17/09/2024

Protocol of the intercomparison at BFS, Neuherberg, Germany on 3rd to 7th June 2024 with the travelling reference spectroradiometer QASUME from PMOD/WRC

Report prepared by Gregor Hülsen

Operator: Gregor Hülsen
Local operator: Sebastian Lorenz

The purpose of the visit was the comparison of global solar irradiance measurements between the Bentham DM300 and the three BTS spectroradiometers, operated by the Bundsamt für Strahlungsschutz (BFS) and the travel reference spectroradiometer QASUME. 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 3:30 UT and 18:30 UT have been analysed.

QASUME was installed on the measurement platform of BFS-Neuherberg in the afternoon of June 3, 2024. 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 was not operational during the campaign. The BTS1, BTS2 and BTS3 are BTS2048 (SN: 35861, 65700 and 35862). The internal shortcut for the 3 BTS are MB, NB and NG. The Bentham spectroradiometer was not running during the campaign, because of instable irradiance measurements.
The intercomparison between QASUME and the local spectroradiometers lasted 4 days, from the morning of June 4 to the afternoon of June 7.

QASUME was calibrated several times during the intercomparison period using a portable calibration system. Three lamps (T61251, T68523 and T157824) 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 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 450 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 (BTS1 and BTS3) and 1 min (BTS2) 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 7.3 min per scan.

DOY	Date	DAY	Weather	Comment (times are in UT)
155	03-Jun	Monday	Overcasted Sky with rain	Installed at 15:30 16:00 start UV measurements
156	04-Jun	Tuesday	Mix of sun and clouds (Cu) Clear sky in the evening	8:05 Calibration T68523 8:20 Calibration T61251
157	05-Jun	Wednesday	Mix of sun and clouds (Cu) Clear sky in the evening	08:40 Turn BTS1 by 120° ccw 13:26 Calibration T68523 13:40 Calibration T157824
158	06-Jun	Thursday	Clear sky in the morning Mix of sun and clouds (Cu) Rainshower in the night	7:40 Calibration T68523
159	07-Jun	Friday	Mix of sun & clouds	8:55 Calibration T68523 12:00 End of Campaign

Results:

In total 185/169/162 (BTS1-BTS3) simultaneous spectra from QASUME and the local instruments are available from the measurement period. Measurements between 3:30 and 19:30 UT have been analysed (SZA smaller than 90°).
On average three BTS spectra were fitted to the scanning QASUME scans. Only scans with sufficient low intensity variability during the 7.3 min scan time were selected for the comparison. Time periods with direct sun were selected using direct irradiance measurements.
The BTS datasets were further filtered for obvious outliers (manually) and with a filter of ±10% of the median ratio for wavelength greater than 310 nm and ±30% for smaller wavelengths.

Conclusions:

A) BTS1 (SN 35861):

1. The average spectral ratio between BTS1 and QASUME is on average +1%. For wavelength <305 nm the BTS1 underestimated the solar irradiance on average by more than 10%. For high solar zenith angles BTS1 strongly overestimates the solar irradiance for wavelengths below 320 nm.
2. The temporal variation of the spectra between BTS1 and QASUME shows a 5% increase on the first day of the campaign. The spectroradiometer was turned by 120 Deg on the second day resulting in a 5% decrease third day. This is an indication for an azimuth error of BTS1.
3. The wavelength shifts of BTS1 relative to the high spectral resolution solar spectrum are between -100 pm and +100 pm in the spectral range 290 nm to 400 nm.

B) BTS2 (SN 65700):

1. The average spectral ratio between both BTS2 and QASUME is below 1%. For high solar zenith angles in strongly overestimates the solar irradiance for wavelengths below 320 nm.
2. The temporal variation of the spectra between BTS2 and QASUME was very stable, with variations less than 2% during the whole campaign.
3. The wavelength shifts of BTS2 relative to the high spectral resolution solar spectrum are between -100 pm and +0 pm in the spectral range 305 nm to 400 nm. For wavelengths below 305 nm higher shifts were calculated (-500 pm and +400 pm).

C) BTS3 (SN 35862):

1. The average spectral ratio between BTS3 and QASUME is on average +2% with a small spectral trend to +5%. For wavelength <305 nm the BTS3 underestimated the solar irradiance on average by more than 10%. For high solar zenith angles BTS3 strongly overestimates the solar irradiance for wavelengths below 320 nm.
2. The temporal variation of the spectra between BTS3 and QASUME was very stable, with variations less than 2% during the whole campaign.
3. The wavelength shifts of BTS3 relative to the high spectral resolution solar spectrum are between -50 pm and +50 pm in the spectral range 290 nm to 400 nm.

Comparison to previous QASUME site visits

No long-term stability could be assessed through a comparison of the QASUME site visits performed in 2004, because the Bentham was not operational at the current campaign.

Summary:

The audit showed that the UV measurements performed at BFS with the BTS spectroradiometer are within the expected combined measurement uncertainty:

$$U_{comp}= sqrt(U_{qas}^2+U_{BFS}^2)$$

With U_{qas} = 1.74%, U_{qas} = 7.34% (y<300 nm) (Hülsen et al., 2016). U_{BFS} was estimated to be 4%. BTS2 is within the uncertainty range of Qasume.

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 the campaign at Neuherberg many measurements were affected by moving clouds. A follow up audit with more stable conditions is suggested.
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 diurnal variability of BTS1 indicate an azimuth error (tilt of the diffuser). This should be investigated in more detail.

References:

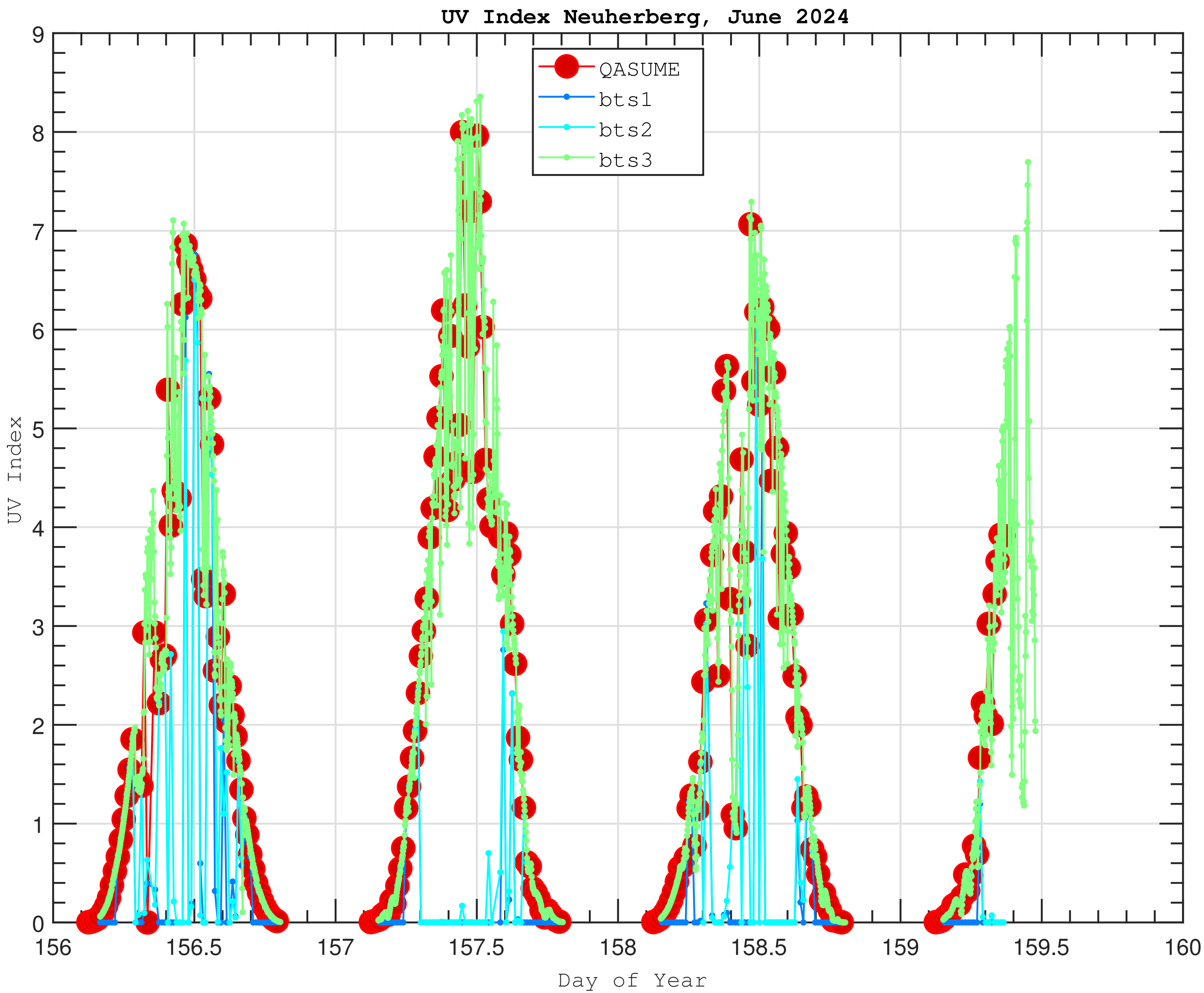
J. Gröbner, I. Kröger, L. Egli, G. Hülsen, S. Riechelmann, and P. Sperfeld, “The high-resolution extraterrestrial solar spectrum (QASUMEFTS) determined from ground-based solar irradiance measurements", Atmos. Meas. Tech., 10, 3375-3383, 2017

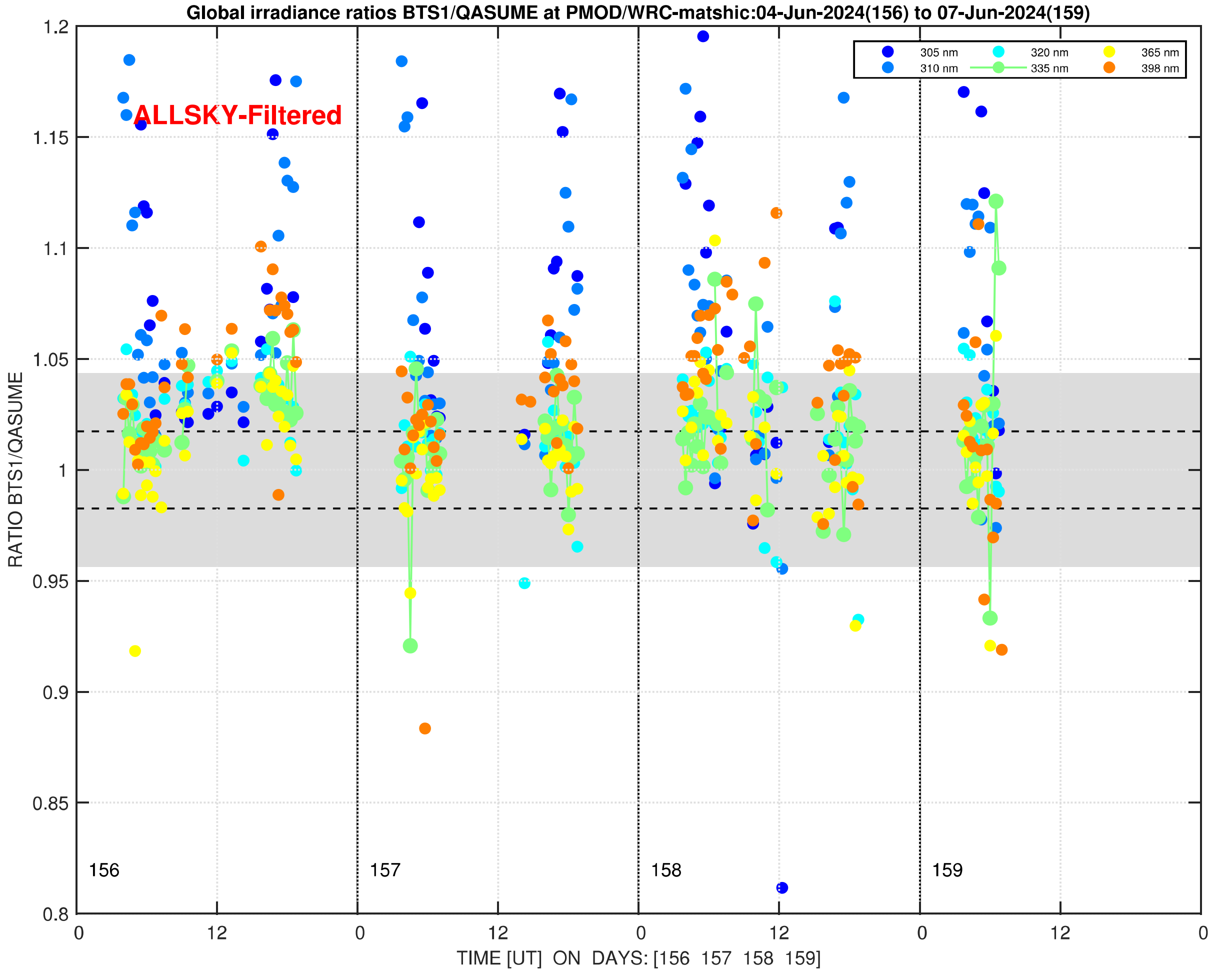
G. Hülsen, J. Gröbner, S. Nevas, P. Sperfeld, L. Egli, G. Porrovecchio, and M. Smid, “Traceability of solar UV measurements using the Qasume reference spectroradiometer", Appl. Opt. 55, 7265-7275, 2016.

