5.5. San Diego (8/17/01 – 8/13/02)

The 2001-2002 season at San Diego includes the period 8/17/01 – 8/13/02. In contrast to other network sites, San Diego serves also as a facility for operator training, test of new system components, and comparison of calibration standards. Scheduled maintenance is performed year-round and during operator training. The measurement of solar spectra is therefore more frequently interrupted than at other sites. The list below gives an overview of the most important non-standard activities during the San Diego Volume 11 season:

- **8/17/01:** Start of the season following operator training
- **9/11/01:** Cleaning of window in optics block. The service was performed after a significant decrease in the instrument's sensitivity was noticed
- **9/19/01:** Replacement of roof-box circulation fan
- **2/21/02, 2/22/02:** PMT cable/connector identification in support of troubleshooting of Ushuaia instrument
- **4/30/02:** Replacement of voltmeter and shunt
- **5/6/2002, 5/7/02:** Operator training
- **8/2/02**: Service PMT cooler power supply
- **8/13/02**: End of season; site operator training

In the first two weeks of the season, the responsivity of the instrument decreased by more than 10% (see Section 5.5.2). The reason of the drift was found to be an oily condensate on the underside of the quartz window that is situated in the instrument's fore optics between cosine collector and shutter. In addition, it was found that a fan, which is used for circulating air in the roof-box, was not functioning and was very hot. The fan is mounted in close proximity of the optics block. It is possible that heat of the fan lead to evaporation of oil, which is used to lubricate the shutter's actuation. The oil may have condensed on the quartz window, leading to the before mentioned decrease in throughput. The change in responsivity could be corrected by adjusting the instrument's calibration and has little effect on the accuracy of published data.

With exception of the problem at the beginning, the system operated normally during the Volume 11 period. Approximately 97.5% of the scheduled data scans are part of the published dataset. Only a small fraction of all solar scans was lost due to technical problems. The majority of the missing scans were superceded by the activities compiled above, and scheduled instrument calibration and maintenance.

5.5.1. Irradiance Calibration

The calibration of Volume 11 solar data is based on lamps 200W028 and 200W029. Both lamps were introduced in 2001 after they had been calibrated by Optronic Laboratories in March 2001. The lamps were compared with the traveling standards M-764 several times during the season. M-764 is used in the network for a number of years, and was also recalibrated by Optronic Laboratories in March 2001. A comparison of 200W028, 200W029 and M-764 performed in April 2001 showed agreement on the ±1% level. A similar good agreement was reached when the lamps were compared in October 2001 (Figure 5.5.1). Unfortunately, lamp 200W029 became misaligned in its holder in May 2002. Figure 5.5.2 indicates that the misalignment lead to a 2% difference of the lamp's irradiance. Lamp 200W029 was therefore not used for calibrating solar data after May 2002; calibrations during the last months of the season were exclusively based on 200W028 and M-764.

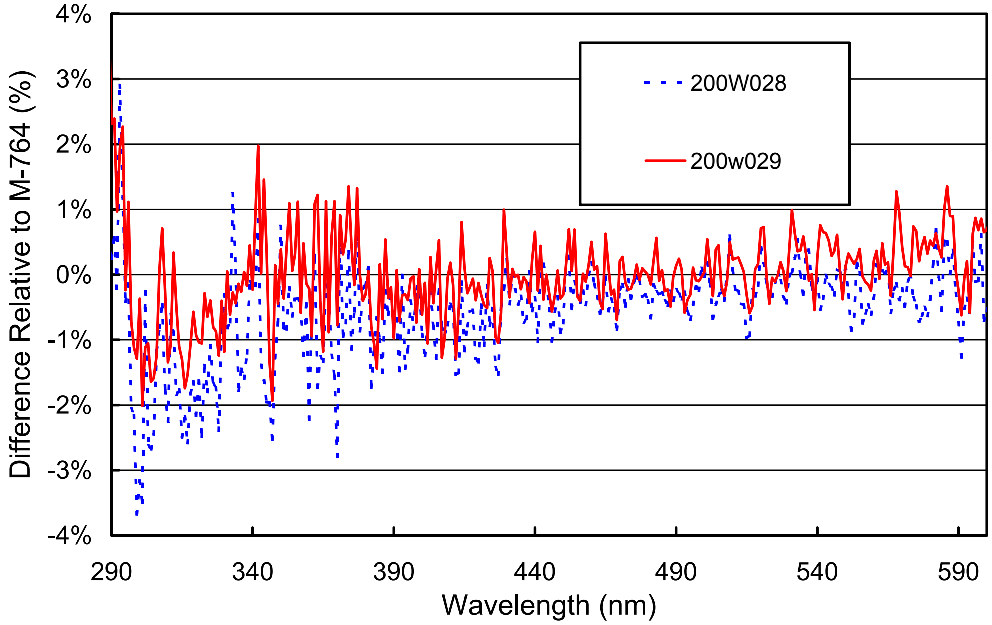

Figure 5.5.1. *Comparison of lamps 200W028 and 200W029 with the traveling standard M-764 in October 2001.*

