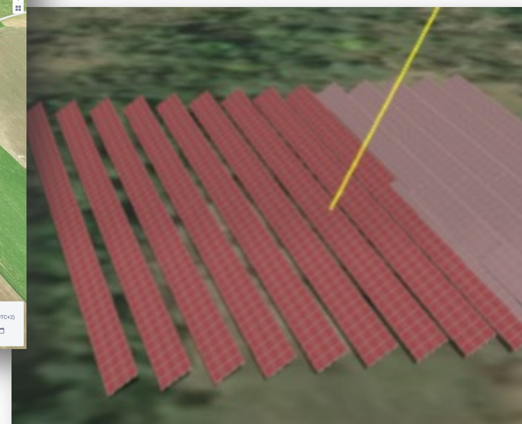
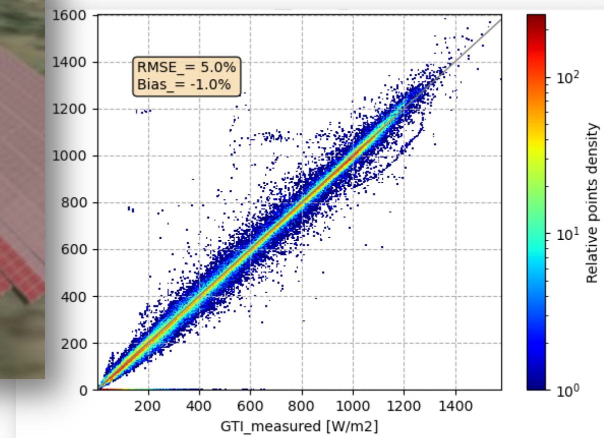




Comparison of ray tracing rendering technique with ground measurements for improved solar radiation modeling

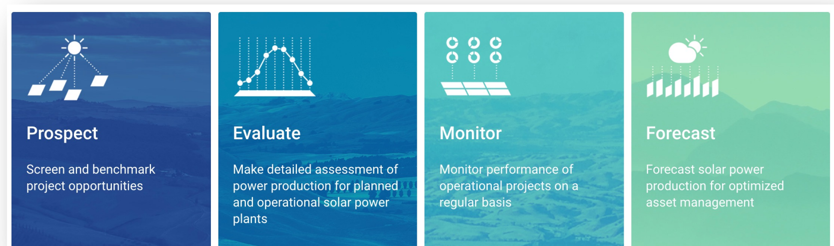
Lukas Dvonc, Peter Orosi, **Tomas Cebecauer**, Branislav Schnierer
Solargis, Slovakia

PVPMC Salt Lake City, 23 - 24 August 2022

About Solargis

Solar resource, meteorological and photovoltaic simulation data, software and expert services for power industry

- Prospection
- Project development
- Monitoring
- Forecasting



1000+ Customers

5000+ projects per year

100+ countries

20+ years of experience in solar industry

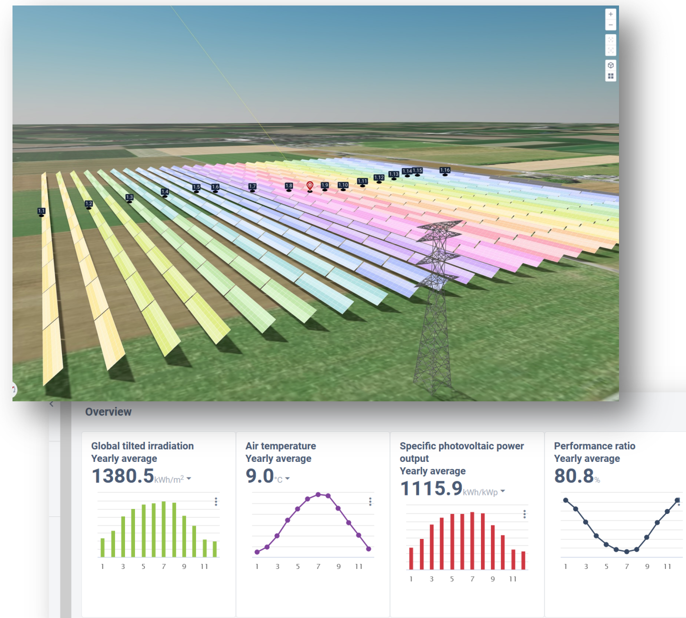
Content

- Next generation of PV simulator
- Ray-tracing algorithm
- Verification of GTI simulation
- Comparison to Bifacial_radiance
- Conclusions and future work

Next generation of PV simulator (SGSIM)

Current status of SGSIM model:

- Includes both ray-tracing and view factor methods
- Detailed scene creation (shading objects, plant layout, …)
- Single diode model, inverter, transformer and cabling models
- Up to 1-minute data resolution, multiyear time series



Validation of the new simulator:

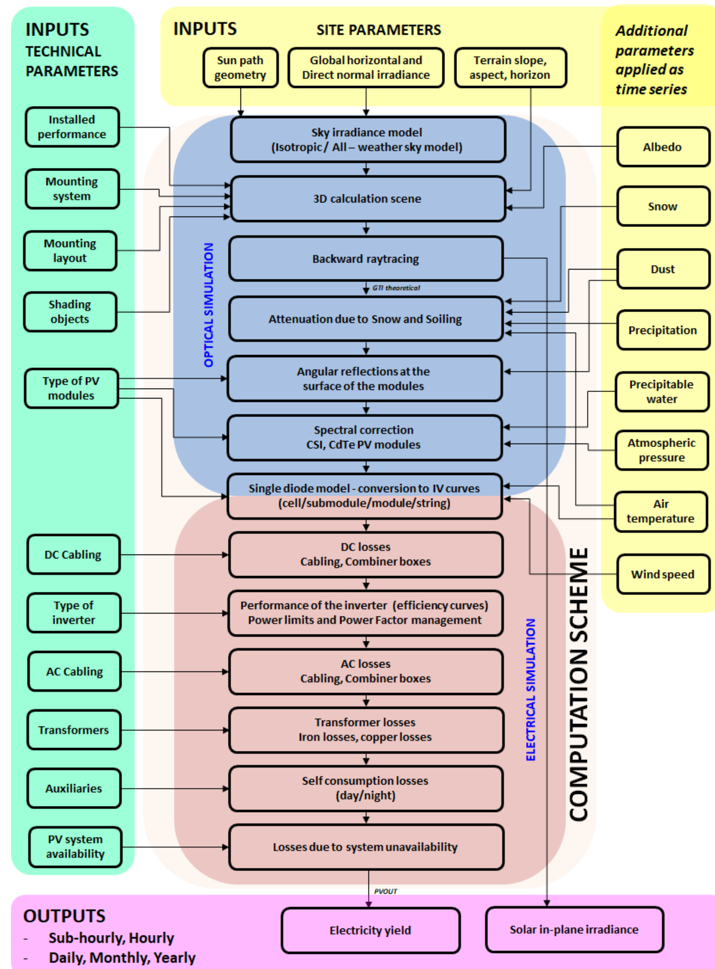
- Optical part : Bifacial_radiance and ground measured data
- Electrical part: LTspice (Analog Devices)

