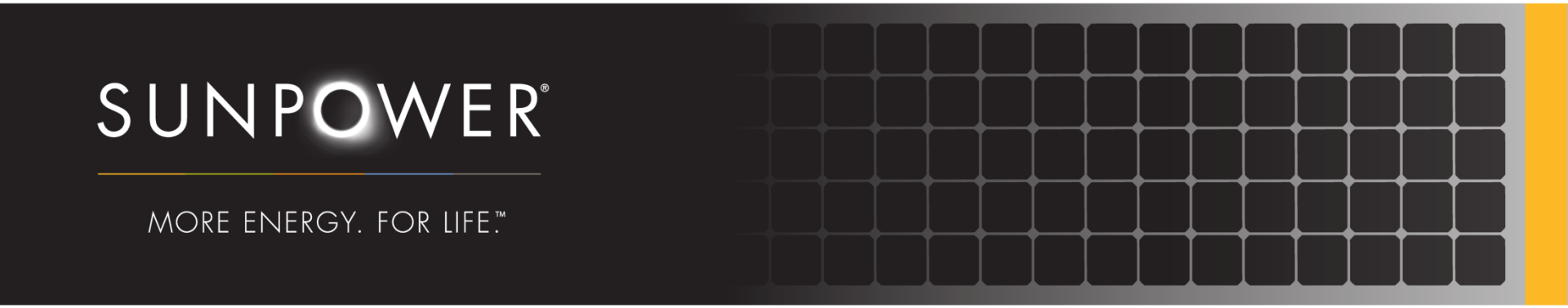


A System Degradation Study of 445 Systems using Year-over-Year Performance Index

Mike Anderson

Presented at the 2013 Sandia PV Performance Modeling Workshop
Santa Clara, CA. May 1-2, 2013
Published by Sandia National Laboratories with the Permission of the Author

Motivation

- **Degradation rates can affect project economics significantly**
  - 0.25%/yr difference on a $2B project has NPV impact of ~$50M

Problem

- **Solar Investors and Consumers** need proof of low degradation
- **Small-scale experiments do not address investor concerns:**
  - Well-controlled experiment may not represent real-world experience
- **Real-world studies are costly, take time and include anomalous behavior:**
  - Extensive data processing and manipulation can affect results
  - Measurement, seasonal or operational variation can lead to uncertainties much larger than what we are trying to measure
  - Lack of long-term fielded systems with current technologies

Approach

- **Use large dataset from installed fleet**
  - 266 systems (86MW) using SunPower modules as old as 5.5 years
  - 179 systems (42MW) using non-SunPower modules (conventional front-contact) as old as 11.5 years
- **Minimize data filtering**
- **Use high accuracy model for expected performance**
- **Use Year-over-Year method to minimize seasonal effects**
- **Use statistics to get high-accuracy median degradation rate**

Year-Over-Year Performance Index Analysis Method

1. **Minimal filtering – remove obviously spurious data**
   - 400 W/m^2 < Irradiance < 2000 W/m^2
   - -40°C < Ambient temperature < 65°C
   - 0 (m/s) < Wind Speed < 50 (m/s)
   - Communication Errors (Flat-lined data)

