Protocol of the intercomparison at FMI, Sodankylä, Finland on May 29 to June 5, 2026, with the travelling reference spectroradiometer QASUME from PMOD/WRC

Report prepared by Gregor Hülsen

Operator: Gregor Hülsen
Local operator: Kaisa Lakkala

The purpose of the visit was the comparison of global solar irradiance measurements between the two Brewer spectrophotometer, FIS and FIA operated by the Finnish Meteorological Institute (FMI) and the travel reference spectroradiometer QASUME. The measurement site is located at Sodankylä; Latitude 67.37 N, Longitude 26.63 E and altitude 179 m.a.s.l. The horizon of the measurement site is free down to at least 85° solar zenith angle (SZA). However, trees are in front of the sun at SZA lower than 80°, which might affect the results as the trees are in a slightly different view angle of the Brewer and QASUME. Measurements between 1:00 UT and 23:00 UT have been analysed.

QASUME was installed on the measurement platform of FMI-Sodankylä in the evening of May 29, 2026. The spectroradiometer was installed next between the Brewer spectrophotometer “FIS” and “FIA” with the entrance optic of QASUME within 2 m to the other instruments. The Brewer Spectrophotometer FIS is a single monochromator (Brewer MkII #037) and the FIA Brewer spectroradiometer is a double monochromator (Brewer MkIII #214).
The intercomparison between QASUME and the Brewer Spectrophotometers lasted 8 days, from the noon of May 29 to the morning of June 5.

QASUME was calibrated several times during the intercomparison period using a portable calibration system. Four lamps (T157824, T157825, T153061 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 ±0.5 % during the intercomparison period. The internal temperature of QASUME was 27.48±0.09°C and the diffuser head was heated to a temperature of 29.05±0.0.41°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 30 minutes from 290 nm to 400 nm, every 0.5 nm, and 3.0 seconds between each wavelength increment. QASUME recorded the spectra with 0.25 nm increments and the Brewers with 0.5 nm increment. Brewer 037 scanned until 325 nm whereas the max. wavelength of Brewer 214 is 365 nm.

DOY	Date	DAY	Weather	Comment (times are in UT)
149	29.May	Friday	Mostly clear sky Diffuse sky in the late night	Installed at 11:00 12:00 start UV measurements 13:42 Calibration T157824
150	30.May	Saturday	Diffuse sky with few rain showers.	10:13 Calibration T157824 10:30 Calibration T68523 10:45 Calibration T153061
151	31.May	Sunday	Mix of sun and clouds Clear sky between 5:30 and 15:30 UT	09:14 Calibration T157824
152	01.Jun	Monday	Mainly raining	14:43 Calibration T157824
153	02.Jun	Tuesday	Mix of sun and clouds Clear sky after 17:00 UT	10:13 Calibration T157824 10:28 Calibration T157825
154	03.Jun	Wednesday	Mix of sun and clouds Diffuse sky between 7:00 and 11:30 UT	
155	04.Jun	Thursday	Mostly diffuse sky Clear sky after 17:00 UT	
156	05.Jun	Friday	Mix of sun and clouds Clear sky between 5:30 and 8:30 UT	10:33 Calibration T157824 10:43 End of Campaign

Results:

In total 223/211 synchronised simultaneous spectra from QASUME and Brewer FIS/FIA (037/214) are available from the measurement period. Measurements between 1:30 and 21:30 UT have been analysed (SZA smaller than 90°).

Conclusions:

A) FIA:

1. The average spectral ratio between FIA and QASUME has a slight spectral trend, from 1.05 at 305 nm decreasing to 0.98 at 365 nm.
2. The temporal variation of the spectra between FIA and QASUME was very stable, with variations less than 2% during the whole campaign.
3. The wavelength shifts of FIA relative to the high spectral resolution solar spectrum are between ±20 pm in the spectral range 290 nm to 365 nm.

B) FIS:

1. The average spectral ratio between FIS and QASUME is 1.01 increasing for wavelength smaller than 305 nm.
2. The temporal variation of the spectra between FIS and QASUME was very stable, with variations less than 2% during the whole campaign.
3. The wavelength shifts of FIS relative to the high spectral resolution solar spectrum are between ±20 pm in the spectral range 290 nm to 325 nm.

Comparison to previous QASUME site visits

The long-term stability of FIA and FIS was assessed by comparing QASUME site visits performed since 2002.

As seen in figure 1 the campaign average ratio of FIA to QASUME are similar within ±4 % since 2018. The measurement in 2014 were lower than QASUME with -6 %.

Figure 2 shows that the campaign average ratio of FIS to QASUME has been stable to within ±1 % since 2018. Measurements before 2014 were slightly higher than QASUME above +4 % except 2010 with +2 %.

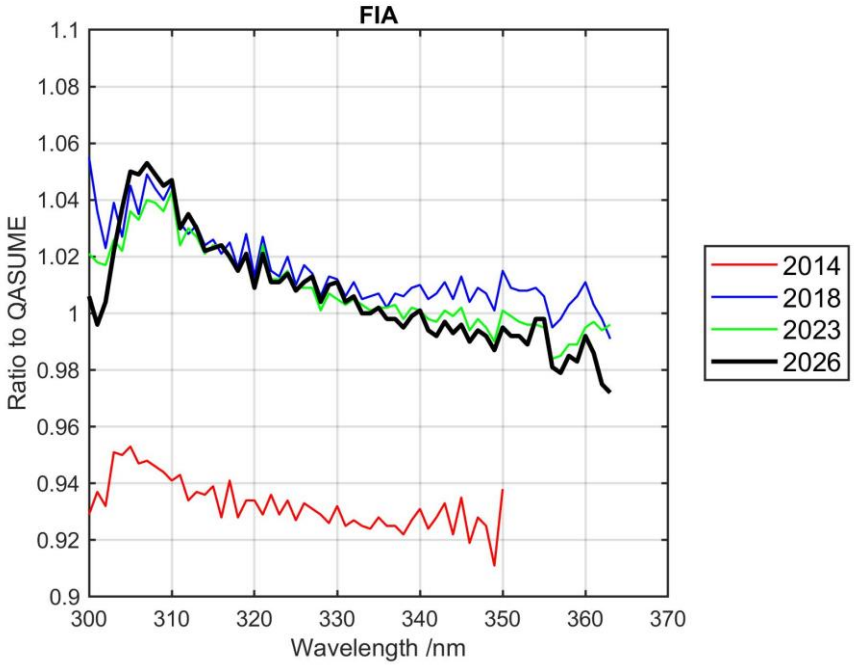


Figure 1 solar spectral ratios of FIA to QASUME averaged over each QASUME site visit

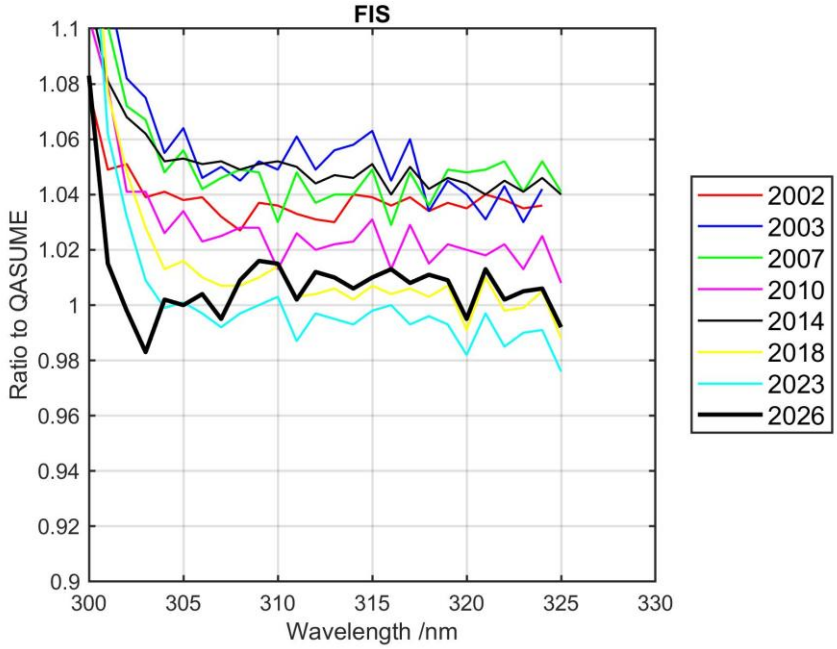


Figure 2 solar spectral ratios of FIS to QASUME averaged over each QASUME site visit.

Summary:

The audit showed that the UV measurements performed at FMI with the Brewer 037 and 214 spectroradiometers are within the expected combined measurement uncertainty:

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

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

The following point 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). 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 FMI.

.

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

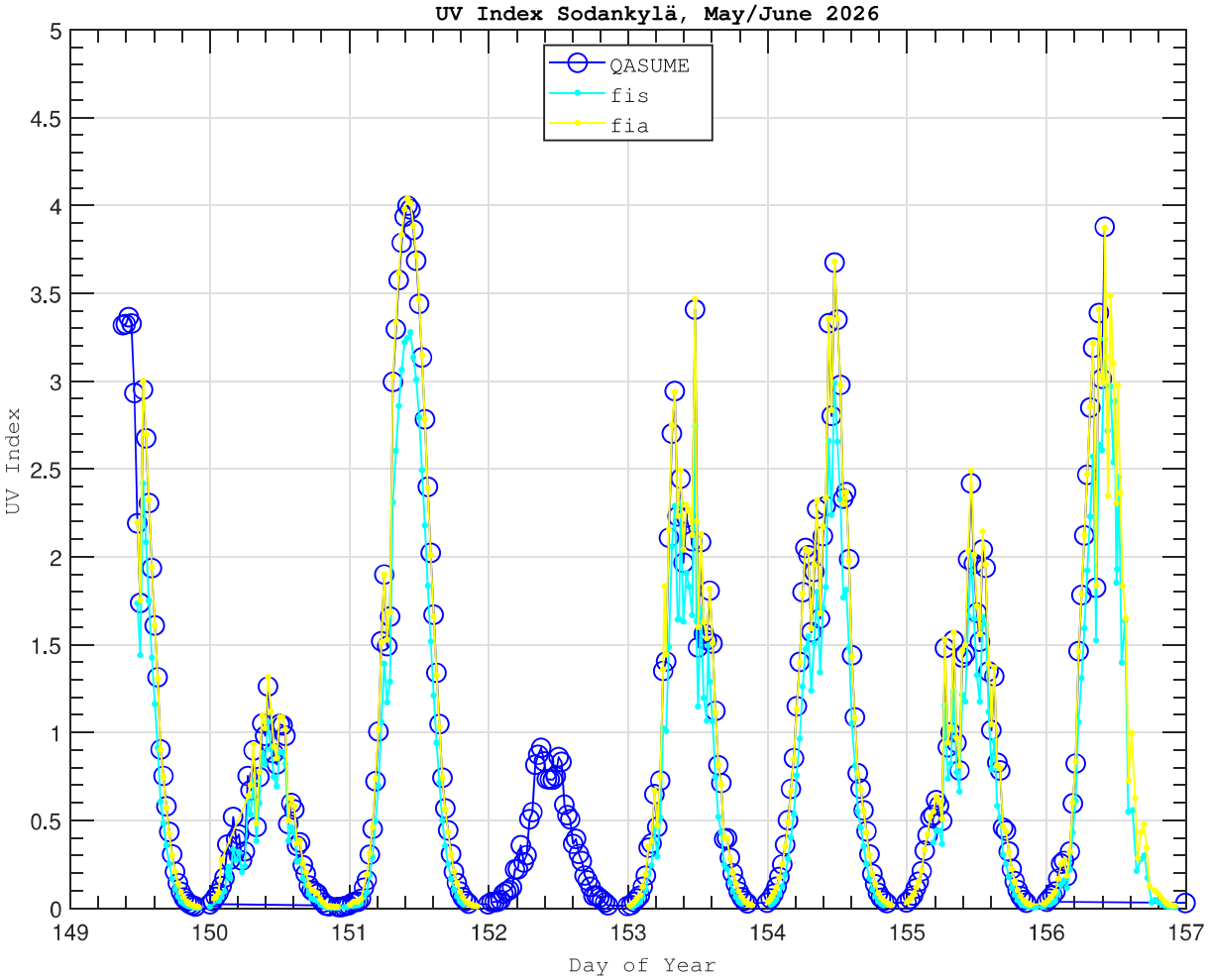
G. Hülsen, J. Gröbner, S. Nevas, P. Sperfeld, L. Egli, G. Porrovecchio, and M. Smid, “Traceability of solar UV measurements using the Qasume reference spectroradiometer", Appl. Opt. 55, 7265-7275, 2016.

