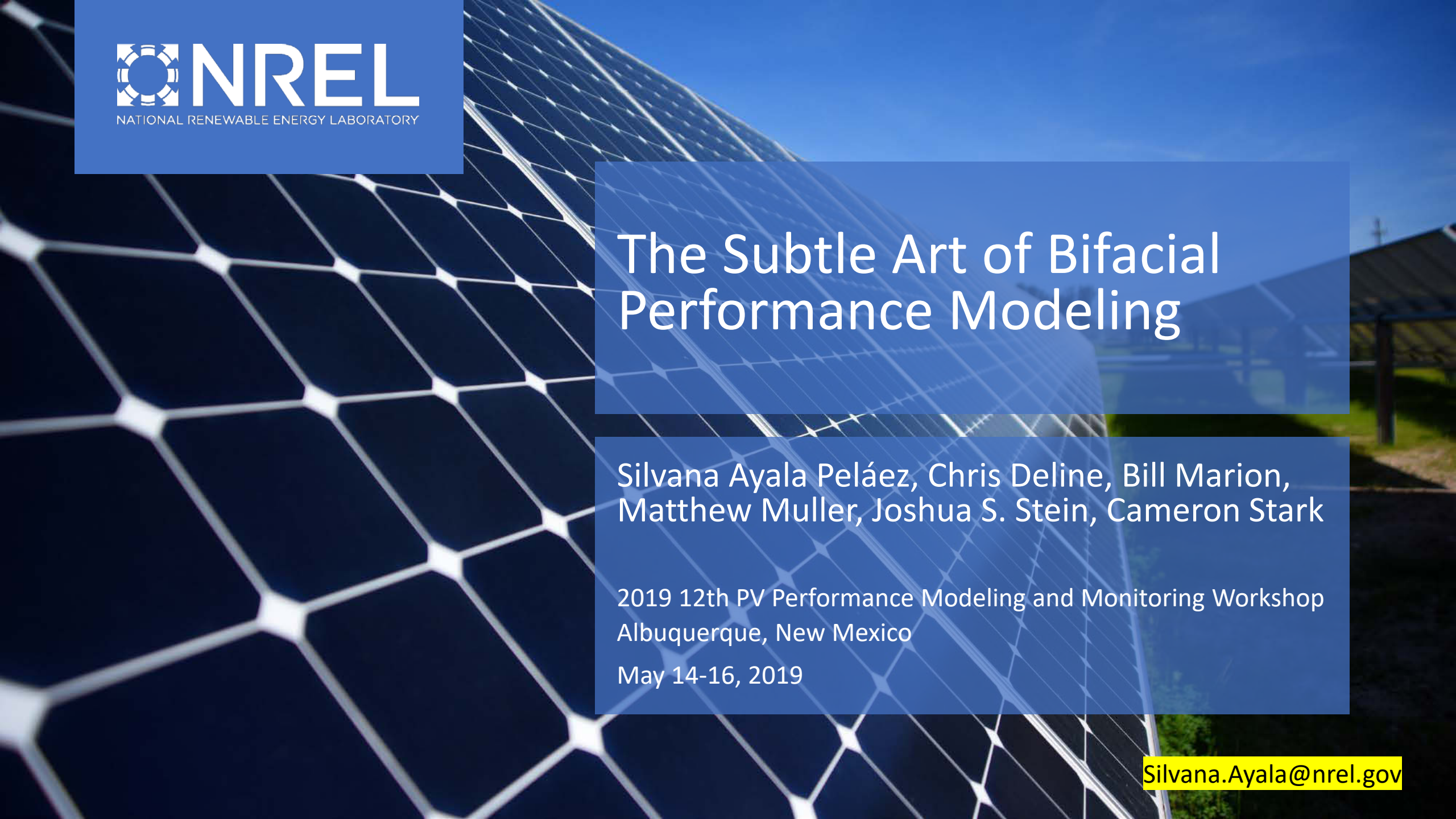

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

The Subtle Art of Bifacial Performance Modeling

Silvana Ayala Peláez, Chris Deline, Bill Marion, Matthew Muller, Joshua S. Stein, Cameron Stark

2019 12th PV Performance Modeling and Monitoring Workshop
Albuquerque, New Mexico
May 14-16, 2019

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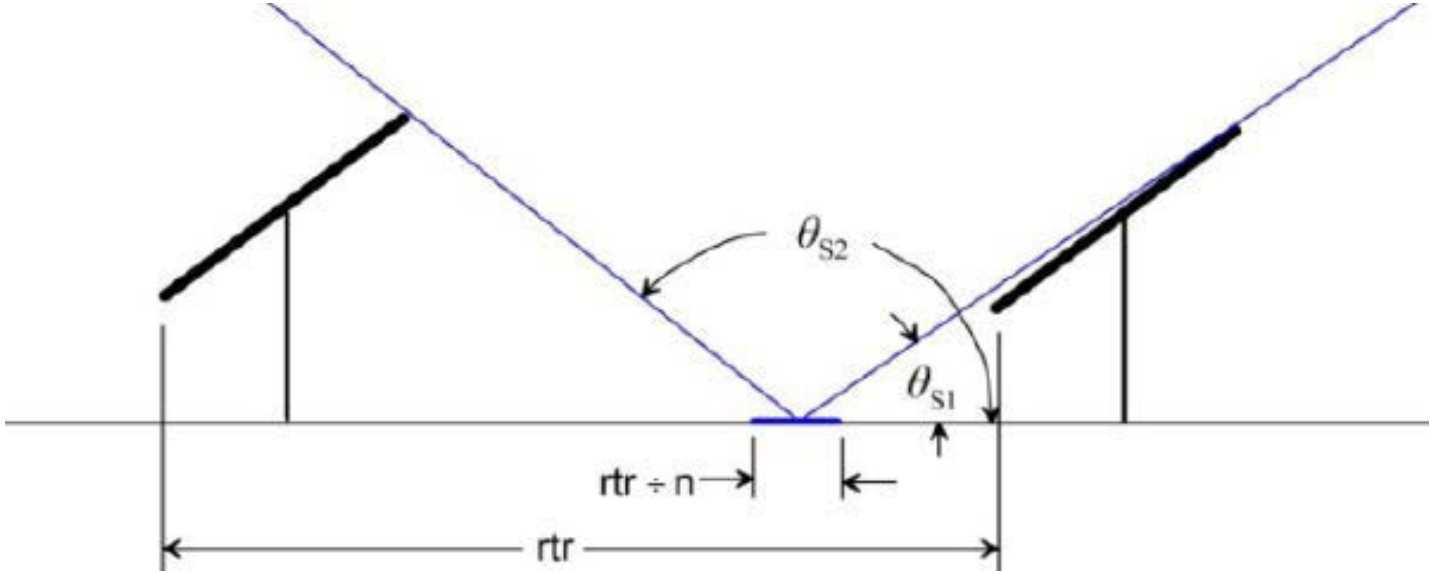
Bifacial performance modeling

The PV industry is set for rapid uptake of bifacial PV if key barriers are eliminated

- accurate performance models,
- standards around the rating of bifacial modules, and
- accurate assessment of site albedo.

View Factor Model for Rear Irradiance



Simple

basic **geometry**

Fast

computationally **inexpensive**

Common

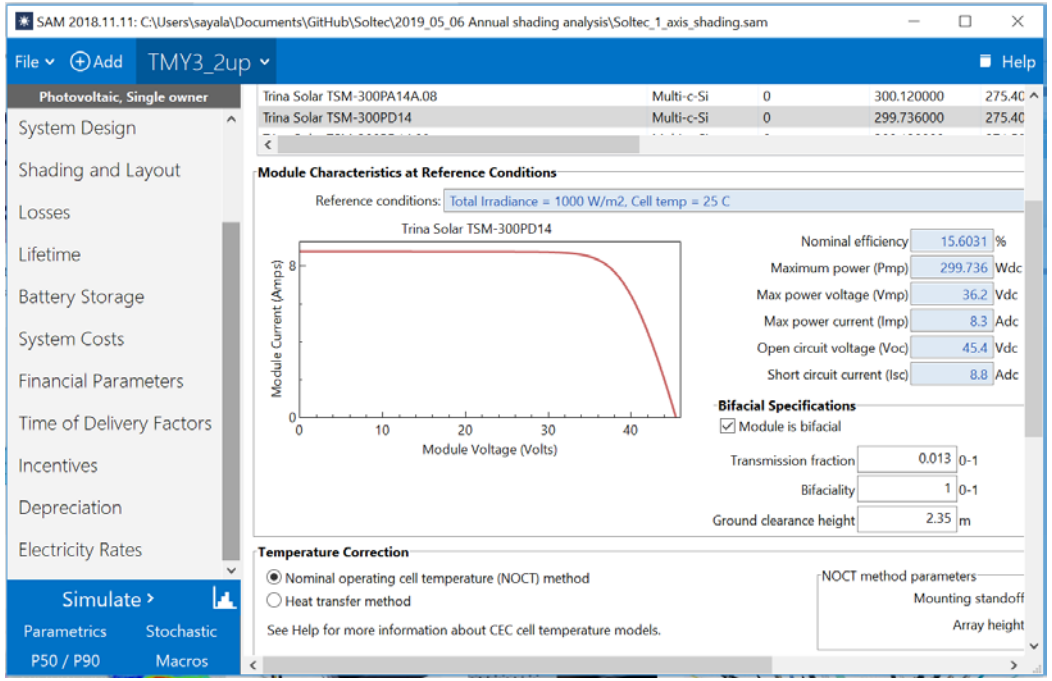
Behind
SAM, Pvsyst, and others

Simple

basic **geometry**

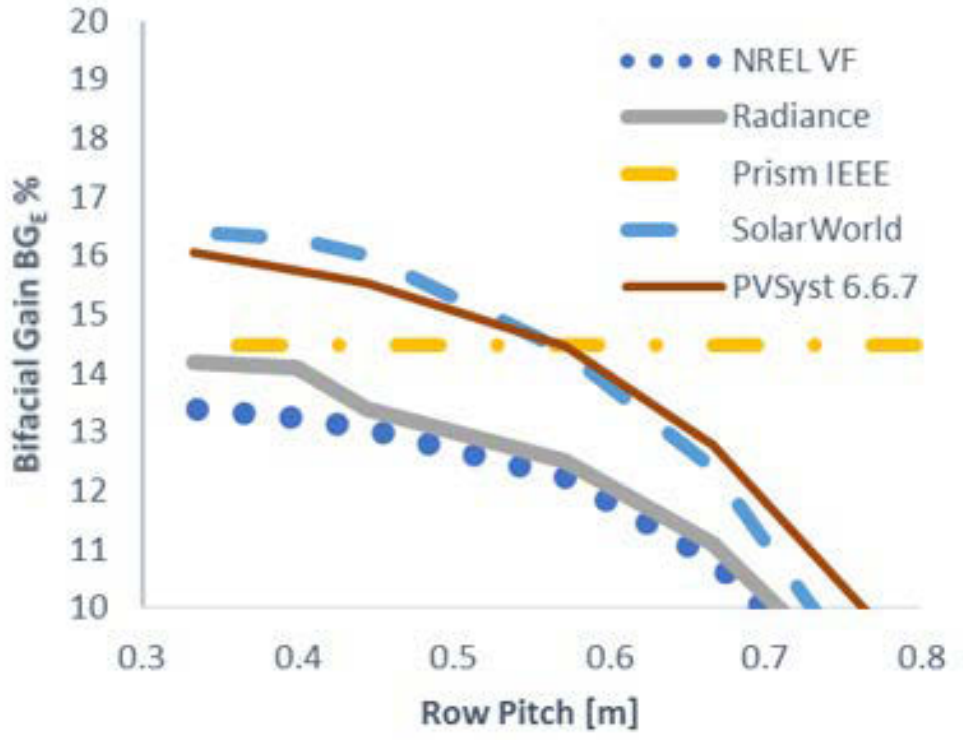
NREL Models

- OPENSource
- Bifacial_vf: https://github.com/NREL/bifacialvf
- Implemented in SAM:

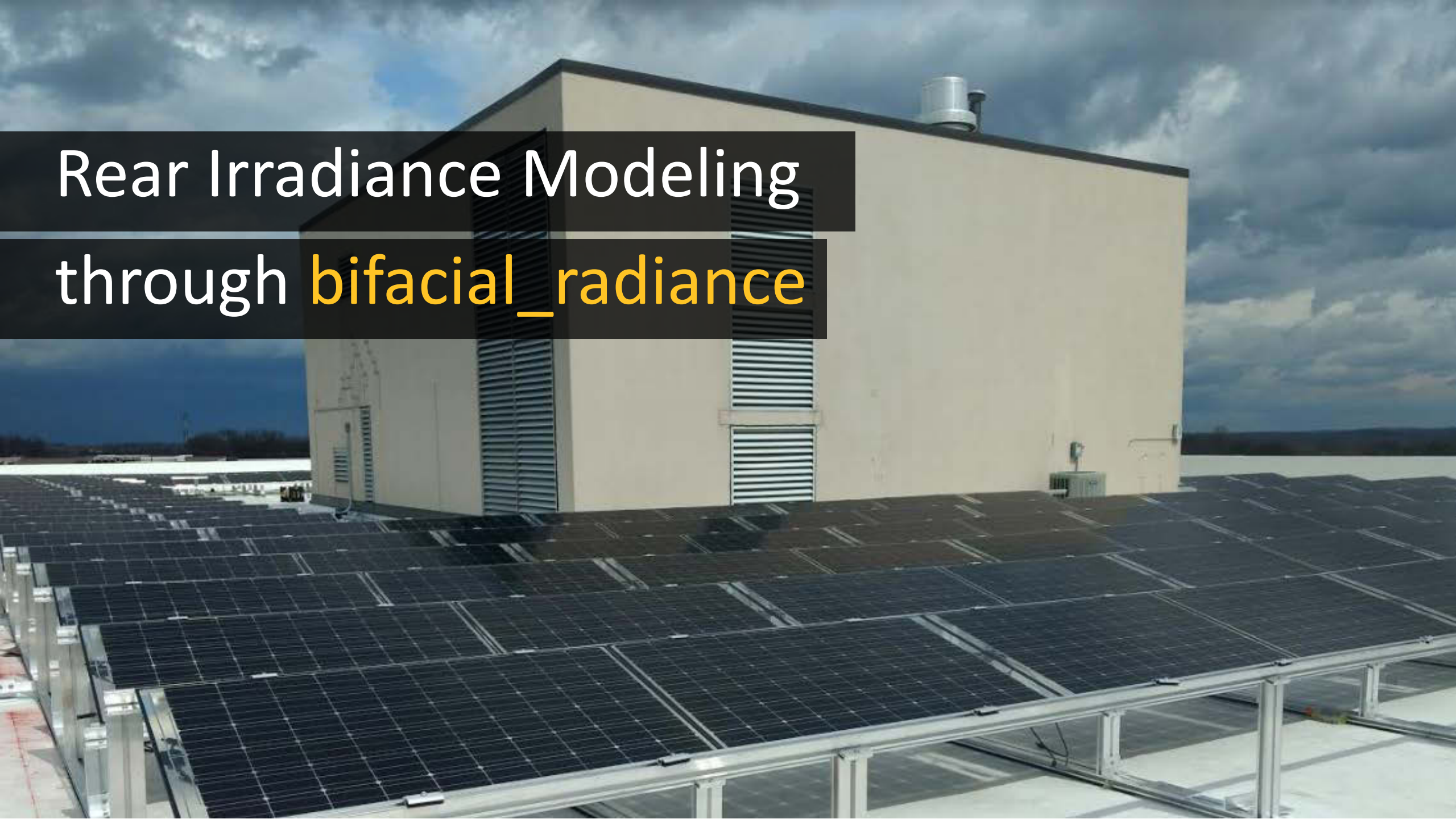


N. DiOrio, C. Deline, "Bifacial simulation in SAM", presented at 5th BifiPV in Denver, CO 2018.

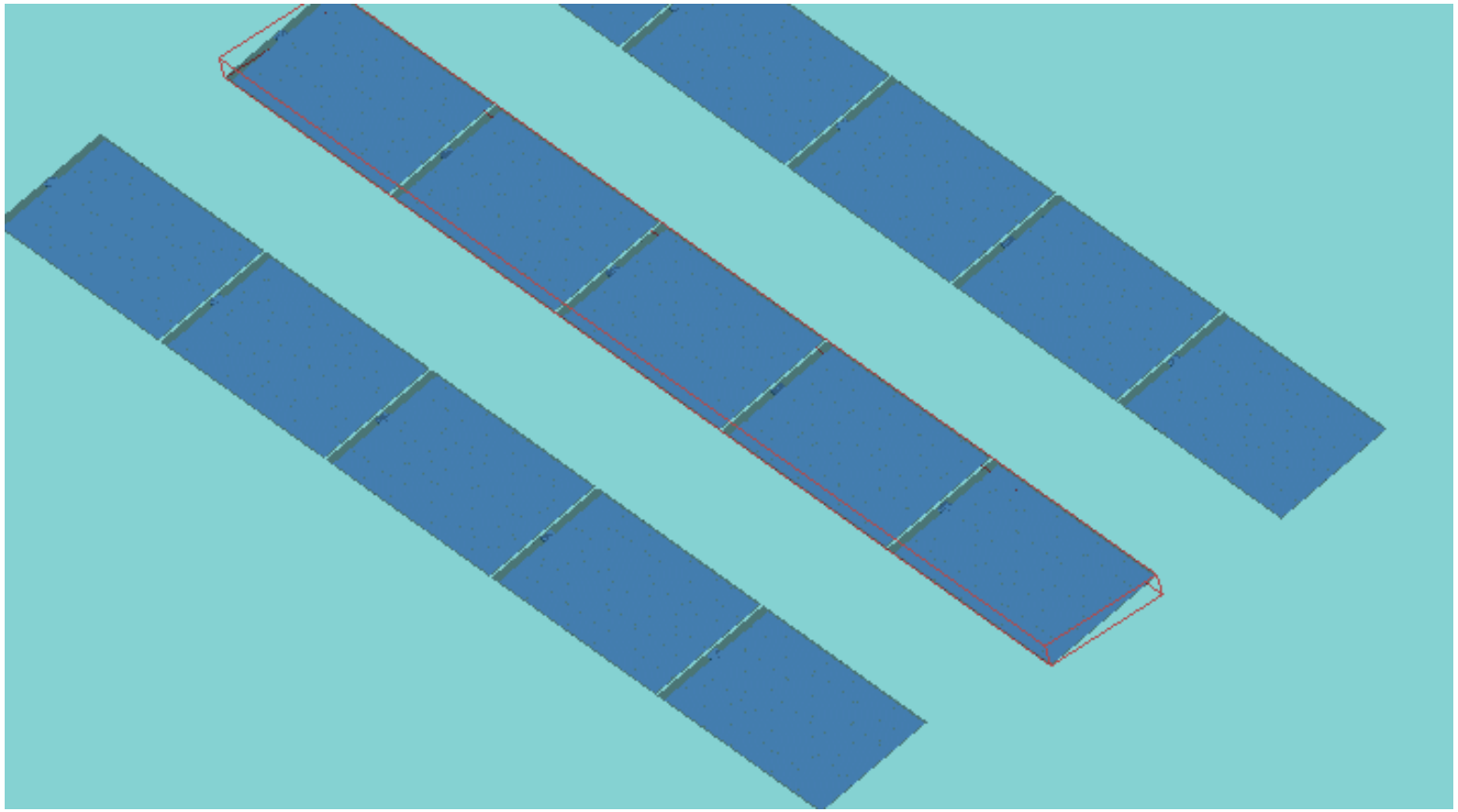
Published Comparison of Models With Validation data:



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, 2019, vol 9 no. 1, pp. 82-88.


