5.5. San Diego (8/16/02 – 8/19/03)

The 2002-2003 season at San Diego includes the period 8/16/02 – 8/19/03. 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 12 season:

- **8/16/02:** Start of the season following operator training
- **9/16/02, 9/17/02:** Comparison of standard lamps
- **9/21/02-9/23/02:** Comparison SUV-100 with SUV-150B
- **10/2/02:** External wavelength scans
- **10/3/02 – 10/7/02:** Comparison SUV-100 with SUV-150B
- **10/7/02:** Comparison of system shunt/voltmeter with reference shunt/voltmeter
- **10/10/02:** Angular response measurements
- **10/11/02:** Replacement of PMT and PMT housing; dark scans
- **10/15/02, 10/16/02:** Modification of new PMT housing; dark scans
- **10/16/02:** Angular response measurements
- **11/15/02 - 12/1/02:** GUV calibrations with SUV spectra
- **1/6/03:** Replacement fan thermoelectric cooler roof box
- **3/14/03:** Replace of system shunt and voltmeter
- **4/21/03 - 4/25/03:** Operator training, which included comparison of standard lamps, performance of external HG scans, replacement of PMT, and realignment of monochromator
- **5/8/03:** Replacement of mercury lamp holder
- **5/9/03:** External wavelength scans
- **5/25/03 - 5/26/03:** Comparison of standard lamps
- **5/25/03 - 5/31/03:** GUV calibrations with SUV spectra
- **5/27/03 – 5/28/03:** Comparison SUV-100 with SUV-150B
- **8/1/03:** Software upgrade
- **8/19/03**: End of season; site operator training

Some of these activities are explained in more detail below:

During the angular response scans performed on 10/10/02 a comparatively high drift in PMT dark current was noticed. Moreover, we had discovered during previous site visits that the PMT housing is not well sealed, causing the condensation of ambient moisture inside the housing. In response to these problems, PMT tube and housing were replaced by new parts on 10/11/02. Tests with the new setup revealed a change in the dark current of the new PMT when the thermoelectric cooler of the housing was switching. The problem was solved by changing the grounding of the housing, and the modified cooler was reinstalled on 10/15/02. The systems performed fine with the new PMT/housing assembly, but the sensitivity of the new PMT was approximately a factor of 3 lower than the sensitivity of the previously installed PMT. This lead to somewhat larger signal noise and larger random errors in calibrated solar data. The original PMT was reinstalled into the new housing during the operator training in April 2003. We have no indication that this swap lead to dark current drifts as observed with this PMT in October 2002. During the end-of-season service it was discovered that the face-window of the new PMT housing had delaminated allowing moisture to leak into the housing. The window was replaced during service, but moisture condensing on the window may have caused some changes in responsivity during the months prior to service.

As has been mentioned in previous Operations Reports, internal wavelength scans have a smaller bandwidth than their external counterparts. This is partly caused by the different light paths for both scan types and the fact that the coupling of the internal mercury lamp is not matched to the f-number of the monochromator. External scans of the 296.73 nm mercury line have typically a bandwidth of 1.0 nm FHWM whereas the bandwidth of internal scans is typically 0.7-0.75 nm. After the system service in August 2002 the bandwidth for internal scans dropped to a anomalous low value of 0.52 nm. In response to the problem, the exit port of holder of the internal mercury lamp was modified from a round opening, which allowed only radiation from the center part of the lamp to reach the entrance of the monochromator, to an elongated hole. With this modification, radiation emitted over the whole length of the pen ray type mercury lamp can reach the monochromator . This geometry is better matched to the monochromator’s f-number and more comparable to the geometry of external scans. The modified holder was installed during mid-season operator training in April 2003. With this holder, the bandwidth of internal mercury scans increased to 0.94 nm, thus becoming comparable to the bandwidth of external scans. We are planning to modify the lamp holders of the instruments at other network sites in the same way.

The fuse of the PMT cooler blew five times during the season. This lead to increased signal noise and a temporary change in PMT sensitivity. The calibration files were adjusted whenever a fuse was replaced (i.e. on 9/9/02, 1/2/03, 1/10/03, 5/29/03, and 7/17/03) . However, the time when a fuse became defective is only known to within one day. In particular solar scans from 12/31/02, 1/6/03, and 7/13/03 are affected.

With exception of the problems described above, the system operated normally during the Volume 12 period. Approximately 92% 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 operator training, upgrades, and instrument calibration and maintenance.

This is the first Volume that provides data from a GUV-511 moderate-bandwidth filter radiometer (see Section 2). These data complement SUV-100 measurements and are also used for quality control. A comparison of GUV-511 and SUV-100 data revealed an upward step of about 8% in SUV-100 data, occurring on 1/31/03. The cause of this level-change could not be found and the step gradually disappeared within the next 1-2 weeks. No correction to SUV-100 data was applied. See Section 5.5.5 for further details.

5.5.1. Irradiance Calibration

The calibration of Volume 12 solar data was mostly based on lamp 200W028. The second site standard 200W029 was only used in August and September 2002. The calibration of this lamp is not reliable as it became misaligned in its holder in May 2002. Lamp 200W028 was frequently compared with the traveling standard M-764 and also with lamps M-763 and 200W022. The latter lamps are long-term standards that are used only two or three time per year. All lamps had been calibrated by Optronic Laboratories in March 2001. The calibration of the M-763 and M-764 was further confirmed during CUCF audits (see Introduction to Section 5).

