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NATIONAL RENEWABLE ENERGY LABORATORY

1977 - 2017

Bifacial PV Performance Models: Comparison and Field Results

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J. Stein (SNL), F. Toor (U. Iowa), S. Ayala (U. Ariz.)

BiFiPV 2017 Workshop – Konstanz Germany

October 26, 2017

Outline

- Project overview
- Rear irradiance models
- Field validation
- Edge effects
- Irradiance nonuniformity

3-Yr Bifacial Research Project (2016-2018)

Collaborative project between Sandia, NREL and University of Iowa
(**pvpmc**.sandia.gov/pv-research/bifacial-pv-project/)

Task 1: Measure Outdoor Bifacial Performance

- Module scale
  - Adjustable rack IV curves (height, tilt, albedo, and backside shading effects)
  - Spatial variability in backside irradiance
  - Effects of backside obstructions
- String scale
  - Fixed tilt rack (tilt, mismatch effects)
  - Single axis tracker (investigate potential)
  - Two-axis tracker
- System scale
  - String level monitoring on commercial systems (validation data)

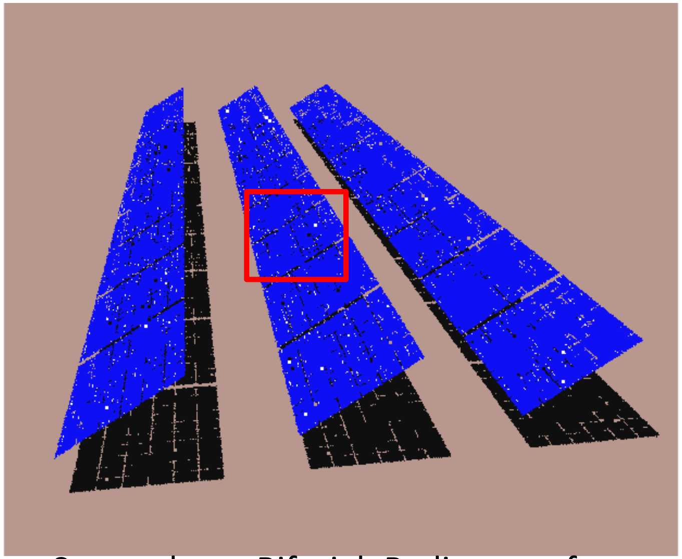
Stein, J. S., D. Riley, M. Lave, C. Deline, F. Toor and C. Hansen (2017). Outdoor Field Performance of Bifacial PV Modules and Systems. 33rd European PV Solar Energy Conference and Exhibition. Amsterdam, Netherlands. SAND2017-10254

3-Yr Bifacial Research Project (2016-2018)

Task 2: Develop Performance Models

Ray Tracing simulation

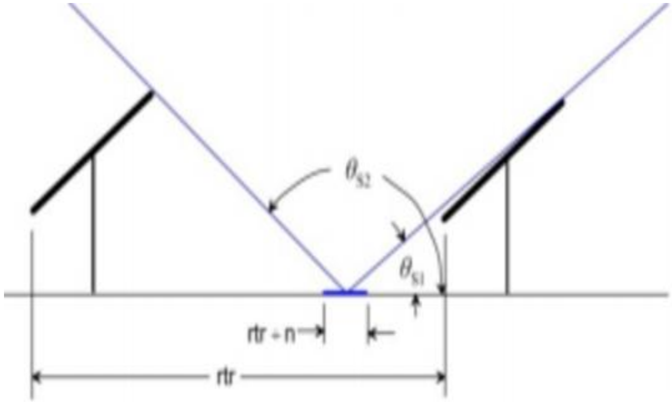
- Bifacial_Radiance software release
  github.com/cdeline/bifacial_radiance
- Configuration analysis publication[1]
  - Effect of row spacing, tilt optimization
  - Validation of model using Sandia field data



Screenshot – Bifacial_Radiance software

View Factor model

- BifacialVF software release
  github.com/cdeline/bifacialVF
- Method publication[2]
  - Model detail and configuration
  - Validation of model using NREL field data
- Integration with SAM software scheduled 2018



View Factor ground reflection geometry

[1] A. Asgharzadeh et al, "Analysis of the impact of installation parameters and system size on bifacial gain and energy yield of PV systems", IEEE PVSC 2017

[2] B. Marion et al., "A Practical Irradiance Model for Bifacial PV Modules", IEEE PVSC 2017 . https://www.nrel.gov/docs/fy17osti/67847.pdf

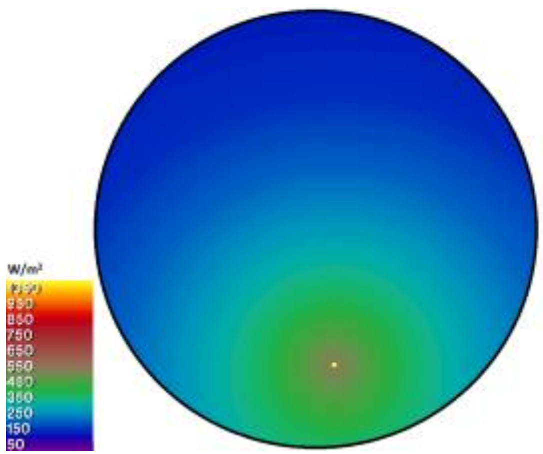
Radiance CumulativeSky pre-processor

Typical ray-tracing approach: use Perez model to generate hourly sky description

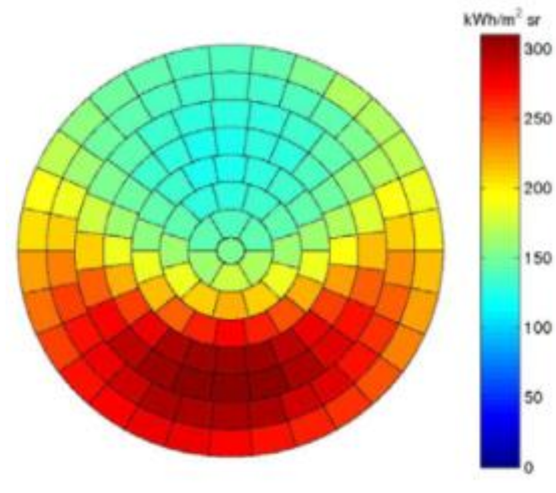
- Runtime = hours for annual simulations

CumulativeSky approach: sum annual hourly irradiance into 145 sky patches

- Runtime = seconds for annual simulation.



