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Artificial Sky Glow in Cracow Agglomeration

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Abstract

This paper presents first results of the measurement of sky glow, caused by the artificial light scattered in atmosphere (i.e. artificial sky glow). Measurements were made in the big city and its surroundings (Cracow, Poland). The boundary of "city light island" was delimitated. Also, the relationship of artificial sky glow to cloud cover and snow-cover has been checked.

Keywords: light pollution, urban agglomeration, night sky, surface brightness, sky glow

Introduction

Artificial sky glow is one of the components of light pollution. It manifests as a glowing of night sky due to dispersion of artificial lighting in the atmosphere. It is not the dominant part of light pollution, but its influence on cities surroundings (as a light pollution sources) is severe. It reaches even the areas, which are protected against the other direct components of light pollution [1, 2]. It is visible even from distant places as a light dome over the city.

This kind of light pollution is mainly concerned by astronomers, because it disturbs visual observations of night sky both in cities and their surroundings. Also, its influence on local ecosystems was found [3]. For example it has been found, that artificial sky glow affects the eutrophication of the lakes. Yellow light, about the wavelength of 590 nm, predominates in this light (emitted by the high pressure sodium lamps) is treated by many organisms as the daylight. The eutrophication of the: Mirror Lake in the White Mountain National Forest, Waban Lake lying 16 km from Boston and the Jamaica Pond in Boston itself were compared. Illumination of the third one was equal to the illumination by the full moon and 100-fold greater, than at the first lake (cloudiness increases additionally this value two- to threefold). This light is visible by fish and crustaceans down to 3 meters so they do not swim near the surface feeding what causes in the excessive expansion of algae in the subsurface zone and the eutrophication of the water reservoir [3, 4]. The common use of streets and squares lighting, even in small communities, especially in holiday resorts, results in significant increase of the artificial sky glow, not only at surroundings of big cities, but at all regions of dense population. Nowadays it is the problem even of astronomical observatories or nature reserves located at deserted places.

The first spectral lines of artificial origin in spectra of the natural sky glow have been noticed already in papers

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from 1970s. [5]. At the same time, the astronomical observatories localized near urban centers noticed distinct deterioration of dark sky [6]. In Poland the fast increasing of this phenomenon can be noticed beginning from the end of 1990s [7].

At this time on a basis of satellite data a map of light emission from the earth surface was created [8]. On the basis of this map a model of visibility of the faint stars was made. After the observational verification it enabled making the map of night sky brightness, visible from earth surface [9].

In Poland another astronomical method of sky background brightness evaluation was developed, using observations of dim comets [10]. First results, published in 2004 [11], are consistent with the model of faint stars visibility and with the map of night sky brightness [8, 9].

The verification of above described astronomical method was made by test measurements and direct measurements of the night sky brightness. It confirmed usefulness of this method [12].

Both above mentioned methods are indirect, but very well verified ones. So far the direct methods of night sky brightness measurement were mainly used for evaluation of this quantity at localizations of astronomical observatories. Its localizations were selected with the purpose of minimalization of light pollution effect [13]. These measurements, though very precise, were not useful for broad application mainly because of the costs of used equipment and its long duration.

The emergence of a small and, first of all, cheap Sky Quality Meter (SQM), produced by Unihedron, enables field measurements at any place [2].

This paper shows the results of SQM measurements of night sky brightness at selected points of Cracow and its surroundings.

Measurement Equipment

Our measurements were made using the Unihedron instrument – Sky Quality Meter (SQM). This instrument was carefully tested at Light Pollution Photometry and Radiometry Laboratory of Light Pollution Science and Technology Institute in Thiene (Italy) [14]. SQM measures surface brightness (S_a) of the sky in the unit of magnitude per square arcsecond (mag/arcsec^2), which is commonly used by the astronomers. This is the unit derived from magnitudo (apparent magnitude, mag, ^{m}), which determines visual sense of star brightness as a point source of light. The unit of mag/arcsec2 determines surface brightness of diffuse astronomical objects such as nebulas, galaxies, comets or just sky background.

The scale of magnitudo is the logarithmic, relative and reverse one, in which object of the brightness 0 mag is 100-fold brighter than object of the brightness 5 mag. It means that the relation between light intensities of two objects (I_A and I_B) and their apparent magnitudes (m_A and m_B) is expressed by formula:

$$\frac{I_A}{I_B} = 100^{\frac{1}{5}(m_B - m_A)} \approx 2.512^{m_B - m_A} \qquad (1)$$

Taking the brightness of object B as the reference brightness one can show, that the magnitude mA can be expressed by formula:

$$m_A = -2.5\log I_A + C \qquad (2)$$

where C is some constant.