Figure 5.5.1 shows a comparison of 200W028, 200W029, and M-763 with the traveling standard M-764 performed in September 2002. Lamps 200W028, M-763, and M-764 agree to within ±1.5%; lamp 200W029 deviates from this group by about 2% due to the misalignment mentioned above.

Figure 5.5.2. shows a comparison of 200W028, M-763, and 200W022 with M-764 performed in May 2002. All lamps agree on the ±1.5% level. The results of Figure 5.5.1 and 5.5.2 are consistent within the comparison uncertainty, indicating that lamp 200W028 remained stable over the period of Volume 12.

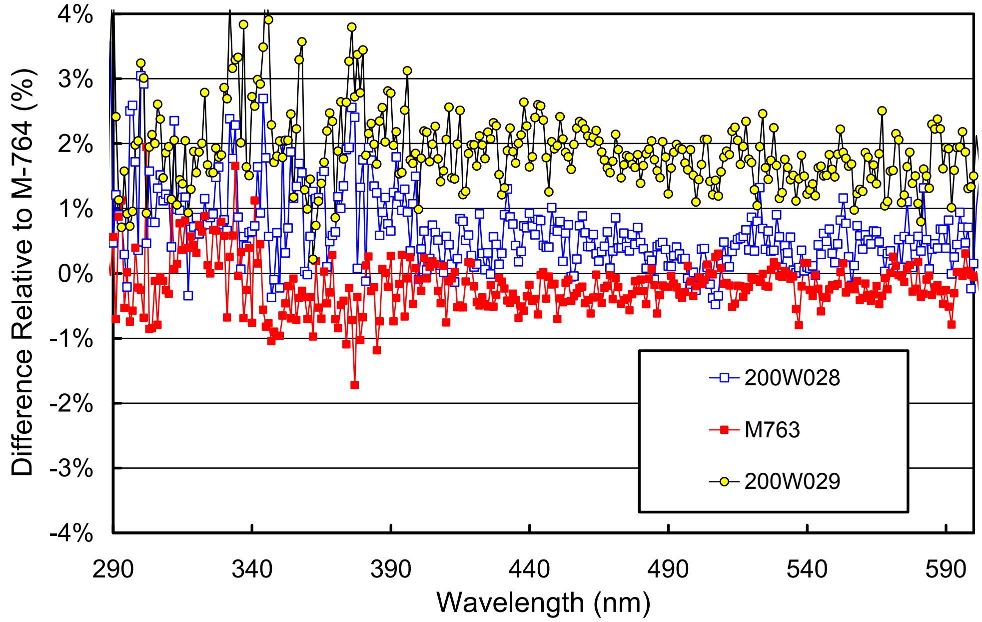

Figure 5.5.1. *Comparison of 200W028, 200W029, and M-763 with the traveling standard M-764 in September 2002.*

