Irradiance Variations of a Pyranometer due to Leveling Issues

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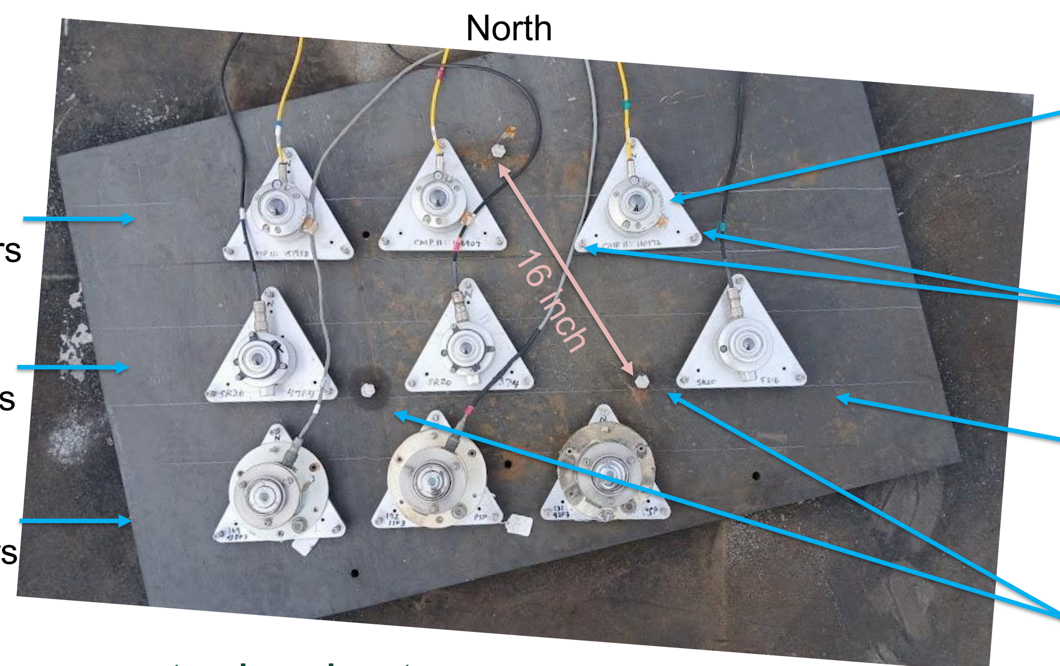
Question 1: How does pyranometer tilt correlate with spirit bubble position?

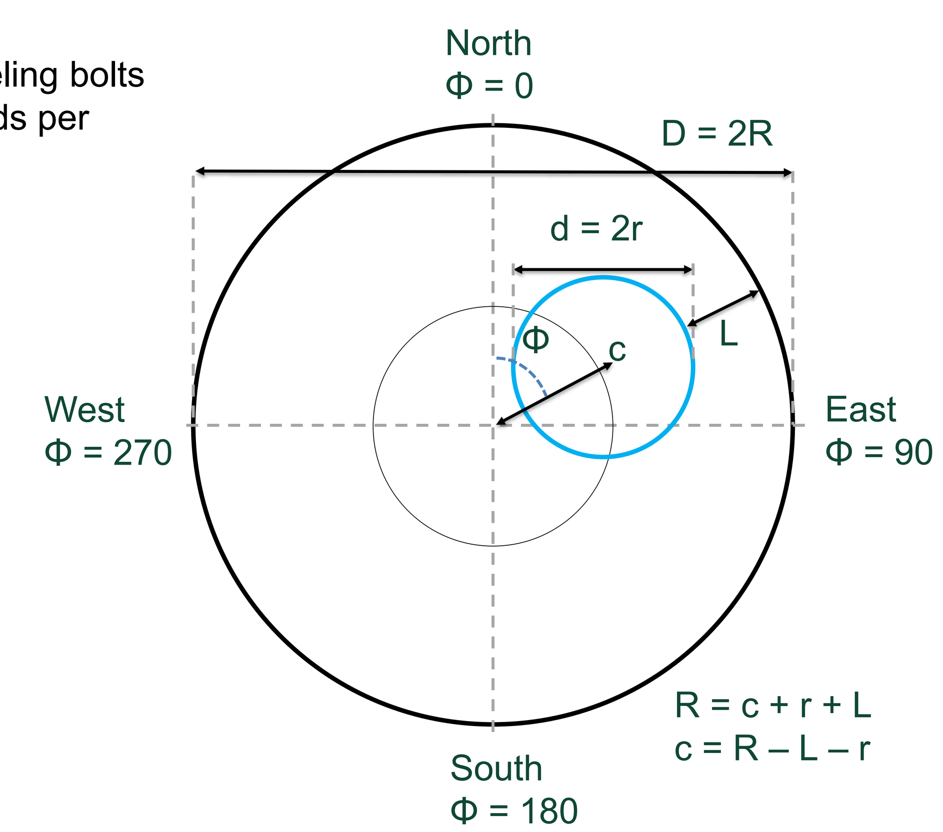
Answer 1: For a CMP11 or SR20, a bubble positioned halfway outside the edge of the reference circle corresponds to a tilt of approximately 0.07°.



