Protocol of the intercomparison at AEMET, Madrid, Spain on September 18 to 22, 2023 with the travelling reference spectroradiometer QASUME from PMOD/WRC

Report prepared by Gregor Hülsen

Operator: Gregor Hülsen
Local operator: Ana Diaz and Jose María San Atanasio

The purpose of the visit was the comparison of global solar irradiance measurements between the spectroradiometer AEM operated by AEMET Madrid and the travel reference spectroradiometer QASUME. The measurement site is located at Madrid; Latitude 40.45 N, Longitude 3.72 W and altitude 680 m.a.s.l.
The horizon of the measurement site is free down to at least 85° solar zenith angle (SZA). Measurements between 5:00 UT and 20:00 UT have been analysed.

QASUME was installed on the measurement platform of AEMET-Madrid in the morning of 18 September 2023. The spectroradiometer was installed next to the AEM spectroradiometer with the entrance optic of QASUME within 1 m to the other instrument. The spectroradiometer in use at AEMET is a Bentham DM300 double monochromator system (AEM). The input optics is a D6 from Bentham UK. The intercomparison between QASUME and AEM lasted four days, from the afternoon of September 18 to the afternoon of September 22, 2023.

QASUME was calibrated several times during the intercomparison period using a portable calibration system. Three lamps (T16573, T68523 and T61251) were used to obtain an absolute spectral irradiance calibration traceable to the primary reference held at PMOD/WRC, which is traceable to PTB. The daily mean responsivity of the instrument based on these calibrations varied by less than 1 % during the 5 days of the intercomparison period (Day of year 261-265). To account for the responsivity change, the responsivity was calculated for each day separately and used for that specific day.
The wavelength shifts relative to the QASUMEFTS (Gröbner et al., 2017) spectrum as retrieved from the MatSHIC analysis were between ±50 pm in the spectral range 290 to 400 nm.

Protocol:

The measurement protocol was to measure one solar irradiance spectrum every 30 minutes from 290 to 400 nm, every 0.25 nm, and 1.5 seconds between each wavelength increment.

DOY	Date	DAY	Weather	Comment (times are in UT)
261	18-Sep	Monday	Mostly diffuse sky	Installed at 7:00 14:20 Calibration T68523
262	19-Sep	Tuesday	Clear sky in the morning Mix of sun and clouds in the afternoon	10:14 Calibration T68523 10:43 Calibration T16573
263	20-Sep	Wednesday	Clear sky in the morning Mix of sun and clouds in the afternoon	10:14 Calibration T68523 10:43 Calibration T61251
264	21-Sep	Thursday	Mostly diffuse sky Rainshower from 10:25-12:20	14:43 Calibration T68523 16:12 End of Campaign

Results:

In total 69 quality controlled synchronised simultaneous spectra from QASUME and AEM, are available from the measurement period. Measurements between 6:30 and 18:00 UT have been analysed (SZA smaller than 90°).

Remarks:

In addition, 65 synchronised simultaneous spectra from QASUME and Brewer 186 were acquired. Brewer 186 is installed next to AEM.

A second revised dataset is available for the calibration period based on a recalibration of the spectroradiometer using 1000 W FEL standards. The results of both intercomparison are shown in the appendix.

Conclusions:

AEM V1:

1. The average spectral ratio between AEM and QASUME has a slight spectral trend from -5% to -3%.
2. The mean spectral ratio is around -5%.
3. The temporal variation of the spectra between AEM and QASUME indicate a small cosine error during the clear sky day, with variations around 3% during the campaign.
4. The spectral ratio between AEM and QASUME show a higher variability during on Tuesday, but not on the other intercomparison days.
5. The wavelength shifts of AEM with respect to a high-resolution reference spectrum are constant during the intercomparison. However, there is a large offset of more than 0.3 nm between 300 nm and 370 nm. The wavelength shift is increasing during the years.

AEM Revised Dataset:

1. The average spectral ratio between AEM and QASUME has a slight spectral trend from 0% to +2%.
2. The mean spectral ratio is around +1%.
3. The temporal variation of the spectra between AEM and QASUME indicate a small cosine error during the clear sky day, with variations around 3% during the campaign.
4. The spectral ratio between AEM and QASUME show a higher variability during on Tuesday, but not on the other intercomparison days.
5. The wavelength shifts of AEM with respect to a high-resolution reference spectrum are constant during the intercomparison. However, there is a large offset of more than 0.3 nm between 300 nm and 370 nm. The wavelength shift is increasing during the years.

Brewer 186:

1. The spectral ratios between the cosine corrected Brewer 186 data and QASUME are very stable during the intercomparison period and do not deviate by more than 1% from QASUME.
2. The temporal variation of the spectra between Brewer 186 and QASUME was very stable, with variations less than 2% during the whole campaign.

Comparison to previous QASUME site visits:

The long-term stability of AEM was assessed by comparing QASUME site visits performed since 2011. As seen in figure 1 the campaign average ratio of AEM to QASUME are similar within ±2 % for the years 2013-2021. In 2011 AEM overestimated solar UV irradiance by more than 10%. The measurement (V1) in 2023 were lower than QASUME with -5 % whereas the revised dataset is again in good agreement.

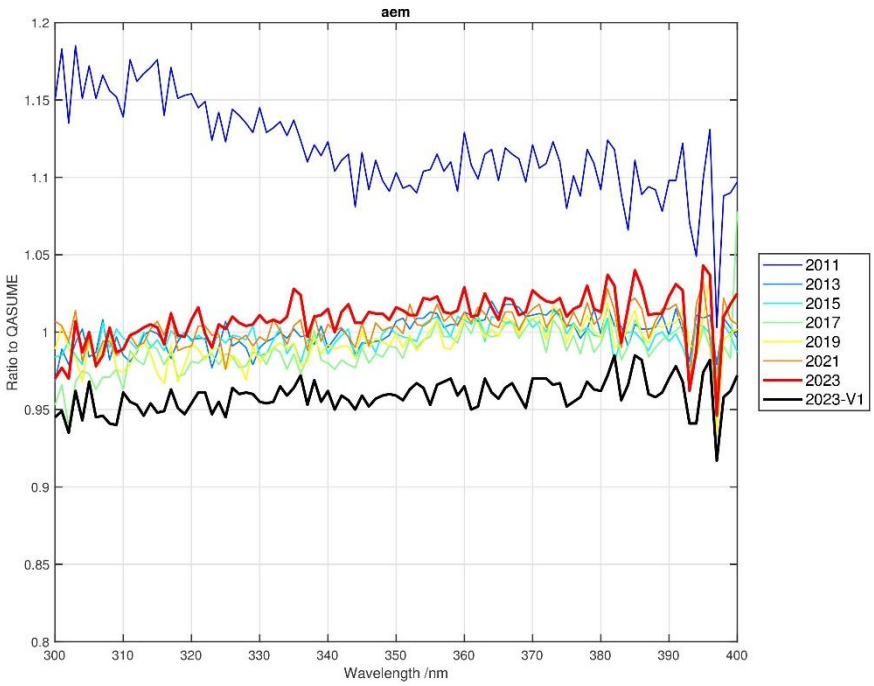


Figure 1: Solar spectral ratios of AEM to QASUME averaged over each QASUME site visit.

Recommendation:

Five percent offset in the spectral ratios AEM to Qasume:

- We strongly recommend investigating the stability of the calibration lamp history (FEL and Monitor Lamps).
- The primary FEL lamp calibration performed in June 2023 should be repeated as soon as possible. Latest before the spectroradiometer is turned off for the winter season. As all four FEL lamps calibration have been measured in June and performed identically only one FEL lamps calibration is sufficient to check this calibration activity.

⇨ ***AEMET performed this task beginning of November 2023 which led to the revised dataset.***

The increase of the ratio from the morning to the evening:

- This could be caused by the hysteresis if the PMT or a small azimuth error. The later can be caused be a mismatch of what the level gauge is telling and the actual orientation of the diffuser.

Wavelength shift of AEM:

- The wavelength settings of AEM need to be updated to account for the spectral offsets observed during the intercomparison.

Slit function of AEM:

- We strongly recommend redoing the slit function measurement using a Mercury Spectral Lamp.

⇨ ***AEMET performed this task beginning of November 2023 which is used the comparison of the revised dataset. The new slit function is similar to the old one.***

Noise of the AEM data:

- The noise seen in the comparison in 2019 and on 19. September 2023 could be an indication for a problem of the decreased signal to noise ratio of the signal recording system (PMT and DAQ). We suggest checking the signal to noise ratio over time (past years).

Cosine Error:

- Comparing the results of this year’s campaign to the previous site visits show no increase of a possible cosine error.

Quality Control 1:

- It is recommended to develop standard operating procedures (SOP) for the yearly and monthly activities. The results should be summarized on a yearly basis in protocols.

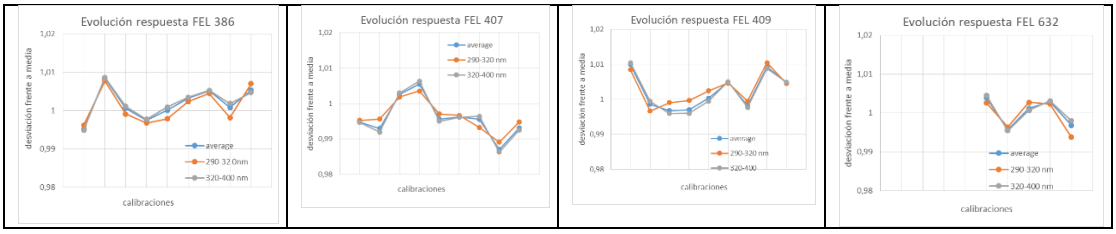
Quality Control 2:

- It is strongly recommended that an internal intercomparison campaign is performed between AEM and the local Brewer 163. A minimum of two days throughout the year are sufficient to show any error in the calibration of either instrument. As both instruments are operated most of the time in parallel a routine to check the ratio AEM/186 all the time would be a powerful tool to have an independent monitor all year around.
- We recommend creating a figure for the ratio AEM/186 starting from the last Qasume-Visit in 2021 until 21. September 2023.

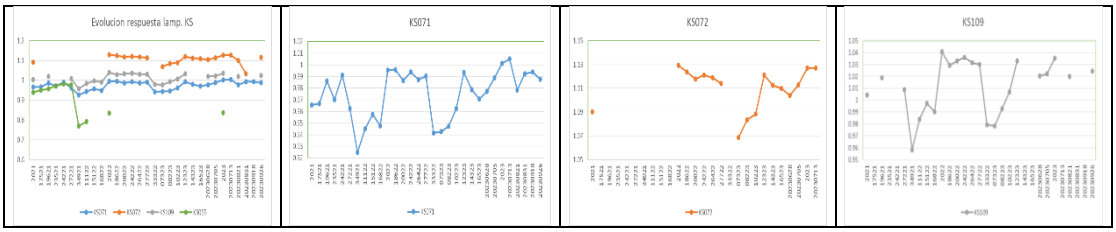
Comments of the Operator:

Currently the software ShicRIVM is applied to all the AEM spectra in order to correct the effect of the wavelength shift.

Since 2015, 1000W lamps calibration is done every year following the SNO-INS-2703 procedure. And the stability of the spectroradiometer AEM is checked with 200W lamps one ore twice per month (SNO-INS-2702). The stability of all the lamps used is monitored as showed in next figures.

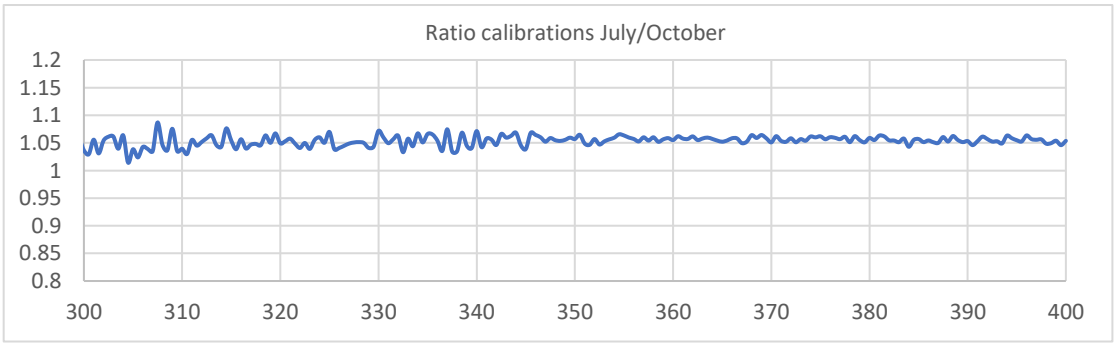


-1000W lamps calibration 2015-2023



-200W lamps 2021-2023

After the preliminary results of the comparison with QASUME that showed lower responsivity o the AEM (more than 5%), and in order to detect a possible systematic error in the last 1000W calibration setup, it was repeated on the 31th of October and a new correction was obtained and apply for the data. The difference between the responsivity file created in summer and the one created in October is shown in the next figure.



Other issues included in this report as cause of the differences between AEM and QASUME (Signal to noise ratio, PMT hysteresis, monochromator wavelength shift, etc) will have to be checked by the manufacturer. Meanwhile, the software ShicRIVM is applied to all the AEM spectra in order to correct the effect of the wavelength shift and the slit function is redone using a Mercury lamp.

