# Analysis of the Dutton et al. IR Loss Correction Technique Applied to ARM Diffuse SW Measurements

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## Introduction

Simple single black detector pyranometers, such as the Eppley Precision Spectral Pyranometer (PSP) used by the Atmospheric Radiation Measurement (ARM) Program, are known to lose energy via infrared (IR) emission to the sky. This is especially a problem when making clear-sky diffuse shortwave (SW) measurements, which are inherently of low magnitude and suffer the greatest IR loss. Dutton et al. (2000) proposed a technique using information from collocated pyrgeometers to help compensate for this IR loss. The technique uses an empirically derived relationship between the pyrgeometer detector data (and alternatively the detector data plus the difference between the pyrgeometer case and dome temperatures) and the nighttime pyranometer IR loss data. This relationship is then used to apply a correction to the diffuse SW data during daylight hours. We have developed an ARM Value Added Product (VAP) called the SW DIFF CORR 1DUTT VAP. The VAP includes quality assessment of the input data, as well as the corrected diffuse SW output. Here we present an analysis of results for the period 8/21/99 through 2/21/01 for the ARM Southern Great Plains (SGP) E13 Central Facility Solar Infrared Station (SIRS) data. One word of caution: the results presented here apply only to collocated ventilated and shaded Eppley PSPs and Precision Infrared Radiometers (PIRs). They do not necessarily apply to other instrument makes/models or operational configurations; for example, unventilated and/or unshaded pyrgeometer data.

## Data Quality Analysis

Table 1 shows a summary of the data quality control (QC) applied as part of the SW DIFF CORR 1DUTT VAP. The first tests are done on the PIR flux, and case and dome temperatures, to ensure reasonable values are used in both the determination of correction function fit coefficients, and for application of the correction itself to the diffuse SW data. The corrected diffuse SW output values are then checked to ensure that they at least fall above the corresponding Rayleigh limit, and that the correction applied is not inordinately large. For some of the tests, failure results in the QC flag indicating to the user that the correction results might warrant closer inspection before use ("questionable"). Other test failures are considered as beyond limits where a viable correction can be applied, and cause the corrected output to be labeled as "bad," and the value is set to "-9999."

For the study period, Figure 1 shows the frequency of occurrence of the various QC test "failures," i.e., data that have been flagged as failing the test. Of the 774,713 data points in the study period, 2.2% were determined to be "questionable," and 2.7% were labeled as "bad."

**Table 1**. SW DIFF CORR 1DUTT VAP QA flags summary.

| Reason | Status | QC Flag Det. Corr. | QC Flag Full Corr. | "Bad" Value | "Bad" Value |
|---|---|---|---|---|---|
| Everything is OK | Good | 0 | 0 | | |
| (PIR Orig-Calc. Diff.) > 2.0 $Wm^{-2}$ | Bad | 16 | 16 | -9999 | -9999 |
| Td ≥ (Tc-0.02K) | Bad | 32 | 32 | -9999 | -9999 |
| (Tc-1.5K) ≤ Td < (Tc-0.2K) | Good | | | | |
| (Tc-2.0K) ≤ Td < (Tc-1.5K) | Q | 64 | 64 | | |
| Td < (Tc-0.2K) | Bad | 128 | 128 | -9999 | -9999 |
| IR_Te > (Ta+1.5K) | Bad | 256 | 256 | -9999 | -9999 |
| (Ta-50.0K) ≤ IR_Te ≤ (Ta+1.5K) | Good | | | | |
| IR_Te < (Ta-50.0K) | Q | 512 | 512 | | |
| Corr_Dif > (Rayl+1.0 $Wm^{-2}$) | Good | | | | |
| Corr_Dif = (Rayl±1.0 $Wm^{-2}$) | Q | 1024 | 1024 | | |
| Corr_Dif < (Rayl-1.0 $Wm^{-2}$), not OVC | Bad | 2048 | 2048 | -9999 | -9999 |
| (Corr_Dif - Org_Dif) > 30.0 $Wm^{-2}$), not OVC | | | | | |
| Corr_Dif Missing | Missing | 8192 | 8192 | -9999 | -9999 |

