Terabase

Interpolation Strategies for 3D Shading

2024

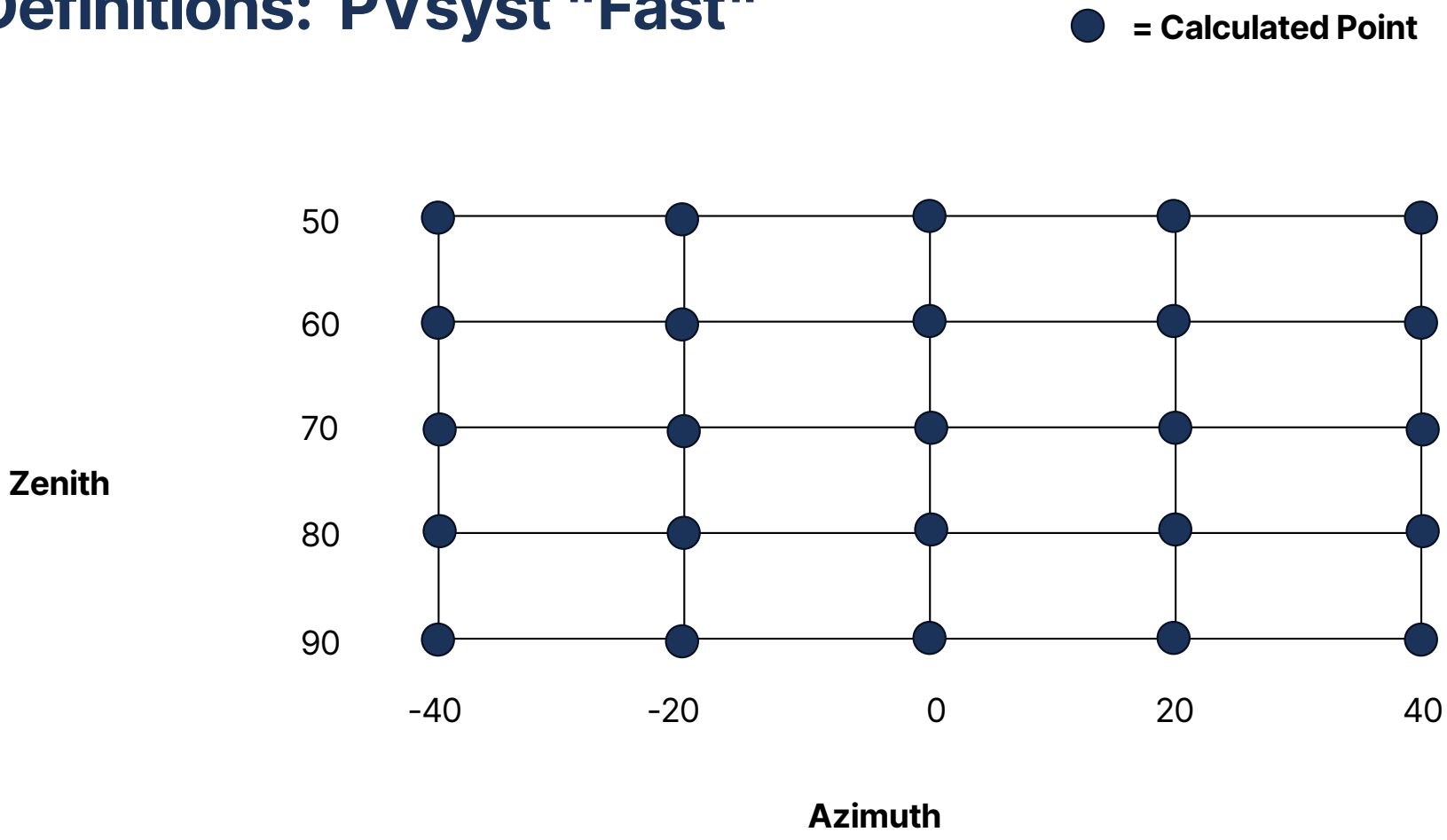
Kurt Rhee & Jason Spokes
Krhee@terabase.energy

Definitions: Interpolation Bins

	PVsyst	PlantPredict
Fast / Quick	20° Azimuth / 10° Zenith	~20° Azimuth / ~10° Zenith
Balanced	N/A	~1° Azimuth / ~1° Zenith
Slow / Detailed	Every time-step	Every time-step

