Preliminary Analysis of Surface Radiation Measurement Data Quality at the SGP Extended Facilities

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Introduction

The Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Program operates surface radiation measurement sites across north central Oklahoma and southeastern Kansas as part of the Southern Great Plains (SGP) network. At the SGP Central Facility (CF), three independent measurements are collocated within a few meters, providing a unique opportunity for producing a high-quality estimate of the actual continuous irradiance record (Shi and Long 2002). At the SGP extended facilities, however, only one set of radiation measurements is available at each location. Thus, the data quality at the extended facilities cannot be assessed by comparison to like measurements, as is done at the CF.

Methodology Used for Data Quality Testing

The primary radiation flux measurements at the SGP extended facilities are obtained from the Solar Infrared Radiation Station (SIRS). In this study, we examine the radiation measurement data at the twenty extended facilities of the SGP network. Table 1 lists the definition of terms used in this study.

The measured data are tested against physically possible and globally extremely rare limits as defined and used in the Baseline Surface Radiation Network (BSRN) recommended data quality control (QC) testing developed by Ells Dutton and Chuck Long. Additional climatological limits and cross-comparisons between measurements, developed by Chuck Long, are also used to test these data. Table 2 shows the BSRN recommended and climatological QC tests. Table 3 and Table 4 show the BSRN and climatological (configurable) cross-comparisons applied in the data QC tests, respectively. The values of C1 to C16 are derived through historical data analysis at these facilities, as shown in the next section.

Results Analysis

Three years of radiation measurement data (1997, 1999, and 2002) at the twenty extended facilities at the SGP site were examined. The climatological limits were determined by the analysis of these data.

Table 1. Definition of terms used in this study.
Global Shortwave (SW): Downwelling Shortwave Hemispheric Irradiance
Diffuse SW: Downwelling Shortwave Diffuse Hemispheric Irradiance
Direct (Normal) SW: Shortwave Direct (Normal) Irradiance
SWup: Upwelling Shortwave Hemispheric Irradiance
LWdn: Downweling Longwave Hemispheric Irradiance
LWup: Upwelling Longwave Hemispheric Irradiance
Sum SW = [(Diffuse SW) + (Direct Normal SW) * μ_0]
SZA = Solar Zenith Angle
μ_0 = Cos(SZA) if SZA ≤ 90°; Else μ_0 = 0.0
S_0 = solar constant at mean Earth-Sun distance
AU = Earth – Sun distance in Astronomical Units
$S_a = S_0/AU^2$ = solar constant adjusted for Earth-Sun distance
σ = Stefan-Boltzmann constant = 5.67 x 10^{-8} $Wm^{-2}K^{-4}$
T_a = air temperature in Kelvin
T_d = pyrgeometer dome temperature
T_c = pyrgeometer case temperature
T_{snw} = Temperature below which "snow" limit is allowed for albedo limit test

Table 2. Physically possible and extremely rare global limits recommended by BSRN and user configurable climatological limits.

		Global SW	Diffuse SW	Direct Nomal SW	SWup	LWdn	LWup
Physically Possible Limits (Global)	Min (Wm^{-2})	-4	-4	-4	-4	40	40
	Max (Wm^{-2})	$S_a*1.5*\mu_0^{1.2}+100$	$S_a*0.95*\mu_0^{1.2}+50$	Sa	$S_a*1.2*\mu_0^{1.2}+50$	700	900
Extremely Rare Limits (Global)	Min (Wm^{-2})	-2	-2	-2	-2	60	60
	Max (Wm^{-2})	$S_a*1.2*\mu_0^{1.2}+50$	$S_a*0.75*\mu_0^{1.2}+30$	$S_a*0.95*\mu_0^{0.2}+10$	$S_a*\mu_0^{1.2}+50$	500	700
Climatological (Configurable) Limits	Min (Wm^{-2})	None	None	none	none	C_5	C_7
	Max (Wm^{-2})	$S_a*C_1*\mu_0^{1.2}+50$	$S_a*C_2*\mu_0^{1.2}+30$	$S_a*C_3*\mu_0^{0.2}+10$	$S_a*C_4*\mu_0^{1.2}+50$	C_6	C_8

Global SW

Figure 1a shows Global shortwave (SW) versus solar zenith angle (SZA) in year 2000 at SGP E2. The red curve is the maximum physically possible limits (PGSWmax), the blue curve is the maximum extremely rare limits (EGSWmax), the green curve is the maximum configurable limits (CGSWmax), and the cyan curve is the Clear-Sky SW envelope (ClrSW). The minimum test limits are not shown in this figure. Figure 1b shows the percent of data failed each of these tests. Figure 1b shows 40% to 60% data failed the minimum Global shortwave (GSW) Physically Possible limit tests; this is due to the infrared (IR) loss of

Table 3. Global cross-comparisons as recommended by BSRN.

