# Protocol of the intercomparison at DSA, Oslo, Norway on May 22 to 26, 2019 with the travelling reference spectroradiometer QASUME from PMOD/WRC

Report prepared by Gregor Hülsen

Operator: Gregor Hülsen

The purpose of the visit was the comparison of global solar irradiance measurements between the travelling reference spectroradiometer QASUME and the Bentham DM150-NRP spectroradiometer operated by DSA (Norwegian Radiation and Nuclear Safety Authority (DSA), former Norwegian Radiation Protection Authority (NRPA).

A second Bentham spectroradiometer from DSA (Bentham DTM300-NR2), three NILU-UV 6-channel instruments and seven GUV instruments (5, 7 and 19 channels, Biospherical Instruments, Inc) were run side-by-side the QASUME spectroradiometer throughout the campaign. Among these instruments were the Norwegian UV-network's travelling reference instrument GUV-9273 and the travelling reference instrument of the Finnish-Argentinian-Antarctic NILU-UV network. In the group of GUV instruments was also a 19-channel GUVis-3511, fitted with a rotating shadow band, that provided direct, diffuse and global spectral irradiances for the cosine corrections of the DSA's NRP and NR2 spectroradiometers. UVI data was submitted for the GUV-9273 for the blind test comparison with the QASUME spectroradiometer. The instrument has served the calibration of the 9 Norwegian UV monitoring stations since 1995 (quality-controlled data from all stations available at https://github.com/uvnrpa), and has undergone extensive QA/QC activities all the years. Calibrations are traceable to QASUME/PMOD-WRC through participation in the FARIN campaign arranged in Oslo in 2005 and two QASUME site audit in 2010 (Oslo) and 2014 (Jokioinen, Finland). See: Johnsen, B., et al. (2008), Intercomparison and harmonization of UV Index measurements from multiband filter radiometers, J. Geophys. Res., 113, D15206, doi:10.1029/2007JD009731; reports auf the QASUME site audits are available on webpage of PMOD/WRC, WCCUV department.

The measurement site is located at DSA; Latitude 59.95 N, Longitude 10.60 E and altitude 130 m.a.s.l. The horizon of the measurement site is free down to 80° solar zenith angle (SZA). Measurements between 2:30 UT and 21:00 UT have been analysed.

QASUME was installed on the measurement platform of DSA in the morning of May 22, 2019. The spectroradiometer was installed next between the Bentham spectrophotometer (NRP, from DSA) and the filter radiometers, with the entrance optic of QASUME within 2 m to the other instruments. The NRP and NR2 are Bentham DM150 and DTM300 spectroradiometers, respectively. NRP is equipped with a D6 entrance optic, and NR2 is equipped with a D7 entrance optic, where both optics are thermostatted, and protected by quartz domes, flushed from inside with dry nitrogen. The intercomparison between

QASUME and the spectroradiometers lasted five days, from the afternoon of May 22nd to the evening of May 26th.

The intercomparison was conducted as a blind intercomparison; i.e. no results were communicated to the operator at DSA before DSA had submitted all data.

QASUME was calibrated several times during the intercomparison period using a portable calibration system. Three lamps (T61252 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 28.21±0.05°C and the diffuser head was heated to a temperature of 28.97±0.54°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 410 nm.

## Protocol:

The measurement protocol was to measure one solar irradiance spectrum every 20 minutes from 290 to 410 nm, every 0.5 nm, and 3.0 seconds between each wavelength increment. QASUME recorded the spectra with 0.25 nm increments and NRP with 0.5 nm increment. The NR2 spectroradiometer was operated in non-synchronized mode to scan the entire wavelength range from 290 to 1100 nm as fast as possible. Wavelength increments were variable throughout each scan (0.25 nm below 410 nm, 0.5nm between 410 and 450 nm, and 1.0 nm above 450 nm

| Date | DAY | Weather | Comment (times are in UT) |
|---|---|---|---|
| 22.mai | Wednesday | Mix of Sun and clouds<br>Rainshower at 11:00 | Installed at 10:00 |
| 23.mai | Thursday | Clear Sky in the morning<br>Clouds in the afternoon<br>with some dropping | 8:55 calibration (T68523) |
| 24.mai | Friday | Rain in the moring<br>Cloud in the afternoon<br>Clear sky in the evening | 15:16 calibration (T68523) |
| 25.mai | Saturday | Clear Sky in the morning<br>Mix of Sun & Clouds<br>with very some dropping | 8:21 calibration (T68523)<br>8:39 calibration (T61252) |
| 26.mai | Sunday | Mix of Sun & Clouds<br>strong wind in the morning | 16:34 calibration (T68523)<br><br>End of Campaign: 17:10 |

**Results:**

In total 211 synchronised simultaneous spectra from QASUME and NRP are available from the measurement period. Measurements between 2:30 and 20:00 UT have been analysed (SZA smaller than 90°).

**Remarks:**

DSA delivered three datasets for the NRP spectroradiometer. They differed by the way of processing the data. They were labelled as follows:

NRP-A: No Cosine Correction, ShicRIVM applied
NRP-B: No Cosine Correction, no ShicRIVM
NRP-C: Cosine Correction, ShicRIVM applied

The dataset used for the calibration report are NRP-C.

Identical types of datasets where delivered for the NR2 spectroradiometer. In addition, UVI data, including10 other dose rate products were supplied by DSA for the NRP and NR2 spectroradiometers, as well as for the network travelling filter radiometer GUV 9273.

**NRP (DM150):**

1. The ratios between NRP and QASUME have on average an offset of -1% for wavelengths longer than 310 nm (figures NRP-C/Qasume).
2. The diurnal variation of the NRP to QASUME ratio is neglectable. However, due to mix of sun and cloudy weather conditions the diurnal dependence of the cosine correction could not be studied over the course of an entire day.
3. The first dataset (figures NRP-A/NRP-C) reveal, that the cosine correction algorithm is in the order of 1-2% during the clear sky moments (afternoon of doy 144 to the morning of 145) which improves the ratio NRP-C/Qasume relative to the ratios shown in the figures NRP-A/Qasume
4. The wavelength shifts, dwl, for the different datasets are shown in figures below. Without shicRIVM a linear relation between dwl and the wavelength starting from +0.1 nm at 300 nm decreasing to -0.17 nm at 410 nm can be observed. After the shicRIVM analysis dwl is stable to better than ±50pm.
5. In the morning of Friday, $24^{th}$ [144], the NRP sensitivity was 5 % higher and recovered to the nominal condition during the day. This could be confirmed with both the comparison to QASUME and the lamp calibration of NRP in the afternoon. Most likely access of humidity inside the diffuser head due to heavy rain was the cause for this error. The constant flow of nitrogen dried the Teflon inside the diffuser during the day.
6. The comparison of the erythemal weighted, uvb and uva irradiance show an average offset of -1.5%, +1.9% and -1.6%. The sensitivity

changes on day 144 is also clearly visible (see figures “UV Index” below).

7. At around 390 nm the sensitivity of NRP is 2% lower than for lower wavelengths. At this wavelength a neutral density is inserted to reduce the high intensity on the photo multiplier tube of the DM150. This explains the difference between the UVB vs. the UVA weighted irradiance.

**NR2 (DTM300):**

1. As the NR2 was not synchronised to Qasume no spectral comparison of the data is possible.
2. The ratio of weighted irradiance UV data from the NR2 dataset to the local instruments have been analysed by Bjørn Johnson (see section “Comments by the local operator”).
3. The wavelength shifts are again better after the shicRIVM analysis, for wavelength below 450 nm. At higher wavelength the analysis if the dwl has a much higher uncertainty.

**GUV-9273:**

The ratio of weighted irradiance UV data from the multifilter radiometer GUV-9273 to the local instruments have been analysed by Bjørn Johnson (see section “Comments by the local operator”).

**Summary:**

To investigate the performance and data processing algorithm of DSA in depth, measurements for clear sky conditions are needed in addition to fast-changing sky conditions. The ratio of the NRP (DM150) instrument to the reference differs by -1 % - which is consistent to all previous intercomparisons.
The sealing of the NRP D6 entrance optic must be checked. The wavelength shift indicates that the wavelength alignment of NRP should be improved to be better than ±50pm *before* the shicRIVM analysis.
The decrease of sensitivity at 390 nm due to the insertion of a neutral density filter indicate, that the filter transmission should be recalibrated.

Both, the NR2 (DTM300) and the GUV9273 UVI, UVB and UVA data are in good agreement to the reference data (see section “Comments by the local operator”). However, the quality of the comparison is much reduced by the difficult sky situations

**DSA Operator:** Bjørn Johnson

**Comments by the local operator:**

Sealing issue of NRP D6 entrance optic: We suspect the water seeped through 3 small setscrew holes midway along the outer cylinder that clamps the internal D6 housing. Water may have evaporated into the cavity of the D6 fiber inlet. An improvement will be to add some silicon to lock these holes.

Due to the non-synchronous scan mode and the unstable sky conditions, it was not possible to directly compare UV-B, UV-A and CIE erythemally weighted irradiances from the NR2 spectroradiometer (Bentham DTM300) with corresponding irradiances measured with the Qasume unit.

Similarly, comparison of irradiance products from the travelling reference filterradiometer GUV9273 was complicated by the effect of rapid cloud fluctuations within the instruments 60 seconds averaging intervals.

Instead, we validated the internal agreement of spectroradometers NRP and NRA relative to GUV9273, interpolating one-minute averages of GUV9273 to the effective time stamp of irradiance products from the spectroradiometers. Results are shown below for 3 days, representing the period from the day that DSA instruments were installed at the roof (day 136), and days 139 and 145, providing fairly stable sky conditions. Figures A, B, C shows ratios of respectively CIE, UVB and UVA for the 3 days. Legend shows mean irradiance ratios for SZA<80.

As synchronous scans of spectroradiometer NRP already had been validated against Qasume, we could indirectly relate irradiance products of NR2 and GUV9273 with the Qasume:

According to the results given in the official report (Result NRP (DM150), point 6), NRP/Qasume was -1.5%, +1.9% and -1.6% for CIE, UV-B and UV-A.

Mean daily ratios for GUV9273/Qasume and NR2/Qasume has been calculated for the 3 selected days:

GUV9273/Qasume = (NRP/Qasume) / (NRP/GUV9273)
Example: CIE-ratios of GUV9273/Qasume = (100-1.5)/ (NRP/GUV9273)

And

NRA/Qasume = (GUV9273/Qasume) * (NRA/GUV9273)

Results are shown in Table D.
Averaged for these 3 days, CIE and UVA irradiances of NR2 and GUV9273 are underestimated relative to Qasume, and UVB overestimated relative to Qasume, in about the same order of magnitude as the direct comparison of

NRP/Qasume. Uncertainties related to sampling time and cloud instabilities are however hard to estimate.

| | | GUV9273/Qasume | | | | NR2/Qasume | |
|---|---|---|---|---|---|---|---|
| **Daynum** | **CIE** | **UVB** | **UVA** | | **CIE** | **UVB** | **UVA** |
| **136** | **-2.2 %** | **2.5 %** | **-3.1 %** | | **-5.0 %** | **-4.1 %** | **-4.6 %** |
| **139** | **-3.9 %** | **0.6 %** | **-1.6 %** | | **-3.9 %** | **-3.0 %** | **-1.1 %** |
| **145** | **-1.6 %** | **2.8 %** | **-1.5 %** | | **-1.5 %** | **-1.6 %** | **-0.7 %** |
| **mean** | **-2.6 %** | **2.0 %** | **-2.1 %** | | **-3.5 %** | **-2.9 %** | **-2.1 %** |

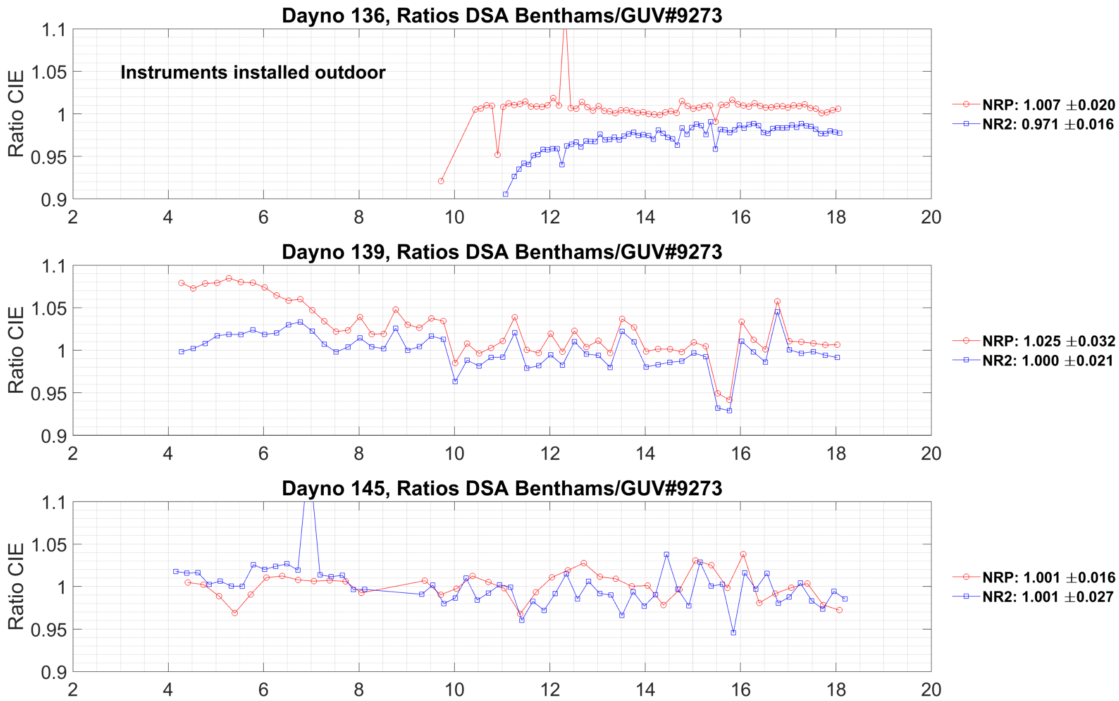



Figure A: CIE-ratios of NRP/GUV9273 and NR2/GUV9273 for 3 selected days. Numbers in legends is mean and sigma for SZA<80.

