Surface Radiation Measurement Data Quality Assessment at the Atmospheric Radiation Measurement Program Tropical Western Pacific and North Slope of Alaska Sites

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

Introduction

The QCRad VAP is being developed to assess the data quality for surface broadband radiation data collected at all Atmospheric Radiation Measurement (ARM) Program facilities, and provide continuity where possible for missing or “bad” shortwave (SW) irradiance from collocated instruments. In previous ARM Science Team Meetings we have presented analyses of data quality assessment for the Southern Gret Plains (SGP) Extended Facilities (Shi and Long 2003), and the techniques and methods used to derive the best estimate of total downwelling shortwave radiation (Shi and Long 2004). We have also shown that the QCRad VAP is effective in identifying and detecting many different types of measurement errors (Shi and Long 2005).

In this study, we present data quality analyses for the ARM Tropical Western Pacific (TWP) and North Slope of Alaska (NSA) sites. Due to the extremes of climate which they monitor, each facility at these sites is unique, adding some complexity to the data quality assessments. We show here examples of data quality assessment for all the data available since deployment at each facility.

Methodology

At the TWP and NSA measurement sites, the surface broadband radiation measurements are produced by the Sky Radiometers on Stand for Downwelling Radiation (SKYRAD) and Ground Radiometers on Stand for Upwelling Radiation. The methodology used in this study is the same as the data analysis for the SGP extended facilities, presented in Shi and Long (2003). However, the limits used to determine the data quality at each facility are unique. These limits are derived from the historical data analyses of each facility. Table 1 shows the limits derived for the TWP Manus and NSA Barrow sites. Also, in this study, the GSW data is corrected for infrared (IR) loss using generic correction factors derived from analysis over years of the relationship between the pyrgeometer detector flux and the unshaded pyranometer night time offset.

Table 1. Extremely rare (1st column) and configurable (2nd column) limits used at Manus and Barrow sites

TWP C1		**NSA C1**		**Explanation of parameters**
8		8		* snow covered ground Ta limit for albedo tests (real, degrees C > 0.0)
0.96	1.02	0.92	1.06	* Max GSW climatological mult. limit factor (real < 1.2)
0.52	0.6	0.8	0.92	* Max DifSW climatological mult. limit factor (real < 0.75)
0.76	0.8	0.8	0.92	* Max DirNSW climatological mult. limit factor (real < 0.95)
0.18	0.22	0.8	0.85	* Max SWup climatological albedo limit factor (real < 1.0)
330	360	100	80	* Min LWdn climatological limit factor (real > 60.0)
465	500	380	400	* Max LWdn climatological limit factor (real < 500.0)
410	380	120	100	* Min LWup climatological limit factor (real > 60.0)
610	630	450	470	* Max LWup climatological limit factor (real < 700.0)
0.3	0.34	0.2	0.25	* SWup max albedo limit for normal ground cover (Ta>Tslim, real<1.0)
0.9	0.98	0.87	0.9	* SWup max albedo limit for snow covered ground (Ta<Tslim, real<1.0)
0.76	0.8	0.58	0.62	* Min LWdn climatological Ta mult. limit factor (real > 0.4)
11	23	11	23	* Max LWdn climatological Ta additive limit factor (real < 25.0)
16	14	14	12	* Min LWup climatological Ta subtractive limit factor (real < 15.0)
16	14	18	16	* Max LWup climatological Ta additive limit factor (real < 25.0)
200	180	180	160	* Climatological LWdn > LWup - limit Factor (min, real < 300.0)
27	20	27	20	* Climatological LWdn < LWup + limit Factor (min, real < 25.0)
10	12	10	20	* Tc & Td within +/- limit of Ta for LWdn, LWup (real, degrees C)
-1.3		-0.8		* Td < (Tc - limit) (real, degrees C)
1		3.5		* Td > (Tc - limit) (real, degrees C)
7		-103		* Min climatological allowable Ta,Td,Tc (degrees C, real > -103.0)
40		75		* Max climatological allowable Ta,Td,Tc (degrees C, real < 75.0)
1050.5		1150		* Clear sky shortwave a coefficient for sumSW
1.095		1.095		* Clear sky shortwave b coefficient for sumSW
1050		1150		* Clear sky shortwave a coefficient for GSW
1.1		1.1		* Clear sky shortwave b coefficient for GSW
0.03	0.2	0.05	0.36	* dry mode coeff.= 0.03; wet mode coeff. = 0.2
0.85		0.95		* Tracker off limit; 0.9 for sgp & nsa