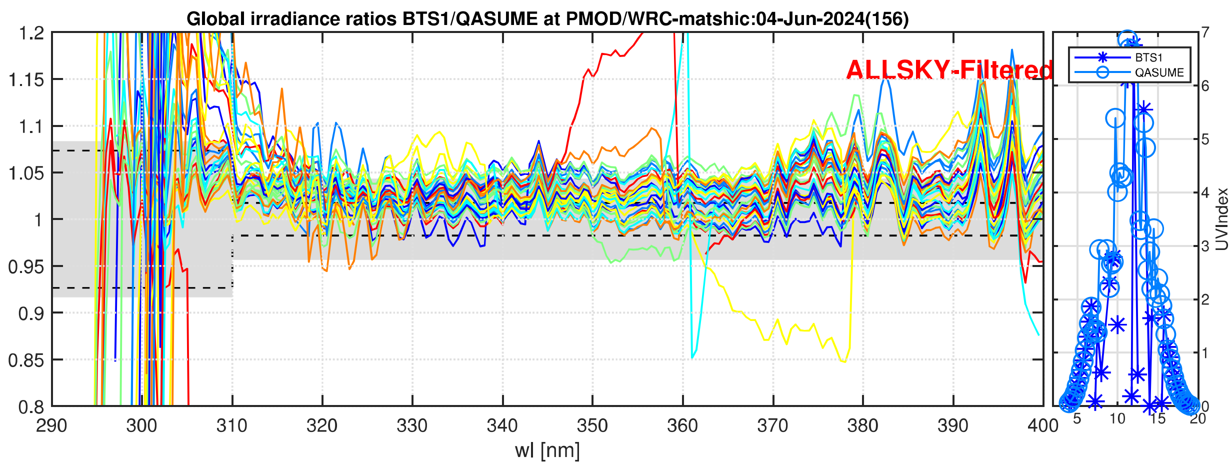
Comments from the operator:

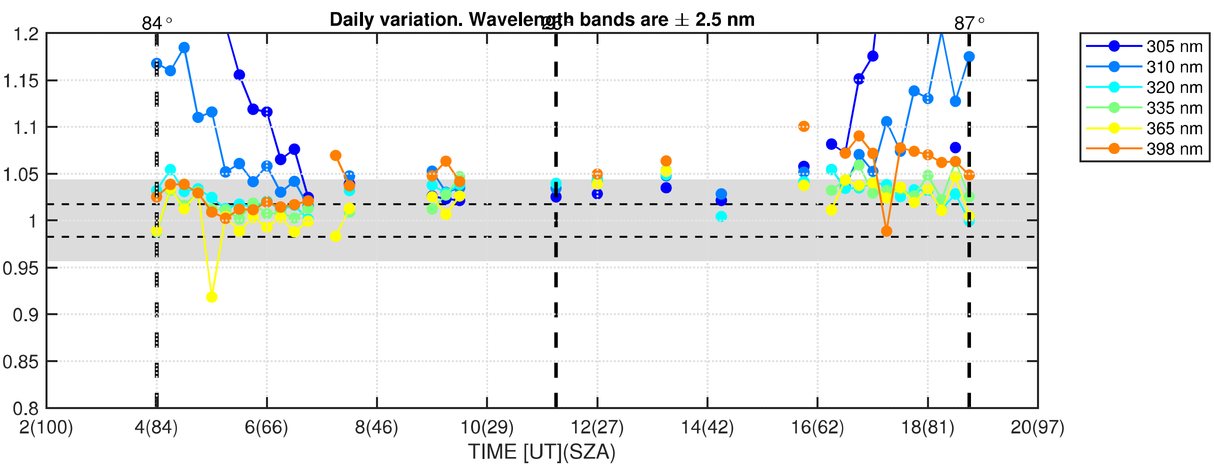
Appendix

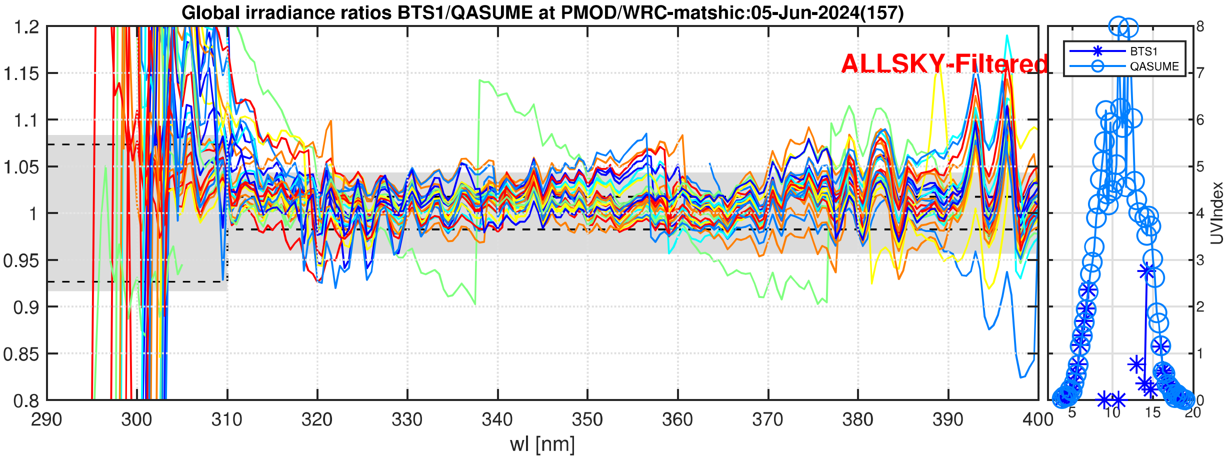
Detailed results for all local spectrophotometers with respect to the reference spectroradiometer QASUME


UV Index Neuherberg, June 2024
QASUME
bts1
bts2
bts3
UV Index
Day of Year
0
1
2
3
4
5
6
7
8
9
156
156.5
157
157.5
158
158.5
159
159.5
160

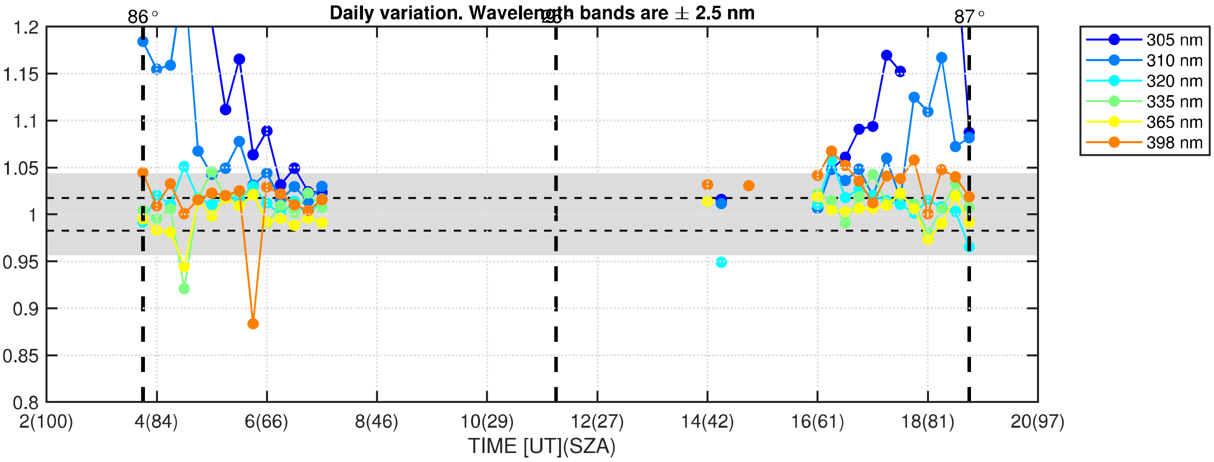

Global irradiance ratios BTS1/QASUME at PMOD/WRC-matshic:04-Jun-2024(156) to 07-Jun-2024(159)
ALLSKY-Filtered
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
156
157
158
159
RATIO BTS1/QASUME
TIME [UT] ON DAYS: [156 157 158 159]


Global irradiance ratios BTS1/QASUME at PMOD/WRC-matshic:04-Jun-2024(156)
ALLSKY-Filtered
wl [nm]
BTS1
QASUME
UVIndex

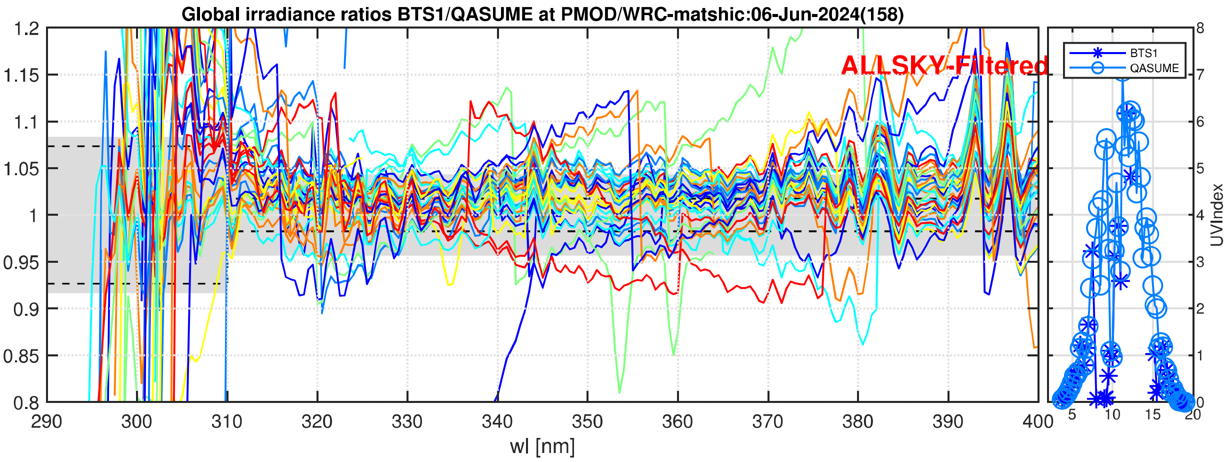

Daily variation. Wavelength bands are ± 2.5 nm
84°
87°
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
TIME [UT](SZA)



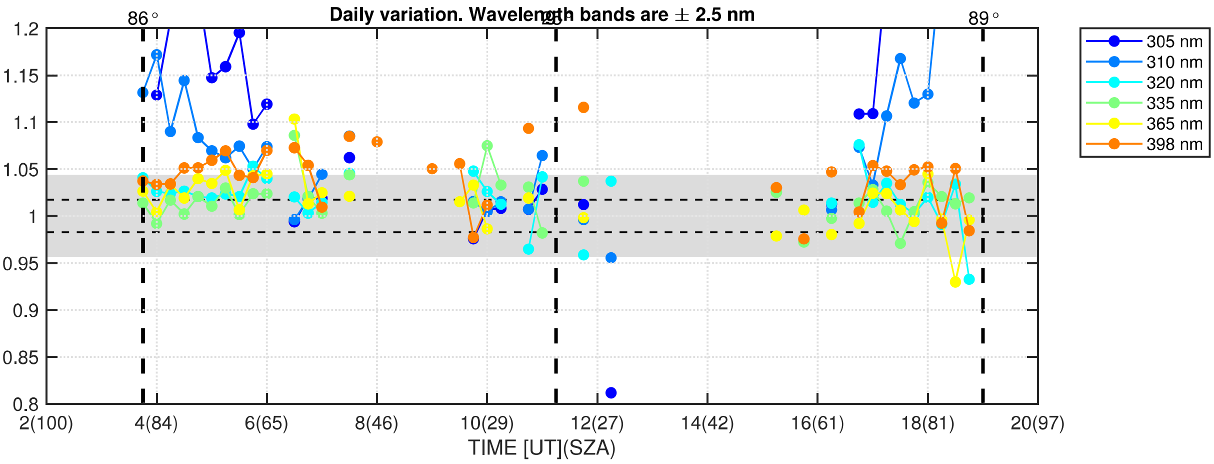
Global irradiance ratios BTS1/QASUME at PMOD/WRC-matshic:05-Jun-2024(157)
ALLSKY-Filtered
wl [nm]
BTS1
QASUME
UVIndex



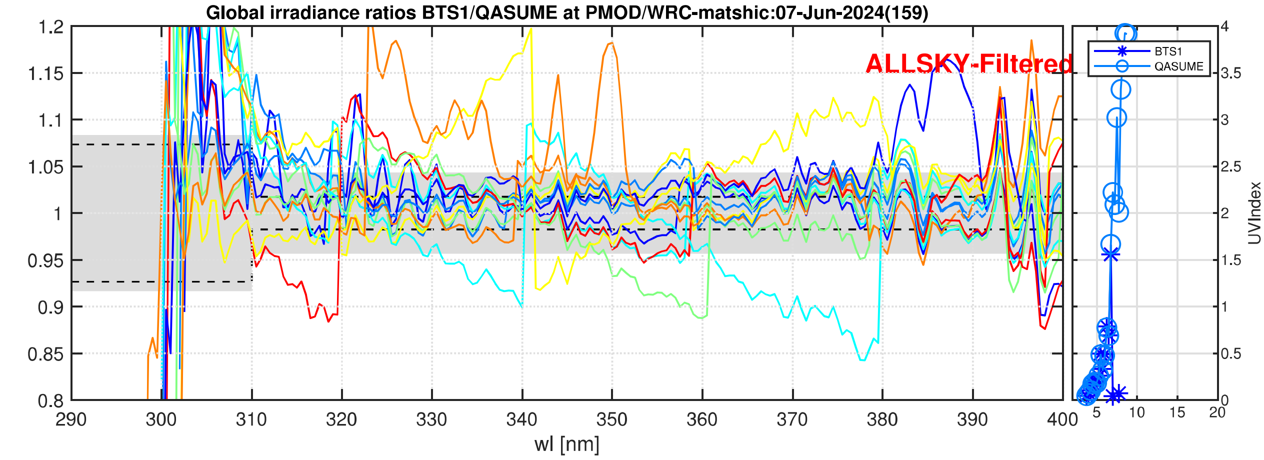
Daily variation. Wavelength bands are ± 2.5 nm
86°
87°
TIME [UT](SZA)
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm



Global irradiance ratios BTS1/QASUME at PMOD/WRC-matshic:06-Jun-2024(158)
ALLSKY-Filtered
wl [nm]
BTS1
QASUME
UVIndex



