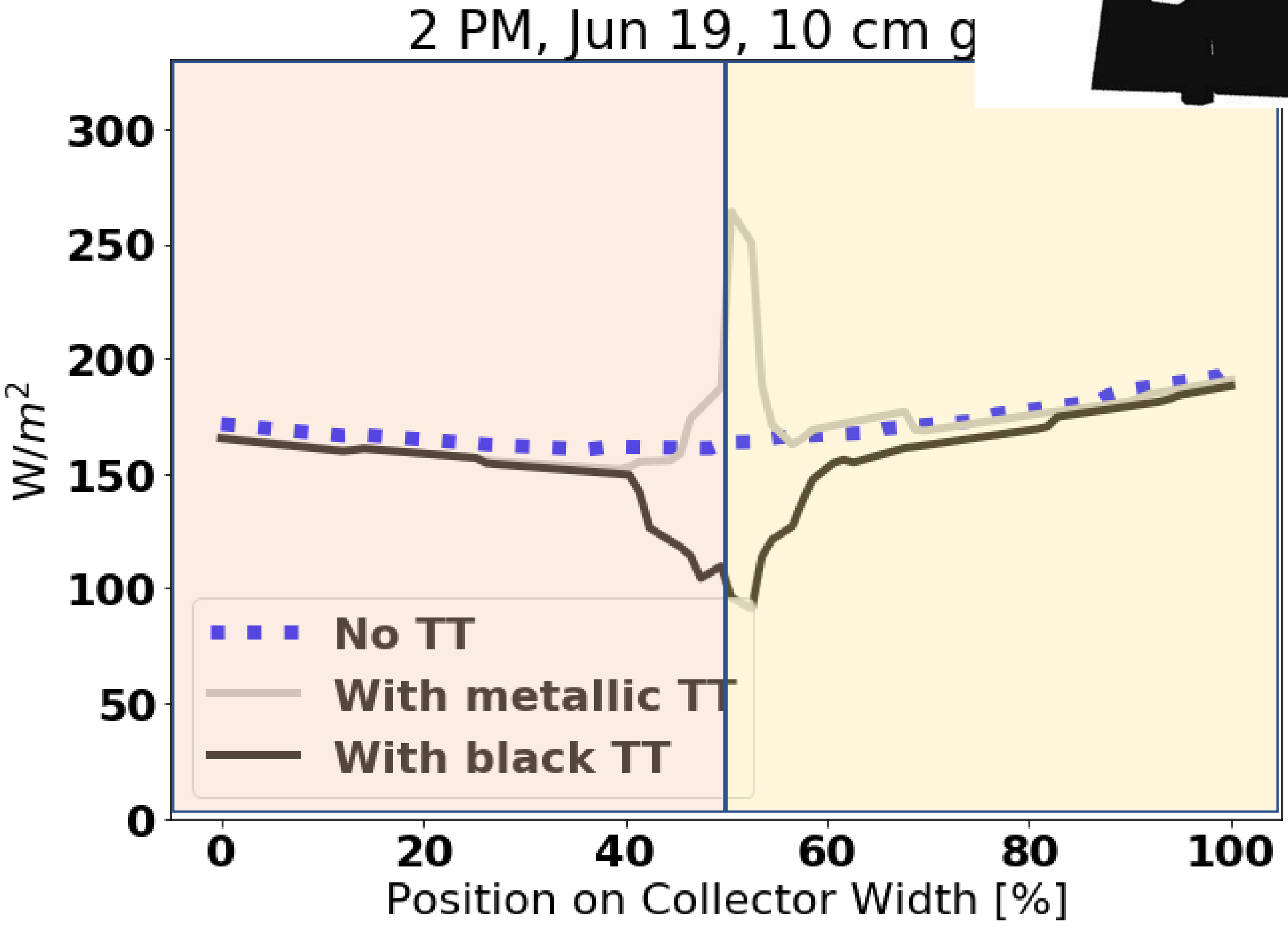


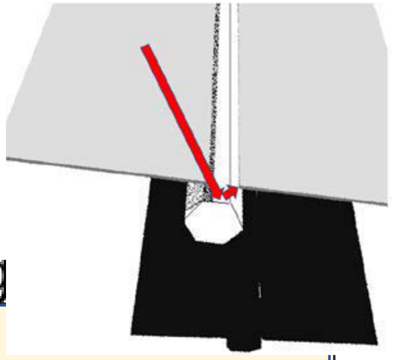
Varying torquetube reflectivity



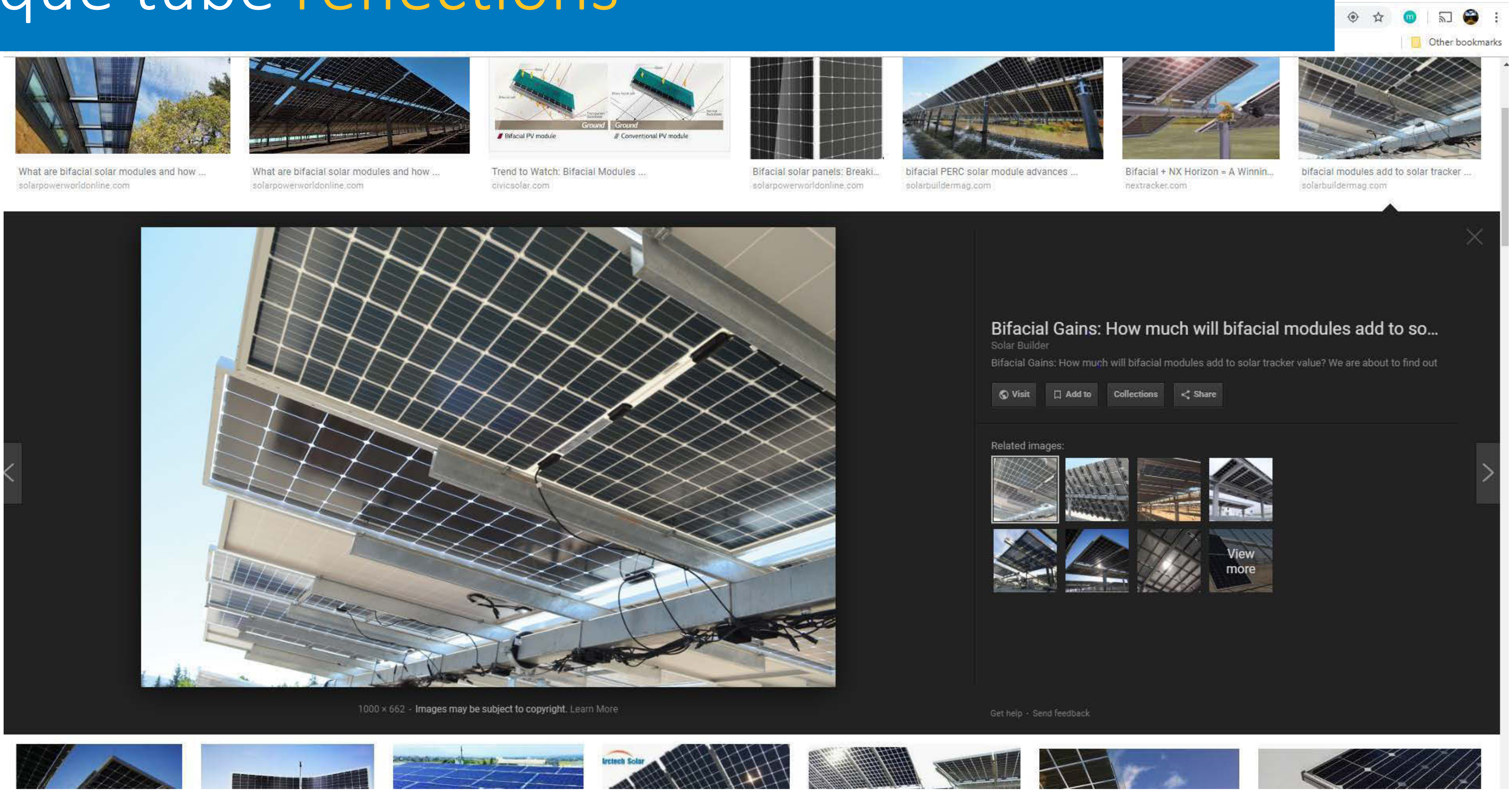
-1.7% Shading Factor

8.5% Shading Factor



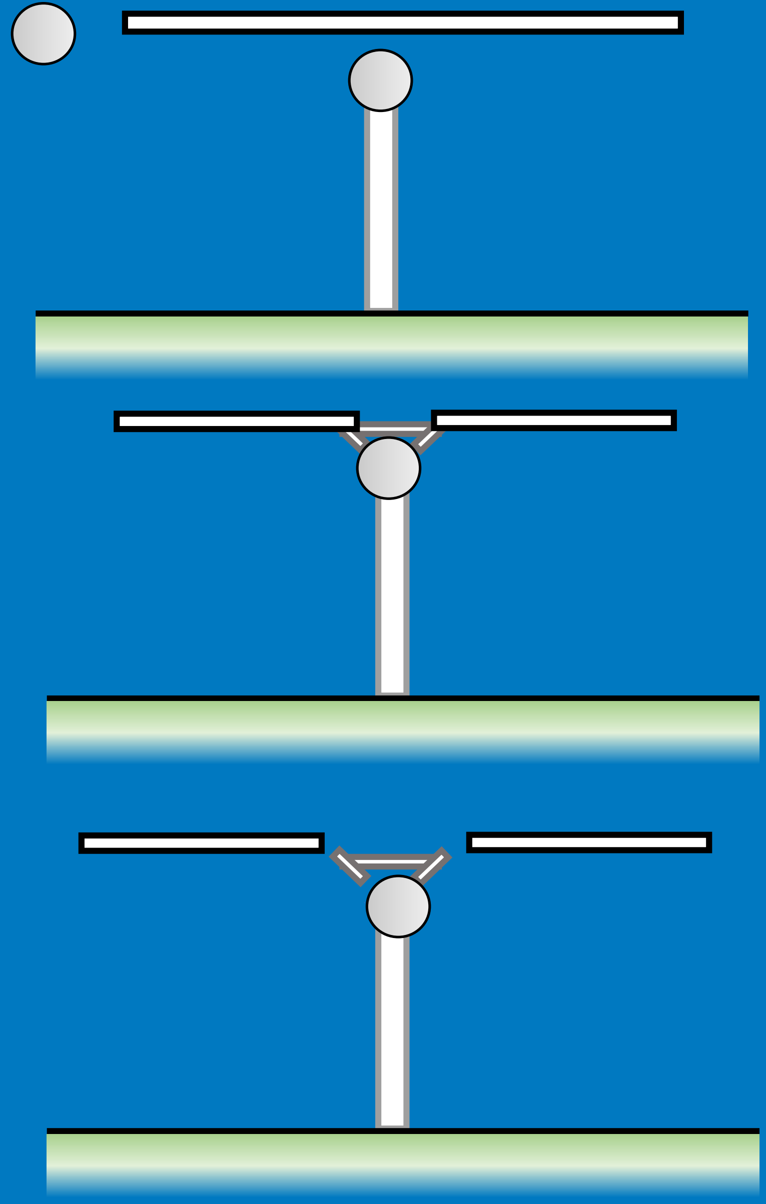


Torque tube reflections

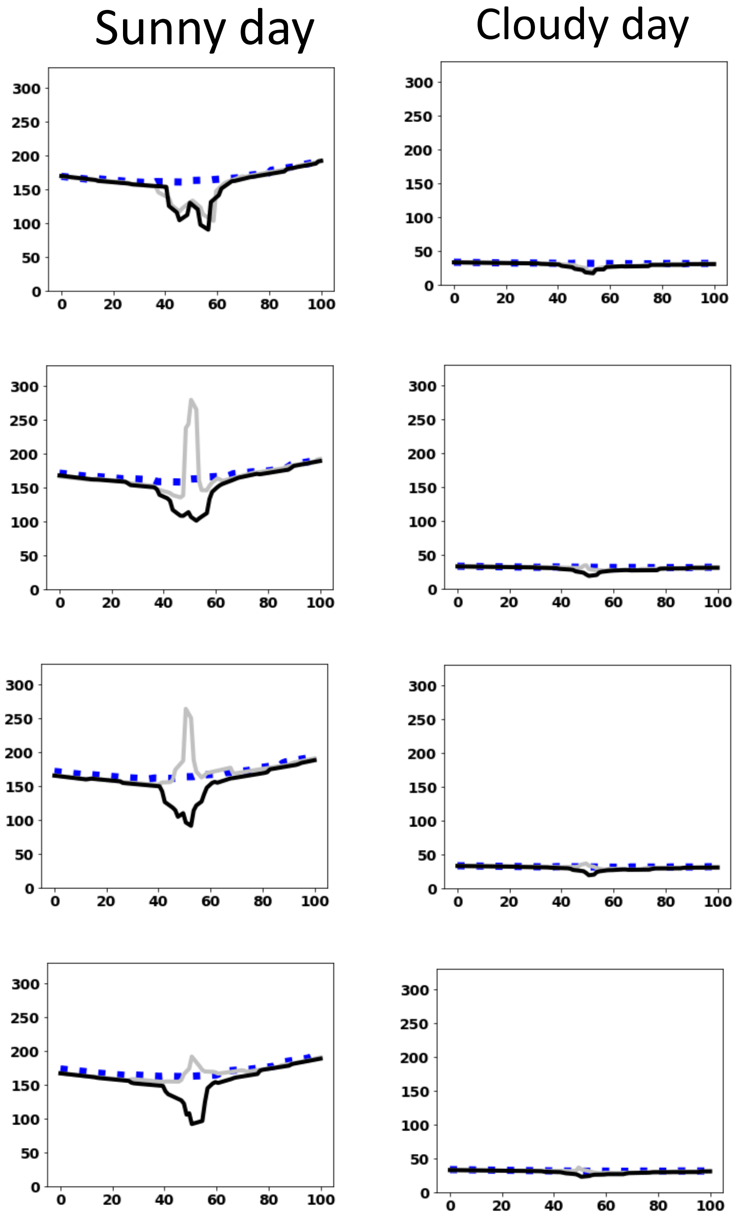


