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RdTools: An Open Source Python Library for PV Degradation Analysis

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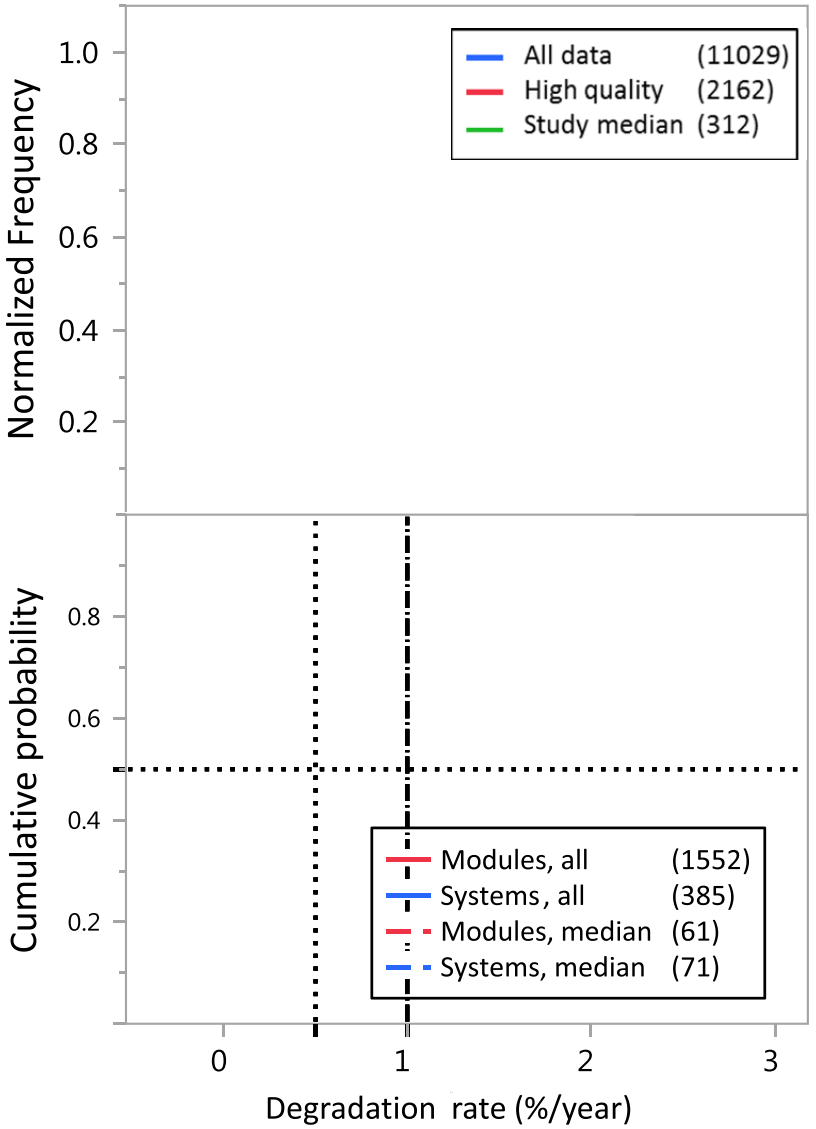
What degradation rate should I use?

