5.7. Summit, Greenland (01/20/15 – 11/22/15)

This section describes quality control of "Volume 25" solar data recorded by the SUV-150B spectro-radiometer and the collocated GUV-511 radiometer at Summit Camp, Greenland, between 01/20/15 and 11/22/15.

In the fall of 2014, the National Science Foundation requested improvements to the safety of operations at Summit by installing a railing around the outside perimeter of the instrument. A railing was deemed necessary to decrease the risk of injuries when operators access the roof of the "Green House" at Summit to calibrate the instrument. Because a railing would cast a shadow on the instrument's radiation collector, the collector assembly was raised by about four feet. This work was performed in July 2015 and required a partial removal and reinstallation of the instrument, and the installation of a longer optical fiber between the instrument's collector and the core system. Because of this work, no SUV data are available for the period 7/15/15 – 7/22/15. The cable connecting the GUV-511 radiometer to its control unit was damaged during the removal of the instrument and a new cable had to be shipped to Summit. For this reason, no GUV data are available for the period 6/26/15 –8/26/15.

Periodic changes in responsivity of the SUV-150B spectroradiometer observed during the last years continued in 2015. These changes are caused by variations in collector efficiency and PMT sensitivity. The chances are now well understood and were corrected during data processing. Residual variations in published data were assessed by comparing SUV-150B data with measurements of the GUV-511 multi-filter radiometer and results of radiative transfer calculations, and are smaller than ±2%.

Measurements of the TSI sensor internal to the SUV-150B were not always correctly recorded. Defective data were not removed from the published databases. Hence TSI measurements should not be used.

The Eppley pyranometer that is co-located with the SUV-150B had the serial number 33120F3 and had been calibrated by Eppley Laboratories on 4/15/2013; the calibration constant is 8.44×10^{-5} V/(W m^{-2}).

The collectors of the SUV-150B and GUV-511 radiometers were shaded by nearby obstacles during some scans. Affected scans were removed from the Version 0 and Version 2 datasets.

A total of 16,358 SUV-150B scans are part of the Summit Volume 25 dataset.

5.7.1. Irradiance Calibration

The on-site irradiance standards used during the reporting period were the lamps 200W027, 200W030, and 200W038. These standards were compared with the traveling standard 200W017 on 7/23/2015. The scales of spectral irradiance of all lamps implemented in 2015 were identical to those used in 2014.

<u>Calibration history of on-site standards 200W027, 200W030, and 200W038</u>
Lamp <u>200W027</u> was originally calibrated on 3/28/01 by Optronic Laboratories. The lamp was recalibrated against the project's traveling standard, lamp 200W017, using "closing" scans performed at Summit on 7/11/07. The lamp was temporarily moved to San Diego and was recalibrated in March 2008 against lamps 200W028 and 200W022. It was recalibrated again in November 2011 against standards 200W017 and 200W038. This calibration was used for processing of solar data of the Volume 21 (2011), Volume 22 (2012), Volume 23 (2013), Volume 24 (2014), and Volume 25 (2015) periods.

Lamp <u>200W030</u> was originally calibrated on 3/28/01 by Optronic Laboratories. The lamp was recalibrated against lamp 200W017 using "closing" scans performed at Summit on 7/11/07. The lamp was recalibrated in June 2009 against 200W017 using "closing" scans of the Volume 18 period. The lamp was recalibrated again in November 2011 against the traveling standards 200W017 and 200W038. This calibration was used for processing of solar data of the Volume 21 (2011), Volume 22 (2012), Volume 23 (2013), Volume 24

(2014), and Volume 25 (2015) periods. The failed on 10/21/15 and was removed from the suite of on-site standards.

Lamp 200W038 was calibrated against lamps 200W028 and 200W022 in April 2008. At this time, the calibration of lamp 200W038 was consistent to that of 200W017.

