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Evaluating Energy Gains on Intelligent Tracker Control Algorithms with Alternating A-B Tests

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Outline

1. Introduction
   - SmarTrack Platform Features
   - Alternating A-B Test

2. SmarTrack Field Validation Examples
   - SmarTrack Backtracking
   - SmarTrack Diffuse

3. Conclusion

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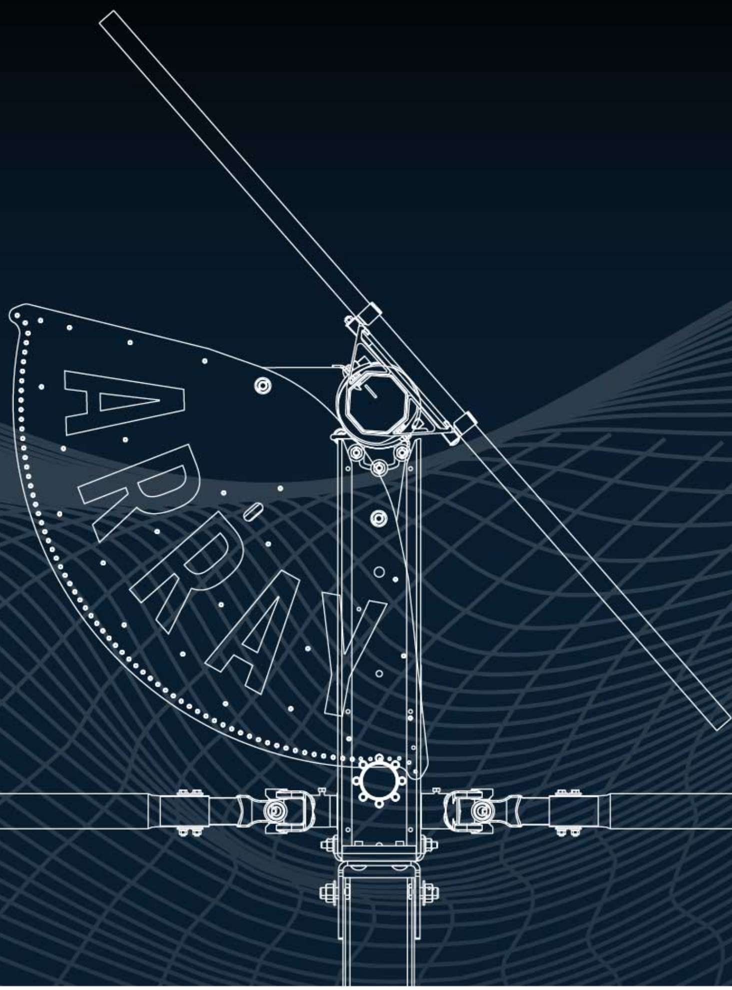
Introduction: SmarTrack and Alternating Test



SmarTrack^{TM} Platform Features

SmarTrack Backtracking

an alternative backtracking model that considers the site slope and row-height variations, combined with a procedure to learn the model parameters.

SmarTrack Diffuse

a unique algorithm that detects persistently cloudy conditions and moves trackers to a flatter position to increase irradiance on the modules.

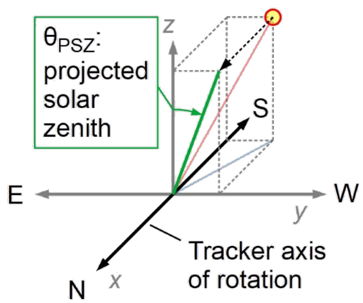
The Backtracking Problem

- Backtracking is used on single-axis trackers to avoid row-to-row shading when the sun is low.
- The generic backtracking developed in 1990s does not consider the site slope or the row-height variations.

$$R = \theta_{PSZ} - \Delta R$$

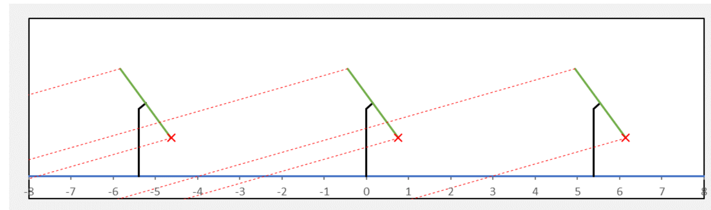
$$\Delta R = \cos^{-1}\left(\frac{\cos\theta_{PSZ}}{GCR}\right)$$

R:	Tracker angle
θ_{PSZ}:	Projected solar zenith; Sun angle projected to tracker axis plane
ΔR:	Backtracking angle
GCR:	Ground coverage ratio

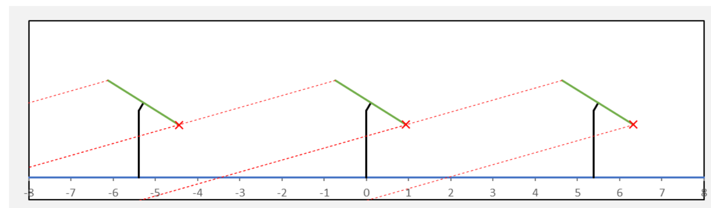


- Neglecting these features results in shading some rows during the backtracking hours.
  => Energy losses compared to flat + perfect construction case

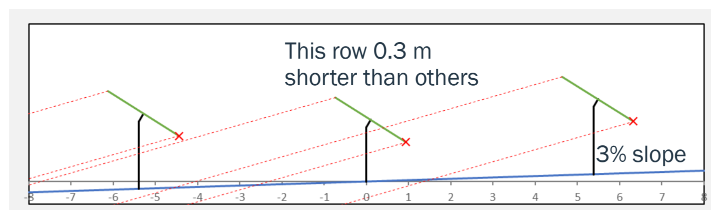
No Backtracking: All rows shaded when sun is low



Generic Backtracking on an Ideal Site: No rows shaded



Generic Backtracking on a Real Site: Some rows shaded



Three Backtracking Strategies

Baseline

Generic backtracking model, layout row spacing

- Does not take effect of slope into account
- Will cause shading loss upslope, AOI losses downslope

Commissioned

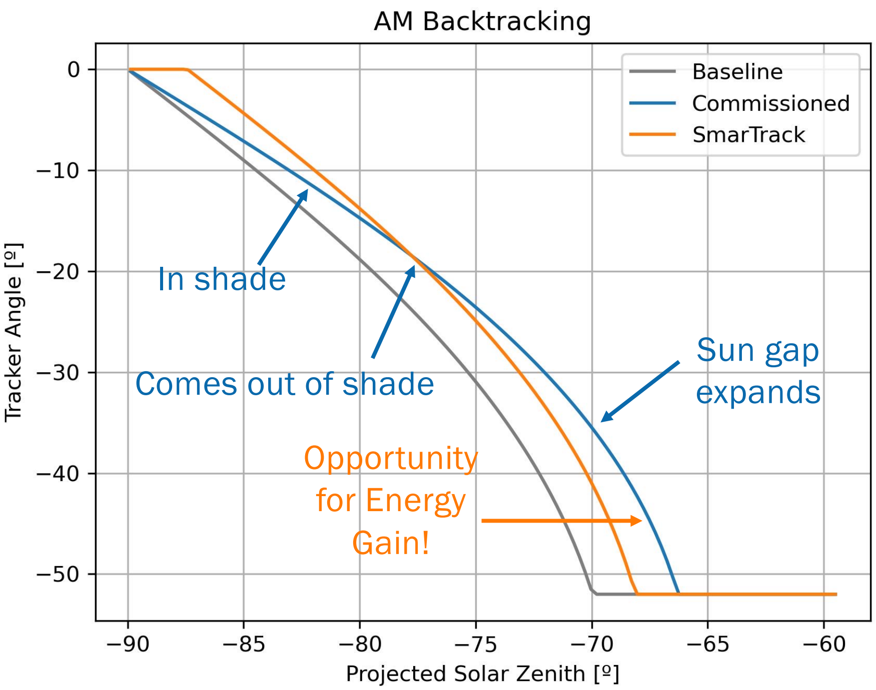
Generic backtracking model, adjusted row spacing

