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Amplification (or not) of Light Pollution due to the presence of clouds

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Abstract

Light emitted or reflected up to the sky can interact with clouds or fog changing Night Sky Brightness (NSB). So the evaluation of NSB in any place can be affected by this meteorological features and needs to be analyzed. To evaluate this effect, data of NSB obtained with the Catalan Light Pollution Network (XCLCat) has been analyzed accurately and shows how the effect is completely different in urban and protected areas. The study including independent cloud coverage data shows how in a city NSB increases dramatically and in a protected area the sky appears darker than in cloudless situation.

1 Introduction

Light Pollution (LP) is any effect generated by artificial light at night (ALAN). Normally Light Pollution is associated with astronomy, but there are many other effects in natural environment, health or power consumption. One of the most common features of LP is the emission of light to the sky, generating skyglow.

The evaluation of LP can be done measuring Night Sky brightness (NSB) using ground-based instruments as telescopes with cameras or stand-alone devices for this purpose. Light emitted or reflected up to the sky can interact with clouds or fog changing dramatically NSB (see for example [4], [5]). So the evaluation of NSB can be clearly affected by presence or absence of clouds. This effect is completely different depending of the nature of the site: dark site or urban polluted site.

2 Catalan Light Pollution Network (XCLCat)

There are different approaches to evaluate Night Sky Brightness to estimate Light Pollution: from the space or from the ground. The first option is based in the idea of using satellite data [3] or data from the International Space Station [9]. The ground based observations can be done using classical photometry with telescopes or using new specially designed devices. In our study we have worked with ground-based measurements using Sky Quality Meter (SQM) devices.

The cooperation of Catalan Service against Light Pollution and Parc Astronòmic Montsec have leaded to a pilot plan of a network for monitoring and evaluation of NSB in different places of Catalonia region [8]. Initially the network had just five devices but in 2016 the network increased to nine devices and in the near future is expected to be integrated in the Air Quality Network (XVPCA) of the Government of Catalonia. Each station of the network is based on Sky Quality Meter devices, mainly SQM-LE version that works connected to Ethernet socket. All the procedure of acquisition and preprocessing of data is done using PySQM software [6]. Currently the devices are installed with two main focus: natural or dark sky protected areas and places that contributes to NSB of these protected sites (see Figure 1 and Table 1).

All the instruments of the XCLCat have been intercalibrated in the specially designed station of Centre d'Observació de l'Univers. Intercalibration consists in a cross-calibration method based in pairing all the instruments, so with this strategy all the devices will show the same value for the same situation. The initial accuracy of a SQM is around 10% and with the intercalibration could be improved to 1% [1, 2, 8].

Figure 1: Map of the current XCLCat stations (2016). The highest concentration is in Starlight protected area of Montsec.

Table 1: Mean Values of NSB during astronomical night in the first five operative stations of XCLCat. It is clearly visible how in Lleida or Barcelona there is no difference when moonlit data are not included, so the lunar cycle will be poorly visible. In the other hand the first two sites listed, belonging to PAM sites, are extremely dark and the Moon effect is clear.

Station	Total sample (mag/arcsec^2)	Moonless sample (mag/arcsec^2)
Àger - COU	20.24	21.38
St. Esteve de la Sarga - OAdM	20.25	21.48
Balaguer	18.13	18.43
Lleida	16.67	16.71
Barcelona - UB	16.67	16.75

3 Interaction of clouds with NSB

One of the difficulties of compare NSB data with clouds is the quality of clouds data, sometimes only synoptic information has been used [4] and not direct measurements of clouds properties. Fortunately XCLCat has some stations that are installed in areas used for environmental studies. This is the case of Montsec Starlight protected area and the city of Barcelona. Both places have installed a ceilometer, an IR laser device that provides real time information of clouds and aerosols [7]. So SQM and ceilometer data have been combined in completely different situations of Light Pollution: dark and urban places.