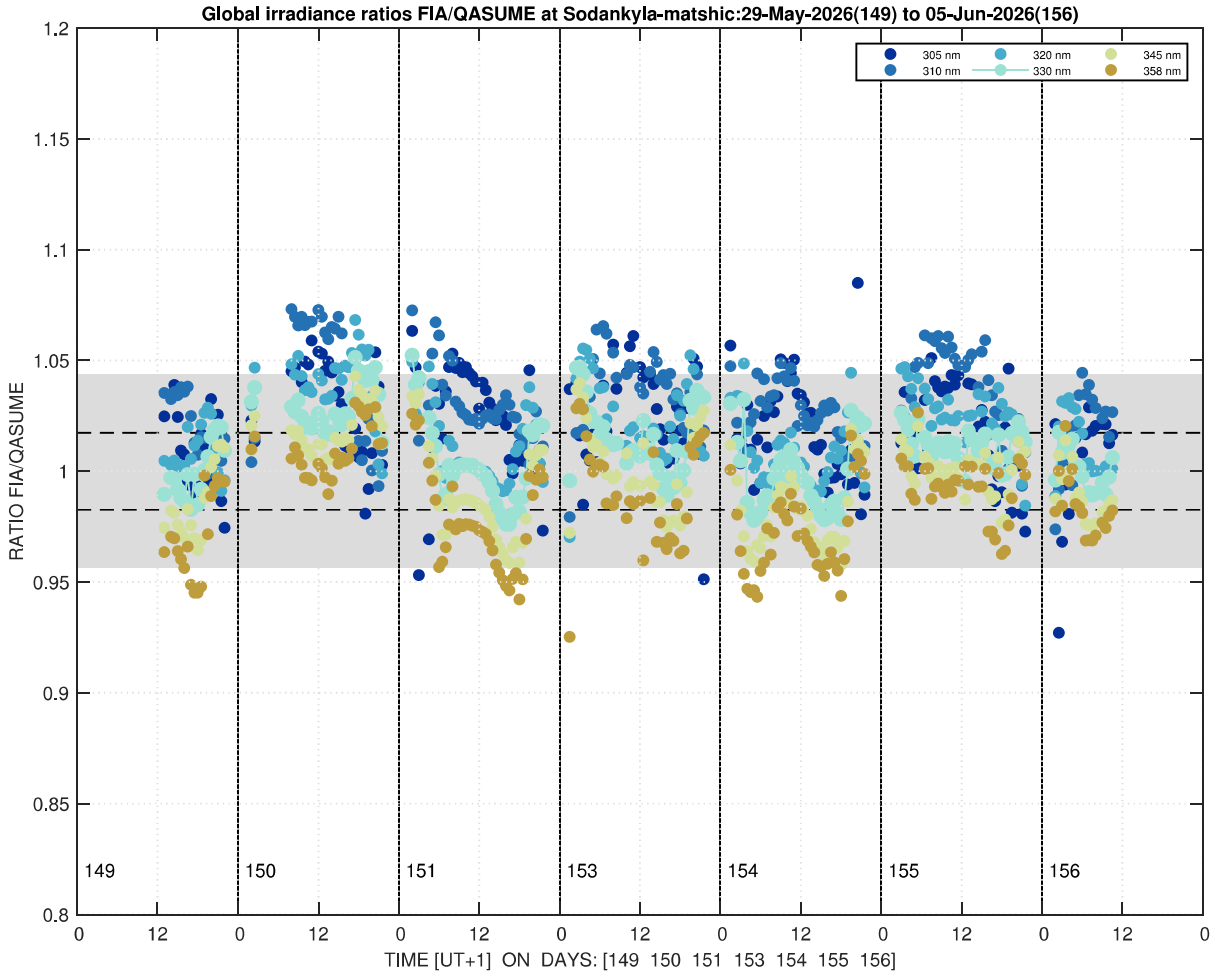
Lakkala, K., Arola, A., Heikkilä,A., Kaurola, J., Koskela, T., Kyrö, E., Lindfors,A., Meinander, O., Tanskanen, A., Gröbner, J. and Hülsen, G.,: Quality assurance of the Brewer spectral UV measurements in Finland. Atmos.Chem. Phys., 8, 3369-3383, 2008

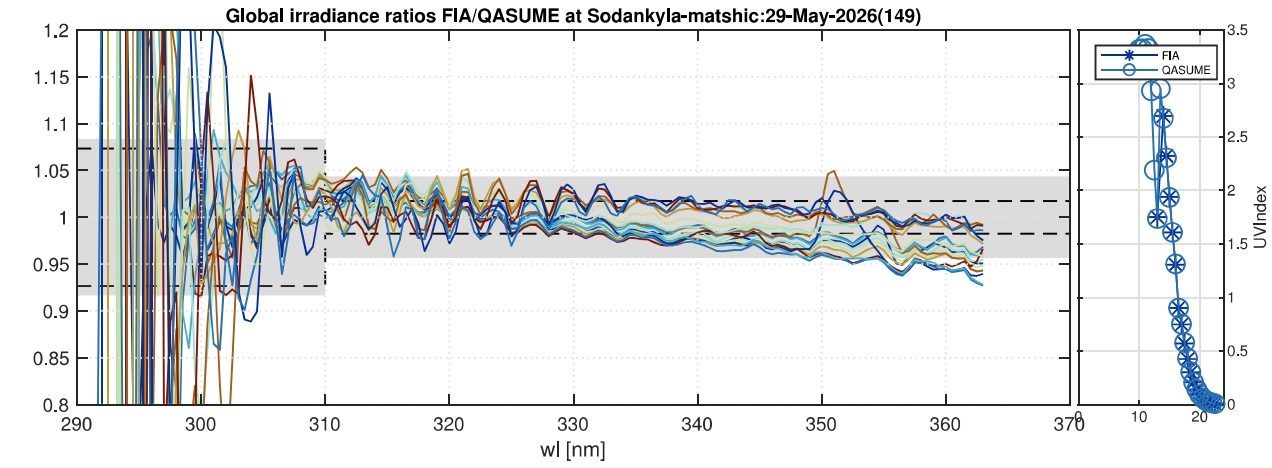
Lakkala, K., Arola, A., Gröbner, J., León-Luis, S. F., Redondas, A., Kazadzis,S., Karppinen, T., Karhu, J. M., Egli, L., Heikkilä, A., Koskela, T., Serrano, A.,and Vilaplana, J. M.: Performance of the FMI cosine error correction method for the Brewer spectral UV measurements, Atmos. Meas. Tech., 11, 5167-5180,
https://doi.org/10.5194/amt-11-5167-2018, 2018

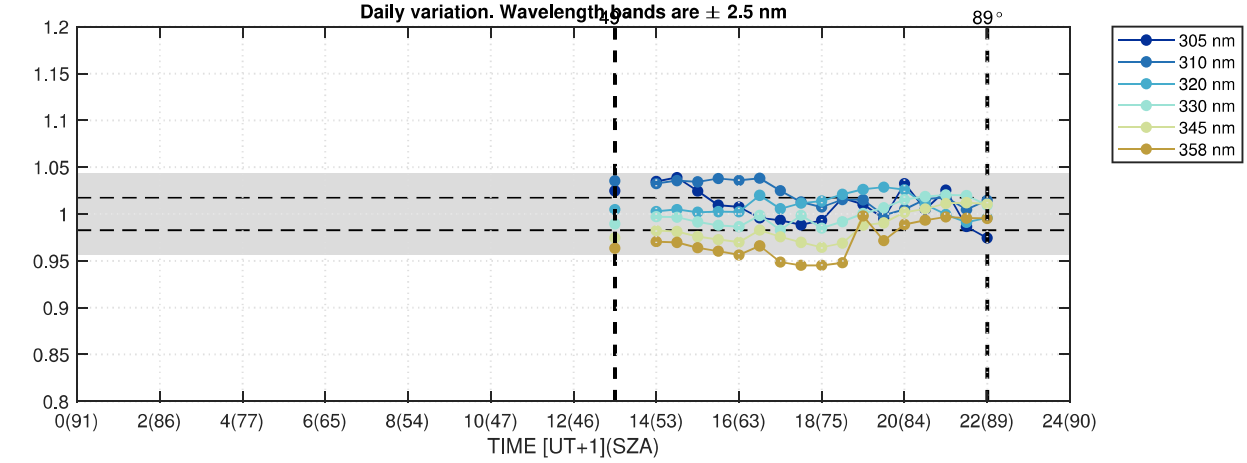
Appendix

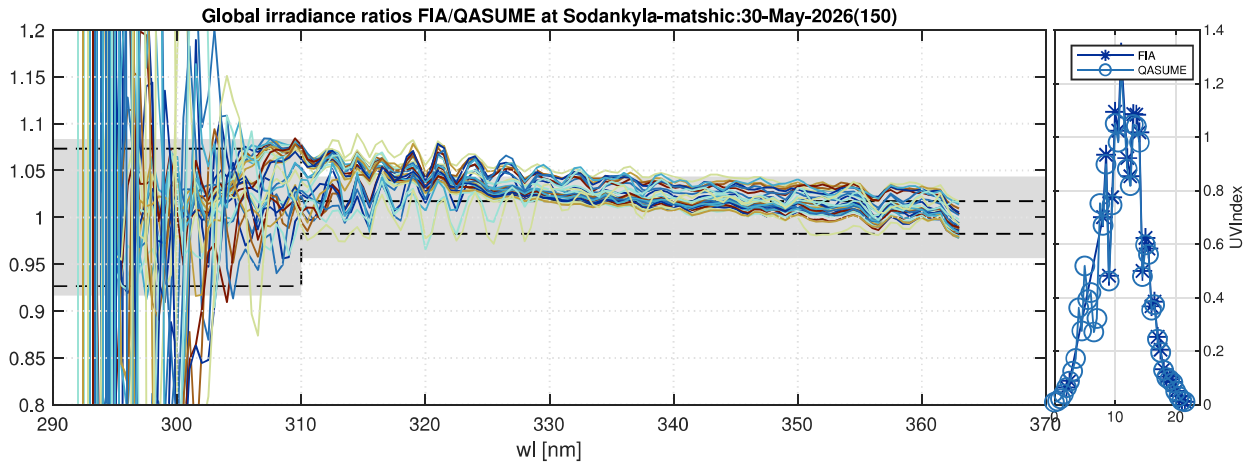
Detailed results for all Brewer spectrophotometers with respect to the reference spectroradiometer QASUME

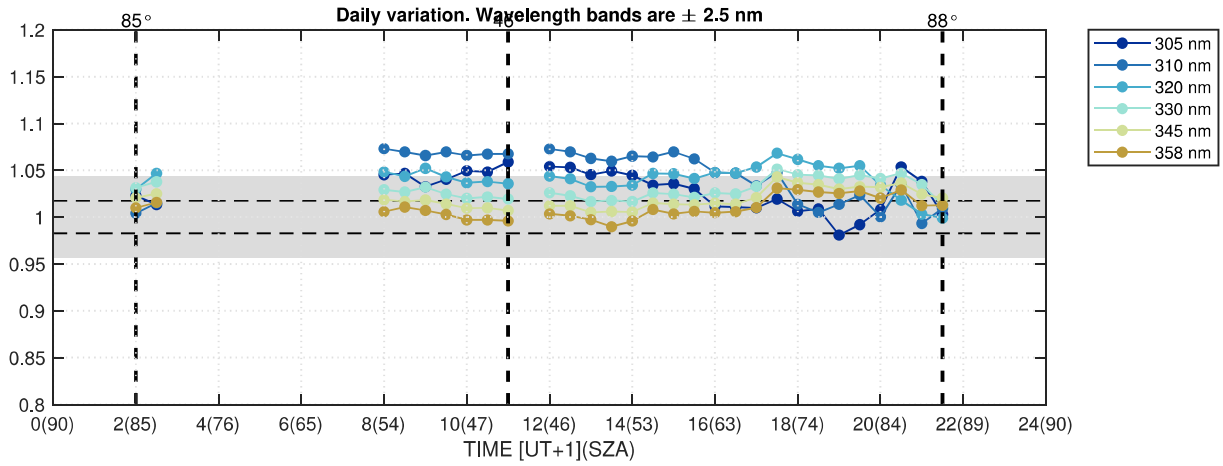

UV Index Sodankylä, May/June 2026
QASUME
fis
fia
UV Index
Day of Year
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
149
150
151
152
153
154
155
156
157

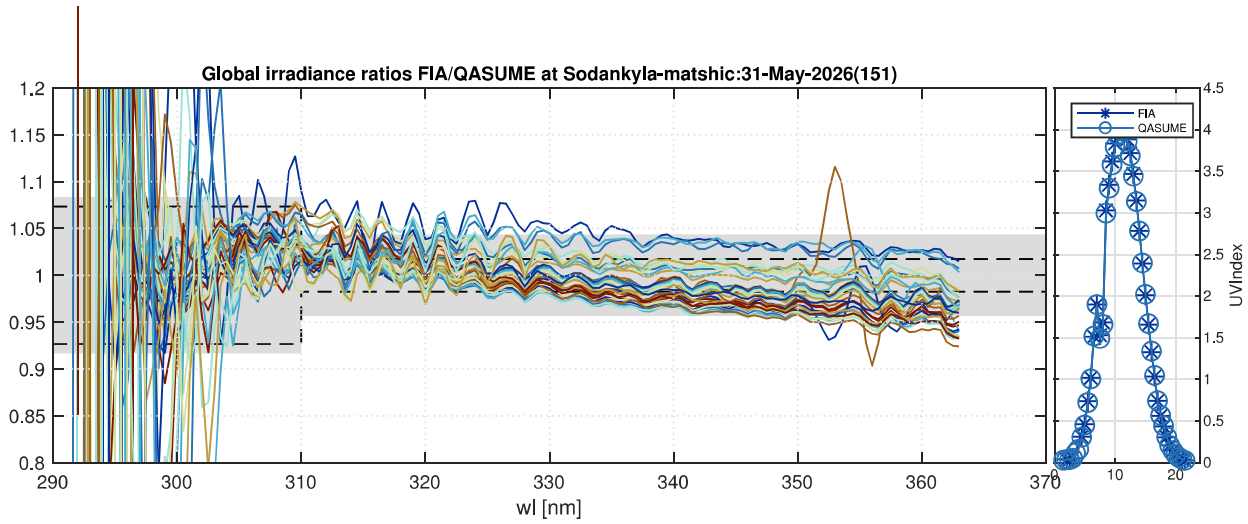

Global irradiance ratios FIA/QASUME at Sodankyla-matshic:29-May-2026(149) to 05-Jun-2026(156)
305 nm
310 nm
320 nm
330 nm
345 nm
358 nm
RATIO FIA/QASUME
149
150
151
153
154
155
156
TIME [UT+1] ON DAYS: [149 150 151 153 154 155 156]

