

Protocol of the intercomparison at LKO, Arosa, Switzerland on July
21 to 28, 2008 with the travelling reference spectroradiometer
QASUME[†] from PMOD/WRC

Report prepared by Gregor Hülsen, Julian Gröbner

Operator: Gregor Hülsen, Julian Gröbner

The purpose of the visit was the comparison of global solar irradiance measurements between the 7 spectroradiometers participating in the 3rd Regional Brewer Calibration Center – Europe (RBCC-E) Campaign (see Figure 1 and Table 1) and the travel reference spectroradiometer QASUME. The measurement site is located at the Lichtklimatische Observatorium (LKO) in Arosa; Latitude 46.78 N, Longitude 9.68 E and altitude 1846 m.a.s.l.. The horizon of the measurement site is free down to ~80° solar zenith angle (SZA), see Figure on Page 35.

QASUME arrived at LKO in the morning of July 21, 2008. The spectroradiometer was installed in line to the Brewer spectrophotometers with the entrance optic of QASUME between 2 and 10 m away from the other instruments. The measurement campaign lasted eight days, from noon of July 21 to the afternoon of July 28; the core comparison days were July 24 to 27.

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 23.1±0.3 °C. The diffuser head was heated to a temperature of 25.7±1.2 °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.

Table 1: Participating Brewer spectrophotometers

Instrument ID	Institution	Operator	Country
#017-MKII	IOS	Ken Lamb	Canada
#040-MKII	MeteoSwiss	Herbert Schill	Switzerland
#072-MKII	MeteoSwiss	Herbert Schill	Switzerland
#156-MKIII	MeteoSwiss	Herbert Schill	Switzerland
#064-MKII	Inst. of Geophysics	Janusz Jaroslowski	Poland
#163-MKIII (ISQ)	PMOD/WRC	Julian Gröbner	Switzerland
#185-MKIII (IZ3)	INM IZAÑA	Alberto Redondas	Spain

[†]The QASUME spectroradiometer B5503 is made available by the Physical and Chemical Exposure Unit of the Joint Research Centre of the European Commission, Ispra, Italy through a collaboration agreement with PMOD/WRC.

Protocol:

The measurement protocol was to measure one solar irradiance spectrum from 290 to 400 nm, every 0.5 nm, and 1.5 seconds between each wavelength increment. The scans were performed approx. every 40 min interspersed with the total column ozone measurements.

July 21 (203) Monday:

QASUME was installed on the measurement site at 10:00 UT. Solar spectra are available from 14:00 UT when the internal temperature of QASUME reached its nominal temperature. Weather conditions were a mix of sun and clouds.

QASUME was calibrated at 15:30 UT.

July 22 (204) Tuesday:

Solar spectra are available from 4:00 to 18:15 UT. Weather conditions were overcast sky with a few raindrops from 9:30 to 13:30 UT.

QASUME was calibrated at 13:41 and 13:51 UT.

July 23 (205) Wednesday:

Solar spectra are available from 3:45 to 19:00 UT. Weather conditions were a mix of sun and clouds.

QASUME was calibrated at 8:11 UT.

July 24 (206) Thursday:

Solar spectra are available from 4:00 to 16:20 UT. Weather conditions were clear sky with a few cirrus and cumulus clouds.

QASUME was calibrated at 4:20 and 16:12 UT.

July 25 (207) Friday:

Solar spectra are available from 7:00 to 16:40 UT. Weather conditions were clear sky with a few cirrus clouds.

QASUME was calibrated at 12:30 UT.

July 26 (208) Saturday:

Solar spectra are available from 3:40 to 15:20 UT. Weather conditions were mostly overcast sky.

July 27 (209) Sunday:

Solar spectra are available from 4:00 to 16:00 UT. Weather conditions were a mix of sun and clouds with two rain periods (10:15 to 12:30 UT and 13:40 to 15:00 UT).

July 28 (210) Monday:

Solar spectra are available from 4:00 to 10:20 UT. Weather conditions were a mix of sun and clouds.

The HeCd-Laser was used between 12:00 to 15:00 UT to measure the slitfunction of Brewer #040, #072 and #156.

End of the campaign at 15:00 UT.

Results:

In total 11 to 117 synchronised simultaneous spectra from QASUME and the Brewer spectrophotometers are available from the measurement period. Measurements from sunrise to sunset have been analysed (taking the horizon of at the measurement site into account).

Remarks:

1. The official UV intercomparison of the instruments was integrated into the ozone calibration period. The first two day were dedicated to the training phase.
2. Although different calibrations and measurements were performed during the campaign, traffic on the roof could be limited. Therefore only few scans are disturbed.
3. The time synchronisation between QASUME and various Brewers could not always be achieved which led to several missing scans.
4. For the production of the calibration certificates all solar scans are excluded which are affected by rain.
5. Brewer #064 was recalibrated during the intercomparison. The two Figures on Page 12 show a 5% improvement of the new calibration.

Brewer Temperature dependence:

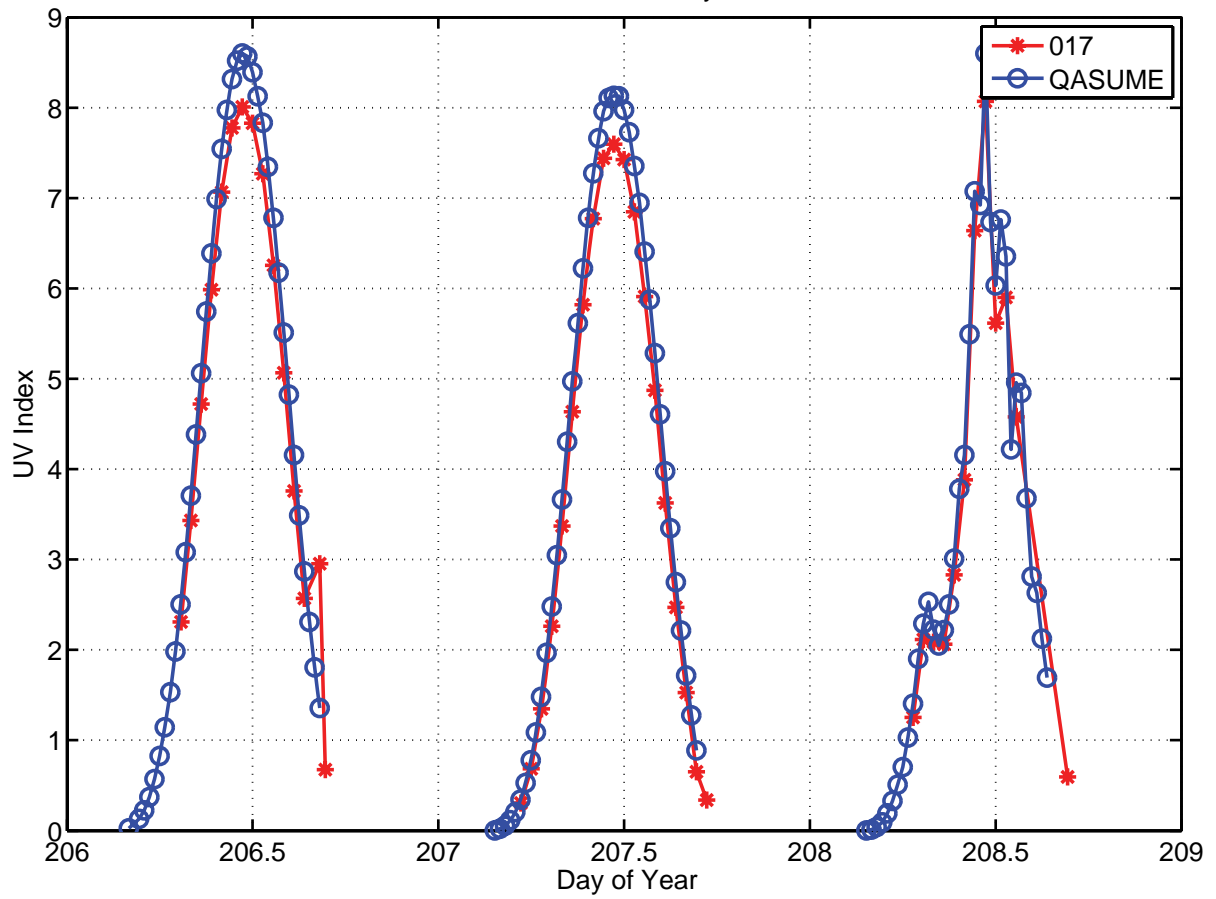
The standard Brewer global UV measurement procedure does not take into account the dependence of the Brewer spectral responsibility to ambient temperature. However several studies have shown, that Brewer spectrophotometers have a temperature dependence which can be as large as 0.9%/K and which depends on wavelength (Cappellani, F., and C. Kochler (2000), Temperature effects correction in a Brewer MKIV spectrophotometer for solar UV measurements, J. Geophys. Res., 105(D4), 4829–4831; Weatherhead, E., et al. (2001), Temperature dependence of the Brewer ultraviolet data, J. Geophys. Res., 106(D24), 34,121–34,129).

At Arosa, due to the high diurnal temperature variations, the temperature dependence of the Brewer spectrophotometers has therefore a significant influence on the global UV measurements as can be seen in the respective ratios relative to the QASUME spectroradiometer which is temperature stabilised. An example can be seen with Brewer #156; the figure on page 34 shows the mean ratio of this Brewer to QASUME vs. temperature. Similar temperature dependencies could be derived for other Brewers as well. In contrast, the stable performance of Brewer #163 can partly be explained by the applied temperature correction of -0.145%/K.

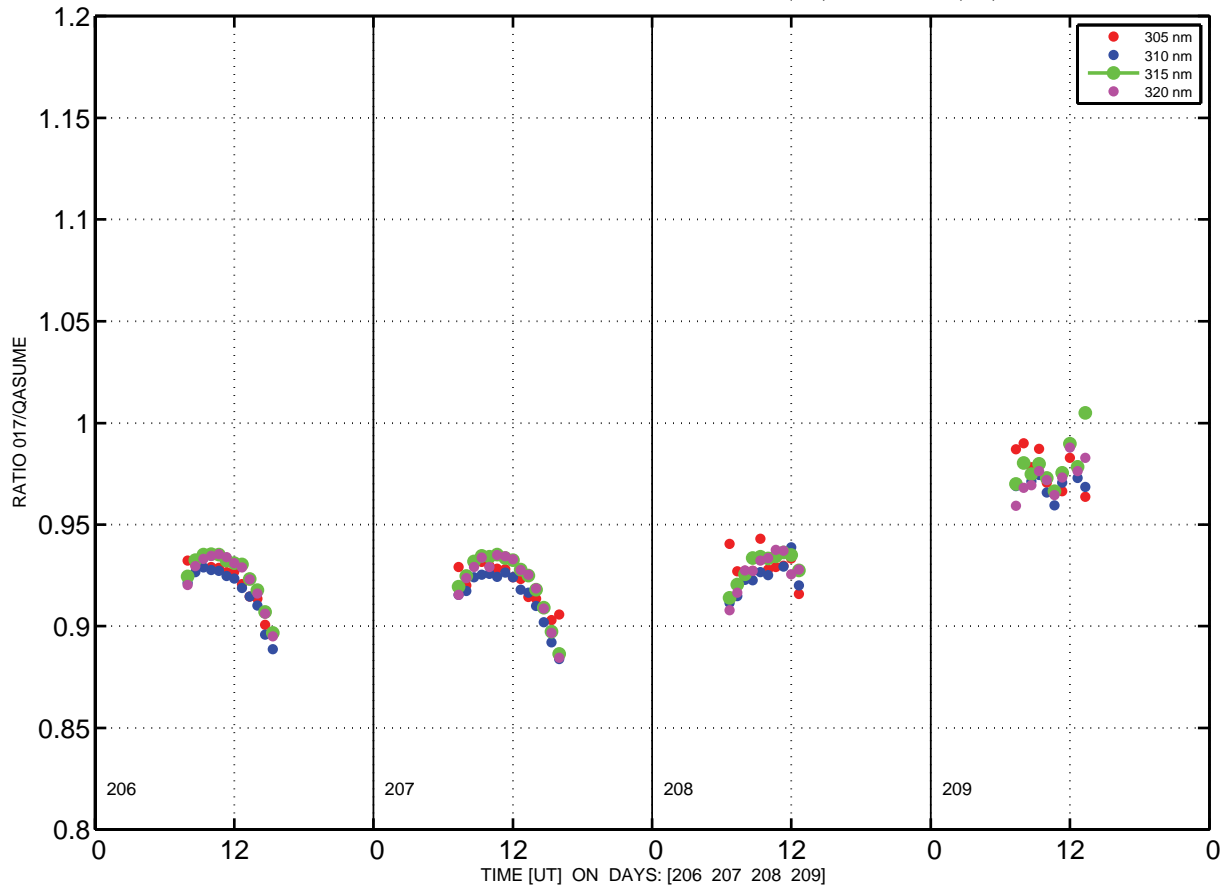
Recommendations:

The variabilities observed between individual Brewer spectrophotometers relative to the QASUME spectroradiometer are due to ambient temperature variations on the one hand (see above paragraph), and to angular response errors which were not accounted for (See for example Gröbner, J., Improved entrance optic for global irradiance measurements with a Brewer spectrophotometer, Applied Optics, 42, 3516-3521, 2003). While a reliable correction of angular response errors requires the modification of the Brewer entrance optic, the temperature dependence can be corrected by applying a suitable spectral temperature correction to global UV measurements. This function should be determined individually for every Brewer using a measurement procedure as described in the refereed literature (see references).

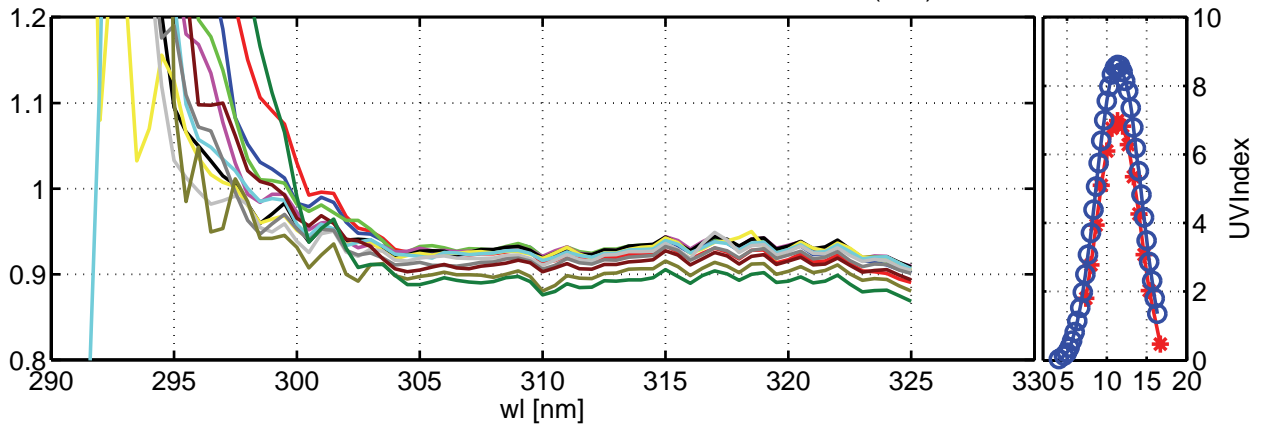
UV Index Arosa, July 2008



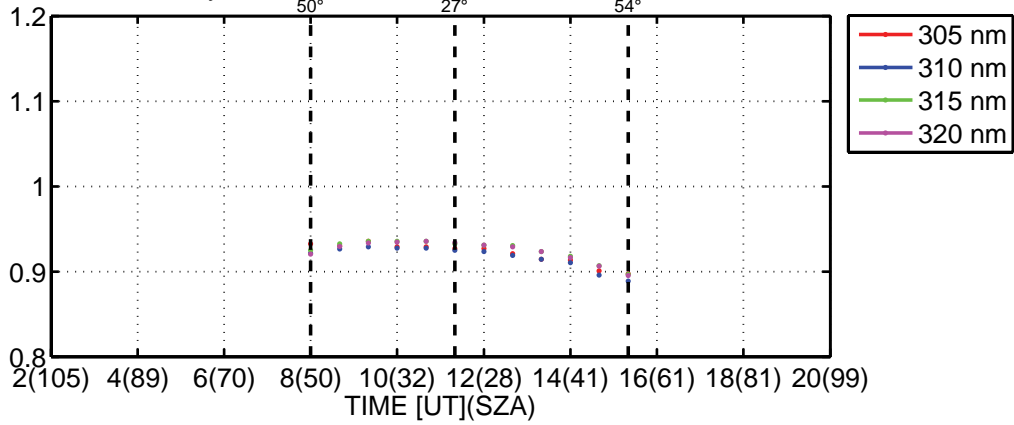
Global irradiance ratios 017/QASUME at Arosa:24-Jul-2008(206) to 27-Jul-2008(209)



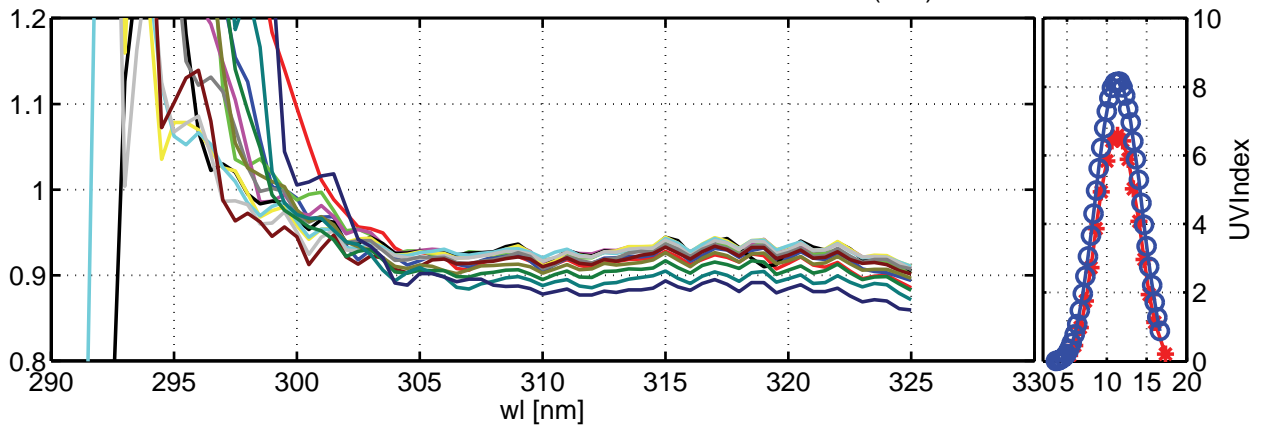
Global irradiance ratios 017/QASUME at Arosa:24-Jul-2008(206)



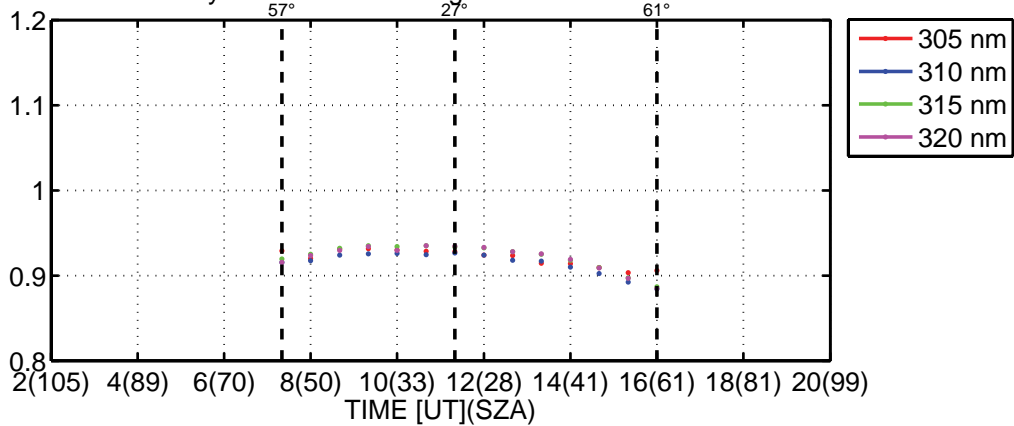
Daily variation. Wavelength bands are ± 2.5 nm



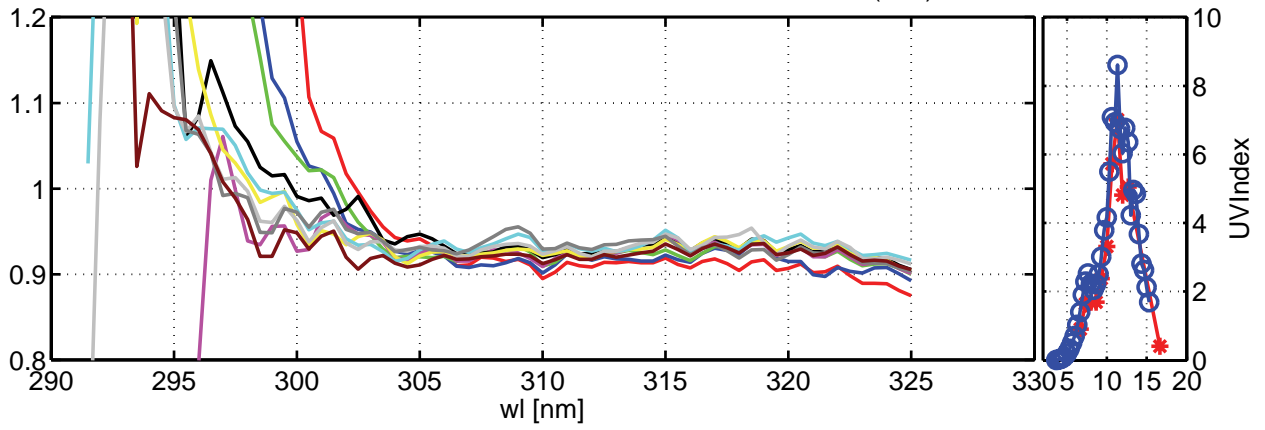
Global irradiance ratios 017/QASUME at Arosa:25-Jul-2008(207)



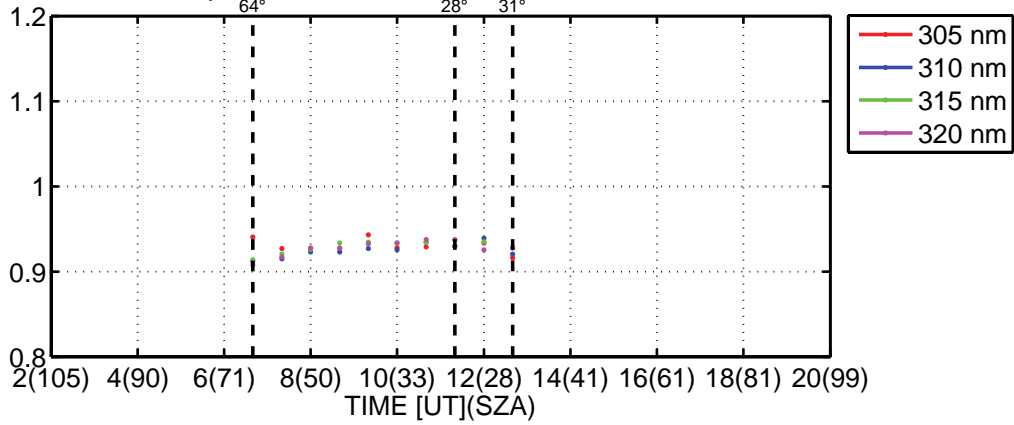
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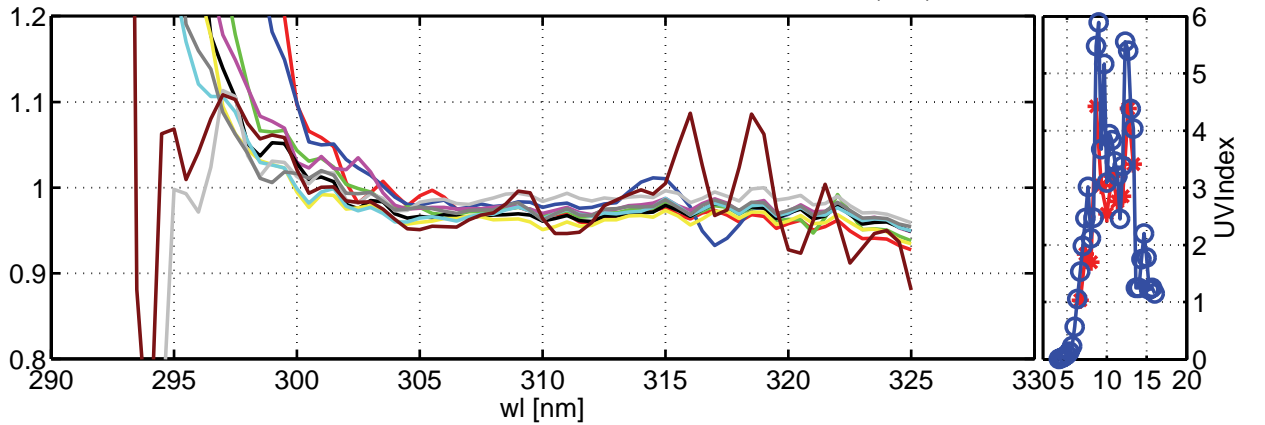
Global irradiance ratios 017/QASUME at Arosa:26-Jul-2008(208)