Calibration history of traveling standard 200W017
Lamp 200W017 was calibrated in June 2007 at BSI with four 1000-Watt FEL lamps provided by the Central UV Calibration Facility (CUCF) at Boulder. This calibration procedure was complicated by the fact that the irradiance scale of the four FEL lamps refers to the detector-based scale of the National Institute of Standards and Technology established in 2000 (NIST2000; *Yoon et al*., 2002), whereas all solar data of the NSF UVSIMN refer to the source-based NIST scale from 1990 (NIST1990, *Walker et al*., 1987). The NIST2000 scale is about 1.3% larger than the NIST1990 scale. Values of spectral irradiance provided in certificates issued by the CUCF were converted to the NIST1990 scale before the calibration was transferred to lamp 200W017. The scale of spectral irradiance of lamp 200W017 was checked in March 2015 against a lamp that is traceable to the NIST primary standard F-616. It was concluded that the June 2007 calibration of the lamp is still accurate to within ±1%.

Figure 5.7.1 compares the scales of spectral irradiance of the on-site standards 200W027, 200W030, and 200W038 with the scale of spectral irradiance of traveling standard 200W017. The comparison is based on absolute scans performed on 7/23/2015. At that time, the scales agreed to within ±2%. The three on-site standards lamps were also compared with each other on 2/12/15, 7/2/15, and 11/5/15. The scales of spectral irradiance agreed to ±2% at all times.

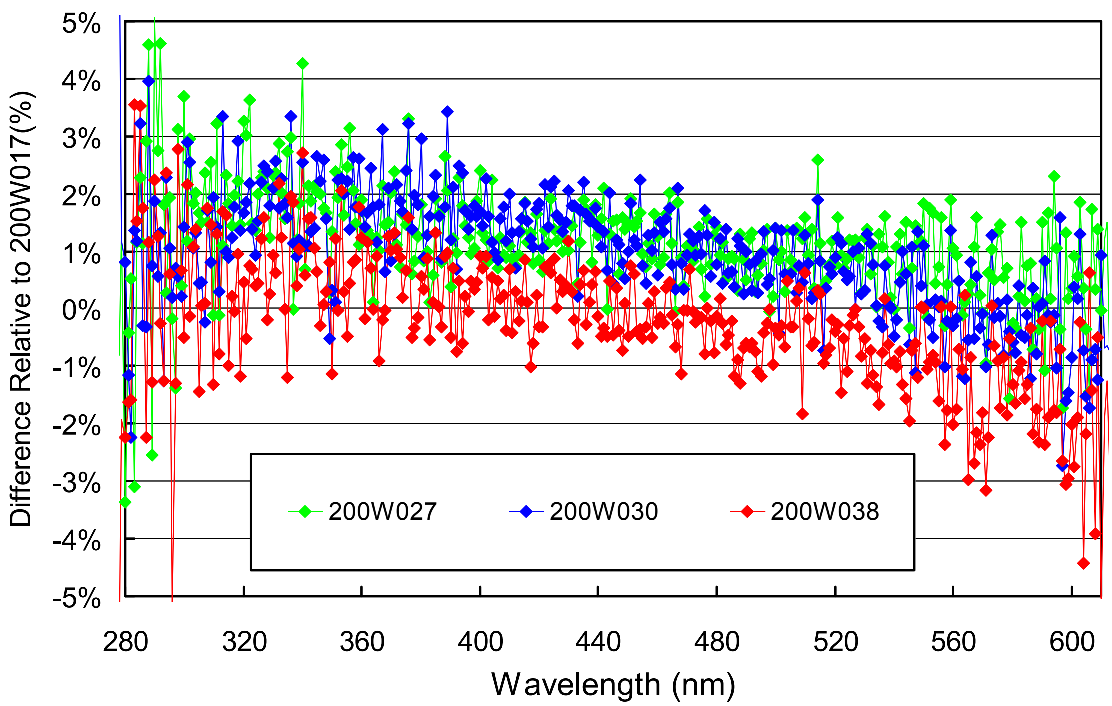

Figure 5.7.1. *Comparison of on-site standards 200W027, 200W030, and 200W038 with the traveling standard 200W017 on 7/23/2015.*

5.7.2. Instrument Stability

The temporal stability of the spectroradiometer is monitored with bi-weekly calibrations utilizing the on-site standards; daily response scans of the internal irradiance reference lamp; and by comparison with the co-located GUV-511 radiometer and results from a radiative transfer model.