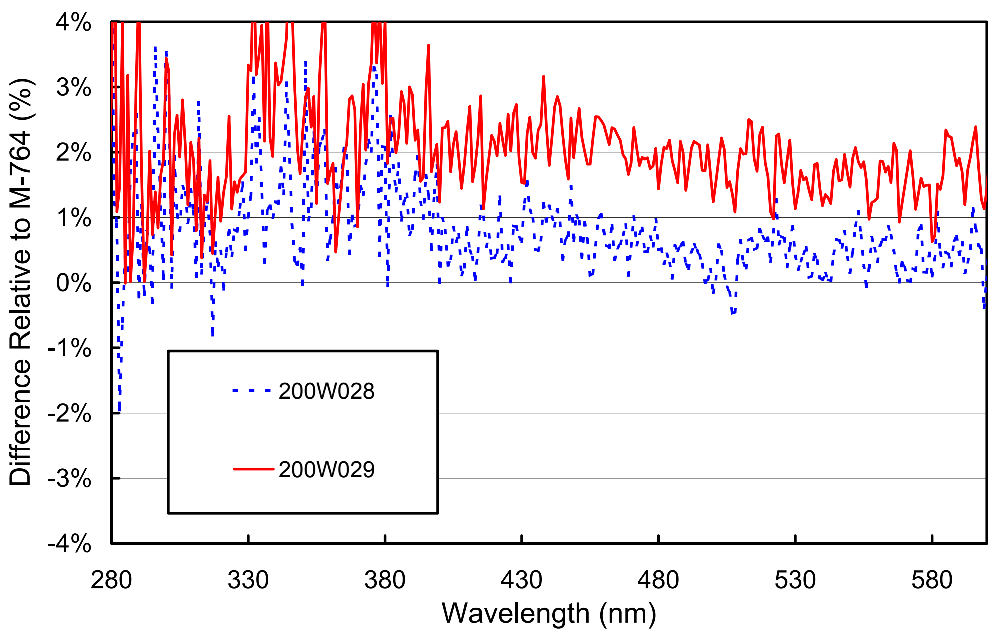

Figure 5.5.2. *Comparison of lamps 200W028 and 200W029 with the traveling standard M-764 in September 2002. Lamp 200W029 became misaligned in its holder in May 2002. This is the likely reason for the 2% difference shown in the plot.*

The traveling standard M-764 was used at all network sites after it was calibrated by Optronic Laboratories in March 2001. As shocks during travel may have changed its calibration, we compared the lamp with the standard M-763. This lamp was also (re)-calibrated in March 2001. It is one of our long-term standards and was used only three times after its calibration. Figure 5.5.3 shows two comparisons of M-764 and M-763. One was performed in April 2001, immediately after the lamps were returned from Optronic Laboratories. The calibration of both lamps agreed to within ±1%. The slight wavelength dependence may be caused by short-term fluctuations or dark drifts of the SUV-100, which was as the transfer radiometer. The second comparison took place in September 2002 and indicates a 1% systematic difference in the calibration of both lamps. This suggests that M-764 has drifted by 1%, as M-763 was virtually not used since the April 2001 comparison. A drift of 1% is still within the uncertainty specification of the lamp's certificates and the comparison procedure. No corrections were applied.

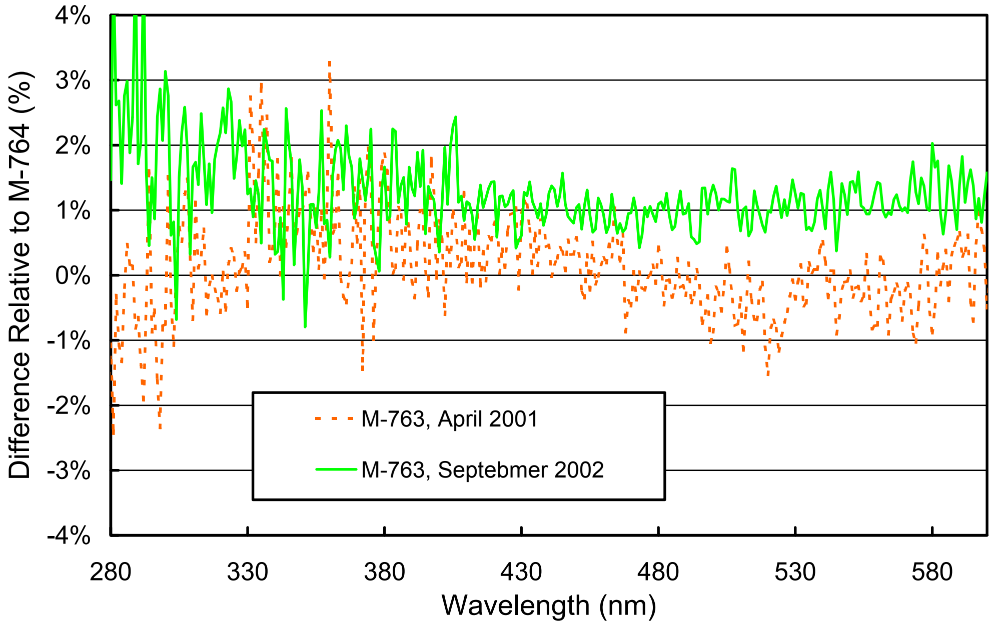

Figure 5.5.3. *Comparison of long-term standard M-763 with traveling standard M-764 in April 2001 and September 2002.*

5.5.2. Instrument Stability

The stability of the spectroradiometer over time is primarily monitored with bi-weekly calibrations utilizing the site irradiance standards and daily response scans of the internal irradiance reference. The stability of the internal lamp is monitored with the TSI sensor, which is independent from possible monochromator and PMT drifts. Usually a new irradiance is assigned to the internal lamp when TSI measurements indicate that this lamp has drifted by more than 2%.

