Protocol of the intercomparison at FMI, Jokioinen, Finland on May 24 to 29, 2010 with the travelling reference spectroradiometer QASUME from PMOD/WRC

Report prepared by Gregor Hülsen, Julian Gröbner

Operator: Gregor Hülsen

The purpose of the visit was the comparison of global solar irradiance measurements between the four spectroradiometers FIJ, FIS, FIB and FID operated by the Finnish Meteorological Institute (FMI) and the travel reference spectroradiometer QASUME. 2 NILU-UV 6-channel instruments (102 and 131) were run side-by-side the QASUME spectroradiometer throughout the campaign.
The measurement site is located at Jokioinen; Latitude 60.81 N, Longitude 23.50 E and altitude 104 m.a.s.l. The horizon of the measurement site is free down to at least 85° solar zenith angle (SZA). Measurements between 2:00 UT and 18:00 UT have been analysed.

QASUME was installed on the measurement platform of the Jokioinen Observatory in the afternoon of May 24, 2010. The spectroradiometer was installed between the four spectroradiometers of FMI with the entrance optic of QASUME within 4 m to the other instruments. The spectroradiometers in use at FMI are the Brewer #107 (FIJ - Jokioinen), the Brewer #037 (FIS - Sodankylä), a Bentham DT150 double monochromator (FIB) and a Diode Array (FID). The intercomparison between QASUME and the FMI spectroradiometers lasted five days, from morning of May 25 to evening of May 29.

QASUME was calibrated several times during the intercomparison period using a portable calibration system. Two lamps (T68522 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 less than ±1 % during the intercomparison period. The internal temperature of QASUME was 25.8±0.1 °C for the first two days. The temperature was lowered by 2 °C in the evening of May 26. After this the temperature was 23.8±0.1 °C. The diffuser head was heated to a temperature of 27.9±0.9 °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 400 nm.

Protocol:

The measurement protocol was to measure one solar irradiance spectrum every 30 minutes from 290 to 400 nm, every 0.5 nm, and 3 seconds between each wavelength increment.

DOY	Date	DAY	Weather	Comment
144	24. Mai	Monday	Rain with few dry periods	Installed at 12:00 UT
145	25. Mai	Tuesday	Mostly overcasted sky Sunny period: 8-10 UT Rain shower at 13:15 UT	Calibrated: 3:12, 3:44 and 14:13 UT using T68522
146	26. Mai	Wednesday	Clear sky in the morning Overcast from 11 UT on Rain after 15:30 UT	Calibrated: 9:14 UT using T68522
147	27. Mai	Thursday	Overcast sky Rain showers throughout the day	Calibrated: 11:12 UT using T68522
148	28. Mai	Friday	Overcast sky	Calibrated: 8:13, 8:29, 8:45 UT using T68523, T61253, T68522 UV scan @ 8:30 missing
149	29. Mai	Saturday	Overcast sky	Calibrated: 6:14 UT using T68522 End of Campaign: 14:00 UT

Results:

In total 135/136/109/143 synchronised simultaneous spectra from QASUME and FIJ/FIS/FIB/FID are available from the measurement period. Measurements between 2:00 and 18:30 UT have been analysed (SZA smaller than 90°).

Spectra disturbed by rain showers and drops have been excluded form the analysis. The 27th May (DOY 147) was therefore completely removed.

Remarks:

I. FIJ (Brewer #107)

1. The ratios between FIJ and QASUME have on average an offset of +5 %, which is comparable to the intercomparison in 2007 (see Figure).
2. The FIJ Brewer #107 was calibrated prior to the intercomparison on 20th May using six FMI lamps. The calibration was repeated twice after the campaign to determine the reliability of the four FMI 1000W primary standards (see comments of the operator). The final data were processed using the mean of the response curves obtained from the lamps D03, D05 and D14 on 20th May.
3. The diurnal variation of the FIJ to QASUME ratio is below 1 %.
4. For all solar scans the wavelength shifts of the FIJ are between ±80 pm.

II. FIS (Brewer #037)

1. The ratios between FIS and QASUME have on average an offset of +2 % for wavelengths longer than 305 nm, which is about 2 % lower than during the intercomparion in 2007 in Sodankylä.
2. The FIS Brewer #037 was calibrated using the FMI Lamp D24 measured in the dark room at Jokioinen on 24th May.
3. Below 305 nm, the measurements of FIS shows higher irradiances which are due to internal stray light of the single monochromator.
4. The diurnal variation of the FIS to QASUME ratio is around 3 %.
5. For all solar scans the wavelength shifts of the FIS are below ±20 pm.

III. FIB (see also comment from the operator)

1. The ratios between FIB and QASUME have on average an offset of +6 % for wavelengths longer than 305 nm.
2. The instrument was calibrated using the FMI Lamp D41 prior to the intercomparison. During the campaign it was calibrated two times using T68522 from PMOD/WRC. A difference of 5 % was found between FMI Lamp D41 and T68522 Lamp calibration (see comments from the operator).

3. On 27 May the dispersion of FIB was measured using an Hg and Cd spectral emission lamps. The large wavelength shifts of -500 pm above 335 nm could be reduced to ±50 pm.

IV. FID

1. The ratios between FID and QASUME have on average an offset of -5 % for wavelengths longer than 315 nm. The difference between the irradiance measurement of FID and all other FMI spectroradiometers is therefore around 10 %, although the calibration of this instrument is based on FMI irradiance scale.
2. The instrument was calibrated prior to the intercomparison on the 19th May using FMI lamps D01 and D41 in May. The response based on D41 was used for the processing of the data.
3. The data of FID was processed as described below (see comments from the operator) to fit the measurement protocol: one solar irradiance spectrum every 30 minutes from 290 to 400 nm, every 0.5 nm, and 3 seconds between each wavelength increment.
4. The ratio FID and QASUME shows a high spectral variability, probably due wavelength dependent slit function of FID.
5. Below 315 nm, the measurements of FID shows higher irradiances which are due to internal stray light of the single monochromator. The erythemal weighted irradiances are overestimated by more than 50 %.

V. NILU-UV

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

1. The agreement between NILU-UV 102 and QASUME is good, with an average ratio of 1.02 and a standard deviation of than 4 %.
2. The average ratio NILU-UV 131 and QASUME is 0.87 and a standard deviation of than 3 %.
3. The ratio of NILU-UV 131 has an average on offset of -20 %.
4. The calibration of the NILU-UV 102 is based on the calibration performed by the manufacturer, Nilu Products, on 30th June 2004.
5. The calibration of the NILU-UV-131 is based on the calibration performed by the manufacturer, Nilu Products, on 7th June 2008.

<u>Comments for the operator:</u>

1.) **FIJ**: Report on the FMI Helsinki Brewer Spectrophotometer 107
Tapani Koskela, September 2010

A revision of the primary dataset was due to

- a need to repeat the laboratory calibrations several times before we could tell which of our 1000W primary standards were reliable and which were not
- the difficulty in determining the instrument response because of an increase in the instrument's noise level during the last 12 months

As a result we obtained new response that was used in processing the revised data set. The revision does not make the QASUME instrument and the site instrument (Brewer #107) to agree better, rather the opposite. The irradiances increase by 1-2%, more at shorter wavelengths and less towards the longer end.

No other changes to the data were introduced.

2.) **FIB**: Report on the FMI Helsinki Bentham Instrument (FIB)
Stelios Kazadzis, 28 May 2010

The instrument was calibrated in the dark room of Jokioinen on May 24, 2010 using a (D41) DXW irradiance calibration source that was calibrated at HUT. The reference plane for measuring the distance from the lamp was initially measured 3.5 mm above the diffuser circle plane because of a miscalculation in the D41 calibration dark room at Jokioinen. Using the recommendation by Gröbner et al.[†] the response was recalculated using as reference plane the plane 4 mm behind the top of the dome.

The instrument performed synchronized measurements for the days 145 and 146 using this irradiance scale. On day 146 absolute calibration levels of Qasume instrument and the FIB instrument were compared. This was done by (both instruments) measuring the T68522 lamp using the QASUME calibrator at the roof. Results showed a ~5% difference in the irradiance scales (fig. 1).

[†] Gröbner J., Blumthaler M.: Experimental determination of the reference plane of shaped diffusers by solar ultraviolet measurement, Optics Letters, Vol. 32 (1), 2007.

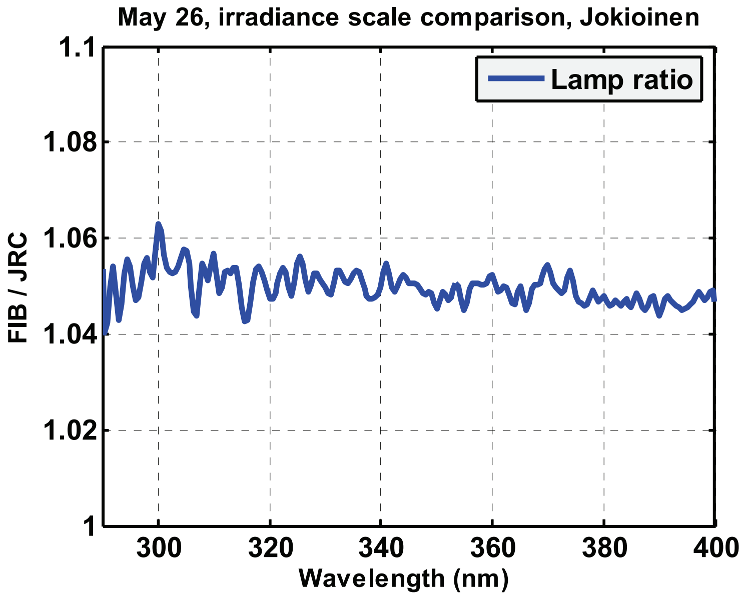


Figure 1.: Irradiance scale comparison using T68522

The wavelength calibration that was used was based on the 2007 calibration having problems in the UVA area due to lack of emission lines. The dispersion measurements were performed on May 27th using emission lines of HG and CD.
On day May 28th (DOY 148) the instrument was recalibrated using the T68522 QASUME lamp at the roof and the new dispersion files. Synchronized measurements for day 148 were based on this calibration and the new dispersion files (the 09:00 UT scan for day 148 was not synchronized).

3.) **FID**: Report on the FMI Helsinki Diode Array spectroradiometer MCS46355
Anu Heikkila, July 2010

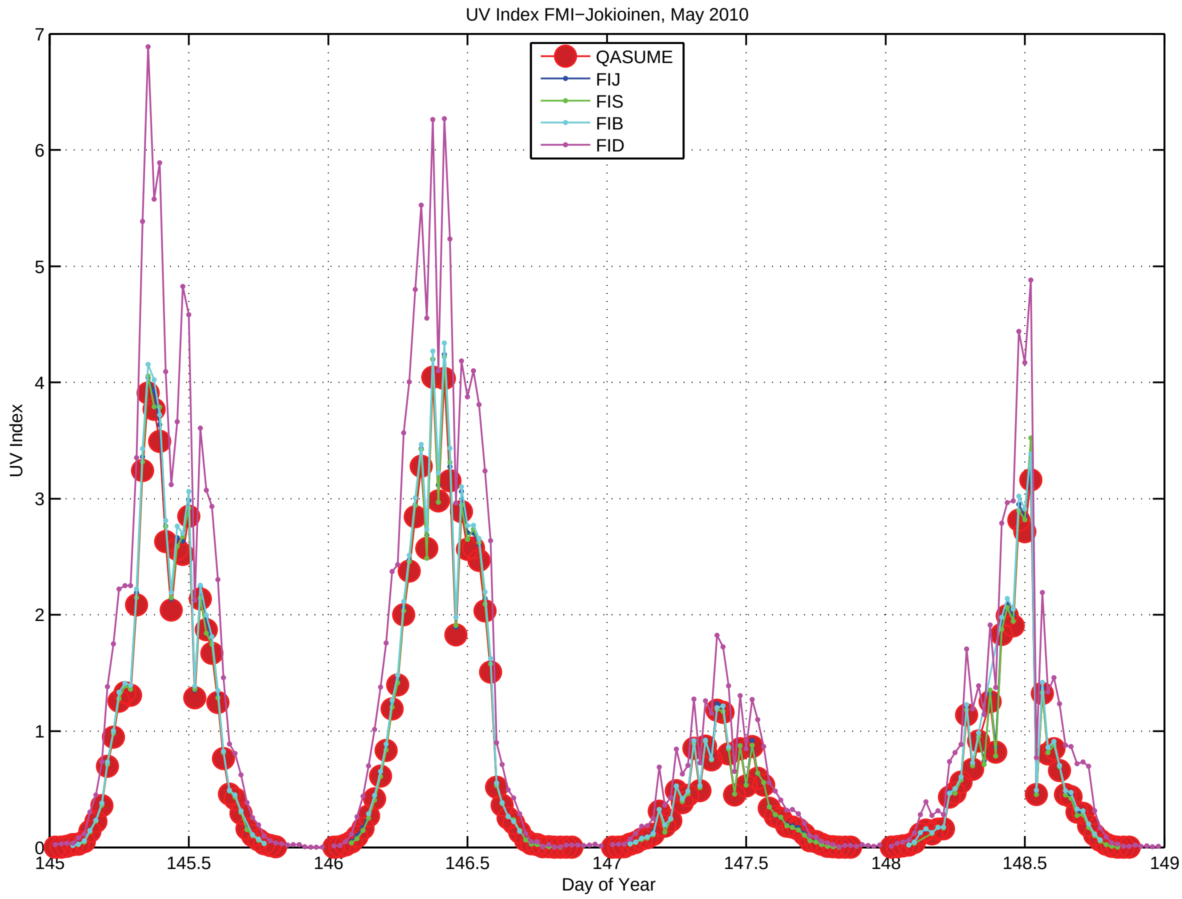
Data processing:

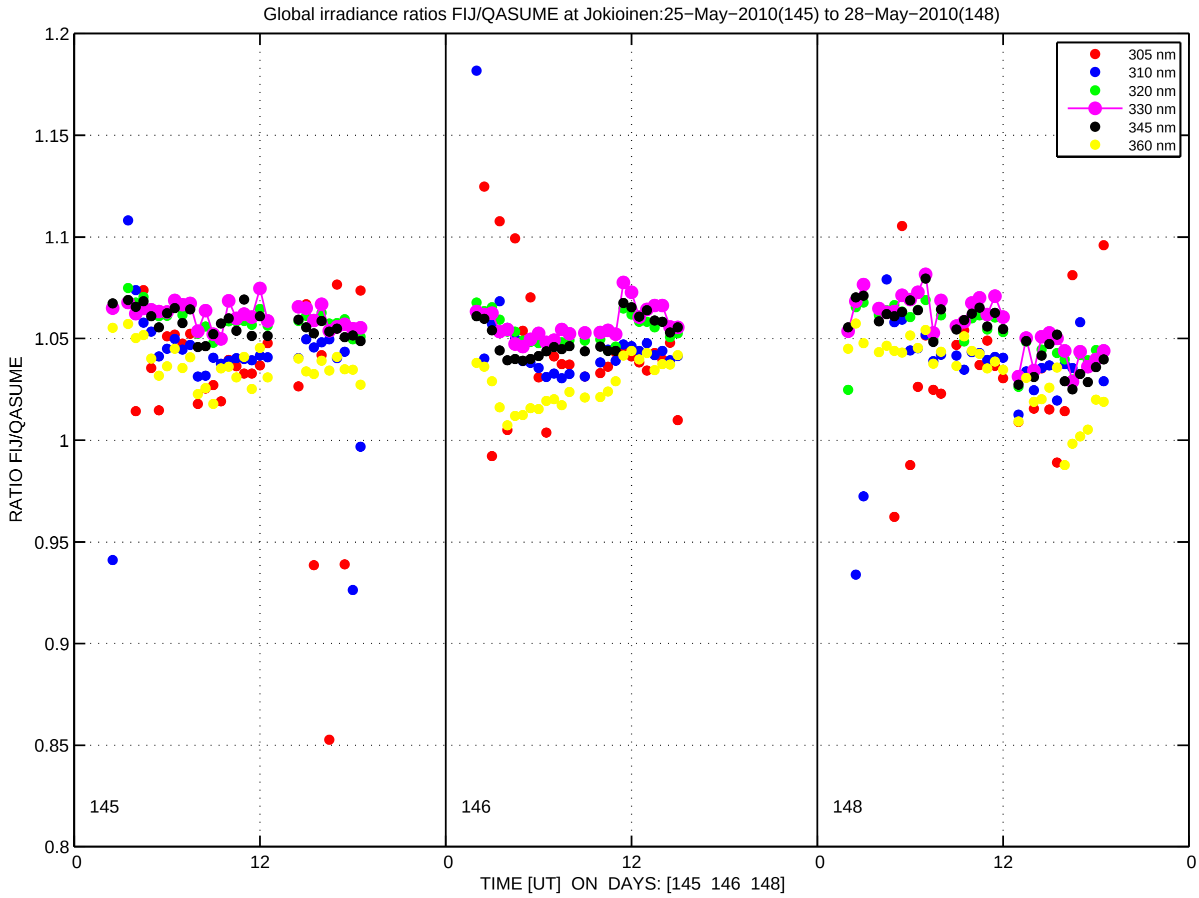
A. No cosine correction has been applied. No deconvolution of slit function has been done.
B. The spectra have been constructed by consecutive measurements of MCS in a patchwork style.
C. From the measurement schedule of QASUME instrument (starting every hour and every half hour, scanning with 0.5 wavelength step and 3s time step), an algorithm has been written that piecewise collects the irradiance values from the measured daily spectra. A best possible temporal match is used as selection criterium. Files jjjhhmmG.fid (letter "d" denoting "diode array") contains these spectra, still in the wavelength resolution of MCS.
D. The constructed spectra are further "resampled" to match the wavelength resolution of QASUME instrument. These spectra are stored in files jjjhhmmG.fic (letter "c" denoting "converted"). A straightforward approach has been used in this first trial, employing a

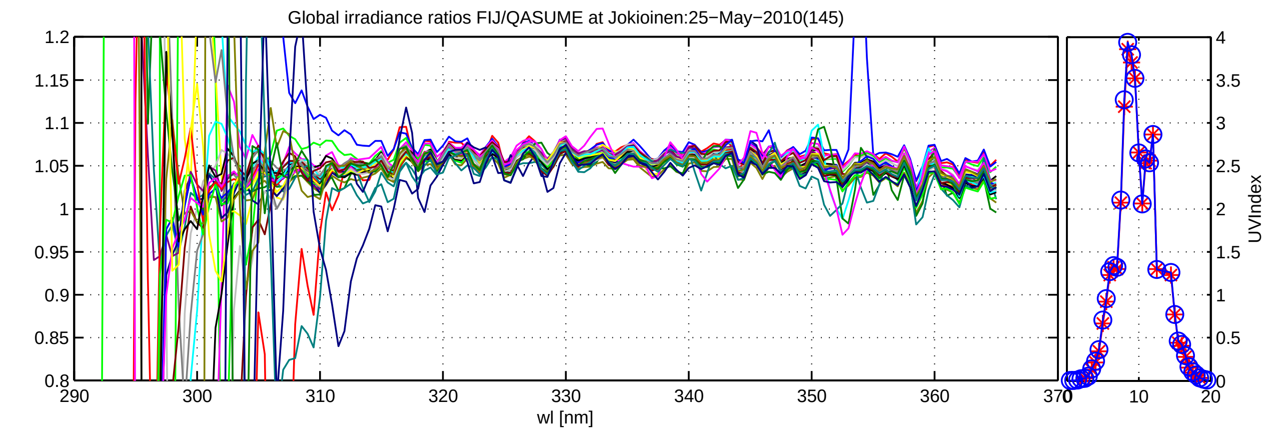
cubic spline interpolation. While this approach will likely result in excessive smoothing and blurring of fine structures in the solar spectra, development of a more sophisticated method should be considered in the future.

