5.5. San Diego (9/25/99 – 8/29/00)

The 1999-2000 season at San Diego includes the period 9/25/99 – 8/29/00. In contrast to other network sites, maintenance and lamp intercomparisons are performed year-round and during operator training. With few exceptions mentioned below, the system operated normally during the period of Volume 9. However, the accuracy of the solar data is slightly reduced because of drifting calibration standards. For unknown reasons, the wavelength calibration of the system was off by 10 nm between 8/15/00 and 8/22/00. This shift is too large to be corrected and one week of data was therefore lost.

On two days, namely 12/16/99 and 6/8/00, the time was erratically reset by one day by the GPS unit. The time-errors were corrected during data analysis; time and solar zenith angle fields of the published composite scans and databases are correctly aligned with the irradiance values. The filenames of the composite scans and the field “DataScan” in the databases, however, were not adjusted, since the filename is the key field of our internal data structure. Therefore, the data scan ED991445.349 (i.e. the first scan that is affected) includes the measurement at 12/16/99 14:45 rather than 12/15/99 14:45. The data scans ED991445.349 – ED990045.350, and ED001230.159-ED000300.160 are affected by the problem.

Approximately 93% of the scheduled data scans are part of the published dataset; 4% of all scans were lost because of technical problems; the remaining scans were superceded by tests and calibrations. The instrument reponsivity drifted by 15% during the season, this drift, however, was corrected during data analysis. Published data are not affected.

5.5.1. Irradiance Calibration

The site irradiance standards for the 1999-2000 season used in San Diego were the lamps 200W010, 200W020, and M-881. Since all lamps drifted during the season, four other lamps, namely M-874, 200W016, 200W022, and M-764, were used in addition to establish instrument calibrations. Table 5.5.1 gives an overview of the history of all seven lamps; more details are given below:

- **Lamp 200W010** has Optronic Laboratory calibrations from November 96 and September 1998. The lamp was re-calibrated at BSI using absolute scans from 4/27/99, and lamp M-764 as the reference standard. A comparison with lamp 200W020 on 9/24/99 (i.e. season opening calibrations Volume 9) revealed that 200W010 had drifted by 3-4% between May and September 1999. Comparisons with other lamp scans from 1999 and 2000 confirmed that the lamp was drifting erratically throughout the entire Volume 9 season. Therefore, the lamp was only used for instrument calibrations if absolute scans of other lamps did not exist and the instrument’s responsivity appeared to have changed. On these few occasions, 200W010 was cross-calibrated against another lamp using data taken immediately before those periods. Thus, 200W010 was used to “bridge” calibrations performed with other lamps rather than being treated as an independent standard.
- **Lamp 200W016** is a long-term standard, which is only used once or twice per year. Its purpose is to preserve the BSI irradiance scale over a long time period. It was calibrated at BSI using absolute scans from November 1998, and lamp M-874 as the reference standard. These scans were part of the CUCF intercomparison in 1998 (see Section 5.1). Since 200W016 was not used between November 1998 and July 2000, it allows to verify the stability of the BSI irradiance over a two year period.
- **Lamp 200W020** has a Optronic Laboratory calibration from September 1998. It was found on 7/12/00 that the lamp was misaligned in its holder. After realignment, irradiance levels changed by 4%. Comparisons with other lamps suggest that the lamp was already misaligned when the Optronic Laboratory calibration took place. The lamp was therefore used with the original Optronic calibration until the day when it was adjusted, and later absolute scans were scaled by the difference caused by the alignment. The lamp became defective in September 2000 and was taken out of service.

- **Lamp 200W022** is a long-term standard like 200W016, and was calibrated at BSI using absolute scans from November 1998, and lamp M-874 as the reference standard. Like 200W016, it was not in use between November 1998 and July 2000, and therefore allows an independent check of the stability of the BSI irradiance scale.
- **Lamp M-764** has an Optronic Laboratory calibration from October 1992. It was used as a site standard at McMurdo until January 1999. Season closing calibrations at McMurdo performed on 1/20/99 confirmed that the lamp's calibration is still valid. It agreed with all three McMurdo standards 200W005, 200W019, and M-543, as well as M-874 to within ±1% (Lamps 200W005 and 200W019 have Optronic Laboratory calibrations from November 1996 and September 1998, respectively). After removal from McMurdo Station, M-764 was used only once until 10/12/00. The lamp was re-calibrated by Optronic Laboratories in March 2001. The new calibration agreed to within 1% with the calibration from October 1992, which was used to process Volume 9 San Diego data.
- **Lamp M-874** has two Optronic Laboratory calibrations from September 1995 and September 1998, the latter calibration was used for Volume 9 San Diego calibrations. The lamp was used as traveling standard until the 2000 site visit in Ushuaia and drifted afterwards. M-874 was therefore used only in 1999 for establishing calibrations of the San Diego instrument.
- **Lamp M-881** has two Optronic Laboratory calibrations from August 1995 and September 1998. Since the lamp had drifted during the Volume 8 season a new calibration was transferred to it in 1999 using absolute scans from 4/27/99, and lamp M-764 as the reference standard. A comparison with lamp 200W020 on 9/24/99 (i.e. season opening calibrations Volume 9) showed agreement on the ±0.5% level, confirming that M-881 remained stable between April and September 1999. However, the lamp drifted afterwards. On 7/7/00, it disagreed by 3-5% from 200W020 (It is not likely that 200W020 drifted during this period since it was not used between 9/24/99 and 7/7/00). Because of lack of alternatives, M-881 was used between December 1999 and July 2000 to establish instrument calibrations. Assuming a linear drift between 12/29/99 and 7/7/00, the drift was corrected by:

$$E_{\mathrm{M881,corrected}}(\lambda,t) = E_{\mathrm{M881}}(\lambda,t) + [E_{\mathrm{200W020}}(\lambda,t_{\mathrm{e}}) - E_{\mathrm{M881}}(\lambda,t_{\mathrm{e}})] \times i_t / i_{t_e},$$

where

- $E_{\mathrm{M881}}(\lambda,t)$ is the uncorrected irradiance assigned to the instrument's internal lamp based on calibrations with M881
- $E_{\mathrm{M881,corrected}}(\lambda,t)$ is the corrected irradiance assigned to the internal lamp
- t is time, with t_e symbolizing 7/7/00
- i is an integer between 0 and 10, incremented by one with each absolute scan; i_{te}=10.

With this definition, $E_{\mathrm{M881,corrected}}(\lambda,t) = E_{\mathrm{M881}}(\lambda,t)$ for the M-881 scan on 9/24/99 (i=0) and $E_{\mathrm{M881,corrected}}(\lambda,t_e) = E_{\mathrm{200W020}}(\lambda,t_{\mathrm{e}})$ for the scan on 7/7/00 (i=i_{te}=10).

Table 5.5.1. Lamps used at San Diego to establish Volume 9 calibrations.

Serial Number	Latest Calibration	Use
200W010	BSI 4/99	Site Standard San Diego Volume 9
200W016	BSI 1/98	Long-term reference
200W020	Optronic 9/98	Site Standard San Diego Volume 9
200W022	BSI 1/98	Long-term reference
M-764	Optronic 10/92	Site Standard McMurdo Vol. 8; new traveling standard
M-874	Optronic 9/98	Traveling Standard
M-881	BSI 4/99	Site Standard San Diego Volume 9

The following figures illustrate the relationship between all lamps, giving confidence in the calibration scale to the San Diego Volume 9 data.

Figure 5.5.1 shows a comparison of lamps M-881and 200W010 with 200W020 at the beginning of the Volume 9 San Diego season. M-881 agrees to within ±0.5% with 200W020, confirming that the calibration of M-881, established with M-764 on 4/27/99 is still valid. As mentioned above, 200W010 drifted by 3-4% between May and September 1999, resulting in the difference of about 4% with respect to 200W020. Figure 5.5.2 shows that M-881 and M-874 agree to within ±1%.

Figure 5.5.3 shows a comparison of lamps 200W016, 200W022 and M-874 with 200W020 on 7/12/00. Since 200W016 and 200W022 have not been used since November 1998 when they were calibrated with M-874, it can be assumed that they represent the BSI calibration scale from 1998. Both lamps agree to within ±1% with 200W020. Since 200W020 was only used once between 9/24/99 and 7/12/00, the comparison of 200W020 and M-881 shown in Figure 5.5.1 can therefore directly be related to the results of Figure 5.5.3. From this it can be concluded that the calibrations of the lamps M-881, 200W016, 200W022, 200W020, and 200W022, as applied to San Diego Volume 9, are consistent on the ±1% level, and that this level also represents the BSI irradiance scale from November 1998. Figure 5.5.2 shows that the calibration of M-874 at the beginning of the season is also in good agreement to this scale. However, as mentioned above, M-874 has drifted in the first half of 2000, leading to the 2-3% discrepancy illustrated in Figure 5.5.3. The drift was further confirmed in March 2001 when M-874 was re-calibrated by Optronic Laboratories

A comparison of lamps 200W010, M-874, and M-881 with 200W020 on 7/7/00 (Figure 5.5.4) confirms the drifts of M-881 and 200W010 with respect to 200W020, which was already mentioned above. The difference of M-874 and 200W020 is consistent with the results shown in Figure 5.5.3.

Figure 5.5.5 finally shows a comparison of lamps 200W010, M-874, 200W016, and 200W022 with M-764 on 10/12/00, which took place during the CUCF intercomparison in 2000. Although this comparison was performed about two months after the end of Volume 9, it gives further insight in the accuracy of the irradiance scale applied to Volume 9 data. Lamps 200W016 and 200W022 agree with M-764 to within ±2%. This is an important finding since M-881 and 200W010 were initially calibrated with M-764. The good agreement of M-764 with the long-term standards 200W016 and 200W022 gives confidence in the calibration of M-764, which in turn served as the reference standard for the re-calibration of M-881 and 200W010. M-874 and 200W010 deviate by about the same amounts from M-764 on 10/10/00 (Figure 5.5.5) and on 7/7/00 (Figure 5.5.4).

From all lamp comparisons performed during the Volume 9 San Diego season it can be concluded that the results are consistent, showing the good agreement of lamps 200W016, 200W020, 200W022, M-764, and M-874 (at the beginning of the season), which can all be linked to calibrations established in 1998. The drifts of 200W010 and M-881complicate the establishment of instrument calibrations but the comparisons with the other lamps gives confidence in the irradiance scale applied to solar data.

