Protocol of the intercomparison at ARPA, Aosta, Italy in May 2023 with the travelling reference spectroradiometer QASUME from PMOD/WRC

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The purpose of the visit was the comparison of global solar irradiance measurements between the spectroradiometer AAO operated by the Sezione Agenti Fisici - Radiazione Ultravioletta Solare, Agenzia Regionale per la Protezione dell'Ambiente (ARPA) and the travel reference spectroradiometer QASUME. The measurement site is located at Valle d'Aosta; Latitude 45.74 N, Longitude 7.34 E and altitude 569 m.a.s.l.
The horizon of the measurement site is free down to at least 80° solar zenith angle (SZA). Measurements between 4:20 UT and 19:00 UT have been analysed.

QASUME was installed at ARPA Aosta 15 May 2023. The spectroradiometer was installed next to AAO with the entrance optic of QASUME within 1 m of AAO. The spectroradiometer in use at ARPA Aosta is a Bentham DTMc300 double monochromator. The intercomparison between QASUME and the ARPA spectroradiometer lasted 3 1/2 days, from the afternoon of May 15 to the evening of May 18, 2023.

QASUME was calibrated several times during the intercomparison period using a portable calibration system. Three lamps (T68522, T68523, and T61251) were used to obtain a 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 %. The internal temperature of QASUME was 26.3±0.15 °C and the diffuser head was heated to a temperature of 28.7±0.4 °C.
The wavelength shifts relative to an extraterrestrial spectrum as retrieved from the matSHIC analysis were between ±50 pm in the spectral range 290 to 500 nm.

Protocol:

The measurement protocol was to measure one solar irradiance spectrum every 30 minutes from 290 to 500 nm, every 0.25 nm, and 1.5 second between each wavelength increment.

DOY	Date	DAY	Weather	Comment (times are in UT)
135	15-May	Monday	Mix of sun and clouds	Installed at 11:00 15:00 calibration T68523
136	16-May	Tuesday	Clear sky in the morning 12:00 Cumulus, overcast	10:20 Calibration T68523, T68522
137	17-May	Wednesday	Mix of sun and clouds Sun partly behind clouds in the morning Rain in the afternoon	8:30 AAO 1000W calib 9:30 T68523 12:55 Install QASUME head in 1000W unit 13:30 Measure F698
138	18-May	Thursday	Mix of sun and clouds	11:55 T68523, T61251
139	19-May	Friday		6:00 QASUME OFF

Results:

In total 110 synchronised simultaneous solar spectra from QASUME and AAO are available from the measurement period. Measurements between 4:30 UT and 18:30 UT have been analysed (SZA smaller than 90°).

The spectra from AAO were corrected for wavelength shift and convolved with a 1 nm triangular slit function before being submitted for the calibration.

Conclusions:

1. The spectral ratios between AAO and QASUME have on average an offset of -1.3 % with a diurnal variability of less than ±2%.
2. **All solar spectra are within the combined expanded uncertainties of AAO (4%) and QASUME (7.3% at wavelengths shorter than 310 nm and 1.7% at longer wavelengths).**

Comparison to previous QASUME site visits

The stability of AAO was assessed by comparing QASUME visits performed since 2006. As seen in figure 1, the campaign average ratio to QASUME has been stable to ±2%, except for the comparison performed in 2017 (the issue was explained in detail by Fountoulakis et al., 2020, ESSD and AAO the spectra were post-corrected accordingly.

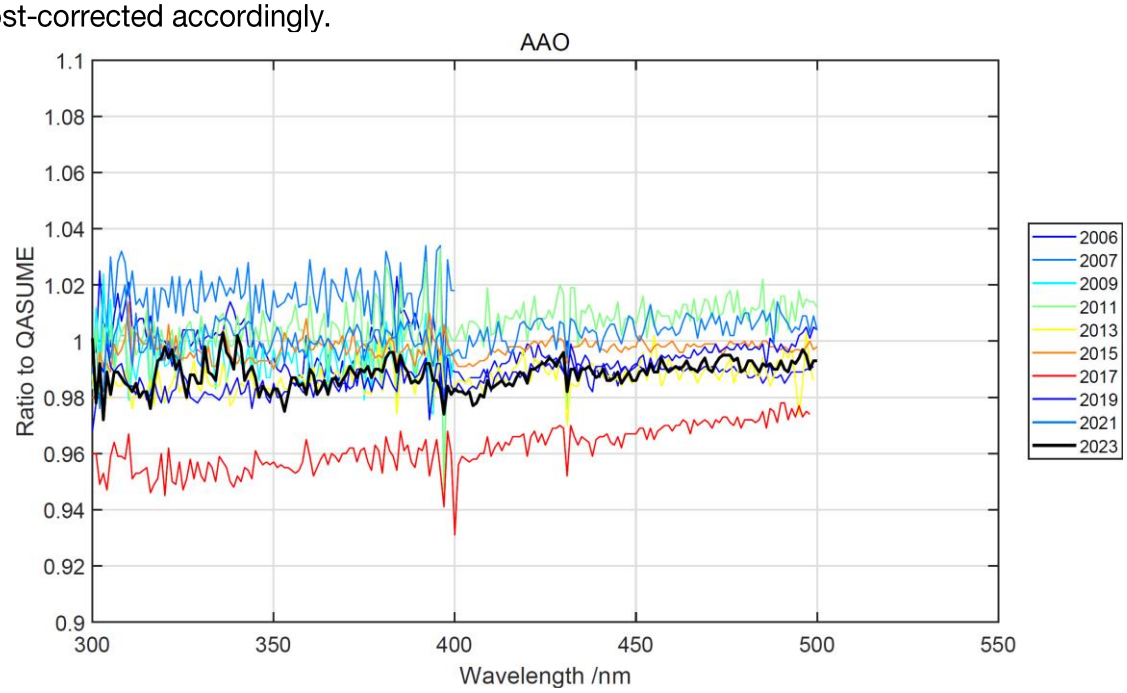


Figure 1 solar spectral ratios of AAO to QASUME averaged over each QASUME site visit.

Comparison of spectral irradiance standards from AAO and QASUME

On 17 May between 8:30 and 14:30 UT, AAO and QASUME measured the 1000W reference standard of ARPA AOSTA. QASUME measured the spectral irradiance of the 1000 W reference standard of AAO (F698) in its dark room facility from 250 nm to 500 nm and compared it to the F698 calibration certificate 2022_2505_02.

A spectrally uniform offset of +0.55% was observed between the spectral irradiance of F698 measured by QASUME and the spectral irradiance certificate

of F698 (Figure 2). The difference is within the combined expanded uncertainty of the QASUME spectral irradiance measurement and the uncertainty stated in the certificate.

The following tests were performed in the 1000W facility:

- Lowering the lamp by 4 mm to place the center of the filament on the alignment axis defined by the center of the entrance optic and the alignment laser: effect <0.1%.
- Placing a cloth over the entrance head, covering the baffle, and removing any back reflections behind the detector: effect <0.1%.
- Checking for back reflections behind the lamp: effect <0.1%.
- Removing the baffle to measure the room reflections: effect +1%.