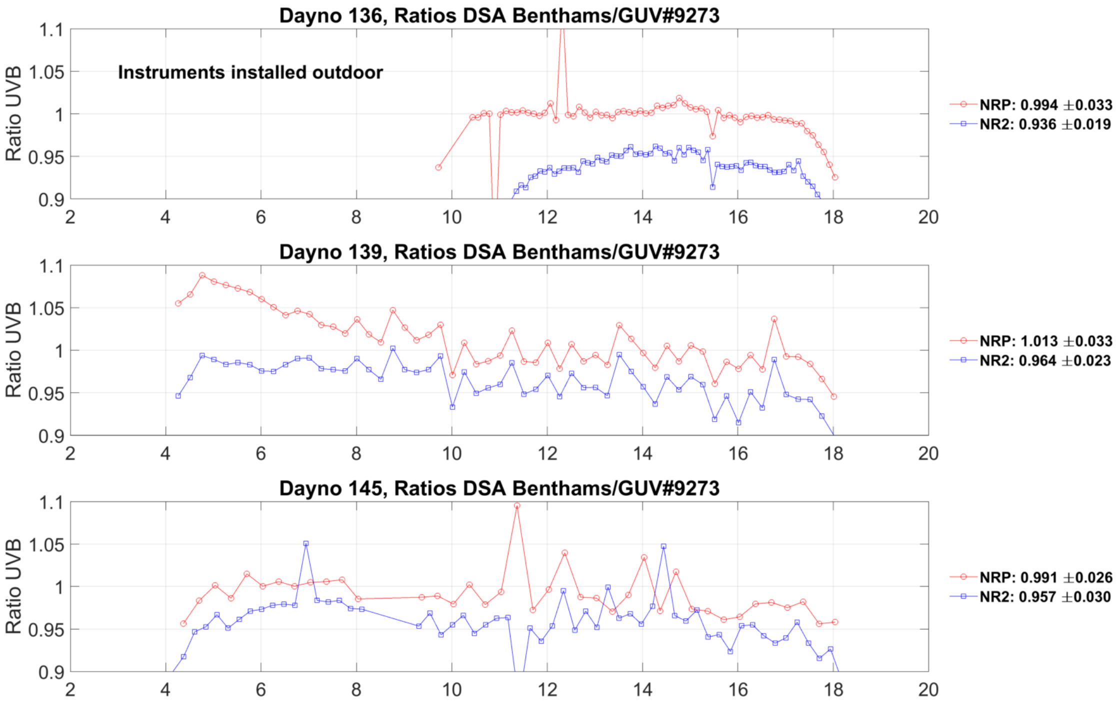



Figure B: Same as Figure A, but for UVB

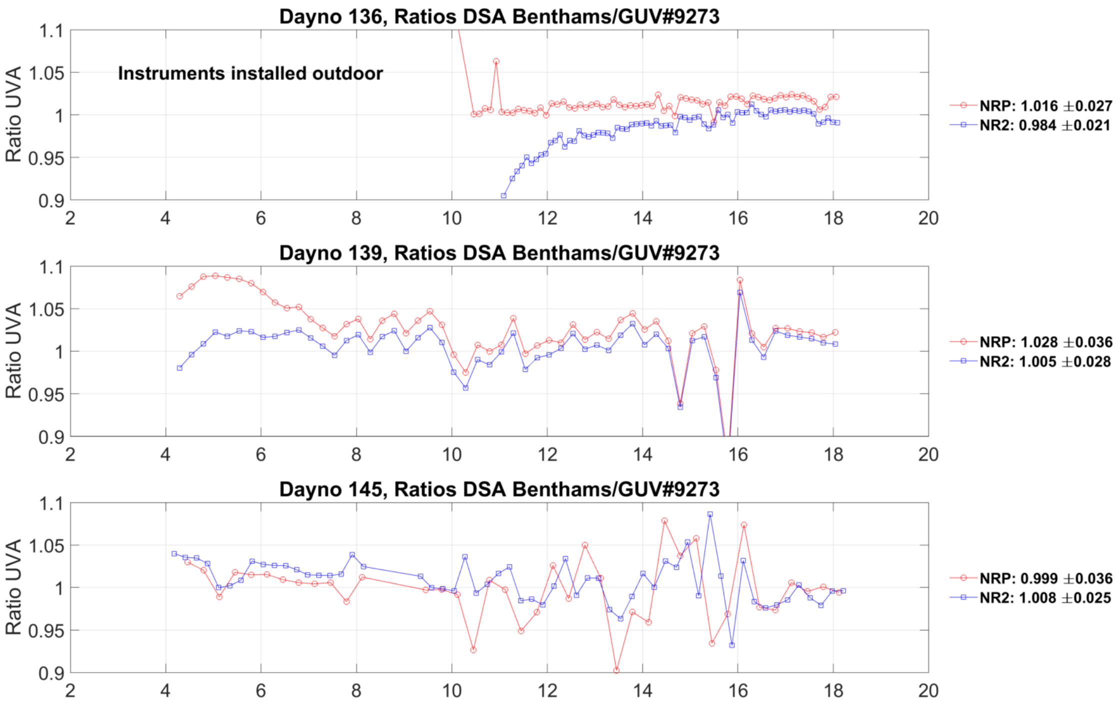
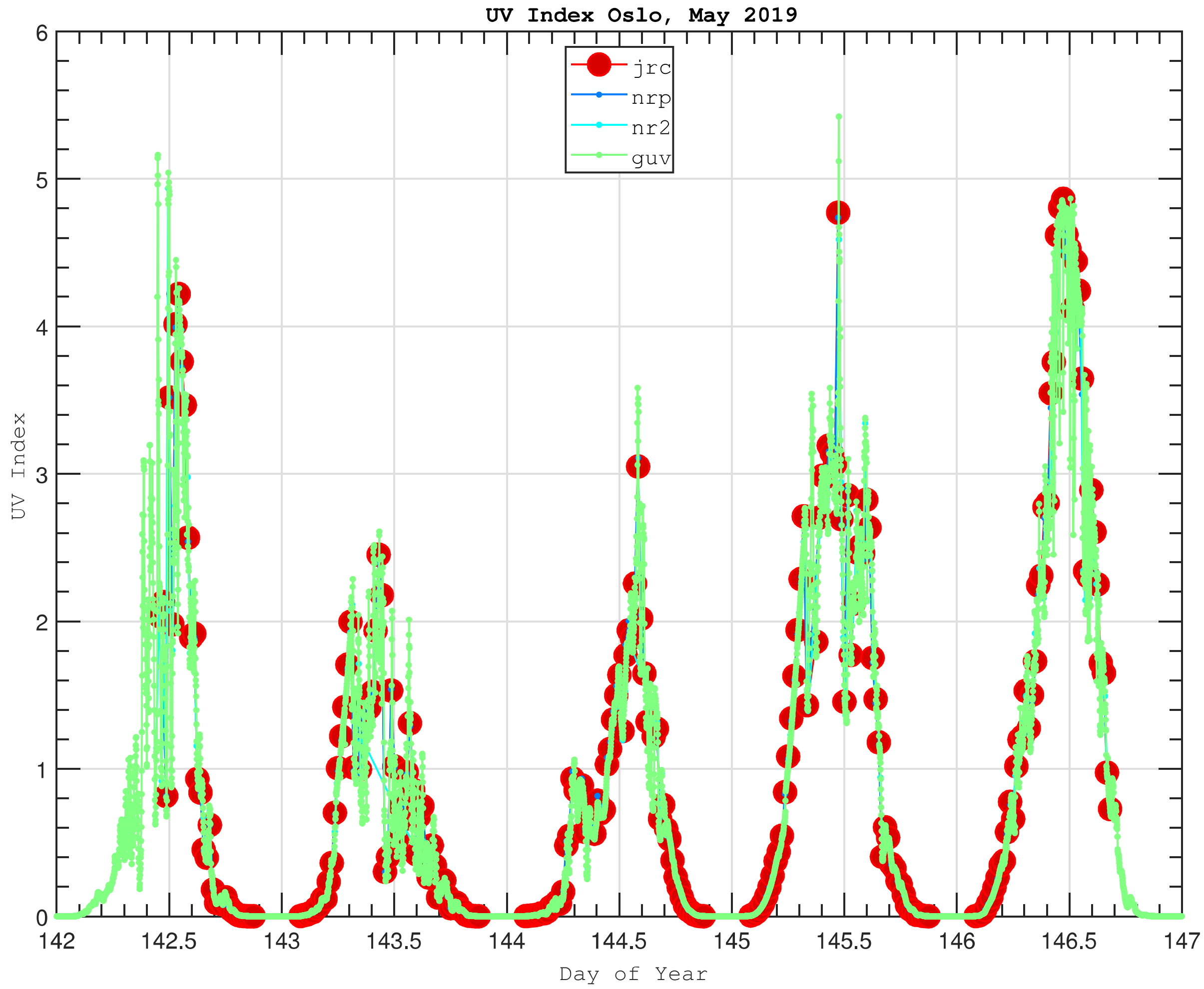
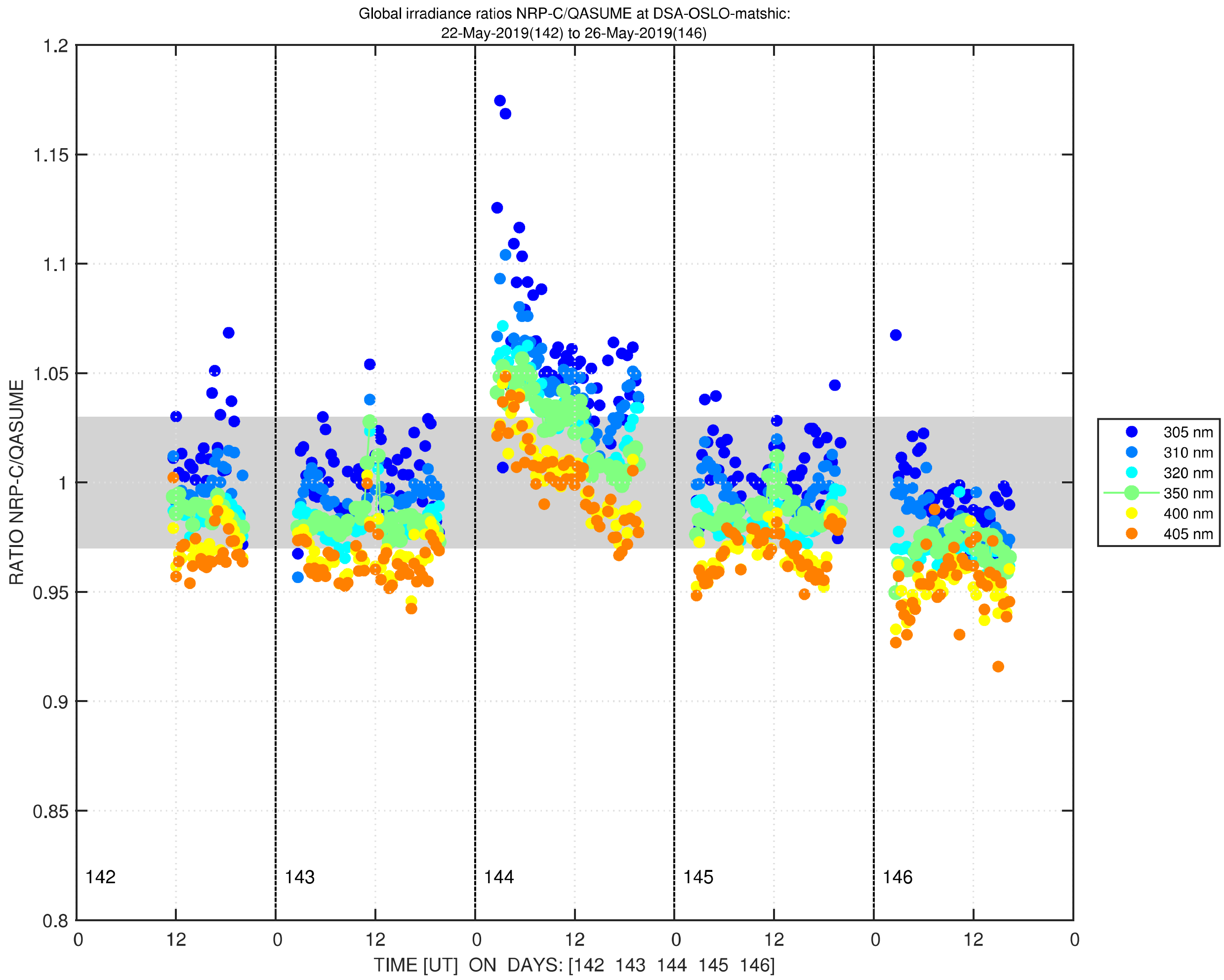
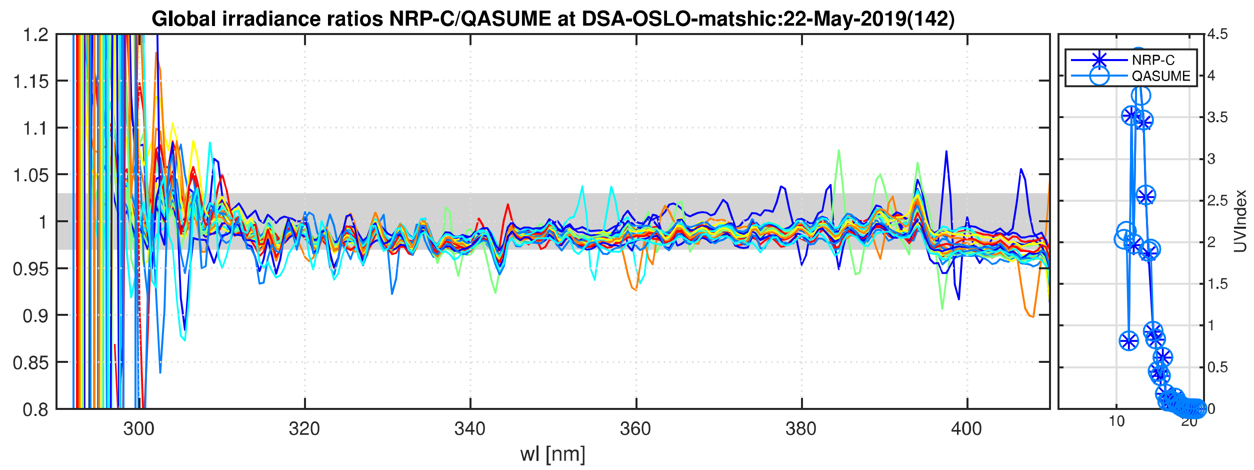


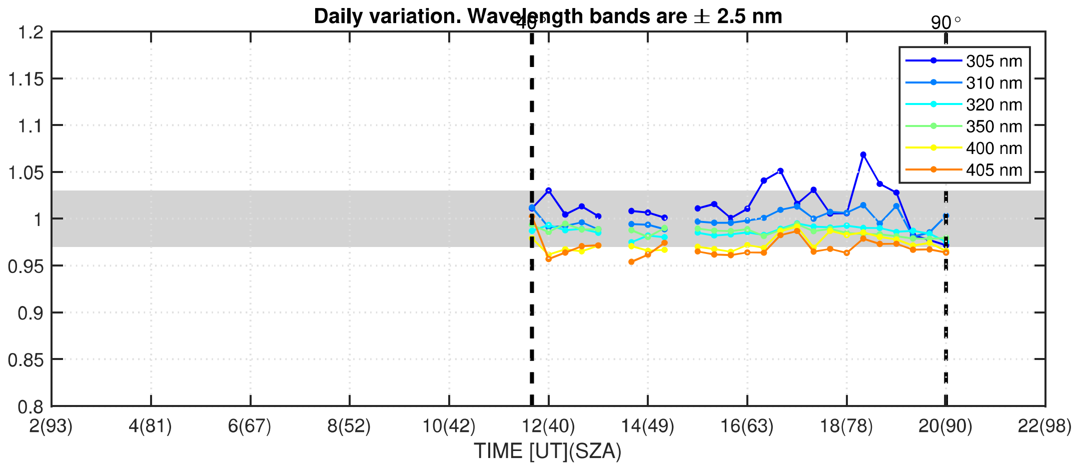

Figure C: Same as Figure A, but for UVA.

