5. Quality Control and Calibration Standards

Successful operation of a network of complex instruments, such as scanning spectroradiometers, depends upon a well-defined approach to quality assurance and quality control (QA/QC). Standards used to calibrate the instruments must be regularly validated and recalibrated, when necessary. The general network's QA/QC program is explained below. Site-specific results of the QC procedures applied to Volume 8 data are given separately by site in the following subsections. This includes discussions on the performance of irradiance standards used for Volume 8 data, the accuracy and stability of the instruments' responsivity, and the accuracy of the wavelength calibration. Some information is intentionally repeated in these subsections, allowing the reader to focus on the site of interest without missing any background information, which may be given in the section of another site.

General Quality Assurance and Quality Control program

The QA/QC program of the NSF UV Spectroradiometer Network includes the following elements:

- Uniformity of instruments in the network
- Standardized procedures, parts, supplies, and operator training
- Standardized data processing procedures including calibration review and implementation of correction methods
- Maintenance of a set of calibration standards that are traceable to national standards laboratories, and their regular recalibration
- Scheduled instrument maintenance
- Careful review of recorded data and application of corrections
- Publication of instrument operating history
- Participation in instrument intercomparisons
- Data analysis and publication by independent scientists
- Publication in refereed journals

All site operators are trained at our San Diego facility, and documented operating procedures are used. Instrument maintenance is performed during annual site visits. A more detailed list of the QA/QC activities is presented in Table 5.1.

Table 5.1. Frequency of data acquisition, quality control/assurance, and publication.

Every 5 minutes
- Temperatures and power checks
- Monochromator position check
- Ancillary sensors measurements
- Detection of system errors by software

Daily
- Responsivity characterization
- Wavelength alignment check
- Checks by the site operators
- On-site preliminary UV-B calculations

Weekly
- Data transfers
- Data archive checks
- System performance reviews
- Preliminary database updates
- System parameter time series and irradiance value checks
- Website updates

Bi-weekly
- System calibration with site standards

Monthly
- Analysis of calibration and standards stability

Yearly
- Operator training at San Diego
- Site visits including:
  - Scheduled maintenance
  - Operation audit (testing)
  - Standards comparison
  - Engineering upgrades
- Reprocessing of all calibrations and data
- Final data check
- Report and CD-ROM generation

Additionally
- Participation in intercomparisons
- Comparisons with radiative transfer models
- Re-evaluation and testing of methods

Operations reports are annually published by Biospherical Instruments to detail the history of each instrument and present quality control data that can aid researchers in using data from the network. Biospherical Instruments also participates in North American and international intercomparisons of spectroradiometers and standards. Many researchers have had access to these data, conducted their own independent analyses, and published their results.

Irradiance Standards used for Volume 8 Data

Table 5.2 gives an overview of the irradiance standards used in the 1998-99 season and their calibration history. Most lamps were calibrated by Optronic Laboratories, a company which provides NIST-traceable calibrations. There are also lamps, however, which were calibrated by Biospherical Instruments using the procedure outlined in Section 4.2.1.5. Some of the standards, which have been deployed for Volume 8, have two sets of calibrations. Several lamps have drifted during the season and therefore different calibrations were used for those lamps during different periods. Also the “traveling standard” (lamp M-874) was affected, which was used at all network sites in order to validate the calibration of standards kept at those sites. The analysis of measurements of M-874 with all other site standards revealed that M-874 has drifted by approximately 2% between February and September 1998. The magnitude of the drift is consistent with the difference in the lamp’s irradiance given in the two calibration certificates that were issued by Optronic Laboratories in August 1995 and September 1998.

The values in the columns “Change between calibrations 1 and 2” in Table 5.2 give an indication of typical changes in the output of lamps during several years. Our observation is that lamps often show abrupt changes rather than uniform drifts. An example is M-874, which changed by 2% between February and September 1998 but was quite stable outside this time range.

