5.7. Summit, Greenland (01/20/13 – 11/23/13)

This section describes quality control of "Volume 23" solar data recorded by the SUV-150B spectroradiometer and the collocated GUV-511 radiometer at Summit Camp, Greenland, between 01/20/13 and 11/23/13.

Periodic changes in responsivity of the SUV-150B spectroradiometer observed during the last years continued in 2013. 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%.

The instrument is located in the "Green House" of Summit Station. The building is resting on compacted snow, tends to tilt over time, and gets buried in snow. In June and July 2013, the building was "dug out" and moved to a new, elevated location, approximately 20 meters away from the previous location. For this relocation, all instruments had to be removed from the building. BSI personnel uninstalled the instrument during a site visit at the end of June 2013 and moved all components to warm storage. The instrument was reinstalled between 7/9/13 and 7/1613. There are no data between 6/28/13 and 7/12/13 because of the relocation.

When the system was reinstalled in July 2013, the software was upgraded to optimize the warm-up sequence of the internal lamp used for "response" scans. This upgrade made the software unfortunately less stable. The software was consequently reverted to the original version on 9/9/13.

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

During the site visit, the system's Eppley PSP pyranometer (Serial Number 33690F3, calibration constant 7.94×10^{-5} V/(W m^{-2}), established by Eppley Laboratories on 7/30/2009) was exchanged by a recently recalibrated pyranometer (Serial Number 33120F3, calibration constant 8.44×10^{-5} V/(W m^{-2}), established by Eppley Laboratories on 4/15/2013). Data analysis confirmed that there is no discernable difference in the calibrated measurements of the two sensors when exposed to the same solar irradiance.

The collectors of the SUV-150B and GUV-511 were shaded by nearby obstacles during some scans. Shading events occurred mostly between 8:30 and 9:00 from mid-April to mid-July. Affected scans were not removed from the Version 0 dataset; however, they were flagged in the Version 2 dataset.

A total of 15,835 SUV-150B scans are part of the Summit Volume 23 dataset.

5.7.1. Irradiance Calibration

The on-site irradiance standards used during the reporting period were the lamps 200W027, 200W030, and 200W038. Lamp 200W043 served as a traveling standard and was used during both site visits.

<u>Calibration history of traveling standards 200W043</u>
Lamp 200W043 was originally calibrated on 6/2/07 against a set of four 1000-W FEL lamps. The lamp was recalibrated again in November 2011 against the project's primary traveling standards 200W017 and lamp 200W038, which at this time agreed with lamp 200W017 to within ±1%.

Lamp 200W017 was originally calibrated against the NIST scale of spectral irradiance established in 1990 (NIST1990 scale). The calibration of lamp 200W017 was checked in November 2012 against several lamps as described in the 2012-2013 Operations Report. At this time, the spectral irradiance scale of this lamp agreed with the NIST1990 scale to within NIST's uncertainty specification. The good agreement gives credence to the November 2011 calibration of the secondary traveling standard 200W043.

Calibration history of on-site standards 200W027, 200W030, and 200W038

Lamp 200W027 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 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), and Volume 23 (2013) periods.

Lamp 200W030 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), and Volume 23 (2013) periods.

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.

Figure 5.7.1 compares the calibration of the on-site standards 200W027, 200W030, and 200W038 with that of the traveling standard 200W043. The comparison is based on absolute scans performed after the reinstallation of the system on 7/15/13. At this time, the calibrations of lamps 200W027, 200W038 and 200W043 agreed almost perfectly, while that of lamp 200W030 is biased high by approximately 1.5%. The three on-site standards were also compared on 2/7/13, 6/26/13, and 11/5/13. At these times, the calibrations of the three lamps agreed to within ±1% and the calibration of lamp 200W030 was not biased high, suggesting that a recalibration of the lamp based on the results obtained on 7/15/13 is not necessary.