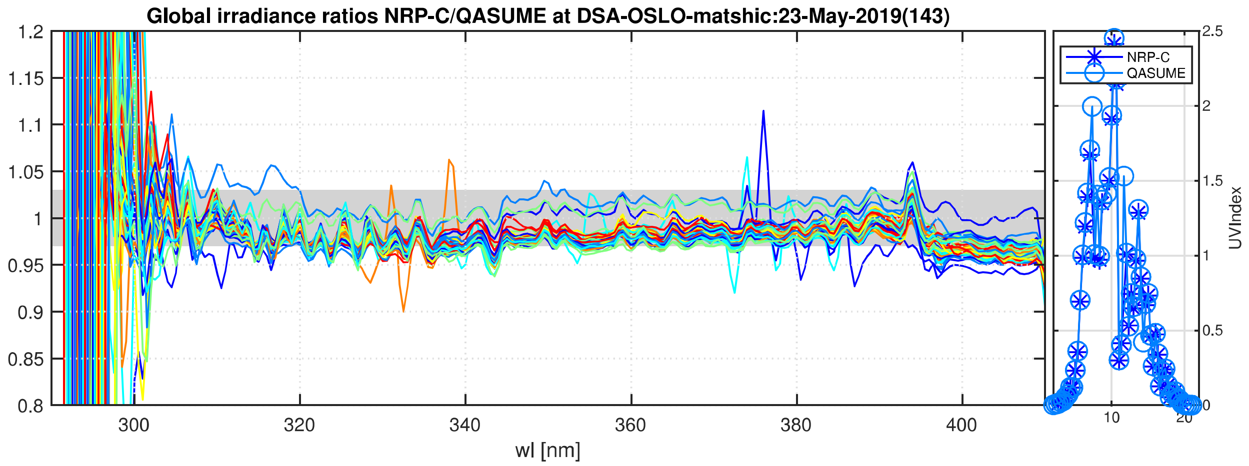


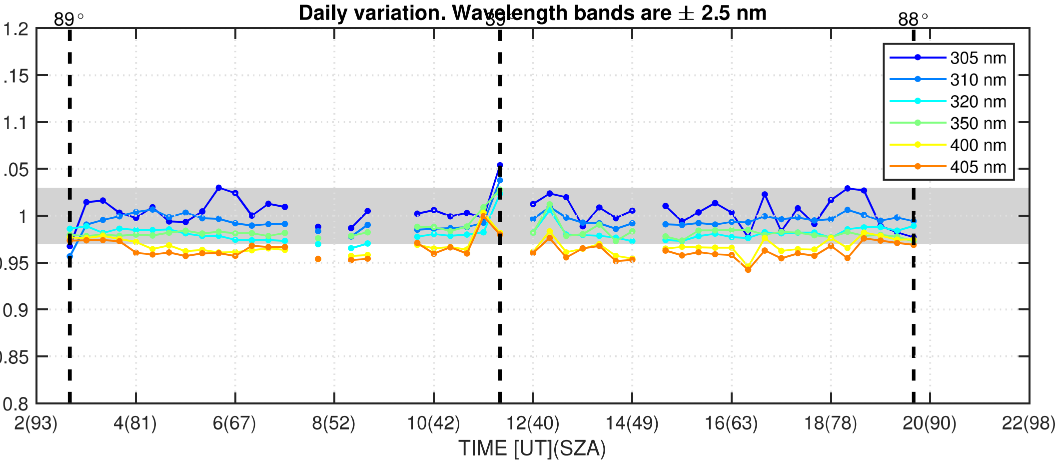
UV Index Oslo, May 2019
jrc
nrp
nr2
guv
UV Index
Day of Year
0
1
2
3
4
5
6
142
142.5
143
143.5
144
144.5
145
145.5
146
146.5
147

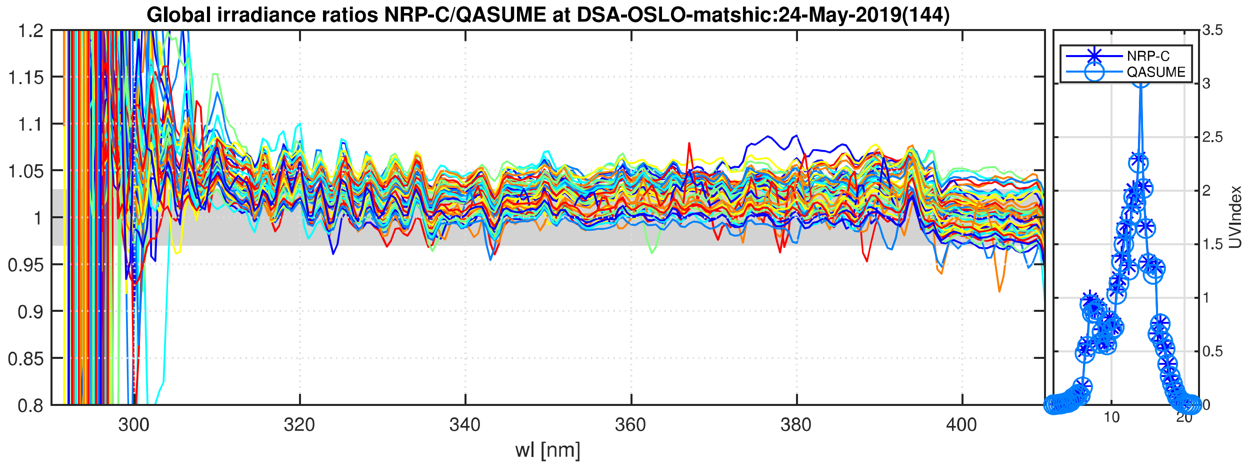

Global irradiance ratios NRP-C/QASUME at DSA-OSLO-matshic:
22-May-2019(142) to 26-May-2019(146)
RATIO NRP-C/QASUME
TIME [UT] ON DAYS: [142 143 144 145 146]
142
143
144
145
146
305 nm
310 nm
320 nm
350 nm
400 nm
405 nm

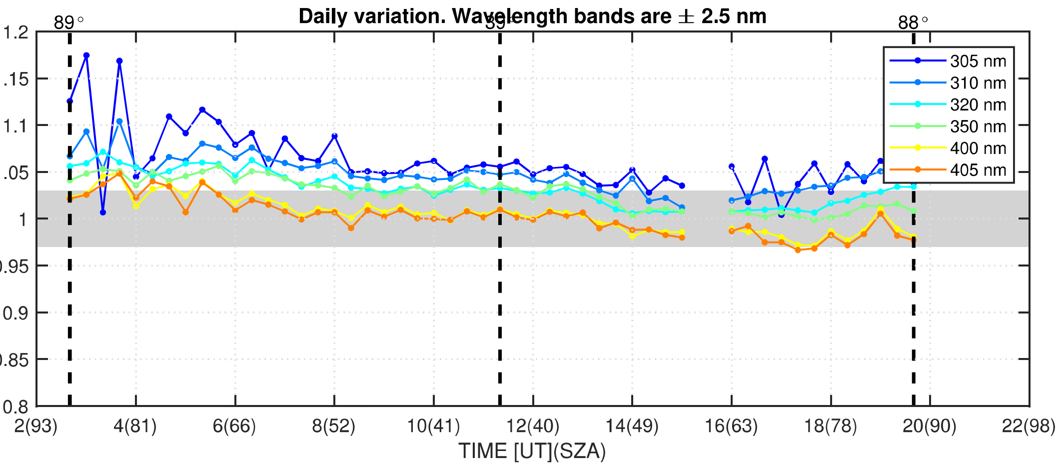

Global irradiance ratios NRP-C/QASUME at DSA-OSLO-matshic:22-May-2019(142)
wl [nm]
NRP-C
QASUME
UVIndex

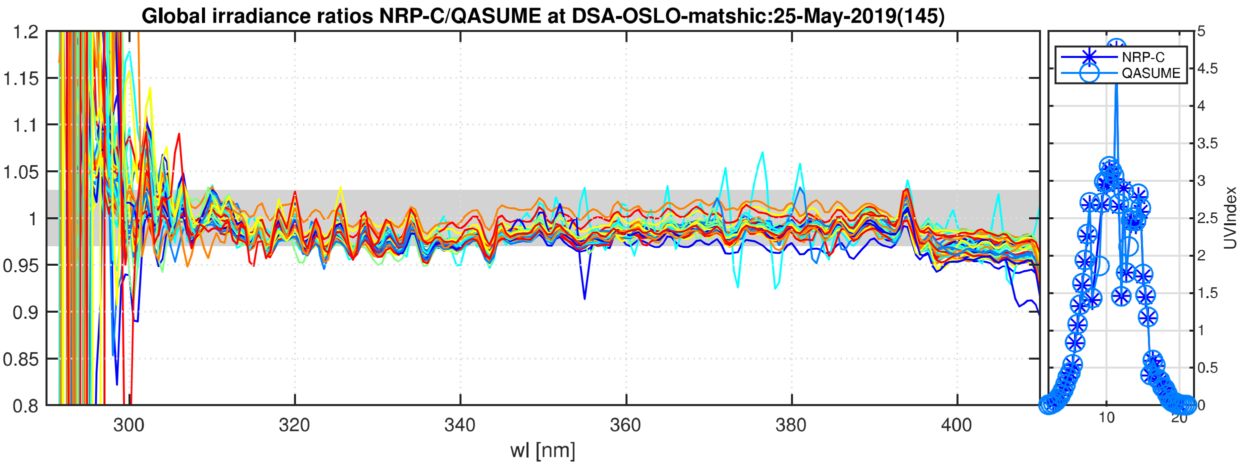

Daily variation. Wavelength bands are ± 2.5 nm
40°
90°
305 nm
310 nm
320 nm
350 nm
400 nm
405 nm
TIME [UT](SZA)

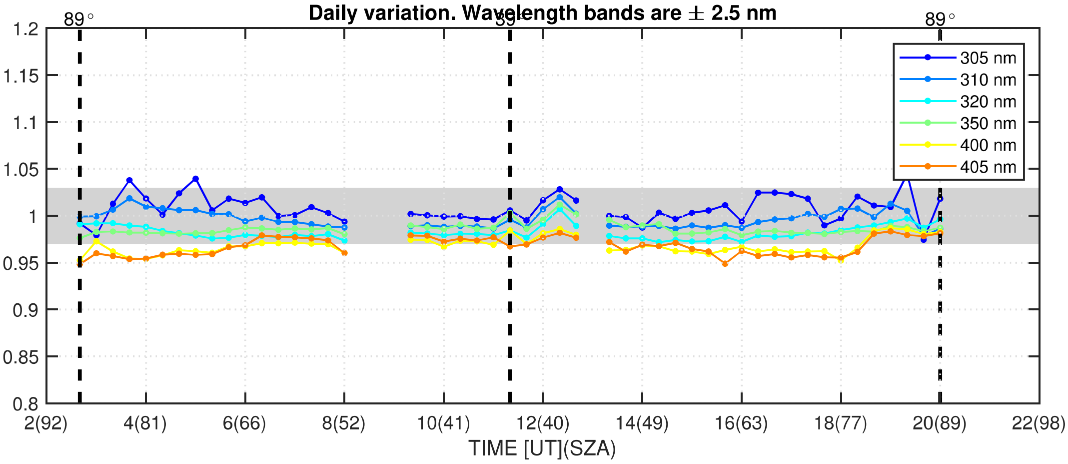

Global irradiance ratios NRP-C/QASUME at DSA-OSLO-matshic:23-May-2019(143)
wl [nm]
NRP-C
QASUME
UVIndex

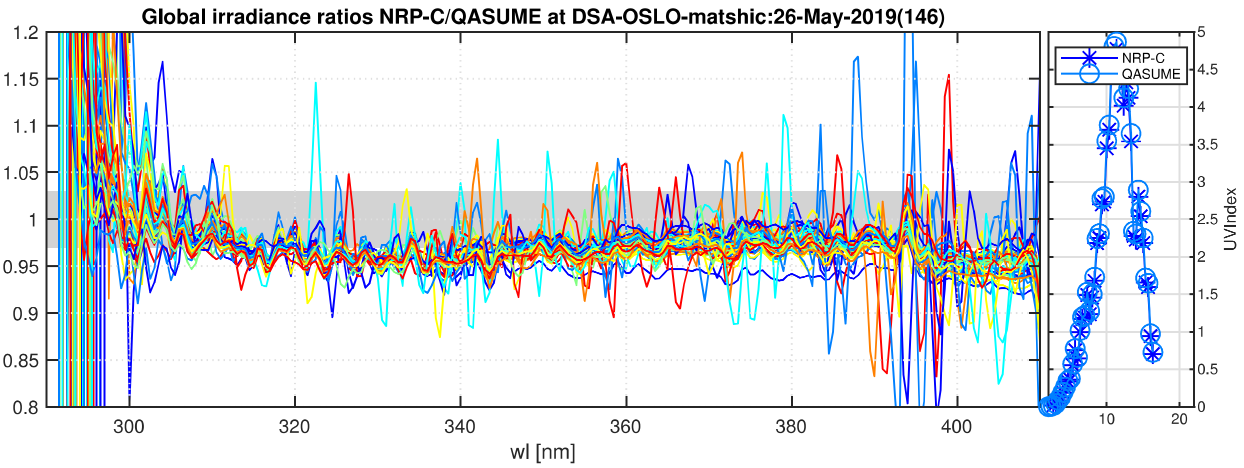

Daily variation. Wavelength bands are ± 2.5 nm
89°
88°
305 nm
310 nm
320 nm
350 nm
400 nm
405 nm
TIME [UT](SZA)

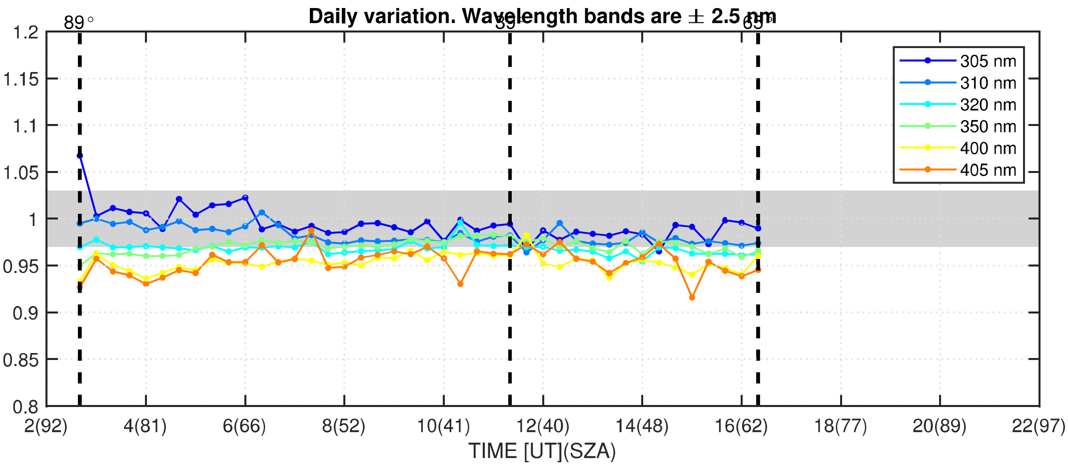

Global irradiance ratios NRP-C/QASUME at DSA-OSLO-matshic:24-May-2019(144)
wl [nm]
NRP-C
QASUME
UVIndex

