

# The subtle art of bifacial performance modeling

Silvana Ayala Peláez, Chris Deline  
Bill Marion, Matthew Mueller  
Joshua Stein, Cameron Stark

12 PVPMC, Albuquerque May 2019

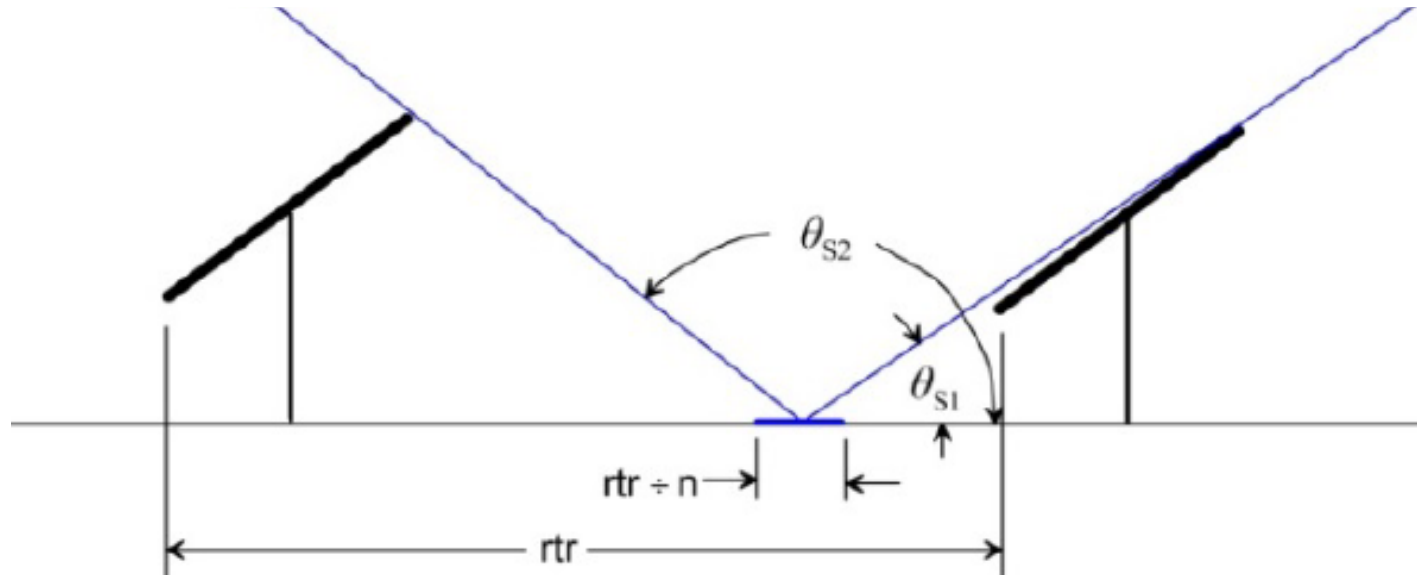


## Bifacial performance modeling

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

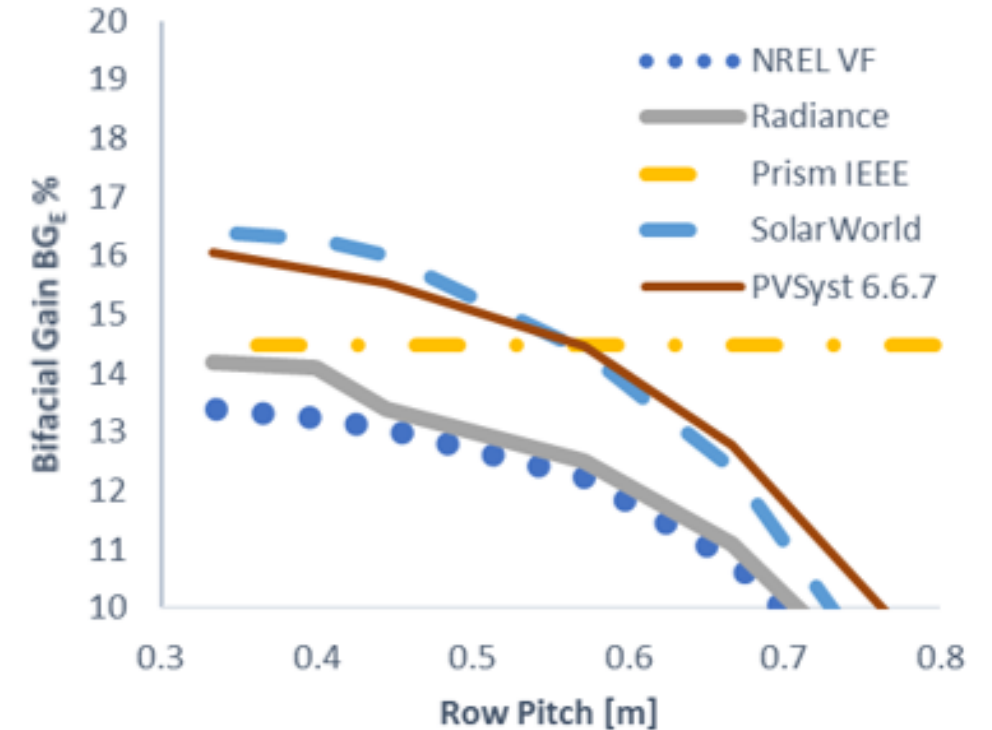
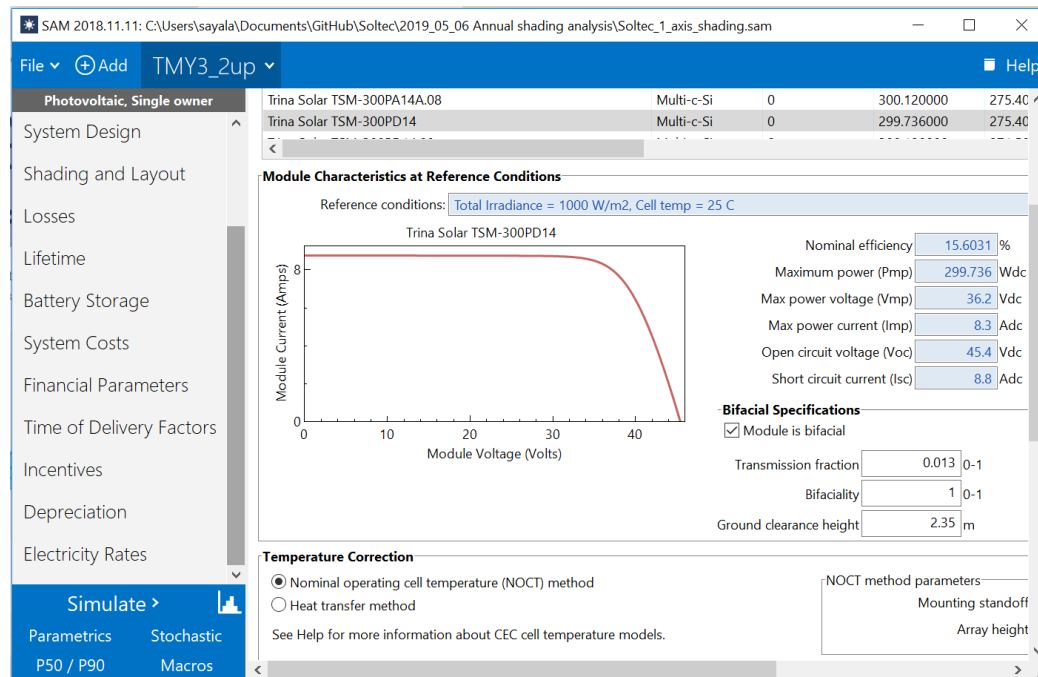
**Behind**  
SAM, Pvsyst, and others

Simple

basic  
geometry<sup>NREL</sup> | 3

# NREL Models

- [Bifacial vf: https://github.com/NREL/bifacialvf](https://github.com/NREL/bifacialvf)



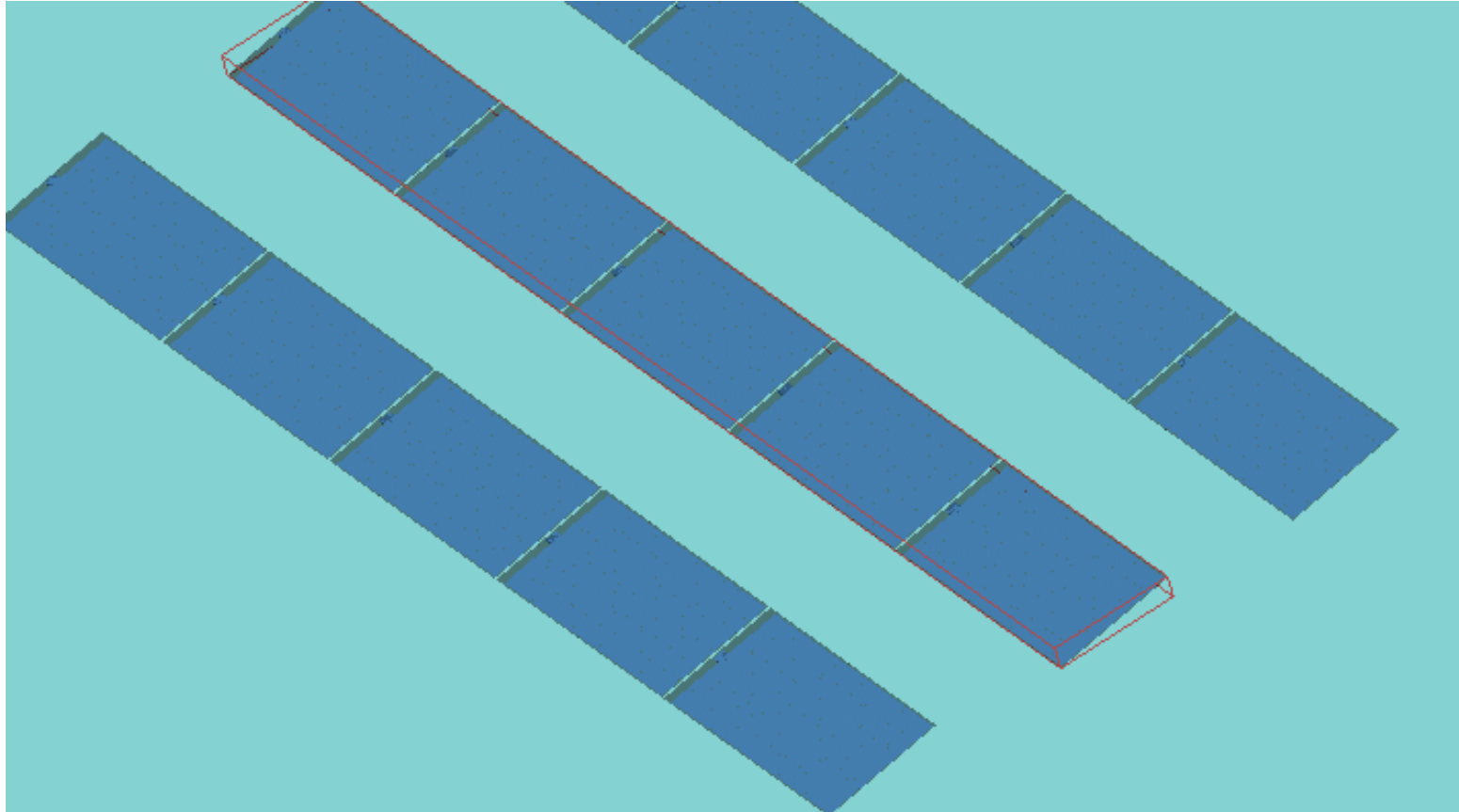
S. Ayala Pelaez, C. Deline, S. MacAlpine, B. Marion, J. Stein, R. Kostuk, "Comparison of bifacial solar irradiance model predictions with field validation" IEEE Journal of Photovoltaics, 2019, vol 9 no. 1, pp. 82-88.

