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/m² net thermal radiation (ventilated)	± 7 W/m²	± 15 W/m²	± 30 W/m²	8 W/m²
Zero offset B response to 5 K/hr change in ambient temperature	± 2 W/m²	± 4 W/m²	± 8 W/m²	< 5 W/m²
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/m²	± 20 W/m²	± 30 W/m²	< ± 20 W/m² (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/m²	5 W/m²	10 W/m²	1 W/m²

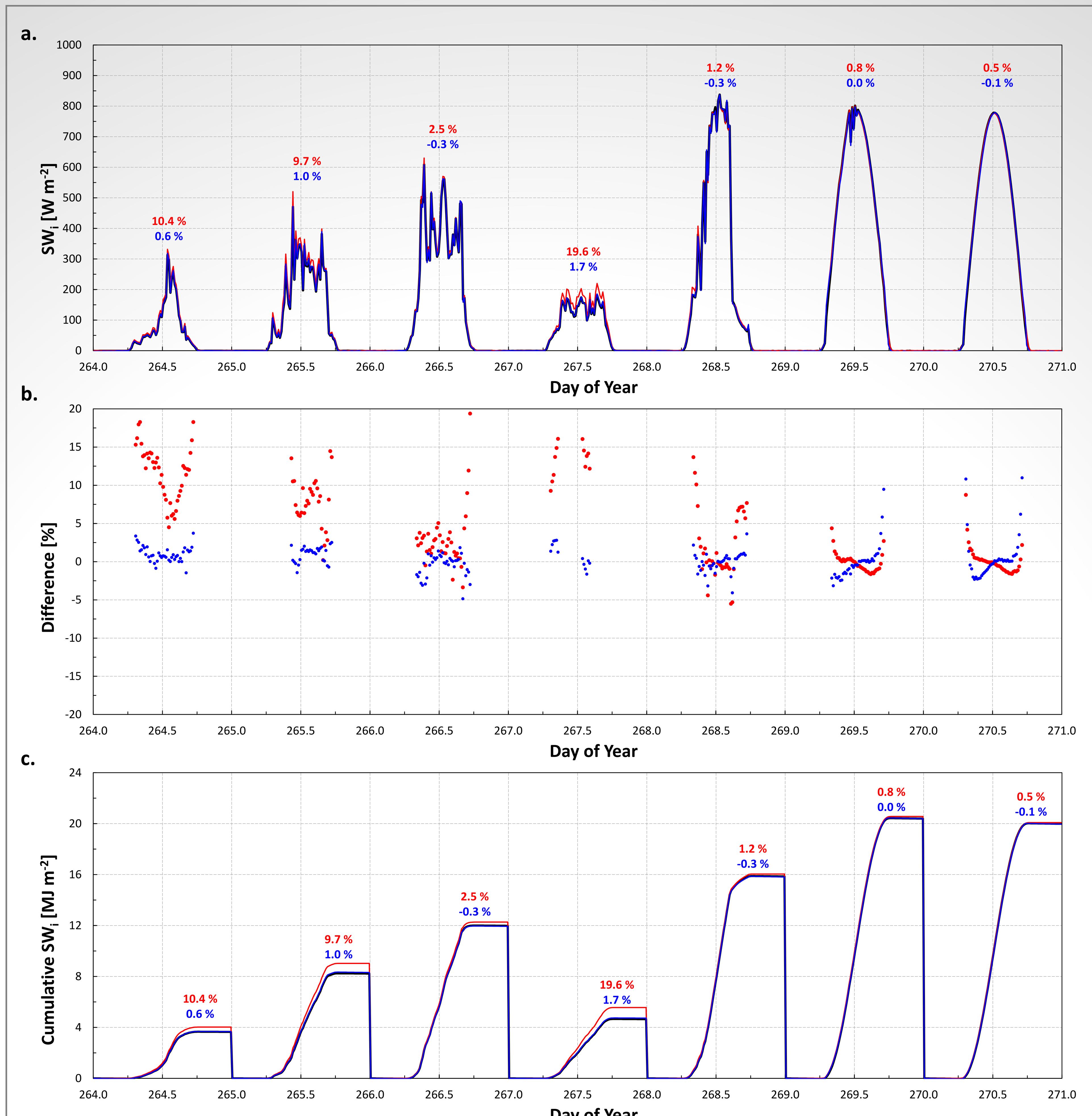

Figure 1. Time series plots of the mean of four **secondary standard** pyranometers (**black**), **CS320** thermopile pyranometer (**blue**), **silicon-cell** pyranometer (**red**). The first 4 days in the series were cloudy to partly-cloudy, the other 3 were sunny to mostly-sunny. **a.** Raw solar (W/m²) 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/m²) with daily deviations from secondary standard sensors displayed (%).