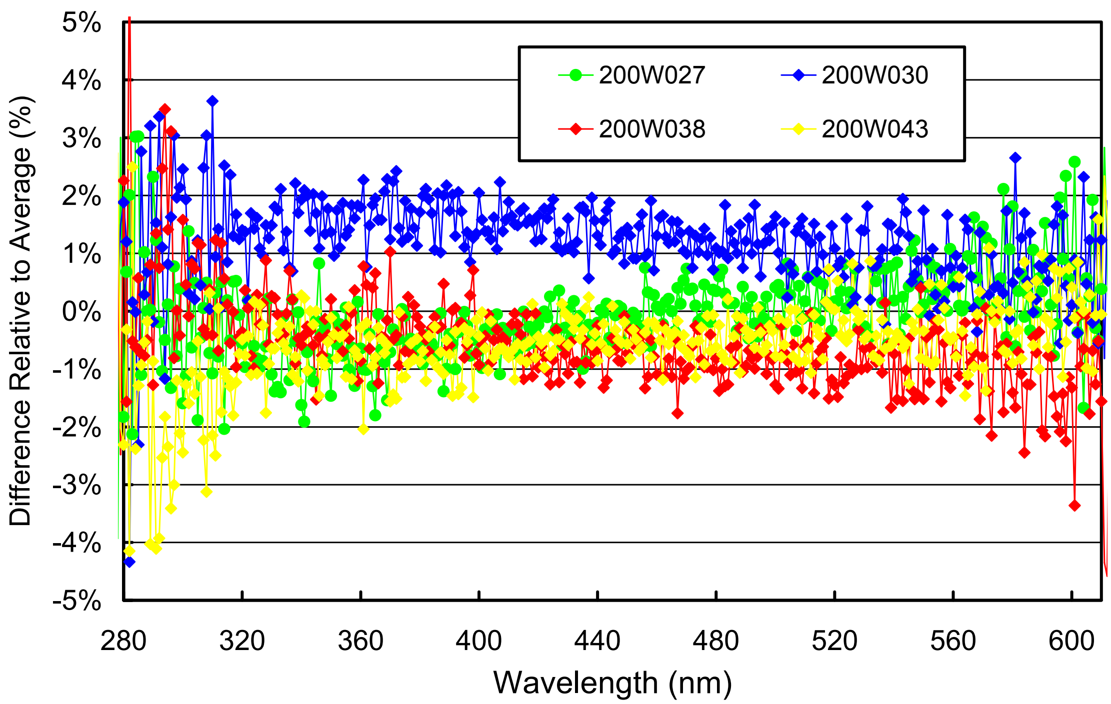

Figure 5.7.1. *Comparison of lamps 200W027, 200W030, 200W038, and 200W043 on 7/15/2013.*

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 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 12/31/13. 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 12/31/13 is similar to that of the original lamp, except of the brief period of 7/15/13 – 9/29/13, which is discussed in more detail below. 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.

After the system reinstallation on 7/15/13, the output of the internal lamp as monitored by the TSI sensor and the PMT decreased at a much larger rate than typical. Between 9/18/13 and 9/29/13, the output of the lamp recovered to that expected from the general trend of the lamp's dimming. The reason for this behavior is unknown. The decline of the output observed between 7/15/13 and 9/18/13 was well defined and solar data could be corrected for this effect. In contrast, the recovery between 9/18/13 and 9/29/13 was rather rapid and data of this period have an additional uncertainty of ±2%.

To account for the combined changes of the throughput of the system's entrance optics and PMT-sensitivity, the reporting period was broken into 14 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. Periods P1 through P4 refer to the period before the instrument relocation and Periods P5 through P10 refer to the period starting with the reinstallation of the instrument. The ratios of irradiance spectra applied in Periods P1 – P4 relative to the spectrum applied in Period P2 are shown in Figure 5.7.3. The ratios of irradiance spectra applied in Periods P6 – P10 relative to the spectrum applied in Period P5 are shown in Figure 5.7.4.

The quality of calibrated solar measurements of the SUV-150B was further assessed by comparison with 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 ±5%. The standard deviation of the ratio calculated from all data with the exception of the outliers discussed below is 1.7%. The ratio tends to be somewhat lower early and late in the year and is highest during the summer. Most outliers occur in June 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 1 meter apart, they are shaded at slightly different times, leading to variations in the ratio. Affected SUV data have been flagged in the Version 2 dataset.

Table 5.7.1. Calibration periods for Summit Volumes 23.