Figure 5.5.4 shows TSI measurements and PMT currents at 300 and 400 nm during response scans. TSI measurements increased by approximately 7% during the season, indicating that the internal irradiance reference lamp became brighter as time progressed. PMT current readings were stable to within ±2.5% and are not following the increase seen by the TSI, as expected. This suggests a slight decrease of the monochromator throughput. The 2% step-change between 9/11/01 and 9/12/01 is caused by inspection of the instrument described below.

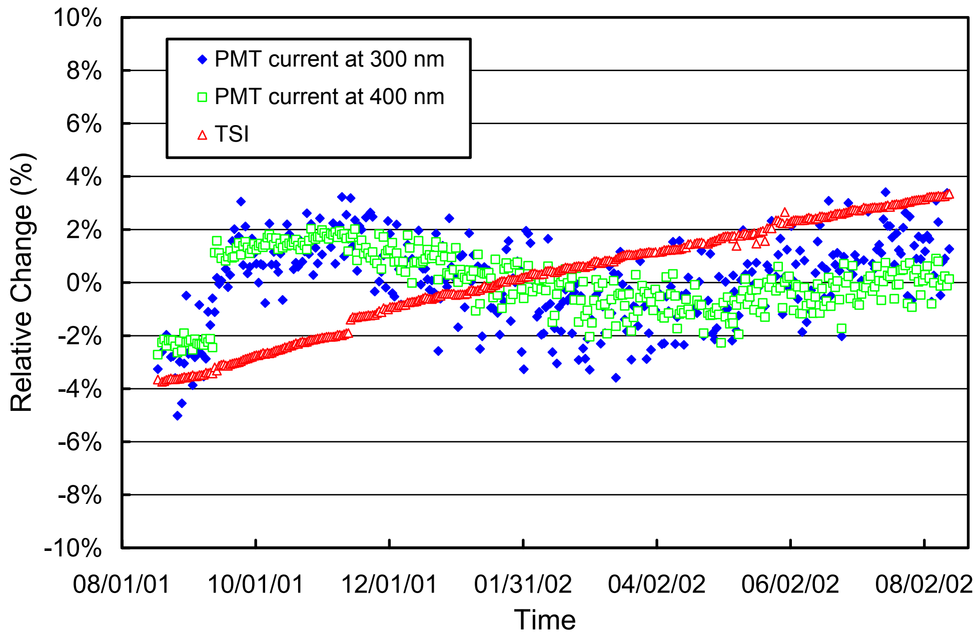

Figure 5.5.4. *Time-series of PMT current at 300 and 400 nm, and TSI signal during measurements of the internal irradiance reference lamp during the San Diego 2001-2002 season. The data is normalized to the average value of the whole season.*

As mentioned in the introduction, the system was affected by contamination of the quartz window inside the optics block. This caused a rapid decrease of the instrument's responsivity during the first three weeks of the season. The change cannot be detected with the internal lamp as the quartz window is not in the light path during scans with this lamp. The light path during solar scans as well as during absolute scans with 200-W standards includes the quartz window. A decrease of the system's responsivity by 10% due to the contamination of the window will lead to a 10% increase in the irradiance assigned to the internal lamp. Tracking the change of the assigned irradiance therefore allows to monitor the change in responsivity.

Figure 5.5.5 shows the change of the spectral irradiance assigned to the internal reference lamp. The graph is reference to the first calibration performed on 8/16/01. The calibration for Period 2 was established on 9/4/01. Figure 5.5.5 indicates that the responsivity of the instrument decreased by 12%, 8%, and 4% at 280 nm, 380 nm, and 600 nm, respectively. The calibration for Period 3 was established on 9/11/01, indicating a further decrease in responsivity. In response to the problem, the instrument was serviced, and the contamination of the quartz window as well as the overheating of the fan were discovered.

From Figure 5.5.5 it is not possible to determine whether the responsivity steadily decreased or whether it was constant for some time, followed by a step-change. By comparing SUV measurements at 305 nm, 320 nm, 340 nm, and 380 nm with corresponding measurements of a GUV-511[1] radiometer, we were able to quantify the change in SUV responsivity over time. The ratios of coincident SUV and GUV measurements steadily declined between the start of the season and 8/31/01. Between 9/1/01 and 9/8/01 the ratios were constant to within ±2%, followed by a 2-3% change on 9/9/01.

