Techniques and Methods Used to Determine the Best Estimate of Total Downwelling Shortwave Radiation

Y. Shi and C. N. Long
Pacific Northwest National Laboratory
Richland, Washington

Introduction

Last year at the Science Team Meeting, we presented the preliminary analysis of surface radiation measurement data quality at the Southern Great Plains (SGP) extended facilities (Shi and Long). The measured radiation data were tested against physically possible and globally extremely rare limits as defined and used in the Baseline Surface Radiation Network recommended data quality control testing. Additional climatological limits and cross-comparisons derived through analysis of the historical data at these facilities were also used to test these data. We also presented an overview of data quality at each Extended Facility, and the methodology used for quality testing.

In this study, we derive the best estimate of total downwelling shortwave (SW) radiation using the sum of direct and diffuse components, and filled any gaps in the sum time series using a fitted relationship between sum and unshaded pyranometer measurements.

Algorithm and Methodology

Table 1 is the definition of terms used in this study. The quality flags obtained from last year's study were used to determine if the radiation data is good. Historical data analysis was performed to determine the certain data constraints used in this study, as described in the next section.

Table 1. Definition of Terms Used in this Study
GSW: SIRS Global Downwelling SW Hemispheric Irradiance
Diff: SIRS Downwelling SW Diffuse Hemispheric Irradiance
Dirn: SIRS SW Direct (Normal) Irradiance
SumSW = Diff + Dirn * cos(SZA)
BBGSW: MFRSR Downwelling SW Hemispheric Irradiance
BEGSW: Best Estimate of the Global Downwelling SW Hemispheric Irradiance
SZA = Solar Zenith Angle

A description of the algorithm used to best estimate the total downwelling SW radiation includes:

1. For any given time, if Dirn and Diff data are good and the ratio of GSW/sumSW and Diff/GSW pass the quality tests, and the difference between sumSW and GSW is less than a certain limit, which is obtained from the historical data analysis as described in the next section, then BEGSW = sumSW.

2. If the above condition is not met, then MFRSR measurements are used as a cross examination of the data quality. Since the sampling rates of the SIRS and the MFRSR instruments are different, it is necessary to average the data over time before we can compare the two measurements.

3. If BBGSW is within the configurable limits (Shi and Long), and both Dirn and Diff are good and the ratio of the averaged values of BBGSW over sumSW or their absolute differences are within certain limits, then again BEGSW = sumSW.

4. If the above condition is not satisfied, then if GSW data is good and the ratio of the averaged values of BBGSW over GSW or their absolute differences are within certain limits, this check indicate that GSW is good and can be used to get the best estimate of the global SW.

5. To use the GSW, we first check the time to see whether this measurement occurs in the morning or in the afternoon. If it occurs in the morning, then GSW is linearly fitted to sumSW using all the "good" morning data. If not enough "good" data (30 data points) is available in the current day, we get the previous day's or next day's (if the previous day's data is not enough) morning data and do the fitting. We check up to one week of data either before or after the current day to find enough data for fitting. If no data available within this time period, then the fitting can not be done. Same algorithm applies to the afternoon data.

6. If none of the above conditions met, then if GSW is good, use GSW as the best estimate.

7. If GSW is missing, then use MFRSR measurement BBGSW as the best estimate.

Limits Used in the Algorithm

Three years of historical data (1999, 2000, and 2002) from SGP E1 were analyzed to help determine the best fitting algorithm and data constraints. The differences between GSW and sumSW are examined. Table 2 shows the percent of data fall within various limits.