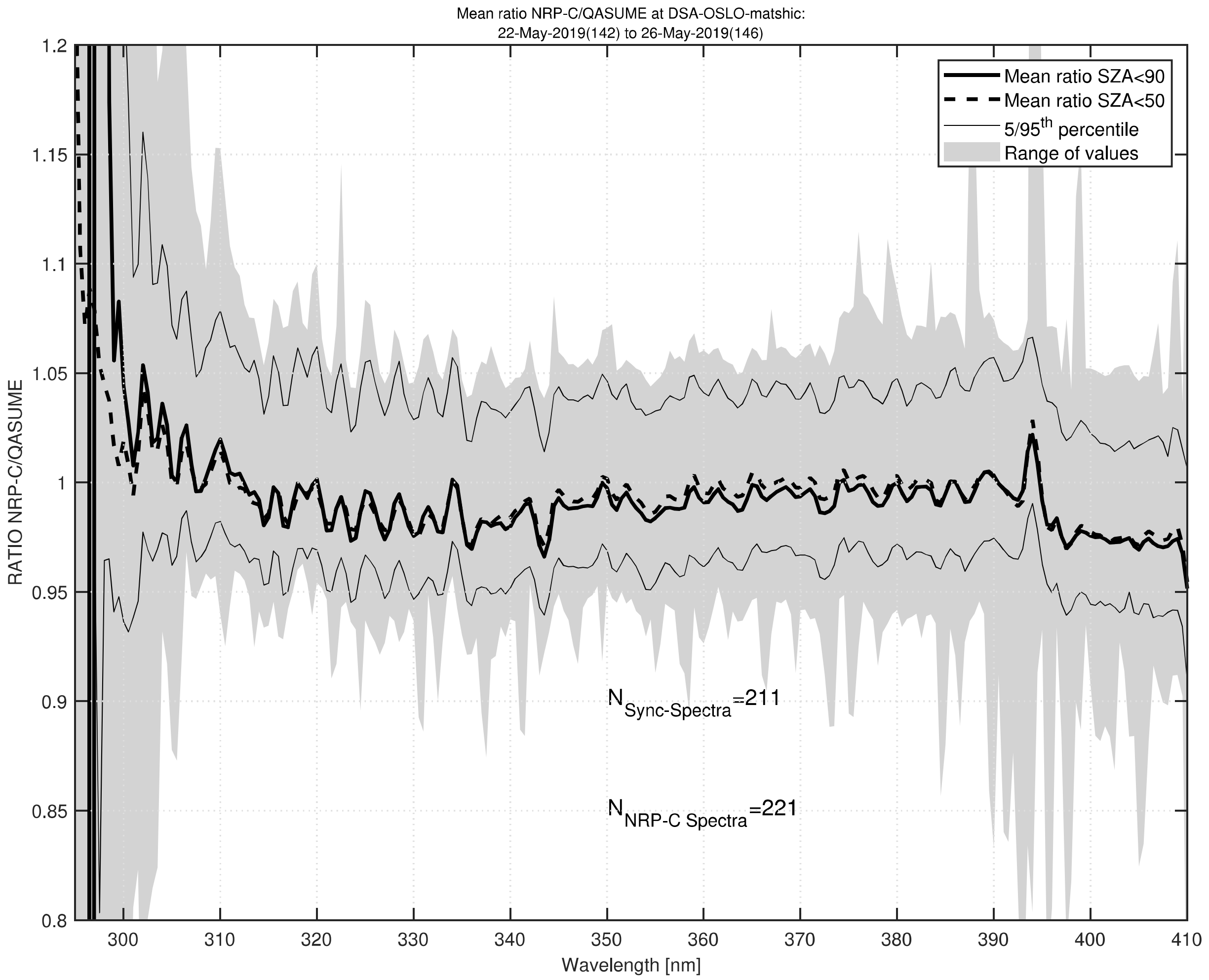

Daily variation. Wavelength bands are ± 2.5 nm
89°
88°
305 nm
310 nm
320 nm
350 nm
400 nm
405 nm
TIME [UT](SZA)

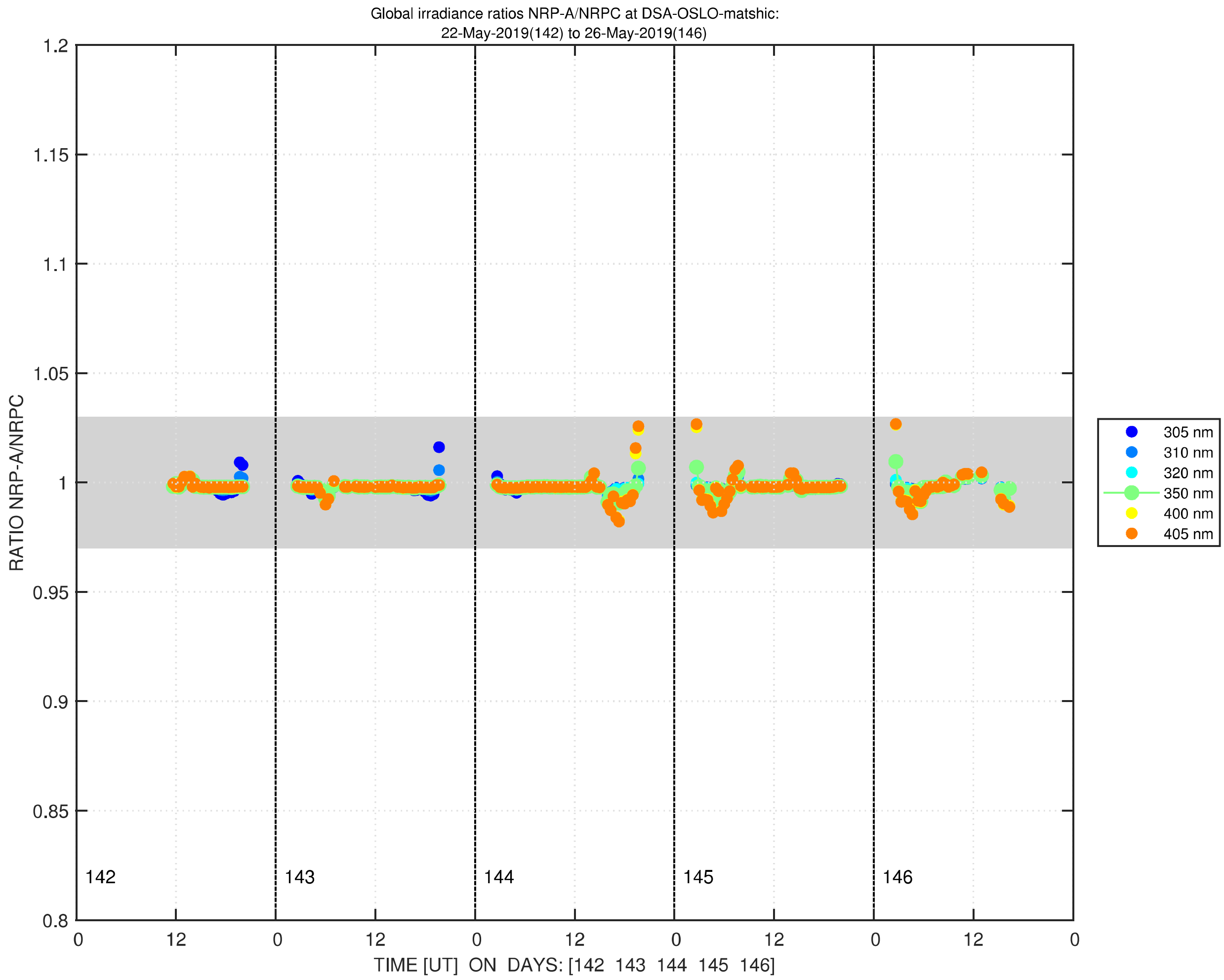

Global irradiance ratios NRP-C/QASUME at DSA-OSLO-matshic:25-May-2019(145)
wl [nm]
NRP-C
QASUME
UVIndex


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

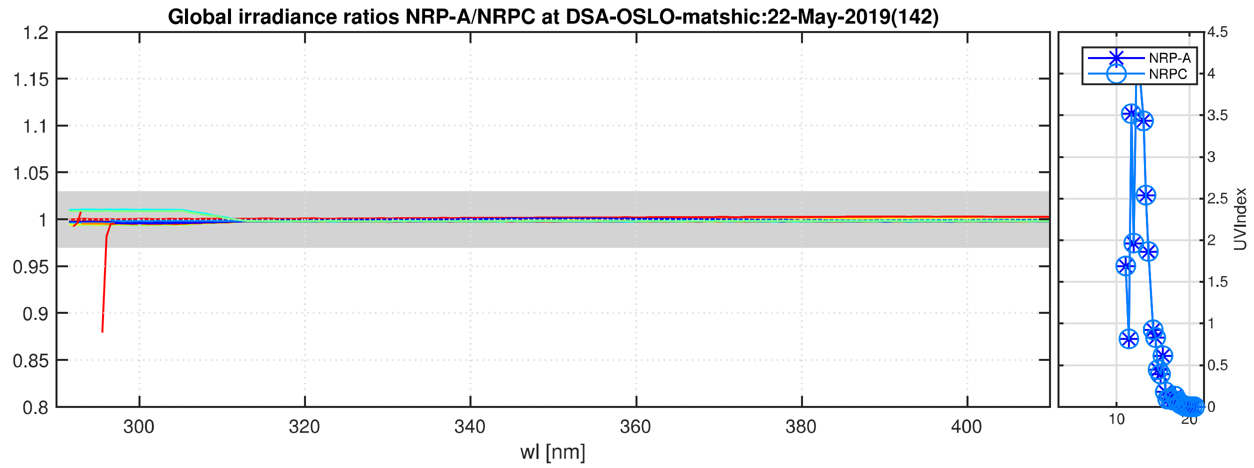

Global irradiance ratios NRP-C/QASUME at DSA-OSLO-matshic:26-May-2019(146)
wl [nm]
NRP-C
QASUME
UVIndex


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

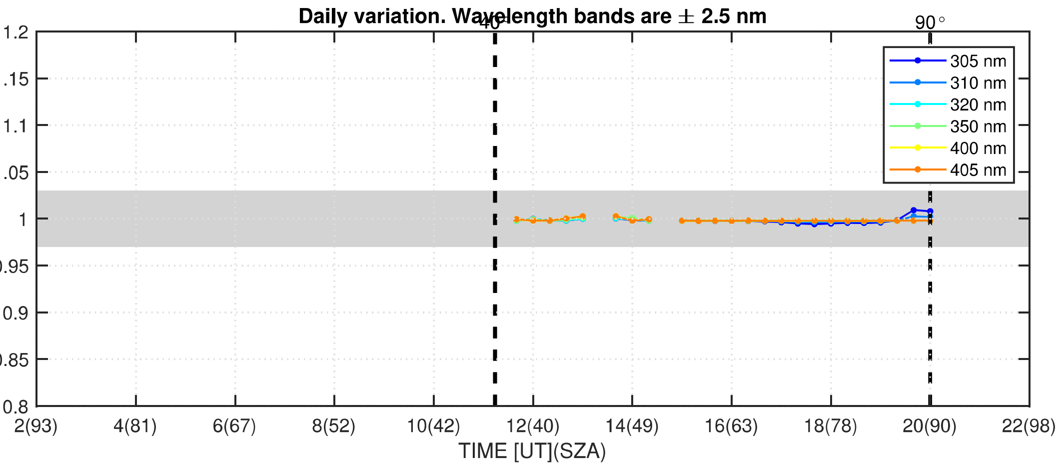

Mean ratio NRP-C/QASUME at DSA-OSLO-matshic:
22-May-2019(142) to 26-May-2019(146)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
Range of values
N Sync-Spectra=211
N NRP-C Spectra=221
RATIO NRP-C/QASUME
Wavelength [nm]
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
300
310
320
330
340
350
360
370
380
390
400
410



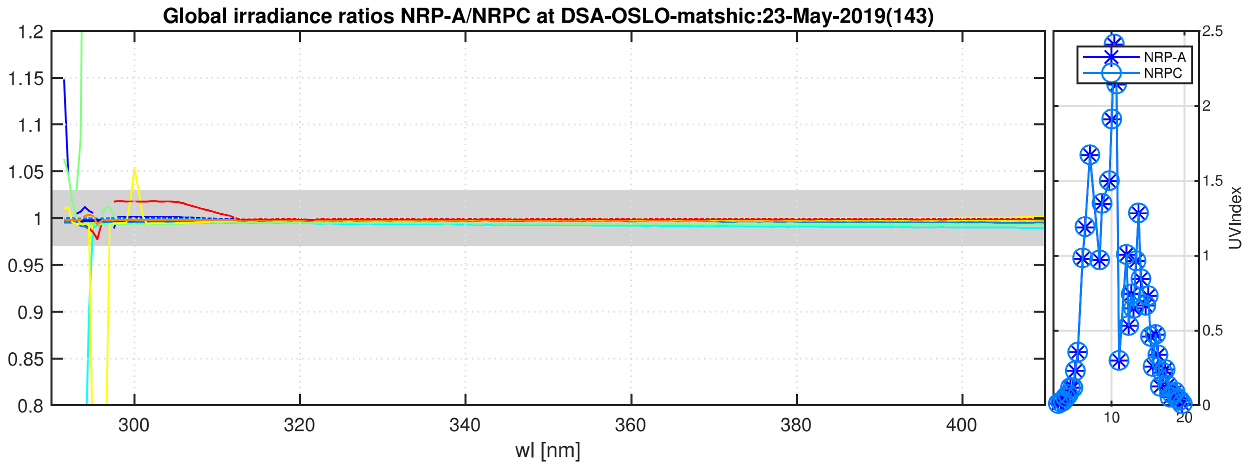
Global irradiance ratios NRP-A/NRPC at DSA-OSLO-matshic:
22-May-2019(142) to 26-May-2019(146)
RATIO NRP-A/NRPC
TIME [UT] ON DAYS: [142 143 144 145 146]
142
143
144
145
146
305 nm
310 nm
320 nm
350 nm
400 nm
405 nm

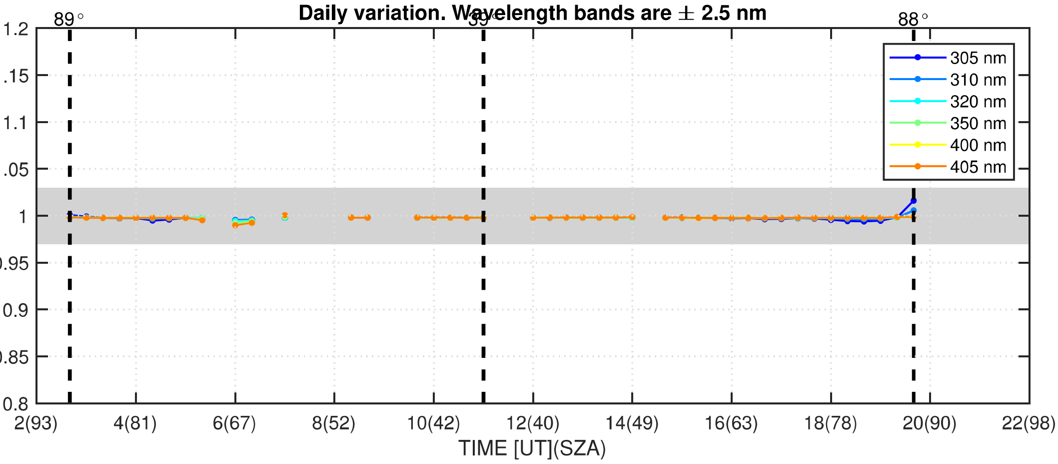



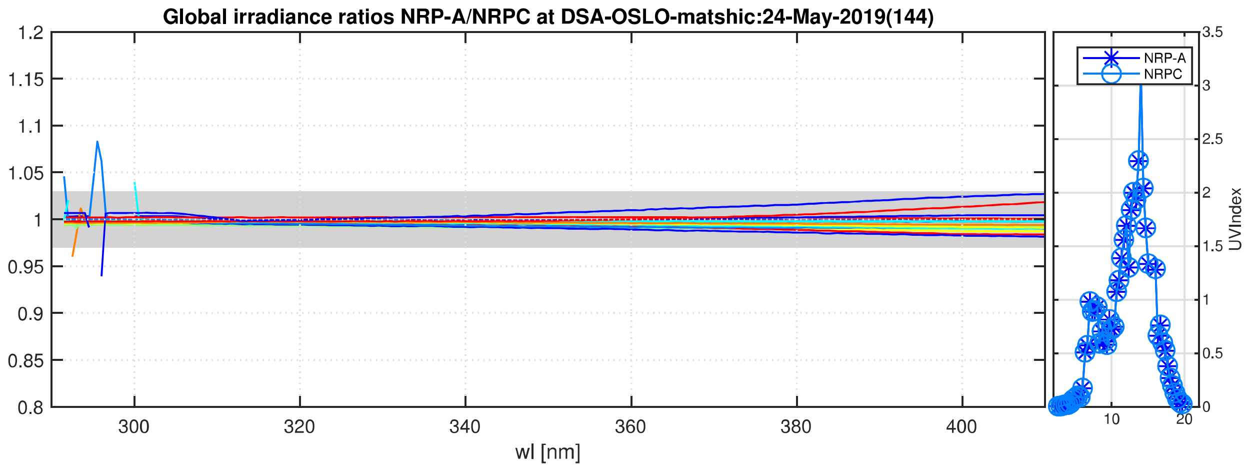
Global irradiance ratios NRP-A/NRPC at DSA-OSLO-matshic:22-May-2019(142)
wl [nm]
NRP-A
NRPC
UVIndex

