QASUME

Report of Ispra intercomparison, May 2002

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Rationale

The project Quality Assurance of Ultraviolet Measurements in Europe (QASUME) aims to develop and deploy a travelling ultraviolet spectroradiometer to encourage and assist quality assurance and long-term stability of absolute calibration of UV monitoring sites in the region.

Maintaining a consistent calibration of ultraviolet spectroradiometers and radiometers is not an easy task, requiring substantial investment in laboratory facilities and personnel. The task is made more challenging by the lack of a definitive calibration standard. The usual calibration source is a tungsten halogen lamp, a standard of spectral irradiance traceable through one or more steps to a National Standards Laboratory (NSL). Lamps of 1000W are generally used in the laboratory, and transfer standards of lower wattage are most frequently used for field calibrations. However, even the NSL secondary standards calibrated directly at the different NSLs fail to agree with each other, both within and between NSLs, and can differ by several percent (Walker et al., 1991; Kiedron et al., 1999; Gröbner et al., 2002). In addition to this intrinsic problem there are many other sources of discrepancy when comparing measurements of solar UV, for example the angular acceptance of the input optics and the slit function of spectroradiometers, or spectral response of radiometers, all of which are less than perfect by varying degrees and differ from instrument to instrument.

In the past the only way to judge the level of consistency between a number of UV spectroradiometers was to gather them all at one site and measure under the same sky in an intercomparison exercise, as illustrated by a previous series of EC intercomparisons (e.g. Gardiner et al., 1993; Webb, 1997; Bais et al., 2001). Despite the progress made in the previous exercises, the intercomparison process has several limitations and faults. There are practical limits to the number of instruments that can be accommodated at one site at any one time. The instruments all have to travel to and from the site risking damage or disturbance of delicate mechanisms in transit, and are then operating in a strange environment that may be alien to their usual conditions. In addition, performance at an intercomparison does not guarantee the same performance on a continuous basis at the home site where routine operation may prove to be better, or worse, than that at the discrete time and remote place of the intercomparison.

The advantage of a travelling standard instrument is that it can be placed side by side with each spectroradiometer at its home site and compared with the normal routine operation of the home instrument. There is no disturbance of the home instrument or its support and quality control procedures, and the site can be visited at intervals to track the stability of the home instrument to the travelling reference. While this is a truer evaluation of a monitoring site, it places strict criteria on the performance and operation of the travelling instrument that must be proven to be stable at a level against which all other instruments will be judged. Such an instrument system has been designed within QASUME and the aim of this intercomparison was to test its initial operation in an intercomparison with six other spectroradiometers that have all performed consistently well in previous intercomparisons. Following this the travelling instrument would then circulate amongst the six home sites for an initial test of its travelling stability.

The purpose of this report is to describe the initial intercomparison exercise.

Intercomparison Site

The intercomparison took place from May 6-17, 2002 at JRC Ispra, Italy ($45^0$48’43’’N, $008^0$37’37’’E) and was hosted by the newly created European reference centre for ultraviolet radiation measurements (ECUV). The instruments were mounted on the flat roof of the Solar House for the solar intercomparison, and the dark room of ECUV was used for lamp measurements and as a calibration facility for the participants if required.

The outdoor platform had been used in an earlier intercomparison (Webb, 1997). It is a flat roof on a one-storey building with access by a wide external staircase. There are trees to the north side of the roof, and a large building to the east (20m high) that shadows the roof from direct beam radiation until SZA of approximately 20^0. However, all instruments have essentially the same sky view, albeit not a perfect flat horizon. The NLR instrument is mounted in its own large truck container and this was parked in the car park to the west of the Solar House, with the diffuser a little lower than those on the roof but considered to have the same sky view. Figure 1 shows the distribution of the instruments on the roof. The surface of the roof had recently been replaced with lightweight green plastic tiles that proved to provide a static environment during the campaign. Power was provided for each instrument by independently fused outlets at intervals around the roof. Beneath the roof ample space was available for the control computers and personnel.

The dark room was about 400 m from the roof in a different building. The laboratory is painted black and has dimensions of 3 x 8 m and a height of about 3.5 m. At the time of the intercomparison it was temperature controlled to about 20 ± 1^o C with a relative humidity of about 60%. Several curtains can be lowered to separate parts of the dark room. Furthermore, two separate setups were provided to accommodate simultaneously (if necessary) the absolute radiometric calibration of either Brewer type spectrophotometers using 1000W DXW lamps in a vertical beam alignment, or the standard FEL-type horizontal alignment setup. The lamp current was controlled to within ±0.17 mA using an electronically controlled feedback loop consisting of a switching power supply, a computer, a voltmeter and a high precision 0.1 Ω power shunt. The two voltmeters with their respective shunts have been intercompared regularly and give identical results to within their respective calibration specifications.

The basic dark room was made available to the participants for calibration purposes, but each group used only their own standards of spectral irradiance for calibration and no intercomparison of standards was undertaken before the initial solar measurements, thus the solar radiation data are completely independent of each other. As a complementary part of the campaign all irradiance standards were measured by one instrument in the dark room.

Participants

ECUV, JRC Ispra, Italy	JRC, ISQ
University of Thessaloniki, Greece	GRT

University of Innsbruck, Austria	ATI
University of Manchester Institute of Science and Technology, UK	GBM
University of Hannover, Germany	DEH
RIVM, Netherlands	NLR
Finnish Meteorological Institute, Finland	FIJ

See appendix A for full list of names and addresses of participants.

Instrument details

Brief details of all instruments are given in table 1. The JRC had two instruments participating in the intercomparison, the travelling instrument (JRC) and a Brewer spectroradiometer (ISQ). All the instruments were scanning spectroradiometers, and while the majority of core monochromators originate from two main manufacturers, each instrument is configured and controlled in different ways by its operator. The Brewer instruments have a limited wavelength range with an upper limit of 365nm, and the NLR instrument measures to 450nm. All other instruments measured to at least 500nm (the longest wavelength that has been analysed). Some of the spectroradiometers are known to be temperature sensitive and in this case they are temperature stabilised. Ideally the input optics should have a perfect cosine response. Where the diffuser and fitting result in a significant difference from this ideal a cosine correction may be applied to the measured data to account at least partially for the physical imperfections of the diffuser.

Instrument ID	Make	Model	Temp. stabilised	FWHM (nm)	Diffuser model	Cosine corrected
JRC	Bentham	DM150	Y	0.8	Schreder	N
ISQ	Brewer	Mk III	N	0.5	Custom	N
ATI	Bentham	DTM300	Y	0.46	Schreder	N
DEH	Bentham	DTM300	Y	0.56	Schreder	N
FIJ	Brewer	Mk III	N	0.57	Brewer	Y
GBM	Bentham	DTM300	Y	0.64	Schreder	N
GRT	Brewer	Mk III	N	0.55	Brewer	Y
NLR	Dilor	XY50	Y	0.32	Bentham	Y

Measurement protocols

Solar measurements

The measurement day analysed here was defined as 0600-1700 UTC (local time = UTC + 2, local noon at 1122 UTC). Synchronised measurements were made from 290 – 500nm with 0.5nm steps and 3s intervals between each step. Measurements were repeated every 30 minutes, beginning on the hour and half hour. The first day of solar measurements was May 8th (Day 128) and was a day of blind intercomparison i.e. all instruments had been independently calibrated and no data exchange or analysis was made until the end of the day. Thereafter, from May 9th – 16th (days 129-136) the same basic measurement schedule was used, ending at 1400 on day 136. Individual instruments were missing for periods while calibrations and other investigations were performed in light of the results that were made available once submitted and processed. Since it was the aim of this exercise to investigate the performance of the travelling instrument it was more instructive to have immediate access to data, after the preliminary blind day. Table 2 shows periods for which each instrument was absent from the basic solar measurement schedule.

Instrument ID	**Day 129**	**Day 130**	**Day 131**	**Day 132**	**Day 133**	**Day 134**	**Day 135**	**Day 136**
JRC					1000 to 1130			
ISQ								
ATI			1600 to 1700	1530 to 1730		1330, 1400	0630, 1100	0700
DEH		0800-1200	0700-0930		0730-1200, 1330-1430, 1530-1630	1230-1330	1600-1630	
FIJ		1530	1030, 1330, 1630		0600, 1700	0600, 0630, 1130	0600, 1130	0730, 1130, after 1300
GBM		0730 to 0900		1530 to 1700	0600	After 1300	1500	
GRT		0630	After 0830	0830	0730	0730 1700	1200 1300	1130 to 1230
NLR	0730 to 1300, 1630	0830	0700 to 1000	1600				

Self-calibration

Each operator was responsible for the calibration of their own instrument before and during the campaign, by whatever means they usually use. The instruments are calibrated for both wavelength alignment and absolute irradiance. Wavelength calibration may be made by reference to the emission lines of a mercury lamp, or the fraunhofer lines in the solar spectrum, and is set before the measurements and also corrected post-scan by some operators. In any case, the analysis software applied to the intercomparison uses the SHICrivm (Slaper et al., 1995) procedure and this corrects for any small wavelength inaccuracies before normalising all data to the equivalent of a measurement made by an instrument with a triangular slit function of 1.0nm.

The absolute irradiance calibration is more challenging, and a variety of standards and methods are used by the operators to define the absolute value of their measurements. The irradiance standards used, and the frequency of calibrations, are listed in tables 3 and 4. Calibrations during the intercomparison were generally made more frequently than in the normal monitoring situation, sometimes in response to problems identified in the solar data (eg GBM), or to check after changes made to the instrument (eg NLR, GRT), or to tightly control stability (eg DEH). Note that all the instruments had been transported to the intercomparison and had been disturbed from their normal monitoring state.