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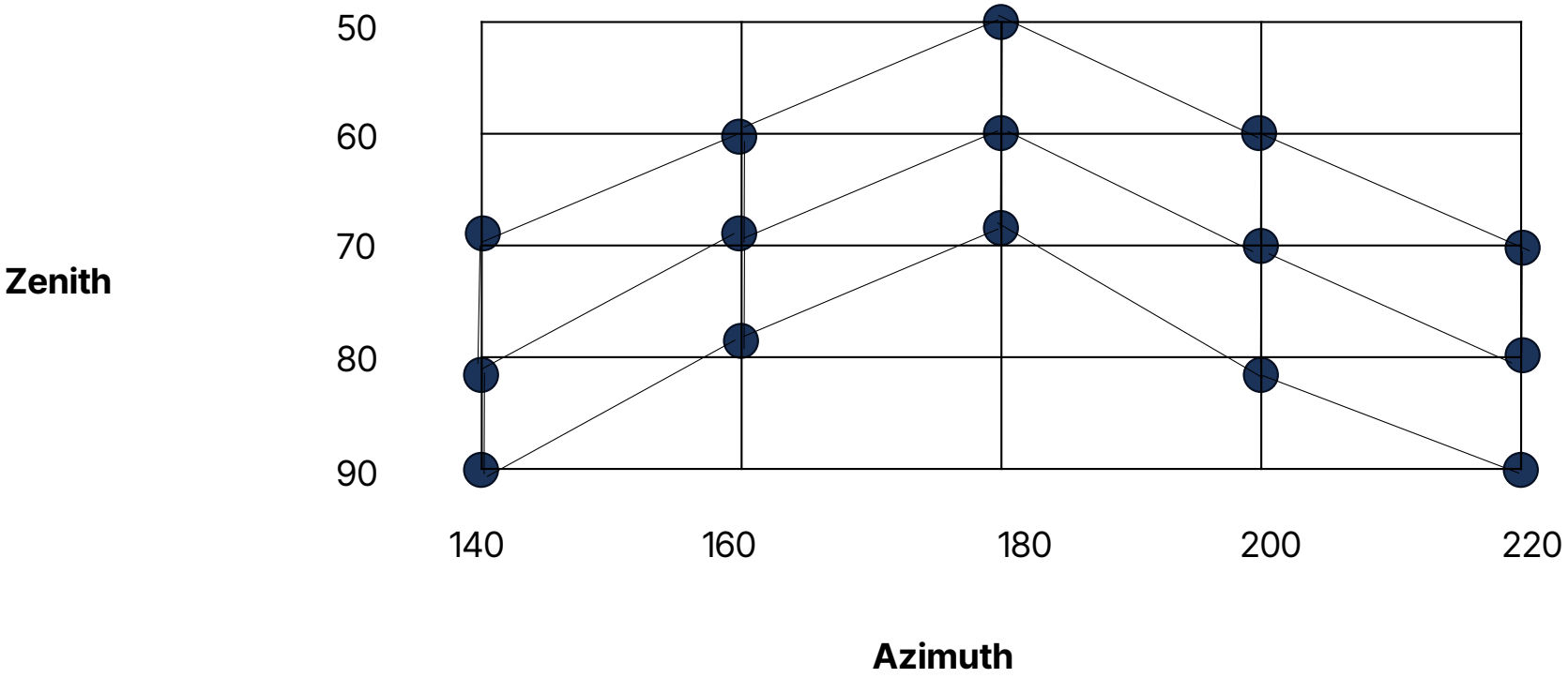
Definitions: PVsyst "Fast"



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Definitions: PlantPredict "Fast"