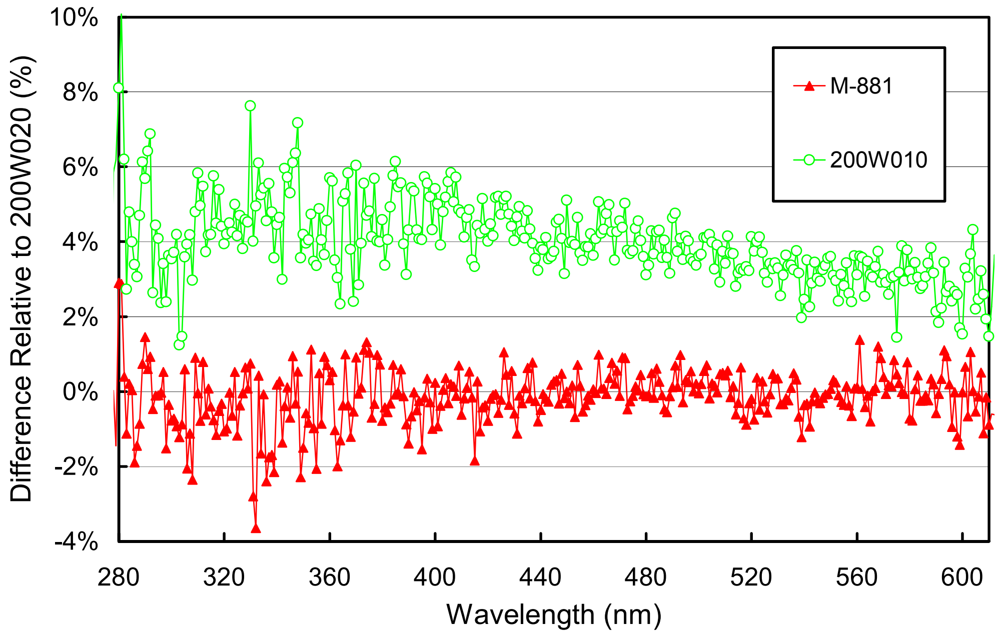

Figure 5.5.1. *Comparison of lamps M-881 and 200W010 with 200W020 on 9/24/99 at the beginning of the Volume 9 San Diego season.*