The calibration scale of Biospherical Instruments was further verified in November 1998 when Patrick Disterhoft from the Central UV Calibration Facility (CUCF) visited Biospherical Instruments. (The CUCF is part of the Surface Radiation Research Branch (SRRB) of NOAA's Air Resources Laboratory and NIST. This laboratory was established in response to a call of the U.S. UV-B Interagency Monitoring Strategy. A major objective of the CUCF is to provides long term, NIST-traceable calibrations for the different U.S. UV-B monitoring activities.) The purpose of the 1998 audit by CUCF was to calibrate the SUV-100 and SUV-150 spectroradiometers in San Diego independently with the CUCF portable field calibrator and the Biospherical Instruments calibration setup, and compare the results. Figure 5.1 shows a comparison of the Biospherical Instruments traveling standard M-874 with three lamps from CUCF. Although the comparison is affected by signal noise, there appears to be a systematic 1-2% difference between M-874 and the CUCF lamps. If solar measurements were calibrated with CUCF standards rather than with lamps calibrated by Optronic Laboratories (like M-874), published data from the network would be lower by 1-2%. Note that the difference of the M-874 from the average of the CUCF standards is only about twice as high as the deviation of the individual CUCF lamps from each other. All CUCF standards were calibrated at CUCF before and after their use at Biospherical Instruments. According to P. Disterhoft, lamps 96600 and 96598 appear to have incurred no change. Lamp 97510, however, showed a 1% change from its previous calibration. This demonstrates that the uncertainties related to the calibration standards and calibration methods of Biospherical Instruments are well comparable to the uncertainties of the CUCF calibrations. We conclude that a calibration uncertainty of ±2% is about the limit that can be achieved for solar irradiance measurements.

Table 5.2. Calibration standards used in the 1998-99 season*.

Site	Standard	Calibration 1	Calibration 2	Change between Calibration 1 and 2		
				@ 300 nm	@ 400 nm	@ 600 nm
Traveling Standard	M-874	Optr. 8/95 **	Optr. 9/98 **	+2.7%	+2.0%	+2.0%
McMurdo	M543	not used				
	M-764	Optr. 10/92				
	200W005	Optr. 11/96				
	200W019	Optr. 9/98[+]				
Palmer	M-700	BSI transfer; establ. 1/93	BSI transfer from M-874 (Optr. 9/98); establ. 2/00‡	+0.9%	+1.8%	+2.8%
	M-765	Optr. 10/92	BSI transfer from M-874 (Optr. 9/98); establ. 2/00‡	+0.1%	+1.0%	+1.8%
	200W007	Optr. 11/96				
South Pole	M-666	not used				
	M-763	Optr. 10/92	BSI transfer from M-874 (Optr. 8/95); establ. 1/98‡	+4%	+3.8%	+3.6%
	200W006	11/96				
Ushuaia	M-698	BSI transfer from M-874 (Optr. 9/98); establ. 8/99‡				
	M-766	Optr. 10/92	BSI transfer from M-874 (Optr. 9/98); establ. 5/00‡	-1.3%	+0.0%	+1.3%
	200W008	Optr. 11/96				
Barrow	M-699	Optr. 9/98				
	M-762	Optr. 10/92	Optr. 9/98	+1.9%	+1.6%	+1.4%
	200W009	Optr. 9/98				
San Diego	M-881	Optr. 8/95	Optr. 9/98	+3.2%	+2.8%	+1.0%
	200W010	Optr. 11/96	Optr. 9/98	+9.6%	+5.7%	+3.9%
	200W020	Optr. 9/98				

* *Some lamps have more than one calibration. The difference between these calibrations is marked in the three rightmost columns (i.e., positive change means that Calibration 2 revealed higher irradiance values). The calibrations that were actually used in the season are shaded.*

** *The analysis of comparisons of the traveling standard M-874 with all other standards used at the network sites revealed that M-874 has drifted by approximately 2% between February and September 1998. The magnitude of the drift is consistent with the difference in the lamp's irradiance measured at Optronic Laboratories. The 8/95 Optronic Laboratories certificate of M-874 was used for the season opening calibrations for McMurdo, Palmer Station, South Pole, and Ushuaia, which took place between January 1998 and April 1998. Because of the lamp's drift, comparisons in April 1998 are dubious, as further explained in Section 5.4. For season opening calibrations at San Diego and Barrow, and all season closing calibrations, the 9/98 Optronic Laboratories calibrations have been applied.*

