Protocol of the intercomparison at ARPA, Aosta, Italy on June 11 16, 2015 with the travelling reference spectroradiometer QASUME from PMOD/WRC

Report prepared by Gregor Hülsen

Operator: Gregor Hülsen
Local Operator: Henri Diemoz

The purpose of the visit was the comparison of global solar irradiance measurements between the spectroradiometer AAO operated by the Sezione Agenti Fisici - Radiazione Ultravioletta Solare, Agenzia Regionale per la Protezione dell'Ambiente (ARPA) and the travel reference spectroradiometer QASUME. The measurement site is located at Valle d'Aosta; Latitude 45.74 N, Longitude 7.34 E and altitude 569 m.a.s.l.
The horizon of the measurement site is free down to at least 80° solar zenith angle (SZA). Measurements between 4:00 UT and 19:00 UT have been analysed.

QASUME was installed at ARPA Aosta at evening of June 11, 2015. The spectroradiometer was installed next to AAO with the entrance optic of QASUME within 1 m of AAO. The spectroradiometer in use at ARPA Aosta is a Bentham DTMc300 double monochromator. The intercomparison between QASUME and the ARPA spectroradiometer lasted five days, from the morning of June 12 to noon of June 16.

QASUME was calibrated several times during the intercomparison period using a portable calibration system. Two lamps (T68522 and T61253) 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 %. The internal temperature of QASUME was 26.08±0.05 °C and the diffuser head was heated to a temperature of 33.3±0.8 °C. In the morning of June 14 the temperature regulation stopped for about 1 hour. This data was excluded from the analysis.
The wavelength shifts relative to an extraterrestrial spectrum as retrieved from the MATSHIC analysis were between ±50 pm in the spectral range 290 to 500 nm.

Protocol:

The measurement protocol was to measure one solar irradiance spectrum every 30 minutes from 290 to 500 nm, every 0.25 nm, and 1.5 seconds between each wavelength increment.

DOY	Date	DAY	Weather	Comment (times are in UT)
162	11. Jun	Thursday	Overcasted Sky	Installed at 19:00
163	12. Jun	Friday	Overcasted Sky	14:00 calibration using T68522
164	13. Jun	Saturday	Morning: Clear Sky Mix of Sun & Clouds Rain in the evening	07:25-08:25 Qasume Head rot (180°) 12:25-13:25: AAO Head rot (180°) 14:23 calibration using T68522
165	14. Jun	Sunday	Overcasted Sky Rain in the morning	07:00 calibration using T68522 07:15 Qasume: New Si-Gel 07:30-10:30: Si-Pump ON 07:32-10:36: Qasume Temp instable 11:22 calibration using T68522 15:53 calibration using T68522 16:10 calibration using T61253
166	15. Jun	Monday	Mix of Sun & Clouds Morning: Clear Sky periods	05:52 calibration using T68522 06:24 - 7:25:AAO Head rot (180°) 09:22 calibration using T68522 13:23 calibration using T68522 17:23 calibration using T68522
167	16. Jun	Tuesday	Rain	End of Campaign: 06:20

Results:

In total 118 synchronised simultaneous spectra from QASUME and AAO are available from the measurement period. Measurements between 4:00 and 19:00 UT have been analysed (SZA smaller than 90°).

Remarks:

1. The ratios between AAO and QASUME have on average an offset of +0.5 %.
2. The diurnal variation of the AAO to QASUME ratio is around 1 % on overcasted days and above 4 % on the sunny days.
3. For all solar scans the wavelength shifts of the AAO are between ±10 pm.

Additional Measurements

1. In order to additionally test the assumption of an azimuth error, the QASUME entrance optics was horizontally turned by 180° on day 164 at 7:25 UTC and turned back at 8:25 UTC. The observed bias of about 3 % suggests that an azimuth error from the entrance optics is likely.
2. The same test was carried out with the AAO entrance optic at noon 164 and in the morning of day 166. The test at noon showed no bias whereas the second test in the morning revealed a small azimuth error in the order of less than 1 %. However this test was performed under sky conditions with cirrus clouds obstructing the direct sun.
3. The sensitivity change of QASUME was measured on day 165 and 166 using T68522. The sensitivity increases from the morning to noon by about 1 %. No detectable change of the sensitivity from the noon to the late afternoon measurement. The sensitivity comes back to the start value during the night.

Conclusion

The measurement indicate a small azimuth error of the QASUME entrance optic with contribute to the diurnal variability on clear sky days. The azimuth error of the AAO head is negligible.
The diurnal variability >4 % found in the intercomparison 2014 seems to be a function of the irradiance intensity on the measurement day: The small UV Index of less than 2 on day 163 cause a variability of less than 1 %, 4 UVI on day 165 cause 2 % and 8 UVI on day 164 lead to 4 % variability - consistent with the measurement in 2014.
Therefore a test of a sensitivity change during a sunny day for the AAO instrument is suggested (see comments from the local operator).

QASUME Data Processing Remarks

1. The transmission changes of the Teflon Diffusor due to temperature changes were correct.
2. No cosine correction was applied assuming that both input optics are identical.
3. On day 163 and 164 the auxiliary Mercury line measurement, monitoring the transmission and wavelength stability of QASUME, were used to account for diurnal sensitivity changes.
4. On day 165 and 166 the sensitivity changes were corrected using the calibration measurements in the morning, noon and evening.

Comments from local operator

During the “Solar UV intercomparison 2014” in Davos (maximum UV Index ~ 9), the ratio AAO/QASUME showed a diurnal variation of about ±4%, with a slight spectral dependence. During the Aosta 2015 campaign (max UV Index ~ 8), similar variations (about ±3%) were observed. These diurnal changes had never seen before 2014.

After QASUME visit, some tests were performed to check whether the observed sensitivity change is ascribable to AAO, e.g. owing to PMT hysteresis.

1. Several lamp calibrations were performed at different times of the day during three sunny days (maximum UV Index ~ 8). The sensitivity decrease relative to the first calibration of each day was lower than 2%. However, a major issue is to separate the effect of possible hysteresis and the temperature dependence of the diffuser head. Indeed, the change between consequent calibrations is clearly correlated to temperature changes of the optics.

Two factors contribute to the warming up of the diffuser during the day. First, the experiments were performed during sunny weather and under very high ambient temperatures (~40°C) and the diffuser head cannot be cooled down (the temperature stabilisation only allows warming of the optics). Second, the calibration was done using a small portable field calibrator (KS-J1011) and the distance between the diffuser head and a 200W lamp is about 15 cm during calibration, which produces a quick warm up of the teflon and the diffuser body through radiative heat transfer;

2. In order to try to compensate for the temperature sensitivity of the diffuser, the correction proposed by Ylianttila and Schreder (2005) was applied to the data. The sensitivity drop slightly decreases from about 2% to <1.5%, with maximum effect in the middle of the afternoon (e.g., Fig. 1).

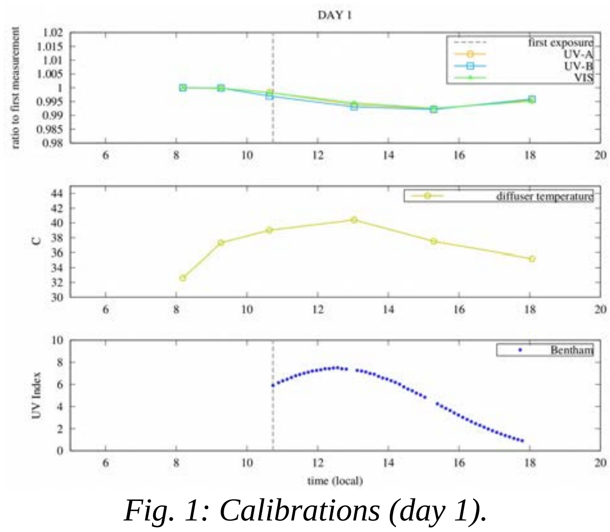


Fig. 1: Calibrations (day 1).

However, correlation with the recorded diffuser temperature is still clear even on a short-term scale (e.g., Fig. 2), which suggests that the temperature is not yet correctly compensated.

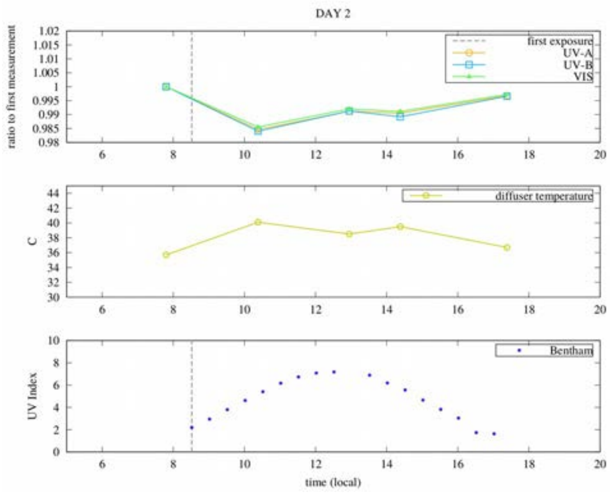


Fig. 2: Calibrations (day 2)

Notably, several calibration in a row without exposing the instrument to sunlight reveal a residual sensitivity decrease of about 0.5% owing to a temperature increase of 8 °C (Fig. 3).

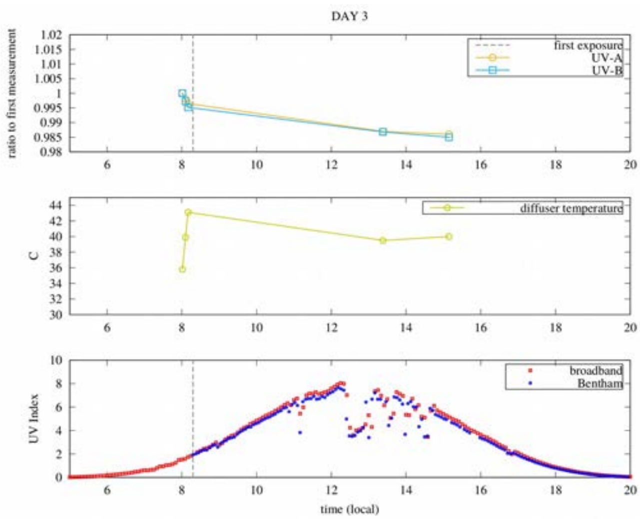


Fig. 3: Calibrations (day 3)

Two reasons can be identified to explain the inefficient temperature compensation:

a. are the coefficients reported in Ylianttila and Schreder (2005) suitable for the AAO optics?

b. is the temperature measured inside the diffuser body (and recorded together with the spectra) representative of the actual teflon temperature?