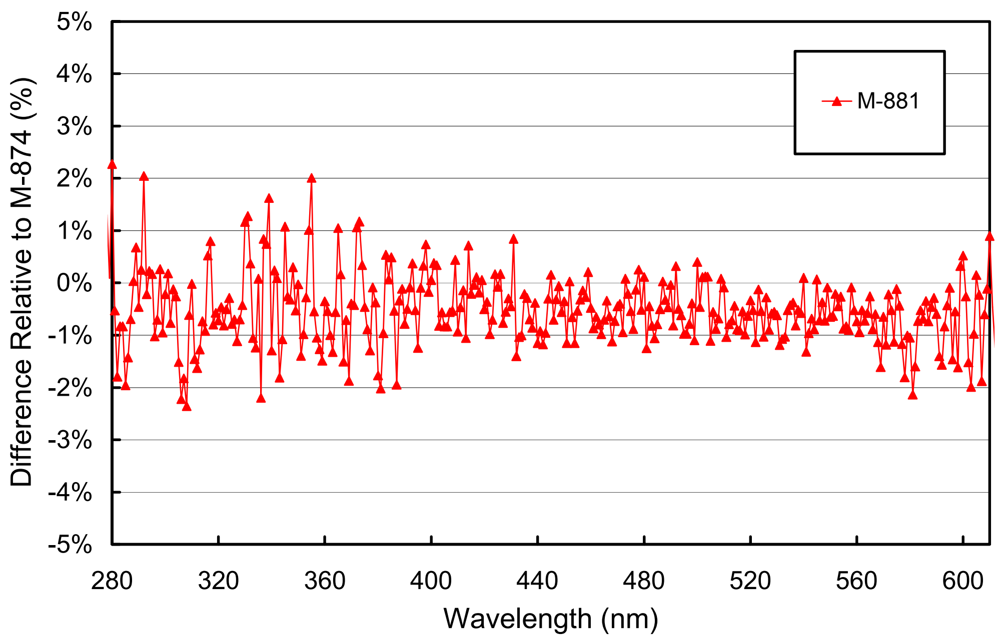

Figure 5.5.2. *Comparison of standard M-881 with M-874 on10/22/99.*

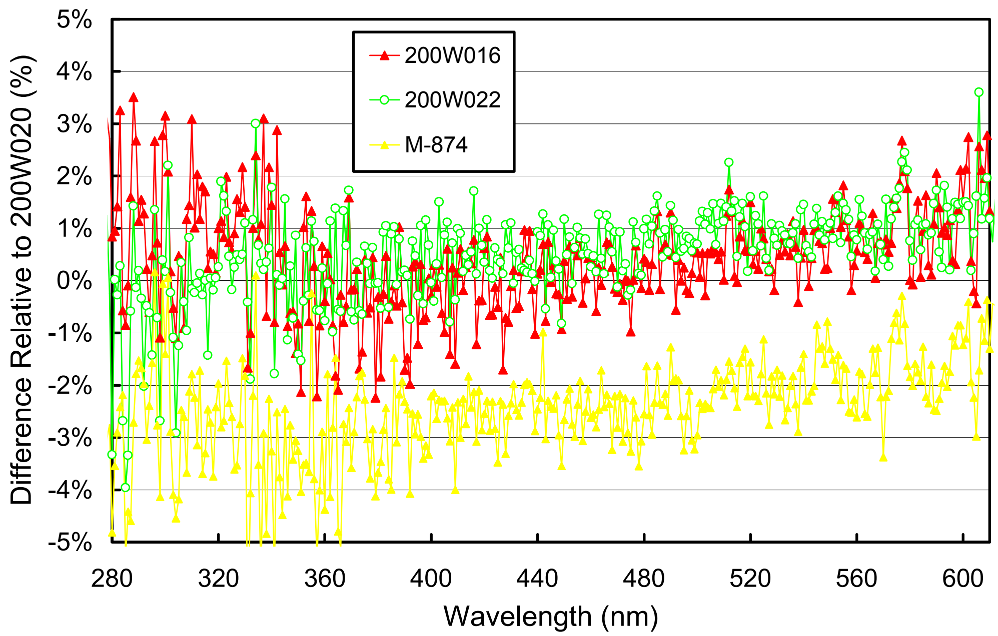

Figure 5.5.3. *Comparison of lamps 200W016, 200W022 and M-874 with 200W020 on 7/12/00.*

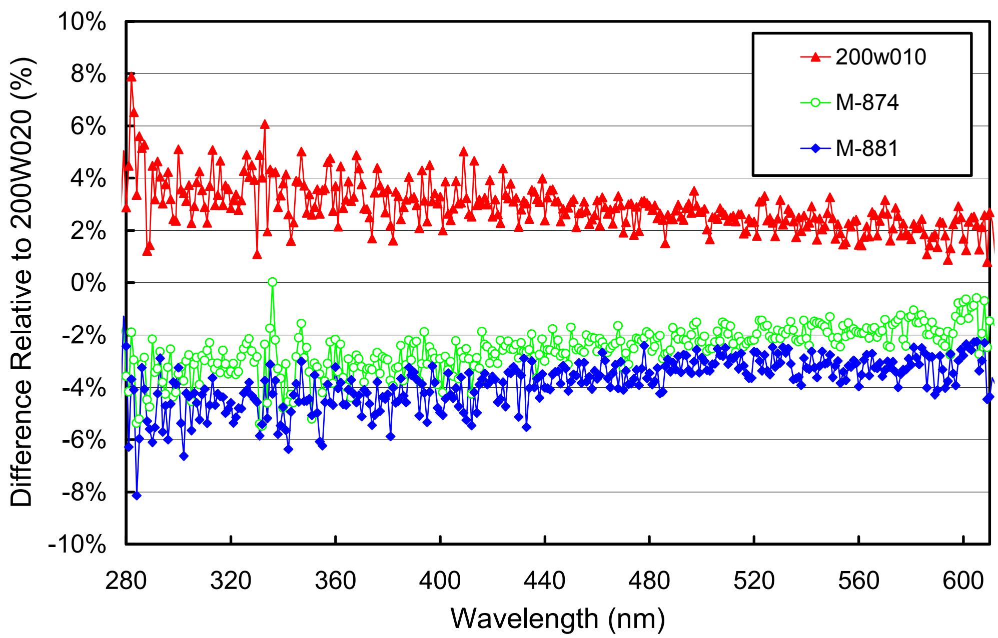

Figure 5.5.4. *Comparison of lamps 200W010, M-874, an M-881 with 200W020 on 7/7/00.*

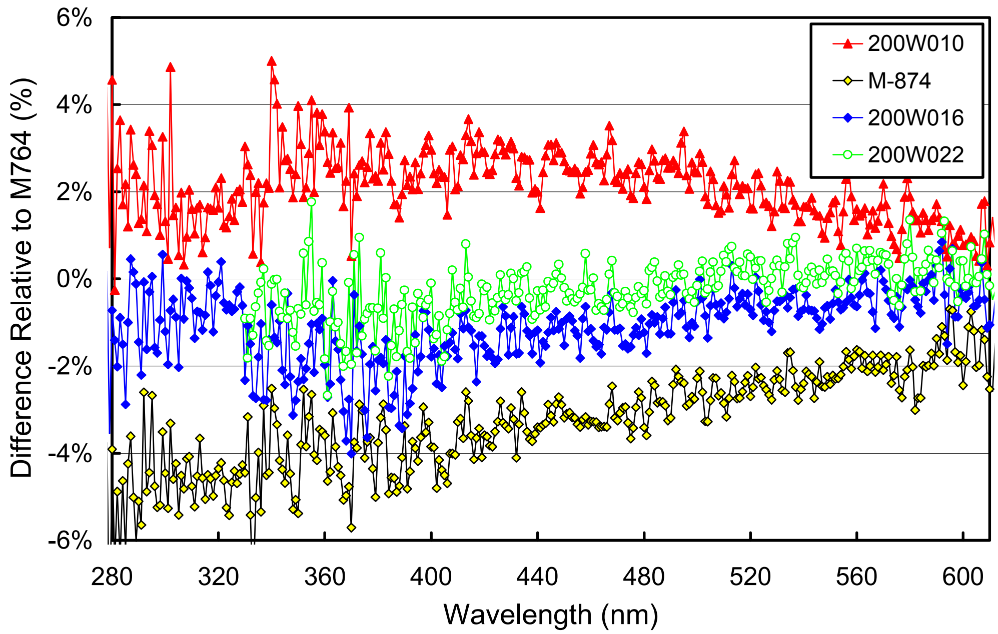

Figure 5.5.5. *Comparison of lamps 200W010, M-874, 200W016, and 200W022 with M874 on10/12/00, during the CUCF intercomparison in 2000.*

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%. This procedure was not applied to San Diego Volume 9 data since the internal lamp was stable to within ±1.0% during the whole season, although absolute calibrations suggested that the irradiance assigned to the lamp has to be adjusted by about 8% during the season. The reason of this discrepancy is unknown, but likely related to changes in the optics block of the instrument.

