5.4. Ushuaia, Argentina (6/28/00– 1/1/02)

The 2000-2001 season at Ushuaia is defined as the time between the site visits 6/21/00 – 6/28/00 and 1/1/02 – 1/4/02. The season opening and closing calibrations were performed on 6/26/00 and 1/1/02 – 1/2/02, respectively. Volume 10 solar data comprises the period 6/28/00 – 1/1/02. Measurements during this period were affected by two system problems. One was related to interference of the PMT Peltier cooler with the PMT signal, and the other was caused by wear of the shutter. The quality of published solar data is only slightly compromised, owing to corrections applied during data processing:

- A new PMT cooler power supply was installed during the 1999 site visit. Compared to its predecessor the temperature regulation is more accurate, which is accomplished via a switching PID controller. The switching introduced noise in the PMT current due to a ground loop. For solar zenith angles smaller than 45° and wavelengths below 345 nm, the detection limit[1] of data until 1/16/01 was consequently reduced to about 0.027 $\mu W\ cm^{-2}\ nm^{-1}$. This value is substantially higher than the typical value 0.001 $\mu W\ cm^{-2}\ nm^{-1}$. The detection limit for solar zenith angles above 45° is about 0.005 $\mu W\ cm^{-2}\ nm^{-1}$; the normal value is 0.0005 $\mu W\ cm^{-2}\ nm^{-1}$ (see Table 2.1. in Chapter 2). The excess noise is noticeable in spectral irradiance data with wavelengths below 302 nm. We recommend not to use data with wavelengths equal to or below 298 nm. The enhanced noise also affects dose-rates calculated with Setlow's action spectrum from DNA damage. The effect on other dose-rates (e.g. "Dose3_CIE_Erythema", "Hunter", "Caldwell") is negligible, because the weighting functions of those dose-rates are centered at longer wavelengths than the "Setlow" action spectrum. At those wavelengths, spectral solar irradiance was sufficiently above the noise level. A first attempt to solve the problem was made during the site visit in June 2000 by improving the ground connection of the PMT, which lead to some improvement. The problem was finally fixed on 1/16/2001 by adjusting the settings of the PMT cooler power supply.

- Abraded paint from the shutter blades collected on the relay lens underneath the shutter. This lead to a gradual decrease of system sensitivity and required frequent adjustment of the instrument's calibration (see Section 5.4.2 below). In particular at the beginning of the season, the calibration accuracy is somewhat reduced.

A total of 28061 scans are part of the published Ushuaia Volume 10 dataset. Only 0.7% of all scans were lost due to technical problems.

During the site visit in June 2000, the PSP and TUVR instruments installed in Ushuaia were replaced by identical instruments that had been calibrated recently by Eppley Laboratory in February 2000. The previous set of instruments was sent after the site visit to Eppley Laboratory for recalibration.

5.4.1. Irradiance Calibration

The irradiance standards for the 2000-2001 Ushuaia season were the lamps 200W008, M-698, and M-766 (All three lamps were also used in the previous season). In addition, lamp 200W026 was introduced as a new standard in September 2001. Lamp M-874 was used as traveling standard at the beginning of the season. It was calibrated by Optronic Laboratories in September 1998. At the end of the season, 200W017 served as traveling standard. It was calibrated by Optronic Laboratories in March 2001.

Lamp 200W008 has an irradiance calibration of Optronic Laboratories from November 1996. The calibration of lamp M-698 was transferred to the lamp by comparing several absolute scans from M-698 and M-874, which were centered around the 1999 site visit. The method of the transfer is described in

[1] Detection limit is defined as the standard deviation of the measured spectral irradiance at 285 nm. At this wavelength, all solar radiation is filtered out by the Earth's ozone layer. The measured value at 285 nm therefore reflects the magnitude of instrument noise, which causes the detection limit

detail in Section 4.2.1.5. Lamp M-766 has an Optronic Laboratories calibration from October 1992. It was recalibrated in a similar fashion as M-698, using 1999 site visit data. The calibrations of all three site standards were the same as in the previous season.

Figure 5.4.1 shows a comparison of all lamps at the beginning of the season (6/26/00). Lamps M698 and M766 agree with the traveling standard M-874 to within ±1%. The difference of 200W008 and M-874 is about 1% in the UV and 2-2.5% in the visible.

All three site standards were compared with each other five times during the Volume 10 season. Figure 5.4.2 shows as an example the result of the comparison performed on 3/23/01. All lamps agreed with each other to within ±1%. A similar level of agreement could also be achieved during the other comparison periods.