E. Three changes in the process of the data has been implemented as regards the first on-site attempt:
    a. The response of the instrument is now solely based on the highest integration time used in dark room for standard lamp measurements. The counts received from the Sun are multiplied with the response and divided by the integration time used in the sky measurement.
       In the first processing, responses derived for each and every integration time were used as such. This approach turned out inapplicable, as the counts measured from the lamp remain well below those received under the Sun, thus remarkably limiting the dynamic range of the laboratory measurements.
    b. The counts are collected from the column I.MEAN[cts] containing the offset corrected counts.
       In the first processing, the counts were erroneously collected from the column I.MEANraw[cts].
    c. The ranges of wavelengths included in the process were extended to cover wavelengths from 280 nm to 410 nm (previously: 290 nm to 400 nm). This was done because the irradiance values obtained for the first and last wavelength considered in the campaign, i.e. 290 nm and 400 nm, seemed to get out-of-range values in the first processing because of the interpolation used for resampling the irradiances on the wavelengths used by the reference instruments. The very same interpolation also occasionally produces negative irradiances when the irradiance levels are very low. In the final step of the processing, the negative irradiances were set to zero and the wavelength range of the output files is set to 290-400nm.

F. After the process of the data, indications on unreliability of both the FMI lamp d01 and d41 arose. However, no other primary lamps were measured in the calibration preceding the campaign on the 19th of May, 2010. Therefore, determination of response as based on alternative measurements was not possible, as in the case of FIJ. This might explain some part of the difference between FID and the other FMI instruments.


UV Index FMI−Jokioinen, May 2010
QASUME
FIJ
FIS
FIB
FID
UV Index
Day of Year
0
1
2
3
4
5
6
7
145
145.5
146
146.5
147
147.5
148
148.5
149


Global irradiance ratios FIJ/QASUME at Jokioinen:25−May−2010(145) to 28−May−2010(148)
RATIO FIJ/QASUME
TIME [UT] ON DAYS: [145 146 148]
145
146
148
305 nm
310 nm
320 nm
330 nm
345 nm
360 nm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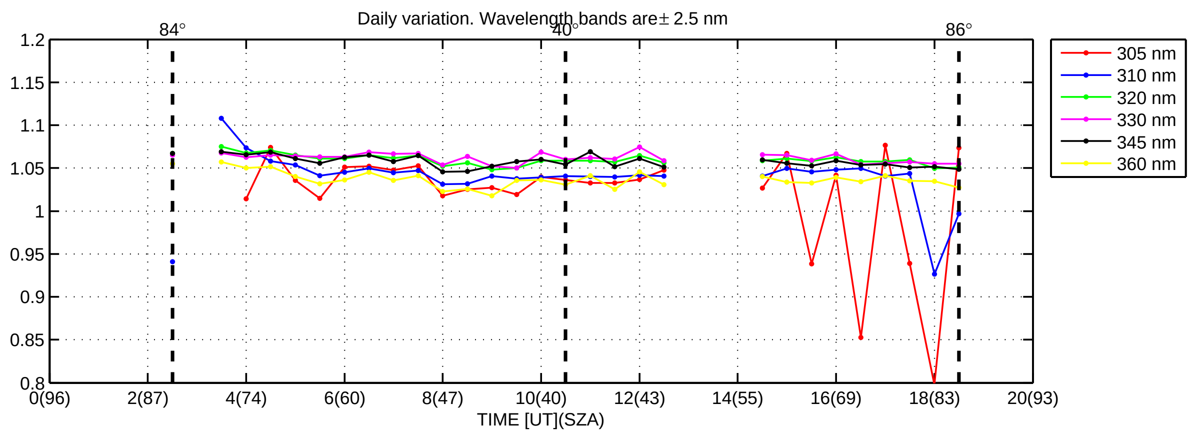
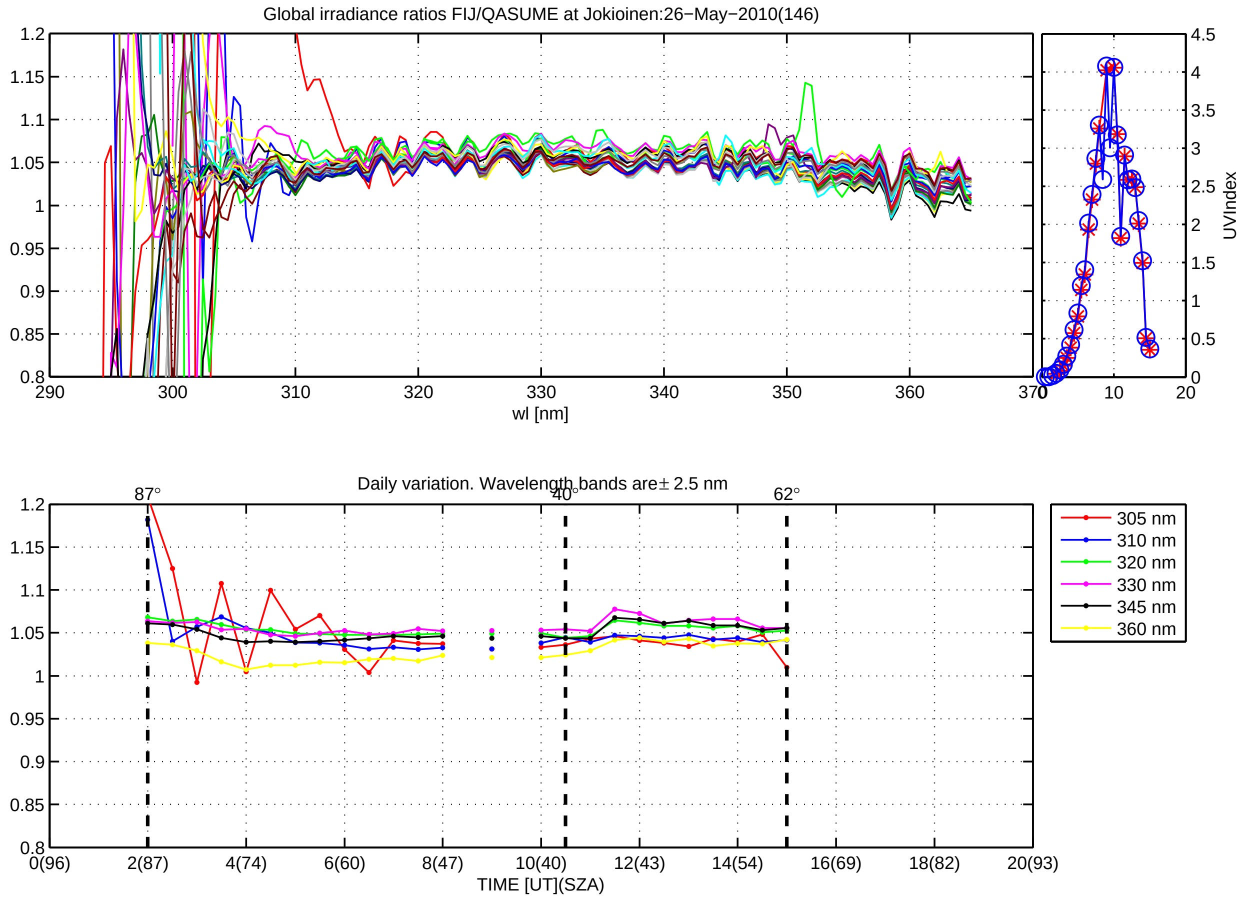
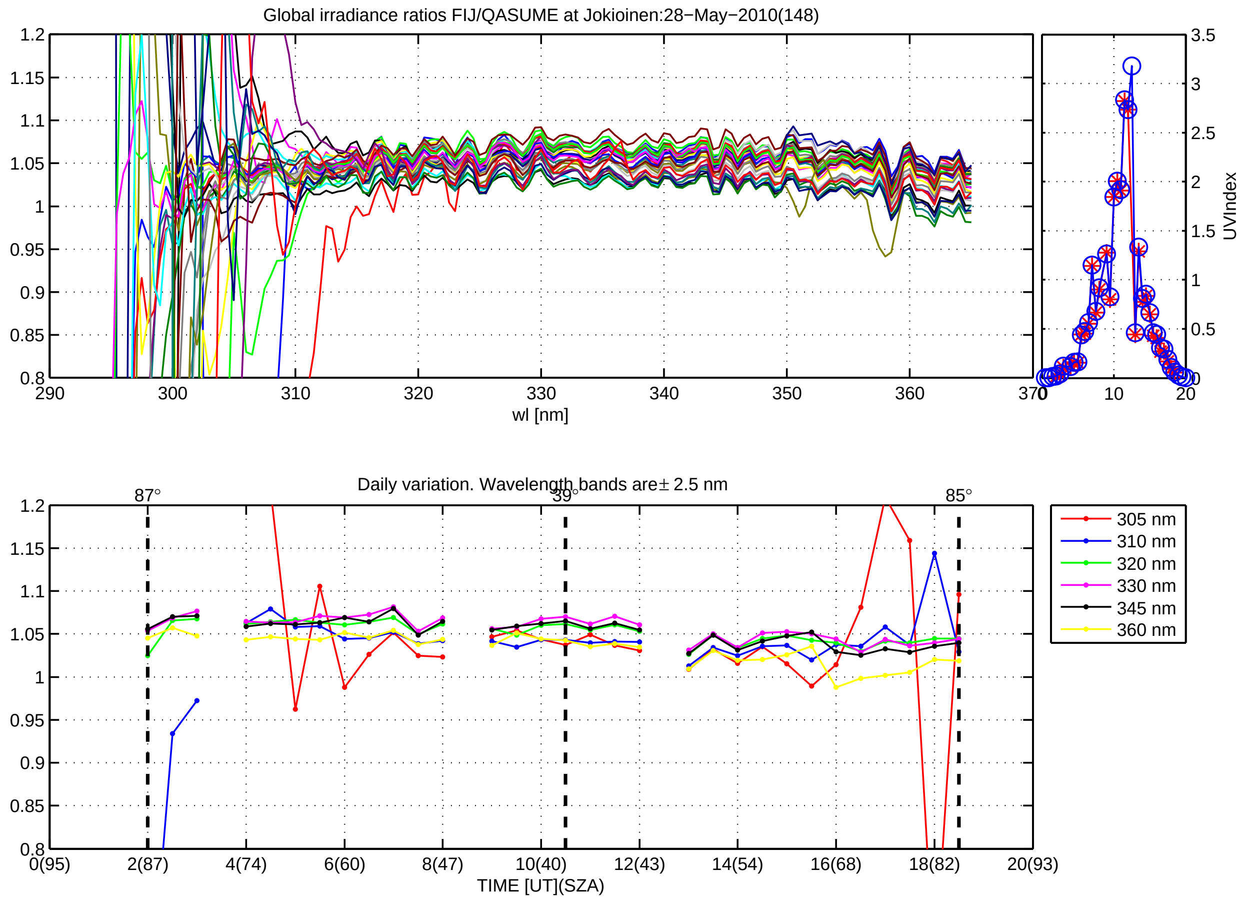
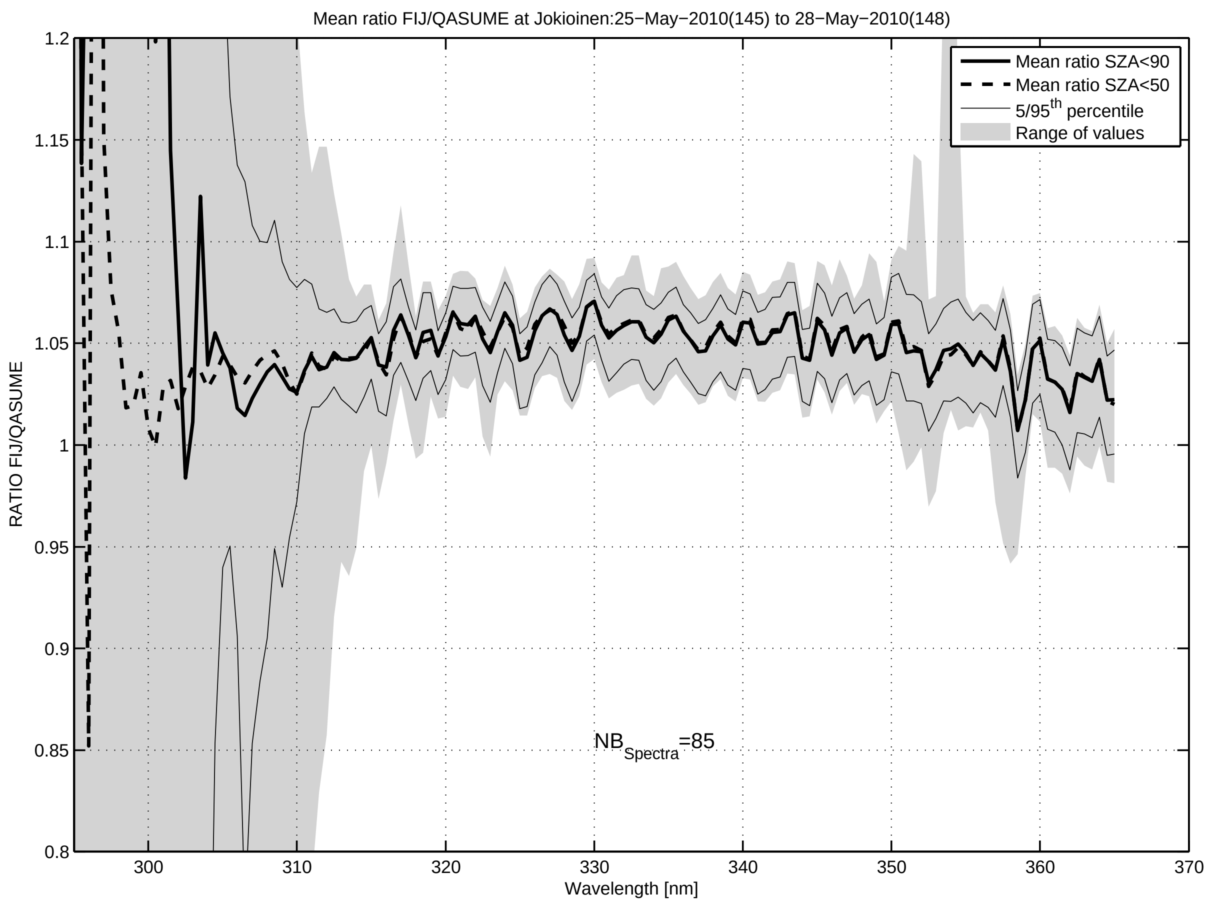
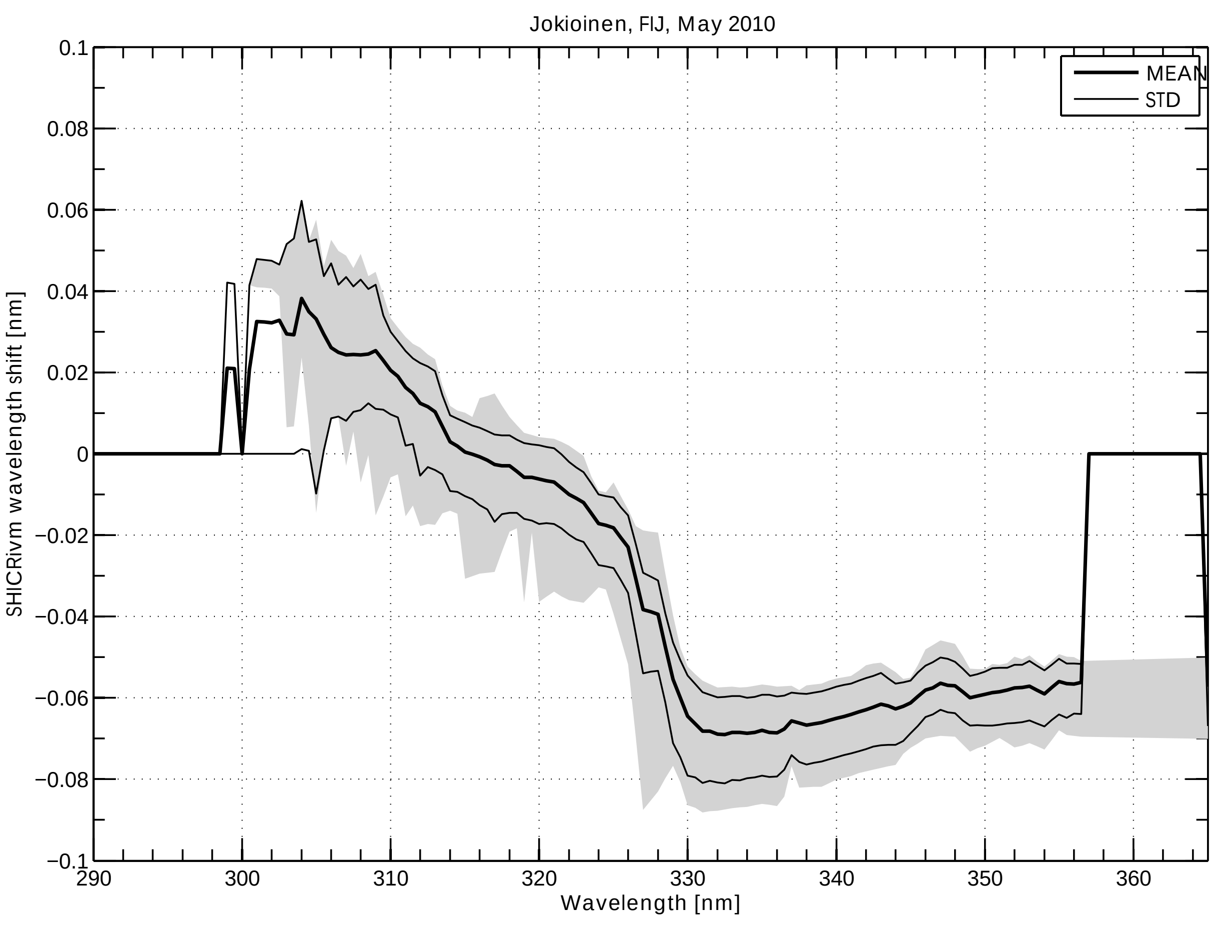
wl [nm]
UVindex