Pyranometer level setup

Experimental setup

1. Level all sensors individually,
2. Adjust large plate screws fraction of a turn
3. Photograph sensors
4. Repeat steps 2,3 for different tilt angles



Analysis method

From photographs measure values D, d, L

Compute c

$c = R - L - r$

c is in cm

Normalize distances

$c' = \frac{c}{R - r}$

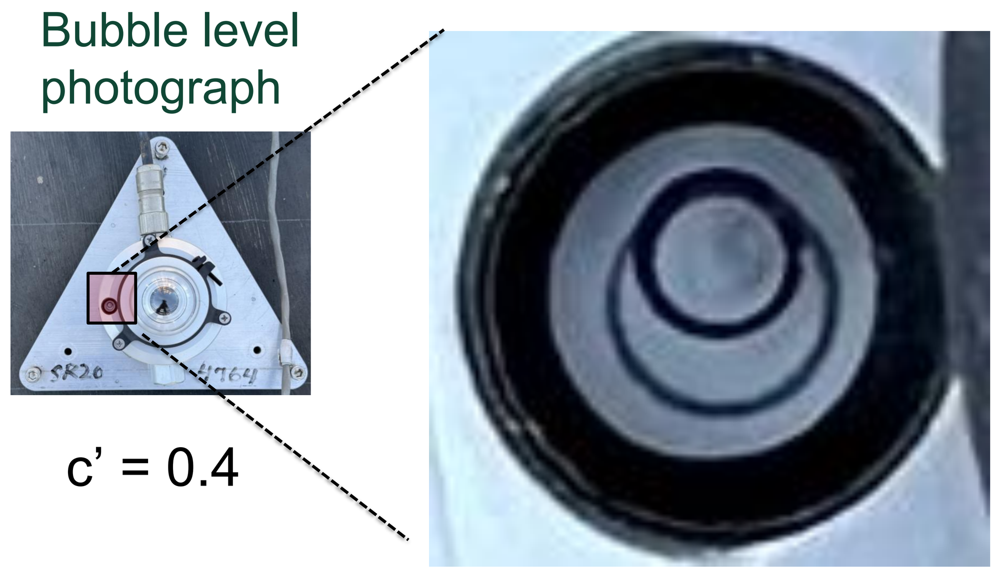
Allows for comparison of different photographs

From bolt turn records compute sensor tilt (θ)