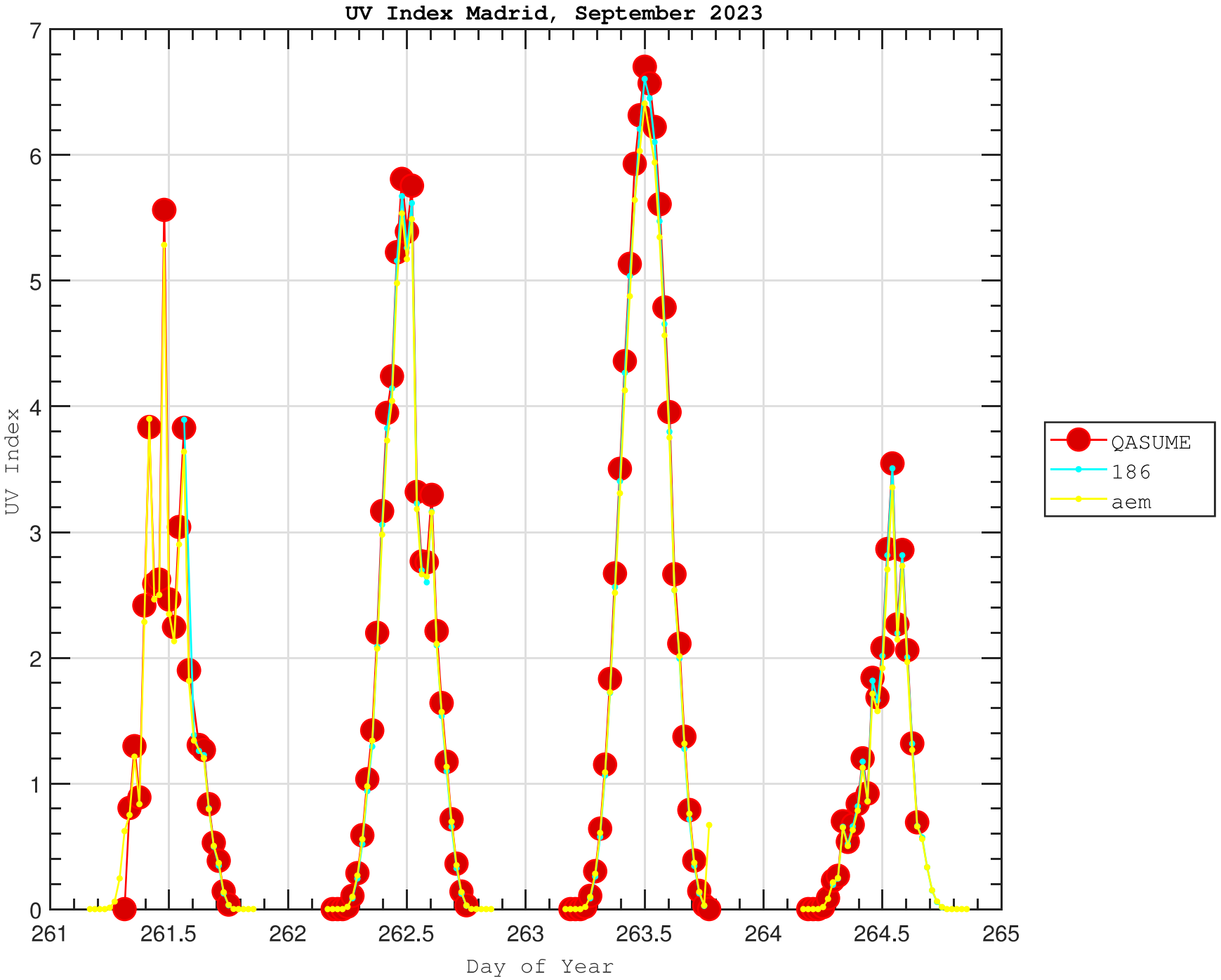
References:

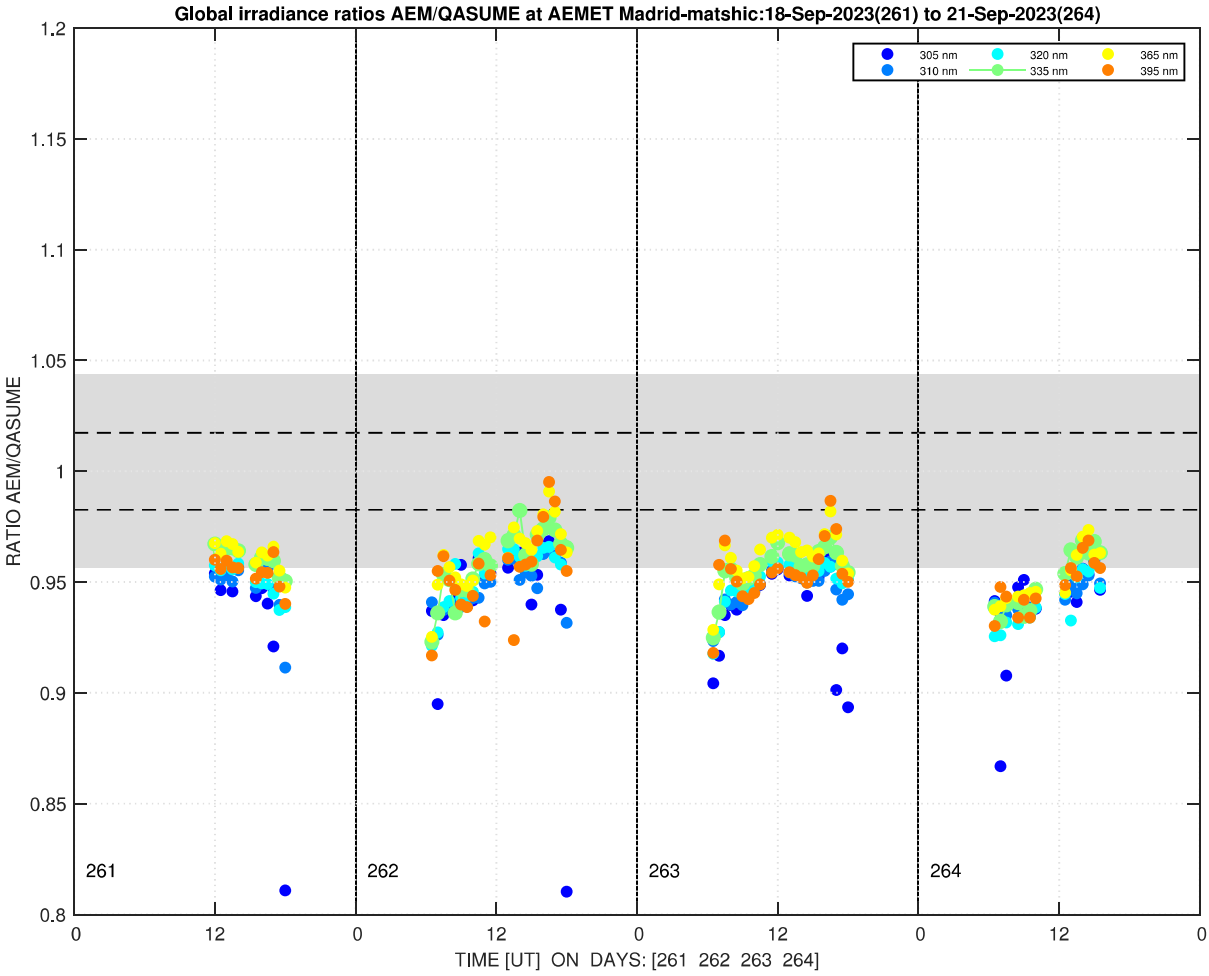
Gröbner, J., Kröger, I., Egli, L., Hülsen, G., Riechelmann, S., and Sperfeld, P.: The high-resolution extraterrestrial solar spectrum (QASUMEFTS) determined from ground-based solar irradiance measurements, Atmos. Meas. Tech., 10, 3375-3383, https://doi.org/10.5194/amt-10-3375-2017, 2017.

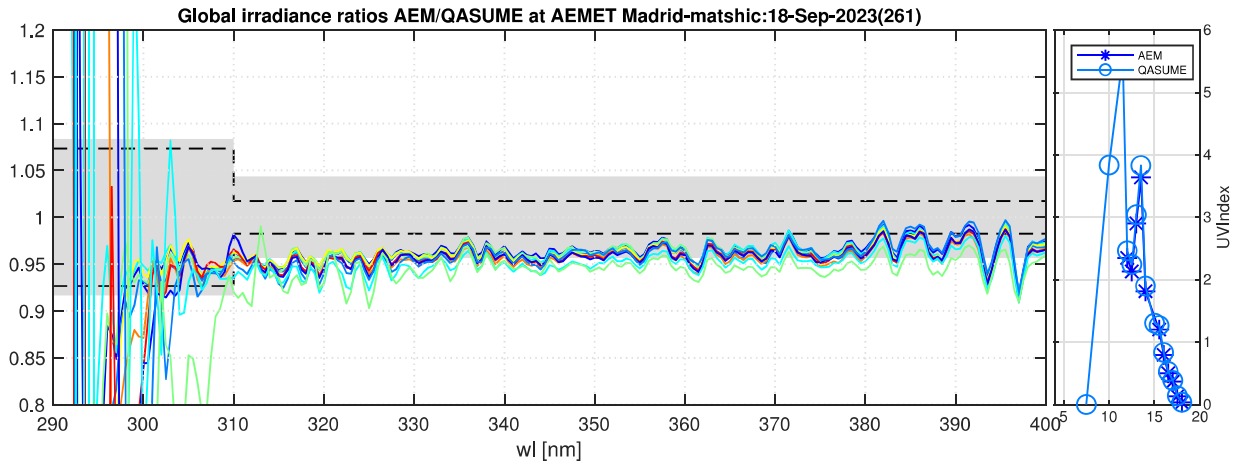
https://eubrewnet.aemet.es/dokuwiki/doku.php?id=codes:uvaccess#uv_corrections_flag

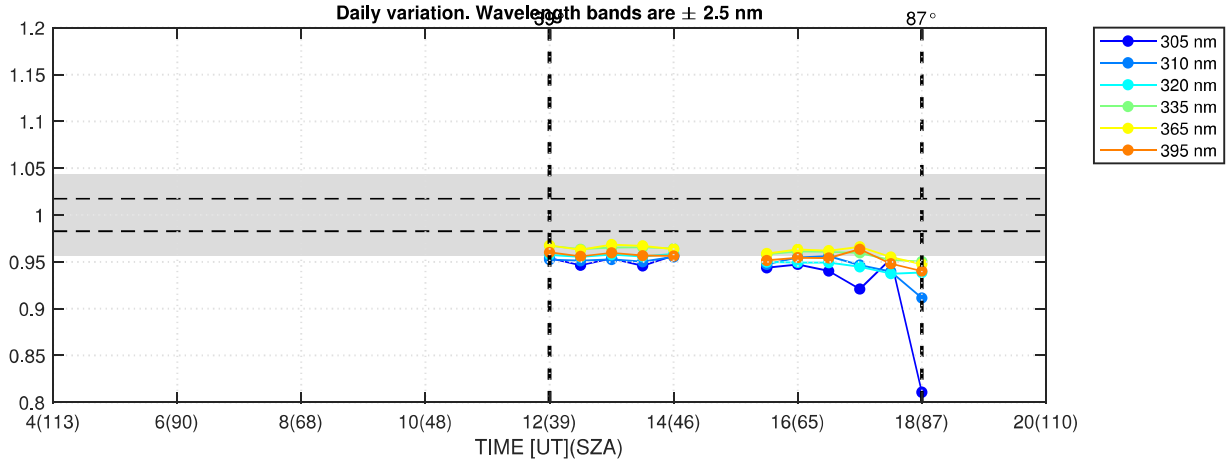
Appendix

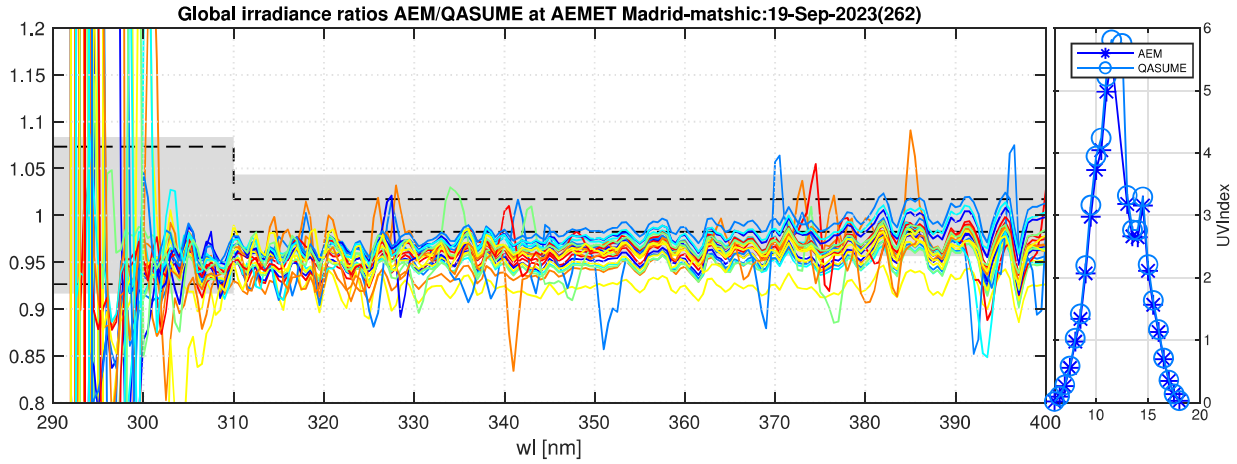
Detailed results for all Brewer spectrophotometers with respect to the reference spectroradiometer QASUME.

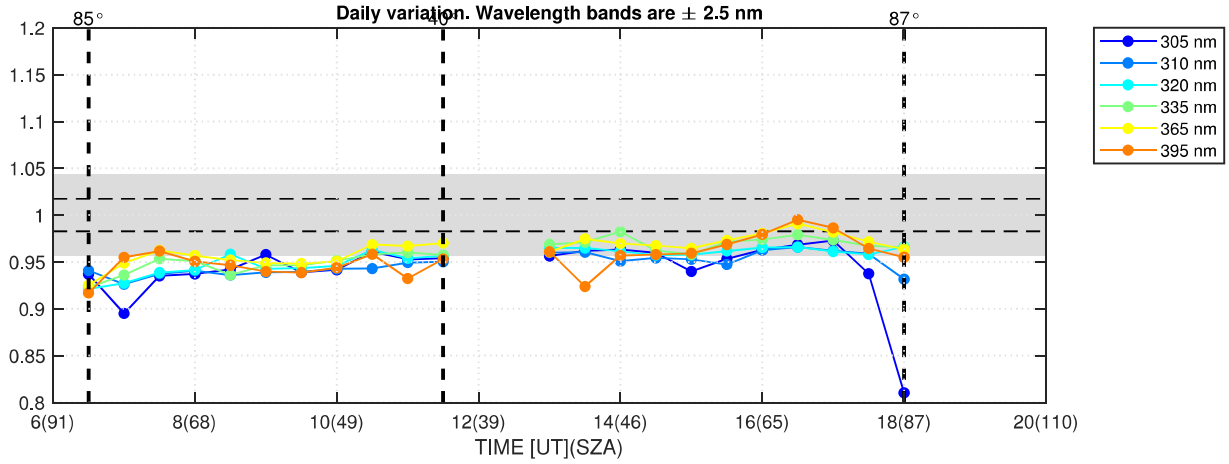

UV Index Madrid, September 2023
UV Index
Day of Year
QASUME
186
aem
0
1
2
3
4
5
6
7
261
261.5
262
262.5
263
263.5
264
264.5
265

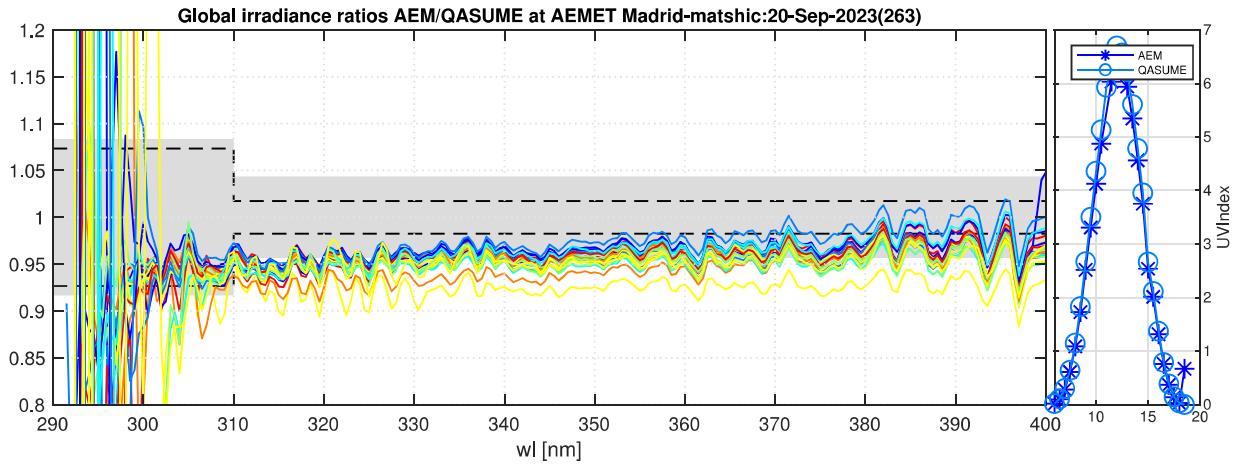

Global irradiance ratios AEM/QASUME at AEMET Madrid-matshic:18-Sep-2023(261) to 21-Sep-2023(264)
305 nm
310 nm
320 nm
335 nm
365 nm
395 nm
RATIO AEM/QASUME
261
262
263
264
TIME [UT] ON DAYS: [261 262 263 264]