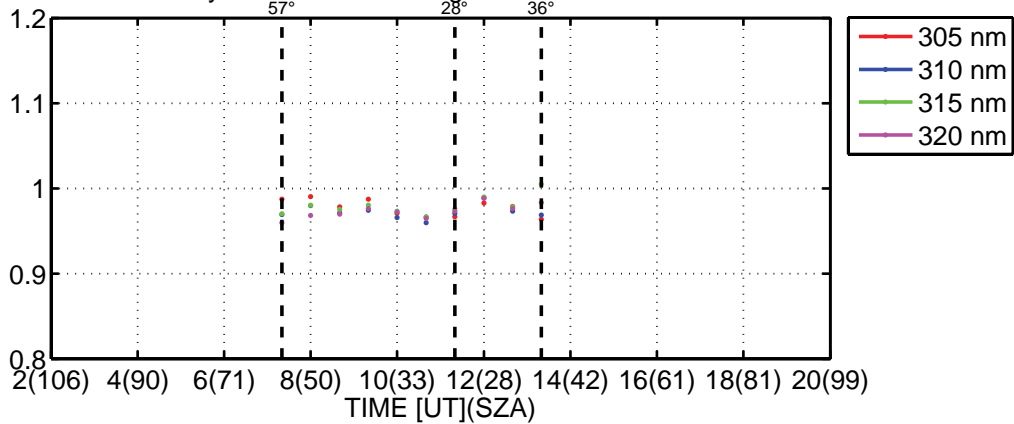
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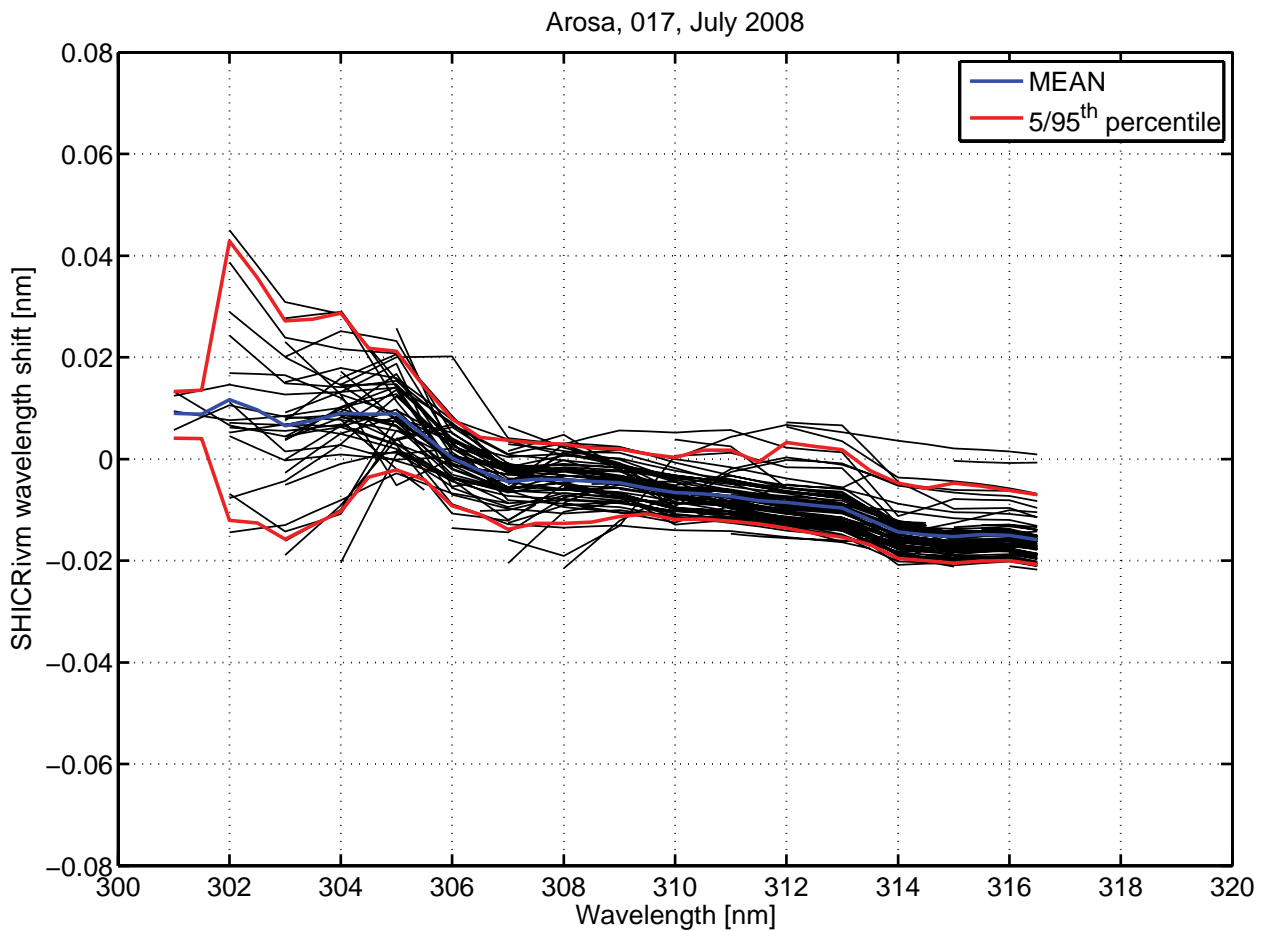
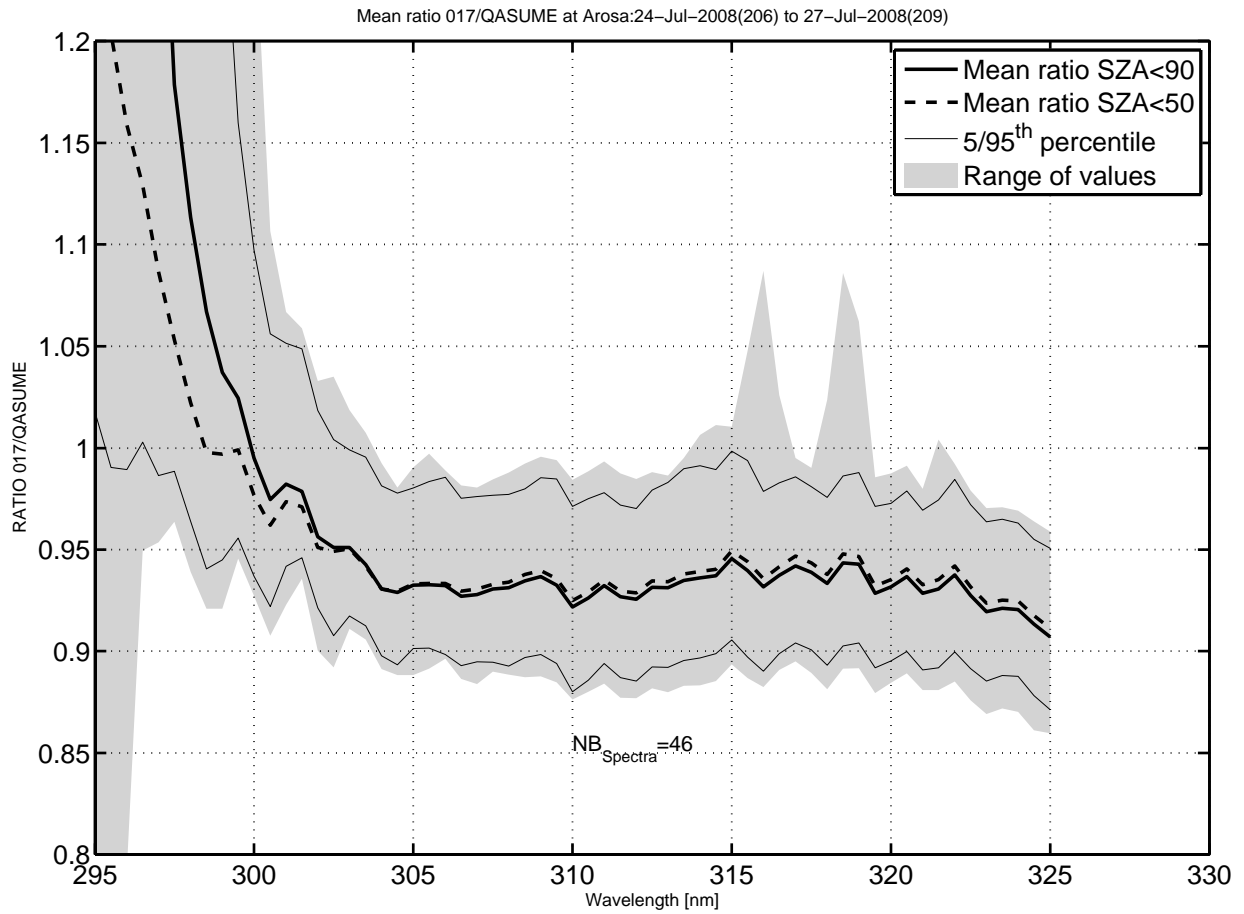


Global irradiance ratios 017/QASUME at Arosa:27-Jul-2008(209)

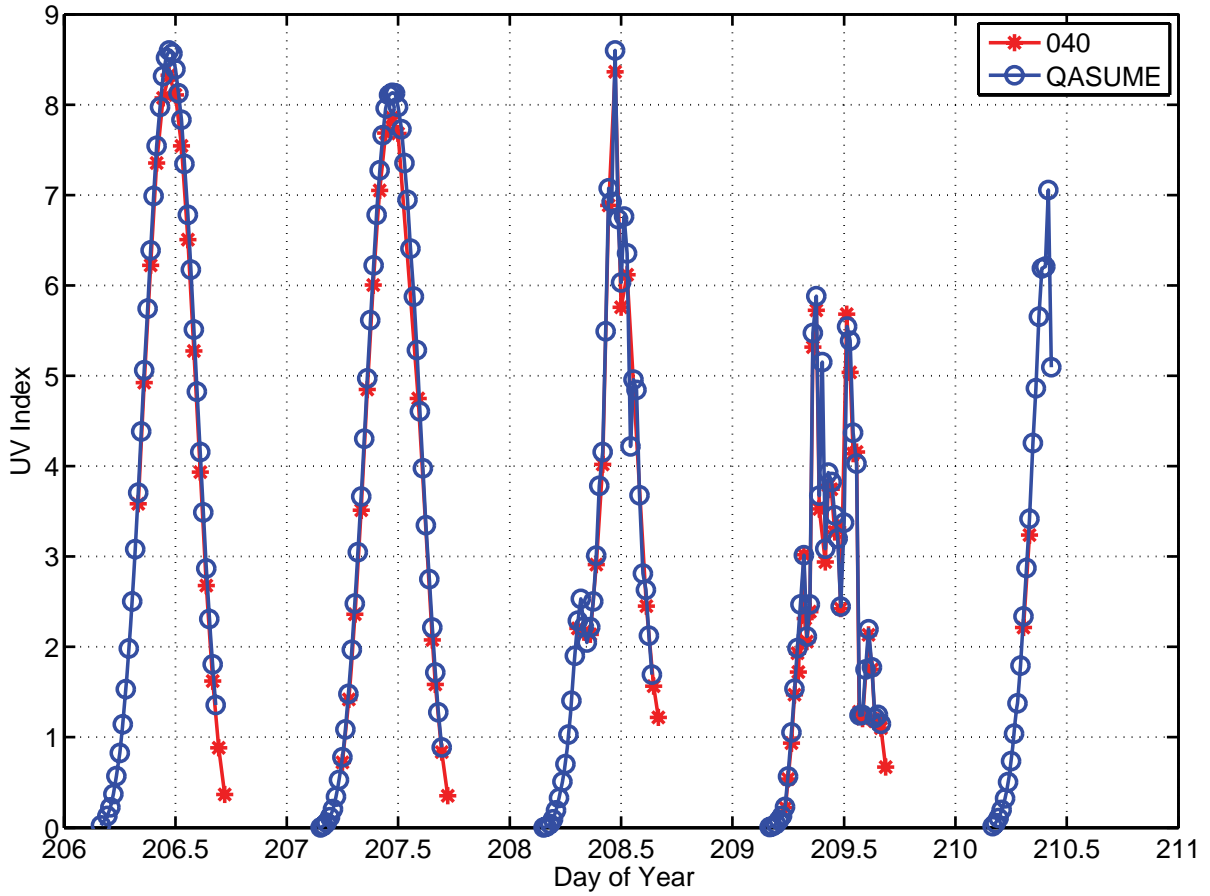


Daily variation. Wavelength bands are ± 2.5 nm

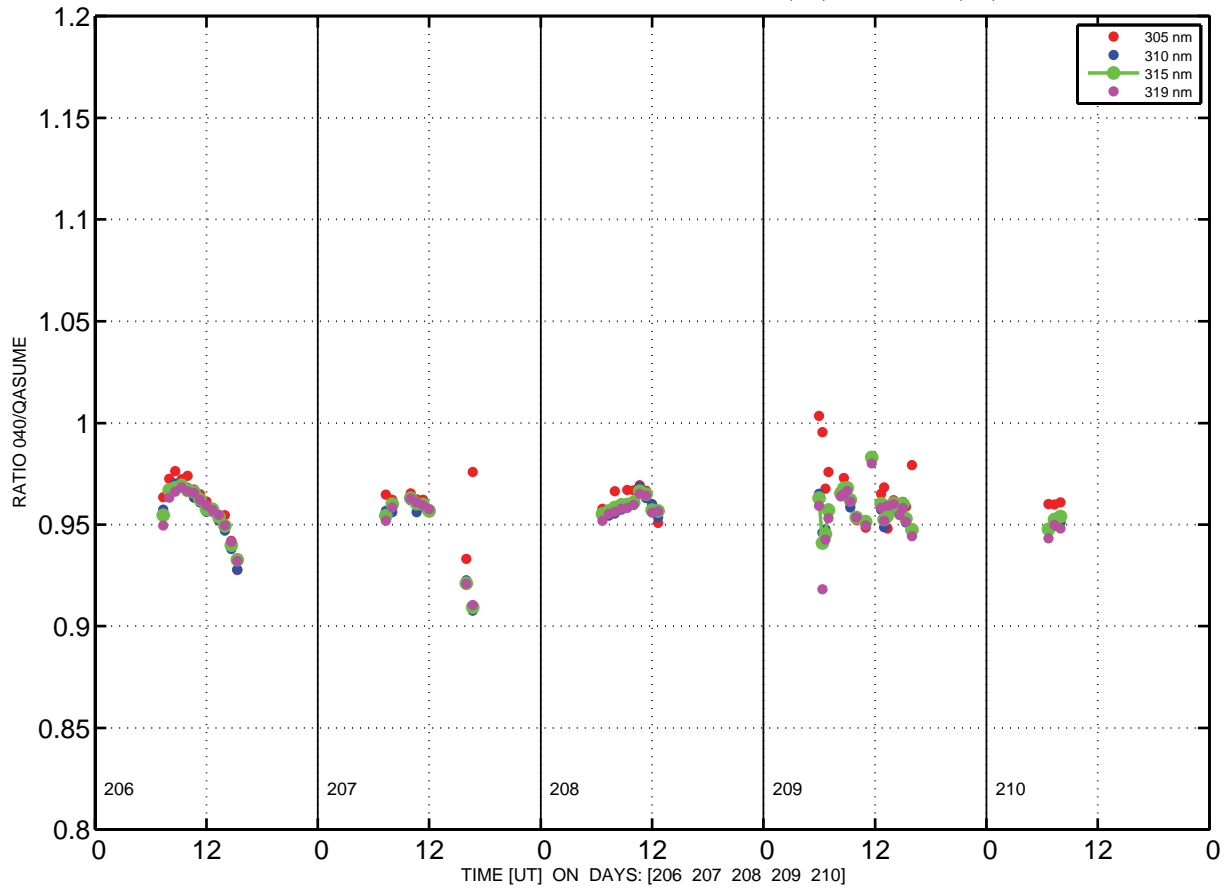




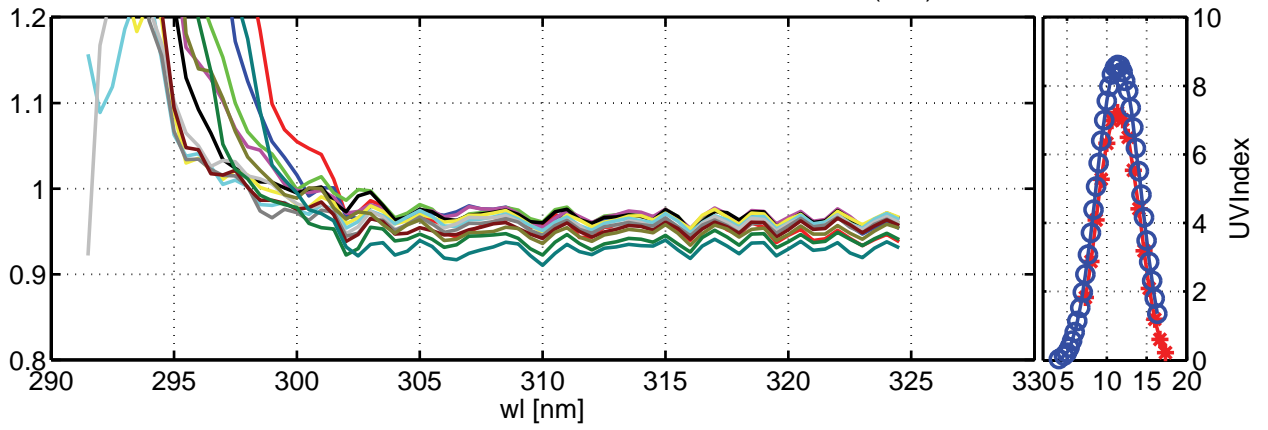
UV Index Arosa, July 2008



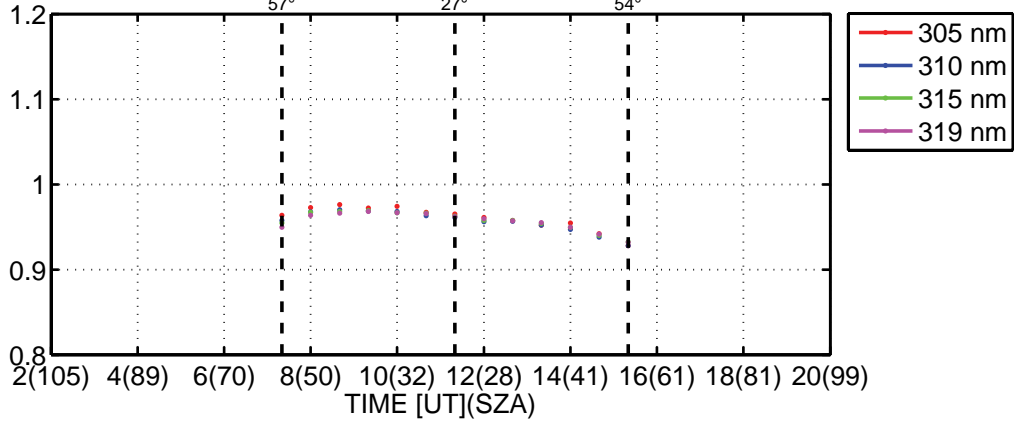
Global irradiance ratios 040/QASUME at Arosa:24-Jul-2008(206) to 28-Jul-2008(210)



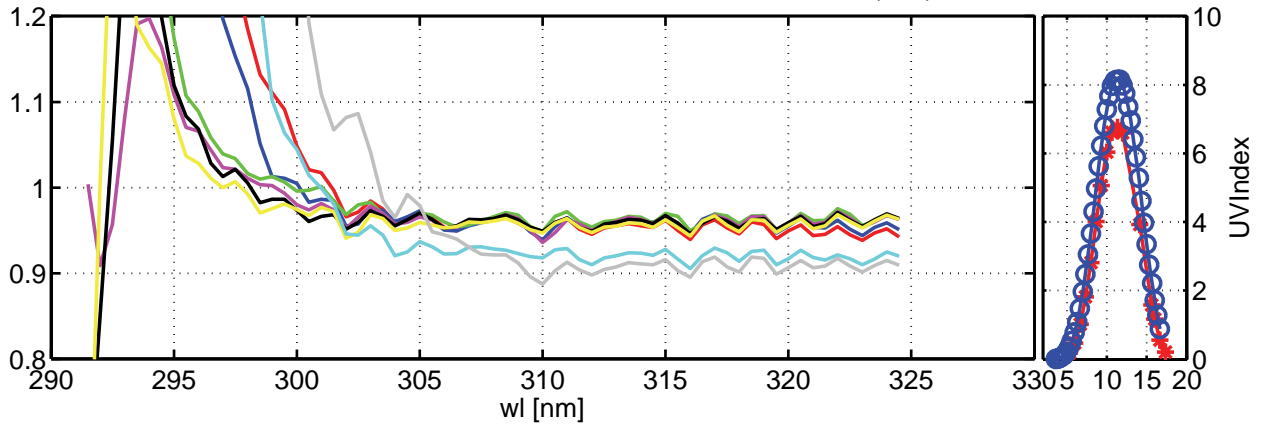
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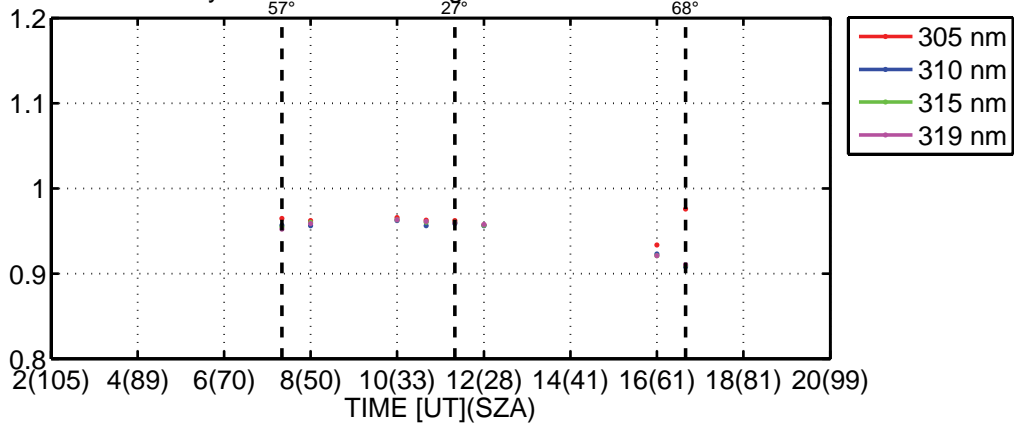
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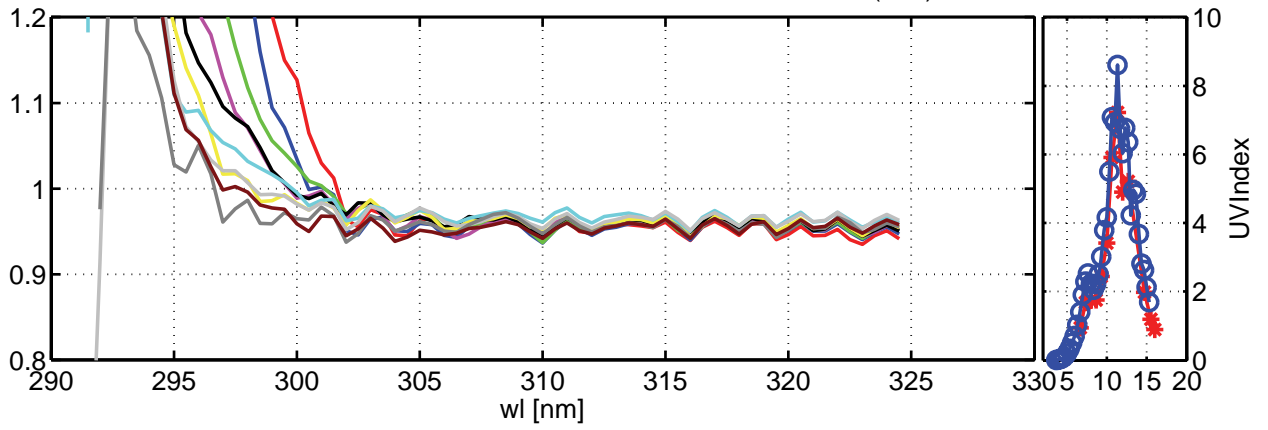
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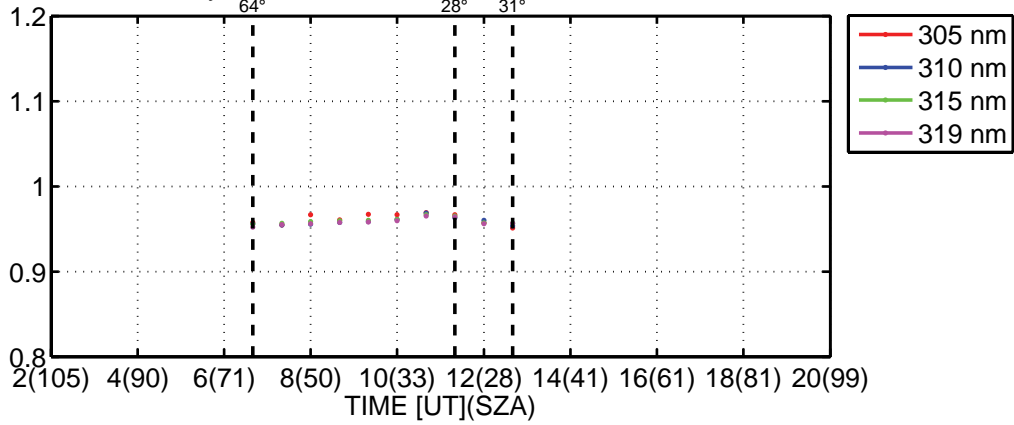
Daily variation. Wavelength bands are ± 2.5 nm