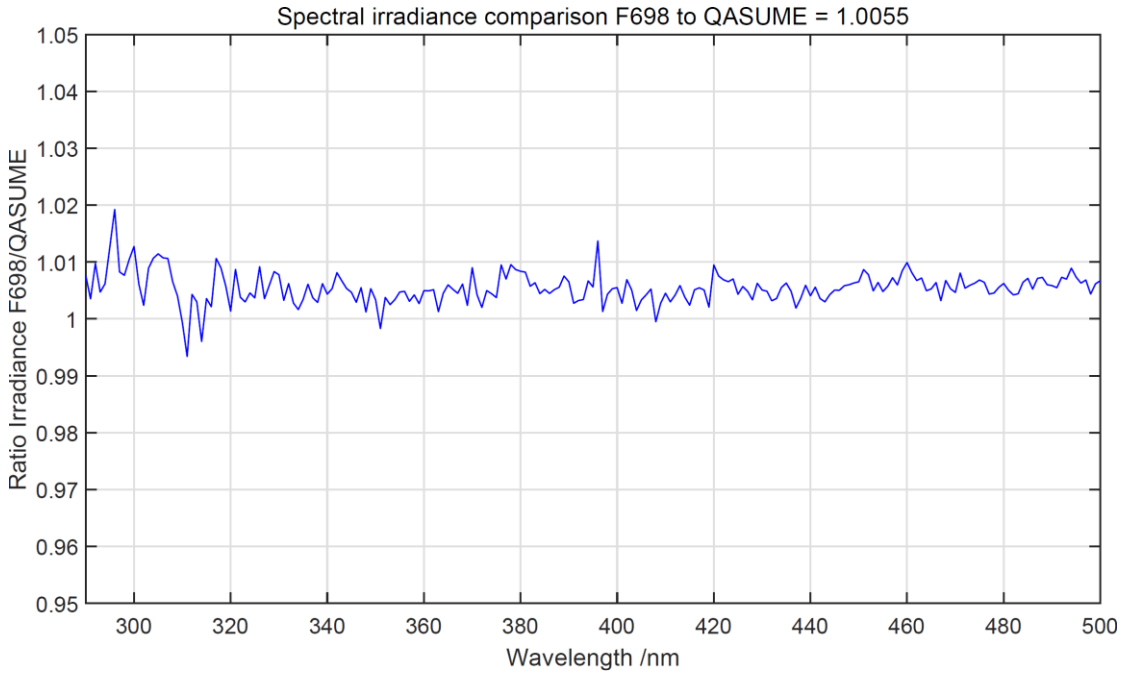


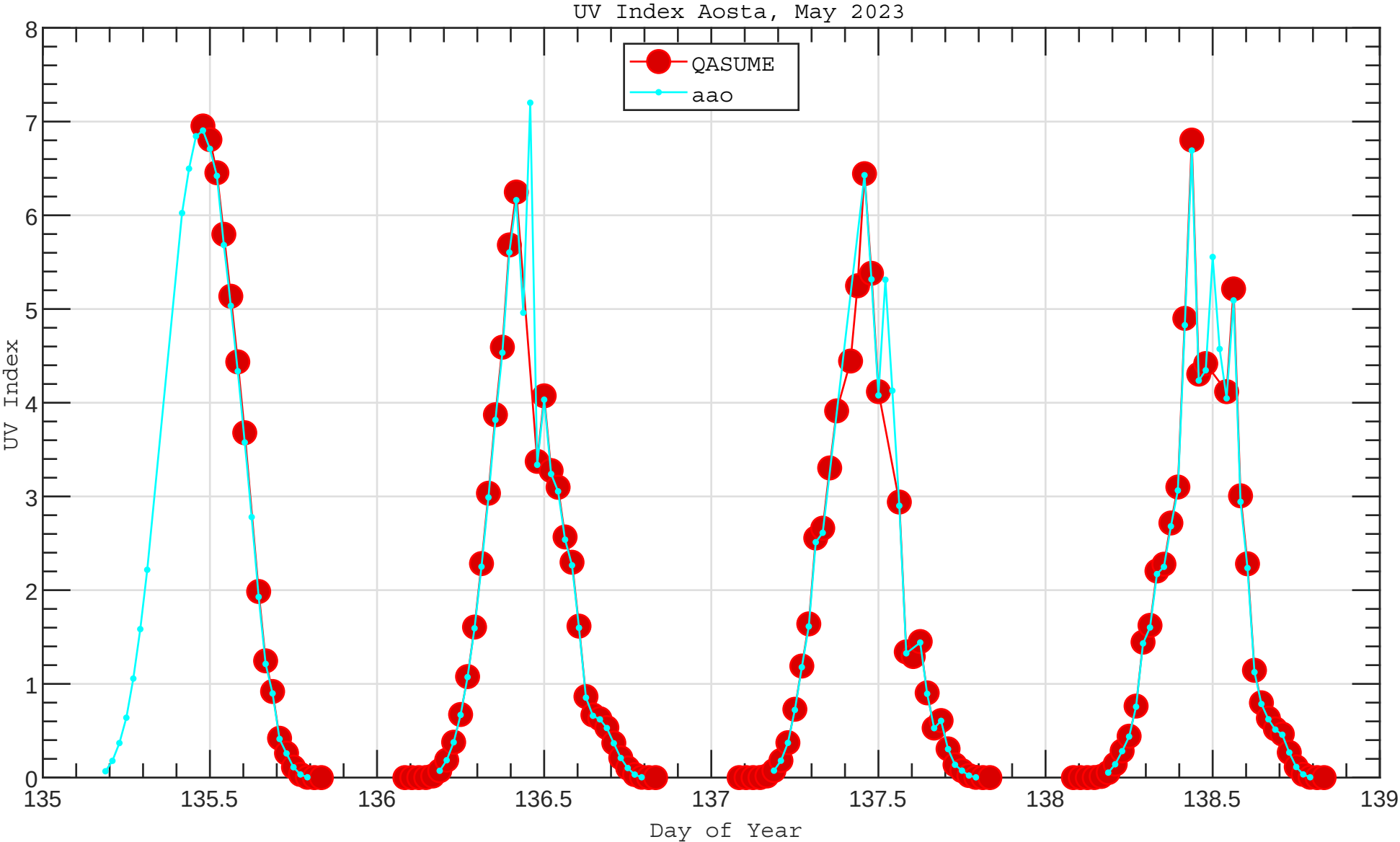
Figure 2 Ratio of spectral irradiance of transfer standard F698 measured with QASUME relative to the calibration certificate 2022_2505_02.

