Working paper: Sky Quality Meter cross-calibration in the BMP project

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Abstract

The BMP project (where BMP comes from *BuioMetria Partecipativa*, i.e. Participatory Dark Sky Quality Monitoring) was started in early 2008 with the aim of collecting quantitative information on light pollution through participatory processes. Nine Sky Quality Meters have been acquired to date for the acquisition of spot measurements, and are being shared across a growing community in Italy. In parallel, other sensors (such as an SQM-LE) have been deployed to collect richer data sets at specific locations.

In order to assess the relative consistency of the collected measurements, we have decided to conduct a cross-calibration of the Sky Quality Meters managed within the project activities.

The calibration set up allowed to generate a set of correction factors to be applied to our measurements, and has confirmed that these correction factors are within the precision range of the instruments, thus reassuring on the consistency of the measures collected over a long period of time. We are now planning to repeat the cross-calibration once a year.

All the material used to build the set-up for the calibration may be easily retrieved on the market, so the proposed setup may be adopted by other groups.

Introduction

The BMP project was started in early 2008 with the aim of collecting quantitative information on light pollution through participatory processes, focusing on Italy as a primary area of interest. BMP stands for "BuioMetria Partecipativa", and may be translated as *Participatory Dark Sky Quality Monitoring*. In three years over 500 measures have been collected by a group of about fifty people, sharing a pool of Sky Quality Meters which started with two instruments and now has ten in total (nine manual and one SQM-LE). The database is also open to data from other SQMs, and currently four other instruments are contributing data to our database. We are providing detailed instructions to each volunteer receiving an instrument, thus insuring that measures taken by different people follow a substantially consistent procedure. More information on the project is available from our website: http://www.pibinko.org/bmp

With the project developing over the years, we have considered the need to check the consistency of readings provided by different instruments, thus leading to recall all instruments to conduct a cross-calibration.

This working paper describes the materials used to build the cross-calibration setup, and the set of measurements conducted. The results obtained are then discussed.

Material required for the construction of the cross-calibration set

For the construction of the cross-calibration device the following material has been used:

- A plastic dark box with one open side (such as a plastic drawer, easily found in do-it-yourself stores);
- 6 green LED lamps (12V DC - GU5.3 connection - 1.4W 30/45 lumen - 50 mm MR16);
- 6 lamp holders GU5.3 connection;
- AC-DC adapter with variable output tension (12-3V) and adequate power;

- White Plexiglas (5 mm thick);
- A potentiometer;
- Glue;
- Polystyrene board (2 cm thick), for the construction of the SQM and lux meter positioning masks.

The source of illumination

To provide a source of illumination, green LEDs have been used, following a suggestion by Unihedron, the manufacturer of the Sky Quality Meters. Green light is recommended since the wavelength range for green (495-570 nm) corresponds to the range of maximum sensitivity for the instruments used (SQMs and lux meter).

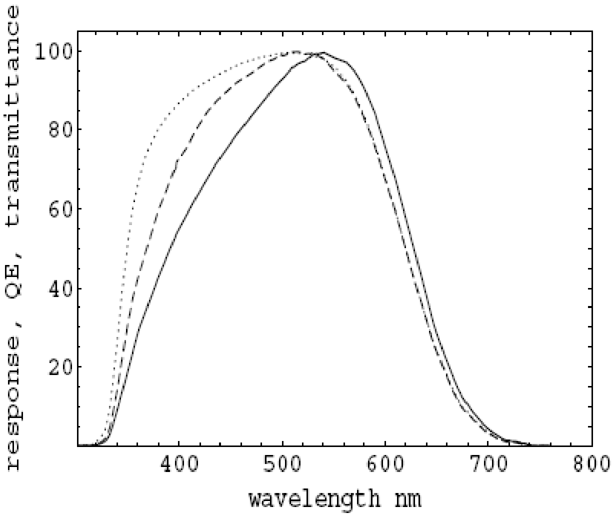

Figure 1: SQM normalized spectral responsivity (solid line), quantum efficiency (dashed line) and filter transmittance (dotted line) [1]

The number and power of the LED lamps has been chosen in order to insure a specific luminance level on the outer side of the Plexiglas plate. This was expected to be corresponding to an SQM level around 8.71 mag/arcsec^2. In fact, this is the light level used by the manufacturer for the initial instrument calibration. At this level the SQM sensor processes the light source once per second (frequency mode).