3. To reduce the contribution of the lamp calibrations over the full spectral range (280-500 nm) to the temperature increase of the optics during the day, the AAO sensitivity was monitored at only few wavelengths, thus remarkably decreasing the duration of the calibration (from ~10 minutes to <1 minute) and allowing more frequent checks. The diffuser temperature still increases a lot during the day due to high ambient temperature and solar irradiance hitting the diffuser body. Again, the drop is ~2% relative to the first calibration (Fig. 4). However, consecutive calibrations in the morning of the next day show a sensitivity decrease of 1% for about 7 °C.

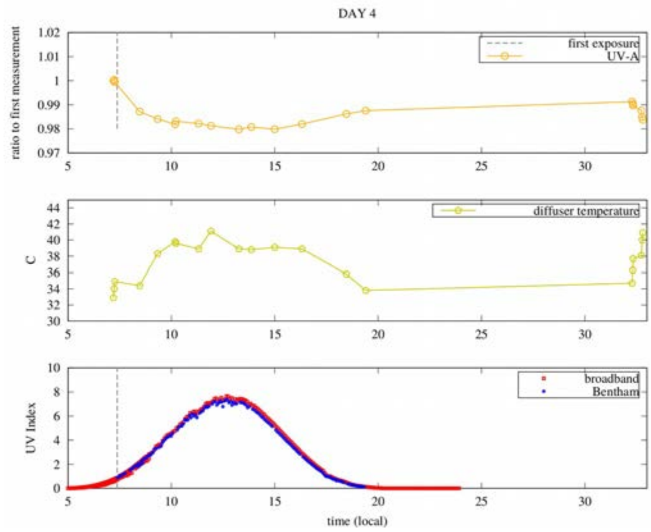


Fig. 4: Calibrations (day 4)

4. Short-term sensitivity changes were also investigated by exposing AAO to sunlight in the middle of the day after a stop of 1 hour and continuously recording the irradiance at only one wavelength (366 nm, where the maximum PMT sensitivity occurs). This value was normalised to the irradiance simultaneously measured by a broadband UV radiometer in order to take account of possible changes in the solar irradiance reaching the ground during the duration of the experiment. The observed drop was ~ 2% after 20 minutes of exposure (Fig. 5). However, it is difficult to extrapolate this result for a full day;

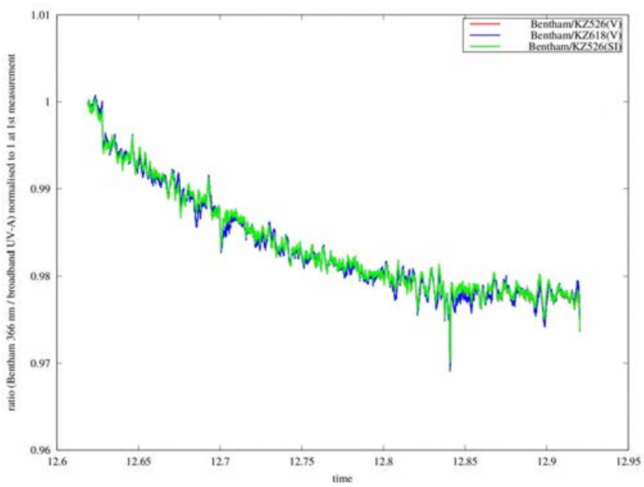


Fig. 5: Short-term sensitivity changes.

5. Irradiance measurements by AAO and colocated broadband UV radiometers during normal operation are within ±1% and do not show any visible diurnal cycle.

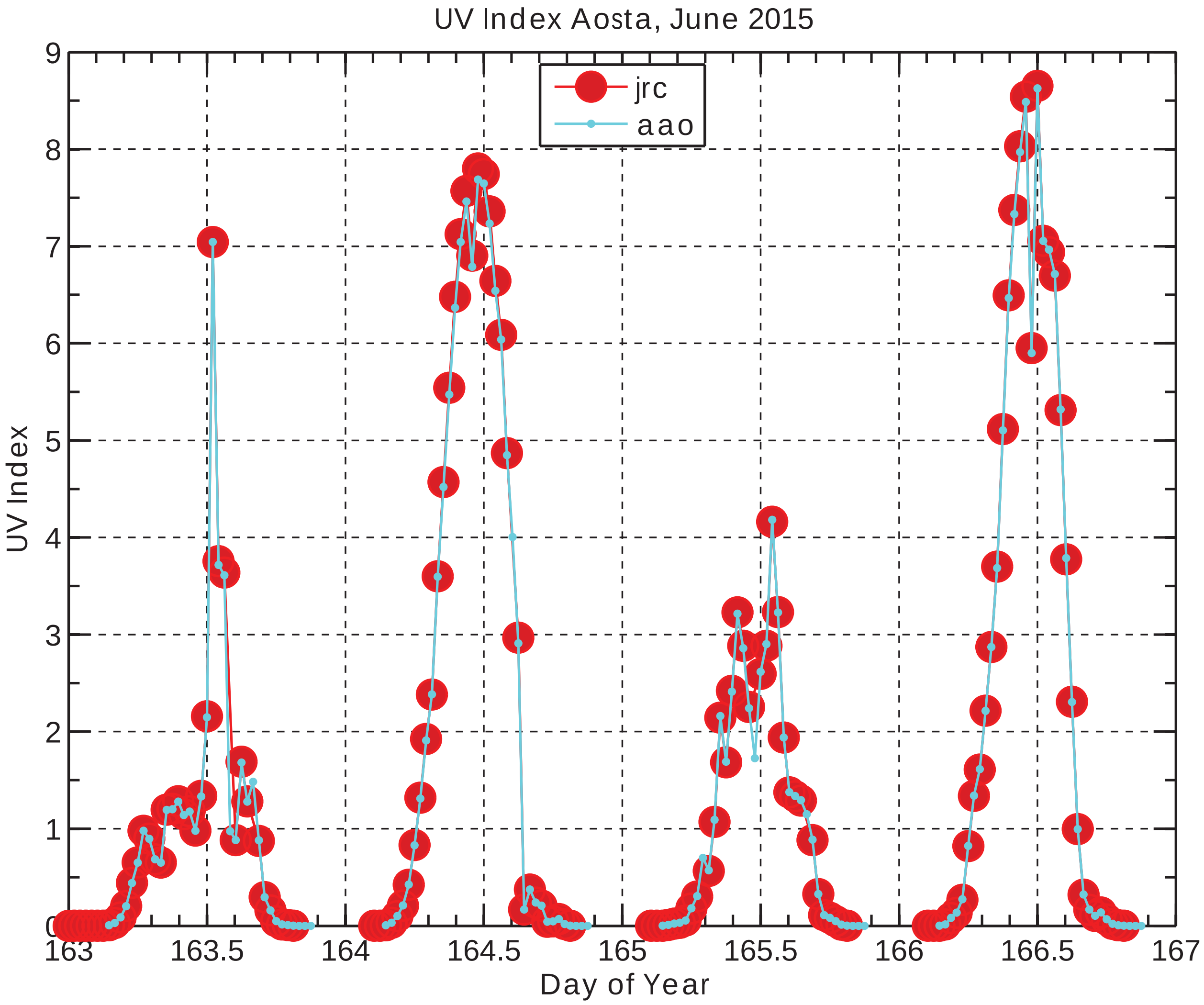
<u>TODO</u>

The core problem being the unexplained variability (0.5-1%) of the sensitivity owing to temperature changes and the related uncertainty in calibrations, more tests are scheduled for the future:

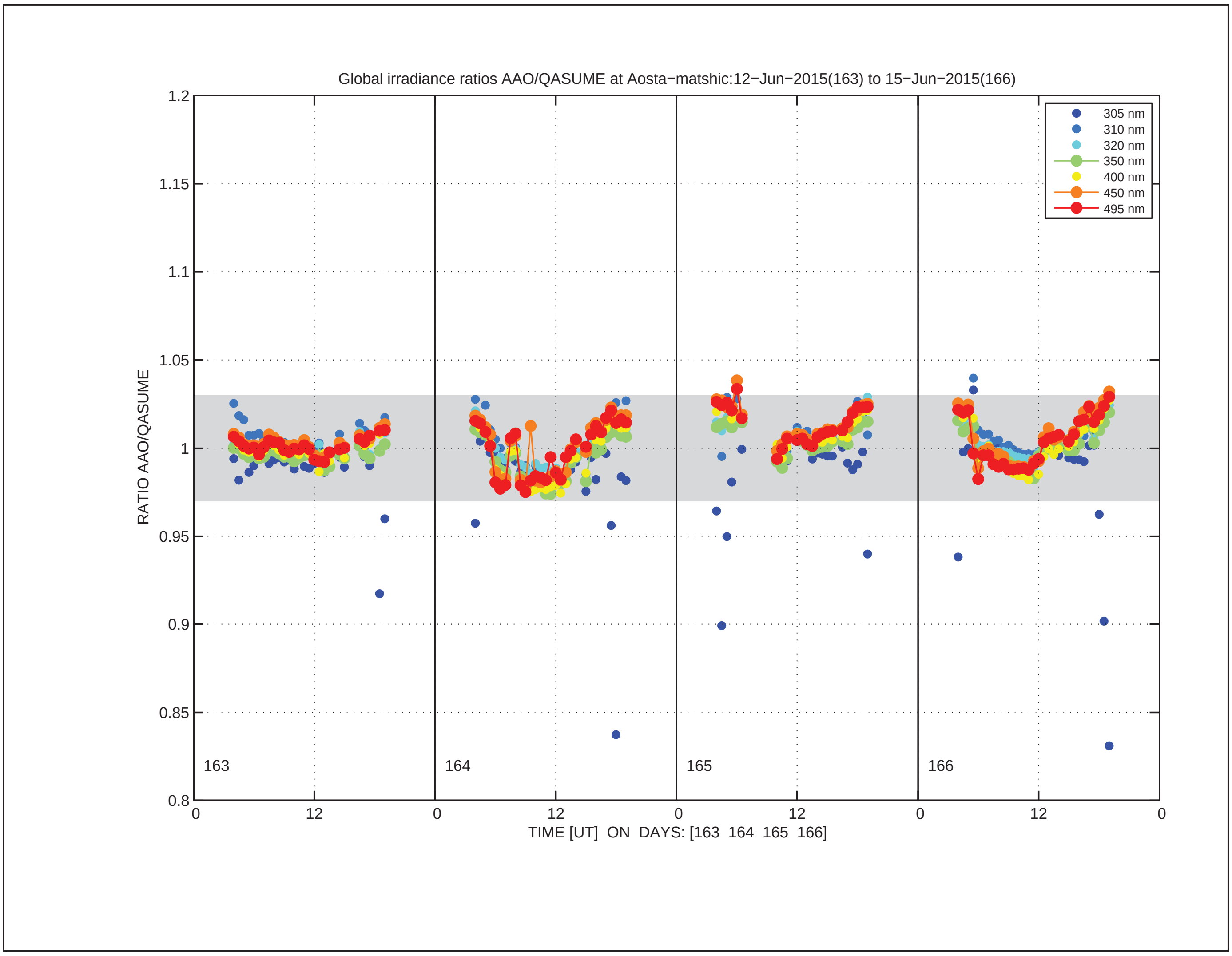
1. Measurements of the diffuser temperature using an infrared thermometer to check whether the temperature recorded in the diffuser body and the teflon temperature agree;

