# 671 Data from a New, Low-Cost Thermopile Pyranometer Compare Well with High-End Pyranometers

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## Introduction

- Early 1960s: silicon-cell pyranometers introduced
  - Much lower price, but less accurate than traditional thermopile pyranometers
  - Narrow spectral response (360-1120 nm) means they require a clear view of the sky and over-estimate solar radiation on cloudy days
  - Low price greatly increases their use in environmental research projects
- 2017: low-cost, digital thermopile pyranometers introduced by Campbell Scientific and Apogee Instruments (CS320)
  - Broad spectral response (385-2105 nm)
    - Correctly measure solar radiation on cloudy days
  - Affordable to environmental research and mesonets without sacrificing accuracy and flexibility
- Not all pyranometers are of the same quality.
  - Three pyranometer categories established by the World Meteorological Organization (WMO) and the International Organization for Standardization (ISO)
  - The ISO categories named "secondary standard," "first class," and "second class" closely correspond to the WMO categories named "High quality," "Good quality," and "Moderate quality" (Jarraud 2014). (Table 1).

## Comparison Method

- Solar radiation data were collected with a Campbell Scientific CR1000 datalogger with an AM16/32B multiplexer and the following co-located pyranometers:
  - CS320 digital thermopile pyranometers (n=10)
  - CS300 silicon-cell pyranometers (n=20)
  - SP Lite2 silicon-cell pyranometers (n=5)
  - LI200 silicon-cell pyranometers (n=5)
  - LI200R silicon-cell pyranometers (n=5)
  - 4 ISO secondary standard pyranometers
    - Kipp & Zonen CM 11
    - Kipp & Zonen CMP 11
    - Hukseflux SR20
    - EKO MS-80

**Table 1**. ISO and WMO pyranometer standards compared to CS320 specifications

| ISO-9060 | Secondary Standard | First Class | Second Class | CS320 Thermopile Pyranometer |
|---|---|---|---|---|
| WMO | High Quality | Good Quality | Moderate Quality | |
| Response time (95%) | < 15 s | < 30 s | < 60 s | < 2 s |
| Zero Offset A due to 200 $W/m^2$ net thermal radiation (ventilated) | ± 7 $W/m^2$ | ± 15 $W/m^2$ | ± 30 $W/m^2$ | 8 $W/m^2$ |
| Zero offset B response to 5 K/hr change in ambient temperature | ± 2 $W/m^2$ | ± 4 $W/m^2$ | ± 8 $W/m^2$ | < 5 $W/m^2$ |
| Stability (Change per year, % full scale) | ± 0.8 % | ± 1.5 % | ± 3 % | < 2 % |
| Linearity | ± 0.5 % | ± 1 % | ± 3 % | < 1 % |
| Directional response (up to 90°) | ± 10 $W/m^2$ | ± 20 $W/m^2$ | ± 30 $W/m^2$ | < ± 20 $W/m^2$ (up to 80°) |
| Percent deviation due to temperature change within an interval of 50 K | 2% | 4% | 8% | < 5% from -15° to 45°C |
| Tilt Response | 0.5% | 2% | 5% | 1% |
| Uncertainty (95% confidence level) Hourly totals | 3% | 8% | 20% | 8% |
| Uncertainty (95% confidence level) Daily totals | 2% | 5% | 10% | 5% |
| Spectral range | 300 to 3000 nm | 300 to 3000 nm | 300 to 3000 nm | 385 to 2105 nm |
| Resolution | 1 $W/m^2$ | 5 $W/m^2$ | 10 $W/m^2$ | 1 $W/m^2$ |

