ARM TR-002

Shortwave (SW) Radiometer Inconsistencies at the Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) Central Facility (CF)

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Abstract

There appears to be a problem with the Southern Great Plains (SGP) Central Facility (CF) Baseline Surface Radiation Network (BSRN) shortwave (SW) measurements. An investigation shows there are large differences between the unshaded precision spectral pyranometer (PSP) values and those of the sum of normal incidence pyrheliometer (NIP) + Diffuse. Comparison with the E13 and C01 Solar Infrared Station (SIRS) measurements suggests that the BSRN PSP has an incorrect calibration applied to the data from about October 23, 1998, through December 31, 1999, and probably continues to the present.

Not surprisingly, comparison between the three radiometer systems shows that the unshaded PSPs have larger disagreements during the winter months when the local solar noon zenith angles are less than the solar zenith angle value the calibration numbers were chosen to represent. This is likely due to differences in cosine response. This is unfortunate, because we end up with the largest magnitude differences at the same time of year that we experience the smallest magnitude daily average incoming solar energy.

Perhaps most disturbing, is that the sum of the IP + diffuse has been consistent between the CF three systems except for this winter. A comparison of the three sums exhibits about the same magnitude spread as that of the comparison of the three unshaded PSPs. The current daily average difference between each system's unshaded PSP and sum is about 6% of the corresponding clear-sky value for all three systems (BSRN, C01 SIRS, and E13 SIRS).

The Atmospheric Radiation Measurement (ARM) enhanced shortwave (ARESE II) experiment is scheduled to occur in early spring 2001. The original ARESE experiment was hindered due to inconsistencies between the ARM SGP CF BSRN and Solar and Infrared Observing System (SIROS) radiometer systems. These two systems were used in many ARESE studies as the primary surface downwelling SW measurements. It is expected that the three current SGP CF radiometer systems will again be called upon to play a major role in the ARESE effort. As such, it is crucial that these three systems be closely inspected before the start of the ARESE experiment, and well monitored and maintained during the experiment. The current inconsistencies between the three systems shown in this report, even in the sum of NIP + diffuse, must be addressed.

Contents

Figures

1. Introduction

The following results were generated from our clear-sky identification and fitting algorithm (Long and Ackerman 2000). This algorithm uses measurements of total (global), diffuse, and direct downwelling SW to detect periods of clear (cloudless) skies. The detected clear-sky measurements are then used to empirically fit daily functions using the cosine of the solar zenith angle as the independent variable on "clear enough" days. The fit coefficients are then interpolated for cloudy days, producing a continuous estimate of clear-sky global, diffuse, and direct downwelling SW. More details of this procedure can be found in Long and Ackerman (2000), available by request from long@essc.psu.edu.

One feature of the clear identification and fitting algorithm is built-in automated data quality control (QC) comparisons for the platform being processed. Thus, the results presented here have already been inspected for and do not contain, data that failed the QC testing. The algorithm also includes keeping track, during detected clear-sky periods, of the difference between the total SW and the sum (direct + diffuse) SW.

2. Results

Figure 1 shows the daily maximum total SW (TSW) – Sum irradiance differences for "clear enough" days during the entire SGP CF BSRN record (1993 - 1999). From the beginning of the data record through much of 1995, there are significant SW differences. Then the increased effort of ARM personnel in the form of calibration and maintenance procedures greatly reduced the irradiance differences up through September 1998. Figure 1 shows a problem that developed in October 1998 that continues to the present. Figures 2 and 3 show the same comparison as in Figure 1, but for the C01 and E13

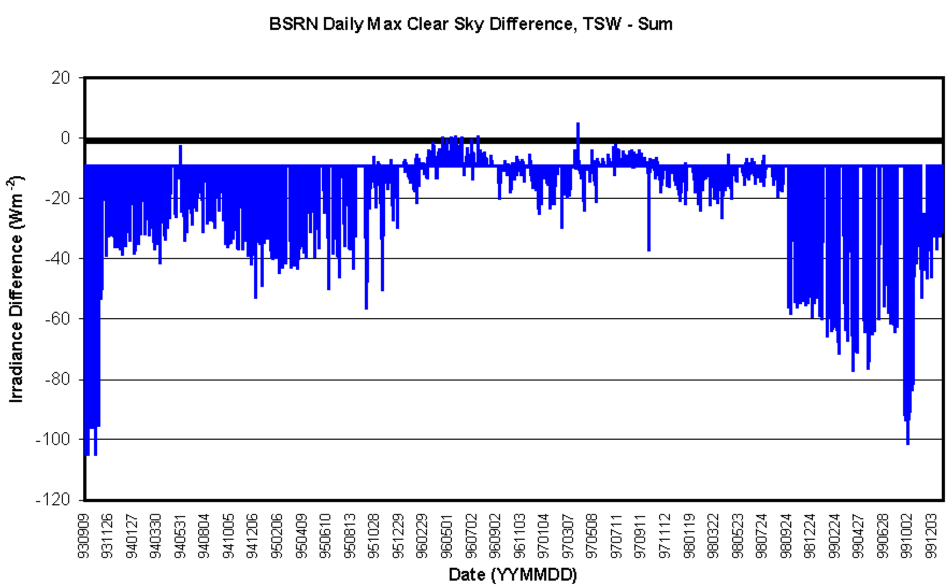

Figure 1. Maximum daily clear-sky difference between the ARM SGP CF BSRN unshaded pyranometer (TSW) and the sum of the direct + diffuse (Sum) from the NIP and shaded pyranometer data.