Daily variation. Wavelength bands are ± 2.5 nm
86°
89°
TIME [UT](SZA)
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm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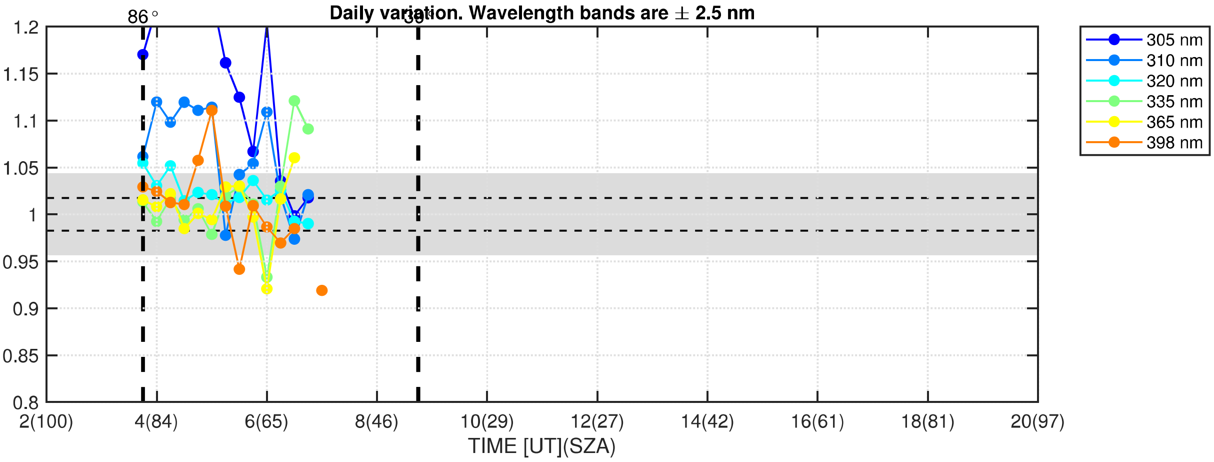
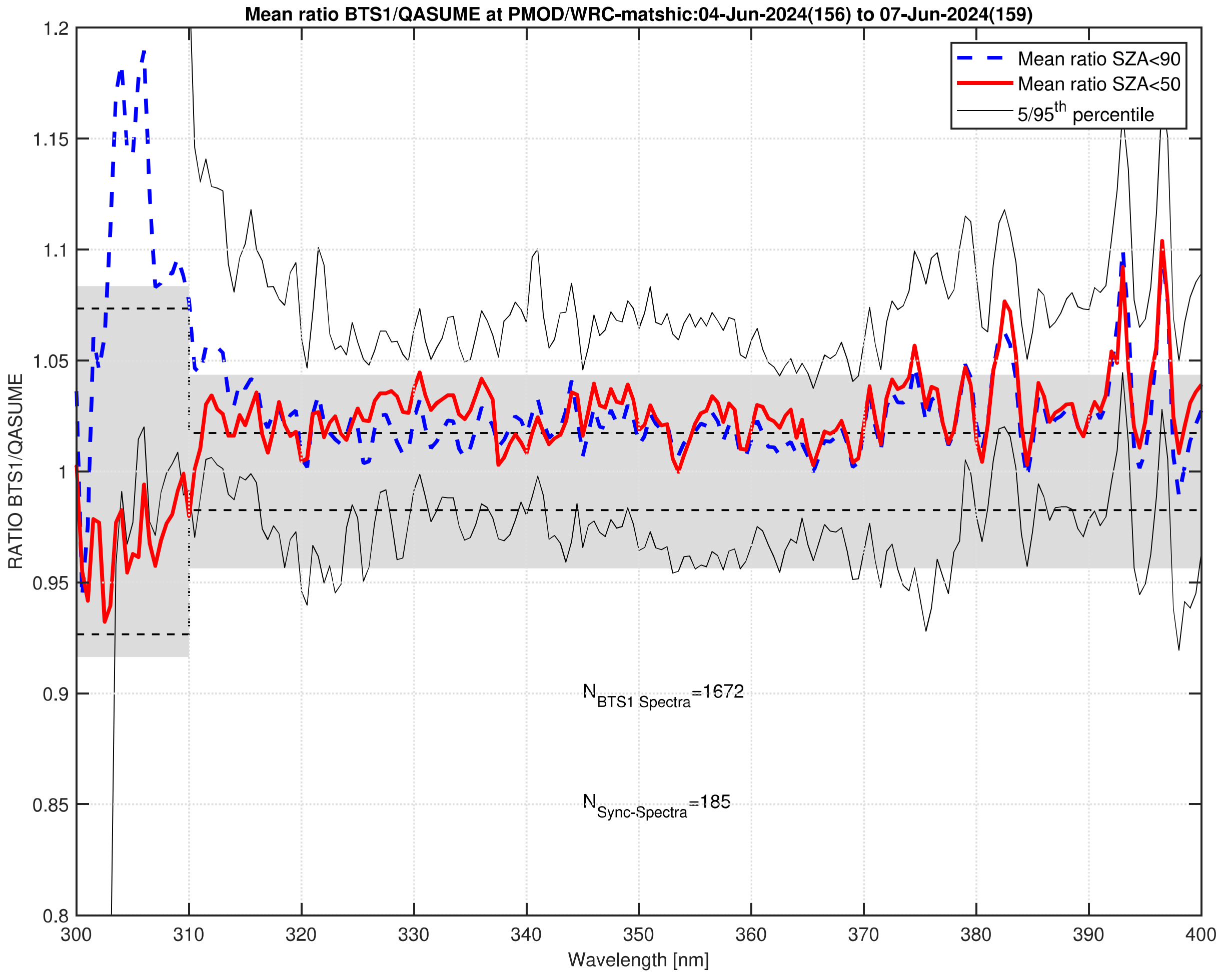
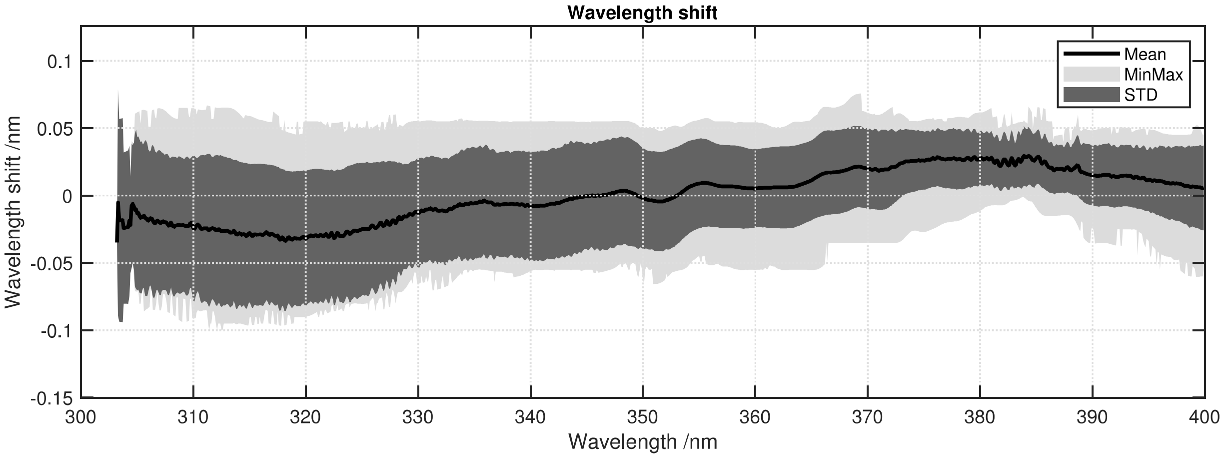
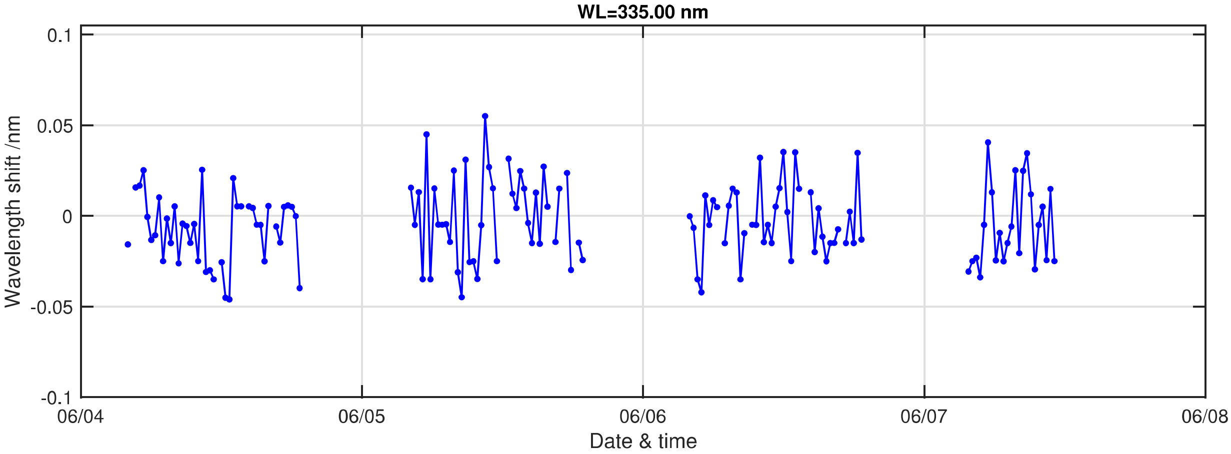
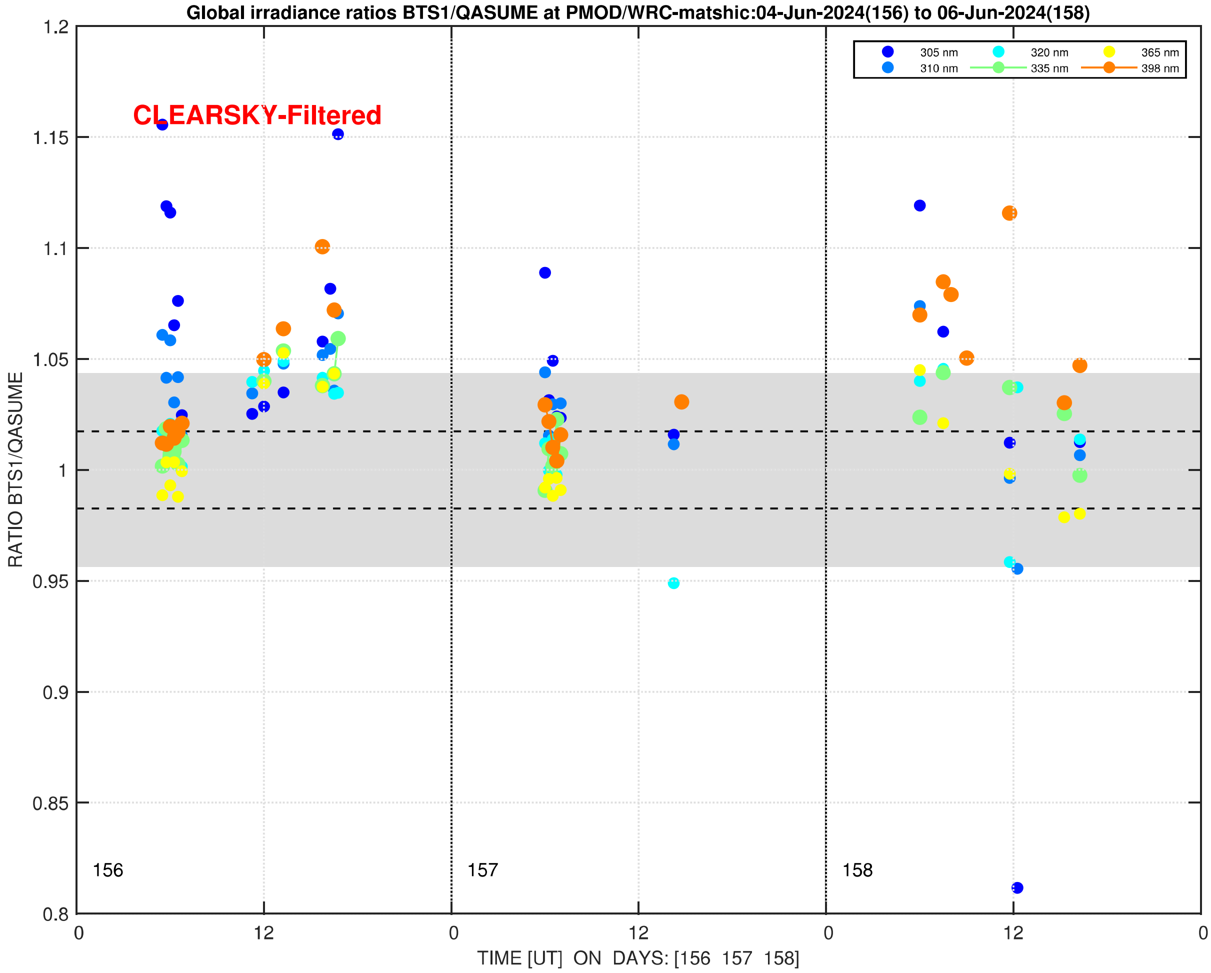
ALLSKY-Filtered
BTS1
QASUME
UVIndex
wl [nm]

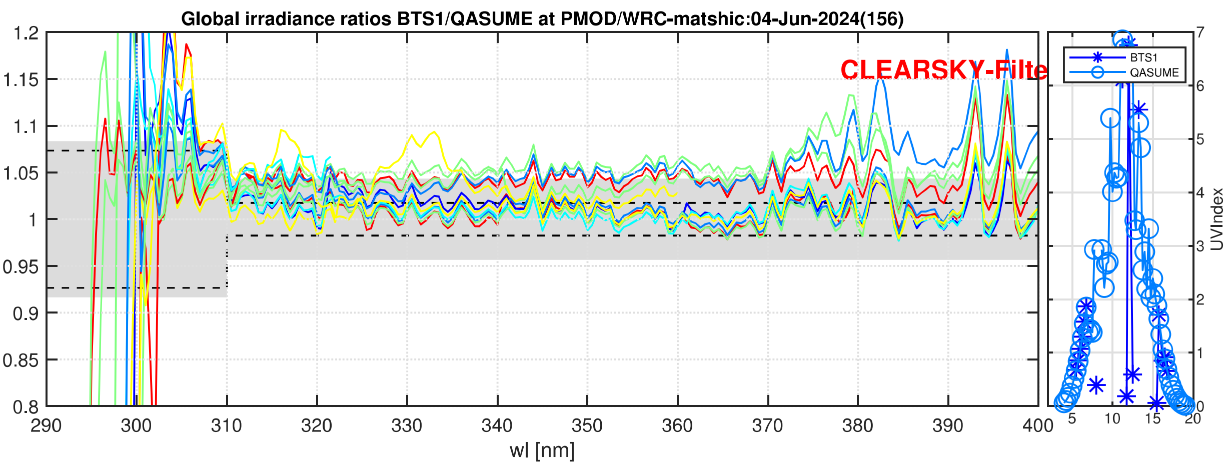

Daily variation. Wavelength bands are ± 2.5 nm
86°
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
TIME [UT](SZA)

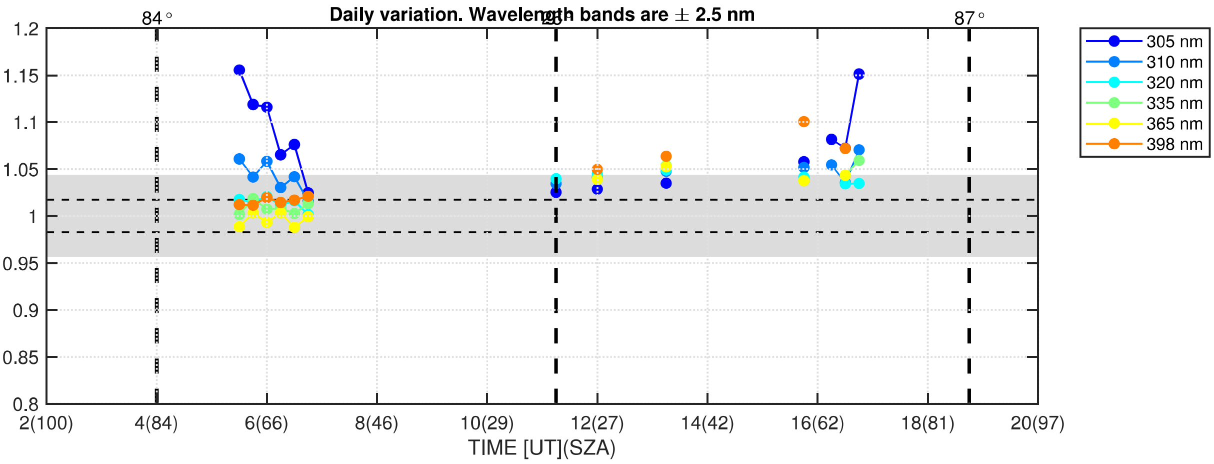

Mean ratio BTS1/QASUME at PMOD/WRC-matshic:04-Jun-2024(156) to 07-Jun-2024(159)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
N BTS1 Spectra =1672
N Sync-Spectra =185
RATIO BTS1/QASUME
Wavelength [nm]

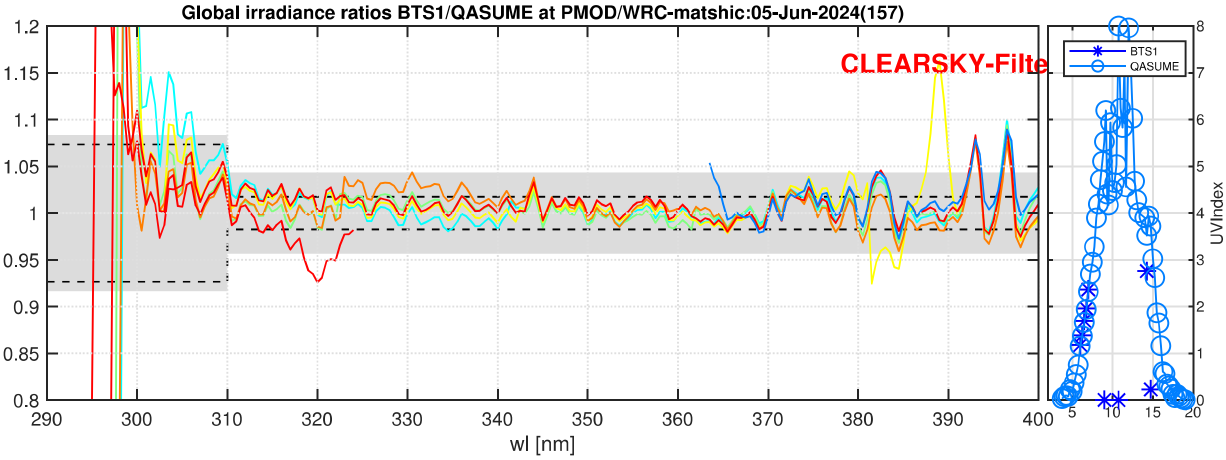

Wavelength shift
Mean
MinMax
STD
Wavelength shift /nm
Wavelength /nm
0.1
0.05
0
-0.05
-0.1
-0.15
300
310
320
330
340
350
360
370
380
390
400

