Protocol of the intercomparison at NIWA, Lauder, New Zealand, from January 29 to February 12, 2016 with the travelling reference spectroradiometer QASUME from PMOD/WRC

Report prepared by Julian Gröbner

Operator: Julian Gröbner
Local Operator NIWA : Michael Kotkamp
Local Operator ARPANSA: Kerryn King

The purpose of the visit was the comparison of global solar irradiance measurements between the spectroradiometers UV-4 and UV-9 operated by the National Institute of Water & Atmospheric Research (NIWA), the spectroradiometer operated by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), and the travel reference spectroradiometer QASUME. The measurement site is located at Lauder; Latitude 45.05 S, Longitude 169.67 E and altitude 370 m.a.s.l. The horizon of the measurement site is free down to at least 85° solar zenith angle (SZA). Measurements were analysed between sunrise and sunset (SZA of 90°).

The spectroradiometers in use at NIWA are double monochromator spectroradiometers. UV-4 uses an entrance optic J1002 from Schreder, while UV-9 uses a self-developed entrance optic. More details can be found on the NIWA web-site at https://www.niwa.co.nz/our-services/instruments/instruments/lauder/uvspec.
The spectroradiometer operated by ARPANSA is a Bentham DM300 double monochromator with the same entrance optic as UV-9. The instrument was deployed on the measurement platform and operated at ambient temperatures.

QASUME was installed at NIWA, Lauder on January 29, 2016. The intercomparison between QASUME and the spectroradiometers lasted thirteen days, from the morning of January 31 to the morning of February 12.

QASUME was calibrated several times during the intercomparison period using a portable calibration system. Three lamps (T68522, T68523 and T61251) 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 2 % with a well-defined diurnal variation. This diurnal variation was not corrected, as it is within the uncertainty budget of QASUME. The internal temperature of QASUME was 26.9±0.5 °C and the diffuser head was heated to a temperature of 33.3±5 °C.

The wavelength shifts relative to an extraterrestrial spectrum as retrieved from the matSHIC analysis were within ±50 pm in the spectral range 300 to 450 nm.

Protocol:

The measurement protocol was to measure one solar irradiance spectrum every 15 minutes from 280 to 450 nm, every 0.2 nm, and 0.7 seconds between each wavelength increment. All times are given in UT (local time +13).
UV-9 followed the protocol. UV-4 was operated in its usual measurement mode (average spectrum from down and up scan) until 9 February. From 10 to 12 February its schedule was modified according to the intercomparison schedule (41-43). ARPANSA was operated in its usual operation mode (average spectrum from down and up scan).

DOY	Date	DAY	Weather	Comment (times are in UT)
29	29. Jan	Friday	Clear sky	Installed at 23:00 UT
30	30. Jan	Saturday	Clear sky	3:20 calibration T68523 3:40 calibration T68522
31	31. Jan	Sunday	Clear sky & some cirrus	0:05 Calibration T68523
32	01. Feb	Monday	Clear sky & some cirrus	0:18 Calibration T68523
33	02. Feb	Tuesday	mix of sun and clouds	2:45 Calibration T68523
34	03. Feb	Wednesday	Clear sky, some cumulus	1:50 Calibration T68523
35	04. Feb	Thursday	Clear sky, then overcast	UV-9 in Lab for calibration
36	05. Feb	Friday	Clear Sky	UV-9 in Lab for calibration 1:05 Calibration T68523
37-38		Saturday Sunday	Clear sky Clear sky	No supervision of instruments
39	08. Feb	Monday	Clear sky	20:35 Calibration T68523
40	09. Feb	Tuesday	Stratus in the morning Mix of sun and clouds	UV-4 in lab for calibration
41	10. Feb	Wednesday	Cirrus and Cirrostratus	UV-4 now synchronised 20:35 T68523 23:05 T68523 1:35 T68523 3:45 T68523
42	11. Feb	Thursday	Clear sky, Mix of sun and clouds	
43	12. Feb	Friday	Clear sky some cumulus	End of Campaign:: 22:00 22:30 1000W calibration of QASUME

Remarks:

The following analysis uses revised datasets submitted by the local operators after the end of the campaign. The original datasets from the three instruments were revised as follows:

- UV-4
    - The wavelength dispersion was revised due to an erroneous wavelength periodicity introduced by the processing software.
    - In the original dataset, the diffuser temperature correction was estimated from the ambient air temperature, even though the diffuser was heated above ambient temperatures.
    - The absolute spectral irradiance calibration was performed during the campaign and the final dataset was submitted after the end of the campaign.
    - The cosine correction applied to the original dataset was erroneous and was resubmitted.
- UV-9
    - The diffuser temperature was estimated from the ambient air temperature. The revised dataset uses the measured temperature of the diffuser.
    - The absolute spectral irradiance calibration was performed during the campaign and the final dataset was submitted after the end of the campaign.
- ARPANSA
    - The absolute spectral irradiance calibration was performed at the end of the campaign and submitted after the end of the campaign.

matSHIC:

The spectra from all instruments were converted to a common wavelength scale defined by a high resolution solar spectrum with a wavelength uncertainty below 0.001 nm. In addition, the spectra were converted to a common resolution of 1nm full width at half maximum (FWHM) in order to improve the comparison between the spectroradiometers.

The measurements were all manually inspected and obvious outliers were removed from the intercomparison. These were mainly due to timing differences between the instruments which under cloudy conditions produced large differences in the comparisons with QASUME.

The solar irradiance spectra of UV-4 and ARPANSA were interpolated to the measurement times of QASUME in order to take the varying solar zenith angle for each wavelength step into account. The effect is negligible around local noon, but becomes significant at solar zenith angles around 50°.

Results:

Spectral irradiance standards comparison

The spectral irradiance standards used to determine the responsivity of the spectroradiometers were measured by the NIWA spectroradiometers UV-4 and UV-9, as well as by QASUME. In Figure 1, the relative difference between three spectral irradiance standards are compared with the QASUME spectral irradiance scale, realised by a set of 250 W lamps, traceable to the German Metrology Institute (PTB) via a set of 6 transfer standards held at PMOD/WRC.

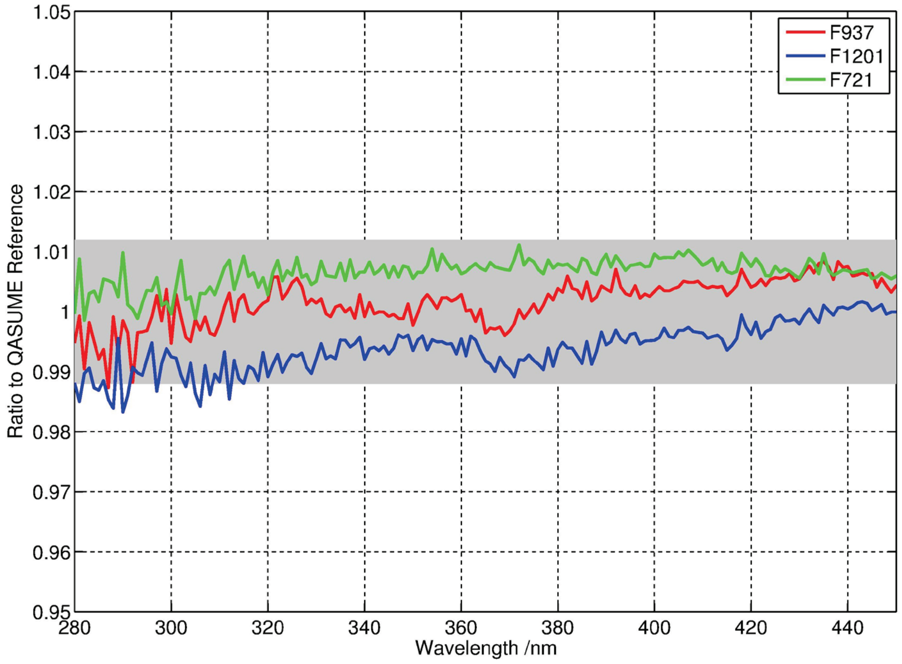


Figure 1 Relative difference of three 1000W FEL transfer standards to the QASUME scale as measured by QASUME on the optical bench of NIWA. F937 and F1201 are from NIWA while F721 was calibrated at PMOD/WRC before the campaign. The gray shaded area represents the expanded uncertainty of the QASUME scale.

As can be seen in Figure 1, the three transfer standards agree to better than ±1%, which is within the uncertainties of the calibration certificates.

Solar intercomparison

The comparison between the solar spectra measured with the spectroradiometers and QASUME are attached to this report.

1) UV-4
    - 362 solar spectra from a total of 686 were used for the analysis.
    - The wavelength shifts determined with matSHIC relative to a high resolution reference spectrum were stable to better than ±20 pm during the whole campaign, both in time and spectrally.
    - From 30 January to 10 February, the UV-4 solar spectra were interpolated to the measurement times of QASUME. These interpolated spectral ratios between the solar spectra measured with UV-4 and QASUME are within ±3% for SZA smaller than 50°. At wavelengths above 400 nm a slight drift in the spectral

ratios is seen, with deviations of up to +4% after local noon, which might be due to the simple interpolation method applied to the UV-4 measurements.
- Between 10 and 12 February UV-4 was measuring synchronously to QASUME from sunrise to sunset. The corresponding spectral ratios to QASUME are within ±3%. Outliers seen on the afternoon of 11 February are probably due to passing clouds.

2) UV-9
- 522 solar spectra from a total of 818 were used for the analysis.
- The spectral wavelength shifts determined with matSHIC relative to a high resolution reference spectrum were between -10 pm and +30 pm for the duration of the campaign. The temporal stability of the wavelength was better than ±10 pm.
- The spectral ratios between the solar spectra measured with UV-9 and QASUME are within ±3% for SZA up to 80°.
- At larger SZA between 80° and 90°, the ratios show a slight drop of about 10%, slightly more pronounced at shorter wavelengths.

3) ARPANSA
- The wavelength shifts of ARPANSA show significant daily variations of up to +0.3 nm, independent of wavelength. The wavelength shifts consistently increase during all days.
- The spectral wavelength shifts show an overall offset of +0.1 nm relative to a high resolution reference spectrum, with a spectral variability of 0.1 nm between 300 nm and 400 nm.
- The spectral ratios between the solar spectra measured with ARPANSA and QASUME are spectrally flat, with an average difference of -5% to -10% relative to QASUME for SZA smaller than about 60°.
- The larger discrepancies seen at SZA above 60° could be due to the timing differences between the two instruments and the limitations of the simple interpolation methodology applied to the ARPANSA spectra.

Conclusion

NIWA

- The reference standards of NIWA and PMOD/WRC which are used to provide traceable measurements of solar UV irradiance to SI are consistent to better than 1% over the wavelength range 300 to 450 nm.
- The solar spectral irradiance measurements between 300 nm and 450 nm of the NIWA spectroradiometers UV-4 and UV-9 are within ±3% of QASUME, which is within the expanded uncertainty bounds of QASUME (gray shaded area in the daily figures).

ARPANSA

- The ARPANSA spectroradiometer has significant wavelength discrepancies and diurnal changes which are probably caused by the ambient temperature variations to which the spectroradiometer is exposed to.
- The solar spectra measured by ARPANSA are between 5% and 10% lower than those measured by QASUME. These differences are larger than what can be explained by the difference in 1000W reference standards and are therefore due to some additional so far unexplained effect.

Comments from the local operator NIWA

The UV4 and UV9 spectrometers sampled irradiances over the wavelength region 285 to 450 nm. The spectral resolution is approximately 0.7 nm (fwhm), and data are sampled at 0.2 nm intervals. Our in-house UV data processing programme, UVP36, was used to process data from both of these instruments. Measurements are referred to the NIST irradiance standard via a series of 1000 W FEL lamps held at NIWA Lauder, which are in turn calibrated by IRL (Wellington, NZ) and Optronics Laboratories (Florida, USA) The programme includes a correlation alignment with the Fraunhofer feature near 390 nm, and non-linear corrections that allow for departures from the expected line positions at other wavelengths, as determined by regular scans of a low pressure mercury source. Corrections are applied to take account of the departures from the true cosine response, and the temperature-dependence of the transmission of the PTFE diffuser. Corrections are also applied to take account of temperature effects in the photomultiplier gain and electronics.

The campaign was extremely useful, as it identified several issues that could be improved in the UV4 instrument. The first of these was the use of a sinusoidal wavelength correction that was inappropriate (a legacy from another instrument). The second was that the PTFE temperature correction was inferred from the air temperature and solar loading, rather that the directly-measured PTFE temperature, which is available for this instrument (also a legacy issue – too many instruments and not enough people to manage them). Finally, we found that the cosine correction was inverted. The first two of these had only a small effect on derived data products (such as erythemally-weighted UV), but the incorrect cosine correction led to unacceptably large errors in inferred UVA irradiances, which were largest (>10%) at SZAs near 60°. Although effects were much smaller in the UVB region of most interest, we will still be reprocessing all data from this instrument, and resubmitting to the NDACC.

The NIWA data processing does not currently include post-processing to deconvolve to a standard slit function, or to correct wavelength with algorithms such as the SCHIC method developed at RIVM by Slaper's group. It would be useful to add this capability in the future. In the interim, it would be useful to compare standard products (e.g., time series of UVI values), as produced directly by NIWA processing, with the corresponding values following the PMOD post-analysis.

Remaining issues

1. Ratios of UV4/QASUME tends to increase over the day, especially for hot days. Although the effect is small, well within experimental uncertainties, this suggests that we could improve the temperature corrections.

2. There is some wavelength dependence in the UV4/QASUME ratios, with ratios at longer wavelengths now being perceptibly (but not ‘significantly’ in terms of overall uncertainty) larger than at shorter wavelengths. This separation was less obvious when the earlier incorrect cosine corrections had been applied. It suggests that we could improve the processing by including wavelength dependence in the cosine corrections. Most diffusers do show a wavelength dependence, but this effect is not currently included in NIWA data processing.

05 April 2016

Comments regarding the 1000W calibration of ARPANSA

The 1000W Lamp calibration on the ARPANSA spectroradiometer was performed on the 11th February 2016 in the optical laboratory of NIWA. For this calibration the spectroradiometer was moved into the laboratory. In addition to the reference standard of ARPANSA, 7-1980, also two NIWA standards 1201 and 937 were measured to link the irradiance scale to NIWA and QASUME. As shown in the figure below, ARPANSA 7-1980 has between 1% and 3% higher irradiances than NIWA and therefore also nearly the same difference to the QASUME transfer standard. From these measurements it is therefore expected that the solar measurements underestimate the solar irradiance by 1% to 3% at 300 nm and 450 nm respectively.

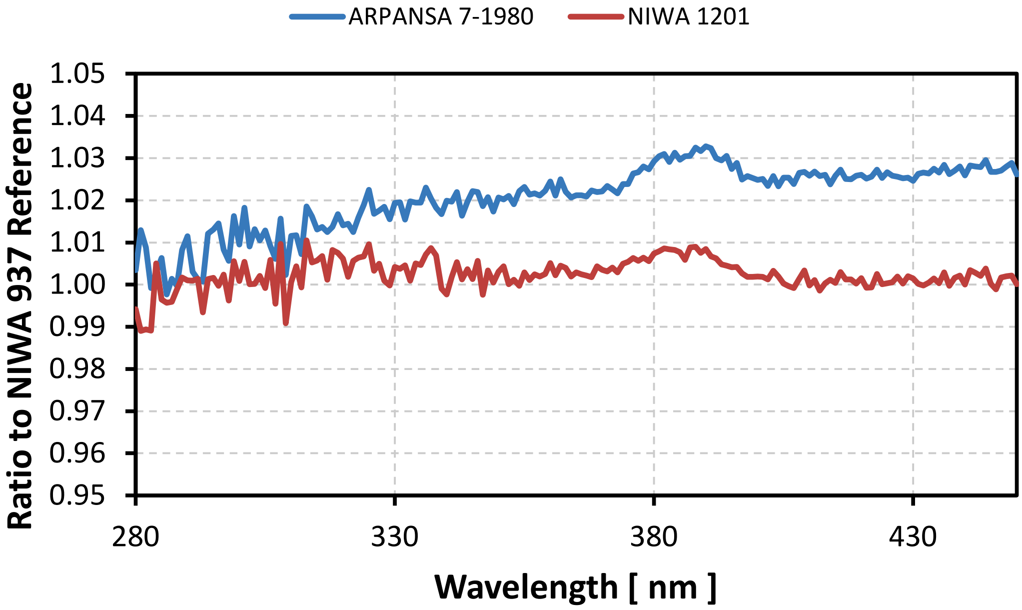
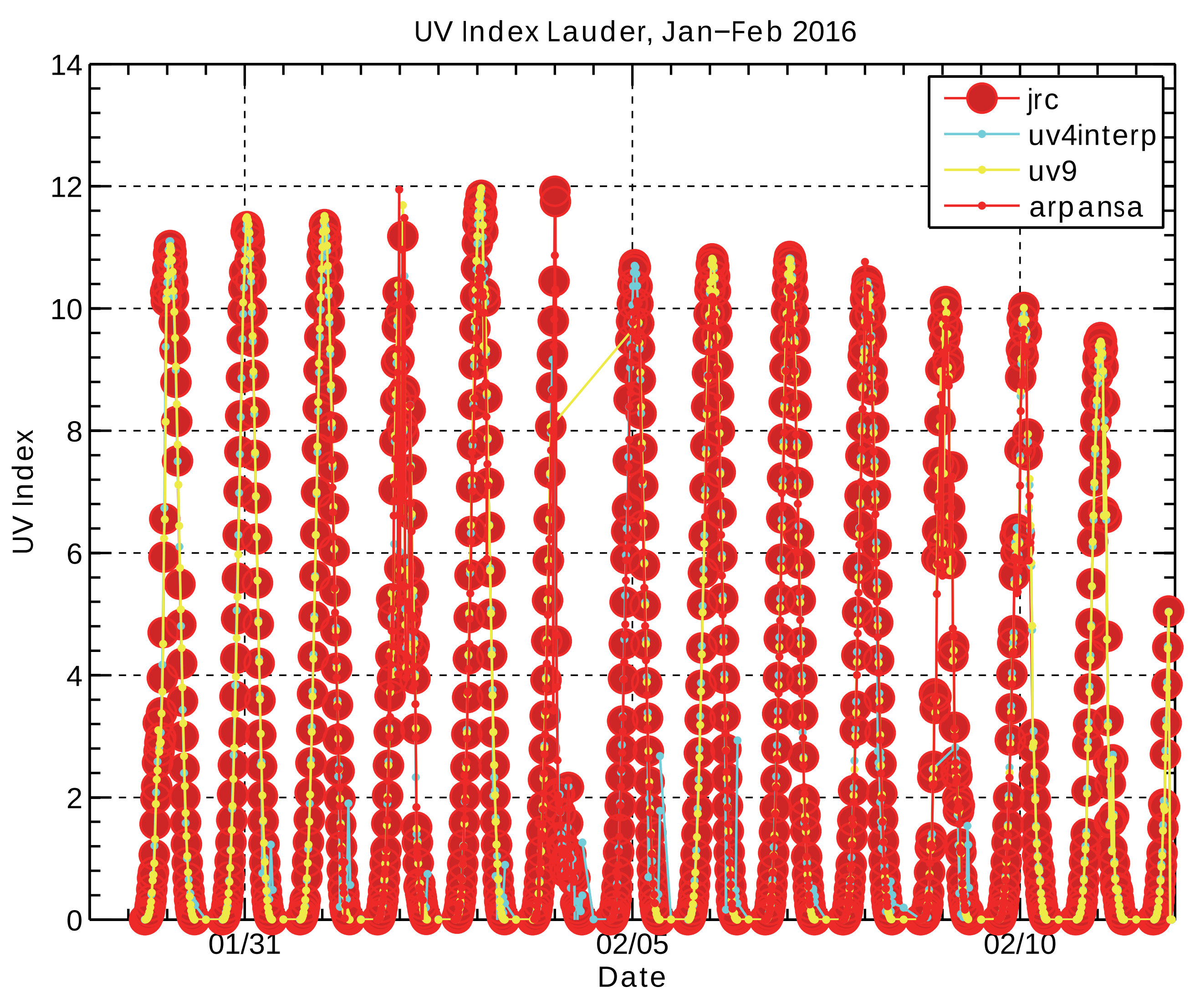
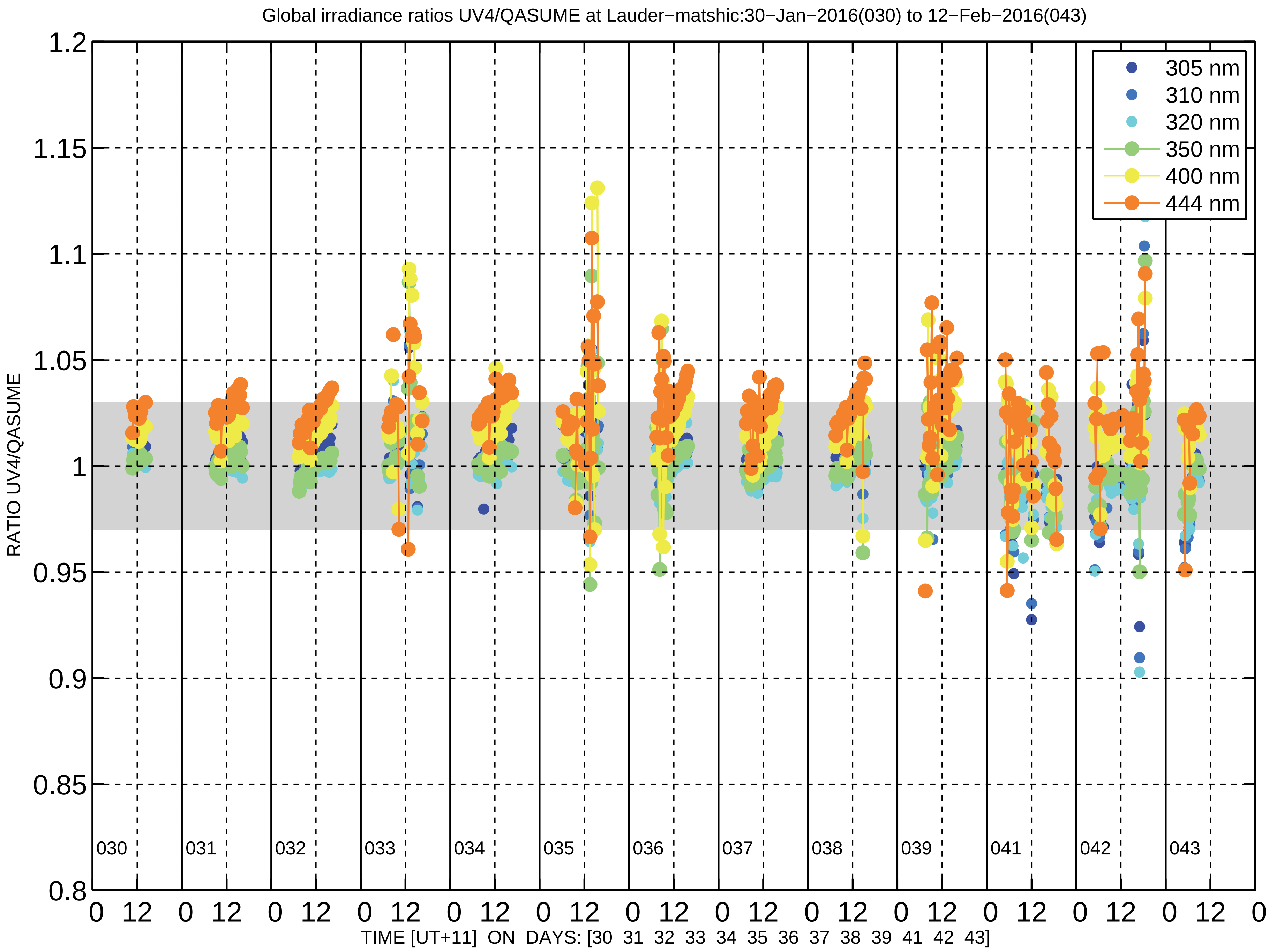


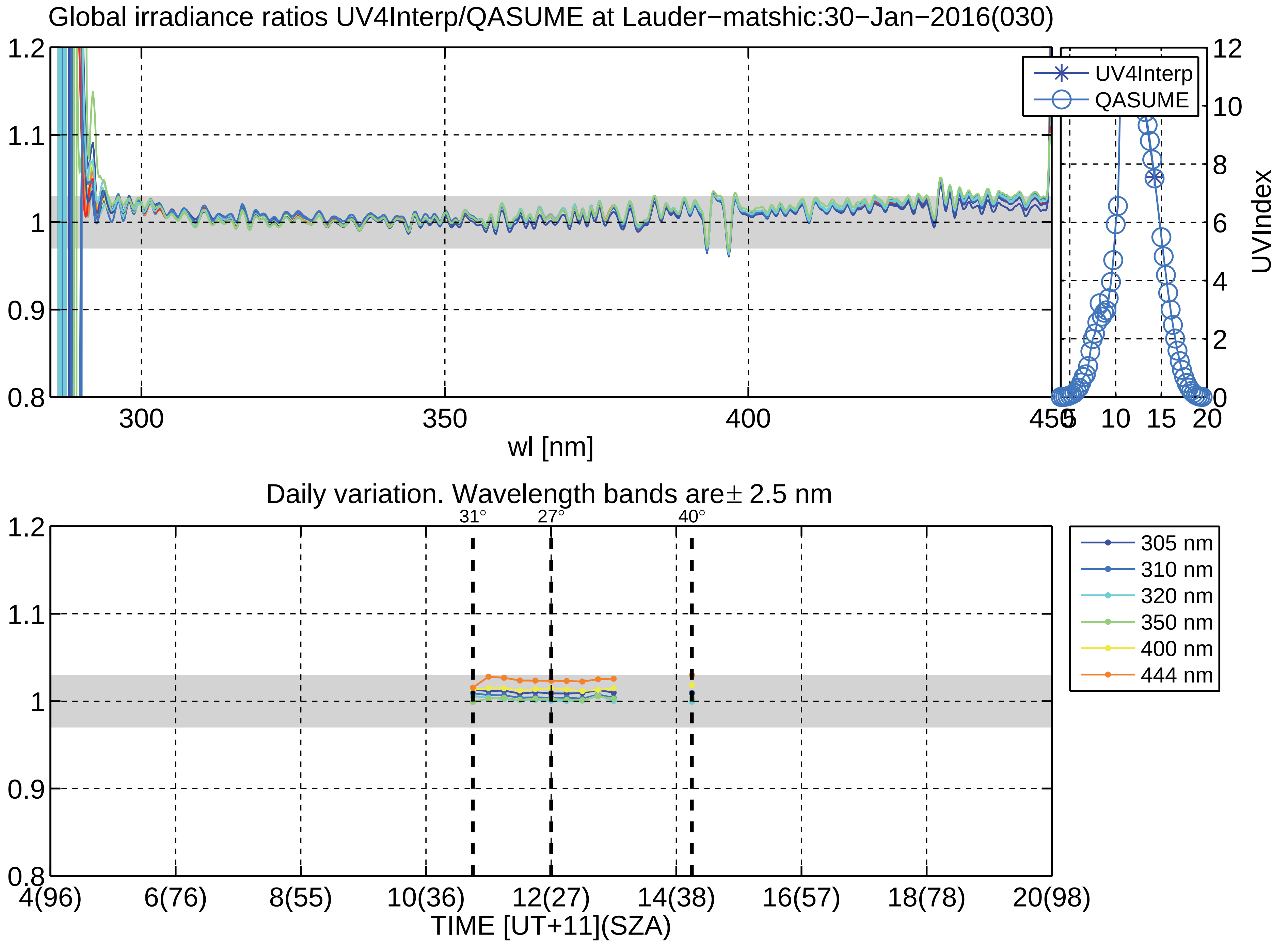
Figure 2 Ratio of calibrations performed by ARPANSA relative to the NIWA 937 transfer standard. The figure was taken from the file "Irradiance lamp comparisons at NIWA.xlsx", 18 March 2016.

