Protocol of the intercomparison at the University of Oslo, Norway on May 30 to June 04, 2010 with the travelling reference spectroradiometer QASUME from PMOD/WRC

Report prepared by Julian Gröbner

Operator: Julian Gröbner

The purpose of the visit was the comparison of global solar irradiance measurements between the spectroradiometers operated by the University of Oslo, Norway (Brewer MKV #042) and the Norwegian Radiation Protection Authority (Bentham DM150, NRP) and the travel reference spectroradiometer QASUME. 12 NILU-UV 6-channel instruments and three 5-channel GUV instruments were run side-by-side the QASUME spectroradiometer throughout the campaign. Among these instruments were the travelling reference instruments used in the African NILU-UV network (Uganda, Tanzania and The Gambia), the NILU-UV network in Tibet, China, the NILU-UV network in Nepal, and the Antarctic NILU-UV network.

The GUV instruments were composed of the travelling reference instrument for the Norwegian UV monitoring network (GUV-9273), a spare travelling reference, and the network station instrument at Blindern, Norway. 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, 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 (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.).

The measurement site is located at Oslo University; Latitude 59.94 N, Longitude 10.72 E and altitude 90 m.a.s.l. The horizon of the measurement site is free down to 85° solar zenith angle (SZA). Measurements between 3:30 UT and 19:00 UT have been analysed.

QASUME was installed on the measurement platform of the University in the afternoon of May 30, 2010. The spectroradiometer was installed next to the local spectroradiometers with the entrance optic of QASUME within 5 m of the other instruments. The intercomparison between QASUME and the local spectroradiometers lasted four days, from morning of May 31 to noon of June 04.

QASUME was calibrated several times during the intercomparison period using a portable calibration system. Two lamps (T68522 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 1 % during the intercomparison period. The internal temperature of QASUME was 24.7±0.3 °C and the diffuser head was heated to a temperature of 27.9±0.8 °C.

The wavelength shifts relative to an extraterrestrial spectrum as retrieved from the SHICRivm 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 30 minutes from 290 to 410 nm, every 0.5 nm, and 1.5 seconds between each wavelength increment. The first two days the measurement frequency was set to 15 minutes, which was reduced to 30 minutes due to the high dark current of the QASUME PMT between solar scans.

DOY	Date	DAY	Weather	Comment
150	30-May	Sunday	Clear sky, few cumulus clouds	Installed at 15:00 UT
151	31-May	Monday	Clear Sky, Cumulus developing, from 10-14:00 UT also in front of sun	Calibrated: 7:14 and 11:14 UT using T68523
152	1-Jun	Tuesday	Clear day, some cirrus	Calibrated: 3:44, 12:14 and 16:29 UT using T68523
153	2-Jun	Wednesday	Mix of sun and clouds – nearly fully overcast with cirrus in the morning turning to altostratus	Calibrated: 4:05, 10:36 using T68522. Brewer 042 stopped at 11:00 UT due to mercury lamp failure
154	3-Jun	Thursday	Clear sky	Calibrated: 10:36, 15:44 UT using T68522
155	4-Jun	Friday	Clear sky	Calibrated: 11:36 UT using T68522, T99661, T68523 End of Campaign at 12:30 UT

Results:

In total 198 synchronised simultaneous spectra from QASUME and NRP and 86 synchronised simultaneous spectra from QASUME and Brewer #042 are available from the measurement period. Measurements between 3:30 and 19:00 UT were analysed (SZA smaller than 85°).

Remarks:

Spectroradiometer NRP

Prior to the submission of NRP spectra, the operator from NRP informed that these spectra likely were 3% too high, based on internal comparisons of the NRP spectroradiometer measurements and measurements from two GUV multiband filterradiometers from NRP. Indeed, the original data supplied by NRP during the campaign was on average 3% higher than QASUME.
NRP investigated the discrepancy after the campaign and provided a revised dataset. The attached comments from NRP describe the applied revisions.

The following comments and figures only refer to the revised dataset.

1. The average relative spectral difference between NRP and QASUME is less than 1% over the wavelength range 300 to 410 nm. The variability, defined by the 5 and 95% percentile is 1% above 320 nm, increasing slightly towards shorter wavelengths.
2. The average relative spectral difference between NRP and QASUME is within 5% down to 296 nm around local noon (SZA lower than 45°). At higher SZA the measurement noise becomes too large to produce reliable comparisons below 300 nm.
3. A distinct diurnal variability symmetric around local noon can be observed on clear days (particularly on Day 154) which is more pronounced at longer wavelengths. The maximal deviations of -4% at 404 nm and of -1% at 350 nm occur around 75° SZA. These deviations are likely due to differences in the angular response of the NRP and QASUME entrance optics.
4. The spectral wavelength shifts are approximately +0.08 nm below 330 nm, a sharp drop to 0.0 nm at 330 nm, then remaining within ±0.05 nm until 400 nm.

Multifilter Radiometer GUV 9273

The erythemal weighted irradiances, expressed as UV indices of the multifilter radiometer GUV 9273 were compared to the UV indices calculated from the solar UV spectra of QASUME.

1. The agreement between GUV9273 and QASUME is excellent, with an average ratio of 1.005 and a standard deviation of less than 2%.
2. A slight diurnal variation of amplitude 2% can be observed in the morning and afternoon on the clear days (see figures) which comes from the different angular responses of the GUV and QASUME.

Spectroradiometer Brewer #042

The original dataset from Brewer #042 was delivered using a calibration from 2005. In the week following this intercomparison, Brewer #042 was calibrated and this new responsivity file was used to calculate a revised dataset. The following report will describe the revised dataset (see also comments from the operator, next page of this report). Measurements of day 151 (31 May), were not fully synchronous and are therefore excluded from this intercomparison.

1. The spectral ratio between 042 and QASUME is on average 0.95 between 310 and 370 nm. There is a distinct dip of 5% in the ratios between 344 and 350 nm which could not be explained so far. Possibly the change of slit 1 to slit 5 in Brewer #042 at 350 nm in combination with the resulting sharp transition could produce this discrepancy.
2. Below 310 nm the ratios increase significantly, in dependence of SZA which is due to stray light in the single monochromator. Similar stray light effects have been observed in other single Brewers.
3. A diurnal variability between 042 and QASUME of 5% can be seen during all days, in addition to a slight drift of about 2% during the day. The largest changes occur around 75° SZA and are more pronounced at longer wavelengths, which is an indication for a significant cosine error of Brewer #042. On clear days 042 measures 8% less than QASUME at SZA larger than 65° (ratio of 0.92) and 5% less around local solar noon (SZA of 38°, ratio of 0.95).
4. The slight drift during the day (-2% between the morning and afternoon) is likely due to the temperature dependence of Brewer #042.
5. A sharp step change of +3% can be seen on day 153 between 6:30 and 7:30 UT. No changes to the instrument were applied. Possibly, this could be due to the well known transmission change of the Teflon diffuser around 19 °C.
6. The wavelength shifts of Brewer #042 are very stable and within ±50 pm during the whole campaign

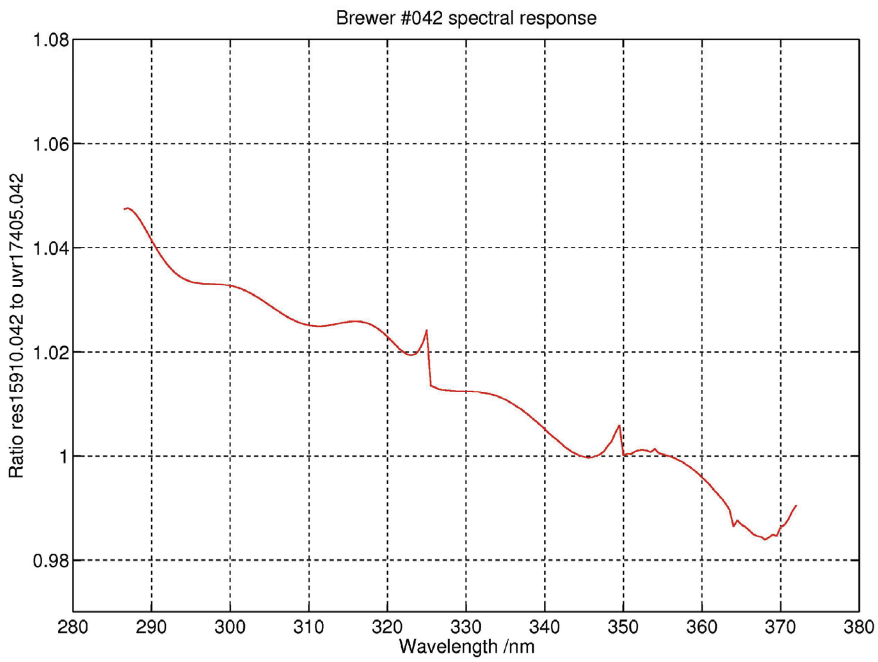
Comments from the operator: Brewer #042

The response-file used to process the Brewer UV spectra was derived by International Ozone Services, INC. (IOS) visit in Oslo on day 174 in 2005. The calibration is traceable to PTB. Annual calibrations by IOS are performed in Oslo using their 1000 W lamps. The IOS visit in June 2009 showed that the calibration differed very little from the 2005 calibration. This is why the response file from 2005 was used during the QASUME visit. IOS visited Oslo the week after the QASUME campaign was finished. A new response file was made which shows some differences from the 2005-response file. The figure below shows the relative difference between the new and original spectral response file of Brewer #042.

The NILU-UV instruments that participated in the campaign were:

- NILU-UV008: FMI, Finland
- NILU-UV027, NILU-UV-029 and NILU-UV115: Stevens Institute of Technology, Hoboken, NJ, USA
- NILU-UV 112 and NILU-UV144: University Oslo, Norway
- NILU-UV 006: University of Bergen, Norway
- NILU-UV 130: Tribhuvan University, Kathmandu, Nepal
- NILU-UV 141 and NILU-UV 142: Tibet University, Lhasa, China.
- NILU-UV 143 and NILU-UV 145: NILU, Norway

The QASUME calibration level will be transferred to the various UV networks via the travelling reference instruments.



Comments of the operator, Bjørn Johnsen, Norwegian Radiation Protection Authority, 20.07.2010:

Before the submission of data of our Bentham DM150 of NRPA, I noted that the UVI and spectral irradiance values of our Bentham spectroradiometer were about 3 % too high compared with two of our GUV radiometers operating as transfer standards for the Norwegian UV monitoring network. The operator from PMOD-WRC, Julian Gröbner, was informed prior to submission of data that NRPA-spectra were about 3 % too high, which also showed to be the case after comparison with the QASUME spectroradiometer.

The reason for this difference was unknown at the time of submission, but after discussions with Julian Gröbner, three possible error sources were addressed for a further investigation after the completion of the intercomparison:

- Errors in the spectroradiometer irradiance calibration
- Uncertainty in the transmission factors of neutral density filters of the NDFAmp filter wheel
- influence of a non-perfect cosine response

<u>Validation of irradiance calibrations:</u>
Repetition of irradiance calibrations, using the same two FEL lamps that has been calibrated by PMOD-WRC in 2008, and a large calibration set-up installed in the optical laboratory of NRPA showed 3 % lower values than those obtained from the compact calibration set-up used before the campaign. Comparison of time-series of lamp current and voltage showed almost the same mean numbers, which excludes any major errors in the setting of lamp current. Further, errors from alignment and setting of distance of the lamp, baffles and front optic of the spectroradiometer was estimated to be very small, as this had been accurately set with a laser and a 50 cm ruler. However, I noted that the air convection around the lamp was restricted by the compact calibration set-up, which may have raised the lamp temperature above the nominal operation temperature.

<u>Validation of filter transmission factors:</u>
New measurements of the filter transmission of each of four ND filters showed in average 0.7 % too high factors. By identifying which filters had been activated during each global scan, corrections were determined for each wavelength step. A maximum error by 1.2 % were calculated for noon clear sky scans.

<u>Validation of cosine response:</u>
The relative cosine response of the optical head was determined for two azimuthal cross sections and wavelengths in the UVB and UVA. The cosine response was symmetric and wavelength independent, but had a deviation of +1 % at 50 º SZA and -3 % at 75º SZA. Using the 380 nm channel of one of the GUV radiometers as proxy for the sky radiance distribution, global sky cosine correction factors were established for each wavelength and sampling moment of the spectroradiometer. The cosine correction factors amounted up to -0.5 % at 50º SZA and 1.0 % at 70º SZA for clear sky conditions and wavelength 400 nm. For completely overcast conditions the correction factors was 0.2 %. For mixed conditions, with enhanced global radiation, the correction factors amounted up to 1.2 % at 70 º SZA.

