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Let's talk about how we can help you reduce uncertainty and increase value!

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Nearly 100 Years of Pyranometer Innovation: Reducing Uncertainty, Increasing Confidence

Introduction & Financial Impact Example

Accurate irradiance data is the invisible thread connecting performance to profit
Irradiance data is not just a technical metric – it's the foundation of trust, accountability, and profitability across the solar value chain. From the moment sunlight hits a pyranometer, the data it generates influences:

- **Performance guarantees** for EPCs and O&M providers
- **Revenue forecasts** for developers and owners
- **Risk assessments** for financiers and investors
- **Grid planning** for utilities
- **Operational decisions** for SCADA and asset managers

When irradiance data is wrong, everything downstream is distorted—performance ratios, financial models, and even legal outcomes. Accuracy matters!

Metric	PR 80%	PR 76%
Annual Revenue	$768,000	$729,600
30-Year Revenue	$36M	$34.2M
Difference		**$1.8M loss**

Performance Ratio is the bridge between irradiance data and financial outcomes. A 4% error in PR isn't just a technical issue – for this 64 MW site it's a $1.8M problem. We use $/MWh from [8] and sun hours from [9].

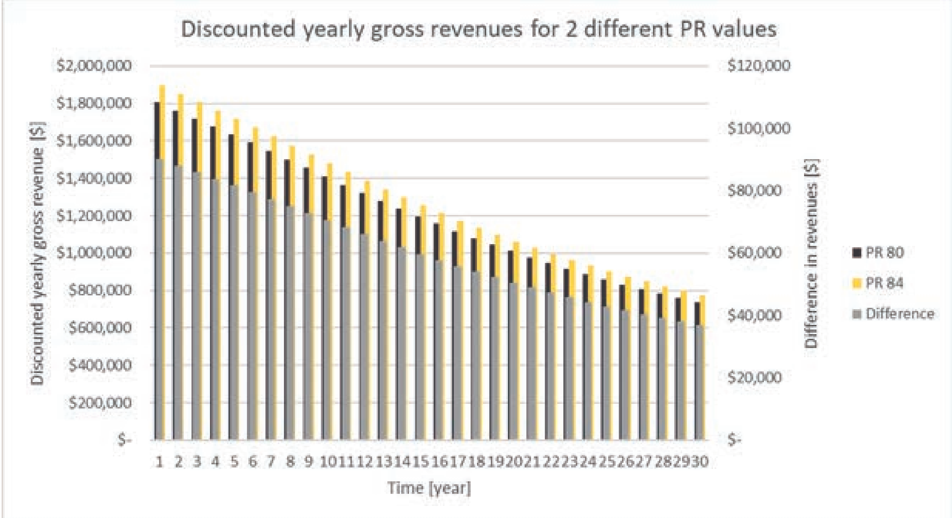
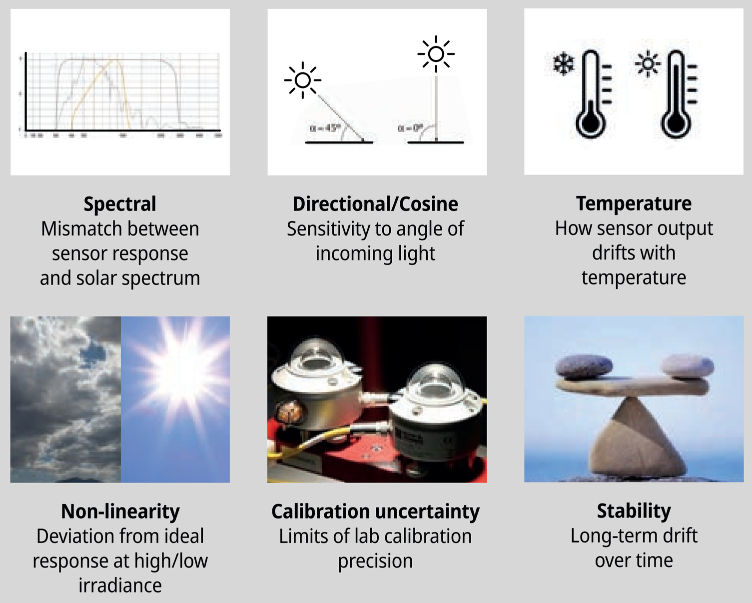


Figure 1: Financial impact of a PV site with a different in PR of 4%.