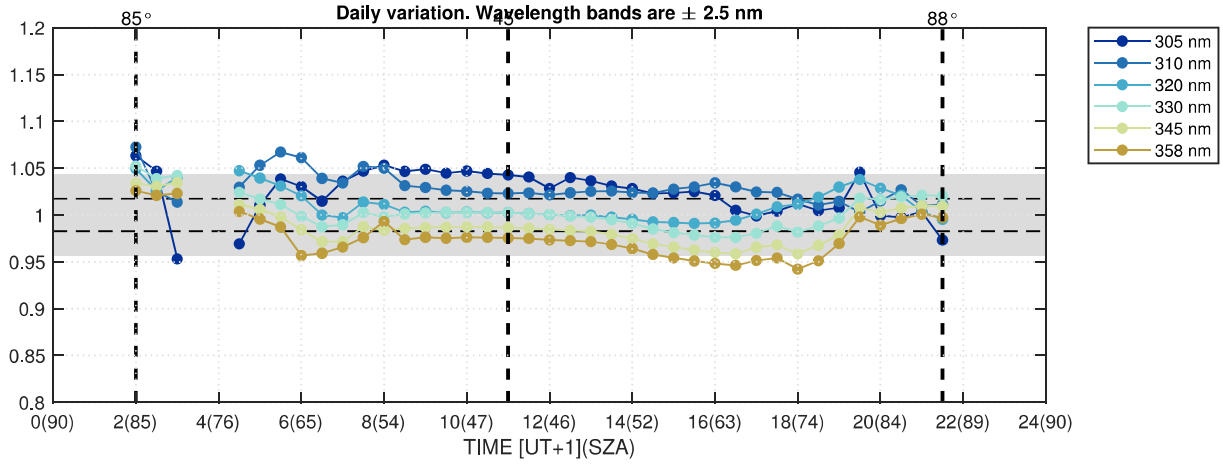

Global irradiance ratios FIA/QASUME at Sodankyla-matshic:29-May-2026(149)
FIA
QASUME
UVIndex
wl [nm]

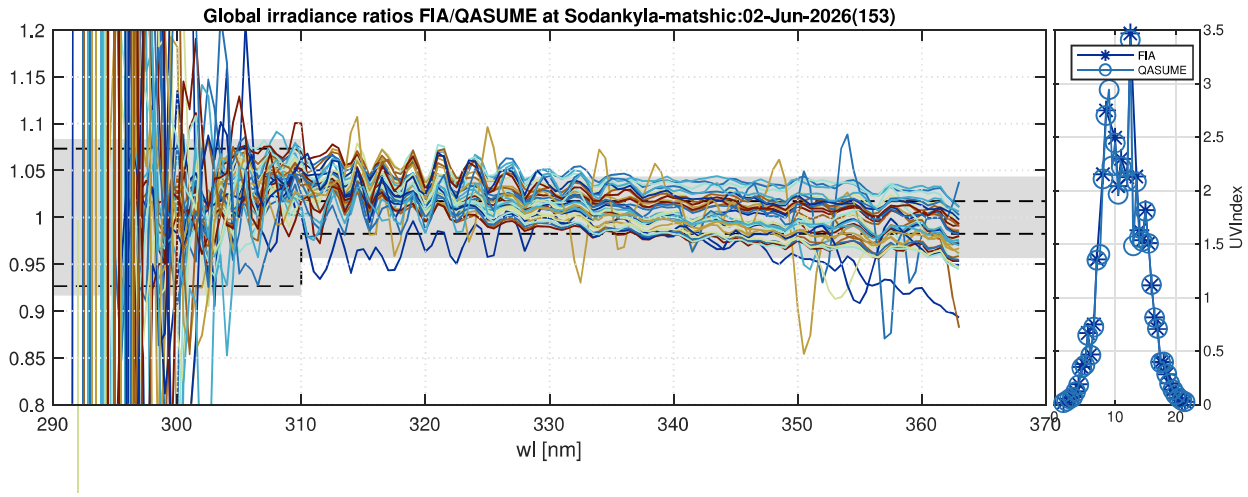

Daily variation. Wavelength bands are ± 2.5 nm
89°
305 nm
310 nm
320 nm
330 nm
345 nm
358 nm
TIME [UT+1](SZA)

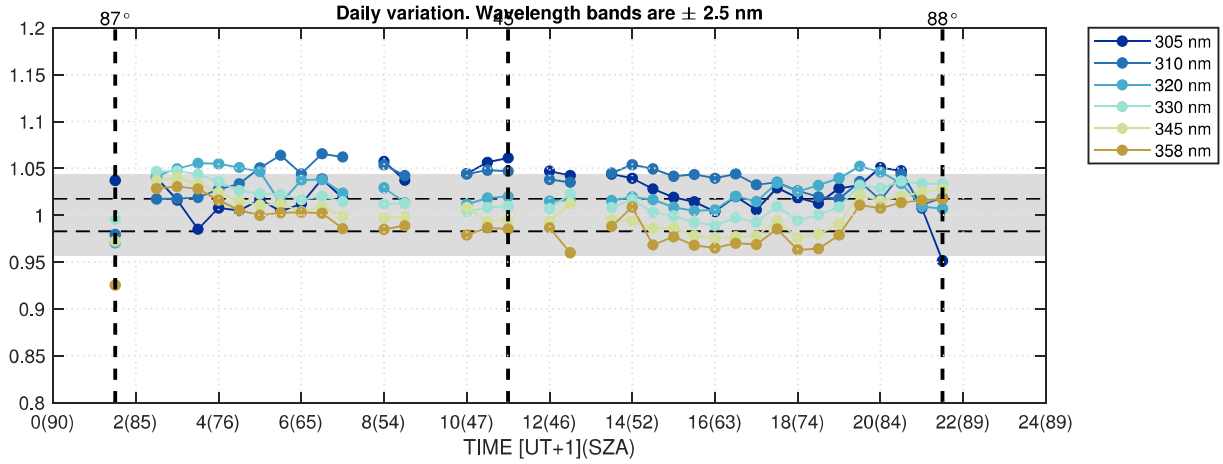

Global irradiance ratios FIA/QASUME at Sodankyla-matshic:30-May-2026(150)
wl [nm]
UVIndex
FIA
QASUME

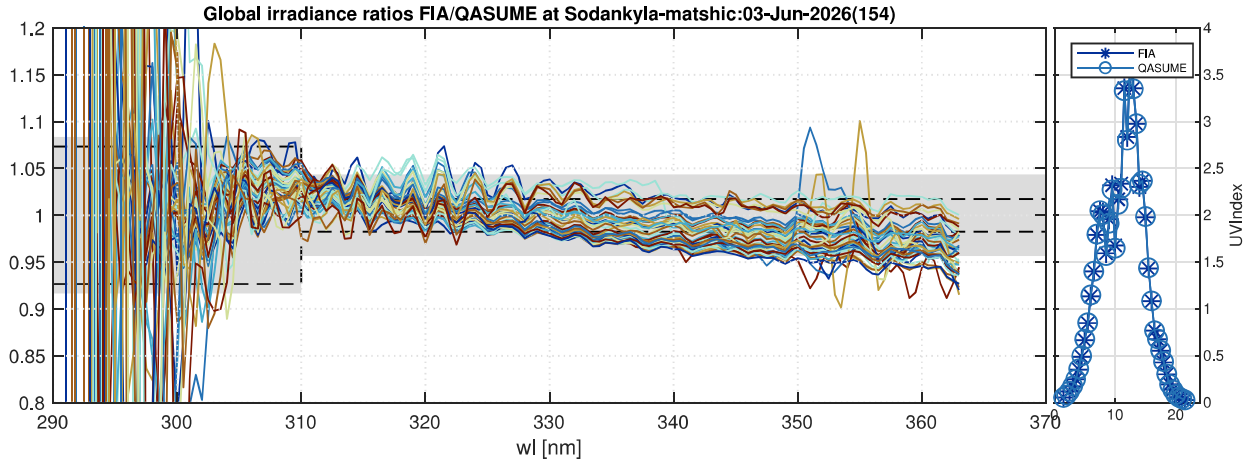

Daily variation. Wavelength bands are ± 2.5 nm
85°
88°
TIME [UT+1](SZA)
305 nm
310 nm
320 nm
330 nm
345 nm
358 nm

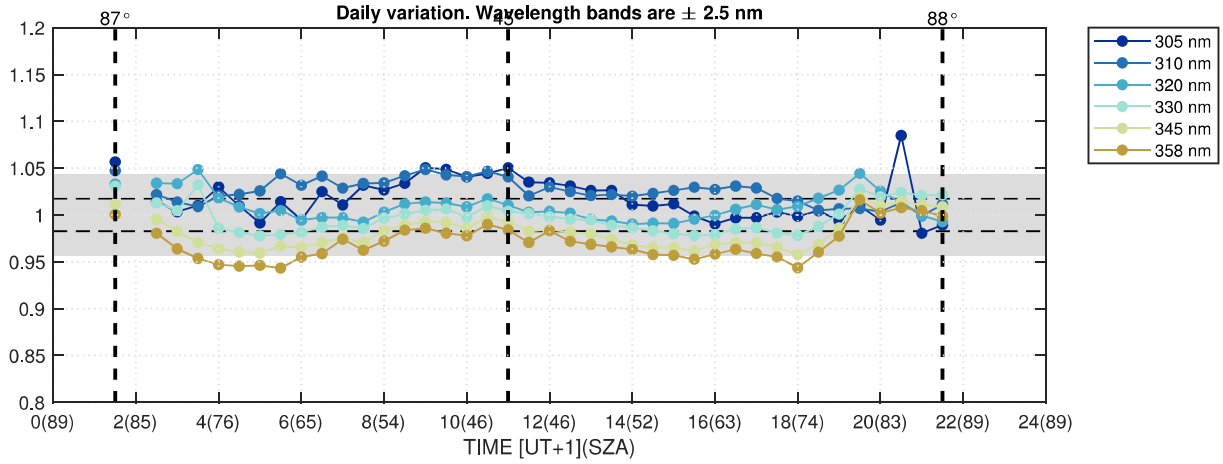

Global irradiance ratios FIA/QASUME at Sodankyla-matshic:31-May-2026(151)
wl [nm]
UVIndex
FIA
QASUME

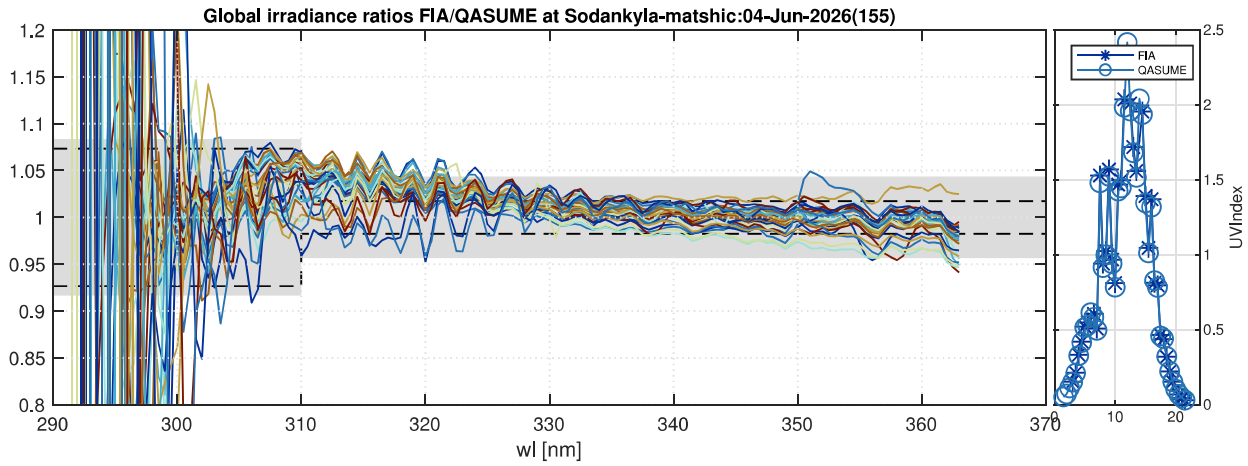

Daily variation. Wavelength bands are ± 2.5 nm
85°
88°
TIME [UT+1](SZA)
305 nm
310 nm
320 nm
330 nm
345 nm
358 nm

