Protocol of the intercomparison at BfS, Neuherberg, Germany on 12 to 13 July 2025 with the travelling reference spectroradiometer QASUME from PMOD/WRC

Report prepared by Gregor Hülsen

Operator: Gregor Hülsen
Local operator: Sebastian Lorenz and Markus Laufmann

The purpose of this follow-up visit was the comparison of global solar irradiance measurements between the Bentham DM300 and three BTS spectroradiometers, operated by the Bundsamt für Strahlungsschutz (BfS) and the travel reference spectroradiometer QASUME. During the last visit in 2024 the Bentham was not operational. The measurement site is located at Neuherberg: Latitude 48.21 N, Longitude 11.59 E and altitude 493 m.a.s.l. The horizon of the measurement site is free down to at least 85° solar zenith angle (SZA). Measurements between 4:15 UT and 18:30 UT have been analysed.

QASUME was installed on the measurement platform of BfS-Neuherberg in the evening of July 11, 2025. The spectroradiometer was installed next between the local spectroradiometers with the entrance optic of QASUME within 2 m to the other instruments. The Bentham spectroradiometer NH1 is a DM300 double monochromator. The three BTS2048 have the SN: 68262, 69387 and 69388). The intercomparison between QASUME and the local spectroradiometers lasted two days, from the morning of July 12 to the afternoon of July 13.

QASUME was calibrated several times during the intercomparison period using a portable calibration system. Two lamps (T61251 and T68523) 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 intercomparison period. The internal temperature of QASUME was 27.7±0.3 °C and the diffuser head was heated to a temperature of 29.1±0.3 °C.
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 15 minutes from 290 nm to 400 nm. The BTS measured continuously in 2 min intervals. QASUME recorded the spectra in 15 min intervals with 0.25 nm increments from 290 nm to 400 nm with results in a measurement time of 11 min per scan.

DOY	Date	DAY	Weather	Comment (times are in UT)
192	11-Jul	Friday	Mix of sun and clouds Rainshower in the night	Installed at 17:45 18:15 start UV measurements
193	12-Jul	Saturday	Clear sky in the Morning Cumulus clouds in the afternoon	09:00 Calibration T61251 14:30 Measurement BFS Lamp 70838 14:48 Calibration T61251 15:05 Calibration T668523
194	13-Jul	Sunday	Clear sky in the Morning Cumulus clouds in the afternoon	12:15 Measurement BFS Lamp 70839 12:31 Calibration T61251 13:30 End of Campaign

Results:

In total 58 (NH1) and 63 (BTS) simultaneous spectra from QASUME and the local instruments are available from the measurement period. Measurements between 4:15 and 18:30 UT have been analysed (SZA smaller than 90°).
On average four BTS spectra were fitted to the scanning QASUME scans. Only scans with sufficient low intensity variability during the 11 min scan time were selected for the comparison.

Conclusions:

A) Bentham NH1:

1. The spectral ratios between NH1 and QASUME are on average minus 3% with a diurnal variability of less than ±2%.
2. The wavelength shifts of NH1 relative to the high spectral resolution solar spectrum are between -150 pm and +150 pm in the spectral range 300 nm to 400 nm.

B) BTS 68262:

3. The spectral ratio between BTS 68262 and QASUME are on average minus 5% with a diurnal variability of around ±5%.
4. For high solar zenith angles BTS 68262 overestimates the solar irradiance for wavelengths below 320 nm.
5. The wavelength shifts of BTS 68262 relative to the high spectral resolution solar spectrum are between -100 pm and +0 pm in the spectral range 300 nm to 400 nm.

C) BTS 69387:

1. The spectral ratio between BTS 69387 and QASUME are on average minus 3% with a diurnal variability of around ±5%.
2. For high solar zenith angles BTS 68387 overestimates the solar irradiance for wavelengths below 310 nm.
3. The wavelength shifts of BTS 69387 relative to the high spectral resolution solar spectrum are between -100 pm and +100 pm in the spectral range 300 nm to 400 nm.

D) BTS 69388:

4. The spectral ratio between BTS 69388 and QASUME are on average minus 3% with a diurnal variability of around ±2%.
5. For high solar zenith angles BTS 69388 overestimates the solar irradiance for wavelengths below 310 nm.
6. The wavelength shifts of BTS 69388 relative to the high spectral resolution solar spectrum are between -50 pm and +0 pm in the spectral range 300 nm to 400 nm.

E) Lamp measurements with Qasume:

The emission from two irradiance standards (L70838 and L70839) from BfS were measured with Qasume in the lamp calibration setup of BfS. From the data the irradiance was calculated and compared to the original certificates of those standards. Although the entrance optic of Qasume was only manually adjusted into the setup to the nominal reference plane, the comparison doesn't show any sign of a 3% calibration error. In contrast irradiance calibration agree well within the estimated uncertainty of the calibration as shown in the figure 1:

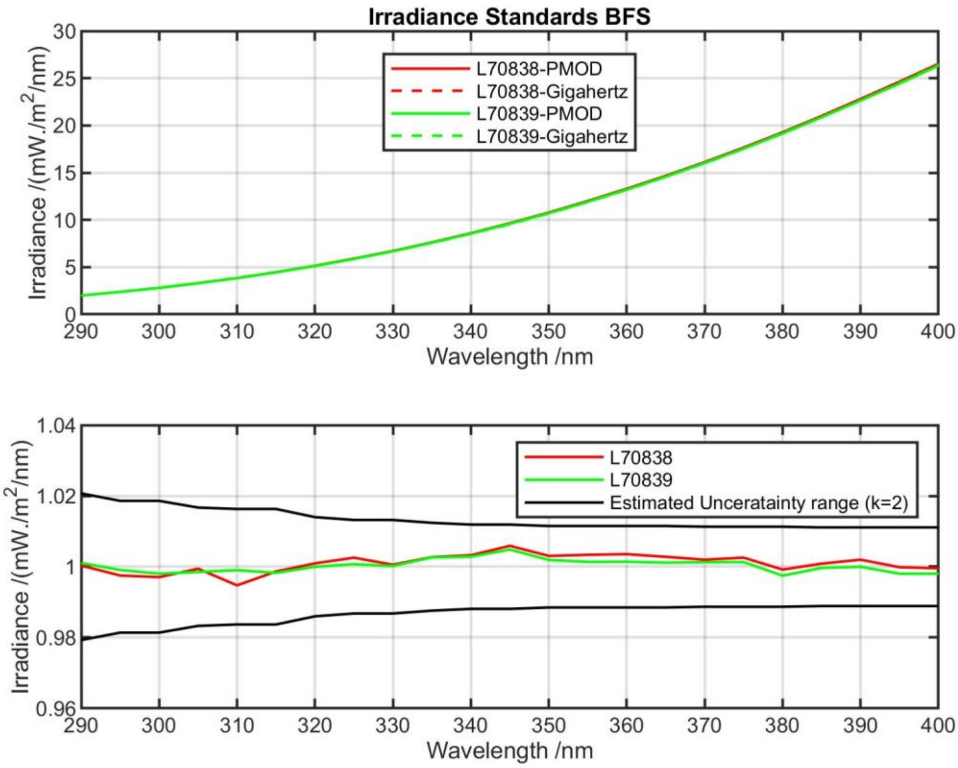


Figure 1: Irradiance spectra of two lamp calibrated with Qasume and Gigahertz. The estimated uncertainty range is taken from a lamp calibration performed at PMOD/WRC.

Irradiance standard comparison between PMOD/WRC and Gigahertz Optik

In October 2025 irradiance standard F481 (PMOD/WRC) was measured at Gigahertz Optik. The comparison of the calibration files shows a perfect agreement as shown in Figure 2.

The 1000 W FEL type irradiance standards of both calibration facilities are traceable to the Physikalisch-Technische Bundesanstalt (PTB, Germany). The experiment shows that at both institutes the calibration of those lamps are identical.

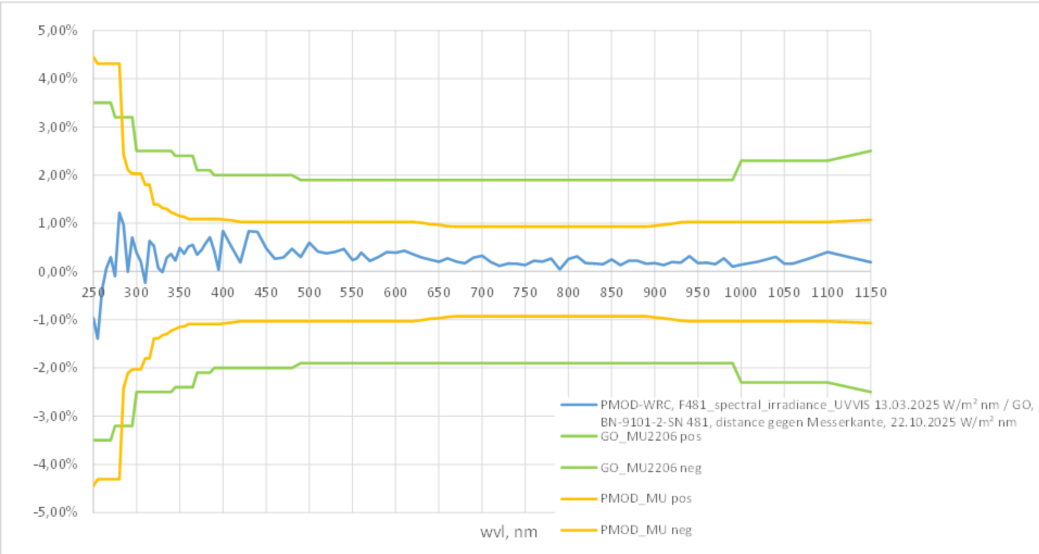


Figure 2: F481 irradiance standard lamp calibrated at PMOD/WRC and Gigahertz Optik.

Comparison to previous QASUME site visits

No long-term stability could be assessed through a comparison of the QASUME site visits performed in 2004 and 2024, because the Bentham NH1 was not in operation in 2004 and not operational in 2024.

In contrast to 2024, for none of the BTS devices compared with QASUME in 2025 was there an indication of an azimuth error (tilt of the diffuser).

Summary:

The audit showed that the UV measurements performed at BfS with the Bentham NH1, BTS 69387 and 69388 spectroradiometers are within the expected combined measurement uncertainty:

$$U_{comp} = \mathrm{sqrt}(U_{qas}^2 + U_{BfS}^2)$$

With U_{qas} = 1.74%, U_{qas} = 7.34% (y<300 nm) (Hülsen et al., 2016). U_{BfS} was estimated to be 4%. BTS 68262 is outside the combined uncertainty range for wavelength between 330 nm till 375 nm.

The following points should be investigated in more detail:

1.) The comparison of the array spectroradiometers relative to the scanning Qasume reference depends on the temporal variability of the incoming irradiance during the scanning time of QASUME. During this follow-up campaign at Neuherberg only few measurements were affected by moving clouds.
2.) The combined expanded uncertainty of the comparison is shown in the Figures (see Appendix) as grey area (dotted lines show the uncertainty of Qasume). As the actual uncertainty budget of the test spectroradiometers are unknown a relative standard uncertainty of 2% (confidence level of 66%) was chosen. We strongly recommend deriving an uncertainty budget for the UV measurements at BfS.
3.) The irradiance calibration of the BfS instruments (BTS and NH1) are currently based on a secondary monitor system using low power tungsten halogen lamps. The long traceability chain of this system increases the uncertainty of the calibration by at least a factor of two. It is therefore recommended to perform an irradiation calibration using a 1000 W primary standard for both spectroradiometer types. Special care should be taken to use the correct reference plane of the receiver optic for these measurements.

References:

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

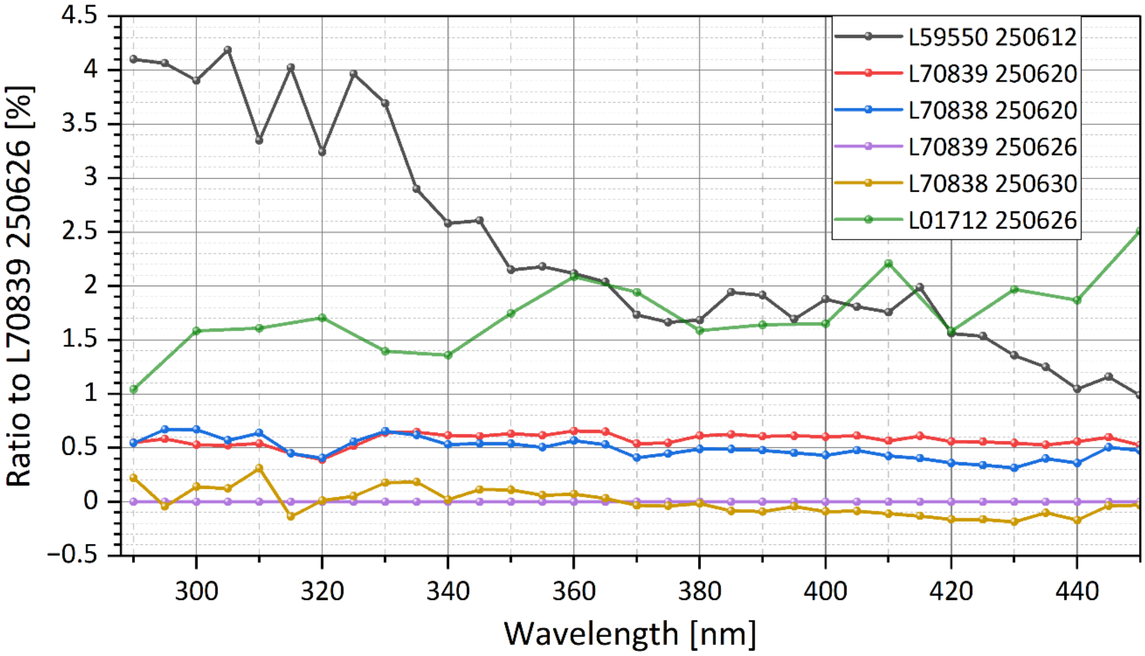
G. Hülsen, J. Gröbner, S. Nevas, P. Sperfeld, L. Egli, G. Porrovecchio, and M. Smid, “Traceability of solar UV measurements using the Qasume reference spectroradiometer", Appl. Opt. 55, 7265-7275, 2016.

