Protocol of the intercomparison at Kirchbichl, IBK, Austria from August 19 to 23, 2024 with the travelling reference spectroradiometer QASUME from PMOD/WRC

Report prepared by Gregor Hülsen

Operator: Christian Thomann
Local operators: Josef Schreder, Barbara Klotz, Regine Gradl and Axel Kreuter

The purpose of the visit was the comparison of global solar irradiance measurements between the spectroradiometer operated by IBK and the travel reference spectroradiometer QASUME. The measurement site is located at Kirchbichl; Latitude 47.494° N, Longitude 12.092° E and altitude 490 m.a.s.l.
The horizon of the measurement site is free down to at least 85° solar zenith angle (SZA). Measurements between 4:30 UT and 17:30 UT were analysed.

QASUME was installed on the roof of the measurement container of IBK in the afternoon of August 19, 2024. The spectroradiometer was installed next to the entrance optic of IBK “ATI” with the entrance optic of QASUME within less than 2 m of “ATI”. The spectroradiometer “ATI” is a double monochromator of type DTM-300 of Bentham. The intercomparison between QASUME and ATI lasted 4.5 days, from the afternoon of Monday August 12 to noon of Friday August 23.

QASUME was calibrated several times during the intercomparison period using a portable calibration system. Four lamps (T16573, T68523, T157824 and T157825) 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 27.8±0.1 °C and the diffuser head was heated to a temperature of 29.1±0.5 °C.
The wavelength shifts relative to QASUMEFTS (Gröbner et al., 2017) spectrum as retrieved from the matSHIC analysis were between ±50 pm in the spectral range 300 to 550 nm.

Protocol:

The measurement protocol was to measure one solar irradiance spectrum every 20 minutes from 290 nm to 450 nm, every 0.25 nm, and 1.5 seconds between each wavelength increment. On Thursday the wavelength range was changed to 290 nm to 550 nm every 30 minutes.

DOY	Date	DAY	Weather	Comment (times are in UT)
232	19-Aug	Monday	Diffuse sky	Installed at 14:00 15:00 start UV measurements
233	20-Aug	Tuesday	Morning: Mostly diffuse Afternoon:Clear sky	11:18 Calibration T68523 12:40 Calibration T157824
234	21-Aug	Wednesday	Mostly diffuse sky Rain during the night	13:18 Calibration T68523 14:00 Calibration T16573
235	02-May	Thursday	Clear sky with cirrus clouds	14:00 Calibration T68523 15:00 Calibration T157825
236	03-May	Friday	Clear sky	12:00 Calibration T68523 12:15 QASUME OFF

Results:

In total 108 synchronised simultaneous spectra from QASUME and ATI are available from the measurement period. Measurements between 4:30 UT and 17:30 UT have been analysed (SZA smaller than 85°).

Conclusions:

1. The spectral irradiances measured by ATI are on average 1.0% lower than those of QASUME.
2. The average ratio between ATI and QASUME decreases during the four days of the intercomparison from unity to around -3%.
3. The temporal variation of the spectra between ATI and QASUME was stable, to within 2% for wavelengths shorter than 400 nm. At longer wavelengths, a diurnal variation of up to 5% could be seen in the SZA range between approximately 45° and 90°, which could be due to a non-accounted cosine error.
   For wavelengths below 310 nm a higher variability was observed. This is very likely due to a small synchronization issue as explained in the comments of the local operator.
4. The wavelength shifts of ATI relative to the high spectral resolution solar spectrum TSIS-1 HSRS are between ±50 pm in the spectral range 300 nm to 550 nm.

Comparison to previous QASUME site visits

The previous QASUME visits were in 2002, 2010 and 2015, see reports at https://www.pmodwrc.ch/en/world-radiation-center-2/wcc-uv/qasume-site-audits/

As seen in figure 1 the campaign average ratio of ATI to QASUME are within ±4 % since 2002.

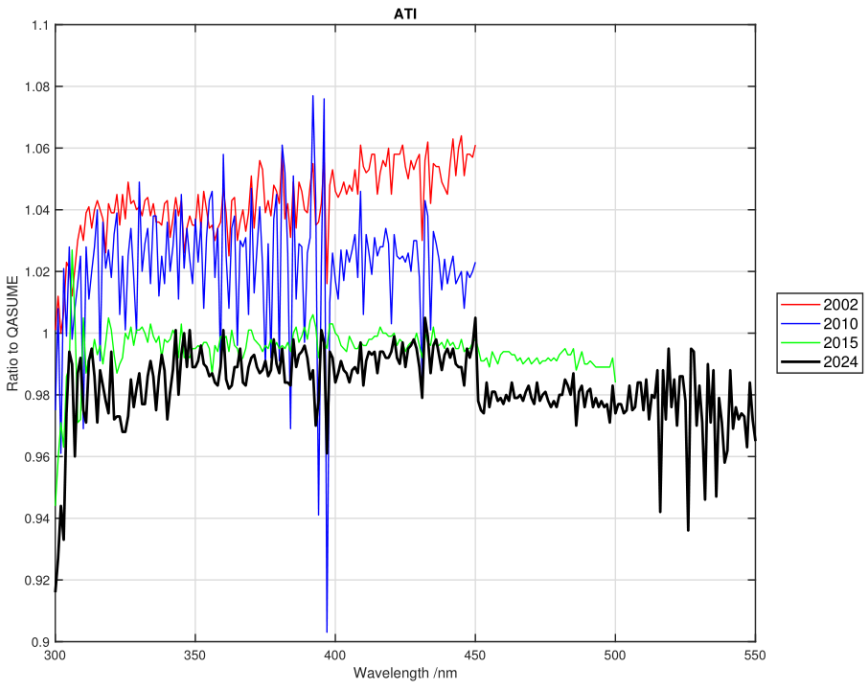


Figure 1: Solar spectral ratios of ATI to QASUME averaged over each QASUME site visit

Summary:

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

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

With U_{qas} = 1.74%, U_{qas} = 7.34% (y<300 nm) (Hülsen et al., 2016). U_{ATI} was estimated to be 4%.

The following points should be investigated in more detail:

1.) The combined expanded uncertainty of the comparison is shown in the Figures (see Appendix) as grey area (dotted lines show the uncertainty of Qasume). We strongly recommend deriving an uncertainty budget for the UV measurements at IBK.
2.) The diurnal variability of ATI indicates a cosine error. 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

QASUME Intercomparison 19.08.2024 – 23.08.2024 Kirchbichl (Container)