Single hourly Perez sky (W/m²)

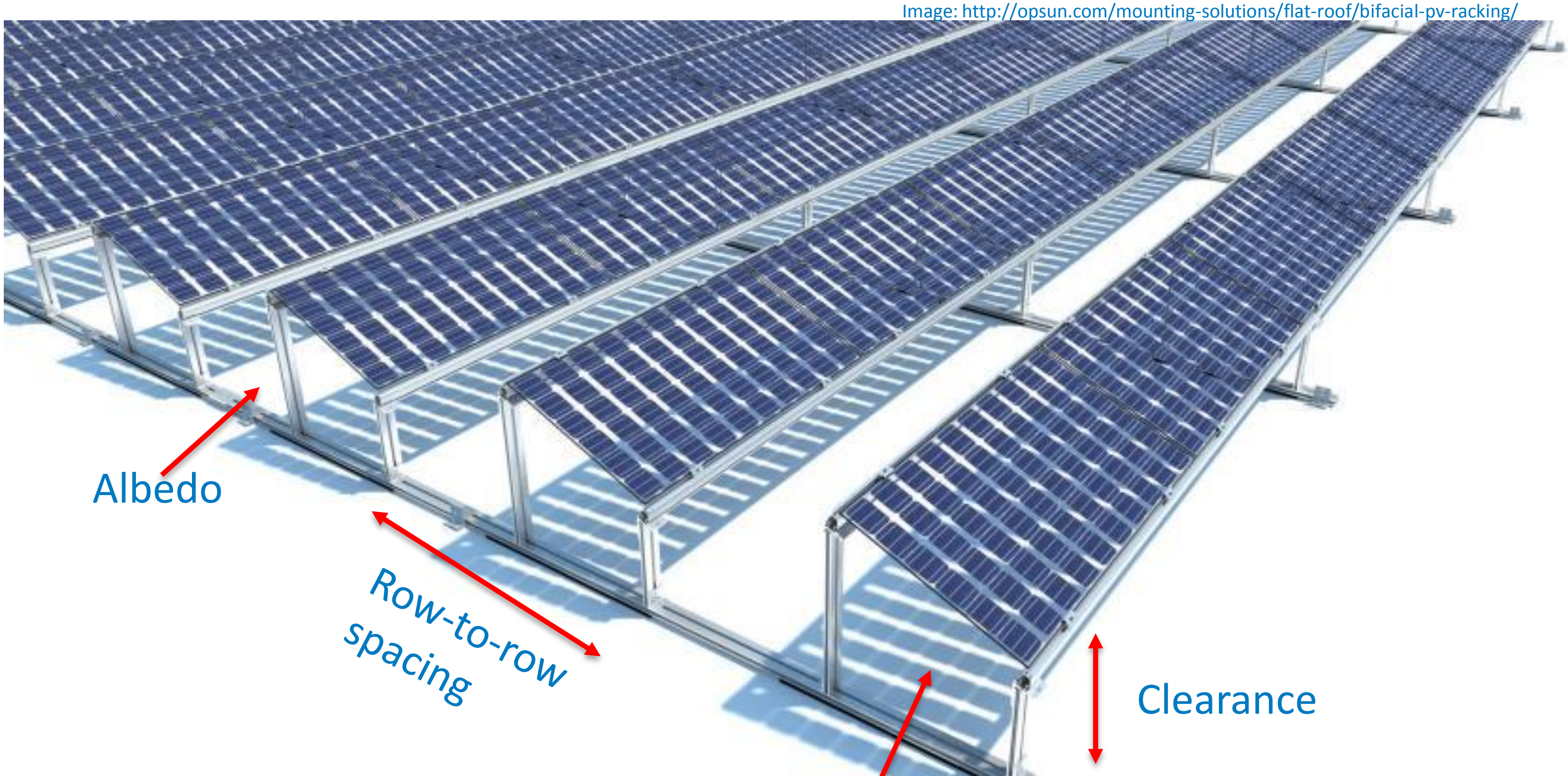


Annual cumulative sky conditions (kWh/m²)

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

Modeling Rear Irradiance – parameters to consider

Image: http://opsun.com/mounting-solutions/flat-roof/bifacial-pv-racking/



Size of array / simulation
Location
Weather
Sky Diffuse Model

Others:
Spacing between cells
Shade obstructions

Bifacial Gain Calculation

$$E_{bifacial} = (1 + BG_E)E_{monofacial}$$

Bifacial Energy Gain =

Module Bifaciality * Rear Irradiance Ratio – *Mismatch, shading loss*

$$\text{Bifaciality} = \frac{P_{mp,rear}}{P_{mp,front}}$$ (from single side flash data)*

$$\text{Rear Irradiance Ratio} = f(albedo, tilt, row\ spacing, height, racking, module\ transparency, climate)$$

Our focus today

* V. Fakhfouri IEC TS 60904-1-2 ED1 (2017)

