

Protocol of the intercomparison at INTA, El Arenosillo, Spain
on July 6 to 13, 2011 with the travelling reference
spectroradiometer QASUME from PMOD/WRC

Report prepared by Gregor Hülsen

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The purpose of the visit was the comparison of spectral global solar irradiance measurements between the 17 spectrophotometers participating in the 6th 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 El Arenosillo; Latitude 37.10 N, Longitude 6.73 W and altitude 50 m.a.s.l.

The horizon of the measurement site is free down to at least 85° solar zenith angle (SZA). Measurements between 5:00 UT and 18:00 UT have been analysed.

QASUME arrived at INTA in the evening of July 06, 2011. The spectroradiometer was installed in line to the Brewer spectrophotometers with the entrance optic of QASUME between 2 and 20 m away from the other instruments. The measurement campaign lasted seven days, from morning of July 07 to the evening of July 13; the core comparison days were July 10-12.

QASUME was calibrated several times during the intercomparison period using a portable calibration system. Three lamps (T68522, T68523, 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 % during the intercomparison period. The internal temperature of QASUME was 25.3 ± 0.1 °C. The diffuser head was heated to a temperature of 29.0 ± 2.0 °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; 8 single and 9 double monochromators.

Instrument ID	Institution	Operator	Country
#017-MKII	IOS	Ken Lamb	Canada
#051-MKIV	DMN	Zaydi Mustapha	Morocco
#070-MKIV	AEMET MADRID	María Lopez	Spain
#075-MKIV	UKMO	Andrew Smedley	U.K.
#117-MKIV	INM MURCIA	Jose Antonio Parodi	Spain
#126-MKII	UKMO	Andrew Smedley	U.K.
#145 MKIII	MSC	Tom McElroy	Canada
#150-MKIII	INTA HUELVA	Jose Manuel Vilaplana	Spain
#151-MKIV	AEMET CORUÑA	Francisco García	Spain
#158-MKIII	Kipp & Zonen	Arjan Hoogendoorn	The Netherlands
#163-MKIII (ISQ)	PMOD/WRC	Gregor Hülsen	Switzerland
#165-MKIII	DMN	Zaidouni Taoufik	Morocco
#166-MKIV	AEMET MADRID	J.M. Santasnasio	Spain
#172-MKIII	UKMO	Andrew Smedley	U.K.
#185-MKIII (IZ3)	AEMED IZAÑA	Alberto Redondas	Spain
#186-MKIII	AEMED MADRID	Jose Montero	Spain
#208-MKIII	Kipp & Zonen	Arjan Hoogendoorn	The Netherlands

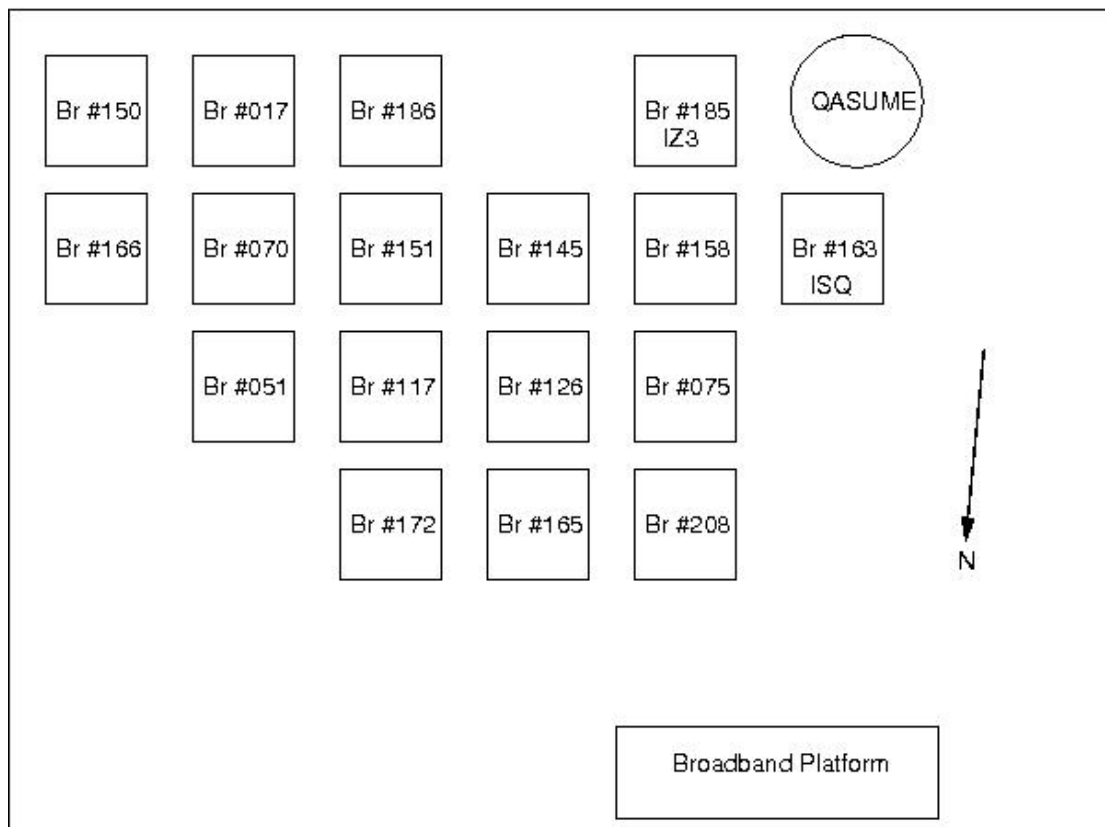


Figure 1: Roof setup at INTA

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 (time in UT)
187	6-Jul	Wednesday	Clear Sky	Installed at 17:30
188	7-Jul	Thursday	Clear Sky	Calibrated: 09:47 using T68522 Calibrated: 10:07 using T68523
189	8-Jul	Friday	Clear Sky	Calibrated: 8:44 using T68523
190	9-Jul	Saturday	Clear Sky	Calibrated: 7:12 using T68523
191	10-Jul	Sunday	Clear Sky	UV Day Calibrated: 8:41 using T68523
192	11-Jul	Monday	Mostly Clear Sky	UV Day Calibrated: 8:43 using T68523
193	12-Jul	Tuesday	Mostly Clear Sky	UV Day Calibrated: 8:42 using T68523
194	13-Jul	Wednesday	Clear Sky	Calibrated: 8:06 using T68523 Calibrated: 8:41 using T68522 Calibrated: 9:11 using T61253
				End of Campaign 17:30

Results:

In total 38 to 96 synchronised simultaneous spectra from QASUME and the Brewer spectrophotometers are available from the measurement period. Measurements between 6:30 and 18:30 UT have been analysed (SZA smaller than 90°).

Remarks:

1. QASUME arrived after the first day of the RBCC-E intercomparison, which was dedicated for the setup and training phase. The official “UV-days” were 10-12 July (191-193). However, synchronized UV scans are also available from the 7th July.
2. Because of the different calibrations and measurements performed during the campaign, traffic on the roof could not be completely omitted. Therefore several scans are disturbed and excluded from the analysis.
3. The time synchronisation between QASUME and various Brewers was very good and a further improvement to the year 2009.

Highlighted Examples:

1. Brewer 150 – Introduced Temperature Correction. The improvement can be seen in the last Figures of the instrument.
2. Brewer 208 – Low Temperature dependence but large cosine error.

Brewer Temperature Dependence:

The standard Brewer global UV measurement procedure does not take into account the dependence of the Brewer spectral responsivity 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 El Arenosillo, due to the diurnal temperature variations, the temperature dependence of the Brewer spectrophotometers has 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. The figures on page 89 to 96 show these ratios plotted as a function of the internal temperature of the Brewers. From this data, the temperature dependencies of the instruments can be derived using a linear fit (see table 2). Using these temperature correction factors the diurnal variations can be partly removed. This can be seen in the stable performance of Brewer #163, which can partly be explained by the applied temperature correction of -0.22 %/K.

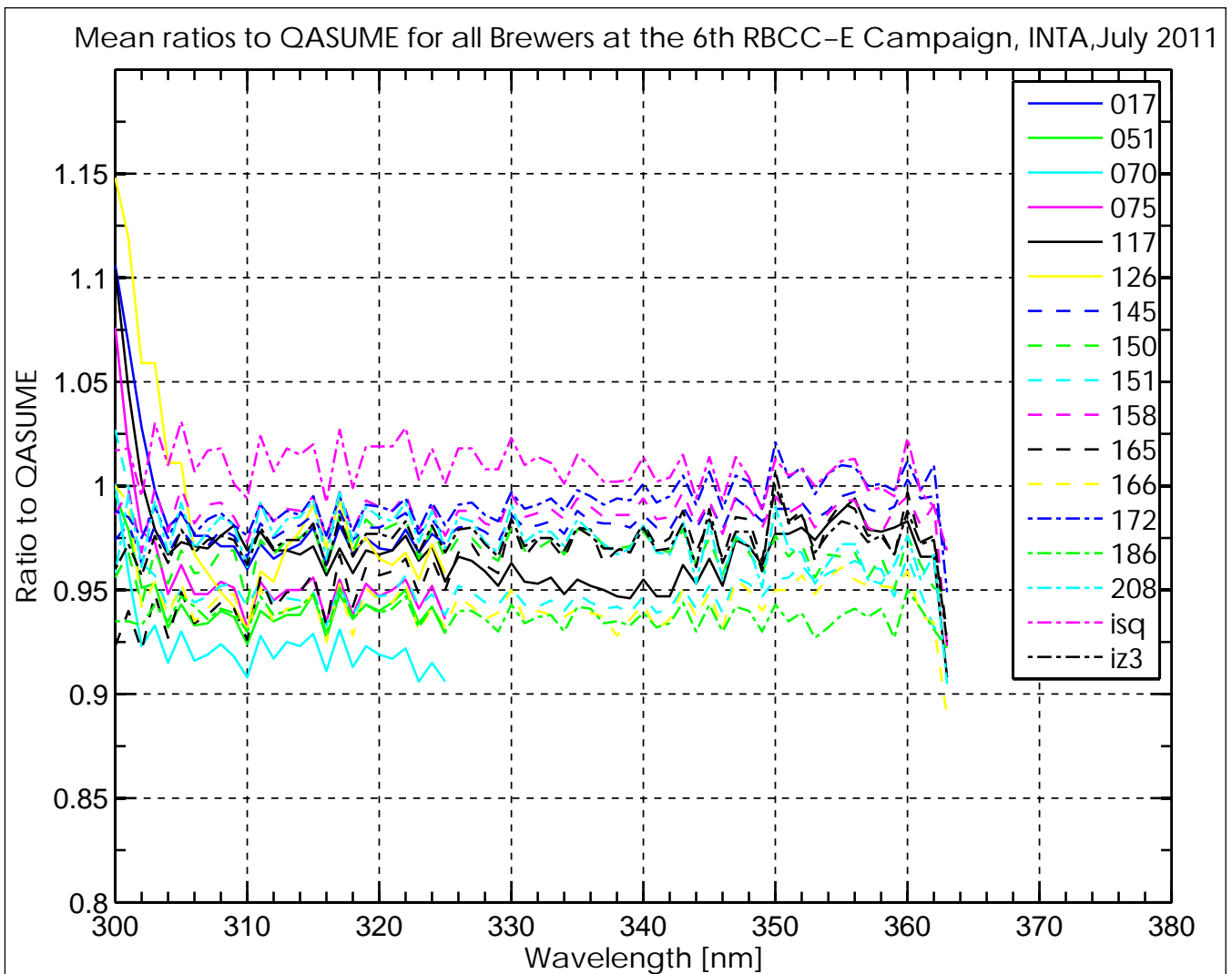
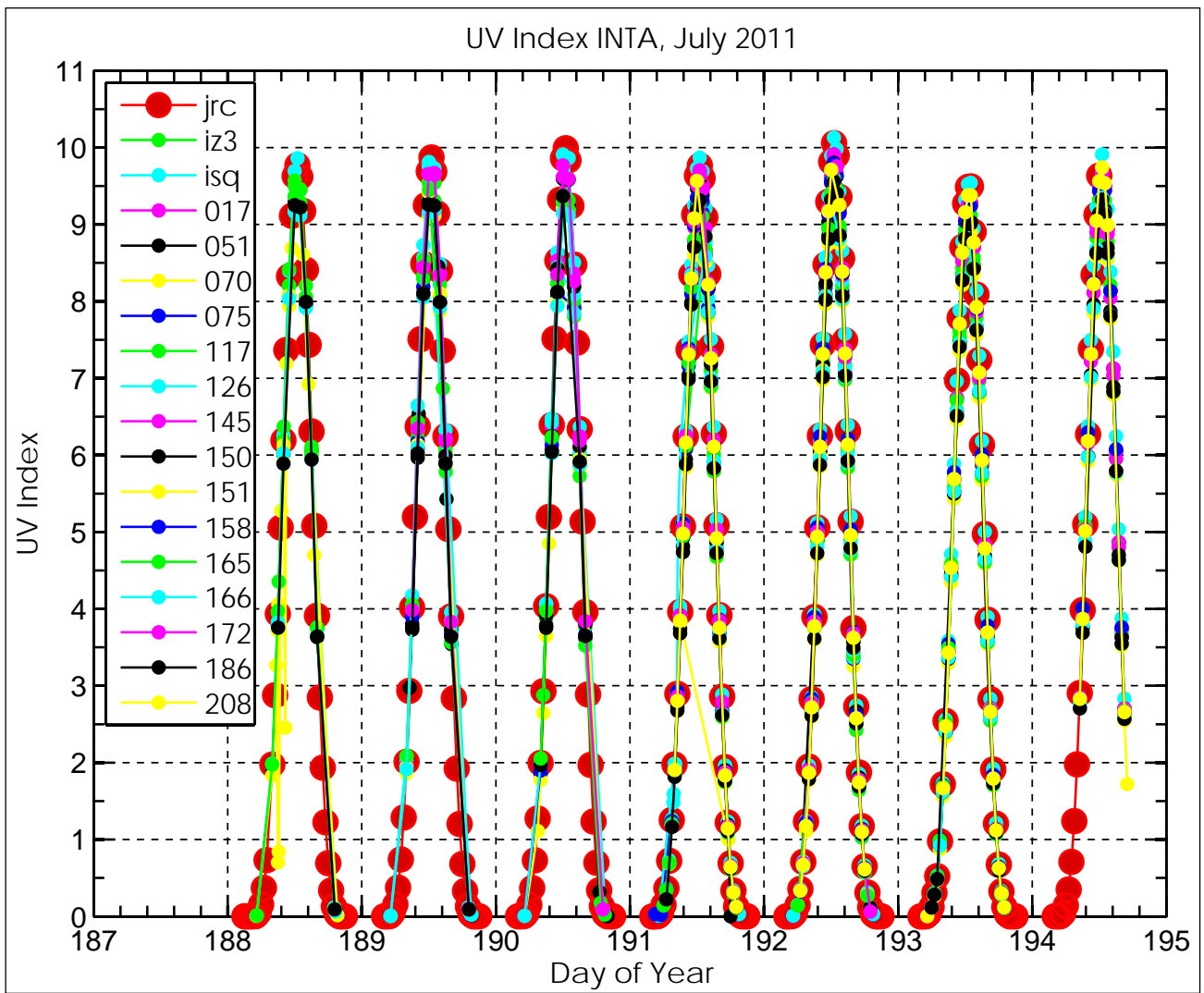
A correction algorithm was also applied to the data of Brewer 150. The improvement is illustrated in the results using a Temperature-Correction (+0.13 %/K) or No-Temperature-Correction (-0.29 %/K).

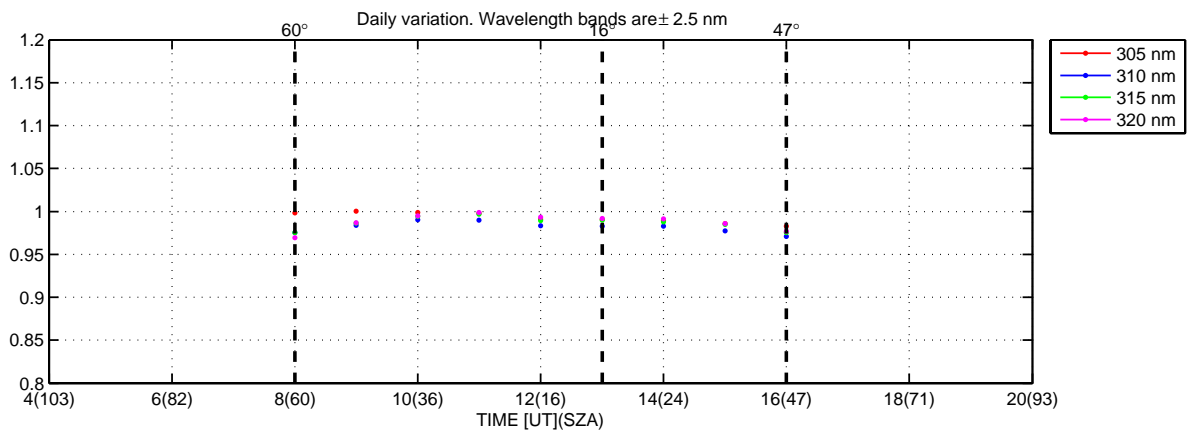
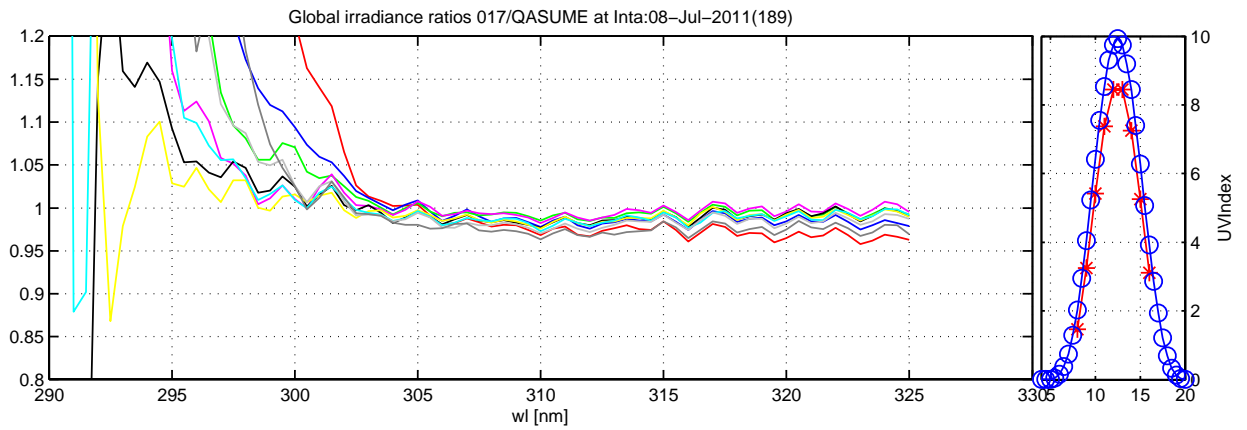
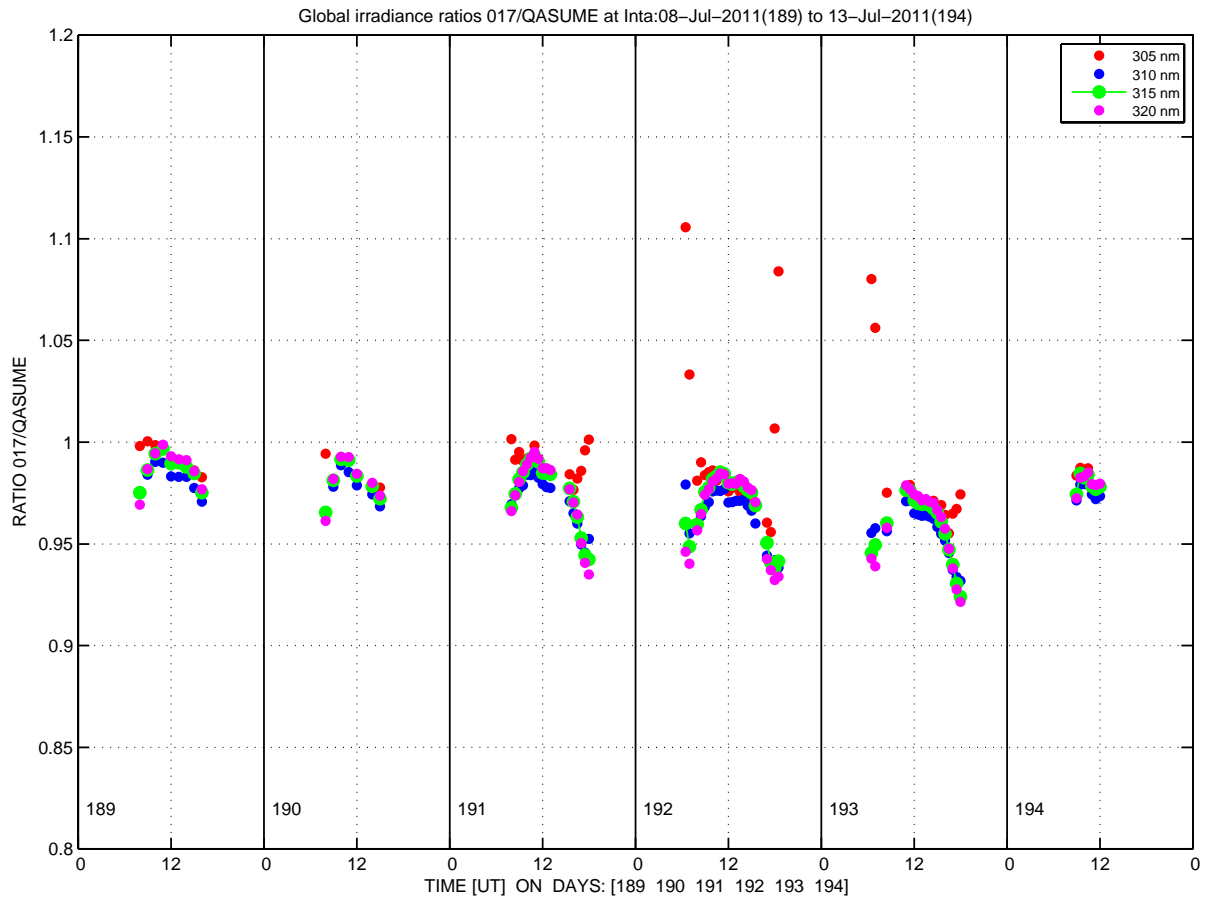
Recommendations:

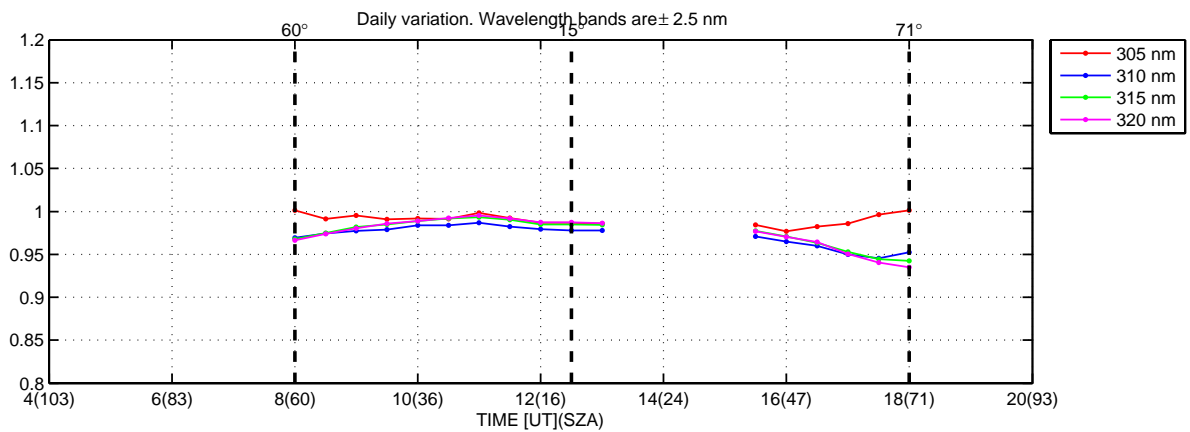
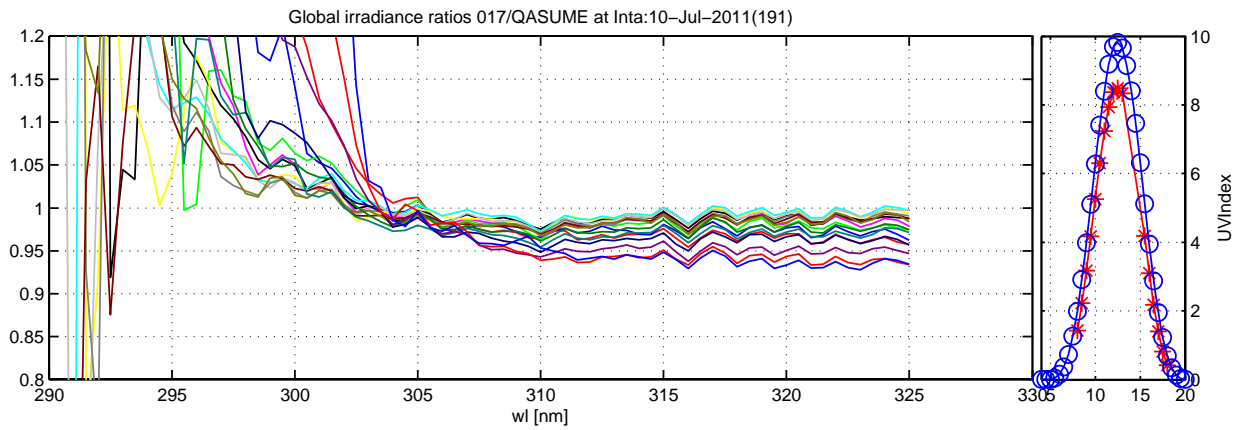
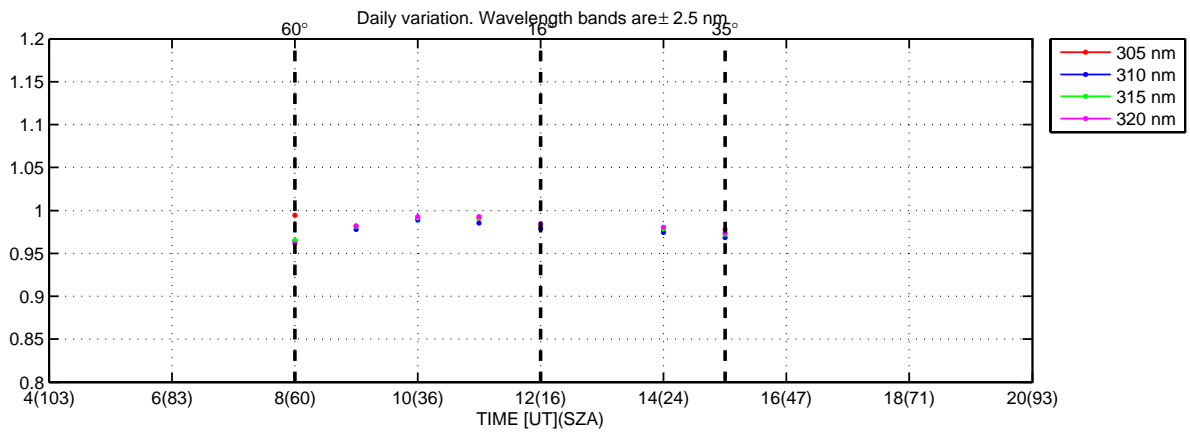
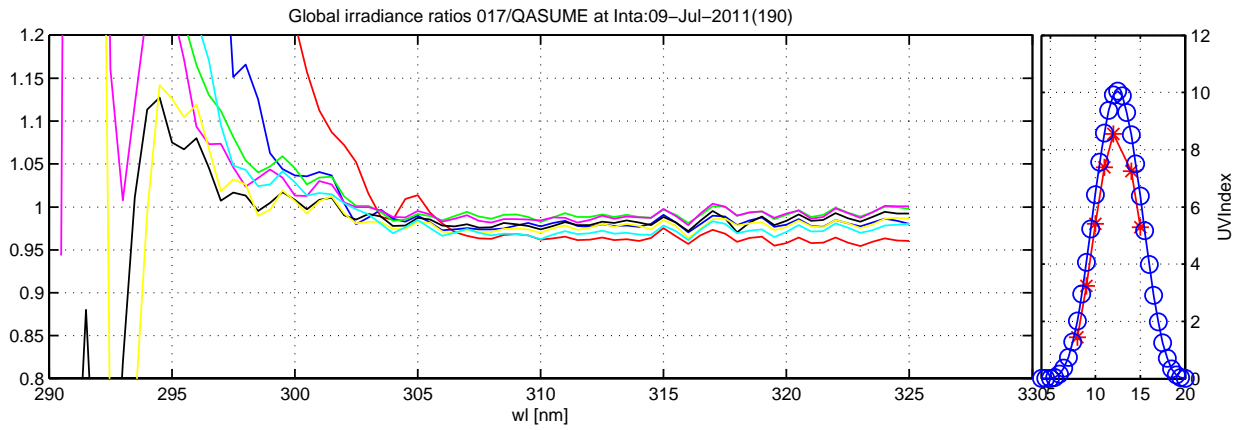
The variabilities observed between individual Brewer spectrophotometers relative to the QASUME spectroradiometer are due to ambient temperature variations on the one hand (see above paragraph), and to angular response errors which were not accounted for (See for example Gröbner, J., Improved entrance 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. The temperature correction factors derived from the diurnal variations of the ratios Brewer to QASUME (table 2) can only serve as an approximation because these variations do not only depend on the temperature. This function should therefore be determined individually for every Brewer using a measurement procedure as described in the refereed literature (see references).

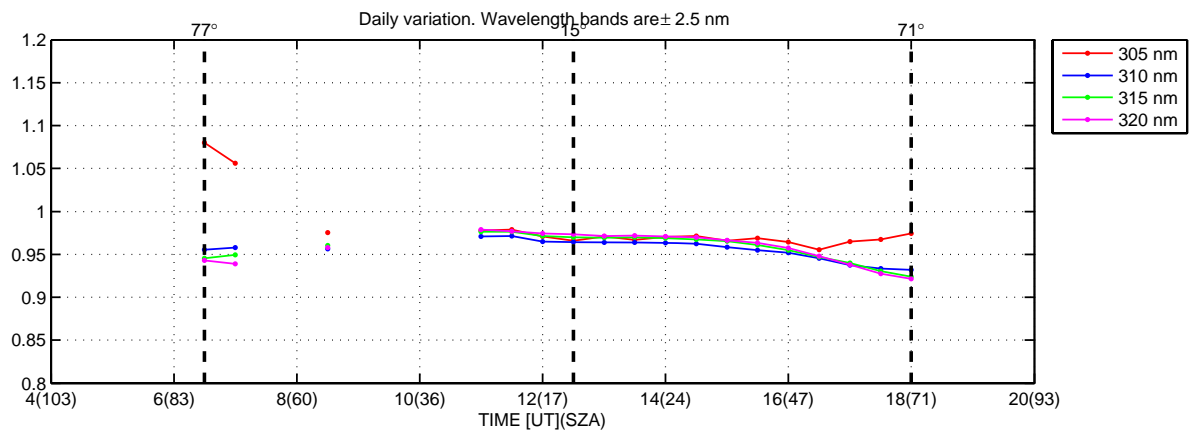
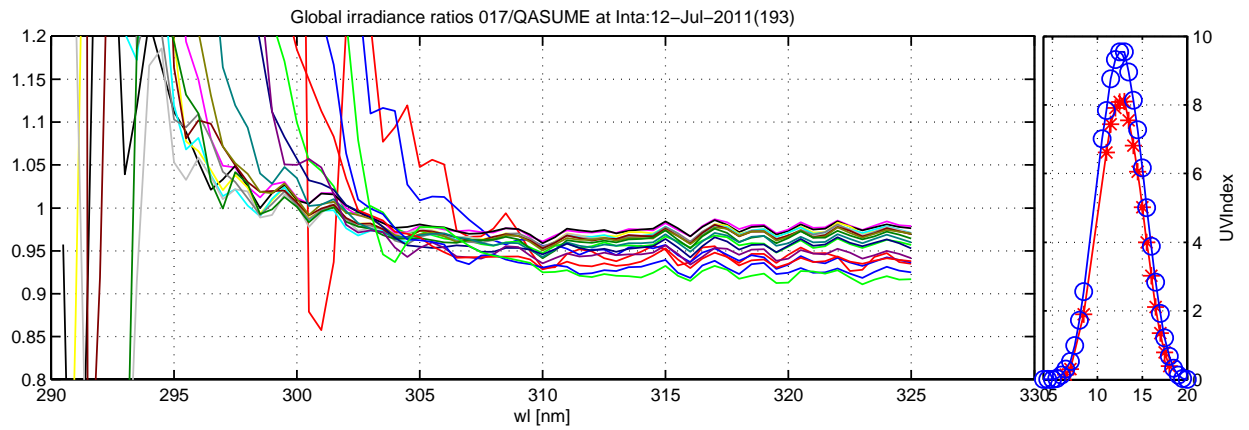
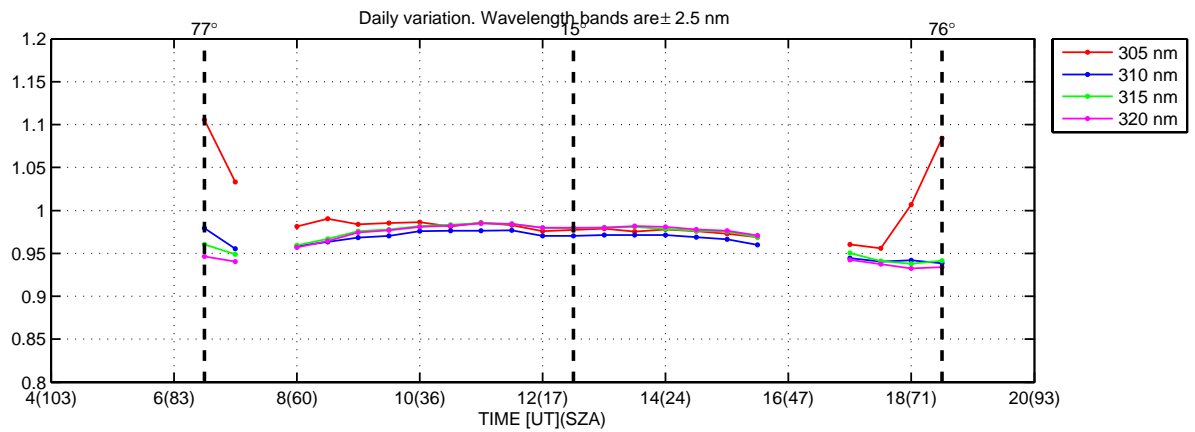
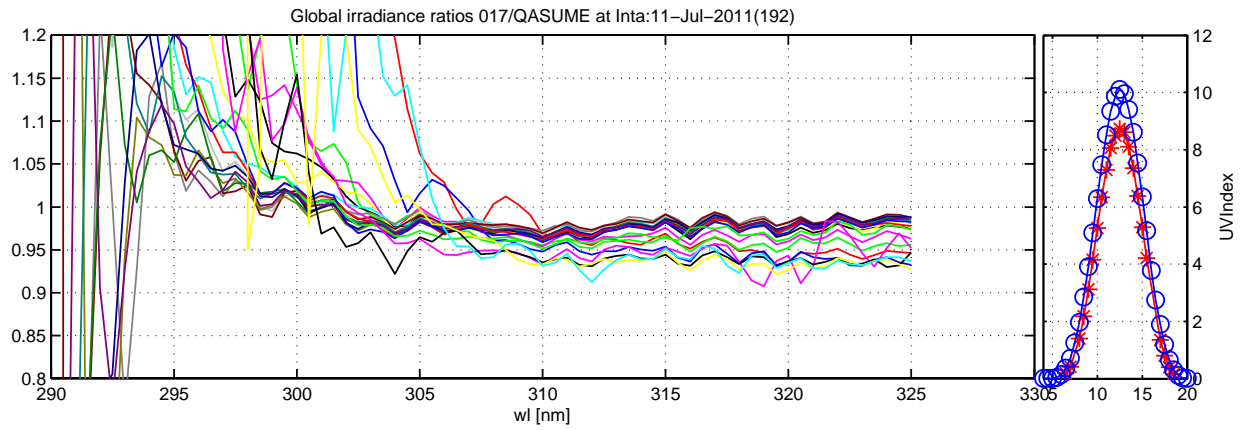
Table 2: Mean values of the ratio Brewer/QASUME (305 – 320/360 nm), the diurnal variability, the wavelength shifts and the Brewer temperature dependencies.

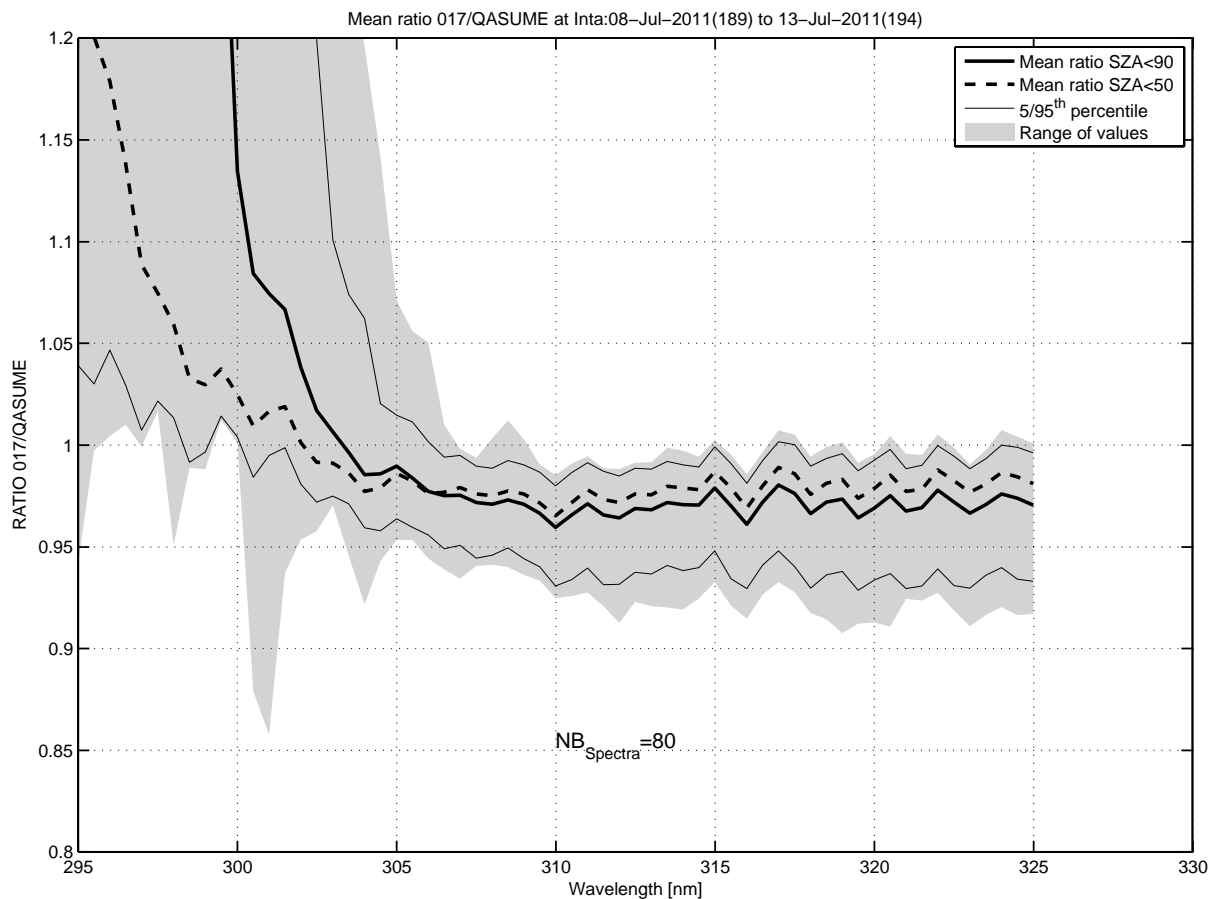
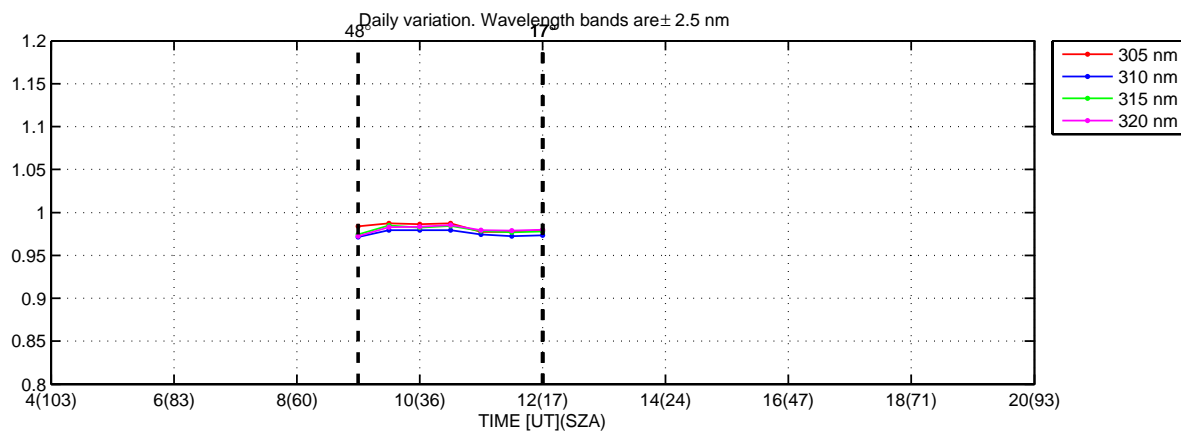
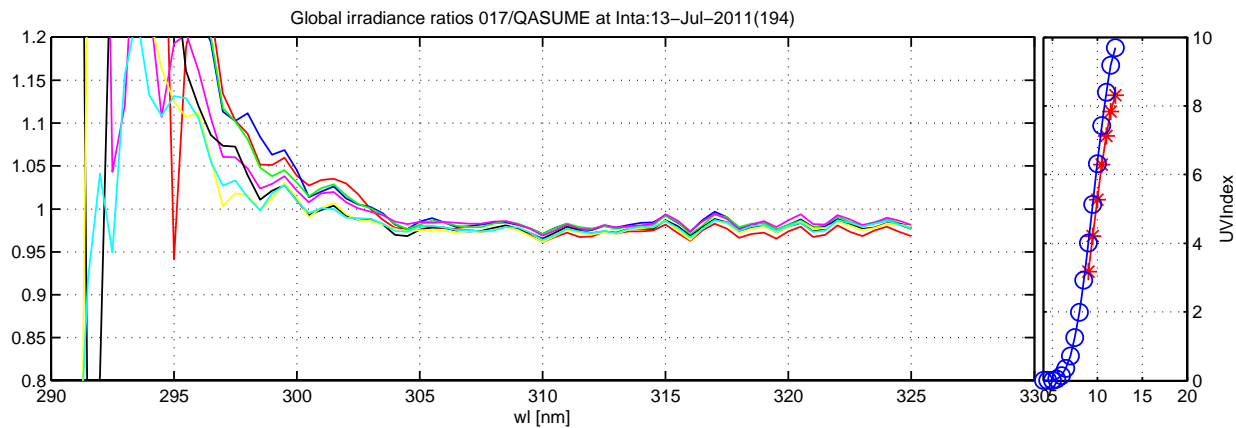
Instrument ID	Brewer to QASUME [%]	Diurnal variability [%]	Wavelength shift [pm]	Temperature Dependence [%/K]
#017	-2	±2	< ± 50	-0.07
#051	-6	±2	-50 .. +80	-0.16
#070	-7	±2	+20 .. +100	0.00
#075	-5	±2	-120 .. -70	-0.26
#117	-3	±3	-20 .. +80	-0.44
#126	-4	±4	< ± 50	-0.66
#145	-2	±2	< ± 50	-0.24
#150	-3	±1	< ± 50	0.13
#151	-5	±3	< ± 50	0.04
#158	-1	±2	< ± 50	-0.50
#163 (ISQ)	1	±1	< ± 50	-0.06
#165	-4	±6	-100 .. -10	0.11
#166	-5	±3	-60 .. +100	-0.10
#172	-1	±2	-10 .. +80	-0.08
#185 (IZ3)	-2	±3	< ± 50	0.33
#186	-6	±2	-80 .. +60	0.24
#208	-2	±5	< ± 50	0.18



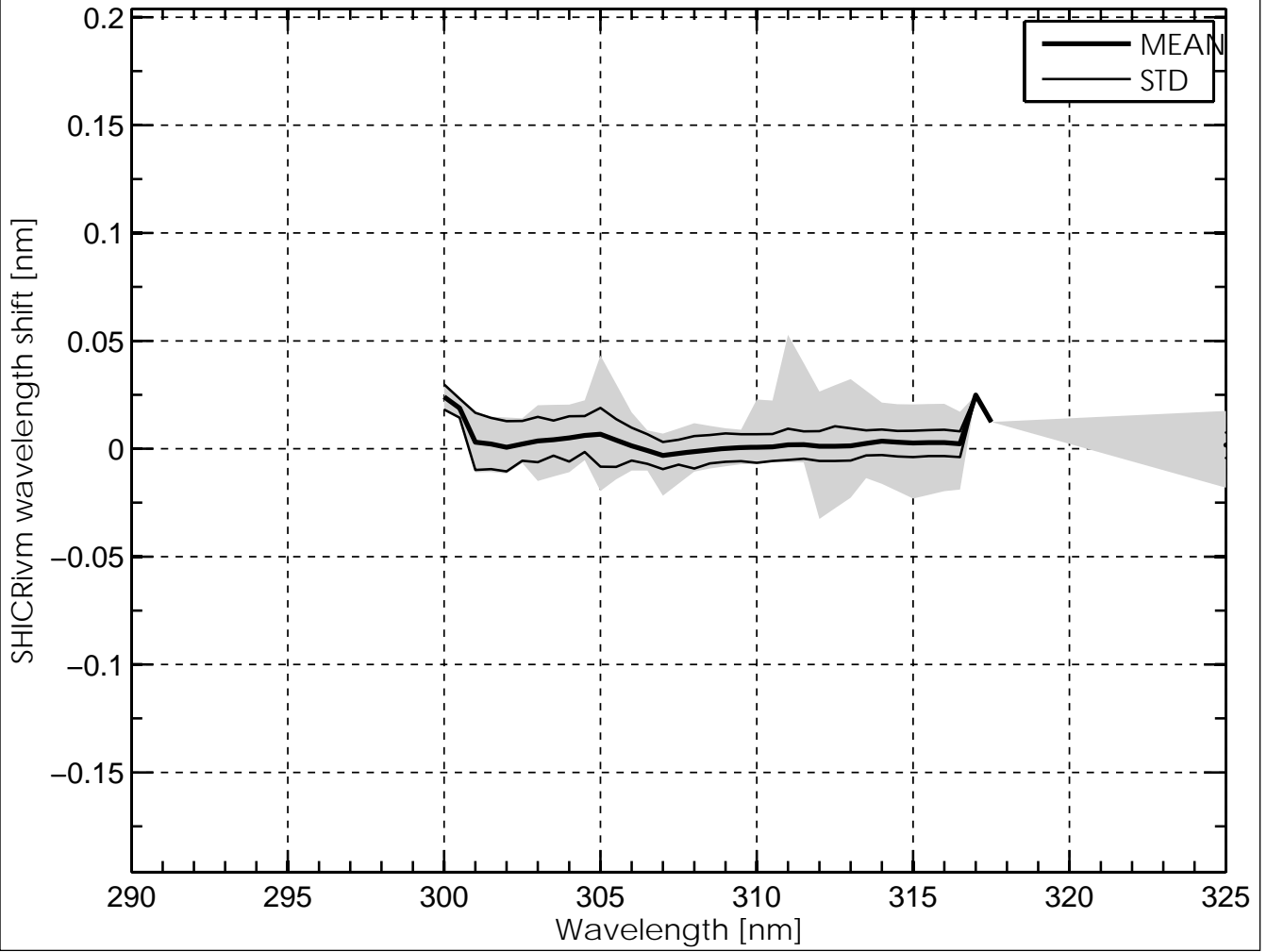




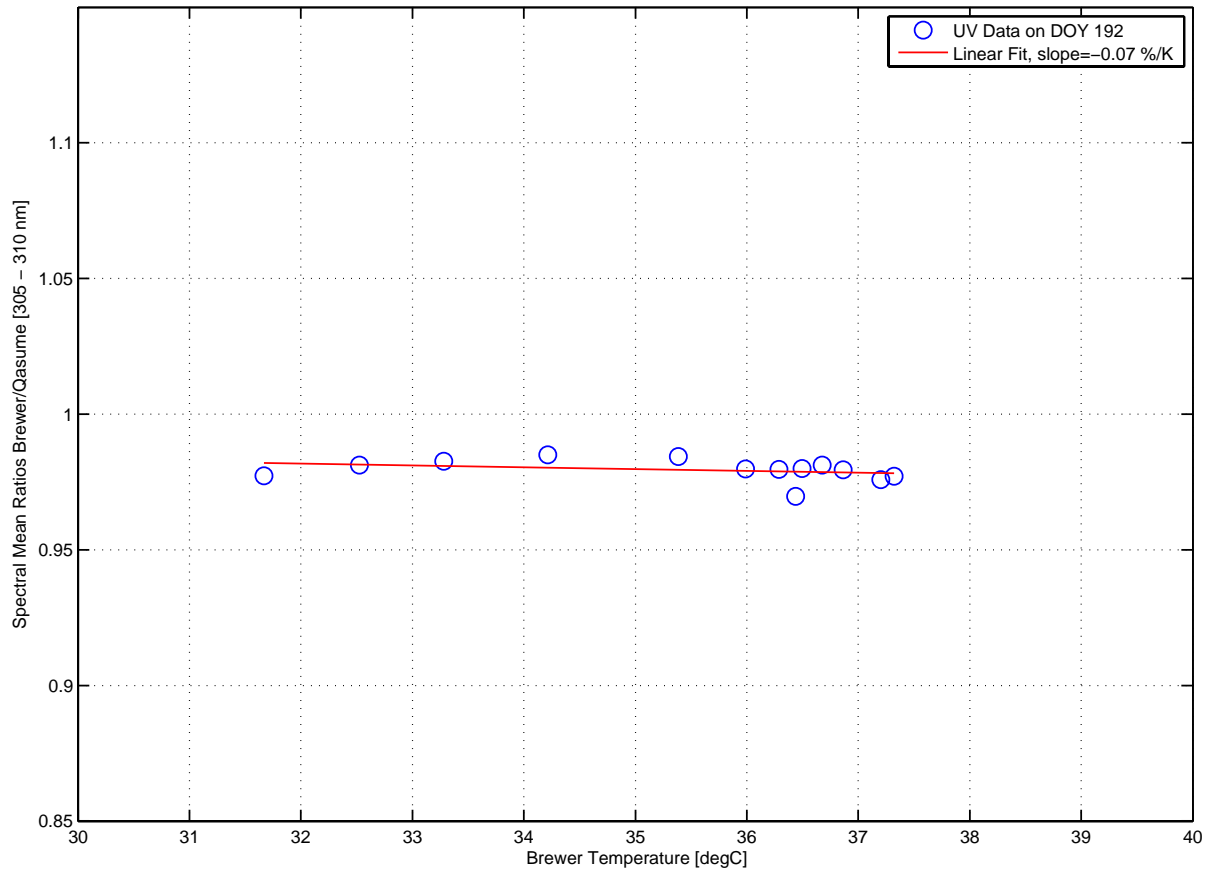


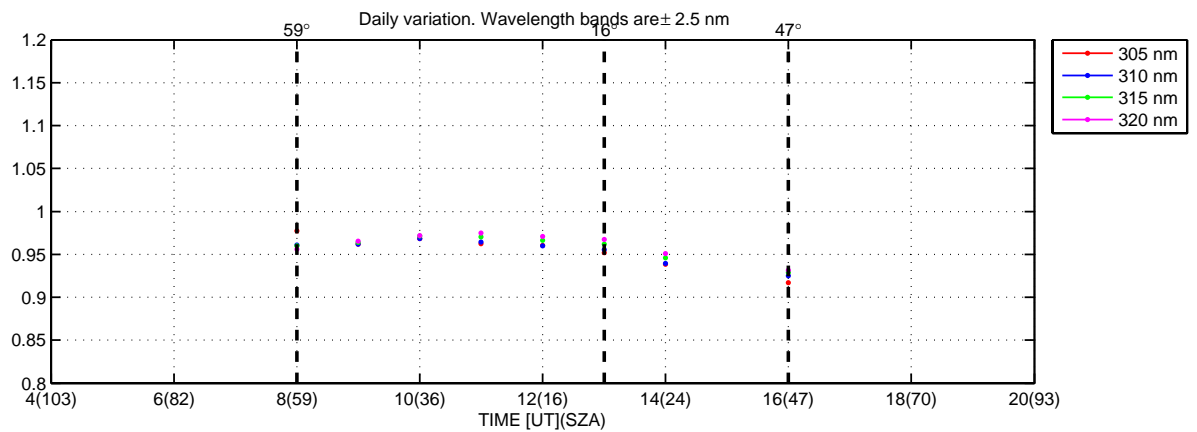
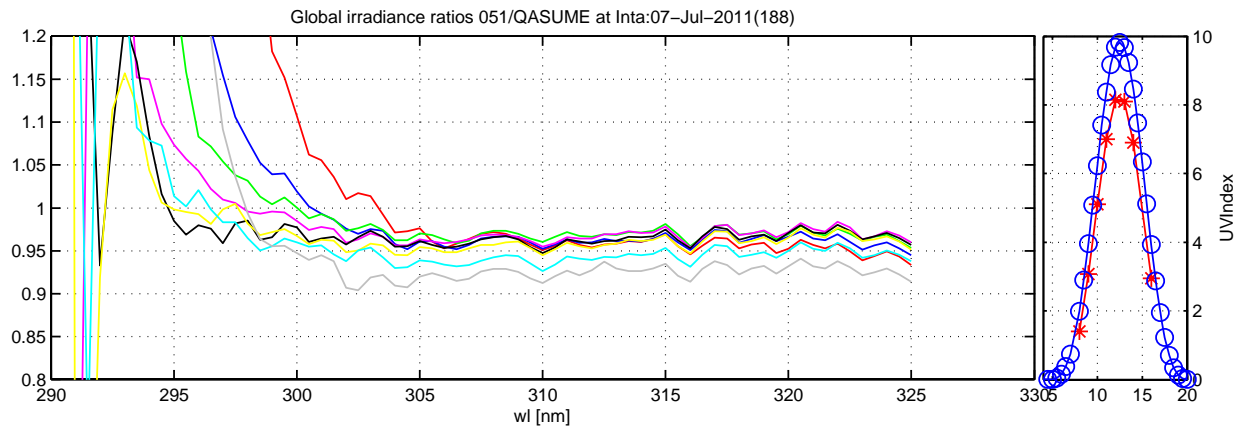
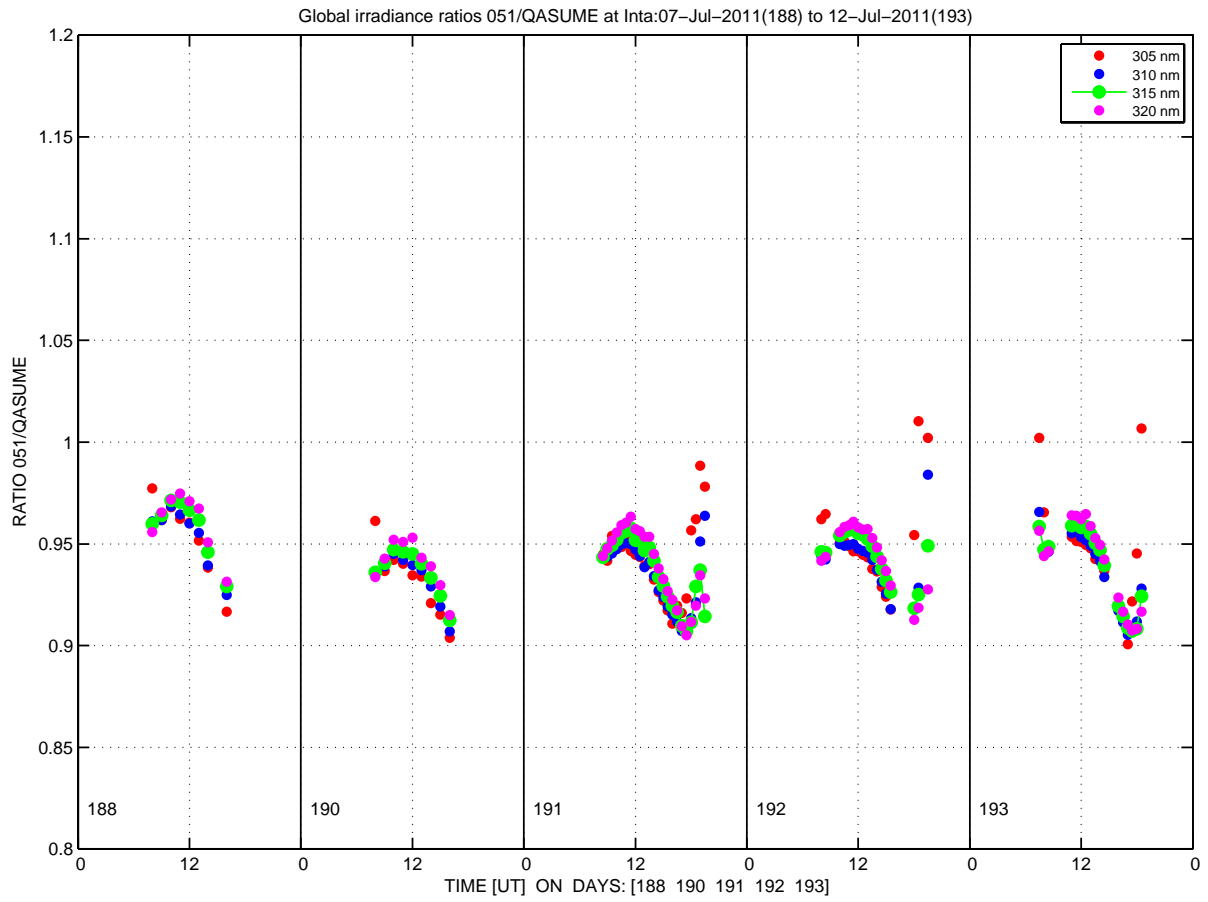


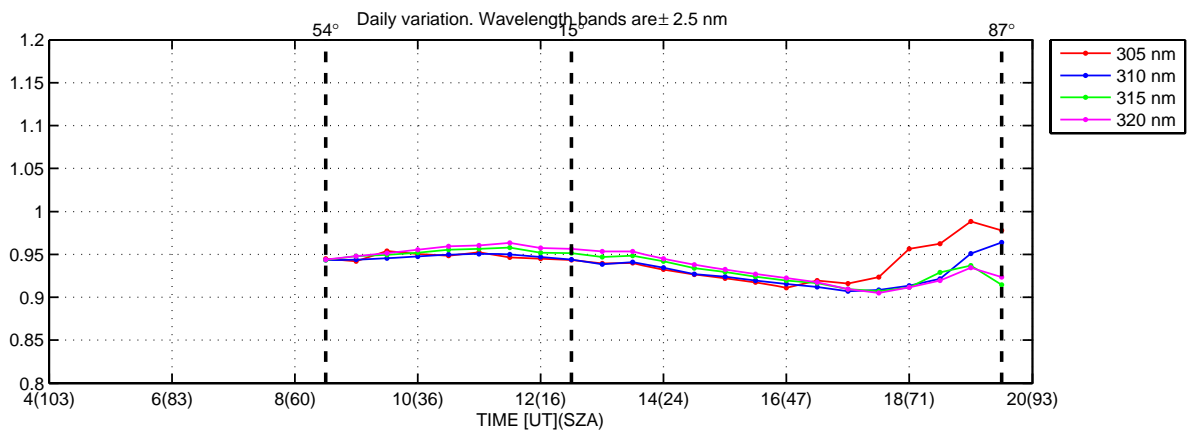
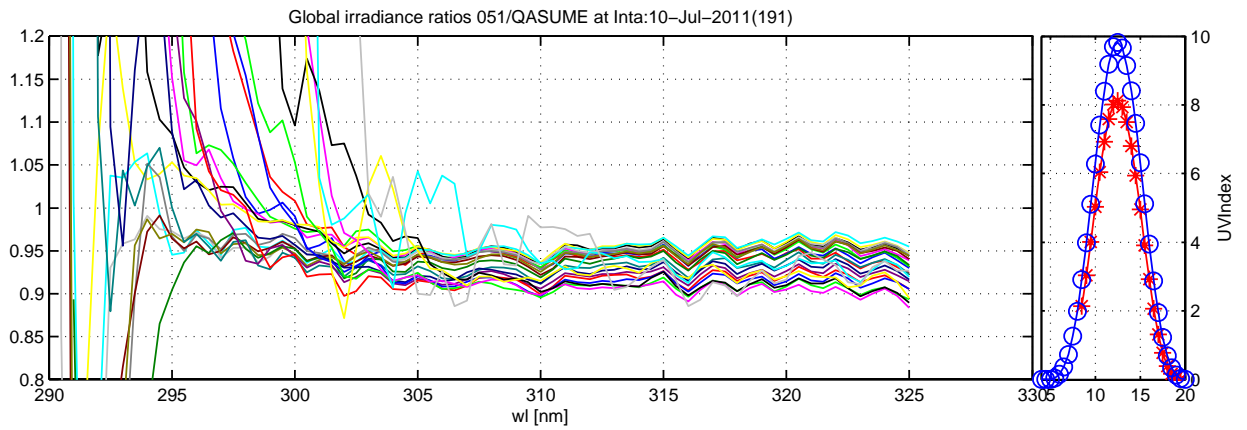
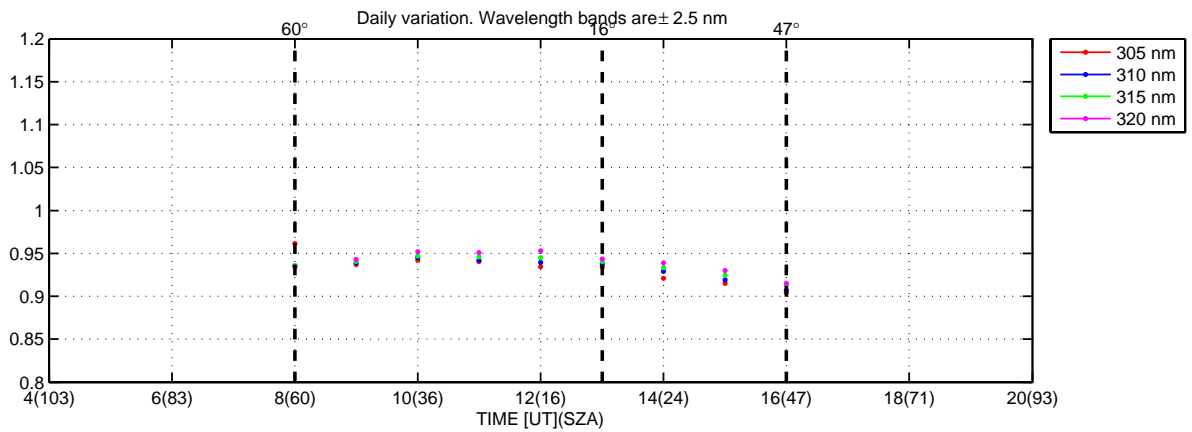
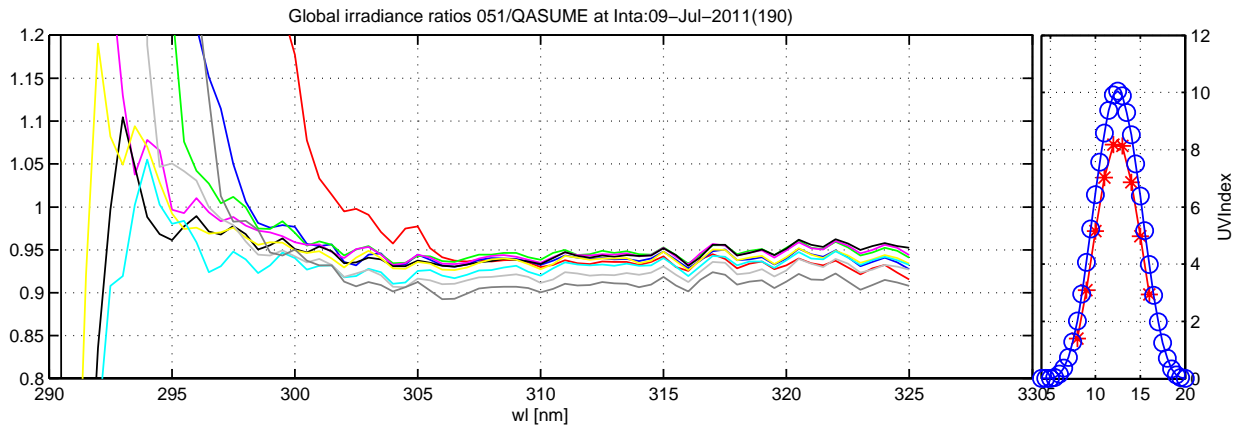
Intra, 017, July 2011

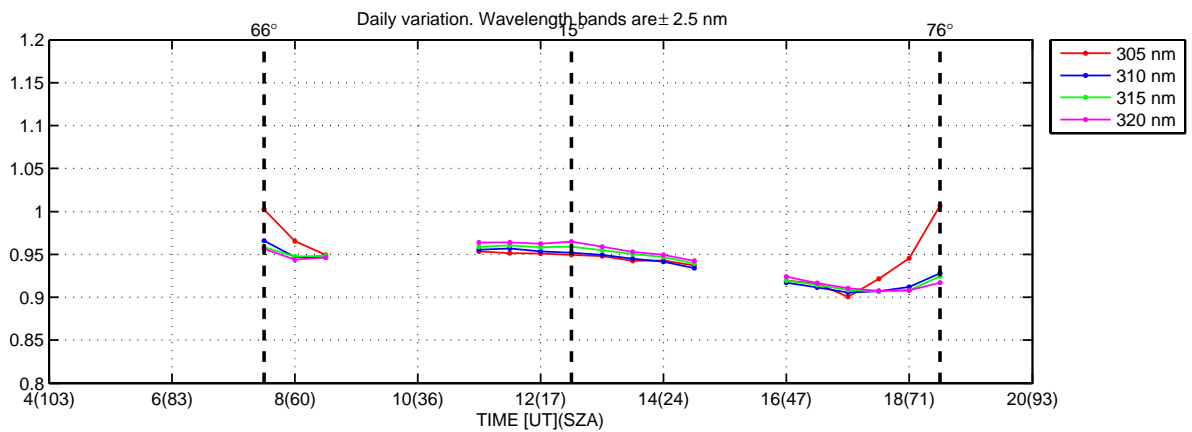
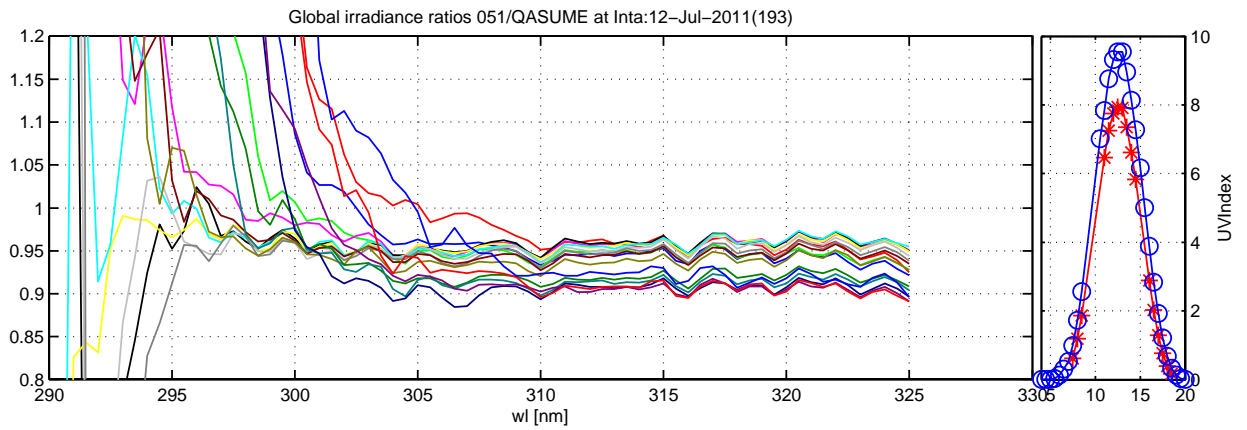
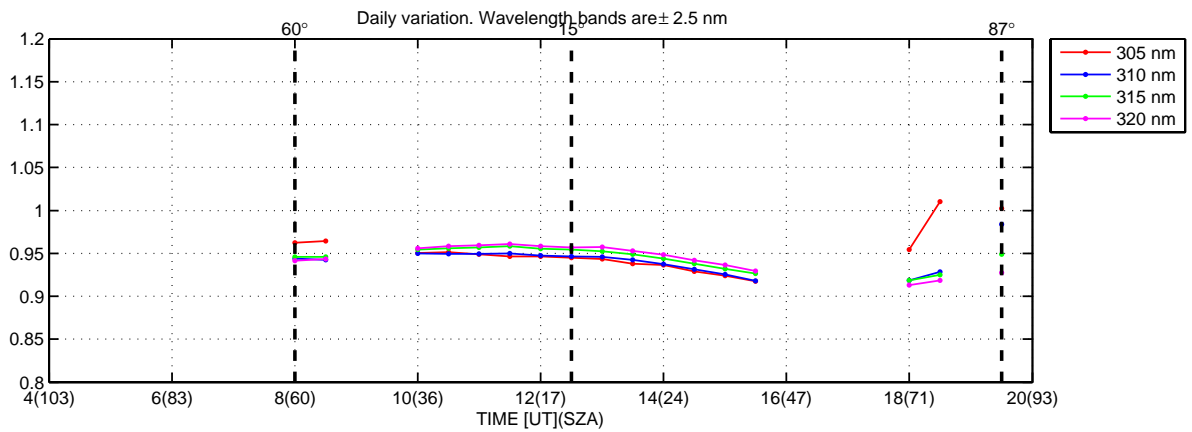
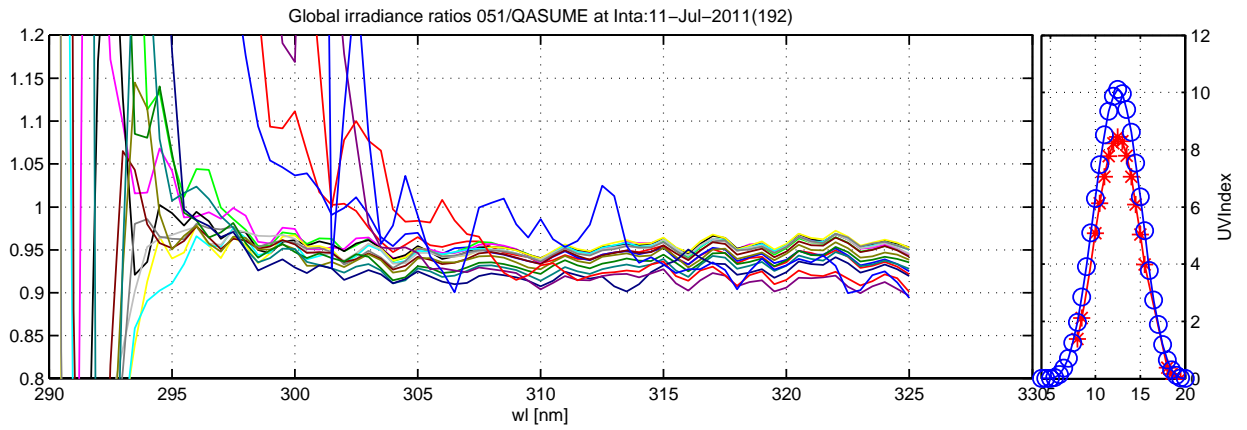