pvlcoe.nrel.gov

Improving consistency

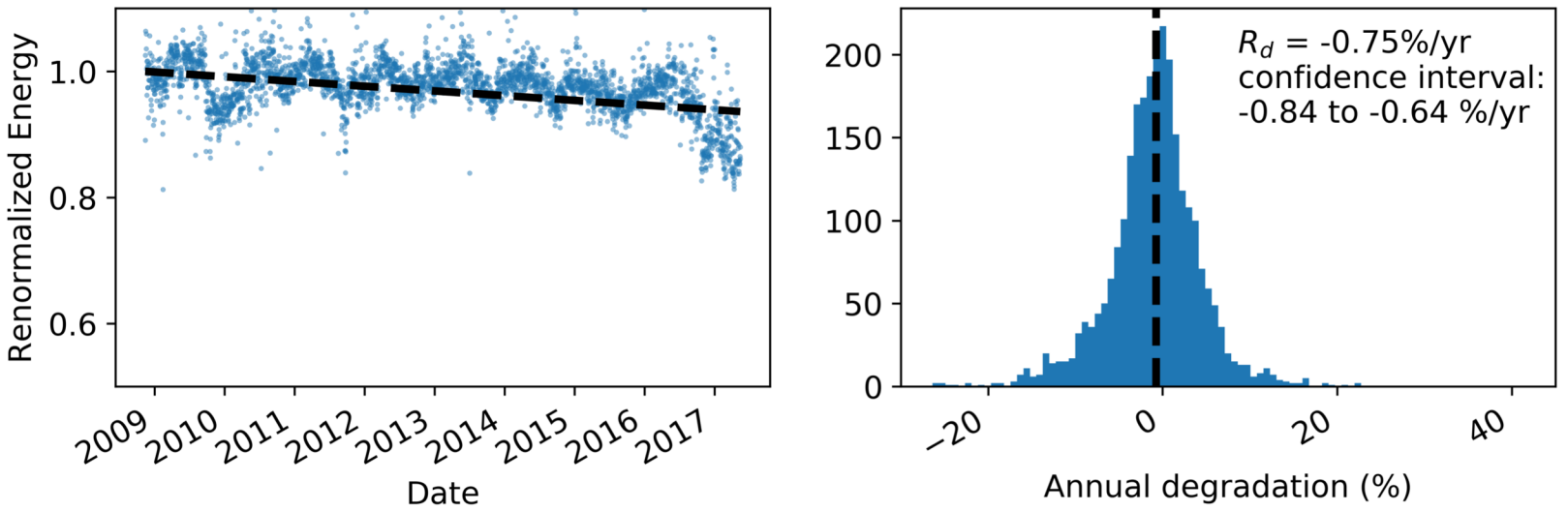
- The literature includes a variety of methods
  - Hard to draw large-scale conclusions
- Decisions, big and small, affect reported results



Jordan et al., "Compendium of photovoltaic degradation rates" *PIP*, *24*(7), pp.978-989, 2016

Our solution: RdTools

Time series performance data → Degradation rate and uncertainty



- Open-source python module for PV data analysis
- API built around Pandas and PVLIB
- Steps:
  - Normalize
  - Filter
  - Aggregate
  - Analyze Rd

Tool flow

System model

Weather & irradiance

PV power or energy

Normalize

PI (original frequency)

Insolation

Filter

Filtered PI

Filtered insolation

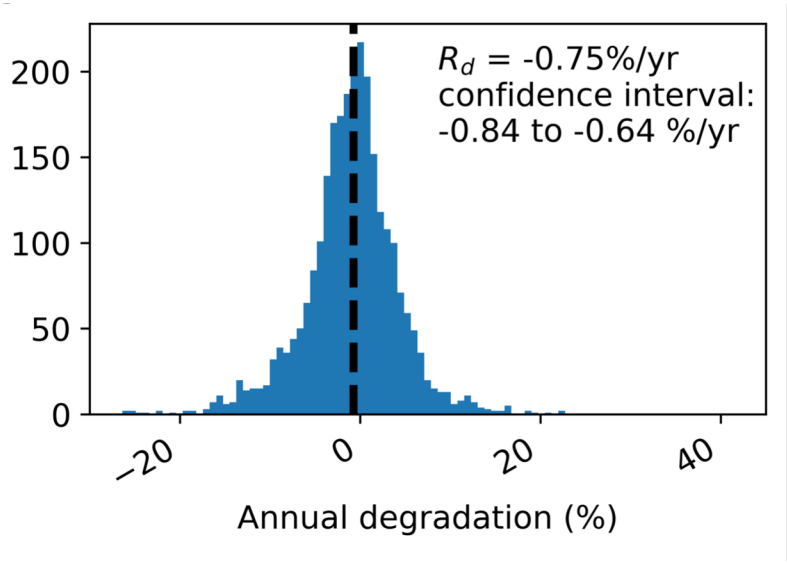
Filtered PI

Filtered insolation

Aggregate

Daily (or weekly, monthly etc.) normalized performance

Analyze Rd



pandas time series

RdTools submodule

Filtering: devil's in the details

- Currently, RdTools provides minimal filtering:
  - Irradiance, temperature, **clipping**
- System vs. module degradation?
  - Where do you draw your degradation boundaries?
  - Tracker downtime etc.?
- Room for innovation:
  - Outliers and outages without introducing bias


NREL image 44729

vs.