Figure 5.4.3 shows a comparison of all lamps at the end of the season (1/1/02). The relative difference of lamps M-698 and 200W008 is similar than that observed during the beginning of the season. However, there is a 2% difference between M-698 and M-766, which is inconsistent to the good agreement of both lamps measured throughout the season. The reason for this shift is unknown.

As mentioned previously, lamps 200W017 and 200W026 are new lamps that were calibrated by Optronic Laboratories in March 2001, jointly with 10 other lamps. A comparison of all lamps was performed at Biospherical Instrument in April 2001 immediately after they had been returned from calibration. This comparison indicated a difference of 1-1.5% between 200W017 and 200W026. This difference is within the calibration uncertainties of Optronic Laboratories. In general, the calibration of lamp 200W017 agreed better than that of 200W026 with the calibration of all other newly calibrated lamps. The difference of 200W017 and 200W026 observed during the season closing calibrations at Ushuaia (Figure 5.4.3) is somewhat larger than the difference of both lamps observed in April 2001. The performance of 200W026 during 2002 will therefore be closely monitored, and the lamp will be recalibrated if necessary. The assumption that 200W017 represents the Optronic Laboratory scale of 2001 leads to the conclusion that the calibrations of the site standards 200W008, M-698, and M-766 agree with this scale to within ±2%.

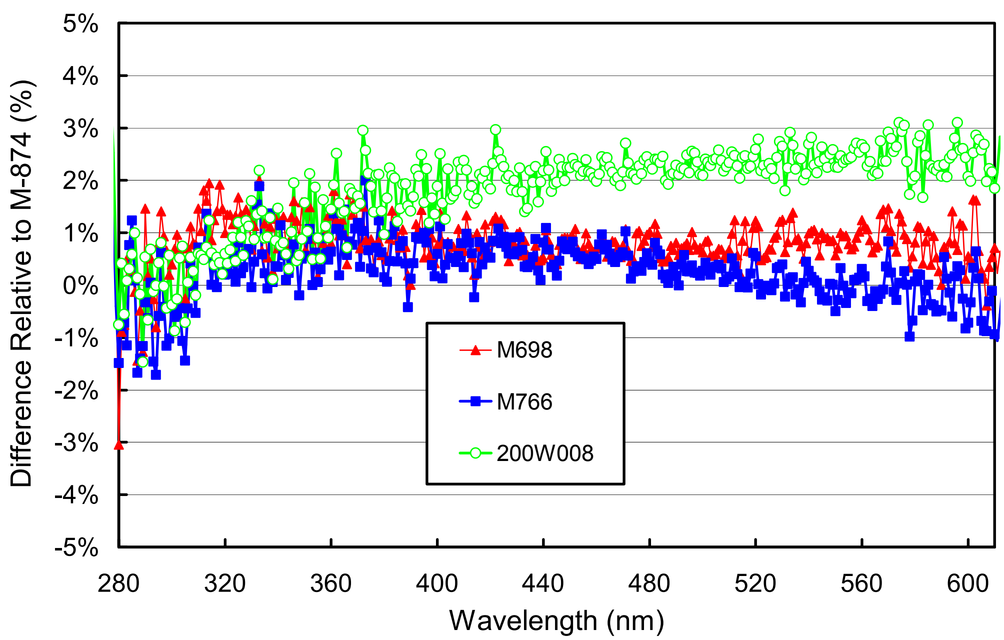

Figure 5.4.1. *Comparison of Ushuaia lamps M-698, and M-766, and 200W008 with the BSI traveling standard M-874 at the beginning of the season (6/26/00).*