Table 2. Percent of GSW-sumSW Data Fall Within Various Limits

GSW-sumSW	1999	2000	2002
5% or 5 W/m^2	69.4%	79.4%	76.1%
5% or 10 W/m^2	72.1%	82.6%	79.4%
5% or 15 W/m^2	74.8%	85.5%	82.6%
5% or 20 W/m^2	80.3%	89.9%	88.3%
10% or 5 W/m^2	93.1%	95.6%	93.3%
10% or 10 W/m^2	94.1%	96.8%	94.4%
10% or 15 W/m^2	94.7%	97.3%	95.0%
10% or 20 W/m^2	96.1%	98.2%	96.2%

After examining the data in detail, we found cases where certain limits should be applied in order to eliminate the "bad" data. Figure 1 shows the total downwelling SW radiation as measured by unshaded pyranometer (GSW) and MFRSR (BBGSW), as well as derived from the SIRS direct normal and diffuse measurements (sumSW) on April 22, 2000. The plot shows the values for samples 990 to 1010. From the plot we can see that sumSW dipped from samples 1001 to 1005, indicating something wrong with the sumSW data. The differences between the GSW and sumSW range from 11.1 W/m^2 (Sample 1005) to 38.4 W/m^2 (sample 1003), and the percent differences range from 11.3% to 50.7%. So, setting proper limits is critical to mark the sumSW data at these samples (1101 to 1105) as "bad" and therefore, use GSW data to derive the best estimate of the total downwelling SW irradiance. After analysis of the three years data, the limits we determined to use are 5% or 20 W/m^2.

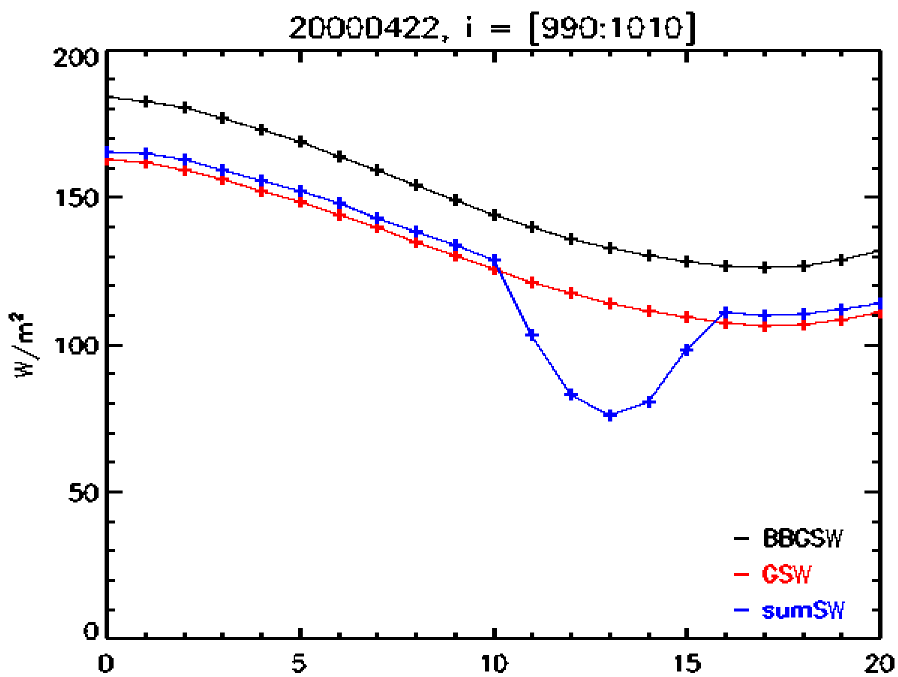

Figure 1. Total downwelling SW radiation as measured by the unshaded pyranometer (red) and MFRSR (black), as well as derived from SIRS direct and diffuse measurements (blue) for April 22, 2000, samples 990 to 1010.

Another limit we need to determine is the relationship between BBGSW and sumSW. We examined both the differences and the ratio of the two fields. The results indicate the absolute and the percent differences vary largely, making it hard to decide which data are good. Figure 2a shows the absolute differences of BBGSW and sumSW as a function of solar zenith angle for SGP E1 2000 daytime data. The differences are up to 350 W/m^2. Figure 2b shows the percent differences of the two fields, which shoot up to more than 1000%.