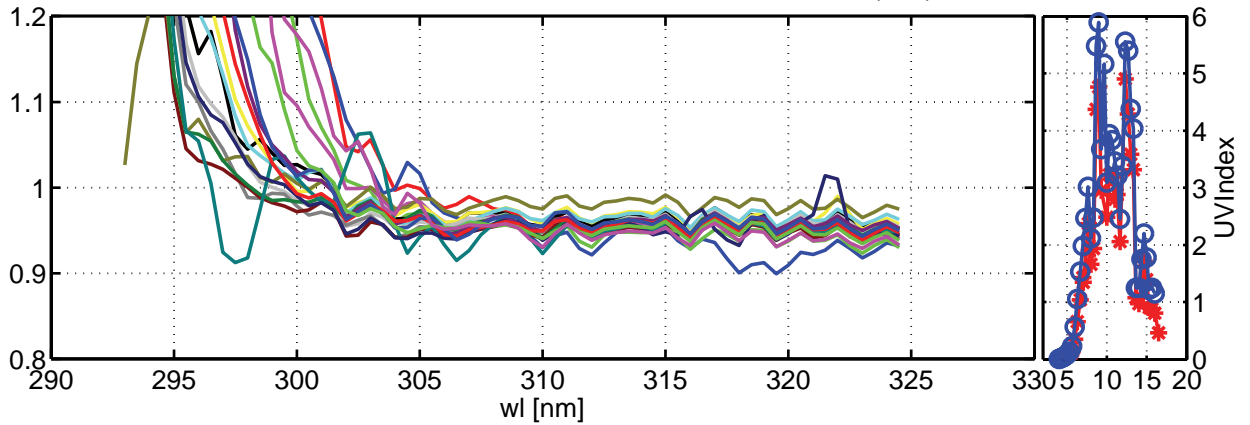
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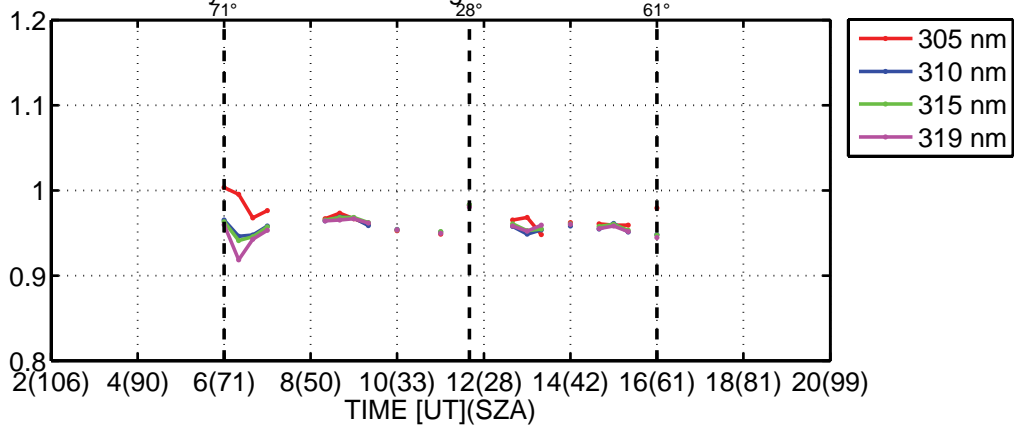
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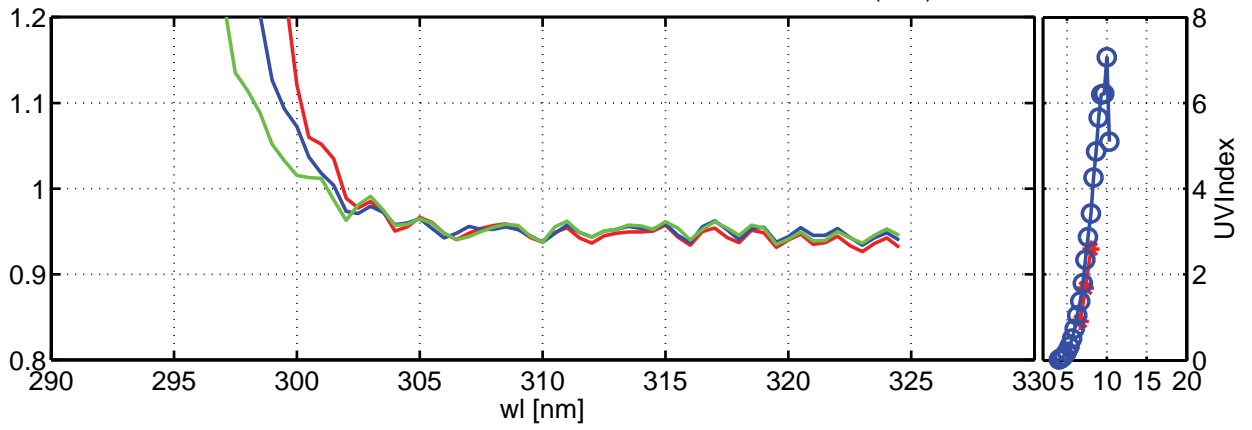
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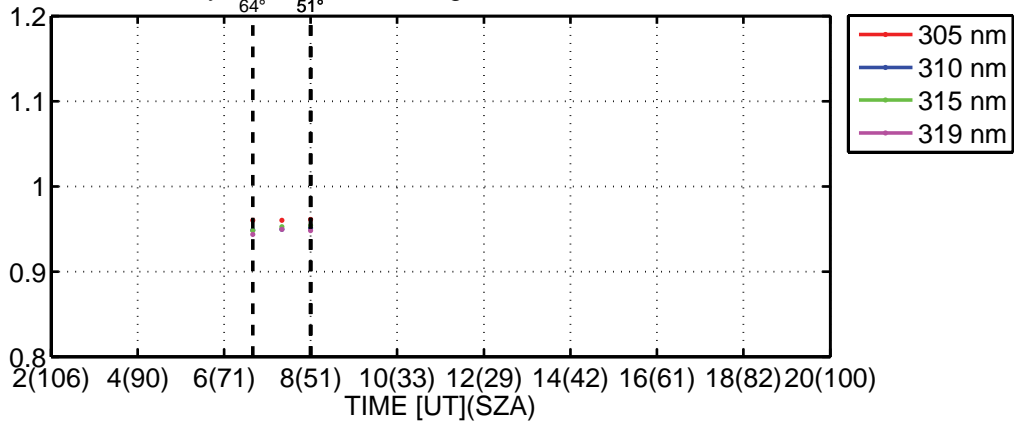
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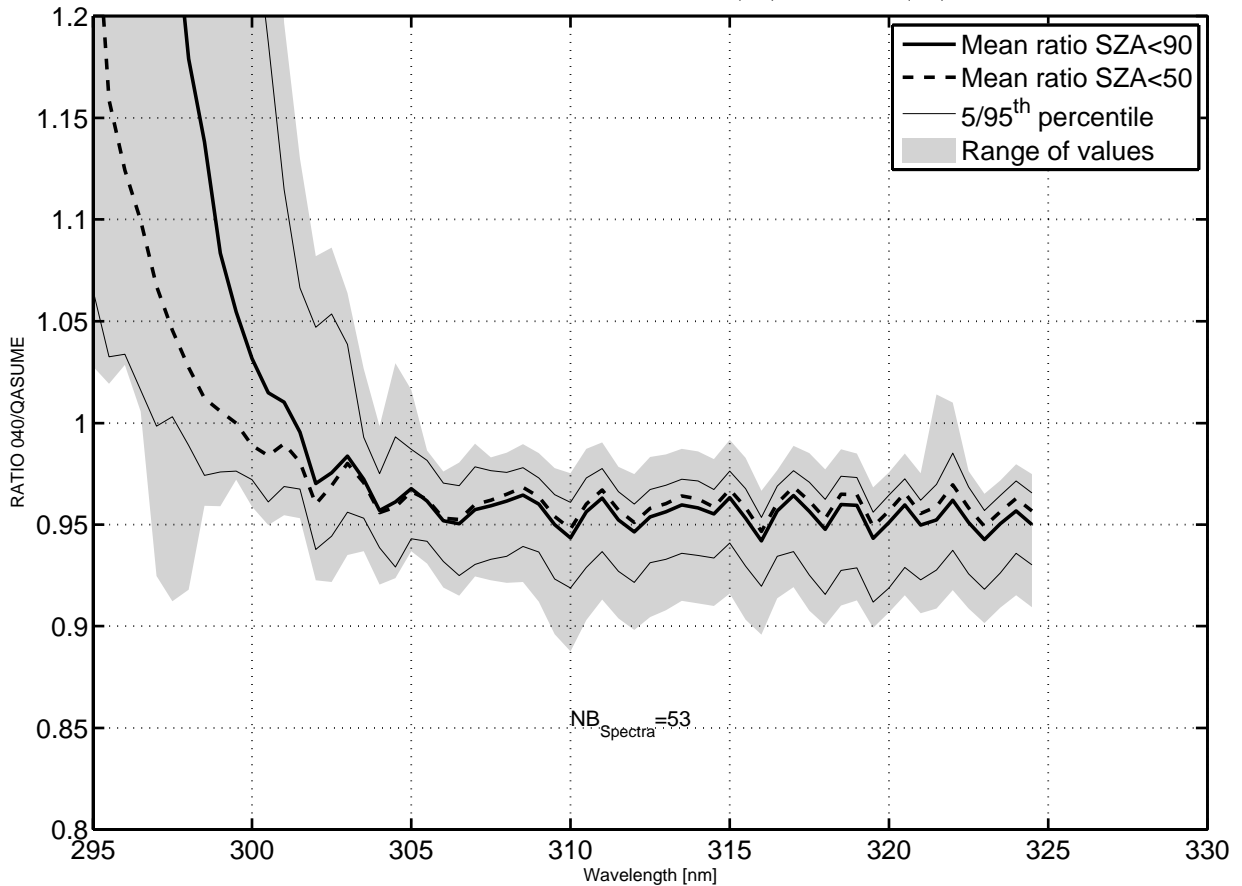
Global irradiance ratios 040/QASUME at Arosa:28-Jul-2008(210)

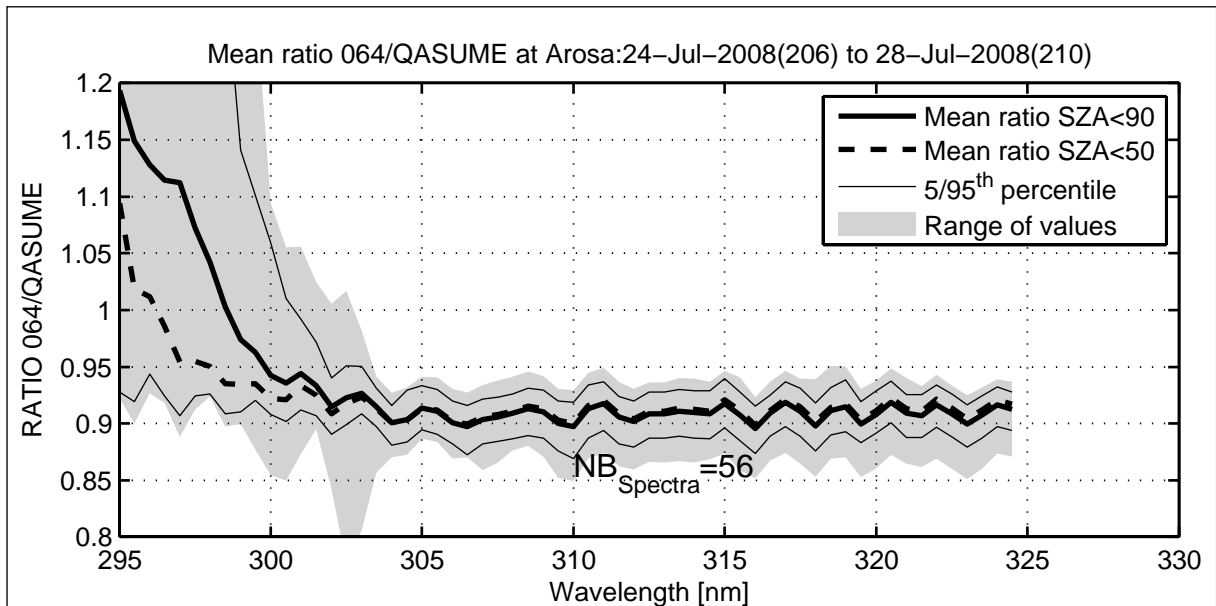
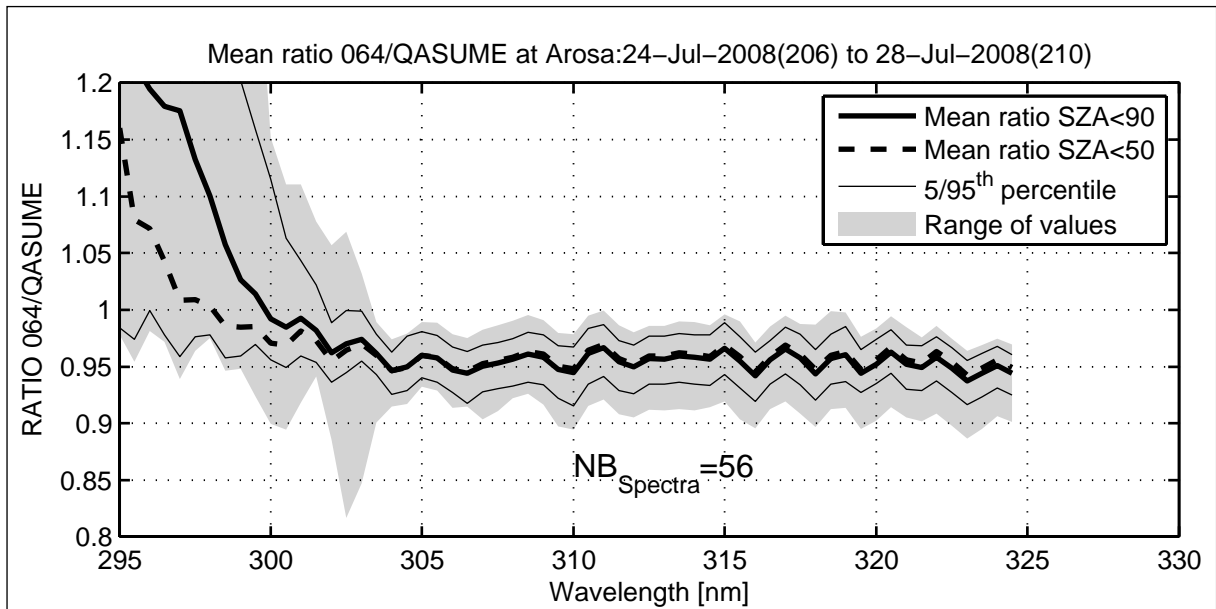
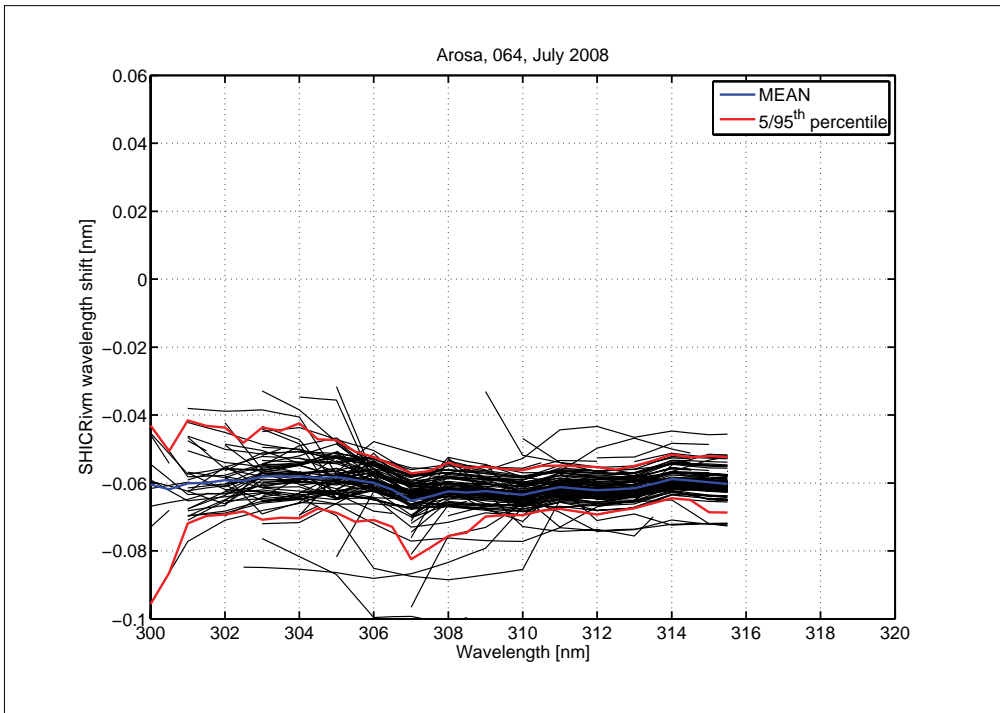


Daily variation. Wavelength bands are ± 2.5 nm

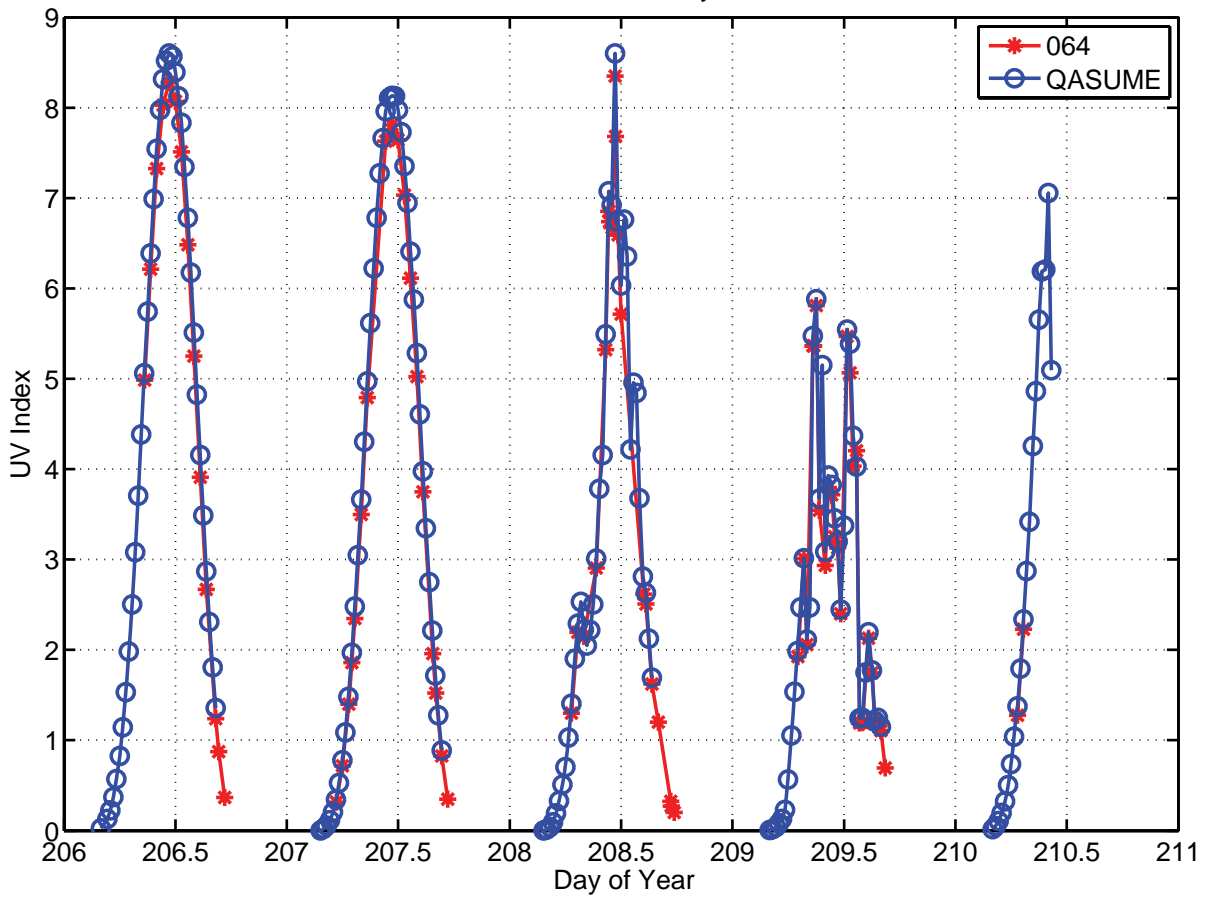


Mean ratio 040/QASUME at Arosa:24-Jul-2008(206) to 28-Jul-2008(210)

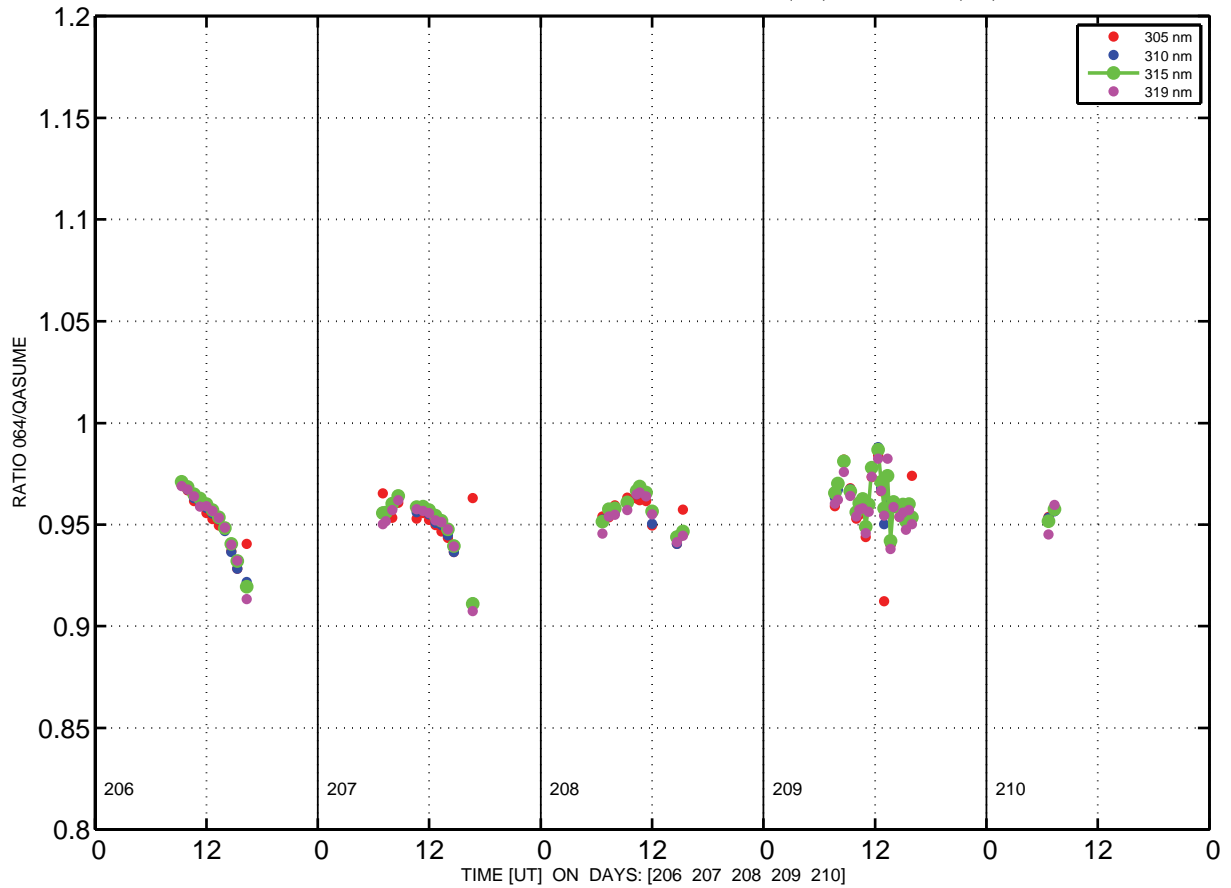




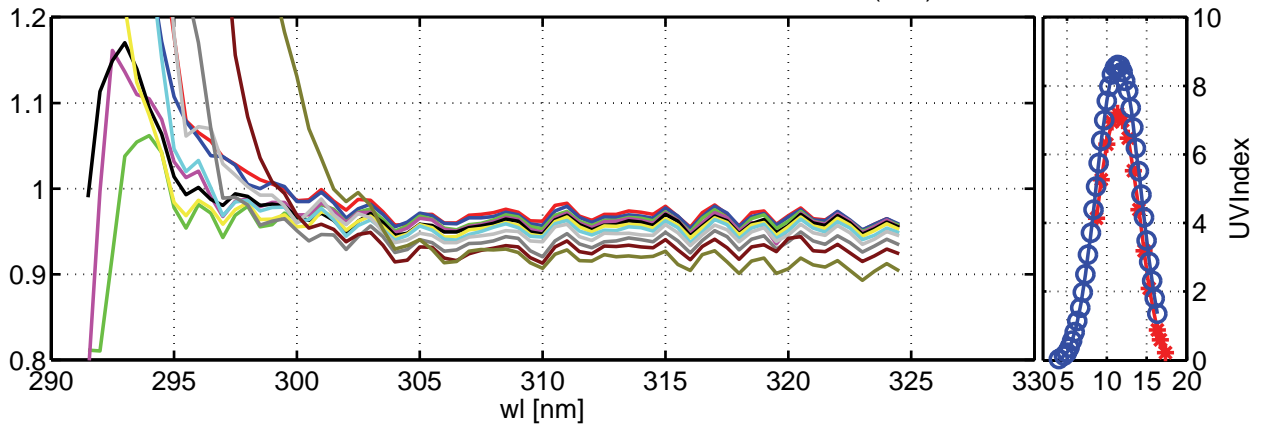
UV Index Arosa, July 2008



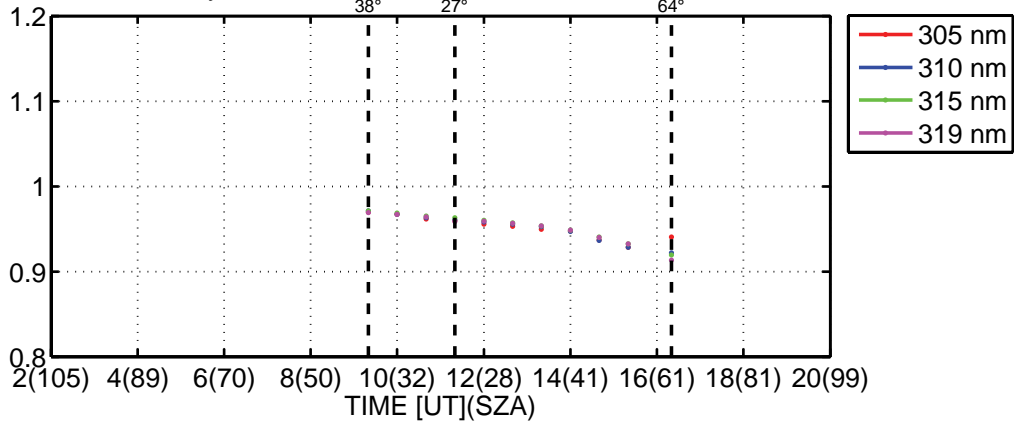
Global irradiance ratios 064/QASUME at Arosa:24-Jul-2008(206) to 28-Jul-2008(210)



