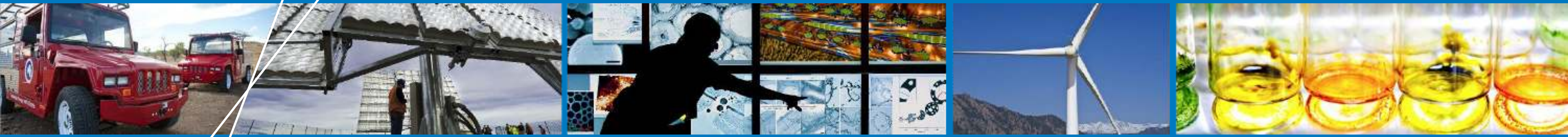
Robust PV Degradation Methodology and Application



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Washington, DC, 6/27/2017

Dirk Jordan, Chris Deline, Sarah Kurtz – NREL

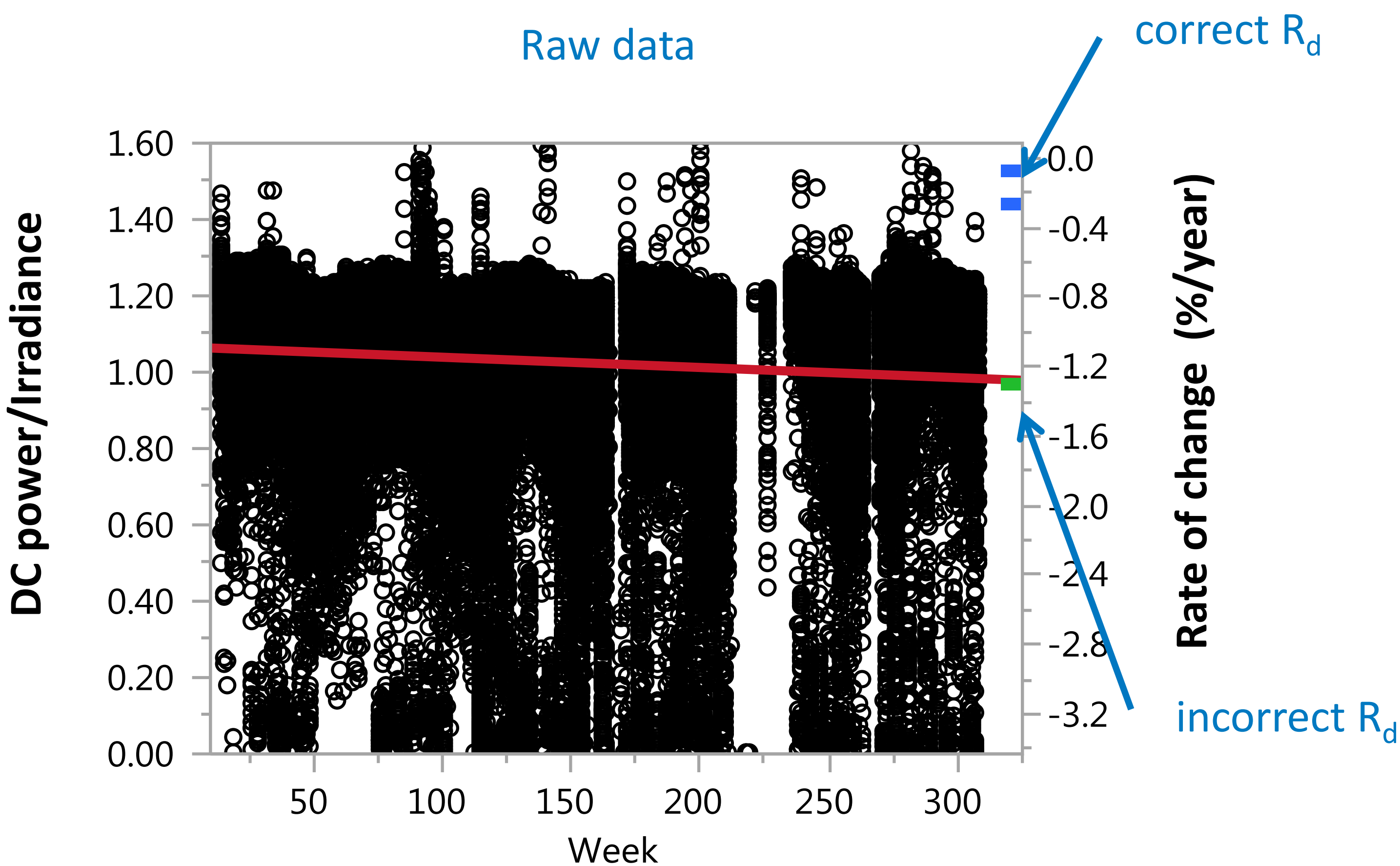
Greg Kimball and Mike Anderson - Sunpower

NREL/PR-5J00-70481

Outline

- **Motivation:** *Why "this the best since sliced bread" (1928)*
- **Method:** *How we slice the bread.*
- **Common headaches:** *Works even if the bread has problems.*
- **Findings:** *Application to different types of bread.*

Challenge of field data - low signal/noise ratio



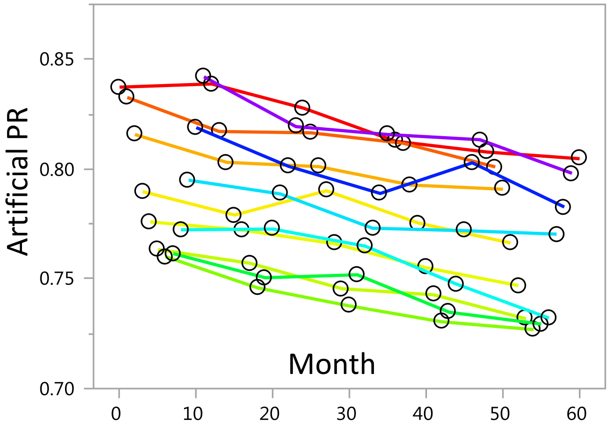
How do we do this?