Rear Irradiance Modeling
through bifacial_radiance

Bifacial_Radiance Model for Rear Irradiance

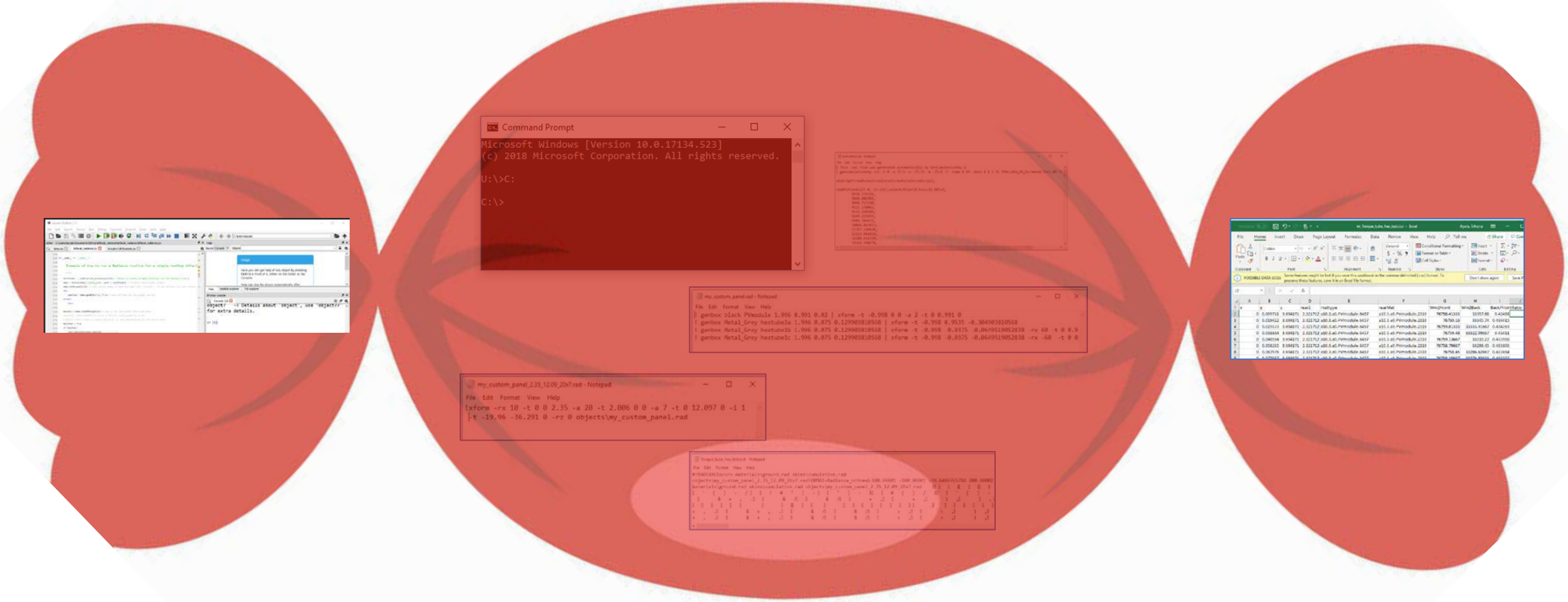


Complicated geometries possible, including racking and terrain.

Radiance uses backward ray-trace to evaluate the irradiance (W/m^2) at the modules

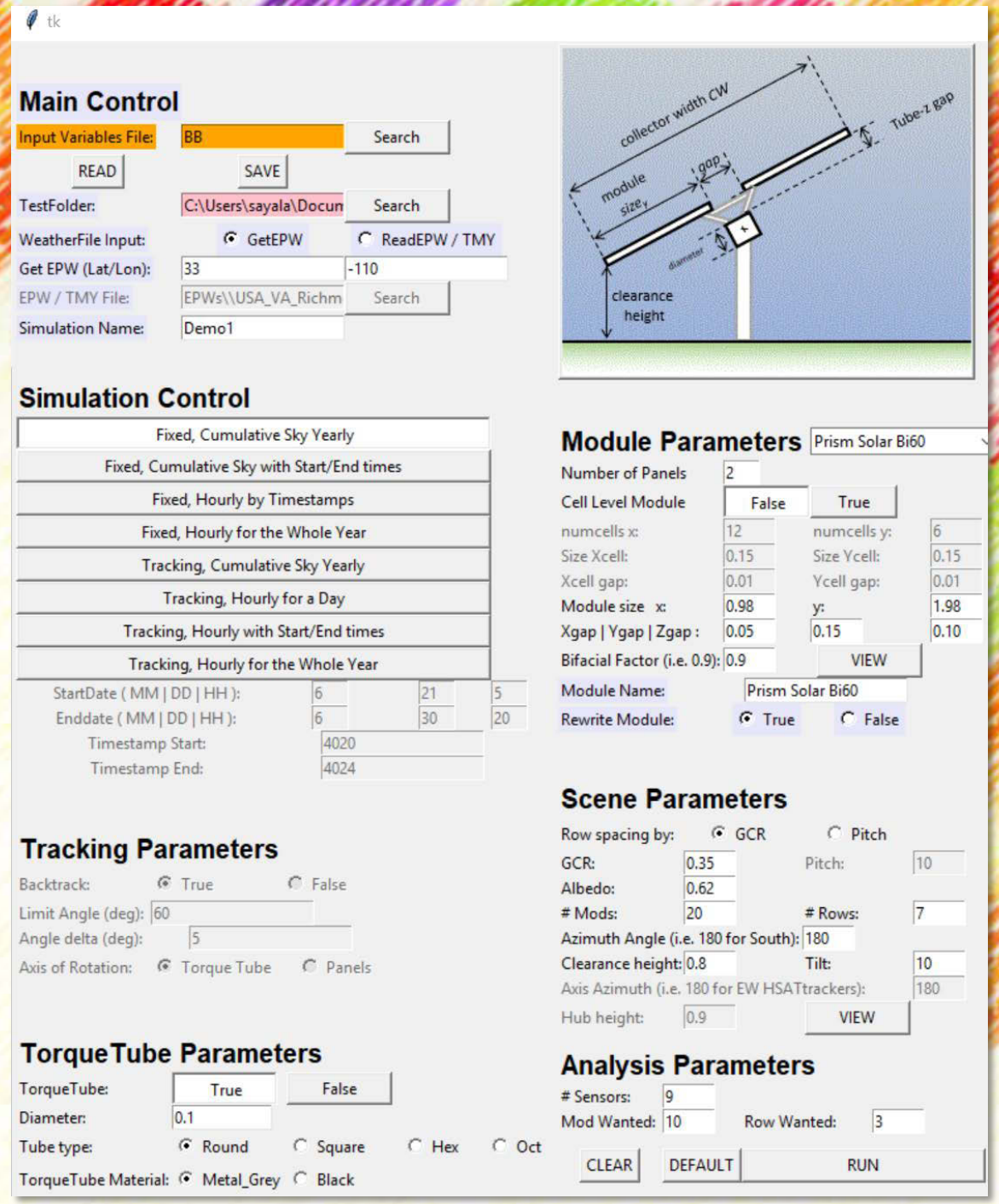
Bifacial_Radiance Model for Rear Irradiance

Open Source!



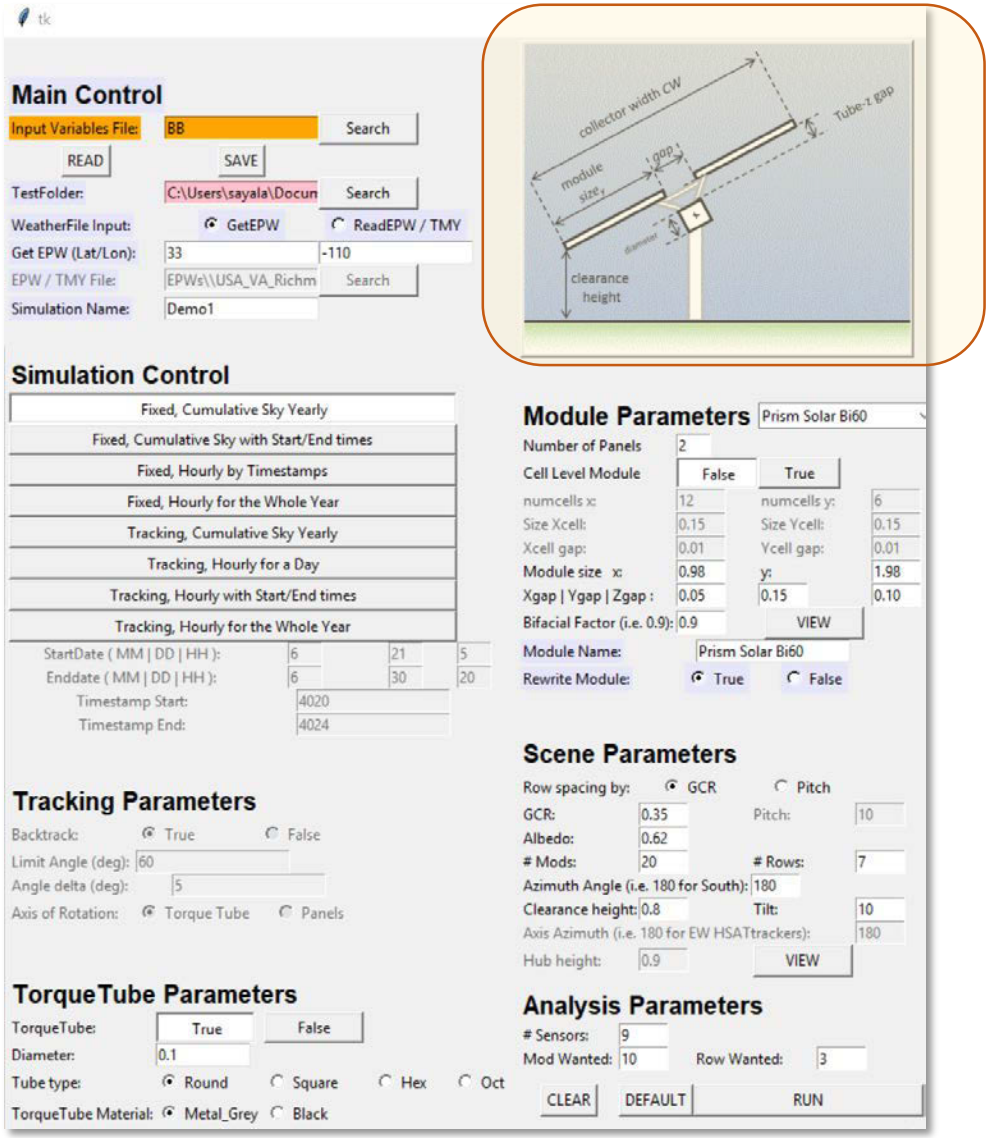
Bifacial_radiance is a python wrapper for calling and using Radiance, with specific functions to generate geometry (text files) related to bifacial pv systems