Figure 5.5.6 shows TSI measurements and PMT currents at 300 and 400 nm during response scans. TSI measurements agree to within ±1.5%, confirming that the internal lamp was stable. PMT currents show a drift of 15-17% over the season, the reason of which is unknown. Note that the drift in instrument responsivity does not affect solar data because the daily response scans are not exclusively performed for monitoring drifts, but also for correcting these drifts. Day-to-day changes, which would affect solar data, are below 0.5%.

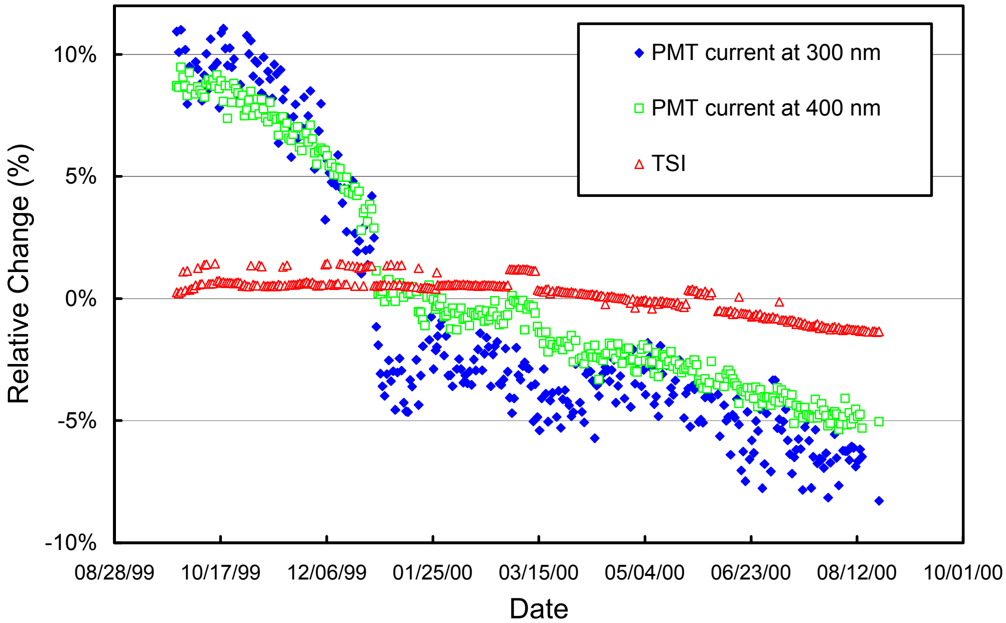

Figure 5.5.6. *Time-series of PMT current at 300 and 400 nm, and TSI signal during measurements of the internal irradiance reference lamp during the San Diego 1999-2000 season. The data is normalized to the average value of the whole season.*

The season was split into six periods, each of which has a different irradiance spectrum assigned to the internal lamp (see Section 4.2.1.2 for details). Table 5.5.2 gives for each period the 1-σ Standard Uncertainty of the calibration spectrum. Note that this uncertainty is only a measure of the variability of calibrations in a given period. It is not the total calibration uncertainty, which includes also uncertainties in the calibration values of standard lamps. The uncertainty for each of these periods is usually the ratio of standard deviation and average irradiance calculated from all calibration files performed in that period. These ratios are plotted in Figure 5.5.7. The standard uncertainty is usually below 2%, except for a subset of Period 2, from 10/12/99 – 10/21/99, which lacks reliable absolute calibrations.

Figure 5.5.8 shows the ratios of irradiance assigned to the internal reference lamp, referenced to Period 1. There is a 4% change in the UV between Period 1 and 2, which leads to the relatively high calibration uncertainty for the 10/12/99 – 10/21/99 period. Note that the calibrations for Periods 4 and 5, which include most of the season, are in good agreement. Period 6 includes effectively only three days, since the remaining days have been lost due to the wavelength offset of 10 nm mentioned above, which could not be corrected.

Table 5.5.2. 1-σ standard uncertainty of system calibration caused by responsivity drifts.

Period			Number of absolute scan	Standard uncertainty in %			Remarks
Label	Start	End		UV-B	UV-A	VIS	
Period 1	09/23/99	10/11/99	3	1.9	1.0	0.4	Standard calibration
Period 2	10/12/99	10/21/99	N/A	2.4	1.5	0.9	Period without absolute scans
Period 2	10/22/99	11/26/99	3	0.8	0.6	0.5	Standard calibration
Period 3	11/27/99	12/16/99	1	1.1	1.0	0.9	Single scan
Period 4	12/17/99	07/07/00	9	1.1	1.0	0.8	Standard calibration
Period 5	07/08/00	08/15/00	7	1.2	0.8	0.5	Standard calibration
Period 6	08/16/00	08/25/00	2	0.7	0.9	0.6	Standard calibration