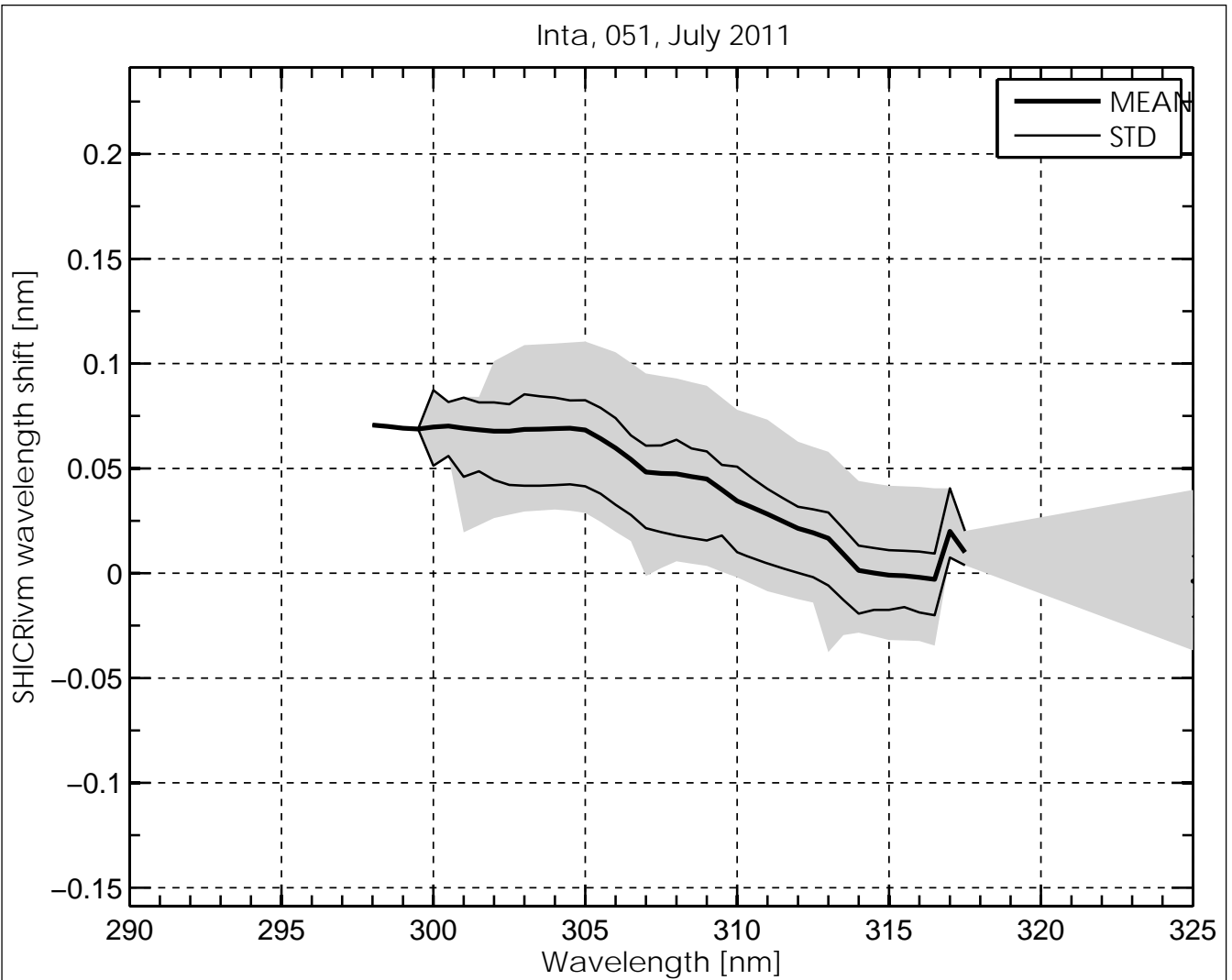
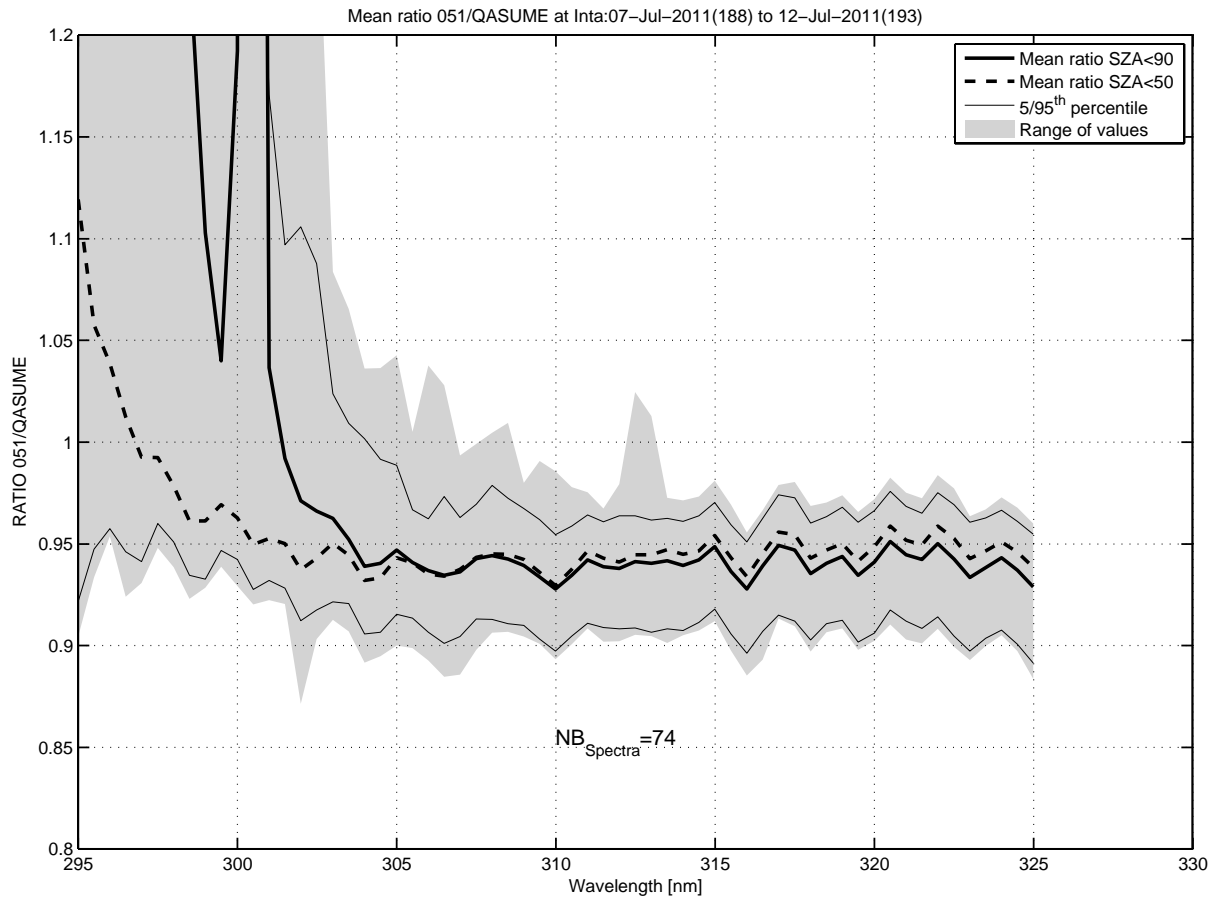
Temperature Dependence of Brewer #017, Intra, July 2011



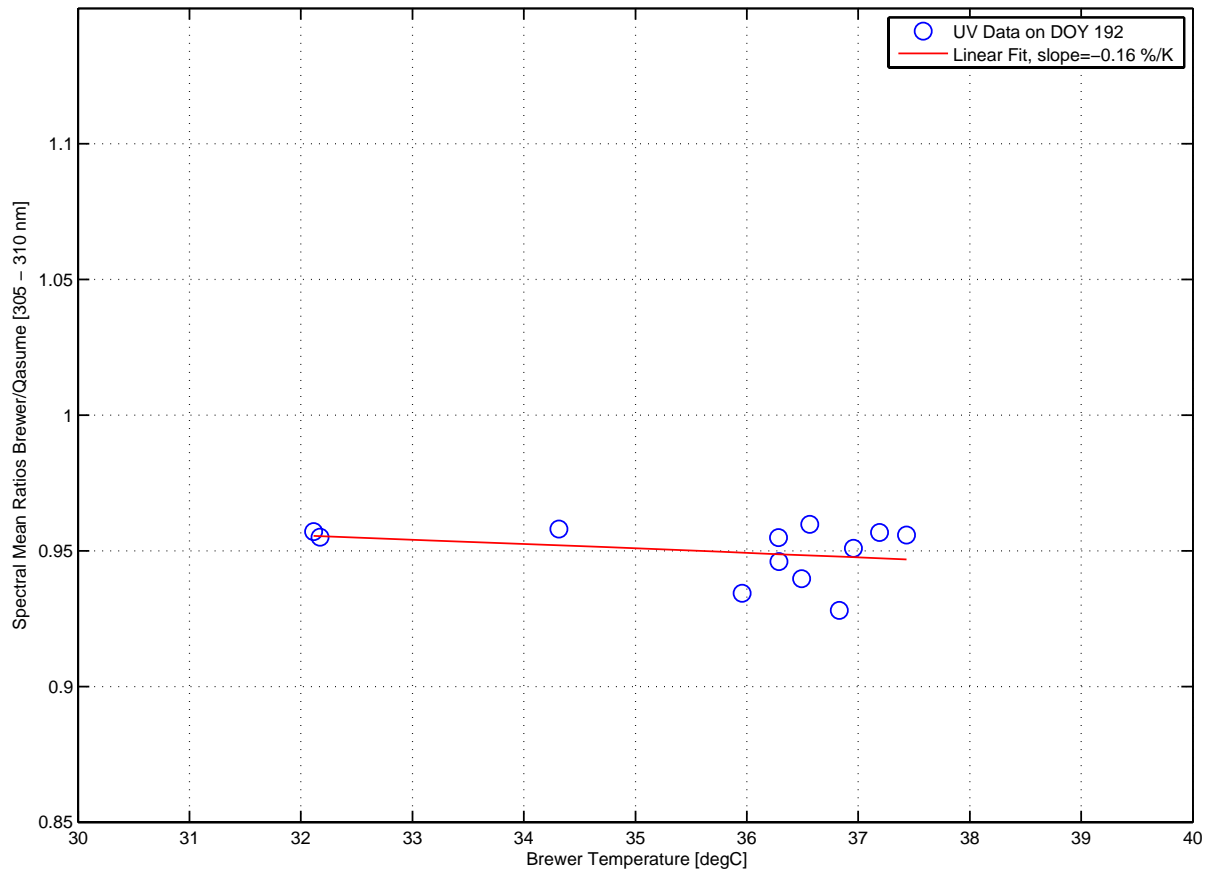




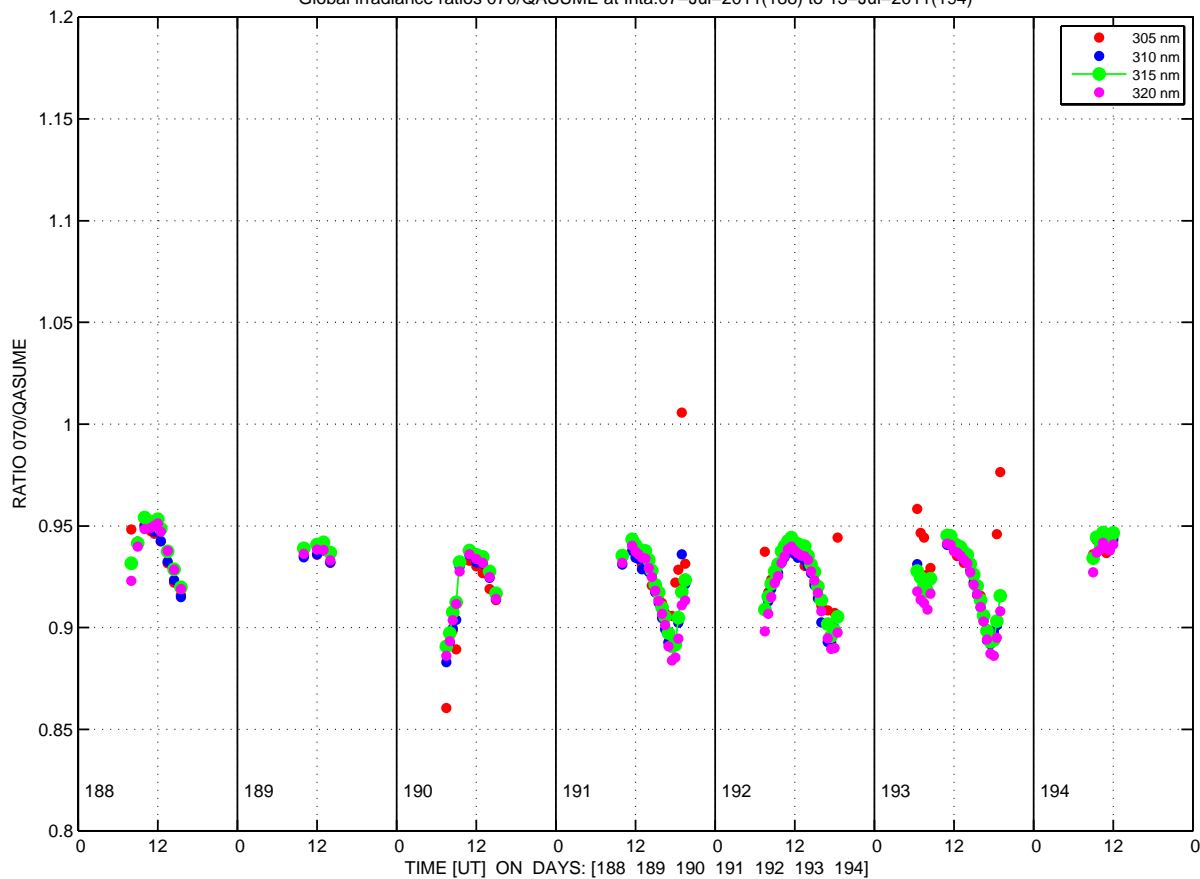




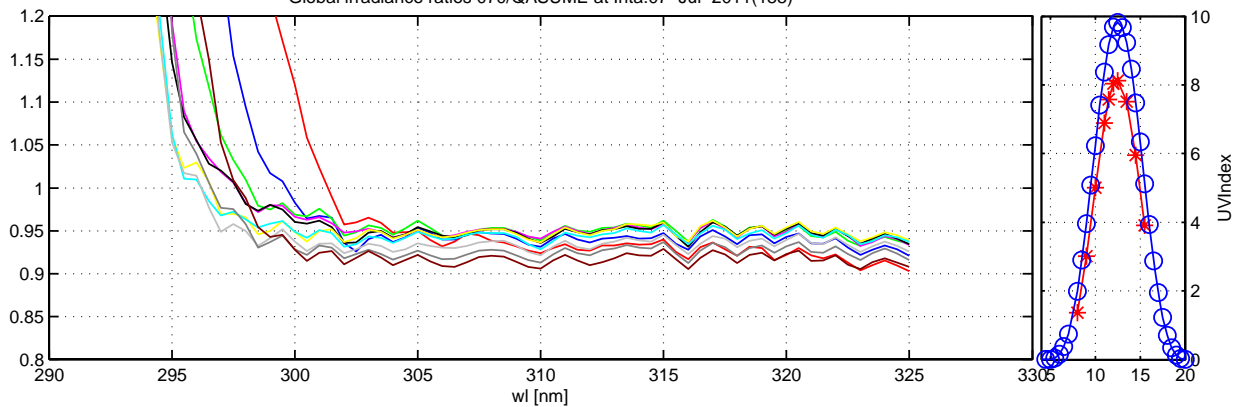
Temperature Dependence of Brewer #051, Intra, July 2011



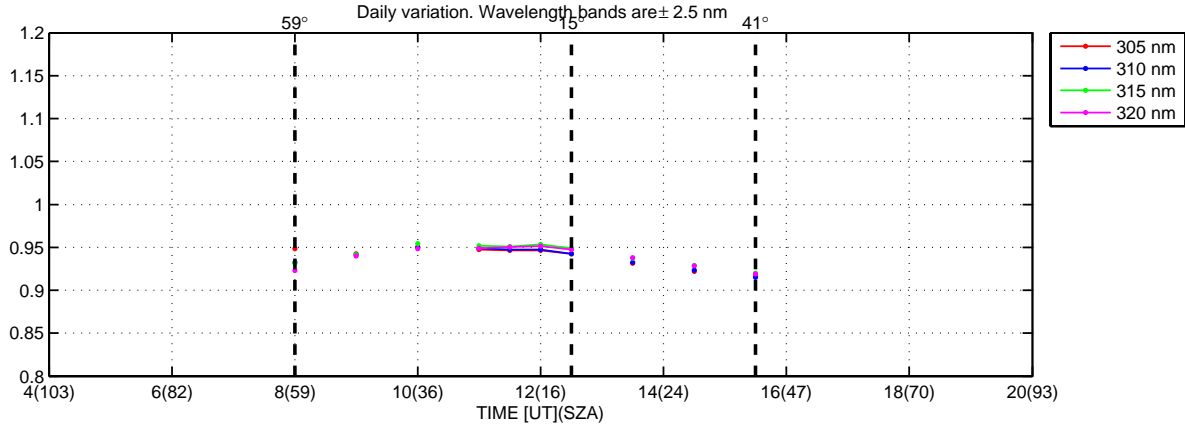
Global irradiance ratios 070/QASUME at Inta:07-Jul-2011(188) to 13-Jul-2011(194)

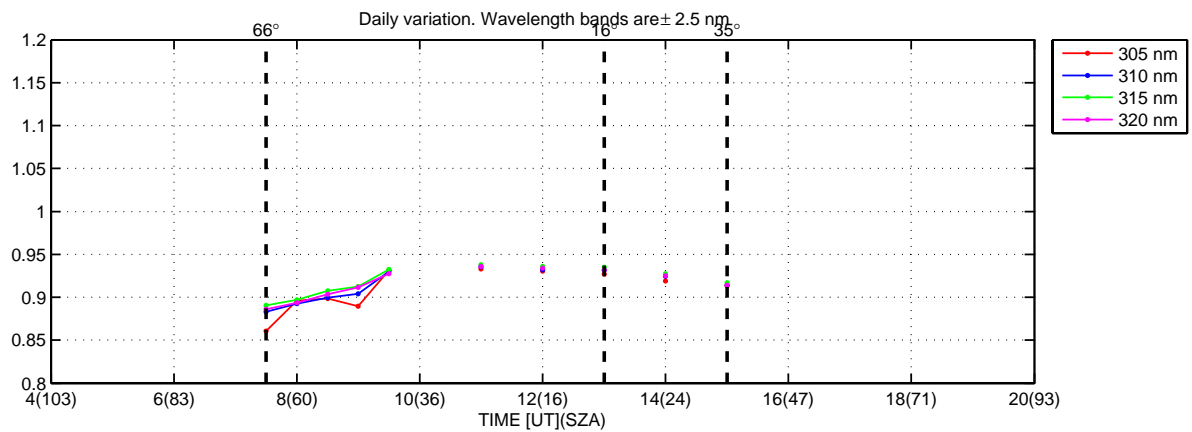
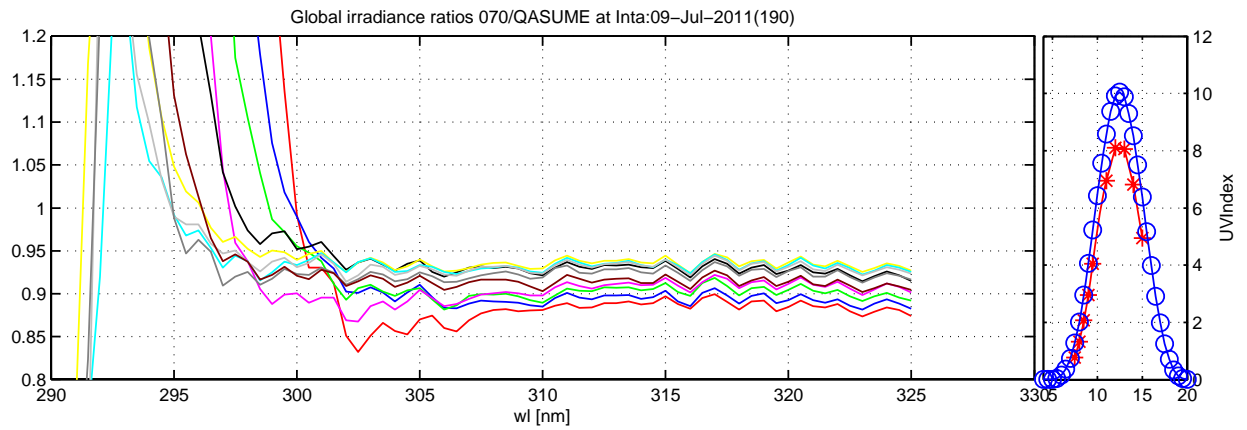
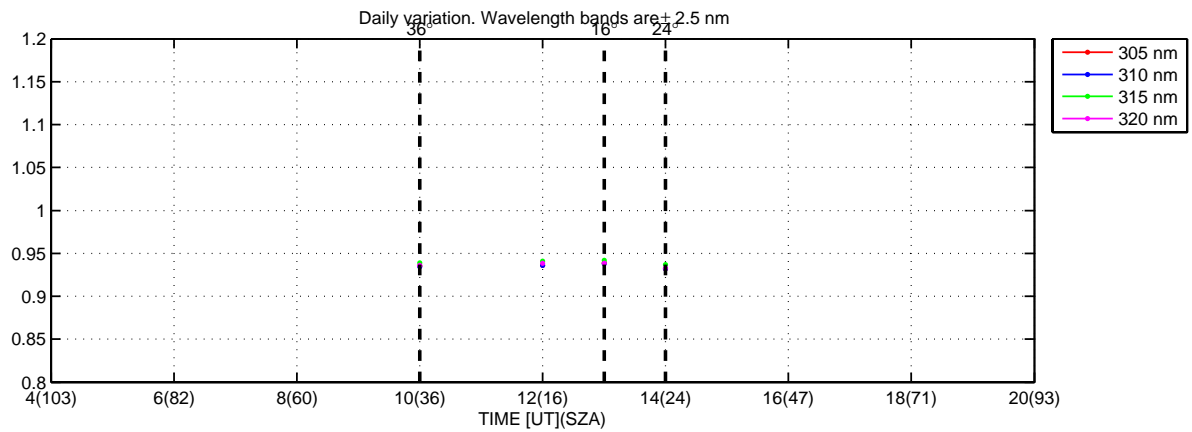
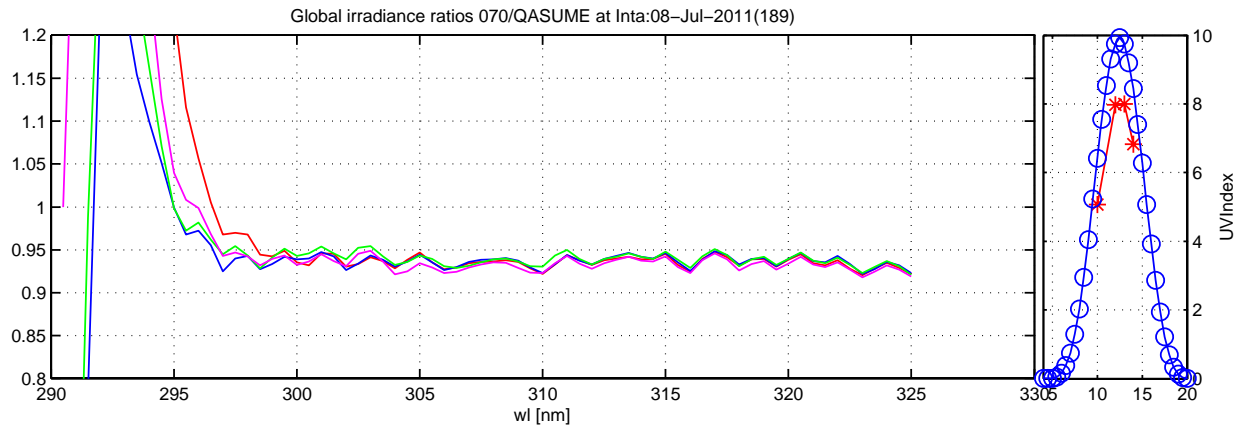


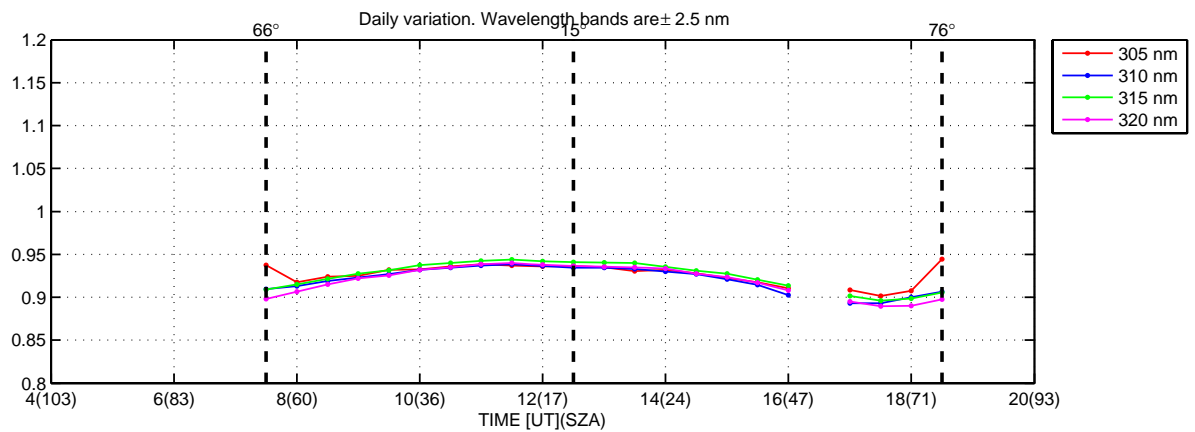
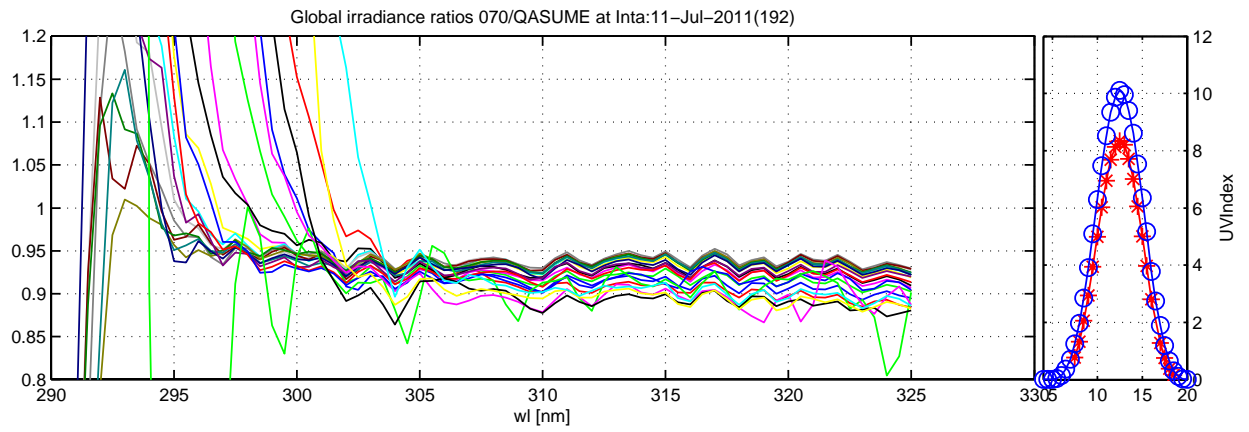
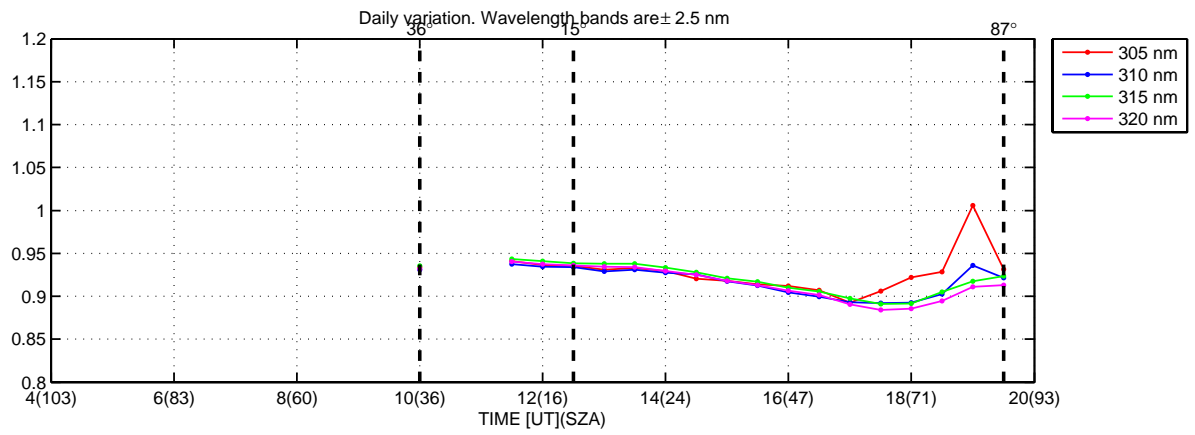
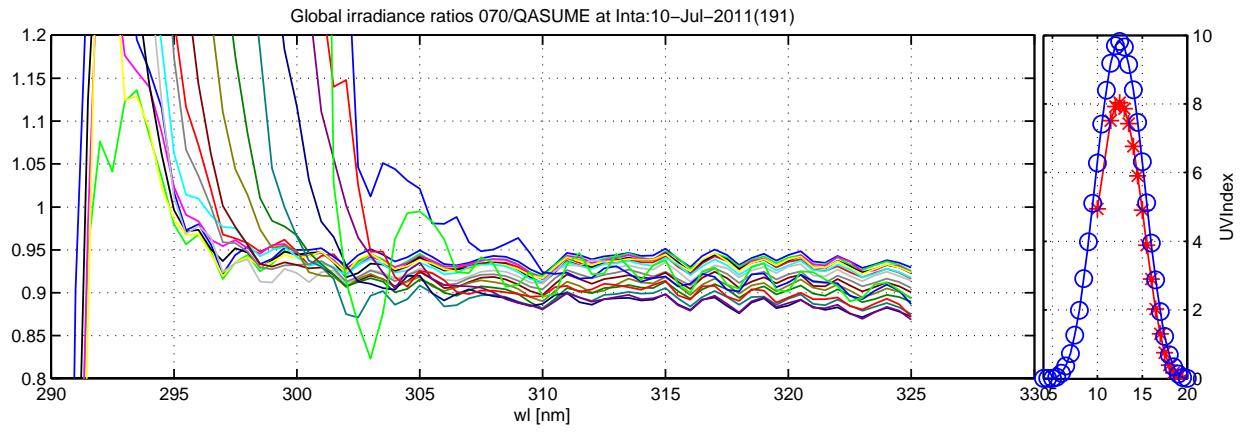
Global irradiance ratios 070/QASUME at Inta:07-Jul-2011(188)

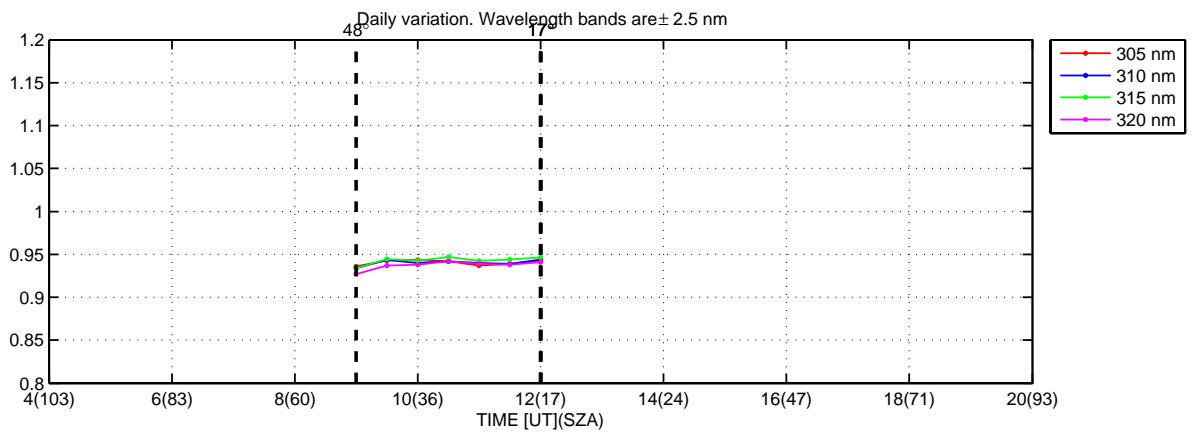
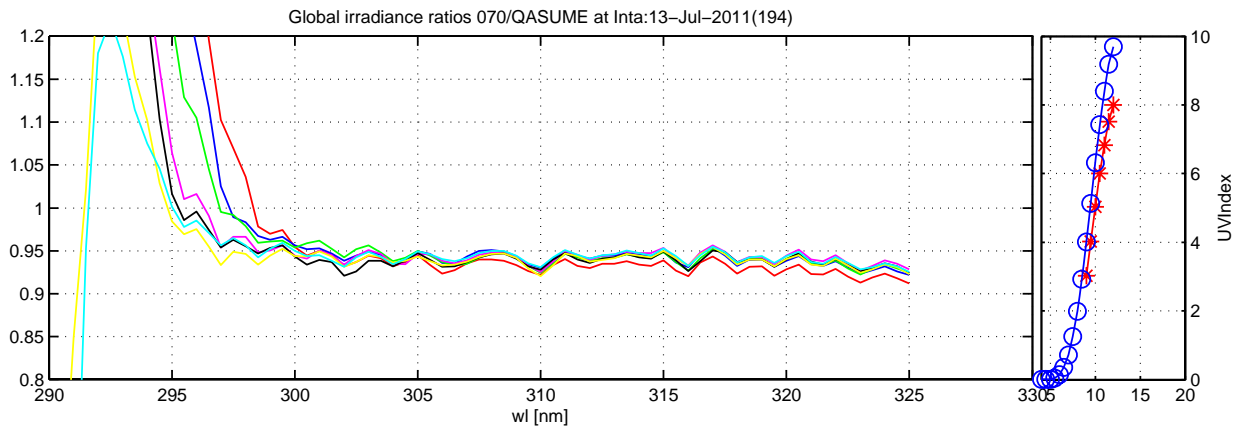
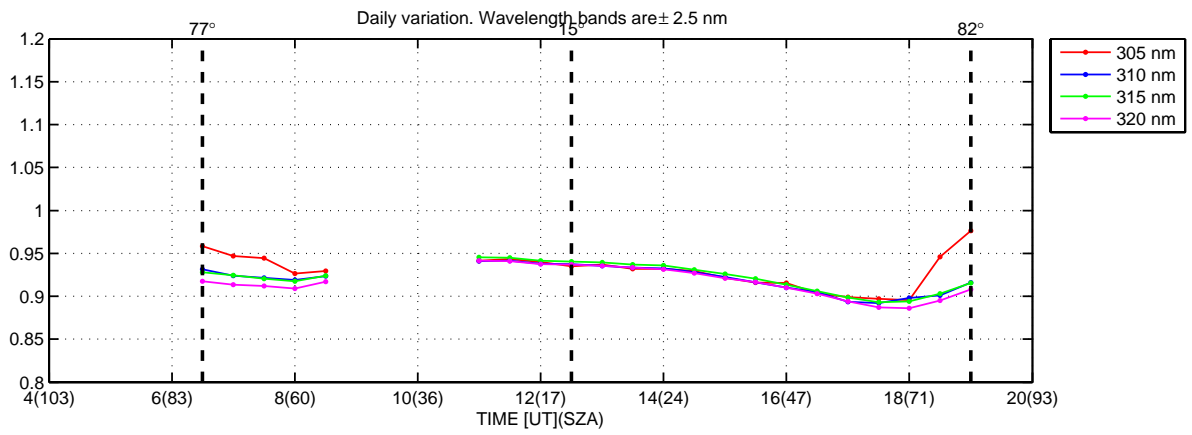
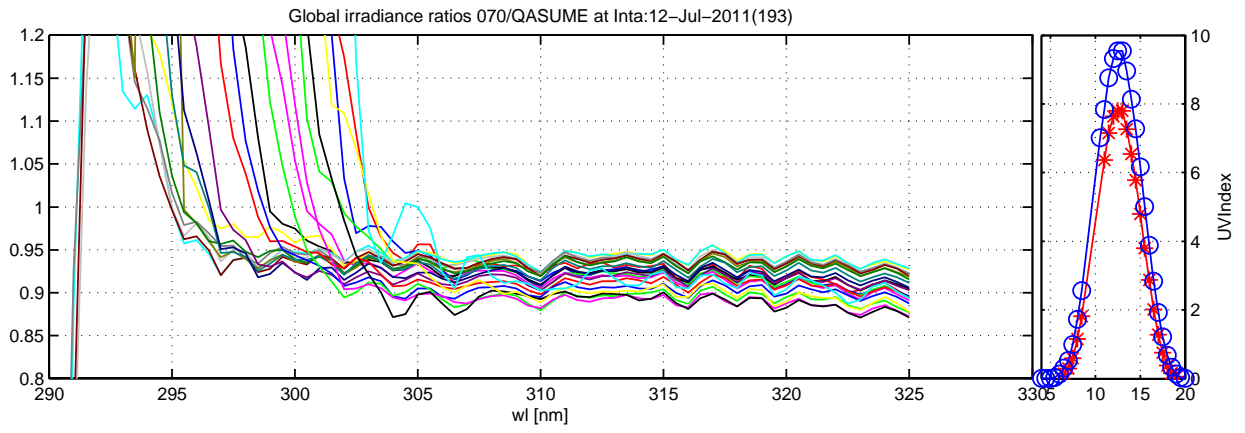


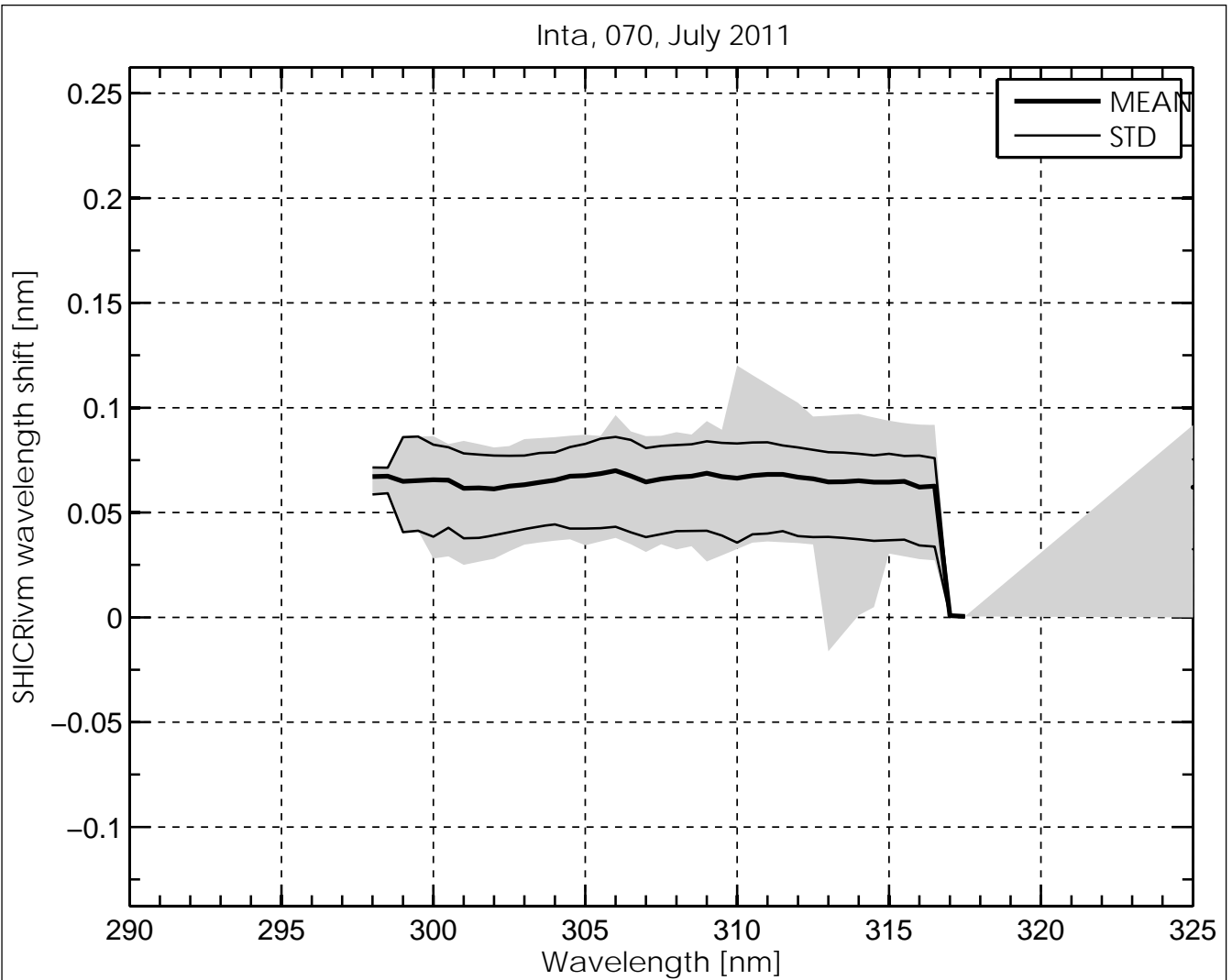
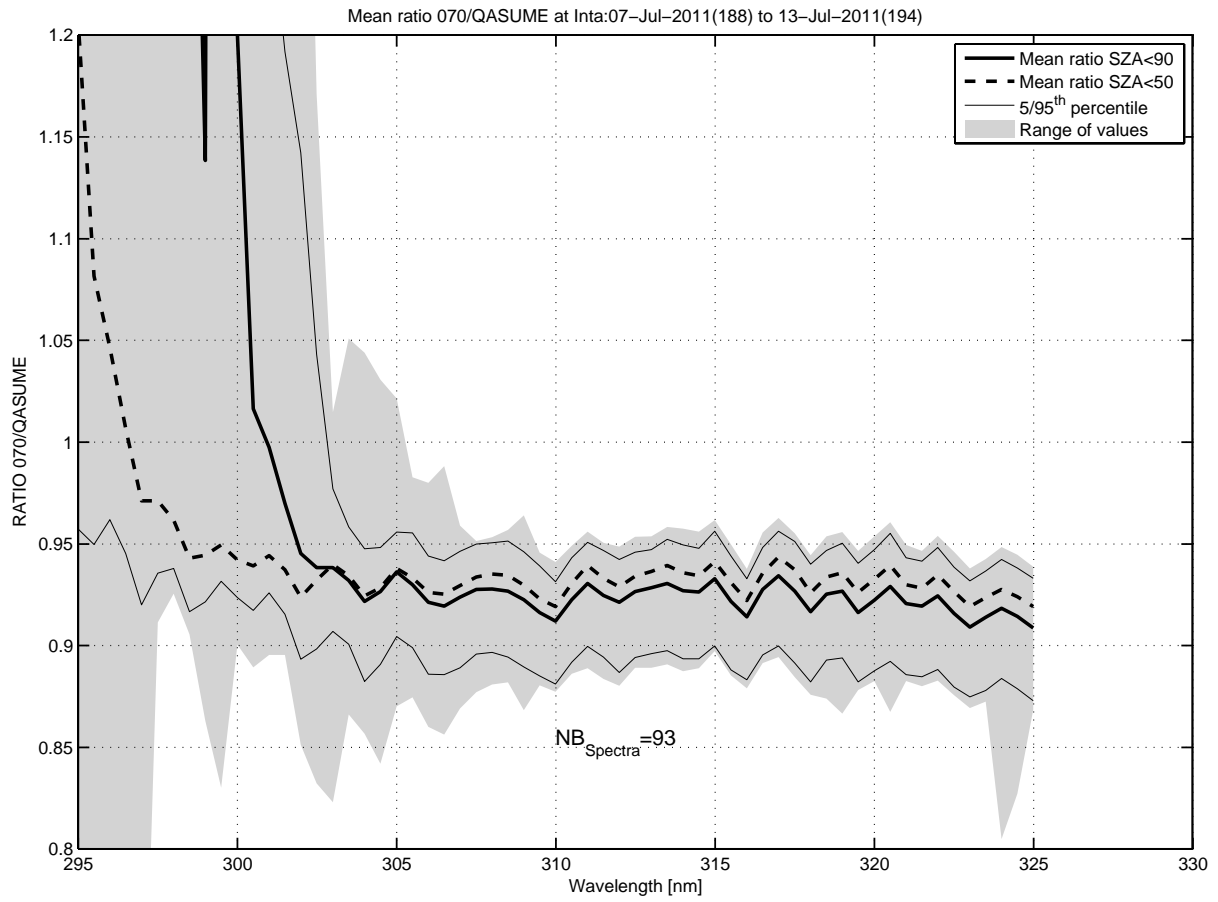
Daily variation. Wavelength bands are ± 2.5 nm



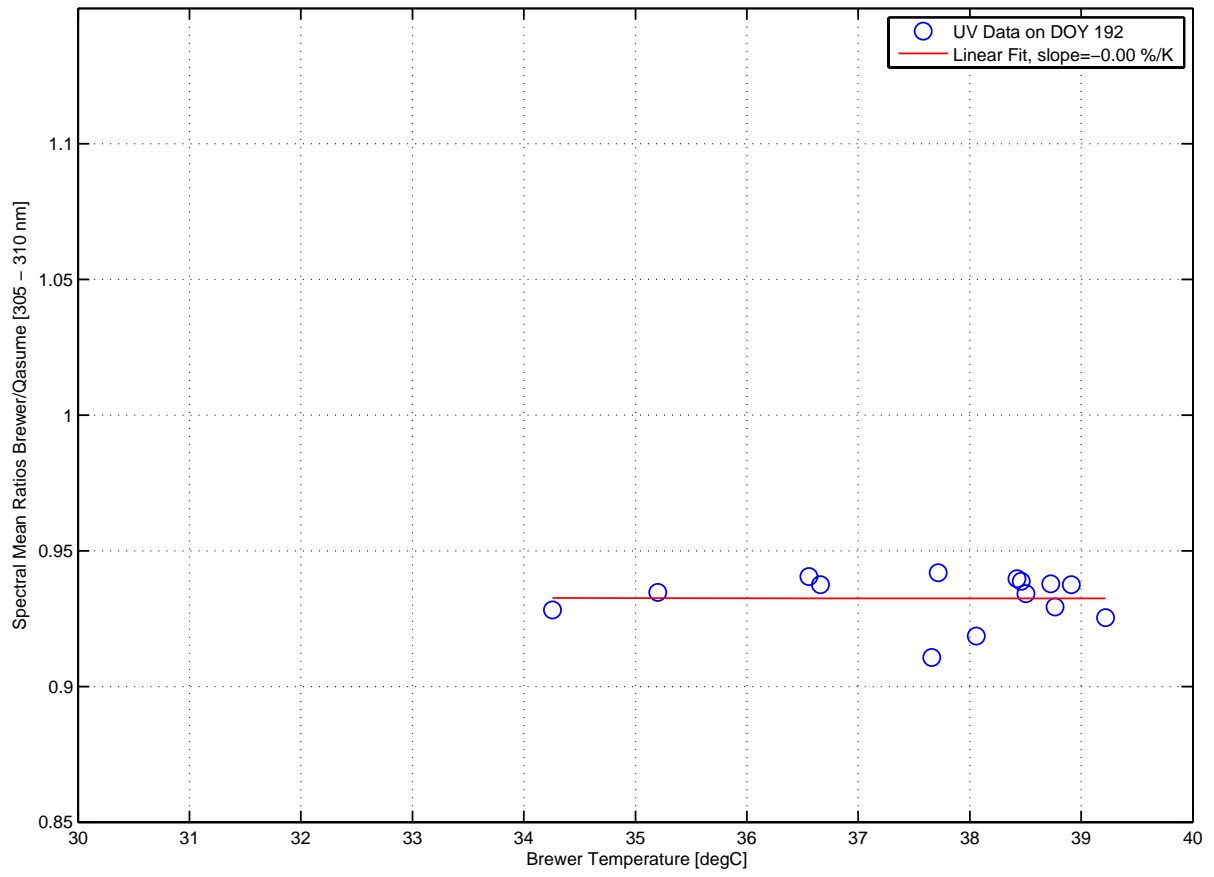




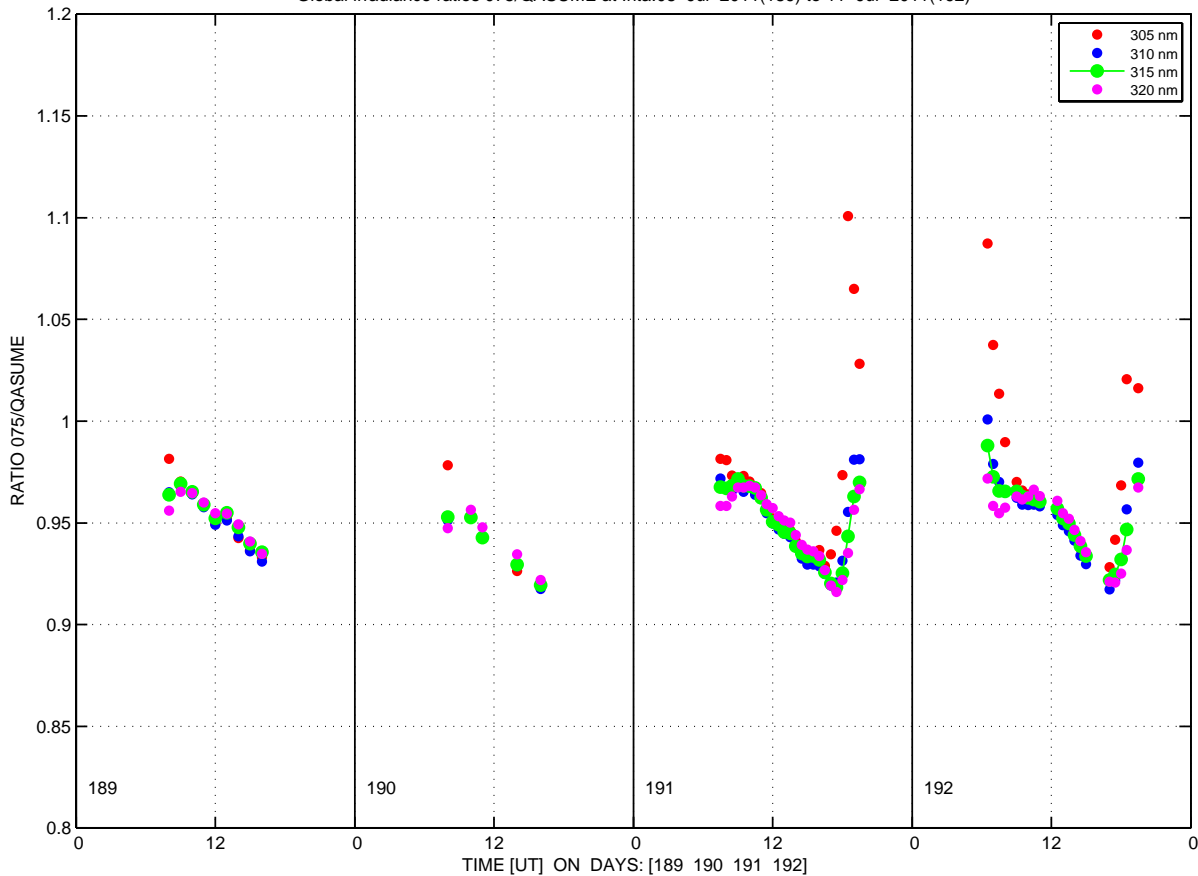




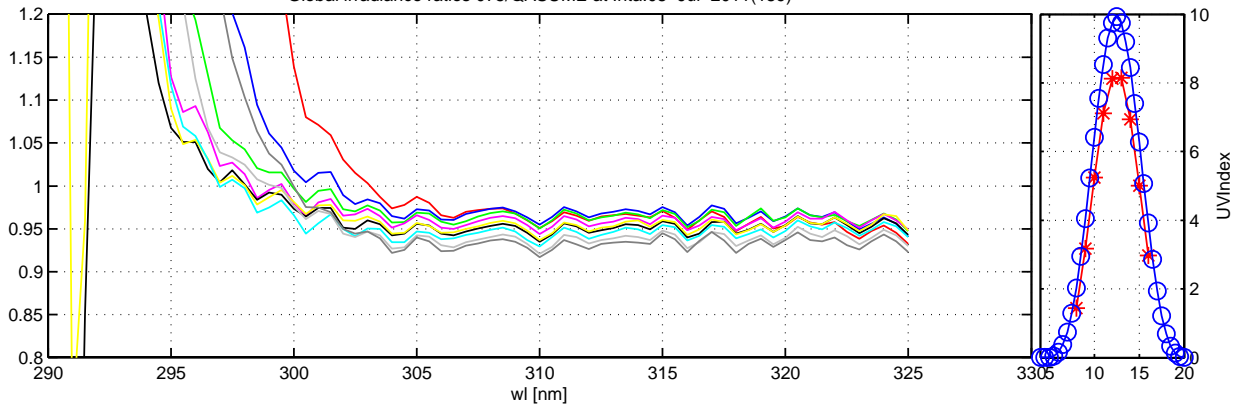
Temperature Dependence of Brewer #070, Inta, July 2011



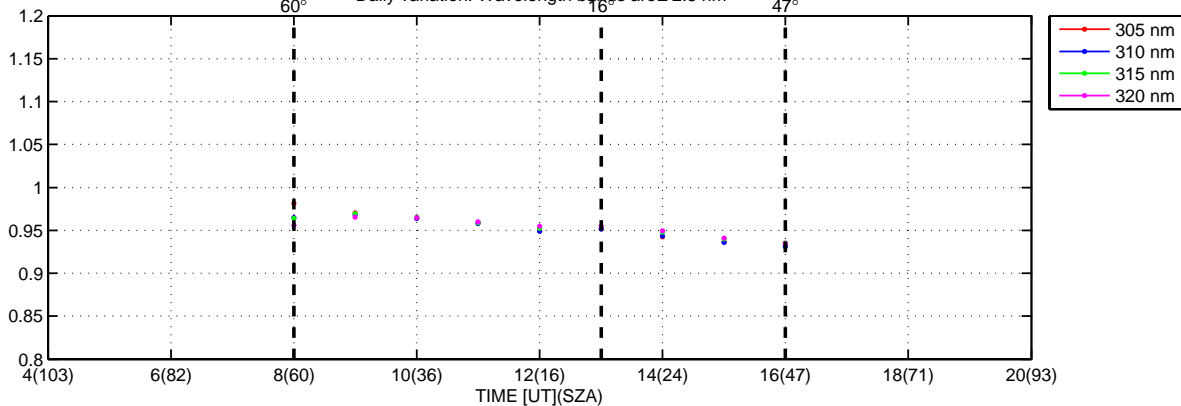
Global irradiance ratios 075/QASUME at Inta:08-Jul-2011(189) to 11-Jul-2011(192)

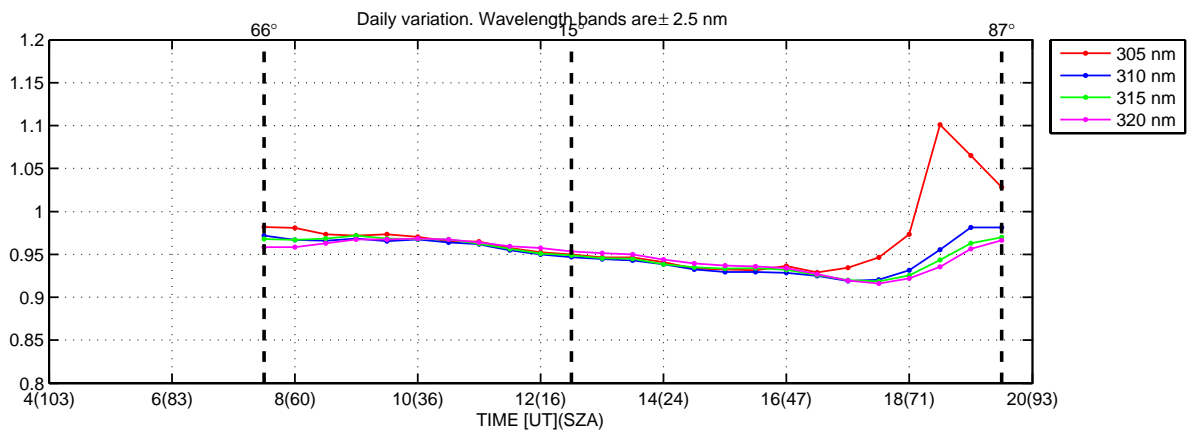
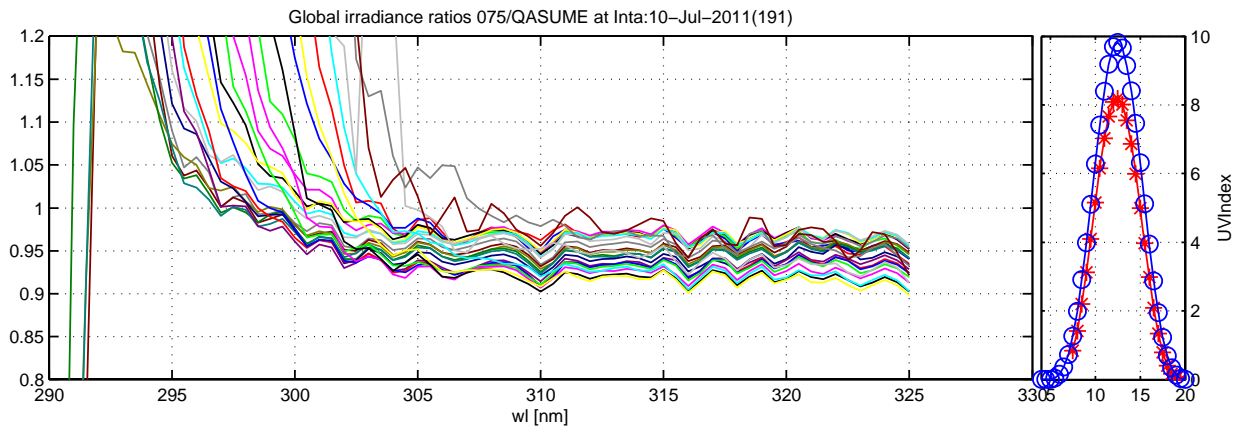
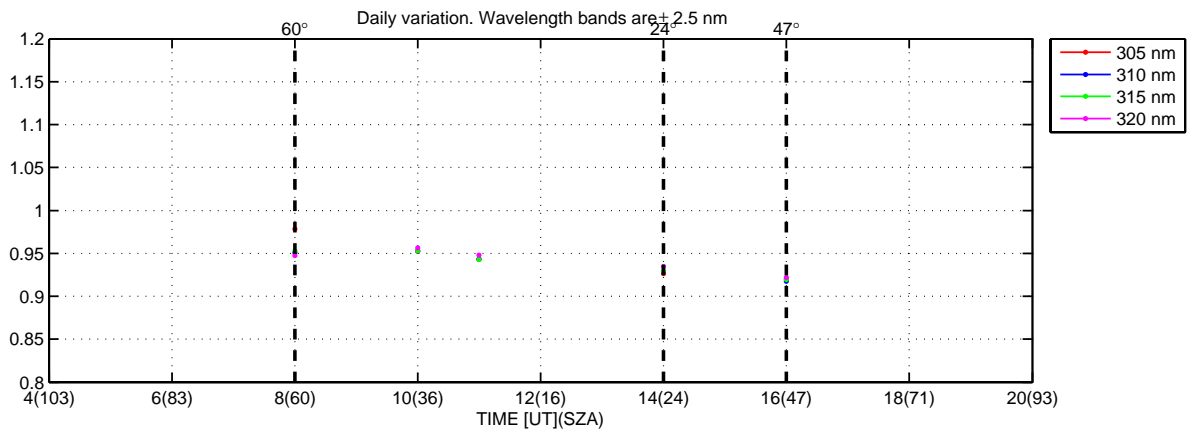
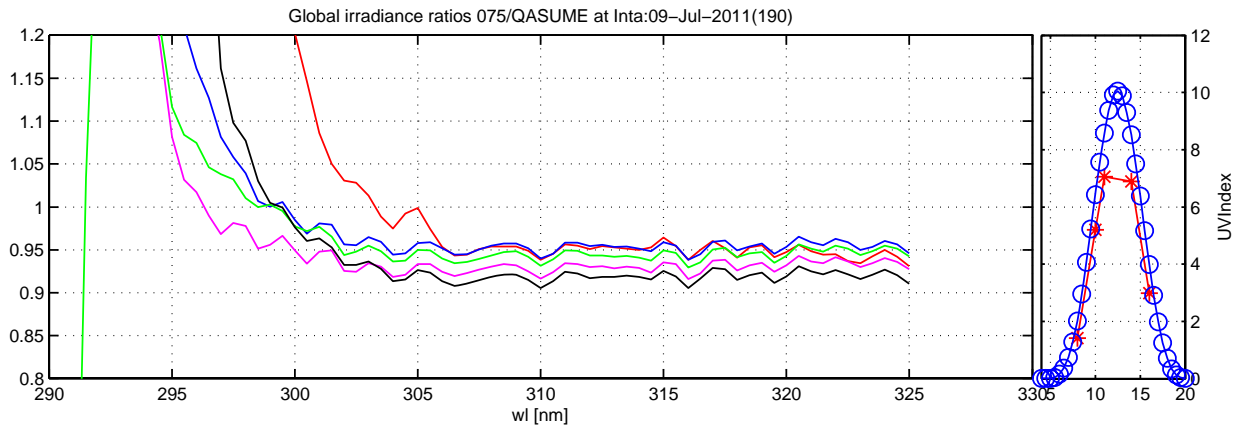


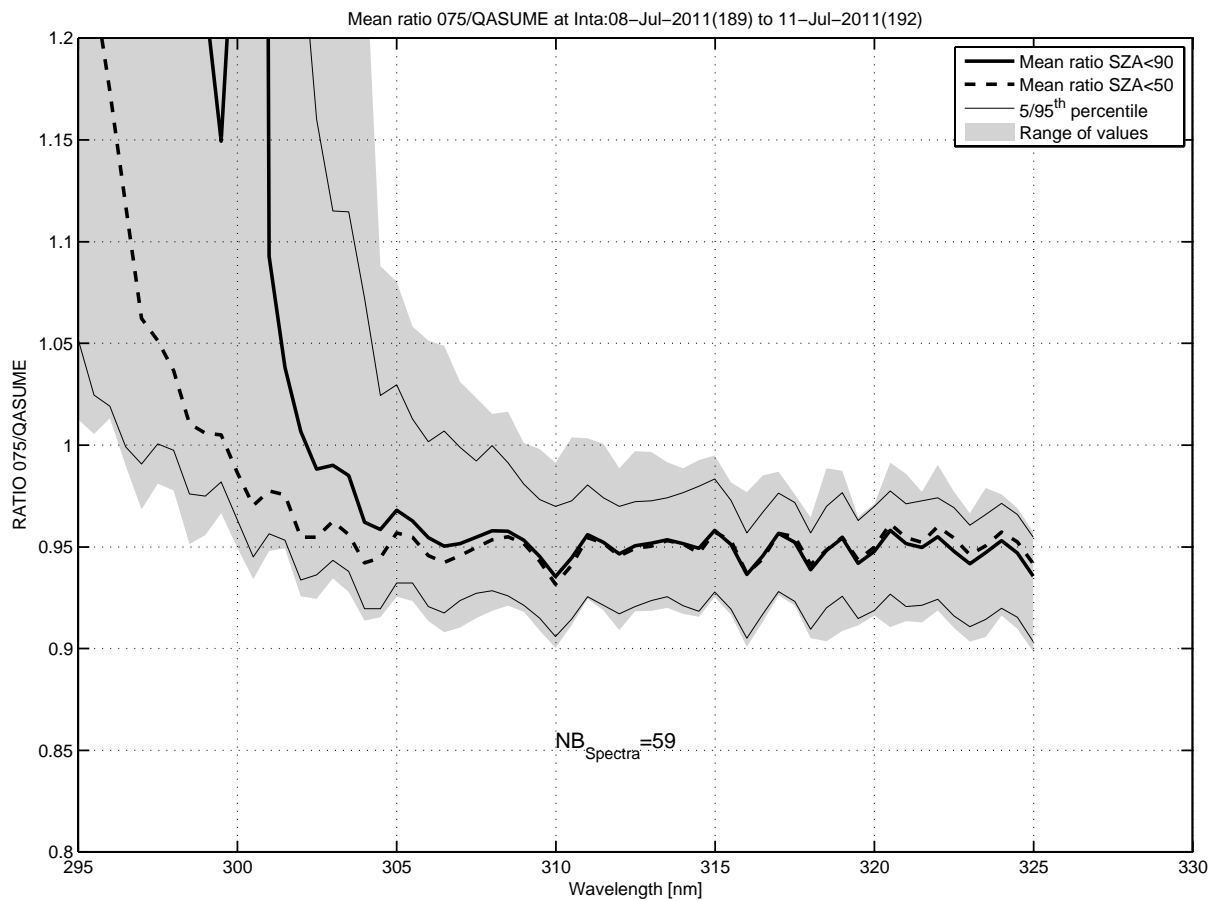
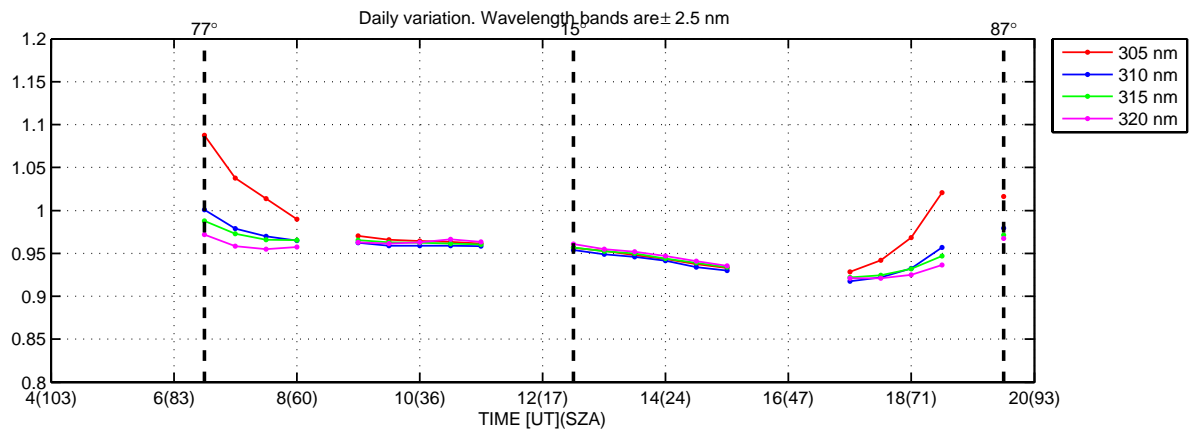
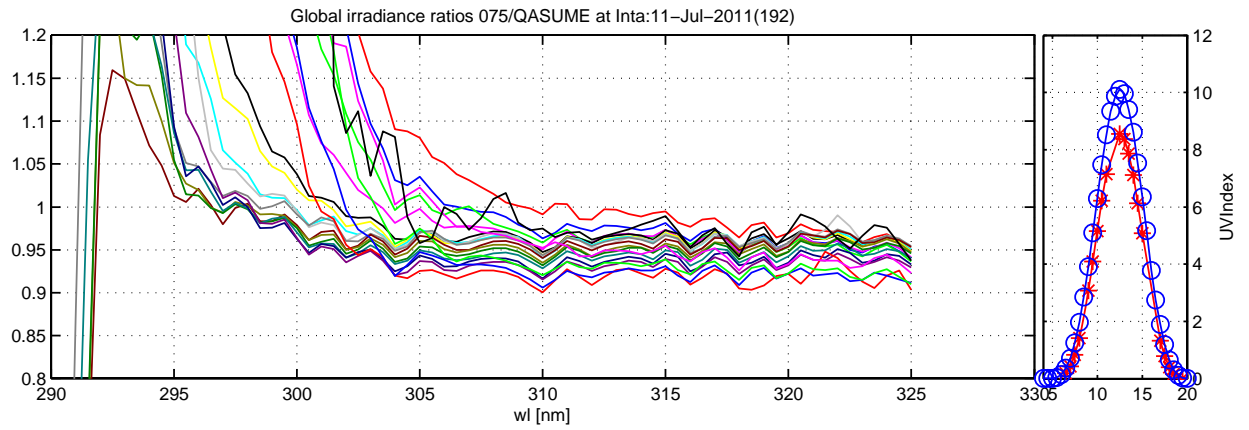
Global irradiance ratios 075/QASUME at Inta:08-Jul-2011(189)



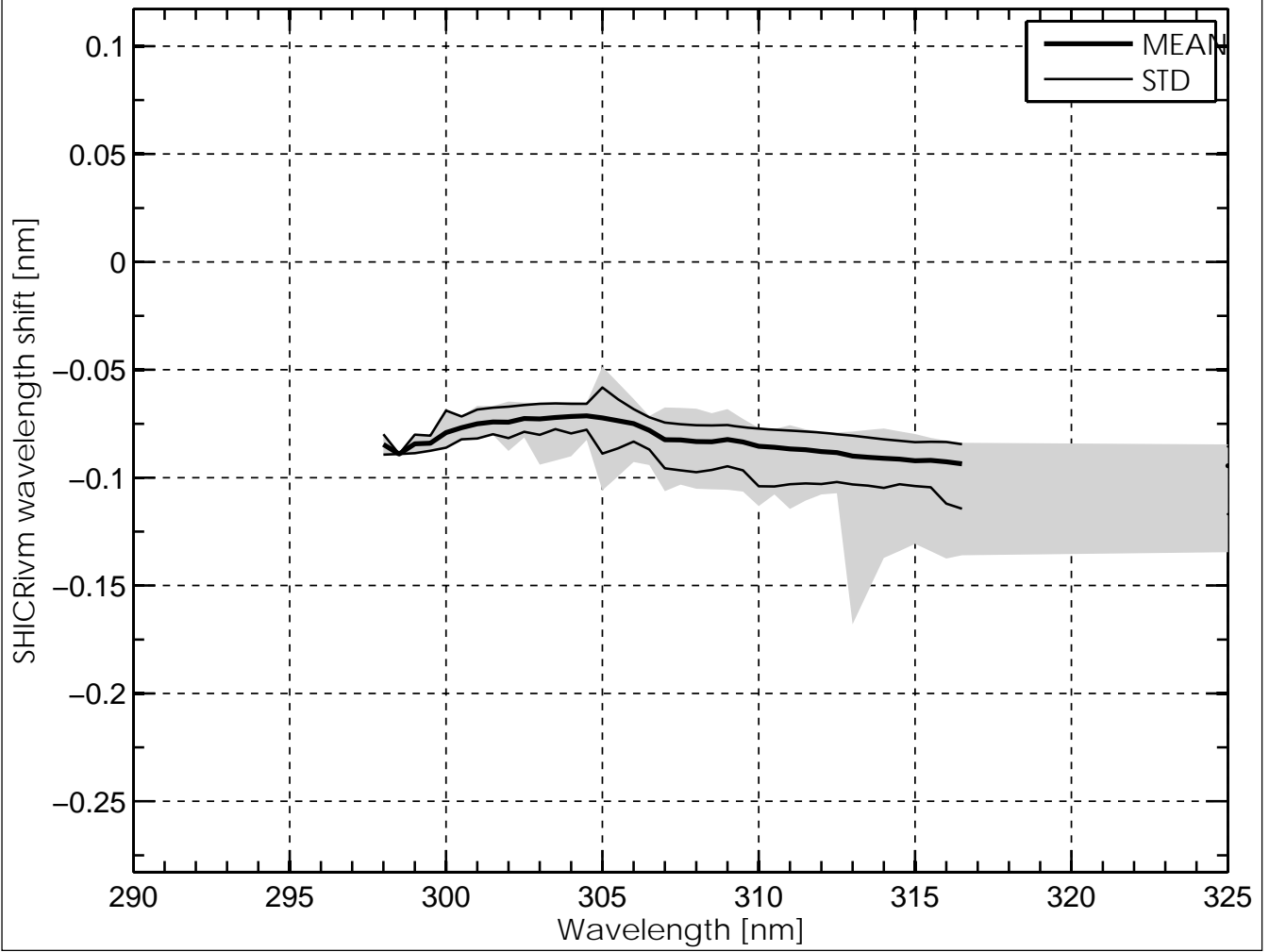
Daily variation. Wavelength bands are ± 2.5 nm



