Sandia National Laboratories

Bifacial Performance Optimization Studies using Bifacial Radiance and High Performance Computing

Joshua S. Stein[1], Matthew Prilliman[1], Cameron Stark[1], John Nagyvary[2], Silvana Ayala Pelaez[3], and Chris Deline[3]

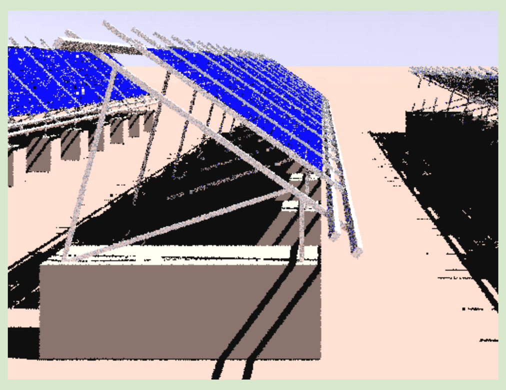
[1]Sandia National Laboratories, [2]Array Technologies, [3]National Renewable Energy Laboratory

Problem Statement

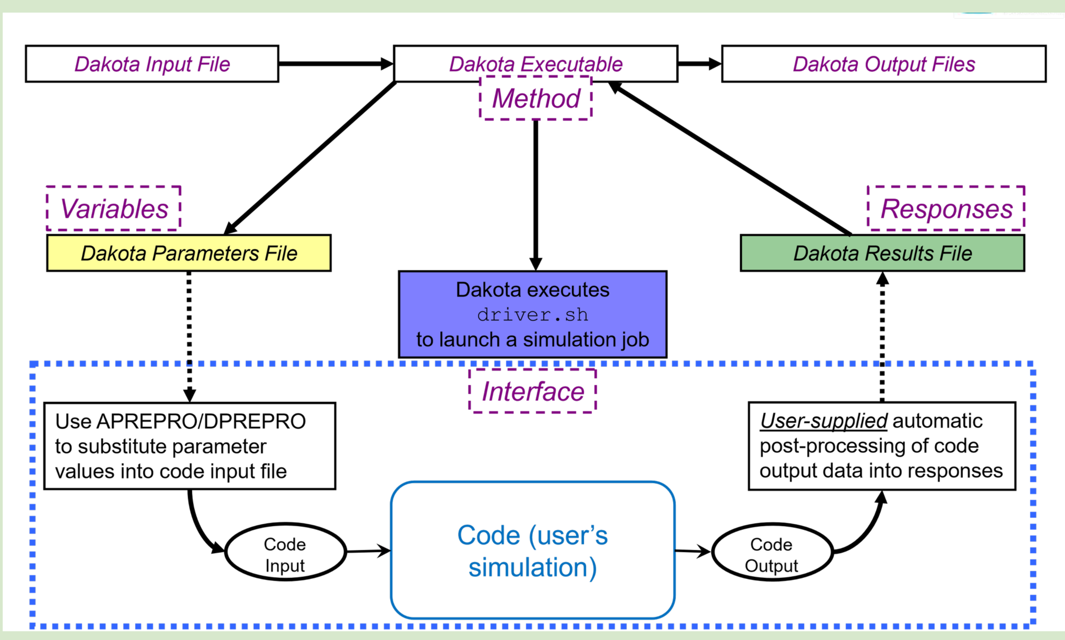
- What is the best system design for bifacial PV on Single axis trackers?
- Bifacial performance is more sensitive to certain parameters not considered that important for monofacial PV performance:
  - Albedo
  - Hub height
  - Tube gap, etc…

Models

- **BIFACIAL_RADIANCE**: NREL Python wrapper predicts incident irradiance using Radiance ray-tracing tools
  - Hourly cell-level incident irradiance calculations for bifacial arrays
  - Fixed tilt and horizontal single-axis tracker systems available
  - Solar position calculations from pvlib-python