[+] *200W019 was only used during the season closing calibrations.*

‡ *Date when lamp measurements have been processed to establish a new set of calibration coefficients*

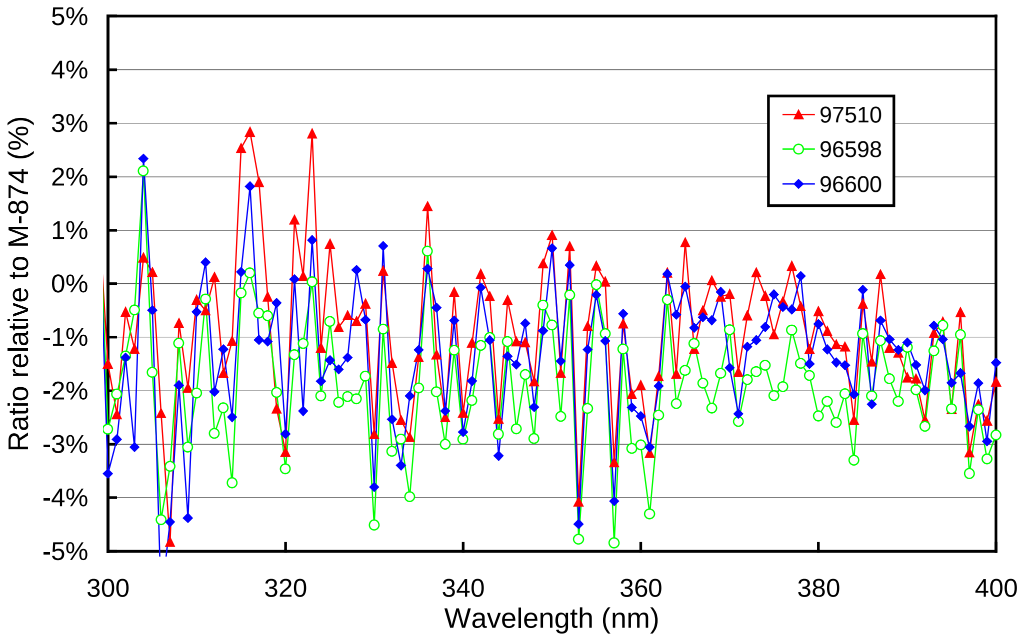

Figure 5.1. *Comparison of the Biospherical Instruments traveling standard M-874 with three lamps (S/N 96598, 57510, and 96600) from the Central UV Calibration Facility (CUCF).*

Analysis of Instrument Stability

In the post-seasonal analysis of instrument performance, stability of both the system responsivity and wavelength stability of the monochromator are carefully reviewed (See Section 4 for details on calibration and data processing protocols). System responsivity is tracked by analysis of the response scans. There are several events that can occur and will introduce a change into the system sensitivity. Where possible, these events are uncovered and corrected during the stability review:

- Intentional change of the system responsivity (PMT high voltage change) to accommodate changing solar radiation levels throughout a day
- Change of the response lamp due to aging, casualty, or replacement
- Change in instrument temperature
- Drifts of the PMT sensitivity or monochromator throughput
- Any alteration to the system including engineering upgrades and routine or unanticipated maintenance

The wavelength stability of the final data is checked by the Fraunhofer correlation method described in Section 4.2.2.2. Since this method requires substantial computational time, typically only one spectrum per day and per site is checked. However, when there is any doubt in the wavelength accuracy during a specific period, all data scans of a day may be processed.

Azimuth Asymmetry

It has been noted in previous Network Operations Reports that measurements of solar irradiance at the South Pole Station depend on the azimuth position of the sun. Since the solar zenith angle at South Pole is fairly constant during a day, the azimuth dependence appears as a sinusoidal oscillation in the data with a periodicity of one day. This wiggle is an artifact of the measurement rather than an actual change of solar irradiance with the azimuth angle. It was not clear until the end of 1999, however, whether only the instrument at South Pole or all network instruments are affected. Characterizations performed during the site visits in spring 2000 revealed that the problem exists at all network sites, although to a different extent. In response to this problem, the irradiance collectors have been modified beginning in January 2000, and measurements with a test apparatus specifically designed for this purpose show that azimuth asymmetries of the modified instruments are generally below ±2% for all wavelengths. As of this writing, data from azimuth asymmetry measurements are further analyzed and will be presented in the Volume 9 Operations Report.