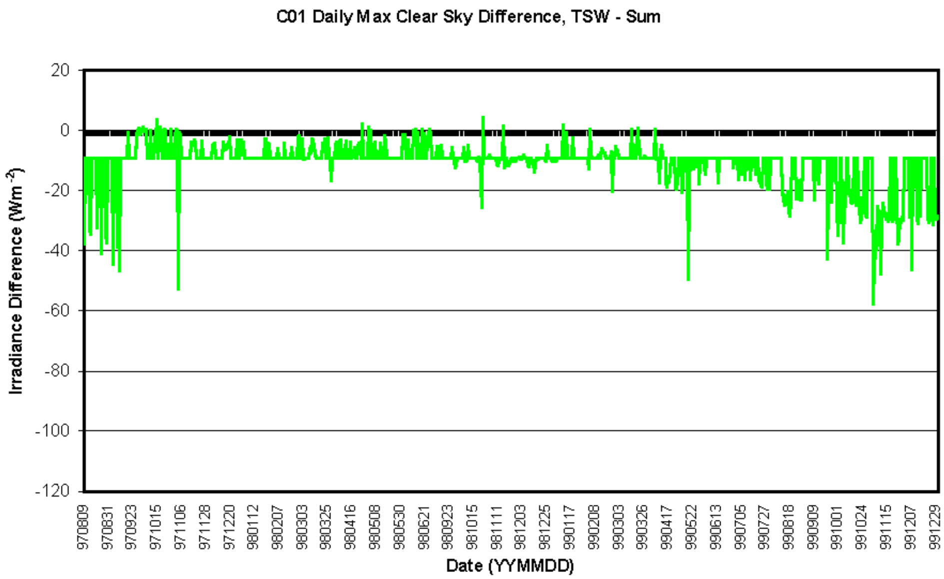

Figure 2. Same as Figure 1, but for the ARM SGP CF C01 data.

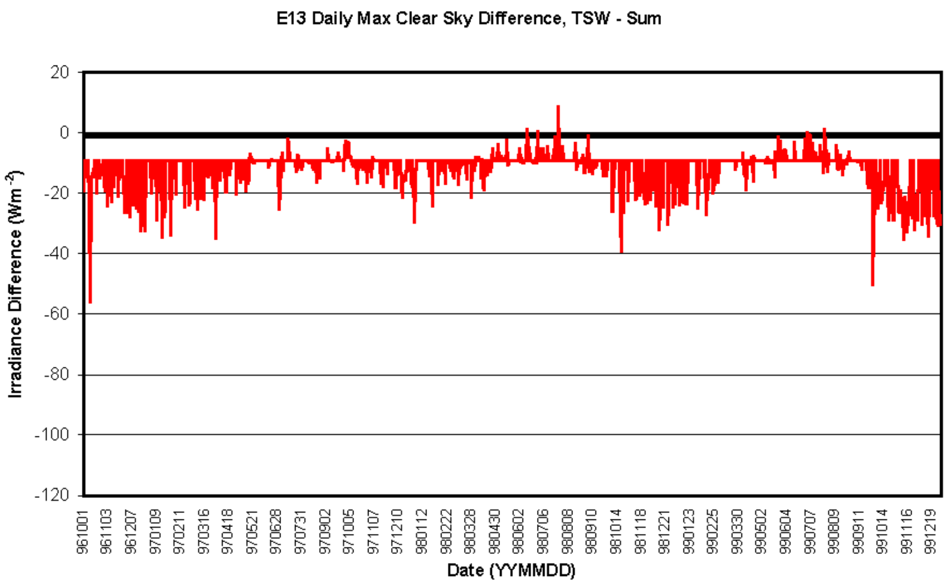

Figure 3. Same as Figure 1, but for the ARM SGP CF E13 data.

radiometer platforms available data records, respectively. Figures 2 and 3 show the magnitude of difference one would normally expect for most of the data record, given the vagaries of continuous long-term radiometer deployments in the mid-latitudes, and with instrument calibrations and radiometer swap-outs once per year. These general differences will be discussed more later, especially those toward the end of the records. For now, it is obvious that the BSRN TSW – Sum differences from October 1998, on, are much larger than the two other platforms.

The abrupt change in the BSRN TSW – Sum difference appears in the record on about October 23, 1998, when the difference jumps in magnitude from about 15 Wm^{-2} to about 55 Wm^{-2}. The difference then varies from 55 Wm^{-2} to a brief period of 100 Wm^{-2}. Another abrupt change occurs about October 18, 1999, where the difference decreases in magnitude to about 30 Wm^{-2}. Figure 4 shows the measured and clear fit irradiance for October 10, 1999, when a maximum difference of about 80 Wm^{-2} occurs at local solar noon. Figure 5 shows the same, but for October 20, 1999, after the difference decreased to a maximum of 30 Wm^{-2} at local solar noon. While this is an improvement, it is still almost 5% of the noon TSW irradiance. In addition, while the difference between the TSW and Sum is about the same morning and afternoon in Figure 4, the difference is smaller in the afternoon than in the morning in Figure 5. Figure 6 and 7 show XY plots of the measured and clear TSW (X axis) versus the corresponding measured and clear Sum (Y axis) for October 10 and 20, 1999, respectively. While there is a large departure from X=Y on October 10 (Figure 6), the differences consistently lie on a line in this plot. For October 20 (Figure 7), however, the measured SW exhibits a “loop” rather than a line. This “loop” feature is persistent throughout the BSRN record from this point on, and is an indication that the unshaded pyranometer (TSW) might not be properly leveled.