Sources of Pyranometer Error

Not All Errors Are Created Equal – But Most Can Be Managed. A dozen sources of error that increase the uncertainty of irradiance measurements, and therefore Performance Ratio calculations, are presented here.

Reduced via Design Innovation (Manufacturer)
Precision by design – because 3% uncertainty is no longer good enough



Spectral Mismatch between sensor response and solar spectrum

Directional/Cosine Sensitivity to angle of incoming light

Temperature How sensor output drifts with temperature

Non-linearity Deviation from ideal response at high/low irradiance

Calibration uncertainty Limits of lab calibration precision

Stability Long-term drift over time

Reduced by Proper Installation & Maintenance (User)
User errors often exceed sensor errors. But with the right tools and training, they're preventable.

Leveling Even a few degrees off can skew readings

Soiling Dust, bird droppings, or snow reduce accuracy

Shading Nearby structures or cables casting shadows

Dew & frost Early morning overestimation

Sensor sitting Edge rows or atypical module positions

Shock damage From mishandling or transport

Pyranometer Placement

In recent years, there has been renewed attention on a subtle yet impactful source of error in PV performance analysis: the placement of POA and rPOA pyranometers within a site. A simulation and field validation study conducted in San Angelo, Texas, revealed that sensor placement can lead to irradiance measurement differences of up to 7.6% between the lowest and highest irradiance locations. Sensors mounted at the center-of-module, in the interior of the center row of the array (which represent 98% of the modules on site) recorded irradiance values approximately 2% lower than those placed at edge-of-array positions. These differences are significant enough to affect performance ratio calculations and, by extension, site valuation. Make sure to consider what analyses and models are being used when you decide where to place the sensor as some performance models has specific placement considerations.

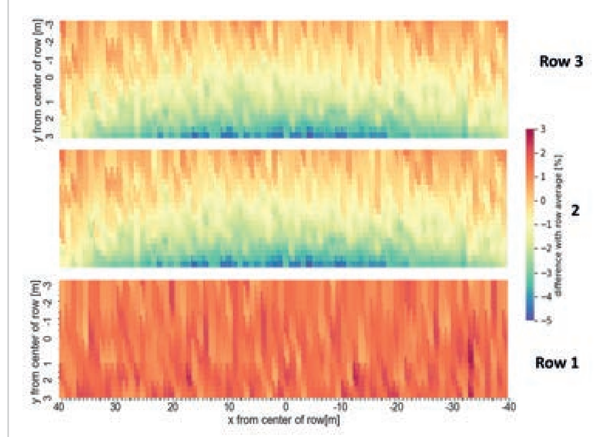


Figure 7: Fixed Tilt irradiance heatmap

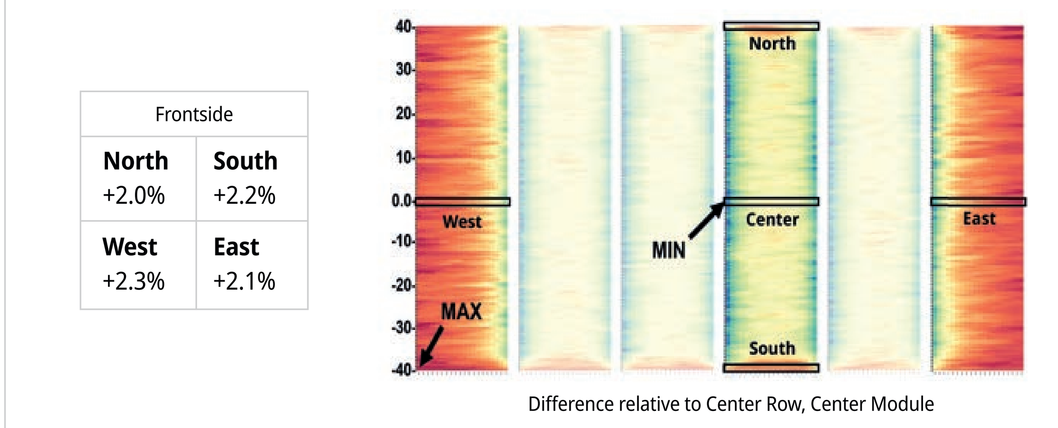


Figure 8: Single-Axis Tracker heatmap

A History of Innovation

ISO 9060:2018 defines three tiers of pyranometer quality, but we built a fourth, the SMP22. With nearly 100 years in pyranometer innovation at Kipp & Zonen, many improvements have been made throughout the years.