Table 3 Calibration Lamps used during the campaign

Instrument ID	Laboratory standard*	Field standard**
JRC	F330 (FEL), PTB via Gigahertz-Optik	2 x 100W in field calibrator, based on 3 x 1000W FEL lamps referenced to F330
ISQ	F330 (FEL), PTB via Gigahertz-Optik	3 x 1000W DXW lamps referenced to F330, stability check in field by 50W lamps.
ATI	F168 (FEL), PTB via Gigahertz-Optik	F168 (FEL)
DEH	100W transfer standard traceable to PTB via Gigahertz-Optik	100W, further transfer lamp in calibrator.
FIJ	D14 (DXW, transfer standard from D03, HUT calibration)	D14
GBM	F502 (FEL), NIST via Optronic laboratories	2 x 200W in field calibrator, based on 3 x 1000W FEL inc. F502.
GRT	S1013 (DXW), NIST via Optronic laboratories	S1013, stability check in field by 2x50W lamps
NLR	S794 (DXW), NIST via Optronic laboratories F273(FEL), PTB. New lamp measured in ECUV dark room but not used as basis of measurement.	S794. Stability check with 200W lamps.

* The highest standard used by the operator and measured in the ECUV laboratory, with the NSL to which it reverts and the accredited supplier if applicable.
** The lamp(s) used to calibrate the instrument directly during the intercomparison, either in the field or in the laboratory.

Table 4 Calibration days for each instrument.

Instrument ID	Prior to campaign	During campaign*	After campaign
JRC	Initial calibration in the dark room of ECUV. No possibility to check calibration change during transport from laboratory to solar house roof.		Using two 100W lamps in a field calibrator. Day 136, 1445. The 100W lamps in the field calibrator were then recalibrated against the 1000W lamp and all campaign data (based on old 100W lamp calibration) was recalculated and resubmitted.
ISQ	In ECUV lab. using 1000W lamps	Using 50W lamps. Day 133, 1800	
ATI	On roof, using	Using 1000W lamp	

	1000W lamp	Day 132, 1530 Day134, 1330 Day 136, 0700	
DEH		Day 130, 0800-1200 Day 131, 0700-0930 Day 131, 1730-1800 Day 133, 0730–0900 Day 133, 100-1200 Day 133, 1530-1630 Day 134, 1230-1330 Day 135, 1600-1630	
FIJ	In ECUV lab. using D14	Day 130, 1530 Day 131, 1030, 1330 Day 134, 1800	
GBM	In ECUV lab. using F502 and then 200W lamps	Using 200W lamps. Day 130, 0820 Day 132, 1530 Day 134, 1630 Day 136, 1730	
GRT	In ECUV lab. using S1013 and then 50W lamps	Using 50W lamps. Day 131, 0845, then 1645 (lab) Day 132, 0710 Day 134, 0710, 1700 Day 136, 1430	
NLR	In own container using S794.	Using S794. Day 131, 0655-1025 Using 200W lamp Day 129, 0725–1320 Day 129, 1630 Day 131, 0837 Day 132, 1555-1625	Day 136, check on 200W lamp

* On the roof unless otherwise stated.

Laboratory standards intercomparison

The laboratory intercomparison of reference standards was held during one whole day, from 6:40 UT to 16:00 UT. In total, seven reference standards from all but one participant were measured, 4 FEL-type lamps in a horizontal alignment, and the remaining three of DXW-type in a vertical alignment setup. The instrument used for the measurements was a temperature stabilised Bentham DM150 fitted with a 6 m long fibre optic and a flat Teflon diffuser with a diameter of 2.5 cm. The stability of this instrument was checked regularly by measuring the same lamp (F270) at regular intervals over the day. Each lamp was measured with the same method, i.e. from 250 to 500 nm at steps of 1 nm. The resolution of the spectrometer was 0.8 nm. The integration time was 1 second. The overall stability of the instrument was ±1%, based on the successive measurements of the same reference lamp. Thus, the intercomparison between the different reference standards can be assumed to be within the same limits of ±1%. The short term variability, i.e. between three successive scans of the same lamp was typically within ±0.5%.

The measurement schedule was the following:
6:40 F270 ON (d=700 mm), 7:00 – 7:28 4 scans from 250:500 every 1 nm.
7:58 F168 ON (d=700 mm), 8:08 – 8:28 3 scans
8:54 F270 ON (d=700 mm), 9:04 – 9:10 1 scan
9:38 F273 ON (d=500 mm), 9:52 – 10:06 3 scans
10:37 F502 ON (d=500 mm), 10:45 – 11:07 3 scans
11:49 F270 ON (d=700 mm), 11:57 – 12:13 2 scans

VERTICAL ALIGNMENT (instrument was not moved, only fibre was displaced from one location to another)
12:36 S1013 ON (d=500 mm), 12:45 – 13:08 3 scans
13:26 S794 ON (d=500 mm), 13:36 – 50 3 scans
14:03 S974 ON (d=500 mm), 14:16 – 14:30 2 scans
14:50 D14 ON (d=500 mm), 15:00 – 15:30 2 scans

HORIZONTAL ALIGNMENT
15:30 F270 ON (d=700 mm), 15:43 – 15:50 1 scan

Weather

The weather during the campaign was not as good as expected and produced challenging conditions for the intercomparison. There were long periods of rain, a situation that has not been encountered in previous intercomparisons and leads to additional uncertainties because of the unknown effect of raindrops on the different input optics. All input optics were covered with a quartz dome; the diffusers of FIJ and NLR are heated, leaving them dry and free of raindrops. When not raining it was generally humid, with a suspicion of condensation inside at least one cosine diffuser that is inadequately dried by the small silica gel capsule supplied. While these conditions were less than desirable they are realistic of the conditions likely to be encountered by the travelling instrument at at least some of the monitoring sites that it visits, and in this respect the campaign produced a pragmatic assessment of the results that can be expected in a tightly scheduled round of site visits.

Brief weather diary:

DAY	128	Cloudy and dry until 0930 UTC, thereafter rain of increasing intensity.
	129	Heavy showers throughout the day.
	130	Some early sun, completely overcast by 0730 UTC, rain at 1500 UTC.
	131	Brief periods of sun in morning, but mainly overcast with showers before 0900 and from 1440-1540.
	132	Clear skies and sun early in the day, then increasing cloud and showers.
	133	Thunderstorm early morning. Cloudy day but clearing late afternoon.
	134	Cloudless to 0730UTC. Clouds increase to 7 octas, then decrease in the afternoon.
	135	Clear skies in the early morning but cirrus increases through the day to cover the sky.
	136	Traces of cirrus cloud but otherwise clear until the campaign end at 1400 UTC.

Analysis software

An analysis software package was developed specifically for the QASUME project. This ensured that all data were processed in an absolutely identical and consistent way. A web based approach was selected to allow all QASUME partners internet access to the central QASUME database and plotting software. This approach would also enable remote submission of data – of value in the subsequent travelling inter-comparison campaign.
The basis of the analysis software was a central QASUME database, with a package of processing, analysis and display software accessed through a central web page. There were two essential aspects to the software:

Initial Data Processing
Under this phase the parameters for each spectrophotometer (slit function, full width half maximum, wavelength step, etc.) were installed into the database. The "source" spectra were then loaded in and processed through the SHICrivm (Slaper et al., 1995) software in daily batches to produce wavelength corrected and standardised spectra (equivalent to an instrument with triangular slit function of 1nm FWHM. Both the source and processed spectra were saved onto the central database.
All data for the Ispra inter-comparison were identically processed in this manner. Initially data were processed with the then-available SHICrivm software, but prior to the generation of this report all data were reprocessed with the latest version of the software delivered shortly after the campaign (Version 5.20 of the SHICcall shell, and 3.035 of the SHICrivm software are currently installed).
All analysis presented within this report, and all data now held on the central QASUME database were derived from output of SHICrivm version 3.035

Analysis, Display and Data Extraction
A central suite of programmes were written to provide a specified set of analyses. These enabled display and comparison of the UV spectra produced by the different spectrophotometers, either individually, as pairs at a particular time, or as time series. All figures in this report have been produced with this software, details are given in individual figure captions.
Data sets can also be extracted from the database, either in the form of the original or processed spectra or as tables of processed data (e.g. ratios against wavelength or time, erythemally effective UV) in a spreadsheet compatible format

Software Installation and Use
The complexity of the database, intensive use of new software, and the several updates to SHICrivm, meant that a certain amount of software "tuning" was required during and after the Ispra Campaign. The analysis software is now in a stable state and is available to all QASUME partners – either on the internet or as a package for self-installation.

Results

The results presented here are based primarily on the original data measured by the operators during the campaign. Very little data was resubmitted after the campaign. The major resubmission was that of the JRC instrument. This instrument was designed to be operated in conjunction with its field calibrator, but due to time constraints the field calibrator was not delivered until the campaign had begun and the JRC calibration on the roof could not be checked through the calibrator and related in the absolute sense to the ECUV standard until after the campaign. This was acknowledged at the start of the campaign and a revision of the JRC data expected. Since this is the instrument that is proposed as the travelling reference it

has been used as the reference instrument in presenting the results here (ie ratios are taken with respect to JRC). The data designated as JRC is the resubmitted (ie final calibration) data of JRC. Any reference to instrument JRX refers to the original data measured and submitted by JRC and is used to illustrate particular points only.
A small amount of data for GRT (day 135, after 1100) was also resubmitted as an incorrect cosine correction had been applied and this was rectified in the resubmission.

Although measurements began at a wavelength of 290nm the generally overcast conditions meant that there was negligible radiation at wavelengths less than 300nm and any comparison of signals below this wavelength is dominated by noise, thus the data are presented from 300nm to either 365nm (the wavelength limit of the Brewer instruments) or 500nm (the next common wavelength limit). Where data are presented at select discrete wavelengths they represent a small waveband of X +/- 2nm where X is the designated wavelength.