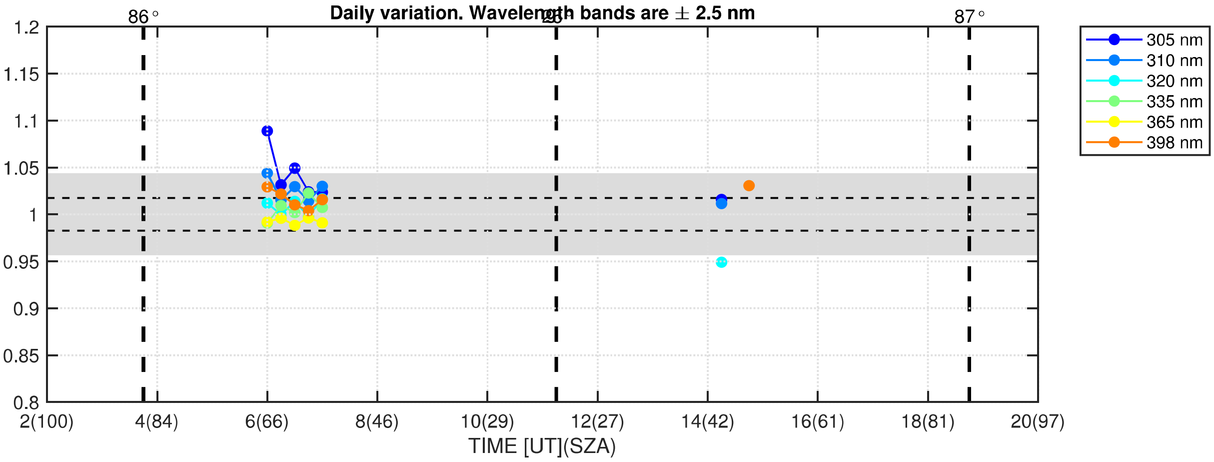

WL=335.00 nm
Wavelength shift /nm
Date & time
0.1
0.05
0
-0.05
-0.1
06/04
06/05
06/06
06/07
06/08

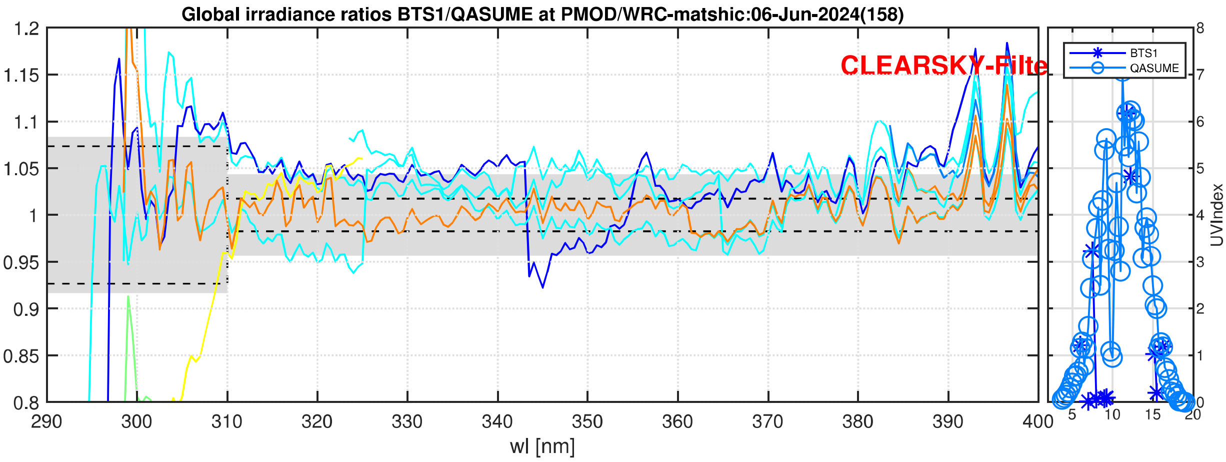

Global irradiance ratios BTS1/QASUME at PMOD/WRC-matshic:04-Jun-2024(156) to 06-Jun-2024(158)
CLEARSKY-Filtered
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
RATIO BTS1/QASUME
156
157
158
TIME [UT] ON DAYS: [156 157 158]

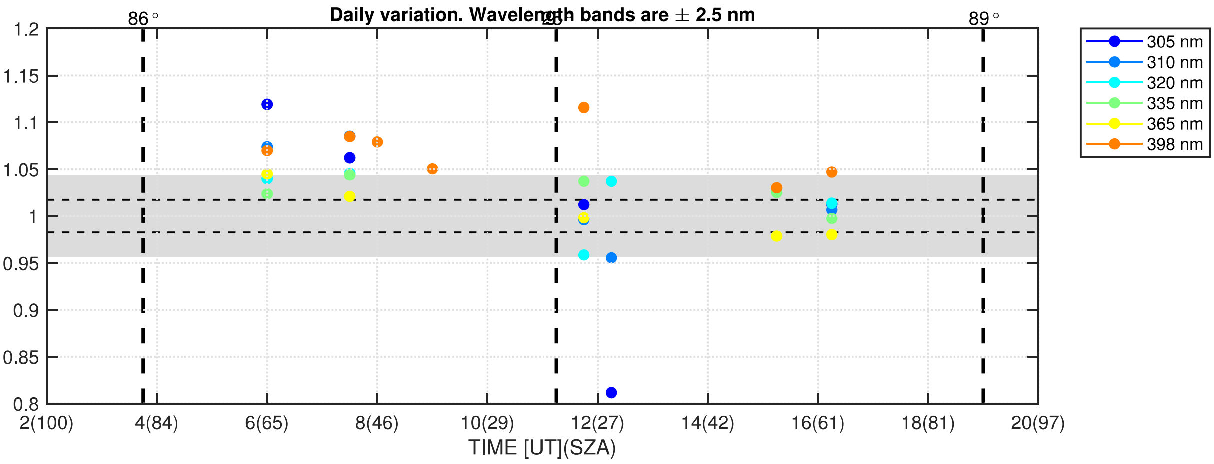

Global irradiance ratios BTS1/QASUME at PMOD/WRC-matshic:04-Jun-2024(156)
CLEARSKY-Filte
BTS1
QASUME
UVIndex
wl [nm]

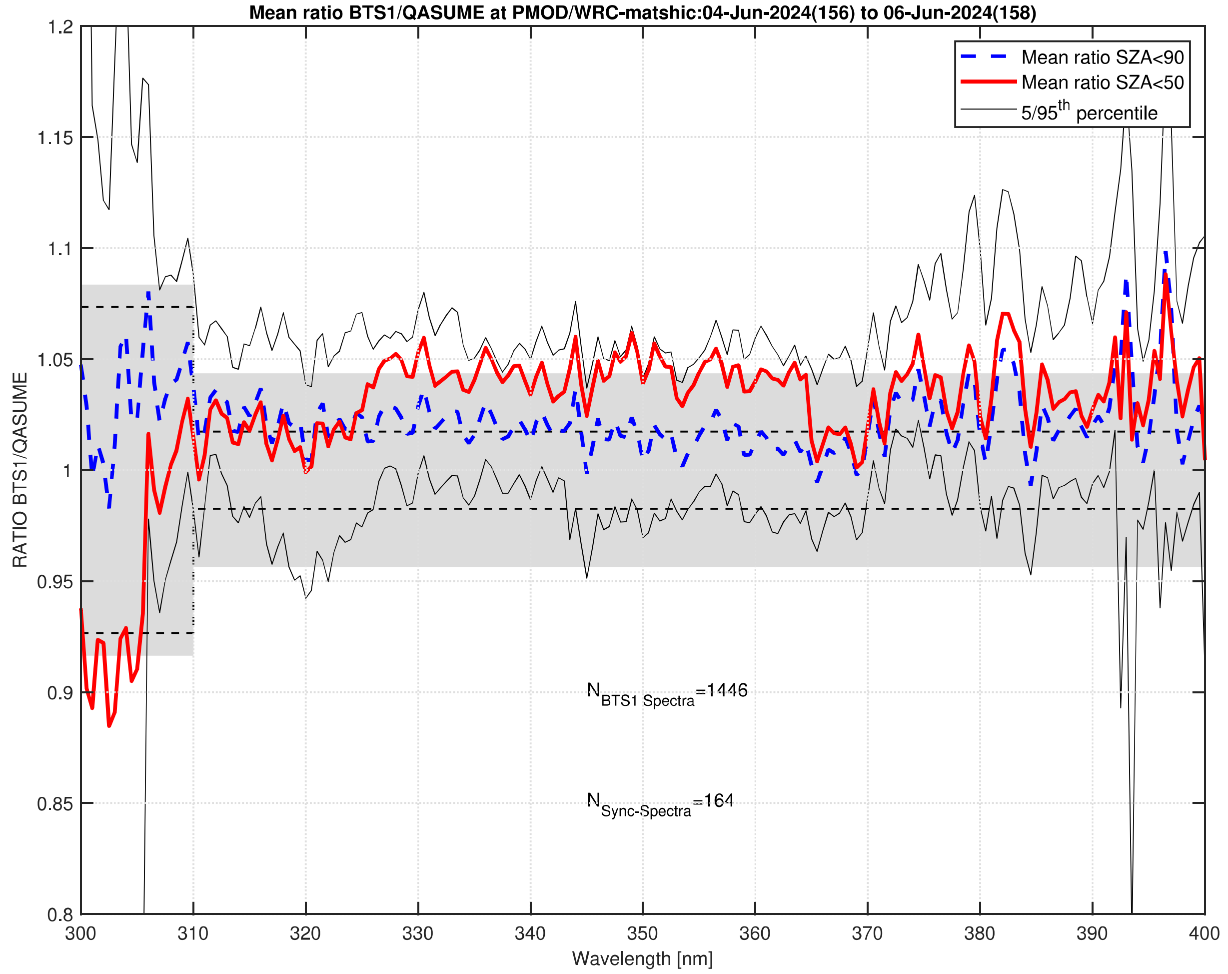

Daily variation. Wavelength bands are ± 2.5 nm
84°
87°
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
TIME [UT](SZA)

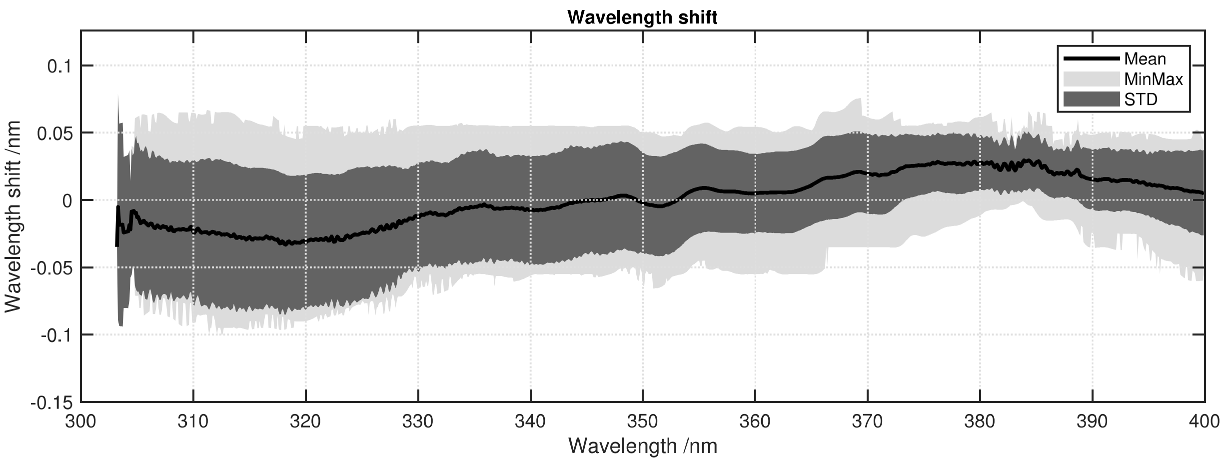

Global irradiance ratios BTS1/QASUME at PMOD/WRC-matshic:05-Jun-2024(157)
CLEARSKY-Filte
BTS1
QASUME
UVIndex
wl [nm]

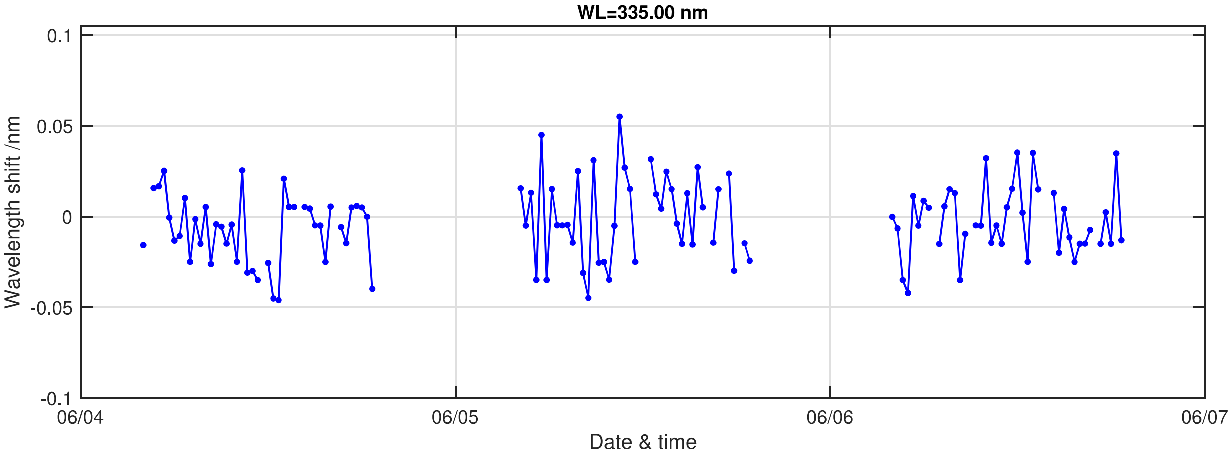

Daily variation. Wavelength bands are ± 2.5 nm
86°
87°
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
TIME [UT](SZA)

