Testing a cloudless model of light pollution propagation on two dark sky regions in Portugal

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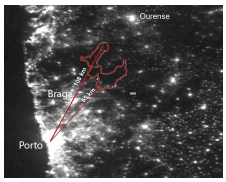
Introduction

Light pollution (LP) affects Mainland Portugal in accordance to its asymmetric demographic distribution. The strongest LP sources are distributed along the densely populated coastal line, whereas the interior north and south of the country is still generally well preserved due to a much lower demographic density. In the period 2010-2014, on selected moonless and cloudless nights, we assessed the skyglow of two dark sky regions (the Peneda-Gerês National Park, a mountain region, and the Lake Alqueva region, typically plain) with a portable Unihedron SQM-L unit pointed handheld to the zenith. The data from the field measurements was used to compare to one light pollution propagation model (Kocifaj, 2007), using calibrated VIIRS DNB satellite upwards radiance (calibration by Zamorano et al, 2012) as input to the model. The results obtained from the model are favourably compared to the field measurements. We proceeded to a set of tests with the model (programmed in MATLAB) to find the best fit. Our best results were achieved by analysing the data by night rather than the global set of data. Our results were used to apply to the classification of the Alqueva as a Starlight Tourism Destination and light pollution guidelines were implemented in the Peneda-Gerês Park's Management Plan.

Fieldwork and the regions under study

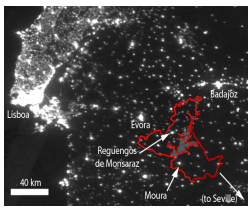
The 710 sq km large Peneda-Gerês National Park (PNPG) is becoming gradually more affected by the close northern coastal line. At the south of the country, the 3 000 sq km current Starlight Tourist Destination Dark Sky Alqueva Reserve (DSA) is a large area still with low levels of light pollution.

To assess the zenithal sky brightness on both regions during astronomical night, we used a portable Unihedron Sky Quality Meter-Lens (SQM-L), under clear and moonless nights. For the PNPG (right) we chose 63 places and took measurements between the years 2010 and 2014. For the Dark Sky Alqueva (left) we took several measurements on 173 places, between the years 2010–2014.



◂ The horseshoe-shaped boundary of the Peneda-Gerês National Park (center) and the distances and the localization of some of the major sources of light pollution. The extreme north of the Park is circa 1.5 times farther from Porto than the south border.

The boundary of the Alqueva Dark Sky Starlight Tourism Destination (DSA) and the distances and the localization of some of the sources of light pollution. This region is at approximately 200 km from the centre of the metropolitan area of Lisbon. ▸



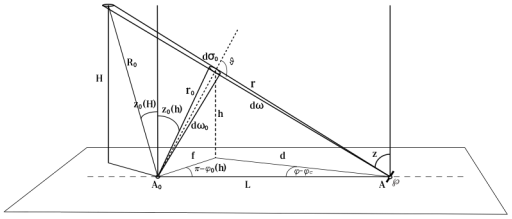
Images credit: Earth Observation Group, NOAA National Geophysical Data Center; available from: ftp://ftp.ngdc.noaa.gov/DMSP/viirs_fire/viirs_html/viirs_ntl.html .

Modelling the propagation of light in the atmosphere

When light propagates in the atmosphere, it interacts with atoms, molecules and aerosols thus suffering diffraction, refraction, and scattering. As a consequence of the latter, artificial night at night (ALAN) increases sky brightness, reducing contrast and interfering with the observation of the majority of astronomical objects, dim by nature.

In 1986 Roy H. Garstang proposed a model of light diffusion that uses several atmospheric variables and parameters, along with geographical characteristics, such as the elevation angle of the city (a circular emitter with its brightness proportional to the population, on that approach) relative to the observer. Amongst other subsequent models based on Garstang's, known as Extended Garstang Models (EGM), we chose Miroslav Kocifaj's model (Kocifaj, 2007) for N sources of light at every chosen azimuths and distances to test its applicability on two dark sky sites, using calibrated radiance data from VIIRS DNB cloud free nighttime satellite images as an input source.

Kocifaj's model also accounts for the presence of clouds and the moon, although in this work those two contributions were not considered since the output of the model was to be compared with measurements taken under clear and moonless skies.



◂ Geometrical interpretation of the light pollution model used in this work (based on figure from Kocifaj, 2007). A_θ, bottom left, is the location of the emitter, φ is the location of the observer, both at ground level.

The equation of radiance that serves our purposes of analysing a cloud-free and moon-free night sky is (Kocifaj, 2007)

$$I_\lambda(z,\varphi) = \frac{A_o I_{\lambda,0}}{\cos z} \int_0^H B\left(Q, q, z_{0,h}\right) \cos^2 z_{0,h} \frac{T_\lambda(h,z,\varphi)}{h^2} \Gamma_\lambda(h,z,\varphi)\, dh$$

where,

$$B(Q,q,z_0) = 2Q(1-q)\cos z_0 + 0.554\, q\, z_0^4 \text{ (Garstang's Equation)}$$

z – Zenithal angle of the incident radiation (observer, $\wp$)

φ – Azimuth of the scattering element as seen from observer $\wp$

z_0 – Zenithal angle of the emitted radiation

$\Gamma_\lambda(h,z,\varphi)$ – Angular distribution of the light scattered at altitude h