Comments from the operator:

Since the overestimation observed in the BTS devices within the UV-B range only occurs at low solar elevations, it does not affect the daily course of the eythemal irradiance (see UVI daily course of measurements in Appendix)

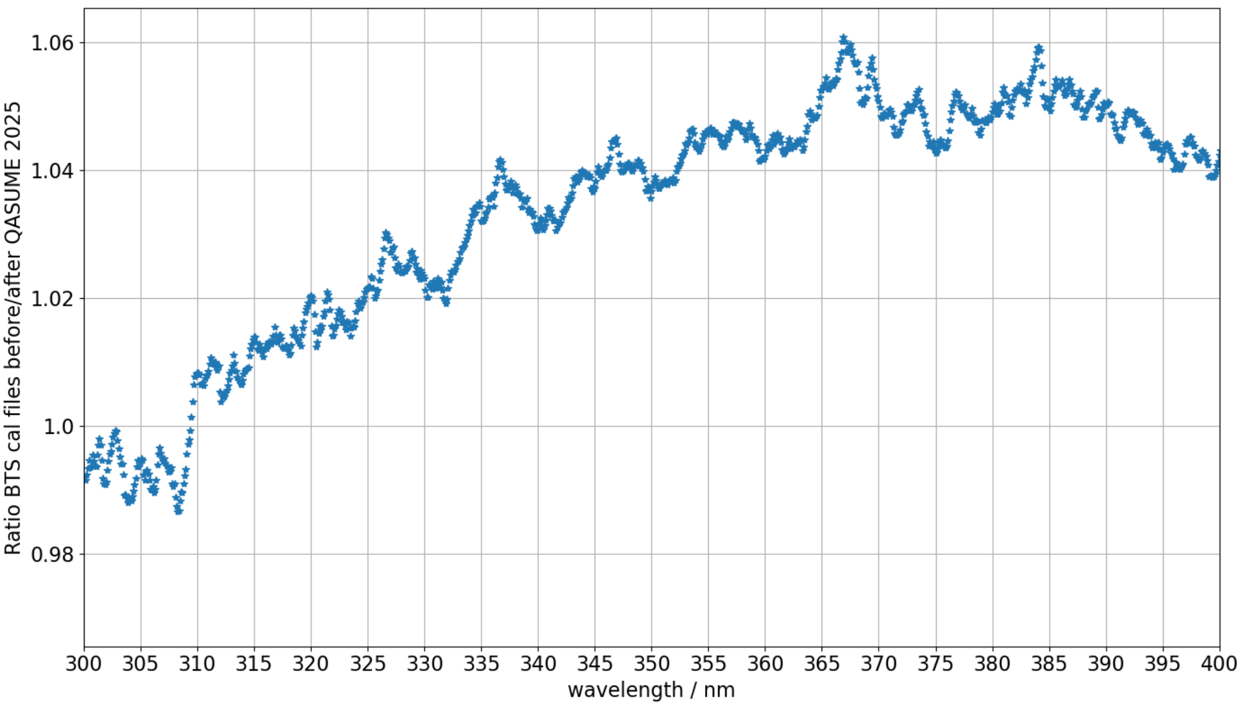
NH1 Calibration before QASUME Site Visit:

For the PTB traceable calibration of NH1 before the QASUME visit, four calibration lamps were compared (L59550, L1712, L70838, L70839). The lamps L70838 and L70839 are two lamps with the latest external calibration certificates, while L1712 is a very old (but stable over the years) calibration lamp. The graph shows the relative deviations of the spectral measurements of the lamps (measured with a DTM300 laboratory system). The differences of 0.5% between L70838 and L70839 in repeated measurements can partly be attributed to differing temperatures/cooling, as the outside temperature reached over 30°C on June 26th and June 30th, while it was only 24°C on June 20th. The NH1 system was re-calibrated before the QASUME visit in QASUME measurement mode using L70838 and L70839.



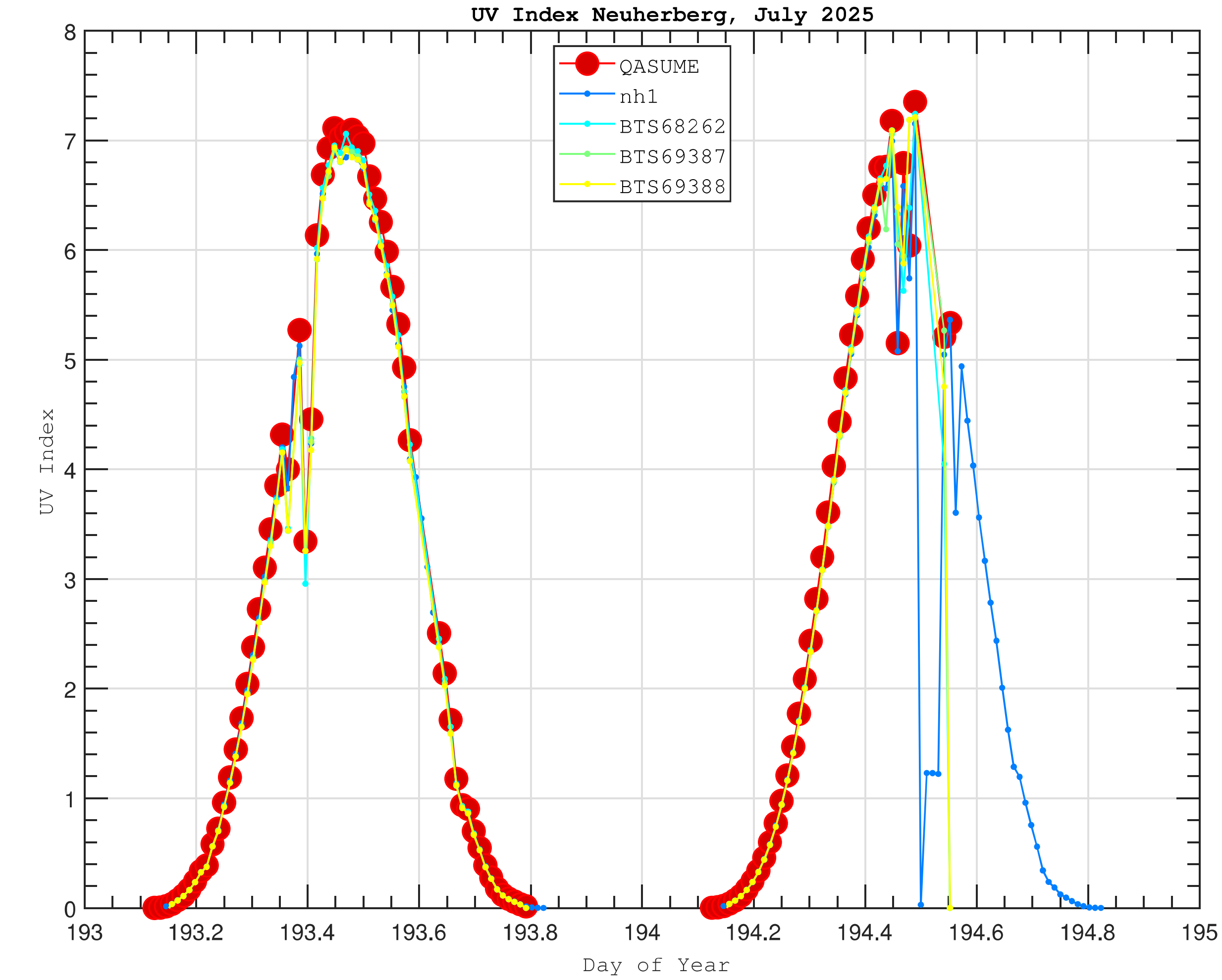
The BTS devices SN69387 and SN69388 (externally calibrated by Gigahertz in November 2024) showed deviations of <1% and 0.5% respectively when checked for calibration by BfS in June 2025 using L70838 and L70839.

The BTS device SN68262 was subjected to a calibration check and recalibrated with L70838 after the QASUME site visit. The percentage change of the calibration file is shown in the following figure. For the spectral range between 310 nm and 365 nm, this results in an estimated deviation from QASUME that is almost exactly at the level of the other BTS instruments and the NH1 double monochromator.

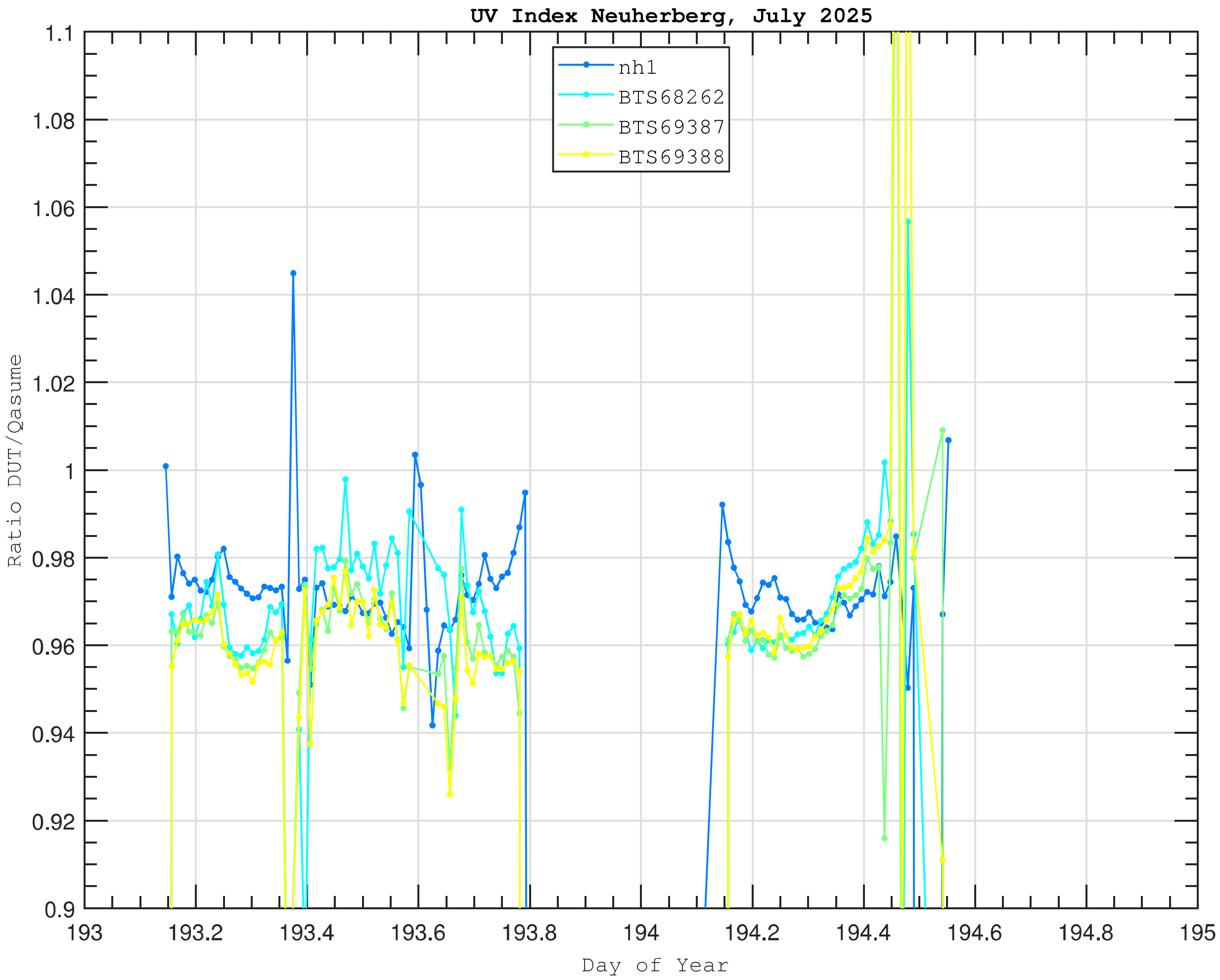

Ratio BTS cal files before/after QASUME 2025
wavelength / nm
1.06
1.04
1.02
1.0
0.98
300
305
310
315
320
325
330
335
340
345
350
355
360
365
370
375
380
385
390
395
400

Appendix

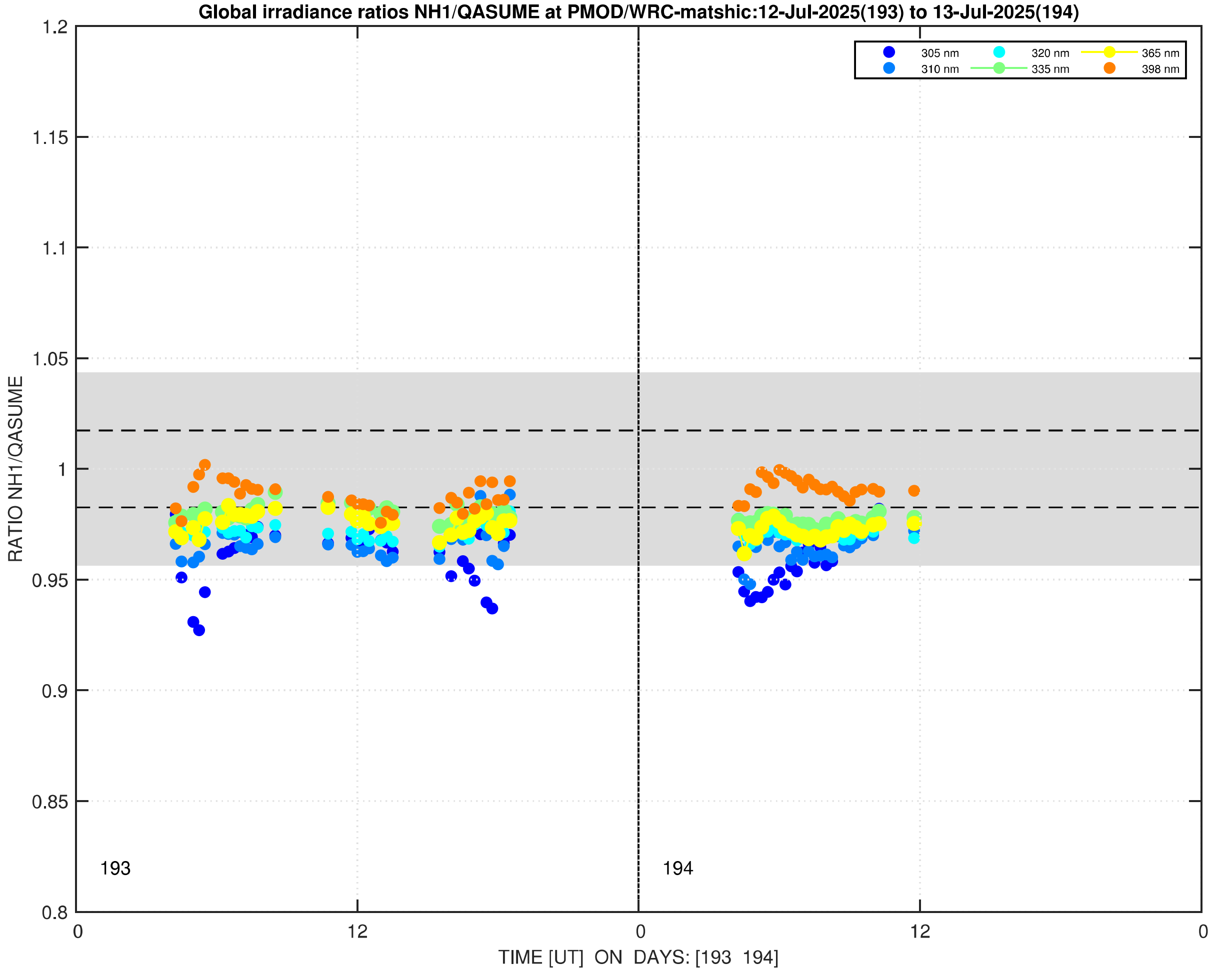
Detailed results for all local spectrophotometers with respect to the reference spectroradiometer QASUME



