A Reproducible Validation of Algorithms for Estimating Array Tilt and Azimuth from Photovoltaic Power Time Series

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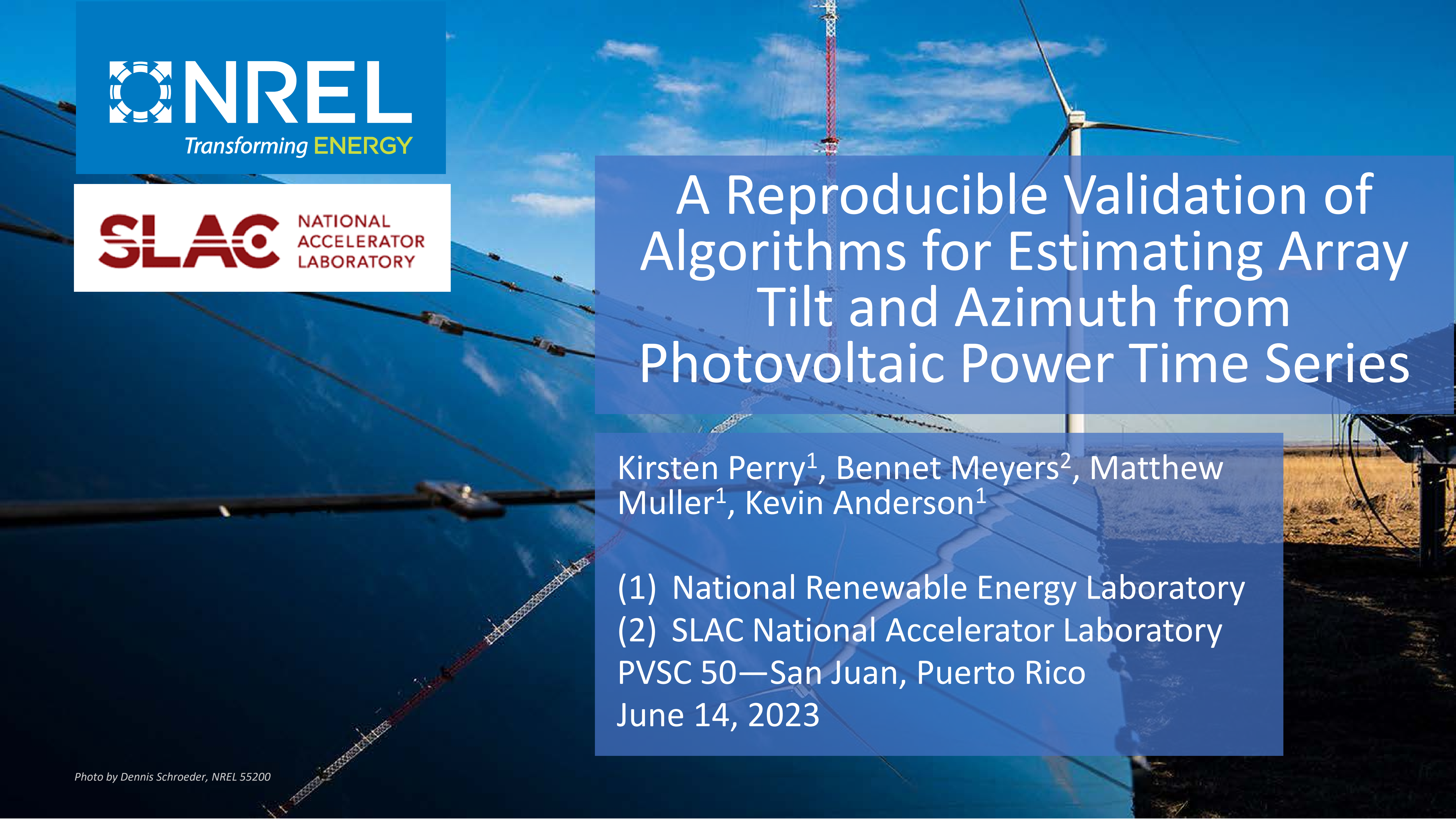