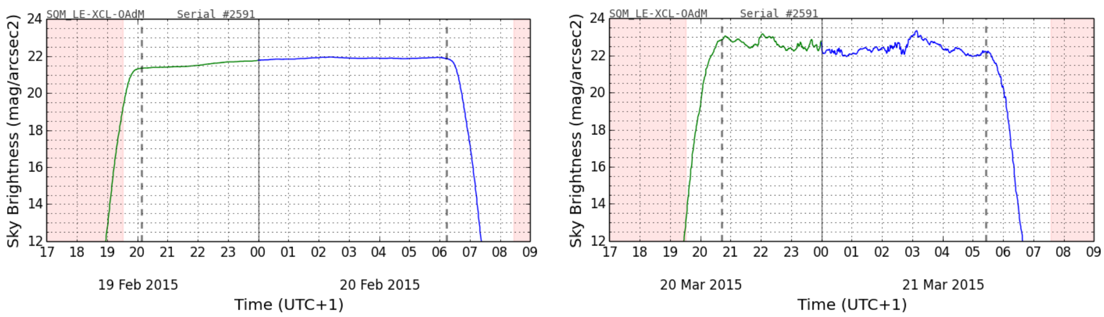

Figure 2: Comparison of two nights of measurements with SQM. Left panel shows a night without clouds. Right panel shows a night with clouds creating oscillations.

The presence of clouds and fog generates oscillations in NSB values obtained with SQM's. In the absence of clouds NSB is more stable in comparison with the presence of clouds as is shown in Fig. 2. In the case of cities or light polluted areas the effect of clouds is to increase the brightness of the sky [4, 5]. This effect is extremely visible in case of fog, also without the use of specific clouds data, just with evaluation of NSB in yearly plots as in Figure 3. This is the case of the city of Balaguer, a small city with not very high light pollution, placed in an area where it is possible to have huge episodes with permanent fog.

In Fig. 3 are clearly visible three periods with permanent fog showing an important increase of NSB up to 14-15 magnitudes per square arcsecond (red vertical stripes).

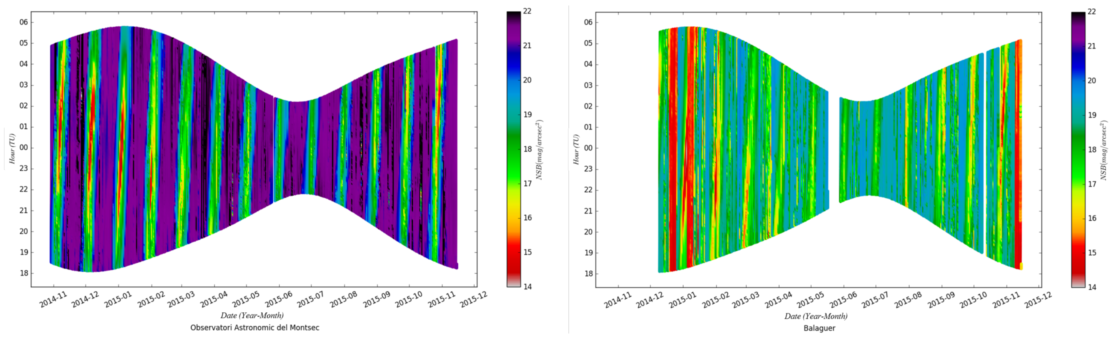

Figure 3: Evolution of close to one year of data in two sites. Left panel shows data from Observatori Astronòmic del Montsec (OAdM) with clearly visible inclined stripes due to lunar cycle. Right panel shows data from Balaguer city with not so many visible lunar cycles and three extremely bright (red coloured) vertical bands caused by fog.

Evaluating how NSB is distributed during the night, with accumulative data of one year, show a different shape depending of the amount of Light Pollution present at the site. In Figure 4 it is plotted in the left panel the distribution of NSB in a protected dark area as Observatori Astronòmic del Montsec (OAdM) and it is clearly visible how the main distribution is around 21-22 mag and scattered measurements are moving to dark part of the plot (higher magnitudes). Opposite to this, in the right panel, there is the case of Barcelona with a brighter distribution dominated by measurements around 17 mag and scattered values appearing in the bottom part of the plot, reaching extreme values up to 13-14 mag. The origin of this effect is directly linked with clouds and how they could affect NSB.