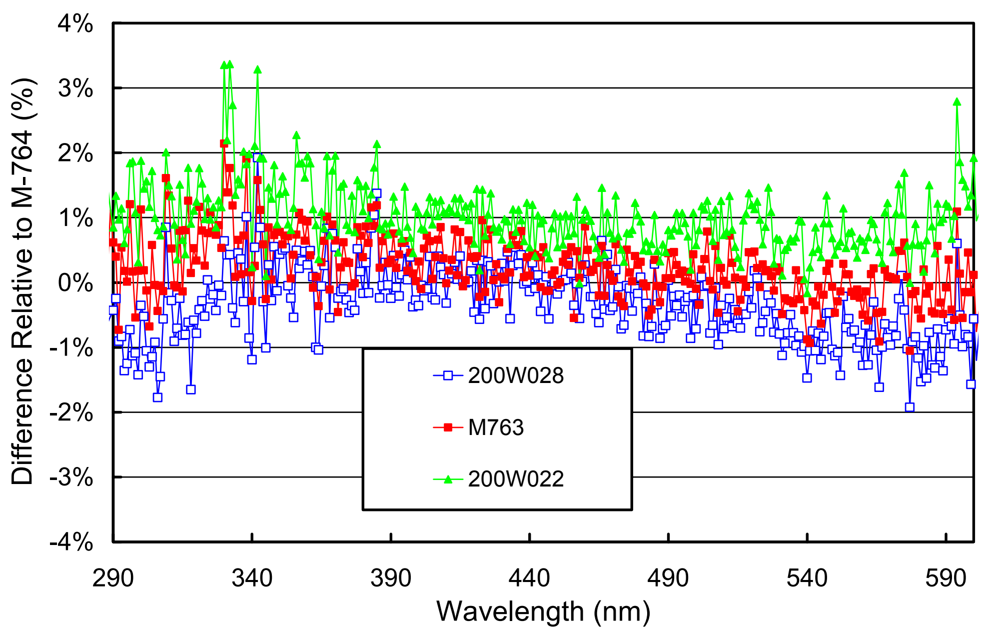

Figure 5.5.2. *Comparison of 200W028, M-763, and 200W022 with M-764 in May 2002*

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 lamp. 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 5.5.3 shows TSI measurements and PMT currents at 300 and 400 nm during response scans. The season is considered in three sections, labeled 1 – 3. TSI and PMT data were normalized to the average value in each section. Section 1 ends on 10/10/02 and encompasses the time interval when the original PMT tube and housing were installed. Section 2 comprises the interval when the new PMT tube and housing were installed. In Section 3, the old PMT was installed in the new housing. Figure 5.5.3 shows that TSI measurements were constant to within ±1% during the entire season, indicating excellent stability of the internal reference lamp. PMT currents in Section 1 and 3 were constant to within ±2% with the exception of the section 7/13/03 – 7/17/03 when the fuse of the PMT cooler had failed. The system calibration was adjusted by 5% during this section, however, as the exact time of the fuse failure is not known, solar measurements from 7/13/03 are subject to 5% uncertainty. During Section, when the new PMT was installed, PMT currents steadily decreased by about 5% with the exception of the short periods 10/12/02 – 10/15/02, 12/31/02 – 1/2/03, and 1/6/03 – 1/9/03. As mentioned before, the grounding of the housing required modification. The section 10/12/02 – 10/15/02 marks the interval immediately after the installation of the new assembly and before the grounding was modified. During the other two short sections the PMT cooler fuse had failed. All changes in system responsivity were corrected using the information from the daily response scans.

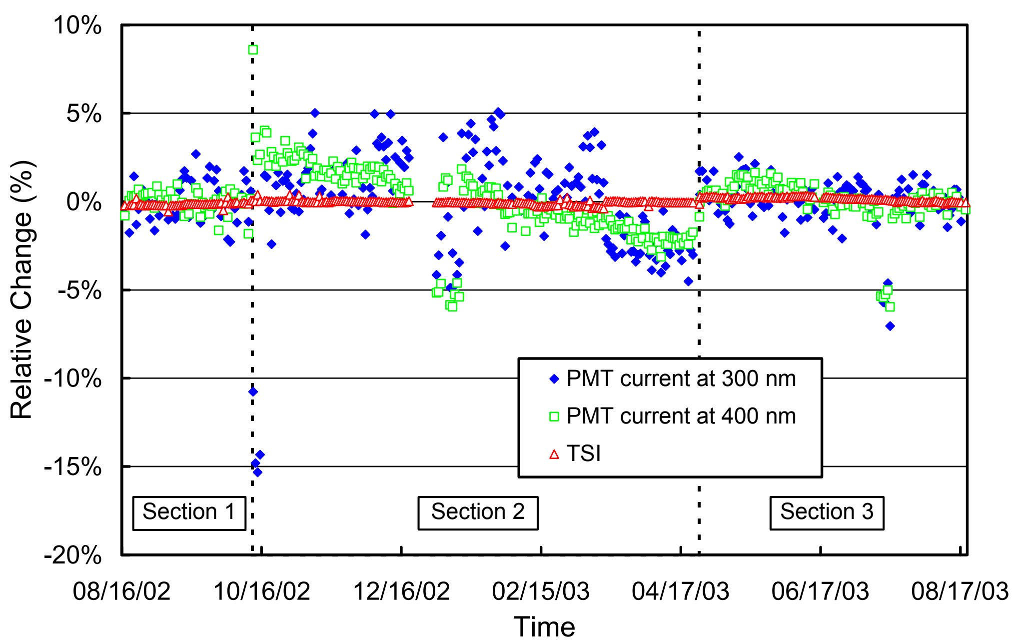

Figure 5.5.3. *Time-series of PMT current at 300 and 400 nm, and TSI signal during measurements of the internal irradiance reference lamp during the San Diego 2002-2003 season. The data is normalized to the average value of each of the three sections indicated in the graph.*

Figure 5.5.4 shows the change of the spectral irradiance assigned to the internal reference lamp. There are large changes in the assigned irradiance owing to mid-season system service, PMT replacement, and installation of the modified mercury lamp holder. Periods of unique calibration functions, labeled P1 – P7, are summarized in Table 5.5.1.

The season opening calibrations, which were performed on 8/16/02, deviate by 3-5% from results of the next calibration on 8/30/02. This change is likely caused by "settling in" of the system after service. The calibration of solar scans during the last two weeks in August 2002 is affected by an additional 4% uncertainty as the temporal behavior of the settling process could not be resolved.

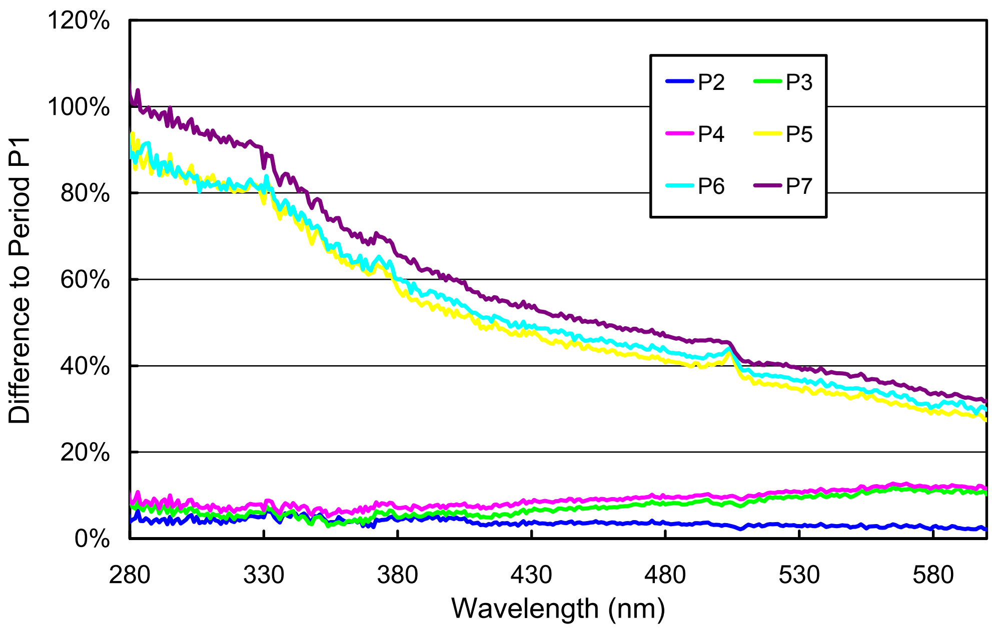

Figure 5.5.4. *Ratios of irradiance assigned to the internal reference lamp. See Table 5.5.1 for period assignment.*