Industry Bifacial Models for comparison

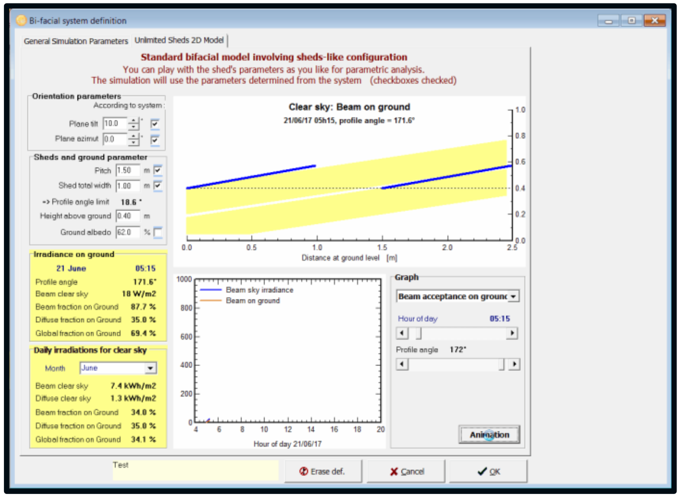
PVSyst – 2D “unlimited sheds” bifacial model

- 6.6.4 update increased bifacial response

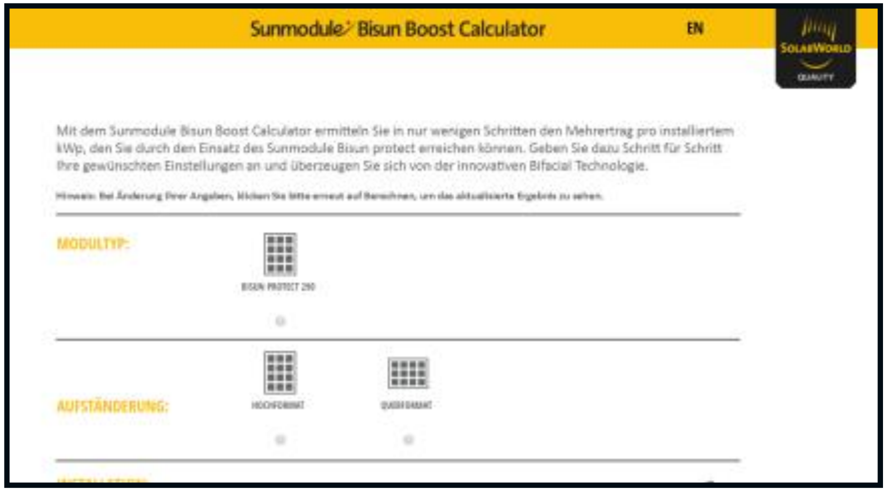
Solar World “Boost Calculator” – web interface