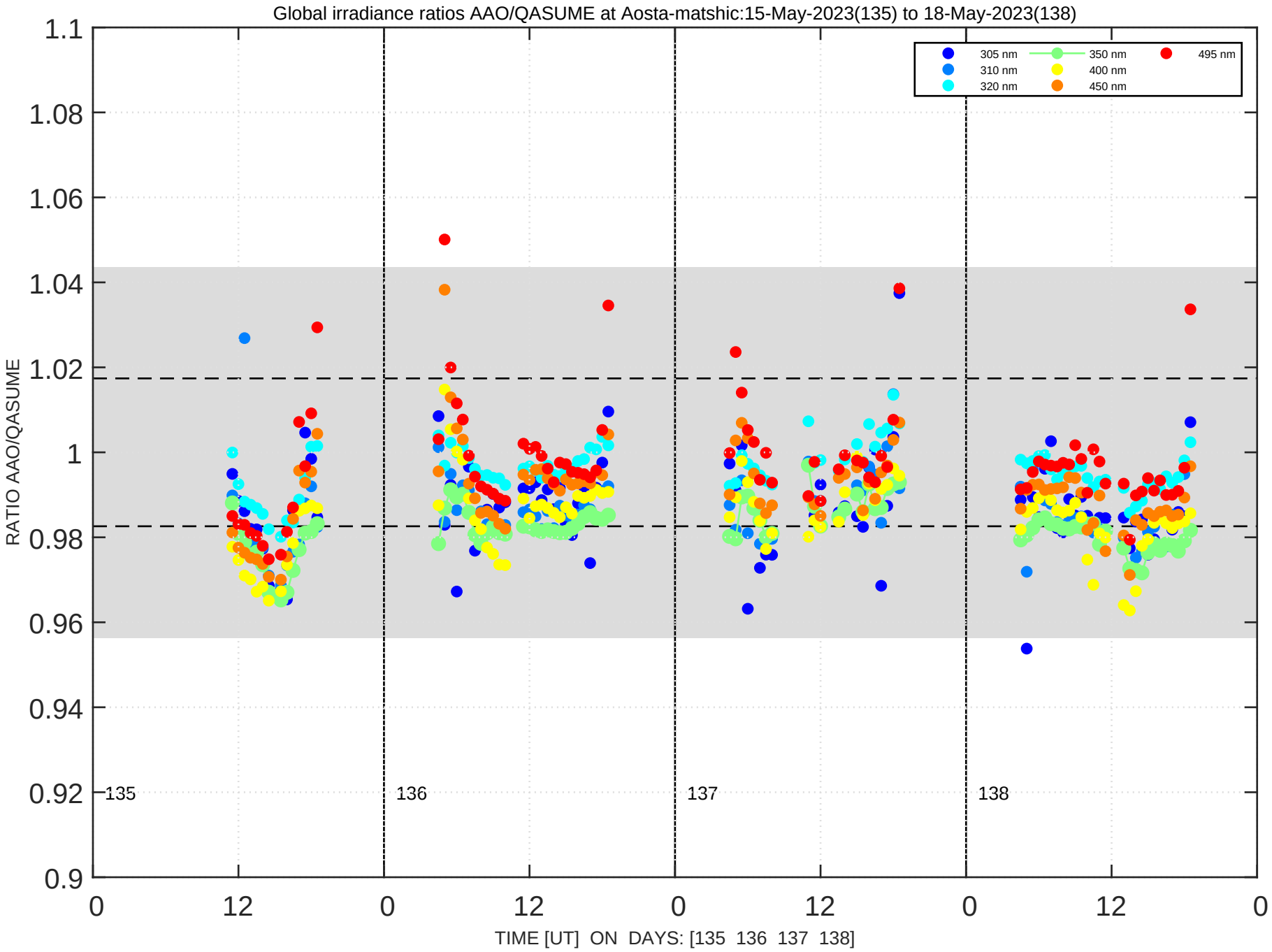
References

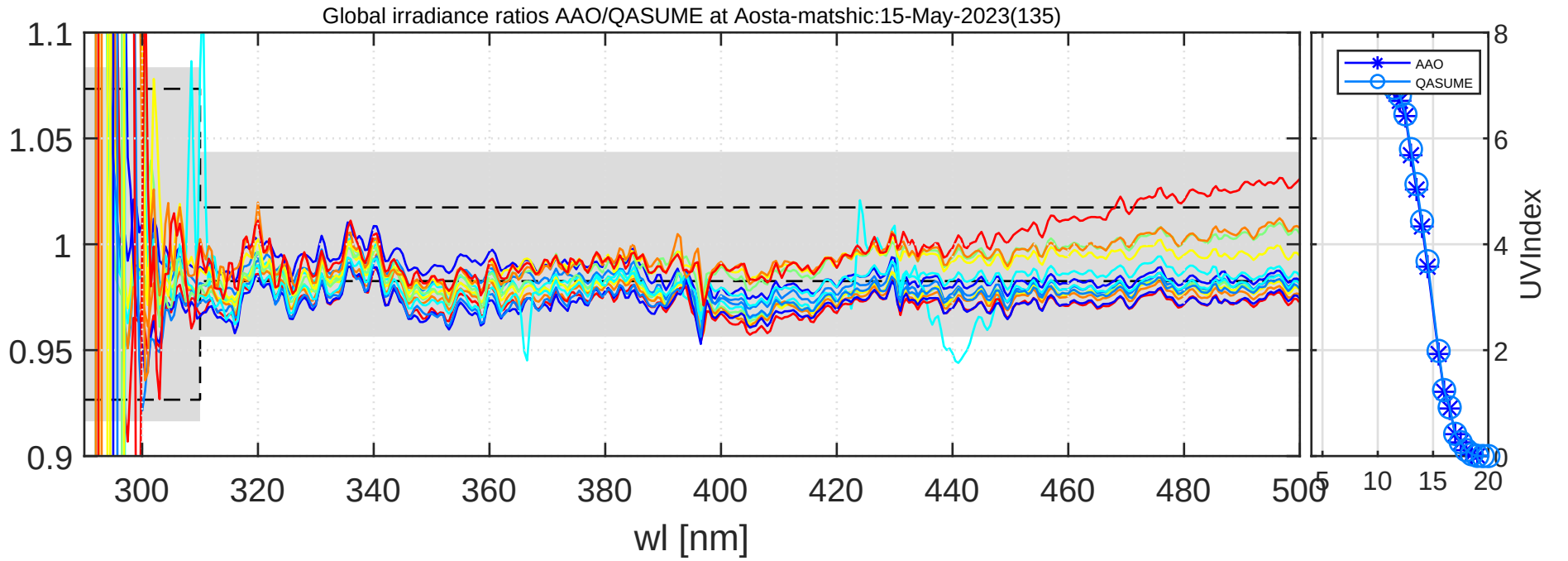
Fountoulakis, I., Diémoz, H., Siani, A. M., Hülsen, G., and **Gröbner, J.**: Monitoring of solar spectral ultraviolet irradiance in Aosta, Italy, Earth Syst. Sci. Data, 12, 2787–2810, https://doi.org/10.5194/essd-12-2787-2020, 2020.