Data Quality Assessment

ARM has three radiation measurement sites at TWP and two at NSA. Here we show results from 1997 to 2000 at these sites for available data. Each site has a summary table below, which shows the percent of data that failed the various QCRad tests. Table 2 shows the results for Nauru (TWP C2) 1999 data. The summary tables allow us to find tendencies in problematic data so that we can explore in more detail. Table 3 explains the testing represented in each box in Table 2.

Table 2. Percent of data failed each testing for TWP C2, 1999 Data.

GSW	0%	0%	0%	0%	0%	2%	
DiffSW	0%	0%	0%	5%	1%	0%	0%
DirSW	1%	1%	1%	0%	0%	9%	
SWup	0%	0%	0%	0%	0%	0%	
LWdn	0%	0%	0%	0%	0%	0%	
LWup	0%	0%	0%	0%	1%	0%	
LWdntoTa	0%	0%	0%	0%			
LWuptoTa	0%	0%	0%	0%			
LWdntoLWup	0%	0%	0%	0%			
TcTd&Ta	0%	0%	0%				
TotalDataAvailable	510158						

Table 3. Results Explanations for Table 2.

GSW	Pmin	Pmax	Emin	Emax	Cmax	GSW/sumSW	
DiffSW	Pmin	Pmax	Emin	Emax	Cmax	DiffSW/GSW	Rayleigh Limits
DirSW	Pmin	Pmax	Emin	Emax	Cmax	Tracker Off	
SWup	Pmin	Pmax	Emin	Emax	Cmax	Swup Test	
LWdn	Pmin	Pmax	Emin	Emax	Cmin	Cmax	
LWup	Pmin	Pmax	Emin	Emax	Cmin	Cmax	
LWdntoTa Test	Pmin	Pmax	Cmin	Cmax			
LWuptoTa Test	Pmin	Pmax	Cmin	Cmax			
LWdntoLWup Test	Pmin	Pmax	Cmin	Cmax			
Tc, Td vs.Ta Test	Tc or Td vs Ta Fails	Tc-Td fails	Ta fails				
TotalDataAvailable	Available data						

Pmin, Pmax = Physically Possible Limits (Global)
Emin, Emax = Extremely Rare Limits (User Defined)
Cmin, Cmax = Configurable Limits (User Defined)

Global Short Wave

ARM radiometers are typically replaced each year with newly calibrated units, though at different dates, as shown in Table 4 for SKYRAD instruments at TWP and NSA. To nominally correct for IR loss in GSW data, we examined all the data from these different radiometer pairs, separated as moist and dry modes as determined by the relative humidity and the differences between the pyrgeometer case temperature and the effective sky brightness temperature (Younkin and Long 2004). The night time GSW data is then compared to the detector flux, as shown in Figure 1, and generic correction coefficients are obtained for each site and facility, as shown in Table 4.

Table 4. Radiometer replacements for SKYRAD instruments and generic correction coefficients.

Site	Facility	Dates of replacements	Generic Correction Coefficients
TWP	C1	9/28/96....2/24/97....4/29/98....3/6/99....4/5/2000	Dry mode=0.03; Moist mode=0.2
TWP	C2	10/28/98....8/9/99....7/6/2000	Dry mode=0.03; Moist mode=0.2
NSA	C1	2/14/98....12/10/98....12/20/99....9/26/2000....6/13/2001	Dry mode=0.05; Moist mode=0.36
NSA	C2	08/21/99....7/20/2000....6/19/2001	Dry mode=0.05; Moist mode=0.36

