ECOST-STSM-ES1207-090215-054249 REPORT
Standardization of Brewer calibration.

Purpose of the STSM

The aim of the Action COST 1207 is to establish a coherent network of European Brewer Spectrophotometer monitoring stations (Eubrewnet) by means of, among others, common approaches, practices and protocols. As regards to the activities of the Working Group 1 (WG1), one of the main tasks would be to develop calibration procedures which ensure the best transfer of calibration constants and traceability to the reference standards.

This Short Term Scientific Mission, was carried out in the Physical Meteorological Observatory / World Radiation Center (PMOD/WRC), Davos, Switzerland, and used the knowledge and the infrastructure of this institution.

In this STSM the main objective was to develop and test a portable system to be used for calibrations using the direct port of the brewer. This device will be validated with

- Laboratory calibrations performed at PMOD and RBCC-E facilities, a set of lamps will be produced to have a common reference at both laboratories and a standard procedure will be documented.
- The direct calibration will be tested using two field devices and Langley calibration at Izaña.
    - The automated rotating shadow band at Izaña
    - The developed Device
- The setup will be used also to study the wavelength calibration inconsistencies found when global port / direct port setups of spectral lamps are used to determine the wavelength calibration of the Brewer.

Description of the work carried out during the STSM

Direct calibration at laboratory procedure

The objective of this first task is to uniform calibration procedures and reference at PMOD and RBCC-E.

We transfer the calibration to an uncalibrated seasoned 1000w tungsten halogen standard lamp (FEL or DXW) using a secondary standard of spectral irradiance traceable to the units $w/m^2 \cdot nm$. The calibration was made by direct comparison using a well-characterized spectroradiometer (QASUME in this case).

The FEL/DXW Transfer standard calibration SOP (PMOD/WRC) was followed.

The calibration procedure is described in ANNEX 1.

Wavelength calibration setup

During the last Arosa campaign in July 2014 several dispersion test were made in all the participant brewer where two sets of measurements were taken, first, through the UV dome, Cd and Hg lamps (also internal Hg lamp), and second using a device that made it possible to measure the lamps through the quartz window with the prism looking to the zenith (Figure 1).

There was no difference using the Hg internal lamp and the external Hg lamp, but it was found a slight difference using the UV dome and the quartz window. Because the sensitivity of Brewer spectrophotometers for direct-sun measurements changes with solar zenith angle (SZA) (*Cede A. et al., 2006*), during the this STSM a third device was used to measure the dispersion lamps through the quartz window but perpendicular to the input window, the *dsp* routine was modified (dsw) to measure this angle and other angles upwards and downwards to study the error of a not exact pointing measurement of the lamp.

The three measurements positions are shown in Figure 1.

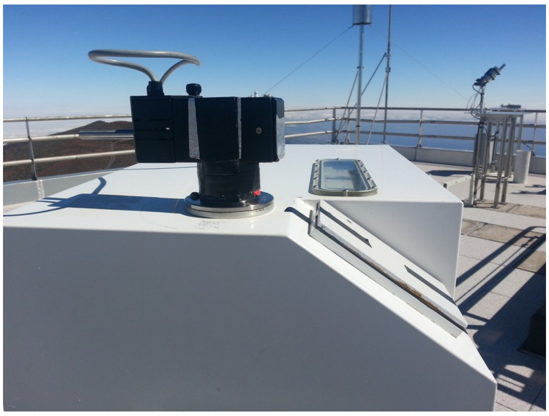
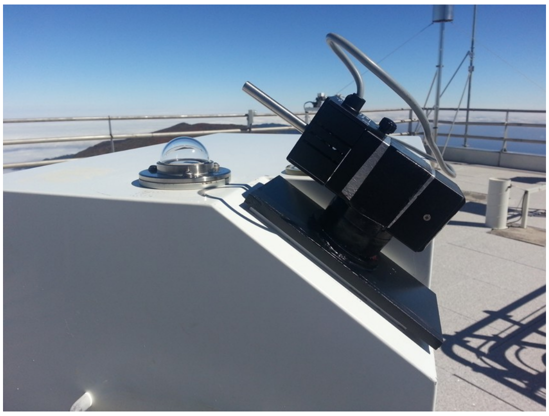


Figure 1. UVB Dome, direct port looking to the zenith and direct port looking normal to the window.



	UVB Dome	Window zenith device	Window normal device	Mean
1023	0,3318	0,3329	0,3339	0,3329
1024	0,3305	0,3287	0,3326	0,3306
1025	0,3290	0,3274	0,3313	0,3292

Table 1. Ozone Absorption coefficients for the operative Calc step and ±1 step for the three measurements with the Hg, Cd and Zn lamps

Comparing the results obtained for the different measurements showed in Table 1 and for the Hg, Cd and Zn lamps we have the results showed in Figure 2.