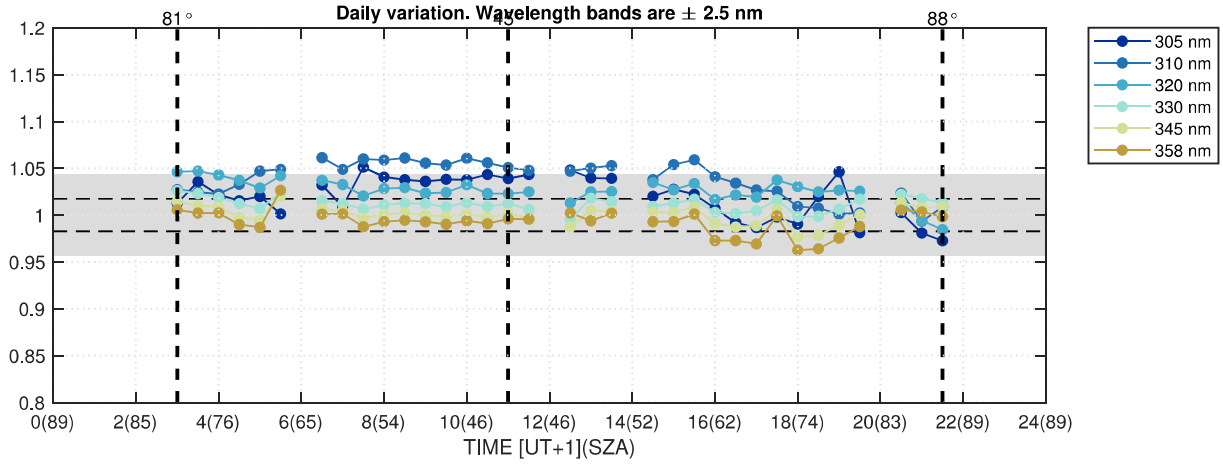

Global irradiance ratios FIA/QASUME at Sodankyla-matshic:02-Jun-2026(153)
wl [nm]
UVIndex
FIA
QASUME

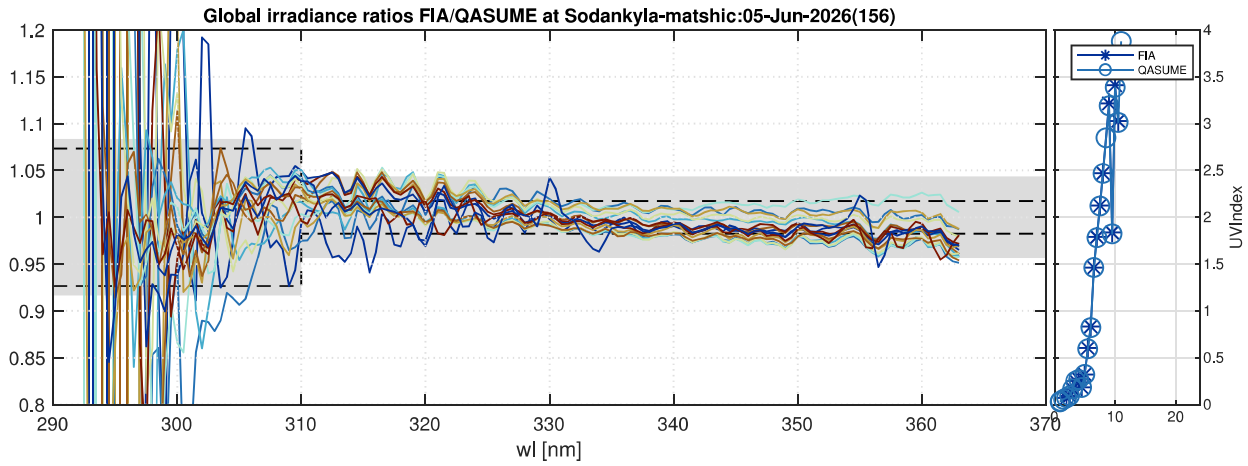

Daily variation. Wavelength bands are ± 2.5 nm
87°
88°
TIME [UT+1](SZA)
305 nm
310 nm
320 nm
330 nm
345 nm
358 nm

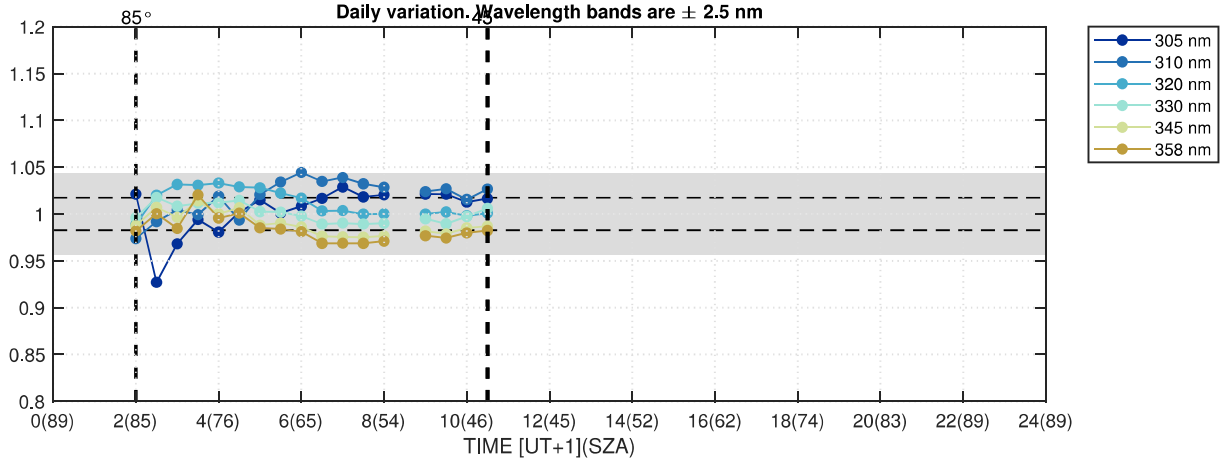

Global irradiance ratios FIA/QASUME at Sodankyla-matshic:03-Jun-2026(154)
wl [nm]
UVIndex
FIA
QASUME

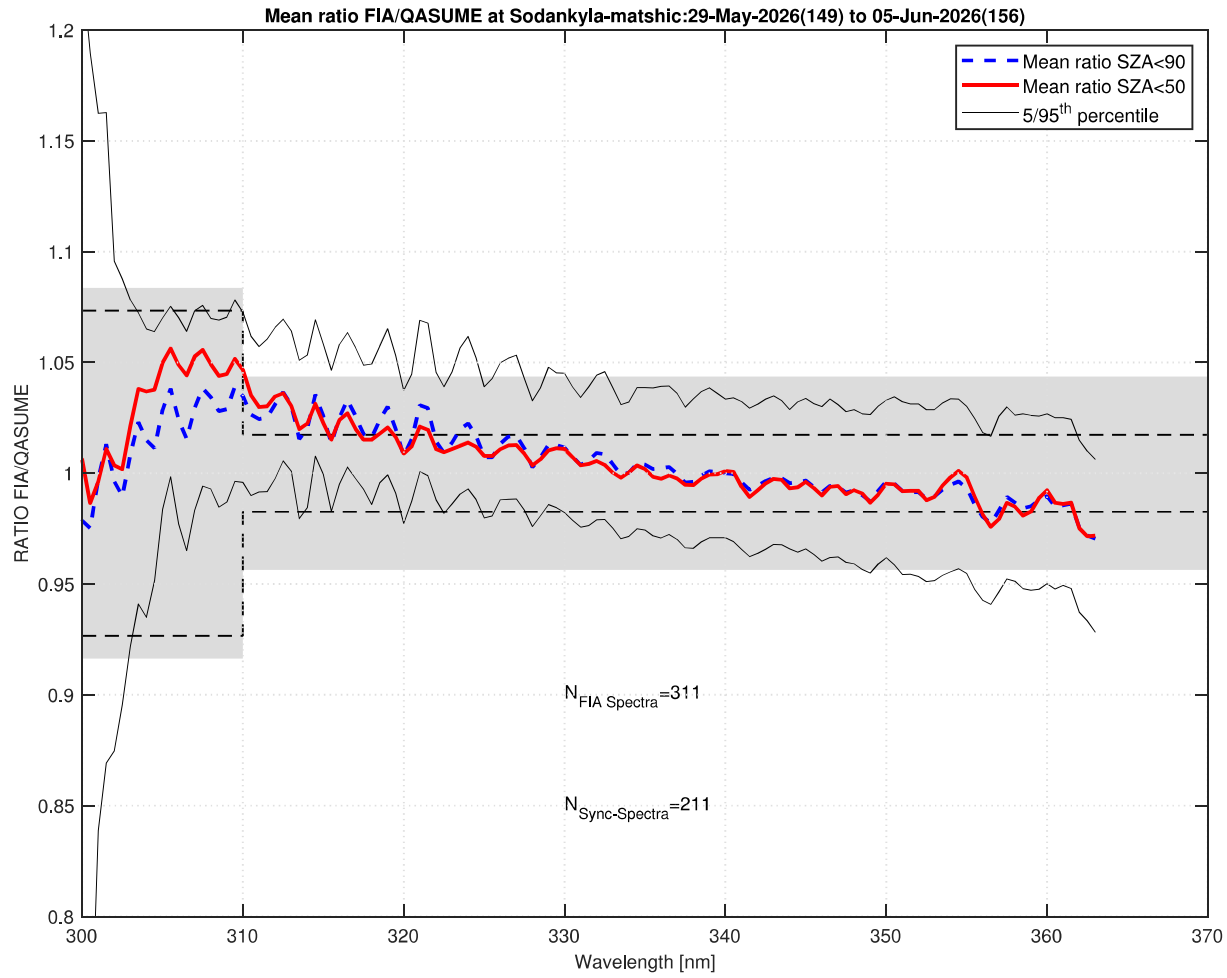

Daily variation. Wavelength bands are ± 2.5 nm
87°
88°
TIME [UT+1](SZA)
305 nm
310 nm
320 nm
330 nm
345 nm
358 nm

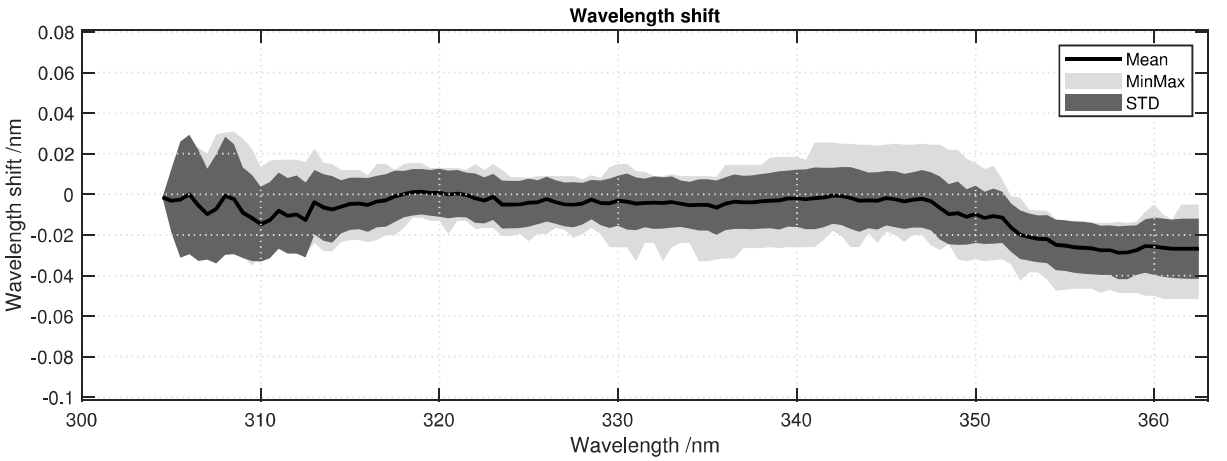

Global irradiance ratios FIA/QASUME at Sodankyla-matshic:04-Jun-2026(155)
FIA
QASUME
UVIndex
wl [nm]

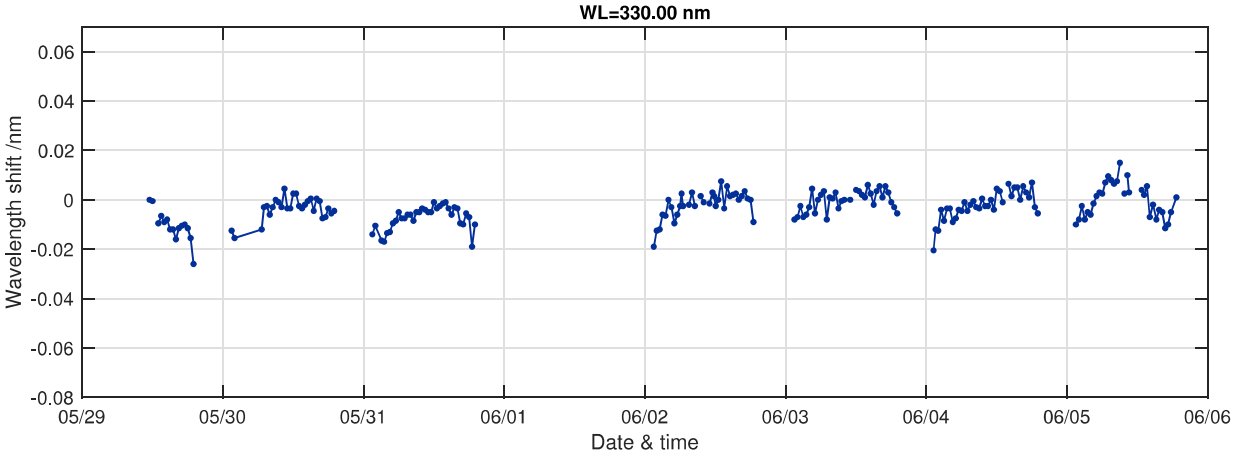

Daily variation. Wavelength bands are ± 2.5 nm
81°
88°
305 nm
310 nm
320 nm
330 nm
345 nm
358 nm
TIME [UT+1](SZA)