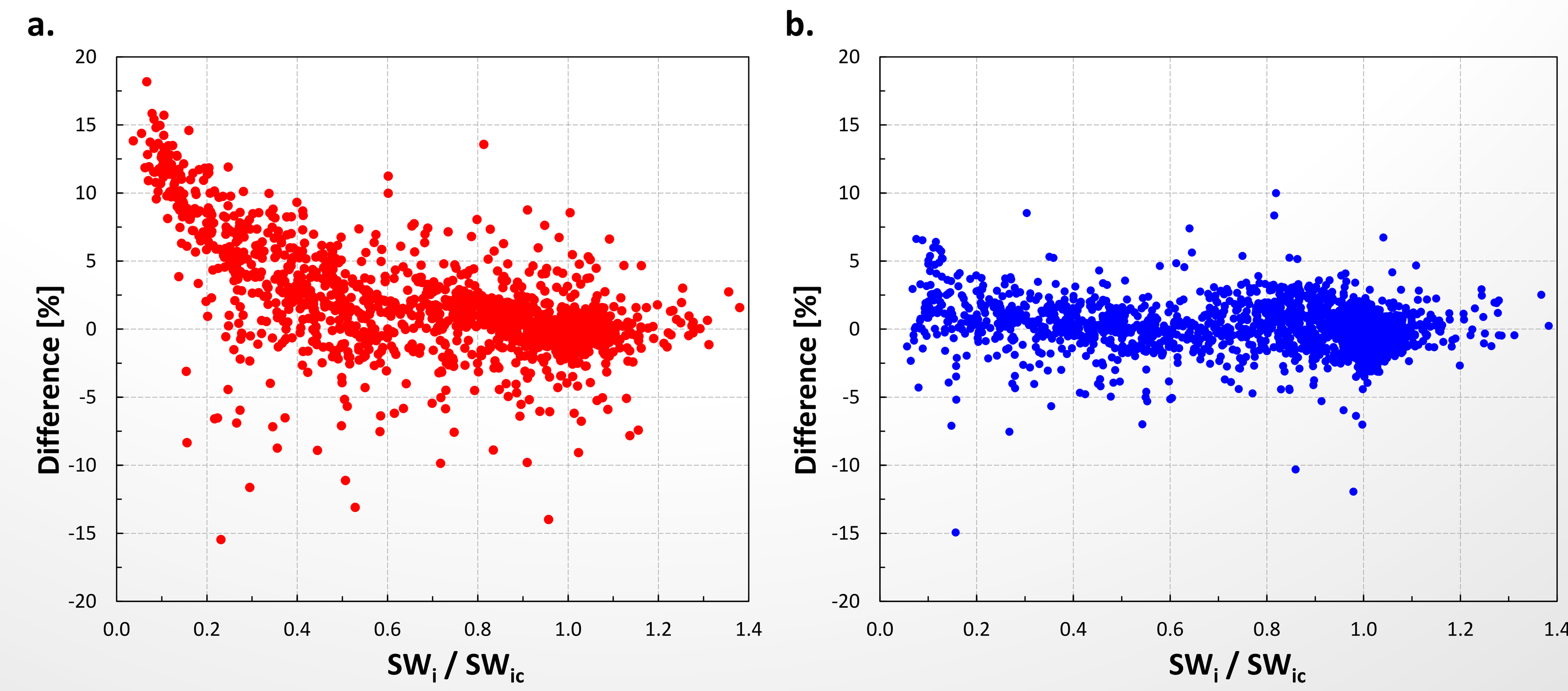

Figure 2. Differences from secondary standard pyranometers. SW_i is measured solar watts and SW_{ic} is modeled clear-sky solar watts. The ratio of the two provides an index to how cloudy it is at a given time. Values of the index greater than 1 indicate reflection from clouds during partly cloudy conditions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