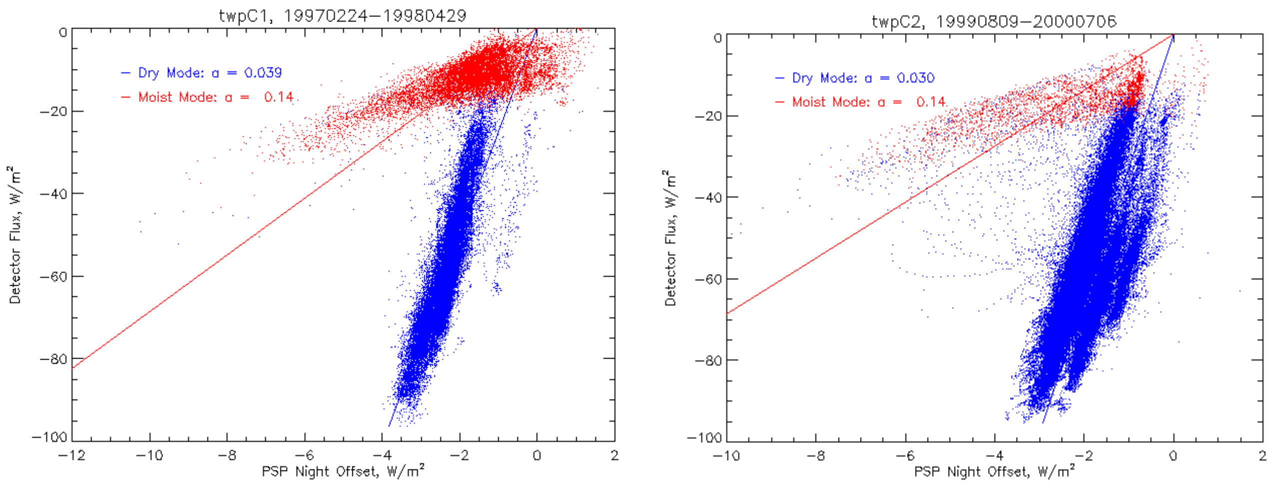

Figure 1. Detector flux vs. night time GSW data with fitting coefficients; Red – Moist mode; Blue - Dry mode; Left: TWP C1 data from 19970224 to 19980429; Right: TWP C2 data from 19990809 to 20000706

The differences between the corrected and uncorrected GSW data can be seen from the percent of data failing the GSW minimum limit tests. Table 5 shows the percent of uncorrected and corrected GSW data that failed the minimum extremely rare limits at each site and facility, providing justification for the IRF Working Group recommendation that an IR Loss correction VAP for unshaded pyranometer measurements be developed.

Table 5. Percent of data failing the GSW minimum limit tests.

Site	Facility	Year	Uncorrected GSW	Corrected GSW
TWP	C1	1997	25%	1%
TWP	C1	1998	18%	1%
TWP	C1	1999	16%	1%
TWP	C1	2000	14%	3%
TWP	C2	1999	10%	0%
TWP	C2	2000	33%	1%
NSA	C1	1999	15%	4%
NSA	C1	2000	20%	9%
NSA	C2	1999	7%	6%
NSA	C2	2000	8%	4%

Table 2 shows that about 2% of the 1999 Nauru data failed the GSW/sumSW test, represented as light blue dots in Figure 2a. These cases mostly occurred from January to April, and then from August to October. The bad data can also be seen in Figure 2b as the dots beyond the minimum (blue line) and the maximum (red line) limits. This disagreement between the sum and unshaded pyranometer SW is exhibited for some years at all sites, as shown in Table 6.

Table 6. Percent of data failing the GSW/sumSW tests.