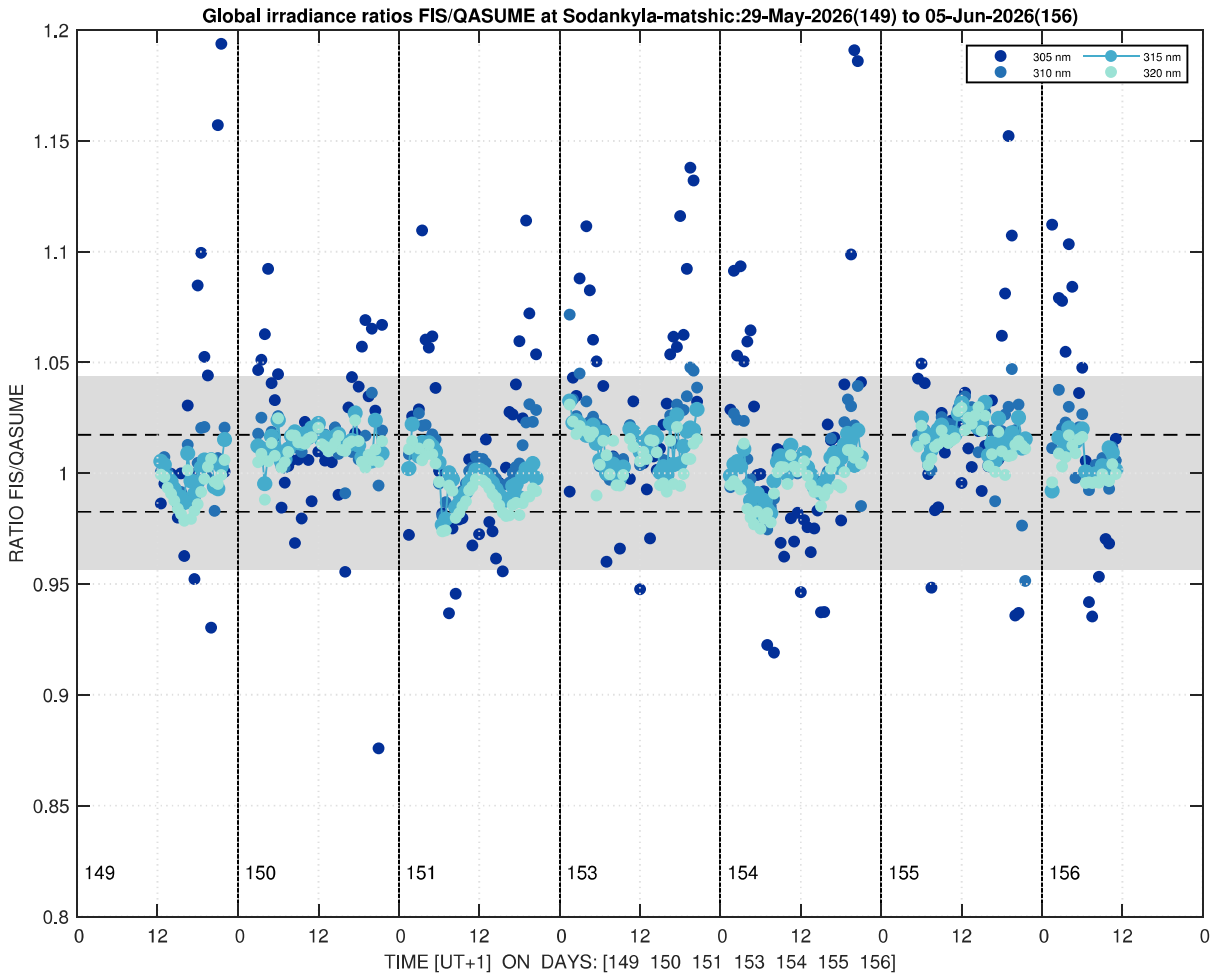

Global irradiance ratios FIA/QASUME at Sodankyla-matshic:05-Jun-2026(156)
FIA
QASUME
UVIndex
wl [nm]

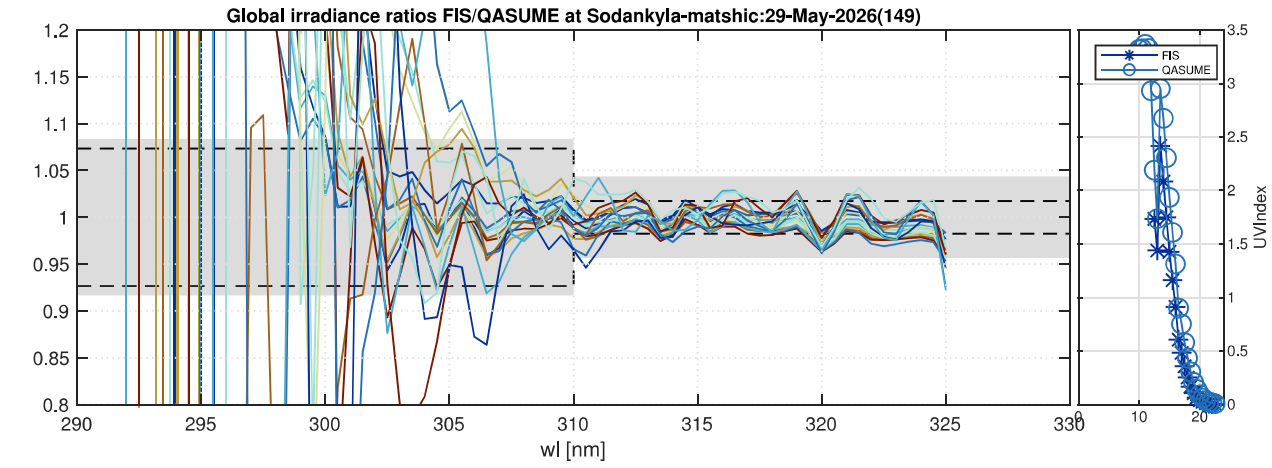

Daily variation. Wavelength bands are ± 2.5 nm
85°
305 nm
310 nm
320 nm
330 nm
345 nm
358 nm
TIME [UT+1](SZA)

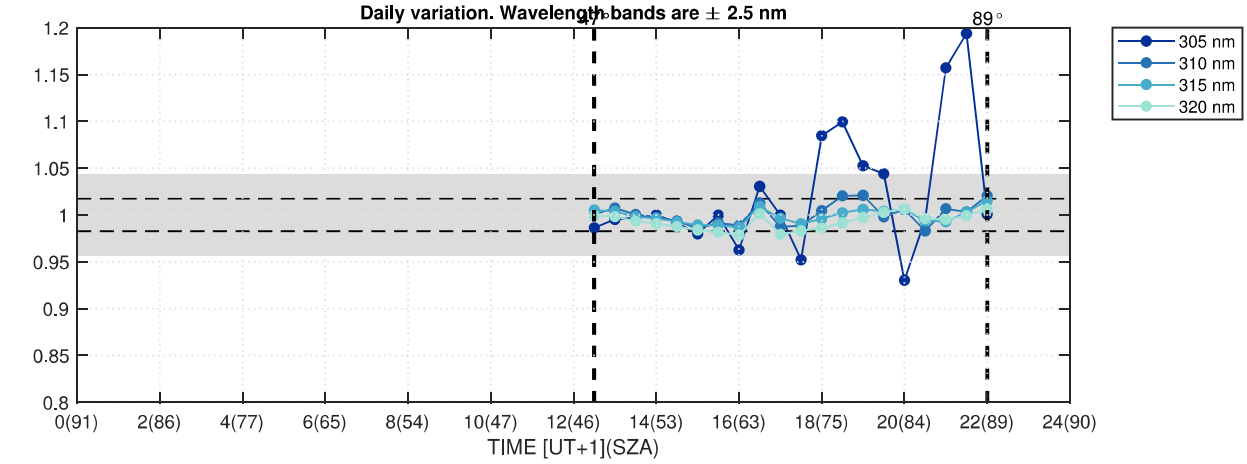

Mean ratio FIA/QASUME at Sodankyla-matshic:29-May-2026(149) to 05-Jun-2026(156)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
RATIO FIA/QASUME
N FIA Spectra=311
N Sync-Spectra=211
Wavelength [nm]

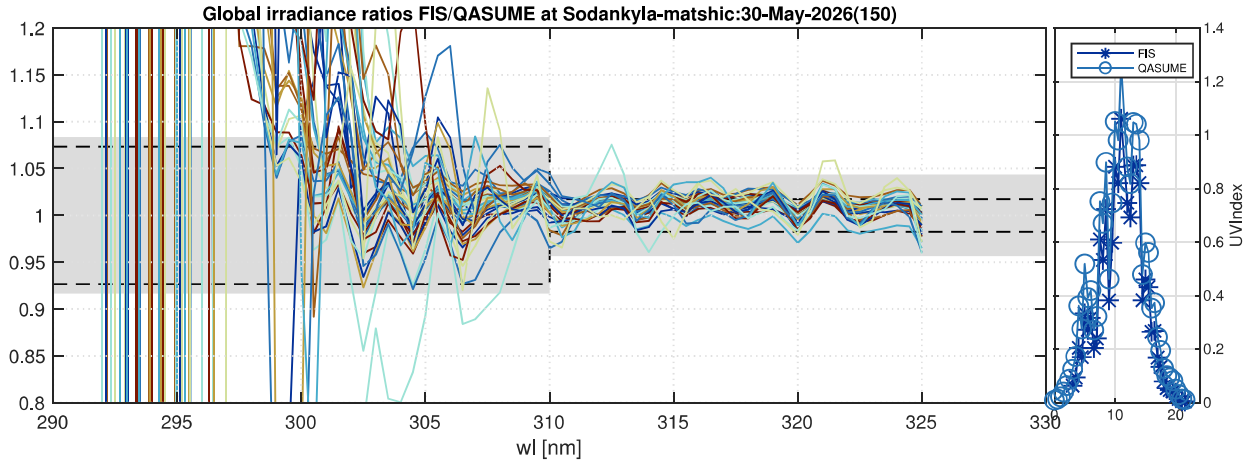

Wavelength shift
Mean
MinMax
STD
Wavelength shift /nm
Wavelength /nm

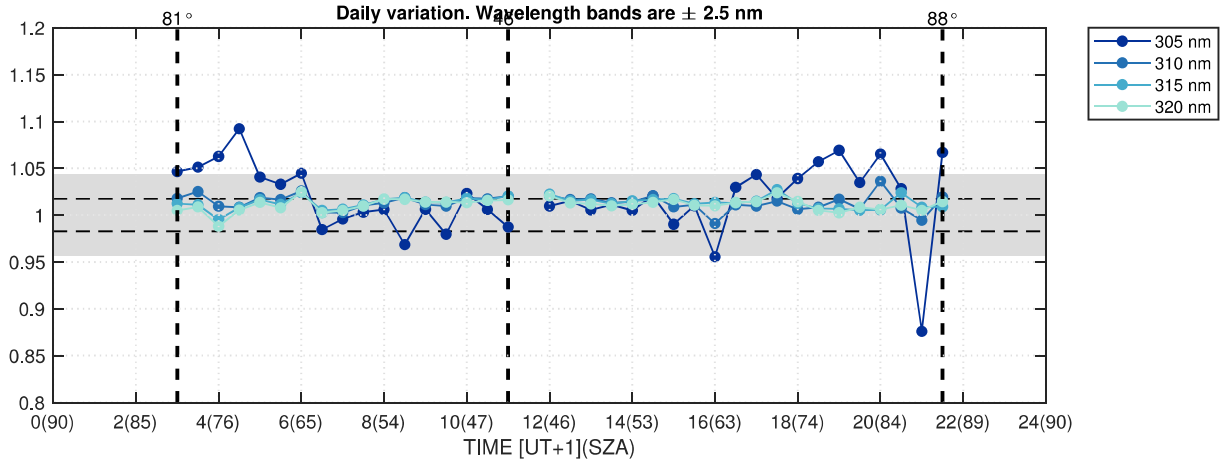

WL=330.00 nm
Wavelength shift /nm
Date & time

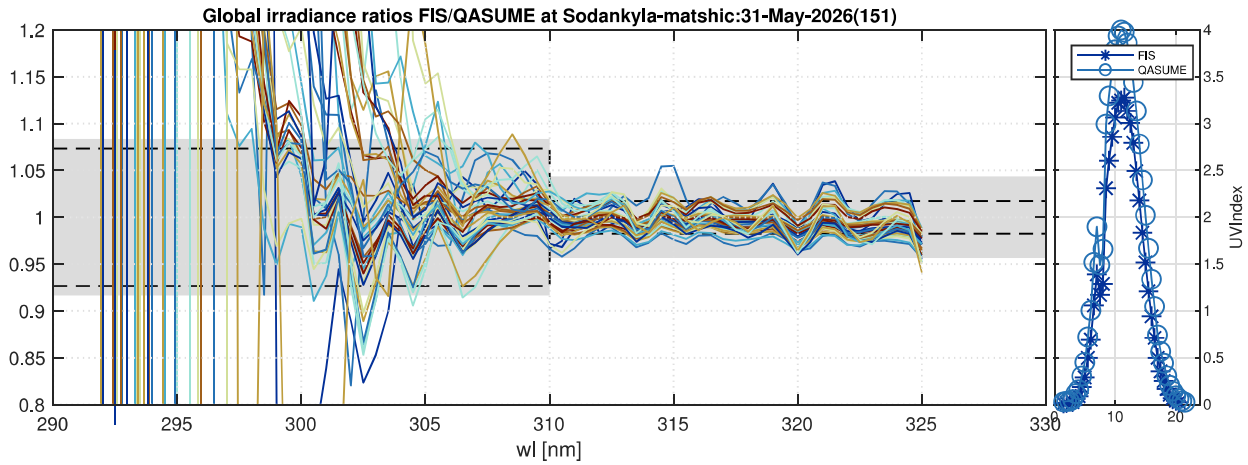

Global irradiance ratios FIS/QASUME at Sodankyla-matshic:29-May-2026(149) to 05-Jun-2026(156)
305 nm
310 nm
315 nm
320 nm
RATIO FIS/QASUME
149
150
151
153
154
155
156
TIME [UT+1] ON DAYS: [149 150 151 153 154 155 156]