The first day (day 128) of the campaign was a blind intercomparison and examples of data from this day are presented first to show the initial performance of all the instruments after independent calibration and operating essentially in isolation. The data are plotted with JRX (the original JRC data) as reference for several reasons. First it allows the true (ie recalibrated) JRC data to be shown on the same graph. It also indicates the change in the measurement once the post-campaign calibration was applied. It can be seen that the resubmitted JRC data differs by between 3 and 7% from the original, the difference increasing with wavelength from 300 to 500nm. This illustrates the importance of the field calibrator in the overall operation of the standard instrument: although the JRC instrument was calibrated in the ECUV laboratory prior to the campaign, its measurements on the roof were not representative of that calibration (a probability acknowledged during the campaign). Finally, although recalibration of JRC was expected, the JRX data are those submitted under blind conditions and maintain the integrity of a “blind day” albeit with an incomplete system operating. Figures 1 and 2 show the spectral ratios of all instruments in the two waveband ranges, 300-365nm and 300-500nm at 0900 UTC (before the rain) and then figures 3 and 4 show the same information at 1200 UTC after several hours of rain.

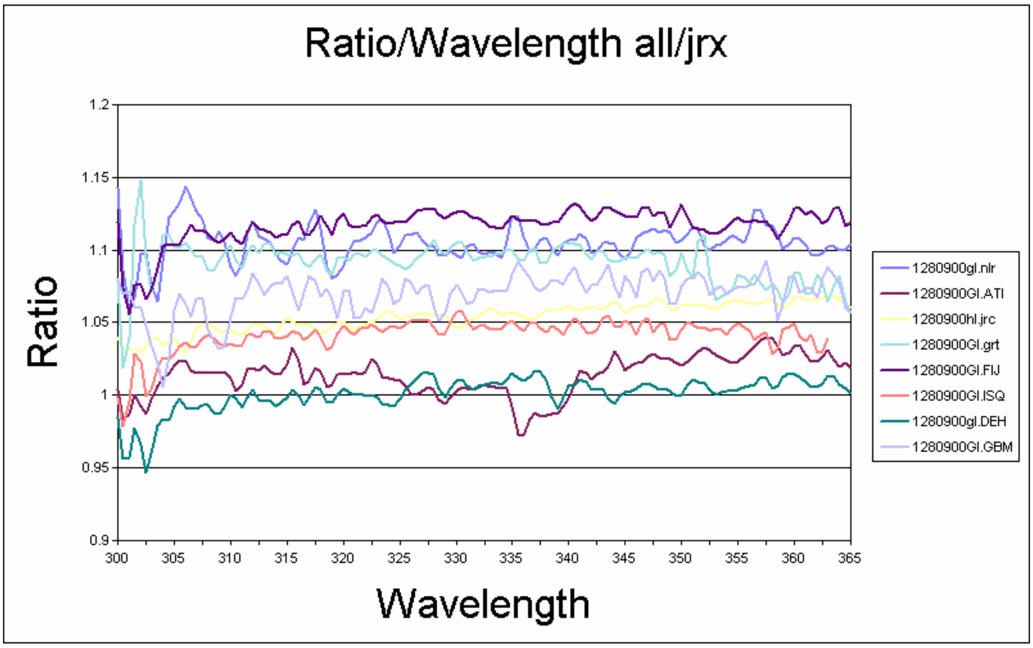

Figure 1 Spectral ratios of all instruments to JRX at 0900, dry conditions

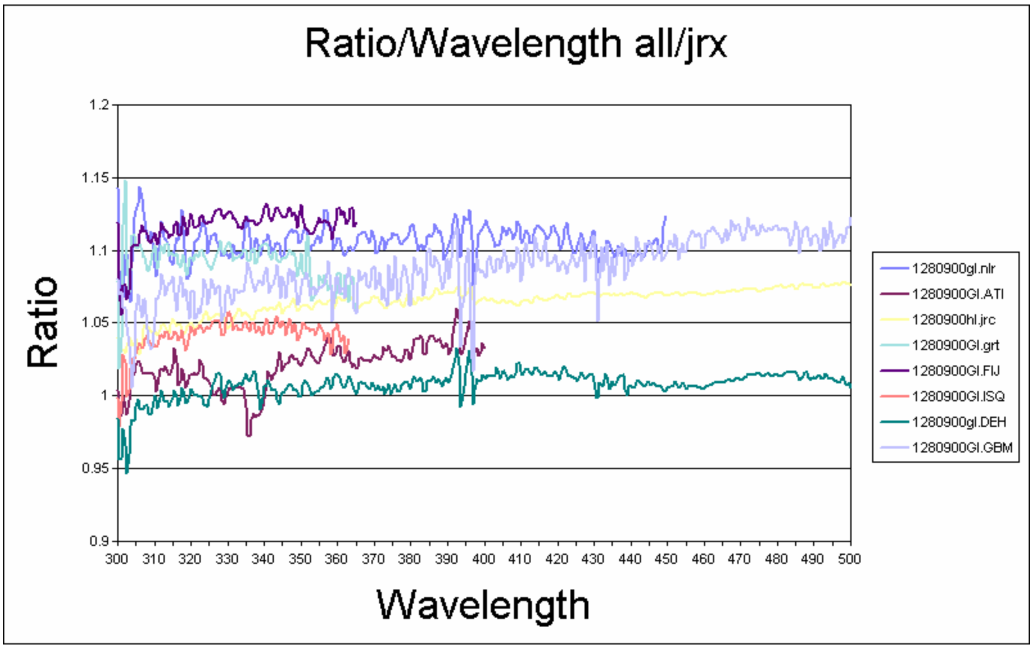

Figure 2 Spectral ratios of all instruments to JRX at 0900, extended wavelength range, dry conditions.

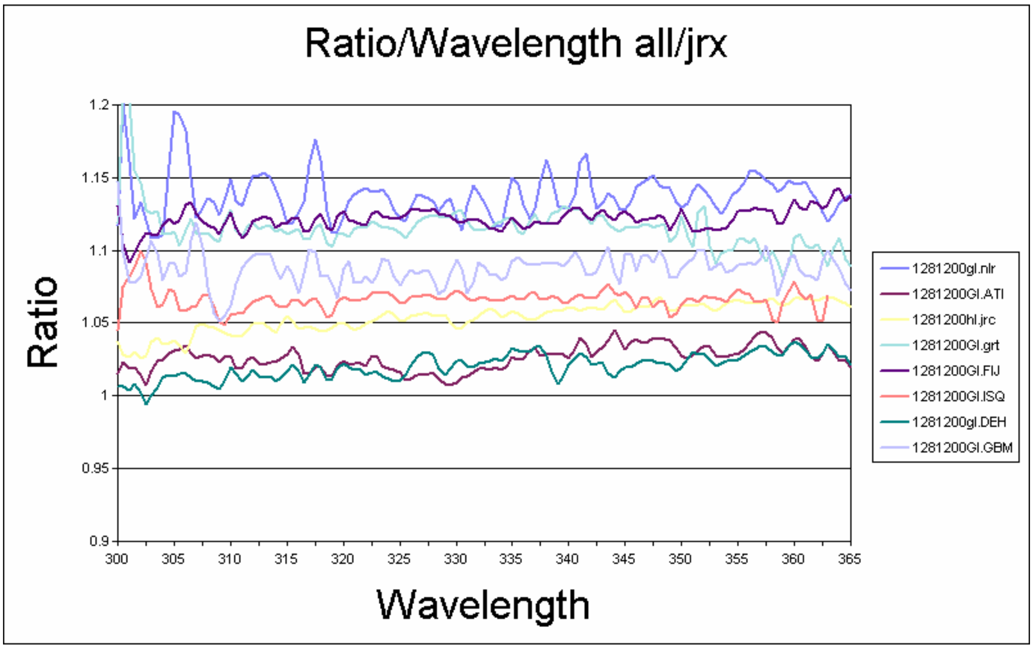

Figure 3 Spectral ratios of all instruments to JRX at 1200, wet conditions

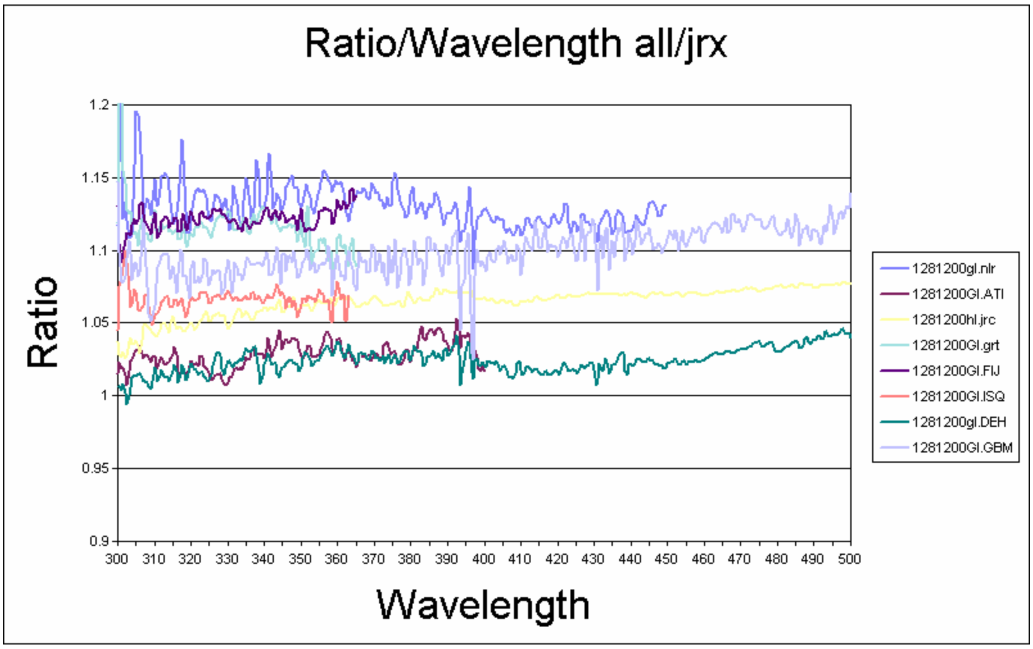

Figure 4 Spectral ratios of all instruments to JRX at 1200, extended wavelength range, wet conditions

The ISQ and JRC data, that revert to the same calibration standard in the same laboratory, are very close to each other, as they should be. These two instruments lie in the centre of a distribution that is disappointingly broad. The spread of the ratios ranges from approximately 1.0 to 1.15. GBM, DEH and ATI form one cluster at 3-5% less than JRC, while GRT, FIJ and NLR form a second cluster at 5-8% greater than JRC. All ratios are essentially spectrally flat, and there is little difference between the corresponding figures for the two time periods. The measurement of FIJ decreases slightly with respect to the other instruments, and all ratios increase slightly (1-2%) from 0900 to 1200, implying that this was a change in the JRX/JRC instrument. Otherwise, for this brief period, everything appears stable.