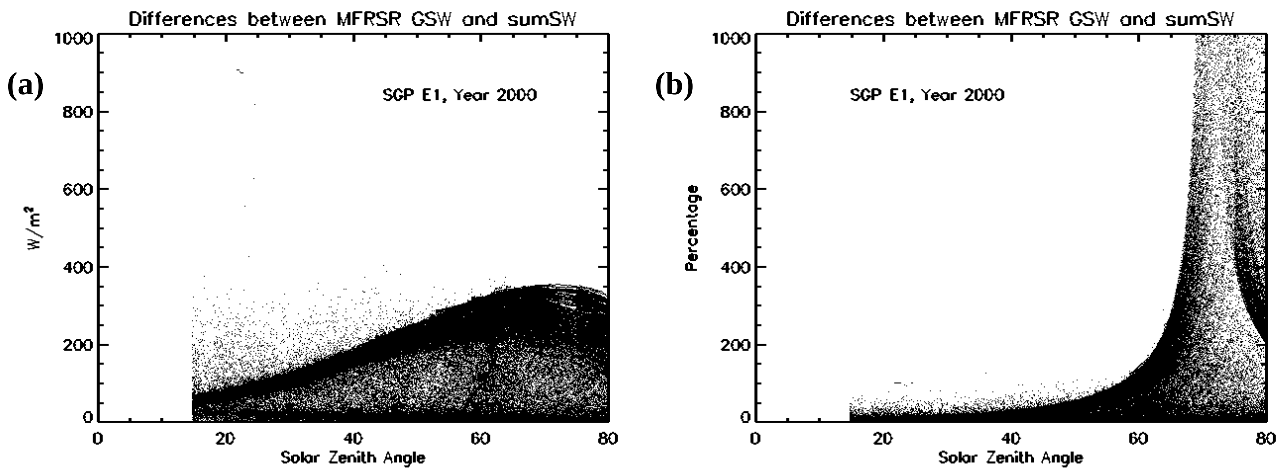

Figure 2. Differences between MFRSR GSW and sumSW at SGP E1, year 2000. (a) Absolute differences and (b) percent differences.

The ratio of the two fields, however, is much consistent. Figure 3 shows the ratio of the BBGSW over sumSW for SGP E1 2000 data. We compared data at 1, 5, 10, and 15 minute averages, as shown in Figures 3a to 3d. The figures show that for 1 minute data, 96.7% data fall with the blue or green limits, while for 5 minute averaged data, the percentage rise to 99.5%. More data fall within the set limits for 10 minute (99.8%) and 15 minute (99.9) averaged data, but may include some apparently "bad" data. For example, taking sample1005 on April 22, 2000, as shown in Figure 1, the 10 minute and 15 minute averaged data would "average out" the difference, making the data point appear good when compare the ratio of BBGSW and sumSW. Same analysis is performed to 1999 and 2002 SGP E1 data. Table 3 lists the analysis results. After evaluation of the results we decided to use the 5 minute averaged data as comparisons. The limits are set as data ratio within ±0.1 of the median value or the absolute differences less than 20 W/m^2. Same criteria apply to BBGSW vs. GSW data.

Four scenarios are examined for fitting unshaded pyranometer data (GSW) to corresponding sum data (sumSW): morning "clearish" data; morning cloudy data; afternoon "clearish" data; and afternoon cloudy data. The results show that using all morning data gets a better fitting result than using "clearish" or cloudy data alone for the fitting, same applies to afternoon data. Table 4 compares the differences of the best estimate downwelling shortwave (BEGSW) with the sumSW data derived from SIRS measurements. The table shows that only 84.8% data fall within 20 W/m^2 and 79.8% data fall within 10% differences using the "four scenario fitting" algorithm, while 99.6% data fall within 20 W/m^2 and 96.3% fall with 10% when using the "all data fitting" algorithm.

