An Improved Daylight Correction for IR Loss in ARM Diffuse SW Measurements

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Introduction

A paper by Cess et al. (2000) notes that some clear-sky diffuse shortwave (SW) measurements they were using from the Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) site exhibited less than Rayleigh magnitude. Remarking that this is a physical impossibility, the obvious conclusion forwarded by the authors was that there was some problem with the ARM SGP diffuse SW data. Shortly thereafter, the problem of infrared (IR) loss from thermopile-based single black detector pyranometers such as the Eppley model precision spectral pyranometer (PSP), then in use by ARM, was "rediscovered" and explained the clear-sky sub-Rayleigh diffuse SW measurements.

A subsequent paper by Dutton et al. (2001) proposes a correction technique using information from a collocated pyrgeometer to help compensate for the pyranometer 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 corresponding nighttime pyranometer IR loss data. This empirically derived nighttime relationship is then used to apply a correction to the diffuse SW data during daylight hours. The authors recommended the use of a relationship between the IR loss of the pyrgeometer detector (in their language the "net IR") and the nighttime pyranometer offset. The fit should be forced through (0,0) such that if there is no IR loss from the pyrgeometer detector, there is assumed no IR loss from the pyranometer.

Long et al. (2001) and Younkin and Long (2002) tested the Dutton et al. (2001) correction method using collocated shaded Eppley models PSP and 8-48 "Black and White" (B&W) data from the ARM SGP Central Facility (CF) in Oklahoma. By design, the model 8-48 pyranometer has no appreciable offset due to IR cooling of its sensor. These two studies show a number of results, including demonstrating that a relationship linking the pyranometer nighttime offset to the temperature difference of the pyrgeometer case and dome, expressed in terms of flux via the Stephan-Boltzman relation, has more tendency toward the (0,0) intercept than a detector flux relationship as suggested by Dutton et al. (2001). As a result of this "better behavior," Younkin and Long (2002) recommend a "full" correction method that includes a three-dimensional (3D) fitting with the pyrgeometer detector, and the case-dome temperature difference factor, as two independent variables. Regardless of whether the Dutton et al.

(2001) "detector only" or the Younkin and Long (2002) "full" recommended corrections are used, Long et al. (2001) show that both correction methodologies completely eliminate the sub-Rayleigh behavior in ARM Oklahoma data noted by Cess et al. (2000). But while the empirical relationships derived using nighttime data do an excellent job of correcting for IR loss at night, they tend to undercompensate for pyranometer IR loss when applied during daylight (Long et al. 2001). This tendency is hinted at in Dutton et al (2001) in their Table 2, and in their statement regarding the single black detector corrected diffuse having a tendency to be less than that obtained from a B&W. Philipona (2002) also noted that daytime negative offsets were larger than those at night, and appeared to be larger than those that would be predicted by the nighttime offset versus pyrgeometer detector relationship alone."

Bi-Model Behavior

Long et al. (2001) noted a bimodal behavior between the pyranometer nighttime offset and the corresponding pyrgeometer detector flux. Figure 1 shows this bimodal behavior in 18 months of nighttime data from the ARM SGP CF. Here, night is defined as six hours centered on local midnight. The red points in Figure 1 are data that have been separated using the simple criteria wherein the sky equivalent blackbody radiating temperature (from the Stephan-Boltzman relation) calculated from the downwelling longwave measurement is within 6°C of the pyrgeometer case temperature, and the ambient relative humidity is greater than 80%. Analysis shows that these separated data occur about 13% to 14% of the time (Long et al. 2001) during this 1.5-year period. This same behavior is evident in the Dutton et al. (2001) Figure 1a, though not as evident due to scarcity of the data in the figure. Note that when these modes are separated, each grouping appears to trend individually toward the (0,0) point, whereas in the aggregate they do not. It is intuitive that if there is no IR loss from the pyrgeometer detector there should be none from the pyranometer. The existence of these two modes helps explain why a single fit to all nighttime data, as in Dutton et al. (2001), does not naturally tend toward the (0,0) point. It is evident that the trend lines for these two different modes should be fit separately for correcting diffuse SW measurements.