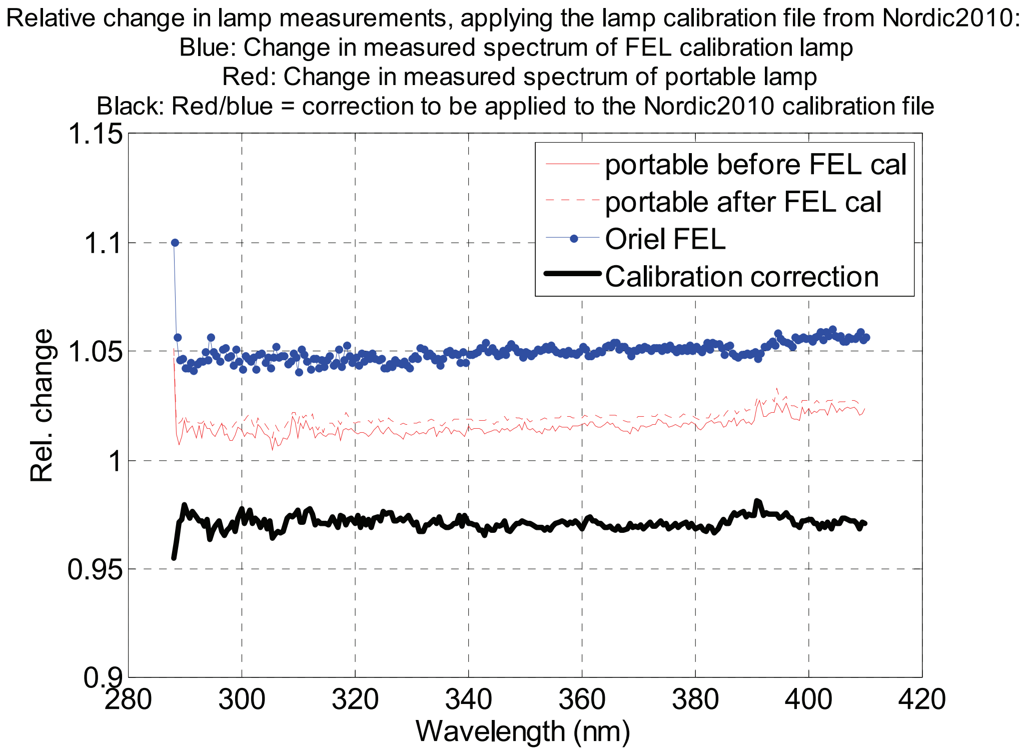


Figure 1 Black curve shows the ratio of the new calibration factors and the calibration factors used as basis for the submission of spectral data

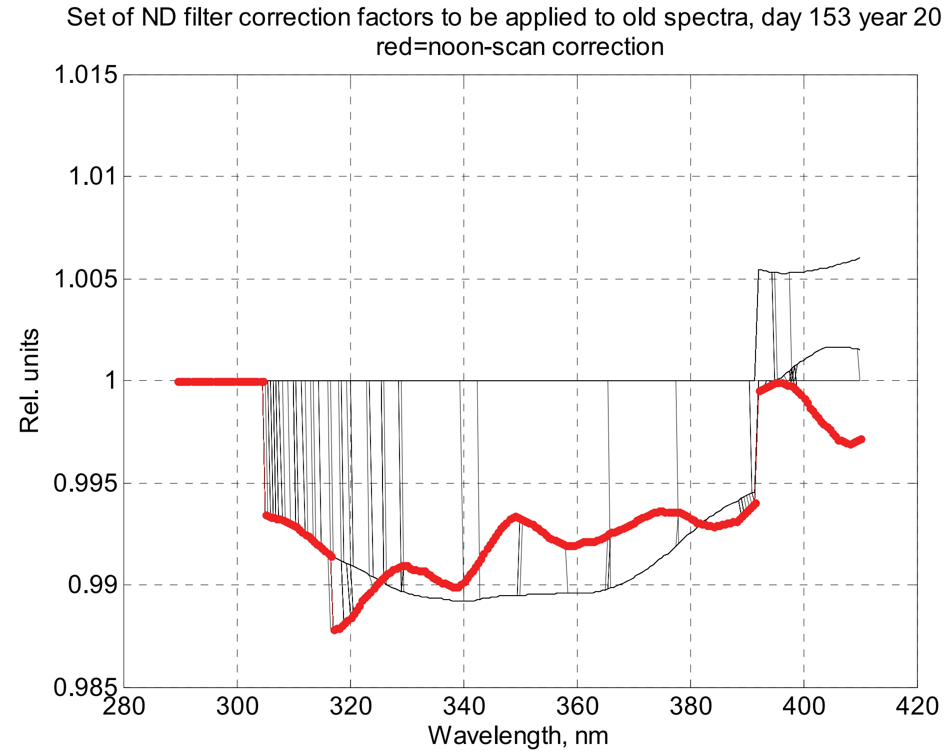


Figure 2 Correction factors for the use of wrong filter transmission factors. Jumps are due to filter changes.

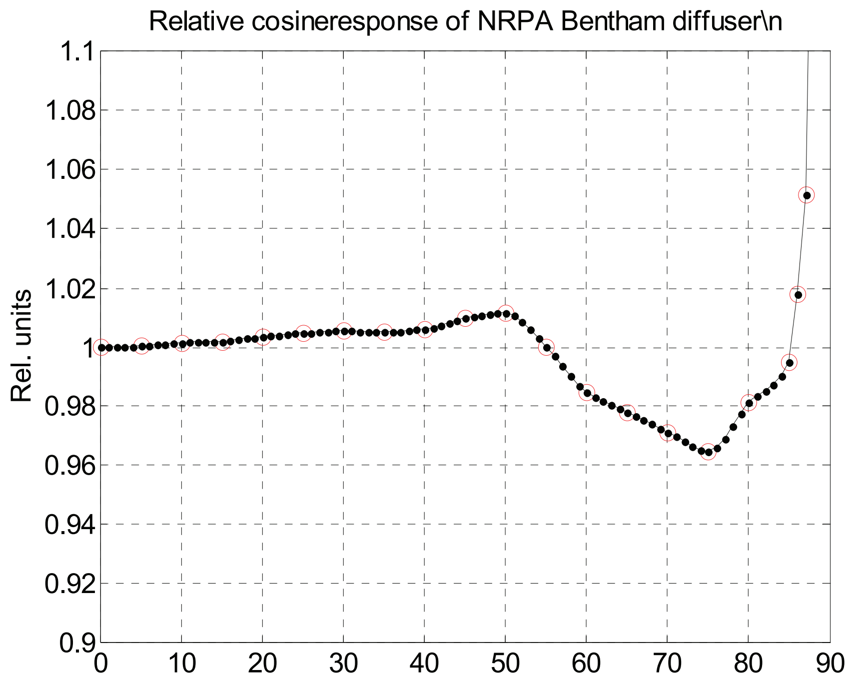
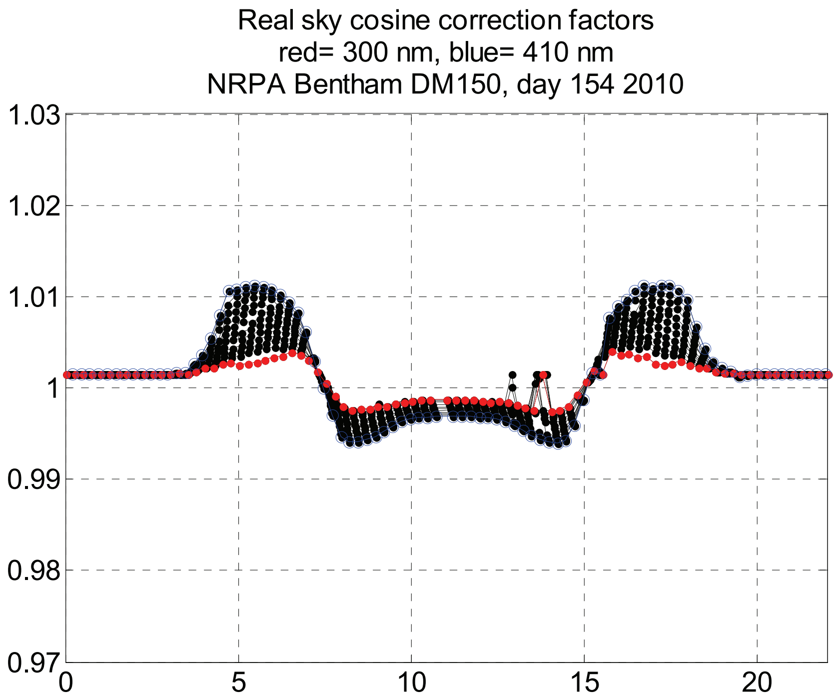
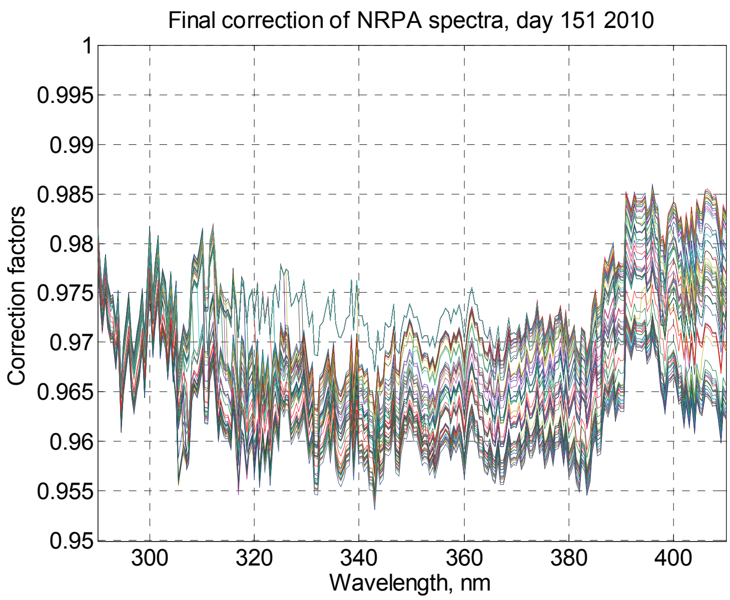


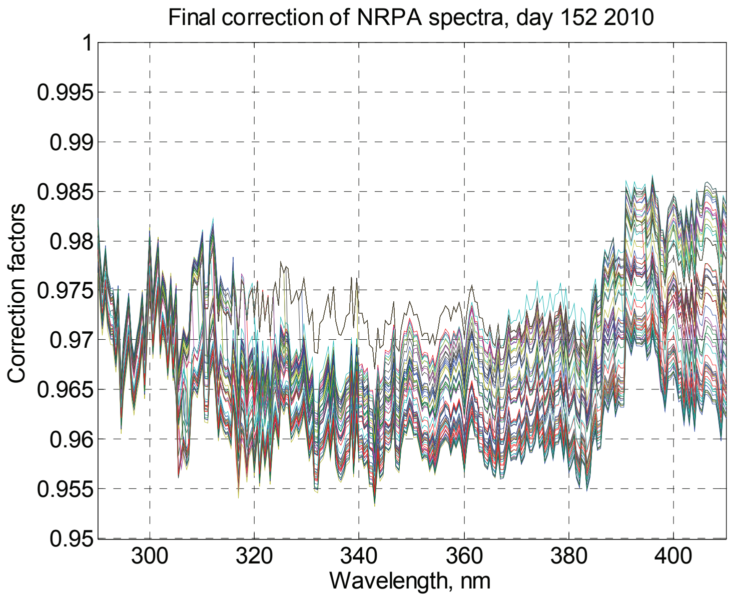
Figure 3 Relative cosine response of the front optic

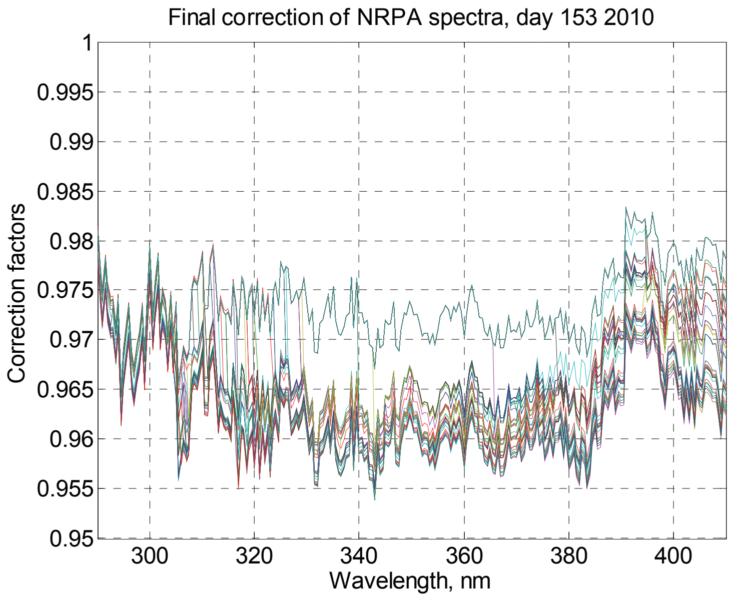


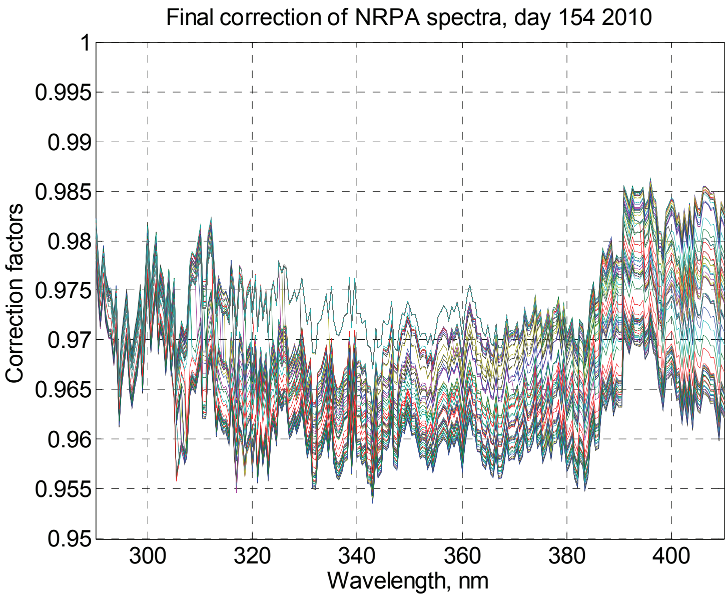
Figur 4 Global sky correction factors for day 154, with mostly clear sky conditions

Below: 5 figures showing the effective correction factors to be applied to the submitted data (days 151 – 155). The correction factors is a multiplication of correction factors of the original irradiance calibration, filter transmission factors and global sky cosine response.