In order to correct for the drift, the calibration of the internal reference lamp was interpolated from the calibrations performed on 8/16/01 and 9/4/01:

[1] The GUV-511 radiometer is a moderate-bandwidth filter instrument, which measures spectral irradiance at 305, 320, 340, and 380 nm, as well as Photosynthetically Active Radiation (PAR). Some sites were equipped with GUV radiometers in 2001.

$$E(\lambda, J) = E_1(\lambda) + [E_2(\lambda) - E_1(\lambda)] \cdot [J - J_1]/[J_2 - J_1]$$

where λ is wavelength

J is Julian Day

$E(\lambda, J)$ is spectral irradiance assigned to the internal lamp at wavelength λ and Julian Day J

$E_1(\lambda)$ is spectral irradiance of the internal lamp determined from the calibration performed on 8/14/01

$E_2(\lambda)$ is spectral irradiance of the internal lamp determined from the calibration performed on 9/4/01

J_1 is 228 (Julian Day of 8/16/01)

J_2 is 244 (Julian Day of 9/1/01)

The formula above was applied for the period 8/16/01 – 8/31/01; the calibration performed on 9/4/01 was used between 9/1/01 and 9/8/01; and the calibration from 9/11/01 was used between 9/9/01 and 9/11/01.

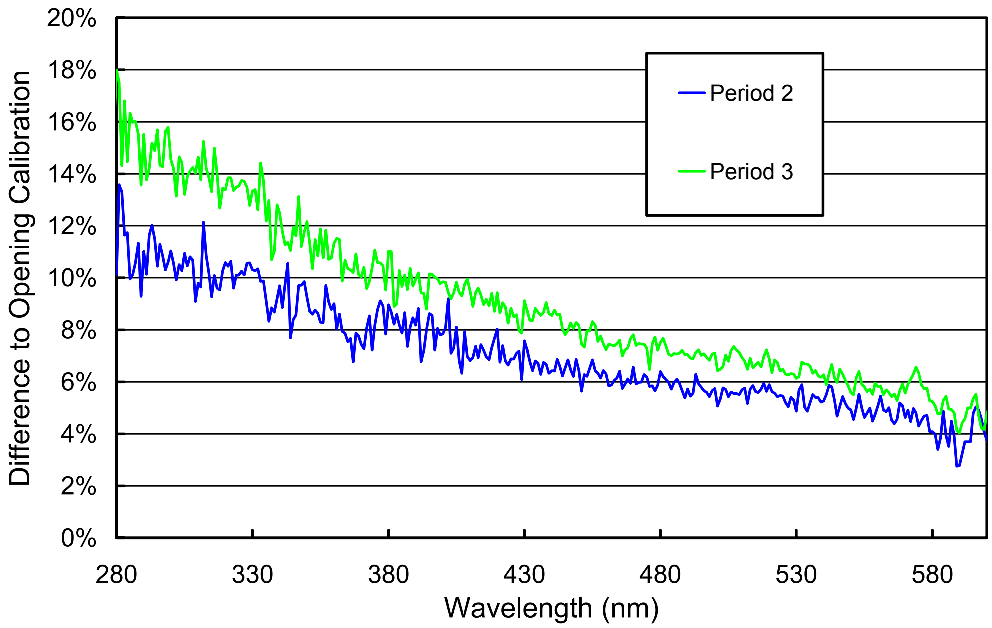

Figure 5.5.5. *Ratios of irradiance assigned to the internal reference lamp during Periods 2 and 3, referenced to the calibration performed on the first day of the season.*

After recalibrating solar measurements with this calibration scheme, we compared GUV measurements again with the SUV data. Figure 5.5.6 shows the ratio of spectral irradiance measured by GUV and SUV at 320 and 380 nm between 8/17/01 and 9/11/01. There is no significant drift, indicating that the change in responsivity of the SUV has been satisfactorily removed by the adjustment of the calibration. The few outliers in the plot are due to the fact that the GUV integrates over one minute whereas the SUV data are instantaneous measurement. This will lead to scatter if clouds move in front of the Sun.

The calibration of the system that was performed on 9/12/01 after the quartz window had been cleaned agreed with the initial calibration on 8/17/01 to within ±0.5% (see Period 4 in Figure 5.5.7). Over the remainder of the season, the responsivity steadily decreased by 5-10%, depending on wavelength, but at a much smaller rate than observed during the first two weeks. Figure 5.5.7 shows the change of the spectral irradiance assigned to the internal reference lamp between 9/12/01 and 8/14/02. The instruments calibration therefore could be adjusted in the usual way with the exception of Period P7B, which was interpolated from the calibrations performed in Periods P7 and P8. During the system operator training in

August 2002, the quartz window was again found to be contaminated, explaining the drift seen during the second part of the season.

Table 5.5.1 gives more information on the calibrations used for each period. For all periods with more than one absolute scan, the standard deviation of the individual spectra contributing to the average spectrum in a given period were calculated. Figure 5.5.7 shows the ratio of the standard deviation and average spectra. The ratios are useful for estimating the variability of the calibrations in each period. Figure 5.5.7 demonstrates that the calibrations performed in each periods are consistent to within 1% (1σ) for wavelength above 350 nm. At shorter wavelengths, the calibrations are affected by noise resulting in a somewhat larger variability.

Table 5.5.1: Assignment of periods.