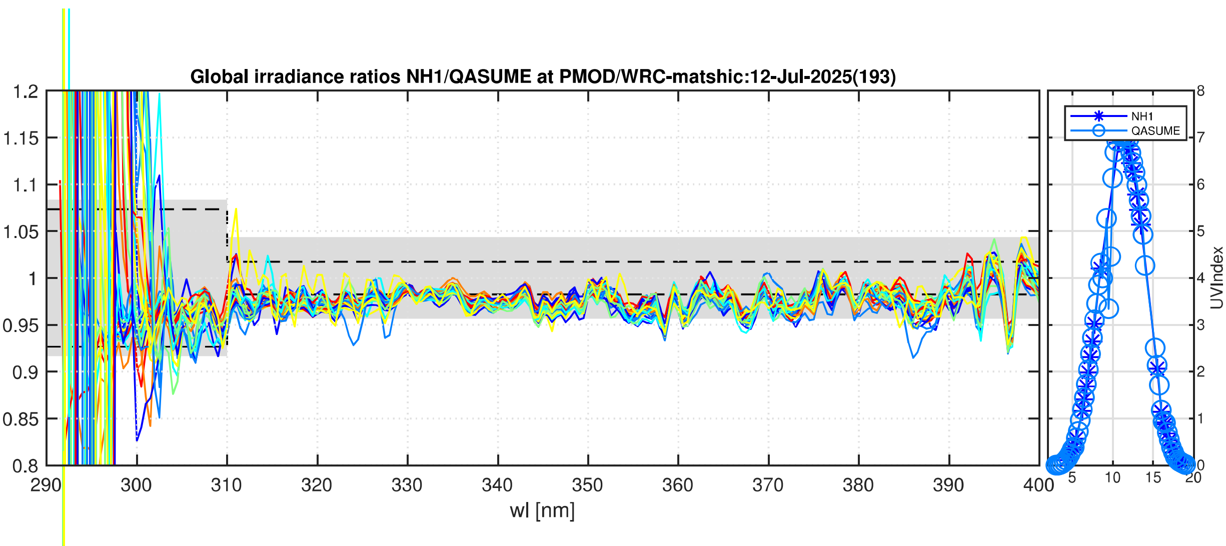
UV Index Neuherberg, July 2025
QASUME
nh1
BTS68262
BTS69387
BTS69388
UV Index
Day of Year



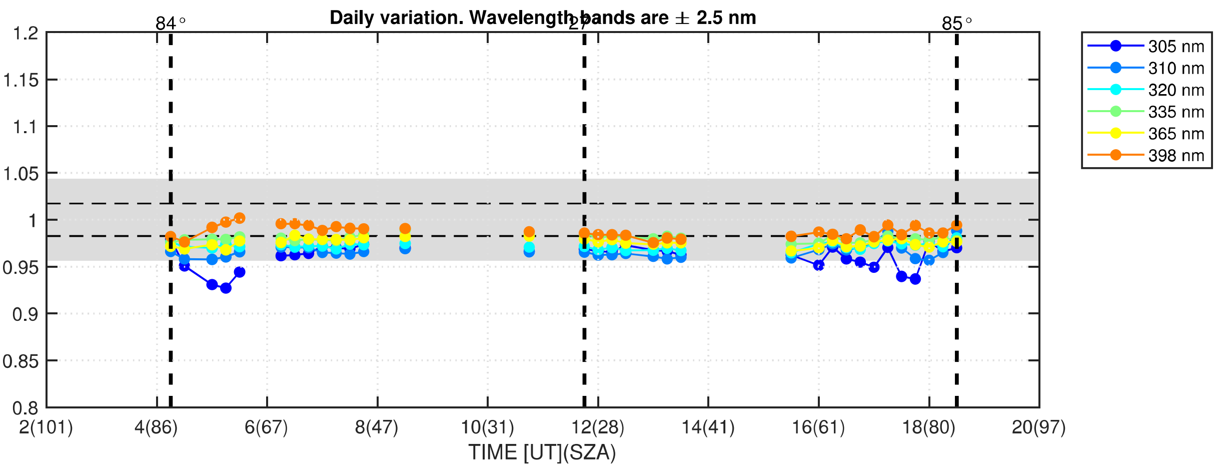
UV Index Neuherberg, July 2025
nh1
BTS68262
BTS69387
BTS69388
Ratio DUT/Qasume
Day of Year



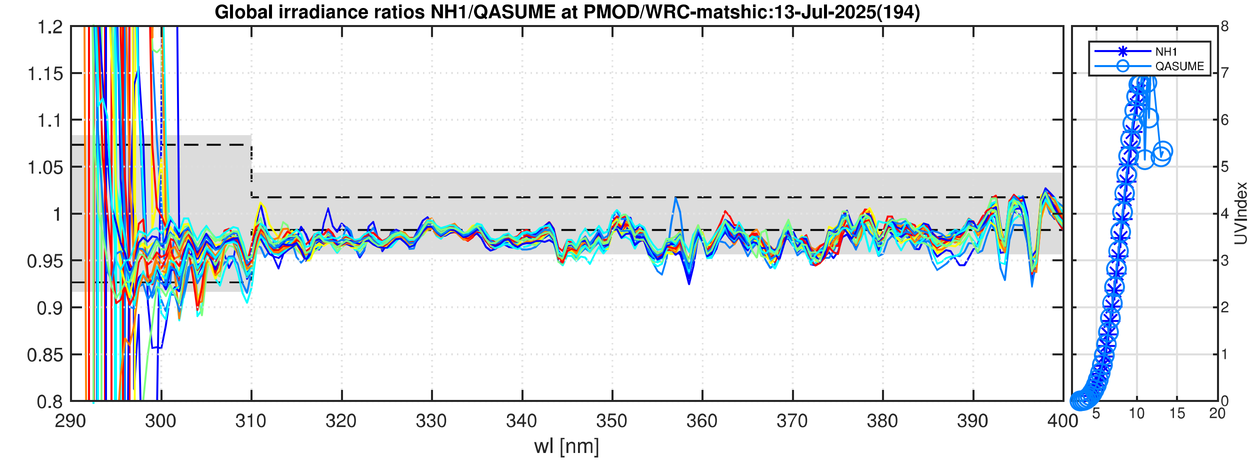
Global irradiance ratios NH1/QASUME at PMOD/WRC-matshic:12-Jul-2025(193) to 13-Jul-2025(194)
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
RATIO NH1/QASUME
193
194
TIME [UT] ON DAYS: [193 194]

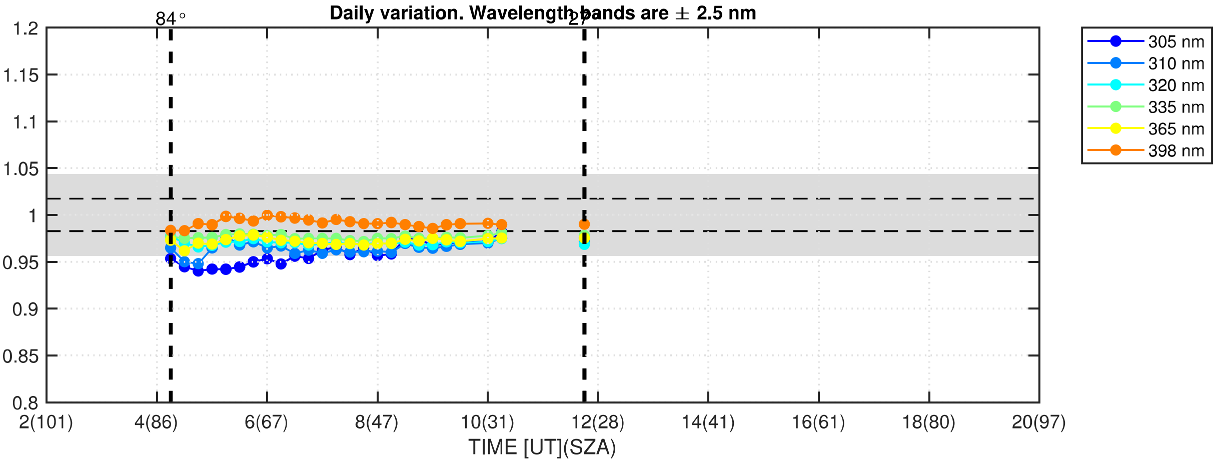


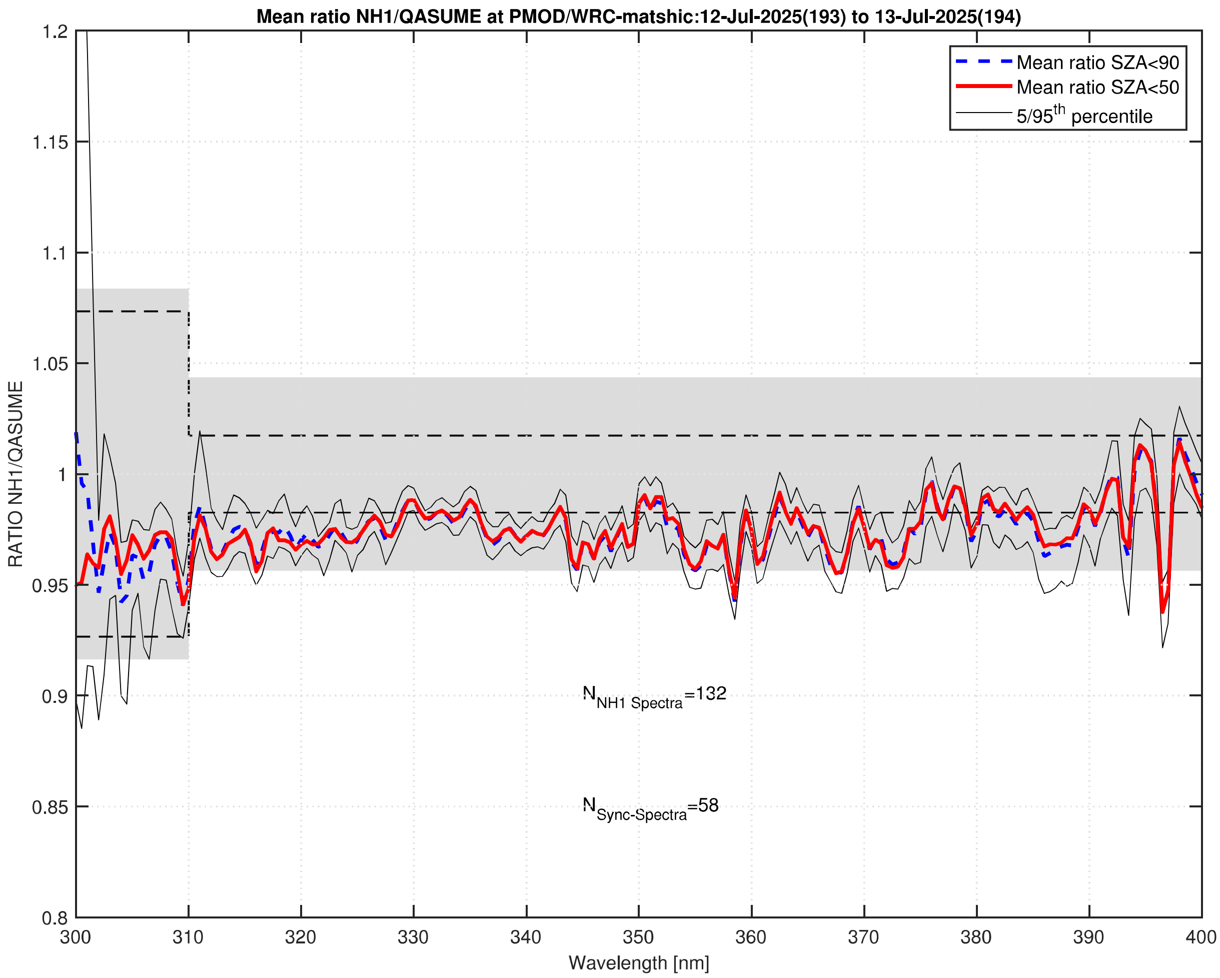
Global irradiance ratios NH1/QASUME at PMOD/WRC-matshic:12-Jul-2025(193)
wl [nm]
NH1
QASUME
UVIndex

