Viewfactor and Raytracing for AgriPV Modeling

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Motivation & Objectives

Agrivoltaic stakeholders seek to understand **plant & vegetation suitability** for **different solar configurations** across **varied geographies**.

Existing modeling tools are inaccessible and geographically limited.

Approach:

-Implemented ground-irradiance calculations into the System Advisor Model

-Improved raytracing weather-to-module performance with ground-irradiance calculations

-Creating a dataset for farmers, solar developers, and researchers to easily compare different agrivoltaic configurations for any location in the United States.

Photo by Werner Slocum / NREL

The InSPIRE Project-

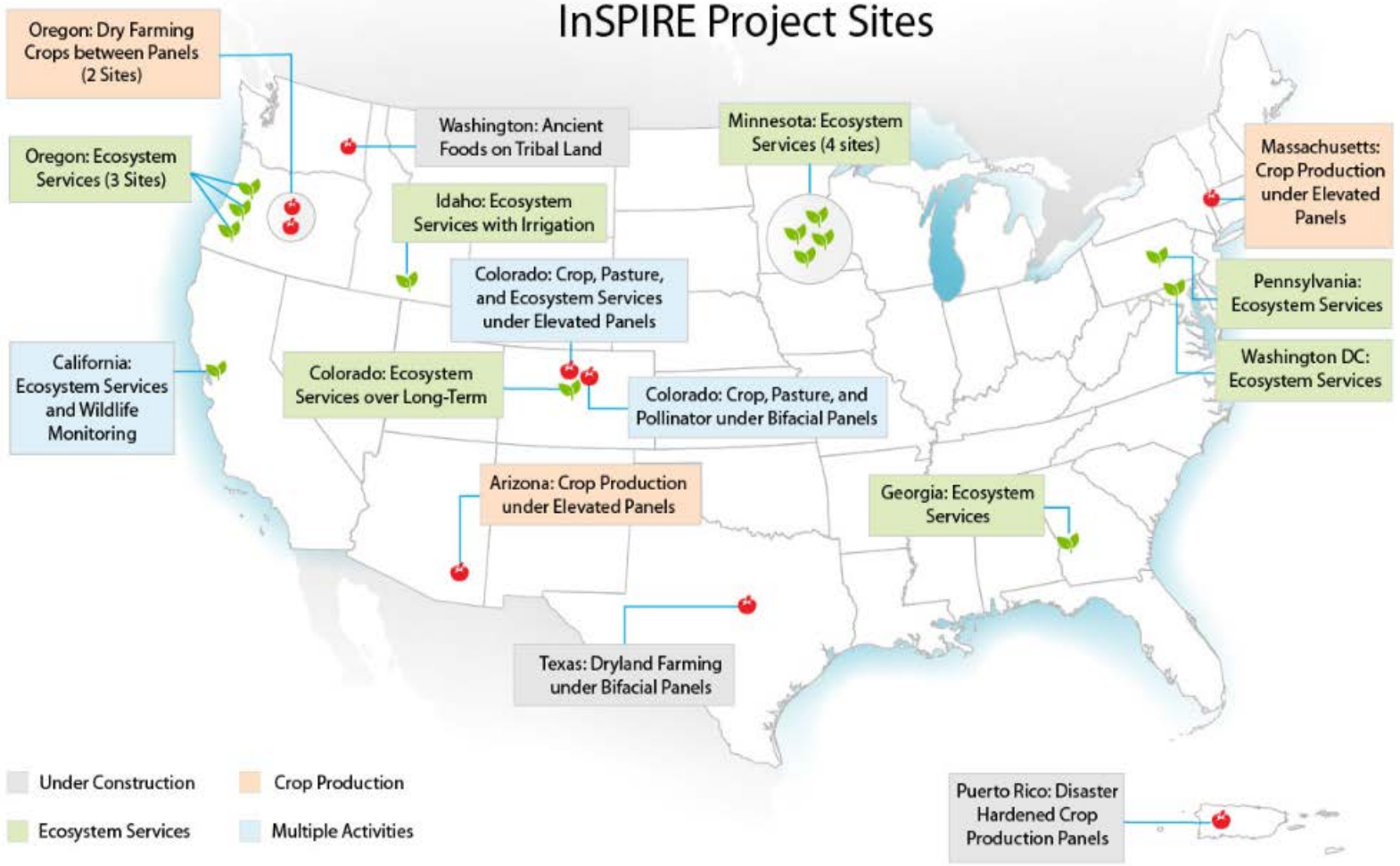
Innovative **S**olar **P**ractices **I**ntegrated with **R**ural Economies and **E**cosystems

- InSPIRE has field research projects across the U.S.

- **Analytical research:**
  - Cost-benefit tradeoffs of different agrivoltaic configurations
  - Assessing research gaps and priorities
  - Tracking agrivoltaic projects across the U.S.

- **Field-based research:**
  - Novel agrivoltaic and traditional utility-scale PV designs integrated with multiple activities
  - Assessing agricultural yields and irrigation requirements in arid environments
  - Grazing standards and best practices
  - Pollinator habitat and ecological services