Result Analysis

To test the effects of the algorithm, we compared the BEGSW with the measured sumSW data. Figures 4a and 4b show the absolute and percent differences of BEGSW and sumSW for year 2000 at SGP E1. The red + represents morning data and blue x represents afternoon data. Figures 4c and 4d are the probability distribution of the absolute and percent differences. We can see that 95.8% data fall within 10 W/m^2 differences and 99.6% fall within 20 W/m^2, while 89.1% and 96.3% data fall within 5% and 10% differences.

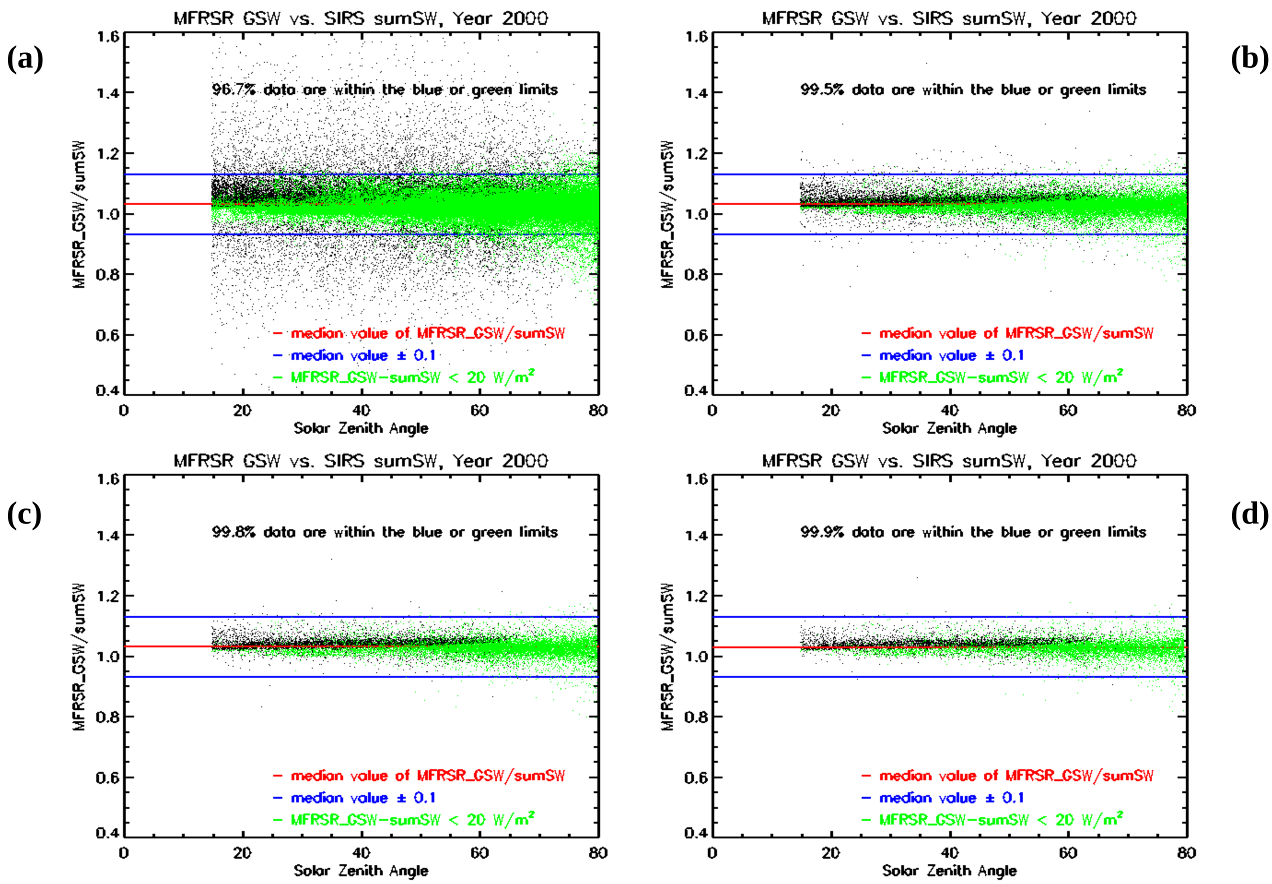

Figure 3. Ratio of MFRSR GSW data vs. SIRS sumSW data at SGP E1, year 2000. (a) 1 minute data, (b) 5 minute data, (c) 10 minute data, and (d) 15 minute data.