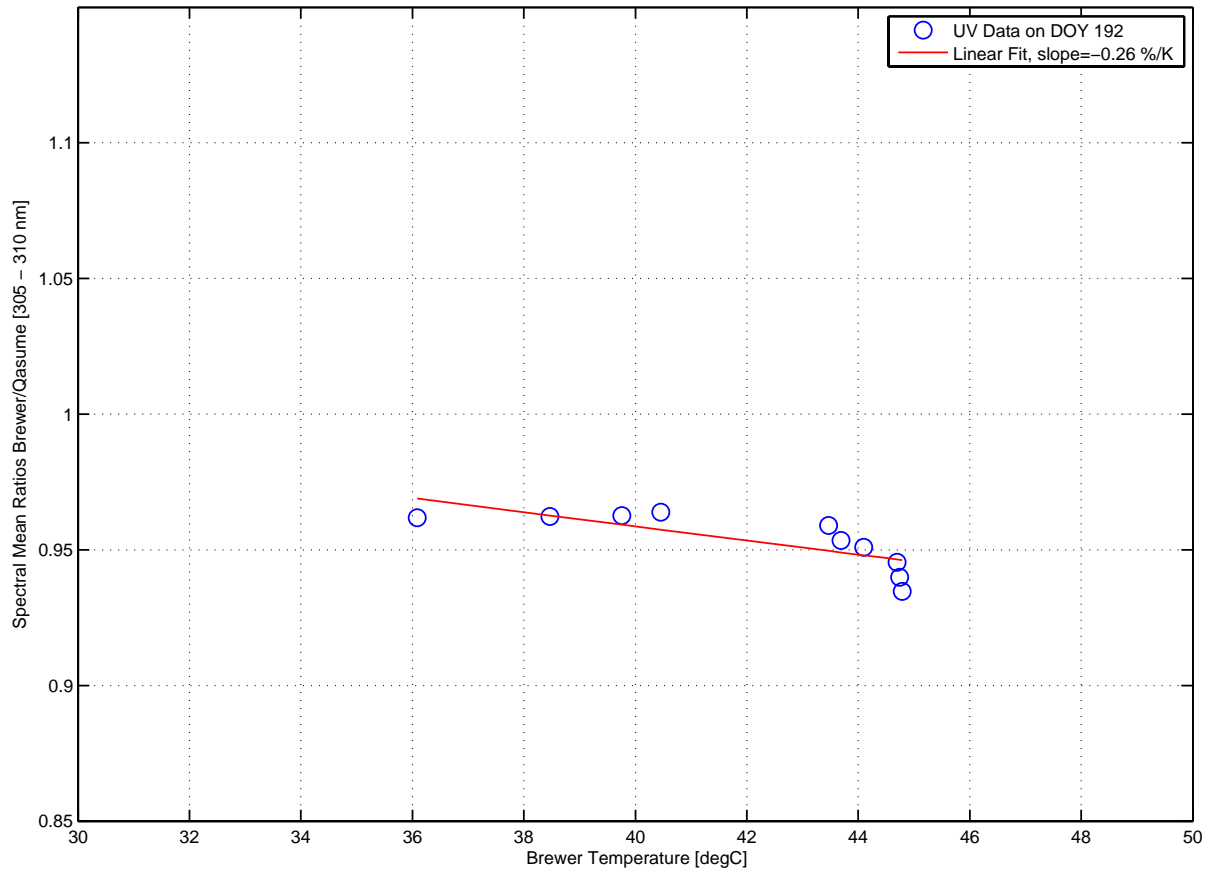




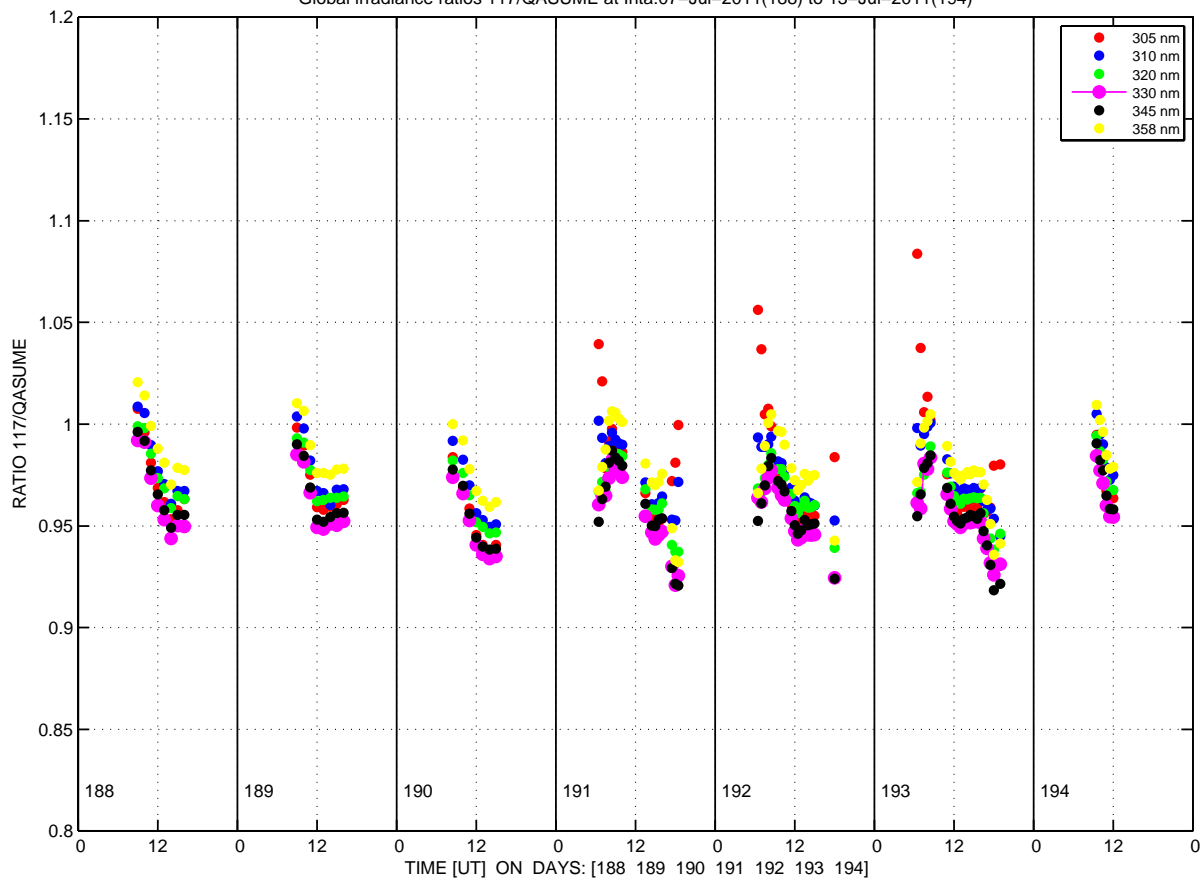
Intra, 075, July 2011



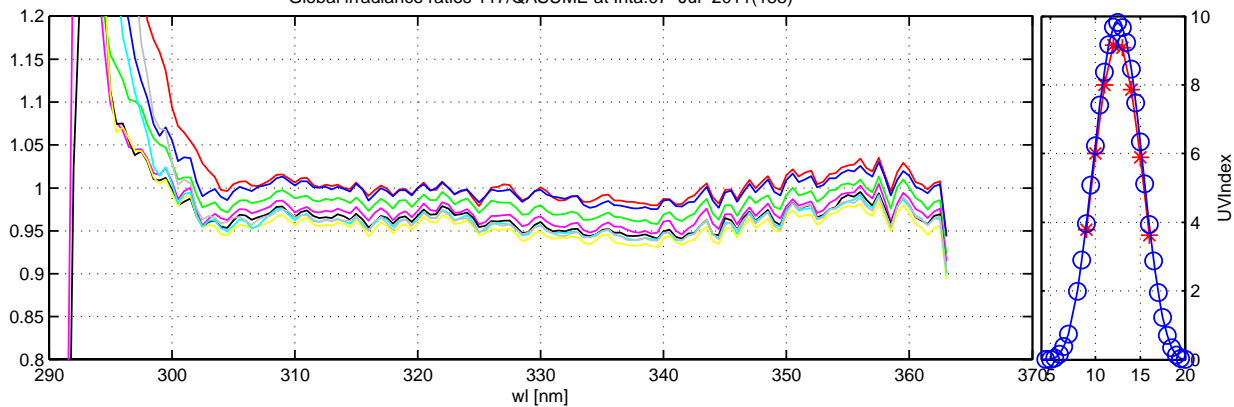
Temperature Dependence of Brewer #075, Intra, July 2011



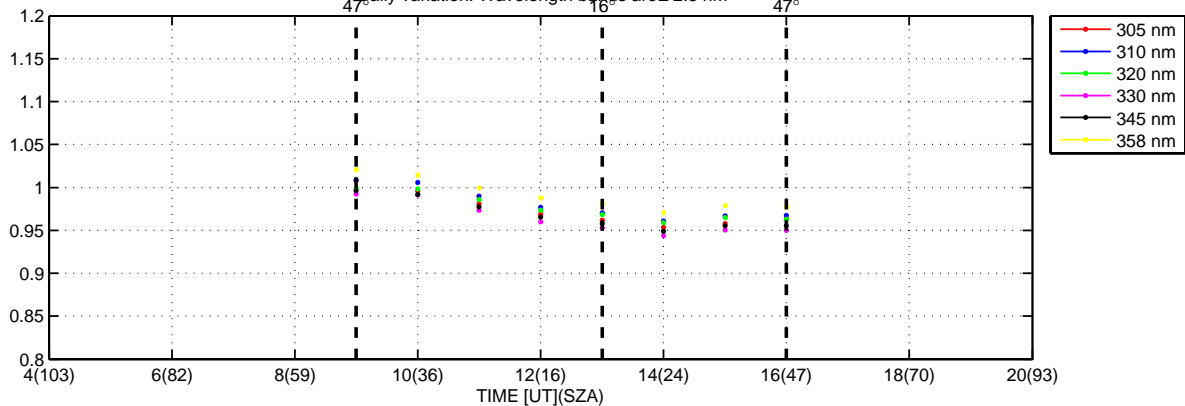
Global irradiance ratios 117/QASUME at Inta:07-Jul-2011(188) to 13-Jul-2011(194)

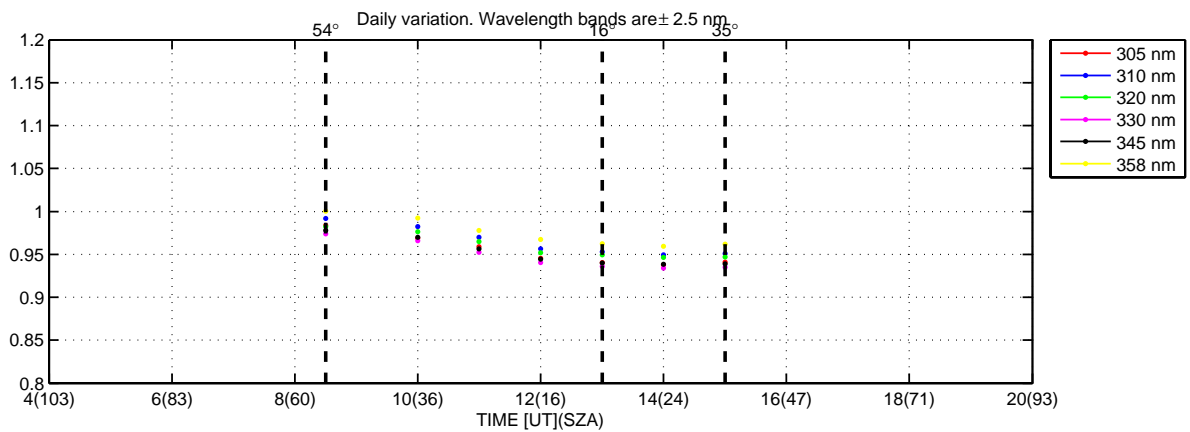
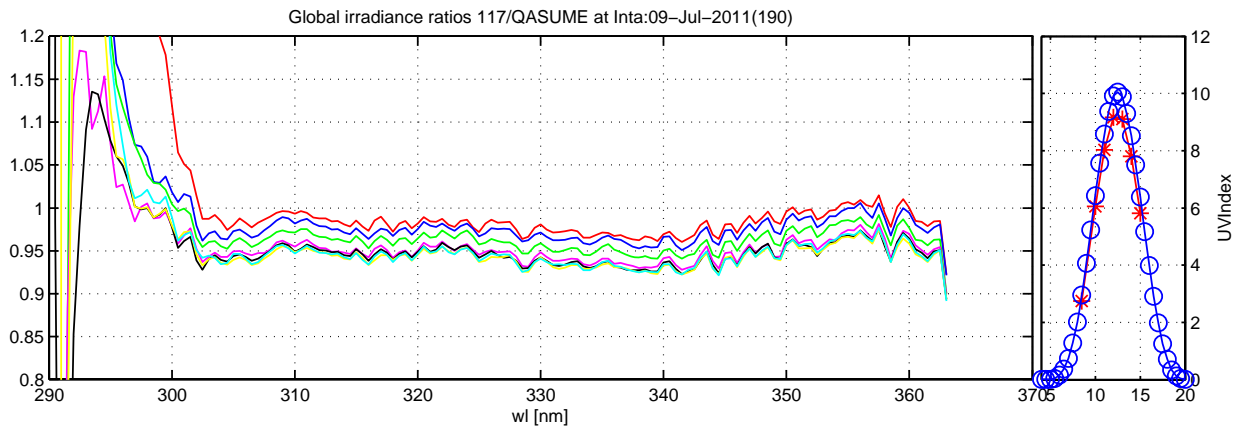
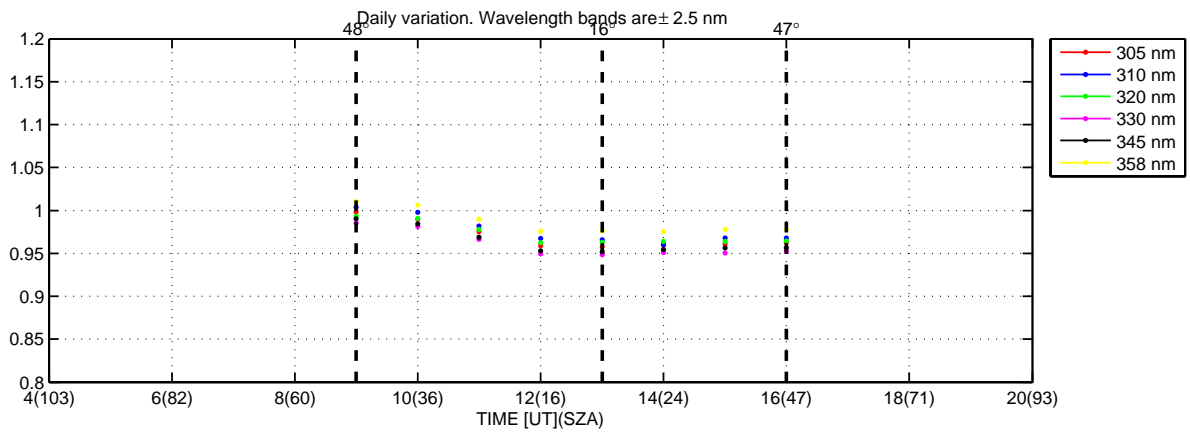
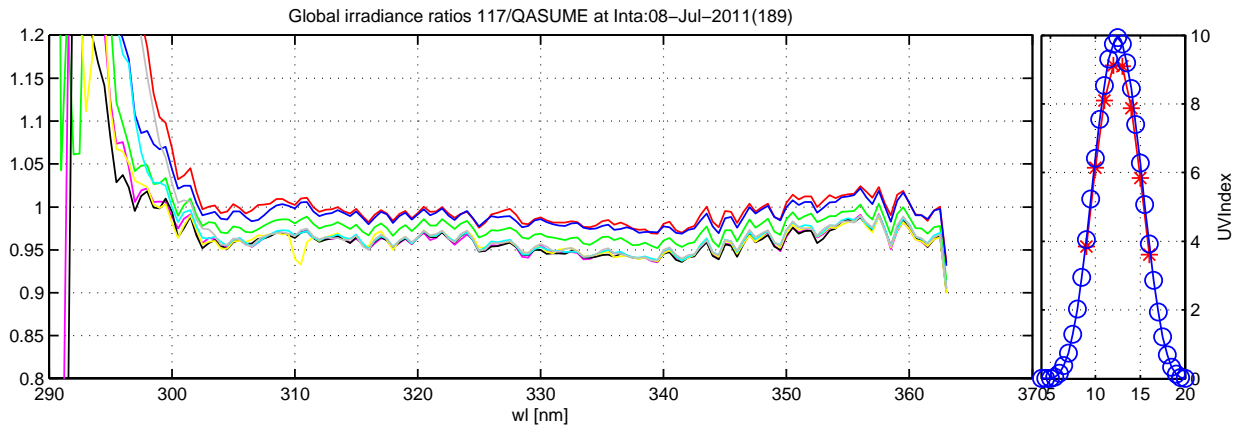


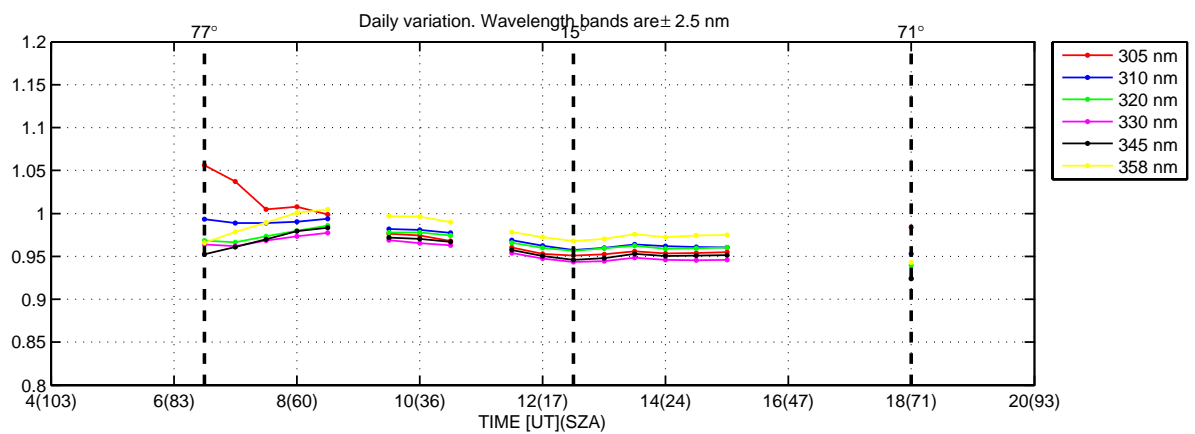
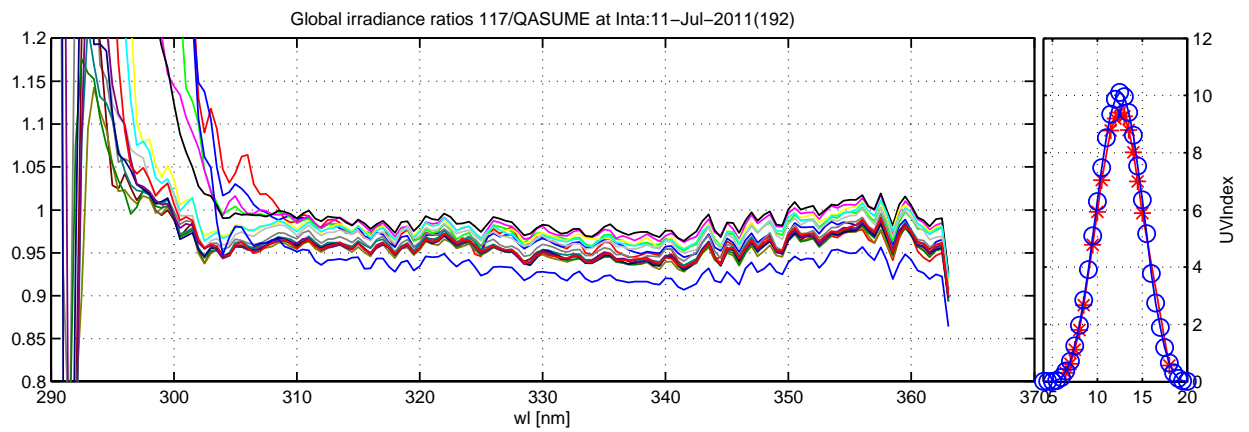
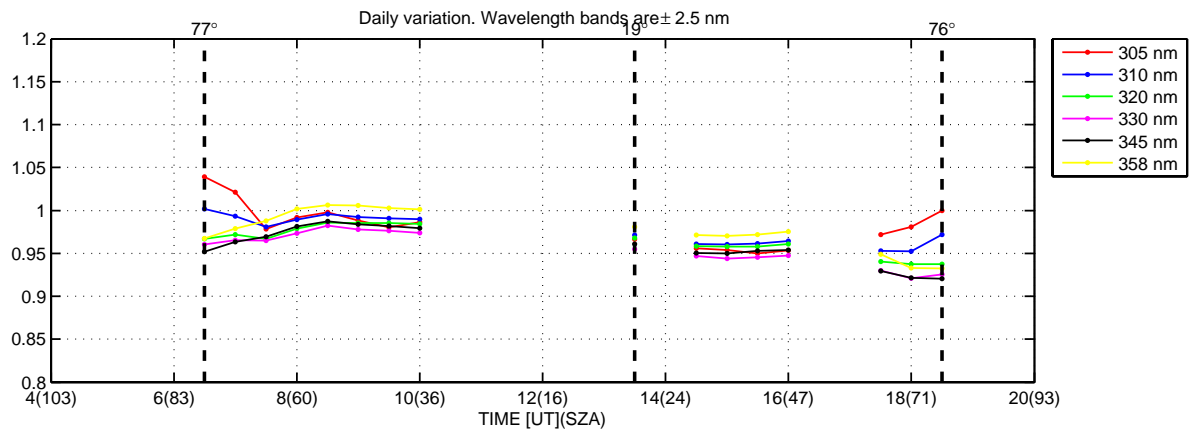
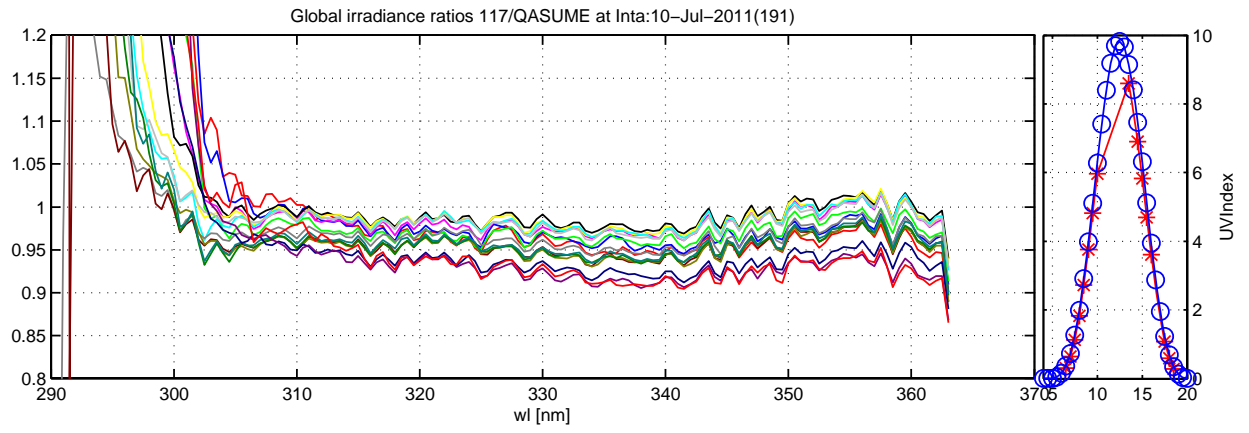
Global irradiance ratios 117/QASUME at Inta:07-Jul-2011(188)

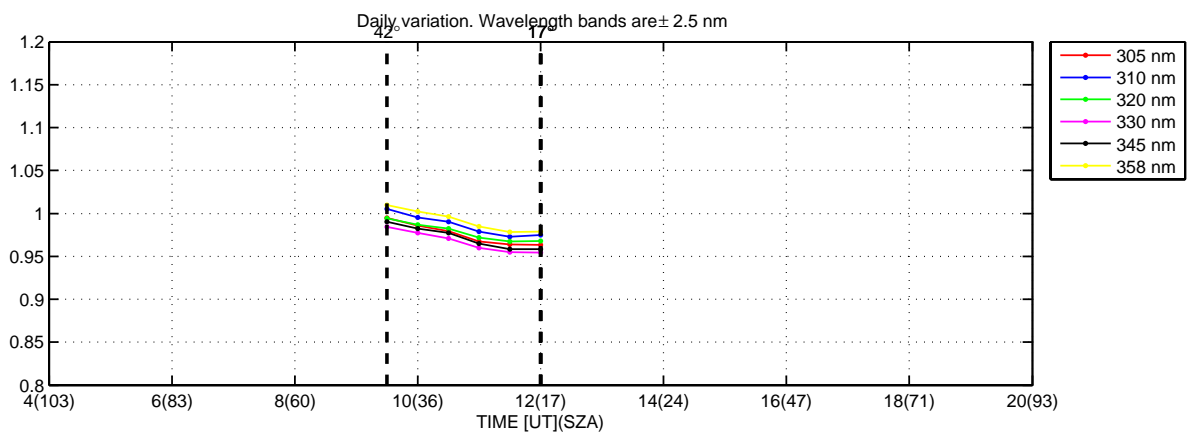
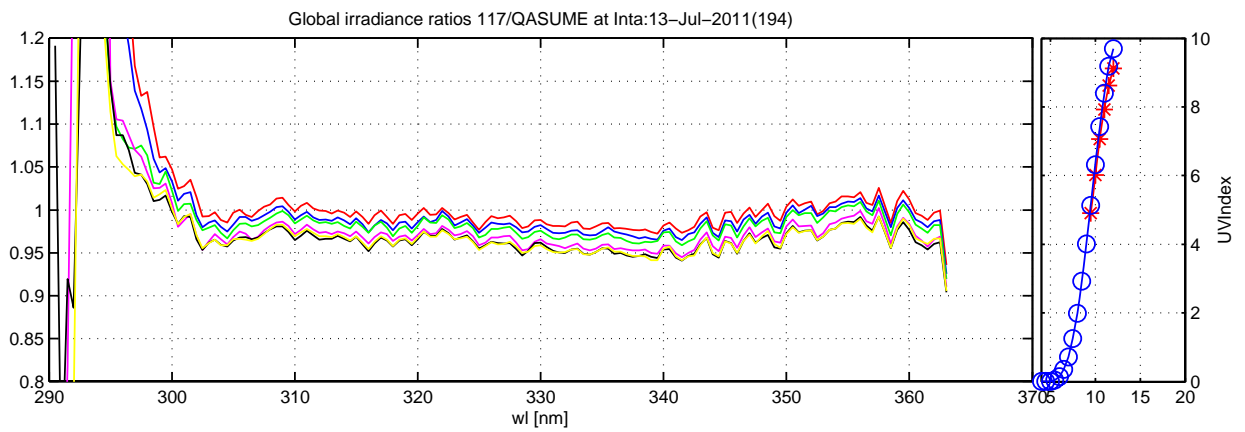
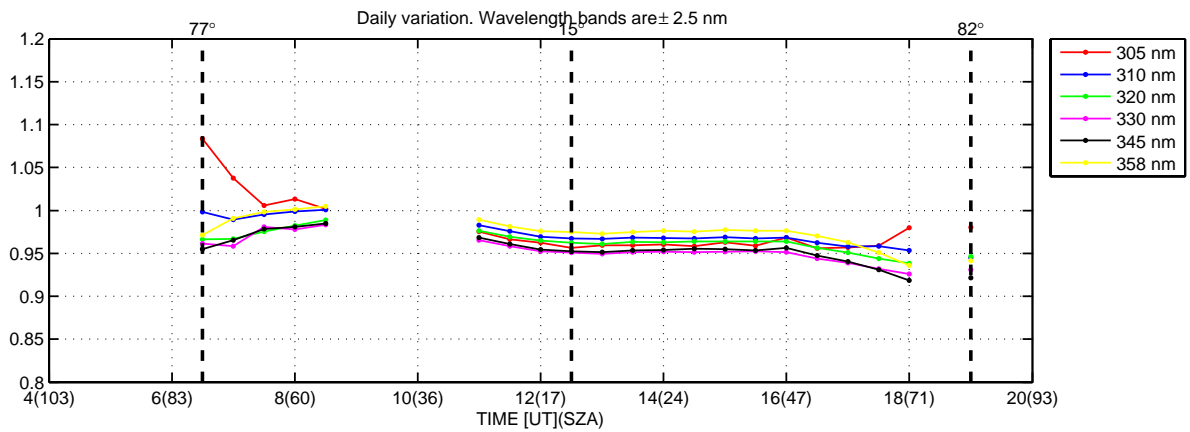
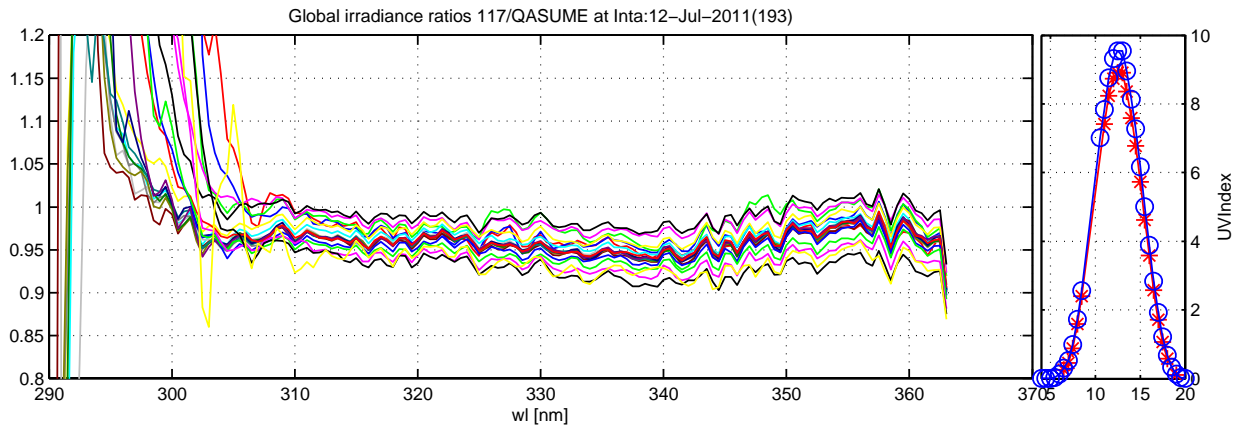


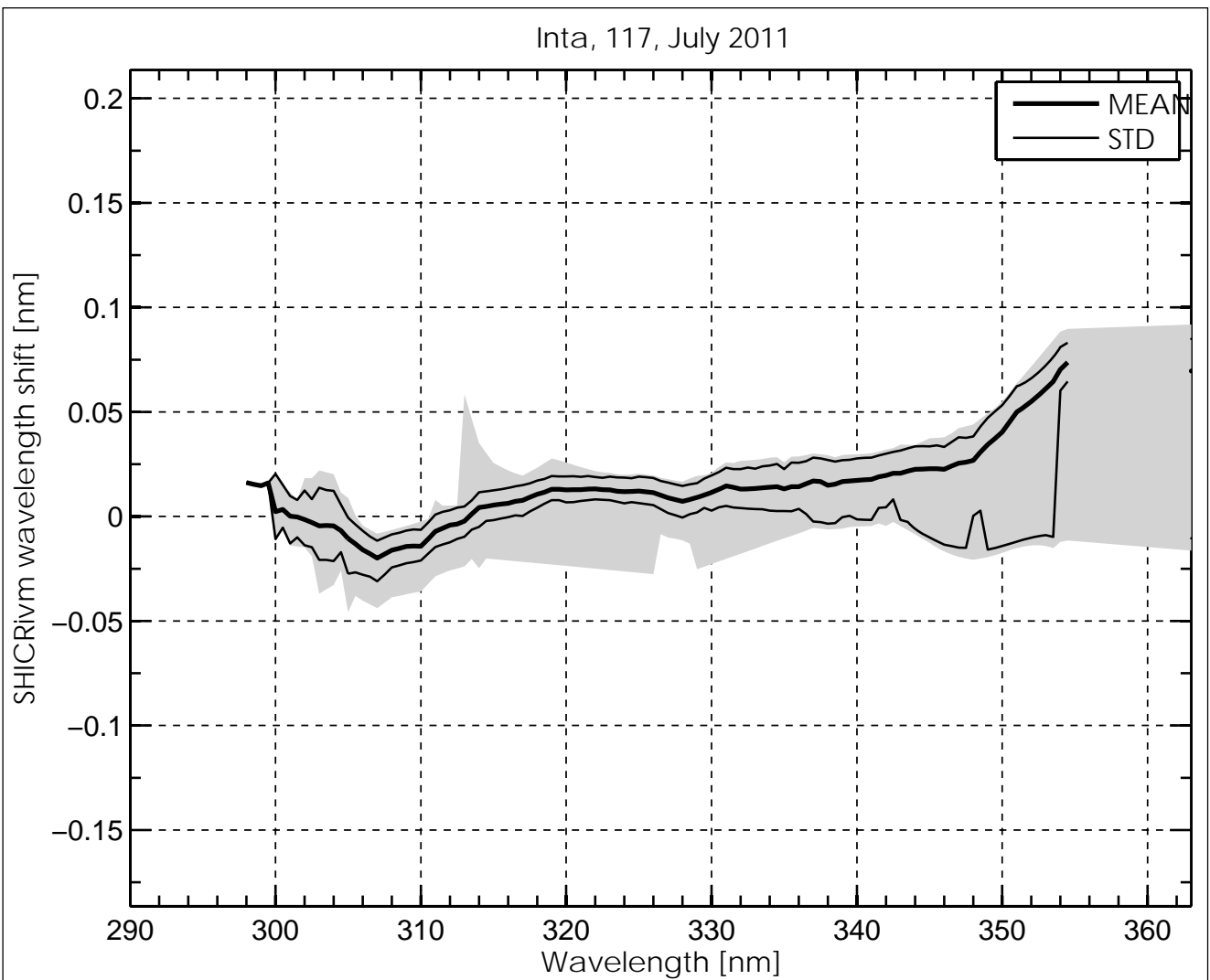
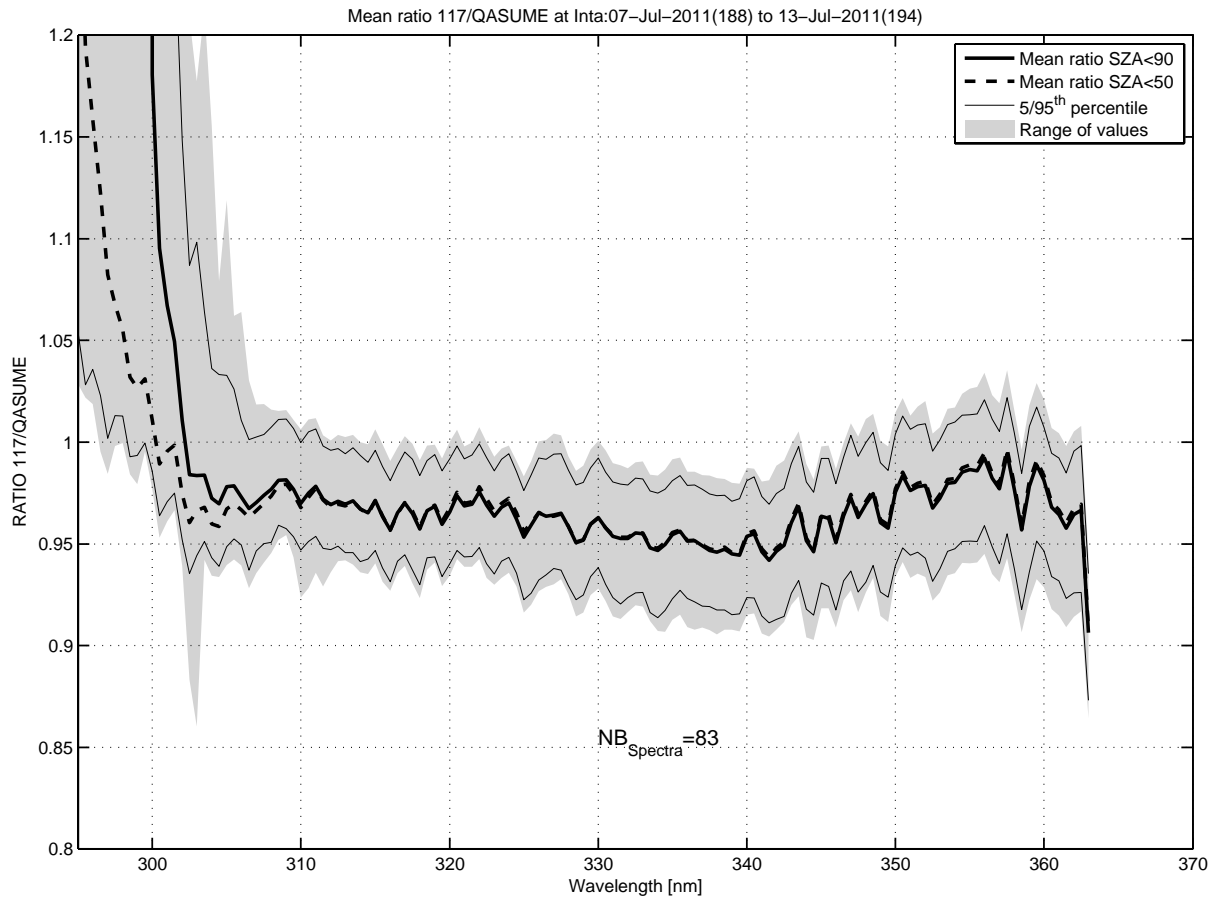
Daily variation. Wavelength bands are ± 2.5 nm



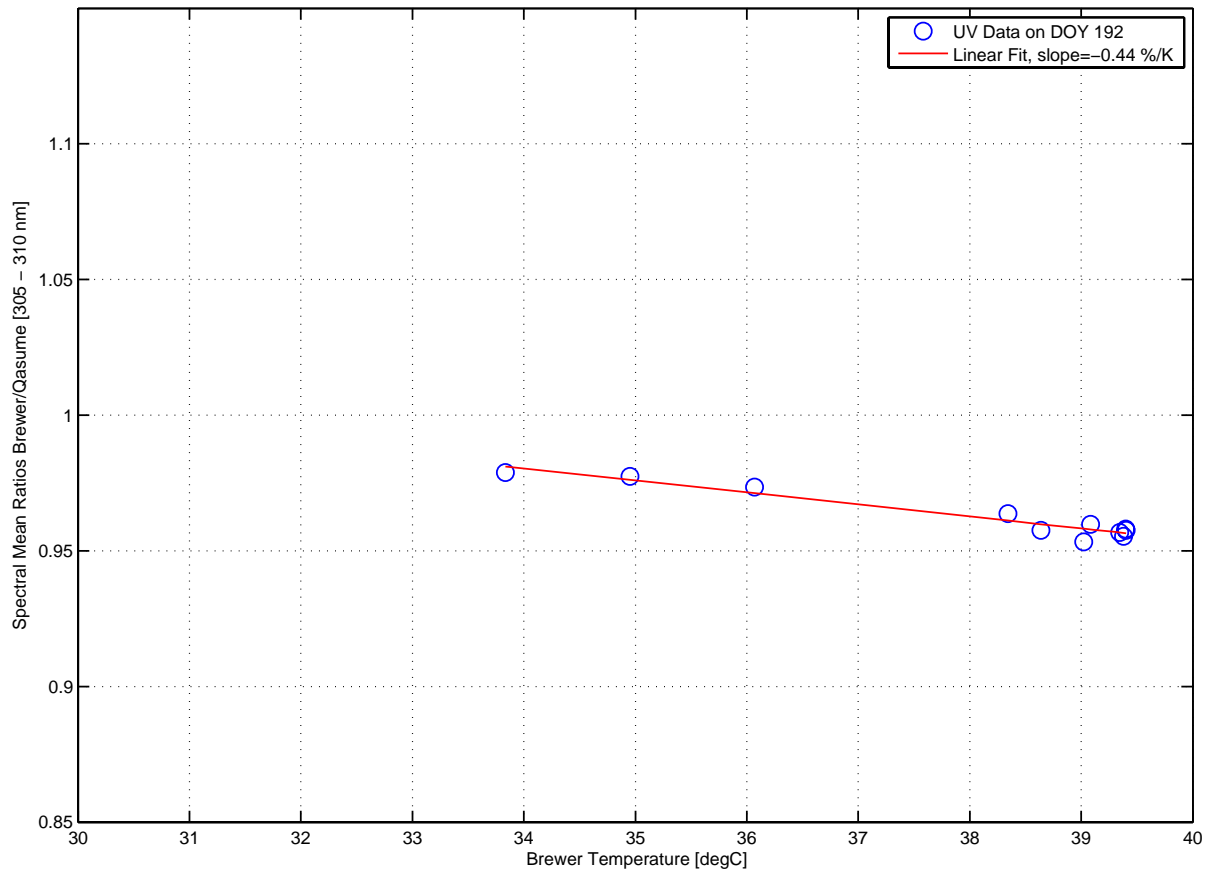




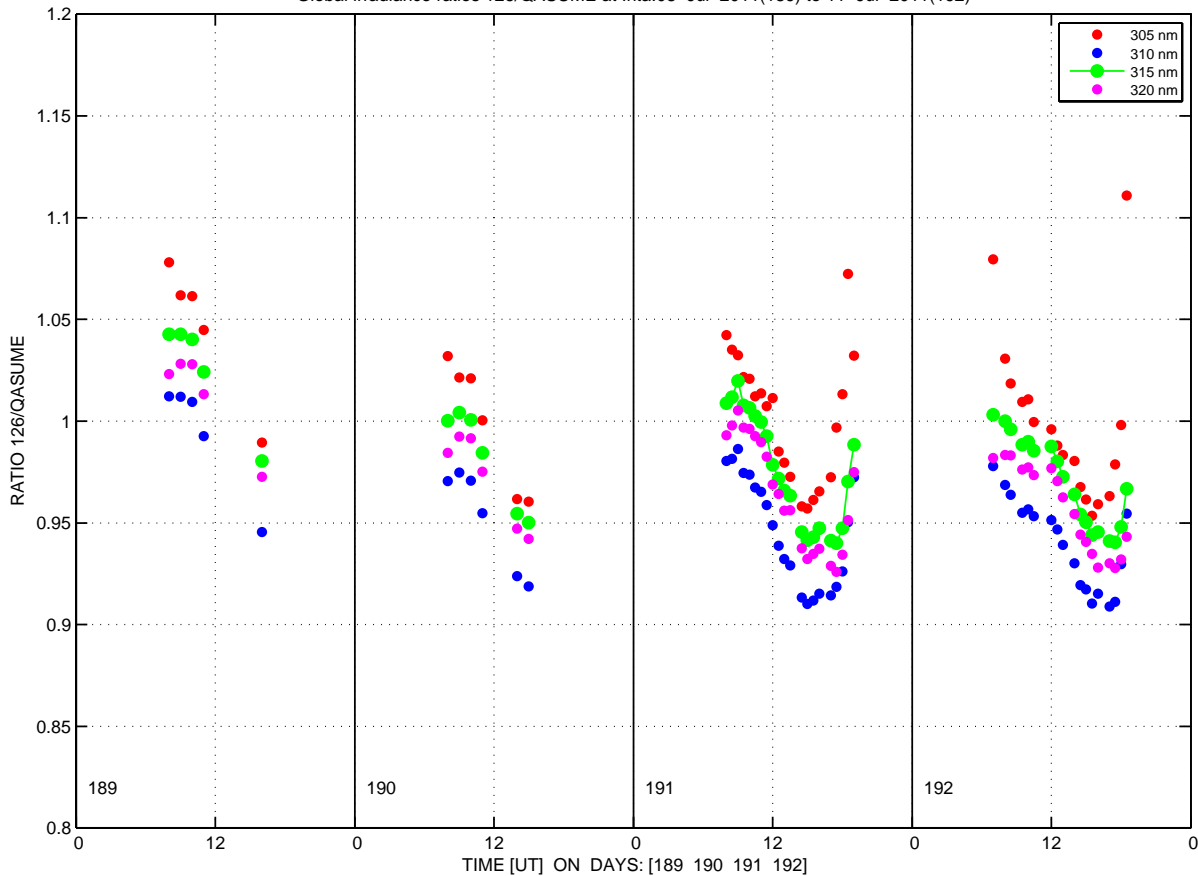




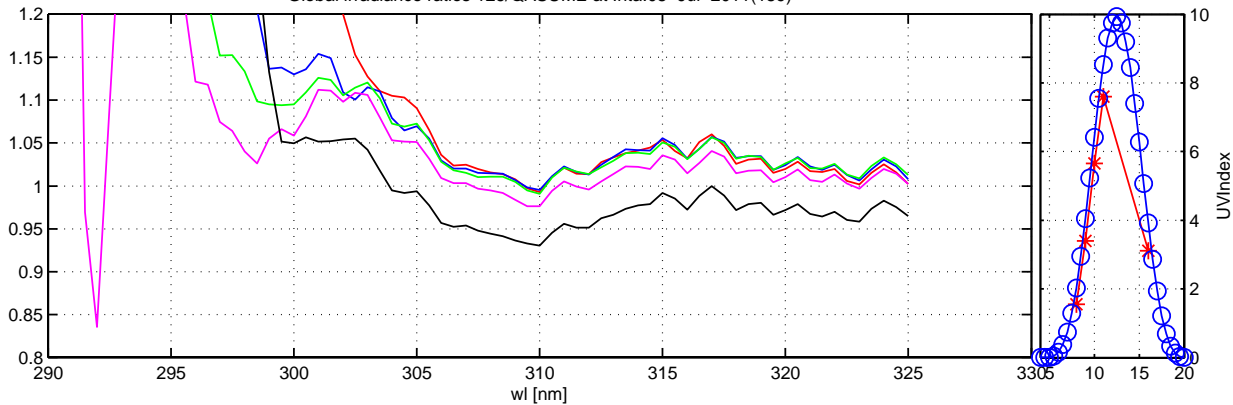
Temperature Dependence of Brewer #117, Intra, July 2011



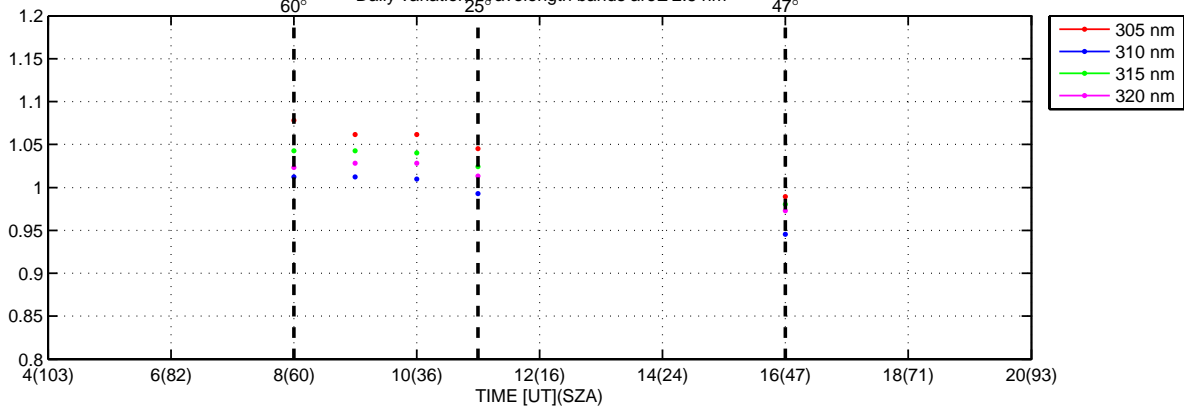
Global irradiance ratios 126/QASUME at Inta:08-Jul-2011(189) to 11-Jul-2011(192)

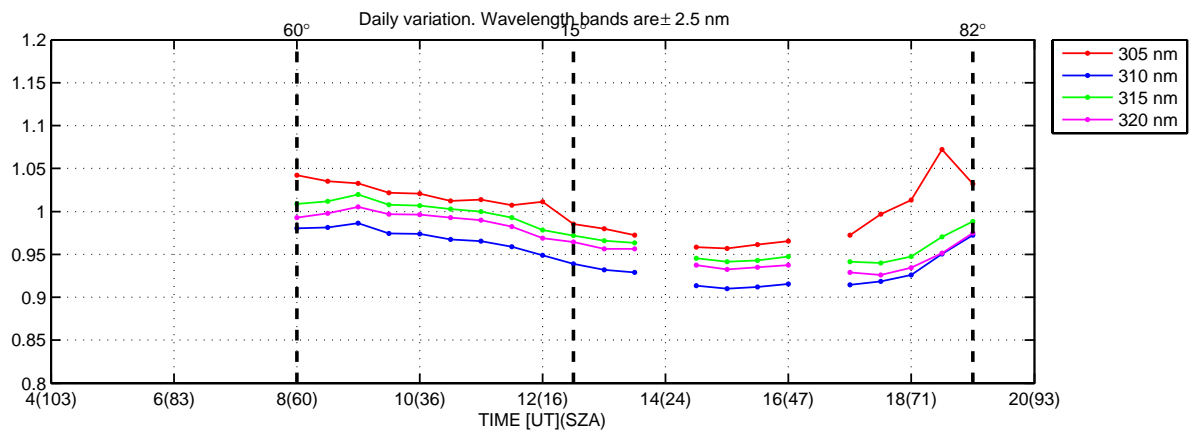
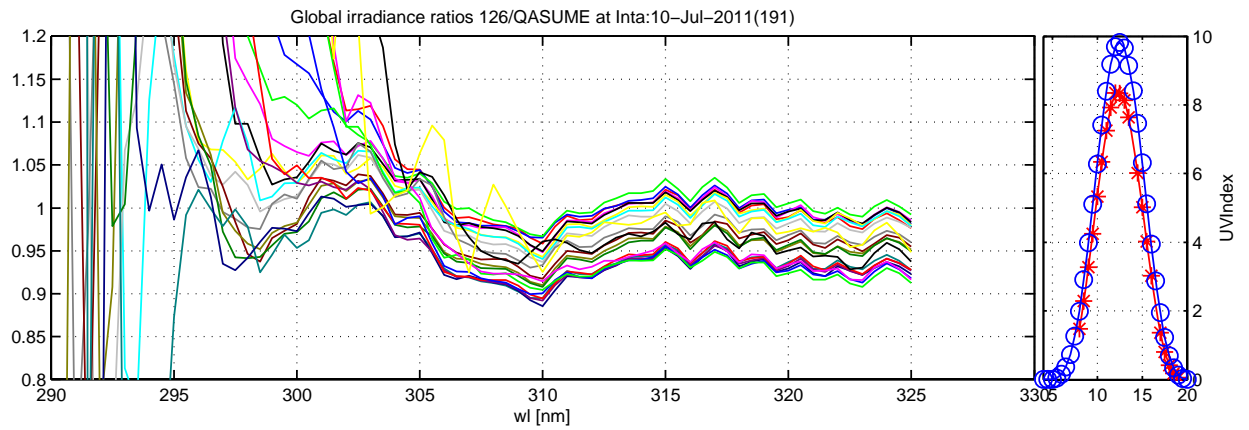
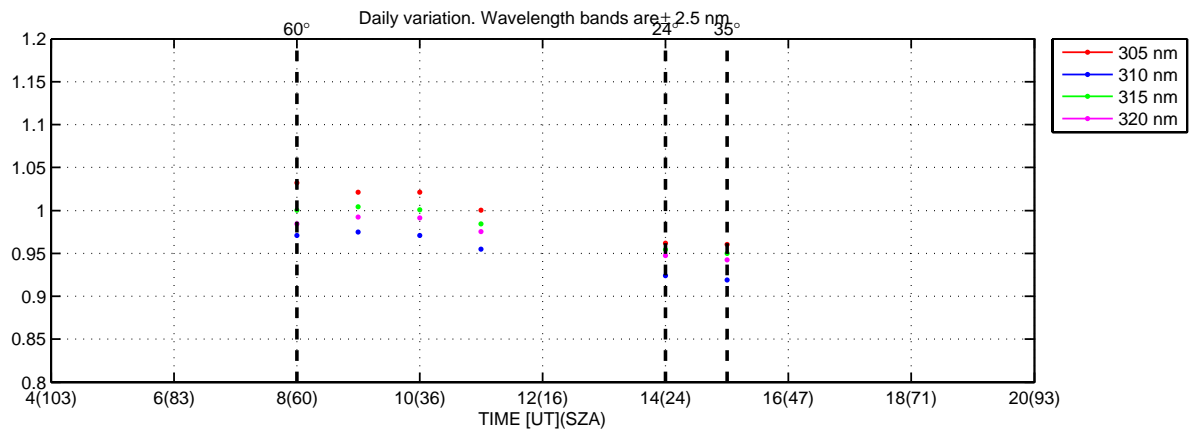
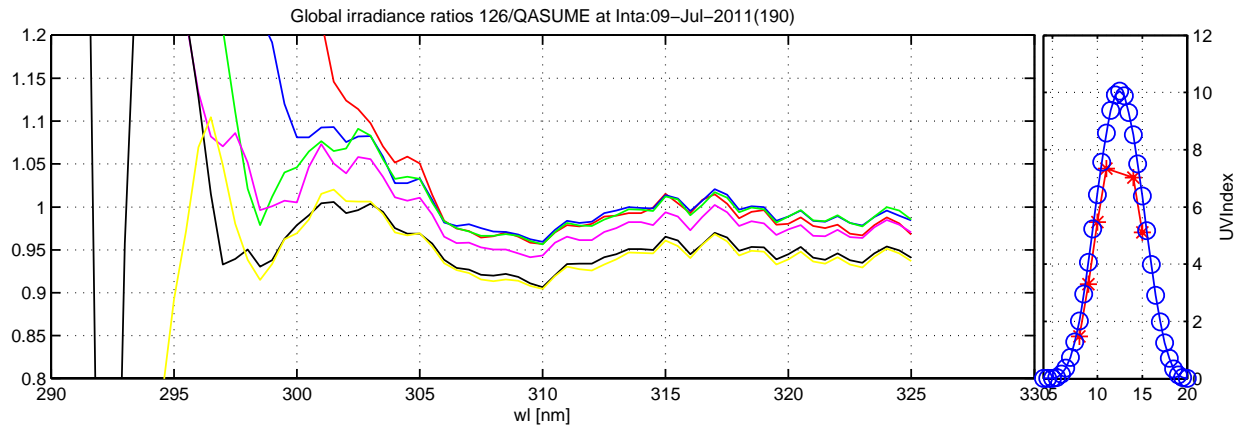


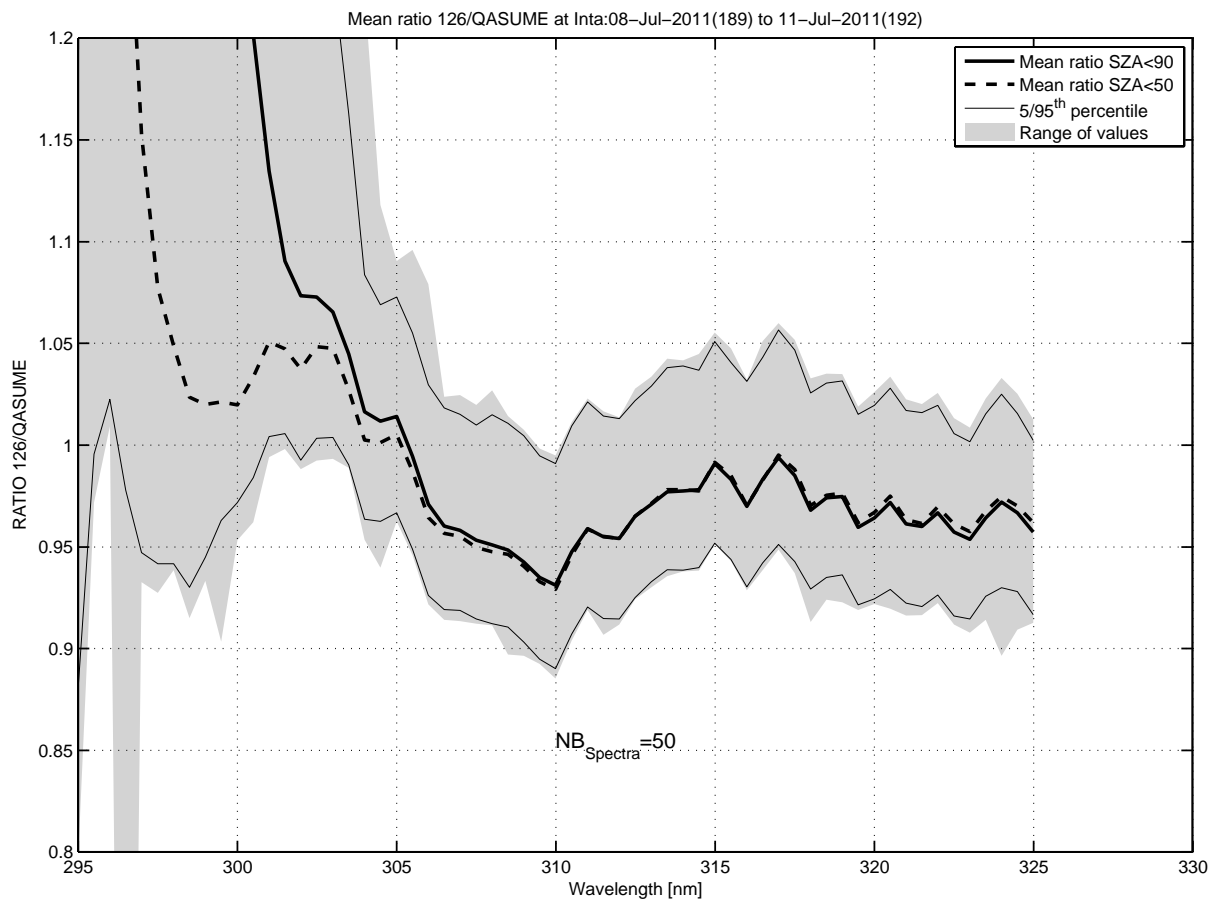
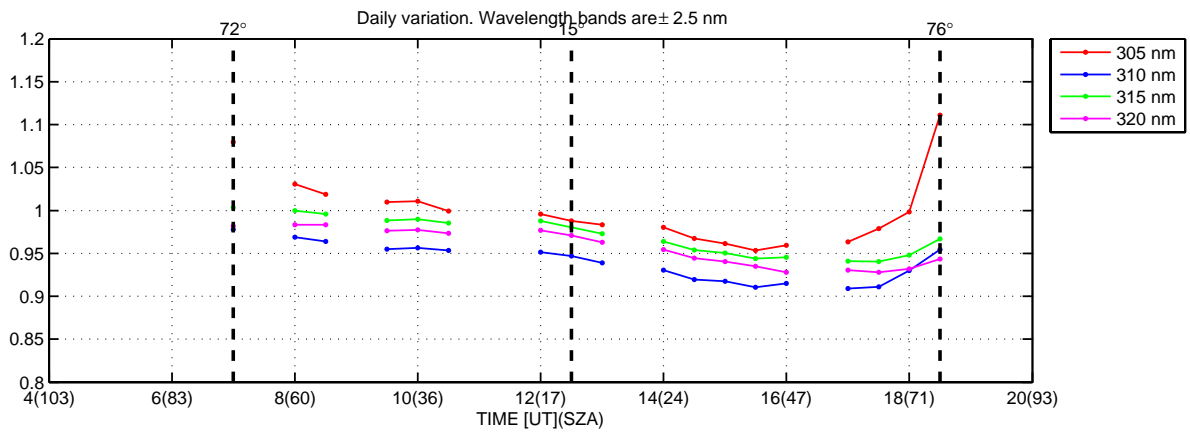
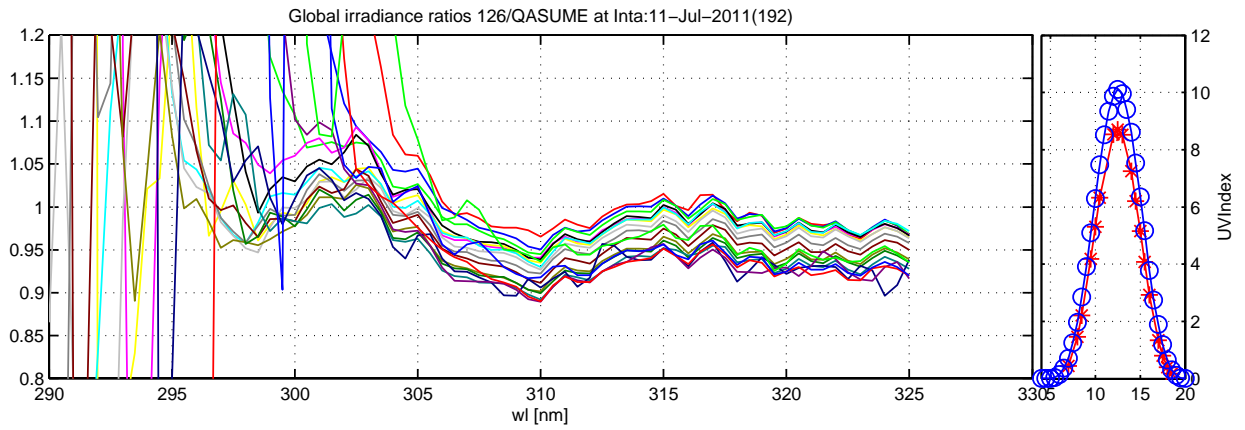
Global irradiance ratios 126/QASUME at Inta:08-Jul-2011(189)



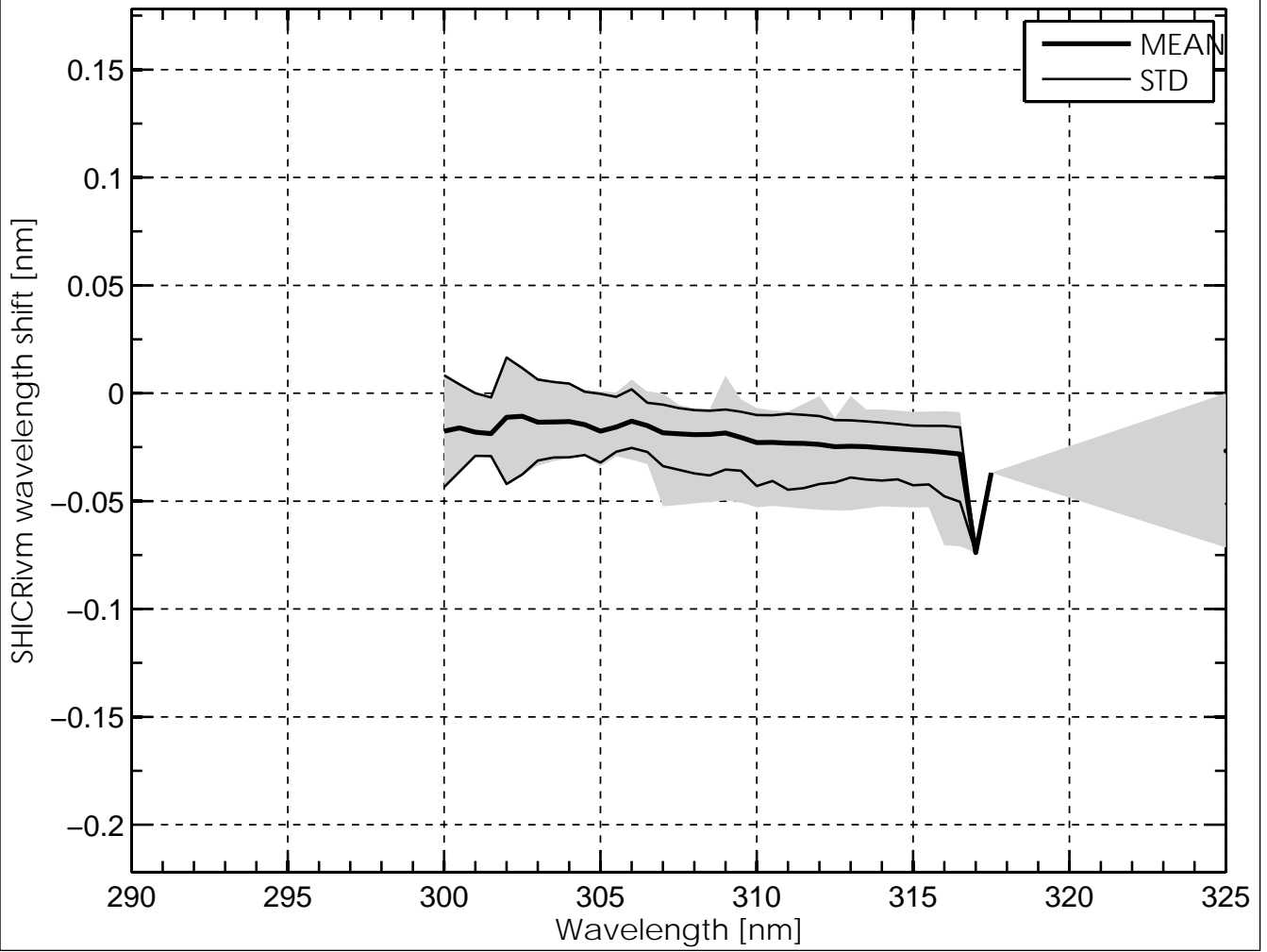
Daily variation, Wavelength bands are ± 2.5 nm



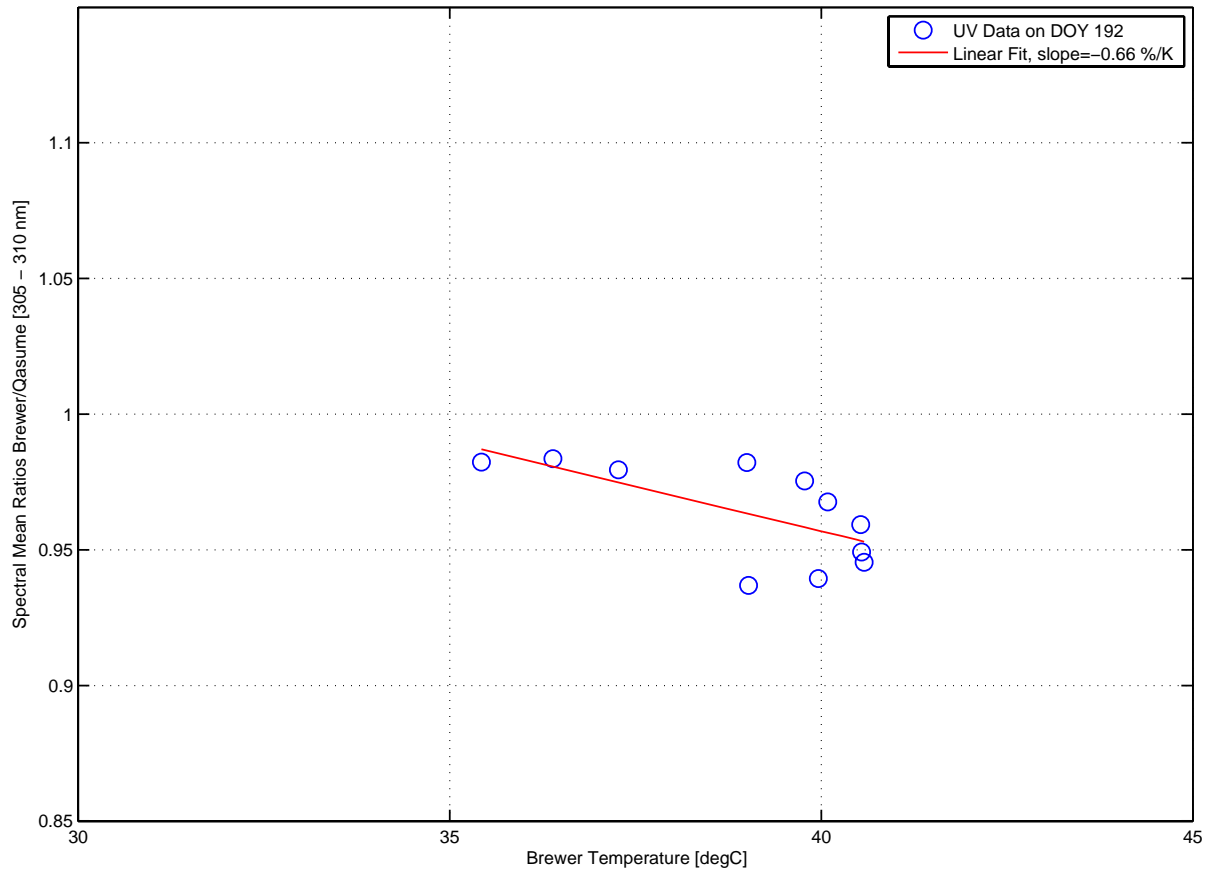




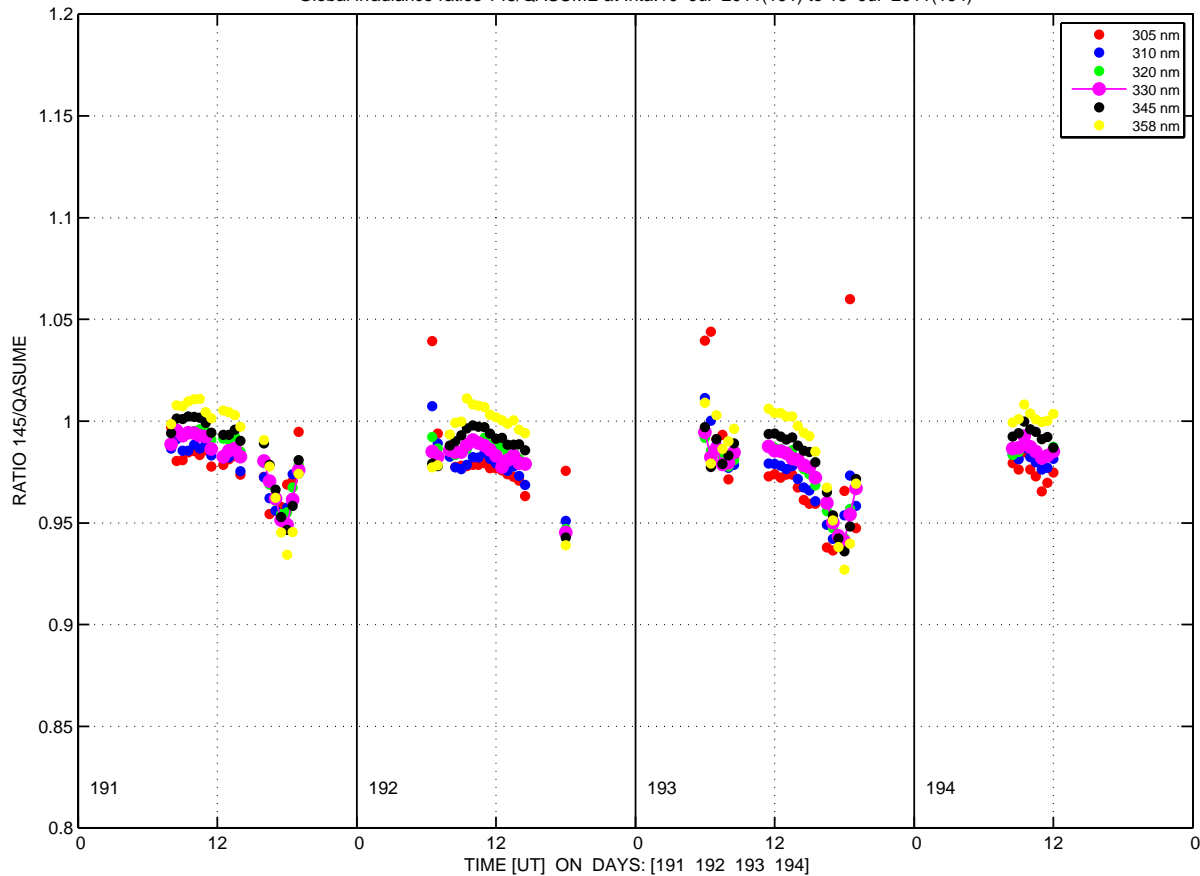
Inta, 126, July 2011



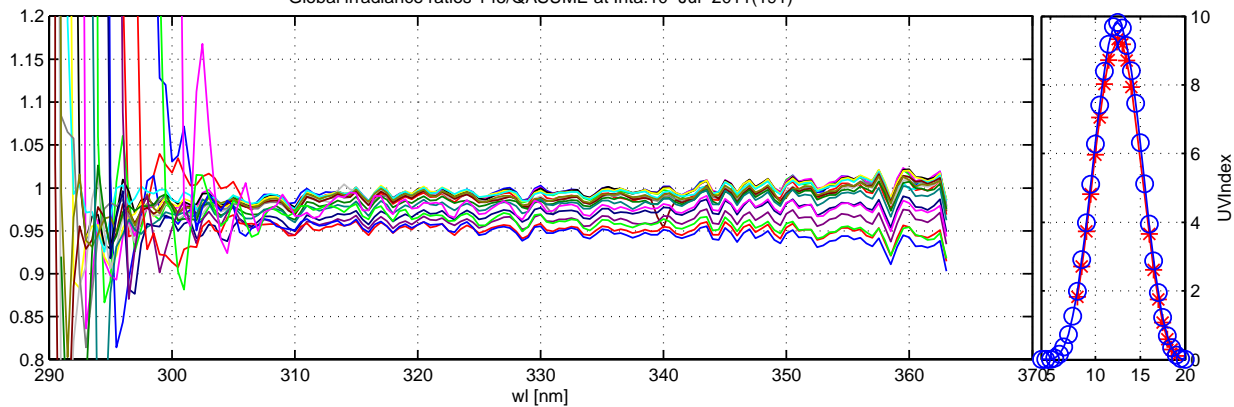
Temperature Dependence of Brewer #126, Inta, July 2011