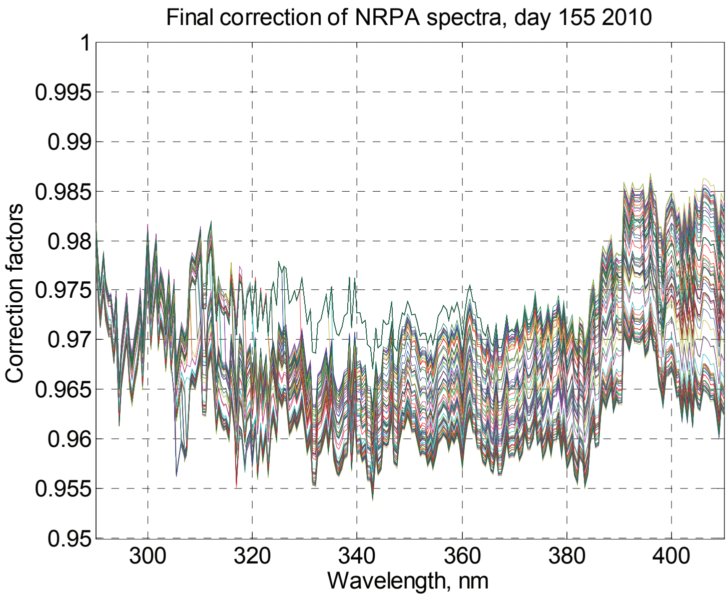



Final correction of NRPA spectra, day 152 2010
Correction factors
Wavelength, nm
1
0.995
0.99
0.985
0.98
0.975
0.97
0.965
0.96
0.955
0.95
300
320
340
360
380
400

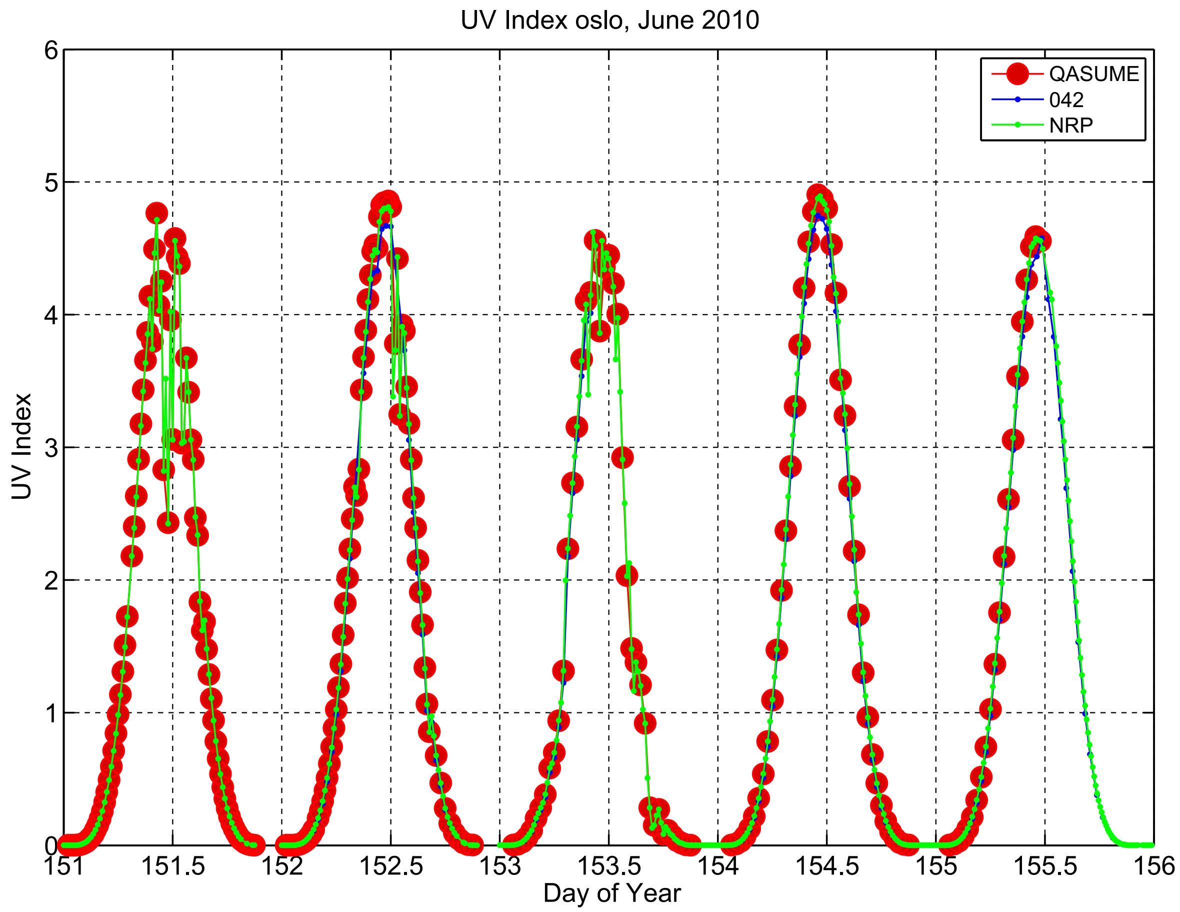

Final correction of NRPA spectra, day 153 2010
Correction factors
Wavelength, nm
1
0.995
0.99
0.985
0.98
0.975
0.97
0.965
0.96
0.955
0.95
300
320
340
360
380
400



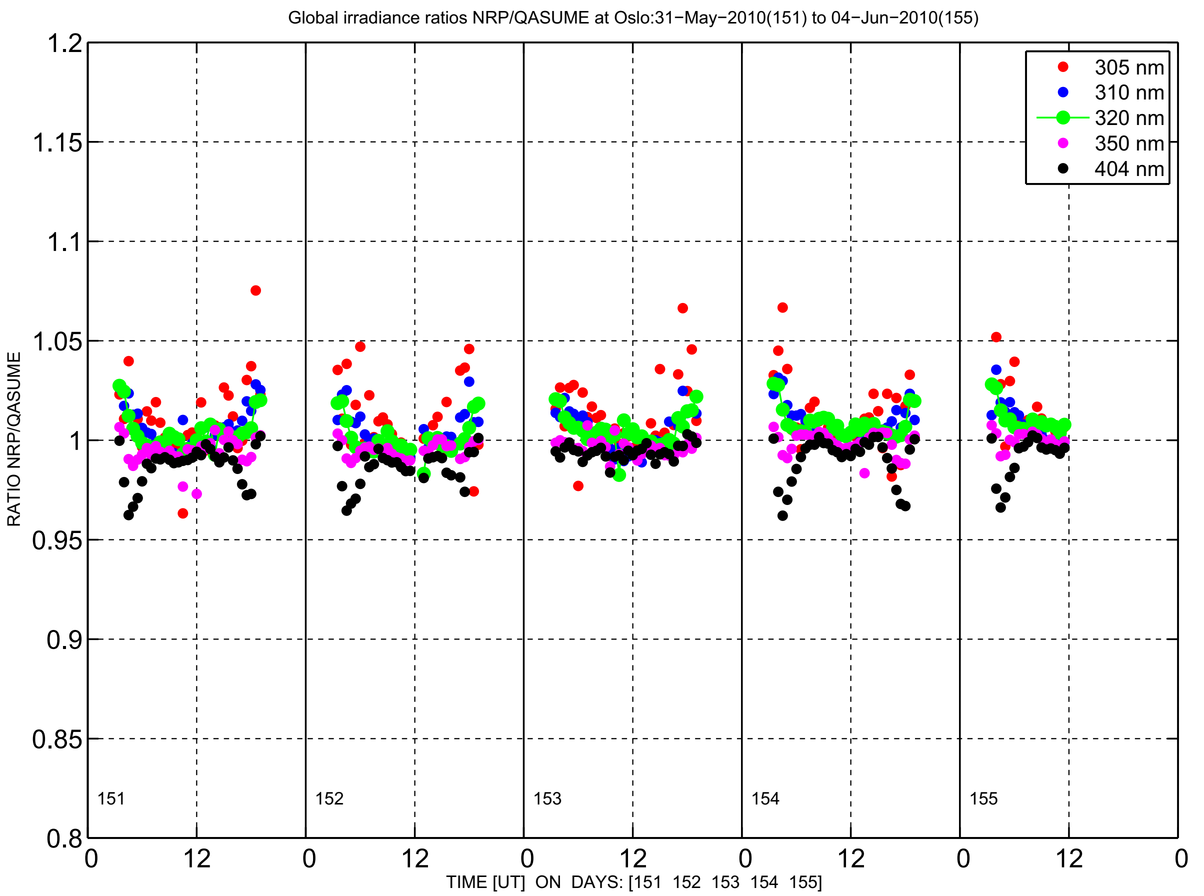
Final correction of NRPA spectra, day 154 2010
Correction factors
Wavelength, nm
1
0.995
0.99
0.985
0.98
0.975
0.97
0.965
0.96
0.955
0.95
300
320
340
360
380
400



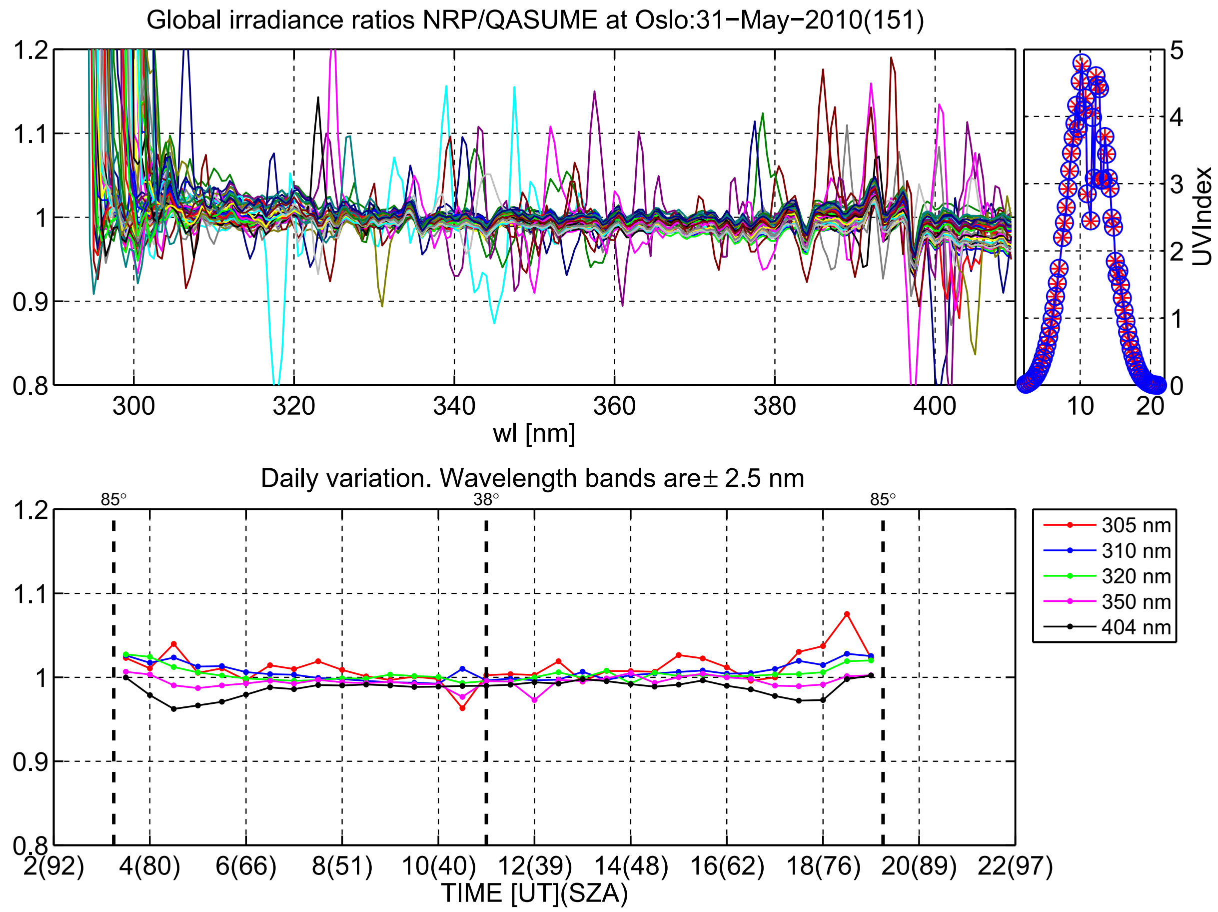
Final correction of NRPA spectra, day 155 2010
Correction factors
Wavelength, nm
1
0.995
0.99
0.985
0.98
0.975
0.97
0.965
0.96
0.955
0.95
300
320
340
360
380
400