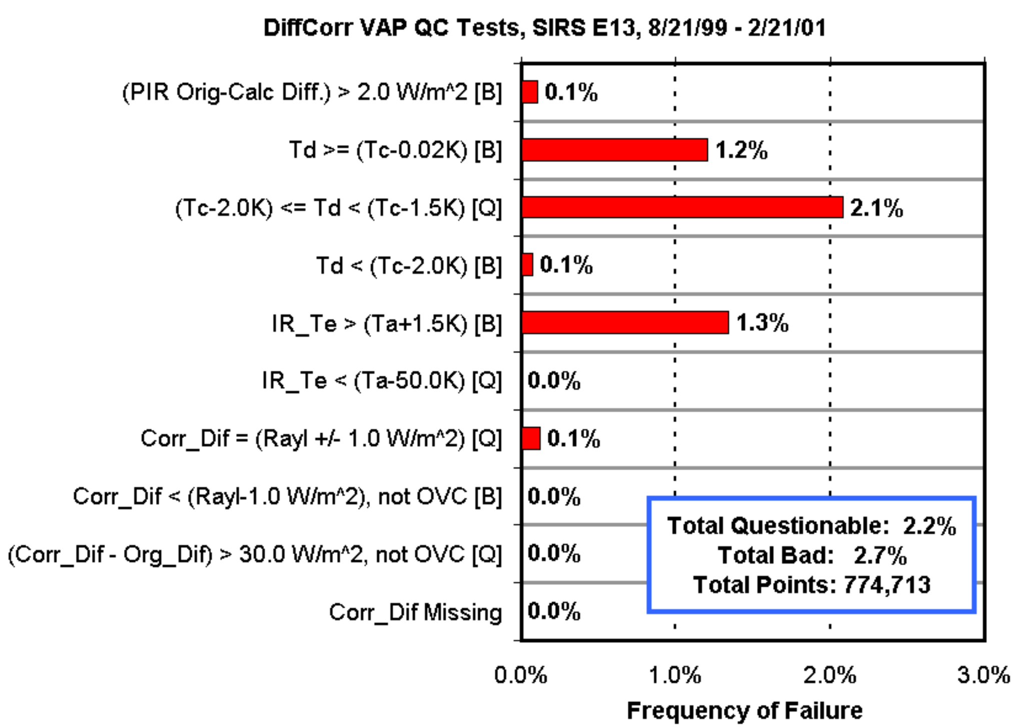


**Figure 1**. Frequency of occurrence of data QC test failures for the study period.

## QC Test Failure Analysis

For the QC test failure frequencies shown in Figure 1, it is of interest to study under what conditions these failures typically occur. Table 2 shows a summary of the most prevalent factors found in the study period corresponding to each QC test shown in Figure 1. For the input PIR data QC tests, with the exception of the first (which is related to data storage and file aberrations), all test failures are related to PIR instrument characteristics. Both the PIR and PSP cases are designed to have relatively large thermal mass, compared to the small thermal mass of the domes. Thus, under conditions of rapid ambient change, the instrument equilibration is slow, and failures are noted due to case and dome temperature differences. Also, the downwelling broadband IR brightness temperature as calculated with the Stephan-Boltzman relationship should not be greater than the ambient air temperature, except under rare circumstances. But both the PIR and air temperature probe measurement systems include some uncertainty in the data values. Even when incorporating an estimate of combined uncertainty (1.5K), the PIR brightness temperature – air temperature test rate failure is still 1.3% in the study data. In these cases, the data indicate humid overcast conditions, likely associated with rain that would tend to affect the PIR case-dome temperature equilibrium state. Likewise, the only time that the corrected diffuse SW values fell below the corresponding Rayleigh limit values was under thick overcast conditions.