https://solarbuildermag.com/featured/bifacial-gains-how-much-will-bifacial-modules-add-to-solar-tracker-value-we-are-about-to-find-out/

Varying Y-gap

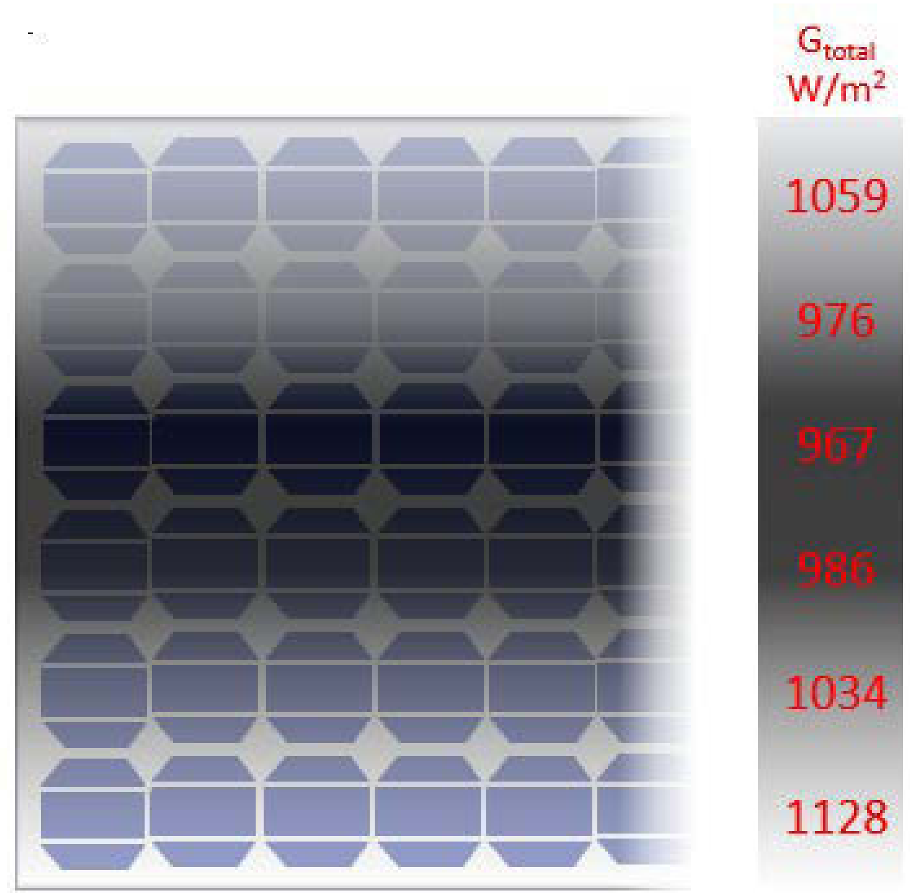


2 pm



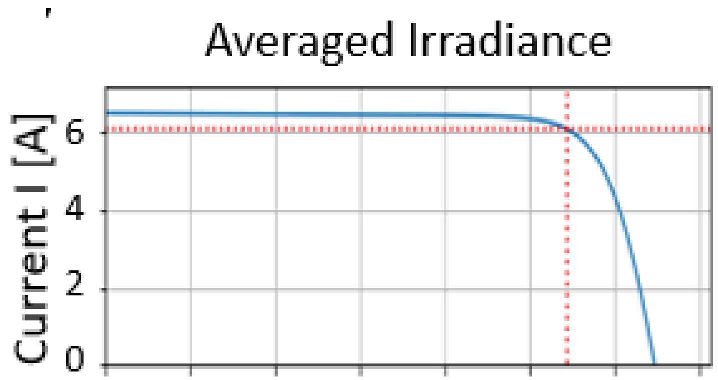
YGAP [cm]	G_{Rear} Shading Factor (Annual) %
0	5.7
5	0
10	-0.2
15	0.4