Photo by Dennis Schroeder, NREL 55200

Background

- Average 33% annual growth in solar industry [1]
- Solar metadata lost during acquisitions
  - Leading residential installer: 500,000 systems
- Metadata: tilt, azimuth, mounting configuration, etc
- Manual entry **OR** costly site inspections
- **Why is having accurate metadata important?**
  - Expected energy yield and degradation rates

Azimuth and tilt on a solar installation

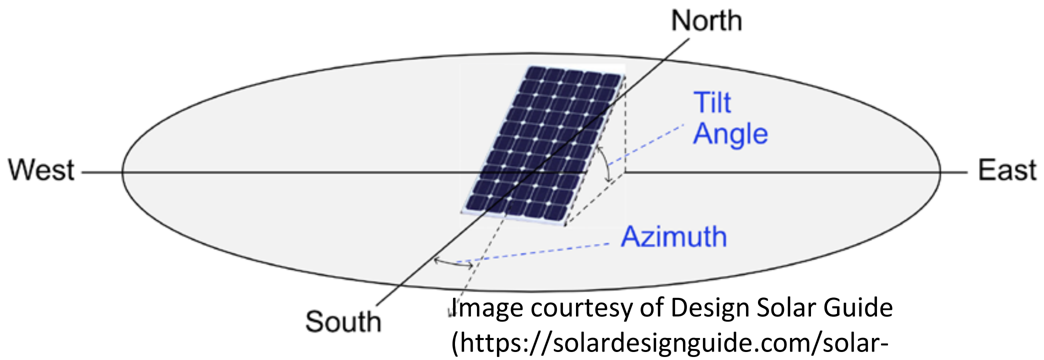


Image courtesy of Design Solar Guide (https://solardesignguide.com/solar-panel-tilt-and-azimuth/)

[1] "US Solar Market Insight," Solar Energy Industries Association (SEIA), 2022

Motivations

- Several time series algorithms exist to estimate the azimuth and tilt of a PV system [1,2,3]
- **A lot of existing research but it's disjointed**
    - Difficult to replicate results
    - No standardized data sets, process, or results
- Benchmark 4 algorithms in Python open-source packages
    - Solar-Data-Tools: https://github.com/slacgismo/solar-data-tools
    - PVAnalytics: https://github.com/pvlib/pvanalytics

[1] Saint-Drenan et al, "An empirical approach to parameterizing photovoltaic plants for power forecasting and simulation," Solar Energy, 2015.
[2] N. Haghdadi et al, "A method to estimate the location and orientation of distributed photovoltaic systems from their generation output data," Renewable Energy, 2017.
[3] A. Londono-Hurtado et al, "Estimation of photovoltaic system location and orientation from power signals," PVSC 2021

