Protocol of the intercomparison at DWD, Lindenberg, Germany on May 29 to June 2, 2024 with the travelling reference spectroradiometer QASUME from PMOD/WRC

Report prepared by Gregor Hülsen

Operator: Gregor Hülsen
Local operator: Lionel Doppler, Steffen Gross

The purpose of the visit was the comparison of global solar irradiance measurements between the Bentham DM300 (BL1), the two BTS spectroradiometers (LI1 and LD1) and the Brewer #118 spectrophotometer, operated by the Deutscher Wetter Dienst (DWD) and the travel reference spectroradiometer QASUME. The measurement site is located at Lindenberg: Latitude 52.21 N, Longitude 14.12 E and altitude 126 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 DWD-Lindenberg in the afternoon of May 29, 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 is a DM300 double monochromator. The BTS LI1 and LD1 are BTS2048 (SN: 43983 and 43984). LI1 is used for global whereas LD1 for direct solar irradiance measurements. For this campaign LD1 was also measuring global solar irradiance. Brewer 118 is a Mk-III double monochromator and has also been compared to QASUME in 2004.
The intercomparison between QASUME and the local spectroradiometers lasted 4 days, from the morning of May 30 to the afternoon of June 2nd.

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 20 minutes from 290 nm to 450 nm, every 0.5 nm, and 3.0 seconds between each wavelength increment. QASUME recorded the spectra in 20 min intervals with 0.25 nm increments from 290 nm to 450 nm.

DOY	Date	DAY	Weather	Comment (times are in UT)
150	29-May	Wednesday	Mix of sun and clouds (Cu) Rainshowers througout the day	Installed at 13:30 14:00 start UV measurements 16:29 Calibration T68523
151	30-May	Thursday	Mix of sun and clouds (Cu) Rainshowers througout the day	9:00 First synchronized scans 9:22 Calibration T68523
152	31-May	Friday	Mix of sun and clouds (Cu) Rain in the night	12:18 Calibration T68523 12:40 Calibration T61251
153	01-Jun	Saturday	Clear sky in the morning Mix of sun and clouds (Cu)	8:37 Calibration T68523
154	02-Jun	Sunday	Mix of sun & clouds Start to rain after 12:00	6:49 Calibration T68523 7:10 Calibration T157824 12:00 End of Campaign

Results:

In total 101 (BL1), 18 (118) and 91-95 (BTS) synchronised simultaneous spectra from QASUME and the local instruments are available from the measurement period. Measurements between 2:00 and 22:00 UT have been analysed (SZA smaller than 90°).

Conclusions:

A) BL1:

1. The average spectral ratio between BL1 and QASUME is on average at unity, but a pronounced spectral variability was found:
    a. For wavelengths shorter than 310 nm the BL1 underestimated the solar irradiance by more than 20%.
    b. Between 310 nm to 380 nm the ratio of BL1 to Qasume is on average +3%.
    c. For wavelengths longer than 380 nm the ratio is around -3%
2. The temporal variation of the spectra between BL1 and QASUME shows a cosine error on the clear sky morning on the 1st June with diurnal variations larger than 5% for wavelength above 400 nm.
3. The wavelength shifts of BL1 relative to the high spectral resolution solar spectrum the QASUMEFTS are between -0.9 nm and +0.6 nm pm in the spectral range 290 nm to 450 nm. The spectral shape of the shifts is typical for an uncorrected DM300.

B) LD1 and LI1 BTS:

1. The average spectral ratio between both BTS and QASUME is around +8%.
2. The temporal variation of the spectra between BTS and QASUME was stable, with variations less than 2% during the whole campaign. For LI1 a variability of more than 4 % was found on the clear sky morning on the 1st June. No suitable data is available for LD1 on this day.
3. The wavelength shifts of LD1 relative to the high spectral resolution solar spectrum are between -50 pm and +50 pm in the spectral range 290 nm to 420 nm. For LI1 the shifts are between -10 pm and +200 pm.

C) Brewer #118:

4. The average spectral ratio between Brewer 118 and QASUME is +7%.
5. The temporal variation of the spectra between 118 and QASUME was stable, with variations less than 2% during the whole campaign. No cosine error was detected because of the limited amount of data and cloudy weather conditions.
6. The wavelength shifts of 118 relative to the high spectral resolution solar spectrum are between -50 pm and 0 pm in the spectral range 290 to 363 nm.

Comparison to previous QASUME site visits

The long-term stability could be assessed by comparing QASUME site visits performed in 2004 and 2024 for Brewer 118.

As seen in figure 1 the campaign average ratio of 118 to QASUME are within ±4 % since 2004. The measurements in 2004 were lower than QASUME with -5 %.

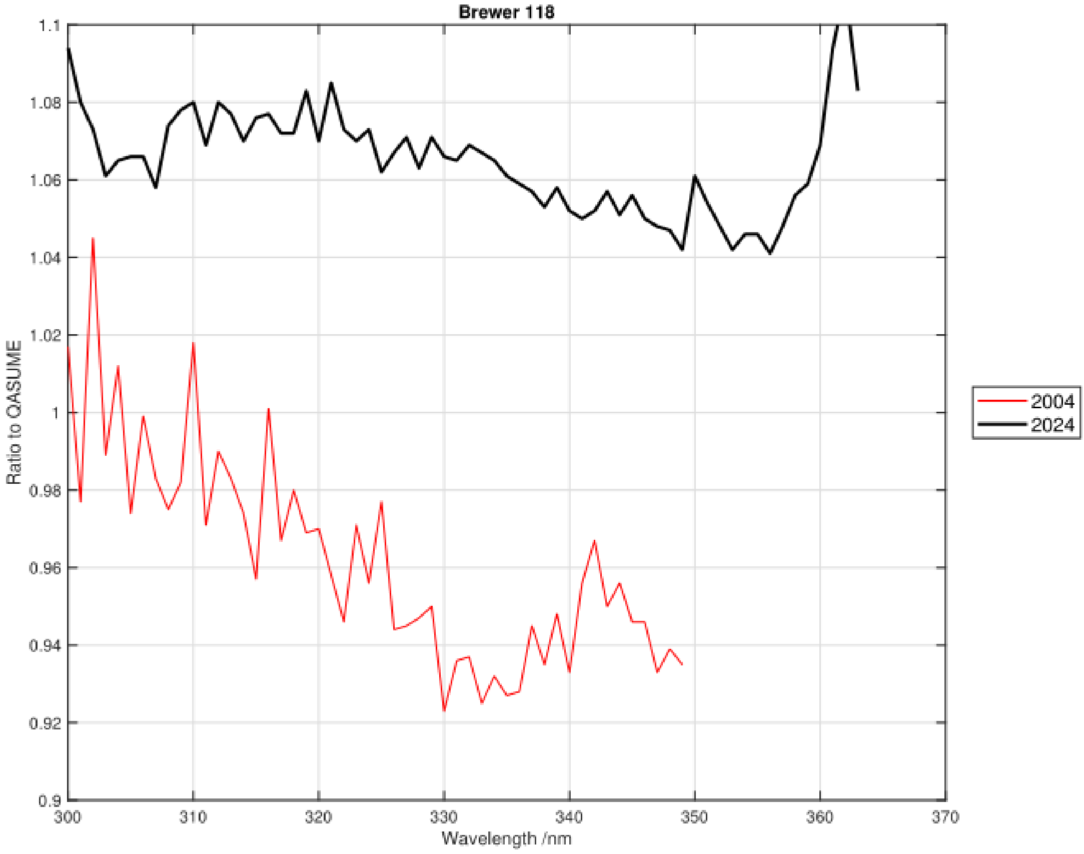


Figure 1: Solar spectral ratios of Brewer 118 to QASUME averaged over each QASUME site visit

Recommendations

The audit revealed a significant number of the UV measurements performed at DWD being out of the expected measurement uncertainty. The following points should be investigated in more detail:

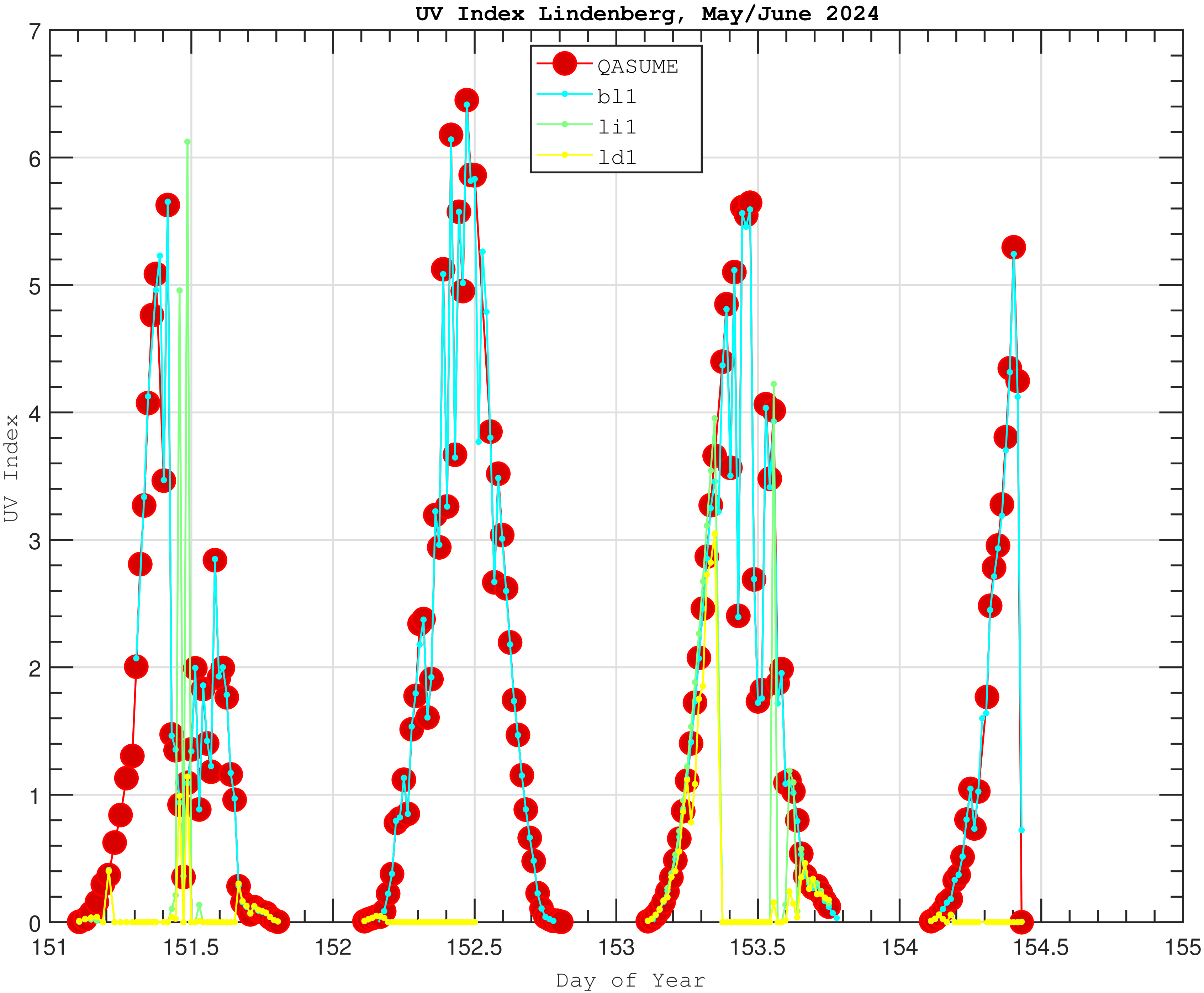
1.) The absolute irradiance scale is based on a single 1000 W irradiance standard. A comparison of this lamp to the large existing FEL Lamps calibrated by PTB at DWD would show potential degradation of individual lamps.
2.) The transfer from the 1000 W FEL lamp to the portable working lamps is done using an Optronics spectroradiometer with an entrance optic different to the one used by the Bentham DM300. In addition, it suffers from low intensity especially in the UVB wavelength range. This is likely to be the source of the low solar irradiance ratios in the UVB relative to Qasume for the BL1.
    a. One suggestion is to increase the sensitivity of the system by using an optical fiber light guide with more individual fibers or one single fiber with a larger diameter to increase the throughput of the system.
    b. Usages of an entrance optic for the transfer instrument with an identical reference plane to BL1.
    c. A full validation of the transfer procedure can be carried out using the Bentham DM300 as transfer instrument, instead of the Optronic spectroradiometer.
3.) The wavelength shift of the BL1 is larger than expected. It shows a typical periodic misalignment for a DM300. A higher polynomial dispersion relation could be derived from spectral emission lamps (Hg, Cd, Zn)
4.) The software in use for the operational spectroradiometers seems to be unsuitable for laboratory characterisations of the instruments. An update or use of other control algorithms (BenWin, custom Matlab code, etc.) would be advantageous.
5.) The measurements of both BTS spectroradiometers overestimate the solar irradiance more than expected for those types of instruments. A recalibration could improve the observed offset to QASUME.
6.) 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 Lindenberg most measurements were affected by moving clouds and rain. A follow up audit with more stable conditions is suggested.
7.) 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 spectroradiometer is 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 DWD.
8.) For the BTS only outdated slit functions are available. Those should be acquired at least before the next intercomparison.
9.) The angular responsivity of the spectroradiometers should be determined especially for the Brewer 118 and the Bentham BL1.

<u>Comments from the operator</u>:

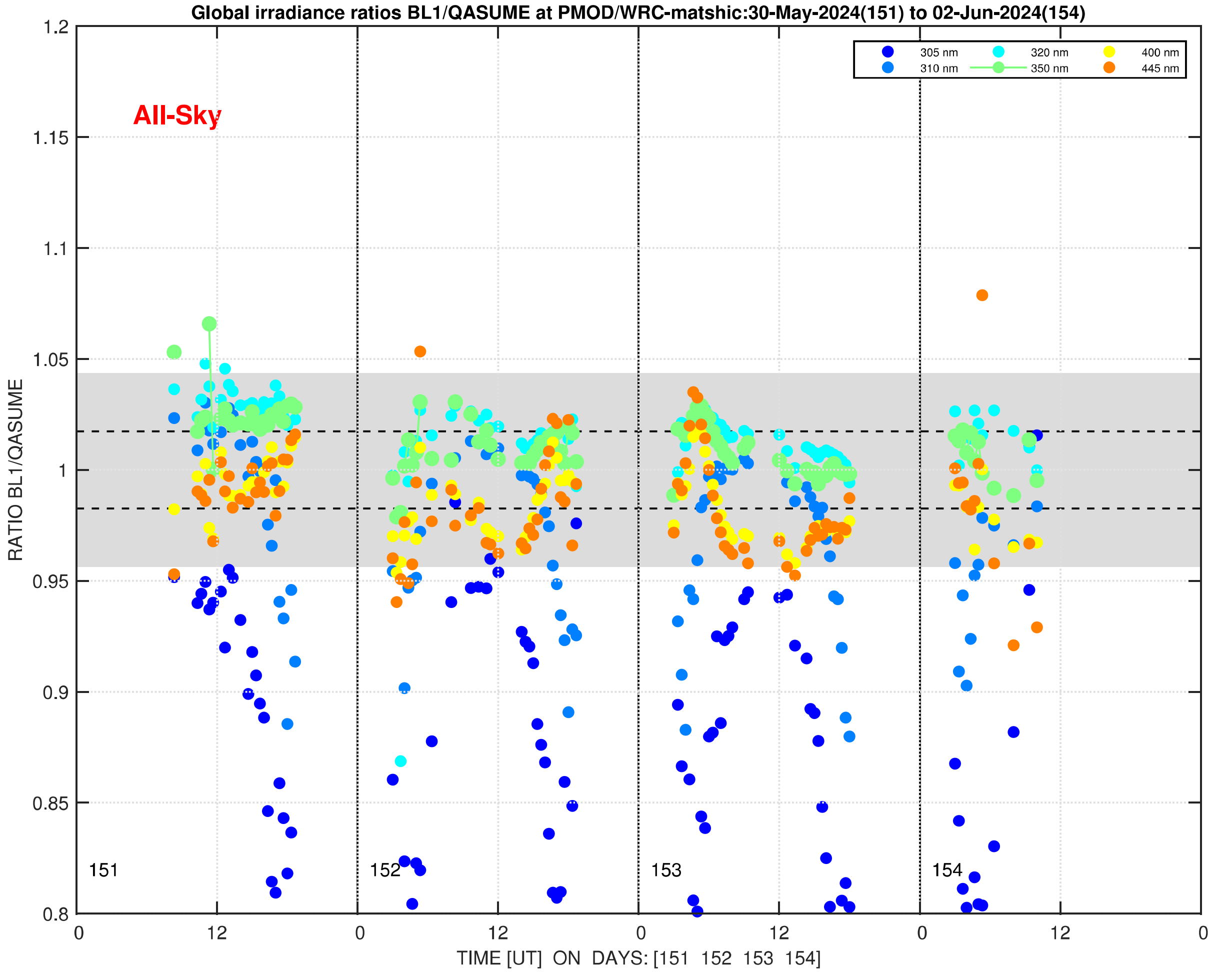
none

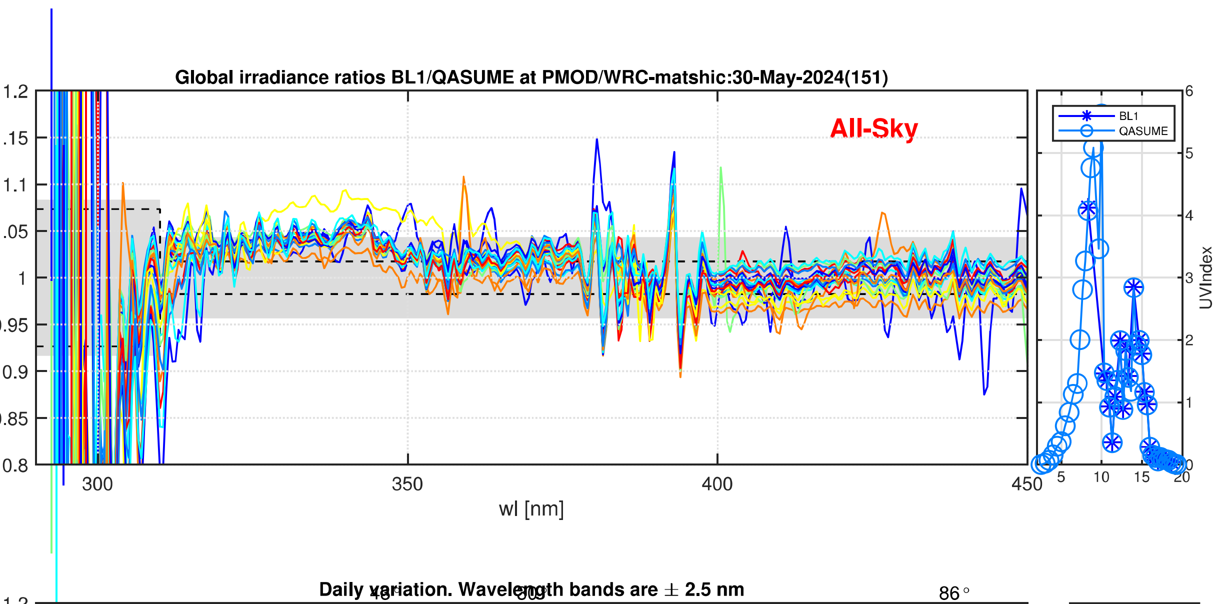
Appendix

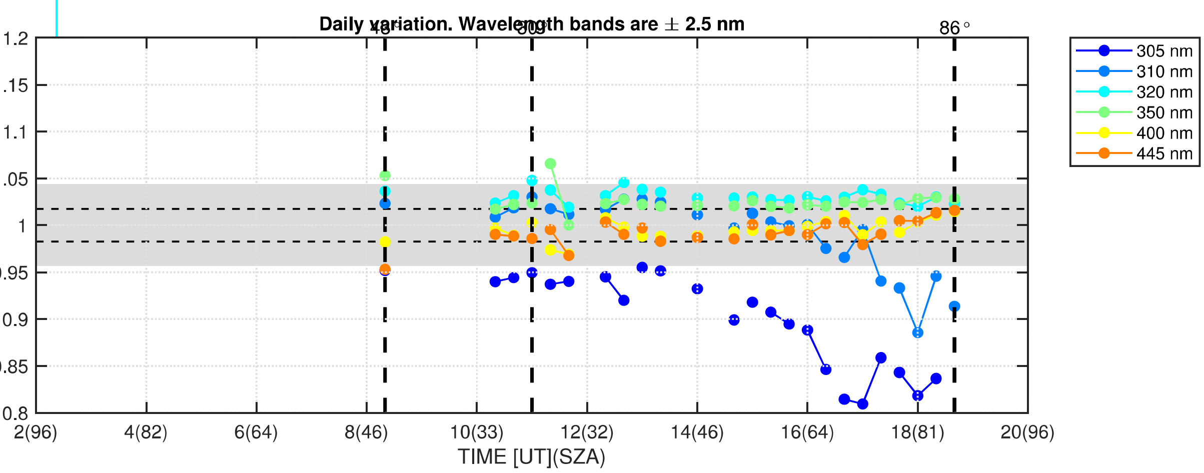
Detailed results for all local spectrophotometers with respect to the reference spectroradiometer QASUME

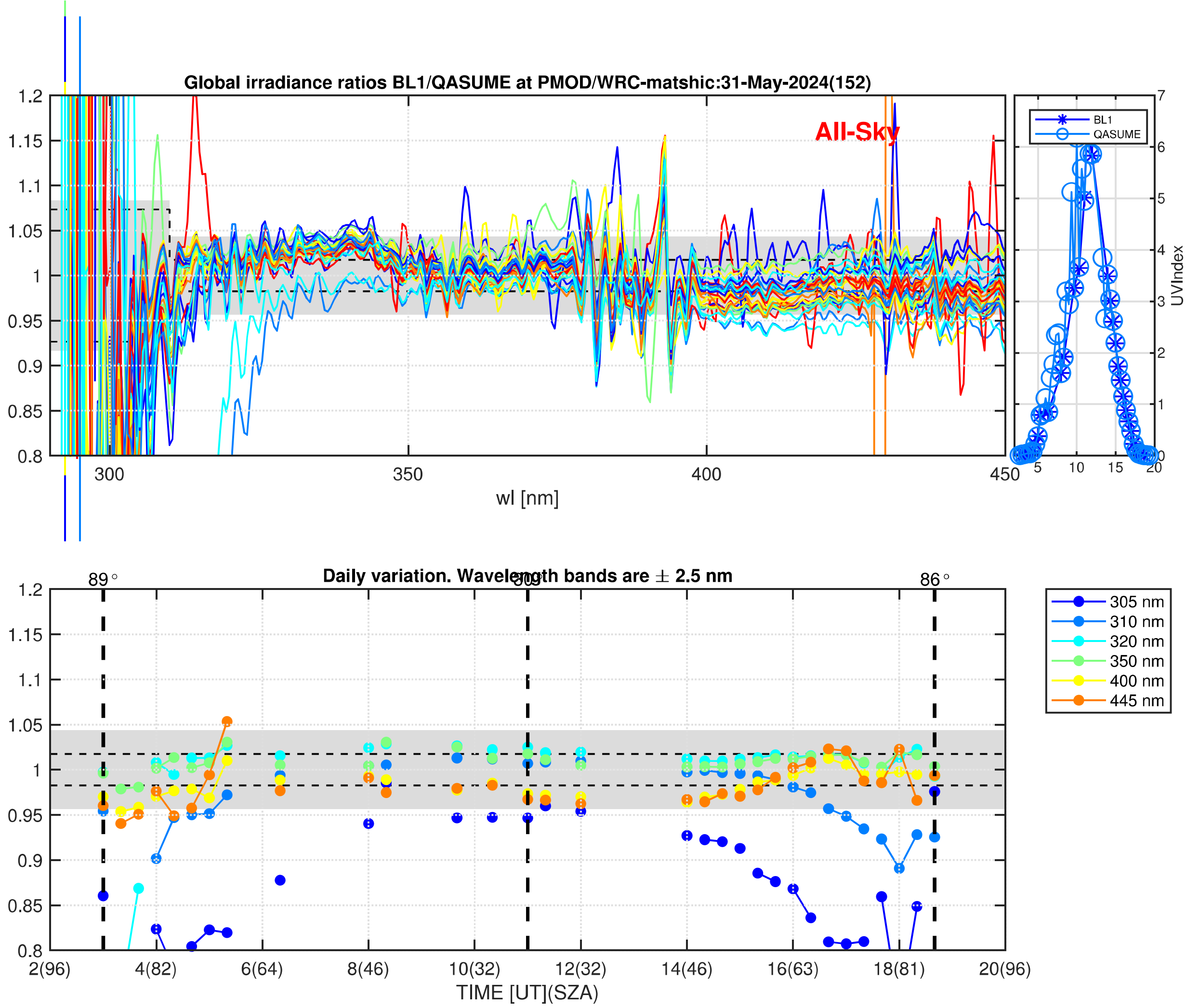


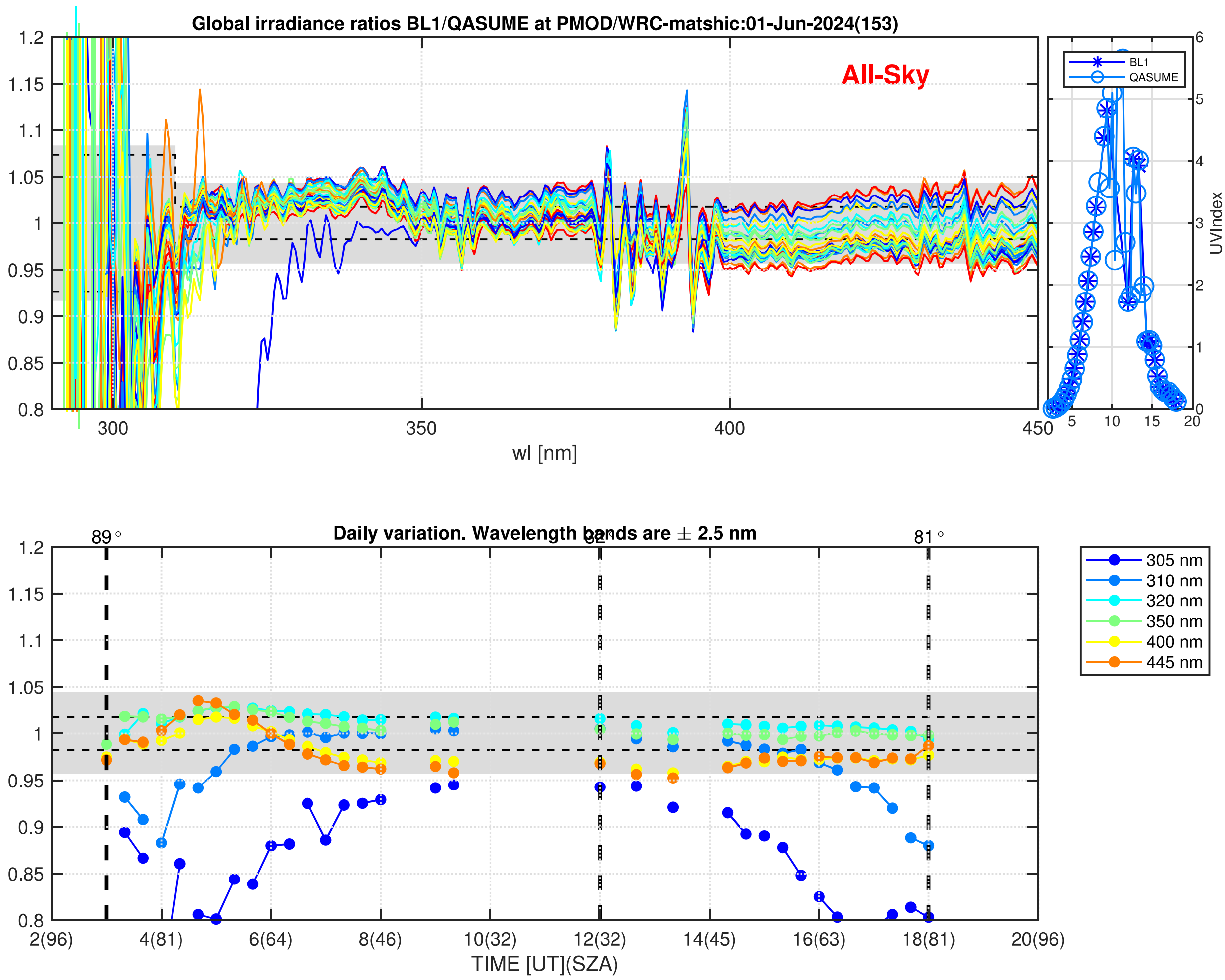
UV Index Lindenberg, May/June 2024
QASUME
bl1
li1
ld1
UV Index
Day of Year
0
1
2
3
4
5
6
7
151
151.5
152
152.5
153
153.5
154
154.5
155

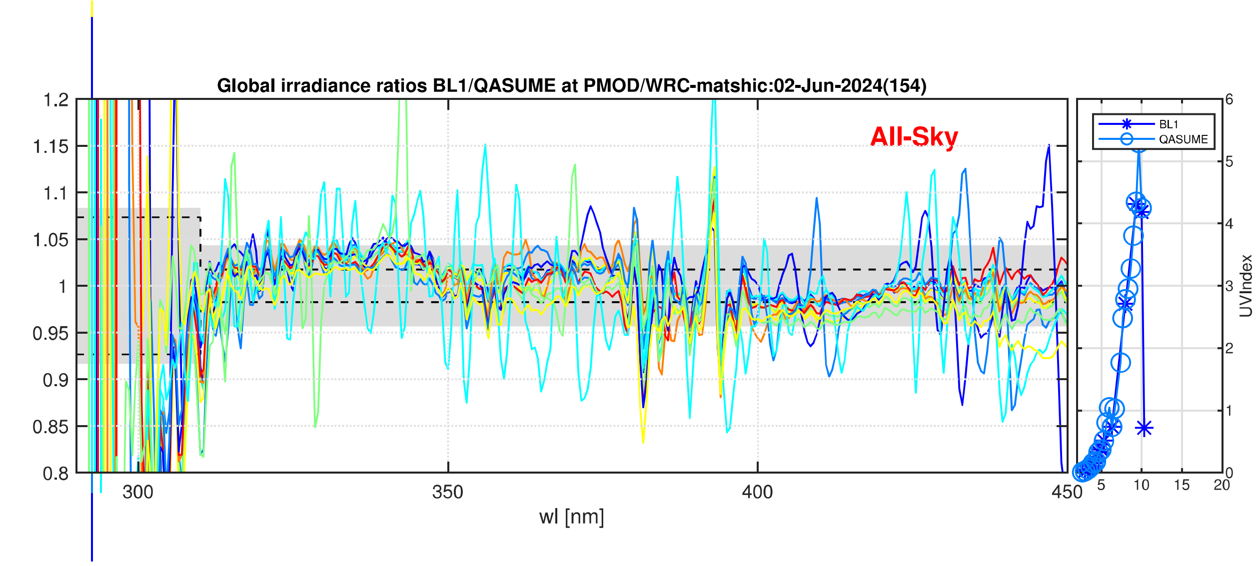

Global irradiance ratios BL1/QASUME at PMOD/WRC-matshic:30-May-2024(151) to 02-Jun-2024(154)
All-Sky
305 nm
310 nm
320 nm
350 nm
400 nm
445 nm
RATIO BL1/QASUME
151
152
153
154
TIME [UT] ON DAYS: [151 152 153 154]