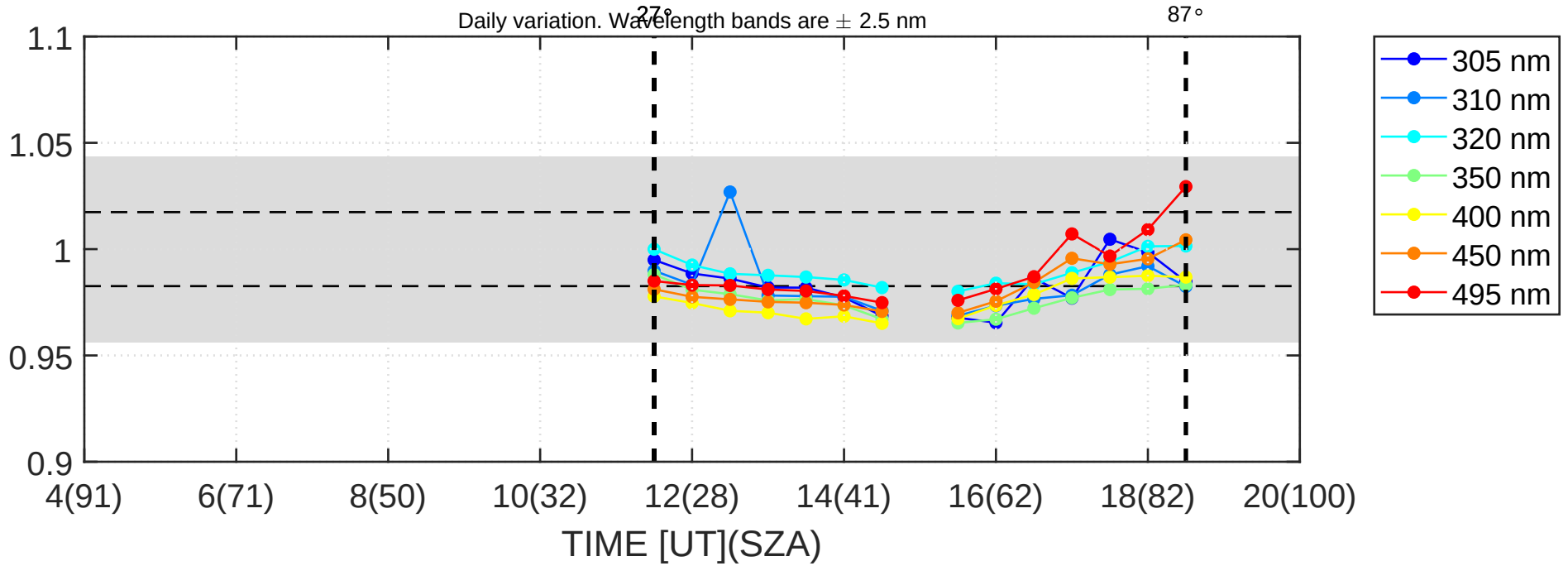
Comments from the local operator:

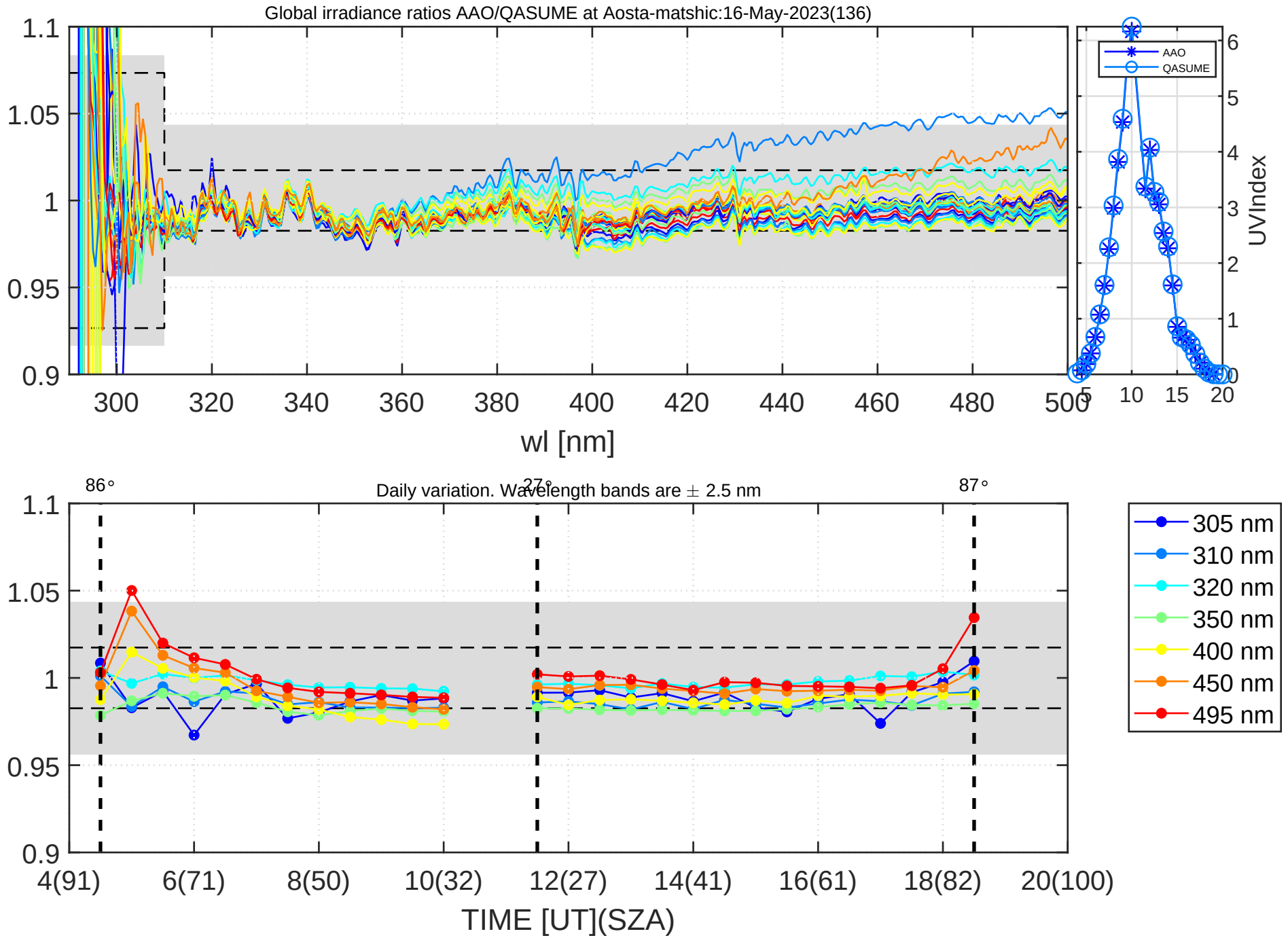
The visit and the additional tests in the laboratory allowed us to understand that our AAO measurements could be further improved by applying a cosine correction for the diffuse component. The irradiance of the final submitted spectra was multiplied by a correction factor of 1/0.991 (0.991 being the diffuse angular error, averaged over the 4 planes). We thank the PMOD operators for the time spent on the additional tests in our lab.