NREL image 40762

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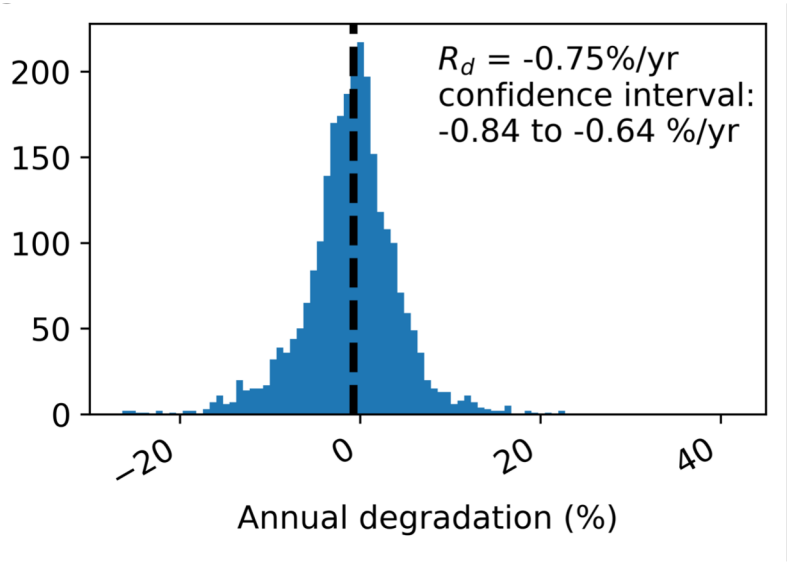
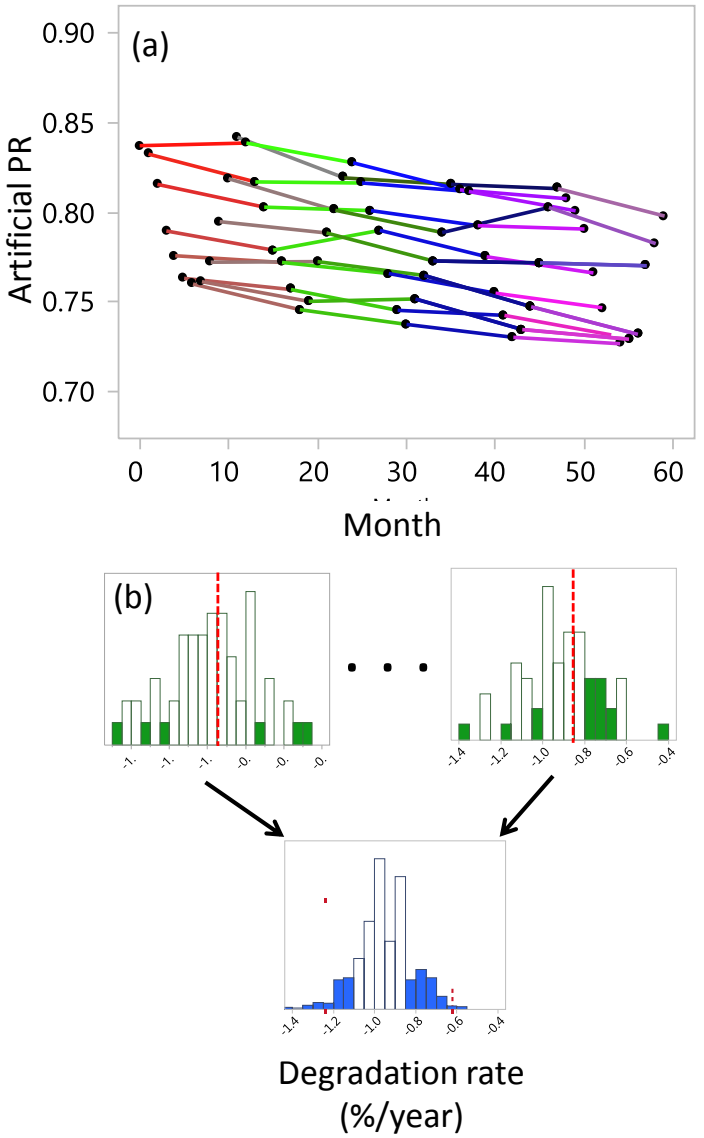