Internal to the instrument's fore optics is a filtered photo diode, called TSI, with a peak sensitivity in the UV. It is used to track changes in the light intensity of the internal reference lamp. By monitoring the TSI while measuring the current of the system's photomultiplier tube (PMT) detector, changes in the lamp's output can be decoupled from drifts in monochromator throughput or PMT sensitivity. Figure 5.7.2 shows changes in TSI readings and PMT currents at 320 and 400 nm, derived from response scans performed between 2/14/06 and 12/31/15. TSI measurements changed by about 10% between 2/14/06 and 6/20/09. The lamp failed and the end of August 2009 and was replaced. Data recorded after this time were scaled downward by a constant factor to better compare with previous measurements. The relative change of the second lamp's intensity as recorded by the TSI between 9/2/09 and 12/31/15 is similar to that of the original lamp, except of the brief period of 7/15/13 – 9/29/13. The trend of PMT currents follows that of the TSI measurements but there is a sinusoidal variation with a periodicity of one year superimposed on the general trend. The highest PMT sensitivity is observed in mid-February of every year, while the lowest sensitivity is observed in August. We attribute this periodicity to a long-term memory of the PMT to the radiation levels it has "seen" during the months prior to the measurement. During the period of winter darkness, the PMT becomes more sensitive, and during the summer months its sensitivity decreases. As the variation is very predictable, it can be well corrected when solar data are processed.

To account for the combined changes of the throughput of the system's entrance optics and PMT-sensitivity, the reporting period was broken into 12 sub-periods and a different irradiance spectrum was applied to the internal lamp in each period. Irradiance spectra were smoothed with an approximating spline to reduce the effect of measurement noise. A summary of the calibration periods is provided in Table 5.7.1. Ratios of irradiance spectra applied in Periods P1B – P4 relative to the spectrum applied in Period P1 are shown in Figure 5.7.3. Periods P1 through P4 include the time before the instrument service in July 2015. Similar ratios for periods commencing after the site visit are shown in Figure 5.7.4.

The quality of calibrated solar measurements of the SUV-150B was further assessed by comparison with data of the GUV-511 radiometer. Figure 5.7.5 shows the ratio of measurements of the GUV's 340 nm channel to measurements of the SUV-150B. The latter have been weighted with the spectral response function of the GUV's channel prior to forming the ratio. Measurements of the two instruments generally agree to within ±3.5%, with the exception of several outliers. The ratio tends to be somewhat lower early and late in the year and is highest during the summer. Most outliers occur between June and August and are related to obstacles in the field of view of either the GUV or the SUV that shade the direct Sun. Because the two instruments are located approximately one meter apart, they are shaded at slightly different times, leading to variations in the ratio. Affected data have been removed from the SUV datasets.

Table 5.7.1. Calibration periods for Summit Volumes 25.

Period name	Period range	Number of absolute scans	Remarks
P1	01/01/15 – 02/28/15	5	
P1B	03/01/15 – 03/22/15	0	Average of Periods P1 and P2
P2	03/23/15 – 04/15/15	3	Average of Periods P2 and P3
P2B	04/16/15 – 05/03/15	0	
P3	05/04/15 – 06/08/15	3	
P3B	06/09/15 – 06/14/15	0	Average of Periods P3 and P4
P4	06/15/15 – 07/16/15	4	
P5	07/17/15 – 08/02/15	6	
P5B	08/03/15 – 08/06/15	0	Average of Periods P5 and P6
P6	08/07/15 – 10/05/15	4	
P7	10/06/15 – 11/15/15	4	
P8	11/16/15 – 12/31/15	1	