Period name	Period range	Number of absolute scans	Remarks
P1	01/01/13 – 01/28/13	1	
P2	01/29/13 – 03/15/13	5	
P2B	03/16/13 – 03/22/13	0	Average of P2 and P3
P3	03/23/13 – 04/26/13	4	
P3B	04/27/13 – 05/07/13	0	Average of P3 and P4
P4	05/08/13 – 06/28/13	9	Last period before relocation
P5	06/29/13 – 07/20/13	3	First period after relocation
P5B	07/21/13 – 07/28/13	0	Average of P5 and P6
P6	07/29/13 – 08/03/13	1	
P6B	08/04/13 – 08/07/13	0	Average of P6 and P7
P7	08/08/13 – 08/25/13	1	
P8	08/26/13 – 09/22/13	2	
P9	09/23/13 – 09/26/13	1	
P10	09/27/13 – 12/31/13	5	

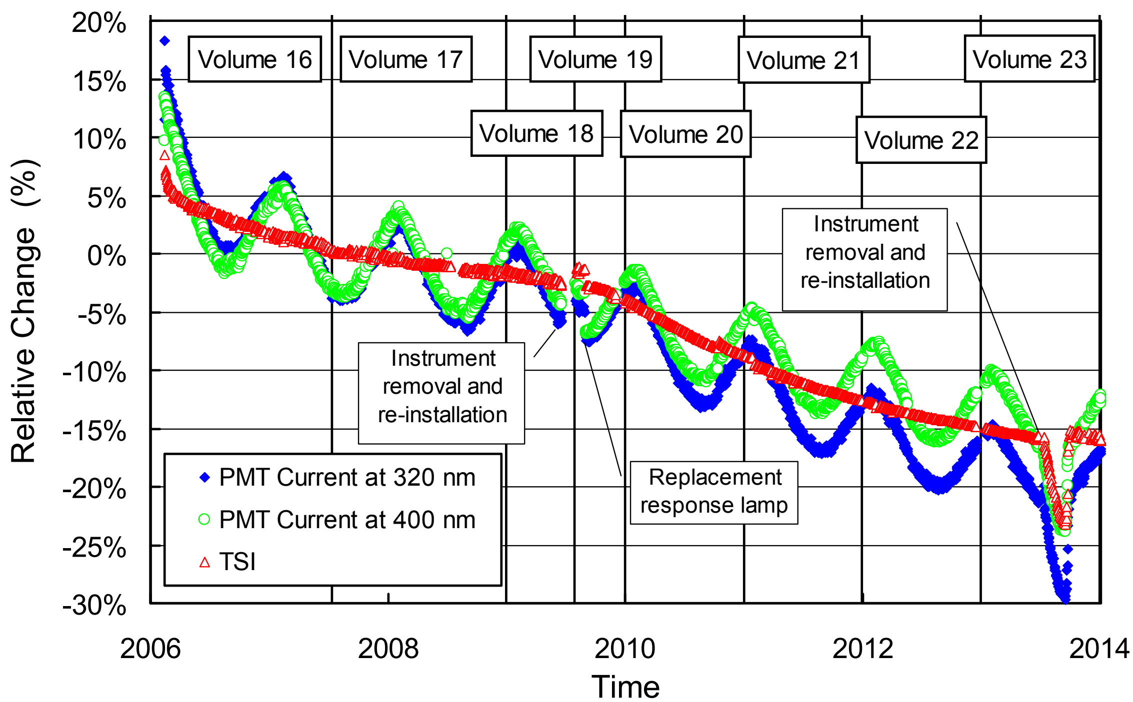

Figure 5.7.2. *Time-series of TSI signal and PMT currents at 320 and 400 nm during measurements of the internal reference lamp performed at Summit between 2/15/06 and 12/31/13. Data from 9/2/10 (date of response lamp replacement) were scaled downward to fit into the existing pattern. Data are normalized to the period 2/14/06 - 6/20/09.*