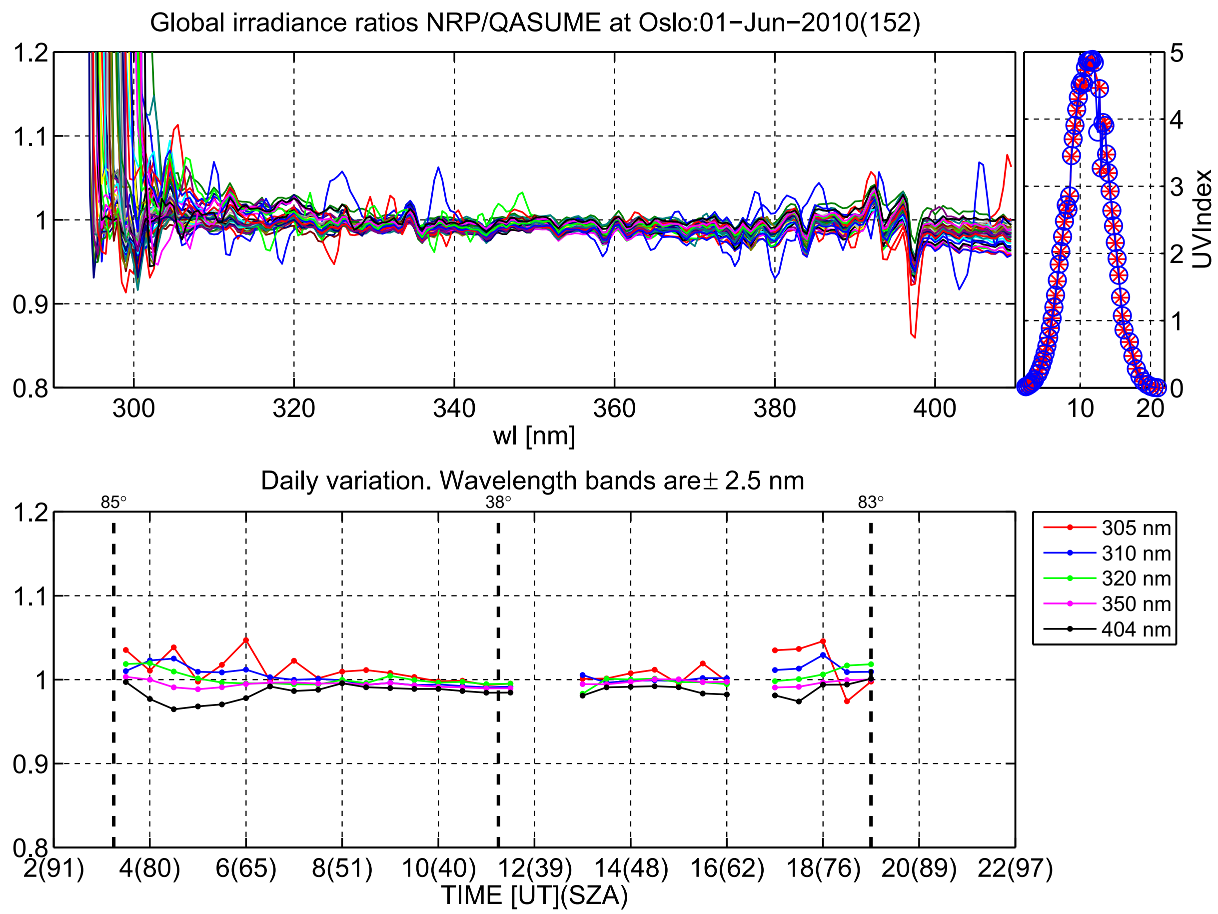


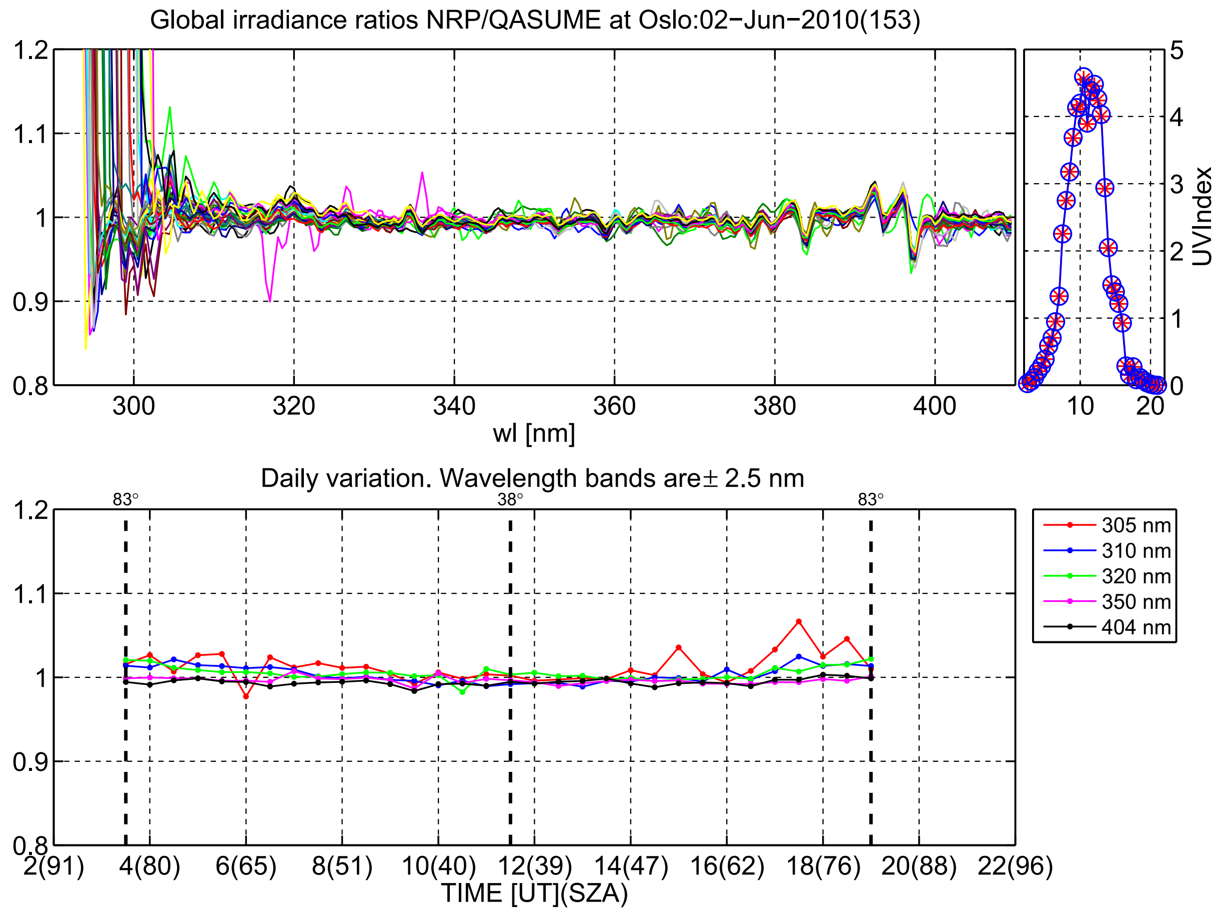
UV Index oslo, June 2010
QASUME
042
NRP
UV Index
Day of Year
0
1
2
3
4
5
6
151
151.5
152
152.5
153
153.5
154
154.5
155
155.5
156

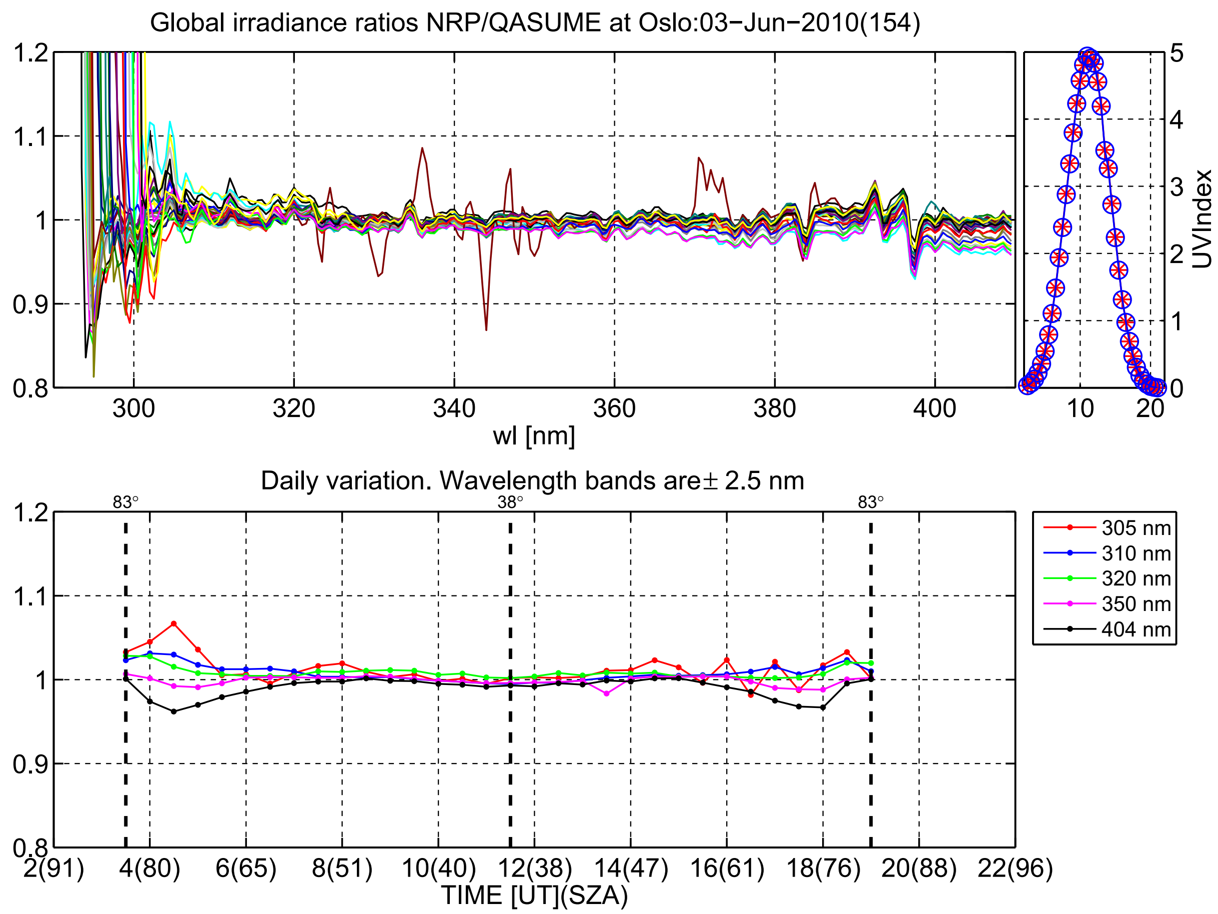


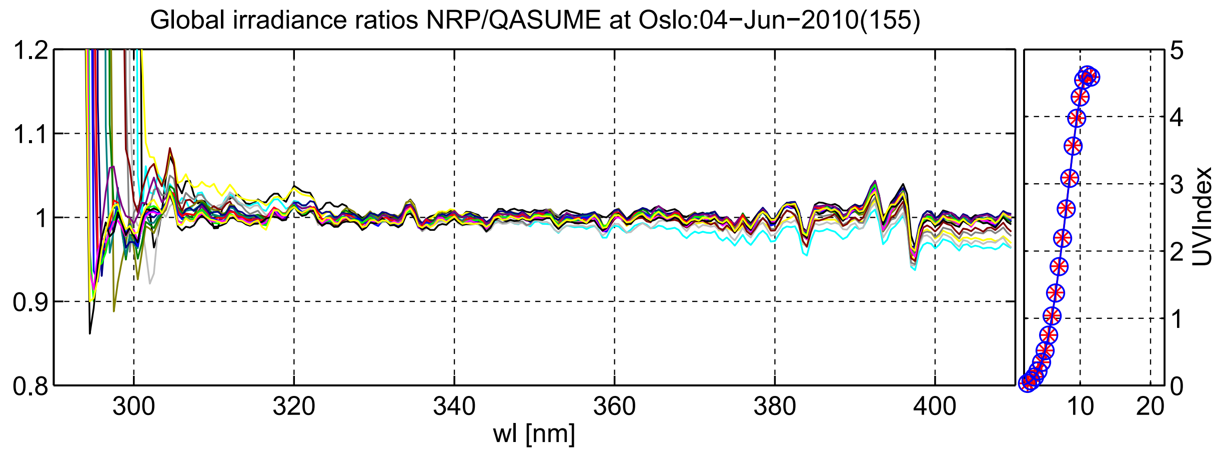
Global irradiance ratios NRP/QASUME at Oslo:31−May−2010(151) to 04−Jun−2010(155)
305 nm
310 nm
320 nm
350 nm
404 nm
RATIO NRP/QASUME
0.8
0.85
0.9
0.95
1
1.05
1.1
1.15
1.2
151
152
153
154
155
0
12
TIME [UT] ON DAYS: [151 152 153 154 155]

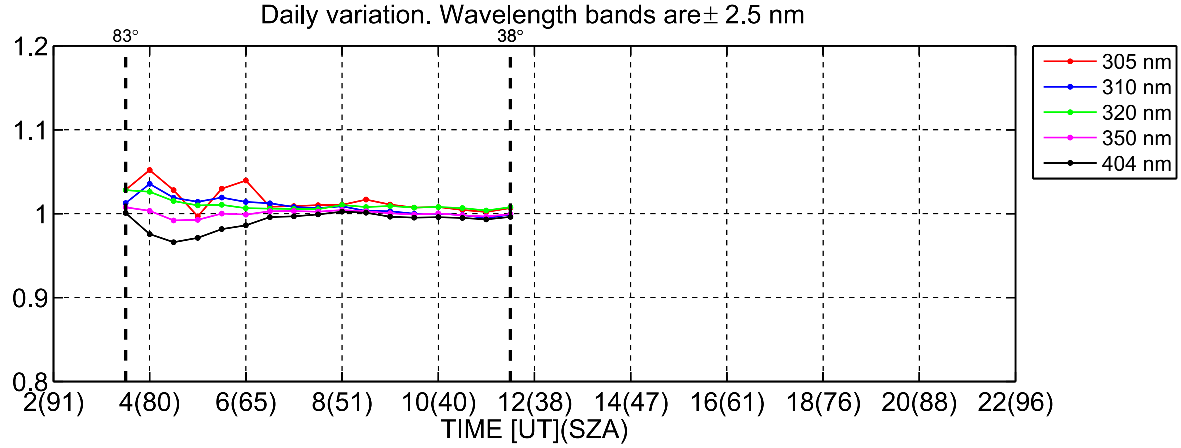

Global irradiance ratios NRP/QASUME at Oslo:31−May−2010(151)
1.2
1.1
1
0.9
0.8
300
320
340
360
380
400
wl [nm]
10
20
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
85°
38°
85°
305 nm
310 nm
320 nm
350 nm
404 nm
2(92)
4(80)
6(66)
8(51)
10(40)
12(39)
14(48)
16(62)
18(76)
20(89)
22(97)
TIME [UT](SZA)

