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 11 data are given separately by site in the following subsections. This includes discussions on the performance of irradiance standards used for Volume 11 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.

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 all calibrations and 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 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.

Verification of the irradiance scale maintained at Biospherical Instruments by CUCF

The irradiance scale of Biospherical Instruments was verified in San Diego 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 the Surface Radiation Research Branch (SRRB) of NOAA's Air Resources Laboratory. 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. The irradiance scale was further verified at national and international intercomparison campaigns. 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.

Irradiance Standards used for Volume 11 Data

Table 5.2 gives an overview of irradiance standards used in the 2001-2002 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 11 have two or more sets of calibrations. Lamp M-764 was the primary traveling standard for the Volume 11 season. This lamp was originally used as site standard at McMurdo. We decided to use it as the new traveling standard because of its exceptional stability. The lamp was recalibrated by Optronic Laboratories in March 2001. The new calibration values differed by less than 1.5% from the original values, which were established in 1992.

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 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 (See Chapter 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 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

The wavelength stability of 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.

Table 5.2. Calibration standards used in the 2001-2002 season*.

Site	Standard	Calibration 1	Calibration 2	Change between Calibration 1 and 2		
				@ 300 nm	@ 400 nm	@ 600 nm
Traveling standards	200W017	3/01				
	M-764	Optr. 10/92	Optr. 3/01	+1.2%	+1.0%	+1.3%
McMurdo	M543	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; 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	BSI transfer from 200W006 and 200W021 establ. 1/00‡				
	200W006	11/96				
	200W021	9/98				
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%
San Diego	M-763	BSI transfer from M-874 establ. 1/98‡	Optr. 3/01	-1.9%	-1.5%	-1.0%
	200W028	Optr. 3/01				
	200W029	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.*

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 (Figure 5.1.) show that azimuth asymmetries of the modified instruments are generally below ±2% for all wavelengths. The effects of the instruments' cosine error[1] have been extensively studied in 2002, and results were published by *Bernhard et al.,* 2003. The paper is available at the website www.biospherical.com/nsf/presentations.asp. 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 www.biospherical.com/NSF/Version2. As of this writing, not all sites have been processed. Please check the website for updates on the Version 2 status.

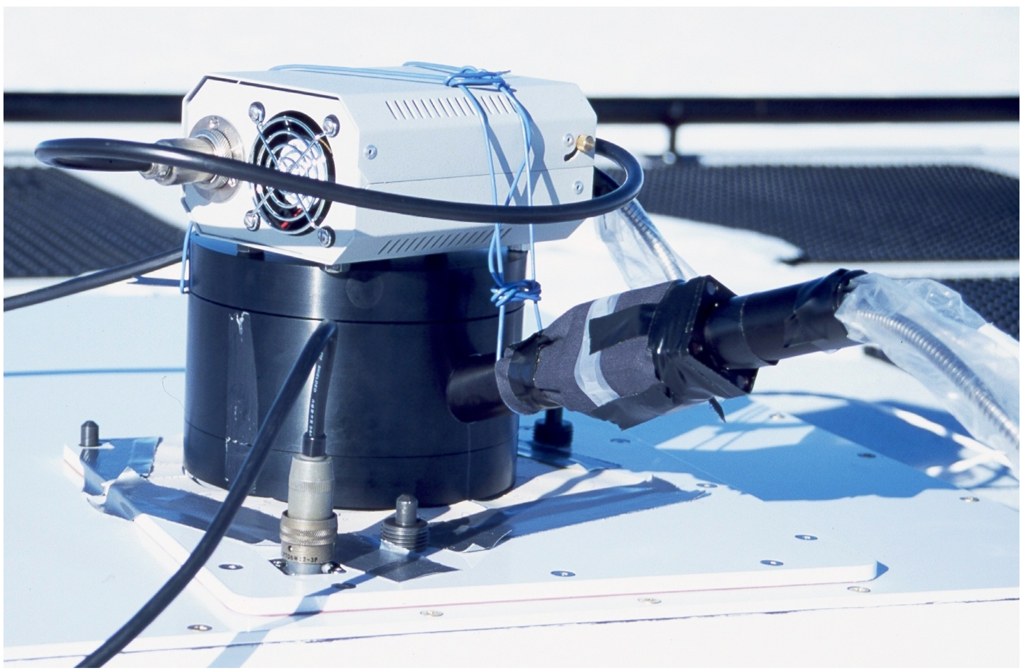

Figure 5.1. *Apparatus for characterizing the angular response of SUV-100 spectroradiometer in operation at the South Pole. The white box on top is a light source, which is coupled via a optical fiber bundle and a baffled tube into the black cylinder shown in the center of the picture. The cylinder has precisely machined openings at 0°, 30°, 45°, 60°, and 70° zenith angles, and can be rotated to arbitrary azimuth angles. With a lens (which is located inside the tube about one focal length away from the end of the fiber) an approximately parallel light beam is produced, pointing toward the center of the collector. By coupling the tube to the different openings, the apparatus is used to measure the angular response at five zenith angels and arbitrary azimuth angles.*

[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° as cos(60°) = 0.5. If the actual signal at 60° were only 45%, the cosine error of the radiometer would be -10%, as (0.45/ 0.5 - 1) * 100% = -10%. In this case, the radiometer would underestimate the true irradiance by 10%.