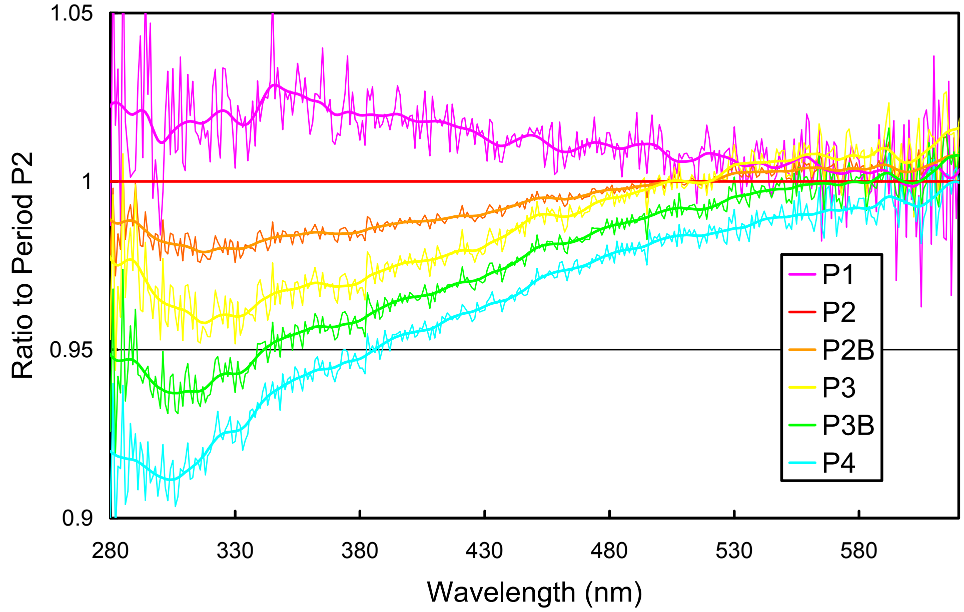

Figure 5.7.3. *Ratios of irradiance assigned to the internal reference lamp in Periods P1 – P4, referenced to the irradiance of Period P2. At the end of Period P4, the Green House, where the instrument is installed, was moved to a new location. Thick lines indicate ratios of the smoothed irradiance spectra used for the calibration of solar measurements.*

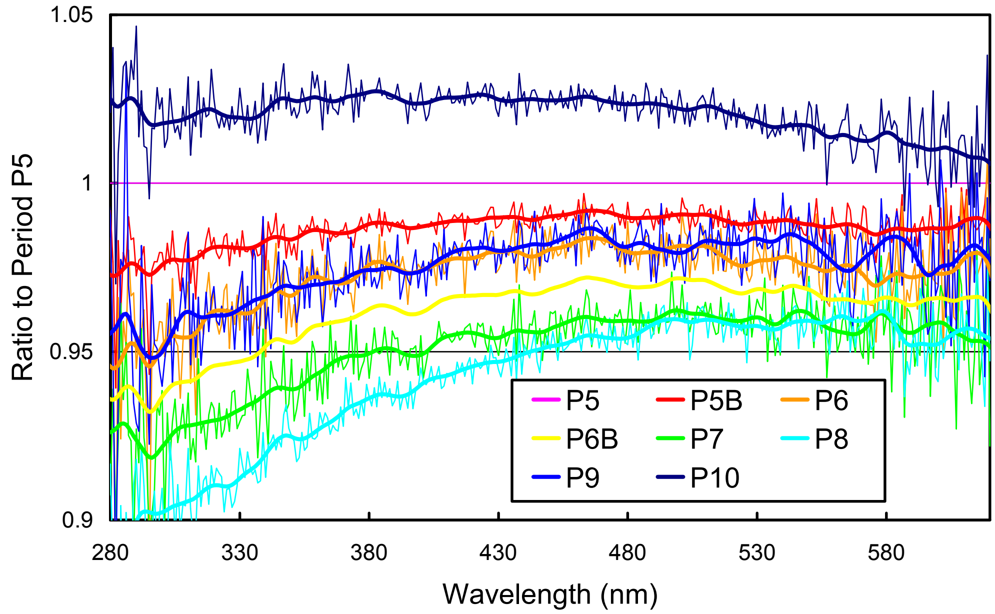

Figure 5.7.4. *Ratios of irradiance assigned to the internal reference lamp in Periods P5 – P10, referenced to the irradiance of Period P5, which is the first period following the reinstallation of the instrument. Thick lines indicate ratios of the smoothed irradiance spectra used for the calibration of solar measurements.*