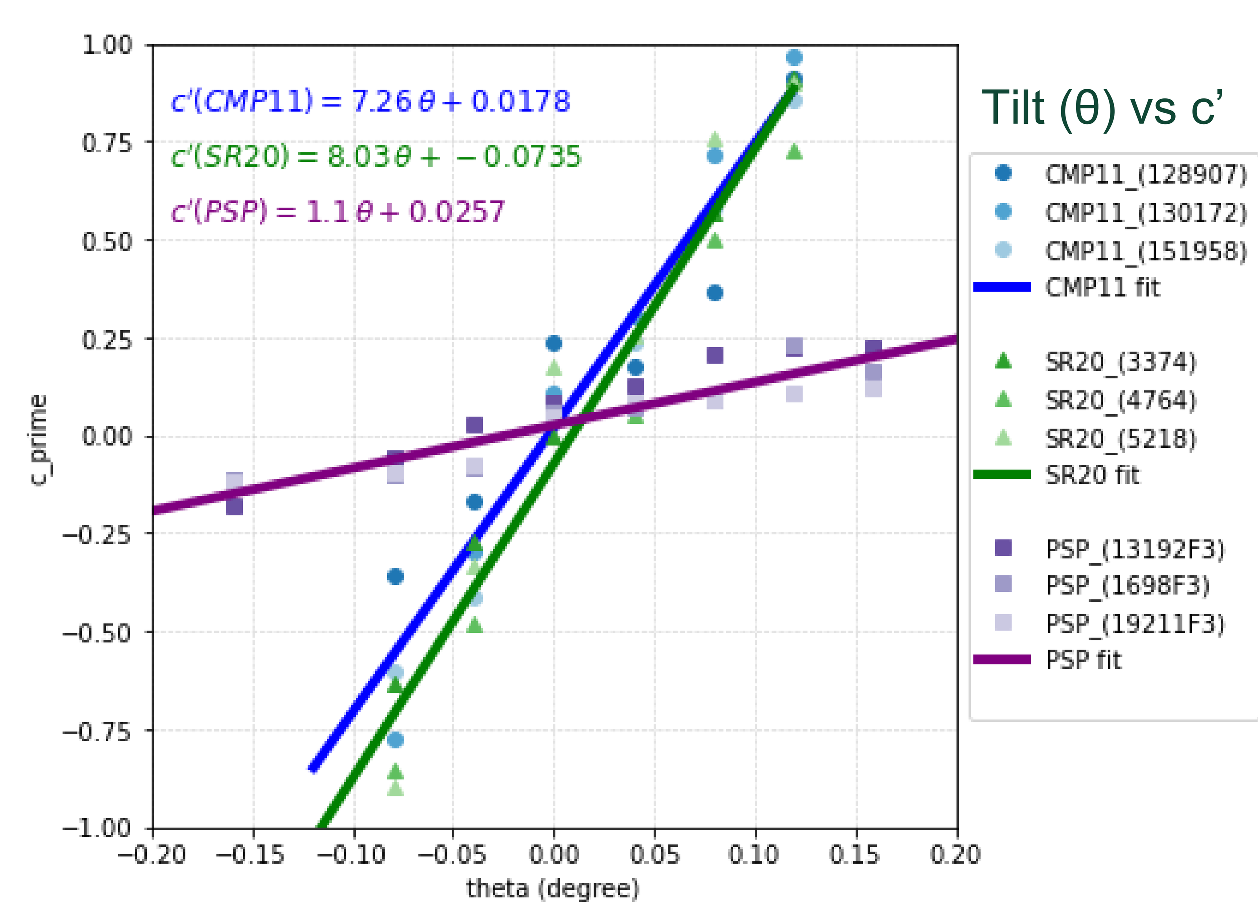
$\theta = \arctan\left(\frac{N * \text{thread\_pitch}}{16'' * 25.4 * \cos(30)}\right)$