Daily variation. Wavelength bands are ± 2.5 nm
40°
90°
305 nm
310 nm
320 nm
350 nm
400 nm
405 nm
TIME [UT](SZA)


Global irradiance ratios NRP-A/NRPC at DSA-OSLO-matshic:23-May-2019(143)
wl [nm]
NRP-A
NRPC
UVIndex


Daily variation. Wavelength bands are ± 2.5 nm
89°
88°
305 nm
310 nm
320 nm
350 nm
400 nm
405 nm
TIME [UT](SZA)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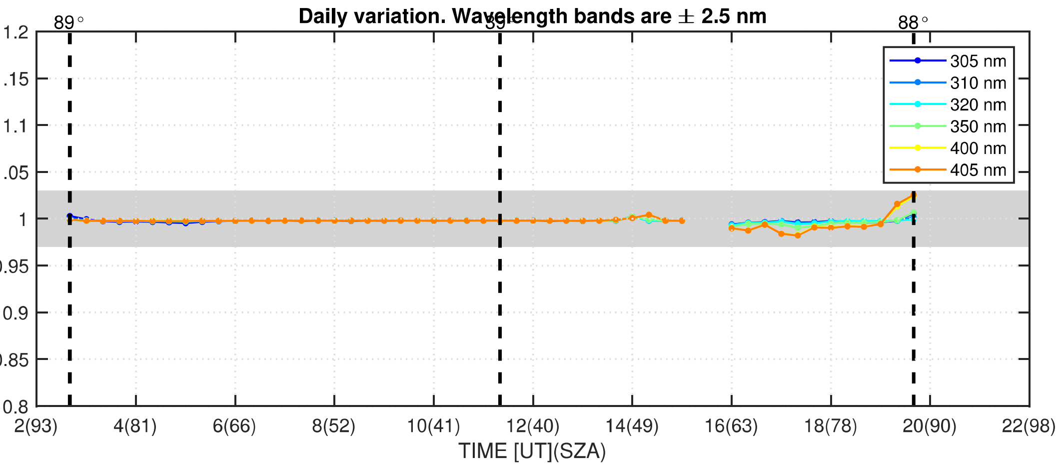
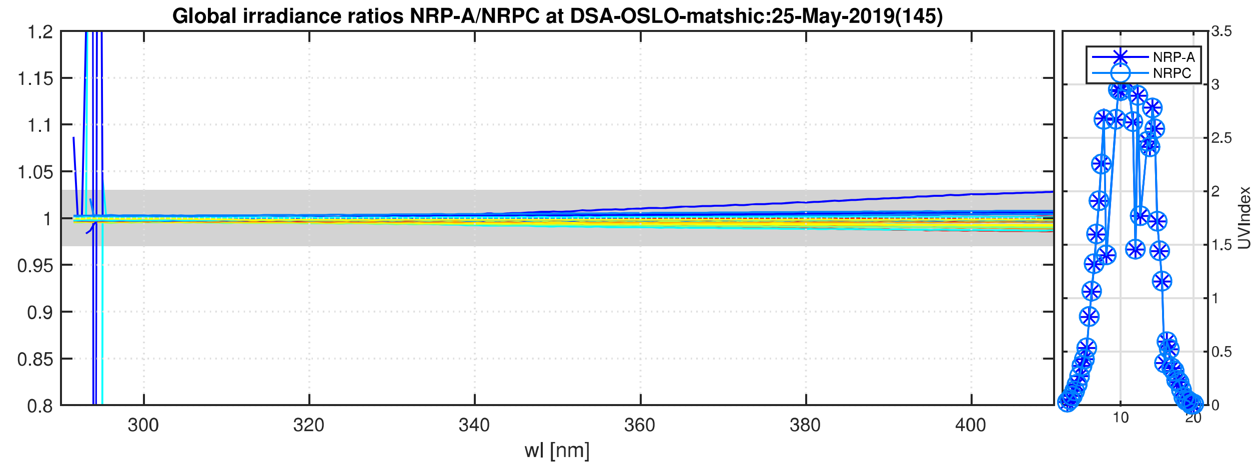
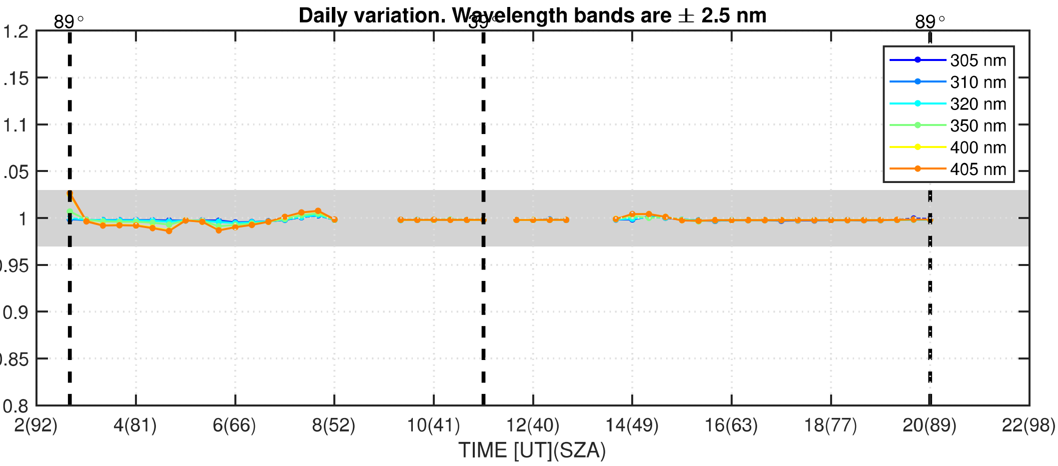
wl [nm]
NRP-A
NRPC
UVIndex


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


Global irradiance ratios NRP-A/NRPC at DSA-OSLO-matshic:25-May-2019(145)
wl [nm]
NRP-A
NRPC
UVIndex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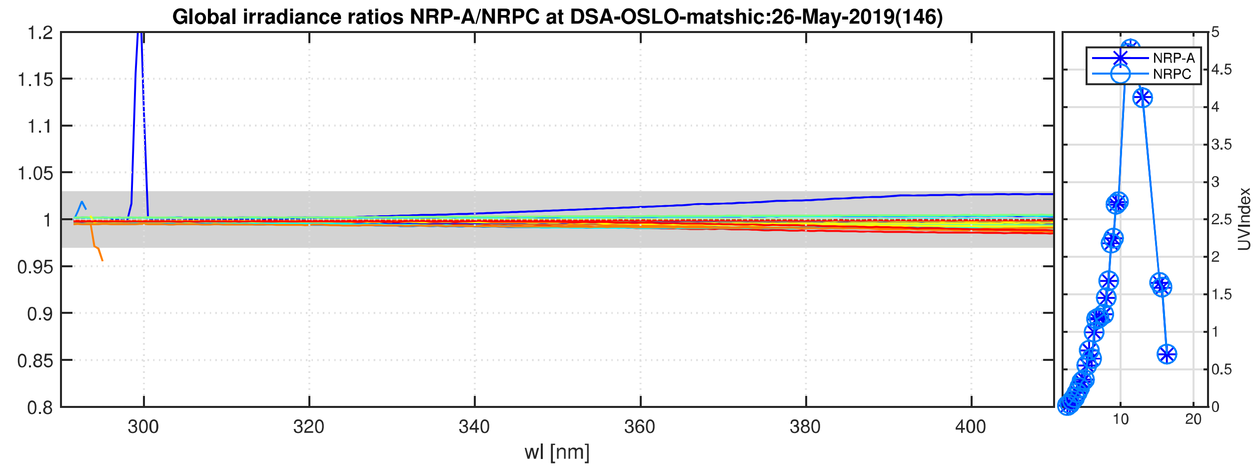
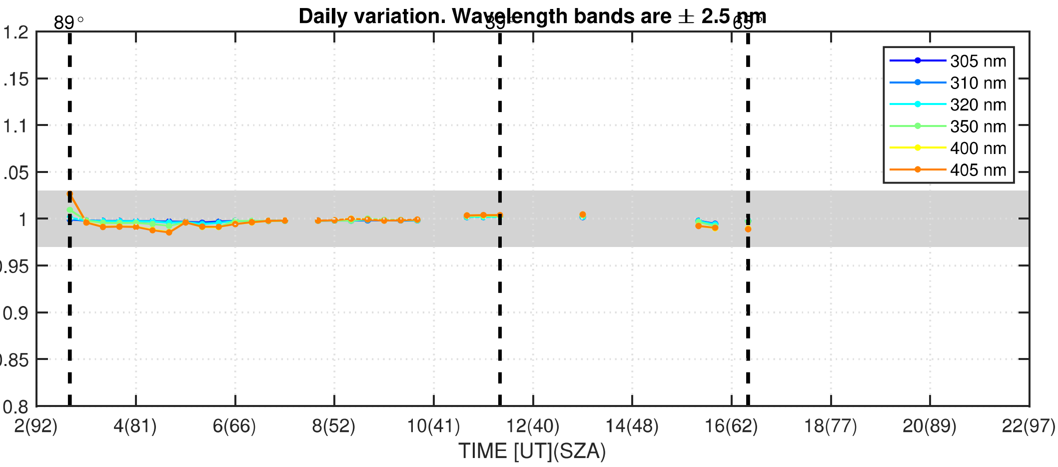
89°
39°
89°
305 nm
310 nm
320 nm
350 nm
400 nm
405 nm
TIME [UT](SZA)