Bi-Modal Detection and Fitting

To reliably detect the two modes and apply corrections both day and night, any methodology must use continually available information. We use collocated measurements of ambient relative humidity (RH), and known characteristics of the pyrgeometer itself. For both the Detector Only and Full corrections, both modes are separated by an ambient RH of about 80%, which is related to the deliquescence point of hygroscopic nuclei and haze formation. This relationship with RH is the reason for dubbing the modes as either "dry" or "moist." The moist mode for the Detector Only method is best detected using the PIR case temperature (T_c) compared to the corresponding sky broadband black body brightness temperature (T_e). We define Detector Only correction "Moist" mode when:

- $(T_c - T_e) < 6.0$ K
- RH > 80%

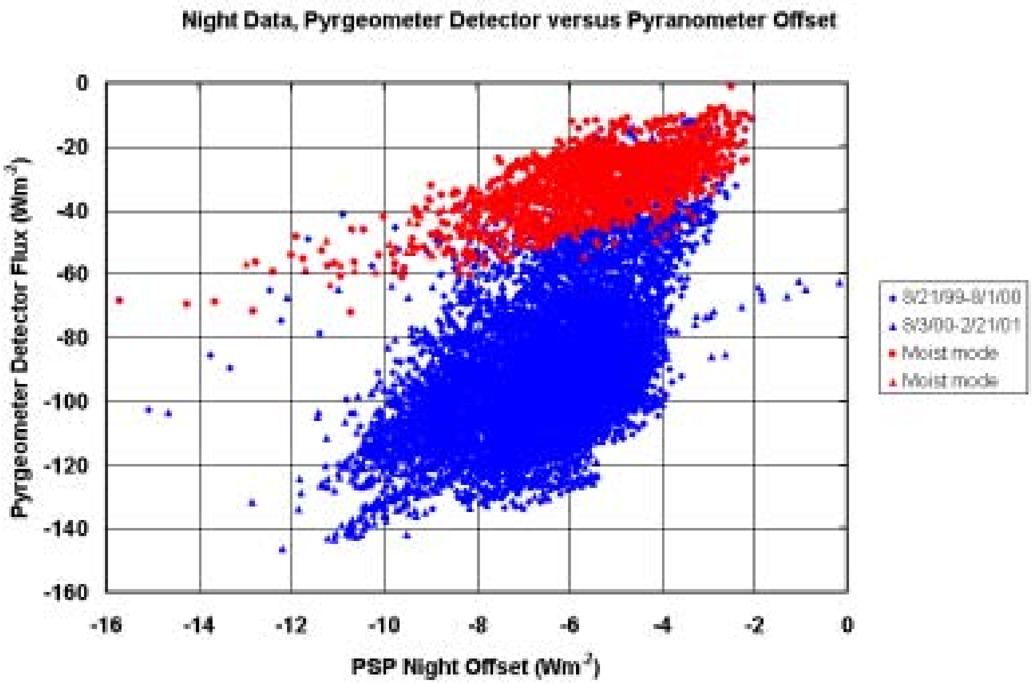

Figure 1. About 1.5 years worth of data from the ARM SGP CF showing the PSP nighttime offset due to IR loss versus the corresponding precision infrared radiometer (PIR) detector flux loss. Red points are those under "moist" conditions.

For the Full correction method, "dry" mode is best detected using a PIR detector flux limit, which is related to the $T_c - T_e$ difference, but more precisely represents the "hinge point" of the case-dome temperature versus detector flux relationship internal to the PIR shown in Figure 2. Thus, in this case we define Full correction "Dry" mode when:

- PIR Detector flux < -100 Wm^{-2}
~ RH < 80%

The methodology employed is similar to that of the original single-mode corrections, except here we detect each mode (dry and moist) separately in the nighttime data, and fit the two modes separately. Then we detect the two modes in the daylight data, and apply the appropriate correction factors. However, we find that these daylight bi-modal correction results show no appreciable improvement in the average daylight under-correction (discussed later in Figure 6) noted by Long et al. (2001). This, at first, is perplexing in that one would expect some improvement during the day given the better fitting at night. But one factor not accounted for yet is that unlike night, daylight includes SW input to the pyranometer, but by design not the pyrgeometer. Thus, the relationship between the two detectors is different during the day than at night.