Global irradiance ratios AEM/QASUME at AEMET Madrid-matshic:18-Sep-2023(261)
AEM
QASUME
UVIndex
wl [nm]


Daily variation. Wavelength bands are ± 2.5 nm
87°
305 nm
310 nm
320 nm
335 nm
365 nm
395 nm
TIME [UT](SZA)


Global irradiance ratios AEM/QASUME at AEMET Madrid-matshic:19-Sep-2023(262)
AEM
QASUME
wl [nm]
UVIndex


Daily variation. Wavelength bands are ± 2.5 nm
85°
40
87°
305 nm
310 nm
320 nm
335 nm
365 nm
395 nm
6(91)
8(68)
10(49)
12(39)
14(46)
16(65)
18(87)
20(110)
TIME [UT](SZA)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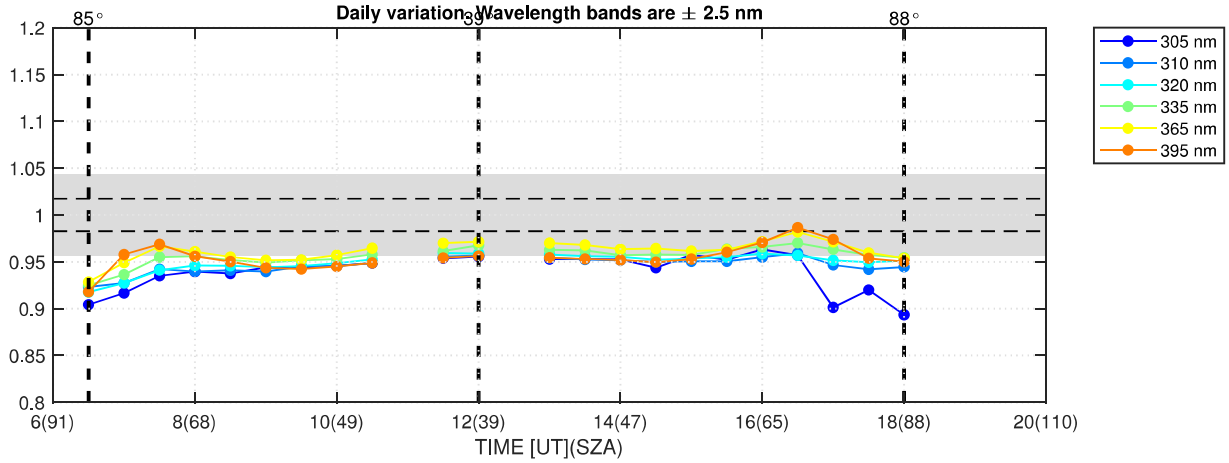
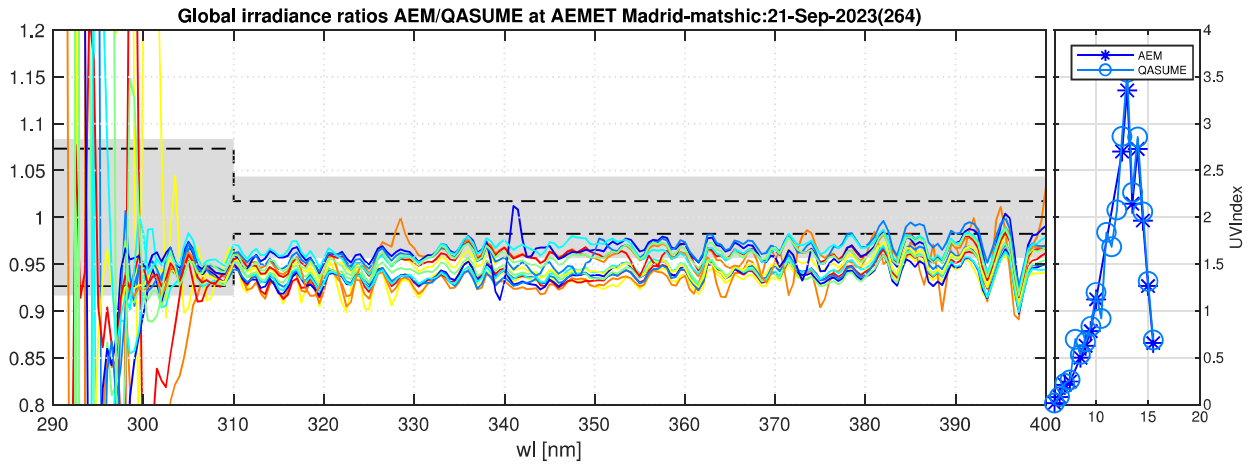
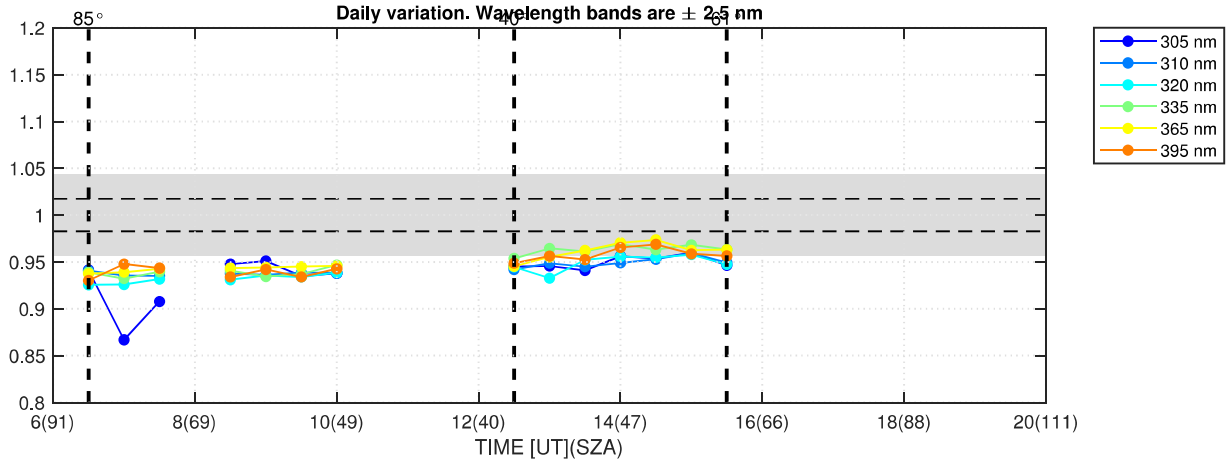
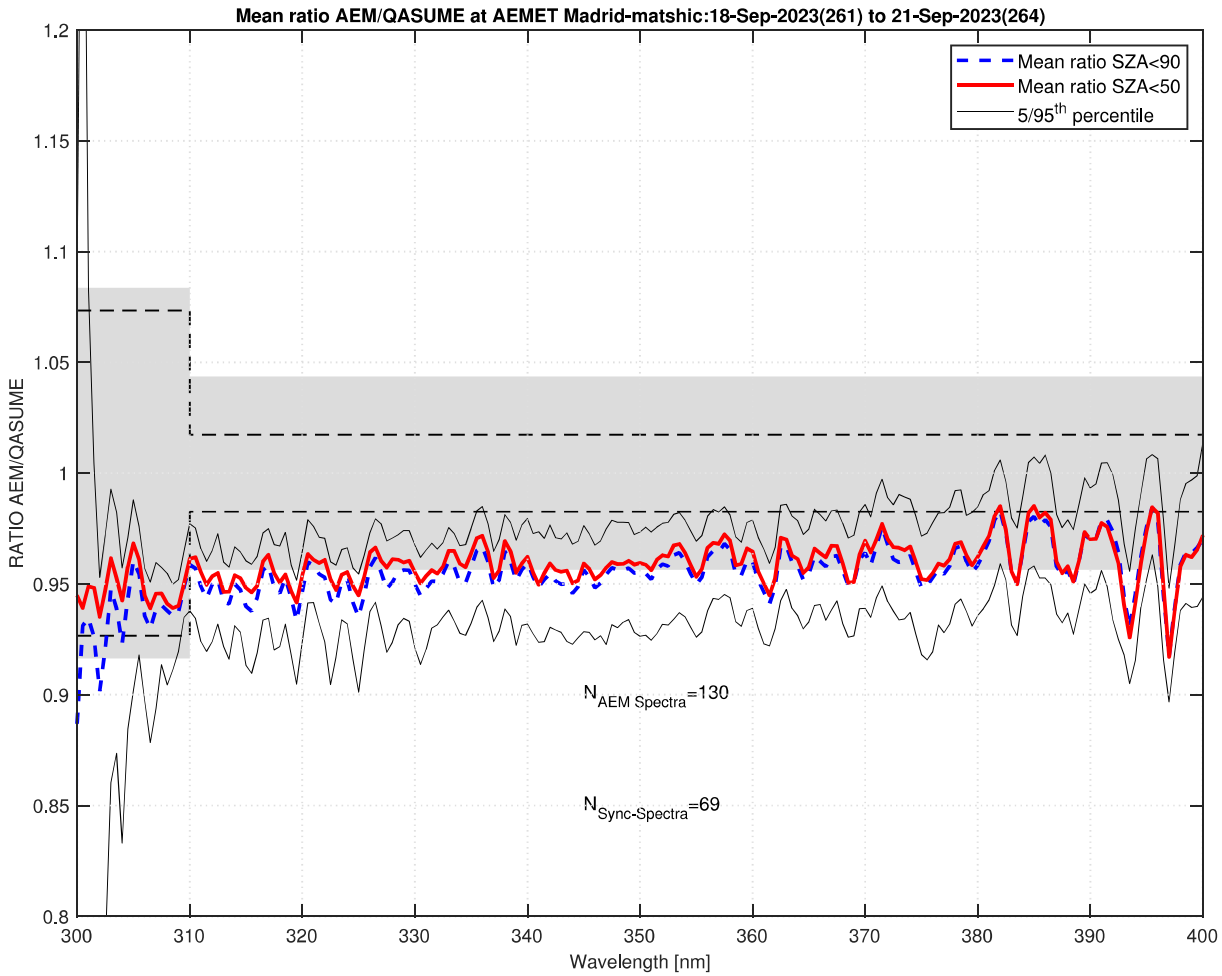
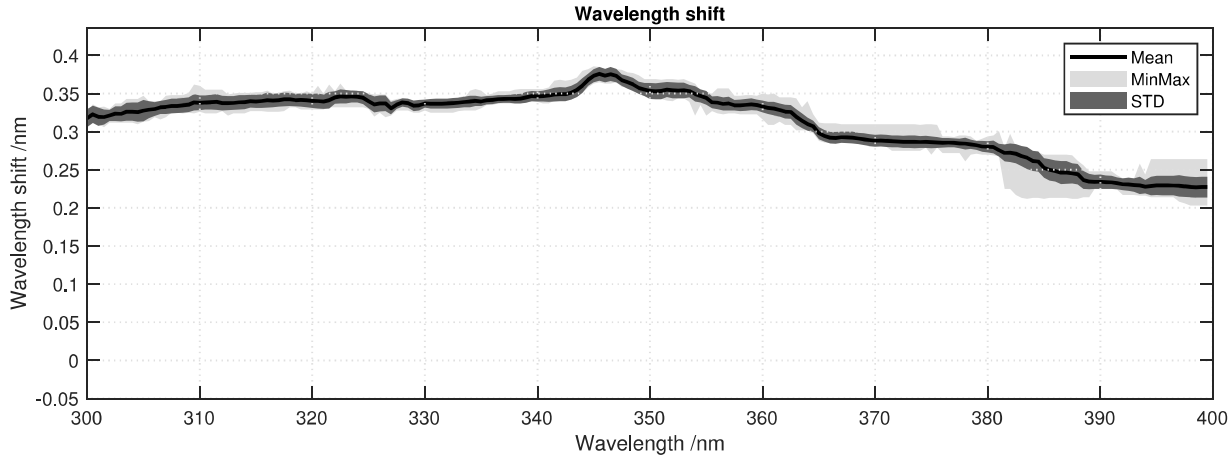
AEM
QASUME
wl [nm]
UVIndex

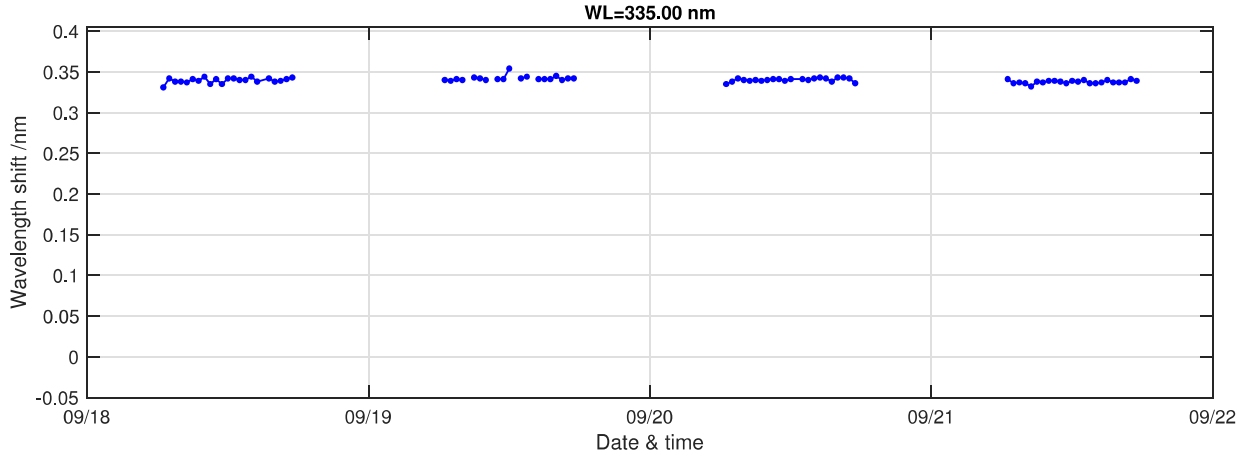

Daily variation. Wavelength bands are ± 2.5 nm
85°
39
88°
305 nm
310 nm
320 nm
335 nm
365 nm
395 nm
6(91)
8(68)
10(49)
12(39)
14(47)
16(65)
18(88)
20(110)
TIME [UT](SZA)


Global irradiance ratios AEM/QASUME at AEMET Madrid-matshic:21-Sep-2023(264)
wl [nm]
AEM
QASUME
UVIndex


Daily variation. Wavelength bands are ± 2.5 nm
85°
TIME [UT](SZA)
305 nm
310 nm
320 nm
335 nm
365 nm
395 nm


Mean ratio AEM/QASUME at AEMET Madrid-matshic:18-Sep-2023(261) to 21-Sep-2023(264)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
RATIO AEM/QASUME
Wavelength [nm]
N AEM Spectra=130
N Sync-Spectra=69


Wavelength shift
Mean
MinMax
STD
Wavelength shift /nm
Wavelength /nm
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
300
310
320
330
340
350
360
370
380
390
400