Some of the differences in the measured absolute irradiances may be attributable to the differences in standards of absolute irradiance on which the calibrations are based ie the differences in the laboratory standards listed in table 3, plus any additional uncertainty incurred in the transfer process(es) from these lamps to the instruments. The differences between the laboratory standards were measured and are detailed in the section on calibration lamps below, followed by figure 2 corrected for the standard lamp differences to show the scale of the residual differences between instruments. The remainder of this section deals with the data as presented, since all monitoring sites must operate with reference to their own standards. In this respect the JRC instrument will be acting as a relative rather than an absolute reference standard, and will fix a site on a relative scale of irradiance and then track its stability at this level through repeated visits over time. It is not the purpose of this project to define the correct absolute scale of spectral irradiance, only to assist in maintaining stability against one arbitrarily provided scale.

As stability is paramount to this project, the remaining figures show the time series of the ratios between pairs of instruments over the whole campaign period, that is days 128 – 136. The ratios are plotted for each instrument in turn vs. JRC for the wavelengths 310, 320, 340 and 360nm, allowing direct comparison between all instruments (figures 5 to 11), and then with the additional wavelengths 400, 430 and 480nm for those instruments making such measurements (figures 12-15). A consistent pattern in all the instrument ratios would imply behaviour attributable to JRC, but the only clear case of this is the increase in ratios throughout day 128, as already seen in figures 1-4. All instruments show evidence of this trend, though some more than others as the increase is also influenced by the behaviour of the other individual instruments.

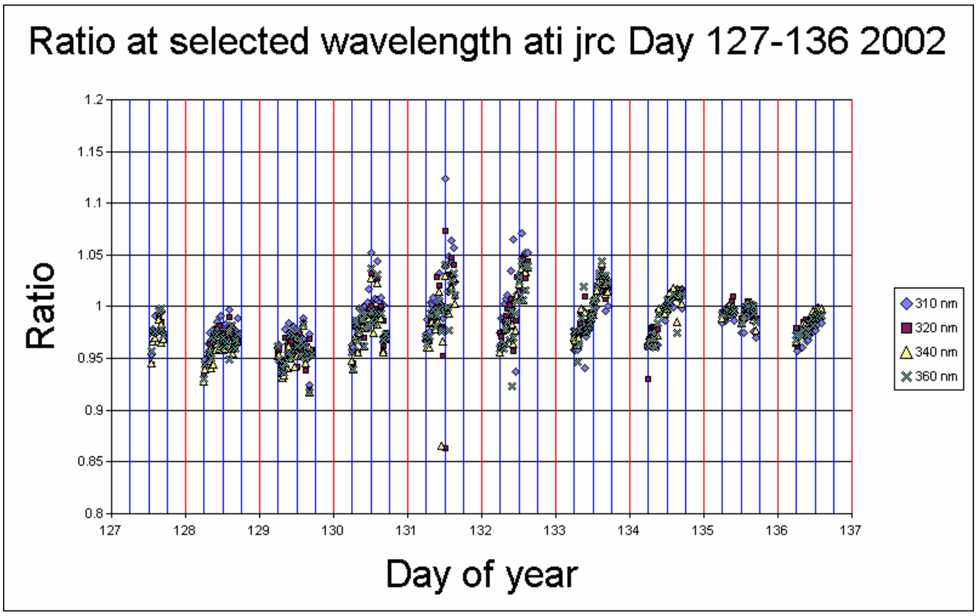

Figure 5 Time series of ratios for ATI and JRC.