Site	Facility	Year	GSW/sumSw
TWP	C1	1997	19%
TWP	C1	1998	27%
TWP	C1	1999	17%
TWP	C1	2000	7%
TWP	C2	1999	2%
TWP	C2	2000	2%
NSA	C1	1999	7%
NSA	C1	2000	17%
NSA	C2	1999	1%
NSA	C2	2000	12%

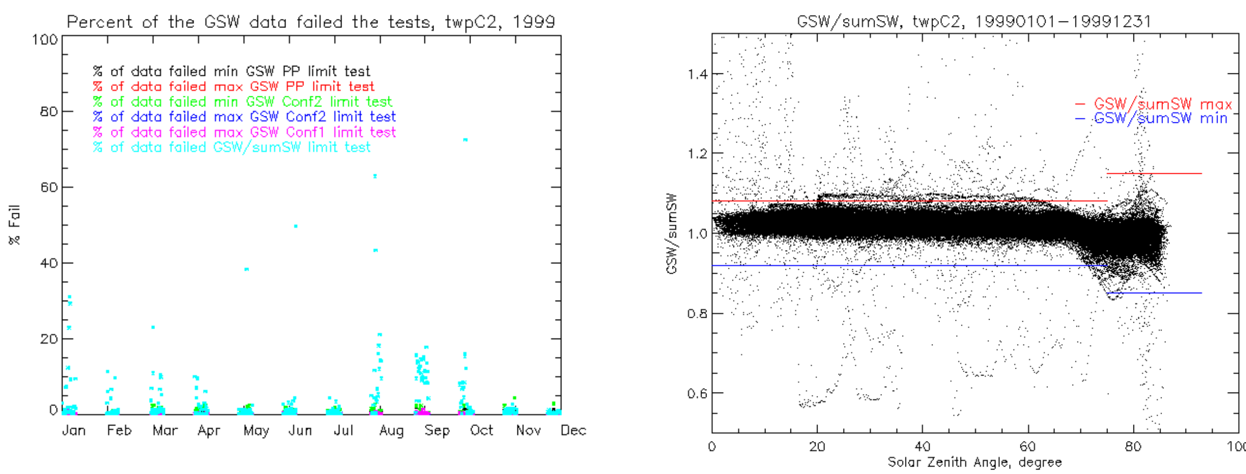

Figure 2. Daily summaries (2a, left) of percent of test failures for 1999 Nauru data. Right plot (2b) shows the 1999 Nauru global over sum SW ratio test by solar zenith angle.

Diffuse and Direct Short Wave

Figure 3a (upper left) shows the 1999 diffuse SW data for Nauru. All the data above the extremely rare limits (blue curve) are known to be bad, while the data above the normal limits (green curve) but below the extremely rare limits are questionable, meaning the data are feasible but occur rarely in this climate. The pink dots in this plot mark the data corresponding to times when the solar tracker was deemed to be off tracking alignment. Table 2 shows that 9% of these data failed the tracker off test. To further investigate these data, we plot the time series of diffuse SW, as shown in Figure 3c (middle left). The "tracker off alignment" data occurred from August to October (pink dots). Figure 3b (top right) shows the corresponding direct SW data, illustrating that most direct SW data fall within the maximum user configurable limits, except for some obviously problematic data. Figure 3d shows the "tracker off" period as in 3c. Figures 3e (diffuse SW) and 3f (direct SW) summarize the percentage of daily failed test data, also showing the August to October tracker problems. Table 7 summarizes the tracker testing results for the various sites.