WL=335.00 nm
Wavelength shift /nm
Date & time
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
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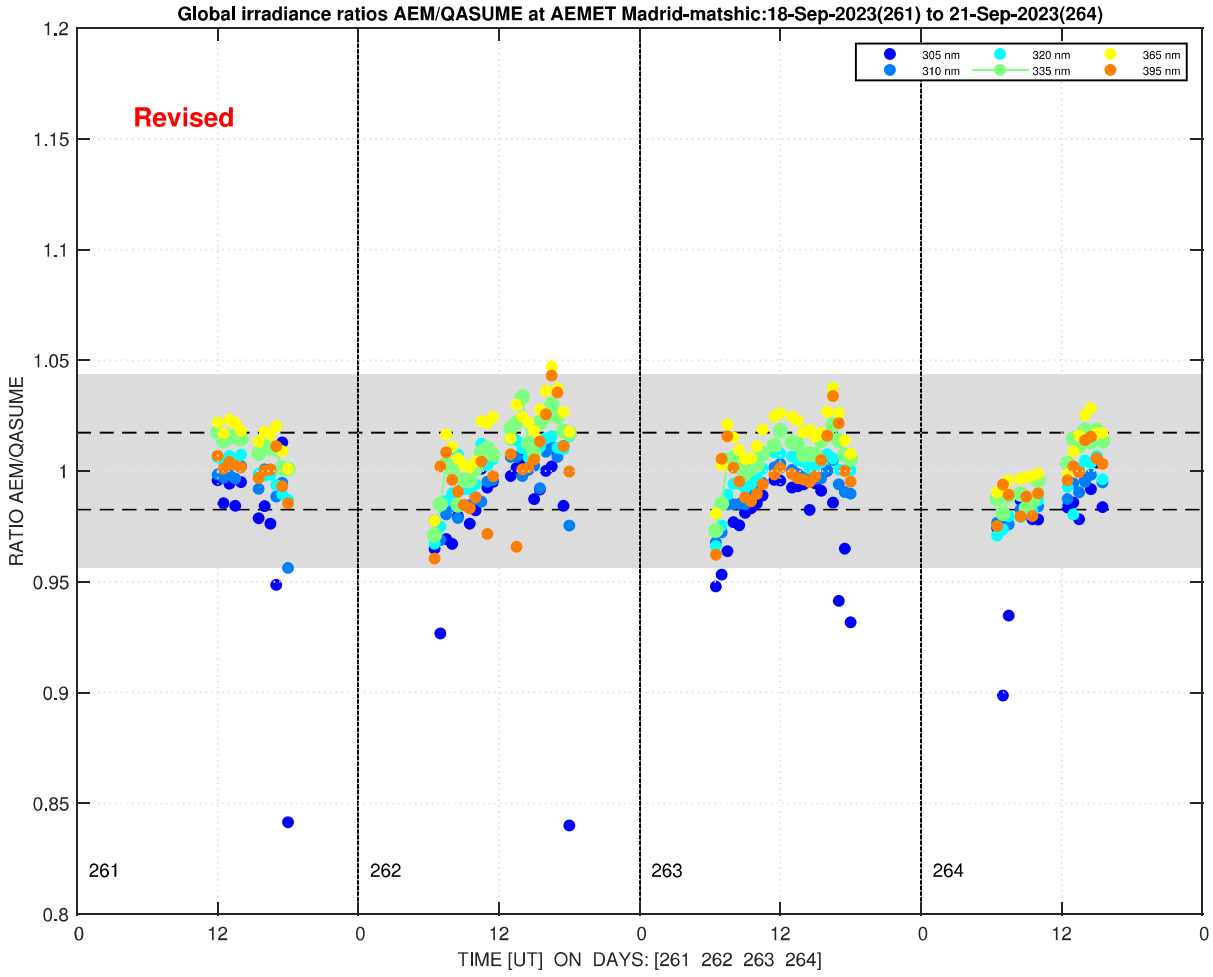
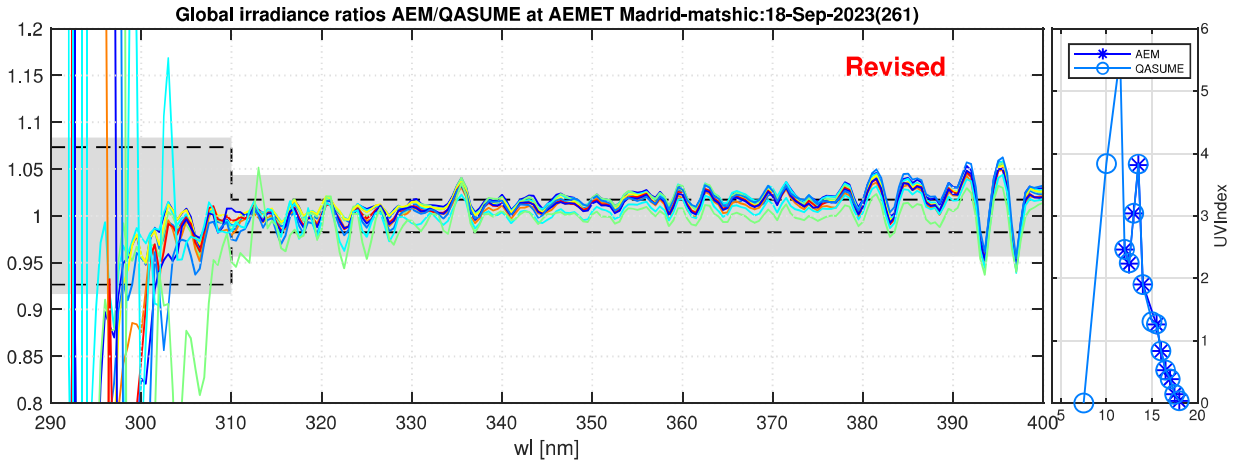
-0.05
09/18
09/19
09/20
09/21
09/22


Global irradiance ratios AEM/QASUME at AEMET Madrid-matshic:18-Sep-2023(261) to 21-Sep-2023(264)
Revised
305 nm
310 nm
320 nm
335 nm
365 nm
395 nm
RATIO AEM/QASUME
261
262
263
264
TIME [UT] ON DAYS: [261 262 263 264]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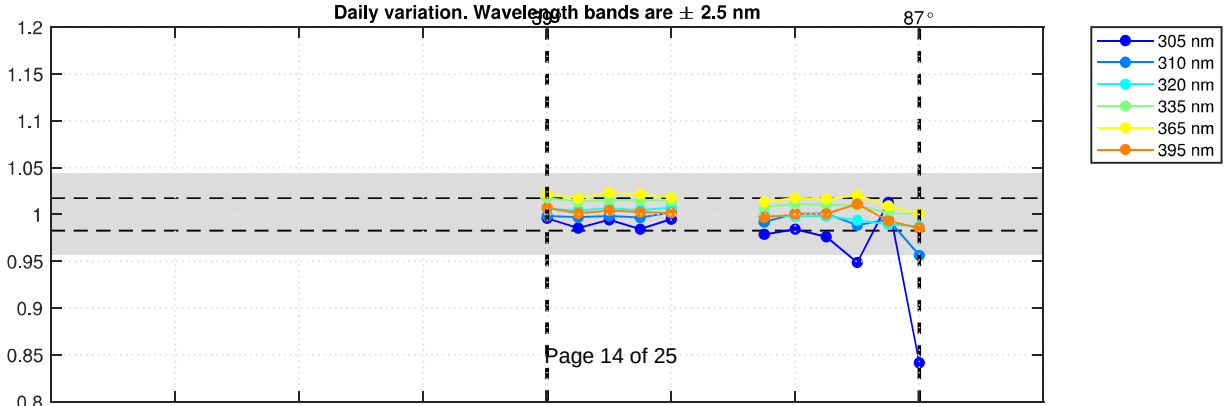
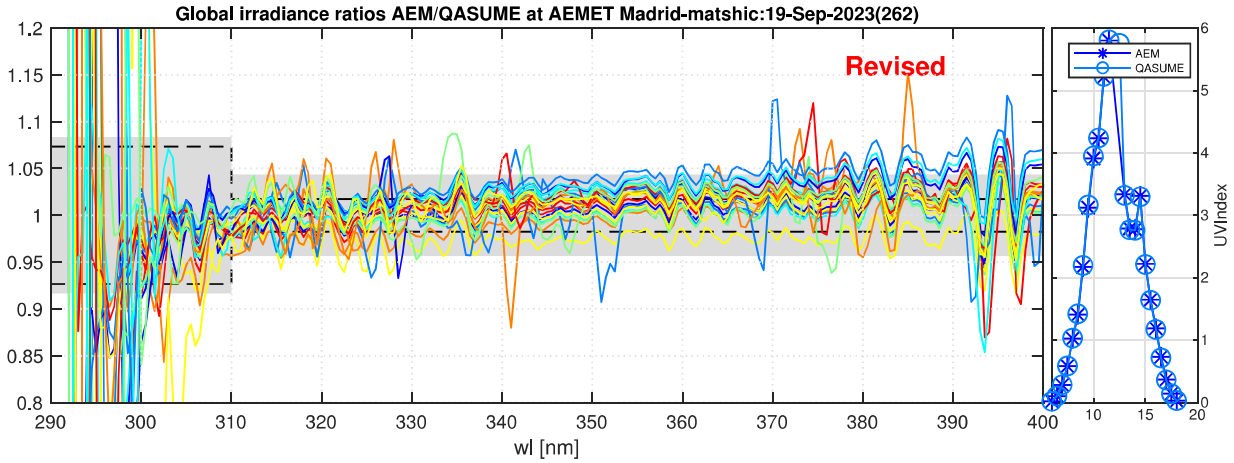
Revised
AEM
QASUME
UVIndex
wl [nm]