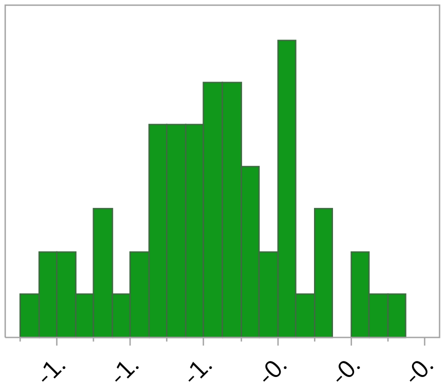
Method

How to slice the bread

Marriage of 2 ideas: Year-on-year + clear-sky

Year-on-year (YOY)[1,2]

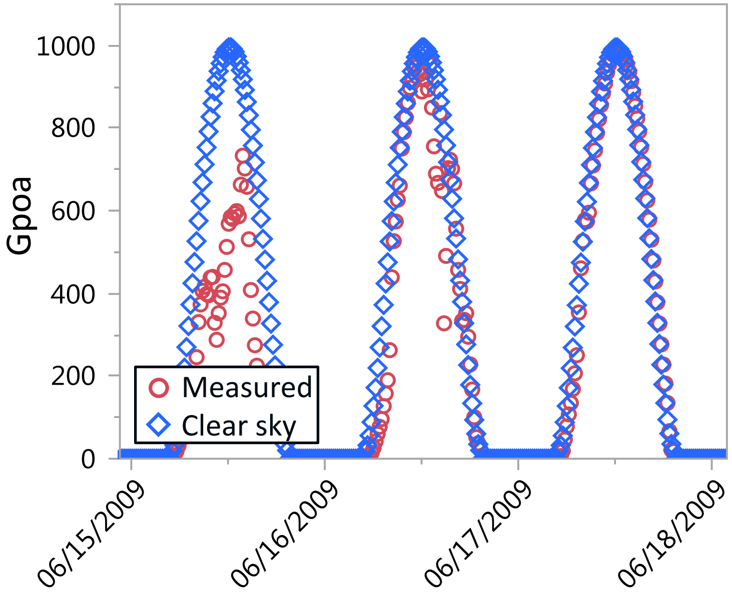




Degradation rate (%/year)

68%, 95% Confidence interval: Bootstrap distribution

Clear sky modeling[3,4]



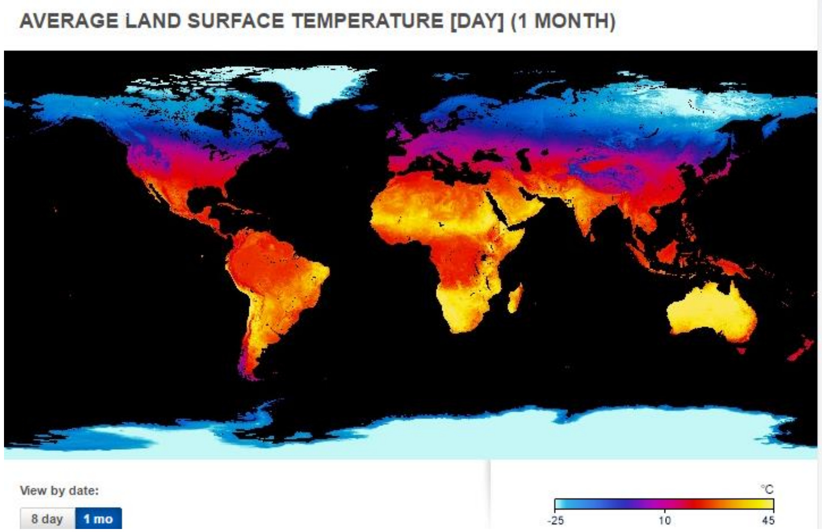
- Clear sky irradiance models report the expected solar resource under clear conditions
- Transposition of the data converts to plane-of-array (POA) irradiance
- PVLIB provides an open-source clear sky model

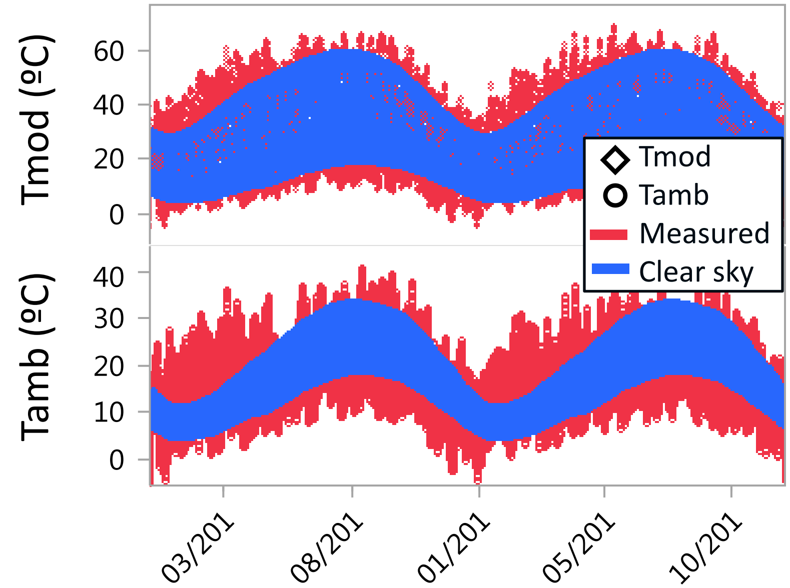
[1]Hasselbrink et al., 39th PVSC, Tampa, FL, USA, 2013.
[2]Jordan et al., 43rd PVSC, Portland, OR, USA, 2016.