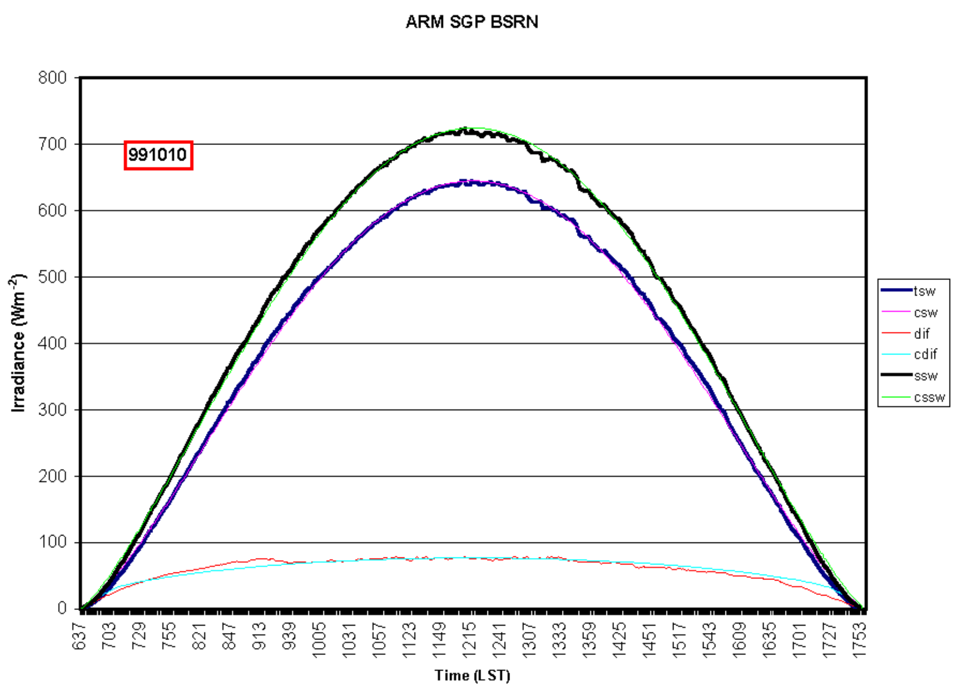

Figure 4. Downwelling measured (TSW) and clear-sky (CSW) total SW, measured (SSW) and clear-sky (CSSW) Sum, and measured (DIF) and clear-sky (CDIF) diffuse irradiance for the SGP CF BSRN platform on October 10, 1999.

Figures 4 through 6 all include both the measured and estimated (fitted) clear-sky SW. This gives some idea of the “goodness of fit” of the clear-sky estimated SW. Since the actual measured SW is highly influenced by clouds, an intercomparison of time series of measured irradiance across platforms is more difficult to interpret. We will use instead the estimated clear-sky SW, since by nature the fitted functions include the instrument characteristics such as the cosine response (Long and Ackerman 2000).

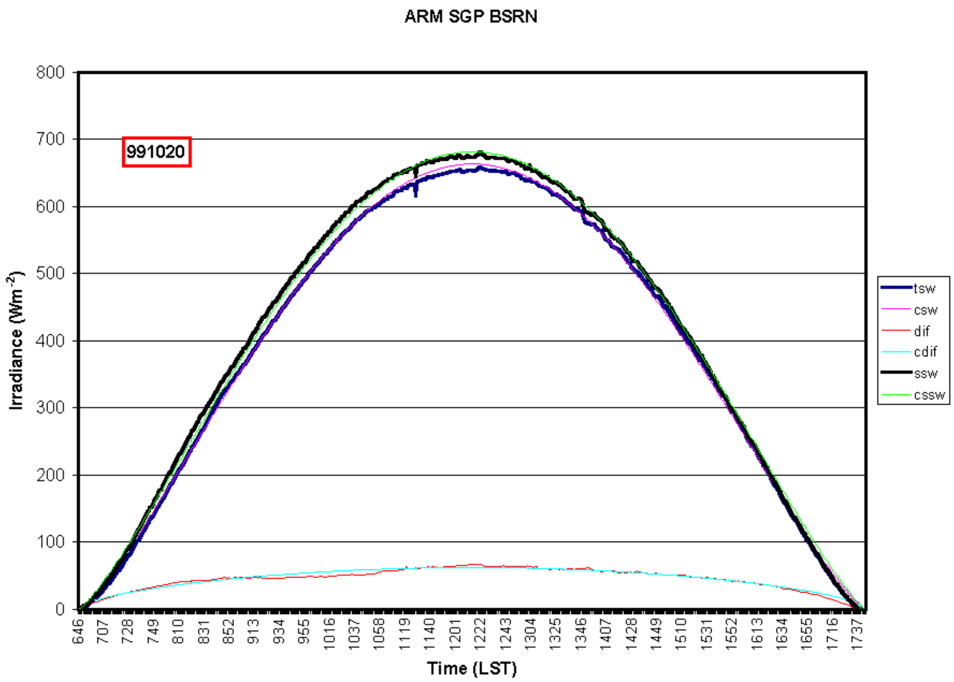

Figure 5. Same as Figure 4, but for the SGP CF BSRN platform on October 20, 1999.

