Improved Measurements of the Diffuse and Global Solar Irradiances at the Surface of the Earth

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Introduction

In recent years, studies have shown significant discrepancies between irradiances measured by pyranometers and those computed using atmospheric radiative transfer models (Kato et al. 1997 and Kato et al. 1999). Questions have been raised about the uncertainty in pyranometer measurements because observed diffuse irradiances sometimes are below pure molecular atmosphere values and because the instruments often produce non-zero signals at nights ranging between -5 and -10 W/m^2.

One of the main uncertainties in Eppley Precision Spectral Pyranometer (PSP) measurements is because of a temperature difference between the dome and the body of the instrument (Haeffelin et al. 2001). This temperature difference drives a thermal radiation heat exchange that modifies the output signal of the PSP, introducing an offset called thermal offset. To track the thermal offset we monitor the temperatures using thermistors installed on the inner dome and body of the PSP.

Measuring the PSP Offset

We derive a relationship between the PSP output and the thermal radiative exchange between the dome and the body based on nighttime data. The PSP offset is defined as

$$\mathrm{Offset}_{\mathrm{Night}} = A\sigma(T_d^4 - T_b^4) + B, \qquad (1)$$

where σ is the Stefan-Boltzman Constant and T_d and T_b are the temperatures of the dome and body of the Pyranometer, respectively.

However, the dome thermistor is somewhat sensitive to solar irradiance; therefore, under high solar irradiance, the temperature gradient in the instrument is underestimated. To correct this irradiance dependency and validate Eq. (1) we compare our offset estimates, based on temperature measurements, to the instrument response when it is quickly shaded from all solar radiation. We cap the dome with a white cup. The thermopile responds immediately to the modified input. The output of the thermopile is then driven only by the thermal radiative exchange between the dome and the body of the PSP, which can be considered constant for thirty seconds. We compare a mean temperature-based offset 10 sec before the capping of the PSP and a mean of the PSP output between 10 and 20 seconds after capping.

Figure 1 is a scatter plot of the temperature-based offset minus capping-based offset versus PSP output. The daytime offset can be expressed as

$$\mathrm{Offset}_{\mathrm{Day}} = A\sigma(T_d^4 - T_b^4) - B(E)^{1/2} + C \,, \tag{2}$$

where, E is the diffuse solar irradiance measured by the PSP.