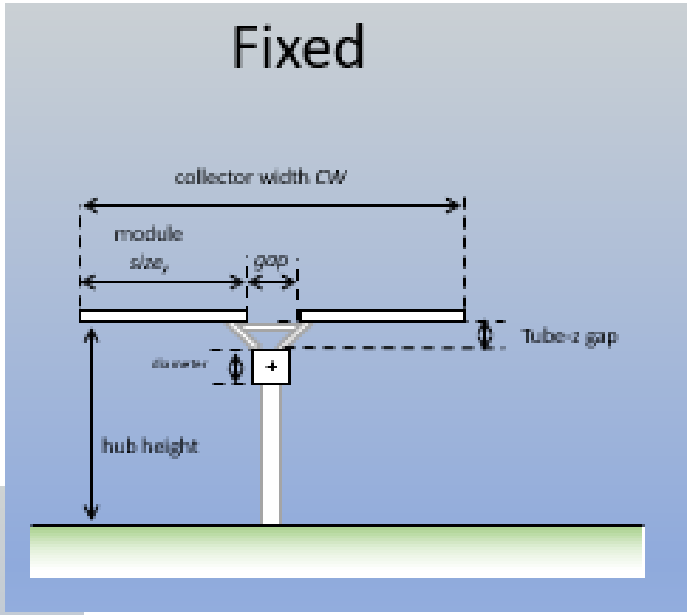
New GUI! v3

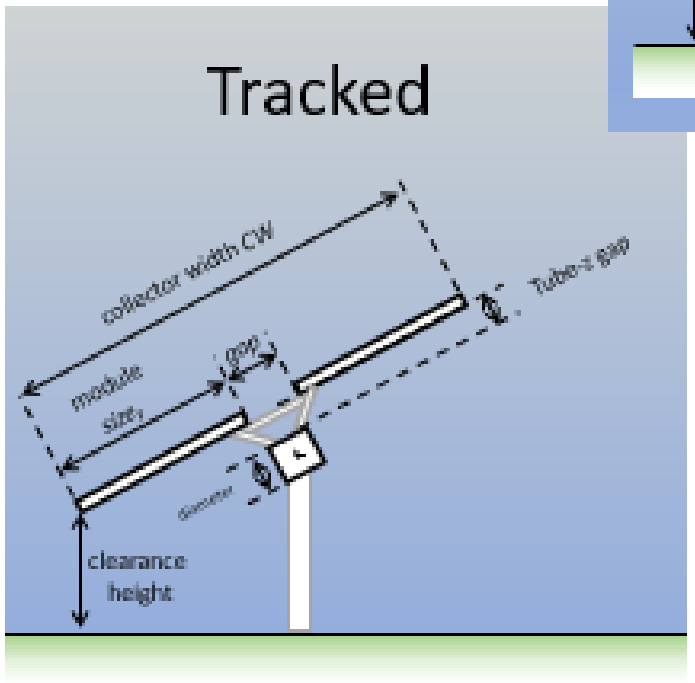


https://github.com/NREL/bifacial_radiance

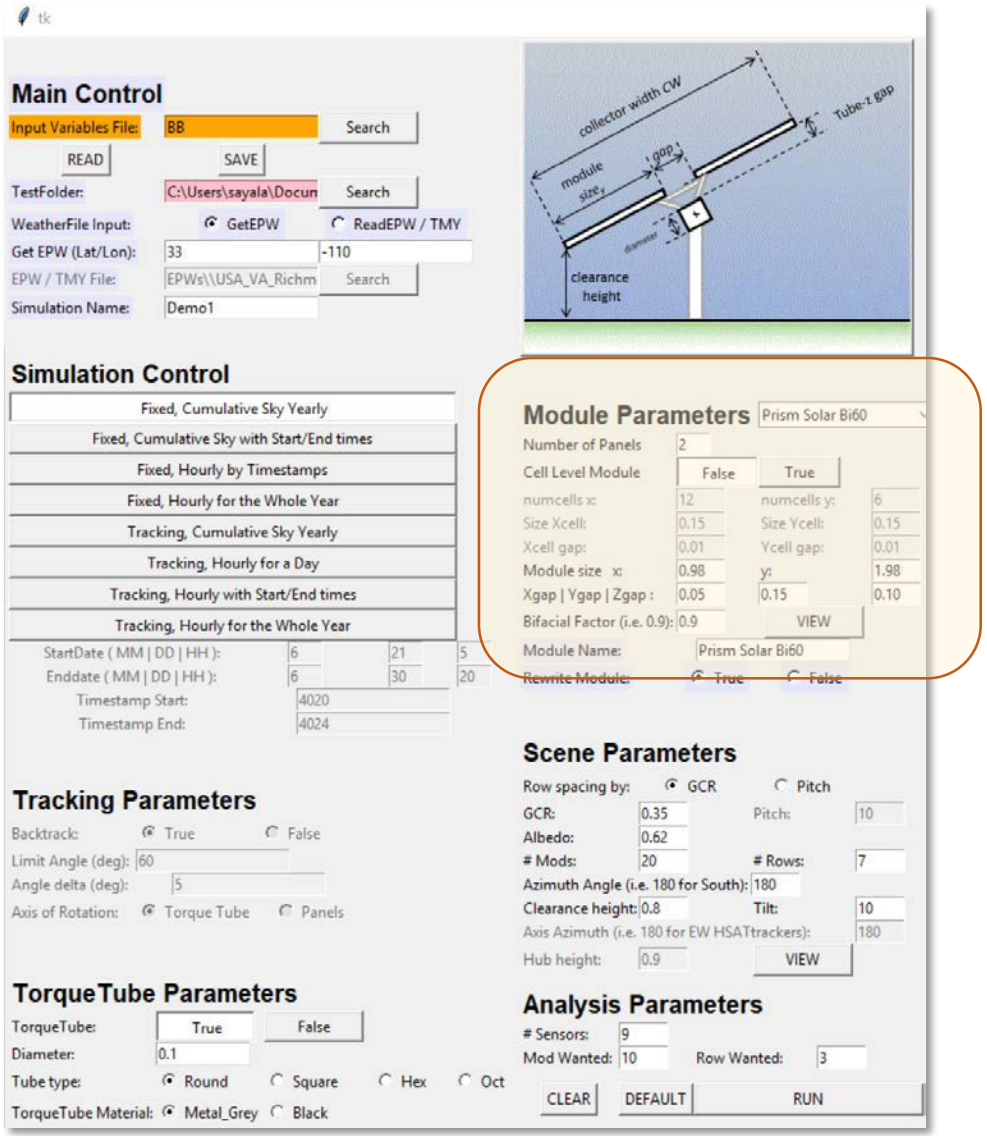
New GUI: features

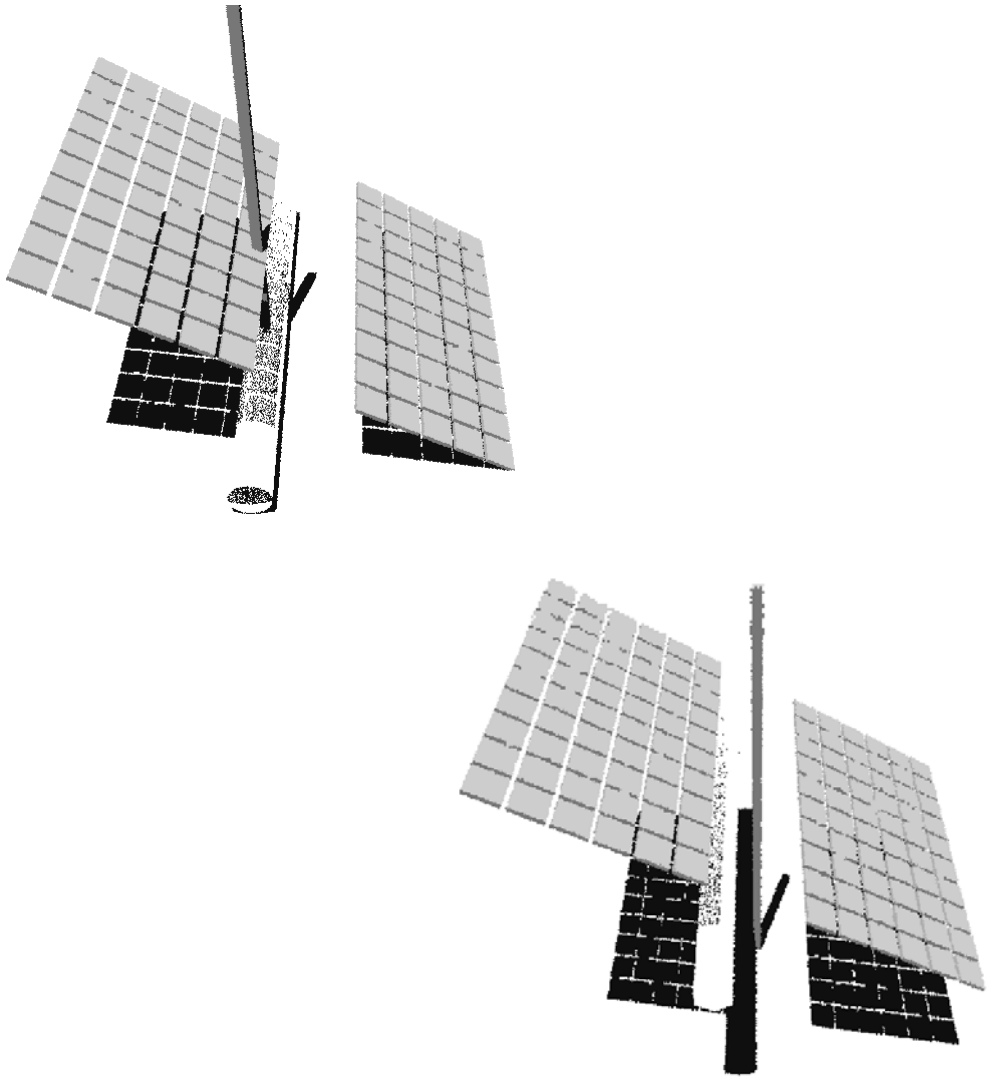




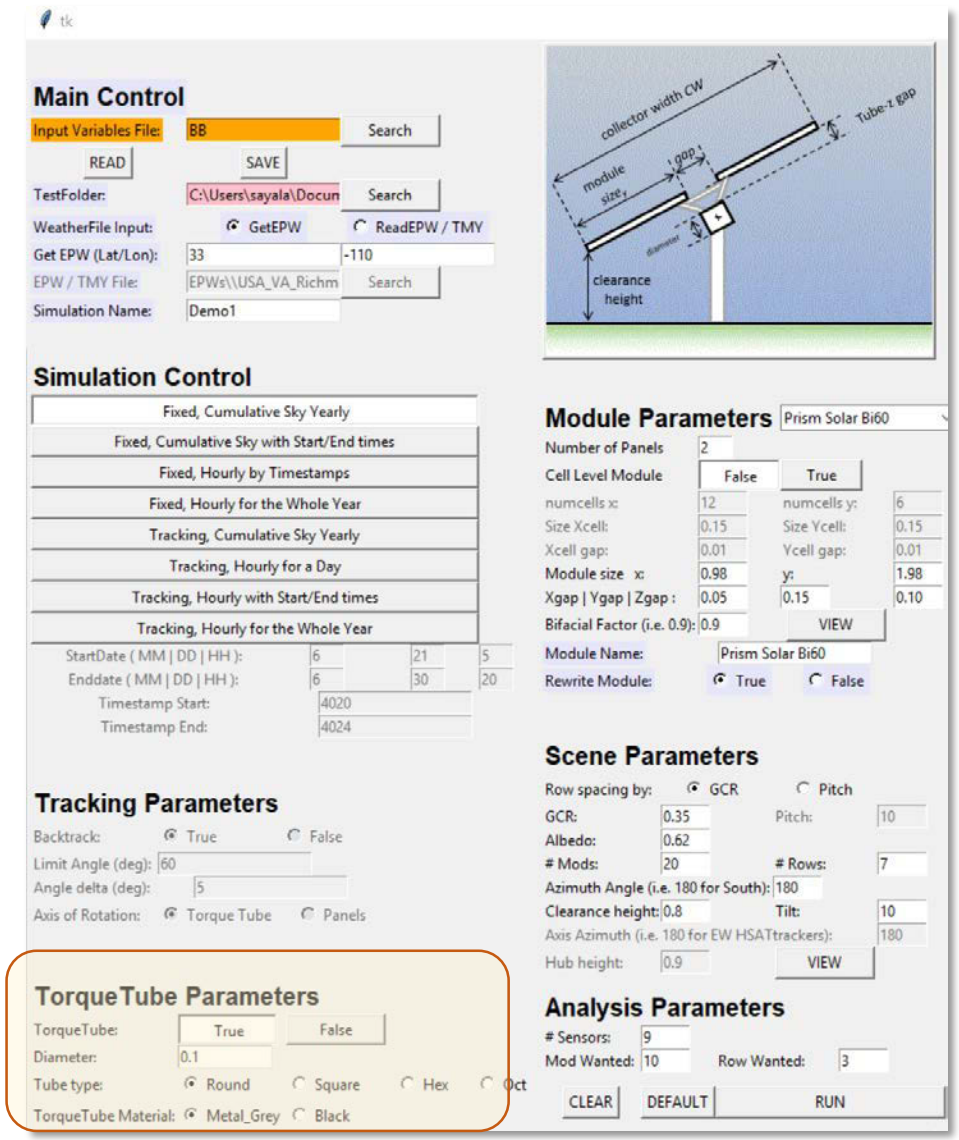


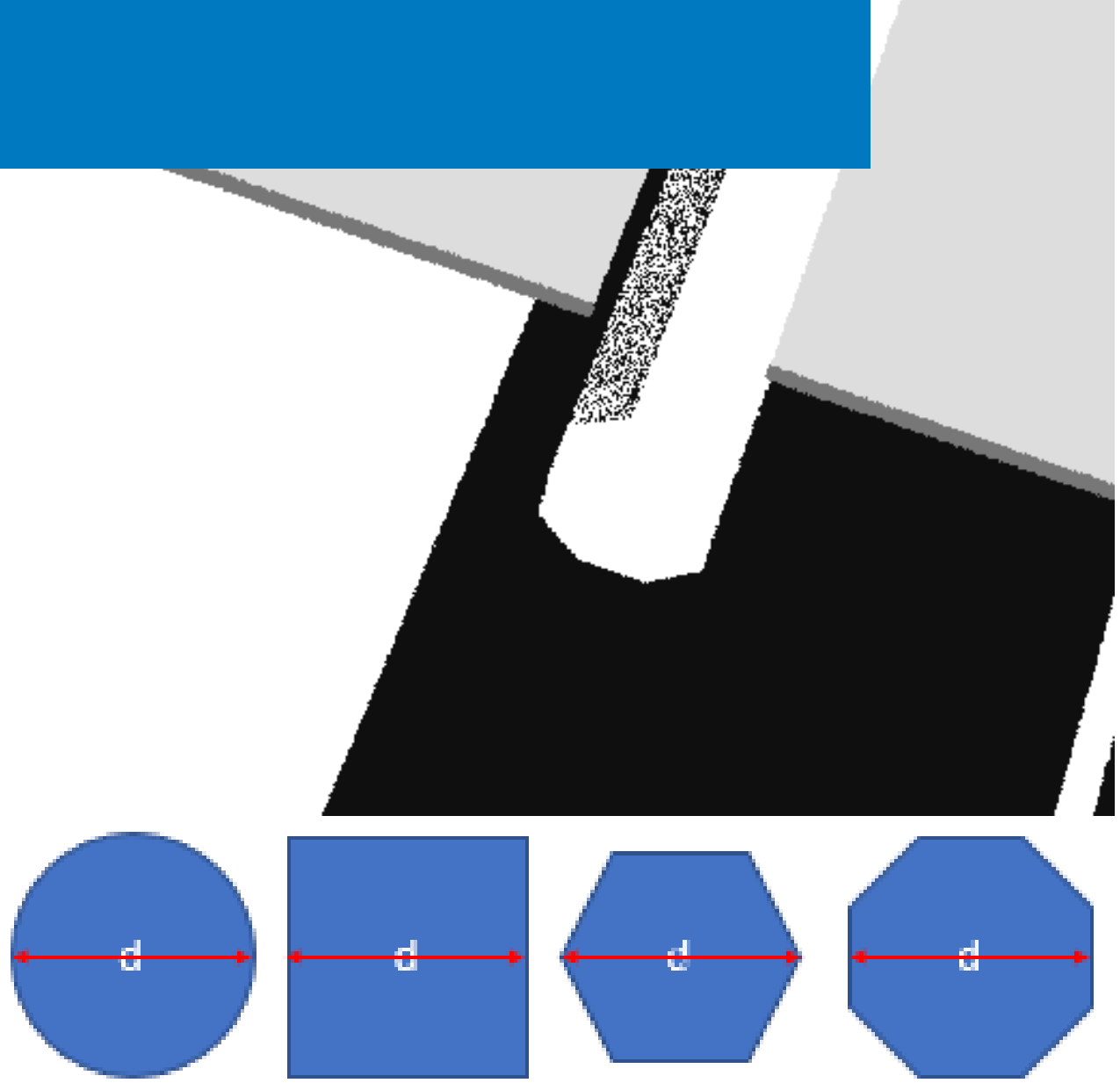
New GUI: features



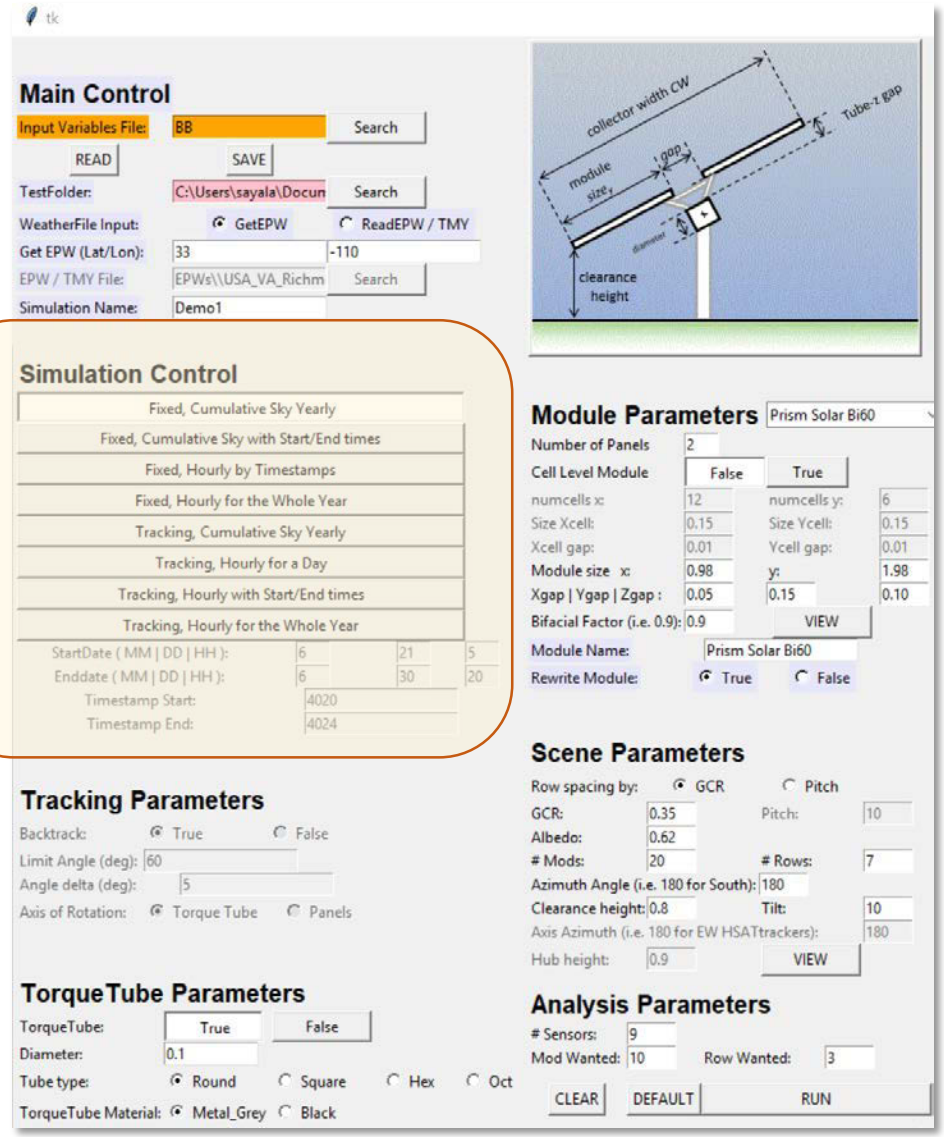


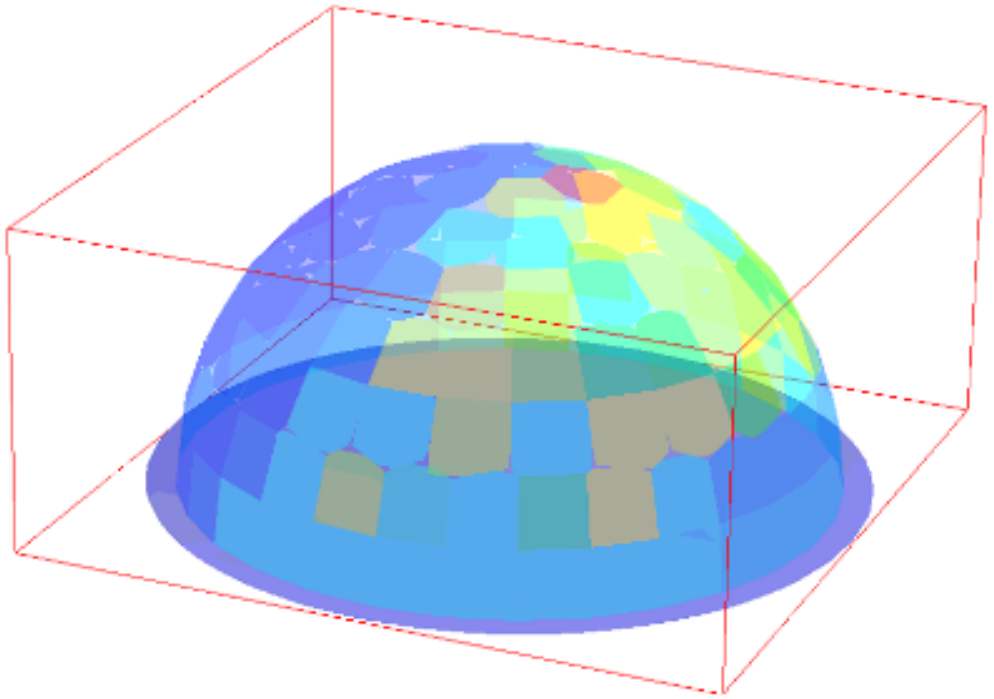
New GUI: features





New GUI: features





Robinson, Stone “Irradiation modelling made simple: the cumulative sky approach” 2004