Table 3. Percent of Data Fall Within Various Limits for the Ratio and Absolute Differences of BBGSW and sumSW

	BBGSW/sumSW or BBGSW – sumSW	±0.05 or 10 W/m^2	±0.05 or 20W/m^2	±0.1 or 10W/m^2	±0.1 or 20/W/m^2
1999	1 minute data	89.0%	92.5%	95.3%	96.2%
	5 minute data	93.2%	95.8%	98.3%	98.9%
	10 minute data	94.6%	97.1%	98.7%	99.2%
	15 minute data	95.3%	97.6%	98.9%	99.3%
2000	1 minute data	91.2%	93.7%	96.2%	96.7%
	5 minute data	95.0%	96.6%	99.3%	99.5%
	10 minute data	96.7%	98.1%	99.7%	99.8%
	15 minute data	97.2%	98.5%	99.8%	99.9%
2002	1 minute data	89.6%	93.2%	95.6%	96.2%
	5 minute data	94.3%	96.7%	98.9%	99.2%
	10 minute data	96.1%	98.1%	99.4%	99.6%
	15 minute data	96.9%	98.6%	99.6%	99.7%

Table 4. Statistics of the Differences Between the BEGSW and the "Good" sumSW Data Using Different Fitting Algorithms

	Four Scenario Fitting Algorithm	All Data Fitting Algorithm
10 W/m^2	71.3%	95.8%
20 W/m^2	84.8%	99.6%
5%	66.9%	89.1%
10%	79.8%	96.3%