- Avoid shade by adjusting AM/PM row spacings manually

SmarTrack

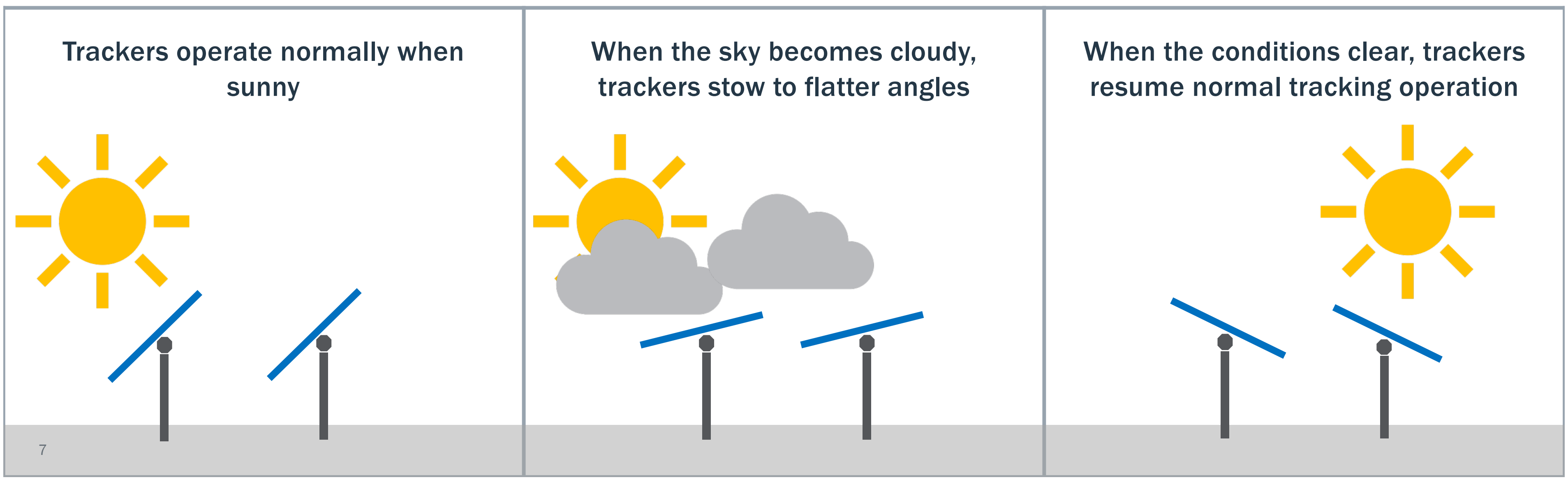
Slope-aware backtracking model, layout row spacing

- Model accounts for cross-axis slope and row-height variations
- Automatic "learning" of optimum inputs per Array's proprietary algorithm
- No additional hardware required



Principles of SmarTrack Diffuse

- Under cloudy conditions, tilting trackers to flatter angles may improve energy production.
- SmarTrack Diffuse applies irradiance decomposition and transposition to on-site GHI measurements to determine when to stow at flatter angles.
- Other factors are considered to minimize the risk of false positives.



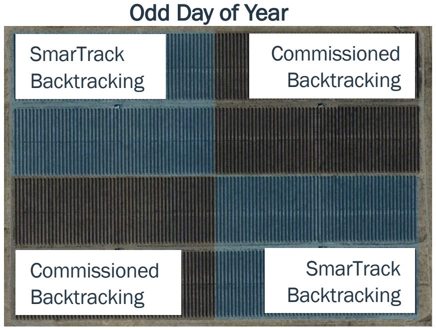
Energy Comparison by Alternating A-B Tests

- Inverters on the site are divided into "Even" and "Odd" groups.
- Each inverter alternates between two modes of operation based on day of year.
- The alternating operation nulls out inverter-to-inverter and motor-block-to-motor-block differences.

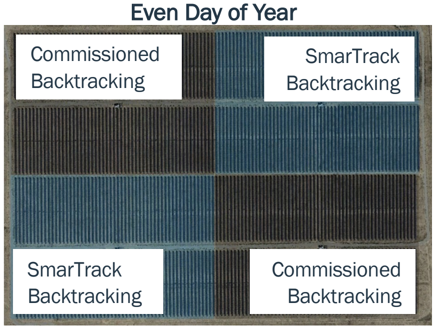
SmarTrack Backtracking

Day of Year	Odd Inverters	Even Inverters
Odd	SmarTrack Backtracking	Commissioned Backtracking
Even	Commissioned Backtracking	SmarTrack Backtracking