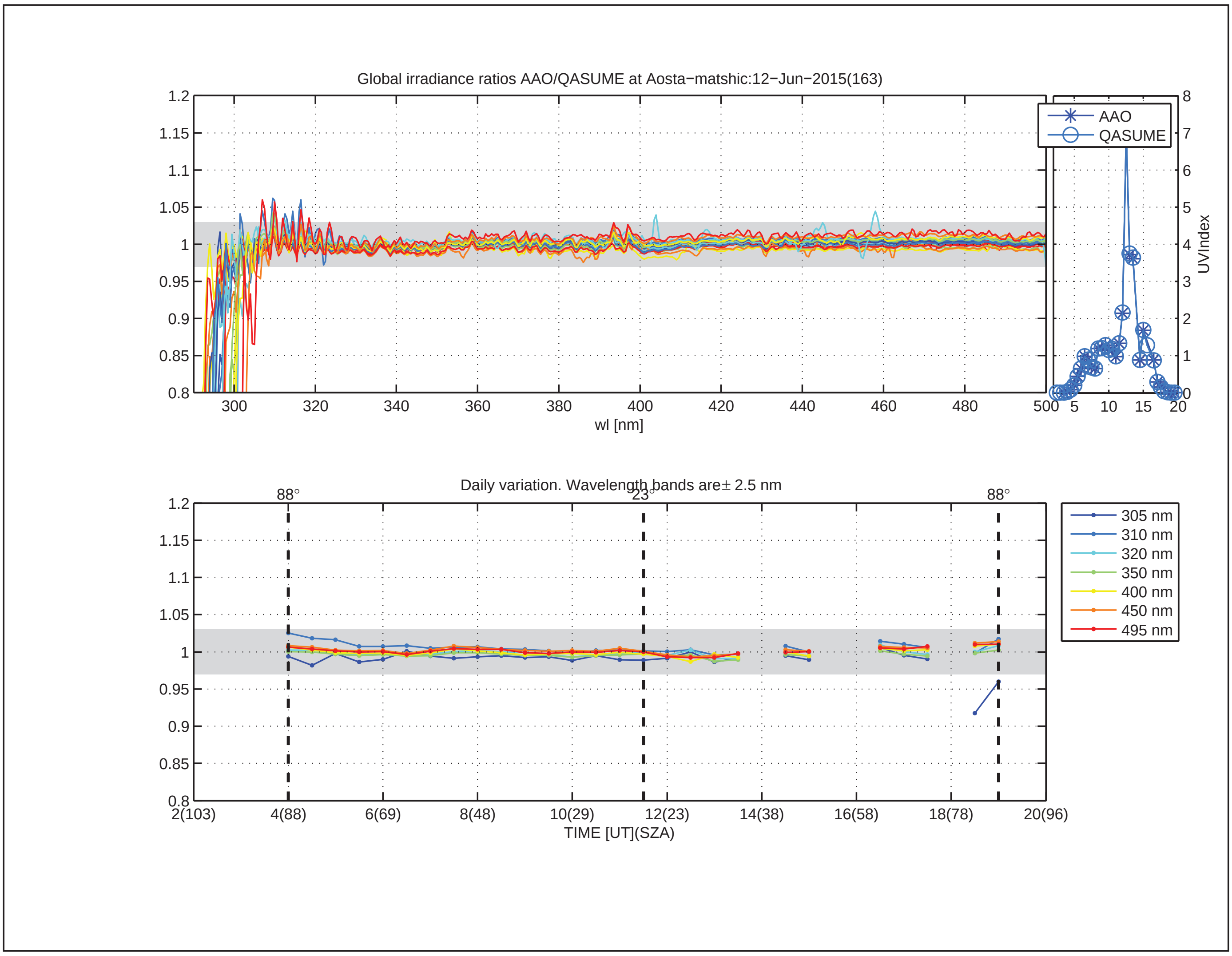
2. A better characterisation of the temperature dependency of AAO optics (several lamp measurements at different temperatures without exposing the instrument to sunlight);

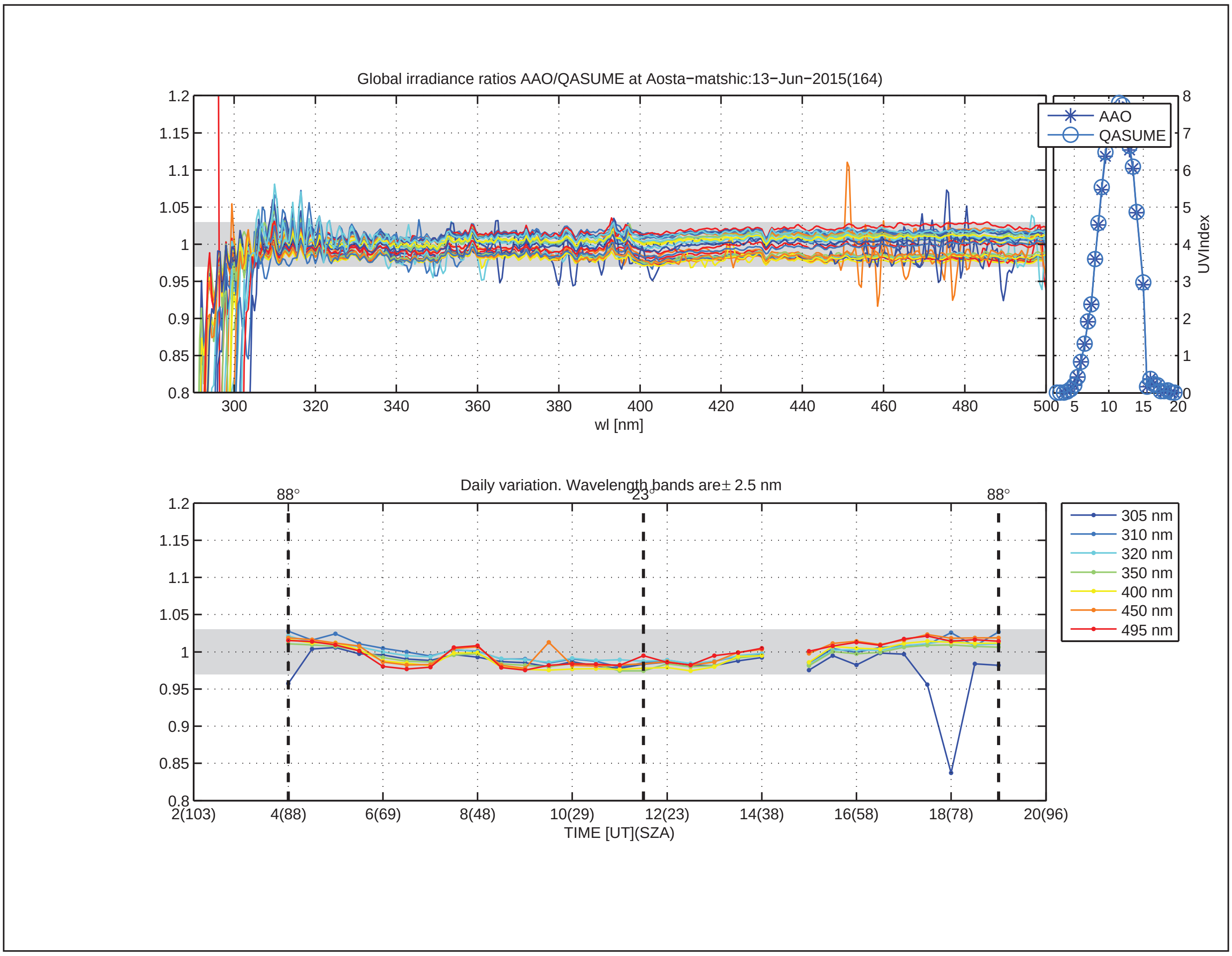
3. Only then, can we understand whether the PMT works correctly or not.