The choice of a 12V voltage (rather than 220V) lamps is due both to safety and practical considerations. In fact, using 220V lamps, a classical 220V power regulator would be required. Cheap regulators normally available on the market do not operate well with low power absorption. Working at a 12V voltage it is possible to use a standard electronic potentiometer on the lamp power source, or to act directly on the output tension from the AC/DC adapter.

The lux meter

The lux meter used for our calibration is an entry level instrument, still meeting the requirements of our project. It is an Iso-Tech ILM 01 with a resolution of 0.01 lux, a precision of ±3% and a spectral sensitivity very close to the one recommended by International Commission on Illumination.

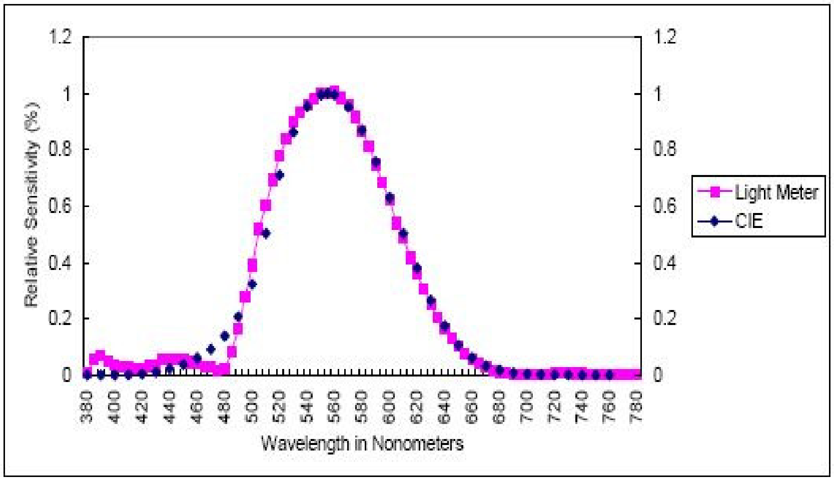

Figure 2: Lux meter spectral sensitivity [2]

Assembling the cross-calibration set

Six equally distanced openings were created for the lamp holders on the bottom of the box. Two Plexiglas plates were cut, matching the size of the open side of the box. The two plates need to be glued together, using a minimum amount of glue, and only on the borders, to avoid affecting the central part of the plate, where the readings are made. A third Plexiglas plate was cut and laid inside the box, on top of the lamps. This is needed in order to make the lighting on the upper plates more homogeneous.