Period			Number of absolute scans	Remarks
Label	Start	End		
P1	08/16/01	08/16/01	2	Standard calibration
P1B	08/17/01	08/18/01	0	Interpolation
P1C	08/19/01	08/20/01	0	Interpolation
P1D	08/21/01	08/22/01	0	Interpolation
P1E	08/23/01	08/24/01	0	Interpolation
P1F	08/25/01	08/26/01	0	Interpolation
P1G	08/27/01	08/28/01	0	Interpolation
P1H	08/29/01	08/31/01	0	Interpolation
P2	09/01/01	09/8/01	1	Single scan
P3	09/09/01	09/11/01	2	Standard calibration
P4	09/12/01	09/16/01	2	Standard calibration
P5	09/17/01	09/29/01	3	Standard calibration
P6	09/30/01	10/18/01	3	Standard calibration
P7	10/19/01	11/14/01	2	Standard calibration
P7B	11/15/01	11/25/01	0	Interpolation
P8	11/26/01	12/04/01	1	Single scan
P9	12/05/01	03/08/02	7	Standard calibration
P10	03/09/02	08/14/02	14	Standard calibration

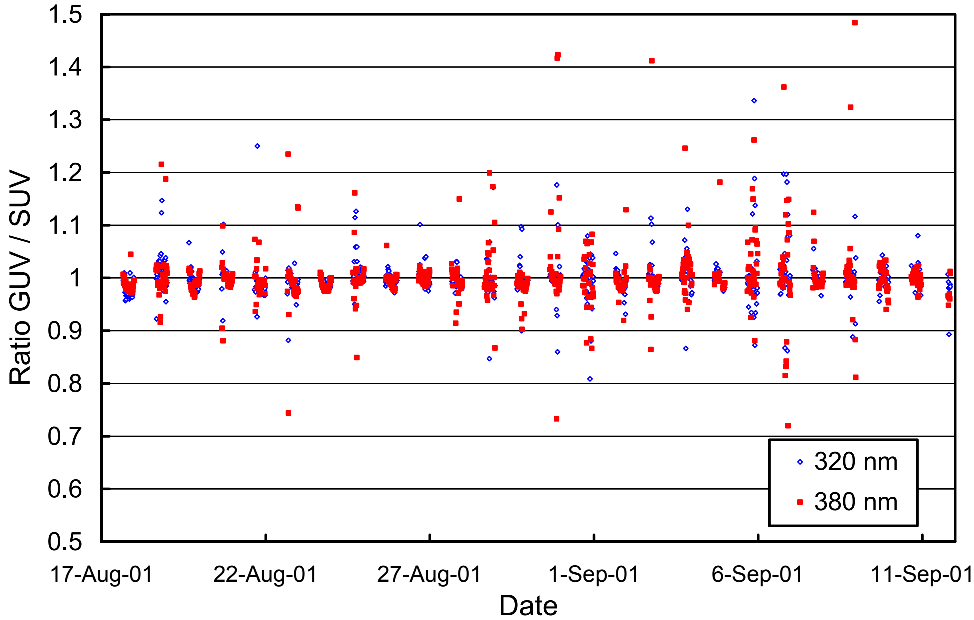

Figure 5.5.6. *Ratio of spectral irradiance measured by GUV and SUV at 320 and 380 nm. Only data with solar zenith angles smaller than 60° are shown.*

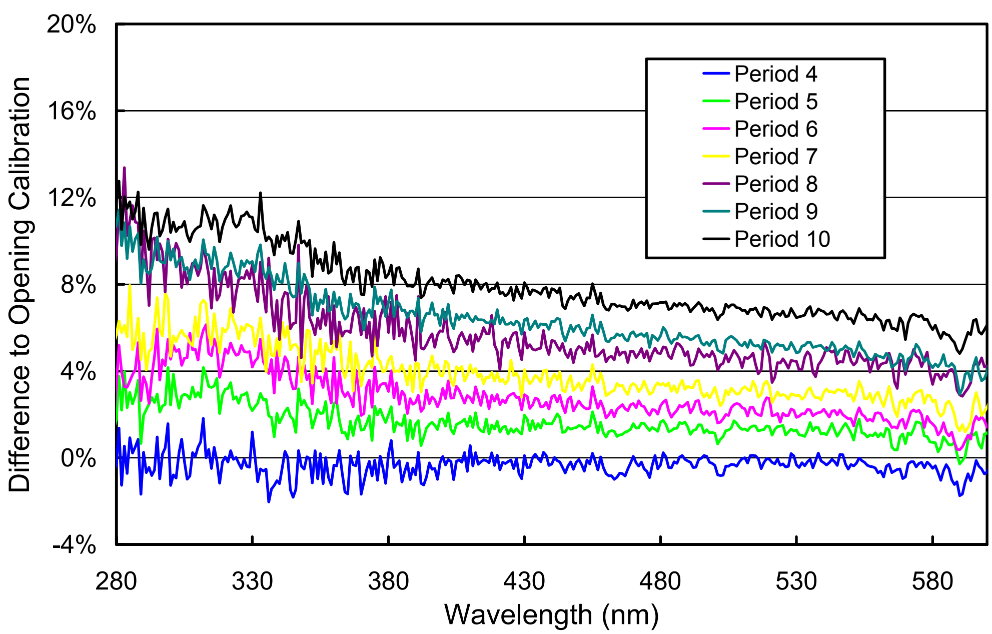

Figure 5.5.7. *Ratios of irradiance assigned to the internal reference lamp between 9/12/01 and the end of the season. The data is referenced to the calibration performed on the first day of the season.*