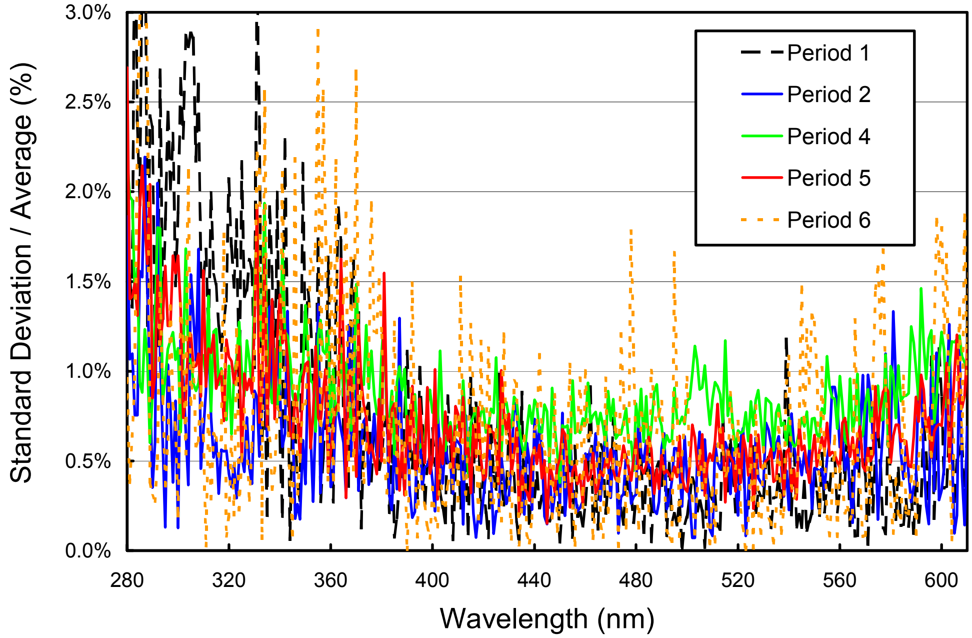

Figure 5.5.7. *Ratio of standard deviation and average calculated from the absolute calibration scans used to establish the calibration of the San Diego spectroradiometer for the 1999-2000 season.*

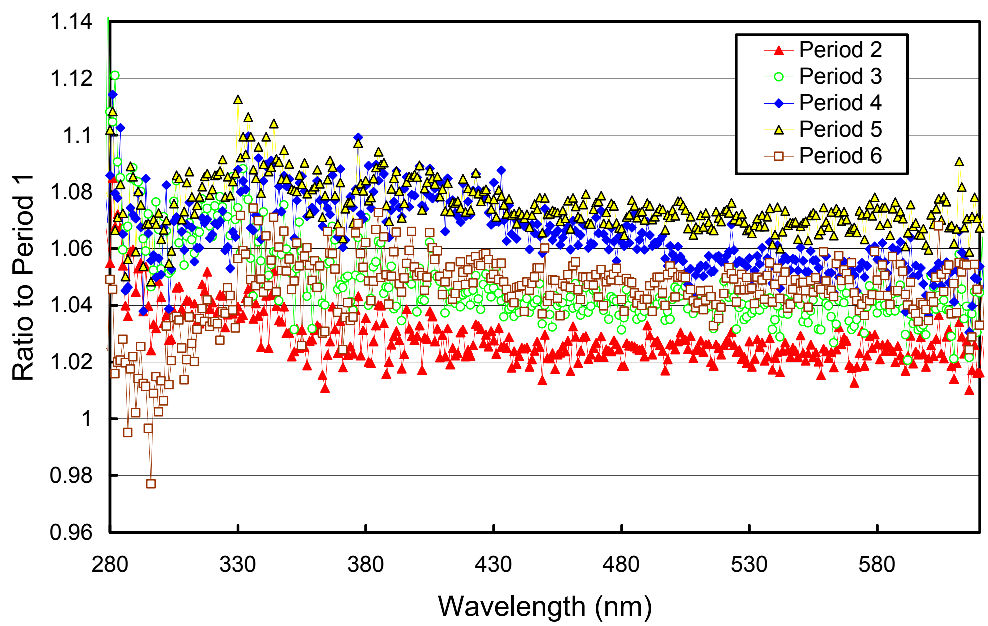

Figure 5.5.8. *Ratios of irradiance assigned to the internal reference lamp, referenced to Period 1.*

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, 383 scans were evaluated. For 76% of the days, the change in offset was smaller than ±0.025 nm; for 95% of all days shifts were below 0.055 nm. Eight scans showed a change larger than ±0.1 nm and the wavelength calibration was adjusted accordingly.

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. The thick line in Figure 5.5.10 shows the resulting correction function that was applied to the Volume 9 San Diego data. The function depends upon wavelength, which is caused by non-linearities of the monochromator drive. In order to demonstrate the difference between the result of the Fraunhofer-correlation method and the method that was historically applied, Figure 5.5.10 also includes the correction function that was calculated with the "old" method, i.e., the function is based on internal wavelength scans only. The average difference between both approaches is approximately 0.11 nm with a somewhat larger difference between 350 and 400 nm. As explained in Section 4.2.2.2, this bias is caused by the different light paths for internal wavelength scans and solar measurements.