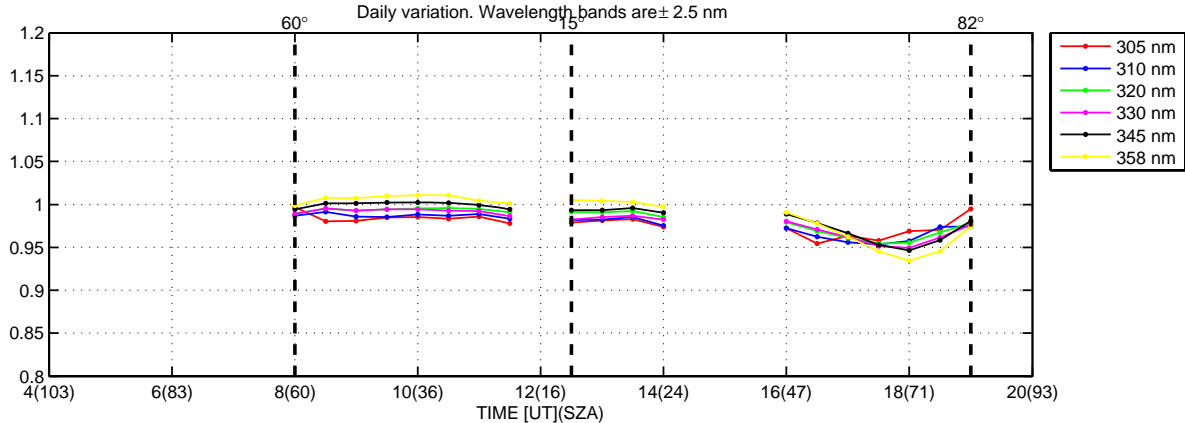
Global irradiance ratios 145/QASUME at Inta:10-Jul-2011(191) to 13-Jul-2011(194)

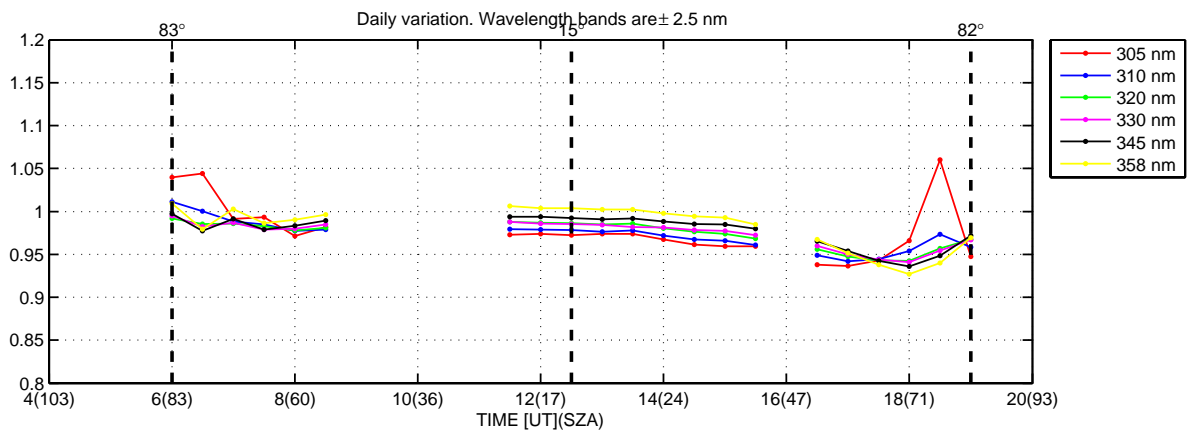
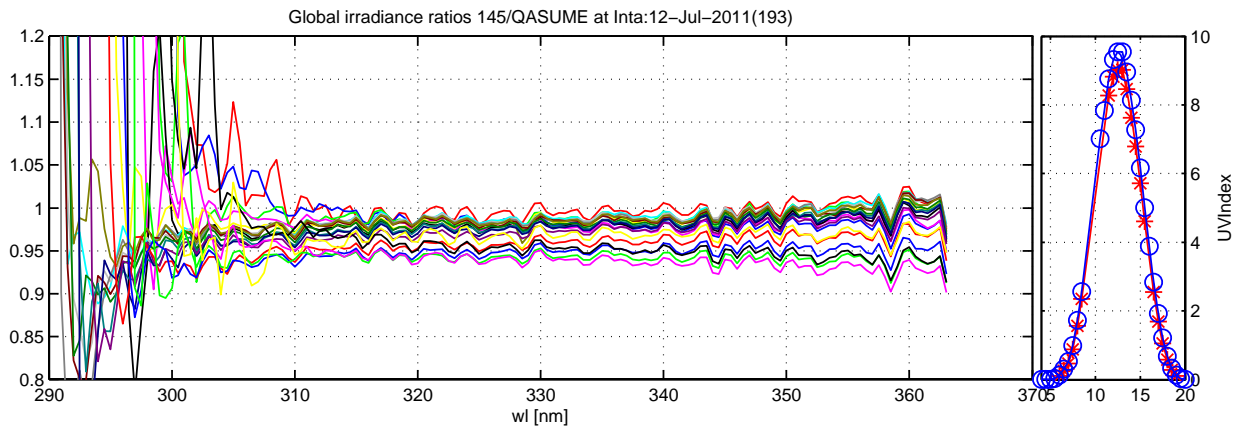
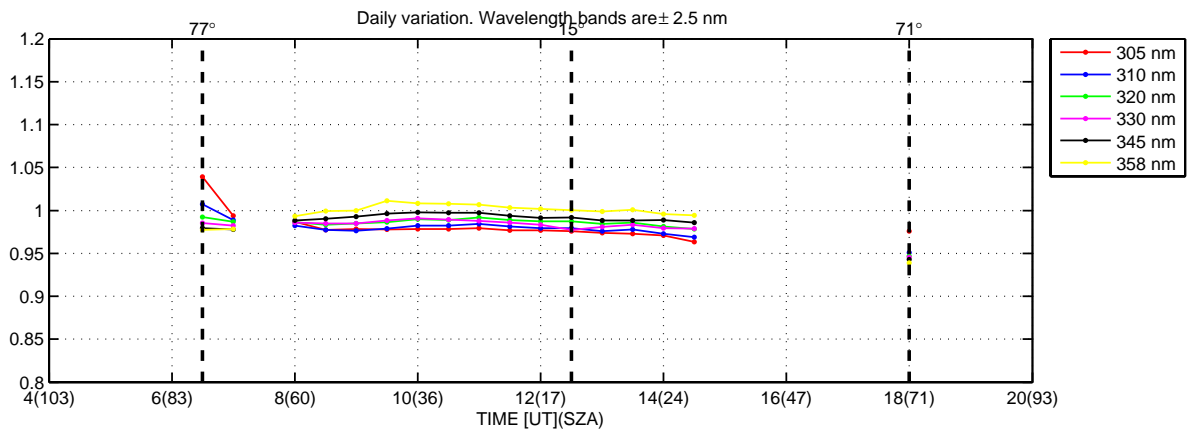
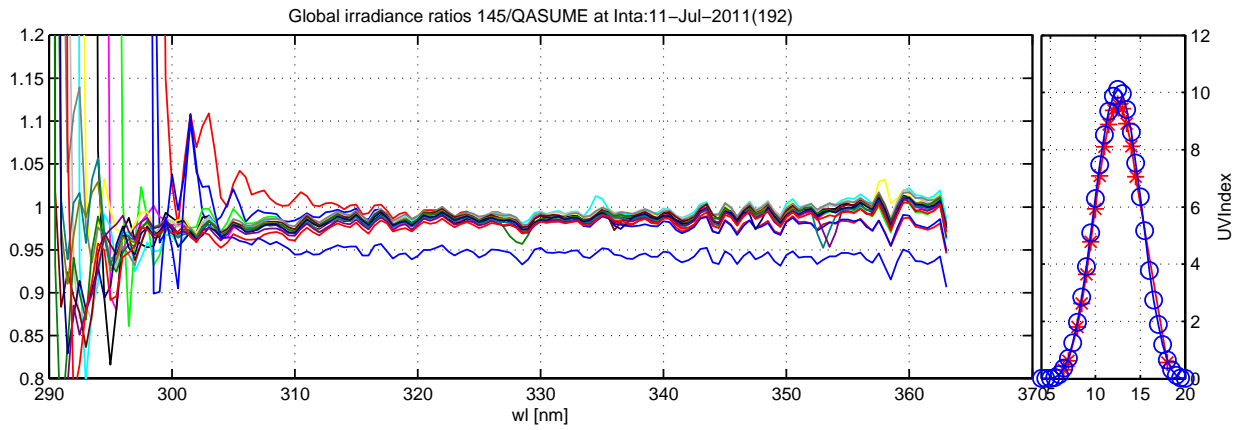


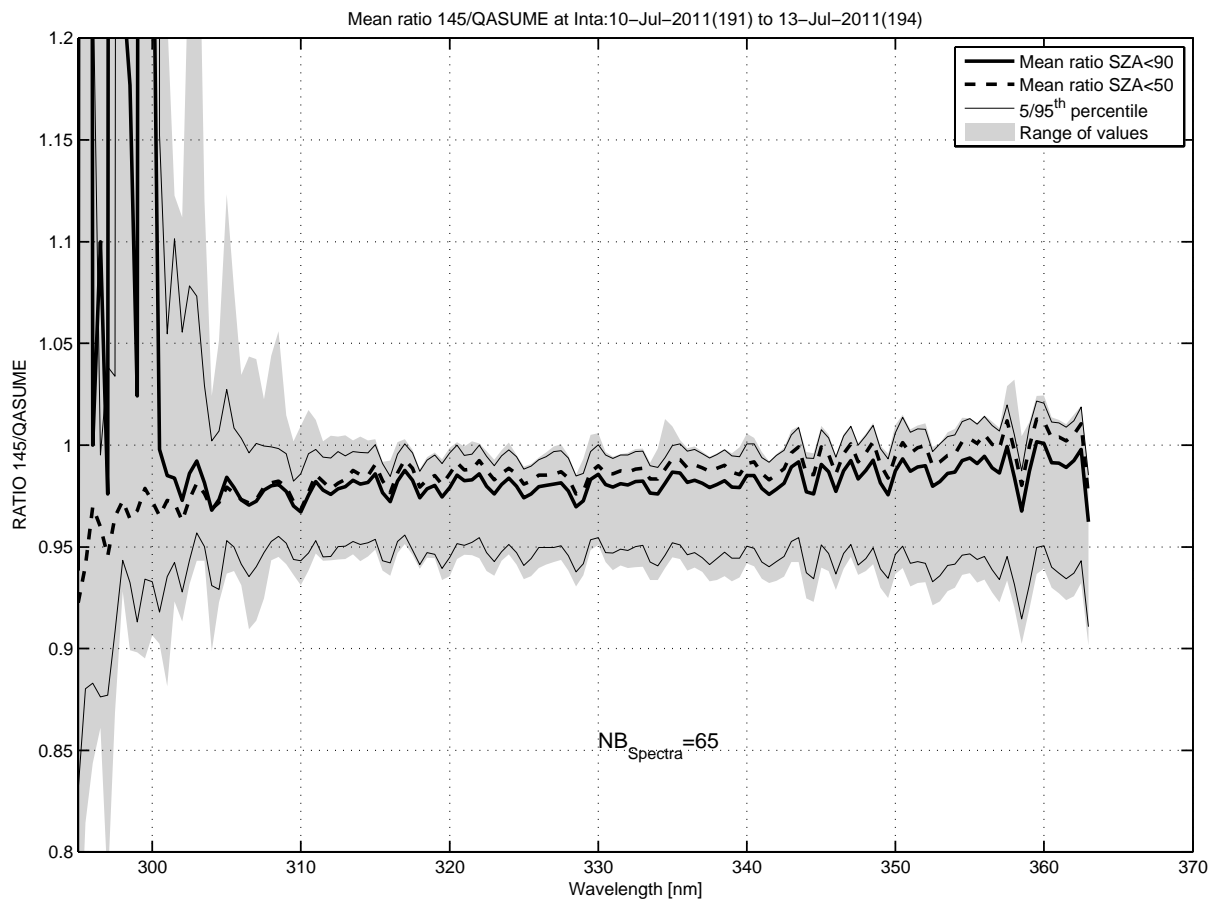
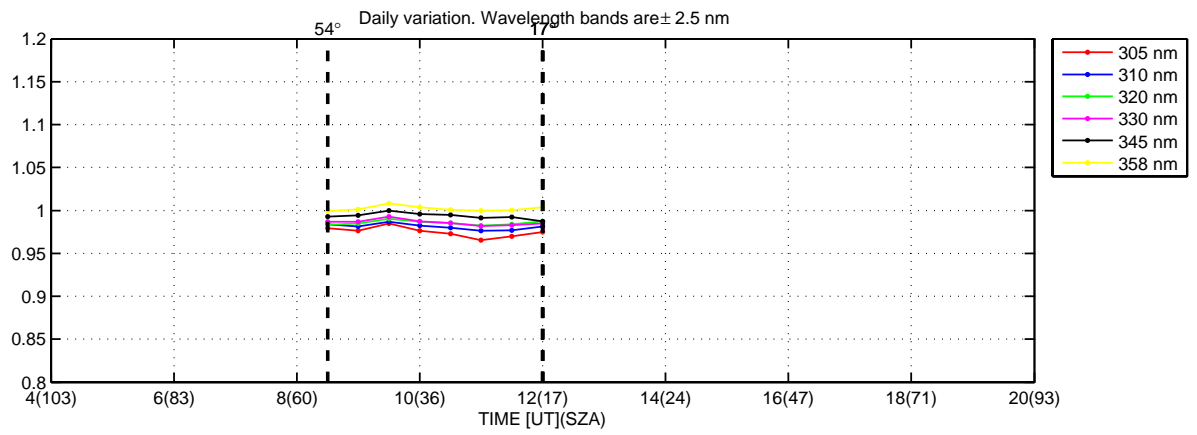
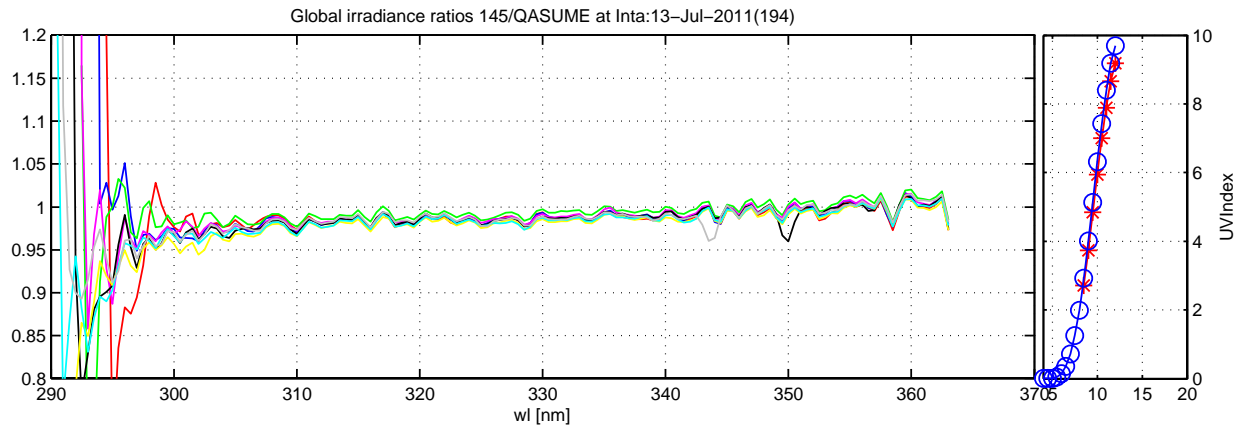
Global irradiance ratios 145/QASUME at Inta:10-Jul-2011(191)



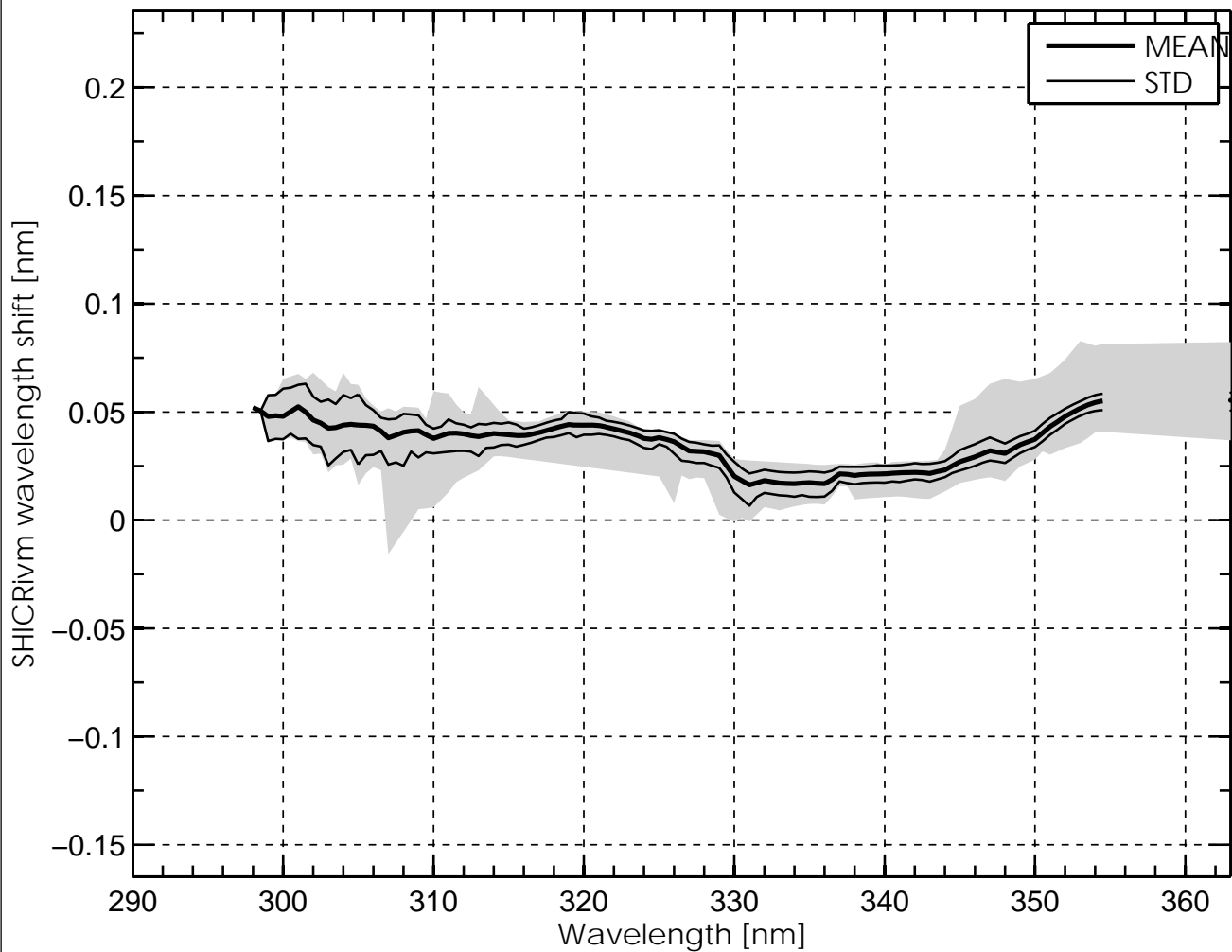
Daily variation. Wavelength bands are ± 2.5 nm



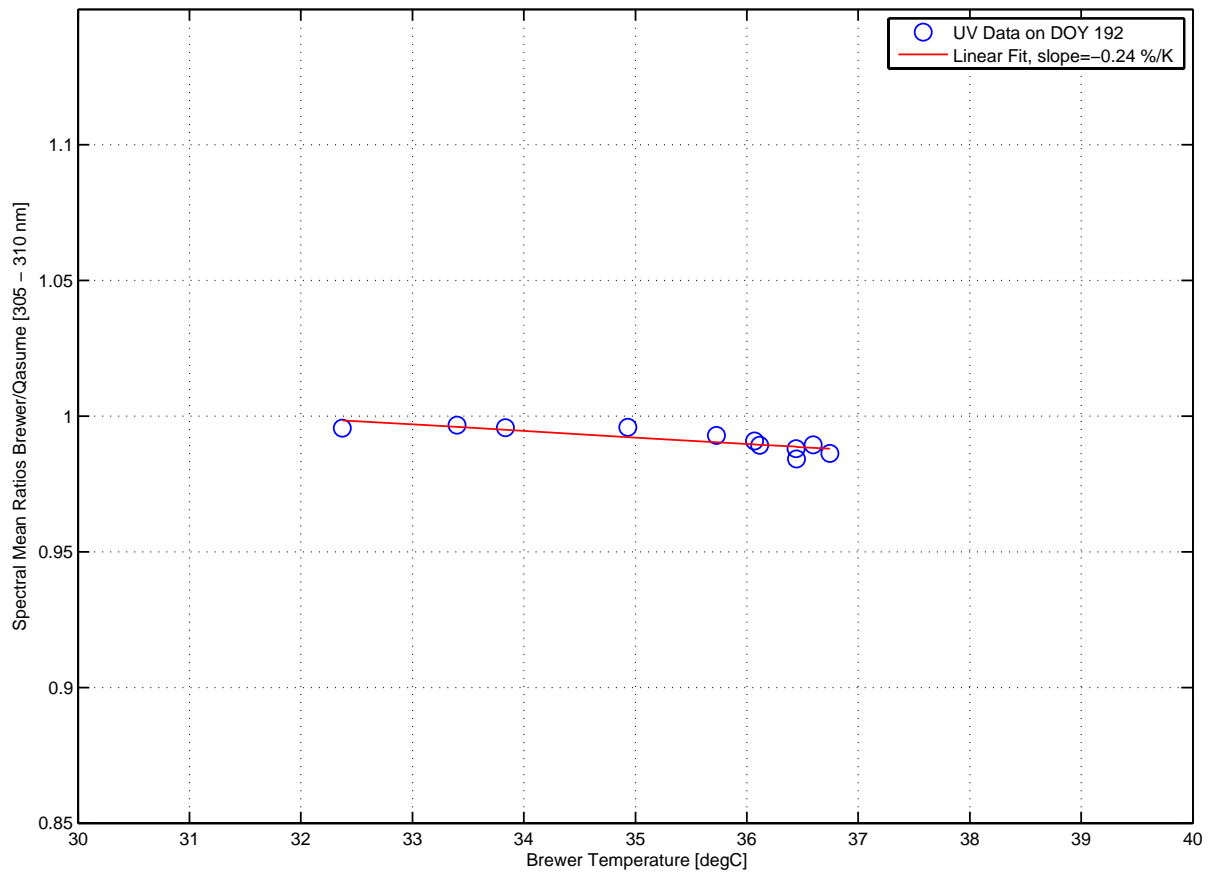


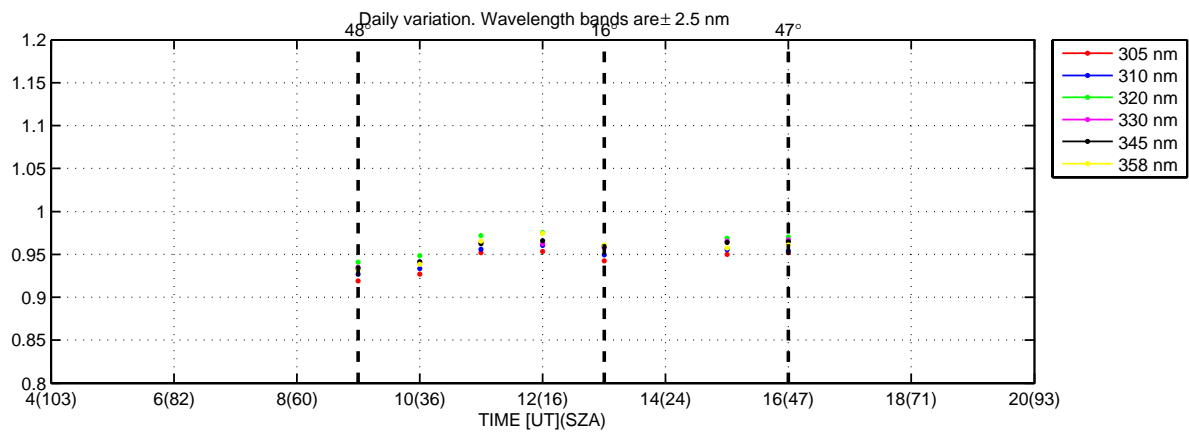
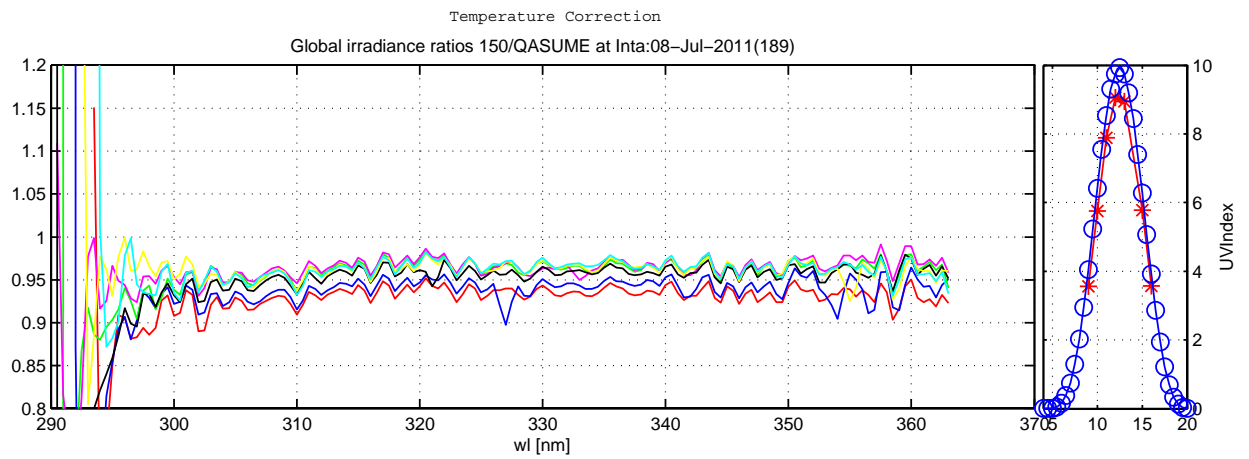
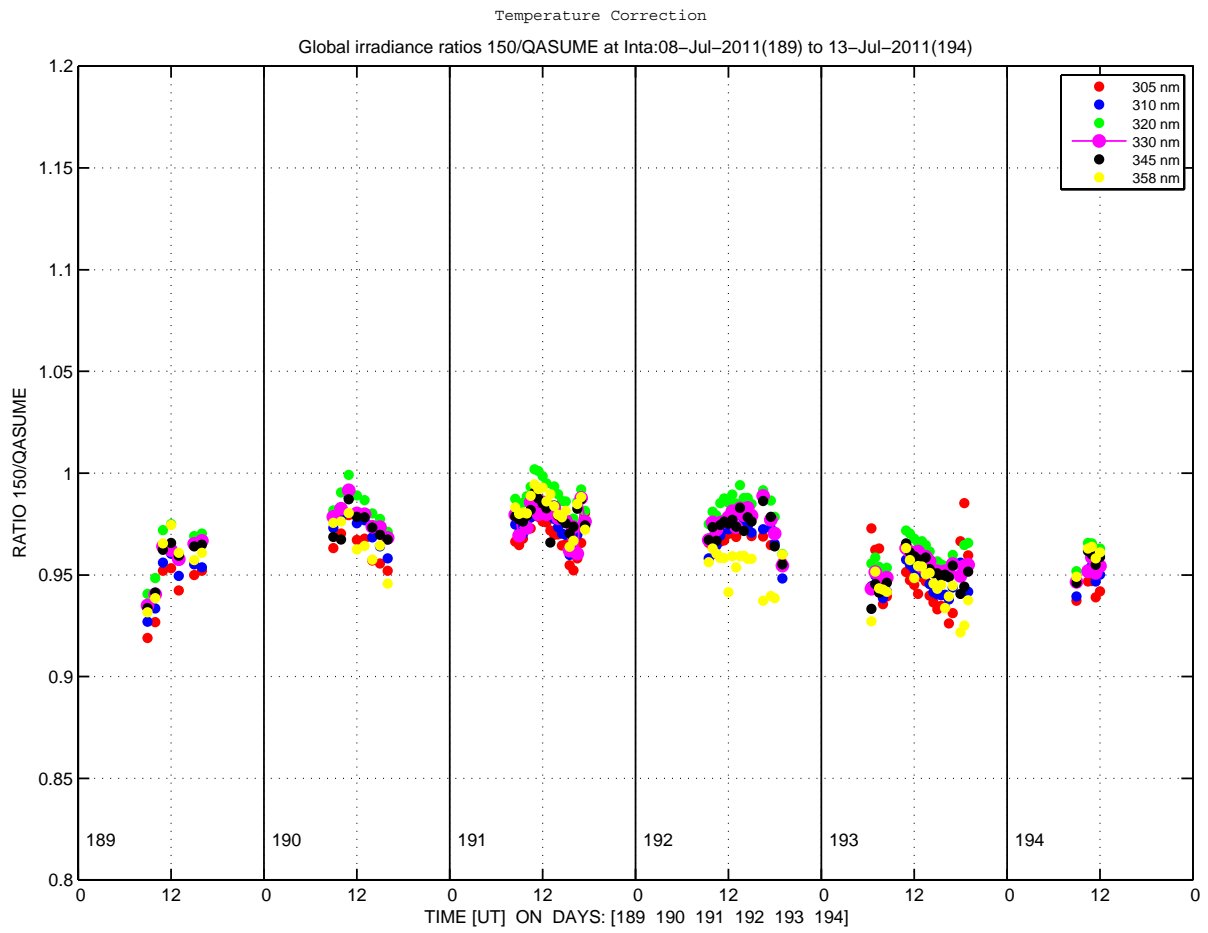


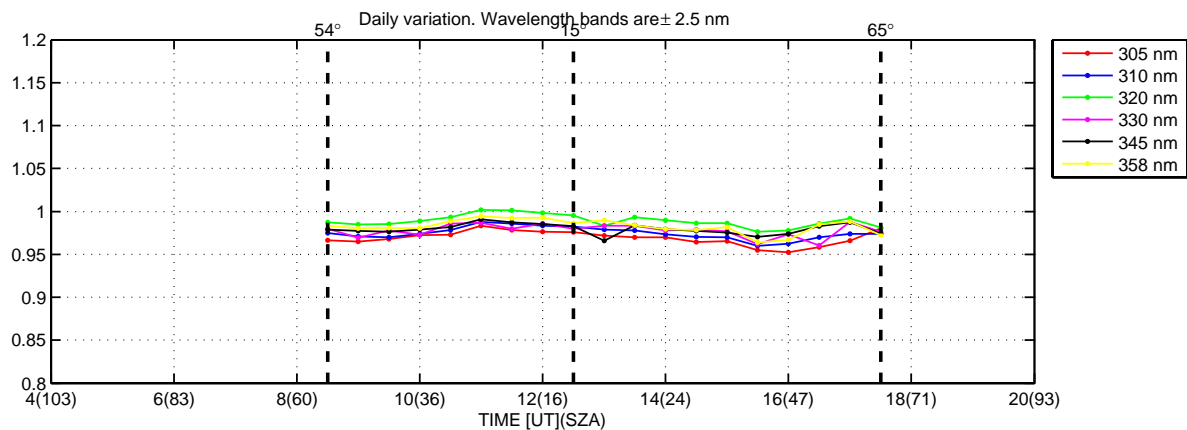
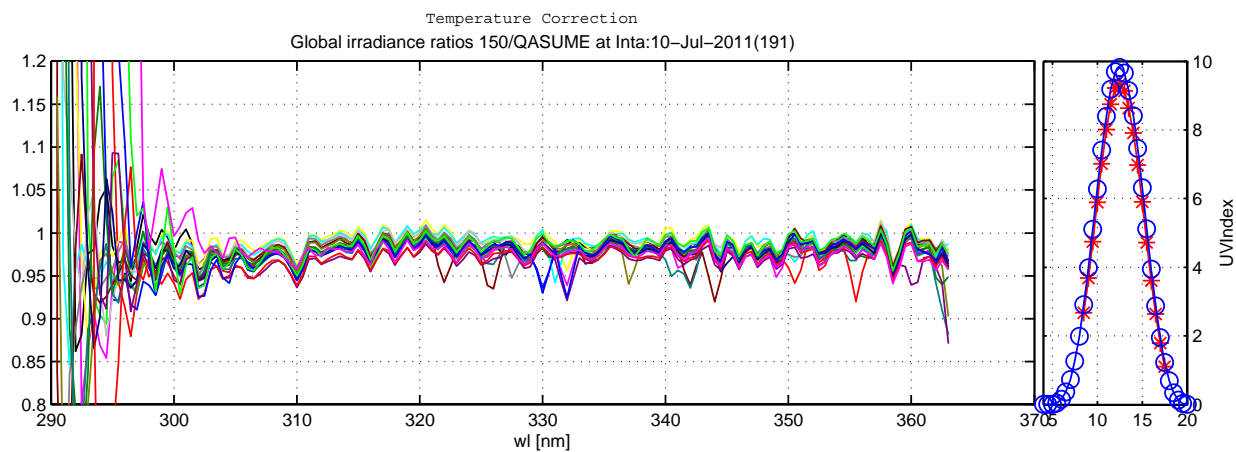
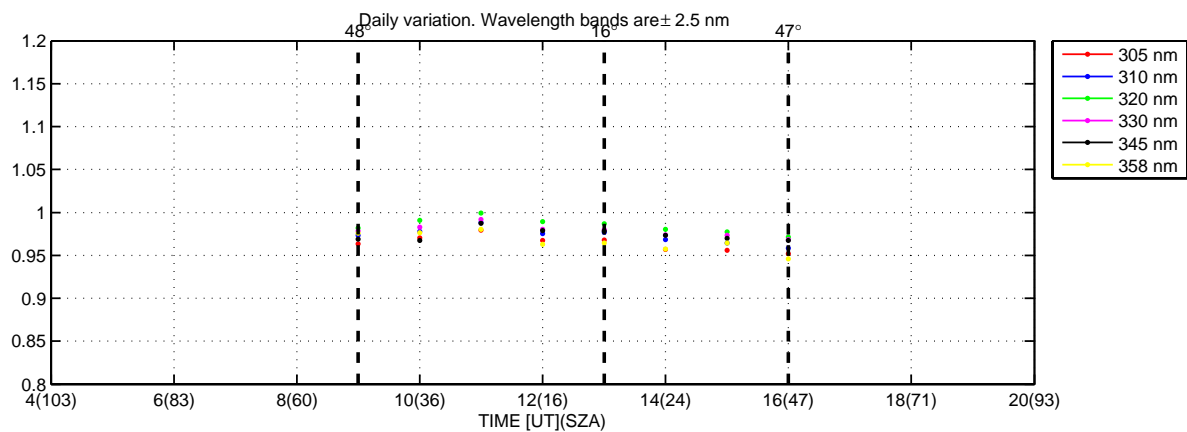
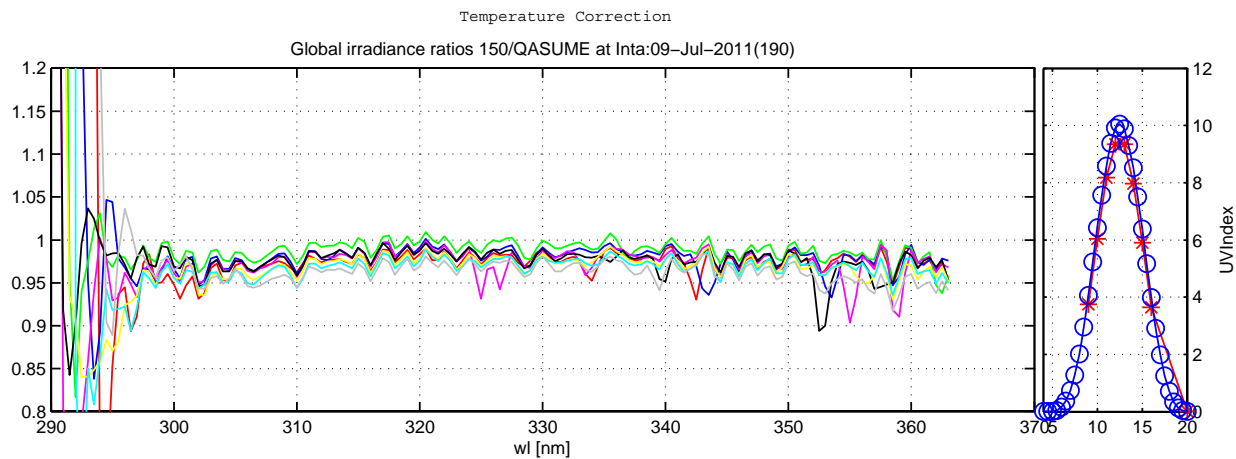
Inta, 145, July 2011

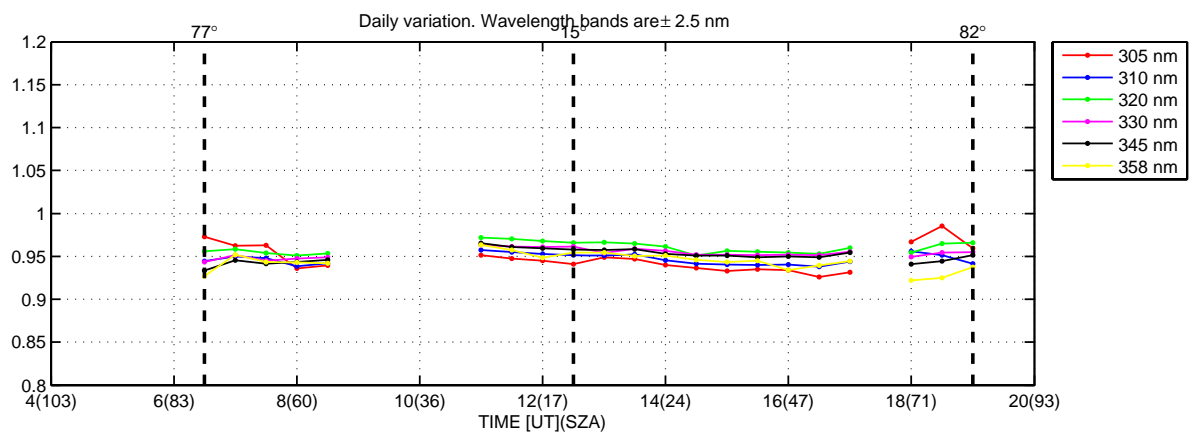
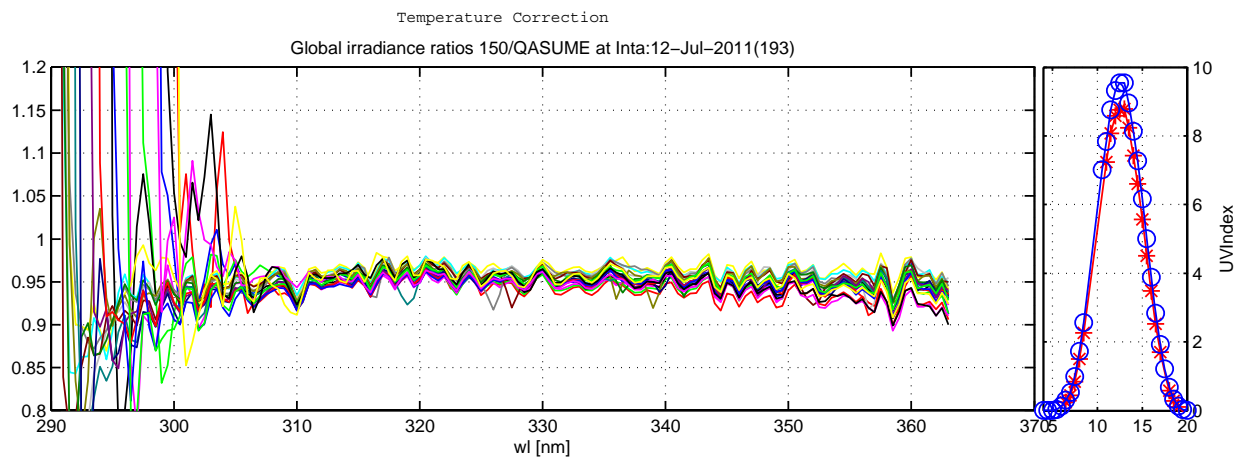
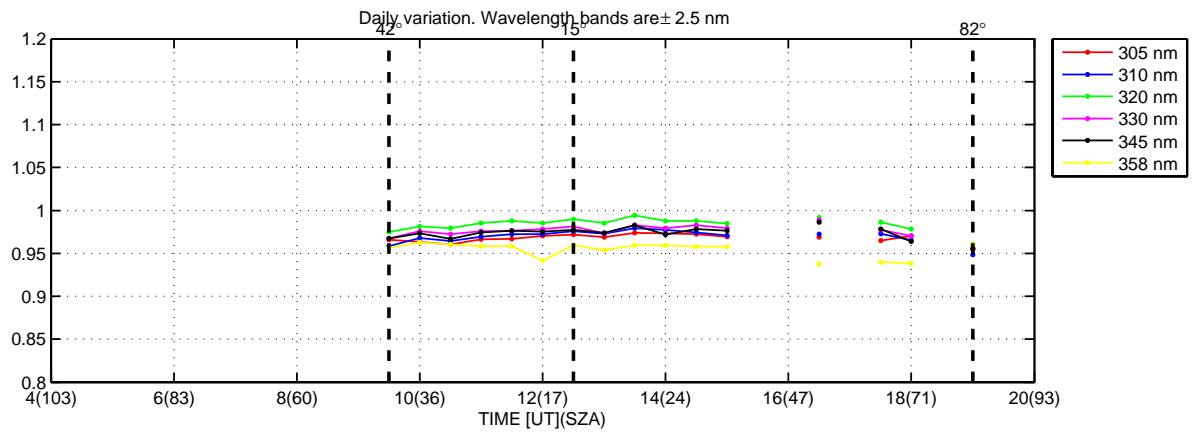
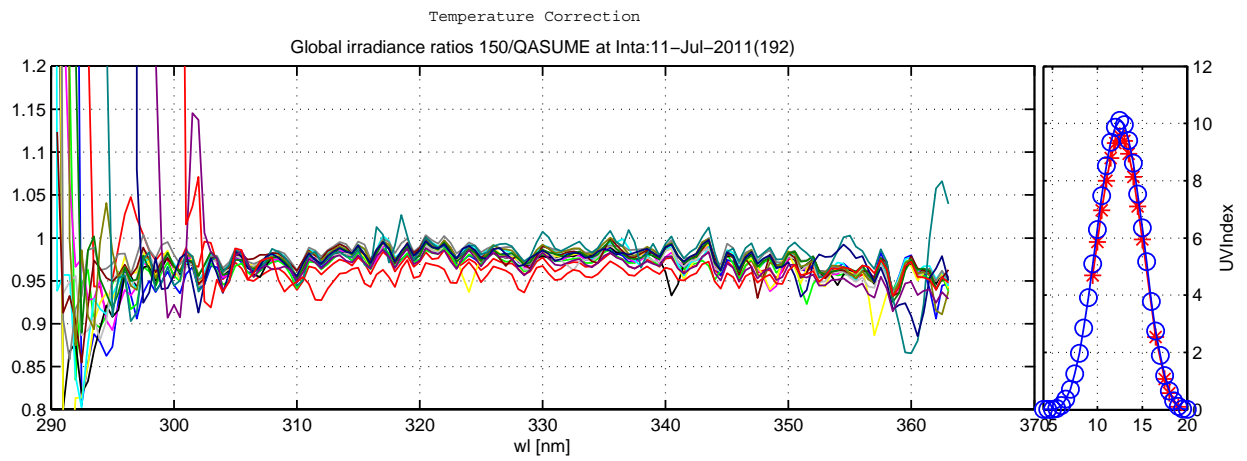


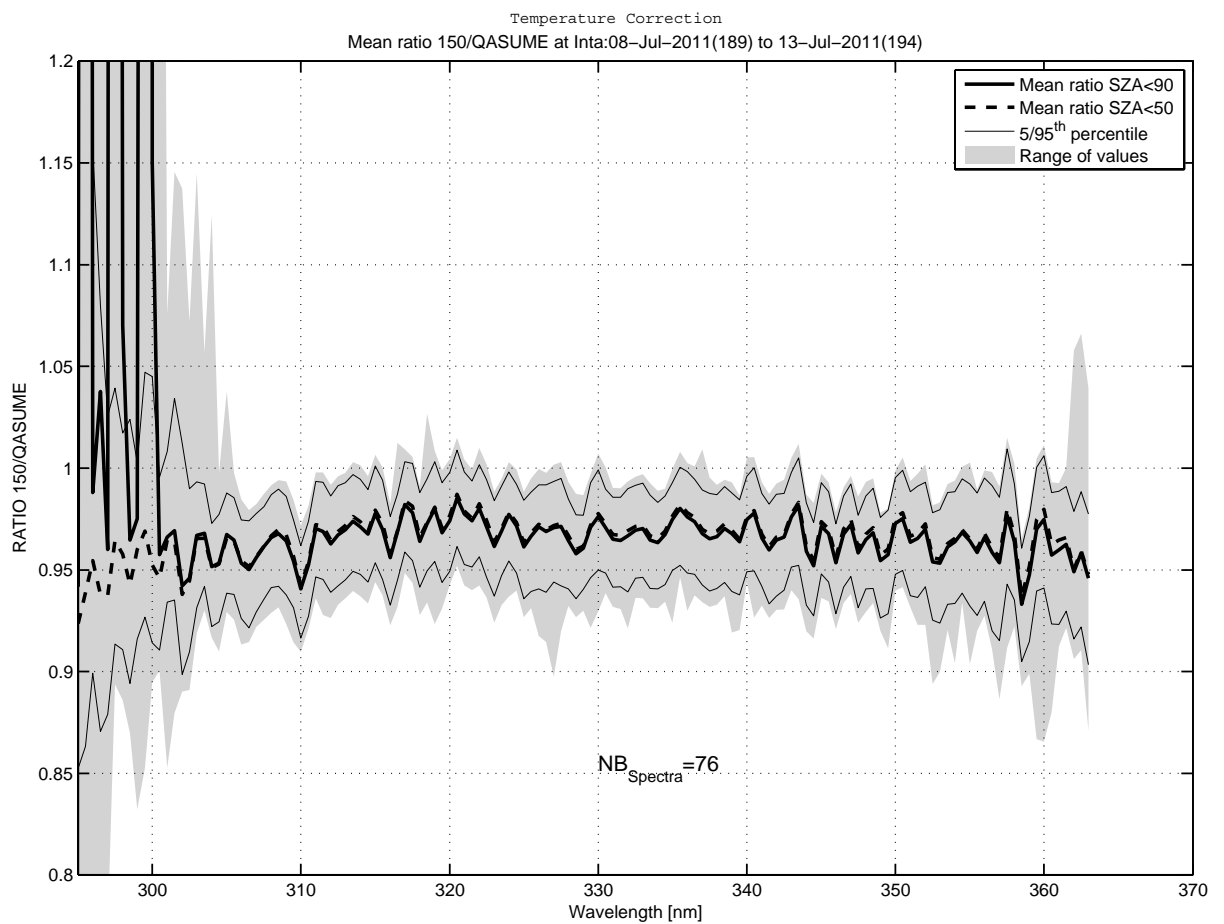
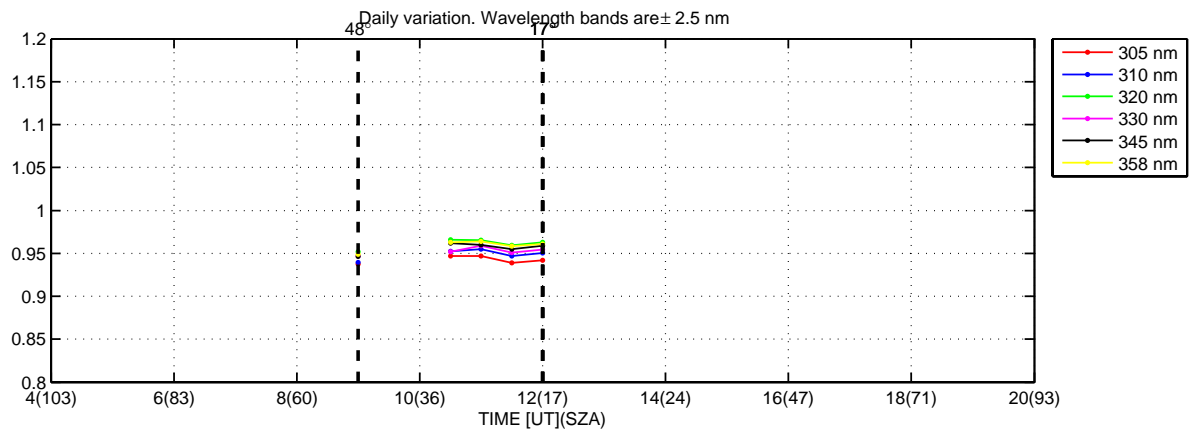
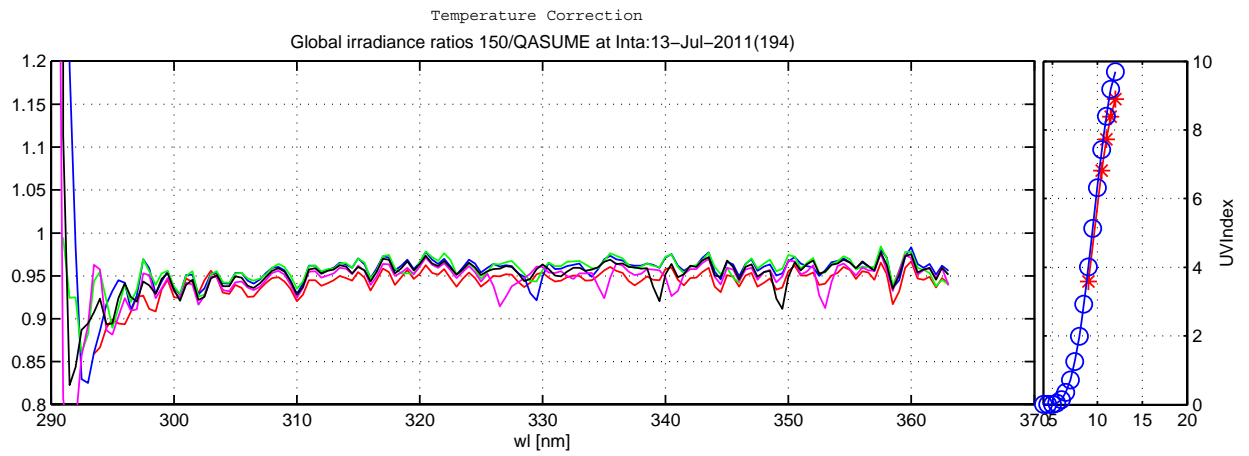
Temperature Dependence of Brewer #145, Inta, July 2011



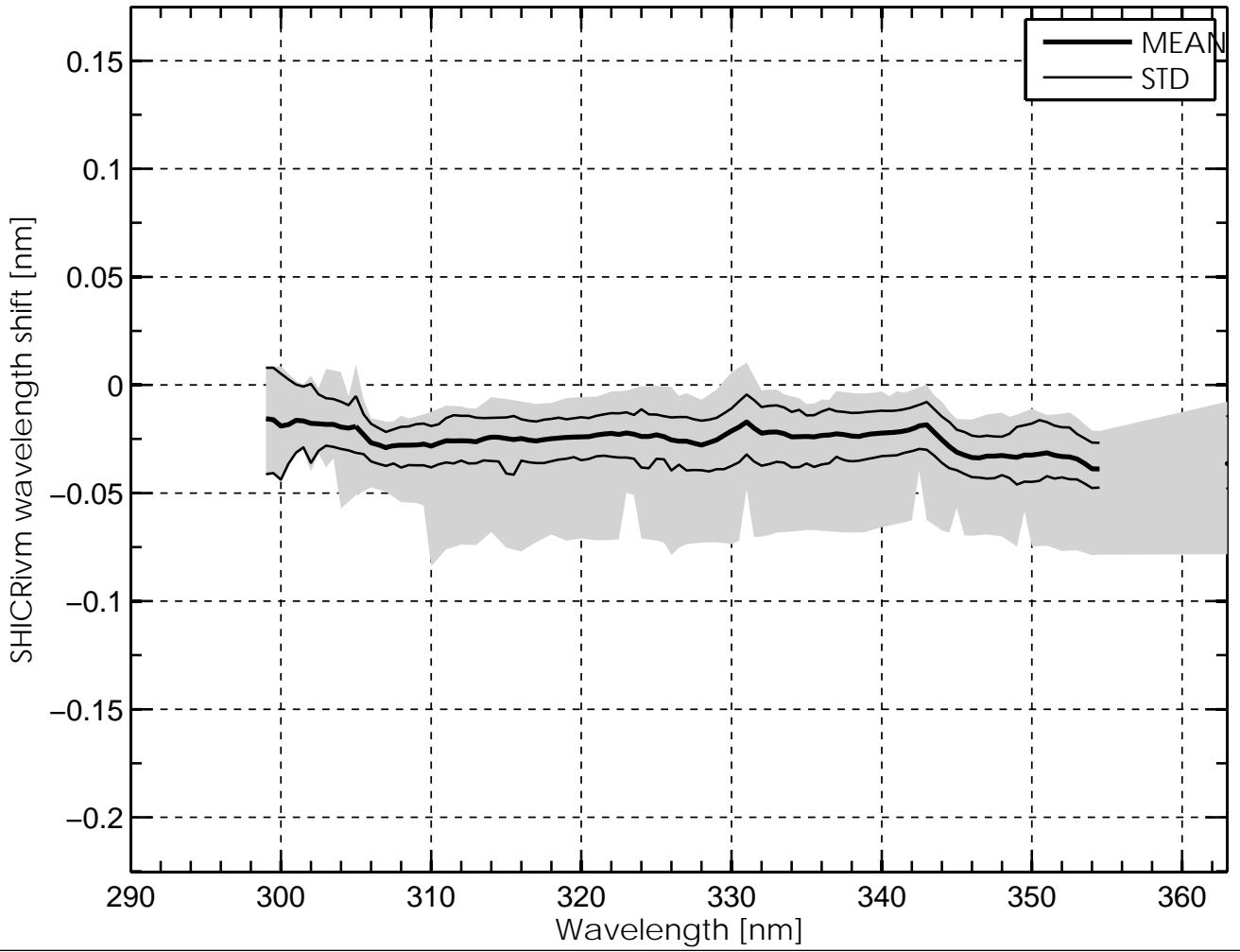






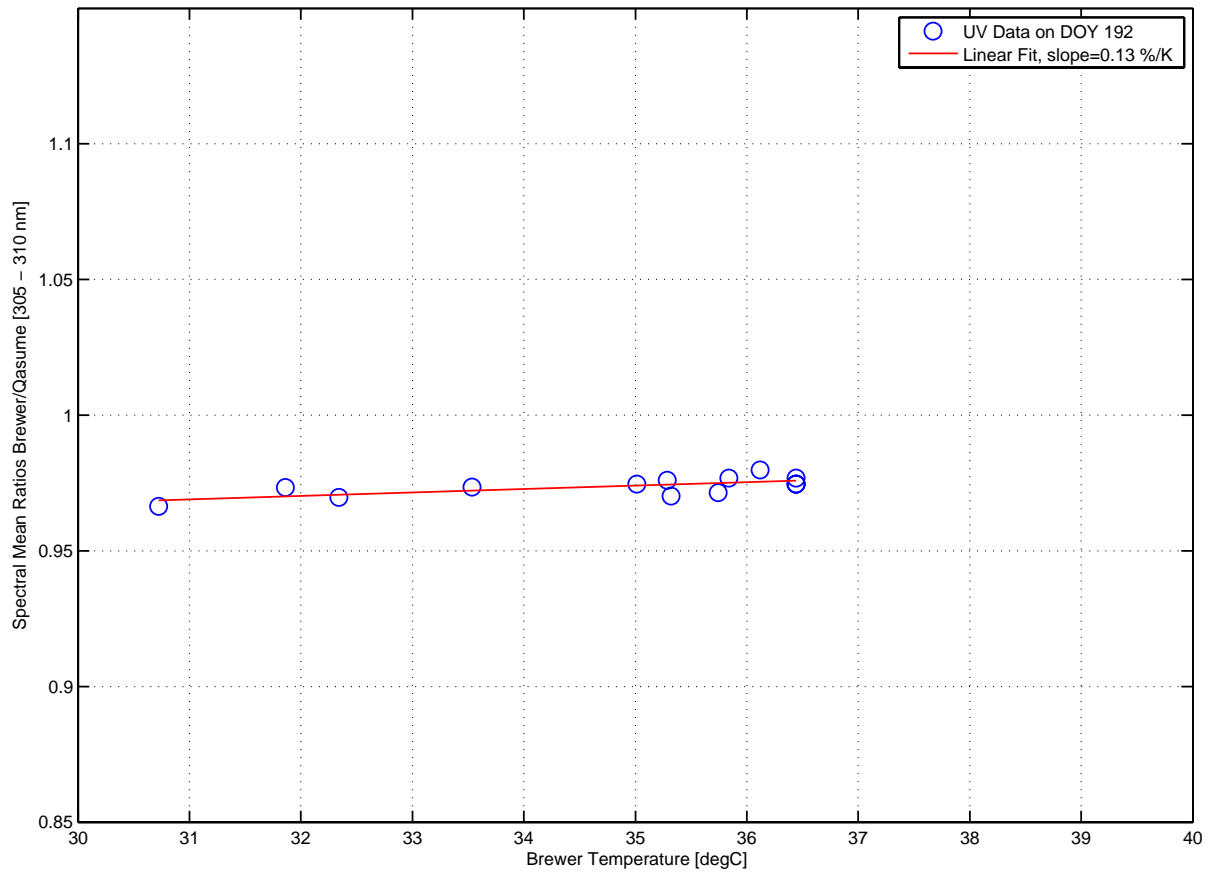


Inta, 150, July 2011



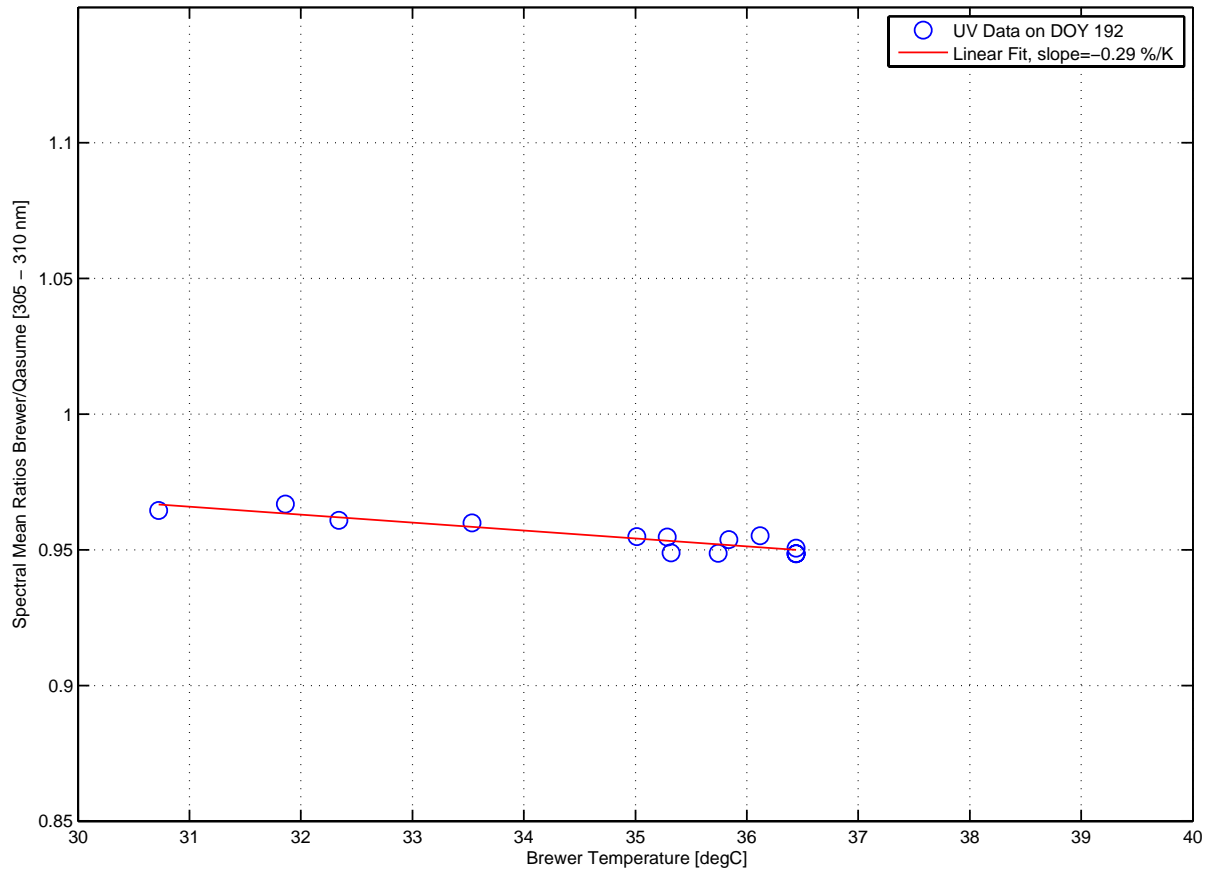
Temperature Correction

Temperature Dependence of Brewer #150, Inta, July 2011

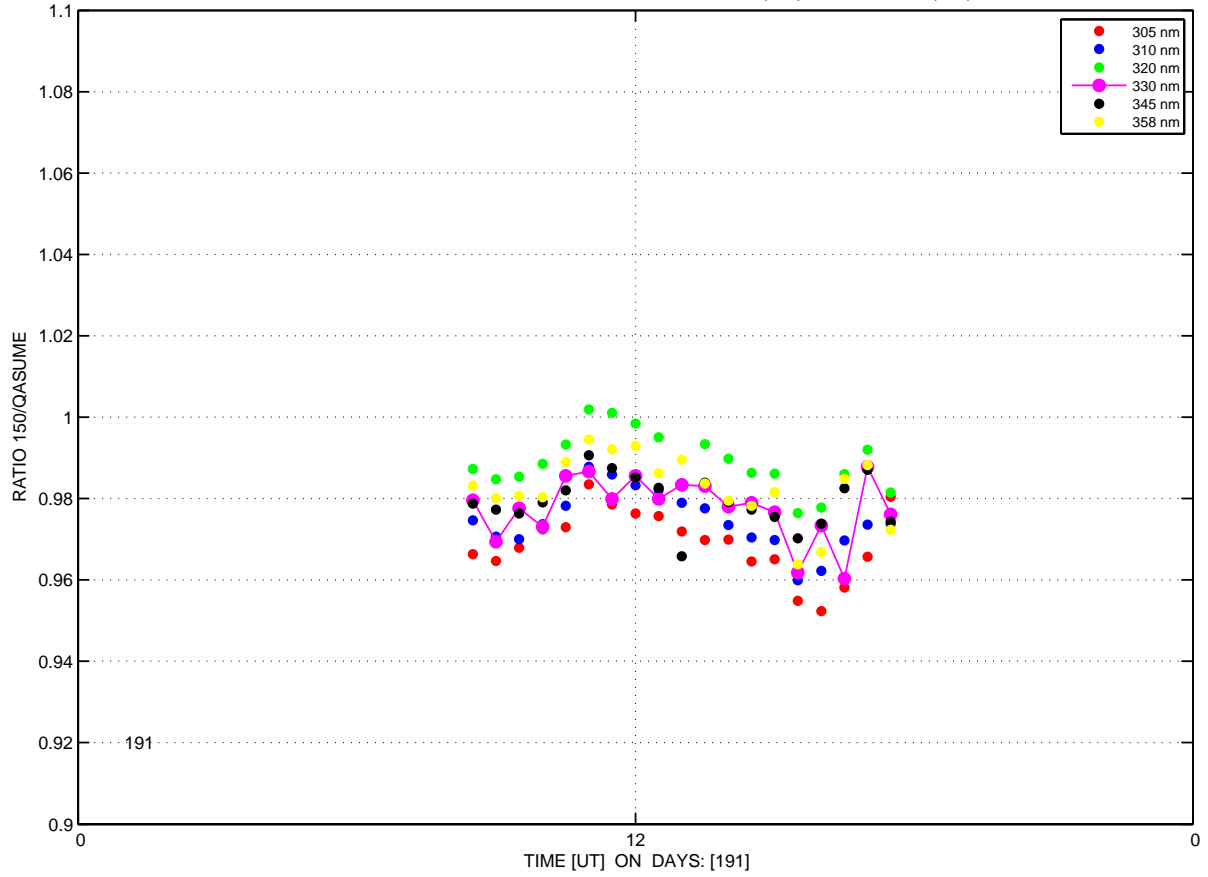


No Temperature Correction

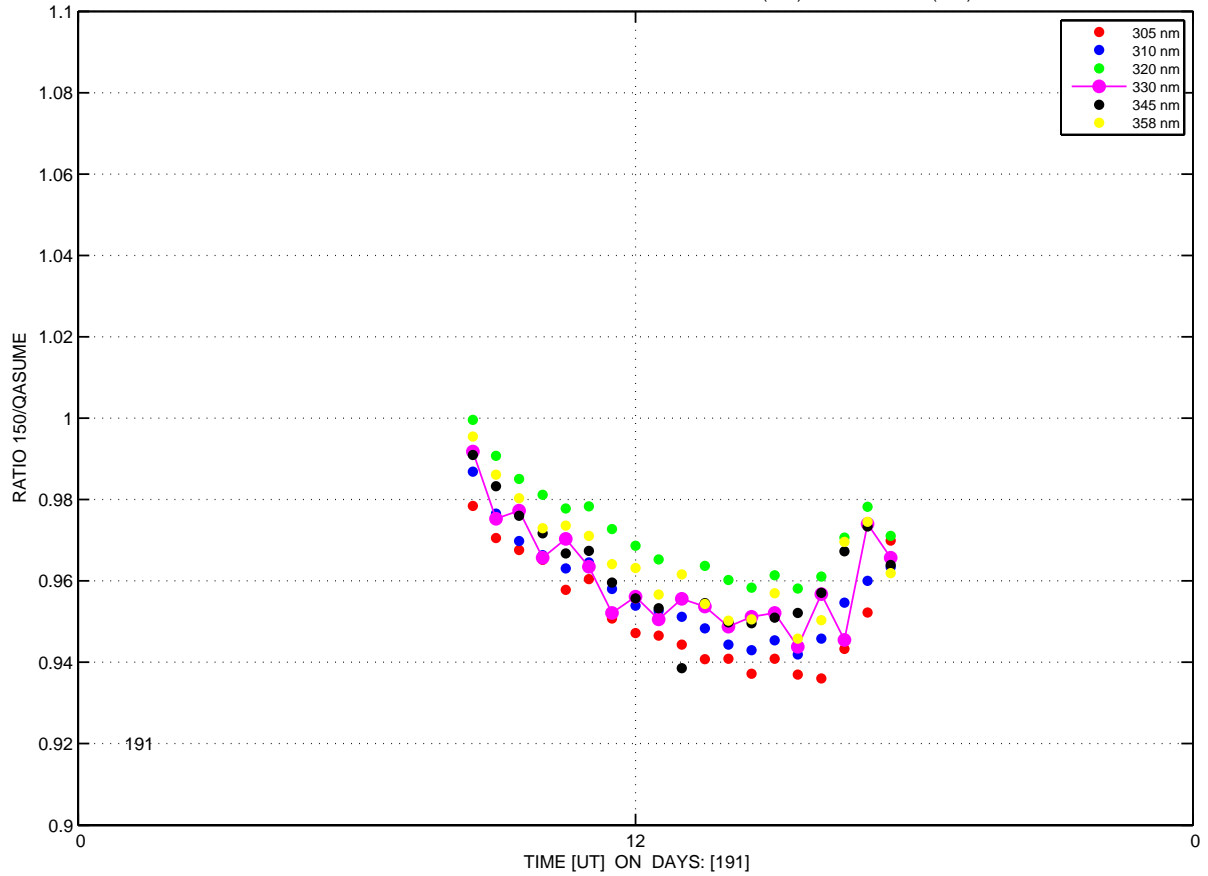
Temperature Dependence of Brewer #150, Inta, July 2011