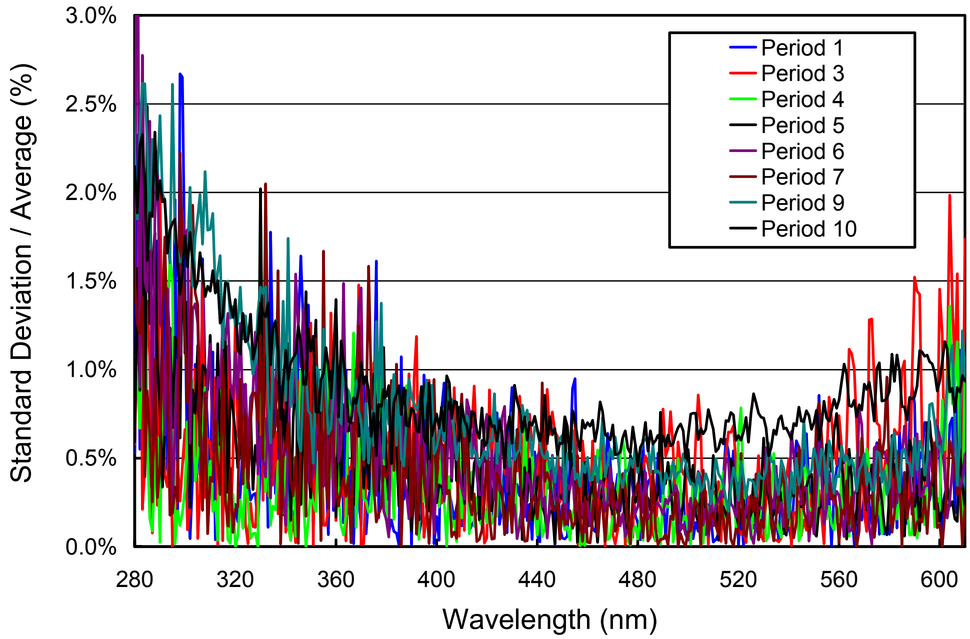

Figure 5.5.8. *Ratio of standard deviation and average calculated from the absolute calibration scans used to establish the calibration of the San Diego spectroradiometer for the 2001-2002 season. Only period with at least two absolute scans are shown.*

5.5.3. Wavelength Calibration

Wavelength stability of the system was monitored with the internal mercury lamp. Information from the daily wavelength scans was used to homogenize the data set by correcting day-to-day fluctuations in the wavelength offset. After this step, there may still be a deviation from the correct wavelength scale, but this bias should ideally be the same for all days. Figure 5.5.9 shows the differences in the wavelength offset of the 296.73 nm mercury line between two consecutive wavelength scans. In total, 418 scans were evaluated. For 90% of the days, the change in offset was smaller than ±0.025 nm; for 98.5% of all days shifts were below 0.055 nm. Six scans showed a change larger than ±0.07 nm, partly caused by system maintenance. The wavelength calibration was adjusted accordingly. The histogram shown in Figure 5.5.9 indicates a better wavelength stability than that observed during the Volume 10 season. This can be attributed to a new peak finding algorithm, which was first implemented for Palmer Volume 11 data. San Diego is the second site where the new procedure was used. The algorithm is based on a Gaussian line fit, which leads to an improved accuracy compared to the tangent method that was used previously. See Section 4 for details.

After the data was corrected for day-to-day wavelength fluctuations, the wavelength-dependent bias between this homogenized data set and the correct wavelength scale was determined with the Fraunhofer-correlation method, as described in Section 4.2.2.2. Figure 5.5.10 shows the resulting correction functions that were applied to the Volume 11 San Diego data. Three different functions were used for three different periods, labeled Period A – C. Site operator training took place between Periods B and C.