- Empirical model, not climate sensitive

http://www.solarworld.de/fileadmin/calculator

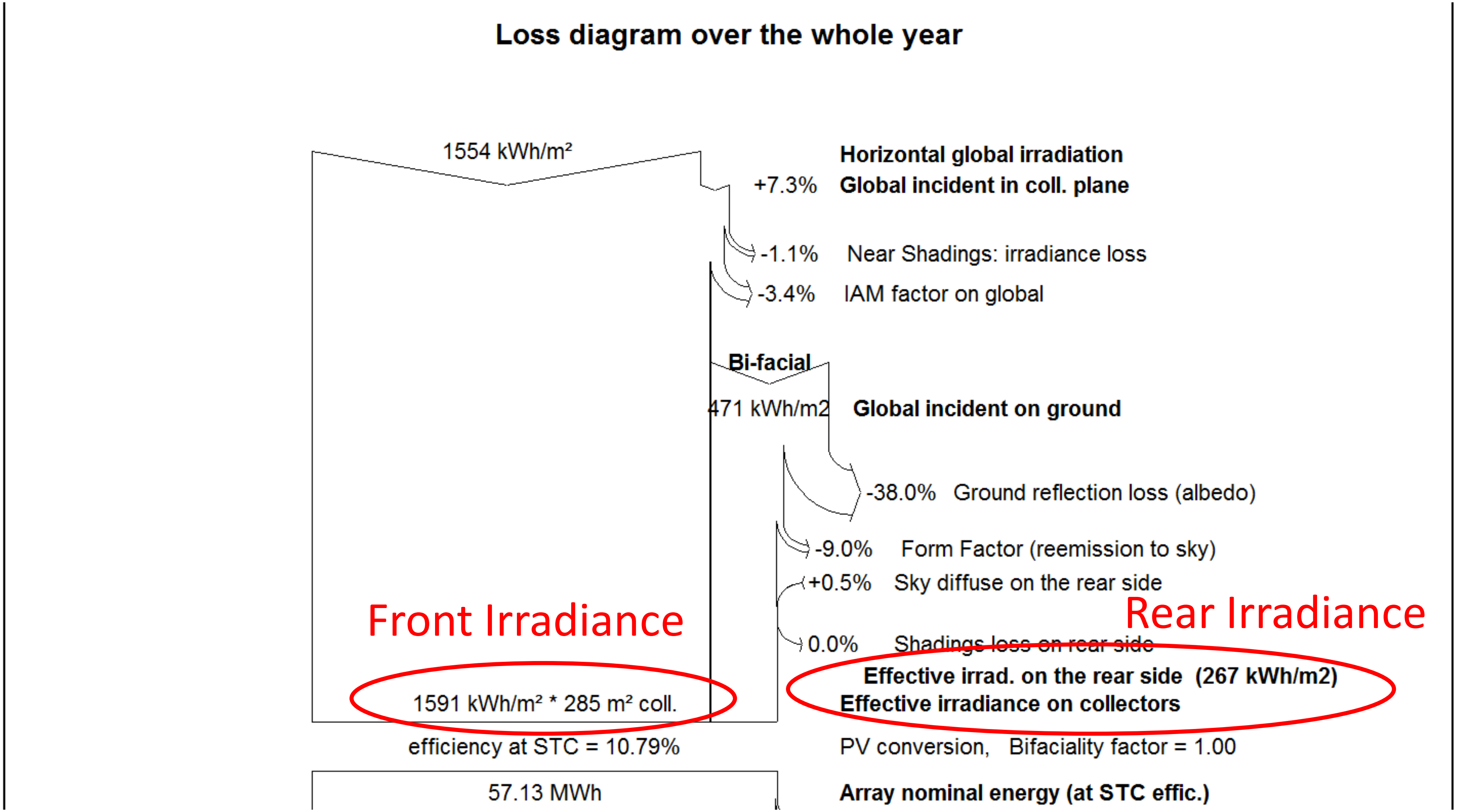


PVSyst 6.6.4 bifacial interface

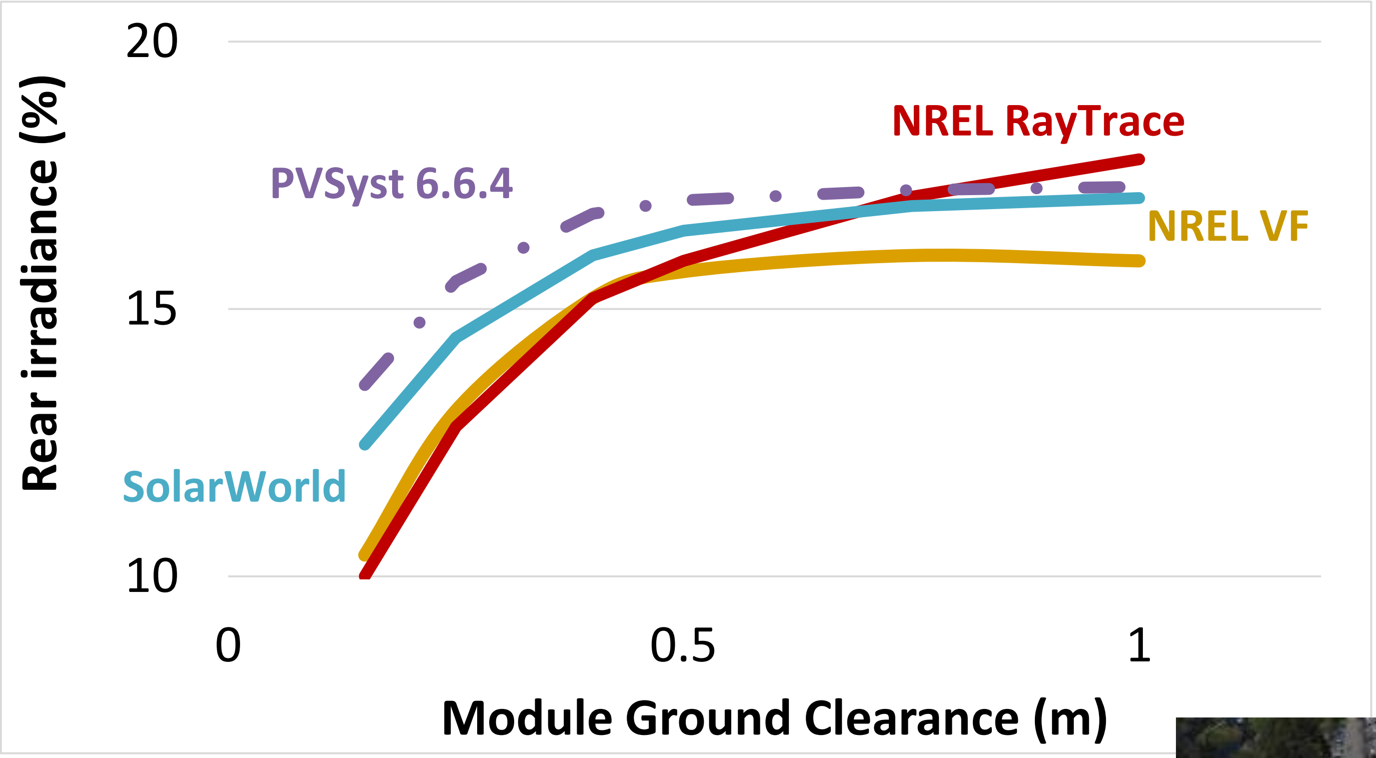


SolarWorld online calculator

PVSyst – Bifacial rear irradiance calculation

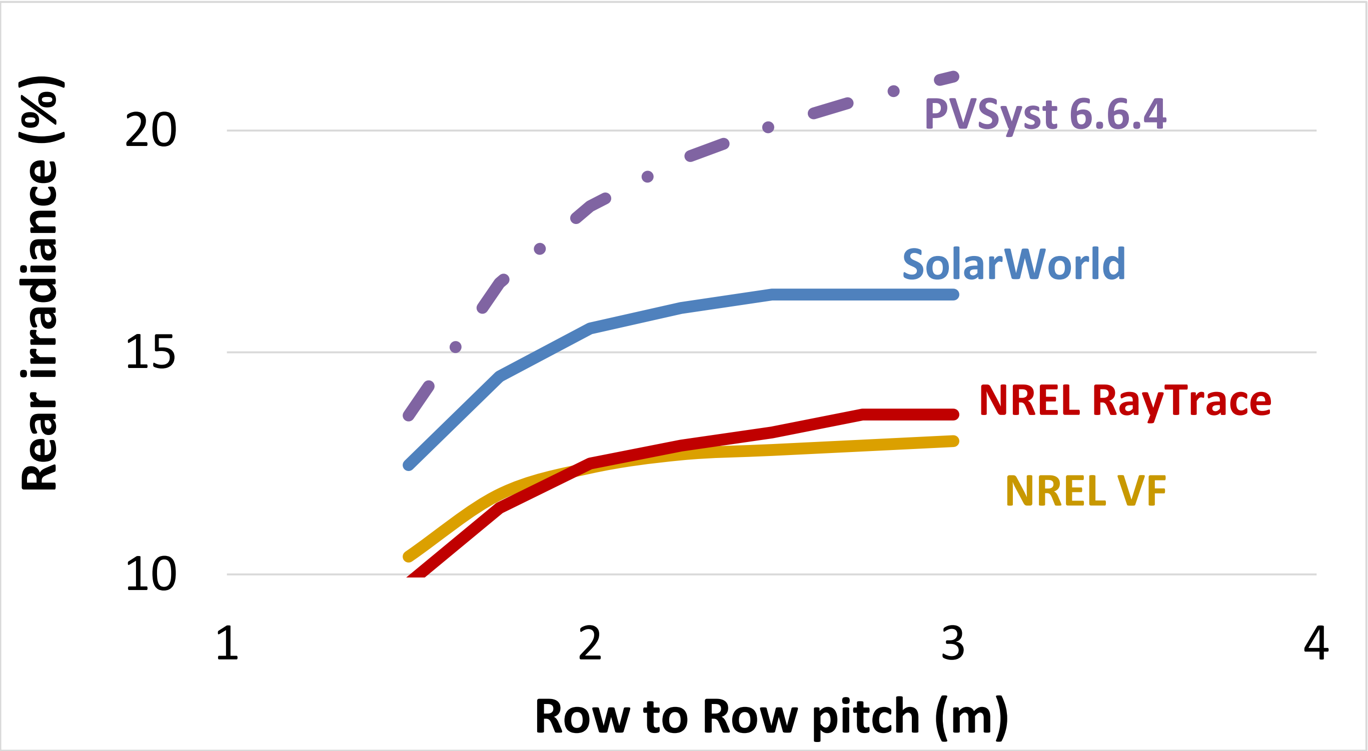