Odd Day of Year



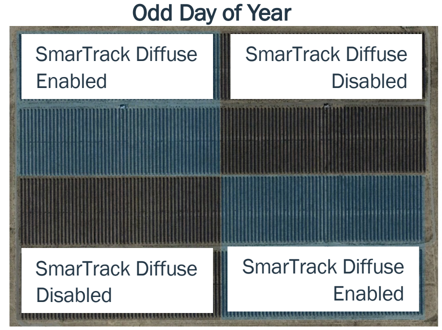
Even Day of Year



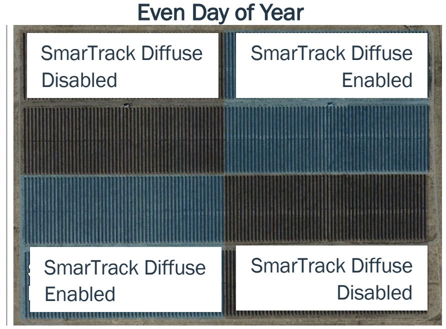
SmarTrack Diffuse

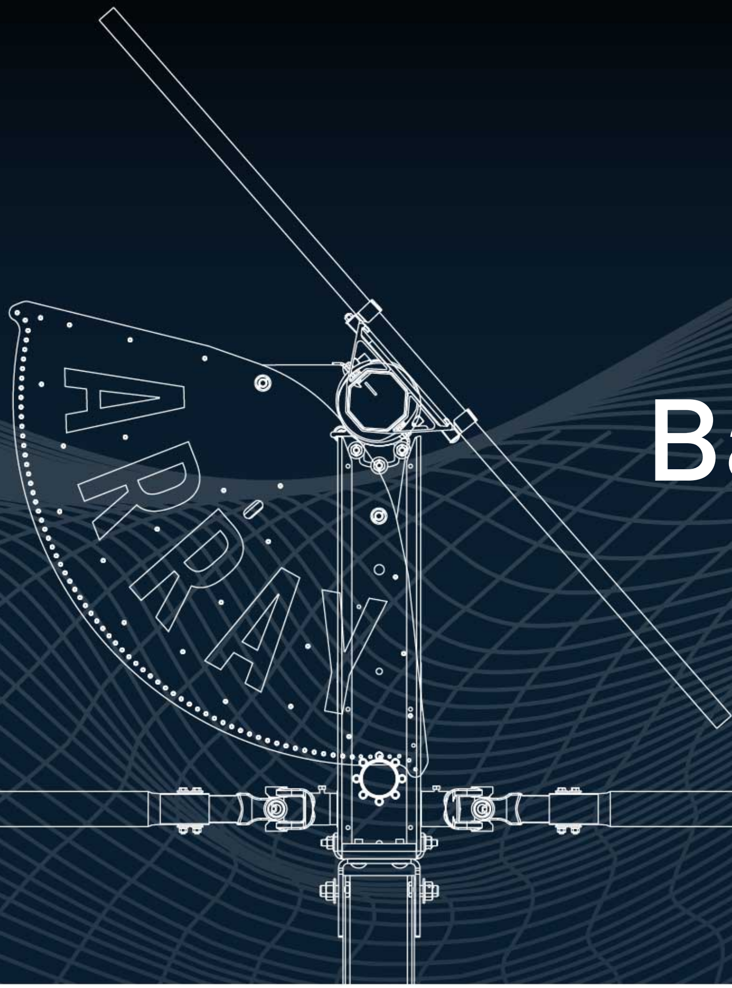
Day of Year	Odd Inverters	Even Inverters
Odd	SmarTrack Diffuse Enabled	SmarTrack Diffuse Disabled
Even	SmarTrack Diffuse Disabled	SmarTrack Diffuse Enabled

Odd Day of Year



Even Day of Year





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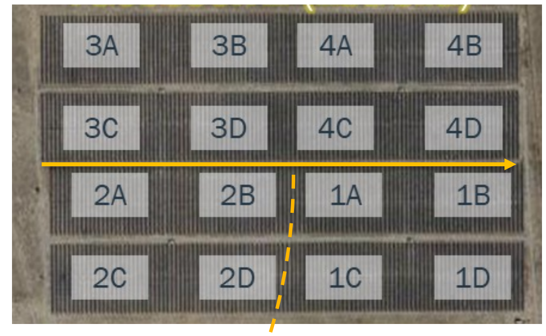
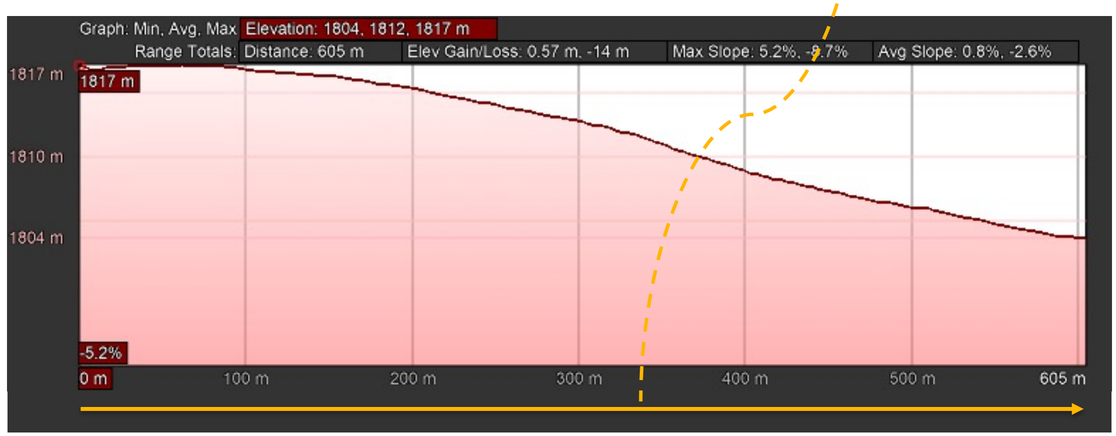
SmarTrack Backtracking Field Evaluation

Backtracking Evaluation Overview

- **Location:** Albuquerque, NM
  - Annual diffuse fraction: ~0.26
- **Site Details:**
  - 12.5 MW_{dc}, 1.25 DC:AC ratio, 36% GCR
  - 16 motor blocks, 4 central inverters
  - Array DuraTrack® HZ v3 trackers
  - Slope ~2% downhill to East
- **Learning Period:**
  - Completed in 15 days (mixed weather)
- **Test Period:** September–October 2020
  - 15 days total
  - 14 days excl. 1 day of inverter issues
- **Data Collected (30s interval):**
  - Inverter input DC voltage + current, AC power
  - Weather data (from an on-site met station, incl. 1 GHI pyranometer)
  - Tracker data





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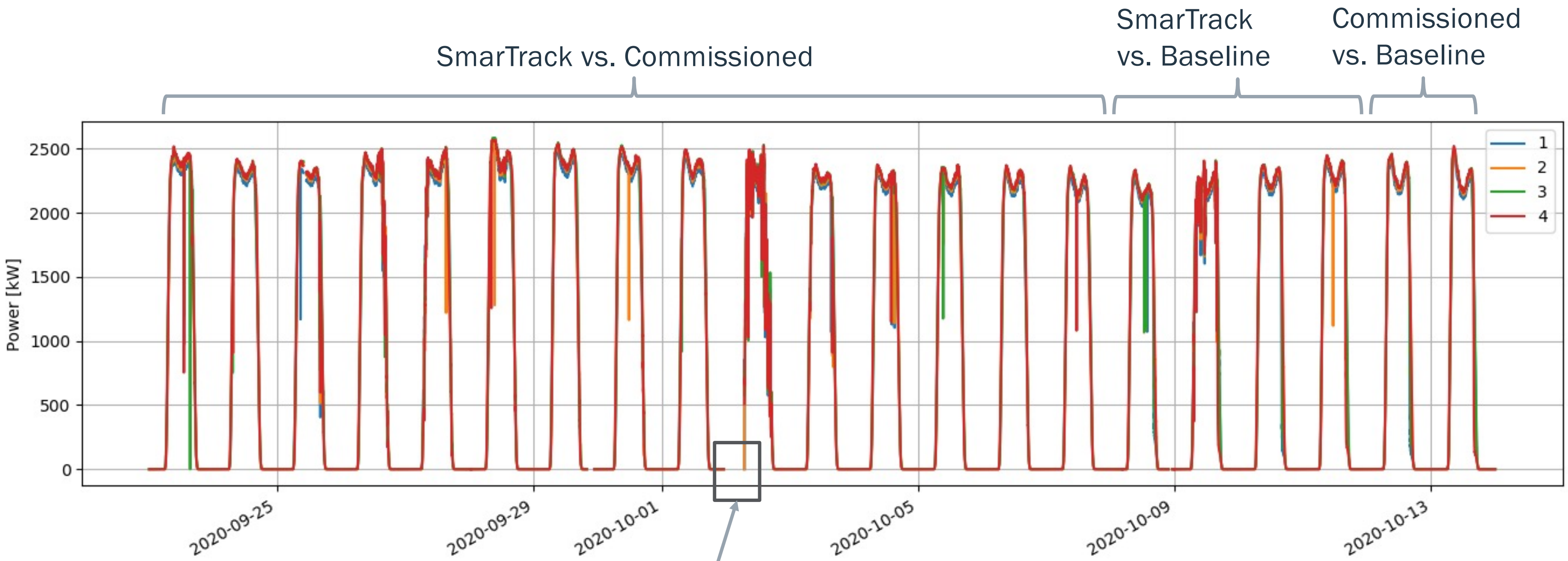
Evaluation-Period Data