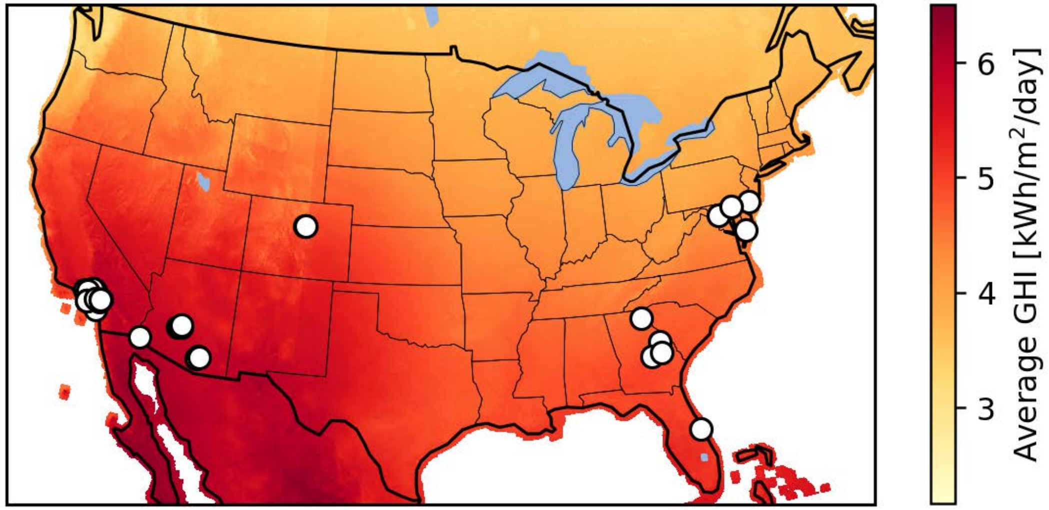
Methods

- Solar-Data-Tools (SDT): Signal decomposition framework [1,2]. Needs measured PV power signal but not lat-long coordinates. 2 variations
- PVAnalytics: 2 algorithms, require lat-long coordinates and measured PV power signal
  - PVWatts 5-based method: Compares measured power to PVWatts simulated power at varying az/tilt
  - PV-Peak method: Compares daily peak irradiance point (quadratic) to simulated clearsky POA peak irradiance at varying az/tilt

[1] A. Londono-Hurtado et al, "Estimation of photovoltaic system location and orientation from power signals," PVSC 2021
[2] B. Meyers, "PVInsight final technical report," Sep 2021.

Methods Continued

- Validation data set
  - 275 AC power inverter data streams
  - 44 fixed-tilt PV systems
  - Wide geographic distribution
  - Validated using Google Earth
  - Data stream issues: clipping, shading
- Standardized test runner for executing algorithms
  - Same computer for consistency