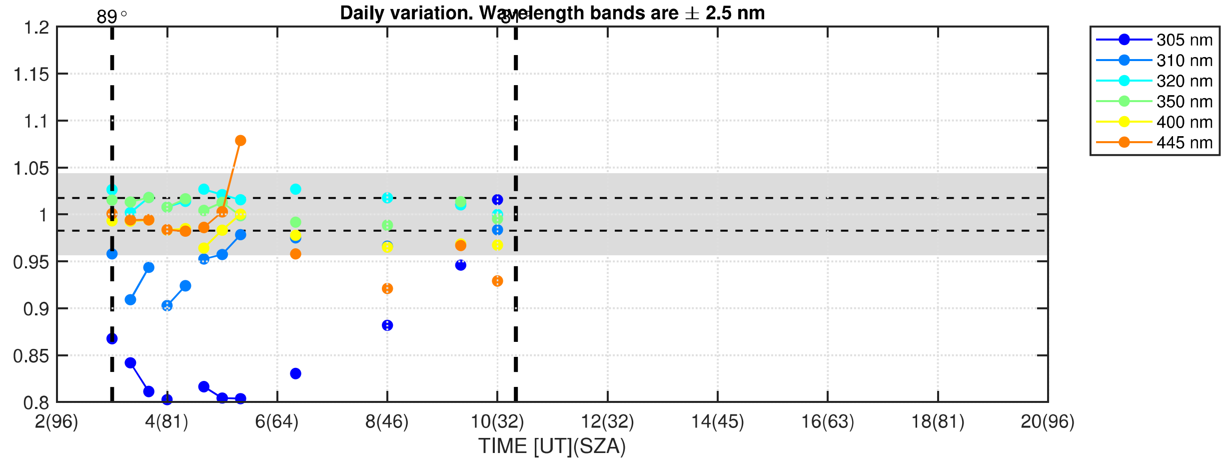

Global irradiance ratios BL1/QASUME at PMOD/WRC-matshic:30-May-2024(151)
All-Sky
wl [nm]
BL1
QASUME
UVIndex

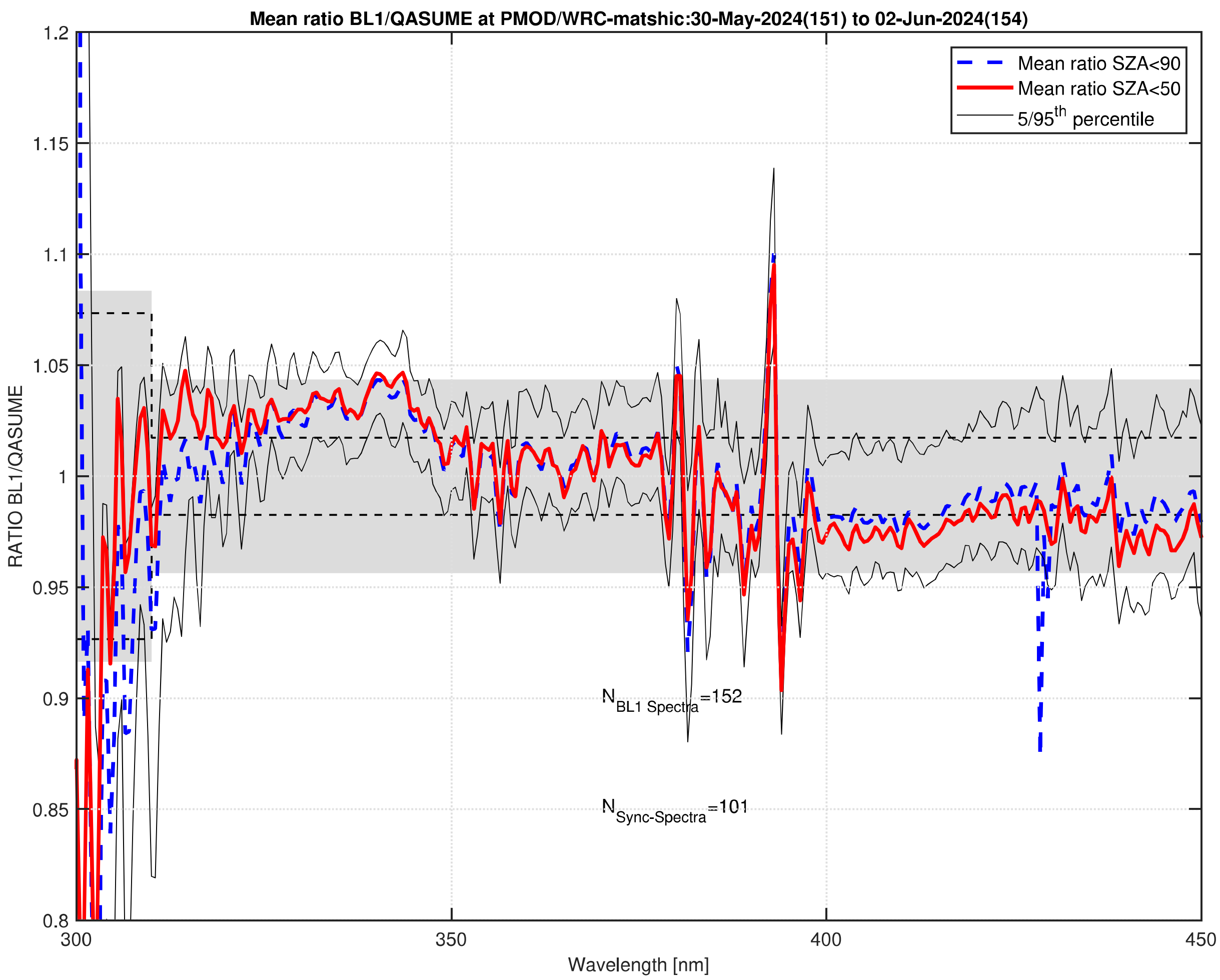

Daily variation. Wavelength bands are ± 2.5 nm
86°
305 nm
310 nm
320 nm
350 nm
400 nm
445 nm
TIME [UT](SZA)

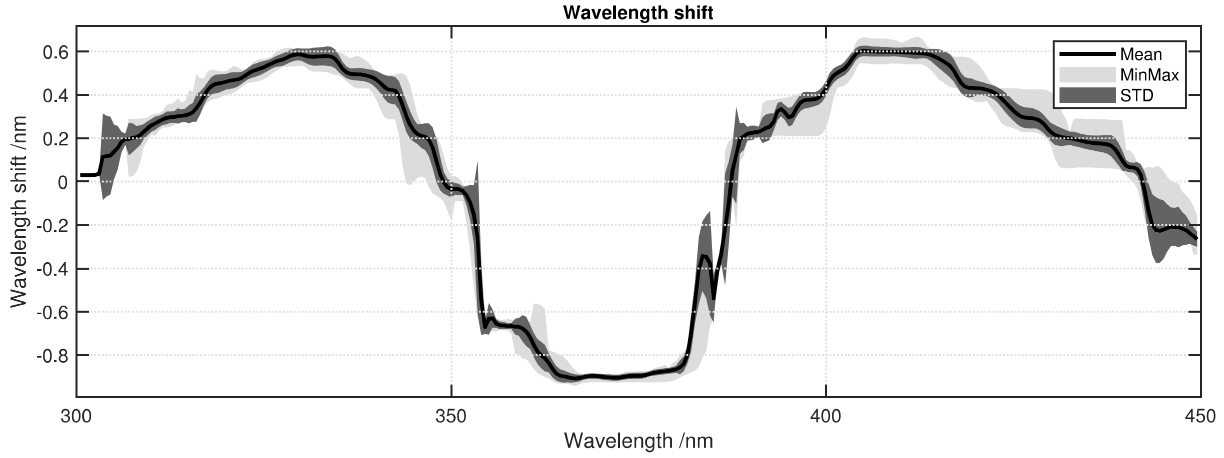

Global irradiance ratios BL1/QASUME at PMOD/WRC-matshic:31-May-2024(152)
All-Sky
wl [nm]
BL1
QASUME
UVIndex
Daily variation. Wavelength bands are ± 2.5 nm
89°
86°
305 nm
310 nm
320 nm
350 nm
400 nm
445 nm
TIME [UT](SZA)

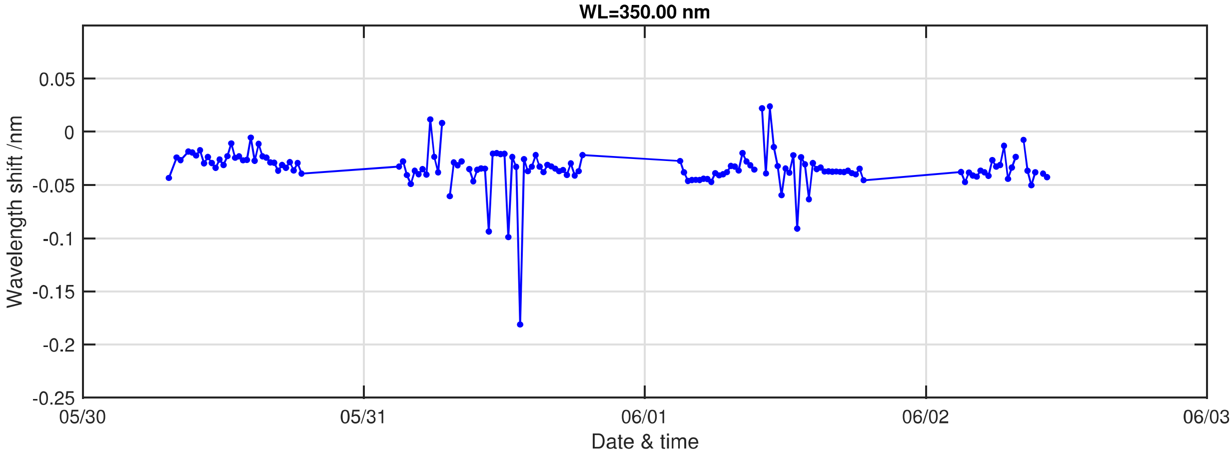

Global irradiance ratios BL1/QASUME at PMOD/WRC-matshic:01-Jun-2024(153)
All-Sky
wl [nm]
BL1
QASUME
UVIndex
Daily variation. Wavelength bands are ± 2.5 nm
89°
81°
305 nm
310 nm
320 nm
350 nm
400 nm
445 nm
TIME [UT](SZA)

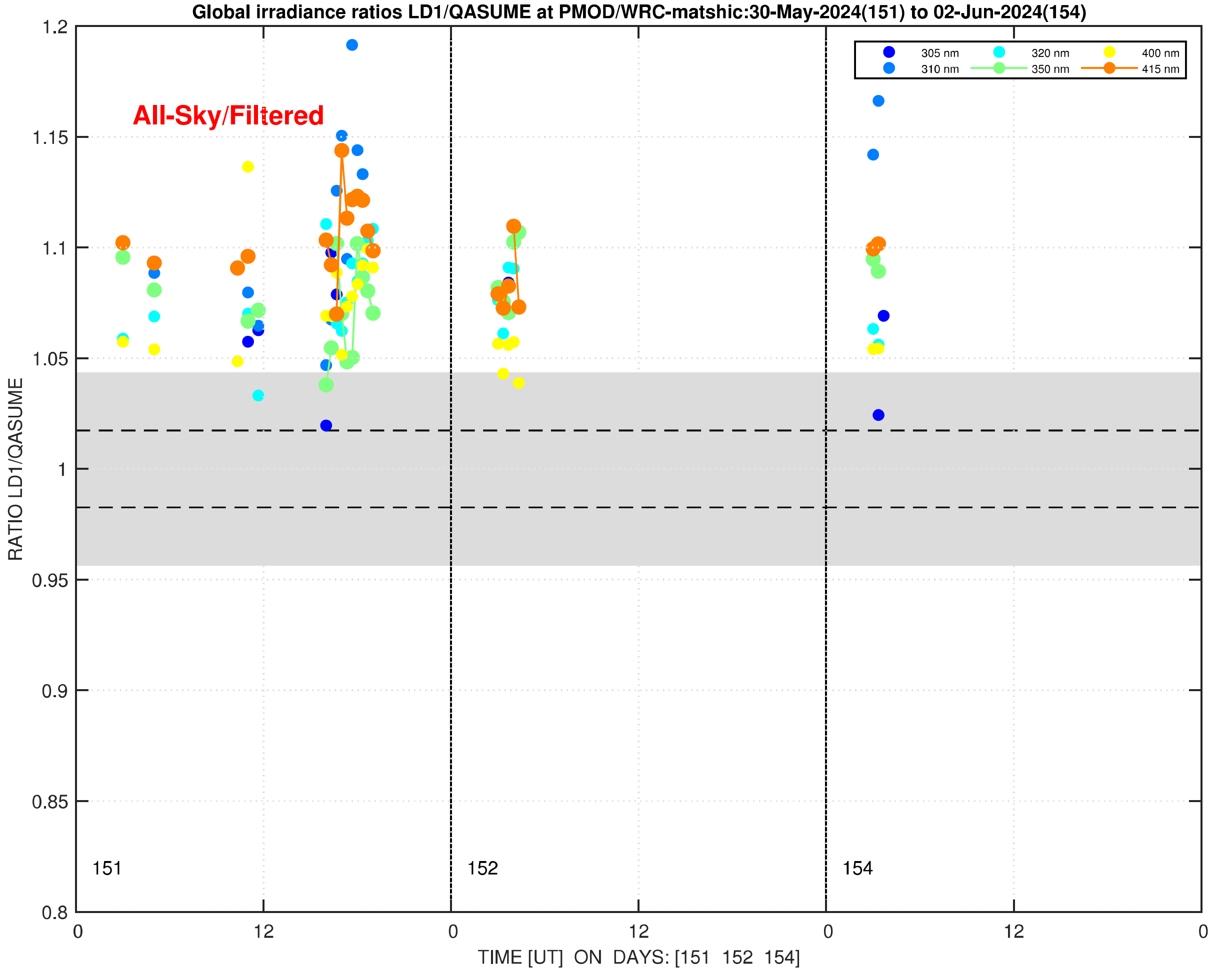

Global irradiance ratios BL1/QASUME at PMOD/WRC-matshic:02-Jun-2024(154)
All-Sky
wl [nm]
BL1
QASUME
UVIndex

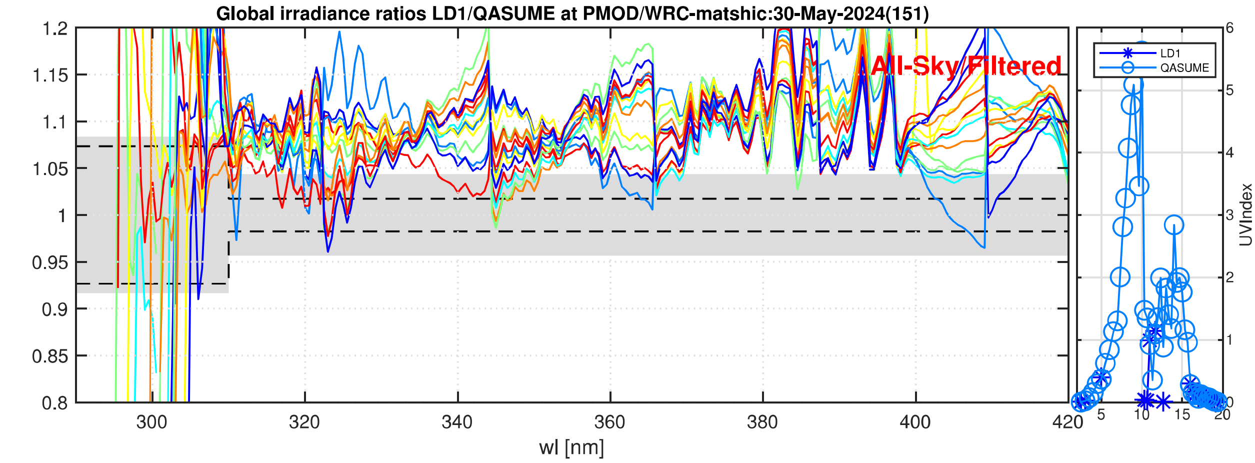

Daily variation. Wavelength bands are ± 2.5 nm
89°
305 nm
310 nm
320 nm
350 nm
400 nm
445 nm
TIME [UT](SZA)