Table 5.5.1: Assignment of calibration periods.

Period			Number of absolute scans	Remarks
Label	Start	End		
P1	08/16/02	08/22/02	2	3-5% drift during first few days of period
P2	08/23/02	10/11/02	10	PMT and PMT housing changed after this period
P3	10/12/02	11/29/02	4	
P4	11/30/02	04/23/03	15	Mid-season training, PMT replacement, monochromator service after this period
P5	04/24/03	04/28/03	1	
P6	04/29/03	05/07/03	1	Mercury lamp holder replaced after this period
P7	05/08/03	08/19/03	15	

Figure 5.5.5 shows the relative standard deviation of the spectra that make up the irradiance assigned to the internal lamp in each period (No data are given for Periods P1, P5 and P6 as less than three absolute scans were performed in these periods). The plot is useful for estimating the variability of the calibrations in each period. As can be seen, calibrations are consistent to within 1.5% (1σ) in all periods for wavelength above 340 nm. At shorter wavelengths, the calibrations are affected by noise resulting in a somewhat larger variability.

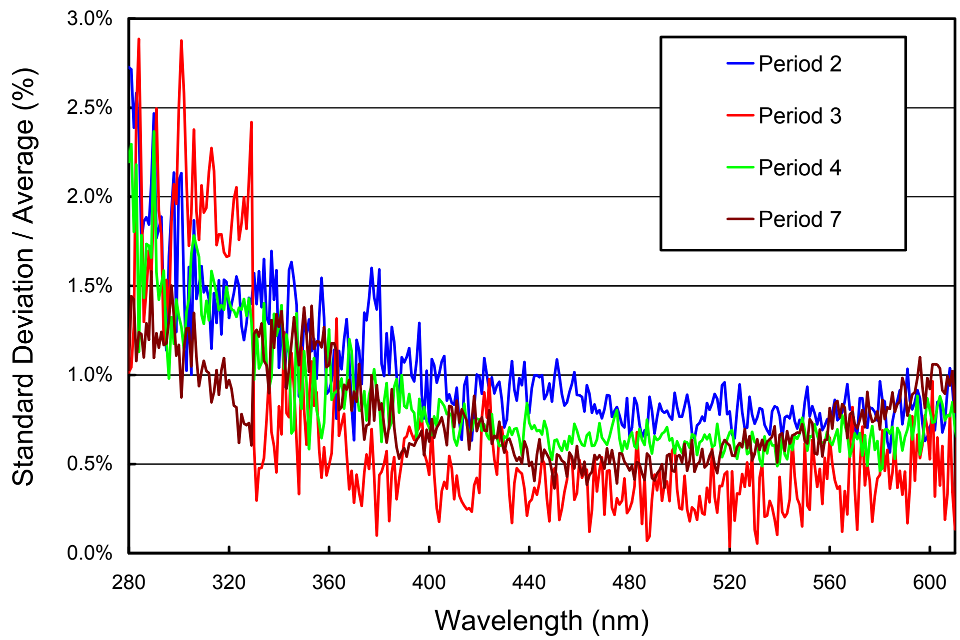

Figure 5.5.5. *Ratio of standard deviation and average calculated from the absolute calibration scans used to establish the calibration of the San Diego spectroradiometer for the 2002-2003 season. Only period with at least three absolute scans are shown.*

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 5.5.6 shows the differences in the wavelength offset of the 296.73 nm mercury line between two consecutive wavelength scans. In total, 410 scans were evaluated. For 91% of the days, the change in offset was smaller than ±0.025 nm; for 96% of all days shifts were below 0.055 nm. Twelve scans showed a change larger than ±0.1 nm, partly caused by system maintenance. The wavelength calibration was adjusted accordingly.

After 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 new Fraunhofer correlation method developed for Version 2 NSF network data. In contrast to the previously used algorithm, shifts for the whole spectral range are determined and results from internal wavelength scans are not required. Eight different functions were applied. Note that the functions fall in two groups. The first group applies to the period before the mid-season system service in April 2003, and the second group to the remainder of the season. The general shift between both groups can be attributed to the monochromator service performed. The correlation algorithm is less reliable between 500 and 600 nm, partly due to the relative weakness of Fraunhofer lines in this spectral range. This may explain the comparatively large scatter of the different correction functions in this interval.