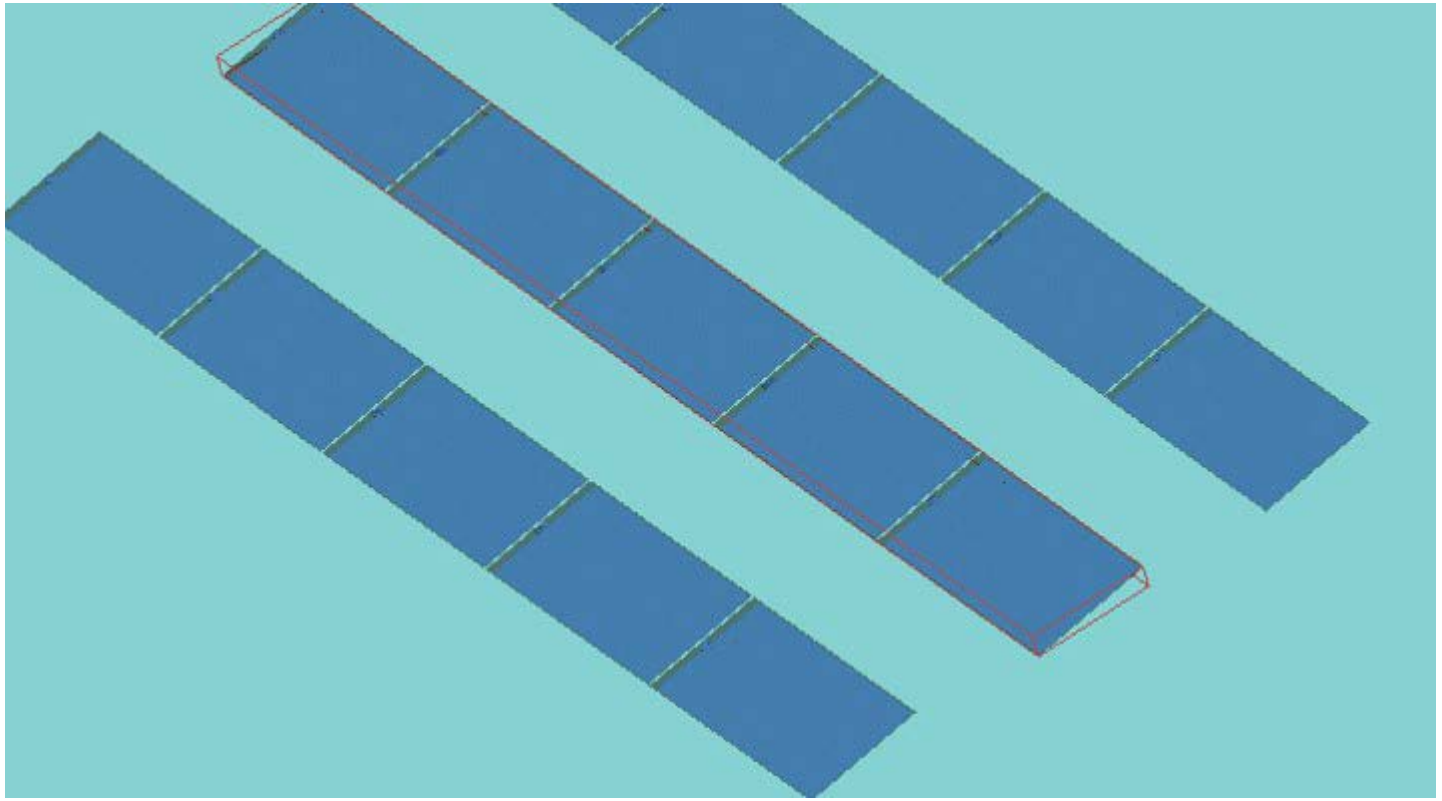
https://openei.org/wiki/InSPIRE

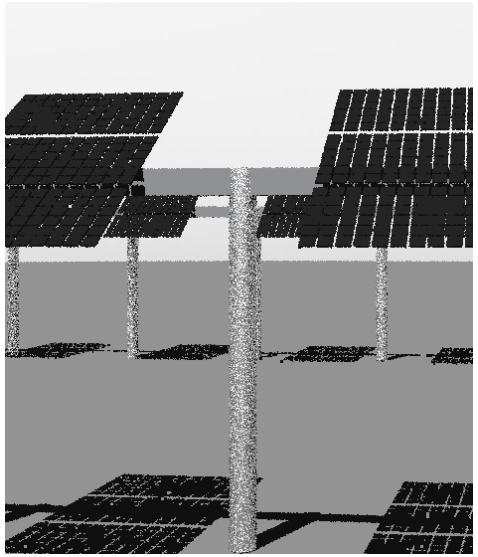


bifacial_radiance

Validated NREL's Open Source Bifacial (and AgriPV) raytracer

https://github.com/NREL/bifacial_radiance





AgriPV Examples:

- Uses backward ray-trace to evaluate the irradiance (W/m^2) at any location in the scene. Much customization!
- Weather → Irradiance → Module Performance calculations with PVLib

View Factor Models for Rear (& Ground) Irradiance

G_{rear} is summed over 180° field-of-view:

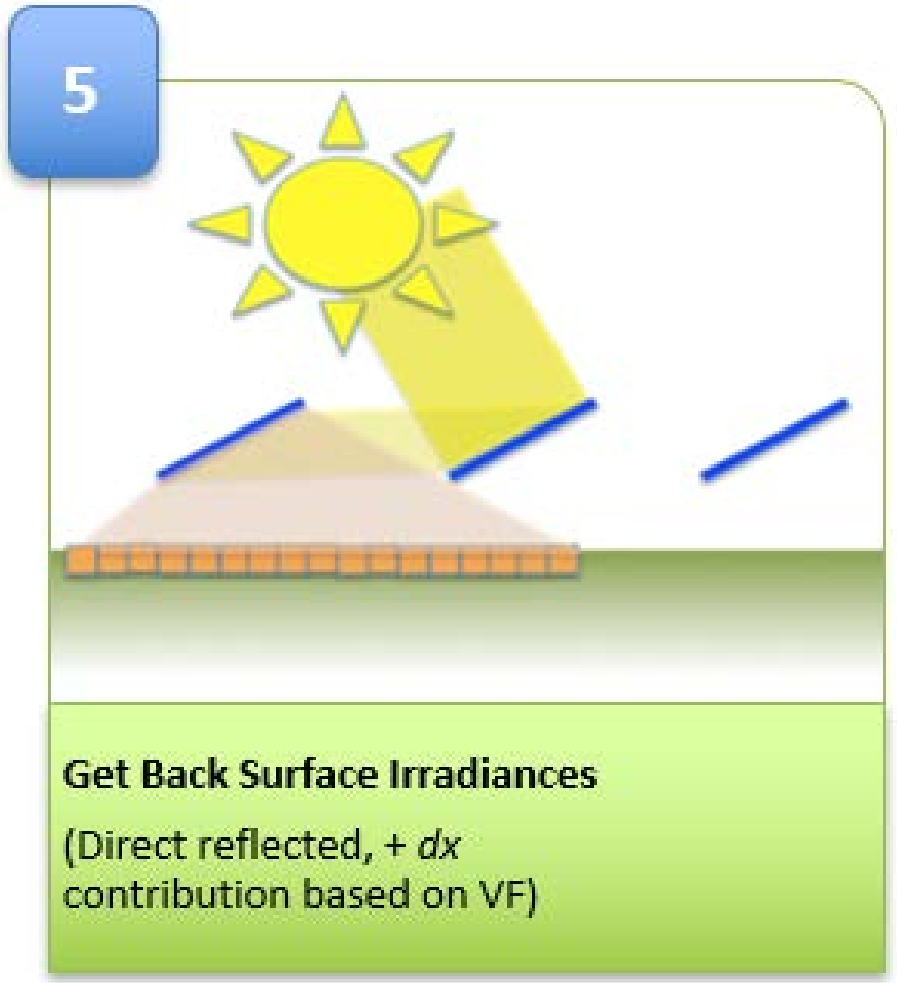
$$\mathrm{G_{rear}} = G_{DNI,rear} + \sum_{i=1^\circ}^{180^\circ} VF_i \cdot F_i \cdot G_i \ ;$$