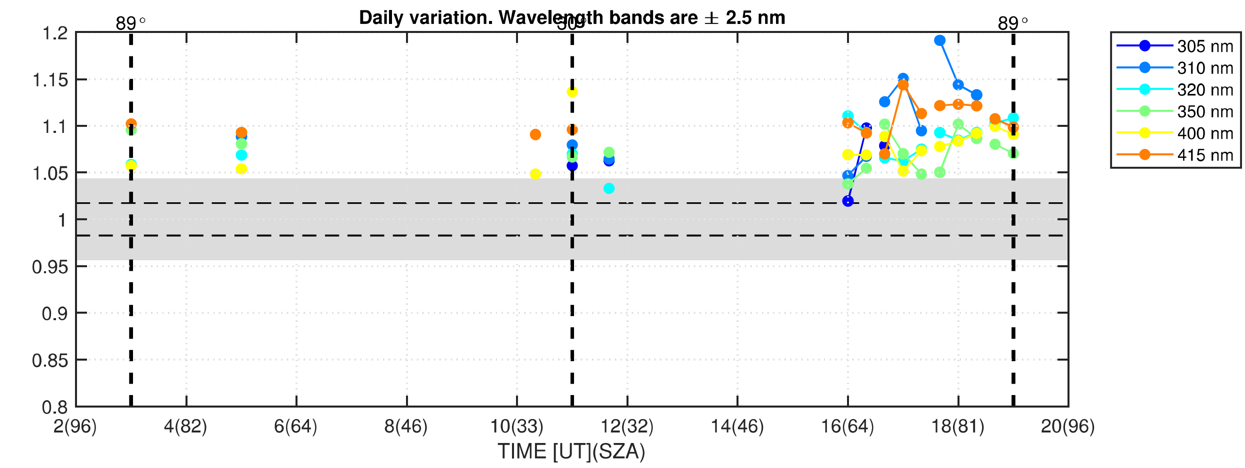

Mean ratio BL1/QASUME at PMOD/WRC-matshic:30-May-2024(151) to 02-Jun-2024(154)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
N BL1 Spectra =152
N Sync-Spectra =101
RATIO BL1/QASUME
Wavelength [nm]

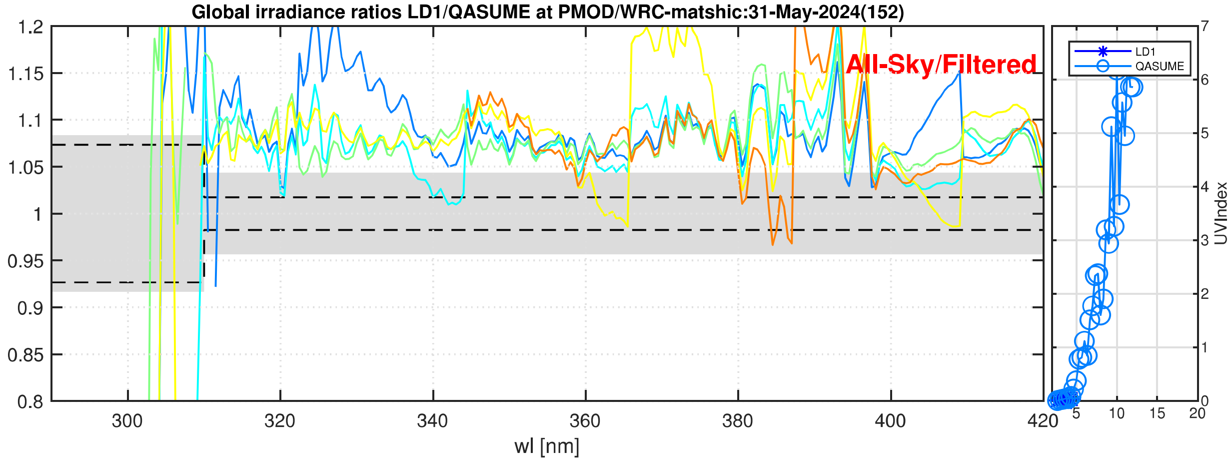

Wavelength shift
Mean
MinMax
STD
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
Wavelength shift /nm
300
350
400
450
Wavelength /nm

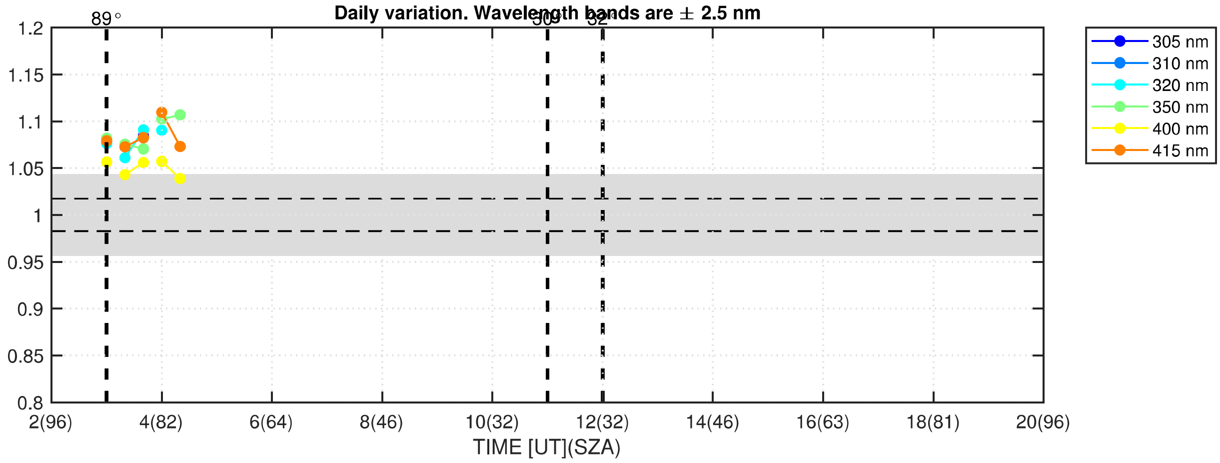

WL=350.00 nm
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
Wavelength shift /nm
05/30
05/31
06/01
06/02
06/03
Date & time

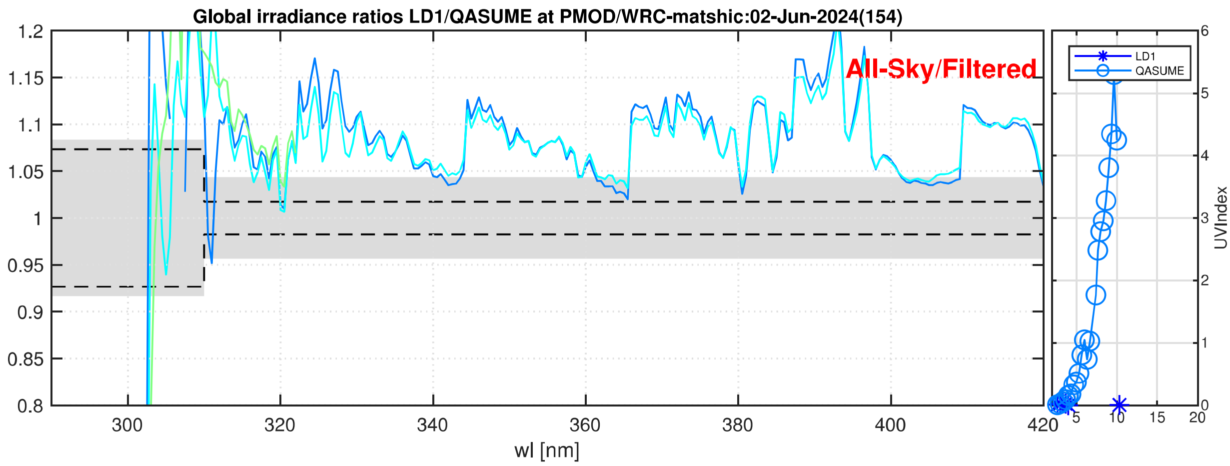

Global irradiance ratios LD1/QASUME at PMOD/WRC-matshic:30-May-2024(151) to 02-Jun-2024(154)
All-Sky/Filtered
305 nm
310 nm
320 nm
350 nm
400 nm
415 nm
RATIO LD1/QASUME
151
152
154
TIME [UT] ON DAYS: [151 152 154]

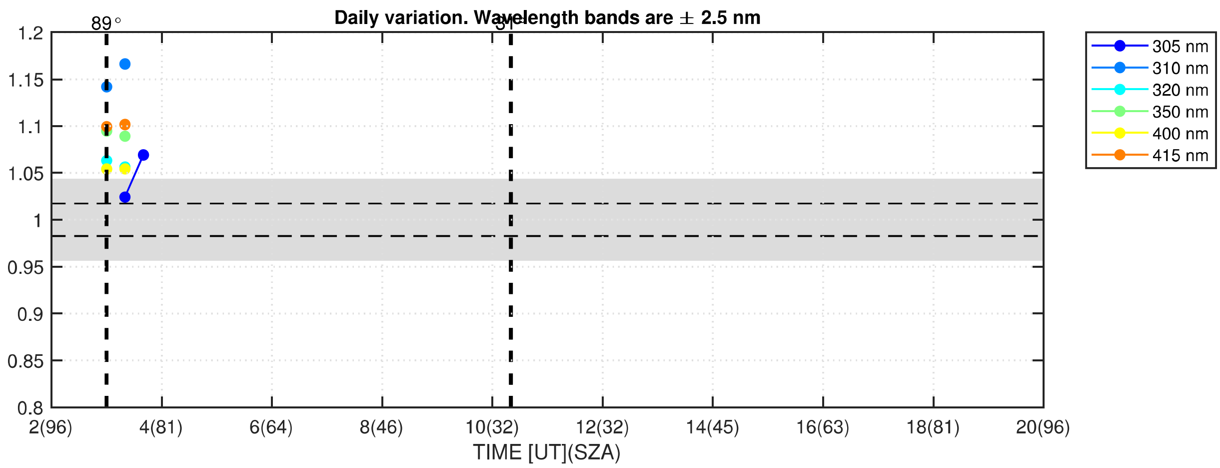

Global irradiance ratios LD1/QASUME at PMOD/WRC-matshic:30-May-2024(151)
All-Sky/Filtered
wl [nm]
LD1
QASUME
UVIndex

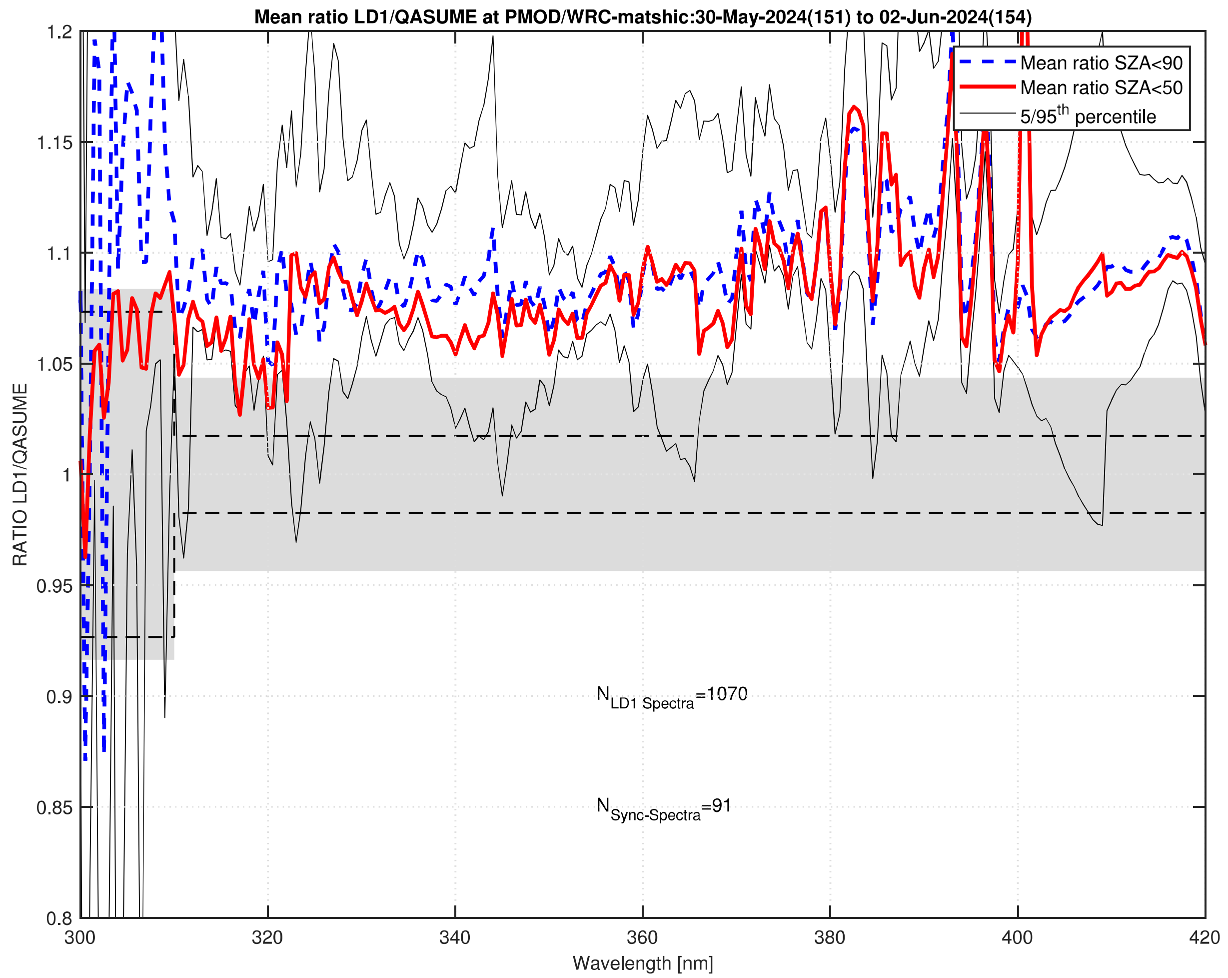

Daily variation. Wavelength bands are ± 2.5 nm
89°
30°
89°
305 nm
310 nm
320 nm
350 nm
400 nm
415 nm
TIME [UT](SZA)


Global irradiance ratios LD1/QASUME at PMOD/WRC-matshic:31-May-2024(152)
All-Sky/Filtered
wl [nm]
LD1
QASUME
UVIndex

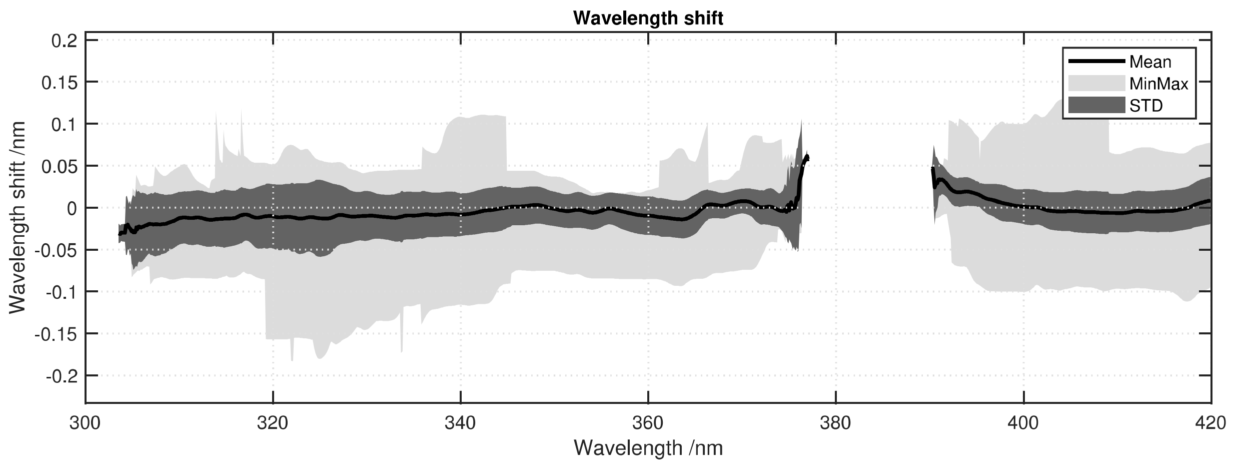

Daily variation. Wavelength bands are ± 2.5 nm
89°
305 nm
310 nm
320 nm
350 nm
400 nm
415 nm
TIME [UT](SZA)