Date	Time (UTC)	Remarks
Monday 19.08.		Whole day cloudy (in between also rain)
	11:00 – 12:45	Calibration measurements of three secondary standards (K5, K7 and K6) - The measurements were within 0.5% in comparison to the measurements done on 22.05.2024
	13:00	Arrival of QASUME, starting to set everything up
	15:00 – 18:00	First measurements: 290:0.25:450, every 20 min (0,20,40), starting at 15:00 UTC, until 18:00 UTC - No proper synchronization between QASUME and ATI yet - due to internet issues, the time synchronization with the internet was not working properly on the spectrometer PC (ATI)
Tuesday 20.08.		Morning cloudy, afternoon got sunny with clear sky, cosinus error for high sza is visible
	04:00 – 12:00	Measurements: 290:0.25:450, synchronized with QASUME 1.5s, every 20 min - due to the internet issue still no time synchronization with the internet at the spectrometer PC
	12:00 – 14:20	- No measurements - Internet issue was solved, by installing a router with a pre-paid card, from 14:20 (UTC) the time of the spectrometer was synchronized with the internet (every 20 min)
	14:20 – 18:00	Measurements: 290:0.25:450
Wednesday 21.08.	04:00 – 12:00	- Whole day cloudy - Measurements: 290:0.25:450, every 20 min / synchronized
Thursday 22.08.		Sunny, clear sky with cirrus clouds
	04:00 – 18:00	Measurements: 290:0.25:550, every 30 min, synchronized 1.5s
	11:00	Temp. Glo Head 37.8°C
Friday 23.08.		Sunny, clear sky
	04:00 – 11:30	Measurements: 290:0.25:550, every 30 min
	05:20	Check of the instrument leveling: ok
	06:30 - 7:26	Rotation of 180° to check for azimuth error (for two spectra at 06:30 and 07:00)
	07:30	Back-Rotation of 180° -> conclusion: no azimuth error, no issues with the glass fiber
	11:30	- Last measurement at 11:30 UTC - Glo head Temp 41.6°C

General Remarks:

- Global head description:
  - Hemisphere shaped Teflon diffusor
  - Heating to up to approximately 22°C decrease the temperature dependency of the Teflon for low temperatures
- No global head temperature measurements available:
  - Usually, the global head temperature is measured routinely. Unfortunately, due to a defect caused by lightning shortly before the campaign the global head temperature was not measured, which led to higher uncertainties in the temperature correction (1-2%).
  - To correct for the global head temperature, additional measurements have been performed on the 28.08. There, the sensitivity of the global head in dependence to the global head temperature has been examined. A sensitivity dependency of 1.5 % between 28°C to 42°C has been found. Therefore, a temperature correction has been applied to the data in dependence on the outside temperature.
- Calibration measurements:
  - 22.05.2024: measurements of three secondary lamps and two primary lamps (traceable to PTB and PMOD)
  - 19.08.2024: measurements of three secondary lamps just before the campaign
  - 28.08.2024: measurements of three secondary lamps and two primary lamps

Result:

- Comparison of 19.08. with 22.05.: the secondary lamps are within 0.5%
- Comparison of 28.08. with 19.08.: the secondary lamps have an offset of -3.5%
- Comparison of 28.08. with 22.05.: the primary lamps have an offset of -4%

We concluded, that on Monday 19.08. after the calibration measurements of the secondary lamps, and during the setup of several instruments (QASUME, BTS from ATI) some impact on the spectrometer led to a loss in sensitivity. Therefore, the data was corrected by 4 % derived from the primary lamp measurements (traceable to PMOD), which also corresponds to the comparison with the QASUME spectroradiometer.

- Cosine Error:
  - On clear sky days, a cosine error of the global head is visible
    - The ARF of the global head has been measured in 2007 (323 nm – 420 nm). Since the influence is small in this region, no correction is applied.
  - To exclude an azimuth error, the global head has been rotated by 180° → no azimuth error could be found
- Time Synchronization Error:
  - For small wavelengths and small angles, a time synchronization issue appeared because the ATI instrument is programmed with a dynamic integration time up to 2 seconds per wavelength step to improve the accuracy of the measured data. Even when operated in synchronized mode, this could lead to prolonged measurement times especially for low intensities. Therefore, the QASUME and ATI measurements diverged as the timing was not synchronized anymore (see Fig. 2).
  - For the next intercomparison, using a step size of 0.5 nm for the ATI instrument should reduce the time delay issue.