Daily variation. Wavelength bands are ± 2.5 nm
87°
305 nm
310 nm
320 nm
335 nm
365 nm
395 nm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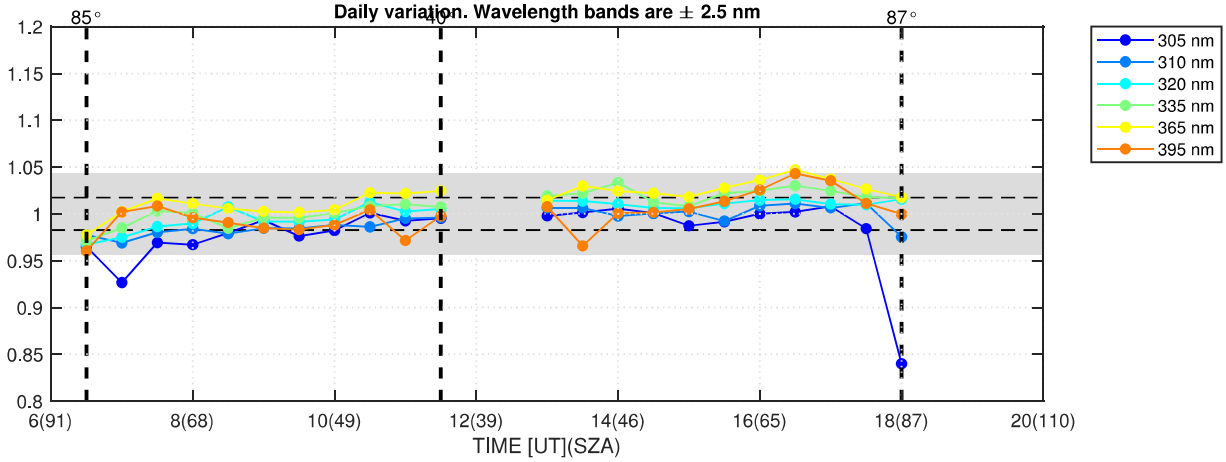
UVIndex
wl [nm]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85°
87°
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365 nm
395 nm
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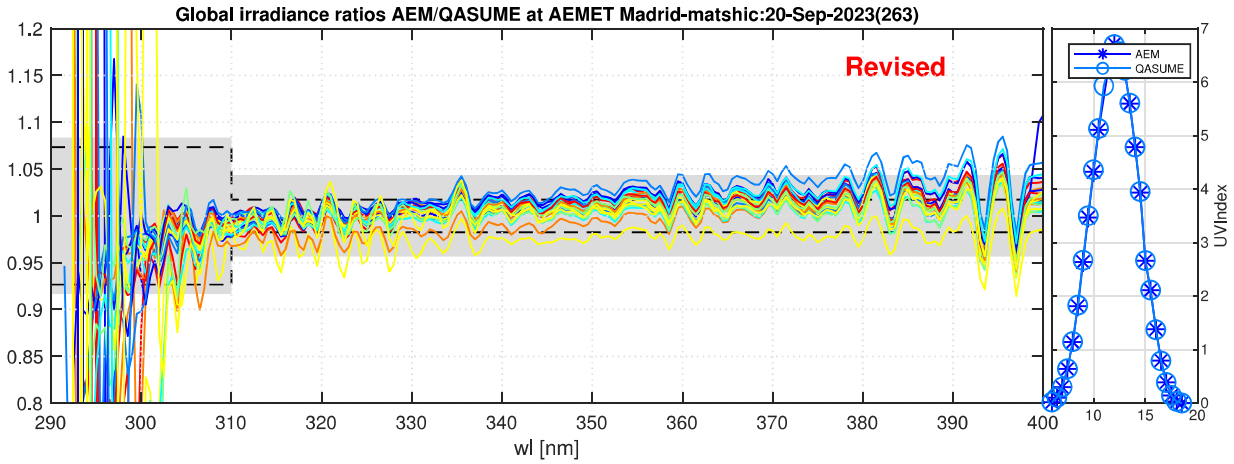
10(49)
12(39)
14(46)
16(65)
18(87)
20(110)
TIME [UT](SZA)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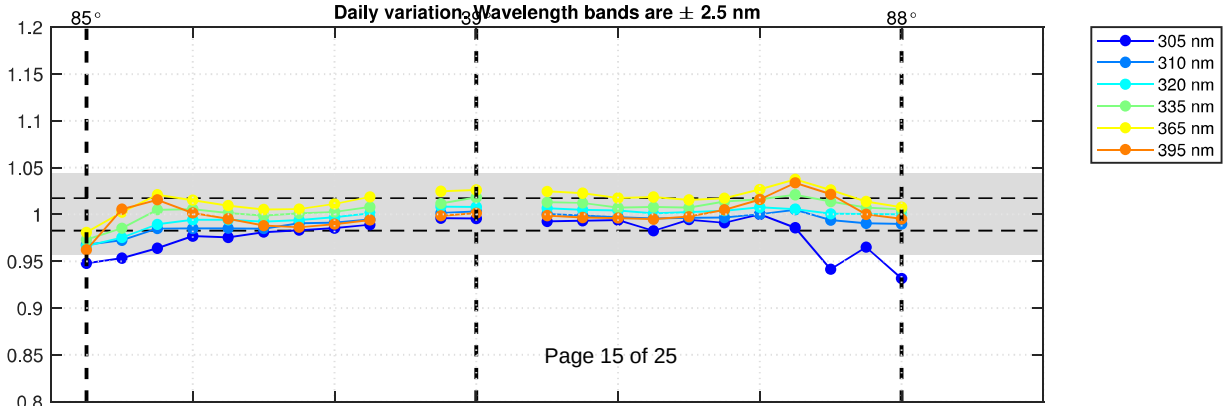
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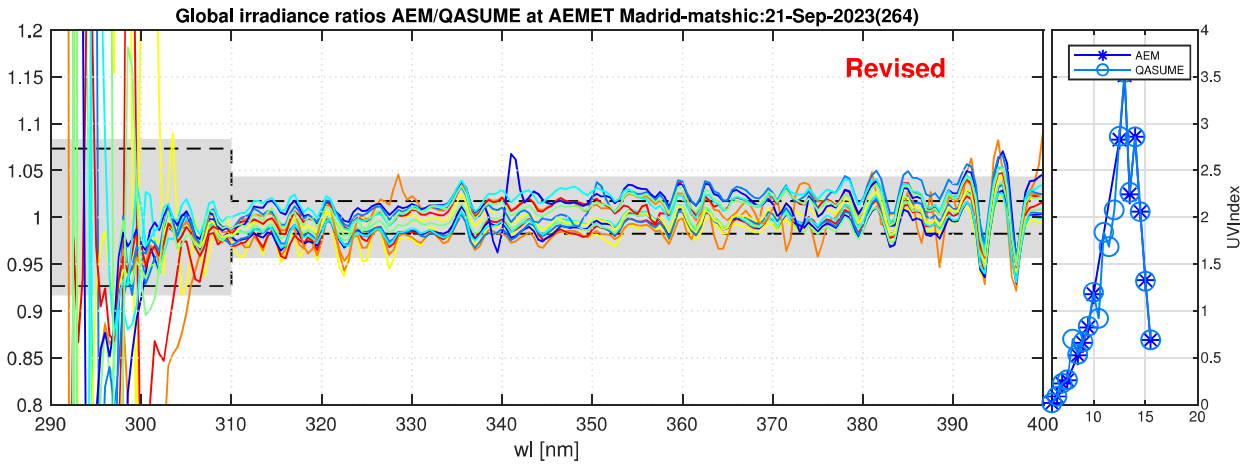
310 nm
320 nm
335 nm
365 nm
395 nm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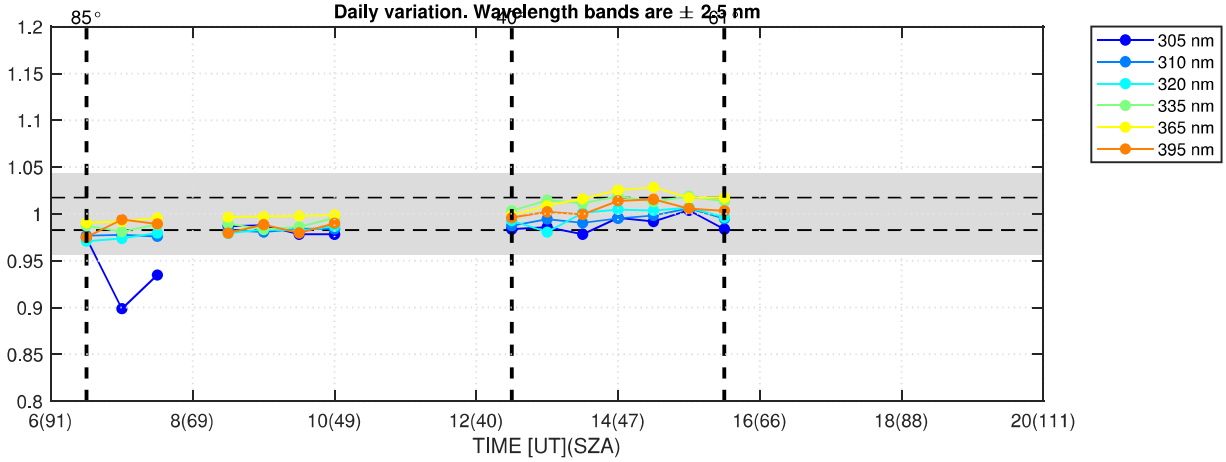
Revised
AEM
QASUME
UVIndex
wl [nm]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310 nm
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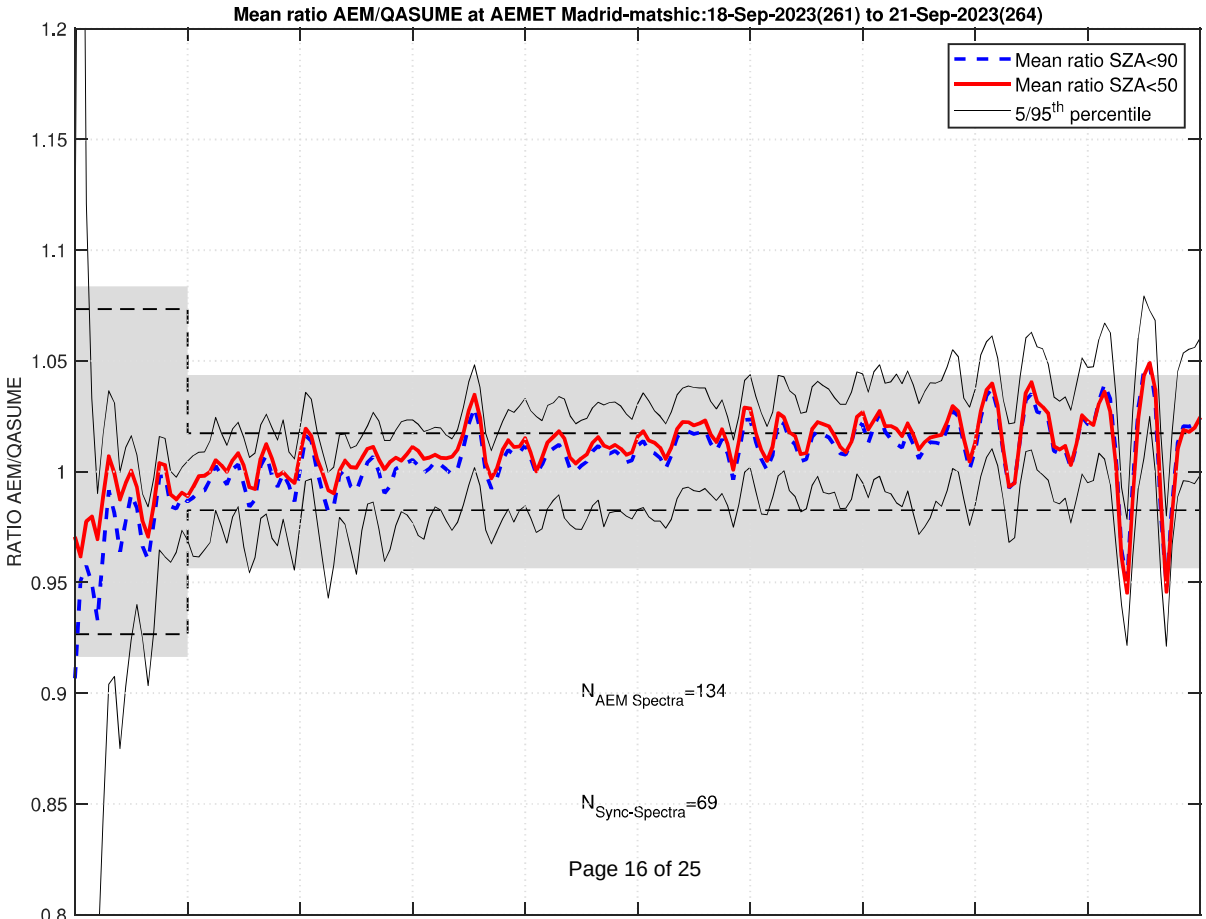
395 nm
TIME [UT](SZA)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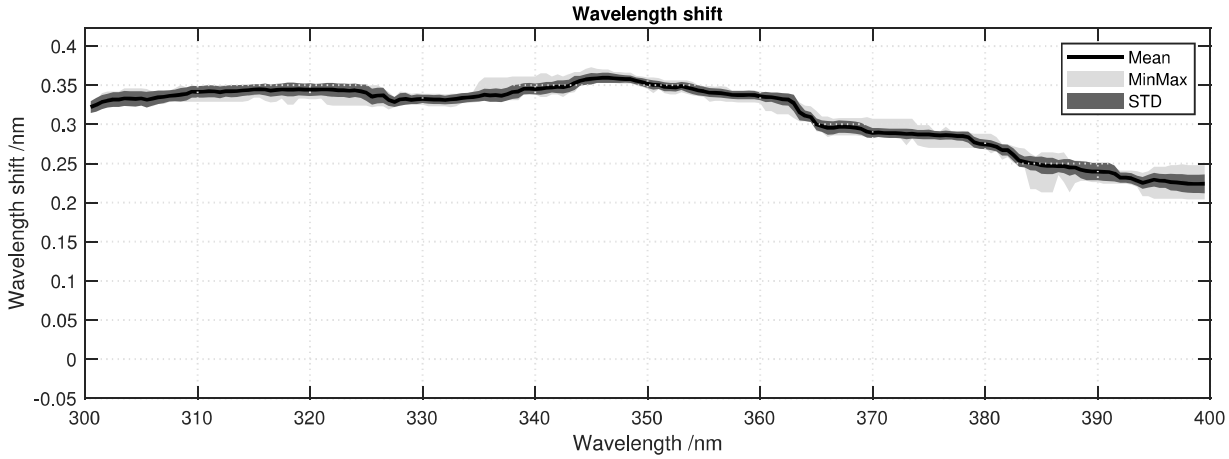
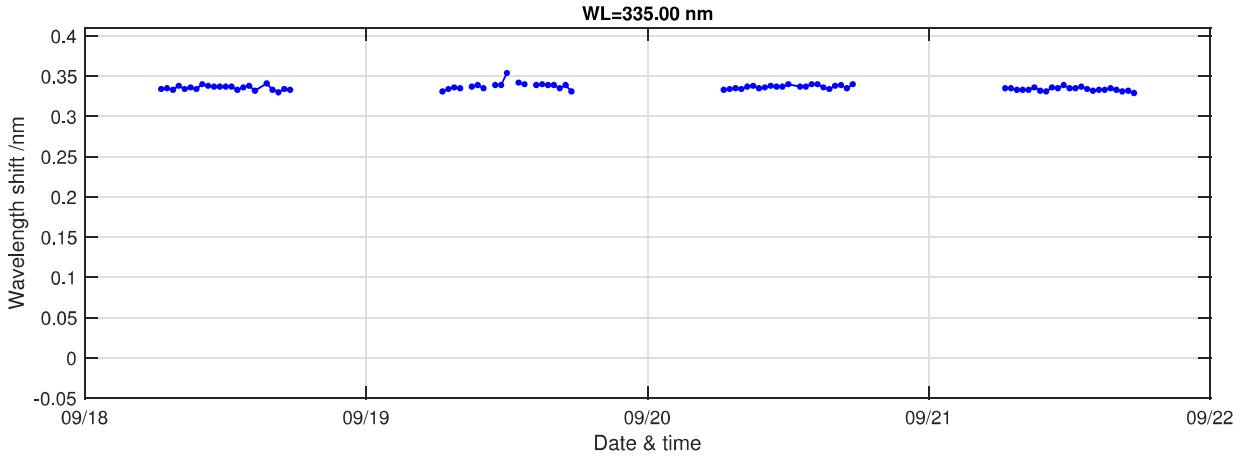
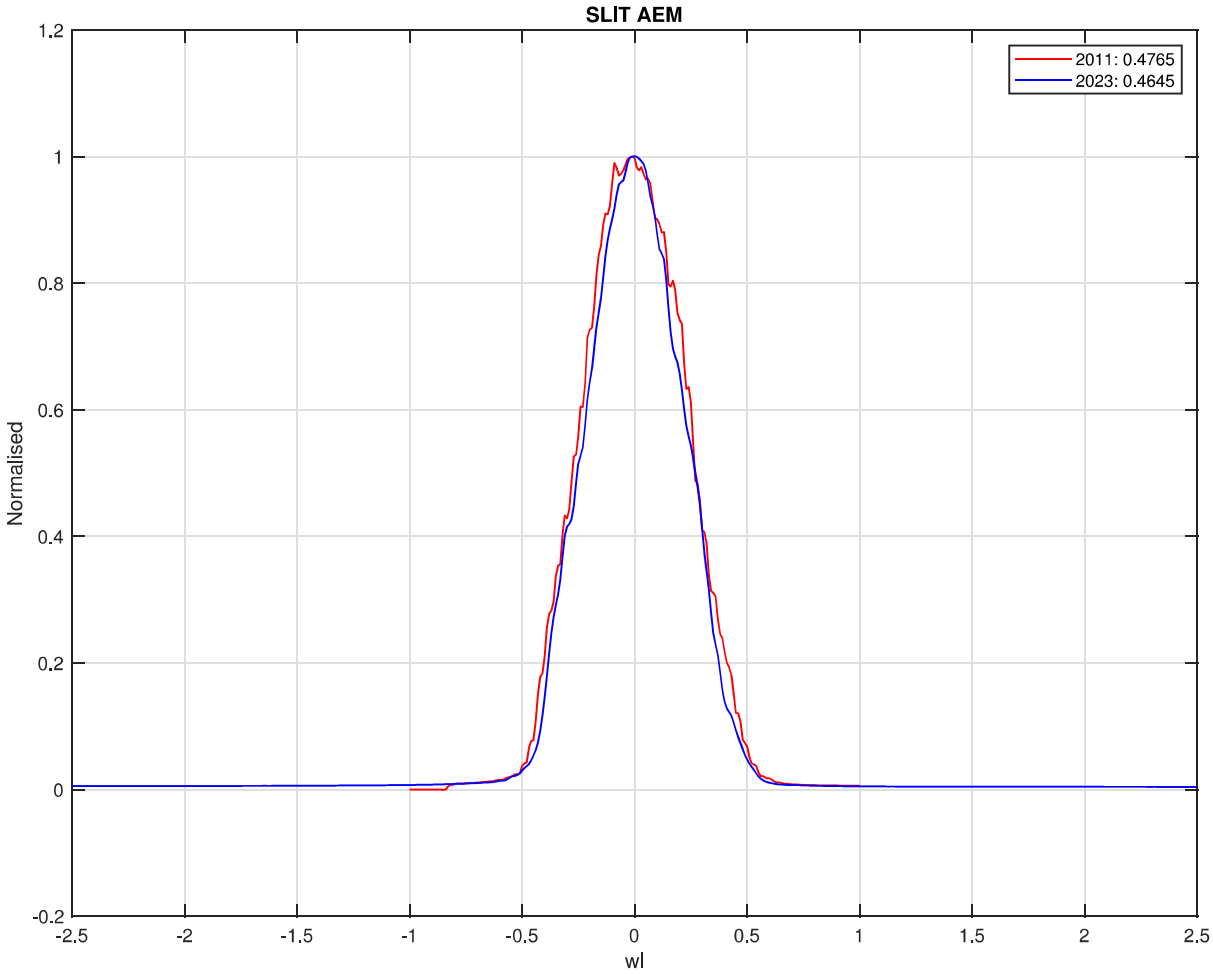
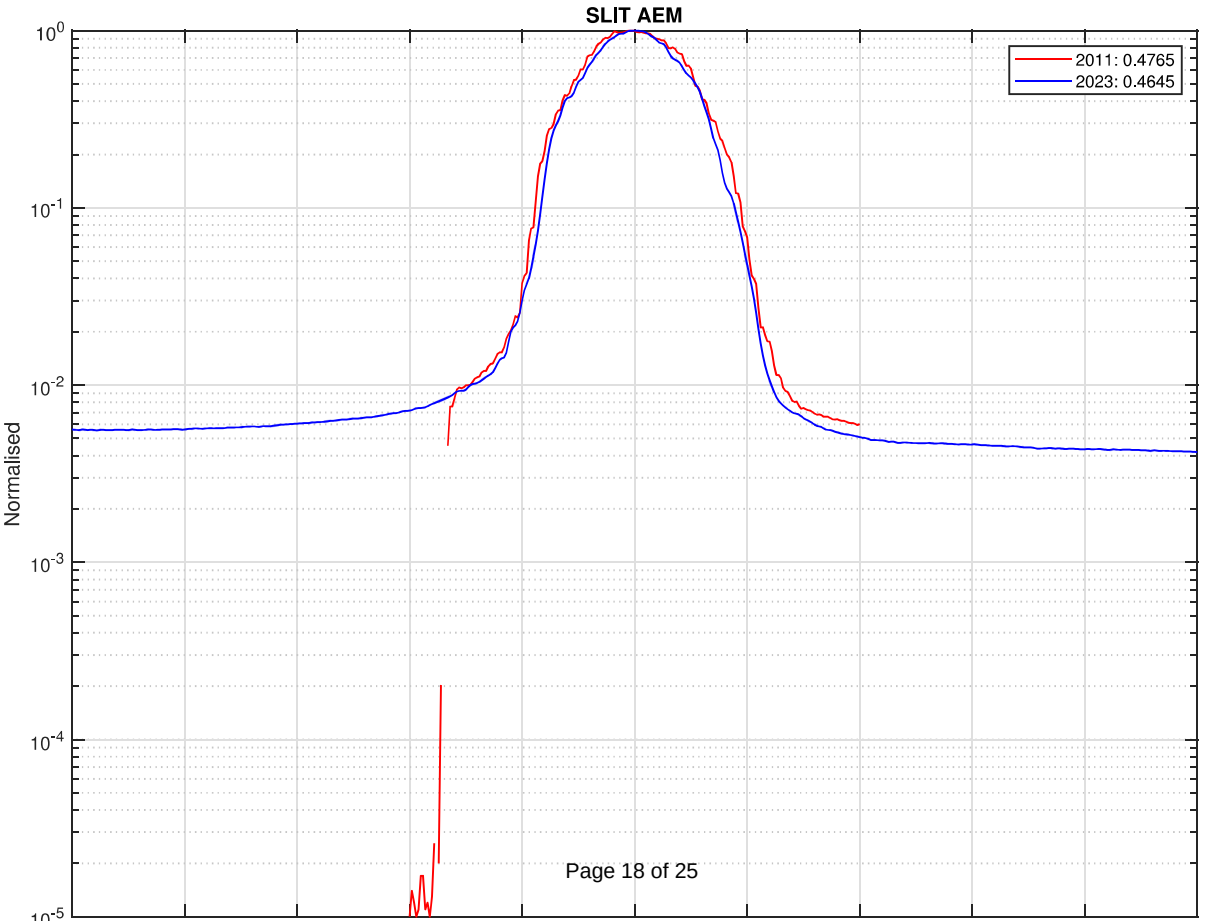
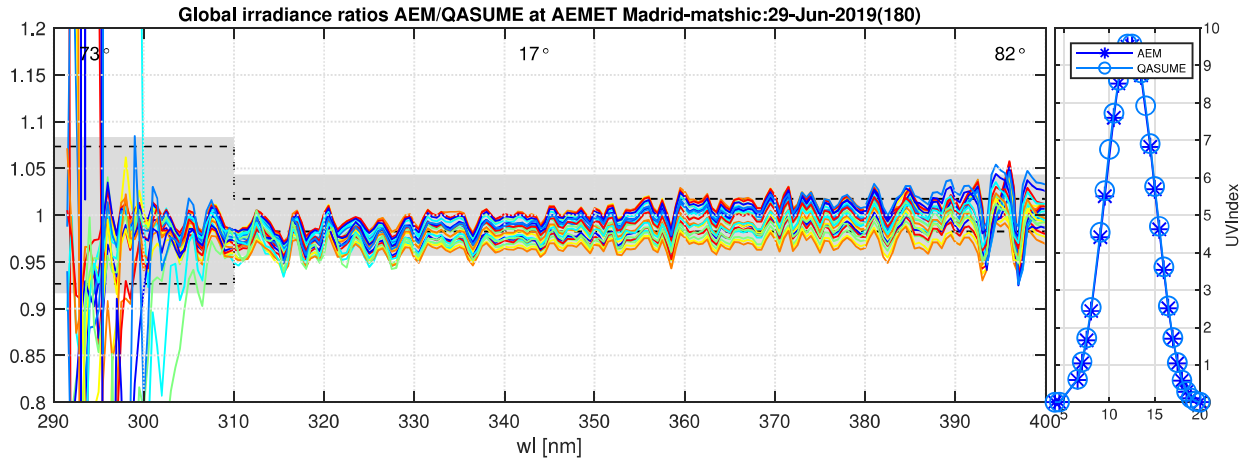