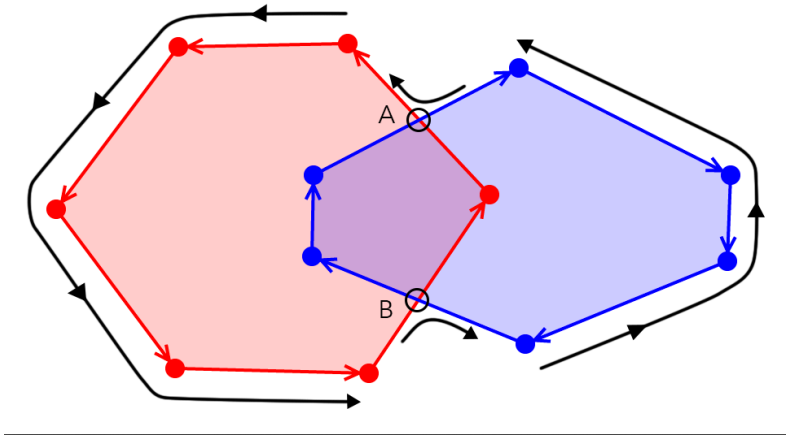


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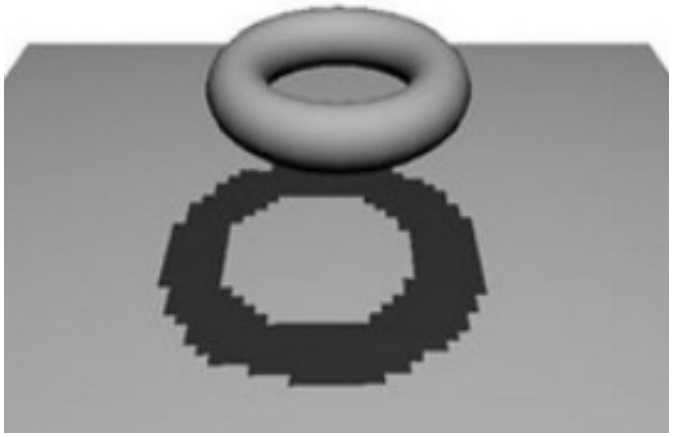
Context

Polygon Clipping



Pixel Counting

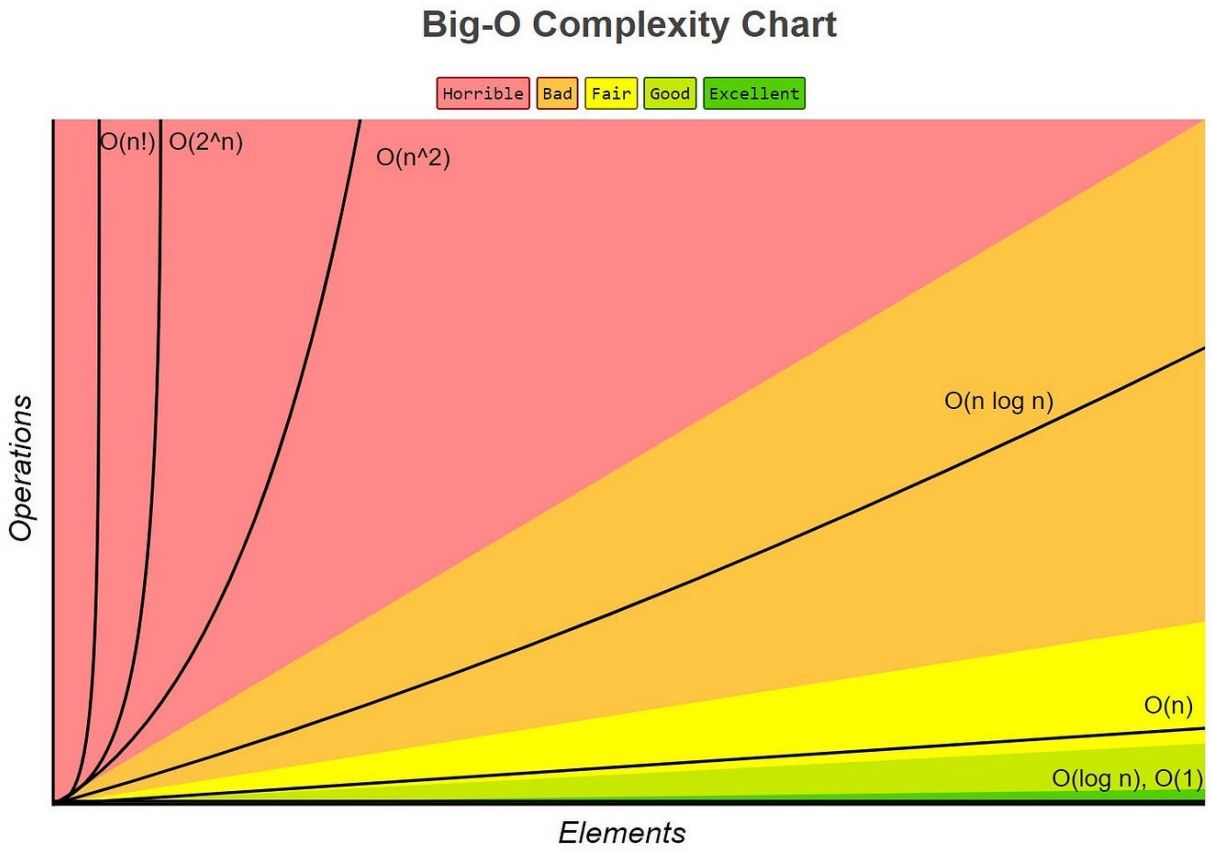
(Ray Tracing, Shadow Mapping, etc.)