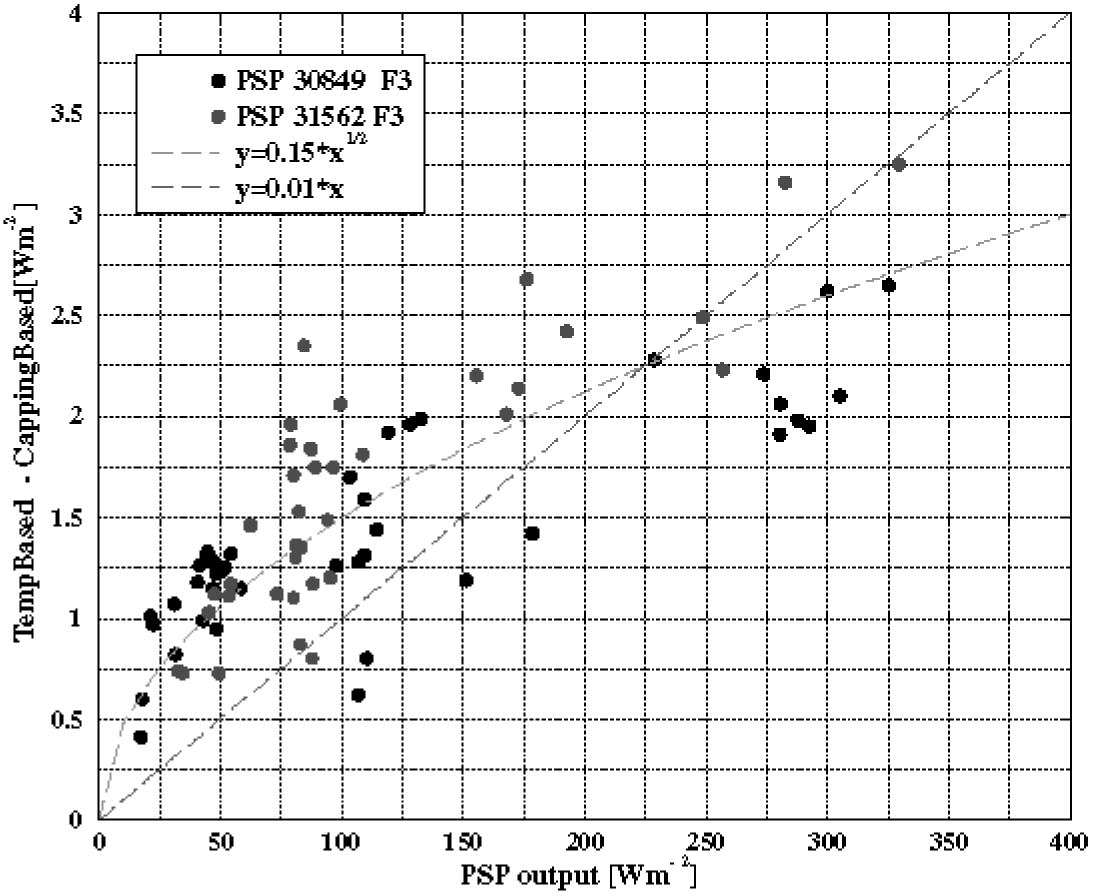

Figure 1. Differences between temperature-based and capping-based offset versus PSP output.

Table 1 shows the offset range for a ventilated and shaded PSP from September to December 2000 at the NASA Langley Roof Top site. The mean of the daytime offset from September to December 2000 was -6.7 Wm^{-2} with a standard deviation of 2.8 Wm^{-2}; however, the offset during nighttime is close to -3.8 Wm^{-2} with a standard deviation of 1 Wm^{-2}.

Table 1. Offset range for a ventilated and shaded PSP.

Sept. to Dec. 2000	Mean (Wm-2)	σ (Wm-2)
Day	-6.7	2.8
Night	-3.8	1.0

Estimating the PSP Offset from Auxiliary Data

Two different methods to retrieve the thermal offset in unmodified PSP have been tested. The first one is a relationship between temperature-based offset and the net infrared (NetIR) from a Pyrgeometer (PIR) as suggested by Dutton et al. (2001). Pyrgeometers are operated next to PSPs in many sites. The latter relationship involves the temperature-based offset and the cloud cover fraction. This latest relationship could be very useful in sites where only PSPs are operated. Both relationships, NetIR and Cloud Fraction, could be very useful to correct historical data.

Estimating the PSP Offset from NetIR Signal

Pyrgeometers are used to measure atmospheric infrared radiation, and they are usually placed with PSPs. The thermopile voltage of the PIR is highly correlated with ambient NetIR (Dutton et al.). The ambient NetIR is one of the main factors that affect the temperature of the dome of the PSP and, therefore, is a significant factor in the thermal offset of the instrument (Dutton et al. 2001).

Therefore, the first correction method consists of deriving a nighttime relationship between the output of adjacent PSPs and PIRs. Once this relationship is found we try to apply it during daytime.

The difference between the daytime temperature-based offset and the offset derived using the NetIR signal is shown in dark. The correction shows a bias of -2 Wm^{-2} and a standard deviation of 1.7 Wm^{-2}.

Estimating the PSP Offset from Cloud Cover Fraction

The temperature of the dome of the PSP is strongly dependent on the ambient NetIR (Dutton et al. 2001). The ambient NetIR depends, in part, on the fraction of cloud cover.