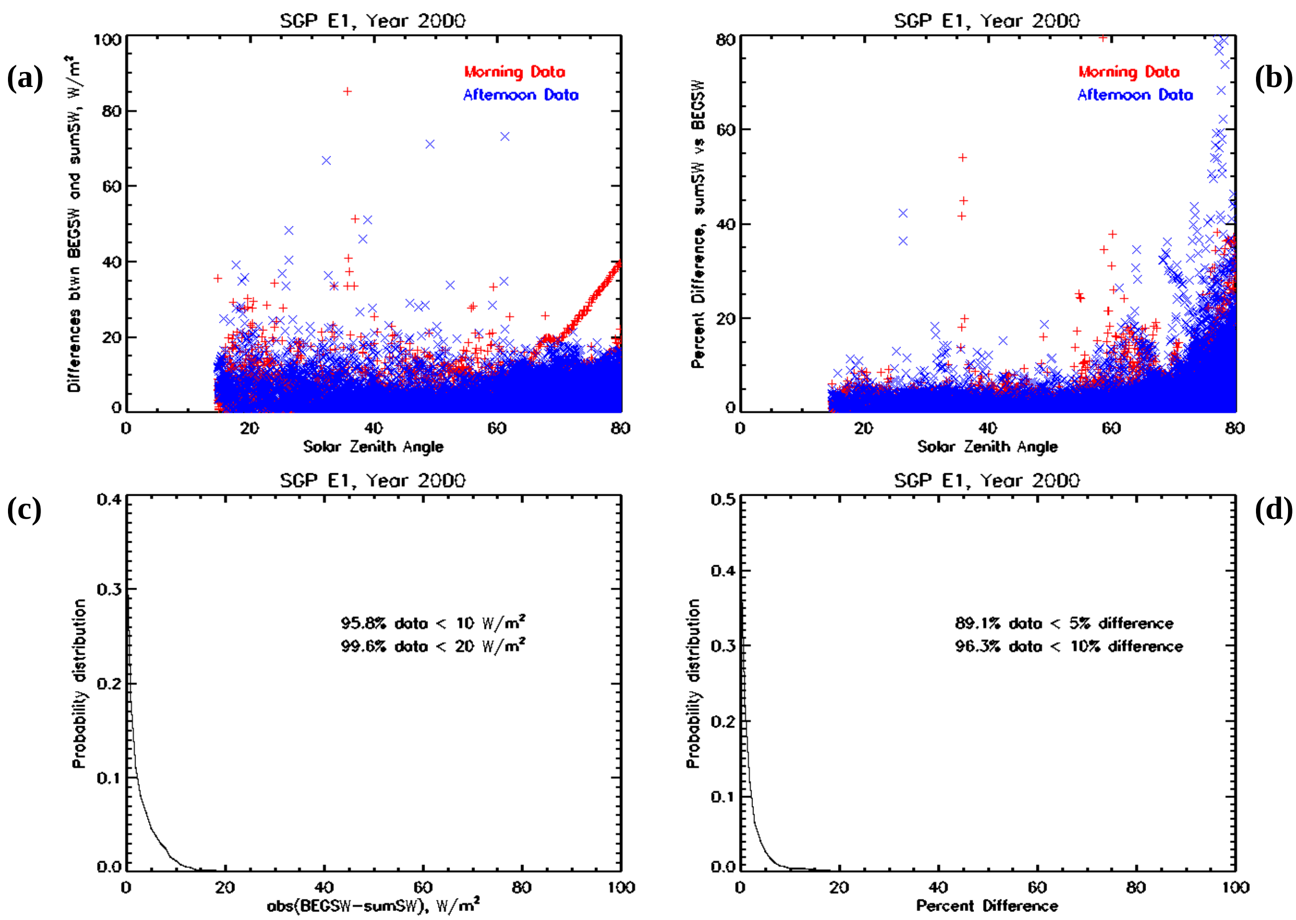

Figure 4. Differences between the best estimate GSW and the sumSW for year 2000 at SGP E1. (a) Absolute difference, (b) percent difference, (c) probability distribution of the absolute difference, and (d) probability distribution of the percent difference.

Table 5 lists the percent of data fall within various limits for the three testing years (1999, 2000, and 2002) at SGP E1. We see that at least 91% of data fall within 10 W/m^2 differences and 99.5% or more data fall within 20 W/m^2 differences. In the mean time, 83.7% data fall within 5% differences and 92.4% data fall within 10% differences.

Table 5. Statistics of the Differences Between the BEGSW and the "Good" sumSW Data

	1999	2000	2002
10 W/m^2	99.4%	95.8%	91.0%
20 W/m^2	100%	99.6%	99.5%
5%	88.5%	89.1%	83.7%
10%	95.7%	96.3%	92.4%

An interesting thing to point out is that on Figure 4a a red line stands out from the plot. Close examination reveals that this happens on August 1, 2000. Figure 5 shows the morning data (1300 to 1900 GMT) on this day. We can see a discontinuity around 1500 to 1600 GMT. By checking into the instrument log we found that yearly instrument calibration swap-out occurred during this time period. The instrument swapping resulted in different relationships between GSW and sumSW. If we fit the GSW data before 1500 GMT to sumSW, the coefficients are b = 6.17029, and a = 1.04141 in the linear relationship sumSW = b + a * GSW. While the fitting coefficients for the data after 1600 GMT are b = 42.7669, and a = 0.923405. If all the morning data are used for the linear fitting, which is what we choose to do, the coefficients are b = 60.567356 and a = 0.913887. This explains why the red line stands out in Figure 4a. The fitted data points are from 1239 to 1402 GMT, which is before the instrument swapping, but the actual fitting coefficients used here are from all the morning data. Therefore the fitting algorithm may not work at the time of instrument swap-out which only happens once a year. The instrument swapping information can be obtained from the instrument logs online at http://www.ops.sgp.arm.gov.