Ratio of (Global SW) over (Sum SW)	• (Global SW)/(Sum SW) should be within ± 8% of 1.0 for SZA < 75°, (Sum SW) > 50 Wm^{-2} • (Global SW)/(Sum SW) should be within ± 15% of 1.0 for 93° > SZA > 75°, (Sum SW) > 50 Wm^{-2} • For (Sum SW) < 50 Wm^{-2}, test not possible
Diffuse Ratio	• (Dif SW)/(Global SW) < 1.05 for SZA < 75°, (Global SW) > 50 Wm^{-2} • (Dif SW)/(Global SW) < 1.10 for 93° > SZA > 75°, (Global SW) > 50 Wm^{-2} • For (Global SW) < 50 Wm^{-2}, test not possible
SWup comparison	• SWup < (Sum SW) [or (Global SW) if (Sum SW) missing or "bad", for (Sum SW) [or (Global SW)] > 50 Wm^{-2} • for (Sum SW) [or (Global SW)] < 50 Wm^{-2}, test not possible • If SWup > (Sum SW) and SWup > (Global SW), SWup = "bad"
LWdn vs. T_a	• $0.4 * \sigma T_a^4 < LWdn < \sigma T_a^4 + 25$
LWup vs. T_a	• $\sigma(T_a - 15)^4 < LWup < \sigma(T_a + 25)^4$
LWdn to LWup comparison	• LWdn < LWup + 25 Wm^{-2} • LWdn > LWup -300 Wm^{-2}

Table 4. Climatological (configurable) comparisons.

"Tracker off" test	• For (Diff SW) > 50 Wm^{-2}, if (Sum SW) / ClrSW > 0.9 [or (Global SW) if (Sum SW) missing or "bad"] AND if (Diff SW) / (Sum SW) > 0.9 [or (Global SW) if (Sum SW) missing or "bad"], then the tracker is not properly following the sun. Here $ClrSW = (a / AU^2) * \mu_0^b$, where a and b are configured by user.
SWup comparison	• SWup < Cx * (Sum SW) + 25 Wm^{-2} [or (Global SW) if (Sum SW) missing or "bad"], for (Sum SW) [or (Global SW)] > 50 Wm^{-2} • for (Sum SW) [or (Global SW)] < 50 Wm^{-2}, test not possible • $Cx = C_9$ if $T_a > T_{snw}$ limit ("normal" ground cover) • $Cx = C_{10}$ if $T_a < T_{snw}$ limit (ground may be "snow covered") • If limit greater than (Sum SW), set equal to (Sum SW) [or (Global SW) if (Sum SW) missing or "bad"]
LWdn to T_a comparison	• $C_{11} * \sigma T_a^4 < LWdn < \sigma T_a^4 + C_{12}$
LWup to T_a comparison	• $\sigma(T_a - C_{13})^4 < LWup < \sigma(T_a + C_{14})^4$
LWdn to LWup comparison	• LWdn < LWup + C_{15} Wm^{-2} • LWdn > LWup – C_{16} Wm^{-2}
Test/compare T_a, T_c, T_d	• $T_a - C_{17} < T_c < T_a + C_{17}$ (for both LWdn and LWup instruments. If have all three, can determine "bad" one) • $T_a - C_{17} < T_d < T_a + C_{17}$ (for both LWdn and LWup instruments. If have all three, can determine "bad" one) • If T_a not available, test not possible • $C_{18} \leq (T_c - T_d) < C19$, if either T_c or T_d "bad", test not possible

the unshaded pyranometer causing negative values at night. The seasonal trend is also shown here since we have longer nights in winter and shorter nights in summer. This IR loss is also shown in the Global SW/Sum SW test.

Figure 1c shows the Global SW/Sum SW ratio versus the SZA. Here, Sum SW is calculated using the shaded precision spectral pyranometer (PSP) data that were corrected for IR loss. Figure 1d shows the same ratio but the Global SW data is also been corrected to the same amount that the diffuse PSP data was corrected. Thus, no IR loss shows in this graph. This result implies that we should be correcting the Global SW measurements for IR loss as we have corrected shaded PSP measurements for IR loss. This result also has implications with respect to current ARM outdoor calibration methodology for PSPs.