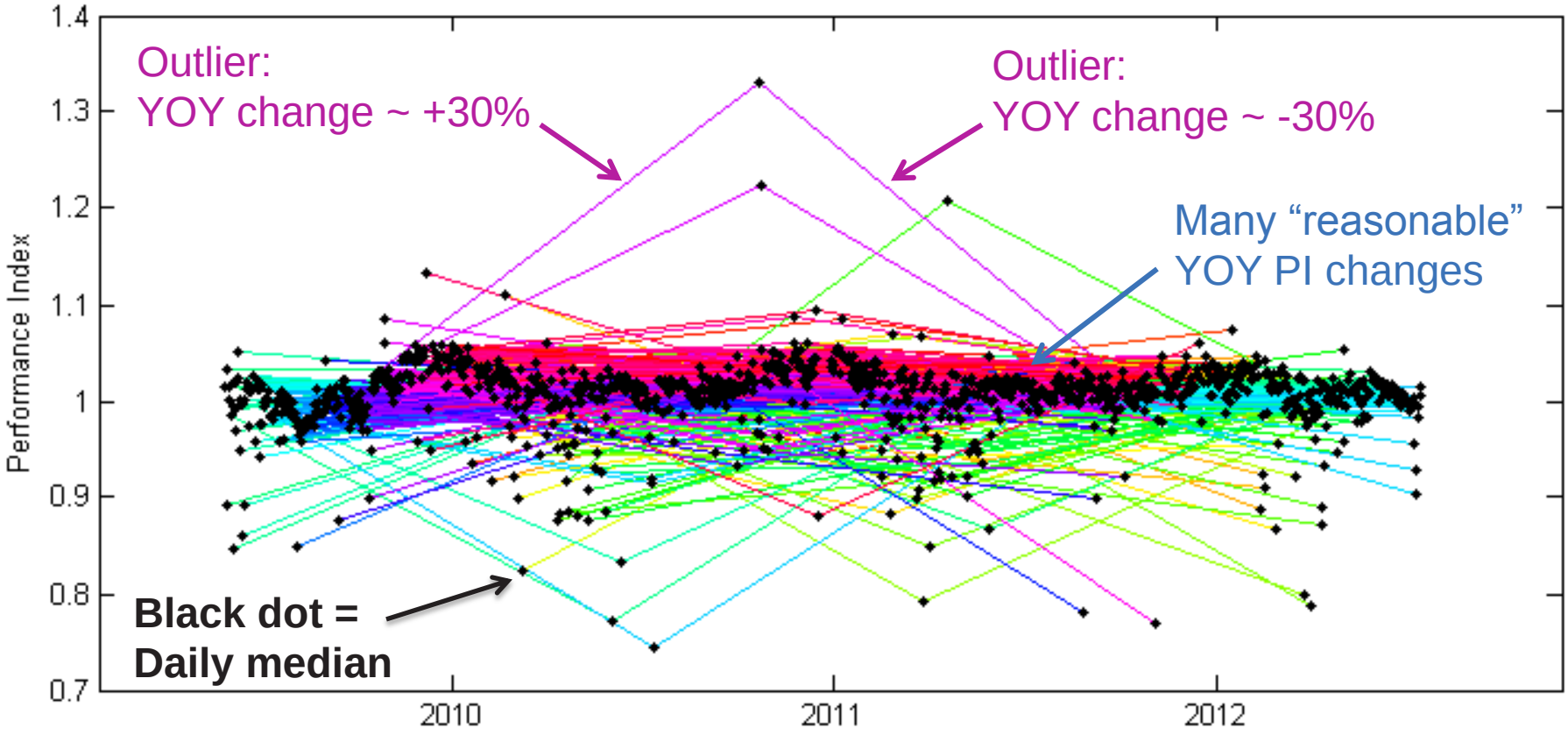
2. **Compute expected power from weather data + performance model**
   - Used SunPower's PVSim simulator (based on Sandia performance model)