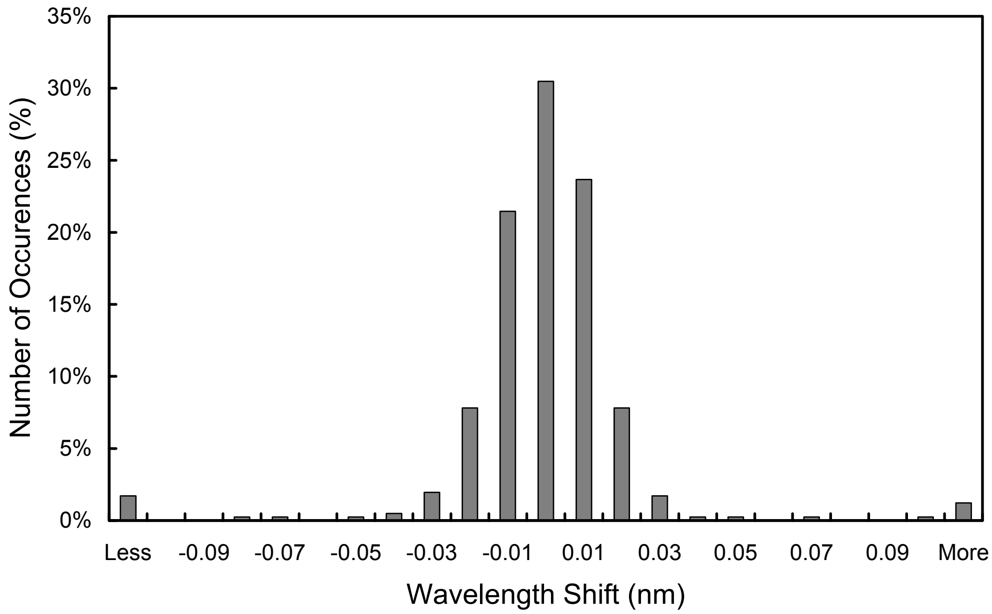

Figure 5.5.6. *Differences in the measured position of the 296.73 nm mercury line between consecutive wavelength scans. The x-labels give the center wavelength shift for each column. The 0-nm histogram column covers the range -0.005 to +0.005 nm. "Less" means shifts smaller than –0.105 nm; "more" means shifts larger than 0.105 nm.*

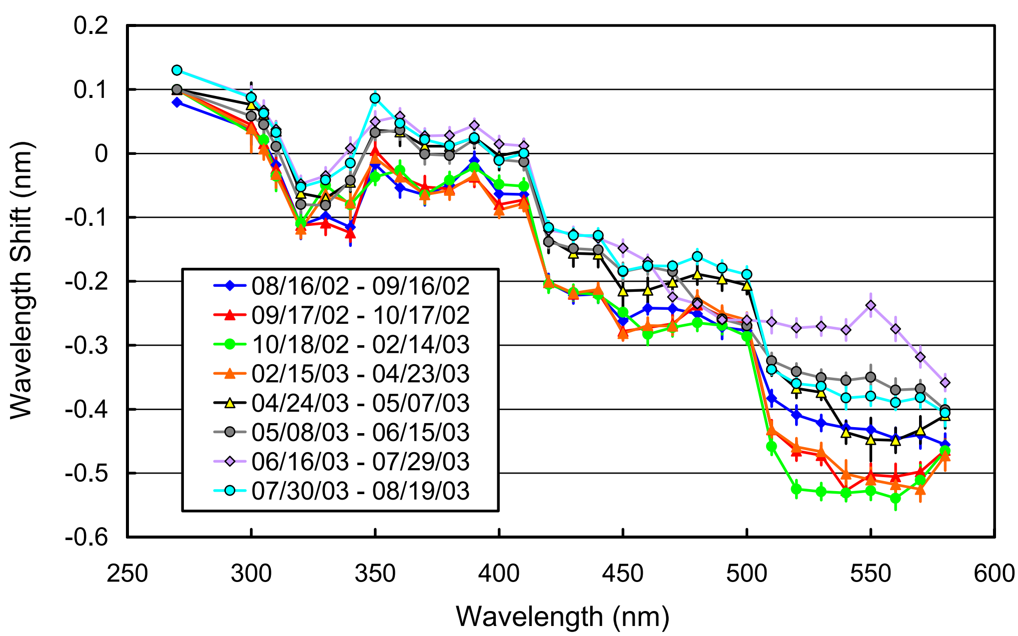

Figure 5.5.7. *Monochromator non-linearity correction functions for the San Diego 2002-2003 season.*

After the data was wavelength corrected using the shift function described above, the wavelength accuracy was confirmed with the Fraunhofer method. The results are shown in Figure 5.5.8 for four UV wavelengths, evaluated for all noontime scans measured during the season. The residual shifts are typically 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. 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 5.5.8.