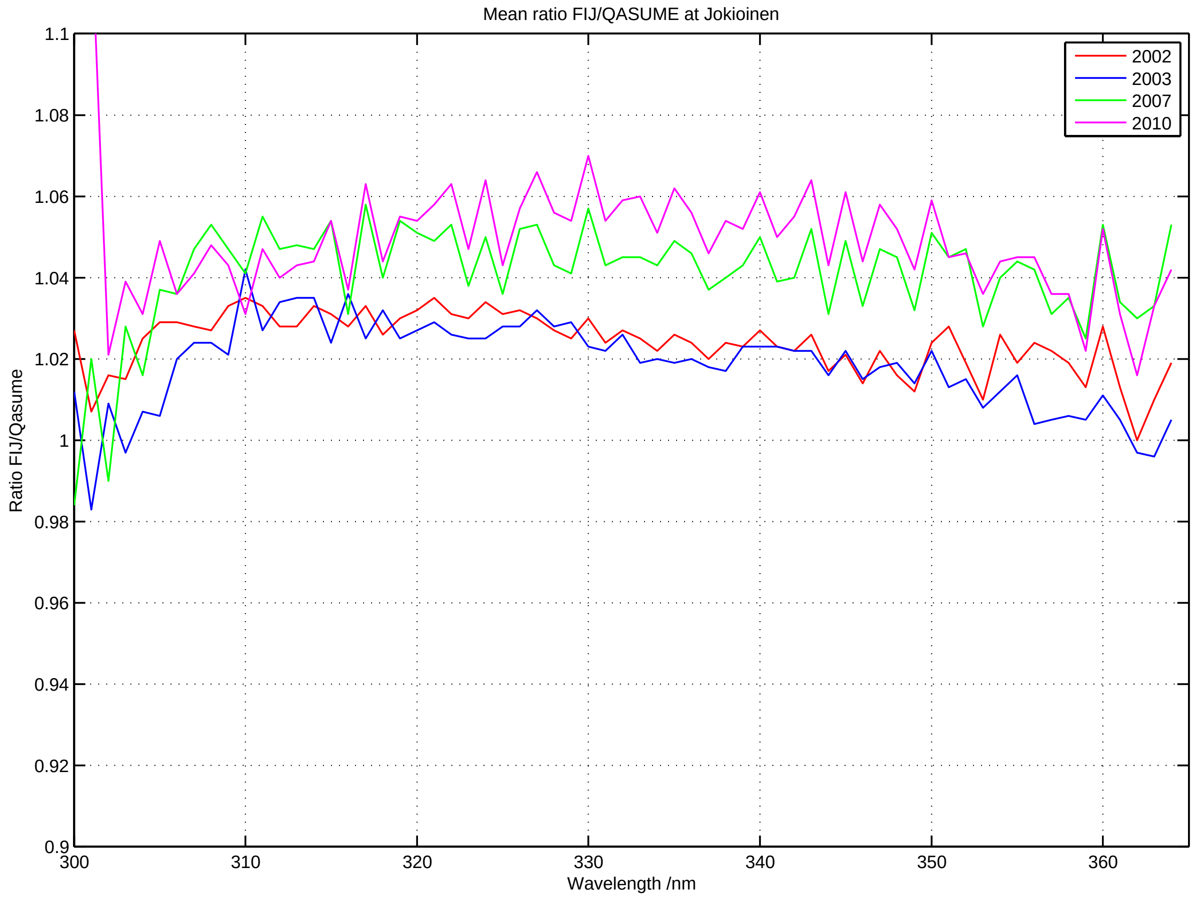

Daily variation. Wavelength bands are± 2.5 nm
84°
40°
86°
TIME [UT](SZA)
305 nm
310 nm
320 nm
330 nm
345 nm
360 nm

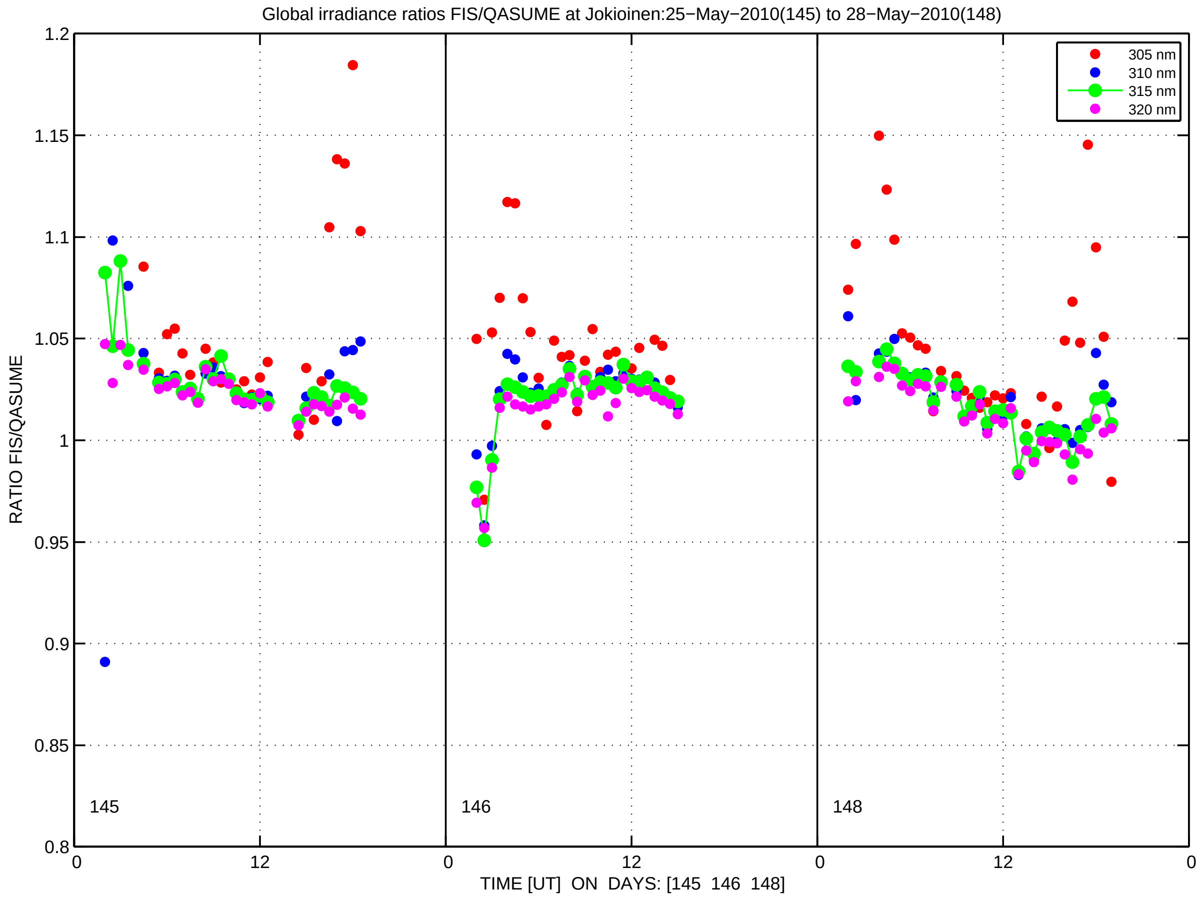

Global irradiance ratios FIJ/QASUME at Jokioinen:26−May−2010(146)
wl [nm]
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
87°
40°
62°
TIME [UT](SZA)
305 nm
310 nm
320 nm
330 nm
345 nm
360 nm

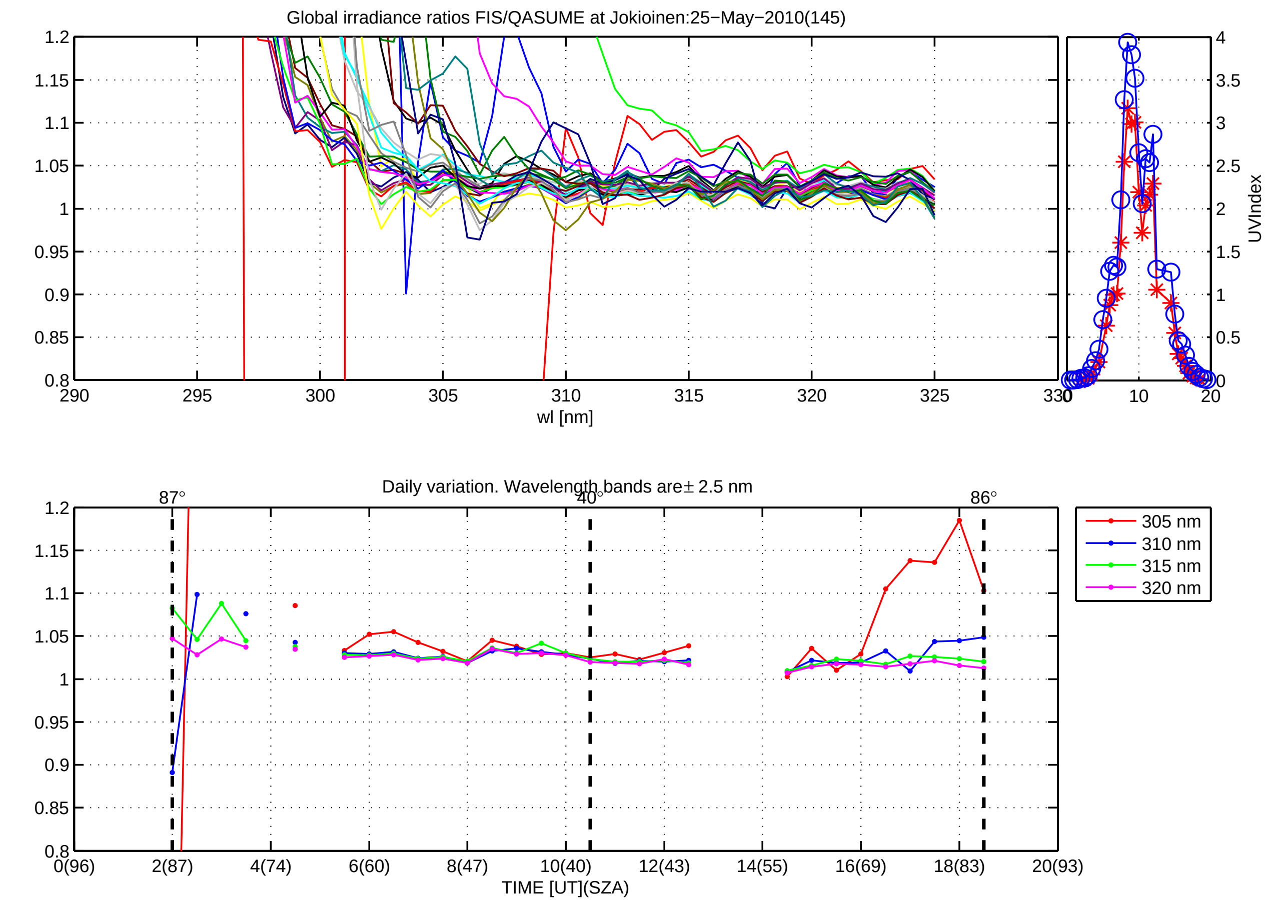

Global irradiance ratios FIJ/QASUME at Jokioinen:28−May−2010(148)
wl [nm]
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
87°
39°
85°
TIME [UT](SZA)
305 nm
310 nm
320 nm
330 nm
345 nm
360 nm

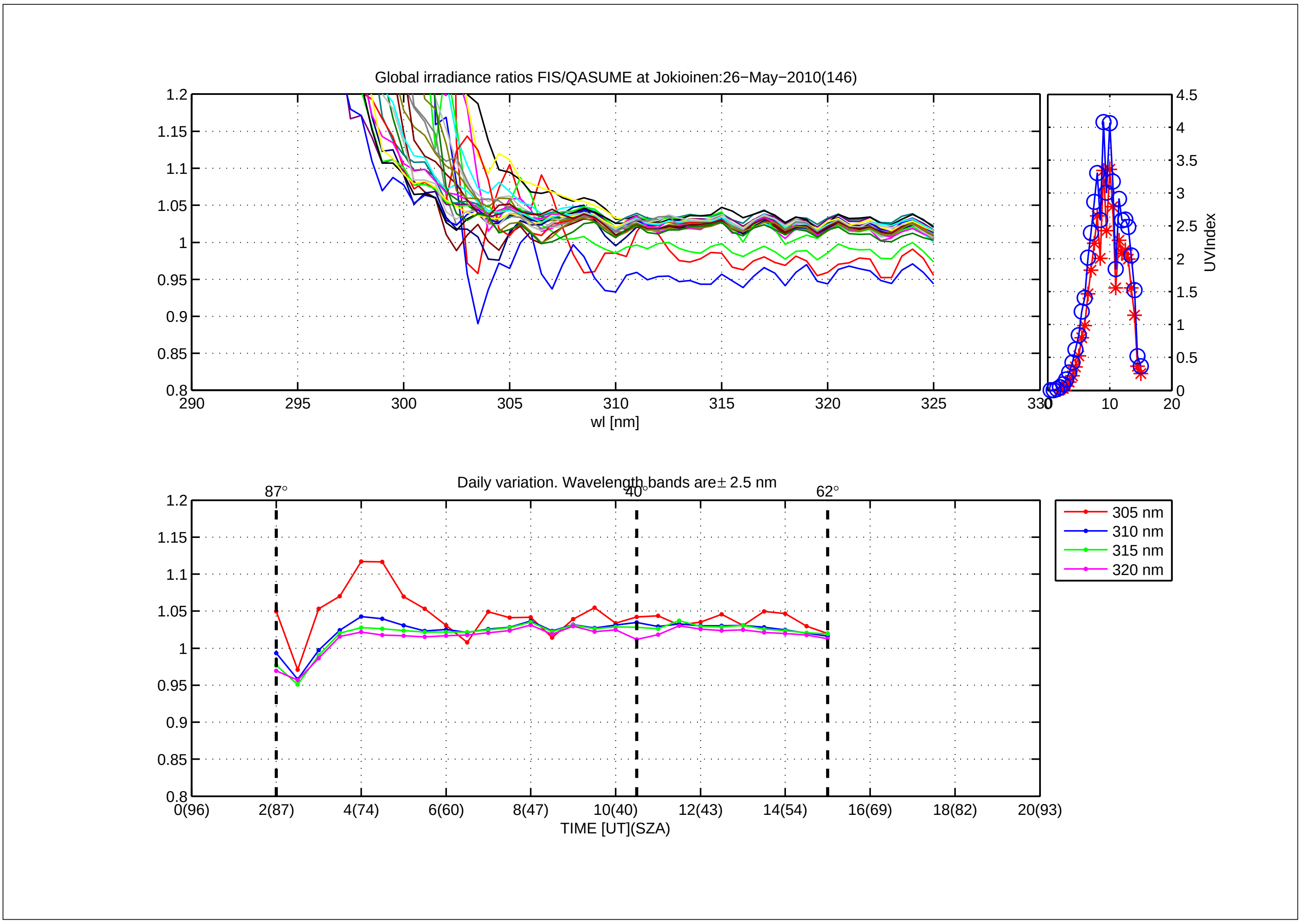

Mean ratio FIJ/QASUME at Jokioinen:25−May−2010(145) to 28−May−2010(148)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
Range of values
NB Spectra=85
RATIO FIJ/QASUME
Wavelength [nm]