3. **Compute Performance Index**

$$\text{PI} = \frac{\text{Measured Output}}{\text{Expected Output}}$$

Year-Over-Year Performance Index Analysis Method

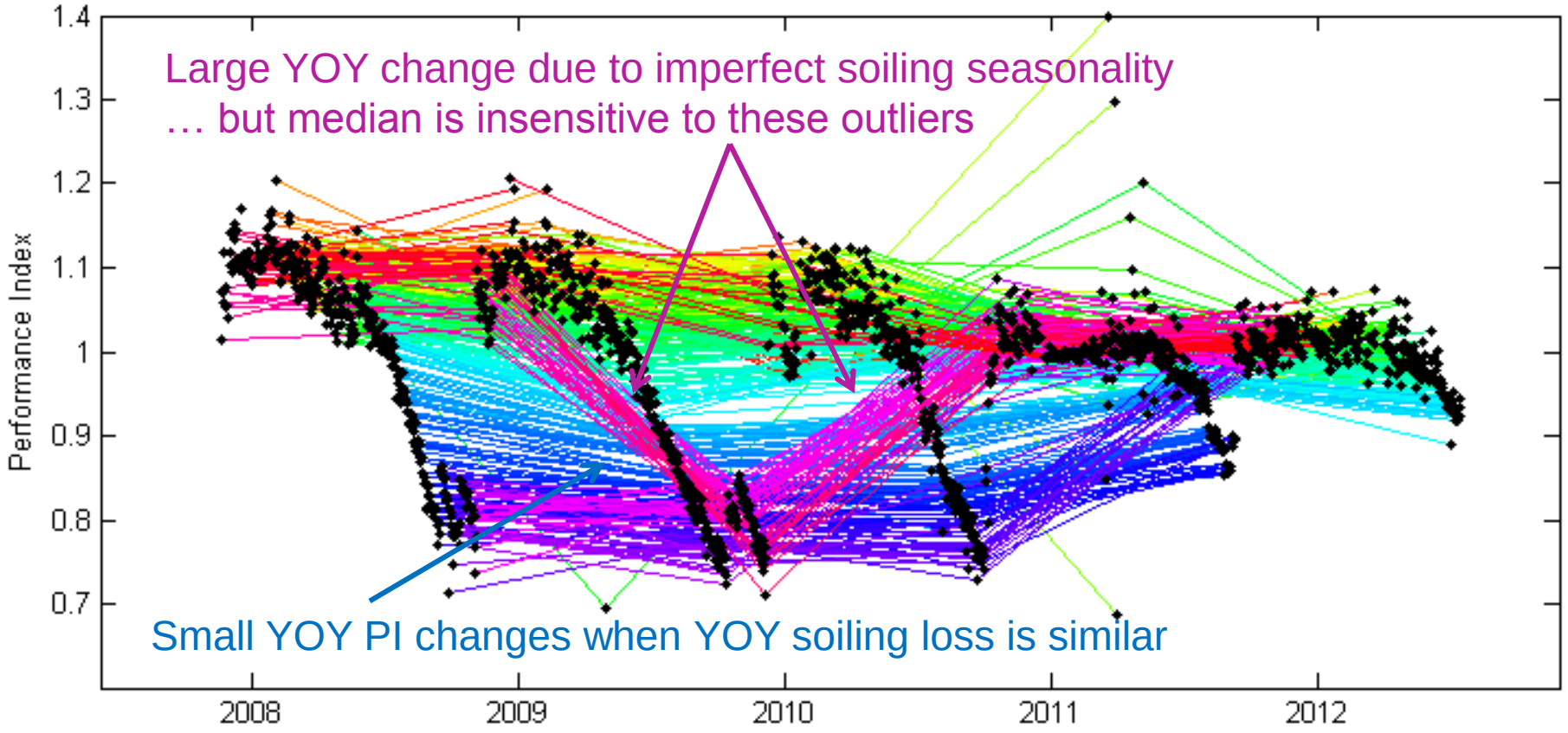
4. **Calculate site YOY degradation rates ($\Delta PI_{n+365/2} = PI_{n+365} - PI_n$)**
   - Colored lines connect YOY PI values for a particular calendar day
   - Minimizes residual seasonal effects and modeling/site characterization errors
   - Yields approximately 365 degradation rates per year



