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Qualifying lighting remodelling in a Hungarian city based on light pollution effects

Z. Kolláth [a,*], A. Dömény [a], K. Kolláth [a,b], B. Nagy [a]

[a] University of West Hungary, Savaria Campus, Institute of Mathematics and Physics, Szombathely, Hungary
[b] Hungarian Meteorological Service, Budapest, Hungary

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ABSTRACT

The public lighting system has been remodelled in several Hungarian cities. In some cases the majority of the old luminaries were fitted with high pressure sodium lamps and they were replaced with white LED lighting with a typical correlated colour temperature of about 4500 K. Therefore, these remodelling works provide a testbed for methods in measurements and modelling. We measured the luminance of the light domes of selected cities by DSLR photometry before and after the remodelling.

Thanks to the full cut off design of the new lighting fixtures we obtained a slight decrease even in the blue part of the sky dome spectra of a tested city. However, we have to note that this positive change is the result of the bad geometry (large ULR) of the previous lighting system. Based on Monte Carlo radiative transfer calculations we provide a comparison of different indicators that can be used to qualify the remodelling, and to predict the possible changes in light pollution.

1. Introduction

Because of the increasing level of light pollution, night sky quality monitoring becomes an important part of nature conservation. We performed imaging sky luminance measurements in Hungary as part of the designation procedure of natural park areas for International Dark Sky Parks (IDSP) recognized by the International Dark Sky Association (IDA). A well-known method of qualifying the loss of energy in the direction of the sky is the measurements based on satellite images (see e.g. [1]). This provides an efficient tool also to survey the changes of light pollution after modifications in the light sources. However, we have to take into considerations in some of the satellite imageries the spectral response of the cameras. The lack of sensitivity in blue light may indicate a decrease in the escaped light in contrast to the real variation.

A possible method to qualify the light pollution over a large area is to make maps of night sky brightness in the selected area. There are different procedures to generate such maps, the simplest one is to measure the mean luminance of a portion of the night sky by a luminance meter (e.g. Sky Quality Meter). To provide indicators on the ecological effects on light pollution it is important to collect as complete data as possible – like the luminance distribution of the whole sky together with spectral information. Single zenith radiance measurements by SQM devices may provide only limited information of the changes during lighting remodelling.

If such measurements are made on a dense enough geographic grid, the skyglow of the territory can be mapped. However, significantly more information can be gathered by imaging photometry of the whole sky. In addition, recent techniques to survey light pollution (e.g.

* Corresponding author.
E-mail address: kollath.zoltan@ttk.nyme.hu (Z. Kolláth).

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[2–4]) provide the spatial distribution of artificial sky luminance as a function of different parameters (wavelength, sky position, etc.). The improvements of Digital Single Lens Reflex (DSLR) cameras provide a new opportunity to monitor the artificial skyglow and light pollution. DSLR cameras that are able to save images in an unaltered raw format, can be calibrated to get measurements of the luminance of the sky on a physical scale. Then the photos of the night sky can be converted to false colour images, which represent the distribution of sky brightness [4]. Such calibrated images of the light domes over cities provide enough information to interpolate or even extrapolate them to a larger area if the measurements are combined with numerical radiation transfer modelling.

In order to interpret the sky brightness measurements and to provide models of the effects of city-lights, numerical calculations should be performed. The general procedure of light pollution modelling uses the spatial distribution and the characteristic properties of light sources together with the physical parameters of the atmosphere as an input for the calculations. Then the solution of the radiation transfer equations constrained by the input parameters provides observable quantities, like the distribution of the luminance of skyglow or illuminance values at different locations. Different methods exist to calculate the solutions of this problem, e.g. by direct integration of the full radiation transfer equations, or some approximate solutions based on simplification of the problem. The basic elements of these methods can be found e.g. in [5,6] and references therein. Another possible way is to perform Monte Carlo simulation of photon packets (see e.g. [7]). This method is widely used in general atmospheric research, but does not yet spread widely in light pollution related works. To simulate the effect of different lighting systems, light sources, weather and atmospheric conditions we have developed a Monte Carlo radiation transfer code [8].