Wavelength shift
Mean
MinMax
STD
Wavelength shift /nm
Wavelength /nm
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
300
310
320
330
340
350
360
370
380
390
400

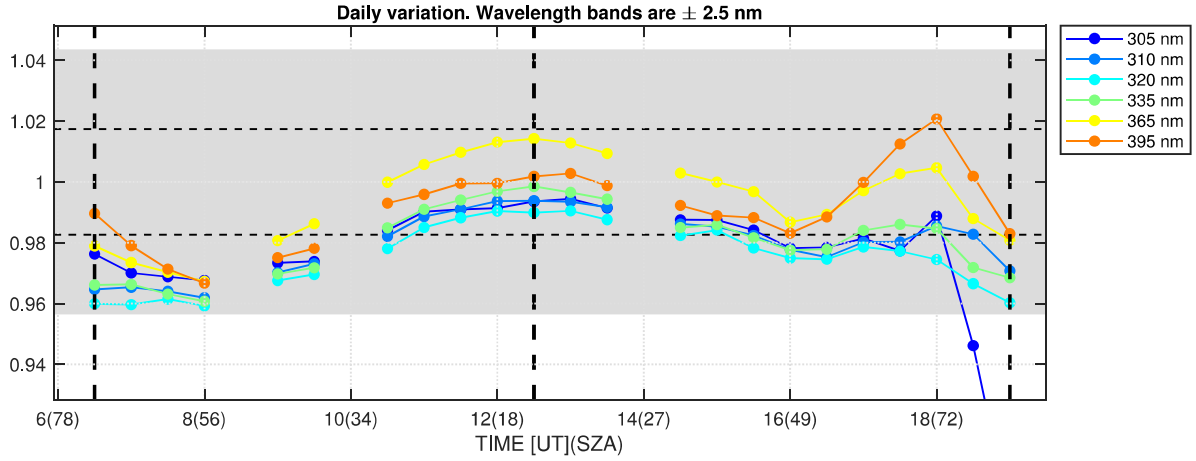

WL=335.00 nm
Wavelength shift /nm
Date & time
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
09/18
09/19
09/20
09/21
09/22


SLIT AEM
2011: 0.4765
2023: 0.4645
Normalised
wl
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5

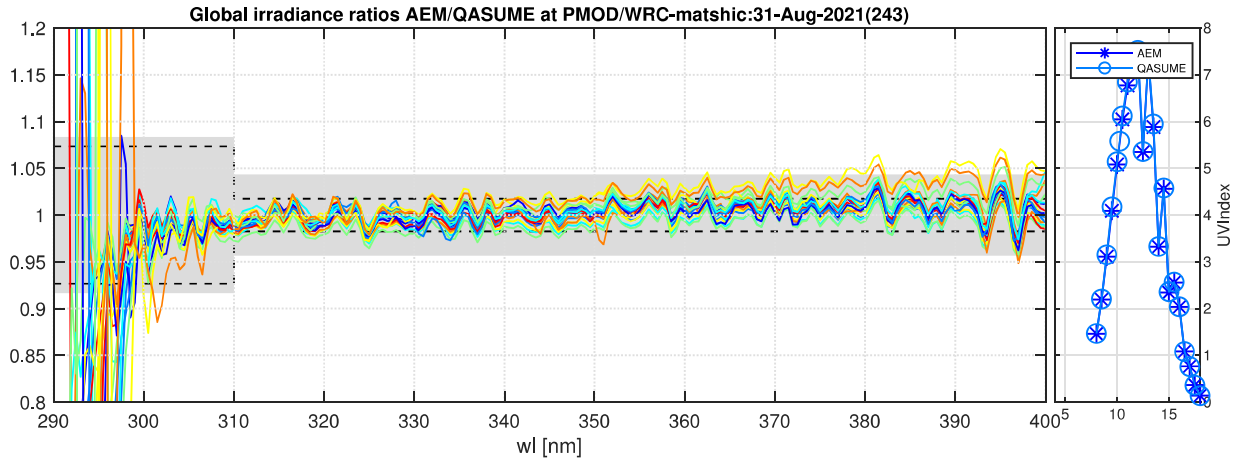

SLIT AEM
2011: 0.4765
2023: 0.4645
Normalised
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}