[3]Holmgren et al., 42nd PVSC, New Orleans, LA,2015.
[4]Stein et al., 43rd PVSC, Portland, OR, 2016.

Model clear-sky temperature

Temperature





Near Earth Observation (NEO) provides average ambient day and night temperature based on climate models

Cell temperature is a function of ambient temperature and irradiance

Source data from Nasa Earth Observatory, derived from MODIS
Available at: https://github.com/kwhanalytics/rdtools/tree/clearsky_temperature

Final modeling details

Normalize performance ratio (PR)

$$PR = \frac{[P_{DC}\ (kW)]}{P_{P_{STC,rated}*} \frac{\left[Irradiance\ POA\ \left(\frac{W}{m2}\right)\right]}{1000\left(\frac{W}{m2}\right)} * (1 + \gamma_{tempco} * ([T_{cell}] - T_{ref}))}$$

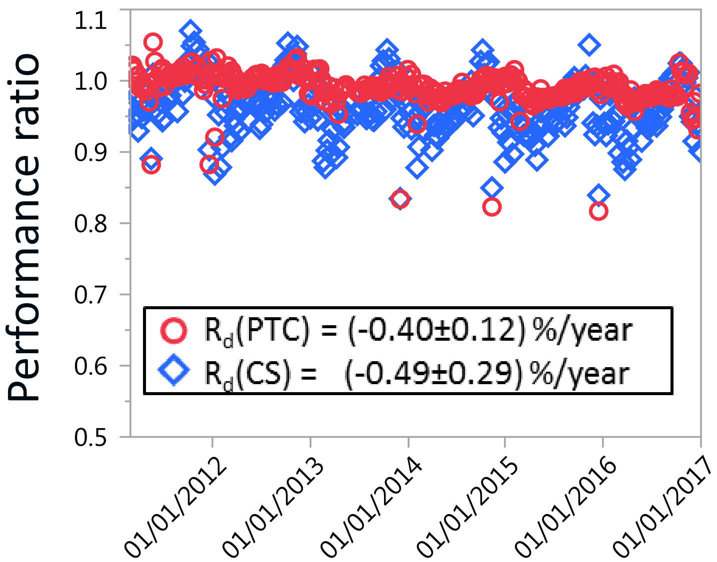
$$PR_{CS} = \frac{[P_{DC}\ (kW)]}{P_{STC,rated} * \frac{\left[Clear\ Sky\ Irradiance\ POA\ \left(\frac{W}{m2}\right)\right]}{1000\left(\frac{W}{m2}\right)} * (1 + \gamma_{tempco} * ([T_{clear\ sky\ cell}] - T_{ref}))}$$

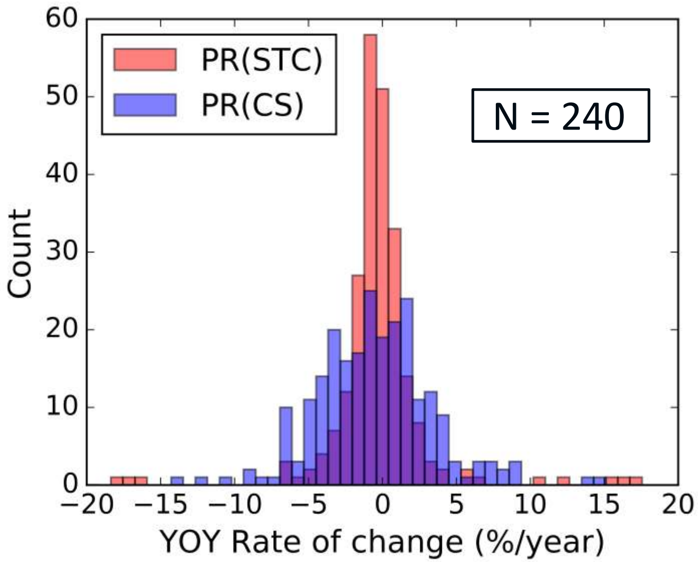
Minimally filter out data:

1. Irradiance <1200 and >200 W/m2 → Eliminate nighttime
2. Clearness index (measured/clear sky Gpoa) <1.1 and >0.9 → Clear sky
3. Power is <99% of capacity → Inverter clipping
4. 3 month rolling median filter with ±30% limits → Outages