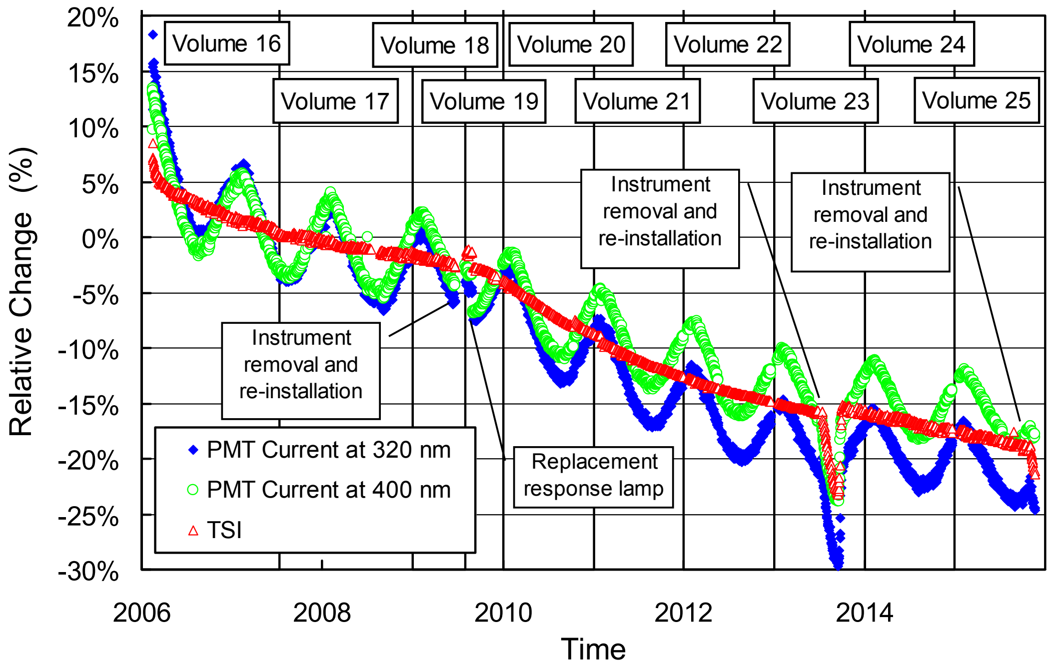

Figure 5.7.2. *Time-series of TSI signal and PMT currents at 320 and 400 nm during measurements of the internal reference lamp performed at Summit between 2/15/06 and 12/31/15. Data from 9/2/10 (date of response lamp replacement) were scaled downward to fit into the existing pattern. Data are normalized to the period 2/14/06 - 6/20/09.*