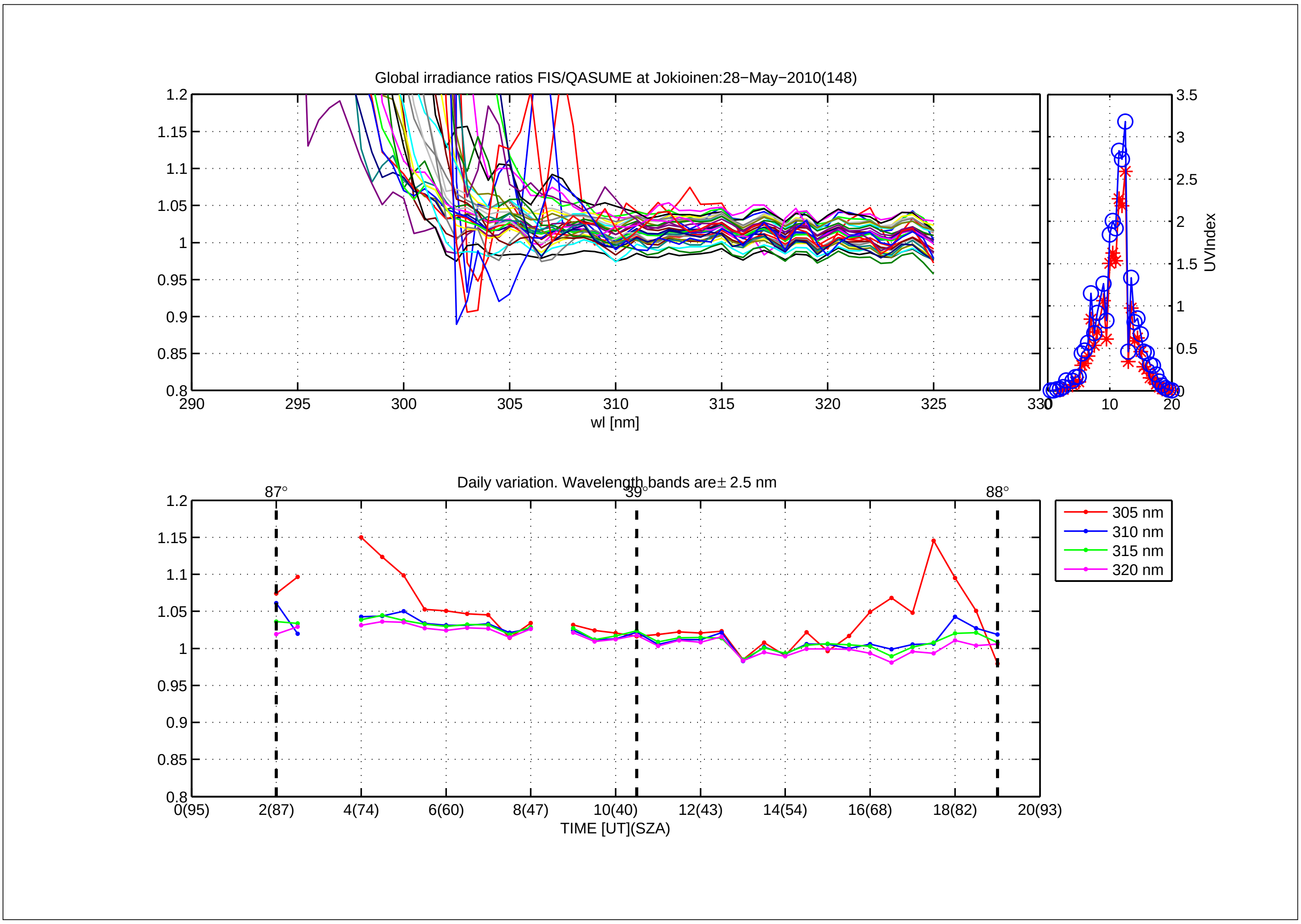

Jokioinen, FIJ, May 2010
MEAN
STD
SHICRivm wavelength shift [nm]
Wavelength [nm]

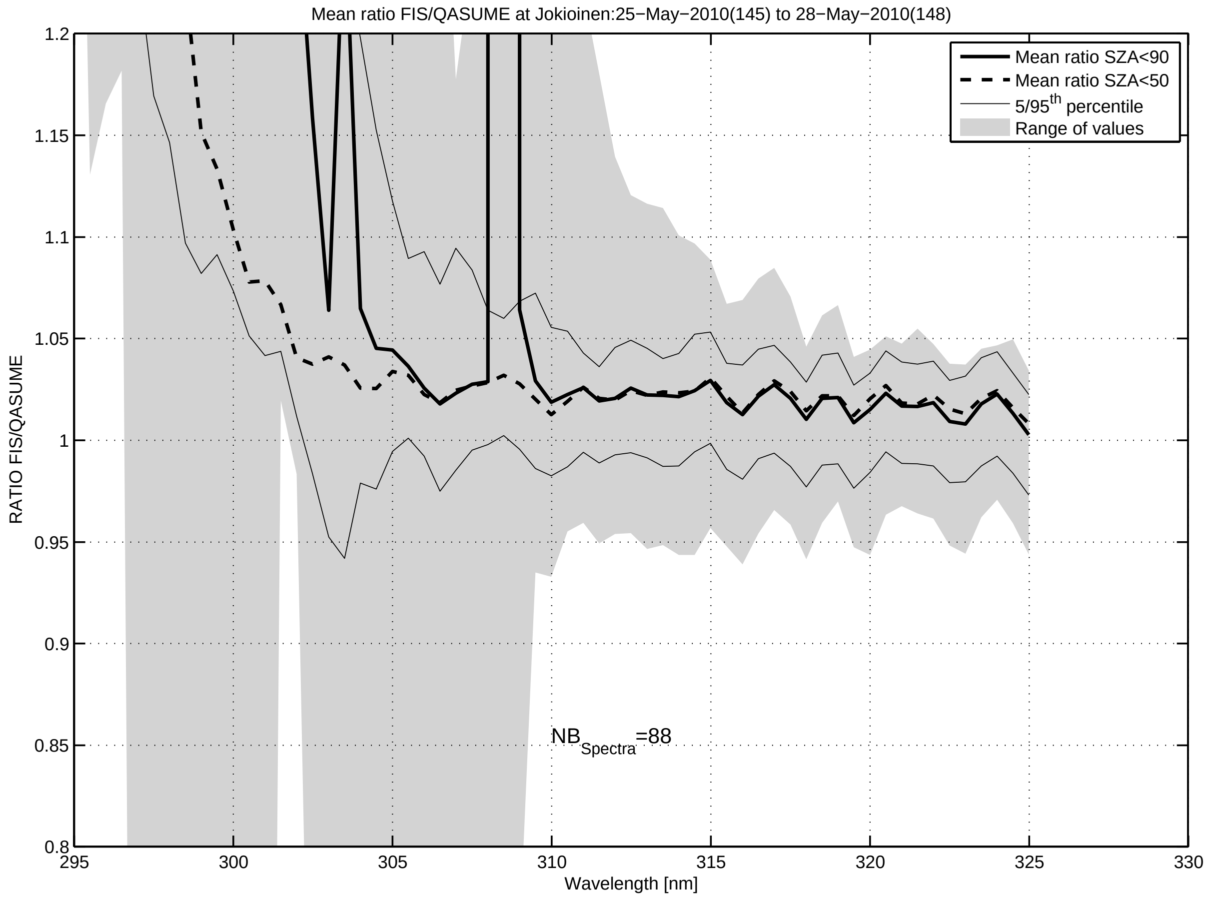

Mean ratio FIJ/QASUME at Jokioinen
Ratio FIJ/Qasume
Wavelength /nm
2002
2003
2007
2010
1.1
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0.9
300
310
320
330
340
350
360

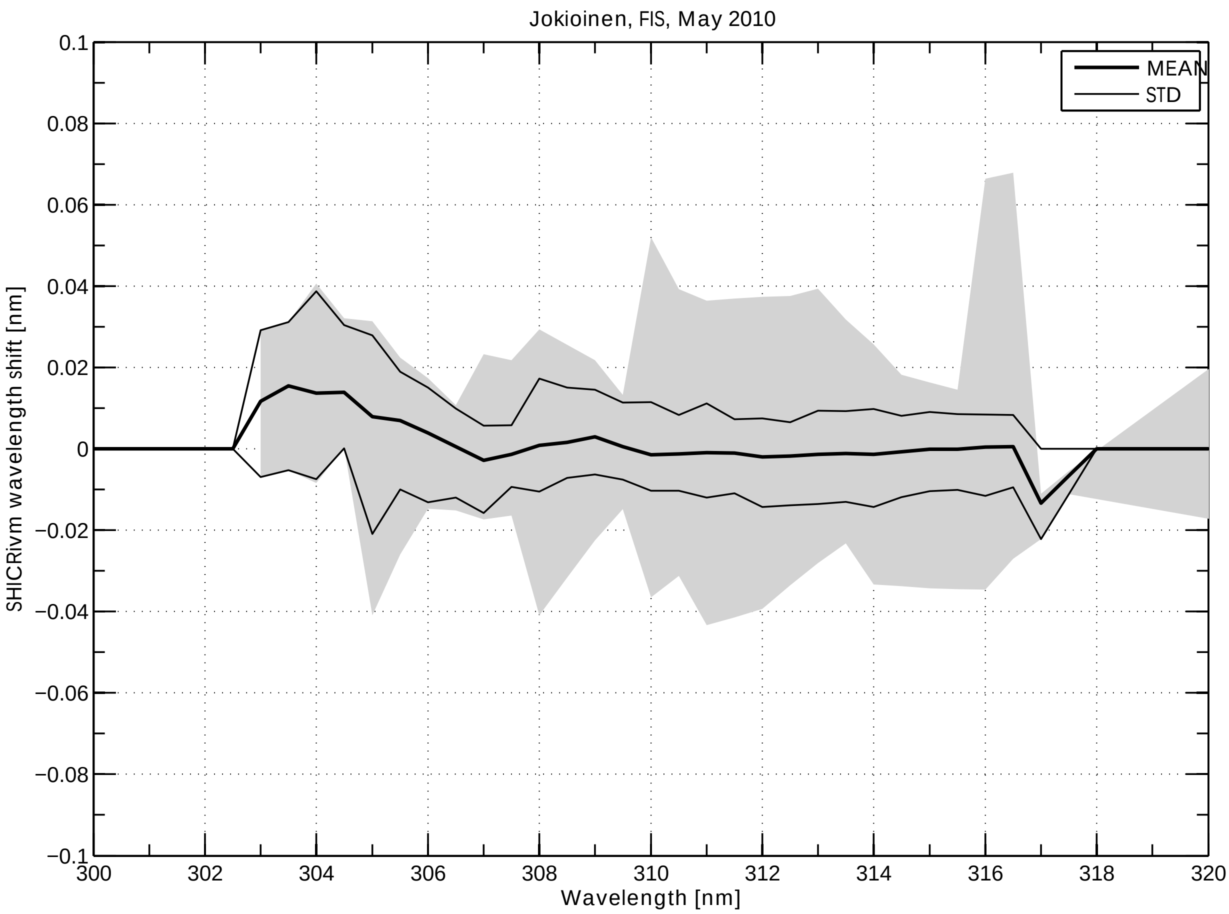

Global irradiance ratios FIS/QASUME at Jokioinen:25−May−2010(145) to 28−May−2010(148)
RATIO FIS/QASUME
TIME [UT] ON DAYS: [145 146 148]
145
146
148
305 nm
310 nm
315 nm
320 nm

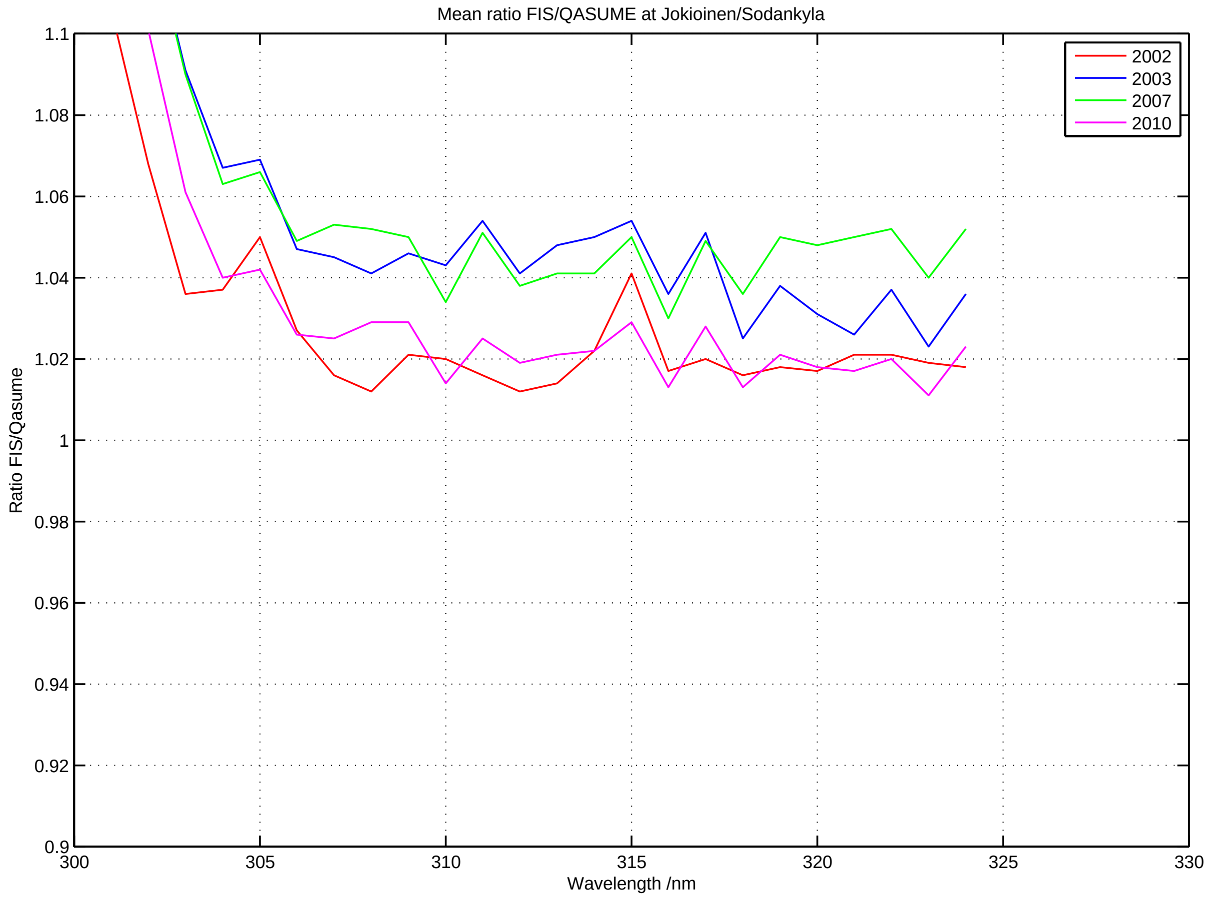

Global irradiance ratios FIS/QASUME at Jokioinen:25−May−2010(145)
wl [nm]
UVindex
Daily variation. Wavelength bands are± 2.5 nm
87°
40°
86°
TIME [UT](SZA)
305 nm
310 nm
315 nm
320 nm