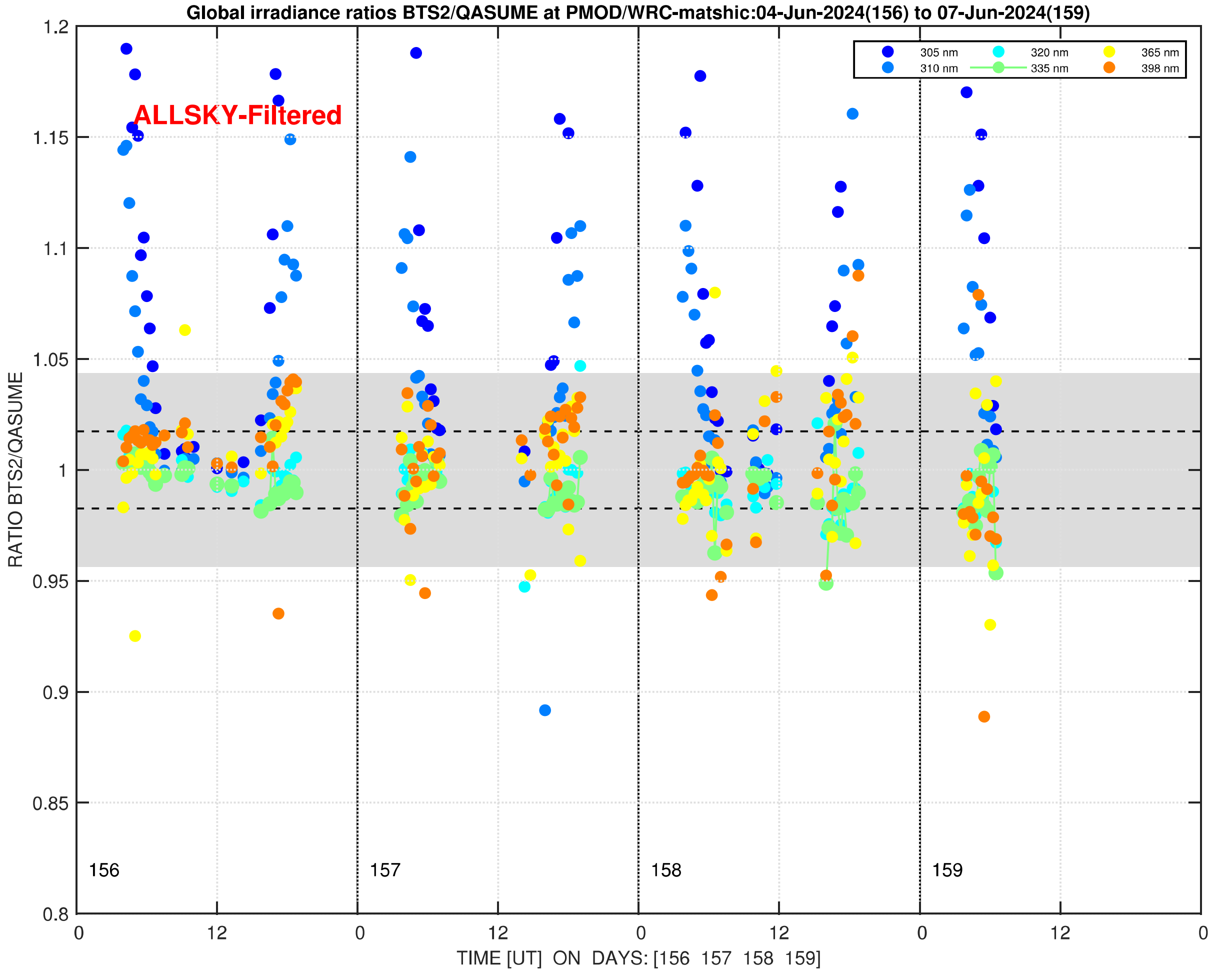

Global irradiance ratios BTS1/QASUME at PMOD/WRC-matshic:06-Jun-2024(158)
CLEARSKY-Filte
BTS1
QASUME
UVIndex
wl [nm]

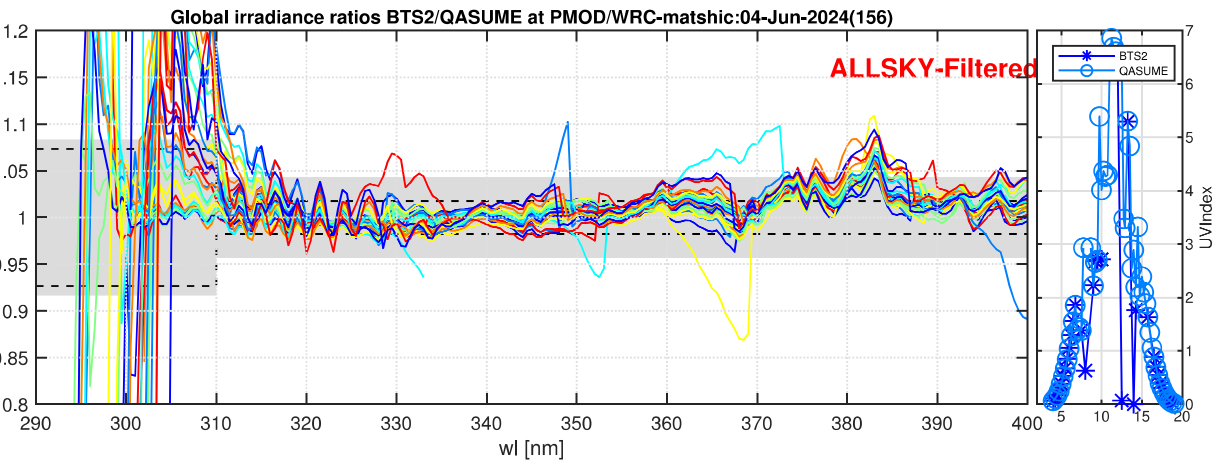

Daily variation. Wavelength bands are ± 2.5 nm
86°
89°
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
TIME [UT](SZA)

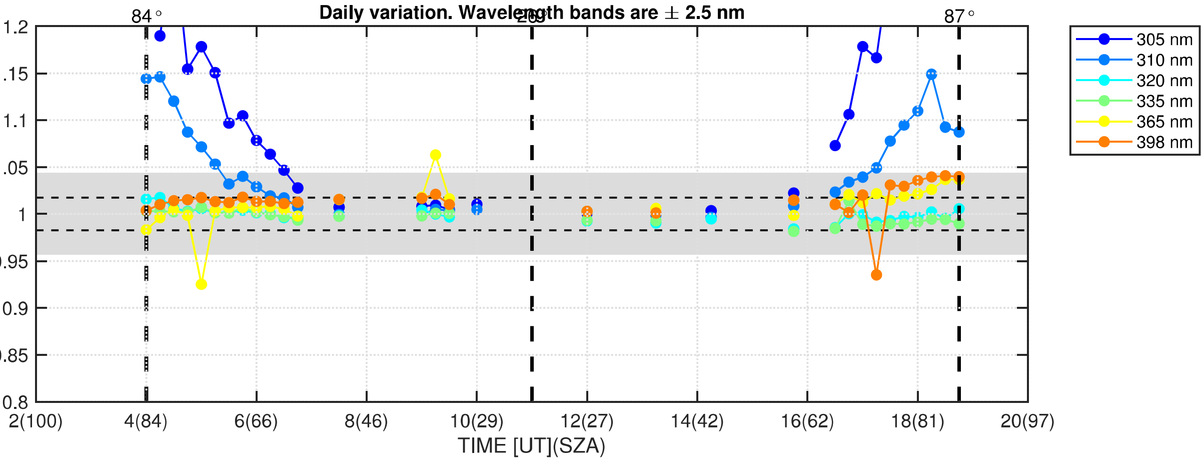

Mean ratio BTS1/QASUME at PMOD/WRC-matshic:04-Jun-2024(156) to 06-Jun-2024(158)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
RATIO BTS1/QASUME
Wavelength [nm]
N BTS1 Spectra =1446
N Sync-Spectra =164

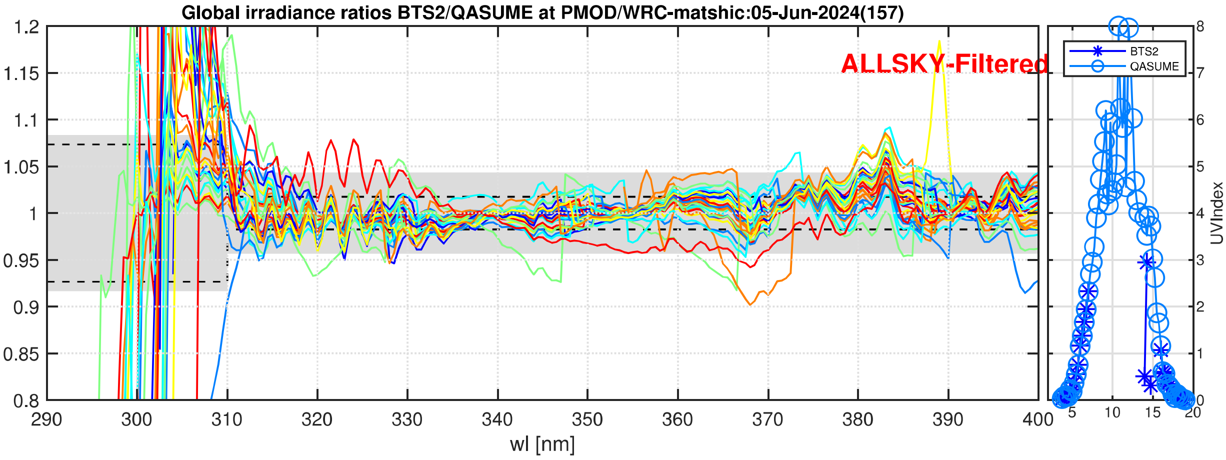

Wavelength shift
Mean
MinMax
STD
Wavelength shift /nm
Wavelength /nm

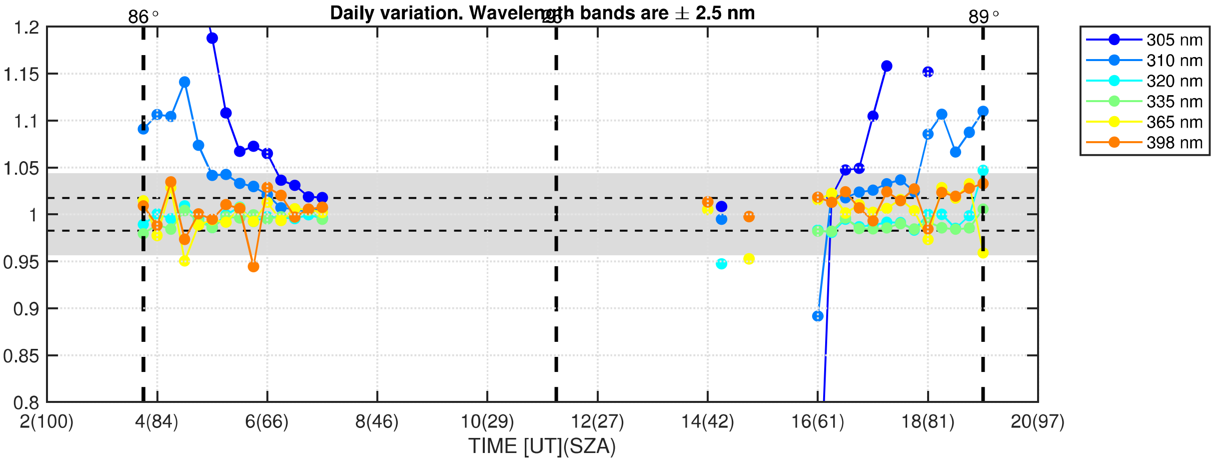

WL=335.00 nm
Wavelength shift /nm
Date & time

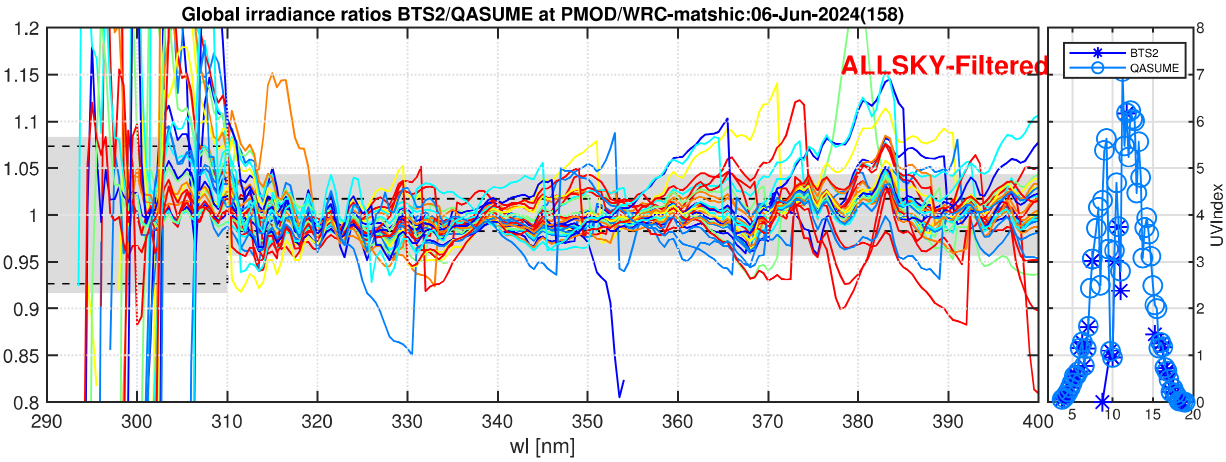

Global irradiance ratios BTS2/QASUME at PMOD/WRC-matshic:04-Jun-2024(156) to 07-Jun-2024(159)
ALLSKY-Filtered
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
RATIO BTS2/QASUME
156
157
158
159
TIME [UT] ON DAYS: [156 157 158 159]

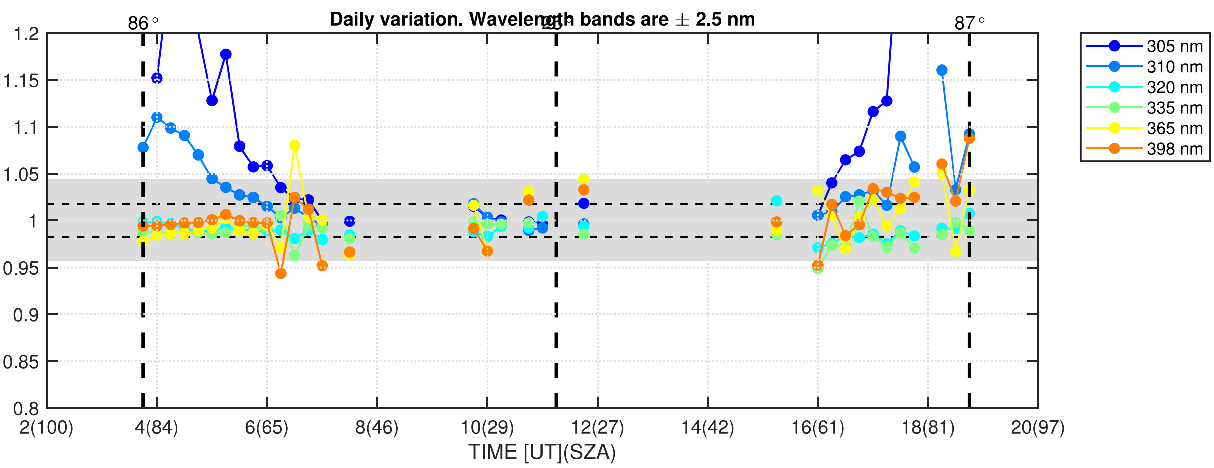

Global irradiance ratios BTS2/QASUME at PMOD/WRC-matshic:04-Jun-2024(156)
ALLSKY-Filtered
BTS2
QASUME
UVIndex
wl [nm]

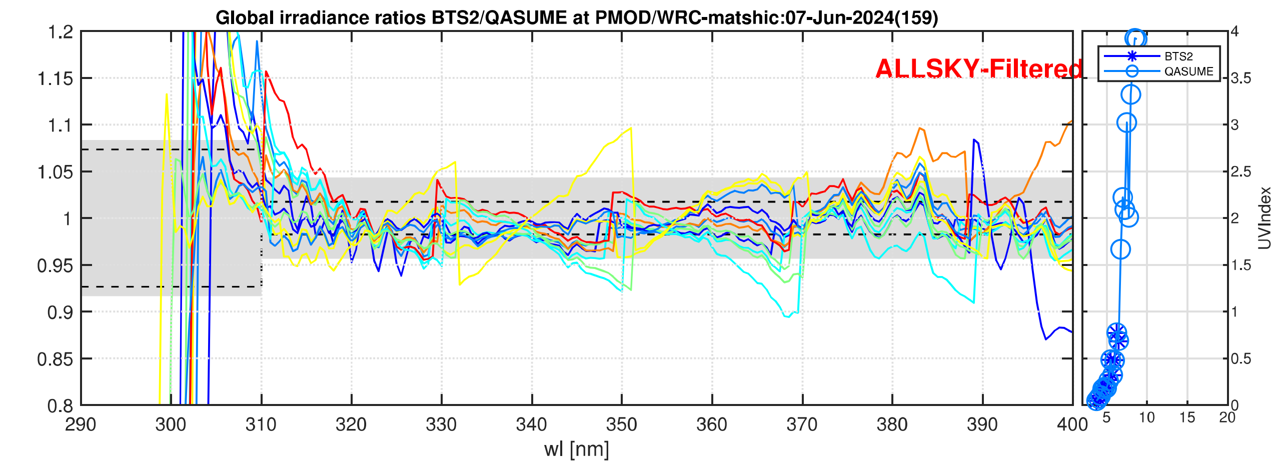

Daily variation. Wavelength bands are ± 2.5 nm
84°
87°
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
TIME [UT](SZA)