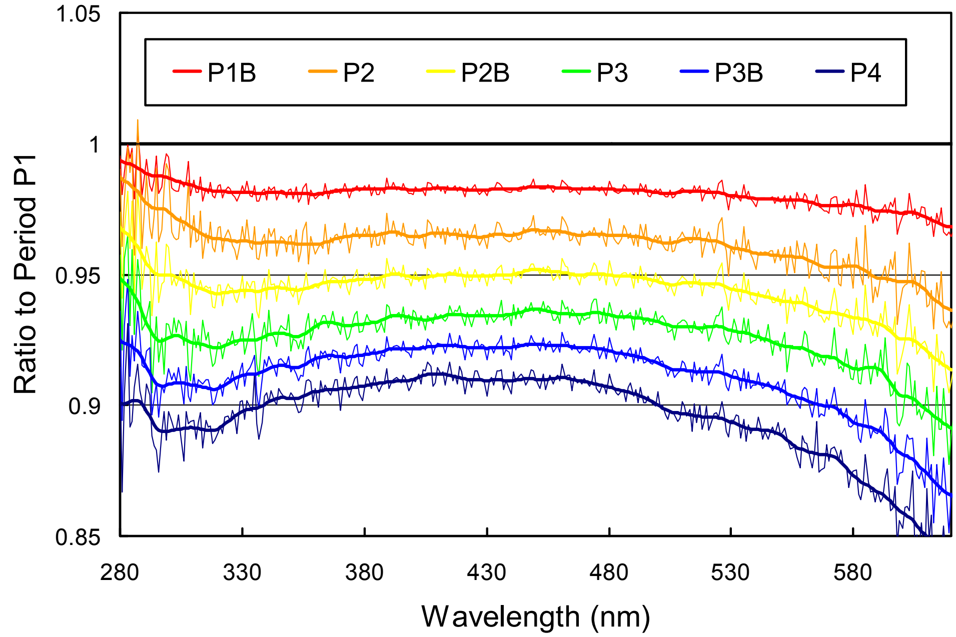

Figure 5.7.3. *Ratios of irradiance assigned to the internal reference lamp in Periods P1B – P4, referenced to the irradiance of Period P1. These periods include the time before the instrument service in July 2015. Thick lines indicate ratios of the smoothed irradiance spectra used for the calibration of solar measurements.*

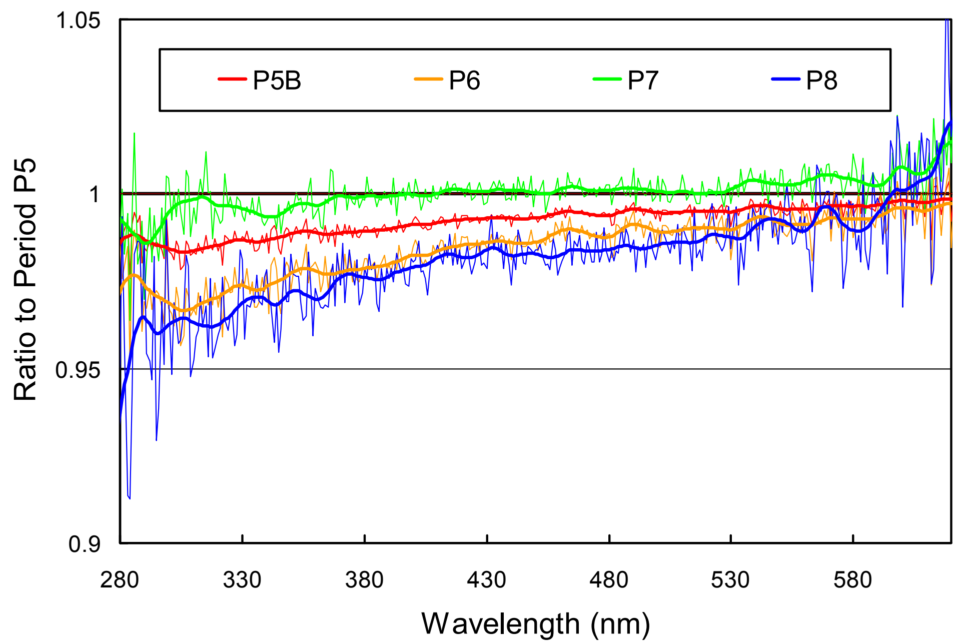

Figure 5.7.4. *Ratios of irradiance assigned to the internal reference lamp in Periods P5B – P8, referenced to the irradiance of Period P5. These periods include the time after the instrument service in July 2015. Thick lines indicate ratios of the smoothed irradiance spectra used for the calibration of solar measurements.*