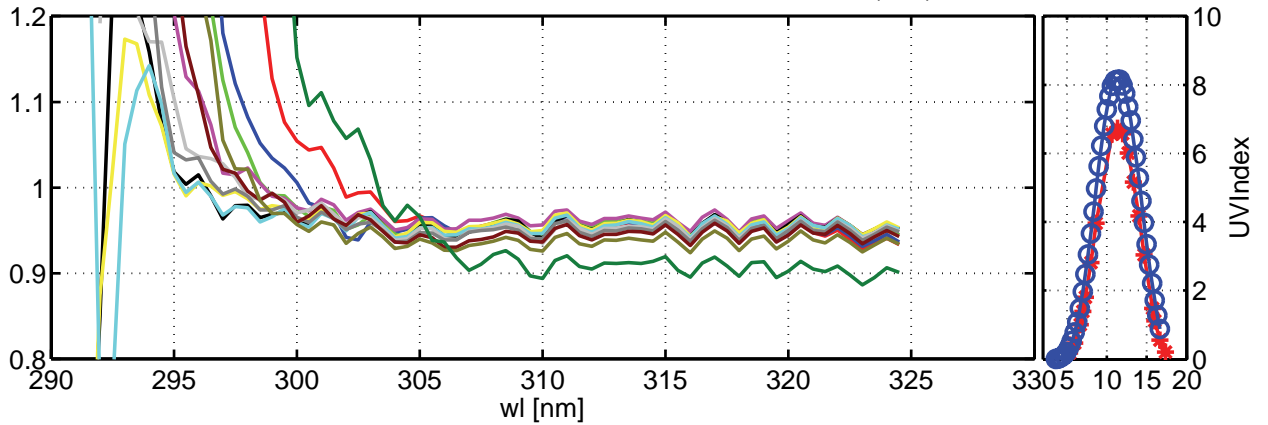
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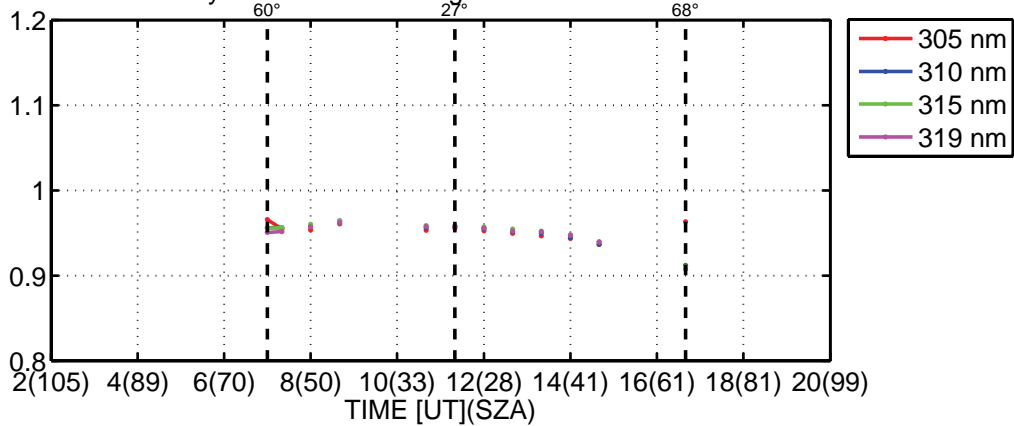
Daily variation. Wavelength bands are ± 2.5 nm



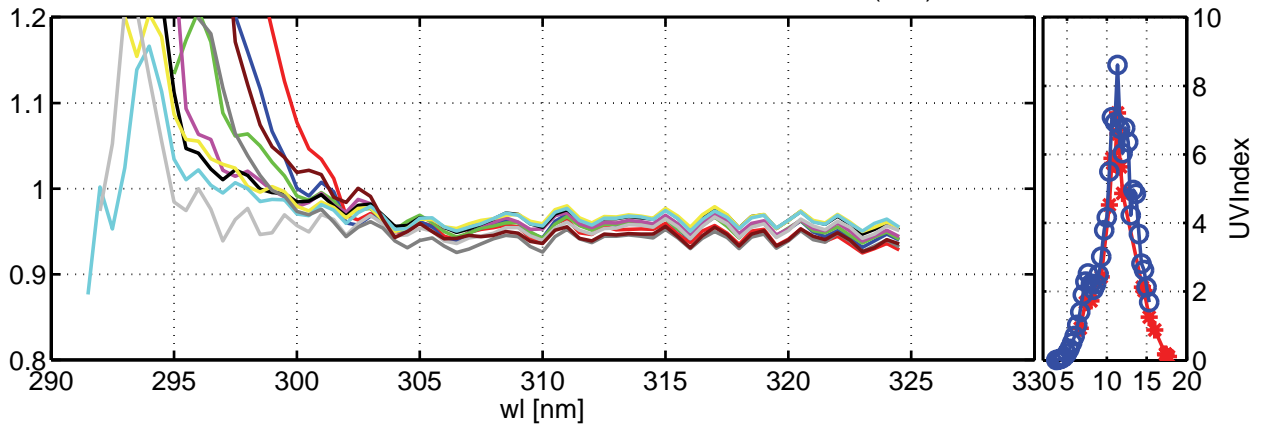
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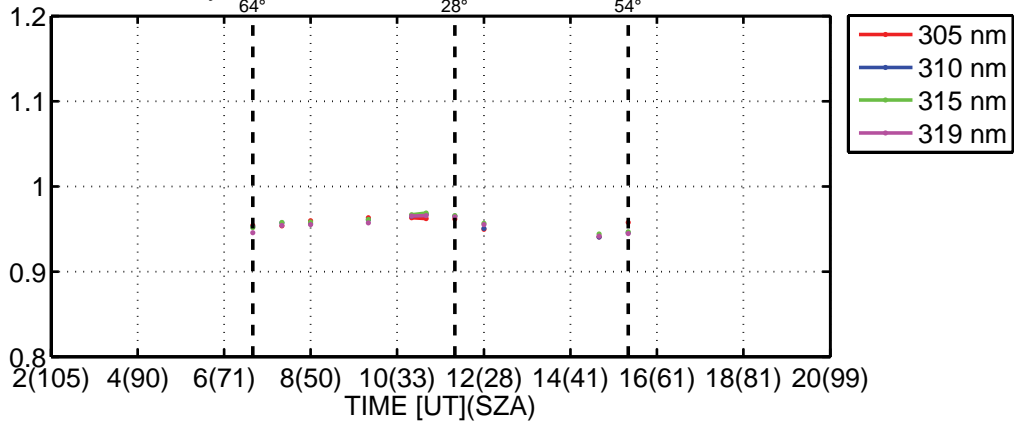
Daily variation. Wavelength bands are ± 2.5 nm



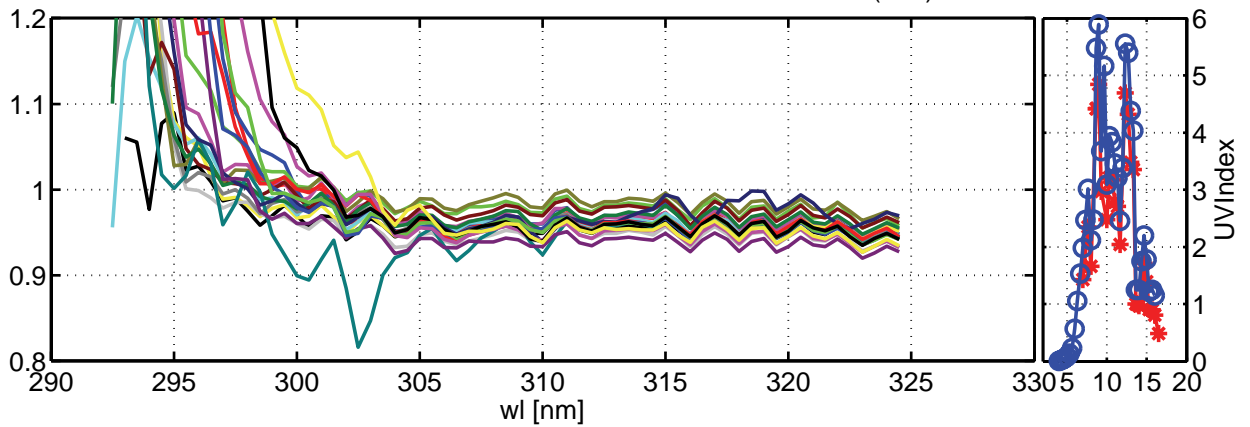
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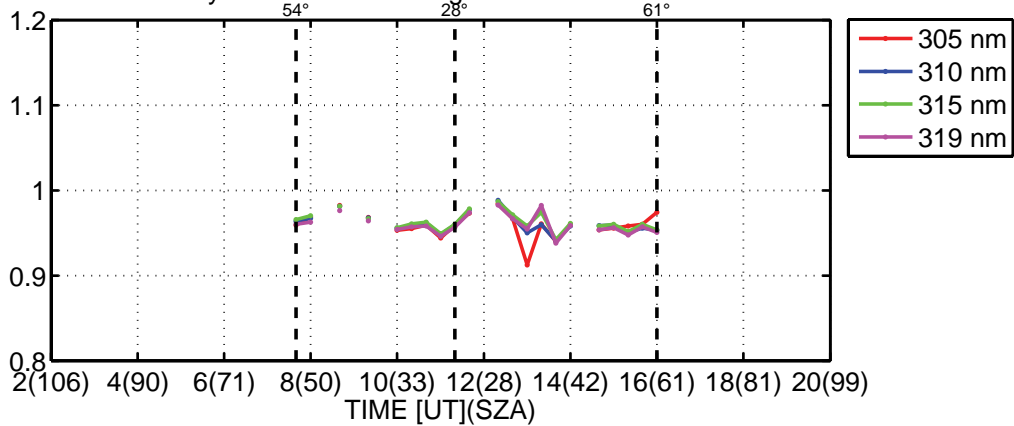
Daily variation. Wavelength bands are ± 2.5 nm



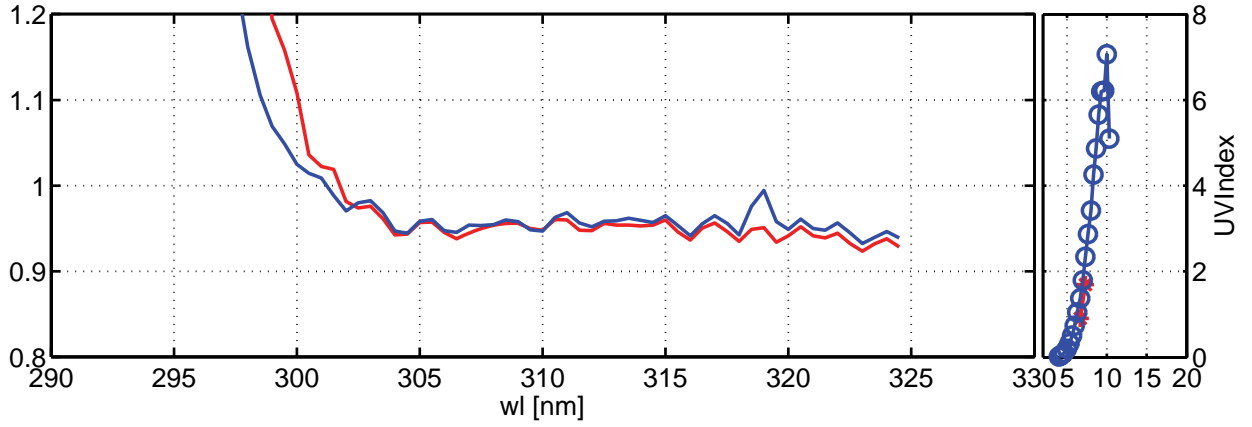
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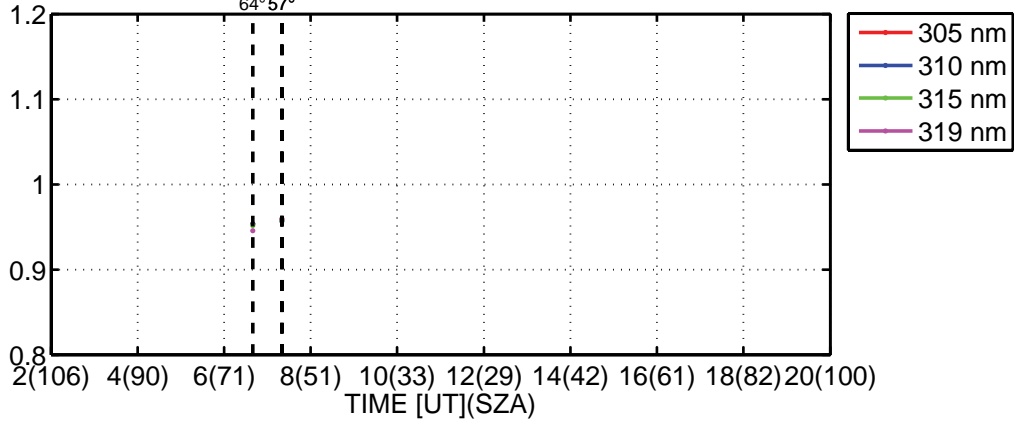
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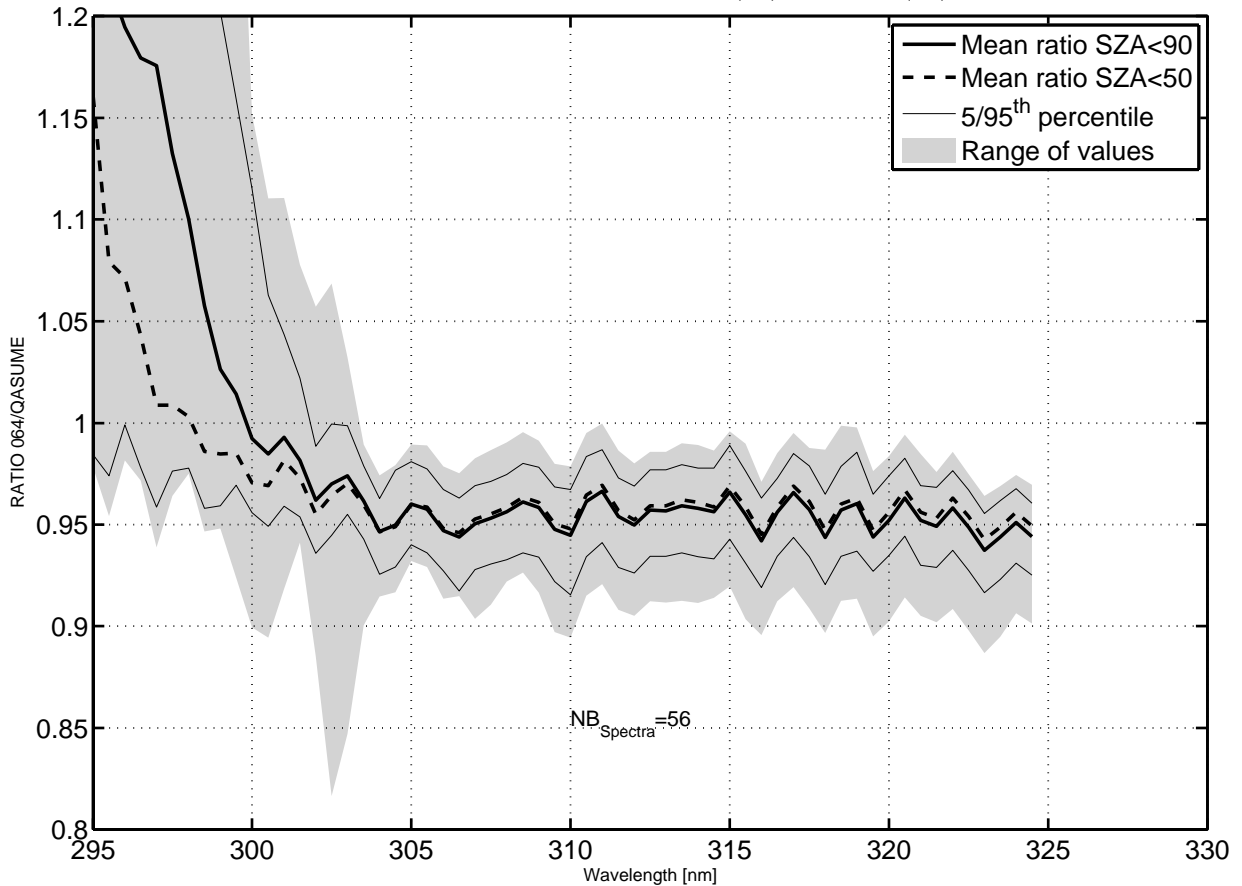
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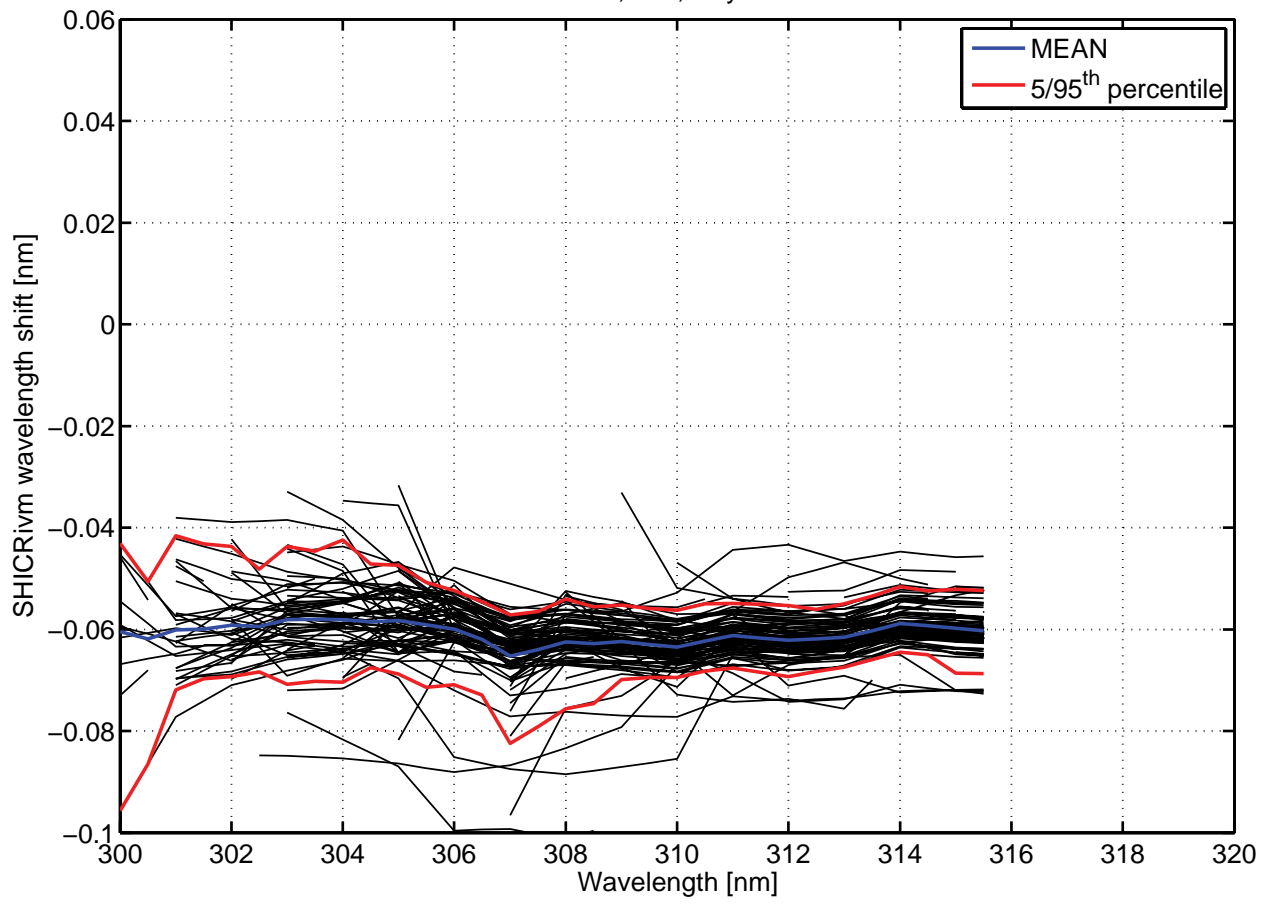
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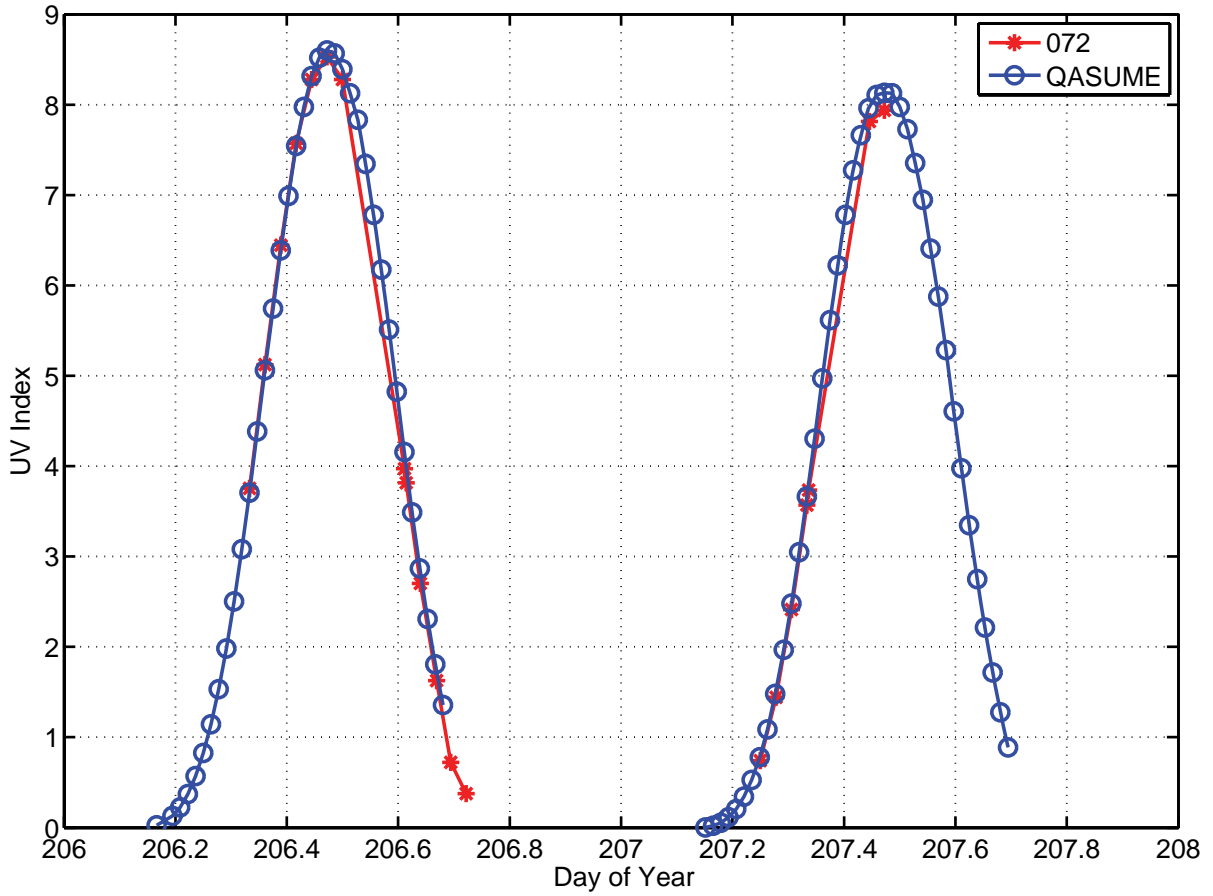
Mean ratio 064/QASUME at Arosa:24-Jul-2008(206) to 28-Jul-2008(210)