https://kurt-rhee.github.io/2024/01/19/a-physical-shade-shape-calculation-algorithm

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Context



3D Shading is Challenging

- 2D Shade is O(1)
- Transposition is O(n)
- 3D Shading Model is:
  - O(n^2) brute force
  - O(n log n) optimally

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How many more calculations?

- Assumptions
  - 500 MWp Plant
  - 550W First Solar Series 7 Module
  - 14 strings / tracker
  - 6 modules / string
  - = 10,823 trackers
  - = 151,515 strings ~= 151,515 shading objects (articulating tracker)

- Calculations
  - O(n^2) = ~23 billion
  - O(n log n) = ~3 million
    - 0.01s per calculation = 30,000s per scene = 8.3 hours
    - 8.3h x 8760 scenes / 0.5 = 36,354 hours

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How many more calculations?

N_timesteps * n (log (n)) / N_cores

- Remove Sun Below Horizon
- **Interpolation**
- Etc.

- Faster computer
- More cores
- More computers



Image Credit: Sandia Center for Computing Research

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	Questions
1	How good is linear interpolation at predicting near shading losses?
2	How much does final graded terrain matter?
3	What does terrain related row to row shading look like at the bookends (totally flat vs. most aggressive buildable terrain possible)

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A Quote

"All flat terrains are the same. Every undulating terrain is undulating in its own way"

Leo Tolstoy (1878)

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Terrain Scenarios

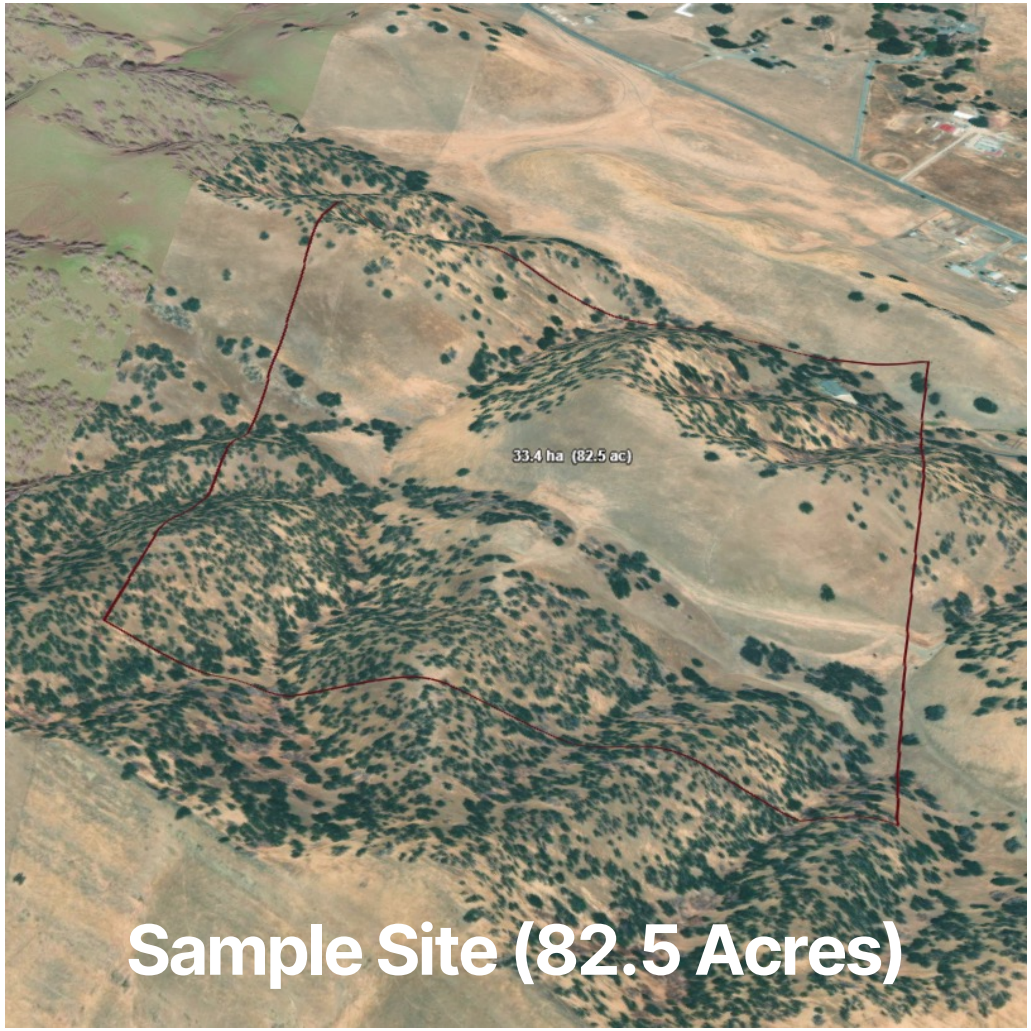
1) **Original Terrain**
   - USGS 1m Resolution