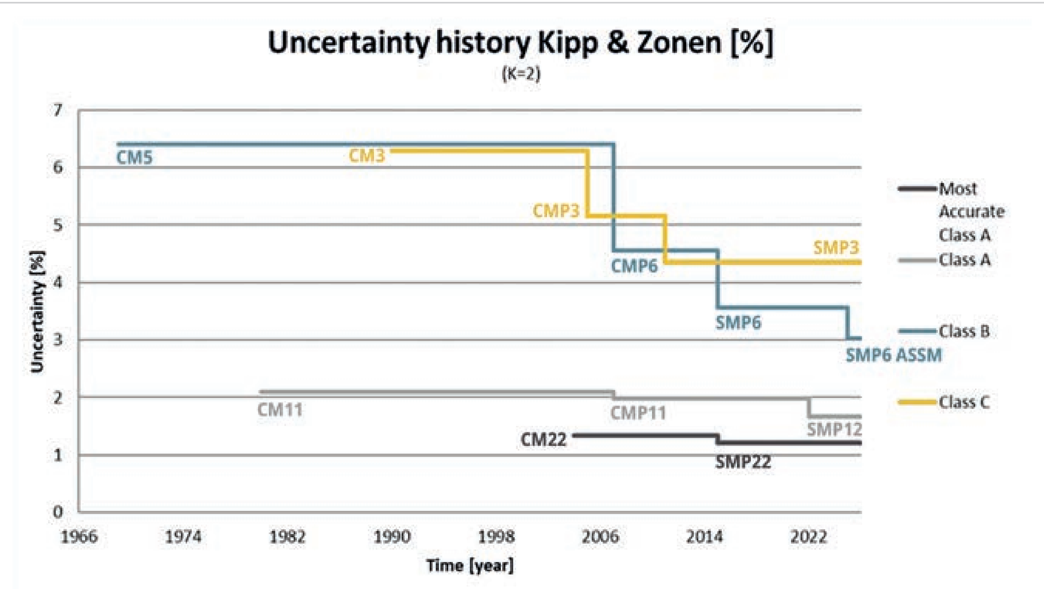
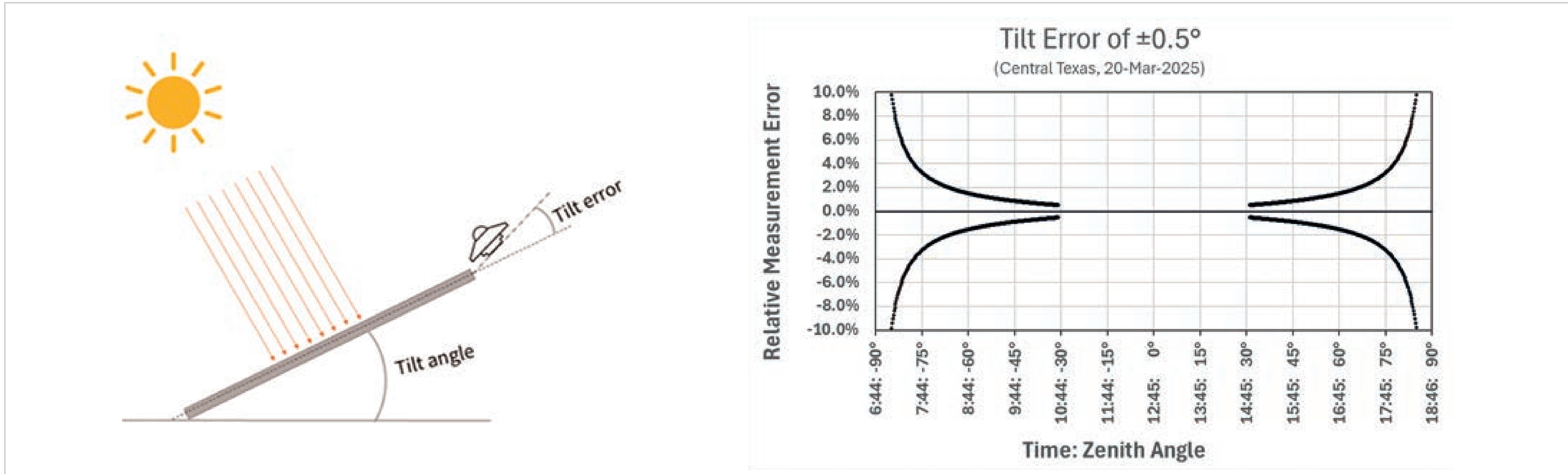