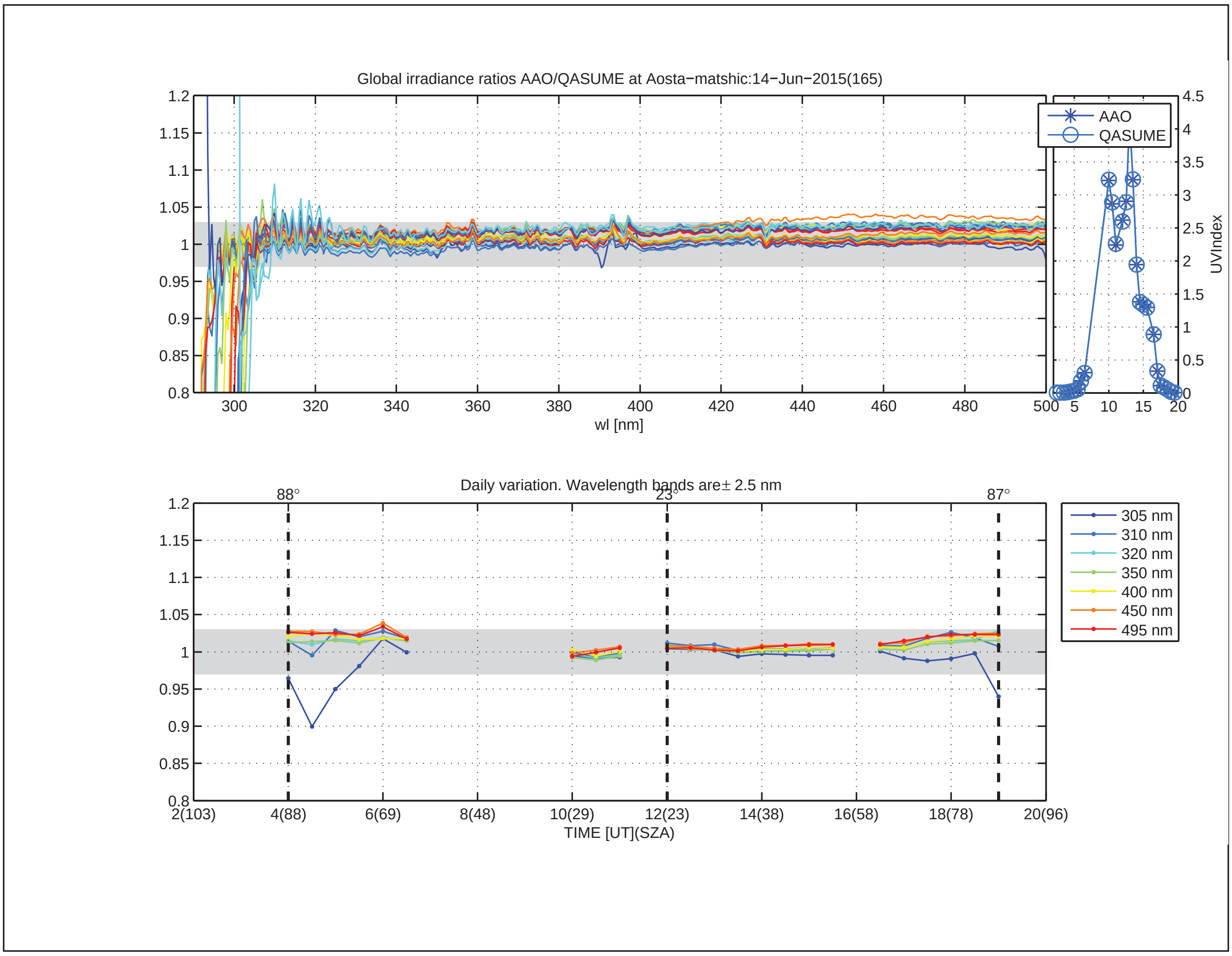


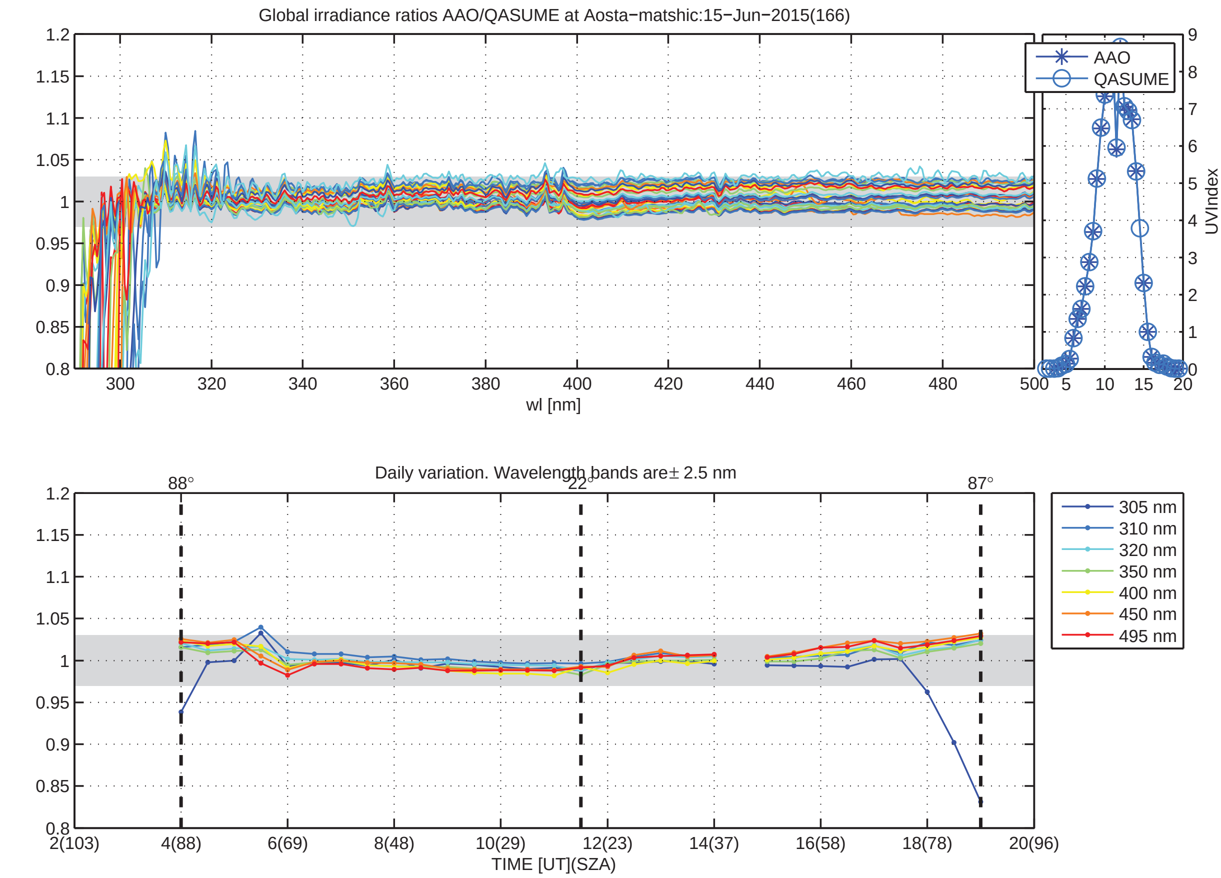
UV Index Aosta, June 2015
jrc
aao
UV Index
Day of Year
0
1
2
3
4
5
6
7
8
9
163
163.5
164
164.5
165
165.5
166
166.5
167


Global irradiance ratios AAO/QASUME at Aosta−matshic:12−Jun−2015(163) to 15−Jun−2015(166)
RATIO AAO/QASUME
TIME [UT] ON DAYS: [163 164 165 166]
163
164
165
166
305 nm
310 nm
320 nm
350 nm
400 nm
450 nm
495 nm

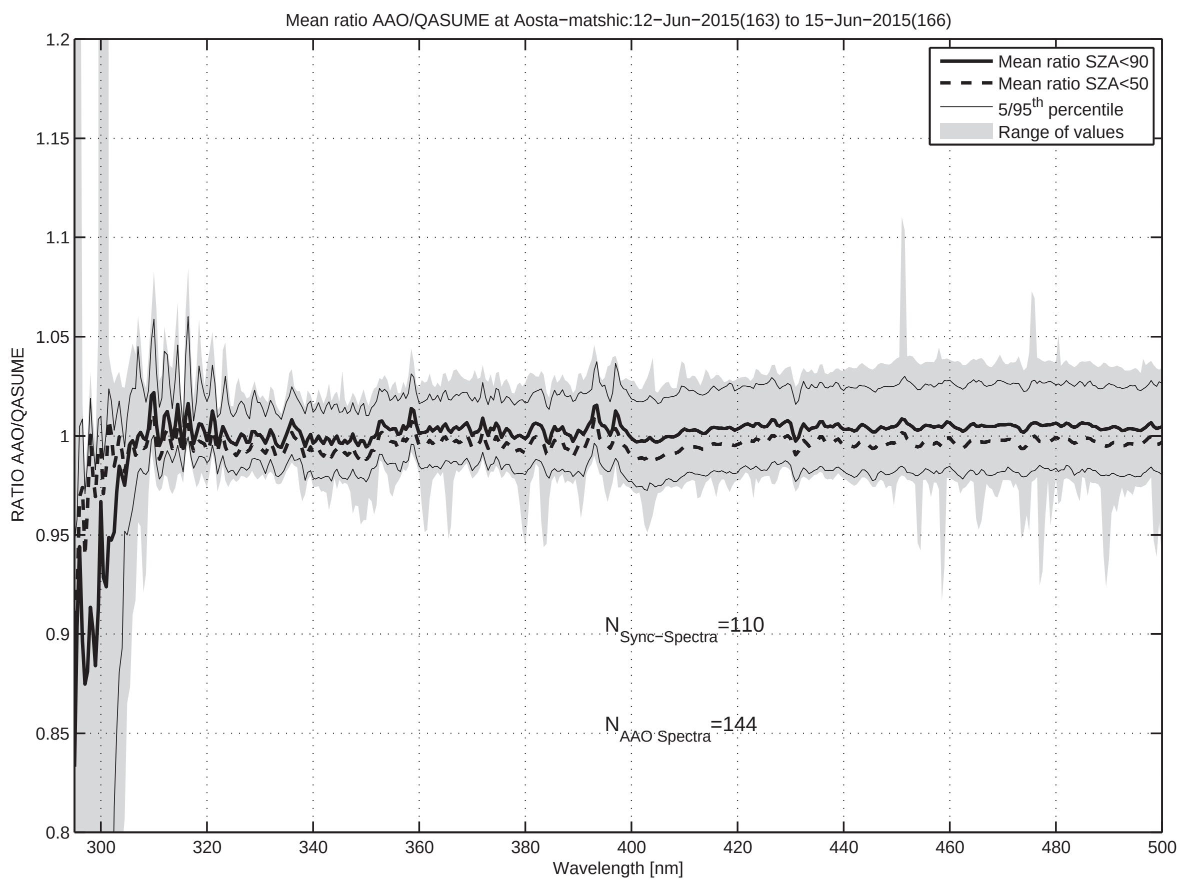

Global irradiance ratios AAO/QASUME at Aosta−matshic:12−Jun−2015(163)
wl [nm]
AAO
QASUME
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
88°
23°
88°
TIME [UT](SZA)
305 nm
310 nm
320 nm
350 nm
400 nm
450 nm
495 nm