$$VF_i = \frac{1}{2} \cdot [\cos(i-1) - \cos(i)] \ ;$$

$$F_i = Incidence\ angle\ modifier(\Theta)$$

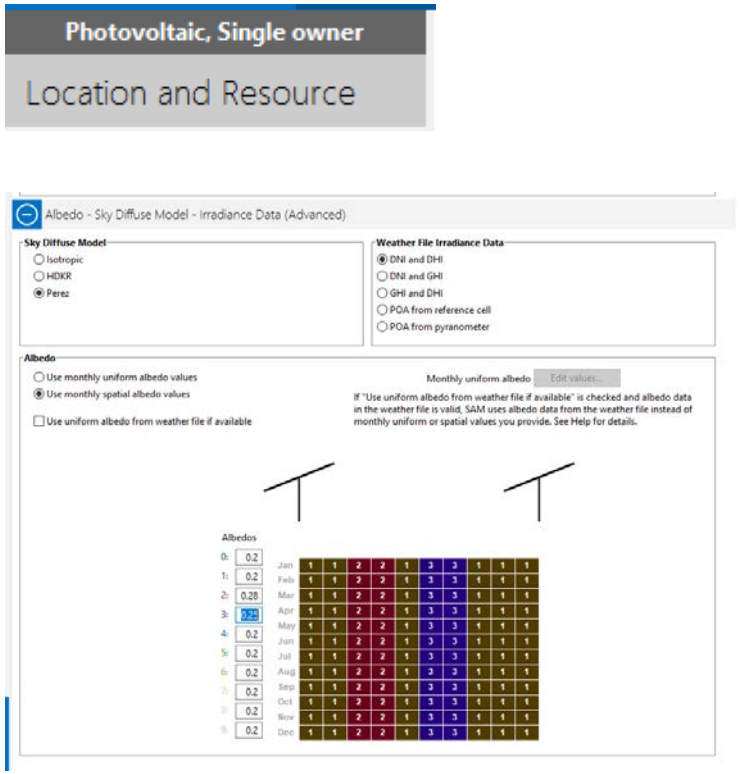
$$G_i = Irradiance\ [G_{sky}, G_{hor}, \rho \cdot G_{ground}] \ ;$$

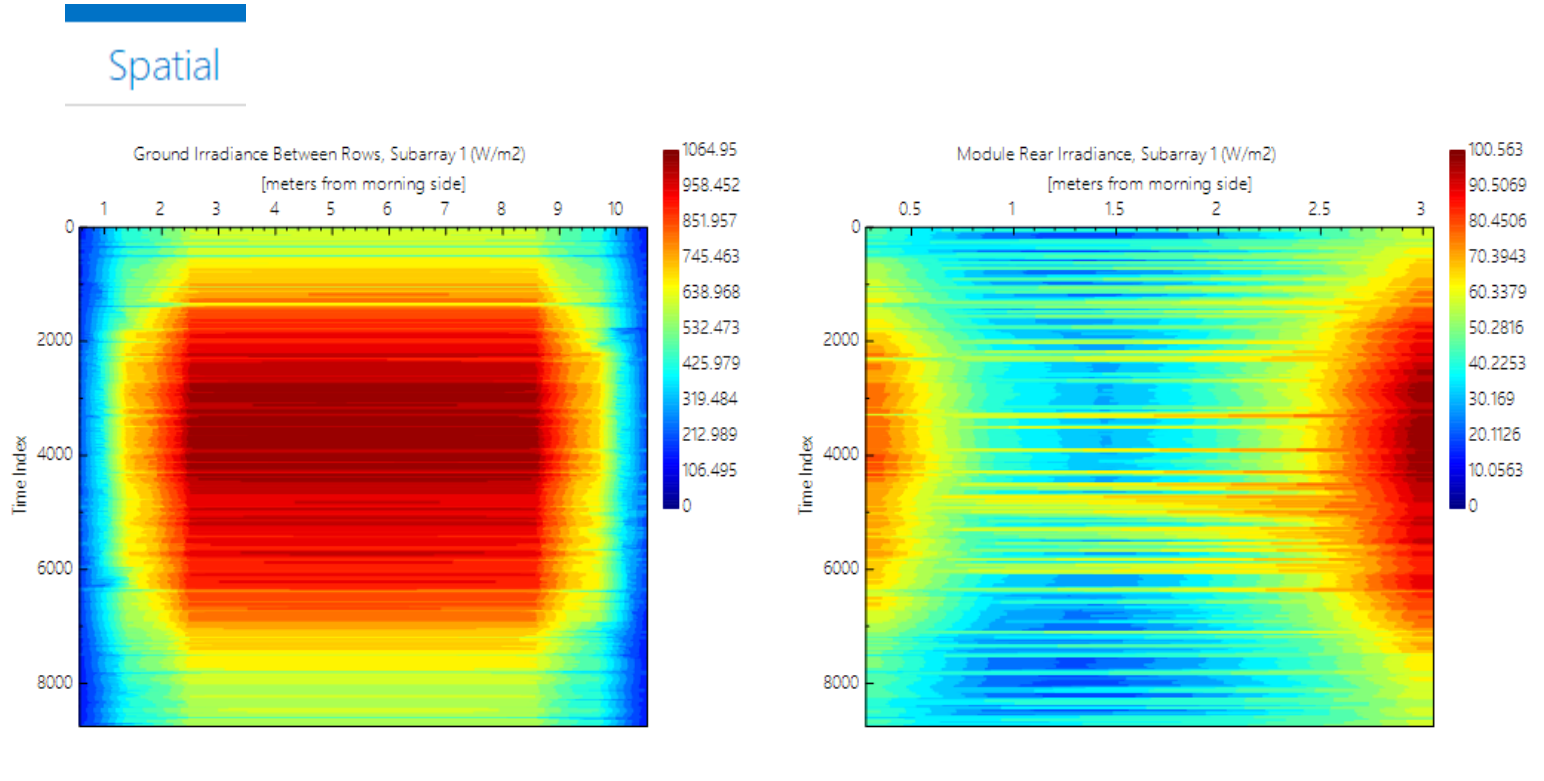
Irradiance sources: sky, ground (shaded or unshaded)