Figure 5.2 shows the azimuth dependence in Volume 8 solar spectral irradiance data from South Pole Station. The effect is most pronounced at long wavelengths. At 600 nm, the oscillation has an amplitude of about ±8% of the daily average. At 320 nm, the variation almost disappears and is almost completely masked by variations due to clouds. The difference can be explained by the fact that radiation at 320 nm is mostly diffuse with only a small contribution from the direct sun. The position of the sun therefore only has a small influence. In contrast, radiation at 600 nm arrives almost exclusively directly from the sun. Note that the azimuth asymmetry is most evident in data when the sun is low. This is the prevailing situation at South Pole. All other network sites experience higher solar elevations than South Pole Station. Systematic errors in solar data are therefore smaller, even if instrument problem were of the same magnitude.

In Figure 5.3, time-series of spectral irradiance at 380 nm are compared with measurements of total irradiance, measured with the PSP, and readings of the TSI sensor. The period depicted is the same as in Figure 5.2. The measurements at 380 nm show less diurnal fluctuations than measurements at 600 nm, as can be expected. The center wavelength of the TSI is about 370 nm. The amplitude of the variations in the spectral measurements at 380 nm should therefore be comparable to the amplitude in the TSI readings. Figure 5.3 shows however that the variation of the TSI signal is smaller than the oscillations in spectral data. This combined with the evidence of the two curves being out of phase are indications that the oscillations are measurement artifacts.

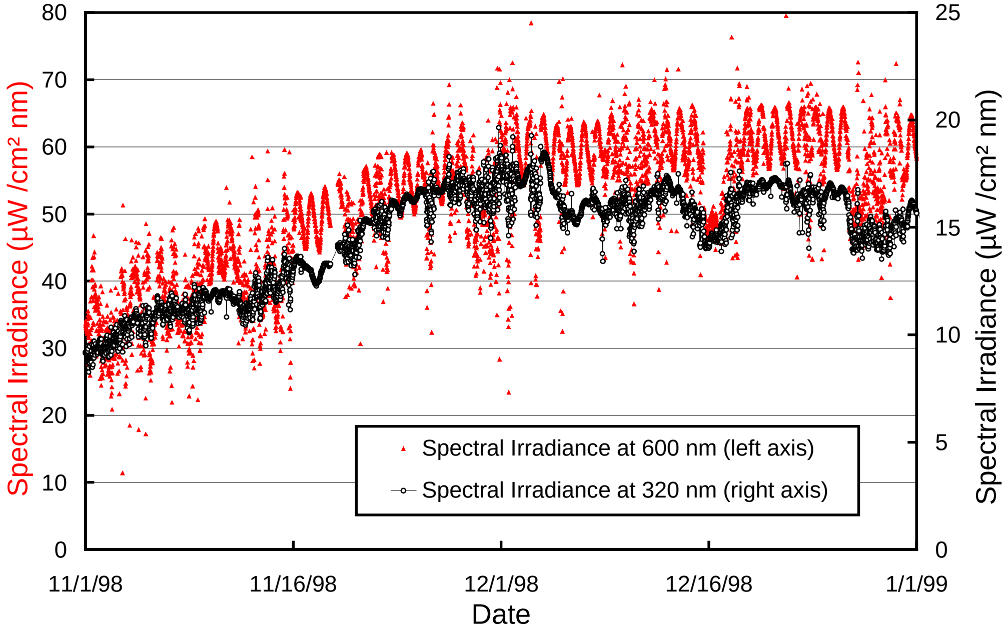

Figure 5.2. *Spectral irradiance at 320 and 600 nm measured at South Pole during November and December 1998.*