Global irradiance ratios AAO/QASUME at Aosta−matshic:13−Jun−2015(164)
wl [nm]
AAO
QASUME
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
88°
23°
88°
305 nm
310 nm
320 nm
350 nm
400 nm
450 nm
495 nm
TIME [UT](SZA)

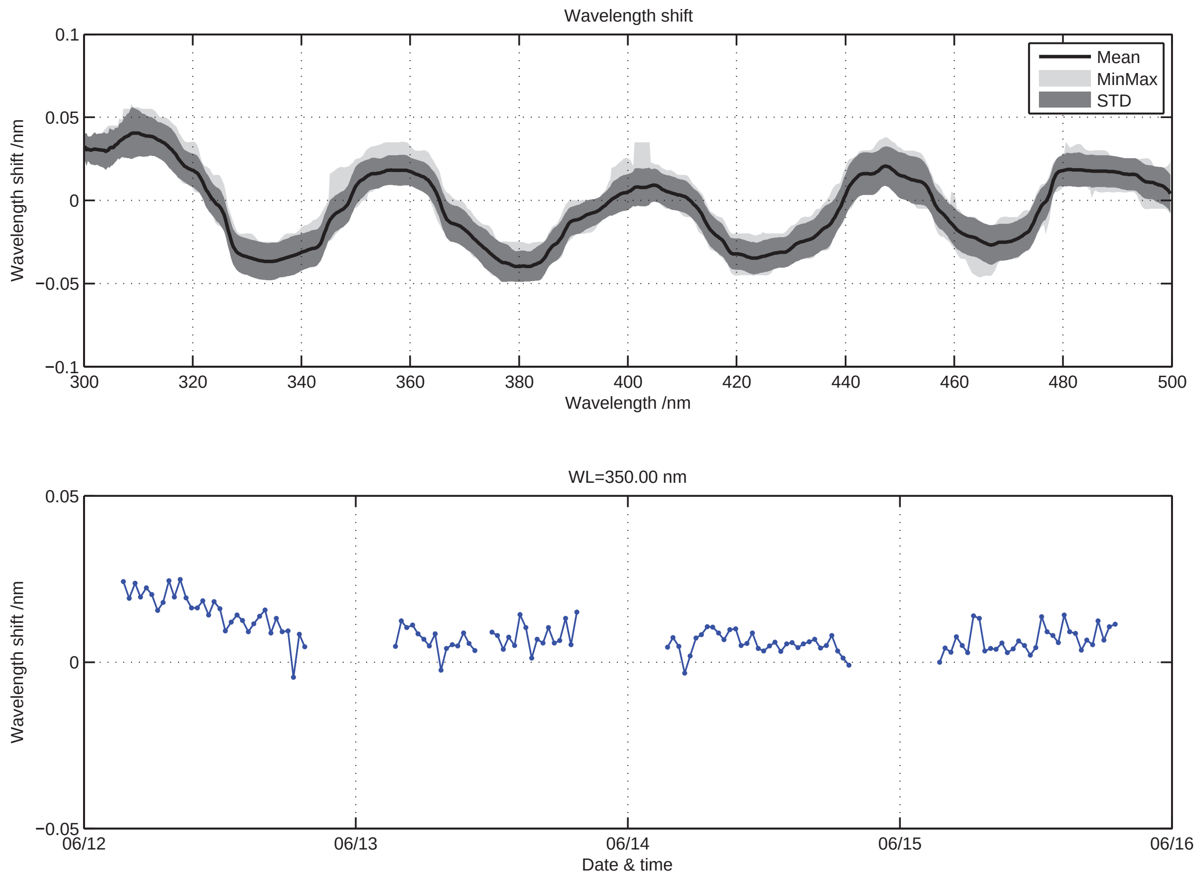

Global irradiance ratios AAO/QASUME at Aosta−matshic:14−Jun−2015(165)
wl [nm]
AAO
QASUME
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
88°
23°
87°
305 nm
310 nm
320 nm
350 nm
400 nm
450 nm
495 nm
TIME [UT](SZA)



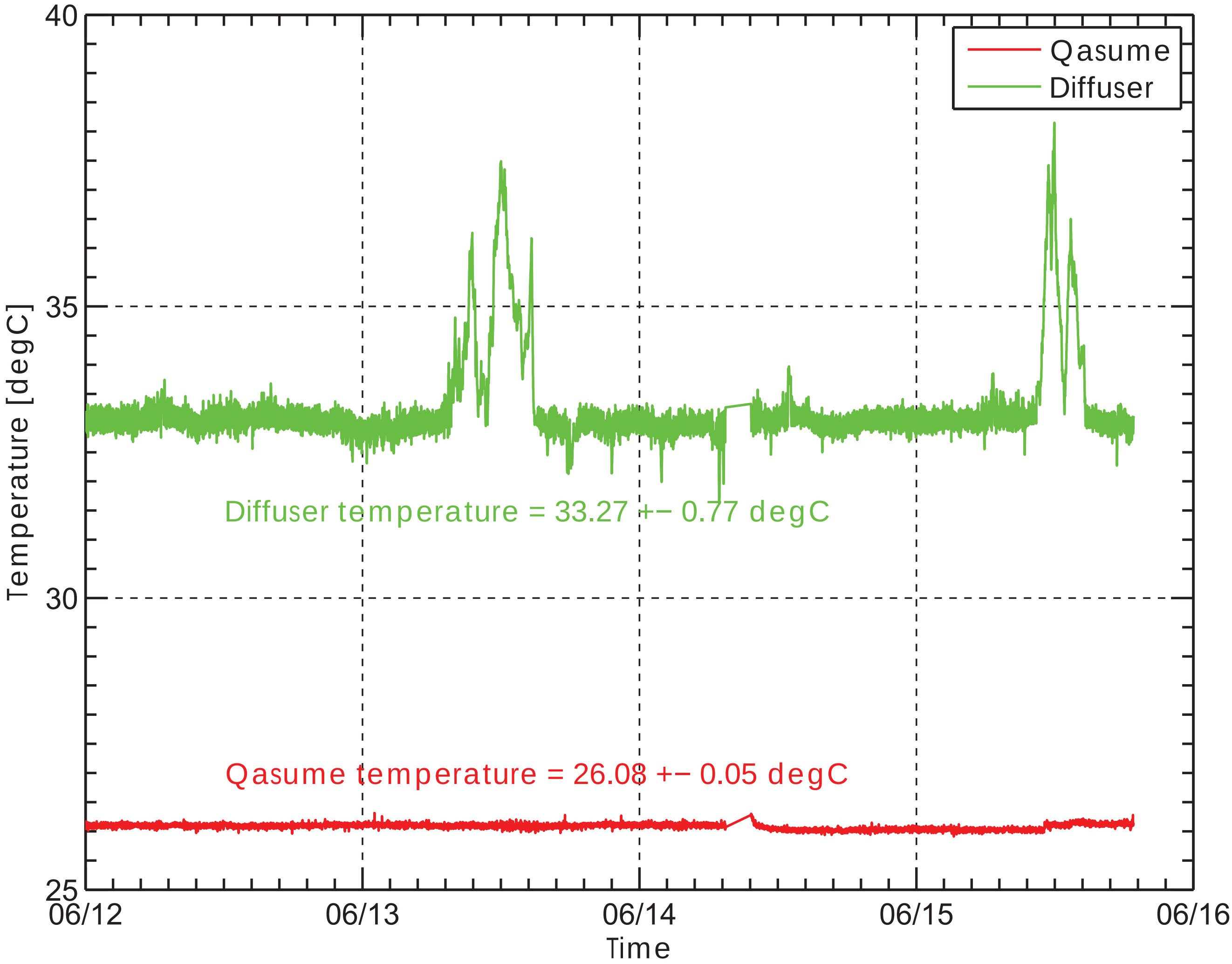
Global irradiance ratios AAO/QASUME at Aosta−matshic:15−Jun−2015(166)
AAO
QASUME
wl [nm]
UVIndex
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
300
320
340
360
380
400
420
440
460
480
500
5
10
15
20
0
1
2
3
4
5
6
7
8
9
Daily variation. Wavelength bands are± 2.5 nm
88°
22°
87°
305 nm
310 nm
320 nm
350 nm
400 nm
450 nm
495 nm
2(103)
4(88)
6(69)
8(48)
10(29)
12(23)
14(37)
16(58)
18(78)
20(96)
TIME [UT](SZA)