The cloud cover fraction is derived using the Long and Ackerman algorithm (Long, Ackerman et al. 1999). The Long-Ackerman algorithm uses measurements of downwelling broadband total and diffuse shortwave irradiance to detect periods of hemispherically clear sky. Figure 3 shows the relationship between cloud fraction and temperature-based offset. The 15 minutes cloud fraction is binned in 5 percent intervals. A mean offset is derived for each cloud fraction bin. The PSP offset is expressed as

$$\text{Offset} = A\ Cf + B, \qquad (3)$$

where, Cf is the cloud fraction.

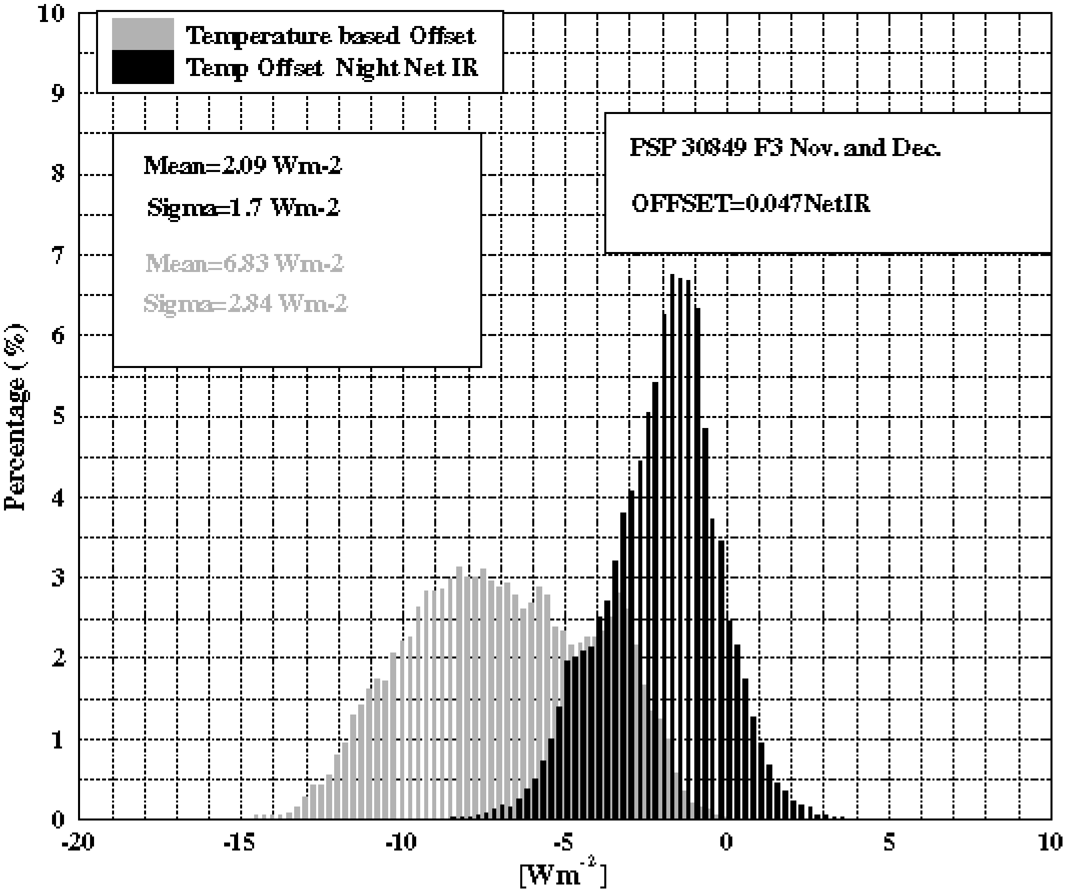

Figure 2. Thermal offset of PSP with (black) and without (gray) correction based on NetIR signal.