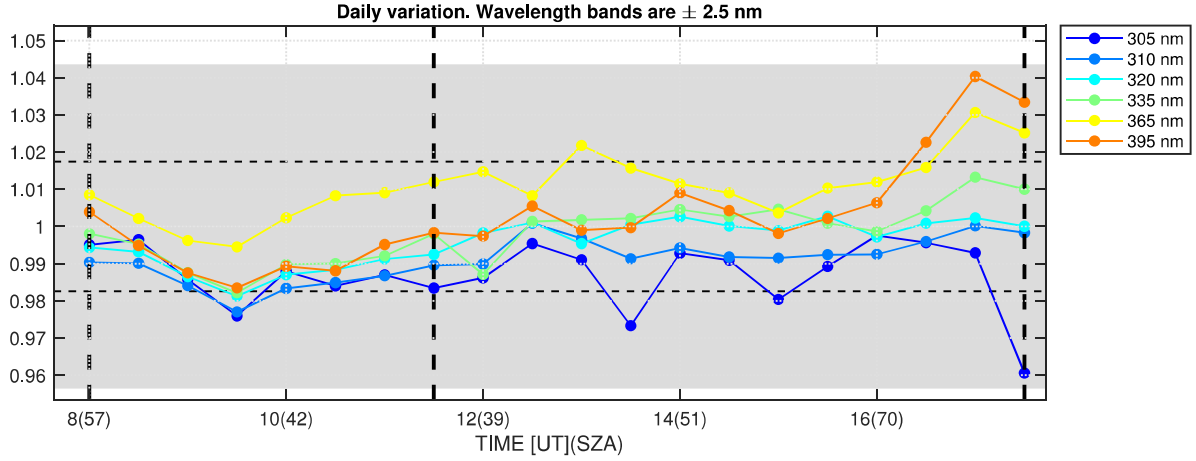
2019

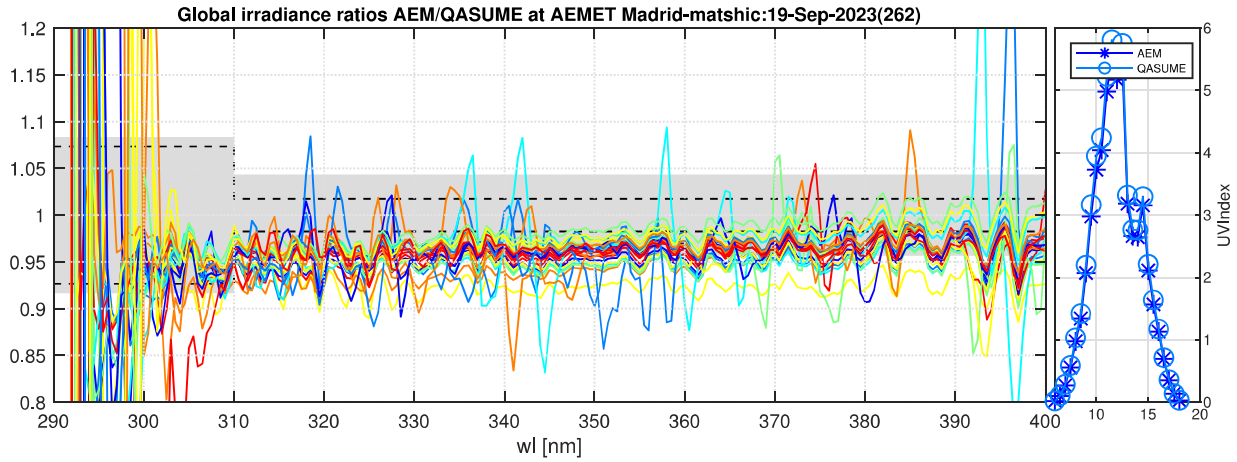


57° 38° 85°

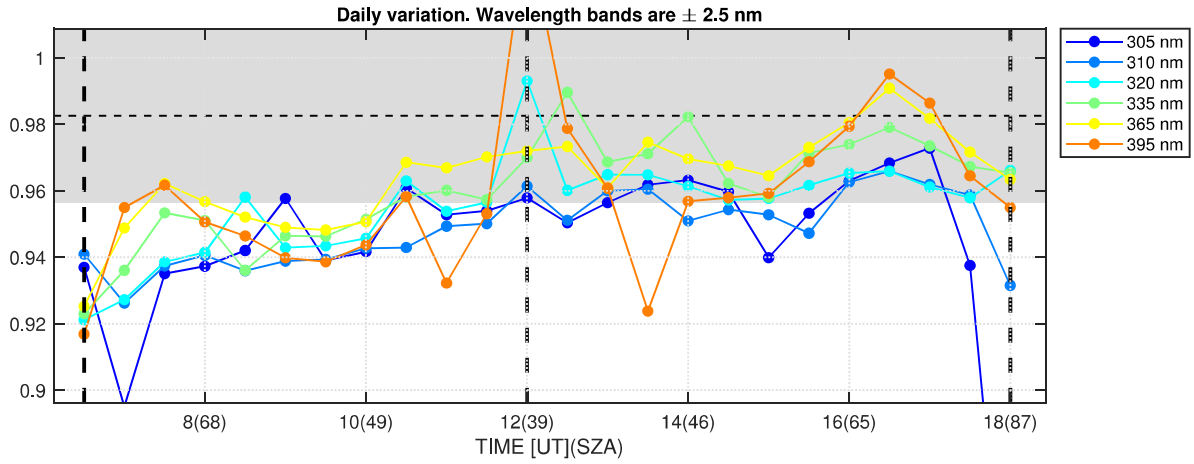


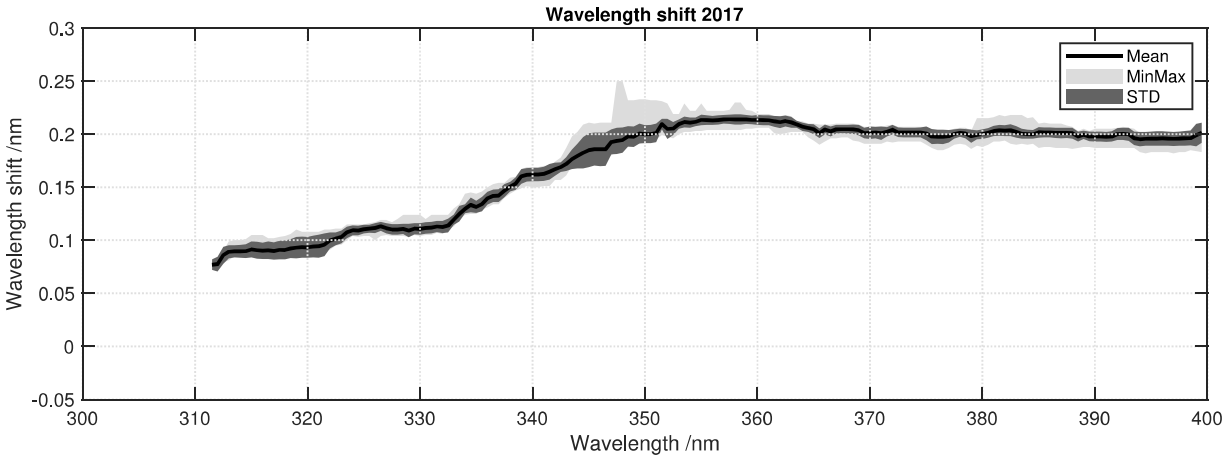
2021



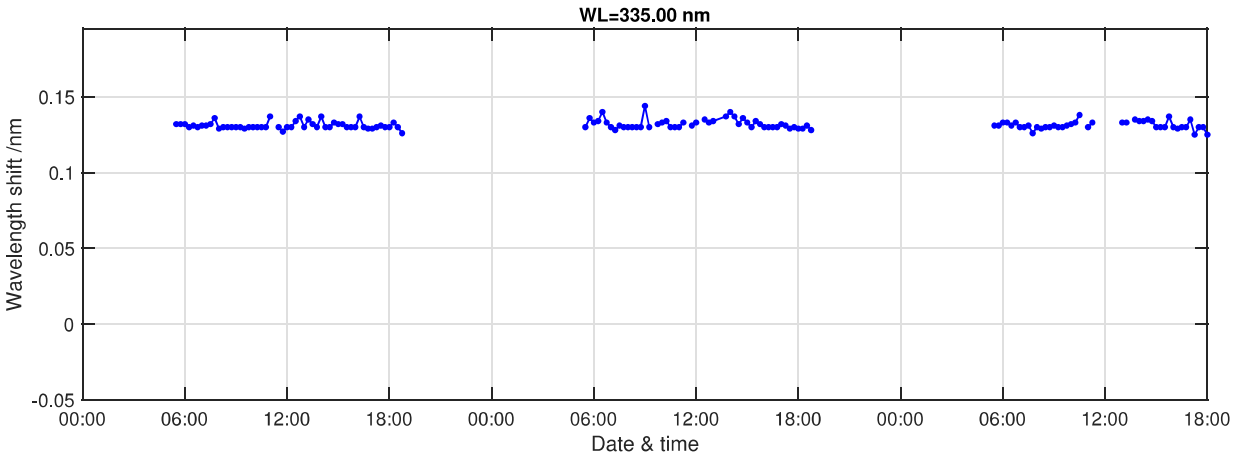

Global irradiance ratios AEM/QASUME at AEMET Madrid-matshic:19-Sep-2023(262)
wl [nm]
UVIndex
AEM
QASUME

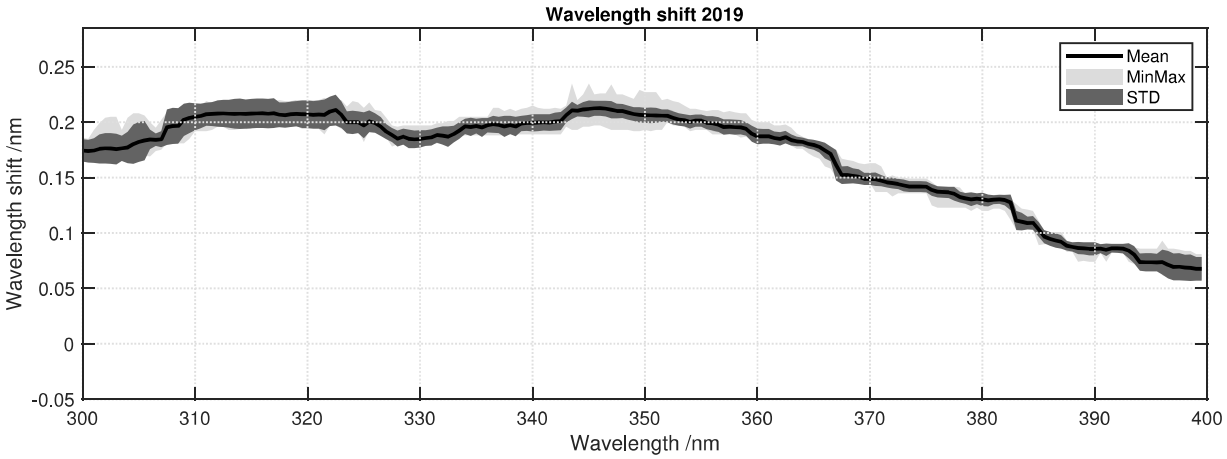
2023


Daily variation. Wavelength bands are ± 2.5 nm
TIME [UT](SZA)
305 nm
310 nm
320 nm
335 nm
365 nm
395 nm