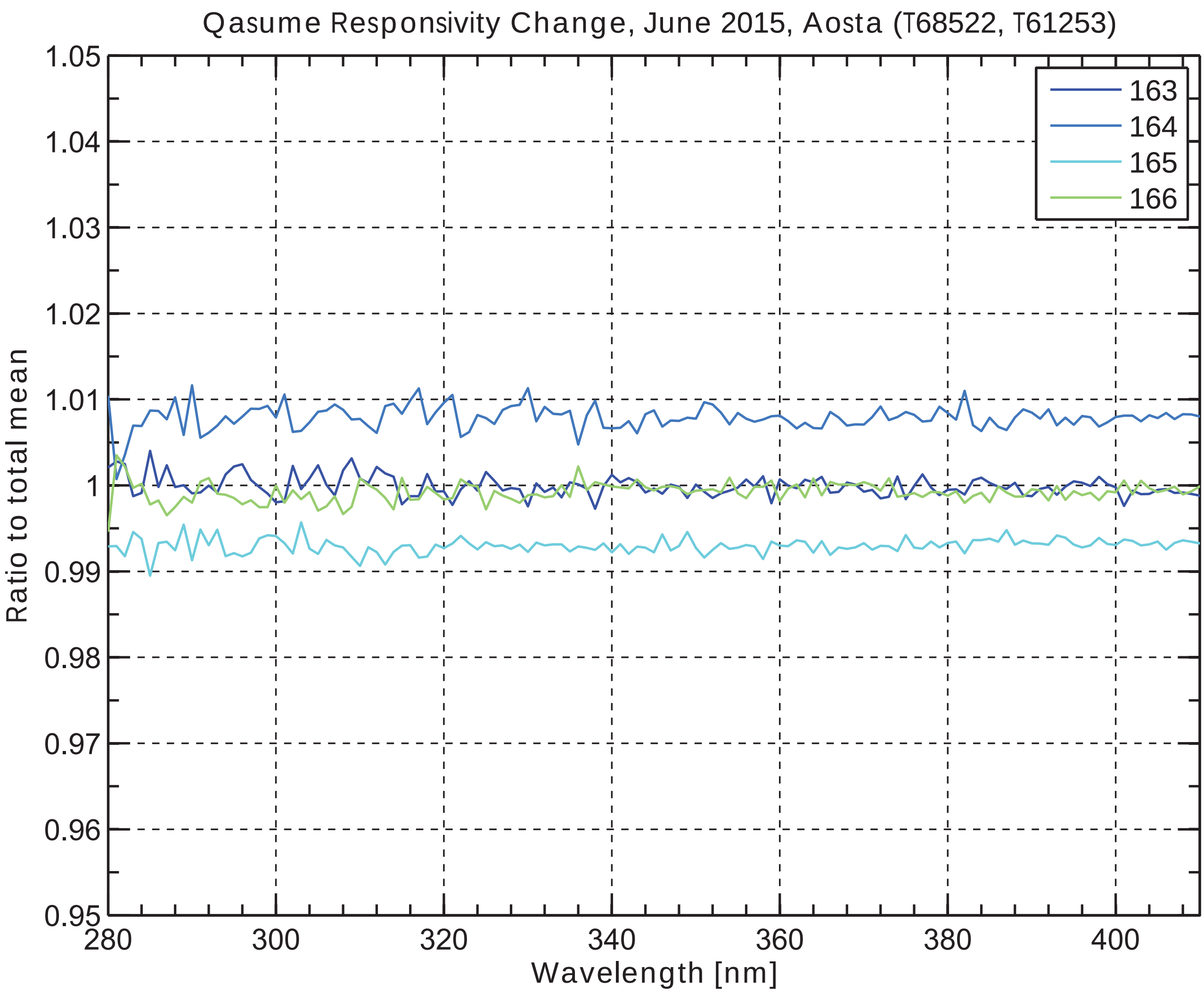
Mean ratio AAO/QASUME at Aosta−matshic:12−Jun−2015(163) to 15−Jun−2015(166)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
Range of values
RATIO AAO/QASUME
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
300
320
340
360
380
400
420
440
460
480
500
Wavelength [nm]
N Sync−Spectra =110
N AAO Spectra =144



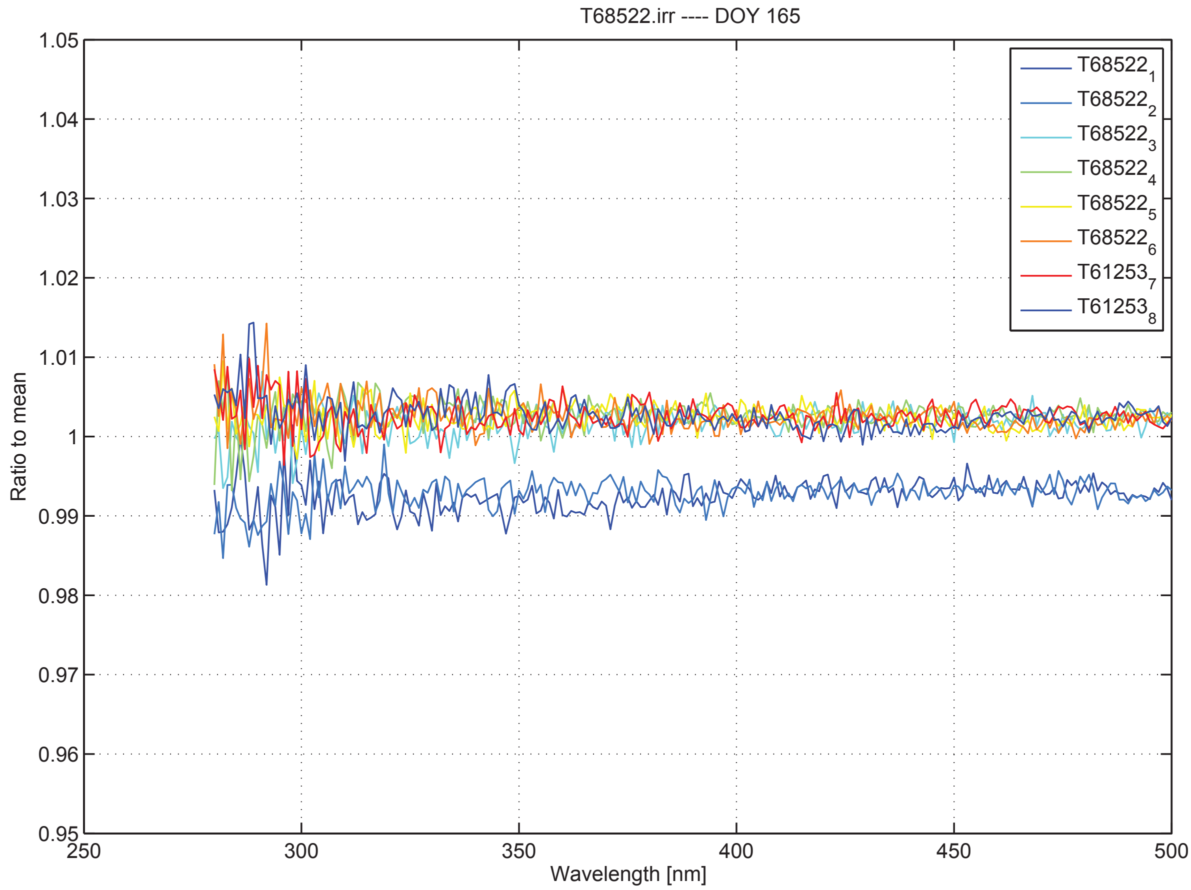
Wavelength shift
Mean
MinMax
STD
Wavelength shift /nm
0.1
0.05
0
−0.05
−0.1
300
320
340
360
380
400
420
440
460
480
500
Wavelength /nm
WL=350.00 nm
Wavelength shift /nm
0.05
0
−0.05
06/12
06/13
06/14
06/15
06/16
Date & time