B. Marion et al., A Practical Irradiance Model for Bifacial PV Modules, 2017
B. Marion, Numerical method for angle-of-incidence correction factors for diffuse radiation incident photovoltaic modules, 2017

System Advisor Model (SAM) Features for AgriPV and Albedo Optimization



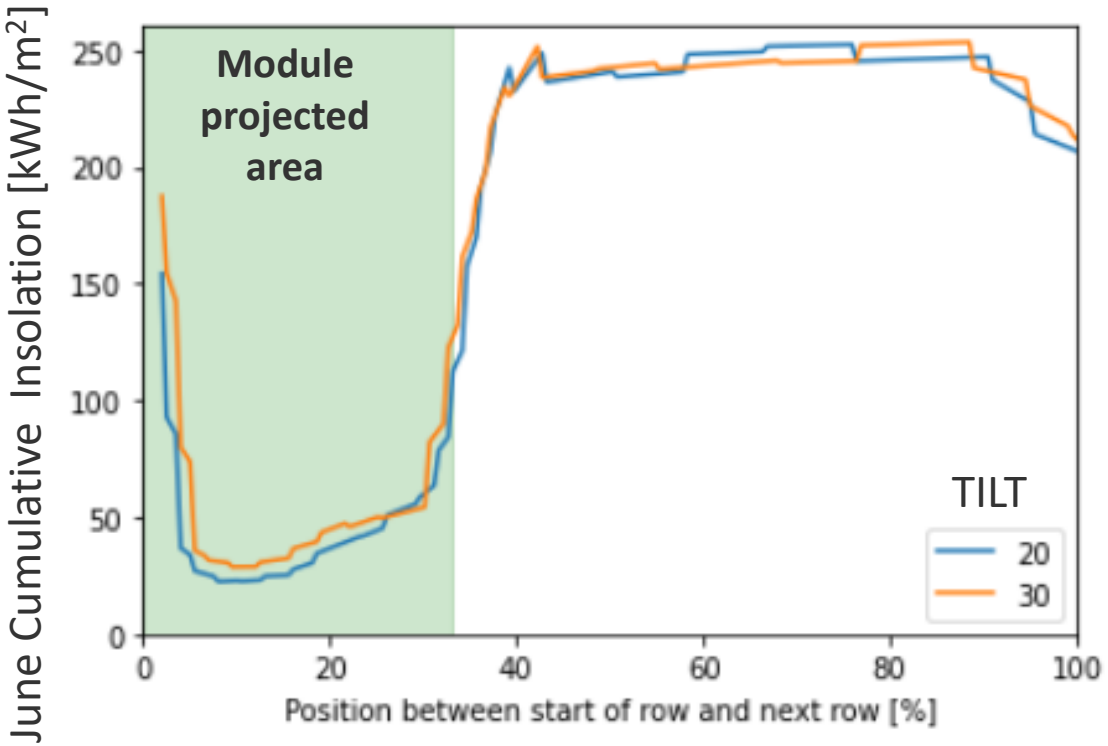


Also accessible through pySAM!