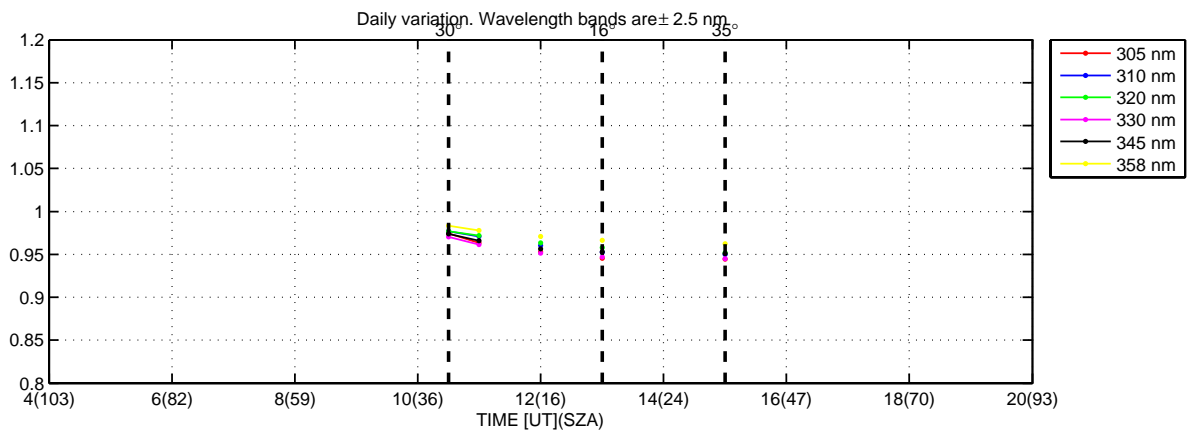
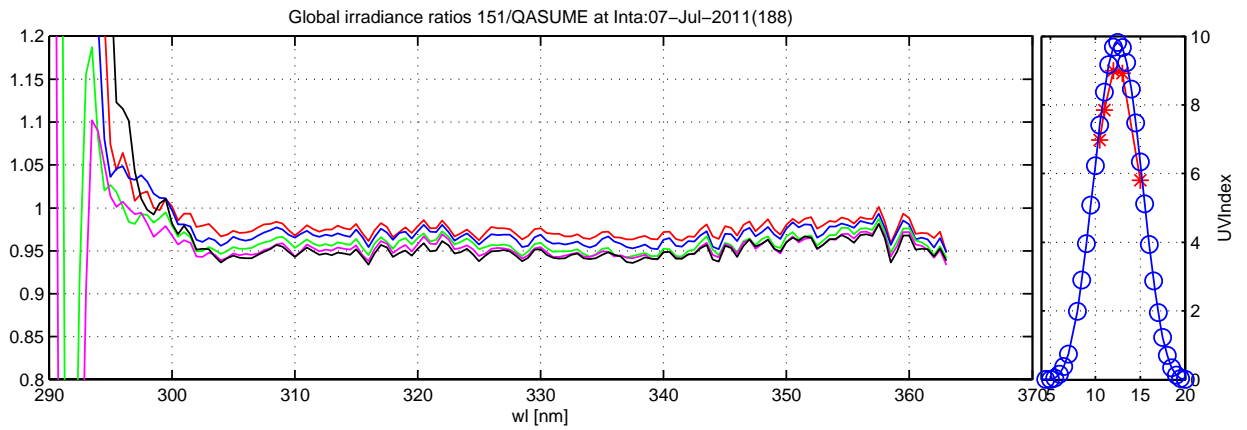
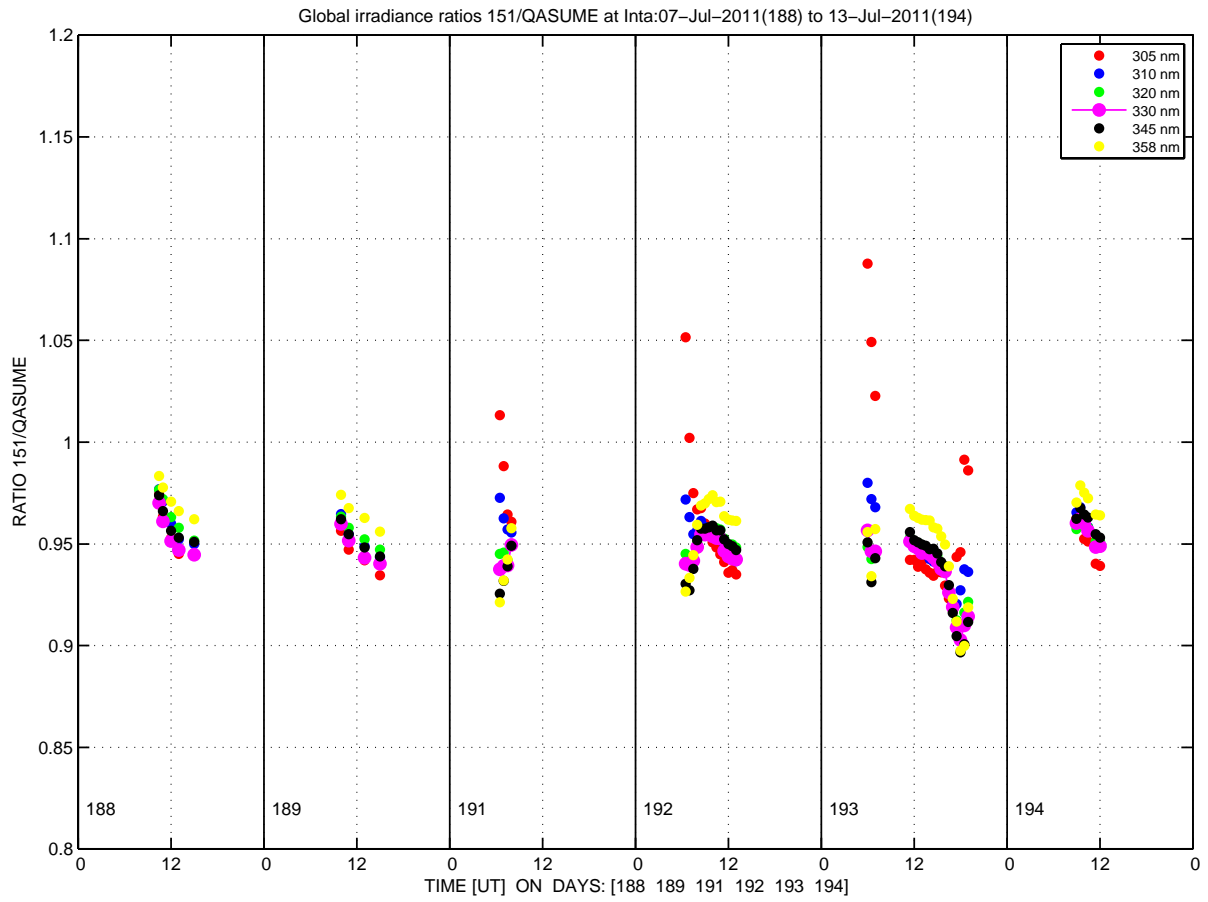


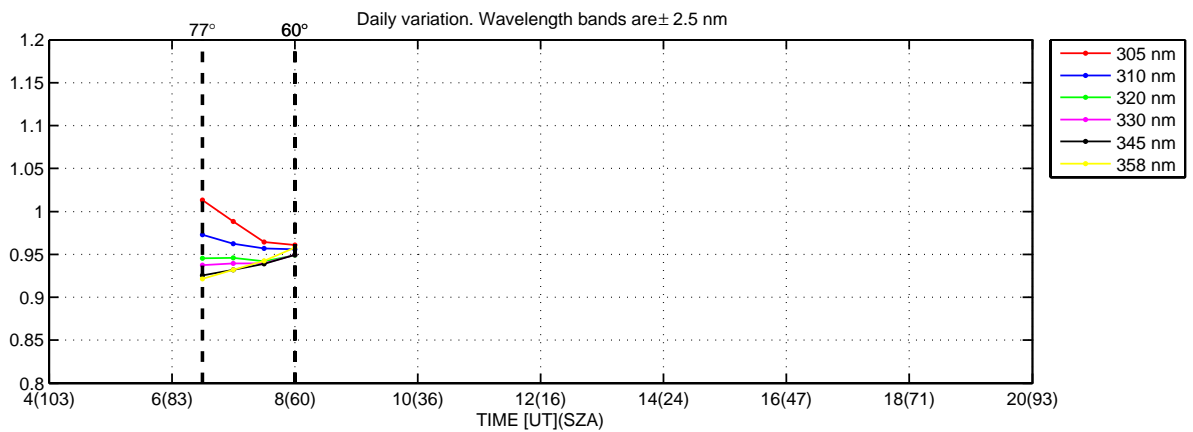
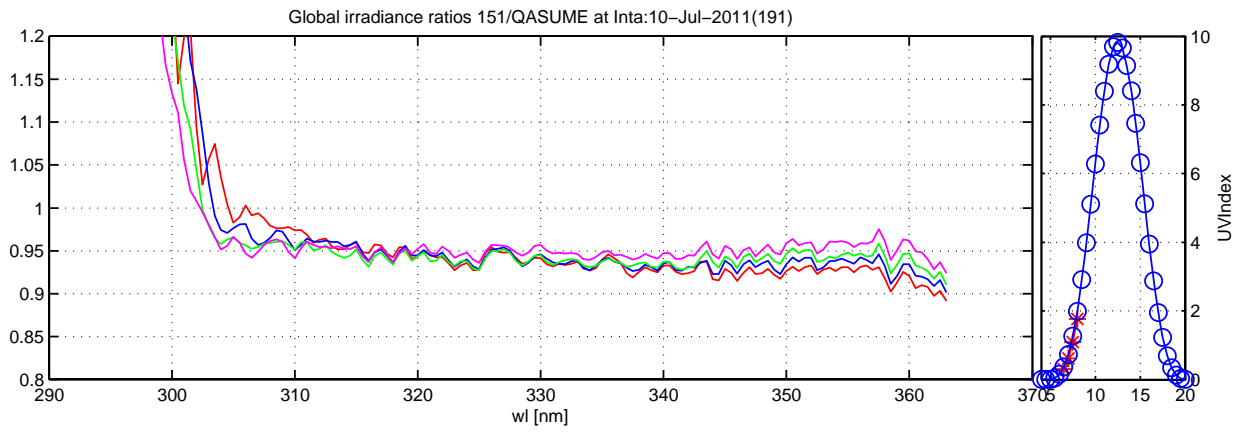
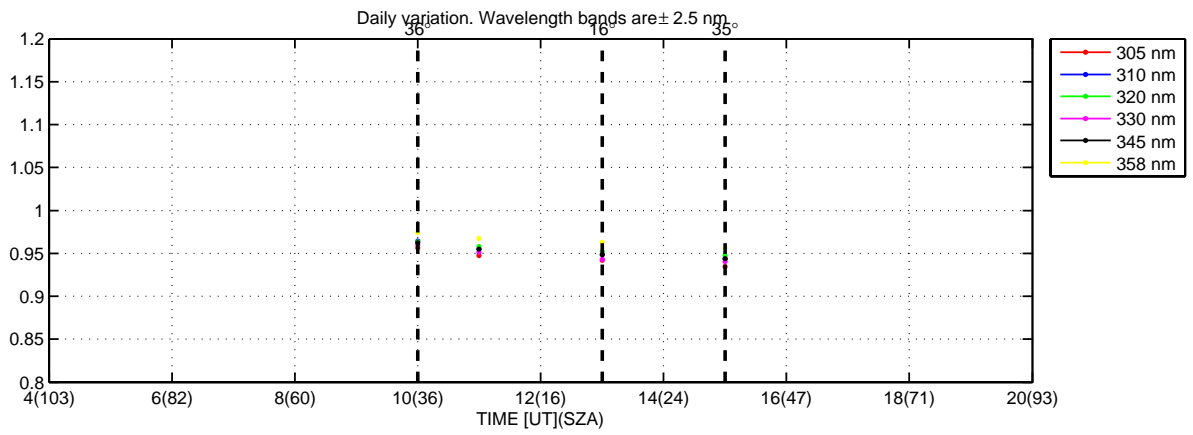
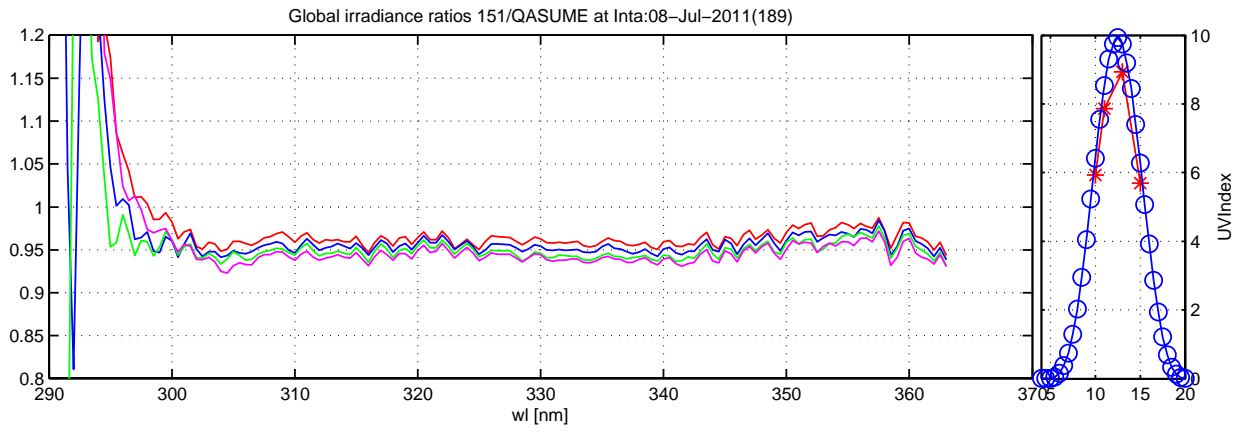
Temperature Correction
Global irradiance ratios 150/QASUME at Inta:10-Jul-2011(191) to 10-Jul-2011(191)

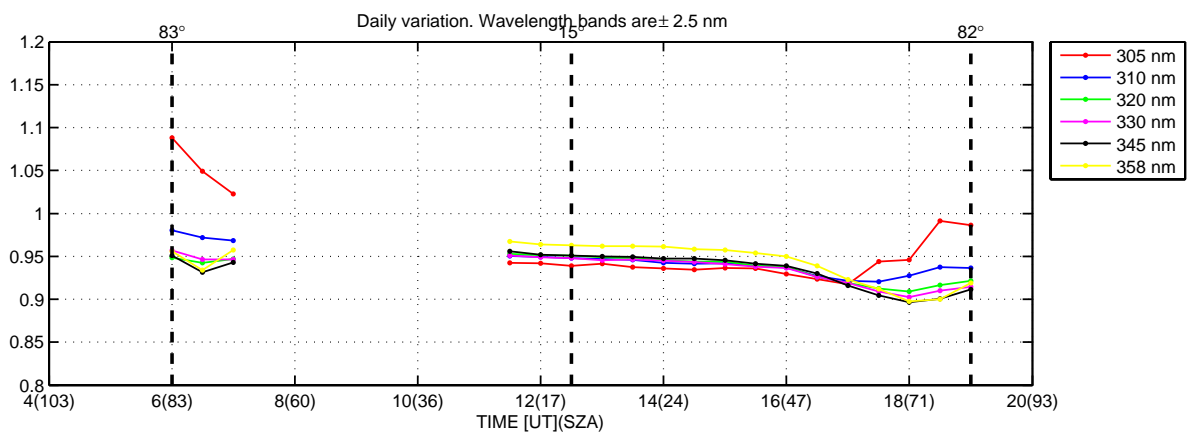
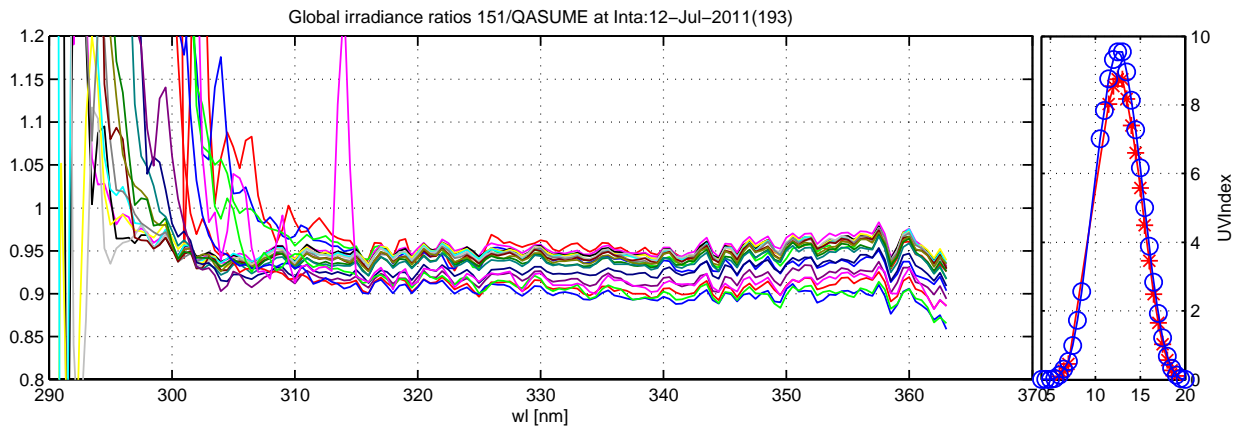
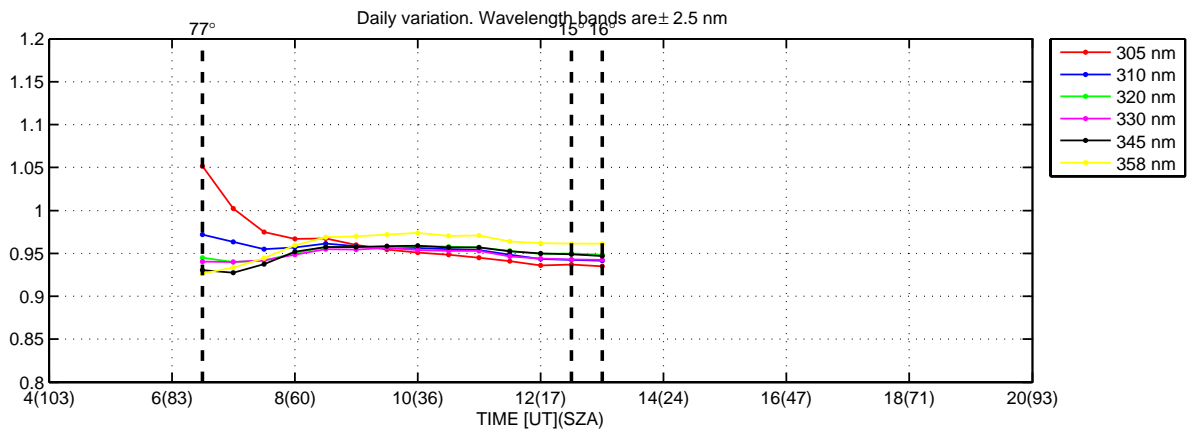
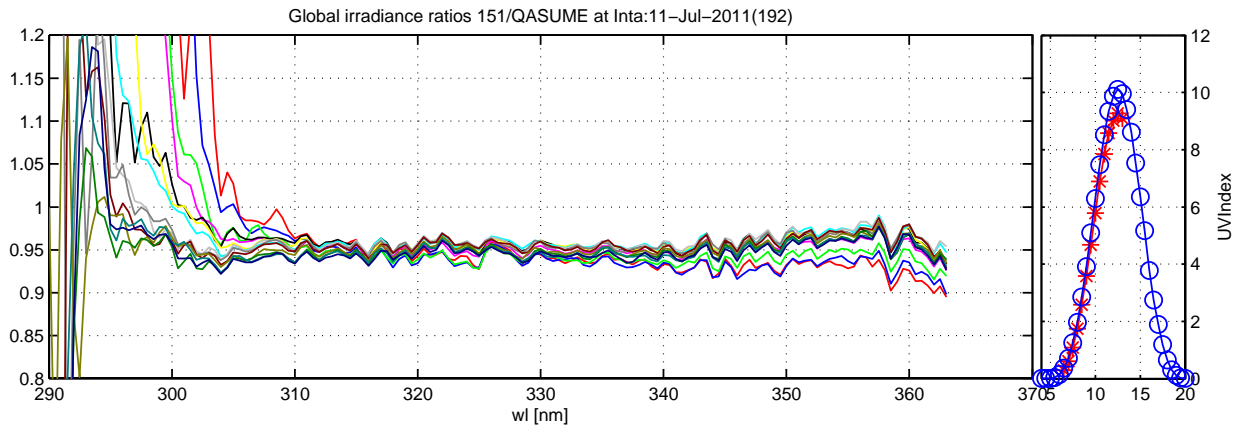


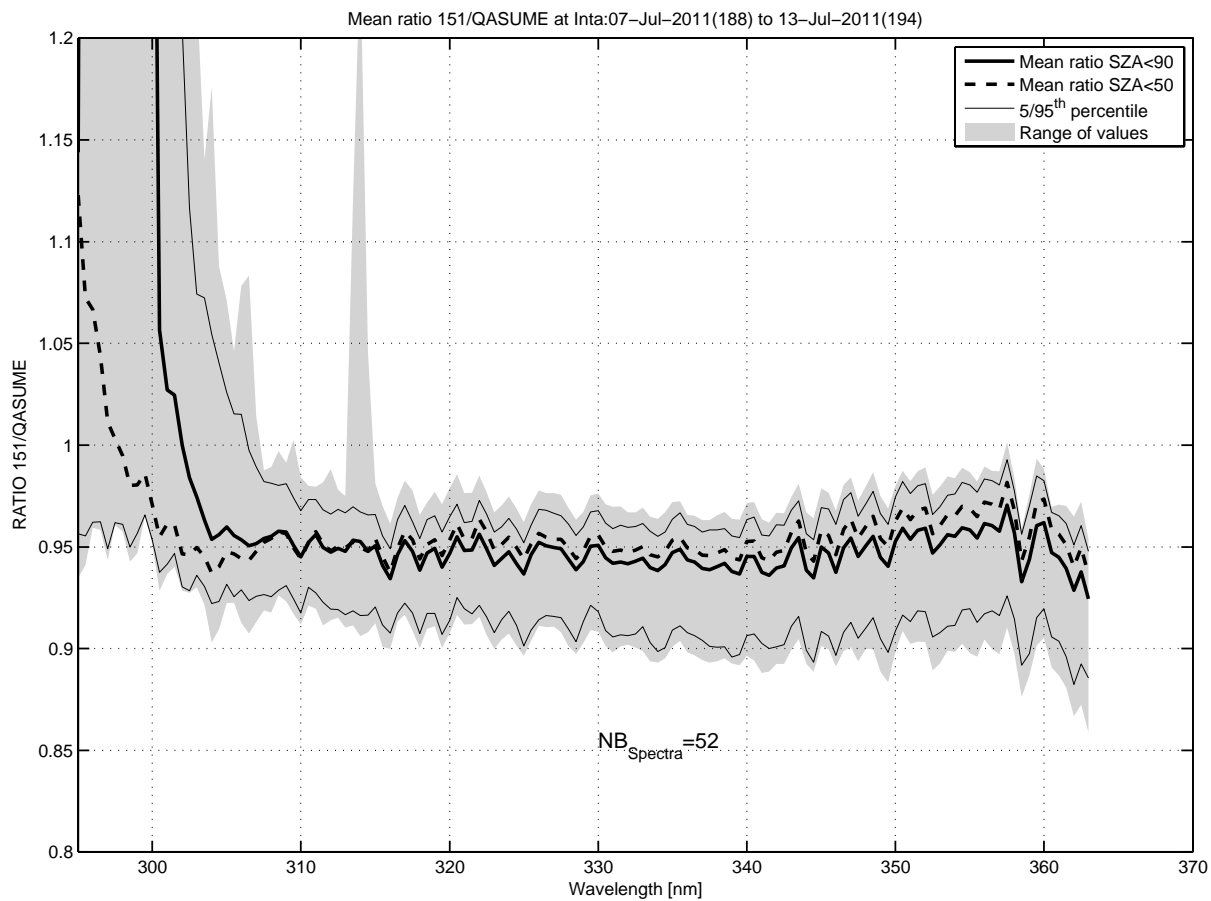
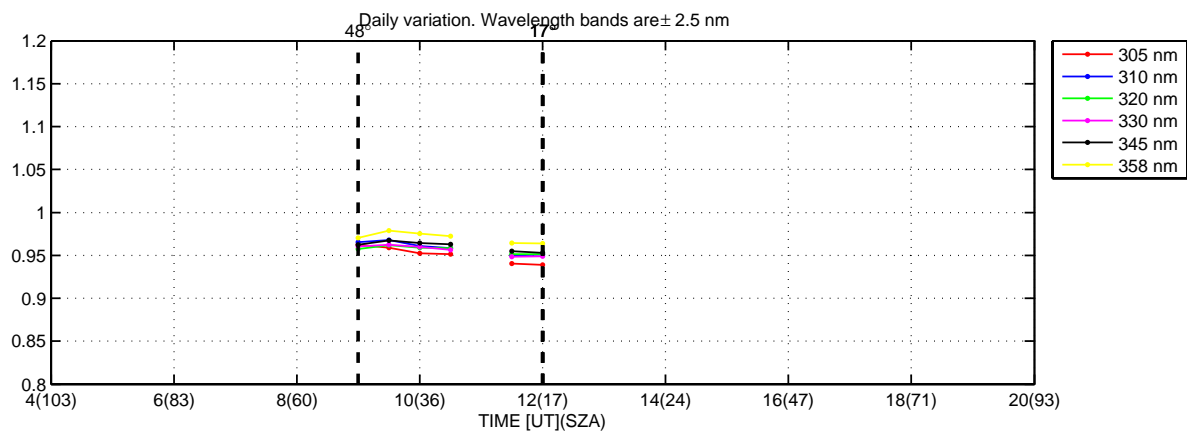
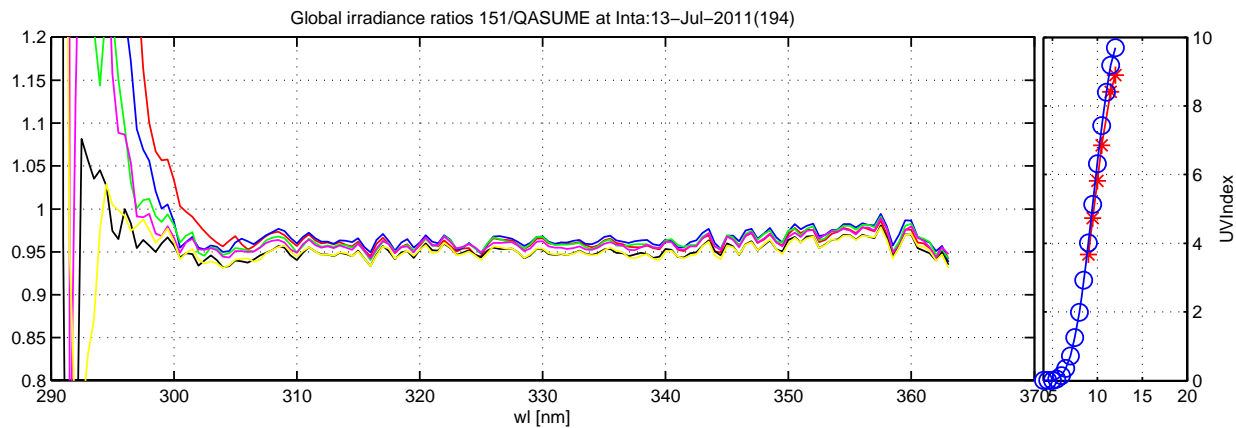
No Temperature Correction
Global irradiance ratios 150/QASUME at Inta:10-Jul-2011(191) to 10-Jul-2011(191)



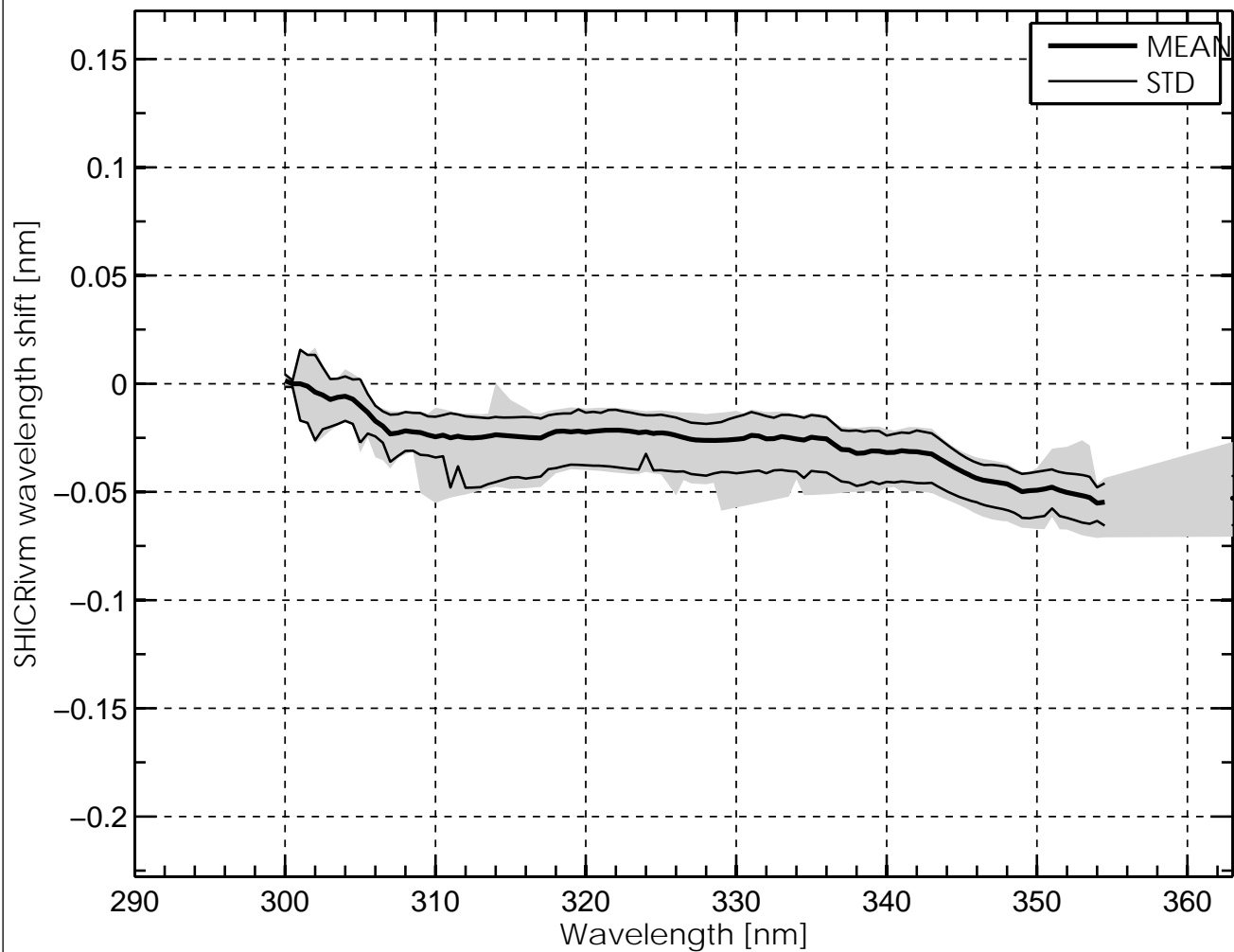




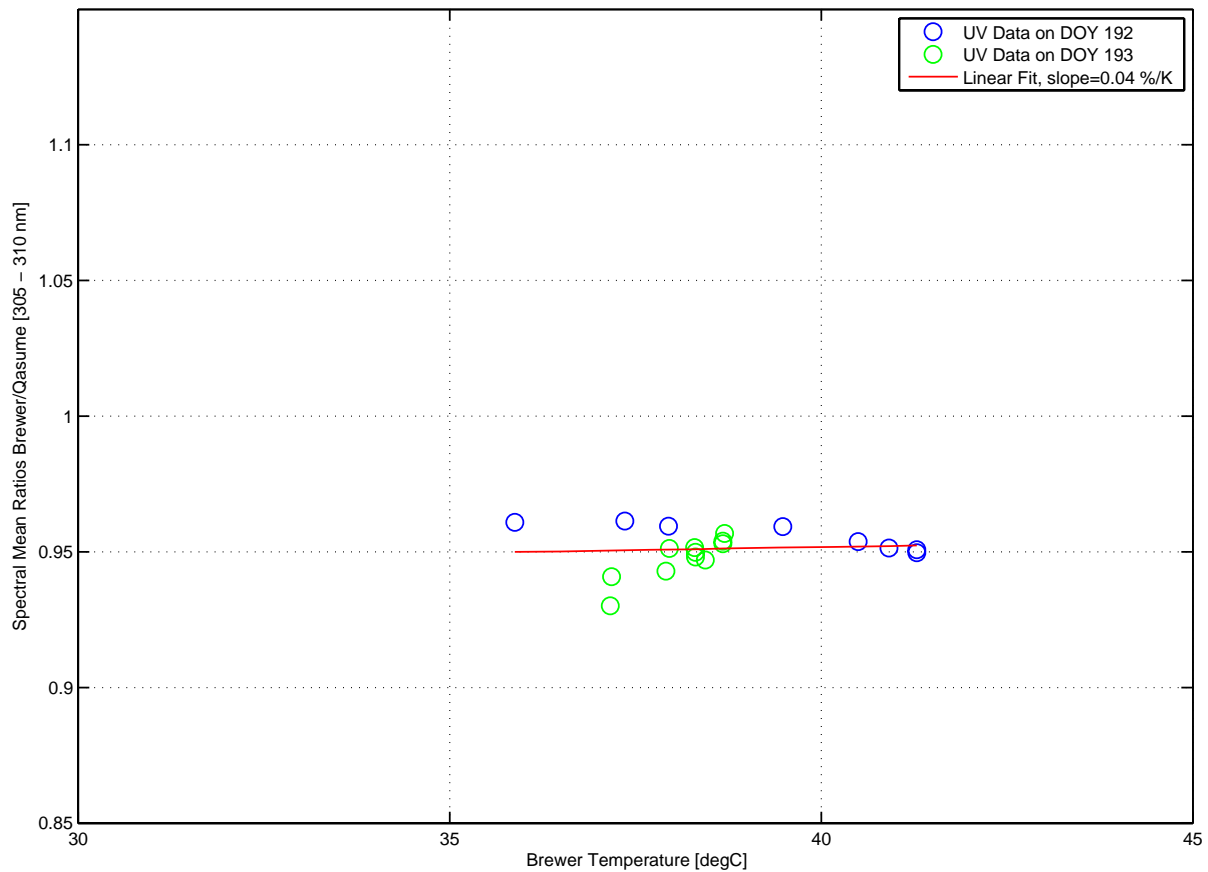




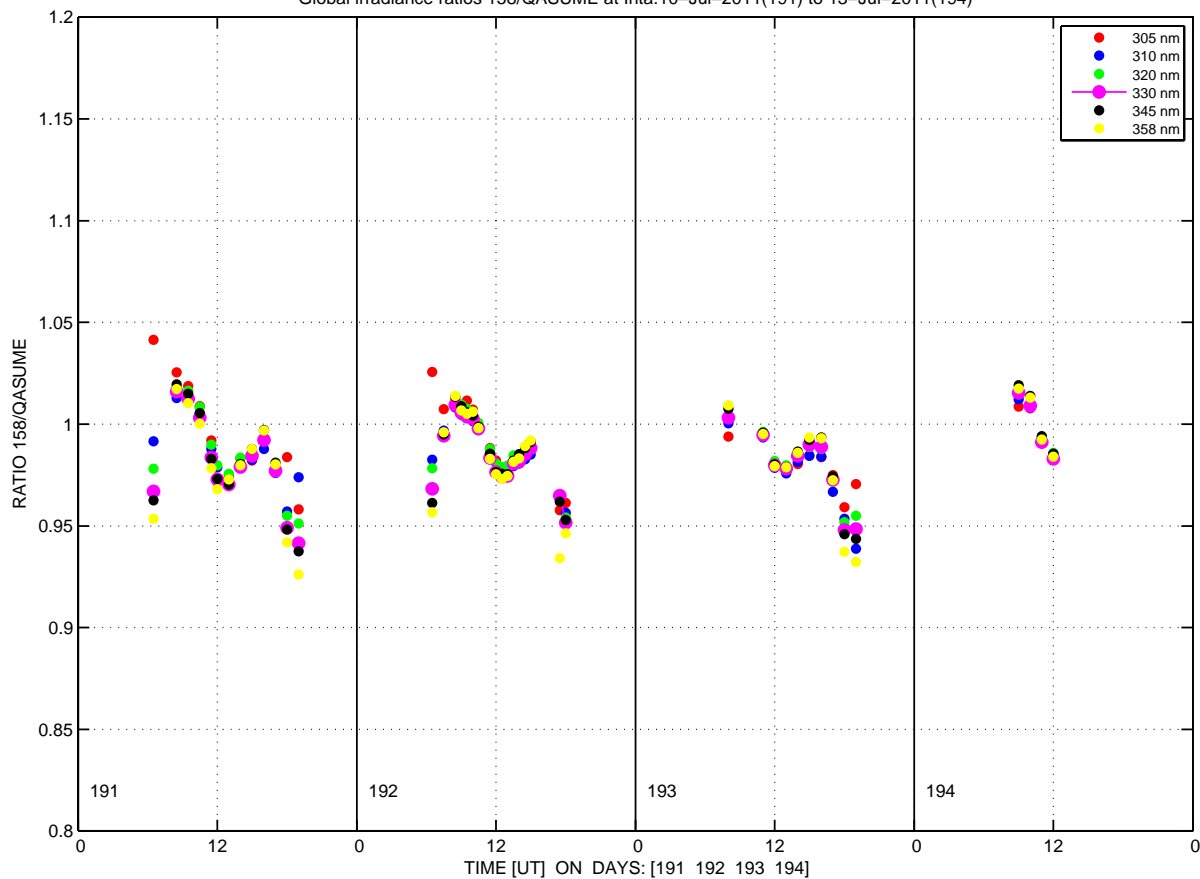
Intra, 151, July 2011



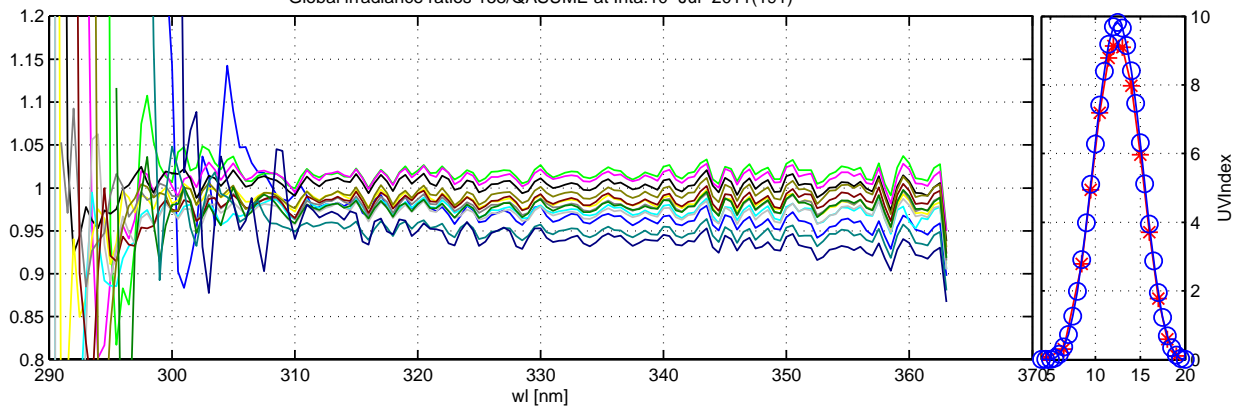
Temperature Dependence of Brewer #151, Intra, July 2011



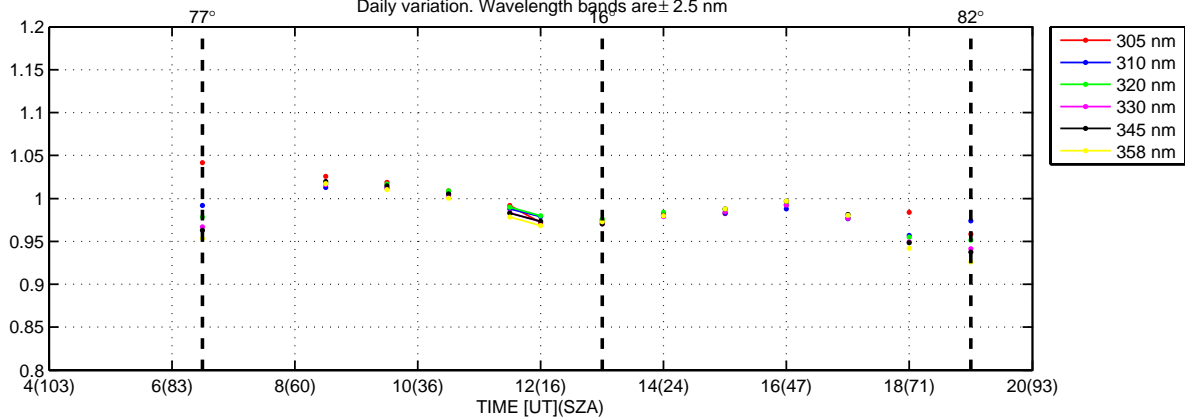
Global irradiance ratios 158/QASUME at Inta:10-Jul-2011(191) to 13-Jul-2011(194)

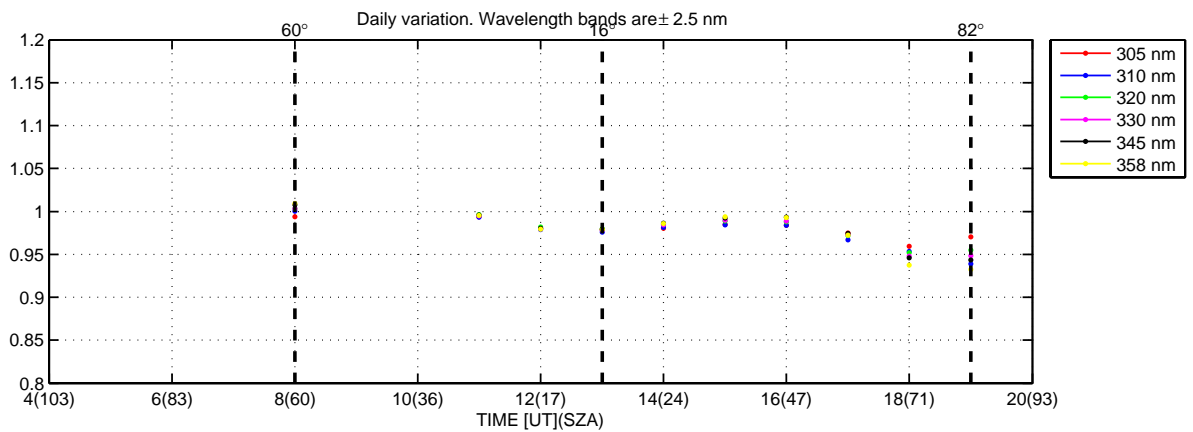
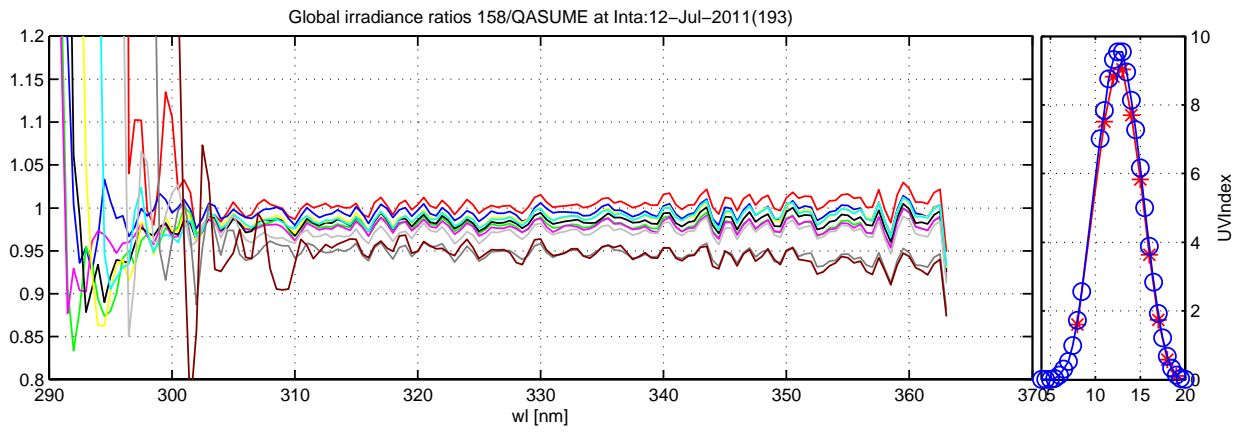
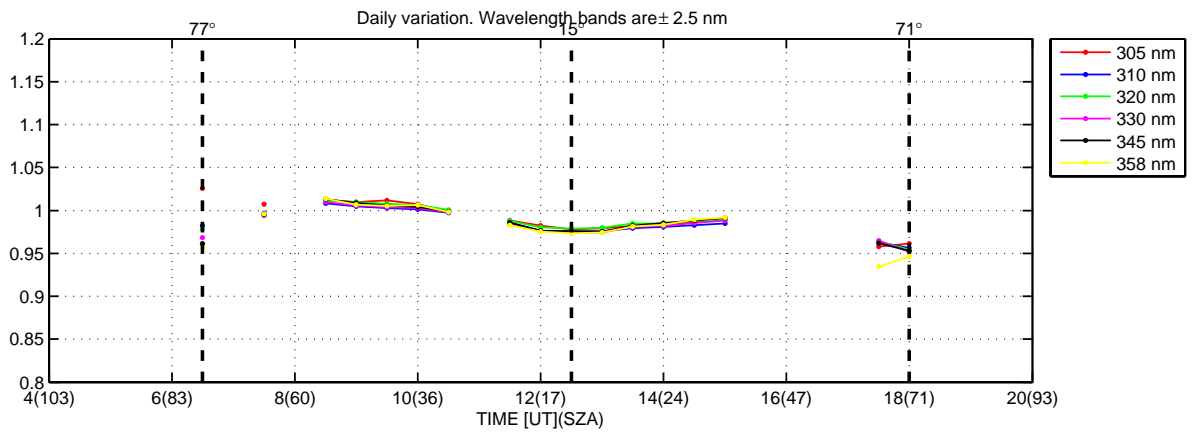
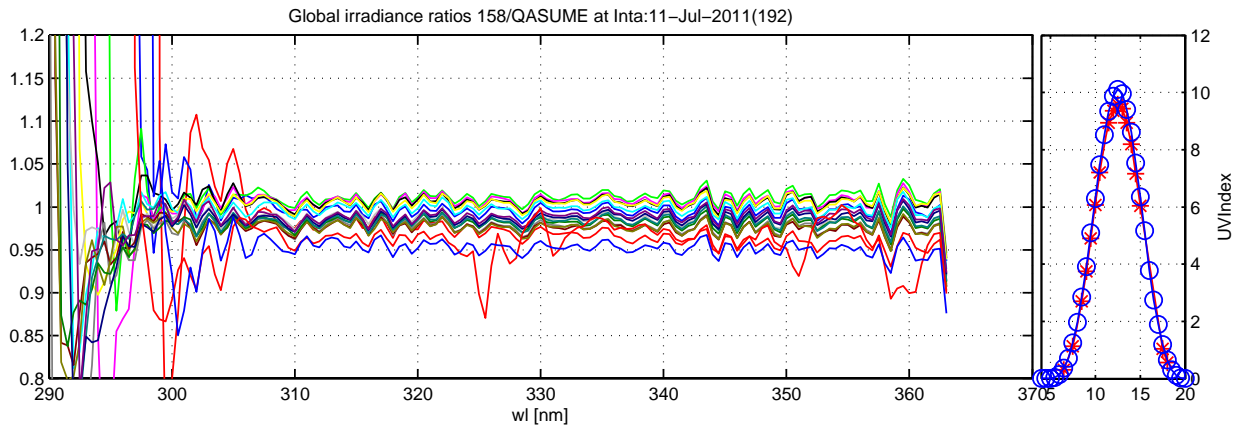


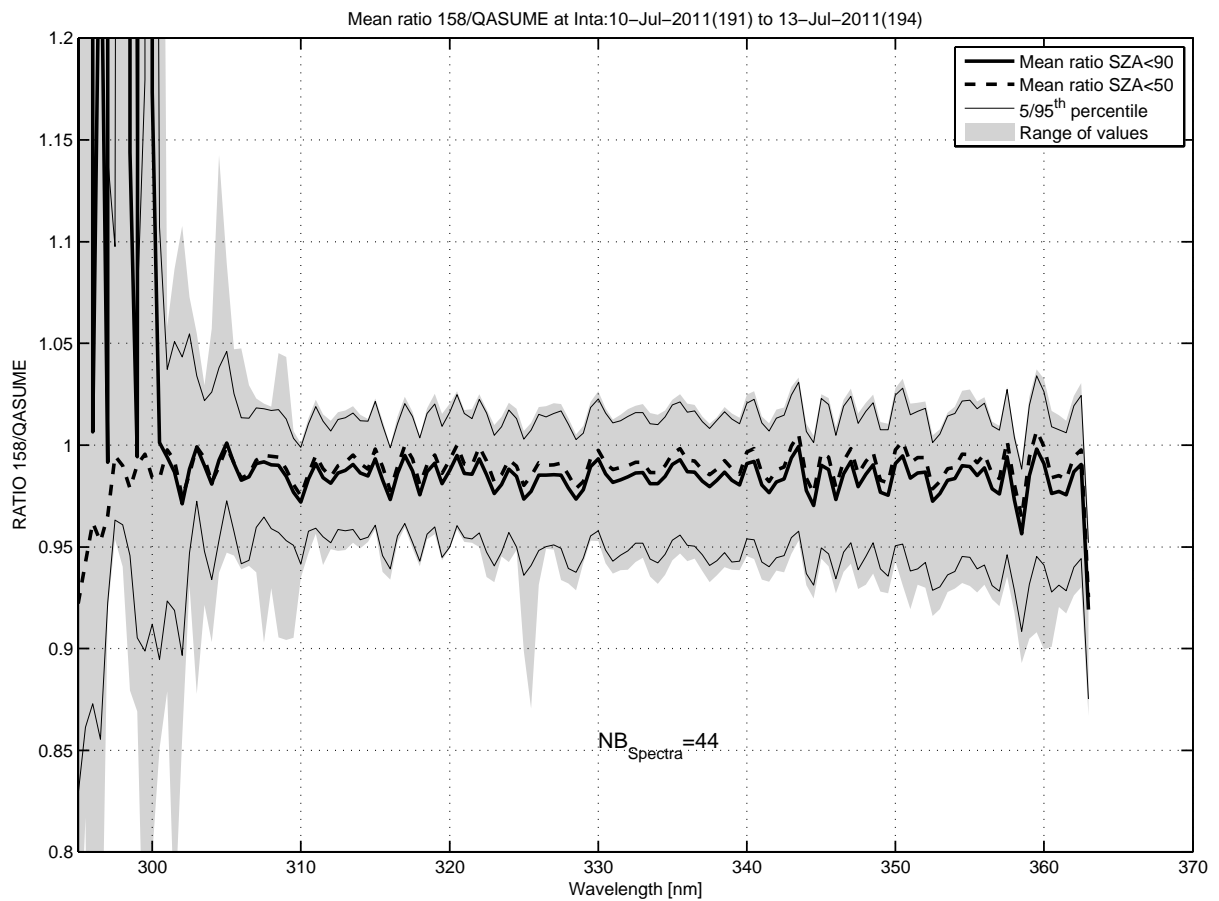
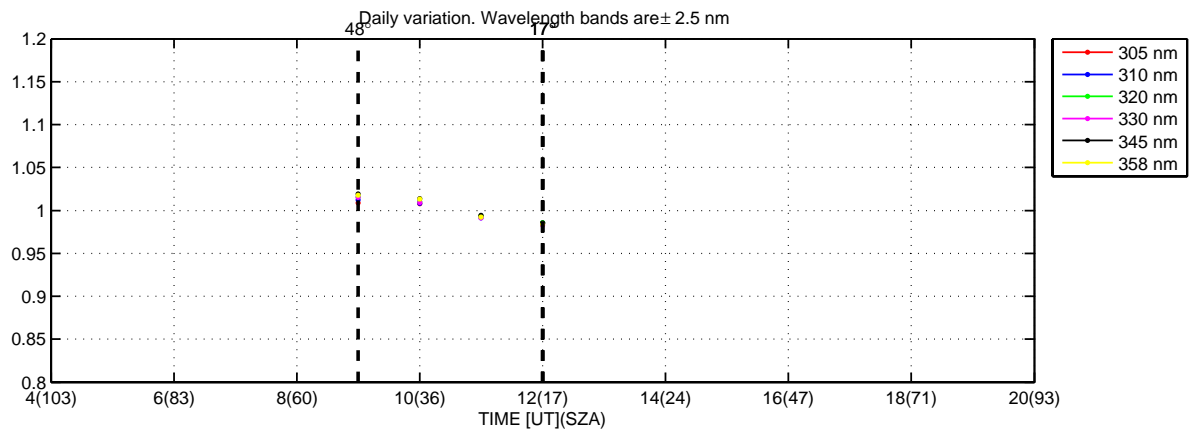
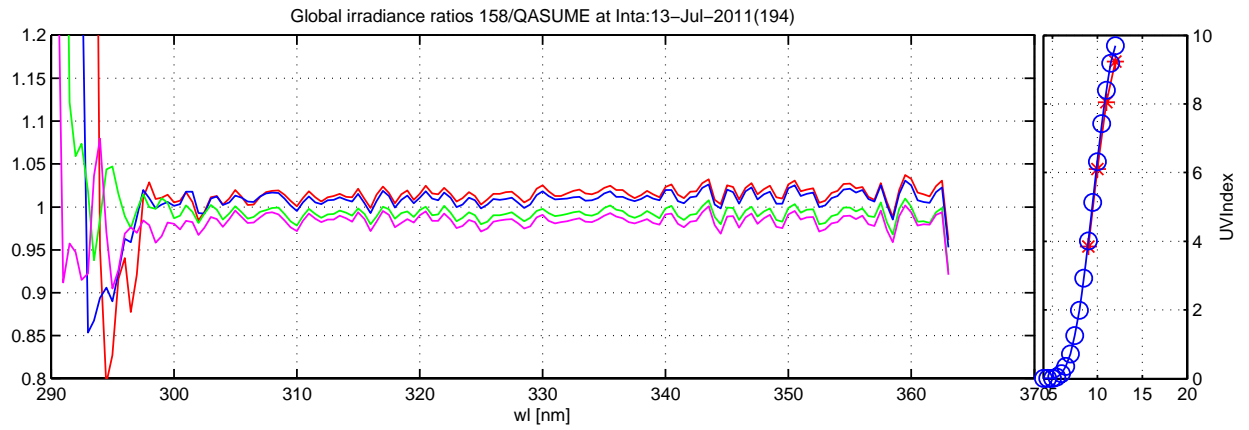
Global irradiance ratios 158/QASUME at Inta:10-Jul-2011(191)



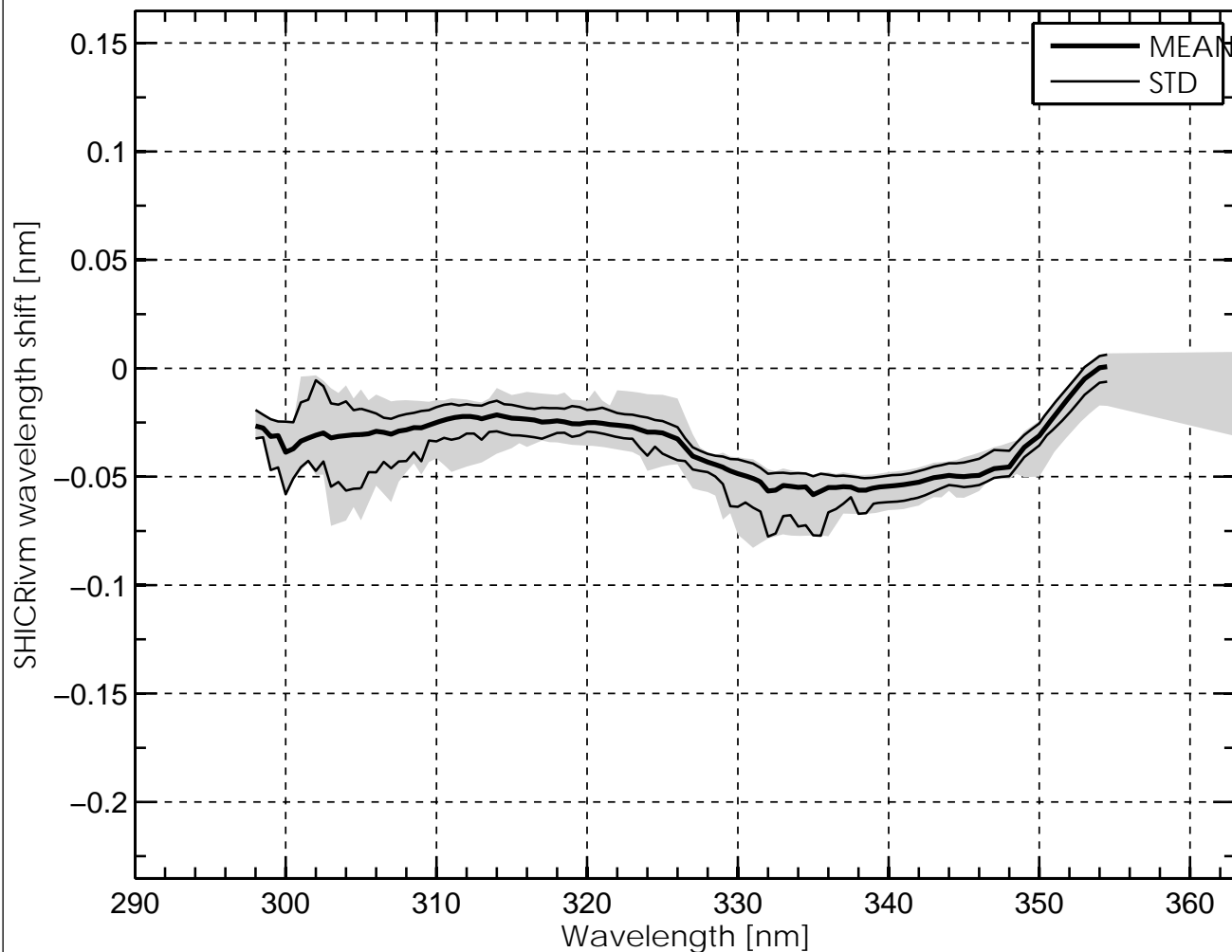
Daily variation. Wavelength bands are ± 2.5 nm



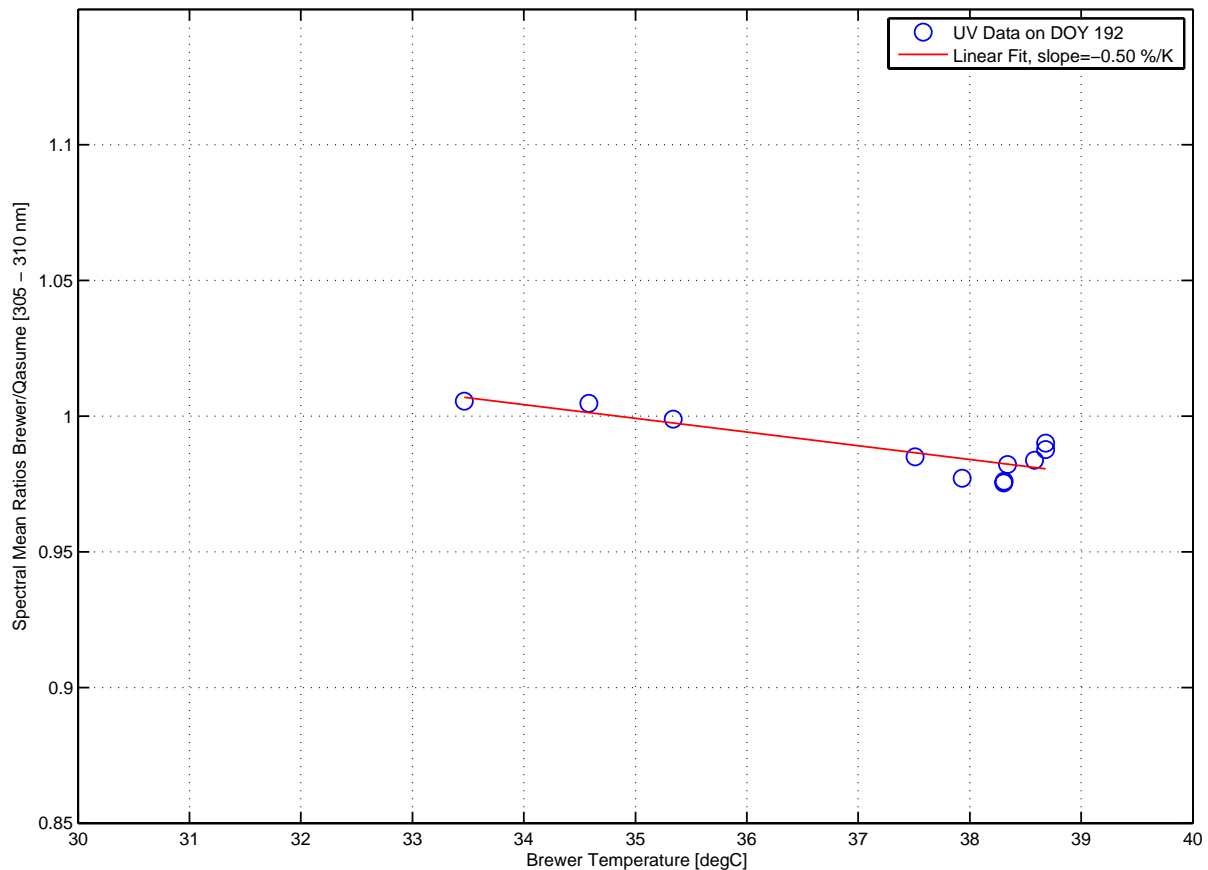


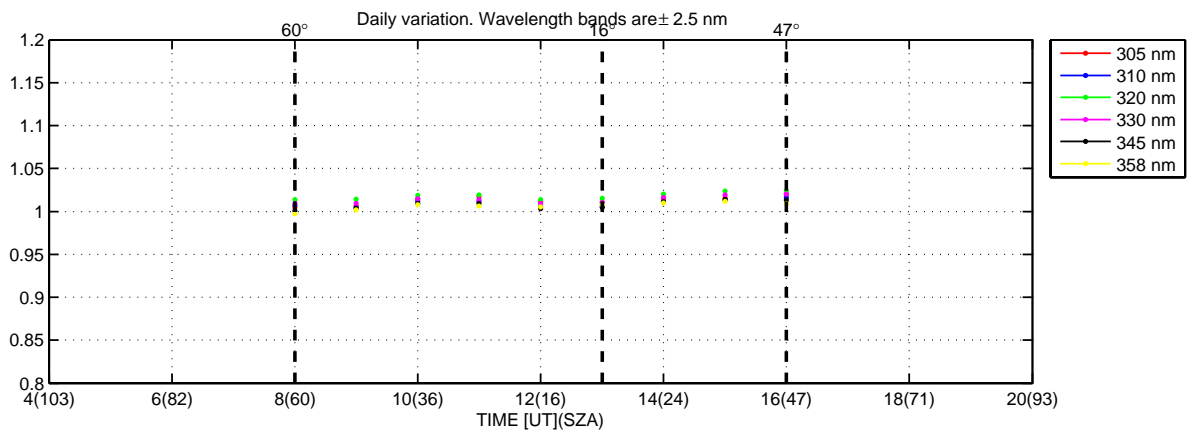
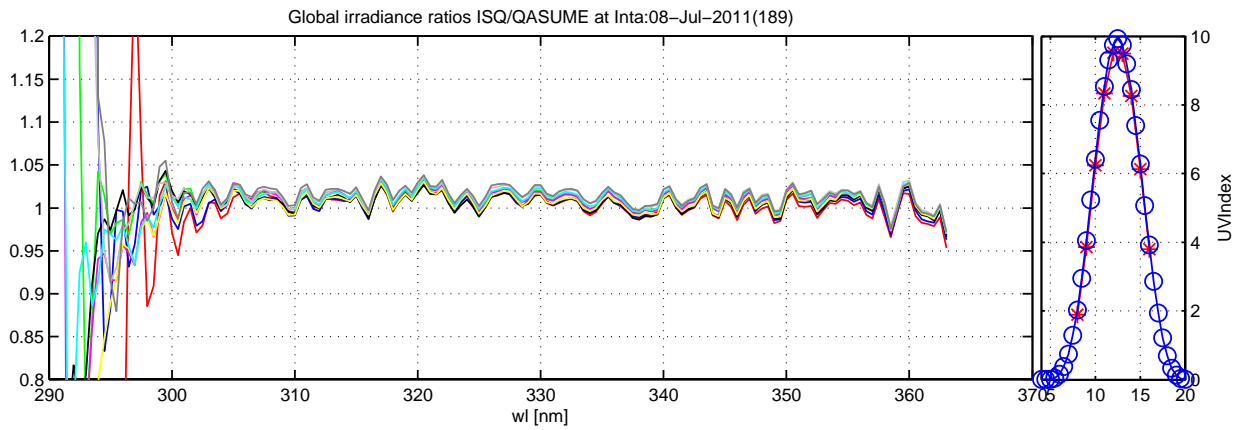
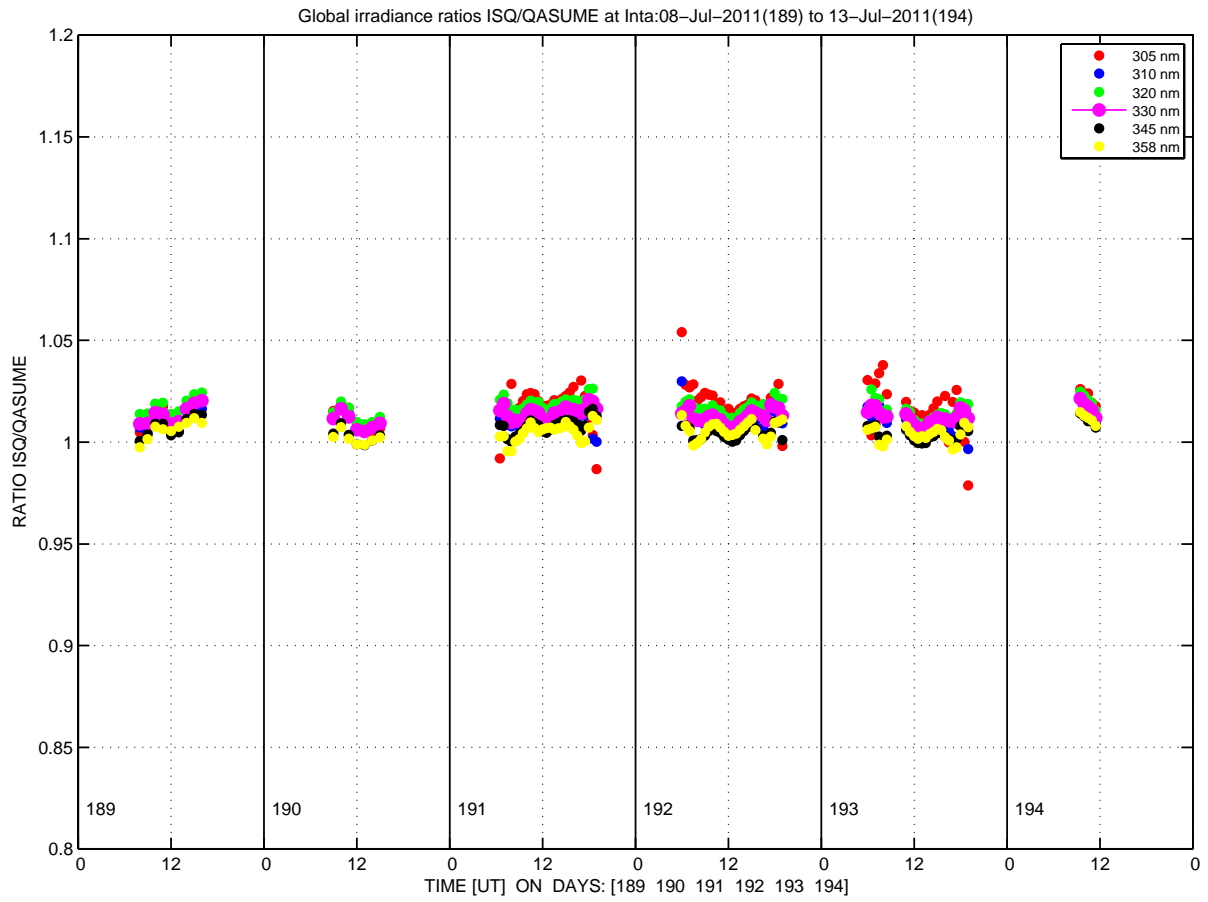


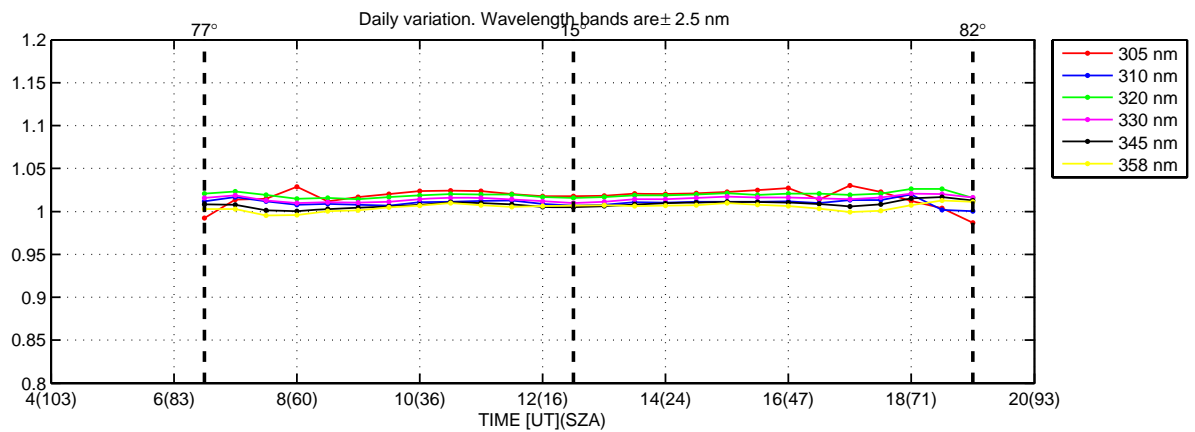
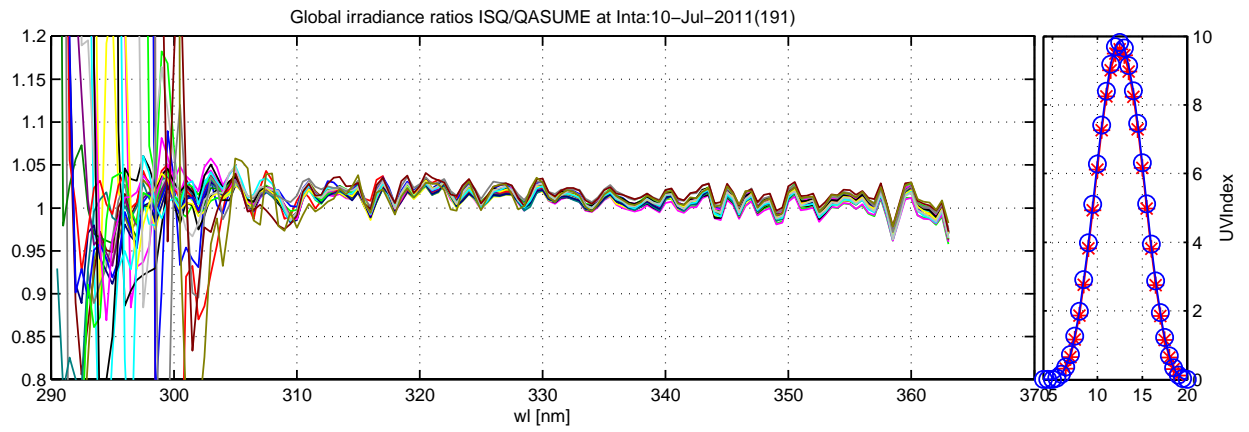
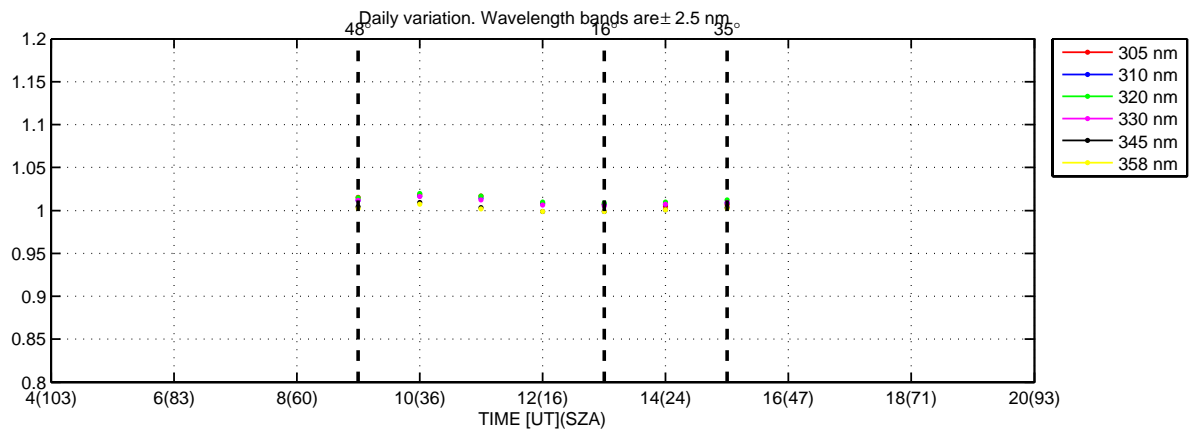
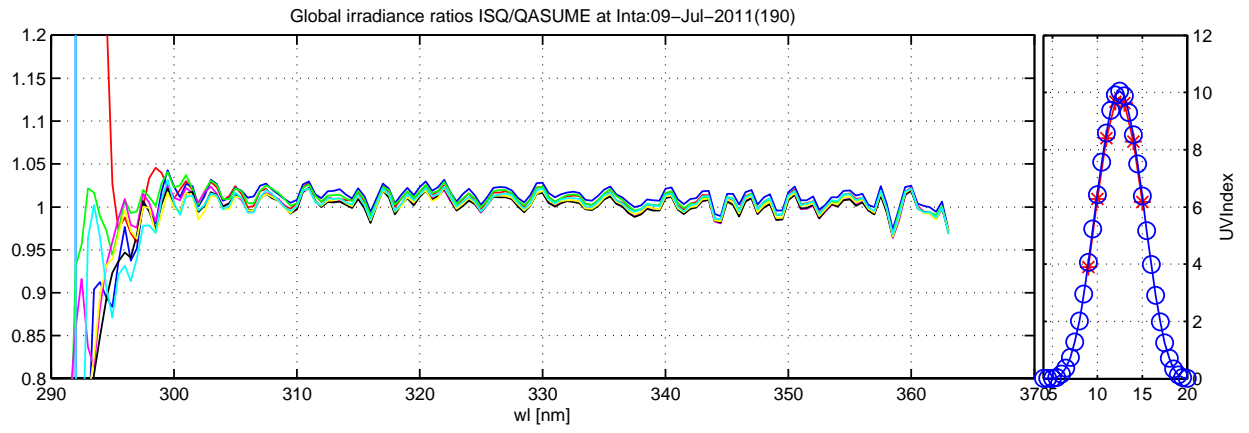
Inta, 158, July 2011