Current challenges

- Improvement of computational performance (view factor, ray-tracing combination, optimization)
- Complex snow and soiling losses models

Computational scheme of SGSIM

- Input site parameters
  - Location, terrain parameters
  - Solar radiation inputs (GHI, DNI)
  - Sun path, solar geometry
- Input meteo and environmental parameters
  - PWAT, TEMP, WS
  - Albedo
  - Rainfall, Snow, Dust
- Input technical parameters
  - Modules type, quantity, mounting, layout
  - Shading objects
  - Cabling
  - Inverters, Transformers, Self consumption, Availability



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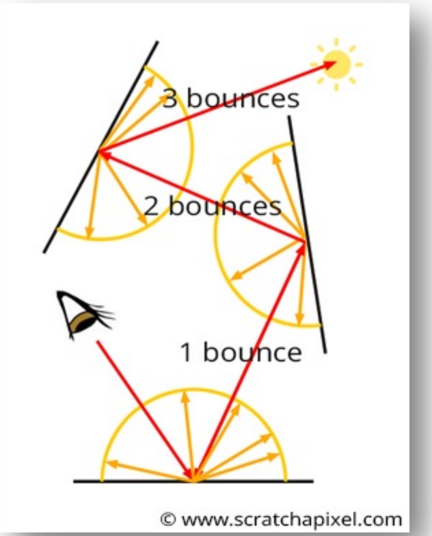
Ray-tracing algorithm



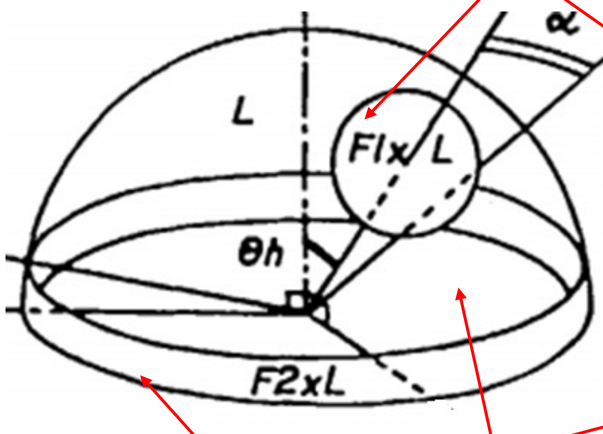
- Custom implementation
- **Monte Carlo backward path-tracing** (from cell to the source of light)
  - Multiple bounces until the source of light is reached
  - Fully converged unbiased per cell solution for Lambertian surfaces (no specular yet)
  - Universal 3D scene $\longrightarrow$ arbitrary panel placement & bifacial simulation
- **Sky model is adapted from Perez models** (uses Solargis data):
  - Isotropic
  - Anisotropic (all-weather sky model)
- Easily extendable to more detailed models of sky (assuming the more detailed sky data is available)

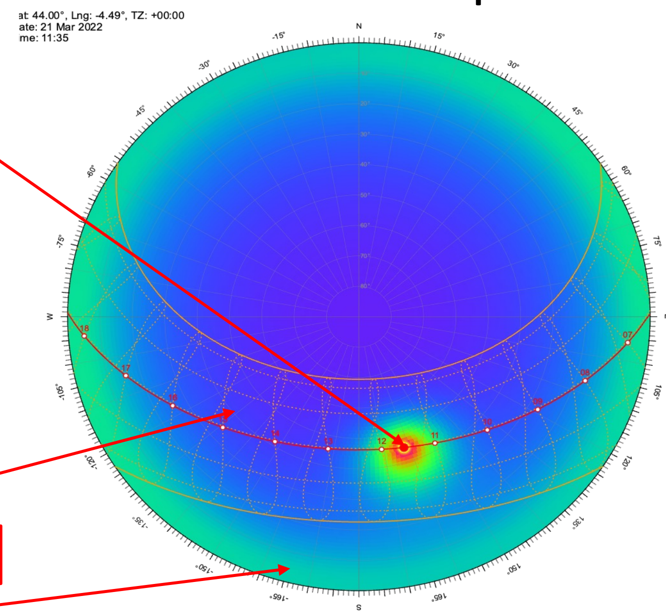
Isotropic vs All-Weather sky model radiance distribution

Isotropic model

Circumsolar “disc”

Anisotropic model





“Isotropic” background

Horizon “band” region

Ray-tracing algorithm

- Backward path-tracing is more effective than forward path-tracing, but still computationally demanding
- Current version is running on GPU
- Example:
  - *Cca 4 MWp power plant*
  - *1 year of time series*
  - *Trackers, backtracking, bifacial*
  - *PV cell level*

No.	Time step	Simulation time
1	Hourly	10 – 15 minutes
2	15 minute	45 – 60 minutes
3	1 minute	9 – 10 hours

- Factors impacting duration of the simulation
  - Amount of time slots – linear dependency
  - Installed capacity – linear in case of the same configuration, possible optimization
  - Path tracing accuracy – tuning of parameters
  - Hardware, Thread count – the more power/count the better, simulation is separated to parallel tasks
  - GPU / CPU – graphic processors dedicated to 3D operations

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Verification of GTI simulation

Verification against Ground measure data (NREL – SRRL BMS station)

- Lat: 39.742, Lon: -105.178, Alt: 1828 m
- 1-min time resolution for all measured data
- Time period – whole year 2021
- Several available pyranometer mounting for different GTI measurement
- Quality check performed for each measured timestamp