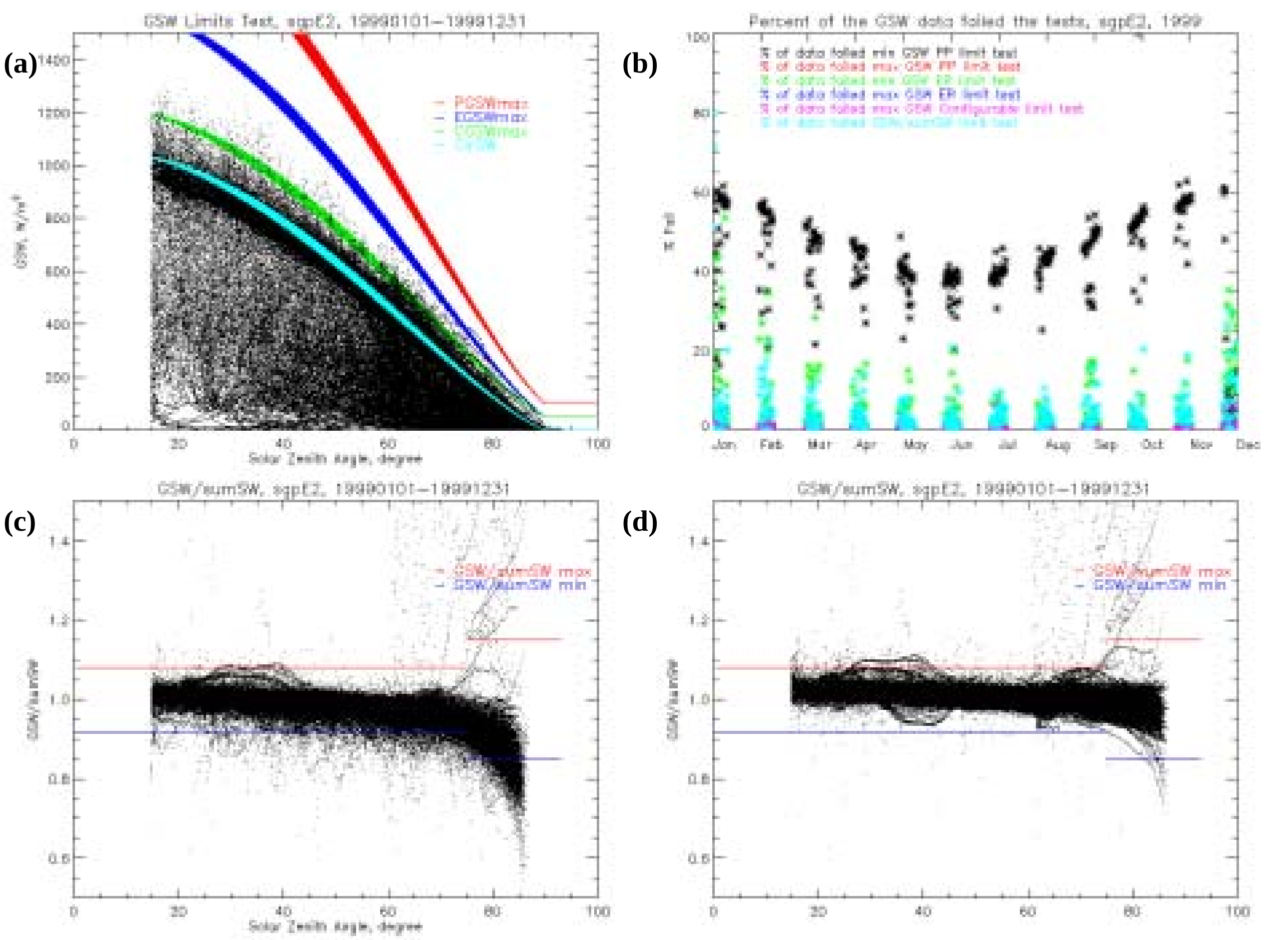

Figure 1. Global SW tests for 1999 SGP E2 data. (a) Top left: GSW vs. SZA showing limits; (b) Top right: daily percent of data that failed GSW testing; (c) Bottom left: ratio of GSW/Sum SW using diffuse SW corrected for IR loss in Sum; (d) Bottom right: ratio of GSW/Sum SW using both corrected diffuse SW and corrected GSW.

Diffuse and Direct SW

Similar to Figure 1, Figure 2a shows the Diffuse SW tests and Figure 2b shows the percent of data failed these tests. The IR loss can also be seen from the DiffSW/GSW test, as shown in Figure 2b and 2c. Figure 2d is the same plot as 2c but using the corrected diffuse and GSW data. Similar tests are done to Direct SW, as shown in Figure 3a and 3b. Most data are well within the defined limits, except for less than 5% of the data that failed minimum extremely rare limit tests.