Global irradiance ratios NRP-A/NRPC at DSA-OSLO-matshic:26-May-2019(146)
wl [nm]
NRP-A
NRPC
UVIndex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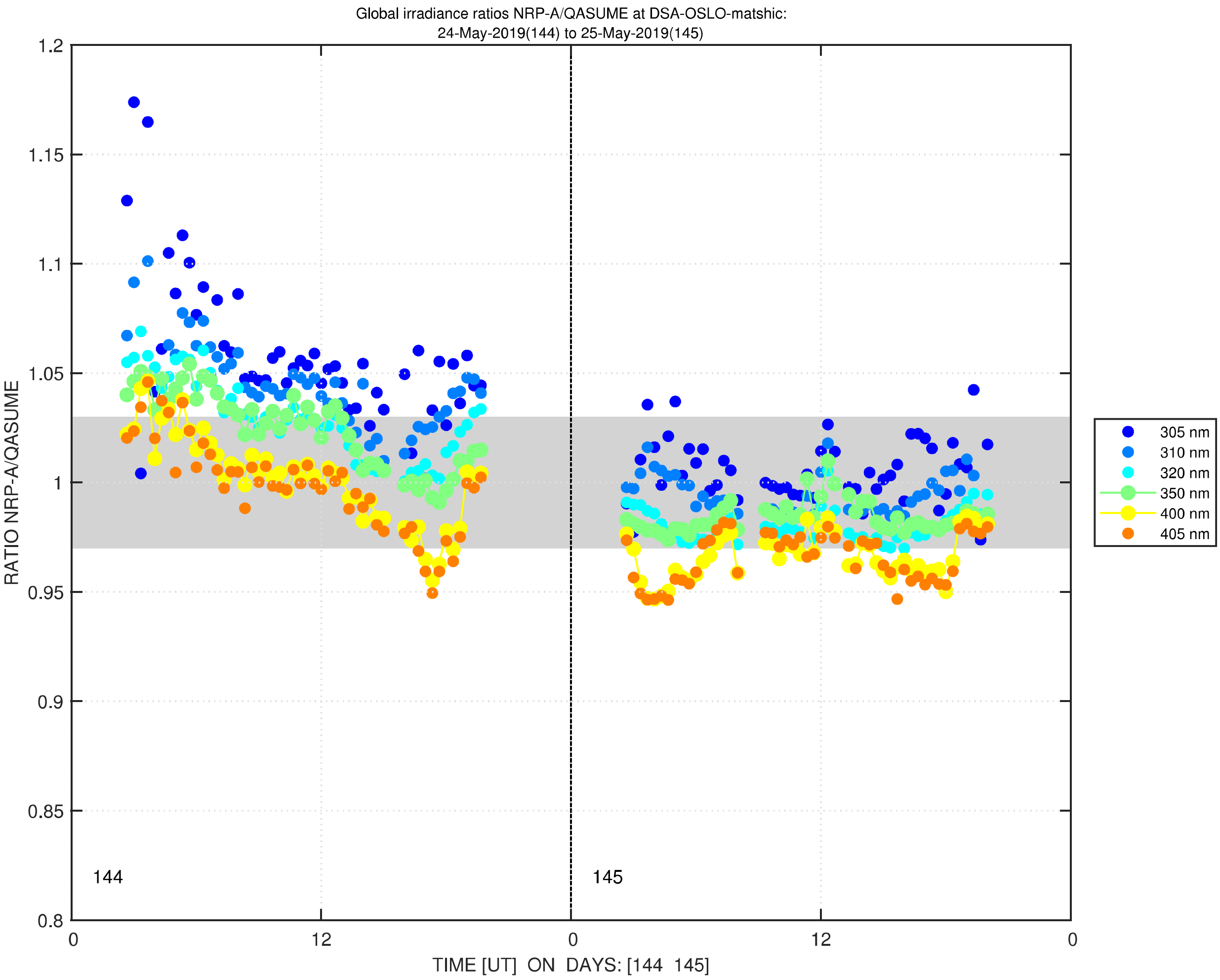
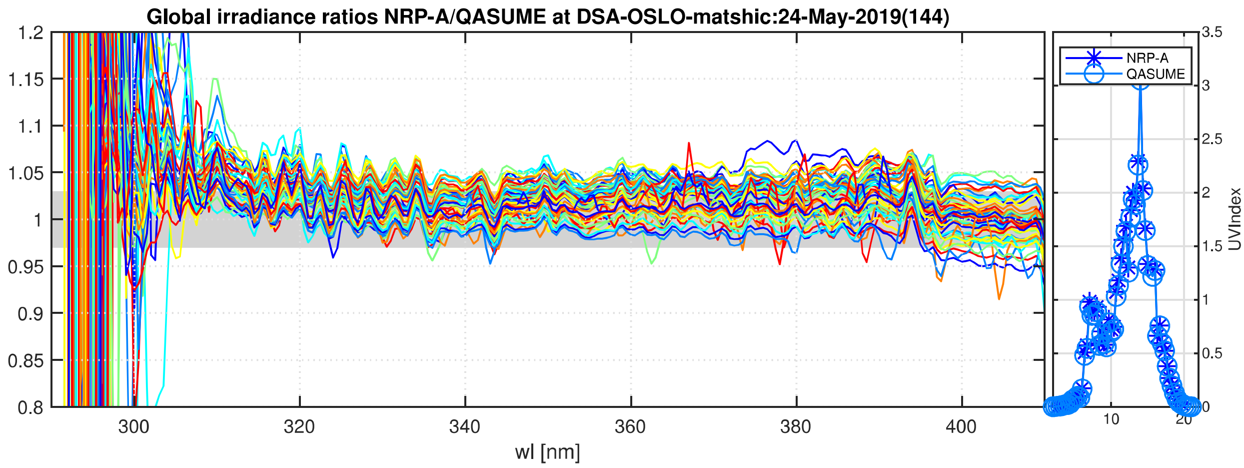
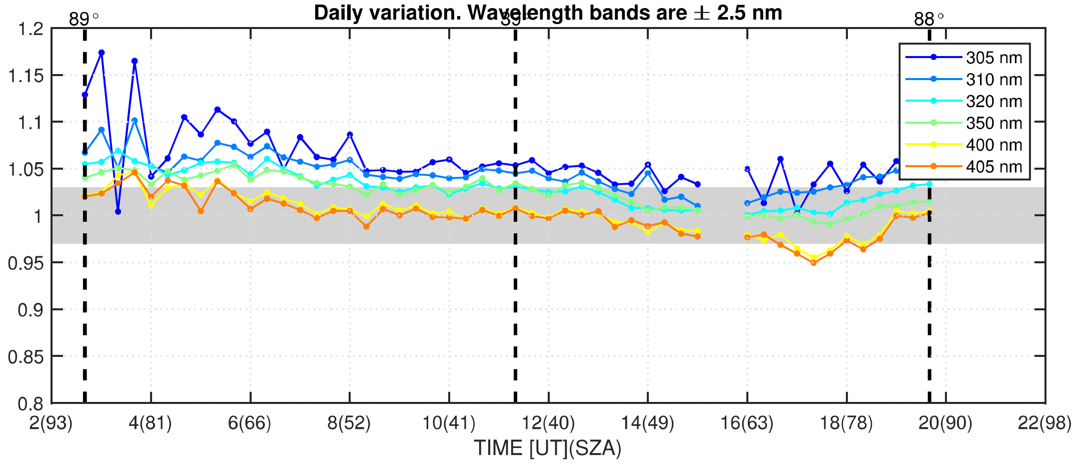
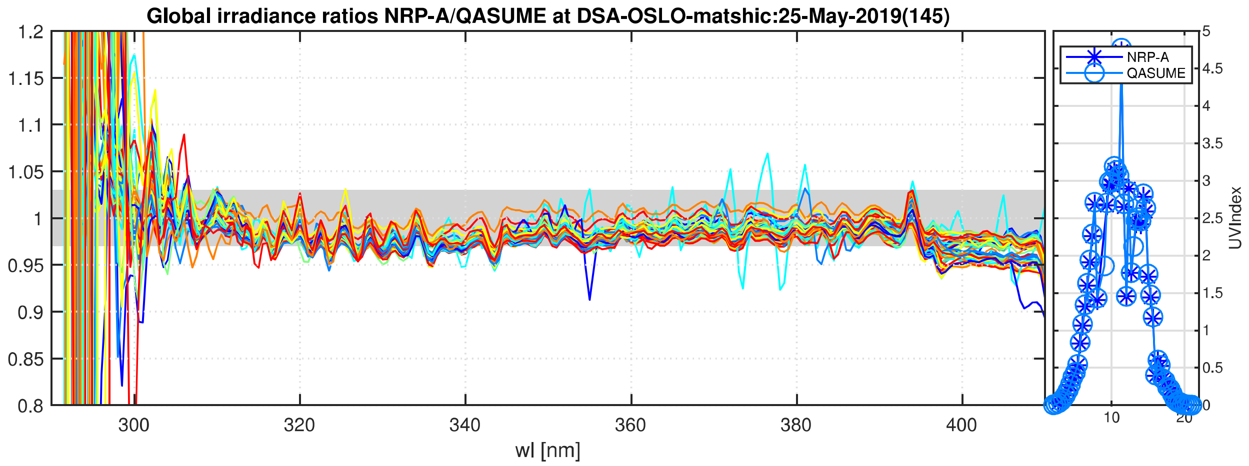
89°
39°
65°
305 nm
310 nm
320 nm
350 nm
400 nm
405 nm
TIME [UT](SZA)

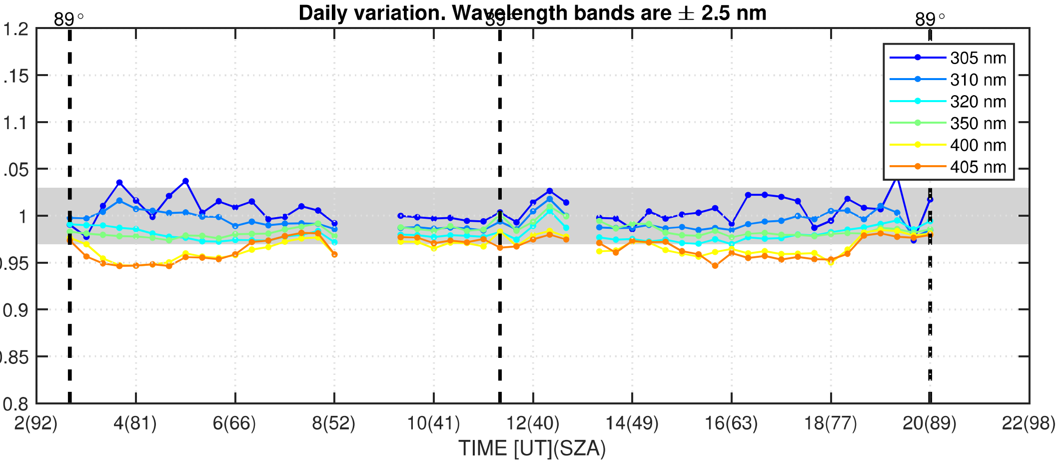

Global irradiance ratios NRP-A/QASUME at DSA-OSLO-matshic:
24-May-2019(144) to 25-May-2019(145)
RATIO NRP-A/QASUME
TIME [UT] ON DAYS: [144 145]
144
145
305 nm
310 nm
320 nm
350 nm
400 nm
405 nm


Global irradiance ratios NRP-A/QASUME at DSA-OSLO-matshic:24-May-2019(144)
wl [nm]
NRP-A
QASUME
UVIndex

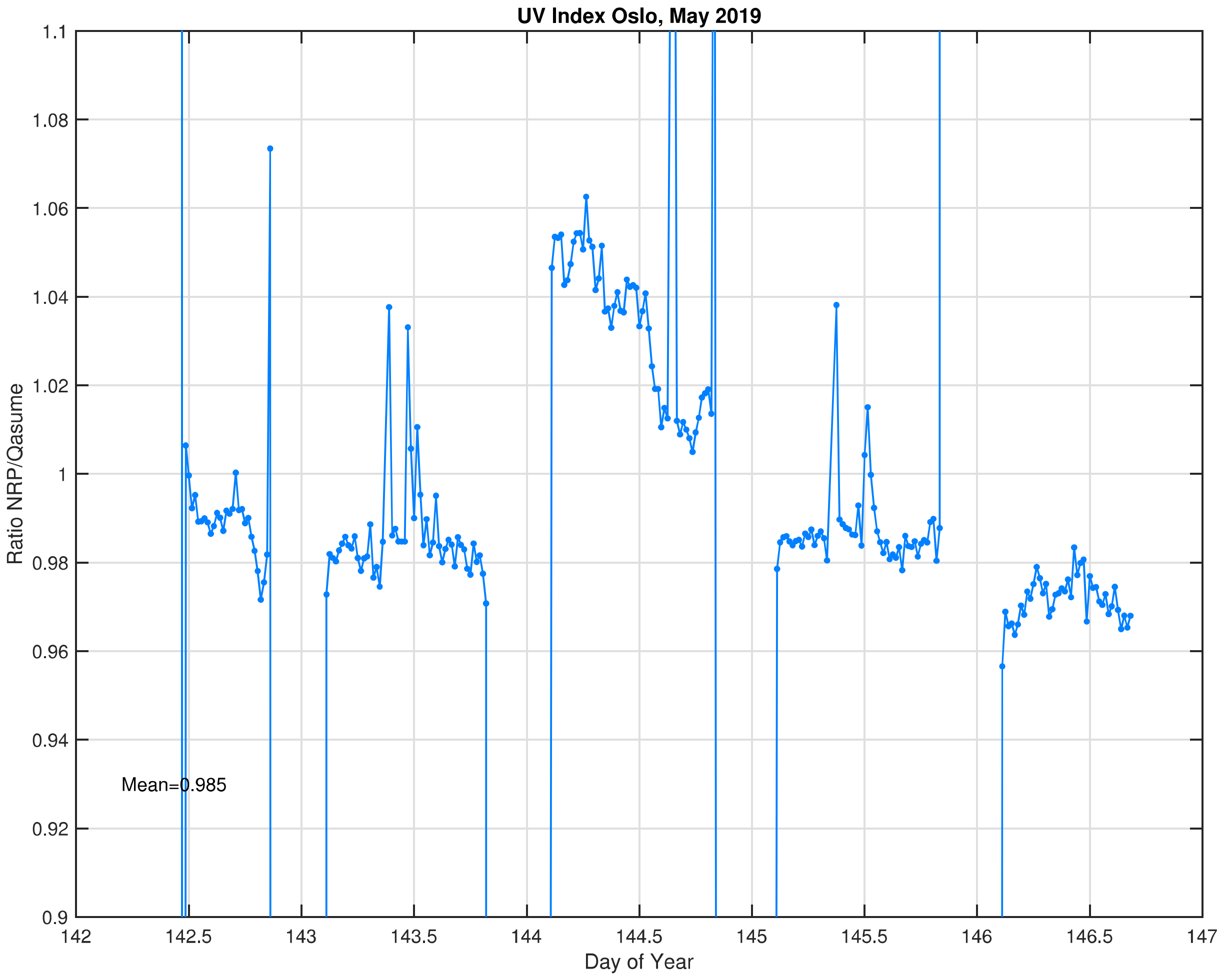

Daily variation. Wavelength bands are ± 2.5 nm
89°
88°
TIME [UT](SZA)
305 nm
310 nm
320 nm
350 nm
400 nm
405 nm