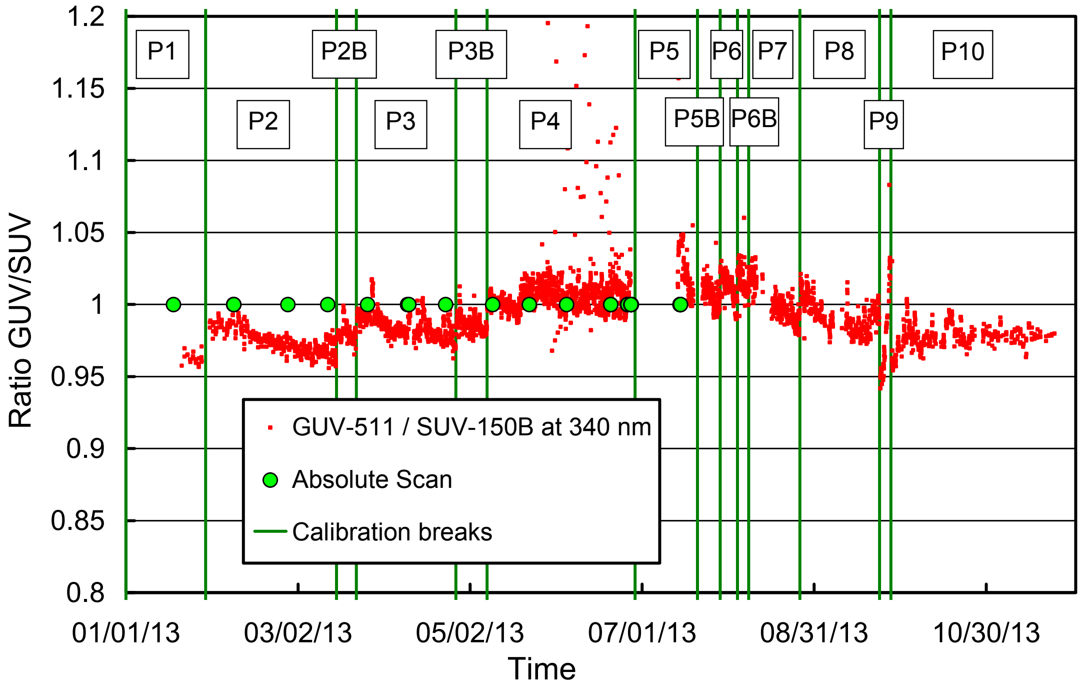

Figure 5.7.5. *Ratios of GUV-511 and SUV-150B measurements at 340 nm.*

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 1/1/13 – 12/31/13. 322 scans were evaluated. For 96.9% 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 -0.037 and +0.028 nm, respectively. These comparatively large changes occurred during the "settling" process of the instrument on the day after the system reinstallation in July 2013. 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. Most of the variations observed are artifacts of the correlation algorithm, which has an uncertainty of about 0.015 nm.

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.

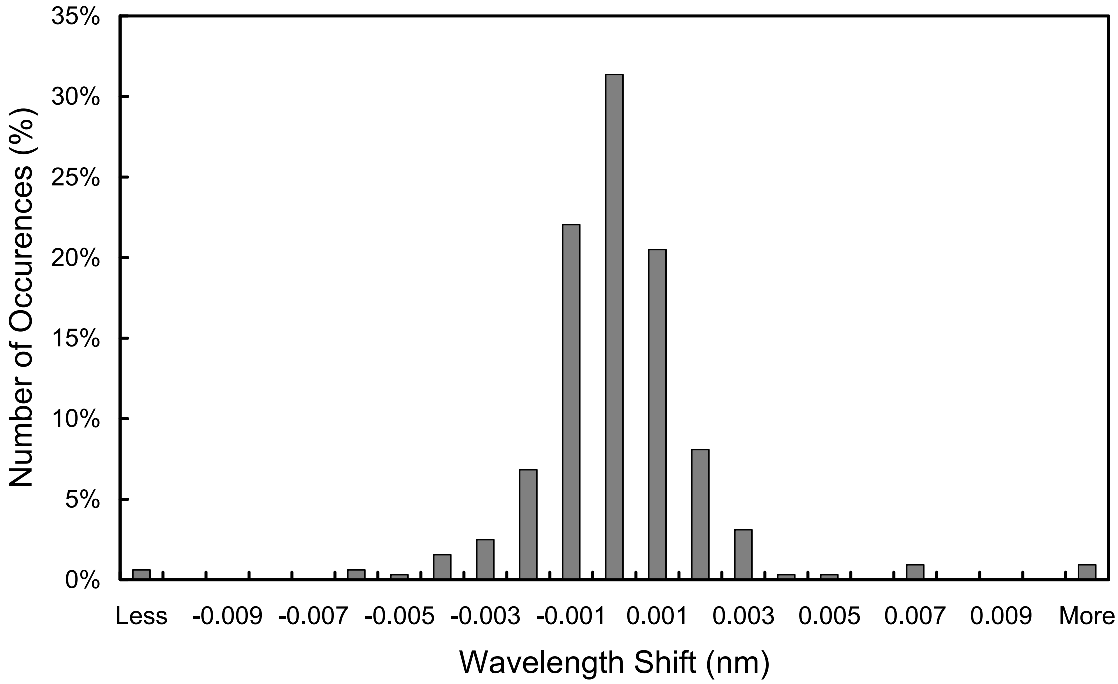

Figure 5.7.6. *Differences in the measured position of the 296.73 nm mercury line between consecutive wavelength scans for the period 1/1/12 – 12/19/12. The labels of the horizontal axis give the center wavelength shift for each column. The 0-nm histogram column covers the range from -0.0005 to +0.0005 nm. "Less" means shifts smaller than -0.0105 nm; "more" means shifts larger than 0.0105 nm.*