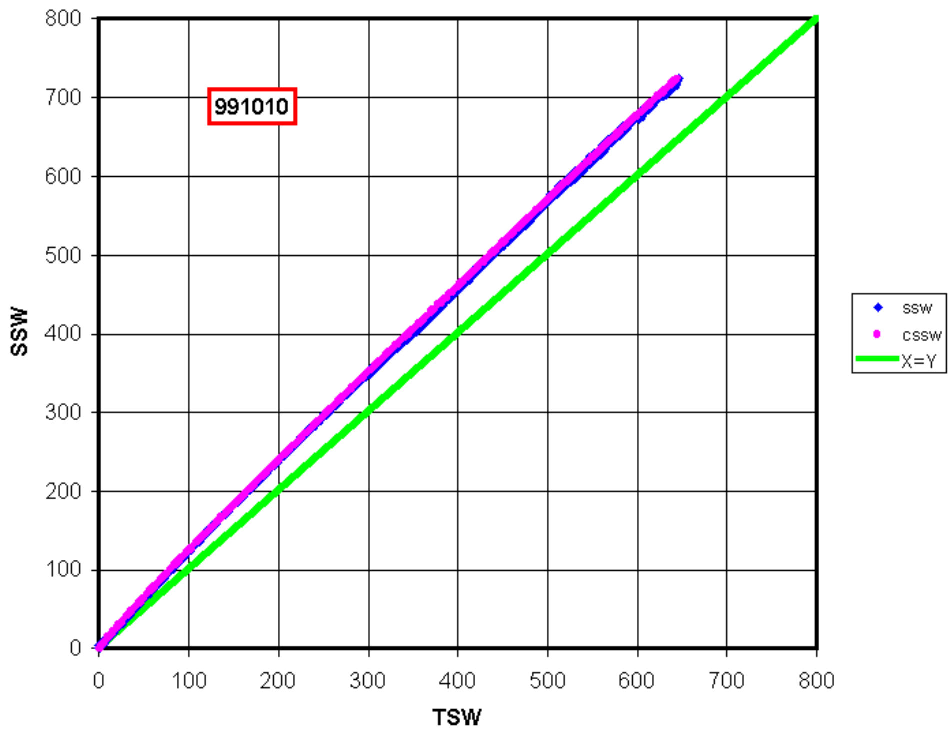

Figure 6. Comparison of corresponding measured (blue) and clear fit (pink) downwelling SW from the unshaded pyranometer (TSW) and the Sum (SSW) for October 10, 1999.

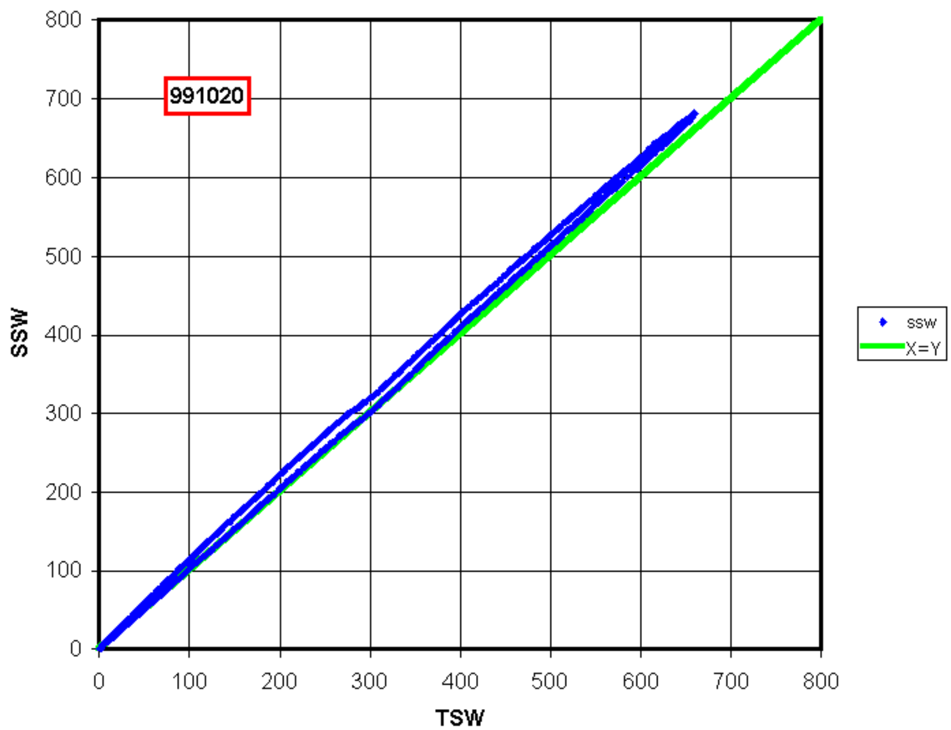

Figure 7. Same as Figure 6, but for October 20, 1999.