Shading plus Electrical Mismatch



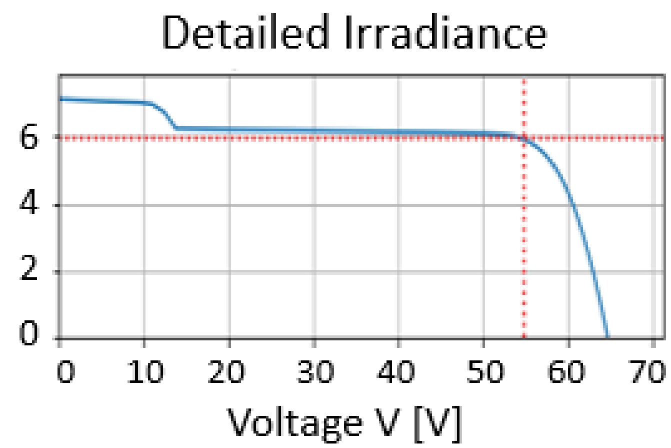
Cairo, June 21st at 2 PM

Averaging Irradiance for the module w.o torque tube ~1031 W/m²



P_0

Detailed Irradiance value w. torque tube



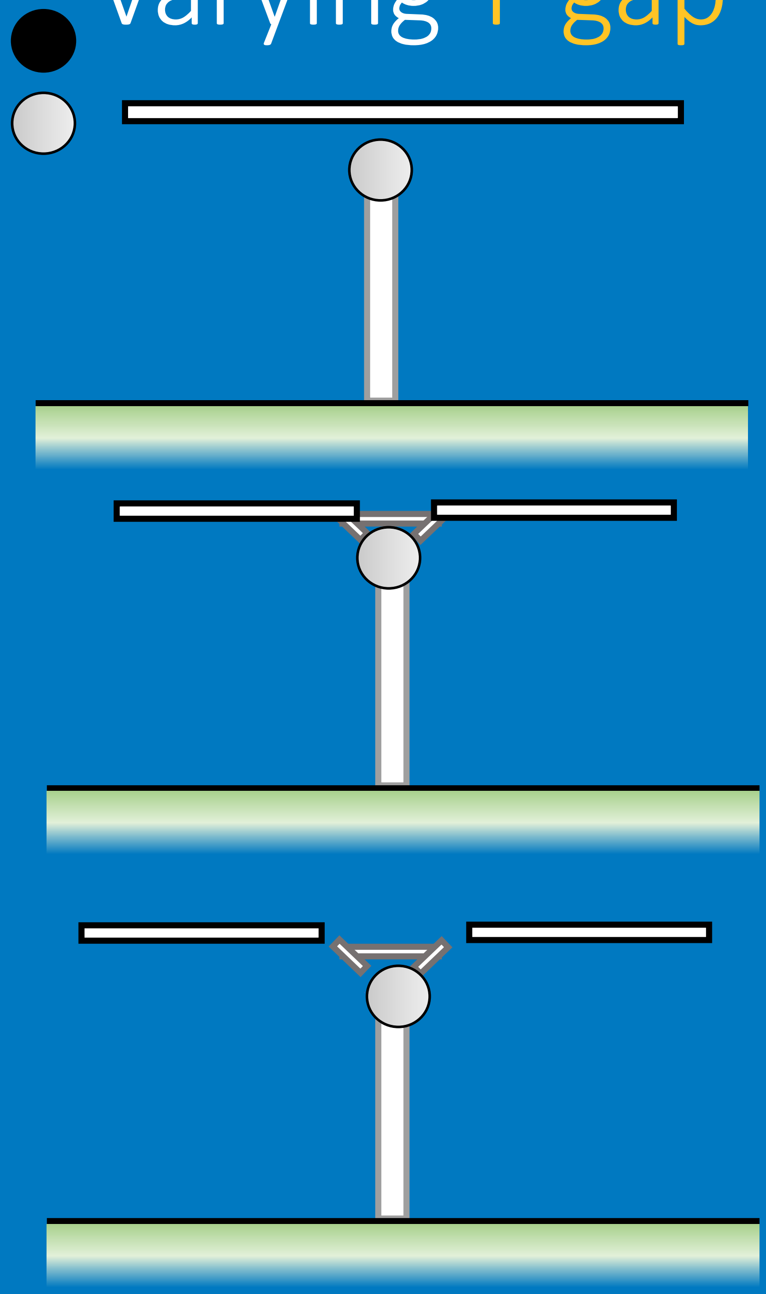
P_1

$$L_{DC} = 1 - \frac{P_1}{P_0} \sim 1\%$$

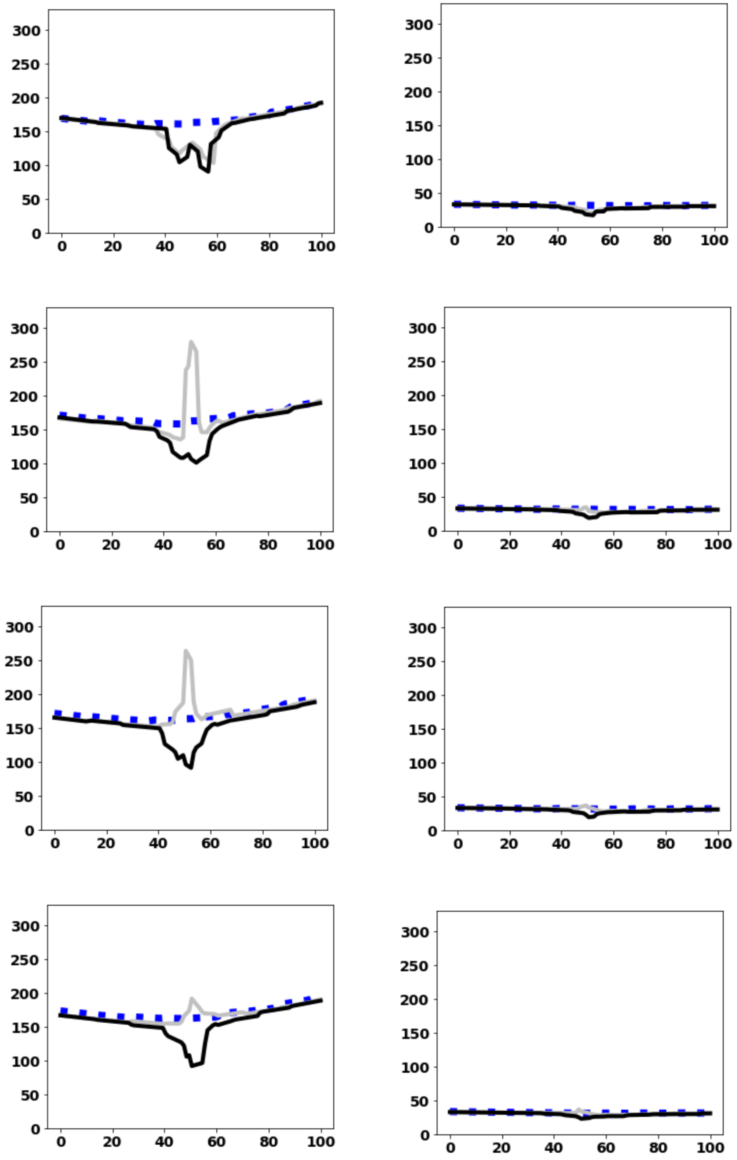
SUNPOWER

PVMismatch OpenSource!: https://github.com/SunPower/PVMismatch

Varying Y-gap



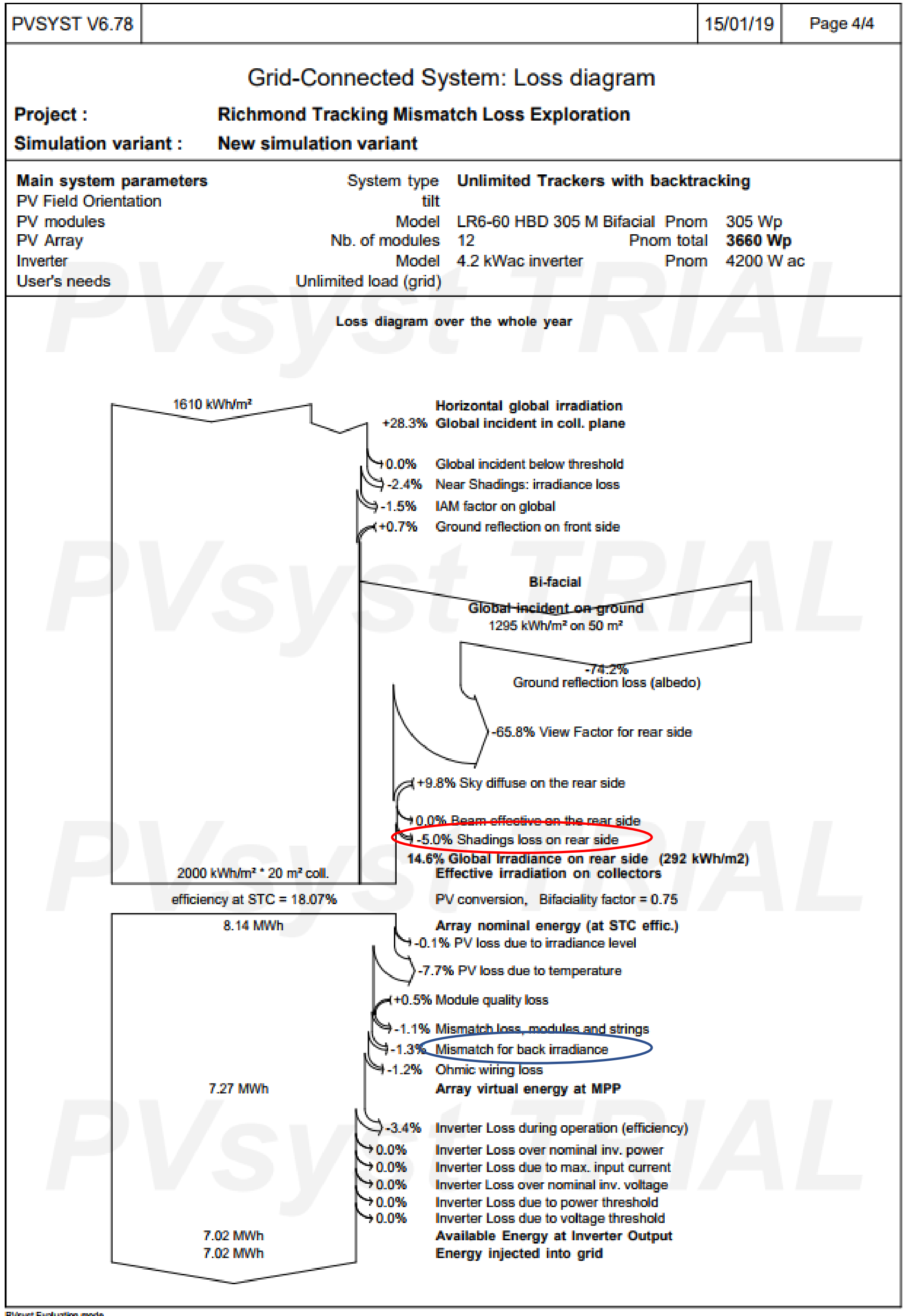
2 pm



YGAP [cm]	G_{Rear} Shading Factor (Annual) %	Total Loss DC %
0	5.7	1.2
5	0	0.5
10	-0.2	0.6
15	0.4	1.1

Loss_{DC} to parameters in PVSyst?

- Structure shading factor, a.k.a. Rear shading factor gets put directly into the loss diagram as “Shading loss on rear side”.
- Mismatch loss factor a.k.a. rear mismatch loss, affects the Mismatch for back irradiance in the loss diagram



