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 15 data are given separately by site in the following subsections. This includes discussions on the performance of irradiance standards used for Volume 15 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.

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
- Periodic re-evaluation of network data, production of new data versions. (The latest version is "Version 2," see: www.biospherical.com/nsf/Version2/)

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 and can also be found at www.biospherical.com/nsf/login/data_QC.asp.

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

Every 5 minutes	***Bi-weekly***
Temperatures and power checks	System calibration with site standards
Monochromator position check	***Monthly***
Ancillary sensors measurements	Analysis of calibration and standards stability
Detection of system errors by software	***Yearly***
Daily	Operator training at San Diego
Data transfers	Site visits including:
Responsivity determination	Scheduled maintenance
Wavelength alignment characterization	Operation audit (testing)
Checks by the site operators	Standards comparison
Weekly	Engineering upgrades
Data archive checks	Reprocessing of calibration and solar data
System performance reviews	Final data check
Preliminary database updates	Report and CD-ROM generation
System parameter time series and irradiance value checks	***Additionally***
Website updates	Participation in intercomparisons
	Comparisons with radiative transfer models
	Re-evaluation of network data

Operations reports are annually published by Biospherical Instruments to detail the history of each instrument and present quality control information 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.

Verification of the irradiance scale maintained at Biospherical Instruments by CUCF

The irradiance scale of Biospherical Instruments was verified in November 1998, October 2000, and April 2002, when Patrick Disterhoft from the Central UV Calibration Facility (CUCF) visited Biospherical Instruments. The CUCF is part of NOAA's Earth Systems Research Laboratory, Global Monitoring Division. This laboratory was established in response to the U.S. UV-B Interagency Monitoring Strategy. A major objective of the CUCF is to provide long term, NIST-traceable calibration standards for the U.S. UV-B monitoring activities. Details of the three audits have been published in the Volume 10 (2000-2001) Network Operations Report. It can be concluded that the irradiance scale used for calibrating solar data of the NSF UV monitoring network is consistent with the source-based NIST1990 irradiance scale.

Calibration standards and operating procedures were further validated during the fifth North American Interagency Intercomparison for UV Spectroradiometers, which was held at Table Mountain, located 8 km north of Boulder, Colorado, from 13 to 21 June 2003. Results of the campaign were published by Wuttke et al. (2006).

Irradiance Standards used for Volume 15 Data

Table 5.2 gives an overview of irradiance standards used in the 2005-2006 season and their calibration history. Most lamps were calibrated by Optronic Laboratories. There are also lamps that were calibrated by Biospherical Instruments using the procedure outlined in Section 4.2.1.5. Some of the standards used for Volume 15 have two or more sets of calibrations. Lamps M-764 and 200W017 were the primary traveling standard for the Volume 15 season. Both lamps were calibrated by Optronic Laboratories in March 2001. Lamp M-764 started to drift in 2005. Lamp 200W017 was used less frequently and its calibration is still valid and was confirmed in 2005 with long-term standards, which we use only very sparingly.

The values in the columns "Change from Calibration 1 to 2" of Table 5.2 give an indication of typical changes in the output of lamps during several years. Our observation is that some lamps show abrupt changes, whereas other lamps exhibit uniform drifts.

Analysis of Instrument Stability

In the post-seasonal analysis of instrument performance, stability of both system responsivity and wavelength stability of the monochromator are carefully reviewed. System responsivity is tracked by analysis of absolute and 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 internal reference lamp due to aging, casualty, or replacement
- Change in instrument temperature
- Drifts of the PMT sensitivity or monochromator throughput
- Changes in the instruments' fore optics
- Any alteration to the system including engineering upgrades and routine or unanticipated maintenance

Table 5.2. Calibration standards used in the 2005-2006 season*.