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



Rear Irradiance Modeling  
through **bifacial\_radiance**

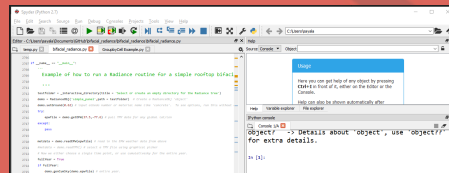
# Bifacial\_Radiance Model for Rear Irradiance



**Complicated geometries possible**, including racking and terrain.

Radiance uses **backward ray-trace** to evaluate the irradiance ( $\text{W}/\text{m}^2$ ) at the modules

# Bifacial\_Radiance Model for Rear Irradiance



```
Command Prompt
Microsoft Windows [Version 10.0.17134.523]
(c) 2018 Microsoft Corporation. All rights reserved.

U:\>C:
C:\>
```

```
my_custom_panel.rad
genbox black Pmodule 1.996 0.991 0.02 | xform -t -0.998 0 0 -a 2 -t 0 0.991 0
genbox Meta1_Grey hextubel1 1.996 0.075 0.129903818568 | xform -t -0.998 0.9535 -0.304903818568
genbox Meta1_Grey hextubel1 1.996 0.075 0.129903818568 | xform -t -0.998 -0.9375 -0.0649519852838 -rx 60 -t 0 0.9
genbox Meta1_Grey hextubel1 1.996 0.075 0.129903818568 | xform -t -0.998 -0.9375 -0.0649519852838 -rx -60 -t 0 0
```

```
my_custom_panel.rad - Notepad
File Edit Format View Help
| genbox black Pmodule 1.996 0.991 0.02 | xform -t -0.998 0 0 -a 2 -t 0 0.991 0
| genbox Meta1_Grey hextubel1 1.996 0.075 0.129903818568 | xform -t -0.998 0.9535 -0.304903818568
| genbox Meta1_Grey hextubel1 1.996 0.075 0.129903818568 | xform -t -0.998 -0.9375 -0.0649519852838 -rx 60 -t 0 0.9
| genbox Meta1_Grey hextubel1 1.996 0.075 0.129903818568 | xform -t -0.998 -0.9375 -0.0649519852838 -rx -60 -t 0 0
```

```
my_custom_panel_2_33_12_09_20x7.rad - Notepad
File Edit Format View Help
| xform -rx 10 -t 0 0 2.35 -a 20 -t 2.006 0 0 -a 7 -t 0 12.097 0 -1 1
| -t -19.96 -36.291 0 -rz 0 objects/my_custom_panel.rad
```

```
my_bifacial_model.rad - Notepad
File Edit Format View Help
PRADIANCEEconomy materials\ground.rad skies\cumulative.rad
objects\my_custom_panel_2_33_12_09_20x7.rad
materials\ground.rad skies\cumulative.rad objects\my_custom_panel_2_33_12_09_20x7.rad
| -t -19.96 -36.291 0 -rz 0 objects/my_custom_panel.rad
```

A screenshot of an Excel spreadsheet showing simulation results. The spreadsheet has columns for 'x', 'y', 'z', 'multitype', 'rearWatt', 'Wm2Front', 'Wm2Back', and 'Back/FrontRatio'. The data is organized in a table with 8 rows of results.

| x | y        | z        | multitype                     | rearWatt             | Wm2Front   | Wm2Back   | Back/FrontRatio |
|---|----------|----------|-------------------------------|----------------------|------------|-----------|-----------------|
| 0 | 0.029712 | 3.896171 | 2.321712 405.340 Pmodule.4657 | 405.340 Pmodule.2310 | 78758.4213 | 3332.04   | 0.0424          |
| 0 | 0.019422 | 3.896171 | 2.321712 405.340 Pmodule.4657 | 405.340 Pmodule.2310 | 78780.16   | 3334.76   | 0.042413        |
| 0 | 0.029333 | 3.896171 | 2.321712 405.340 Pmodule.4657 | 405.340 Pmodule.2310 | 78789.8233 | 3333.5167 | 0.042413        |
| 0 | 0.038844 | 3.896171 | 2.321712 405.340 Pmodule.4657 | 405.340 Pmodule.2310 | 78799.48   | 3332.0967 | 0.042411        |
| 0 | 0.048354 | 3.896171 | 2.321712 405.340 Pmodule.4657 | 405.340 Pmodule.2310 | 78799.1367 | 3332.02   | 0.042398        |
| 0 | 0.057865 | 3.896171 | 2.321712 405.340 Pmodule.4657 | 405.340 Pmodule.2310 | 78799.7967 | 3328.45   | 0.042396        |
| 0 | 0.067375 | 3.896171 | 2.321712 405.340 Pmodule.4657 | 405.340 Pmodule.2310 | 78798.45   | 3326.6267 | 0.042364        |
| 0 | 0.076886 | 3.896171 | 2.321712 405.340 Pmodule.4657 | 405.340 Pmodule.2310 | 78798.1067 | 3324.8016 | 0.042351        |

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!

[https://github.com/NREL/bifacial\\_radiance](https://github.com/NREL/bifacial_radiance)

tk

### Main Control

Input Variables File:    
   
TestFolder:    
WeatherFile Input:  GetEPW  ReadEPW / TMY  
Get EPW (Lat/Lon):    
EPW / TMY File:    
Simulation Name:

### Simulation Control

|  |
|--|
| Fixed, Cumulative Sky Yearly               |
| Fixed, Cumulative Sky with Start/End times |
| Fixed, Hourly by Timestamps                |
| Fixed, Hourly for the Whole Year           |
| Tracking, Cumulative Sky Yearly            |
| Tracking, Hourly for a Day                 |
| Tracking, Hourly with Start/End times      |
| Tracking, Hourly for the Whole Year        |

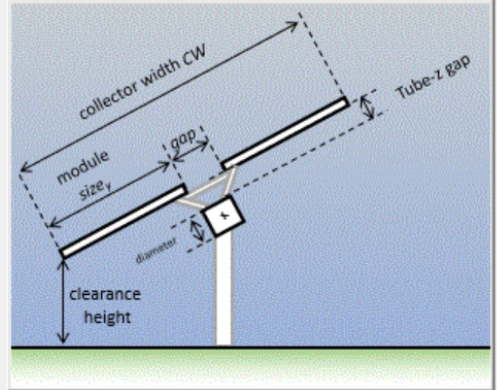
StartDate ( MM | DD | HH ):     
Enddate ( MM | DD | HH ):     
Timestamp Start:   
Timestamp End:

### Tracking Parameters

Backtrack:  True  False  
Limit Angle (deg):   
Angle delta (deg):   
Axis of Rotation:  Torque Tube  Panels

### TorqueTube Parameters

TorqueTube:    
Diameter:   
Tube type:  Round  Square  Hex  Oct  
TorqueTube Material:  Metal\_Grey  Black



### Module Parameters

Prism Solar Bi60

Number of Panels:   
Cell Level Module:    
numcells x:  numcells y:   
Size Xcell:  Size Ycell:   
Xcell gap:  Ycell gap:   
Module size x:  y:   
Xgap | Ygap | Zgap:     
Bifacial Factor (i.e. 0.9):    
Module Name:   
Rewrite Module:  True  False

### Scene Parameters

Row spacing by:  GCR  Pitch  
GCR:  Pitch:   
Albedo:   
# Mods:  # Rows:   
Azimuth Angle (i.e. 180 for South):   
Clearance height:  Tilt:   
Axis Azimuth (i.e. 180 for EW HSATtrackers):   
Hub height:

### Analysis Parameters

# Sensors:   
Mod Wanted:  Row Wanted:



# New GUI: features

**Main Control**

Input Variables File:

TestFolder:

WeatherFile Input:  GetEPW  ReadEPW / TMY

Get EPW (Lat/Lon):

EPW / TMY File:

Simulation Name:

**Simulation Control**

|  |
|--|
| Fixed, Cumulative Sky Yearly               |
| Fixed, Cumulative Sky with Start/End times |
| Fixed, Hourly by Timestamps                |
| Fixed, Hourly for the Whole Year           |
| Tracking, Cumulative Sky Yearly            |
| Tracking, Hourly for a Day                 |
| Tracking, Hourly with Start/End times      |
| Tracking, Hourly for the Whole Year        |

StartDate (MM | DD | HH):

Enddate (MM | DD | HH):

Timestamp Start:

Timestamp End:

**Tracking Parameters**

Backtrack:  True  False

Limit Angle (deg):

Angle delta (deg):

Axis of Rotation:  Torque Tube  Panels

**TorqueTube Parameters**

TorqueTube:

Diameter:

Tube type:  Round  Square  Hex  Oct

TorqueTube Material:  Metal\_Grey  Black

**Module Parameters** Prism Solar Bi60

Number of Panels:

Cell Level Module:

|                     |                                   |                                   |                                   |
|---------------------|-----------------------------------|-----------------------------------|-----------------------------------|
| numcells x:         | <input type="text" value="12"/>   | numcells y:                       | <input type="text" value="6"/>    |
| Size Xcell:         | <input type="text" value="0.15"/> | Size Ycell:                       | <input type="text" value="0.15"/> |
| Xcell gap:          | <input type="text" value="0.01"/> | Ycell gap:                        | <input type="text" value="0.01"/> |
| Module size x:      | <input type="text" value="0.98"/> | y:                                | <input type="text" value="1.98"/> |
| Xgap   Ygap   Zgap: | <input type="text" value="0.05"/> | <input type="text" value="0.15"/> | <input type="text" value="0.10"/> |

Bifacial Factor (i.e. 0.9):

Module Name:

Rewrite Module:  True  False

**Scene Parameters**

Row spacing by:  GCR  Pitch

GCR:  Pitch:

Albedo:

# Mods:  # Rows:

Azimuth Angle (i.e. 180 for South):

Clearance height:  Tilt:

Axis Azimuth (i.e. 180 for EW HSATrackers):

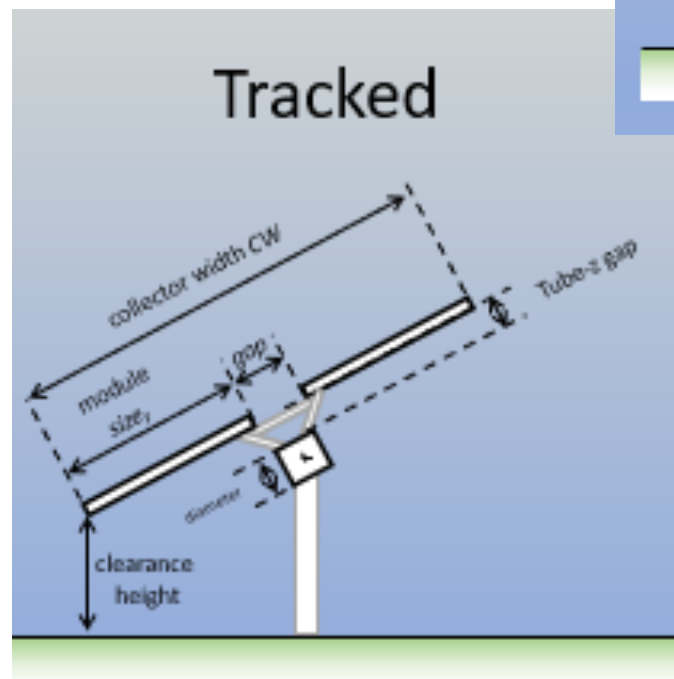
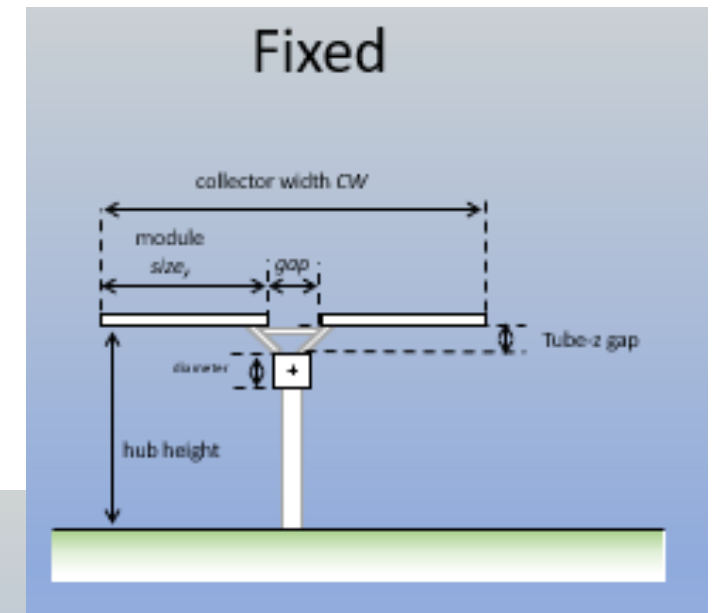
Hub height:

**Analysis Parameters**

# Sensors:

Mod Wanted:  Row Wanted:

The diagram shows a perspective view of a solar collector. It consists of a central vertical hub of diameter 'diameter' and height 'clearance height'. Two rectangular modules of 'module size' are mounted on the hub, separated by a 'gap'. The total width of the collector is 'collector width CW'. The distance from the center of the hub to the end of the collector is 'Tube-z gap'.

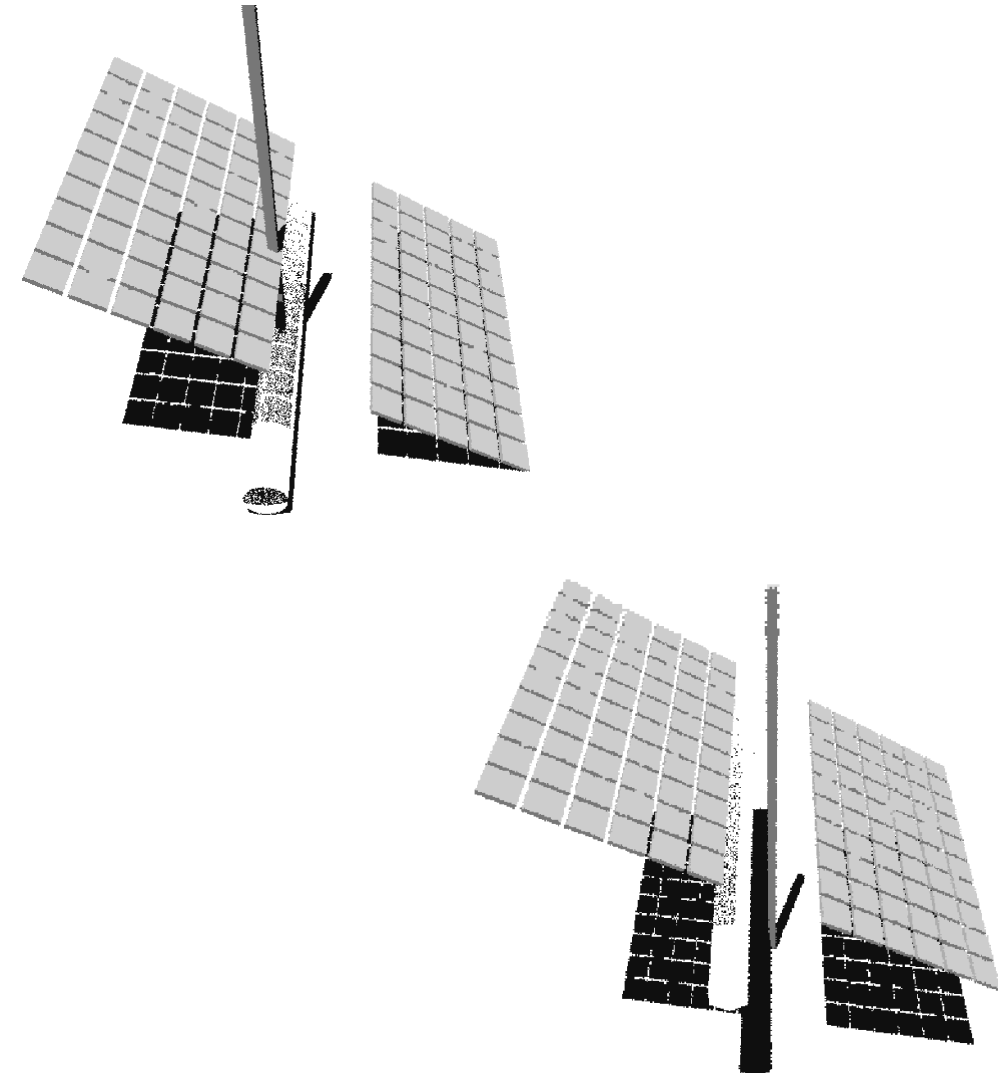


# New GUI: features

The screenshot displays a software interface with several sections:

- Main Control:** Includes fields for 'Input Variables File' (BB), 'TestFolder' (C:\Users\sayala\Docum), 'WeatherFile Input' (GetEPW, ReadEPW / TMY), 'Get EPW (Lat/Lon)' (33, -110), 'EPW / TMY File' (EPWs\USA\_VA\_Richm), and 'Simulation Name' (Demo1).
- Simulation Control:** A list of simulation modes such as 'Fixed, Cumulative Sky Yearly' and 'Tracking, Hourly for the Whole Year', along with date and time range inputs.
- Tracking Parameters:** Settings for 'Backtrack' (True), 'Limit Angle (deg)' (60), 'Angle delta (deg)' (5), and 'Axis of Rotation' (Torque Tube).
- TorqueTube Parameters:** Options for 'TorqueTube' (True/False), 'Diameter' (0.1), 'Tube type' (Round, Square, Hex, Oct), and 'TorqueTube Material' (Metal\_Grey, Black).
- Module Parameters:** A highlighted section for 'Prism Solar Bi60' with settings for 'Number of Panels' (2), 'Cell Level Module' (False/True), 'numcells x/y', 'Size Xcell/Ycell', 'Xcell gap/Ycell gap', 'Module size x/y', 'Xgap | Ygap | Zgap', 'Bifacial Factor' (0.9), 'Module Name', and 'Rewrite Module' (True/False).
- Scene Parameters:** Settings for 'Row spacing by' (GCR/Pitch), 'GCR' (0.35), 'Pitch' (10), 'Albedo' (0.62), '# Mods' (20), '# Rows' (7), 'Azimuth Angle' (180), 'Clearance height' (0.8), 'Tilt' (10), 'Axis Azimuth' (180), and 'Hub height' (0.9).
- Analysis Parameters:** Settings for '# Sensors' (9), 'Mod Wanted' (10), and 'Row Wanted' (3).

A 3D diagram in the top right shows a solar collector with labels: 'collector width CW', 'module size y', 'gap', 'diameter', 'clearance height', and 'Tube-z gap'.

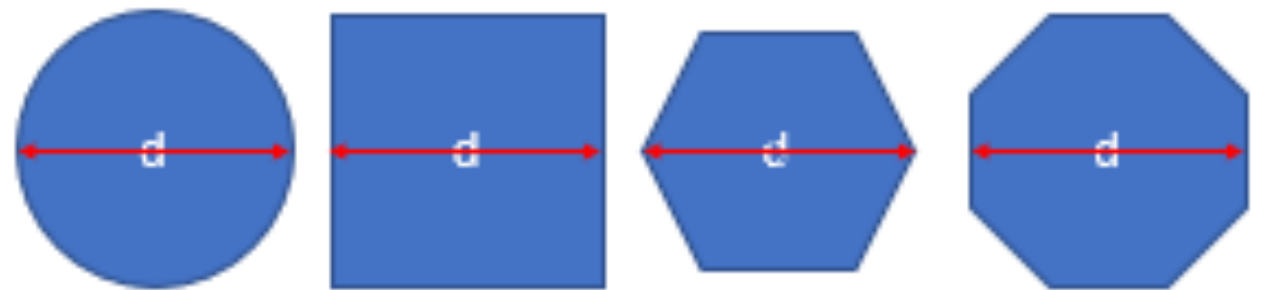
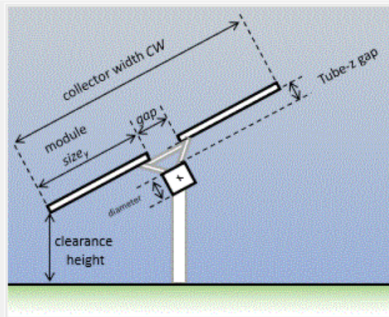


# New GUI: features

The screenshot displays a software interface with several sections:

- Main Control:** Includes fields for 'Input Variables File' (BB), 'TestFolder' (C:\Users\sayala\Docum), 'WeatherFile Input' (GetEPW), 'Get EPW (Lat/Lon)' (33, -110), 'EPW / TMY File' (EPWs\USA\_VA\_Richm), and 'Simulation Name' (Demo1).
- Simulation Control:** A list of simulation modes such as 'Fixed, Cumulative Sky Yearly' and 'Tracking, Hourly for the Whole Year', along with date and time input fields.
- Tracking Parameters:** Includes 'Backtrack' (True), 'Limit Angle (deg)' (60), 'Angle delta (deg)' (5), and 'Axis of Rotation' (Torque Tube).
- TorqueTube Parameters:** A highlighted section with 'TorqueTube' (True), 'Diameter' (0.1), 'Tube type' (Round), and 'TorqueTube Material' (Metal\_Grey).
- Module Parameters:** Configures 'Prism Solar Bi60' with settings for 'Number of Panels' (2), 'Cell Level Module' (True), 'numcells x/y', 'Size Xcell/Ycell', 'Xcell gap/Ycell gap', 'Module size x/y', 'Xgap/Ygap/Zgap', 'Bifacial Factor' (0.9), 'Module Name', and 'Rewrite Module' (True).
- Scene Parameters:** Sets 'Row spacing by' (GCR), 'GCR' (0.35), 'Pitch' (10), 'Albedo' (0.62), '# Mods' (20), '# Rows' (7), 'Azimuth Angle' (180), 'Clearance height' (0.8), 'Tilt' (10), 'Axis Azimuth' (180), and 'Hub height' (0.9).
- Analysis Parameters:** Includes '# Sensors' (9), 'Mod Wanted' (10), and 'Row Wanted' (3).

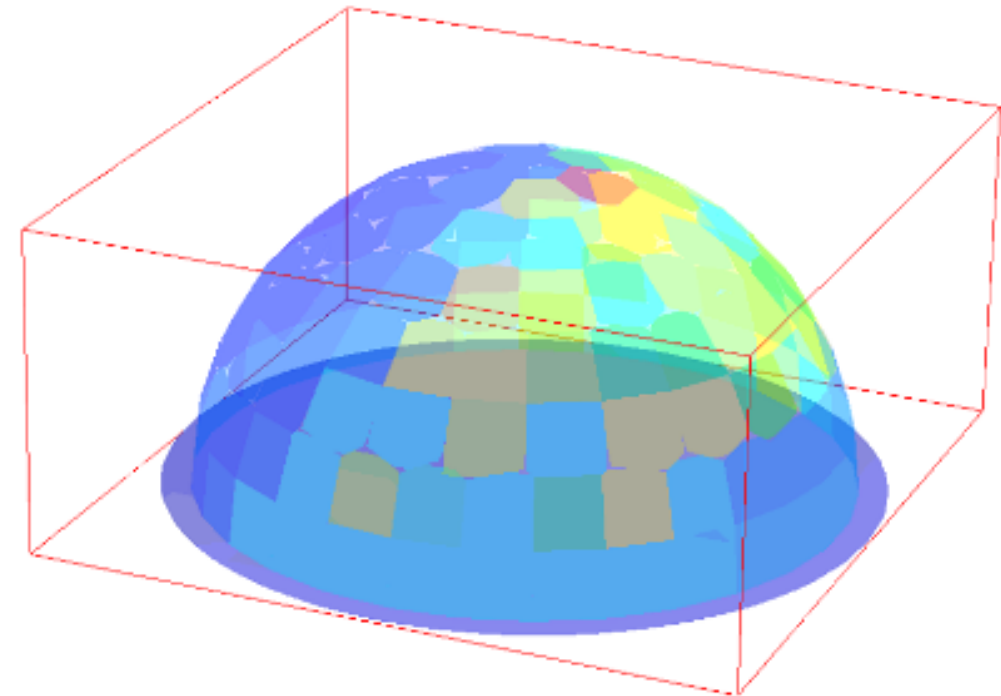
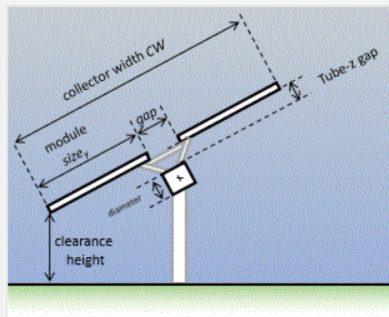
Buttons for 'READ', 'SAVE', 'SEARCH', 'VIEW', 'CLEAR', 'DEFAULT', and 'RUN' are also visible.



# New GUI: features

The screenshot displays a comprehensive software interface with several key sections:

- Main Control:** Includes fields for 'Input Variables File' (BB), 'TestFolder' (C:\Users\sayala\Docum), 'WeatherFile Input' (GetEPW), 'Get EPW (Lat/Lon)' (33, -110), 'EPW / TMY File' (EPWs\USA\_VA\_Richm), and 'Simulation Name' (Demo1).
- Simulation Control:** A table of simulation modes such as 'Fixed, Cumulative Sky Yearly', 'Fixed, Cumulative Sky with Start/End times', 'Fixed, Hourly by Timestamps', 'Fixed, Hourly for the Whole Year', 'Tracking, Cumulative Sky Yearly', 'Tracking, Hourly for a Day', 'Tracking, Hourly with Start/End times', and 'Tracking, Hourly for the Whole Year'. It also includes date and time selection fields.
- Module Parameters:** Configures 'Prism Solar Bi60' with settings for 'Number of Panels' (2), 'Cell Level Module' (False/True), 'numcells x/y' (12/6), 'Size Xcell/Ycell' (0.15/0.15), 'Xcell gap/Ycell gap' (0.01/0.01), 'Module size x/y' (0.98/1.98), 'Xgap | Ygap | Zgap' (0.05/0.15/0.10), 'Bifacial Factor' (0.9), 'Module Name' (Prism Solar Bi60), and 'Rewrite Module' (True).
- Scene Parameters:** Sets 'Row spacing by' (GCR/Pitch), 'GCR' (0.35), 'Pitch' (10), 'Albedo' (0.62), '# Mods' (20), '# Rows' (7), 'Azimuth Angle' (180), 'Clearance height' (0.8), 'Tilt' (10), 'Axis Azimuth' (180), and 'Hub height' (0.9).
- Tracking Parameters:** Controls 'Backtrack' (True/False), 'Limit Angle' (60), 'Angle delta' (5), and 'Axis of Rotation' (Torque Tube/Panels).
- TorqueTube Parameters:** Sets 'TorqueTube' (True/False), 'Diameter' (0.1), 'Tube type' (Round/Square/Hex/Oct), and 'TorqueTube Material' (Metal\_Grey/Black).
- Analysis Parameters:** Defines '# Sensors' (9), 'Mod Wanted' (10), and 'Row Wanted' (3).