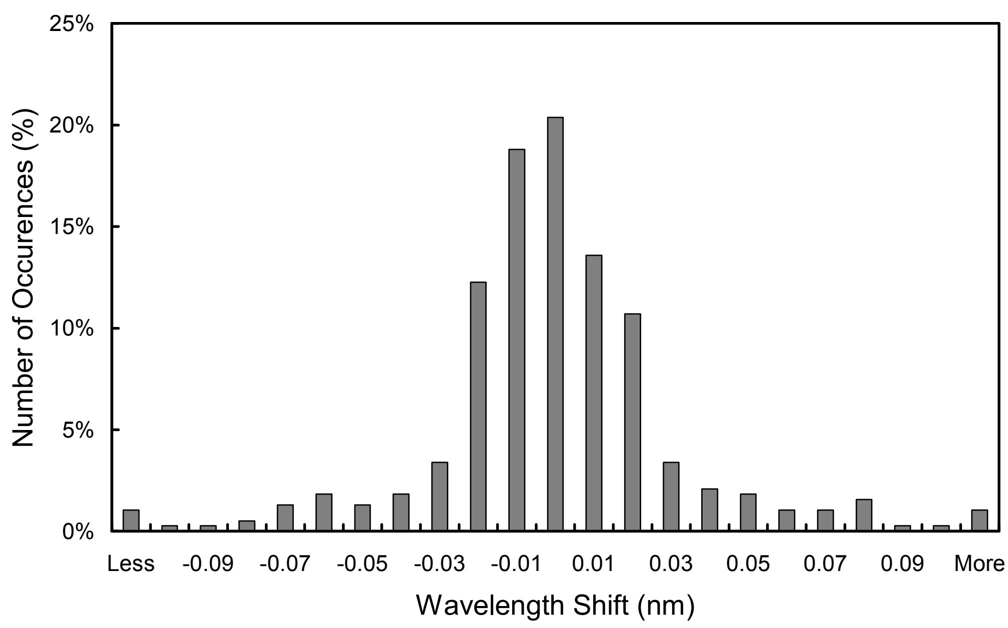

Figure 5.5.9. *Differences in the measured position of the 296.73 nm mercury line between consecutive wavelength scans. The x-labels give the center wavelength shift for each column. The 0-nm histogram column covers the range -0.005 to +0.005 nm. "Less" means shifts smaller than –0.105 nm; "more" means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

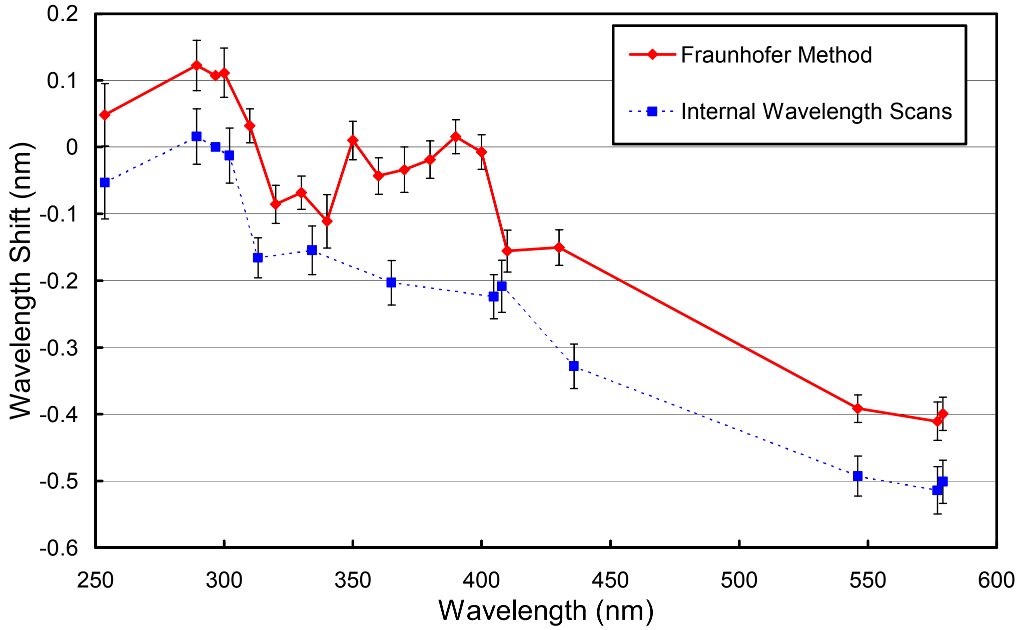

Figure 5.5.10. *Monochromator non-linearity for the San Diego 1999-2000 season. Solid line: Correction function calculated with the Fraunhofer-correlation method, applied to correct the San Diego Volume 9 data. Broken line: Correction function calculated with the method that was historically applied. The offset difference between both methods is 0.11 nm. The error bars show the 1σ standard deviation of the wavelength shift for the season.*

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 with somewhat larger shifts around 1/7/00. 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).

