



Irradiance Measurements for Capacity Testing

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- What capacity test standard method are you using?
 - ASTM E2848
 - IEC 61724-2
 - Other

- What is your preferred primary irradiance source for capacity testing?
 - Class A Pyranometer
 - Calibrated Reference Module
 - Reference Cell
 - Other

- Class A pyranometer (ISO 9060 & IEC 61724-1)
 - Total shortwave & spectrally flat
 - 280 - 3000 nm
 - Well characterized & established
 - Feature rich
 - Suitable for all cell chemistries
- Matched Calibrated Reference Module (MCRM)
 - Effective irradiance + soiling
 - Identical spectral & angular response
 - Reduces modeling complexity and uncertainty
 - Total POA Bifacial
- Reference Cell
 - Spectrally selective irradiance
 - ~300 - 1200 nm
 - Reduced spectral (cSi only) & angular mismatch



- Irradiance available to PV array for power conversion
 - Typically pyranometer data corrected for optical and thermal mismatch
- Effective Irradiance can be measured directly
 - Relationship between I_{sc} and irradiance is linear

$$G = G_{STC} \left(\frac{I_{sc} \left\{ 1 - \frac{\alpha_{I_{sc}}}{100} (T_c - T_0) \right\}}{I_{sc_0}} \right)$$

G = Temperature-Corrected Effective Irradiance

G_{STC} = Irradiance at STC (1000 W/m²)

I_{sc} = Short Circuit Current

I_{sc_0} = Short Circuit Current at STC

$\alpha_{I_{sc}}$ = Temperature Coefficient of I_{sc}

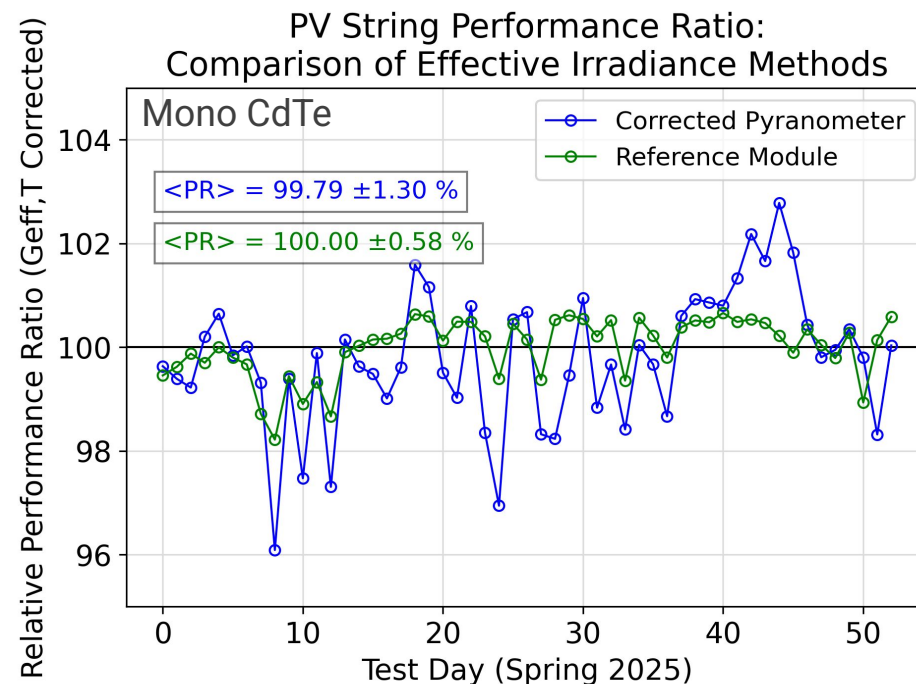
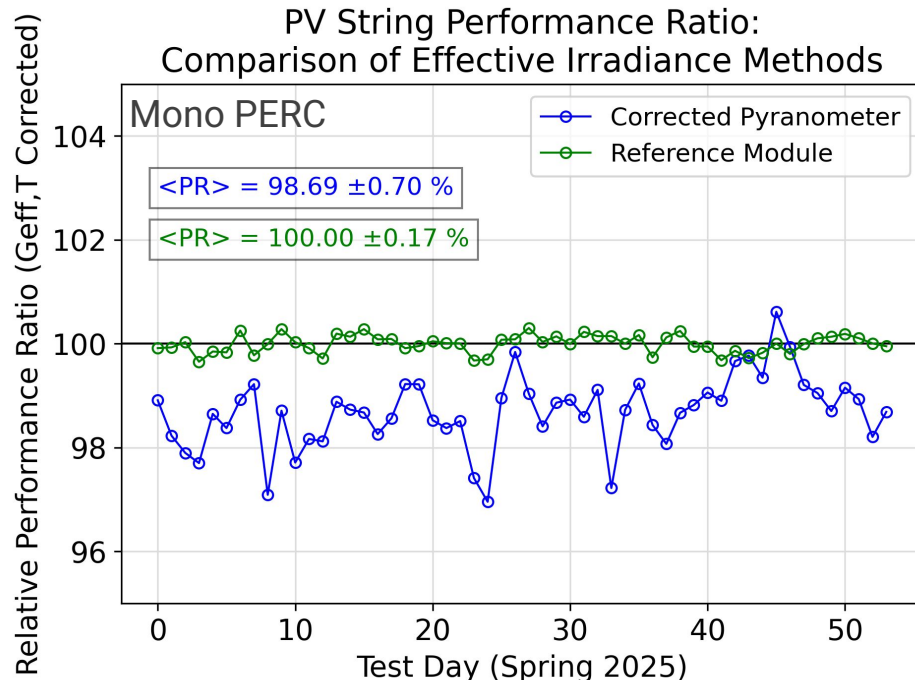
T_c = Cell Temperature