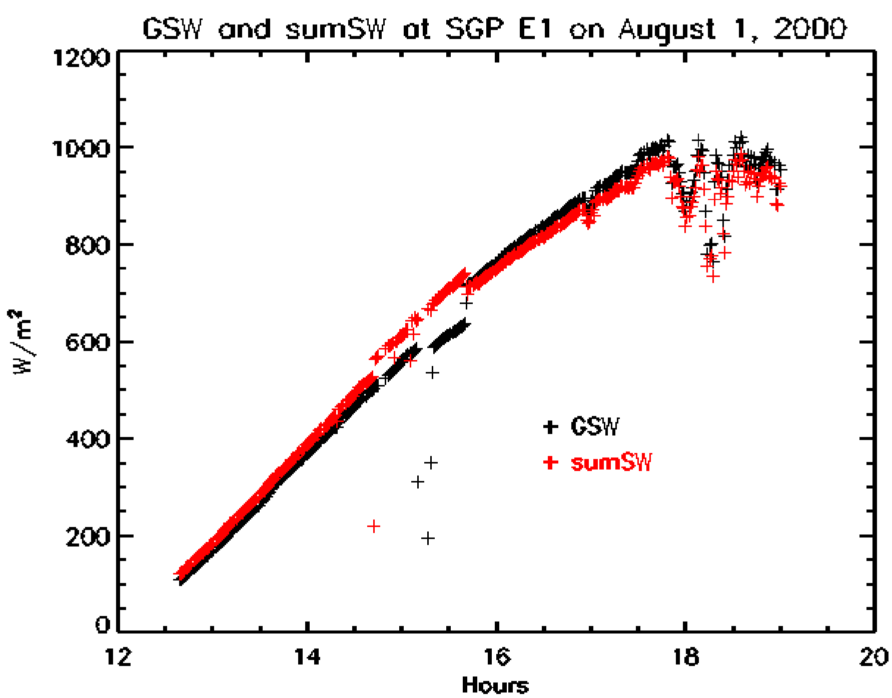

Figure 5. sumSW (red) and GSW (black) from SIRS measurement at SGP E1 on August 1, 2000.

Figures 6a to 6d compare the best estimate results with the measurement data for some typical days at SGP E1 data. In the plots, green represents the best estimate of total downwelling shortwave radiation (GSW); Blue represents sumSW data derived from SIRS direct normal and diffuse measurements; Red represents unshaded pyranometer measurement (GSW); and black represents the total downwelling radiation from MFRSR measurement (BBGSW). From the plots we see that green data points fall on the blue curves in most cases. This indicates that the best estimate values of GSW are essentially sumSW data except when sumSW data is “bad”. When the sumSW data is bad, the GSW data is used to derive the best estimate value, using BBGSW data as a cross check to the data quality. This is especially apparent in Figure 6b, where BEGSW follows GSW closely when sumSW dips away from the rest of the measurements.