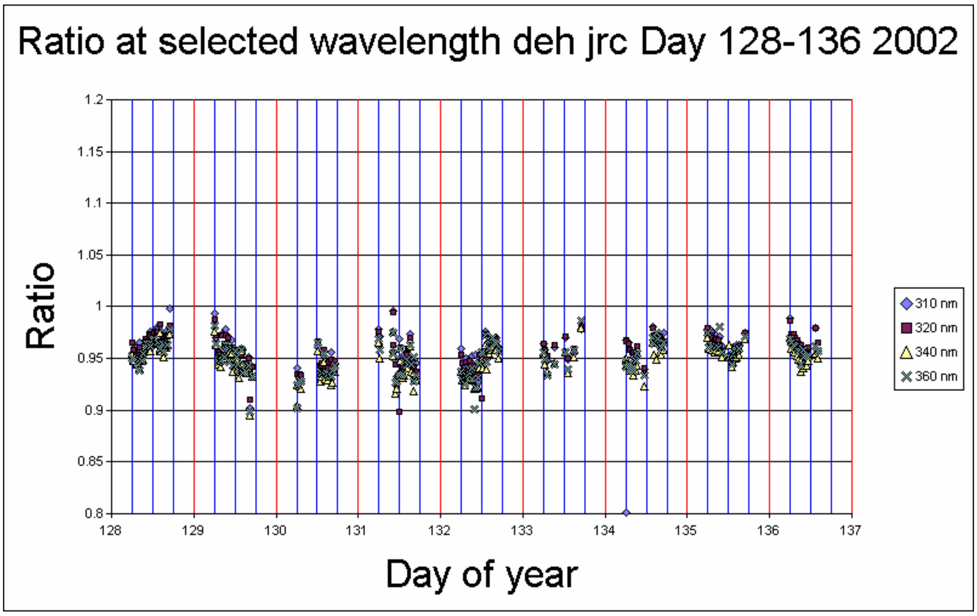

Figure 6 Time series of ratios for DEH and JRC

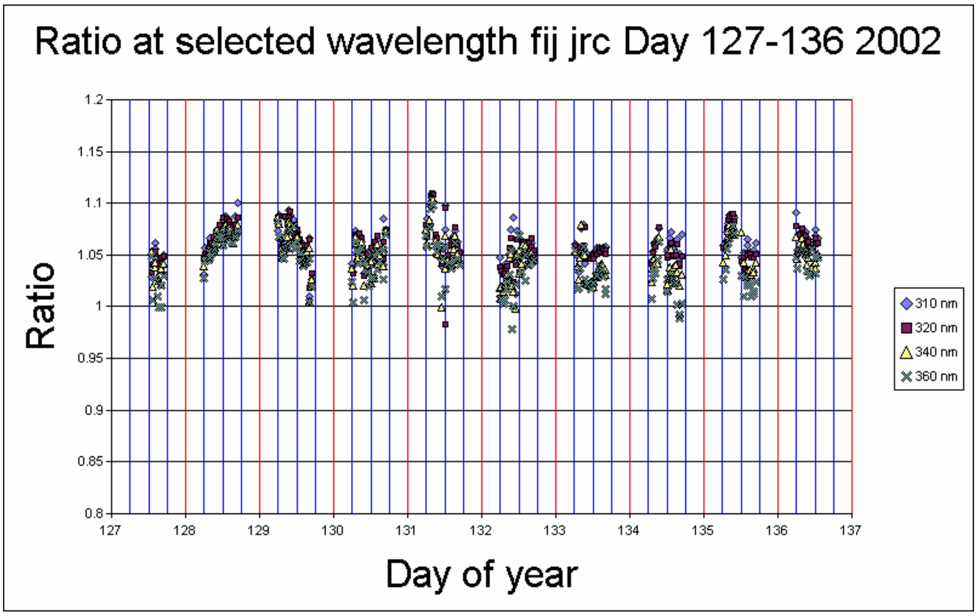

Figure 7 Time series of ratios for FIJ and JRC

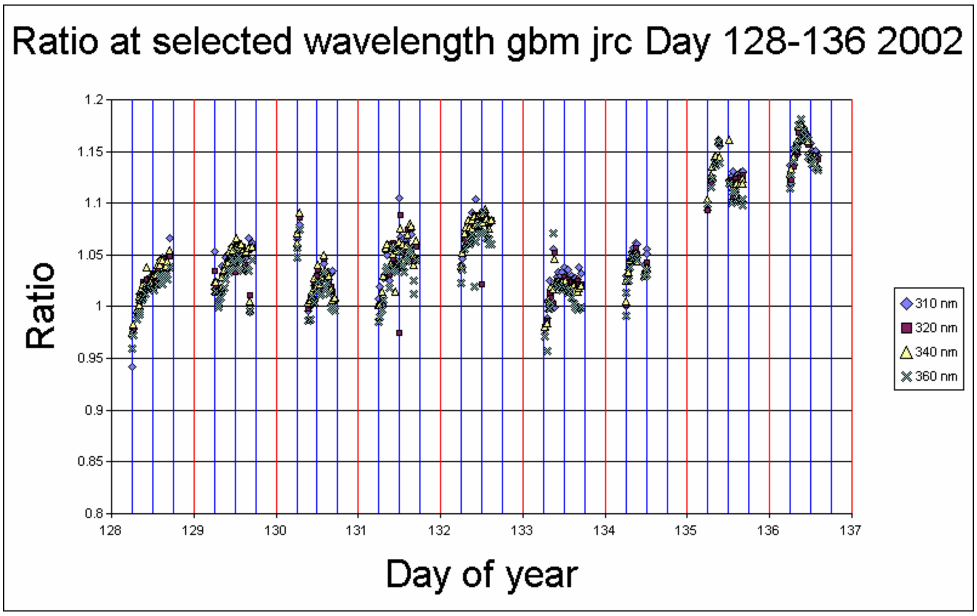

Figure 8 Time series of ratios for GBM and JRC

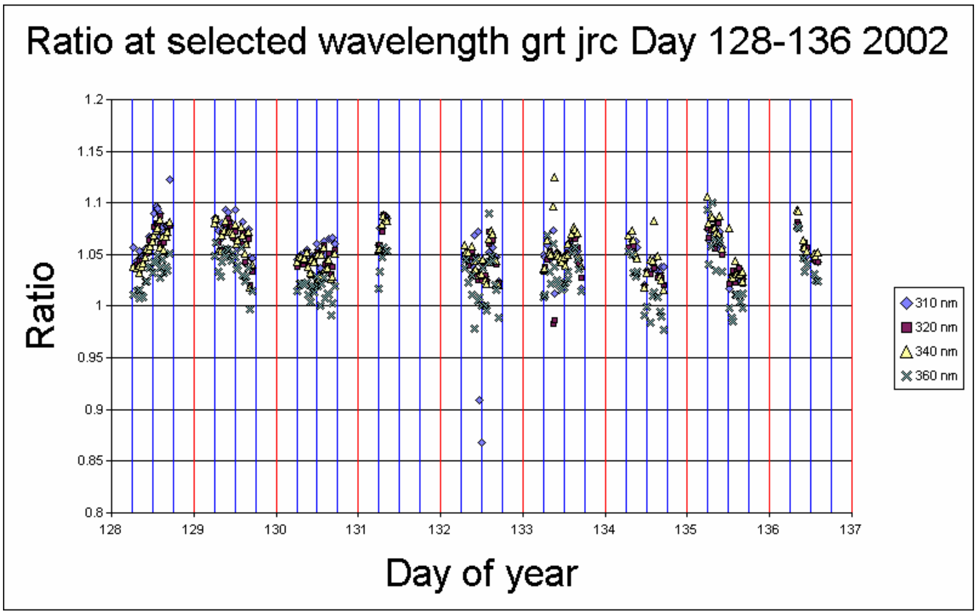

Figure 9 Time series of ratios for GRT and JRC

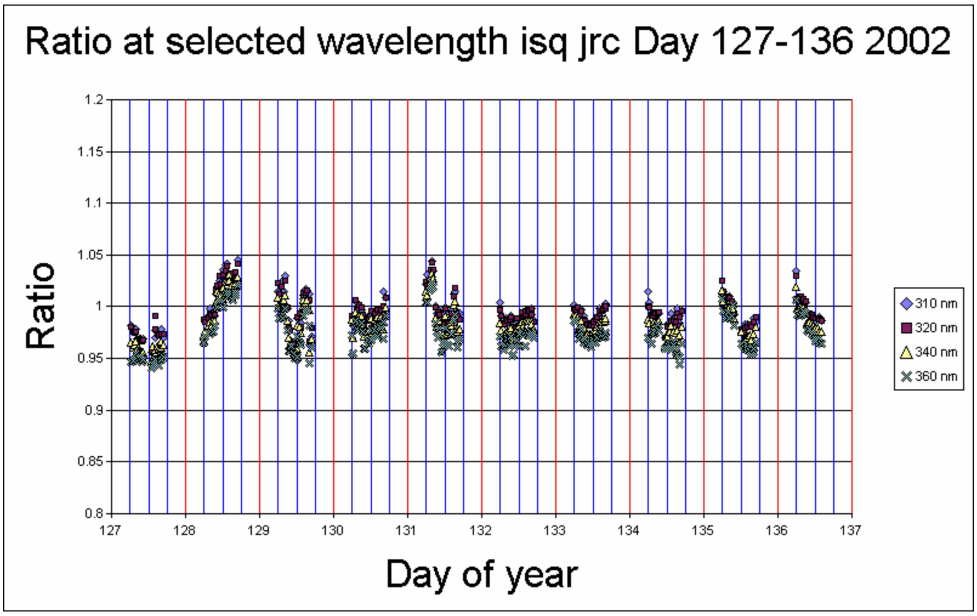

Figure 10 Time series of ratios for ISQ and JRC

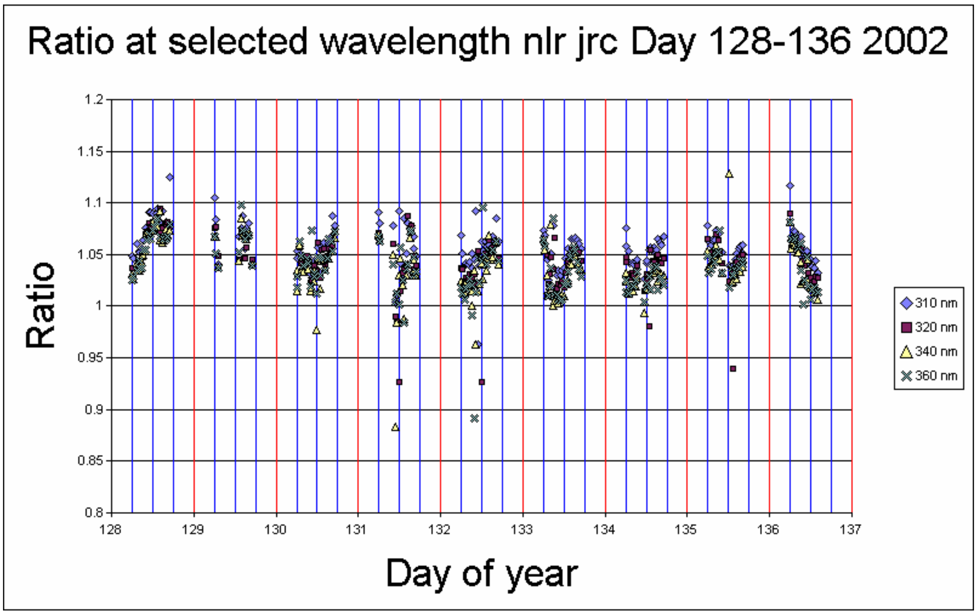

Figure 11 Time series of ratios for NLR and JRC

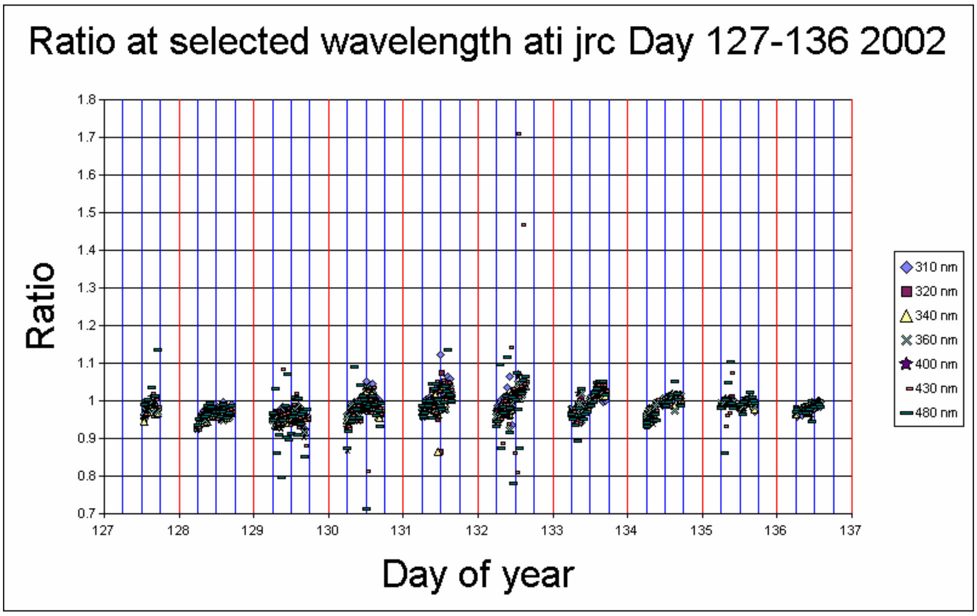

Figure 12 Time series of ratios for ATI and JRC, extended wavelength range and scale

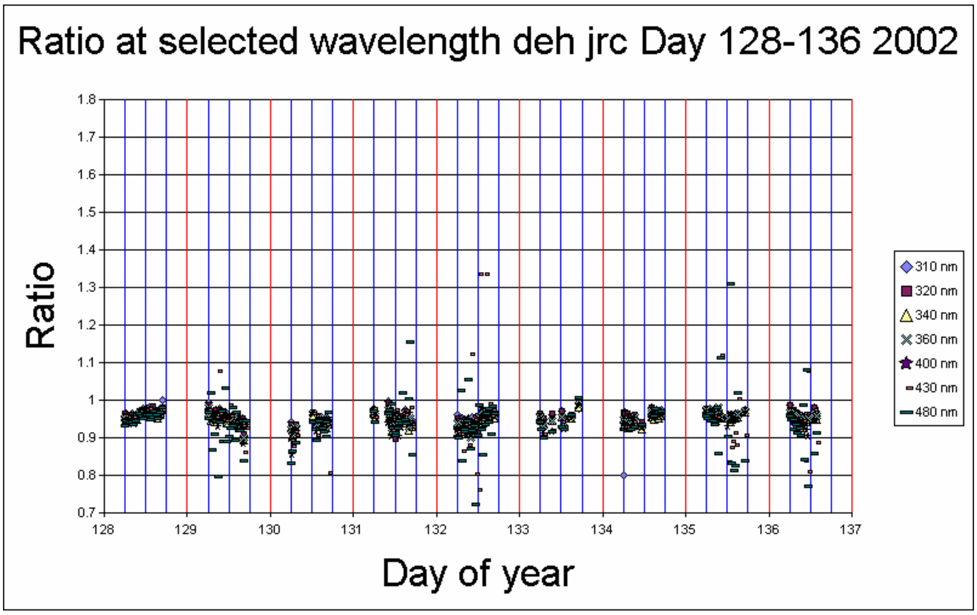

Figure 13 Time series of ratios for DEH and JRC, extended wavelength range and scale