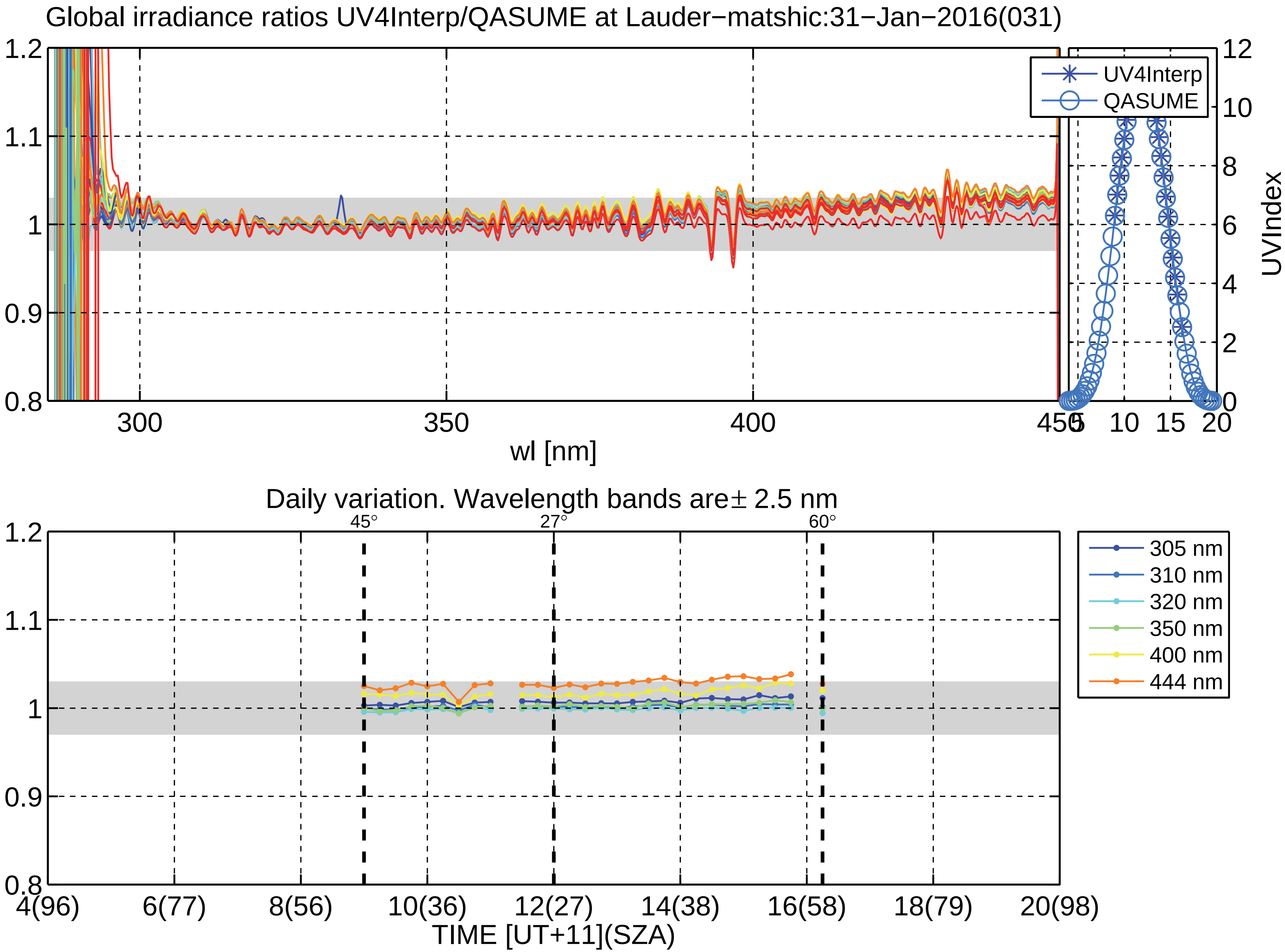


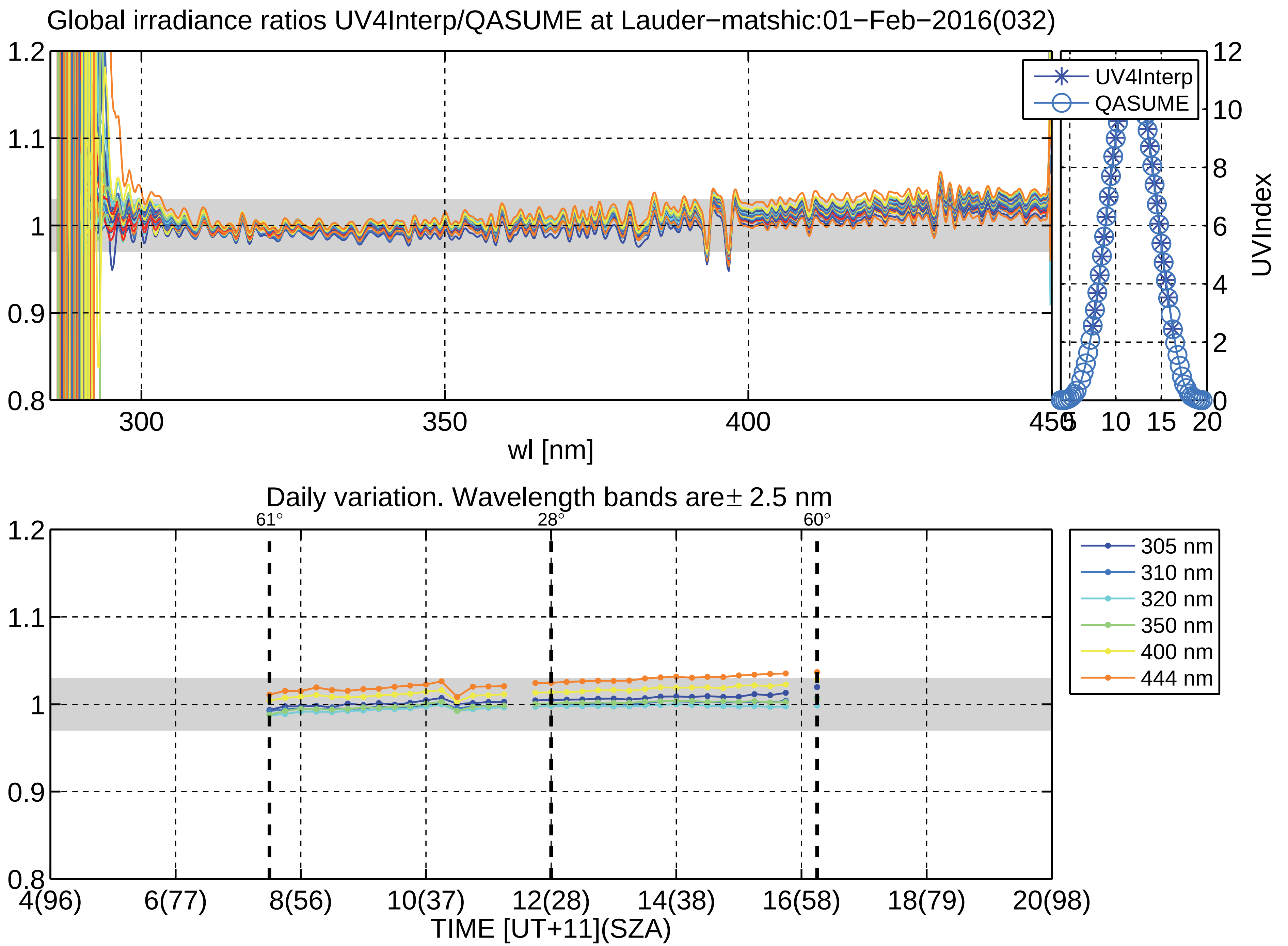
UV Index Lauder, Jan−Feb 2016
UV Index
Date
0
2
4
6
8
10
12
14
01/31
02/05
02/10
jrc
uv4interp
uv9
arpansa

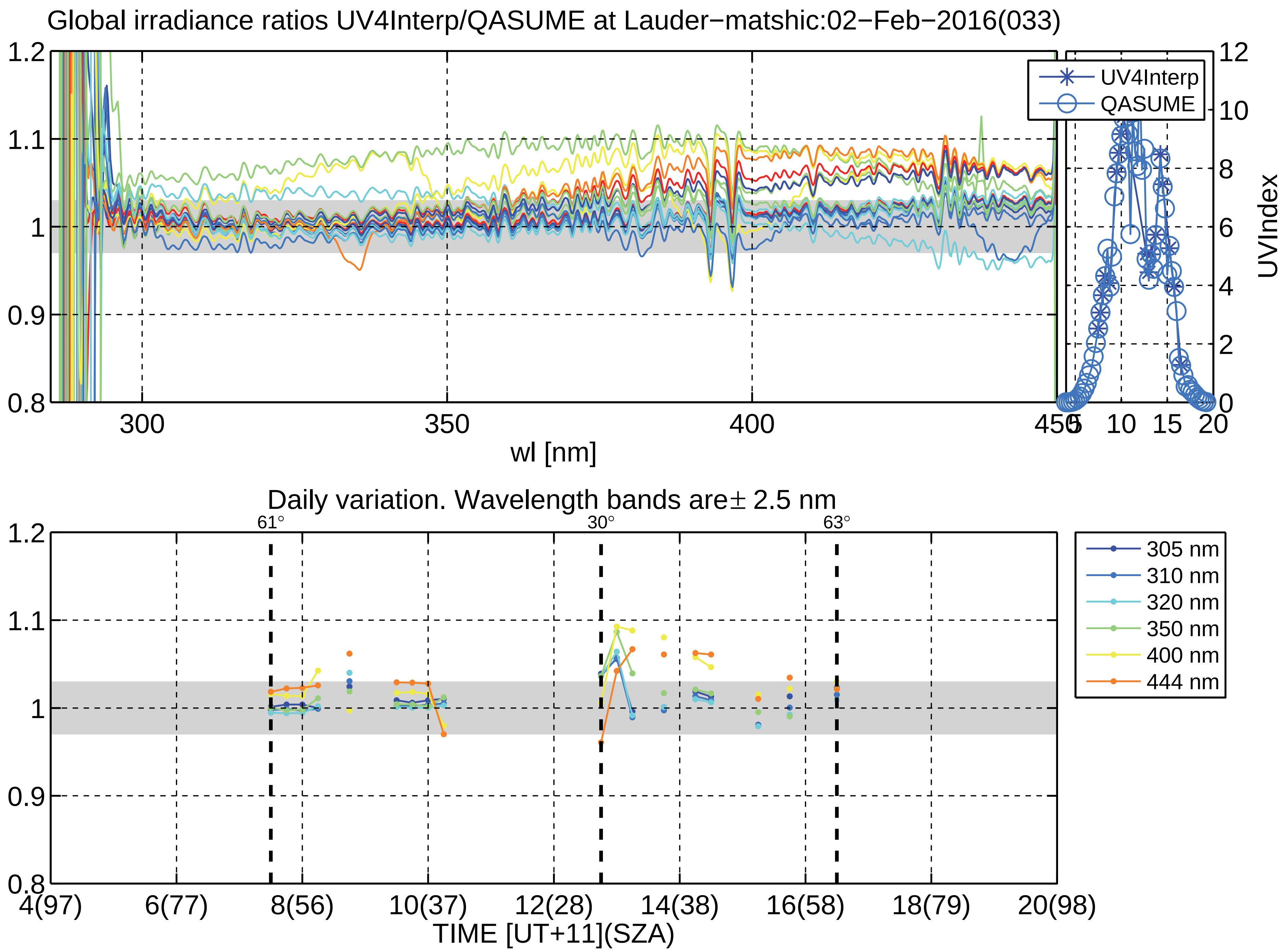


Global irradiance ratios UV4/QASUME at Lauder−matshic:30−Jan−2016(030) to 12−Feb−2016(043)
RATIO UV4/QASUME
TIME [UT+11] ON DAYS: [30 31 32 33 34 35 36 37 38 39 41 42 43]
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
030
031
032
033
034
035
036
037
038
039
041
042
043
0 12 0 12 0 12 0 12 0 12 0 12 0 12 0 12 0 12 0 12 0 12 0 12 0 12 0

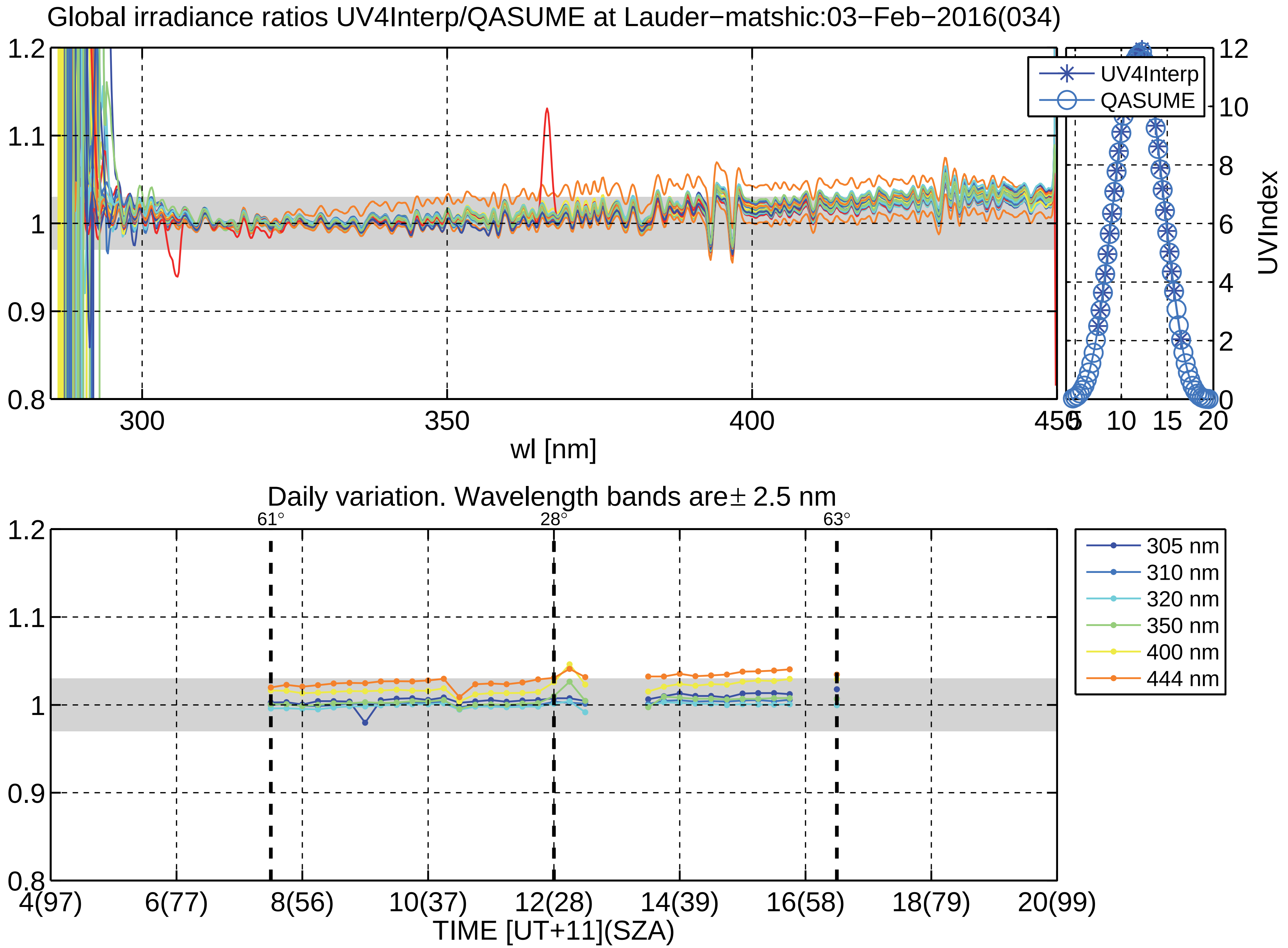

Global irradiance ratios UV4Interp/QASUME at Lauder−matshic:30−Jan−2016(030)
1.2
1.1
1
0.9
0.8
300
350
400
450
wl [nm]
UV4Interp
QASUME
UVIndex
12
10
8
6
4
2
0
5
10
15
20
Daily variation. Wavelength bands are± 2.5 nm
31°
27°
40°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
4(96)
6(76)
8(55)
10(36)
12(27)
14(38)
16(57)
18(78)
20(98)
TIME [UT+11](SZA)

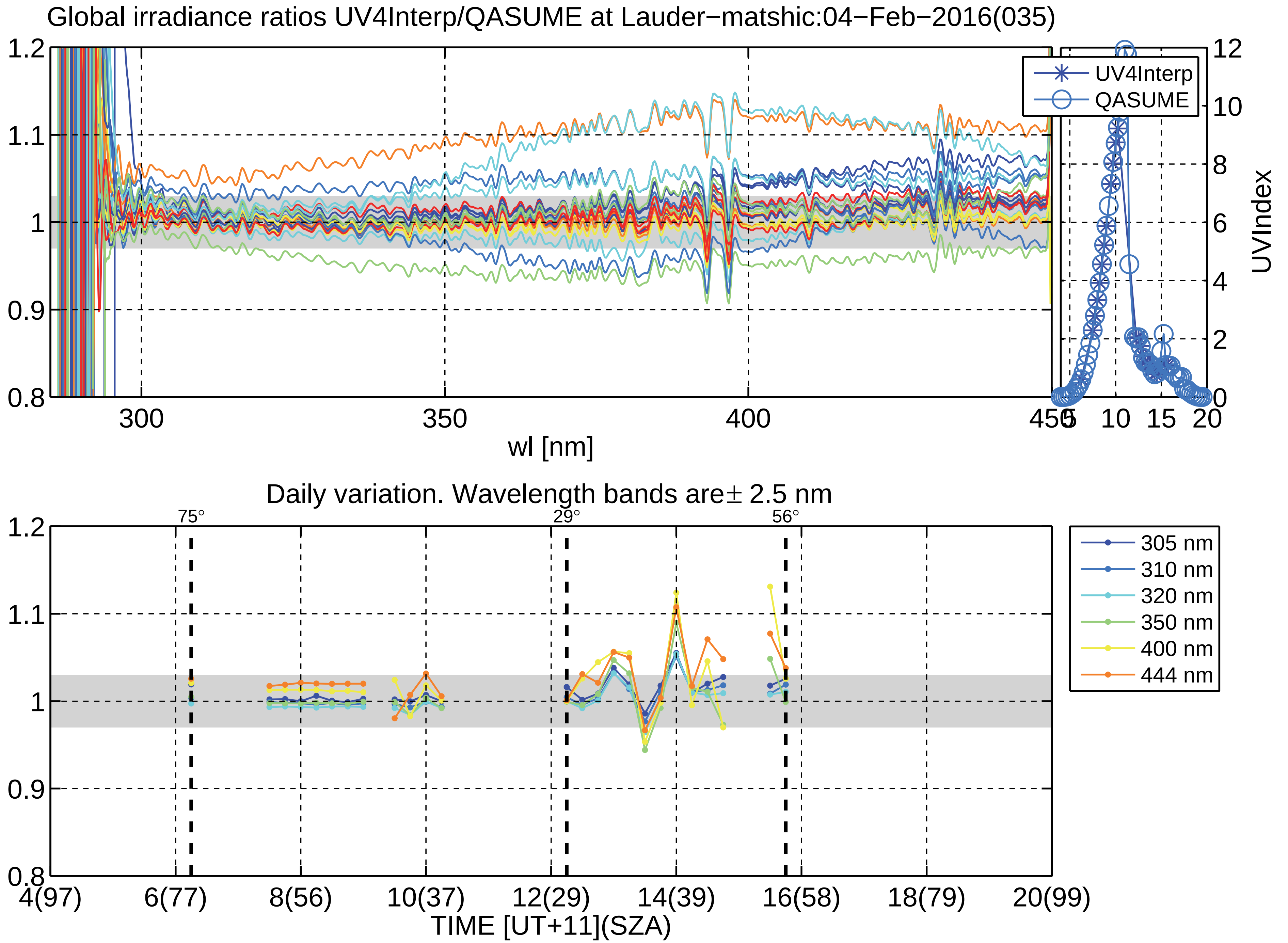

Global irradiance ratios UV4Interp/QASUME at Lauder−matshic:31−Jan−2016(031)
1.2
1.1
1
0.9
0.8
300
350
400
450
wl [nm]
UV4Interp
QASUME
5
10
15
20
12
10
8
6
4
2
0
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
45°
27°
60°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
4(96)
6(77)
8(56)
10(36)
12(27)
14(38)
16(58)
18(79)
20(98)
TIME [UT+11](SZA)


Global irradiance ratios UV4Interp/QASUME at Lauder−matshic:01−Feb−2016(032)
1.2
1.1
1
0.9
0.8
300
350
400
450
wl [nm]
UV4Interp
QASUME
12
10
8
6
4
2
0
5
10
15
20
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
61°
28°
60°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
4(96)
6(77)
8(56)
10(37)
12(28)
14(38)
16(58)
18(79)
20(98)
TIME [UT+11](SZA)

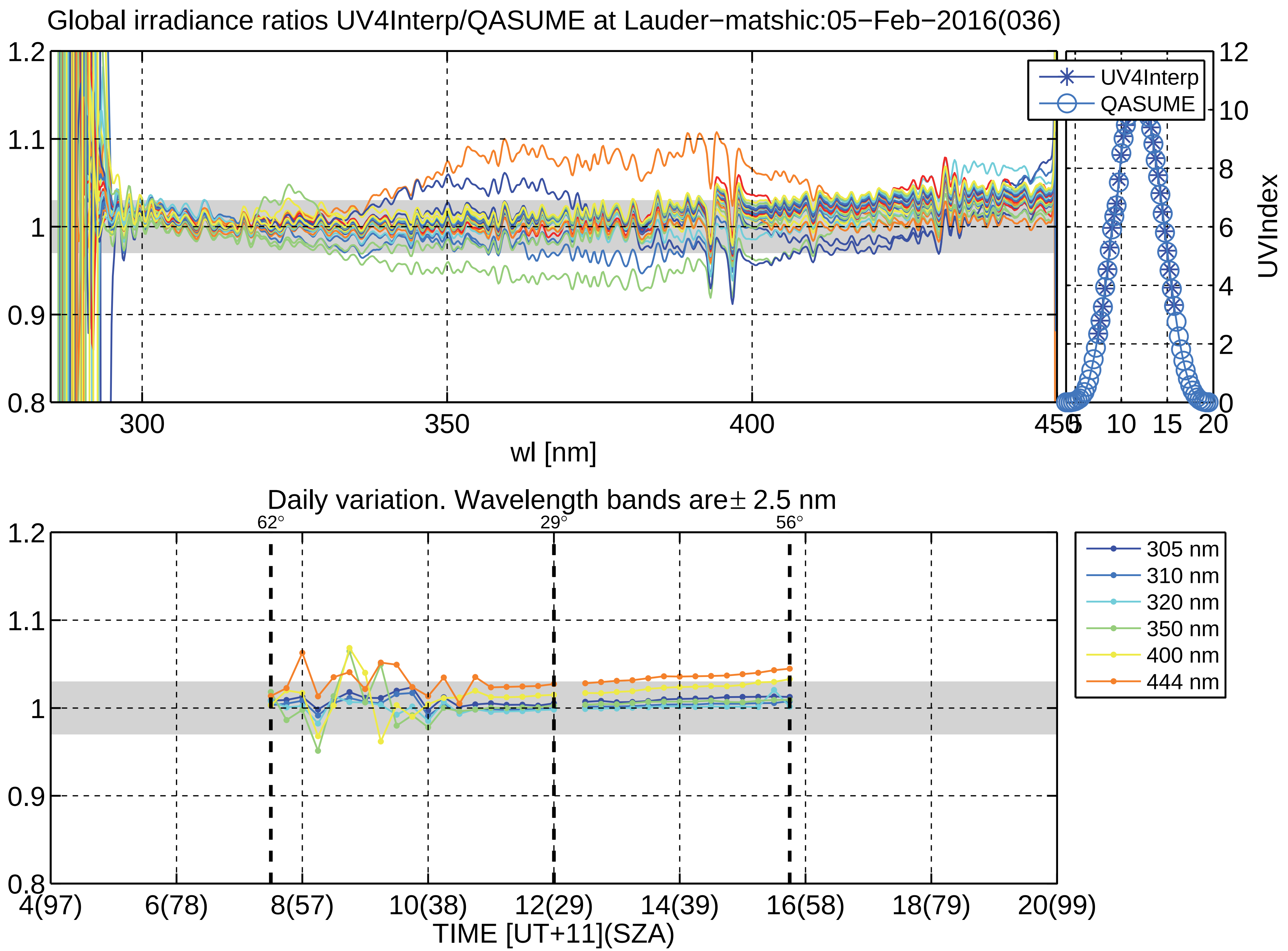


Global irradiance ratios UV4Interp/QASUME at Lauder−matshic:02−Feb−2016(033)
1.2
1.1
1
0.9
0.8
300
350
400
450
wl [nm]
UV4Interp
QASUME
UVIndex
12
10
8
6
4
2
0
5
10
15
20
Daily variation. Wavelength bands are± 2.5 nm
61°
30°
63°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
4(97)
6(77)
8(56)
10(37)
12(28)
14(38)
16(58)
18(79)
20(98)
TIME [UT+11](SZA)