Figure 2: Over nearly 100 years, Kipp & Zonen has reduced uncertainty from over 6% to just over 1%.

CM11 – CM22: Quartz domes for improved spectral and directional accuracy
CM11 – SMP10: Digital signal processing and temperature compensation
SMP10 – SMP12: Integrated heating, tilt and humidity diagnostics
CM22 – SMP22: Ultra-low uncertainty, ISO-accredited calibration, fast response
CMP10 Series: Inner drying cartridge: 10-year maintenance interval
SMP Series: Smart electronics for faster response and better temperature behavior
ASSM Calibration: Reduced reference uncertainty, no directional error during calibration

Pyranometer Installation & Maintenance

After choosing the right location, ensuring a sensor is installed pointing in the correct direction (e.g. level for Global Horizontal Irradiance) is critical during installation. Verifying it remains pointing in the desired direction is a key maintenance item, as well as keeping the dome free from soiling, dew and frost that all negatively impact irradiance measurements.



Visualization of Errors Throughout A Clear-Sky Day

The following graphs quantify the worst-case error for Kipp & Zonen Class C, B and A sensors. The largest sources of error directional response, temperature response and calibration uncertainty as well as the smaller sources are improved through material quality, double domes or layered optics, larger sensor mass, and many production technique advancements.

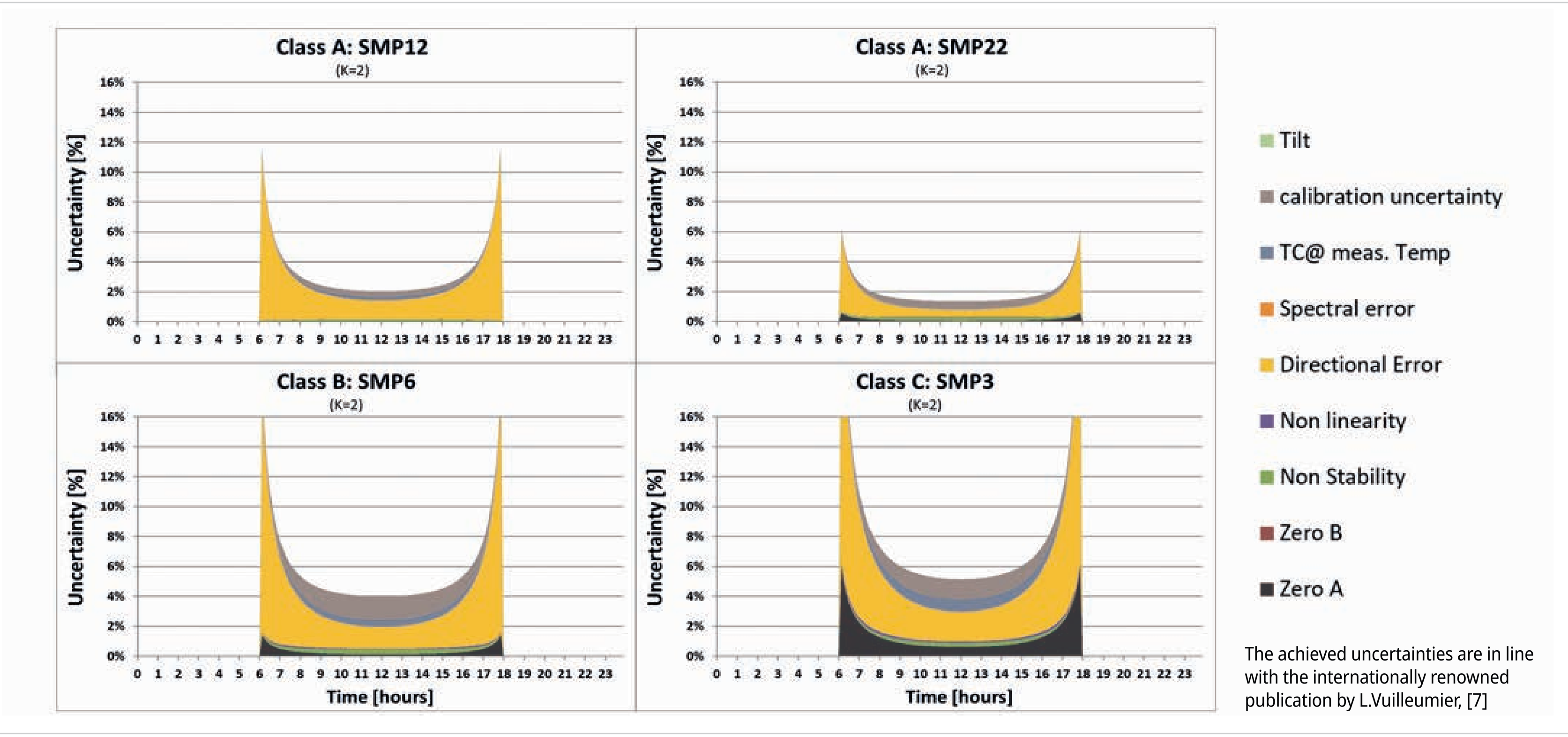


Figure 3, 4, 5, 6: Stacked uncertainty charts showing the difference in uncertainty in Class C, B and A pyranometers throughout a clear-sky day for POA irradiance.

Shared Responsibilities = Shared Success

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$$PR = \left(\sum_k \frac{P_{out,k} \times \tau_k}{P_0}\right) \Big/ \left(\sum_k \frac{G_{i,k} \times \tau_k}{G_{i,ref}}\right)$$