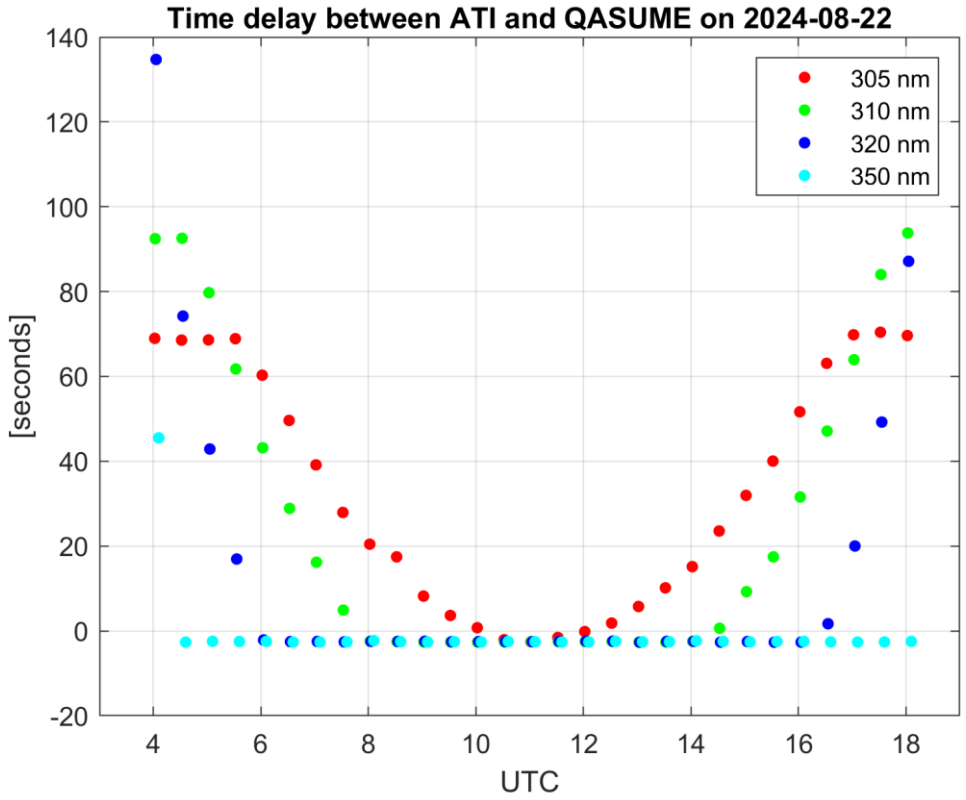
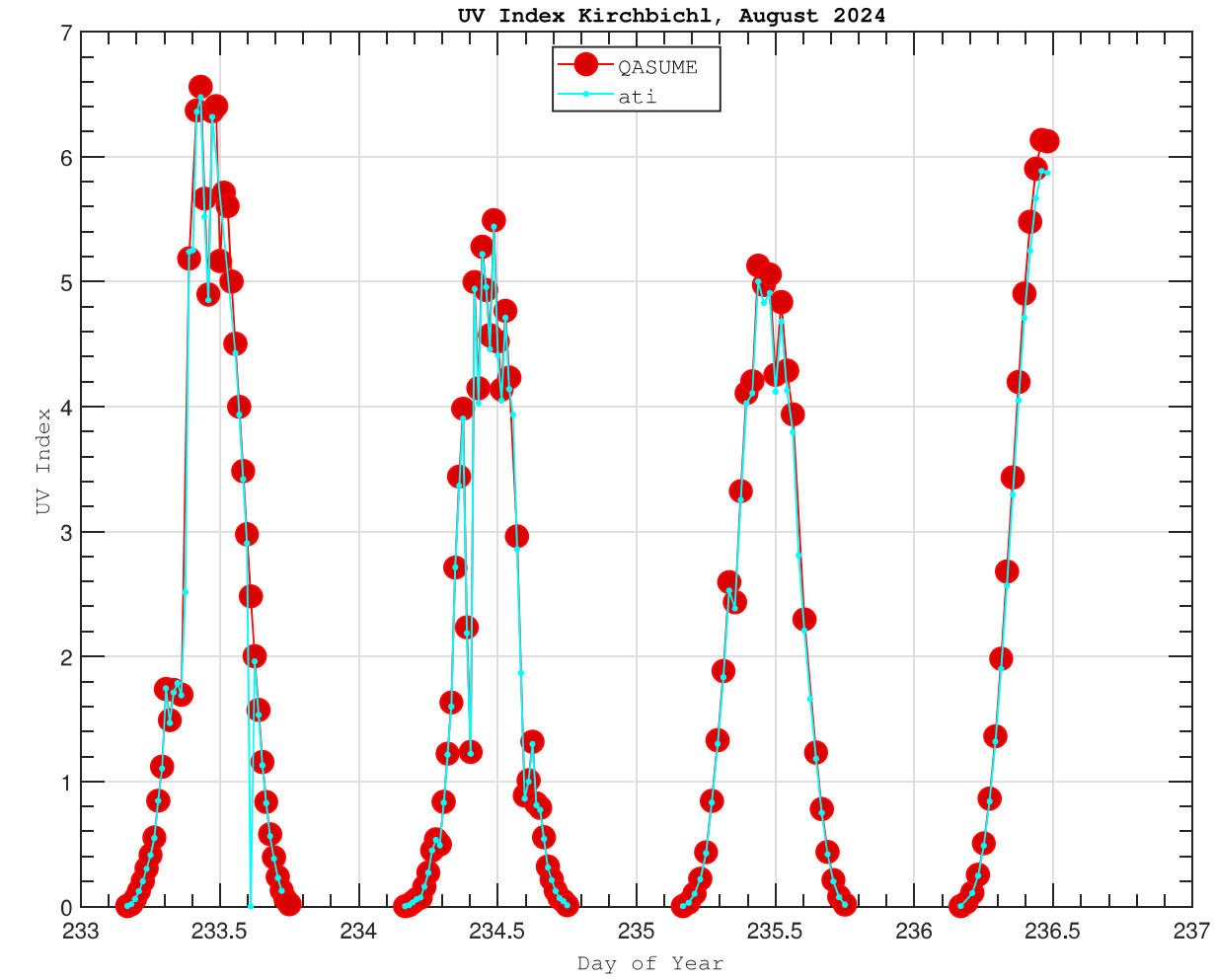
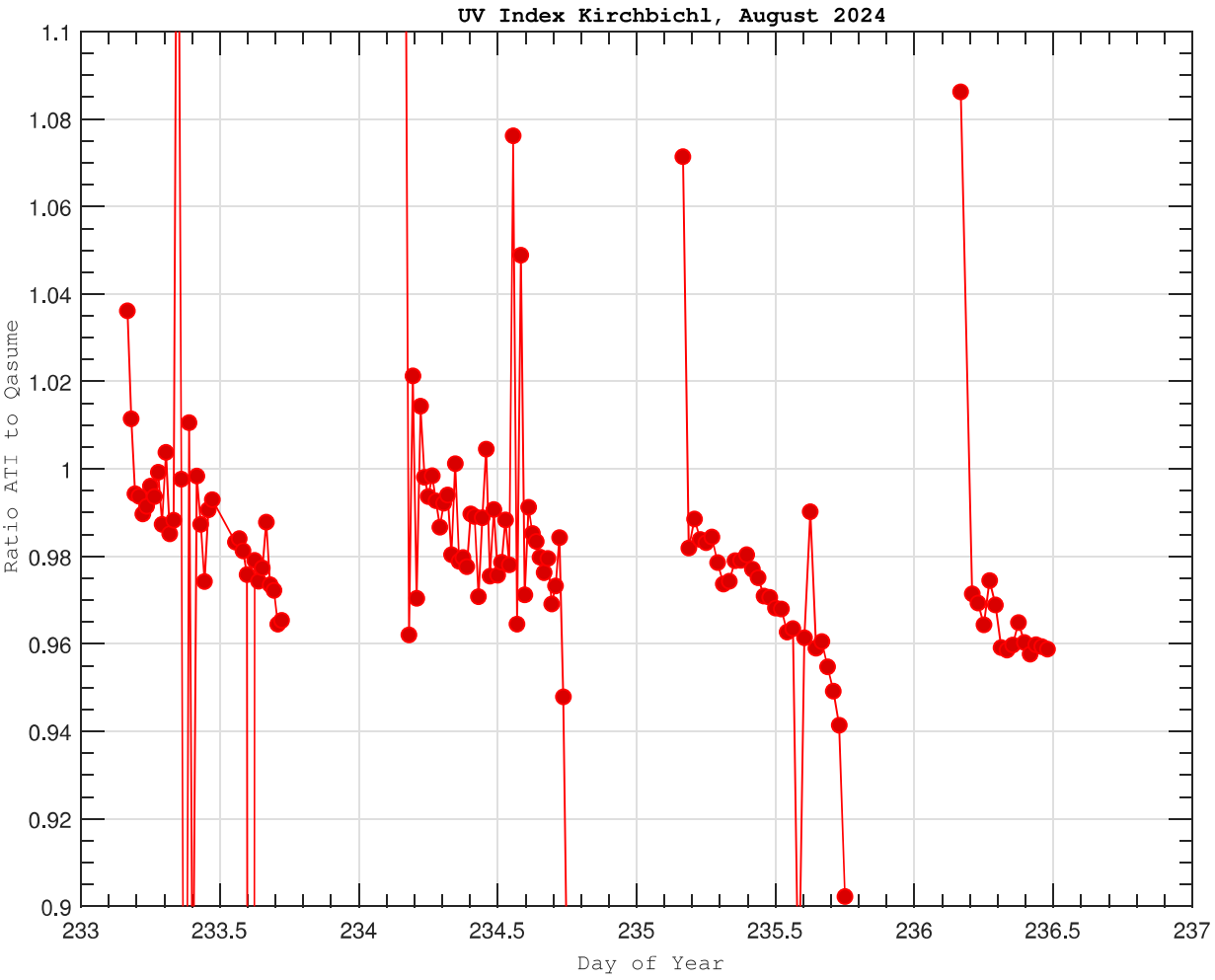