Clear sky method: trade precision for accuracy

NREL example





Use measured irradiance if sensor is well-calibrated

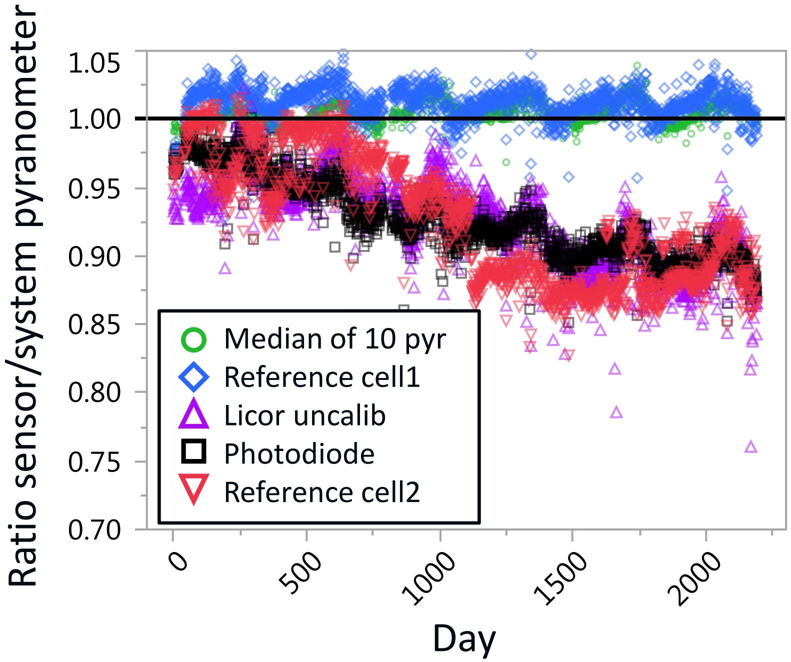
Common headaches

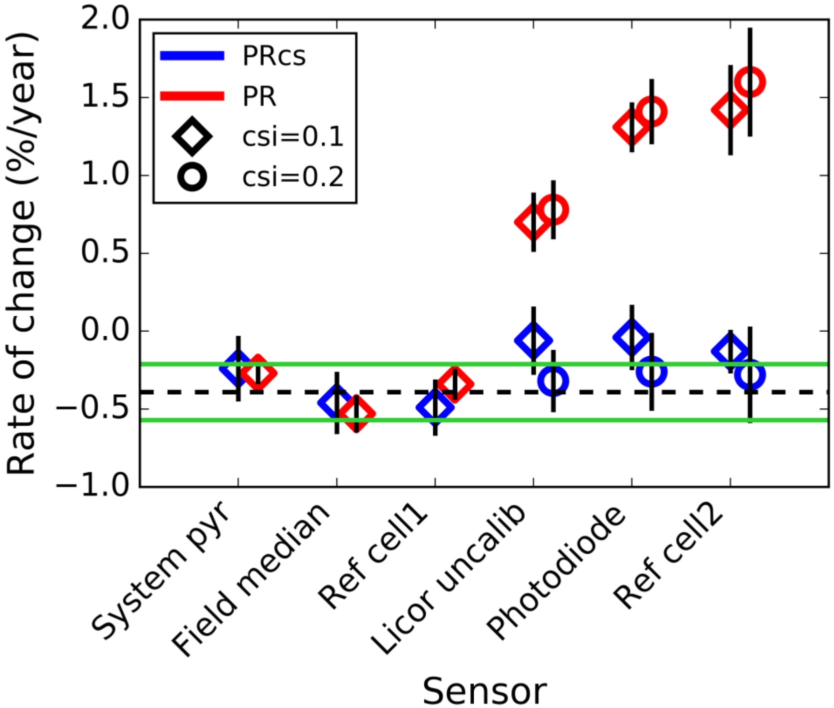
Will it work if the bread is bad or has problems?

Irradiance sensor: the biggest headache for field data

- ✓ What irradiance (temperature) sensor did you have?
- ✓ Was it calibrated?
- ✓ How often was it calibrated?
- ✓ Can you prove it?

Works even with drifting sensor!



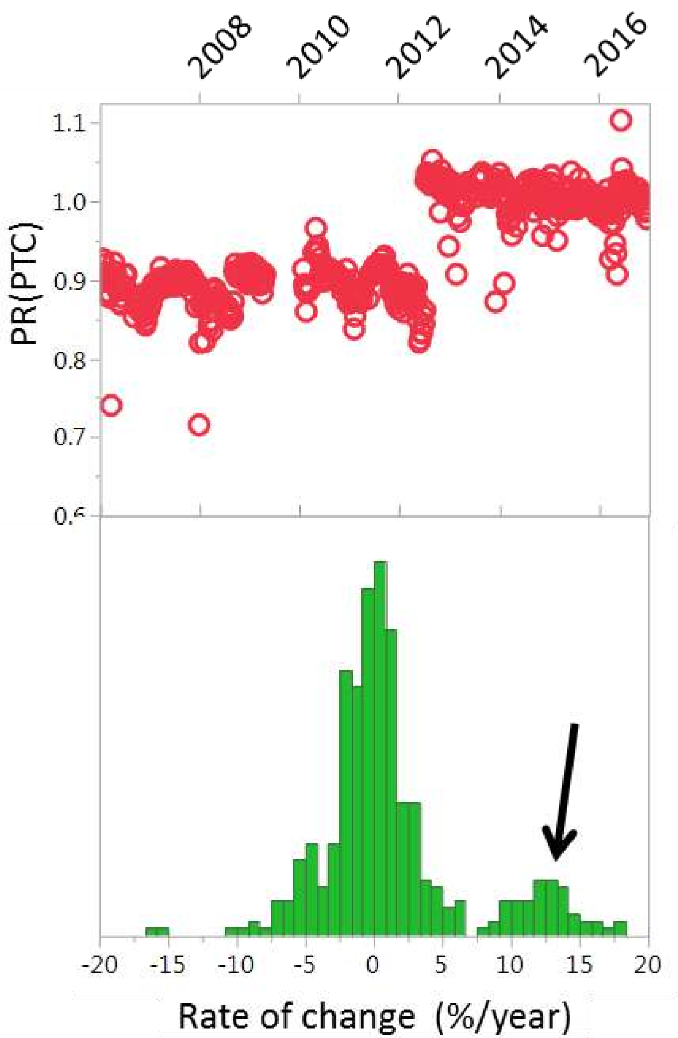


Ratio of listed Gpoa sensor to calibrated pyranometer

Some sensors drift at 1.5 – 2 %/year!

