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# Data Filtering Impact on PV Degradation Rates and Uncertainty


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## 1 Introduction

***Important to know Power decline over time accurately***

***Degradation rates (Rd)***

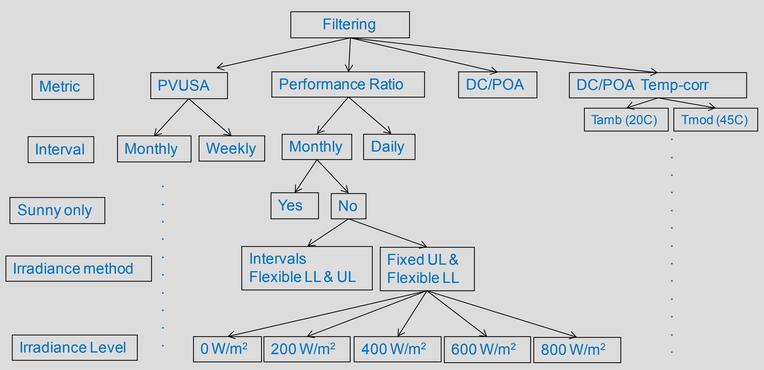
***1. Financially:***
- ***Cash flow***
- ***Uncertainty directly related to risk***

***2. Technically:***
- ***Lifetime prediction***
- ***Product improvement***

***Comprehensive list of uncertainties on known systems including***

1. ***Instrumentation specifications***
2. ***Instrumentation calibrations***
3. ***Data filtering***

## 2 Data Filtering Criteria



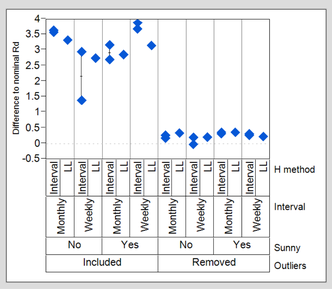

*DC/POA Temp-corr = DC Power/ Plane-of-array Irradiance, temperature-corrected*

***Automation***

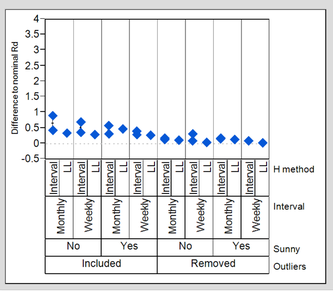
***Generates 300 – 500 Degradation rates per System***

## 3 PVUSA Sensitivity to Outliers

***Data availability: 50 Months***




***Data availability: 103 Months***




**Variance Components**

| Component | Var Component | % of Total | 20 40 60 80 | Sqrt(Var Comp) |
|---|---|---|---|---|
| Outliers | 1.2060503 | 84.4 | | 1.0982 |
| Sunny[Outliers] | 0.0343074 | 2.4 | | 0.1852 |
| Interval[Outliers,Sunny] | 0.0664989 | 4.7 | | 0.2579 |
| H method[Outliers,Sunny,Interval] | 0.0246104 | 1.7 | | 0.1569 |
| Within | 0.0969496 | 6.8 | | 0.3114 |
| Total | 1.4284166 | 100.0 | | 1.1952 |

**Variance Components**

| Component | Var Component | % of Total | 20 40 60 80 | Sqrt(Var Comp) |
|---|---|---|---|---|
| Outliers | 0.01434024 | 39.1 | | 0.11975 |
| Sunny[Outliers] | 0.00267874 | 7.3 | | 0.05176 |
| Interval[Outliers,Sunny] | 0.00218334 | 6.0 | | 0.04673 |
| H method[Outliers,Sunny,Interval] | 0.00213419 | 5.8 | | 0.04620 |
| Within | 0.01532825 | 41.8 | | 0.12381 |
| Total | 0.03666476 | 100.0 | | 0.19148 |

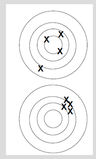
***Most of variation for PVUSA comes from outliers***

***Less critical with more data***

## 4 Evaluation of Rd

***Goal: 1. Determine "correct" Rd=nominal Rd accurately***
***2. Determine it with precision, i.e. small uncertainty***

***Accuracy vs. Precision***

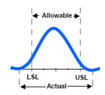


***Good accuracy***
***Bad precision***

***Good precision***
***Bad accuracy***

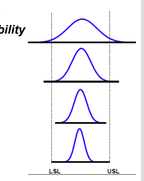
***Capability metric: Cp***

$$C_p = \frac{USL - LSL}{6 \cdot \sigma}$$




***USL: Upper Specification Limit***
***LSL: Lower Specification Limit***

| Cp | Interpretation |
|---|---|
| < 1.0 | Poor Capability |
| 1.0 – 1.5 | Marginal |
| >1.5 | Good |
| >2.0 | Excellent |




***Disadvantage of Cp: No information where in interval distribution falls***

***Capability Index - Cpk***

$$C_{pk} = \min\left[\frac{USL - mean}{3 \cdot Std\,Dev}, \frac{mean - LSL}{3 \cdot Std\,Dev}\right]$$