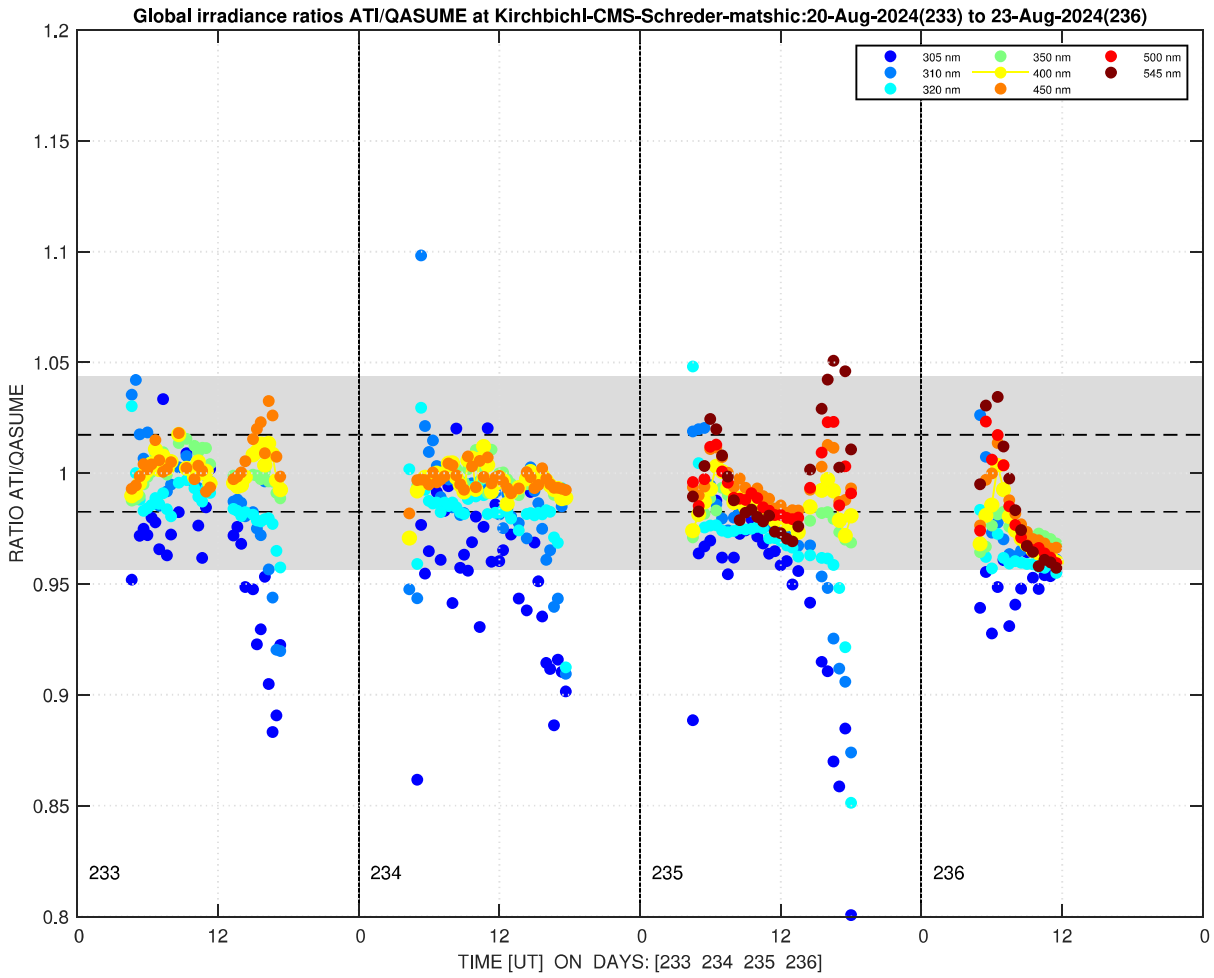
Fig. 2: Time delay between ATI and QASUME, due to the dynamic integration time of ATI. The delay is large for small intensities.

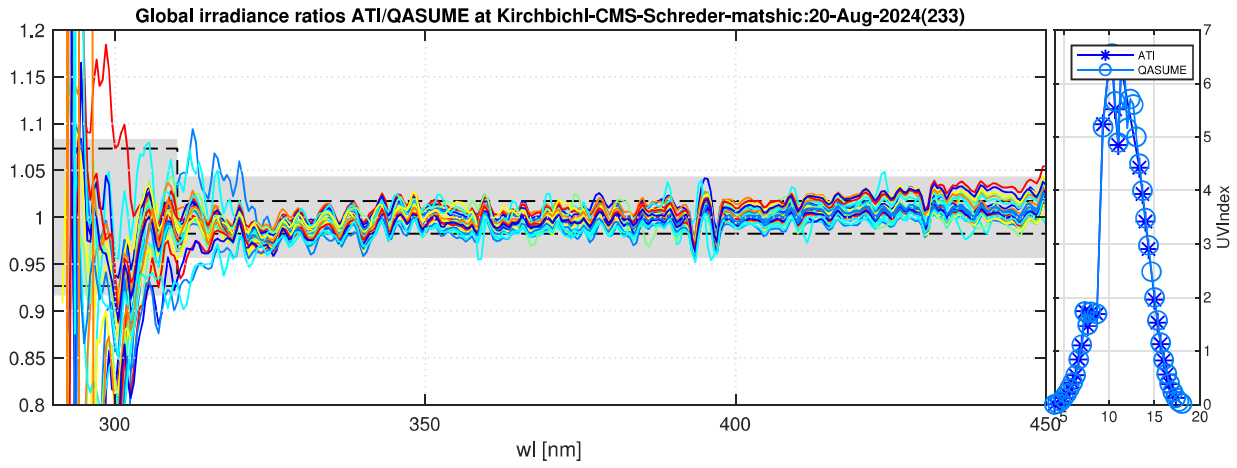
Appendix

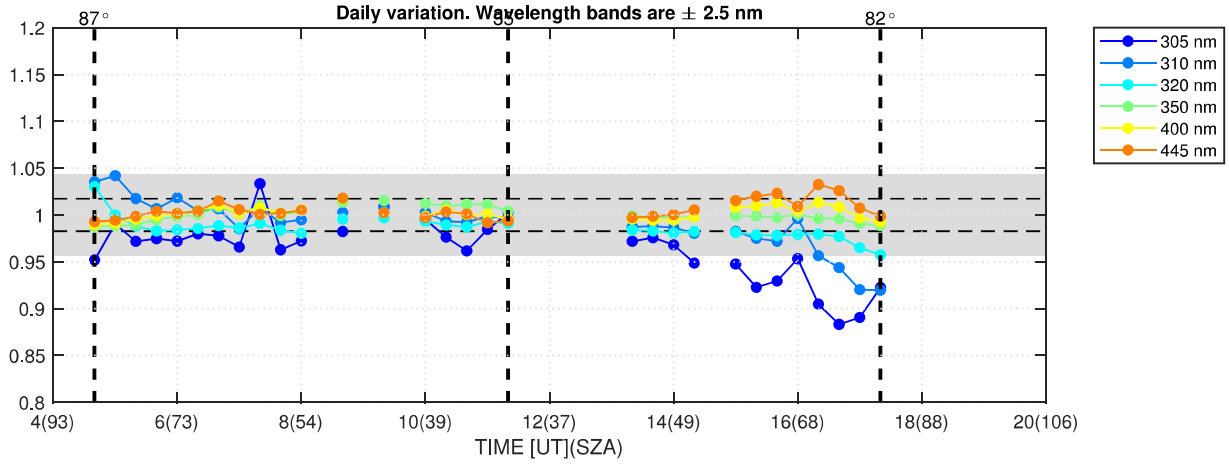
Detailed results for all local spectrophotometers with respect to the reference spectroradiometer QASUME