Figure 4 shows the distribution of daytime-temperature-based offset for the NASA Larc PSP during November and December 2000. The difference between the daytime temperature-based offset and the offset found using the cloud fraction relationship appears in dark in Figure 4. The correction provides a mean close to zero $\mathrm{Wm^{-2}}$ and a standard deviation of 1.8 $\mathrm{Wm^{-2}}$. This method is a good first-order estimate; however, it leaves out some of the instantaneous variations of the offset. Under overcast conditions, large uncertainty remains because the offset depends on cloud height.

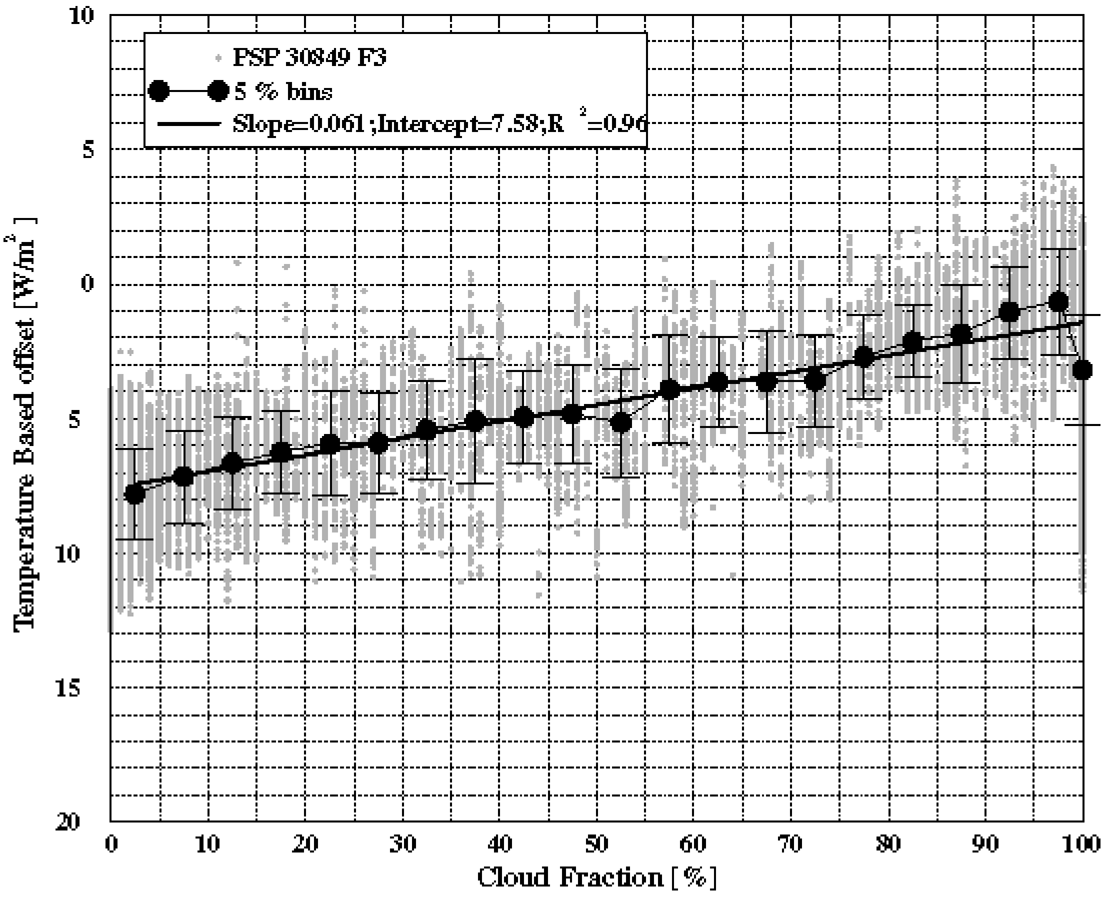

Figure 3. Relationship between cloud fraction and temperature-based offset.