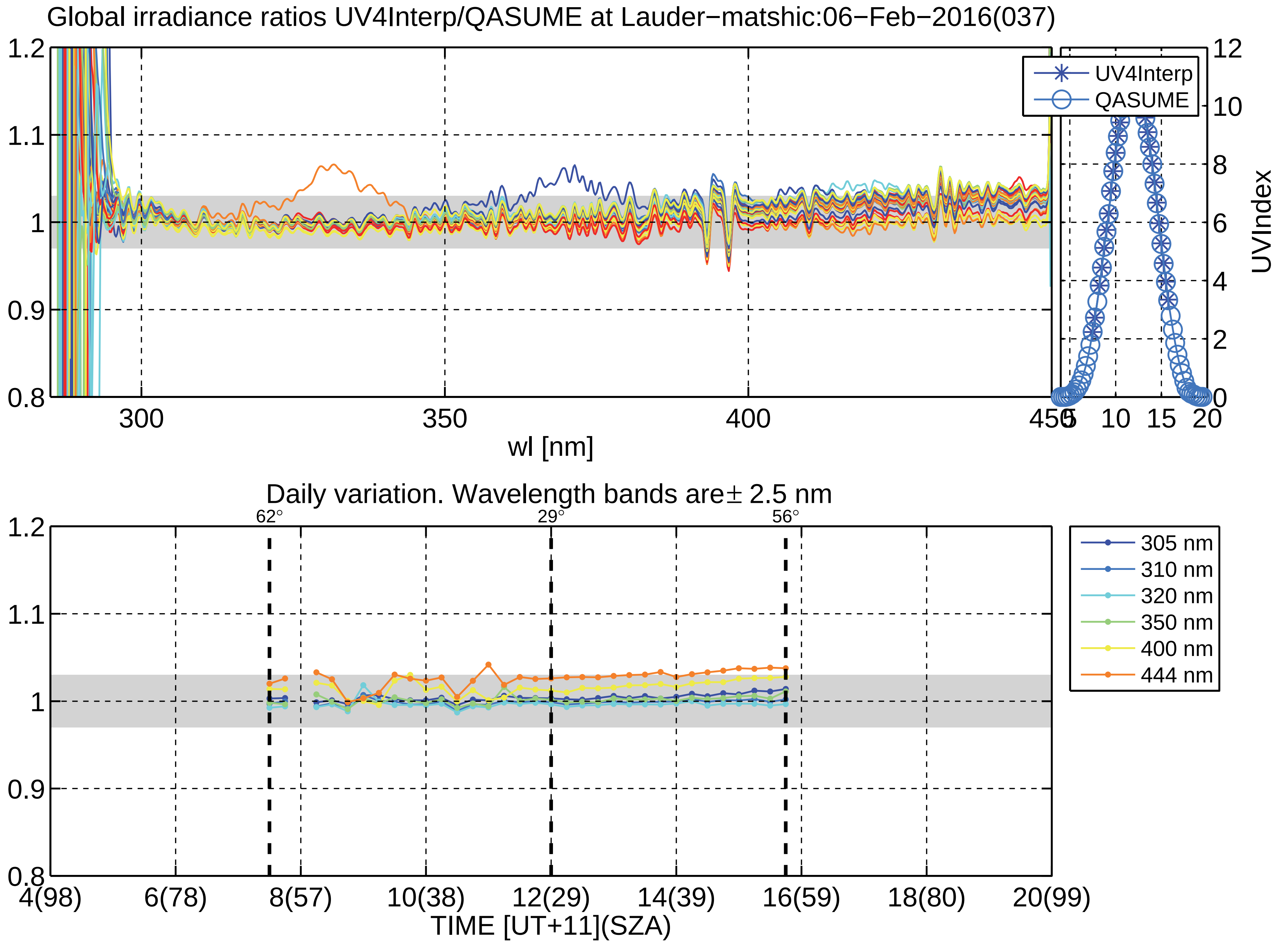

Global irradiance ratios UV4Interp/QASUME at Lauder−matshic:03−Feb−2016(034)
UV4Interp
QASUME
UVIndex
wl [nm]
Daily variation. Wavelength bands are± 2.5 nm
61°
28°
63°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
TIME [UT+11](SZA)
4(97)
6(77)
8(56)
10(37)
12(28)
14(39)
16(58)
18(79)
20(99)



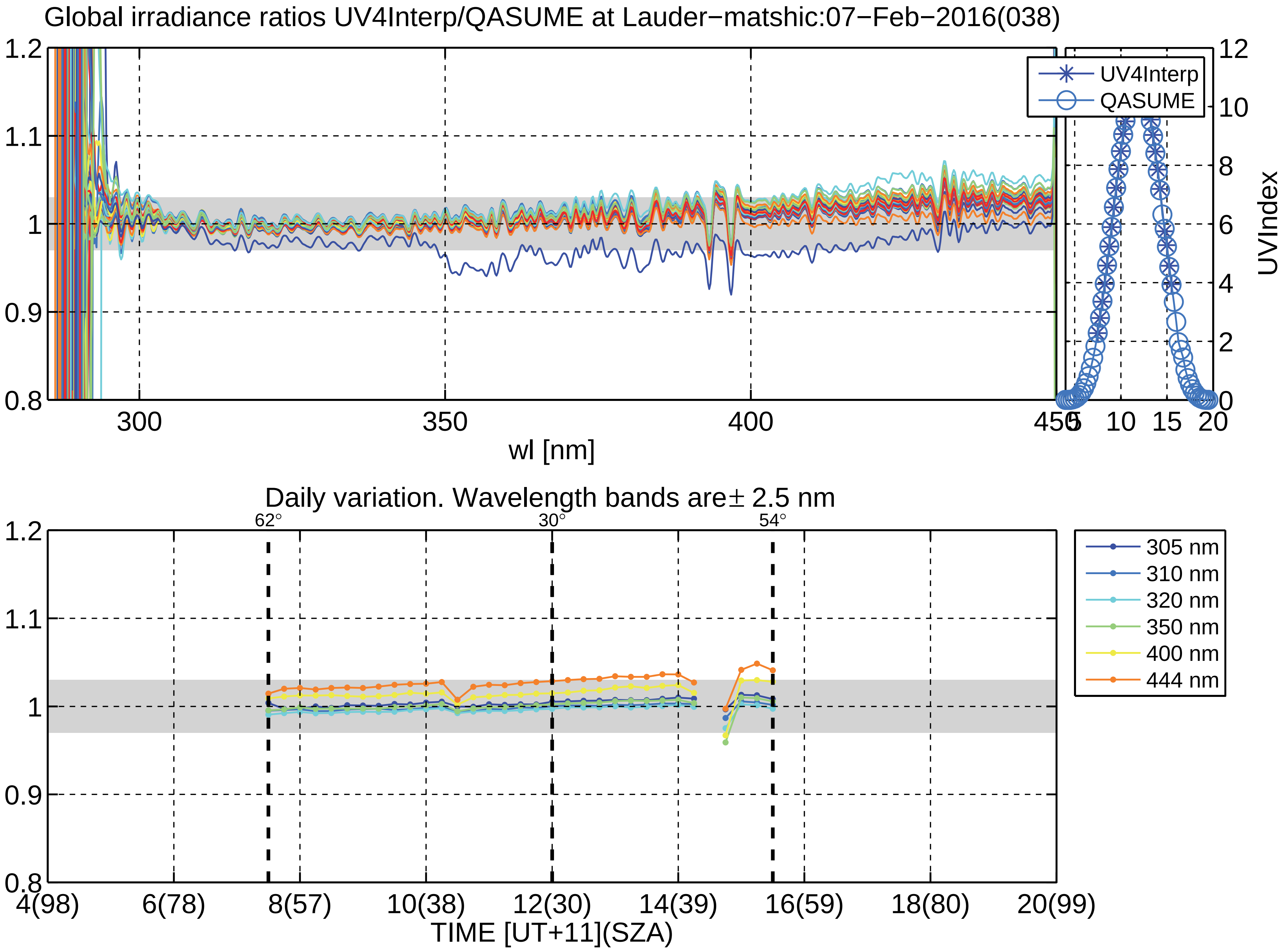
Global irradiance ratios UV4Interp/QASUME at Lauder−matshic:04−Feb−2016(035)
1.2
1.1
1
0.9
0.8
300
350
400
450
wl [nm]
UV4Interp
QASUME
UVIndex
12
10
8
6
4
2
0
5
10
15
20
Daily variation. Wavelength bands are± 2.5 nm
75°
29°
56°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
4(97)
6(77)
8(56)
10(37)
12(29)
14(39)
16(58)
18(79)
20(99)
TIME [UT+11](SZA)



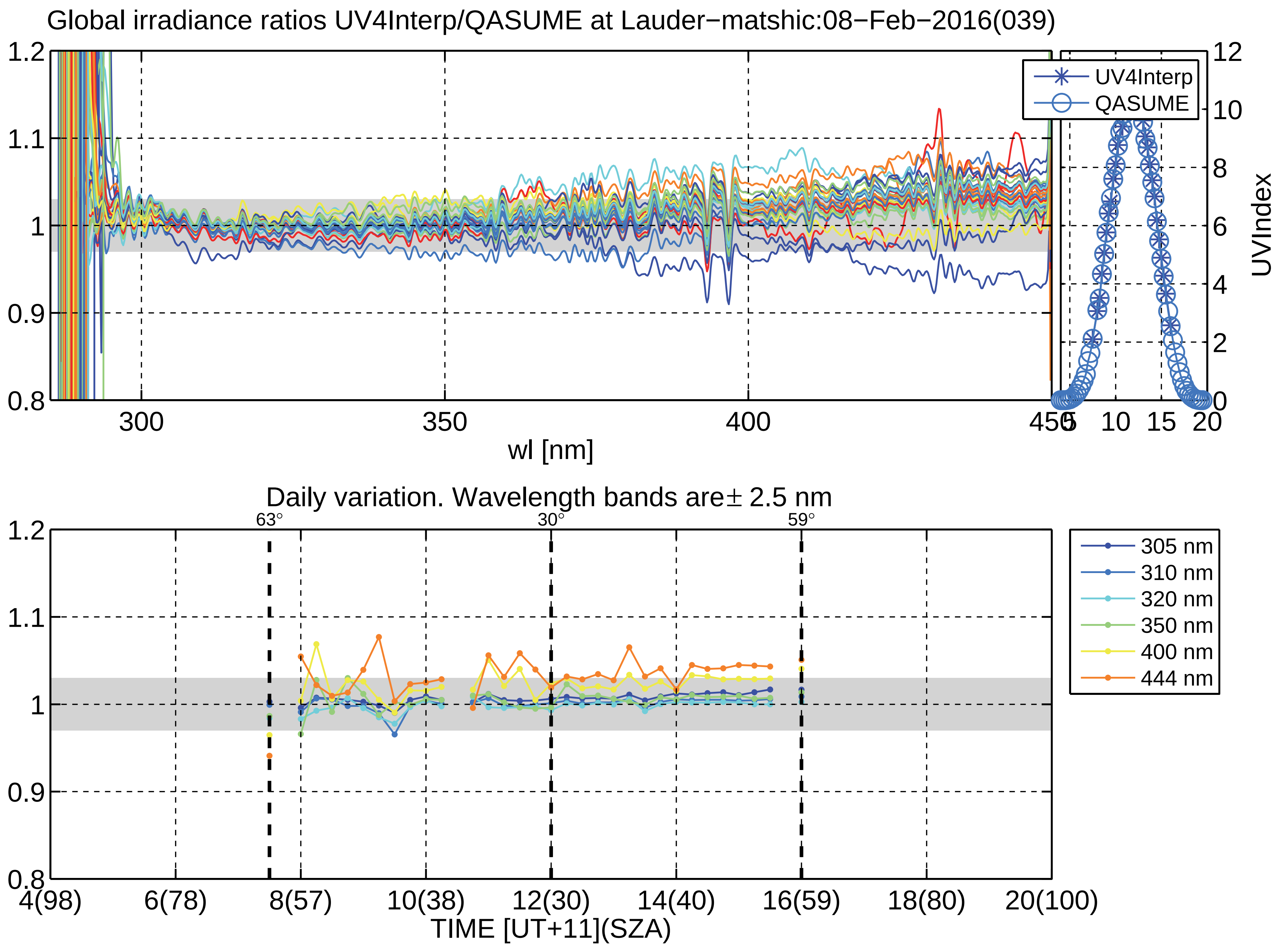
Global irradiance ratios UV4Interp/QASUME at Lauder−matshic:05−Feb−2016(036)
1.2
1.1
1
0.9
0.8
300
350
400
450
wl [nm]
UV4Interp
QASUME
12
10
8
6
4
2
0
5
10
15
20
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
62°
29°
56°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
4(97)
6(78)
8(57)
10(38)
12(29)
14(39)
16(58)
18(79)
20(99)
TIME [UT+11](SZA)



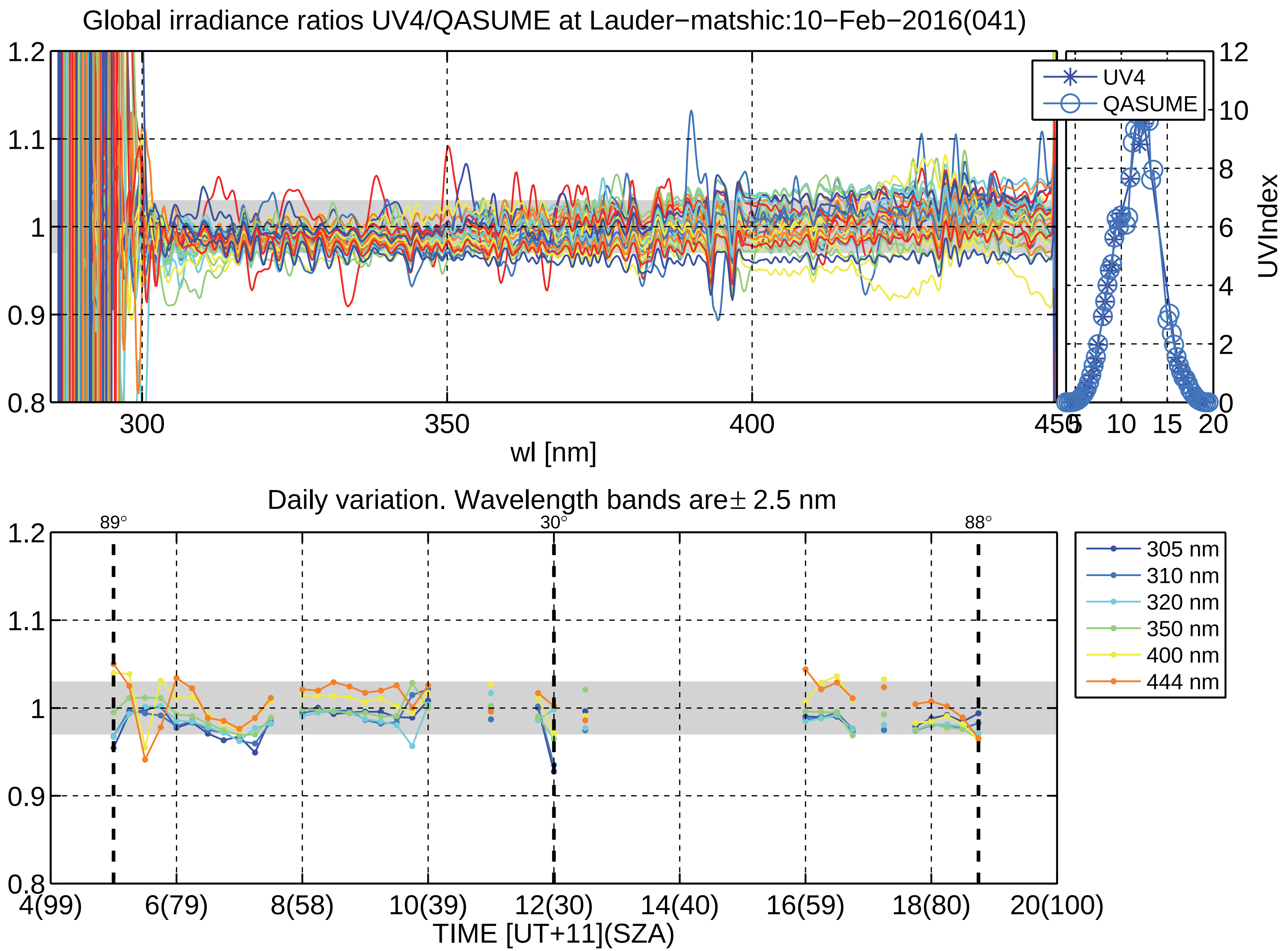
Global irradiance ratios UV4Interp/QASUME at Lauder−matshic:06−Feb−2016(037)
1.2
1.1
1
0.9
0.8
300
350
400
450
wl [nm]
UV4Interp
QASUME
12
10
8
6
4
2
0
5
10
15
20
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
62°
29°
56°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
4(98)
6(78)
8(57)
10(38)
12(29)
14(39)
16(59)
18(80)
20(99)
TIME [UT+11](SZA)



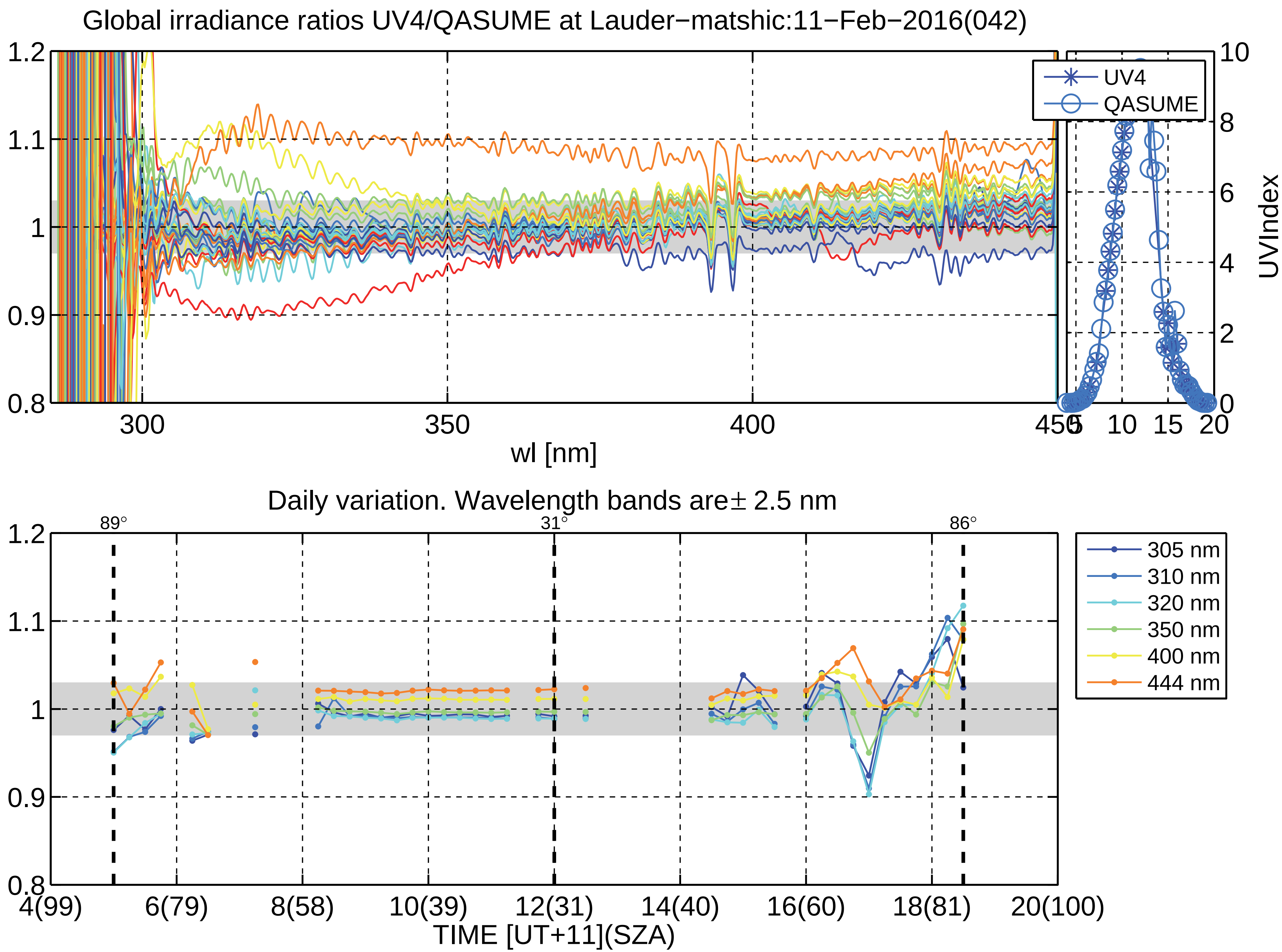
Global irradiance ratios UV4Interp/QASUME at Lauder−matshic:07−Feb−2016(038)
1.2
1.1
1
0.9
0.8
300
350
400
450
wl [nm]
UV4Interp
QASUME
12
10
8
6
4
2
0
5
10
15
20
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
62°
30°
54°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
4(98)
6(78)
8(57)
10(38)
12(30)
14(39)
16(59)
18(80)
20(99)
TIME [UT+11](SZA)

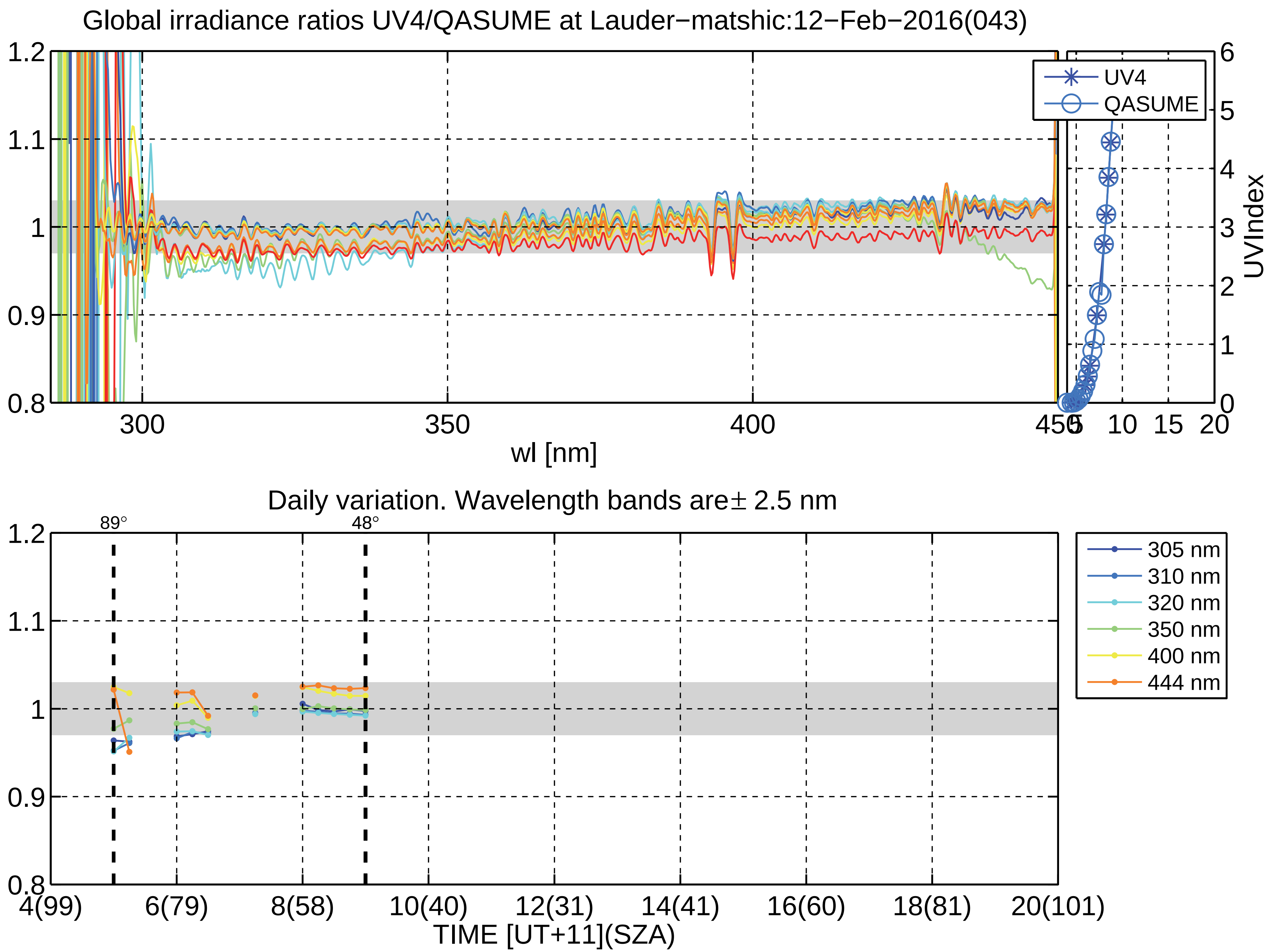


Global irradiance ratios UV4Interp/QASUME at Lauder−matshic:08−Feb−2016(039)
1.2
1.1
1
0.9
0.8
300
350
400
450
wl [nm]
UV4Interp
QASUME
12
10
8
6
4
2
0
UVIndex
5
10
15
20
Daily variation. Wavelength bands are± 2.5 nm
63°
30°
59°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
4(98)
6(78)
8(57)
10(38)
12(30)
14(40)
16(59)
18(80)
20(100)
TIME [UT+11](SZA)

