Measuring and modelling light pollution at the Zselic Starry Sky Park

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Abstract. One of the first ‘International Dark-sky Parks’ in Europe was established at the Zselic Landscape Protection Area in Hungary. A special monitoring program has been carrying on to survey the quality of the night sky using ‘Sky Quality Meters’ and DSLR cameras. The main conclusion of our measurements is that the local villages have only a minimal effect on the quality of the sky. There are light-domes due to the neighbouring cities only close to the horizon, the main source of obtrusive light is the city of Kaposvár. The anthropogenic component of zenith luminance of the night sky is obtained as the function of the distance from the city centre of Kaposvár. Our data were modelled by radiation transfer calculations. These results can help to draw attention to the energy emitted useless to the space and to protect our nocturnal landscape of nature parks for the next generations.

1. Introduction
At the Zselic Landscape Protection Area, Hungary an extensive program has been started to conserve the excellent night sky quality of the region. The International Dark-Sky Association announced the designation of two additional Dark Sky Parks on November 15, 2009: Galloway Forest Park in Scotland, UK and the Zselic Landscape Protection Area in Hungary, simultaneously became the first European International Dark Sky Park. Recognition as an International Dark Sky Park requires intense long term planning, retrofitting and preservation efforts to fulfil the application prerequisites.

The Zselic region, which is located in the South-West part of Hungary, is one of the best locations for dark skies in the county. The area of the protected park is more than 9000 hectares, and its major part is woodland. The Zselic Landscape Protection Area has excellent night sky quality, on clear nights the artificial component of the night sky brightness does not exceed the natural luminance of the sky. The Milky Way, the zodiacal light and other faint phenomena are clearly visible by naked-eye on a clear night.

Artificial lighting, when poorly designed, does not lit only the desired area and a large amount of light out of this area is usually wasted. This has energetic consequences hence the wasted luminous flux has to be paid by the community, and the production of the wasted energy has again negative effects on our environment. On the other hand our environment cannot only be polluted by emission of different materials but also by undesired light. The wasted luminous flux makes its effect somewhere else, e.g. it can cause serious changes in the natural environment and ecosystem and increases the luminance of the night sky. To determine this effect on a nature park, night sky luminance measurements and radiation transfer calculations should be performed.
The US National Park Service started first monitoring of the night sky at natural protected areas like national parks in 2001 (Duriscoe, Luginbuhl & Moore 2007). These data are also used for the protection of the nocturnal visual resource. This system also allows comprehensive characterization of sky conditions at astronomical observatories. Luginbuhl et al. (2009) used the same type of observations to test the predictions of light pollution models. In this paper we show our methods of measurements used in the Zselic Starry Sky Park and the interpretation of our data.

2. Observational methods
There are plenty of methods to estimate the quality of the night sky. Most of them are visual estimates of the limiting magnitude (the faintest star which can be visible by naked eyes) or the number of stars observable in a fixed region of the sky. These methods work well to describe the expected view of the night sky; however, they depend on subjective factors, like the eye-sight of the observer. To map and monitor the light pollution of the park and its neighbourhood it was necessary to find methods to measure the quality of the sky in a reproducible way with calibrated instruments. The natural quantity that describes the ‘darkness’ of the nocturnal environment is the luminance of the sky.

It is expected that the luminance of the sky varies on a distance scale of a few kilometres,
so it was necessary to perform a field survey to map the distribution if sky brightness thorough
the park area and in its neighbourhood. The geographic co-ordinates of the measurements
were registered with a precision of at least 100 meters. At normal conditions there are no
detectable changes of zenith luminance on this distance scale. We used a GPS device or a
detailed topographic map of the region to get the geographic co-ordinates. The locations were
recorded in Universal Transverse Mercator (UTM) co-ordinates. The UTM co-ordinates can
be practical when one uses topographic map with this scale, and it also provides the distances
between measurement locations and the exact directions of polluting light sources easily. When
needed, UTM data are converted to standard longitude-latitude data.

2.1. Luminance measurements
We selected a portable photometer with high enough sensitivity to measure the subtle light of the
rural night sky. A simple device, the Sky Quality Meter (SQM) by Unihedron was designed for
this purpose, and it is used widely for light pollution monitoring. SQM is a handheld device; it
collects the light from a relatively large solid angle (1.5 steradian, approximately a cone with a 42
degrees half angle). The device displays the average luminance of this solid angle in astronomical
units: magnitude per square arcsecond (mag/arcsec$^2$). SQM is temperature calibrated and gives
the luminance with the precision of 0.1 mag/arcsec$^2$, which is equivalent to 10 percent in linear
luminance (cd/m$^2$) units. Laboratory tests of this instrument were presented by Cinzano (2007).