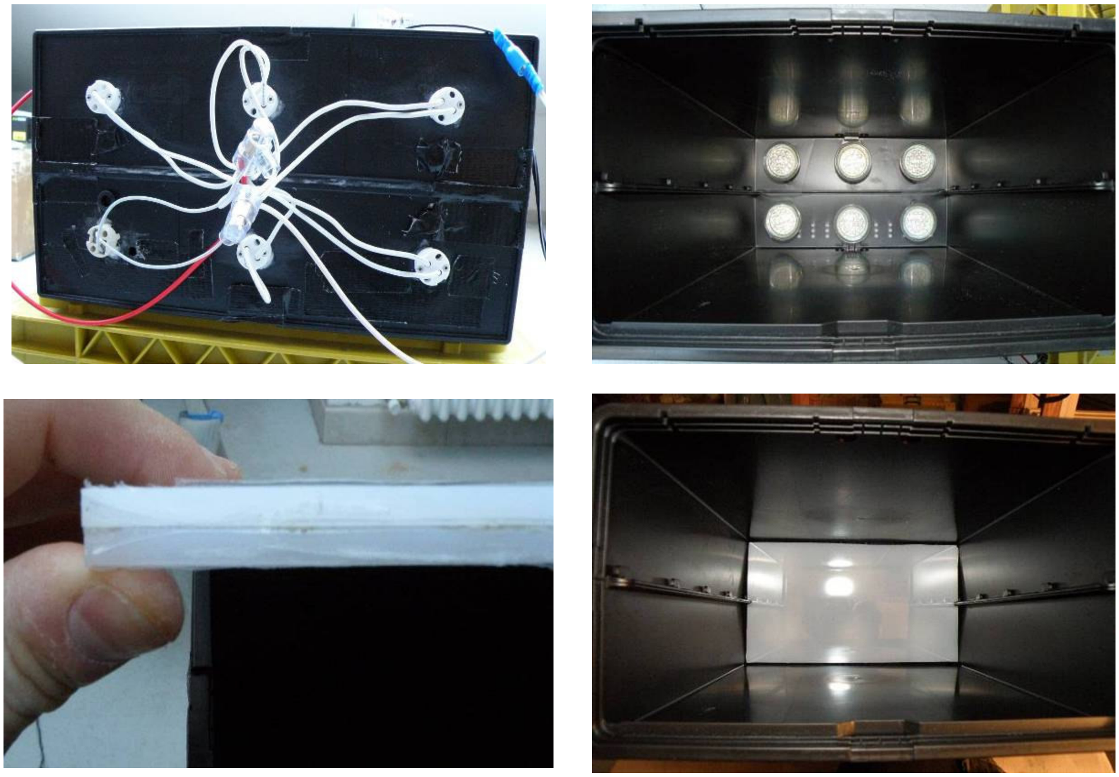

Figure 3: Calibration box

The polystyrene board is used to build masks to ease the positioning both of the SQMs and of the lux meter, and to make sure that the position of the instruments remains the same across different measures. Since the two different SQM models, with or without lens, have a slightly different design (with the sensor being placed respectively at the centre or on the side of the top face of the unit), different masks were created for the two models, so that in all cases the sensor would be placed in the same spot of the Plexiglas plate.

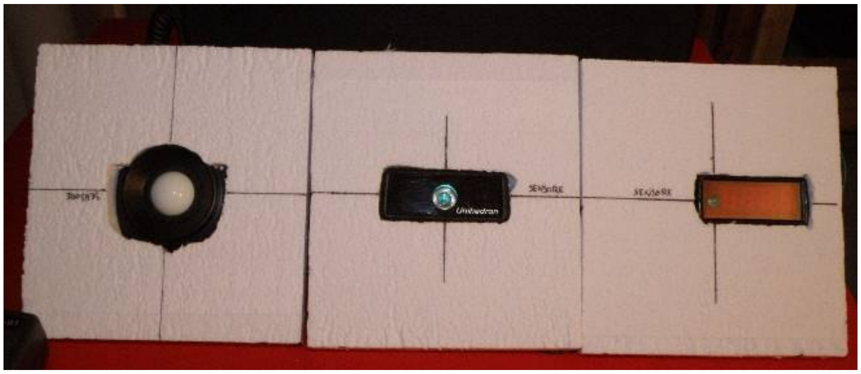

Figure 4: Positioning masks for different sensors

Furthermore, the shape of the mask was crafted so that the lux meter could be positioned as close as possible to the illuminated plate, and at the same distance of the SQM sensors from the centre.

Figure 5: Various views of the calibration set

Execution of the cross-calibration test

We conducted the test on the pool of instruments currently used in the BMP project: five standard SQMs, four SQMs with lens, and one LE model, not shown in the picture. Before conducting the test, a set of fresh batteries was installed.

Figure 6: The nine SQMs subject to the cross-calibration.

The test has been conducted in a totally darkened room, in order to avoid the presence of unwanted light.

Figure 7: Calibration setup

The uniformity of the Plexiglas plate illuminance has been verified by scanning several times the surface with the light meters, and it has been confirmed to be very good.