Hourly

Cumulative

Cumulative Tracking

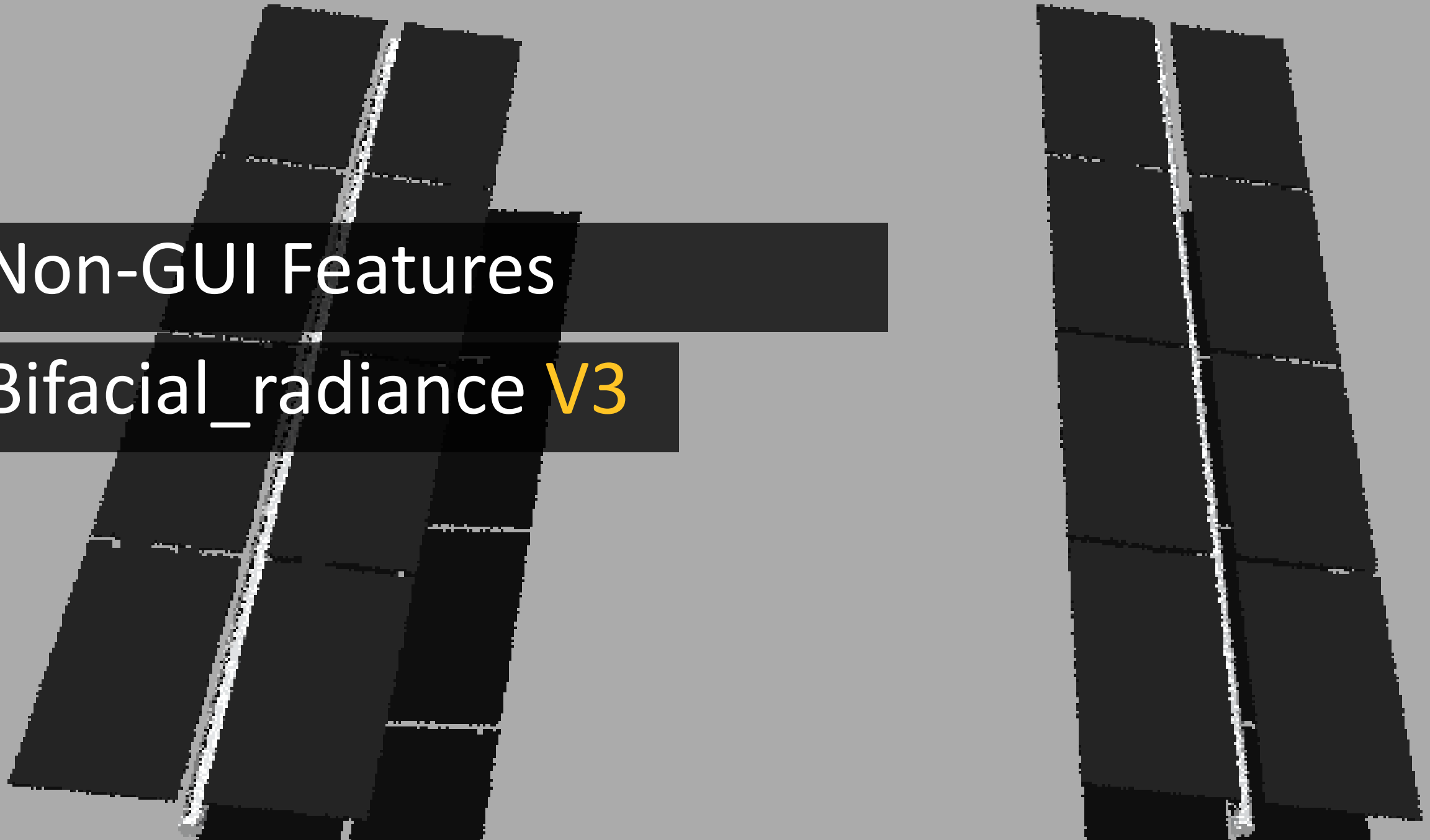
S. Ayala Pelaez, C. Deline, P. Greenberg, J. S. Stein, and R. K. Kostuk, “Model and Validation of Single-Axis Tracking with Bifacial PV - Preprint,” IEEE Journal of Photovoltaics, 2019, vol 9 no. 3, pp. 715-721.

High Performance Computing Integration

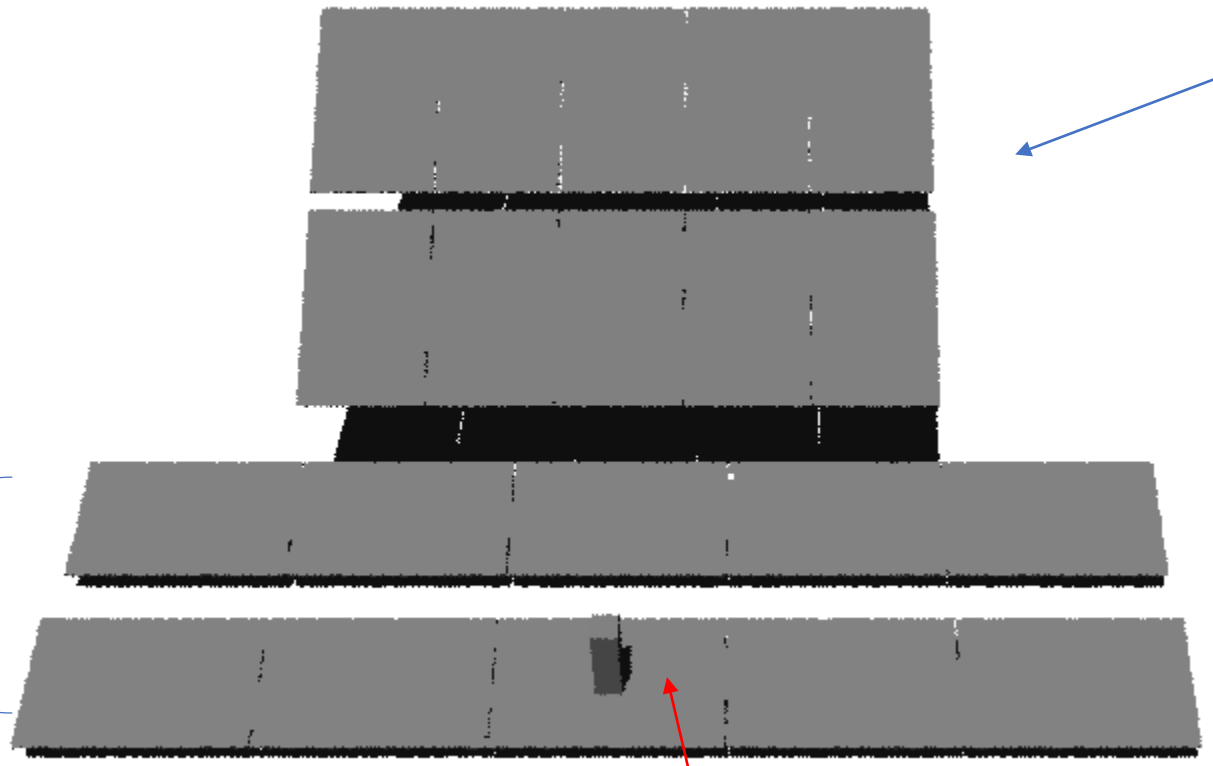
Yearly hourly simulations take
4 days on a PC,
HPC RUNS in 1 Minute!

Non-GUI Features

Bifacial_radiance V3



Multiple SceneObjects

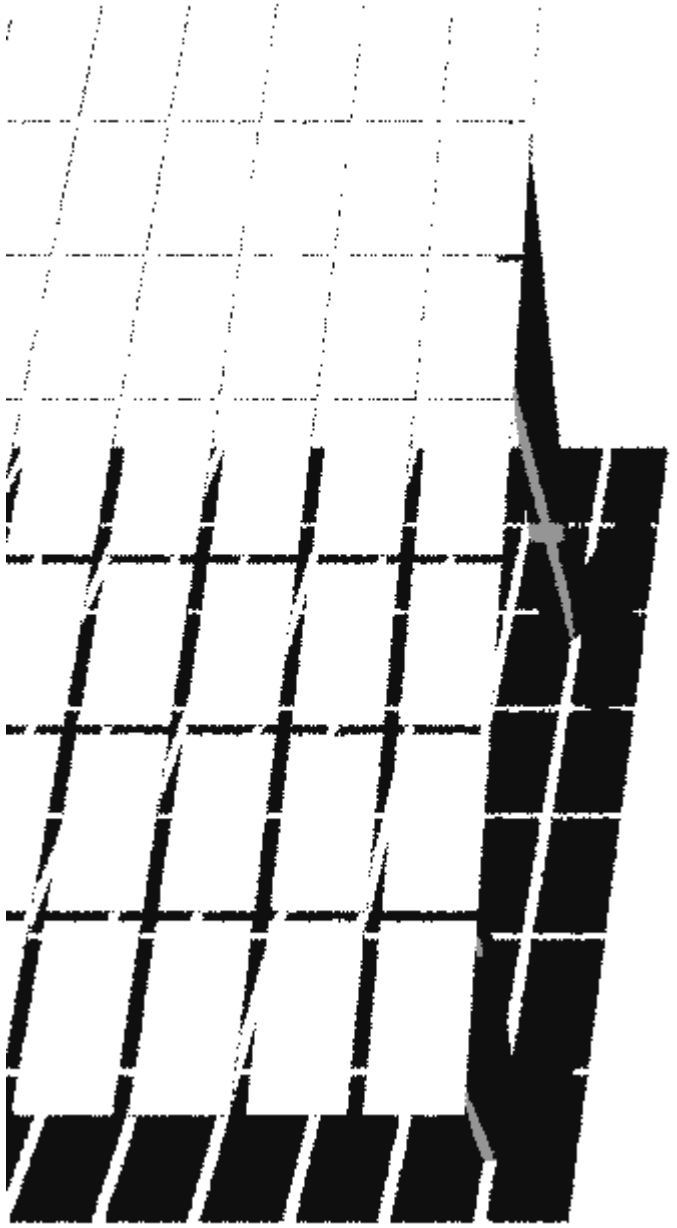


Second set of Panels
“sceneObj2”
1 row, five 2-UP modules

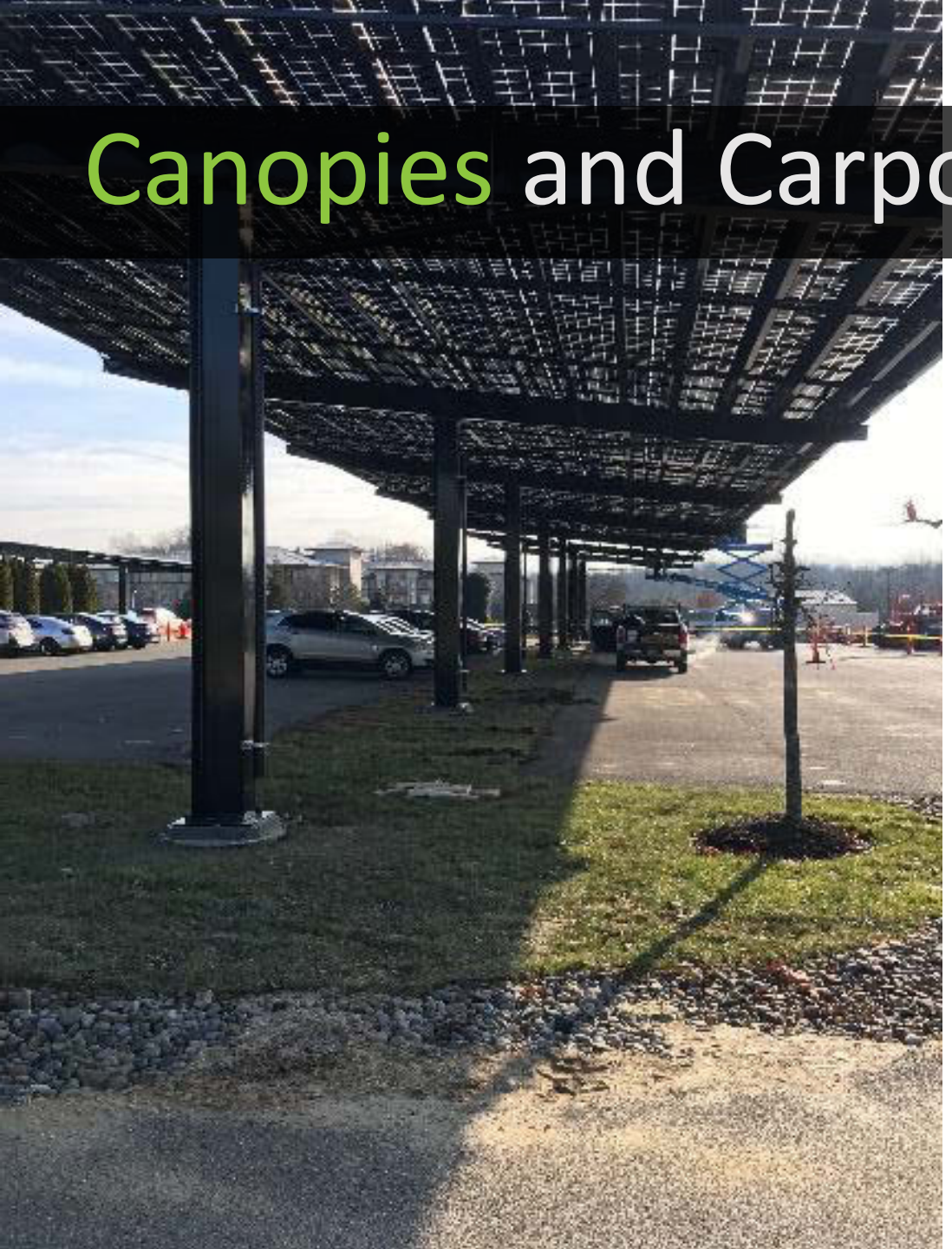
Set of Panels 1:
“sceneObj1”
2 rows of 5 modules
in landscape

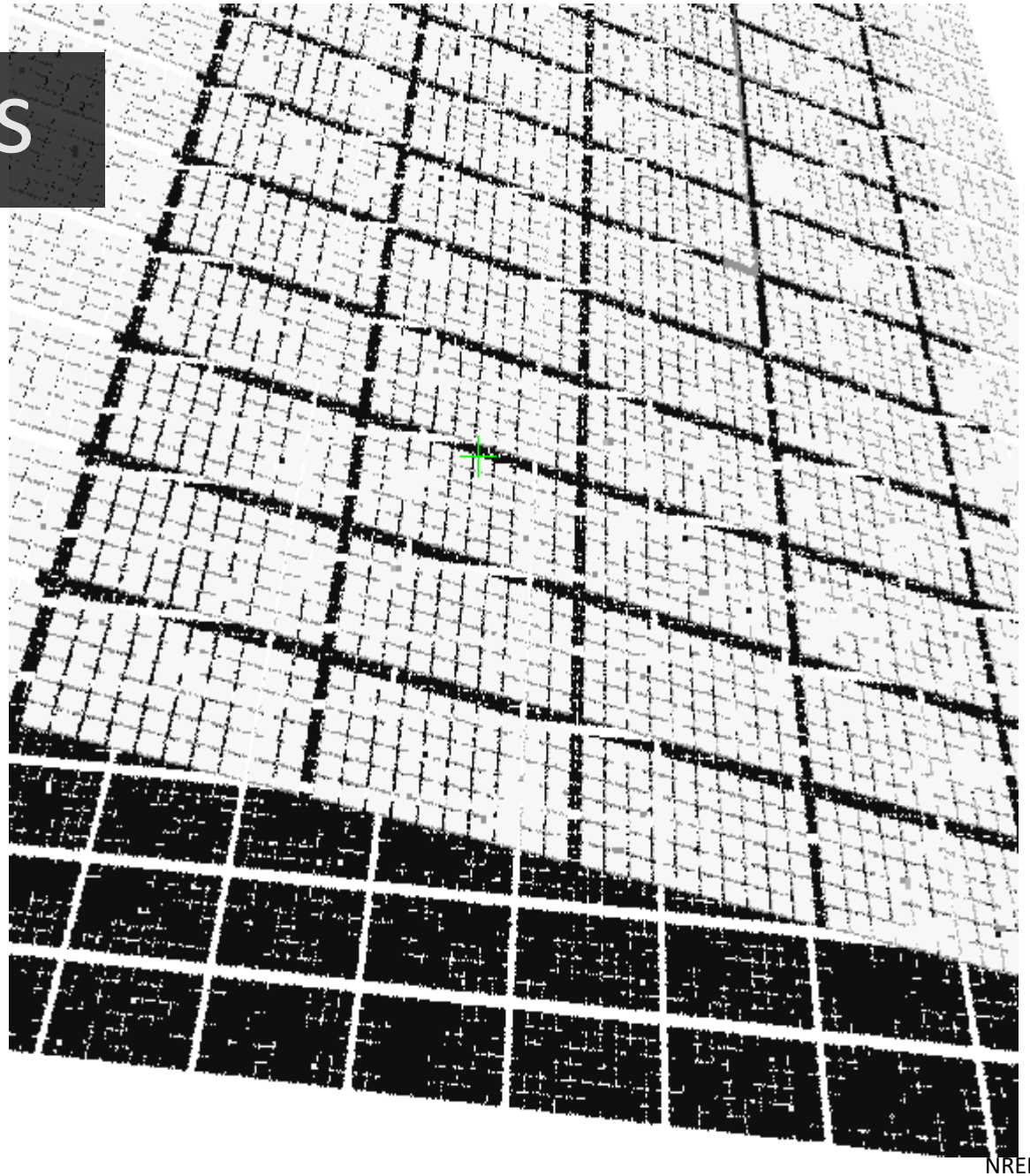
Origin Marker (0,0)