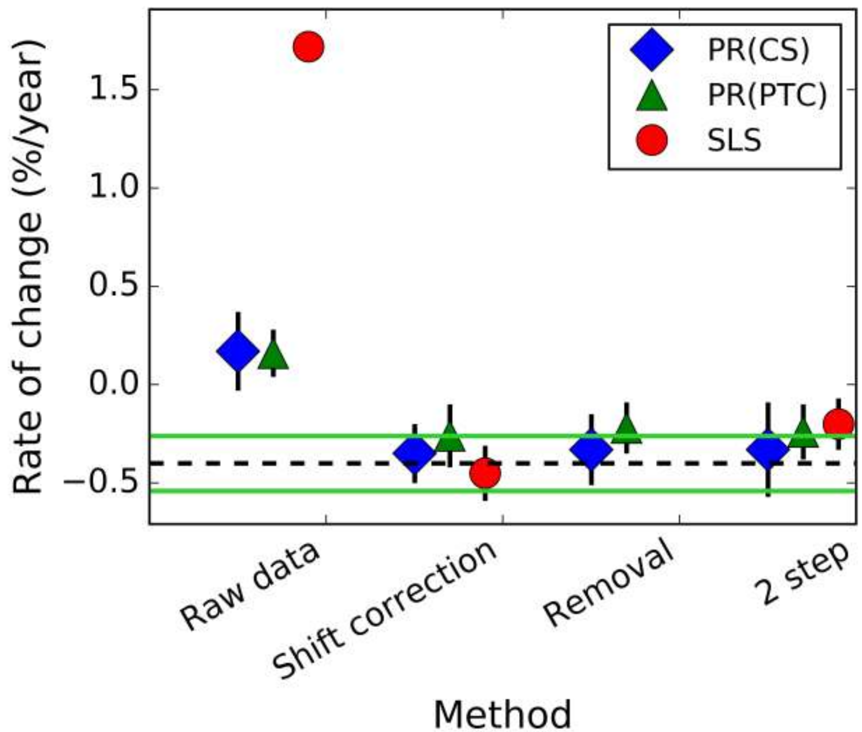
Green interval: ca. 10 more conventional time series analyses and independent tests such as I-V measurements

Works even with data shifts



Data shift options:

1. *Ignore → get in trouble*
2. Correct the data shift statistically[1]
3. Remove second peak
4. Analyze separately in 2 sections