$\theta = \arctan\left(\frac{N * 1.954\ \text{mm}}{352\ \text{mm}}\right)$

Bubble level photograph

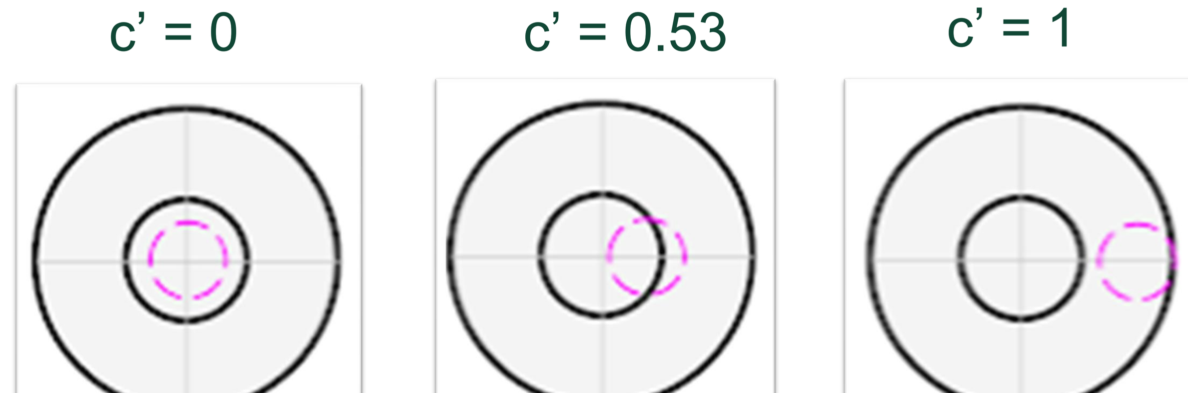


c' = 0.4



Tilt (θ) vs c'

Bubble position vs tilt (diagram)



References

[1] Best Practices Handbook for the Collection and Use of Solar Resource Data for Solar Energy Applications: Third Edition. April - 2021 ISBN 978-3-907281-19-2

[2] Peterson, J., & King, M. (2025). *Irradiance Variations of a Pyranometer due to Leveling Issues.*

[3] Vignola, F., Michalsky, J., & Stoffel, T. (2019). *Solar and infrared radiation measurements.* CRC press.

Question 2: How much does a 0.07° pyranometer tilt (bubble halfway to the circle edge) affect responsivity during component summation calibration?

Answer 2: Very little. Bubble-in-circle tilts produce only ~0.1% bias, smaller than normal day-to-day variability. Standard leveling practice is sufficient.

CMP11 and SR20 pyranometers mounted on triangular leveling plates for precise tilt control.

1. Responsivity definition

$$R_{horiz} = \frac{\mu V_{horiz}}{DNI_{ref}\,Cos(Z) + DHI_{ref}}$$

Calibrate tilted sensor from horizontal reference

$$R_{tilt} = \frac{\mu V_{tilt}}{DNI_{ref}\,Cos(Z) + DHI_{ref}}$$

2. The irradiance incident on the sensor is dependent on the sun location and the tilt of the sensor

$$GHI_{ref} = DNI_{ref}\,Cos(Z) + DHI_{ref} \qquad POA = DNI_{ref}\,Cos(AOI) + DHI_{ref}$$

$$Cos(AOI) = Cos(Z)\,Cos(\theta) + Sin(Z)\,Sin(\theta)\,Cos(A - \Phi_{surface})$$

3. We assume that the horizontal responsivity is the true responsivity

$$R_{horiz} = R_{truth}$$

4. The sensor generates μV proportional to the incident irradiance. The true responsivity of the sensor is a conversion factor between irradiance and μV.

$$\mu V_{horiz} = R_{horiz} * GHI_{ref} \qquad \mu V_{tilted} = R_{horiz} * POA$$

5. Compute percent difference between two responsivity values

$$R_{tilt\_\%dif} = \frac{R_{tilt} - R_{horiz}}{R_{horiz}} * 100$$

$$R_{tilt\_\%dif} = \frac{DNI * (Cos(AOI) - Cos(Z))}{GHI_{ref}} * 100$$

2. $R_{tilt\_\%dif} = \dfrac{\frac{\mu V_{tilt}}{DNI\,Cos(Z)+DHI} - \frac{\mu V_{horiz}}{DNI\,Cos(Z)+DHI}}{\frac{\mu V_{horiz}}{DNI\,Cos(Z)+DHI}} * 100$

3. $R_{tilt\_\%dif} = \dfrac{\mu V_{tilt} - \mu V_{horiz}}{\mu V_{horiz}} * 100$

4. $R_{tilt\_\%dif} = \dfrac{POA - GHI_{Ref}}{GHI_{Ref}} * 100$

5. $R_{tilt\_\%dif} = \dfrac{(DNI_{ref}\,Cos(AOI) + DHI_{ref}) - (DNI_{ref}\,Cos(Z) + DHI_{ref})}{GHI_{Ref}} * 100$

Percent difference due to tilt issues is smaller than the day-to-day variation