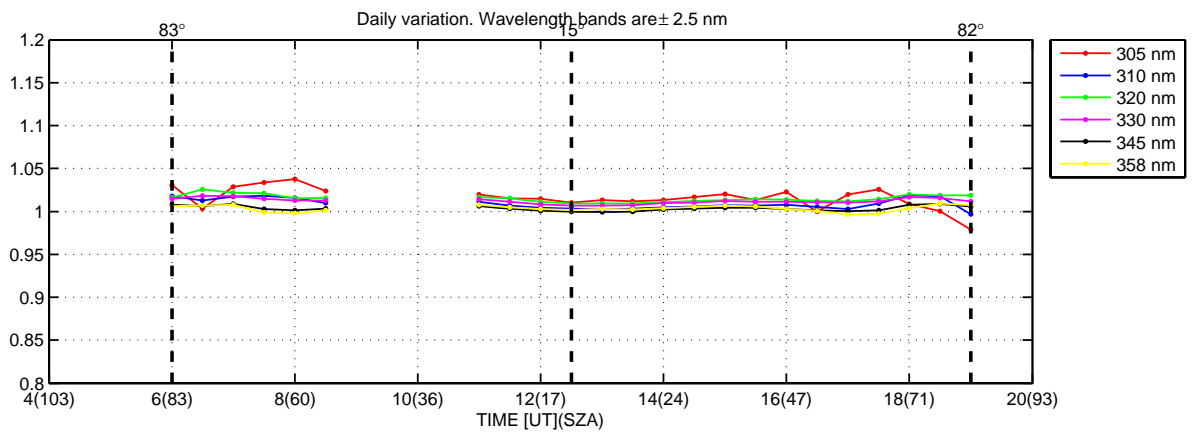
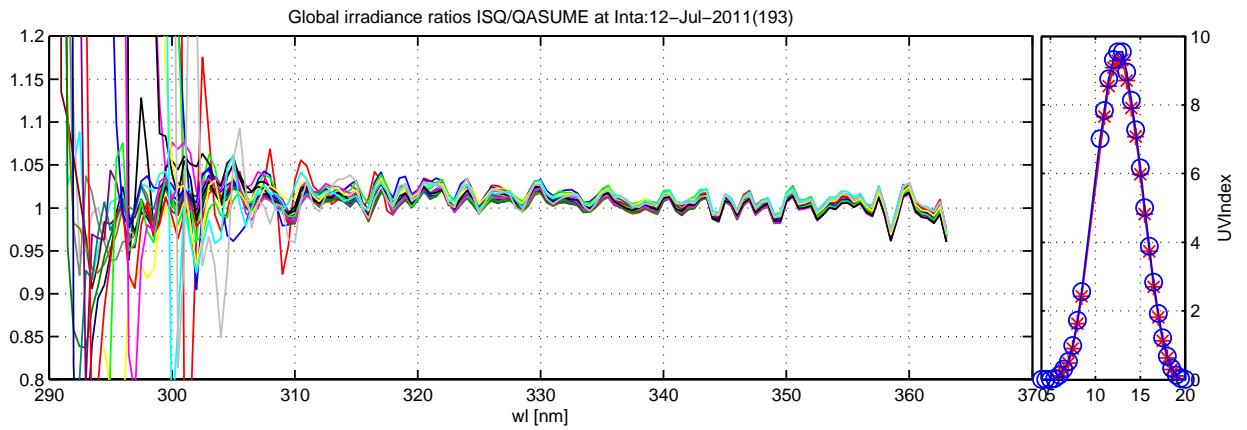
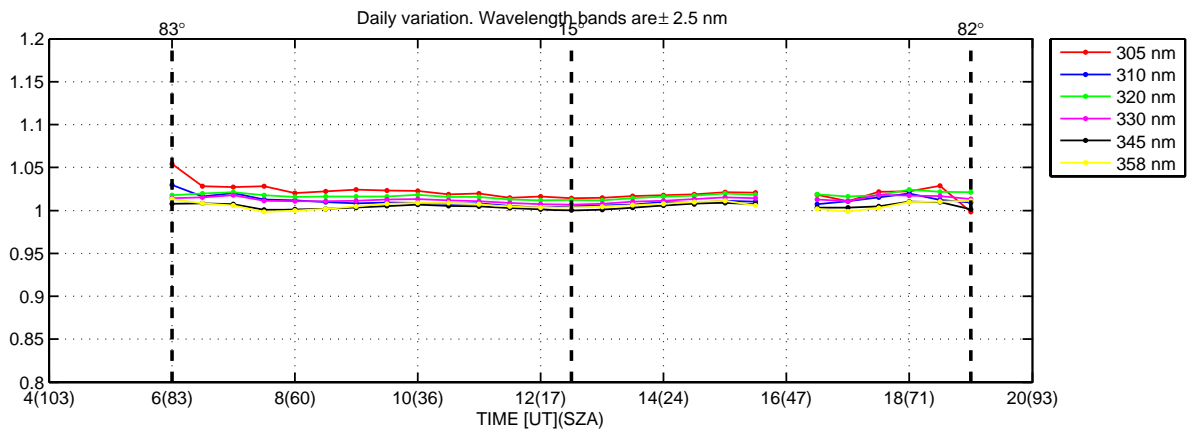
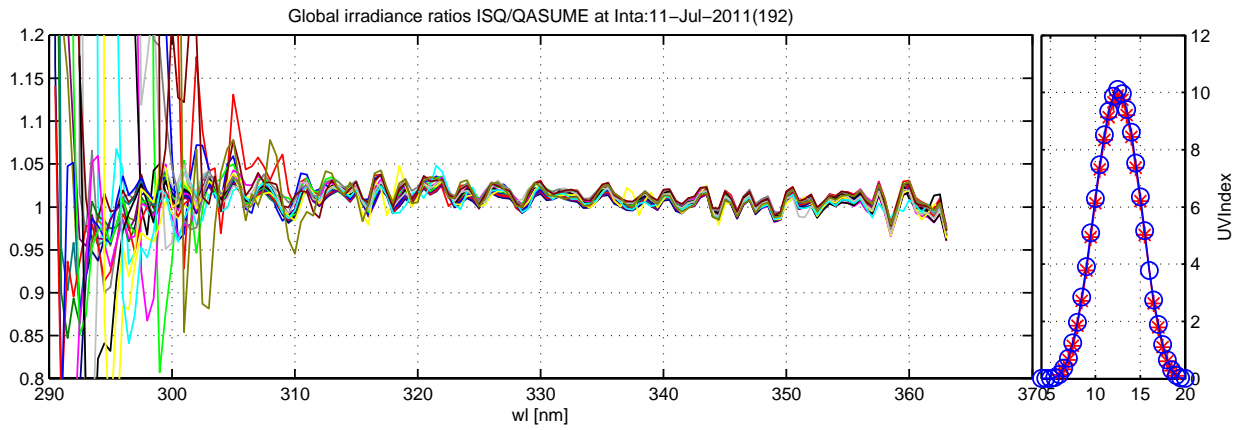


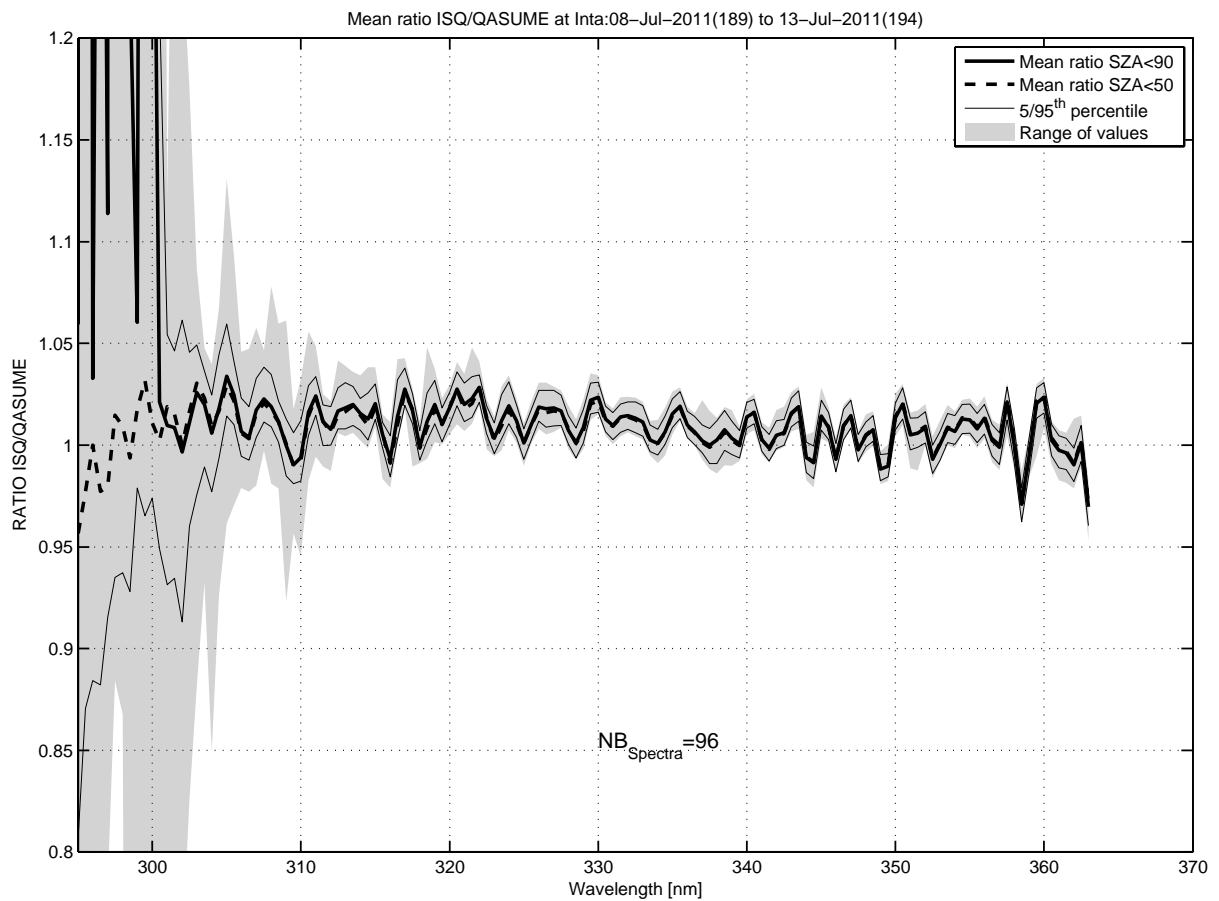
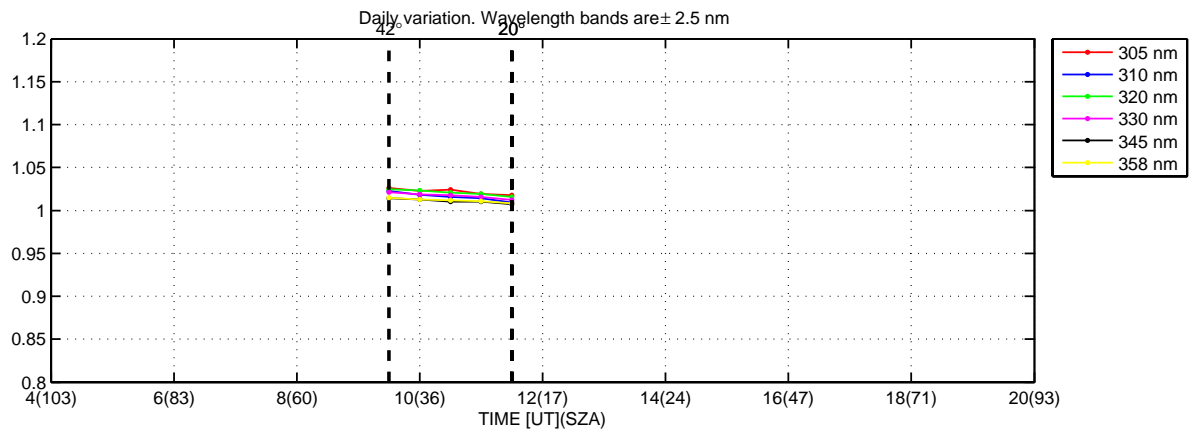
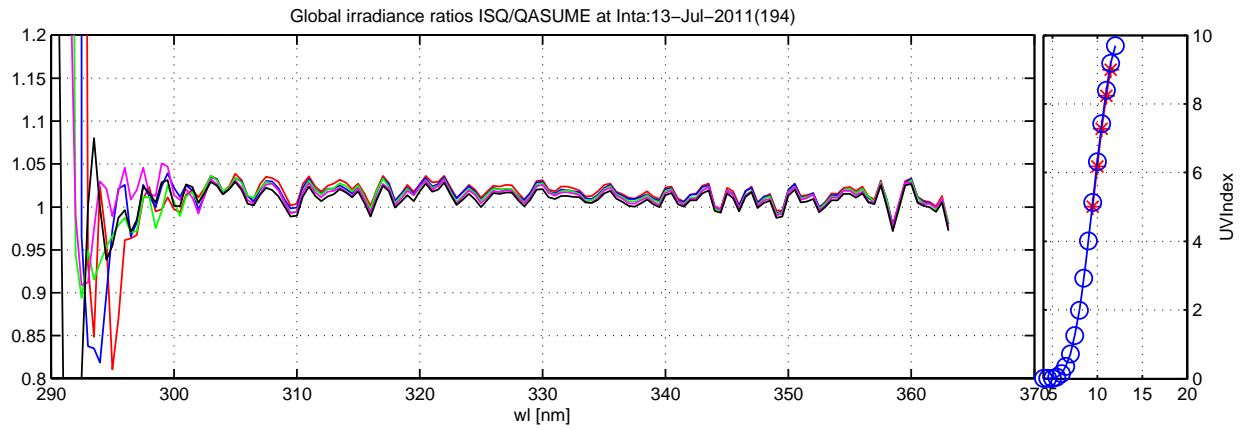
Temperature Dependence of Brewer #158, Inta, July 2011



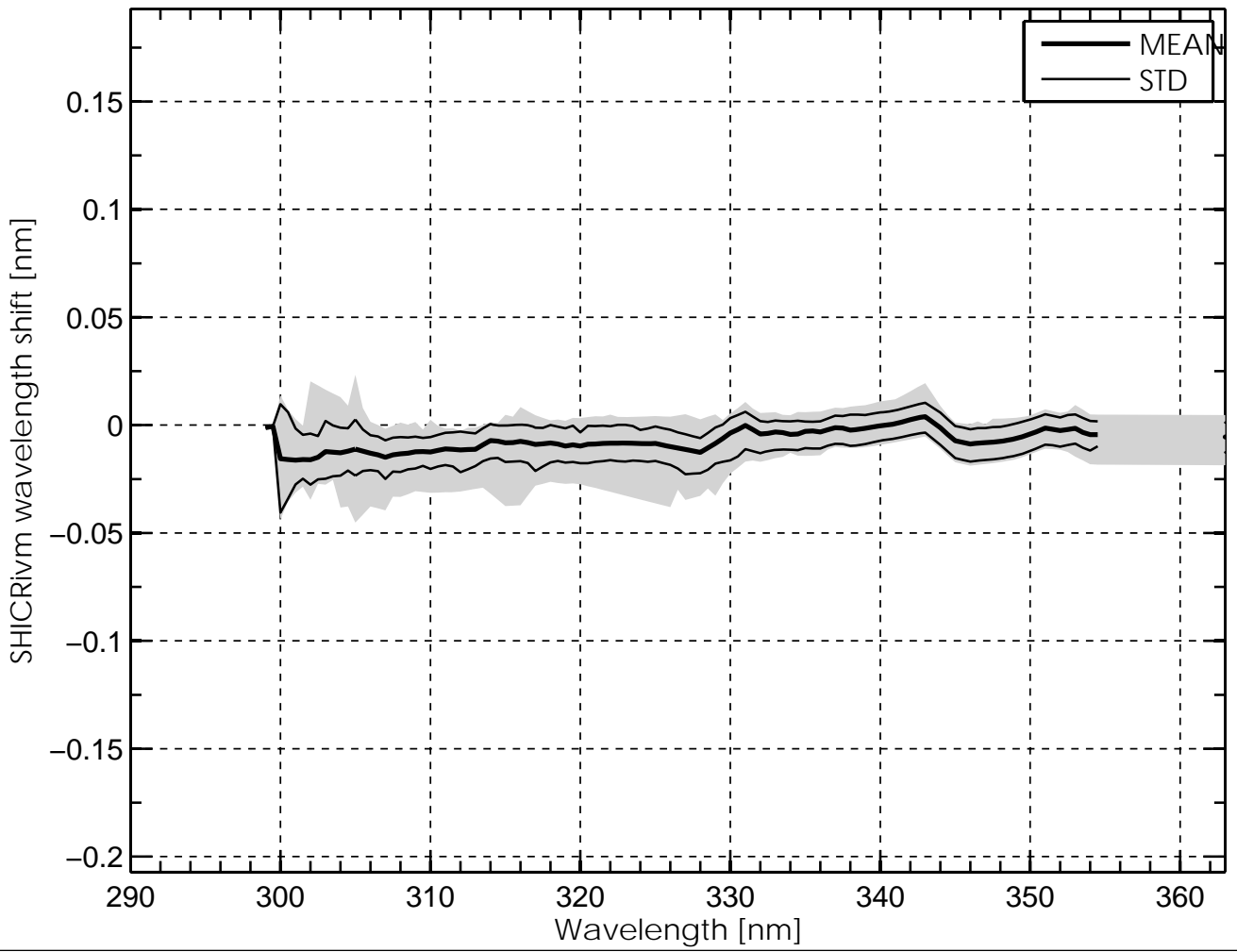




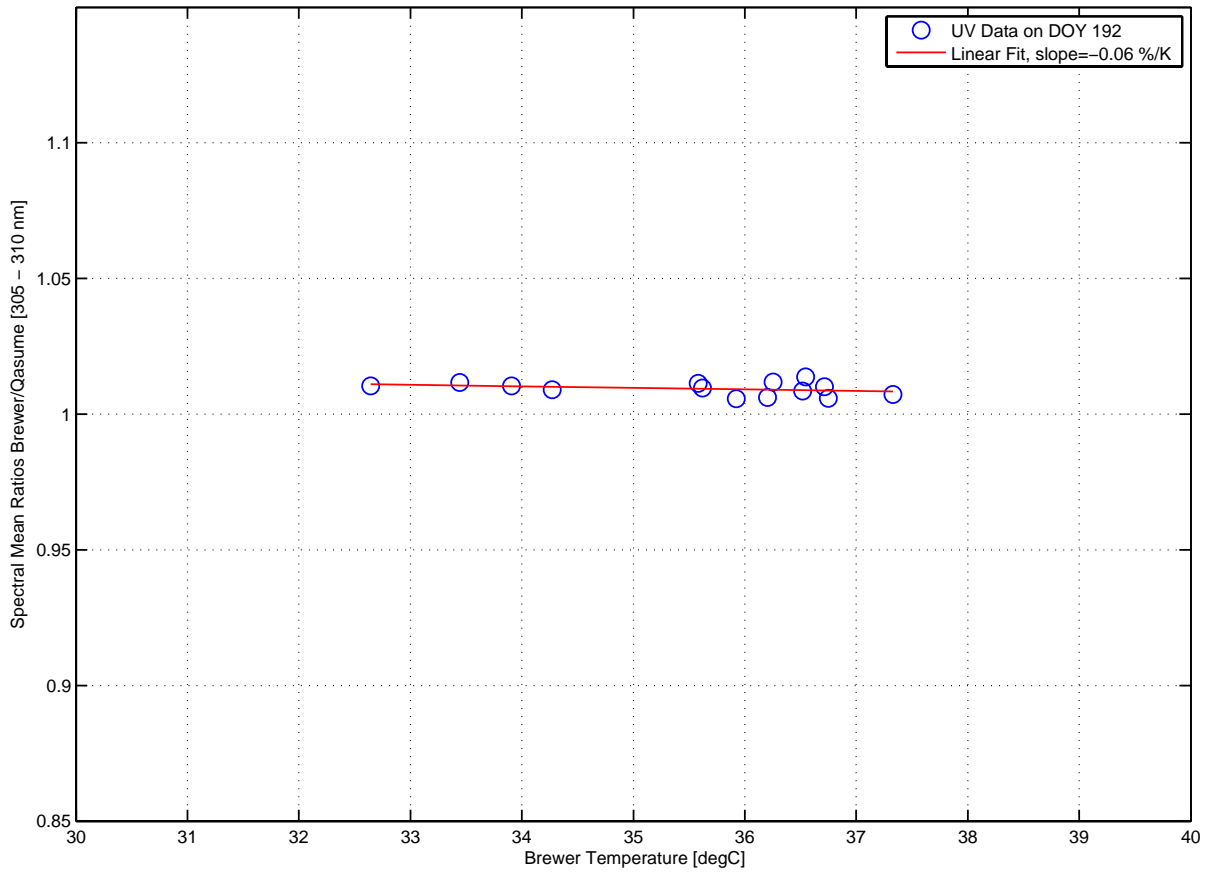


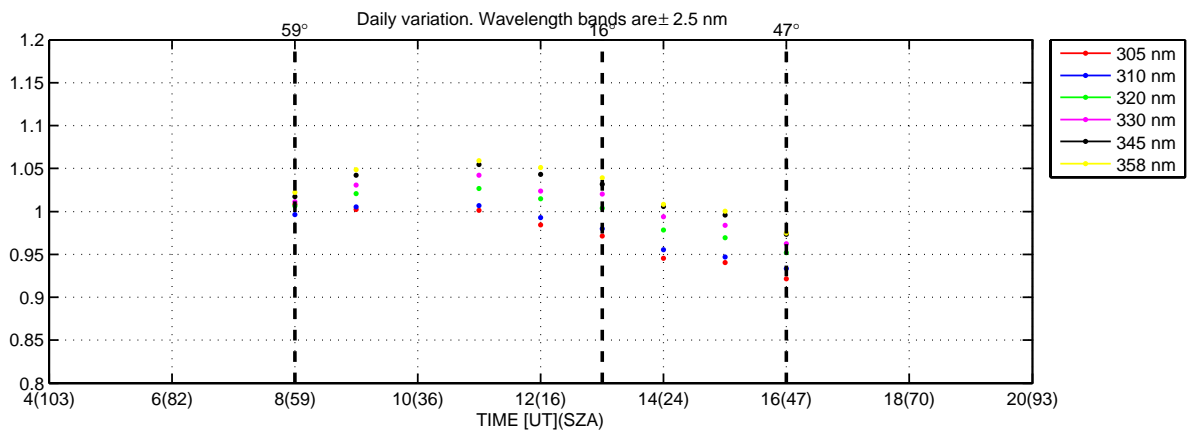
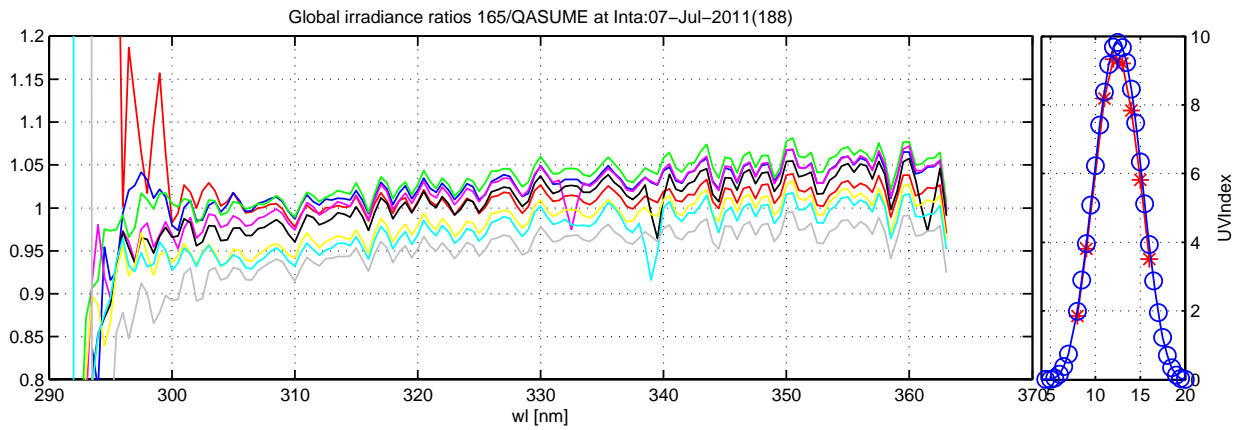
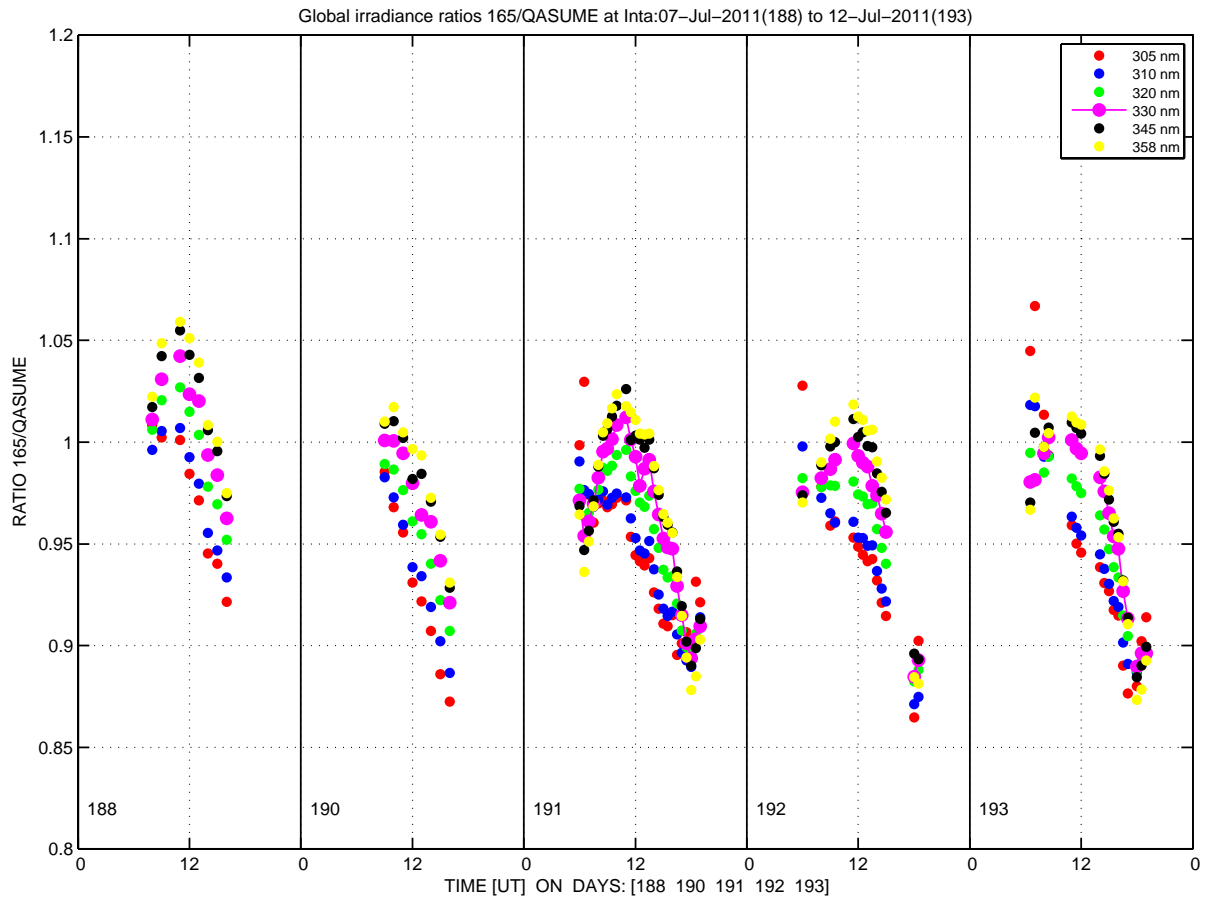


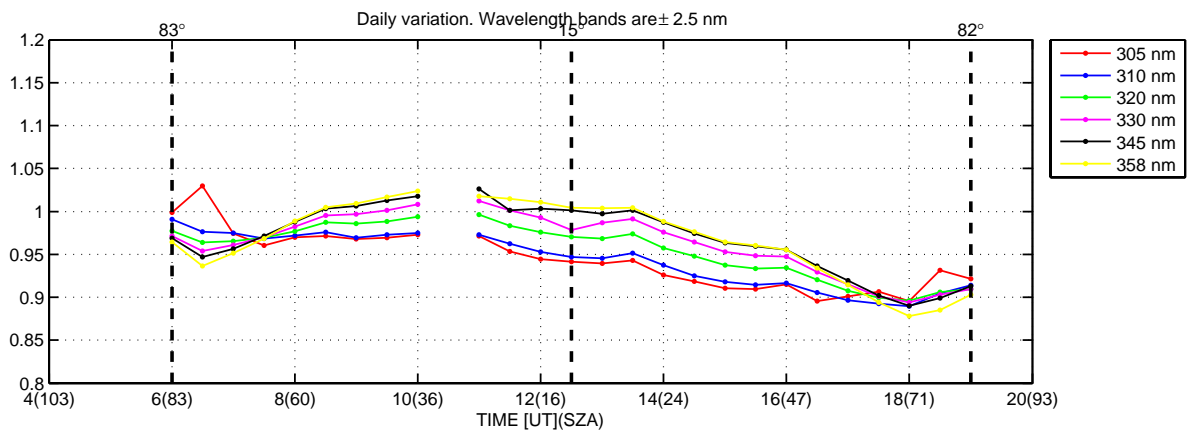
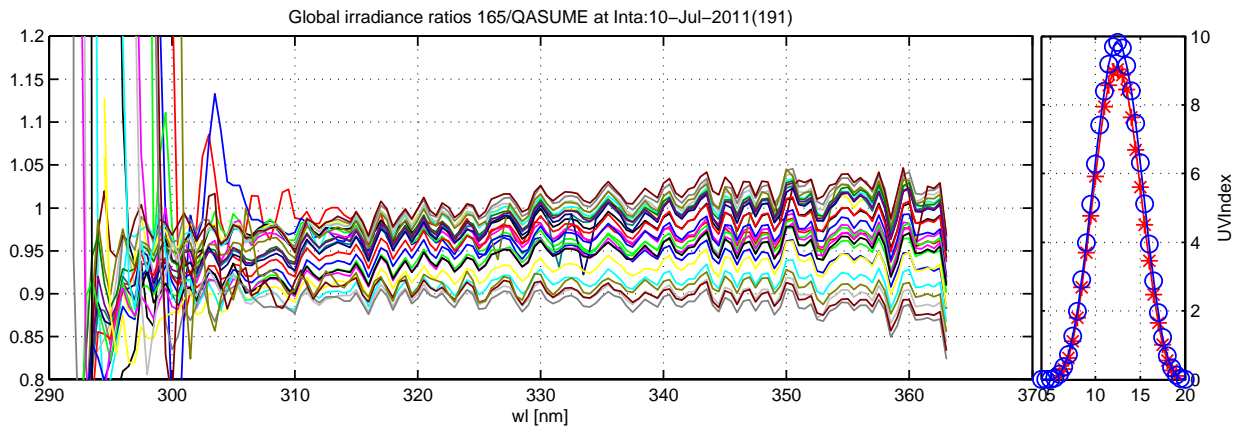
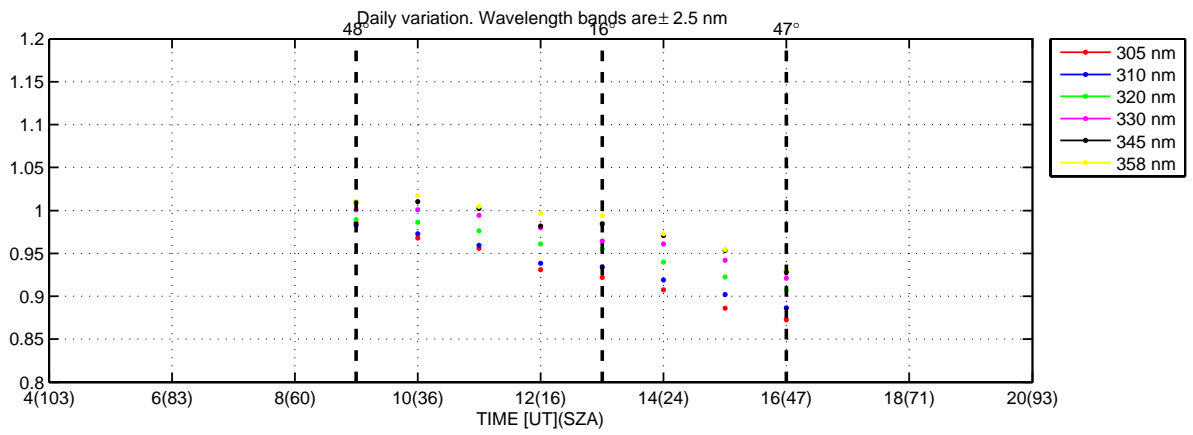
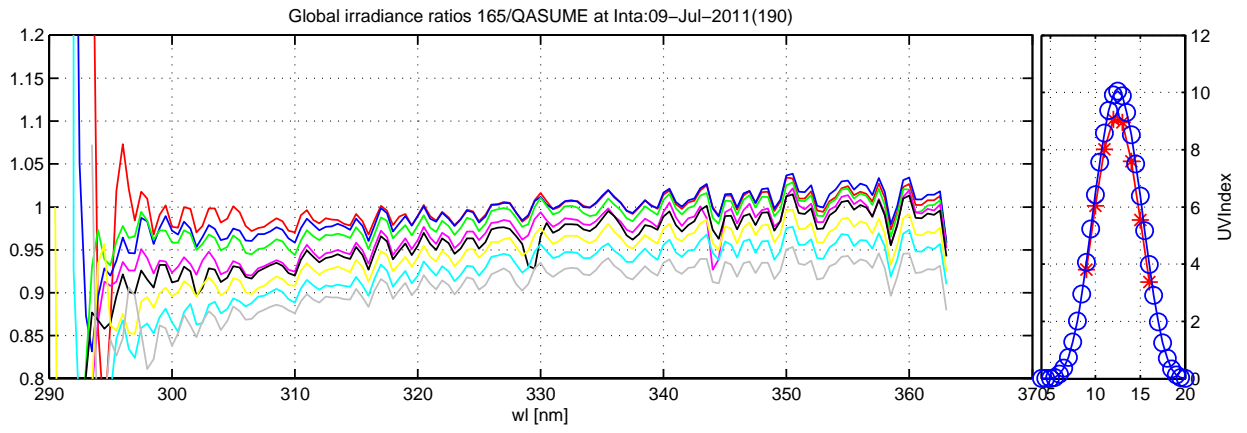
Intra, ISQ, July 2011

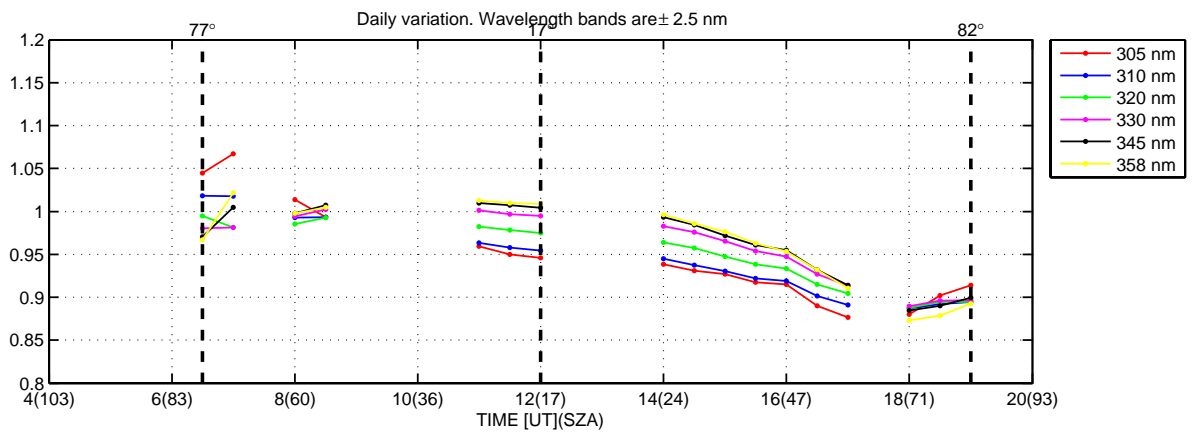
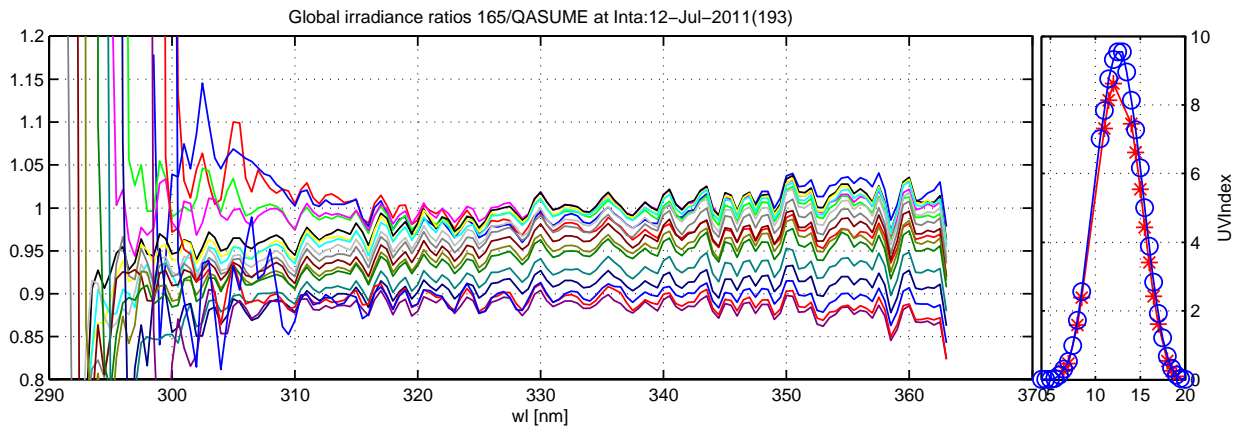
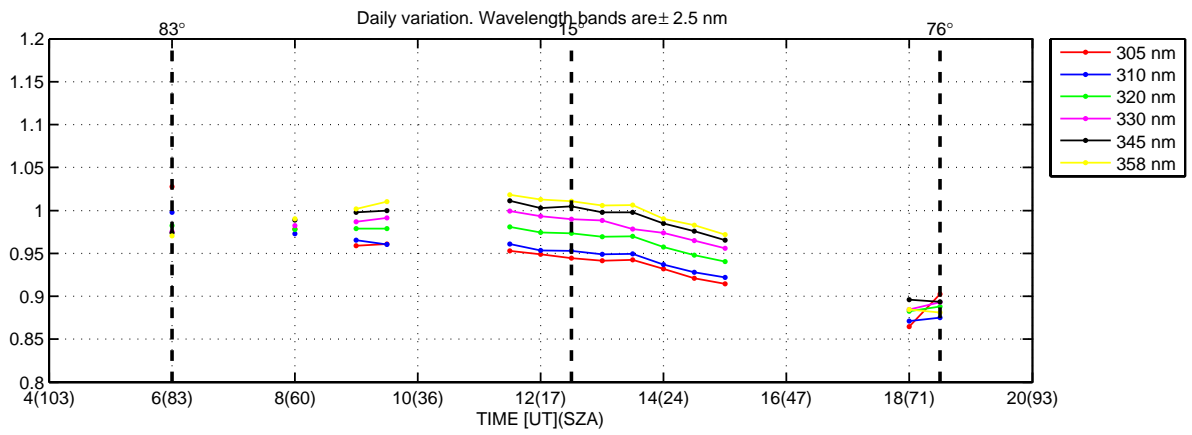
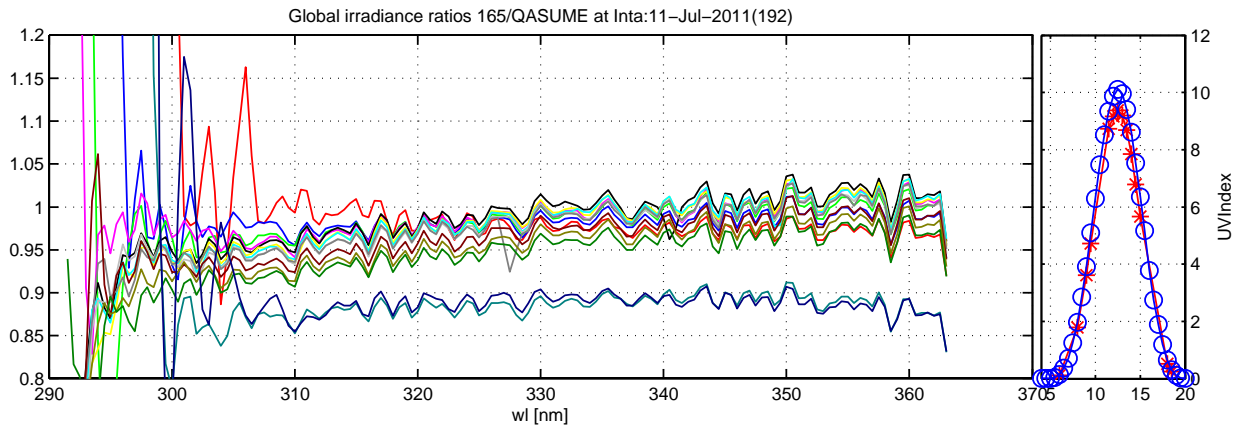


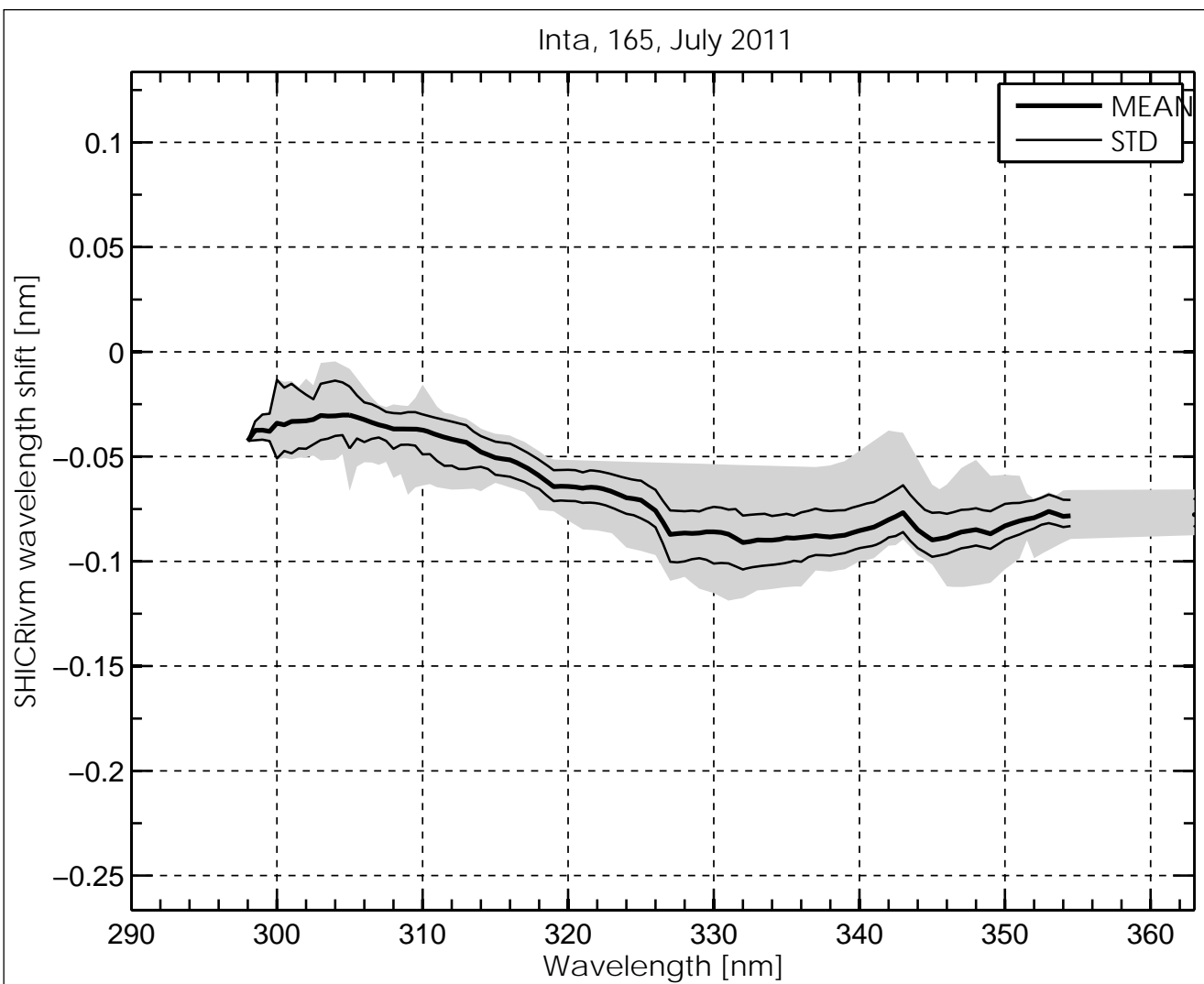
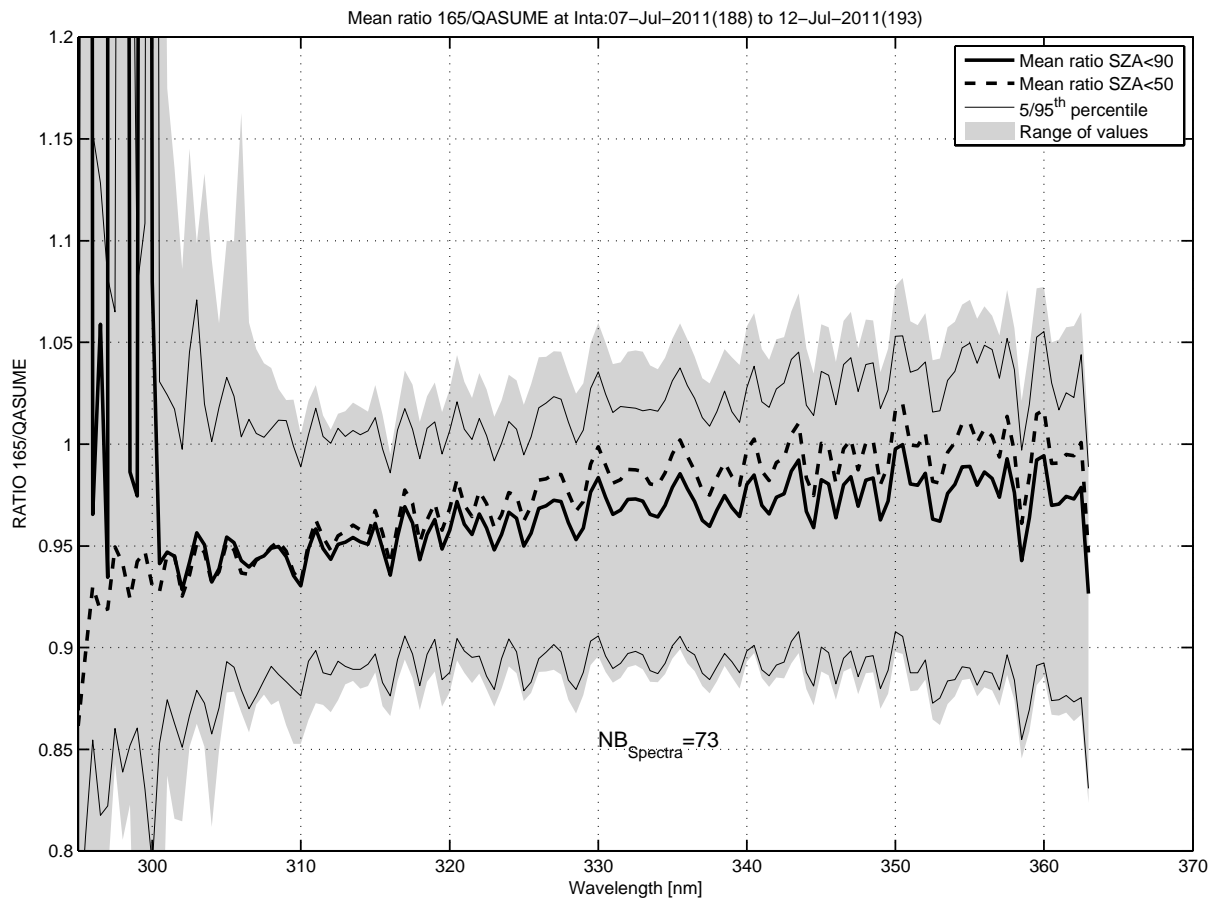
Temperature Dependence of Brewer #isq, Intra, July 2011



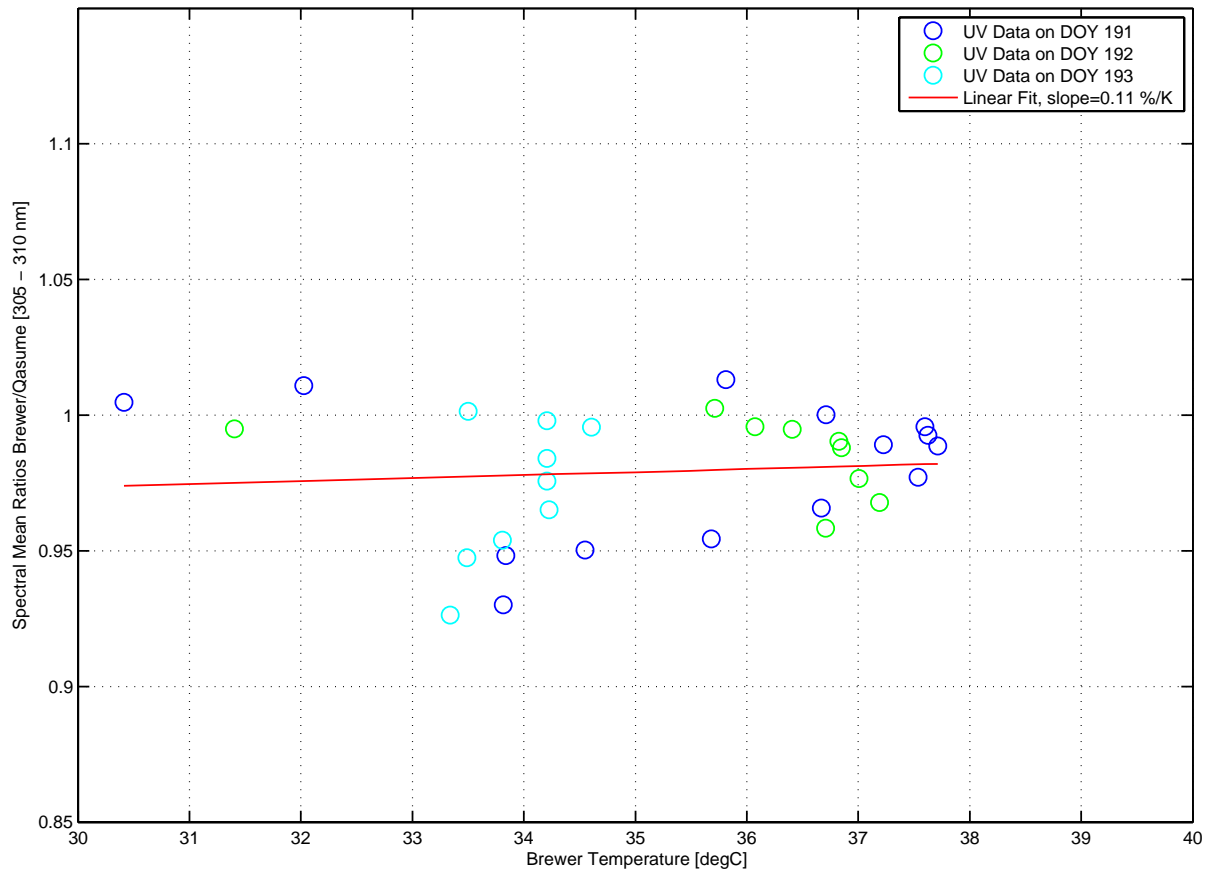


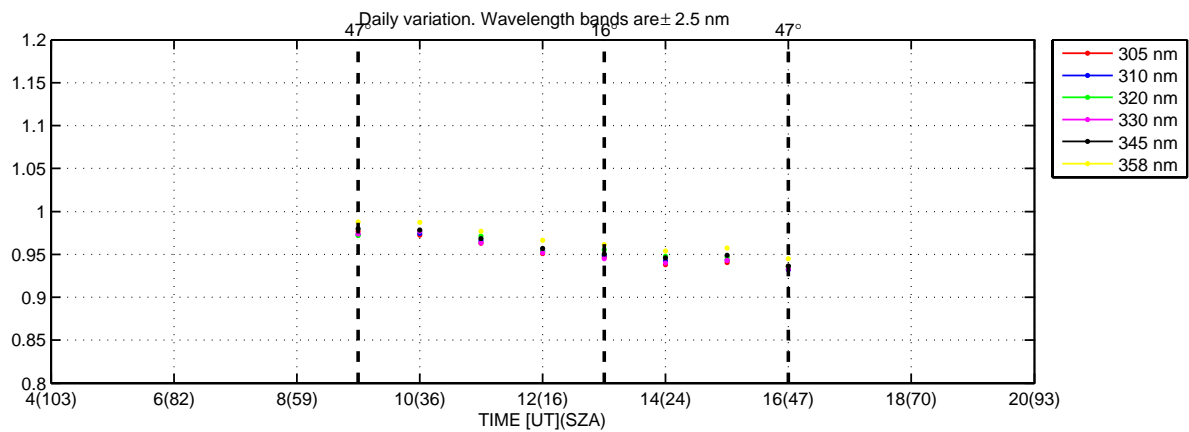
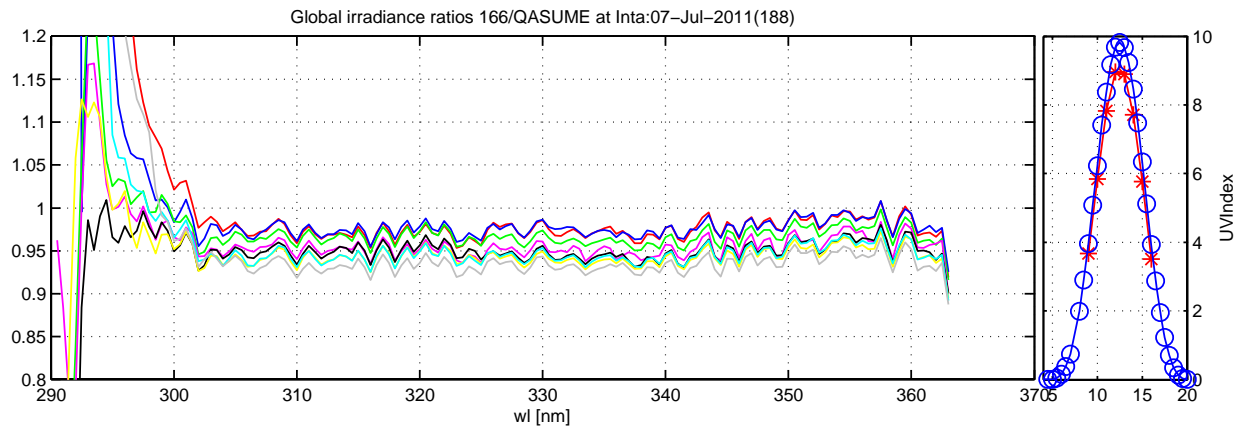
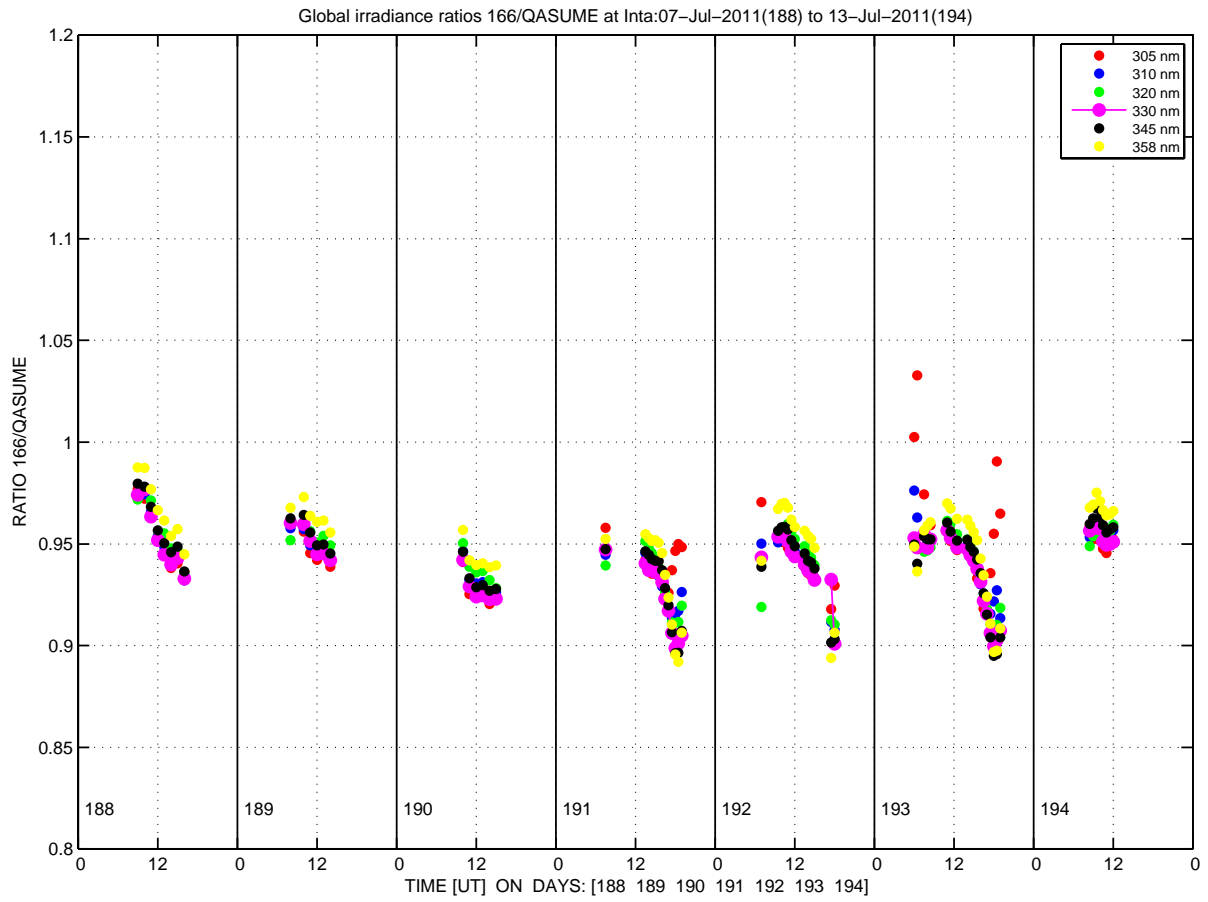


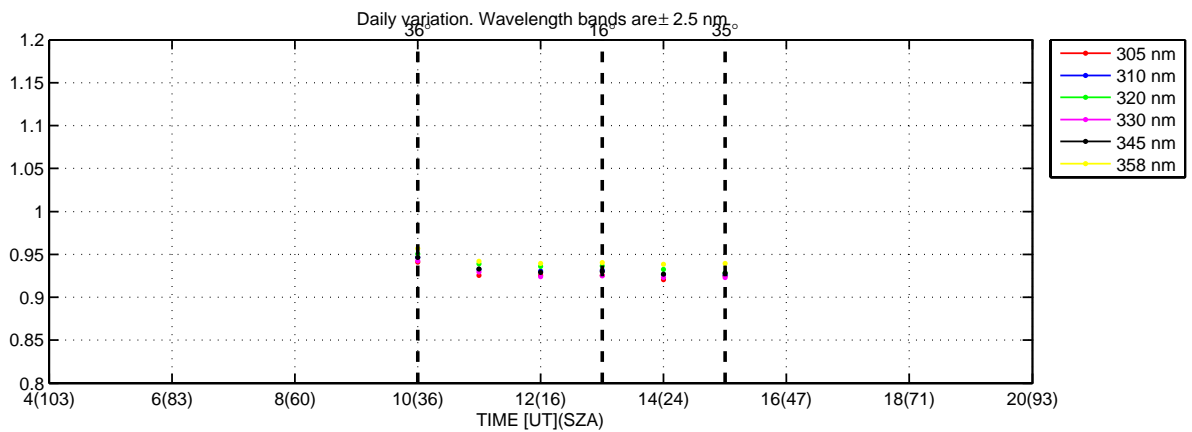
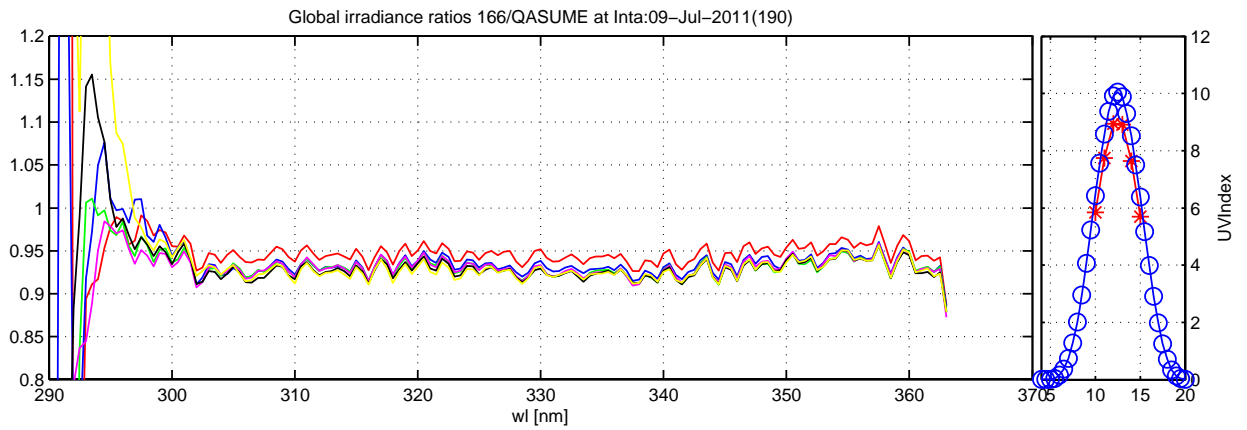
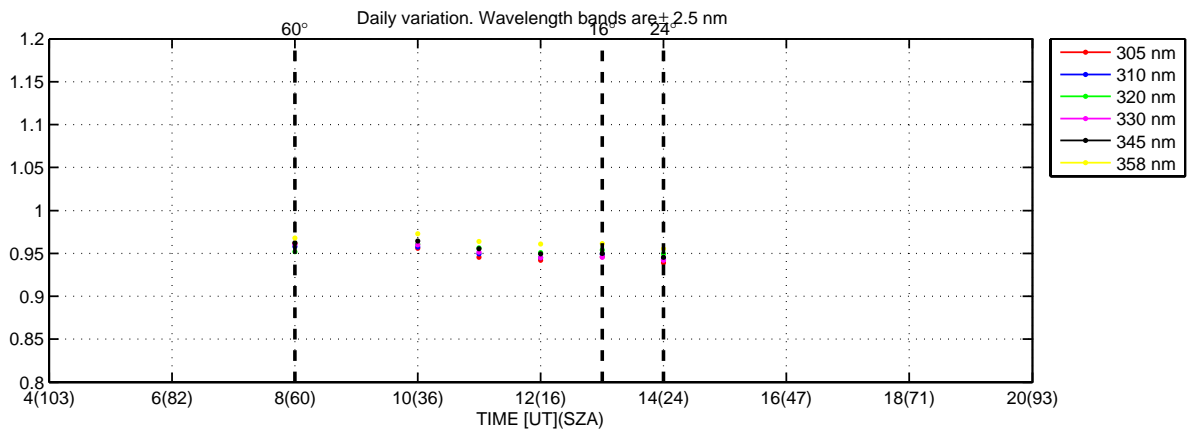
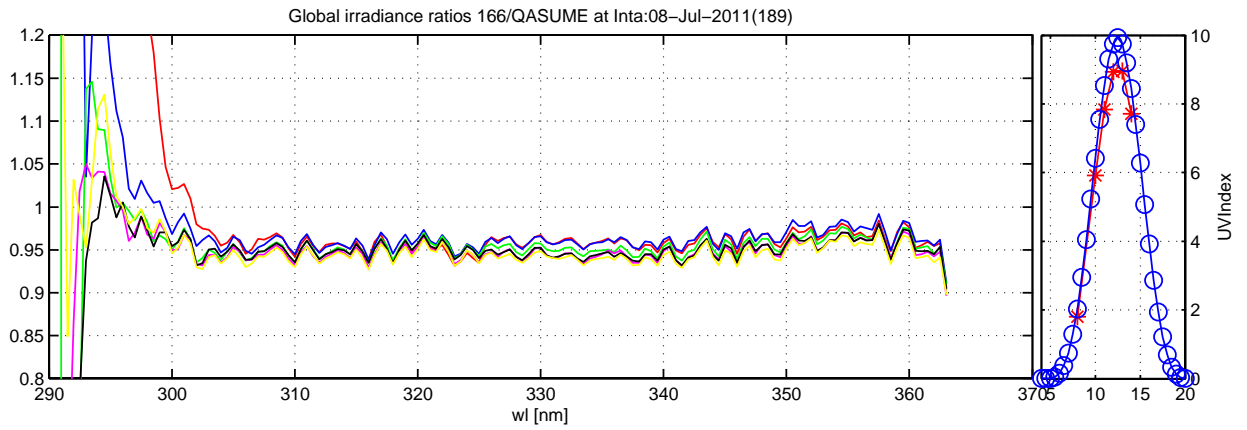


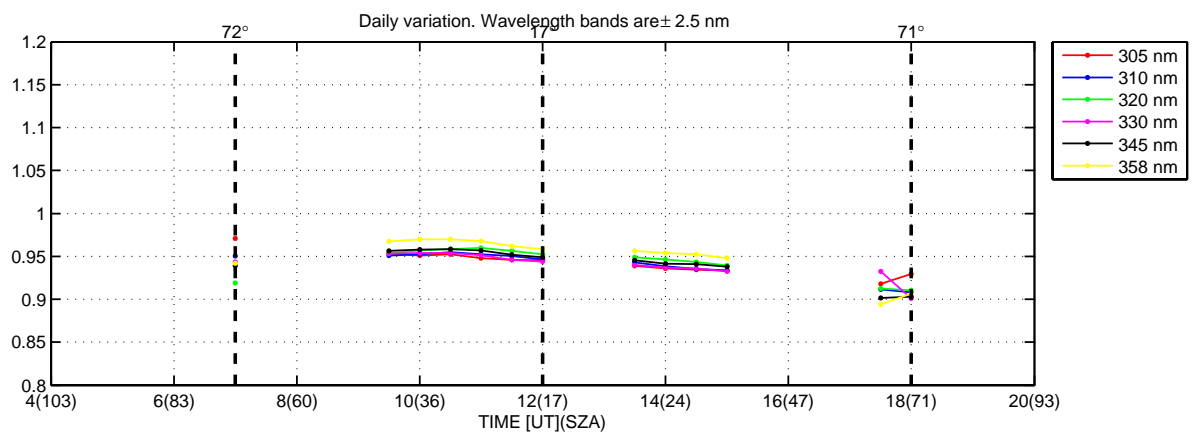
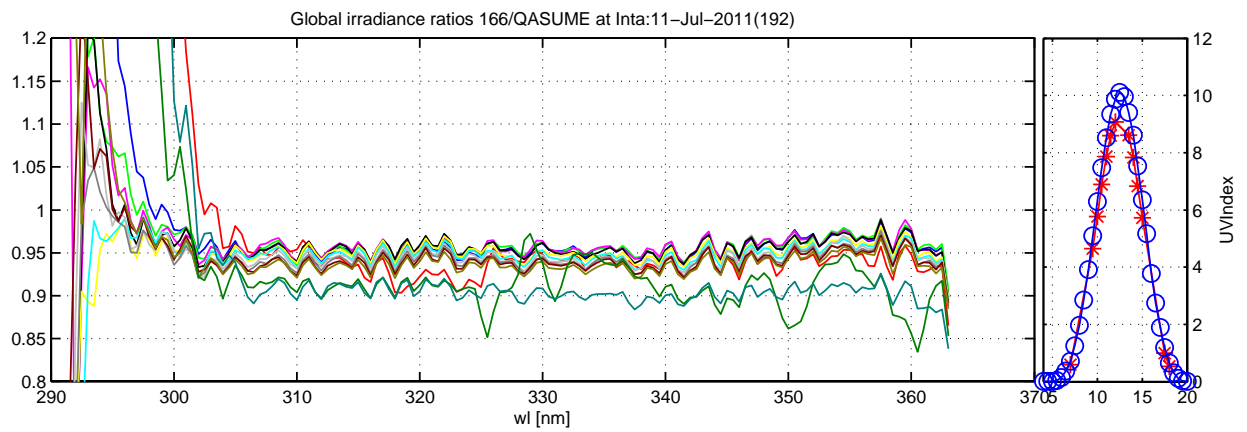
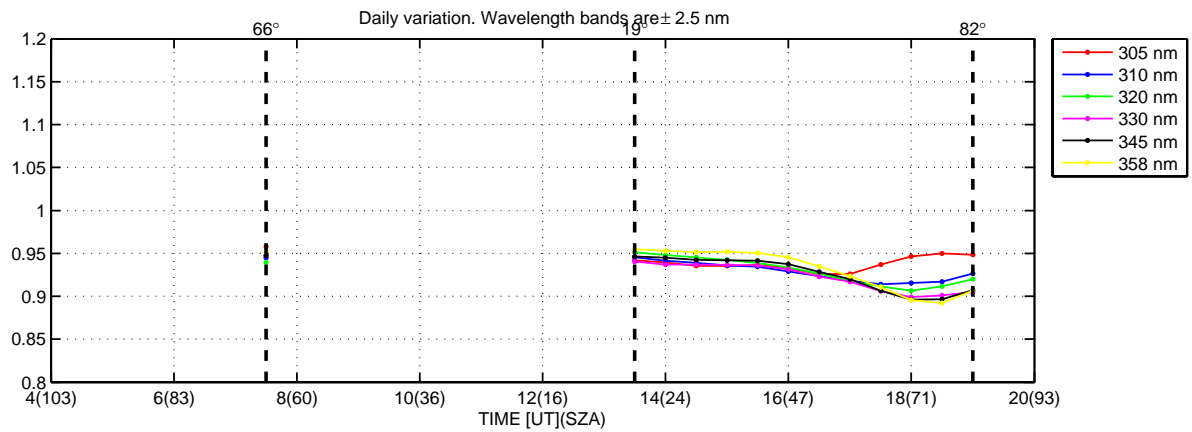
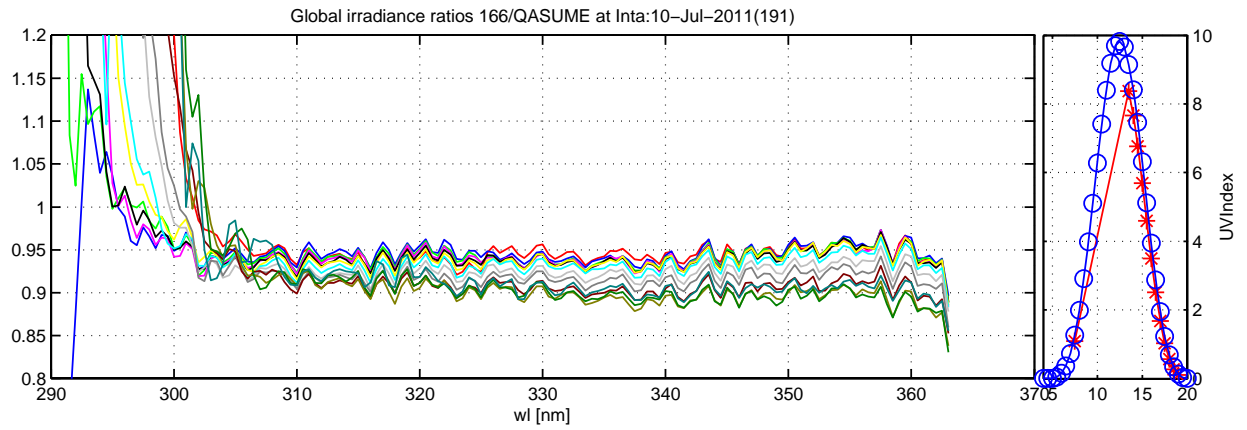