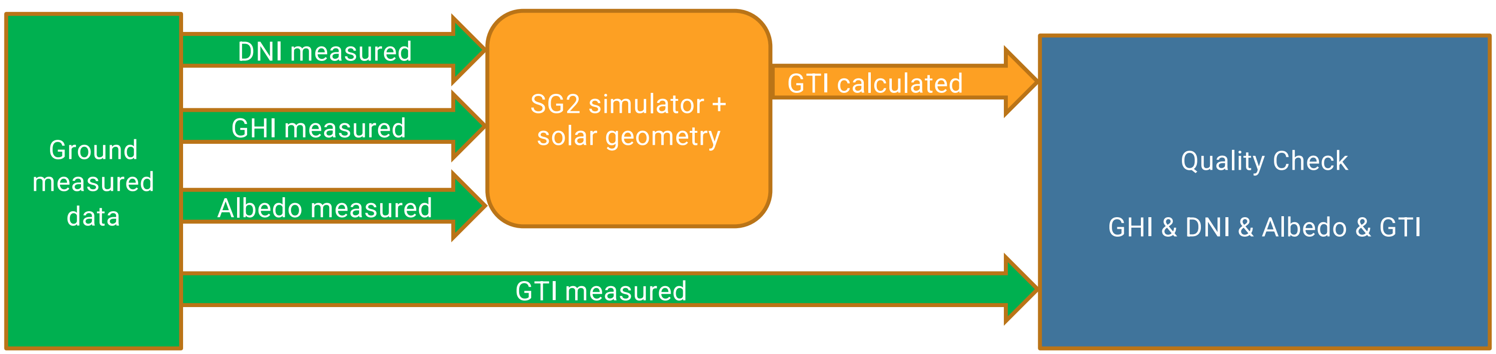
Measured quantity [W/m^2]	Device type
GHI	Global_CMP22
DNI	Direct_CHP12
GTI south, 40° tilt	CMP22
GTI east, west, north, south 90° tilt	LI200 , (PSP for north orientation)
GTI NS tracker (no limit angles)	CMP22
GTI 2-axis tracker (no limit angles)	CMP22

Source: NREL

Verification of GTI simulation

Goal is to validate the integration of backward ray-tracing & transposition model implementation

- Simulated GTI with no losses was taken to comparison
- Perez isotropic (iso) & Perez All-weather (aniso) sky models have been used for GTI simulation
- RMSD and Bias evaluated for each mounting
- Only data/timestamps which pass quality check has been taken as valid
- 1-min and 15-min measured data used for analysis



Verification of GTI simulation

General results overview

Data aggregation	RMSD [%]				Bias [%]			
	1-min data		15- min data		1-min data		15- min data	
Sky model	ISO	ANISO	ISO	ANISO	ISO	ANISO	ISO	ANISO
2-axis tracker	6.7	6.5	6.0	5.9	-0.7	-1.1	-0.4	-0.7
1-axis N-S tracker	5.2	5.0	4.4	4.2	-0.5	1.0	-0.2	0.6
Fixed tilt **40° South** oriented	5.1	5.0	4.0	3.9	-0.7	-1.0	-0.4	-0.7
Fixed tilt **90° South** oriented	10.5	9.6	10.1	9.1	-6.9	-6.0	-6.8	-5.6
Fixed tilt **90° East** oriented	16.0	15.8	16.1	15.8	-11.2	-10.6	-11.1	-10.5
Fixed tilt **90° West** oriented	13.9	14.9	13.4	14.5	-7.9	-9.5	-7.6	-9.0
Fixed tilt **90° North** oriented	23.6	20.8	24.1	21.5	-14.1	-10.5	-14.3	-10.7

Verification of GTI simulation

General results overview

Data aggregation	RMSD [%]				Bias [%]			
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Sky model	ISO	ANISO	ISO	ANISO	ISO	ANISO	ISO	ANISO
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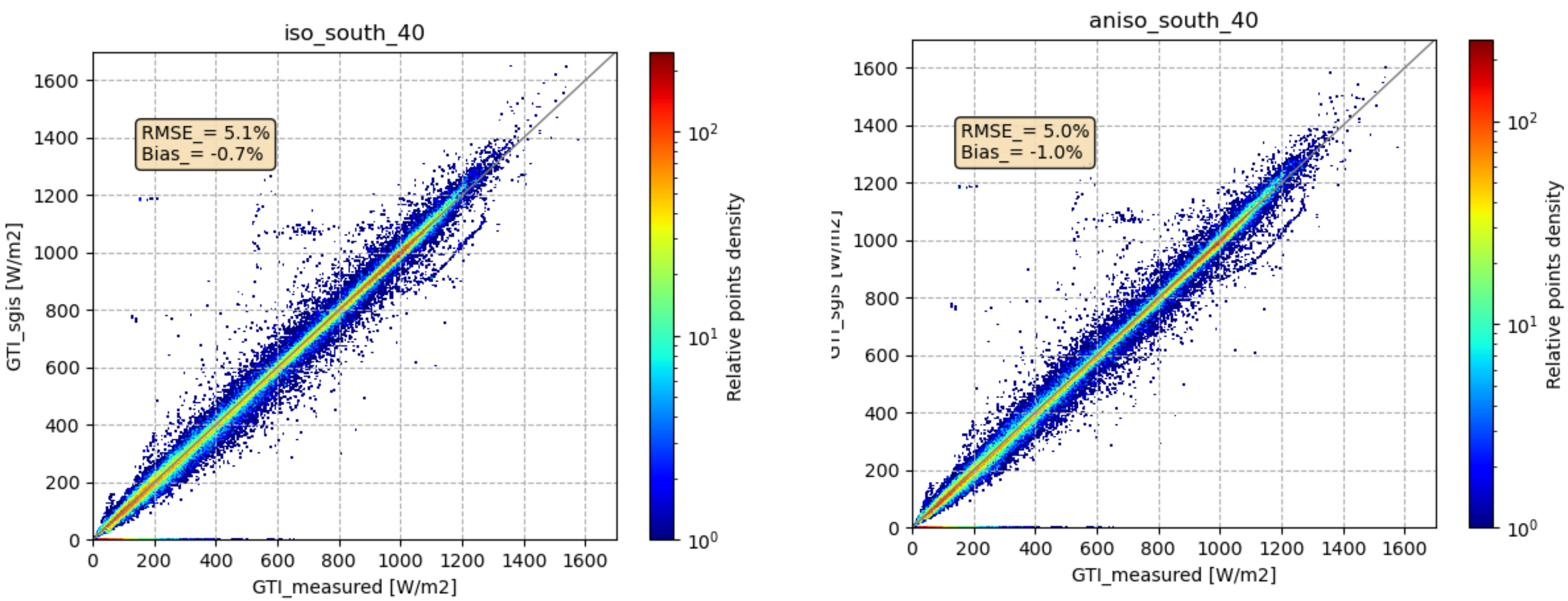
Fixed tilt **90° North** oriented	23.6	20.8	24.1	21.5	-14.1	-10.5	-14.3	-10.7