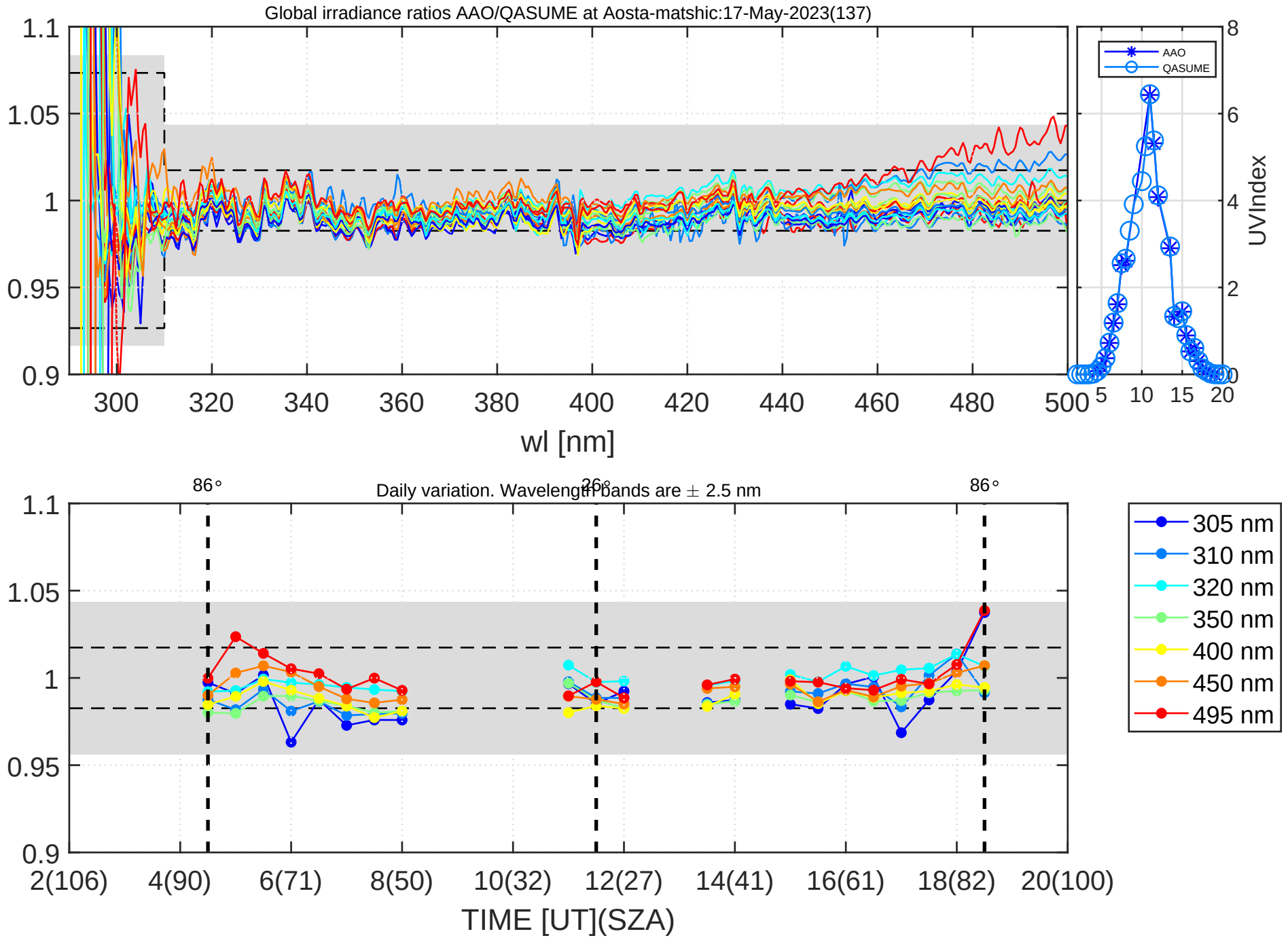

UV Index Aosta, May 2023
QASUME
aao
UV Index
Day of Year
0
1
2
3
4
5
6
7
8
135
135.5
136
136.5
137
137.5
138
138.5
139