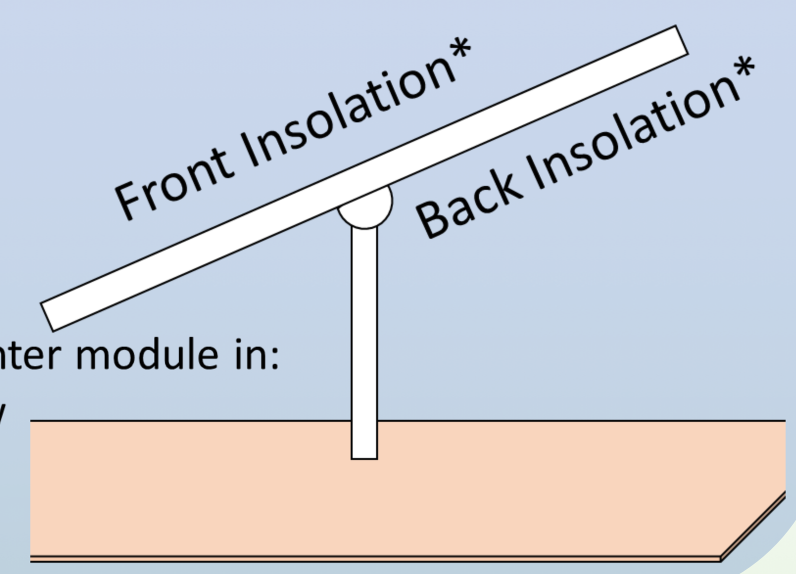
- **DAKOTA**: Sandia developed optimization software
  - Automatic parameter sampling (Latin Hypercube Sampling) for robust sensitivity, optimization studies
  - Parallel processing suited for multi-core HPC environment



- HPC cluster: 71 Teraflop peak cluster with 168 dual socket, 8-core 2.7 GHz Intel Sandy Bridge processors with 64 GB of RAM per node.

Approach

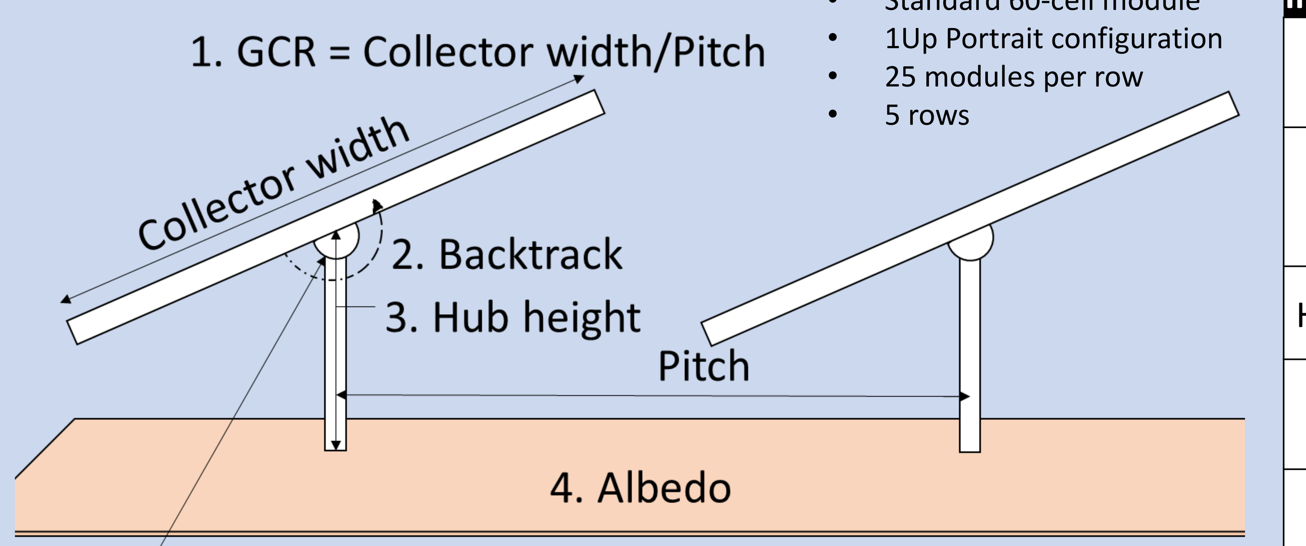
- Latin Hypercube Sampling (LHS): Random sampling from uniform probability bins with reordering to minimize cross correlation
- 100 realizations: annual simulations for 3 HSAT test cases:
  1. **36-day annual sample with wide albedo range**
  2. **36-day annual sample with albedo range .15-.25 (typical ground conditions)**
  3. **365-day annual approximation with .15-.25 albedo range**
  4. **36-day annual sample with albedo range .75-.85 (snow conditions)**
- 36 day annual samples include max, min, median daily insolation for each month
- Outputs analyzed with Stepwise Regression where variables are sequentially added to regression until ~95% of the variability is accounted for.
- Model outputs:
  - Irradiance on front and back of each cell