Site	Standard	Calibration 1	Calibration 2	Change from Calibration 1 to 2		
				@ 300 nm	@ 400 nm	@ 600 nm
Traveling standards	200W017	Optr. 3/01				
	M-764	Optr. 10/92	Optr. 3/01	+1.2%	+1.0%	+1.3%
McMurdo	M-543	BSI transfer from M-874 establ. 1/99‡	BSI transfer from M-764 establ. 4/02‡	+1.7%	+1.7%	+1.6%
	200W005	BSI transfer from M-764 establ. 4/02‡ (used up to 12/05)	BSI transfer from 200W017 establ. 2/06‡	-1.4%	-2.0%	-2.4%
	200W019	Optr. 9/98				
Palmer	M-700	BSI transfer from M-874 (Optr. 9/98); establ. 2/00‡	BSI transfer from 200W017 (Optr. 3/01); establ. 6/06‡	+1.9%	+0.9%	-0.1%
	M-765	BSI transfer from M-874 (Optr. 9/98); establ. 2/00‡	BSI transfer from 200W017 (Optr. 3/01); establ. 6/06‡	+2.8%	+1.7%	+0.6%
	200W007	Optr. 11/96	BSI transfer from 200W017 (Optr. 3/01); establ. 6/06‡	+1.4%	+0.8%	+0.1%
South Pole	M-666	BSI transfer from 200W006 and 200W021 establ. 1/00‡	BSI transfer from 200W017 (Optr. 3/01); establ. 2/06‡	+1.7%	+2.1%	+2.5%
	200W006	Optr. 11/96	BSI transfer from M-764 (Optr. 3/01); establ. 4/04‡	+4.3%	+3.2%	+2.2%
	200W021	Optr. 9/98	BSI transfer from 200W017 (Optr. 3/01); establ. 2/06‡	+1.7%	+1.5%	+1.4%
Ushuaia	M-698	BSI transfer from M-874 (Optr. 9/98); establ. 8/99‡	BSI transfer from 200W017 (BSI 6/07) and 200W038 (BSI 4/08); establ. 7/08‡	+2.1%	+1.9%	+1.5%
	M-766	BSI transfer from M-874 (Optr. 9/98); establ. 5/00‡	BSI transfer from 200W017 (BSI 6/07) and 200W038 (BSI 4/08); establ. 7/08‡	0%	-1.0%	-1.3%
	200W008	Optr. 11/96	BSI transfer from 200W017 (BSI 6/07) and 200W038 (BSI 4/08); establ. 7/08‡	+8%	+2.7%	-0.4%
	200W026	Optr. 3/01				
San Diego	M-763	BSI transfer from M-874 establ. 1/98‡	Optr. 3/01	-1.9%	-1.5%	-1.0%
	200W022	Optr. 3/01				
	200W028	Optr. 3/01	BSI transfer from M-763 (Optr. 3/01) and 200W017 (Optr. 3/01); establ. 4/05‡	+4.2	+3.1	+2.0
Barrow	M-699	Optr. 9/98	Optr. 3/01	+0.5%	+0.4%	+0.3%
	M-762	Optr. 9/98	Optr. 3/01	+0.9%	+0.8%	+0.7%
	200W009	Optr. 9/98	Optr. 3/01	+5.1%	+3.7%	+2.3%
Summit	200W027	Optr. 3/01	BSI transfer from 200W030 (Optr. 3/01); establ. 12/06‡	+1.7%	+1.3%	+0.8%
	200W030	Optr. 3/01				

* *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.*

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

Starting with Volume 12, solar data from the SUV-100 spectroradiometer have been compared with measurements of GUV radiometers (Section 2.3). These comparisons help to uncover drifts or outliers in data from the SUV-100. Results of these comparisons are also documented in the following sections.

Cosine errors of SUV-100 spectroradiometers

"Version 0" data discussed in this report have not been corrected for the cosine error[1] of the entrance optics of SUV-100 and SUV-150B spectroradiometers. "Version 2" data have been corrected for this error and are published at www.biospherical.com/NSF/Version2. As of this writing, Version 2 data of all sites but San Diego are available. Please check the website for updates on the Version 2 status. We encourage researchers to use Version 2 data due to their higher accuracy.

[1] The cosine error describes the deviation of a radiometer's angular response from the ideal cosine law: if a light source illuminating the radiometer is moved from the zenith (incidence angle = 0°) to larger incidence angles, the radiometer's signal should change proportional to the cosine of the incidence angle. For example, at an incidence angle of 60° the signal should only be 50% of the signal at incidence angle = 0° because cos(60°) equals 0.5. If the actual signal at 60° were only 45%, the cosine error of the radiometer would be –10%, since (0.45/ 0.5 - 1) * 100% = –10%. In this case, the radiometer would underestimate the true irradiance by 10%.