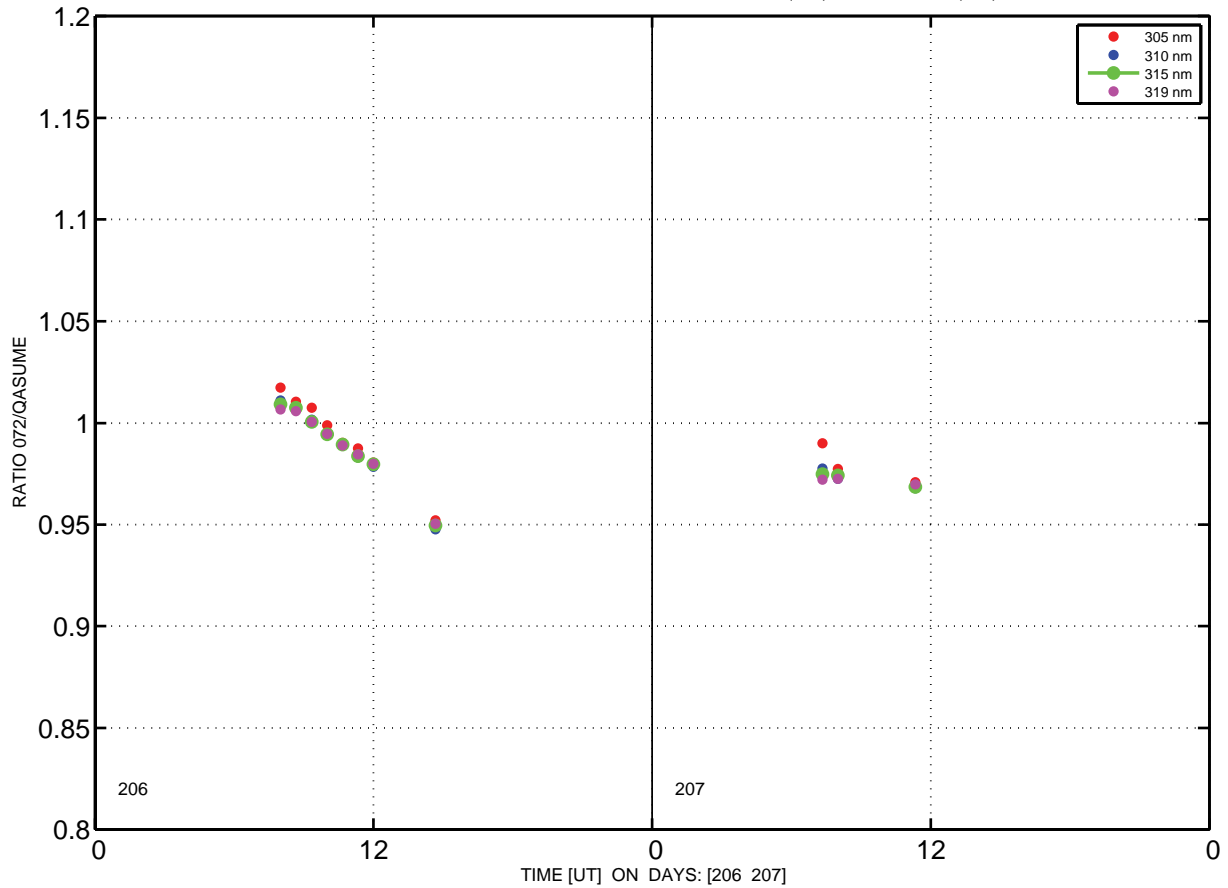
Arosa, 064, July 2008



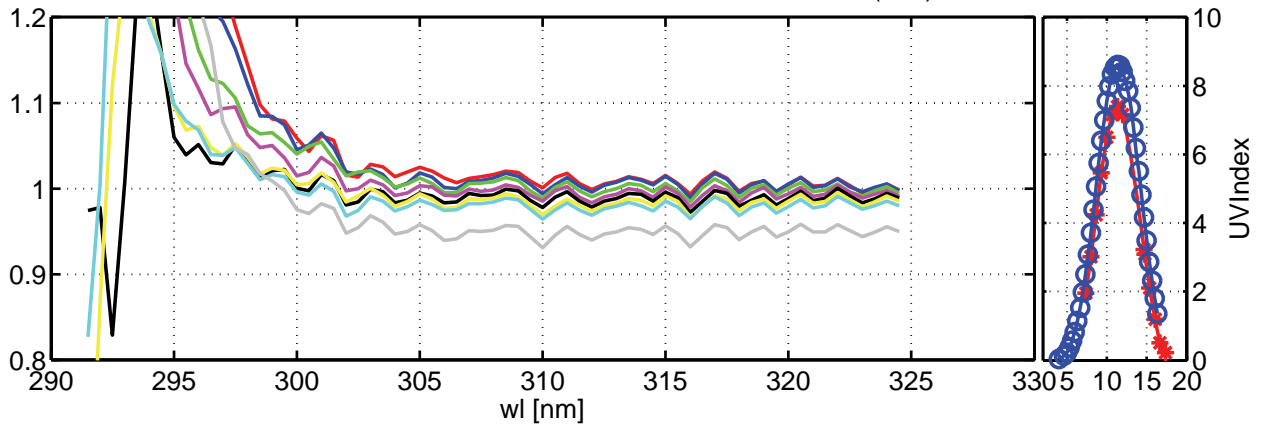
UV Index Arosa, July 2008



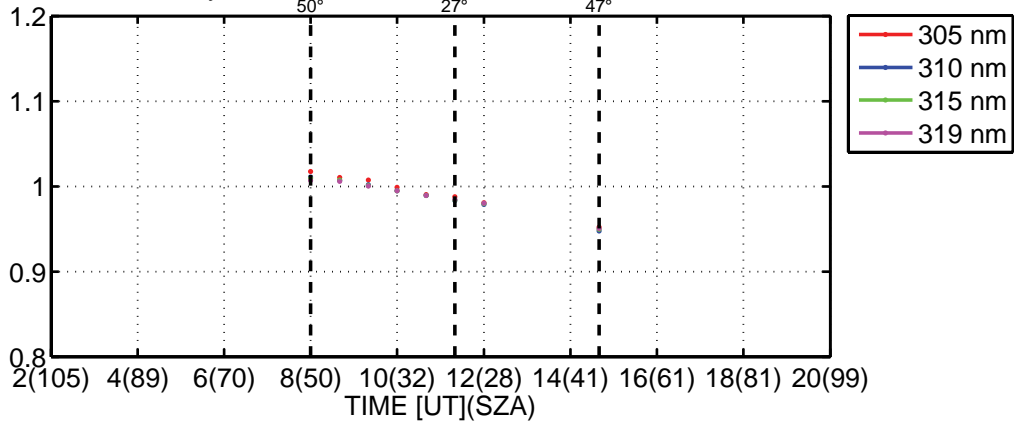
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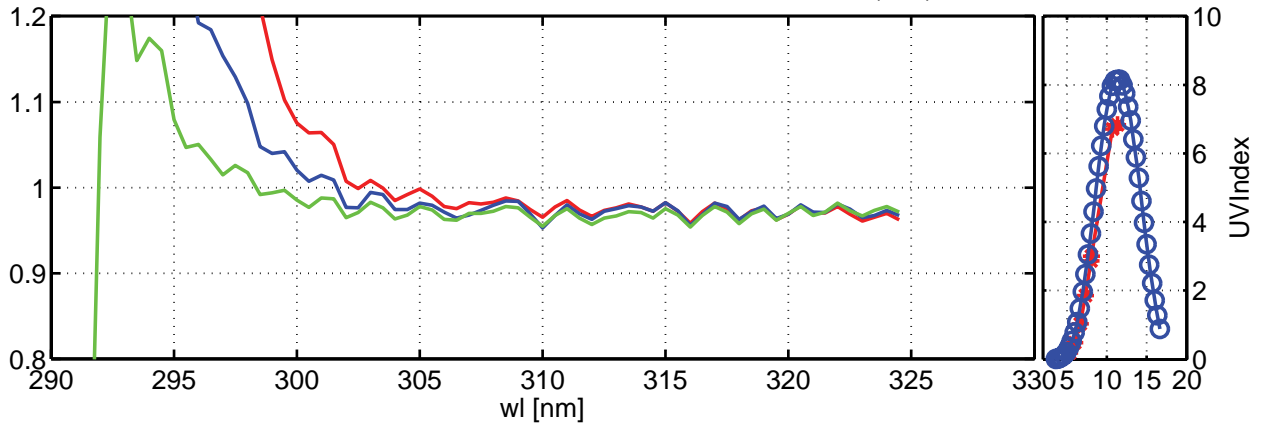
Global irradiance ratios 072/QASUME at Arosa:24-Jul-2008(206)



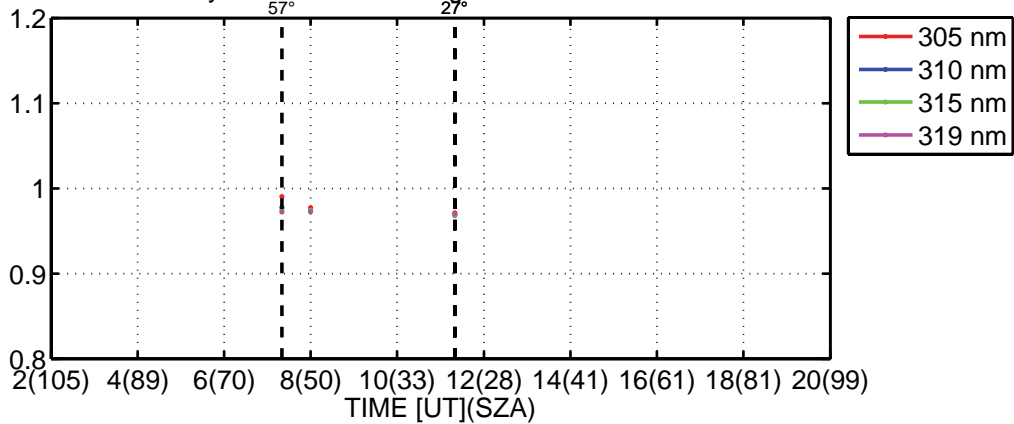
Daily variation. Wavelength bands are ± 2.5 nm

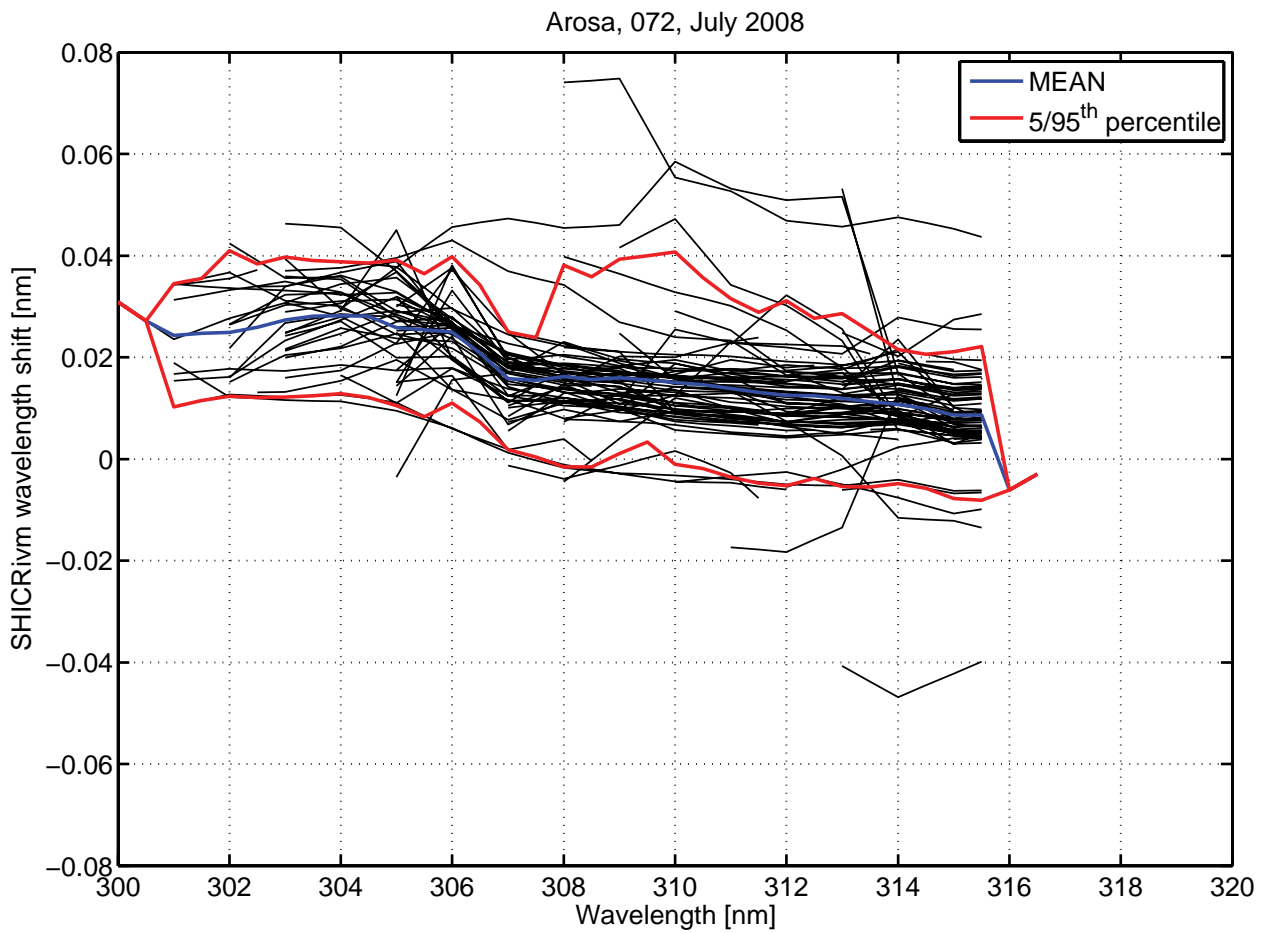
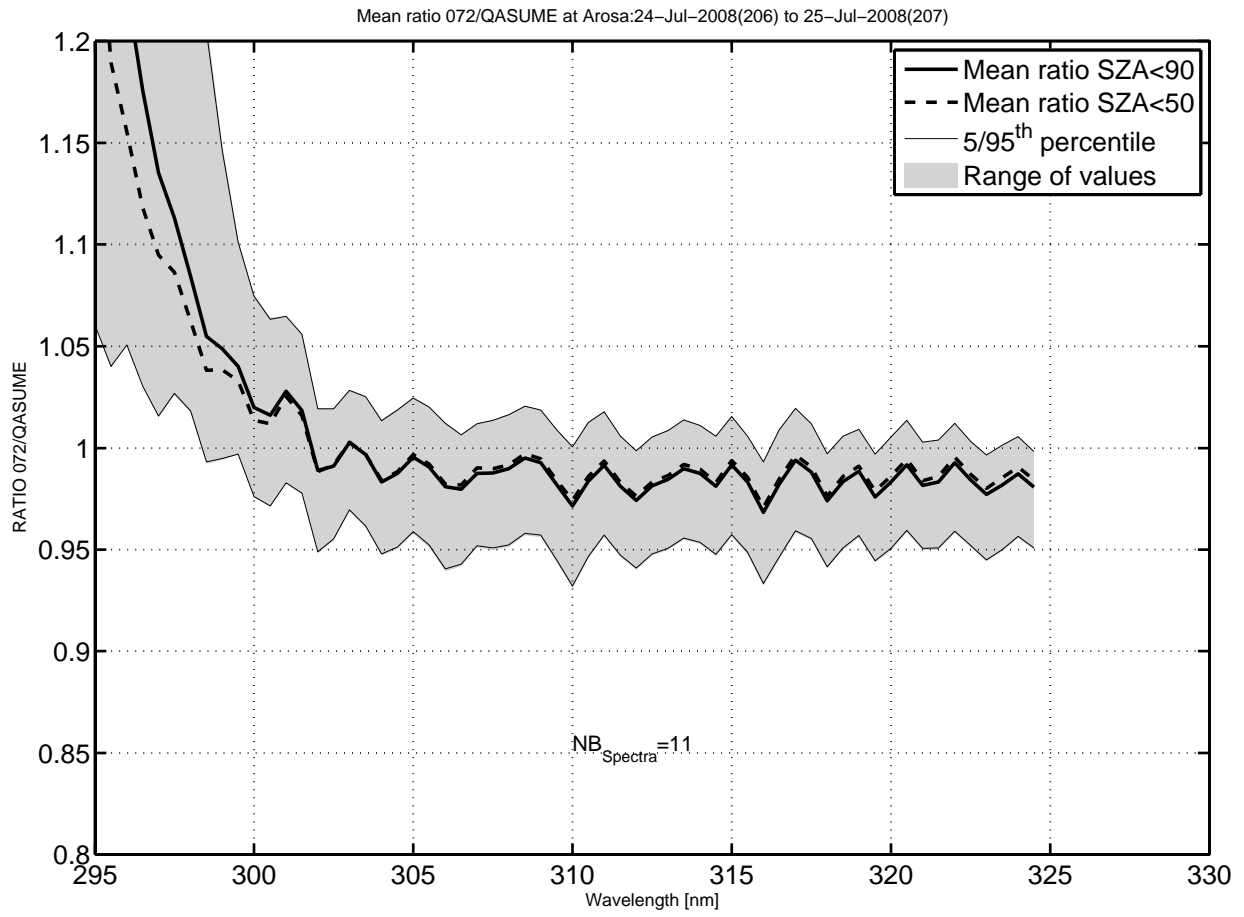


Global irradiance ratios 072/QASUME at Arosa:25-Jul-2008(207)

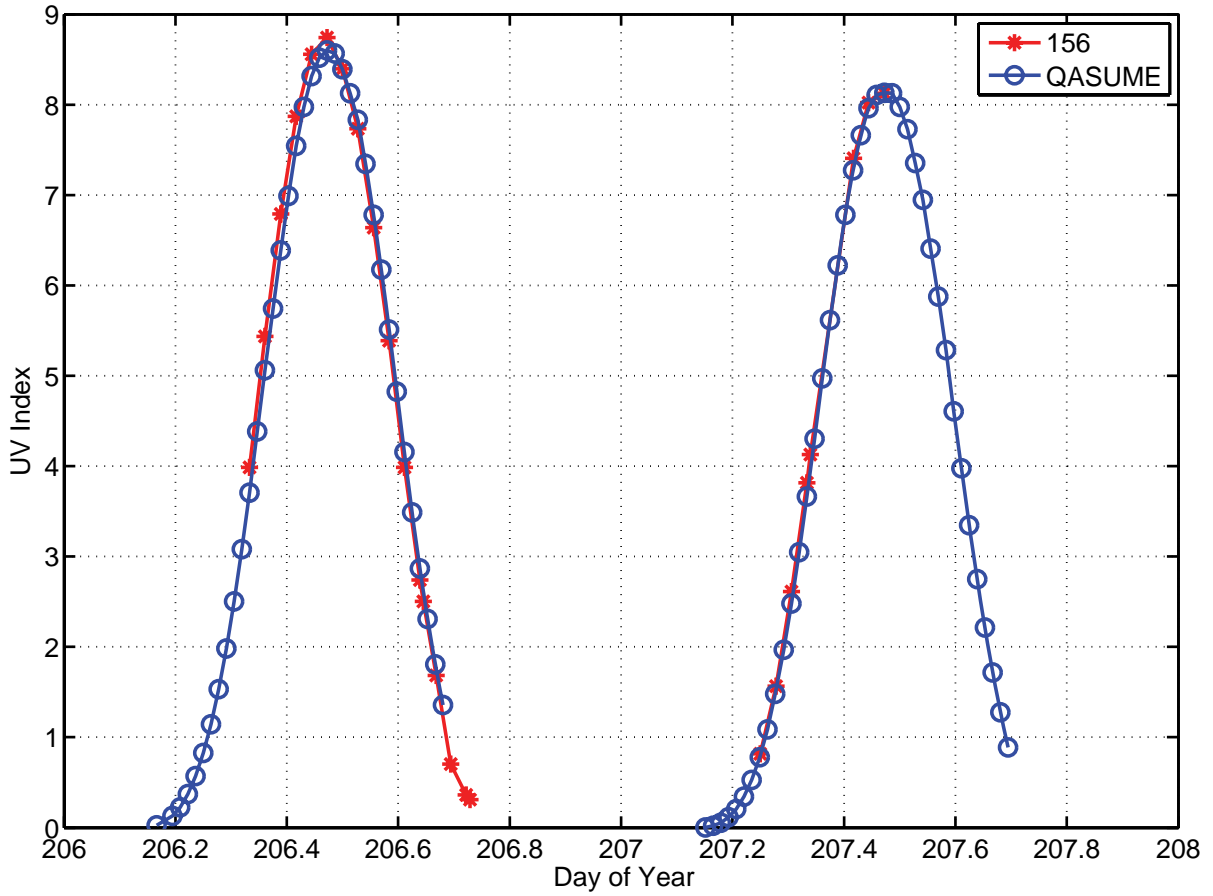


Daily variation. Wavelength bands are ± 2.5 nm

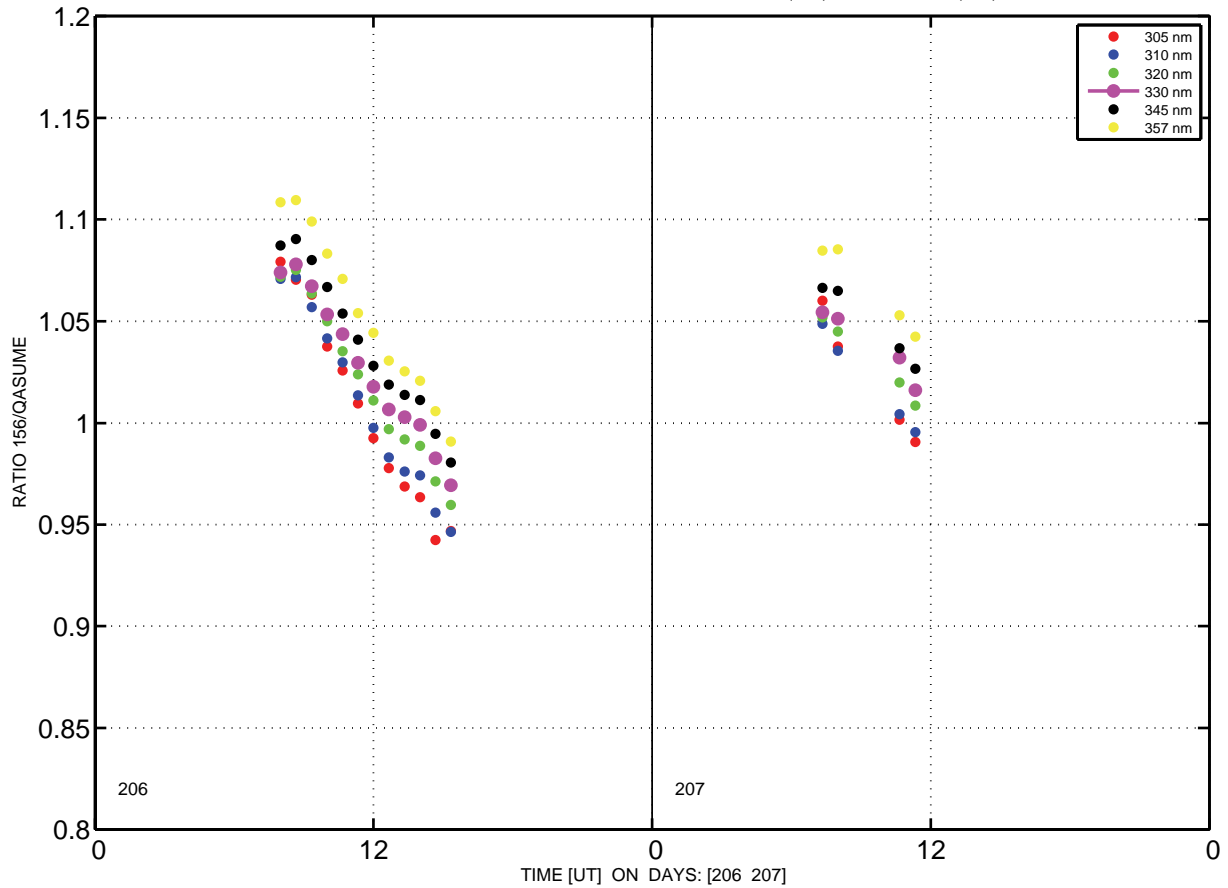




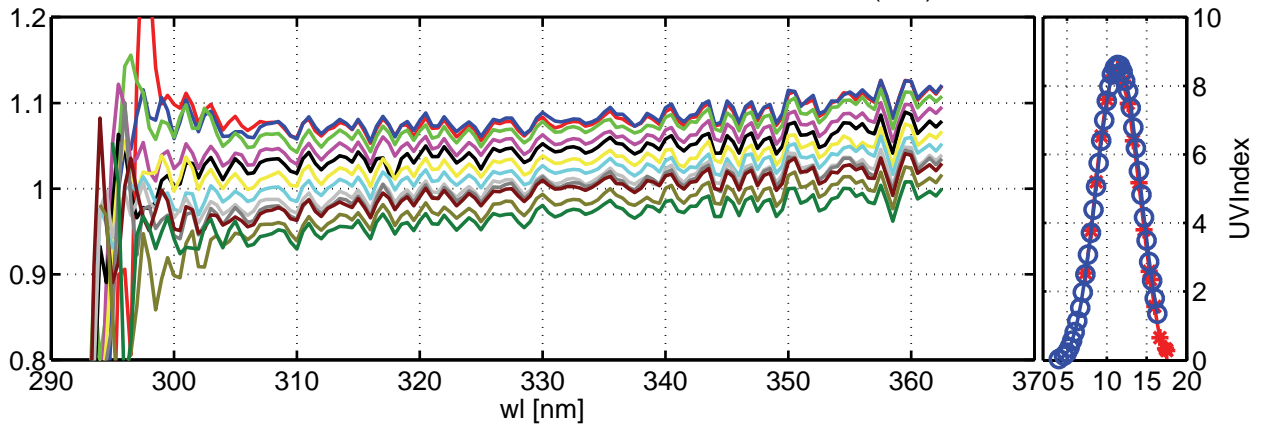
UV Index Arosa, July 2008



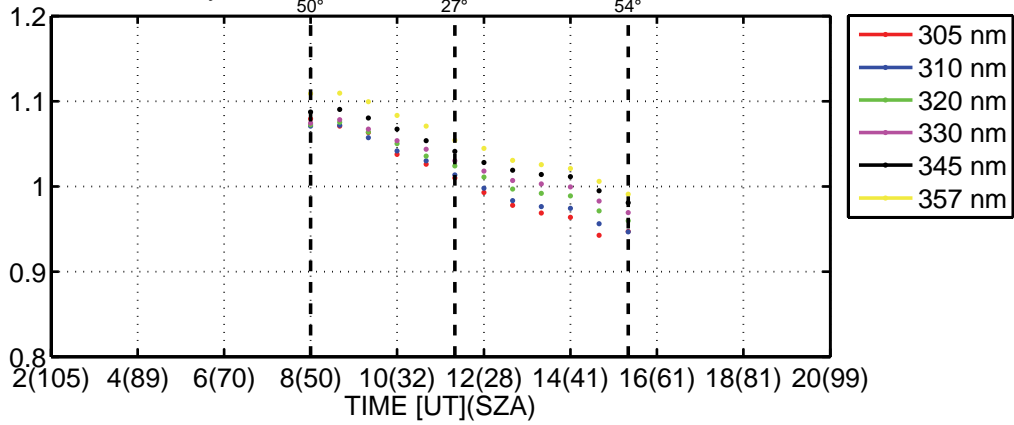
Global irradiance ratios 156/QASUME at Arosa:24-Jul-2008(206) to 25-Jul-2008(207)



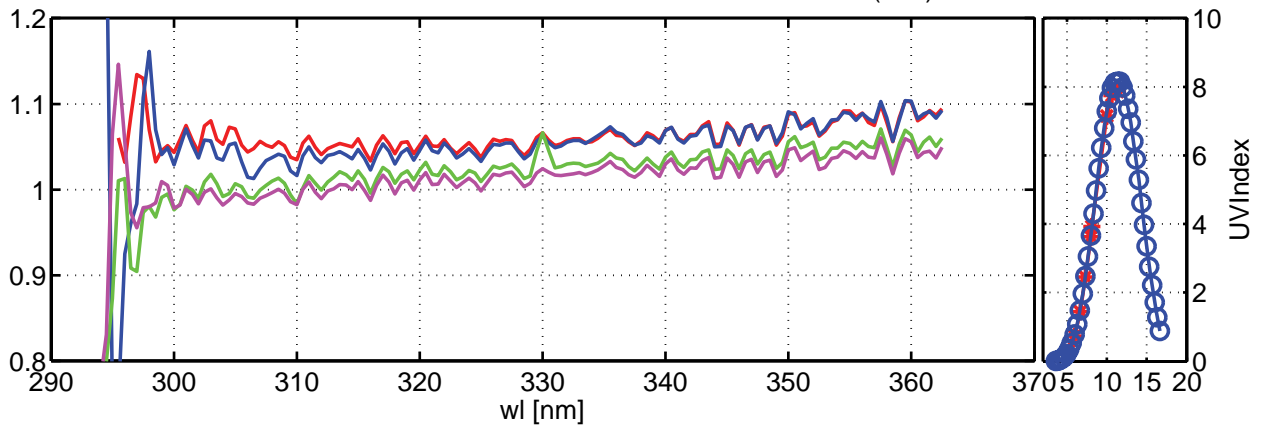
Global irradiance ratios 156/QASUME at Arosa:24-Jul-2008(206)



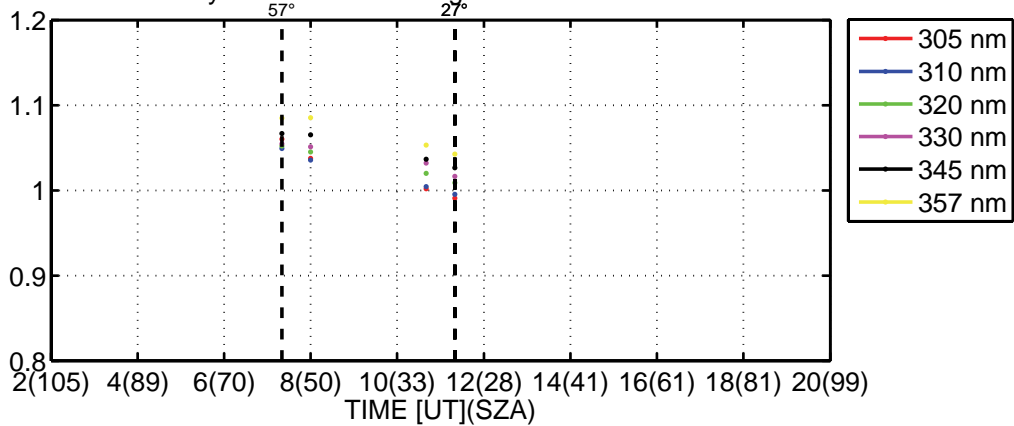
Daily variation. Wavelength bands are ± 2.5 nm