We have been monitoring the sky quality using SQM since January 27, 2007. All of our
measurements were taken with the device pointing to the zenith. The necessary conditions to
perform a field survey were the followings:

- Moonless night.
- No clouds or fog.
- The Sun is at least 18 degrees below the horizon (astronomical twilight).
- No direct light from artificial sources reaches the detector of the device.

2.2. Measurements by all sky imaging
Recent Digital Single Lens Reflex (DSLR) cameras provide a new opportunity to monitor the
quality of the night sky and light pollution. Cameras that are able to save images in an unaltered
raw format, can be calibrated to get measurements of the luminance of the sky in a physical
scale. Then the photo of the night sky can be converted to false colour images, which represents
the distribution of sky luminance. Our experiments show that commercial DSLR cameras can
easily reach 10 percent precision (e.g. 0.1 mag/arcsec$^2$), when calibrated thoroughly.

Our standard settings for light pollution monitoring in dark locations are the followings:

- Canon EOS 350D camera (some parallel tests with EOS 50D, 450D and 300D)
- Sigma 4.5mm f2.8 EX DC circular fisheye lens
- ISO 800 setting
- $T=180$ s exposure time
- $f=2.8-3.5$ aperture

We developed our own software (dclum) to process raw images and to calibrate the camera.
The camera and the lens were calibrated in co-operation with the University of Pannonia
at Veszprém and the Technical College of Budapest. The system was first calibrated in a
photometry lab and then with a high performance imaging luminance meter under real sky
conditions. To get as precise calibration as possible, we used different types of standard
measurements and then compared the results: The laboratory measurements were used also
to fit the effect of vignetting of the lens. The calibration was performed in standard photopic
luminance scale (unit of cd/m$^2$). Then the measurements can be transformed to mag/arcsec$^2$ units with a good approximation. An example of the resulting luminance map is displayed on Figure 1.

We have cross correlated the DSLR measurements integrated with the sensitivity curve of SQM with parallel SQM measurements. The results are satisfactory as they agree within 0.1 mag/arcsec$^2$ (10%). We also checked the linearity of the CCD by multiple exposures and different light levels. It is concluded that the raw images of a digital camera can be used for our purposes since the calibration errors do not exceed the precision needed for light pollution monitoring.

The precision of our treatment is clearly demonstrated with a simple experiment: The light-dome of Budapest was photographed from a vantage point at a distance of 80 km from the Capital (Piszkéstető Mountain Station, Konkoly Observatory). A 5% decrease of the city’s light dome is clearly measurable during the switch off of the ornamental lights in Budapest.

3. Models
To interpret the sky brightness measurements and to provide models of the light pollution in the park we have developed a Monte-Carlo radiation transfer code. In clear air (no clouds), the propagation of light is determined by Rayleigh scattering for molecules and by Mie scattering for aerosols. Absorption is negligible in the visible range of electromagnetic radiation. The mean free path of photons in terrestrial atmosphere is several tens of kilometres, depending on the aerosol content and elevation. It gives a natural choice to use Monte-Carlo simulation of the light propagation the observed photometric quantities are statistical averages of photon packets. For detailed description of Monte-Carlo radiation transfer calculations see e.g. Spada et al. 2006.

To take into consideration the effect of different humidity and aerosol content we calculated model sequences with different zenith extinction. A standard atmospheric model for clear air was used, and we fitted the aerosol content to get a fixed zenith extinction. In this way we obtained a one parameter models sequence which well represents the behaviour of the atmosphere in clear (cloudless) nights.

4. Measurements
The main conclusion of our measurements is that the local settlements have only a minimal effect on the quality of the sky. The luminance is only slightly increased in the vicinity of small villages. The lights from the city of Kaposvár, North of the area mostly affect the sky background. Inside the Landscape Protection Area the quality of the night sky is better than 21.0 mag/arcsec$^2$, typically around 21.3-21.4 mag/arcsec$^2$. There is a clear increase in night sky luminance North of the park area, but acceptable conditions can be found for stargazing even at those locations. To display the quantitative results, we plotted the luminance of the night sky, as the function of the distance from the city centre of Kaposvár (Figure 2). For this plot we converted the SQM measurements to the standard luminance scale (cd/m$^2$). It provides a more natural way to subtract the background sky brightness ($L_0$), which represents the natural sky luminance and the overall sky brightness from distant artificial sources. SQM measurements are plotted for a night with snow coverage at the region of Kaposvár (red dots), and for selected nights with similar atmospheric quality (blue crosses).