Data partially missing due to communication issues; 10/2 excluded from analysis

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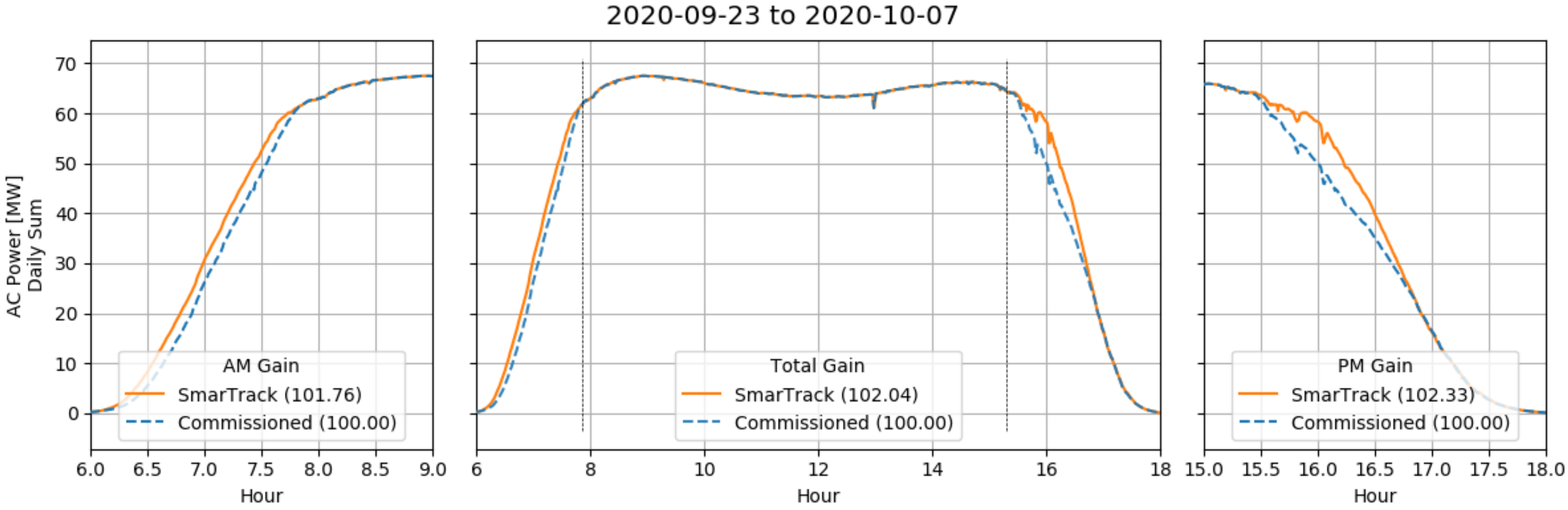
SmarTrack vs. Commissioned

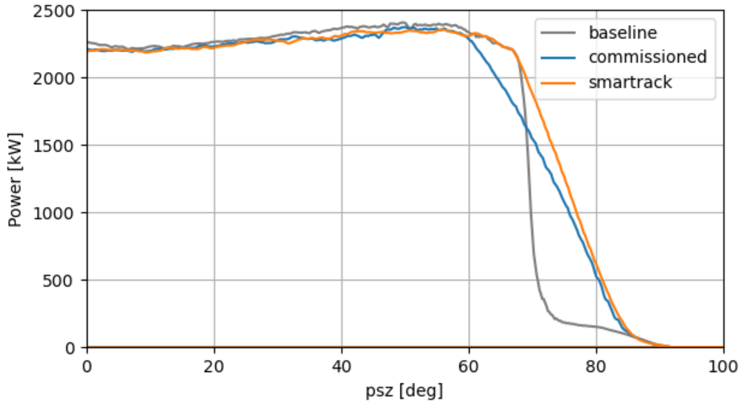
$$Energy\ Gain = \frac{Cumulative\ Production\ by\ SmarTrack\ Inverters}{Cumulative\ Production\ by\ Commissioned\ Inverters} - 1$$

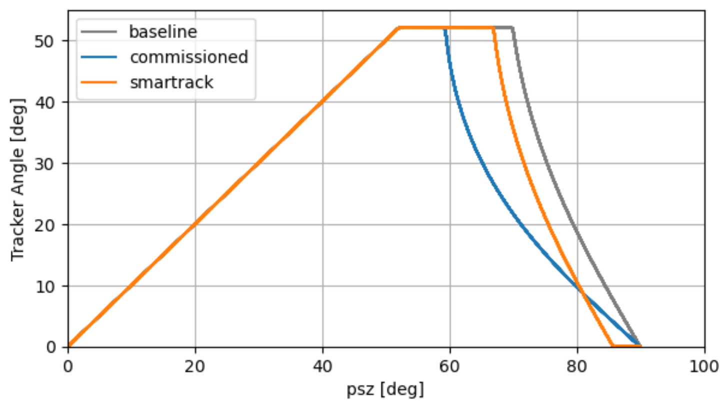
Energy gain observed = 2.04%



SmarTrack vs. Commissioned vs. Baseline

Comparison	Evaluation Period	Observed Gains
SmarTrack / Commissioned	09/23–10/07 (15 days)	+2.04 %
Commissioned / Baseline	10/12–10/13 (2 days)	+2.53 %
SmarTrack / Baseline	10/08–10/11 (4 days)	+4.42 %





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Commissioned Backtracking

As-Commissioned Operation

No module shading, but uncaptured sunlight apparent in bands on the ground.

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SmarTrack Backtracking

Still no module shading, but SmarTrack optimizes sunlight capture with little to no light visible on the ground.