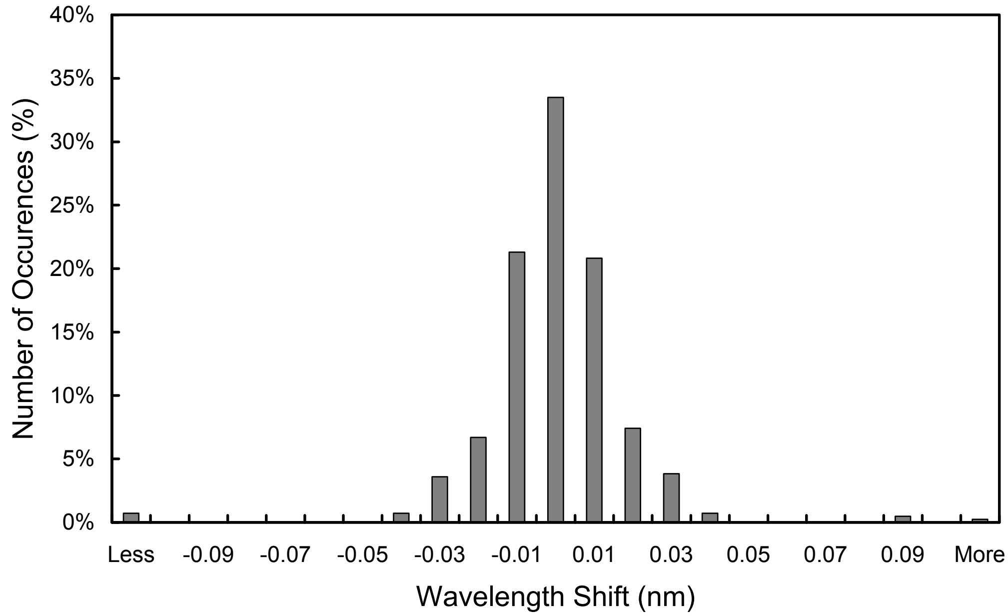

Figure 5.5.9. *Differences in the measured position of the 296.73 nm mercury line between consecutive wavelength scans. The x-labels give the center wavelength shift for each column. The 0-nm histogram column covers the range -0.005 to +0.005 nm. "Less" means shifts smaller than –0.105 nm; "more" means shifts larger than 0.105 nm.*

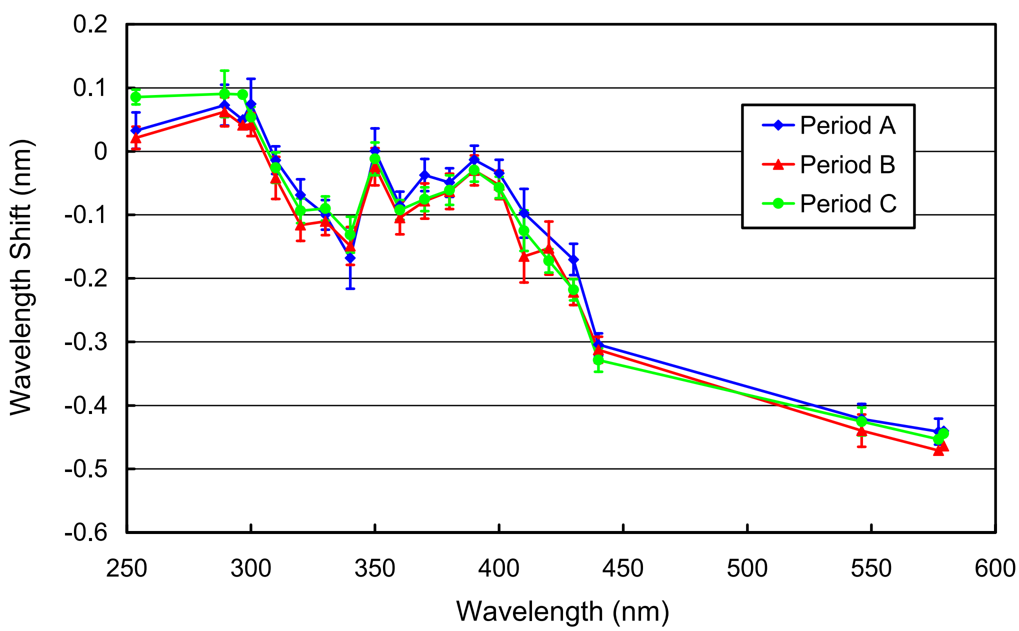

Figure 5.5.10. *Monochromator non-linearity for the San Diego 2001-2002 season for Periods A (8/17/01-10/24/01), Period B (10/25/01 - 5/6/02), and Period C (5/7/02 - 8/13/02).*

After the data was wavelength corrected using the shift function described above, the wavelength accuracy was confirmed again with the Fraunhofer method. The results are shown in Figure 5.5.11 for four UV wavelengths, evaluated for all noontime scans measured during the season. The residual shifts are generally smaller than ±0.05 nm. The actual wavelength uncertainty may be larger due to wavelength fluctuations of about ±0.02 nm during the day, and possible systematic errors of the Fraunhofer-correlation method (see Chapter 4). When clouds move in front of the Sun spectra will get distorted, which may confuse the correlation algorithm. This, and not real wavelength shifts, are the reason for the few outliers seen in Figure 5.5.11.

Although data from the external mercury scans do not have a direct influence on the data products, they are an important part of instrument characterization. Figure 5.5.12 illustrates the difference between internal and external mercury scans measured in March 2001. Note that this measurement is part of the Volume 10 dataset as no external mercury scans were performed during the period of Volume 11. The peak of the external scans, agrees approximately with the nominal wavelength of 296.73 nm, whereas the peak of the internal scans is shifted about 0.12 nm to shorter wavelengths. External scans have a bandwidth of about 1.03 nm FWHM, whereas the bandwidth of the internal scan is only 0.75 nm. Since external scans have the same light path as solar measurements, they more realistically represent the monochromator bandpass relevant to solar scans.