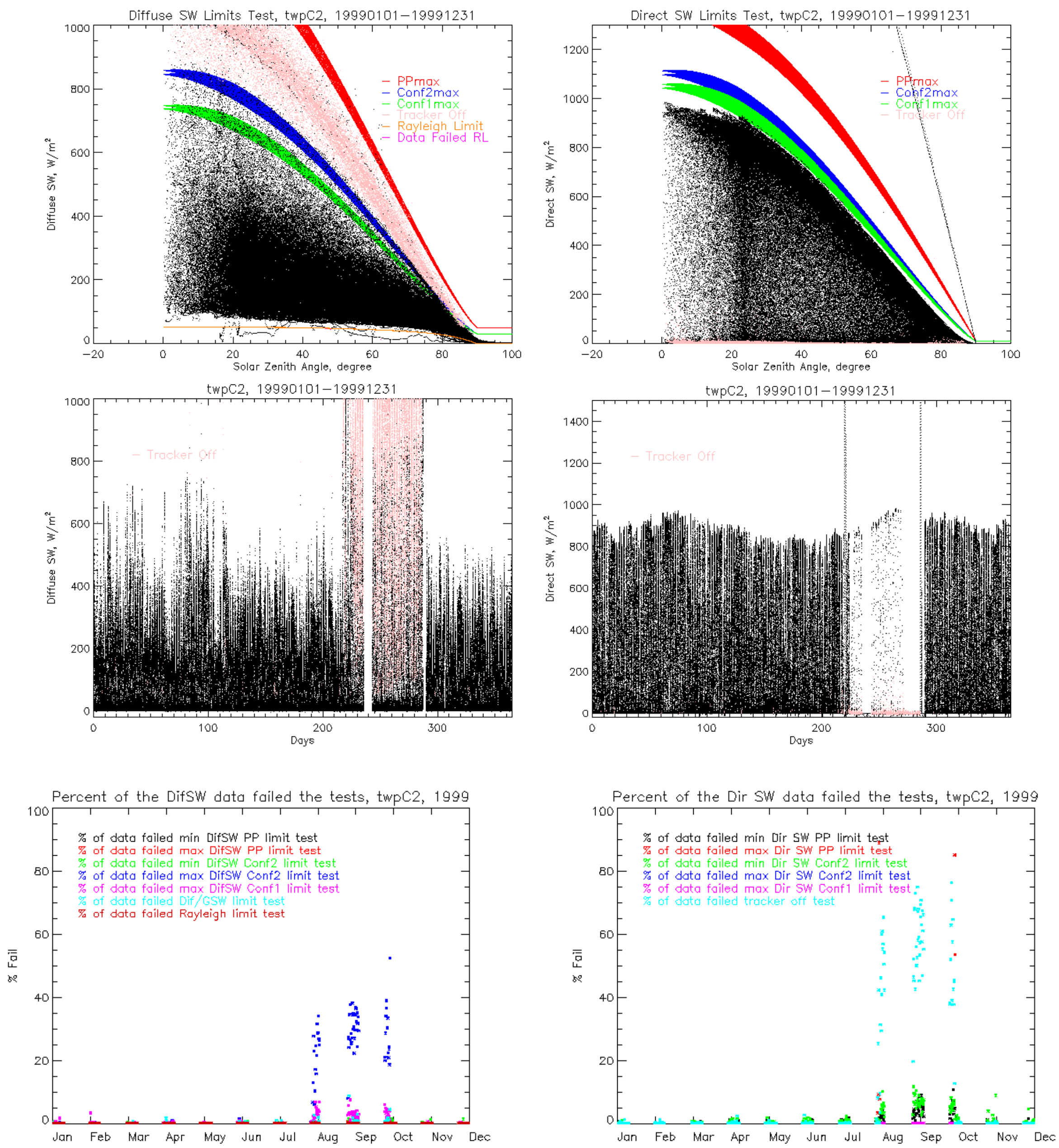

Figure 3. Diffuse (left plots) and Direct (right plots) SW testing results for 1999 Nauru data.

Table 7. Percent of data failing solar tracking tests.

Site	Facility	Year	Tracker Off
TWP	C1	1997	0%
TWP	C1	1998	1%
TWP	C1	1999	3%
TWP	C1	2000	0%
TWP	C2	1999	9%
TWP	C2	2000	0%
NSA	C1	1999	0%
NSA	C1	2000	0%
NSA	C2	1999	7%
NSA	C2	2000	0%

Upwelling Short Wave

Figure 4a (upper left) shows the time series of upwelling SW for the 1999 Nauru data. Note that at around day 220 the upwelling SW data exhibits unrealistically high values. This also shows in the temperature-screened SWup test shown in Figure 4b (upper right), where these data exceed the max albedo limit for near freezing temperatures (blue line). Unrealistically high values were also found in Manus 1999 and Nuaru 2000 data, (Figure 4c [lower left] & 4d [lower right]). At the NSA Barrow site all the SWup data drop sharply after a certain date, associated with the spring melt, as shown in Figure 5.