Model intercomparison - height



Low tilt high albedo rooftop application
Richmond VA, 1.5m row spacing, 10º tilt, 0.62 albedo

Model intercomparison – row spacing



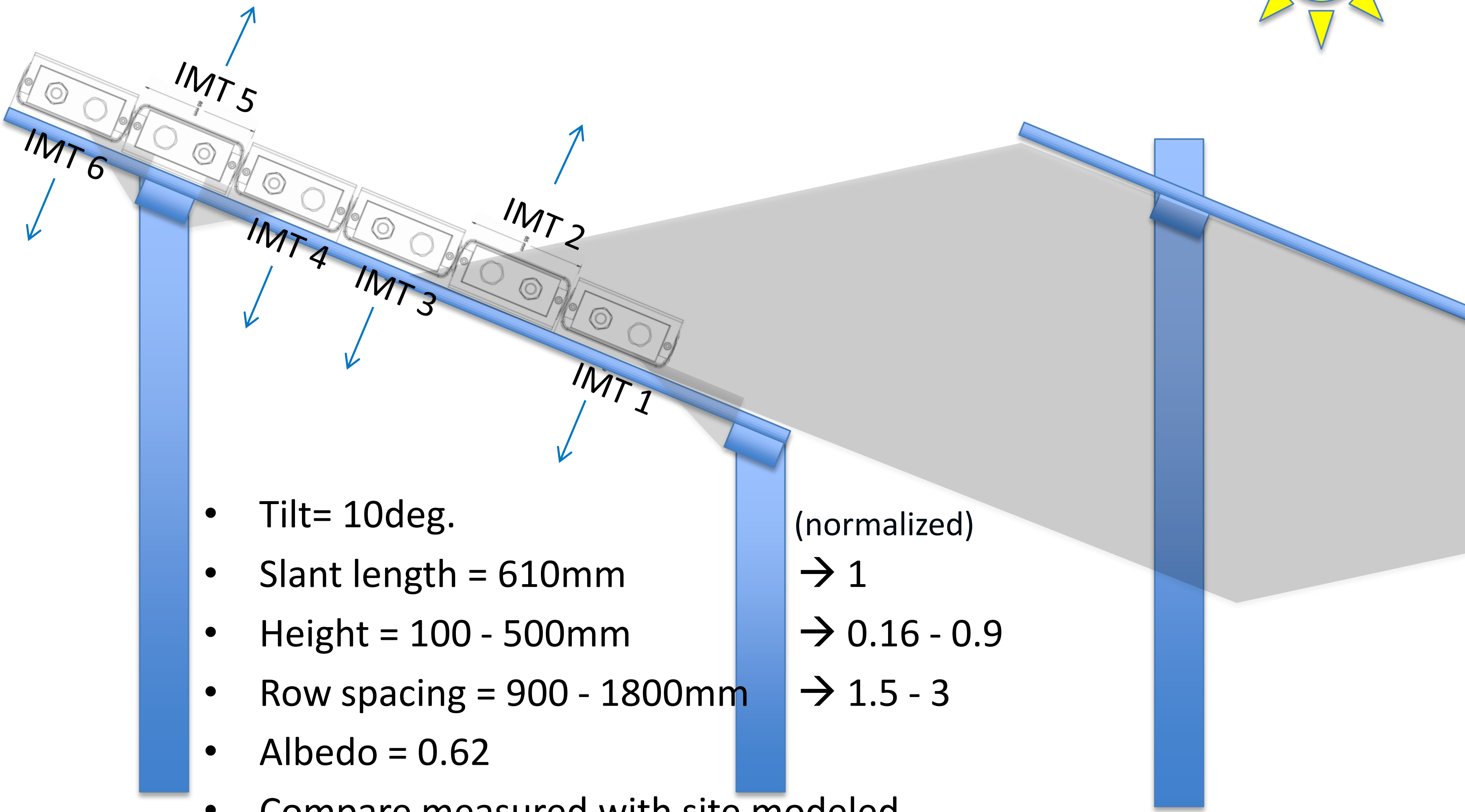
Low tilt high albedo rooftop application
Richmond VA, 0.15 m height, 10º tilt, 0.62 albedo