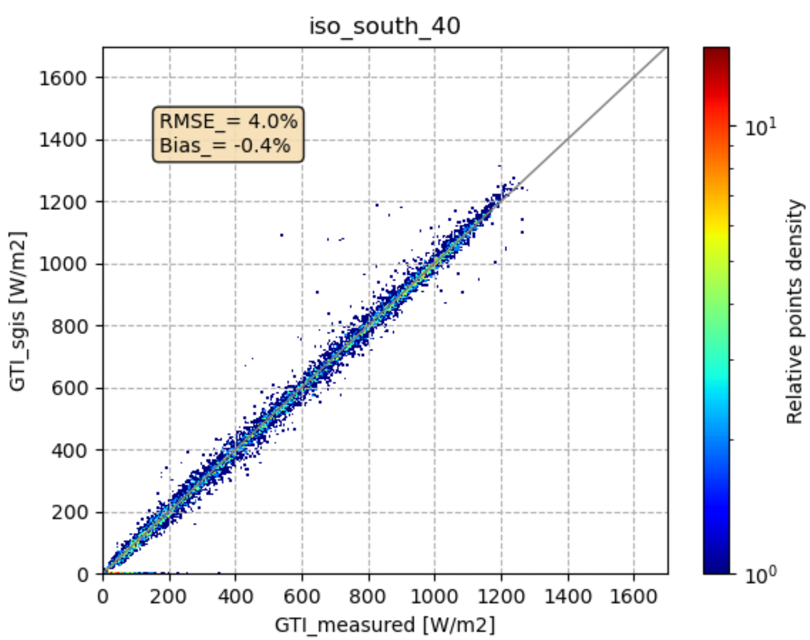
Verification of GTI simulation

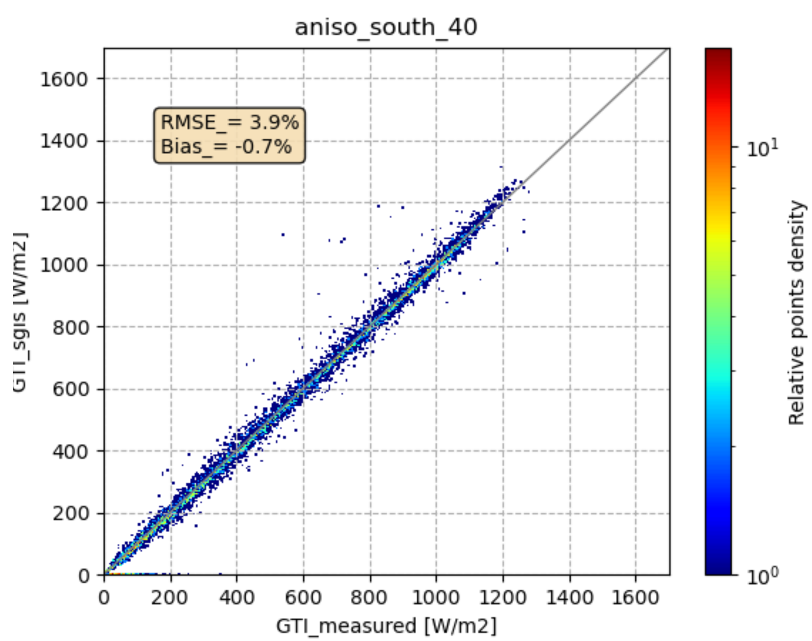
40° tilt, south oriented : 1-minute data



Verification of GTI simulation

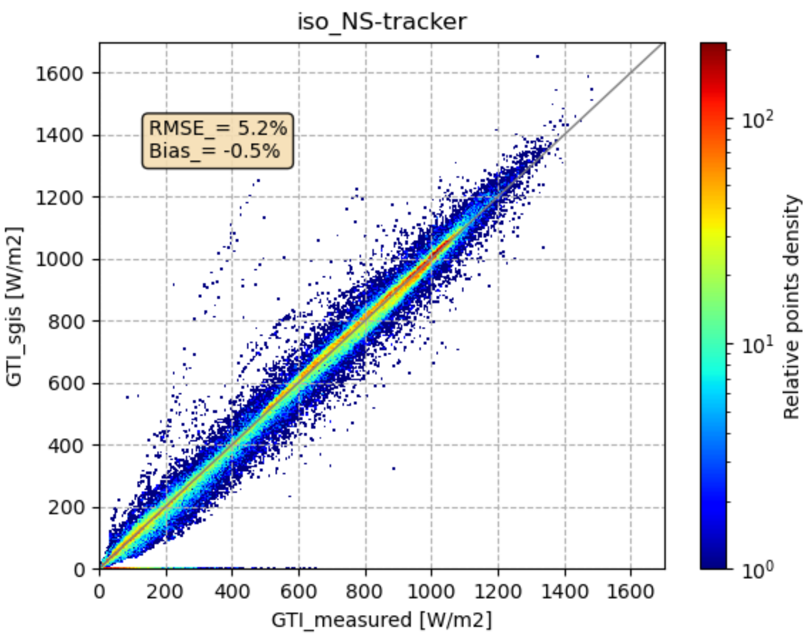
40° tilt, south oriented: 15-minute data