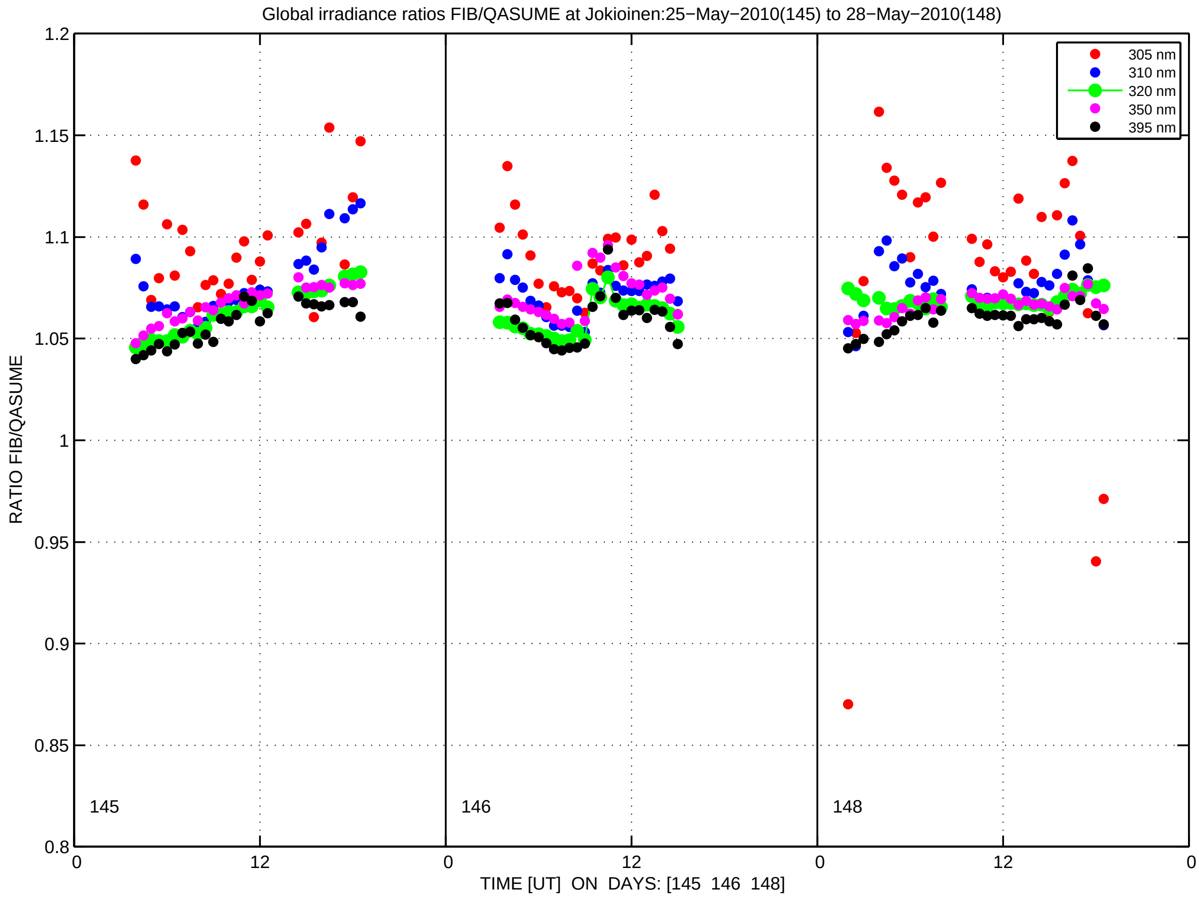

Global irradiance ratios FIS/QASUME at Jokioinen:26−May−2010(146)
wl [nm]
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
87°
40°
62°
305 nm
310 nm
315 nm
320 nm
TIME [UT](SZA)
0(96)
2(87)
4(74)
6(60)
8(47)
10(40)
12(43)
14(54)
16(69)
18(82)
20(93)

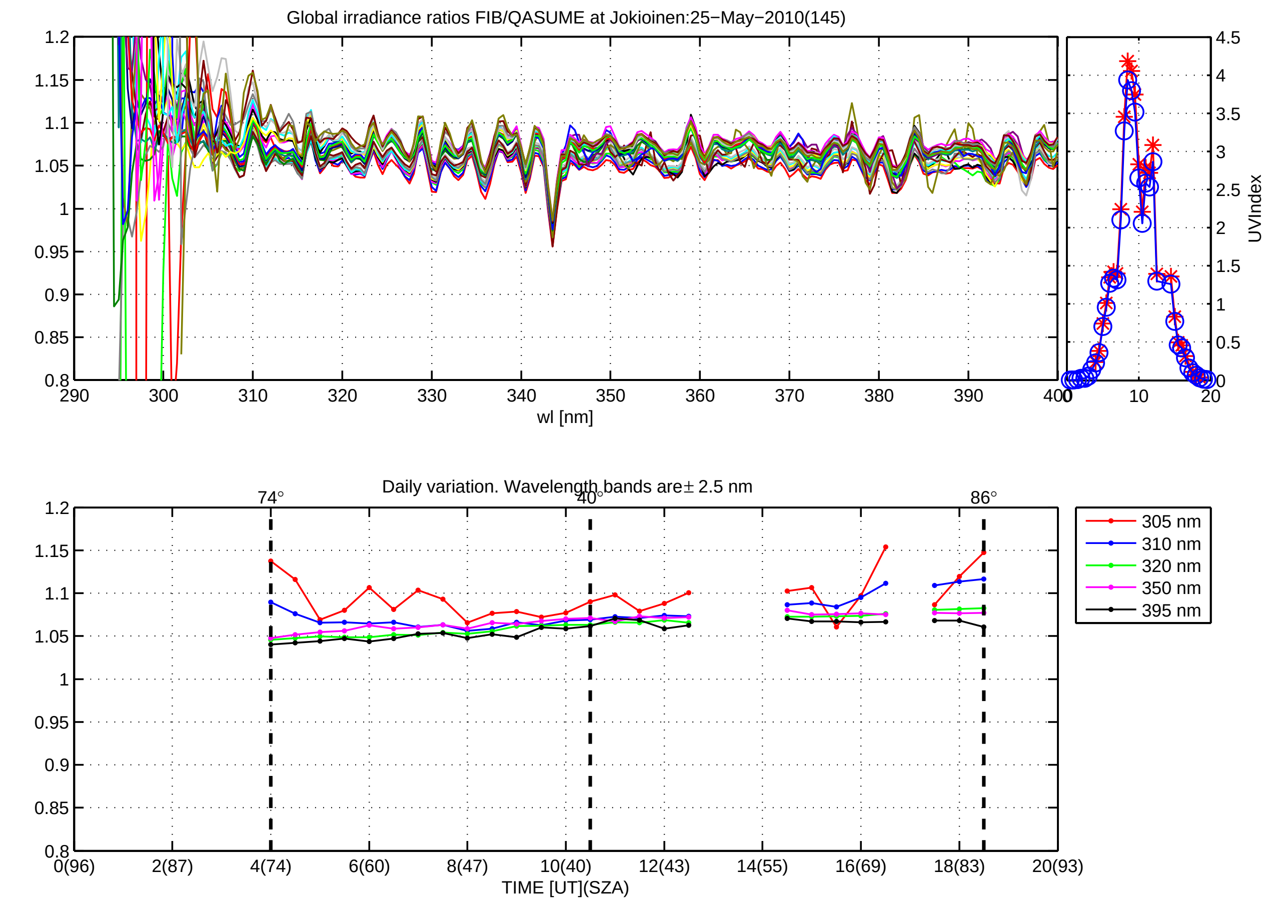

Global irradiance ratios FIS/QASUME at Jokioinen:28−May−2010(148)
wl [nm]
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
87°
39°
88°
305 nm
310 nm
315 nm
320 nm
TIME [UT](SZA)
0(95)
2(87)
4(74)
6(60)
8(47)
10(40)
12(43)
14(54)
16(68)
18(82)
20(93)

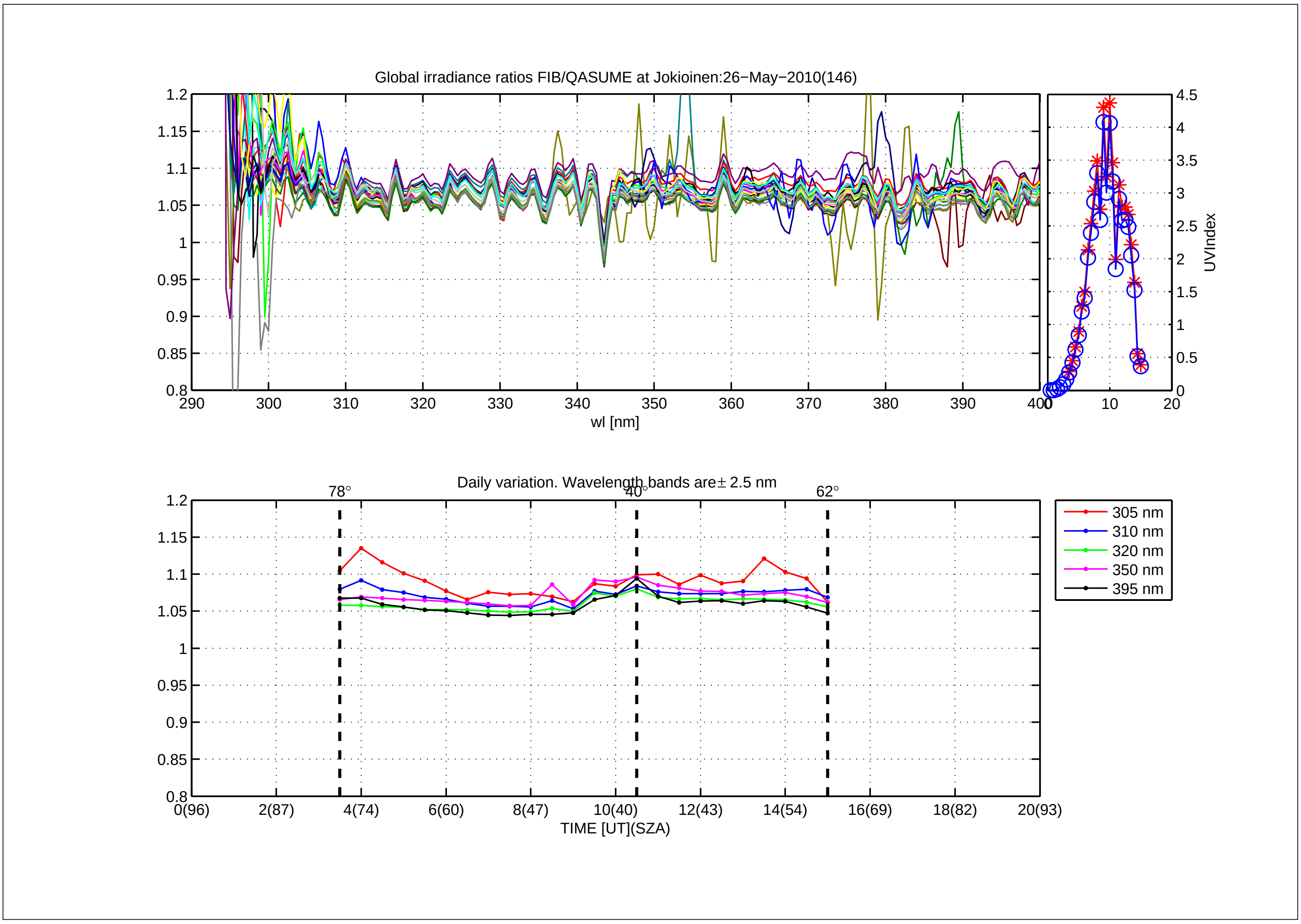

Mean ratio FIS/QASUME at Jokioinen:25−May−2010(145) to 28−May−2010(148)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
Range of values
RATIO FIS/QASUME
Wavelength [nm]
NB Spectra =88


Jokioinen, FIS, May 2010
MEAN
STD
SHICRivm wavelength shift [nm]
Wavelength [nm]


Mean ratio FIS/QASUME at Jokioinen/Sodankyla
Ratio FIS/Qasume
Wavelength /nm
2002
2003
2007
2010
1.1
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0.9
300
305
310
315
320
325
330


Global irradiance ratios FIB/QASUME at Jokioinen:25−May−2010(145) to 28−May−2010(148)
RATIO FIB/QASUME
TIME [UT] ON DAYS: [145 146 148]
145
146
148
305 nm
310 nm
320 nm
350 nm
395 nm


Global irradiance ratios FIB/QASUME at Jokioinen:25−May−2010(145)
wl [nm]
UVindex
Daily variation. Wavelength bands are± 2.5 nm
74°
40°
86°
TIME [UT](SZA)
305 nm
310 nm
320 nm
350 nm
395 nm