Year-Over-Year Performance Index Analysis Method

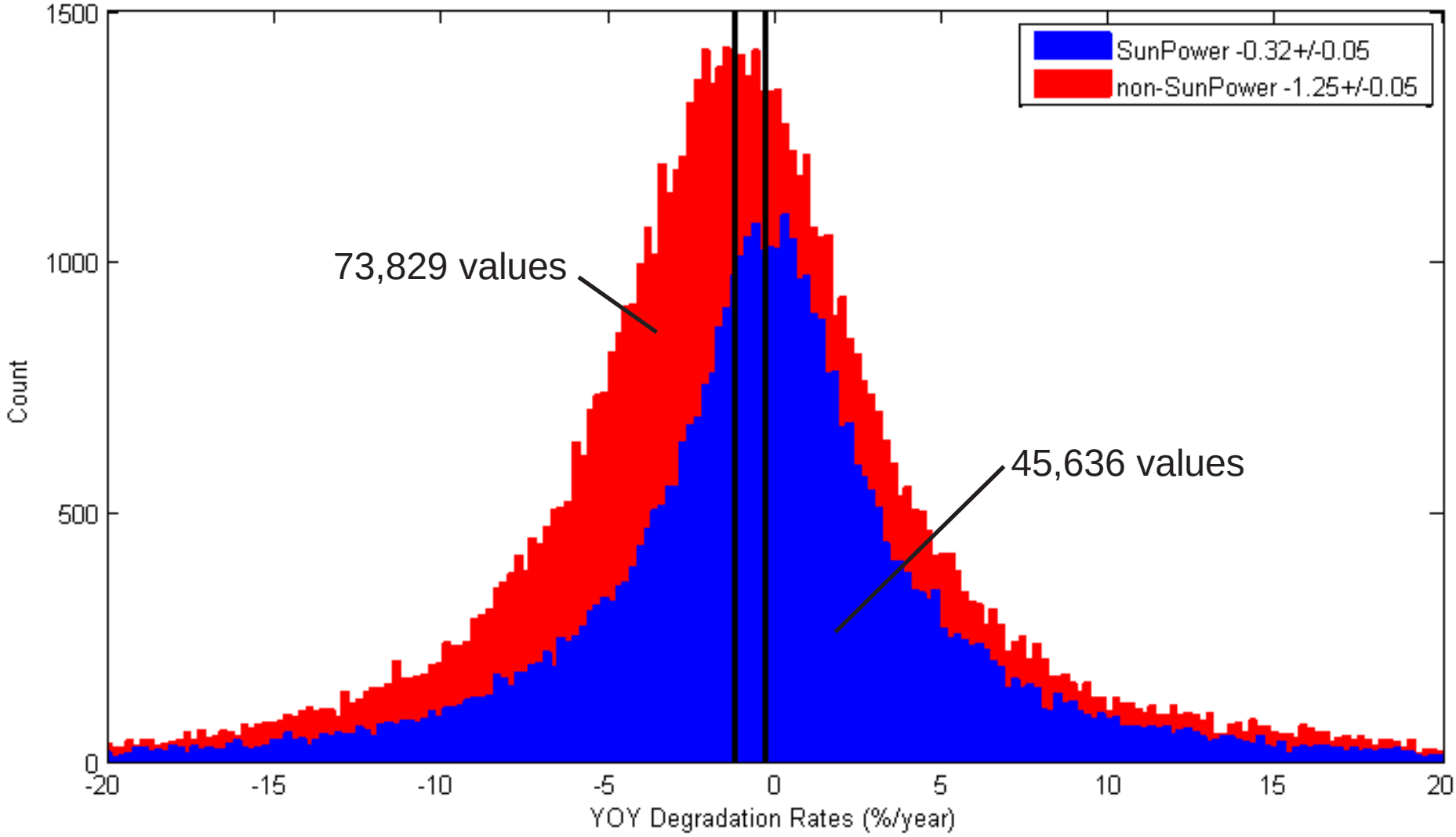
What happens at heavy seasonal-soiling sites?

- Soiling was not accounted for in the new and clean expected calculation.
- The YOY approach is still applicable for sites that experience soiling to the degree that soiling is seasonally repeatable.