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SmarTrack vs. Commissioned Backtracking

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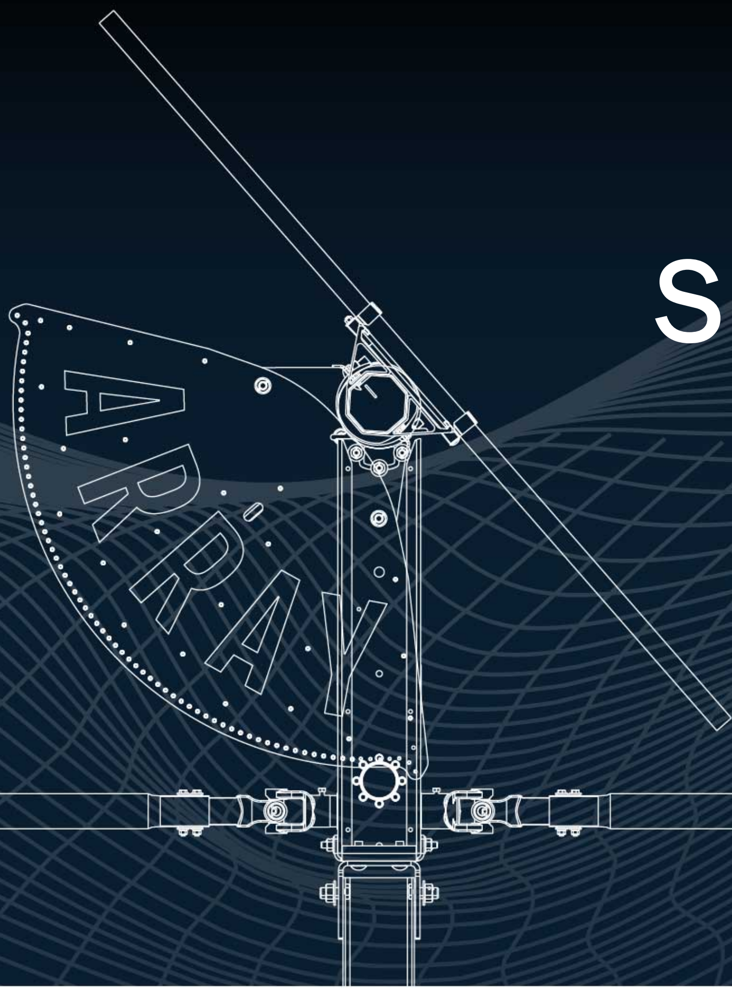
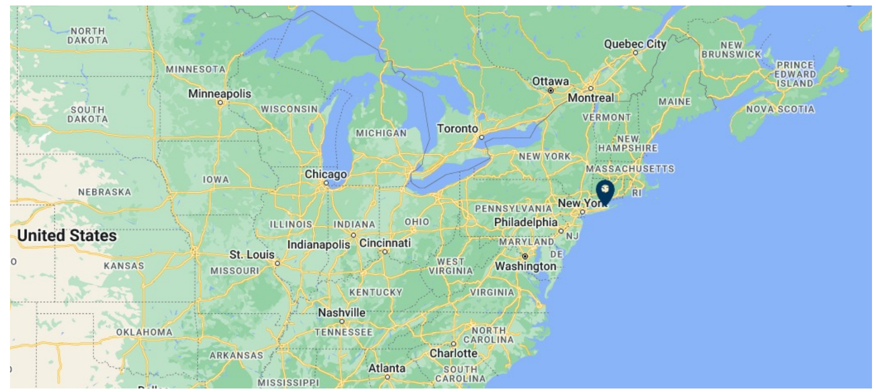
SmarTrack Diffuse Field Evaluation



Diffuse Evaluation Overview

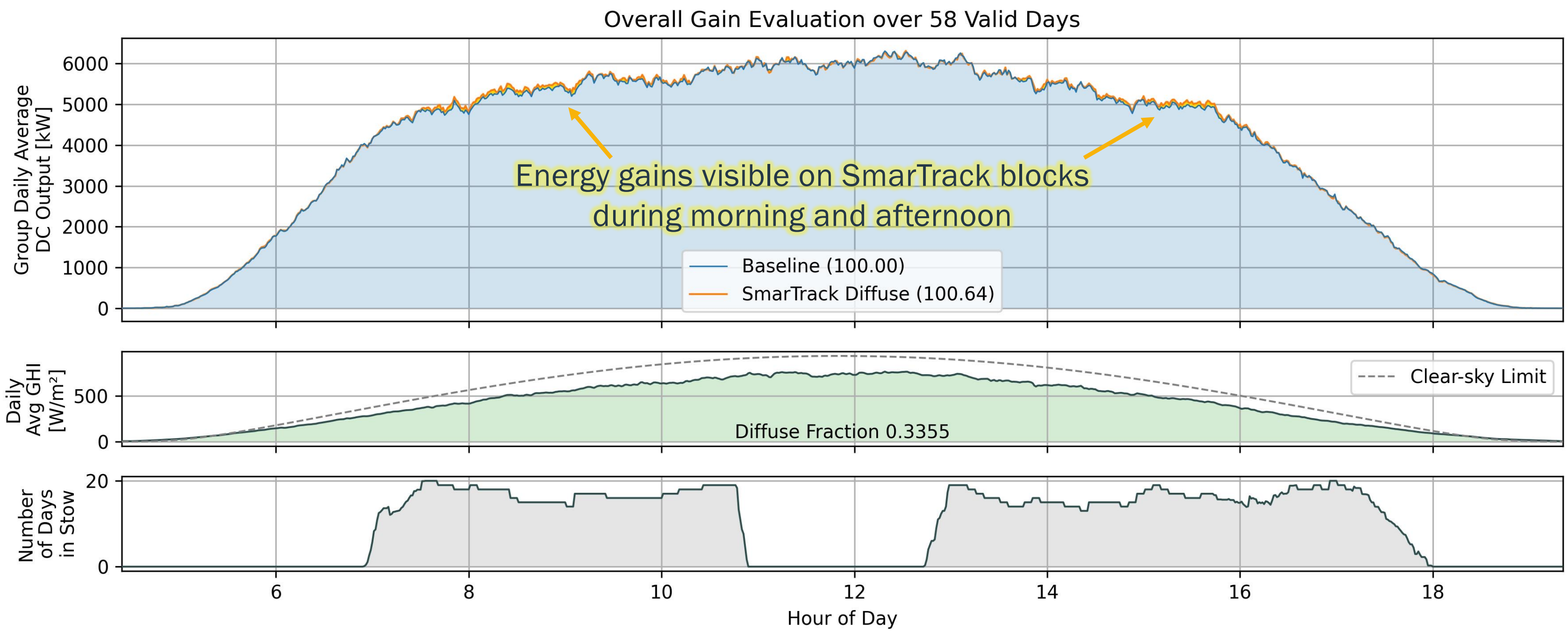
- **Location:** New York, USA
  - Annual diffuse fraction: 0.30–0.40
- **Site Details:**
  - 23 MW_{dc}, 1.05 DC:AC ratio, 44% GCR
  - 7 central inverters total, 6 for evaluation
  - Array DuraTrack® HZ v3 trackers
- **Test Period:** April–July 2021
  - 68 days total
  - 58 days excl. 10 days of inverter issues
- **Data Collected (1-min interval):**
  - Inverter input DC voltage + current, AC power
  - Weather data (from on-site met stations, incl. two GHI pyranometers)
  - Tracker data