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**

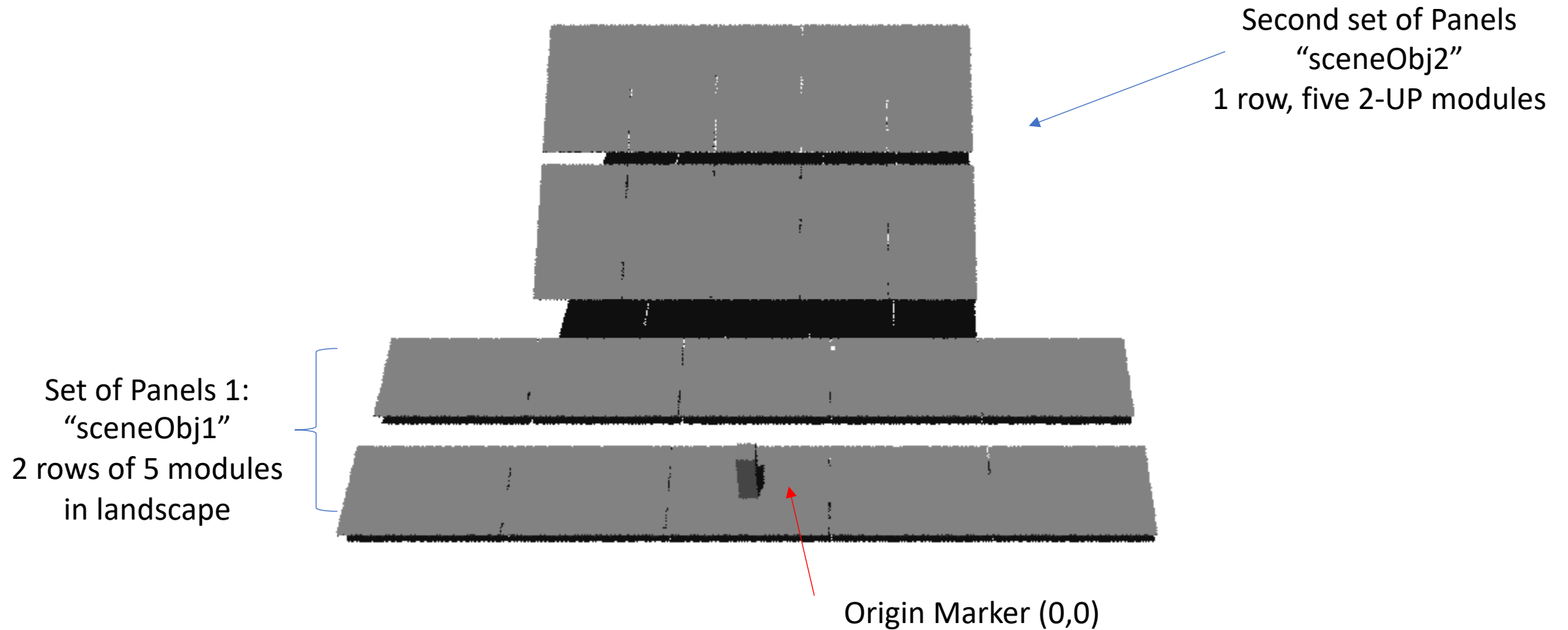




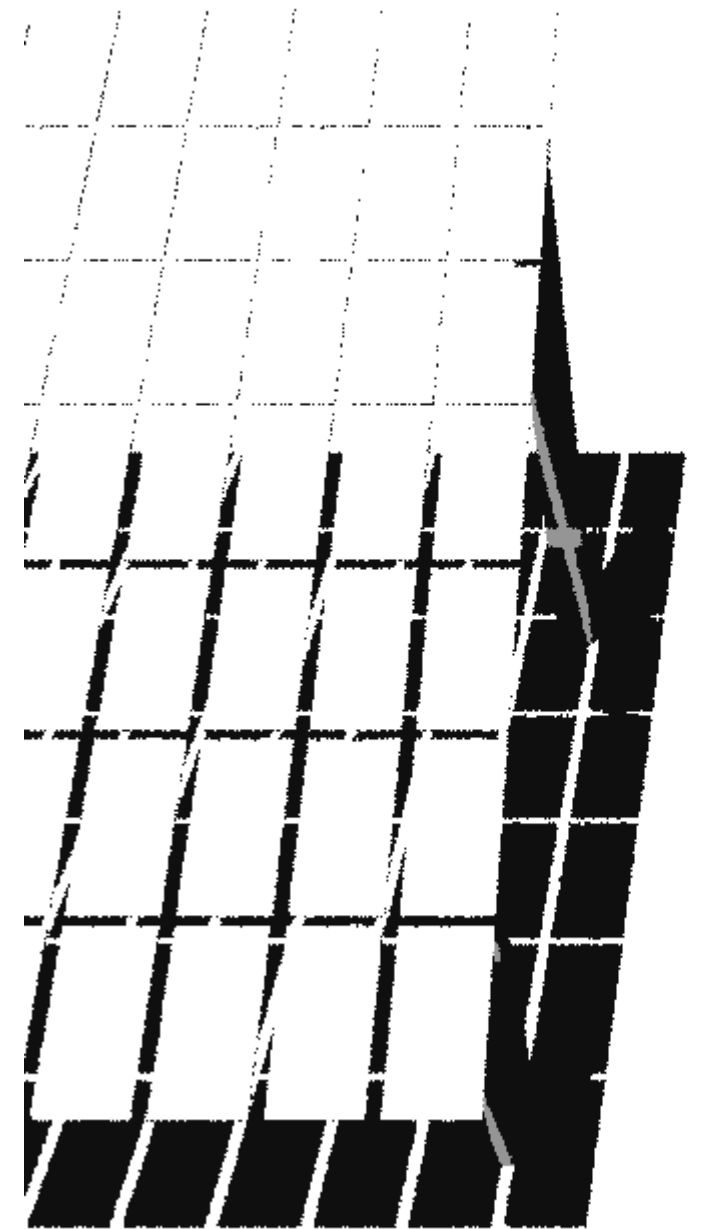
Non-GUI Features

Bifacial\_radiance V3

# Multiple SceneObjects

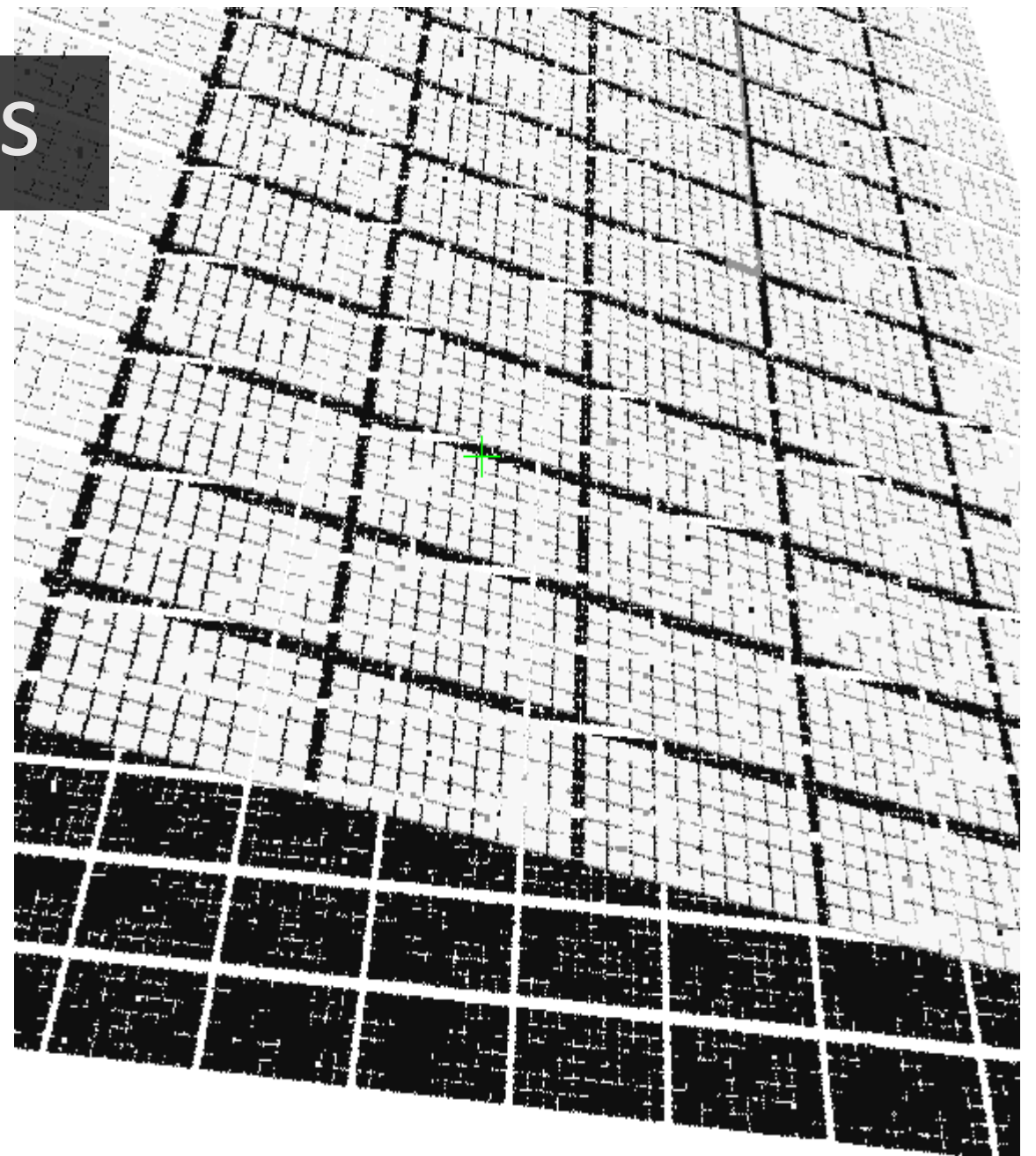


# Canopies and Carports

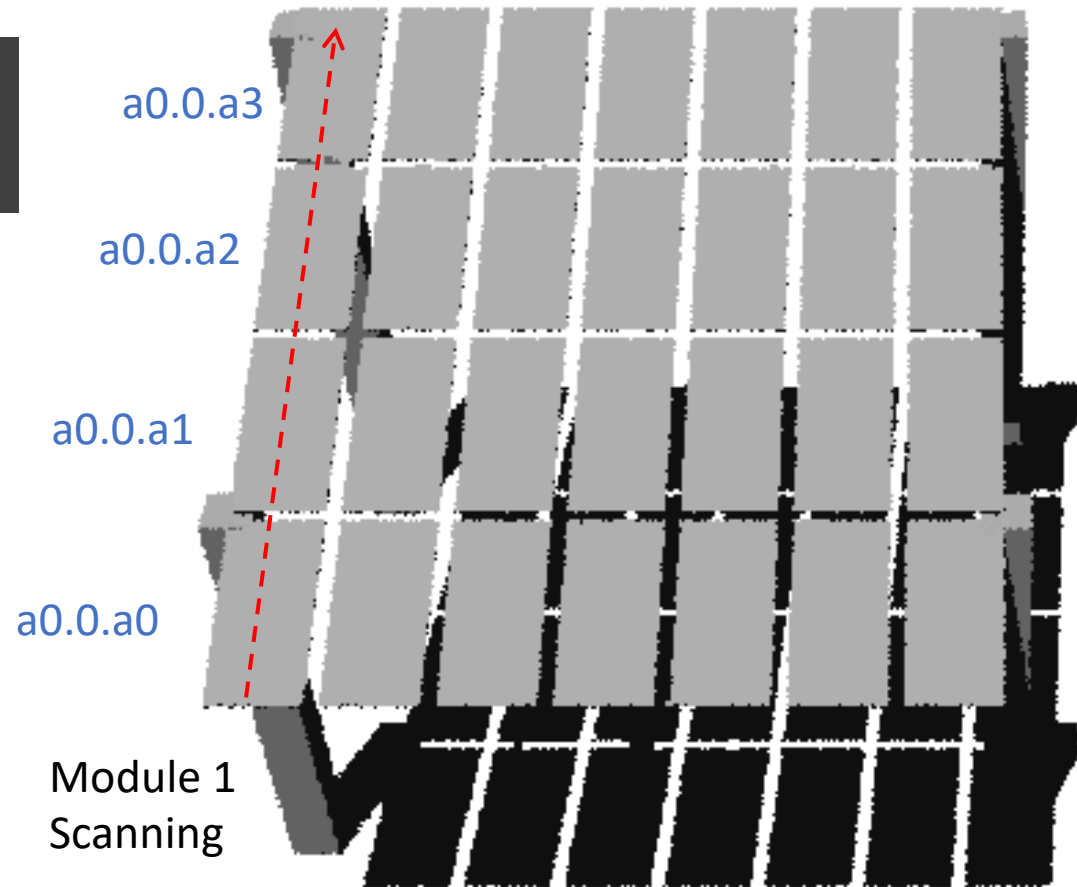




# Canopies and Carports

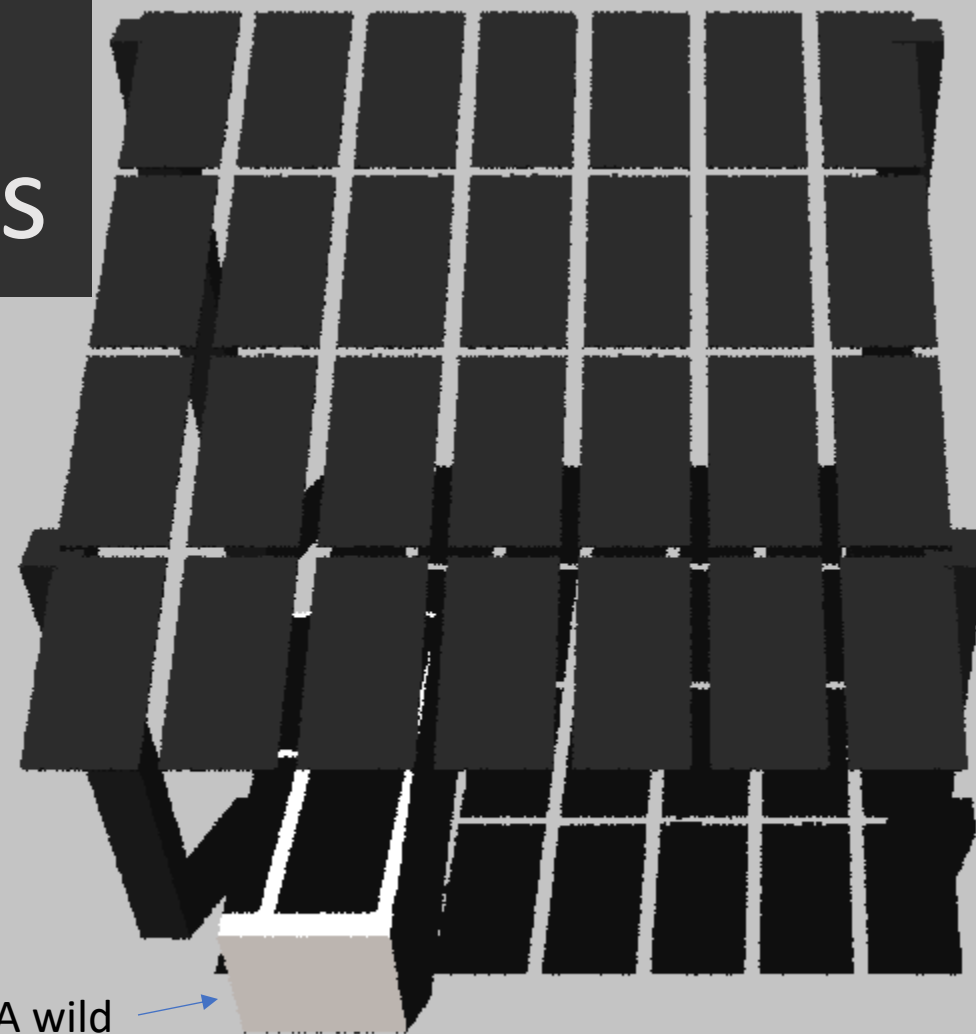


# Canopies and Carports



| 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

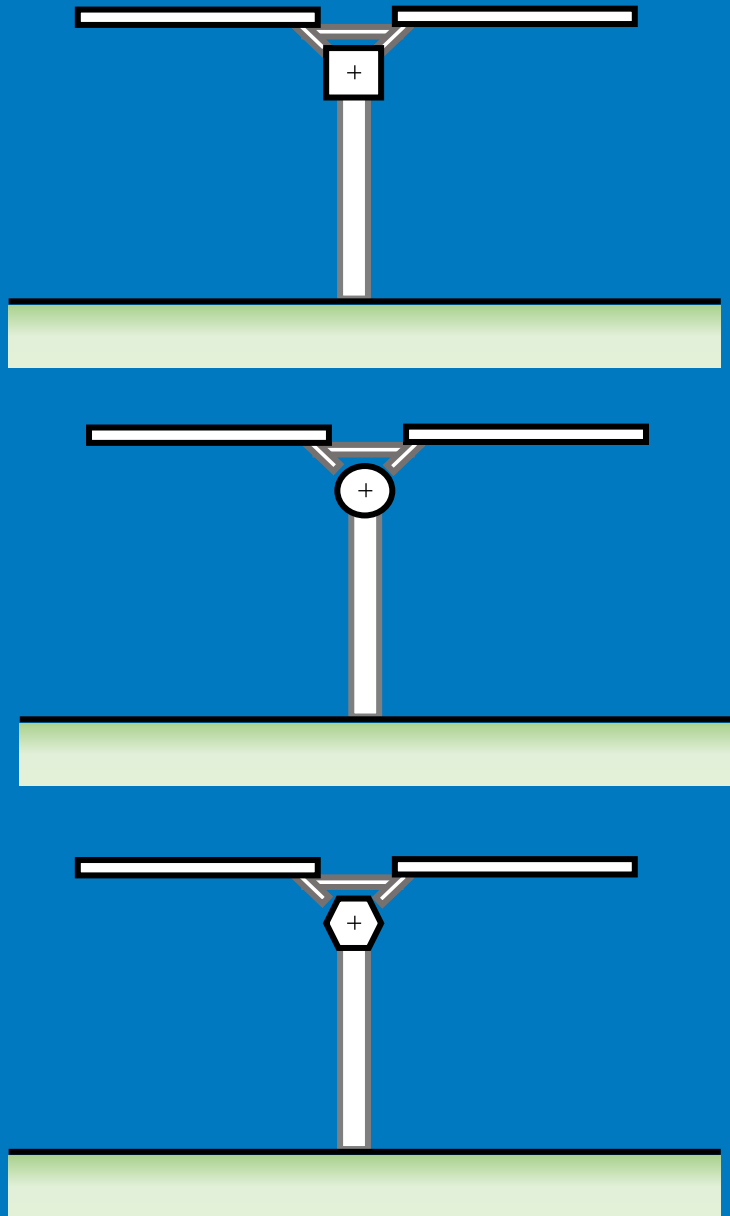


A wild  
white car appears!