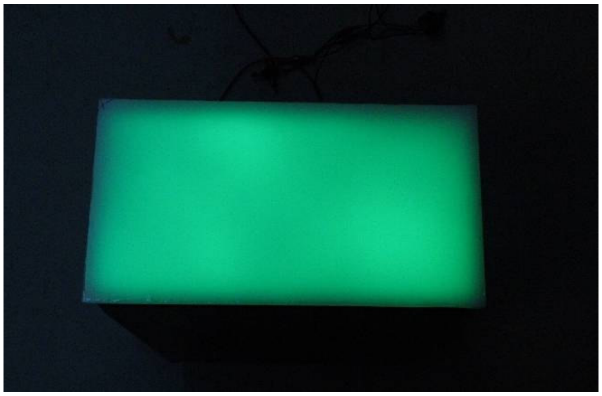

Figure 8: A view of the Plexiglas plate illuminated by the green LEDs

The only problem which emerged during the initial testing of the cross-calibration device was given by the fact that, with the first setup, the six LED lamps were not sufficient to provide an illuminance reaching SQM measures around 8.71 mag/arcsec^2. The maximum luminance attainable on the outer side of the plate resulted around 9.2 mag/arcsec^2. For this reason, it was decided to try and use a single Plexiglas plate on the top of the box. With this setup, the 8.71 mag/arcsec^2 level could easily be reached, while encountering a slight decrease in the uniformity of illuminance, with a variability from left to right around 2.5 lux at an illuminance level around 200 lux. However, recalling that:

- the relative position of the instruments remains constant;
- the variability around 3 lux is in fact lower than the instrumental error of the lux meter, and
- the SQM precision (0.1 mag/arcsec^2) corresponds to a decreasing value of illuminance, as plate illuminance decreases (for levels around 200 lux, 0.1 mag/arcsec^2 corresponds to approximately 2.3 lux, for levels around 0.05 lux corresponds to 0.0002644 lux)

we decided to consider the illuminance variability deriving from the use a single Plexiglas plate as acceptable.

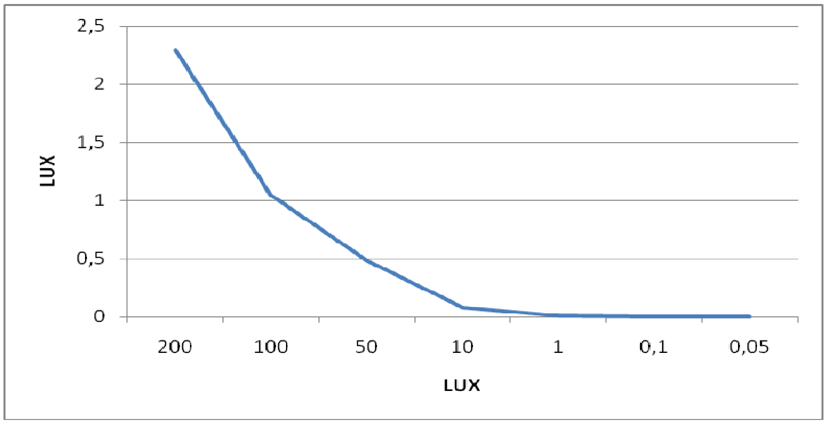

Figure 9: Equivalence between lux and mag/arcsec^2 at different illuminance levels of the calibration box Plexiglas plate

The test at 200 lux has thus been conducted with a single upper plate, while the other tests have been conducted using two upper plates.

Tests have been conducted for three different illuminance levels:

1. 200 lux (corresponding to about 8.6 mag/arcsec^2)
2. 0.05 lux (corresponding to about 18.6 mag/arcsec^2)
3. luminance corresponding to about 21 mag/arcsec^2 (the actual lux meter reading in these conditions is not reliable)

Having set the illuminance level, and keeping it constant, we have conducted the test for each instrument. The first 4-5 readings of each SQM were discarded, allowing the sensor to reach its operating temperature, after which ten readings were recorded. These measurements led to defining an average reading for each of the instruments, as well as an overall average. The latter value was used as a baseline value, in relation to which correction factors were subsequently calculated for each of the SQMs.

Test #2 represented the instrumental limit of our lux meter. Lower lighting levels were leading to exceedingly high variability in the lux readings, not allowing to repeat the measurements exactly in the same conditions.

Test #3 cannot in fact be repeated, since we were not able to measure the exact illuminance level. However it has been conducted, since it represents a condition of actual use of the instruments.