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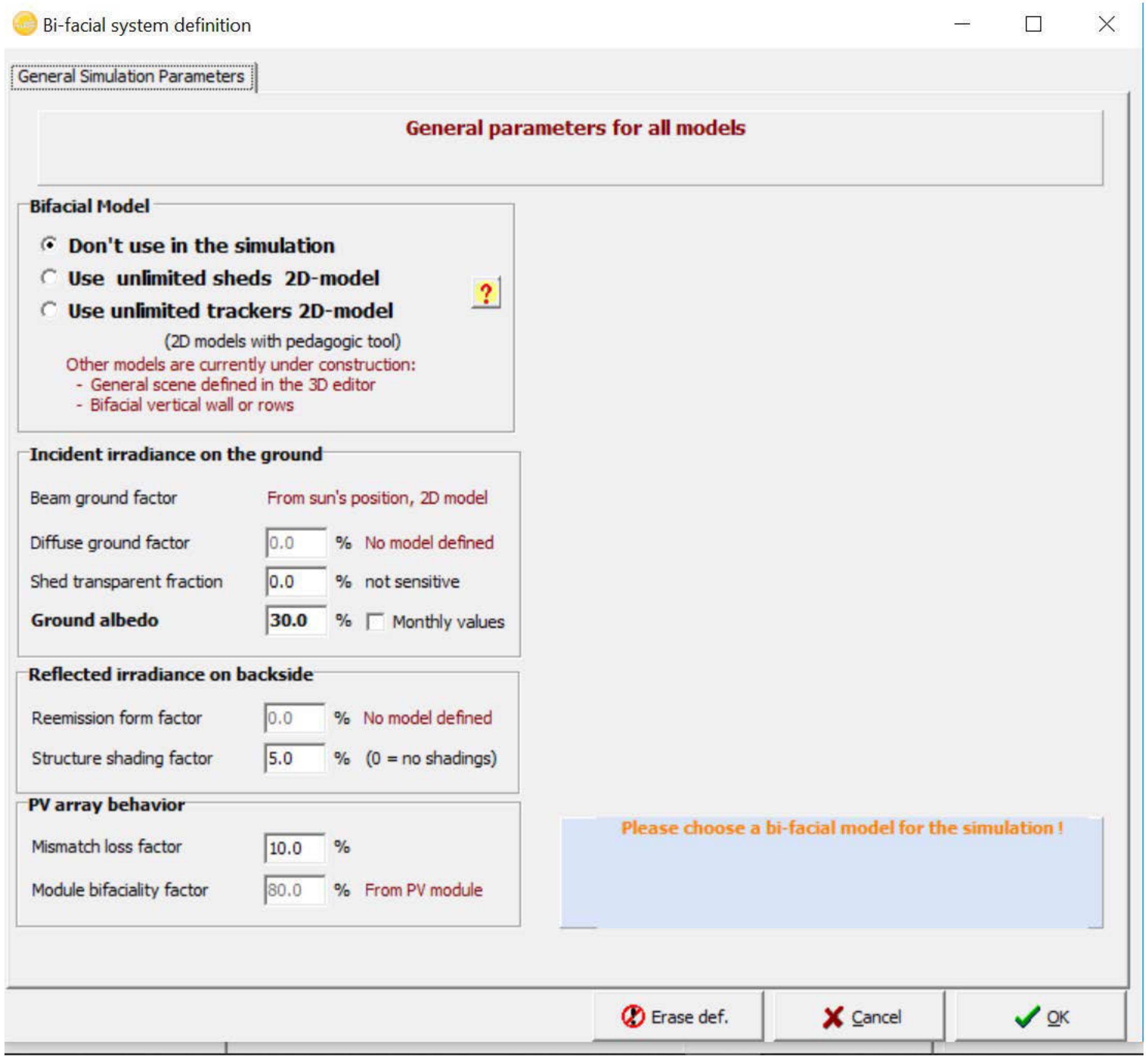
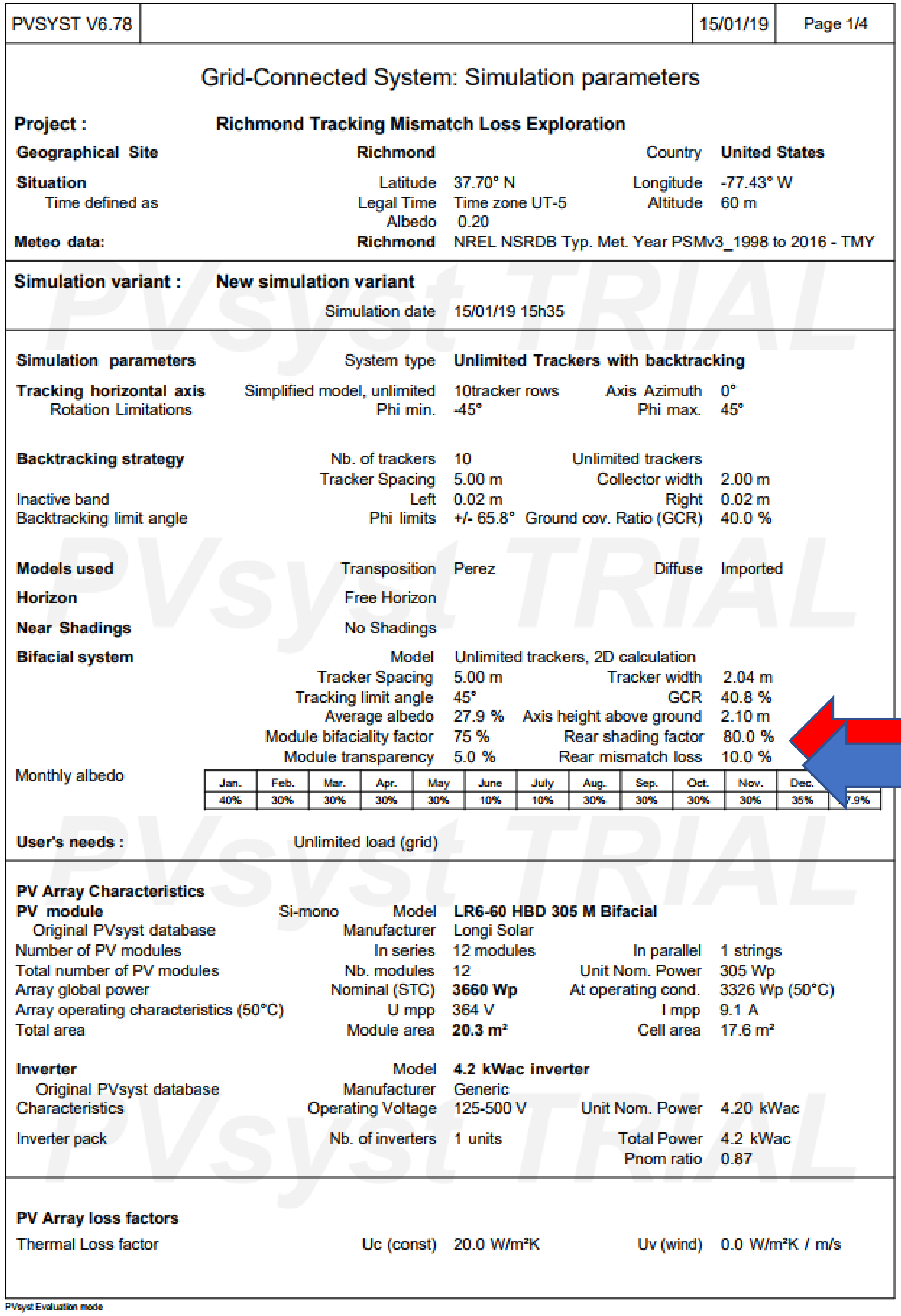
Grid-Connected System: Loss diagram

Project : **Richmond Tracking Mismatch Loss Exploration**
Simulation variant : **New simulation variant**

Main system parameters	System type	**Unlimited Trackers with backtracking**		
PV Field Orientation	tilt			
PV modules	Model	LR6-60 HBD 305 M Bifacial	Pnom	305 Wp
PV Array	Nb. of modules	12	Pnom total	**3660 Wp**
Inverter	Model	4.2 kWac inverter	Pnom	4200 W ac
User's needs	Unlimited load (grid)			





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Grid-Connected System: Simulation parameters

Project : **Richmond Tracking Mismatch Loss Exploration**

Geographical Site **Richmond** Country **United States**

Situation Latitude 37.70° N Longitude -77.43° W
Time defined as Legal Time Time zone UT-5 Altitude 60 m
Albedo 0.20

Meteo data: **Richmond** NREL NSRDB Typ. Met. Year PSMv3_1998 to 2016 - TMY

Simulation variant : **New simulation variant**
Simulation date 15/01/19 15h35

Simulation parameters System type **Unlimited Trackers with backtracking**

Tracking horizontal axis Simplified model, unlimited 10tracker rows Axis Azimuth 0°
Rotation Limitations Phi min. -45° Phi max. 45°

Backtracking strategy Nb. of trackers 10 Unlimited trackers
Tracker Spacing 5.00 m Collector width 2.00 m
Inactive band Left 0.02 m Right 0.02 m
Backtracking limit angle Phi limits +/- 65.8° Ground cov. Ratio (GCR) 40.0 %

Models used Transposition Perez Diffuse Imported

Horizon Free Horizon

Near Shadings No Shadings

Bifacial system Model Unlimited trackers, 2D calculation
Tracker Spacing 5.00 m Tracker width 2.04 m
Tracking limit angle 45° GCR 40.8 %
Average albedo 27.9 % Axis height above ground 2.10 m
Module bifaciality factor 75 % Rear shading factor 80.0 %
Module transparency 5.0 % Rear mismatch loss 10.0 %

Monthly albedo

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	[illegible]
40%	30%	30%	30%	30%	10%	10%	30%	30%	30%	30%	35%	[illegible]7.9%

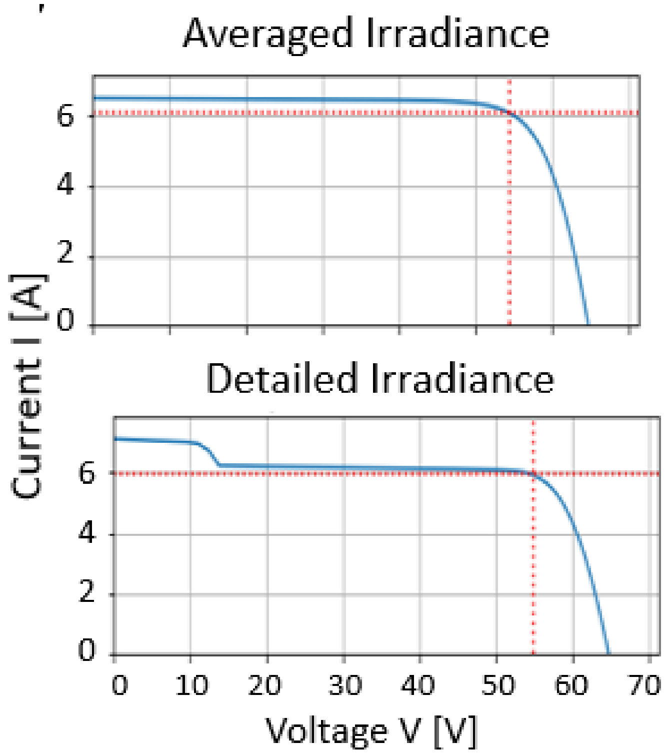
User's needs : Unlimited load (grid)

PV Array Characteristics
PV module Si-mono Model **LR6-60 HBD 305 M Bifacial**
Original PVsyst database Manufacturer Longi Solar
Number of PV modules In series 12 modules In parallel 1 strings
Total number of PV modules Nb. modules 12 Unit Nom. Power 305 Wp
Array global power Nominal (STC) **3660 Wp** At operating cond. 3326 Wp (50°C)
Array operating characteristics (50°C) U mpp 364 V I mpp 9.1 A
Total area Module area **20.3 m²** Cell area 17.6 m²

Inverter Model **4.2 kWac inverter**
Original PVsyst database Manufacturer Generic
Characteristics Operating Voltage 125-500 V Unit Nom. Power 4.20 kWac
Inverter pack Nb. of inverters 1 units Total Power 4.2 kWac
Pnom ratio 0.87

PV Array loss factors
Thermal Loss factor Uc (const) 20.0 W/m²K Uv (wind) 0.0 W/m²K / m/s

Shading Factor and Rear Electrical Mismatch Factors



P_0

P_1

$$P_0 = \left(G_{F_0} + G_{R_0} \cdot \varphi\right) \cdot \eta_0$$

$$P_1 = \left(G_{F_0} + G_{R_0} \cdot \varphi\right) \cdot \eta_0 \cdot (1 - L_{DC})$$