Global irradiance ratios FIB/QASUME at Jokioinen:26−May−2010(146)
wl [nm]
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
78°
40°
62°
TIME [UT](SZA)
0(96)
2(87)
4(74)
6(60)
8(47)
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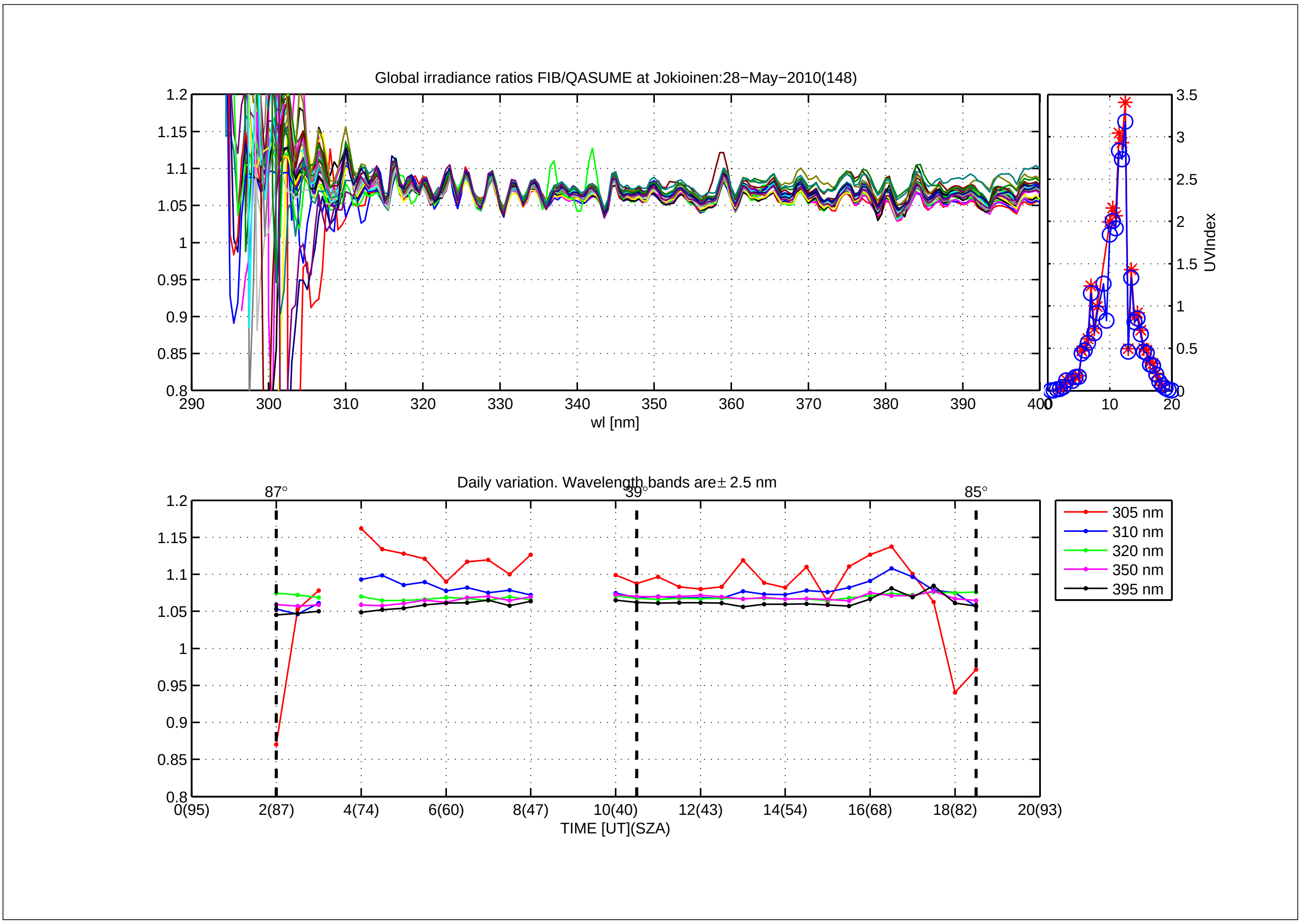
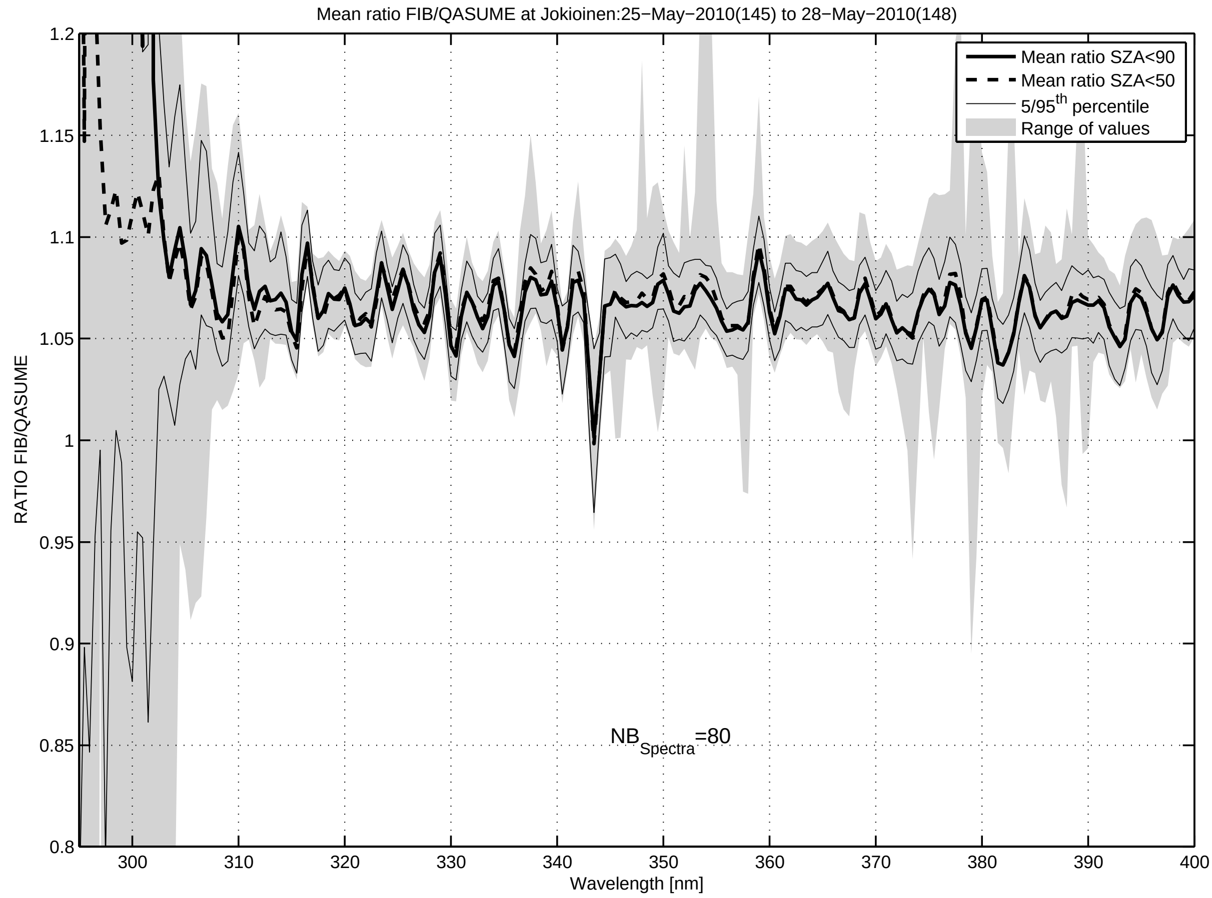
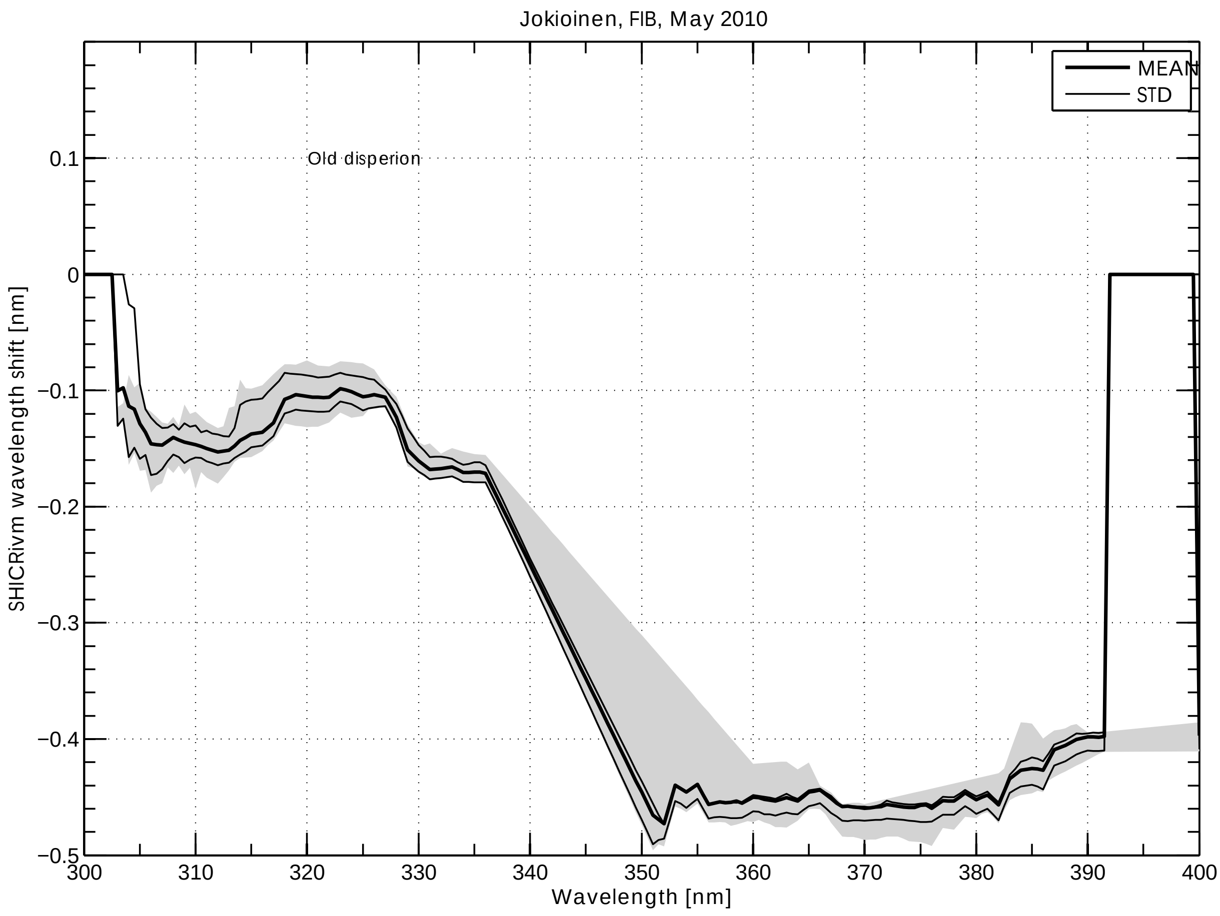
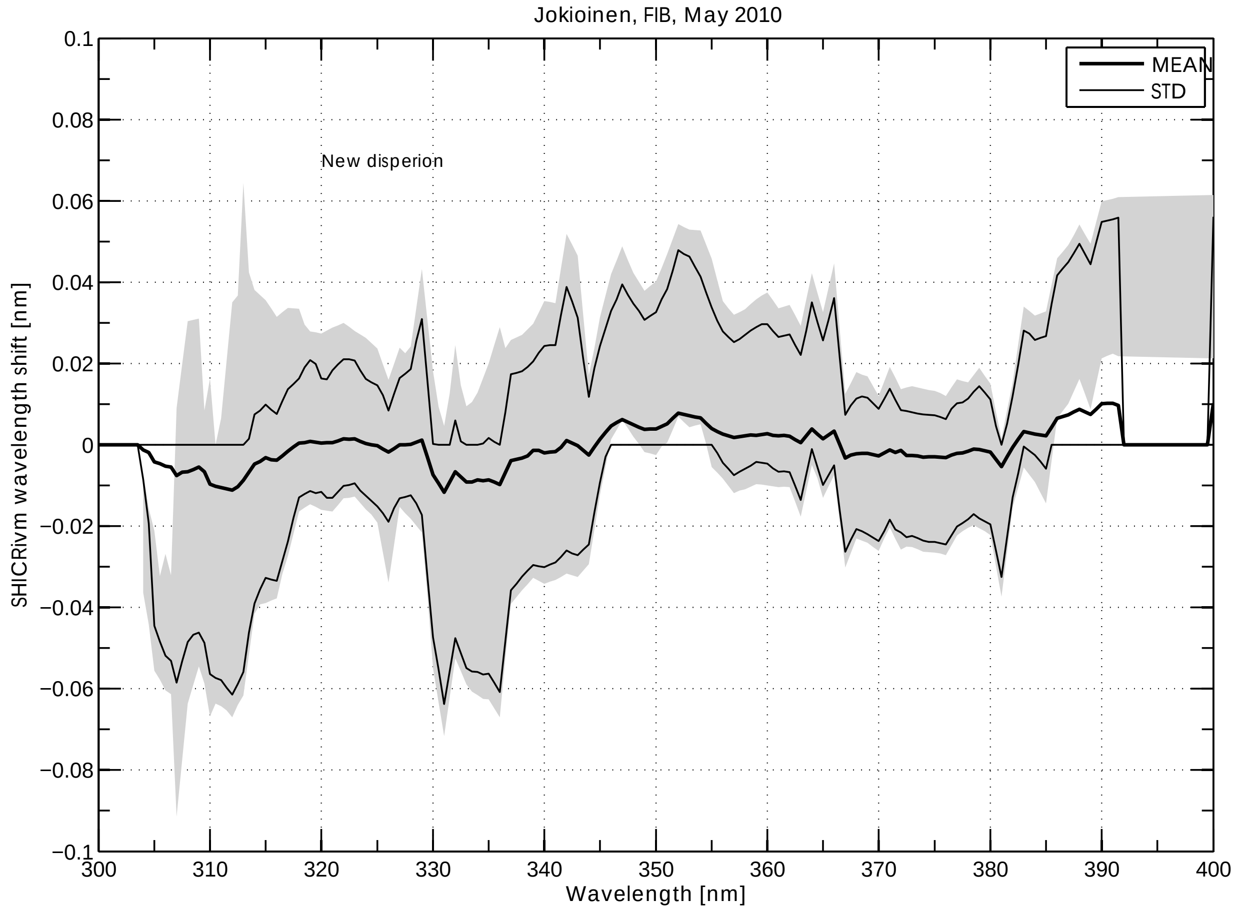
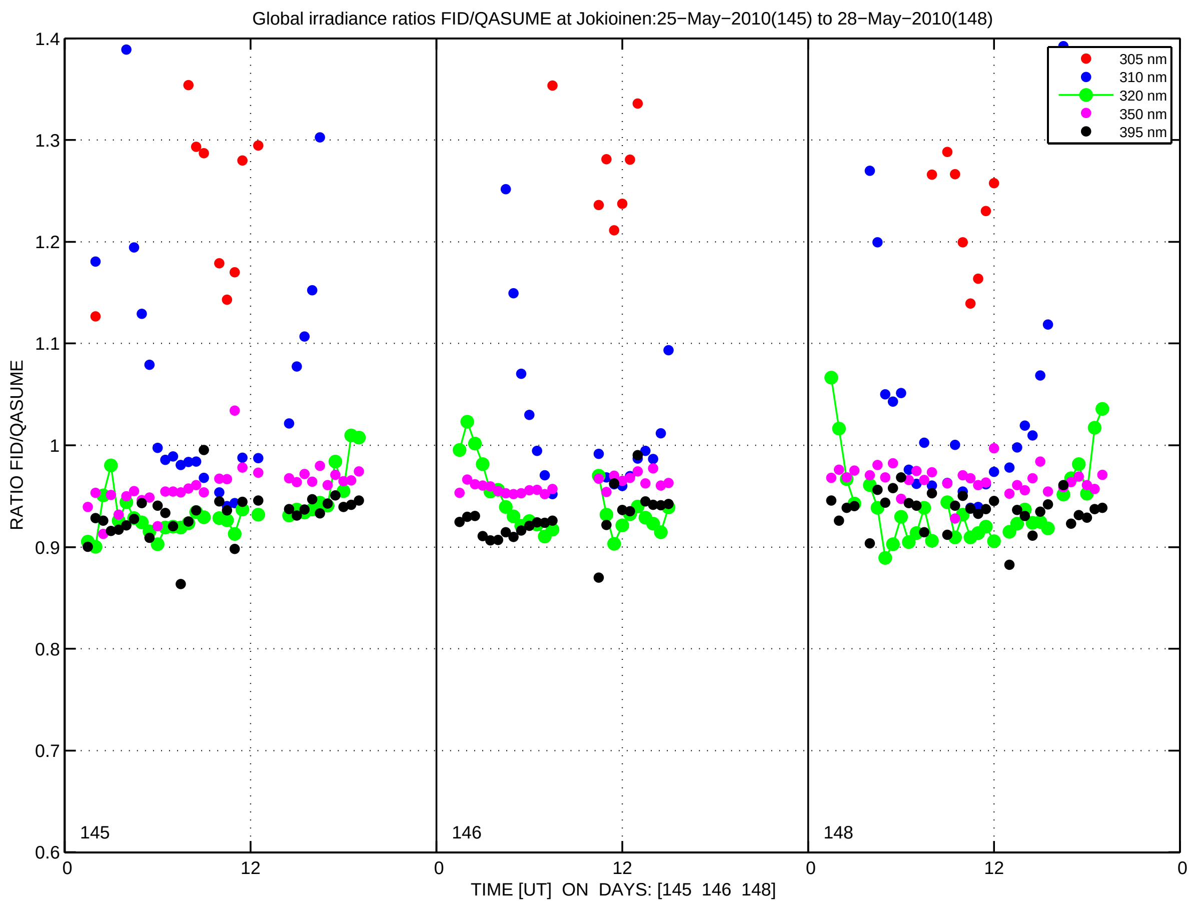
12(43)
14(54)
16(69)
18(82)
20(93)
305 nm
310 nm
320 nm
350 nm
395 nm


Global irradiance ratios FIB/QASUME at Jokioinen:28−May−2010(148)
wl [nm]
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
87°
39°
85°
TIME [UT](SZA)
0(95)
2(87)
4(74)
6(60)
8(47)
10(40)
12(43)
14(54)
16(68)
18(82)
20(93)
305 nm
310 nm
320 nm
350 nm
395 nm

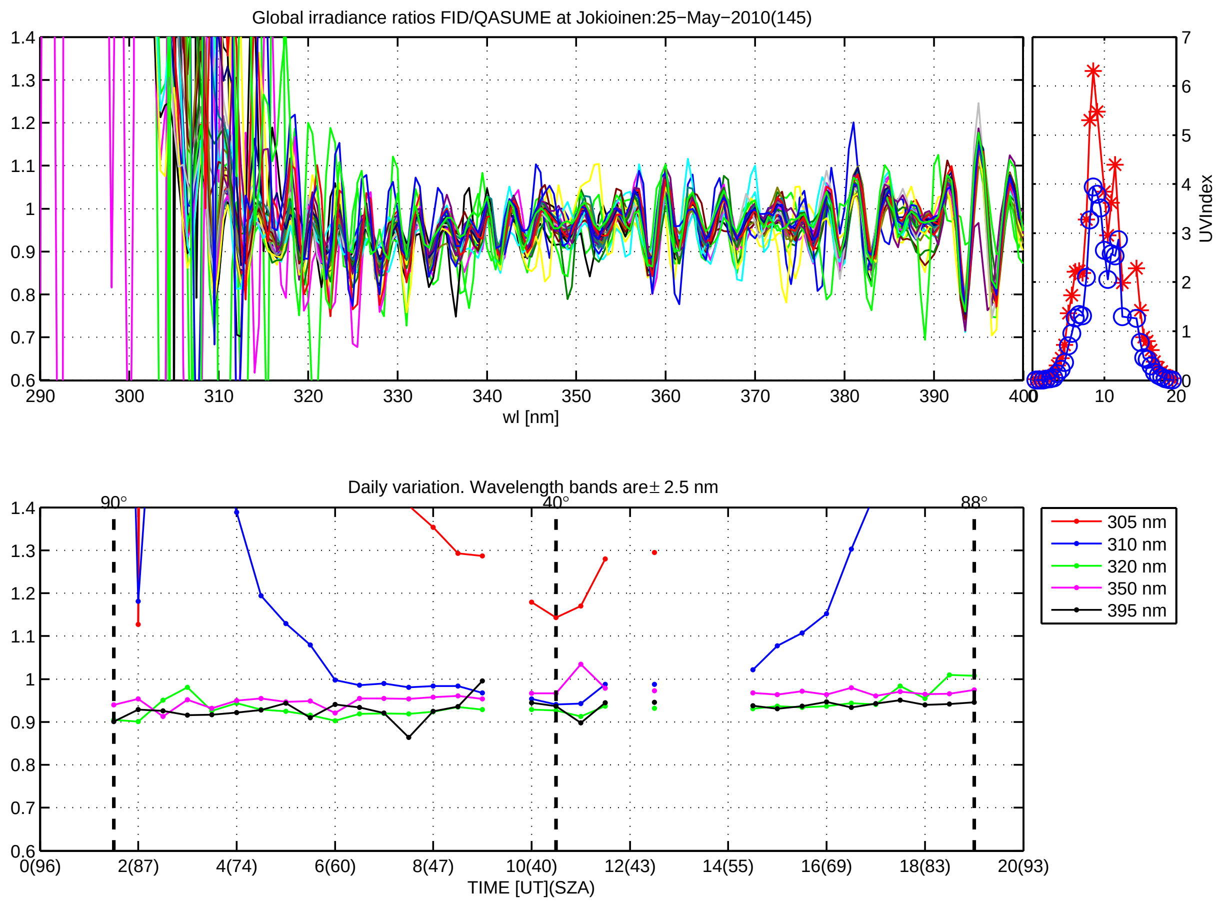

Mean ratio FIB/QASUME at Jokioinen:25−May−2010(145) to 28−May−2010(148)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
Range of values
RATIO FIB/QASUME
NBSpectra=80
Wavelength [nm]


Jokioinen, FIB, May 2010
MEAN
STD
Old disperion
SHICRivm wavelength shift [nm]
Wavelength [nm]