Not as good agreement

Field Validation: 3-row mock array
Adjustable spacing, tilt, height

Field Validation: 3-row mock array Low ground clearance configuration

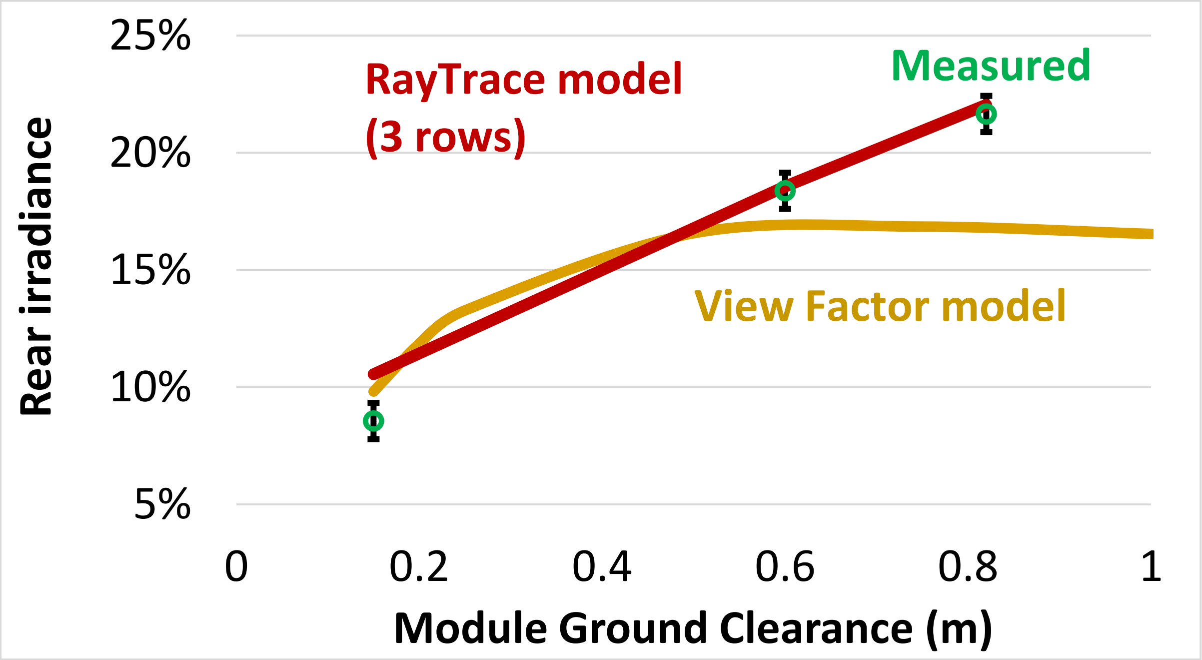
Mock array configuration - 4 rear, 2 forward facing irradiance



- Tilt= 10deg.
- Slant length = 610mm
- Height = 100 - 500mm
- Row spacing = 900 - 1800mm
- Albedo = 0.62
- Compare measured with site modeled conditions

(normalized)
→ 1
→ 0.16 - 0.9
→ 1.5 - 3

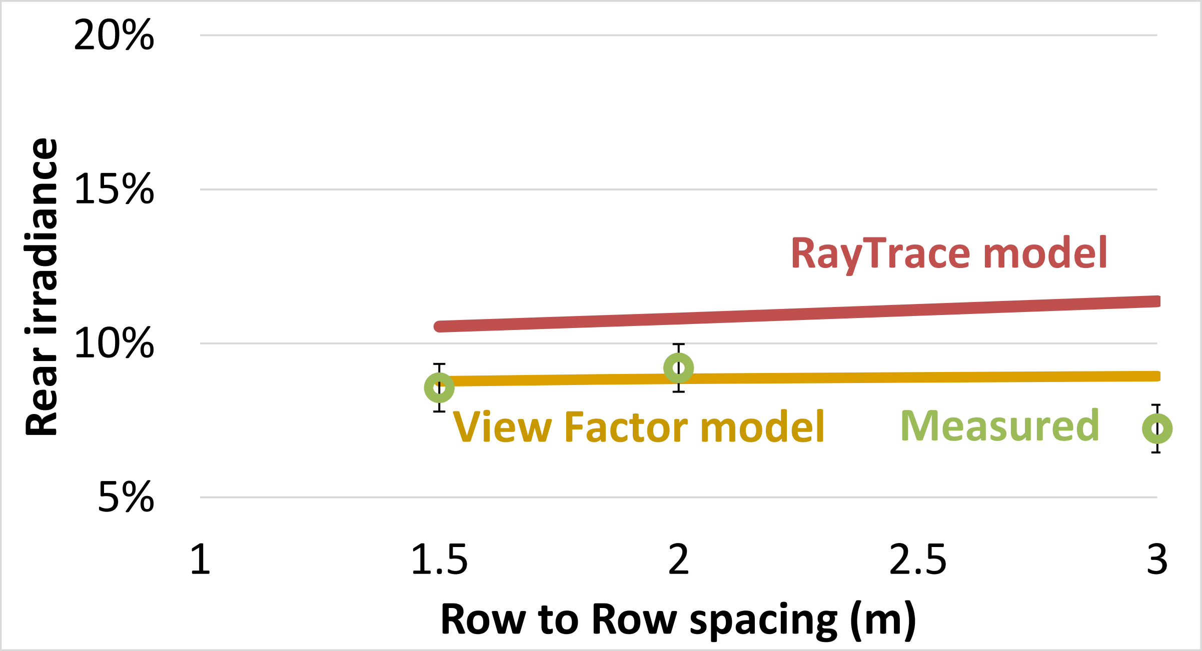
Mock Array – comparison with NREL models - Height



$$\frac{G_{rear,meas} - G_{rear,model}}{G_{rear,meas}} < 3\%$$

- 2 months field data
- RayTrace model reflects finite experiment size at high ground clearance.