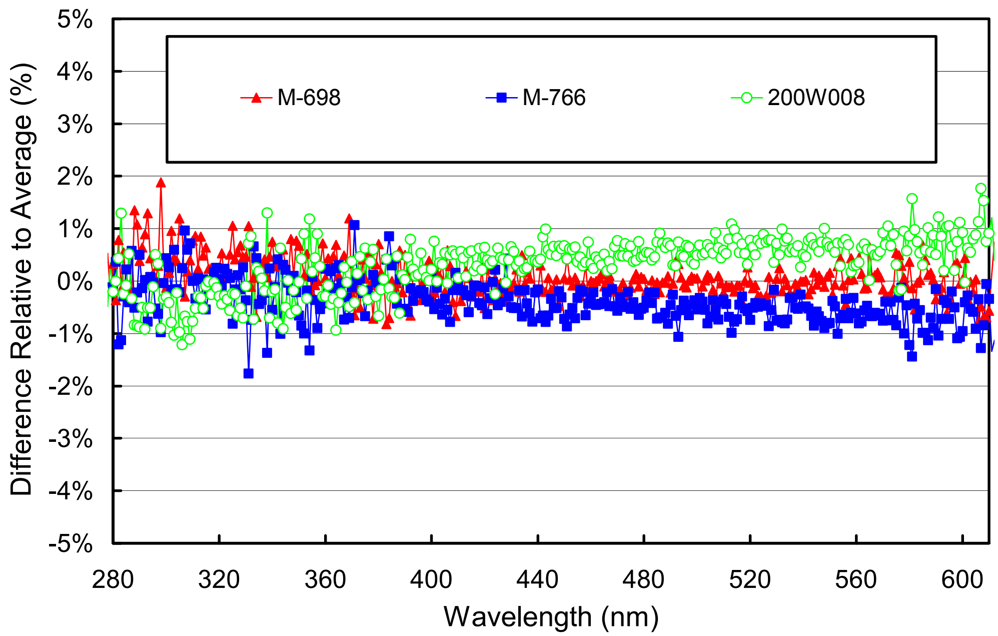

Figure 5.4.2. *Comparison of Ushuaia lamps M-698, and M-766, and 200W008 with each others on (3/23/01).*

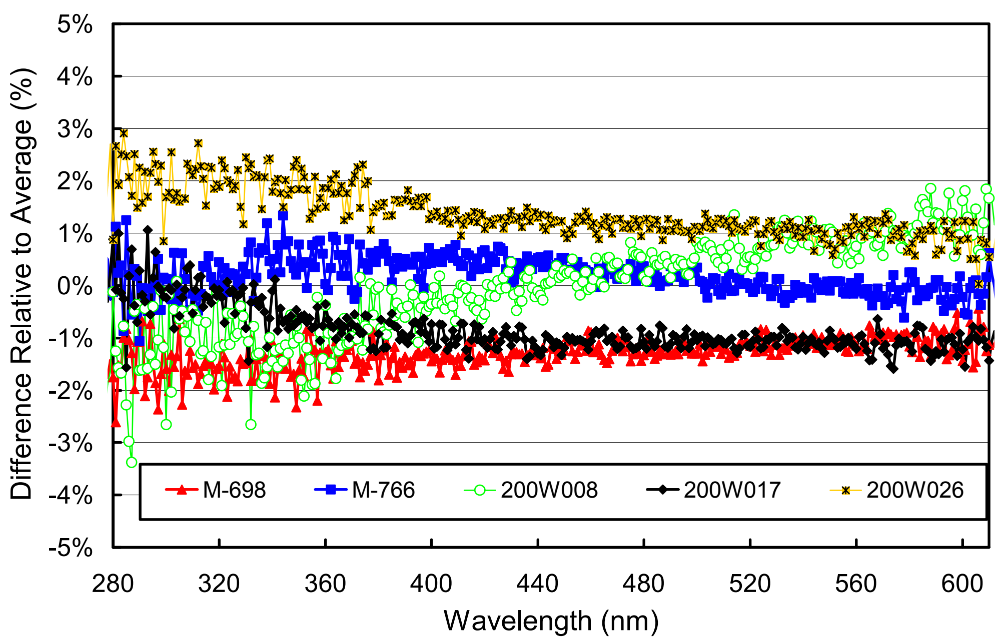

Figure 5.4.3. *Comparison of Ushuaia lamps M-698, and M-766, 200W008, and 200W026 and the BSI standard 200W017 at the end of the season (1/1/02).*

5.4.2. Instrument Stability

The stability of the spectroradiometer over time is primarily monitored with bi-weekly calibrations utilizing 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.

By logging the PMT currents at several wavelengths during response scans, changes in instrument responsivity can be detected. Figure 5.4.4 shows the changes in TSI readings and PMT currents at 300 and 400 nm, derived from the daily response scans of the entire season. TSI measurements suggest that the internal lamp became darker by 3% during the season, and this decrease is well tracked by the PMT currents. The reason for the 1.5% upward jump of PMT current on 8/15/00 is unknown. The 1% change of PMT currents on 1/15/01is due to adjustment of the PMT temperature, which affected its sensitivity. In general, the good tracking of TSI and PMT measurements suggest that monochromator and PMT were stable to within ±1.5% during the entire season.