Canopies and Carports

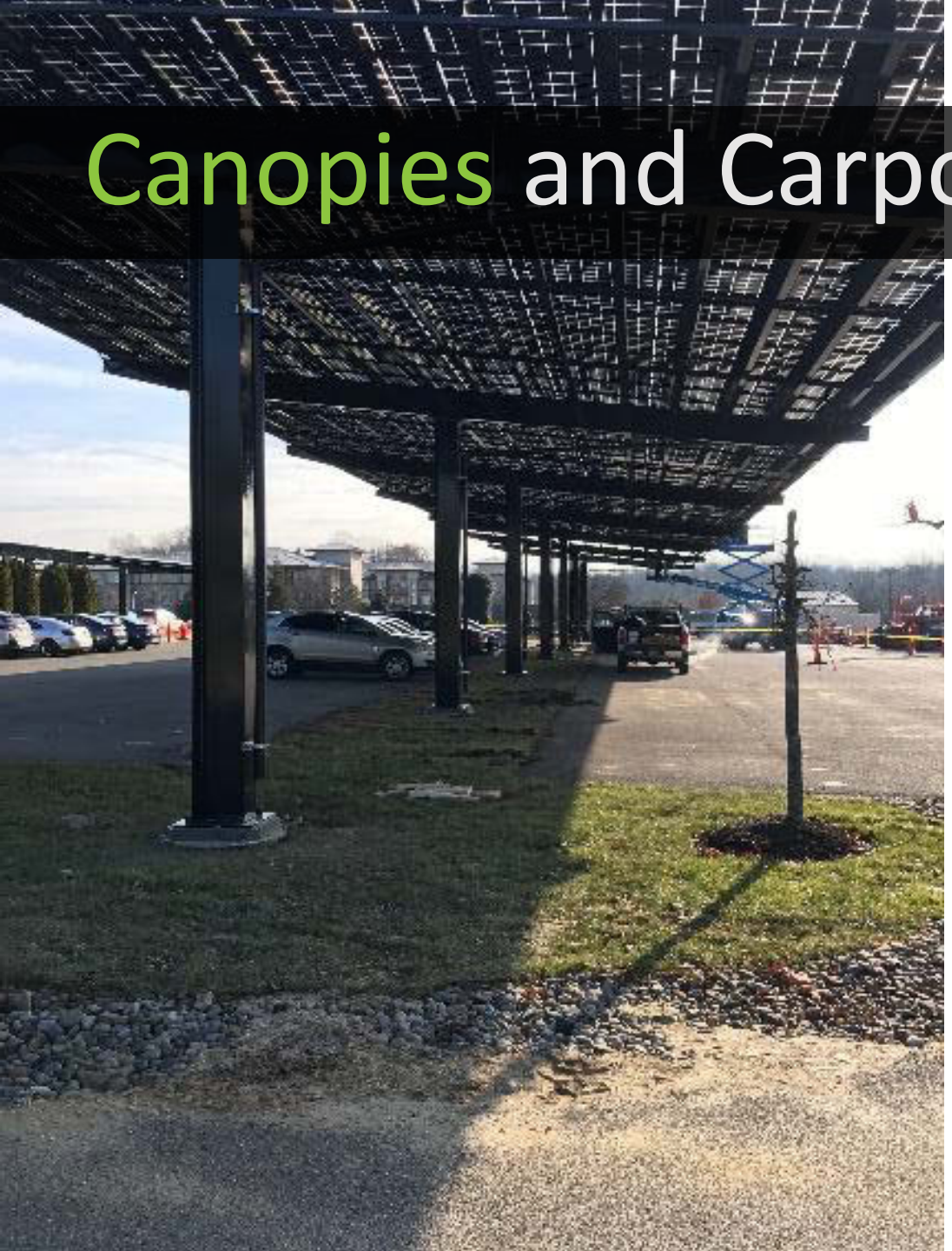


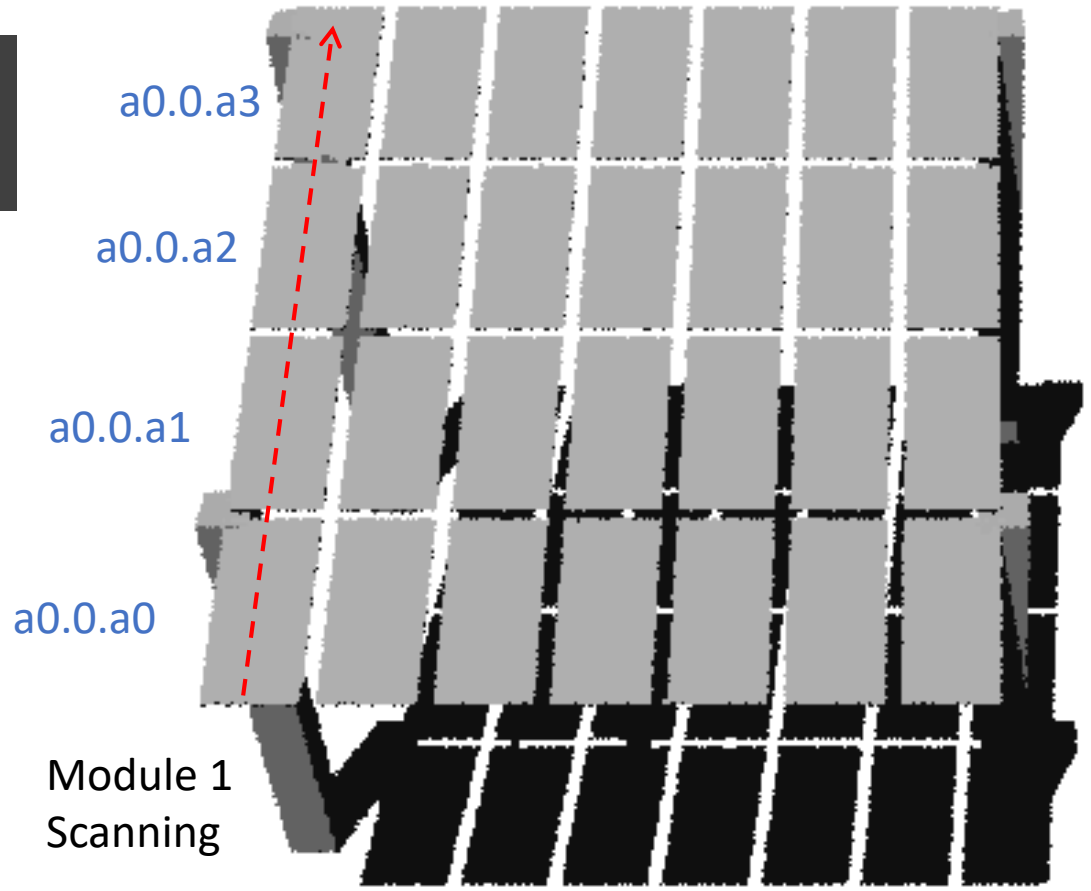
Canopies and Carports





Canopies and Carports

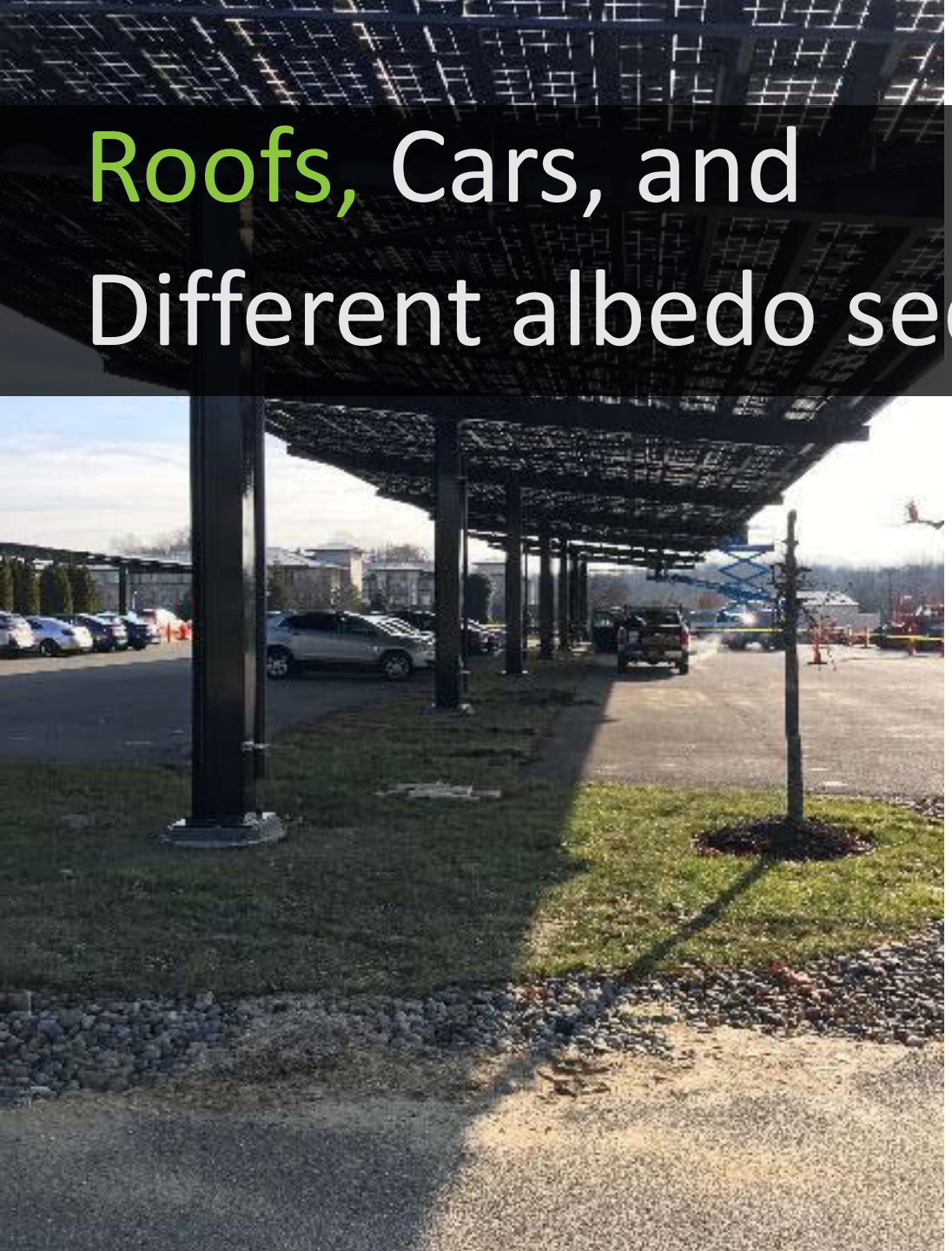


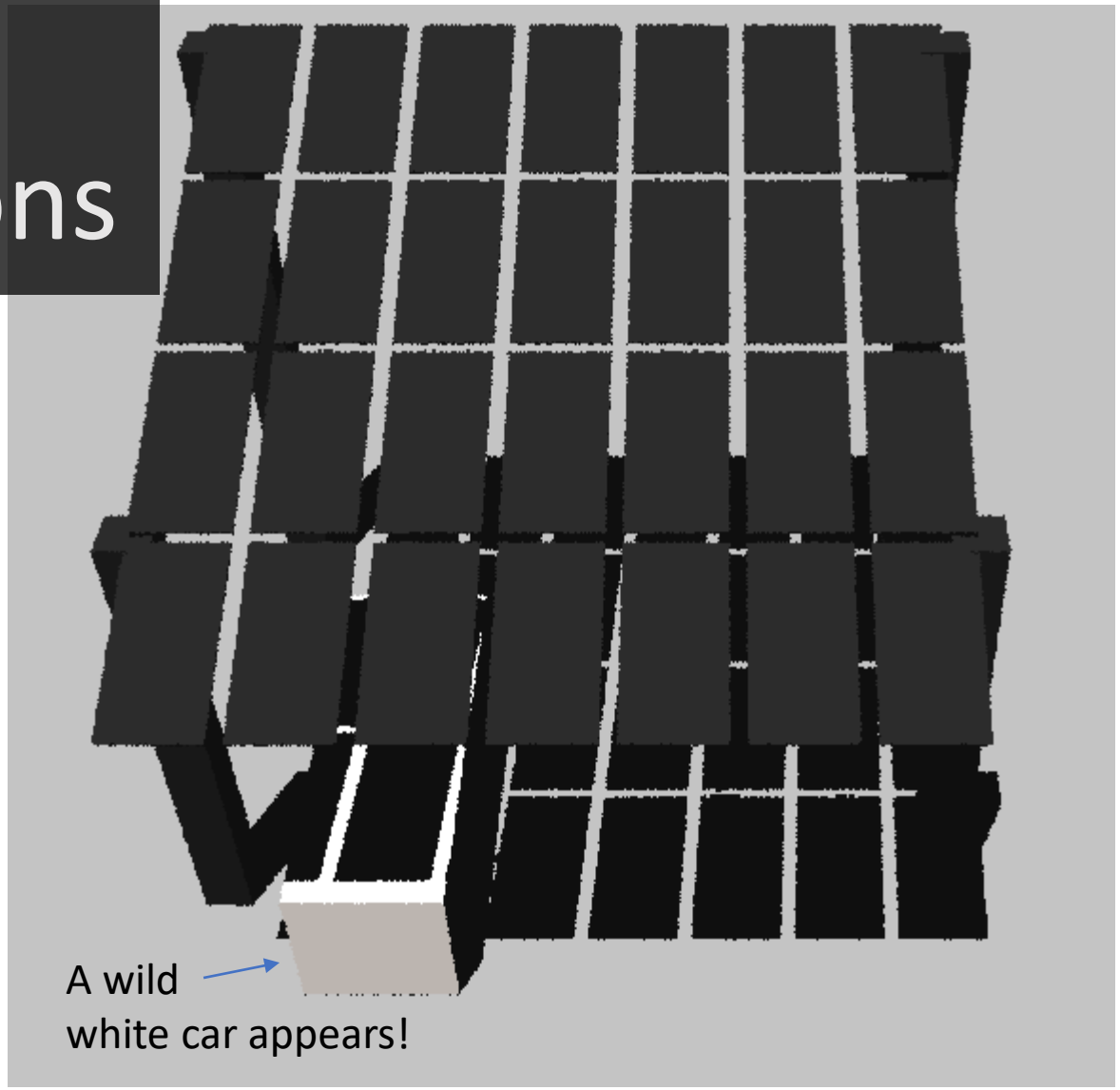


irr_HotelCaprortMod1.csv

	x	y	z	rearZ	mattype	rearMat	Wm2Fron	Wm2Back
3	-3.3	-3.62011	4.42757	4.33757	a0.0.a0.PrismSolar.6457	a0.0.a0.PrismSolar.2310	787.6552	161.1096
4	-3.3	-3.43446	4.49514	4.40514	a0.0.a0.PrismSolar.6457	a0.0.a0.PrismSolar.2310	787.6781	158.4337
39	...	...	...	...	...	...	...	...
40	...	...	...	...	...	...	...	...
41	-3.3	3.063169	6.860084	6.770084	a0.0.a3.PrismSolar.6457	a0.0.a3.PrismSolar.2310	787.4609	139.0144
42	-3.3	3.248815	6.927654	6.837654	a0.0.a3.PrismSolar.6457	a0.0.a3.PrismSolar.2310	787.4696	135.2156
43	-3.3	3.434462	6.995223	6.905223	a0.0.a3.PrismSolar.6457	a0.0.a3.PrismSolar.2310	787.4783	132.7424
44	-3.3	3.620109	7.062793	6.972793	a0.0.a3.PrismSolar.6457	a0.0.a3.PrismSolar.2310	787.4871	129.142

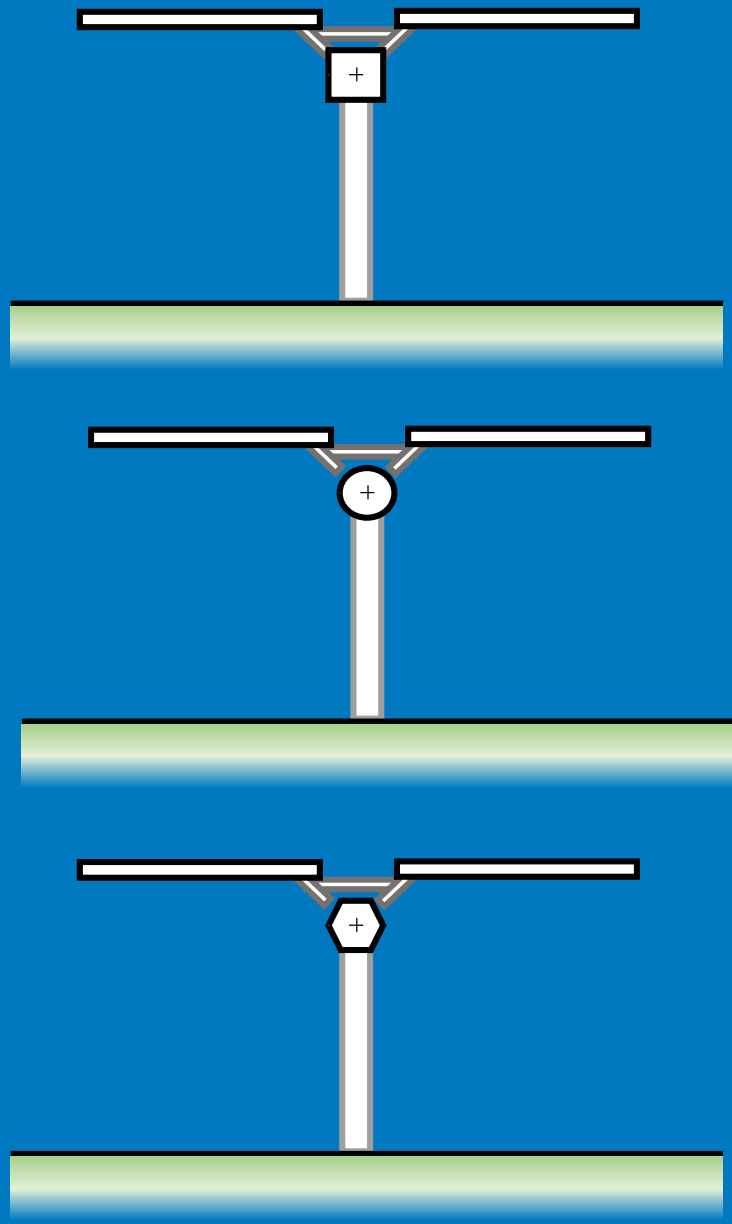
Roofs, Cars, and Different albedo sections