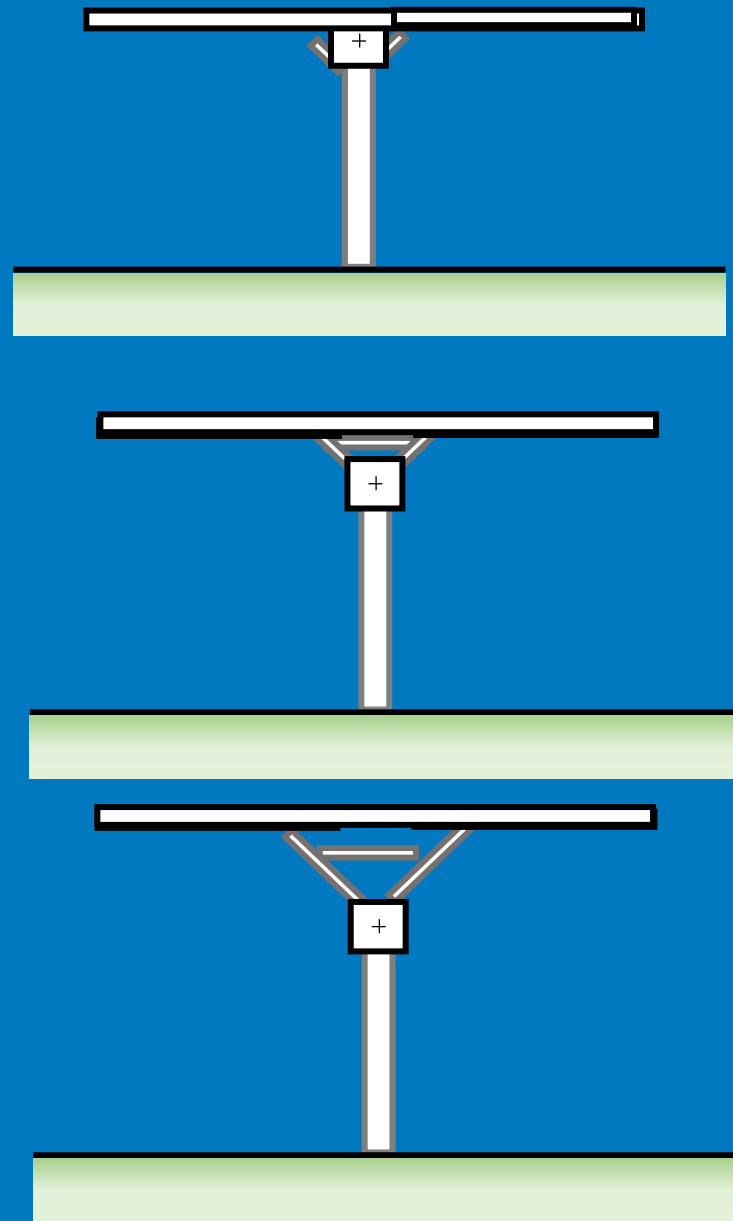


Tracking and Torque tube  
Hourly-yearly simulations

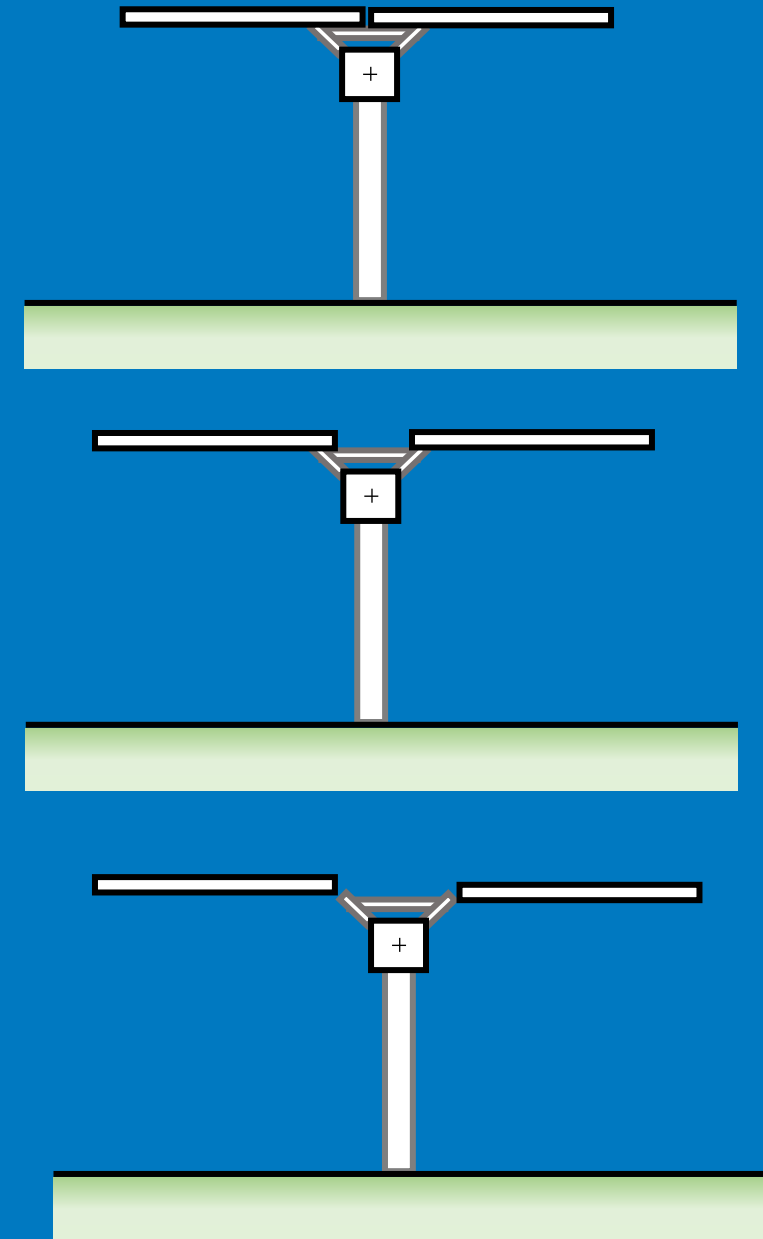
# Varying torquetube shape



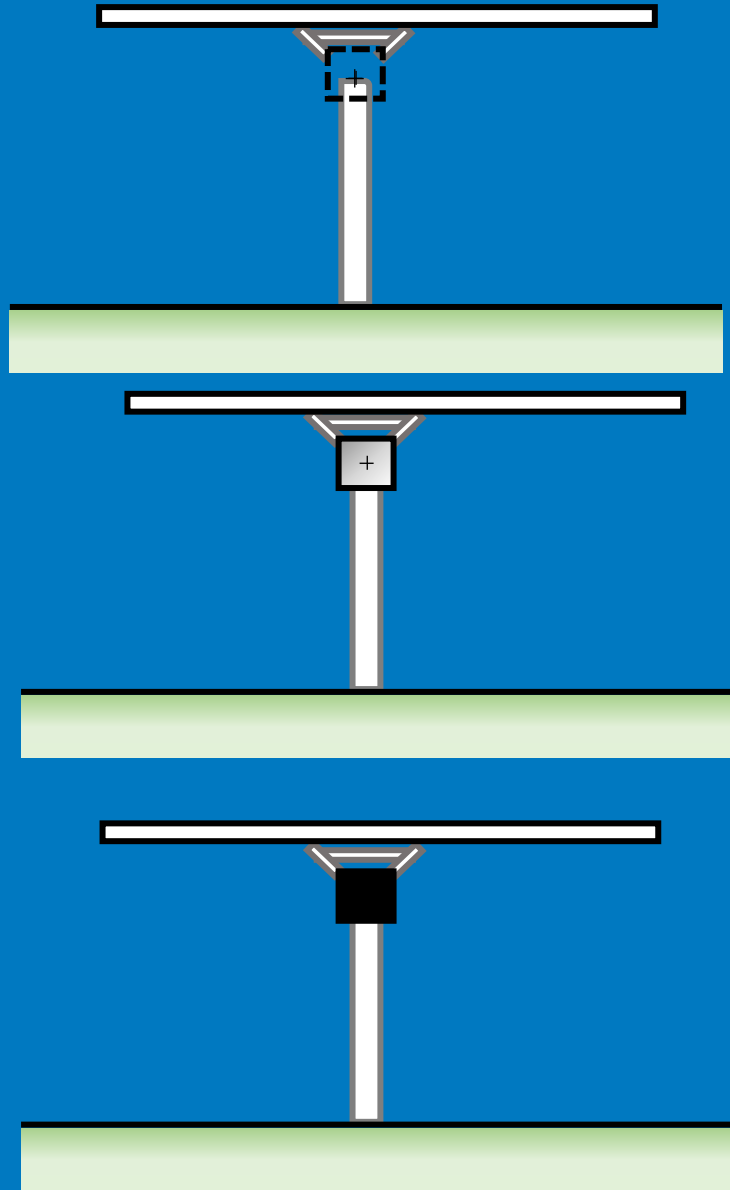
# Varying zgap



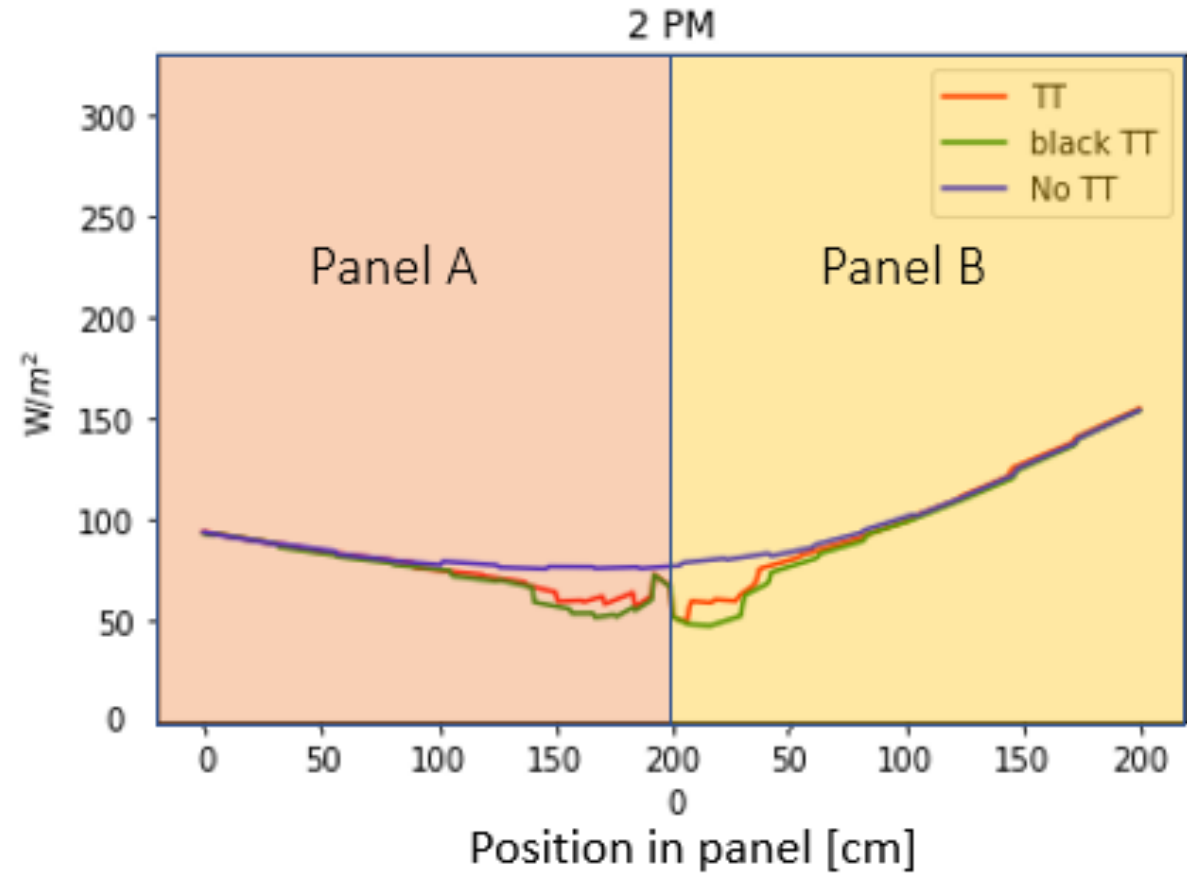
# Varying ygap



# Varying torquetube reflectivity

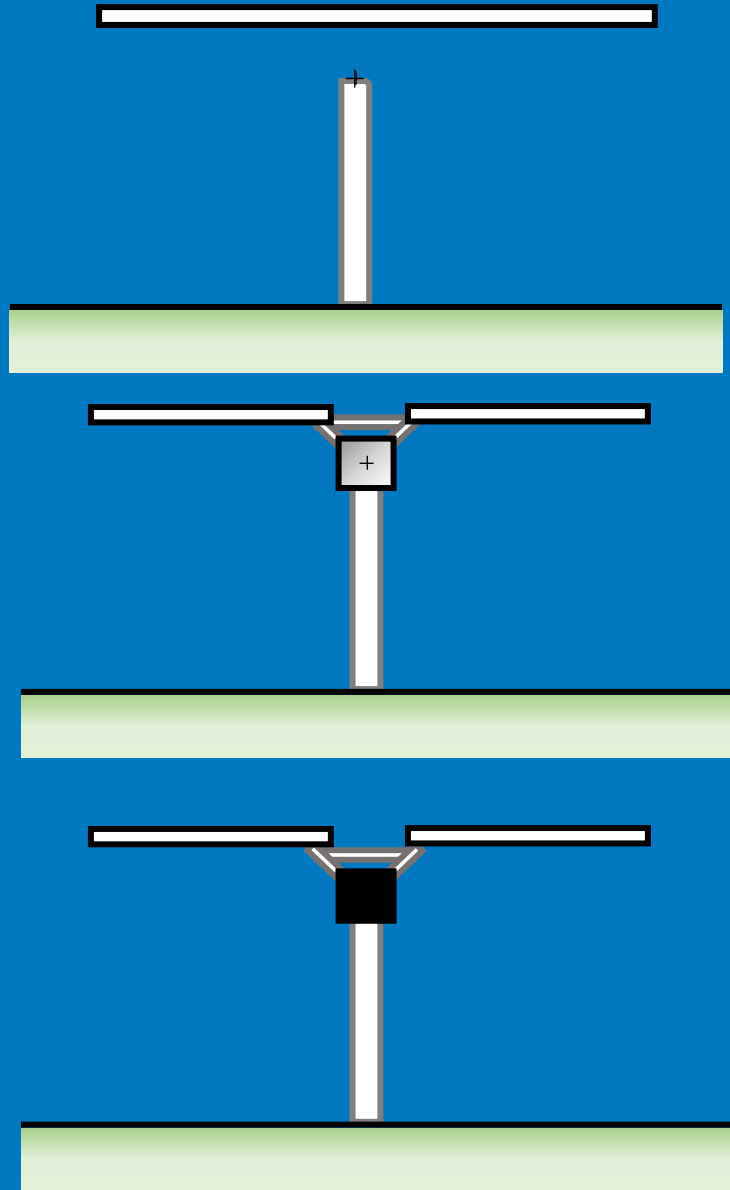


a)

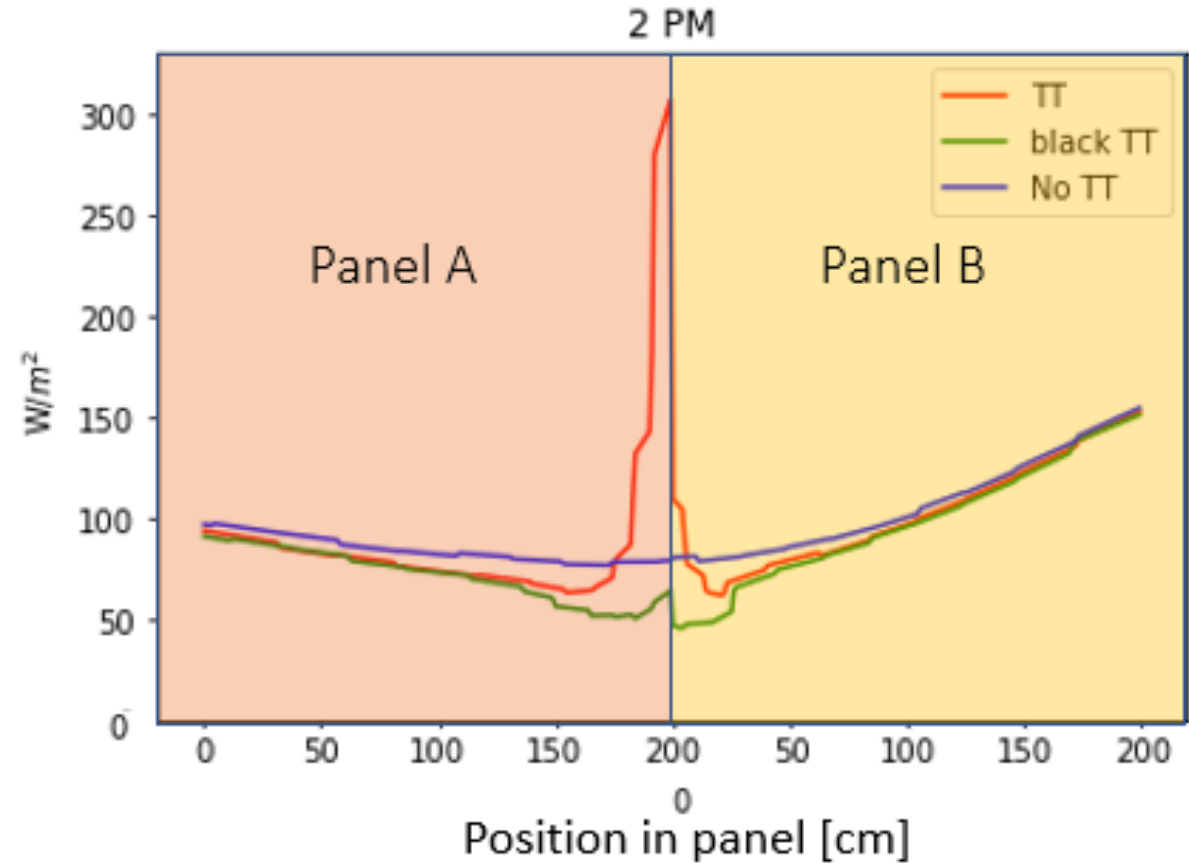


$$\text{Shading factor} = \frac{\sum_{n=0}^N G_{rear} \text{ (no tube)}}{\sum_{n=0}^N G_{rear} \text{ (with tube)}}$$

# Varying torquetube reflectivity



b)



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

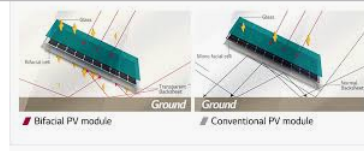
# Torque tube reflections



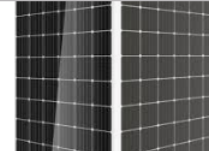
What are bifacial solar modules and how ...  
solarpowerworldonline.com



What are bifacial solar modules and how ...  
solarpowerworldonline.com



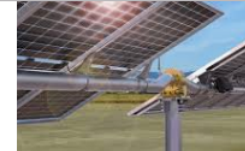
Trend to Watch: Bifacial Modules ...  
civicsolar.com



Bifacial solar panels: Breaki...  
solarpowerworldonline.com



bifacial PERC solar module advances ...  
solarbuildermag.com



Bifacial + NX Horizon = A Winnin...  
nexttracker.com



bifacial modules add to solar tracker ...  
solarbuildermag.com



1000 x 662 - Images may be subject to copyright. Learn More

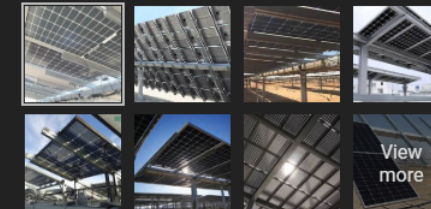
## Bifacial Gains: How much will bifacial modules add to so...

Solar Builder

Bifacial Gains: How much will bifacial modules add to solar tracker value? We are about to find out

Visit Add to Collections Share

Related images:



View more

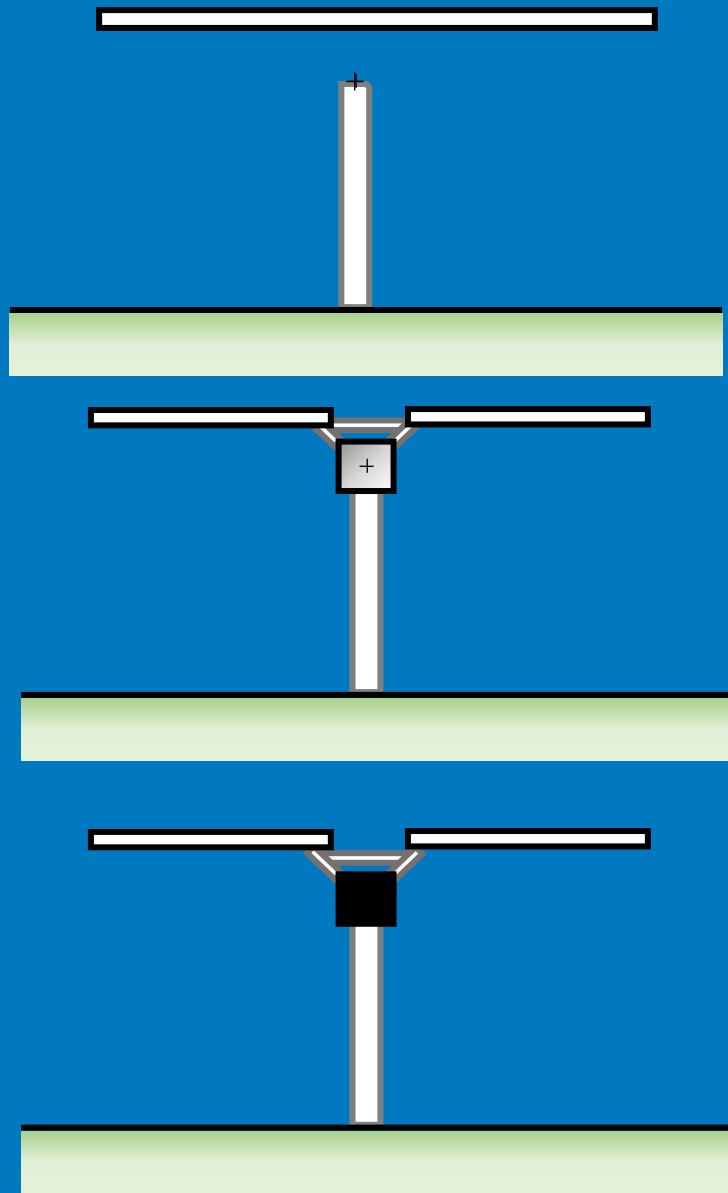
Get help - Send feedback



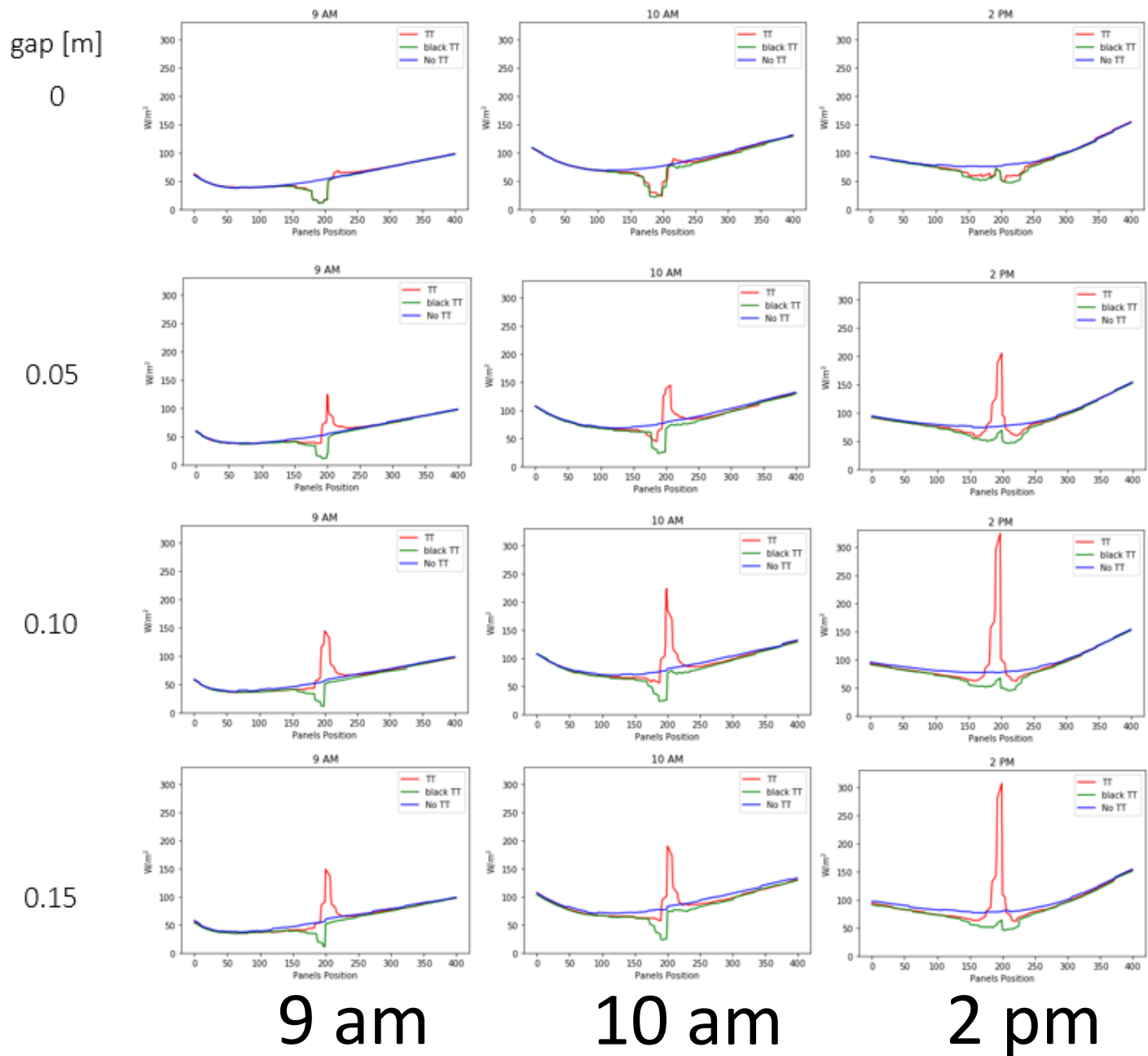
<https://solarbuildermag.com/featured/bifacial-gains-how-much-will-bifacial-modules-add-to-solar-tracker-value-we-are-about-to-find-out/>



# Varying torquetube reflectivity

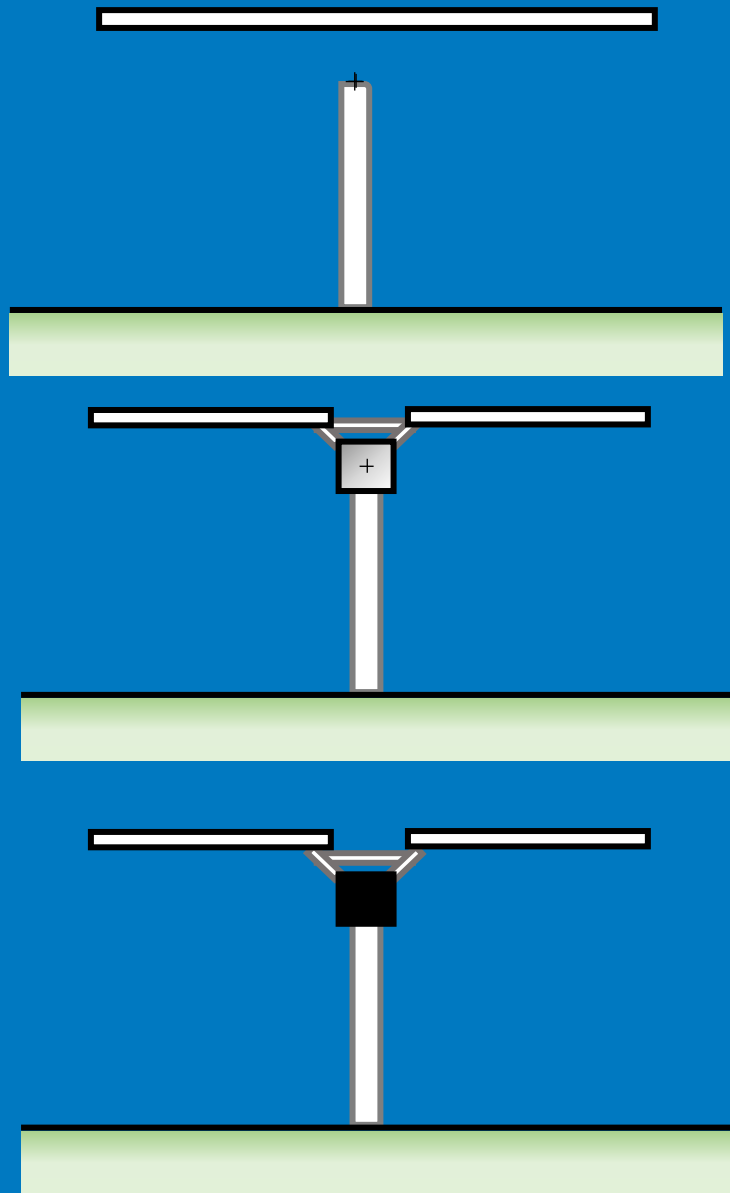


2 UP – 16 JUN Sunny day

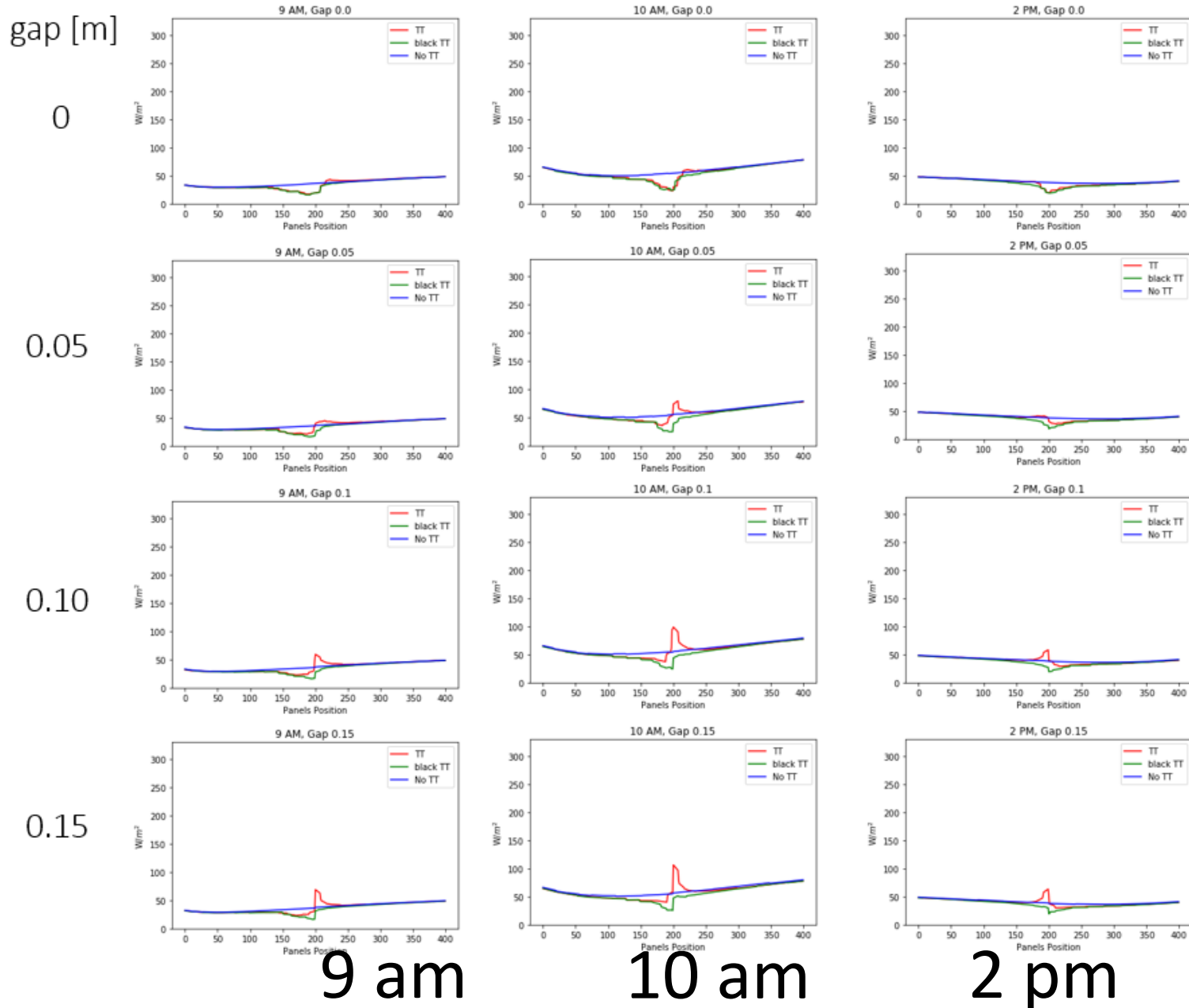


9 am      10 am      2 pm

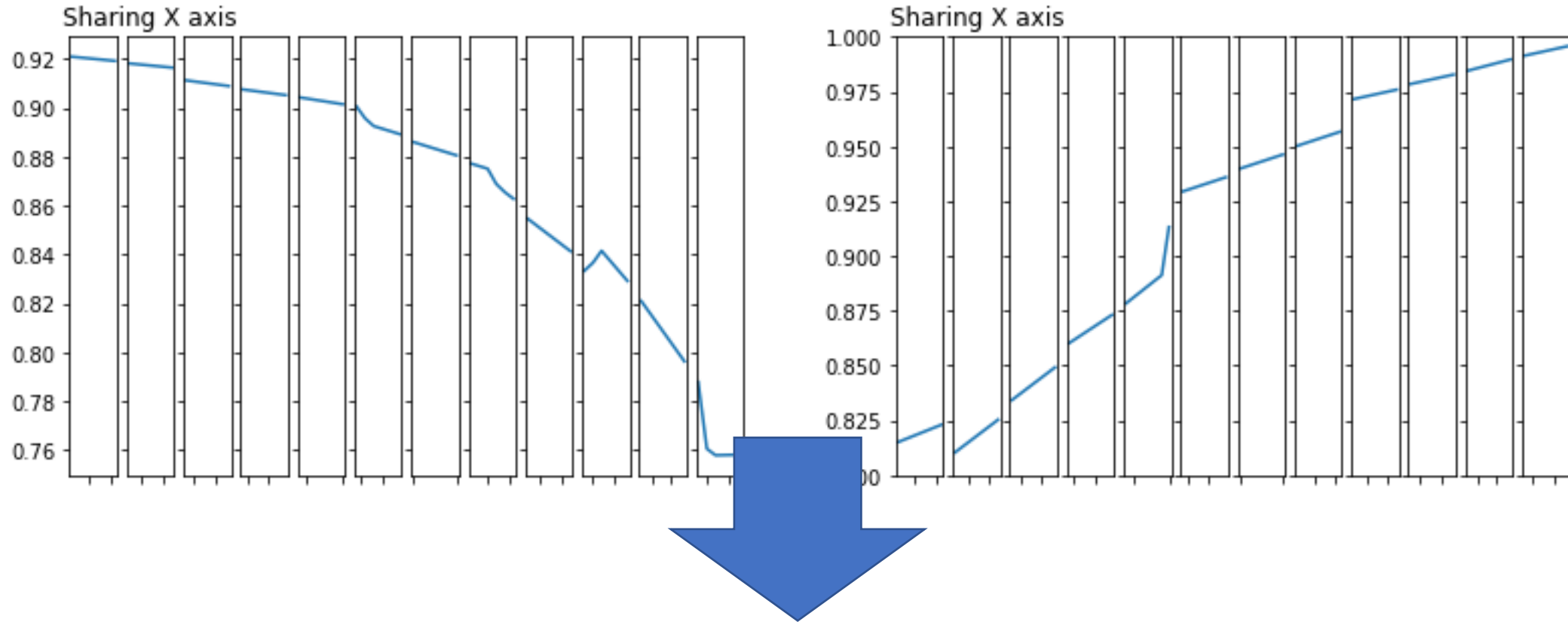
# Varying torquetube reflectivity



2 UP – 10 JUN Cloudy day



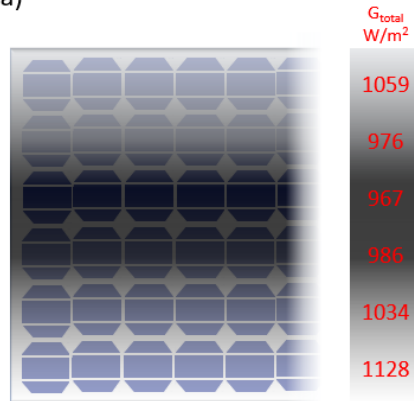
# Shading to Electrical Mismatch



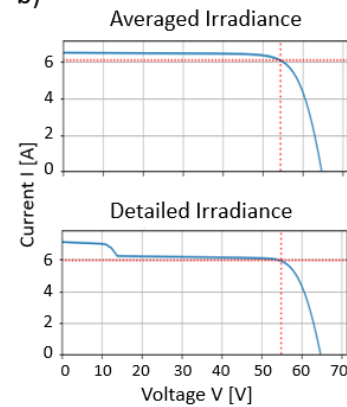
Bifacial radiance **Analysis module**  
ties to PVMismatch