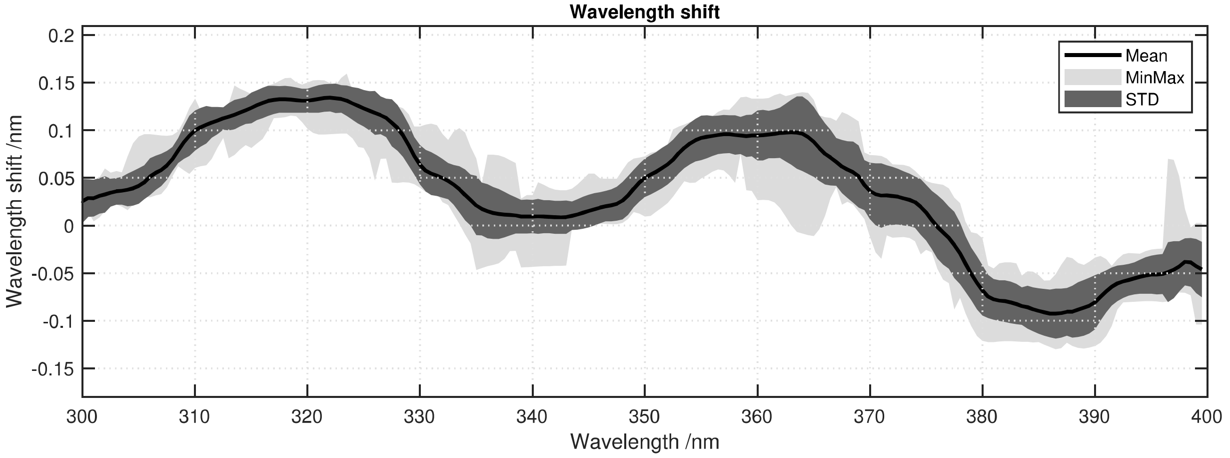


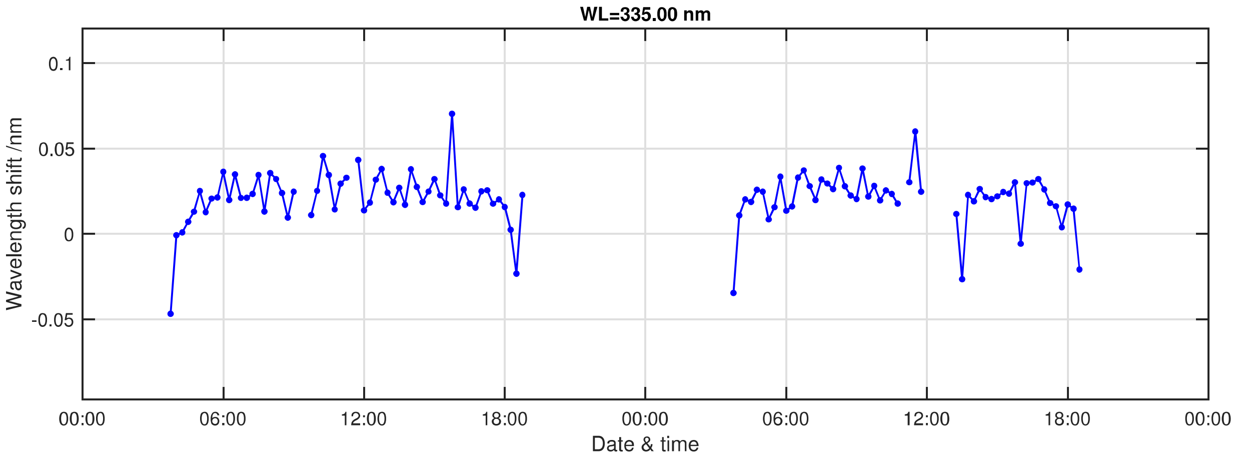
Daily variation. Wavelength bands are ± 2.5 nm
84°
27°
85°
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
TIME [UT](SZA)

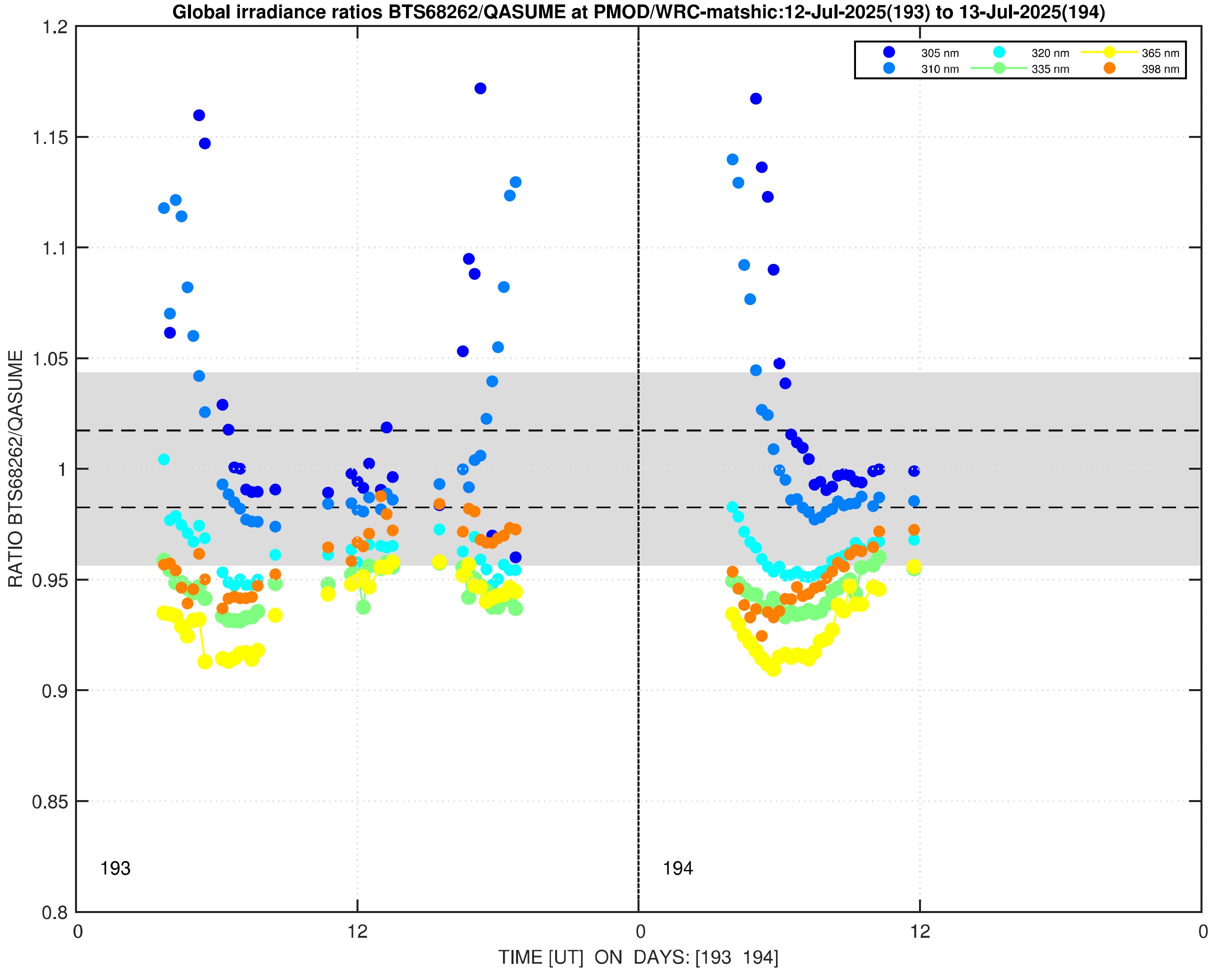

Global irradiance ratios NH1/QASUME at PMOD/WRC-matshic:13-Jul-2025(194)
wl [nm]
NH1
QASUME
UVIndex

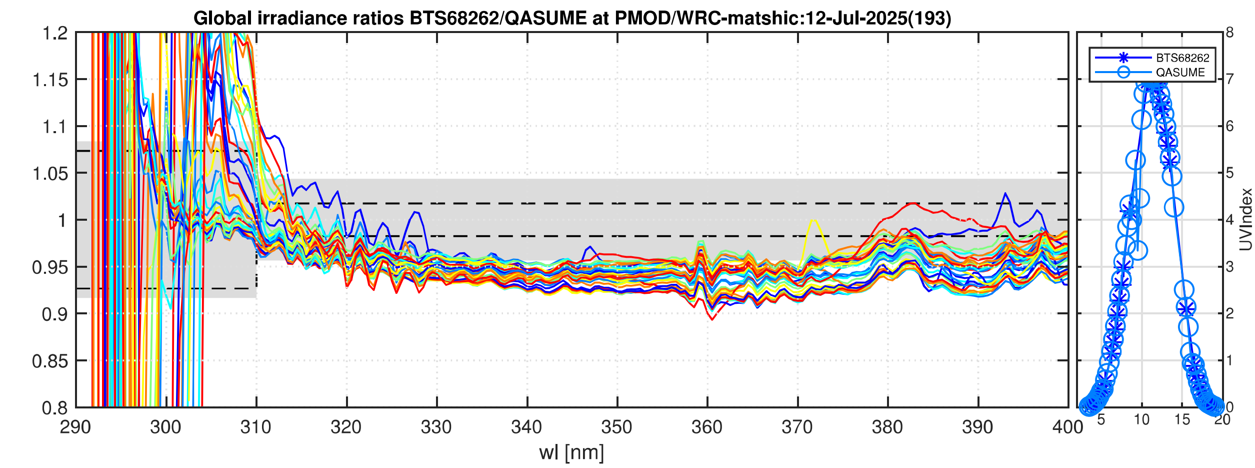

Daily variation. Wavelength bands are ± 2.5 nm
84°
27°
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
TIME [UT](SZA)

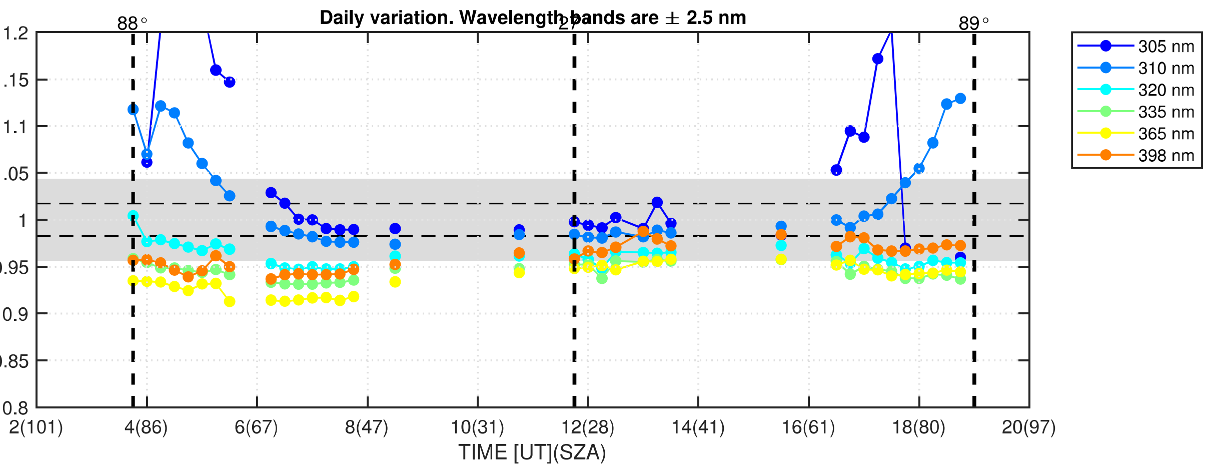

Mean ratio NH1/QASUME at PMOD/WRC-matshic:12-Jul-2025(193) to 13-Jul-2025(194)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
RATIO NH1/QASUME
N NH1 Spectra=132
N Sync-Spectra=58
Wavelength [nm]

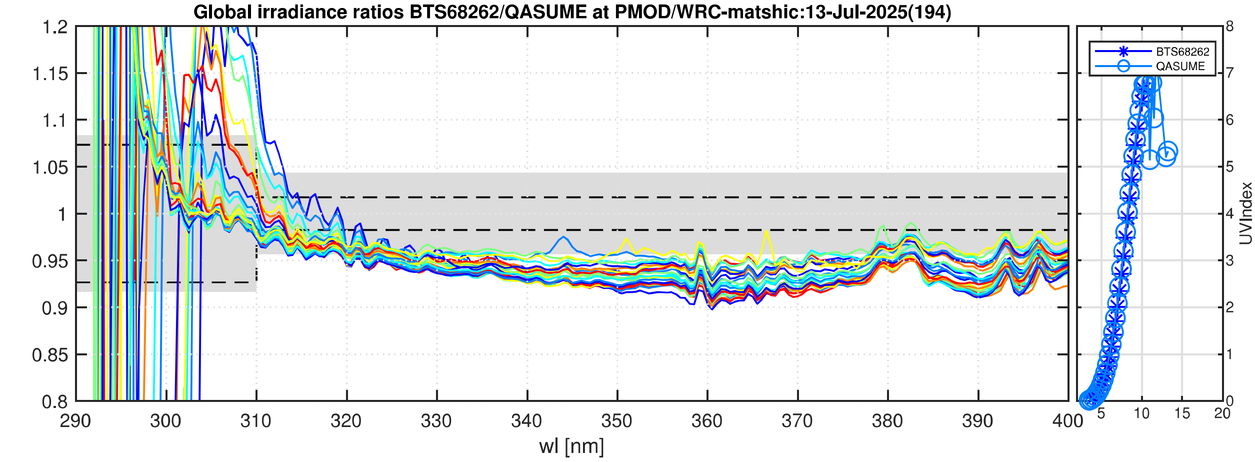

Wavelength shift
Mean
MinMax
STD
Wavelength shift /nm
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
300
310
320
330
340
350
360
370
380
390
400
Wavelength /nm


WL=335.00 nm
Wavelength shift /nm
0.1
0.05
0
-0.05
00:00
06:00
12:00
18:00
00:00
06:00
12:00
18:00
00:00
Date & time

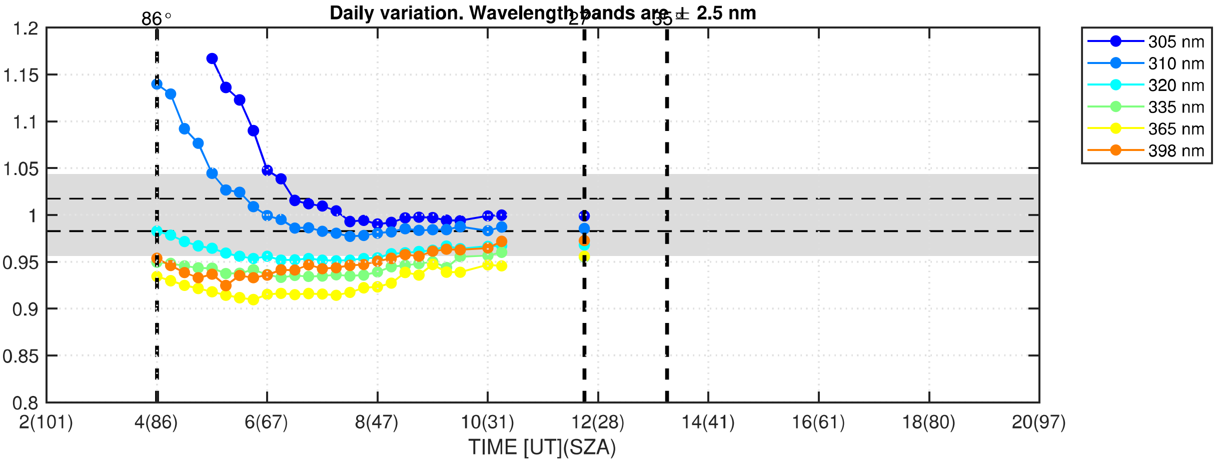

Global irradiance ratios BTS68262/QASUME at PMOD/WRC-matshic:12-Jul-2025(193) to 13-Jul-2025(194)
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
RATIO BTS68262/QASUME
193
194
TIME [UT] ON DAYS: [193 194]