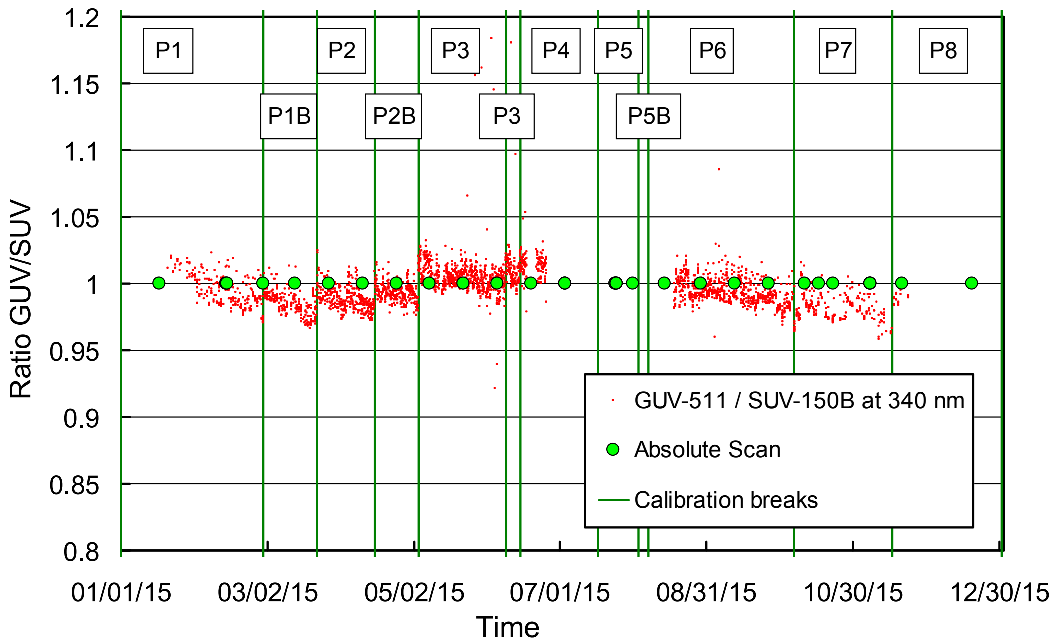

Figure 5.7.5. *Ratios of GUV-511 and SUV-150B measurements at 340 nm. Breaks in the calibration of SUV data and the times of absolute scans are also indicated.*

5.7.3. Wavelength Calibration

Wavelength stability of the system was monitored with the internal mercury lamp. Figure 5.7.6 shows the differences in the wavelength offset of the 296.73 nm mercury line between pairs of consecutive wavelength scans for the period 1/1/14 – 12/21/14. 281 scans were evaluated. For 99.3% of the scans is the difference in the wavelength offset to neighboring scans less than ±0.0055 nm. Minimum and maximum shifts between consecutive scans were -0.007 and +0.007 nm, respectively. These larger shifts are related to changes of the system implemented during the site visit in July 2015. Note that the wavelength stability of the system is a factor of 10 better than that of SUV-100 spectroradiometers used at other sites. The SUV-150B has superior stability due to the use of high-resolution optical encoders that are used in a closed feedback loop with the stepper-motor controllers.

After the data were 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-line correlation method used for Version 2 processing (*Bernhard et al., 2004*; see also Section 4.2.2.2). Due to the good wavelength stability of the system, only one correction function had to be applied for the entire reporting period (Figure 5.7.7). Since the position of the monochromator's gratings is determined by optical encoders, irregularities in the monochromator drive are inconsequential. This explains the smoothness of the functions.

After data was corrected using this function, the wavelength accuracy of all noontime scans was verified with the "Version 2" Fraunhofer-line correlation algorithm. Results are shown in Figure 5.7.8. Residual wavelength errors are smaller than ±0.03 nm, with few exceptions. However, the pattern of the residuals is different for the periods before and after the system service in July 2015. There is also a small change in the pattern occurring around 10/22/15. To further improve the wavelength accuracy of final data, three different correction functions were used for the processing of Version 2 data.