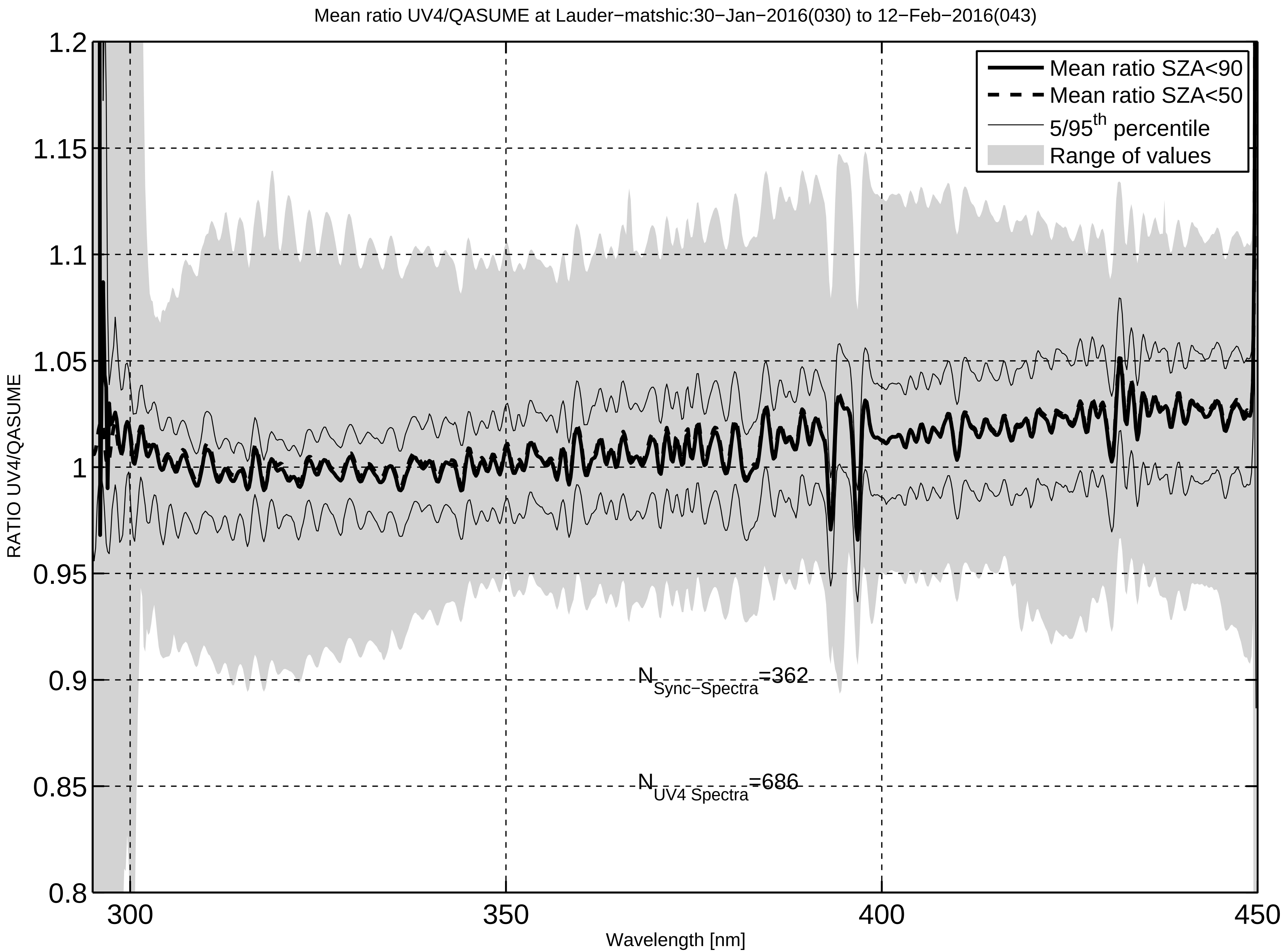


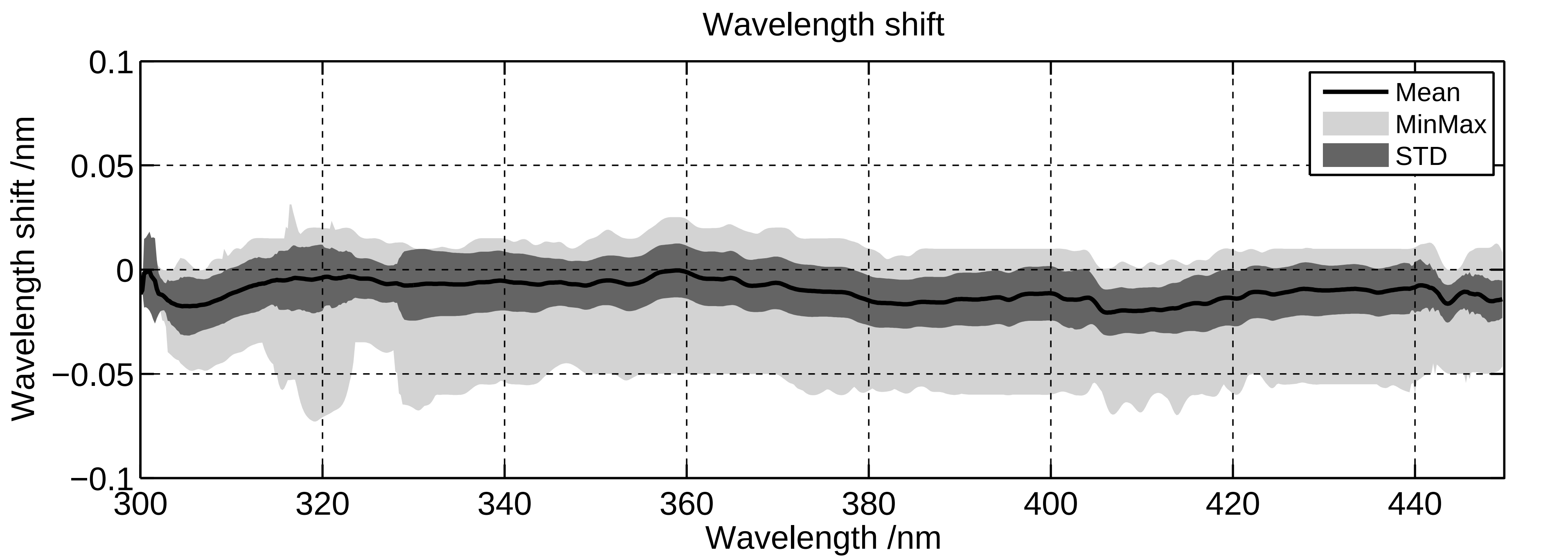
Global irradiance ratios UV4/QASUME at Lauder−matshic:10−Feb−2016(041)
1.2
1.1
1
0.9
0.8
300
350
400
450
wl [nm]
UV4
QASUME
12
10
8
6
4
2
0
5
10
15
20
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
89°
30°
88°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
4(99)
6(79)
8(58)
10(39)
12(30)
14(40)
16(59)
18(80)
20(100)
TIME [UT+11](SZA)

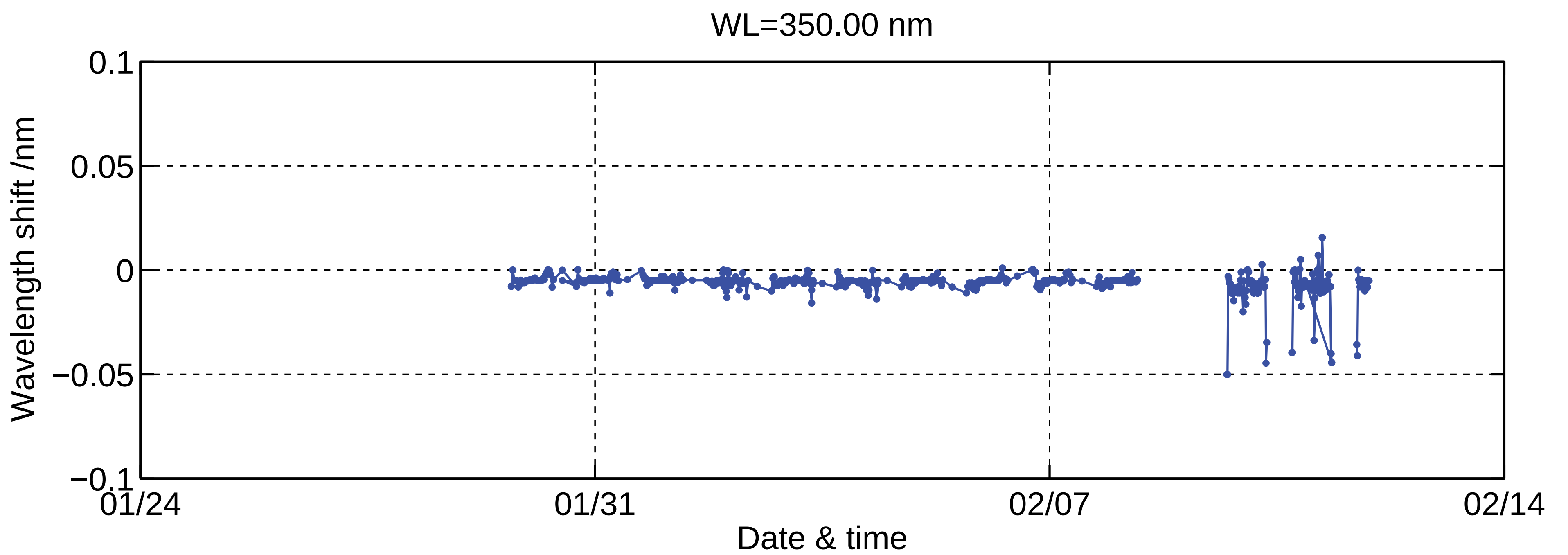

Global irradiance ratios UV4/QASUME at Lauder−matshic:11−Feb−2016(042)
1.2
1.1
1
0.9
0.8
300
350
400
450
wl [nm]
UV4
QASUME
10
8
6
4
2
0
5
10
15
20
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
89°
31°
86°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
4(99)
6(79)
8(58)
10(39)
12(31)
14(40)
16(60)
18(81)
20(100)
TIME [UT+11](SZA)

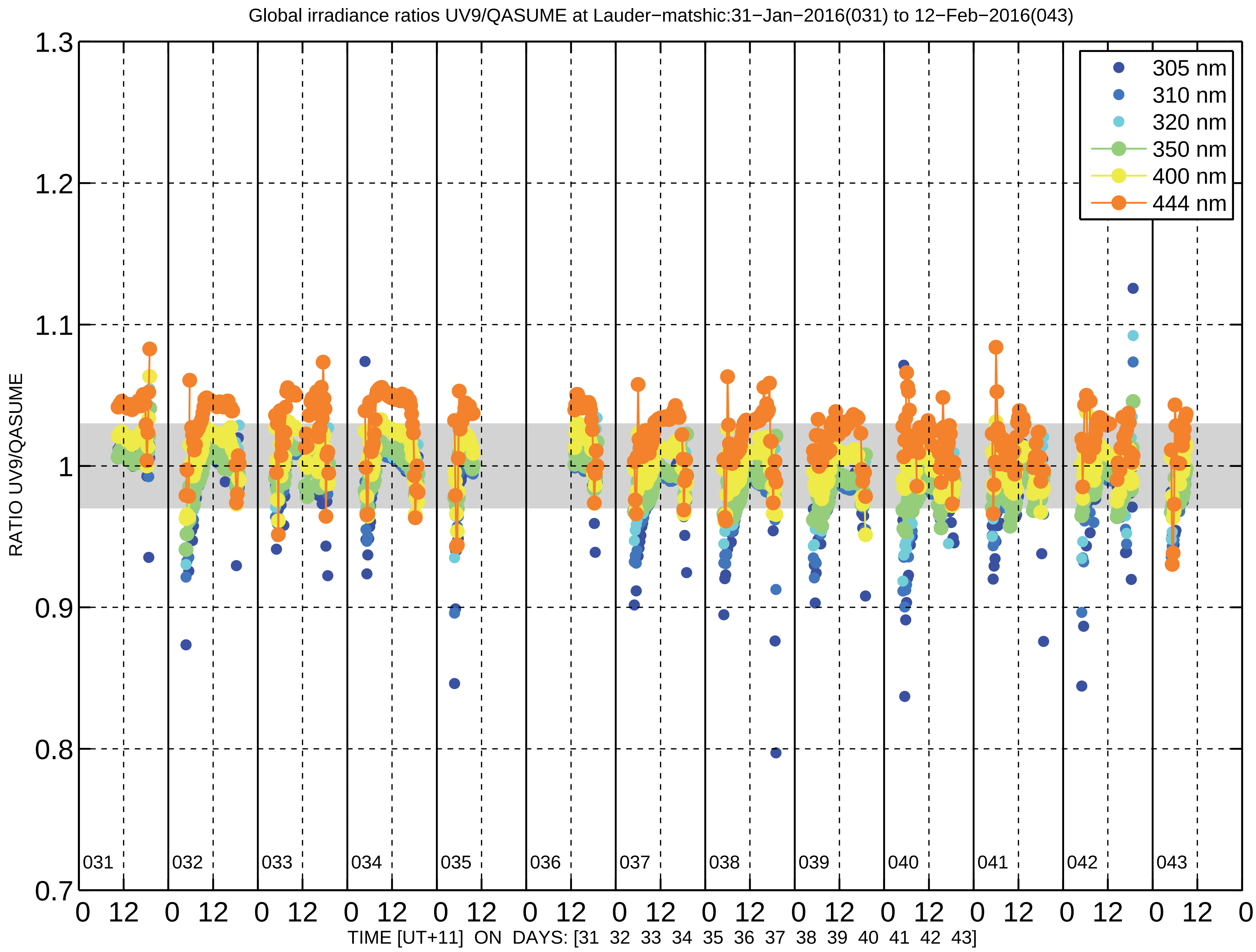


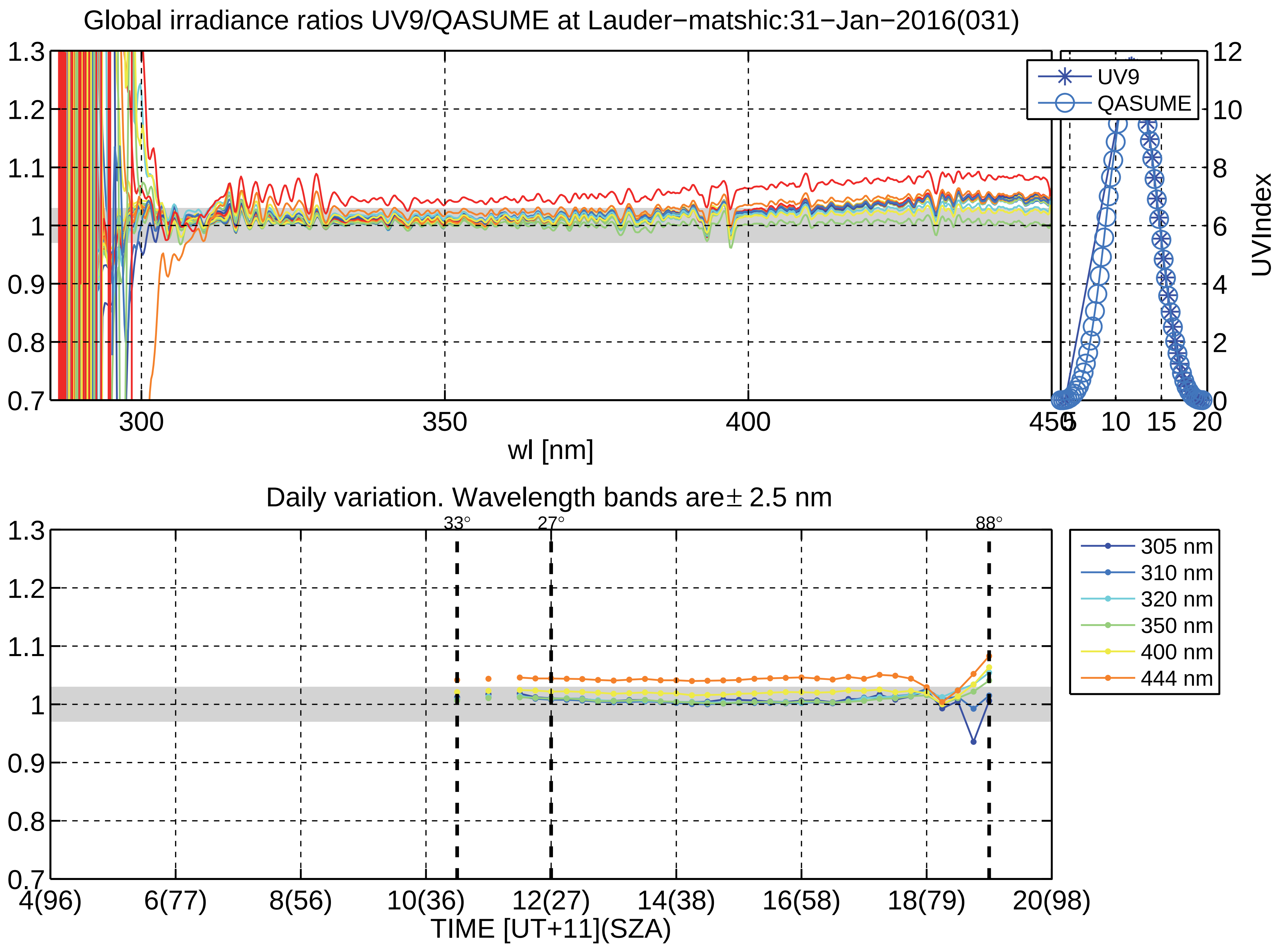
Global irradiance ratios UV4/QASUME at Lauder−matshic:12−Feb−2016(043)
1.2
1.1
1
0.9
0.8
300
350
400
450
wl [nm]
UV4
QASUME
6
5
4
3
2
1
0
5
10
15
20
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
89°
48°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
4(99)
6(79)
8(58)
10(40)
12(31)
14(41)
16(60)
18(81)
20(101)
TIME [UT+11](SZA)

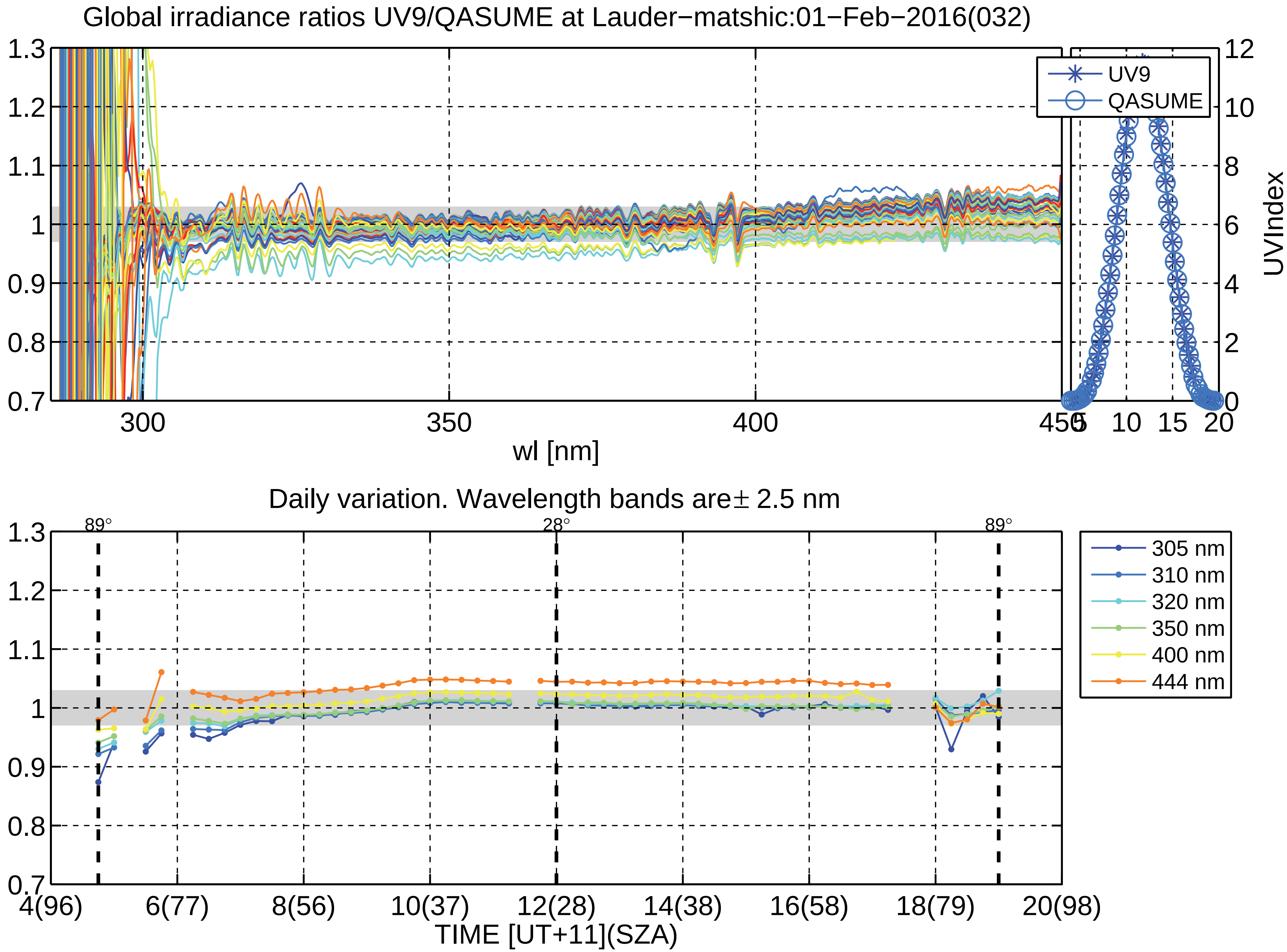

Mean ratio UV4/QASUME at Lauder−matshic:30−Jan−2016(030) to 12−Feb−2016(043)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
Range of values
N Sync−Spectra =362
N UV4 Spectra =686
RATIO UV4/QASUME
Wavelength [nm]
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
300
350
400
450

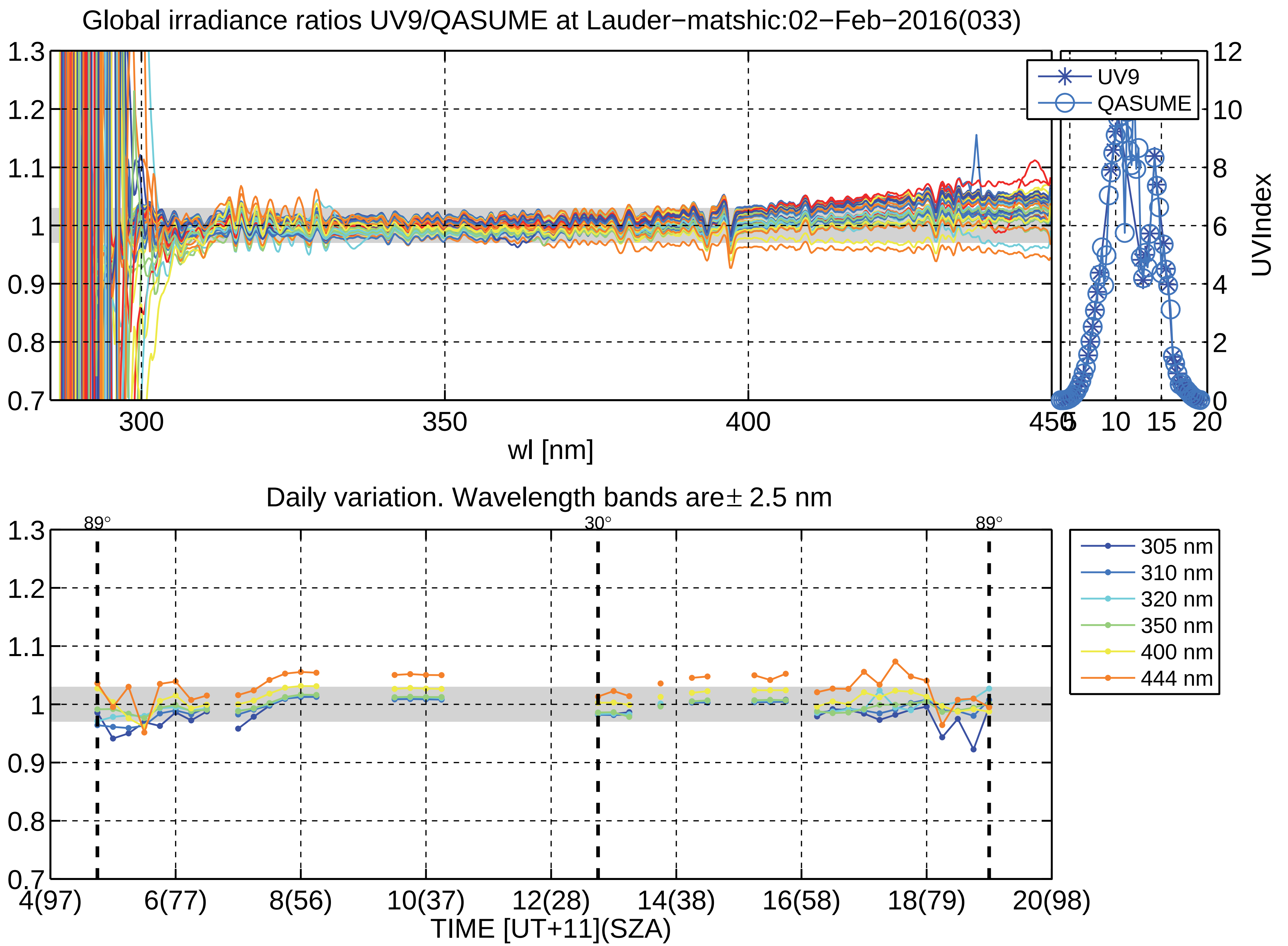

Wavelength shift
Mean
MinMax
STD
0.1
0.05
0
−0.05
−0.1
300
320
340
360
380
400
420
440
Wavelength /nm
Wavelength shift /nm


WL=350.00 nm
0.1
0.05
0
−0.05
−0.1
01/24
01/31
02/07
02/14
Date & time
Wavelength shift /nm

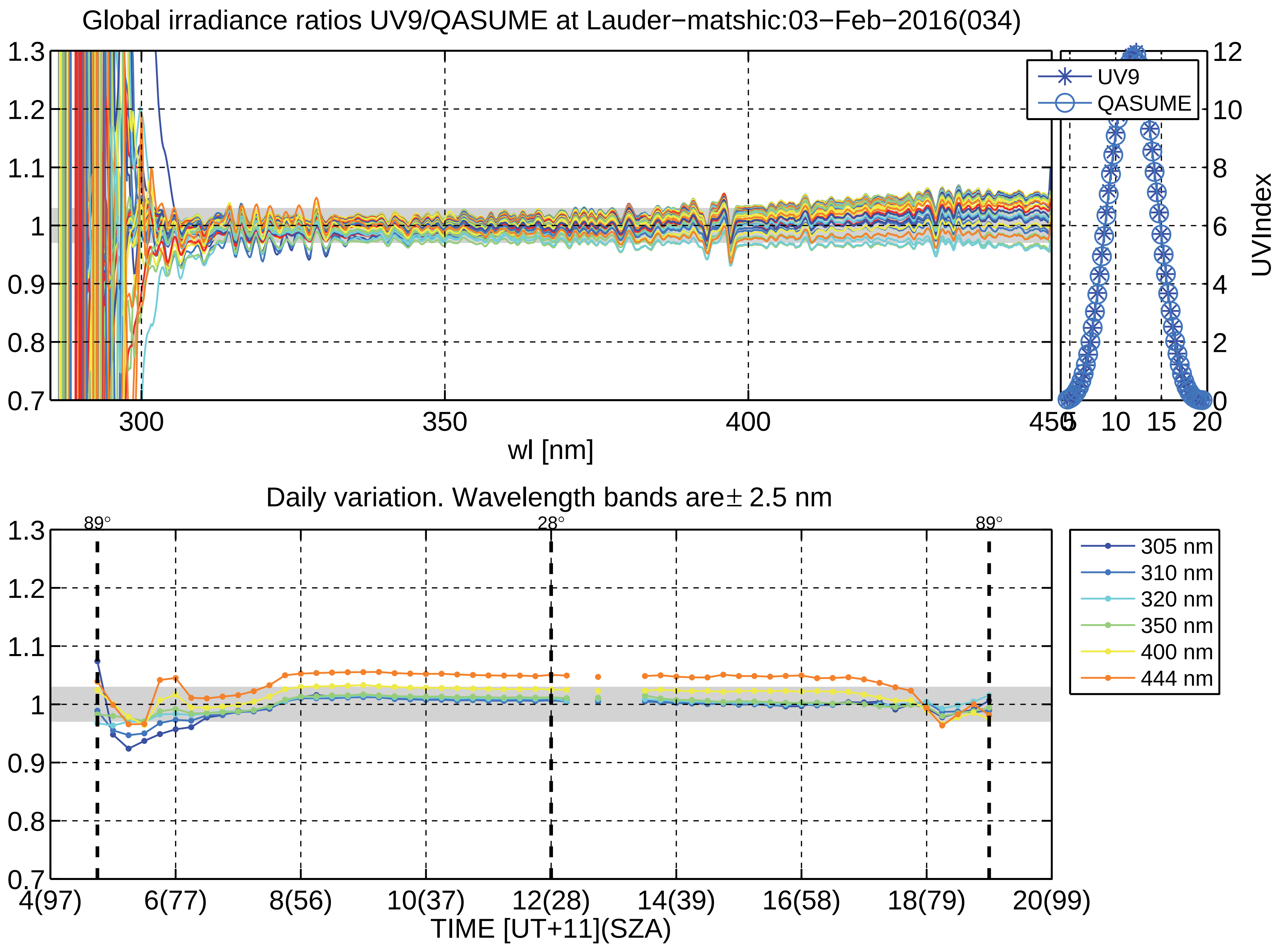

Global irradiance ratios UV9/QASUME at Lauder−matshic:31−Jan−2016(031) to 12−Feb−2016(043)
RATIO UV9/QASUME
TIME [UT+11] ON DAYS: [31 32 33 34 35 36 37 38 39 40 41 42 43]
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
031
032
033
034
035
036
037
038
039
040
041
042
043
1.3
1.2
1.1
1
0.9
0.8
0.7