Through-the-collector calibrations with the irradiance standards unfortunately showed that the overall system sensitivity decreased by about 30% between June 2000 and end of 2001. Inspection of the instrument's optics block during the site visit in January 2002 revealed that abrasion from the shutter had collected on the instrument's relay lens, decreasing its transmission. To correct for the loss in sensitivity, the instrument's calibration was broken into 14 periods, assigned in Table 5.4.1.

Table 5.4.1 Calibration periods Ushuaia Volume 10.

Period name	Period range
P1	06/28/00 – 07/02/00
P2	07/03/00 – 08/14/00
P3	08/15/00 – 09/18/00
P4	09/19/00 – 11/27/00
P5	11/28/00 – 12/26/00
P6	12/27/00 – 01/23/01
P7	01/24/01 – 03/06/01
P8	03/07/01 – 04/28/01
P9	04/29/01 – 06/12/01
P10	06/13/01 – 08/21/01
P11	08/22/01 – 09/17/01
P12	09/18/01 – 11/14/01
P13	11/15/01 – 12/26/01
P14	12/27/01 – 01/06/02

Figure 5.4.5 shows the irradiance spectra applied to the internal lamp in these periods, divided by the spectrum for Period 1. The difference between two consecutive calibration functions is typically smaller than 2%, with following exceptions:

- The ratio P2 / P1 is 1.038 in the UVB. Since there are no calibration scans between 6/26/00 and 7/13/00, the exact time of the change in sensitivity could not be determined and solar data during this period is therefore affected by increased uncertainty.
- There is a 6-8% change in the calibration between P3 and P2. The reason for this change could not be determined. The exact time is uncertain, too, as there are no calibration scans between 8/15/00 and 8/29/00. A comparison of TSI measurements performed during solar scans with coincident spectral measurements suggested, however, that the change in responsivity occurred immediately after the calibration scan on 8/15/00. The break between P2 and P3 was therefore set to 8/15/00.
- There is a 4% change in the calibration between P4 and P3. Similarly as in the two cases above, the exact time of the change could not be determined. Encompassing calibrations were performed on 9/14/00 and 9/22/00. The calibration during this period is affected by increased uncertainty.

As explained in Section 4.2.1.2, the irradiance assigned to the internal lamp in each period is the average of individual spectra sampled in that period. The standard deviation of the individual spectra allows estimating the variability of the calibrations in each given period. Figure 5.4.6 shows that the standard deviation is less than 1.5% of the average for all 14 periods.

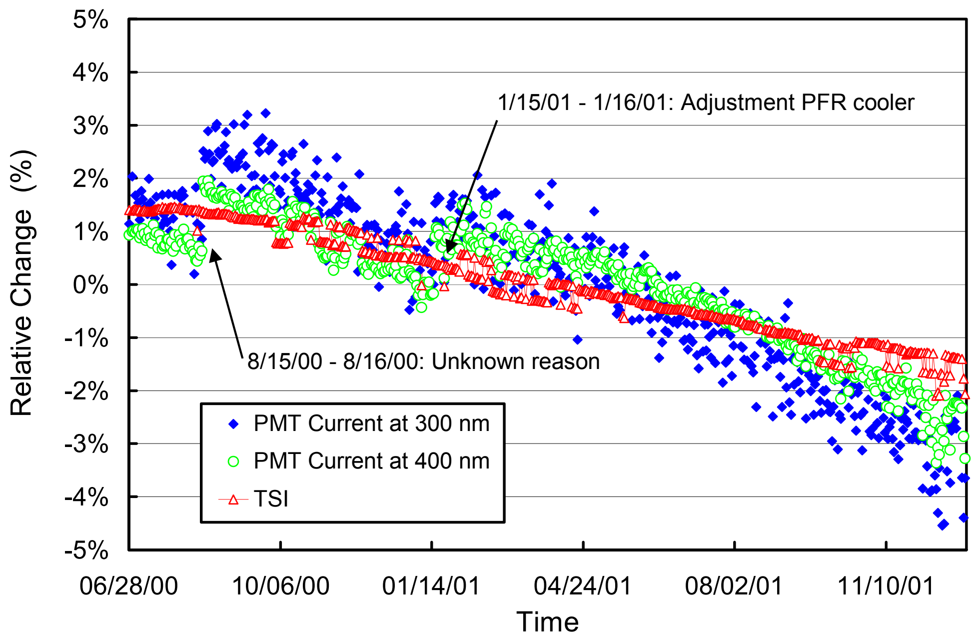

Figure 5.4.4. *Time-series of PMT current at 300 and 400 nm and TSI signal during measurements of the response lamp during the Ushuaia 2000-2001 season.*