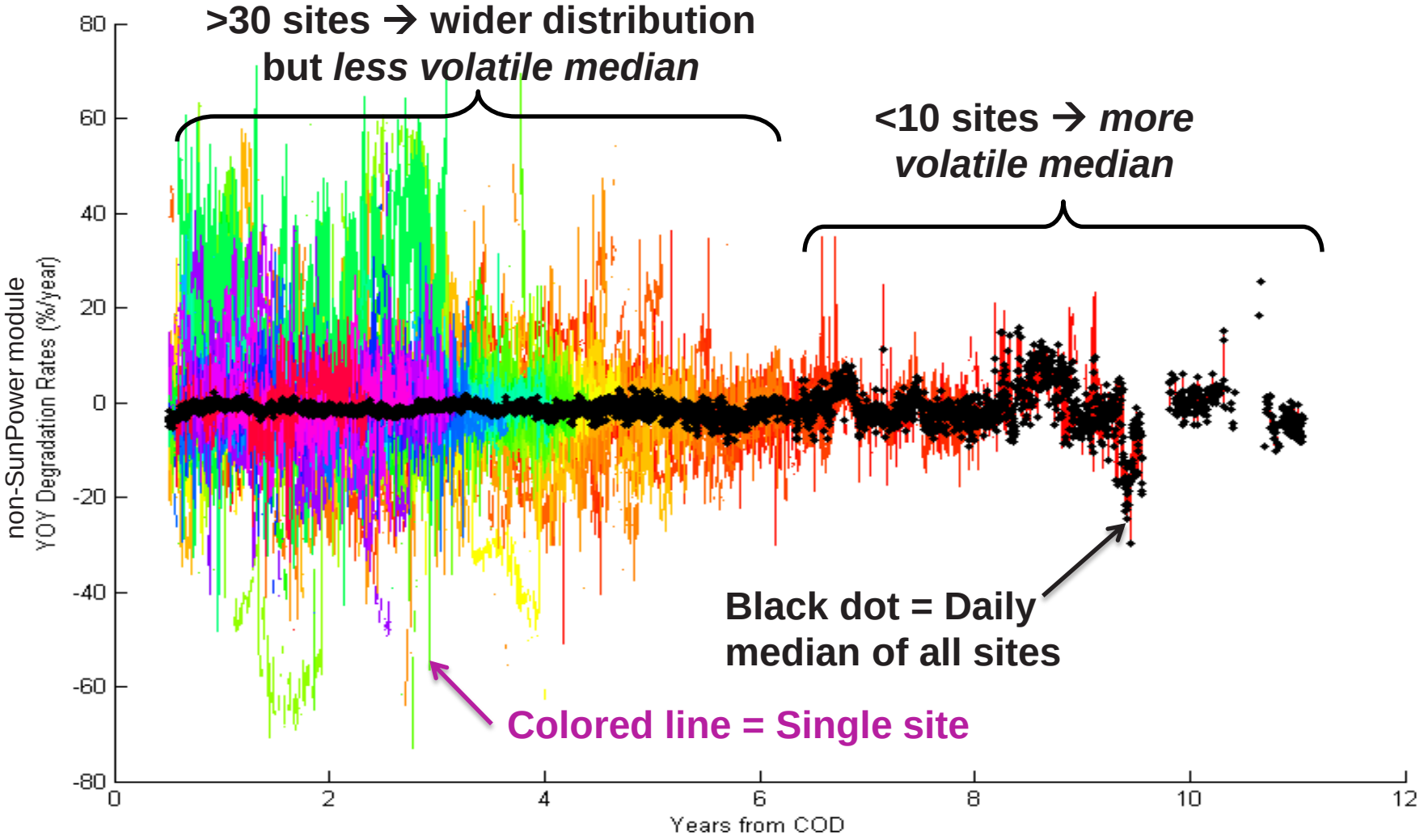
Year-Over-Year Performance Index Analysis Method