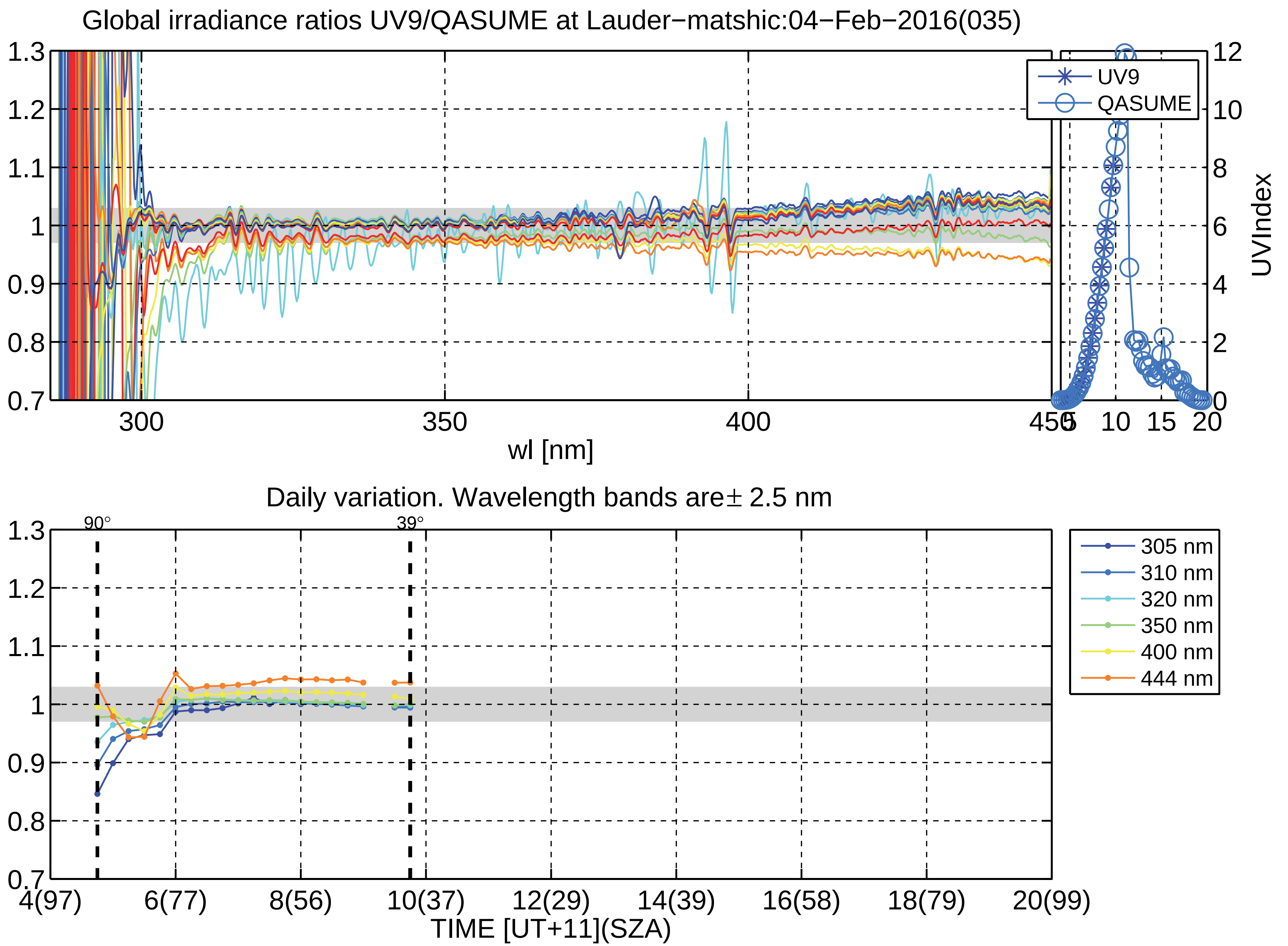

Global irradiance ratios UV9/QASUME at Lauder−matshic:31−Jan−2016(031)
UV9
QASUME
UVIndex
wl [nm]
Daily variation. Wavelength bands are± 2.5 nm
33°
27°
88°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
TIME [UT+11](SZA)


Global irradiance ratios UV9/QASUME at Lauder−matshic:01−Feb−2016(032)
UV9
QASUME
wl [nm]
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
89°
28°
89°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
TIME [UT+11](SZA)

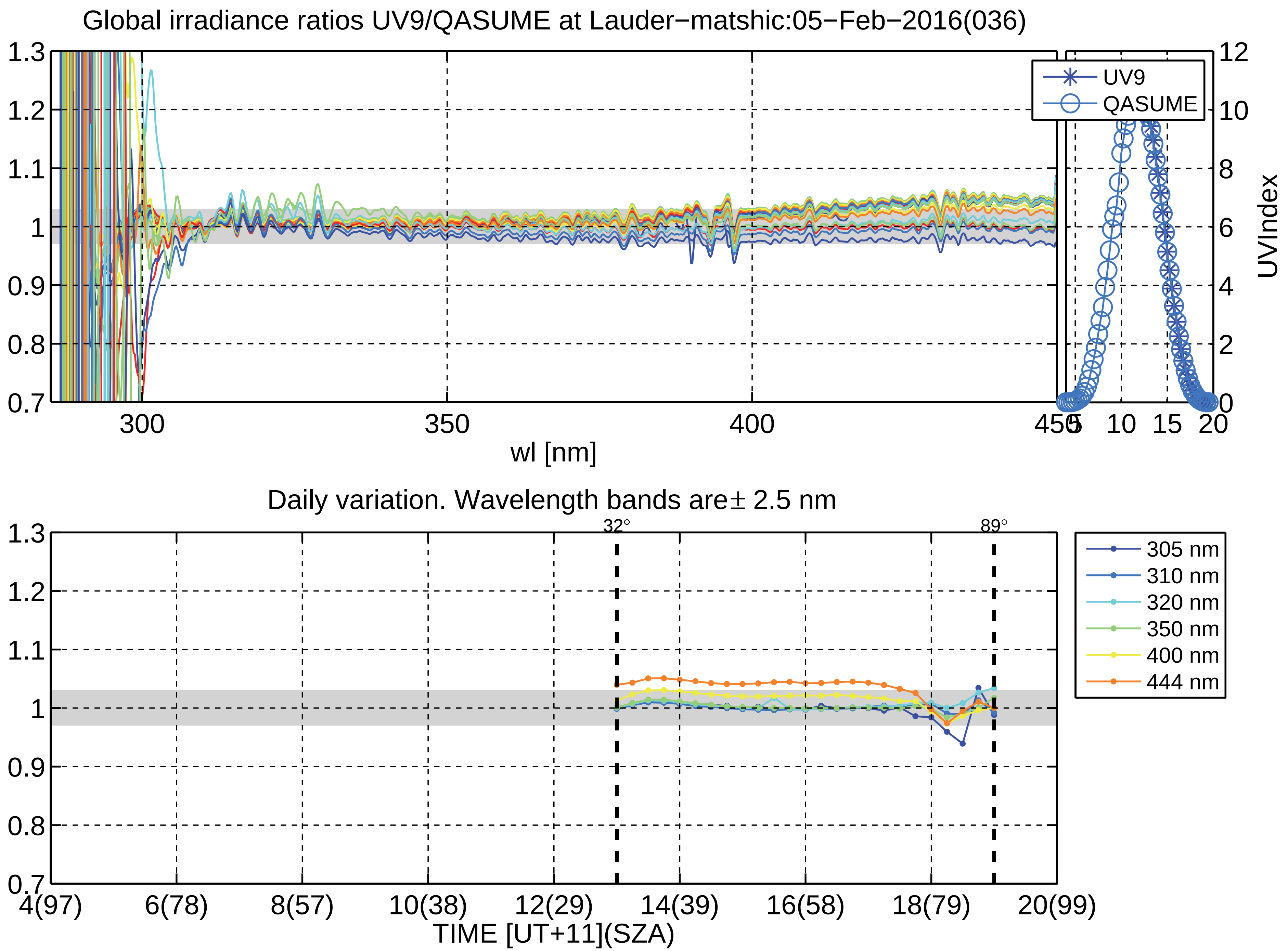


Global irradiance ratios UV9/QASUME at Lauder−matshic:02−Feb−2016(033)
1.3
1.2
1.1
1
0.9
0.8
0.7
300
350
400
450
wl [nm]
UV9
QASUME
12
10
8
6
4
2
0
5
10
15
20
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
89°
30°
89°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
4(97)
6(77)
8(56)
10(37)
12(28)
14(38)
16(58)
18(79)
20(98)
TIME [UT+11](SZA)

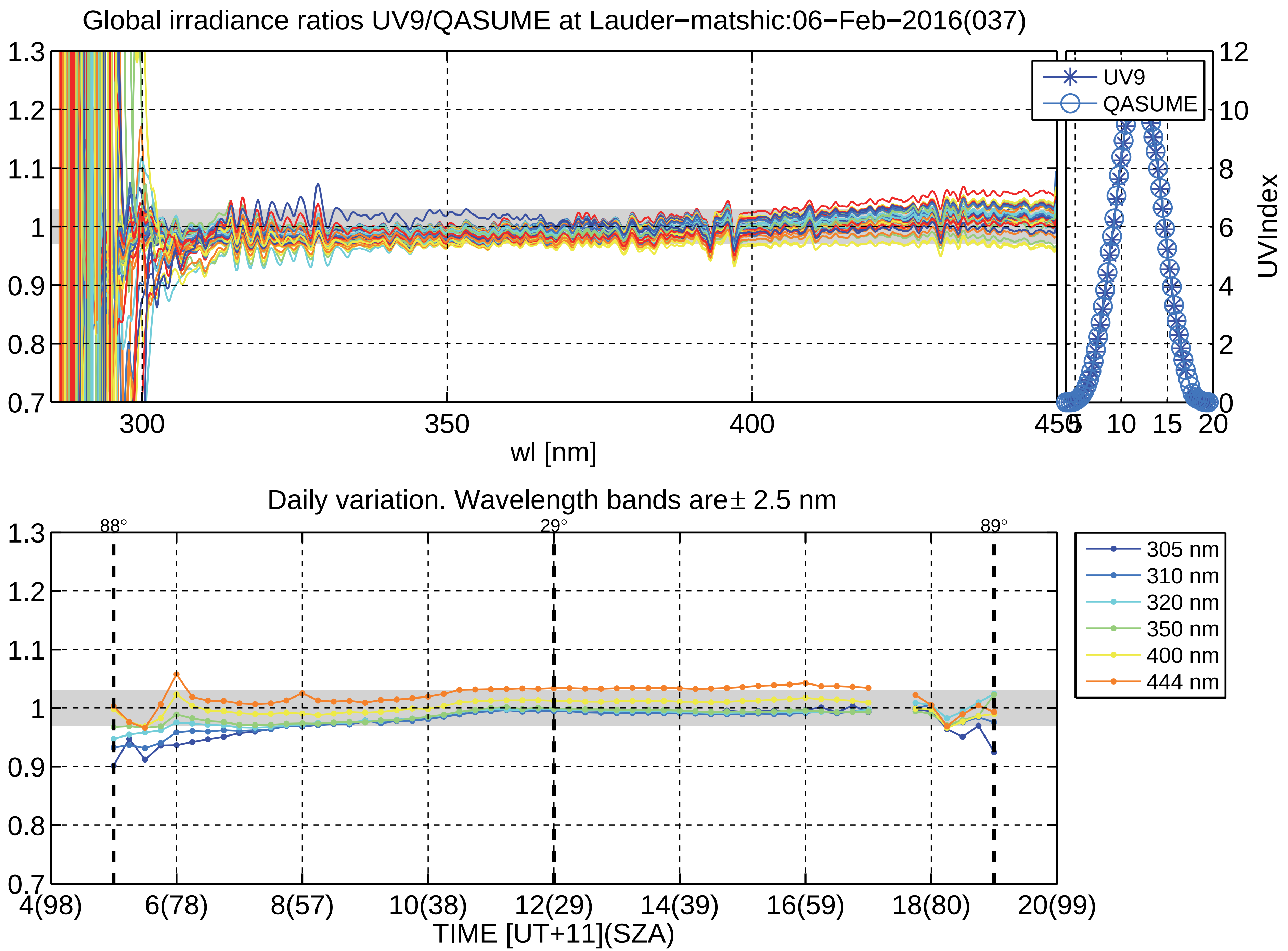

Global irradiance ratios UV9/QASUME at Lauder−matshic:03−Feb−2016(034)
1.3
1.2
1.1
1
0.9
0.8
0.7
300
350
400
450
wl [nm]
UV9
QASUME
12
10
8
6
4
2
0
5
10
15
20
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
89°
28°
89°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
4(97)
6(77)
8(56)
10(37)
12(28)
14(39)
16(58)
18(79)
20(99)
TIME [UT+11](SZA)

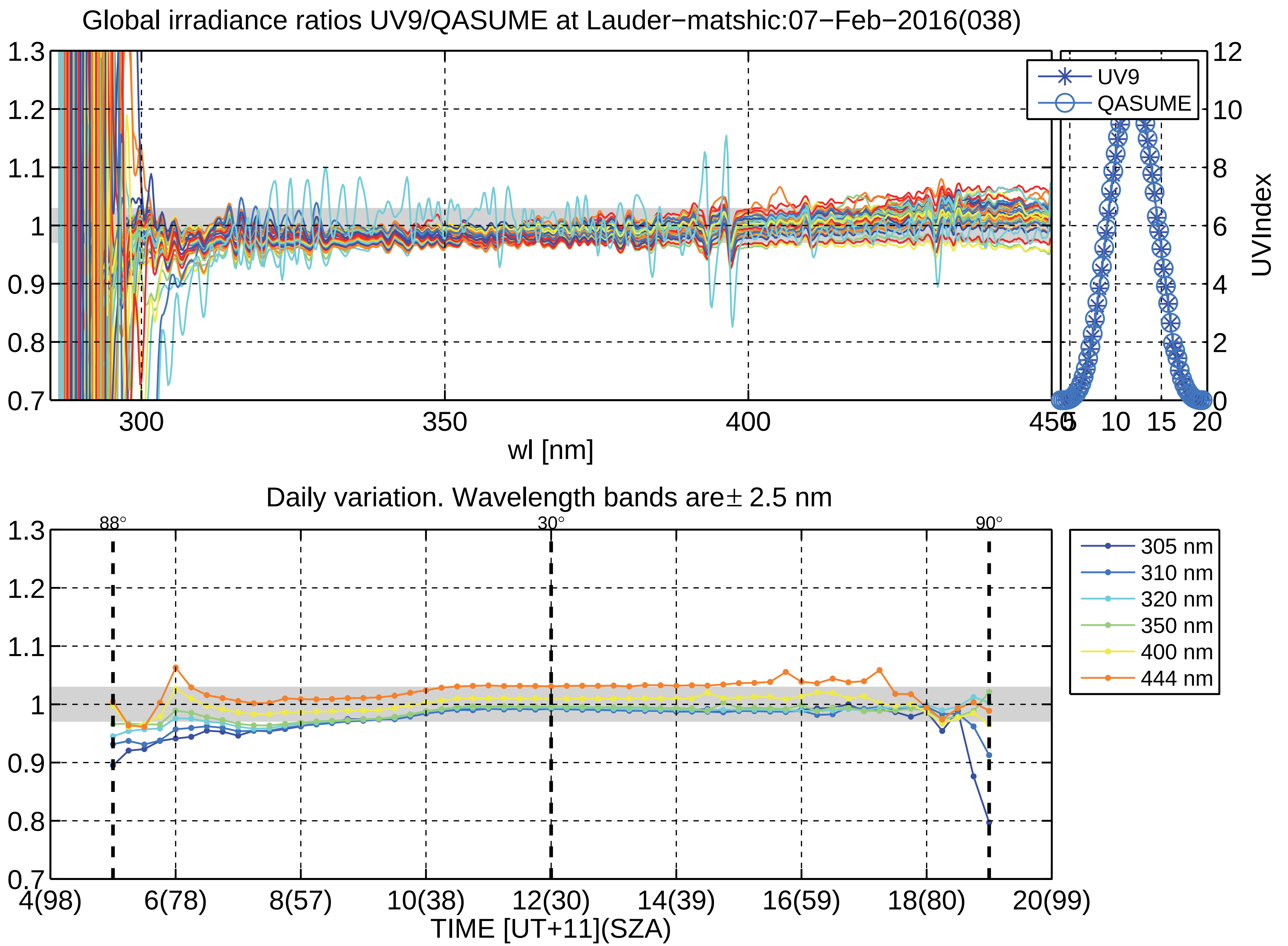


Global irradiance ratios UV9/QASUME at Lauder−matshic:04−Feb−2016(035)
UV9
QASUME
UVIndex
wl [nm]
Daily variation. Wavelength bands are± 2.5 nm
90°
39°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
TIME [UT+11](SZA)

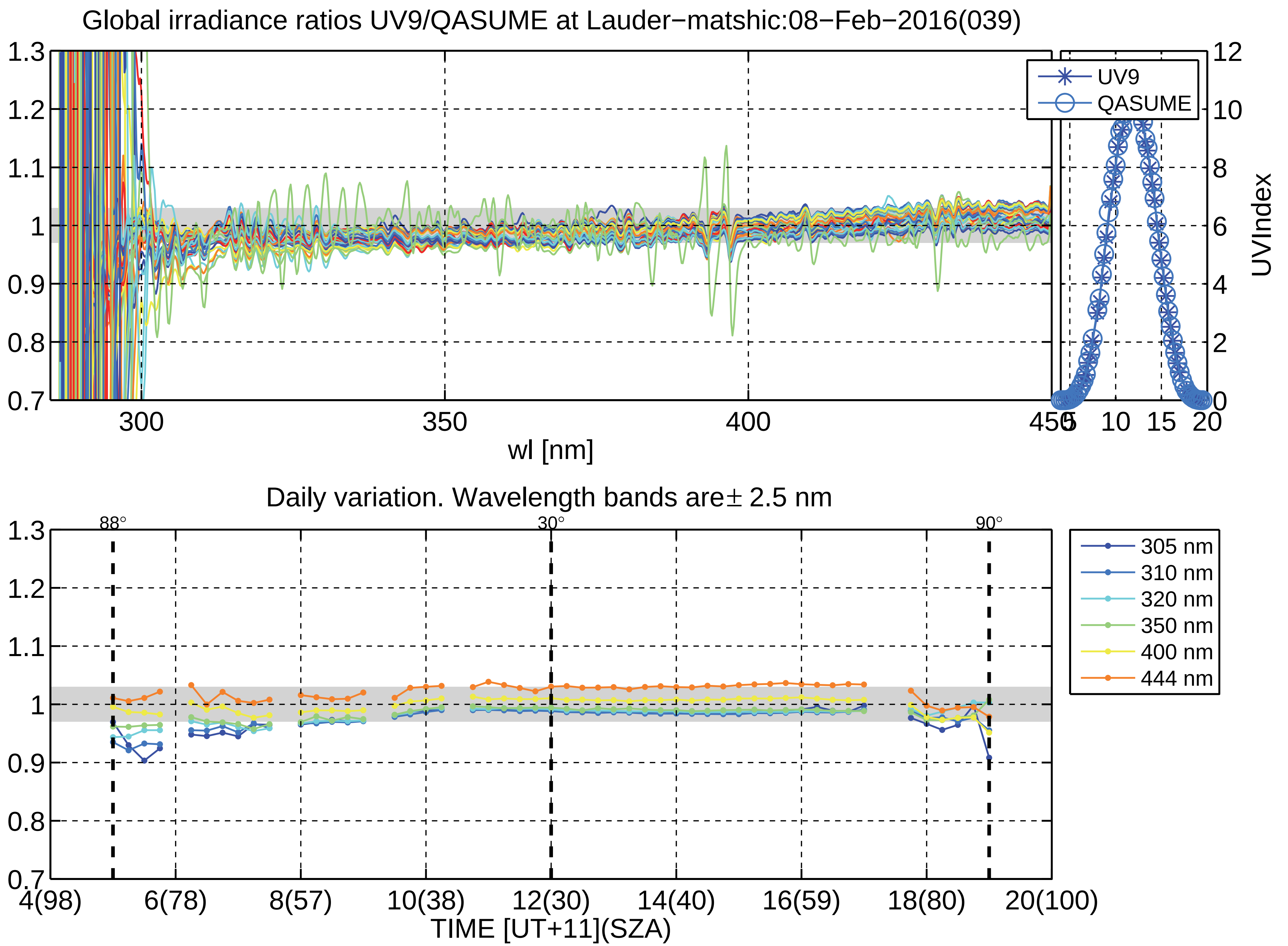


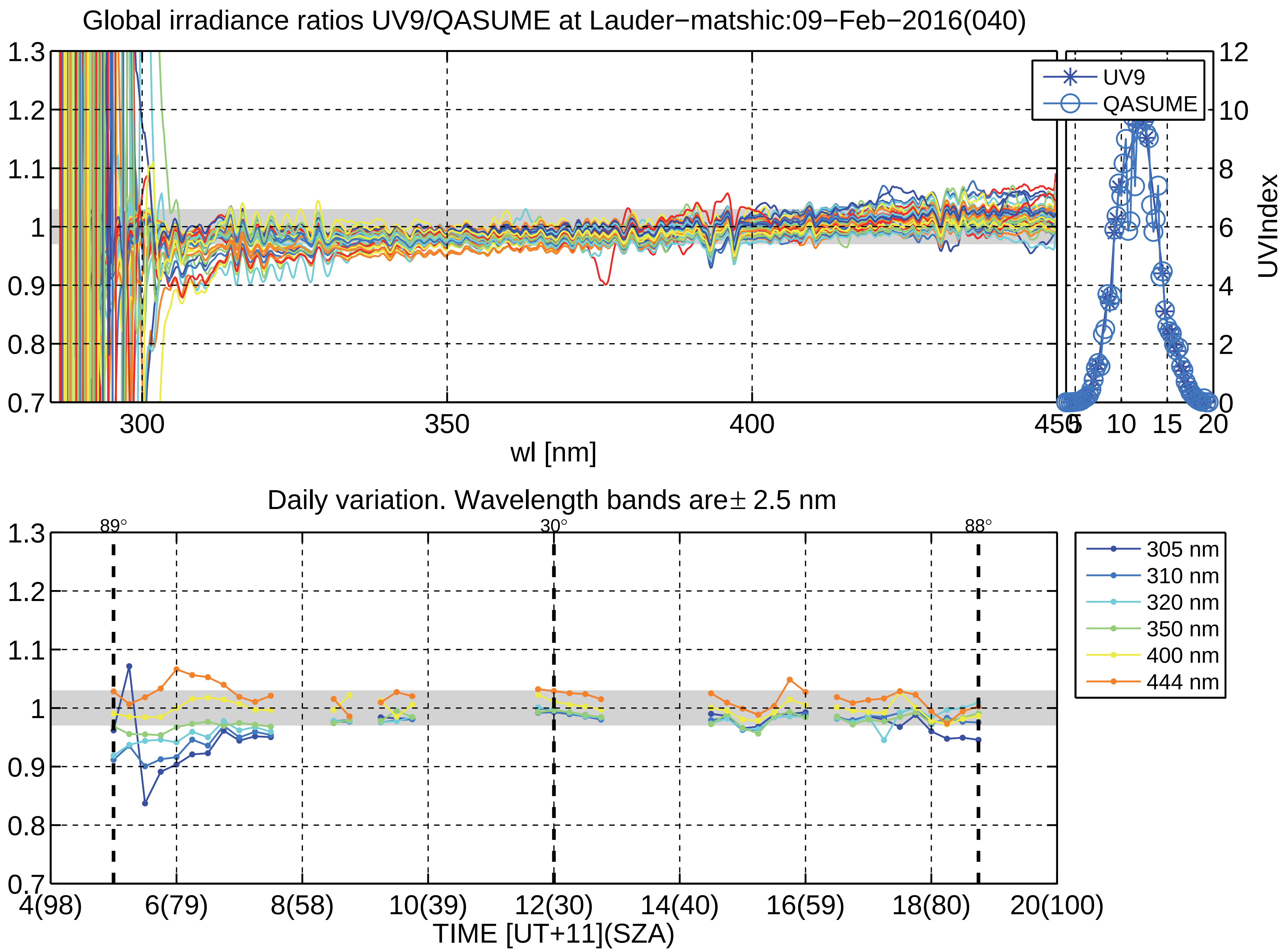
Global irradiance ratios UV9/QASUME at Lauder−matshic:05−Feb−2016(036)
1.3
1.2
1.1
1
0.9
0.8
0.7
300
350
400
450
wl [nm]
UV9
QASUME
12
10
8
6
4
2
0
5
10
15
20
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
32°
89°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
4(97)
6(78)
8(57)
10(38)
12(29)
14(39)
16(58)
18(79)
20(99)
TIME [UT+11](SZA)

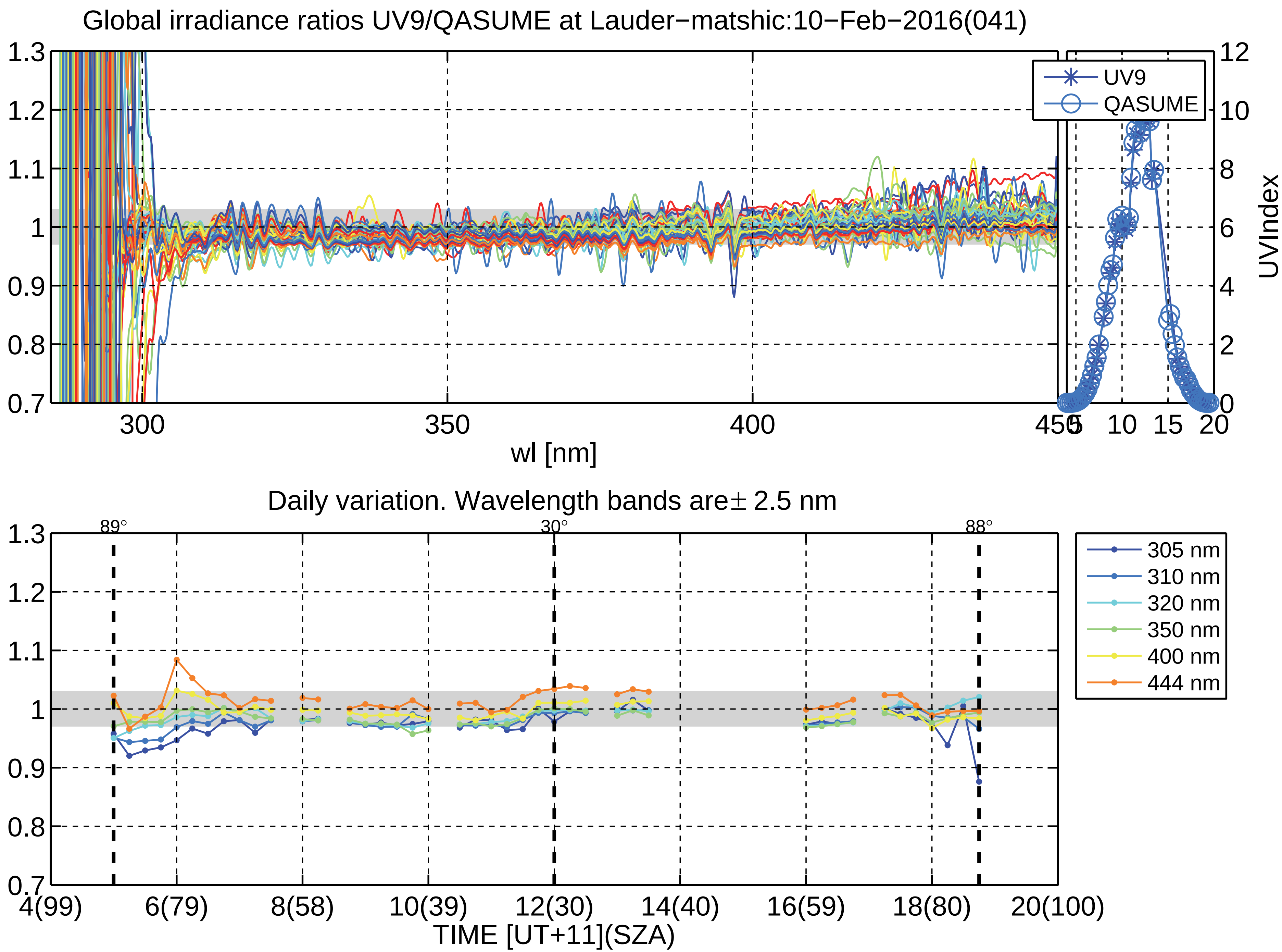

Global irradiance ratios UV9/QASUME at Lauder−matshic:06−Feb−2016(037)
1.3
1.2
1.1
1
0.9
0.8
0.7
300
350
400
450
wl [nm]
UV9
QASUME
12
10
8
6
4
2
0
5
10
15
20
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
88°
29°
89°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
4(98)
6(78)
8(57)
10(38)
12(29)
14(39)
16(59)
18(80)
20(99)
TIME [UT+11](SZA)