Global irradiance ratios BTS68262/QASUME at PMOD/WRC-matshic:12-Jul-2025(193)
wl [nm]
BTS68262
QASUME
UVIndex

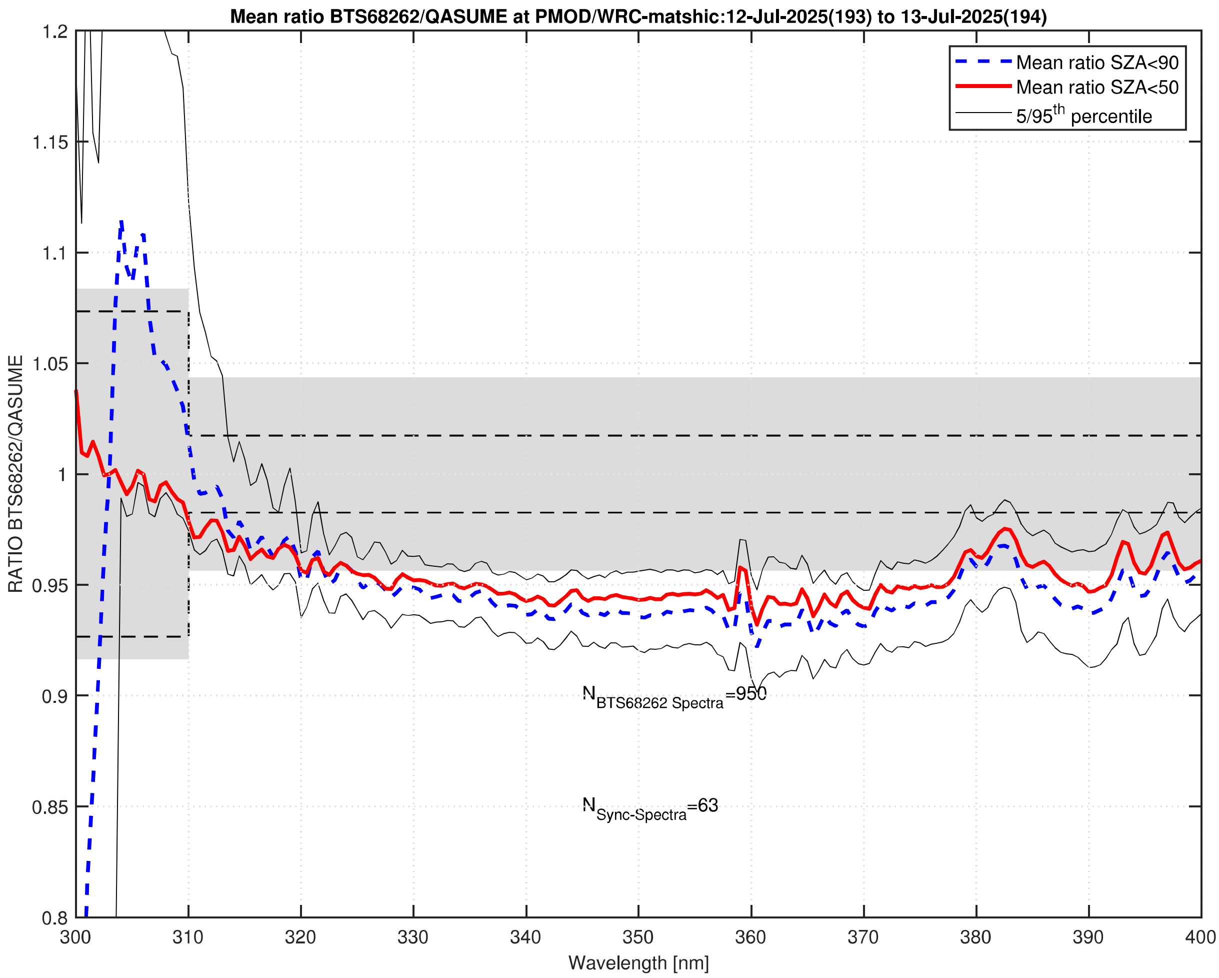

Daily variation. Wavelength bands are ± 2.5 nm
88°
27°
89°
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
TIME [UT](SZA)



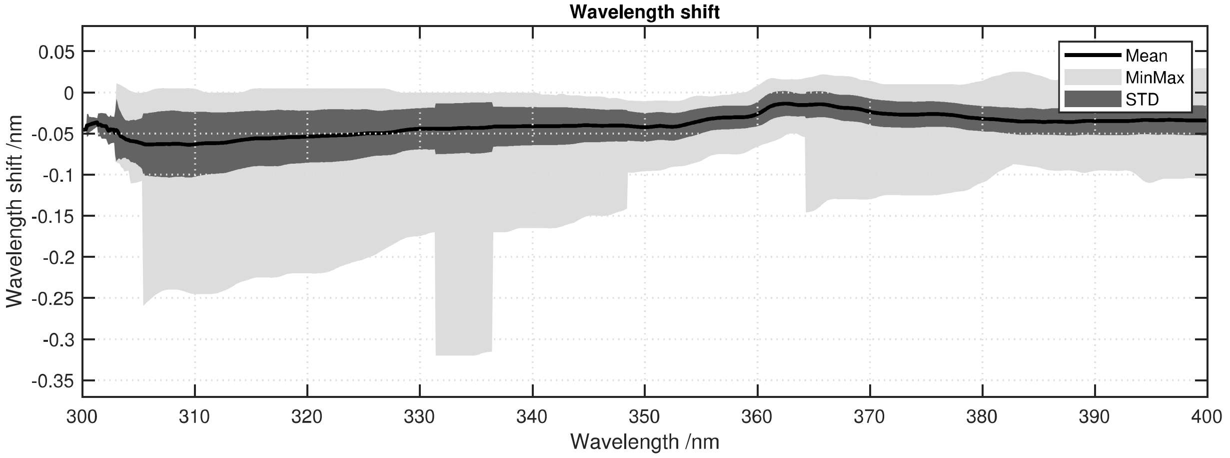
Global irradiance ratios BTS68262/QASUME at PMOD/WRC-matshic:13-Jul-2025(194)
wl [nm]
BTS68262
QASUME
UVIndex



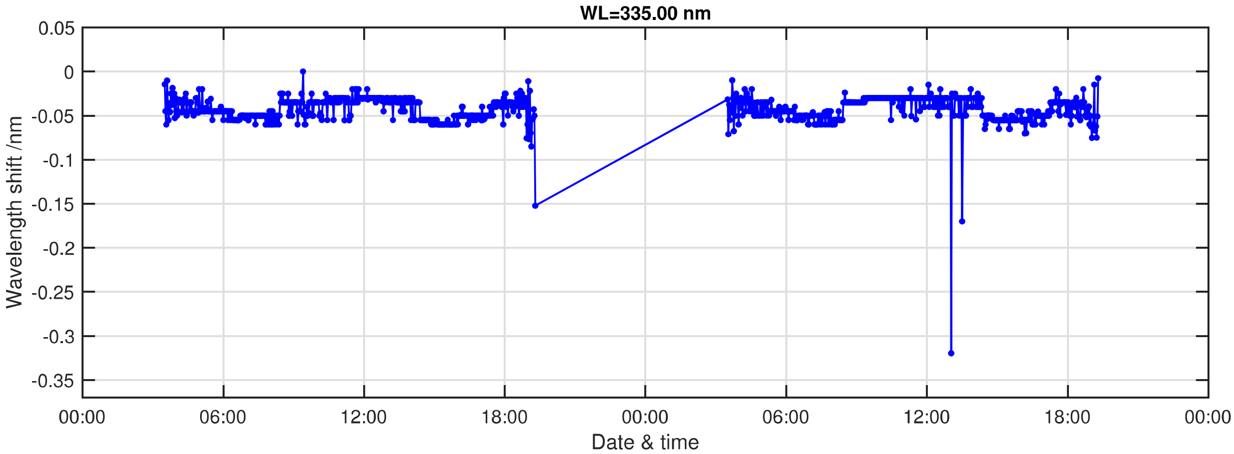
Daily variation. Wavelength bands are ± 2.5 nm
86°
27
35
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
TIME [UT](SZA)



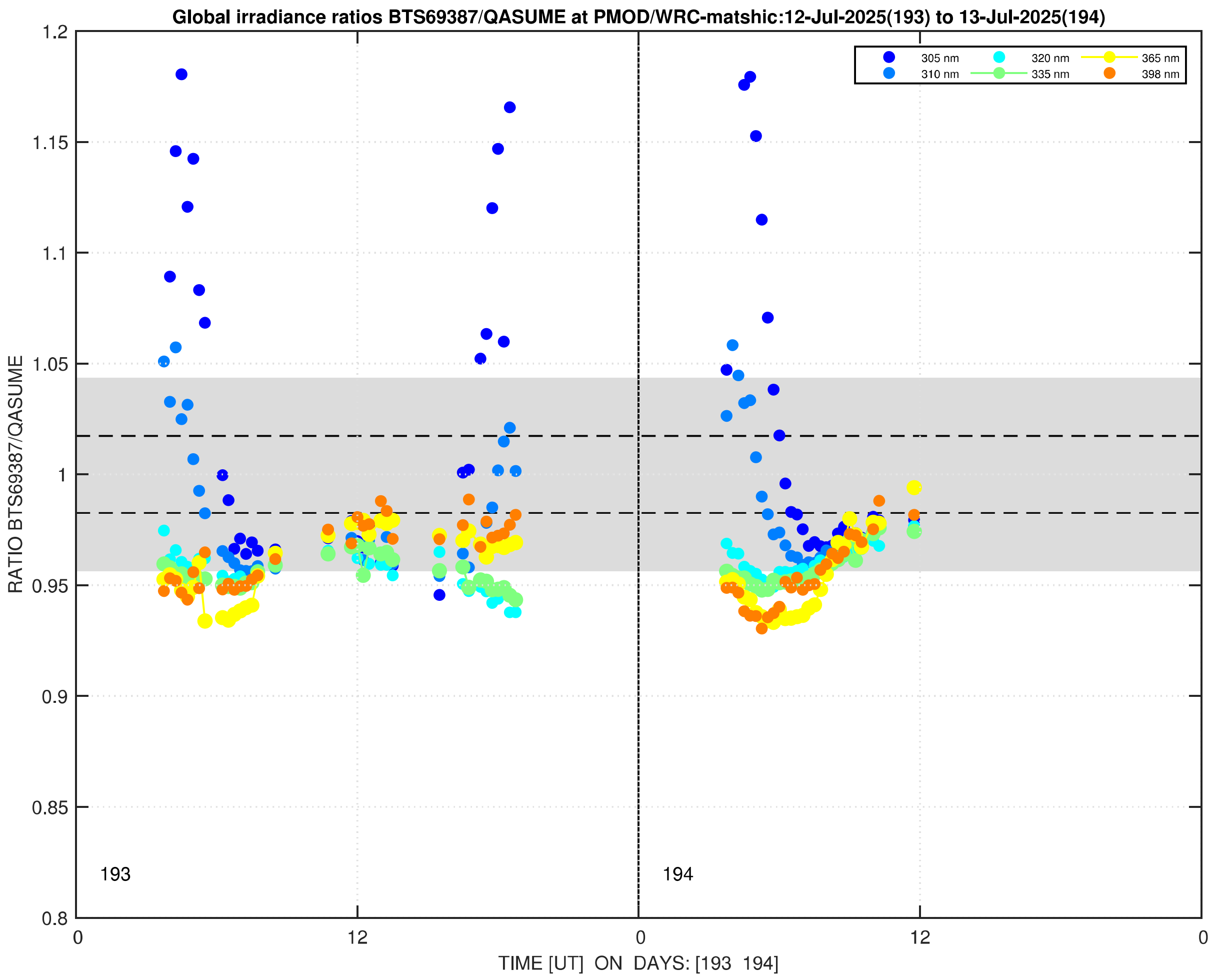
Mean ratio BTS68262/QASUME at PMOD/WRC-matshic:12-Jul-2025(193) to 13-Jul-2025(194)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
$N_{BTS68262\ Spectra}$=950
$N_{Sync-Spectra}$=63
RATIO BTS68262/QASUME
Wavelength [nm]



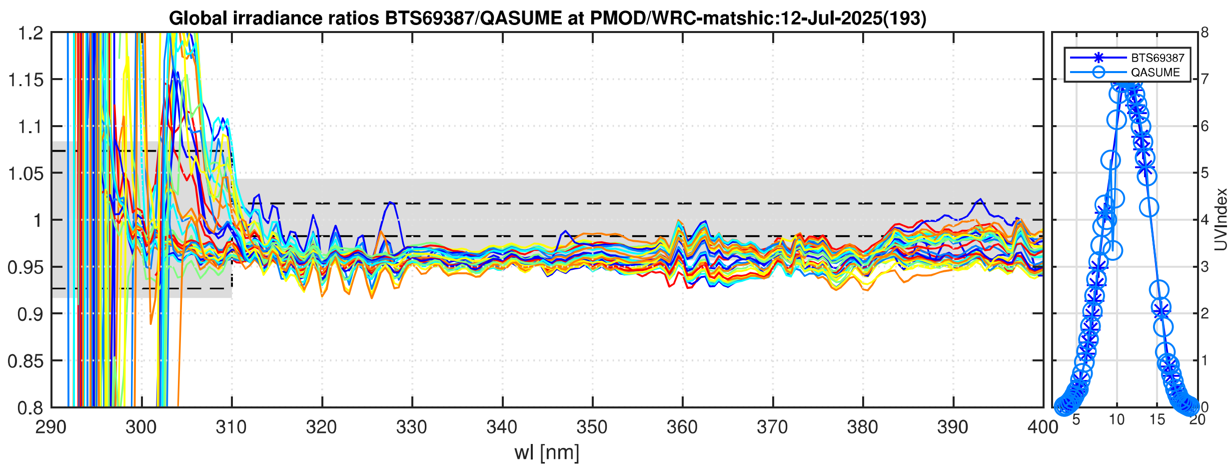
Wavelength shift
Mean
MinMax
STD
Wavelength shift /nm
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
300
310
320
330
340
350
360
370
380
390
400
Wavelength /nm