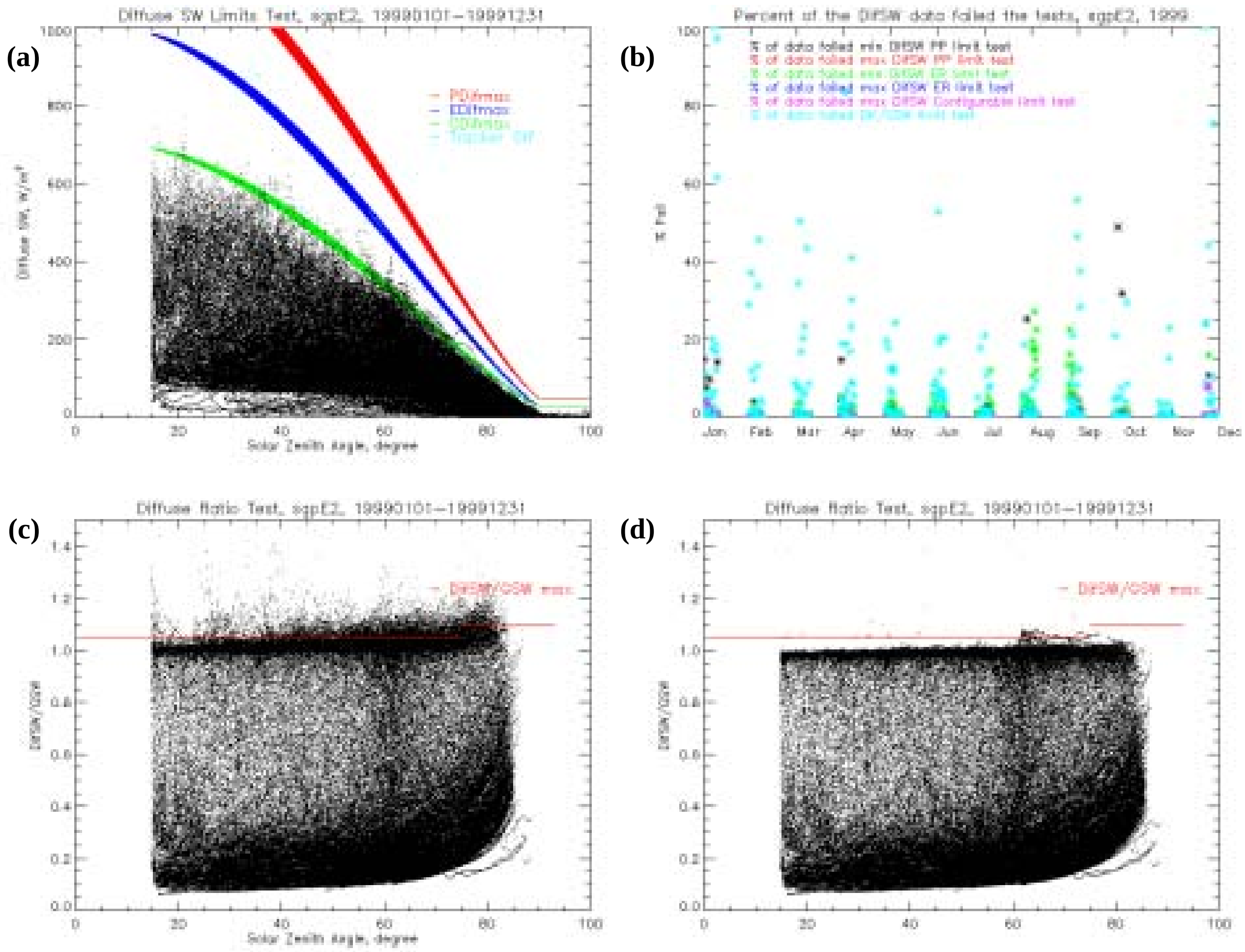

Figure 2. Diffuse SW tests for 1999 SGP E2 data. (a). Top left: DiffSW vs. SZA showing limits; (b). Top right: daily percent of data that failed DiffSW testing; (c) Bottom left: ratio of DiffSW/GSW using DiffSW corrected for IR loss; (d) Bottom right: ratio of DiffSW/GSW using both corrected DiffSW and corrected GSW.