Figure 3 shows the day and night relationships between the PIR detector flux, and the PSP IR loss (top panels). For the Detector Only correction, the slope of a simple least squares fitted line through (0,0) for the moist mode is about the same both day and night (top left). But the dry mode day slope is of

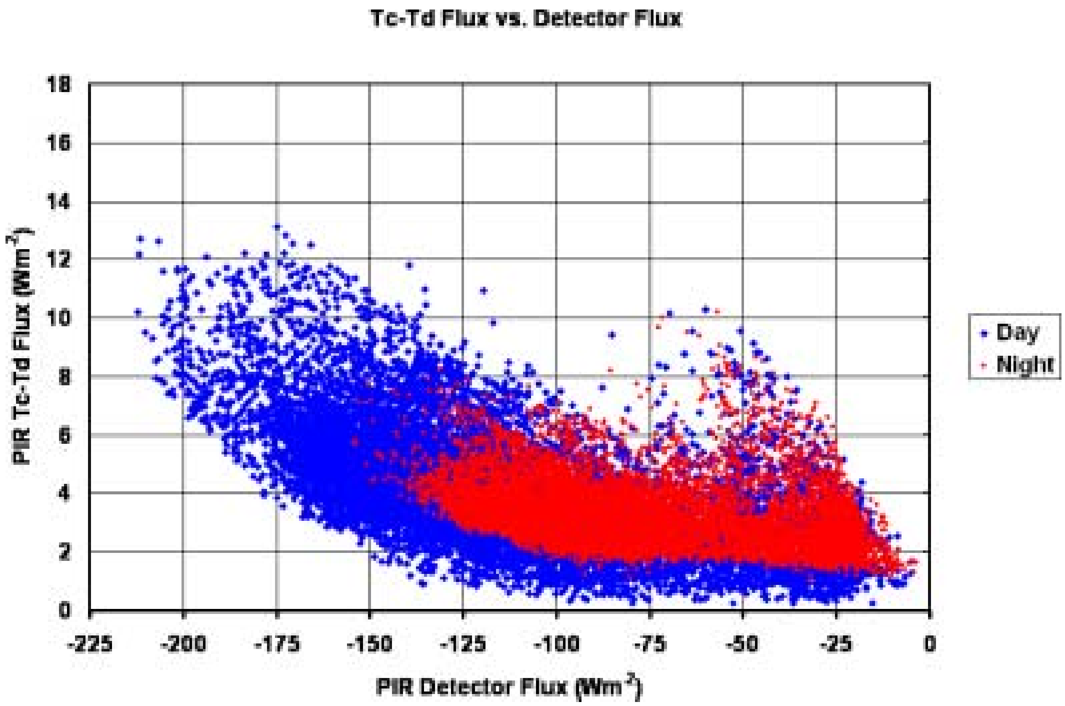

Figure 2. Relationship between PIR detector flux and the case-dome temperature term expressed as black body flux for the same data as that in Figure 1. Note that the relationship changes from uncorrelated to correlated at a detector flux of about -100 Wm^{-2}. Also note the greater occurrence of larger detector flux loss during day than at night.

significantly greater magnitude than the night dry mode slope (top right). In the case of the Full correction (bottom panels), we plot the residual difference after the PIR case-dome temperature portion of the correction has been applied. In the Full correction case both the moist and dry day fit slopes are of significantly greater magnitude than the night fits. However, the overall magnitude (note figure Y axis scales) of the moist mode detector portion of the correction is small (bottom left) compared to the dry mode (bottom right)

Adjusted Daylight Correction

The day-night difference does not affect the pyrgeometer case-dome temperature flux to pyranometer IR loss relationship, but is related to the detector term only. So for both the Full and Detector Only corrections, we multiply only the detector portion of the correction by an adjustment factor during daylight. Iteration of the available data sets (results shown below) to achieve the best results for both the mean and standard deviation of residuals between corrected values and co-located Eppley 8-48 B&Ws yields the adjustment factors:

- 1.4 for Detector Only correction, applied for dry mode only
- 2.0 for detector part of Full Correction, applied for both dry and moist modes

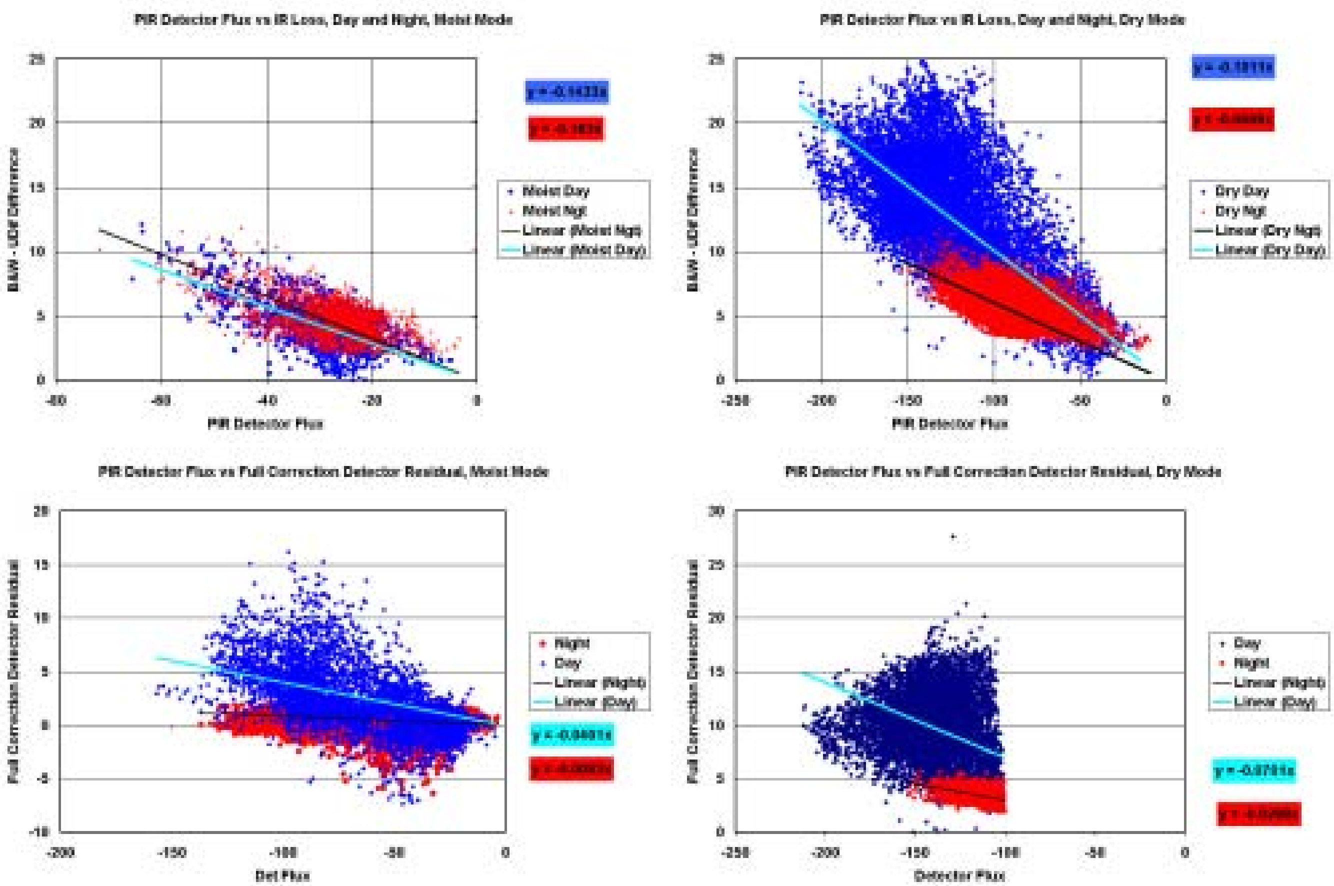

Figure 3. Day (blue) and night (red) relationships between the PIR detector flux, and the PSP IR loss (top panels), for the detector only correction moist mode (above left) and dry mode (above right). For the full correction (bottom panels), the residual difference after the PIR case-dome temperature portion of the correction has been applied for the moist (below left) and dry (below right) modes.