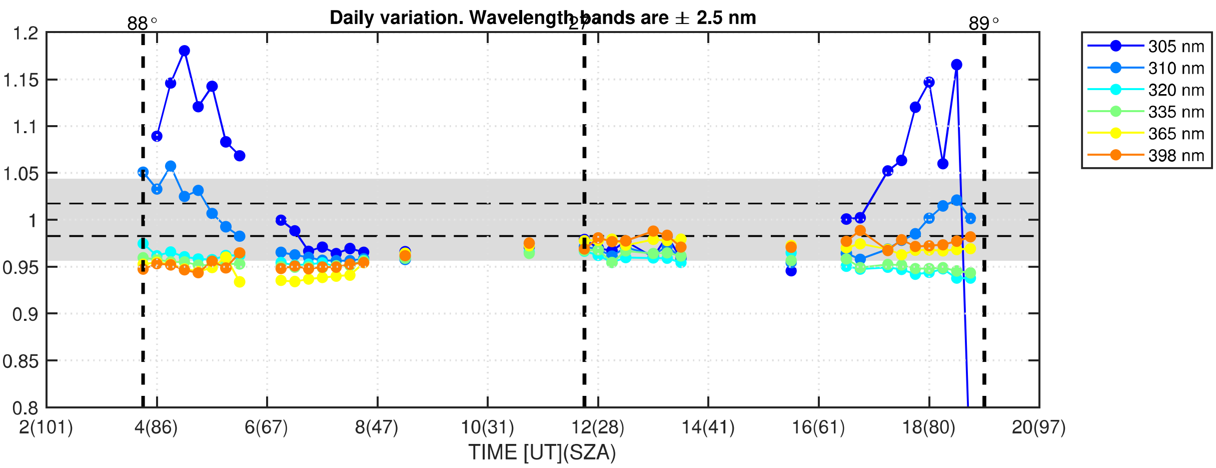
WL=335.00 nm
Wavelength shift /nm
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
00:00
06:00
12:00
18:00
00:00
06:00
12:00
18:00
00:00
Date & time



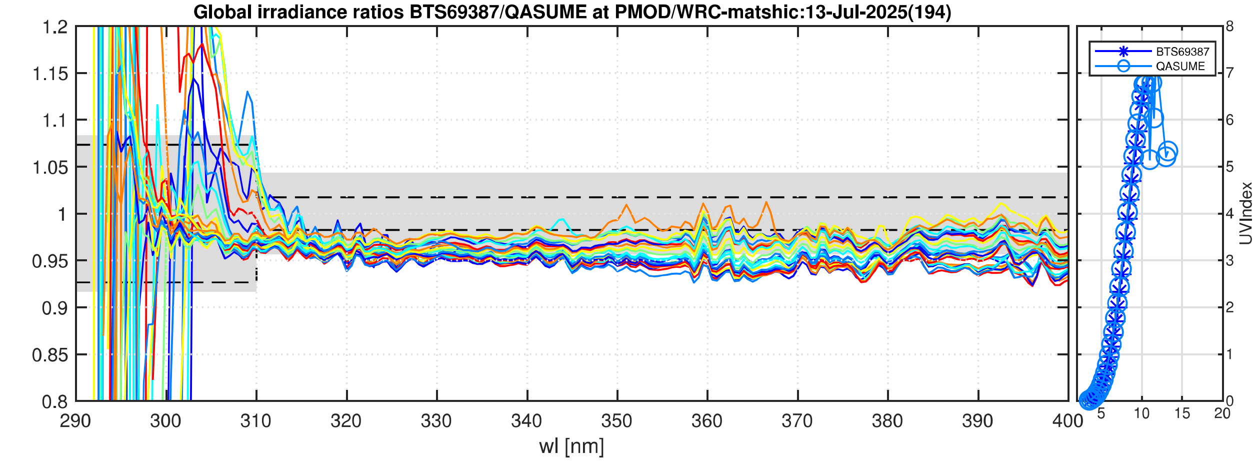
Global irradiance ratios BTS69387/QASUME at PMOD/WRC-matshic:12-Jul-2025(193) to 13-Jul-2025(194)
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
RATIO BTS69387/QASUME
193
194
TIME [UT] ON DAYS: [193 194]



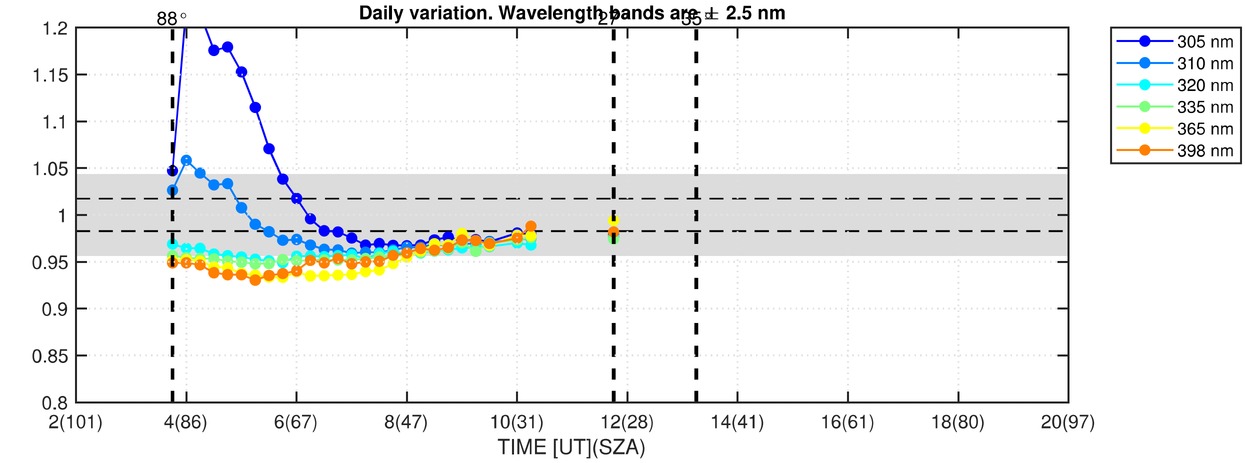
Global irradiance ratios BTS69387/QASUME at PMOD/WRC-matshic:12-Jul-2025(193)
wl [nm]
BTS69387
QASUME
UVIndex



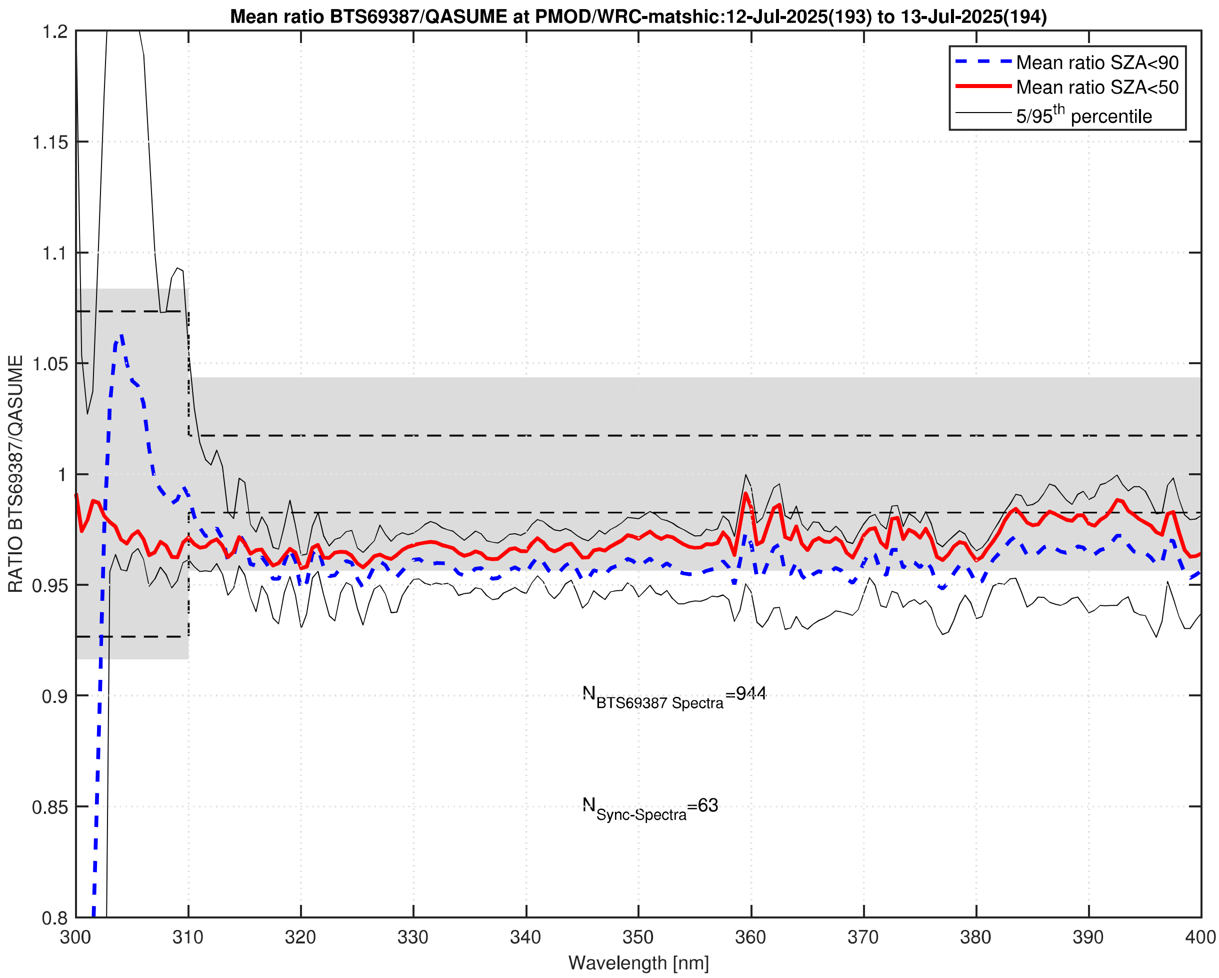
Daily variation. Wavelength bands are ± 2.5 nm
88°
27°
89°
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
TIME [UT](SZA)



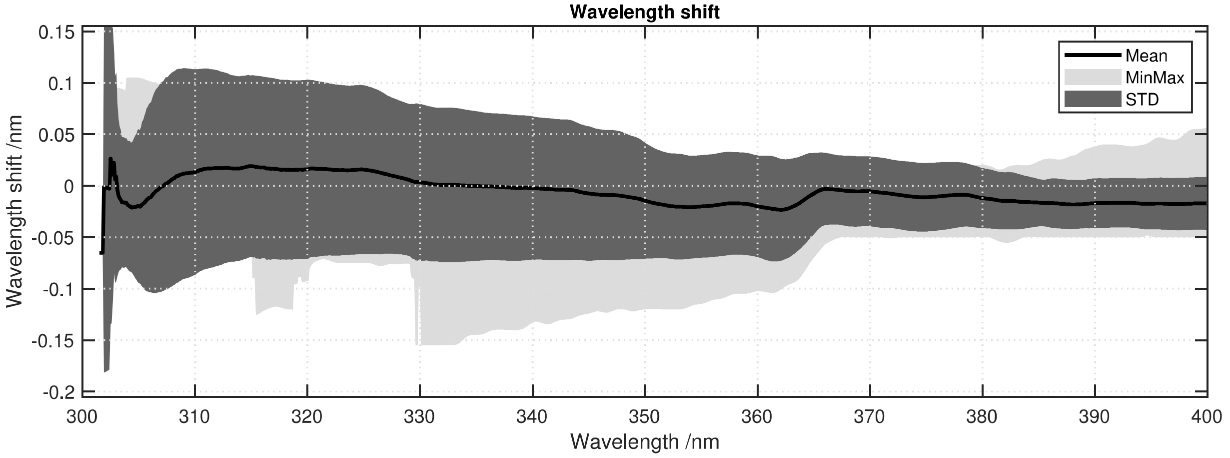
Global irradiance ratios BTS69387/QASUME at PMOD/WRC-matshic:13-Jul-2025(194)
wl [nm]
BTS69387
QASUME
UVIndex