pandas time series

RdTools submodule

Rd Analysis

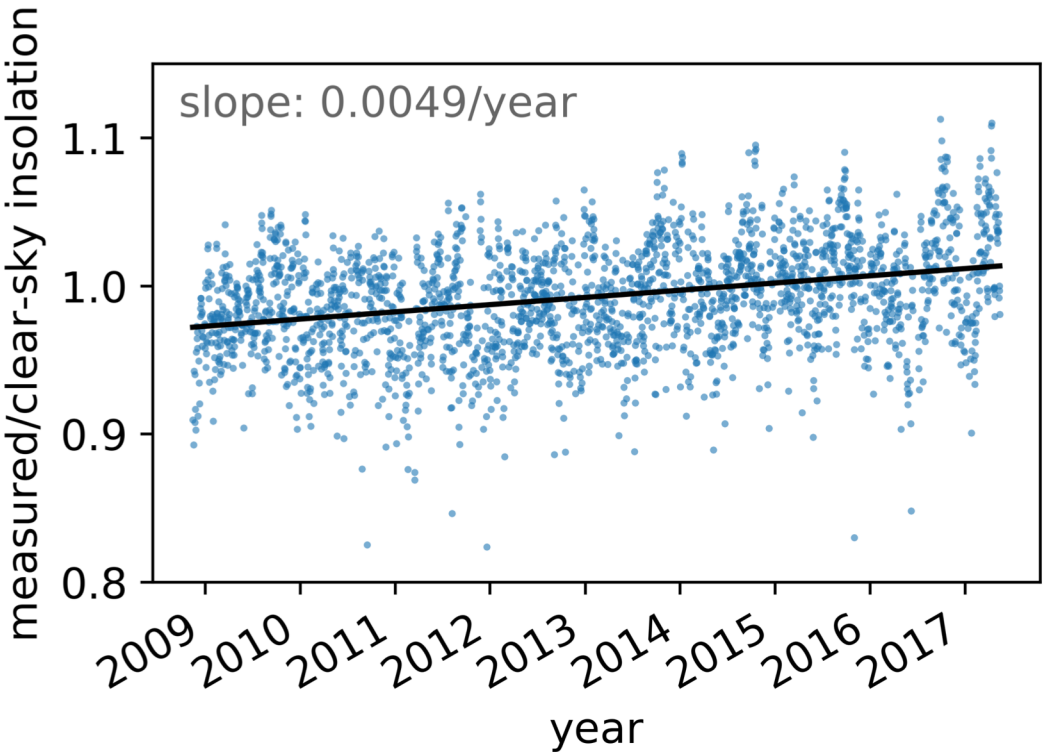
- Currently, RdTools provides three Rd calculation methods:
  - Least-squares regression
  - Classical decomposition
  - **Year-on-year**
- Year-on-year is robust to seasonality and outliers
- Don't forget the confidence interval



Jordan, Deceglie, & Kurtz. "PV degradation methodology comparison—A basis for a standard." 43rd IEEE PVSC, pp. 0273-0278. IEEE, 2016.

Challenge: Pyranometer bias over time

Irradiance sensor drifts or recalibrations cause artifacts in PI time series thus bias in Rd



ratio of measured to modeled daily insolation during clear-sky conditions

Solution: Normalize using only clear-sky times and modeled irradiance

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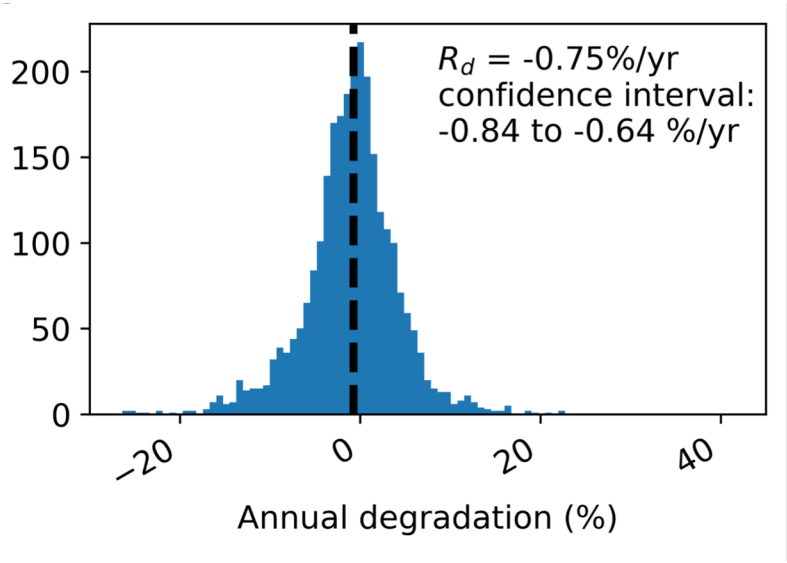