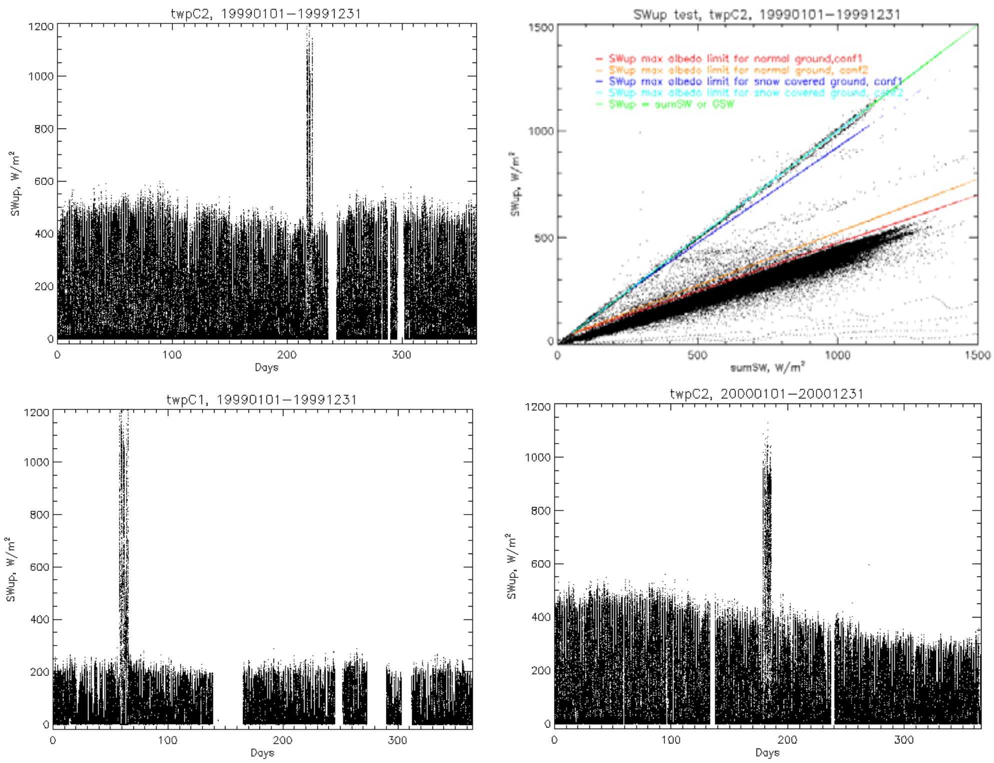

Figure 4. Upwelling SW time series from Nauru (both left, and lower right plots) and temperature-screened test for the 1999 data (upper right).