Conclusions

The thermal offset of a PSP has been characterized using thermistors placed in the dome and the body of the instrument. The offset has been validated during daytime and is used as a reference to assess other methods to correct historical PSP data. A relationship between offset and NetIR and a relationship between offset and cloud cover fraction are proven to be valid to correct the offset.

However, the NetIR presents a bias of around 2 Wm^{-2}. This bias is not present in the cloud fraction relationship. We must test the cloud fraction method further to determine if it is a suitable way to find the offset in situations where the NetIR signal is not available. The cloud fraction relationship still presents some uncertainties related to the effect of cloud height.

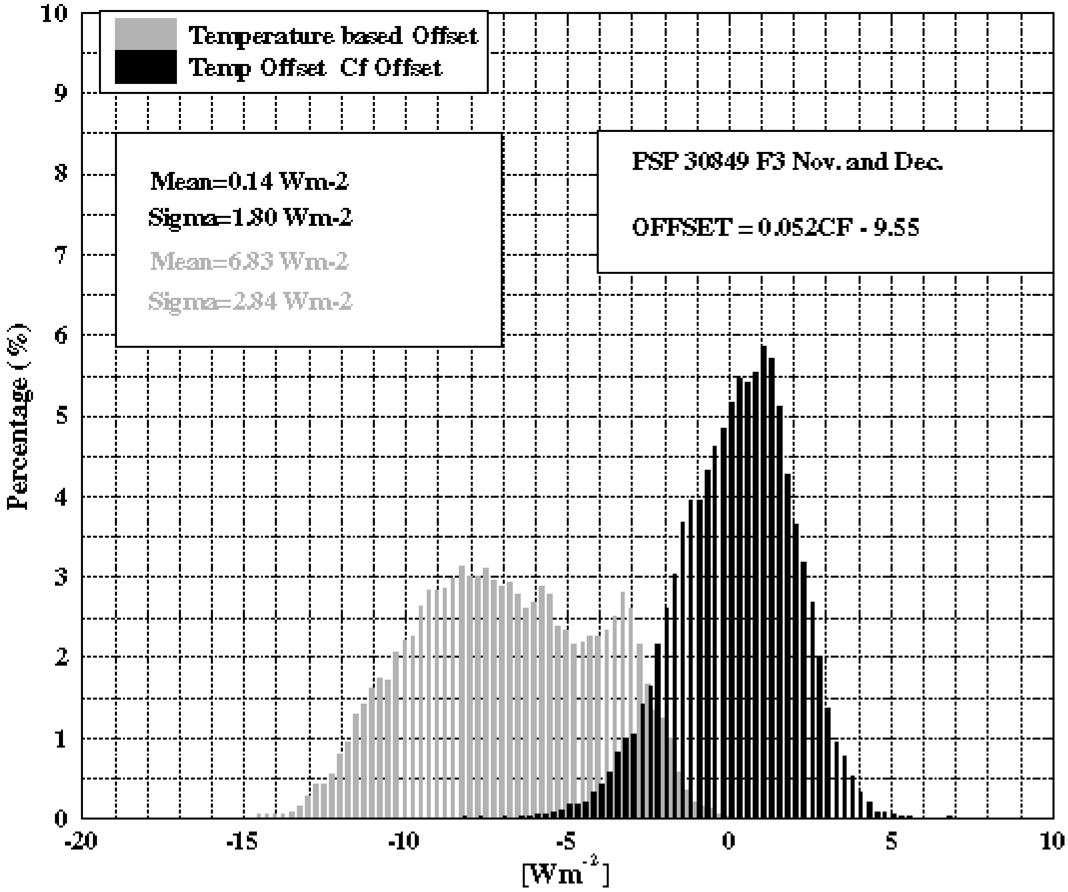

Figure 4. Thermal offset of PSP with (Black) and without (gray) correction based on cloud fraction.

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