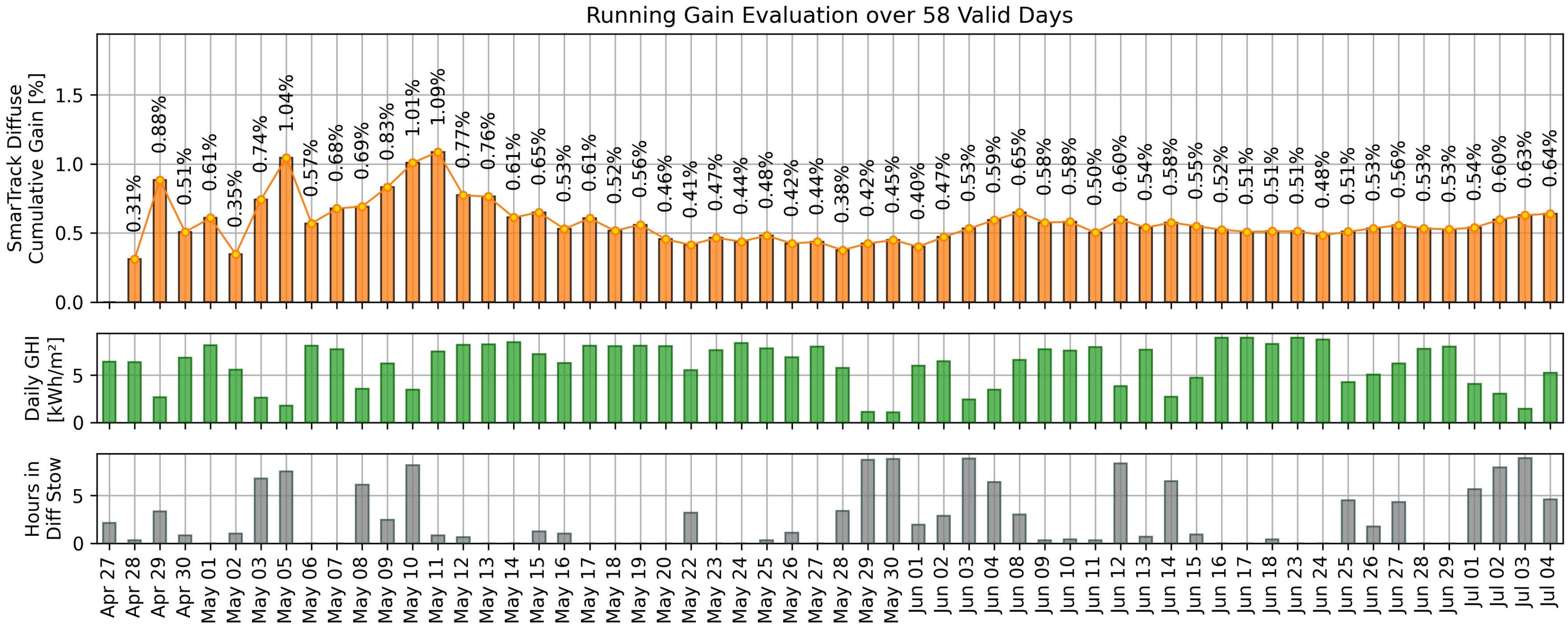
Evaluation Results – Total Energy Gain

$$Energy\ Gain = \frac{Cumulative\ Production\ by\ SmarTrack\ inverters}{Cumulative\ Production\ by\ Baseline\ inverters} - 1$$

Energy gain observed = 0.64%

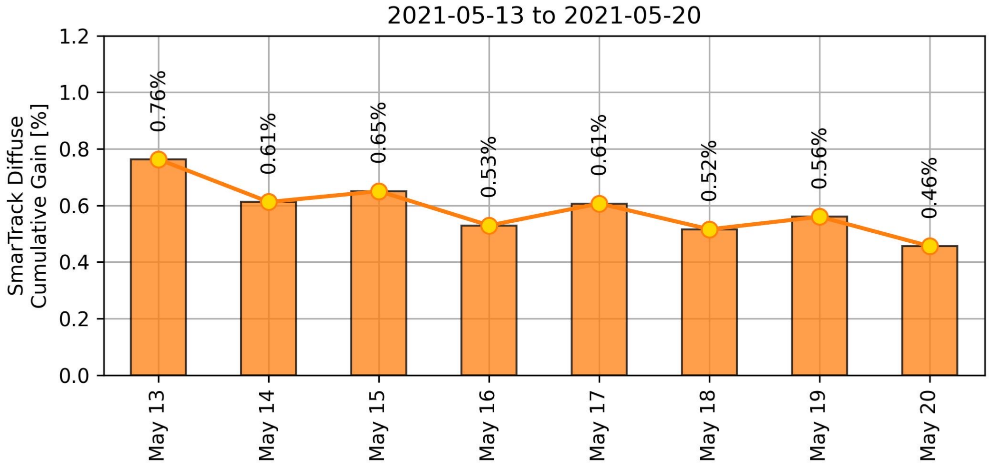


Evaluation Results – Daily Cumulative Gain

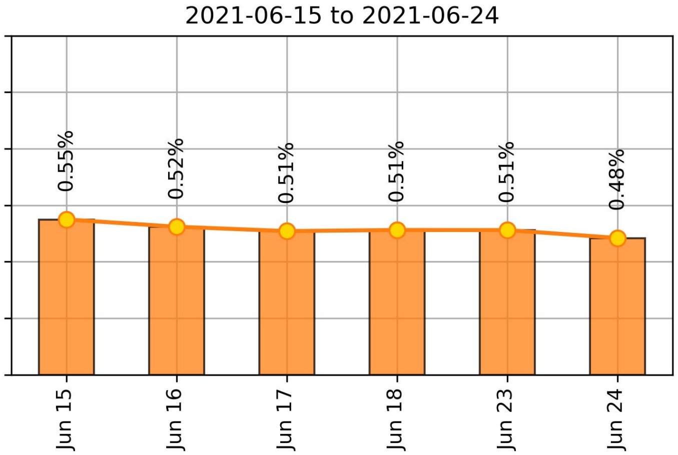


Canceling Out DC Differences with Alternating A-B Tests

- Group-to-group DC differences are a major source of uncertainty in PV energy studies.
- The DC differences cause "oscillations" in the daily cumulative gain from the alternating test.
- As more data accumulates, however, the oscillations become smaller.



Oscillations ~ ±0.09 %p



Oscillations ~ ±0.01 %p

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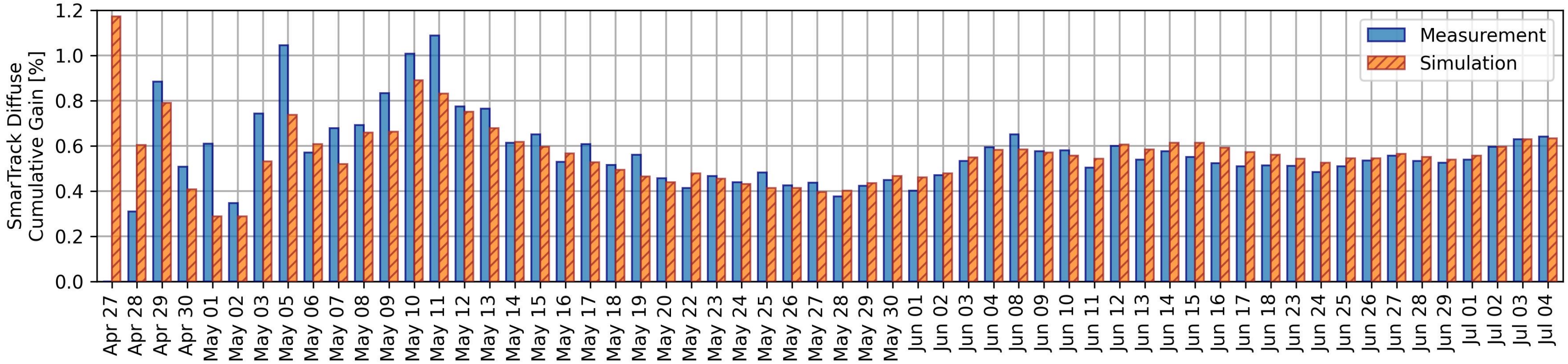
Simulation of Field Evaluation Test