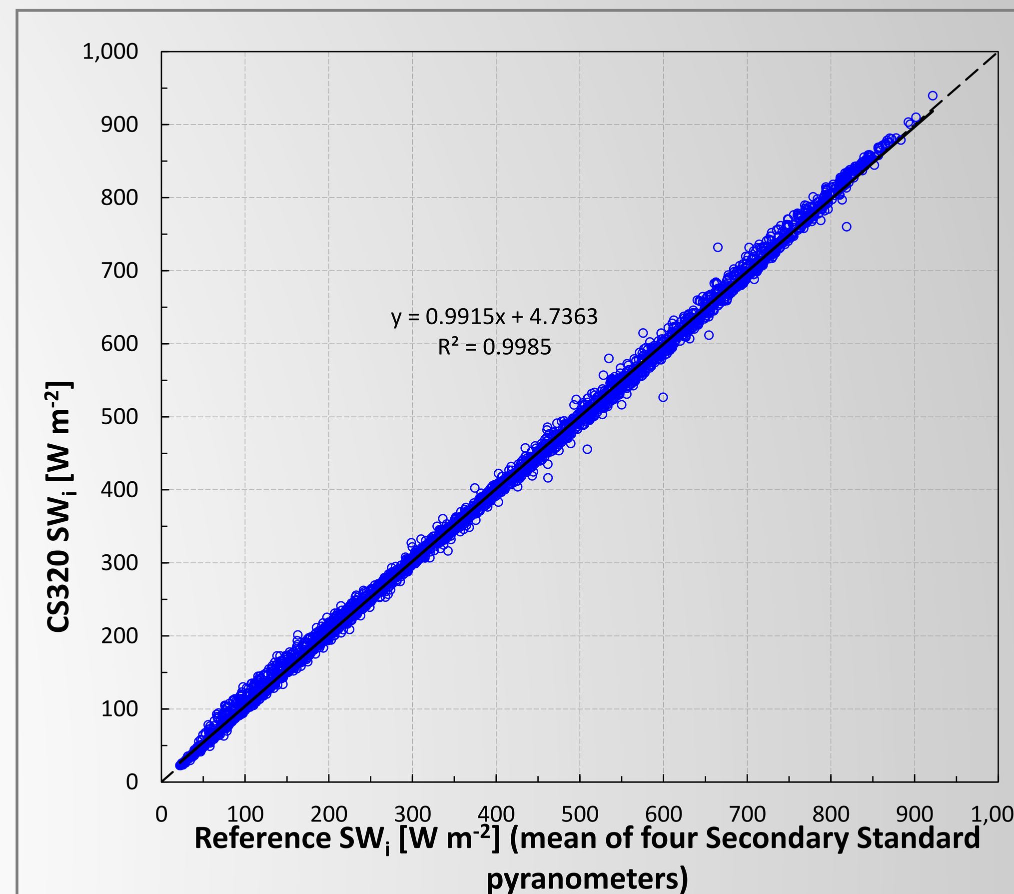

Figure 3. One-to-one plot of solar radiation measured by secondary standard versus CS320 pyranometers

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.
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- Tanner, Bertrand D. "Automated weather stations." *Remote Sensing Reviews* 5, no. 1 (1990): 73-98.