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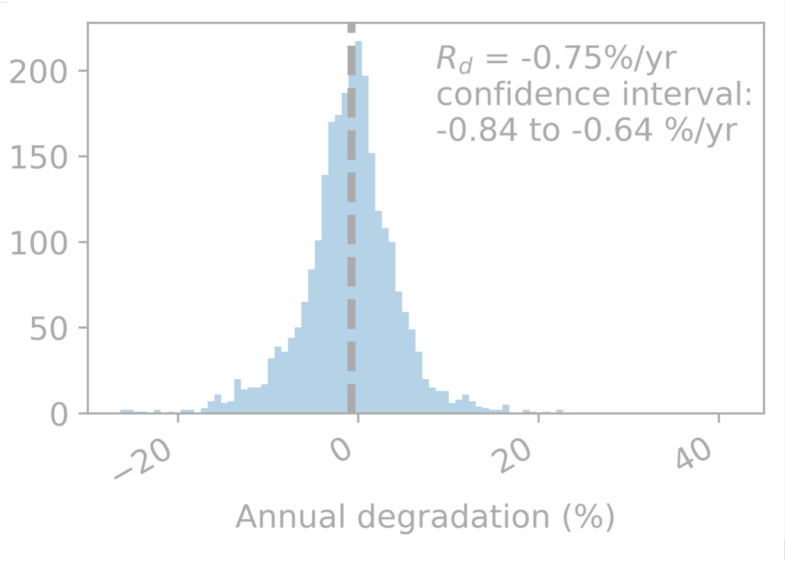
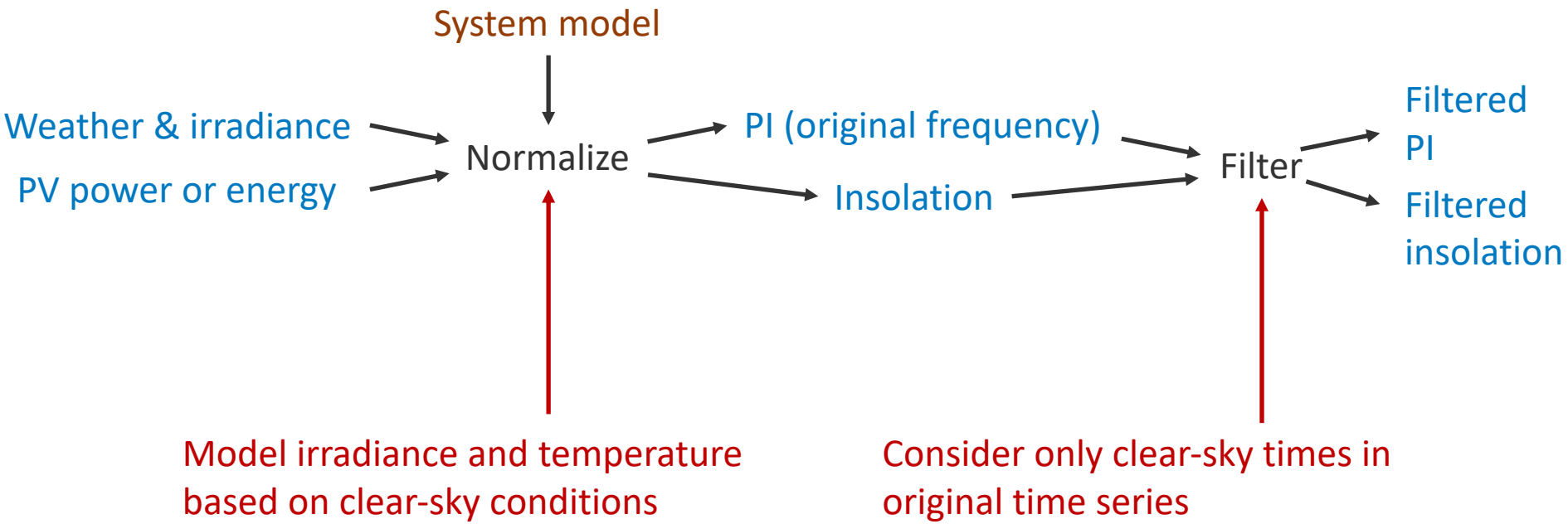