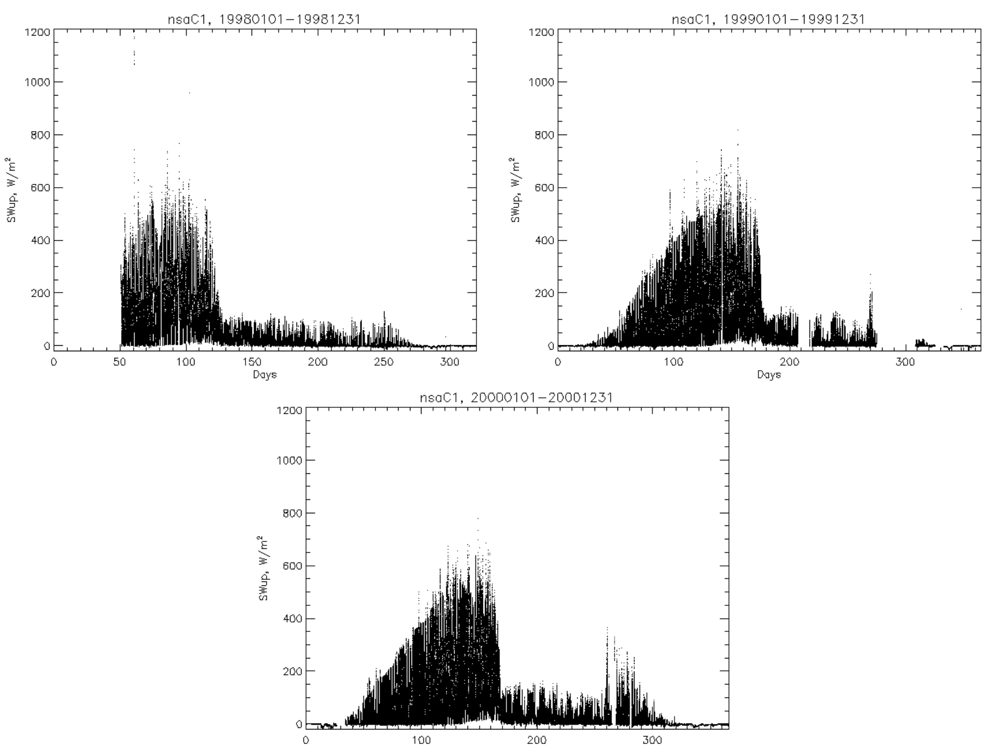

Figure 5. Upwelling SW time series from Barrow for 1998 (left), 1999 (middle) and 2000 (right).

Downwelling and Upwelling Long Wave

Figure 6 shows the time series of upwelling Long Wave (LW) for Nauru for the years 1998 (upper left, data collection starts on October 29), 1999 (upper right), and 2000 (lower left). In all three years the upwelling LW data exhibits anomalously low values for the same periods that the upwelling SW data exhibits unrealistically high values (Figure 4). These periods are likely correlated with TWP RESET visits where the downward facing instruments are faced upward for comparison to the normally upward facing instruments. The LWup-SWup anomaly correlation is not always reversely true though. At the beginning of 2000, the upwelling LW data are anomalously low (Figure 6 lower left) but the upwelling SW seems OK (Figure 4d). The downwelling LW data tends to behave fairy well at Nauru, as the example plot of 2000 downwelling LW data (lower right) shows.