5. Obtain median degradation rate from fleet distribution



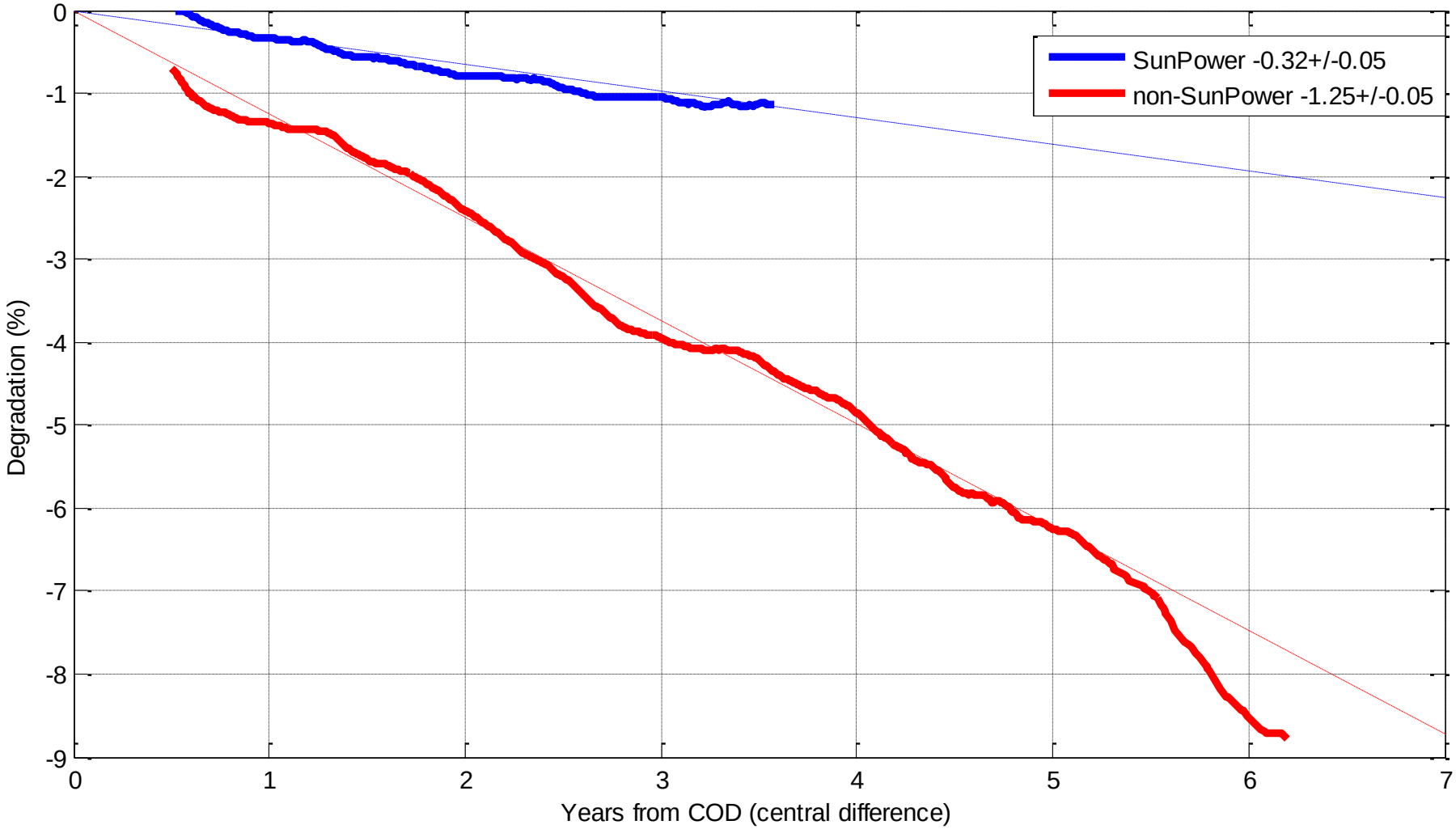
Degradation over time

Behavior with system age can be obtained by calculating fleet median YOY slope at each day from COD



Degradation over time

… and these Daily median YOY slopes can be integrated to yield imputed degradation curve



Conclusions

- **Year-Over-Year Performance Index Change Analysis** is a powerful and practical technique for assessing the median degradation of a large fleet of systems
  - √ **ROBUST**: Insensitive to noise, absolute accuracy errors, and soiling.
    - ➢ Median is stable to filtering of “outliers”, skewness is near zero.
  - √ **PRACTICAL**: Requires only AC inverter data and essential met data
    - ➢ No need for module removal, cleaning and flash testing, or curve tracing
  - √ **RELEVANT**: Uses data from a live, real-world fleet
    - ➢ Module manufacturers can prove their real-world track record
- **A system-level degradation study of 445 systems** representing 3.2 million module-years of monitored data indicated that:
  - 266 systems (86MW) using SunPower modules as old as 5.5 years show median degradation rate = -0.32% ± 0.05% (95% confidence) per year
  - 179 systems (42MW) using non-SunPower modules (conventional front-contact) as old as 11.5 years show median degradation rate = -1.25% ± 0.05% (95% confidence) per year
  - Degradation over these time frames are generally linear

For more information

- A white paper on this material can be found at either the website for this workshop, or at the Sandia National Laboratories PV Performance Modeling Collaborative (PVPMC) website http://pvpmc.org/documents/

SUNPOWER®

MORE ENERGY. FOR LIFE.™