Figure 8 shows the time series of daily (24-hour) average estimated clear-sky SW for both the unshaded pyranometers (csw) and Sum (cssw) for all three SGP CF platforms. To make the plot less cluttered, the clear unshaded pyranometer SW (csw) is referenced to the right Y axis, with an axis minimum of 0 Wm^{-2}. The clear Sum SW (cssw) is referenced to the left axis, with an axis minimum of 100 Wm^{-2}. In this plot, there are some deviations between the BSRN and E13 radiometers (the C01 hadn't come on line at this point) during the summer in 1997. From October 23, 1998, on, it is obvious that the BSRN unshaded pyranometer (Bcsw) is reading too low compared to the C01 and E13 unshaded pyranometers, as well as all three Sums. Note that during the winter, with the exception of 1997, the differences between platforms for the unshaded pyranometers increases more than is typical during the rest of the year. This is likely due to the individual pyranometer cosine response characteristics. During the winter at the SGP, the local solar noon zenith angles are less than the solar zenith angle BORCAL value the calibration numbers are chosen to represent. This increased uncertainty is unfortunate, because we end up with the largest magnitude differences at the same time of year that we experience the smallest magnitude daily average incoming solar energy. On the other hand, the Sums agree better all year round, with the exception of the current winter.

Figure 9 shows each platform TSW – Sum daily average difference from Figure 8, normalized by their respective Sum to give a value as a percentage of clear-sky Sum. In this plot, the seasonal dependence of TSW – Sum agreement is apparent. From Figure 9, the BSRN difference problem amounts to 7% to 12 % of the corresponding clear-sky value, compared to 1% to 2% and 1% to 4% for C01 and E13 platforms, respectively, during the same period. The exception here is shown on the far

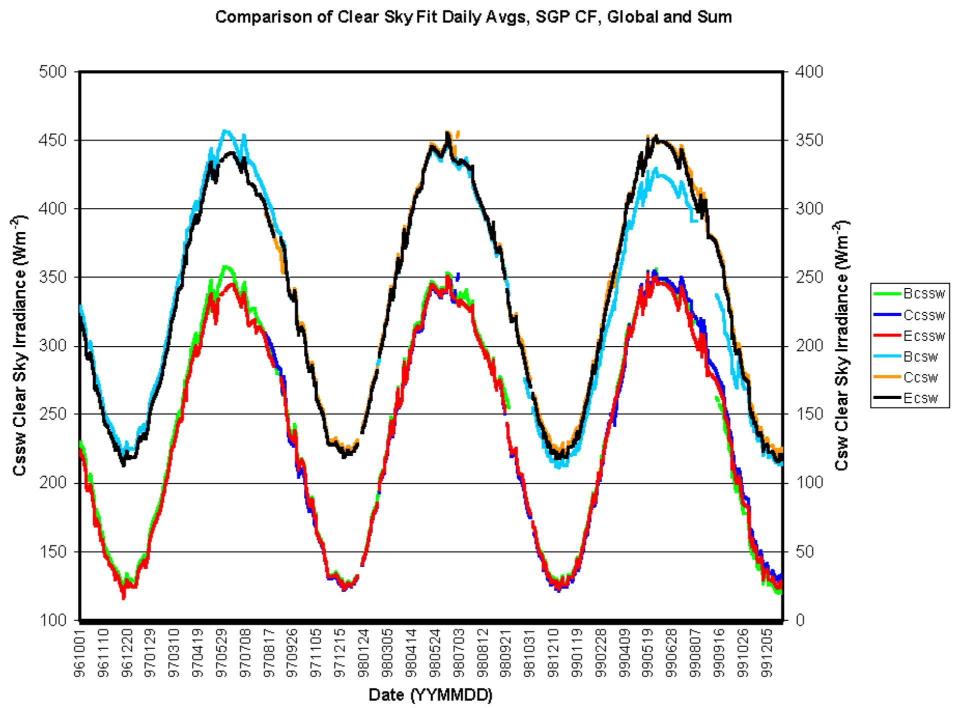

Figure 8. Daily average estimated downwelling clear-sky SW for the SGP CF BSRN, C01, and E13 Sum results (cssw) are referenced to the left Y-axis, unshaded pyranometer results (csw) are referenced to the right Y-axis.