1%

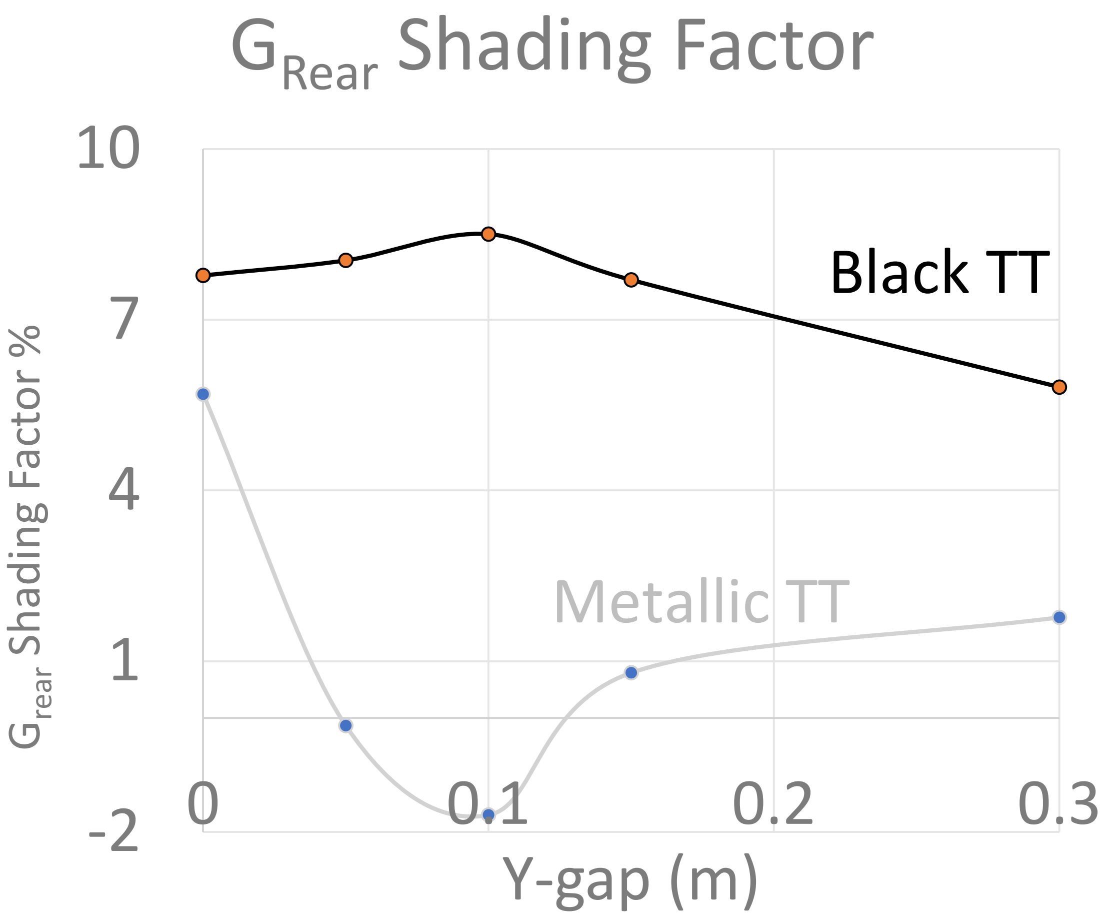
$$P_1 = \left(G_{F_0} + (1 - X) G_{R_0} \cdot \varphi\right) \cdot \eta_0$$

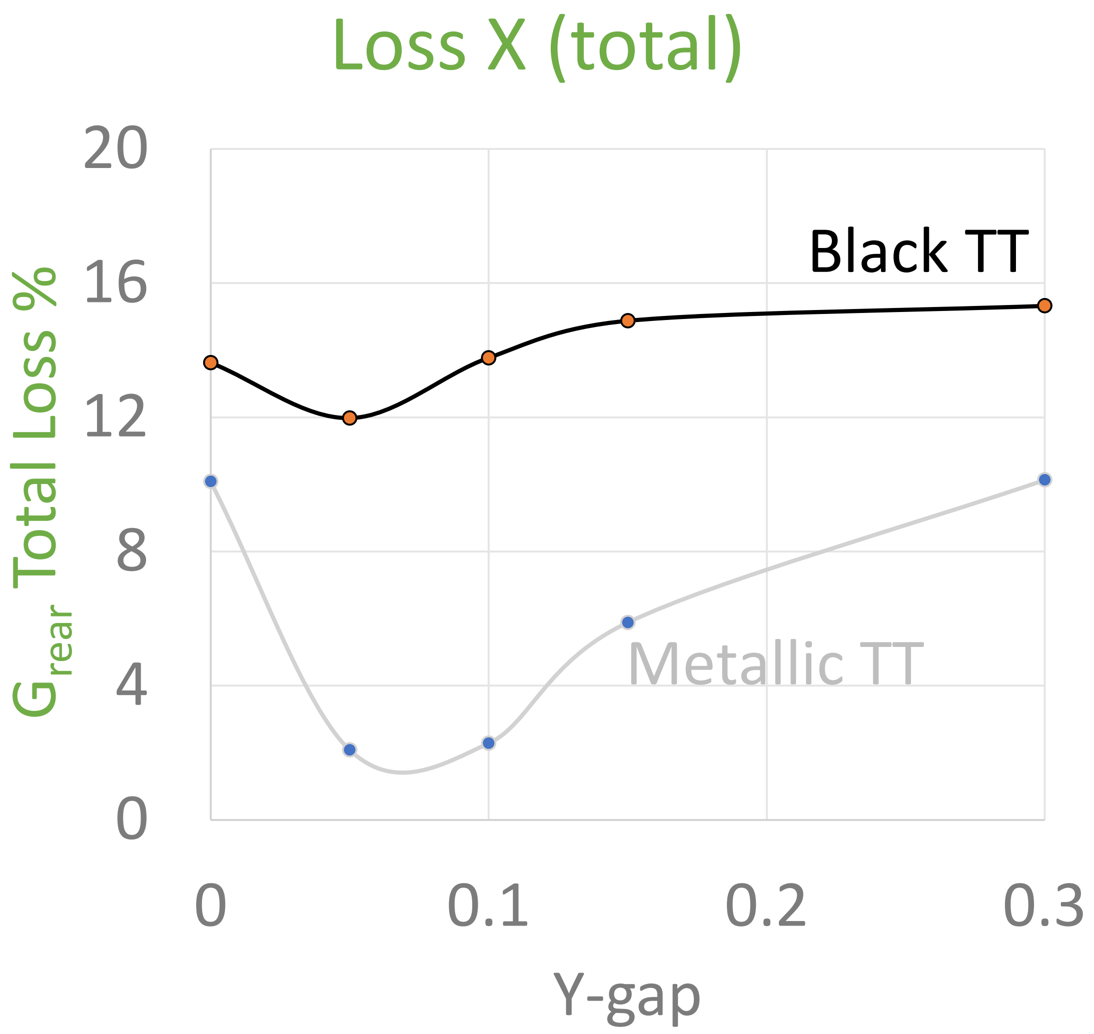
$$X = L_{Inherent\ Mismatch} + L_{Structural\ Shading}$$