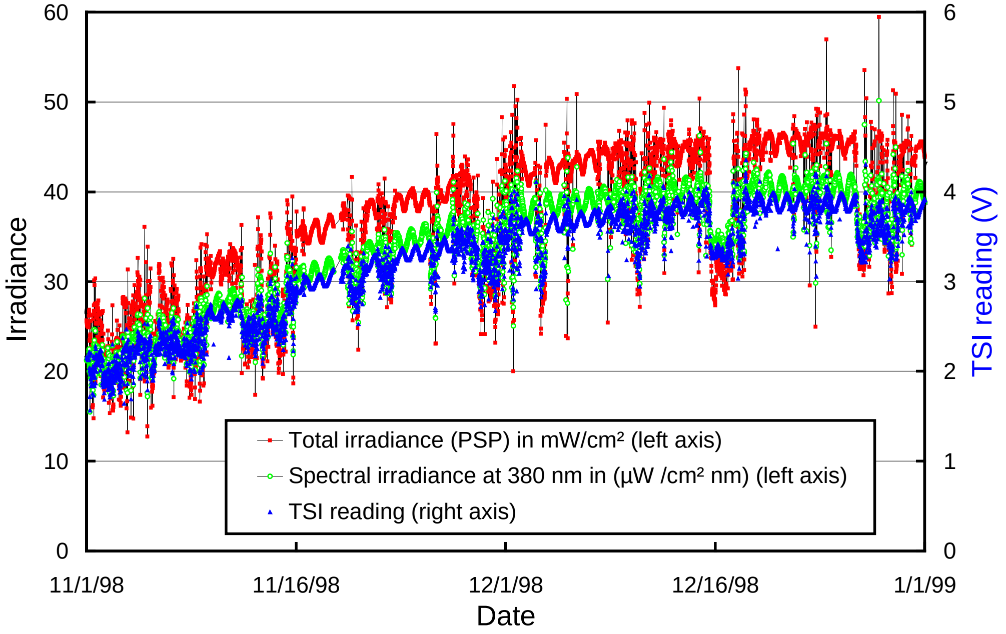

Figure 5.3. *Comparison of total irradiance measured by the PSP (highest curve), spectral irradiance at 380 nm (middle curve), and TSI signals (lowest curve).*

Note that also the PSP measurements show a diurnal variation of about ±2.5%. This is surprising because the PSP is a completely independent instrument, which is not linked to the spectroradiometer's foreoptics. This indicates that the PSP may also be affected by azimuthal errors, or that it was not correctly leveled. Because of the high solar zenith angles prevailing at South Pole, small leveling errors do cause significant effects.

From Figure 5.2 and Figure 5.3 it can be concluded that UV data are affected by the azimuth asymmetry by up to ±4%. At shorter UV-A wavelengths or at wavelengths in the UV-B the asymmetry diminishes or almost disappears. The accuracy of daily averages or daily doses is only slightly reduced, as most of the systematic errors cancel out when measurements are integrated over one day.

Final Quality Control of Level 3 Data

The quality of Level 3 data after implementation of all corrections is checked with the following protocol:

- Examination of all irradiance calibrations with 200-Watt standards. This includes intercomparisons of on-site and traveling standards as well as standards with a new calibration. If discrepancies occur, standards are recalibrated or excluded and the corrected dataset is re-processed with the modified scale of irradiance.
- With the Fraunhofer-correlation method, the wavelength accuracy is checked between 300 and 440 nm. If there are systematic wavelength shifts larger than 0.1 nm, the wavelength offsets are adjusted or modified functions used to describe monochromator non-linearity are implemented.
- Based on data from the internal irradiance and wavelength standards, and from measurements of other built-in or ancillary sensors (e.g., TSI, temperature, ground, wavelength-position sensor, PSP, and TUVR) the dataset is screened for drifts and “outliers,” requiring remedial action to be considered.
- Data of the current season are compared with data from previous years. This is done to assess system changes.
- On occasion, selected measured spectra are compared with results from radiative transfer models.
- The contents and format of data to be published are checked against those of the internal databases maintained at Biospherical Instruments.