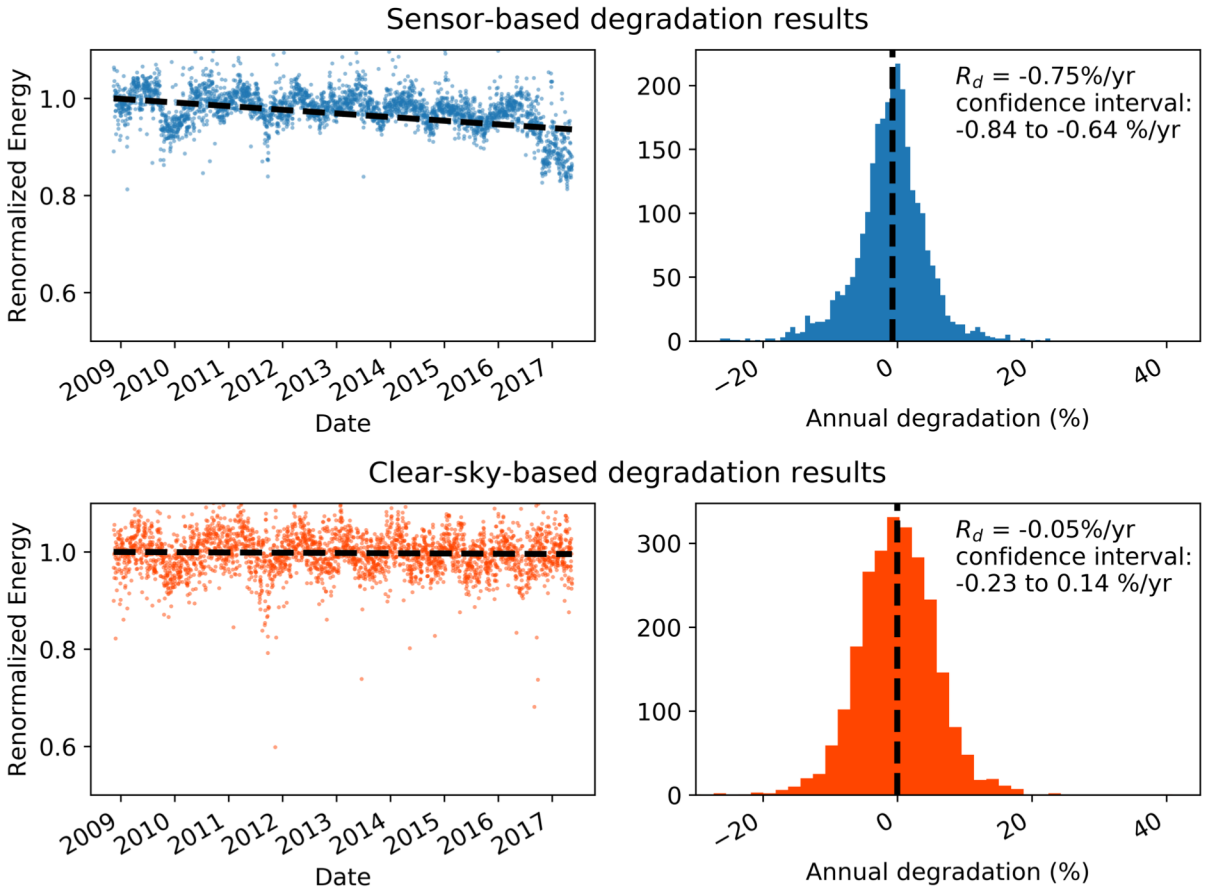
Clear sky approach



Differences between sensor-based and clear-sky

- D. Jordan et al. ”Robust PV degradation methodology and application" IEEE JPV 8(2), 2018.
- Kimball, Jordan, and Deline “Clear sky irradiance and temperature models for mitigating sensor drift in PV system degradation analysis” 8th PVPMC 2017.

Clear sky results



Clear-sky approach helps eliminate bias due to sensor drift

Conclusion

- RdTools is an open source python library for PV degradation analysis
  - Expanded analysis of outdoor performance coming soon (soiling, outages, etc.)
- Required data:
  - PV energy/power time series (several years)
  - Weather/irradiance data (consider external sources e.g. NSRDB)
- Precision over accuracy in models and measurements

- Read me and examples: https://github.com/NREL/rdtools
- install: pip install rdtools
- Contact: rdtools@nrel.gov

Thank you

- Our contributors on GitHub
- kWh Analytics
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- Anubhav Jain and Ben Ellis (LBL)
- DuraMAT Consortium

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