- PlantPredict (www.plantpredict.com) allows sub-hourly simulation and custom tracker angles.
- Measured weather data + DC field matching test site + custom tracker angles per Baseline or SmarTrack Diffuse algorithm => Simulation of field evaluation
- PlantPredict simulations predicted 0.63% overall energy gain for the field evaluation period. We achieved 0.64%.



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Conclusion

- The alternating A-B test is an effective strategy to validate gains in performance due to operational differences on a site.
- This test is particularly successful at cancelling out group-to-group differences in DC production as data accumulates.
- This work showed successful use of the test for:
  - SmarTrack Backtracking, an alternative backtracking model with learned parameters that accounts for site slope and row-height variations. A significant gain, 2.04%, was observed over Commissioned backtracking for a utility-scale sloped site in NM.
  - SmarTrack Diffuse, a tracker control algorithm designed to increase energy production under diffuse conditions. Measurable energy gains of 0.64% were observed during a field evaluation test at a utility-scale NY site.


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Supplementary

Predicting Gains via Modeling

Representative Inverter Pair Selection

- Choose a pair of inverters whose SmarTrack-to-Commissioned gain is close to the site-wide value.

Build Performance Model

- Power plant components & design matched to as-built
- Validate with evaluation-phase data

Annual Performance Simulation

- Use TMY data as weather input

PLANTPREDICT

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Predicted vs Observed Gains (Evaluation Period)

Comparison	Observed Gains	Predicted Gains
SmarTrack / Commissioned	+1.96 %	+2.42% (0.46 pp overestimate)
Commissioned / Baseline	+2.43 %	+3.21% (0.78 pp overestimate)
SmarTrack / Baseline	+4.26 %	+5.77% (1.51 pp overestimate)

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Annual Gain Estimates

- **Weather data:** TMY3 for Albuquerque International Sunport

Comparison	Annual Gains	Annual Gains, Corrected
SmarTrack / Commissioned	+1.93 %	+1.47% (1.93–0.46)
Commissioned / Baseline	+2.25 %	+1.47% (2.25–0.78)
SmarTrack / Baseline	+4.21 %	+2.70% (4.21–1.51)

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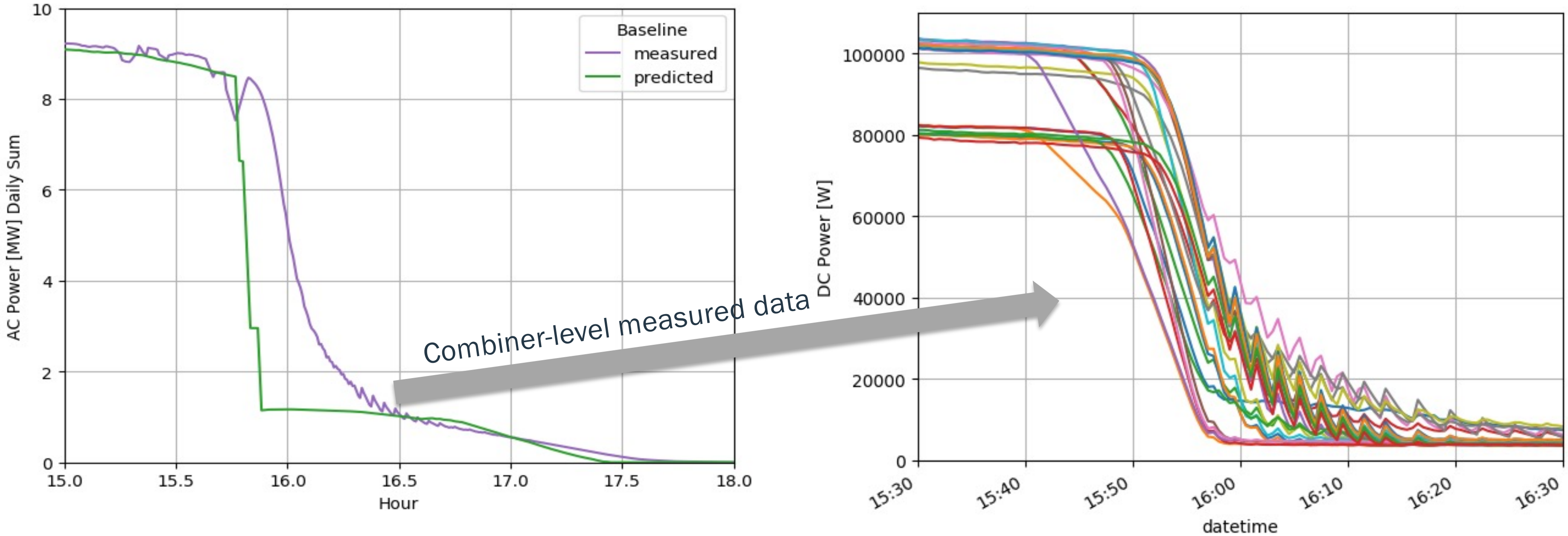
Simulating Energy Production in Shaded Case is Challenging!



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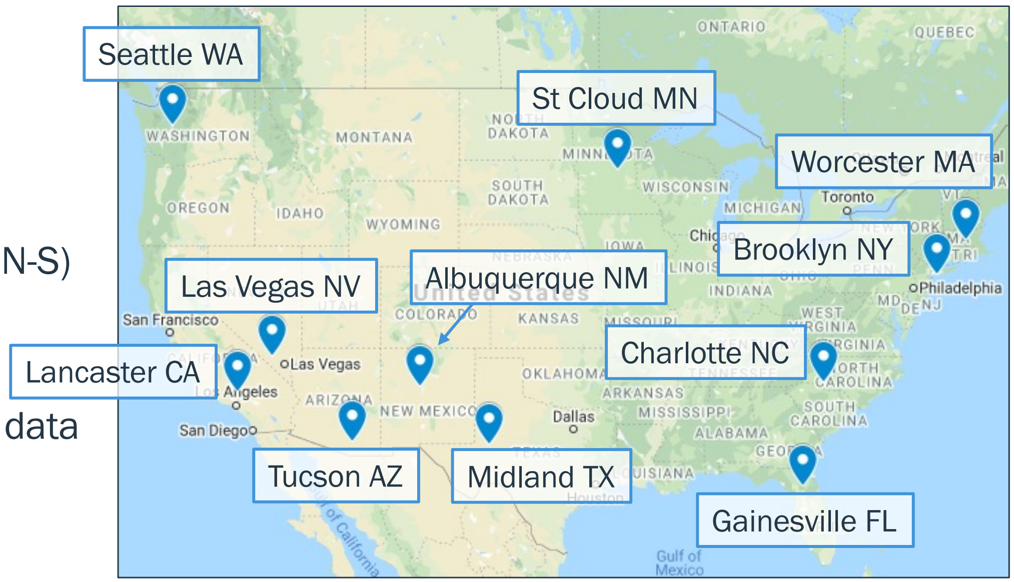
Annual Gain Estimation at Different US Locations - Method