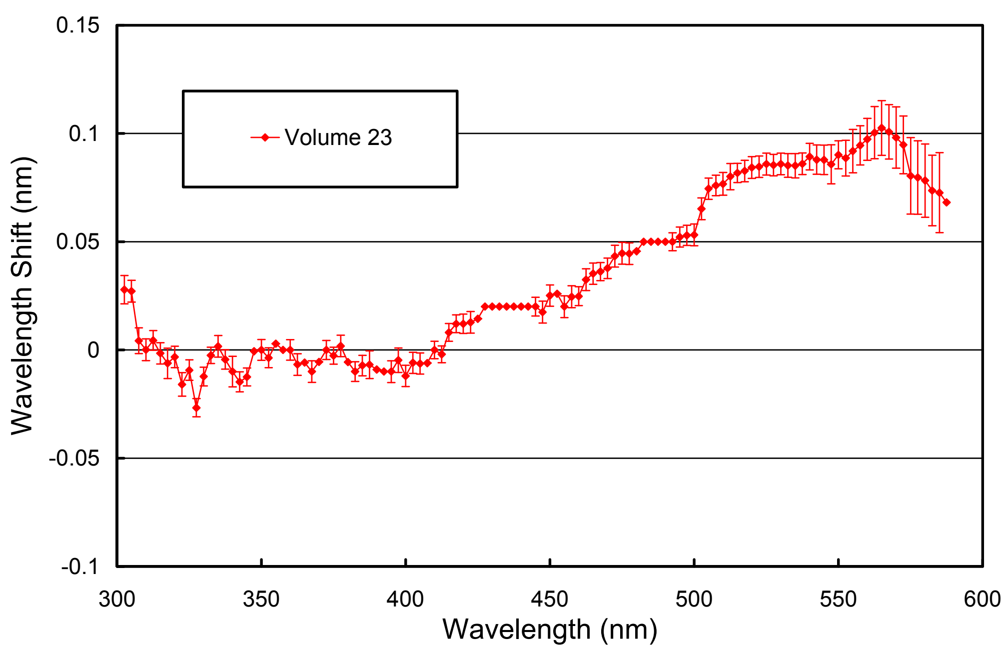

Figure 5.7.7. *Monochromator non-linearity correction functions of Volume 23 data.*