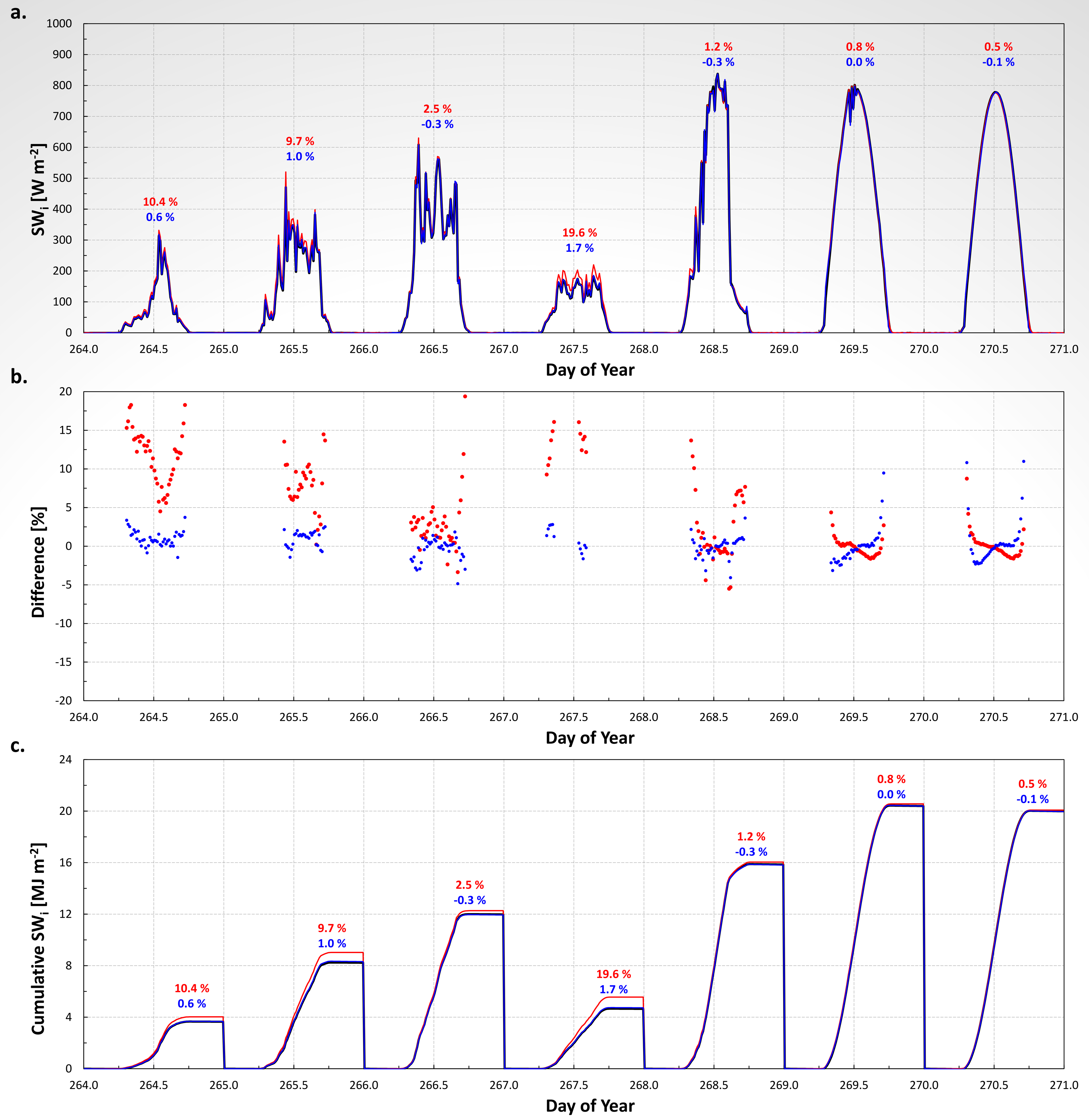


**Figure 1.** Time series plots of the mean of four **secondary standard** pyranometers (**black**), **CS320** thermopile pyranometer (**blue**), **silicon-cell** pyranometer (**red**). The first 4 days in the series were cloudy to partly-cloudy, the other 3 were sunny to mostly-sunny. **a.** Raw solar ($W/m^2$) with mean daily deviations (%) from secondary standard sensors displayed. **b.** Deviations (%) from secondary standard sensors of CS320 and silicon-cell pyranometers. **c.** Cumulative solar radiation ($MJ/m^2$) with daily deviations from secondary standard sensors displayed (%).