- Simulation tool: PlantPredict
- Simulated power plant
  - 35% GCR
  - 1.25 DC:AC ratio
  - Single-axis tracker (axis orientation: N-S)
- Locations + weather data
  - 11 locations across USA
  - 5-minute resolution NSRDB PSM v3 data at each location for 2019 used as weather inputs
  - Annual diffuse fraction: 0.2 to 0.4
- Annual gain estimated by comparing AC output of Baseline and SmarTrack Diffuse tracker angle cases



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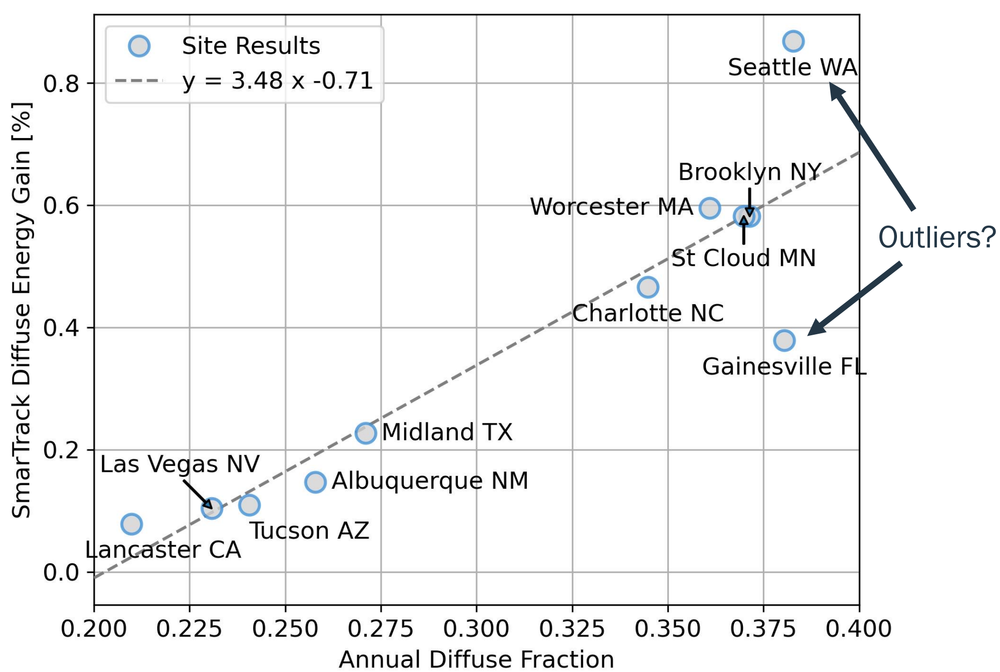
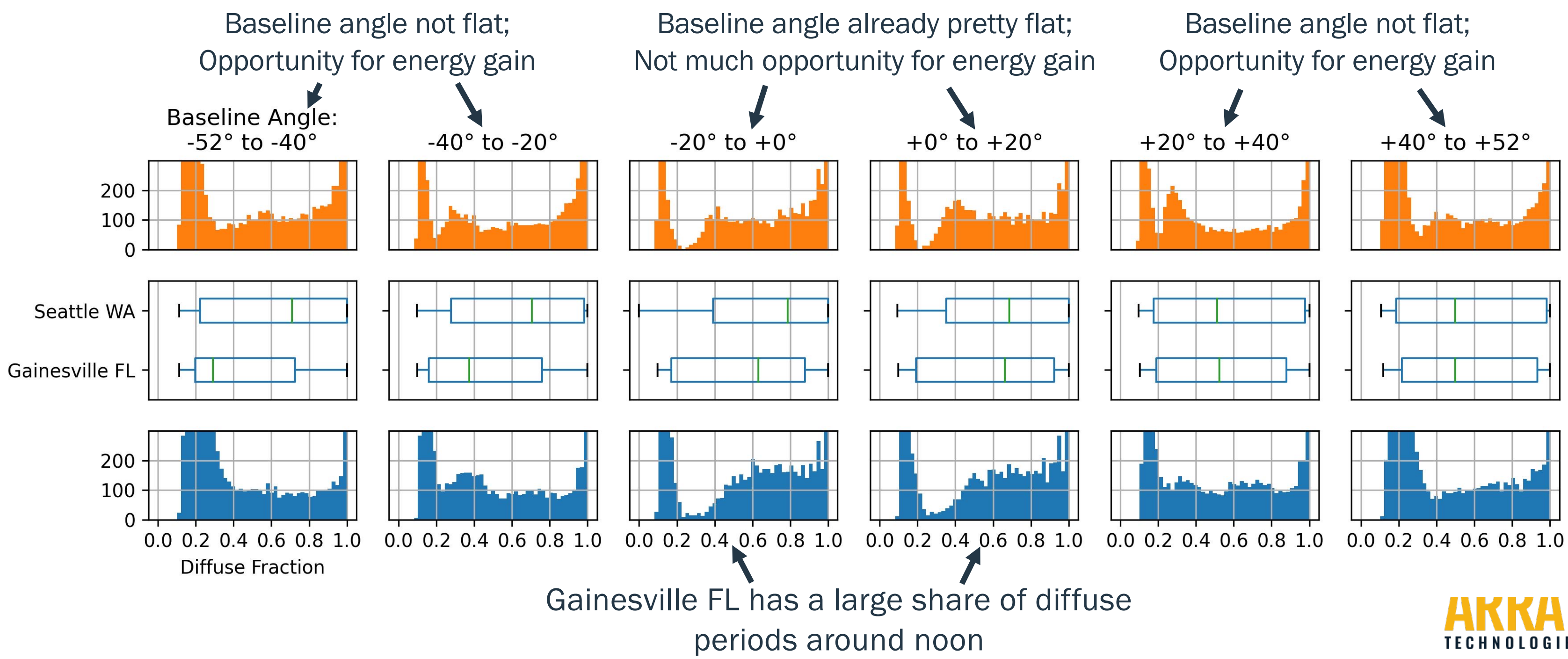
Annual Gain Estimation at Different US Locations – Results

- Expected SmarTrack Diffuse energy gain increased with increasing annual fraction.
- Nine out of 11 locations fell very close to the best-fit line.
- Seattle WA and Gainesville FL seemed to be outliers.
  - Annual diffuse fraction ~0.38 for both sites
  - Seattle WA: 0.87% gain expected
  - Gainesville FL: 0.38% gain expected



Closer Look into
Gainesville FL vs Seattle WA Weather Data

- Diffuse fraction for each 5-min period in NSRDB PSM v3 data binned per Baseline tracker angle



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