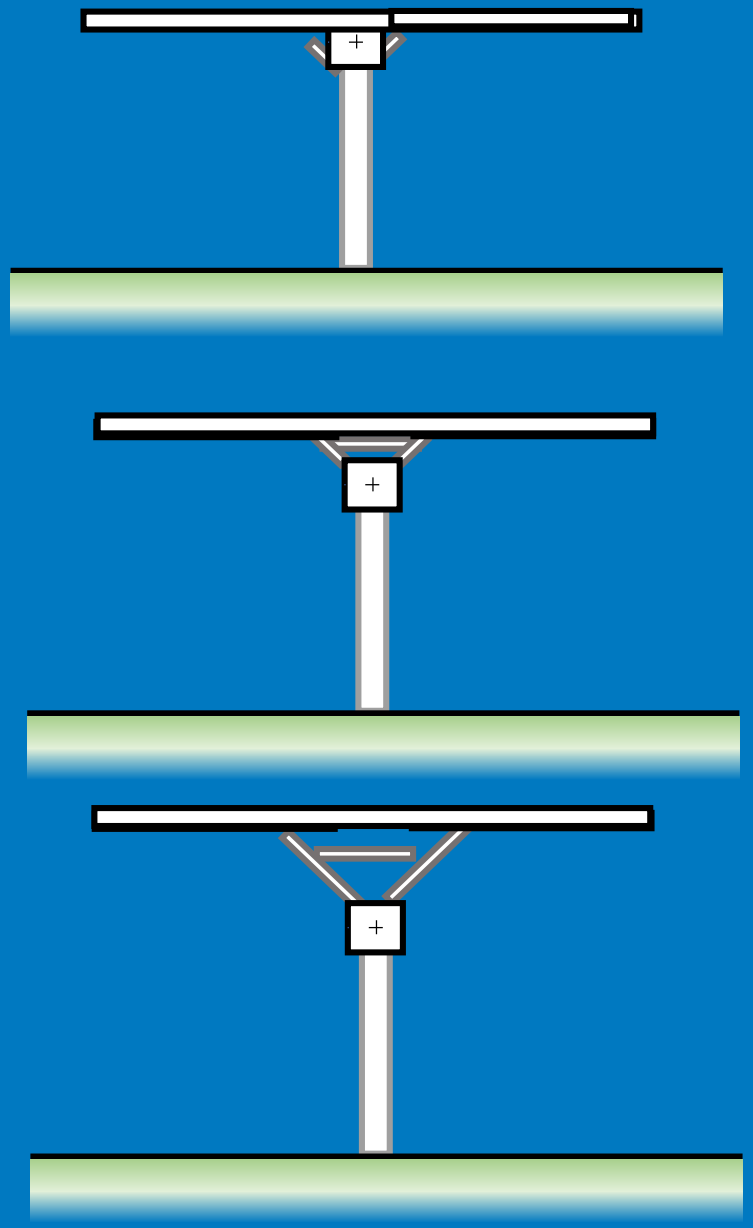



Tracking and Torque tube
Hourly-yearly simulations
(a teaser)

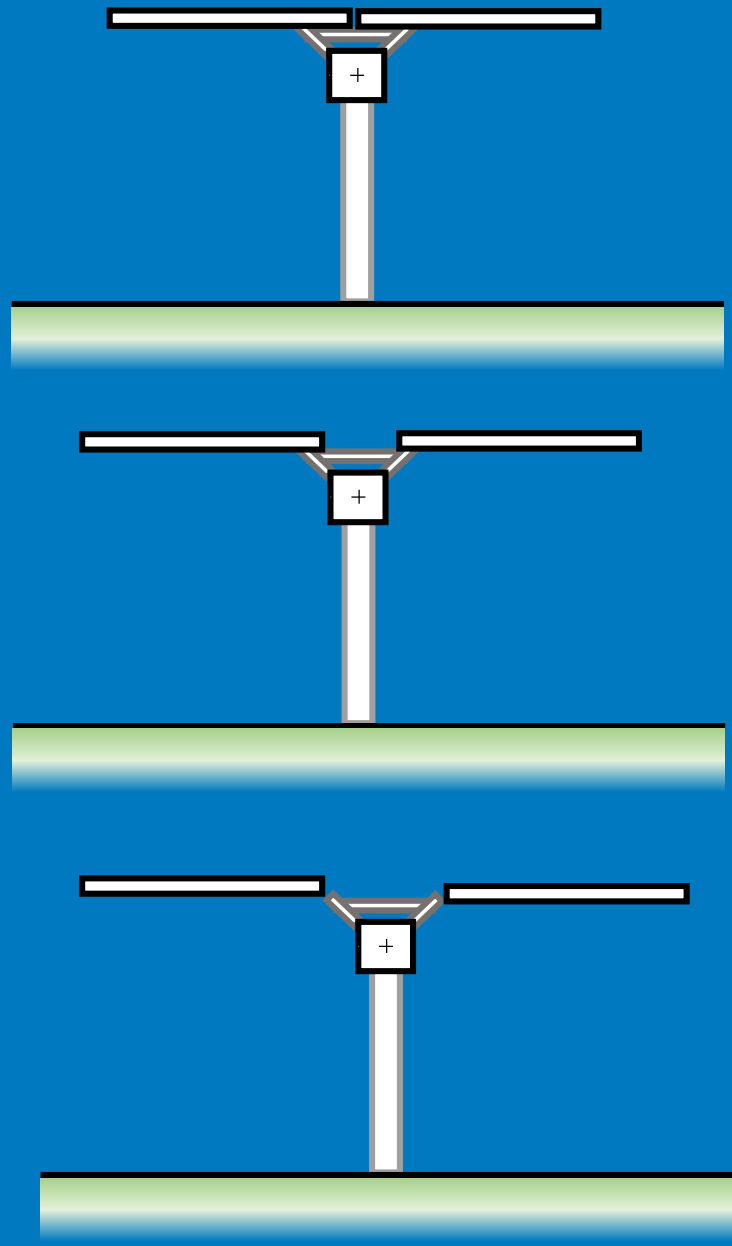
Varying torquetube shape



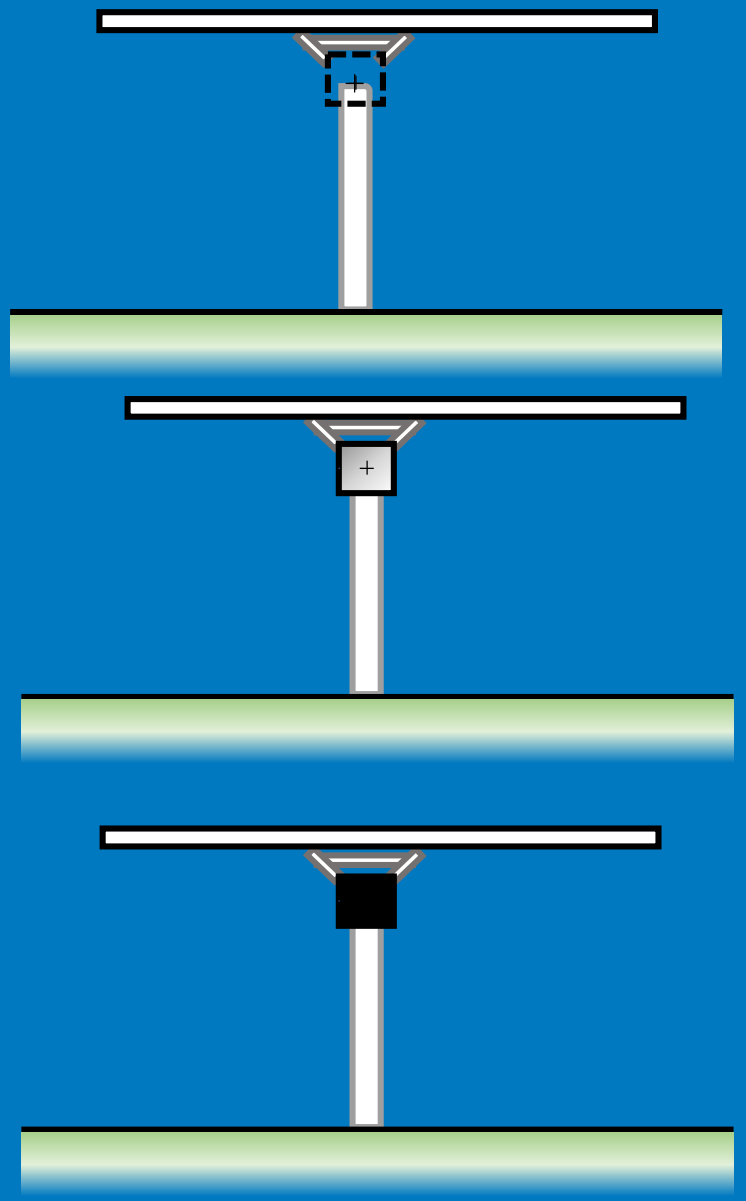
Varying zgap



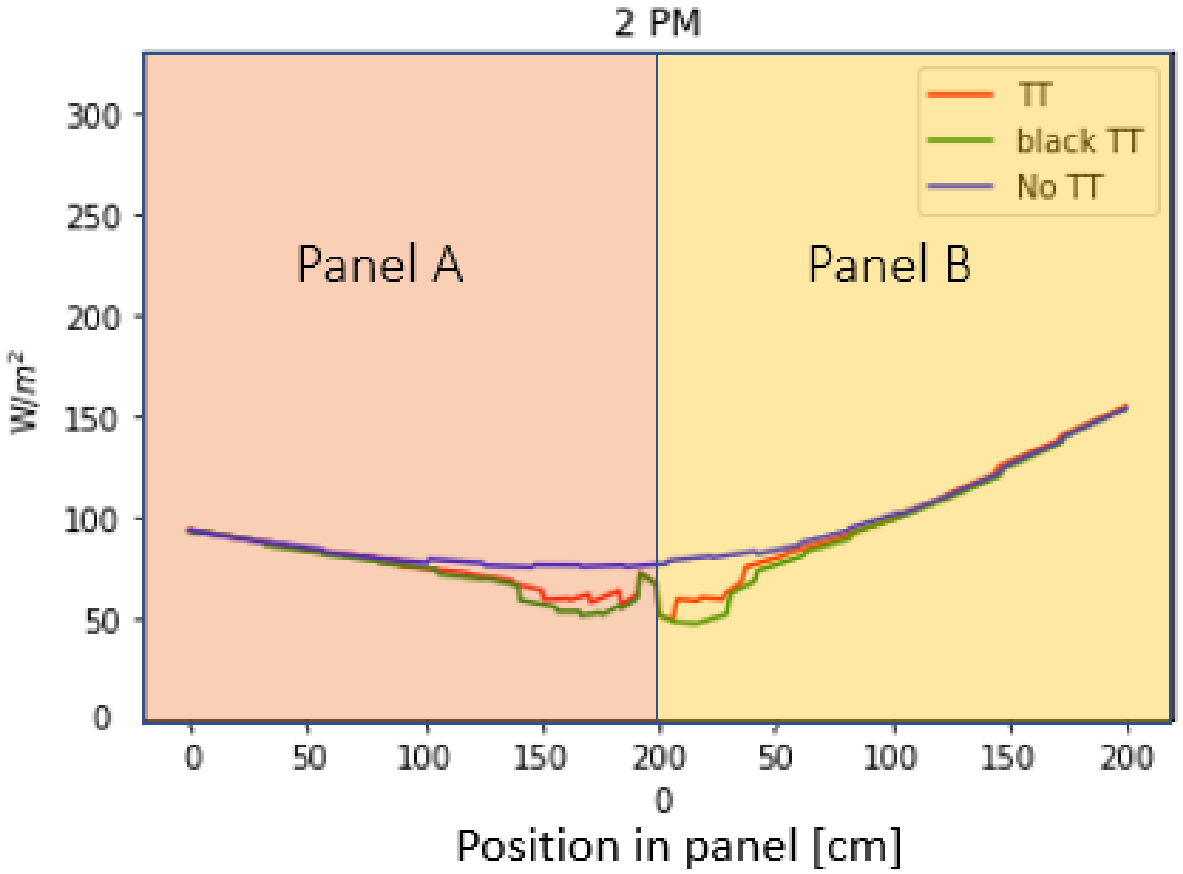
Varying ygap



Varying torquetube reflectivity

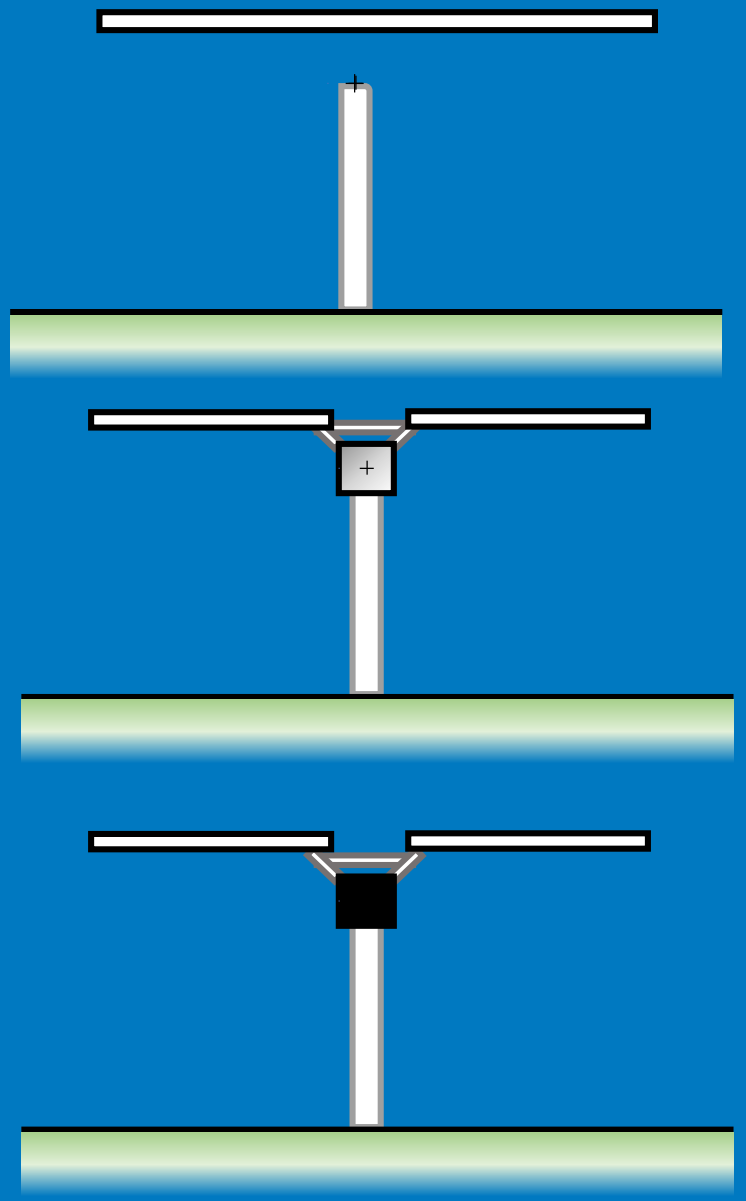


a)

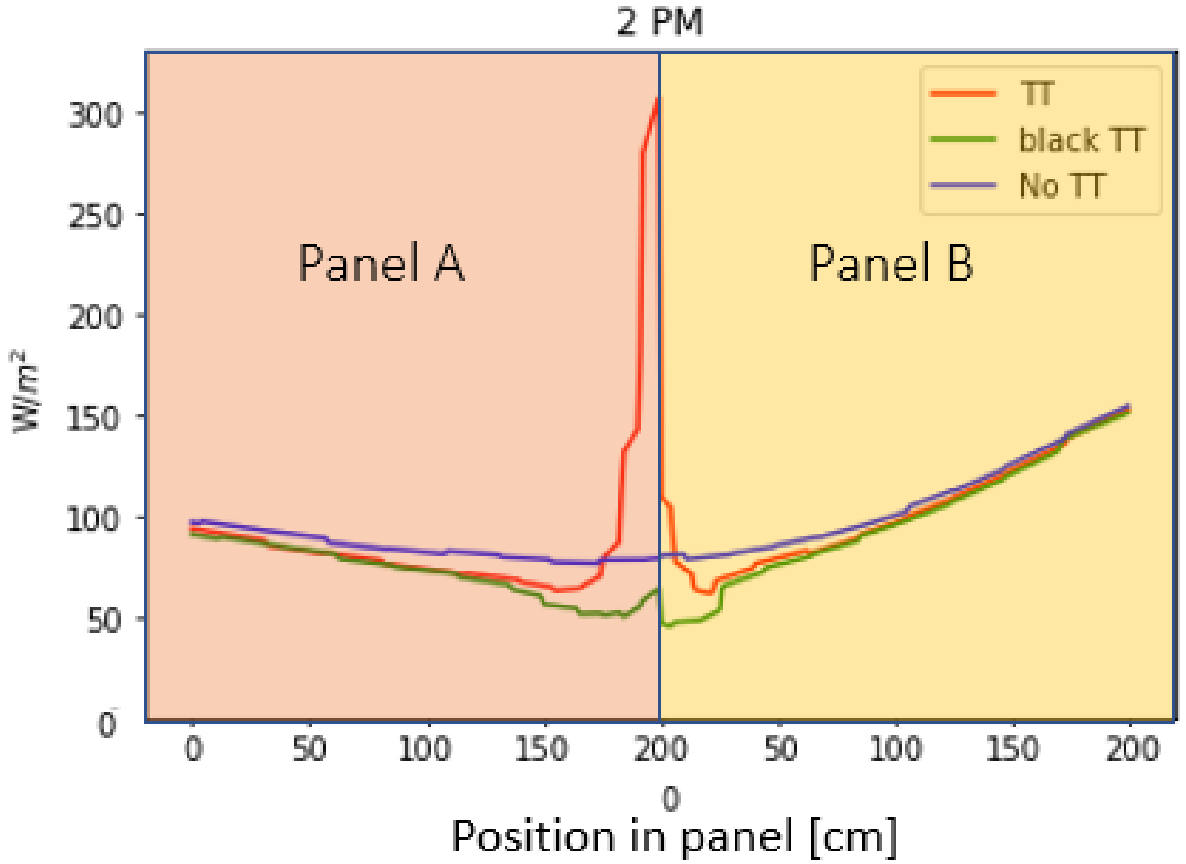


$$Shading\ factor = \frac{\sum_{n=0}^{N} G_{rear}\ (no\ tube)}{\sum_{n=0}^{N} G_{rear}\ (with\ tube)}$$