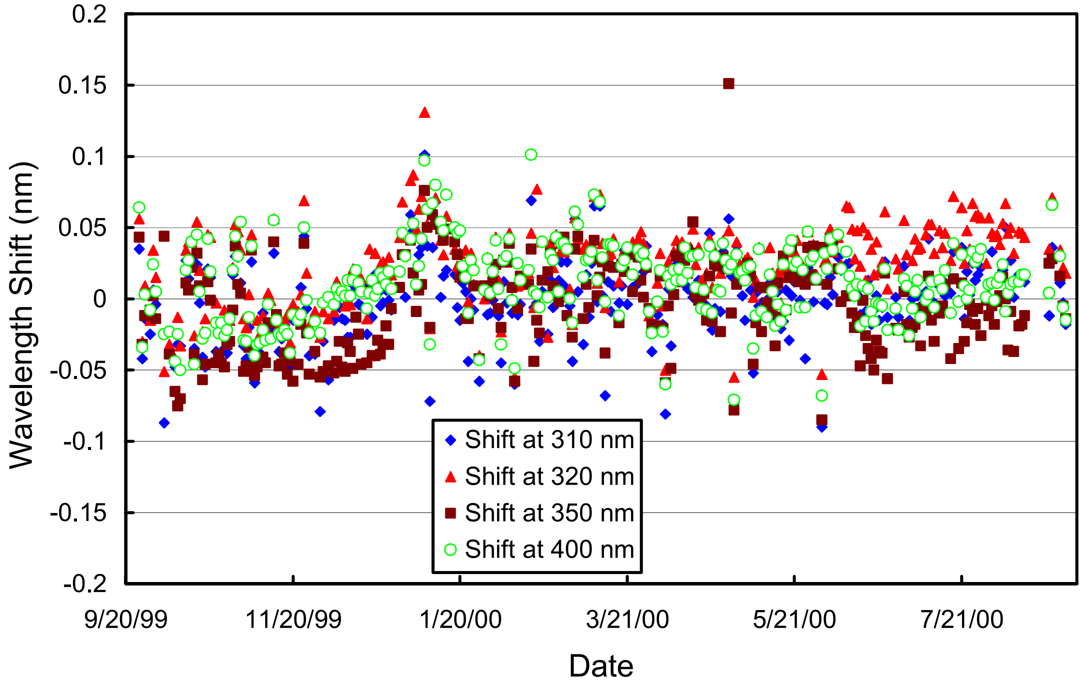

Figure 5.5.11. *Check of the wavelength accuracy of the final data at four wavelengths by means of Fraunhofer correlation. The noontime measurement has been evaluated for each day of the season.*

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 during October 1999 and August 2000. The wavelength scale of the figure is the same as applied during solar measurements. 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 0.14 nm to shorter wavelengths. External scans have a bandwidth of about 1.00 nm FWHM, whereas the bandwidth of the internal scan is only 0.70 nm. Since external scans have the same light path as solar measurements, they more realistically represent the monochromator bandpass relevant to solar scans. The bandwidth for the scans recorded in October 1999 is slightly larger than the bandwidth in August 2000.

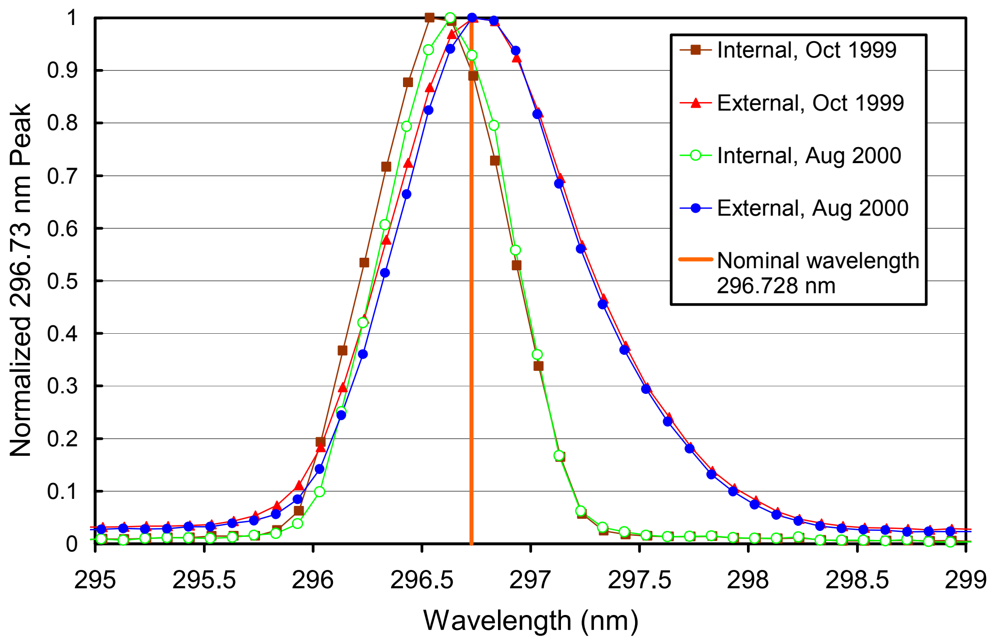

Figure 5.5.12 *The 296.73 mercury line as registered by the PMT from external and internal sources.*

5.5.4. Missing Data

A total of 15712 scans are part of the published San Diego Volume 9 dataset. These are 93% of the scans scheduled. Approximately 4% of all scans were missed due to technical problems and 3% were superceded by tests and calibrations. Since the installation at San Diego serves as the test and training facility for the entire network a higher number of missing solar scans can be expected. Of all missing scans, 411 were superceded by absolute, and 44 by wavelength scans. 15 data scans were lost on 10/11/99 and 10/22/99 when the calibration equipment was still in place during solar scans. 44 scans were lost on 3/22/00 due to a full storage medium, and 86 data scans were missed on 6/5/00 and 6/6/00 for similar reasons. Various tests (amongst others measurement of the system's angular response on 8/23/00 and 8/25/00, Y2K-testing and adjustment of electronics on 12/27/99 and 12/28/99, external wavelength scans on 10/11/99) caused a loss of 122 data scans. Eight scans were lost on 3/17/99 when a hard disk drive was exchanged.
For unknown reasons, the wavelength calibration of the system was off by 10 nm between 8/15/00 and 8/22/00. This shift is too large to be corrected. A total of 367 scans were lost. Similar problems with the wavelength alignment caused a loss of 42 scans on 10/3/99 and 10/4/99.