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Technical Report

A Method to Correct the Night-Time Offsets of Solar Pyranometers

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Abstract

This is a method to correct for night-time offset measured by solar pyranometers using a correction function of the pyranometer parameters or a correction function of some environmental parameters that describe the pyranometer thermodynamics. The correction function is used to correct the pyranometer readings during daytime.

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1. Introduction

It has been observed that pyranometers measure offset radiation when there is no short-wave radiation or at solar zenith angles greater than 90° (night-time offset)[1]. This offset radiation is thought to be attributed to the long-wave radiation measured by the pyranometer and the thermal gradient between the hot and the reference junctions of the pyranometer thermopile. The measured long-wave radiation is a result of the temperature difference between the pyranometer dome and case, and a part of the long-wave incoming (sky) radiation that is not filtered by the pyranometer dome. The temperature gradient in the pyranometer thermopile is a result of the thermal response lag time between the reference and hot junctions of the thermopile. When there is a change in the ambient temperature, the thermal response time (TRT) of the reference junction is slower than the TRT of the hot junction because the reference junction is inside the thermal mass of the pyranometer. These conditions are present during solar zenith angles less than 90° (daytime), and it is believed that they cause errors in measuring the short-wave radiation of the sun when using pyranometers. These errors are of greater magnitudes when the pyranometer's sensor is blocked from the sun, when a shading disk, shadow band or a cloud blocks the direct beam. The errors are of larger magnitude when the sun is shining on the detector. When the sun is shining on the pyranometer sensor, it is believed that the temperature gradient has a higher value.

To correct for the offset radiation during daytime, a correction function is suggested. The correction function is a function of the pyranometer's dome and case temperatures and the incoming long-wave radiation. The night-time data is used to perform a regression to calculate the constants of this function. During the daytime, the pyranometer's dome and case temperatures and the incoming long-wave radiation are measured and substituted in the correction function to calculate the offset correction. Then, to correct the pyranometer radiation readings, the offset correction is subtracted from the measured radiation.

If the dome and case temperatures cannot be measured, another set of data can be used. It is believed that the pyranometer's thermodynamics are dependent on ambient temperature, wind speed, humidity, and the surrounding out-going (up-welling) and in-coming (down-welling) infrared radiation. The out-going and in-coming infrared radiation would be appropriate to use, in the regression, if they were measured by the pyranometer. A good compromise is to use a pyrgeometer in the proximity and the same set-up conditions of the pyranometer (for example, being installed on a tracker, metal plate, solid plate, and ventilated). Replacing the pyranometer temperatures by the environmental data and a pyrgeometer is only appropriate when the pyranometer's sensor is blocked from the sun. Once the pyranometer's sensor is exposed to the sun, the pyranometer's thermodynamics are different than the nighttime, then, the regression will be realistic if the pyranometer dome and case temperatures are measured directly, not estimated by the environmental conditions.

2. Required Data

The following data is required to correct for the fraction radiation:

1. Night-time off-set readings, in W/m^2, of the pyranometer under test, for solar zenith angles greater than 95°

2. Temperature readings, in Kelvin, of the dome (T_d) and case (T_c) of the pyranometer under test, for solar zenith angles greater than 95°

3. Down-welling infrared radiation, in W/m^2.

The approximate dome temperature can be measured using a thermistor embedded in the dome rim. The case temperature can be measured using a thermistor embedded in the case body in the proximity of the reference junction of the thermopile.

If there are no thermistors installed in the pyranometer, the data can be substituted by ambient temperature, wind speed, relative humidity, and the net and downwelling infrared radiation in the same proximity of the pyranometer under test. The net and downwelling infrared radiations are measured using pyrgeometers, therefor; the results of using these data are not as accurate as using thermistors, because they only describe the thermodynamics of the pyrgeometer not the pyranometer under test. The errors resulting from using the infrared radiation can be minimized by setting up the pyrgeometer as close as possible as the pyranometer under test setup.

3. Regression Equation

$$W_{offset} = A + B * \sigma * (T_d^4 - T_c^4) + C * W_{incoming} + D * (T_d - T_c), \qquad 3.1$$

Equation 3.1 is used for regression when using pyranometers with thermistors,
where:
- W_{offset} is the offset radiation, measured by the test pyranometer, at solar zenith angles greater than 95°, in W/m^2
  - σ is the Stefan-Boltzmann constant, $5.6697E^{-8}$ $W/m^2/K^4$
  - T_d and T_c are the pyranometer dome and case temperatures, in Kelvin
  - $W_{incoming}$ is the in-coming infrared radiation measured by a pyrgeometer, in W/m^2
  - A, B, C, and D are the regression constants.

$$W_{offset} = A + B * W_{net} + C * W_{inc} + D * (T_{sky} - T_c) + E * T_{amb} + F * S_w + G * RH, \qquad 3.2$$

Equation 3.2 is used for regression when using pyranometers without thermistors, where:

- W_{net} is the net infrared radiation measured by a pyrgeometer, in W/m^2. The pyrgeometer is set up to measure the down-welling infrared radiation, and near the test pyranometer.
- W_{inc} is the incoming infrared radiation measured by the pyrgeometer, in W/m^2
- T_{sky} is the approximate sky temperature, in Kelvin, calculated as follows,

$$T_{sky} = \sqrt[4]{\frac{W_{inc}}{\sigma}}, \qquad 3.3$$

- T_c is the approximate pyrgeometer case temperature, in Kelvin, calculated as follows,

$$T_c = \sqrt[4]{\frac{W_{inc} - W_{net}}{\sigma}}. \qquad 3.4$$

- T_{amb} , S_w and RH are the ambient temperature, wind speed, and relative humidity, respectively, measured near the test pyranometer
- A, B, C, D, E, F, and G are the regression constants.