**Table 2**. Conditions under which QC test failures typically occur during the study period.

| QC Test | Factors |
|---|---|
| (PIR Orig-Calc. Diff.) > 2.0 $Wm^{-2}$ [B] | Unknown problem |
| Td ≥ (Tc-0.02K) [B] | 99.6% daylight occurrences, happens when air temperature is rapidly INCREASING |
| (Tc-2.0K) ≤ Td < (Tc-1.5K) [Q] | 96% daylight occurrences, average DifSW = 70 $Wm^{-2}$, average PIR Det. = 165 $Wm^{-2}$, Ta ~ 4-6K colder than Tc and Td |
| Td < (Tc-0.2K) [B] | No day/night dependence; happens when air temperature is rapidly DECREASING |
| IR_Te > (Ta+1.5K) [B] | Average RH = 92% ± 11%, mostly DifSW = TSW, but about 50% time other things going on too |
| IR_Te < (Ta-50.0K) [Q] | No occurrences |
| Corr_Dif = (Rayl±1.0 $Wm^{-2}$) [Q] | 100% time under overcast conditions |
| Corr_Dif < (Rayl-1.0 $Wm^{-2}$), not OVC [B] | No occurrences |
| (Corr_Dif - Org_Dif) > 30.0 $Wm^{-2}$), not OVC [Q] | No occurrences |
| Corr_Dif Missing | Original DifSW missing, etc. |

# IR Loss Correction Fitting

As detailed in Dutton et al. (2000), the diffuse SW IR loss correction is based on collocated pyrgeometer data. At night, when there is no solar irradiance input to the pyranometer, a relationship is determined between the pyrgeometer detector flux (and the pyrgeometer case and dome temperatures in the case of the "full" correction), and the nighttime negative values from the pyranometer. For the SW DIFF CORR 1DUTT VAP, we use data from 0300 Universal Time Coordinates (UTC) to 0900 UTC each night to determine the correction equation fit coefficients. This time range is roughly centered on local midnight, and far away from summer sunrise and sunset when there might possibly be instrument equilibrium concerns. We do not adjust this nightly time range for the longer nights of winter, because that would then bias the fitting toward winter by default due to the increased number of values each night.

Figure 2 shows 15-minute averages of the nighttime data that were used for determining the fit coefficients for this study. The blue points represent the year covering from 8/21/99 to 8/1/00. On 8/2/00, the E13 instruments were exchanged for newly calibrated ones, and the red points cover the time range from 8/3/00 to 1/21/01, when the shaded diffuse instrument was exchanged for an Eppley 8-48 Black and White (B&W) pyranometer. As noted in Dutton et al. (2000), we see here the same bimodal type distribution in the relationship between the PSP IR loss and the PIR detector flux. Our study is still in progress, and to date the cause of this bimodal distribution is still unexplained. However, our analysis shows that the points marked in yellow (Figure 2) occur about 13% of the time, and are associated with moist, heavy overcast conditions when the PIR brightness temperature is within ±20°C of the air temperature. We use an iterative method that eliminates outliers from the fitting; thus, these points are not included in the fit lines (brown for the red points, light blue for the blue points) in Figure 2.