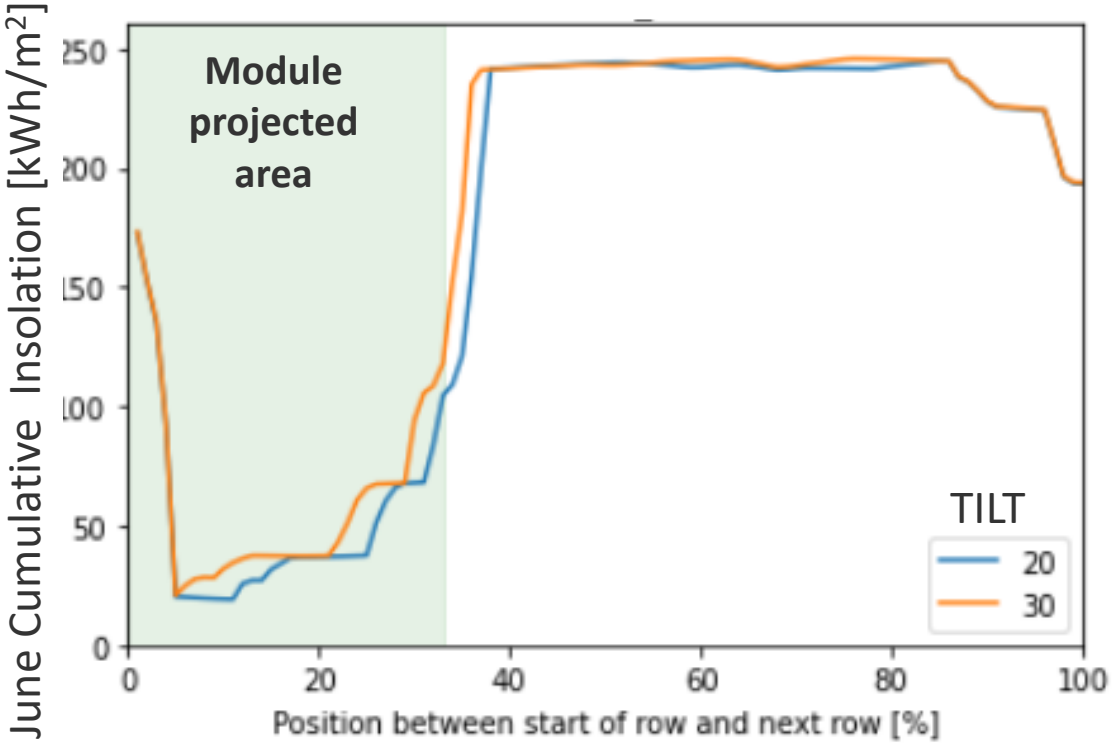
Comparisons

Fixed-tilt Setup

bifacial_radiance



view factor

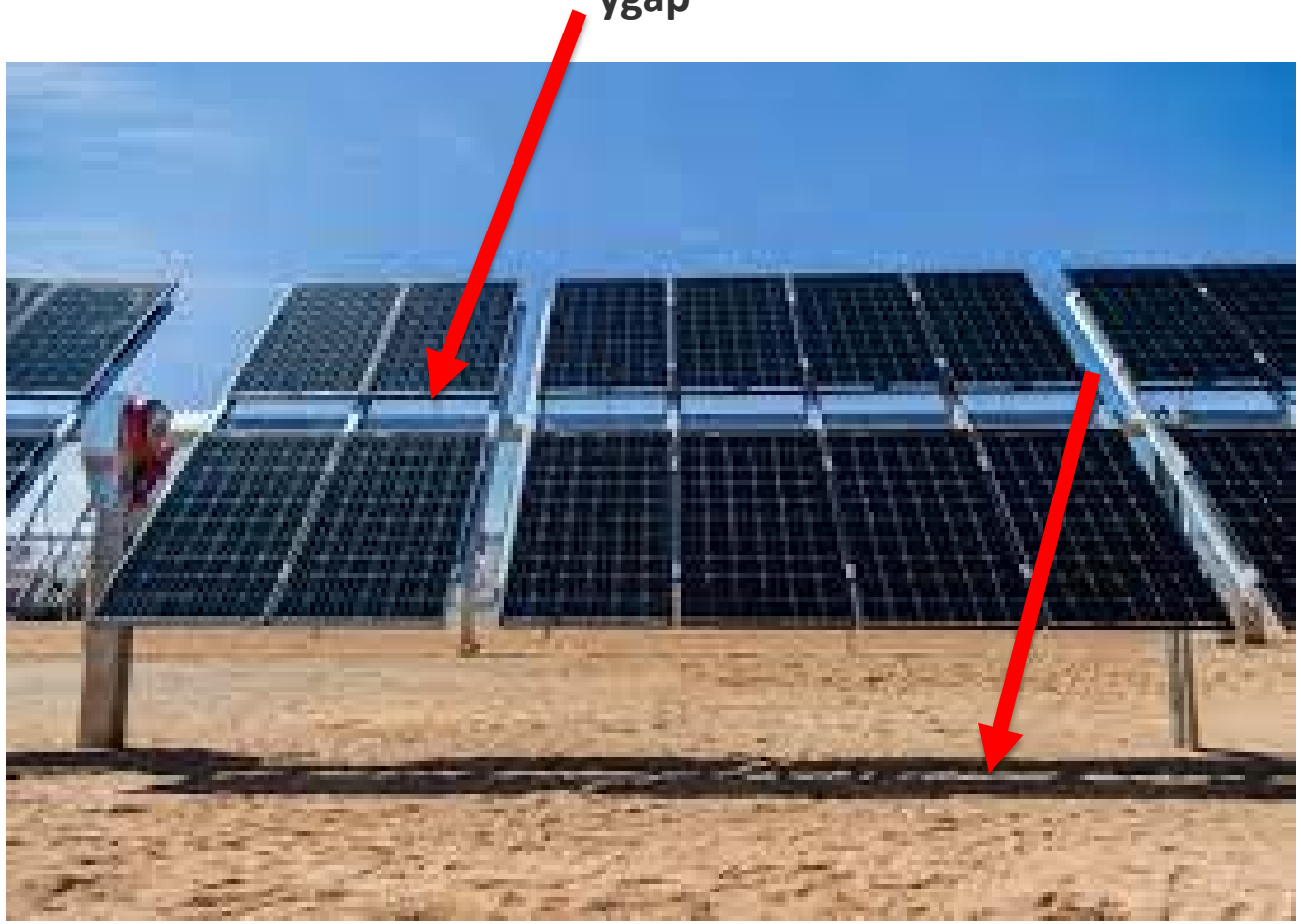


Sun high on the sky, main shade underneath modules

Clearance height, and pitch also give good results, MBD 1-2%

Transmission Factor Comparisons

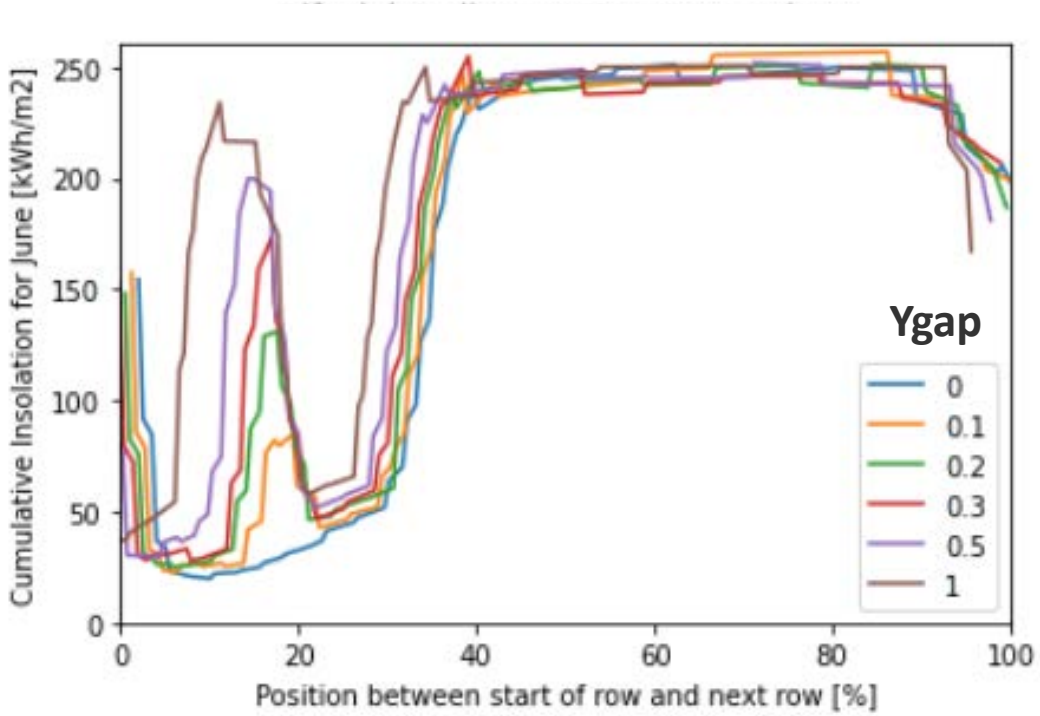
View factor uses a ‘transmission factor’ to account for space between cells, and space between modules along the row (xgap). Can it also account for spaces between modules across the collector width (ygap) for Ground Irradiance evaluation?