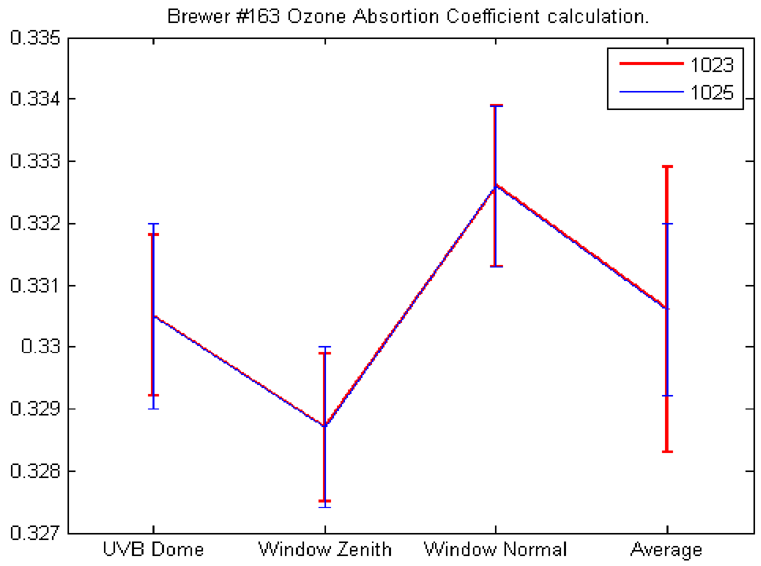


Figure 2: Ozone Absorption Coefficient calculated and comparison with ±1 step

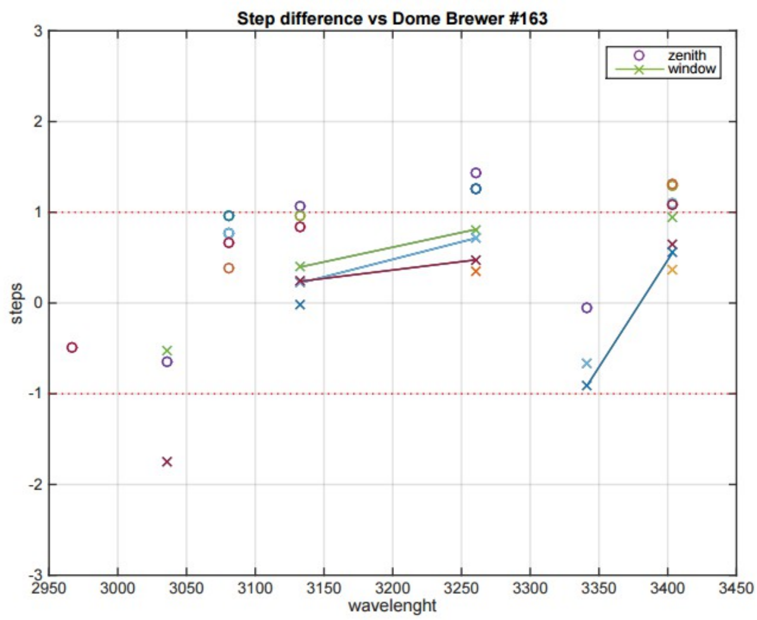


Figure 3: Step difference using the UVB dome or the direct port

There is no significant improvement using the direct port window either the zenith vision device or the normal vision device, we are moving in a 1 step window (Figure 3), the real upgrading comes from the increase in the counts that yields in signal to noise ratio improvement, getting to the point that the line in 326,1 nm is near to the saturation (A ND filter should be used).

We can observe from the results a deviation using the direct port window that could come from the window polarization. When we measure using the UVB dome we obtain:

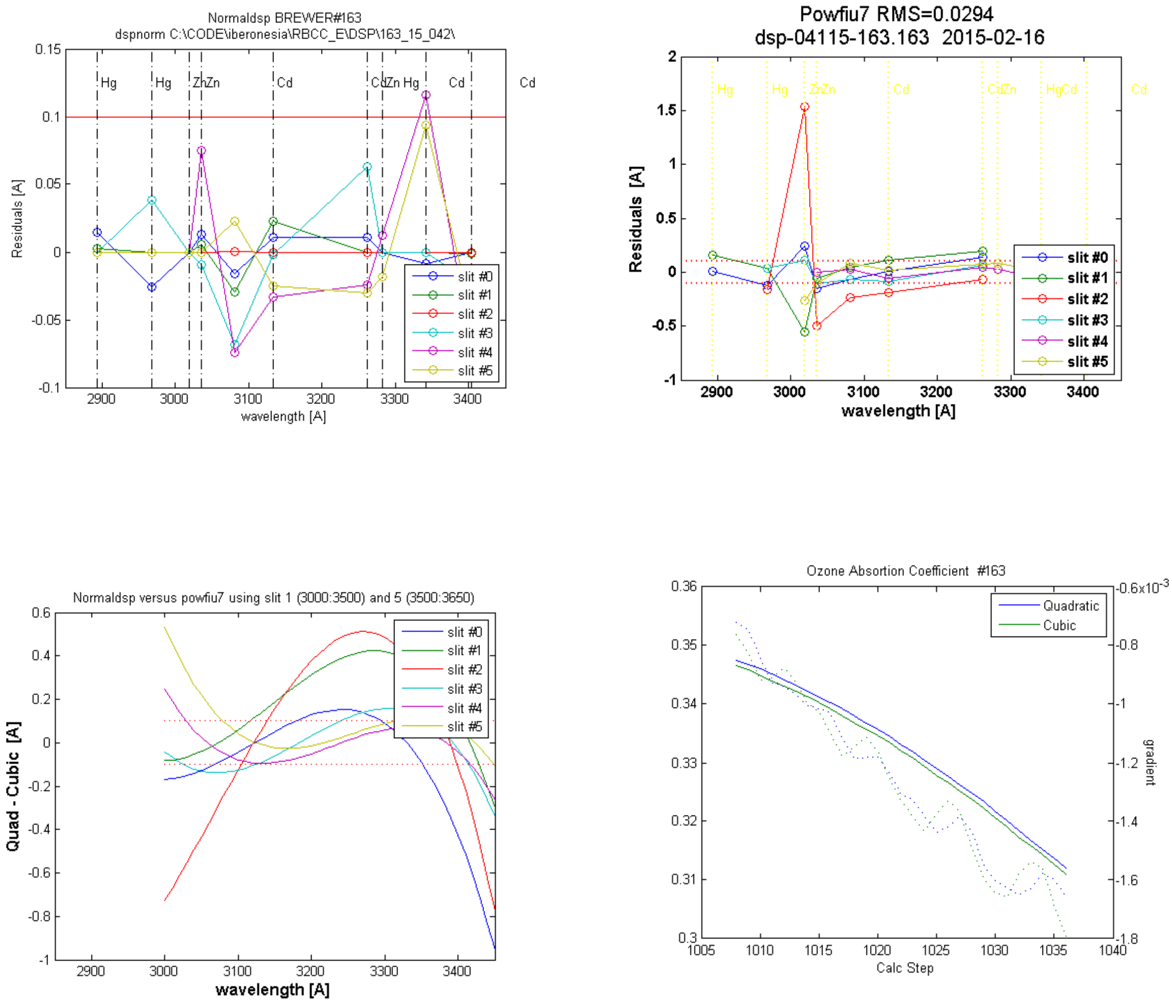


Figure 4: Using UVB dome

When using the device for the window looking to the zenith we obtain:

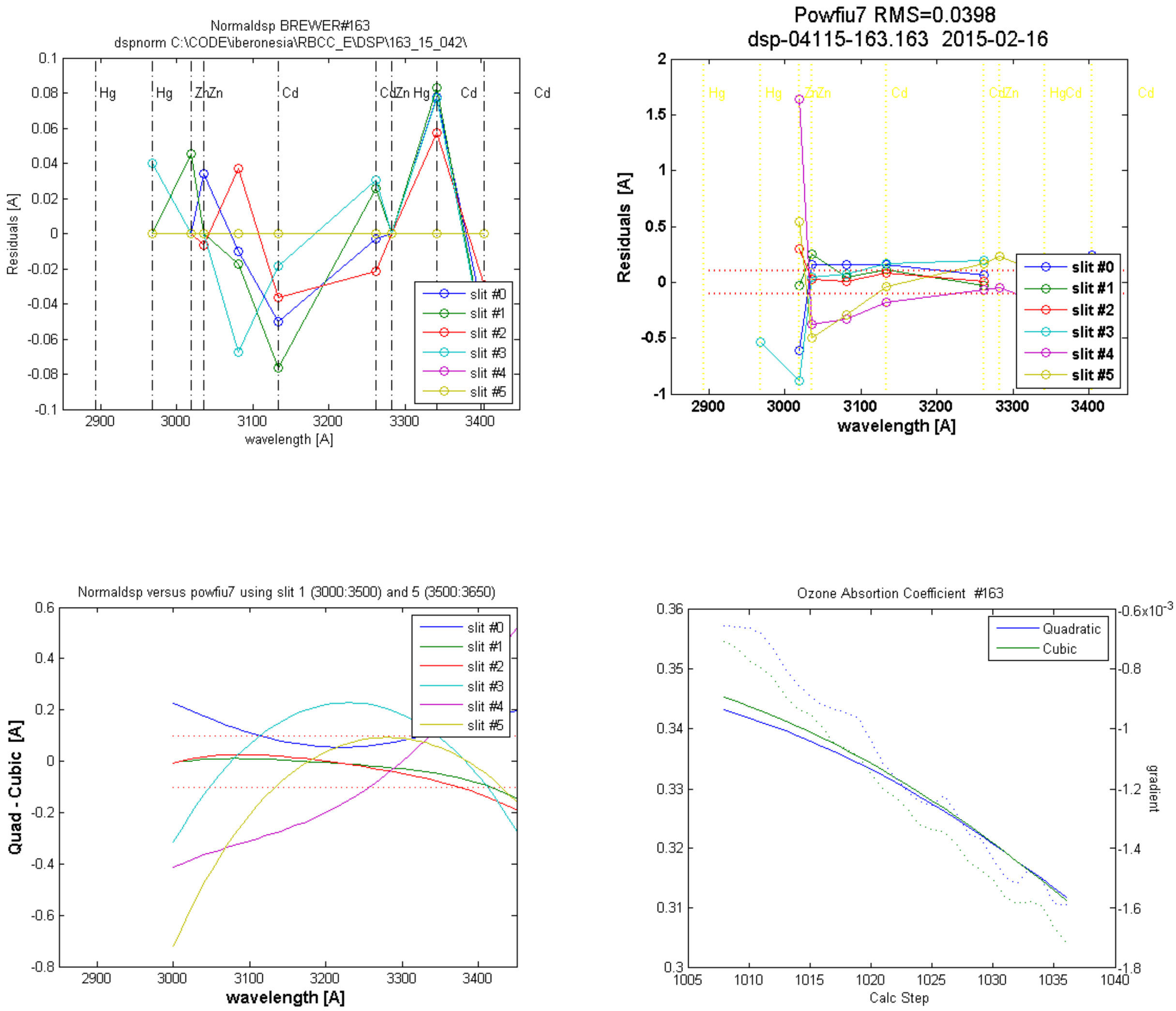


Figure 5: Using window looking zenith

When using the device for the window looking in normal direction we obtain:

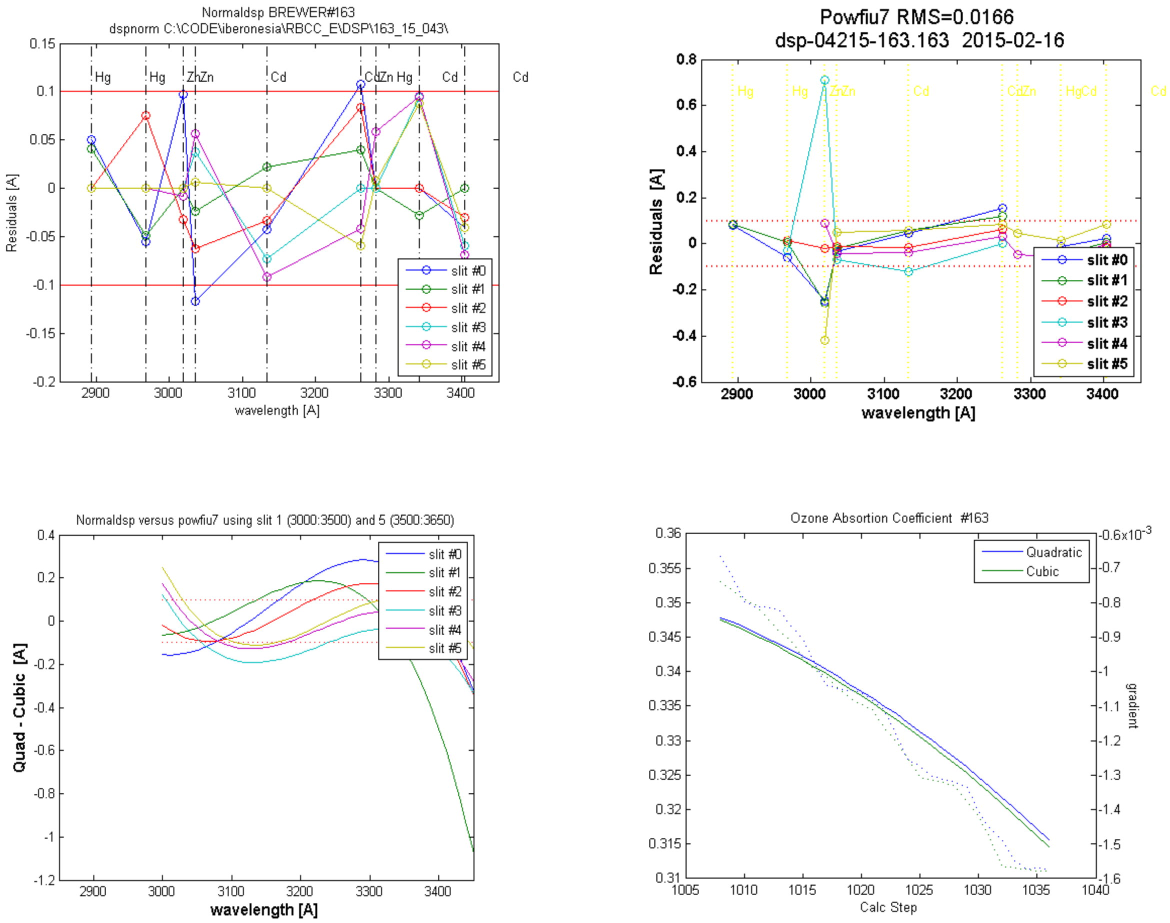


Figure 6: Using window looking normal

In this three sets of figures (4, 5 and 6) the first figure shows the residuals for the quadratic fit, the second, the residuals for the cubic fit and the third the dispersion Quadratic-cubic fit for each slit. The line in 301,8 nm is wrong and appears as an outlier, but is not considered in the calculations.

Using the normal vision device for the direct port brings us to a smaller dispersion between quadratic and cubic fitting comparing with the zenith vision direct port and also improves the intensity of the lines comparing with the UVB dome measurements.

Tracking changes in Brewer absolute calibration.

Spectral measurements of direct solar ultraviolet irradiance have a wide range of applications in atmospheric sciences, our main interest is the determination of the Aerosol optical depth.

Several methods for the absolute calibration of direct spectral irradiances are described in (*Kazadzis, S. et al.,2005*). As the ozone measurement calibration are tracked by tests on the internal lamps, this is not suitable to track absolute calibration of the direct component. This would be of the main interest for AOD measurements.

Indirectly, calibration of direct-Sun spectra could be done by using simultaneous absolute spectral measurements of global and diffuse solar irradiance. This method looks quite simple but has several restrictions as described in (*Bais, A. F., 1997*).

Taking advantage of the laboratory facilities of the PMOD/WRC we performed laboratory calibration with 1000W DXW quartz-halogen lamp (IZ20) following the method described in (*Kazadzis, S. et al.,2005*). Using a zenith angle between 30º to 45º and with the lamp at a distance of 270 cm when the apparent size of the filament as seen by the input optics of the Brewer is almost equal to the apparent size of the sun.

The irradiance at this distance will be calculated from the lamp irradiance calibration certificate referenced to 50 cm distance, using the inverse distance square law.

We also made some tests with a device built to use the 200w lamps in the direct port with the zenith prism pointing to the zenith, this system would be very useful as it is a portable system to track the calibrations made in laboratory, this would make unnecessary to move the instrument to a laboratory and could be very useful to use it in campaigns.

To align the brewer direct port to the 1000w lamp we made first a manual azimuth orientation, and then with a modified TU routine we seek for the maximum intensity in zenith. After the first group of measurements we checked the illumination in the Iris and we realized a small deviation in the focusing, for the second set of measurements we made a fine azimuth pointing with a modified SI routine.

The different measurements we made are showed in figure 6.

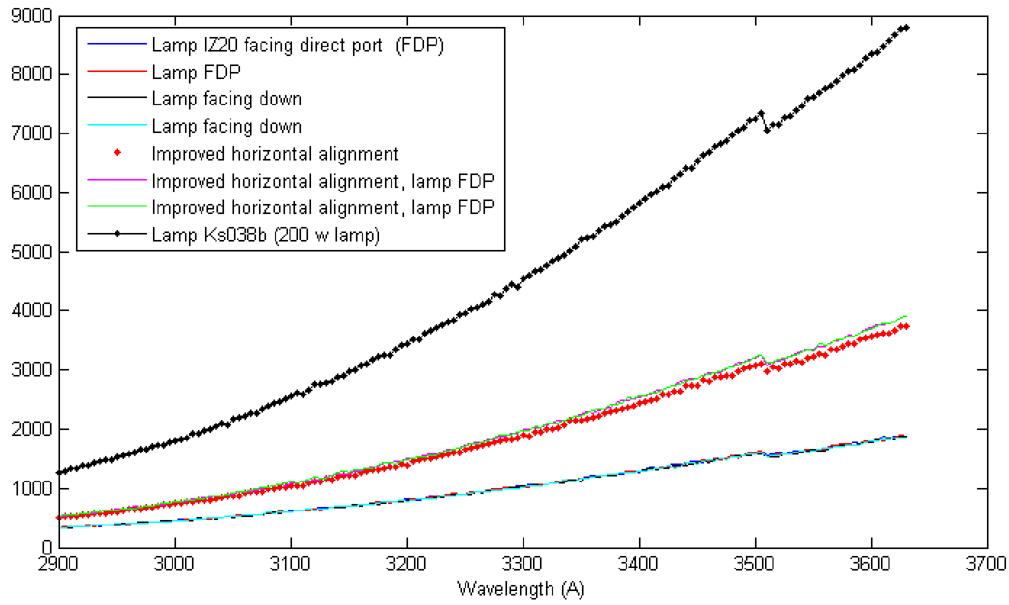


Figure 7: Measurements in the direct port

From the data showed in figure 6 we must highlight the importance of a very precise alignment and focusing in the lamp, in this case, a wrong focusing yields on differences than goes from a 35% in the lower wavelengths to more than a 50% in the highest wavelengths.