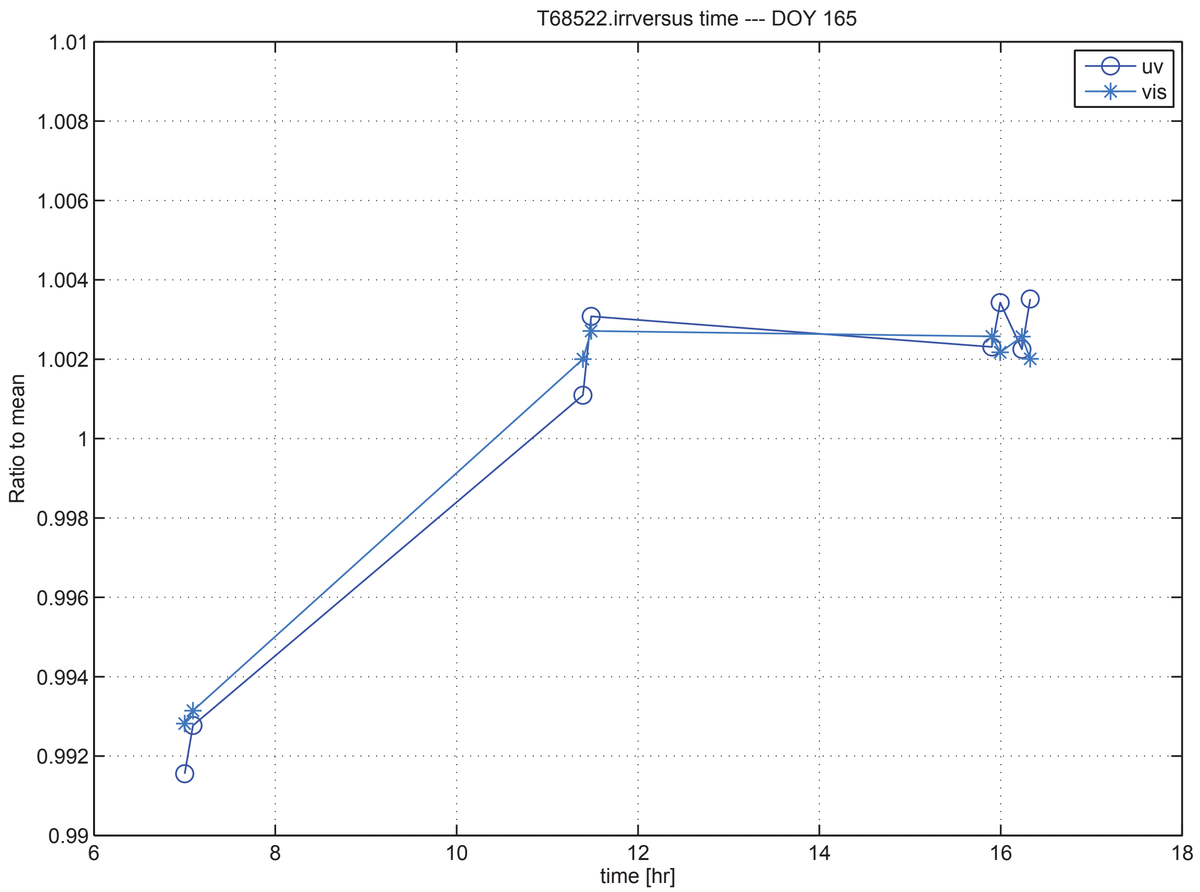


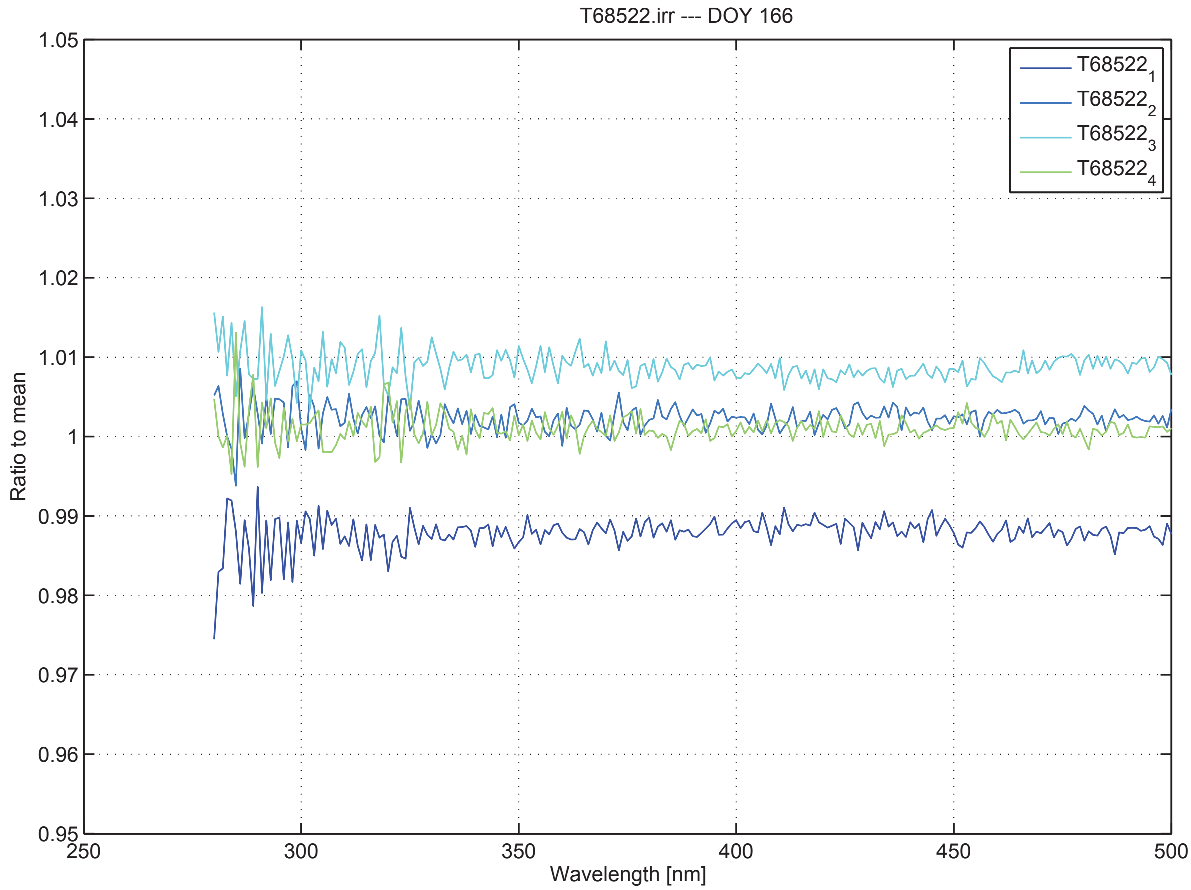
Qasume
Diffuser
Diffuser temperature = 33.27 +− 0.77 degC
Qasume temperature = 26.08 +− 0.05 degC
Temperature [degC]
40
35
30
25
06/12
06/13
06/14
06/15
06/16
Time

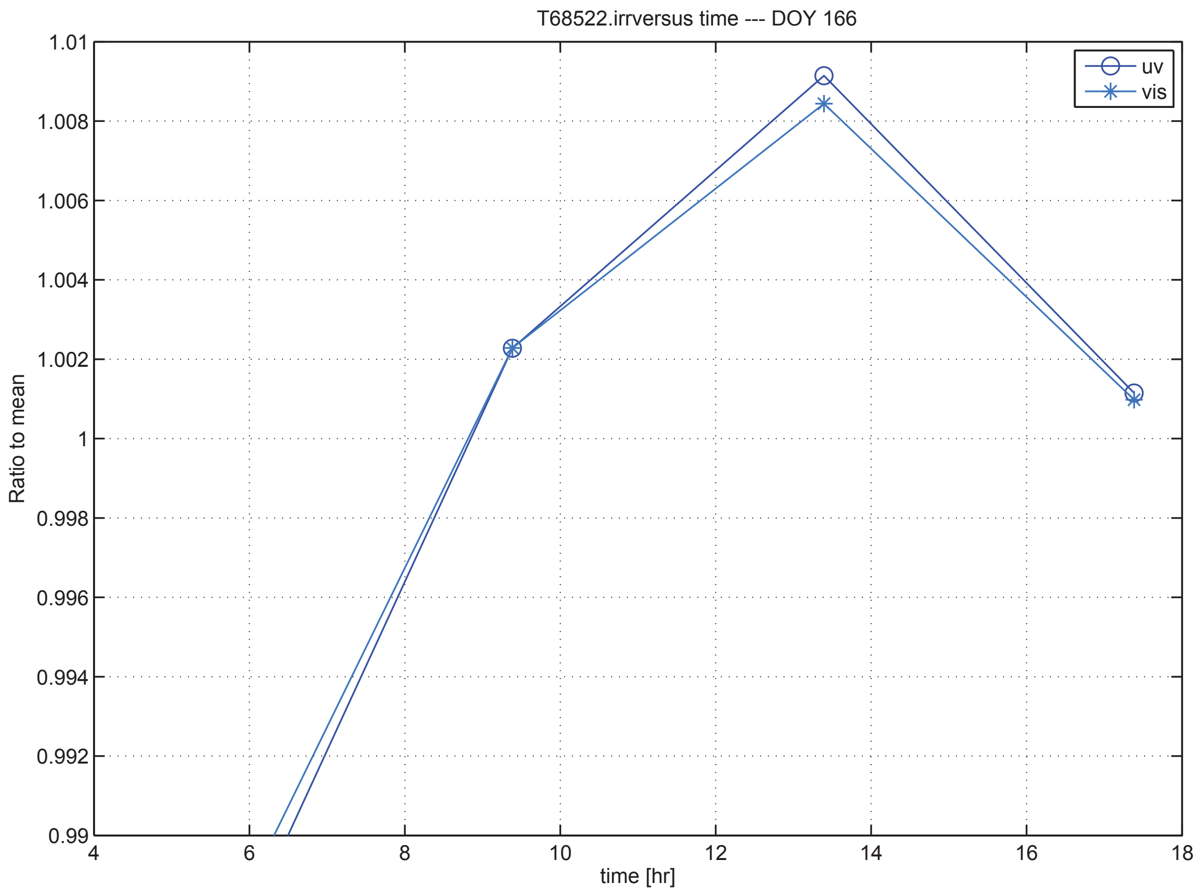


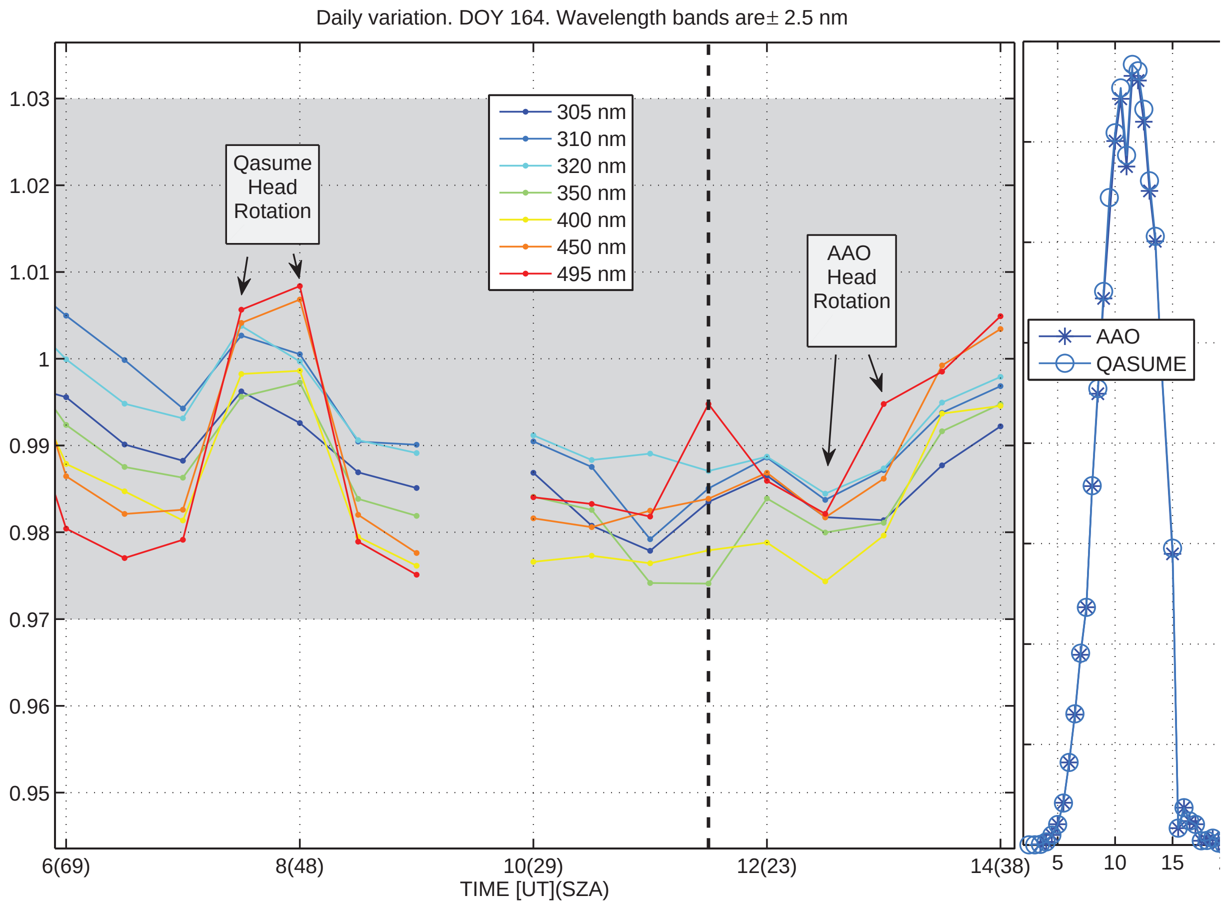
Qasume Responsivity Change, June 2015, Aosta (T68522, T61253)
163
164
165
166
Ratio to total mean
1.05
1.04
1.03
1.02
1.01
1
0.99
0.98
0.97
0.96
0.95
280
300
320
340
360
380
400
Wavelength [nm]