***The more positive the better!***

***How do you know what the correct/"nominal" Rd interval should be?***

***Determine Rd in 9 different ways → most likely Rd is included in the interval***

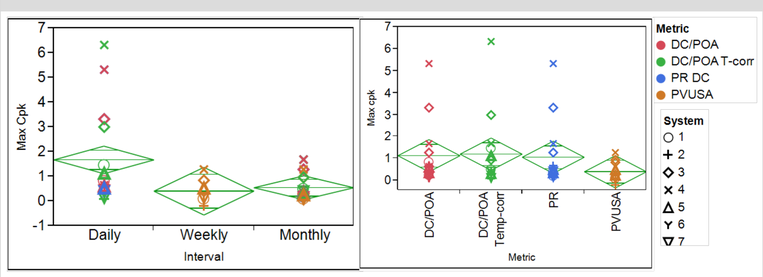
***Example Table:***

| Rd= | Uncertainty= | Method= | Interval= |
|---|---|---|---|
| -0.52= | 0.04= | PVUSA SLS= | = |
| -0.53= | 0.02= | PVUSA CI Decomp= | Monthly= |
| -0.52= | 0.04= | PVUSA ARIMA= | Monthly= |
| -1.13= | 0.03= | Performance Ratio Linear Fit= | Monthly= |
| -1.54= | 0.02= | PR CI Decomp= | Monthly= |
| -1.09= | 0.02= | PR ARIMA= | Monthly= |
| -1.15= | 0.01= | Performance Ratio Linear Fit= | Daily= |
| -0.32= | 0.09= | Field IV= | Quarterly= |
| -0.47= | 0.01= | DC/POA temp-corrected= | Daily= |
| -0.53= | 0.05= | Overall median a pooled Standard deviation= | = |

***Use Cpk to judge accuracy and precision***

## 5 Cpk for 7 systems

***Symbols refer to different systems at NREL***
***Colors refer to different metric***




***95% confidence interval with mean crossbars shown***

***Daily interval show significantly higher cpk →i.e. more accurate & precise than monthly***

***(PVUSA was not done daily but weekly)***

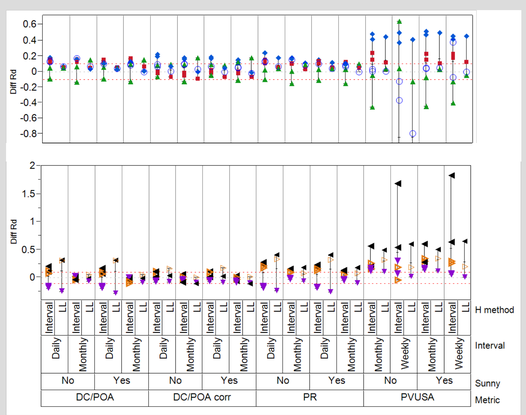
***DC/POA, DC/POA Temp-corr and PR significantly higher than PVUSA***

***Not much difference when all rates are compared for DC/POA, DC/POA Temp-corr and PR but DC/POA Temp-corr has the highest values***

***Daily metrics preferred over monthly***

## 6 Data Filtering Impact on Rd

***Interval: 200 W/m2 Irradiance interval around 800W/m2***
***LL: Upper Irradiance interval fixed at 1200 W/m2, lower limit at 800 W/m2***



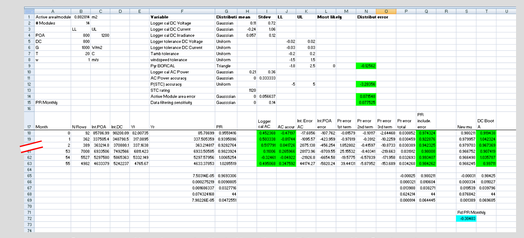

***DC/POA Temp-corr most consistently w/in 0.1%/year***

## 7 Total Uncertainty Calculation

***List of uncertainties:***
1. ***Data logger calibration for DC voltage & current (based on data from historical calibrations)***
2. ***Data logger tolerances (manufacturers' specifications)***
3. ***Pyranometer calibrations (NREL's BORCAL[1])***
4. ***STC rating uncertainty***
5. ***Data filtering sensitivity as determined from previous slide***

***Use Excel® Monte Carlo Add-in Modelrisk®***

***Procedure:***
***Assign distributions to list of uncertainties (Gaussian, Uniform, Triangle..)***
***Take random number from each distribution and add to each monthly/weekly/daily value***
***Repeat 1000 times***
***Complete entire procedure for each metric/interval/system***



***Green cells: Input distribution; Blue cell: Output***

***Spreadsheet Modeling***

[1] ***Myers DR et al., 2004, NREL Conference Paper NREL/CP-560-36320.***
[2] ***http://www.vosesoftware.com/***

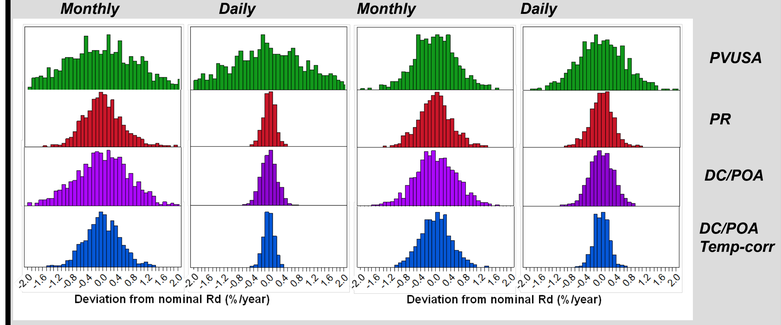
## 8 Monte Carlo Results

***Field exposure: 4-5 years***

***1 x-Si System***

***Field exposure: 5 years***

***1 Thin-film System***




***PVUSA least precise***

***DC/POA Temp-corr most precise***

## 9 Conclusion

- ***Data filtering has a big impact on assessing long-term degradation***
- ***PVUSA is most sensitive to outliers, particularly for shorter field exposure***
- ***Daily metrics are preferred over monthly metrics***
- ***DC/POA Temp-corr is most consistent in determining Rd w/in 0.1%/year***
- ***Total uncertainty fluctuates somewhat from dataset to dataset – DC/POA Temp-corr best performing***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