Results and discussion

The recorded results are reported in the following tables. As it can be seen, the corrections to be applied to each SQM fall within the 0.1 mag/arcsec^2 range, with only three slight exceptions. Since 0.1 mag/arcsec^2 is the instrument precision reported by the manufacturer, this result is reassuring, as it confirms that no exceeding relative deviations in the readings occur from one instrument to another.

The analysis of the sets of ten measures per instrument, collected at the different illuminance levels, does not expose significant issues. An increase in the uncertainty of the measurements is noted in darker conditions. While the absolute values of the corrections are comparable for all three tests, the most reliable test is always the one conducted at 200 lux. In fact, it was expected to observe lower SQM readings for the standard instrument (without lens), while slightly higher readings were expected for the models with lens (possibly due to a slight absorption of light from the lens itself). As shown in the Table 1, in test #1 all the positive correction factors are associated to the standard models, while all the negative values are associated to L or LE models. The standard deviation of the readings and the MIN-MAX analysis appears consistent across the different instruments in test #1, while a higher variability is observed in the other two tests (Table 2).In relation to this aspects, results appeared to be somewhat more uncertain for the darkest tests. For these reasons we have chosen to base the correction factor on the test conducted with the higher illuminance level

			Test #1: 200 lux		Test #2: 0,05 lux		Test #3: 21 (mag/arcsec^2)	
SQM name	Type	Model	10-value average (mag/arcsec^2)	CORRECTION (mag/arcsec^2)	10-value average (mag/arcsec^2)	CORRECTION (mag/arcsec^2)	10-value average (mag/arcsec^2)	CORRECTION (mag/arcsec^2)
Cariddi	S	3513	8.57	0.02	18.70	-0.08	20.92	0.05
Scilla	S	3103	8.52	0.07	18.56	0.07	20.94	0.03
Fungoagnello	S	4933	8.55	0.04	18.55	0.07	21.01	-0.05
El segundo	S	3030	8.51	0.08	18.49	0.13	20.94	0.03
Aleph con zero	S	2665	8.52	0.07	18.63	0.00	20.97	0.00
Maira	L	4816	8.69	-0.10	18.60	0.02	21.03	-0.06
Dorce	L	4861	8.61	-0.02	18.63	0.00	20.89	0.08
Maple Leaf	L	4172	8.62	-0.03	18.69	-0.07	21.02	-0.06
Campari	L	3874	8.71	-0.12	18.81	-0.19	21.03	-0.06
Eppursimuove	LE	586	8.60	-0.01	18.57	0.05	20.92	0.04
Overall average (mag/arcsec^2)			8.59		18.62		20.97	

Table 1: SQM measurements and corrections

			Test #1: 200 lux				Test #2: 0,05 LUX				Test #3: 21 mag/arcsec^2			
SQM name	Type	Model	MAX on 10 readings (mag/arcsec^2)	MIN on 10 readings (mag/arcsec^2)	MAX-MIN (mag/arcsec^2)	STD.DEV on 10 readings (mag/arcsec^2)	MAX on 10 readings (mag/arcsec^2)	MIN on 10 readings (mag/arcsec^2)	MAX-MIN (mag/arcsec^2)	STD.DEV on 10 readings (mag/arcsec^2)	MAX on 10 readings (mag/arcsec^2)	MIN on 10 readings (mag/arcsec^2)	MAX-MIN (mag/arcsec^2)	STD.DEV on 10 readings (mag/arcsec^2)
Cariddi	S	3513	8.57	8.57	0.00	0.00	18.79	18.63	0.16	0.05	21	20.88	0.12	0.04
Scilla	S	3103	8.53	8.52	0.01	0.00	18.61	18.51	0.1	0.03	21	20.91	0.09	0.03
Fungoagnello	S	4933	8.57	8.55	0.02	0.01	18.60	18.50	0.1	0.03	21.05	20.96	0.09	0.04
El segundo	S	3030	8.52	8.50	0.02	0.01	18.53	18.46	0.07	0.03	21.04	20.87	0.17	0.05
Aleph con zero	S	2665	8.53	8.50	0.03	0.01	18.67	18.56	0.11	0.04	21.01	20.94	0.07	0.03
Maira	L	4816	8.70	8.68	0.02	0.01	18.65	18.56	0.09	0.04	21.09	20.99	0.1	0.03
Dorce	L	4861	8.62	8.61	0.01	0.00	18.67	18.56	0.11	0.04	20.95	20.8	0.15	0.04
Maple Leaf	L	4172	8.62	8.61	0.01	0.00	18.75	18.65	0.1	0.04	21.09	20.94	0.15	0.04
Campari	L	3874	8.71	8.71	0.00	0.00	18.91	18.79	0.12	0.03	21.12	20.95	0.17	0.06
Eppursimuove	LE	586	8.60	8.59	0.01	0.01	18.59	18.53	0.06	0.03	20.97	20.86	0.11	0.05