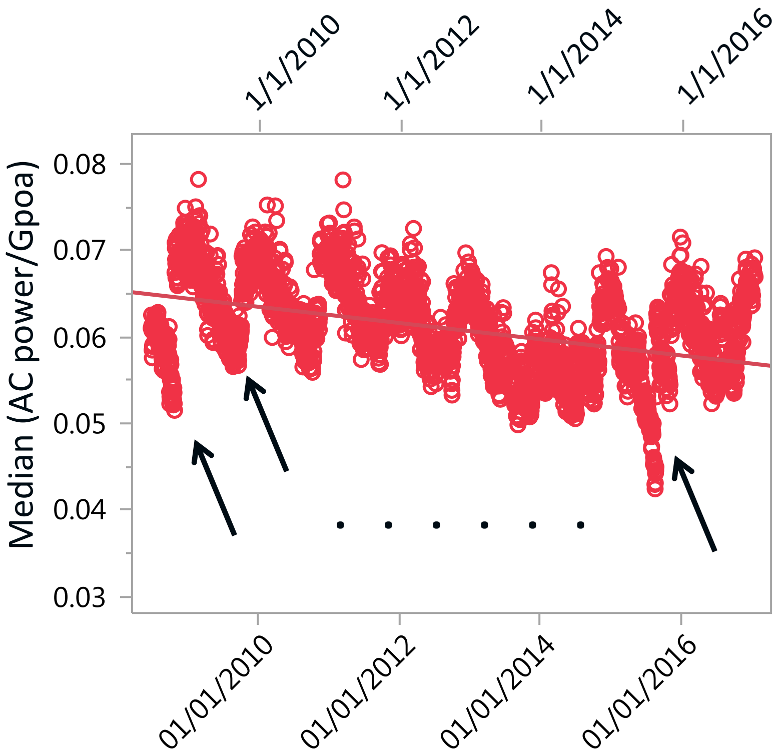


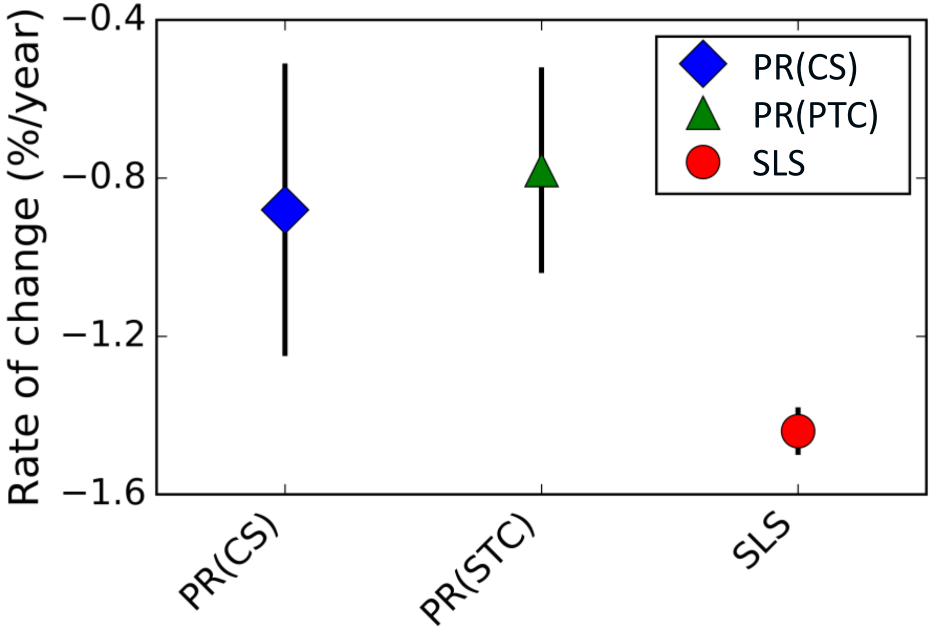
SLS: standard least square regression

[1]Jordan et al., 35th PVSC, Honolulu, HI, 2010.

Works in the presence of soiling

Southern California site



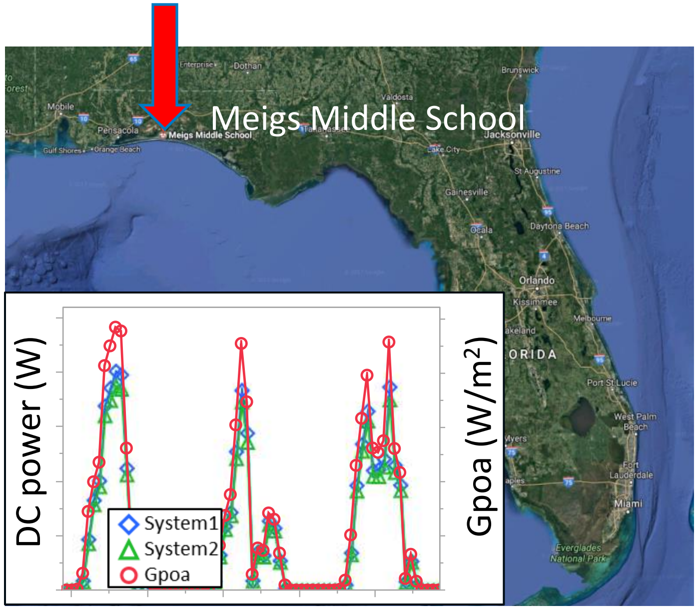


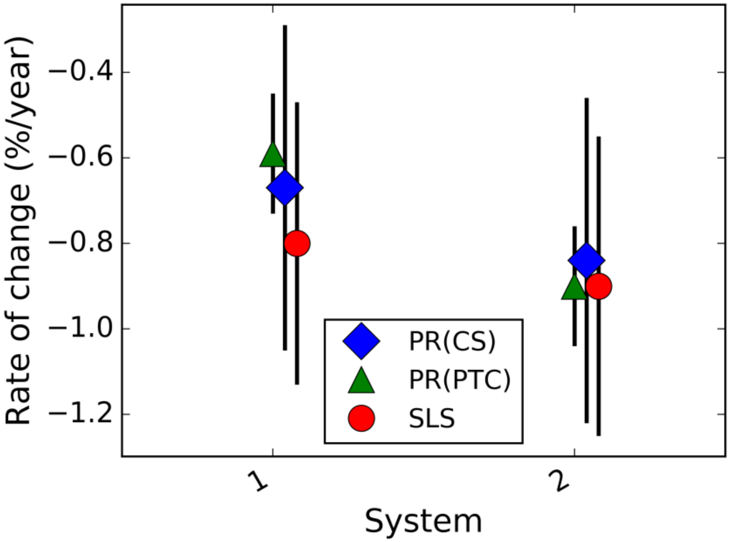
Some of the soiling intervals are pointed by arrows