T_0 = Cell Temperature at STC (25° C)



Field Results: Comparison of Effective Irradiance Methods

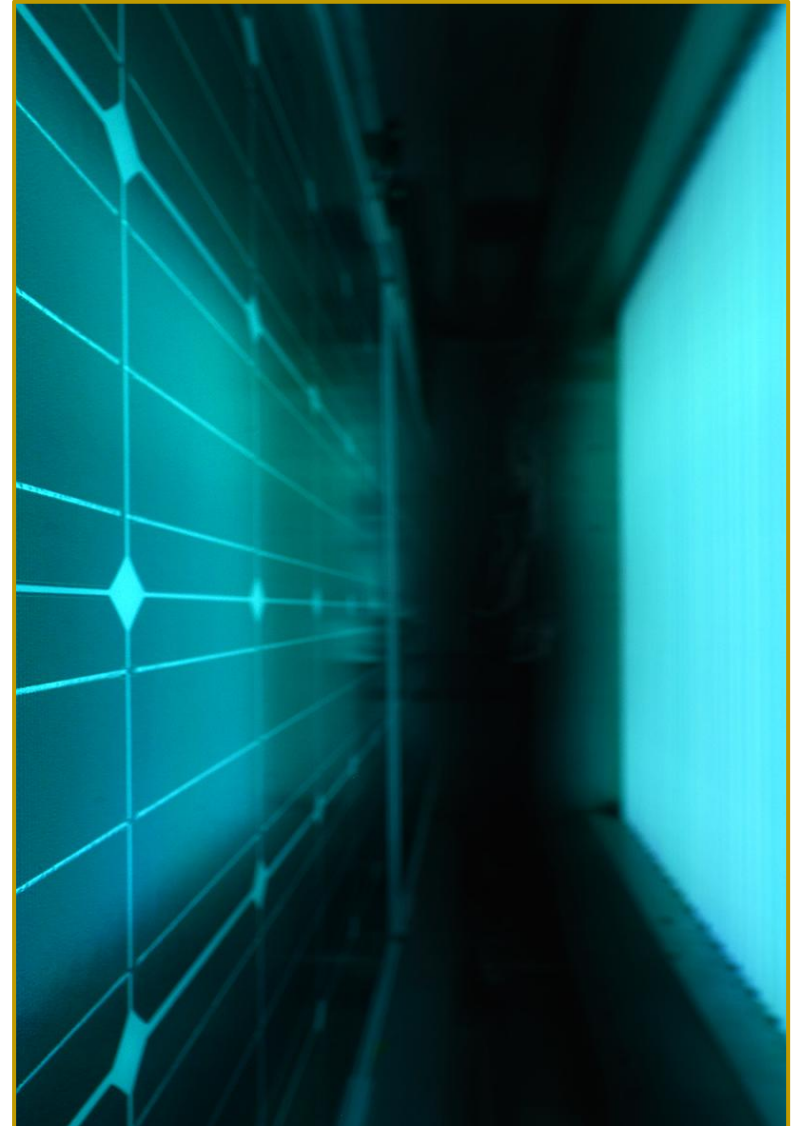
Albuquerque, NM



- Energy Model: Pvlib
 - Pyranometer spectral mismatch (pvspec)
 - Pyranometer IAM mismatch (Martin-Ruiz)
- +/-3 hours solar noon
- Clear sky filter $>600 \text{ W/m}^2$