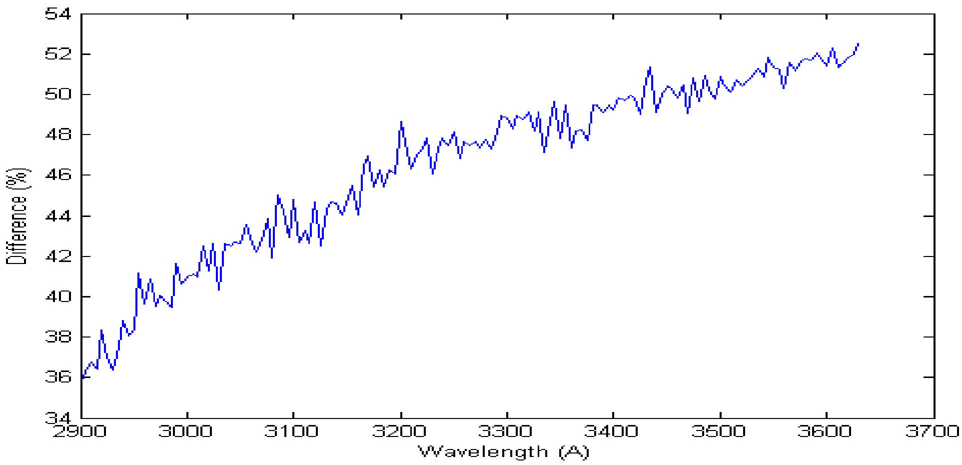


Figure 8: difference derived from an incorrect pointing to the lamp

Another detail we have seen in the data is a difference in the lamp voltage depending in the orientation of the lamp. We switched on the lamp three times, two of them with the face that sees the dome during a normal 1000w calibration at 50 cm facing to the direct port window (We will call this “rotated”) and once with this face looking down.

Position	Intensity (mean)	Voltage (mean)
Rotated	8,0001 ± 5.6510e-005	116,7268 ± 0,0044
Normal	8,0001 ± 1.7976e-005	116,8750 ± 0,0323
Rotated 2	8,0001 ± 4.8346e-005	116,7586 ± 0,0175

Table 2: Lamp IZ20 intensities and voltages.

Using the ratio of each of the two scans with the correct brewer orientation for the 1000w lamp and the 200w lamp (ks038b), we have a beginning point to track the brewer direct port calibration (Figure 9).

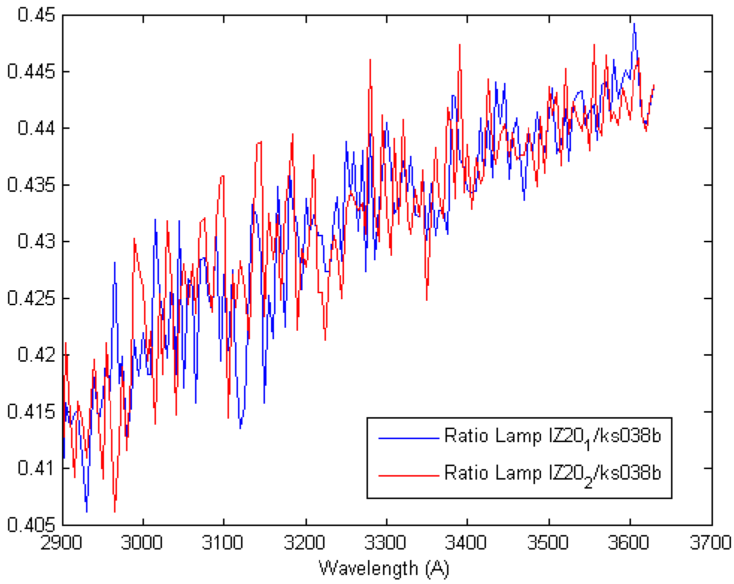


Figure 9: Ratios 1000w lamp/200w lamp (direct port device)

Instrument characterization

As an important step for this work we have made an instrument characterization. We have measured the angular response of the instrument and also measured the Slits with a UV Laser (325 nm).

Angular response

Using the facilities of the PMOD optics laboratory we measured the angular response of the Brewer #163.

The most critical step in this measurement is the alignment of all the system which includes the check of the repeatability in the movement of the motorized arm that holds the lamp.

Once checked the alignment we proceed to determine the straylight, using the lamp T99661 and shadowing the Brewer dome from the direct light beam we measured the angles -90, -45 0, 45 and 90.

The measurement schedule is the one showed in the tables below.

Measurements North																		Test	
0°	+10°	+20°	+30°	+35°	+40°	+50°	+55°	+60°	+65°	+70°	+75°	+80°	+82°	+84°	+86°	+88°	+90°	+60°	+30°

Measurements South																		Test	
0°	-10°	-20°	-30°	-35°	-40°	-50°	-55°	-60°	-65°	-70°	-75°	-80°	-82°	-84°	-86°	-88°	-90°	-60°	-30°

The results obtained presents a 0,5° difference between the north and the south plane (Figure 4 and 5).

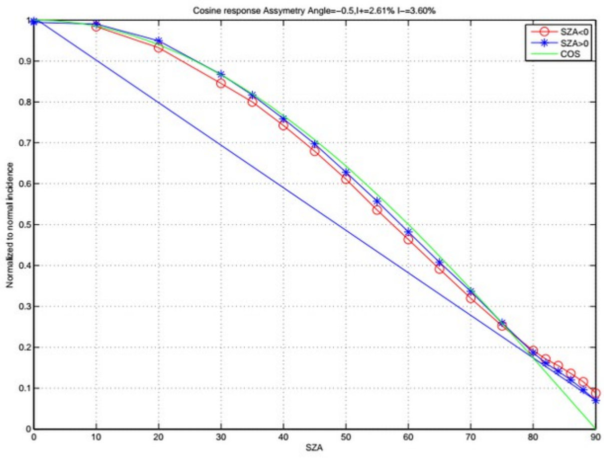


Figure 10: Measurement of the Brewer #163 angular response N-S plane.

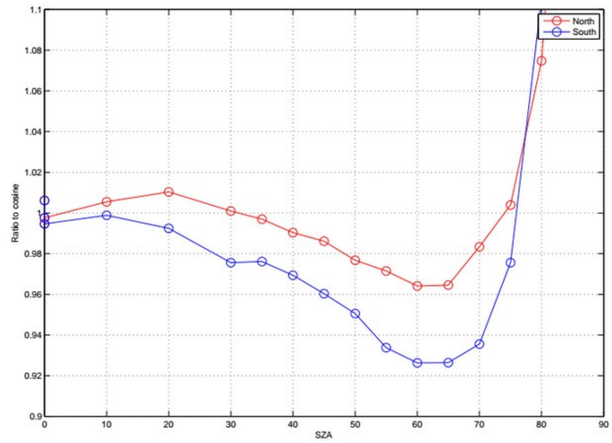


Figure 11: Error N-S

To check the this difference between both planes we used the measurements at 60° and -60° (S2 routine) modifying the zenith drive dome position from the original of 2242 steps (operative ICF) to 2242, 2252 and 2257 with a very small improvement.