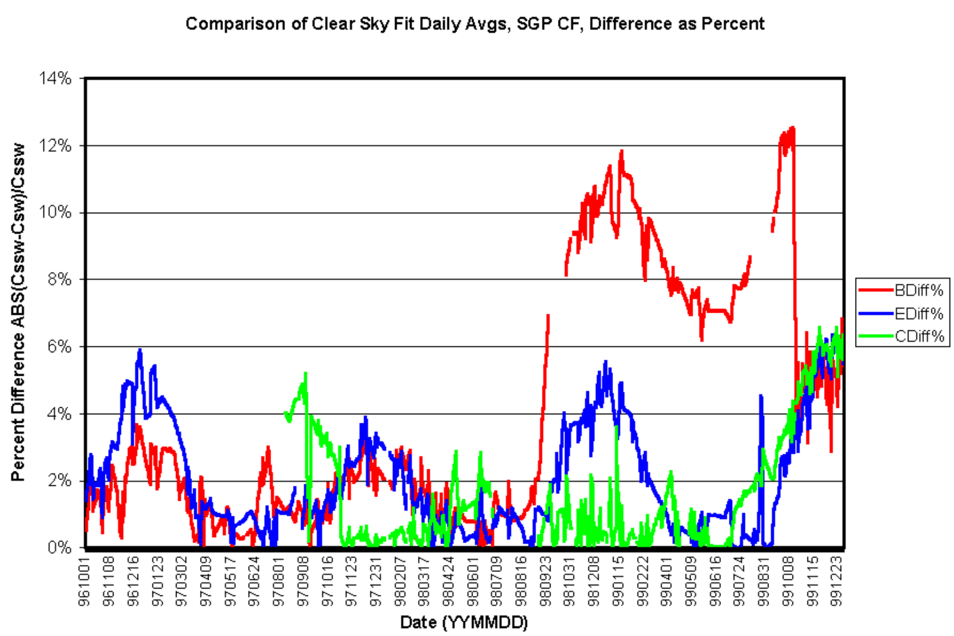

Figure 9. BSRN, C01, and E13 individual platform TSW - Sum daily average differences from Figure 8, normalized by their respective Sum to give a value as a percentage of clear-sky Sum.

right in Figure 9, where all three platforms show a 6% difference. This last is particularly disturbing, since we depend on the Sum values to be our most accurate measurement of downwelling SW. It is a truism in data QC that having two independent measurements of the same quantity allows one to identify when a problem occurs, but of themselves give no indication which measurement is correct. Having a third independent measurement does allow one to identify which measurement is likely the odd one out. We are fortunate in this case to have three independent measurement platforms.

Figures 10 through 13 show the measured downwelling SW for December 31, 1999. This day was fairly clear, and is the last day in the current processed lot of SGP data. Figure 10 shows the downwelling total SW as measured by the three unshaded pyranometers. Unfortunately here, we are in the winter season and no two pyranometers agree any better with one another than with the third. From the previous figures presented here, this is not surprising. Note also that the BSRN agrees better with the E13 in the afternoon than in the morning, the same symptom as in Figure 7 for October 20, 1999.

Figure 11 shows the measured downwelling Sum SW for the same day as in Figure 10. In this case, with the Sums, we would expect there to be better agreement between the platforms than for the unshaded pyranometers, as there was in previous years. However, we see almost the same spread between the downwelling SW measurements as in Figure 10. The Sum involves measurements from two instruments, the NIP and the shaded pyranometer. Figure 12 shows the three platform direct and diffuse components that went in to each platform Sum. Here we see that the C01 and E13 direct measurements are in excellent agreement, but the BSRN direct is less than these. On the other hand, the BSRN and E13 diffuse show good agreement, while the C01 diffuse is larger. For the direct, the BSRN difference appears to be a linear offset form the C01 and E13 direct, i.e., different by a simple multiplicative factor of the magnitude as is shown in Figure 13. In Figure 13 the difference between the E13 and BSRN direct has been normalized by the E13 direct, and the plot shows almost a constant 2.5% difference across the day. But the C01 diffuse seems to almost be constant offset from the other two (Figure 13), which produces a much larger percentage difference in the morning and afternoon, but maintains its irradiance difference magnitude even when the E13 and BSRN diffuse go to zero (Figure 12). These results indicate that there are problems with the BSRN NIP and the C01 shaded pyranometer, but the two problems are different.

3. Conclusions

This analysis points out some serious problems with the SW radiometers at the SGP CF. Here is my interpretation as to what those problems are, given what I have seen in the data:

1. The BSRN unshaded PSP was swapped out on about October 23, 1998. At this time, an incorrect calibration factor was entered into the system for this instrument. On about October 18, 1999, the radiometers were again swapped out. Things improved but it still appears there might be an error in the calibration coefficient. If we can determine the correct calibration coefficients that should be applied to the voltage measurements for the BSRN global SW measurements, then these data can be reprocessed. Figures 7 and 12 also indicate that the unshaded PSP is currently not leveled properly.