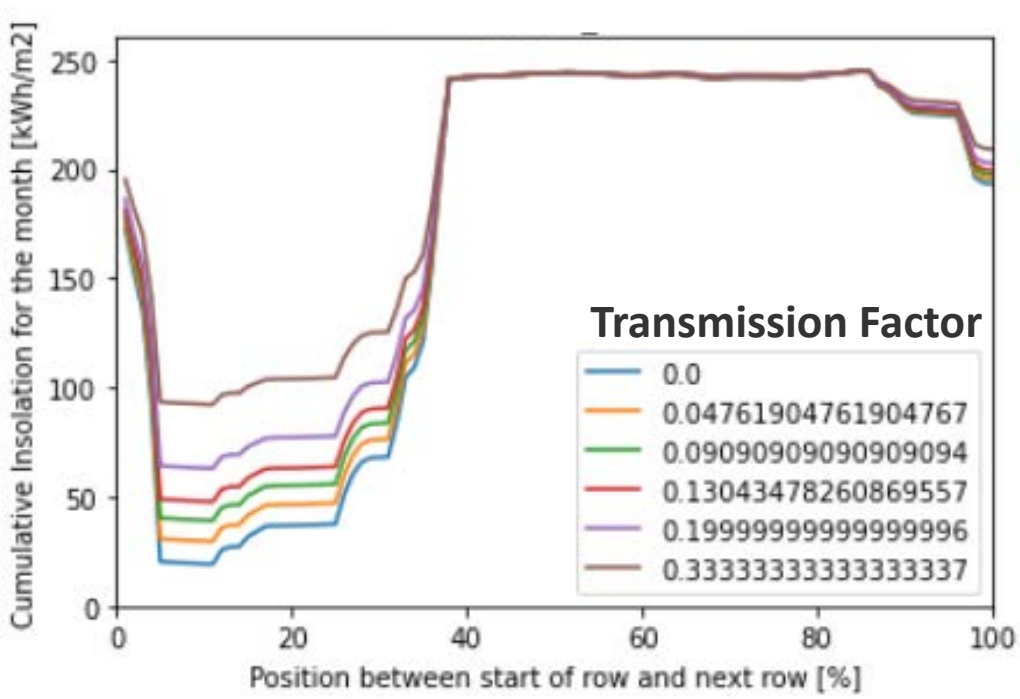
Soltec.com image borrowed from Google

Transmission Factor Comparisons

bifacial_radiance



view factor



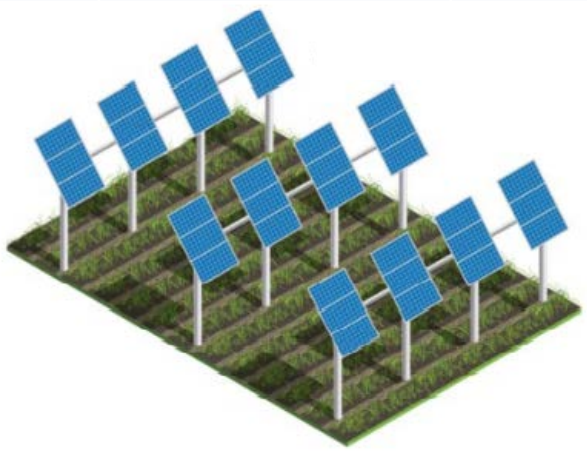
The FWHM insolation of the ‘lobe’ matches the average ground insolation of the various transmission factors

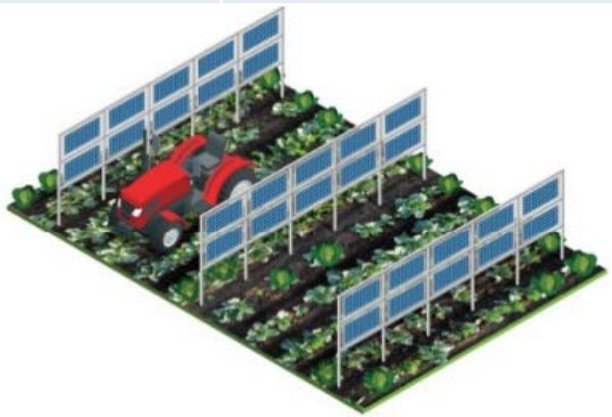
Spatio-temporal simulations

Scenario	System Type	Racking	Panel Tilt	Hub Height (m)	Row Spacing (m)	Panel Spacing (m)
1	Conventional utility-scale	1-axis tracking	-50° to 50°	1.5	5	0
2	Elevated panels	1-axis tracking	-50° to 50°	2.4	5	0
3	Elevated & intra-row spaced panels	1-axis tracking	-50° to 50°	2.4	5	1
4	Utility-scale with 2x edge-to-edge spacing	1-axis tracking	-50° to 50°	1.5	8	0
5	Utility-scale with 3x edge-to-edge spacing	1-axis tracking	-50° to 50°	1.5	11	0
6	Conventional utility-scale	Fixed tilt	Latitude*	1.5	Variable**	0
7	Elevated panels	Fixed tilt	Latitude*	2.4	Variable**	0
8	Elevated & intra-row spaced panels	Fixed tilt	Latitude*	2.4	Variable**	1
9	Utility-scale with 2x edge-to-edge spacing	Fixed tilt	Latitude*	1.5	Variable**	0
10	Vertical bifacial	Fixed vertical	90°	2	8.6	0