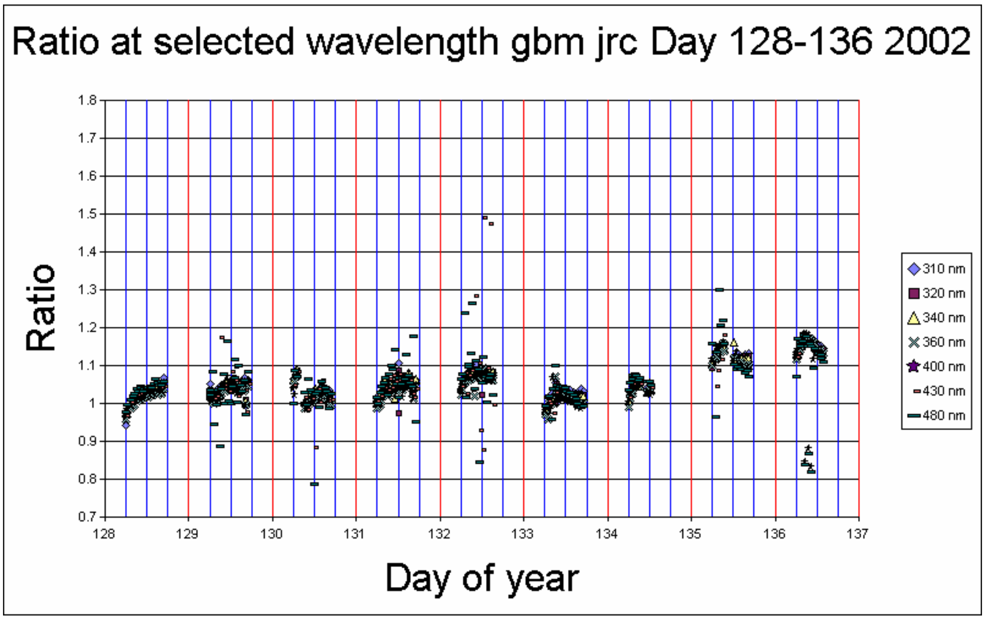

Figure 14 Time series of ratios for GBM and JRC, extended wavelength range and scale

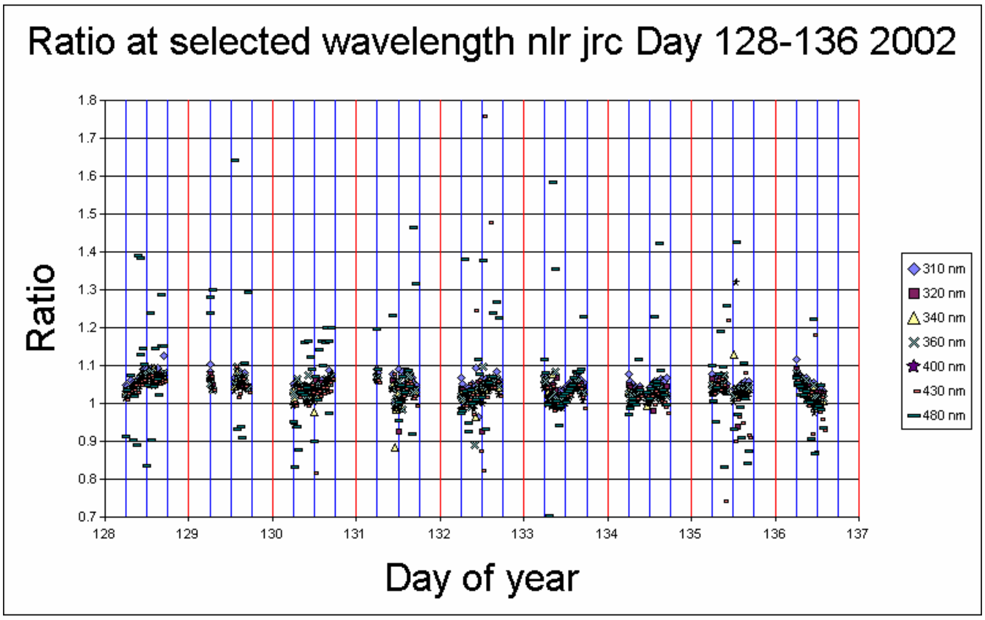

Figure 15 Time series of ratios for NLR and JRC, extended wavelength range and scale

In terms of the overall stability for the 9 days of measurements, most instruments are constant with respect to JRC, though with different degrees of scatter with wavelength and individual times. One instrument, GBM, clearly has problems in several respects (discussed below), and ATI has increasing ratios on several days, with an additional longer term increase and then decrease of a few percent at the shortest wavelengths. For all other instruments diurnal and longer term variations are more random but some of the characteristic behaviours are described below.

The smallest variation, and the greatest stability with respect to JRC was shown by ISQ, the other instrument operated by JRC. In this case the average difference in the data is 2-3% (ISQ lower than JRC) and on many days all data is between 0-5% less than JRC. On day 128 there is a systematic increase of 8-9% throughout the day in the ratio (similar to that for GRT and NLR), but this is not apparent on any subsequent day. There is some indication of a small diurnal change on days 129 and 131-135, though this is small. It is most pronounced on days 129 and 131, both of which had showers and dry periods: it has been suggested that raindrops on the diffuser domes have differential effects and introduce additional uncertainty in the intercomparison. ISQ has a new custom made cosine diffuser (Gröbner, 2002), while JRC uses a Schreder diffuser. However, the comments below must also be borne in mind.

The following information has recently been supplied by JRC: After the intercomparison and during the first travel round, a distinct azimuth dependence of the directional response of the JRC input optic was observed and confirmed both by rotating the input optic during solar measurements, as well as in the laboratory. The directional response varies by up to 6-7% with varying azimuth which explains most of the diurnal patterns seen in this and later intercomparisons with this instrument.

During the intercomparison, the diffuser was at the same orientation for the whole intercomparison period up to and including day 134. On the following days (135 and 136), the diffuser was rotated several times to observe possible azimuth effects. As mentioned in the previous paragraph, there is a distinct azimuth dependency which was not known during the

Ispra intercomparison, which could account for some of the different diurnal variations observed in these last two days, compared to the previous ones.

FIJ, DEH, NLR and GRT all show good stability over the campaign period, general fluctuations with both time and wavelength being within a 10% band, although with the odd anomaly (eg 1630 scan on day 129 for DEH). NLR and GRT have more outliers (greater scatter) than the other two instruments: in both cases this is probably because of a lack of perfect synchronisation during the scans. GRT shows a diurnal decrease of about 10% on day 135, and a less pronounced decrease on days 134 and 136, while for NLR a clear diurnal decrease is evident only on day 136. FIJ does not show the same clear sky zenith angle dependency mentioned in above for ISQ, and there is no early morning data from GRT on these days. Both these instruments have Brewer diffusers to which a cosine correction is applied.

The ATI instrument is reasonably stable, with a small increase and then decrease in sensitivity during the campaign. This is most obvious at the shorter wavelengths (figure 16), with days 130-132 being 5% higher than the days before and after. At 360nm (figure 17) the difference is about 3%. There is a clear diurnal variation on days 130-134 that is slightly greater in the data at the longer wavelengths. The ratio to JRC increases during the morning and then decreases again later in the afternoon. This diurnal cycle covers a 10% range. It is not apparent on day 135 or 136 after the instrument position had been changed on the roof at 1100, day 135 (and see also comments on JRC input optics). The recalibrations on the roof with the 1000 W lamp on days 132, 134 and 136 were in agreement with the original calibration on day 127 within about 2% (for wavelengths above 320 nm). Therefore no changes were made to the instrument's calibration throughout the campaign. No real explanation for the behaviour of the ATI instrument on days 130-134 could be found, it is only striking that the problems started after a period of very humid weather and disappeared when the weather became dry again at the end of the campaign.