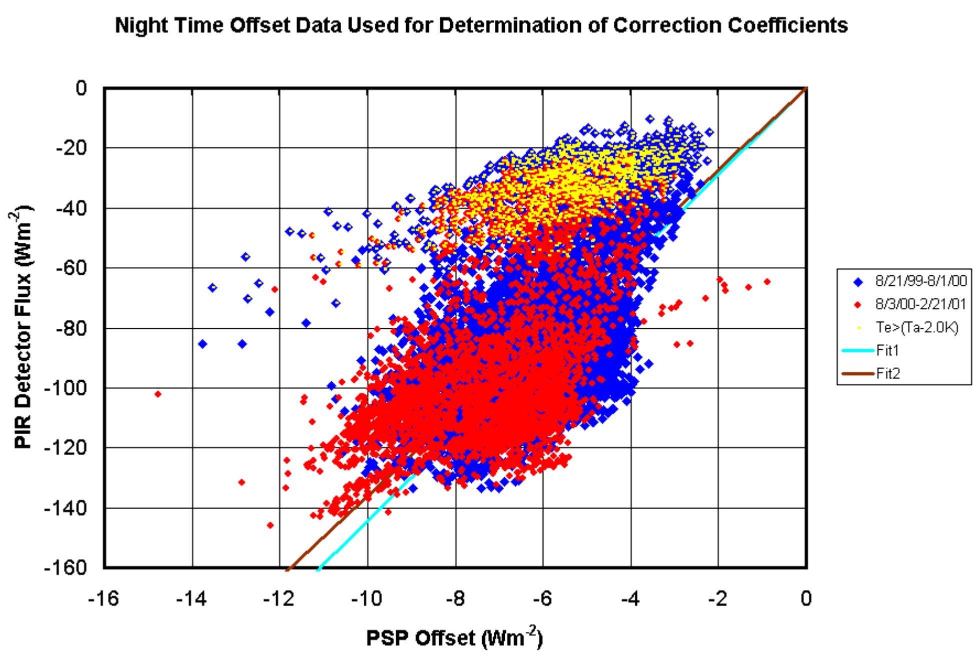


**Figure 2**. Nighttime PSP offset versus PIR detector flux used in this study.

Figure 3 shows the frequency of occurrence of the difference between the original and corrected diffuse SW data depicted in Figure 2, and the corresponding collocated SIRS C1 shaded B&W. The B&W instrument by design is resistant to the IR loss problem. As shown, the original uncorrected PSP data (OD) averaged about a 6 $Wm^{-2}$ IR loss in this nighttime data, compared to the B&W. Both the detector-only (DD) and full-corrected (FD) PSP data average is about 0 $Wm^{-2}$, though the full correction difference appears to have less variability, as evidenced by the smaller average absolute deviation compared to the detector-only correction.

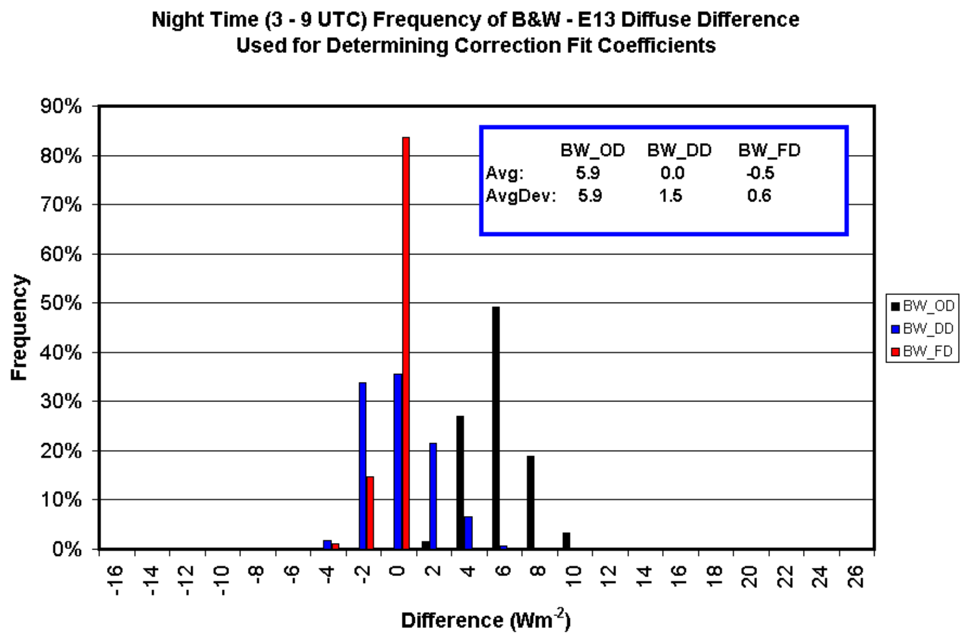


**Figure 3**. Frequency of B&W - Corrected diffuse SW differences for nighttime data used in determining fit coefficients.