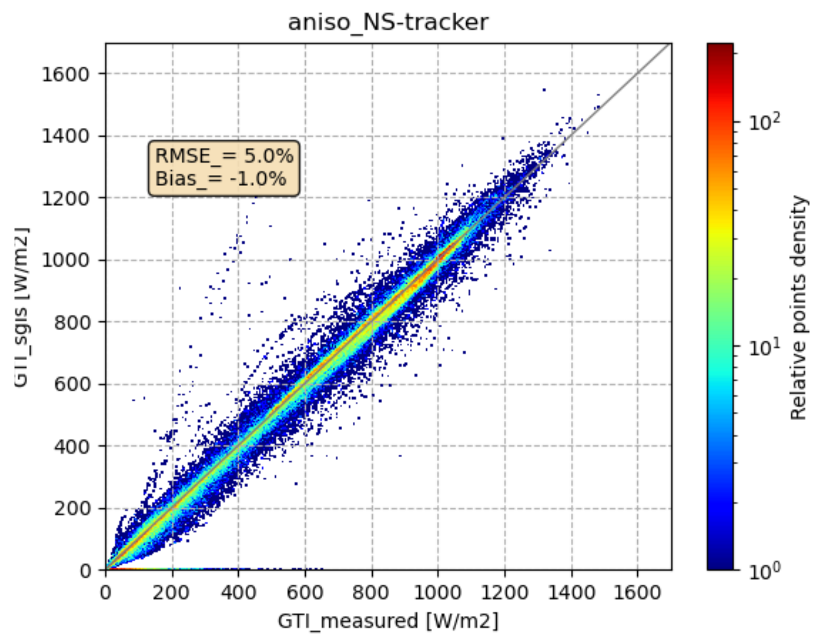




Verification of GTI simulation

Single axis NS tracker: 1-minute data





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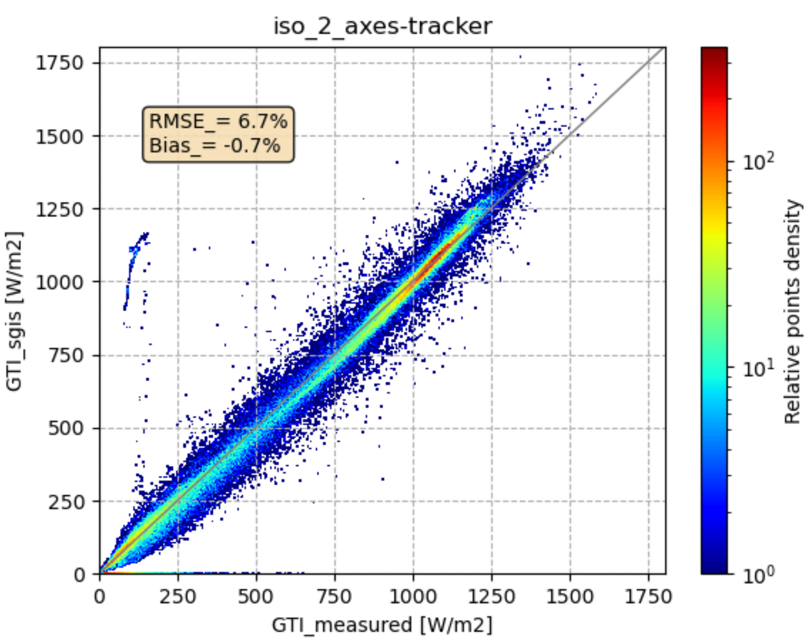
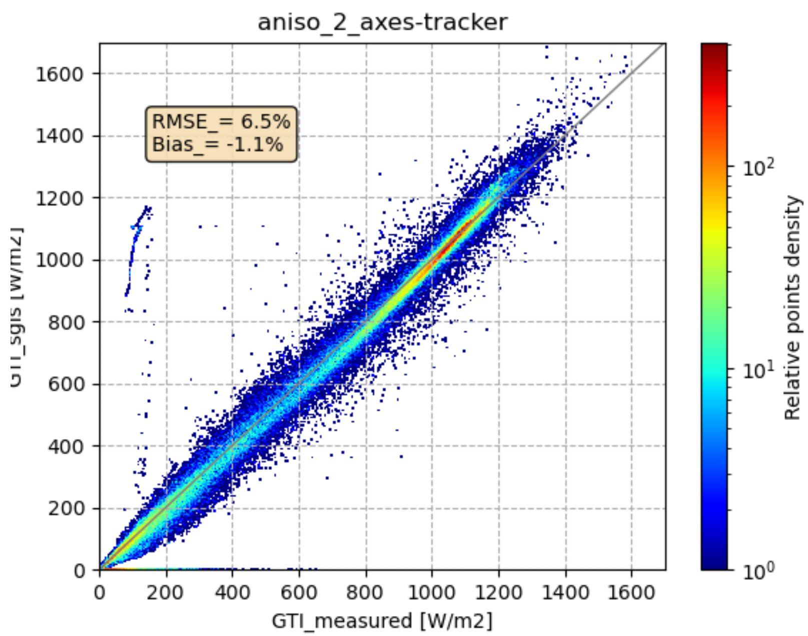
Verification of GTI simulation

2-axis tracker: 1-minute data





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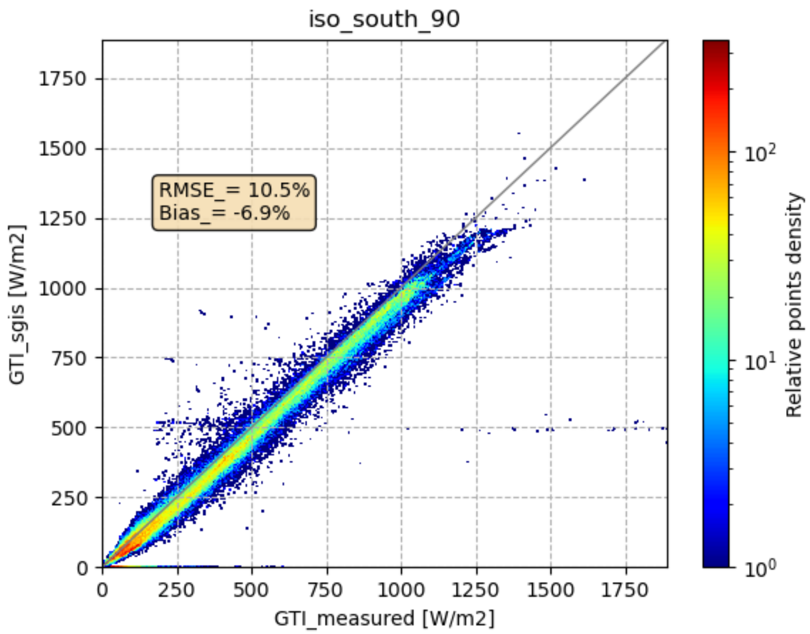
Verification of GTI simulation