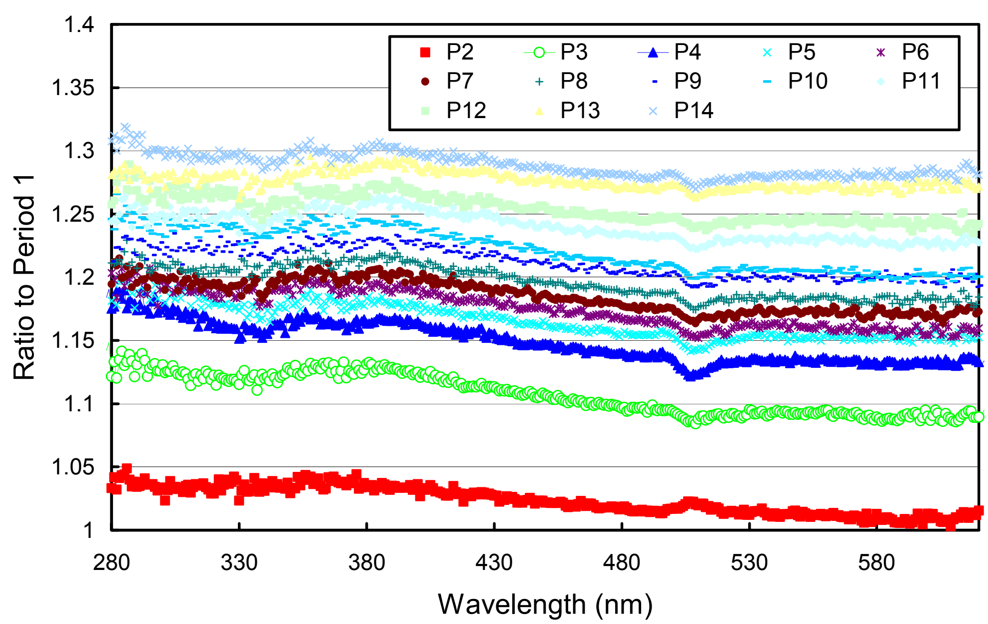

Figure 5.4.5. *Ratios of irradiance assigned to the internal reference lamp in Period 2-14, reference to the irradiance of Period 1.*

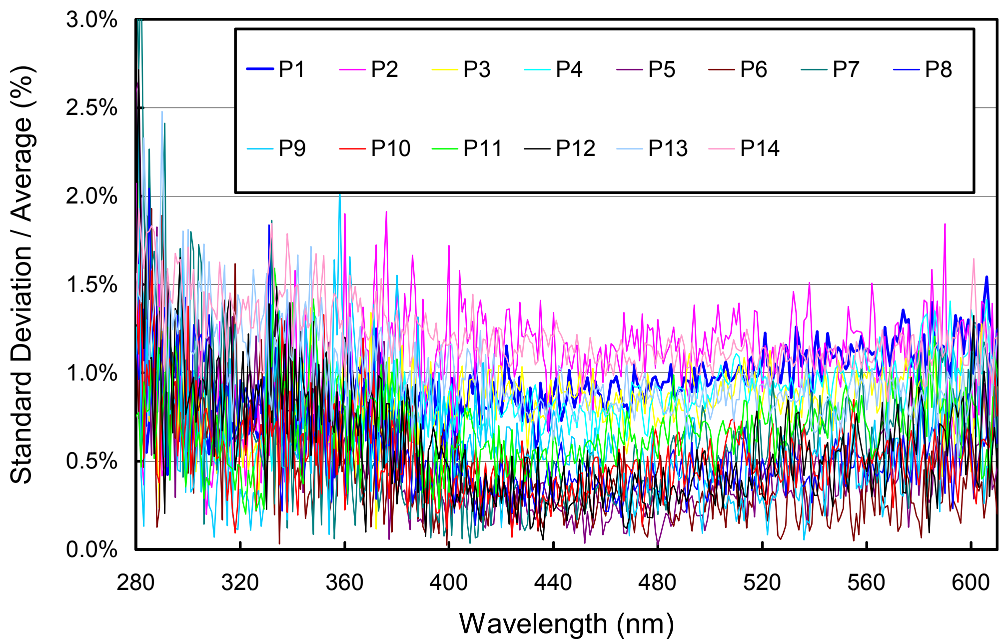

Figure 5.4.6. *Ratio of standard deviation and average calculated from the absolute calibration scans measured during the Ushuaia 2000-2001 season. The ratio is calculated separately for each of the 14 periods.*

