

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 14 data are given separately by site in the following subsections. This includes discussions on the performance of irradiance standards used for Volume 14 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

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.

<i>Every 5 minutes</i>	<i>Bi-weekly</i>
Temperatures and power checks	System calibration with site standards
Monochromator position check	<i>Monthly</i>
Ancillary sensors measurements	Analysis of calibration and standards stability
Detection of system errors by software	<i>Yearly</i>
<i>Daily</i>	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
<i>Weekly</i>	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	<i>Additionally</i>
Website updates	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 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 14 Data

Table 5.2 gives an overview of irradiance standards used in the 2004-2005 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 14 have two or more sets of calibrations. Lamps M-764 and 200W017 were the primary traveling standard for the Volume 14 season. Both lamps were calibrated by Optronic Laboratories in March 2001. Lamp M-764 started to drift in 2005. Lamp 200W007 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 between calibrations 1 and 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 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 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 2004-2005 season*.

Site	Standard	Calibration 1	Calibration 2	Change between Calibration 1 and 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	Optr. 11/96	BSI transfer from M-764 establ. 4/02‡	+1.7%	+1.6%	+1.4%
	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‡				
	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				
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				
	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				
	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.

** Lamp 200W006 was dropped during the site visit in 2004 and recalibrated.

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

The wavelength stability of final data is checked either by the Fraunhofer-line correlation methods 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.

Starting with Volume 12, solar data from the SUV-100 spectroradiometer have been compared with measurements of GUUV 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 and azimuth error of SUV-100 spectroradiometers

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 one 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 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 of all instruments have been modified in 2000. Measurements with a test apparatus specifically designed for this purpose (see previous Operations Report) show that azimuth asymmetries of the modified instruments are generally below $\pm 2\%$ for all wavelengths. The effects of the instruments' cosine error¹ have been extensively studied in 2002, and results were published by Bernhard et al. (2004a). Based on these results, we decided to reprocess the entire dataset of the NSF's UV Monitoring Network. The processed dataset is called "Version 2" and available at the website www.biospherical.com/NSF/Version2. As of this writing, only Version 2 data for McMurdo, Palmer, South Pole, and Barrow are available. Please check the website for updates on the Version 2 status.

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 $\cos(60^\circ)$ 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%.