# Electrical Mismatch Model

a) Bifacial total irradiance

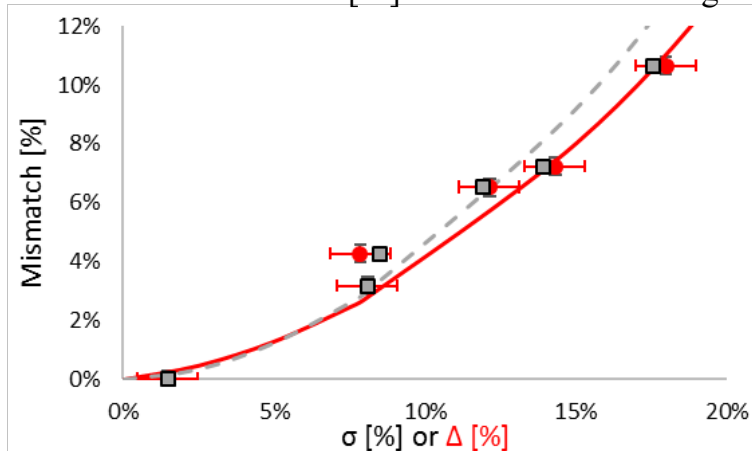


b) Bifacial mismatch loss calculation



- 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 ( $\sigma$ ) or MAD ( $\Delta$ ) of  $I_{sc}$

Mismatch loss  $M$ [%] for indoor IV shading tests

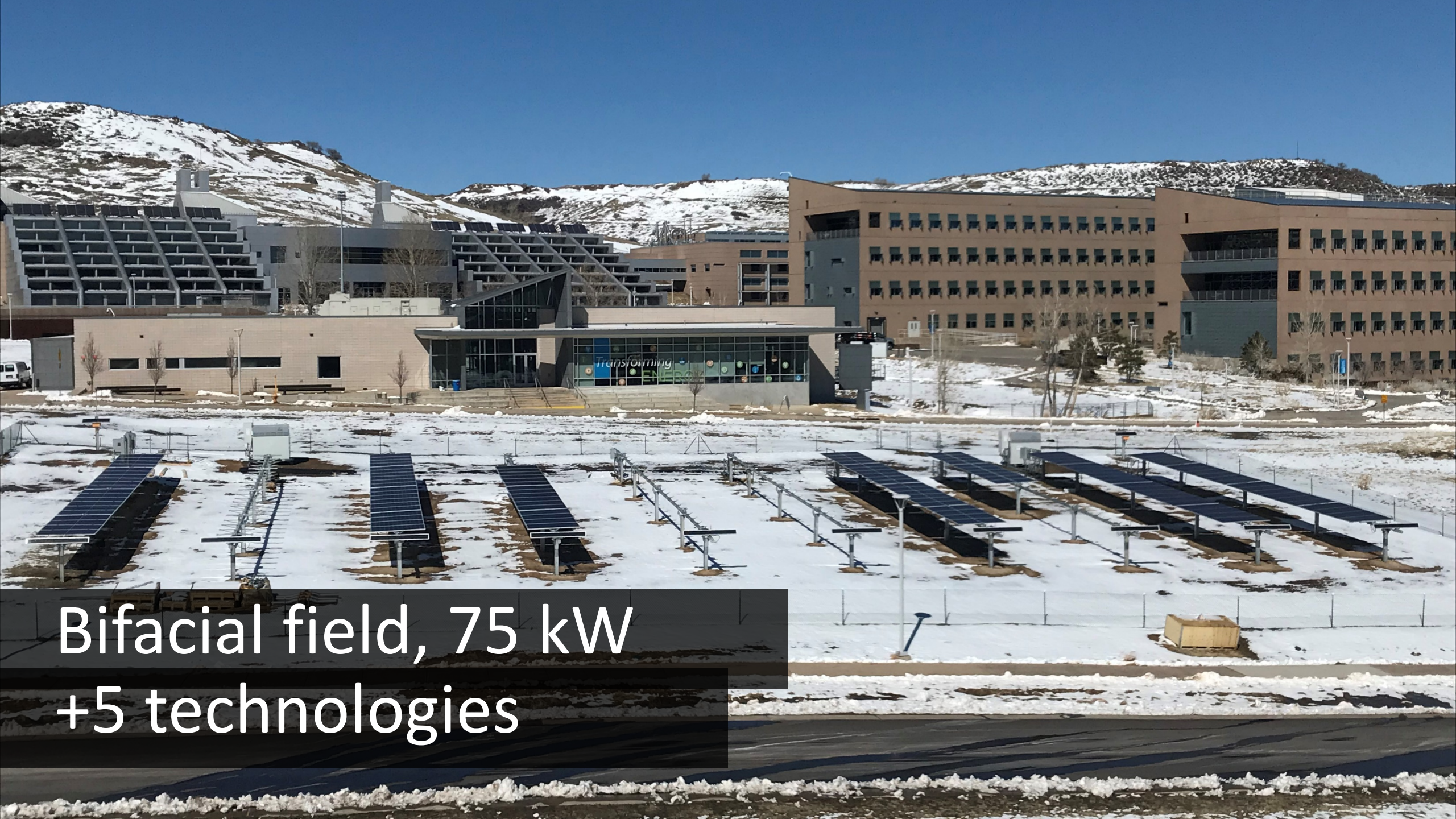


$$M[\%]_{Fit1} = e^{1.067 + 1.82 * \ln(\sigma[\%])}$$

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

- EU-PVSEC Oral Paper Accepted

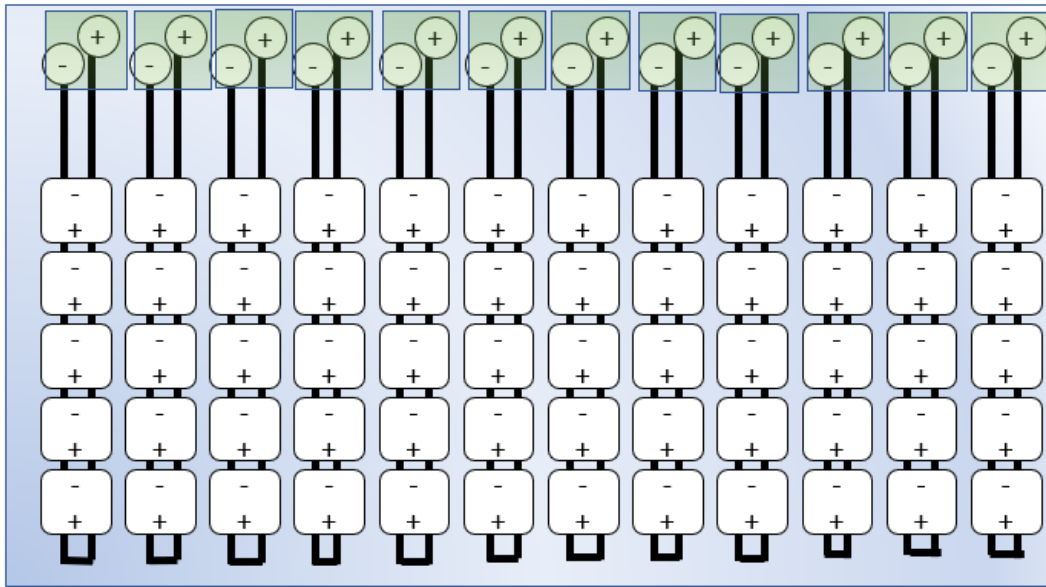
C. Deline, S. Ayala Pelaez, S. MacAlpine, C. Olalla, C. "Bifacial PV Mismatch Loss and Parameterization". EUPVSEC 2019



Bifacial field, 75 kW  
+5 technologies

# Electrical Mismatch Model Validation

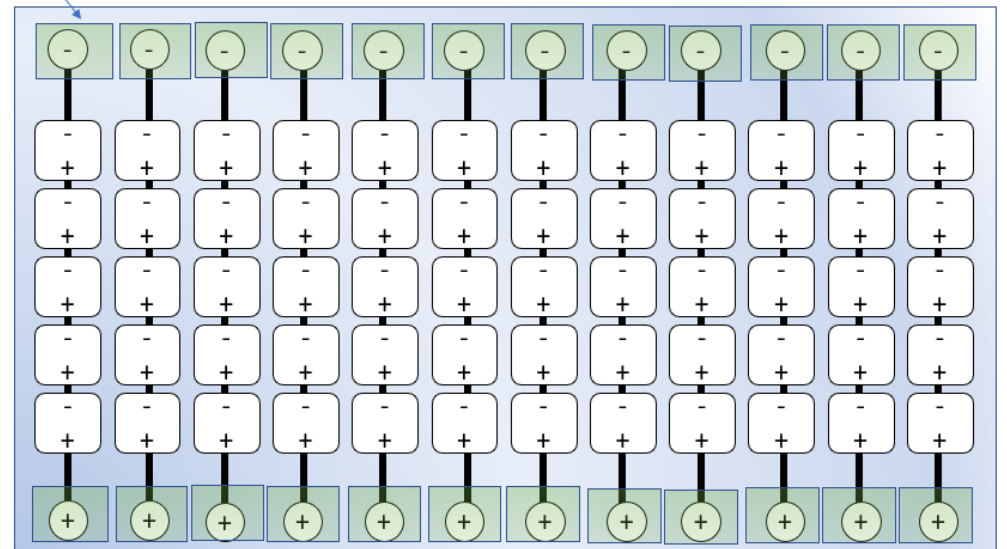
- Custom modules to measure shading loss of Torque Tube
- Strung cross-wise with multiple junction boxes for sub-module Isc measurement



Long Edge, 12 cells

Short Edge, 5 cells (Monofacial)

Junction boxes



Long Edge, 12 cells

Short Edge, 5 cells

Look for **more**



12<sup>th</sup>. PVPMC (Albuquerque)

- New GUI Release
  - Subtleties of modeling bifacial modules.
- 



46<sup>th</sup> IEEE PVSC (Chicago)

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



36<sup>th</sup> EU PVSEC (Marseille)

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



6<sup>th</sup> Bifi PV Workshop (Amsterdam)

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

# Ultimate Goal

- 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.



# Thank you

---

[www.nrel.gov](http://www.nrel.gov)

**[A portion of] The research was performed using computational resources sponsored by the Department of Energy's Office of Energy Efficiency and Renewable Energy and located at the National Renewable Energy Laboratory.**

This work was authored [in part] by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under Solar Energy Technologies Office (SETO) Agreement Number 34910. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government.



# Ultimate Goal

(2D models with pedagogic tool)

Other models are currently under construction:

- General scene defined in the 3D editor
- Bifacial vertical wall or rows

## Incident irradiance on the ground

Beam ground factor From sun's position, 2D model

Diffuse ground factor  % From 2D model

Shed transparent fraction  % not sensitive

**Ground albedo**  %  Monthly values

## Reflected irradiance on backside

Reemission form factor  % From 2D model

Structure shading factor  % (0 = no shadings)

## PV array behavior


Mismatch loss factor  %


Module bifaciality factor  % From PV module


## Monthly ground albedo values

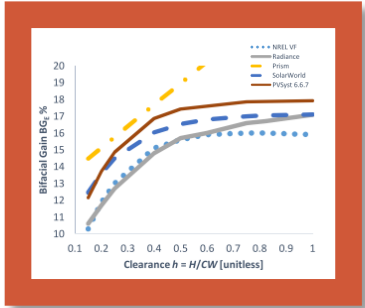
|       |                                     |      |                                     |       |                                     |
|-------|-------------------------------------|------|-------------------------------------|-------|-------------------------------------|
| Jan.  | <input type="text" value="40.0"/> % | May  | <input type="text" value="30.0"/> % | Sept. | <input type="text" value="30.0"/> % |
| Feb.  | <input type="text" value="30.0"/> % | June | <input type="text" value="10.0"/> % | Oct.  | <input type="text" value="30.0"/> % |
| March | <input type="text" value="30.0"/> % | July | <input type="text" value="10.0"/> % | Nov.  | <input type="text" value="30.0"/> % |
| April | <input type="text" value="30.0"/> % | Aug. | <input type="text" value="30.0"/> % | Dec.  | <input type="text" value="35.0"/> % |

Set all as year

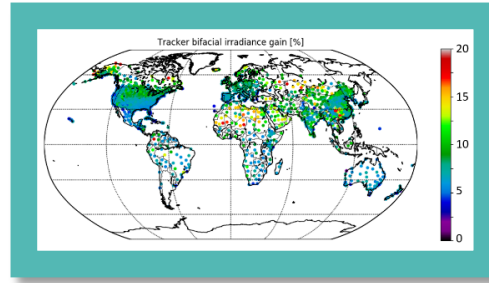
 Erase def.

 Cancel

 OK



Single-axis tracking model



Albedo database



Assess system performance impact from rear irradiance shading and electrical mismatch



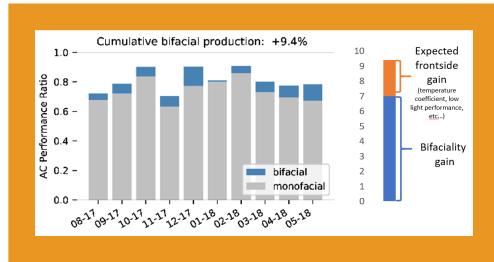
2017

Comparison of models and validation with test-bed data



2018

Framework to calculate bifacial gain with field data



2019

Standards for bifacial rating