Global irradiance ratios LD1/QASUME at PMOD/WRC-matshic:02-Jun-2024(154)
All-Sky/Filtered
wl [nm]
LD1
QASUME
UVIndex

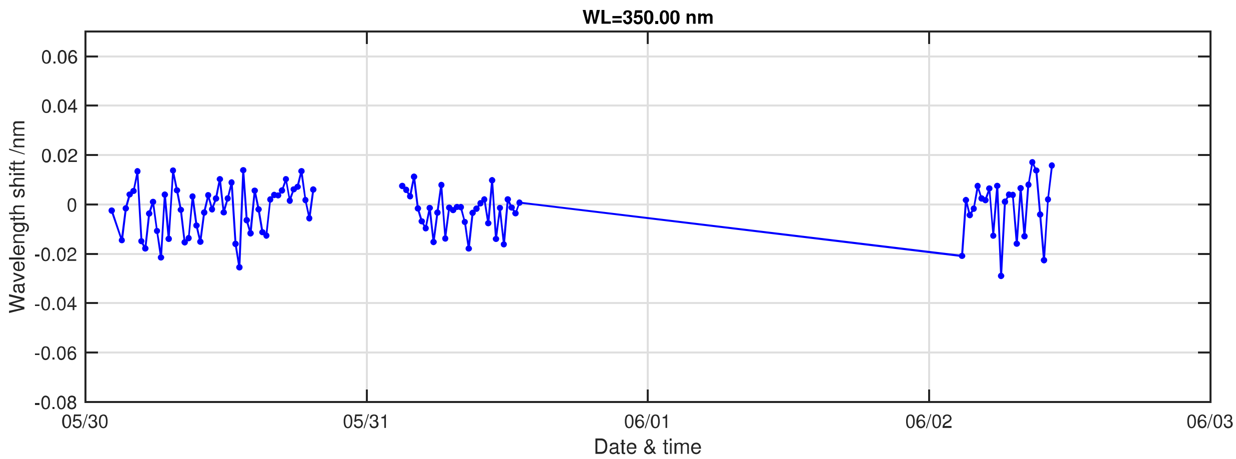

Daily variation. Wavelength bands are ± 2.5 nm
89°
305 nm
310 nm
320 nm
350 nm
400 nm
415 nm
TIME [UT](SZA)



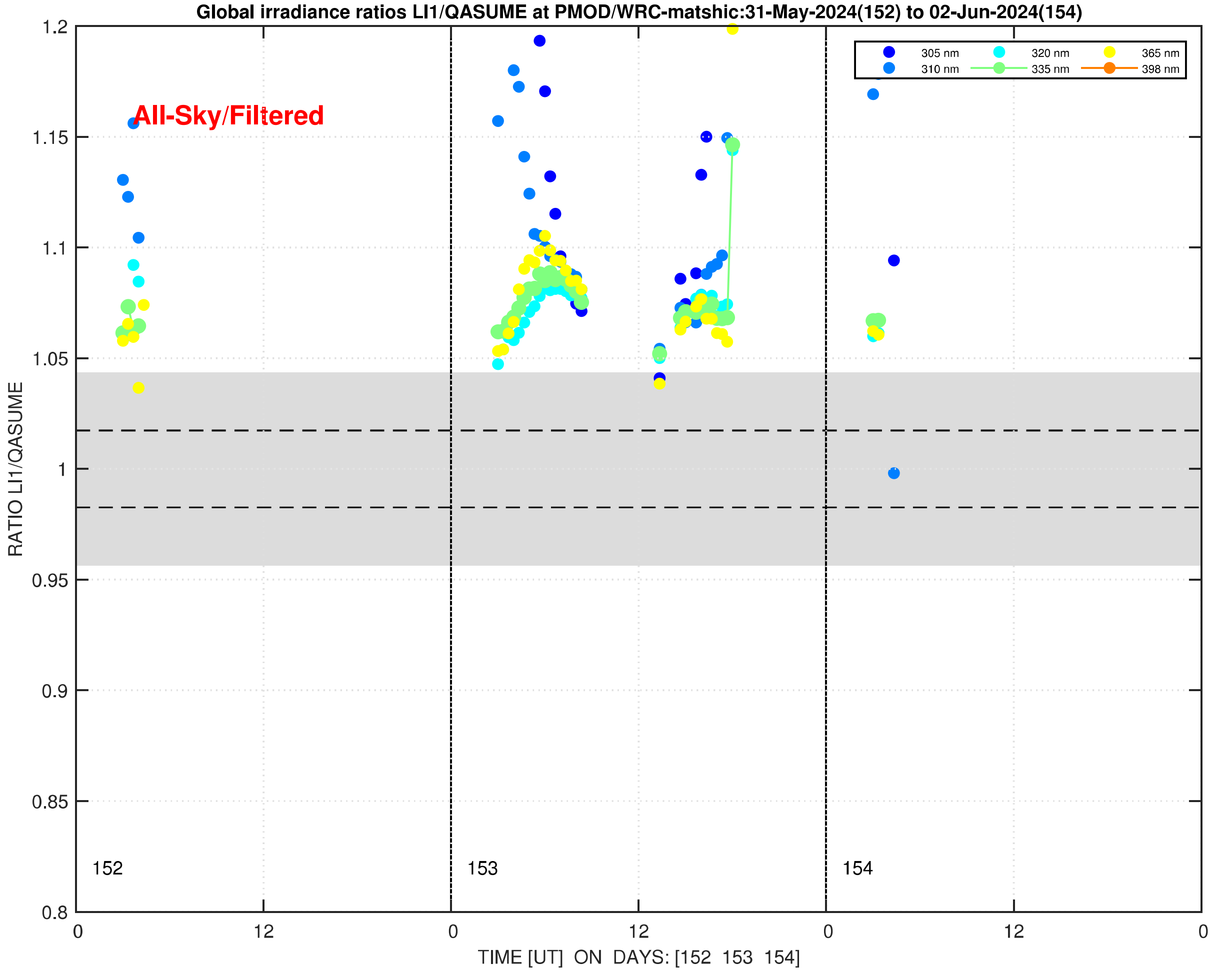
Mean ratio LD1/QASUME at PMOD/WRC-matshic:30-May-2024(151) to 02-Jun-2024(154)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
RATIO LD1/QASUME
Wavelength [nm]
N LD1 Spectra =1070
N Sync-Spectra =91

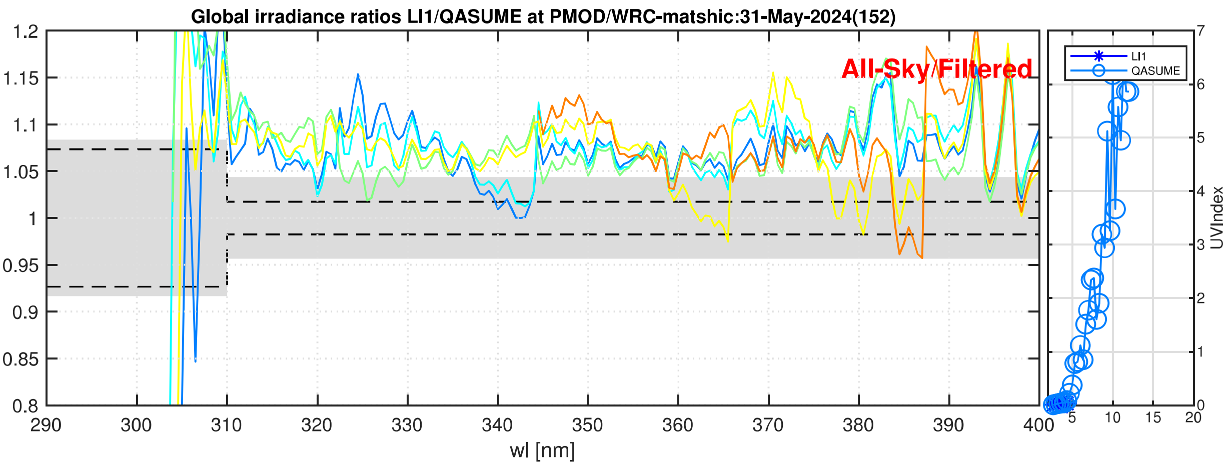


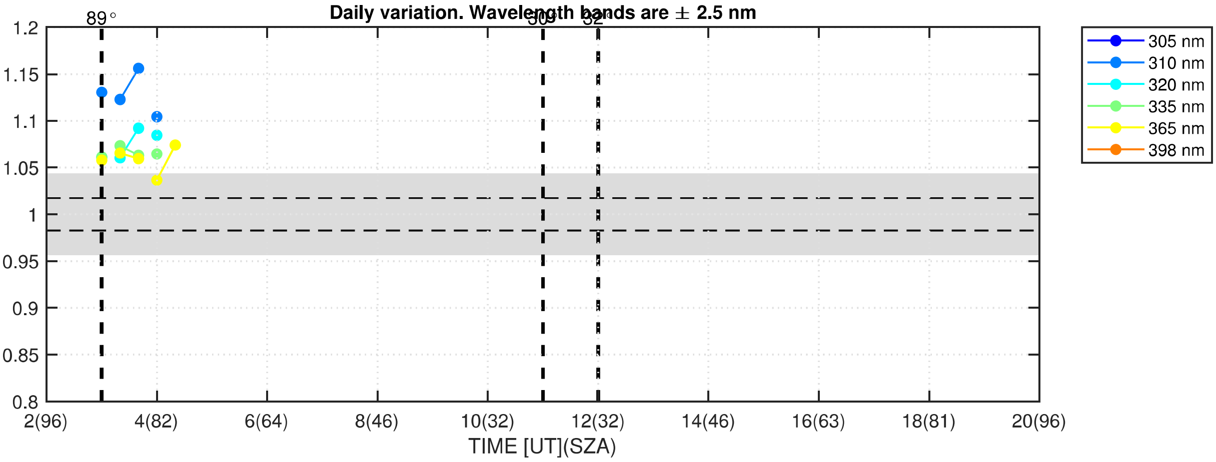
Wavelength shift
Mean
MinMax
STD
Wavelength shift /nm
Wavelength /nm

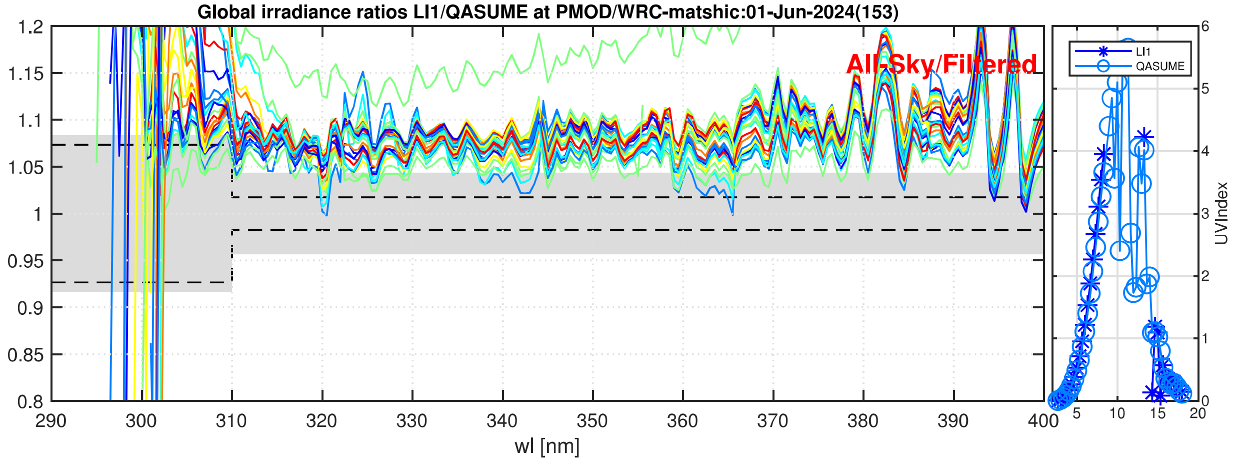


WL=350.00 nm
Wavelength shift /nm
Date & time
05/30
05/31
06/01
06/02
06/03

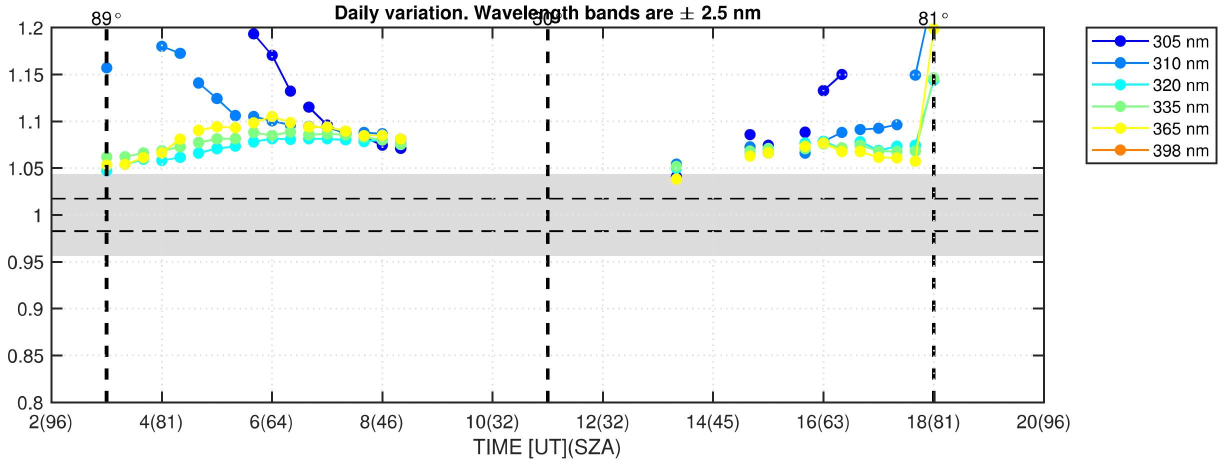

Global irradiance ratios LI1/QASUME at PMOD/WRC-matshic:31-May-2024(152) to 02-Jun-2024(154)
All-Sky/Filtered
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
RATIO LI1/QASUME
152
153
154
TIME [UT] ON DAYS: [152 153 154]


Global irradiance ratios LI1/QASUME at PMOD/WRC-matshic:31-May-2024(152)
All-Sky/Filtered
LI1
QASUME
UVIndex
wl [nm]