5.4.3. Wavelength Calibration

Wavelength stability of the system was monitored with the internal mercury lamp. Figure 5.4.7 shows the differences in the wavelength offset of the 296.73 nm mercury line between two consecutive wavelength scans. In total, 553 scans were evaluated. For 94% of the scans is the difference in the wavelength offset to neighboring scans less than ±0.055 nm. Changes larger than ±0.1 nm occurred for 12 scans (2%), and were usually caused by manual wavelength setting. The wavelength assignment of final data 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 Chapter 4. The thick lines in Figure 5.4.8 shows the correction function. Because of the small signal levels, the correction at 300 nm is more uncertain than at longer wavelengths as indicated by the error bars. In order to demonstrate the difference between the result of the Fraunhofer-correlation method and the method that was historically applied, Figure 5.4.8 also includes a correction function that was calculated with the "old" method, i.e., the function is based on internal wavelength scans only. There is a difference of about 0.09 nm between both functions in the UV.

After the data was wavelength corrected using the shift function described above, the wavelength accuracy was tested again with the Fraunhofer method. The results for noon-time spectra are shown for four UV wavelengths in Figure 5.4.9. Residual shifts are usually smaller than ±0.05 nm and only few days show shifts greater than ±0.1 nm. The actual wavelength uncertainty may be a little larger due to possible systematic errors of the Fraunhofer-correlation method (see Section 4.2.2).

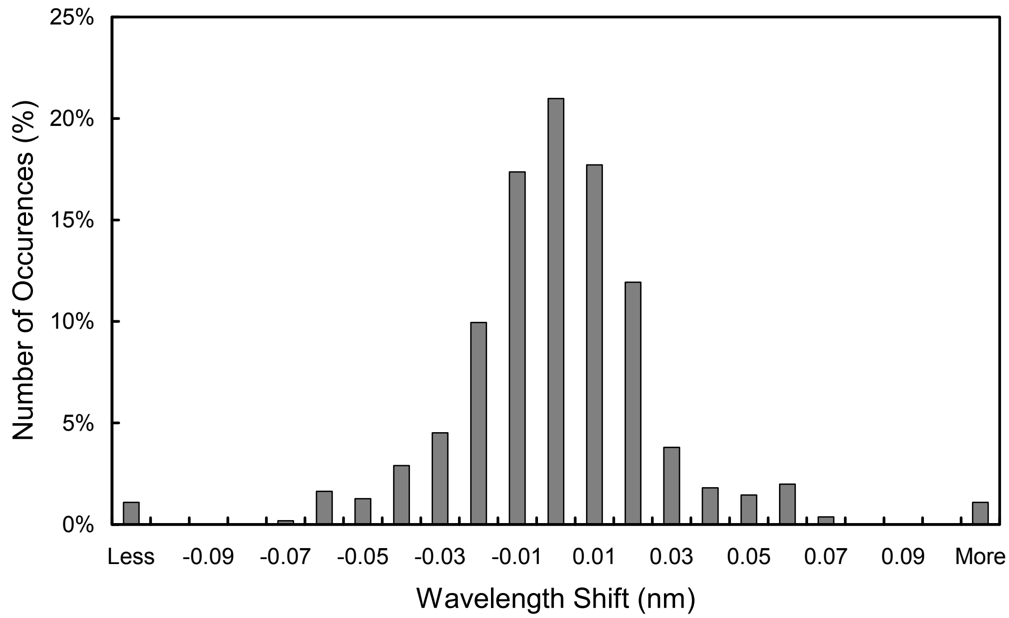

Figure 5.4.7. *Differences in the measured position of the 296.73 nm mercury line between consecutive wavelength scans. The labels of the horizontal axis give the center wavelength shift for each column. The 0-nm histogram column covers the range from -0.005 to +0.005 nm. "Less" means shifts smaller than -0.105 nm; "more" means shifts larger than 0.105 nm.*

