Overnight measurements of the sky brightness as a method for assessing the cloudiness

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Abstract—Determining the state of cloudiness at night is always a problem, especially at low levels of light pollution. This paper presents an innovative method of assessing the cloudiness of the night sky solely on the basis of all-night measurements of the brightness of the sky using generally available SQM meters. Using the numerical method of calculating the discrete derivative of overnight brightness of the night sky from time it is possible not only to distinguish a cloudless sky from a cloudy one, but even to distinguish high level clouds from medium or low.

When developing measurement data for the brightness of the night sky, there is often a problem of determining the state of the atmosphere at the time of measurement. Particularly important, especially in the aspect of astroclimate analysis for astronomical purposes, is the identification of measurements done during cloudless nights. Moreover, as has already been shown [1], the main natural factor that increases the brightness of the night sky in the presence of light pollution are clouds. With an increase of cloudiness in light polluted areas, the brightness of the night sky increases due to the scattering of artificial light on the clouds. The most contributing are the lowest-level clouds, in particular the ones of Stratus genus [2]. In areas that are free from light pollution, the overcast sky is darker than the cloudless one, because the clouds obscure natural light sources, such as stars, planets and the Moon, without scattering any ground-based artificial lights. It was found that the shape of the curve representing the brightness of the night sky vs. the cloudiness is one of the best indicators of the level of light pollution [3]. This means that the ability to determine the presence of clouds in the sky and their possible genus is extremely important for the proper position assessment of astronomical observations.

In order to determine the effect of cloudiness on the brightness of the night sky, the simplest solution is to analyse the measurements of the surface brightness of the sky and parallel all-sky images made at the same measuring point. It is also possible to use data from a meteorological station operating near such a measuring station, preferably equipped with a nephelometer. However, this situation is extremely rare, most often the only available data are automatic measurements of the surface brightness of the night sky made by using the Sky Quality Meter (SQM). In order to solve this seemingly unsolvable problem, a method was developed to recognize the cloudless sky, and under certain conditions even to determine the genus of cloudiness of the night sky, based only on continuous, all-night measurements of surface brightness using the SQM-LE automatic meter.

The measurement data from years 2015÷2019 were used, obtained at three sites representing various types of environment: mountains, on the summit of Suhora in the Gorce mountains (SUH); lowland, on the Dobczycki Reservoir (DOB); urban, in the Krakow suburbs at the Astronomical Observatory of the Jagiellonian University "Fort Skala" (FSK) and also urban at the Scientific Station of the Institute of Geography and Spatial Management of the Faculty of Geography and Geology of the Jagiellonian University in the Botanical Garden in the centre of Kraków (BOT). For the SUH and FSK measuring station the all-sky photographs of the night sky were taken at the same time as the sky brightness SQM measurements. In the case of DOB and BOT measuring stations, cloudiness data were determined at the meteorological stations of the Jagiellonian University operating in these areas. At all these stations, the SQM-LE meters have measured the surface brightness of the sky (S_a) every night from sunset to sunrise at intervals of 5÷10 minutes. As a result, a data base with a total volume of 67 records (summer months) to 191 records (winter months) was created for each measurement night. The SQM-LE meters give the measured values of S_a in astronomical units of magnitude per square arc second (mag/arcsec^2). These units are used exclusively in astronomy, but in this paper the luminance of the night sky is also given, expressed in the SI units, corresponding to given sky surface brightness. A photometric unit of luminance, i.e. the measure of visual impression that receives an eye from a luminous surface in the International System of Units (SI) is a candela per square meter (cd/m^2).

In the case of astronomical surface brightness in the visible spectrum, the relationship is given [4]:

$$3.2\cdot 10^{-6}\ \mathrm{cd/m^2} = 26.33\ \mathrm{mag/arcsec^2} \qquad (1)$$

For this reference point we get:

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$$[\text{mag/arcsec}^2] = 12.59 - 2.5 \cdot \log([\text{cd/m}^2]) \quad (2)$$

or vice versa:

$$[\text{cd/m}^2] = 108930 \cdot 10\text{^}(-0.4 \cdot [\text{mag/arcsec}^2]) \quad (3)$$

Due to very low surface brightness of the night sky, in this case the unit used is a millicandela per square meter (mcd/m^2).

Analysing the all-night measurements of S_a at the SUH measuring station and, to some extent, at the FSK measuring station, it was noticed that depending on changes in cloudiness, the shape of the surface brightness plot vs. time, S_a (T), also changed in a characteristic way. This is related to changes in the brightness of the light polluted night sky caused by changing cloudiness throughout the night. It was stated that clear nights can be distinguished qualitatively on the basis of such plots. In order to enable a quantitative analysis of the described relationship, an analytical method was developed that allows, above all, simple identification of cloudless, clear nights.