Mock Array – comparison with models – Row spacing

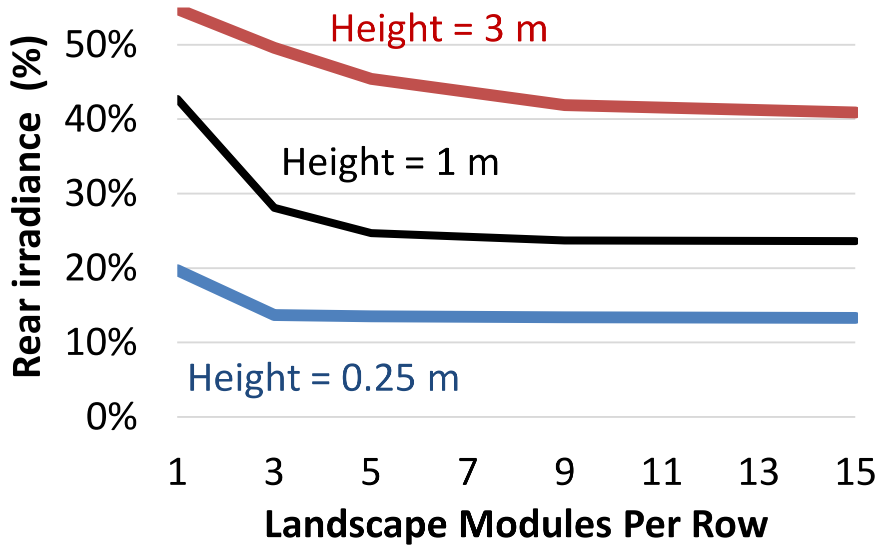


$$\frac{G_{rear,meas} - G_{rear,model}}{G_{rear,meas}} < 20\%$$

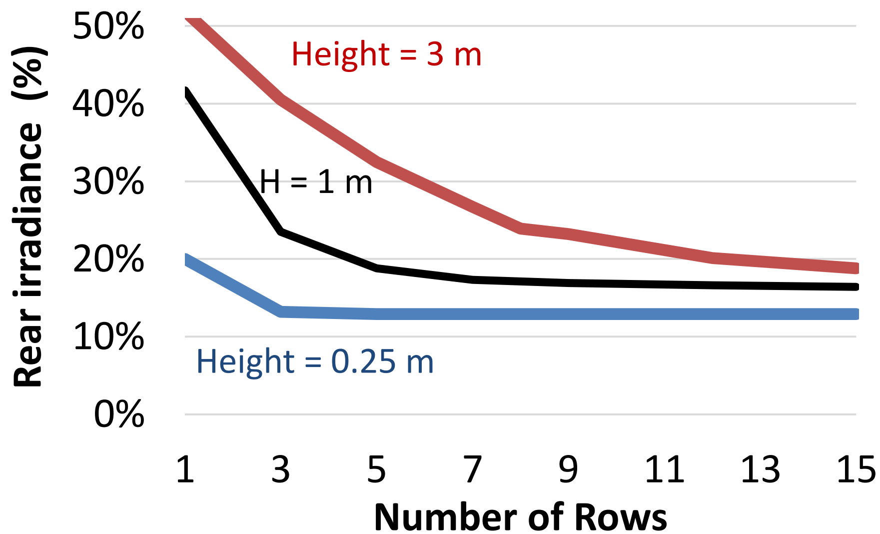
- OK agreement. Additional conditions under test

System Modeling – Edge Effects

Modules / row



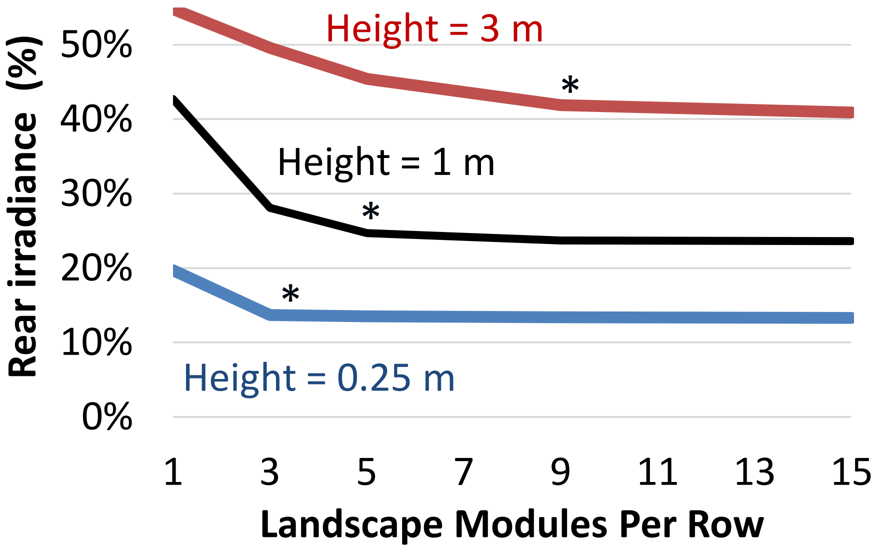
Total # Rows



Richmond VA, 1.5 m row spacing, 10^{o} tilt, 0.62 alb.
1m landscape module width
20 modules, 3 rows default