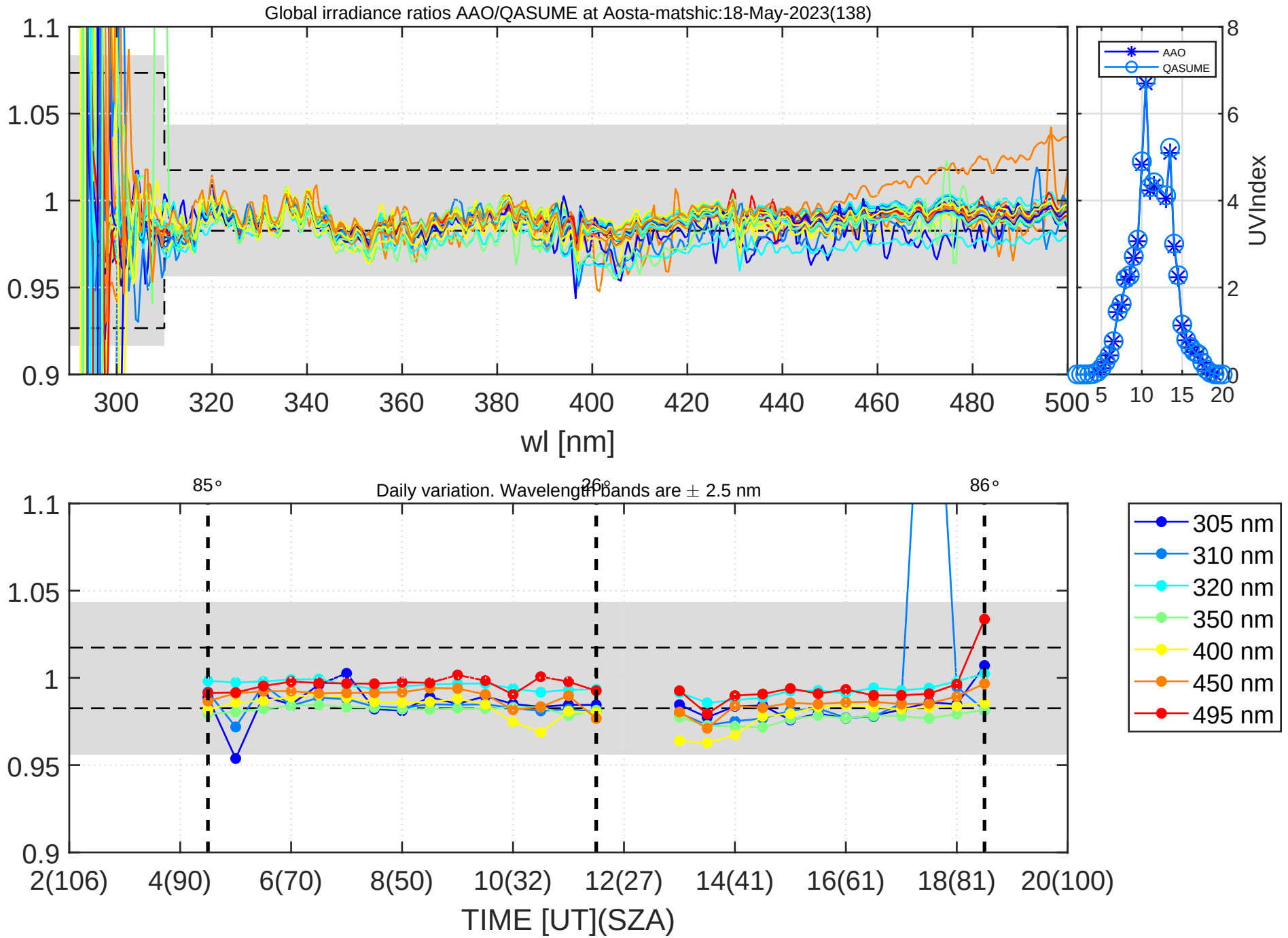

Global irradiance ratios AAO/QASUME at Aosta-matshic:15-May-2023(135) to 18-May-2023(138)
305 nm
310 nm
320 nm
350 nm
400 nm
450 nm
495 nm
RATIO AAO/QASUME
1.1
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0.9
135
136
137
138
0
12
0
12
0
12
0
12
0
TIME [UT] ON DAYS: [135 136 137 138]

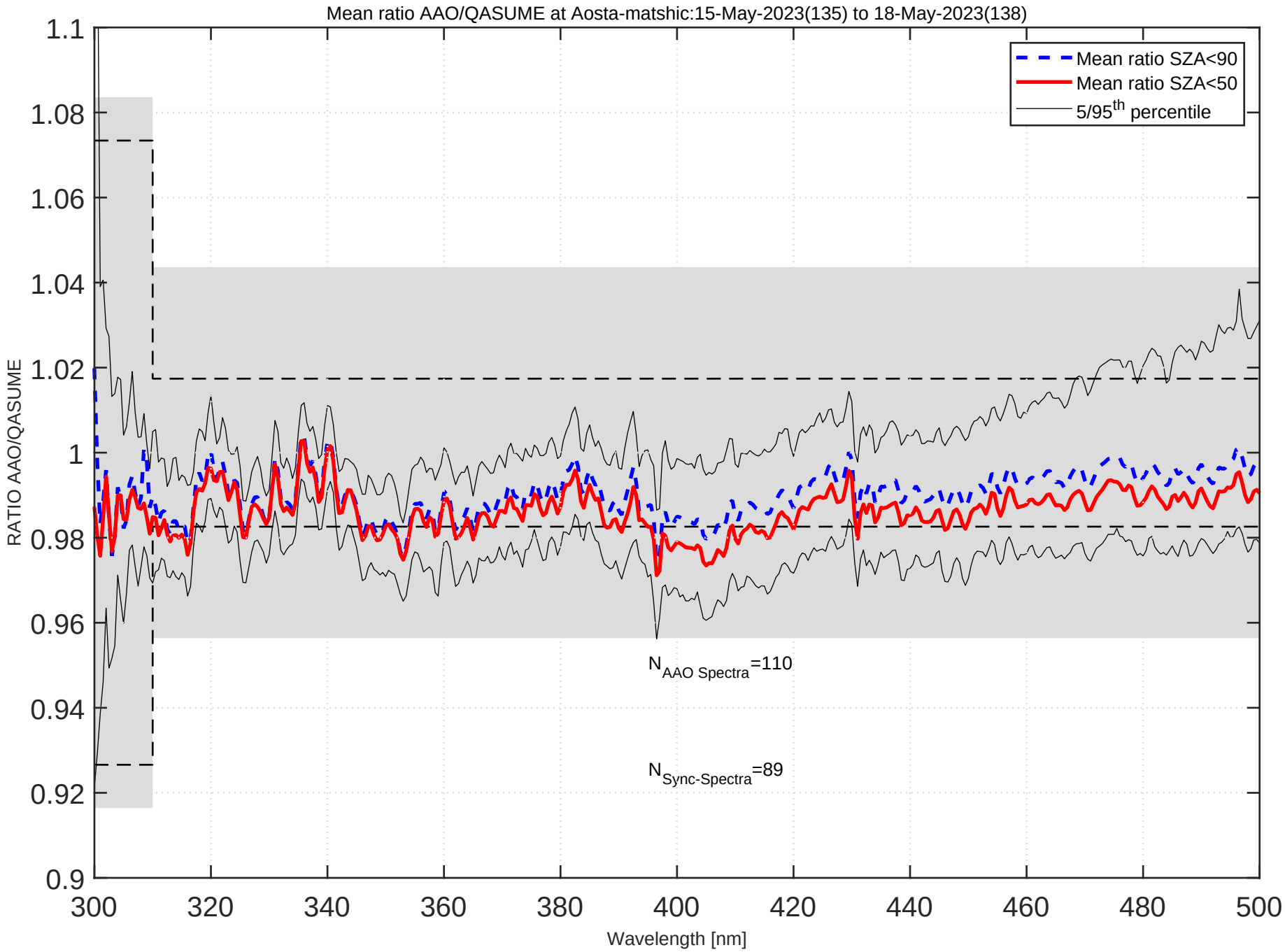

Global irradiance ratios AAO/QASUME at Aosta-matshic:15-May-2023(135)
1.1
1.05
1
0.95
0.9
300
320
340
360
380
400
420
440
460
480
500
wl [nm]
AAO
QASUME
8
6
4
2
0
5
10
15
20
UVIndex