Varying torquetube reflectivity

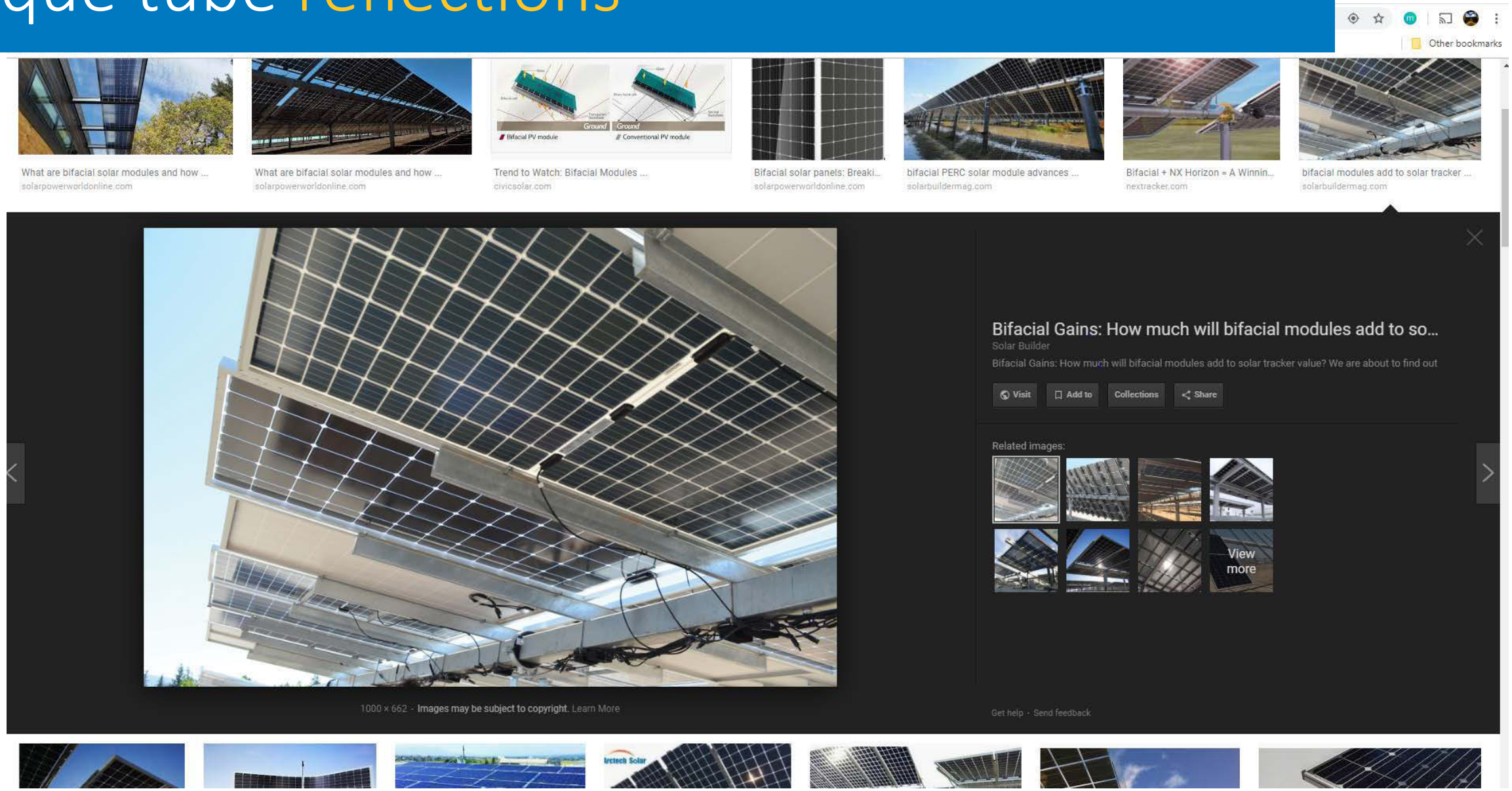


b)



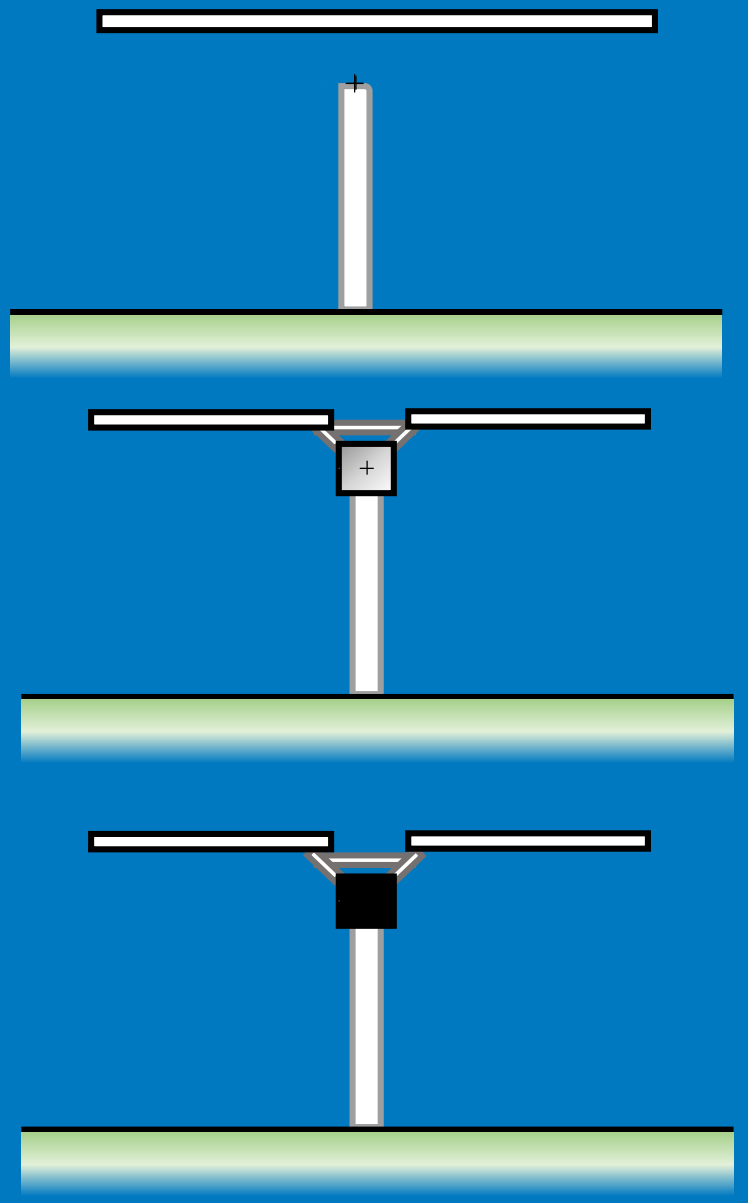
$$Shading\ factor = \frac{\sum_{n=0}^{N} G_{rear}\ (no\ tube)}{\sum_{n=0}^{N} G_{rear}\ (with\ tube)}$$

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 torquetube reflectivity



2 UP – 16 JUN Sunny day

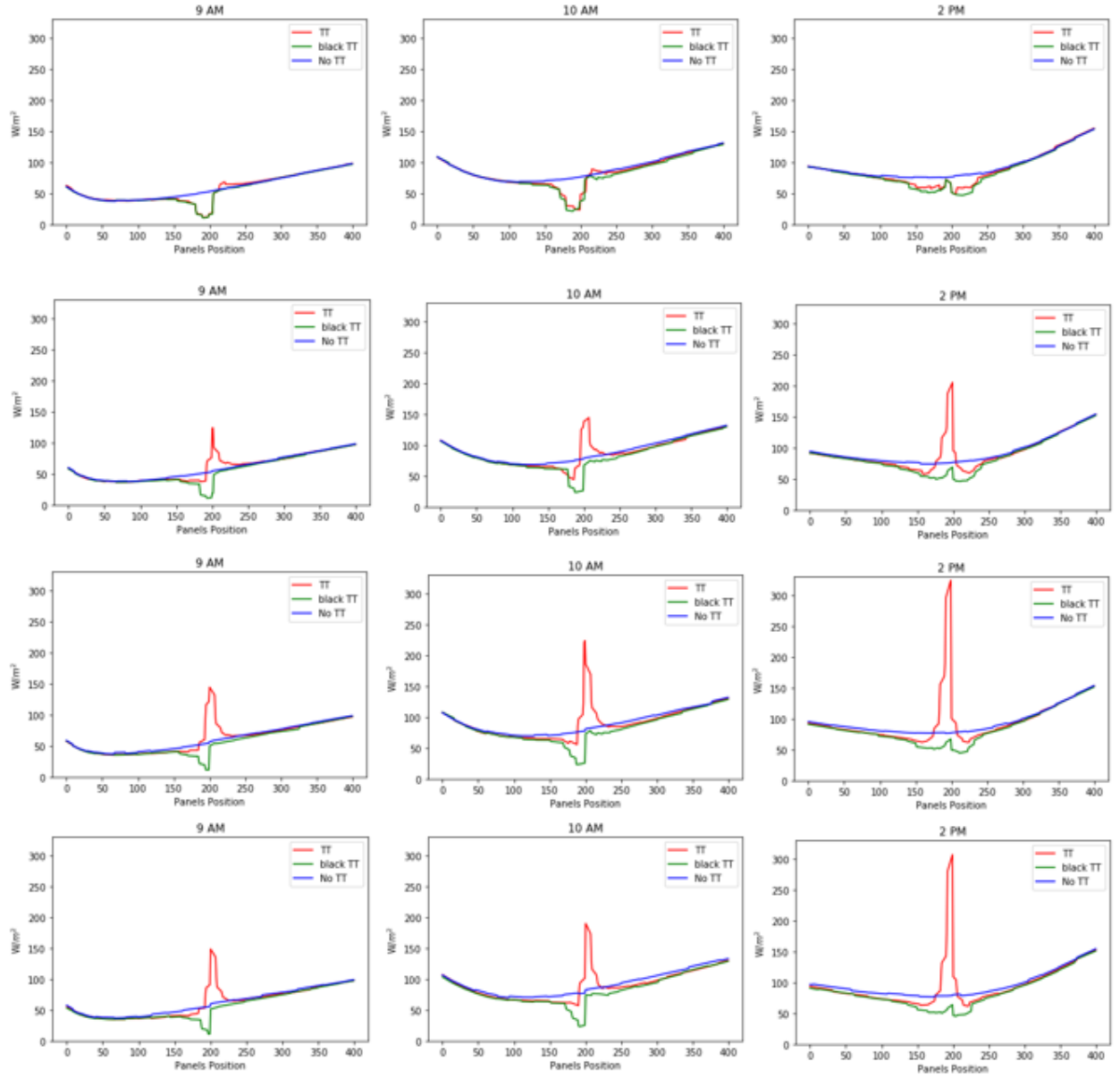
gap [m]

0

0.05

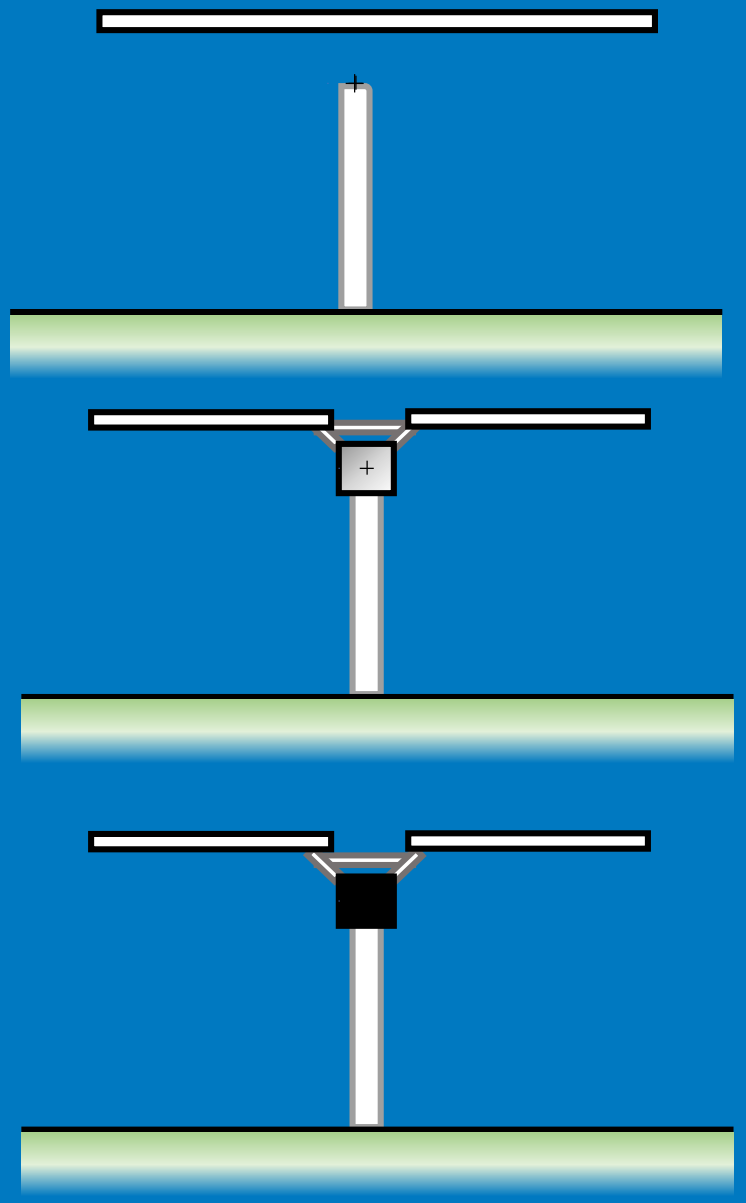
0.10

0.15



9 am 10 am 2 pm

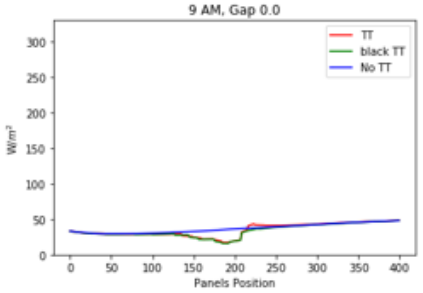
Varying torquetube reflectivity

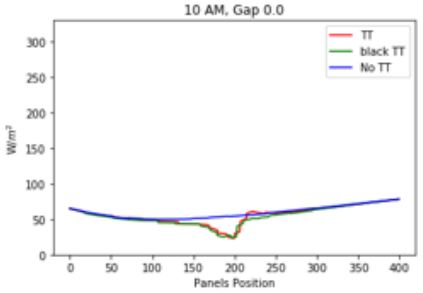


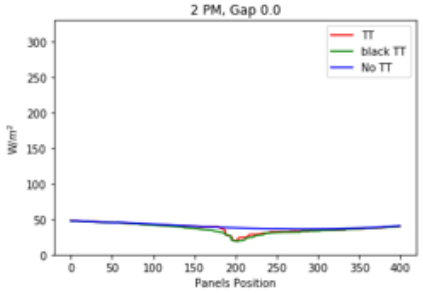
2 UP – 10 JUN Cloudy day

gap [m]

0







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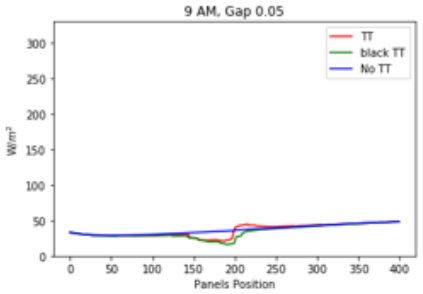

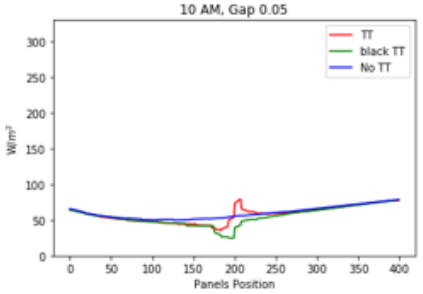

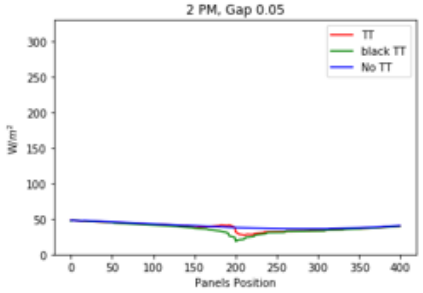

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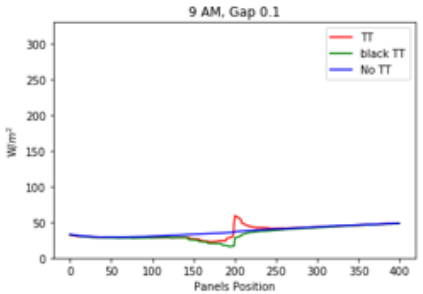