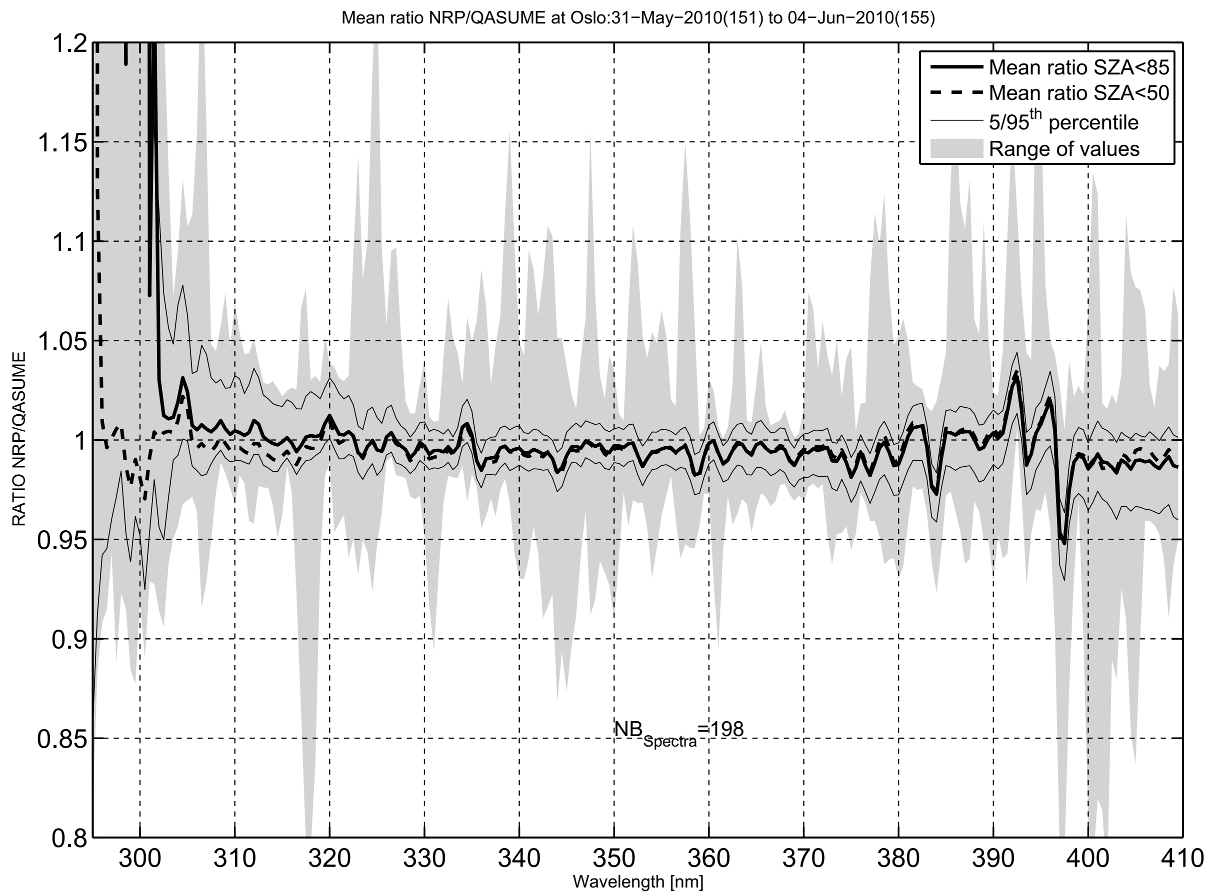

Global irradiance ratios NRP/QASUME at Oslo:01−Jun−2010(152)
1.2
1.1
1
0.9
0.8
300
320
340
360
380
400
wl [nm]
10
20
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
85°
38°
83°
305 nm
310 nm
320 nm
350 nm
404 nm
2(91)
4(80)
6(65)
8(51)
10(40)
12(39)
14(48)
16(62)
18(76)
20(89)
22(97)
TIME [UT](SZA)

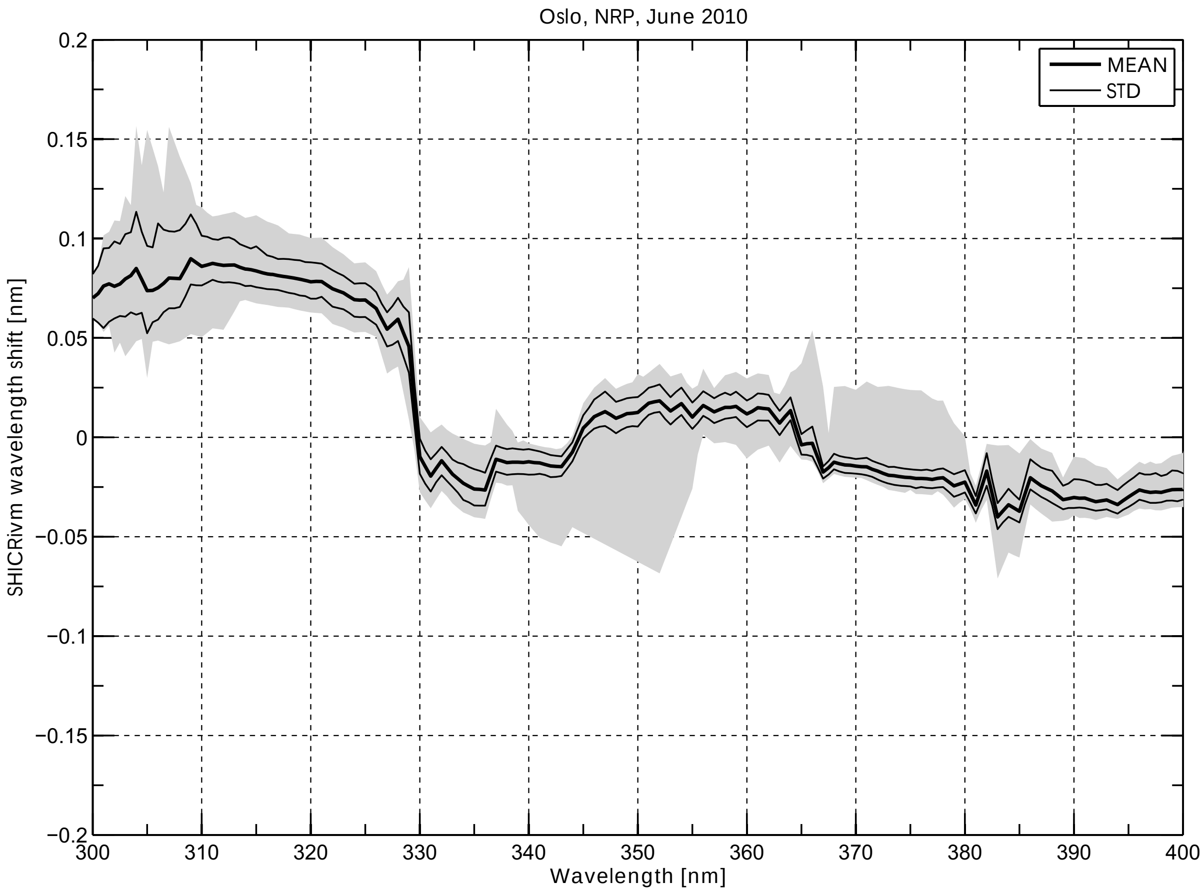

Global irradiance ratios NRP/QASUME at Oslo:02−Jun−2010(153)
1.2
1.1
1
0.9
0.8
300
320
340
360
380
400
wl [nm]
5
4
3
2
1
0
10
20
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
83°
38°
83°
305 nm
310 nm
320 nm
350 nm
404 nm
2(91)
4(80)
6(65)
8(51)
10(40)
12(39)
14(47)
16(62)
18(76)
20(88)
22(96)
TIME [UT](SZA)


Global irradiance ratios NRP/QASUME at Oslo:03−Jun−2010(154)
1.2
1.1
1
0.9
0.8
300
320
340
360
380
400
wl [nm]
5
4
3
2
1
0
10
20
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
83°
38°
83°
305 nm
310 nm
320 nm
350 nm
404 nm
2(91)
4(80)
6(65)
8(51)
10(40)
12(38)
14(47)
16(61)
18(76)
20(88)
22(96)
TIME [UT](SZA)

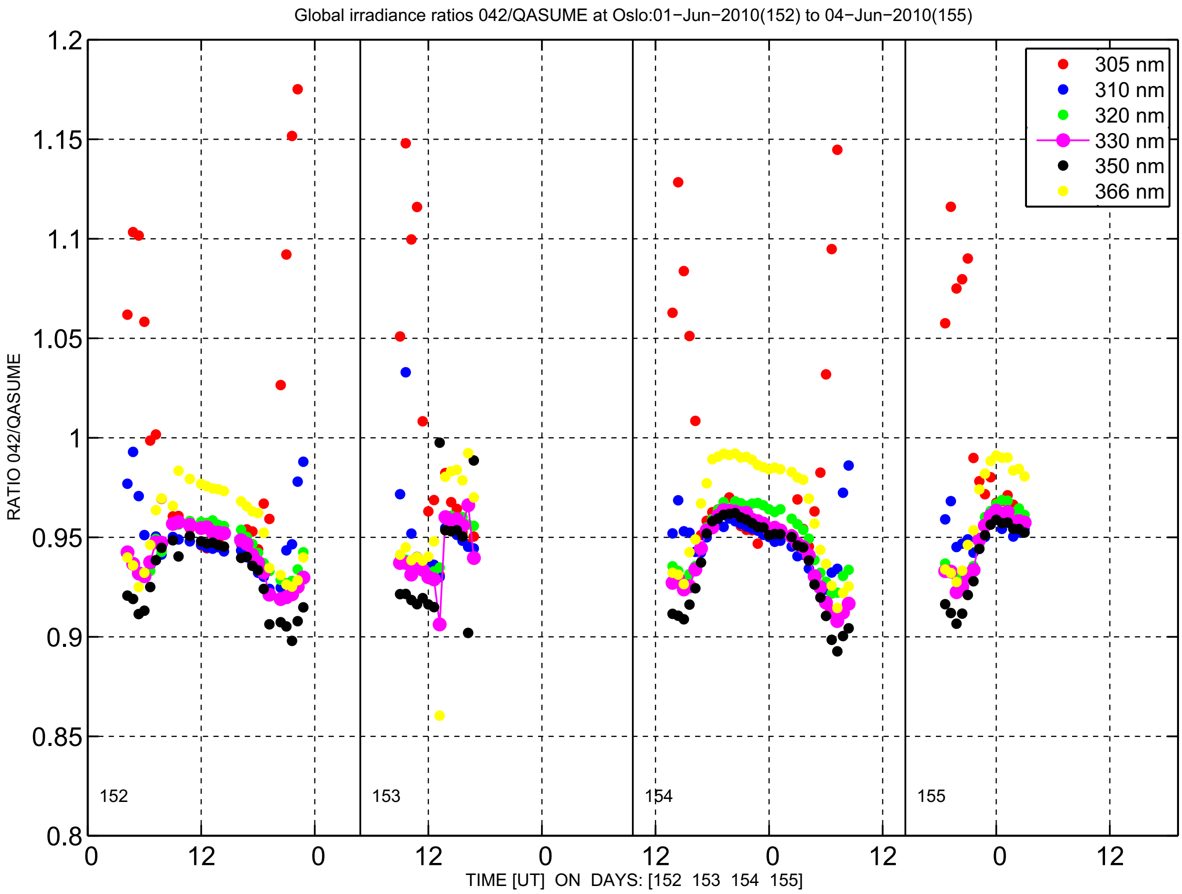

Global irradiance ratios NRP/QASUME at Oslo:04−Jun−2010(155)
1.2
1.1
1
0.9
0.8
300
320
340
360
380
400
wl [nm]
0
1
2
3
4
5
10
20
UVIndex


Daily variation. Wavelength bands are± 2.5 nm
83°
38°
1.2
1.1
1
0.9
0.8
2(91)
4(80)
6(65)
8(51)
10(40)
12(38)
14(47)
16(61)
18(76)
20(88)
22(96)
TIME [UT](SZA)
305 nm
310 nm
320 nm
350 nm
404 nm

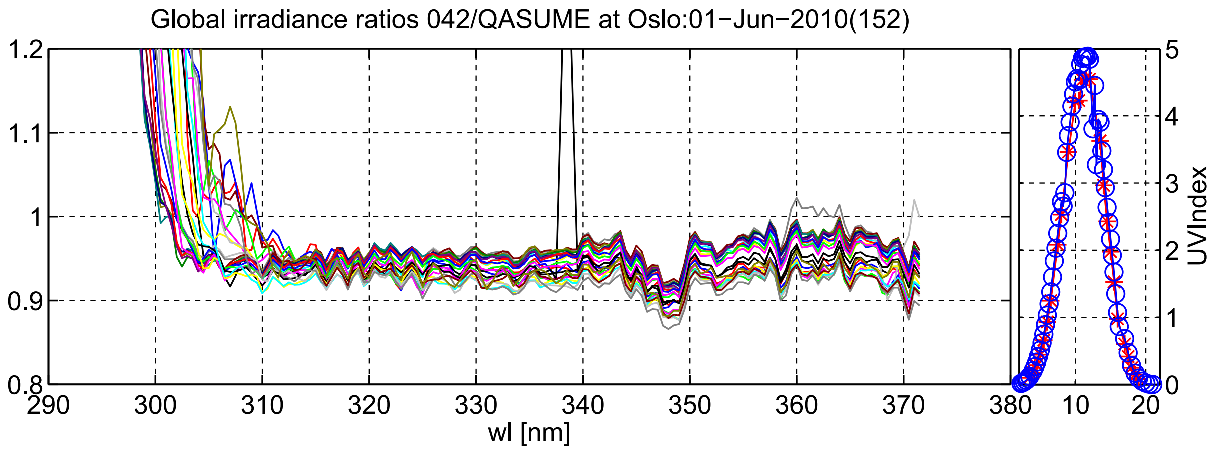

Mean ratio NRP/QASUME at Oslo:31−May−2010(151) to 04−Jun−2010(155)
Mean ratio SZA<85
Mean ratio SZA<50
5/95th percentile
Range of values
RATIO NRP/QASUME
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
NBSpectra=198
300
310
320
330
340
350
360
370
380
390
400
410
Wavelength [nm]