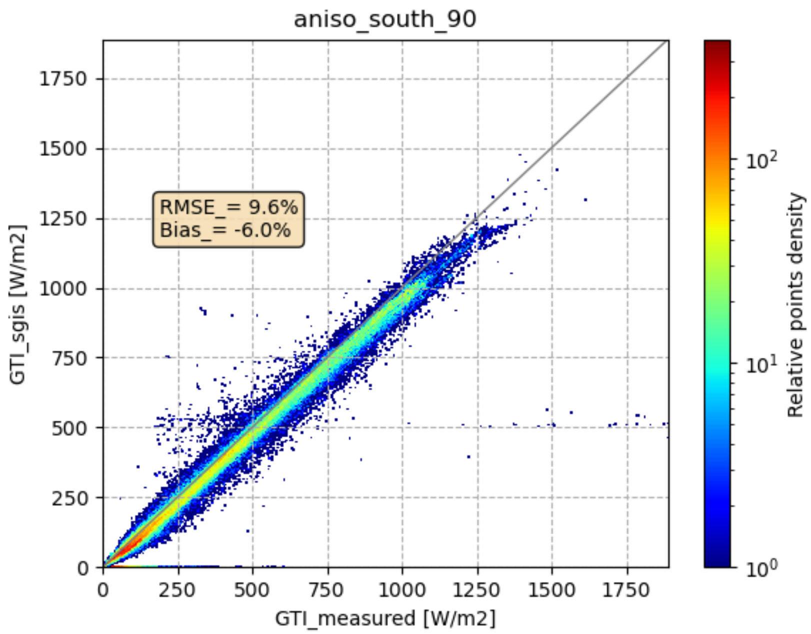
General results overview

Data aggregation	RMSD [%]				Bias [%]			
	1-min data		15- min data		1-min data		15- min data	
Sky model	ISO	ANISO	ISO	ANISO	ISO	ANISO	ISO	ANISO
2-axis tracker	6.7	6.5	6.0	5.9	-0.7	-1.1	-0.4	-0.7
1-axis N-S tracker	5.2	5.0	4.4	4.2	-0.5	1.0	-0.2	0.6
Fixed tilt **40° South** oriented	5.1	5.0	4.0	3.9	-0.7	-1.0	-0.4	-0.7
Fixed tilt **90° South** oriented	10.5	9.6	10.1	9.1	-6.9	-6.0	-6.8	-5.6
Fixed tilt **90° East** oriented	16.0	15.8	16.1	15.8	-11.2	-10.6	-11.1	-10.5
Fixed tilt **90° West** oriented	13.9	14.9	13.4	14.5	-7.9	-9.5	-7.6	-9.0
Fixed tilt **90° North** oriented	23.6	20.8	24.1	21.5	-14.1	-10.5	-14.3	-10.7

Verification of GTI simulation

South oriented 90 tilt: 1-minute data





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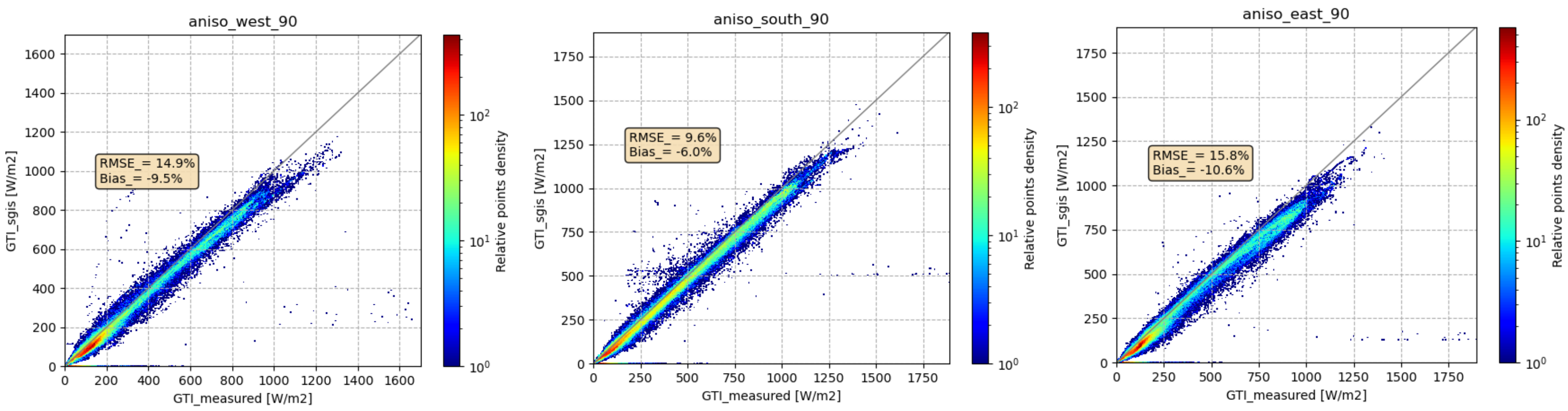
Verification of GTI simulation

Vertical oriented panels (west, south, east): 1-minute data



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Verification of GTI simulation

General results overview

Data aggregation	RMSD [%]				Bias [%]			
	1-min data		15- min data		1-min data		15- min data	
Sky model	ISO	ANISO	ISO	ANISO	ISO	ANISO	ISO	ANISO
2-axis tracker	6.7	6.5	6.0	5.9	-0.7	-1.1	-0.4	-0.7
1-axis N-S tracker	5.2	5.0	4.4	4.2	-0.5	1.0	-0.2	0.6
Fixed tilt **40° South** oriented	5.1	5.0	4.0	3.9	-0.7	-1.0	-0.4	-0.7
Fixed tilt **90° South** oriented	10.5	9.6	10.1	9.1	-6.9	-6.0	-6.8	-5.6
Fixed tilt **90° East** oriented	16.0	15.8	16.1	15.8	-11.2	-10.6	-11.1	-10.5
Fixed tilt **90° West** oriented	13.9	14.9	13.4	14.5	-7.9	-9.5	-7.6	-9.0
Fixed tilt **90° North** oriented	23.6	20.8	24.1	21.5	-14.1	-10.5	-14.3	-10.7