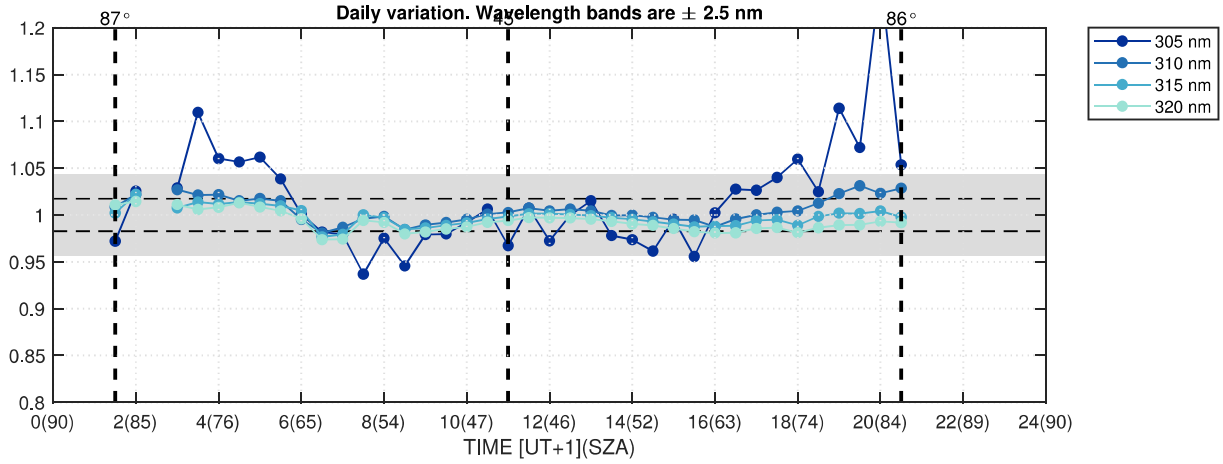

Global irradiance ratios FIS/QASUME at Sodankyla-matshic:29-May-2026(149)
FIS
QASUME
UVIndex
wl [nm]

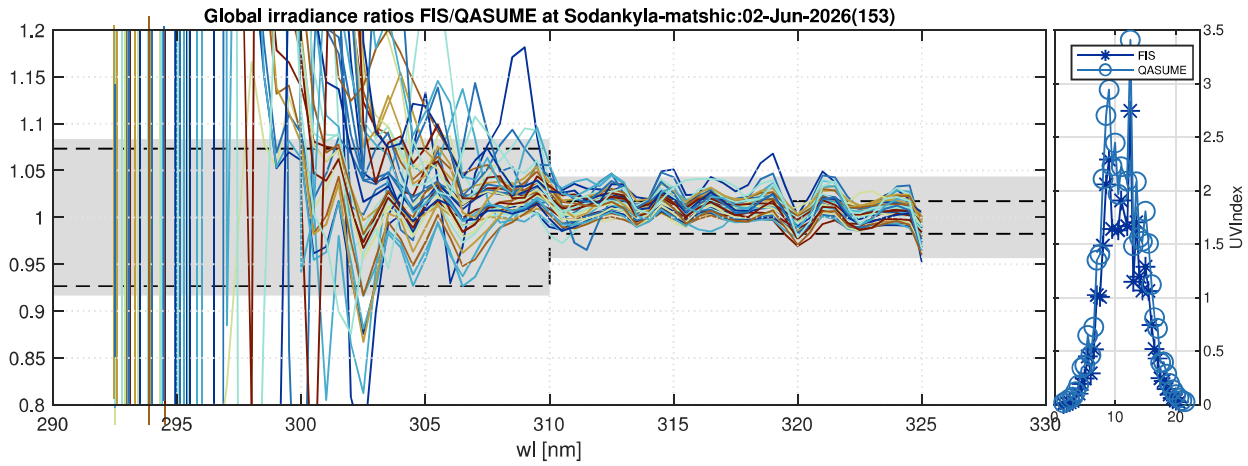

Daily variation. Wavelength bands are ± 2.5 nm
89°
305 nm
310 nm
315 nm
320 nm
TIME [UT+1](SZA)

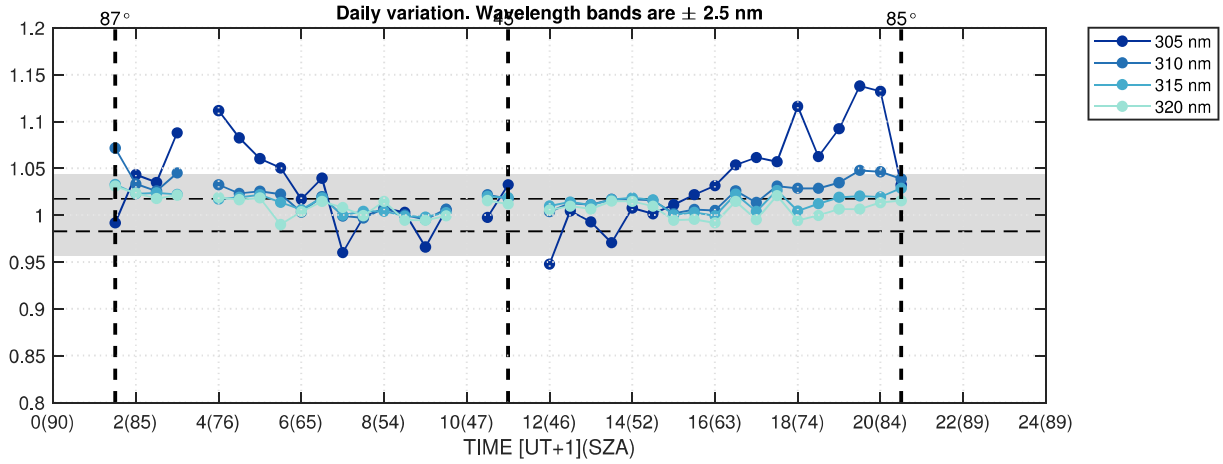

Global irradiance ratios FIS/QASUME at Sodankyla-matshic:30-May-2026(150)
wl [nm]
FIS
QASUME
UVIndex

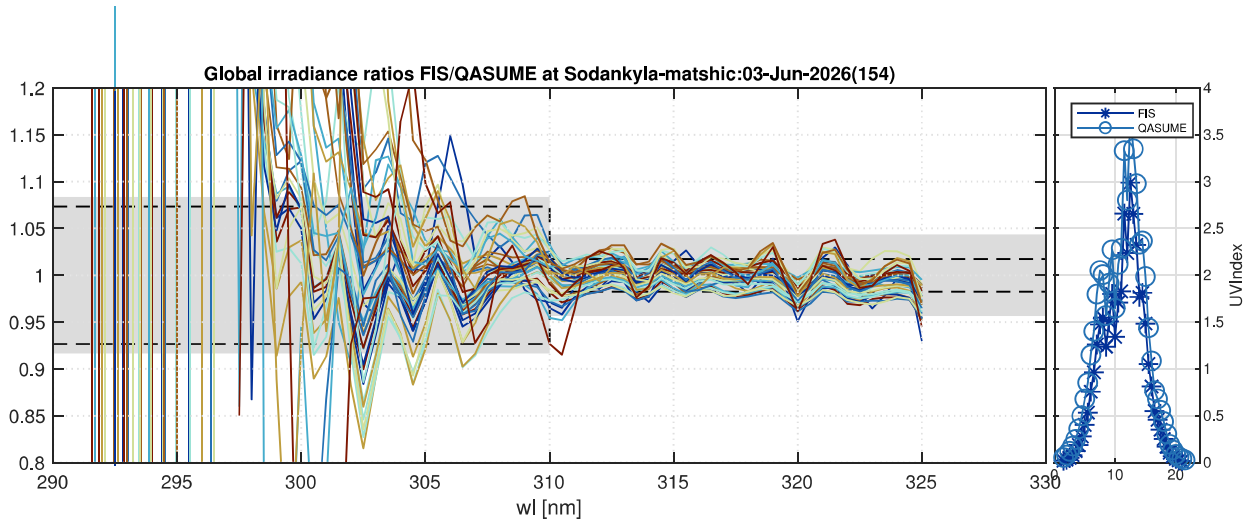

Daily variation. Wavelength bands are ± 2.5 nm
81°
88°
305 nm
310 nm
315 nm
320 nm
TIME [UT+1](SZA)

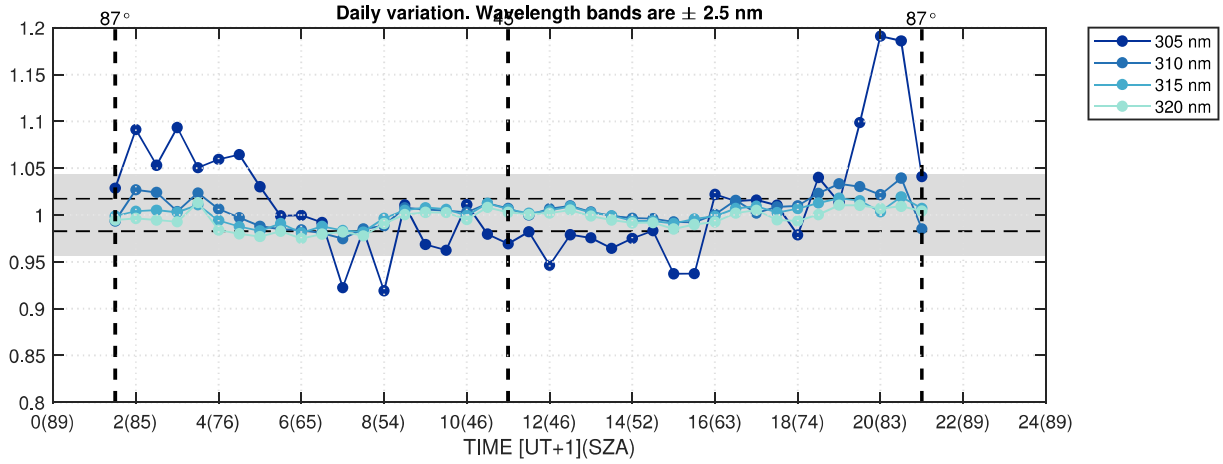

Global irradiance ratios FIS/QASUME at Sodankyla-matshic:31-May-2026(151)
wl [nm]
FIS
QASUME
UVIndex

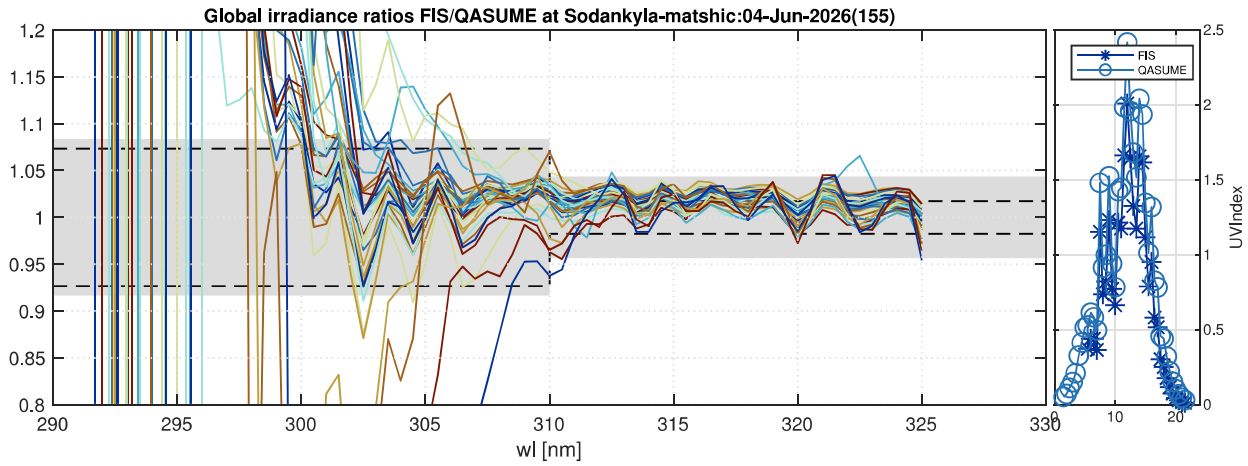

Daily variation. Wavelength bands are ± 2.5 nm
87°
86°
305 nm
310 nm
315 nm
320 nm
TIME [UT+1](SZA)