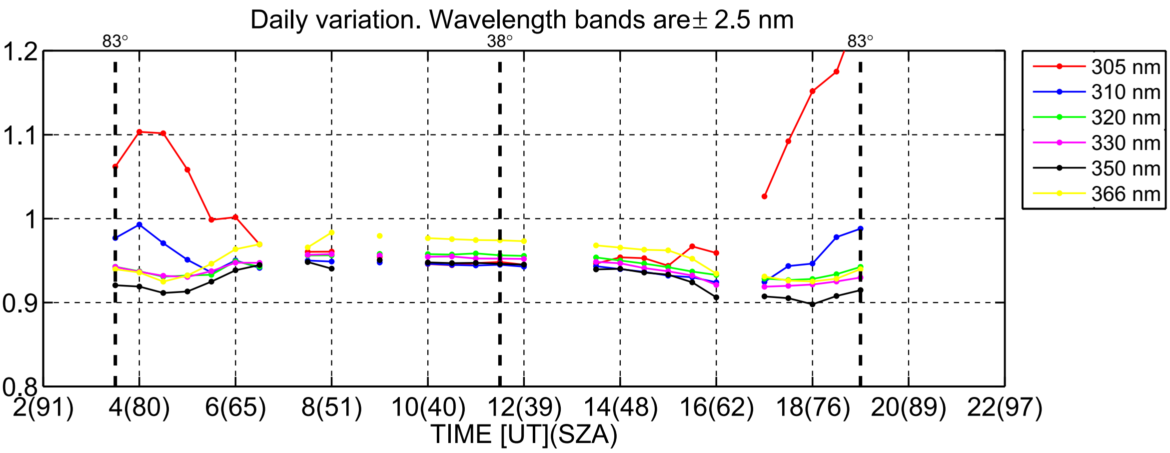
Oslo, NRP, June 2010
MEAN
STD
SHICRivm wavelength shift [nm]
Wavelength [nm]
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
300
310
320
330
340
350
360
370
380
390
400



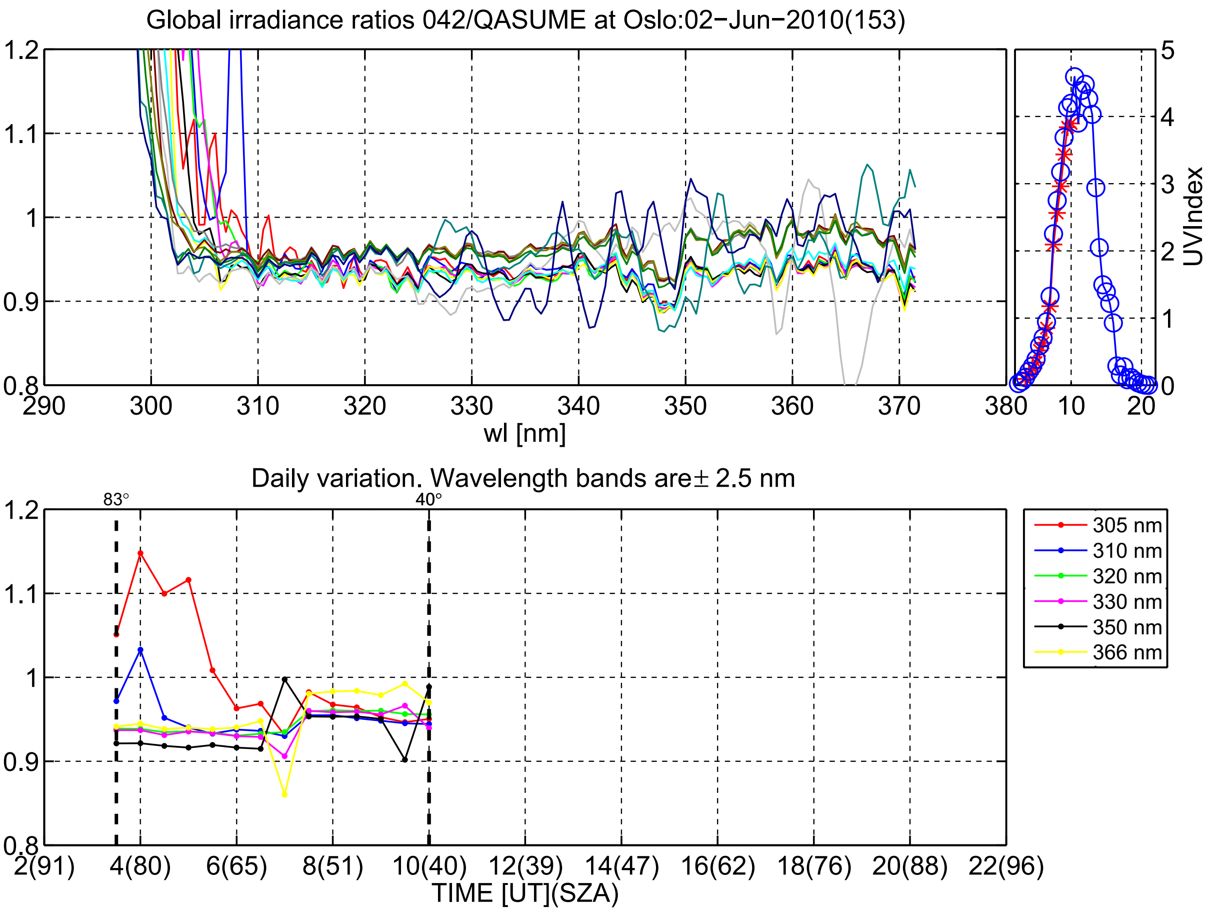
Global irradiance ratios 042/QASUME at Oslo:01−Jun−2010(152) to 04−Jun−2010(155)
RATIO 042/QASUME
TIME [UT] ON DAYS: [152 153 154 155]
305 nm
310 nm
320 nm
330 nm
350 nm
366 nm
152
153
154
155

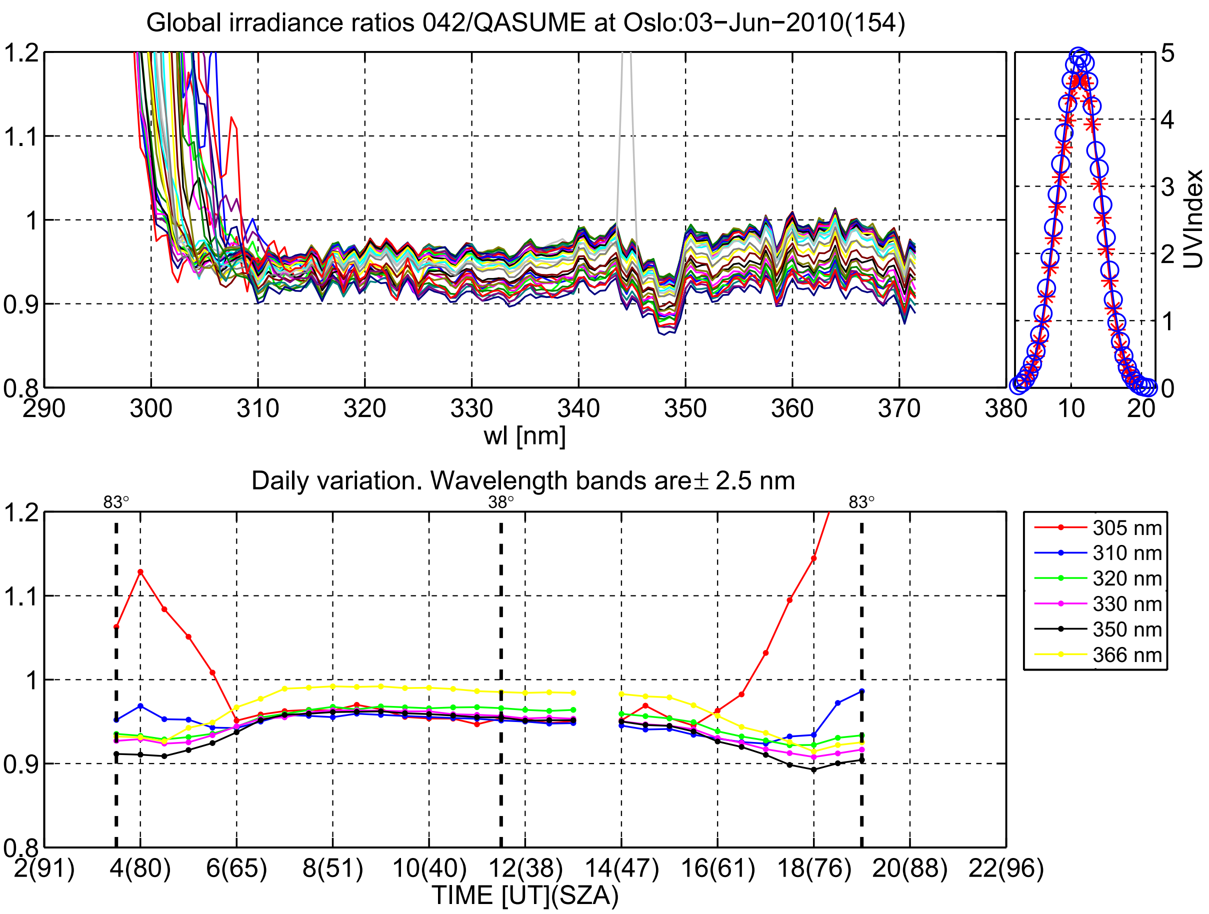


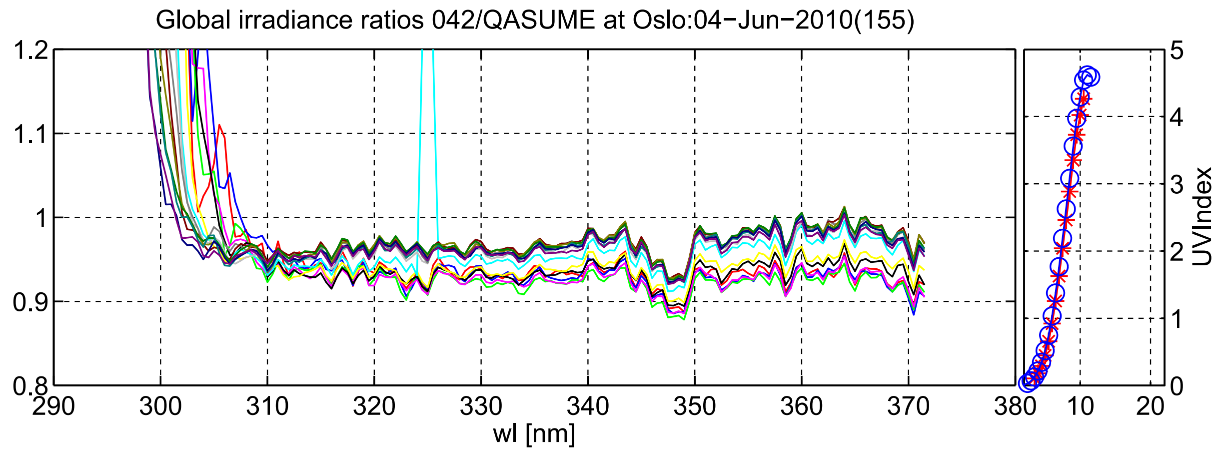
Global irradiance ratios 042/QASUME at Oslo:01−Jun−2010(152)
wl [nm]
UVIndex



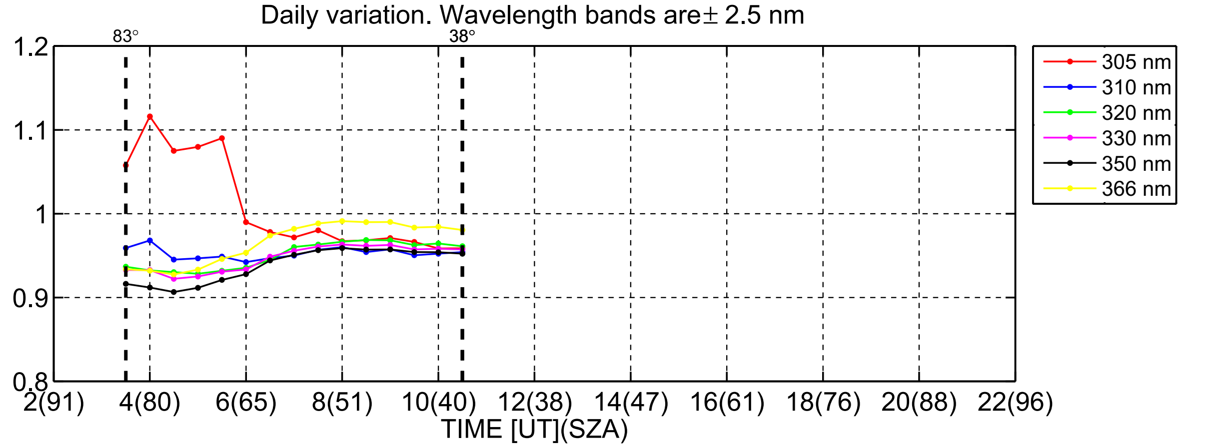
Daily variation. Wavelength bands are± 2.5 nm
83°
38°
83°
TIME [UT](SZA)
305 nm
310 nm
320 nm
330 nm
350 nm
366 nm