- 15 sec measurements
 - 1 min avg
- Single axis tracking 1P
- No clipping

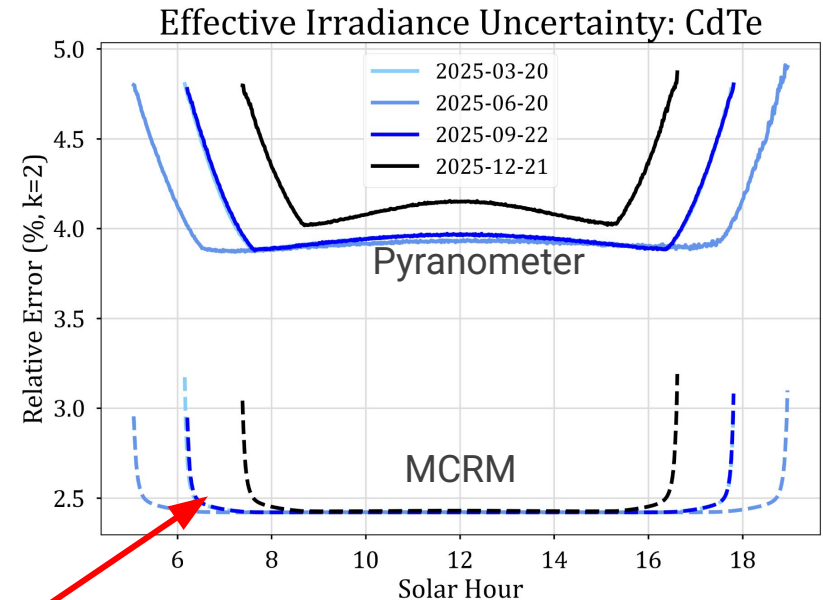
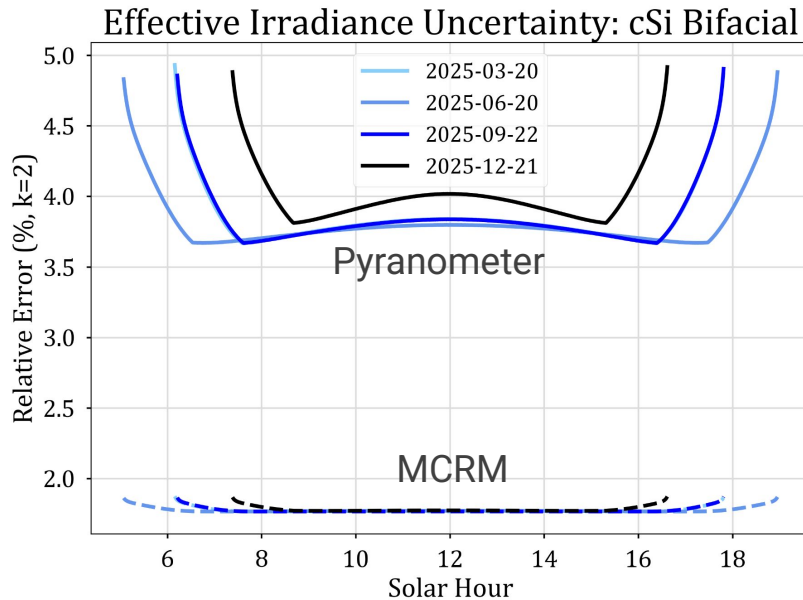
- Same make, model, and BOM
- Nameplate QA batch test to establish distribution
 - 1-2 pallets
- Representative samples
- Electrically stabilize
- Calibrate/characterize IEC 60904
 - Isc, TempCo
 - ISO 17025 accredited lab
 - Nameplate values are not adequate
- Careful placement
 - Avoid edges, row ends, module gaps and other microclimates
- Plan for spares
- Configure PV modeling software to ignore spectral and IAM



Pyranometer (Class A) Stack	MCRM
1. Calibration	Calibration
2. Pyranometer Intrinsic Uncertainty	MCRM Intrinsic Uncertainty
3. Module Temperature	Module temperature
4. Soiling	PV Module Shunt
5. Diffuse Shading	Soiling
6. Spectral Mismatch	
7. IAM Mismatch	
8. Thermal Mismatch	
9. Viewfactor Mismatch	
10. Bifaciality Mismatch	