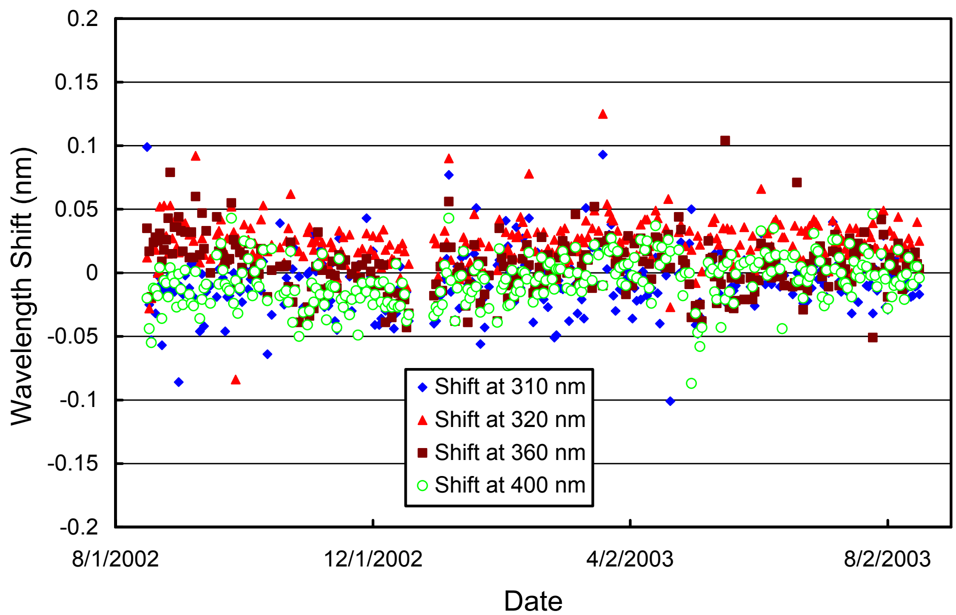

Figure 5.5.8. *Check of the wavelength accuracy of the final data at four wavelengths by means of Fraunhofer correlation. The noontime measurements have been evaluated for each day of the season.*

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 5.5.9 shows internal and external mercury scans measured in 2002 and 2003. External scans recorded in October 2003 and May 2003 are rather similar, indicating that mid-season monochromator service did not change the band pass of the system relevant for solar measurements: the bandwidth was 1.09 nm in both cases. Internal scans on the other hand show large variations. Between the system services in August 2002 and April 2003, the bandwidth of internal scans was 0.52 nm, which is abnormally low as the bandwidth of internal scans typically varies between 0.7 and 0.75 nm. Realignment of the monochromator during system service in April 2003 increased the bandwidth to a more normal value of 0.78 nm. A replacement of the mercury lamp holder in May 2003 increased the bandwidth to 0.93 nm. As mentioned in the introduction to this section, there is a better f-number match with the modified lamp holder as it allows radiation from the whole length of the mercury lamp to reach the entrance slit of the monochromator. (With the old holder, which had a circular opening centered in the middle of the pen ray type mercury lamp, only radiation from the center of the lamp was illuminating the monochromator). The main purpose of internal scans is to monitor and correct daily fluctuations in the monochromator's wavelength setting. For this correction, the shape of line scans is not very important. As the final wavelength calibration is based on the Fraunhofer line correlation method, variations in the bandwidth of internal mercury scans do not affect solar data.

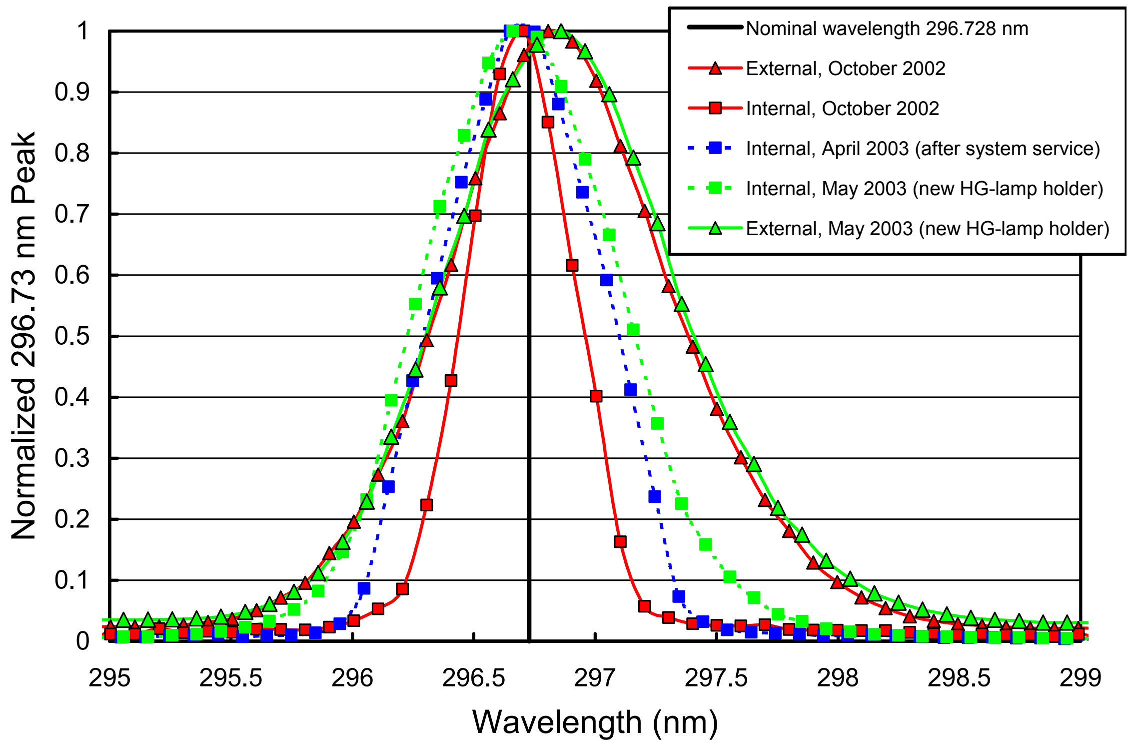

Figure 5.5.9. *The 296.73 mercury line as registered by the PMT from external and internal sources.*

5.5.4. Missing Data

A total of 16959 scans are part of the published San Diego Volume 12 dataset. These are 92% of all scans scheduled between 8/16/02 and 8/19/03. Approximately 2% of all scans were superceded by calibrations performed throughout the season. Mid-season operator training in April 2003 lead to a loss of 233 scans (1.3%). Additional reasons for missing solar data are technical problems (0.7%), operator errors (3.2%), and additional system service and upgrades. Table 5.5.2 describes the gaps in the published solar data in more detail.