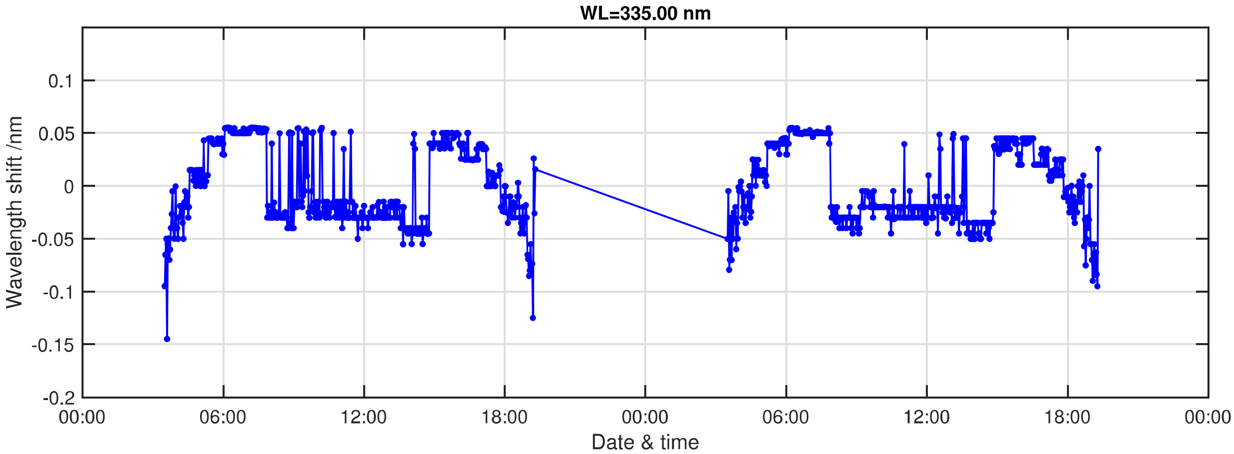


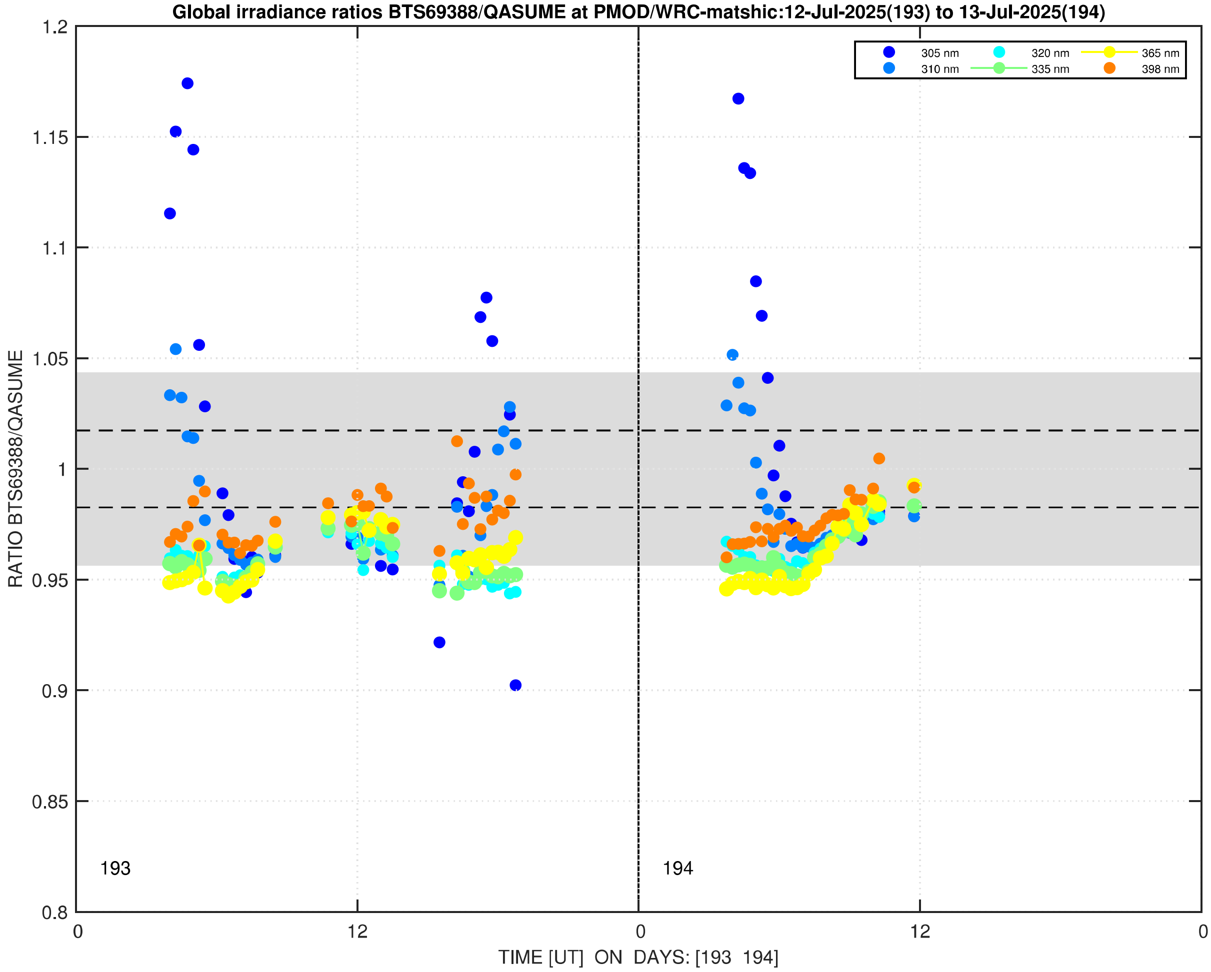
Daily variation. Wavelength bands are ± 2.5 nm
88°
27°
35°
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
TIME [UT](SZA)



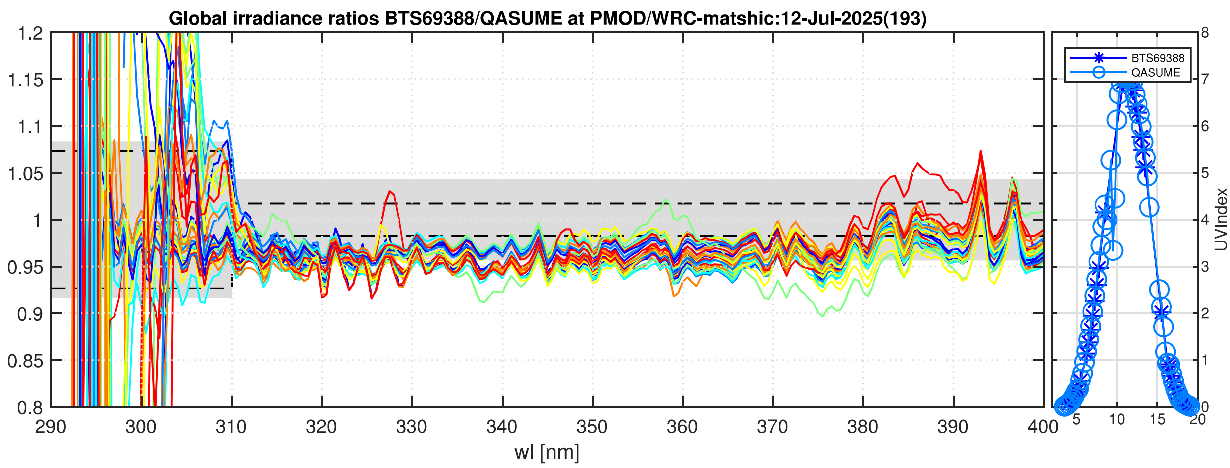
Mean ratio BTS69387/QASUME at PMOD/WRC-matshic:12-Jul-2025(193) to 13-Jul-2025(194)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
N BTS69387 Spectra =944
N Sync-Spectra =63
RATIO BTS69387/QASUME
Wavelength [nm]


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

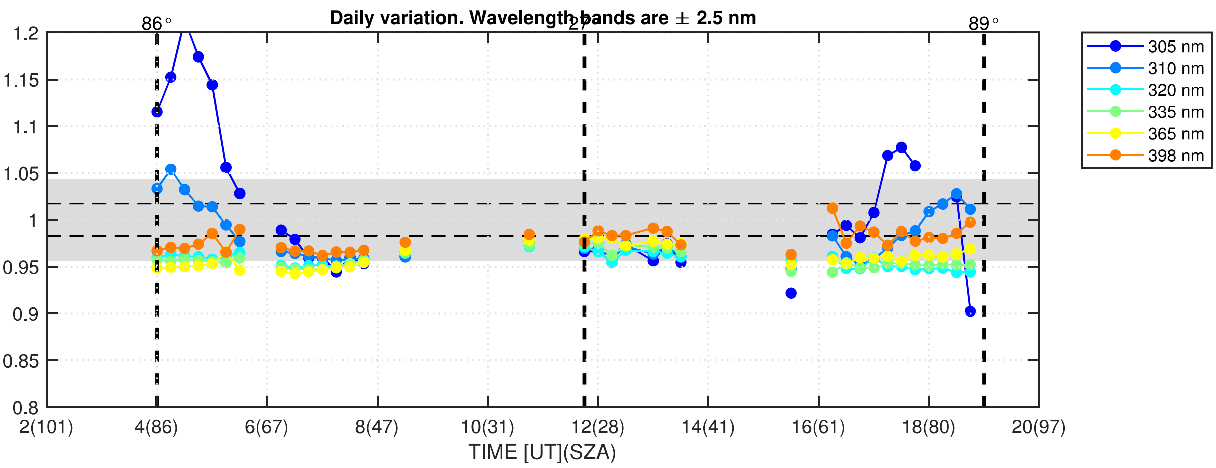

WL=335.00 nm
Wavelength shift /nm
Date & time



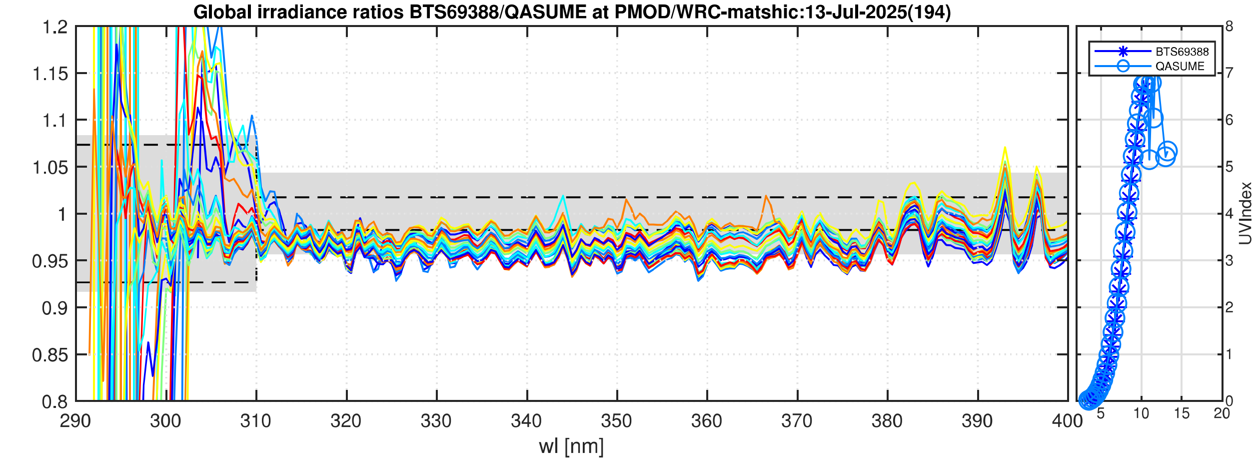
Global irradiance ratios BTS69388/QASUME at PMOD/WRC-matshic:12-Jul-2025(193) to 13-Jul-2025(194)
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
RATIO BTS69388/QASUME
193
194
TIME [UT] ON DAYS: [193 194]

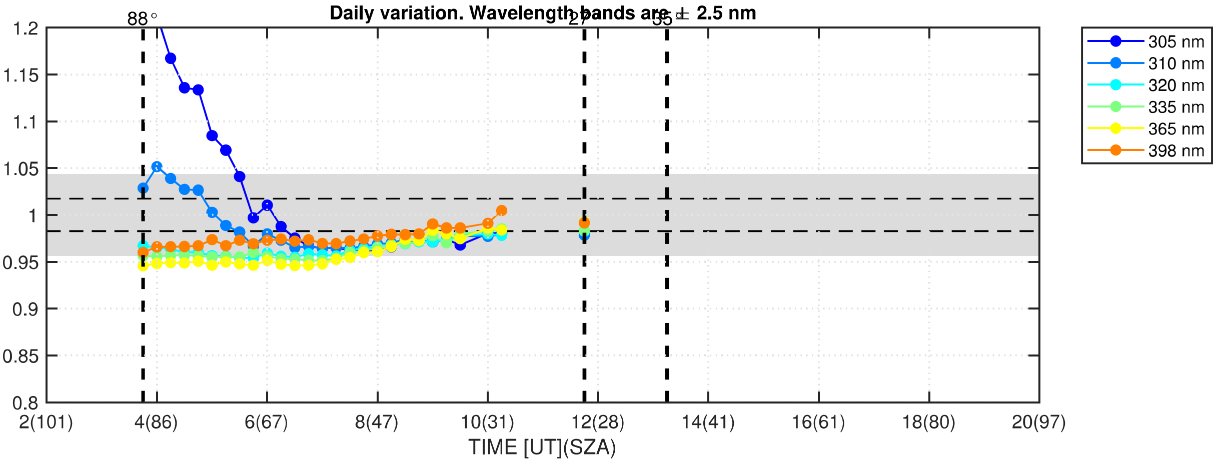


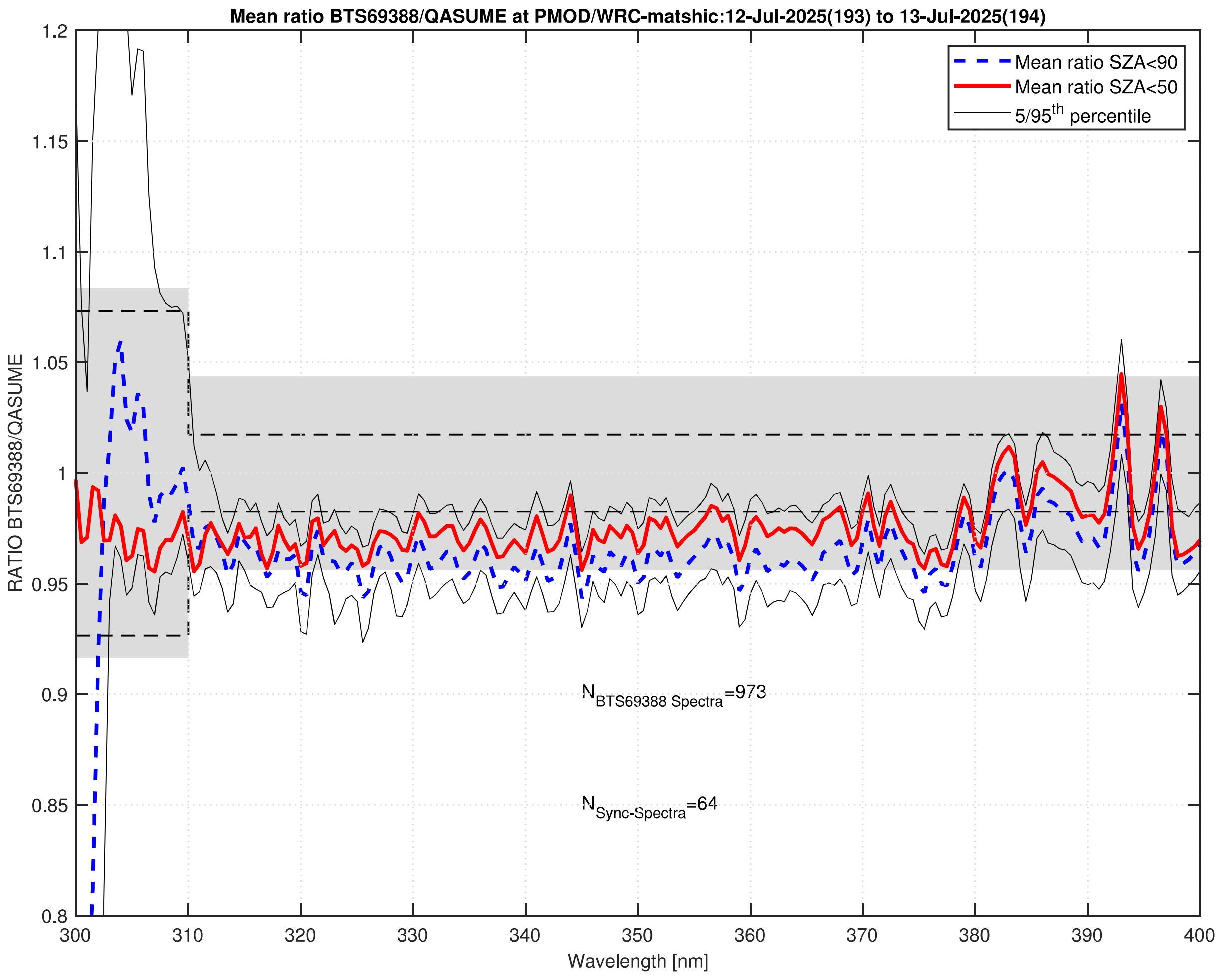
Global irradiance ratios BTS69388/QASUME at PMOD/WRC-matshic:12-Jul-2025(193)
wl [nm]
BTS69388
QASUME
UVIndex