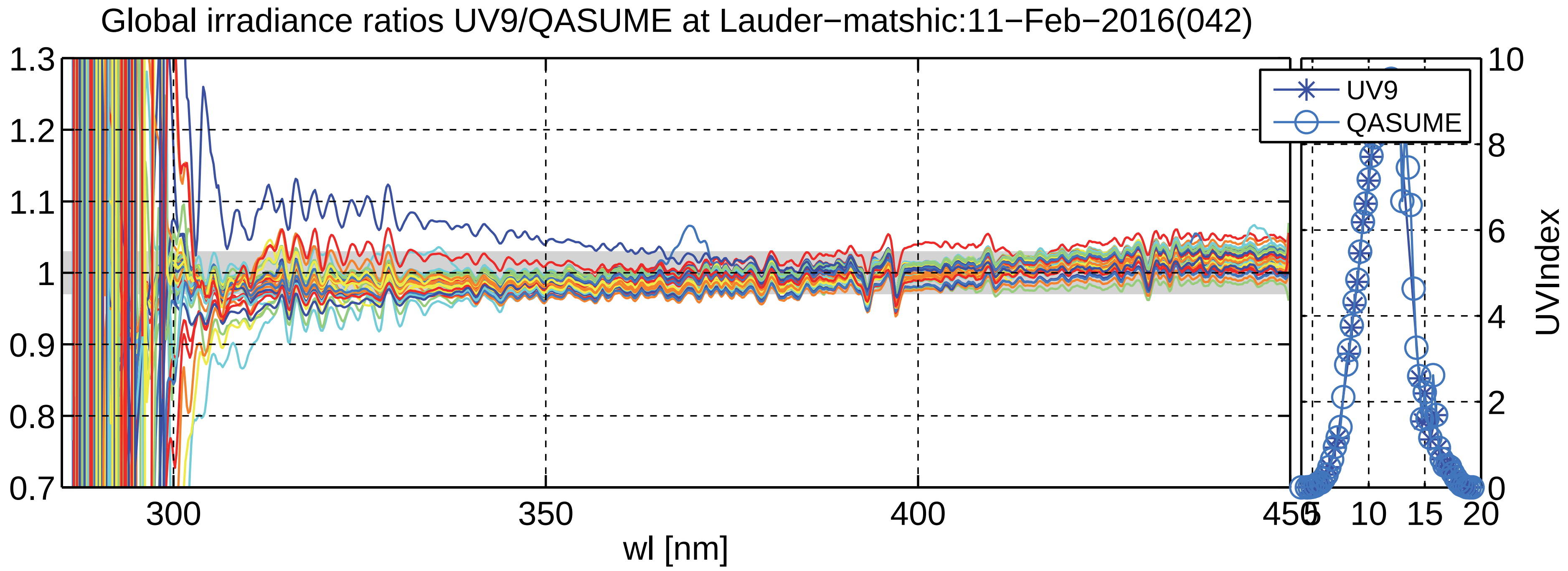
Global irradiance ratios UV9/QASUME at Lauder−matshic:07−Feb−2016(038)
1.3
1.2
1.1
1
0.9
0.8
0.7
300
350
400
450
wl [nm]
UV9
QASUME
12
10
8
6
4
2
0
5
10
15
20
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
88°
30°
90°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
4(98)
6(78)
8(57)
10(38)
12(30)
14(39)
16(59)
18(80)
20(99)
TIME [UT+11](SZA)

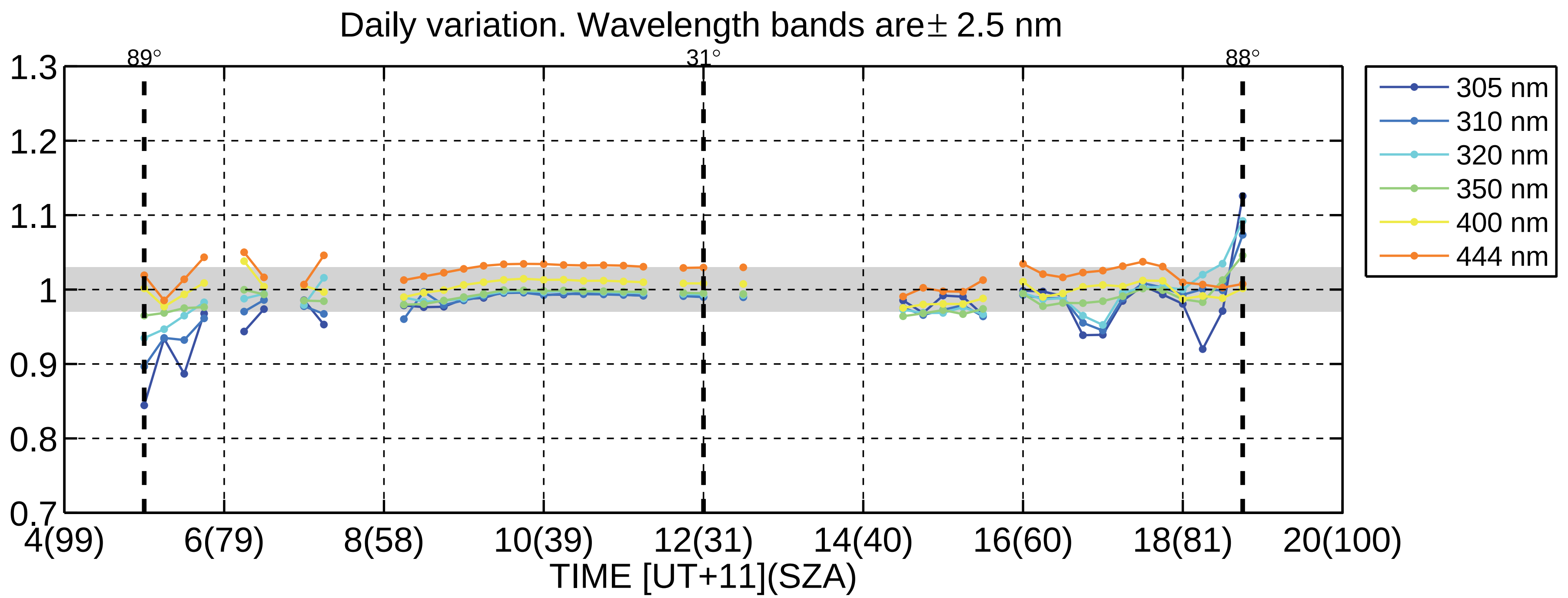

Global irradiance ratios UV9/QASUME at Lauder−matshic:08−Feb−2016(039)
1.3
1.2
1.1
1
0.9
0.8
0.7
300
350
400
450
wl [nm]
UV9
QASUME
12
10
8
6
4
2
0
5
10
15
20
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
88°
30°
90°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
4(98)
6(78)
8(57)
10(38)
12(30)
14(40)
16(59)
18(80)
20(100)
TIME [UT+11](SZA)

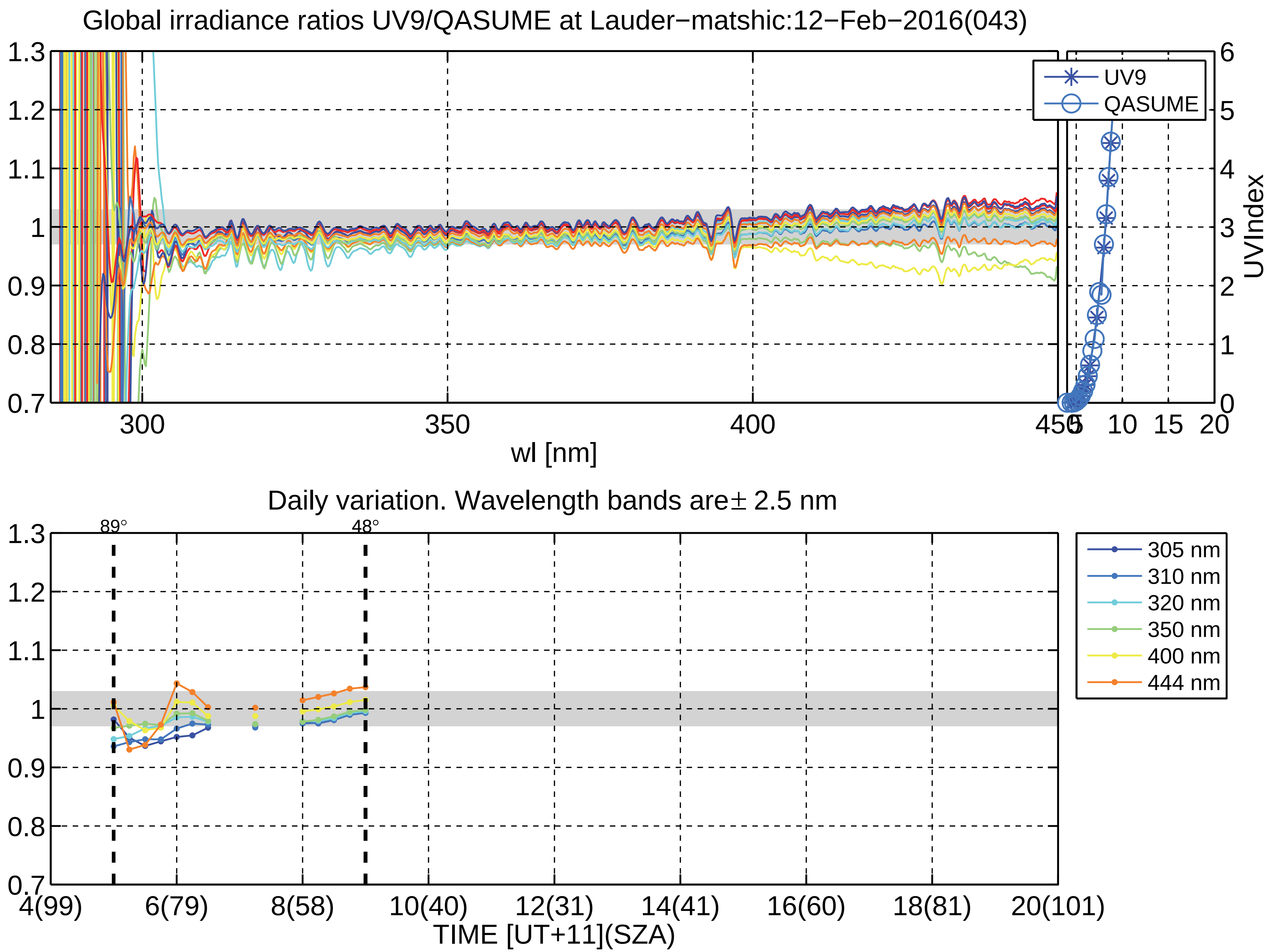

Global irradiance ratios UV9/QASUME at Lauder−matshic:09−Feb−2016(040)
1.3
1.2
1.1
1
0.9
0.8
0.7
300
350
400
450
wl [nm]
UV9
QASUME
12
10
8
6
4
2
0
5
10
15
20
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
89°
30°
88°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
4(98)
6(79)
8(58)
10(39)
12(30)
14(40)
16(59)
18(80)
20(100)
TIME [UT+11](SZA)



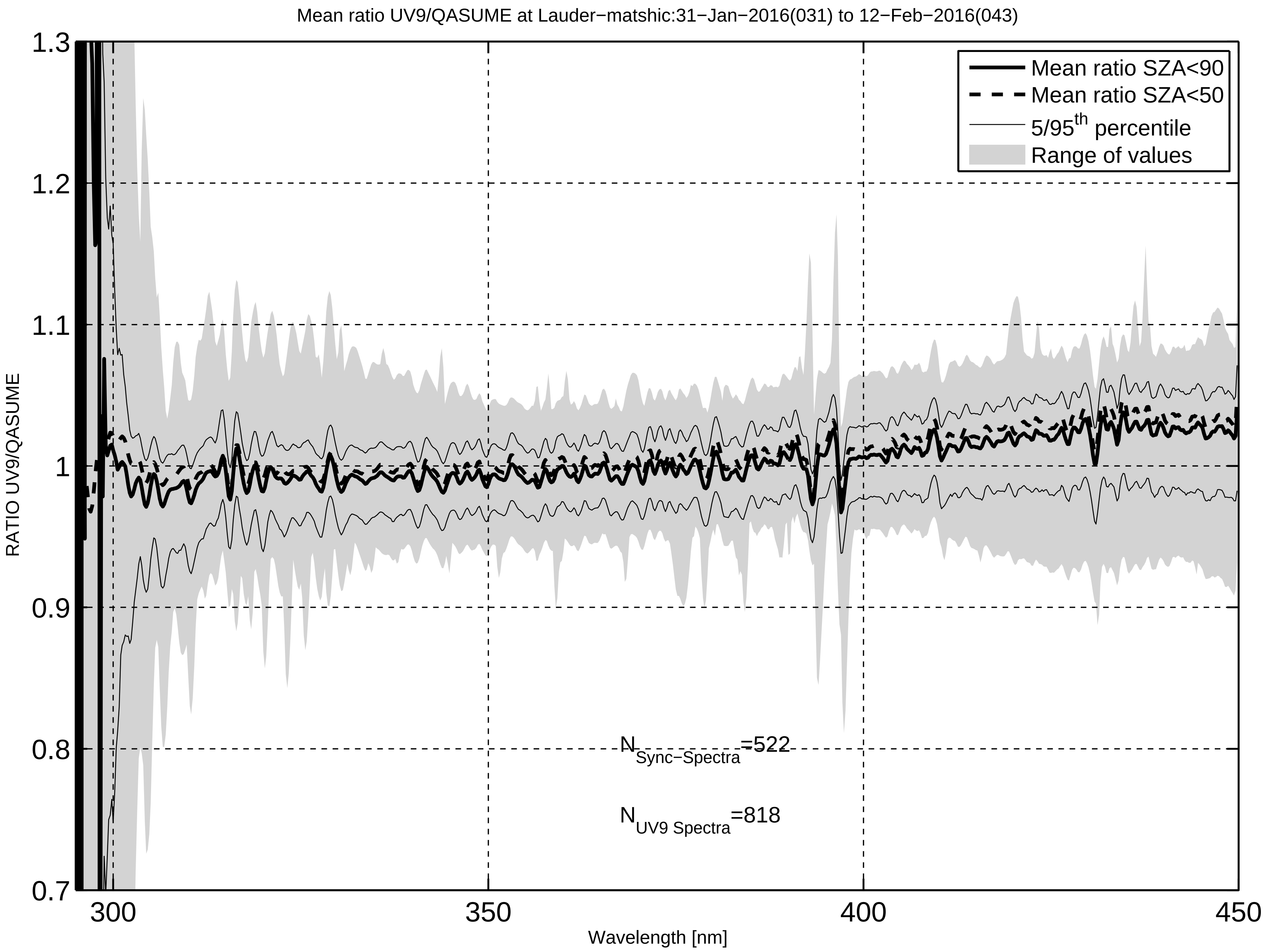
Global irradiance ratios UV9/QASUME at Lauder−matshic:10−Feb−2016(041)
1.3
1.2
1.1
1
0.9
0.8
0.7
300
350
400
450
wl [nm]
UV9
QASUME
12
10
8
6
4
2
0
5
10
15
20
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
89°
30°
88°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
4(99)
6(79)
8(58)
10(39)
12(30)
14(40)
16(59)
18(80)
20(100)
TIME [UT+11](SZA)


Global irradiance ratios UV9/QASUME at Lauder−matshic:11−Feb−2016(042)
wl [nm]
UVIndex
UV9
QASUME
1.3
1.2
1.1
1
0.9
0.8
0.7
300
350
400
450
5
10
15
20
0
2
4
6
8
10

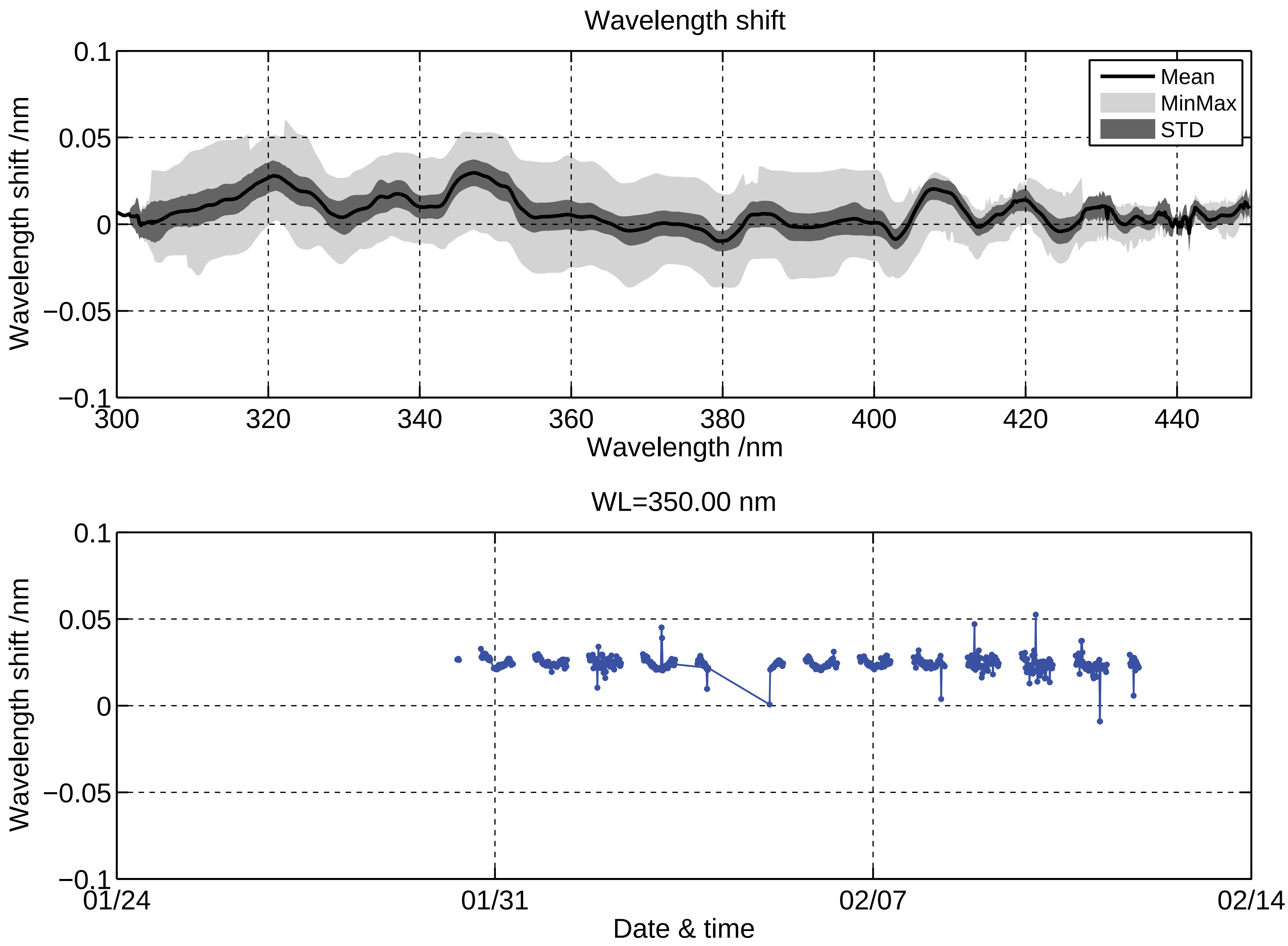

Daily variation. Wavelength bands are± 2.5 nm
89°
31°
88°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
1.3
1.2
1.1
1
0.9
0.8
0.7
4(99)
6(79)
8(58)
10(39)
12(31)
14(40)
16(60)
18(81)
20(100)
TIME [UT+11](SZA)

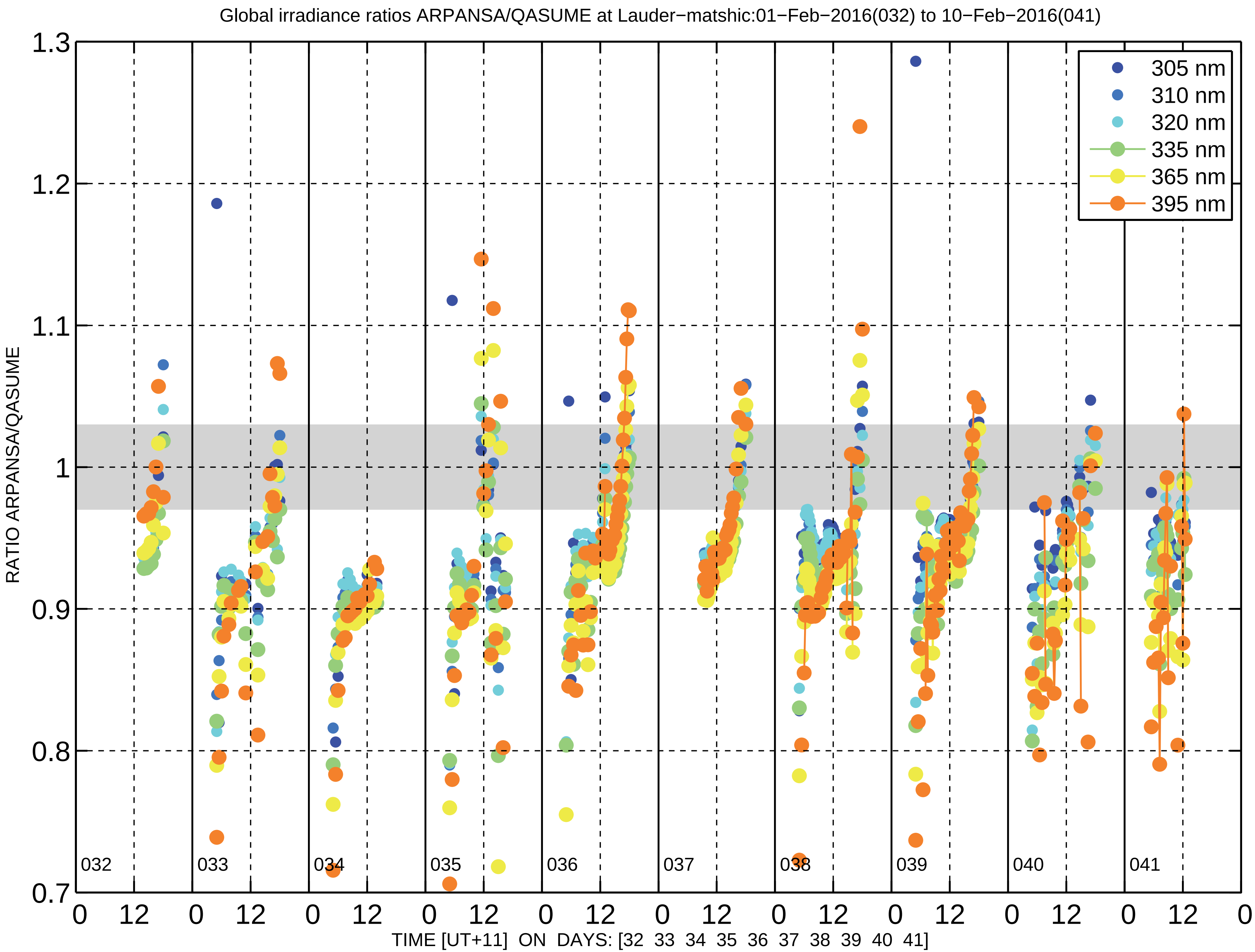


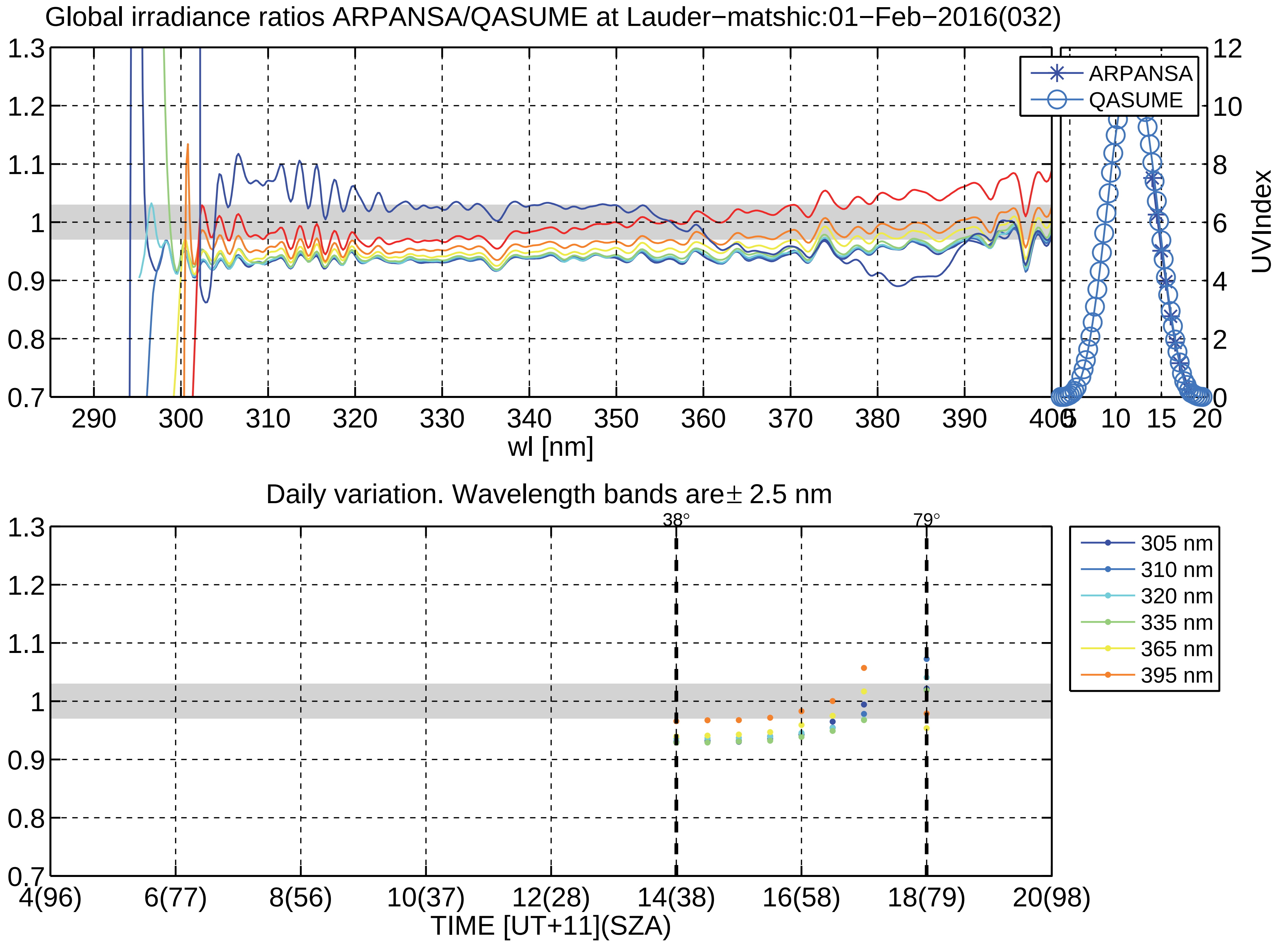
Global irradiance ratios UV9/QASUME at Lauder−matshic:12−Feb−2016(043)
1.3
1.2
1.1
1
0.9
0.8
0.7
300
350
400
450
wl [nm]
UV9
QASUME
6
5
4
3
2
1
0
5
10
15
20
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
89°
48°
305 nm
310 nm
320 nm
350 nm
400 nm
444 nm
4(99)
6(79)
8(58)
10(40)
12(31)
14(41)
16(60)
18(81)
20(101)
TIME [UT+11](SZA)