Summary of Simulated Designs

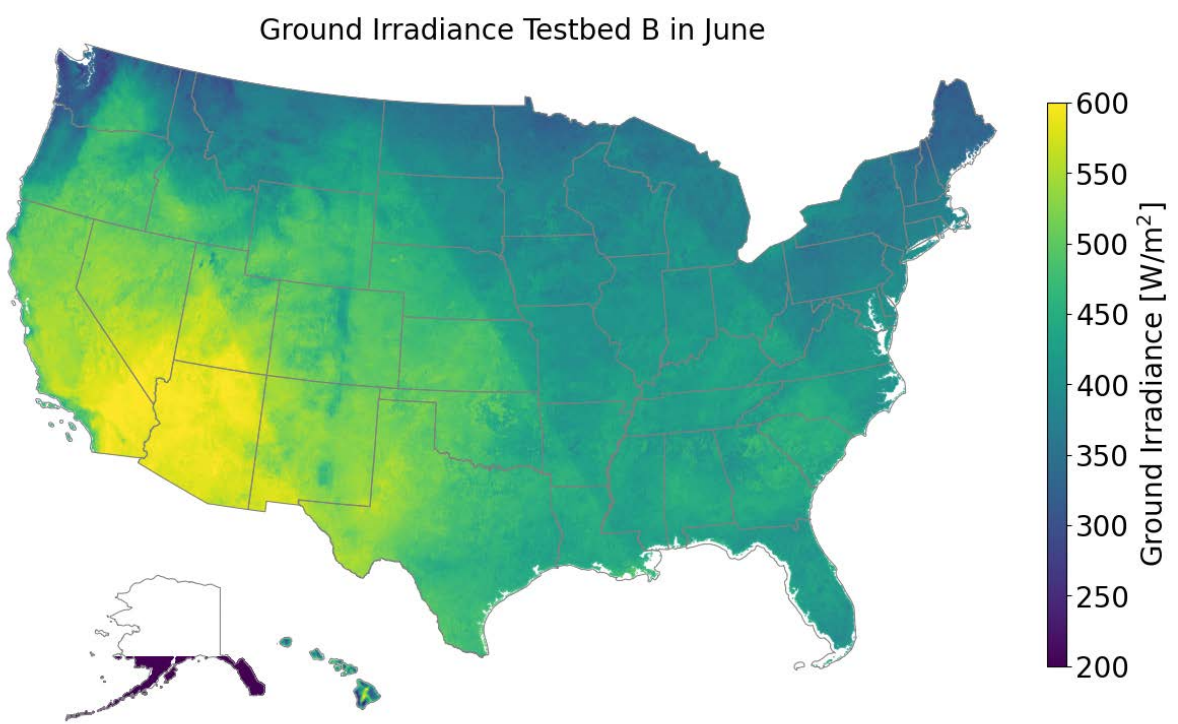
*For fixed-tilt systems:
Panel Tilt = min(latitude, 40°)
**Row spacing set to prevent interrow shading on winter solstice at 9am





Horowitz, Kelsey, Vignesh Ramasamy, Jordan Macknick and Robert Margolis. 2020. Capital Costs for Dual-Use Photovoltaic Installations: 2020 Benchmark for GroundMounted PV Systems with Pollinator-Friendly Vegetation, Grazing, and Crops. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-77811. https://www.nrel.gov/docs/fy21osti/77811.pdf.