## Rayleigh Limit Calculations

For calculation of the Rayleigh limit diffuse SW used in output data QC, we used the SBDART model, with the "US62" model atmosphere. This model atmosphere includes 1.4 cm of precipitable water vapor, and 0.35 atm-cm of ozone. Rayleigh diffuse SW values were calculated for each 5° of solar zenith angle, and for surface pressure ranging from 920 to 1020 mb in 10-mb increments, shown in Figure 4 (blue points). For the VAP calculations, a 5th order polynomial equation was fitted to the model output results (red points in Figure 4), with $\mu_0$ and surface pressure as the two independent variables. Comparison between the model calculations and fitted values shows very good agreement. Given the typical range of surface pressures measured at the SGP site of 980 to 1000 mb, the worst agreement (for a solar zenith angle of 75°) is significantly less than 0.5 $Wm^{-2}$.

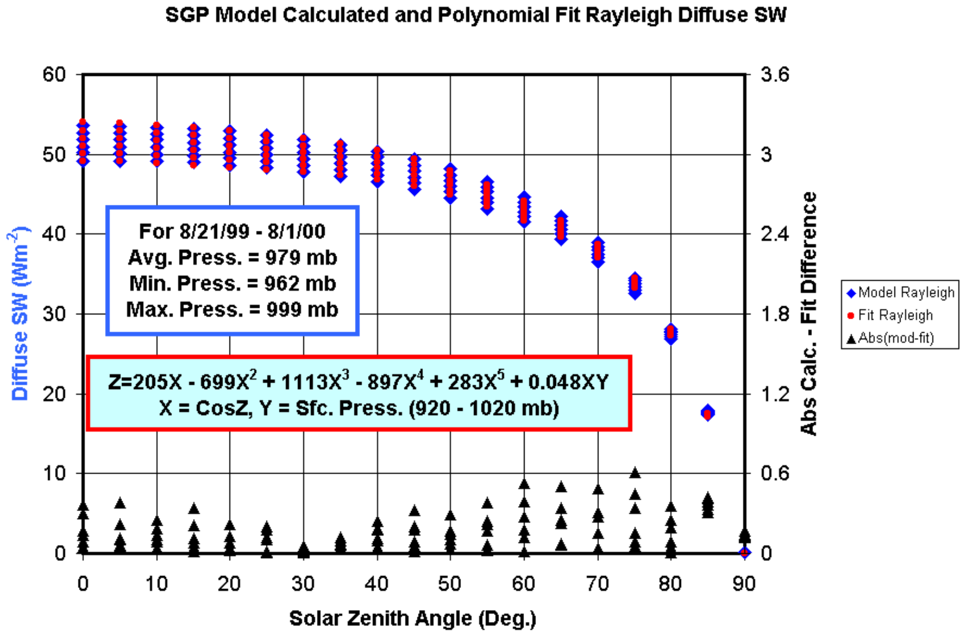


**Figure 4**. Comparison of model calculated and polynomial fit Rayleigh diffuse SW for the SGP site.

## Sub-Rayleigh Uncorrected Data

For the daylight (solar zenith angle [SZA] ≤ 80°) *uncorrected* shaded PSP, 8.3% of the data exhibited sub-Rayleigh values. These data are plotted in Figure 5 as the difference between the unshaded and shaded PSPs. As is shown, the sub-Rayleigh data exhibit two distinct groupings: those that occur under clear sky and those that occur under thick overcast, the latter when the shaded and unshaded PSP values are about equal. When these two groupings are separated, the *uncorrected* clear-sky diffuse SW data exhibited sub-Rayleigh behavior 3.6% of the time. However, after either the detector-only or full IR loss correction is applied, at no time under *clear skies* does the *corrected* diffuse SW exhibit sub-Rayleigh values (see Figure 1).

## Comparison between B&W and PSP Diffuse SW

The IR loss correction coefficients are determined from nighttime data, when there is no SW irradiance. During the day, however, by design SW irradiance is absorbed by the PSP detector that is not being absorbed by the PIR detector. Given this, how well does the correction work during daylight hours? Figure 6 shows a histogram plot of frequency of occurrence of the difference between the daylight diffuse SW irradiance measured by a shaded B&W and the study shaded PSP. The B&W is designed so that IR loss is minimal. The uncorrected PSP data (OD) shows a distinct bias compared to the B&W, on average an IR loss of about 11 $Wm^{-2}$, and a bimodal distribution. The bias is reduced to about 2 $Wm^{-2}$ for the corrected data (DD and FD) for all-sky conditions. For clear skies (Figure 7), the uncorrected average IR loss is about 14 $Wm^{-2}$, compared to an average of about 3 $Wm^{-2}$ for the corrected data. Under clear skies, the diffuse SW is inherently of low magnitude, while at the same time the IR loss is greatest. Note that for clear skies, 39% of the time the PSP IR loss is 15 $Wm^{-2}$ or greater!

