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

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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 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

Anisotropic model

Circumsolar “disc”

“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*
- 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

<table>
<thead>
<tr>
<th>No.</th>
<th>Time step</th>
<th>Simulation time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hourly</td>
<td>10 – 15 minutes</td>
</tr>
<tr>
<td>2</td>
<td>15 minute</td>
<td>45 – 60 minutes</td>
</tr>
<tr>
<td>3</td>
<td>1 minute</td>
<td>9 – 10 hours</td>
</tr>
</tbody>
</table>
Content

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

<table>
<thead>
<tr>
<th>Measured quantity [W/m²]</th>
<th>Device type</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHI</td>
<td>Global_CMP22</td>
</tr>
<tr>
<td>DNI</td>
<td>Direct_CHP12</td>
</tr>
<tr>
<td>GTI south, 40° tilt</td>
<td>CMP22</td>
</tr>
<tr>
<td>GTI east, west, north, south 90° tilt</td>
<td>Li200, (PSP for north orientation)</td>
</tr>
<tr>
<td>GTI NS tracker (no limit angles)</td>
<td>CMP22</td>
</tr>
<tr>
<td>GTI 2-axis tracker (no limit angles)</td>
<td>CMP22</td>
</tr>
</tbody>
</table>

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**

<table>
<thead>
<tr>
<th>Data aggregation</th>
<th>RMSD [%]</th>
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<tr>
<td>Sky model</td>
<td>ISO ANISO</td>
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<td>6.7 6.5</td>
<td>6.0 5.9</td>
</tr>
<tr>
<td>1-axis N-S tracker</td>
<td>5.2 5.0</td>
<td>4.4 4.2</td>
</tr>
<tr>
<td>Fixed tilt 40° South oriented</td>
<td>5.1 5.0</td>
<td>4.0 3.9</td>
</tr>
<tr>
<td>Fixed tilt 90° South oriented</td>
<td>10.5 9.6</td>
<td>10.1 9.1</td>
</tr>
<tr>
<td>Fixed tilt 90° East oriented</td>
<td>16.0 15.8</td>
<td>16.1 15.8</td>
</tr>
<tr>
<td>Fixed tilt 90° West oriented</td>
<td>13.9 14.9</td>
<td>13.4 14.5</td>
</tr>
<tr>
<td>Fixed tilt 90° North oriented</td>
<td>23.6 20.8</td>
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## Verification of GTI simulation

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Verification of GTI simulation

40° tilt, south oriented: 1-minute data

iso\_south\_40

RMSE = 5.1%
Bias = -0.7%

aniso\_south\_40

RMSE = 5.0%
Bias = -1.0%
Verification of GTI simulation

40° tilt, south oriented: 15-minute data

![Graph showing verification of GTI simulation data](iso_south_40)

![Graph showing verification of GTI simulation data](aniso_south_40)
Verification of GTI simulation

Single axis NS tracker: 1-minute data

iso_NS-tracker

RMSE = 5.2%
Bias = -0.5%

aniso_NS-tracker

RMSE = 5.0%
Bias = -1.0%
Verification of GTI simulation

2-axis tracker: 1-minute data

![Graphs showing comparison between GTI simulation and measured data for iso_2_axes_tracker and aniso_2_axes_tracker.](image)

- **iso_2_axes_tracker**: RMSE = 6.7%, Bias = -0.7%
- **aniso_2_axes_tracker**: RMSE = 6.5%, Bias = -1.1%
## Verification of GTI simulation

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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-axis tracker</td>
<td>6.7  6.5</td>
<td>6.0  5.9</td>
<td>-0.7  -1.1</td>
<td>-0.4  -0.7</td>
</tr>
<tr>
<td>1-axis N-S tracker</td>
<td>5.2  5.0</td>
<td>4.4  4.2</td>
<td>-0.5  1.0</td>
<td>-0.2  0.6</td>
</tr>
<tr>
<td>Fixed tilt 40° South oriented</td>
<td>5.1  5.0</td>
<td>4.0  3.9</td>
<td>-0.7  -1.0</td>
<td>-0.4  -0.7</td>
</tr>
<tr>
<td>Fixed tilt 90° South oriented</td>
<td>10.5  9.6</td>
<td>10.1  9.1</td>
<td>-6.9  -6.0</td>
<td>-6.8  -5.6</td>
</tr>
<tr>
<td>Fixed tilt 90° East oriented</td>
<td>16.0  15.8</td>
<td>16.1  15.8</td>
<td>-11.2 -10.6</td>
<td>-11.1 -10.5</td>
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<td>Fixed tilt 90° West oriented</td>
<td>13.9  14.9</td>
<td>13.4  14.5</td>
<td>-7.9  -9.5</td>
<td>-7.6  -9.0</td>
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<td>Fixed tilt 90° North oriented</td>
<td>23.6  20.8</td>
<td>24.1  21.5</td>
<td>-14.1 -10.5</td>
<td>-14.3 -10.7</td>
</tr>
</tbody>
</table>
Verification of GTI simulation

South oriented 90 tilt: 1-minute data

- iso_south_90
  - RMSE = 10.5%
  - Bias = -6.9%

- aniso_south_90
  - RMSE = 9.6%
  - Bias = -6.0%
Verification of GTI simulation

Vertical oriented panels (west, south, east): 1-minute data
## Verification of GTI simulation

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<td>2-axis tracker</td>
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The table above shows the RMSD and Bias values for different data aggregation methods, with values ranging from 1 to 15 minutes. The highest values are highlighted in red, indicating areas where further investigation might be needed.
Verification of GTI simulation

North oriented vertical panels: 1-minute data

iso_north_90

RMSE = 23.6%
Bias = -14.1%

Relative points density

aniso_north_90

RMSE = 20.8%
Bias = -10.5%

Relative points density
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
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)
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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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