2) **Complex Terrain**
   - Graded to meet Nevados mechanical limitations

3) **Medium Terrain**
   - Graded to meet Nextracker XTR Pro / ATI OmniTrack mechanical limitations

4) **Mild Terrain**
   - Graded to meet Nextracker Horizon / ATI DuraTrack HZ v3 mechanical limitations

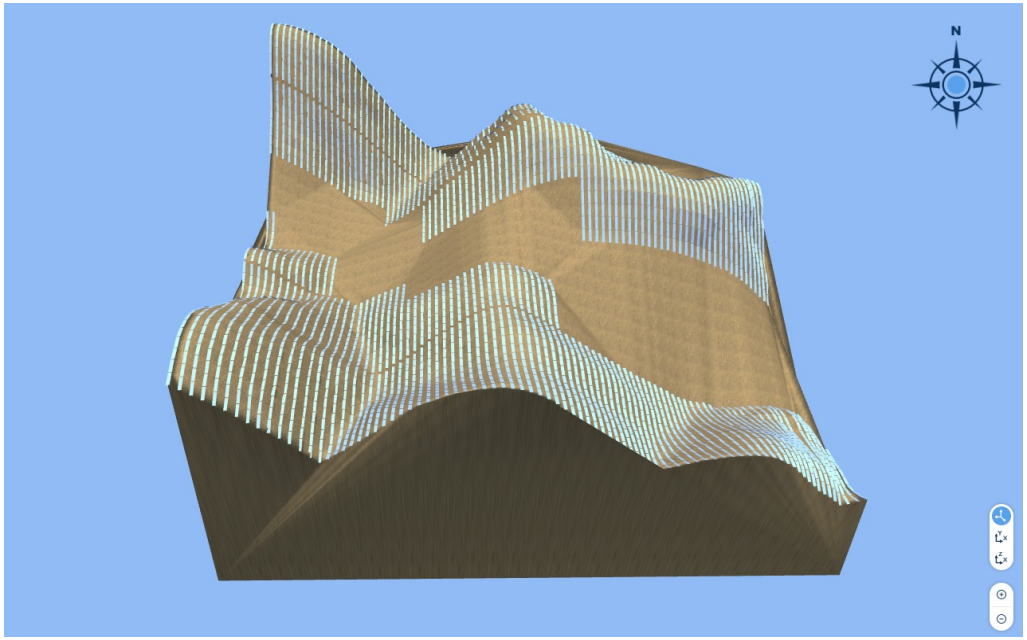
5) **Flat Terrain**



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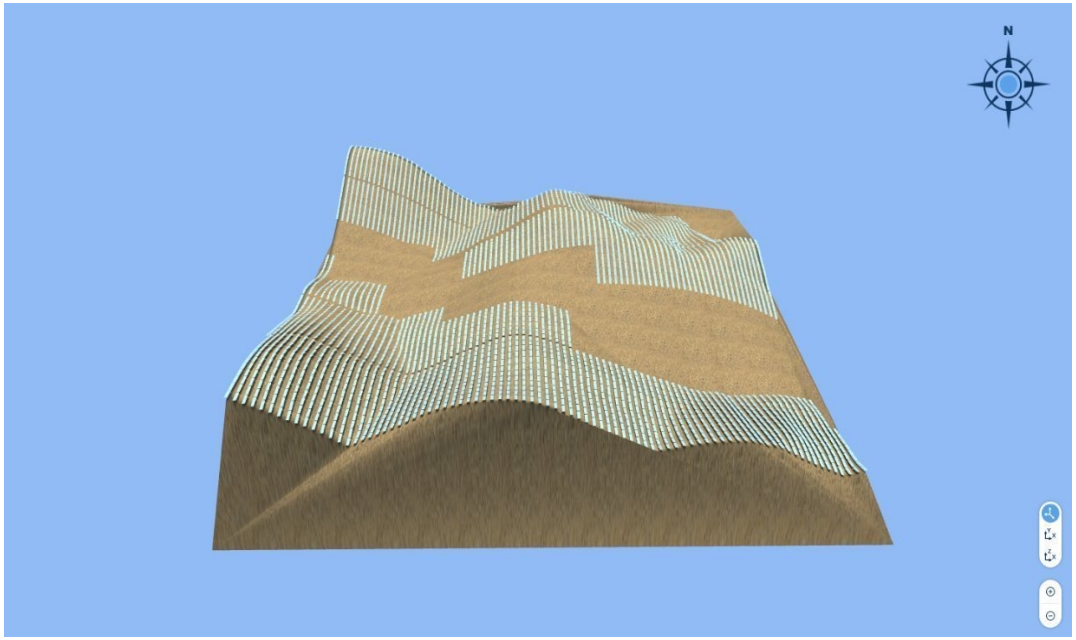