We also performed Monte Carlo atmospheric radiation transfer calculations to interpret our measurements. On Figure 2, we displayed the trends from these calculations with solid lines. The upper line represents twice as large luminance values as the lower curve does. Both curves are calculated for clear (low humidity and aerosol content) air.

With $L_0=0.00032$ cd/m$^2$ the distribution of measurements can be well represented with the models. This value agrees with our darkest measurements (21.5-21.6 mag/arcsec$^2$) in the region. There is a clear overall trend in sky luminance measurements, agreeing with the radiation transfer
Figure 2. Artificial sky brightness as a function of the distance from the city of Kaposvár. Blue dots: normal ground conditions; red dots: snow coverage; lines: radiation transfer models.

calculations. The deviations from this trend are due to the measurements being taken close to local polluting sources, to changes in weather conditions and to instrumental noise. The dotted horizontal lines indicate the $L=0.00025$ and $0.00075 \text{cd/m}^2$ (equal to, and three times larger than the natural sky luminance). The vertical line shows the distance of the closest border of the LPA to the city. We can conclude that the quality of the sky inside the Zselic Landscape Protection Area is above the limits of silver tier of the International Dark-Sky Association, even at snowy conditions.

There is another interesting conclusion one can draw from the above measurements. The increased reflexivity of the ground by snow coverage doubled the luminance of the sky. It suggests that a significant component of light pollution inside the LPA originates from ground reflection. Taking into consideration that the ground reflection increased from the normal 0.1-0.2 values to the numbers related to the mixture of snow and wet road (0.6-0.8), the ratio of direct to reflected components of sky brightness can be estimated. These calculations show, that up to 50% of the sky glow due to Kaposvár could be eliminated, if only fully shielded fixtures were used in Kaposvár. The measurements together with the radiation transfer calculations can be used, to argue for a Lighting Master Plan in Kaposvár.

The luminance calibrated images are displayed on a false colour scale to display the luminance distribution on the sky. The major obtrusive sources can be clearly identified when such images (after a mirroring) are displayed on a map of the region. It is also possible to get the spatial dependence of sky quality inside the Landscape protection area.

Based on all sky luminance distributions, it is easy to determine different single quantities, like a simulated SQM value ($\text{SQM}_{\text{sim}}$), or the total sky brightness above 20 degrees ($\text{TSB}_{20}$, see
e.g. Duriscoe, Luginbuhl & Moore 2007). These quantities also demonstrate the excellent night time quality of the Zselic region.

The spatial distribution of the luminance of the sky is visualized with better clarity, if the circular map is transformed to the plane of azimuth and elevation. These images show that the light dome of Kaposvár is limited to elevations below 20 degrees even from a closest location (Figure 3).

![Figure 3](image.png)

**Figure 3.** Luminance distribution of the sky as a function of azimuth and altitude. The same colour scale is used as in Figure 1.

5. Conclusion

We have performed sky quality (night sky luminance) measurements in the Zselic Landscape Protection Area and its vicinity. It is demonstrated that both the Sky Quality Meter and a DSLR camera are suitable for taking quick luminance measurements in remote locations. The pocket size, handheld device is especially useful for mapping light pollution at multiple locations during a one-night long monitoring session. All sky cameras (e.g. DSLR cameras with circular fisheye lens) give additional information in sky quality. The main light pollution source in the park is the city of Kaposvár. Our sky background measurements show that the light pollution due to these light sources is reduced to acceptable level in the distance of 7 km from the city centre and these lights do not have any serious effect at the Zselic Starry Sky Park region. Local settlements have only very limited effect on night sky quality. Everywhere inside the landscape protection area the quality of the sky is better than the minimal requirements for the silver tier recommended by the International Dark Sky Association.

We fitted the sky luminance measurements as a function of distance from the centre of Kaposvár by the results of radiation transfer calculations of light pollution. With the models it is also possible also predict any degradation or improvement in sky quality related to changes in the artificial light sources in the neighbourhood. We plan to use these predictive models to negotiate with municipalities, stakeholders and designers of lighting systems in the region in order to avoid any increase of light pollution at the Dark Sky Preserve. We continue monitoring the sky quality to notice any changes that need corrective steps. We plan to establish a grid of fixed measuring stations in the Zselic region to provide automatic and continuous monitoring of the luminance of the night sky.

References

Cinzano P 2007 *ISTIL Internal Report* 9
Duriscoe D M, Luginbuhl C B, Moore C A 2007 *PASP* 119 192
Luginbuhl C B, Duriscoe D M, Moore C W, Richman A, Lockwood G W, Davis D R 2009 *PASP* 121 204
Spada F, Krol M C, Stammes P 2006 *Atmospheric Chemistry and Physics Discussions* 6 4823