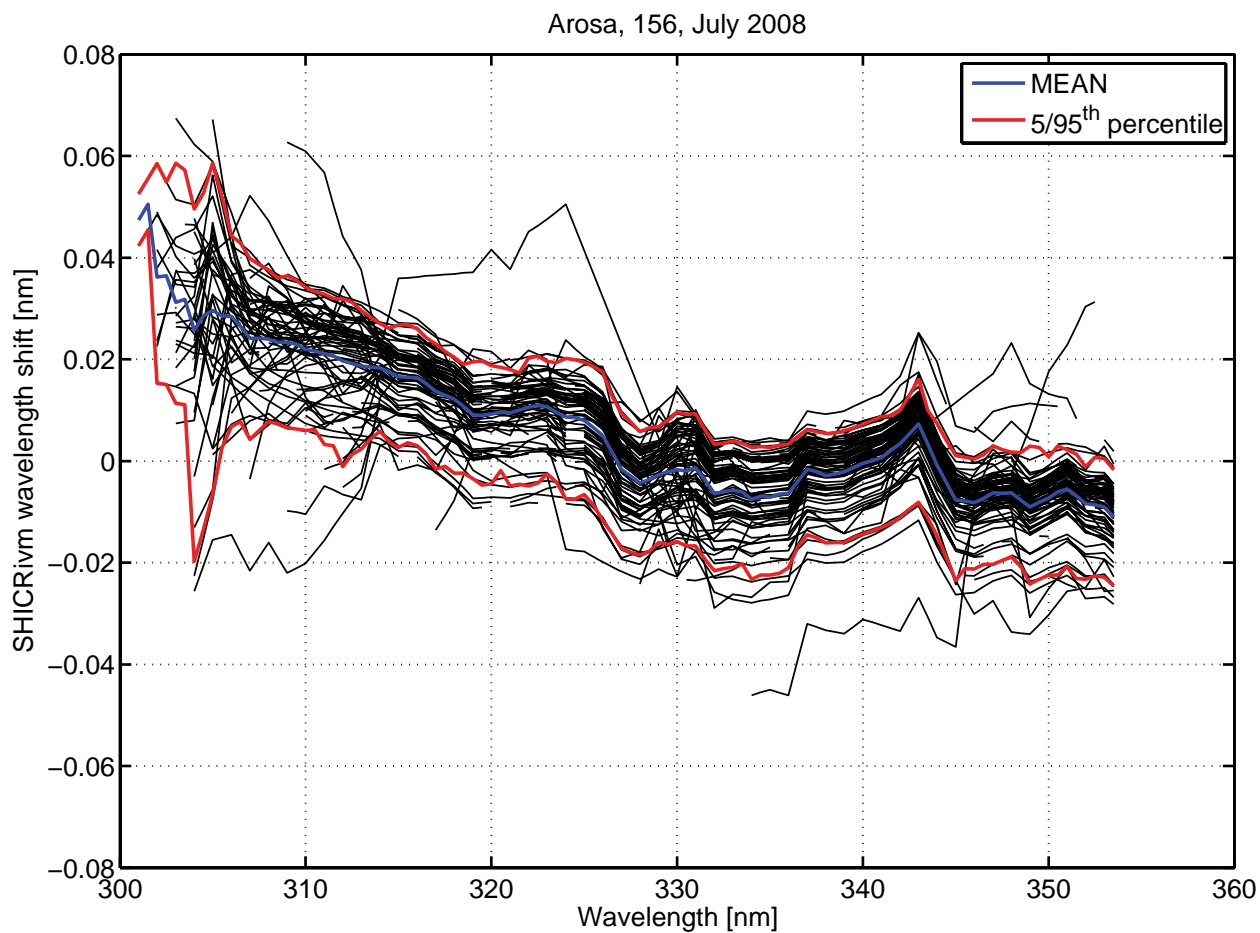
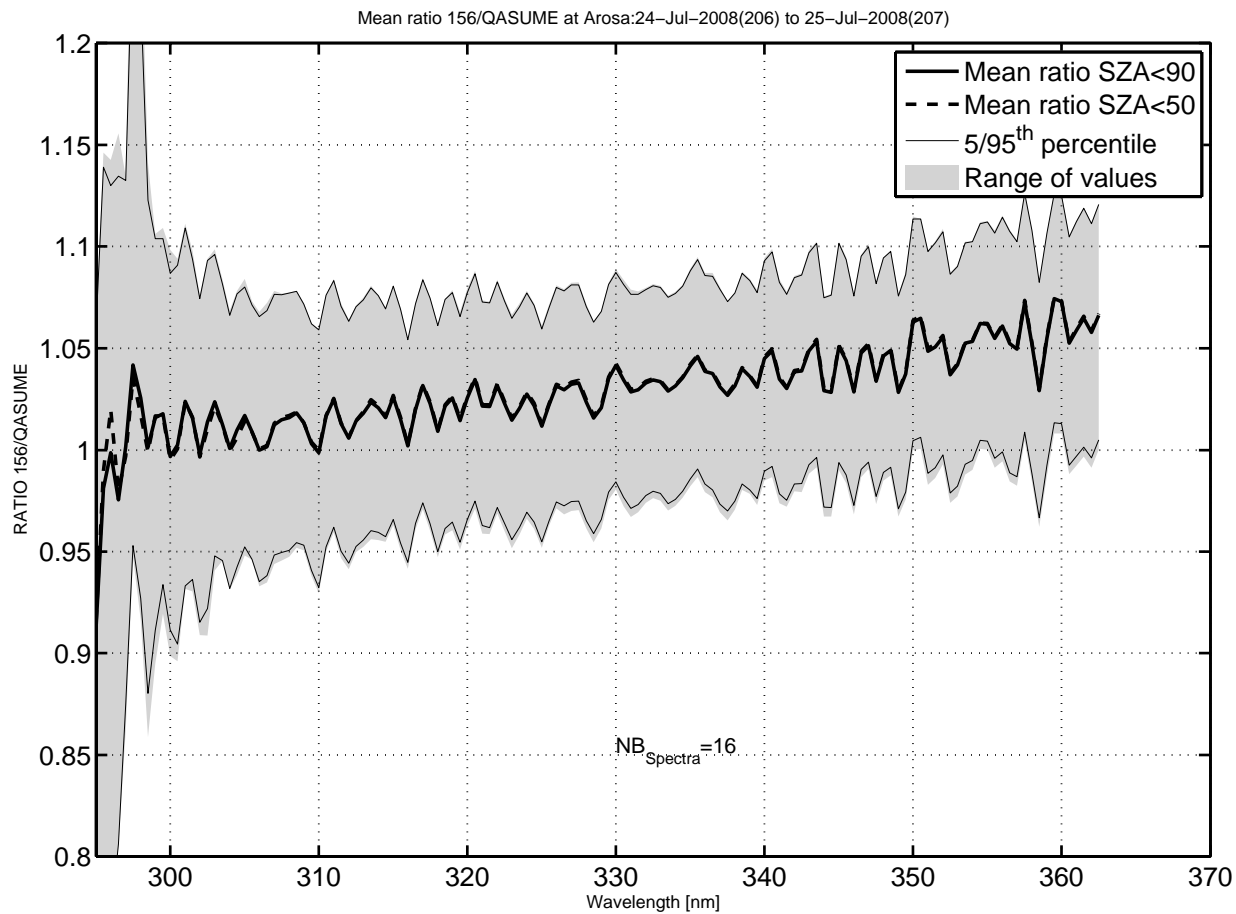


Global irradiance ratios 156/QASUME at Arosa:25-Jul-2008(207)

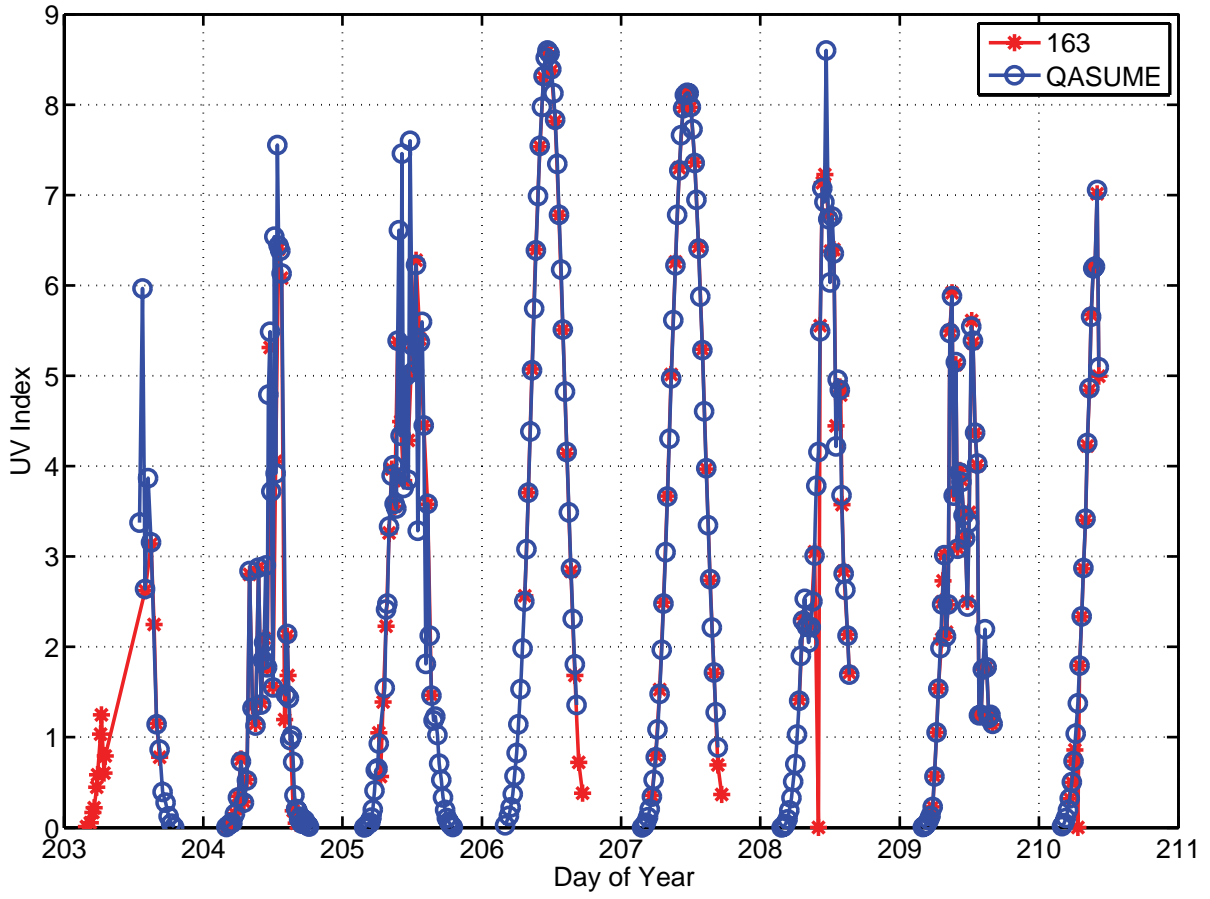


Daily variation. Wavelength bands are ± 2.5 nm

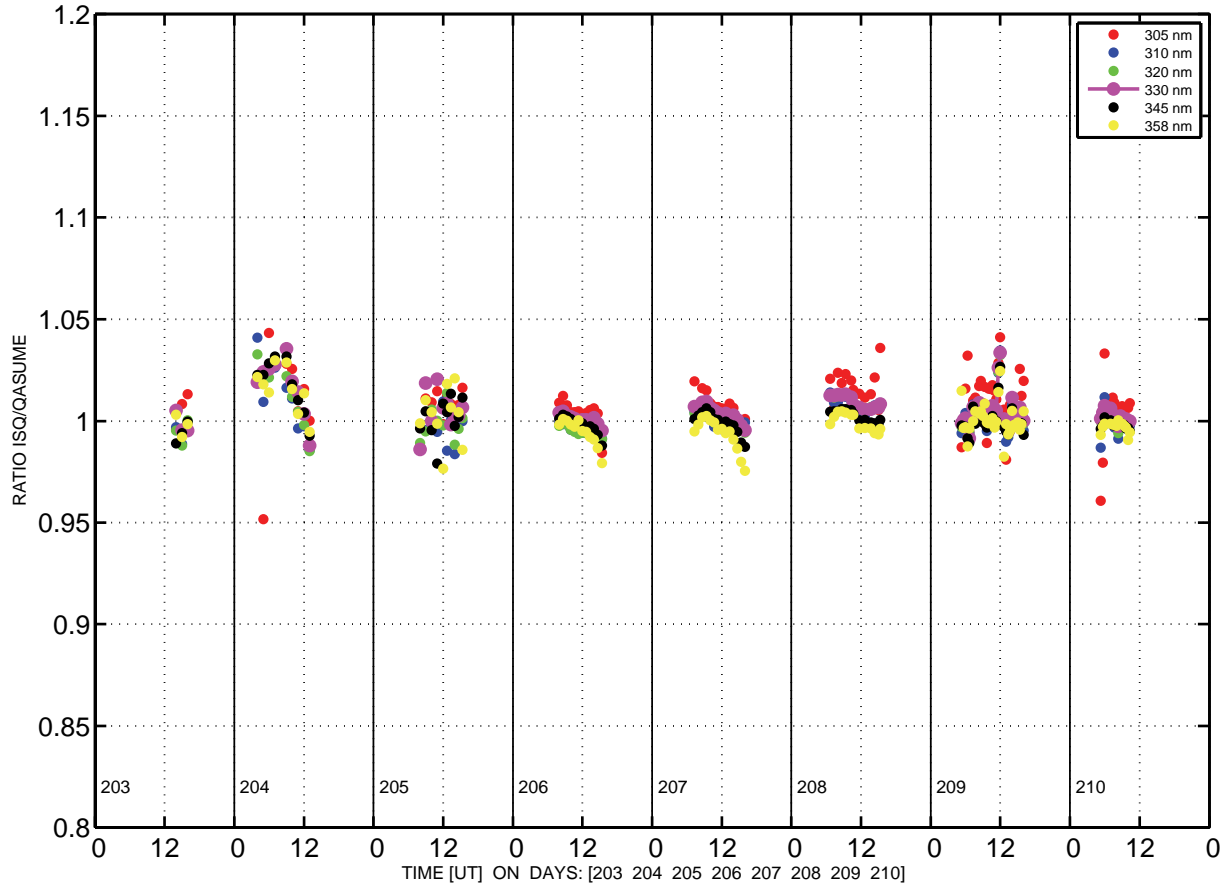




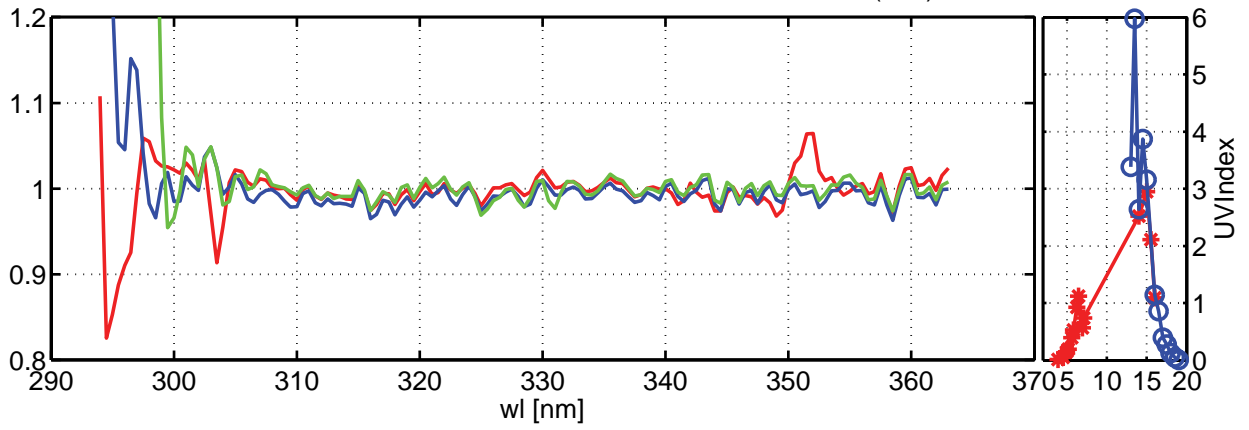
UV Index Arosa, July 2008



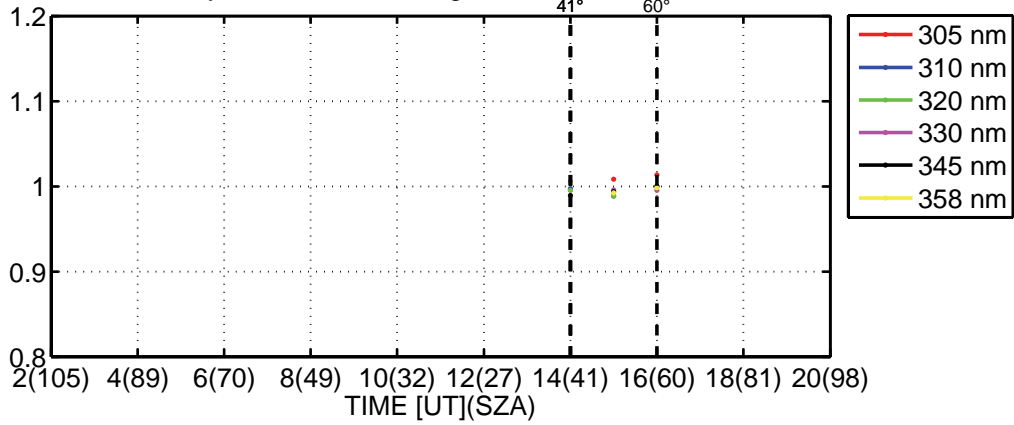
Global irradiance ratios ISQ/QASUME at Arosa:21-Jul-2008(203) to 28-Jul-2008(210)



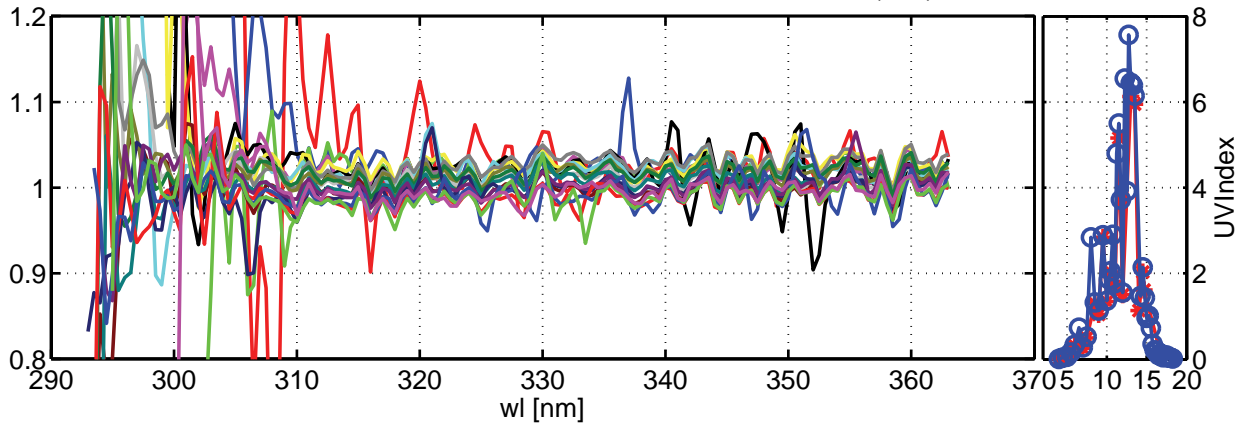
Global irradiance ratios ISQ/QASUME at Arosa:21-Jul-2008(203)



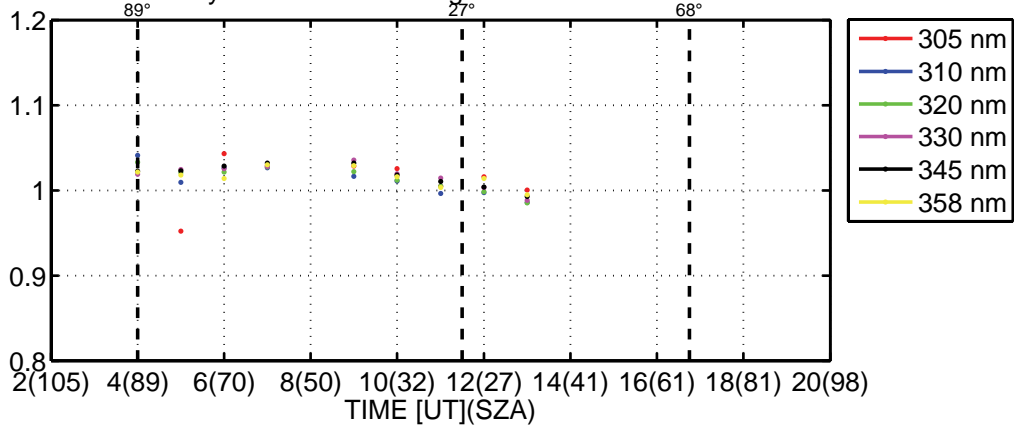
Daily variation. Wavelength bands are ± 2.5 nm



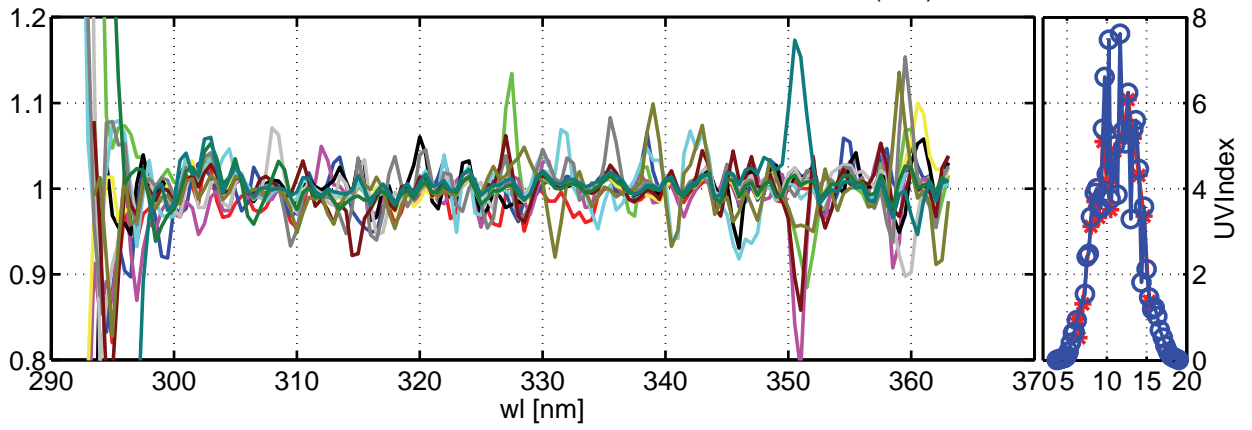
Global irradiance ratios ISQ/QASUME at Arosa:22-Jul-2008(204)



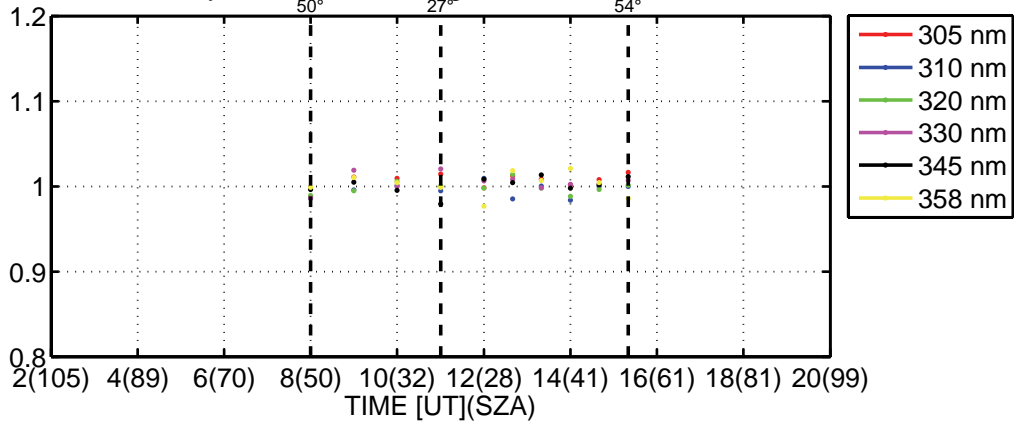
Daily variation. Wavelength bands are ± 2.5 nm



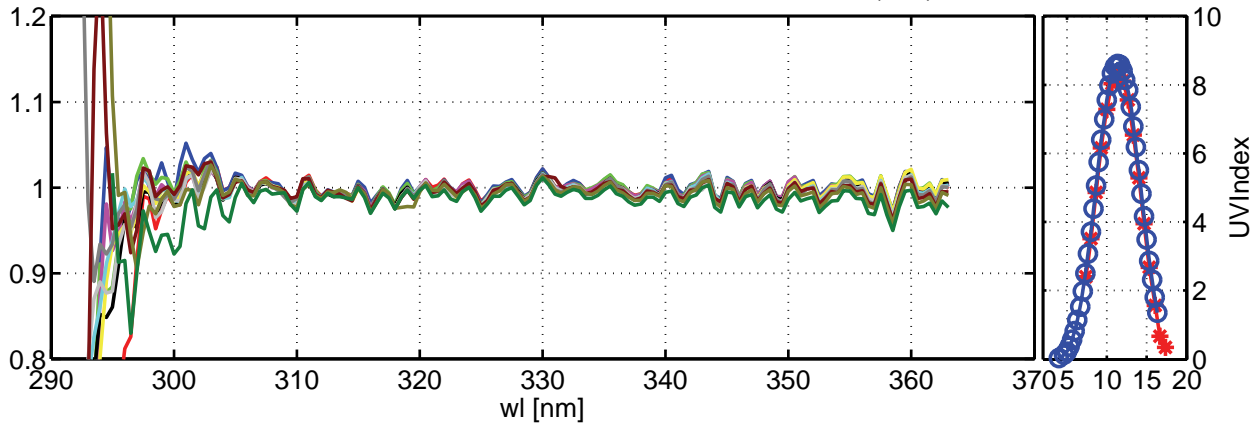
Global irradiance ratios ISQ/QASUME at Arosa:23-Jul-2008(205)