2. Measurements before and after a lighting remodelling

SLR cameras provide a new opportunity for scientific measurements of radiance or luminance distributions [9]. The great advantage of DSLR measurements is that it results in imaging photometry or radiometry. Together with a fisheye lens the system provides information on the whole upper hemisphere with a single exposure. Compared to other imaging photometric systems (like CCD cameras) it is highly transportable, suitable for field work in remote locations. The method has been proved to be an effective tool to characterize potential dark sky parks (e.g. [4]).

However, DSLR cameras are designed to provide pleasant images for everyday and artistic use. Then they cannot be used for measurements ‘off-the-shelf’, but only after some sort of calibration. The precision of the measurements depends mostly on our calibration procedure and on the camera itself. When calibrated thoroughly, DSLR cameras provide a new opportunity to monitor the brightness (luminance) of the night sky and light pollution. For our purposes the cameras which save the data in a raw format (the digital numbers of each pixel without any colour calibration and data compression) are superior. Jpeg files incorporate lots of preprocessing which risks the calibration. Raw files provide a better dynamic range as well. The CMOS sensors and the analogue-to-digital conversion of modern cameras provide a linear measuring possibility in up to a 1–4000 dynamic range with a single exposure. That is usually enough for night sky monitoring, and higher dynamic range can be obtained with HDR imaging. Then the limit of the dynamic range is determined by the possible exposure times. For precise measurements, dark frames (images with the same exposure, but with the lens cap is on) have to be taken. Dark images can be used to compensate for the noise in the sensor and electronics and to set the black level. A couple of dark images can be used for a whole night.

We performed night sky radiance measurements before and after a lighting remodelling of several Hungarian cities. Here we present a representative example of our studies. We used a Canon EOS 6D camera with a Samyang 14 mm f/2.8 lens. For the recent study we selected the following exposure parameters: ISO 3200, exposure time 32 s, aperture f/2.8. The same results were obtained with ISO 1600 and longer exposures. The dates of the measurements campaigns were July 5/6, 2014 (before remodelling) and August 28/29, 2014 (after remodelling). Based on MACC-II data (https://www.gmes-atmosphere.eu/) the aerosol optical depth was very similar during the two nights, in the order of 0.1. We selected both night with clear and moonless sky. Sky luminance is displayed in natural sky units NSU (see Jechow et al., [13]). The results photographed at a distance of 7 km from the city centre are displayed in Fig. 1. Sky brightness is decreased after remodelling in all colour bands, more in the visual and the red channels and in a less extent in the camera's blue channel. This result is quite natural, since the relative blue content of the light output is increased as the orange dominated Sodium lighting was replaced with LED lights with enhanced blue content.

In order to obtain quantitative results from the DSLR images, the vertical illuminance was estimated at the observing site by integrating the sky luminance. Based on the NSU units used in Fig. 1, we present the illuminance also in NSU (i.e. the vertical illuminance given by the quarter sphere with 1 NSU uniform luminance). With this unit the vertical illuminance decreased from $E_{v,1} = 3.1$ NSU to $E_{v,2} = 2.4$ NSU after the remodelling. We estimated the illuminance due to the natural and artificial background at the same location by the DSLR imagery taken at the opposite direction and at sites further from the city. A good estimate of the background is $E_{v,0} = 1.8$–2.0 NSU. Then the real ratio of the illuminance component caused by the lights of Szekszárd is $(E_{v,1} - E_{v,0})/(E_{v,2} - E_{v,0}) \approx 2.4$, which represent a significant decrease at least in photopic spectral range.

Parallel SQM-L measurements at the zenith provided sky brightness values around 21.1–21.2 mag/arcsec^2 at the measurement location, with some indication of 0.1 mag/arcsec^2 decrease after remodelling, although this change is within the errorbar of measurements. Again, using the