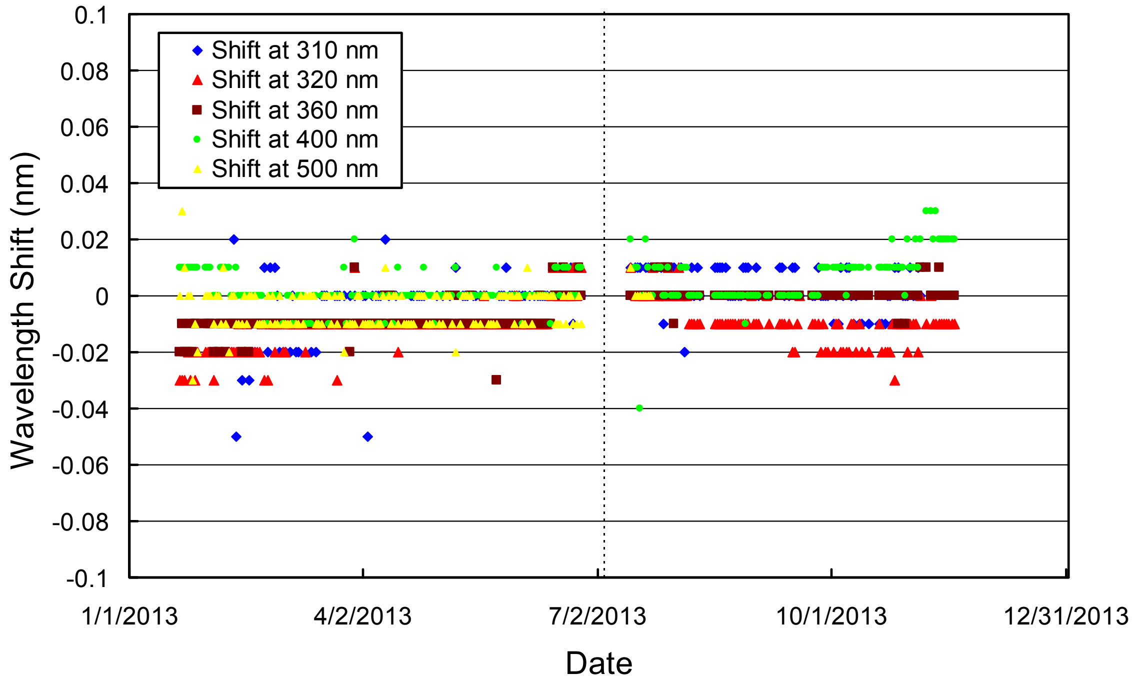

Figure 5.7.8. *Wavelength accuracy check of "Version 0" Volume 23 data at five wavelengths in the UV and visible by means of Fraunhofer-line correlation. All noontime measurements have been evaluated. The vertical broken line indicates the period when the system was out of operation due to the Greenhouse relocation.*

5.7.4. Missing Data

A total of 15,835 scans are part of the Summit Volume 23 dataset. Missing periods are summarized in Table 5.7.2.

Table 5.7.2. Incomplete days in the Summit Volume 23 dataset.

Period	Reason
01/28/13 – 01/29/13	Software error (Error "91")
06/26/13 – 07/13/13	Site visit
08/10/13 – 08/12/13	Unknown
08/13/13 – 08/15/13	Operator error
09/04/13	Software error (Error "91")
09/06/13 – 09/09/13	Problem setting PMT high-voltage. Reverting to previously installed software version (from version 2.2.167 back to 2.2.166)
09/30/13	Software error (Error "91")
10/13/13 – 10/14/13	Software error (Error "91")
11/05/13	Execution of several absolute scans
11/07/13	Software error (Error "91")
11/09/13	Software error (Error "91")

5.7.5. GUV Data

The GUV-511 radiometer, which is installed next to the SUV-150B, was calibrated against SUV-150B measurements following the procedure outlined in Section 4.3.1. From the calibrated measurements, data products were calculated (Section 4.3.2). Figure 5.7.9 shows a comparison of GUV-511 and SUV-150B erythemal irradiance for the Volume 23 period. For solar zenith angles (SZA) smaller than 80°, measurements of the two instruments agree to within ±2.0% (±1σ). We advise data users to use SUV-150B rather than GUV-511 data whenever possible, in particular for low-Sun conditions.

Figure 5.7.10 shows a comparison of total ozone measurements from the GUV-511, SUV-150B (Version 2), and Ozone Monitoring Instrument (OMI). The SUV-150B data agree well with OMI observations. The average ratio SUV/OMI is 1.016, and the standard deviation of the ratio is 2.4%. This good agreement—even at large SZAs—is achieved by using ozone profiles in the inversion algorithm, which were measured at Summit by NOAA's Global Monitoring Division close in time to the UV observations. The average ratio GUV / OMI for SZAs smaller than 80° is 0.987 and the standard deviation of the ratio is 3.8%. The calculation of total ozone from GUV data is based on one standard ozone profile via a lookup table, which may not be appropriate in the spring when the total ozone column is large. Because of this profile effect, GUV measurements tend to be too small in the spring, in particular if the SZA is large. For solar zenith angles larger than 80°, measurements of the GUV's 305 nm channel are close to the detection limit. GUV ozone data at large SZAs become unreliable and should not be used.