As is known, the value informing about the variability of a given parameter is its derivative. In the absence of time changes in the sky brightness, the derivative dS_a/dT is equal to zero, whereas any change in brightness will result in its non-zero values. As part of analysis of available measurement data for each overnight measurement of $S_a(T)$, the dS_a/dT derivative vs. the time was plotted. The analysed data refer to the measurements done in a non-continuous manner, and therefore numerical calculations of the discrete derivative dS_a/dT were done. In order to achieve the highest possible accuracy, a numerical method of central finite differences was used. It was found that on the basis of the obtained plots, it is possible not only to distinguish cloudless nights from overcast ones, but even, although with less certainty, to distinguish high level and low-level clouds. Significantly, the possible presence of the Moon is irrelevant, because changes in the brightness of the sky associated with its movement across the sky are very slow and do not cause significant changes in the course of the derivative function.

It has been shown that the most complete picture of cloudiness changes is obtained in the case of an area with a low level of light pollution. The SUH measuring station is located in such an area (Fig. 1). In this case, changes in the value of the derivative dS_a/dT during the cloudless night do not exceed 0.5 mag/arcsec^2/hour. In the case of high-level clouds reflecting the light coming from distant ground sources [2], this value does not exceed 1.0 mag/arcsec^2/hour. For medium and low-level clouds even the low intensity light coming from nearby villages causes changes in dS_a/dT exceeding even 2.0 mag/arcsec^2/hour.

This means that the above-mentioned method, which can be described as a "derivative method", allows for a certain distinction between a cloudless and an overcast sky. In the case of areas with low levels of light pollution, it seems that it is possible to distinguish high level clouds from low and medium level clouds. Of course, for another measuring place such identification should be verified on the basis of measurements done during few randomly selected nights, together with the visual clouds identification.

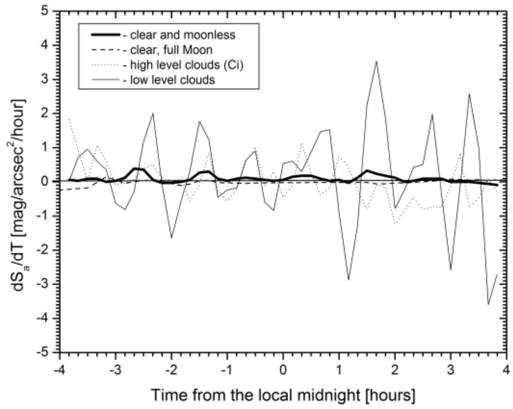

Fig.1. Numerical derivative dS_a/dT for few nights at the SUH measuring station (measurements: January and February 2016).

Similar analysis done in areas with a medium or high degree of light pollution, where the measuring point is located inside the light island of the given locality (DOB - Dobczyce, FSK - Kraków, BOT - Kraków), shows analogical dependencies (Fig. 2). However, in this case the changes in the night sky brightness associated with low level cloudiness (Stratus genus) are much more violent. In such an environment even a slightly low level of clouds causes a clear change in the course of the dS_a/dT curve.

Currently, analogical analyses are underway for measurements done on the recently launched measuring station in Niepołomice (MOA) which, like SUH and FSK, is equipped with the all-sky camera taking continuous photos of the night sky. Preliminary results seem to confirm the effectiveness of the described method also in this case.

It should be emphasized that the described method of derivatives is of primary importance in the case of so-called astronomical light pollution, associated with the scattering of light on aerosols of the cloudless sky. This method allows to extract from measurement database the cloudless nights with the help of only automatic measurements of the brightness of the night sky without any available meteorological data. This is particularly important in the case of analysis of the impact of particulate matter on the brightness of the night sky [5] and, of course, in the assessment of the so-called astroclimate at a given observation site. These places are always chosen in the low light-polluted areas where visual assessment of cloudiness at night is difficult, if possible. The derivative method makes it possible to determine the impact of clouds, in particular the high-level ones, on the brightness of the night sky in such an environment.

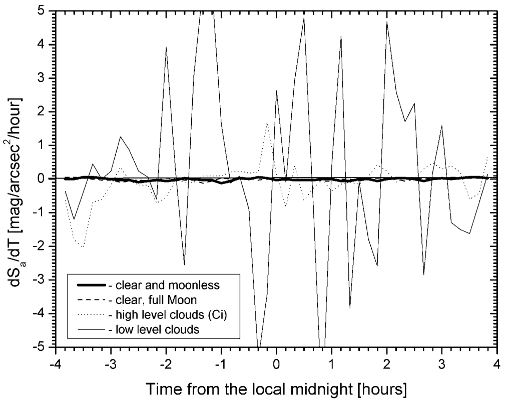

Fig. 2. Numerical derivative dS_a/dT for few nights at the BOT measuring station (measurements: January and February 2019).

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