Upwelling SW

Figure 4 shows the upwelling SW test results. The data between the green (configurable maximum SWup limits) and blue (extremely rare maximum SWup limits) curves in Figure 4a are snow effects, as shown in Figure 4b between the red and the blue curves. Figure 4c shows the daily percent of data that

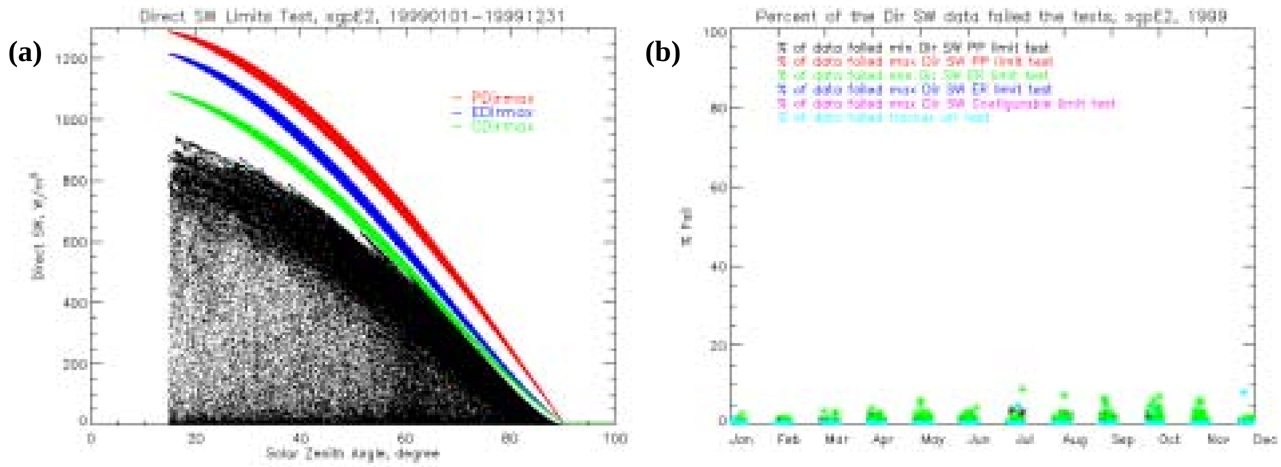

Figure 3. Direct SW tests for 1999 SGP E2 data. (a) Left: DirSW versus SZA showing limits; (b) Right: daily percent of data that failed DirSW testing.