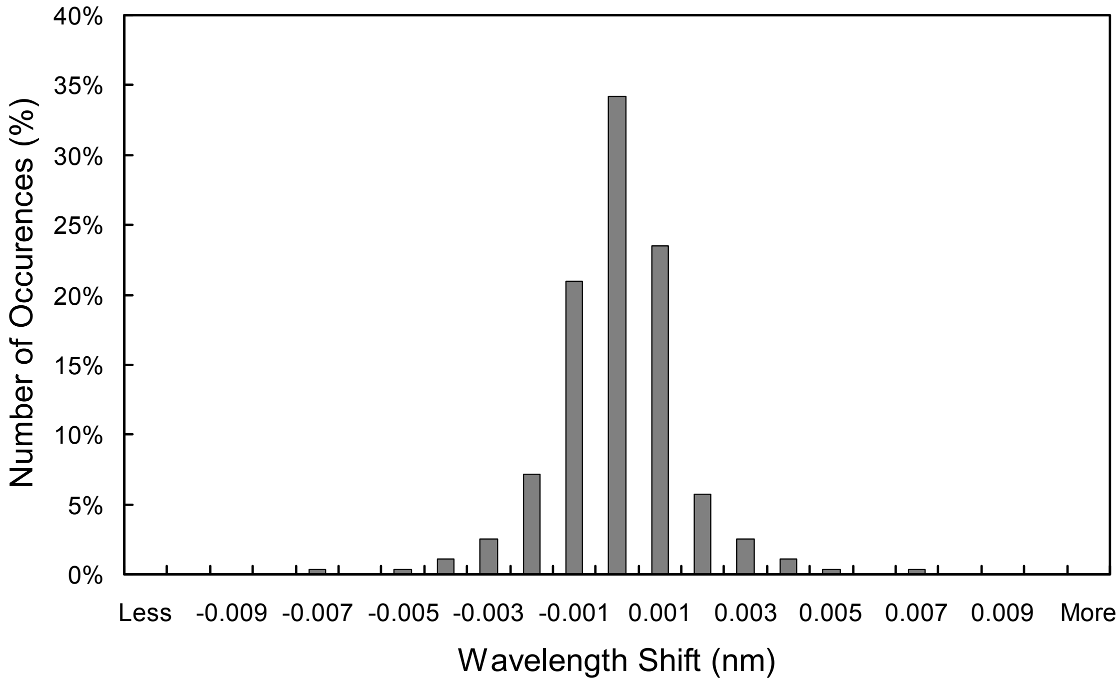

Figure 5.7.6. *Differences in the measured position of the 296.73 nm mercury line between consecutive wavelength scans for the period 1/20/15 – 11/22/15. The labels of the horizontal axis give the center wavelength shift for each column. The 0-nm histogram column covers the range from -0.0005 to +0.0005 nm. "Less" means shifts smaller than -0.0105 nm; "more" means shifts larger than 0.0105 nm.*