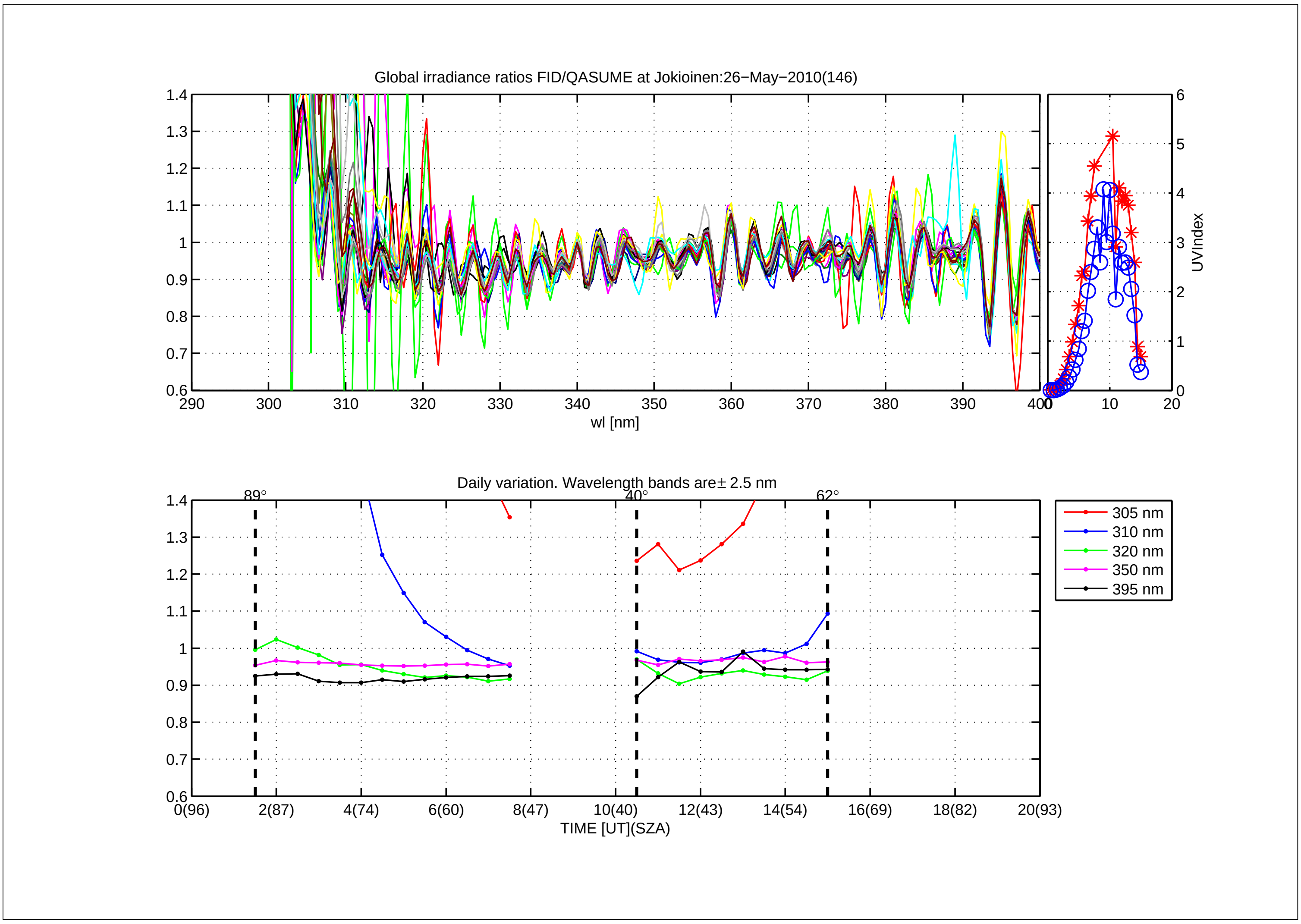

Jokioinen, FIB, May 2010
New disperion
MEAN
STD
SHICRivm wavelength shift [nm]
Wavelength [nm]
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
−0.1
300
310
320
330
340
350
360
370
380
390
400

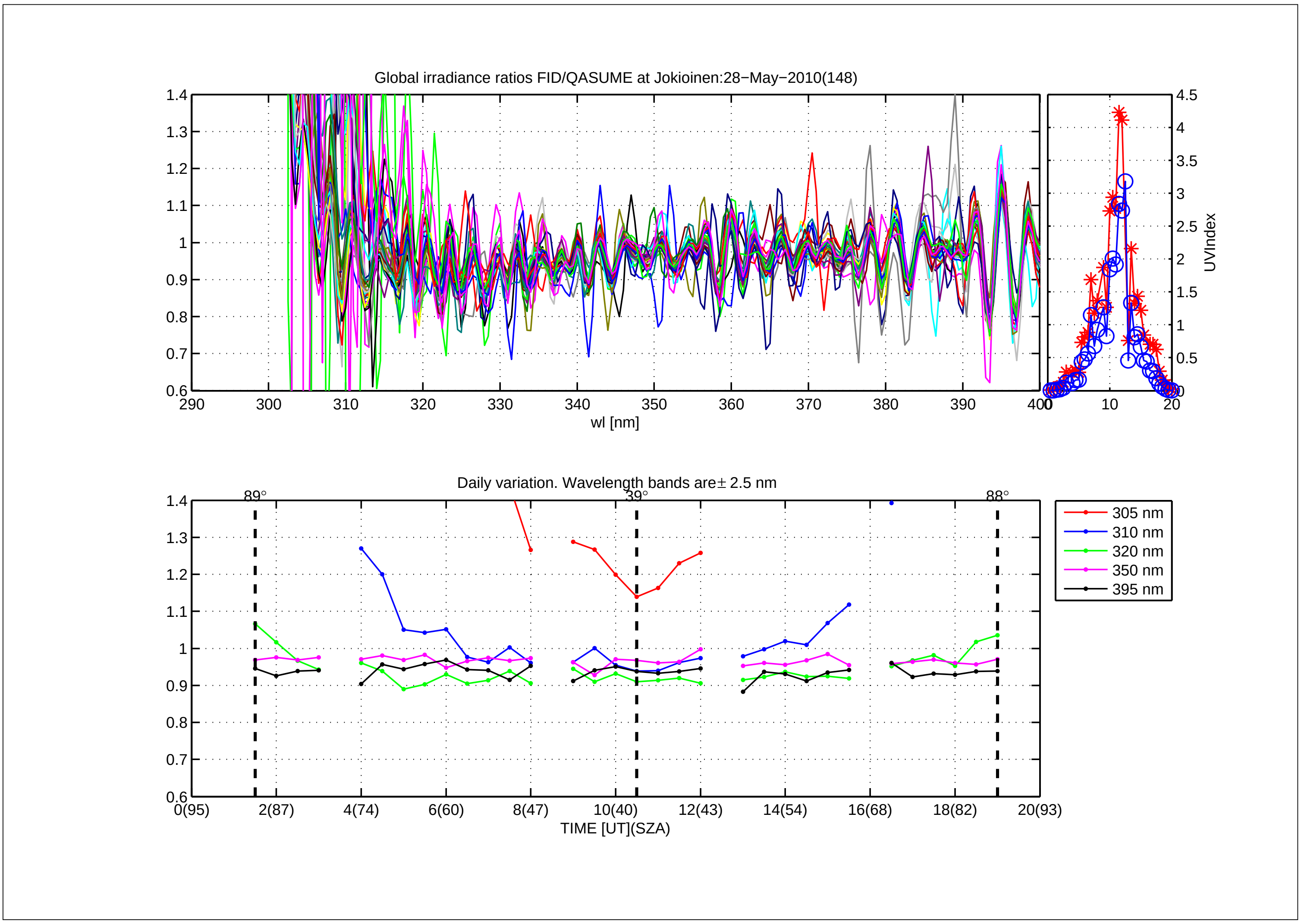


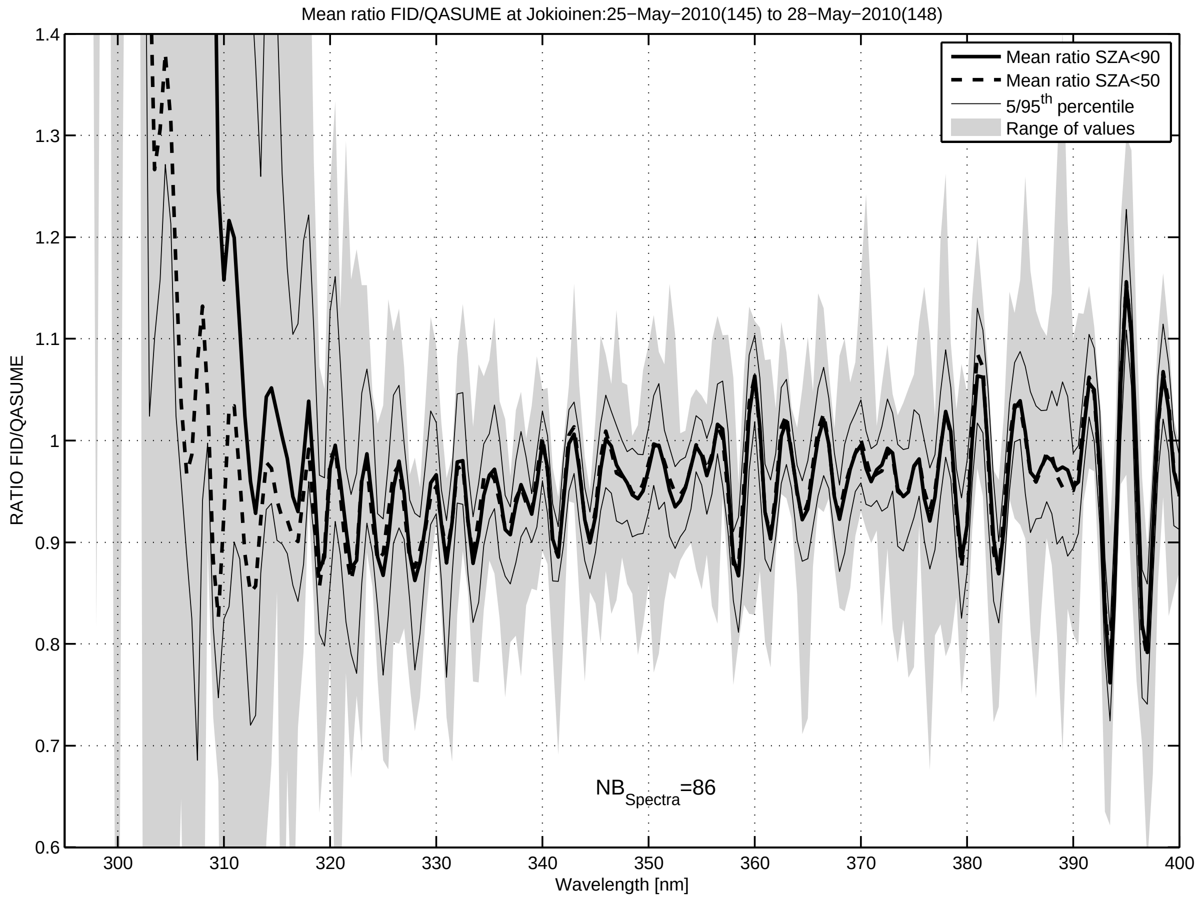
Global irradiance ratios FID/QASUME at Jokioinen:25−May−2010(145) to 28−May−2010(148)
RATIO FID/QASUME
TIME [UT] ON DAYS: [145 146 148]
145
146
148
305 nm
310 nm
320 nm
350 nm
395 nm

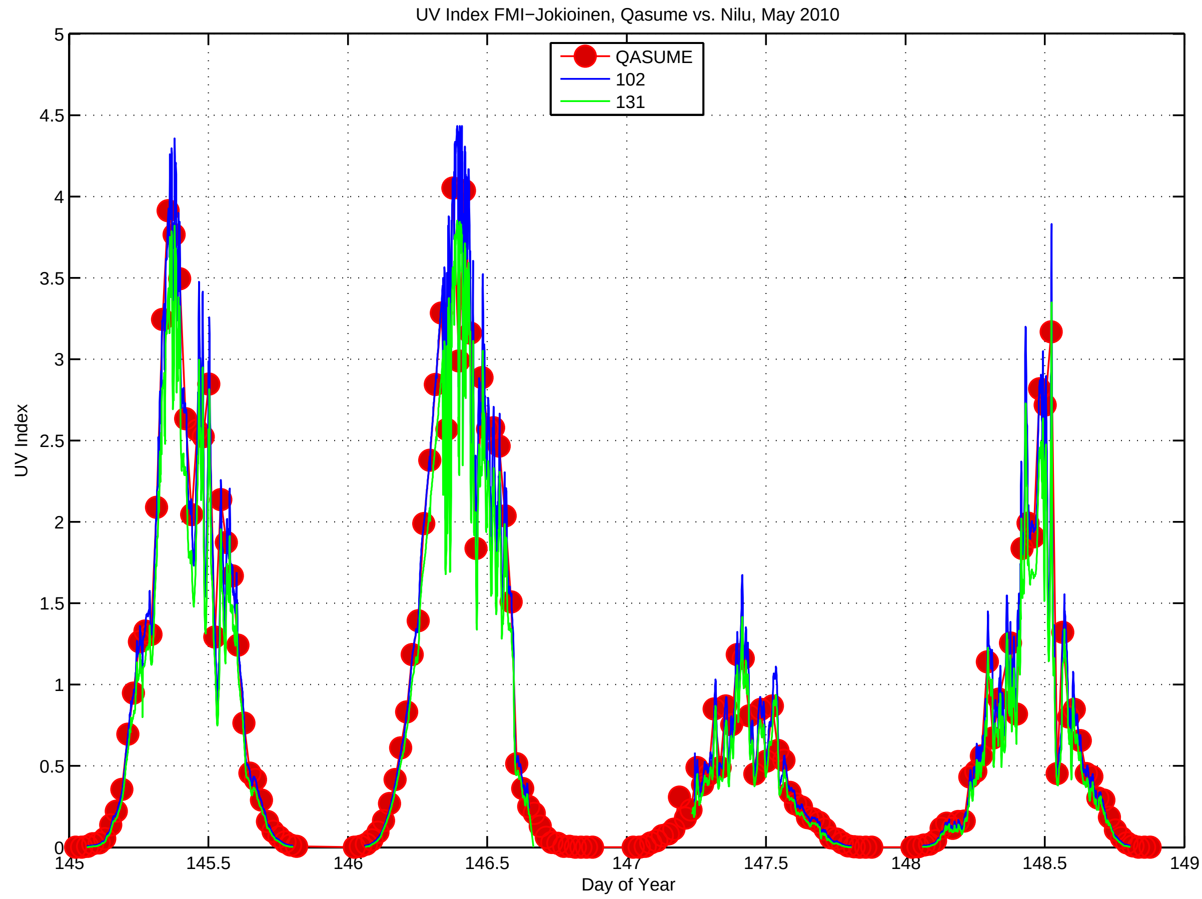


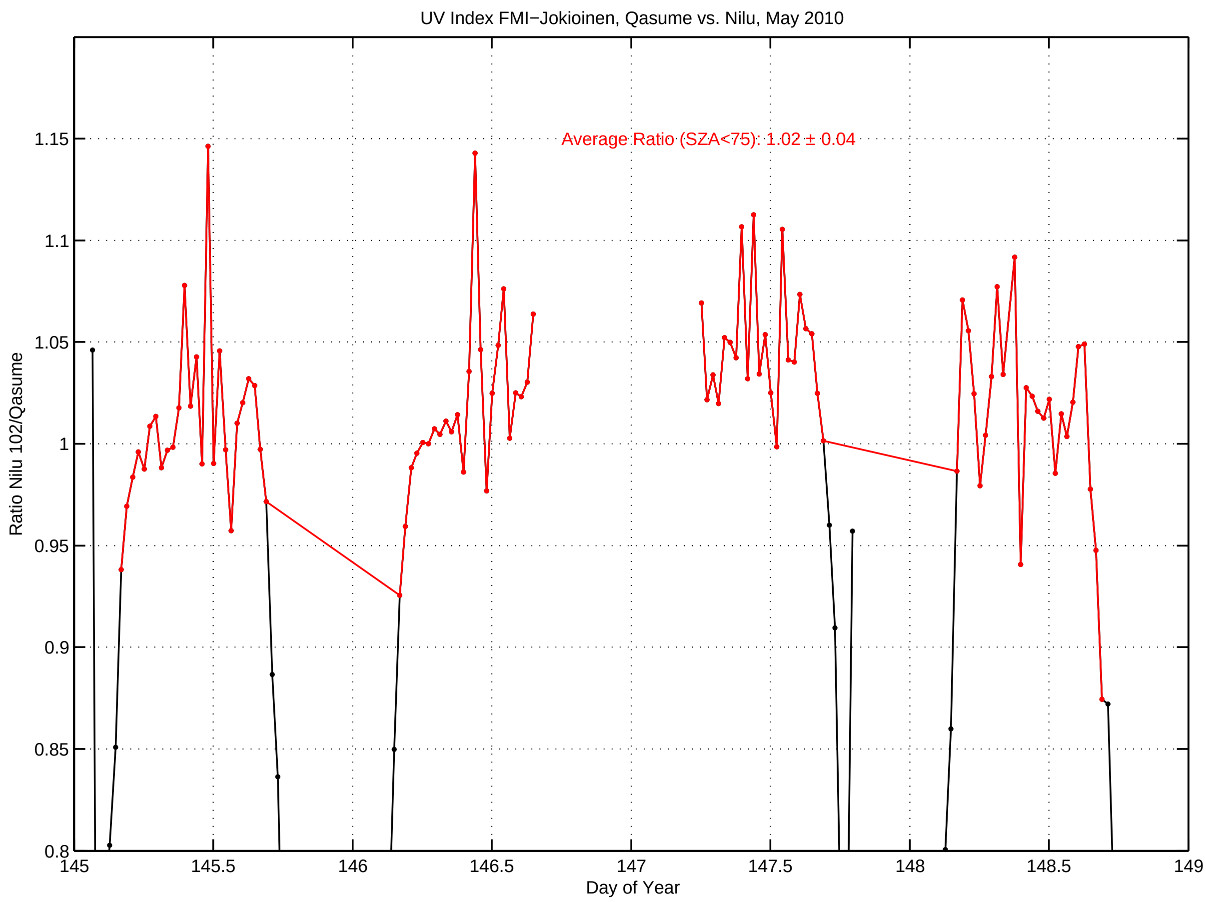
Global irradiance ratios FID/QASUME at Jokioinen:25−May−2010(145)
wl [nm]
UVindex
Daily variation. Wavelength bands are± 2.5 nm
90°
40°
88°
TIME [UT](SZA)
0(96)
2(87)
4(74)
6(60)
8(47)
10(40)
12(43)
14(55)
16(69)
18(83)
20(93)
305 nm
310 nm
320 nm
350 nm
395 nm