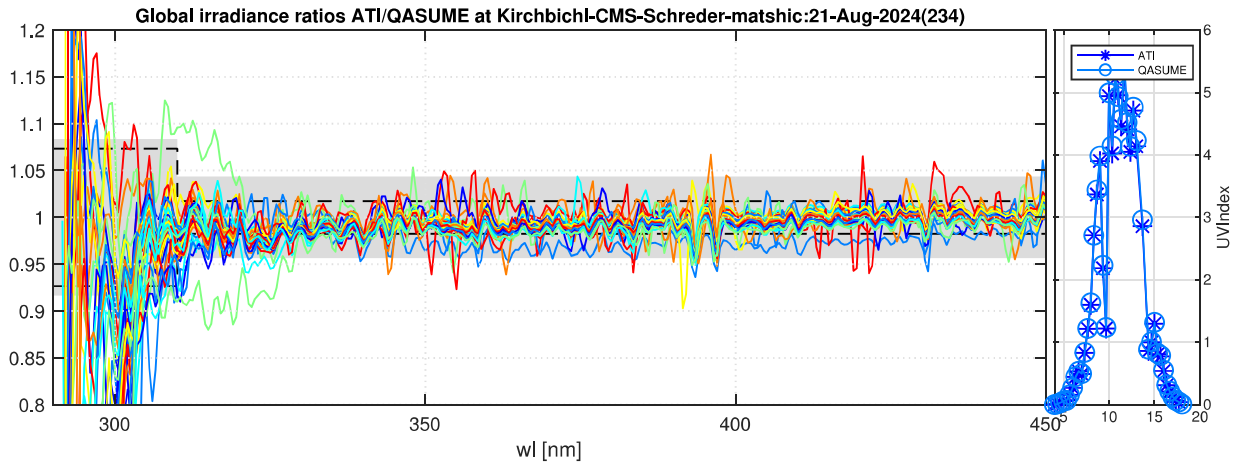

UV Index Kirchbichl, August 2024
QASUME
ati
UV Index
Day of Year
0
1
2
3
4
5
6
7
233
233.5
234
234.5
235
235.5
236
236.5
237

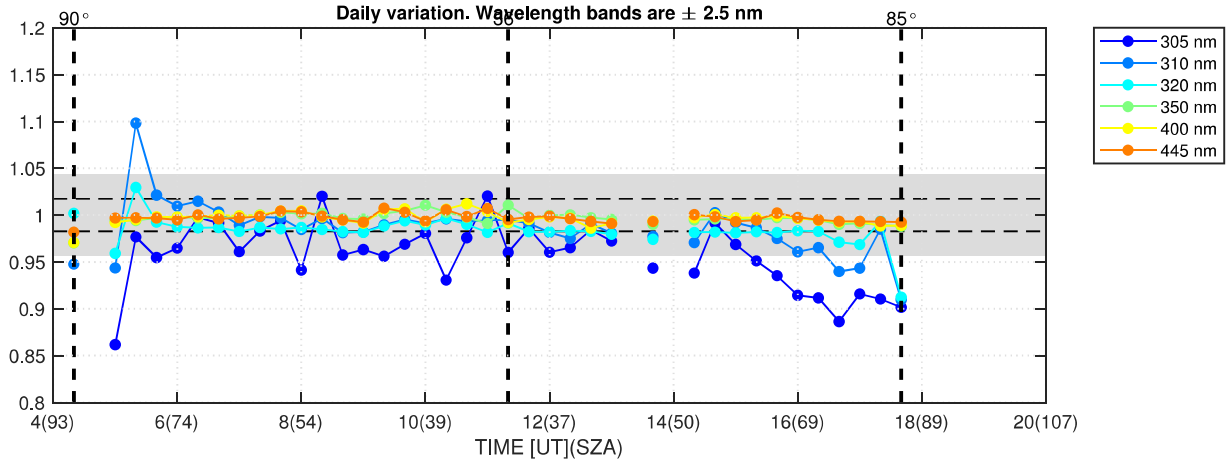

UV Index Kirchbichl, August 2024
Ratio ATI to Qasume
Day of Year
0.9
0.92
0.94
0.96
0.98
1
1.02
1.04
1.06
1.08
1.1
233
233.5
234
234.5
235
235.5
236
236.5
237

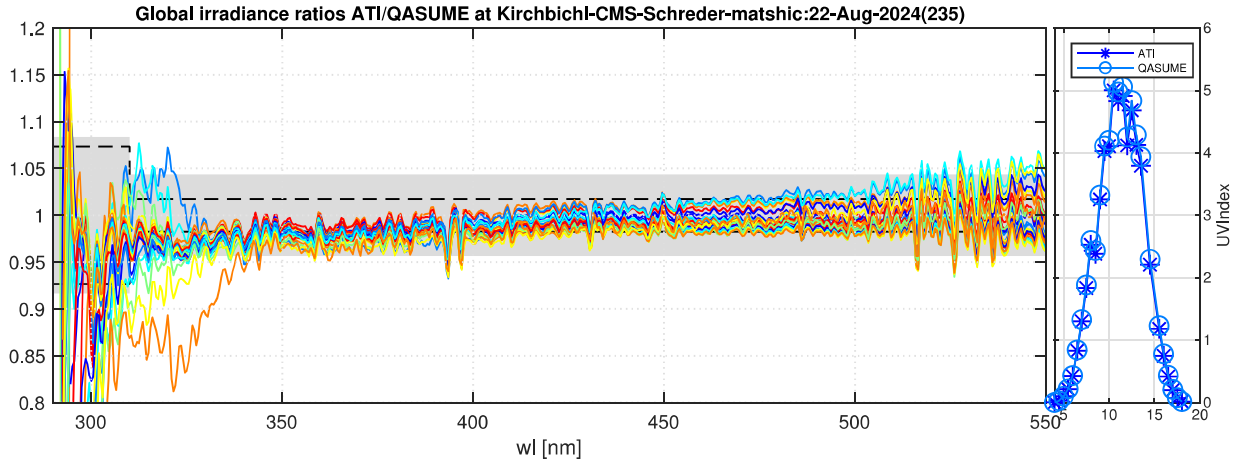

Global irradiance ratios ATI/QASUME at Kirchbichl-CMS-Schreder-matshic:20-Aug-2024(233) to 23-Aug-2024(236)
305 nm
310 nm
320 nm
350 nm
400 nm
450 nm
500 nm
545 nm
RATIO ATI/QASUME
233
234
235
236
TIME [UT] ON DAYS: [233 234 235 236]

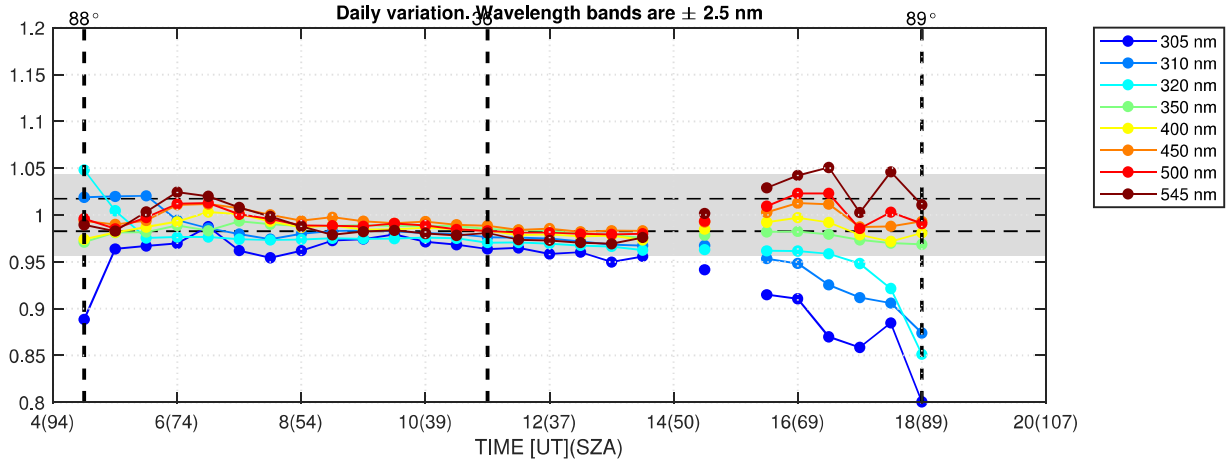

Global irradiance ratios ATI/QASUME at Kirchbichl-CMS-Schreder-matshic:20-Aug-2024(233)
ATI
QASUME
UVIndex
wl [nm]