Original Terrain



Terrain	Value
Avg. E/W Slope between 2 tracker piles	43.0°
Max N/S Slope in 1 tracker (end to end)	48.7°
Max N/S Articulation (pile to pile)	14.6°

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Complex Terrain

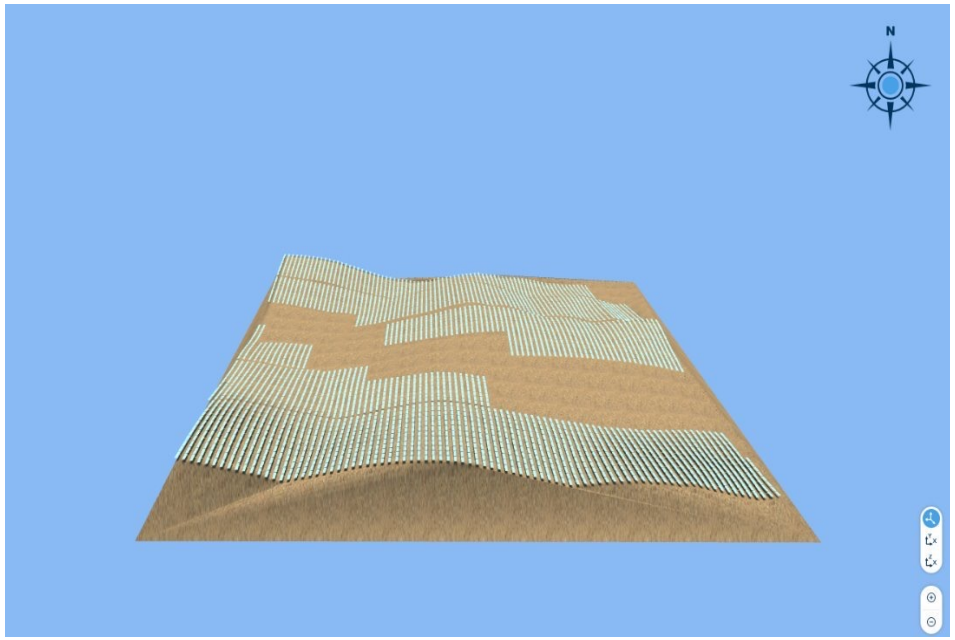


Terrain	Value
Avg. E/W Slope between 2 tracker piles	23.7°
Max N/S Slope in 1 tracker (end to end)	20.5°
Max N/S Articulation (pile to pile)	14.6°