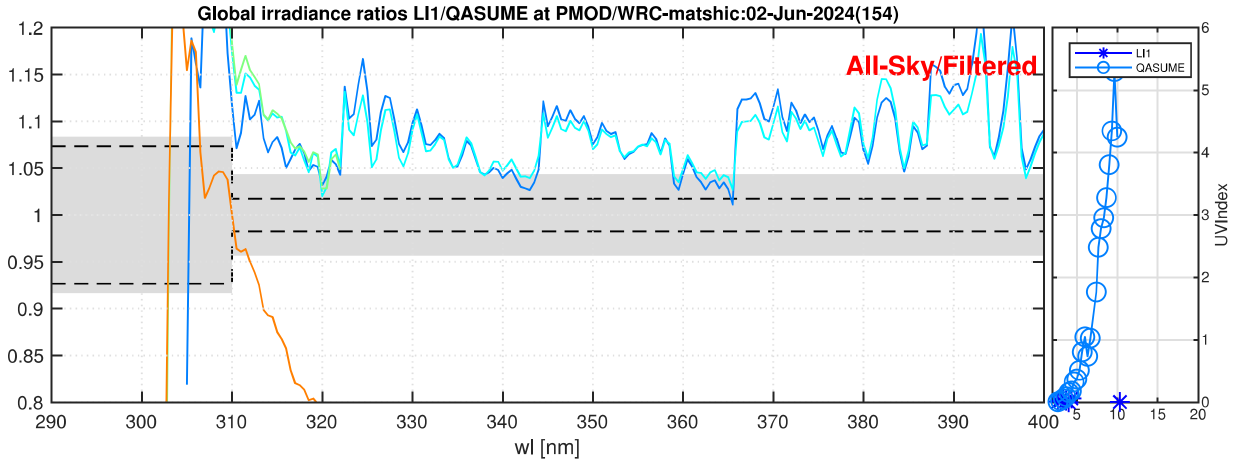

Daily variation. Wavelength bands are ± 2.5 nm
89°
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
TIME [UT](SZA)



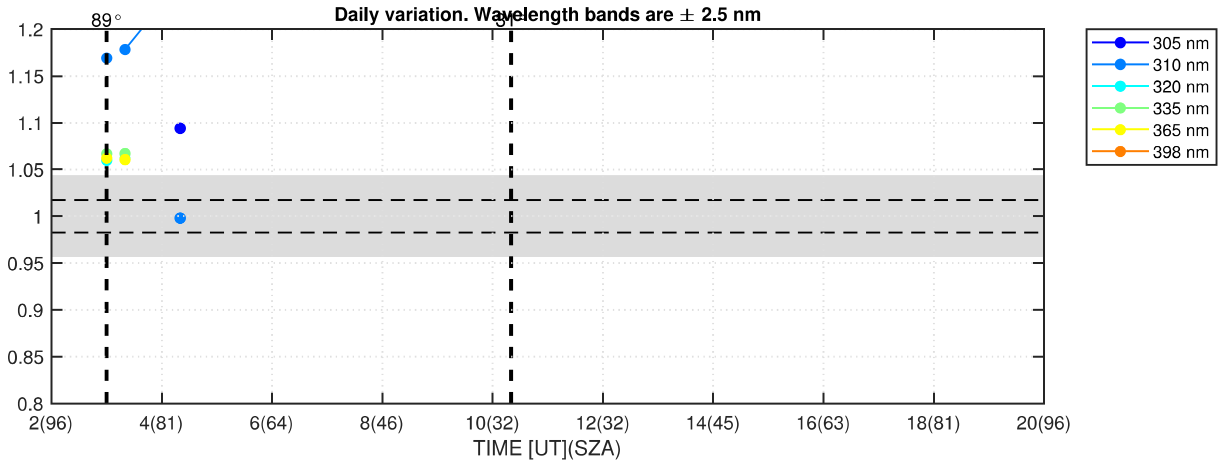
Global irradiance ratios LI1/QASUME at PMOD/WRC-matshic:01-Jun-2024(153)
All-Sky/Filtered
wl [nm]
LI1
QASUME
UVIndex



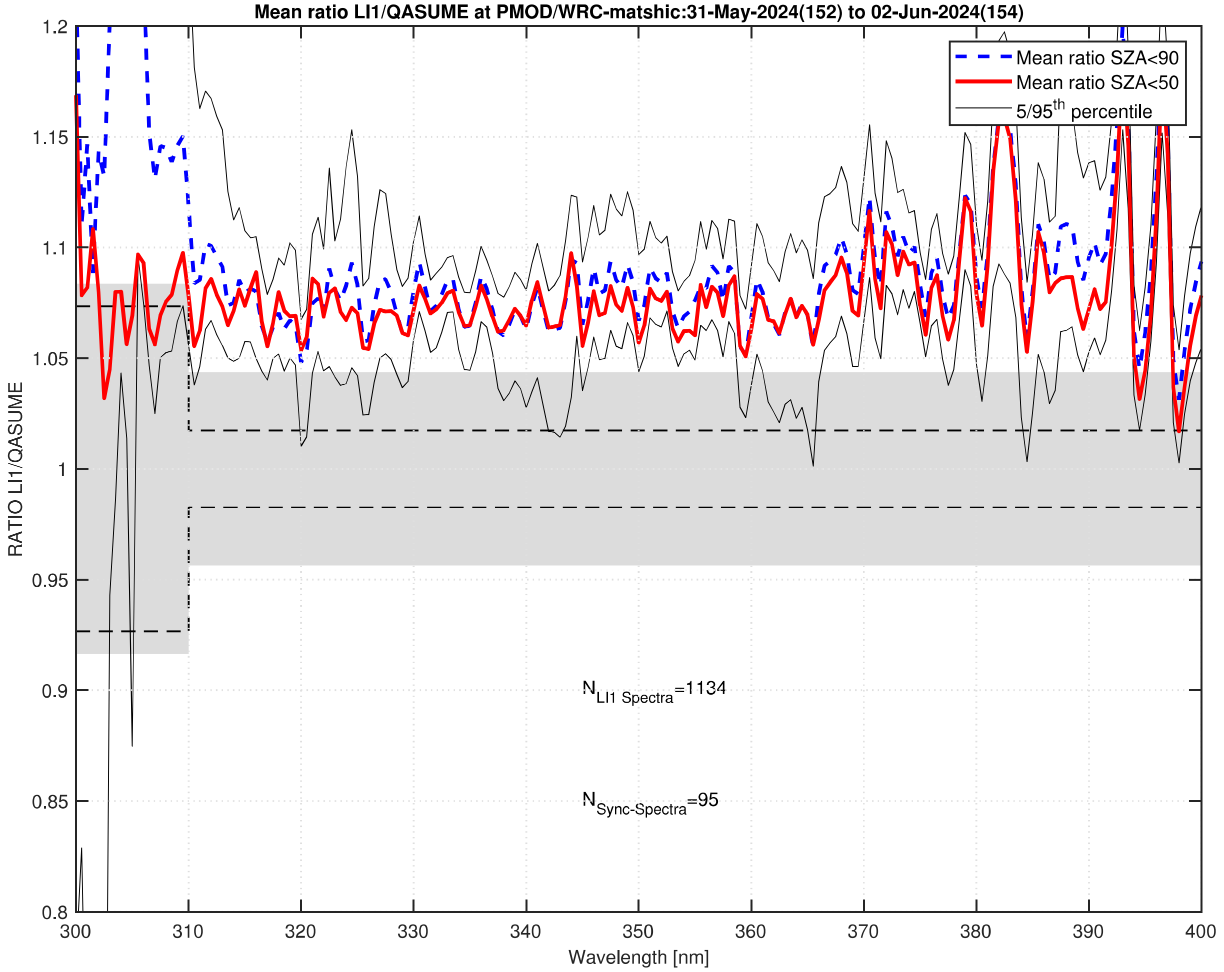
Daily variation. Wavelength bands are ± 2.5 nm
89°
81°
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
TIME [UT](SZA)

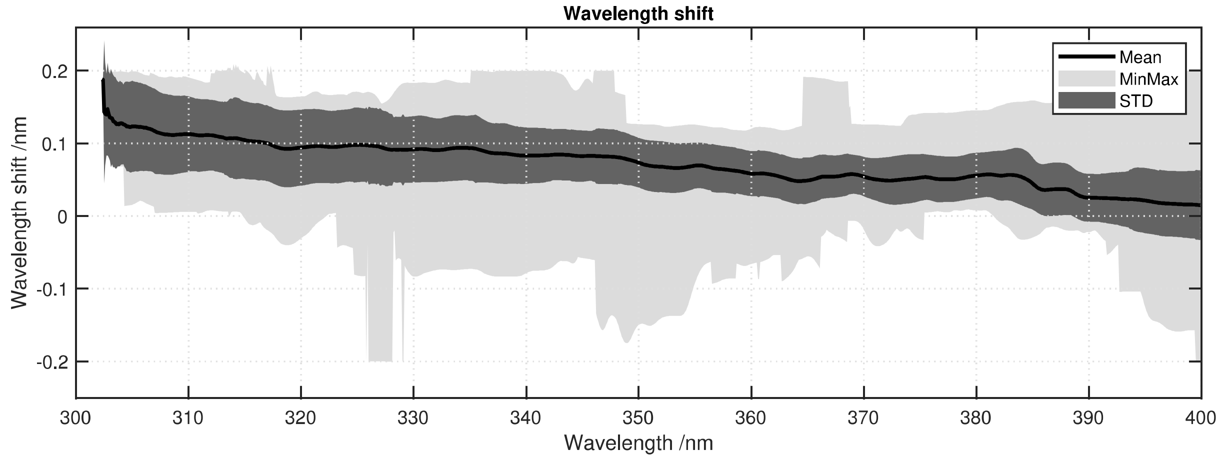


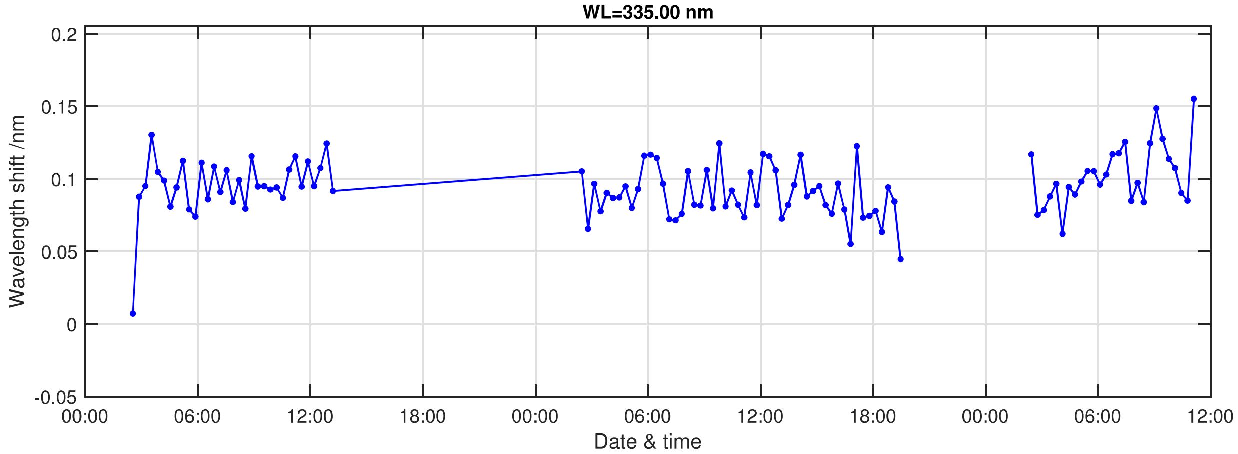
Global irradiance ratios LI1/QASUME at PMOD/WRC-matshic:02-Jun-2024(154)
All-Sky/Filtered
wl [nm]
LI1
QASUME
UVIndex

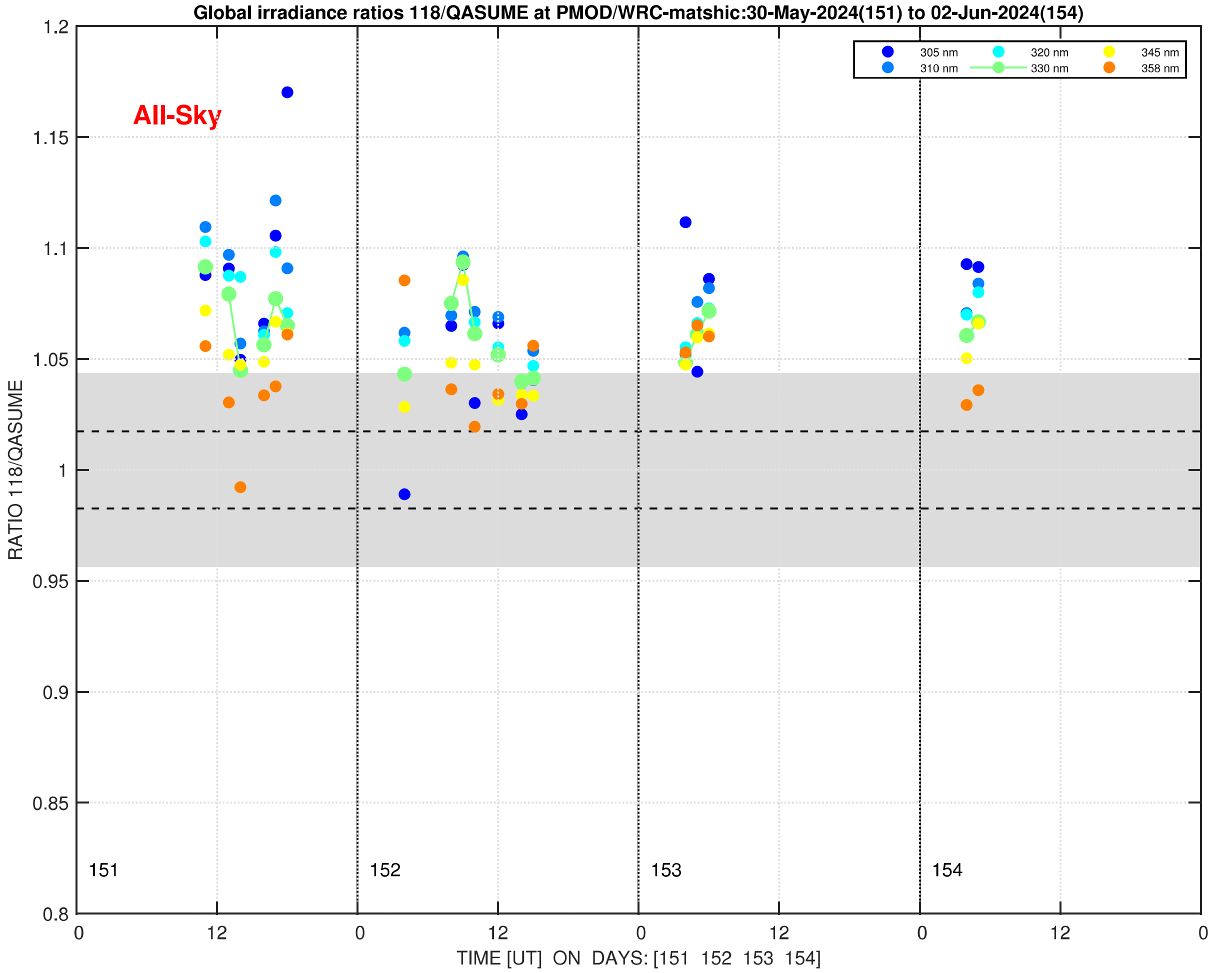


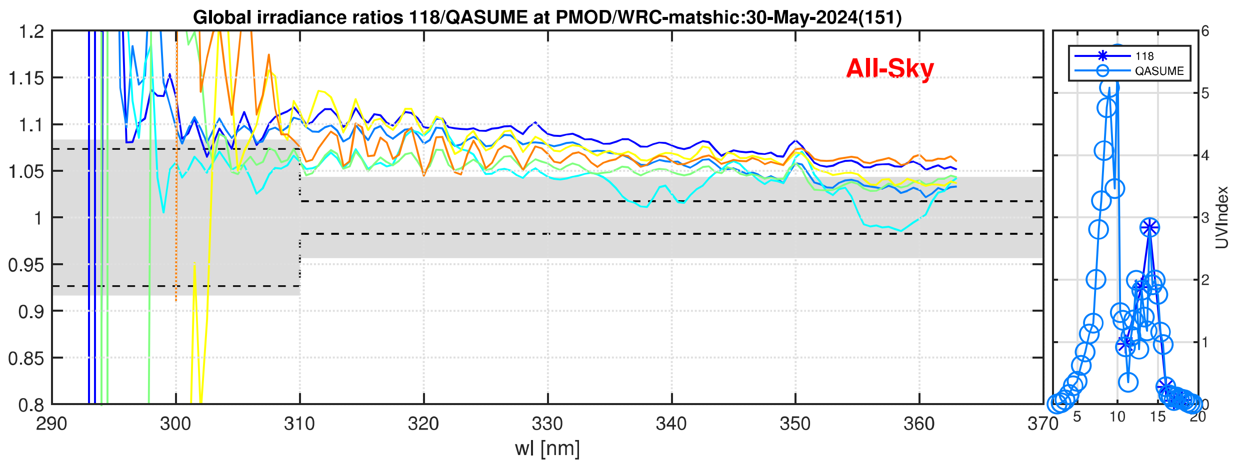
Daily variation. Wavelength bands are ± 2.5 nm
89°
305 nm
310 nm
320 nm
335 nm
365 nm
398 nm
TIME [UT](SZA)