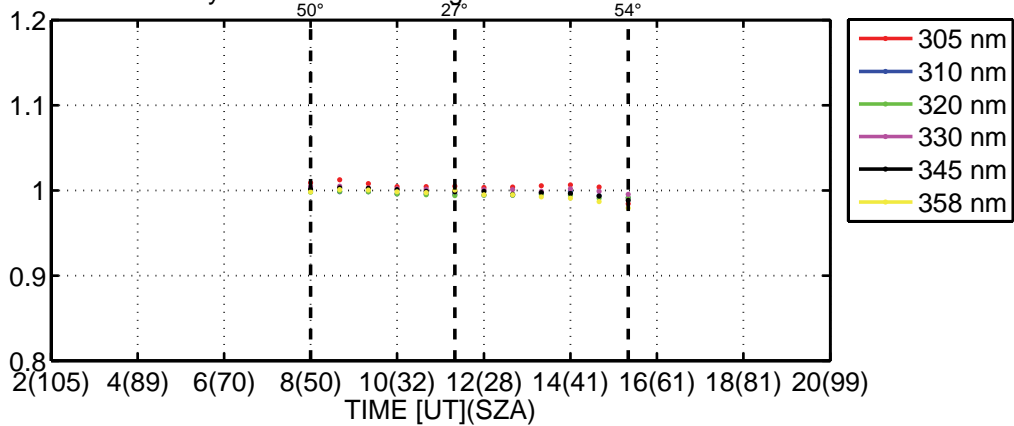
Daily variation. Wavelength bands are ± 2.5 nm



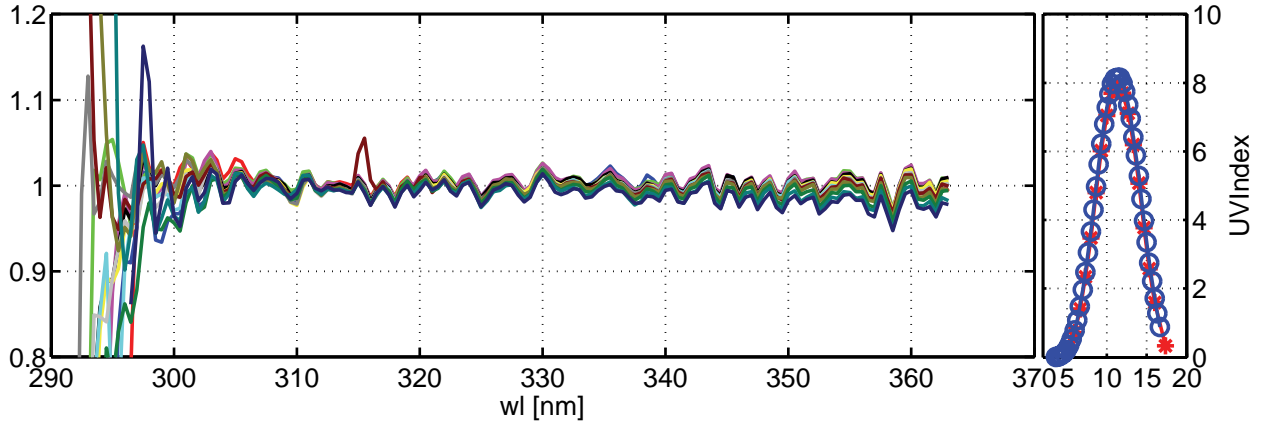
Global irradiance ratios ISQ/QASUME at Arosa:24-Jul-2008(206)



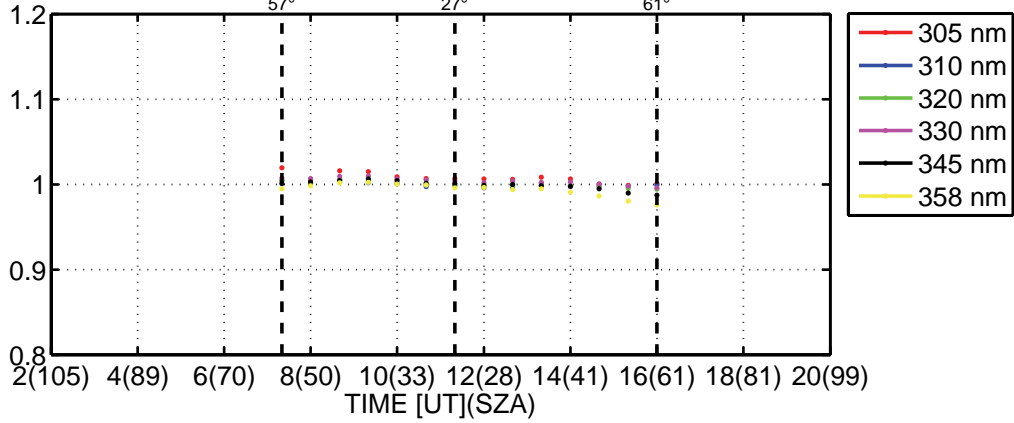
Daily variation. Wavelength bands are ± 2.5 nm



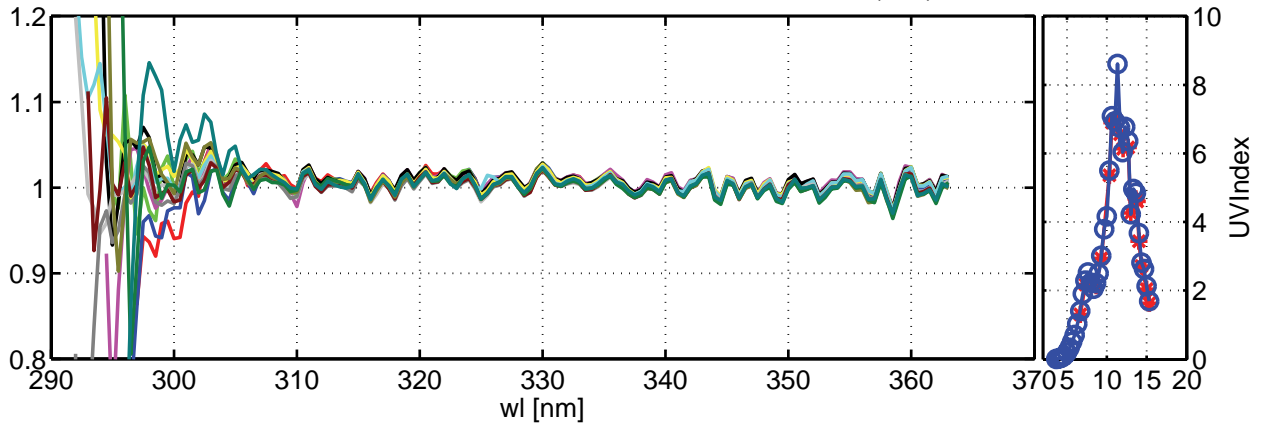
Global irradiance ratios ISQ/QASUME at Arosa:25-Jul-2008(207)



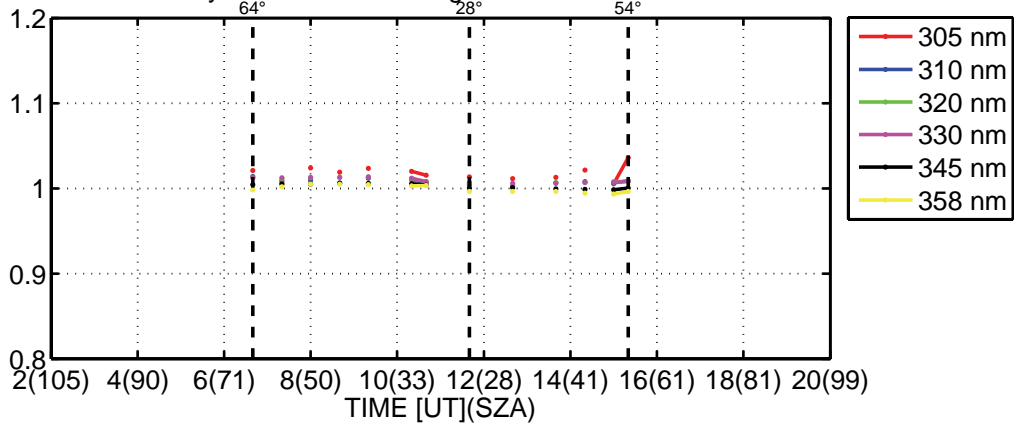
Daily variation. Wavelength bands are ± 2.5 nm



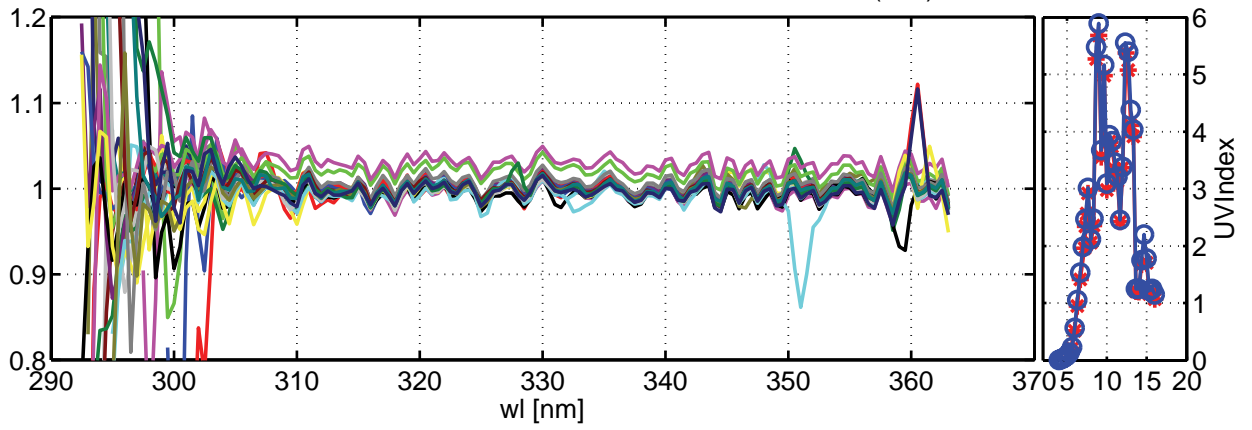
Global irradiance ratios ISQ/QASUME at Arosa:26-Jul-2008(208)



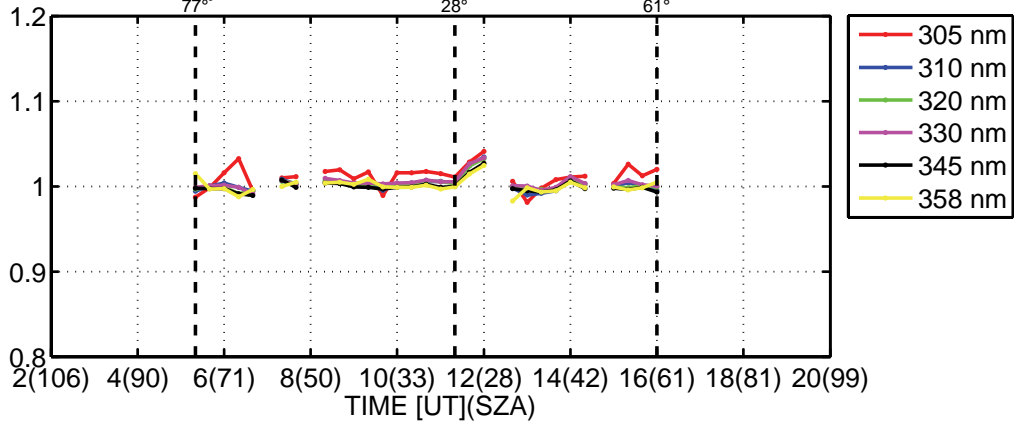
Daily variation. Wavelength bands are ± 2.5 nm



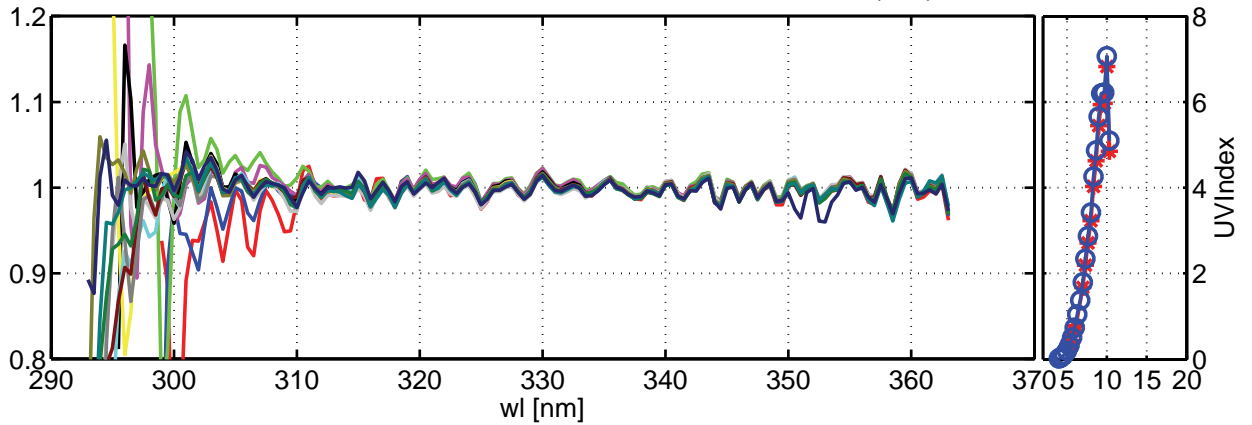
Global irradiance ratios ISQ/QASUME at Arosa:27-Jul-2008(209)



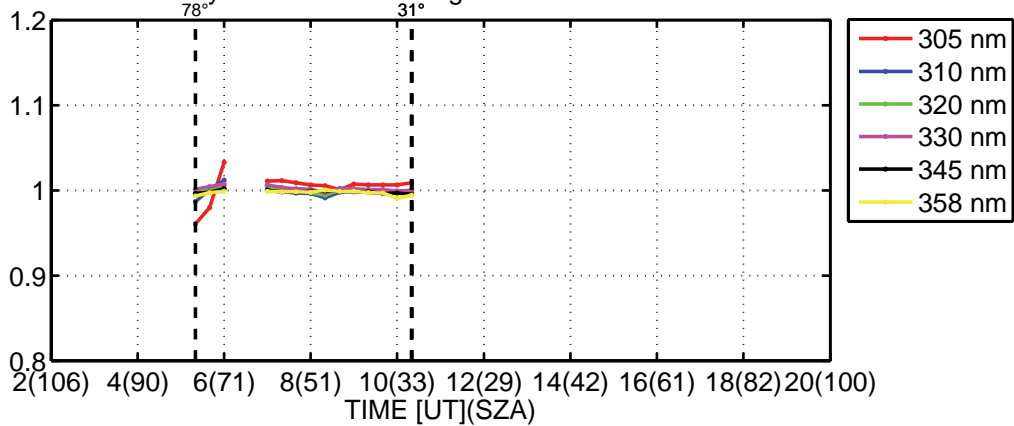
Daily variation. Wavelength bands are ± 2.5 nm



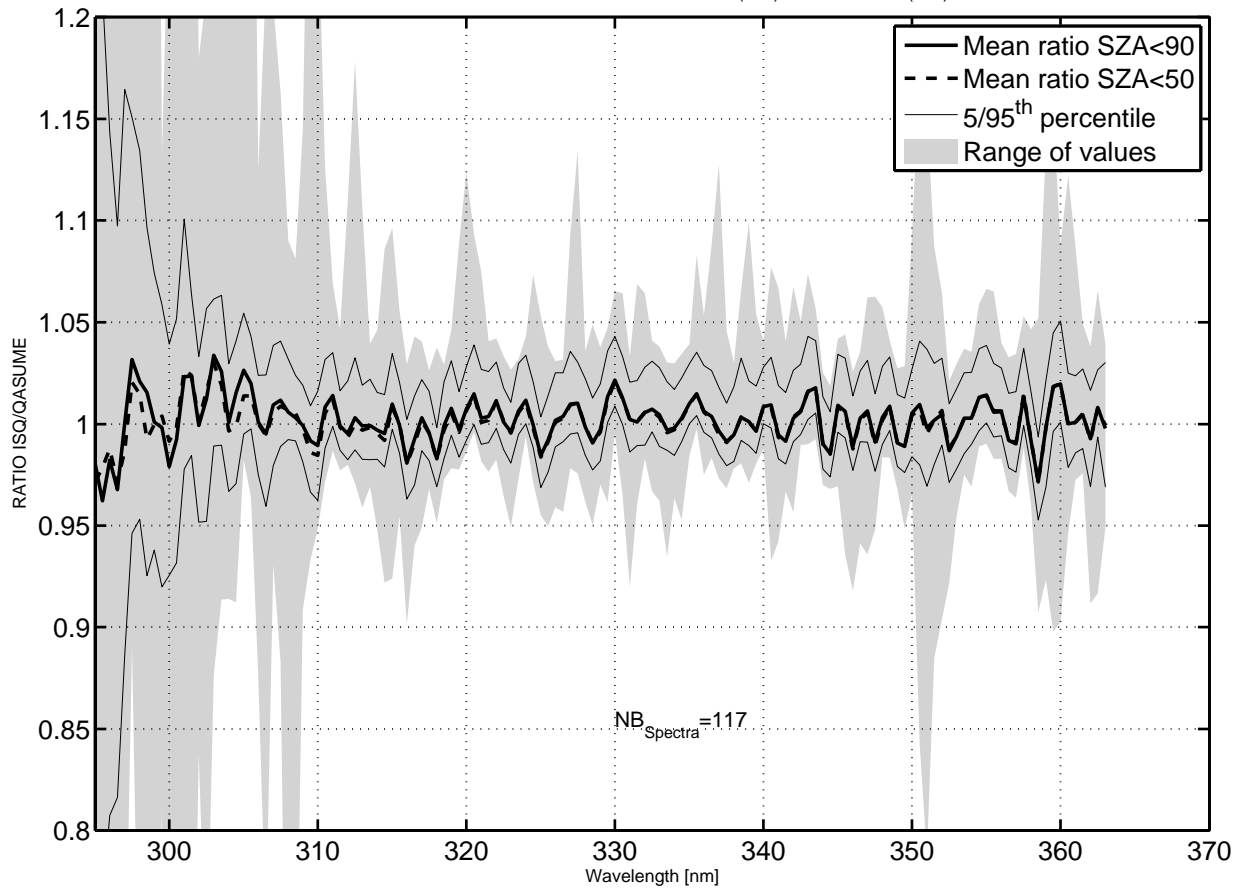
Global irradiance ratios ISQ/QASUME at Arosa:28-Jul-2008(210)



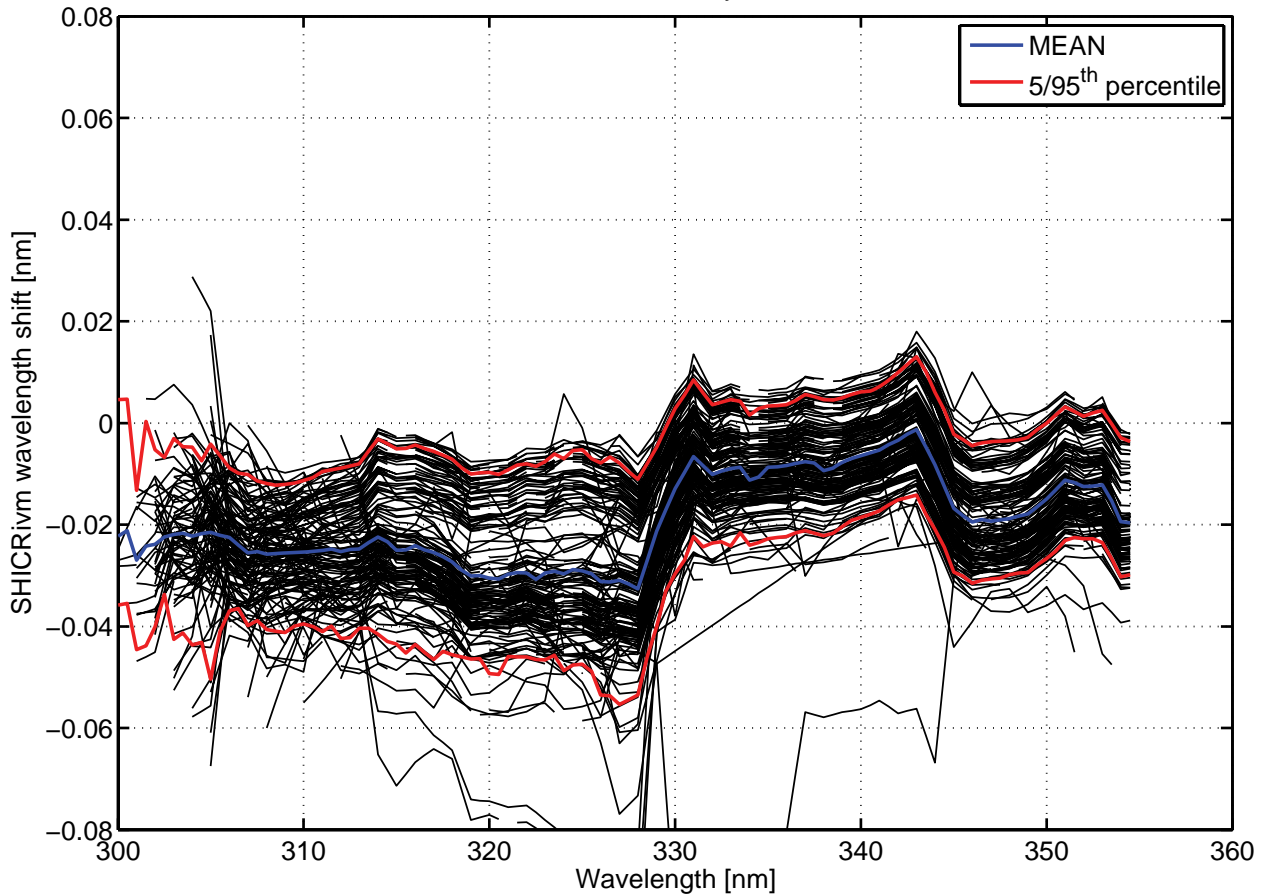
Daily variation. Wavelength bands are ± 2.5 nm



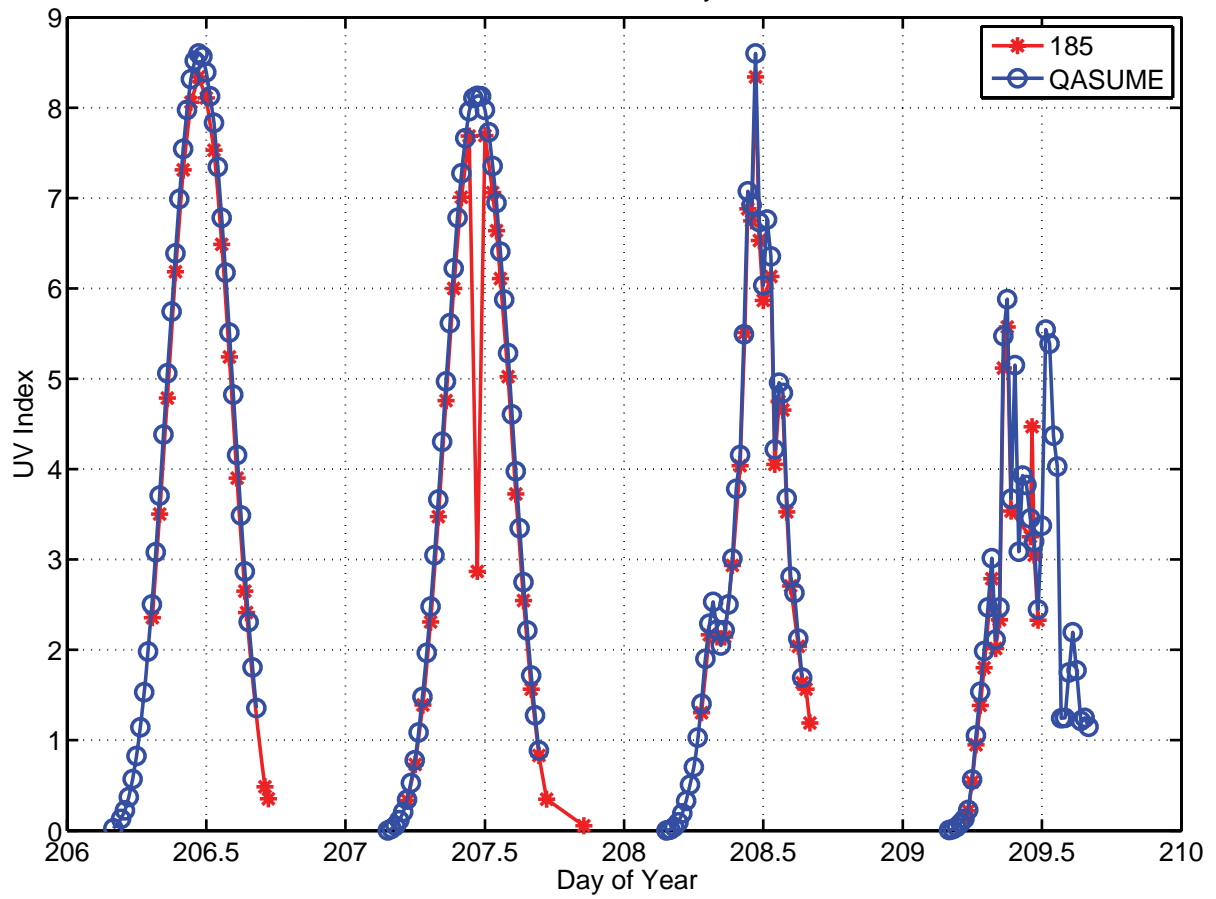
Mean ratio ISQ/QASUME at Arosa:21-Jul-2008(203) to 28-Jul-2008(210)