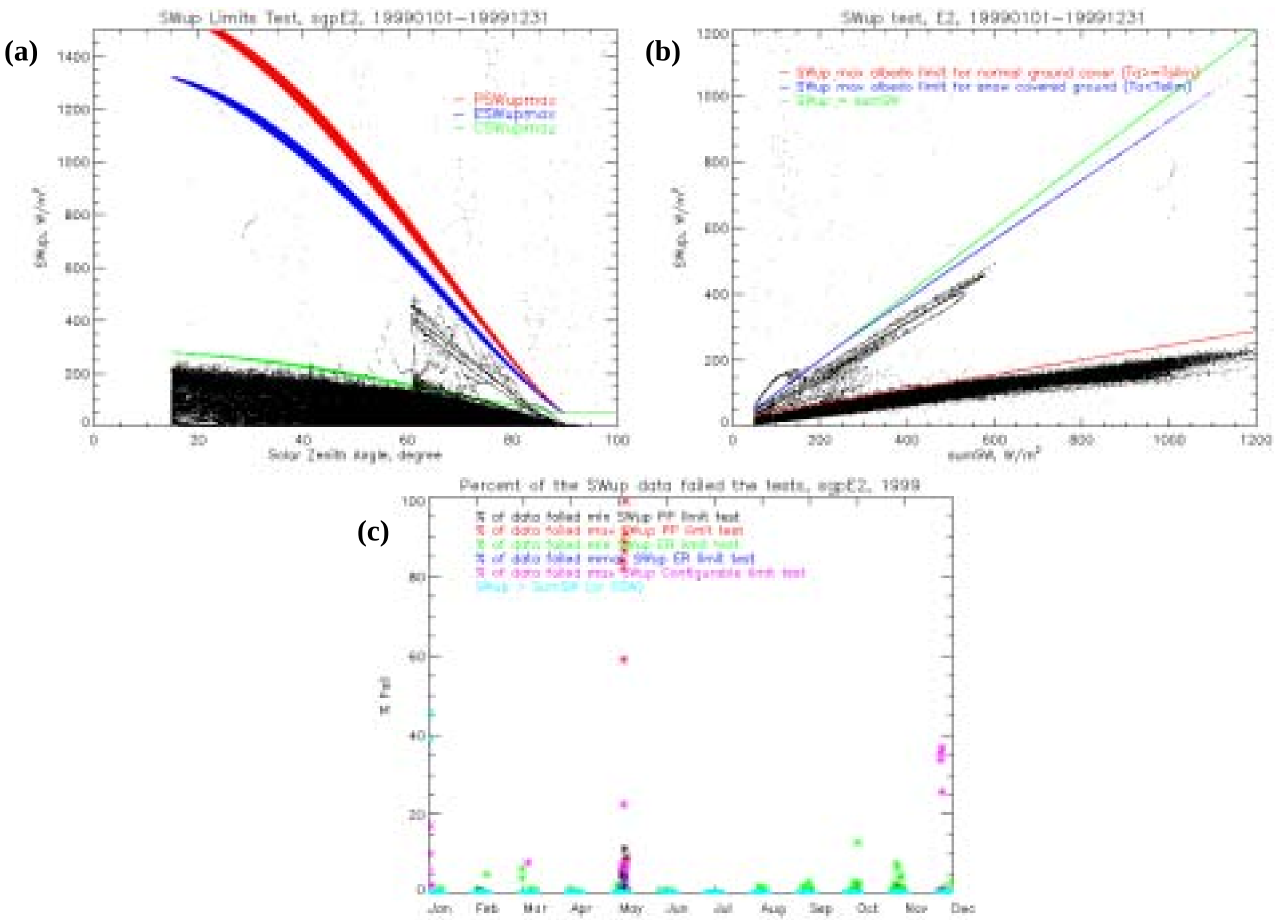

Figure 4. Upwelling SW tests for 1999 SGP E2 data. (a) Top left: SWup vs. SZA showing limits; (b) Top right: SWup vs. SumSW showing limits; (c) Bottom: daily percent of data that failed SWup testing.

failed the testing. It shows some data in December and January exceeded the SWup maximum configurable limits but were below the extremely rare limits, again indicating possible snow events. This graph also shows some data in May exceeded the maximum configurable limits or maximum physically possible limits, these data are shown both in Figure 4a and 4b as the scattered black dots, indicating something wrong with the instrument.

Downwelling and Upwelling LW

Figure 5 and Figure 6 show the downwelling LW and upwelling LW tests, respectively. Most data are well within the defined limits.