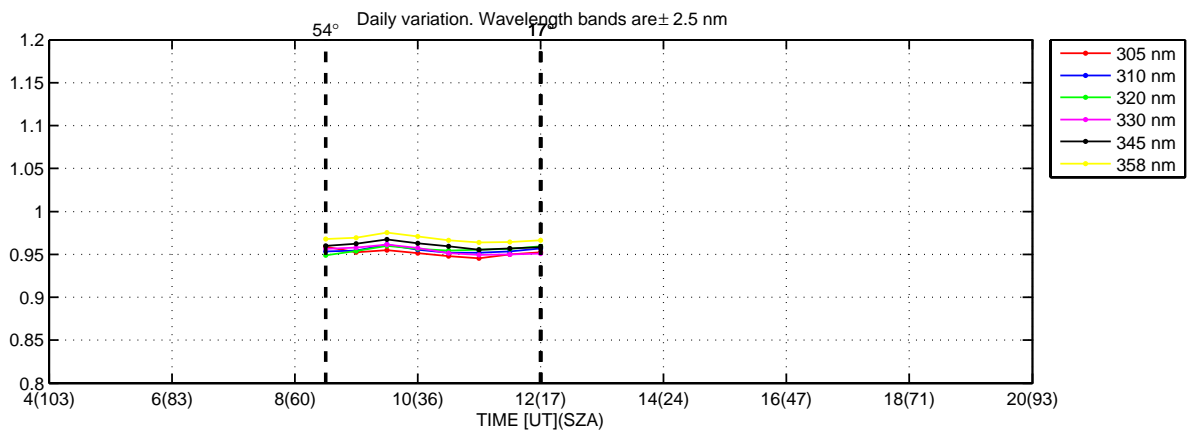
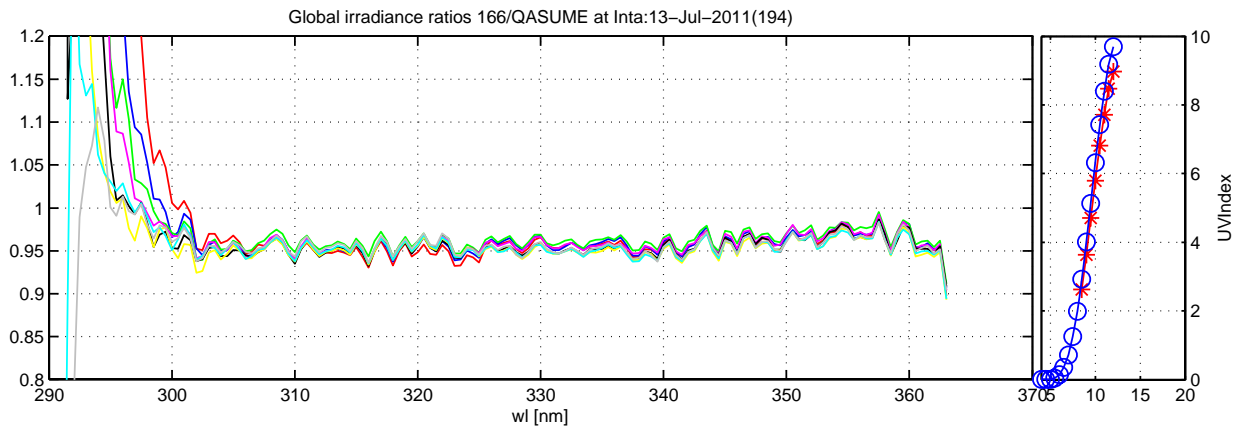
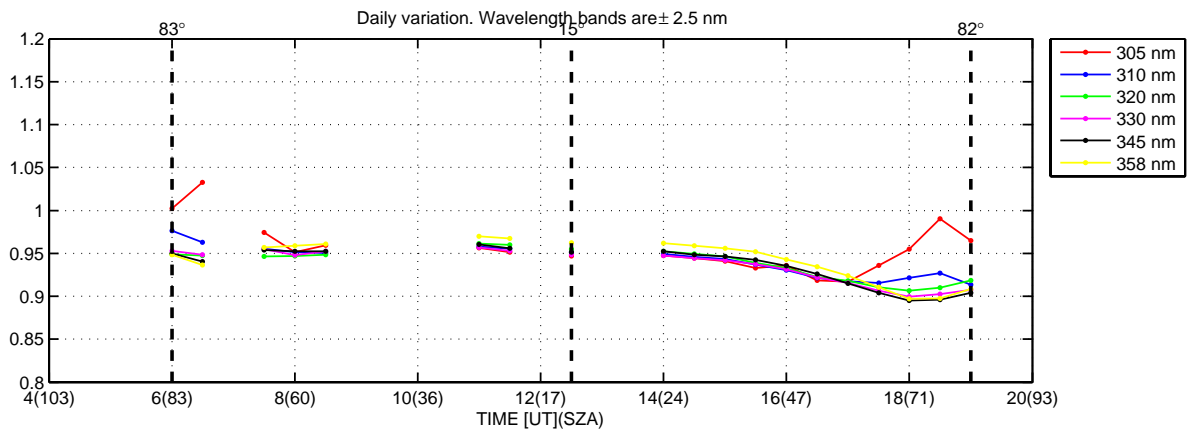
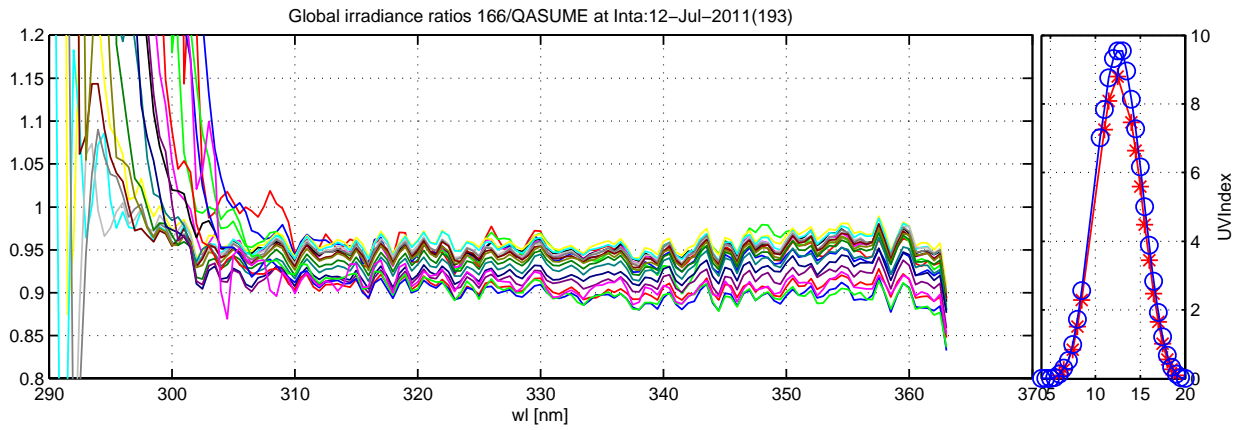
Temperature Dependence of Brewer #165, Intra, July 2011

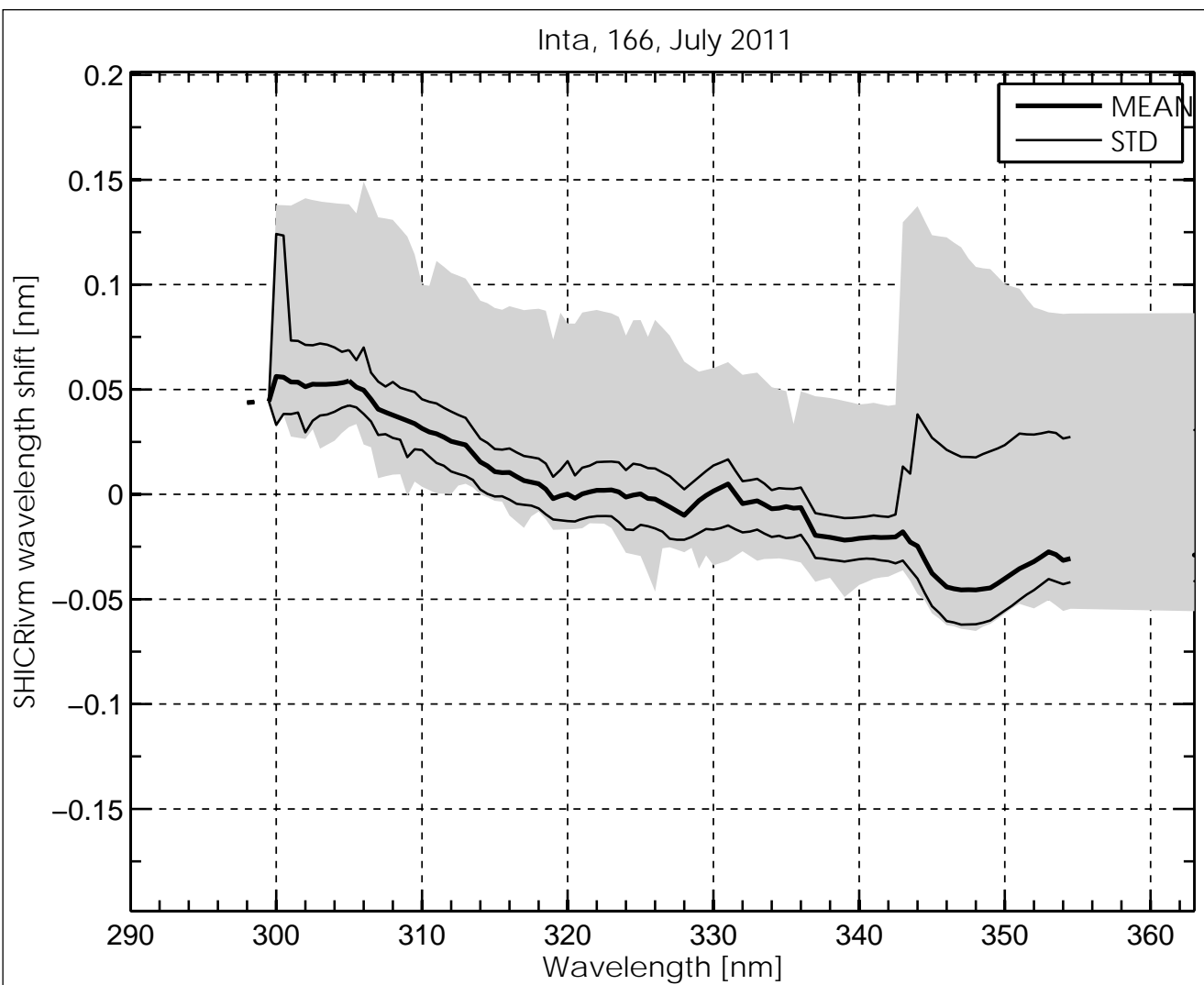
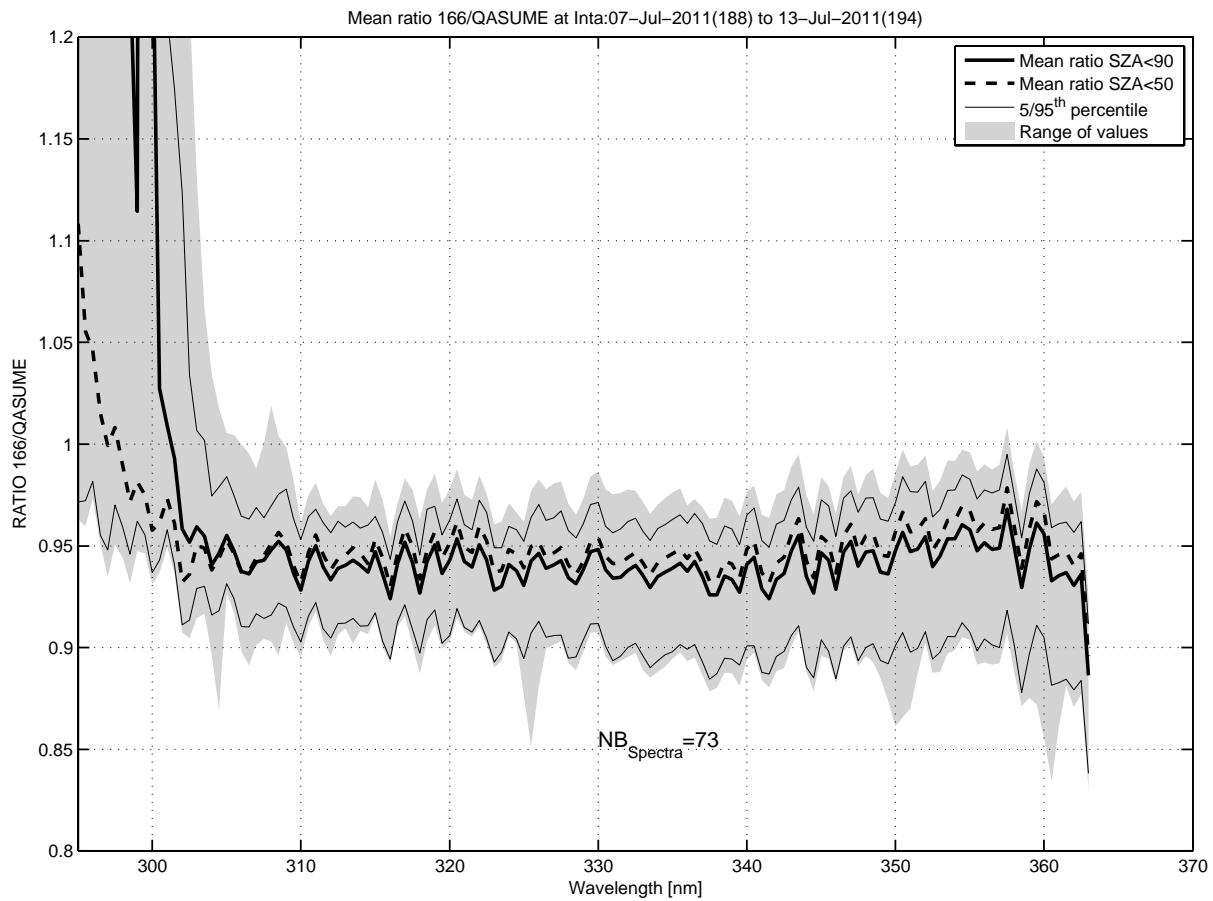




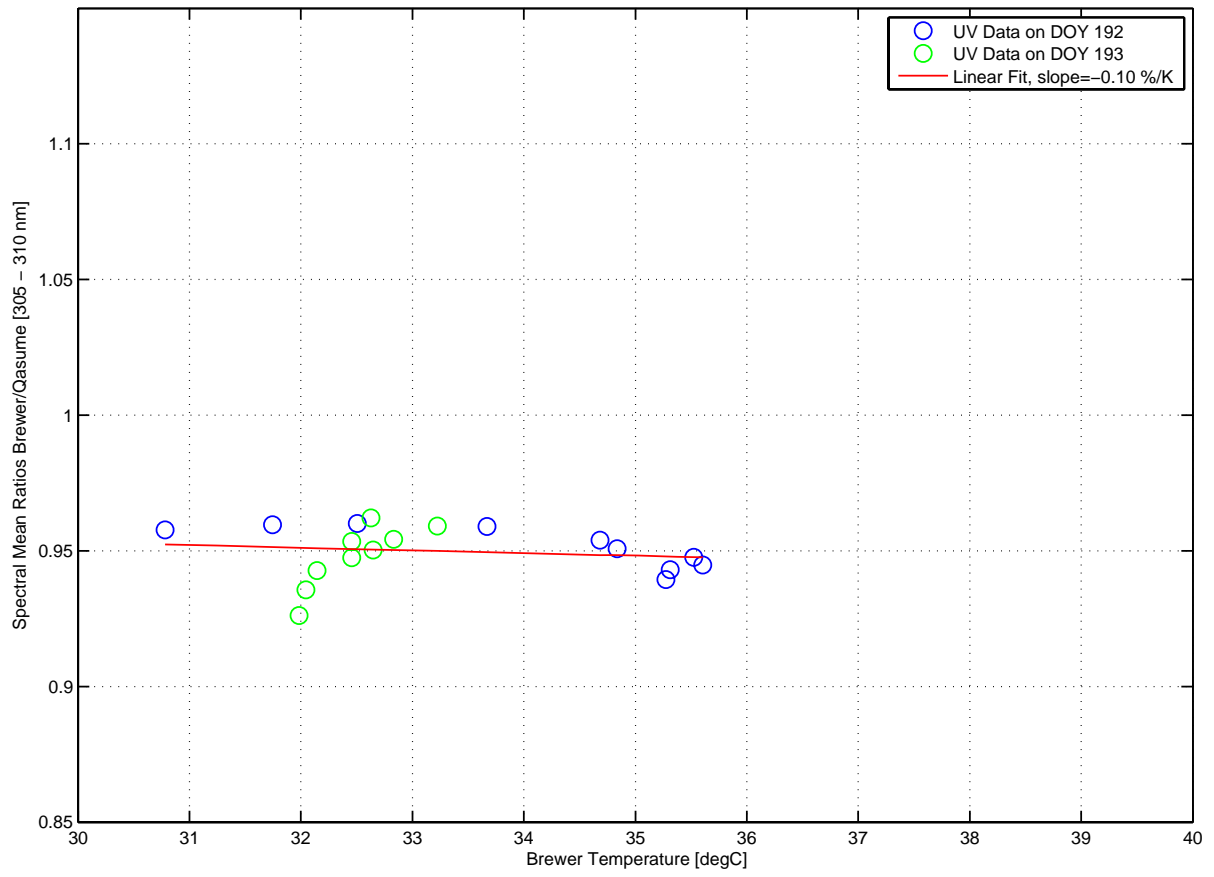




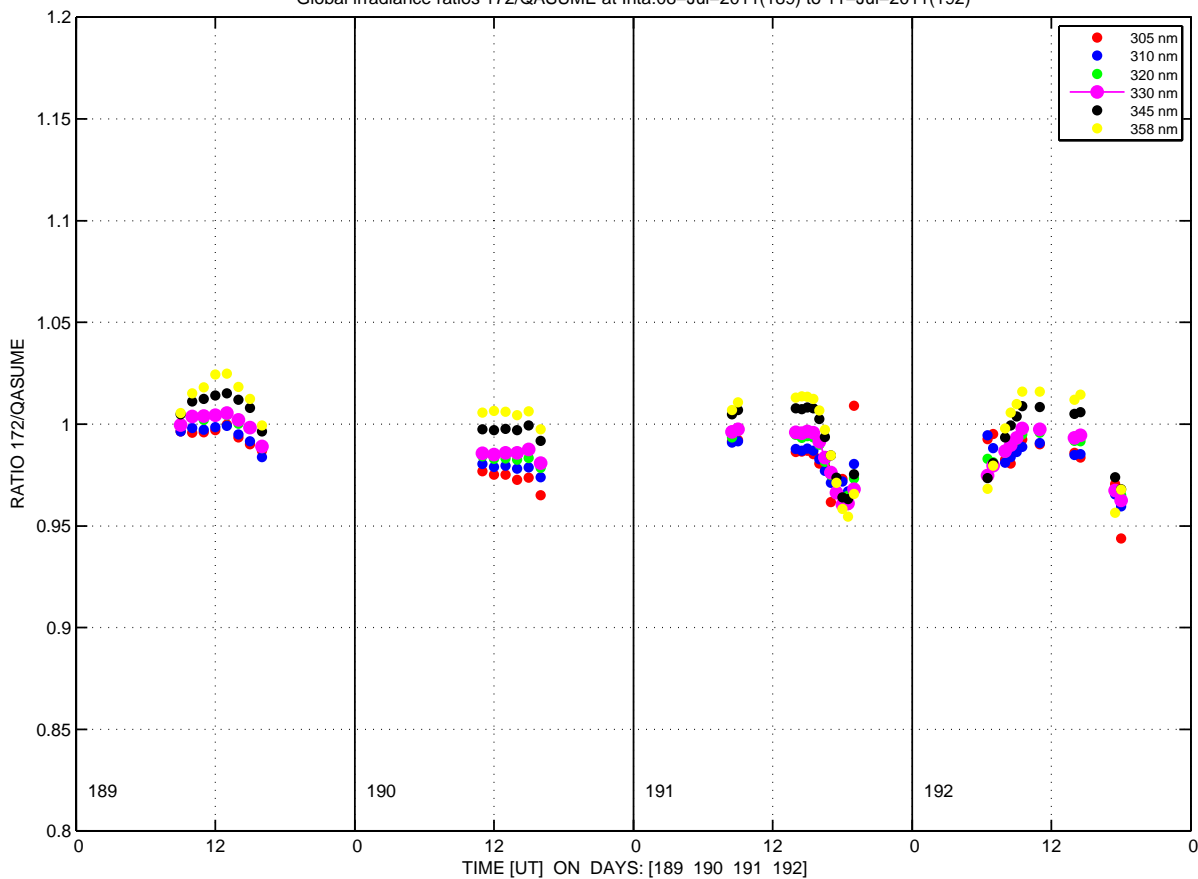




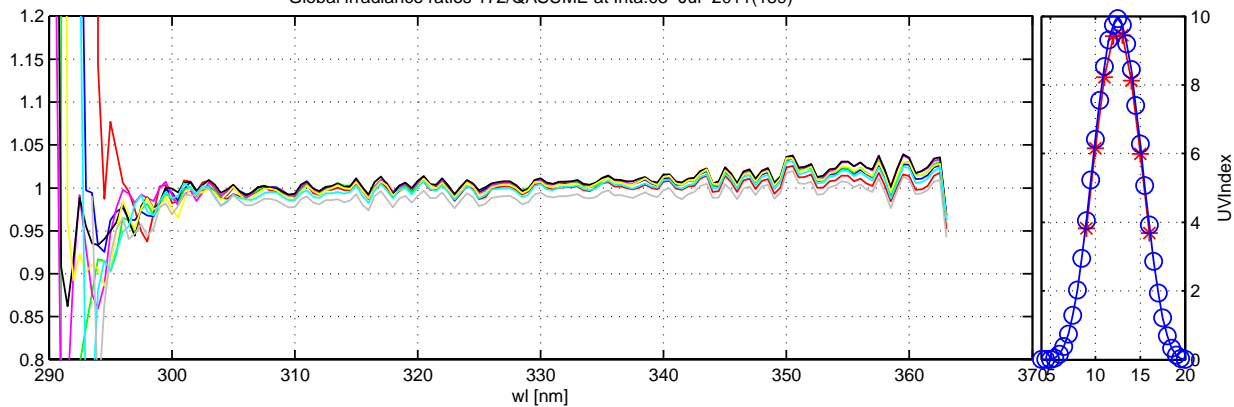
Temperature Dependence of Brewer #166, Intra, July 2011



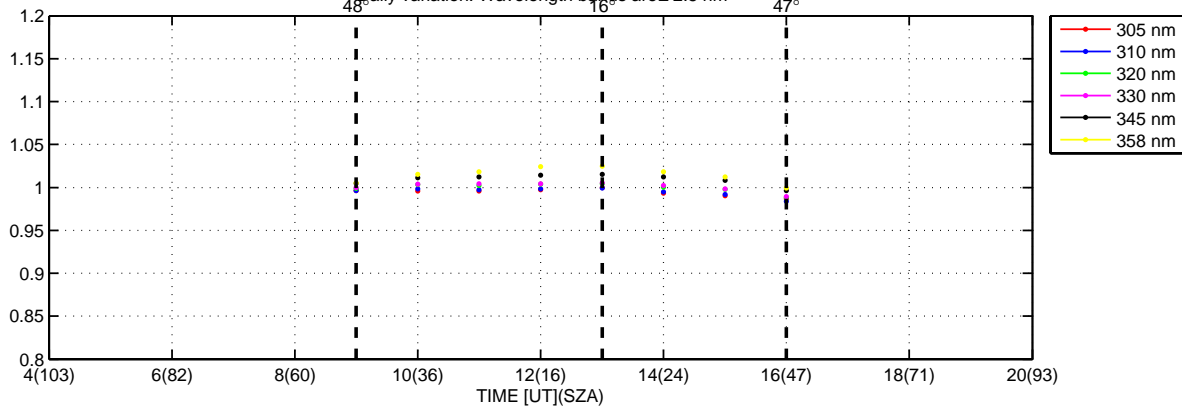
Global irradiance ratios 172/QASUME at Inta:08-Jul-2011(189) to 11-Jul-2011(192)

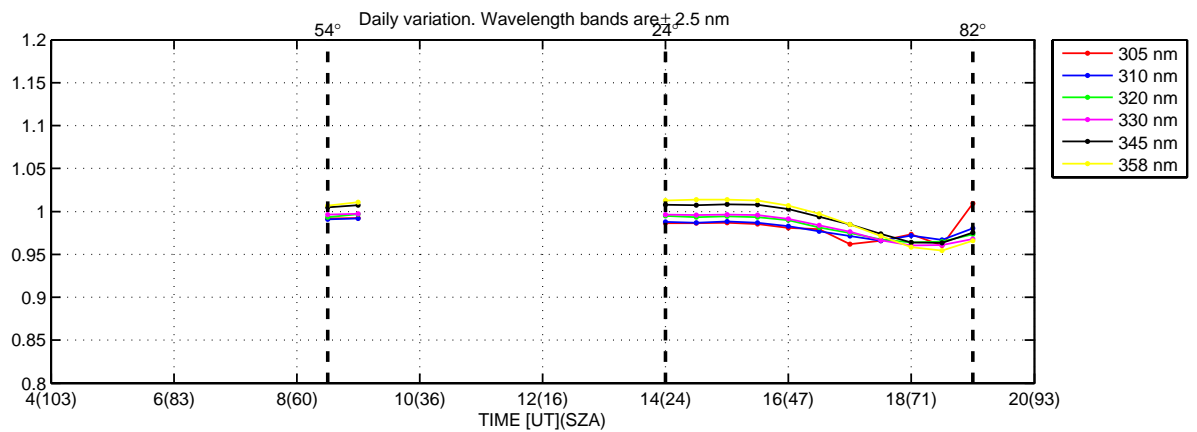
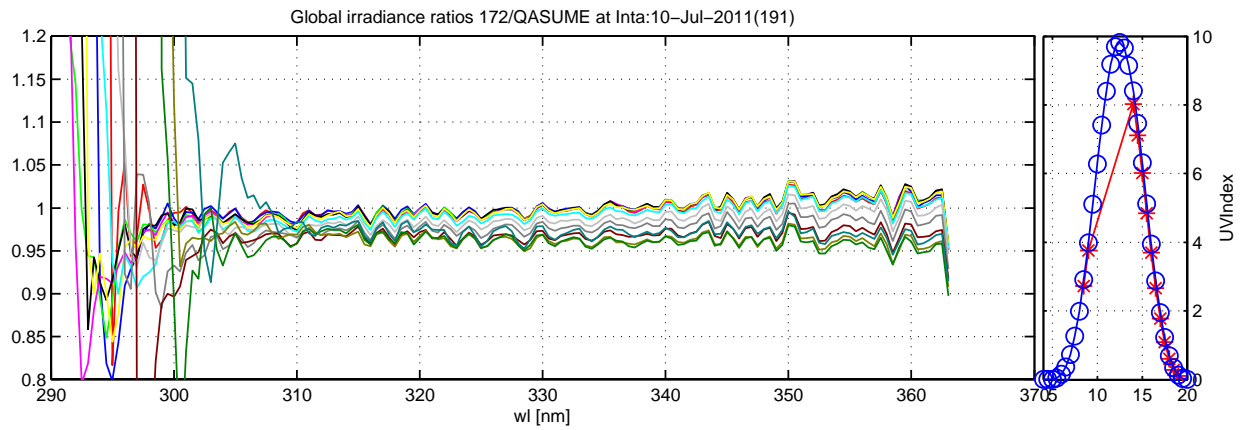
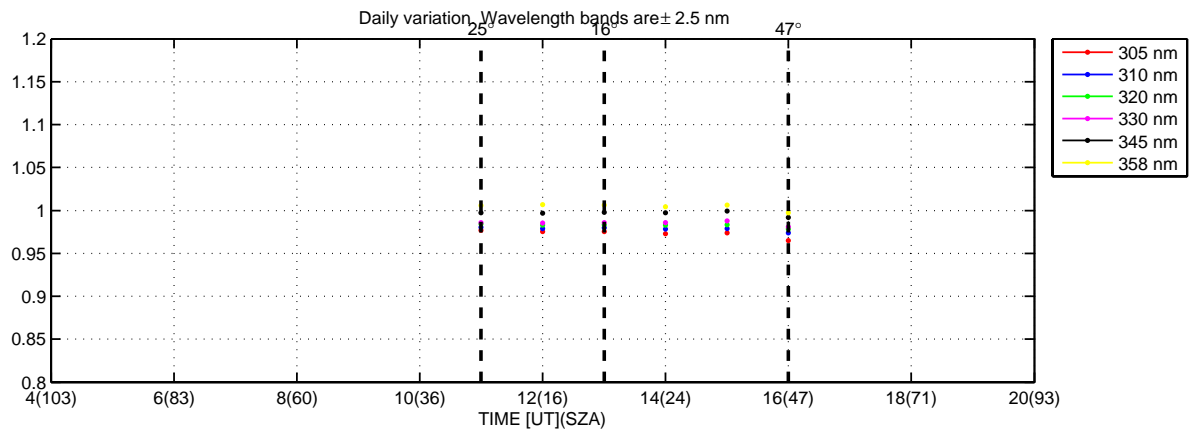
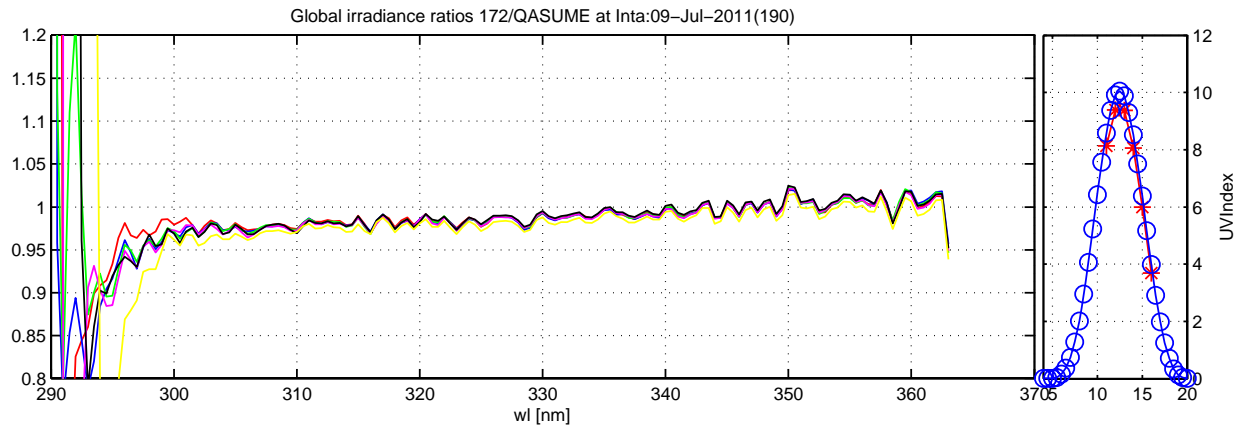


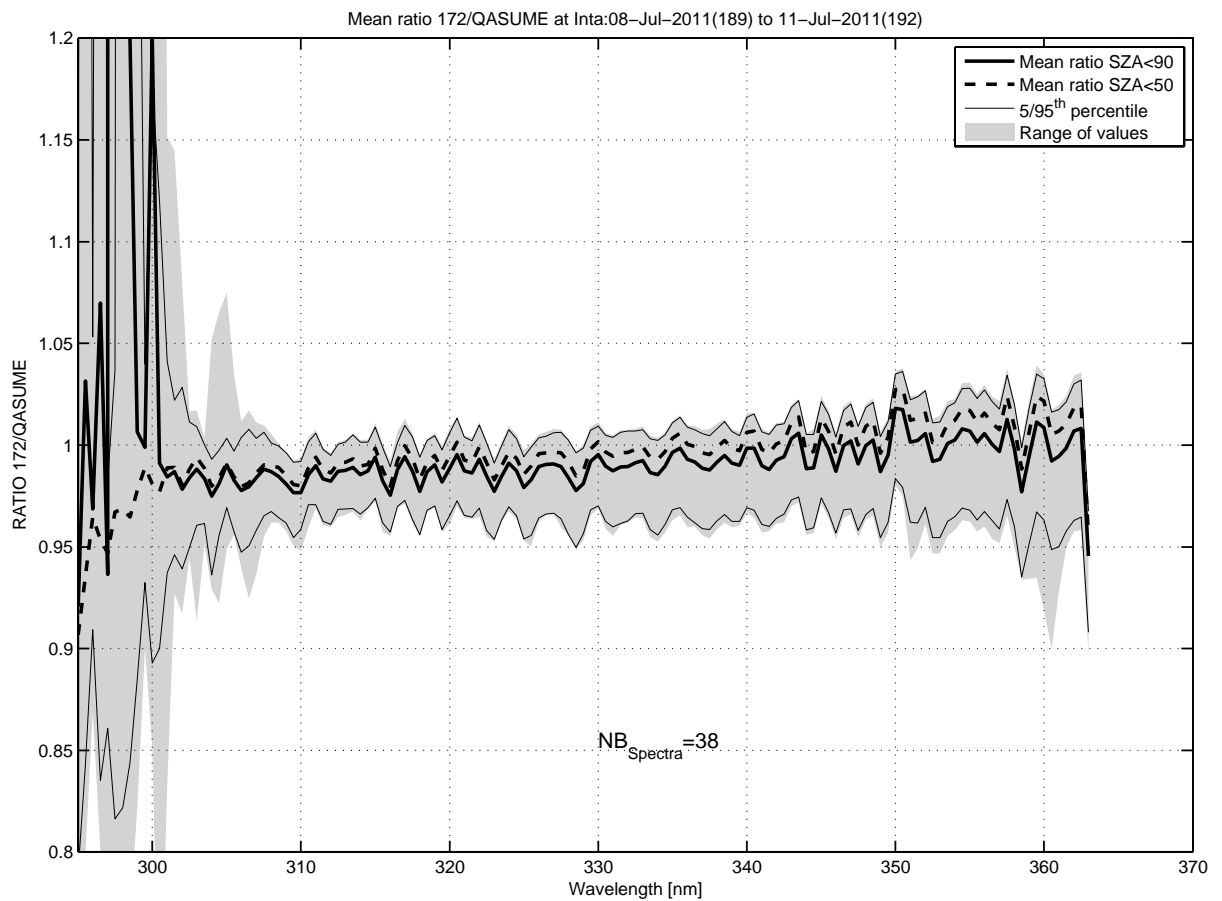
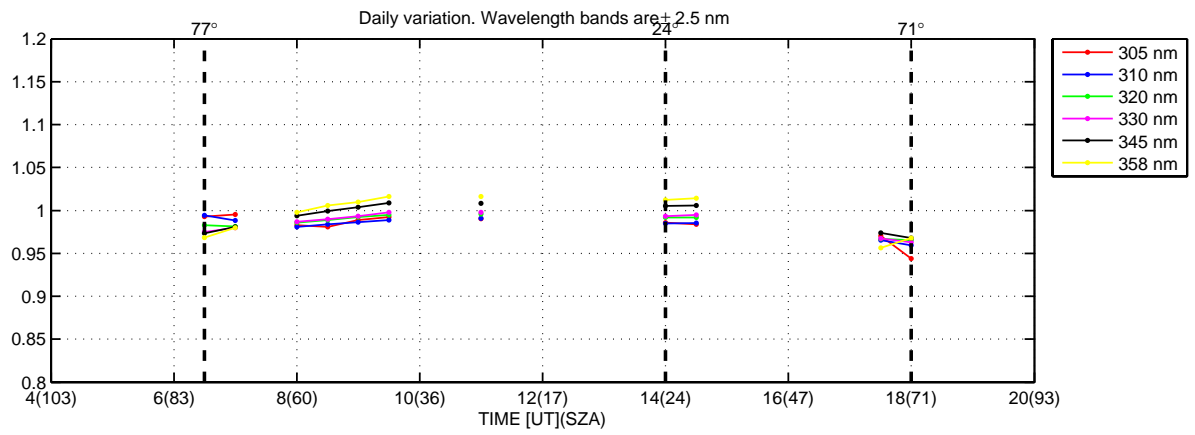
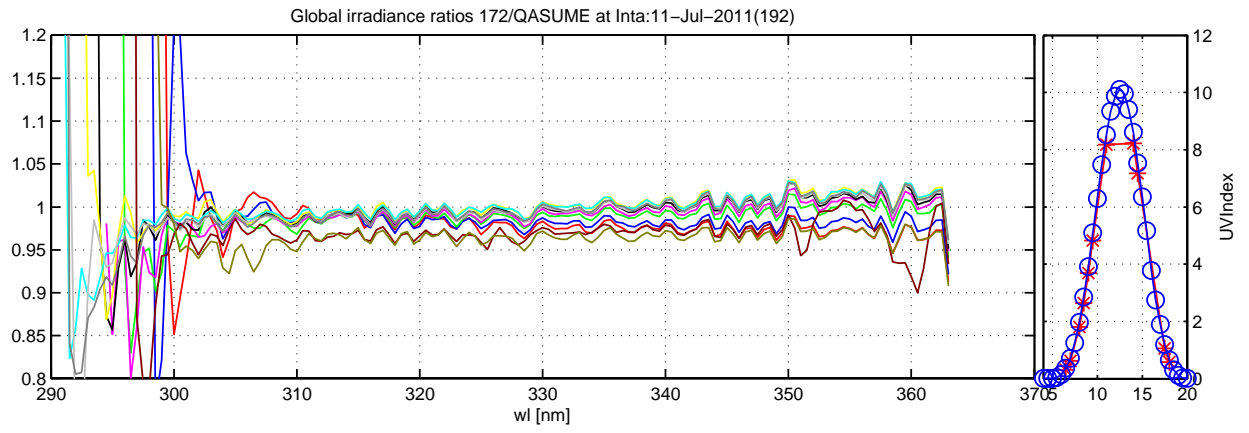
Global irradiance ratios 172/QASUME at Inta:08-Jul-2011(189)



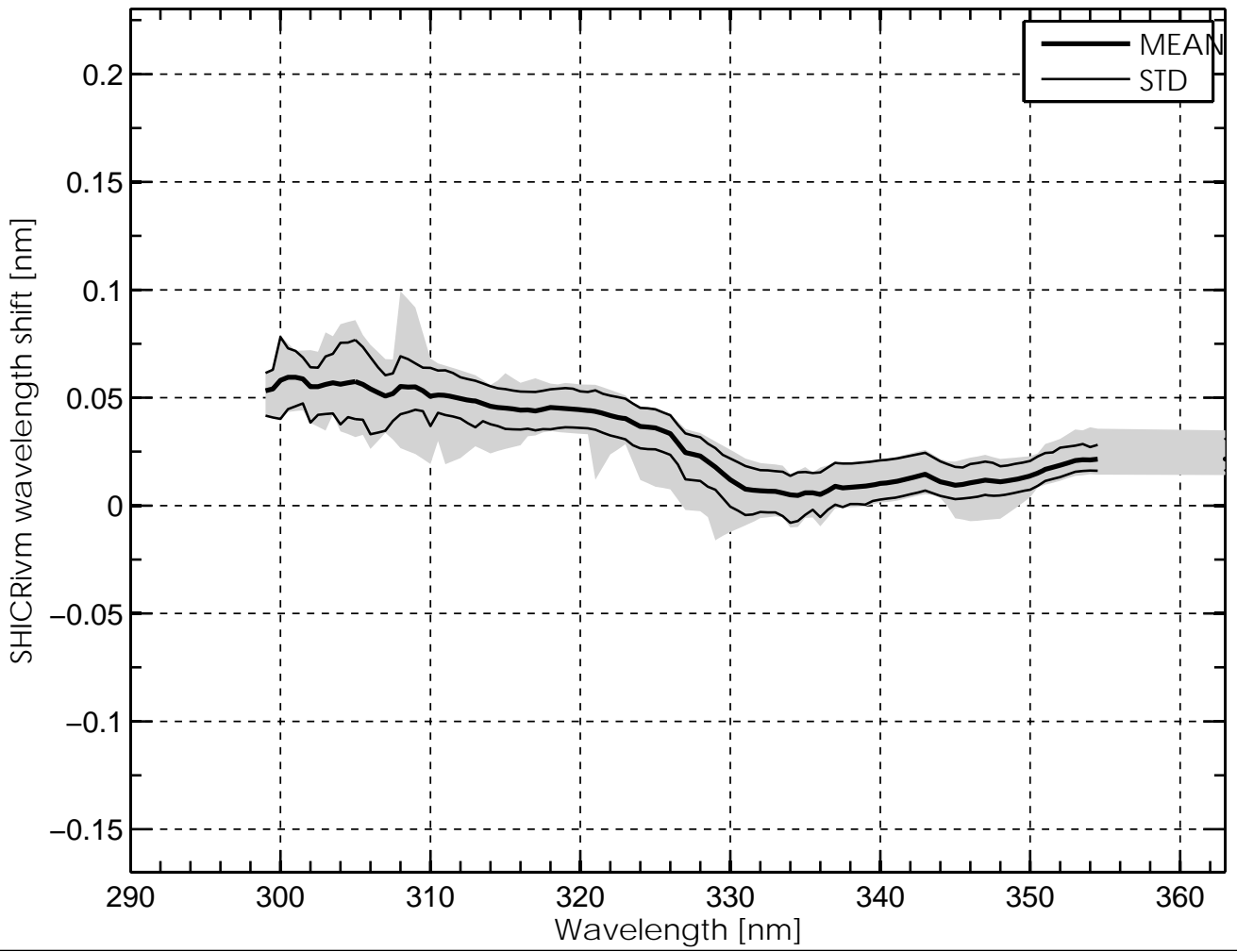
Daily variation. Wavelength bands are ± 2.5 nm



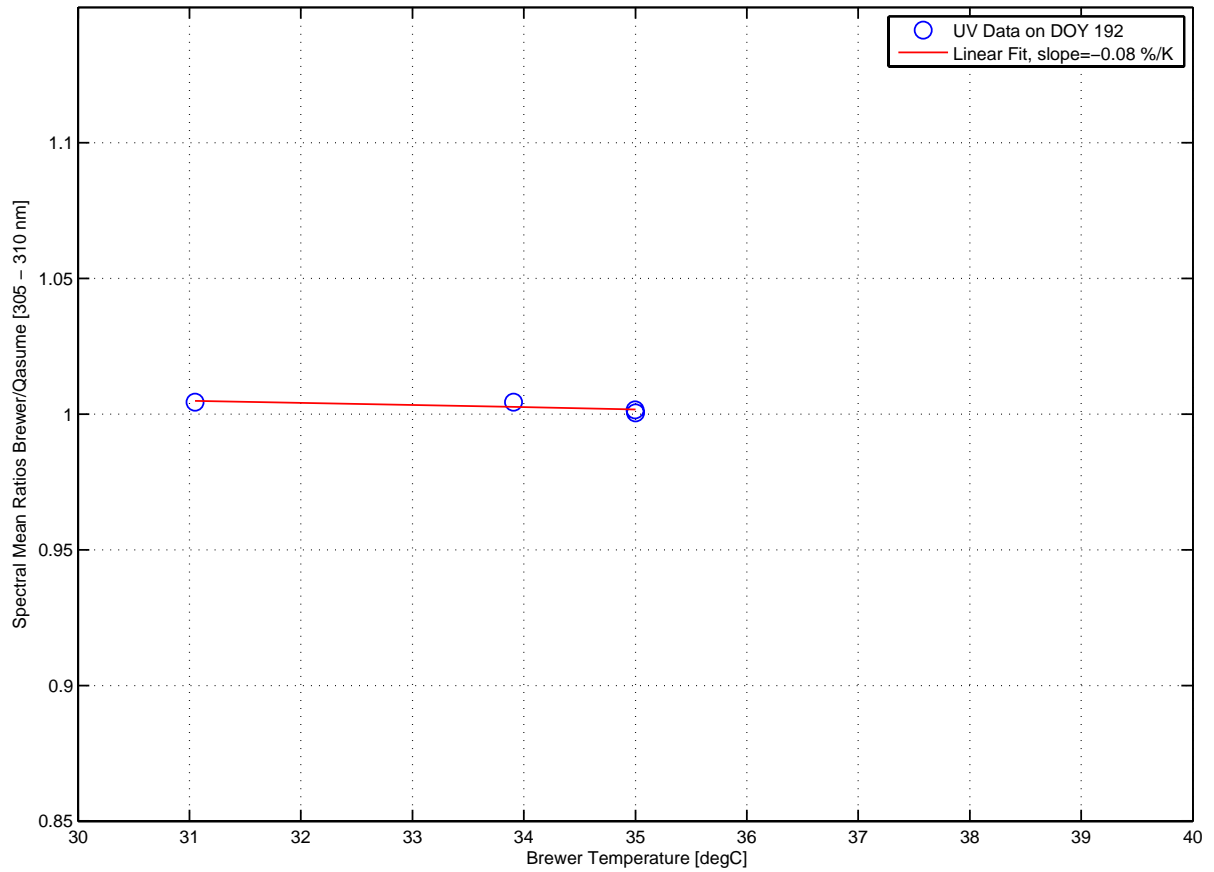


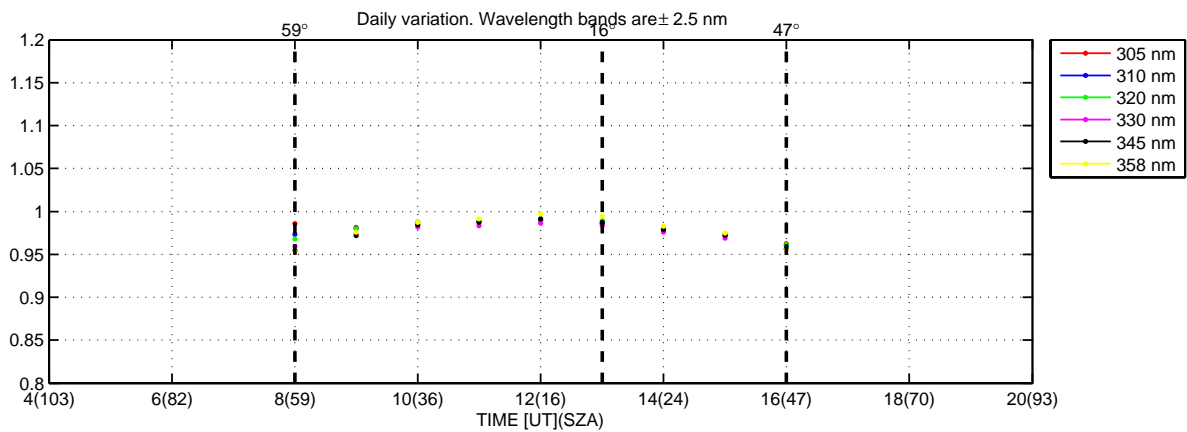
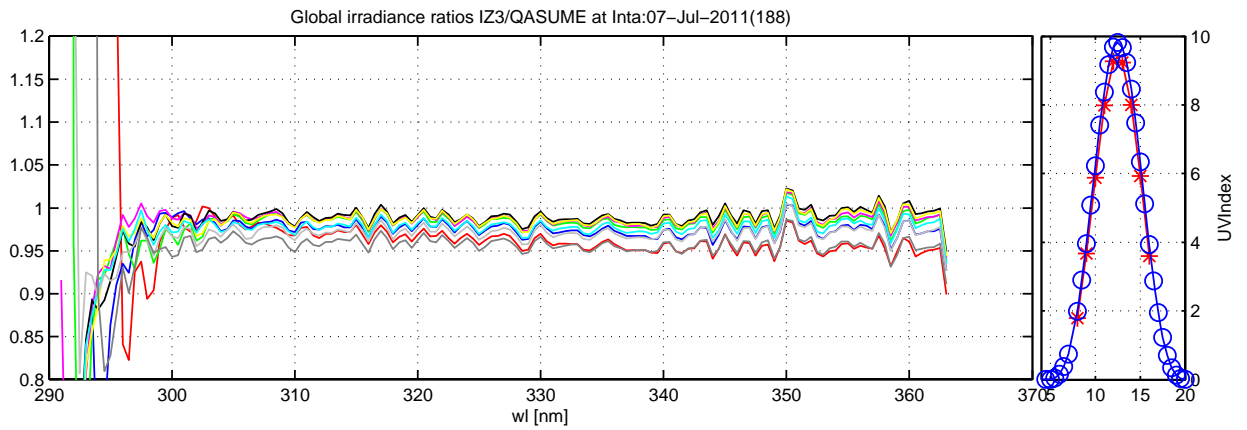
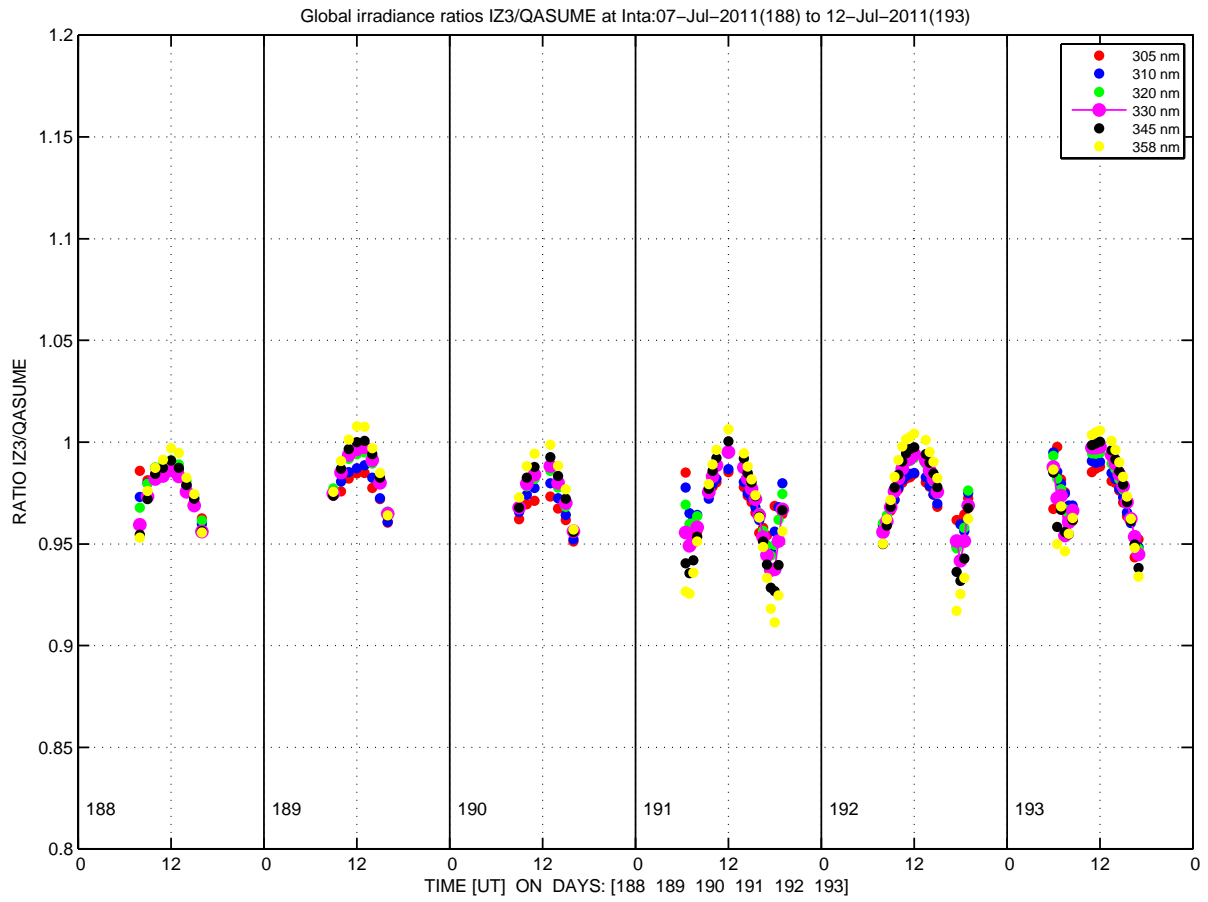


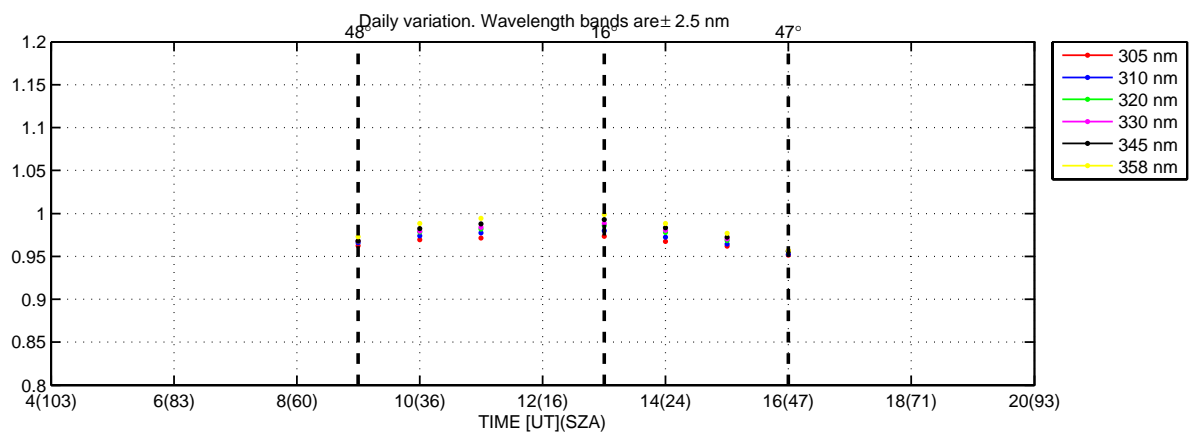
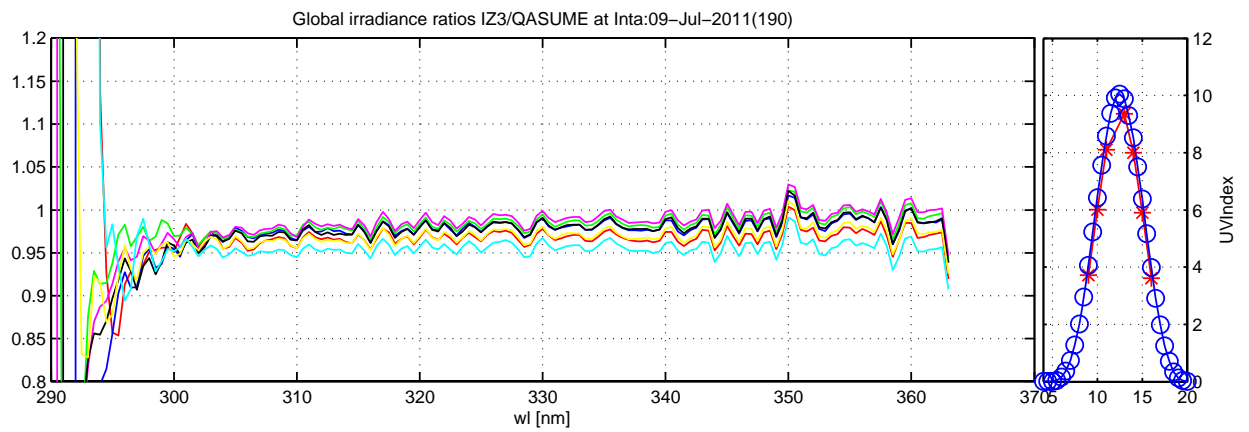
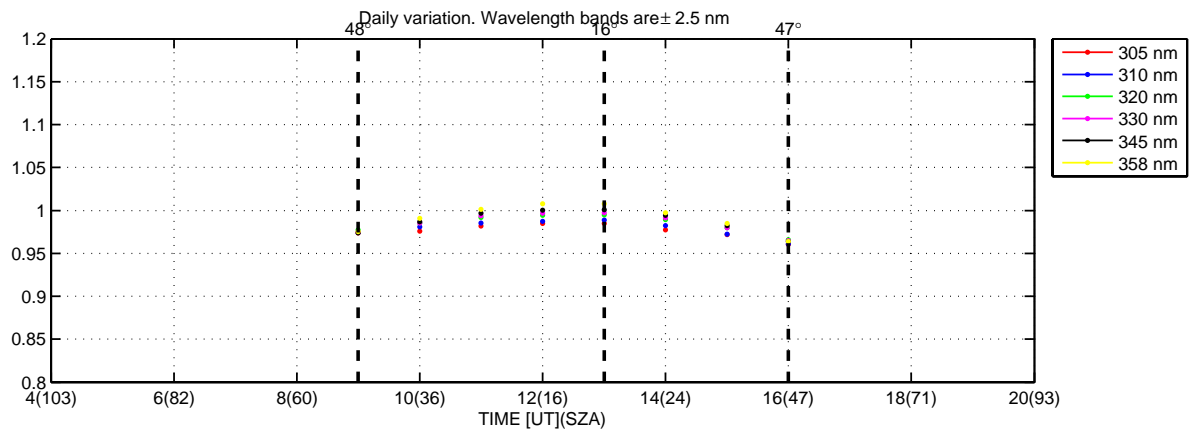
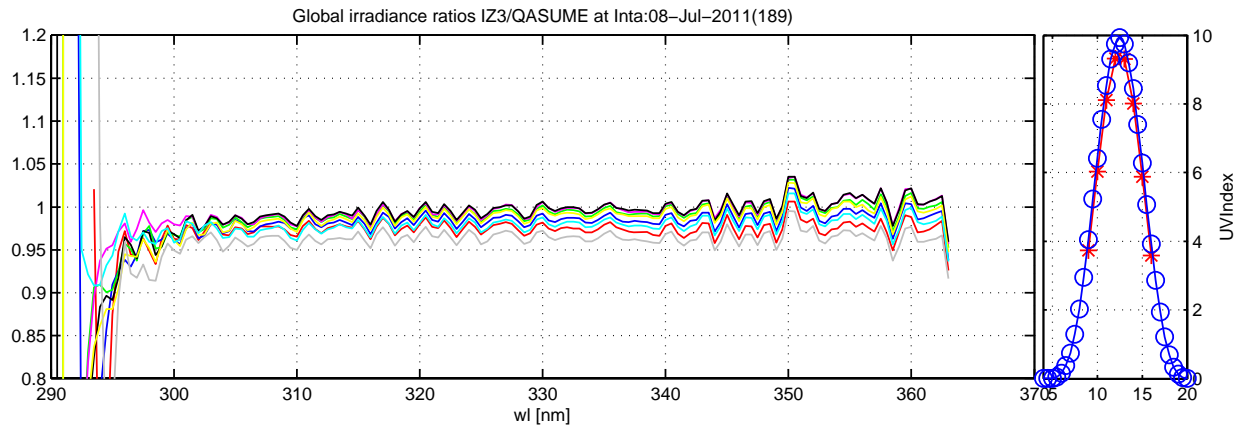
Inta, 172, July 2011

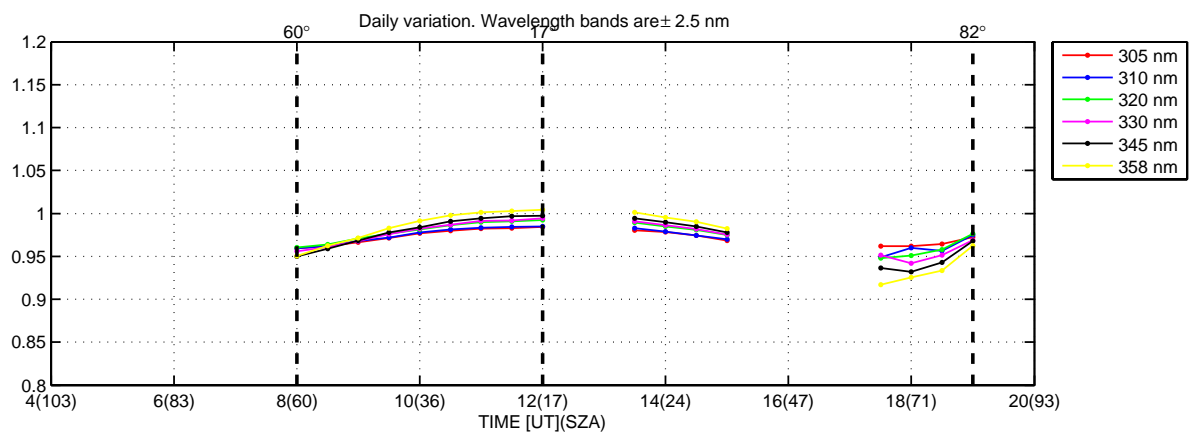
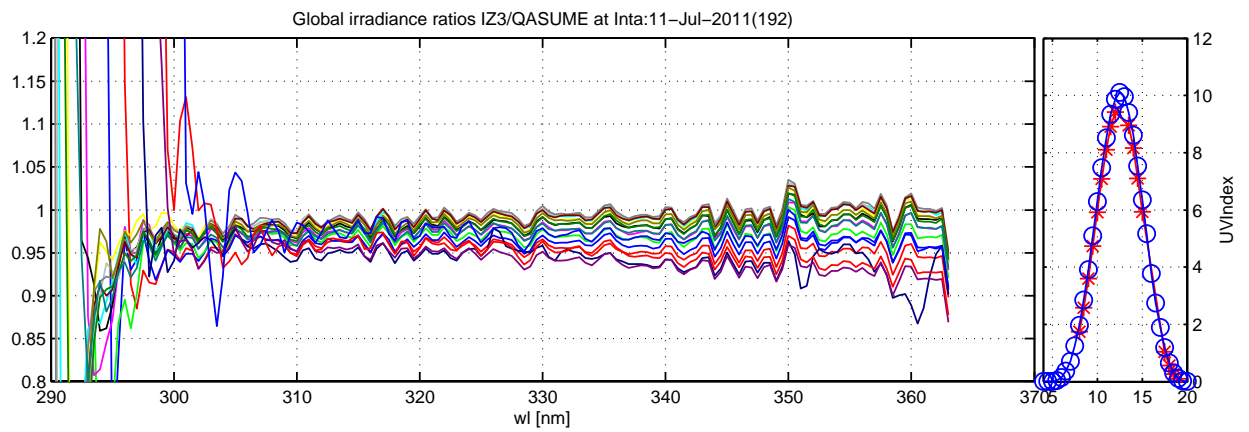
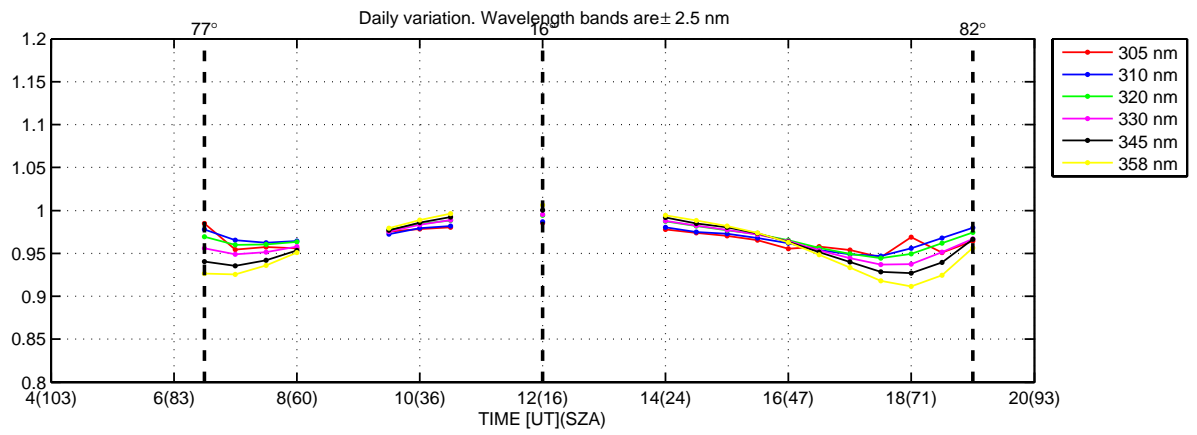
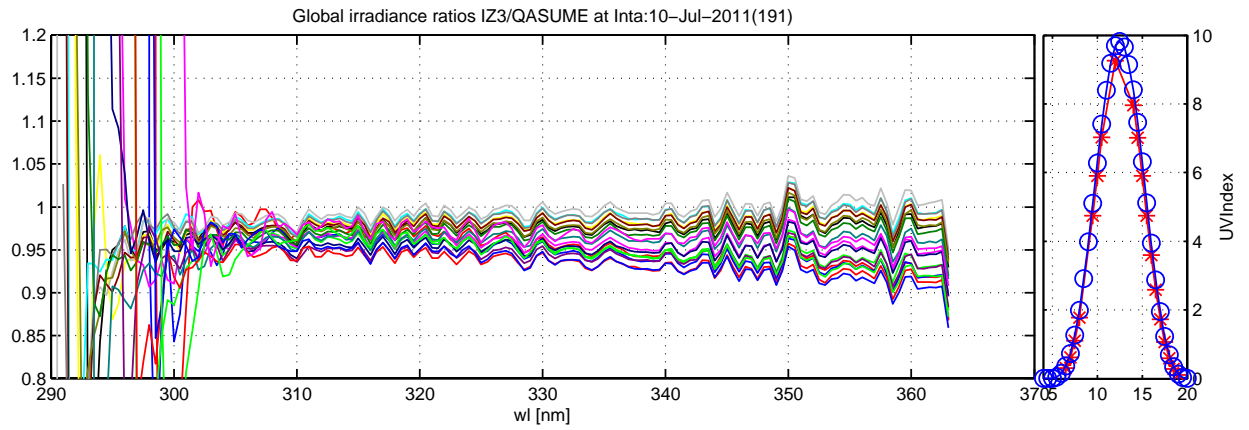


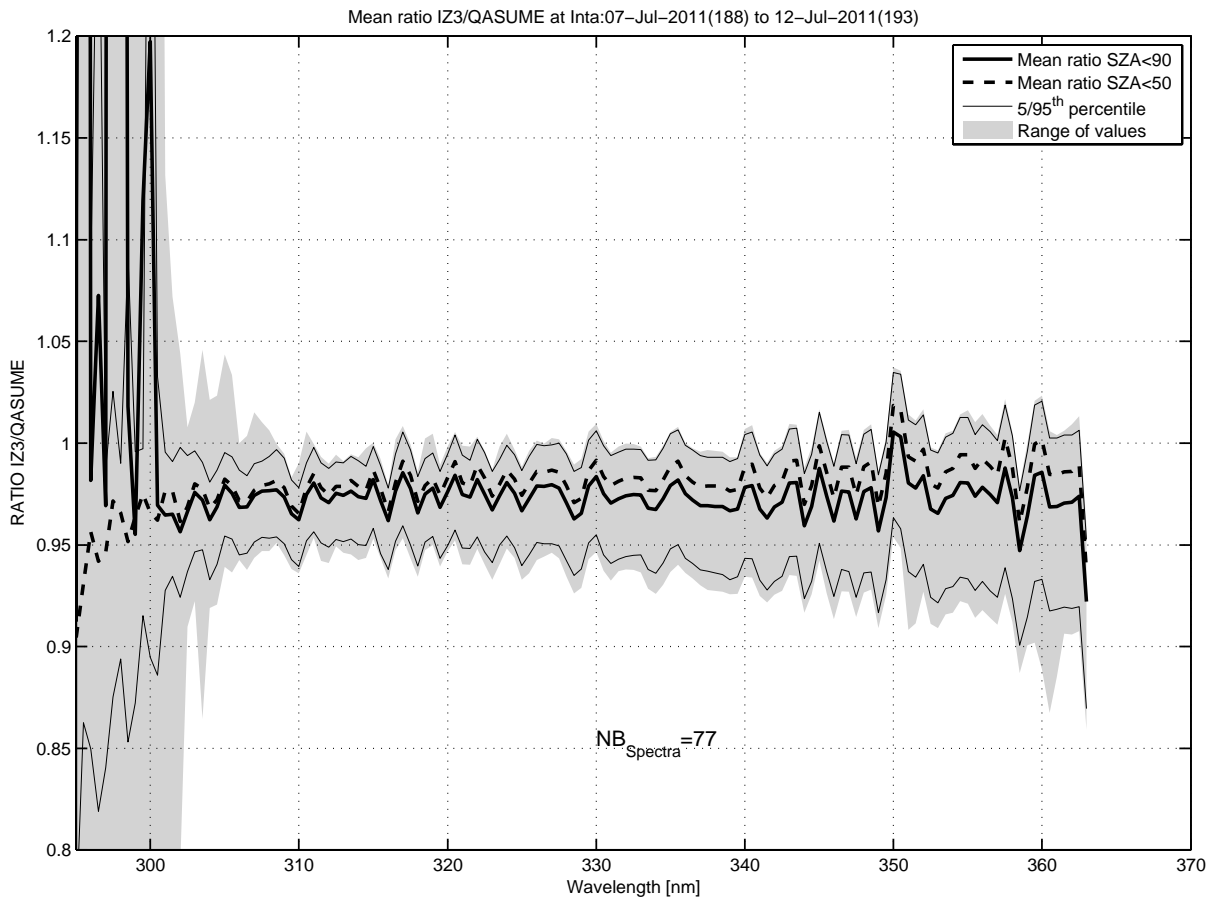
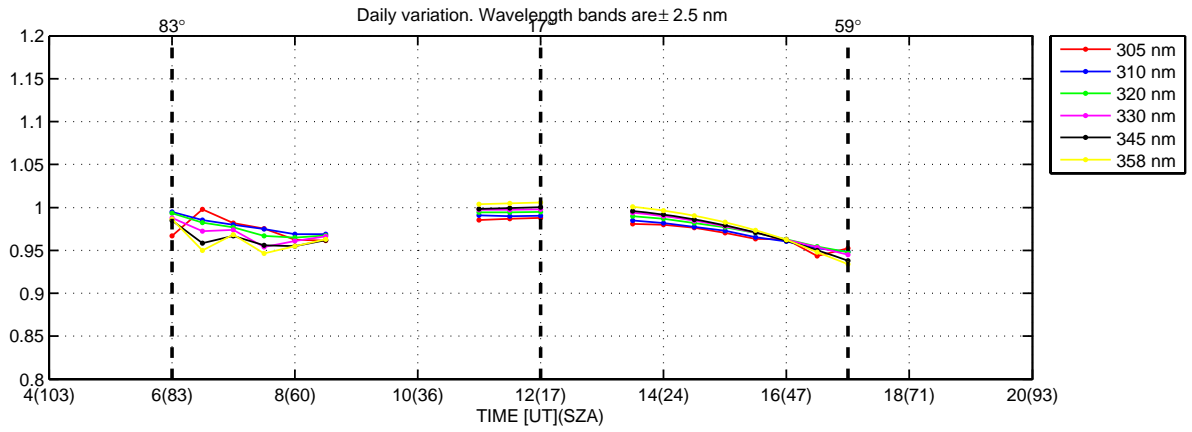
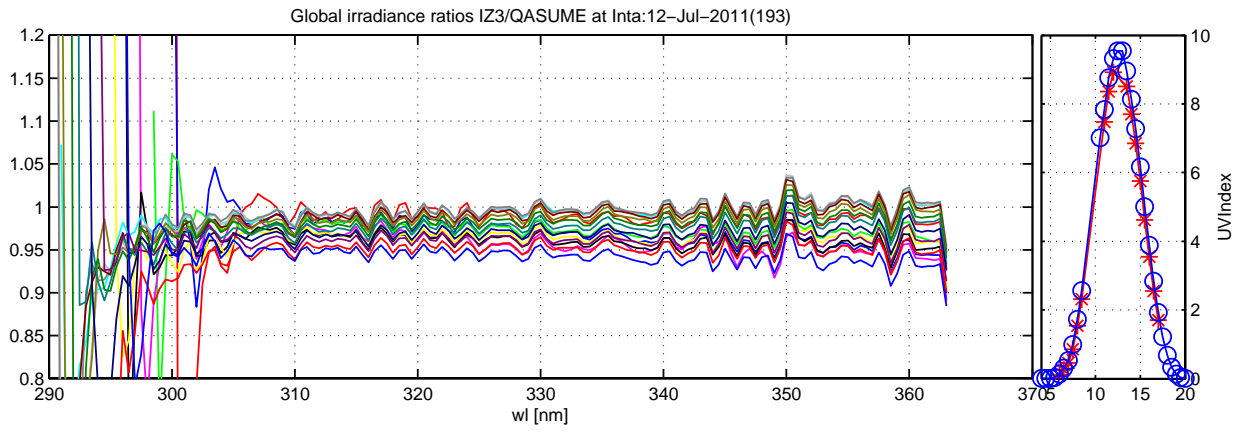
Temperature Dependence of Brewer #172, Inta, July 2011