Global irradiance ratios BTS2/QASUME at PMOD/WRC-matshic:05-Jun-2024(157)
ALLSKY-Filtered
wl [nm]
BTS2
QASUME
UVIndex

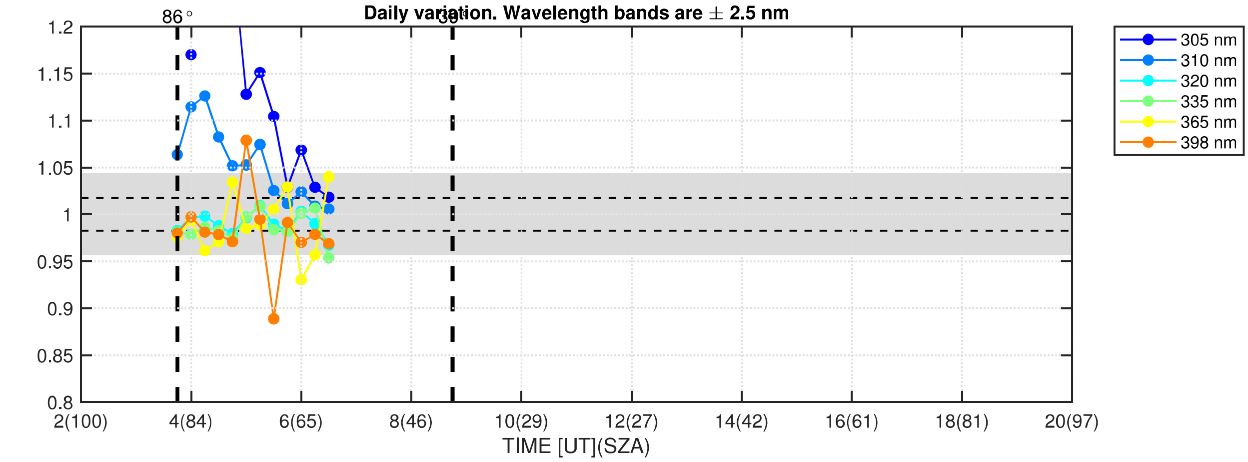

Daily variation. Wavelength bands are ± 2.5 nm
86°
89°
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
TIME [UT](SZA)


Global irradiance ratios BTS2/QASUME at PMOD/WRC-matshic:06-Jun-2024(158)
ALLSKY-Filtered
wl [nm]
BTS2
QASUME
UVIndex

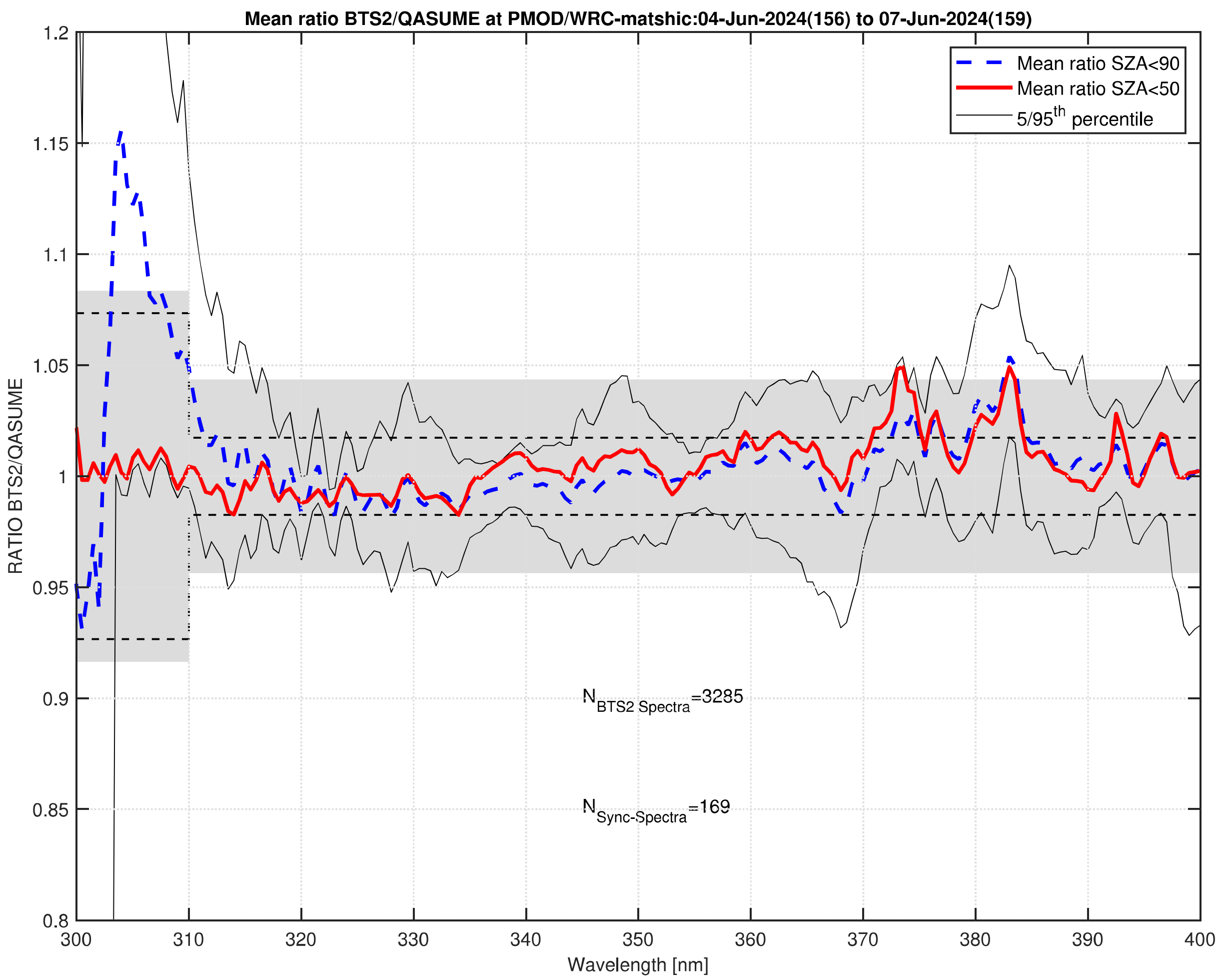

Daily variation. Wavelength bands are ± 2.5 nm
86°
87°
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
TIME [UT](SZA)



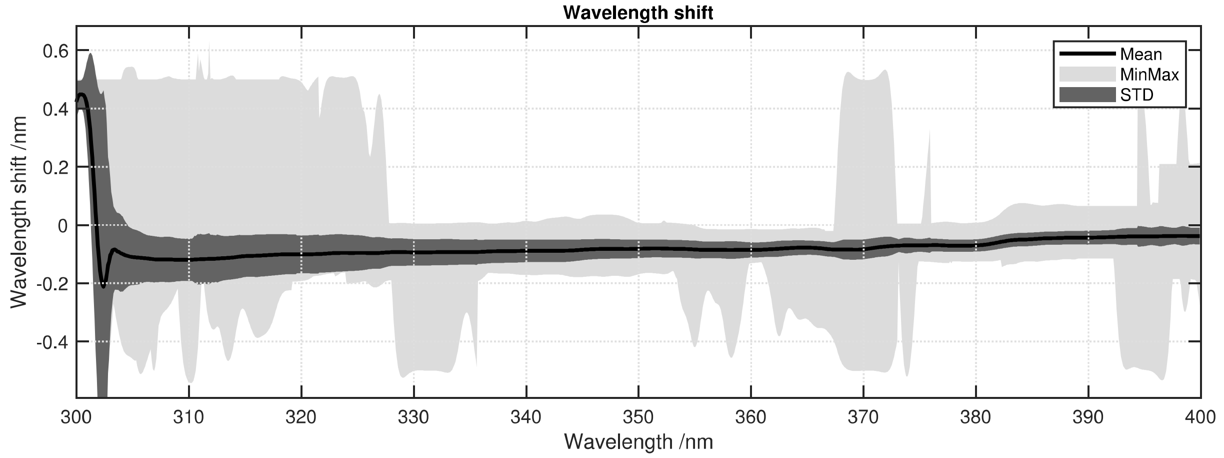
Global irradiance ratios BTS2/QASUME at PMOD/WRC-matshic:07-Jun-2024(159)
ALLSKY-Filtered
wl [nm]
BTS2
QASUME
UVIndex

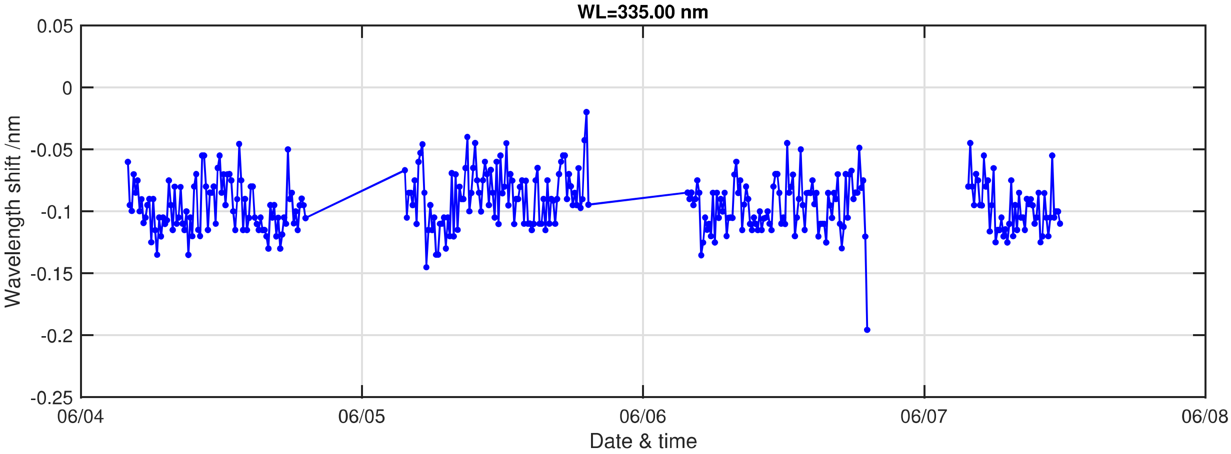


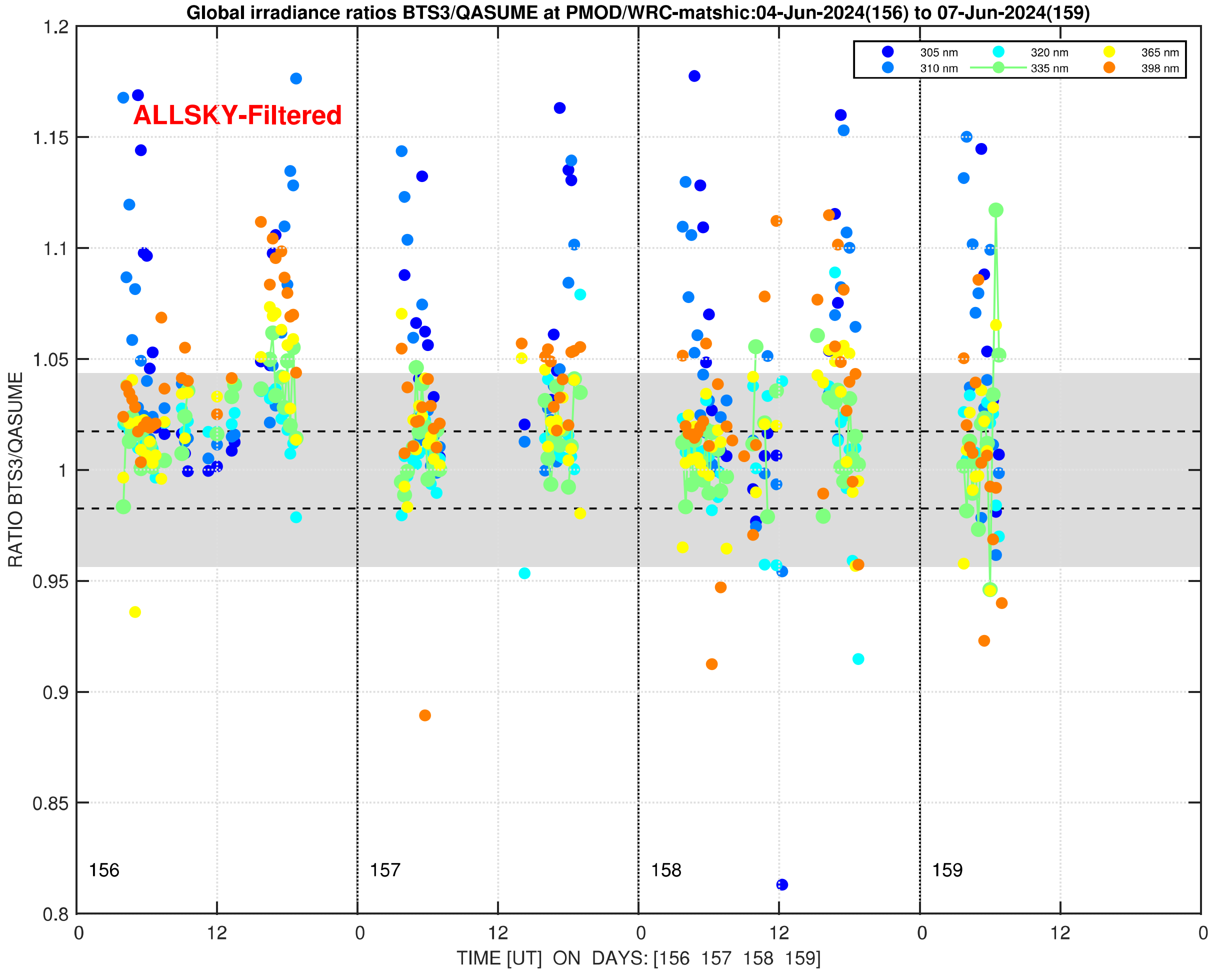
Daily variation. Wavelength bands are ± 2.5 nm
86°
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
TIME [UT](SZA)