Global irradiance ratios 042/QASUME at Oslo:02−Jun−2010(153)
wl [nm]
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
83°
40°
305 nm
310 nm
320 nm
330 nm
350 nm
366 nm
TIME [UT](SZA)

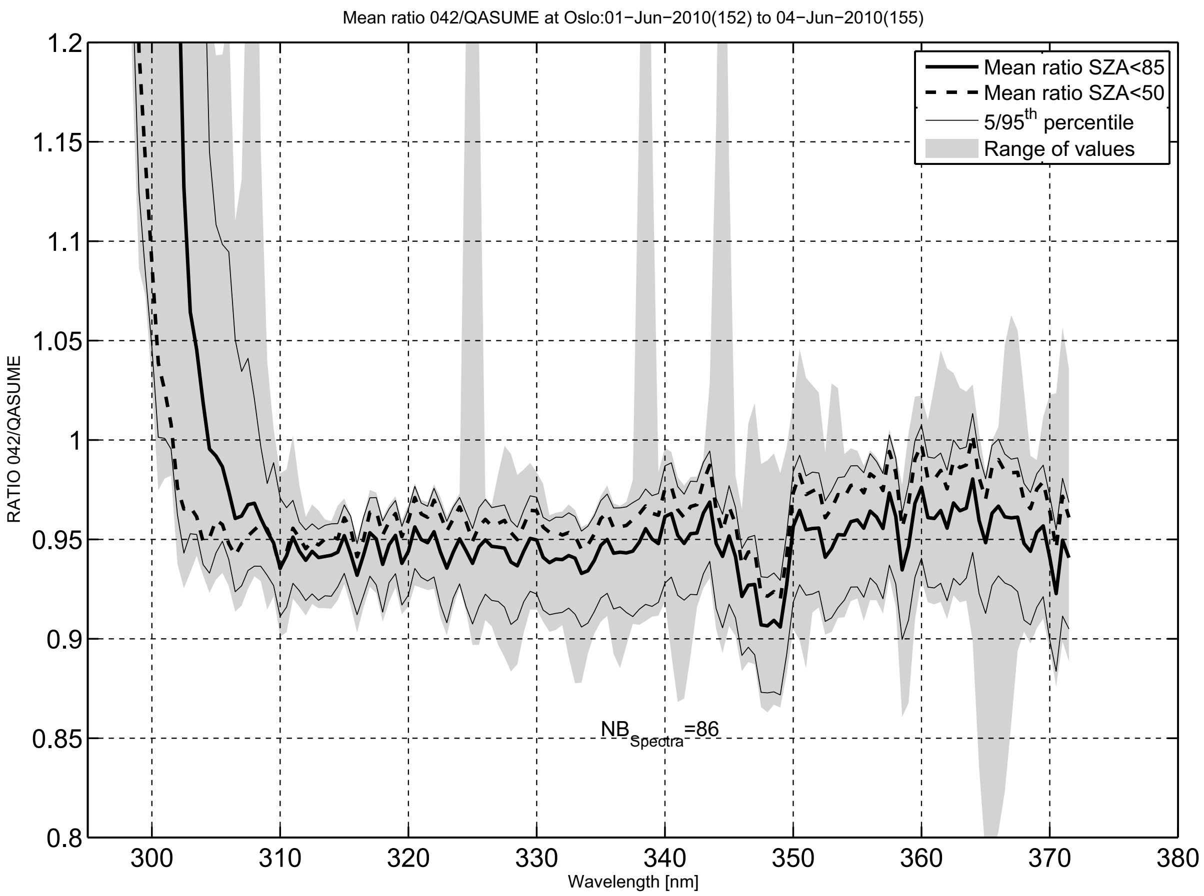

Global irradiance ratios 042/QASUME at Oslo:03−Jun−2010(154)
wl [nm]
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
83°
38°
83°
305 nm
310 nm
320 nm
330 nm
350 nm
366 nm
TIME [UT](SZA)



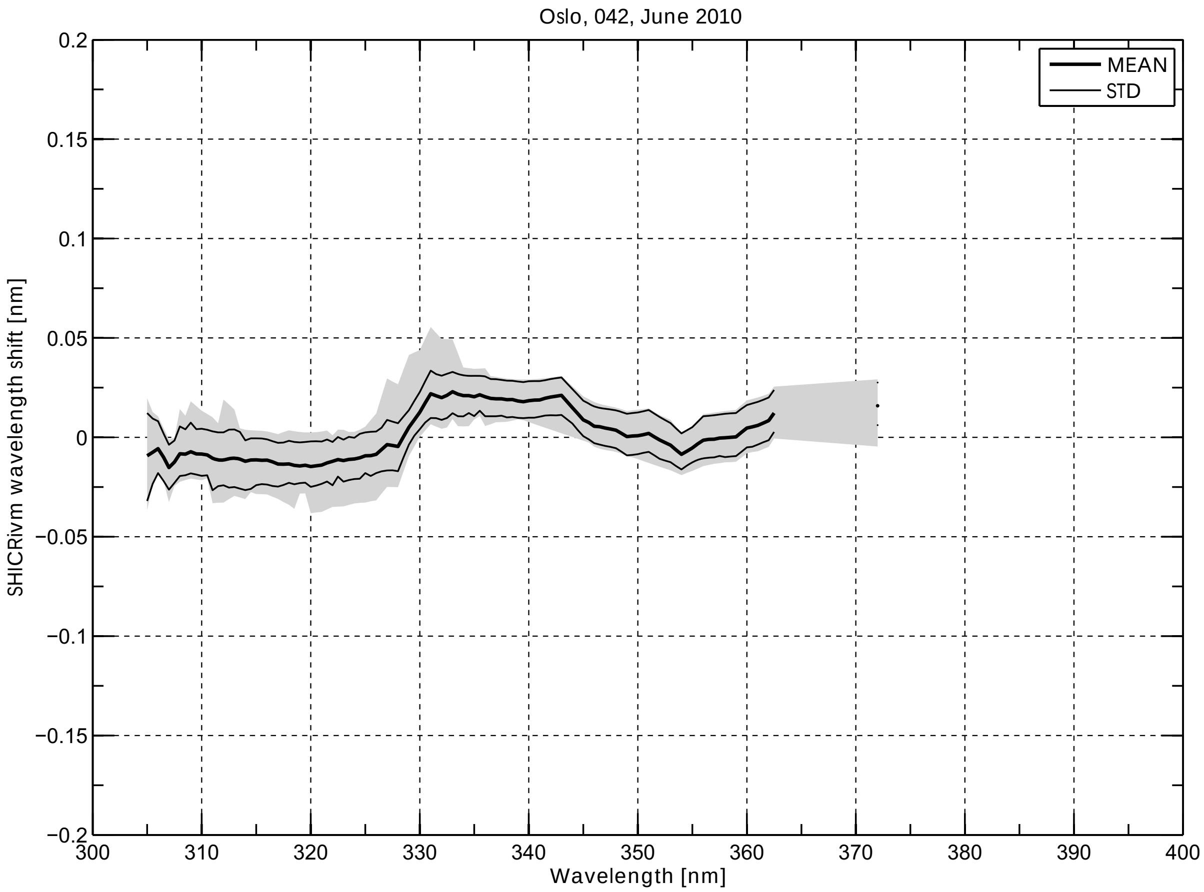
Global irradiance ratios 042/QASUME at Oslo:04−Jun−2010(155)
wl [nm]
UVIndex



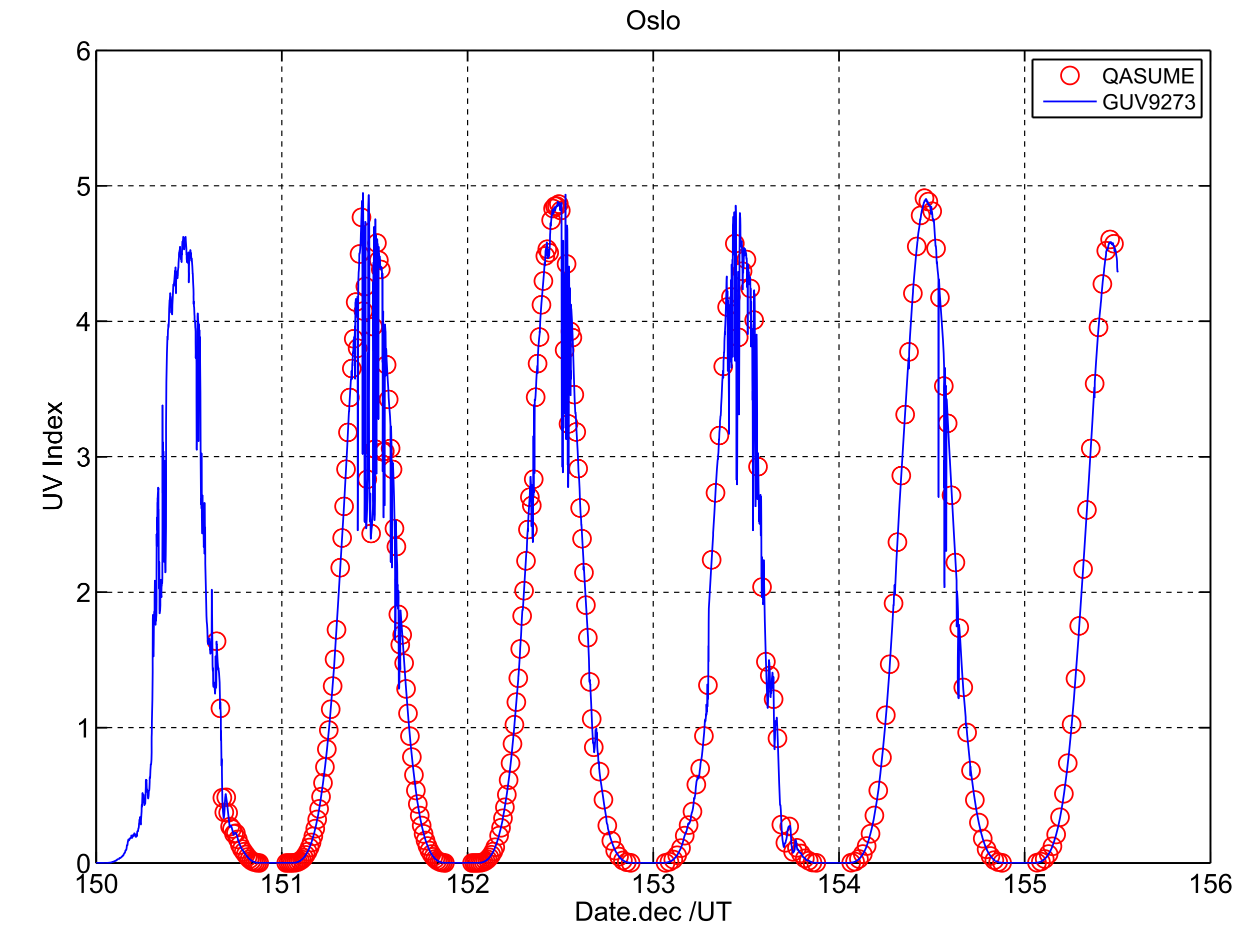
Daily variation. Wavelength bands are± 2.5 nm
83°
38°
305 nm
310 nm
320 nm
330 nm
350 nm
366 nm
TIME [UT](SZA)