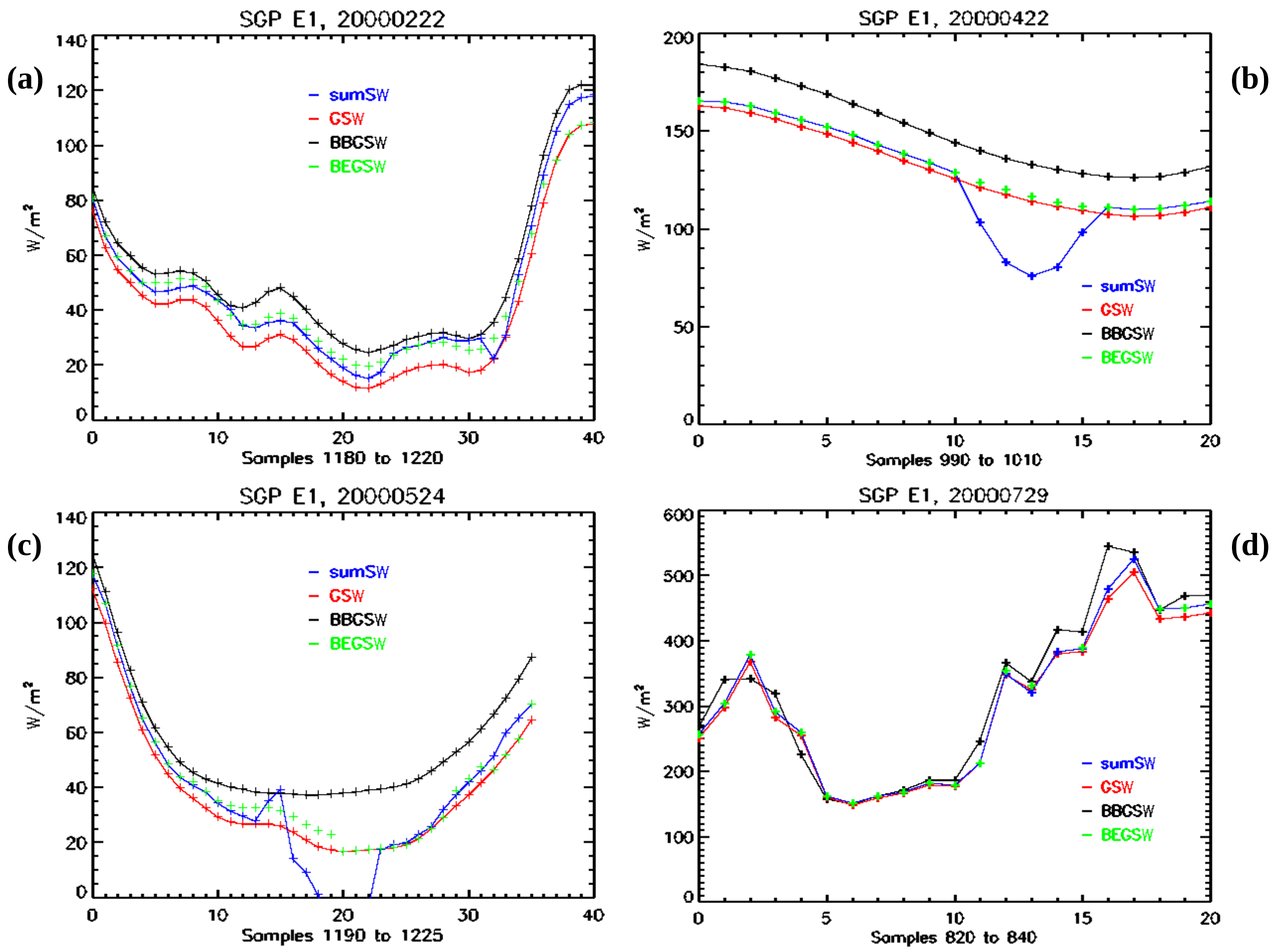

Figure 6. BEGSW and the measured data at SGP E1. (a) Samples 1180 to 1220 on February 22, 2000, (b) samples 990 to 1010 on April 22, 2000, (c) samples 1190 to 1225 on May 24, 2000, and (d) samples 820 to 840 on July 29, 2000.

Summary and Conclusion

In this study, we analyzed three years of radiation measurement data (1999, 2000, and 2002) at SGP E1. Limits and data constraints were determined as a result of the statistical analysis of these historical data. We explored four scenario fitting and all data fitting algorithms. The results show that the best fitting algorithm is to separate the morning and afternoon data and use all the good morning (or afternoon) data to fit the morning (or afternoon) "bad" data. Limits and data constraints were determined as a result of the statistical analysis of these historical data. Our study also shows that the fitting algorithm may not work at the time of instrument swap-out which happens once a year.

Corresponding Author

Y. Shi, Yan.Shi@pnl.gov, (509) 375-6858