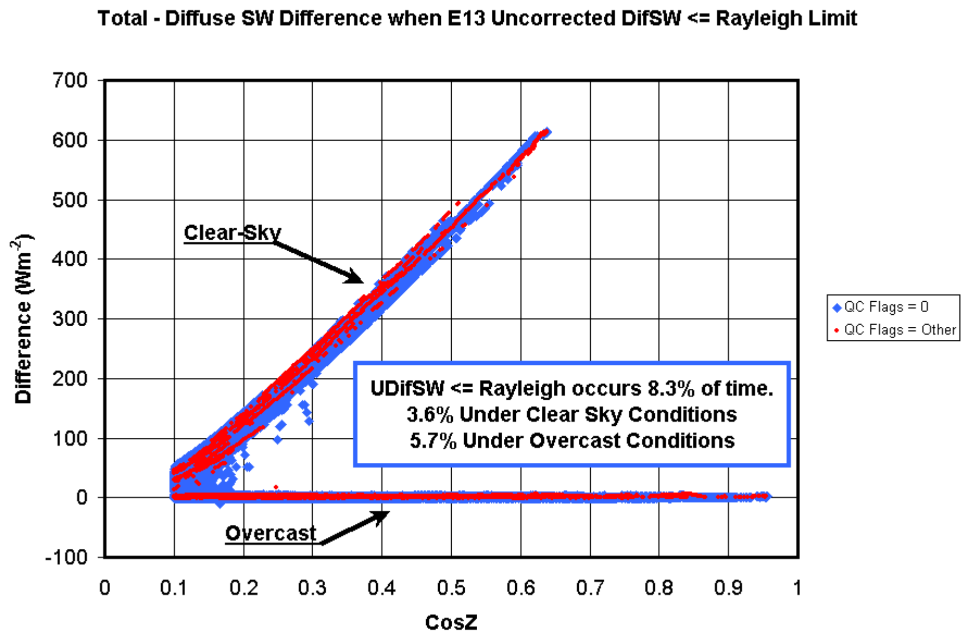


**Figure 5**. Difference between shaded and unshaded PSPs for sub-Rayleigh uncorrected diffuse SW.

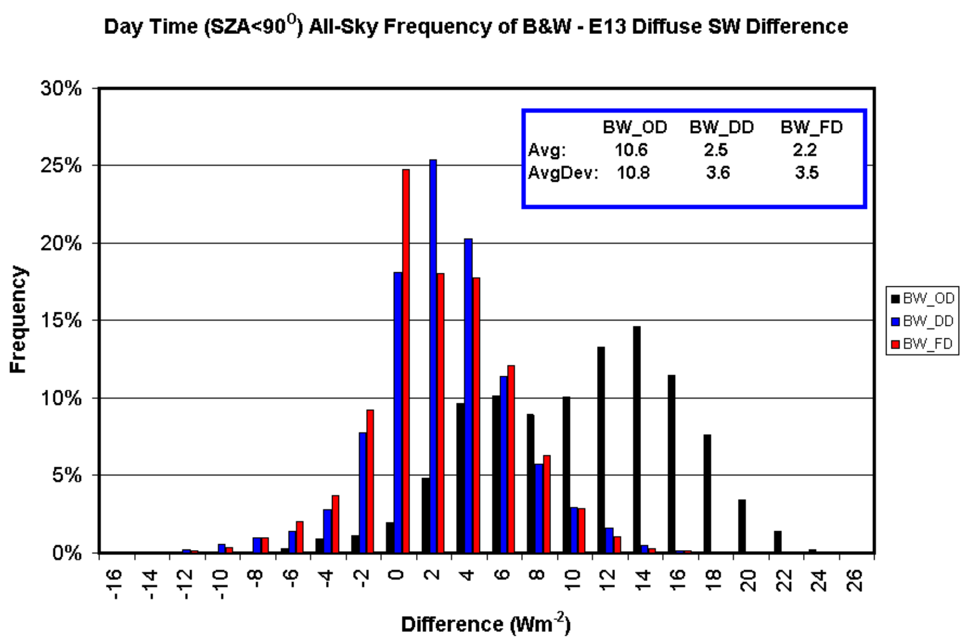


**Figure 6**. Comparison of model calculated and polynomial fit Rayleigh diffuse SW for the SGP site.

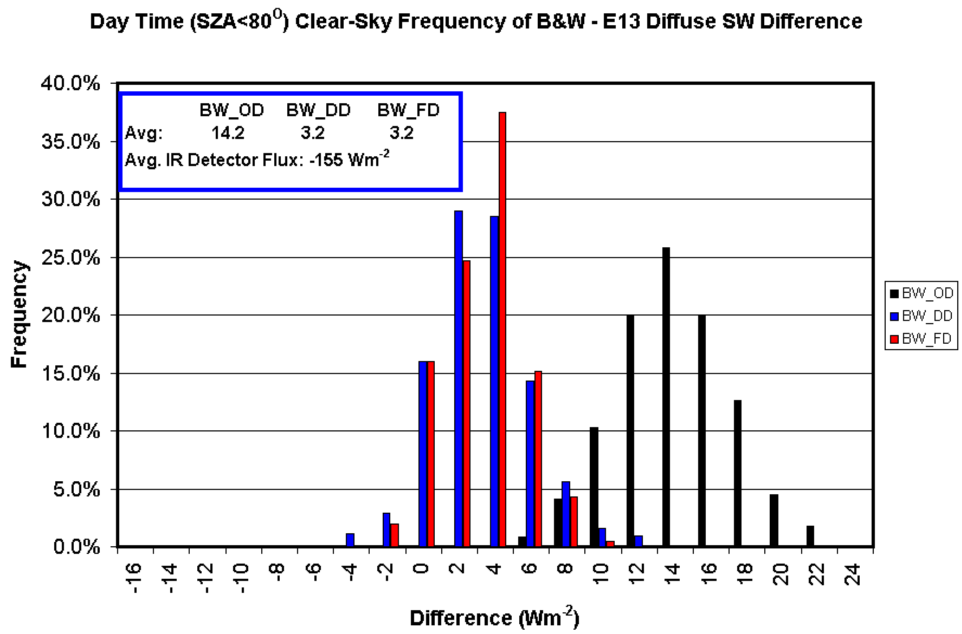


**Figure 7**. Difference between shaded and unshaded PSPs for sub-Rayleigh uncorrected diffuse SW.

## Summary

- The SW DIFF CORR 1DUTT VAP includes data QC tests for both input and output data.
- The VAP output includes the measured SW (diffuse, direct, and total) and IR irradiance and
  - both “detector-only” and “full” corrected diffuse SW values
  - corresponding met data (air temperature, RH, surface pressure)
  - the PIR detector flux, and case and dome temperatures, for users who might want to determine their own IR loss corrections
  - Rayleigh diffuse SW limit calculation.
- Daylight corrected diffuse SW is on average within 2 to 3 $Wm^{-2}$ of corresponding B&W values.
- While uncorrected clear-sky PSP diffuse SW is sub-Rayleigh 3.6% of the time, corrected clear-sky diffuse SW is never sub-Rayleigh.
- Under clear-sky conditions, PSP IR loss is 15 $Wm^{-2}$ or greater 39% of the time at the SGP site.

## Reference

Dutton, E. G., J. J. Michalsky, T. Stoffel, B. W. Forgan, J. Hickey, D. W. Nelson, T. L. Alberta, and I. Reda, 2000. Measurement of broadband diffuse solar irradiance using current commercial instrumentation with a correction for thermal offset errors. *J. Atmos. and Ocean. Tech.*, **18**(3), 297-314.