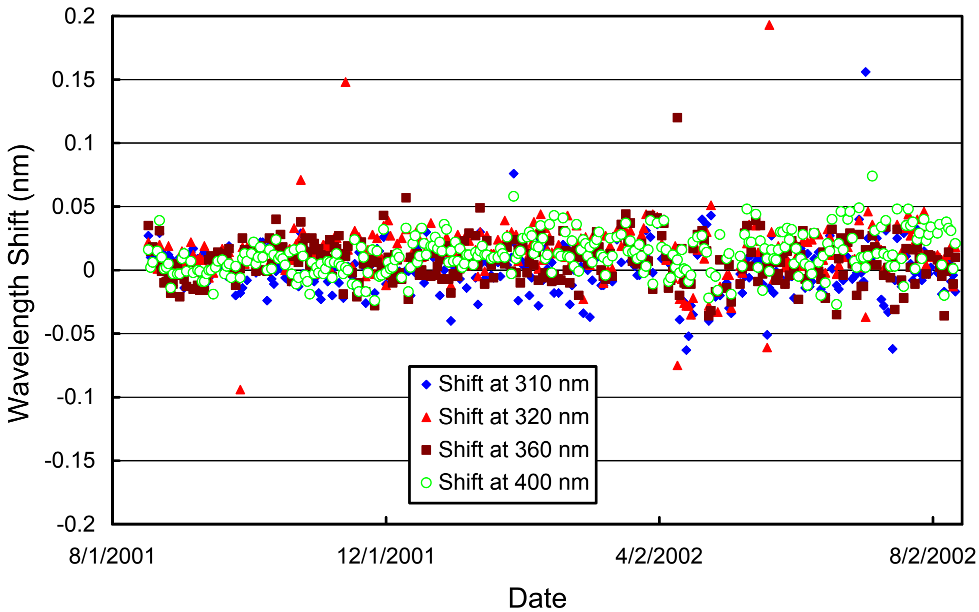

Figure 5.5.11. *Check of the wavelength accuracy of the final data at four wavelengths by means of Fraunhofer correlation. The noontime measurements have been evaluated for each day of the season.*

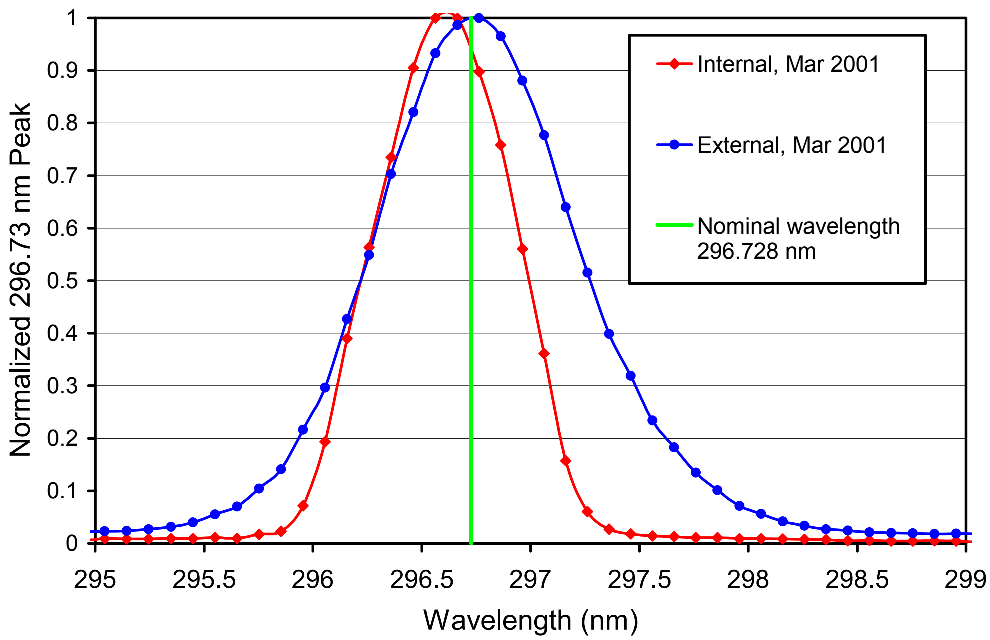

Figure 5.5.12. *The 296.73 mercury line as registered by the PMT from external and internal sources.*

5.5.4. Missing Data

A total of 17639 scans are part of the published San Diego Volume 11 dataset. These are 97.5% of all scans scheduled between 8/17/01 and 8/13/02. Approximately 1.7% of all scans were superceded by scheduled calibrations performed throughout the season. Technical problems lead to a loss of 0.5% of all scans. The rest of the missing scans were lost due to system service (0.1%); and support of other sites, including operator training (0.3%) Table 5.5.1 describes the gaps in the published solar data in more detail.

Table 5.5.1 Missing scans San Diego Volume 11.

Time Period	Scans missing	Reason
9/11/01 - 9/12/01	17	Inspection collector; cleaning quartz window optics block
9/19/01	4	Replacement of roof-box circulation fan
2/15/02	7	Support SUV-150 development
2/21/02 - 2/22/02	17	Check PMT cooler cabling in support for site visit Ushuaia
3/18/01	4	Unknown
3/18/02 - 3/19/02	34	Communication problem
4/24/02	20	Unknown
4/30/02	6	Exchange instrument shunt and voltmeter
5/6/02 – 5/7/02	32	Mid-season operator training