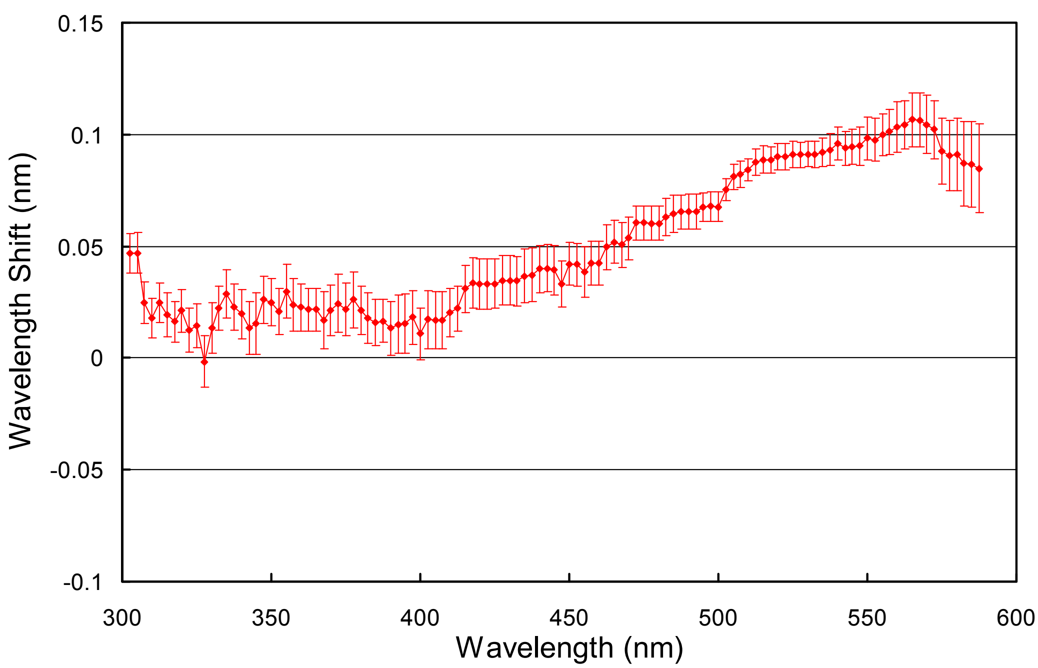

Figure 5.7.7. *Monochromator non-linearity correction functions of Volume 25 data.*

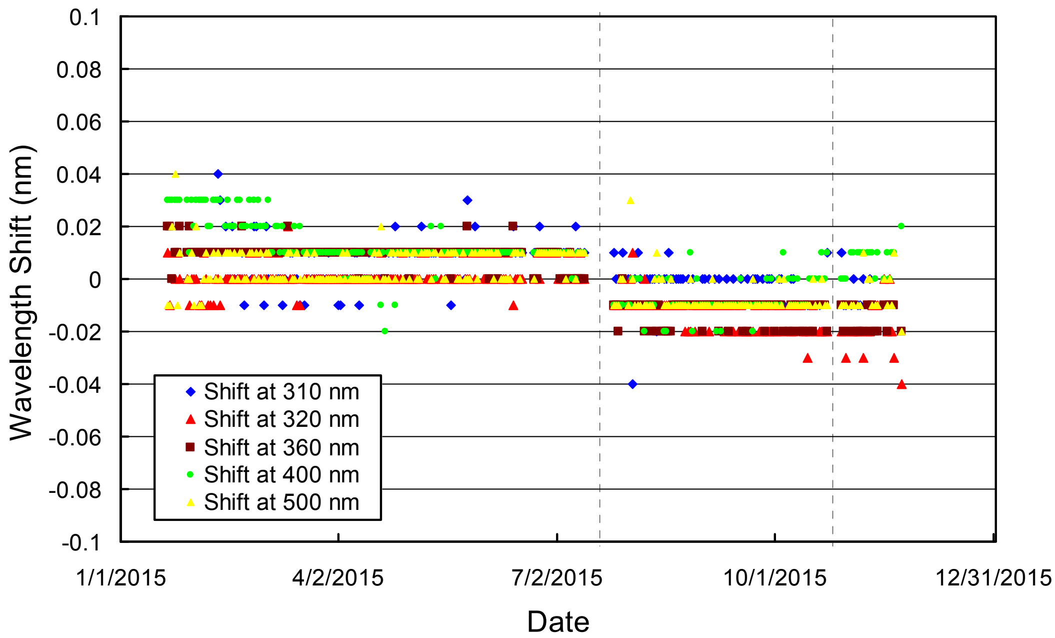

Figure 5.7.8. *Wavelength accuracy check of "Version 0" Volume 25 data at five wavelengths in the UV and visible by means of Fraunhofer-line correlation. All noontime measurements have been evaluated. The wavelength correction was further refined during the processing of Version 2 and vertical lines indicate times when these post-correction functions were changed.*

5.7.4. Missing Data

A total of 16,358 SUV-150B spectra are part of the Summit Volume 25 dataset. Missing periods are summarized in Table 5.7.2.

Table 5.7.2. Incomplete days in the Summit Volume 25 dataset.

Period	Reason
01/26/15 – 01/27/15	unknown
06/18/15 – 06/20/15	unknown
07/15/15 – 07/22/15	Site visit; system upgrade
10/24/15 – 10/25/15	Software error
10/31/15	Software of operator error
11/14/15	Software error