11%

$$X = \frac{L_{DC}}{BG} + L_{DC}$$

10%

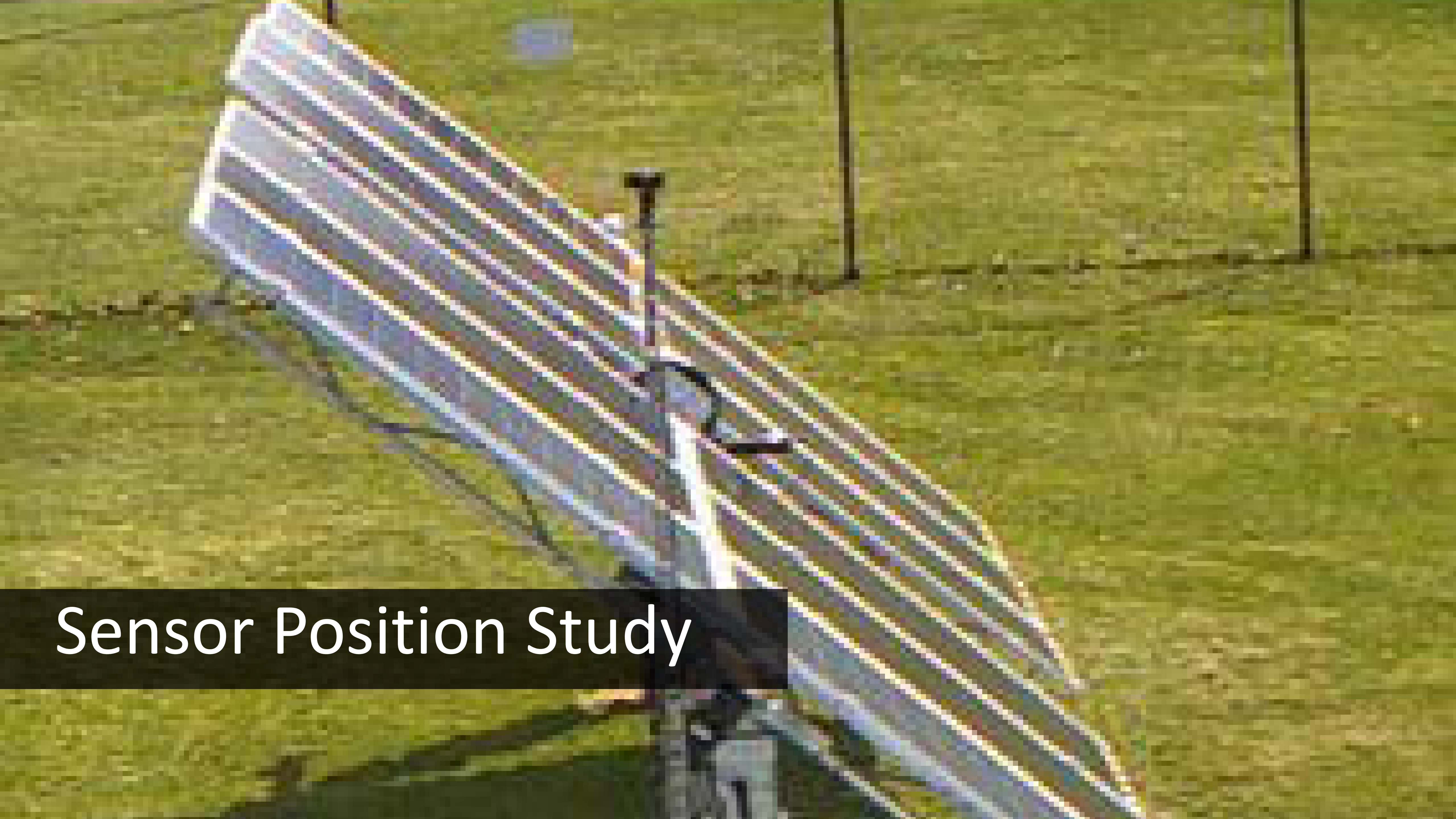




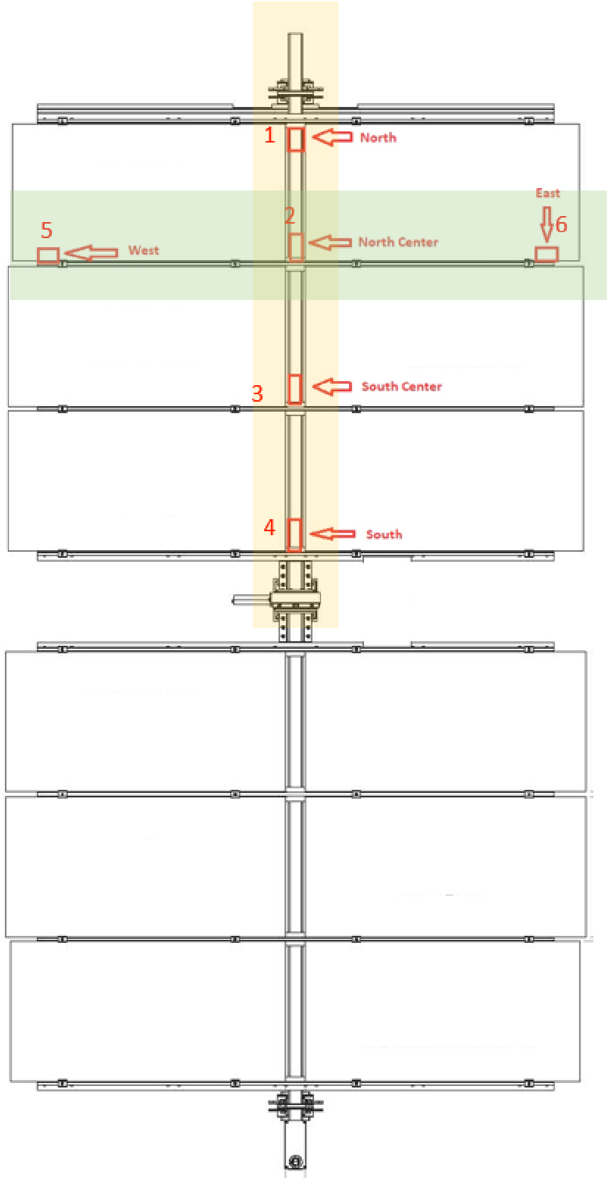
G_{rear} Shading Factor: -0.1 to 8.1 % metallic

7.8 – 8.5 % black

Sensor Position Study



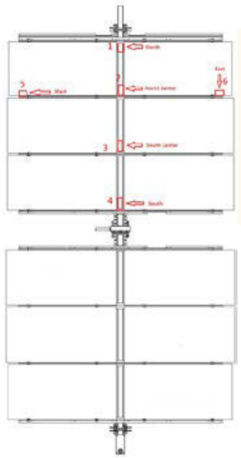
Rear-Irradiance Modeling at different locations in the tracker

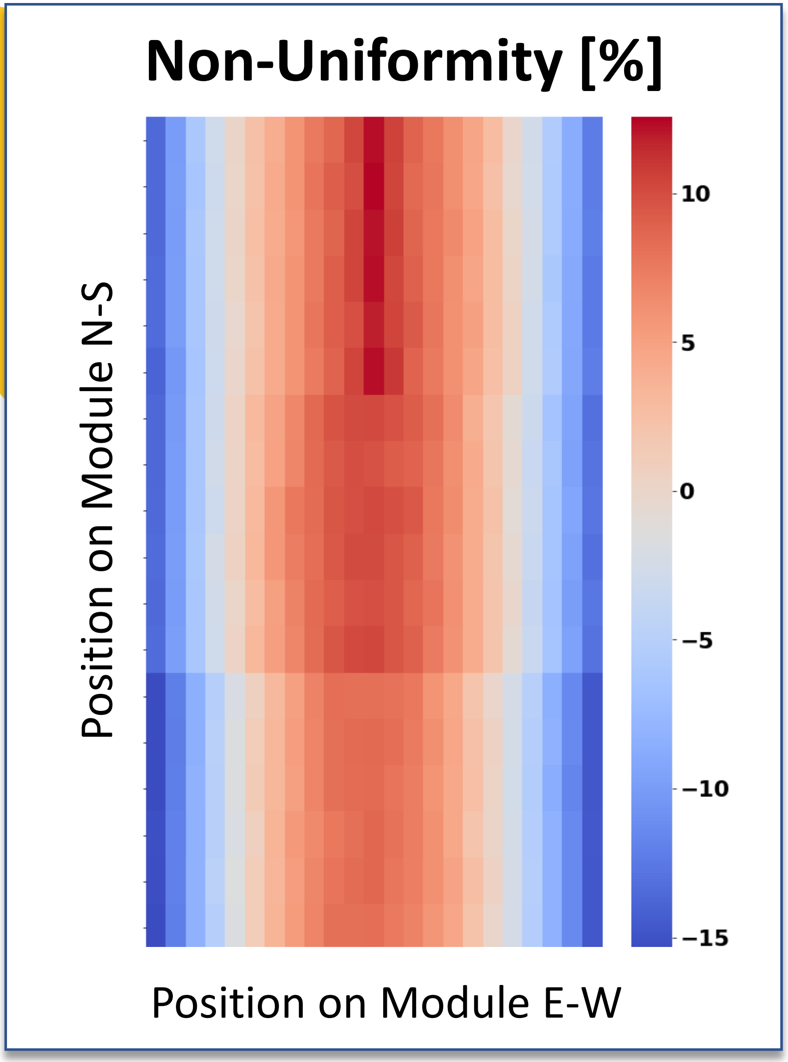


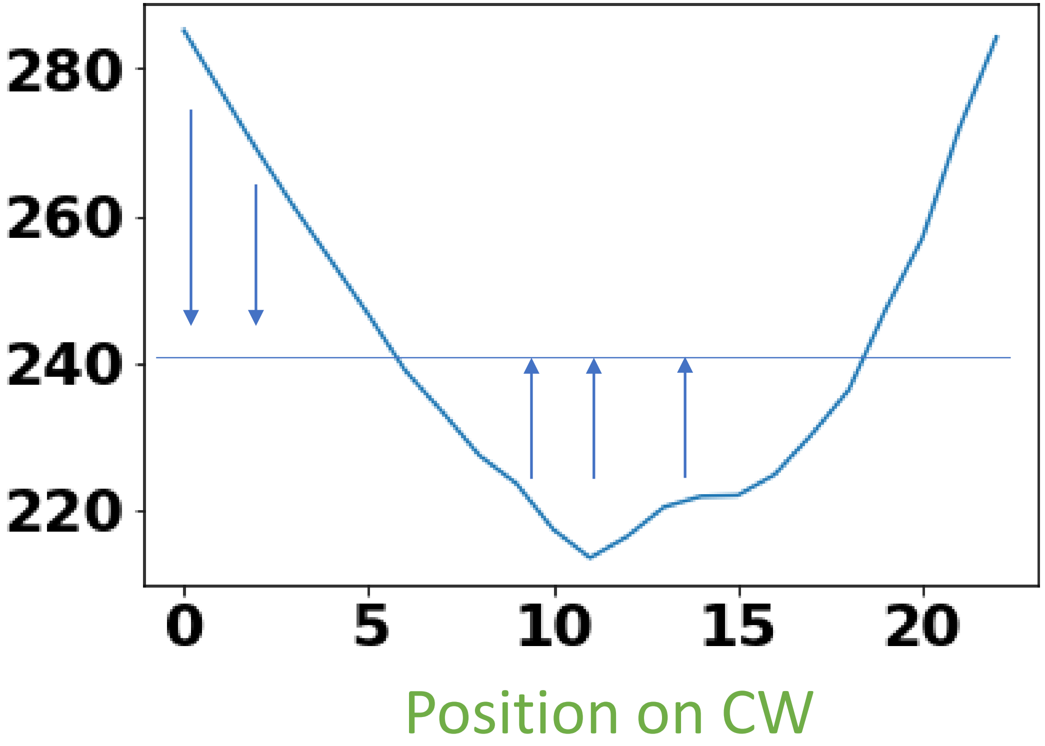
- Single row of HSAT, N-S oriented on Jackson, Michigan
- Data collected for 4 months, Dec. 2018 to April 2019.
- 45.9% DHI to DNI ratio for location
- Albedo measured on location.

CYPRESS CREEK
RENEWABLES

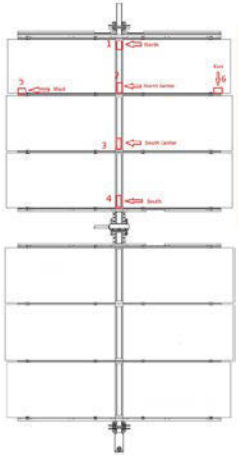
MBE and RMSE of Sensor location modeled value vs. average modeled value of north-part of the array for 1 day