Accuracy is a shared responsibility:
We've minimized design errors; now it's up to the field teams to minimize user and environmental ones.
Data quality drives value:
From PR calculations to financial modeling, every stakeholder benefits from better irradiance data.
Improving measurement uncertainty directly improves PR% uncertainty:
Calculated energy ($G_{i,k}$) is directly proportional to measured energy ($P_{out,k}$)

OTT HydroMet's Manufacturer Role	Your Role
Sensor Design	Sensor Siting
Calibration	Installation
Diagnostics	Maintenance
Innovation	Data Integrity

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References: [1] "Simulation and Validation of Bifacial Irradiance Sensor Mounting Position", Korevaar et al. EU PVSEC 2020; [2] "Strategies for Rear Irradiance Monitoring", Riedel et al., PVPMC 2023; [3] "Bifacial photovoltaic Technology: recent advancements, simulation and Performance measurement", M. Aghaei et al., 2022, ISBN:978-1-83968-858-4; [4] "Simulation of POA front irradiance sensor mounting position", Korevaar et al., PVPMC 2023, Mendrisio; [5] "Improving Performance Ratio Calculations by Optimizing Front POA Irradiance sensor Position", Nitzel et al., PVPMC 2024, Salt Lake City; [6] Ayala Pelaez and Deline, (2020). bifacial_radiance: a python package for modeling bifacial solar photovoltaic systems. Journal of Open Source Software, 5(50), 1865, https://doi.org/10.21105/joss.01865; [7] L. Vuilleumier, et al., "Accuracy of ground surface broadband shortwave radiation monitoring", Journal of Geophysical Research: Atmospheres, 2014; [8] https://emp.lbl.gov/sites/default/files/utility-scale_solar_2022_technical_brief.pdf; [9] Smets A, Jäger K, Isabella O, van Swaaij R, Zeman M. Solar Energy: The physics and engineering of photovoltaic conversion, technologies and systems. Cambridge: UIT Cambridge Limited, 2016. 462 p.