*Both for center module in:
1. Center row
2. East row

Approach

- Model inputs:



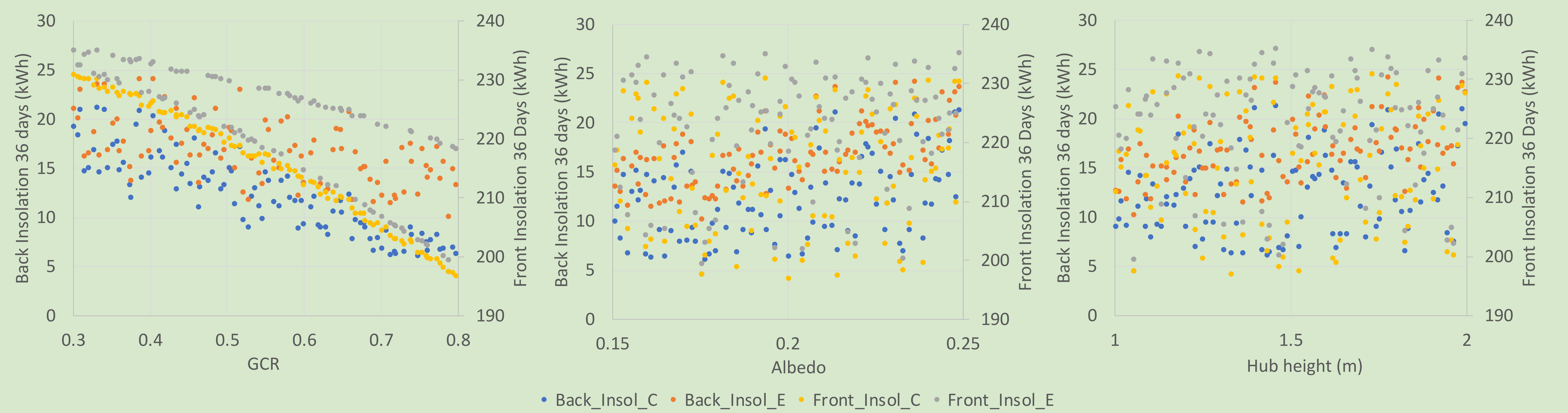
- Standard 60-cell module
- 1Up Portrait configuration
- 25 modules per row
- 5 rows

5. Tube shape: [Round, Octagonal, Square, Hexagonal]
6. Tube gap: Distance between torque tube and back of module

Inputs	Description	Type	Range	Units
GCR	Collector width/row-to-row distance	Float	.3-.8	meters/meters
Albedo	Ratio of light reflected by ground	Float	1. [.10-.80] 2-3. [.15-.25] 4. [.75-.85]	None
Hub height	Height of tracker from ground	Float	1-2	meters
Tube gap	distance of module from torque tube in Z	Float	1-10	centimeters
Backtrack	True= backtracking False="true" tracking	Boolean	True, False	none
Tube shape	Shape of torque tube	String	Round, Oct, Square, Hex	none

Results

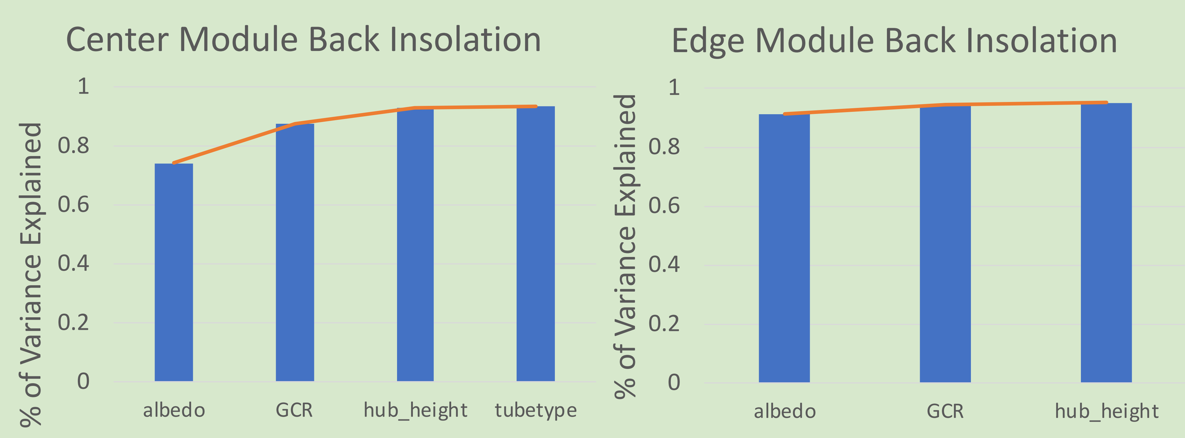
- Results of albedo range .15-.25 study show that GCR and albedo have the most influence on the variability of both the front and rear irradiance received, particularly in the center row where row-to-row shading due to GCR has greater effect.