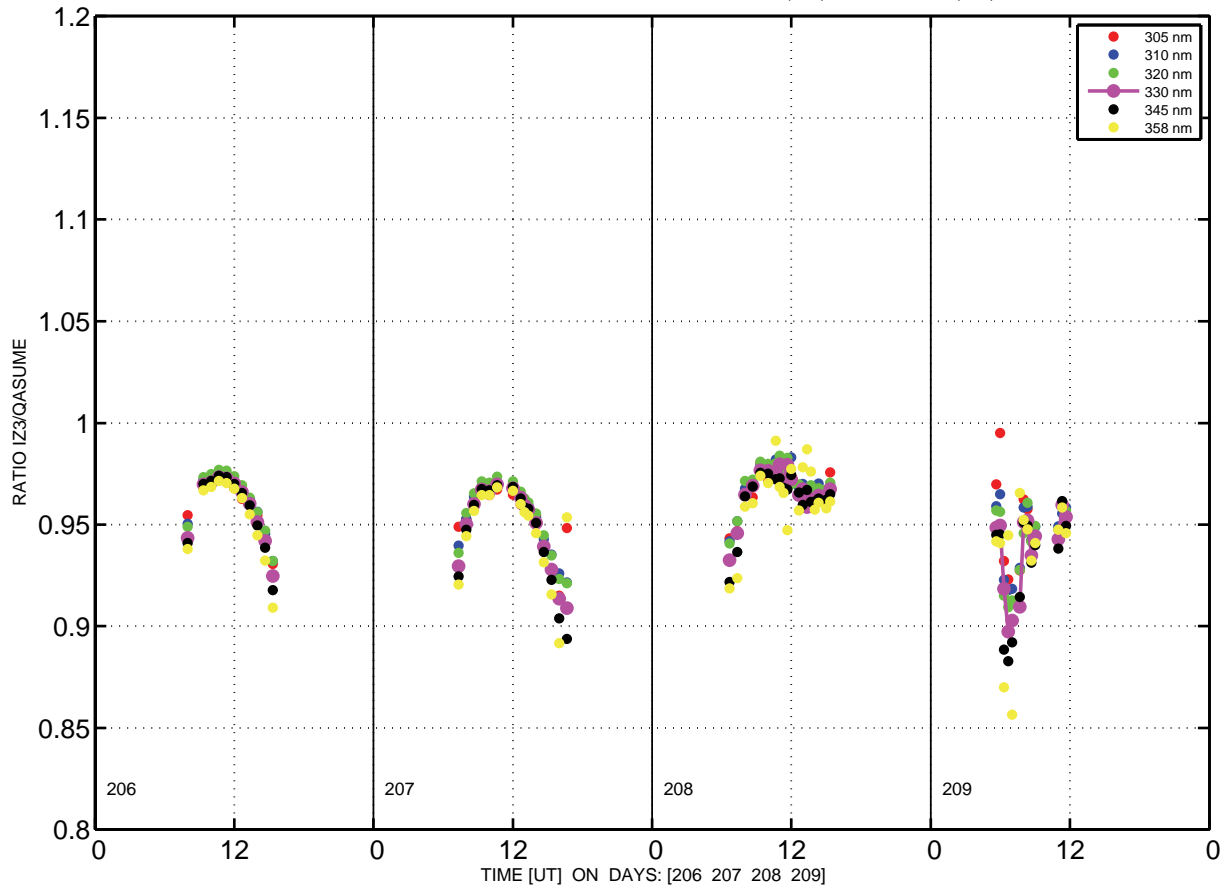
Arosa, 163, July 2008



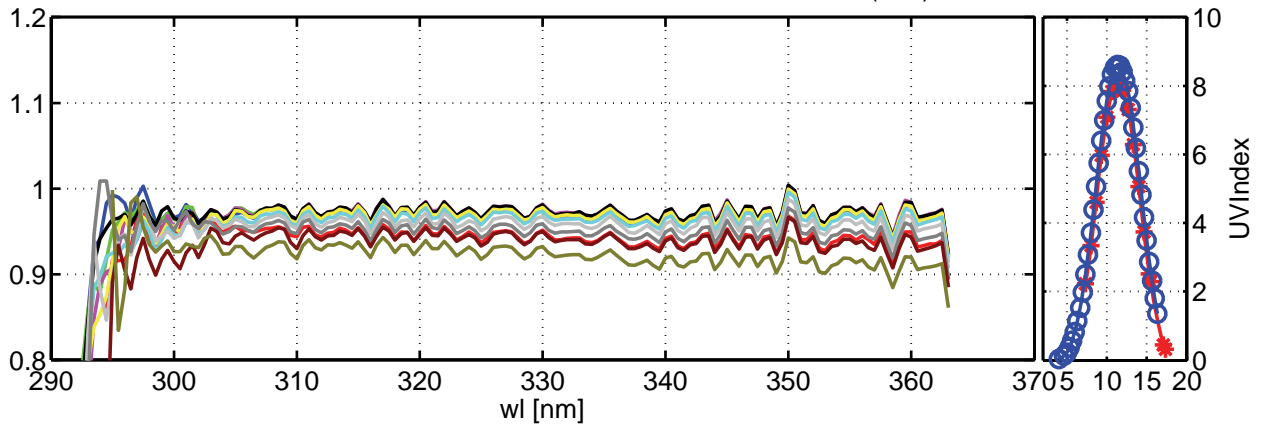
UV Index Arosa, July 2008



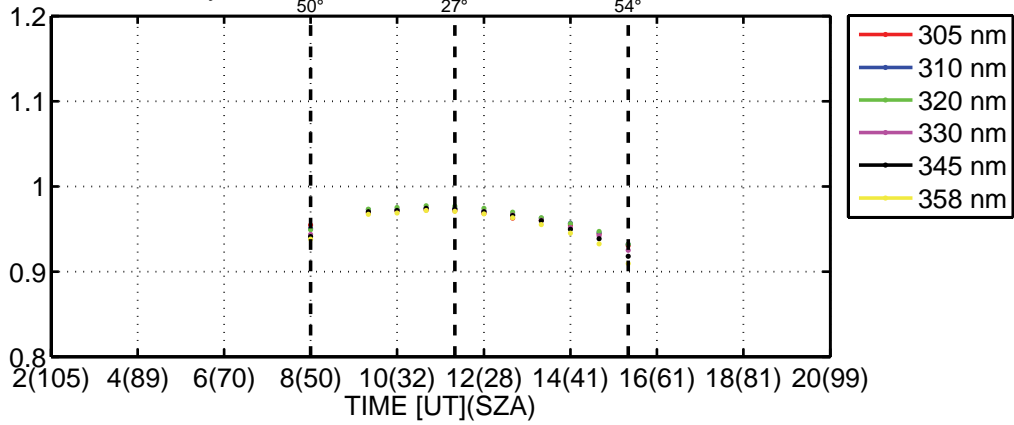
Global irradiance ratios IZ3/QASUME at Arosa:24-Jul-2008(206) to 27-Jul-2008(209)



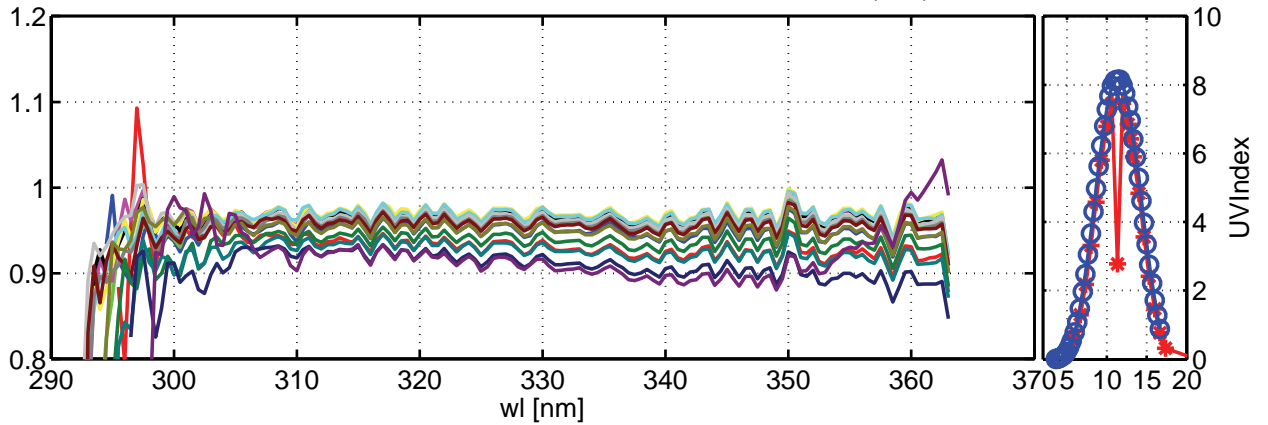
Global irradiance ratios IZ3/QASUME at Arosa:24-Jul-2008(206)



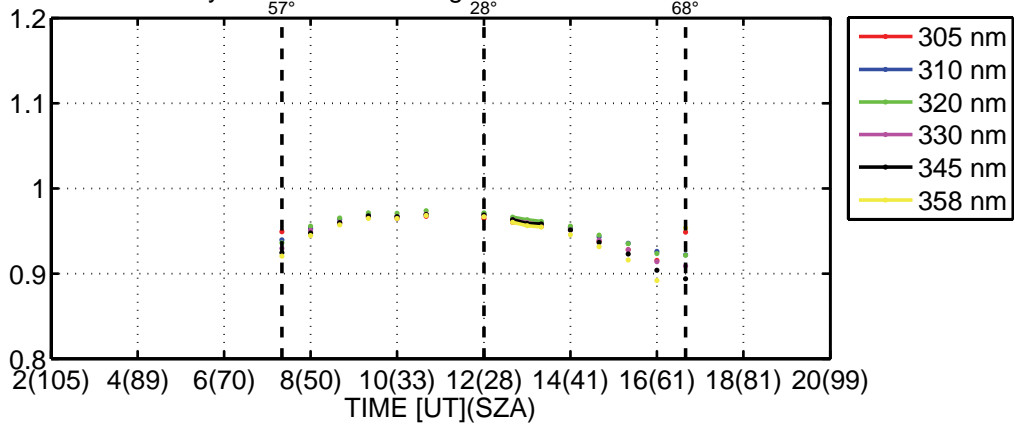
Daily variation. Wavelength bands are ± 2.5 nm



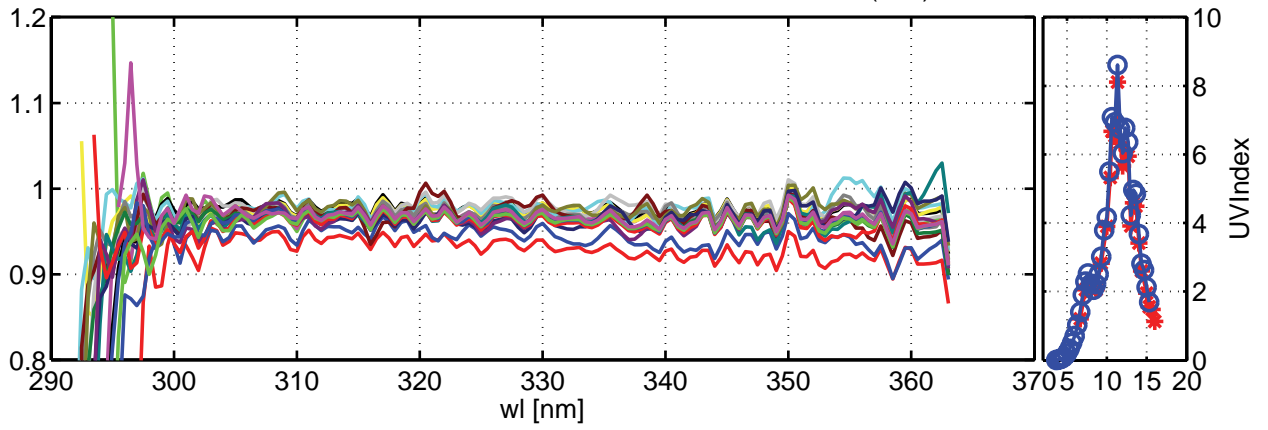
Global irradiance ratios IZ3/QASUME at Arosa:25-Jul-2008(207)



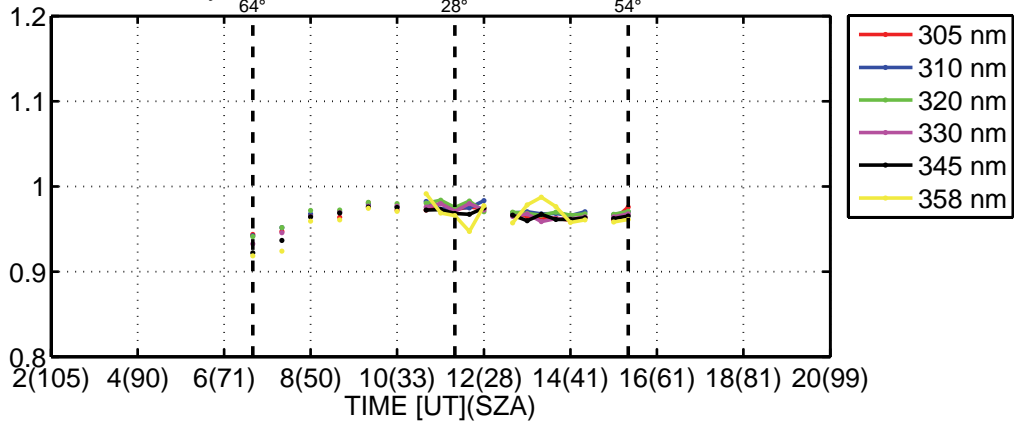
Daily variation. Wavelength bands are ± 2.5 nm



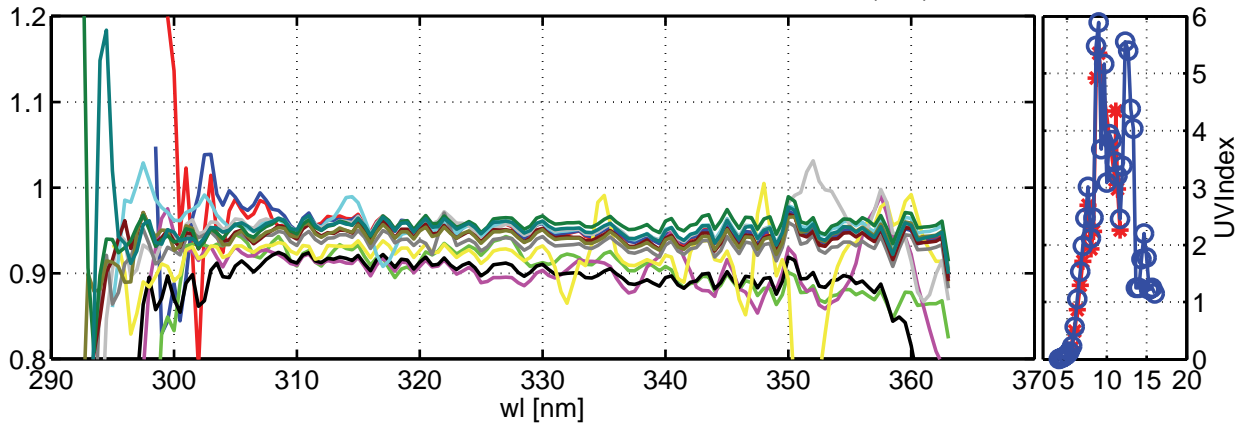
Global irradiance ratios IZ3/QASUME at Arosa:26-Jul-2008(208)



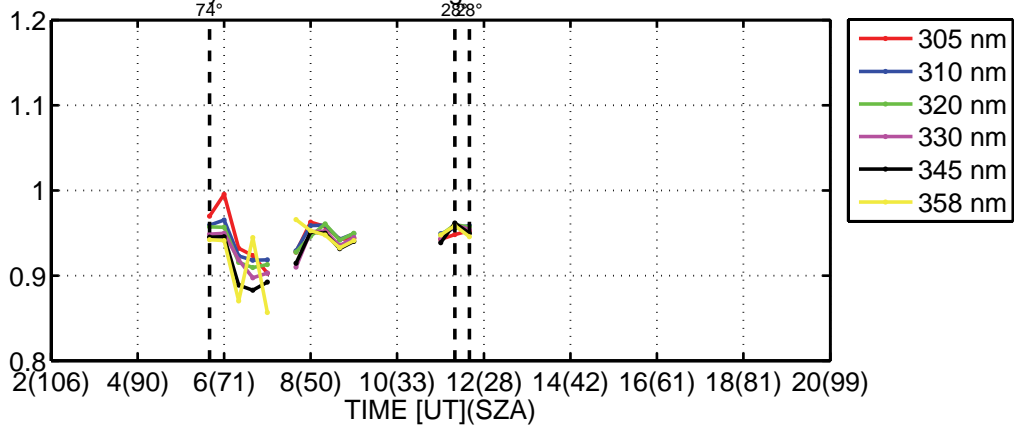
Daily variation. Wavelength bands are ± 2.5 nm



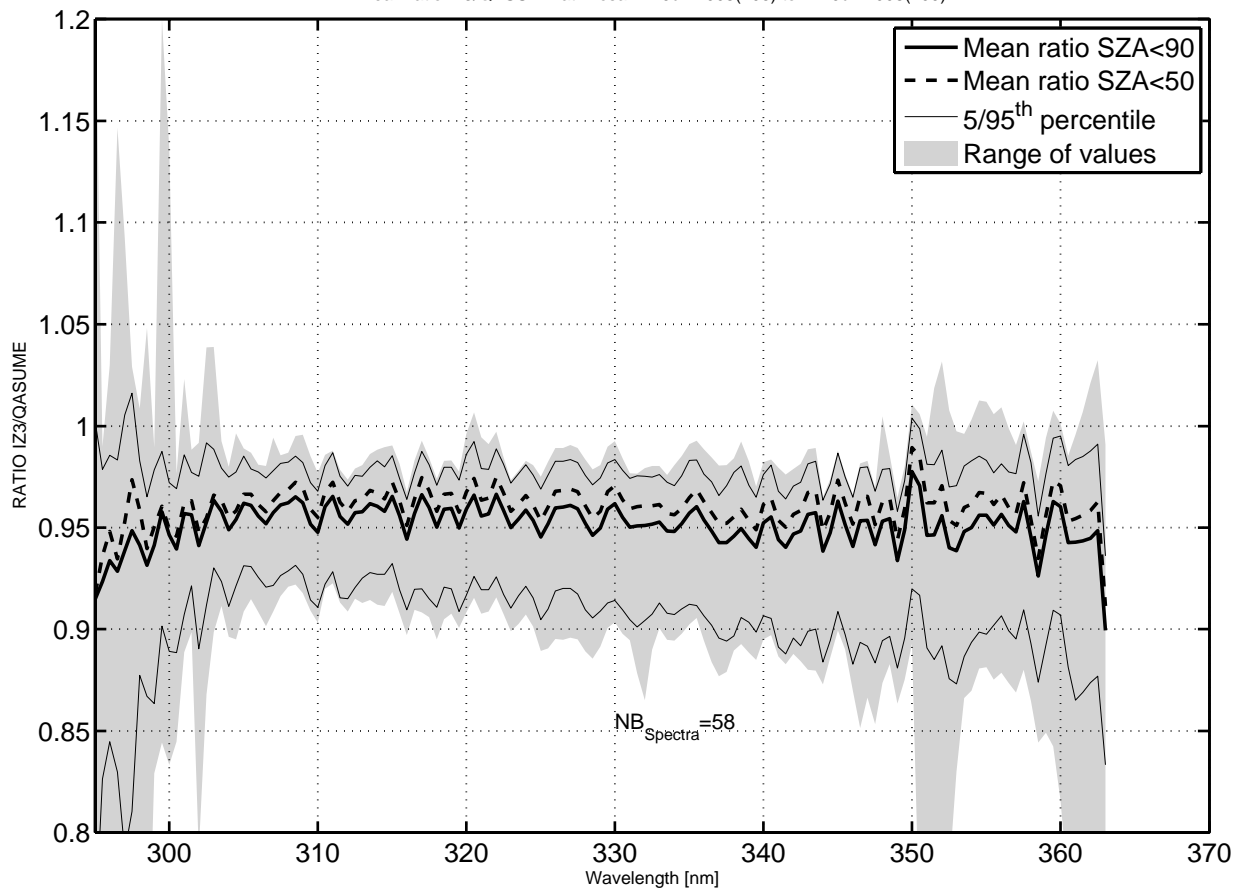
Global irradiance ratios IZ3/QASUME at Arosa:27-Jul-2008(209)



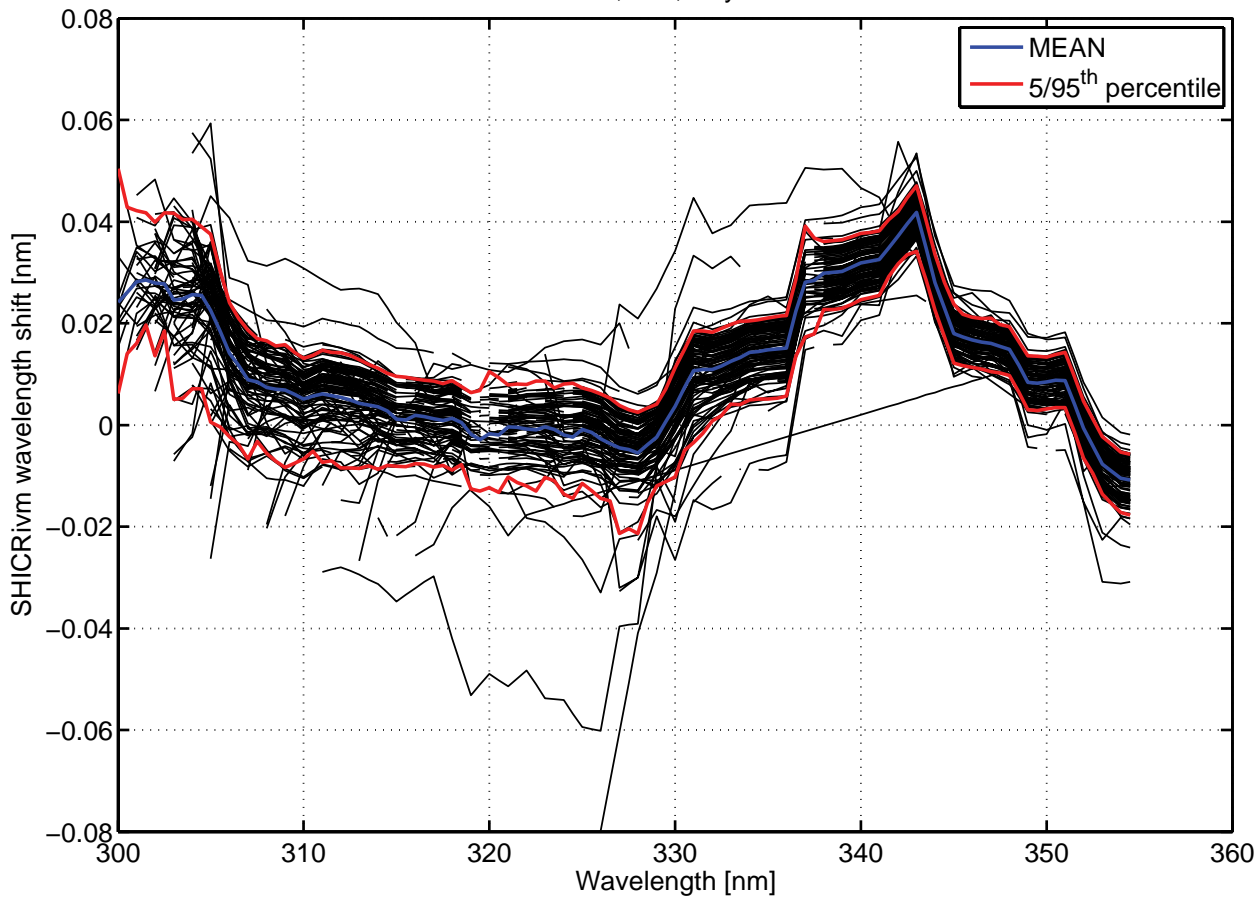
Daily variation. Wavelength bands are ± 2.5 nm



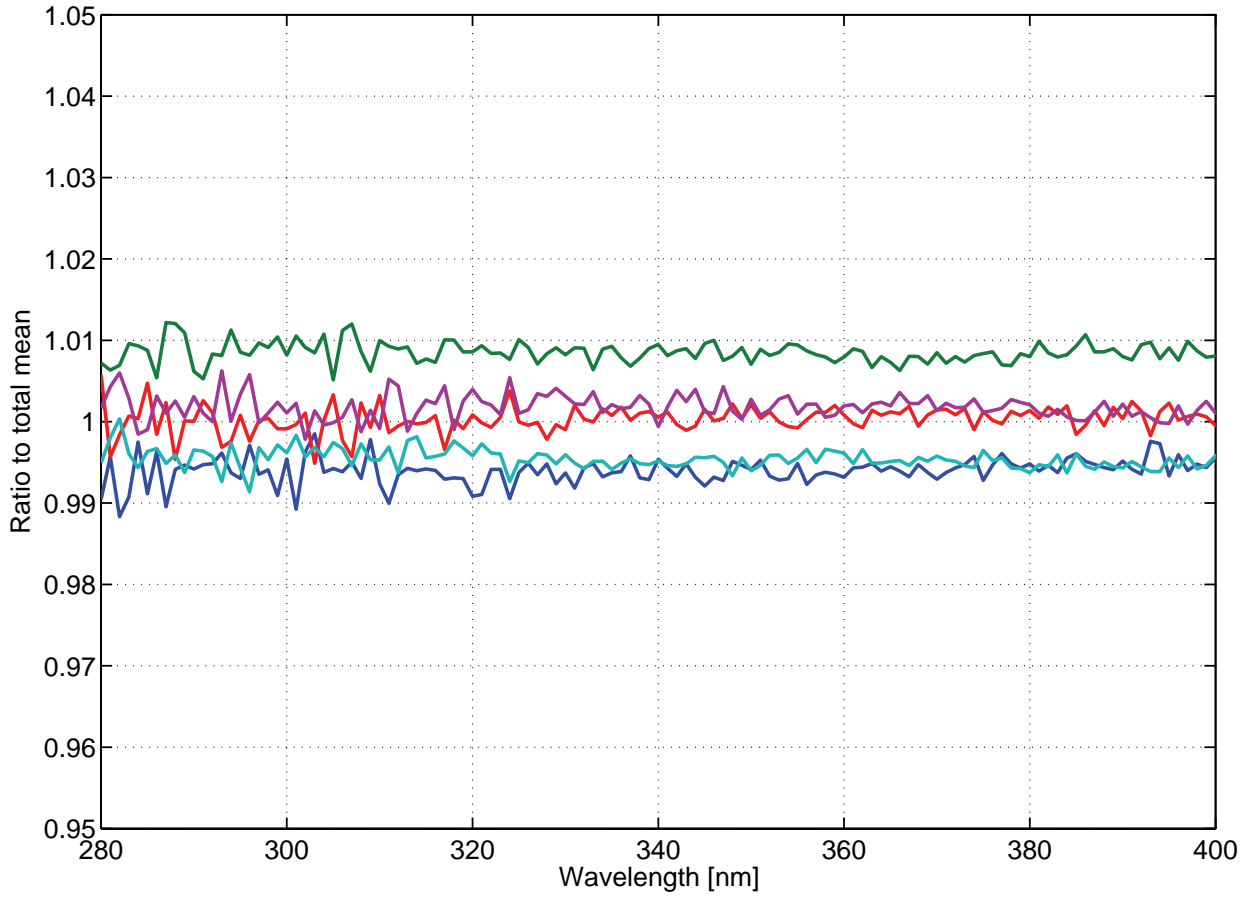
Mean ratio IZ3/QASUME at Arosa:24-Jul-2008(206) to 27-Jul-2008(209)



Arosa, 185, July 2008



Spectral Responsivity change of QASUME, Arosa, July 2008, T68522, T68523



Temperature dependence of Brewer #156, Arosa, July 2008