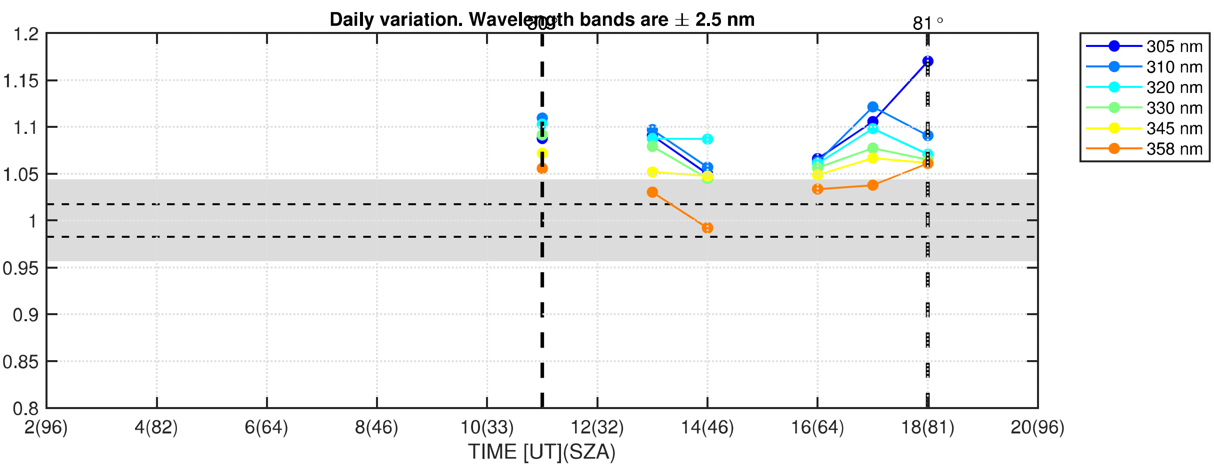

Mean ratio LI1/QASUME at PMOD/WRC-matshic:31-May-2024(152) to 02-Jun-2024(154)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
RATIO LI1/QASUME
N LI1 Spectra=1134
N Sync-Spectra=95
Wavelength [nm]

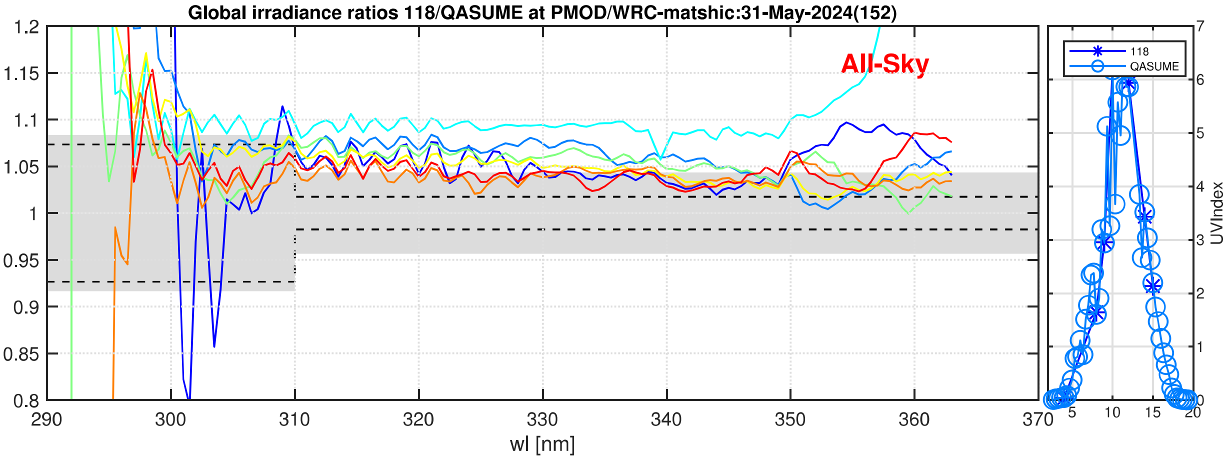

Wavelength shift
Mean
MinMax
STD
Wavelength shift /nm
Wavelength /nm

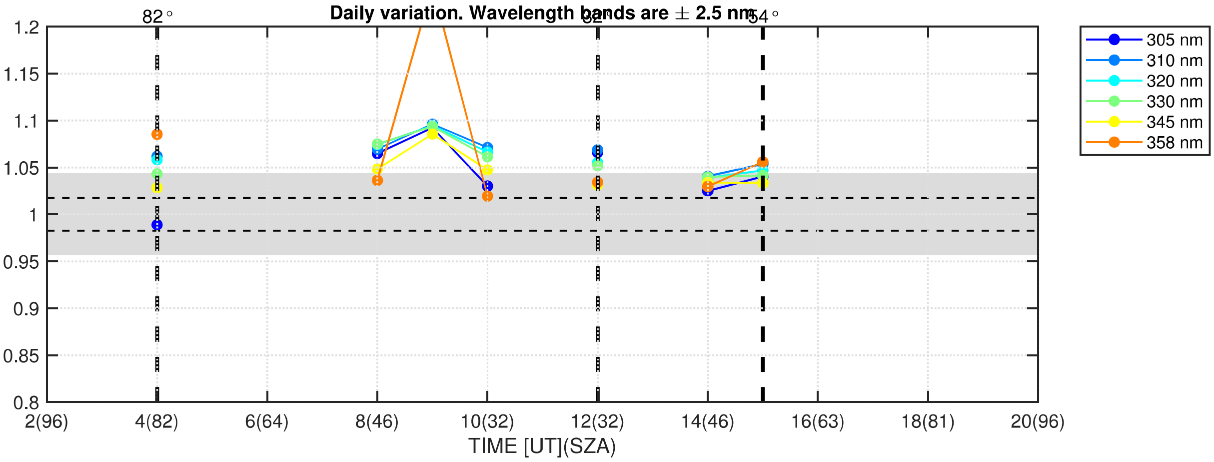

WL=335.00 nm
Wavelength shift /nm
Date & time

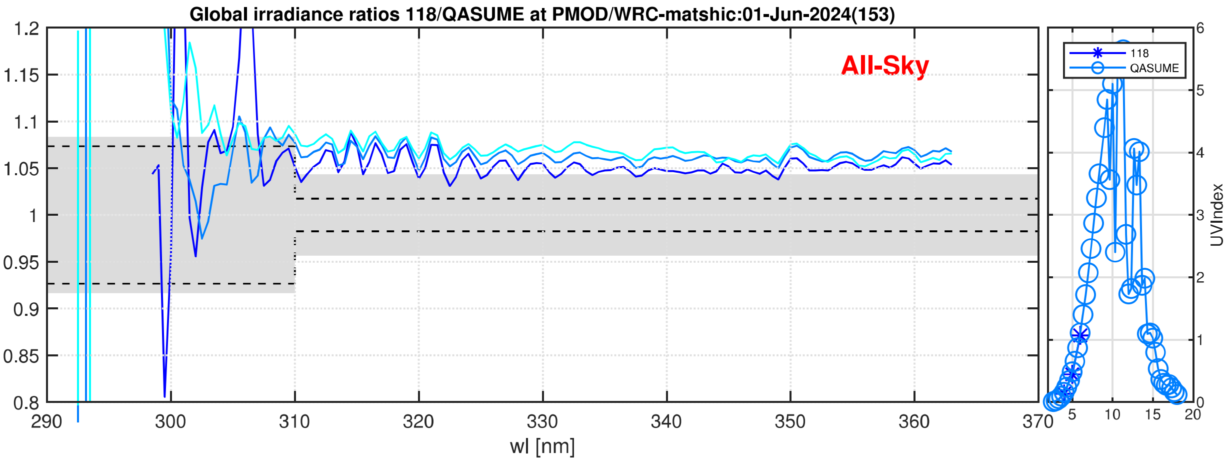

Global irradiance ratios 118/QASUME at PMOD/WRC-matshic:30-May-2024(151) to 02-Jun-2024(154)
All-Sky
305 nm
310 nm
320 nm
330 nm
345 nm
358 nm
RATIO 118/QASUME
151
152
153
154
TIME [UT] ON DAYS: [151 152 153 154]

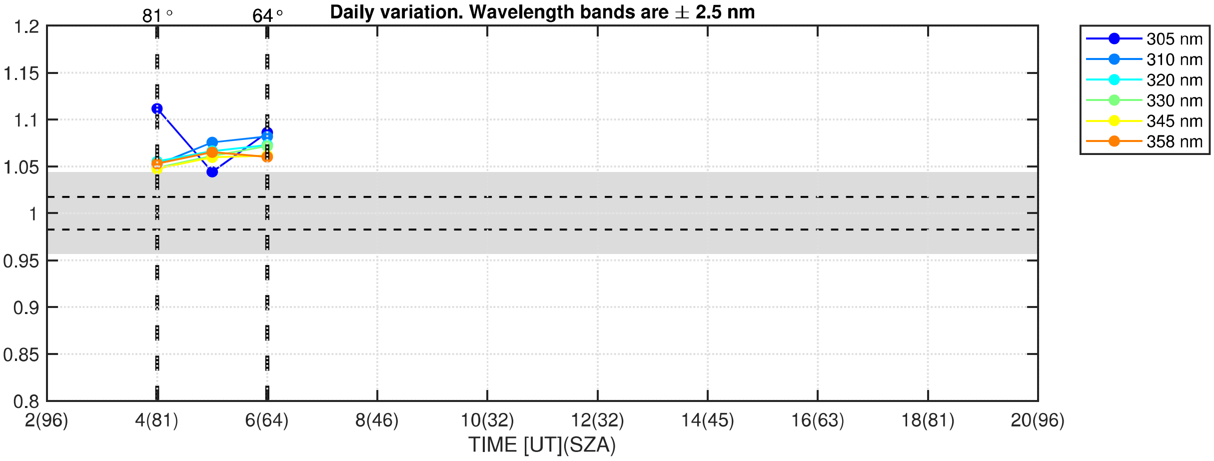

Global irradiance ratios 118/QASUME at PMOD/WRC-matshic:30-May-2024(151)
All-Sky
118
QASUME
UVIndex
wl [nm]

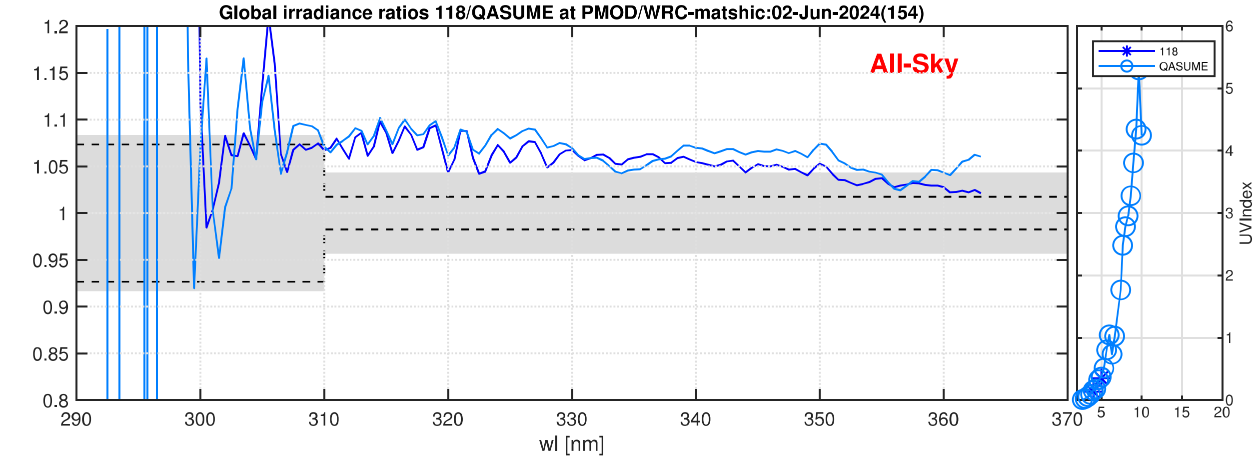

Daily variation. Wavelength bands are ± 2.5 nm
81 °
305 nm
310 nm
320 nm
330 nm
345 nm
358 nm
TIME [UT](SZA)


Global irradiance ratios 118/QASUME at PMOD/WRC-matshic:31-May-2024(152)
All-Sky
wl [nm]
118
QASUME
UVIndex

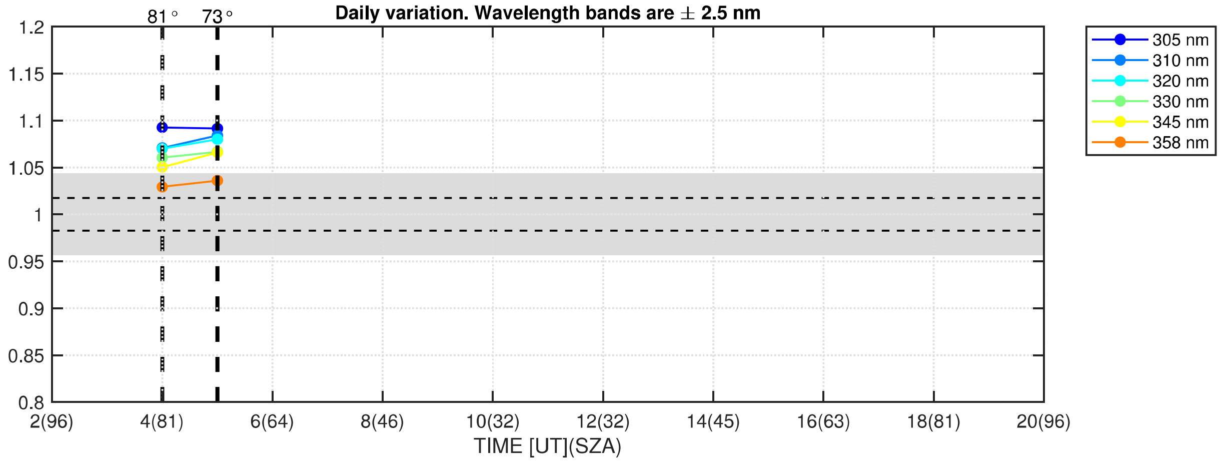

Daily variation. Wavelength bands are ± 2.5 nm
82°
32°
54°
305 nm
310 nm
320 nm
330 nm
345 nm
358 nm
TIME [UT](SZA)


Global irradiance ratios 118/QASUME at PMOD/WRC-matshic:01-Jun-2024(153)
All-Sky
wl [nm]
118
QASUME
UVIndex