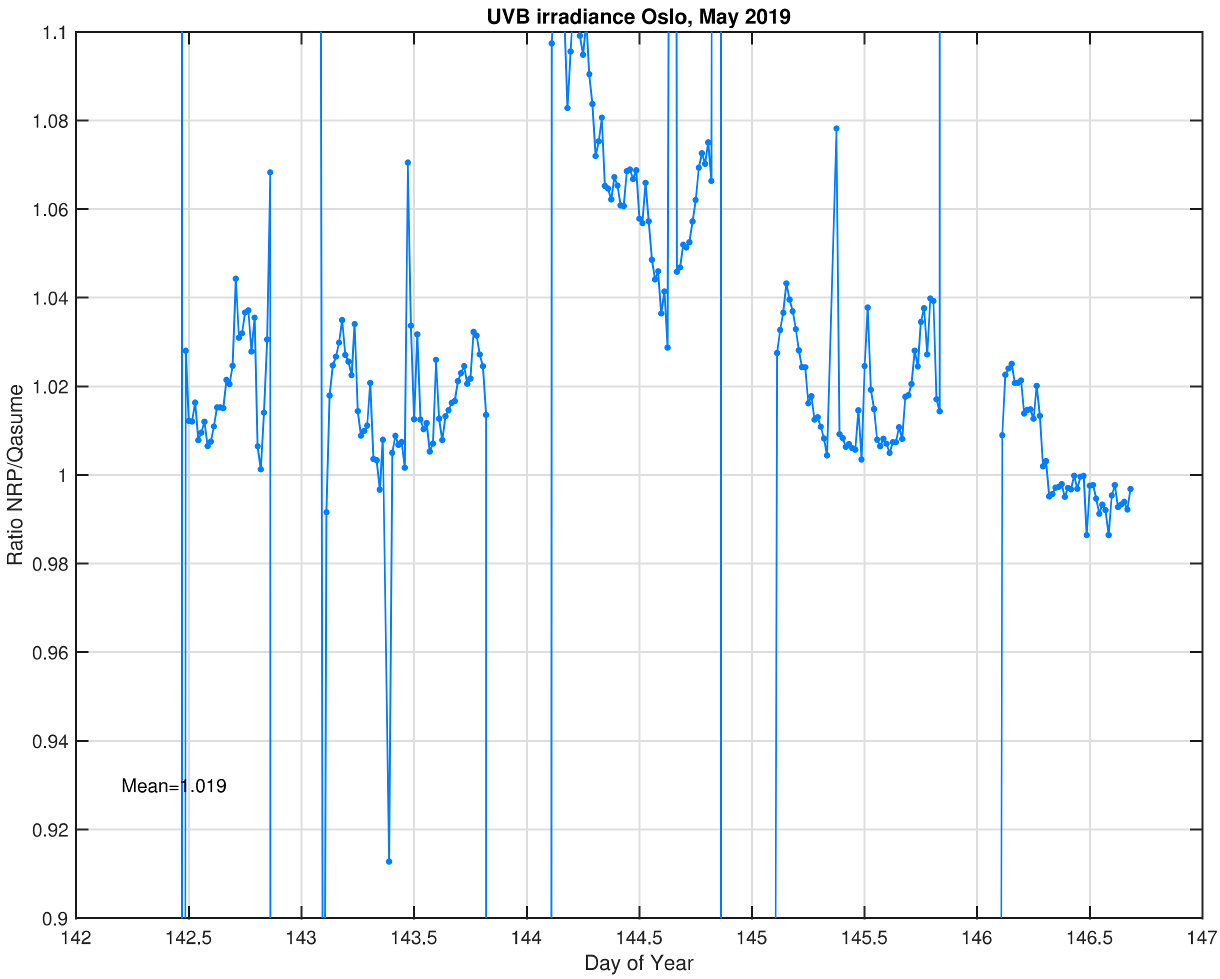


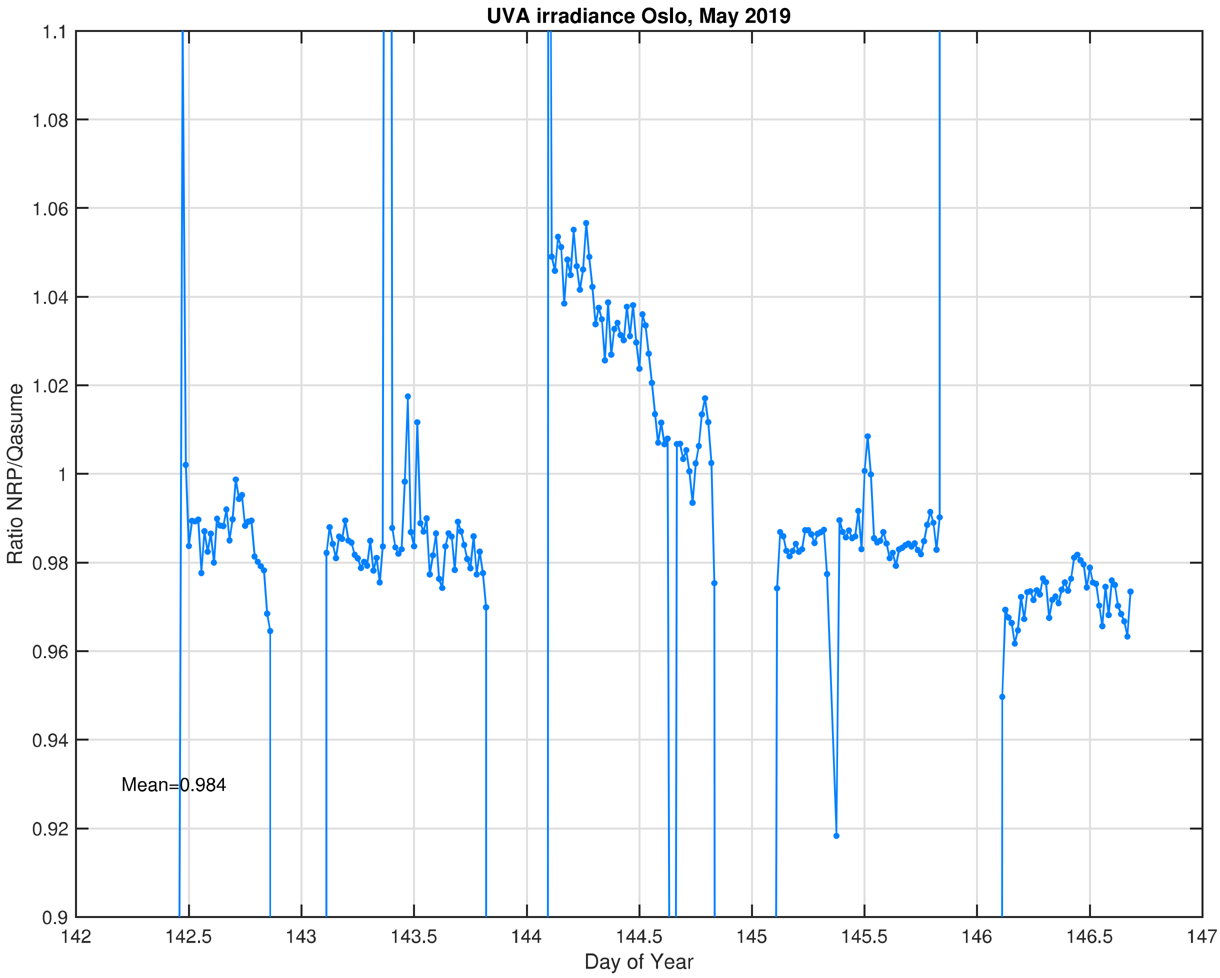
Global irradiance ratios NRP-A/QASUME at DSA-OSLO-matshic:25-May-2019(145)
wl [nm]
NRP-A
QASUME
UVIndex

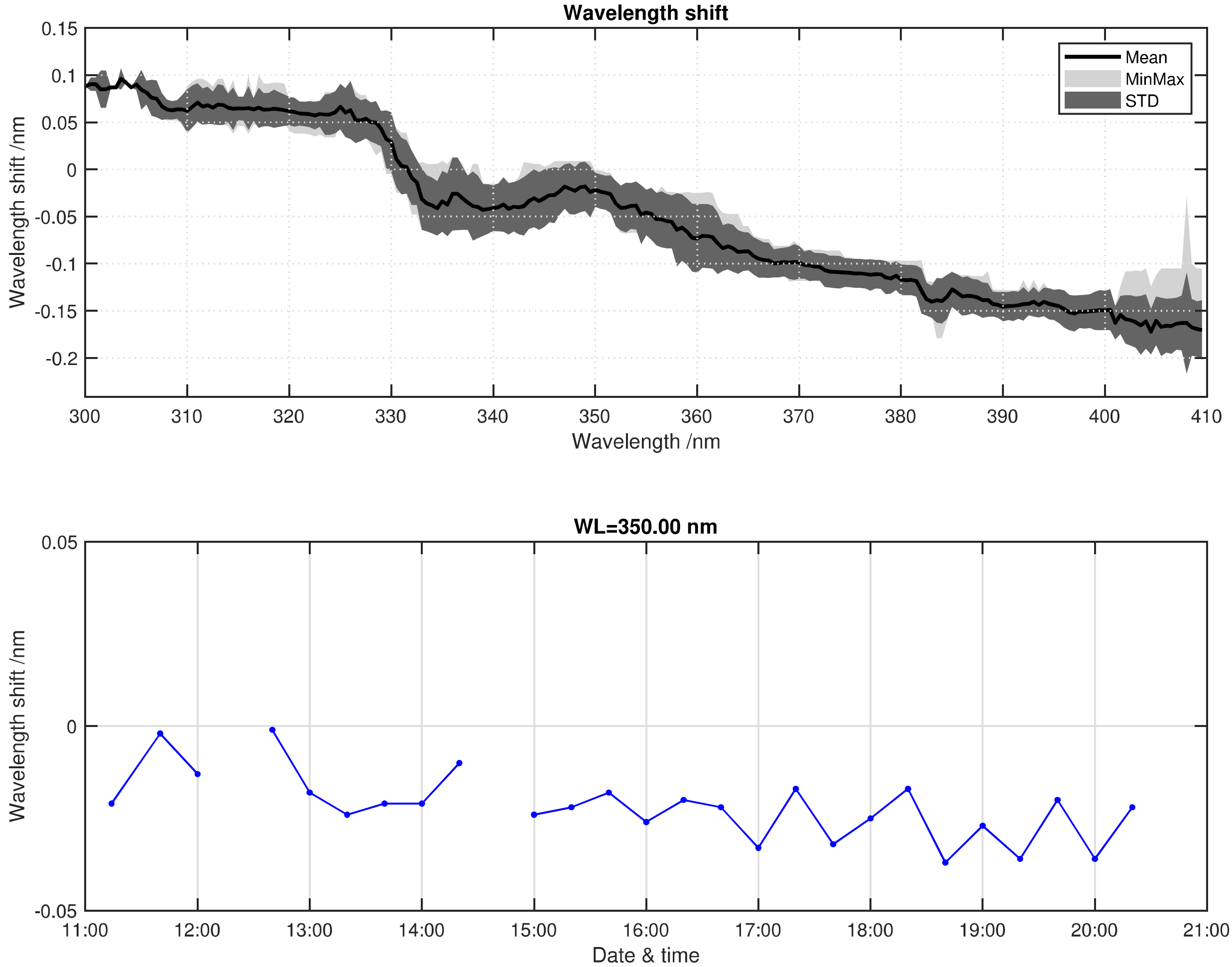
Daily variation. Wavelength bands are ± 2.5 nm
89°
39°
89°
305 nm
310 nm
320 nm
350 nm
400 nm
405 nm
TIME [UT](SZA)


UV Index Oslo, May 2019
Ratio NRP/Qasume
Day of Year
Mean=0.985
1.1
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0.9
142
142.5
143
143.5
144
144.5
145
145.5
146
146.5
147

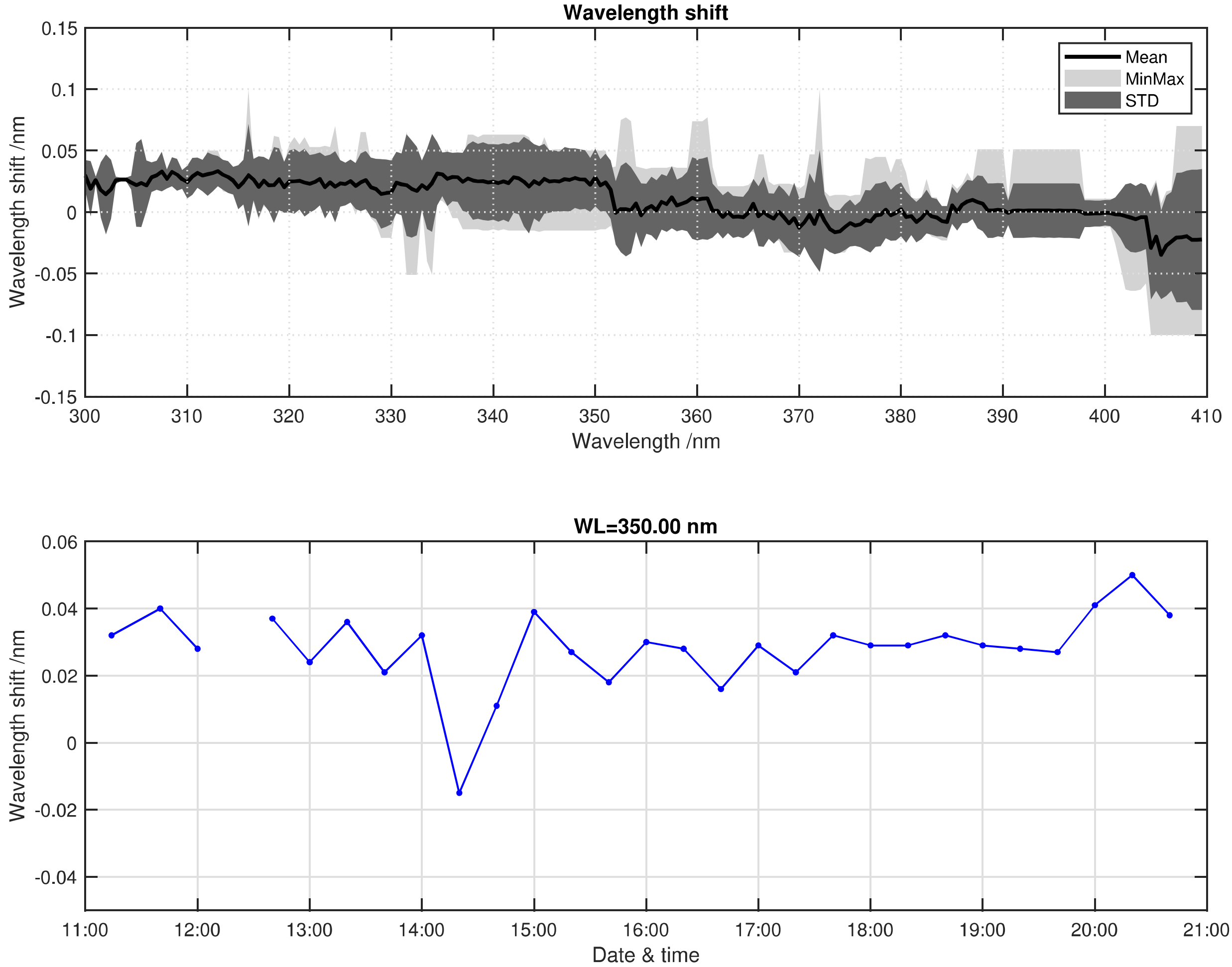

UVB irradiance Oslo, May 2019
Ratio NRP/Qasume
Day of Year
Mean=1.019
1.1
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0.9
142
142.5
143
143.5
144
144.5
145
145.5
146
146.5
147


UVA irradiance Oslo, May 2019
Ratio NRP/Qasume
Day of Year
Mean=0.984
1.1
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0.9
142
142.5
143
143.5
144
144.5
145
145.5
146
146.5
147