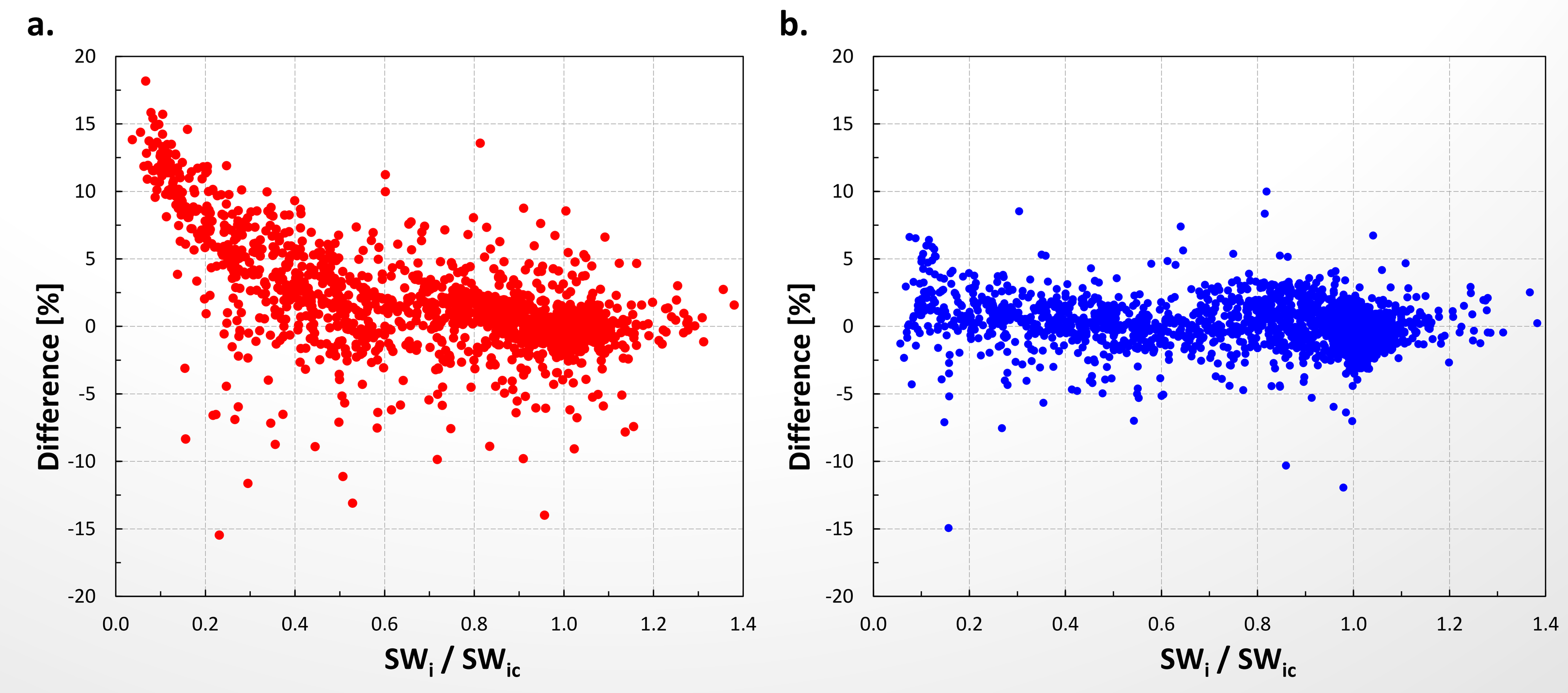


**Figure 2.** Differences from secondary standard pyranometers. $SW_i$ is measured solar watts and $SW_{ic}$ is modeled clear-sky solar watts. The ratio of the two provides an index to how cloudy it is at a given time. Values of the index greater than 1 indicate reflection from clouds during partly cloudy conditions causing readings higher than clear-sky conditions. **a.** **silicon-cell**. **b.** **CS320**.

## Results

- Overall, data from the recently introduced CS320 showed strong agreement with secondary standard pyranometers and a marked improvement over silicon-cell pyranometers (Figs. 1-3)
- As expected, the greatest differences were during cloudy to partly-cloudy days where differences between silicon-cell and secondary standard pyranometers were often 10-20% whereas the CS320 data were most often within 2% (Figs. 1, 2)
- The relatively large differences as expressed in percentages (Fig. 1b) at low solar angle (morning and evening) are of small absolute magnitude
- The relationship between data from secondary standard versus the CS320 is virtually 1:1 with small variance (Fig. 3)