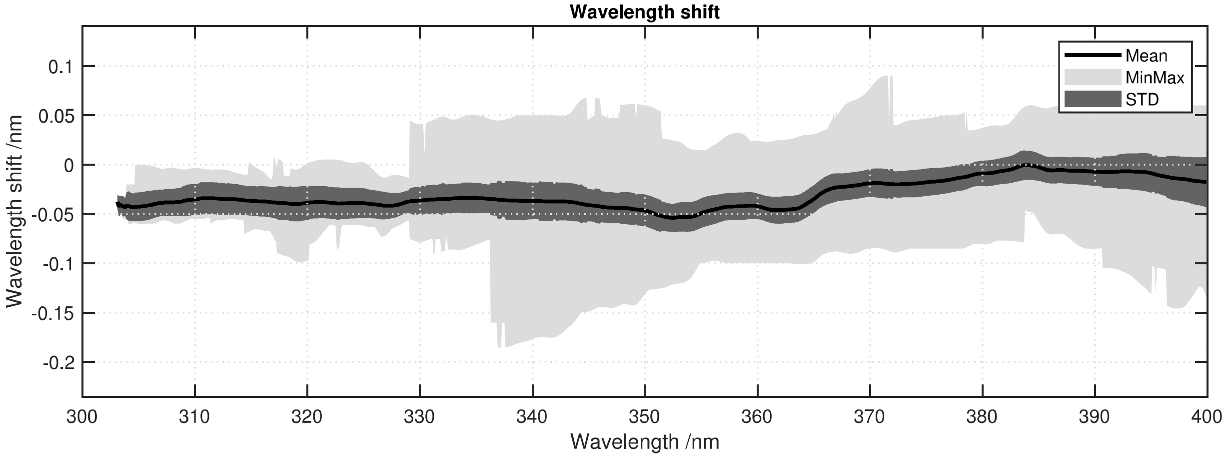


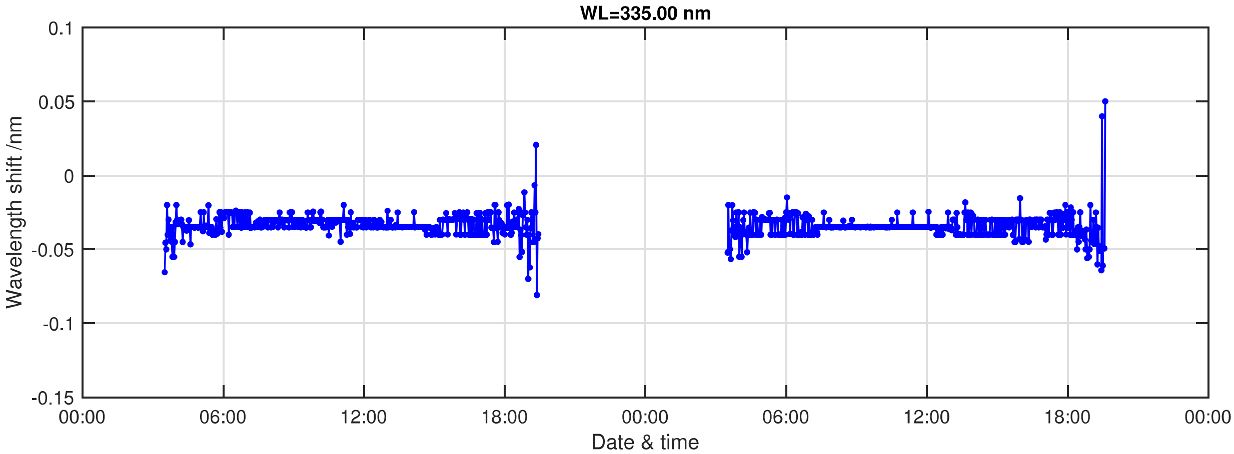
Daily variation. Wavelength bands are ± 2.5 nm
86°
27°
89°
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
TIME [UT](SZA)

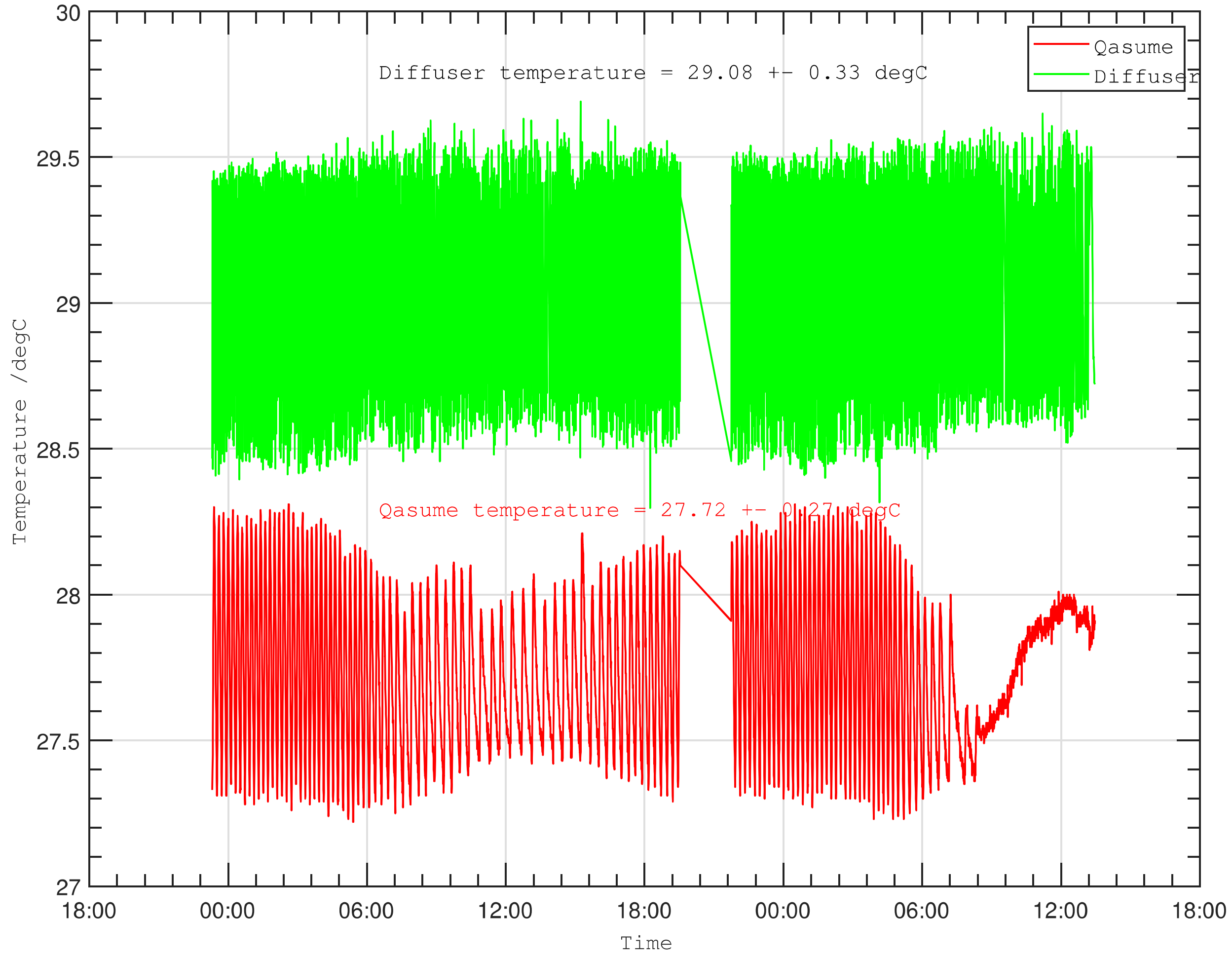

Global irradiance ratios BTS69388/QASUME at PMOD/WRC-matshic:13-Jul-2025(194)
wl [nm]
BTS69388
QASUME
UVIndex

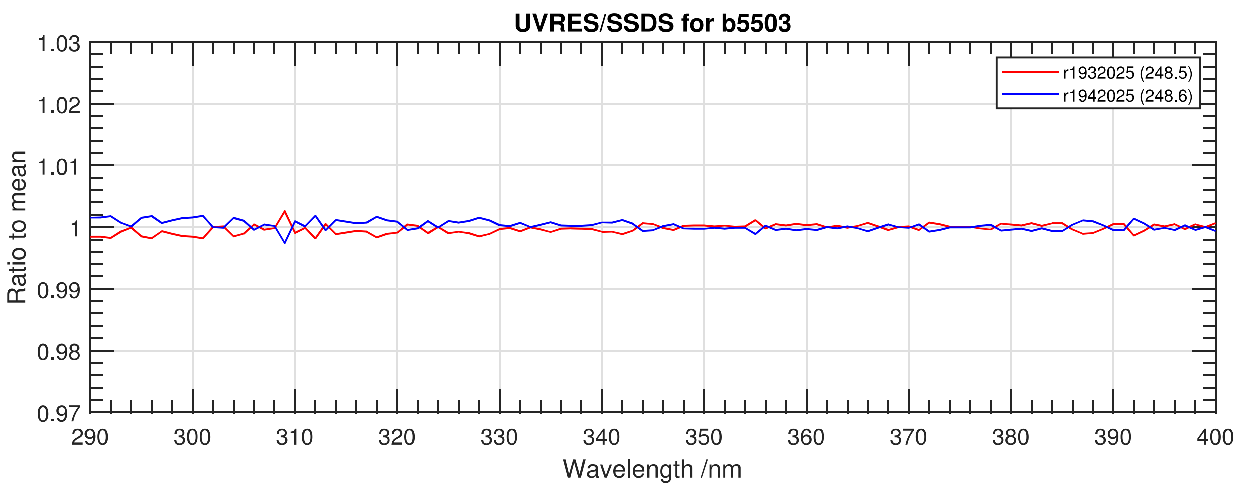

Daily variation. Wavelength bands are ± 2.5 nm
88°
27
35
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
TIME [UT](SZA)

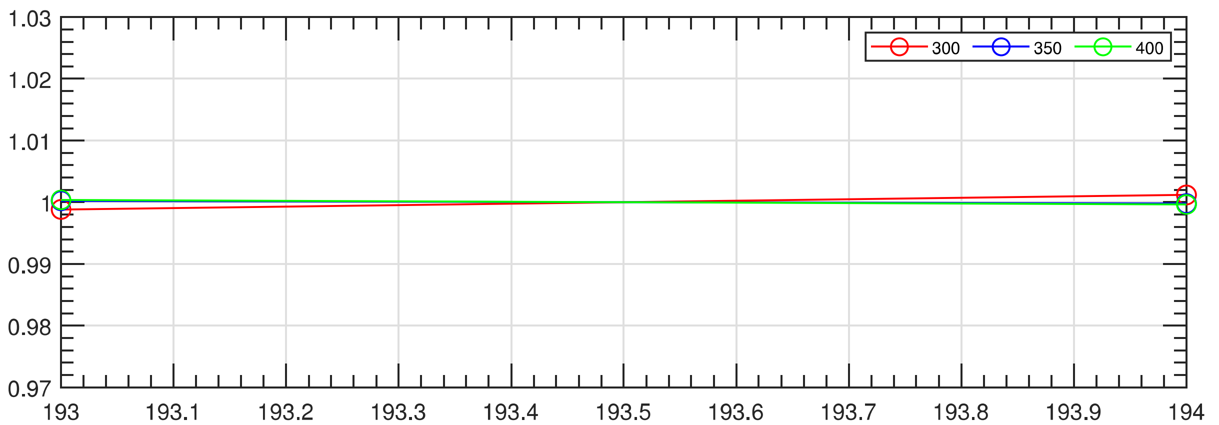

Mean ratio BTS69388/QASUME at PMOD/WRC-matshic:12-Jul-2025(193) to 13-Jul-2025(194)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
RATIO BTS69388/QASUME
N BTS69388 Spectra =973
N Sync-Spectra =64
Wavelength [nm]


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


WL=335.00 nm
Wavelength shift /nm
Date & time
0.1
0.05
0
-0.05
-0.1
-0.15
00:00
06:00
12:00
18:00
00:00
06:00
12:00
18:00
00:00


Diffuser temperature = 29.08 +- 0.33 degC
Qasume temperature = 27.72 +- 0.27 degC
Qasume
Diffuser
Temperature /degC
Time
30
29.5
29
28.5
28
27.5
27
18:00
00:00
06:00
12:00
18:00
00:00
06:00
12:00
18:00


UVRES/SSDS for b5503
r1932025 (248.5)
r1942025 (248.6)
Ratio to mean
Wavelength /nm
1.03
1.02
1.01
1
0.99
0.98
0.97
290
300
310
320
330
340
350
360
370
380
390
400


300
350
400
1.03
1.02
1.01
1
0.99
0.98
0.97
193
193.1
193.2
193.3
193.4
193.5
193.6
193.7
193.8
193.9
194


BTS
Qasume
NH1


BTS 69388
BTS 68262
BTS 69387