Zenith drive step	-60° (S2 Meas.)	+60° (S2 Meas.)	Diff.
2242	4248	4570	286
↗ 2244	4244	4505	261
↗ 2252	4318	4505	187
↗ 2257	4241	4580	339
↘ 2227	3130	4952	-1822

Table 3: Measured counts for different zenith drive positions (↗ Increasing steps, ↗ decreasing steps).

Performing a TU scan over an external lamp we have the results plotted in figure, being the limit of the Zenith motor 2300 steps.

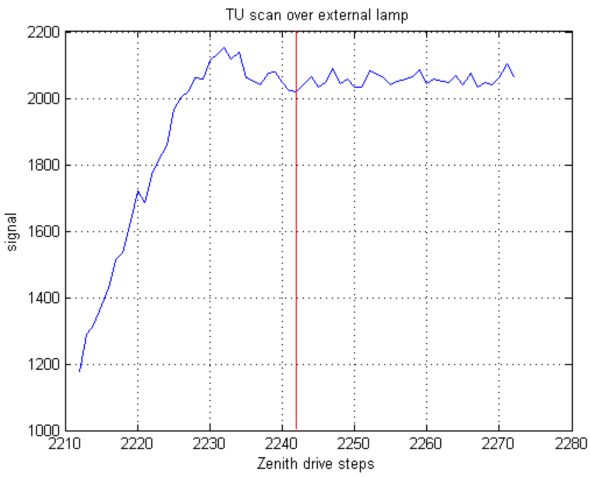


Figure 12: TU scan over external lamp. Maximum should be in 2242 steps.

Laser measurements

We have used the He-Cd Laser of the PMOD emitting in 325nm and a modified CZ routine to measure this peak with all the slits.

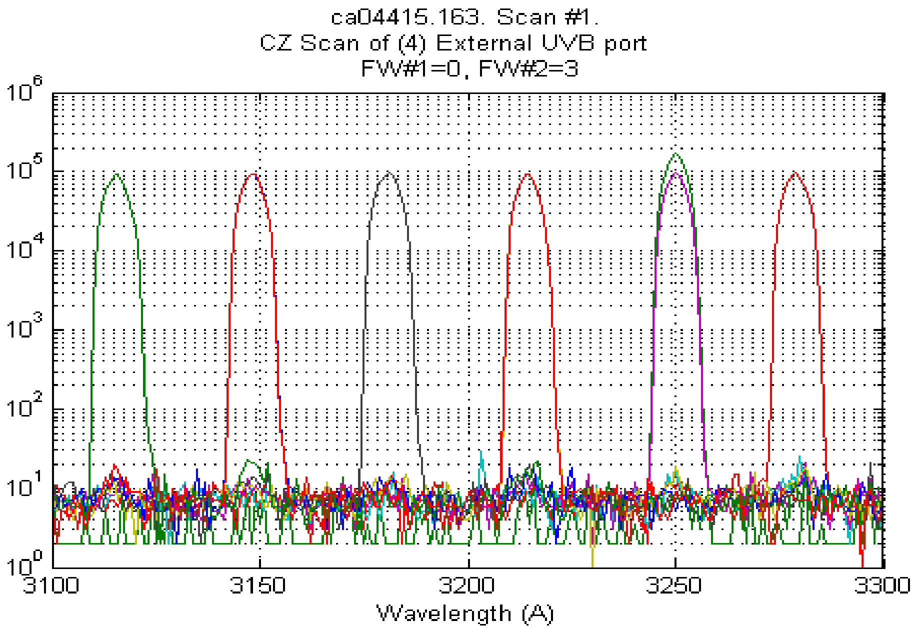
First of all we have to scan the peak using the CZ routine with a high attenuation filter combination to detect the correct filters to don't saturate the photomultiplier. For the first measurements we used an external ND filter in a filter holder, but from the results we determined that it had a strong dependence on the filter alignment and position (Strong differences in attenuation with very small differences in the inclination), we discard this option of changing the external filter and left a fixed external ND filter of 1,5 and worked for the rest of measurements with the brewer internal filters.

Scanning from 3245-3255Å (0.5Å step) with the CZ routine we determined the filters combination showed in the table 4.

	CU (left wing)		CA (Core)		CD (right wing)	
UVB Dome	Ext. ND filter	1,5	Ext. ND filter	1,5	Ext. ND filter	1,5
	FW#1	3 C.A.	FW#1	3 C.A.	FW#1	3 C.A.
	FW#2	0 C.A.	FW#2	0 C.A.	FW#2	0 C.A.
Scan range	2900-3105Å (5Å step)		3095-3300Å (5Å step)		3282-3400Å (5Å step)	
Direct port	Ext. ND filter	1,5	Ext. ND filter	1,5	Ext. ND filter	1,5
	FW#1	3 C.A.	FW#1	2,32	FW#1	3 C.A.
	FW#2	0 C.A.	FW#2	1,91	FW#2	0 C.A.
Scan range	2900-3105Å (5Å step)		3095-3300Å (5Å step)		3282-3400Å (5Å step)	

Table 4. Laser measurements configurations.

Figure 13: Laser beam alignment



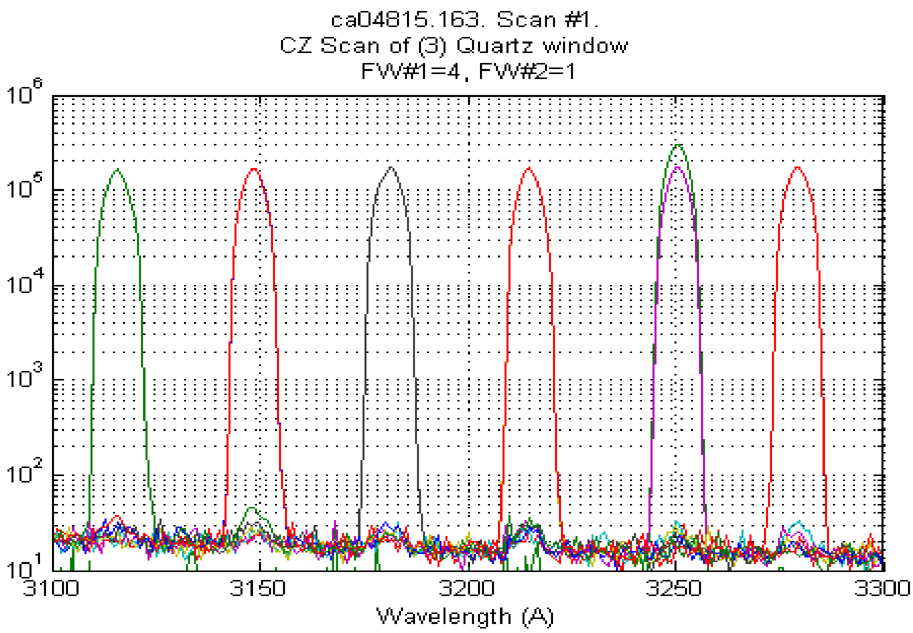


Figure 14: Laser measurements, using the UVB Dome and the direct port.