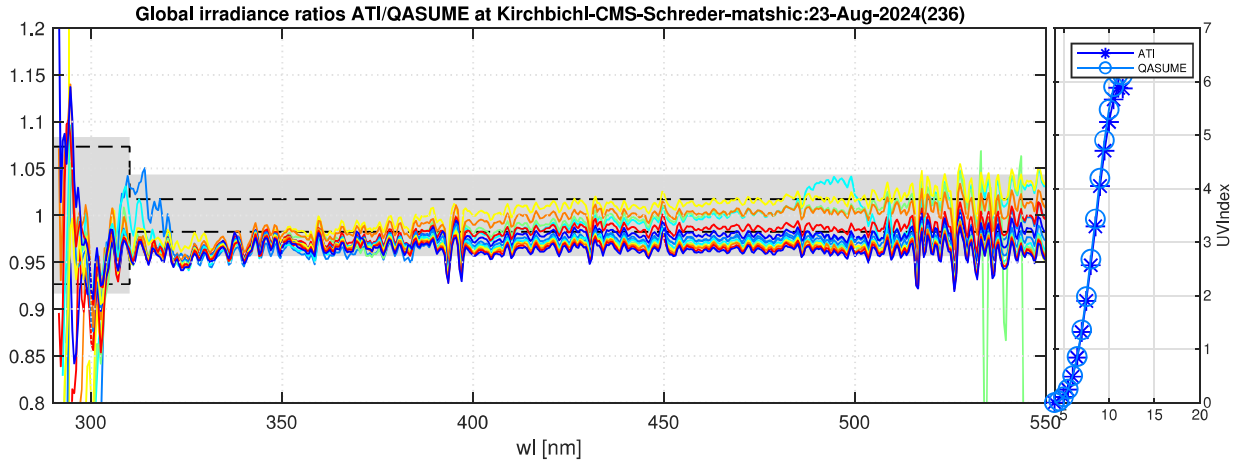

Daily variation. Wavelength bands are ± 2.5 nm
87°
82°
305 nm
310 nm
320 nm
350 nm
400 nm
445 nm
TIME [UT](SZA)

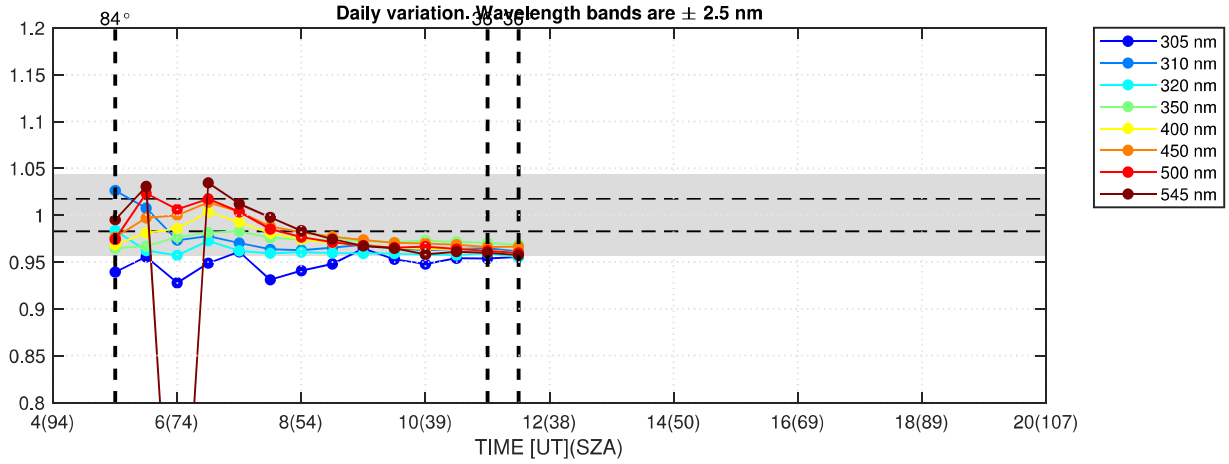

Global irradiance ratios ATI/QASUME at Kirchbichl-CMS-Schreder-matshic:21-Aug-2024(234)
ATI
QASUME
UVIndex
wl [nm]