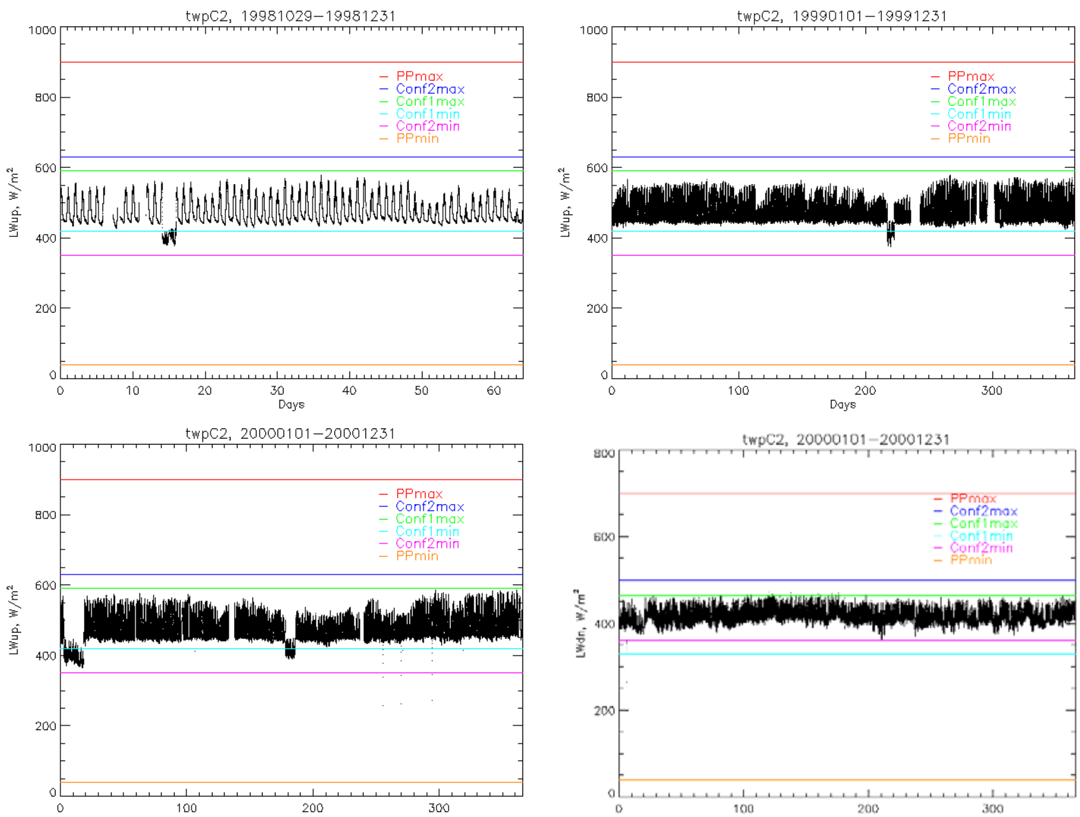

Figure 6. Upwelling LW time series from Nauru (both top, and lower left plots) and downwelling LW for 2000 (lower right).

Summary

The QCRad VAP is very useful in identifying various problems in the surface broadband radiation data records. The automated QCRad VAP is useful when run each day for identifying significant problems which can then be quickly rectified by Site Operations and Instrument Mentors. But also, as the examples presented here illustrate, more subtle longer-term problems and tendencies in the data record can be identified when the QCRad VAP is run in "batch" mode over longer time periods. The VAP code produces daily summaries of the number of test failures, as shown in Figures 2 and 3. It is our expectation to run the QCRad VAP on a monthly basis and analyze the results to help identify these occurrences. Table 8 is an example summary of problematic data found as part of the analyses presented here.

Table 8. Example summary of problematic NSA and TWP data.

TWP C1 1997	1. July 20 ~ August 20, GSW/sumSW ratio too high=> direct normal low
	2. January 1 ~ February 27, LWupTd exceptionally high (from 350 to over 600 K)
TWP C1 1998	1. April 23- May 2, SWup, LWup, & LWupTc data are bad
	2. August 22 – 26, No data
	3. August 12 – 14, Tracker off
TWP C1 1999	1. October 28 – September 11, Tracker off
	2. 19990525-0614, 1002-1017, 0904-0909, No data
	3. February 28 – March 7, SWup & LWup data bad
TWP C1 2000	1. March 28 – April 2, SWup, LWup, & LWupTc&Td data bad
TWP C2 1999	1. August 25 – 31, No data
	2. August 6 – October 15, Tracker off
	3. August 6 – 11, Swup, LW up, & LWupTc data bad
	4. March 6 – 7, Ta data noisy
TWP C2 2000	1. January 4 – 20, Lwup data not normal
	2. 20000104 –0120 & 0627 – 0705, Swup, & LWupTc data bad

References

Shi, Y, and CN Long. 2003. "Preliminary Analysis of Surface Radiation Measurement Data Quality at the SGP Extended Facilities." In *Proceedings of the Thirteenth Atmospheric Radiation Measurement (ARM) Program Science Team Meeting*, Broomfield, Colorado, March 31-April 4.

Shi, Y, and CN Long. 2004. "Techniques and Methods used to determine the Best Estimate of Total Downwelling Shortwave Radiation." In *Proceedings of the Fourteenth Atmospheric Radiation Measurement (ARM) Program Science Team Meeting Proceedings*, Albuquerque, New Mexico, March 22-26.

Shi, Y, and CN Long. 2005. "Examples of Detecting Measurement Errors with the QCRad VAP." In *Proceedings of the Fifteenth Atmospheric Radiation Measurement (ARM) Program Science Team Meeting*, Daytona Beach, Florida, March 14-18.

Younkin, K, and CN Long. 2004. "Improved Correction of IR Loss in Diffuse Shortwave Measurements: An ARM Value Added Product." Atmospheric Radiation Measurement Program Technical Report, ARM TR-009, Available via http://www.arm.gov/publications/techreports.stm.