Description of the main results obtained

A detailed description of the procedure for the 1000W lamps calibration transfer is presented in the Annex 1 of this report.

In the case of the wavelength calibration setup we have tried to determine the best technique or setup to have the most accurate results. From the results we can ensure that the main source of difference is the direct port window polarization. But using either the zenith position or the normal position doesn't improve the UVB dome measurements results.

Finally in the case of the Brewer absolute calibration of the direct spectral irradiance we reproduced the measurements described in (*Kazadzis, S. et al.,2005*) and compared them with the ones obtained with a portable system. Future measurements during the next Regional Brewer Calibration Center for Europe (RBCC-E) intercomparison campaign that will be held in Huelva in June 2015 will be needed to “track” the behavior of the direct port. From the measurements taken in the PMOD laboratory we have a starting point for this track.

Future collaboration with the host institution

New sets of measurements will be made during the next Regional Brewer Calibration Center for Europe (RBCC-E) intercomparison campaigns to “track” the behavior of the direct port.

Foreseen publications/articles resulting or to result from the STSM

New measurements must be taken to study the viability of the portable calibration track system.

This measurements will also be made to the brewers in the Izaña atmospheric research center (IARC), joined with absolute calibrations using the automated rotating shadow band. This last measurements couldn't have been made before the finishing of this report because we have had not the best weather conditions (wind, clouds or both together) that made the automated rotating shadow band useless.

If positive results are obtained and the absolute calibration could be linked to the device calibration, this could be used as a secondary calibration device. All the procedure and the technique should be described in a detailed paper.

A new set of dispersion measurements will be taken during the next Regional Brewer Calibration Center for Europe (RBCC-E) intercomparison campaign that will be held in Huelva in June this year, these measurements, together with the ones made during the Arosa 2014 campaign will allow us to have a big set of measurements to study the different behavior of the different brewer in the network.

References

Cede, A., Kazadzis S., Kowalewski M., Bais A., Kouremeti, N., Blumthaler, M., and Herman, J.. Correction of direct irradiance measurements of Brewer spectrophotometers due to the effect of internal polarization, GEOPHYSICAL RESEARCH LETTERS, VOL. 33, L02806, 2006.

Bais, A. F., Absolute spectral measurements of direct solar irradiance with a Brewer spectrophotometer, Appl. Opt., 36, 5199-5204, 1997

Kazadzis, S., Bais, A. F., Kouremeti, N., Gerasopoulos, E., Garane, K., Blumthaler, M., Schallhart, B. and Cede, A., Direct spectral measurements with a Brewer spectroradiometer: absolute calibration and aerosol optical depth retrieval, APPLIED OPTICS Vol. 44, No. 9 20 March 2005.

ANNEX 1

The calibration procedure described below is done by direct comparison between a calibrated light source and the device to be calibrated using a well-characterized spectroradiometer (Qasume in this case).

1. Before we begin the calibration.

- The warm up time of the instrument before the beginning of the measurements must be at least 1 day.
- The wavelength alignment of the instrument must be checked with an external HG lamp.

2. Setup mounting.

- Mount FEL lamps in Pos A and Pos B, positions, connect the power and monitor cables (Fig. 4).
- Mount the DXW device and the lamp.

3. FEL alignment procedure

- Put the alignment jig in its position lamp 1 and lamp 2.
- Adjust the horizontal orientation of the FEL lamps.
- Adjust the orientation of the First FEL lamp and the QASUME head using the laser and the alignment jig
    - Bidirectional laser defines the horizontal optical axis, then, the bidirectional laser must be leveled. The height of the laser must be adjusted to point the QASUME head and the FEL jig cross line.
    - The FEL lamp jig must be aligned normal to the optical axis (laser back reflection).

  - The QASUME head orientation must be aligned with the mirror tool normal to the optical axis (laser back reflection).

- Adjust the distance between the first FEL lamp and the QASUME head
- All this procedure must be followed with the two FEL lamps.
- Remove both FEL jigs
- Cover the optical table with black clothes.

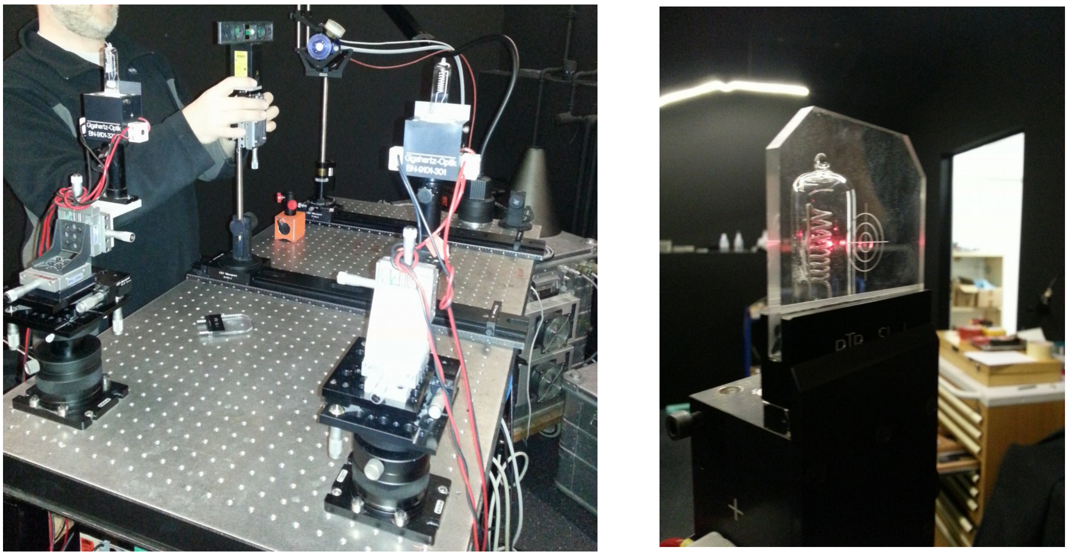


Figure 15: Alignment procedure

4. DXW alignment.

- Connect the power and monitoring cables in the lamp holder.
- Insert the lamp in the lamp holder attending to the polarity. The way the lamp is calibrated and measured will be kept for the rest of it's lifetime, the normal position is: positive right and the lamp seal looking to the holder. The lamp filament must be leveled horizontal at this moment.