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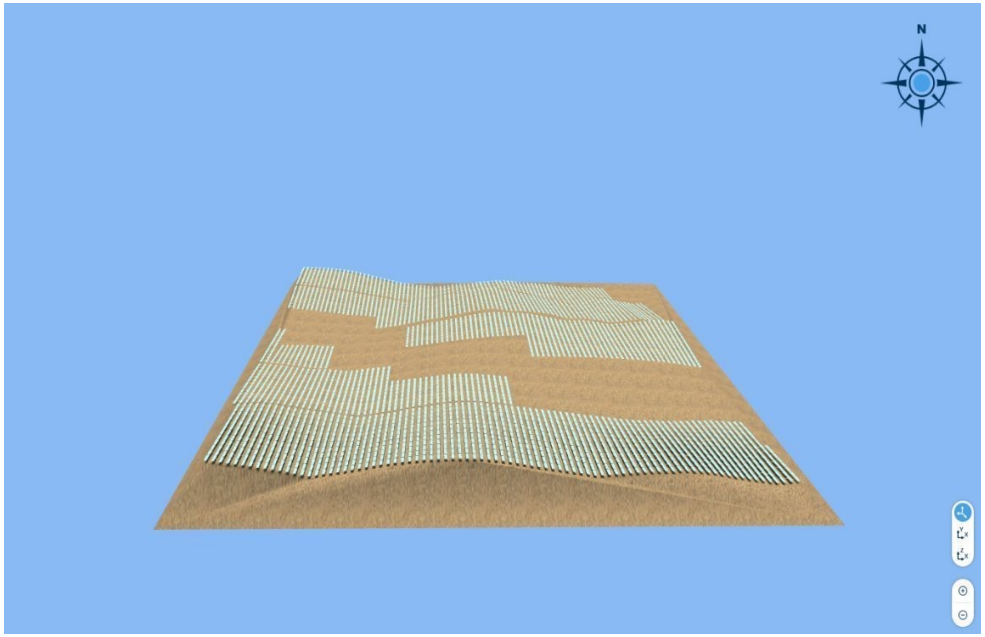
Medium Terrain



Terrain	Value
Avg. E/W Slope between 2 tracker piles	10.8°
Max N/S Slope in 1 tracker (end to end)	8.5°
Max N/S Articulation (pile to pile)	1.5°

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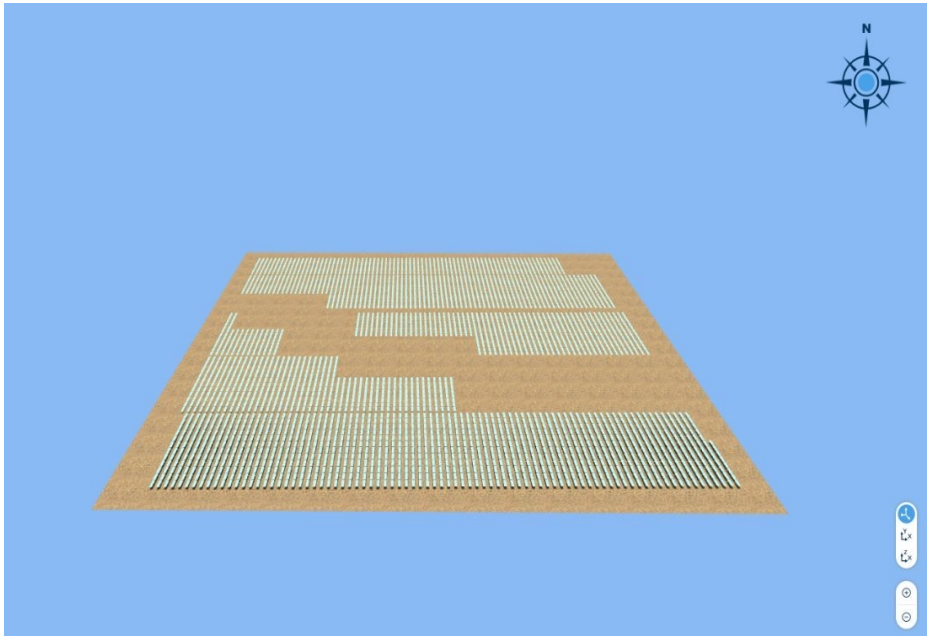
Mild Terrain



Terrain	Value
Avg. E/W Slope between 2 tracker piles	8.2°
Max N/S Slope in 1 tracker (end to end)	8.5°
Max N/S Articulation (pile to pile)	0°

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Flat Terrain



Terrain	Value
Avg. E/W Slope between 2 tracker piles	0°
Max N/S Slope in 1 tracker (end to end)	0°
Max N/S Articulation (pile to pile)	0°

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System

- Desert Center, CA
- 15 MWdc
- Horizontal Single Axis Tracker
- Backtracking (GCR based)
- 40% GCR

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Caveats

- No shading due to terrain
- No electrical mismatch losses
- Shading is on beam portion only

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Energy Lost Due to Near Shading Excluding Mismatch [%]