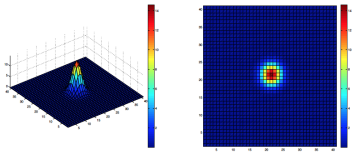
h – Altitude of the scattering element of the atmosphere (from the ground up to the max. height of H=100 km)

$T_\lambda(h,z,\varphi)$ – Global transmission function

Enhancements

Since we were comparing areas covered by a constant circular field of view (FOV) of the SQM-L, we used a Zenithal Equal Area projection (also known as Lambert Azimuthal Equal-Area projection), characterized by the fact that regions of equal size of a map correspond to equal solid angles in the sky. Consequently, it allows to integrate over solid angles across the FOV by integrating over the corresponding regions of the flat map (Bará, Nievas, Sánchez de Miguel, & Zamorano, 2014).

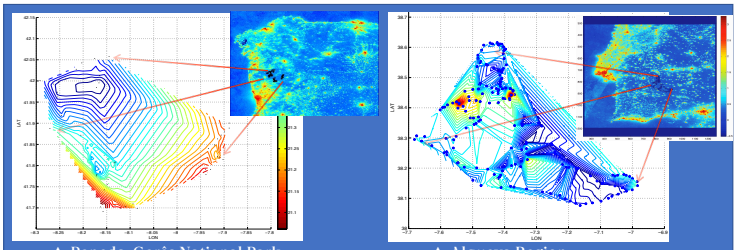
To account for the angular response of the SQM-L, a compensation has also been added to the model (Tilve et al., 2014) to better simulate real conditions of measurement with the device.



◂ Representation in MATLAB of the simulated field of view (FOV) of the SQM-L, at left, in perspective, at right, a view from top. Applying the FOV over the outcome for the radiance of the sky predicted by Kocifaj's model, allows achieving the result a real SQM-L would acquire.

Results

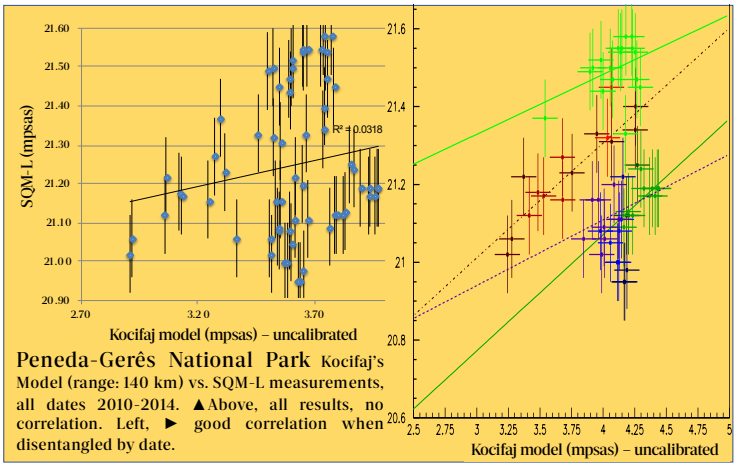
Results from the measurements with the SQM-L



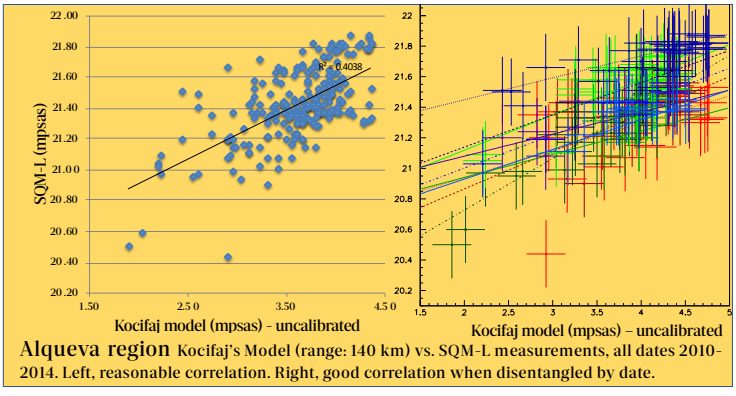
▲ Peneda-Gerês National Park ▲ Alqueva Region

The MATLAB contour plots above present the isolines from all the SQM-L readings (average values) on each of the regions in the period 2010-2014. Each dot in the contour plots below represents a spot where the measurements were taken. Satellite images: NOAO/NGDC; Zamorano, J. et al.

Fit of Kocifaj's model with VIIRS DNB (2012) to the SQM-L readings



Peneda-Gerês National Park Kocifaj's Model (range: 140 km) vs. SQM-L measurements, all dates 2010-2014. ▲Above, all results, no correlation. Left, ▶ good correlation when disentangled by date.



Alqueva region Kocifaj's Model (range: 140 km) vs. SQM-L measurements, all dates 2010-2014. Left, reasonable correlation. Right, good correlation when disentangled by date.

Conclusion

The results of the implementation of (Kocifaj, 2007) model of light pollution using the calibrated VIIRS DNB data confront favourably with the SQM-L readings of Peneda-Gerês and Alqueva, particularly when data is organized by night (date) of campaign.

References

Bará, S, Nievas, M., Sánchez de Miguel, A., & Zamorano, J. (2014). Zernike analysis of all-sky night brightness maps. *Applied Optics*, 53(12), 2677–86. doi:10.1364/AO.53.002677.

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