SLS: standard least square regression

Simple regression overestimates the degradation

Works in cloudier climates too





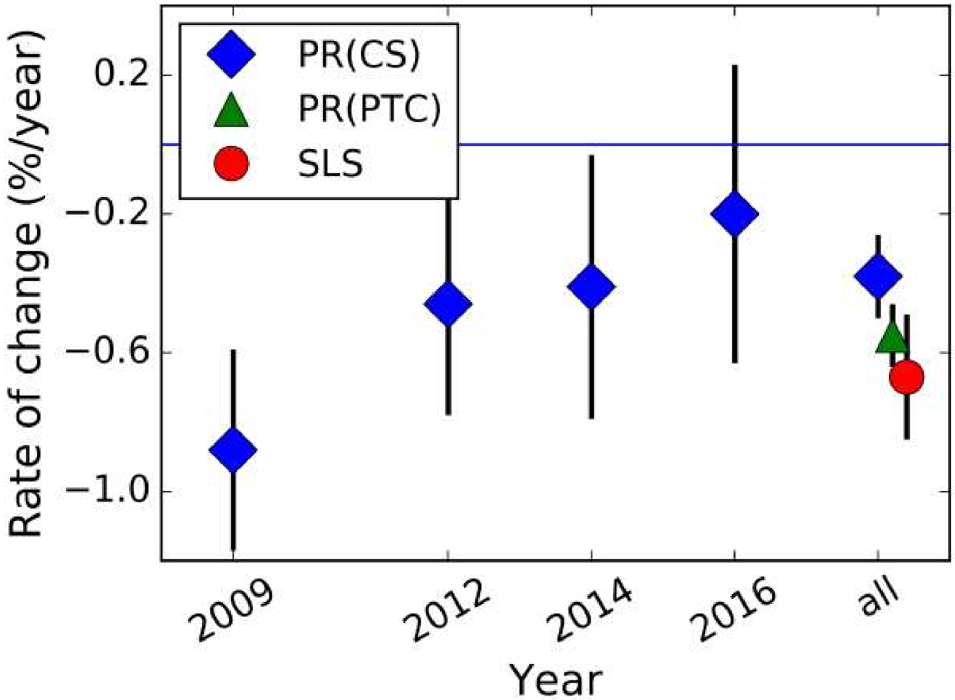
SLS: standard least square regression

Tradeoff: the cloudier the climate the longer the times series

Davis et al. Progress in PV, 2012.

For nonlinearities break series into subsection

HIT module system at NREL



SLS:
standard least square regression

Non-linear degradation, dominated by Voc

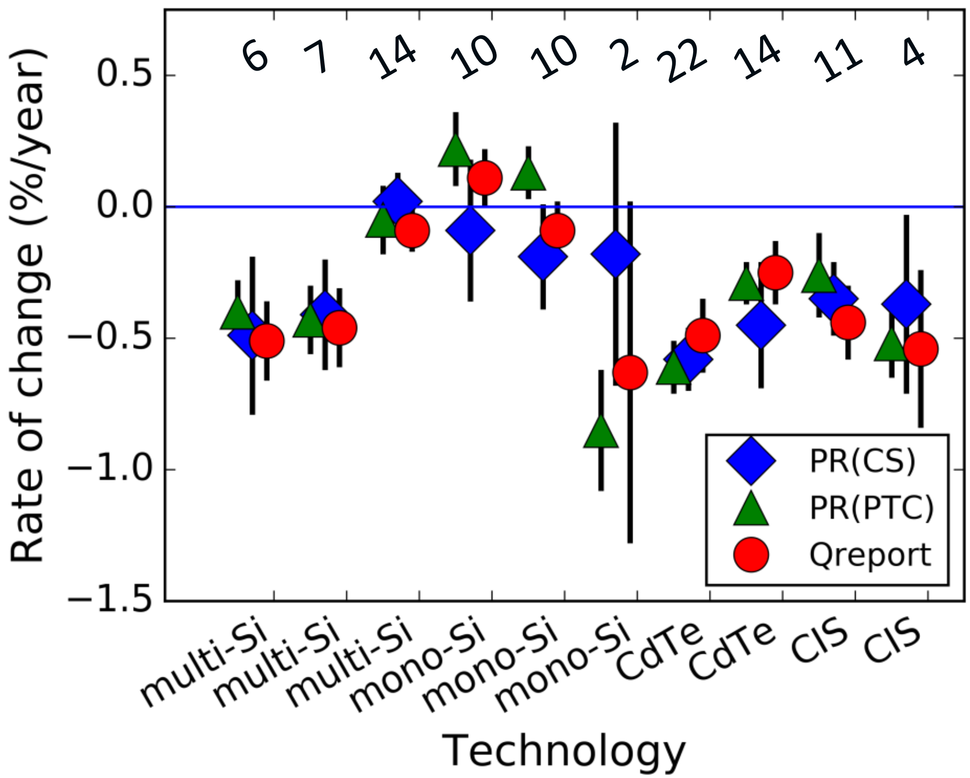
Jordan et al. Fri, 11 am , PVSC, 2017

Findings

Application to different types of bread.

Validation of method against conventional analysis

10 systems at NREL

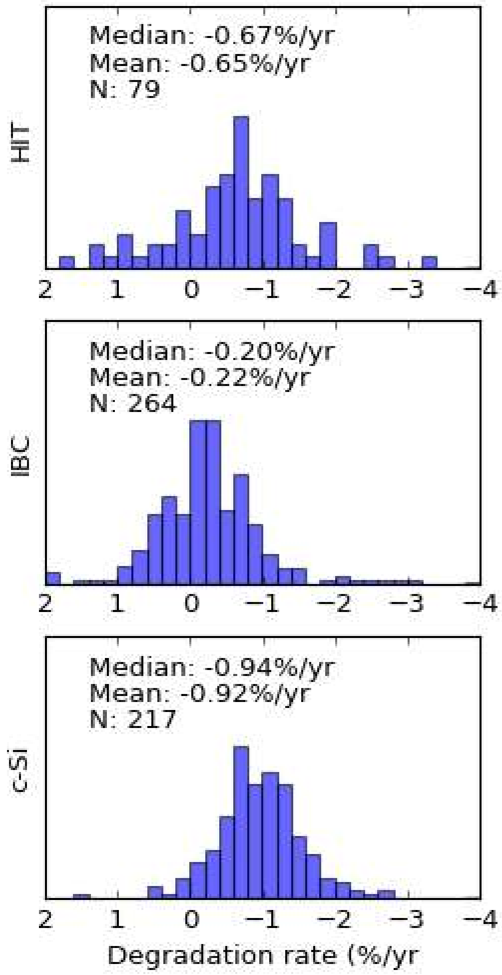


Field exposure (years)

NREL prepares quarterly reports on PV performance based on time series analyses, outdoor + indoor IV measurements.