Table 2: Statistical data on SQM measurements

Conclusions

The possibility of conducting a cross-calibration on a relatively significant number of instruments has allowed to confirm, after a period of use between one and three years, a set of findings.

1. The models with lens yield slightly lower SQM values compared to the standard models, probably because of the lens itself. The correction factors we have calculated now allow us to integrate in the same database and in a more accurate manner, readings from instruments with and without lens. This could increase data reliability for projects like the BMP project, that use both standard and L models;

2. It is important to discard the first 4-5 readings of any measurement event, in order for the sensor to reach its operating temperature;

3. The experimental setup allows conducting test also for illuminance levels below 0.05 lux. However, in this case, a lux meter of higher accuracy should be used. Furthermore, at low light levels the tests appear to be more sensitive to errors deriving from factors such as voltage changes, lower uniformity in illuminance of the Plexiglas plates, and unwanted lights. It should also be considered that even small variations of illuminance in darker conditions lead to extremely varying SQM readings, as show in the chart above. For all these reasons, and seeing the results of the tests, we think that – while it is necessary to conduct tests at low luminance levels to test instruments reliability, it is also correct to consider the correction factors deriving from the test at 200 lux, since in these conditions most of the possible error sources have a more limited impact.

4. While no unexpected readings were recorded, Table 2 indicates that the uncertainty in the measurements increases as luminance decreases. In order to obtain a finer assessment of the SQMs in such conditions, a more robust cross-calibration setup would be required (with higher quality components). However, based on our current requirements, we believe that the proposed setup is adequate to conduct a cross-calibration.

5. For measurements conducted in the field, the second decimal digit may have little weight;

6. Our tests seem to confirm that the calibration of the instruments is lasting in time (our first SQM was acquired in early 2008);

7. The setup we have created with the calibration box, together with the process we have defined, will allow us to repeat the test in the future, and to generate correction factors for new SQMs we may acquire between two calibration periods. It also may be adopted by users from other groups to improve the quality of evaluations on data sets derived by multiple instruments.

Acknowledgements

We would like to thank Anthony Tekatch from Unihedron and Fabio Falchi from Cielobuio (Italy) for their precious suggestions in defining the design of the cross-calibration setup and in the adopted process.

References

[1] Cinzano P. (2005) Night sky photometry with sky quality meter. Technical Report 9, ISTIL. V1.4.

[2] Lux meter Iso-Tech ILM – 01 User Manual

[3] Unihedron (2009) Sky Quality Meter Lens Ethernet Users manual. Unihedron, Grimsby, Ontario, 1.13 edition

Appendix: SQM-LE calibration with and without dome

Figure 10: Outdoor housing

With the proposed setup it was possible also to assess light absorption from the Plexiglas dome used in the fixed SQM-LE measurement station deployed within the BMP project in January 2011. The system may be easily adapted to other types of external SQM casing.

A guide, represented by a PVC tube inserted in the polystyrene board, was installed on top of the cross-calibration box. This tube is wide enough to contain the whole SQM-LE casing. The casing is attached to the tube, insuring that the SQM sensor is always at the same distance from the lighting source.

Since in this case the objective was simply to determine the light absorption due to the presence of the Plexiglas dome, it was chosen to conduct the measurements with a relatively high light level, so as to minimize the effect of the potential error sources, as discussed above.

Measures were conducted at two illuminance levels (100 and 200 lux), both with and without the dome. It has been found that the light absorption by the dome leads to a difference of 0.12 mag/arcsec^2.

Figure 11: Calibration setup for SQM outdoor housing