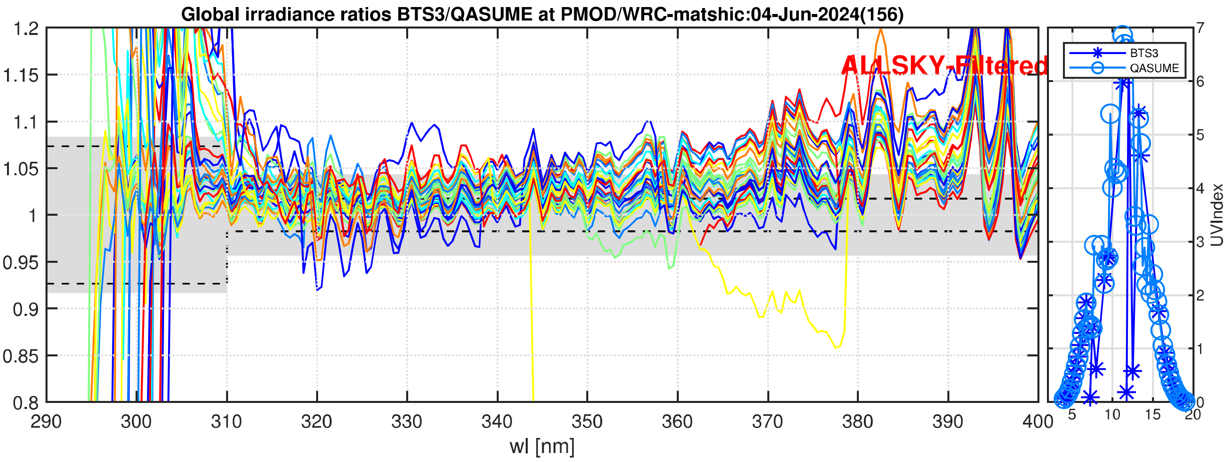


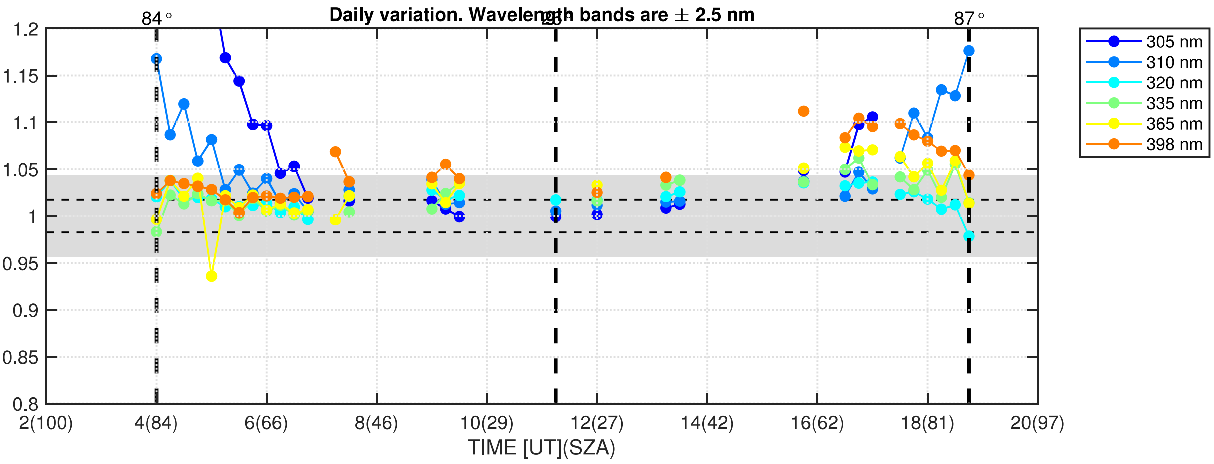
Mean ratio BTS2/QASUME at PMOD/WRC-matshic:04-Jun-2024(156) to 07-Jun-2024(159)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
RATIO BTS2/QASUME
N BTS2 Spectra =3285
N Sync-Spectra =169
Wavelength [nm]

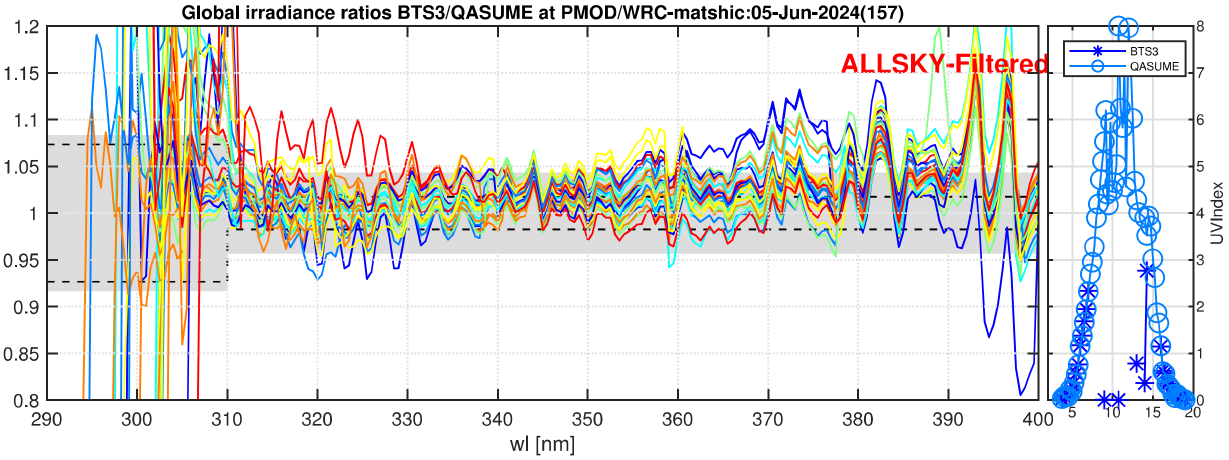

Wavelength shift
Mean
MinMax
STD
Wavelength shift /nm
0.6
0.4
0.2
0
-0.2
-0.4
300
310
320
330
340
350
360
370
380
390
400
Wavelength /nm

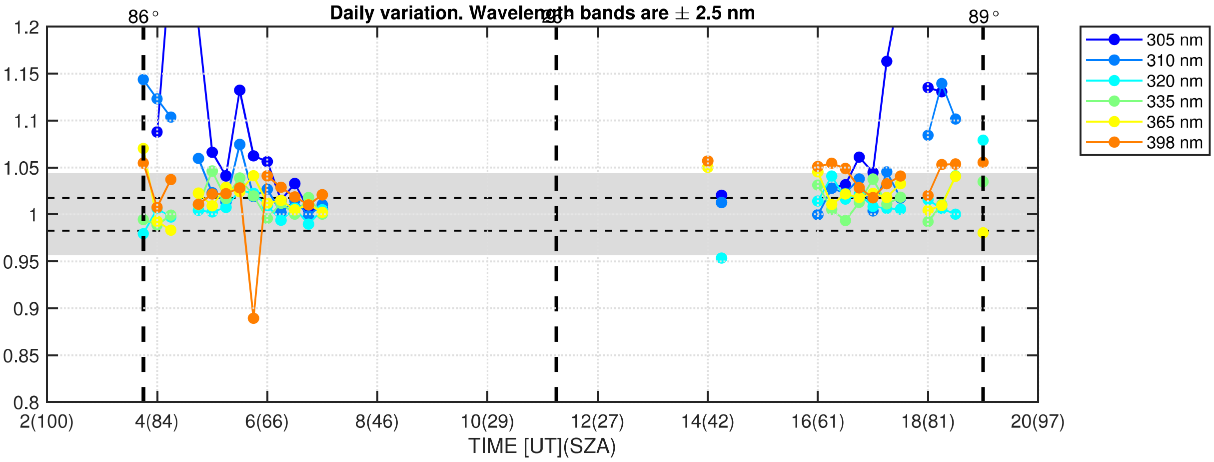

WL=335.00 nm
Wavelength shift /nm
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
06/04
06/05
06/06
06/07
06/08
Date & time

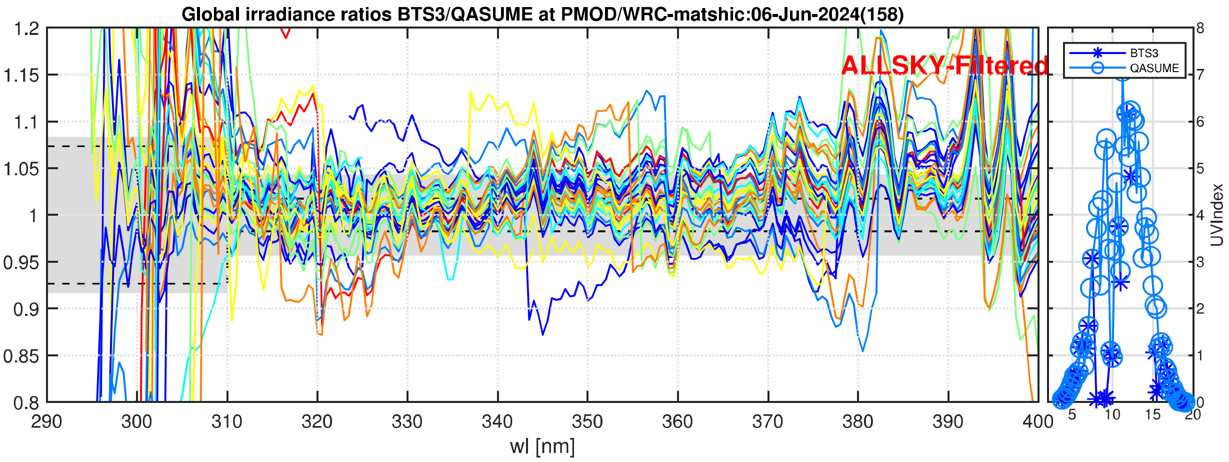

Global irradiance ratios BTS3/QASUME at PMOD/WRC-matshic:04-Jun-2024(156) to 07-Jun-2024(159)
ALLSKY-Filtered
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
RATIO BTS3/QASUME
156
157
158
159
TIME [UT] ON DAYS: [156 157 158 159]

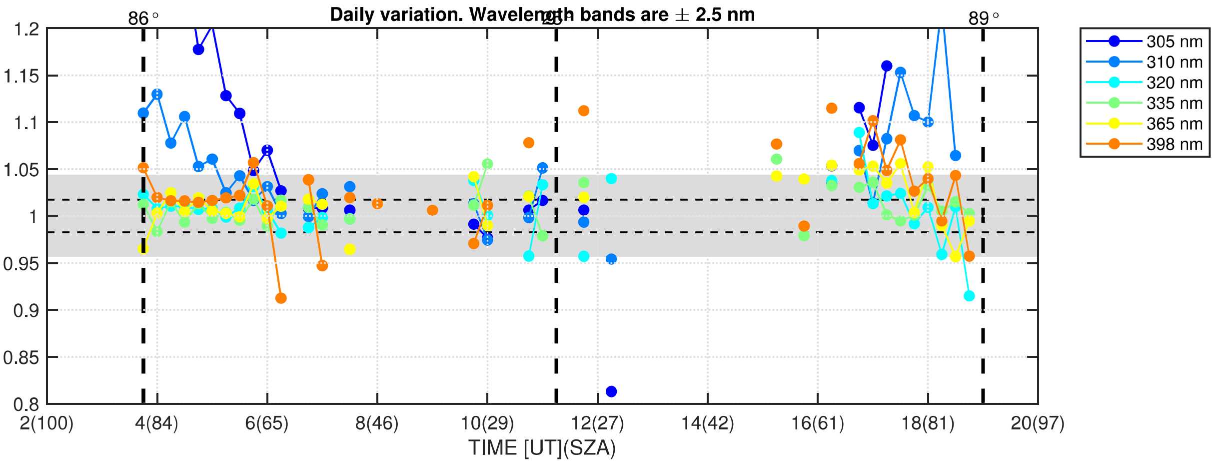

Global irradiance ratios BTS3/QASUME at PMOD/WRC-matshic:04-Jun-2024(156)
ALLSKY-Filtered
wl [nm]
BTS3
QASUME
UVIndex

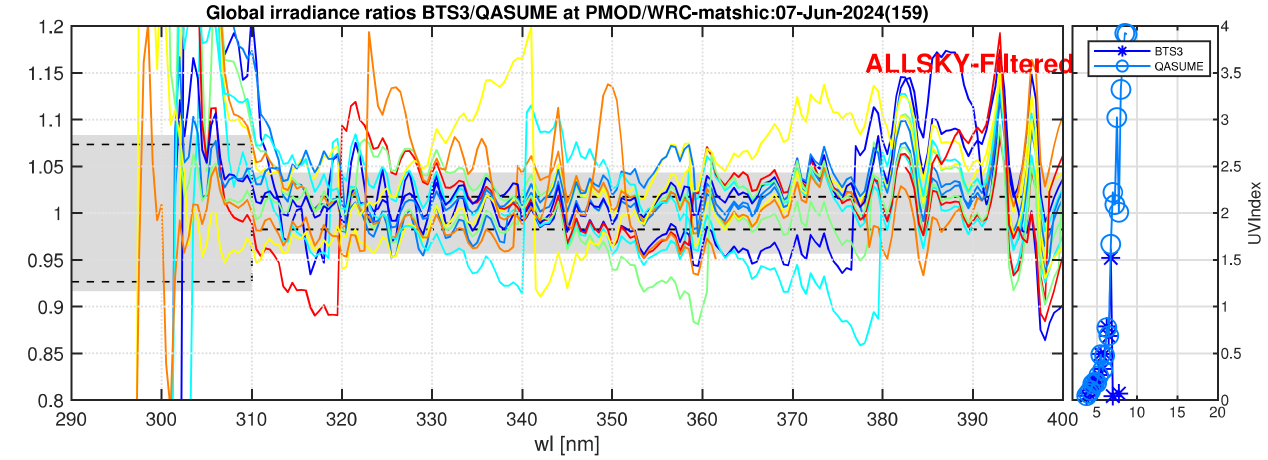

Daily variation. Wavelength bands are ± 2.5 nm
84°
87°
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
TIME [UT](SZA)

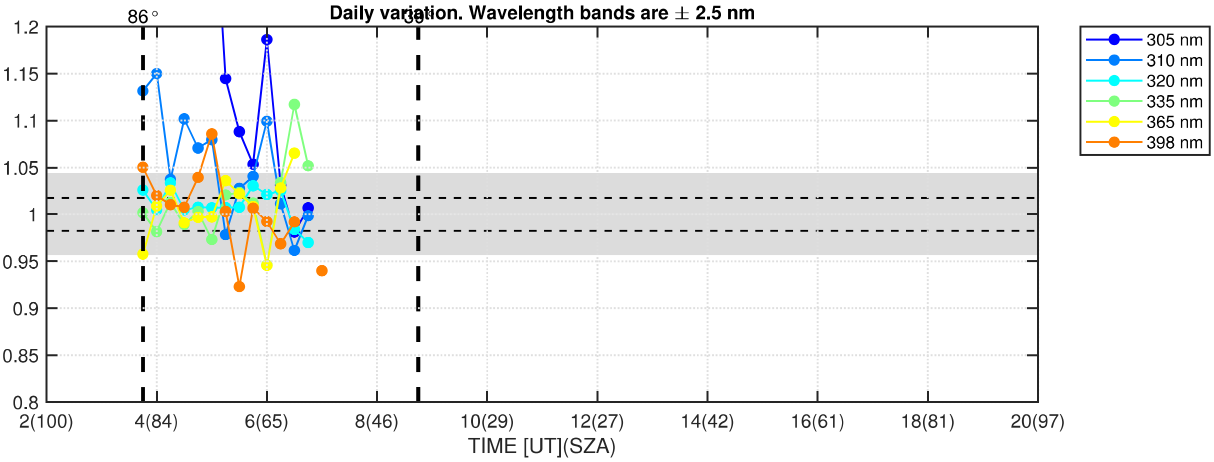

Global irradiance ratios BTS3/QASUME at PMOD/WRC-matshic:05-Jun-2024(157)
ALLSKY-Filtered
BTS3
QASUME
UVIndex
wl [nm]