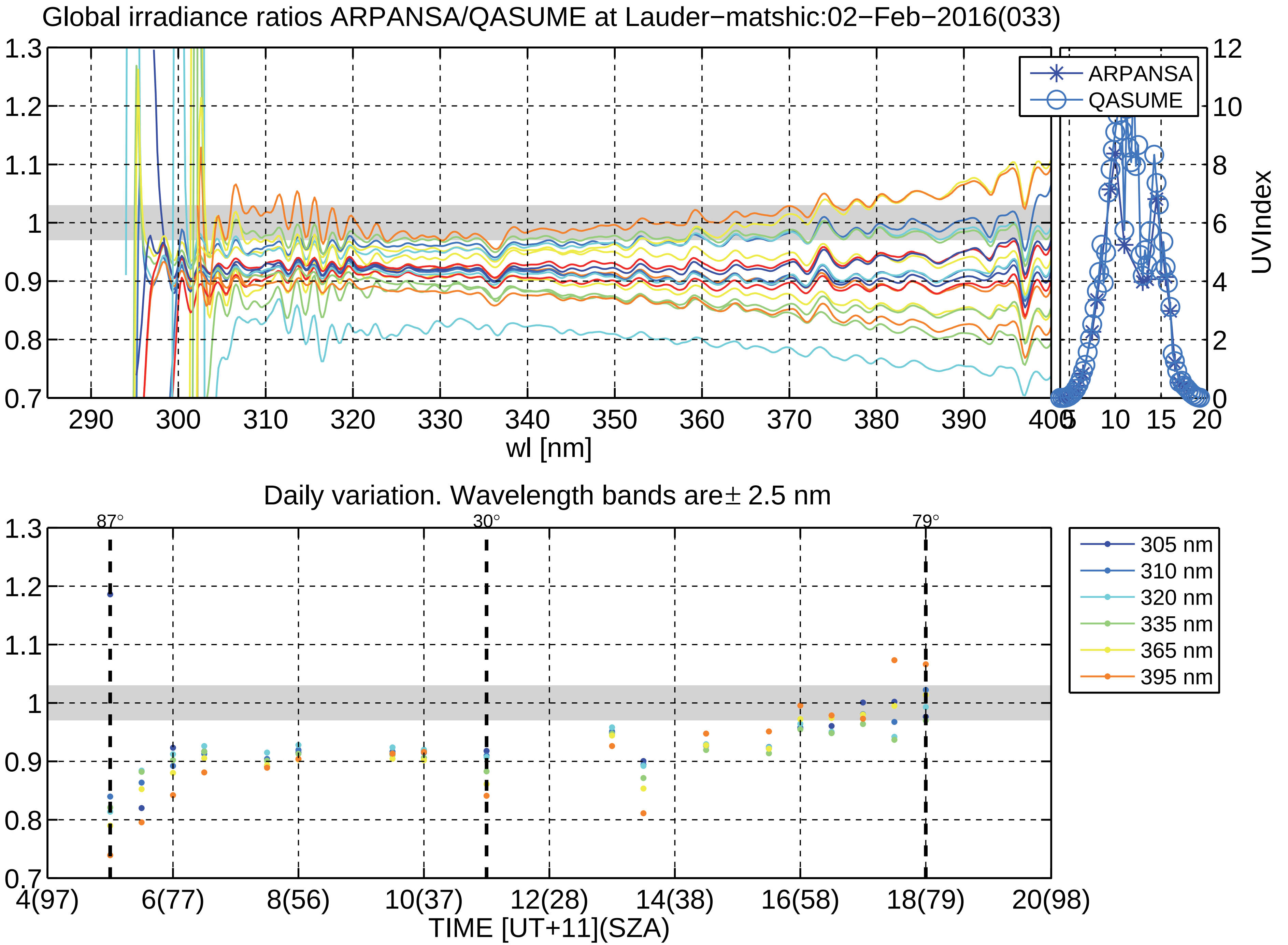


Mean ratio UV9/QASUME at Lauder−matshic:31−Jan−2016(031) to 12−Feb−2016(043)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
Range of values
RATIO UV9/QASUME
1.3
1.2
1.1
1
0.9
0.8
0.7
300
350
400
450
Wavelength [nm]
N Sync−Spectra =522
N UV9 Spectra =818

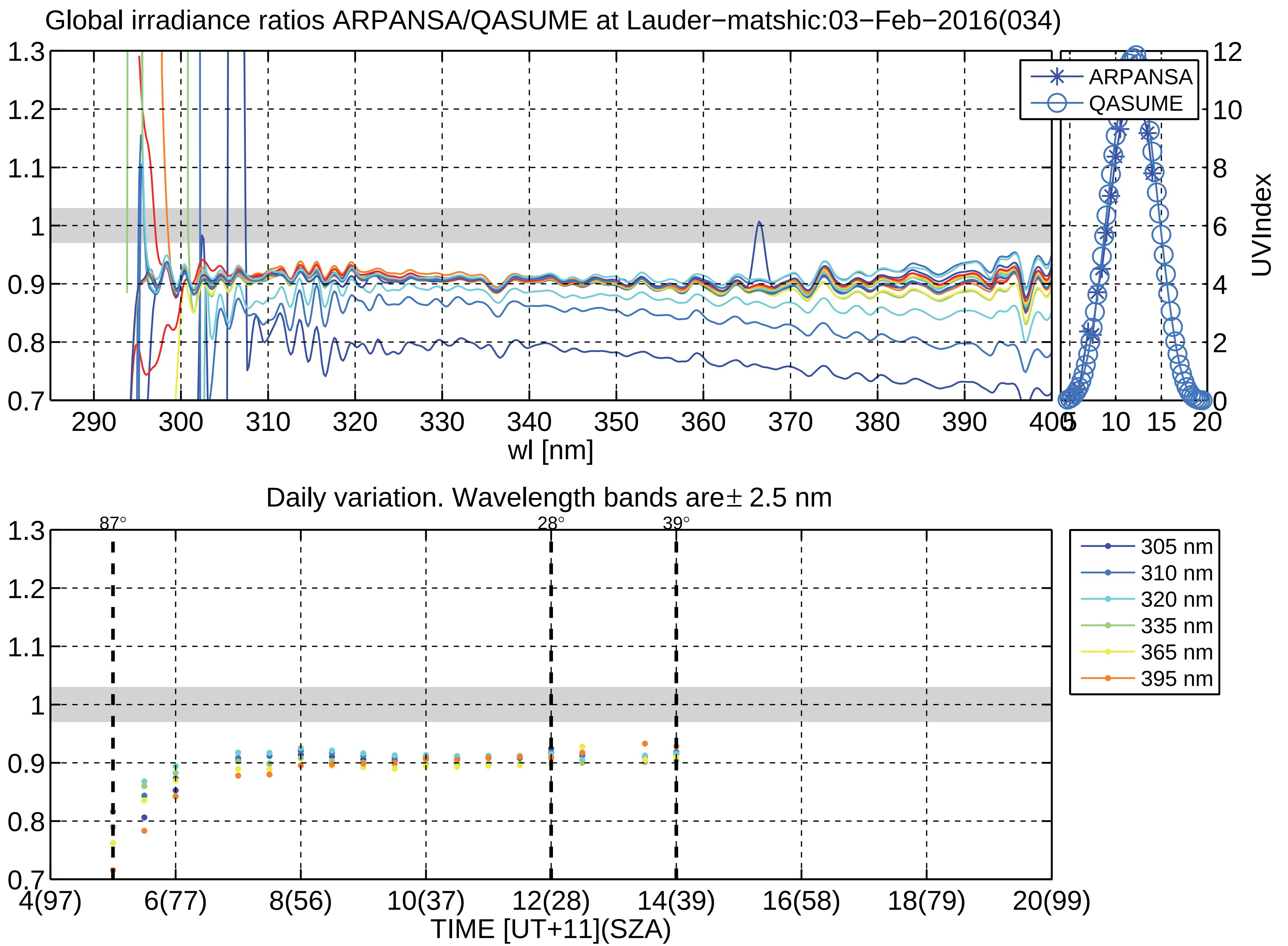

Wavelength shift
Mean
MinMax
STD
0.1
0.05
0
−0.05
−0.1
Wavelength shift /nm
300
320
340
360
380
400
420
440
Wavelength /nm
WL=350.00 nm
0.1
0.05
0
−0.05
−0.1
Wavelength shift /nm
01/24
01/31
02/07
02/14
Date & time


Global irradiance ratios ARPANSA/QASUME at Lauder−matshic:01−Feb−2016(032) to 10−Feb−2016(041)
RATIO ARPANSA/QASUME
TIME [UT+11] ON DAYS: [32 33 34 35 36 37 38 39 40 41]
305 nm
310 nm
320 nm
335 nm
365 nm
395 nm
032
033
034
035
036
037
038
039
040
041
1.3
1.2
1.1
1
0.9
0.8
0.7
0
12

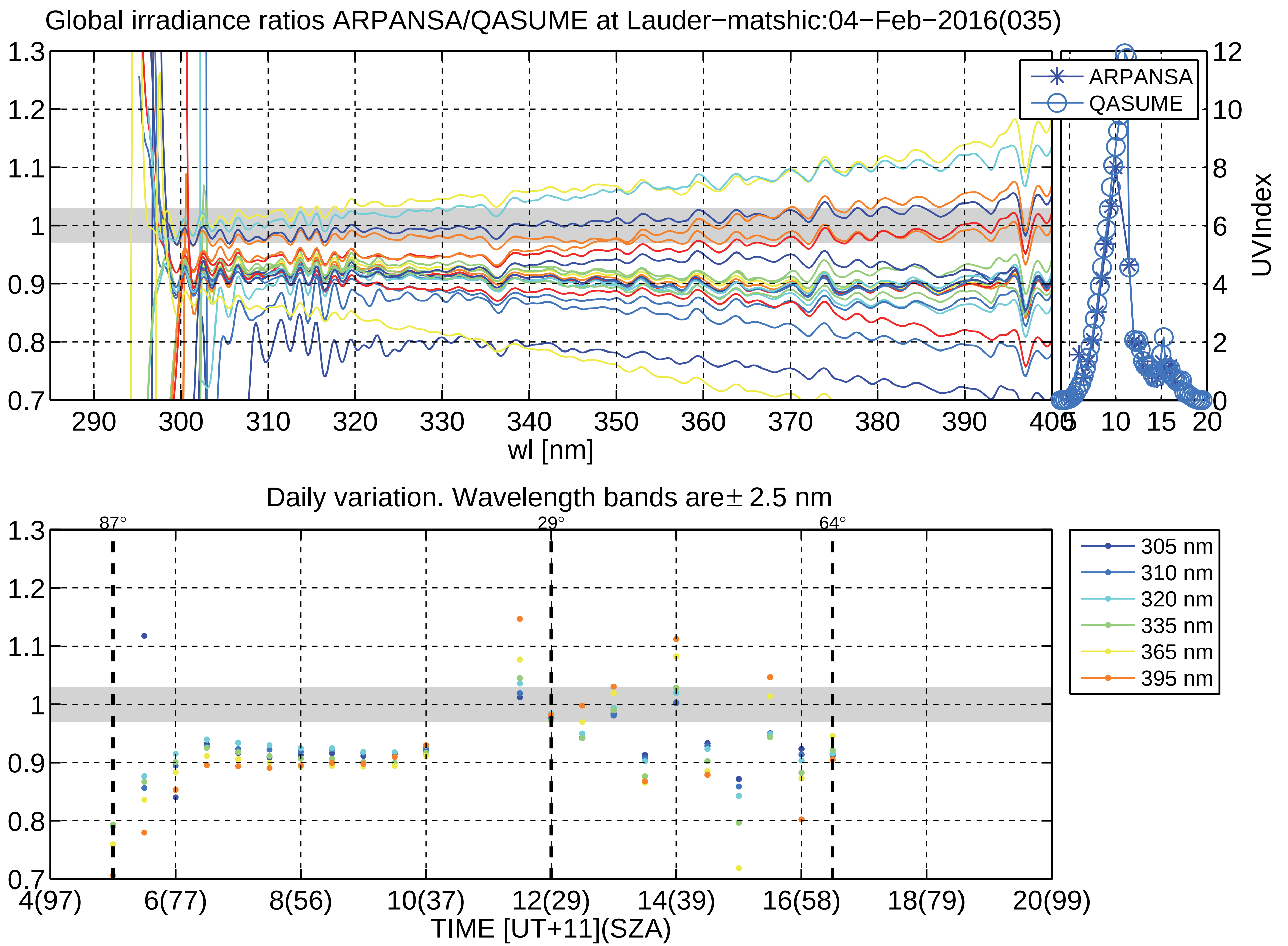

Global irradiance ratios ARPANSA/QASUME at Lauder−matshic:01−Feb−2016(032)
1.3
1.2
1.1
1
0.9
0.8
0.7
290
300
310
320
330
340
350
360
370
380
390
400
wl [nm]
ARPANSA
QASUME
5
10
15
20
12
10
8
6
4
2
0
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
38°
79°
305 nm
310 nm
320 nm
335 nm
365 nm
395 nm
4(96)
6(77)
8(56)
10(37)
12(28)
14(38)
16(58)
18(79)
20(98)
TIME [UT+11](SZA)



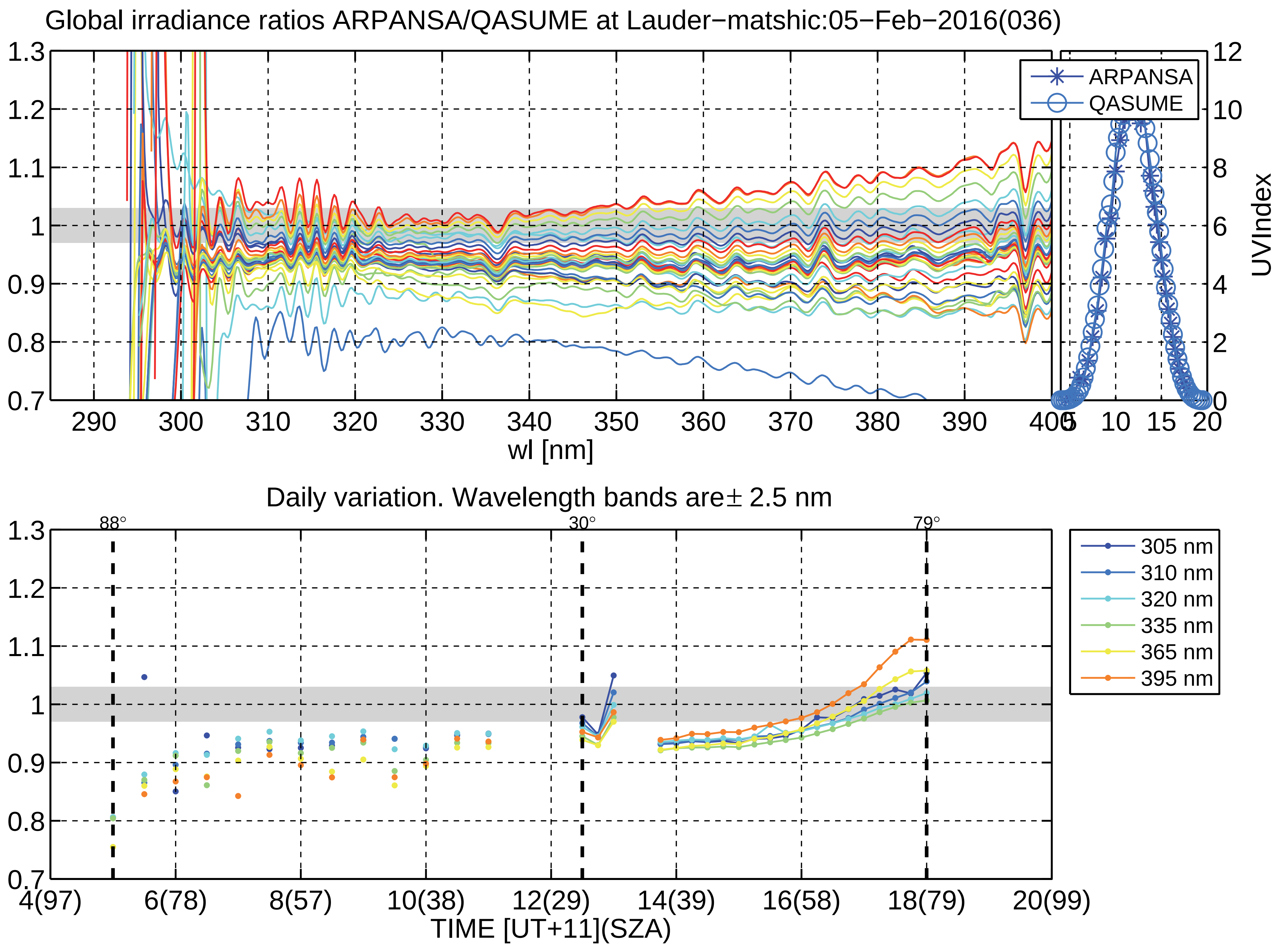
Global irradiance ratios ARPANSA/QASUME at Lauder−matshic:02−Feb−2016(033)
ARPANSA
QASUME
wl [nm]
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
87°
30°
79°
305 nm
310 nm
320 nm
335 nm
365 nm
395 nm
TIME [UT+11](SZA)



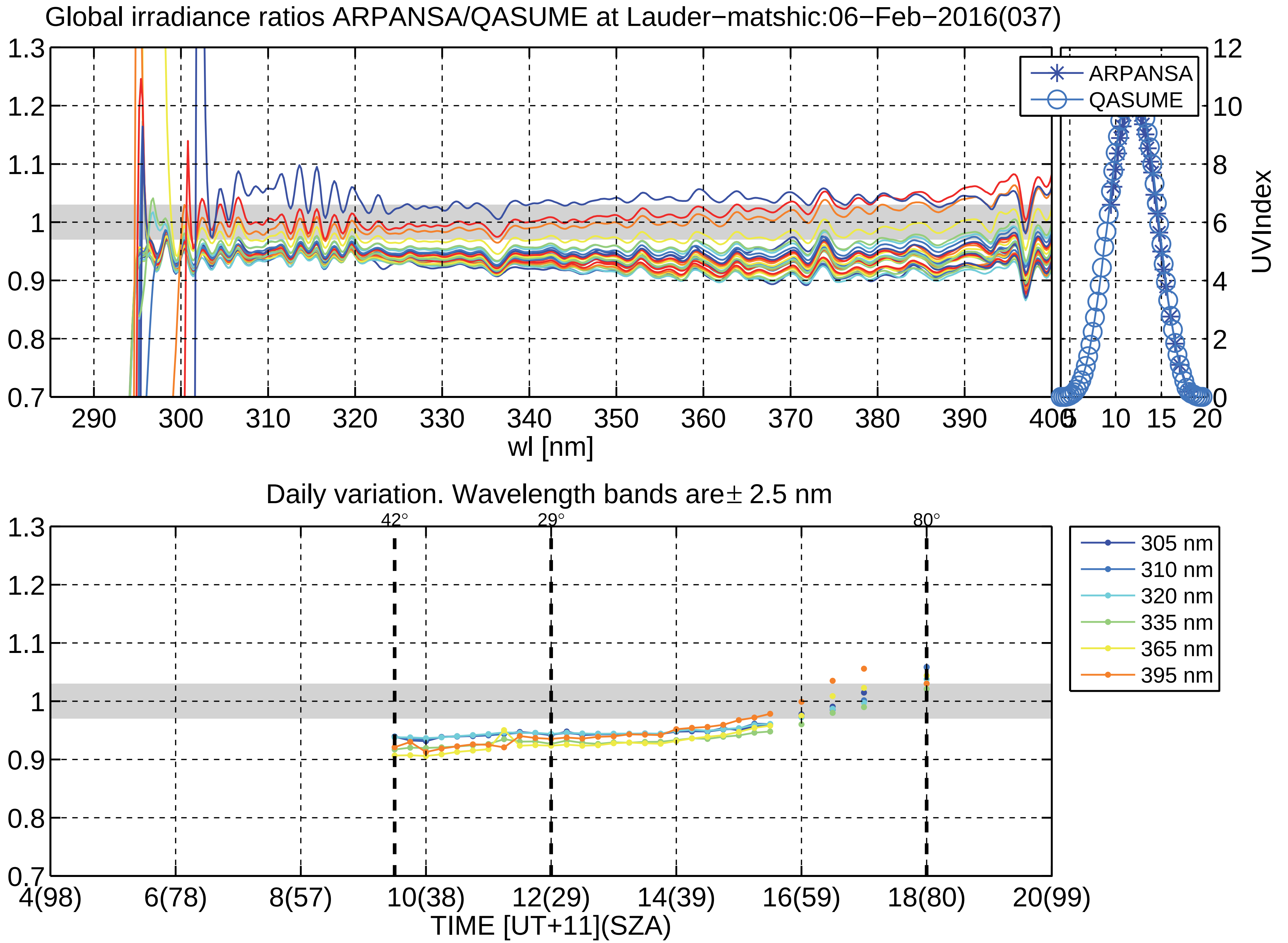
Global irradiance ratios ARPANSA/QASUME at Lauder−matshic:03−Feb−2016(034)
1.3
1.2
1.1
1
0.9
0.8
0.7
290
300
310
320
330
340
350
360
370
380
390
400
wl [nm]
ARPANSA
QASUME
5
10
15
20
12
10
8
6
4
2
0
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
87°
28°
39°
305 nm
310 nm
320 nm
335 nm
365 nm
395 nm
4(97)
6(77)
8(56)
10(37)
12(28)
14(39)
16(58)
18(79)
20(99)
TIME [UT+11](SZA)



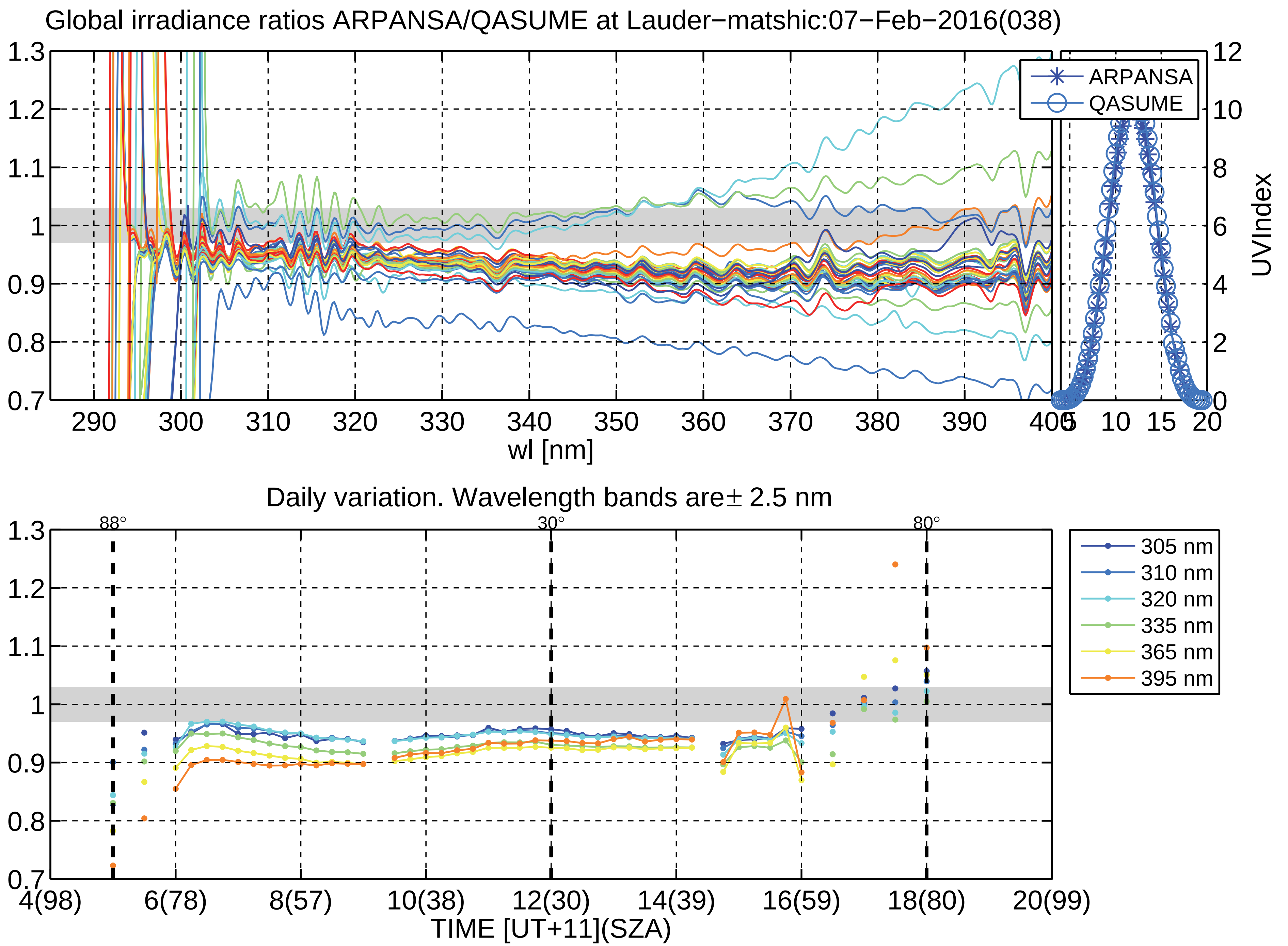
Global irradiance ratios ARPANSA/QASUME at Lauder−matshic:04−Feb−2016(035)
ARPANSA
QASUME
UVIndex
wl [nm]
Daily variation. Wavelength bands are± 2.5 nm
87°
29°
64°
305 nm
310 nm
320 nm
335 nm
365 nm
395 nm
TIME [UT+11](SZA)