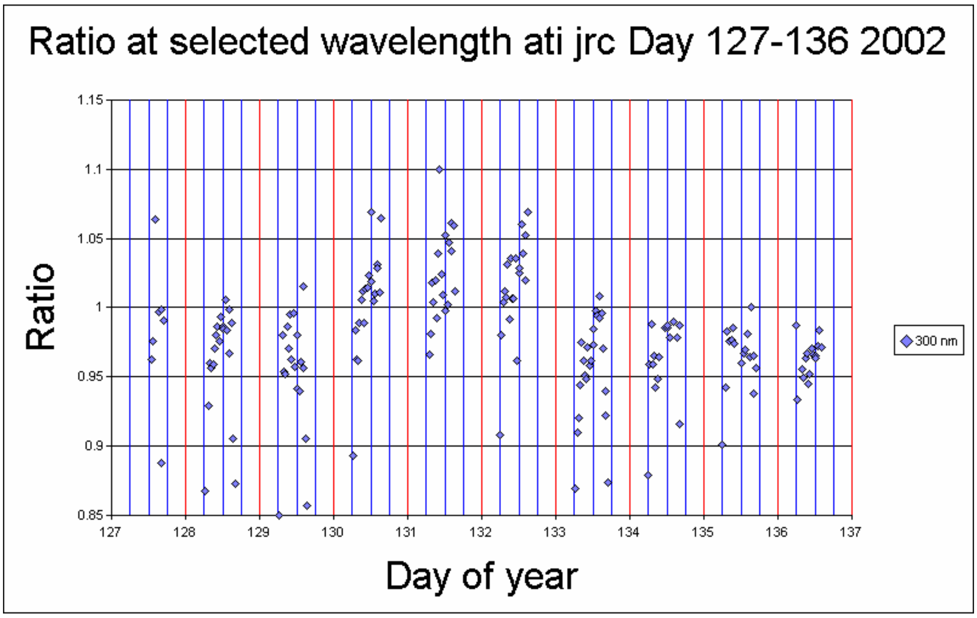

Figure 16 Time series of ratios ATI and JRC at 300nm

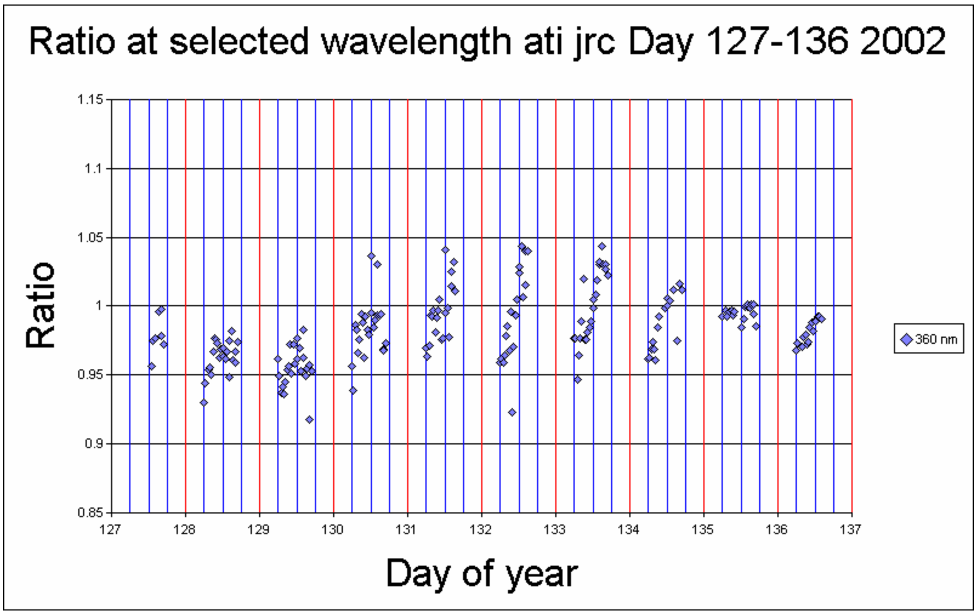

Figure 17 Time series of ratios ATI and JRC at 360nm

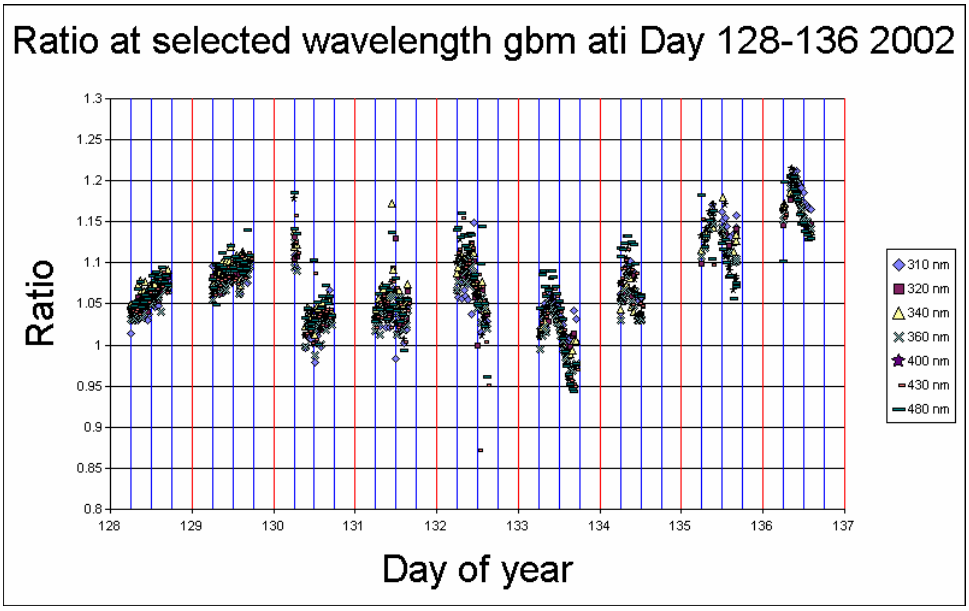

Figure 18 Time series of ratios GBM and ATI, extended wavelength range

The GBM instrument has the most problems of the group. It shows both a diurnal and a long term variation. The diurnal variation is very similar to that of ATI, indeed if the ratio GBM to ATI is plotted (figure 18) there is no diurnal change apparent on days 128 - 131, only the gradual drift of GBM, implying almost identical diurnal behaviour of the two instruments. On days 132 – 134 many investigations were made to try and identify this problem. Both instruments use a Schreder diffuser, and this was the first suspect. The GBM instrument was left undisturbed while the ATI diffuser was warmed up (to 40^0C) for some hours to test whether temperature was an issue. The ATI diffuser was then rotated several times to look for azimuthal effects. After that the temperature stabilisation of both instruments was inspected and checked. The electrical supply and the constant static on the roof were also suspected but could not be measured or logically correlated to the diurnal change. No solution was found to the problem and a diurnal change remained for both instruments, although it became unsynchronised between GBM and ATI (see figures 6, 11 and 16). Finally, the position of

ATI on the roof was changed on day 135, changing instrument alignment and the power supply series to the instrument. Thereafter the diurnal change with respect to JRC disappeared for ATI, but no definitive explanation for the effect was ever found. The GBM instrument that had remained untouched as a reference continued to show a diurnal change with respect to JRC throughout the campaign. When considering these results the earlier comments about the JRC diffuser should be borne in mind.

In addition to this diurnal variation the GBM instrument has a long term drift, with sensitivity increasing throughout the campaign. This was apparent in the calibrations of the instrument that agreed with the increases observed during the solar measurements. After the calibration checks on days 130 and 132, the new calibrations were applied (evident in the time series plot), but it is clear that the drift continues throughout the campaign. Immediately before the campaign the GBM instrument had one new grating installed, and was also rehoused in a new temperature stabilised container. It is possible that one or other of these modifications resulted in the observed behaviour although it is not clear how. The Schreder diffuser has a small silica gel capsule with little contact between the silica and the air in the diffuser, and no method of circulating the air past the silica. The GBM silica capsule had lost its blue (dry) colour in the journey from UMIST and was replaced at the start of the campaign. It was hypothesised that there was initially condensation in the diffuser that was dried out in the first few days leading to an increase in sensitivity. After several days the capsule had to be replaced again, but it is difficult to see how condensation in the diffuser could explain the continued rise in signal of the instrument, although it may have been a contributory factor (see also comments on ATI). Clearly there are several factors that require further investigation here.

At longer wavelengths (figures 12 – 15) all instruments show similar behaviour to that at wavelengths < 365nm. The scale of the graph has been increased to show all data points and all instruments have more data points with large deviations from the normal ratios, especially at 430 and 480nm. Day 132 seems particularly bad in all cases, and some of these instances of high ratios are the same for all four instruments eg two measurements at 430nm just after noon, implying that these points at least may be attributable to JRC.

Calibration lamps

The standard of spectral irradiance used by each group were measured in the ECUV laboratory, and their ratios to the ECUV lamp F270, a working standard, are shown in figure 19. The ECUV standard itself is based on F330 PTB via Gigahertz) and F324 (direct from PTB). The two standards differ by less than 0.5% from each other. Note that S273 was not used as a basis for calibration during the campaign, but is a new lamp from PTB provided for comparison.