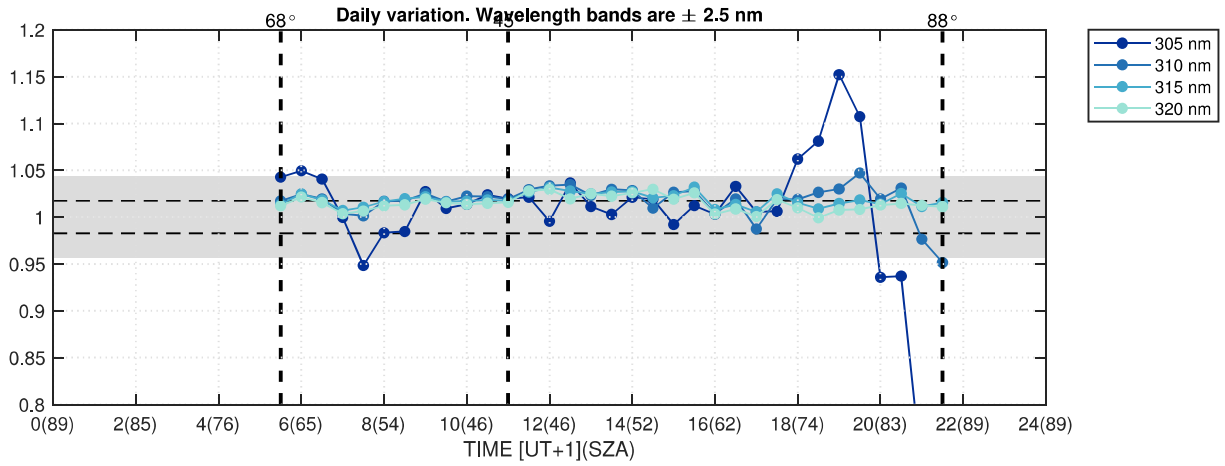

Global irradiance ratios FIS/QASUME at Sodankyla-matshic:02-Jun-2026(153)
wl [nm]
UVIndex
FIS
QASUME

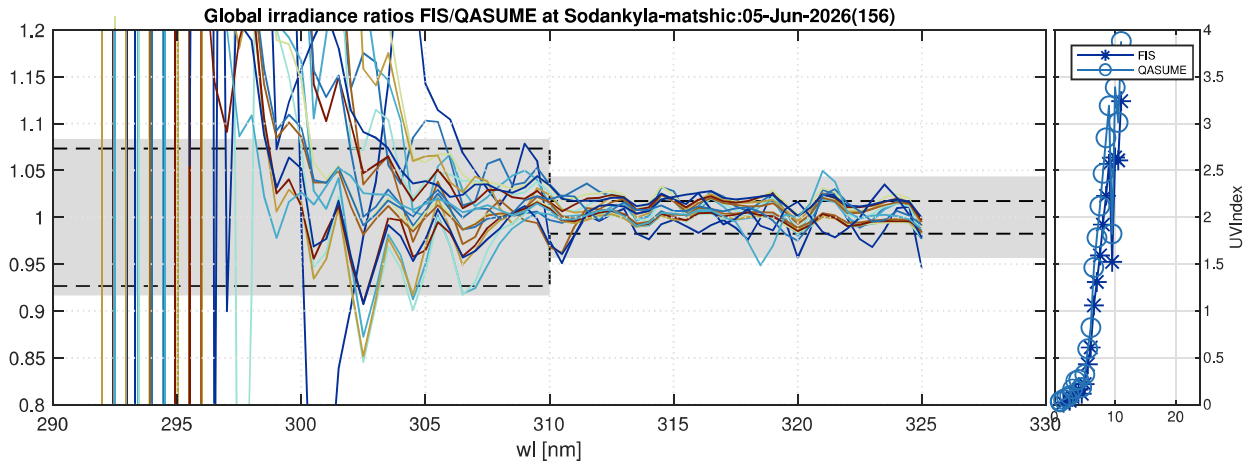

Daily variation. Wavelength bands are ± 2.5 nm
87°
85°
TIME [UT+1](SZA)
305 nm
310 nm
315 nm
320 nm

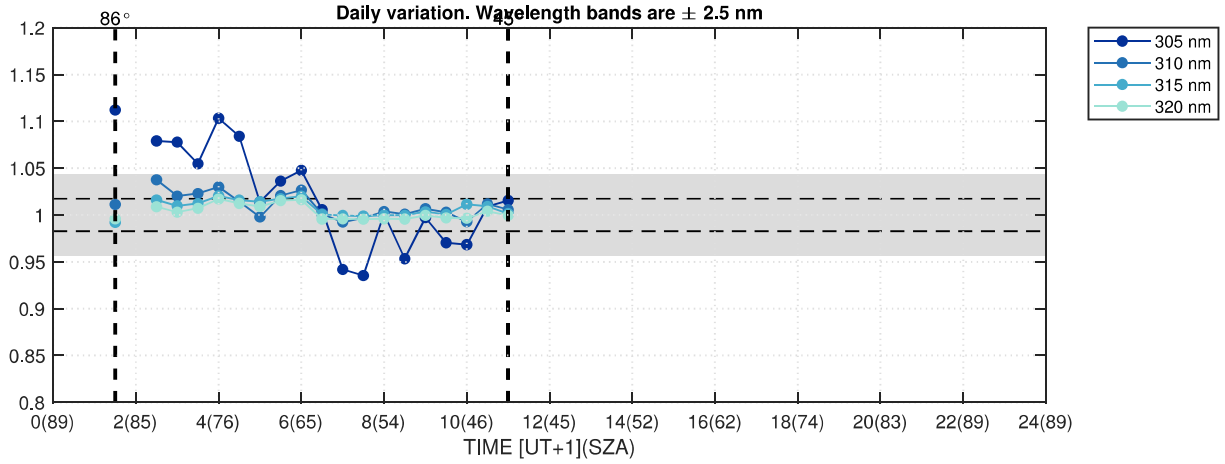

Global irradiance ratios FIS/QASUME at Sodankyla-matshic:03-Jun-2026(154)
wl [nm]
UVIndex
FIS
QASUME

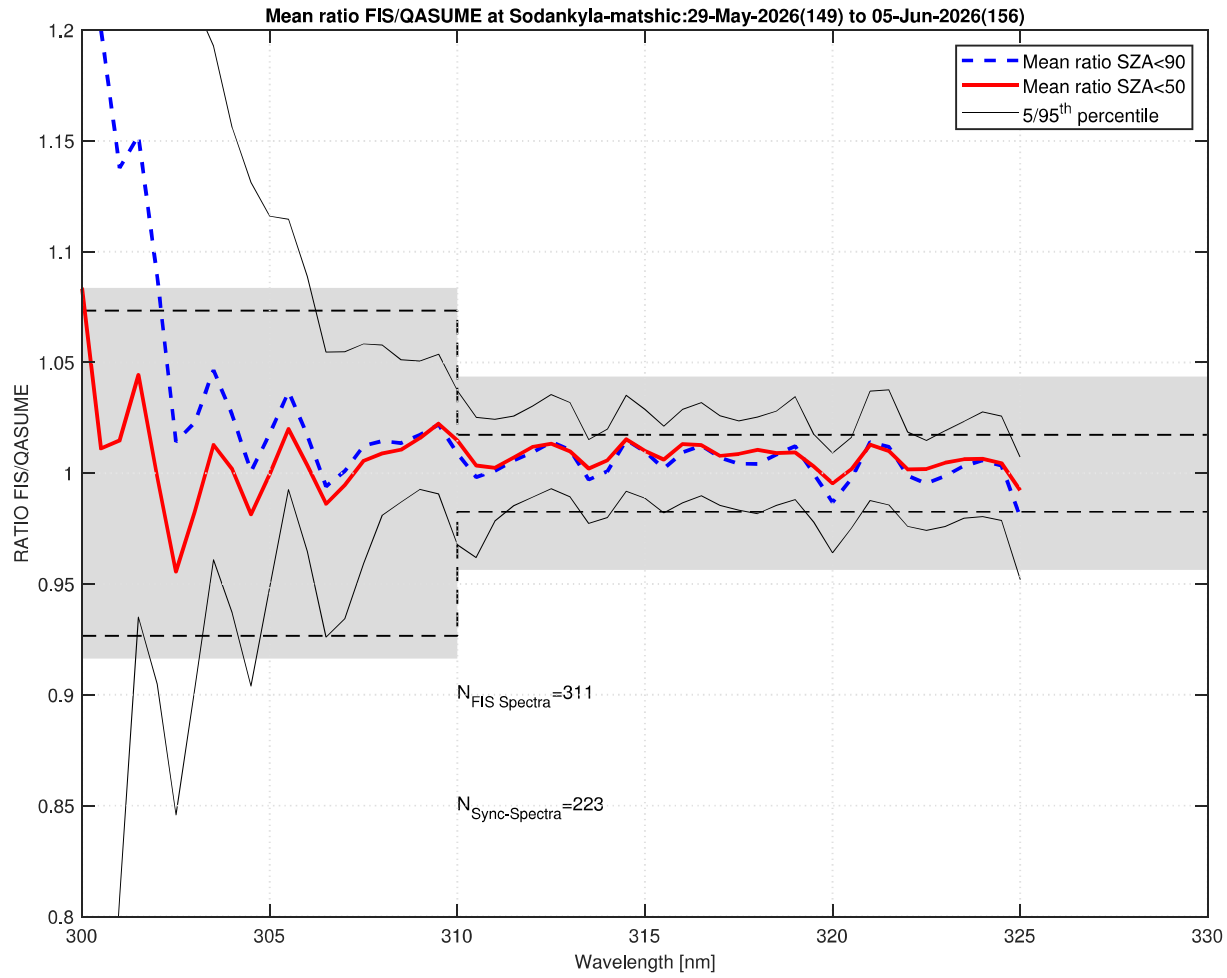

Daily variation. Wavelength bands are ± 2.5 nm
87°
87°
TIME [UT+1](SZA)
305 nm
310 nm
315 nm
320 nm

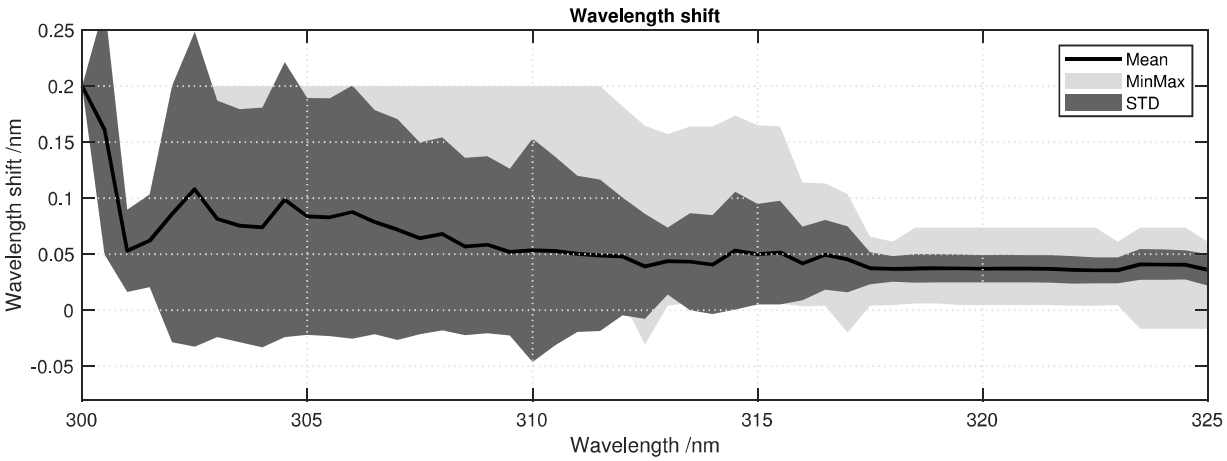

Global irradiance ratios FIS/QASUME at Sodankyla-matshic:04-Jun-2026(155)
wl [nm]
UVIndex
FIS
QASUME