Good agreement between new and conventional analysis

Analysis of Sunpower fleet



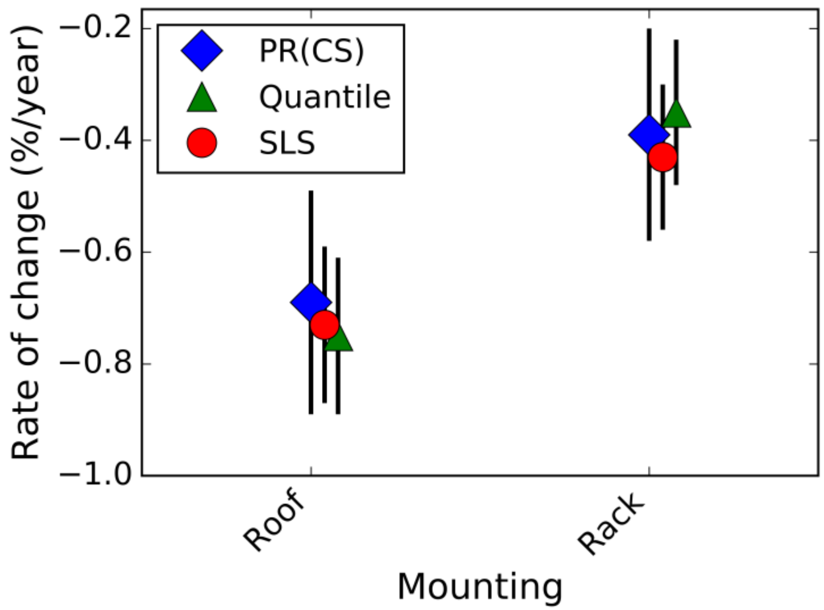
Divided into 3 different x-Si technologies

Interdigitated back contact (IBC) module systems showed lower median degradation rate.

Hot climate & mounting difference

<u>One interesting example only</u>

Disclaimer: may not be statistically representative



Desert knowledge center – Australia

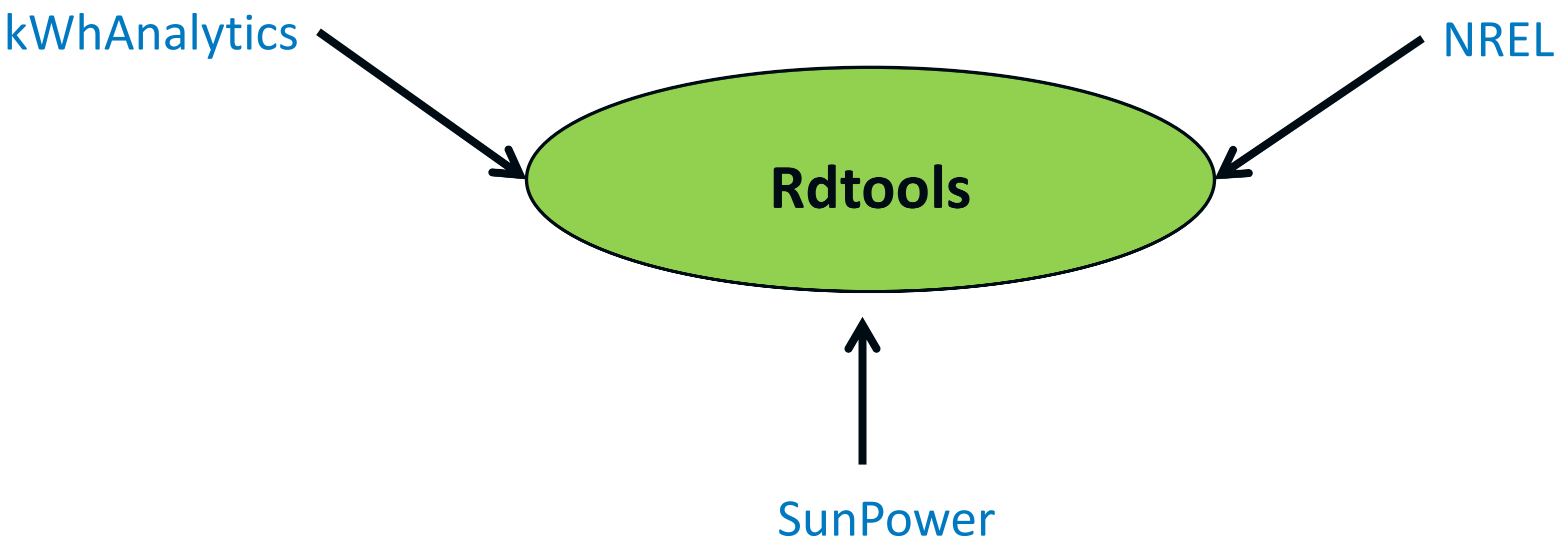
BP systems, rack and roof mounted

Can achieve relatively low degradation in desert location.
Mounting may have substantial impact on degradation.

Mikofski et al., PVSC, 2012

Software will be free & publicly available

Software written in Python and available on Github



Beta version available later this summer!

Conclusion

- **Method:**
  1. Use YoY approach
  2. Use clear sky modeled irradiance (Thank you PVLIB)
  3. Use clear sky temperature (Thank you NASA)

- **It is accurate even in most common field issues such sensor drift/problems, data shifts, soiling, non-linearities etc.**

- **PRcs prevents poor sensors from looking like AMAZING performance!**

Acknowledgments

Thank you for your attention

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Ambarish Nag
Ben Bourne
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National Renewable Energy Laboratory
15013 Denver West Parkway, MS 3411
Golden, CO 80401, USA
dirk.jordan@nrel.gov

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