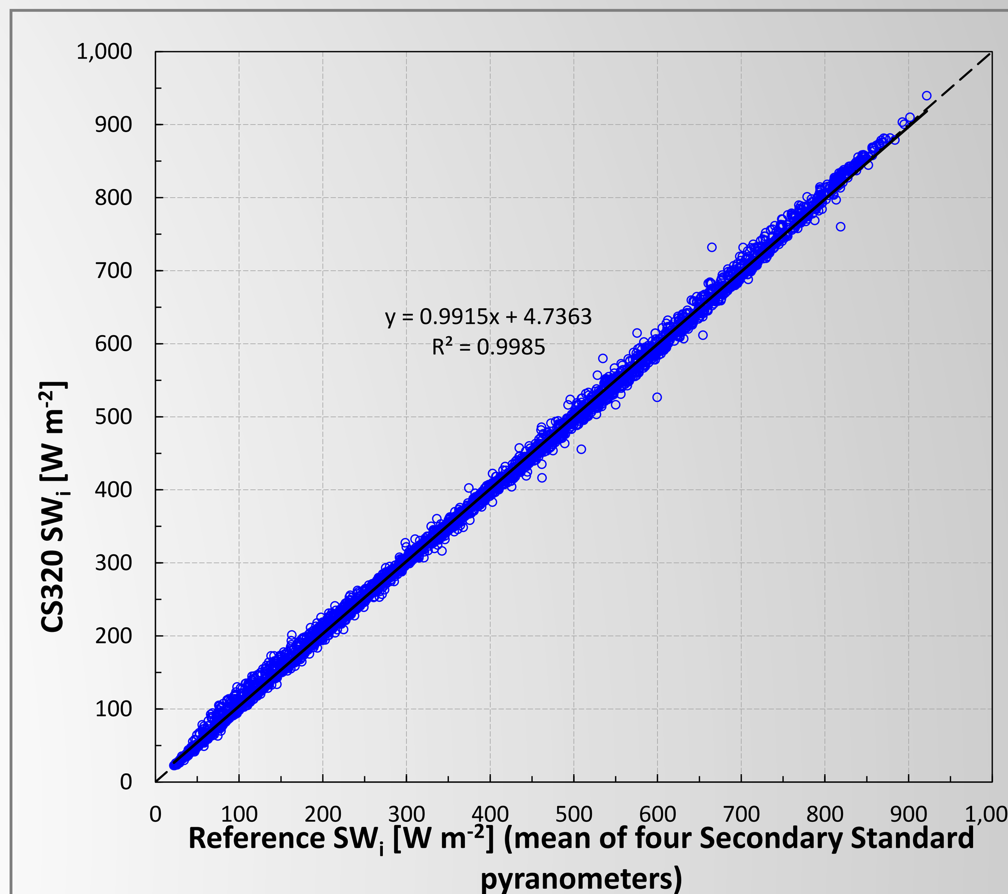


**Figure 3**. One-to-one plot of solar radiation measured by secondary standard versus CS320 pyranometers

**Table 2**. General (US) price ranges for pyranometers

| Pyranometer | Price Range |
|---|---|
| Silicon-cell | \$300 - \$500 |
| Second Class | \$900 - \$1,000 |
| First Class | \$2,000 - \$2,100 |
| Secondary Standard | \$3,000 - \$4,000 |
| CS320 | \$400 |

## Summary and Additional Features

- Data from the CS320 compare favorably with high-end pyranometers (Figs 1-3), offering a strong improvement in measurements over silicon-cell pyranometers
- Priced similarly to silicon-cell (Table 2)
- Internal heater to reduce errors from dew, frost, rain, and snow
- Dome shape head allows sensor to shed dew and rain
- SDI-12 digital output, compatible with all current Campbell Scientific dataloggers and other dataloggers compliant with the SDI-12 standard
- Calibration data stored in sensor – no changes to program required after routine re-calibrations
- Detachable cable from sensor head for fast easy sensor swap / servicing
- Built-in tilt sensor that simplifies installation, diagnostics, and remote troubleshooting
- Designed for long-term stability
- Not intended for markets that require ISO certification

## References:

- Jarraud, M. "Guide to meteorological instruments and methods of observation (WMO-No. 8)." *World Meteorological Organisation: Geneva, Switzerland* (2014): 233.
- ISO 9060:1990 Solar energy — Specification and classification of instruments for measuring hemispherical solar and direct solar radiation, International Organization for Standardization, Geneva, Switzerland: 3-4.
- Tanner, Bertrand D. "Automated weather stations." *Remote Sensing Reviews* 5, no. 1 (1990): 73-98.