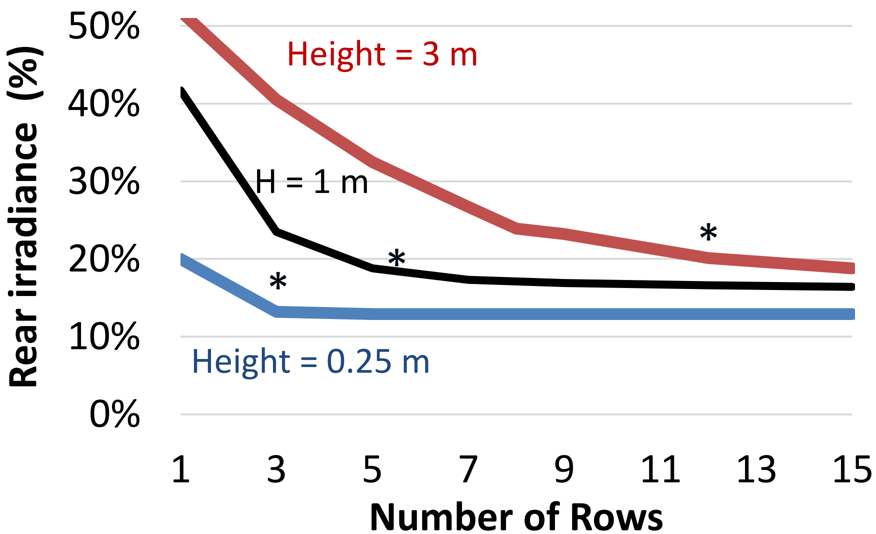
System Modeling – Edge Effects

Modules / row



* = 1% edge effect

Total # Rows



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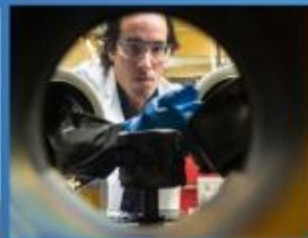


Thank you!

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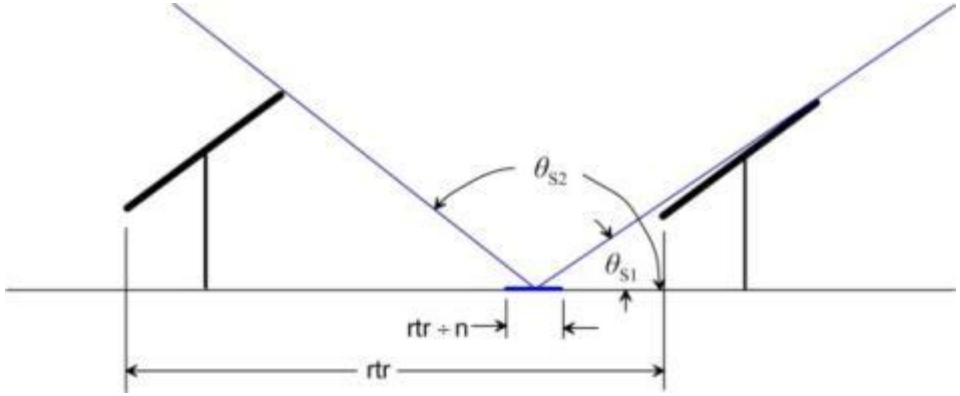
BACKUP SLIDES

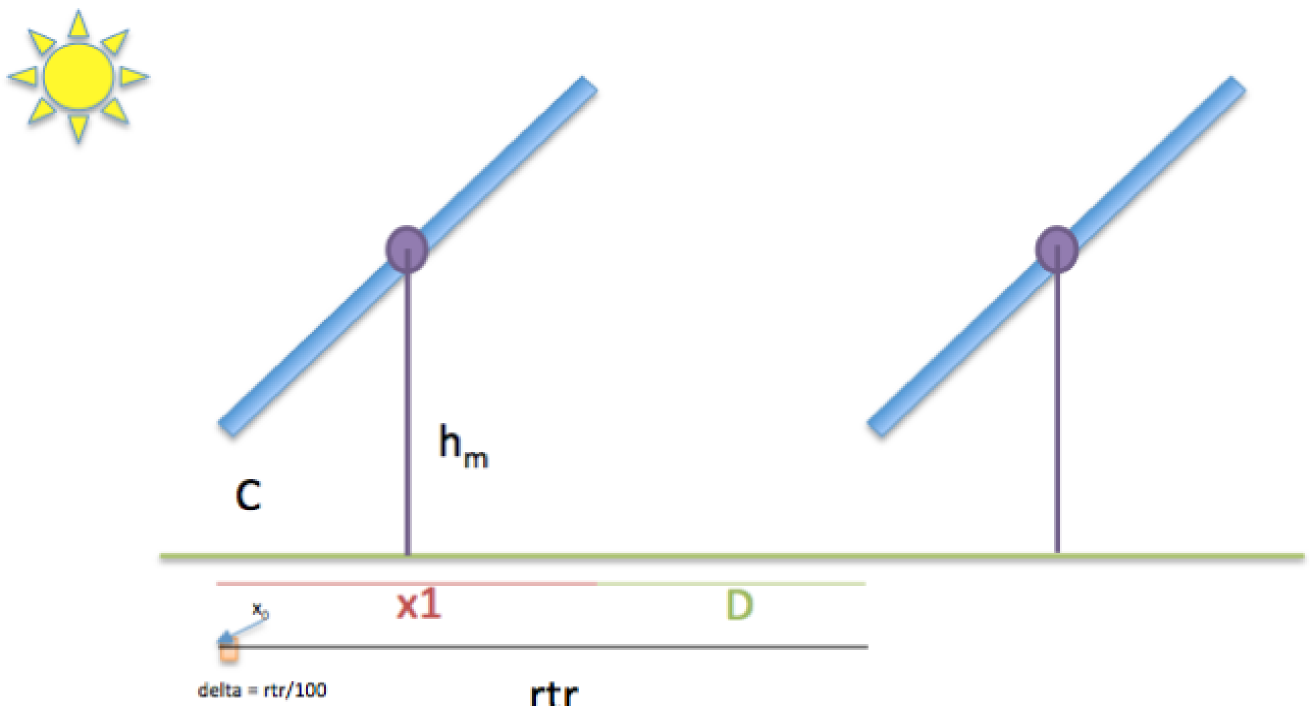
NREL View Factor Model[1]

- Ground divided into *n* segments in row-to-row direction and shading determined for each
- Irradiance on each ground segment found using view of the sky (configuration factors)
- Rear side irradiance is sum of sky, ground reflected, object reflected components
- Runtime 4 seconds for annual simulation



[1]B. Marion, "A Practical Irradiance Model for Bifacial PV Modules", *IEEE PVSC*, 2017.

Ongoing work: Single-axis tracking



Improvement: the view factor model has been extended to apply to bifacial tracking PV systems. Field validation is underway.