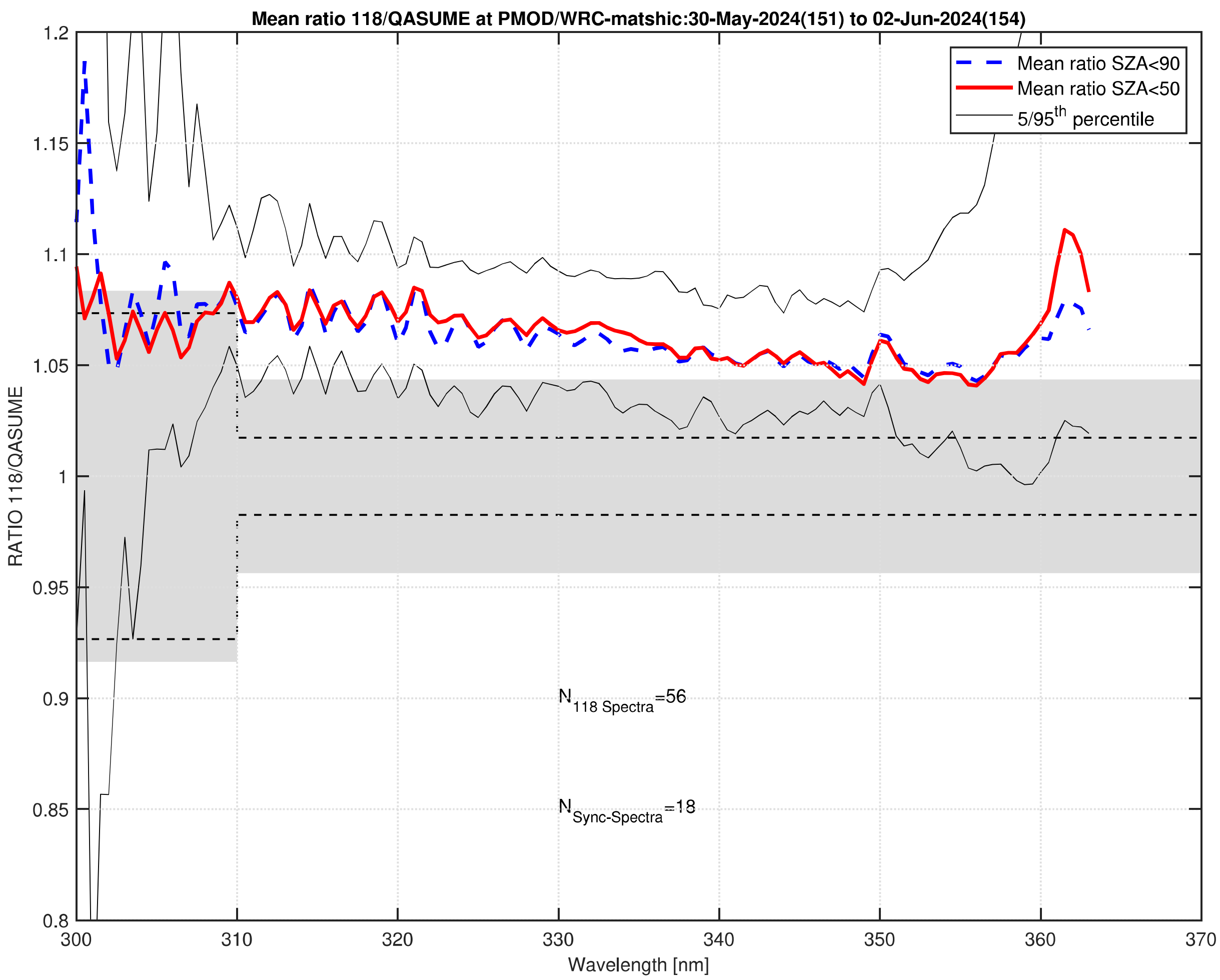

Daily variation. Wavelength bands are ± 2.5 nm
81°
64°
305 nm
310 nm
320 nm
330 nm
345 nm
358 nm
TIME [UT](SZA)



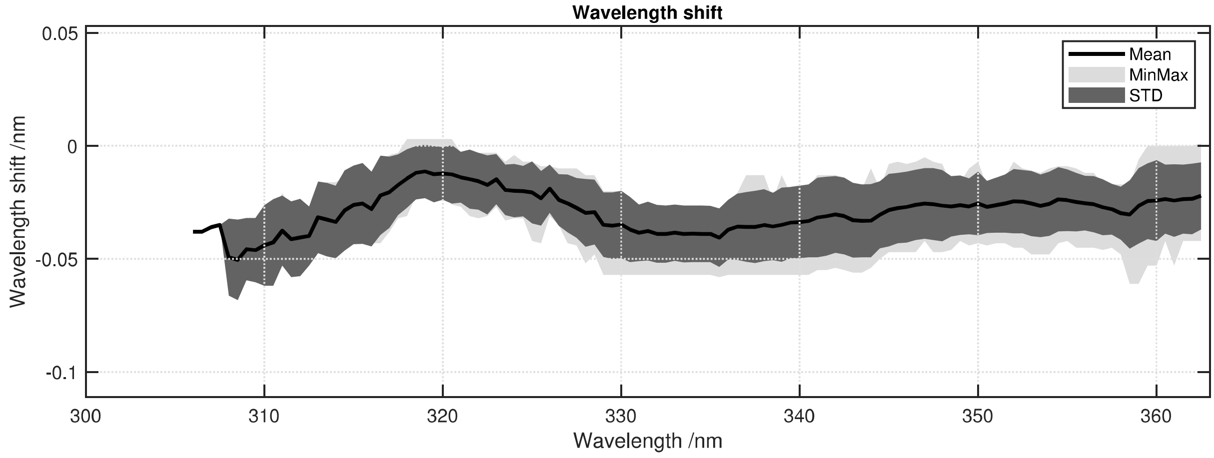
Global irradiance ratios 118/QASUME at PMOD/WRC-matshic:02-Jun-2024(154)
All-Sky
wl [nm]
118
QASUME
UVIndex



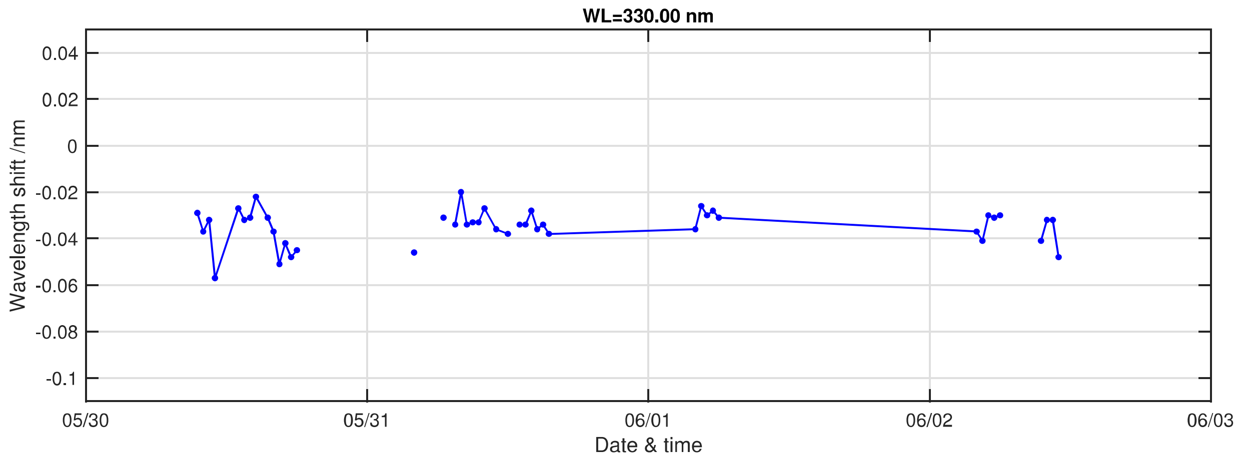
Daily variation. Wavelength bands are ± 2.5 nm
81°
73°
305 nm
310 nm
320 nm
330 nm
345 nm
358 nm
TIME [UT](SZA)



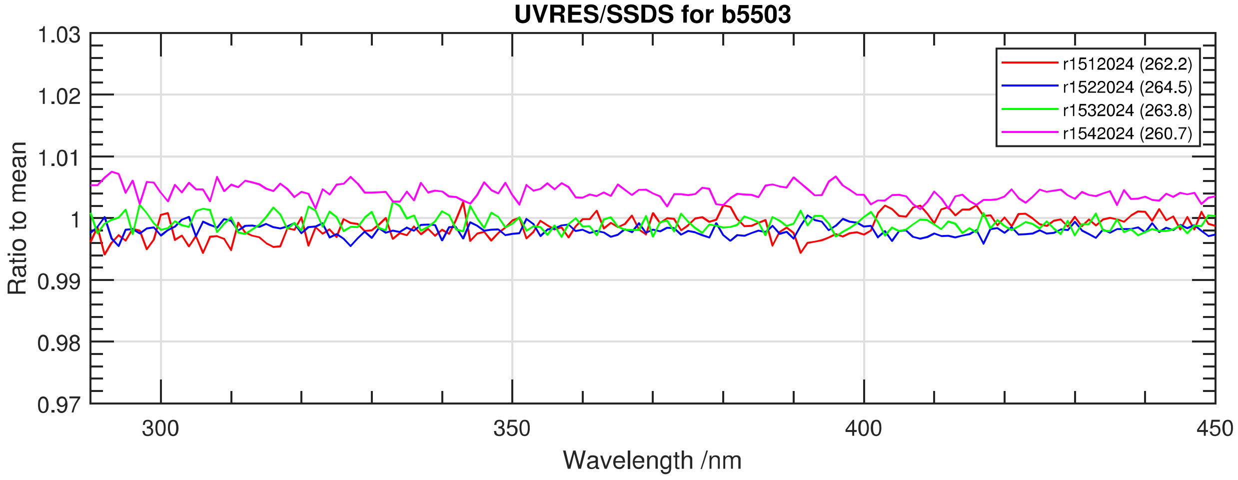
Mean ratio 118/QASUME at PMOD/WRC-matshic:30-May-2024(151) to 02-Jun-2024(154)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
RATIO 118/QASUME
N118 Spectra=56
NSync-Spectra=18
Wavelength [nm]

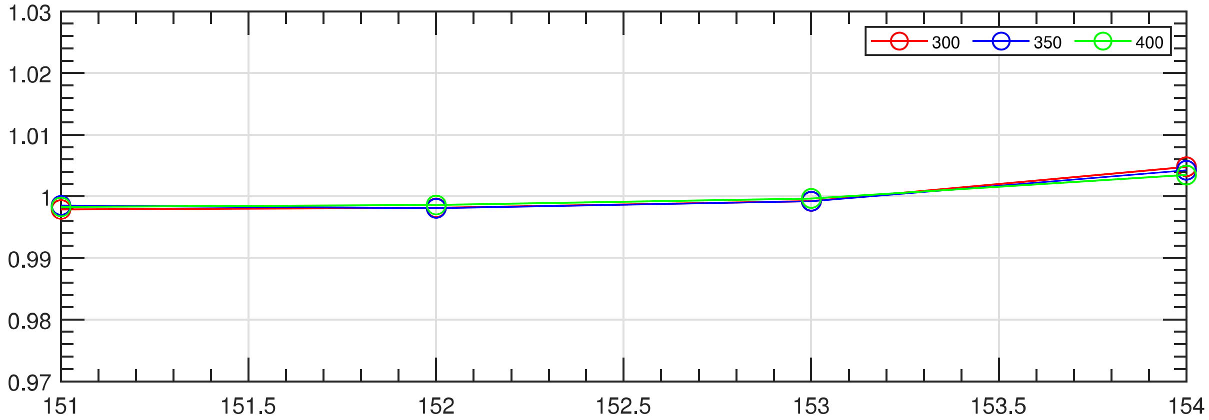


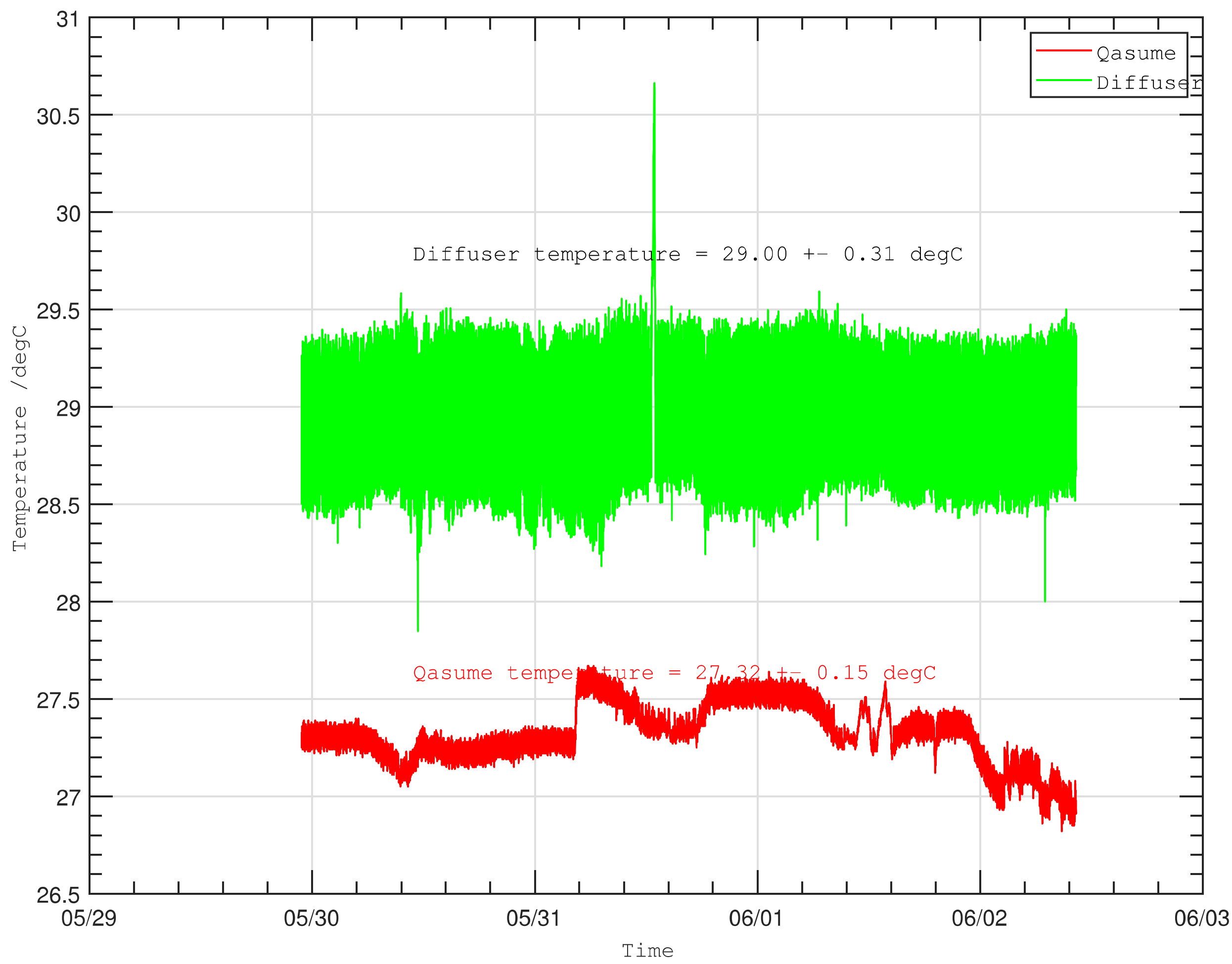
Wavelength shift
Mean
MinMax
STD
Wavelength shift /nm
0.05
0
-0.05
-0.1
300
310
320
330
340
350
360
Wavelength /nm



WL=330.00 nm
Wavelength shift /nm
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
05/30
05/31
06/01
06/02
06/03
Date & time


UVRES/SSDS for b5503
Ratio to mean
Wavelength /nm
r1512024 (262.2)
r1522024 (264.5)
r1532024 (263.8)
r1542024 (260.7)


300
350
400


Qasume
Diffuser
Diffuser temperature = 29.00 +- 0.31 degC
Qasume temperature = 27.32 +- 0.15 degC
Temperature /degC
Time


Qasume
BL1
BTS
pmod wrc
pmod wrc
pmod wrc
pmod wrc


Qasume
BL1
Li1
Ld1