4. Correcting the Pyranometer Reading

To correct the pyranometer readings at solar zenith angles less than 90° (during day-time), the parameters in Equations 3.1 or 3.2, are measured at the same time the irradiance is measured, then Equation 4.1 is used to calculate the corrected irradiance for the pyranometer readings,

$$W = \frac{V}{RS} - W_{offset}. \qquad 4.1$$

where:

- W is the corrected global solar irradiance measured by a pyranometer, in W/m^2
- V is the output voltage of the pyranometer, in μV
- RS is the pyranometer responsivity, in μV/W/m^2
- W_{offset} is the fraction radiation, in W/m^2, calculated using equation 3.1 or 3.2 and the regression constants calculated using the data of solar zenith angles greater than 95°.

5. Regression Results

Figure 1 shows the measured and calculated night-time offsets for pyranometer model PSP serial number 17878F3, and the measured night-time offset of pyranometer model 8-48 serial number 32331, from 3/31/1999 to 4/16/1999. Equation 3.2 and the environmental data, collected at the Solar Radiation Research Lab (SRRL) at the National Renewable Energy Laboratory (NREL), were used for the regression.

To evaluate the regression's result when using the correction function during daytime, a pyranometer model 8-48, serial number 32331 is chosen as a reference instrument to measure the diffuse irradiance. It's measured diffuse irradiance is compared with the uncorrected and the corrected diffuse, measured by pyranometer model PSP, serial number 17878F3. Figure 1 shows that the measured magnitude of the offset, measured by pyranometer model 8-48, is less than 0.8 W/m^2. This means that, during daytime, the uncertainty of the measured diffuse irradiance, using pyranometer model 8-48, is mainly the pyranometer's uncertainty, which is ± 5% of reading[2].

Figure 2 shows that the difference between the measured diffuse by the pyranometer model 8-48, and the uncorrected diffuse measured by the pyranometer model PSP is 25 W/m^2, at 14:00 Mountain Standard Time. This means that the PSP offset is from -30 to -20 W/m^2 during the daytime, at 14:00 Mountain Standard Time, (the ± 5 W/m^2 band is due to the uncertainty of measuring the diffuse using either pyranometers, the uncertainty is approximately ± 5% of reading).

The total uncertainty of the corrected diffuse (U) is,

$$U = \sqrt{U_{reg}^{2} + U_{pyr}^{2}} \qquad 5.1$$

where:

- U_{reg} is the uncertainty of the regression, in W/m^2,

$$U_{reg} = \sqrt{E^2 + (2 * S)^2} \qquad 5.2$$

- U_{pyr} is the uncertainty of the measured diffuse irradiance using the pyranometer, in W/m^2.

Table 1 shows the regression results of different sets of environmental parameters using the same data set. Using the results from Table 1, and U_{pyr} equals ± 5 W/m^2, U will yield ± 6.3 W/m^2.

Figure 2 shows that the difference between the measured diffuse by the pyranometer model 8-48, and the corrected diffuse, using the regression, measured by the pyranometer model PSP is 6 W/m^2, at 14:00 Mountain Standard Time. This means that the correction function is an approximate way to correct for the offset radiation of a pyranometer.

