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Indoor calibration of Sky Quality Meters: Linearity, spectral responsivity and uncertainty analysis

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ABSTRACT

The indoor calibration of brightness sensors requires extremely low values of irradiance in the most accurate and reproducible way. In this work the testing equipment of an ISO 17025 accredited laboratory for electrical testing, qualification and type approval of solar photovoltaic modules was modified in order to test the linearity of the instruments from few mW/cm^2 down to fractions of nW/cm^2, corresponding to levels of simulated brightness from 6 to 19 mag/arcsec^2. Sixteen Sky Quality Meter (SQM) produced by Unihedron, a Canadian manufacturer, were tested, also assessing the impact of the ageing of their protective glasses on the calibration coefficients and the drift of the instruments. The instruments are in operation on measurement points and observatories at different sites and altitudes in Southern Switzerland, within the framework of OASI, the Environmental Observatory of Southern Switzerland. The authors present the results of the calibration campaign: linearity; brightness calibration, with and without protective glasses; transmittance measurement of the glasses; and spectral responsivity of the devices. A detailed uncertainty analysis is also provided, according to the ISO 17025 standard.

1. Introduction

Public and private street lighting, among many other sources of light, have extended impressively both in small villages and in large cities of the most developed and growing countries in the last decades and have inevitably changed our lifestyle, together with the night skyline. It is well-known [1] that a variety of adverse health effects may be caused by light pollution (or photopollution), which is defined as the alteration of light levels in the outdoor environment (from those present naturally) due to man-made sources of light [2]. The effect is now recognized worldwide, thanks to the activity of associations like International Dark-Sky Association (IDA [3]) and thanks to the last improvements in satellite imaging for defense and meteorological applications [4,5].

Light pollution is particularly strong in small and densely populated areas such as Southern Switzerland, as highlighted in Fig. 1. The cooperation between Dark-Sky Switzerland, the *Sezione della Protezione dell'Aria dell'Acqua e del Suolo* (SPAAS, the department of air, water and land protection) of canton Ticino and some Swiss astronomical observatories led in 2010 to the creation of a permanent network of monitoring stations all over the region (see Fig. 1c).

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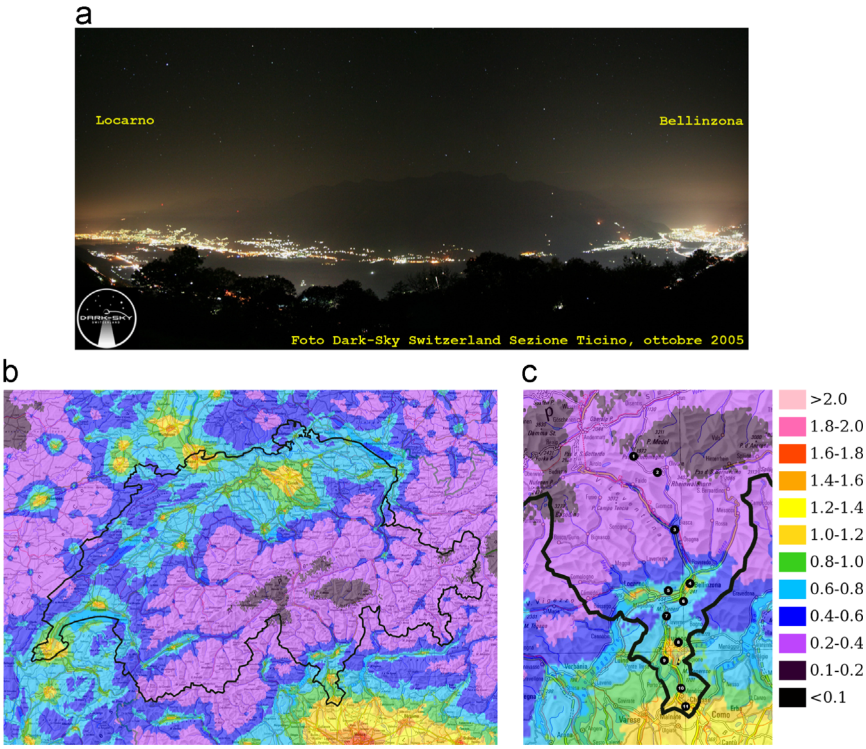

Fig. 1. Light pollution in Southern Switzerland: (a) a picture from Dark-Sky Switzerland (October 2005); (b) Swiss map of light pollution; (c) a detail of canton Ticino, Southern Switzerland. Color code corresponds to a decrease in magnitude as shown in the legend. Points of installation of monitoring stations with Sky Quality Meters are shown. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

One of the main measurement unit in use to date for light pollution monitoring is the Sky Quality Meter^{TM} (SQM) by Unihedron, a Canadian manufacturer specialized in portable tools for metrology in physics and astronomy [6]: 16 of them are now in use among the partners within the framework project OASI, the Environmental Observatory of Southern Switzerland. Measured data can be downloaded on OASI website [7].

Monitoring the measurement data is the mandate of the University of Applied Sciences and Arts of Southern Switzerland (SUPSI, in the Italian acronym), but after 5 years from the first installation, concerns have arisen among partners on the ageing and consequent misalignment of the instruments and on the possible drift of the aged instruments with respect of the new ones. The need of a reliable testing procedure in a controlled, indoor environment led to a measurement campaign held at the ISO 17025 accredited laboratory for photovoltaic terrestrial module testing at SUPSI, whose results are reported in this work.

The experimental equipment of the photovoltaic laboratory have been modified to allow for extremely low reliable level of irradiance for both total and spectral responsivity measurements: the equipment is described in Section 2. The results illustrated in this work confirm those previously published by Cinzano [8], while adding a detailed uncertainty calculation (Section 3) performed according to the requirements of ISO 17025 standard, and extending the measurement of spectral responsivity above the 800 nm limit, where an unexpected non-zero response of the SQM is here reported.

The work will serve as a useful tool and best-practice guideline to research institutes testing similar devices for sky darkness monitoring.

2. Experimental equipment

2.1. The Sky Quality Meter by Unihedron

Fig. 2a shows a picture of the sixteen SQM testing instruments.

The testing instruments give measurements of brightness as magnitude per steradians (mag/arcsec^2), a dimensionless unit proportional to the negative exponential of brightness: thereafter the brighter an object appears in the dark sky, the lower is the measured magnitude. The detector is a crystalline silicon (c-Si) photodiode TSL237 by Texas Advanced Optoelectronic Solutions (TAOS), electrically connected to a current-to-frequency converter: the output frequency is proportional to the intensity of the incident light, thus giving a reliable and precise measurement even at minimum values of brightness (largest values of apparent magnitude).

The c-Si photodiode is covered by a color compensating filter HOYA CM-500, with reported non-zero spectral transmittance between 350 and 750 nm, thus sensitive to visible light only (see Fig. 3).