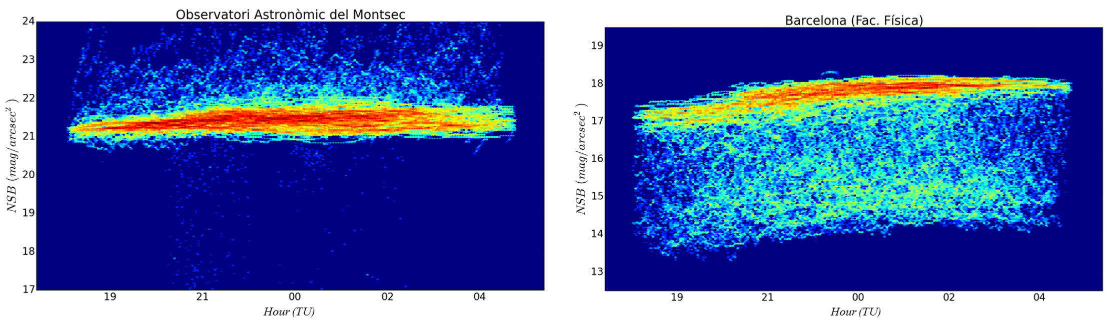

Figure 4: Distribution of NSB data during nighttime for one year. Left panel shows data from OAdM and data are centered in 21-22 mag with scattered measurements moving to the darkest possible values. Right panel shows an opposite situation from Barcelona with scattered values moving to extremely bright part of the plot (13-14 mag).

Table 2: Mean magnitudes of NSB measured in Barcelona with different configuration of clouds

Sample	Number of Measurements	Magnitudes (mag/arcsec ^{2})	σ_{mag} (mag/arcsec ^{2})
Total	27645	16.79	1.21
Without Clouds	14375	17.71	0.40
With Clouds	13270	15.79	0.99
Low Clouds	8427	15.53	0.96
Medium Clouds	3643	16.07	0.84
High Clouds	1200	16.81	0.63

Adding available information of ceilometer data, in the city of Barcelona and in Montsec protected area, is possible to do a combined study to evaluate in detail how clouds can change NSB in both situations. The study of combined data in Barcelona city center leads us to a clear example of how the clouds are amplifying the effect of Light Pollution. The case of Barcelona, as seen in right panel of Figure 4, NSB could be six times brighter (more than 2 mag) with clouds in comparison of a clear (no clouds) night. As seen in Table 2 the comparison of the effect of different kinds of clouds show how low clouds are clearly leading to the biggest increase of the effect of light and high clouds are generating a tiny effect on the measurement of NSB in a extremely polluted area as Barcelona.

For the first time the evaluation of this effect in a natural protected area is done. The case study is Montsec mountain range as specially protected dark sky area. In this place clouds are not amplifying the effect of light. The effect is just in the opposite direction because clouds can block natural sources and NSB can be reduced to extremely dark measurements (see left panel of Fig. 4 and Table 3). This effect is especially important in the Observatori Astronòmic del Montsec site in the top of the mountain, without no lights in the surrounding, where the extreme NSB values have been measured (up to 24 mag) with low clouds on the night sky.

Table 3: Mean magnitudes of NSB measured in Observatori Astronòmic del Montsec with different configuration of clouds

Sample	Number of Measurements	Magnitudes (mag/arcsec ^{2})	σ_{mag} (mag/arcsec ^{2})
Total	66492	21.47	0.59
Without Clouds	31752	21.44	0.56
With Clouds	34740	21.50	0.62
Low Clouds	7837	21.82	0.88
Medium Clouds	15537	21.50	0.60
High Clouds	11366	21.29	0.21

4 Conclusions

For the first time Catalonia has a permanent network to evaluate Night Sky Brightness, currently it is equipped with nine stations. All the SQM devices have been previously inter-calibrated. These devices are installed in a mix of protected and urban areas so comparison studies can be done. The presence of fog or clouds modifies the measurements of NSB obtained with SQM. Using only SQM data it is easy to identify intensive fog periods in the cities because fog generates a huge increasing of NSB in light polluted areas. Measurements could reach 14-15 magnitudes per square arcsecond. Also without ceilometer data it is observed how in the protected areas scattered measurements are moving to the darkest part of the plot. In the other hand in light polluted areas scattered values are appearing in the brightest parts of the plots.

Combining SQM and ceilometer data clouds effect is easy to determine. In the case of Barcelona (light polluted area) measurements show an increase up to 2 magnitudes of NSB due to the presence of low clouds. Also medium and high clouds have a tiny impact increasing NSB. In the case of Montsec (protected area) clouds can darken the sky giving the darkest possible values of an SQM. The reason is clear, in a protected area without light pollution, clouds are not reflecting artificial lights and are also blocking natural features as Milky Way, Zodiacal light or stars from the sky, generating an important darkening of the sky.

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