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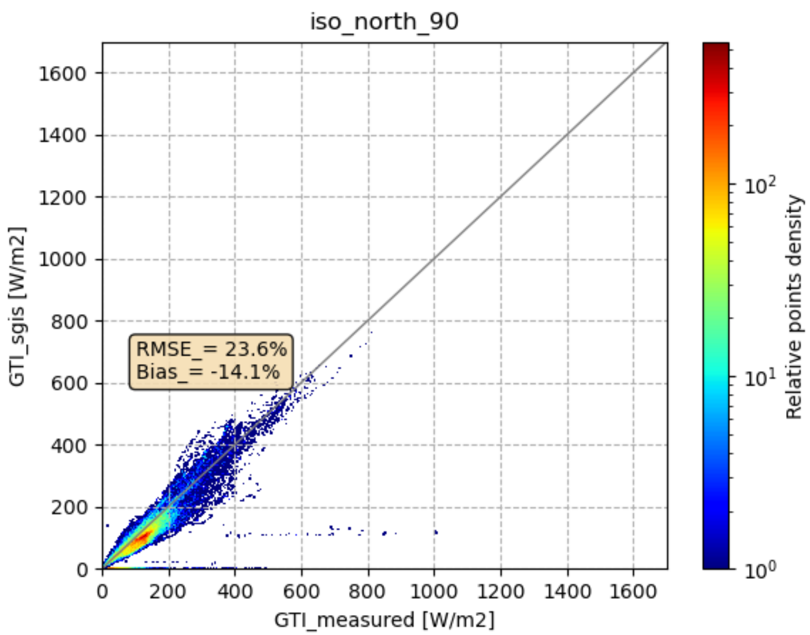
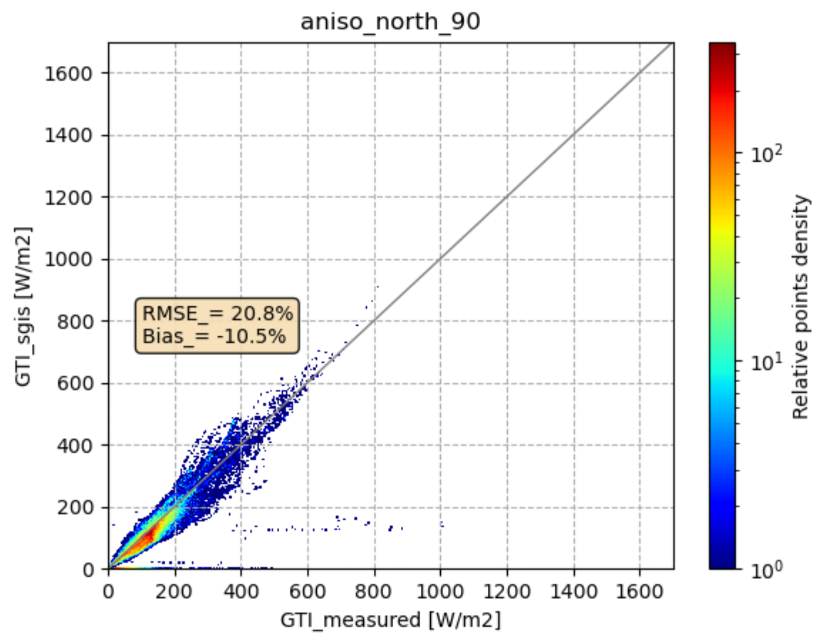
Verification of GTI simulation

North oriented vertical panels: 1-minute data





Verification of GTI simulation

Sources of discrepancies:

- **model limitations (sky model, ray-tracing)**
- **accuracy of GTI measurements**
  - east, west, north, south 90° tilt (LI200 instrument)
  - north 90° tilt (PSP)
- **representativeness of ground albedo**
  - Simple local albedo was used, Lambertian assumption
  - complex 3D scene was not simulated
- **local shading**

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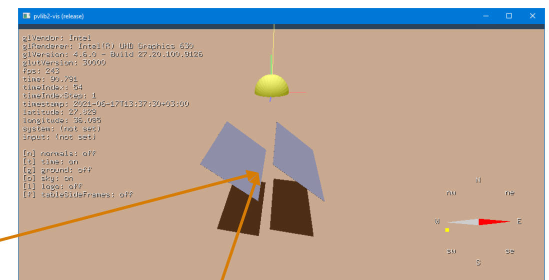
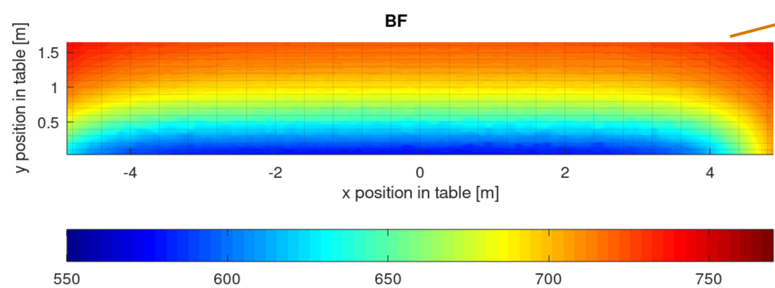
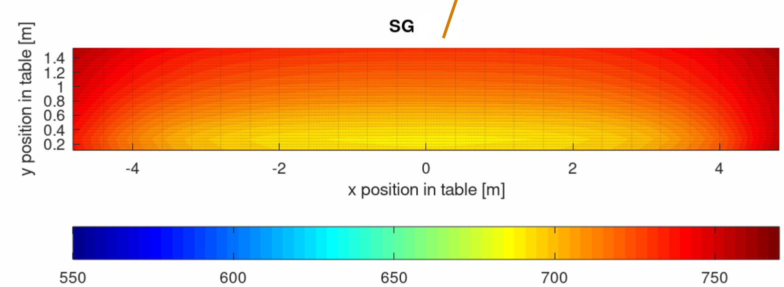
Comparison to Bifacial_radiance

Verification against NREL ray-tracing software package

- Distribution of GTI over the panel front surface has been compared
- Very good match for unshaded panel areas (front panel, upper part of panel)
- Non negligible differences for Isotropic model - in case of diffuse shades (lower part of panels) has been found even if no direct shades occurred.
- Perez All-weather sky model resolved the differences