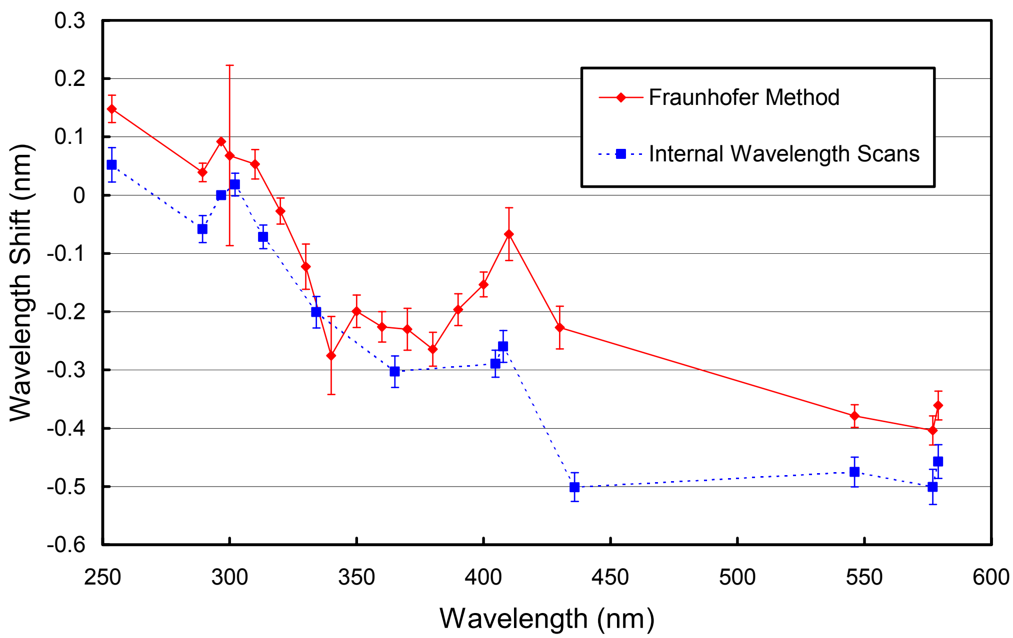

Figure 5.4.8. *Monochromator non-linearity for the Ushuaia 2000-2001 season. Heavy line: Correction function calculated with the Fraunhofer-correlation method, applied to correct the Ushuaia Volume10 data. Thin broken line: Correction function calculated with the method that was historically applied. The offset difference between both methods in the UV is 0.09 nm. The error bars are the 1σ standard deviation of the wavelength shift for the season.*

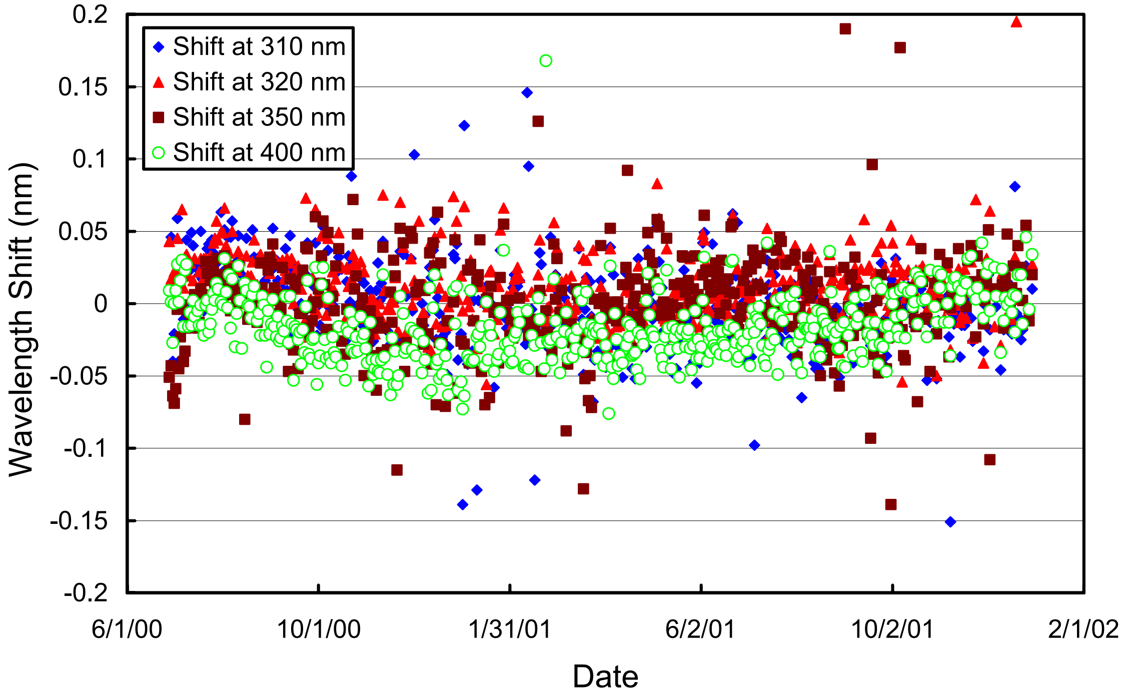

Figure 5.4.9. *Wavelength accuracy check of the final Ushuaia Volume 10 data at four wavelengths by means of Fraunhofer correlation.*