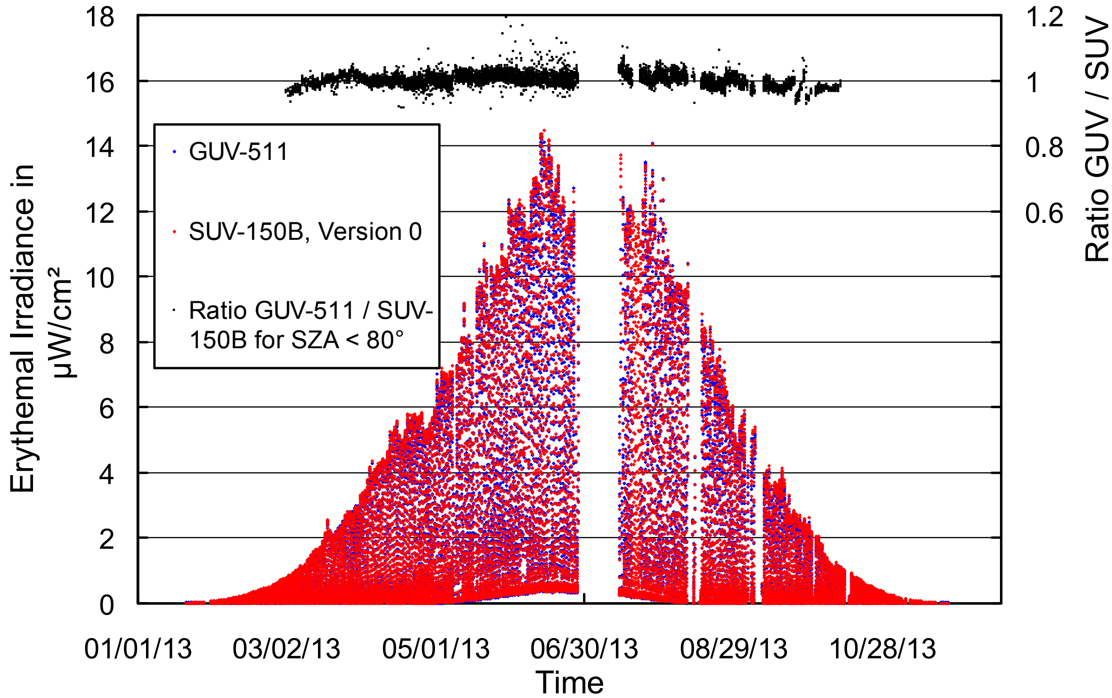

Figure 5.7.9. *Comparison of erythemal irradiance measured by the SUV-150B spectroradiometer and the GUV-511 radiometer.*

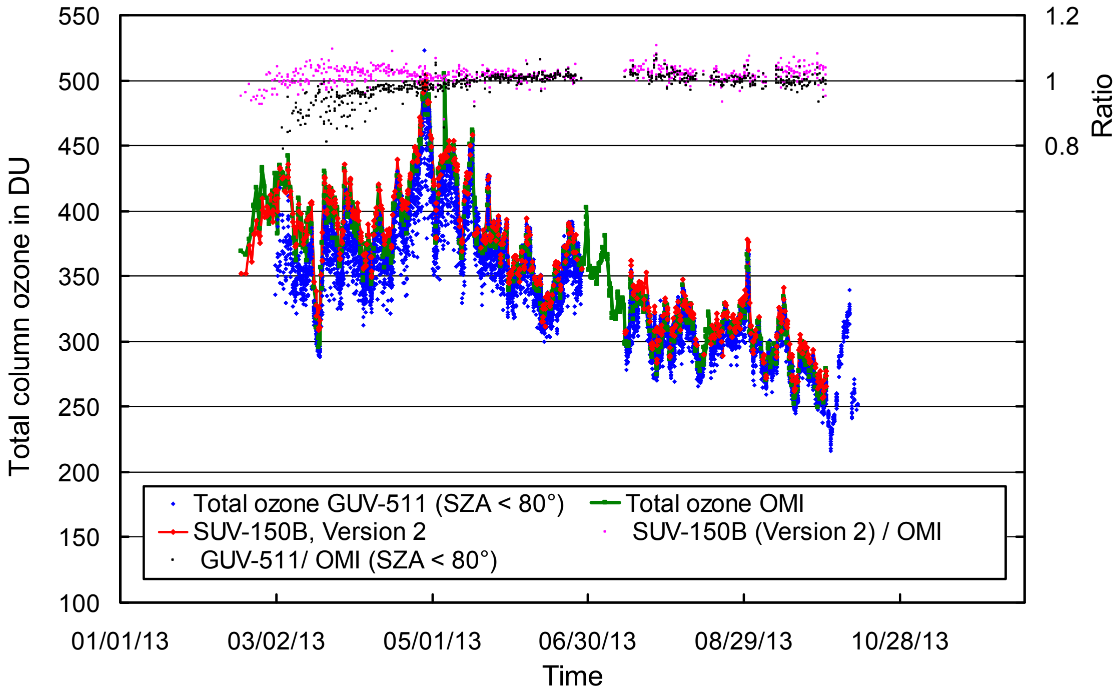

Figure 5.7.10. *Comparison of total column ozone measurements from GUV-511, SUV-150B (Version 2 data), and OMI. GUV-511 measurements are plotted in 15 minute intervals. For calculating the ratio of data sets, only measurements concurrent with the OMI overpass were evaluated.*