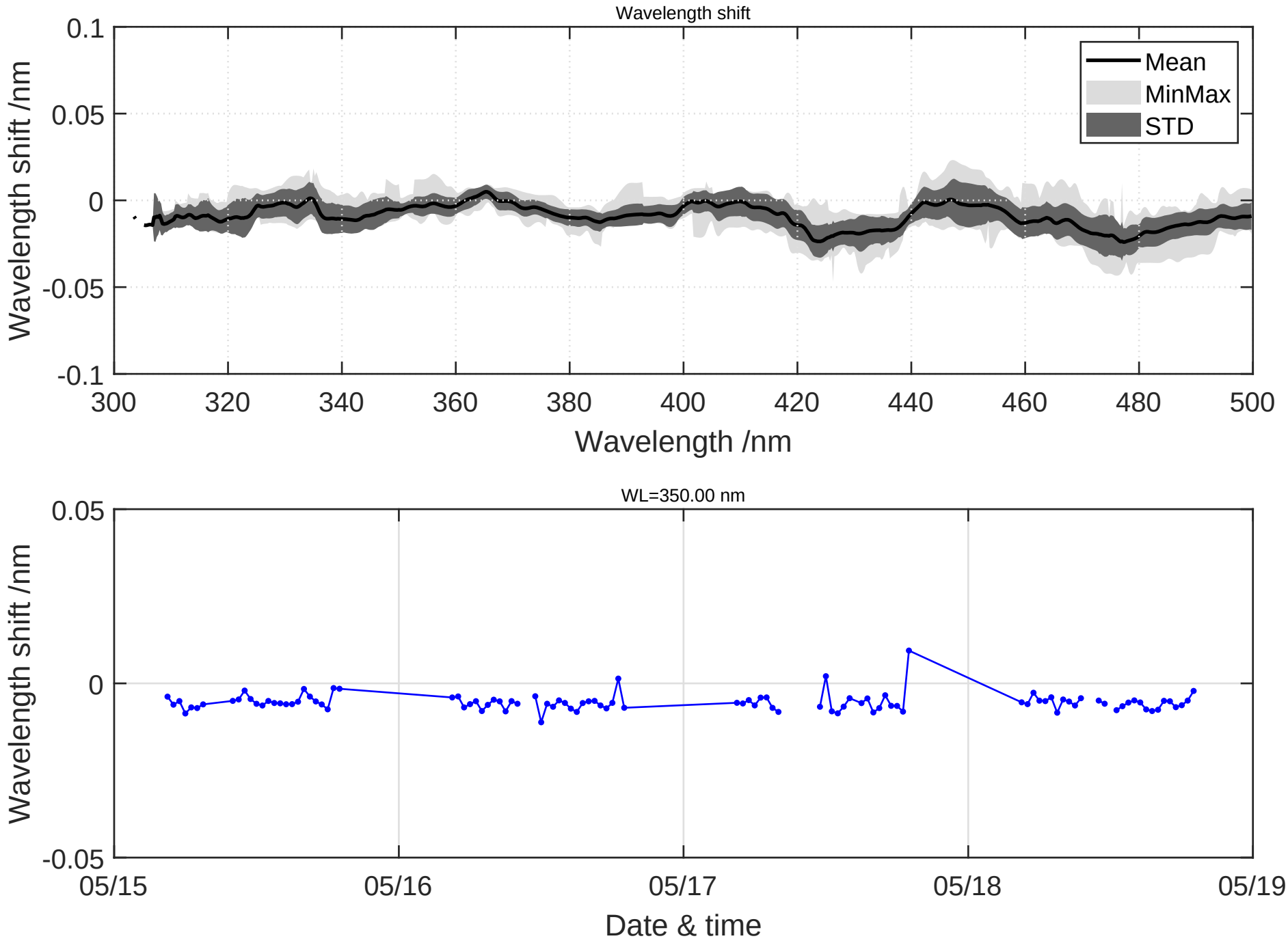

Daily variation. Wavelength bands are ± 2.5 nm
27°
87°
1.1
1.05
1
0.95
0.9
4(91)
6(71)
8(50)
10(32)
12(28)
14(41)
16(62)
18(82)
20(100)
TIME [UT](SZA)
305 nm
310 nm
320 nm
350 nm
400 nm
450 nm
495 nm

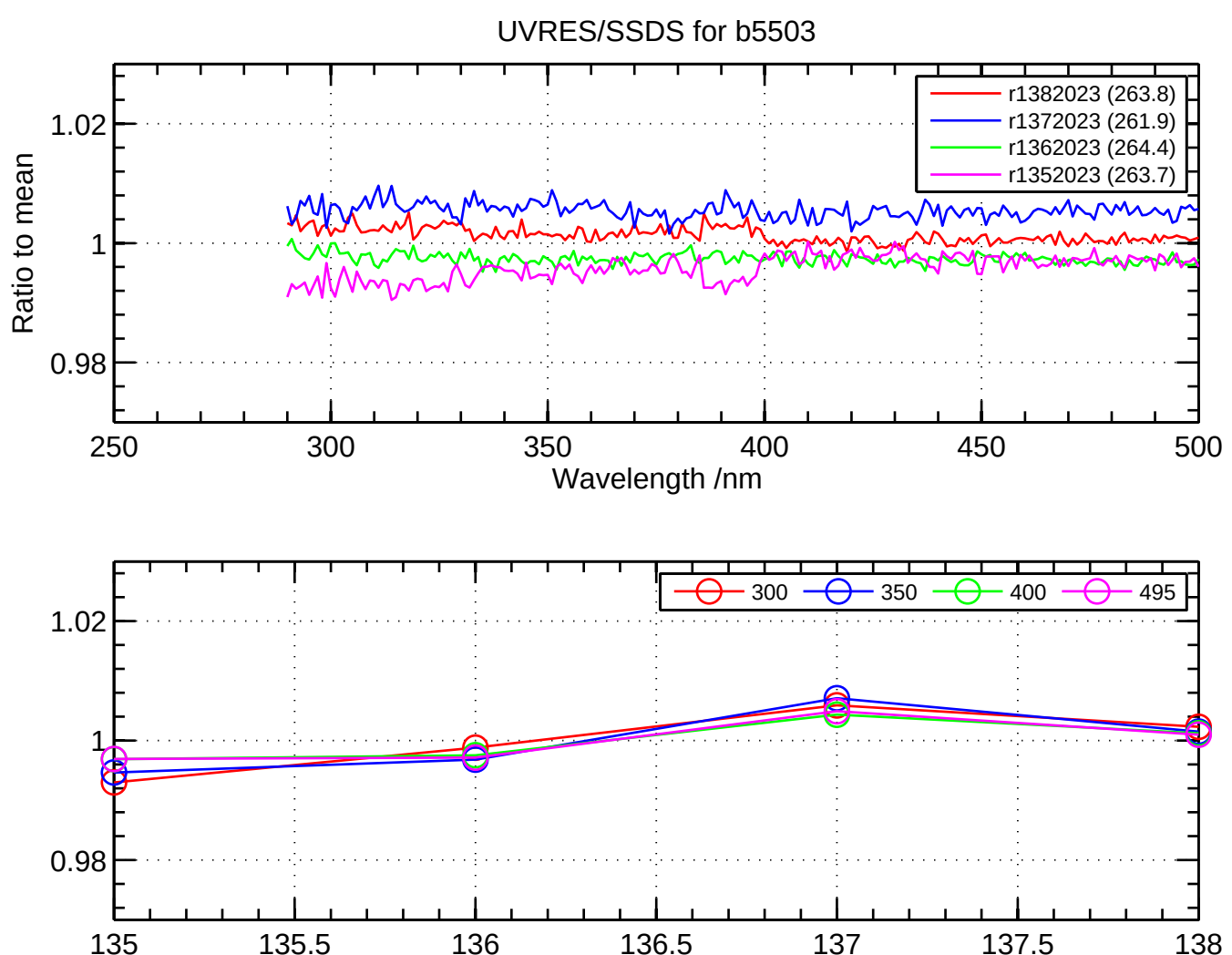

Global irradiance ratios AAO/QASUME at Aosta-matshic:16-May-2023(136)
1.1
1.05
1
0.95
0.9
300
320
340
360
380
400
420
440
460
480
500
wl [nm]
AAO
QASUME
UVIndex
6
5
4
3
2
1
0
5
10
15
20
86°
27°
87°
Daily variation. Wavelength bands are ± 2.5 nm
4(91)
6(71)
8(50)
10(32)
12(27)
14(41)
16(61)
18(82)
20(100)
TIME [UT](SZA)
305 nm
310 nm
320 nm
350 nm
400 nm
450 nm
495 nm