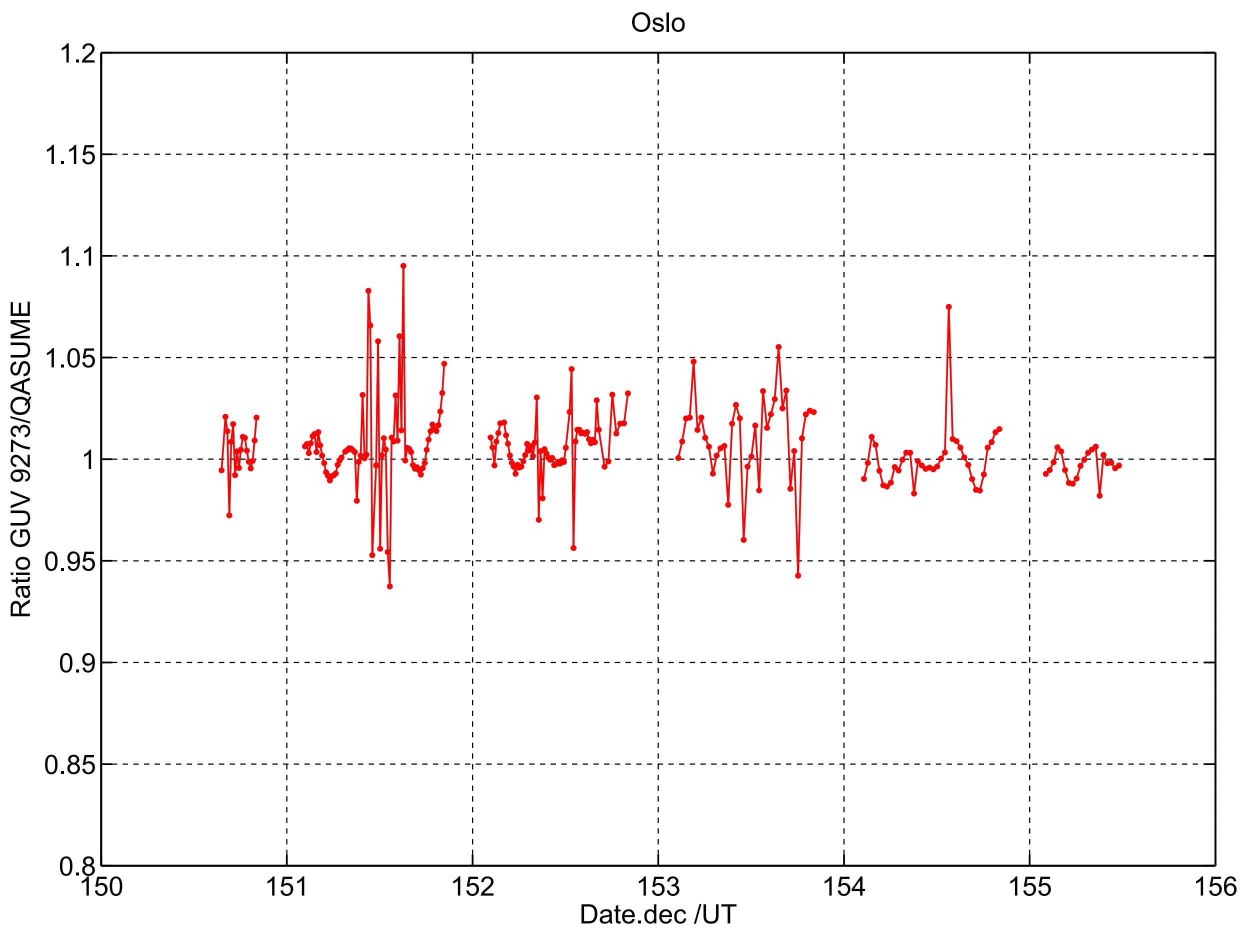


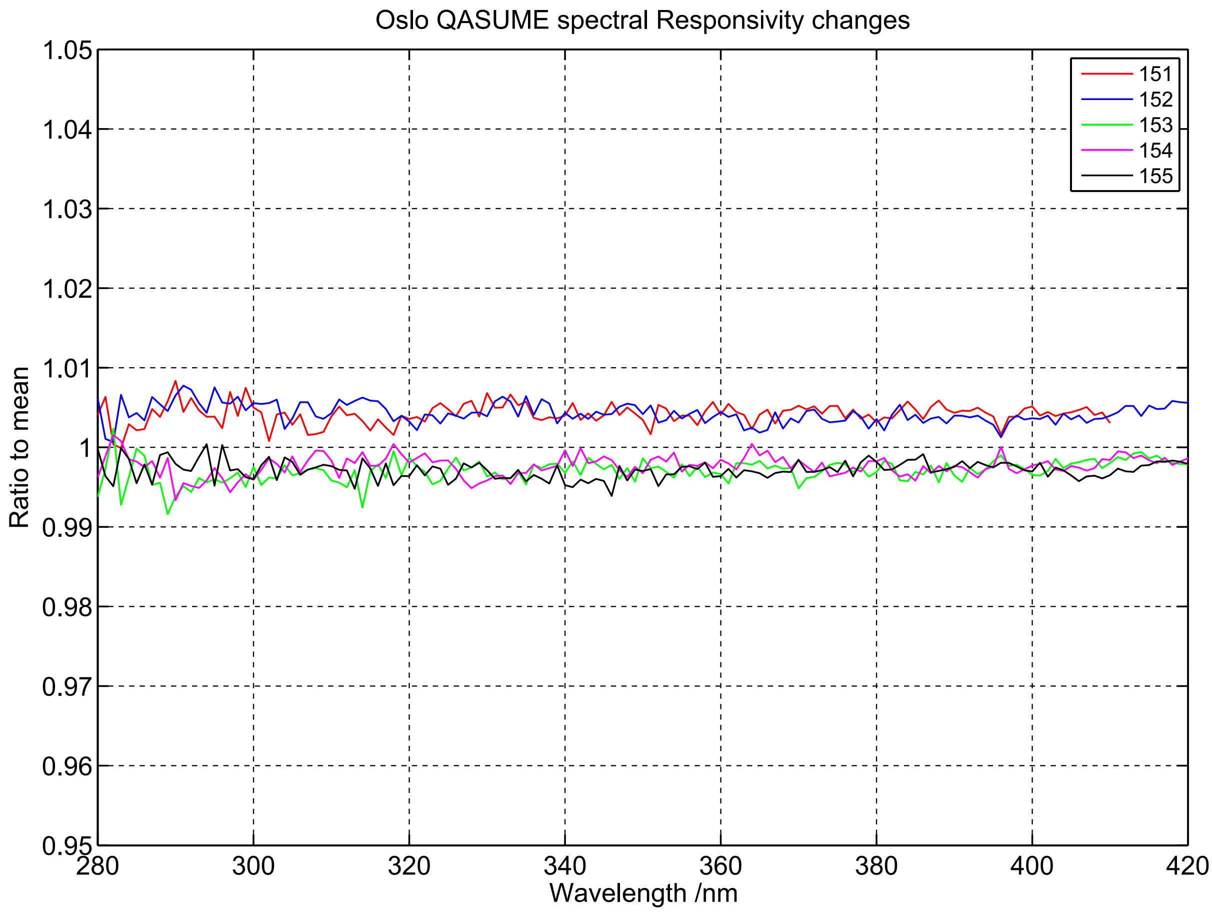
Mean ratio 042/QASUME at Oslo:01−Jun−2010(152) to 04−Jun−2010(155)
Mean ratio SZA<85
Mean ratio SZA<50
5/95th percentile
Range of values
RATIO 042/QASUME
NBSpectra=86
Wavelength [nm]

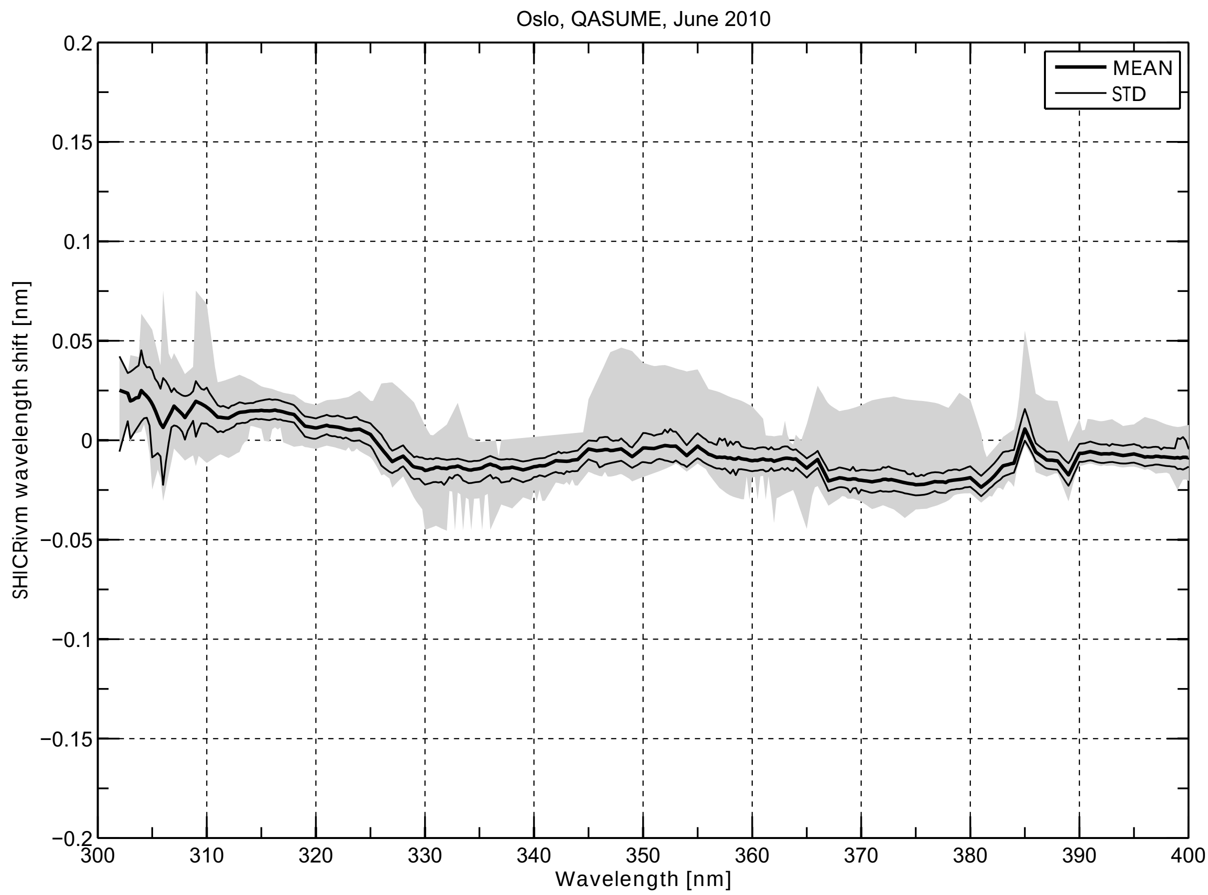


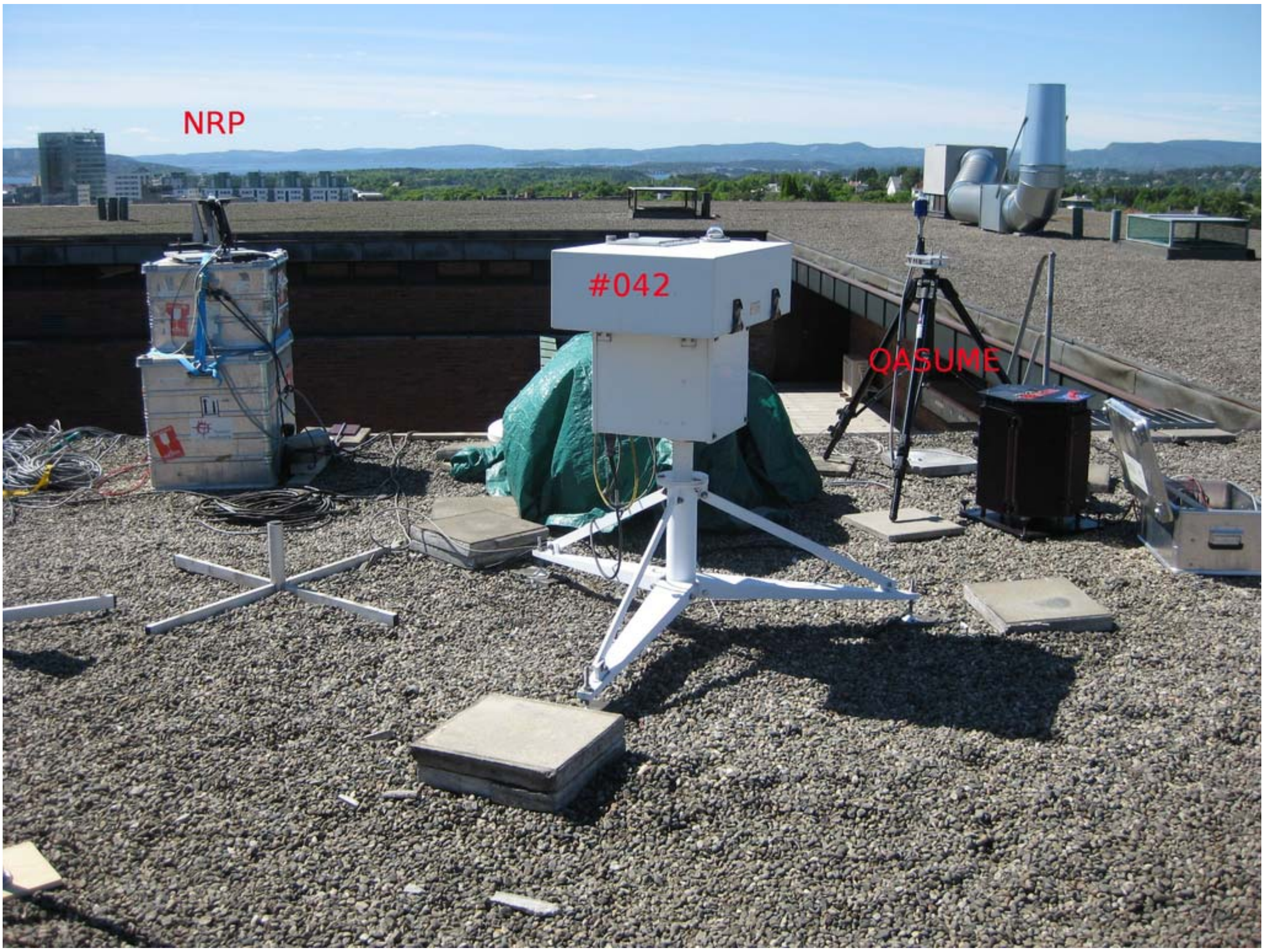
Oslo, 042, June 2010
MEAN
STD
SHICRivm wavelength shift [nm]
Wavelength [nm]
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
300
310
320
330
340
350
360
370
380
390
400


Oslo
QASUME
GUV9273
UV Index
Date.dec /UT
0
1
2
3
4
5
6
150
151
152
153
154
155
156


Oslo
Ratio GUV 9273/QASUME
Date.dec /UT
0.8
0.85
0.9
0.95
1
1.05
1.1
1.15
1.2
150
151
152
153
154
155
156


Oslo QASUME spectral Responsivity changes
1.05
1.04
1.03
1.02
1.01
1
0.99
0.98
0.97
0.96
0.95
Ratio to mean
280
300
320
340
360
380
400
420
Wavelength /nm
151
152
153
154
155


Oslo, QASUME, June 2010
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
SHICRivm wavelength shift [nm]
300
310
320
330
340
350
360
370
380
390
400
Wavelength [nm]
MEAN
STD


NRP
#042
QASUME