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 5.4.10 illustrates the difference between internal and external mercury scans collected during the season opening site visit. Data from the closing visit are not available. 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 0.07 nm to shorter wavelengths. External scans have a bandwidth of about 1.02 nm FWHM, whereas the bandwidth of the internal scan is only 0.70 nm. As external scans have the same light path as solar measurements, they more realistically represent the monochromator bandpass relevant to solar scans.

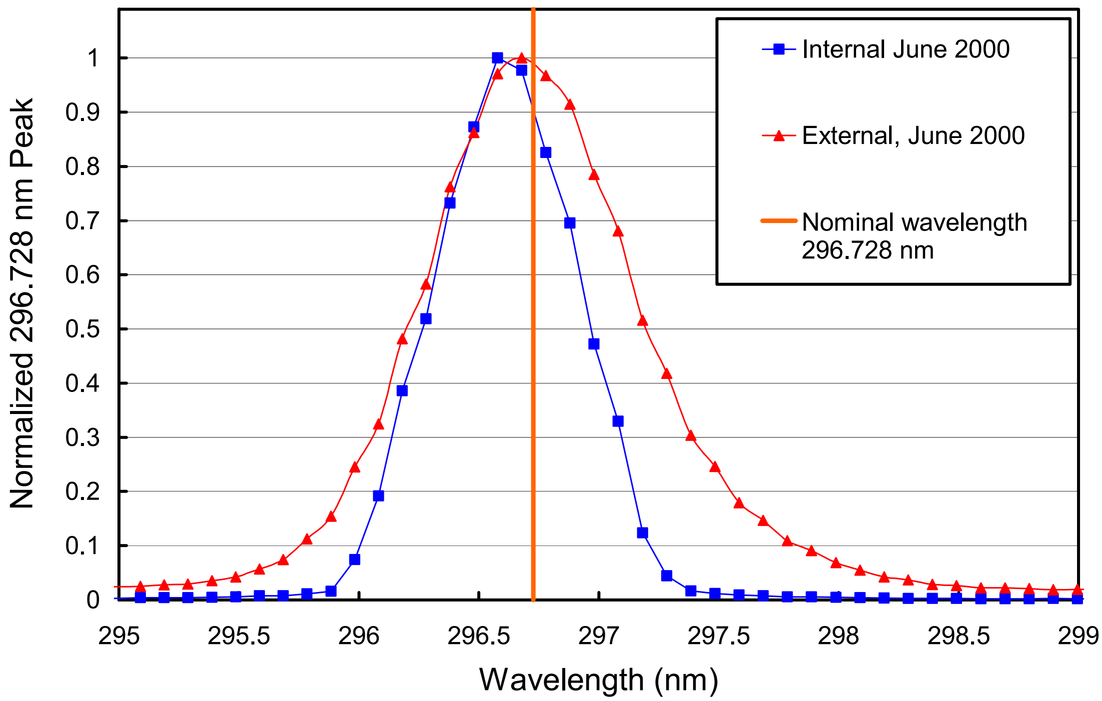

Figure 5.4.10. *The 296.73 mercury line as registered by the PMT from external and internal sources. The wavelength scale is the same as applied for solar measurements, i.e., it is based on a combination of internal scans and the Fraunhofer-correlation method. It is assumed that the wavelength registration of the monochromator did not shift between internal and external scans, which were close in time.*

5.4.4. Missing Data

A total of 28061 scans are part of the published Ushuaia Volume 10 dataset. These are 97.5% of the scans scheduled. Approximately 0.7% of all scans were missed due to technical problems. Of all missing scans, 408 were superseded by absolute, and 9 by wavelength scans. On several occasions, measurements were correctly performed but not stored on data disks. Due to this problem, 14; 15; and 129 scans were lost on March 15-16, 2000; 8/20/01; and October 26-28, 2001, respectively. The GPS unit erroneously reset the computer clock by one day on 10/25/01. The time stamp of the recorded scans was corrected during data processing, however, 48 scans were not recorded.