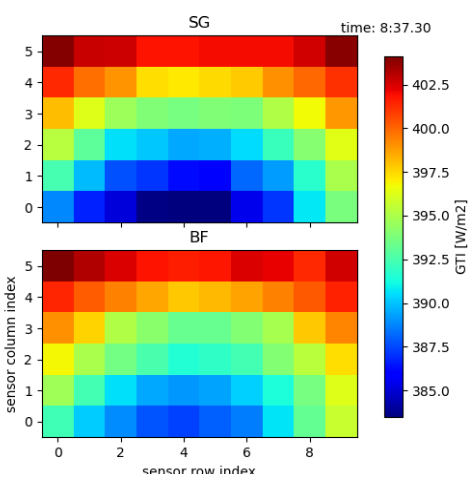


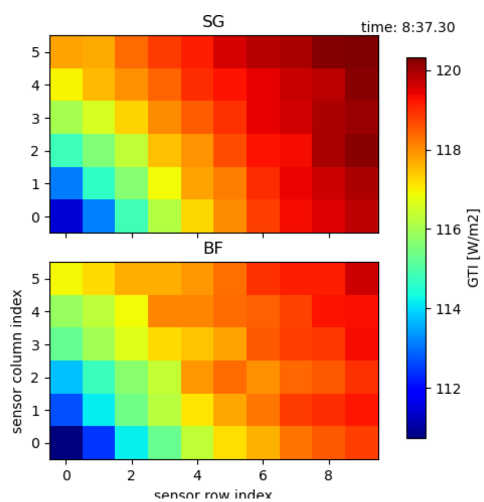


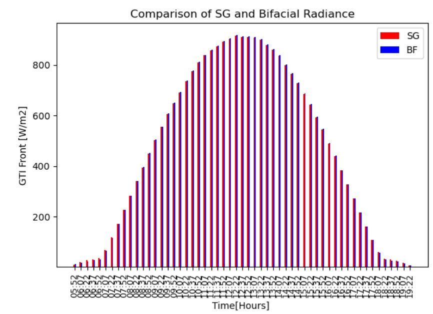


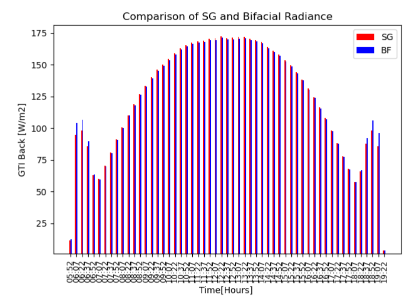
Comparison to Bifacial_radiance

- Updated sky model = very good overlap between SG2 and Bifacial_radiance results on both front and rear panel sites
- Small differences caused by stochastic nature of ray-tracing method









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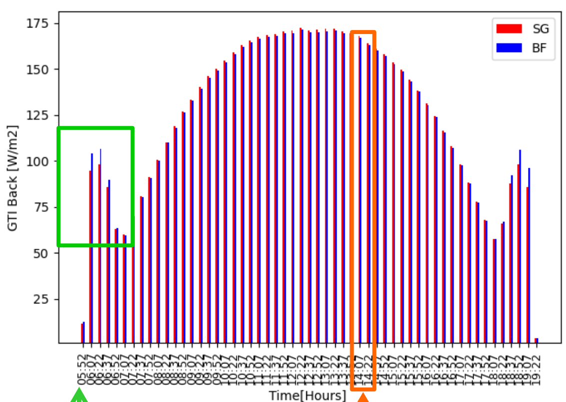
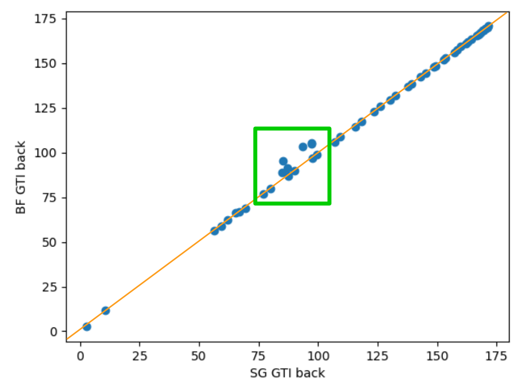
Verification of shading simulation – Bifacial_radiance

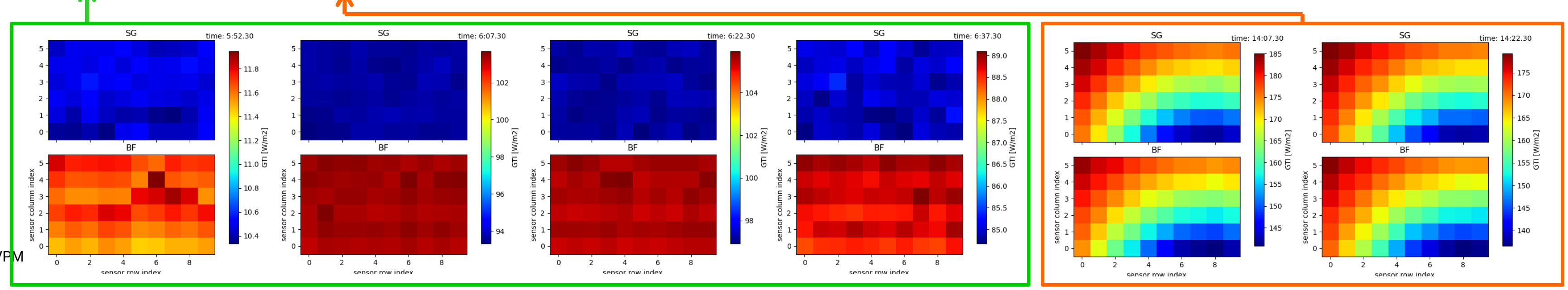
- **Optical part of simulation – Ray tracing method**
- Saudi Arabia site – Clear sky – 17th June 2021 – 2 rows of PV modules – **Back side**





- Good match during day
- Morning / evening differences

=> Diffuse (SG) vs. diffuse + specular reflection (Radiance)



PVPM

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Conclusions and future work

- Good match of ray-tracing + aniso sky model with Bifacial_radiance

- Good match in case of “sun oriented” panel surface (trackers and 40° tilted south oriented surface)
- Highest discrepancies for surfaces when mainly DIF and reflected irradiance is present.

Future work

- Additional analysis of input data (far horizon, surrounding scene, reflections,…)
- Further development in basic research is required (sky model, ground reflection)
- Possible upgrade of reflection phenomena (specular reflection) could improve the results match

Thank you for your attention !

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