Applying this "adjusted correction" methodology, Figure 4 shows both the Detector Only and Full corrections exhibit a significant decrease in the daylight residual at SGP between the bi-mode and adjusted bi-mode corrections. Where the original bi-modal correction methodology left an average residual under correction of about 4 Wm^{-2} during daylight (left panel), the adjusted bi-modal correction average residual is decreased to only about 1 Wm^{-2} (right panel) for both the Full and Detector Only corrections. Significant improvement is also exhibited when the methodology is applied to two datasets from the National Oceanic and Atmospheric Administration (NOAA) Air Resources Laboratory (ARL) Surface Radiation Budget Network (SURFRAD) network sites of Desert Rock and Pennsylvania State University (PSU) in Figure 5. For Desert Rock, the average daylight residual from the original bi-modal Full correction methodology is about 6 Wm^{-2} (top left) for the period shown, but decreases to less than 2 Wm^{-2} for the adjusted Full correction (top right). Results for the Rock Springs research site at PSU show a decrease in the average daylight residual from 1.5 Wm^{-2} (bottom left) to 0.5 Wm^{-2} (bottom right) for the period shown.

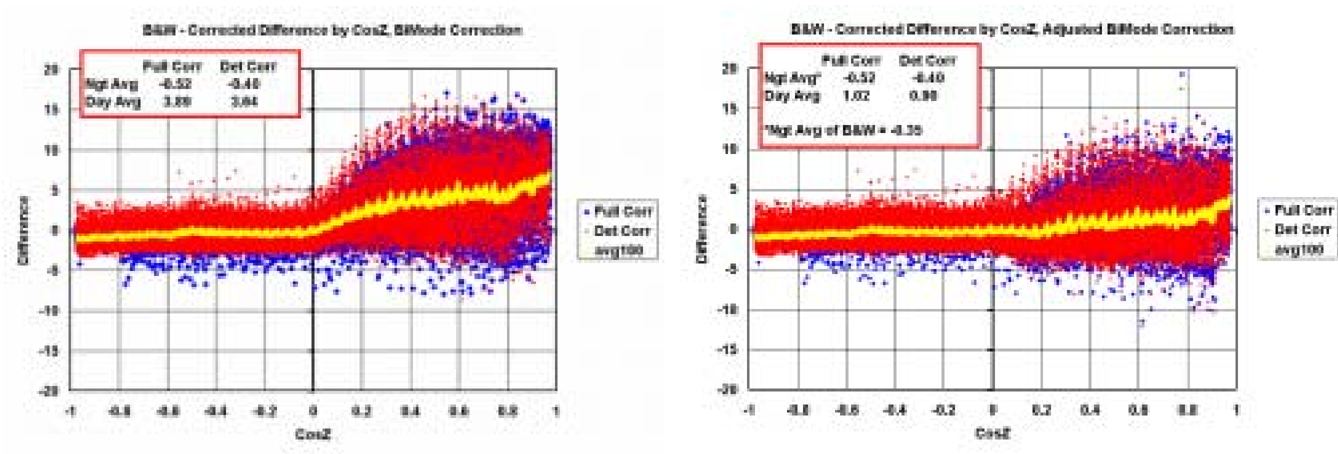

Figure 4. Residual differences between corrected PSP diffuse values and those from collocated Eppley 8-48 B&Ws for bi-mode (left) and adjusted bi-mode (right) methods for SGP data, by cosine of the solar zenith angle (CosZ). Blue is for Full correction, red for Detector Only correction. Yellow represents a 100-point running mean by CosZ through the data.