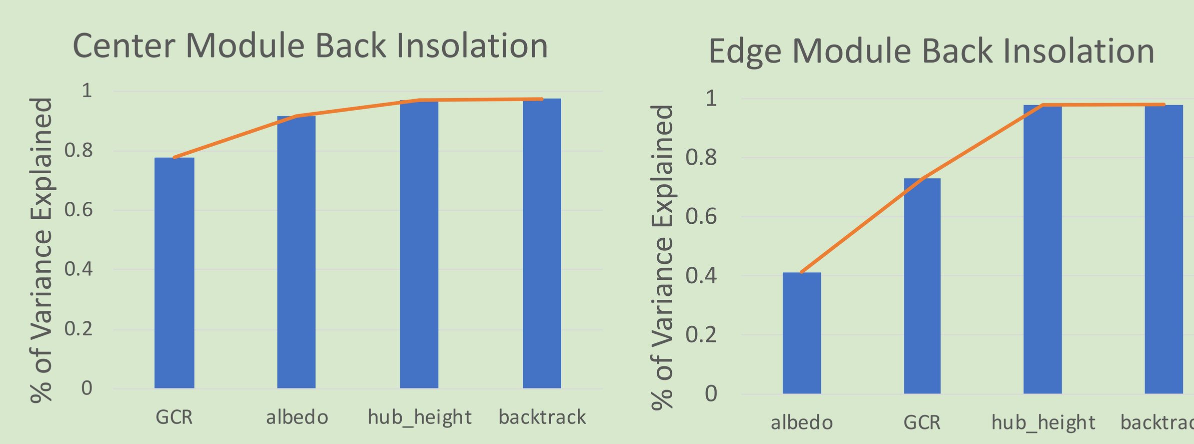
- **Stepwise Regression** results show that the insolation variability for edge modules is most explained by albedo when values are low, while the center modules behavior is dominated by changes in GCR.

- Comparison of the Annual and 36-day results shows that nearly identical dependencies, validates the use of 36-day representative samples for future studies.