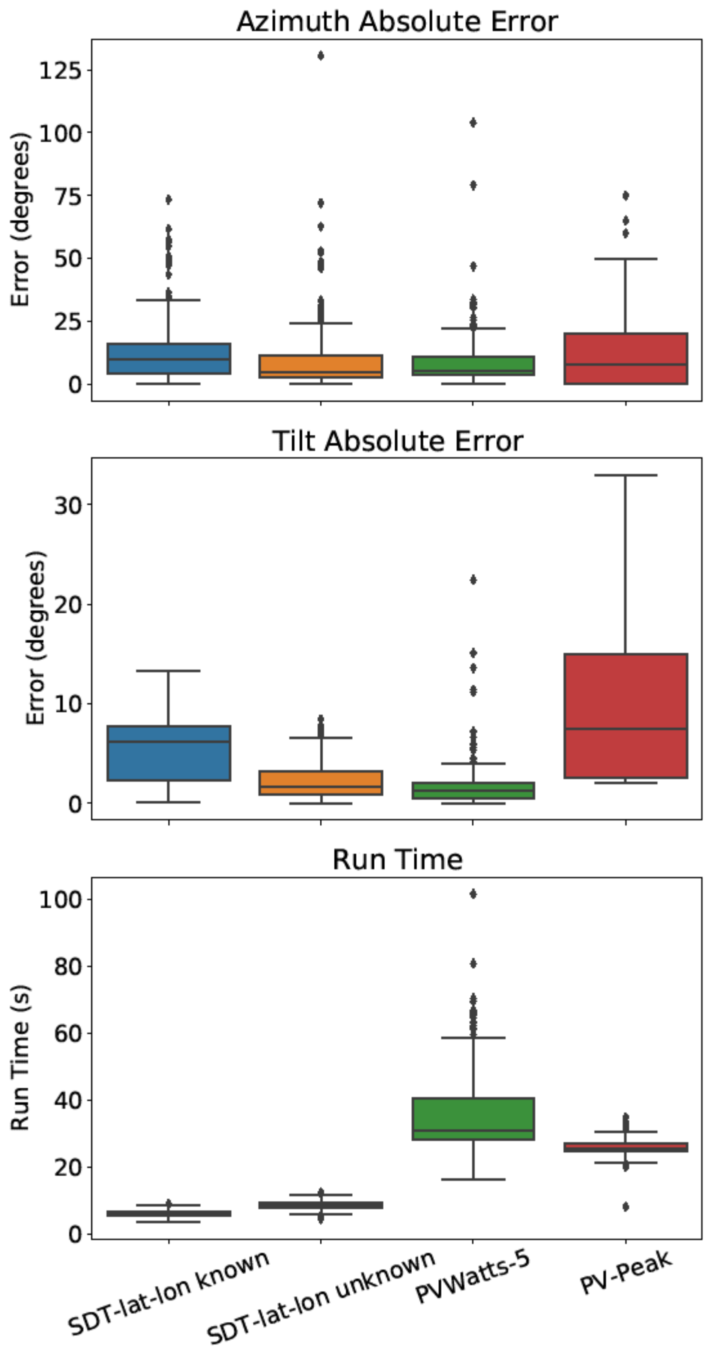


Map of PV systems used in the validation data set.

Results

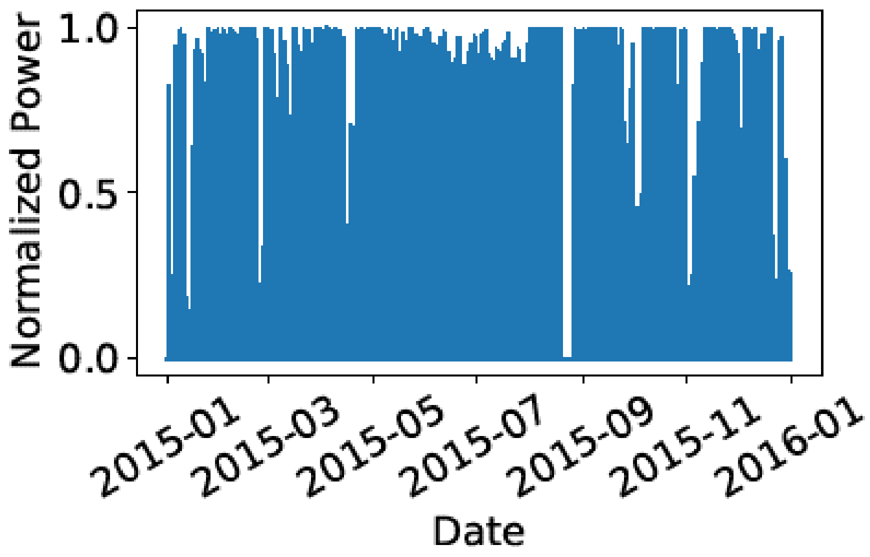
- Median absolute error: predicted vs actual tilt and azimuth
- PVWatts-based and SDT (unknown lat-long) top performers
- SDT algorithm fastest by a factor ~5x
  - PVWatts-based method requires pulling NSRDB PSM3 data

Algorithm	Median Azimuth Error (degrees)	Median Tilt Error (degrees)	Median Run Time (seconds)
SDT (lat-long known)	10.12	6.24	**6.02**
SDT (lat-long unknown)	**4.94**	1.66	8.64
PVAnalytics PVWatts-5	5.19	**1.21**	30.87
PVAnalytics PV-Peak	8	7.51	25.66



Case Study: Clipping

- System with heavy inverter clipping
- Azimuth/tilt error below
- Most algorithms relatively robust to clipping
  - Clipped data periods removed in pre-processing
  - PV-Peak: high tilt error