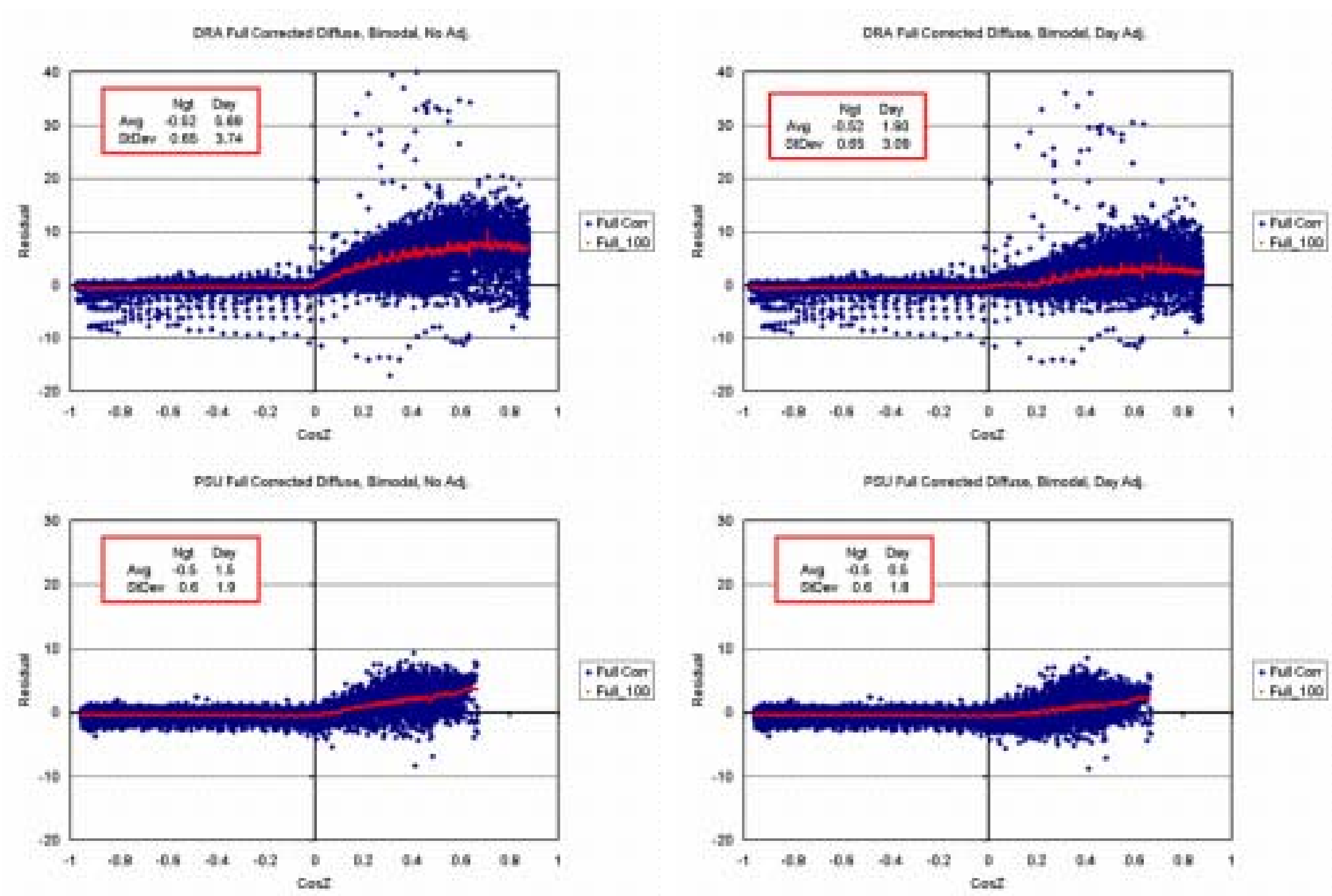

Figure 5. Same as Figure 4, but Full correction only, for the NOAA/ARL SURFRAD sites located at Desert Rock, Nevada (top), and Rock Springs Research site at PSU (bottom).