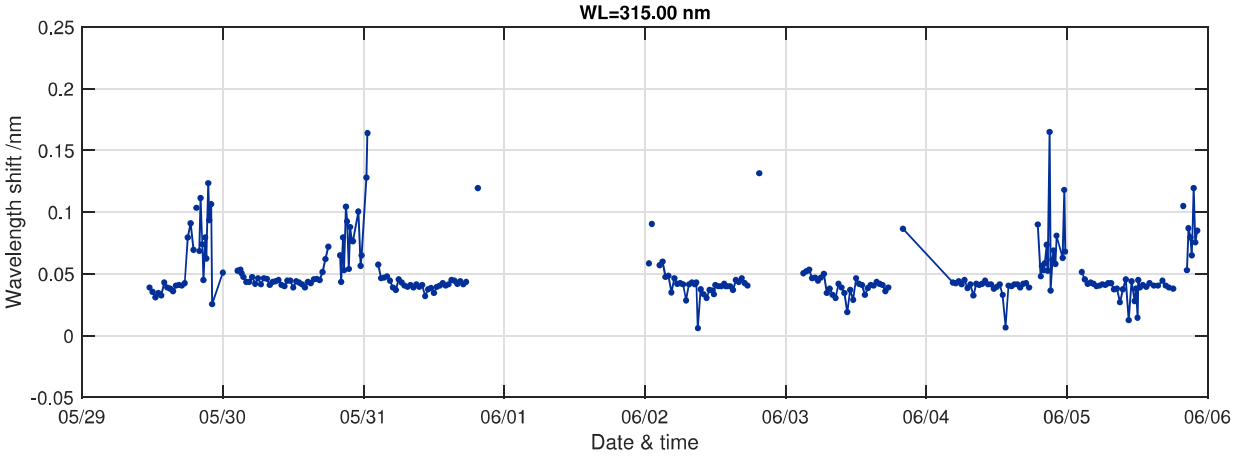

Daily variation. Wavelength bands are ± 2.5 nm
68°
88°
305 nm
310 nm
315 nm
320 nm
TIME [UT+1](SZA)

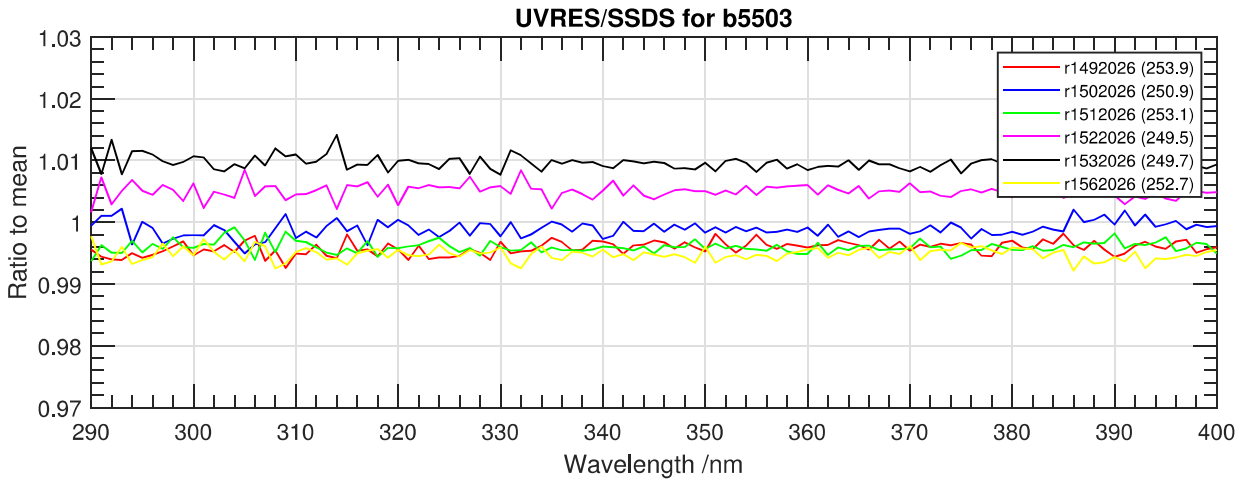

Global irradiance ratios FIS/QASUME at Sodankyla-matshic:05-Jun-2026(156)
wl [nm]
UVIndex
FIS
QASUME

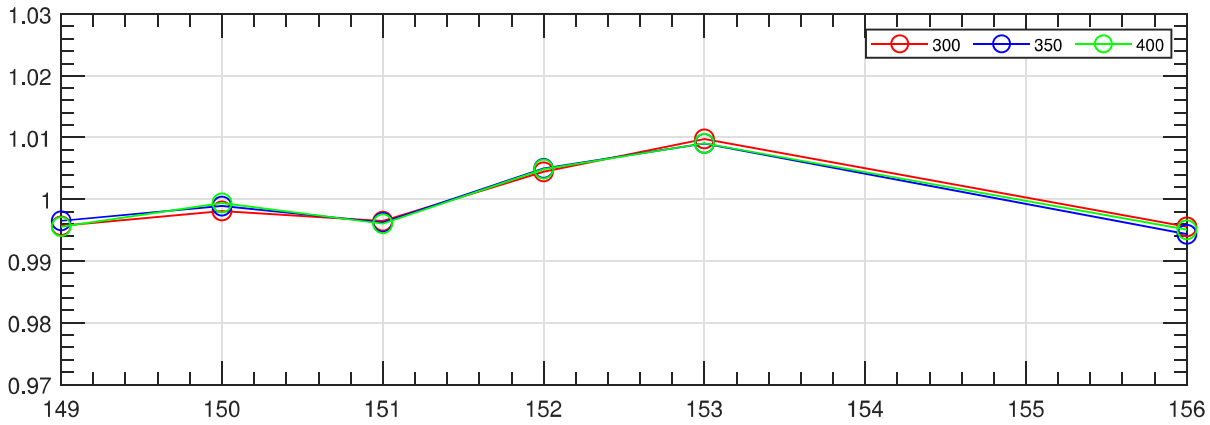

Daily variation. Wavelength bands are ± 2.5 nm
86°
305 nm
310 nm
315 nm
320 nm
TIME [UT+1](SZA)

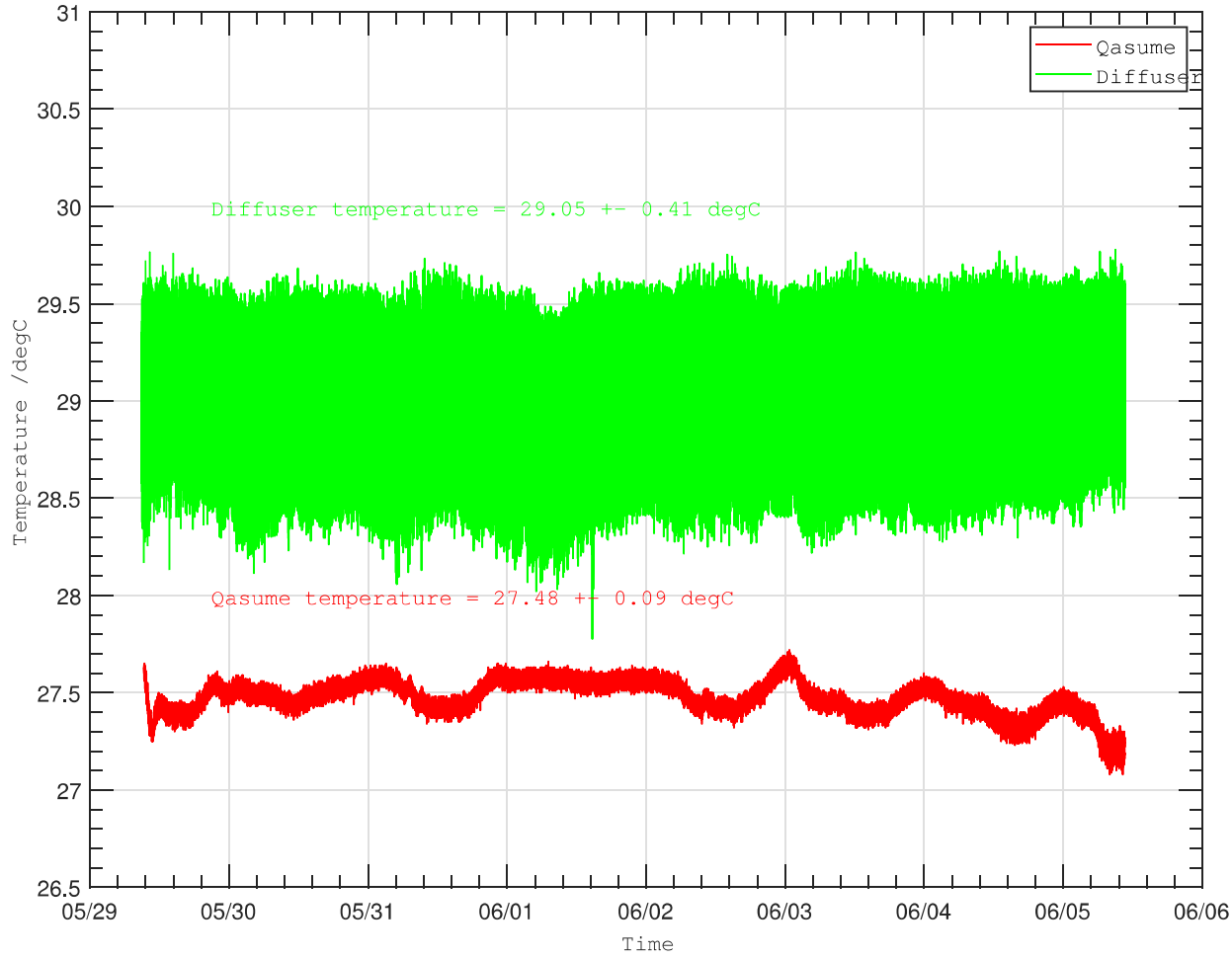

Mean ratio FIS/QASUME at Sodankyla-matshic:29-May-2026(149) to 05-Jun-2026(156)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
RATIO FIS/QASUME
Wavelength [nm]
N FIS Spectra=311
N Sync-Spectra=223

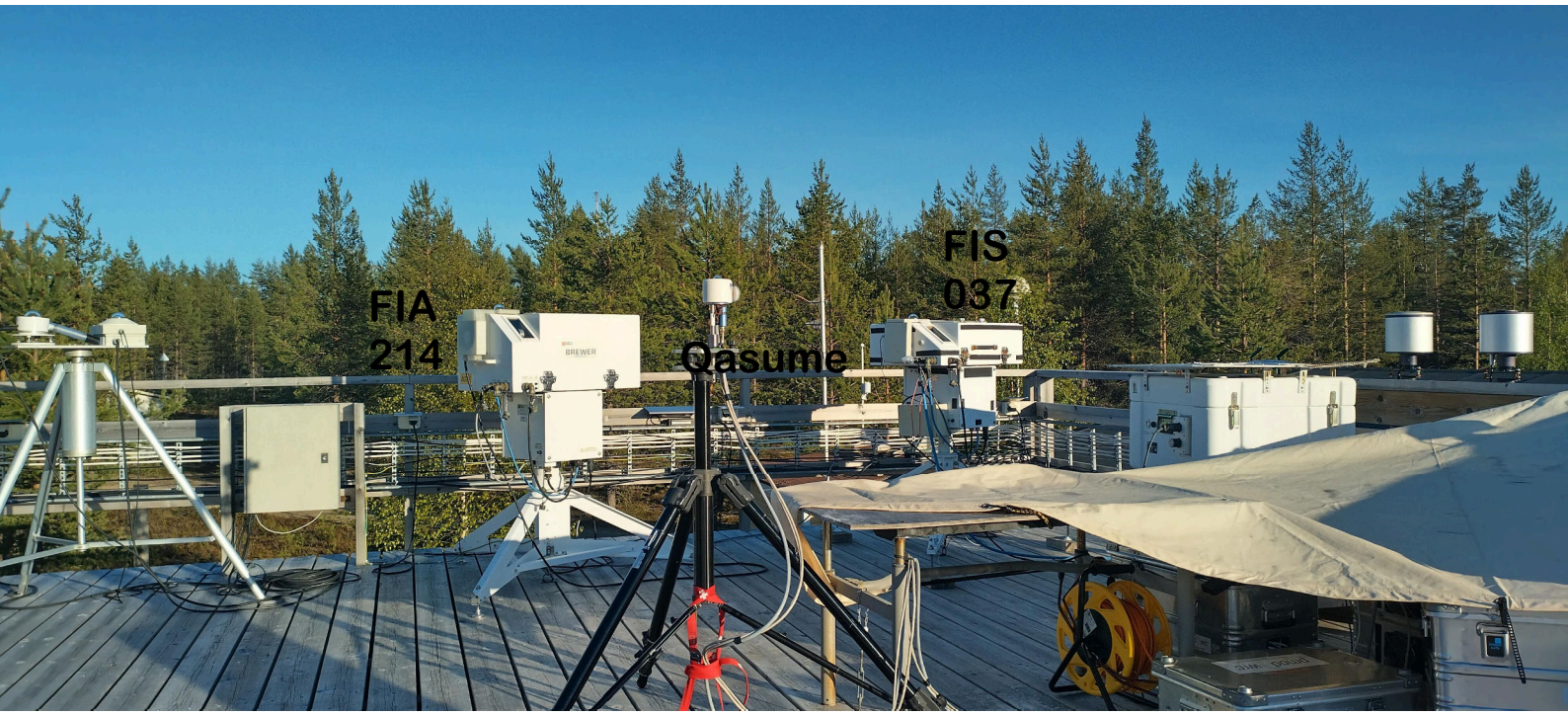

Wavelength shift
Mean
MinMax
STD
Wavelength shift /nm
Wavelength /nm


WL=315.00 nm
Wavelength shift /nm
Date & time


UVRES/SSDS for b5503
r1492026 (253.9)
r1502026 (250.9)
r1512026 (253.1)
r1522026 (249.5)
r1532026 (249.7)
r1562026 (252.7)
Ratio to mean
Wavelength /nm


300
350
400


Qasume
Diffuser
Diffuser temperature = 29.05 +- 0.41 degC
Qasume temperature = 27.48 +- 0.09 degC
Temperature /degC
Time


FIA
214
Qasume
FIS
037