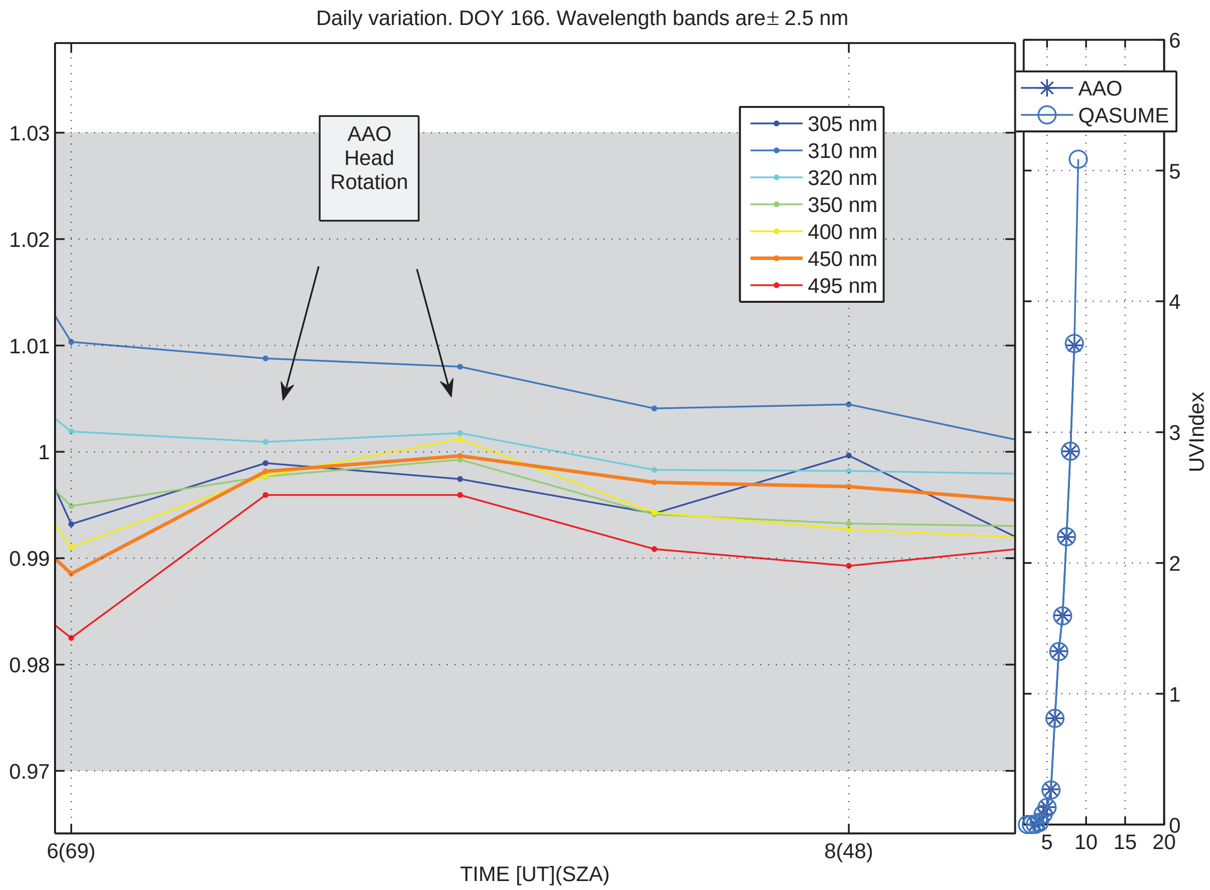

T68522.irr ---- DOY 165
1.05
1.04
1.03
1.02
1.01
1
0.99
0.98
0.97
0.96
0.95
250
300
350
400
450
500
Ratio to mean
Wavelength [nm]
T68522$_1$
T68522$_2$
T68522$_3$
T68522$_4$
T68522$_5$
T68522$_6$
T61253$_7$
T61253$_8$

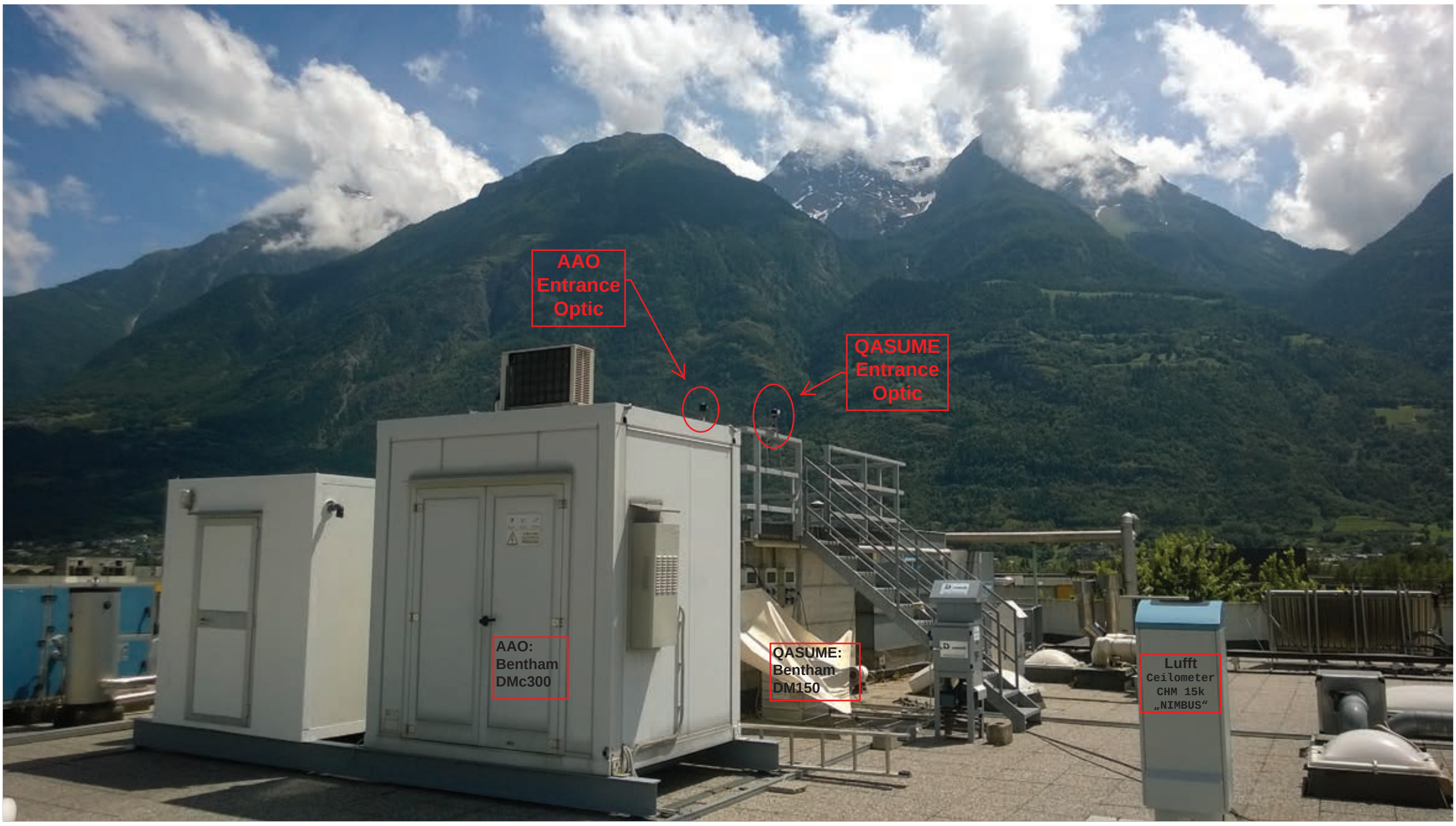

T68522.irrversus time --- DOY 165
1.01
1.008
1.006
1.004
1.002
1
0.998
0.996
0.994
0.992
0.99
6
8
10
12
14
16
18
Ratio to mean
time [hr]
uv
vis


T68522.irr --- DOY 166
T68522_1
T68522_2
T68522_3
T68522_4
Ratio to mean
Wavelength [nm]
1.05
1.04
1.03
1.02
1.01
1
0.99
0.98
0.97
0.96
0.95
250
300
350
400
450
500


T68522.irrversus time --- DOY 166
uv
vis
Ratio to mean
time [hr]
1.01
1.008
1.006
1.004
1.002
1
0.998
0.996
0.994
0.992
0.99
4
6
8
10
12
14
16
18


Daily variation. DOY 164. Wavelength bands are± 2.5 nm
1.03
1.02
1.01
1
0.99
0.98
0.97
0.96
0.95
Qasume Head Rotation
305 nm
310 nm
320 nm
350 nm
400 nm
450 nm
495 nm
AAO Head Rotation
6(69)
8(48)
10(29)
12(23)
14(38)
TIME [UT](SZA)
AAO
QASUME
5
10
15


Daily variation. DOY 166. Wavelength bands are± 2.5 nm
1.03
1.02
1.01
1
0.99
0.98
0.97
AAO Head Rotation
305 nm
310 nm
320 nm
350 nm
400 nm
450 nm
495 nm
6(69)
8(48)
TIME [UT](SZA)
AAO
QASUME
0
1
2
3
4
5
6
UVIndex
5
10
15
20


AAO Entrance Optic
QASUME Entrance Optic
AAO: Bentham DMc300
QASUME: Bentham DM150
Lufft Ceilometer CHM 15k „NIMBUS"