Terrain	No Bin	1/1	10/20
Original (Terrain Following)	15.26	15.22	14.86
Complex (Terrain Following)	10.50	10.52	10.23
Medium (Terrain Following)	5.46	5.48	5.42
Mild (Standard)	4.47	4.48	4.42
Flat	2.08	2.08	2.08

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Error Metrics of Shade Fraction at Different Bin Widths

Bin Width: 1 degree zenith, 1 degree azimuth

Terrain	MBE [%]	RMSE [%]	R^2
Original (Terrain Following)	-0.0030	0.0019	0.99998
Complex (Terrain Following)	-0.0001	0.0024	0.99997
Medium (Terrain Following)	0.000002	0.0025	0.99997
Mild (Standard)	0.00004	0.0026	0.99997
Flat	0.0	0.0	1.0

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Error Metrics of Different Bin Widths

Bin Width: 10 degrees zenith, 20 degrees azimuth

Terrain	MBE [%]	RMSE [%]	R^2
Original (Terrain Following)	-0.0027	-0.028	0.996
Complex (Terrain Following)	-0.0035	-0.024	0.997
Medium (Terrain Following)	-0.0063	0.0341	0.995
Mild (Standard)	-0.0081	0.0597	0.985
Flat	0.0	0.0	1.0

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Conclusions

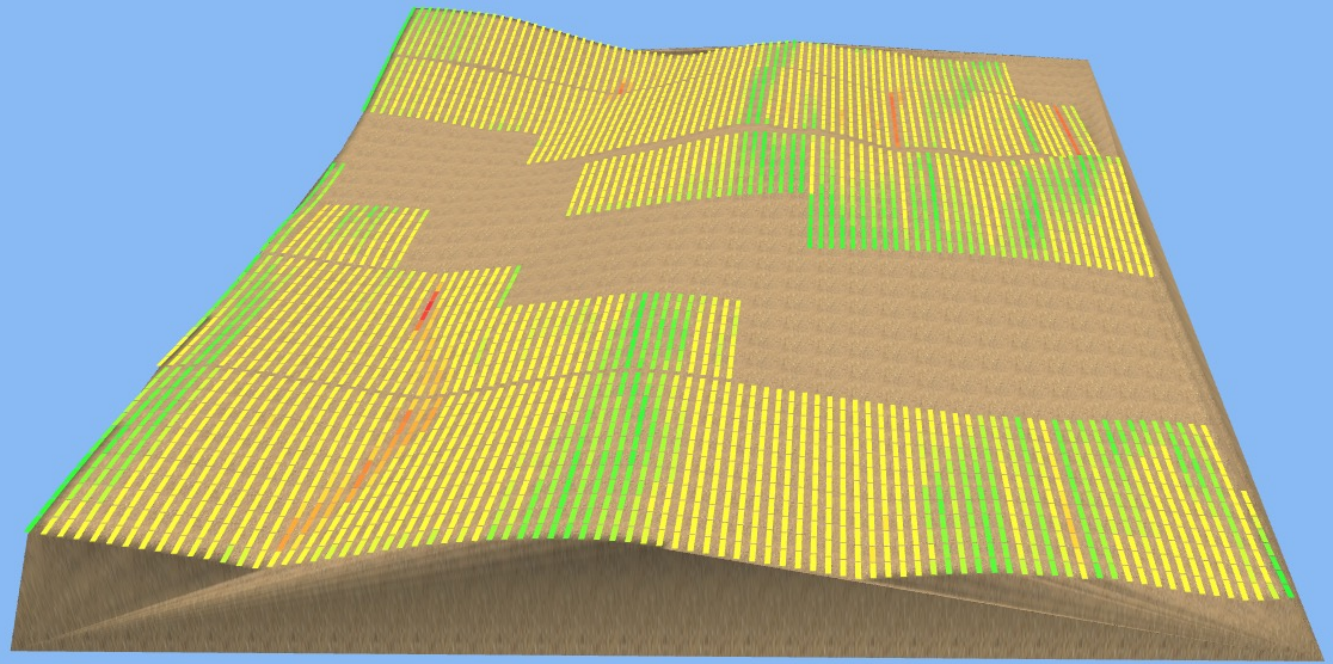
- Coarse bin width (10/20) should be sufficient for medium terrain or less
  - This may not be true for scenes with thin shade objects

- Fine bin width (1/1) should be sufficient for all terrain scenarios.

- As-built geometry is critical for quantifying shade losses.

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Thank You!



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