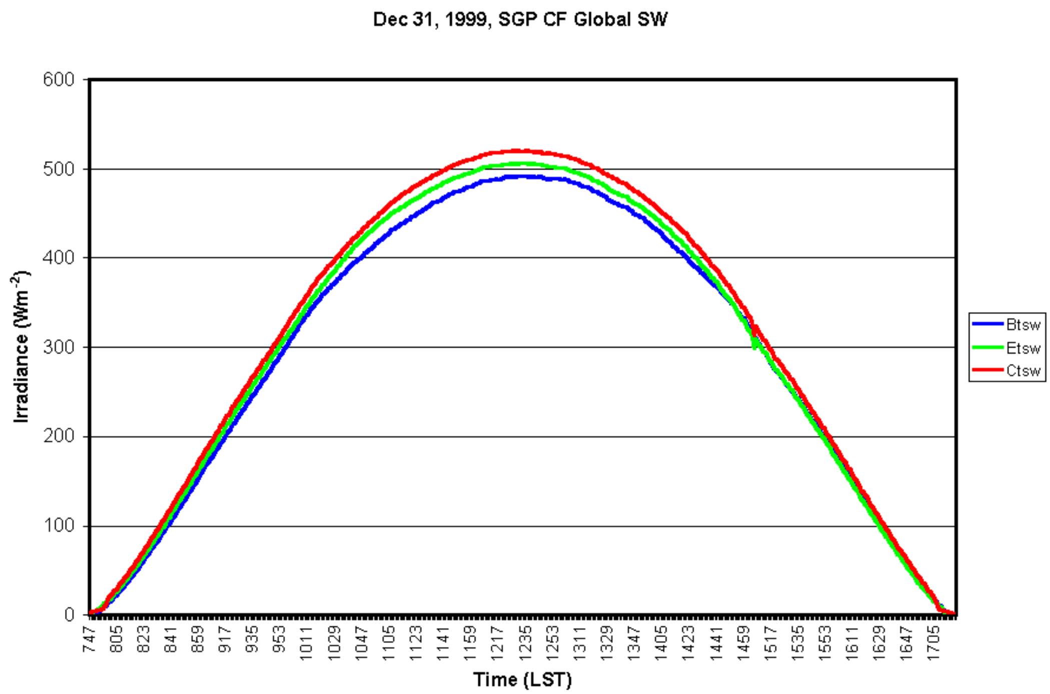

Figure 10. ARM SGP CF BSRN (Btsw), C01 (Ctsw), and E13 (Etsw) individual platform unshaded pyranometer measurements from December 31, 1999.

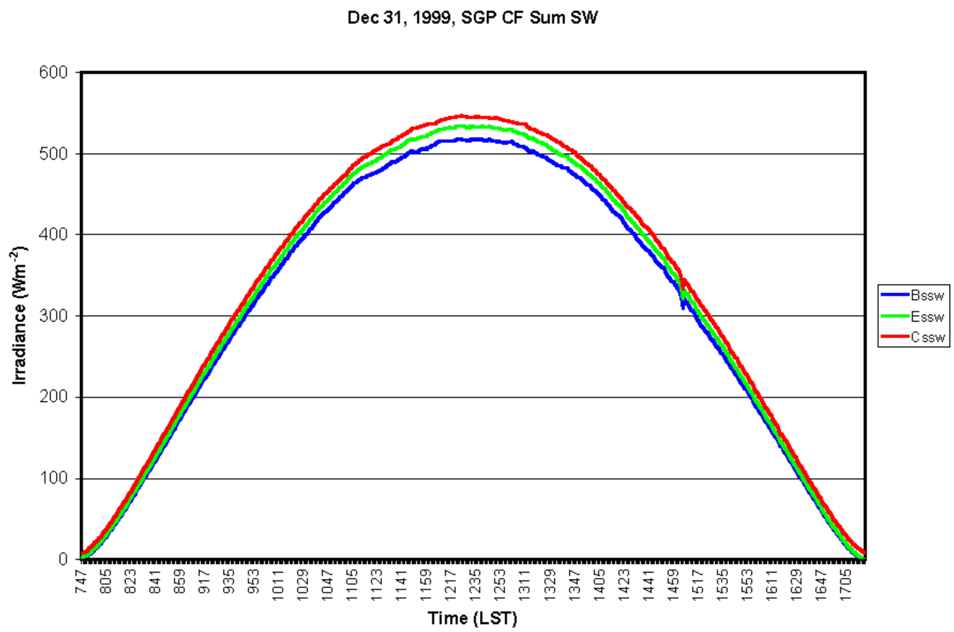

Figure 11. ARM SGP CF BSRN (Bssw), C01 (Cssw), and E13 (Essw) individual platform Sum (direct + diffuse) measurements from December 31, 1999.

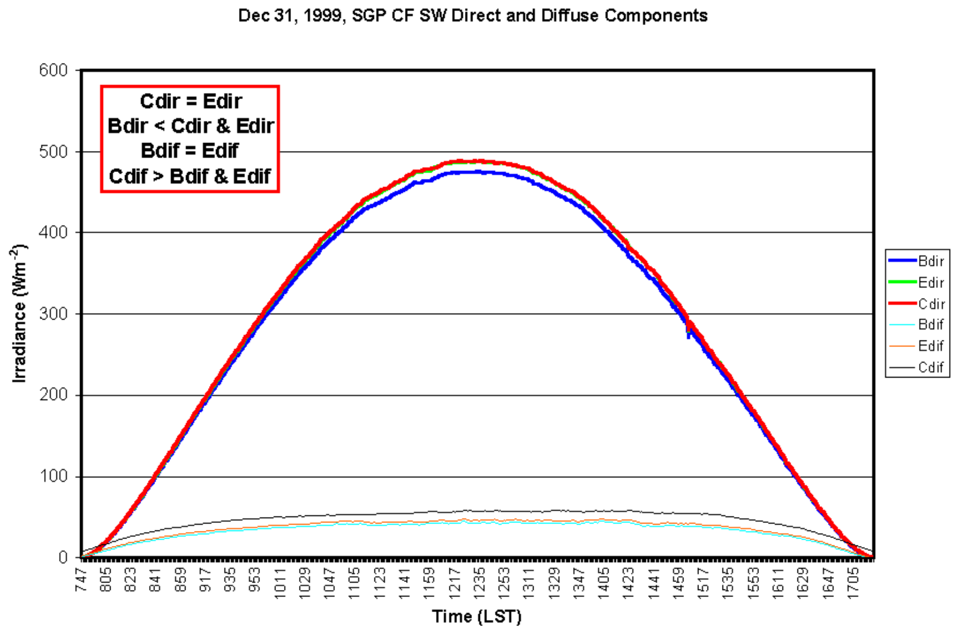

Figure 12. ARM SGP CF BSRN (Bdir, Bdif), C01 (Cdir, Cdif), and E13 (Edir, Edif) individual platform component direct and diffuse measurements from December 31, 1999.