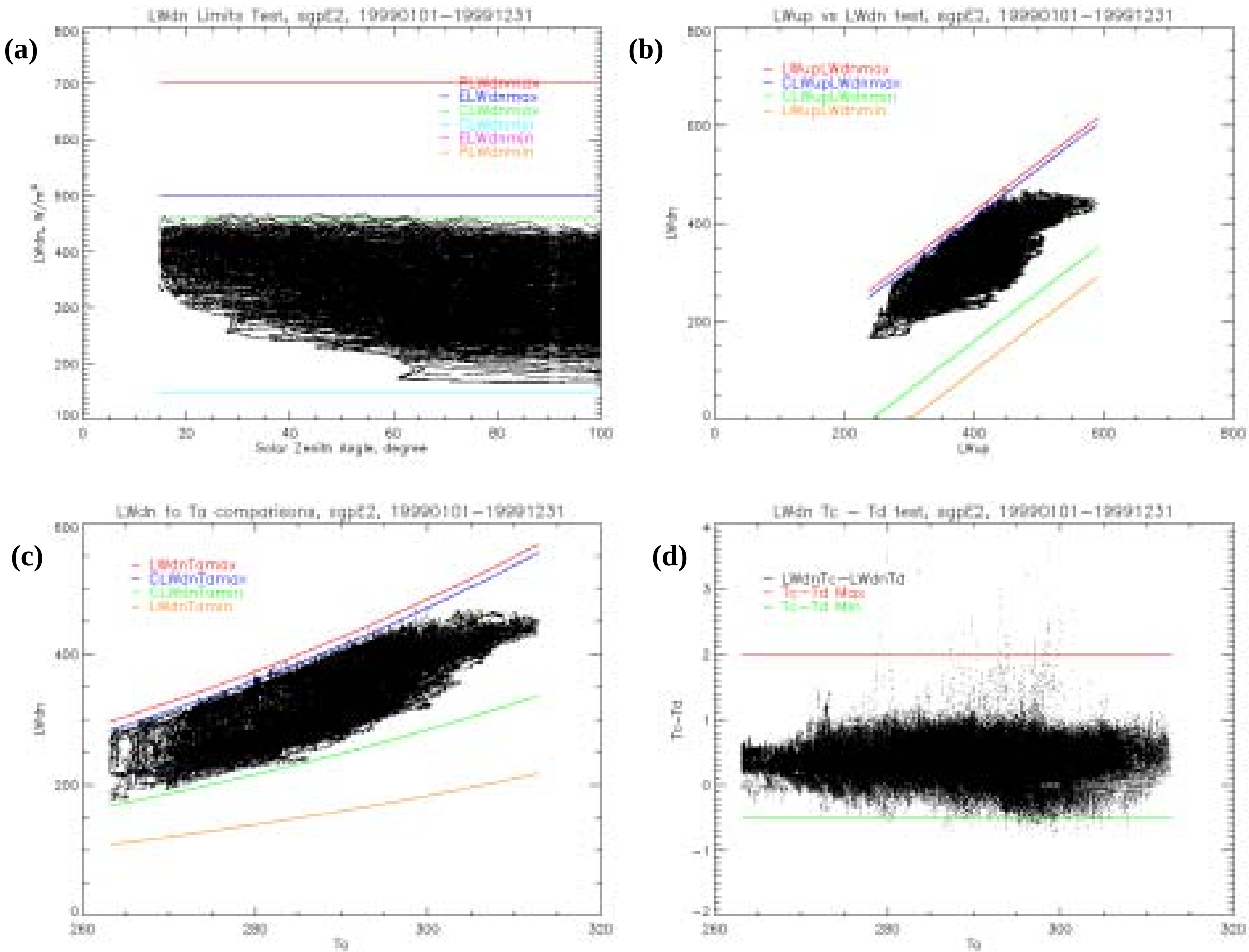

Figure 5. Downwelling LW tests for 1999 SGP E2 data, with limits shown in each graph. (a) Top left: LWdn vs. SZA; (b) Top right: LWdn vs. LWup; (c) Bottom left: LWdn to Ta comparisons; (d) Bottom right: Tc – Td tests.

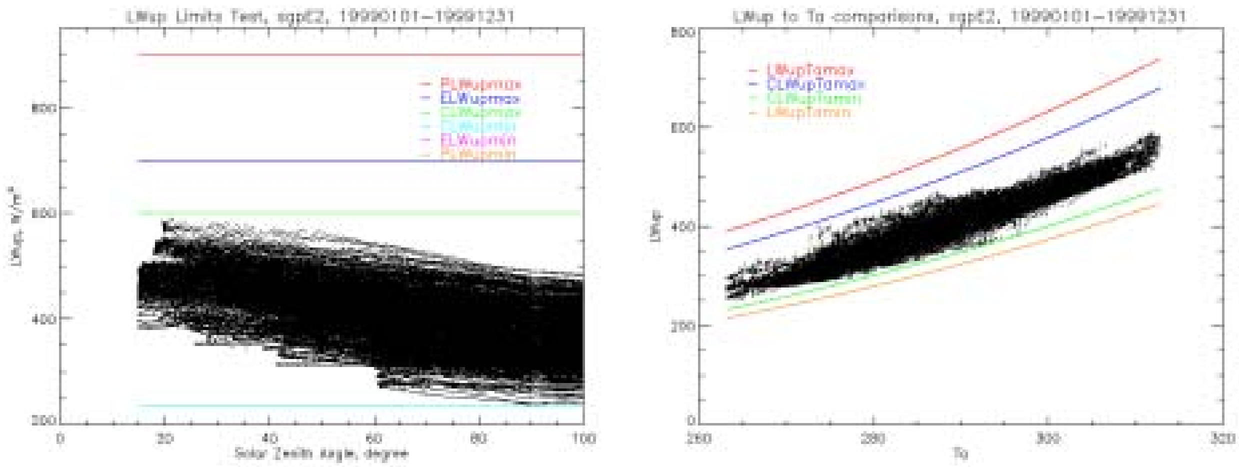

Figure 6. Upwelling LW tests for 1999 SGP E2 data. (a) Left: LWup vs. SZA showing limits; (b) Right: LWup to Ta comparisons showing limits.

Summary and Conclusion

In this study, we examined three years of historical data (1997, 1999, and 2002) at the SGP site's twenty extended facilities and obtained a set of configurable limits that applies to all the facilities at the SGP site. Table 5 is a summary of the percent of data that failed the QC tests in 1997, 1999, and 2002 at SGP E2. It shows that 42% of the data in all the three years tested failed the minimum GSW physically possible limits due to the IR loss of the unshaded pyranometer. This IR loss also shows up in the GSW minimum extremely rare limit tests (5% to 7% failure) and in the GSW/SumSW and DiffSW/GSW tests (3% to 23% failure). The diffuse SW, on the other hand, only failed the minimum PP limits for 4% in 1997 and 1% in 1999, since the diffuse data was corrected for IR loss (Younkin and Long 2002). Moreover, virtually all the 2002 diffuse data passed the minimum PP limit tests, after the measurement was switched to shaded B/W instruments. Most of the direct SW data fall within the limits, with only 1% of data failed the extremely rare limits in all three years and 1% data in 1997 failed the "tracker off" tests. The SWup data also behaves well; with only 1% data greater than sumSW in 1997, thus failed the user defined maximum limits and 1% data failed the minimum extremely rare limits in 2002. Tests to the downwelling LW and upwelling LW show that only 4% of the upwelling LW data in 1997 failed the minimum PP limits. We also tested the air temperature, used in some tests, and only 1% data in 1999 and 2002 were deemed unacceptable.