- Adjust the orientation of the DXW lamp and the QASUME head with the QASUME head mirror tool.

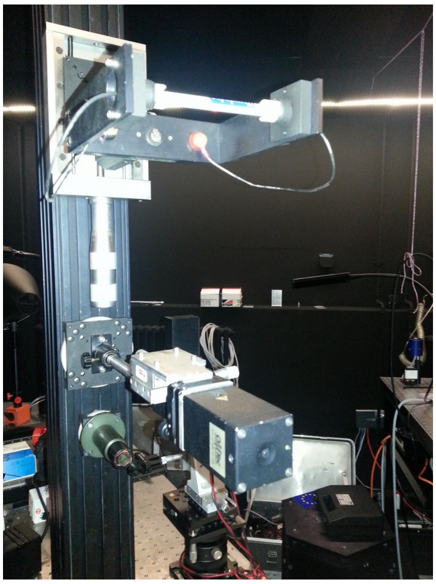


Figure 16: Alignment of the DXW lamp

- Adjust the distance DXW-Lamp – QASUME head. In this case the distance between the lamp reference plane and the reference plane of the QASUME head is 498,2 mm
- Cover with the black clothes all the no black parts.

5. Calibration Schedule

- Start the calibration sequence with one or two secondary standard and one primary standard.
    - Secondary standard are used to monitor the stability of QASUME during the calibration, must be measured at the beginning and the end of the calibration. Stability of QASUME should be ±0,5% in the 300-400 nm region (average).

- After a lamp measurement wait at least 30 minutes before removing the lamp from the socket.

6. Measurement

- Check that all the no black parts are covered with black clothes and the FEL jigs has been removed.
- Ramp up the lamp.
- Install the baffle and check the alignment using the shadow on the wall.

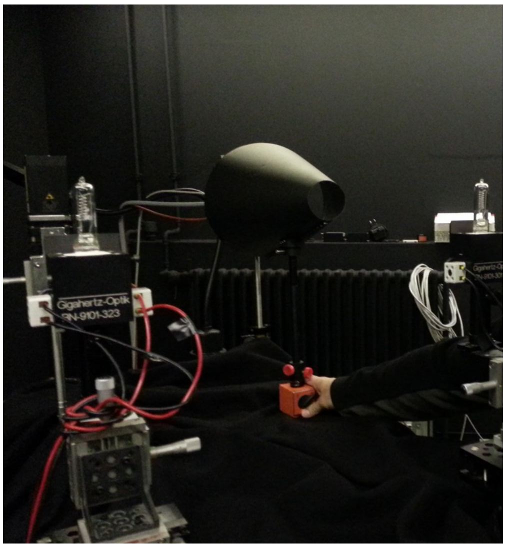


Figure 17: Baffle alignment procedure

- Turn off all the lights in the room.
- Warm up the lamp for at least 15 minutes.
- Scan the spectra with QASUME twice.
- Check that the standard deviation between both scans is less than ±0,5% for wavelengths over 300 nm.

- If scans are correct ramp down the lamp, if not, repeat the scan of the lamp. If after three scans the values are not correct, calibration must be stopped and must be investigated which the problem is.

After the laboratory calibration an irradiance file will be calculated for each calibrated lamp, in this case we measured two new seasoned lamps IZ19 and IZ20.

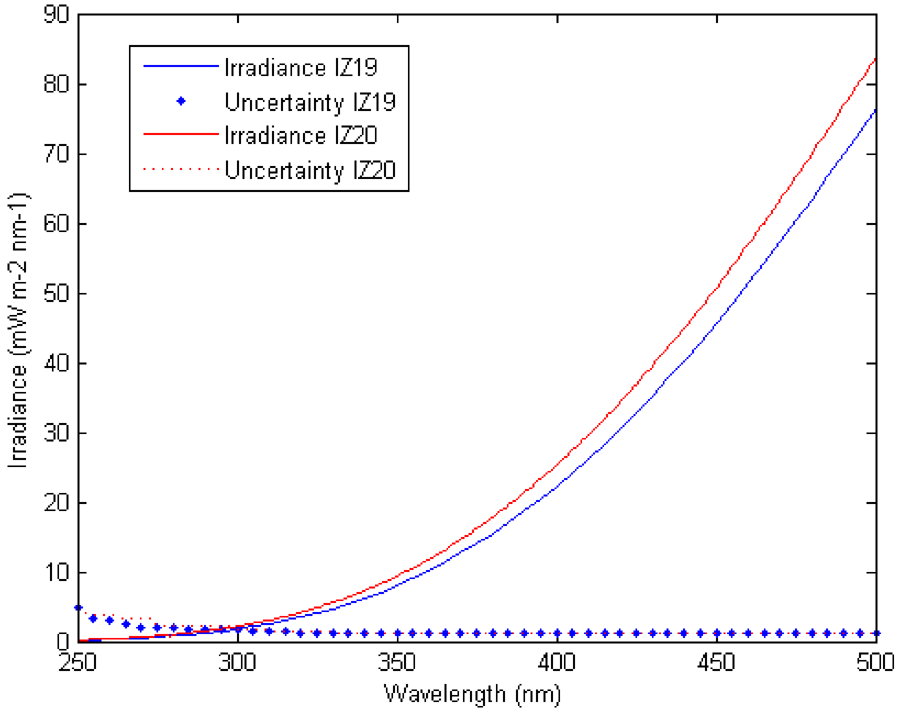


Figure 18: Irradiance (mW m-2 nm-1) for lamps IZ19 and IZ20 and uncertainty (%)