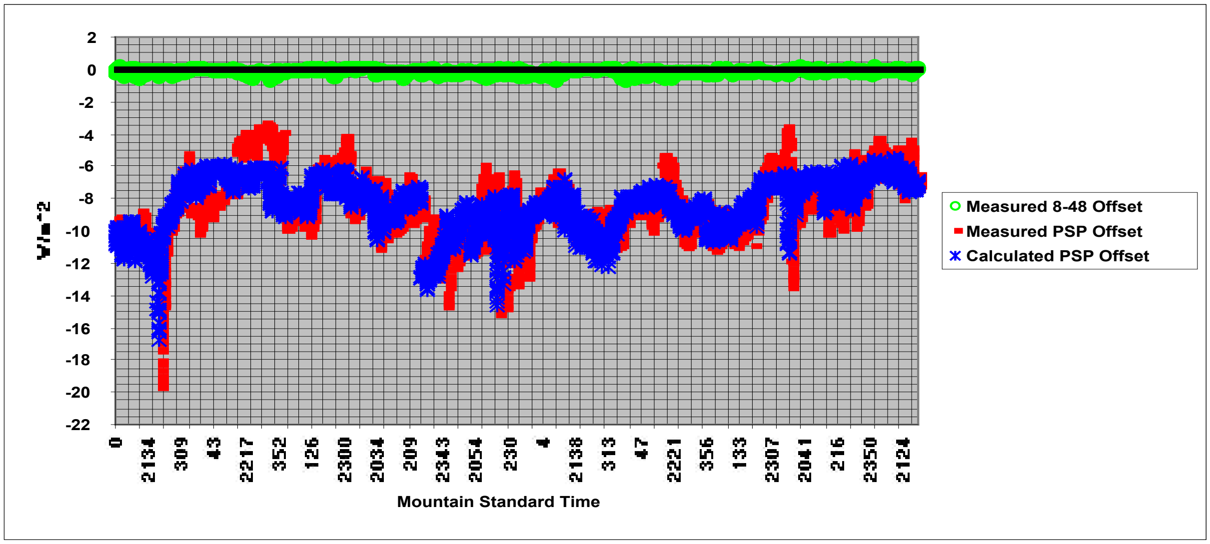

Figure 1. Measured and calculated offset for PSP S/N 17878F3, and measured offset by 8-48 S/N 32331, from 3/31/1999 to 4/16/1999

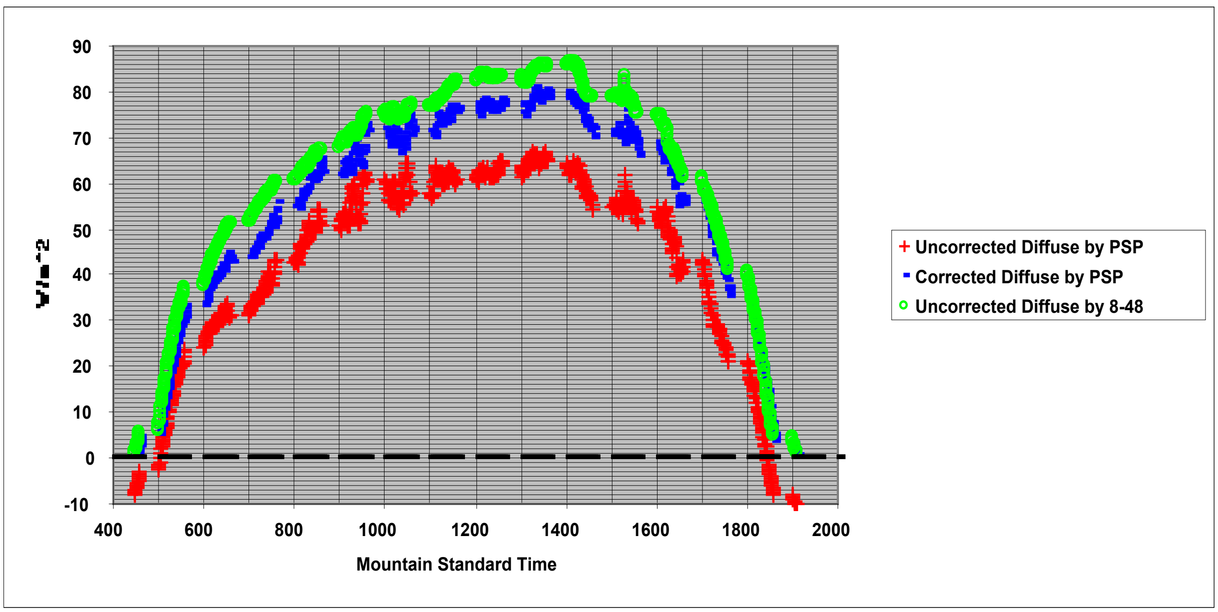

Figure 2. The measured diffuse by corrected and uncorrected PSP S/N 17878F3, and uncorrected 8-48 S/N 32331 on 5/16/1999

Table 1. Regression Results Using Different Sets of Environmental Parameters

Environmental Parameters	E^2 (W/m^2)	S (W/m^2)
W_{net} , W_{inc} , and (T_{sky} - T_c)	2.0	3.7
W_{net} , W_{inc} , (T_{sky} - T_c), and T_{amb}	1.6	2.2
W_{net} , W_{inc} , (T_{sky} - T_c), T_{amb} , S_w , and RH	1.3	1.8

where:

- E^2 is the average of the squared regression errors, where E is the difference between the measured and calculated offsets of the PSP pyranometer
- S is the standard deviation of the squared regression errors.

6. Conclusion

1. The environmental parameters can, approximately, describe the thermodynamics of a pyranometer and can be used to correct for its nighttime offset if the sun is blocked from its sensor.

2. When the sun is not blocked from the pyranometer sensor, it is strongly recommended to use Equation 3.1 for the regression.

3. From Table 1, using more environmental parameters in Equation 3.2 will decrease the errors and the standard deviation of the errors, resulting from using the regression.

4. It is recommended to use larger data set for the regression in order to include all possible environmental conditions at the site where the pyranometer is used.

7. References

1. Gulbrandsen, A. "on the use of pyranometers in the study of spectral solar radiation and atmospheric aerosols" *Journal of Applied Meteorology*, Vol. 4 pp 1-16, 1960.

2. National Renewable Energy Laboratory (NREL), *NREL BORCAL reports*, Golden, Colorado.