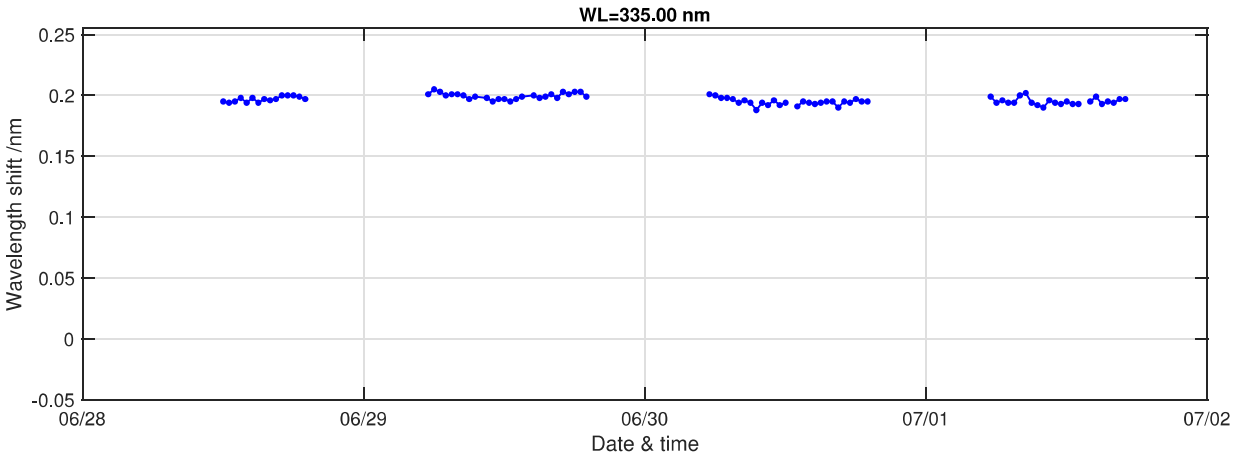

Wavelength shift 2017
Mean
MinMax
STD
Wavelength shift /nm
Wavelength /nm

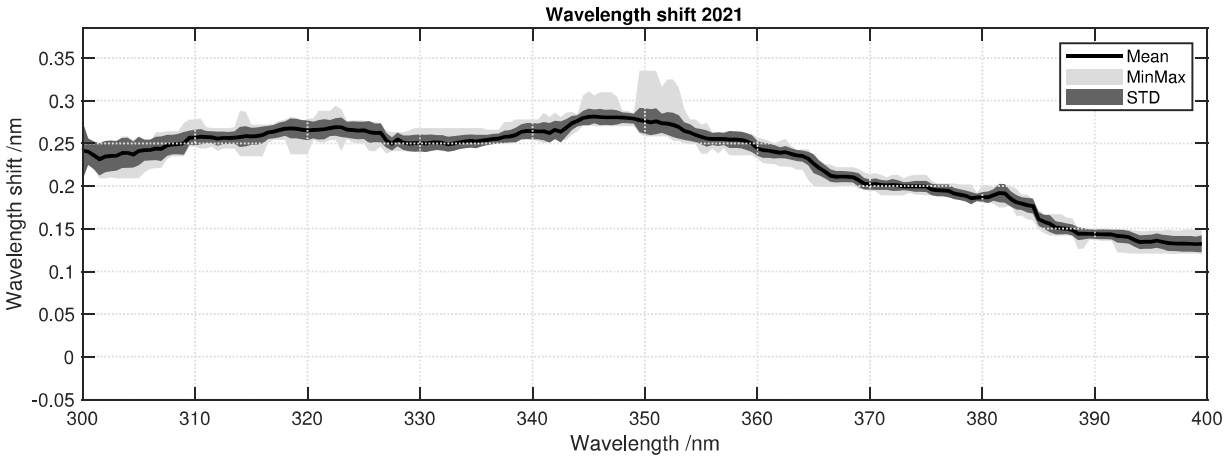
2017


WL=335.00 nm
Wavelength shift /nm
Date & time

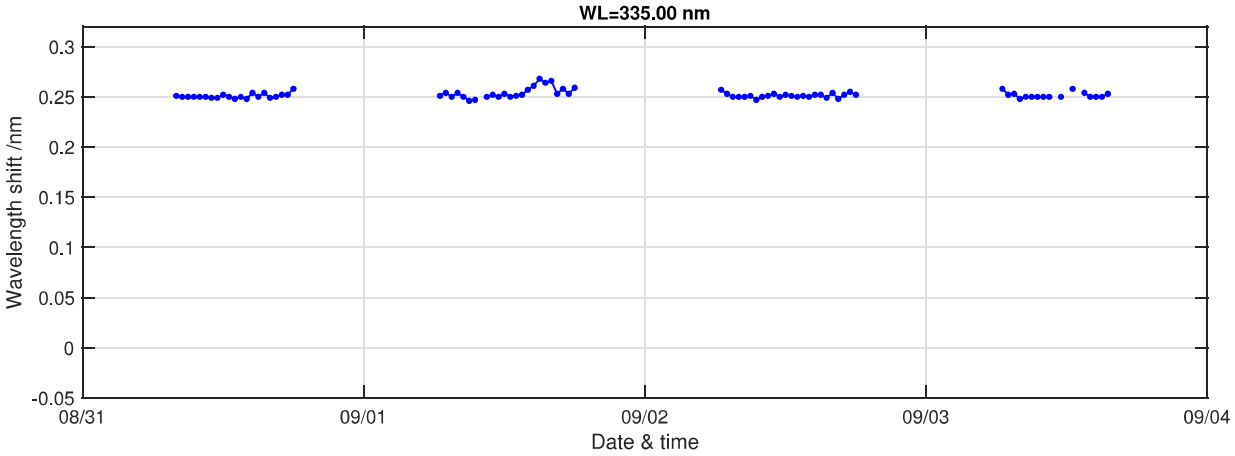

Wavelength shift 2019
Mean
MinMax
STD
Wavelength shift /nm
Wavelength /nm

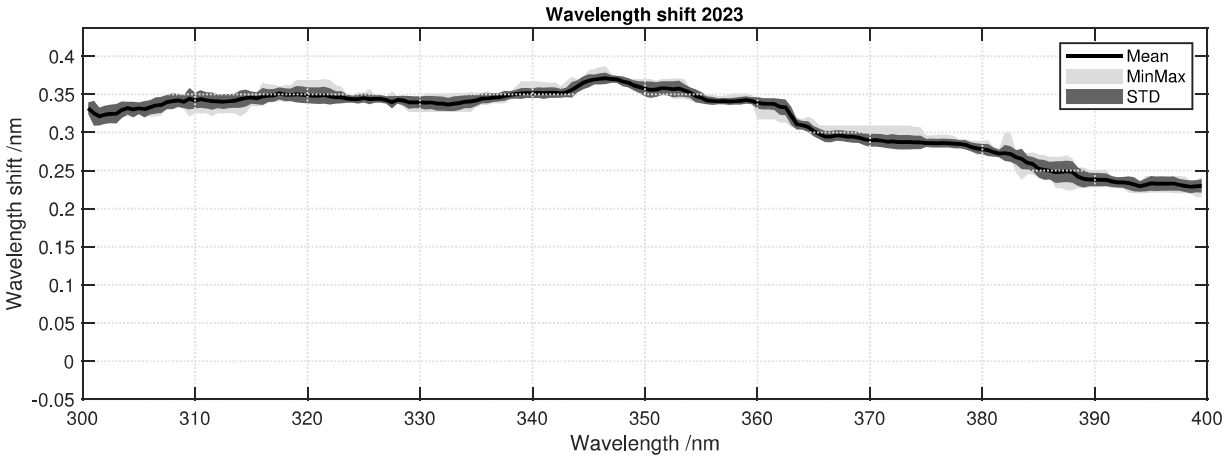
2019


WL=335.00 nm
Wavelength shift /nm
Date & time

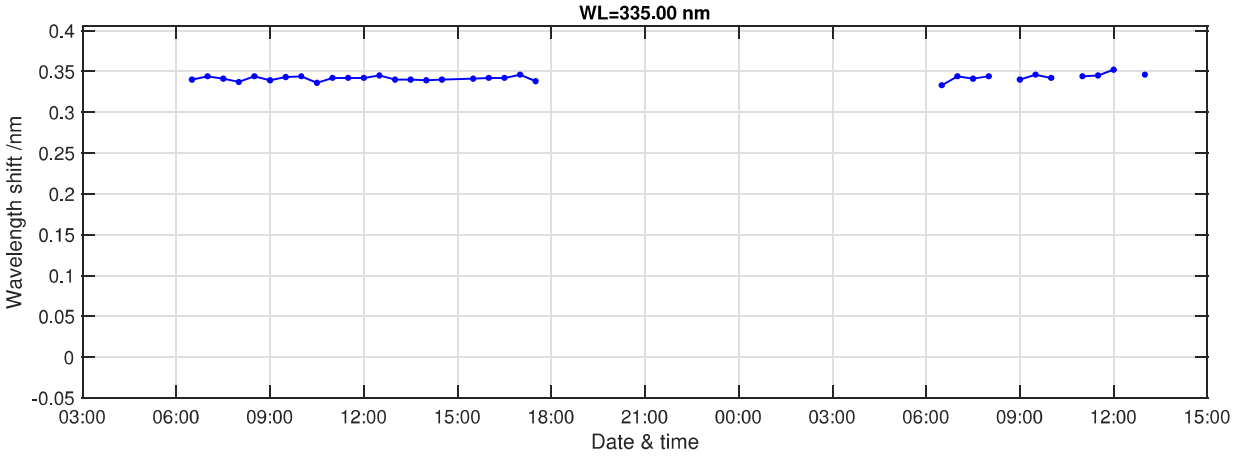

Wavelength shift 2021
Mean
MinMax
STD
Wavelength shift /nm
Wavelength /nm

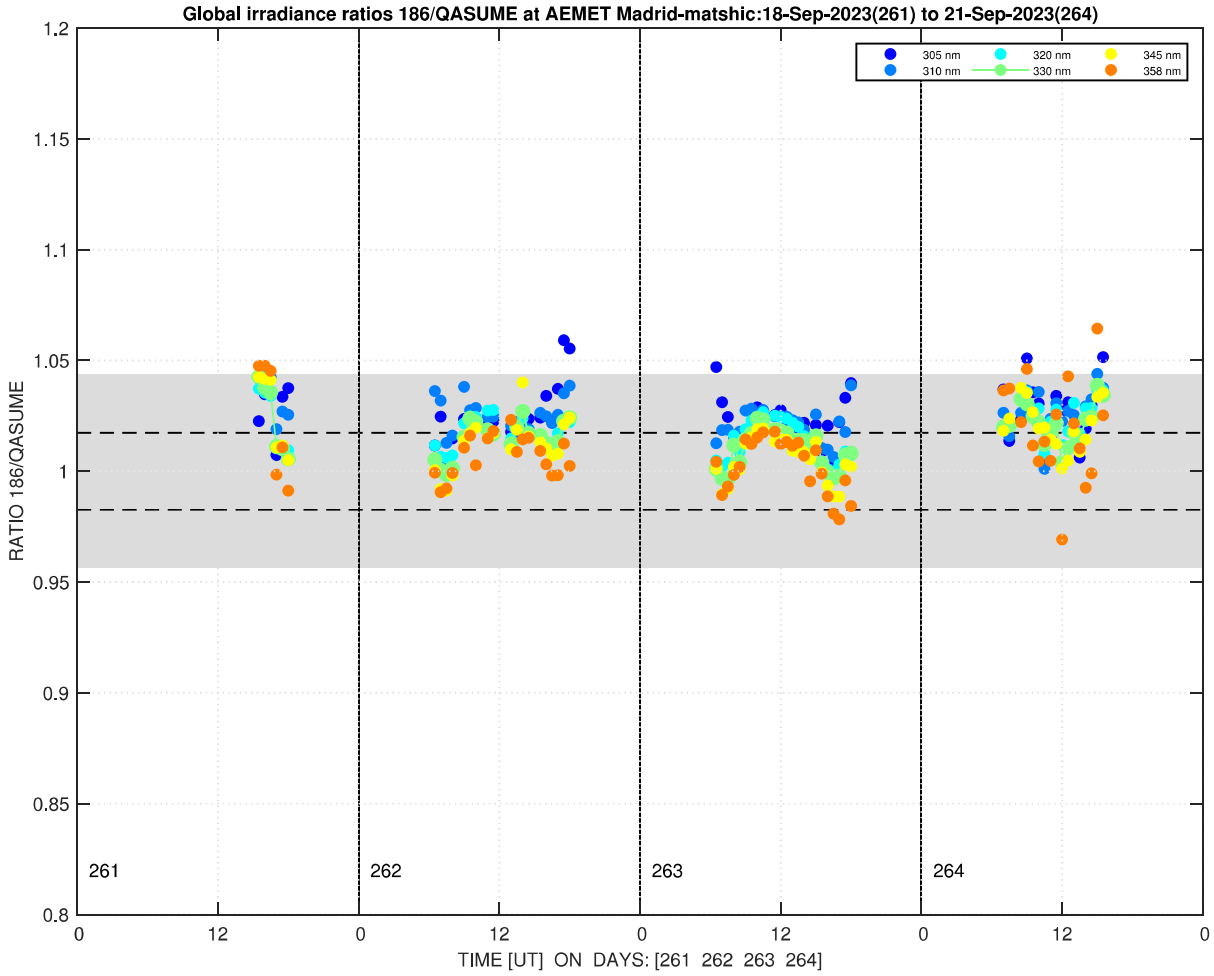
2021

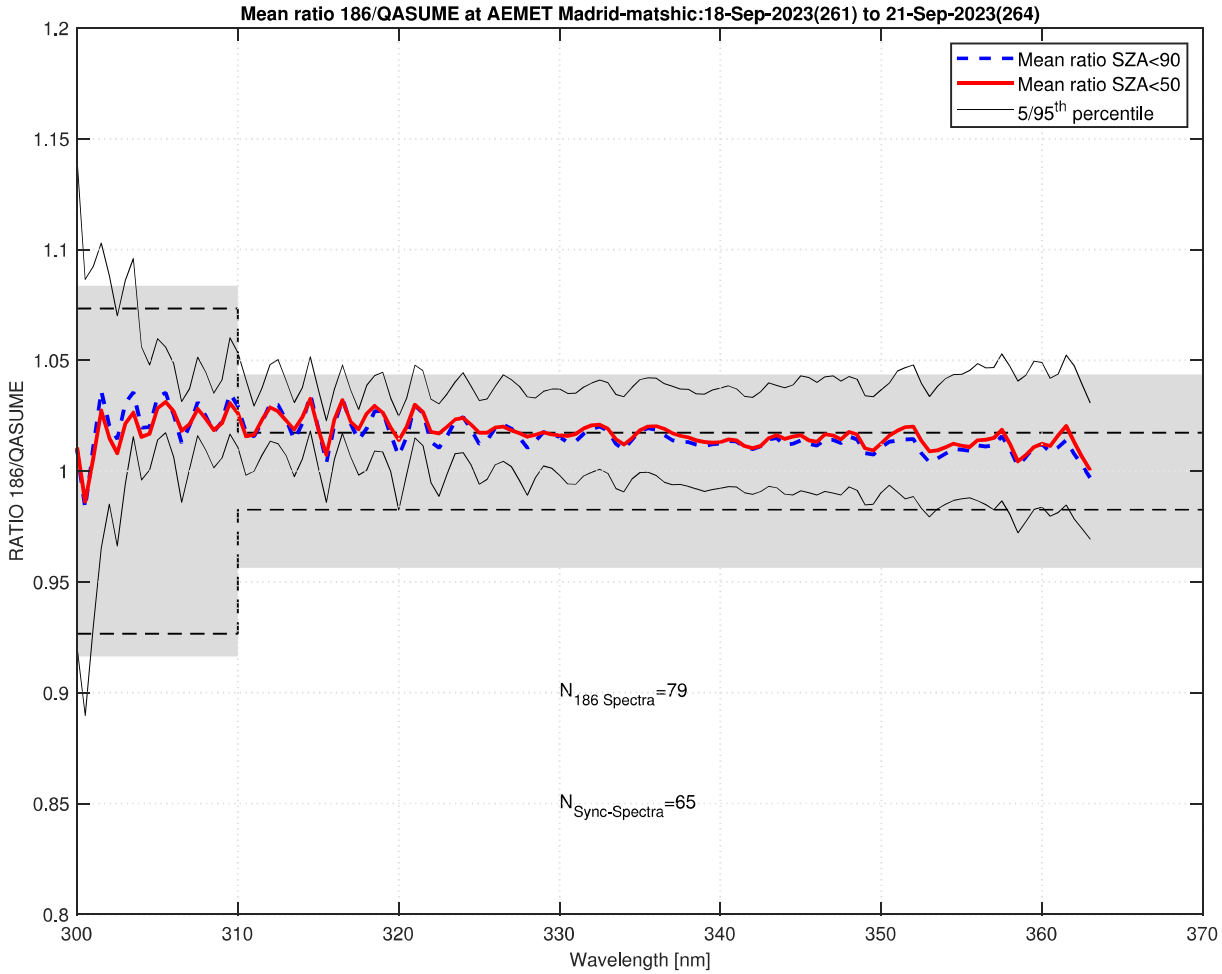

WL=335.00 nm
Wavelength shift /nm
Date & time

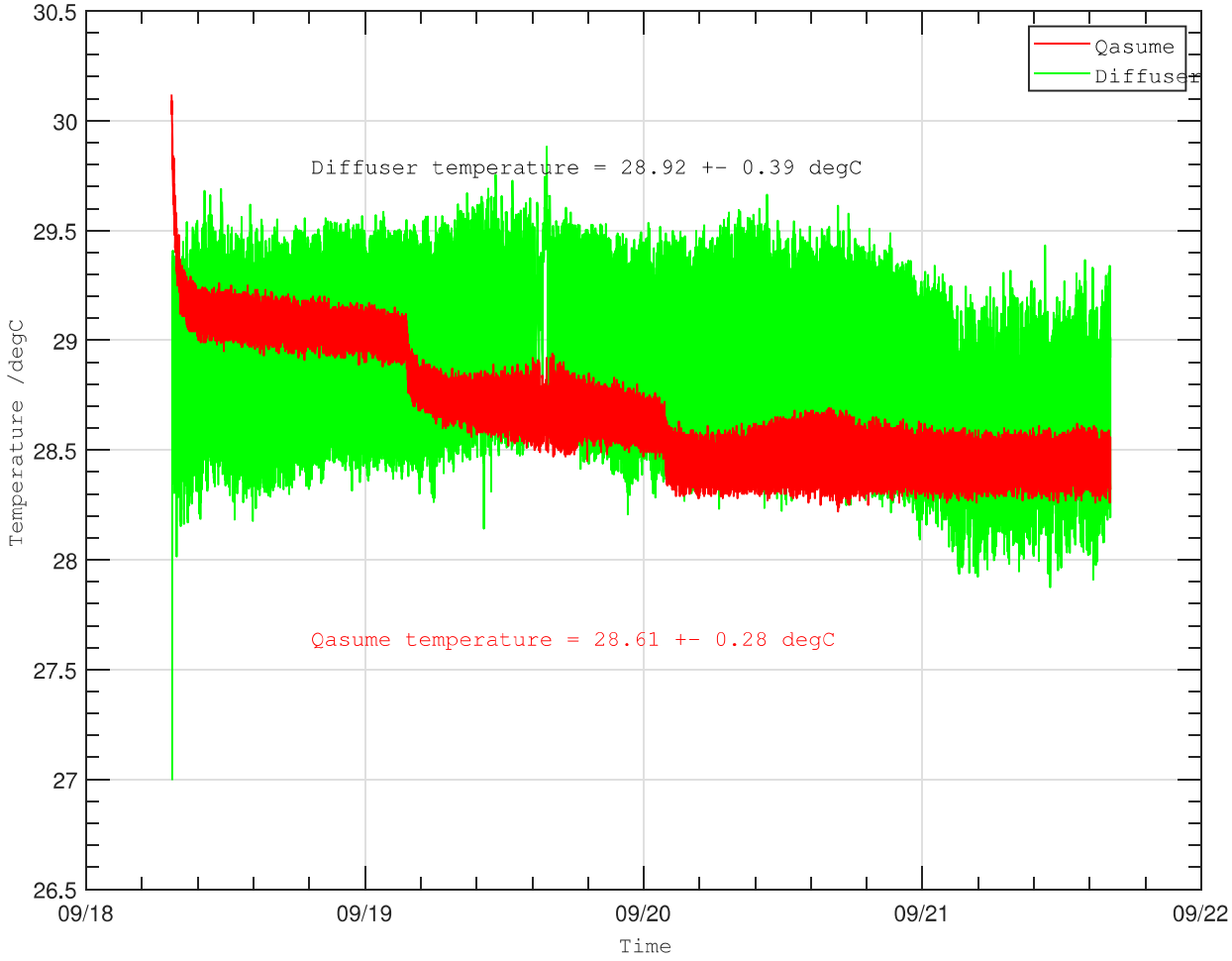

Wavelength shift 2023
Mean
MinMax
STD
Wavelength shift /nm
Wavelength /nm

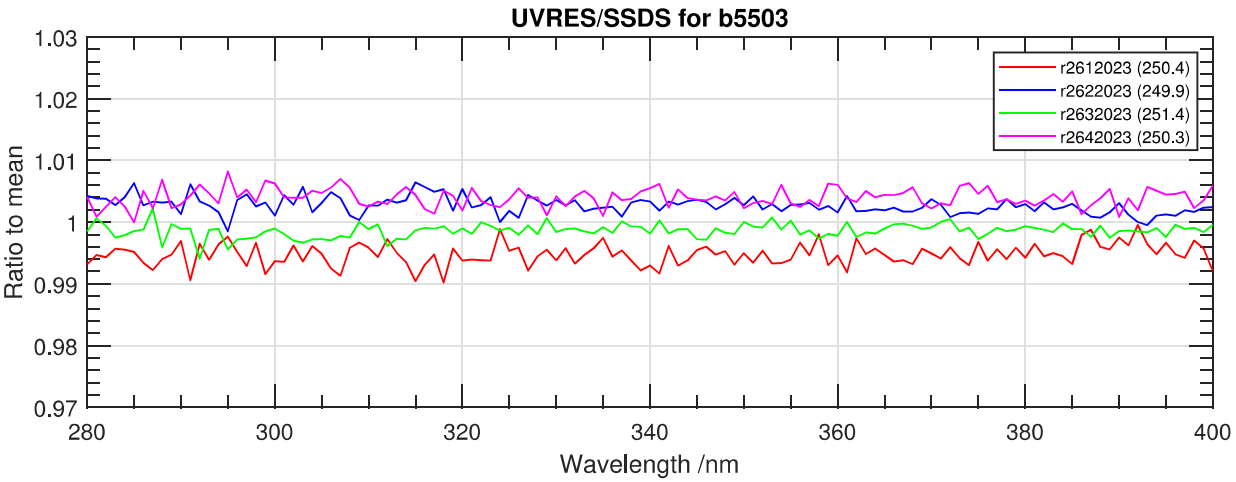
2023

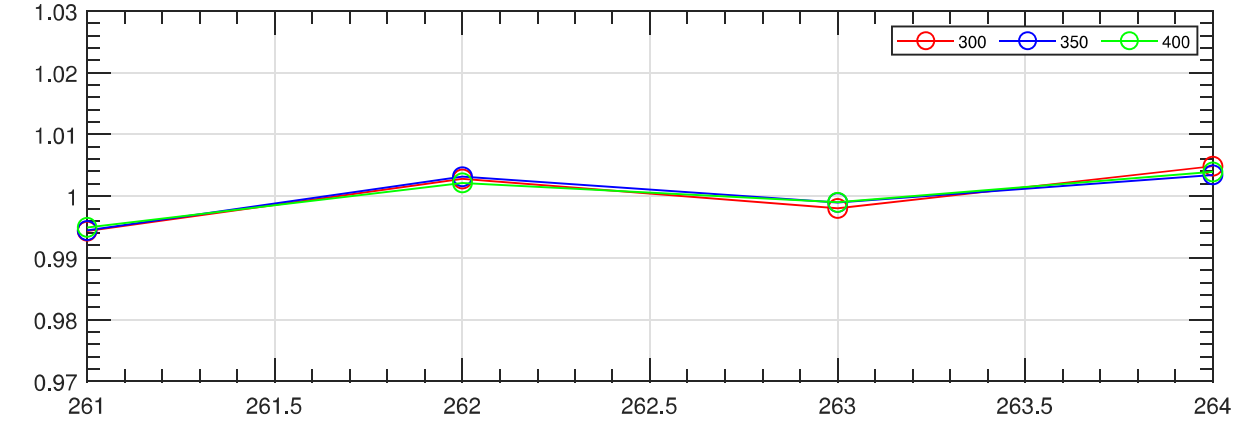

WL=335.00 nm
Wavelength shift /nm
Date & time


Global irradiance ratios 186/QASUME at AEMET Madrid-matshic:18-Sep-2023(261) to 21-Sep-2023(264)
305 nm
310 nm
320 nm
330 nm
345 nm
358 nm
RATIO 186/QASUME
261
262
263
264
TIME [UT] ON DAYS: [261 262 263 264]


Mean ratio 186/QASUME at AEMET Madrid-matshic:18-Sep-2023(261) to 21-Sep-2023(264)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
RATIO 186/QASUME
N186 Spectra=79
NSync-Spectra=65
Wavelength [nm]


Qasume
Diffuser
Diffuser temperature = 28.92 +- 0.39 degC
Qasume temperature = 28.61 +- 0.28 degC
Temperature /degC
Time
30.5
30
29.5
29
28.5
28
27.5
27
26.5
09/18
09/19
09/20
09/21
09/22


UVRES/SSDS for b5503
r2612023 (250.4)
r2622023 (249.9)
r2632023 (251.4)
r2642023 (250.3)
Ratio to mean
Wavelength /nm
1.03
1.02
1.01
1
0.99
0.98
0.97
280
300
320
340
360
380
400


300
350
400
1.03
1.02
1.01
1
0.99
0.98
0.97
261
261.5
262
262.5
263
263.5
264


AEM
Brewer 186
Qasume