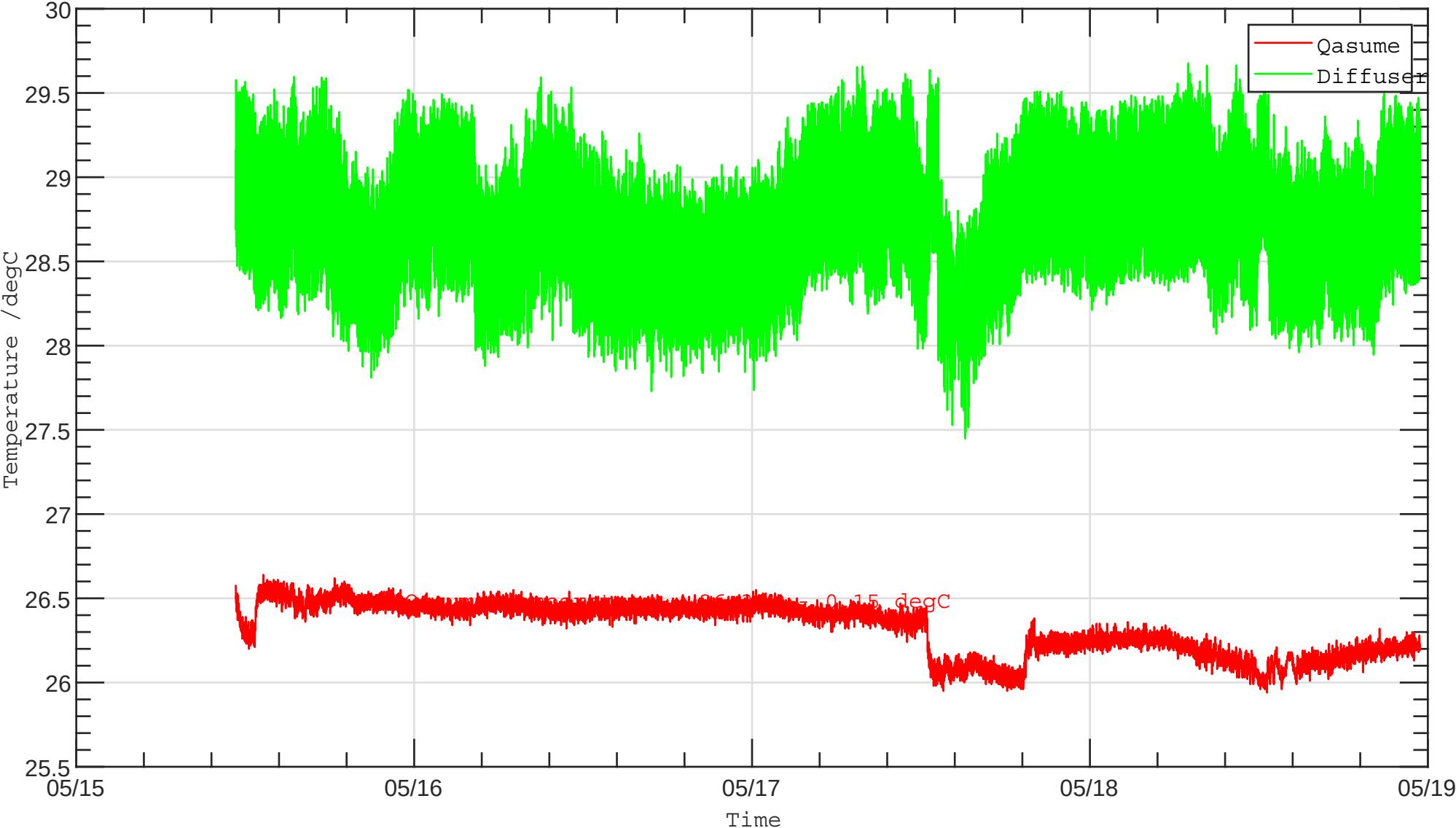

Global irradiance ratios AAO/QASUME at Aosta-matshic:17-May-2023(137)
1.1
1.05
1
0.95
0.9
300
320
340
360
380
400
420
440
460
480
500
wl [nm]
AAO
QASUME
8
6
4
2
0
5
10
15
20
UVIndex
Daily variation. Wavelength bands are ± 2.5 nm
86°
26°
86°
2(106)
4(90)
6(71)
8(50)
10(32)
12(27)
14(41)
16(61)
18(82)
20(100)
TIME [UT](SZA)
305 nm
310 nm
320 nm
350 nm
400 nm
450 nm
495 nm


Global irradiance ratios AAO/QASUME at Aosta-matshic:18-May-2023(138)
1.1
1.05
1
0.95
0.9
300
320
340
360
380
400
420
440
460
480
500
wl [nm]
AAO
QASUME
8
6
4
2
0
5
10
15
20
UVIndex
Daily variation. Wavelength bands are ± 2.5 nm
85°
26°
86°
2(106)
4(90)
6(70)
8(50)
10(32)
12(27)
14(41)
16(61)
18(81)
20(100)
TIME [UT](SZA)
305 nm
310 nm
320 nm
350 nm
400 nm
450 nm
495 nm


Mean ratio AAO/QASUME at Aosta-matshic:15-May-2023(135) to 18-May-2023(138)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
RATIO AAO/QASUME
Wavelength [nm]
N AAO Spectra=110
N Sync-Spectra=89
1.1
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0.9
300
320
340
360
380
400
420
440
460
480
500


Wavelength shift
Mean
MinMax
STD
Wavelength shift /nm
0.1
0.05
0
-0.05
-0.1
300
320
340
360
380
400
420
440
460
480
500
Wavelength /nm
WL=350.00 nm
Wavelength shift /nm
0.05
0
-0.05
05/15
05/16
05/17
05/18
05/19
Date & time


UVRES/SSDS for b5503
r1382023 (263.8)
r1372023 (261.9)
r1362023 (264.4)
r1352023 (263.7)
Ratio to mean
1.02
1
0.98
250
300
350
400
450
500
Wavelength /nm
300
350
400
495
1.02
1
0.98
135
135.5
136
136.5
137
137.5
138


Qasume
Diffuser
Temperature /degC
Time
30
29.5
29
28.5
28
27.5
27
26.5
26
25.5
05/15
05/16
05/17
05/18
05/19