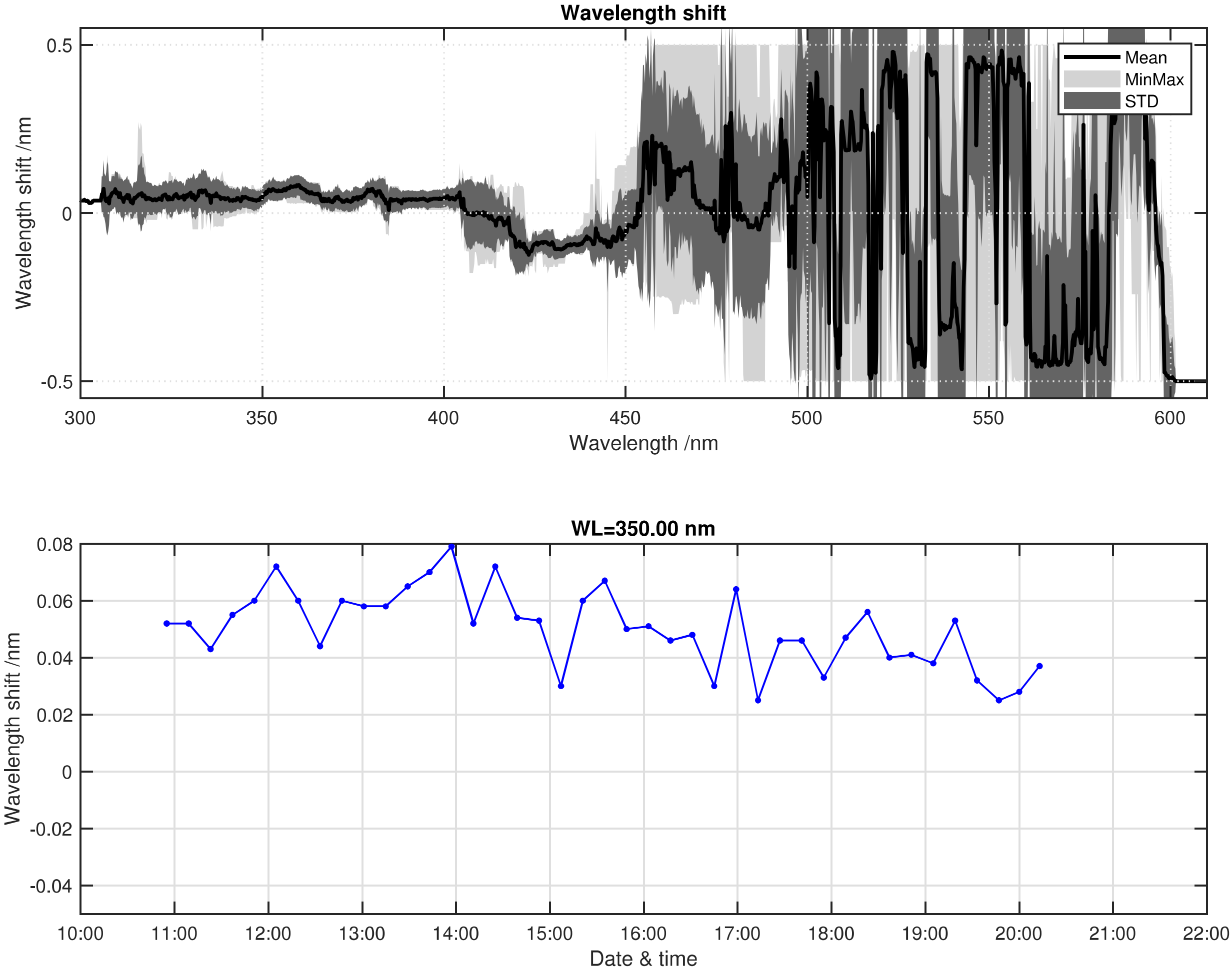
## NRP-B: no shicRIVM



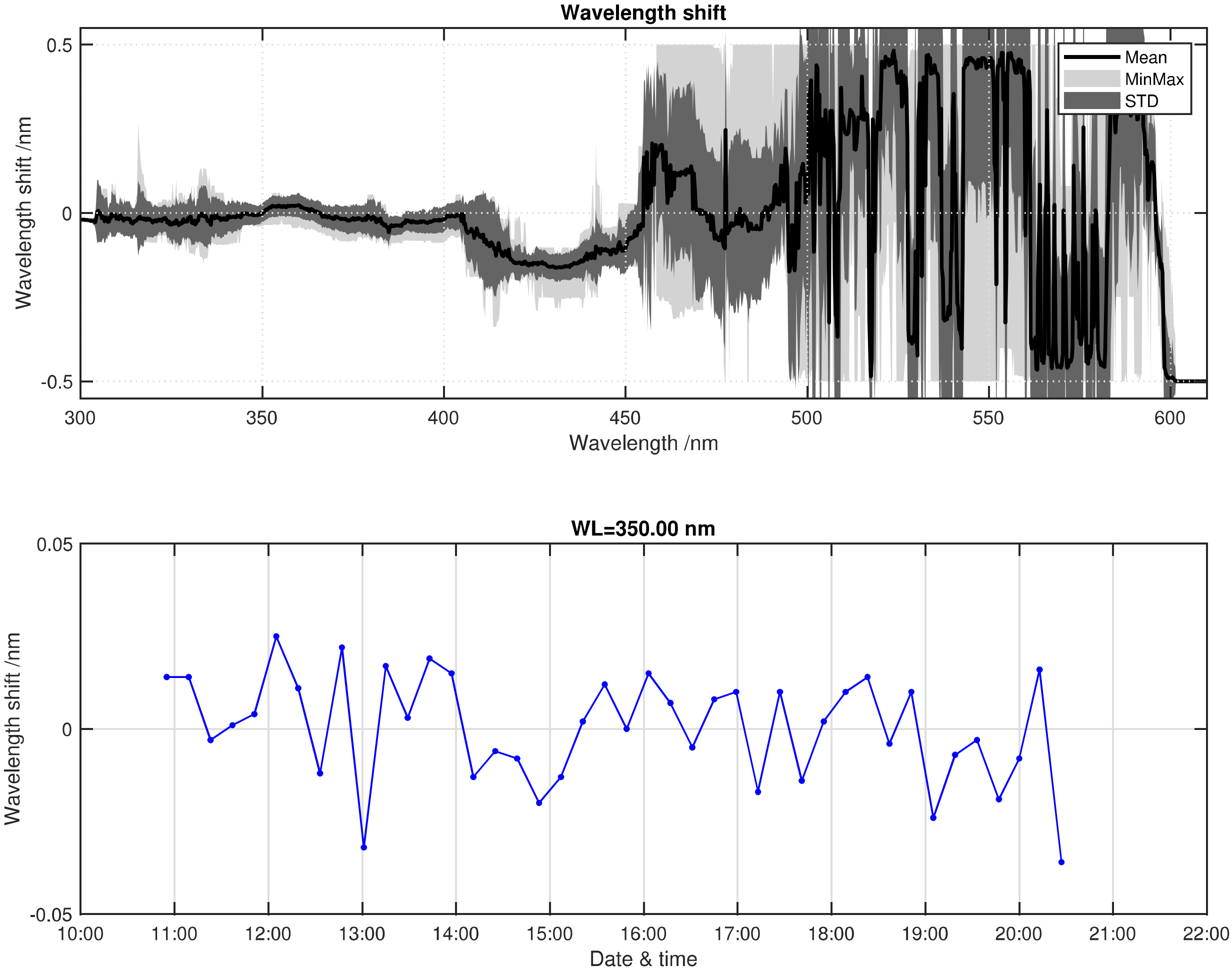

## NRP-C: after shicRIVM

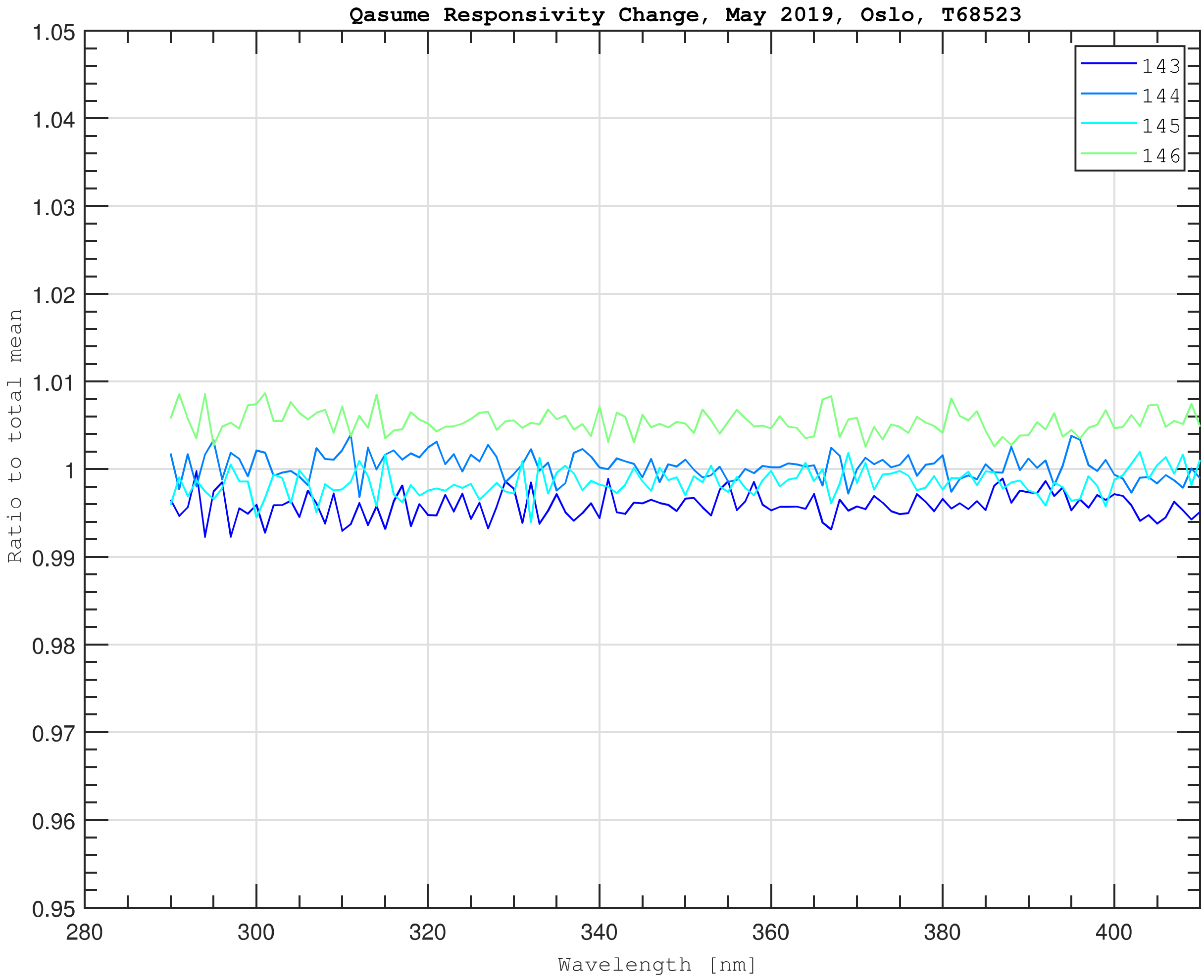


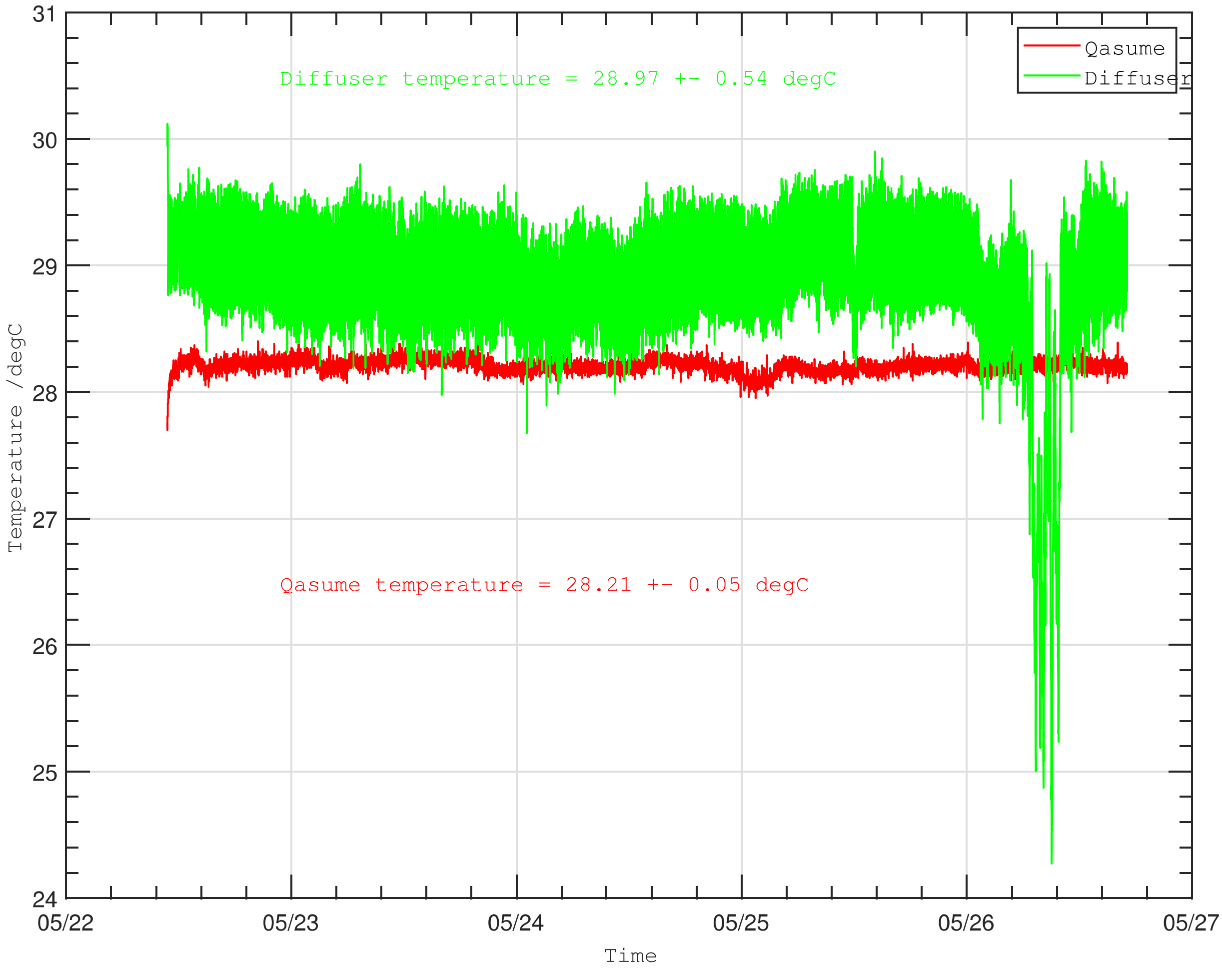
## NR2-B: no shicRIVM

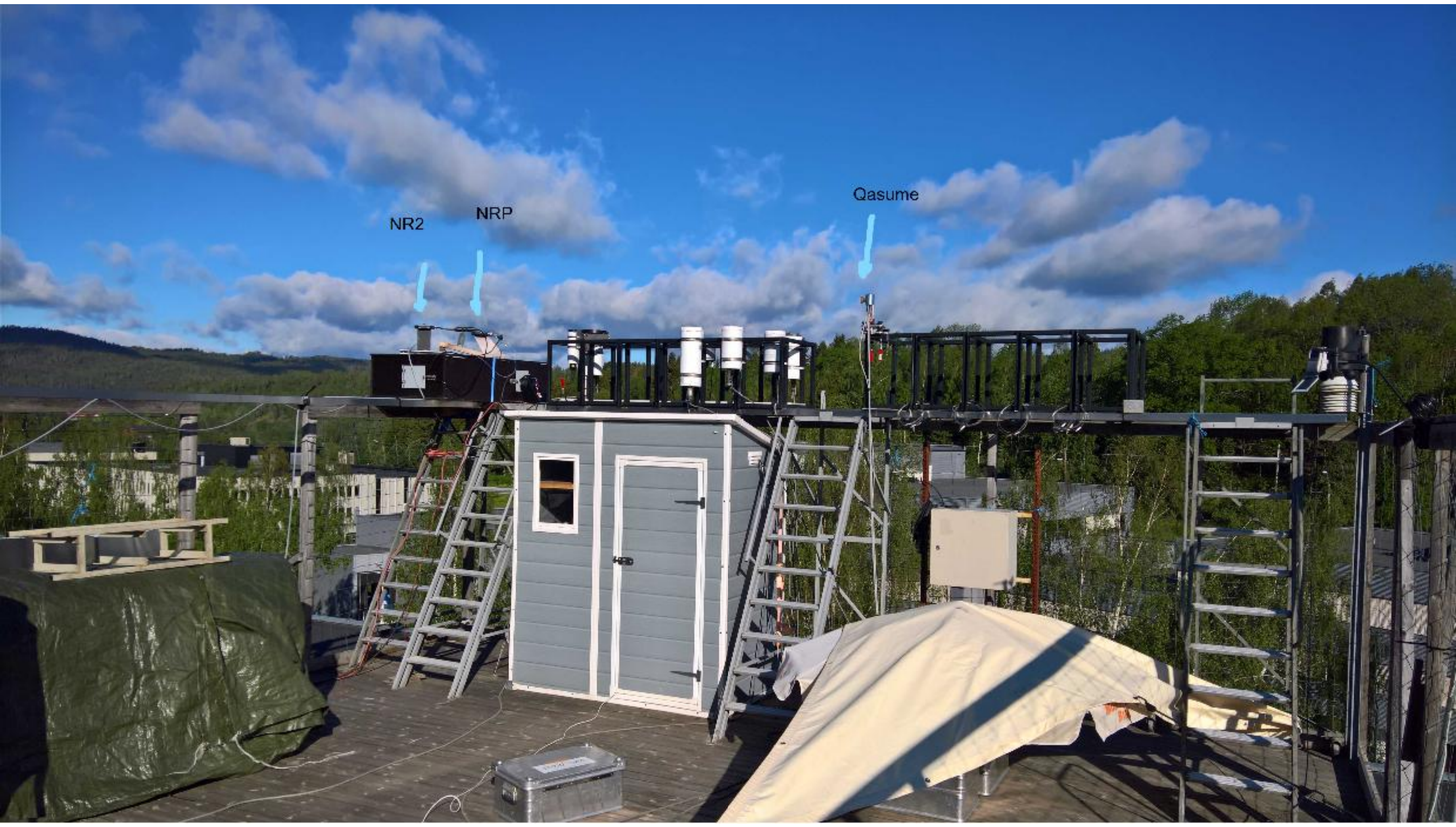



## NR2-C: after shicRIVM




Qasume Responsivity Change, May 2019, Oslo, T68523
143
144
145
146
Ratio to total mean
Wavelength [nm]
1.05
1.04
1.03
1.02
1.01
1
0.99
0.98
0.97
0.96
0.95
280
300
320
340
360
380
400


Qasume
Diffuser
Diffuser temperature = 28.97 +- 0.54 degC
Qasume temperature = 28.21 +- 0.05 degC
Temperature /degC
Time
31
30
29
28
27
26
25
24
05/22
05/23
05/24
05/25
05/26
05/27


NR2
NRP
Qasume