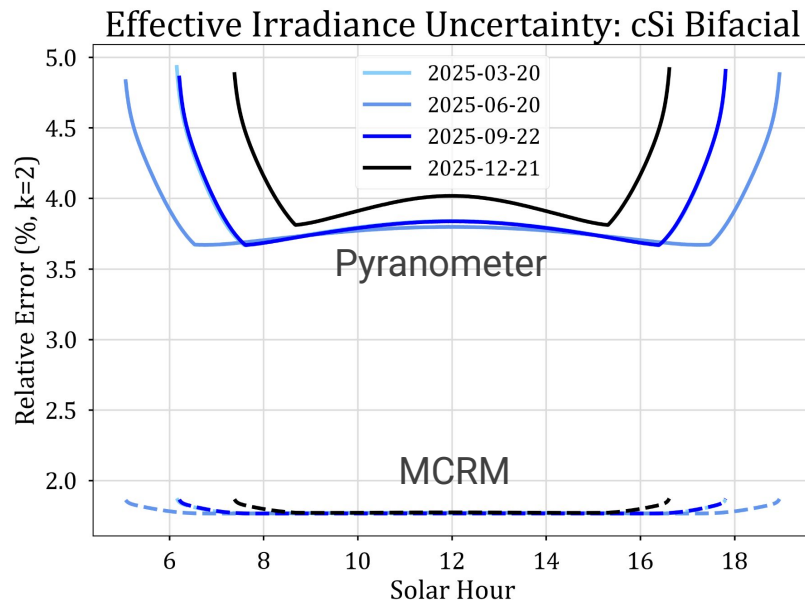
- Root Sum Squared (RSS) uncertainty analysis
 - Pvlb Monte-Carlo simulations
 - GR PVTL
- Clear-sky data only
 - Both solstices and equinoxes
- Pyranometer & MET
 - ISO 9060:2018 & IEC 61724-1:2021
- MCRM calibration
 - ISO 90604 indoor
 - ISO 17025
- Atmospheric Spectral
 - Lee & Panchula 2016
- IAM
 - Martin & Ruiz 2001; 2002; 2004
- No soiling



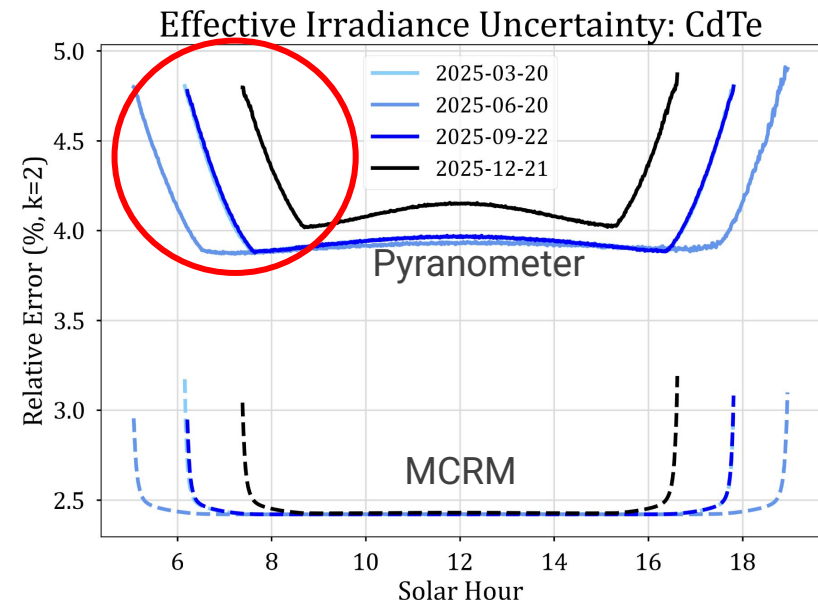


- MCRM uncertainty: calibration dominates
 - CdTe low-light, shunt + ADC increase
 - CdTe uncertainty greater due to instability of I_{sc} with indoor cal
- Pyranometer uncertainty: calibration, sensor intrinsic error, & spectral mismatch dominate

- Pyranometer uncertainty increase morning/evening Air Mass dependent
- Largest uncertainty when array not clipping and capacity tests are commonly performed



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Conclusions

- Use of MCRM as the primary irradiance source minimizes effective irradiance modeling complexity and uncertainty
 - ABQ, NM PVTL results show reduced bias, variability, and uncertainty as compared to pyranometer with corrections
 - Lowest RMS error obtained following the draft IEC 61724-2:2024 standard using a calibrated reference module (Deline et al 2024)
 - <https://www.nrel.gov/docs/fy24osti/88890.pdf>
 - ASTM E2848: Reference module uncertainty <2%
 - <https://store.astm.org/e2848-13r18.html>
- We can hedge capacity testing risk with manageable fixed cost deploying both pyranometers and MCRMs
 - Shorten capacity testing issue resolution timescales and improve stakeholder confidence

Future Work

- Further refine RSS analysis
 - Independent contributing source sensitivity & weighting
 - Compare ABQ results to NREL uncertainty tool
- Incorporate spectral data and AOD

The logo for GroundWork, featuring the word "GroundWork" in a white sans-serif font. A small icon of a plant with a circular base is positioned between the "G" and "r".

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The words "Thank You" in a large, bold, yellow sans-serif font, centered over the image.

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