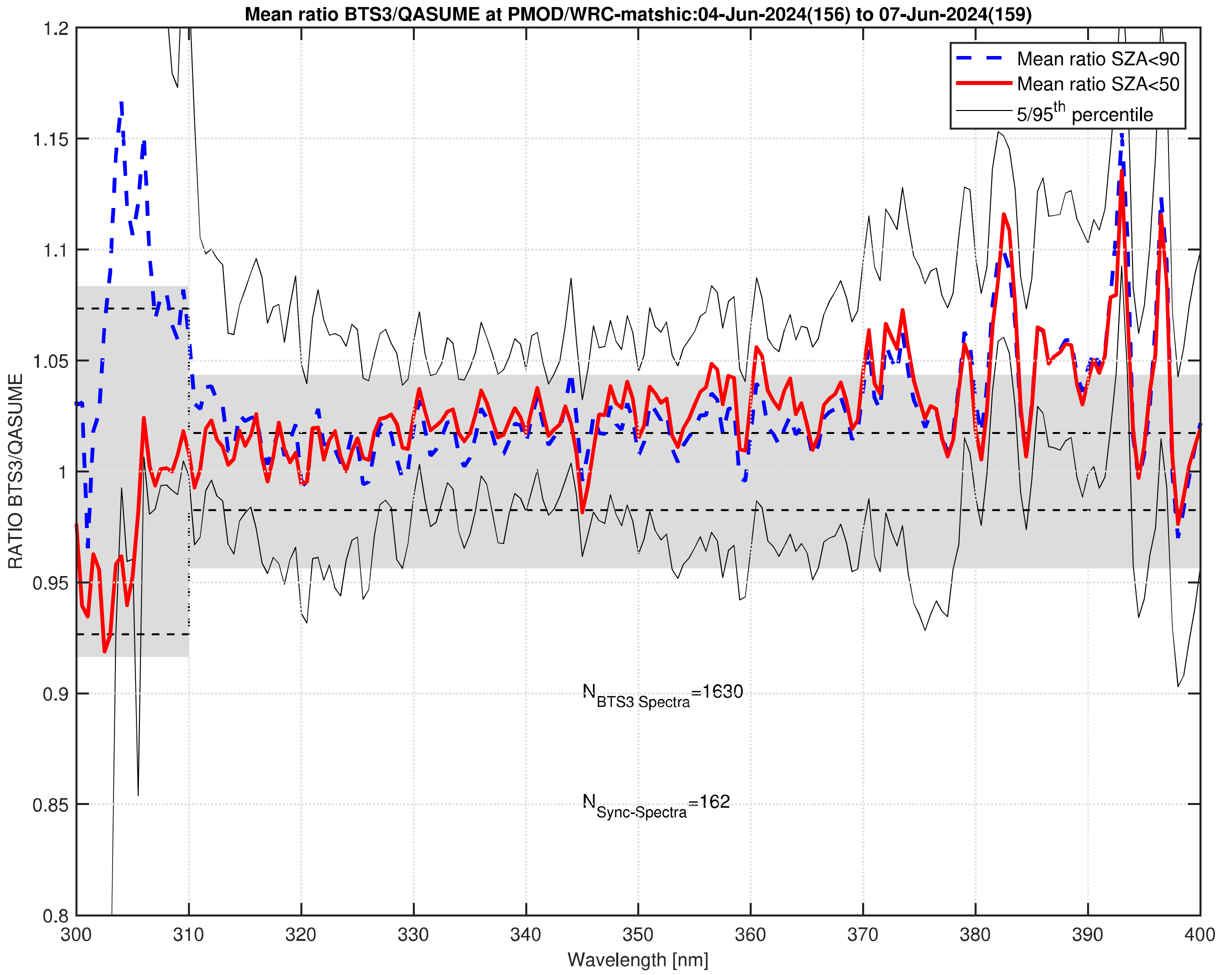

Daily variation. Wavelength bands are ± 2.5 nm
86°
89°
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
TIME [UT](SZA)

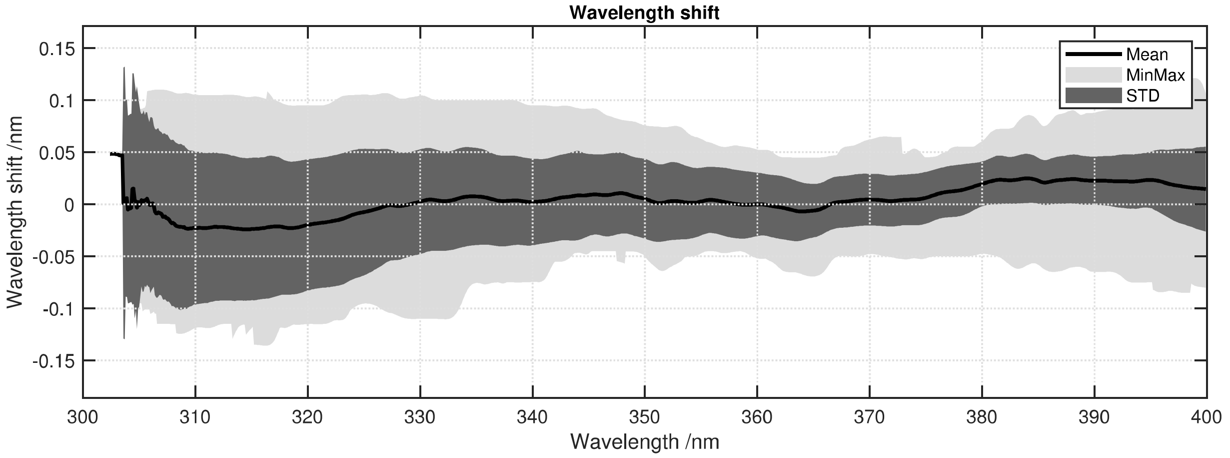

Global irradiance ratios BTS3/QASUME at PMOD/WRC-matshic:06-Jun-2024(158)
ALLSKY-Filtered
BTS3
QASUME
UVIndex
wl [nm]

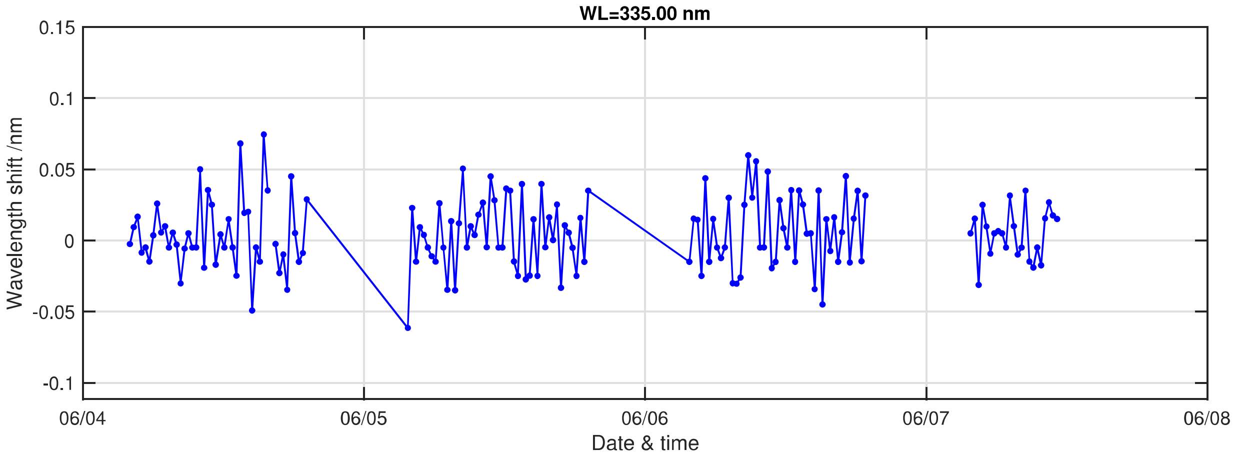

Daily variation. Wavelength bands are ± 2.5 nm
86°
89°
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
TIME [UT](SZA)

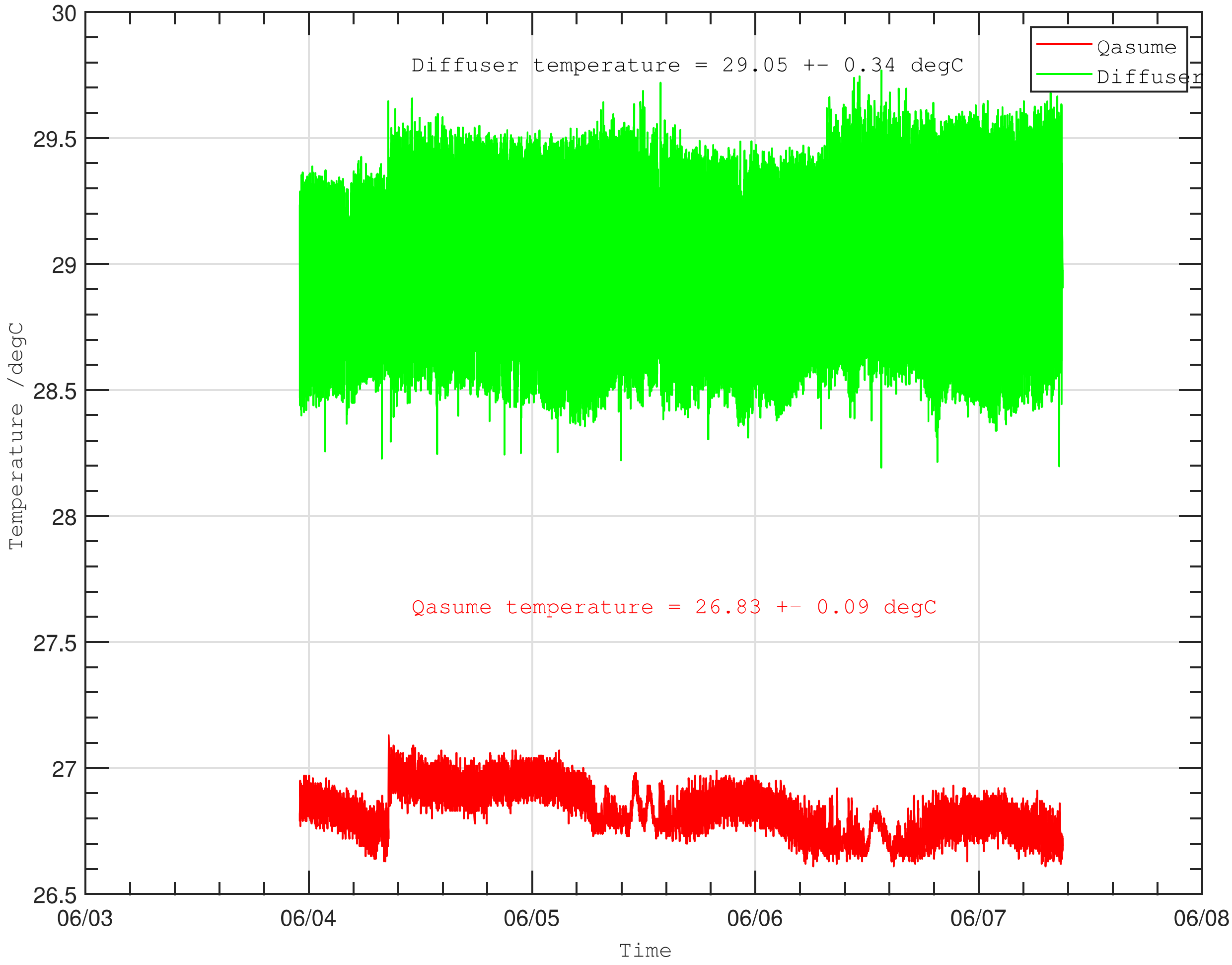

Global irradiance ratios BTS3/QASUME at PMOD/WRC-matshic:07-Jun-2024(159)
ALLSKY-Filtered
BTS3
QASUME
UVIndex
wl [nm]

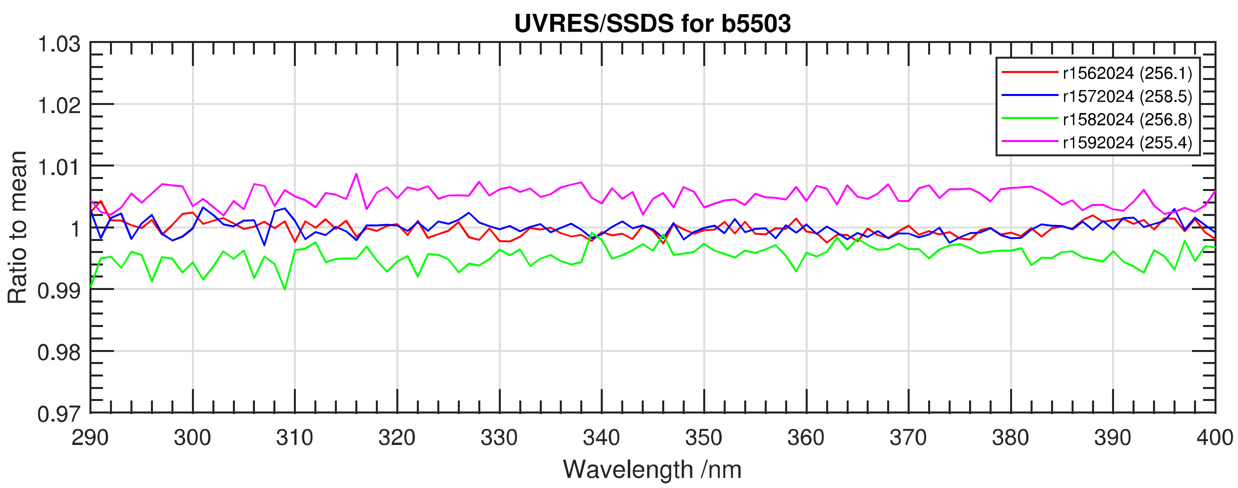

Daily variation. Wavelength bands are ± 2.5 nm
86°
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
TIME [UT](SZA)

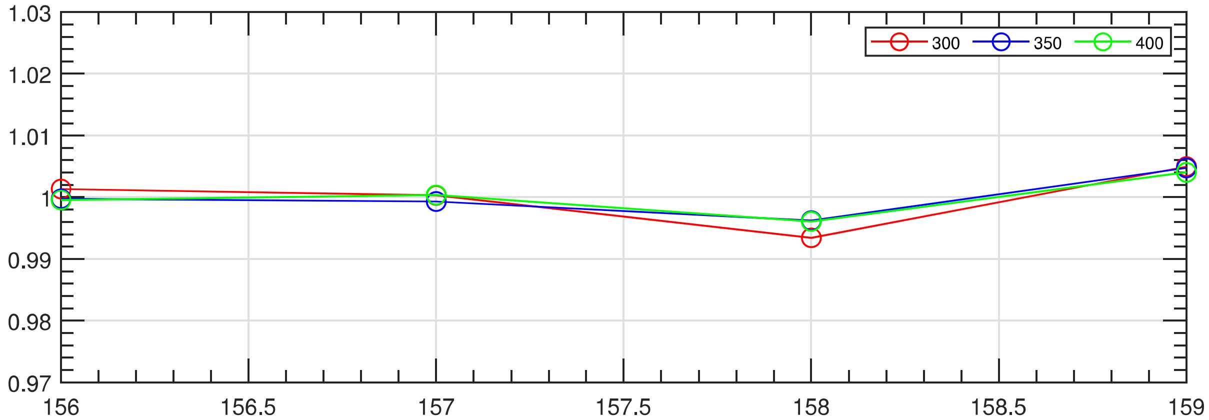

Mean ratio BTS3/QASUME at PMOD/WRC-matshic:04-Jun-2024(156) to 07-Jun-2024(159)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
RATIO BTS3/QASUME
N BTS3 Spectra =1630
N Sync-Spectra =162
Wavelength [nm]


Wavelength shift
Mean
MinMax
STD
Wavelength shift /nm
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
0.15
0.1
0.05
0
-0.05
-0.1
06/04
06/05
06/06
06/07
06/08
Date & time


Diffuser temperature = 29.05 +- 0.34 degC
Qasume temperature = 26.83 +- 0.09 degC
Qasume
Diffuser
Temperature /degC
Time
30
29.5
29
28.5
28
27.5
27
26.5
06/03
06/04
06/05
06/06
06/07
06/08


UVRES/SSDS for b5503
r1562024 (256.1)
r1572024 (258.5)
r1582024 (256.8)
r1592024 (255.4)
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
156
156.5
157
157.5
158
158.5
159


BTS1
BTS2
BTS3
Qasume