Table 5.5.2 Missing scans San Diego Volume 12 (gaps due to calibration activities are not included).

Time Period	Scans missing	Reason
9/9/02	18	System control computer erroneously turned off; replacement fuse
10/2/02	4	External wavelength scans
10/7/02	8	Instrument collector shaded
10/7/02 – 10/8/02	12	Preparation comparison with SUV-150B spectroradiometer
10/10/02 – 10/11/02	15	Angular response and dark measurements
10/11/02	14	PMT tube and cooler replacement
10/12/02	7	Dark scans
10/15/02 – 10/16/02	71	Testing of PMT tube and housing, dark scans
10/16/02	7	Angular response measurements
10/17/02	16	Testing
12/20/02 – 12/30/02	420	Automatic scanning erroneously disabled
1/6/03	5	Replacement fan thermoelectric cooler roof box
1/10/03	5	Replacement fuse PMT cooler
3/5/03 – 3/6/03	16	Instrument collector shaded
3/10/03	13	Bad response scan
3/14/02	17	Replacement digital multimeter and shunt
4/2/03 – 4/3/03	4	Adjustment system sensitivity
4/21/03 – 4/25/03	201	Mid-season system service and operator training
5/6/03 – 5/7/03	31	Software problem
5/7/03	39	No suitable wavelength and response scan for pairing with data scan
5/8/03 – 5/9/03	16	Replacement of internal mercury lamp; external wavelength scans
5/29/03	2	Replacement fuse PMT cooler
6/15/03 – 6/18/03	166	Hard drive full
7/30/03	5	Software problem

5.5.5. GUV Data

During 2001, we started deploying Biospherical Instruments GUV-511 moderate-bandwidth filter radiometer at network sites in close proximity to the collector of the SUV-100. The GUV-511 instrument provides measurements in four approximately 10 nm wide UV bands centered at 305, 320, 340, and 380 nm, as well as photosynthetically active radiation (PAR). From data recorded at these wavelengths, total column ozone, spectral integrals, and dose rates for a large number of action spectra is calculated and made available in near real-time via the website http://www.biospherical.com/nsf/login/update.asp. Details about calibration and calculation of data products are at http://www.biospherical.com/nsf/presentations/SPIE_paper_5156-23_Bernhard.pdf. In addition to providing data via the Internet, the radiometer is also used to quality control SUV-100 measurements.

Figure 5.5.10 shows a comparison of GUV-511 and SUV-100 erythemal irradiance based on final Volume 12 data. For SZA smaller than 80°, 96.8% of the data agree to within ±10% with each other. The agreement for some data products (e.g. DNA damaging variation) may be worse than that for erythema due to principal limitations in calculating dose-rates from the four GUV-511 channels when the Sun is low and when the data product in question is heavily weighted toward wavelengths below 310 nm. We therefore advise data users to use SUV-100 rather than GUV-511 data when possible, in particular for low-Sun conditions.

The red arrow in Figure 5.5.10 indicates a step-change in the ratio of data of the two instruments. A comparison of the SUV-100 data with a second GUV-511 exhibited the same step-change, suggesting that the problem is caused by SUV-100 data. Further analysis revealed that the step occurred immediately after a calibration scan of the SUV-100 that was performed on 1/31/03. This calibration scan is consistent with the absolute calibrations performed on 1/17/03 and 2/14/03. The cause of the problem could not be determined, but the ratio GUV-511 / SUV-100 indicates that the problem has disappeared by mid February. This an example how GUV-511 can help to uncover problems in the SUV-100 data set that would go undetected otherwise.

Note that a new data set of SUV-100 data, named "Version 2" is currently in preparation (see http://www.biospherical.com/nsf/Version2/Version2.asp). Version 2 data are corrected for the cosine error of the SUV-100 spectroradiometer. Version 2 erythemal data are approximately 6% higher than the Version 0 data that are discussed in this report. GUV measurements were calibrated both against cosine error corrected and uncorrected SUV-100 data, and both data sets were published. Preliminary GUV data made available via the website http://www.biospherical.com/nsf/login/update.asp are based on the calibration with the cosine corrected SUV-100 data set, and are therefore approximately 6% higher than data plotted in Figure 5.5.10.