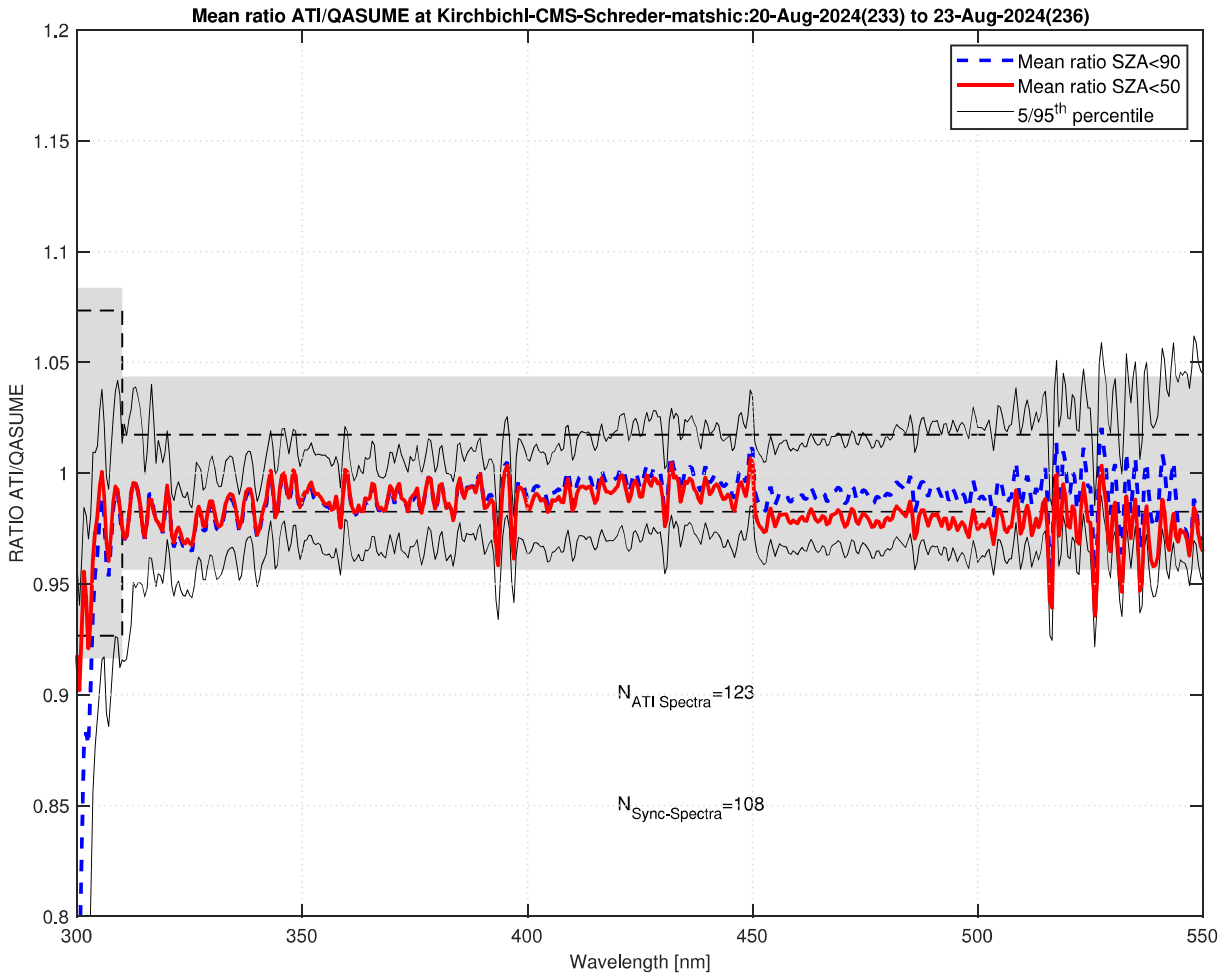

Daily variation. Wavelength bands are ± 2.5 nm
90°
85°
305 nm
310 nm
320 nm
350 nm
400 nm
445 nm
TIME [UT](SZA)

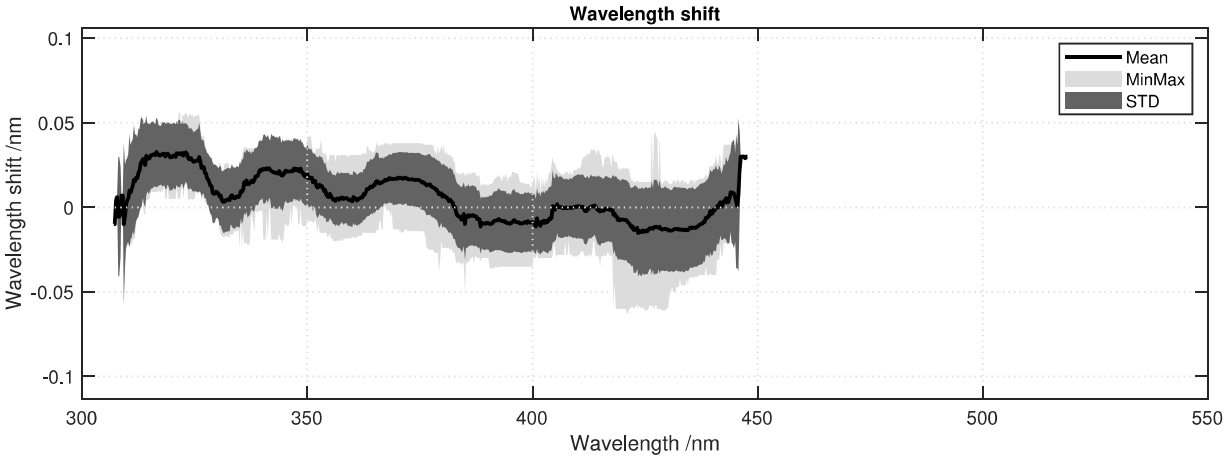

Global irradiance ratios ATI/QASUME at Kirchbichl-CMS-Schreder-matshic:22-Aug-2024(235)
ATI
QASUME
UVIndex
wl [nm]

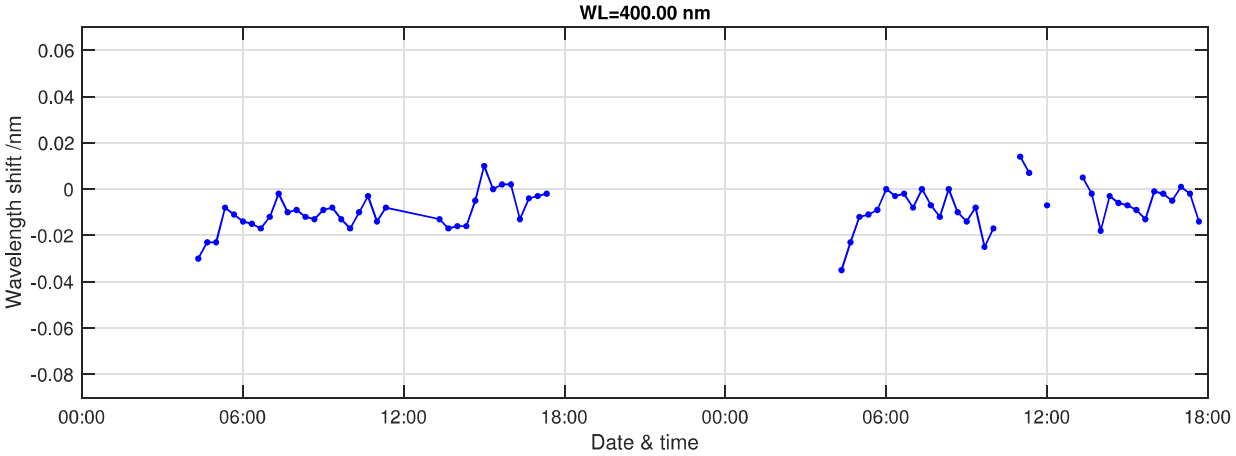

Daily variation. Wavelength bands are ± 2.5 nm
88°
89°
305 nm
310 nm
320 nm
350 nm
400 nm
450 nm
500 nm
545 nm
TIME [UT](SZA)