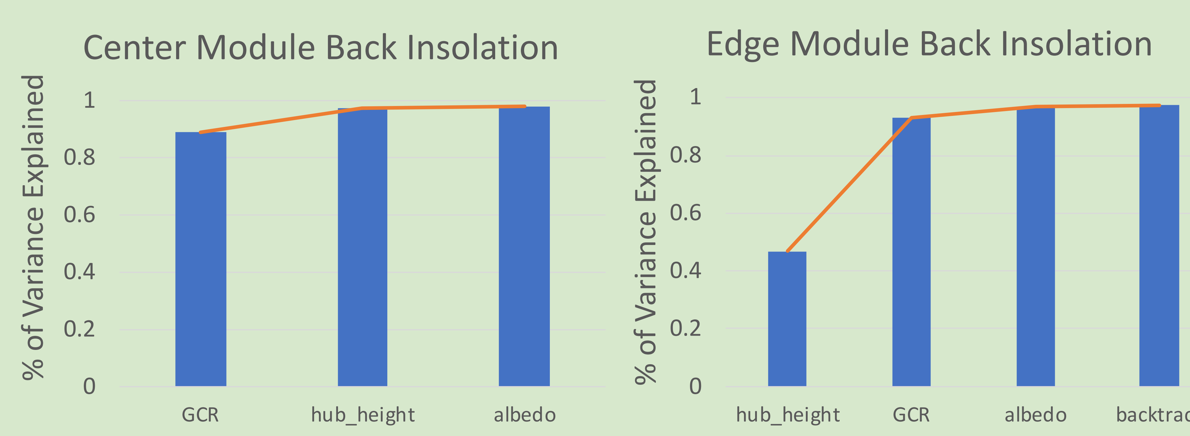
Albedo Range .10-.80



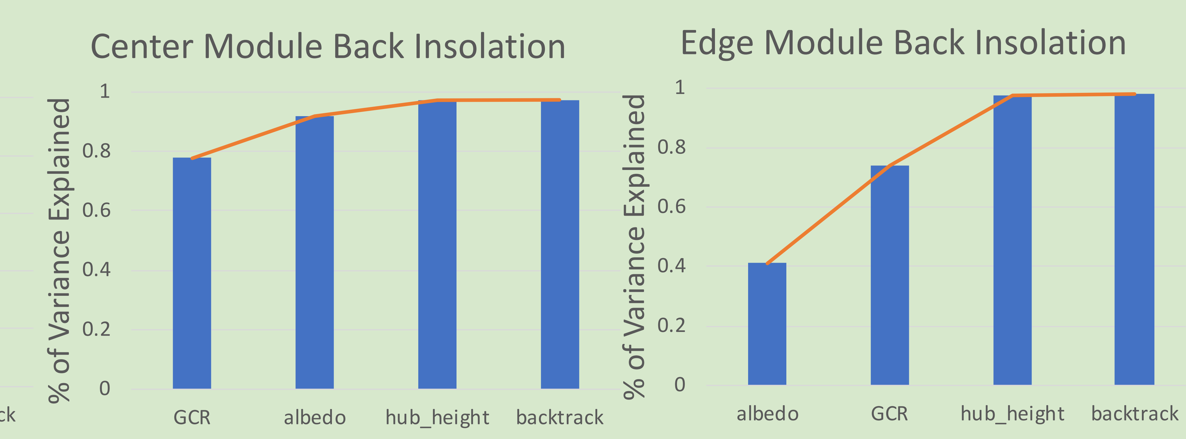
Albedo Range .15-.25 (Annual)



Albedo Range .75-.85



Albedo Range .15-.25 (36 days)



- Bifacial_radiance allows for cell-level irradiance scans; these scans show that the torque tube can limit the irradiance received in the center cells of a module

Albedo Range .75-.85

Summer: Std Dev = 24.9 W/m^2

397	398	397	395	402	402
379	378	377	373	372	372
360	359	361	361	359	359
353	354	347	347	354	354
347	347	346	347	345	344
348	348	346	347	352	352
359	359	361	361	356	356
376	375	371	371	376	376
395	395	396	396	395	398
424	424	424	426	426	426

Winter: Std Dev = 13.3 W/m^2

123	123	123	123	123	125
115	115	117	117	117	116
110	109	109	109	109	111
102	102	102	104	104	103
98	98	98	98	97	99
94	94	94	94	94	93
88	88	89	89	89	90
87	87	87	87	87	87
85	85	84	84	84	85
85	85	85	83	83	83

Albedo Range .15-.25

Summer: Std Dev = 5.5 W/m^2

84	85	85	85	84	84
81	81	81	80	80	80
77	77	77	77	77	77
74	74	75	75	75	75
73	73	74	74	72	72
73	73	73	73	73	73
76	76	77	77	77	77
79	79	80	80	79	79
85	84	84	84	85	86
91	91	90	90	90	90

Winter: Std Dev = 1.7 W/m^2

34	34	34	34	34	34
33	33	33	33	33	33
31	31	31	31	31	32
31	31	31	31	30	30
30	30	30	30	30	30
30	30	30	29	29	29
29	29	29	29	29	29
29	29	29	29	29	29
29	29	29	29	29	30
30	30	30	30	30	30

Higher albedo results in a larger Stdev, meaning that these conditions could result in more electrical mismatch.

Findings

- Albedo and GCR are the most influential parameters
  - Finding high albedo sites or enhancing albedo may be justified.
- Hub height and backtracking are of secondary importance.
- Tube gap and tube shape appear to not be very influential parameters.

Acknowledgements

- Bifacial_Radiance developed at NREL:
  - (https://github.com/NREL/bifacial_radiance)
- Dakota developed at Sandia National Laboratories:
  - (https://dakota.sandia.gov)

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.
SAND No. SAND2019-9944 C