An examination of all the data at the extended facilities in these three years reveals that on average 40% of the GSW data failed the minimum PP limit tests, from the minimum of 26% at E10 and E24 in 1997 to the maximum of 51% at E18 in 1999 (Figure 7). This IR loss is also indicated in the GSW minimum extremely rare limit tests, in which the average failure for all the facilities over the three test years is 9%. The failure is 10% for GSW/SumSW test and 6% for DiffSW/GSW test, again because of the IR loss of the GSW. Most of the other radiation components fall within the limits as expected, with a few percent of data failing occasionally, indicating infrequent instrument malfunctions.

Table 5. Percent of data failed the QC tests in 1997, 1999, and 2002 at SGP E2.

			Global SW			Diffuse SW			Direct SW			SWup			LWdn			LWup		
	Year		1997	1999	2002	1997	1999	2002	1997	1999	2002	1997	1999	2002	1997	1999	2002	1997	1999	2002
Physically Possible	Min		42	42	42	4	1	0	0	0	0	0	0	0	0	0	0	4	0	0
	Max		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Extremely Rare	Min		6	5	7	3	1	0	1	1	1	0	0	1	0	0	0	0	0	0
	Max		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
User Defined	Min														0	0	0	0	0	0
	Max		0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0
GSW/SumSW			23	5	5															
DiffSW/GSW						3	5	0												
Tracker Off									1	0	0									
SWup > SumSW												1	0	0						
LWdn & LWup to Ta tests	Global	Min													0	0	0	0	0	0
		Max													0	0	0	0	0	0
	User Defined	Min													0	0	0	0	0	0
		Max													0	0	0	0	0	0
LWdn to LWup tests	Global	Min													0	0	0			
		Max													0	0	0			
	User Defined	Min													0	0	0			
		Max													0	0	0			
Tc &Td vs Ta															0	0	0			
Tc - Td															0	0	0			
Ta tests															0	1	1			

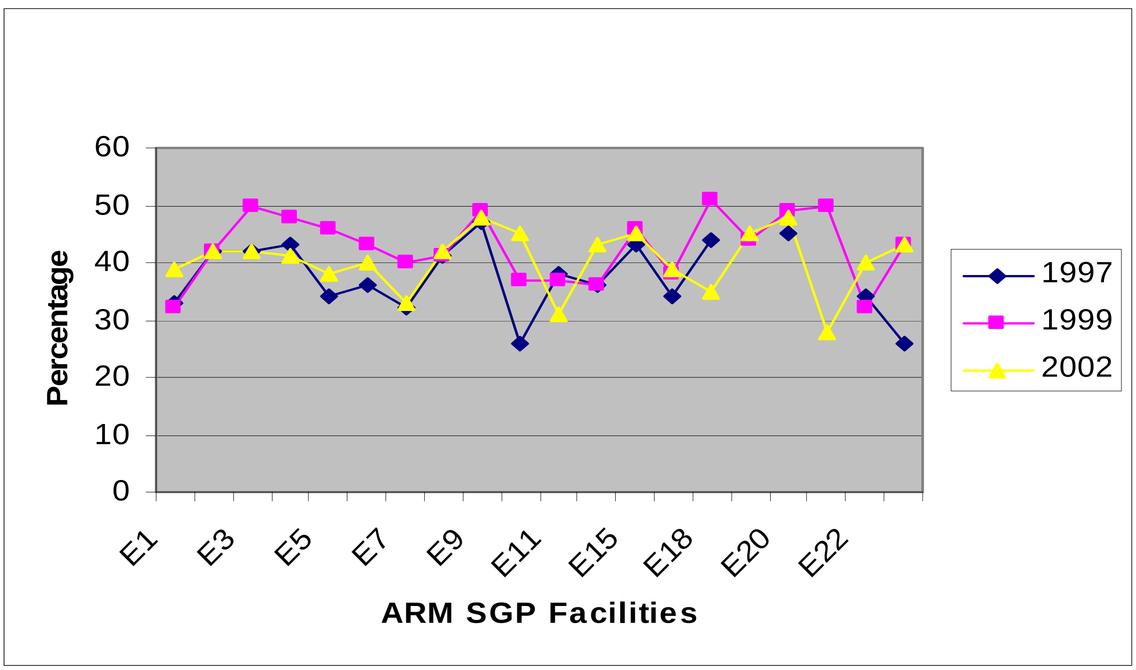

Figure 7. Percent of data failed the minimum GSW physically possible limit tests.

Future works for this study include filling in gaps in the downwelling SW components using multifilter rotating shadowband radiometer data when the radiation measurements are "bad," and using clear-sky coefficients determined by the data for testing, rather than generic ones. A value-added procedure is being developed (QCRad) to make this data quality testing and data continuity effort an operational product.

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