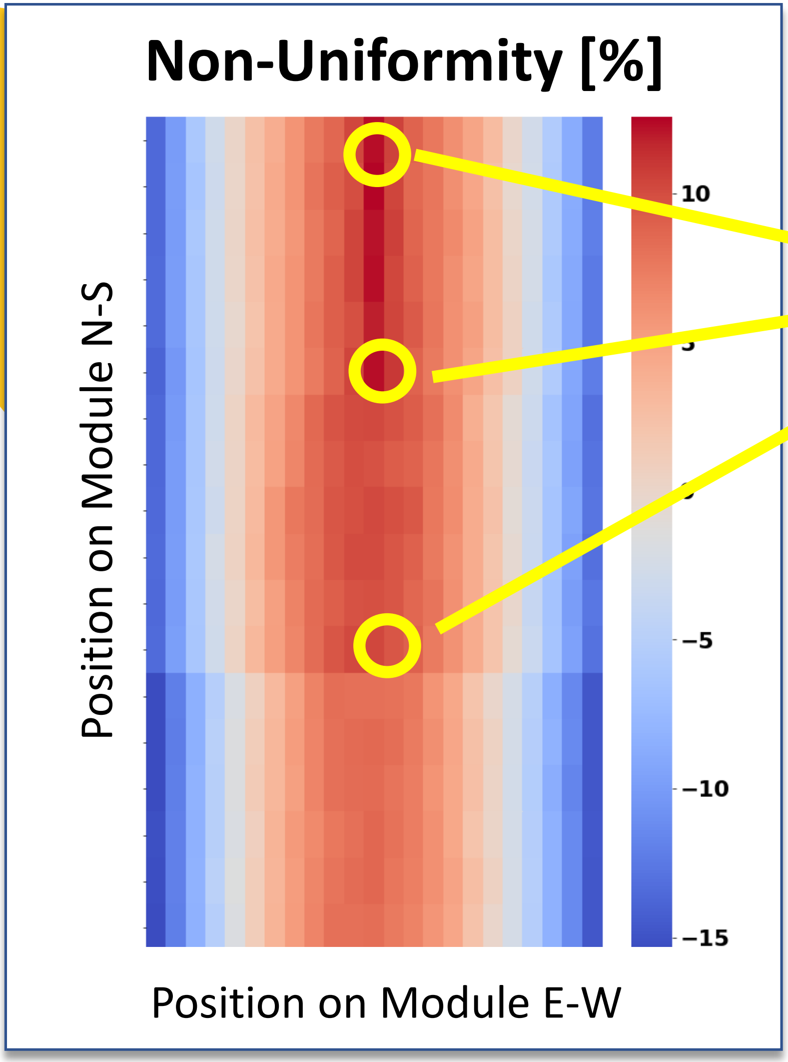






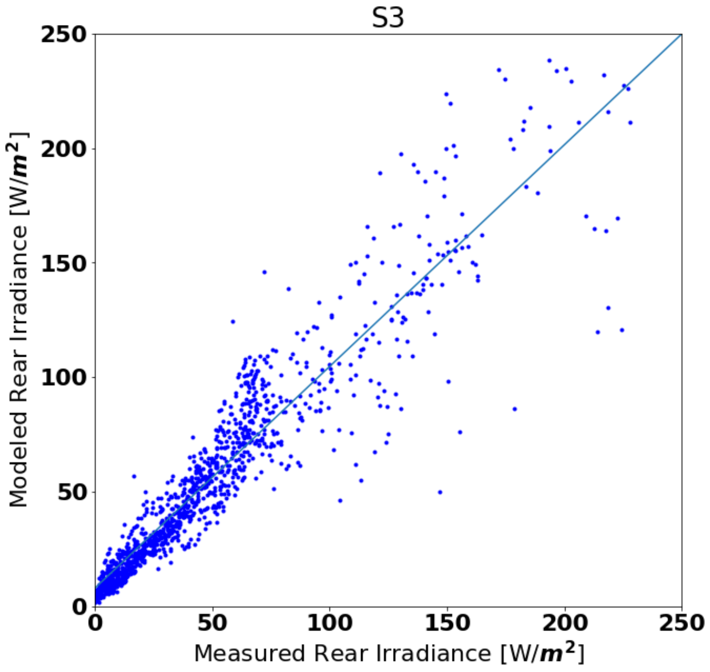
MBE and RMSE of Sensor location modeled value vs. average modeled value of north-part of the array for 1 day





MBE
2.5-8
W/m^2

RMSE
~20 W/m^2



Conclusions

- Shading optical loss for modeled systems is between 2-8%
- Gap + torquetube reflections equal potential energy gains
- System mismatch loss (Dc losses) are around 1%, but must be propagated backwards to reflect the losses at the Grear irradiance level for implementation in current softwares.
- Grear irradiance measurements must account for non-uniformities and equipment shading. Avoid ends and middles of the modules for sensor placements.

Thank you

www.nrel.gov

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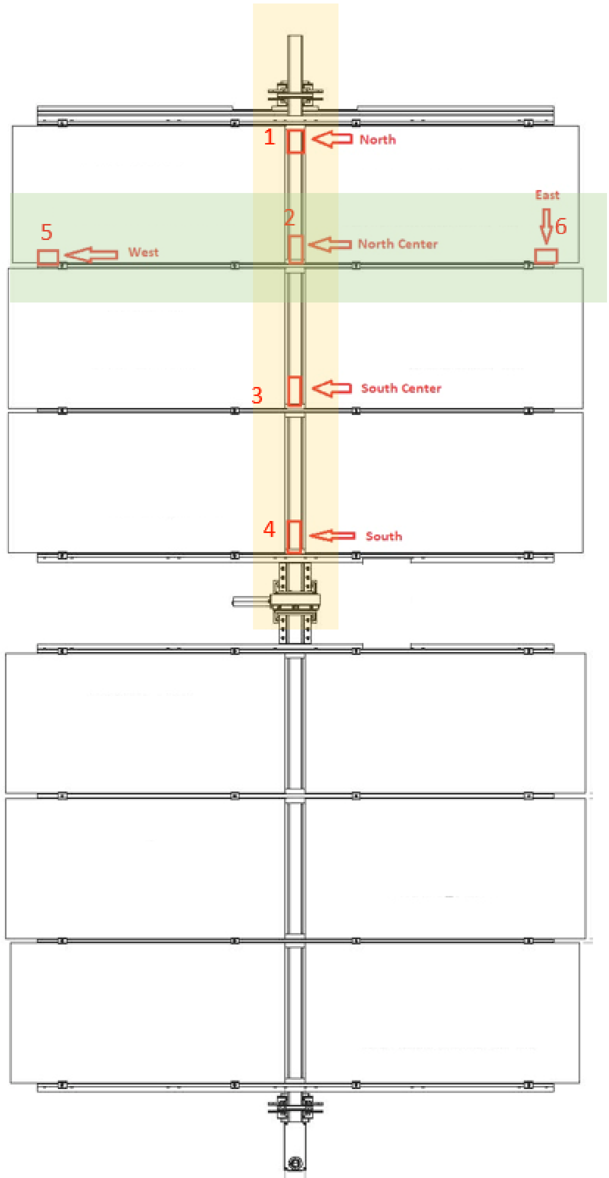
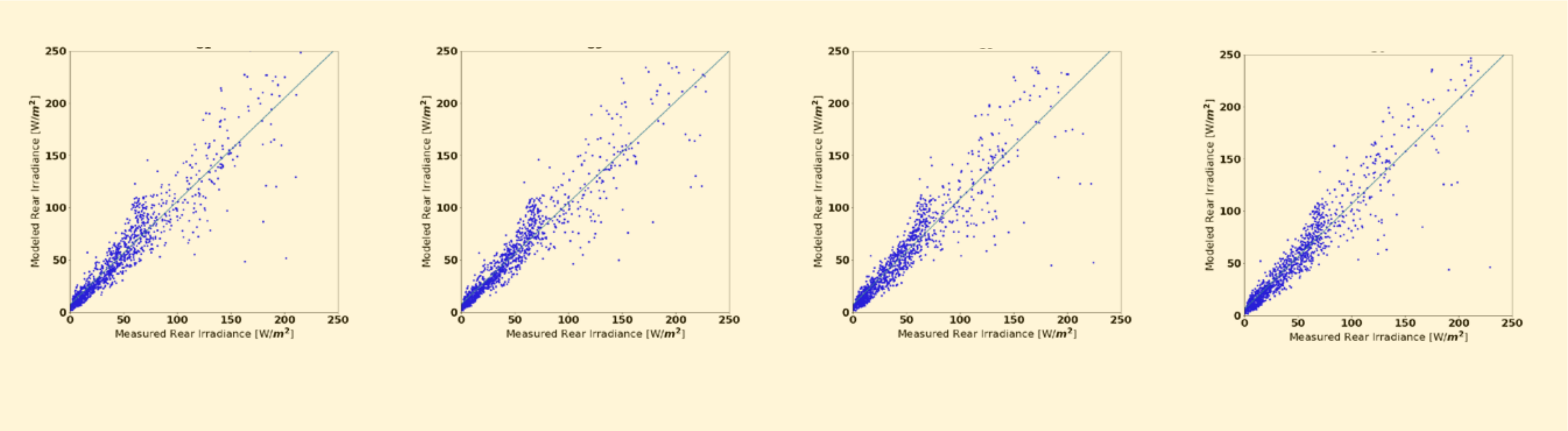
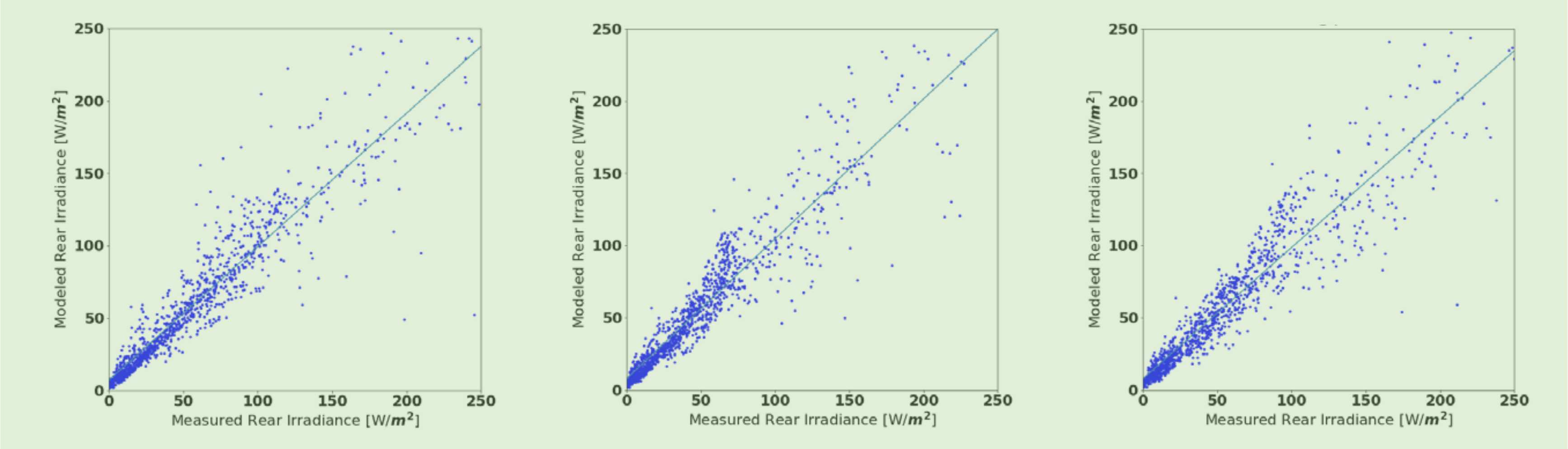
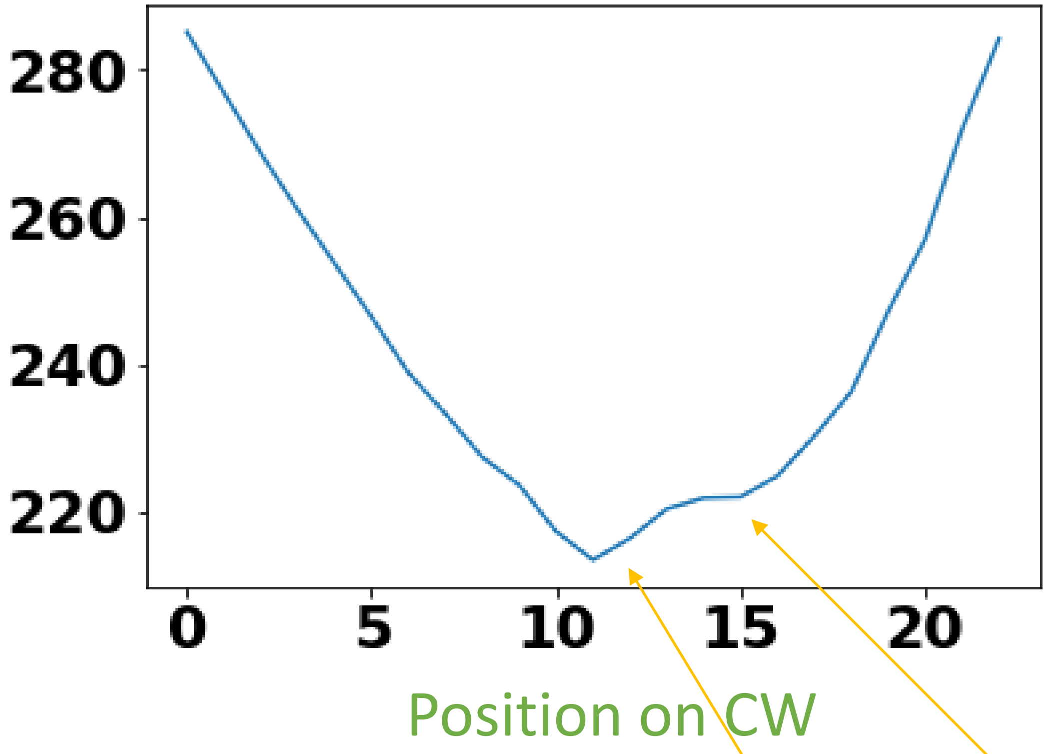
Measured vs. modeled Rear Irradiances, overall modeling accuracy at any position