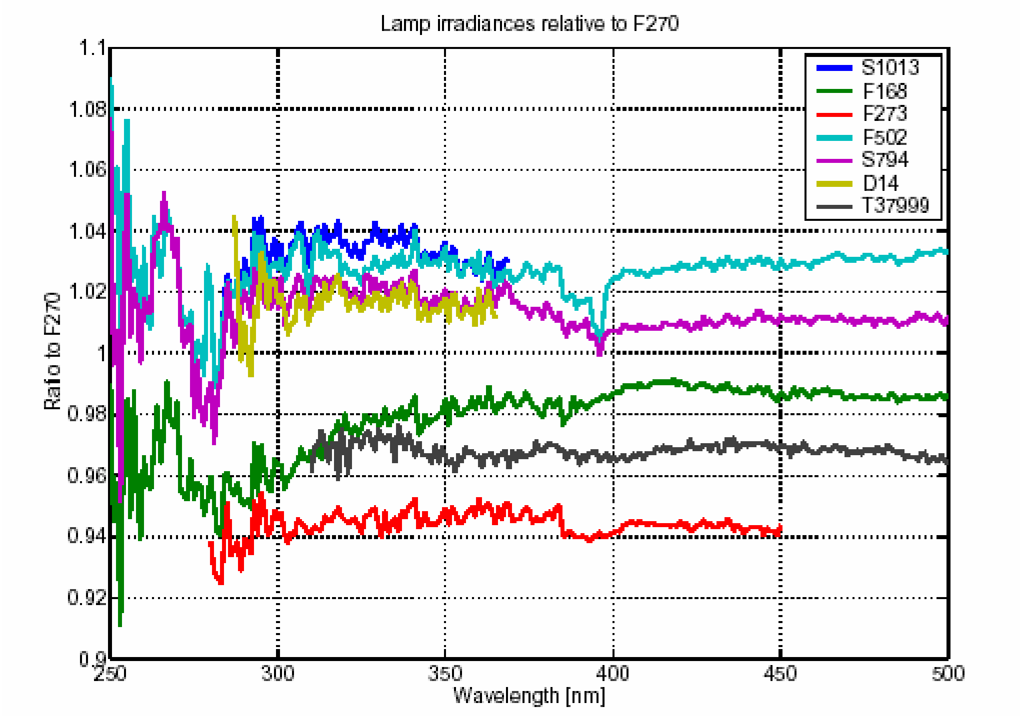

Figure 19 Ratios of all calibration lamps to ECUV lamp F270

The lamps used by the partners, acquired from a variety of sources and in a variety of configurations, are spread over a +/-4% band from the ECUV standard, excluding S273 that differs by 6%. F270 is a working standard traceable to PTB. The three standards with ratios less than 1.0 also revert to PTB, while those with ratios above 1.0 revert to NIST, or in the case of D14 to HUT. This systematic difference may be fortuitous in this small sample, with a 4-6% difference between PTB and NIST, and a 2% range for NIST traceable standards compared to a 6% range for PTB traceable standards. Whether the clustering is representative of a larger sample or not, there is clearly a significant element of UV data differences that could be attributed to the calibration standards available to the different groups.

As an example of the effect of the calibration standards, the blind day ratios at 0900 (figure 2) have been corrected for the differences in calibration standards (figure 19) and the results are shown in figures 20 and 21.

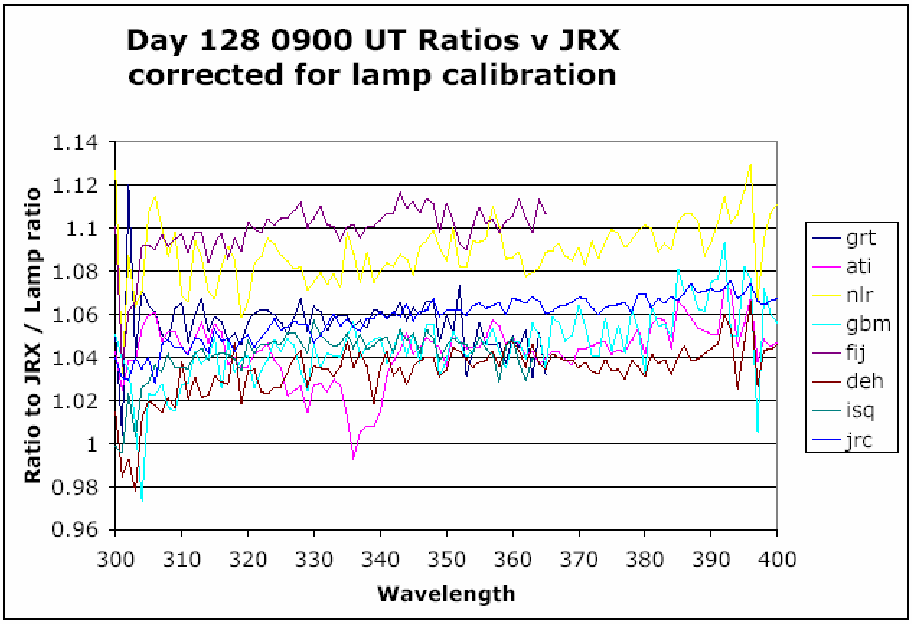

Figure 20 Ratio to JRX on blind day 128 at 0900, corrected for lamp ratios (ie figure 2 corrected for lamp ratios)

Note that this is the corrected version of figure 2 with ratios to JRX. The recalibrated JRC data and the ISQ data have not been corrected since the reference for lamp correction is the ECUV working standard. Thus the JRC line, at between 1.04 and 1.06, should be taken as the reference line with which to compare all the other data. Alternatively, the lamp corrected data can be compared with the JRC data directly, as in figure 21.

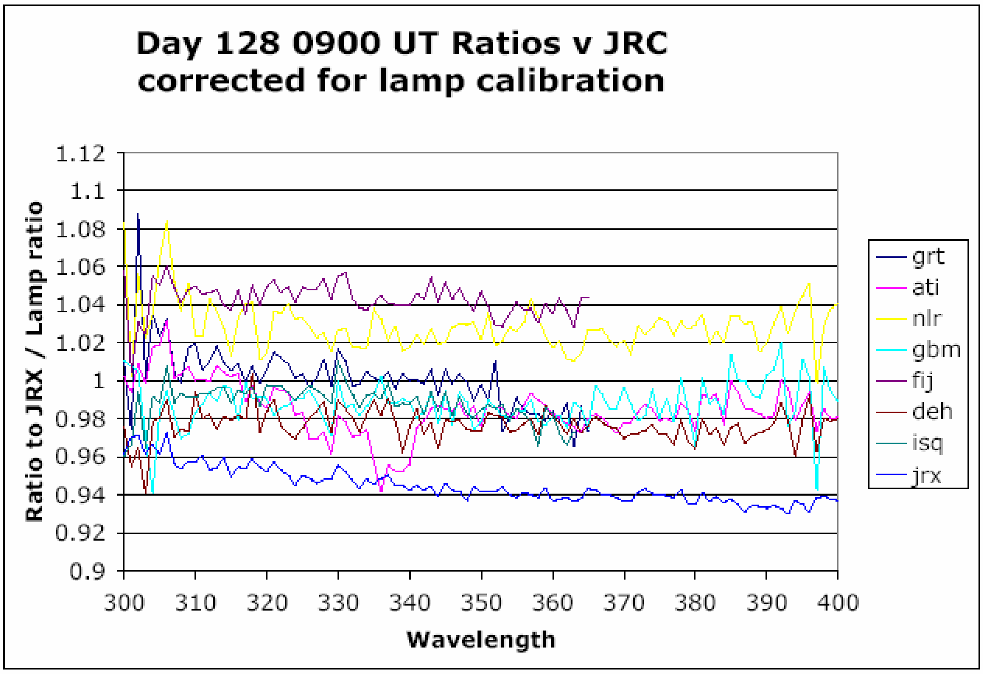

Figure 21 Ratio to JRC on blind day 128 at 0900, corrected for lamp ratios (ie figure 2 corrected for lamp ratios and recalibration of JRC instrument)

It is clear that correcting the data for the differences in the lamps improves the agreement between the instruments. All 8 instruments are now within a 10% band, and 6 of them lie within a 4% band, the two outliers being FIJ and NLR (ignoring JRX that shows only the change made to the JRC data on correction). Before accounting for lamp differences the 8 instruments were fairly evenly spread across a 12% range. It is easy to postulate, and difficult to prove, that a number of minor uncertainties of 1% or so from various causes (e.g. cosine responses, calibration transfers) can lead to the small 4% range of measurements in figure Y.

Conclusions

The aim of the QASUME intercomparison was to validate the JRC instrument and its operation as a suitably stable and quality controlled resource upon which to base a regional travelling standard spectroradiometer for UV measurements. It is accepted that the absolute basis of UV calibration remains in doubt, with discrepancies within and between standards laboratories, so on a global basis the QASUME standard must be considered as a relative standard only. Nonetheless, this intercomparison also enabled the range of standards in use, and the position of the JRC standard within that range, to be identified. Based on comparison of lamp irradiances and the scans corrected for the lamp differences, the ECUV standard, and the subsequent performance of the JRC instrument, lies in the midst of the range of absolute standards (and their application) currently in use in Europe. Thus, it is well suited to the task of regional reference.

The reference standards of the measurement sites will not, in general, have been compared to the standard of ECUV. As seen from figure 2, a representative range of absolute irradiance scales can lead to 12% (±6%) differences in UV measurements. Accounting for the absolute irradiance standards reduced the range of measurements for 6 instruments to 4%, or +/-2%. It is not the purpose of ECUV to define the true UV irradiance scale through arbitrary purchase of their own calibration standard (that is a task for the National Standards Laboratories). Nonetheless, the absolute scale carried by the ECUV facility has proved to represent the central scale in use at several independent European laboratories and can be taken as an absolute regional reference. If a site agrees to within 6% with ECUV then they can be said to be within the regional norm, while agreement to within 2% is the highest level of consensus that can be expected. Sites that deviate by more than 6% from the ECUV instrument indicate that further exploration of the site irradiance standard, instrument and operating protocols are required to identify the source of the discrepancies. The travelling instrument has, by consensus, no major flaws in its performance, and should reliably identify changes greater than this 6% if it proves stable in its operational mode, and the question of the azimuth affecting the diffuser can be resolved.

The travelling instrument is intended to visit UV monitoring sites throughout Europe, and as such must undertake intercomparisons in the conditions prevailing at the time of each visit: it may not always be possible to await a series of clear sky days. The QASUME intercomparison was conducted in weather conditions that were less than ideal for the purpose, with little in the way of clear skies, and many days hampered by rain. As such, it was a realistic test for the situation the travelling instrument might face, but the rain, and lack of direct beam radiation may have both introduced additional uncertainty and effects (eg raindrops on input optics) and hidden others (eg zenith angle dependencies). The time courses of ratios between other instruments and JRC are not as invariant as one might have hoped, and at least one problem has since been identified with the JRC input optics. With the exception of the UMIST instrument, the other variations are reasonably small and difficult to allocate to a specific cause, given the weather conditions and the confounding fact of the azimuth effect in the reference instrument. Since there are temporal changes of several percent in all instrument ratios, the proposed requirement of two full days of comparison data at a measurement site is clearly justified, and ideally with a range of weather conditions including some clear sky data and if possible without rain.

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