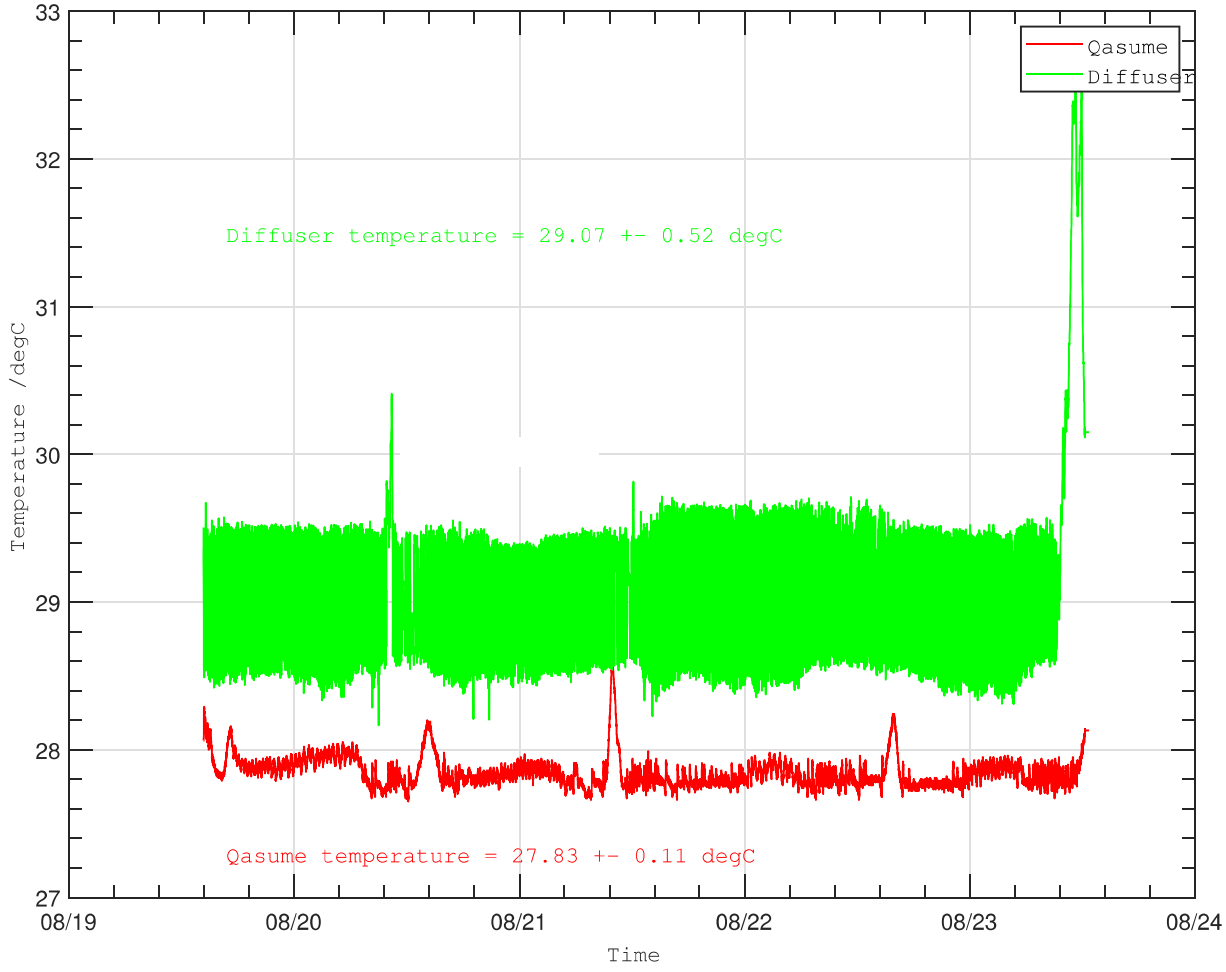

Global irradiance ratios ATI/QASUME at Kirchbichl-CMS-Schreder-matshic:23-Aug-2024(236)
ATI
QASUME
UVIndex
wl [nm]

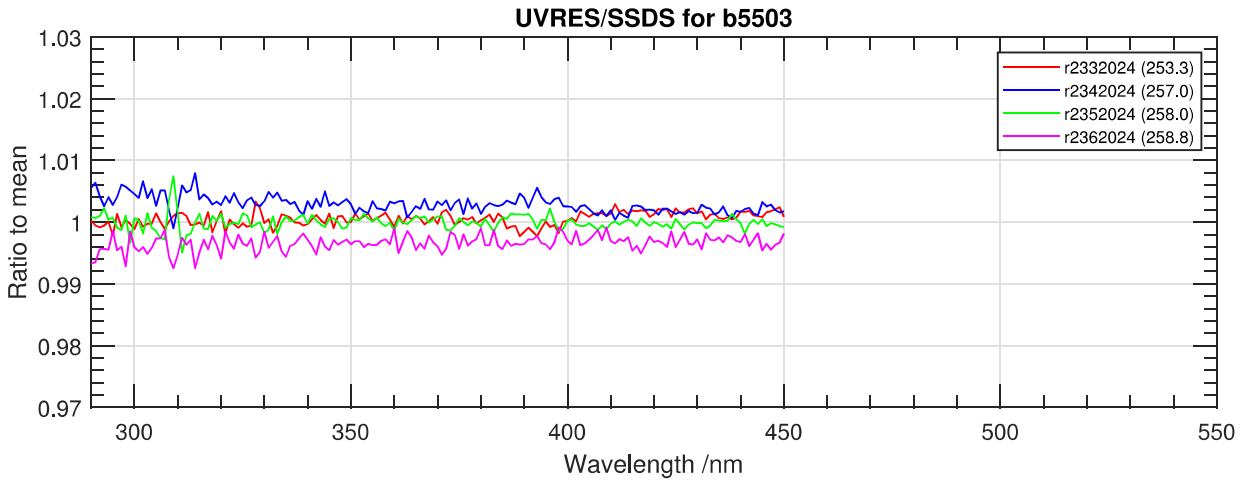

Daily variation. Wavelength bands are ± 2.5 nm
84°
305 nm
310 nm
320 nm
350 nm
400 nm
450 nm
500 nm
545 nm
TIME [UT](SZA)

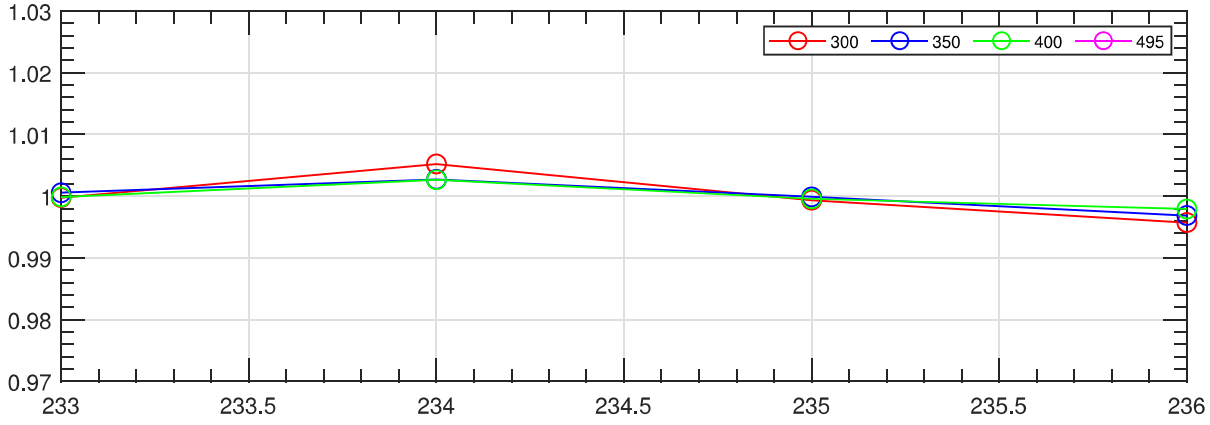

Mean ratio ATI/QASUME at Kirchbichl-CMS-Schreder-matshic:20-Aug-2024(233) to 23-Aug-2024(236)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
RATIO ATI/QASUME
N ATI Spectra=123
N Sync-Spectra=108
Wavelength [nm]


Wavelength shift
Mean
MinMax
STD
Wavelength shift /nm
0.1
0.05
0
-0.05
-0.1
300
350
400
450
500
550
Wavelength /nm


WL=400.00 nm
Wavelength shift /nm
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
00:00
06:00
12:00
18:00
00:00
06:00
12:00
18:00
Date & time


Qasume
Diffuser
Diffuser temperature = 29.07 +- 0.52 degC
Qasume temperature = 27.83 +- 0.11 degC
Temperature /degC
Time
33
32
31
30
29
28
27
08/19
08/20
08/21
08/22
08/23
08/24


UVRES/SSDS for b5503
r2332024 (253.3)
r2342024 (257.0)
r2352024 (258.0)
r2362024 (258.8)
Ratio to mean
Wavelength /nm
1.03
1.02
1.01
1
0.99
0.98
0.97
300
350
400
450
500
550


300
350
400
495
1.03
1.02
1.01
1
0.99
0.98
0.97
233
233.5
234
234.5
235
235.5
236


pmod wrc
AHBC 0095
NATIONAL CALIBRATION CENTER
ATI
Qasume