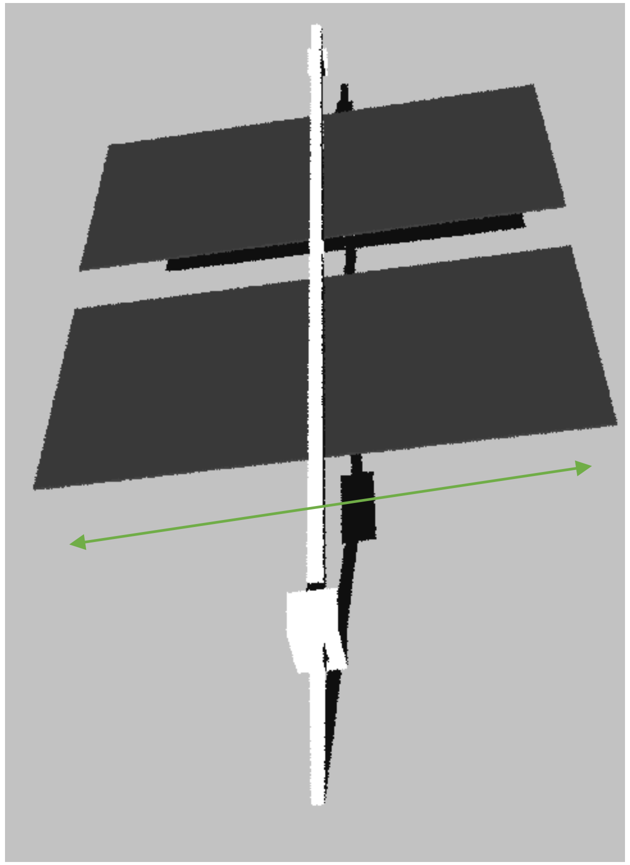






In-plane torque-tube causes a different shading profile

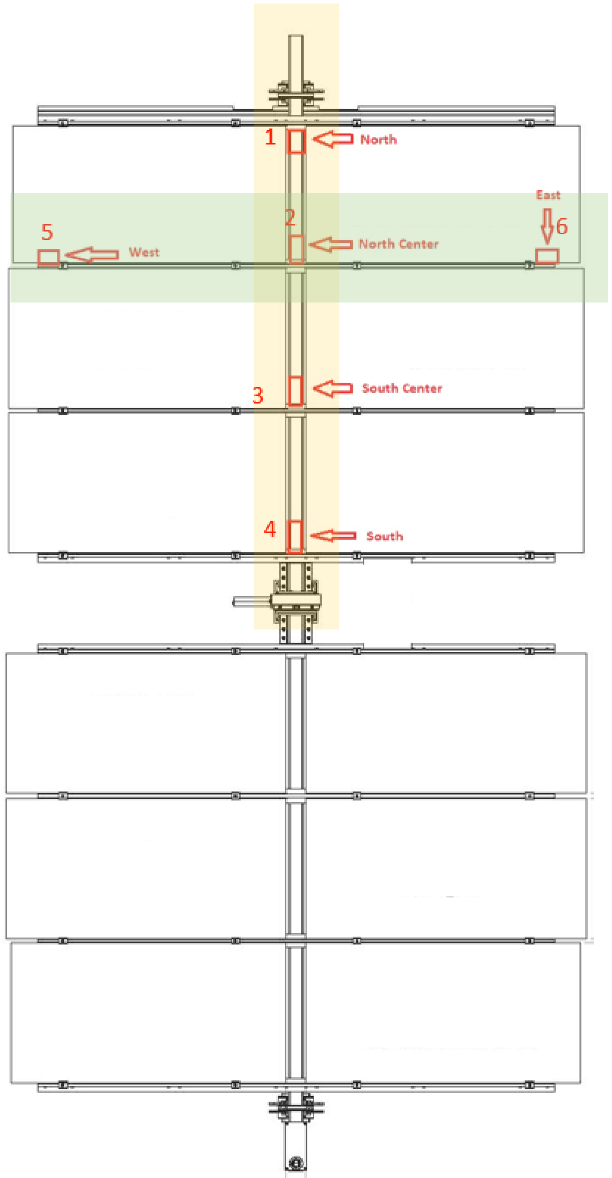


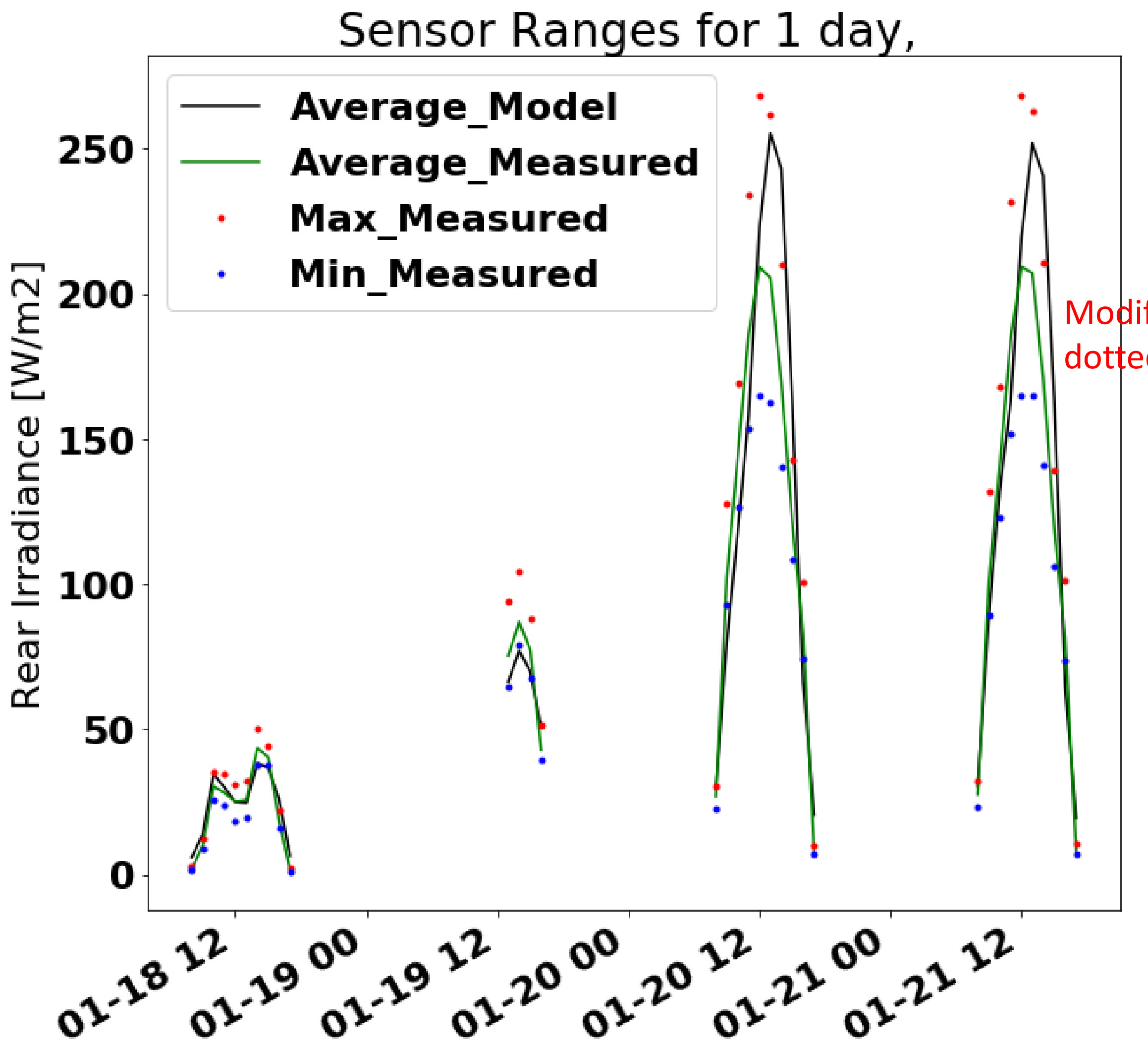


In-plane torque-tube shading.

Sensor location for sensors located at torque tube

Measured vs. modeled Rear Irradiances, overall modeling accuracy at any position





Modify Average Measured to be dotted line