Methodology & Process



Pull NSRDB data for 50,000+ locations in the United States

Define solar configurations for analysis with bifacial_radiance & SAM

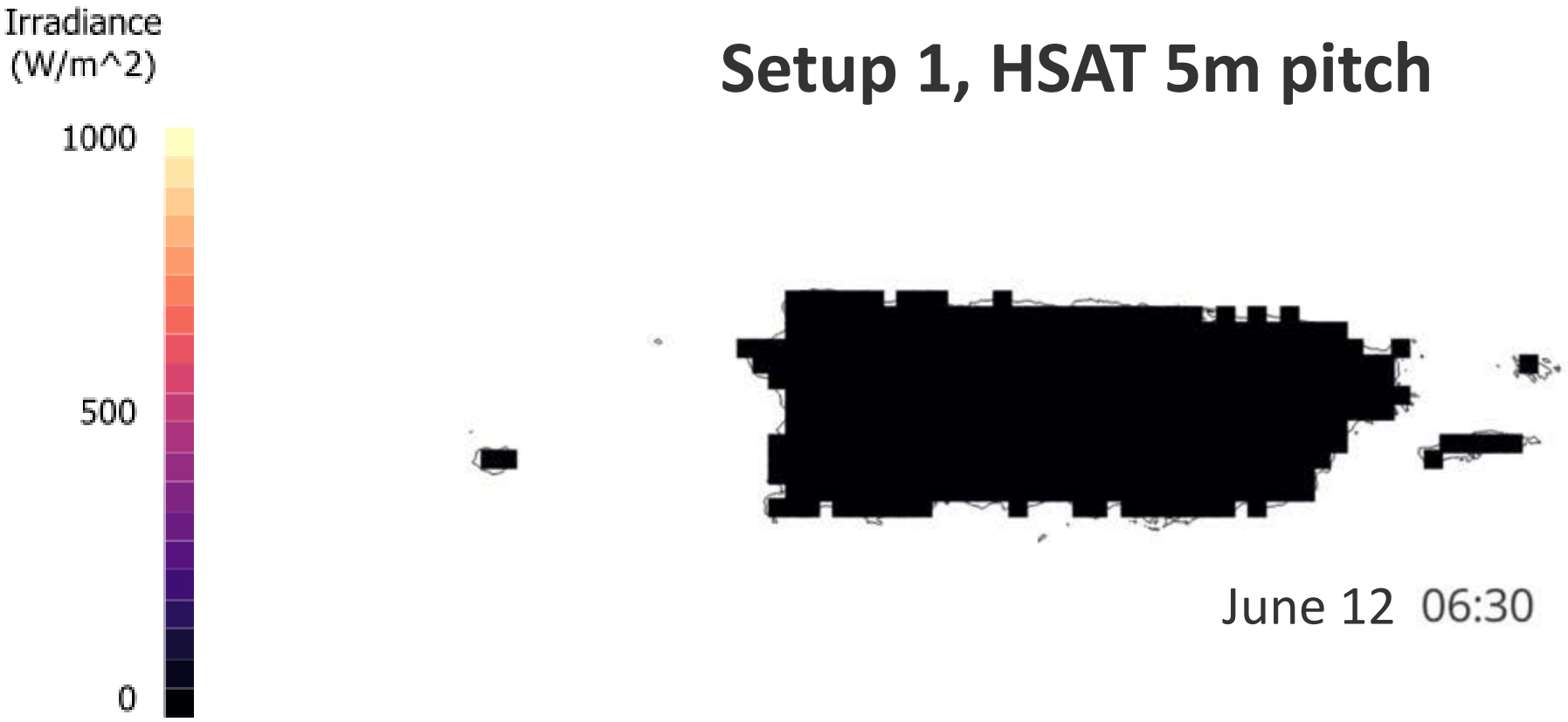
Run HPC simulations

Compile & process simulation data

Publish simulation data with maps & analysis

Develop online tool to streamline data access & visualization

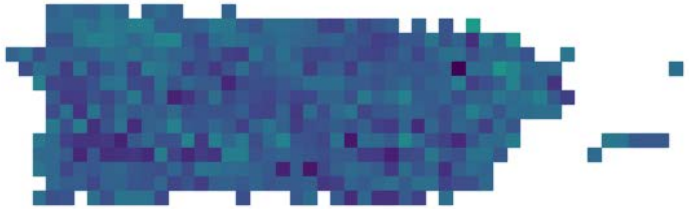
Puerto Rico



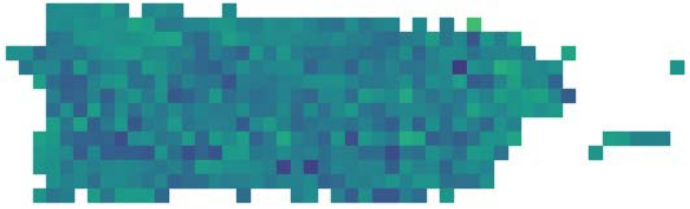
~4 km x pixels, resolution of NSRDB database

Edge-to-Edge Irradiance Factor
June 12th

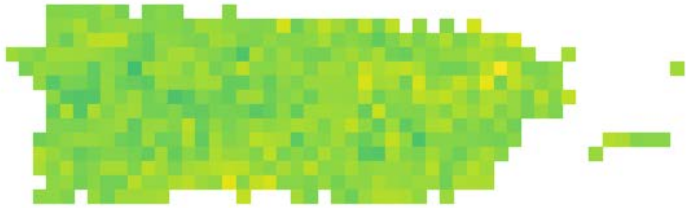
Conventional HSAT



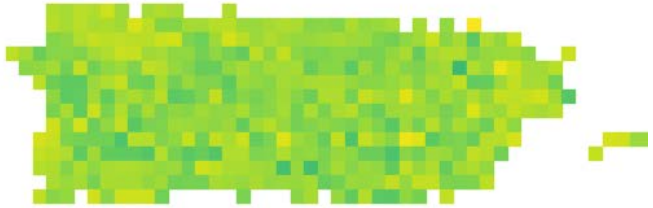
Elevated Panels



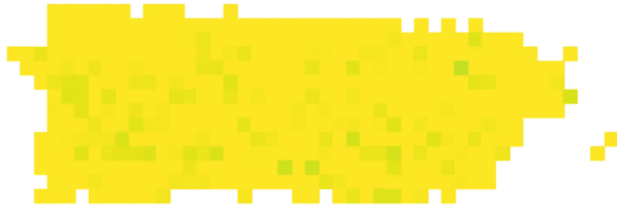
Elevated Panels & 1 m module-gaps

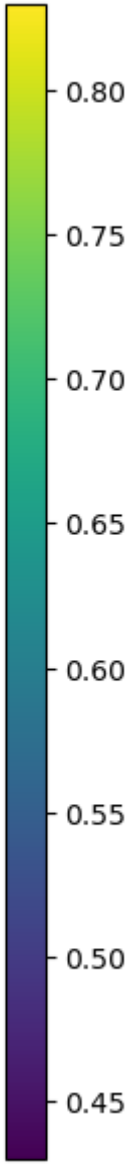


0.25 GCR



0.18 GCR





Bifacial Agricultural Research at NREL

- Nine crops were planted at the beginning of the season:

Carrots, kale, basil, chard, beans, two types of tomatoes and two types of peppers

- Each crop was planted in three rows within the panels, as well as a control

BARN Season 1 Results

- Most crops did *at least as well* between the solar panels as they did in the control

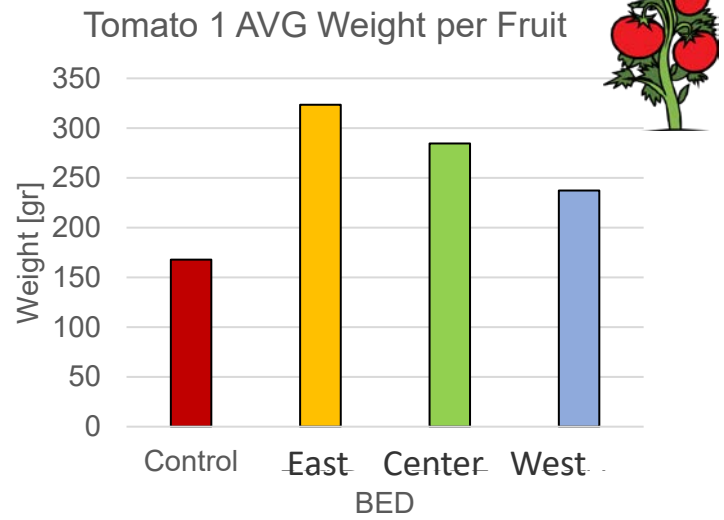
Best Performance Based on Yield Weight

	Control	East Bed	Central Bed	West Bed
Chard			x	
Kale		x		
Basil				x
Carrot	x			
Tomato 1		x		
Tomato 2		x		
Pepper 1				x
Pepper 2			x	

Carrots were the only crops that performed distinctly better in the control

Tomato 1 was harvestable earlier in the control than the under-panel tomatoes.

Basil also flowered earlier on Control.



Module Level Performance used to evaluate gain of the bifacial modules from the Crops

$$Gain = \frac{Power_{CropModules}}{Power_{ControlModules}}$$

$\pm$ 0%

3 years of Open-source data!
https://datahub.duramat.org/dataset/best-field-data

Conclusions

- We got good agreement for VF and raytrace. For complicated setups raytrace provides more customization. *bifacial_radiance* has various features supporting AgriPV.
- SAM now can present the ground incident irradiance values as output, and can have spatially and time varying albedo
- We are in the process of doing raytracing simulations of different configurations for the whole US, to make agriPV considerations accessible through the InSPIRE website.
- Conventional HSAT AgriPV ongoing at NREL. No change in the PV output performance, and equal or better Agricultural output.

openei.org/wiki/InSPIRE
github.com/NREL/bifacial_radiance
datahub.duramat.org/dataset/best-field-data

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