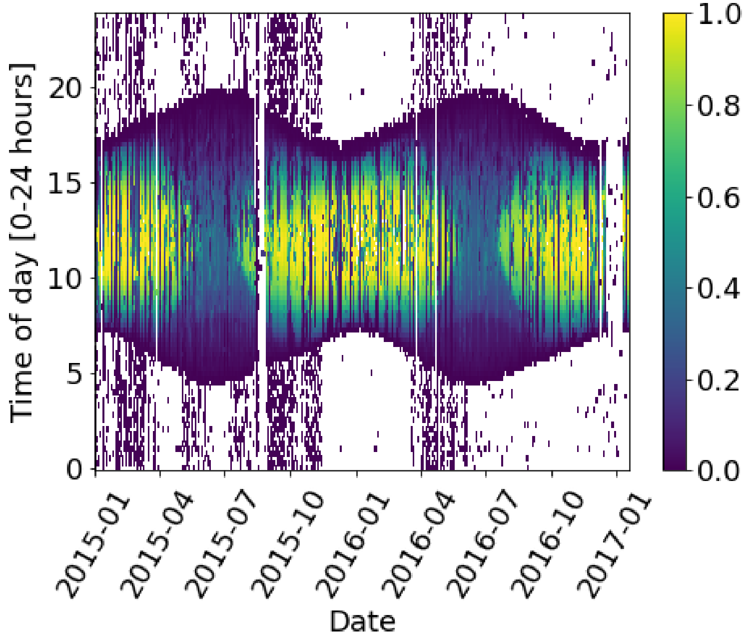
AC power signal of heavily clipped system

Algorithm	Azimuth Absolute Error (degrees)	Tilt Absolute Error (degrees)
SDT (lat-long known)	5.32	9.49
SDT (lat-long unknown)	4.57	2.52
PVAnalytics PVWatts	7.33	2.08
PVAnalytics PV-Peak	0	23

Case Study: Shading

- Heavily shaded system
  - Located on side of parking garage on NREL campus
  - High tilt: 60 degrees
- All algorithms robust at estimating azimuth (low error)
- High tilt error for PVWatts model (~22 degrees)
- Higher tilt error for most algos compared to median

Algorithm	Azimuth Absolute Error (degrees)	Tilt Absolute Error (degrees)
SDT (lat-long known)	0.88	7.99
SDT (lat-long unknown)	0.45	5.72
PVAnalytics PVWatts-5	0.41	22.44
PVAnalytics PV-Peak	0	5

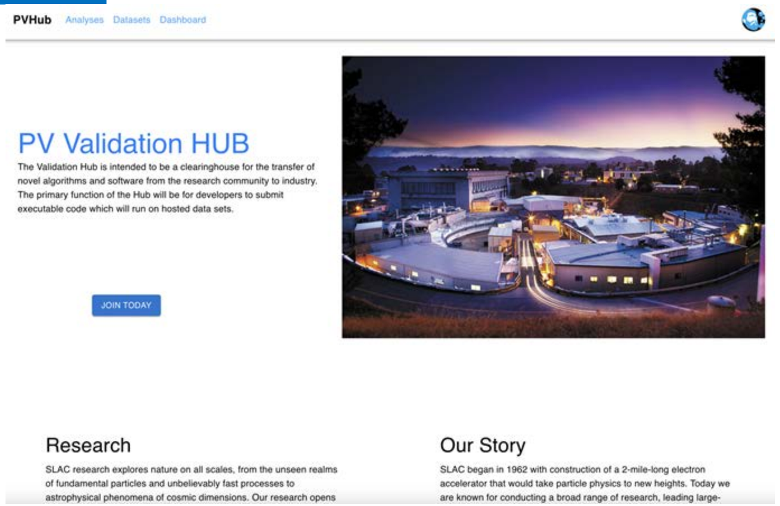


PV power heatmap for an inverter stream in heavily shaded system

Integration into PV Validation Hub

- **How does this research play into the bigger picture?**
- Analysis and data sets incorporated into the PV Validation Hub
  - Website for validating PV analytics algorithms
    - *Degradation, soiling, time shift estimation, etc.*
  - Well-curated validation data sets and procedures
  - Side-by-side comparison of different algorithms
  - Public leaderboards and documentation
  - Expected public launch date: end of 2023

PV Validation Hub main web page



Take PV Validation Hub survey here:

Thank you!

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