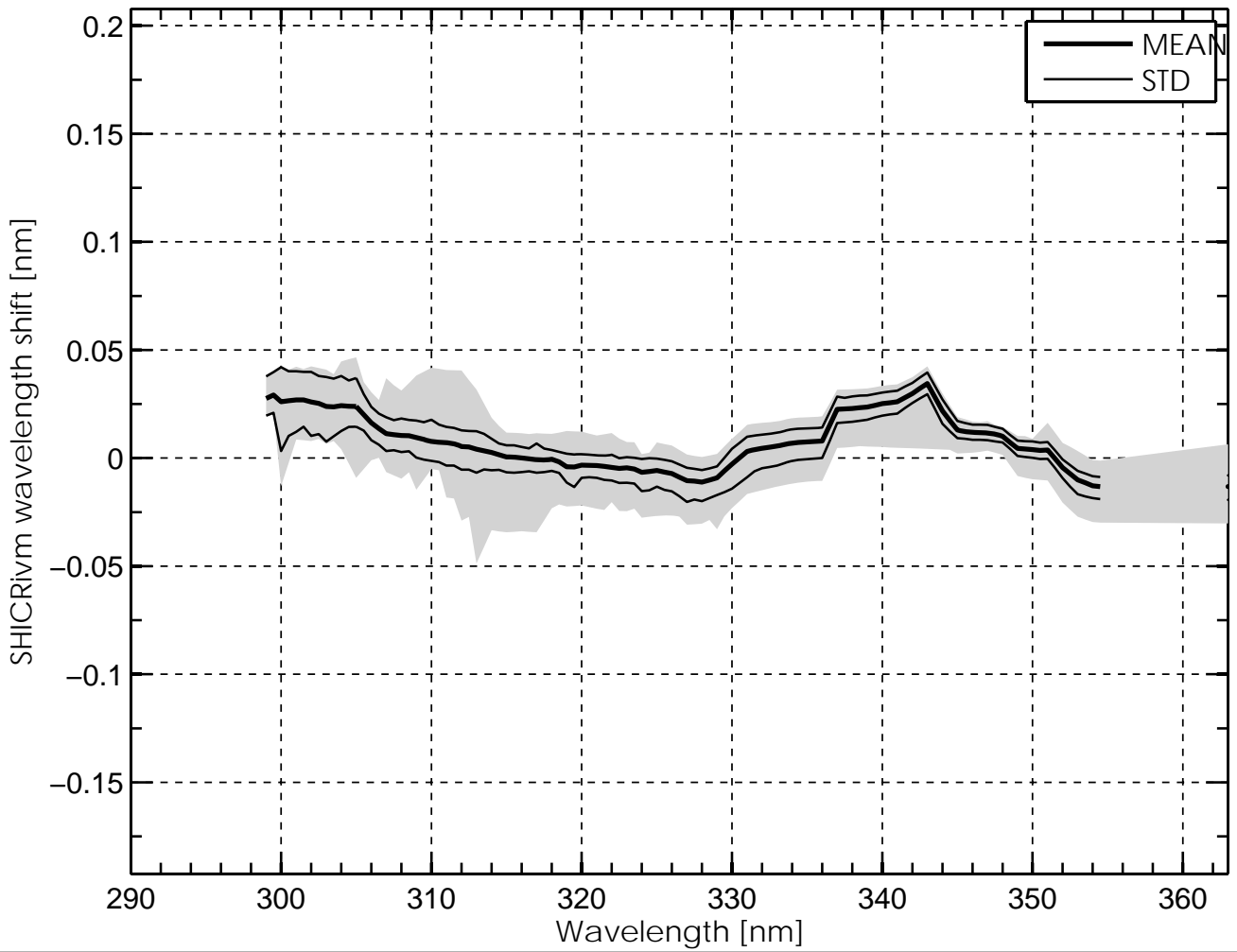




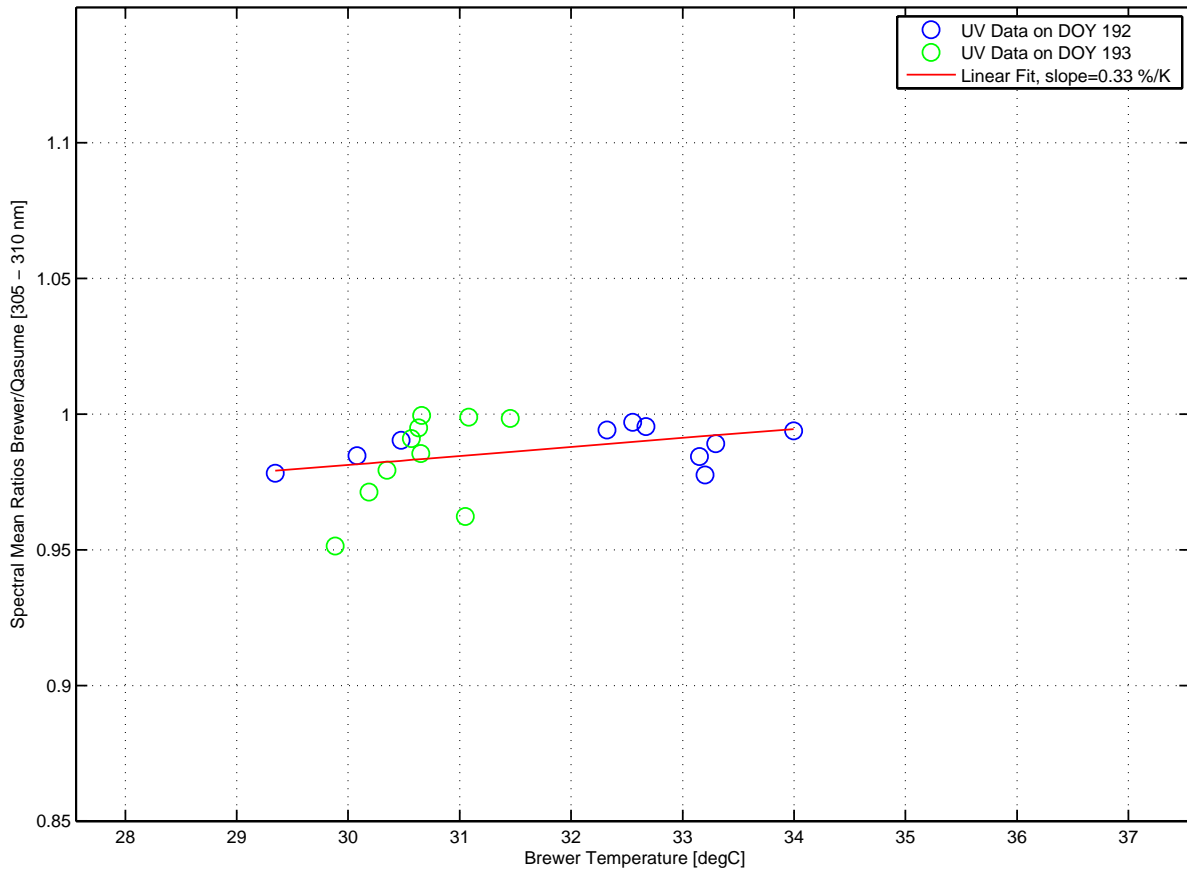


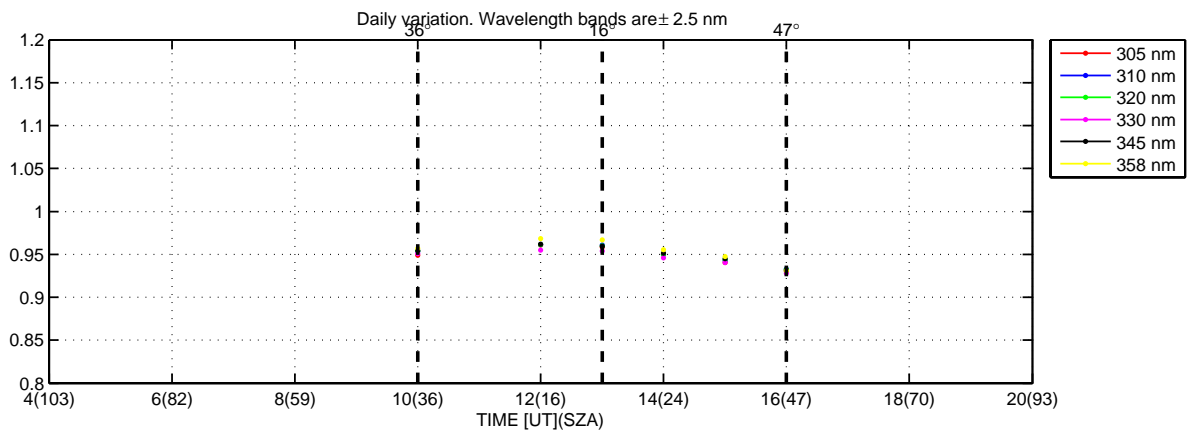
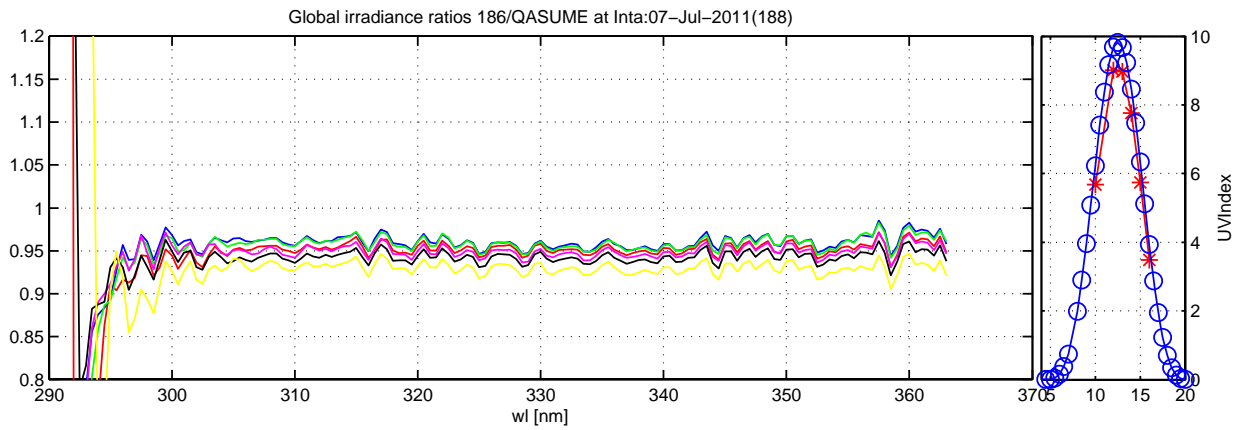
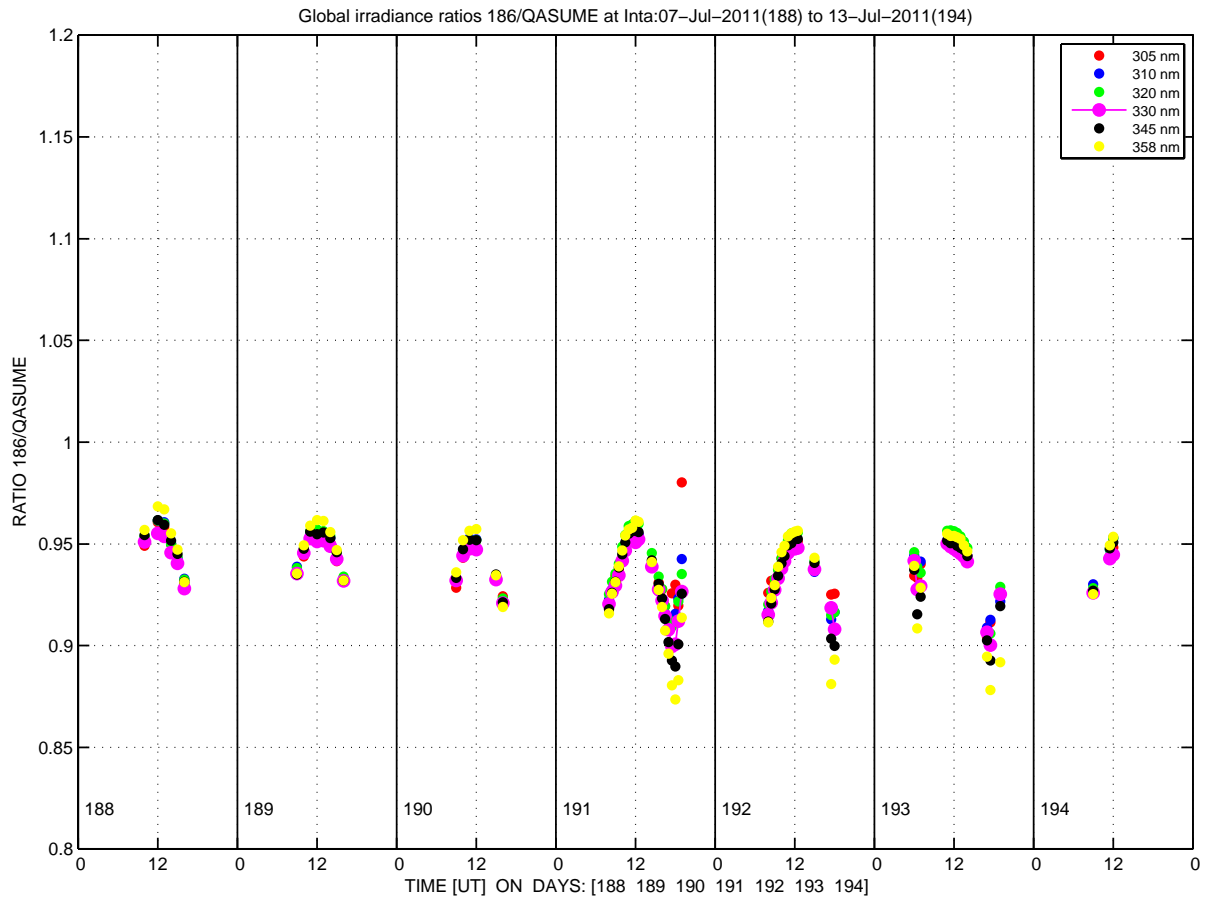


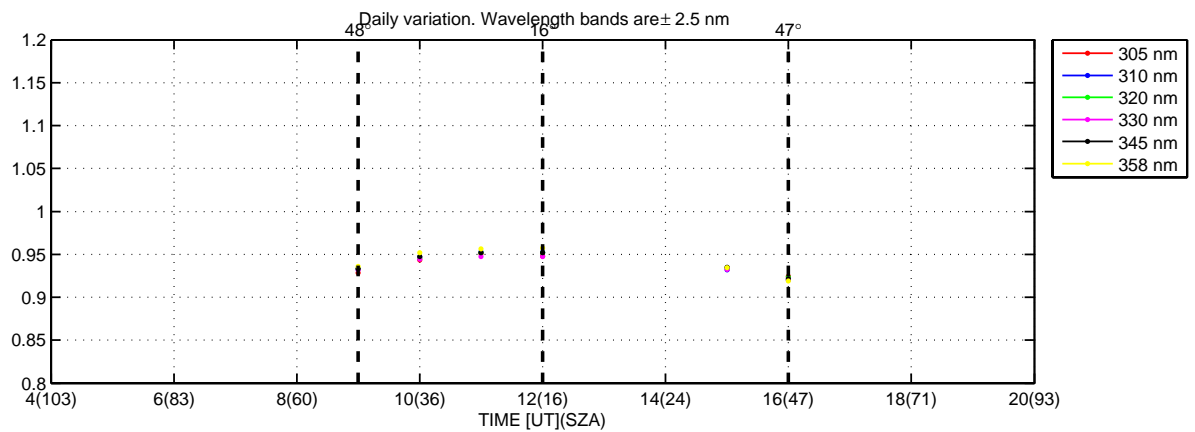
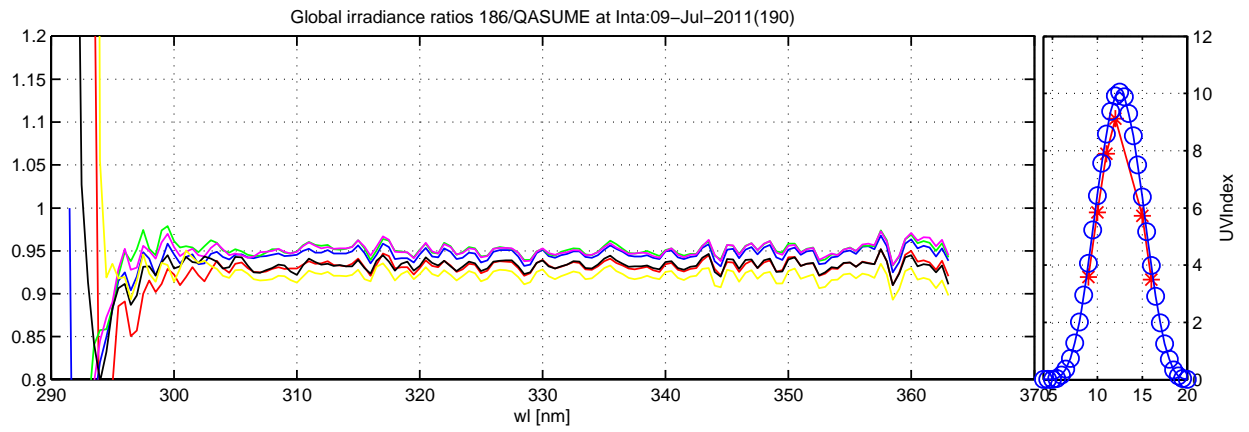
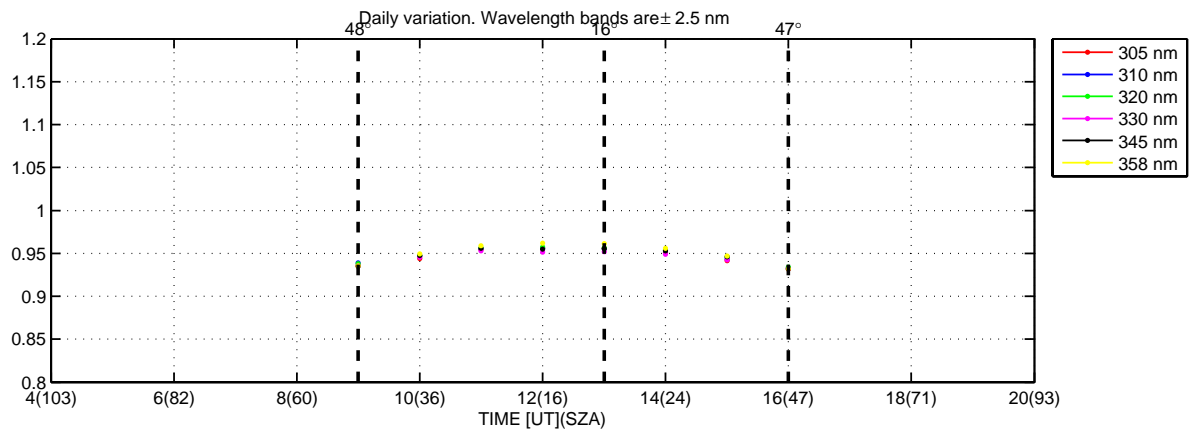
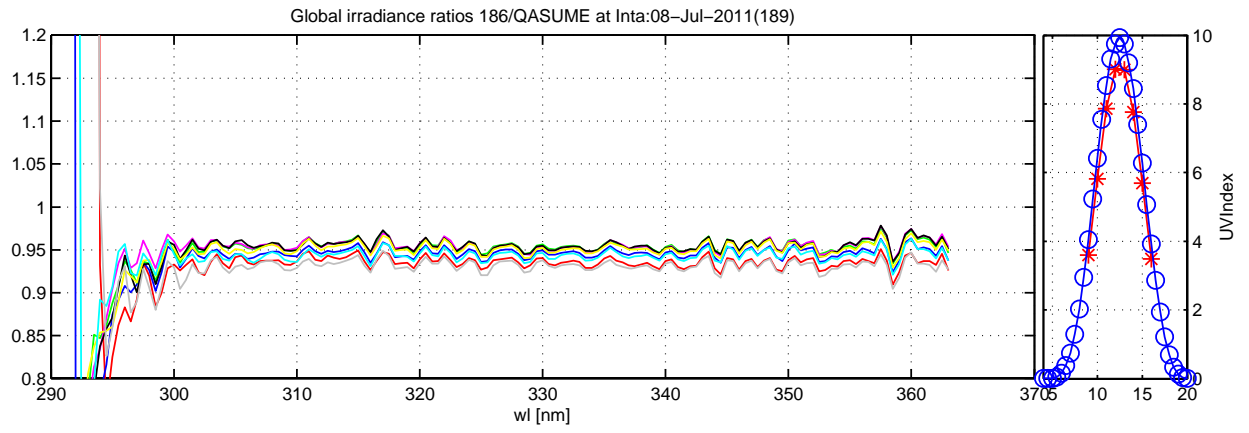
Intra, IZ3, July 2011

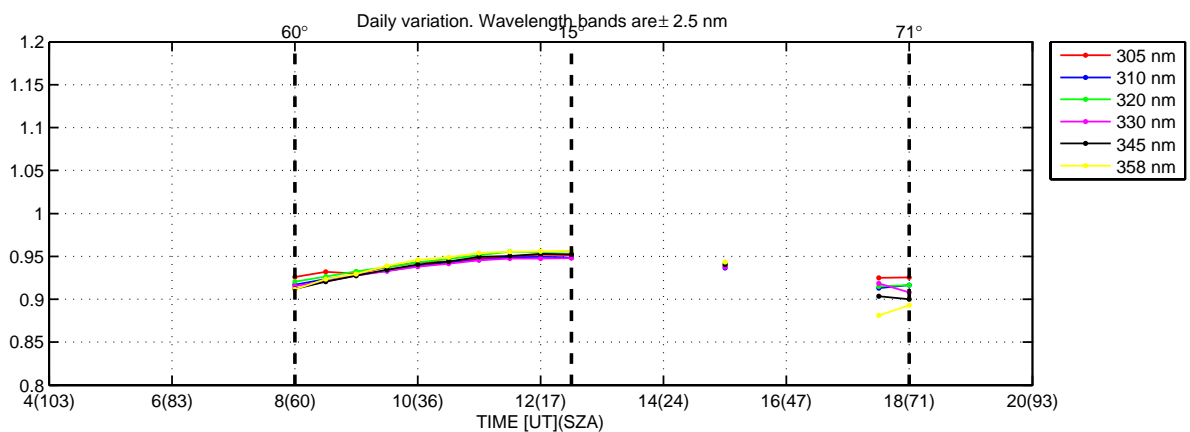
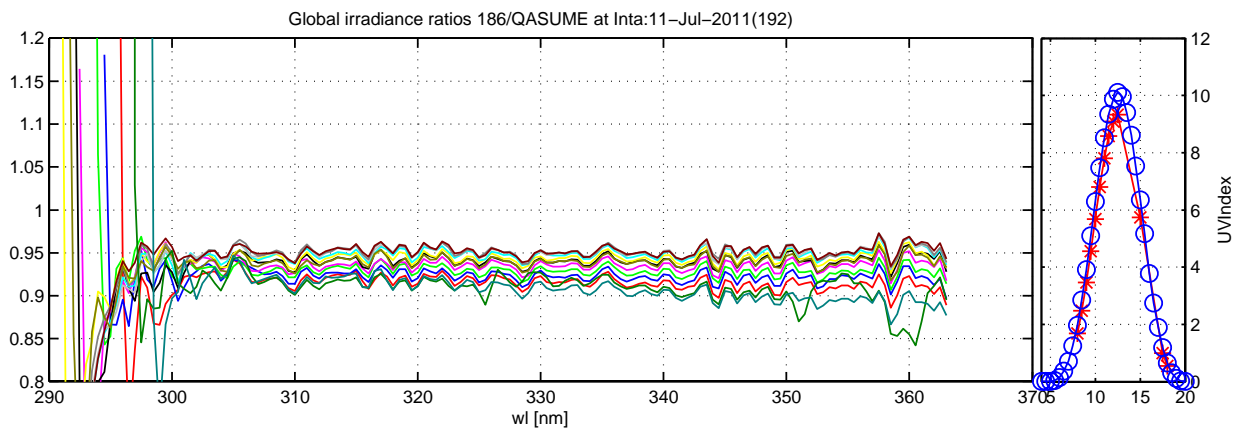
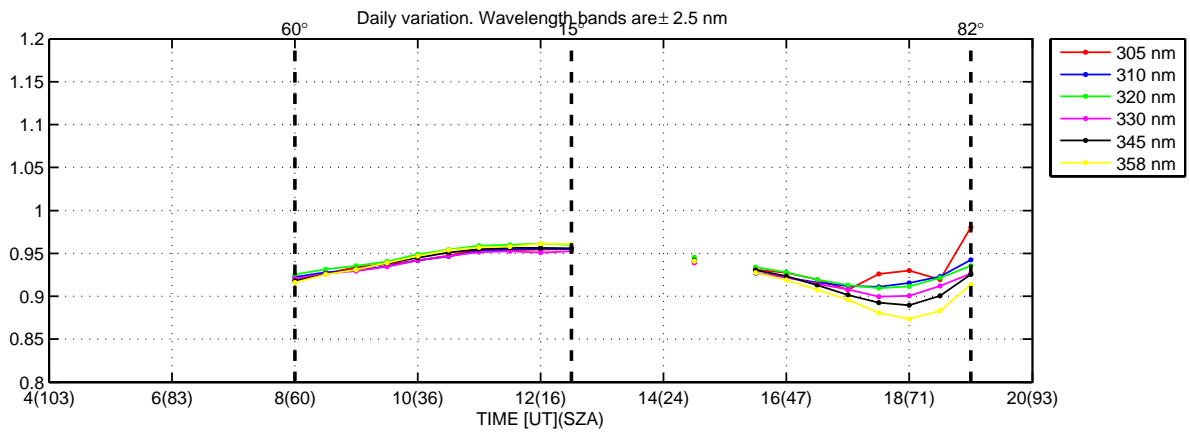
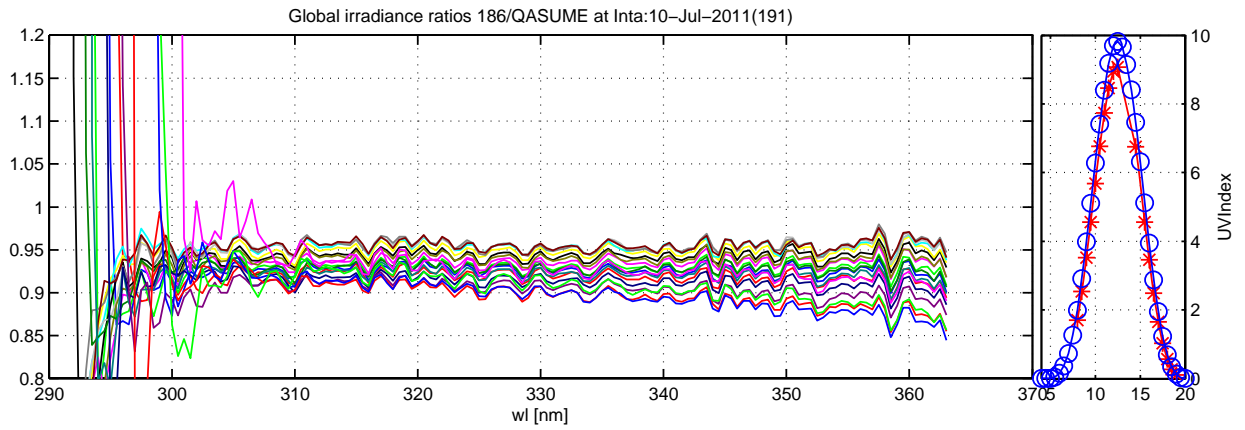


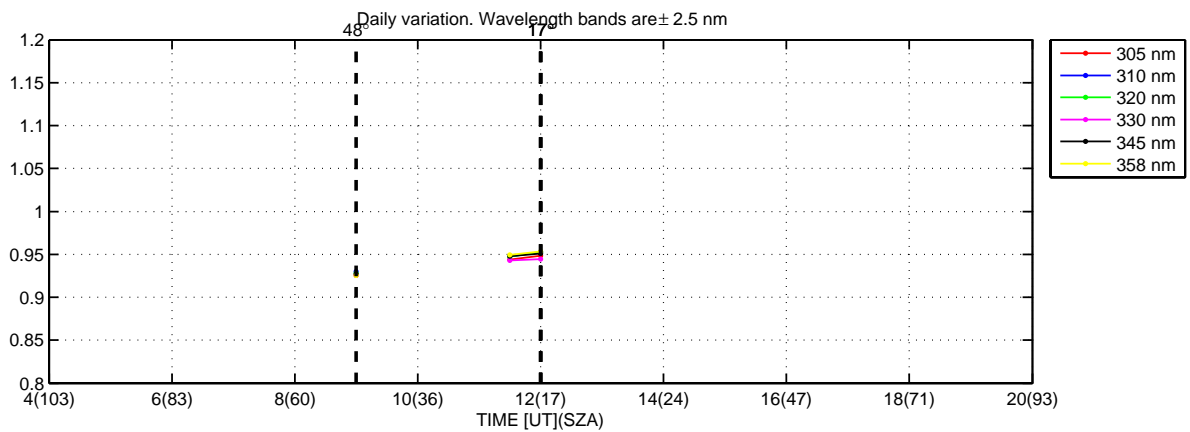
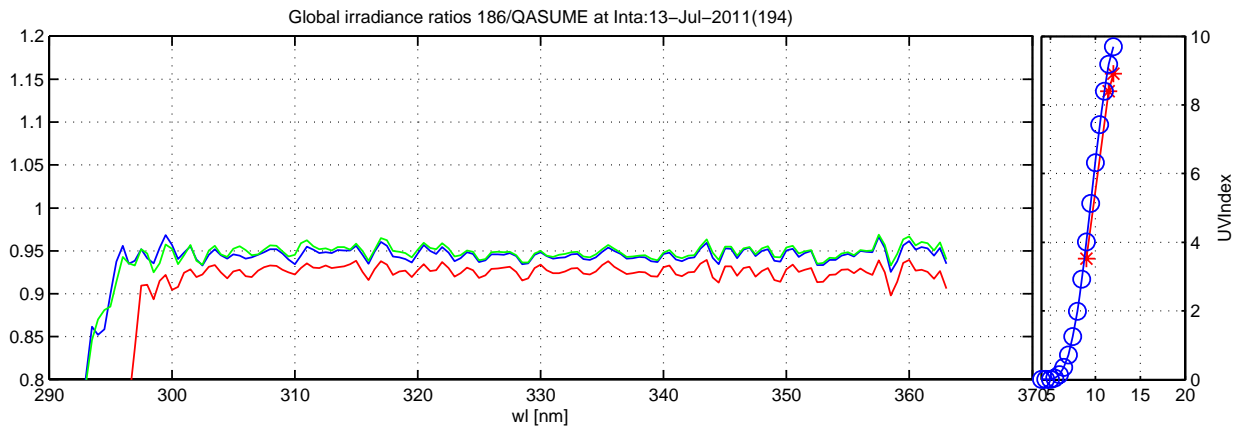
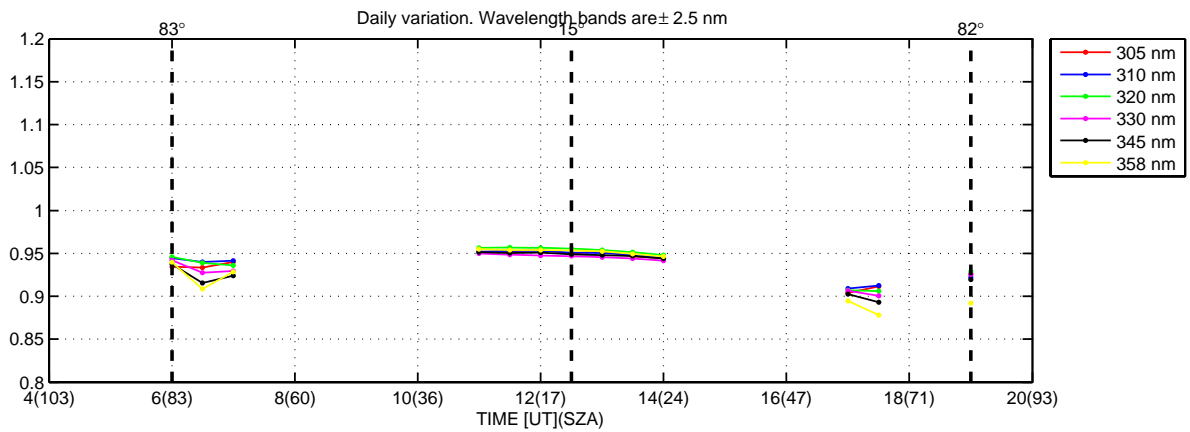
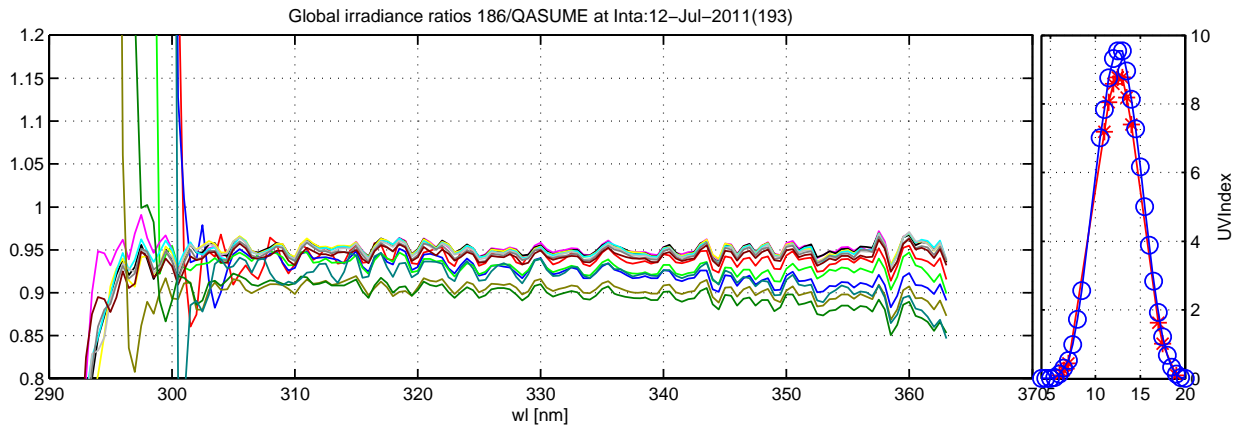
Temperature Dependence of Brewer #iz3, Intra, July 2011

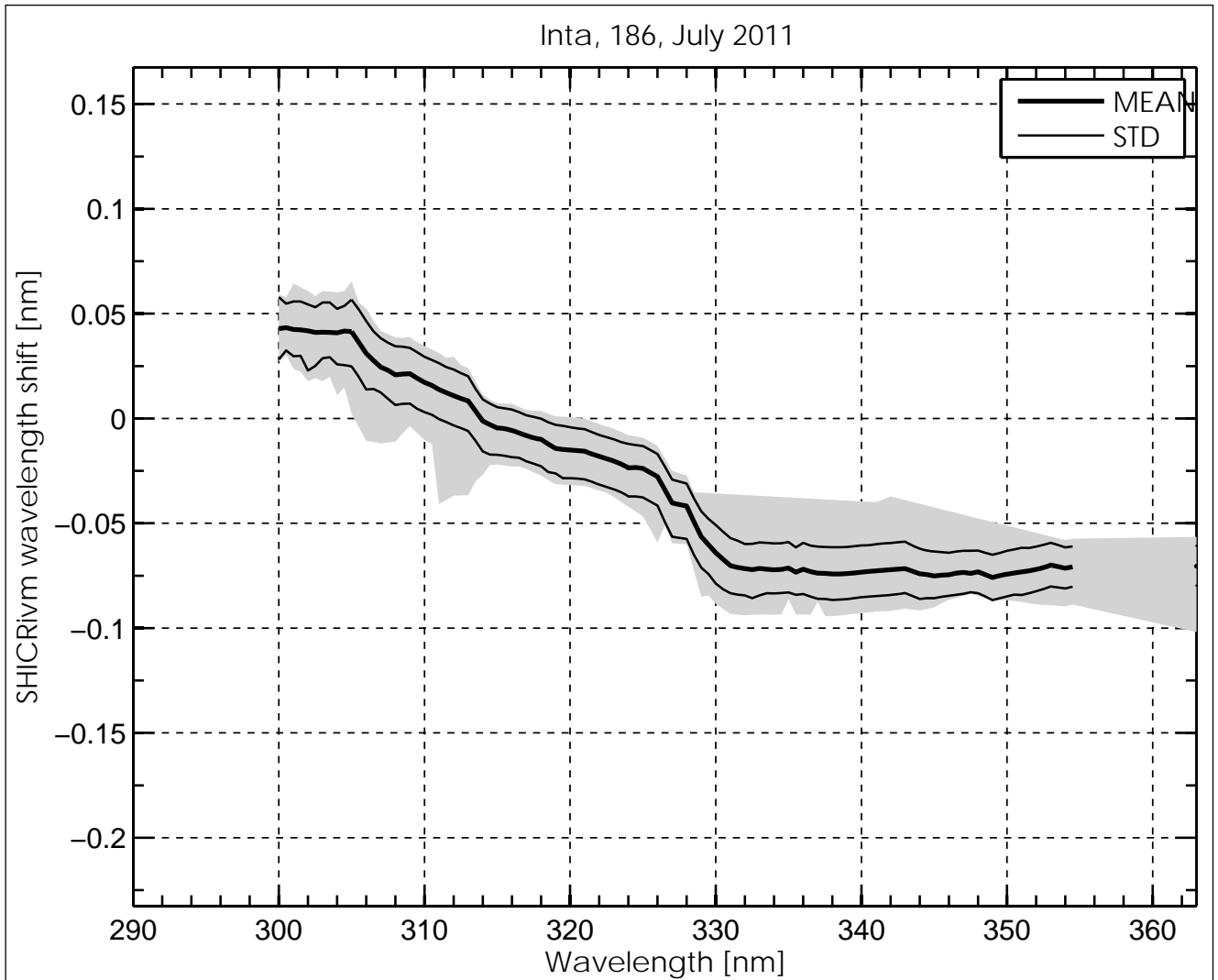
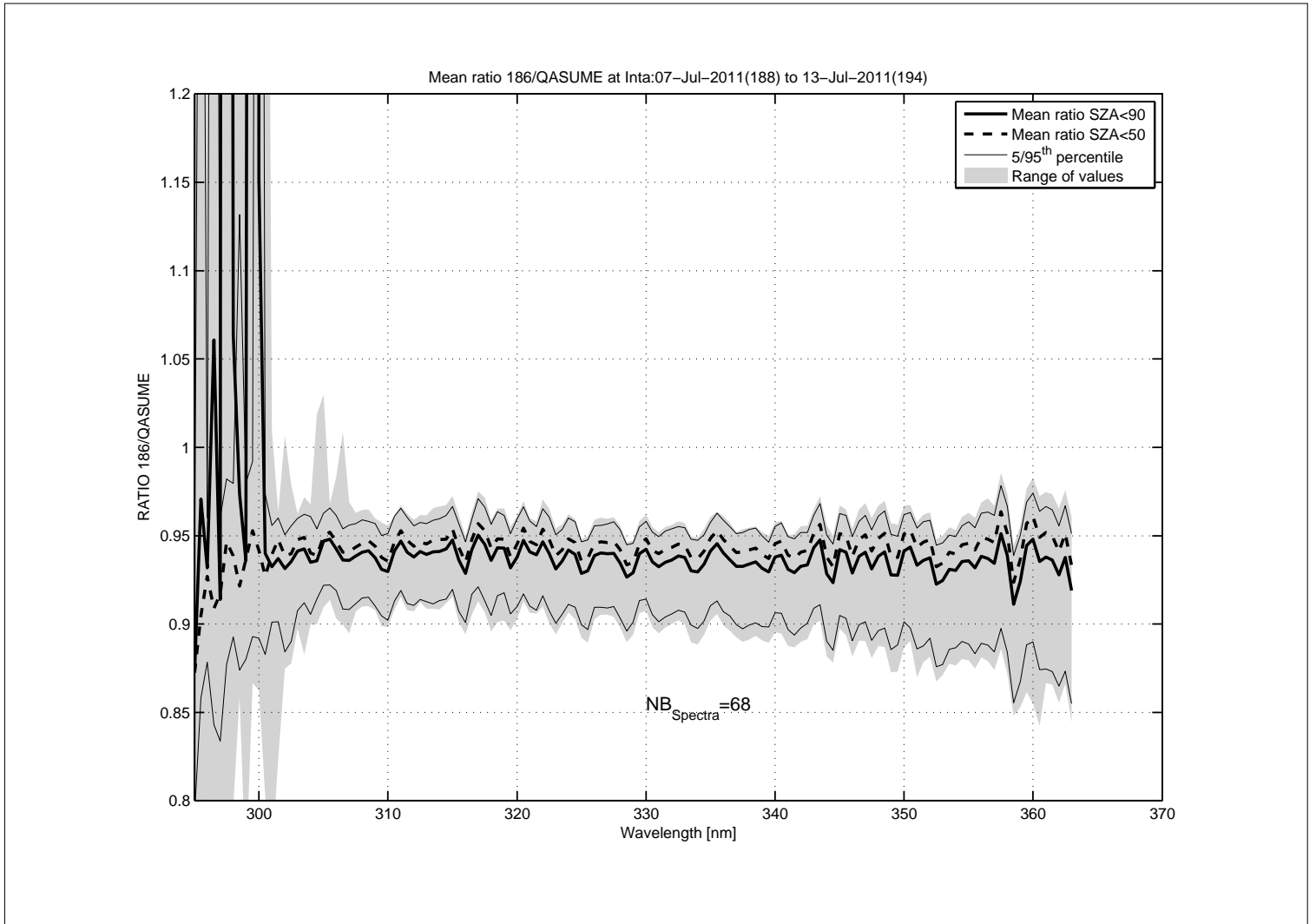




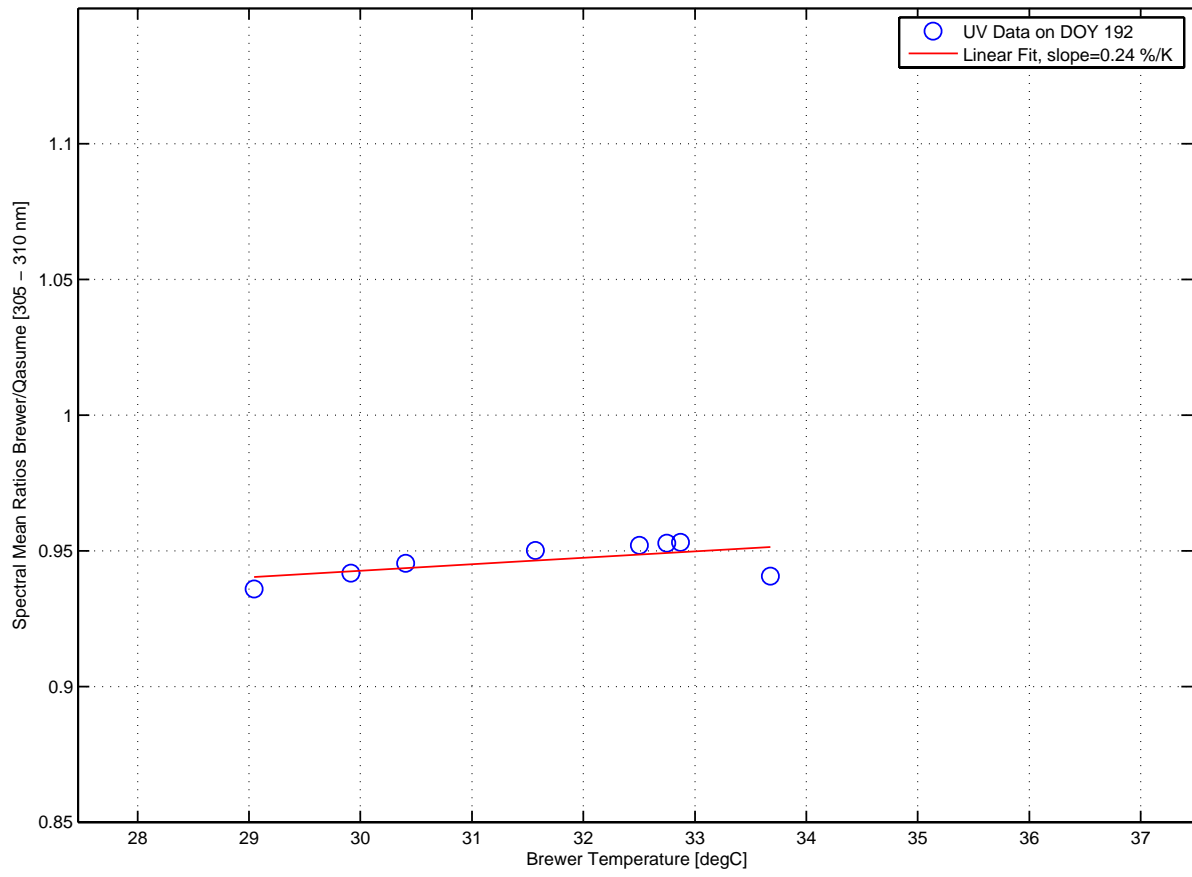




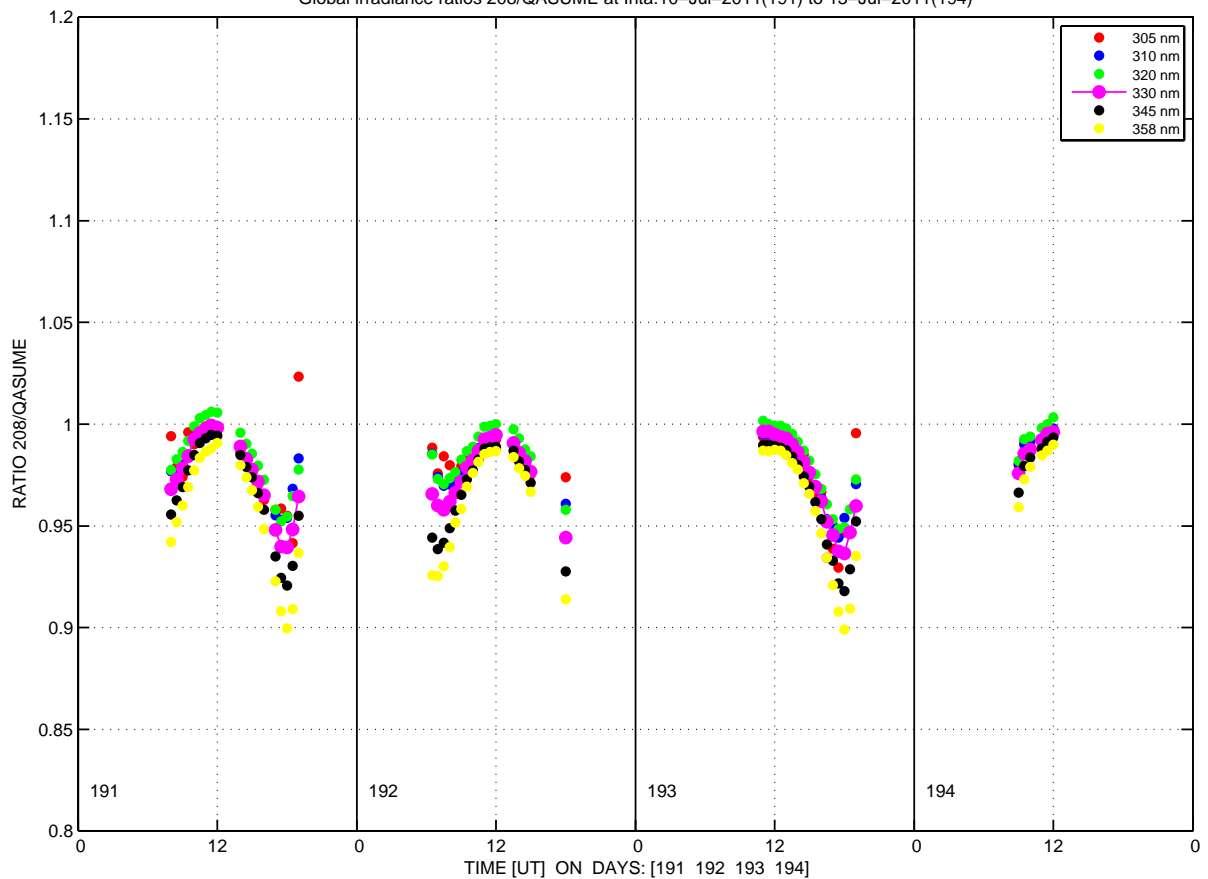




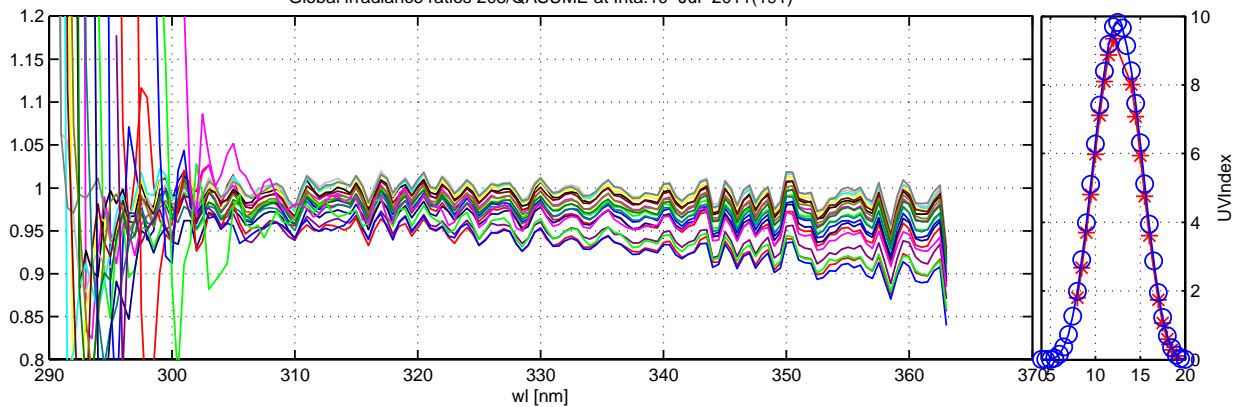
Temperature Dependence of Brewer #186, Inta, July 2011



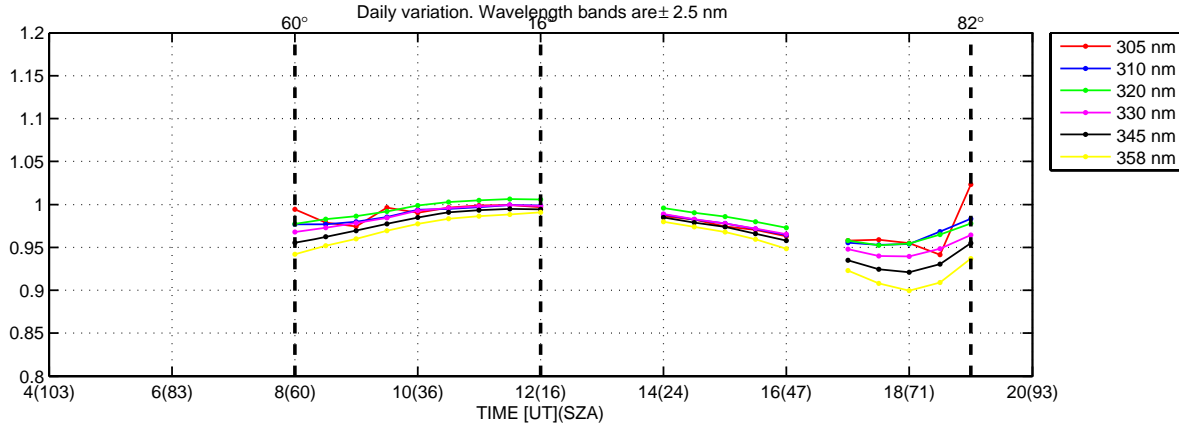
Global irradiance ratios 208/QASUME at Inta:10-Jul-2011(191) to 13-Jul-2011(194)

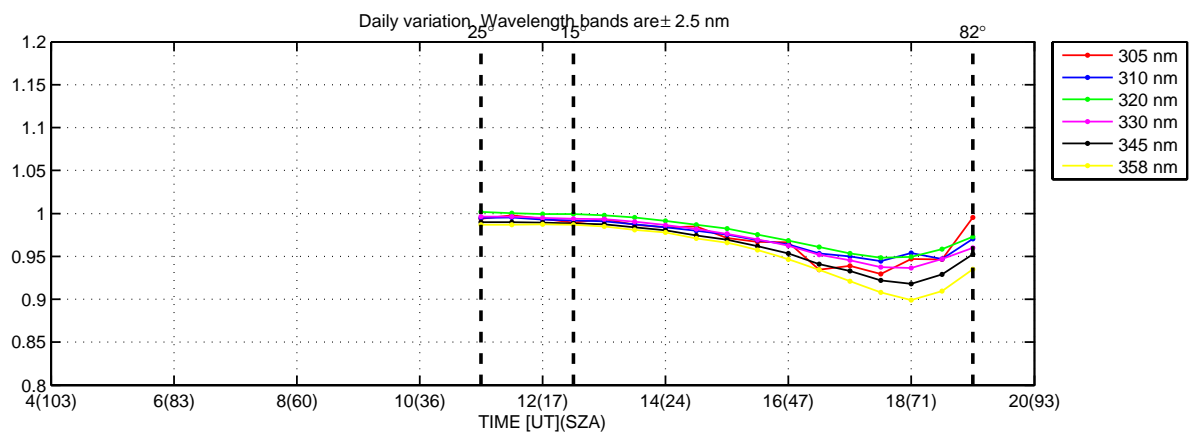
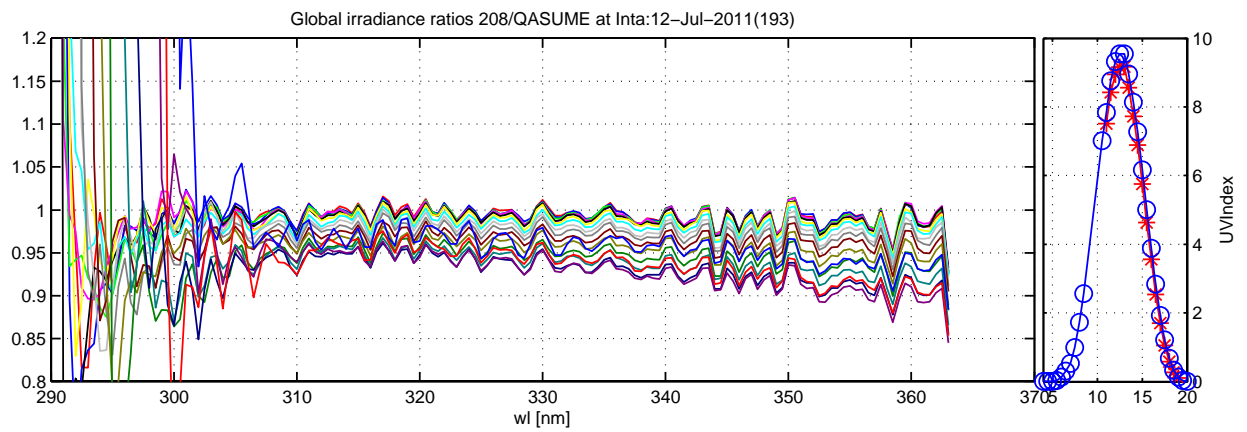
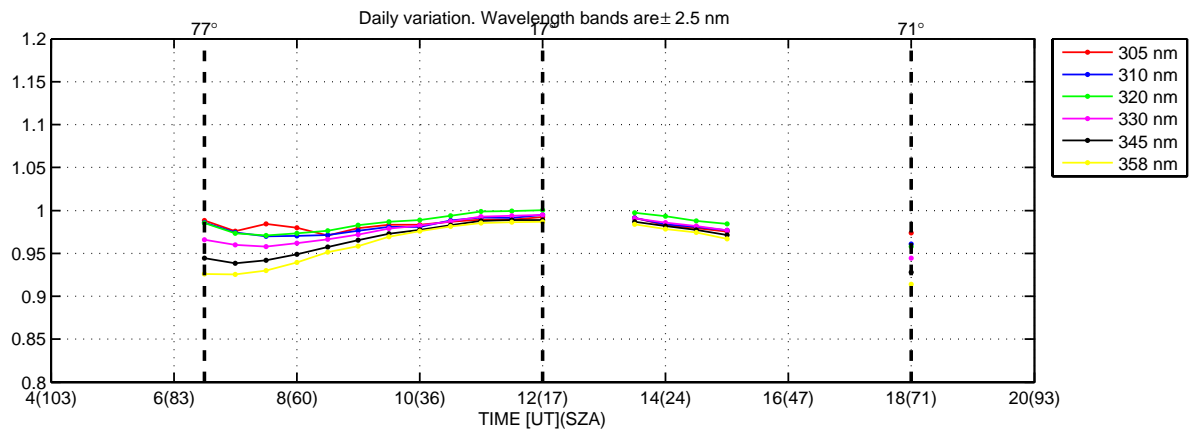
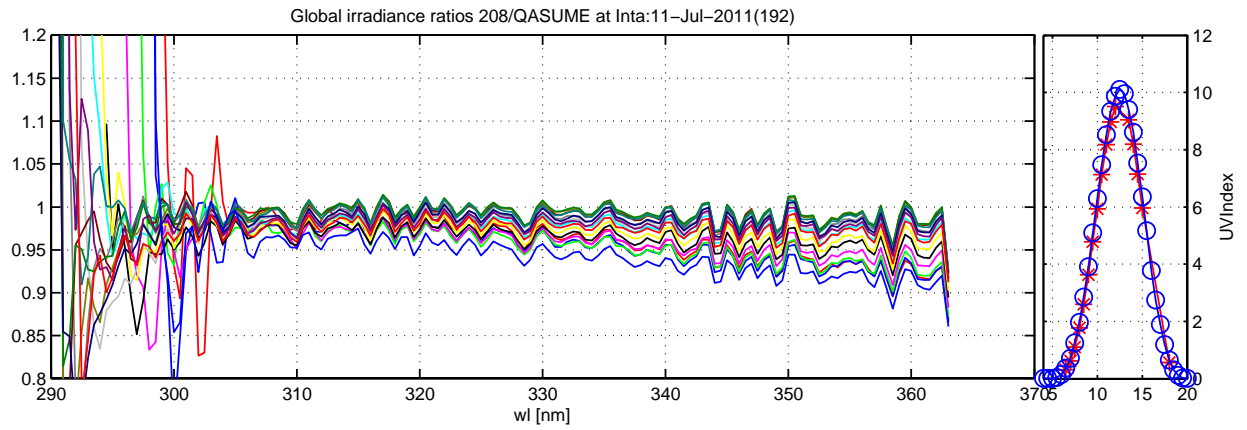


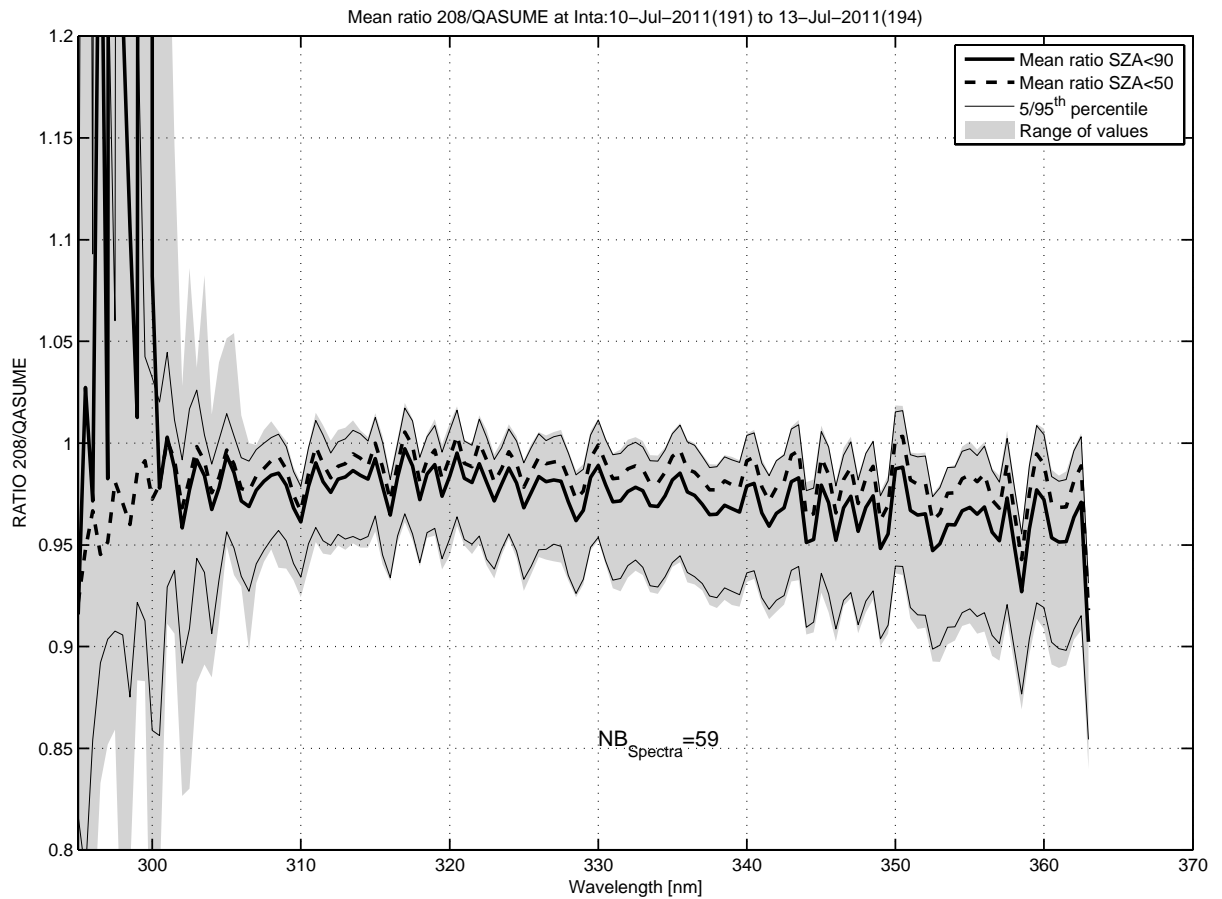
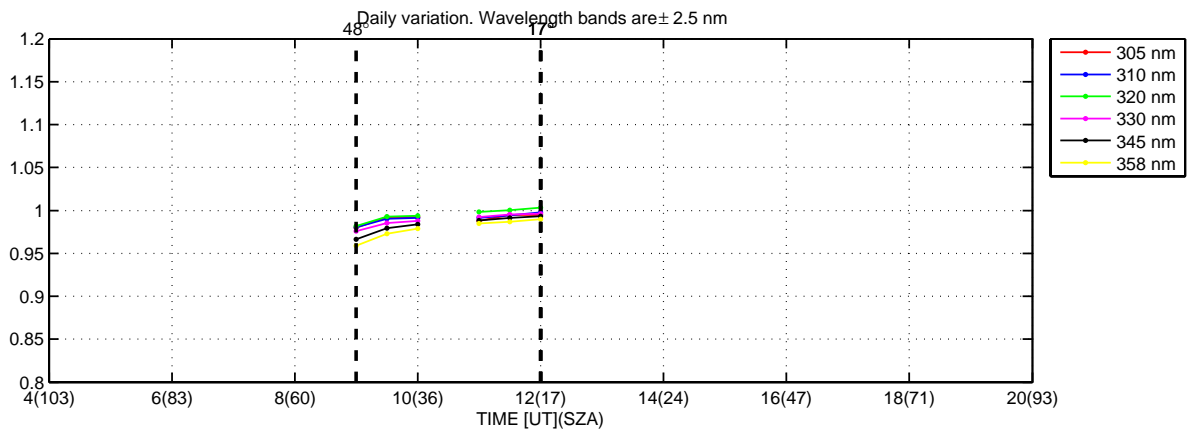
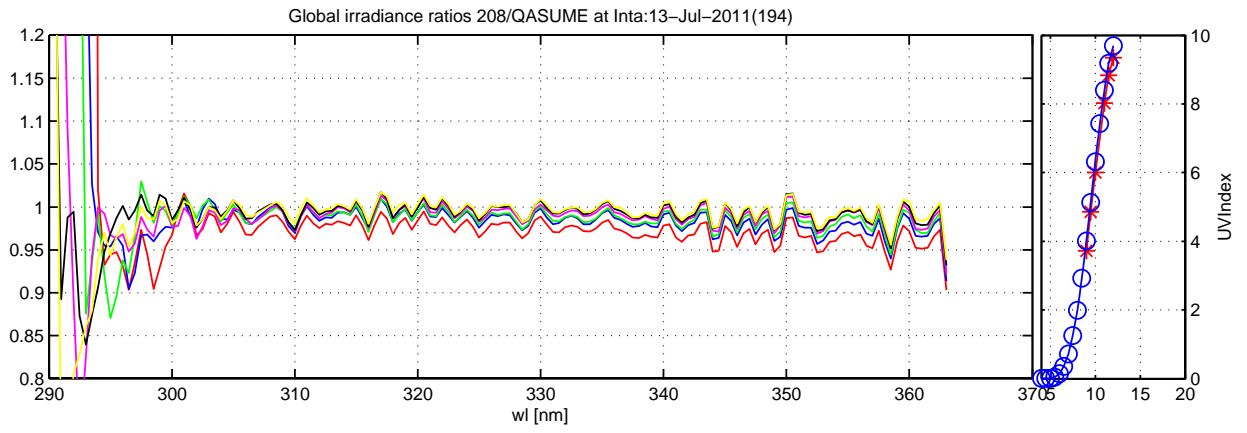
Global irradiance ratios 208/QASUME at Inta:10-Jul-2011(191)



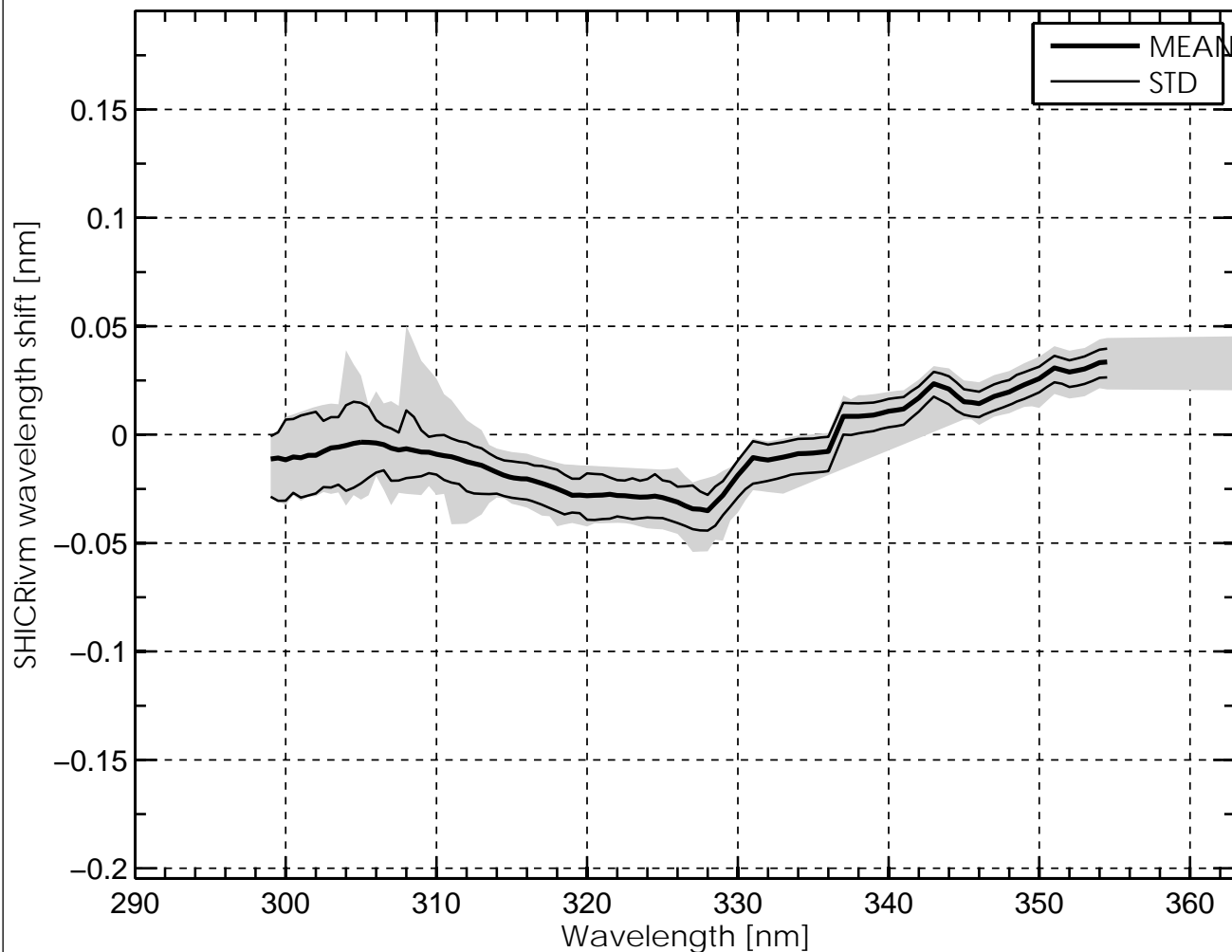
Daily variation. Wavelength bands are ± 2.5 nm







Intra, 208, July 2011



Temperature Dependence of Brewer #208, Intra, July 2011