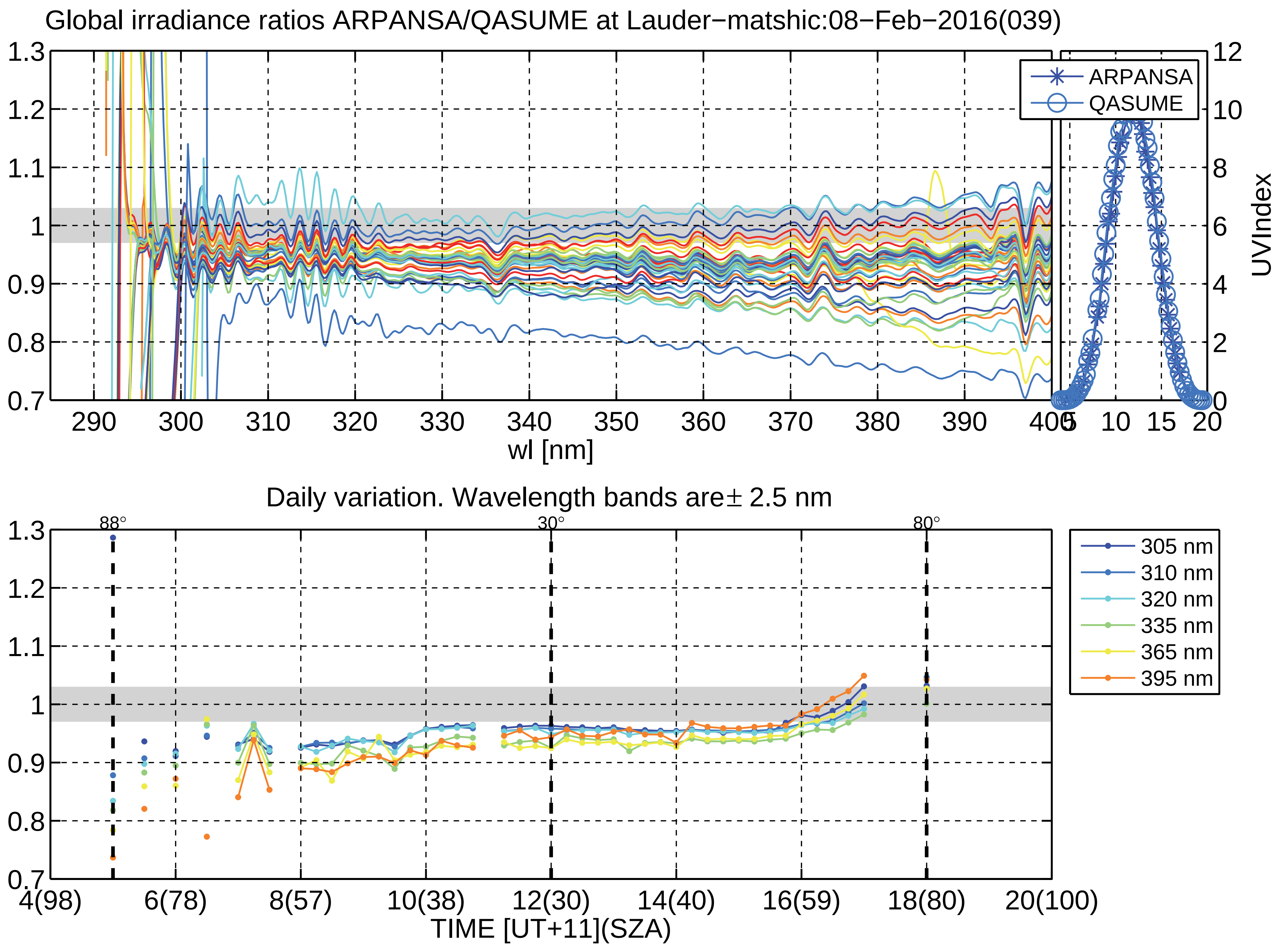
Global irradiance ratios ARPANSA/QASUME at Lauder−matshic:05−Feb−2016(036)
ARPANSA
QASUME
UVIndex
wl [nm]
Daily variation. Wavelength bands are± 2.5 nm
88°
30°
79°
305 nm
310 nm
320 nm
335 nm
365 nm
395 nm
TIME [UT+11](SZA)

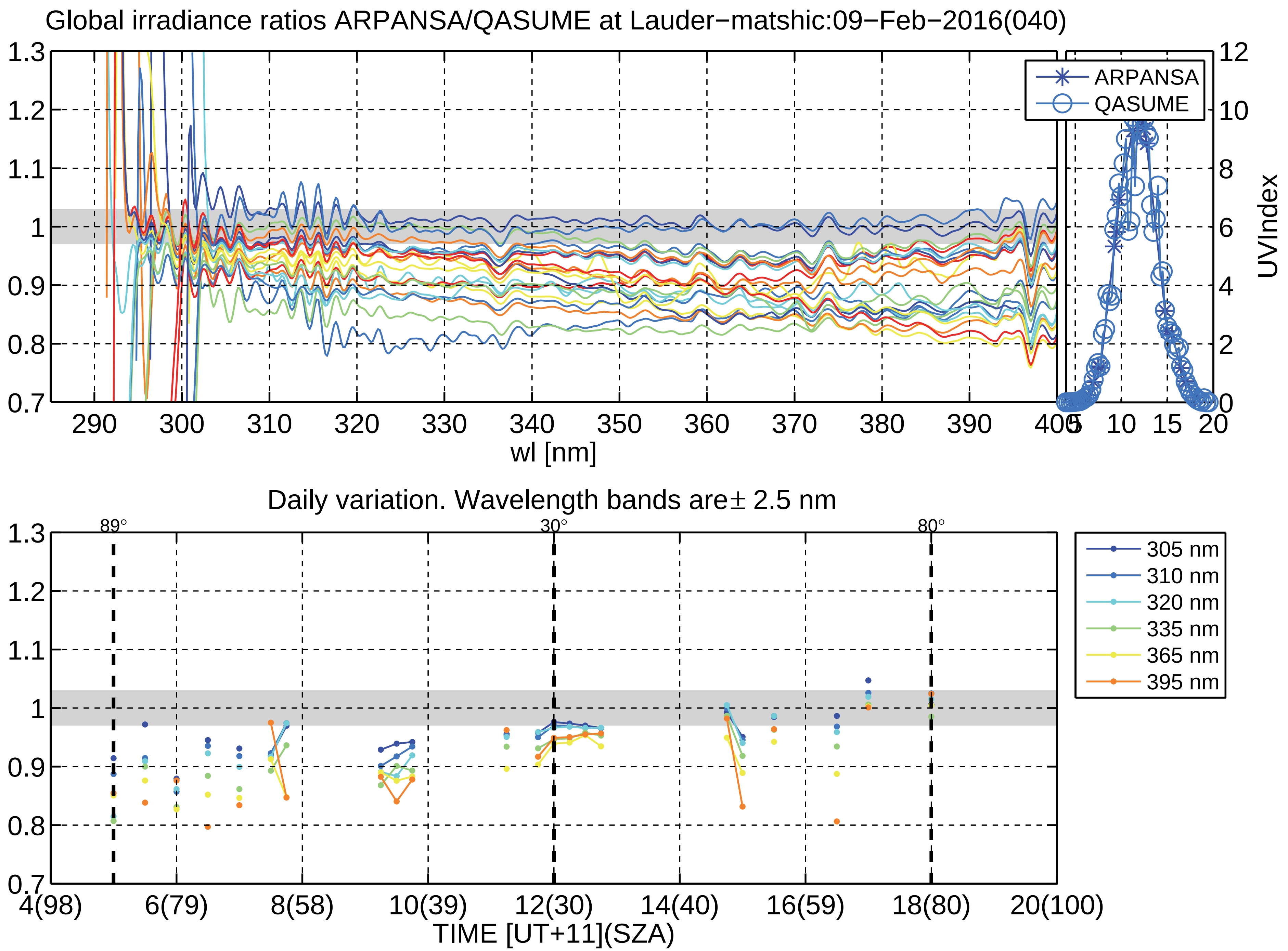


Global irradiance ratios ARPANSA/QASUME at Lauder−matshic:06−Feb−2016(037)
ARPANSA
QASUME
UVIndex
wl [nm]
Daily variation. Wavelength bands are± 2.5 nm
42°
29°
80°
305 nm
310 nm
320 nm
335 nm
365 nm
395 nm
TIME [UT+11](SZA)

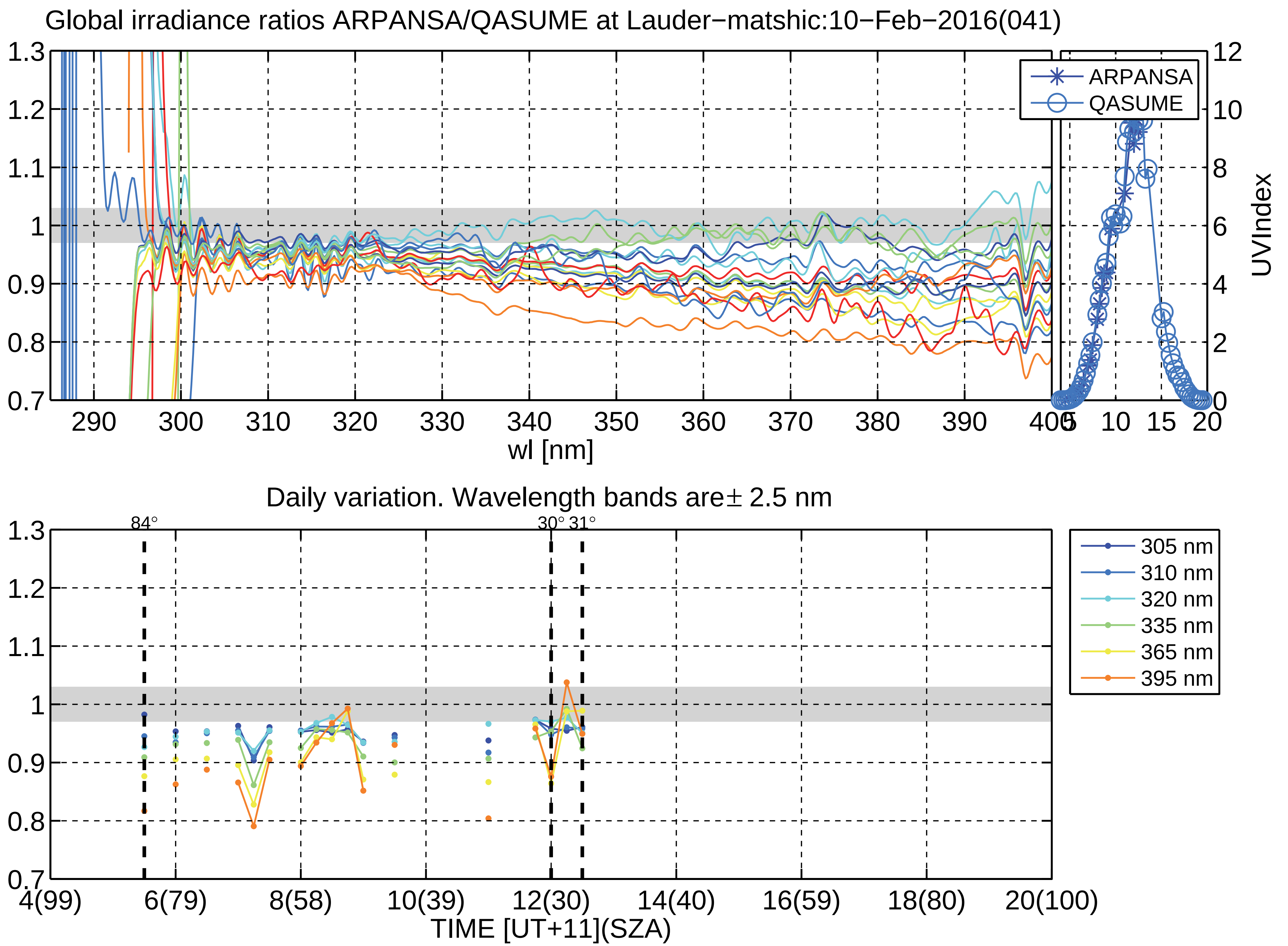


Global irradiance ratios ARPANSA/QASUME at Lauder−matshic:07−Feb−2016(038)
1.3
1.2
1.1
1
0.9
0.8
0.7
290
300
310
320
330
340
350
360
370
380
390
400
wl [nm]
ARPANSA
QASUME
12
10
8
6
4
2
0
UVIndex
5
10
15
20
Daily variation. Wavelength bands are± 2.5 nm
88°
30°
80°
305 nm
310 nm
320 nm
335 nm
365 nm
395 nm
4(98)
6(78)
8(57)
10(38)
12(30)
14(39)
16(59)
18(80)
20(99)
TIME [UT+11](SZA)

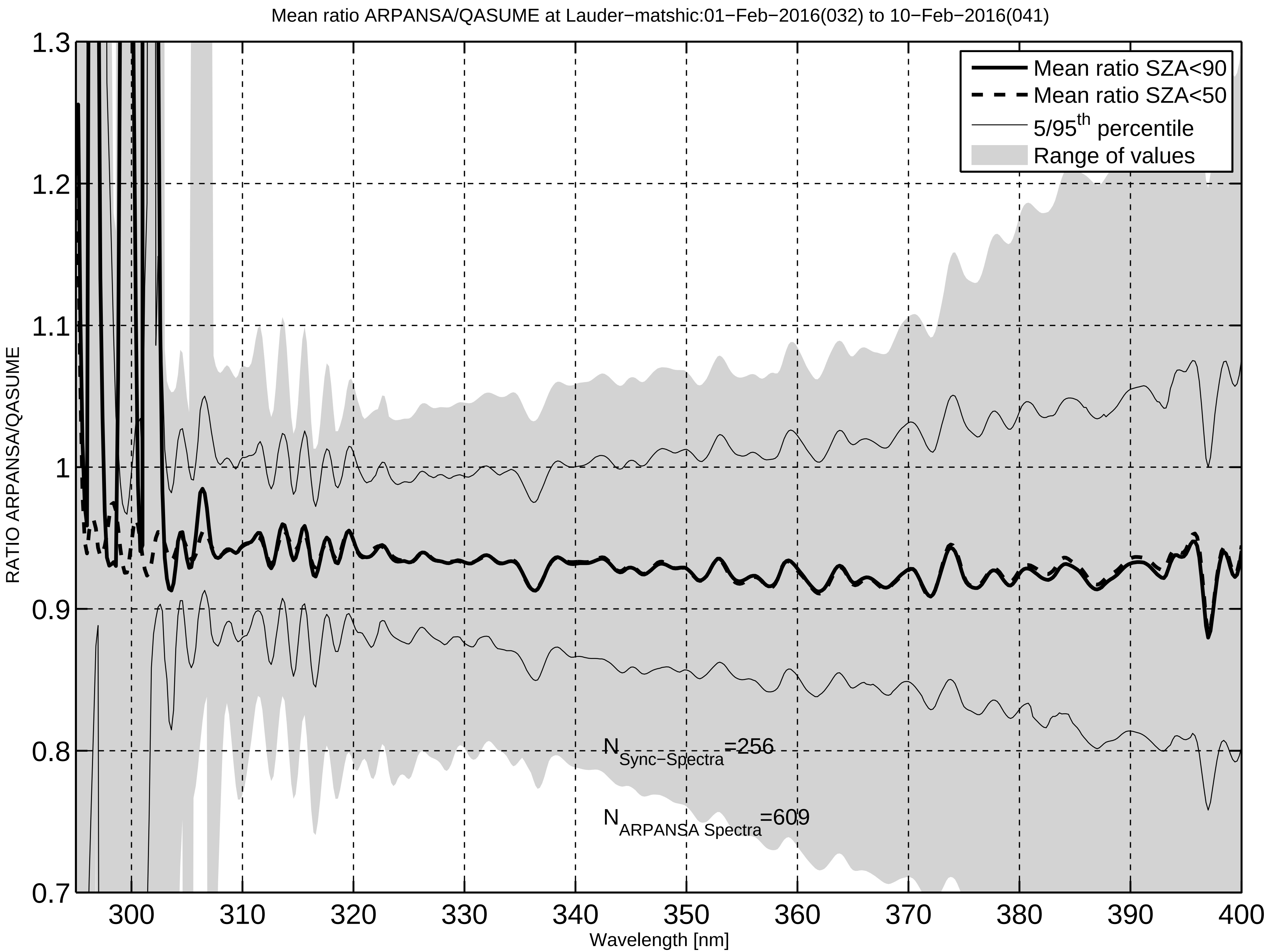

Global irradiance ratios ARPANSA/QASUME at Lauder−matshic:08−Feb−2016(039)
1.3
1.2
1.1
1
0.9
0.8
0.7
290
300
310
320
330
340
350
360
370
380
390
400
wl [nm]
ARPANSA
QASUME
5
10
15
20
12
10
8
6
4
2
0
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
88°
30°
80°
305 nm
310 nm
320 nm
335 nm
365 nm
395 nm
4(98)
6(78)
8(57)
10(38)
12(30)
14(40)
16(59)
18(80)
20(100)
TIME [UT+11](SZA)



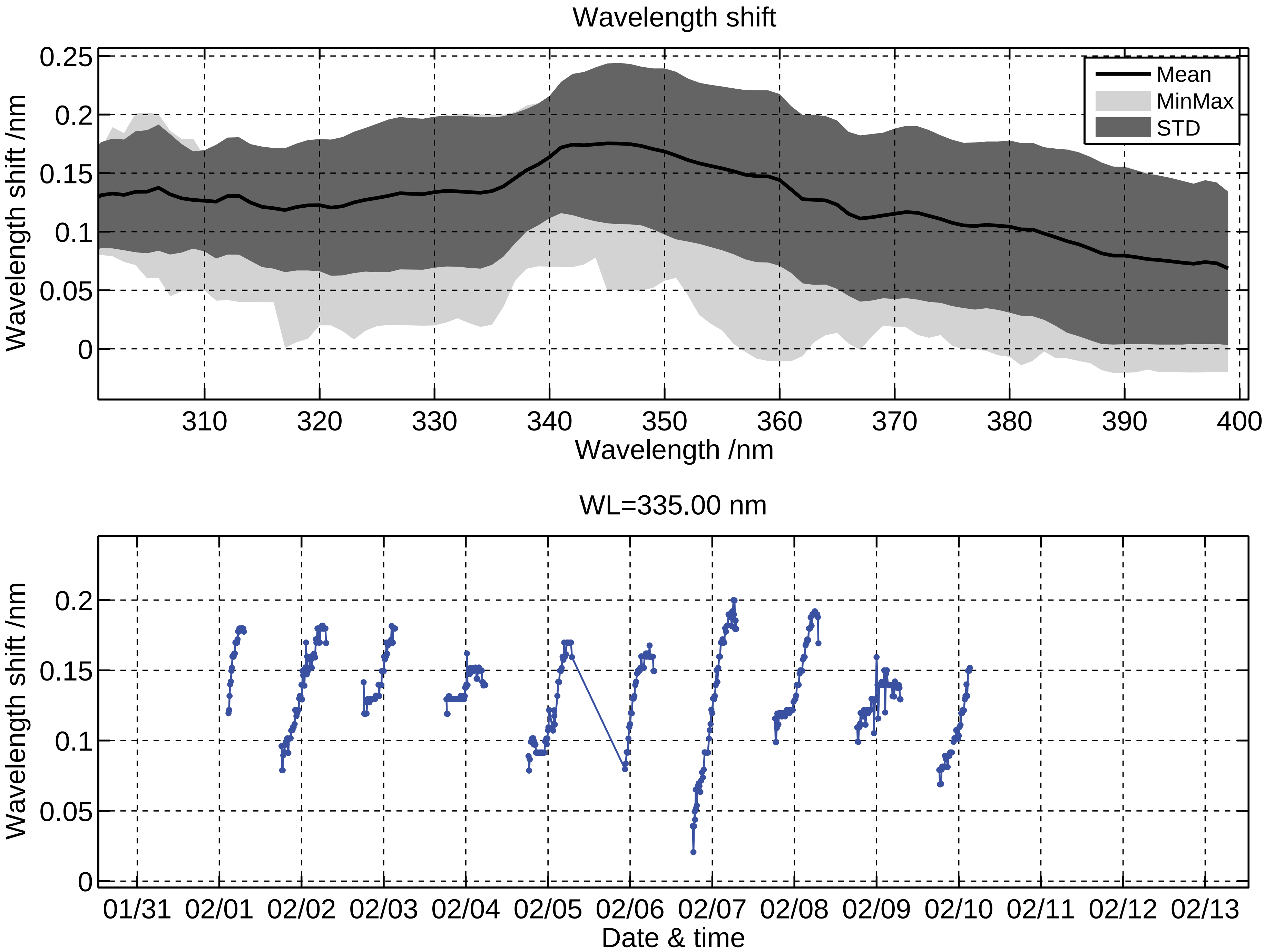
Global irradiance ratios ARPANSA/QASUME at Lauder−matshic:09−Feb−2016(040)
ARPANSA
QASUME
UVIndex
wl [nm]
Daily variation. Wavelength bands are± 2.5 nm
89°
30°
80°
305 nm
310 nm
320 nm
335 nm
365 nm
395 nm
TIME [UT+11](SZA)

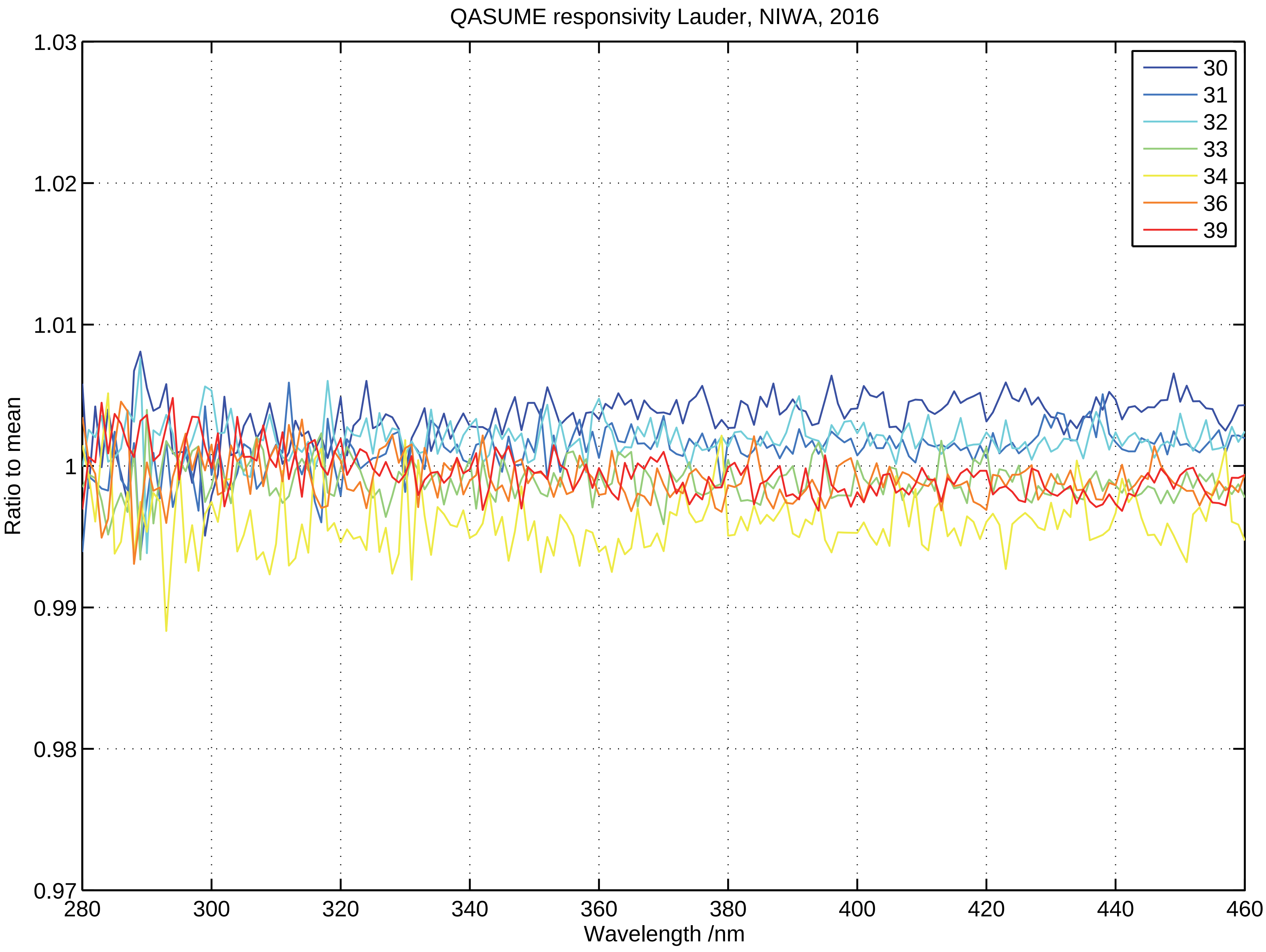


Global irradiance ratios ARPANSA/QASUME at Lauder−matshic:10−Feb−2016(041)
wl [nm]
UVIndex
ARPANSA
QASUME
Daily variation. Wavelength bands are± 2.5 nm
84°
30° 31°
305 nm
310 nm
320 nm
335 nm
365 nm
395 nm
TIME [UT+11](SZA)



Mean ratio ARPANSA/QASUME at Lauder−matshic:01−Feb−2016(032) to 10−Feb−2016(041)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
Range of values
RATIO ARPANSA/QASUME
Wavelength [nm]
N Sync−Spectra =256
N ARPANSA Spectra =609
1.3
1.2
1.1
1
0.9
0.8
0.7
300
310
320
330
340
350
360
370
380
390
400


Wavelength shift
Mean
MinMax
STD
Wavelength shift /nm
0.25
0.2
0.15
0.1
0.05
0
310
320
330
340
350
360
370
380
390
400
Wavelength /nm
WL=335.00 nm
Wavelength shift /nm
0.2
0.15
0.1
0.05
0
01/31
02/01
02/02
02/03
02/04
02/05
02/06
02/07
02/08
02/09
02/10
02/11
02/12
02/13
Date & time



QASUME responsivity Lauder, NIWA, 2016
Ratio to mean
Wavelength /nm
1.03
1.02
1.01
1
0.99
0.98
0.97
280
300
320
340
360
380
400
420
440
460
30
31
32
33
34
36
39