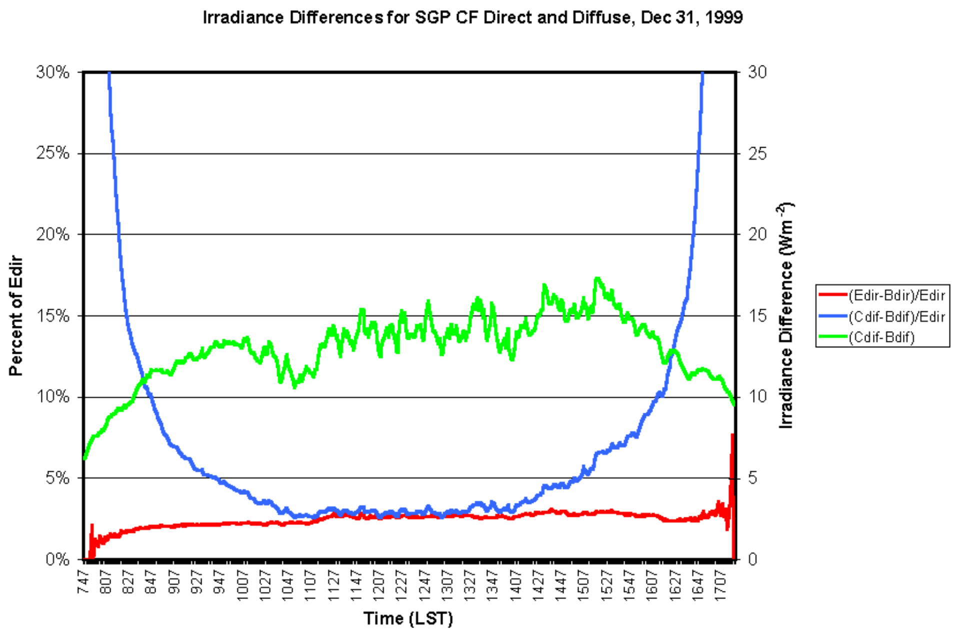

Figure 13. ARM SGP CF E13 - BSRN direct difference (red) and C01 – BSRN diffuse difference normalized by the E13 direct (left Y-axis), and the C01 – BSRN diffuse difference (green, right Y-axis) from December 31, 1999.

2. The C01 TSW – Sum max difference shows an increasing trend (Figure 2) from about August to October 1999. About November 2, 1999, there was a jump in magnitude to about 30 Wm^{-2}, with some larger occasional excursions. Closer inspection of the Sum component data shows a problem with the C01 diffuse PSP. From the date shown in Figures 12 and 13, either the logger channel voltage has drifted, or the channel voltage was not correctly zeroed in October 1999, if there was that type of maintenance performed (instrument swap out) at that time. If the latter, then the diffuse data should be correctable if the logger channel is now properly zeroed and the magnitude of the zero correction needed is noted.

3. The E13 TSW – Sum difference shows an increase on about September 29, 1999, to about 25 to 30 Wm^{-2}. Closer inspection of the Sum component data shows a problem with the E13 NIP. From Figures 12 and 13, my guess is that the NIP has a wrong calibration coefficient applied to the detector voltage output. Again, if we can determine what the correct calibration coefficient is that should be applied to the NIP voltage measurements, then these data can be reprocessed.

   I believe the SGP CF BSRN, E13, and C01 data will play a role in the upcoming ARESE II experiment in early spring 2001, as well as the concurrent Cloud IOP. One of the difficulties encountered in the original ARESE experiment was the inconsistencies in the CF surface SW measurements, at the time only the BSRN and E13 SIROS platforms. These inconsistencies were pointed out in Long (1996), and were of significant magnitude, as are those shown here. In light of this, I think it prudent to have all three systems carefully inspected before the start of ARESE II, to make sure they are running well, all PSPs level, all calibration coefficients correct, and all logger channels properly zeroed. Then the three systems should be carefully monitored during the experiment. Perhaps this should be common practice for any IOP for which the surface radiative energy budget is a significant part. The ARM SGP CF radiometers are intended to be the long-term benchmark for the SGP network. As such, we may need closer monitoring of their performance.

4. References

Long, C. N., and T. P. Ackerman, 2000: Identification of clear-skies from broadband pyranometer measurements and calculation of downwelling shortwave cloud effects. *J. Geophys. Res.*, accepted.

Long, C. N., 1996: Report on broadband solar radiometer inconsistencies at the ARM SGP Central Facility during ARESE. Atmospheric Radiation Measurement Technical Report, ARM TR-003.