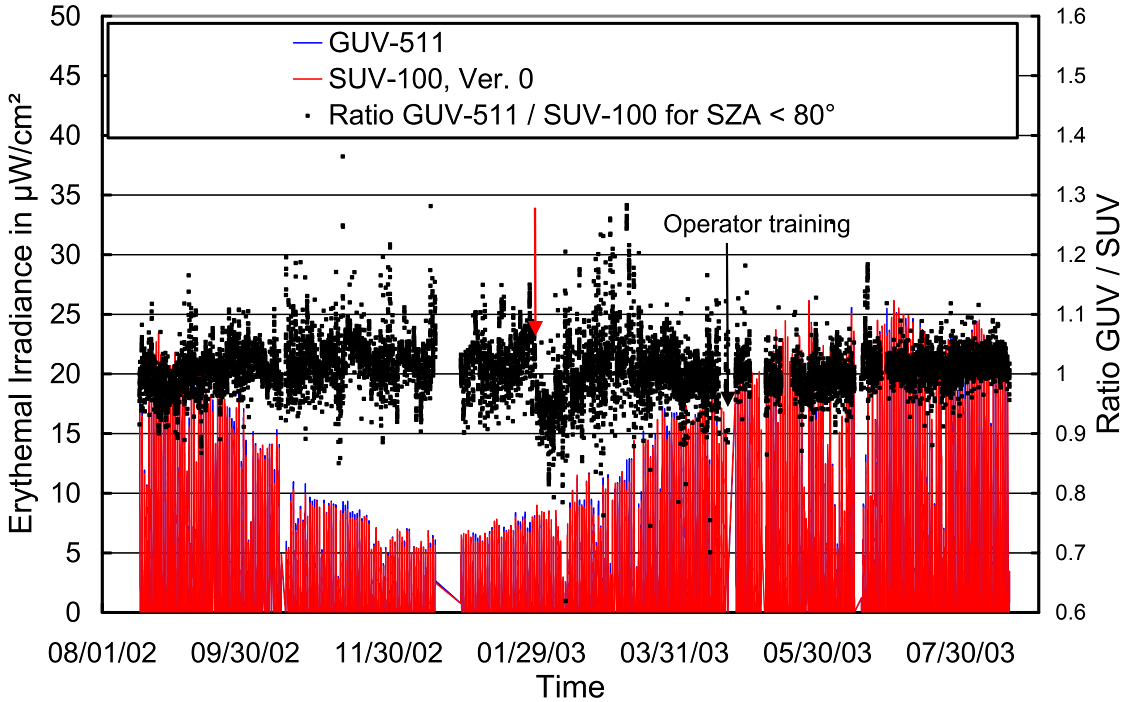

Figure 5.5.10. Comparison of erythemal irradiance measured by the SUV-100 spectroradiometer and the GUV-511 radiometer. All data is based on "Version 0" (cosine-error uncorrected) data. See text for explanation of the step indicated by the red arrow.

Figure 5.5.11 shows a comparison of total ozone measurements from the GUV-511 and NASA/TOMS Earth Probe satellite (Version 7). GUV-511 ozone values were calculated as described in http://www.biospherical.com/nsf/presentations/SPIE_paper_5156-23_Bernhard.pdf. TOMS ozone values are on average 4.5% lower than GUV-511 data. The discrepancy is still under investigation.

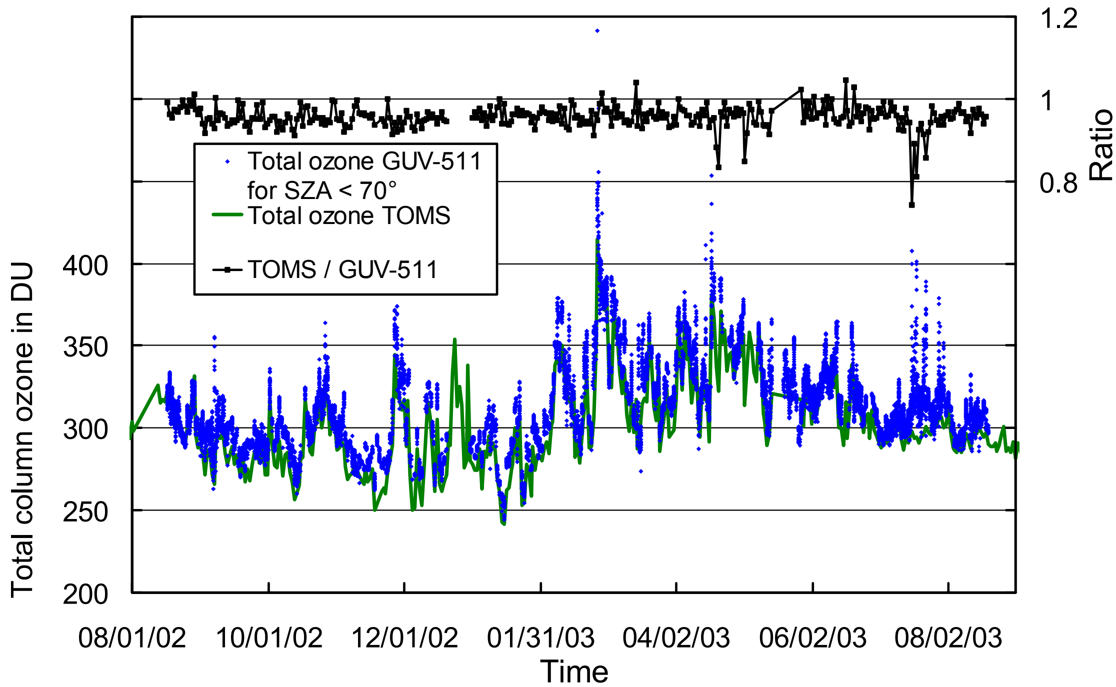

Figure 5.5.11. *Comparison of total column ozone measurements from GUV-511 and NASA/TOMS Earth Probe satellite. GUV-511 measurements are plotted in 15 minute intervals. For calculating the ratio of both data sets only GUV-511 measurements coincident with the TOMS overpass were evaluated.*