Frequency distributions of the residual differences between the ARM SGP PSPs and B&Ws for daylight show that the adjusted correction methodology also slightly decreases the spread of the residuals compared to the other methods, as evidenced by smaller standard deviations from X = Y (Figure 6).

Figure 6 summarizes both the Detector Only (left) and Full (right) correction results for daylight with solar elevation angles greater than 10 degrees. The average IR loss for the data is about 13 Wm^{-2}, and exhibits a bi-modal distribution (black line). The Detector Only single fit and bi-modal fit corrections eliminate the bi-modality, and both decrease the average residual to about 4 Wm^{-2} compared to collocated Eppley 8-48 B&W data. In the case of the Full single fit and bi-modal fit corrections, the average residual is 4-5 Wm^{-2}, but the original bi-modality is still evident in the residual distributions. For both the Detector Only and Full adjusted bi-modal corrections, the average residual decreases to about 1 Wm^{-2}, with the Full corrections being slightly better in both average and standard deviation of the residuals.

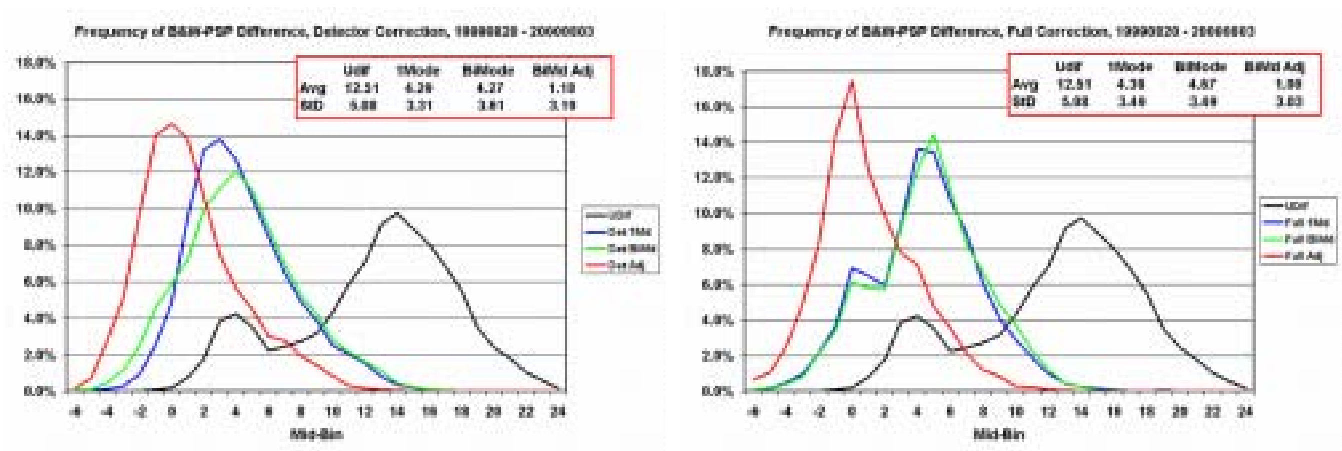

Figure 6. Frequency of residual differences between PSP diffuse measurements and collocated Eppley B&W for daylight (solar elevation greater than about 10°) corrections using detector only (left) and full (right) correction methodology. Black is for uncorrected PSP diffuse SW (Udif). Green is for single mode correction (1Mode), blue is for bi-mode correction (BiMode). Red is for bi-mode adjusted correction (BiMd Adj).

Summary

An improved methodology has been developed for correcting for the IR loss in ARM shaded Eppley PSP diffuse SW measurements. The Dutton et al. (2001) single-fit methodology decreased the original IR loss problem in the aggregate by a factor of about 3, (from an all-sky average of 12 Wm^{-2} to 4 Wm^{-2} in Figure 6). The methodology presented here improves the correction by a factor of about 4 again over the single-fit correction, decreasing the average residual (compared to a B&W) to about 1 Wm^{-2}. This new methodology has been included in the ARM Diffuse Correction Value Added Product. All past ARM SGP network PSP-measured diffuse SW has now been thus corrected, with correction of Tropical Western Pacific and North Slope of Alaska data currently in progress.

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