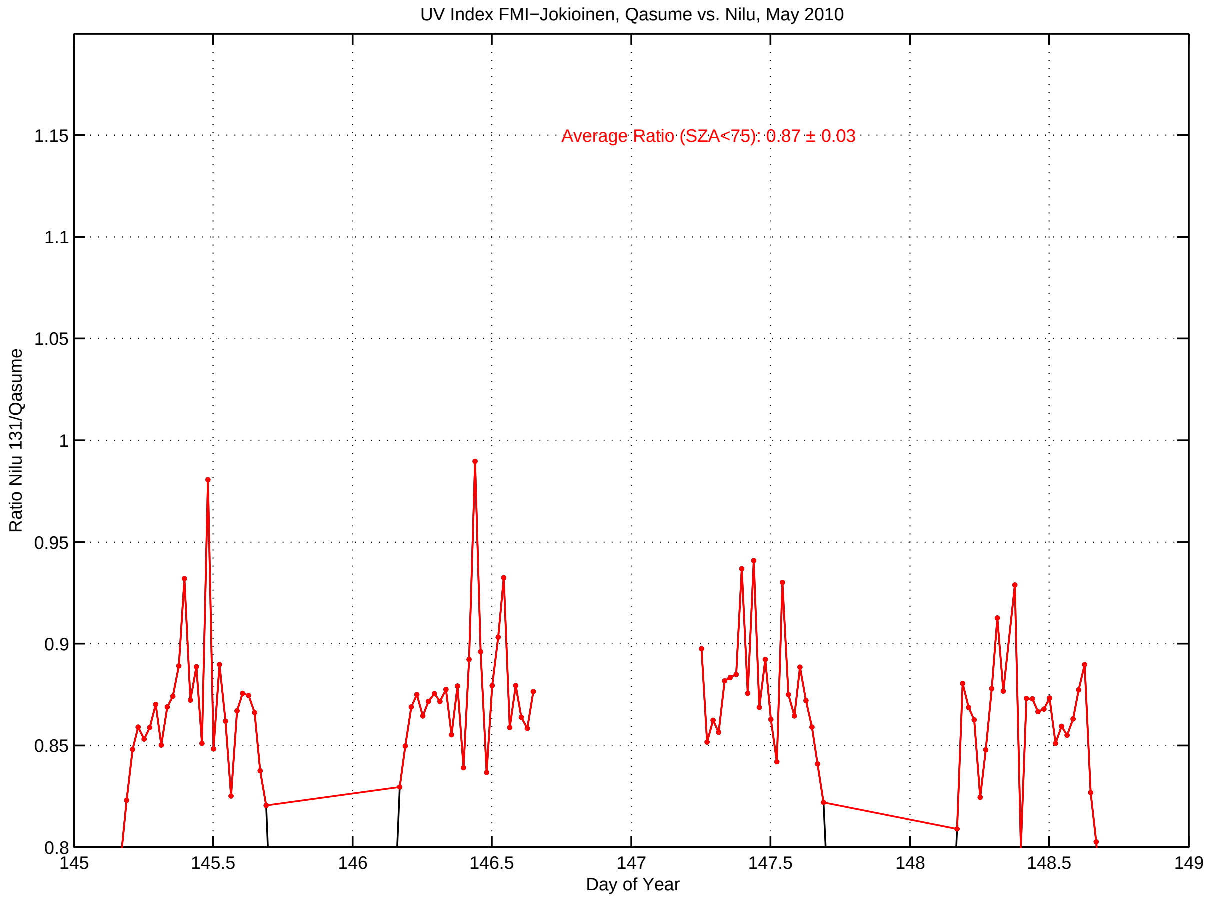

Global irradiance ratios FID/QASUME at Jokioinen:26−May−2010(146)
wl [nm]
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
89°
40°
62°
305 nm
310 nm
320 nm
350 nm
395 nm
TIME [UT](SZA)


Global irradiance ratios FID/QASUME at Jokioinen:28−May−2010(148)
wl [nm]
UVIndex
Daily variation. Wavelength bands are± 2.5 nm
89°
39°
88°
305 nm
310 nm
320 nm
350 nm
395 nm
TIME [UT](SZA)

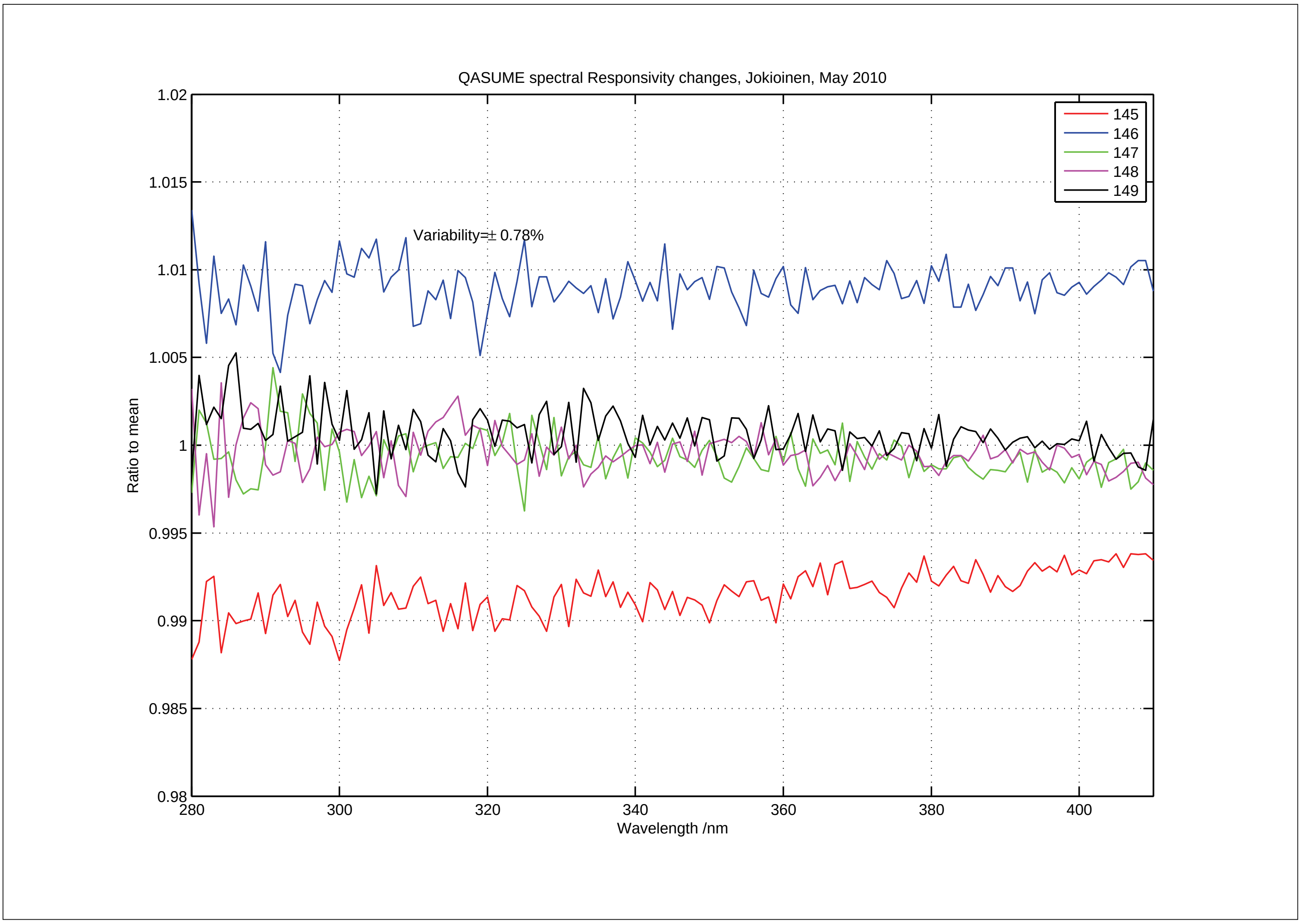

Mean ratio FID/QASUME at Jokioinen:25−May−2010(145) to 28−May−2010(148)
Mean ratio SZA<90
Mean ratio SZA<50
5/95th percentile
Range of values
RATIO FID/QASUME
Wavelength [nm]
NB_Spectra=86

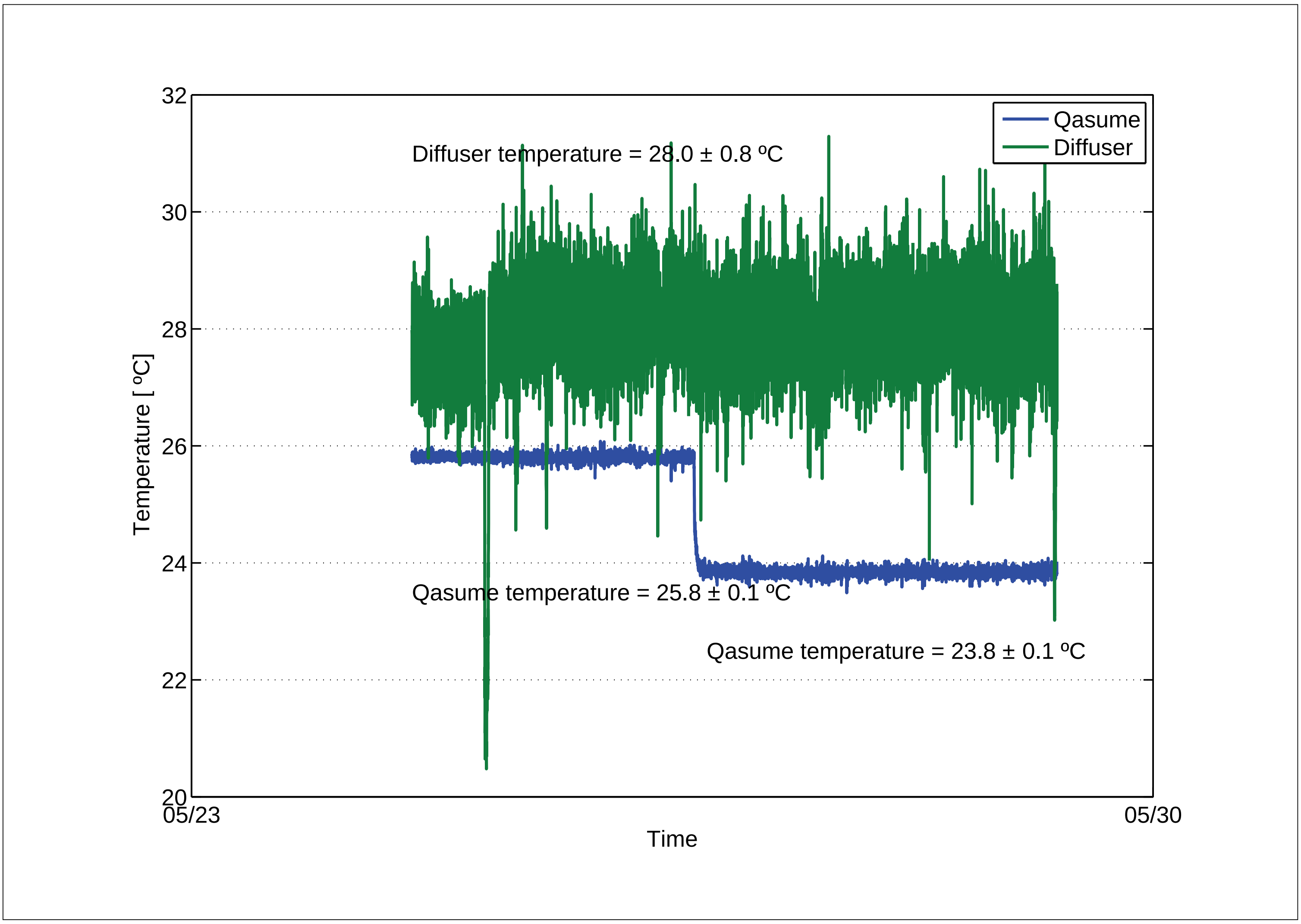

UV Index FMI−Jokioinen, Qasume vs. Nilu, May 2010
QASUME
102
131
UV Index
Day of Year
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
145
145.5
146
146.5
147
147.5
148
148.5
149

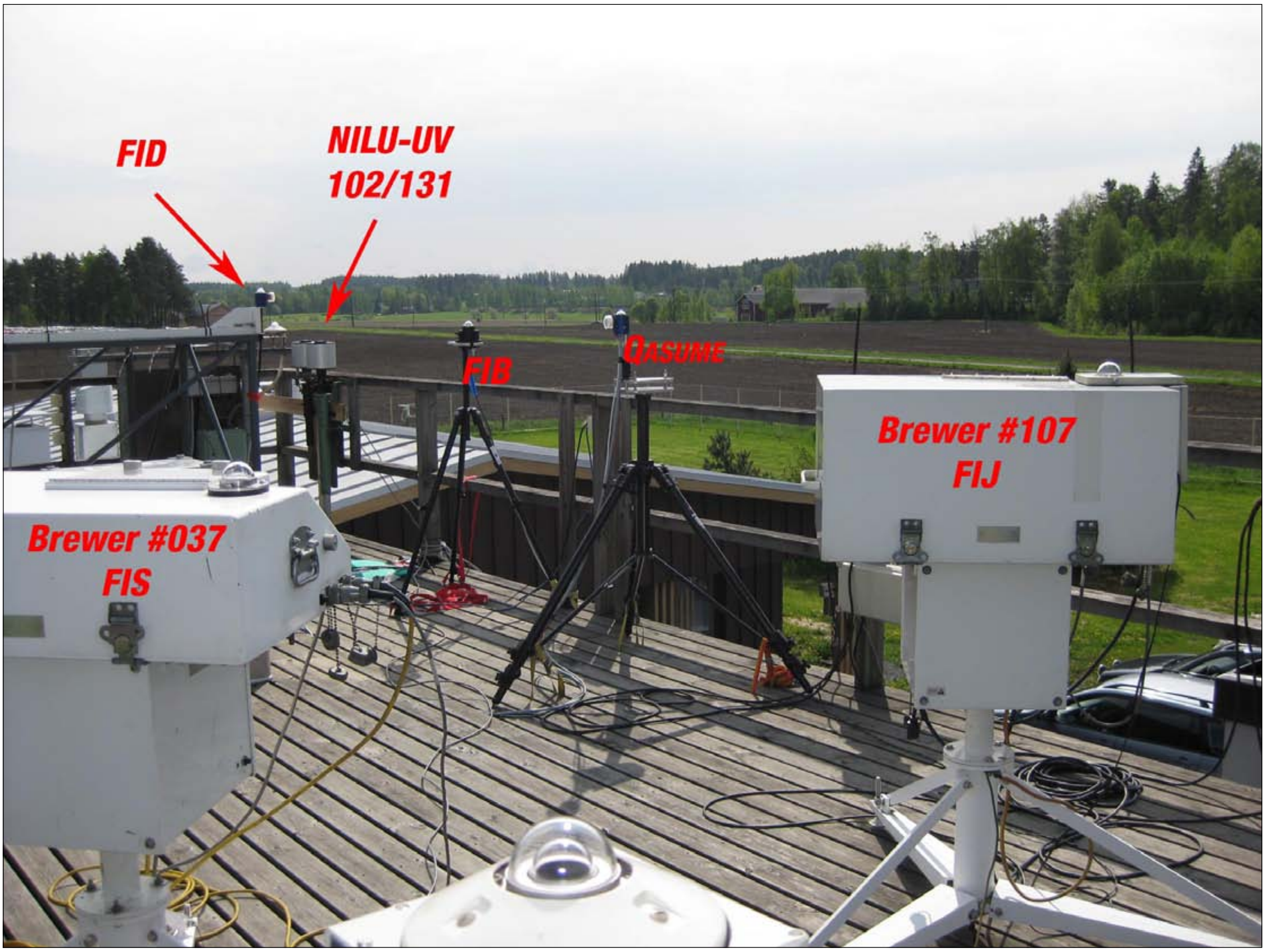

UV Index FMI−Jokioinen, Qasume vs. Nilu, May 2010
Average Ratio (SZA<75): 1.02 ± 0.04
Ratio Nilu 102/Qasume
Day of Year
0.8
0.85
0.9
0.95
1
1.05
1.1
1.15
145
145.5
146
146.5
147
147.5
148
148.5
149



UV Index FMI−Jokioinen, Qasume vs. Nilu, May 2010
Average Ratio (SZA<75): 0.87 ± 0.03
Ratio Nilu 131/Qasume
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
145
145.5
146
146.5
147
147.5
148
148.5
149
Day of Year


QASUME spectral Responsivity changes, Jokioinen, May 2010
145
146
147
148
149
Variability=± 0.78%
Ratio to mean
Wavelength /nm
1.02
1.015
1.01
1.005
1
0.995
0.99
0.985
0.98
280
300
320
340
360
380
400


Qasume
Diffuser
Diffuser temperature = 28.0 ± 0.8 ºC
Qasume temperature = 25.8 ± 0.1 ºC
Qasume temperature = 23.8 ± 0.1 ºC
Temperature [ºC]
Time
32
30
28
26
24
22
20
05/23
05/30


FID
NILU-UV
102/131
FIB
QASUME
Brewer #107
FIJ
Brewer #037
FIS