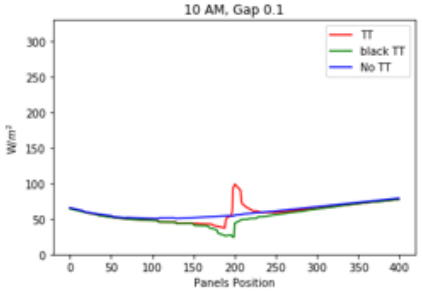

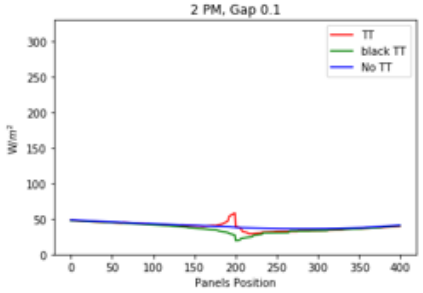

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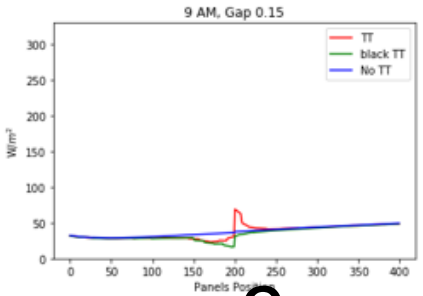
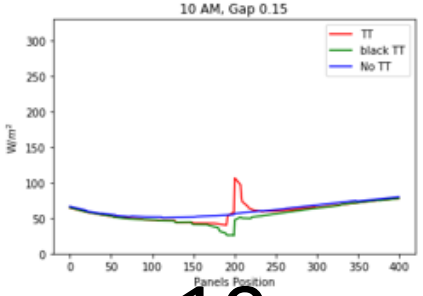
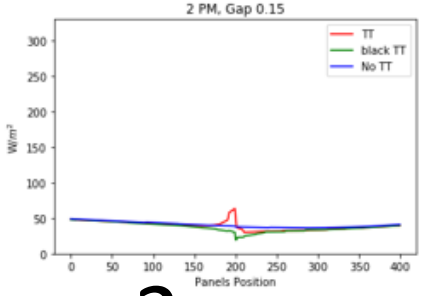
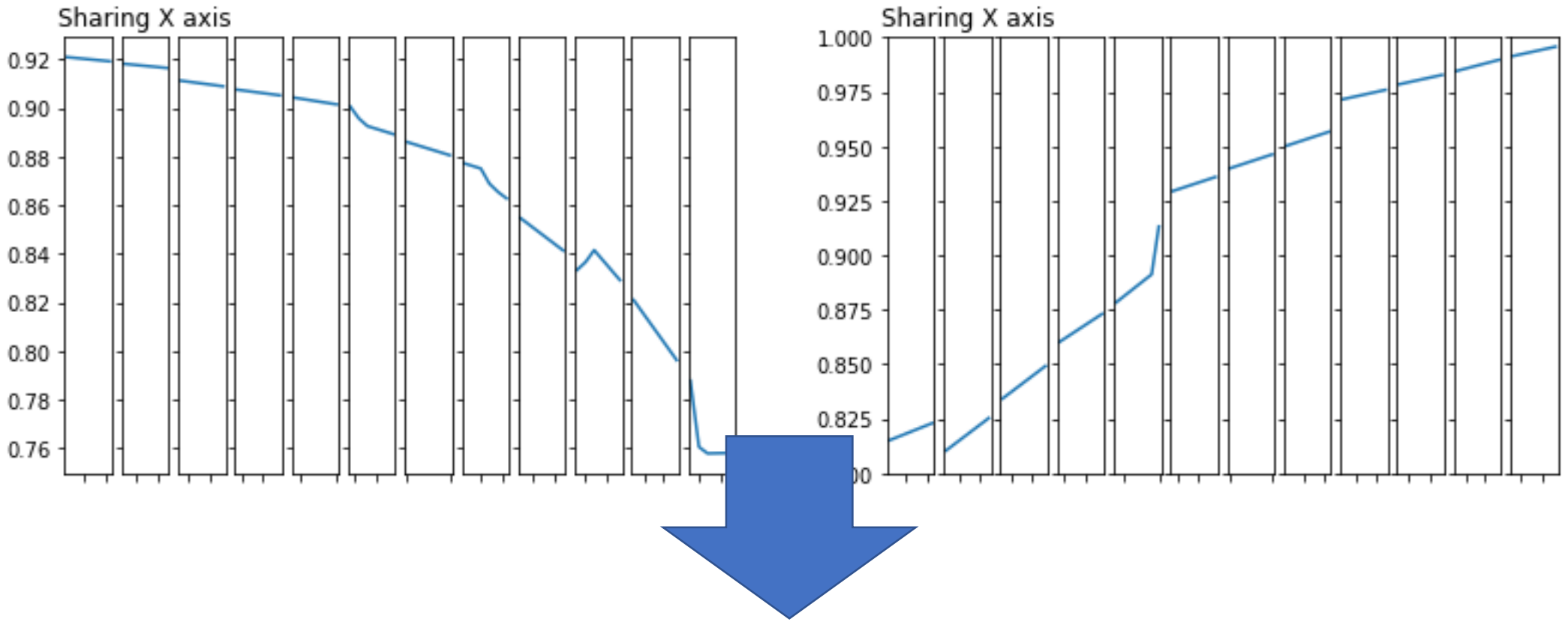






9 am 10 am 2 pm

Shading to Electrical Mismatch

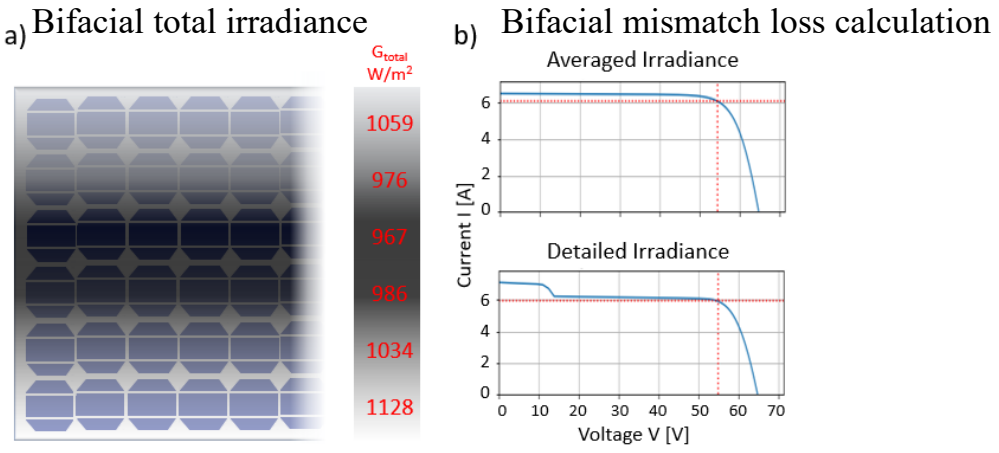


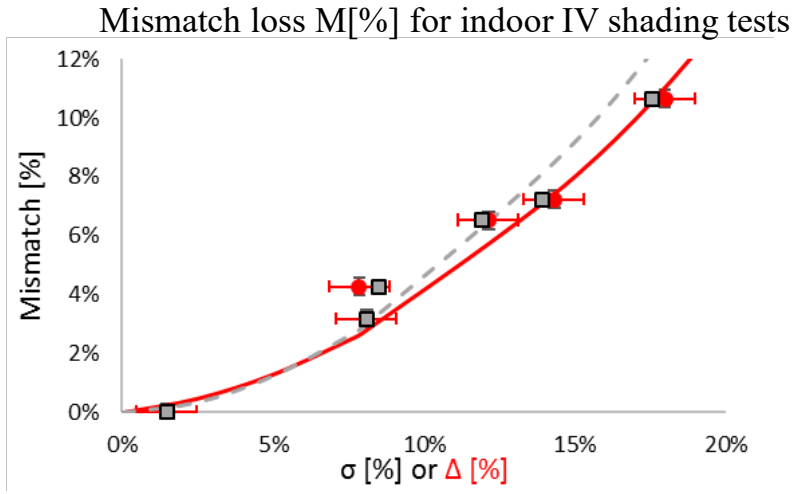
Bifacial radiance Analysis module ties to PVMismatch

SUNPOWER®

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

Electrical Mismatch Model





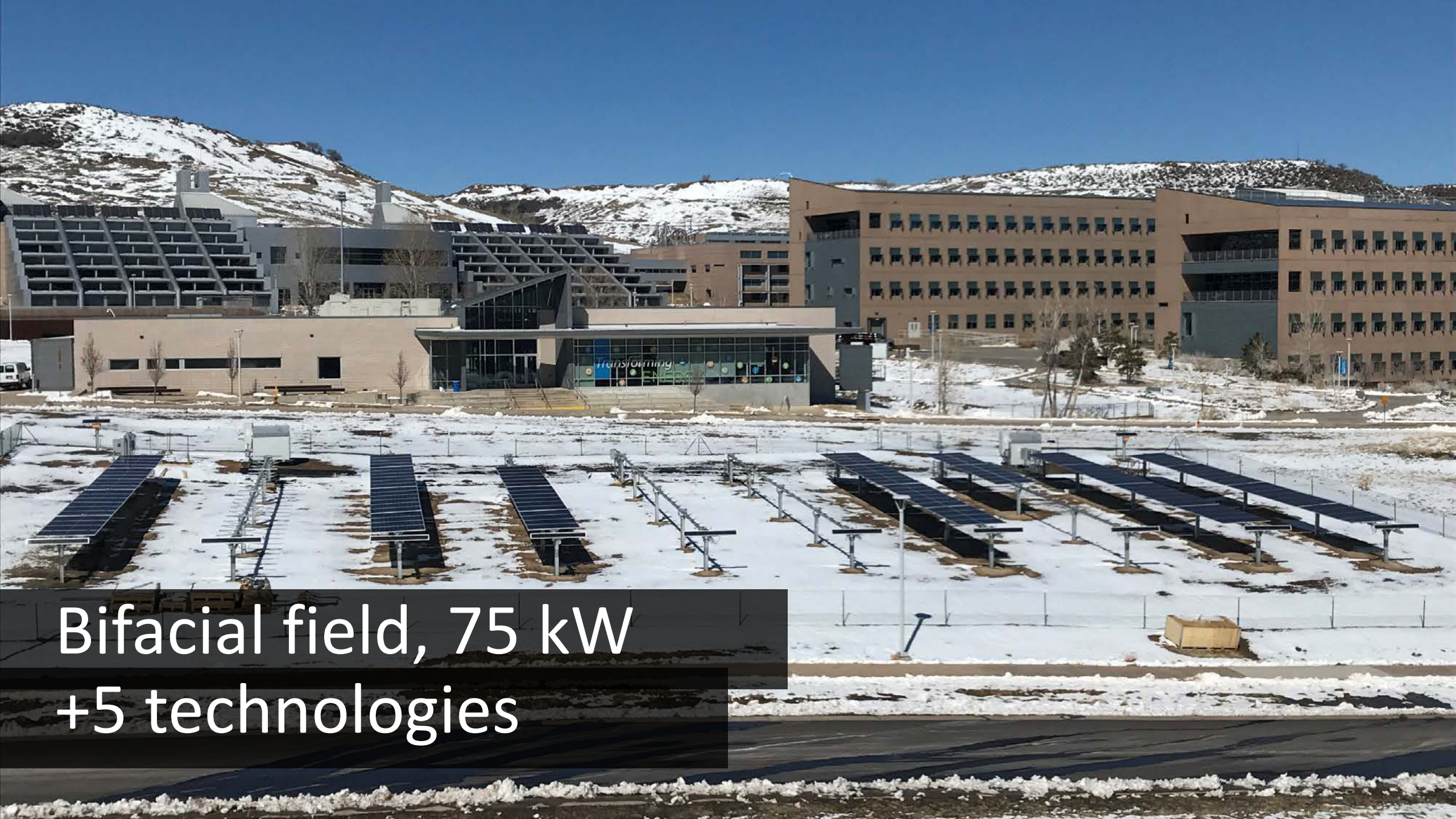
- Front + rear irradiance distribution depends on the mounting and site conditions.
- Irradiance mismatch causes additional loss relative to uniform assumption
- Empirical model provides good fit based on st.dev (σ) or MAD (Δ) of I_{SC}

$$M[\%]_{Fit1} = e^{1.067 + 1.82 * \ln(\sigma[\%])}$$

$$M[\%]_{Fit3} = 0.12\,\Delta[\%] + 2.77\,\Delta[\%]^2$$

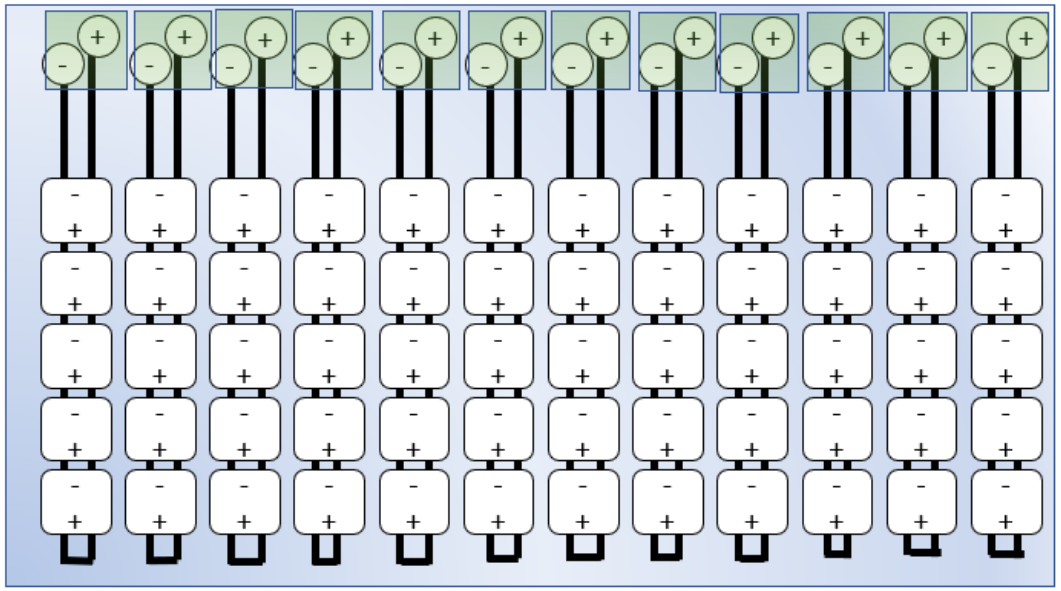
- EU-PVSEC Oral Paper Accepted

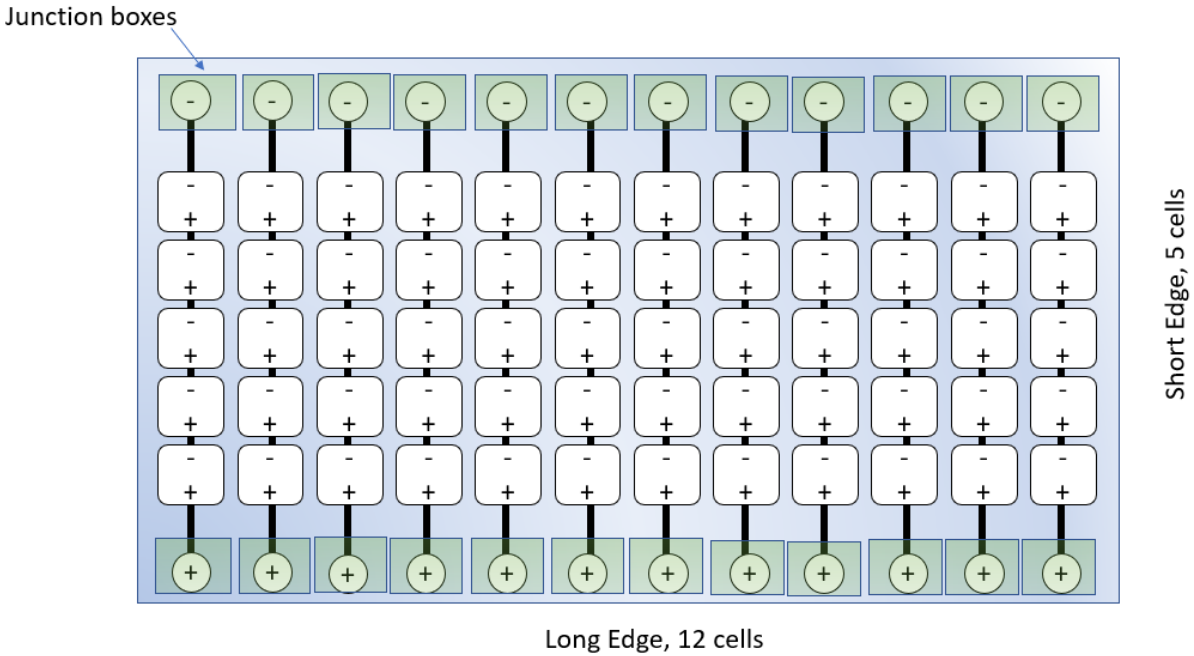
C. Deline, S. Ayala Pelaez, S. MacAlpine, C. Olalla, C. "Bifacial PV Mismatch Loss and Parameterization". EUPVSEC 2019


Bifacial field, 75 kW
+5 technologies

Electrical Mismatch Model Validation

- Custom modules to measure shading loss of Torque Tube
- Strung cross-wise with multiple junction boxes for sub-module Isc measurement





Look for more

12th. PVPMC (Albuquerque)

- New GUI Release
- Subtleties of modeling bifacial modules.

46th IEEE PVSC (Chicago)

- Conference plenary talk, Workshop: Overview of bifacial PV status,
- Oral Session: shading effects on bifacial trackers.

36th EU PVSEC (Marseille)

- Oral Session: electrical mismatch and shading.
- Progress in Photovoltaic journal?

6th Bifi PV Workshop (Amsterdam)

- Oral Session: NREL bifacial field measurements of electrical mismatch and shading.
- Oral Session: Albedo updates.

Conclusions

- Complete overhaul of internal geometry creation.
  - Improved scanning functions.
  - Cell level module creation enabled.
  - Many customization options of the geometry in response to identified needs of industry and research.
  - Appending of terrain, structures and things made easier.
- (currently) Streamlining functions and input parameters for seamless interaction with GUI, HPC and regular use.
- Analysis functions, tying with PVMismatch.
- Ongoing work to calculate and relate shading loss and electrical mismatch.
- Doing validation with real systems (need more! E-mail us for collaborations)
- Need beta-testers for GUI and software. Jupyter journals, youtube videos and support available ☺

Thank you

www.nrel.gov

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NREL/PR-5K00-74009

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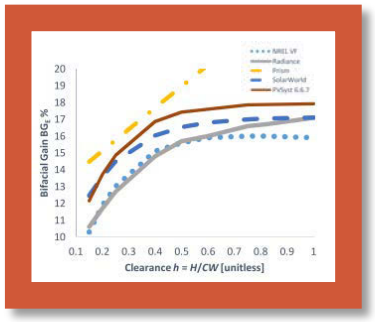
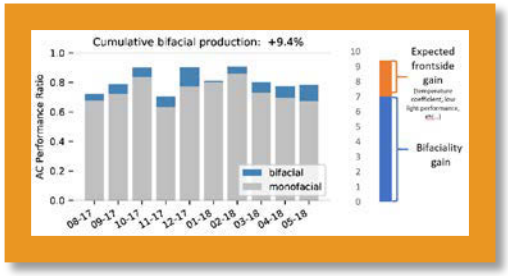


2017

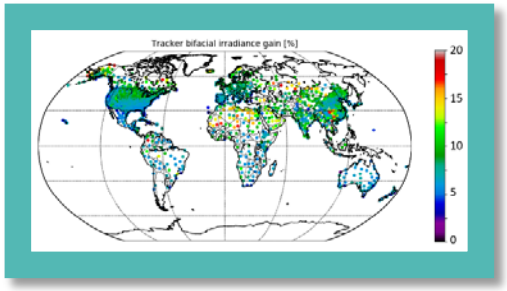
Comparison of models and validation with test-bed data

Single-axis tracking model

2018



Framework to calculate bifacial gain with field data



Albedo database

2019

Standards for bifacial rating

Assess system performance impact from rear irradiance shading and electrical mismatch