We define the surface brightness Sa as apparent magnitude of the surface unit of diffuse object. Intensity of the light emitted by surface unit is expressed by quotient of total light intensity IA of this object and its surface A. So, according to (2):

$$\begin{aligned} Sa &= -2.5\log\frac{I_A}{A} + C = -2.5\log I_A + 2.5\log A + C \\ &= m_A + 2.5\log A \end{aligned} \qquad (3)$$

The unit of surface brightness in the International System of Units (SI) is candela per square meter (cd/m^2). Following SQM specification, relation between these two units describes formula:

[cd/m^2] = 10.8 · 104 · 10^(-0.4 · [mag/arcsec^2]) (4)

By reason of reference to other publications, concerning night sky brightness, we will use the scale of [mag/arcsec^2].

Profile of spectral sensibility of SQM differs from standard profile of V-band filter used to the photometric measurements at visual band range. The range of its spectral sensibility is much wider. It needs to give evaluation of the difference between quantity given by SQM and quantity measured with V-band sensibility. For the clear night sky and for the sky polluted by artificial light the differences SQM – V are +0.06 and +0.08 respectively [14]. Hereafter we will give values of SQM scale.

During our measurements we used narrow angle model of Unihedron instrument (SQM-L). According to manufacturer specification the half width of the half maximum sensitivity is ~10°, whereas 10-fold decrease in sensitivity is achieved at angle of declination from axis of ~19°.

Value of 5 mag higher (i.e. 100-fold lover brightness) is achieved at angle of declination from axis of ~40°.

During measurements we used also the high performance light pollution interference filter IDAS LPS (International Dark-Sky Association Light Pollution Suppression filter). It's transmittance at the selected fragments of visual band is well-matched to suppress the most powerful spectral lines of main light pollution sources – mercury-vapor and low- and high pressure sodium lamps. For instance, according to our measurements, in the spectral range of the most powerful double sodium line (the main component of light pollution), the transmittance of IDAS LPS filter is about 2 %.

Measurement Method

Taking into account the instrument characteristic and the aim of our measurement (sky brightness determination), we assumed the following principles:

- Measurement was made by detector directed to zenith.
- Measurement was made in a place without any direct illumination by any artificial source of light.
- Measurement was recorded with accuracy of 0.1 mag/arcsec^2 as a mean value of at least 5 readings.
- There may not be any screening object at the angle of measurement (~40° from axis).
- Measurement was repeated with IDAS LPS filter attached.
- Measurements have been made every day about local midnight, if possible.
- Measurements have been made at every weather conditions, and weather conditions have been recorded by the observer (especially cloud amount, mistiness and snow-cover).

Measurements were made at 10 selected, fixed points in Cracow and its surroundings. Three of them were located at big multifamily housing estates, three of them were located at residential housing areas, and the last four were located at city surroundings.

Besides measurements at fixed points, measurements have been made occasionally at points spaced by 5 km at different directions up to 50 km from the centre of Cracow. They have been made at moonless nights (close to the new moon), at conditions of clear, cloudless sky. The goal of these measurements was delimitation of „city light island" of Cracow agglomeration.

Discussed measurements were made from half of November 2008 to half of April 2009, so at the autumn-winter-spring time. Mean number of measurements for one fixed point exceeds 100.

Results

„City light island" of Cracow

The main our goal was delimitation of the „city light island" of Cracow. Measurements were made at directions: south-western (Fig. 1a), western (Fig. 1b), north-western (Fig. 1c), northern (Fig. 1d), north-eastern (Fig. 1e) and eastern (Fig. 1f). As one can see "light island" of Cracow ends predominantly at distance of about 25 km from the centre. Only at western and eastern directions it ranges further (up to 30 km), and more further one can see glow of neighbor big cities: Tarnów (at eastern direction) and Oświęcim (at western direction). On the other hand, the boundary of light pollution at north-western direction is nearer – about 20 km from centre of Cracow.

It is worth to note, that outside of the Cracow glow, especially at northern direction, one can found places where value of S_a exceeds 21 mag/arcsec^2. This value is only 1 mag/arcsec^2 worse than reported maximal value for unpolluted sky (conf. Table 1 in [13], values for V-band).

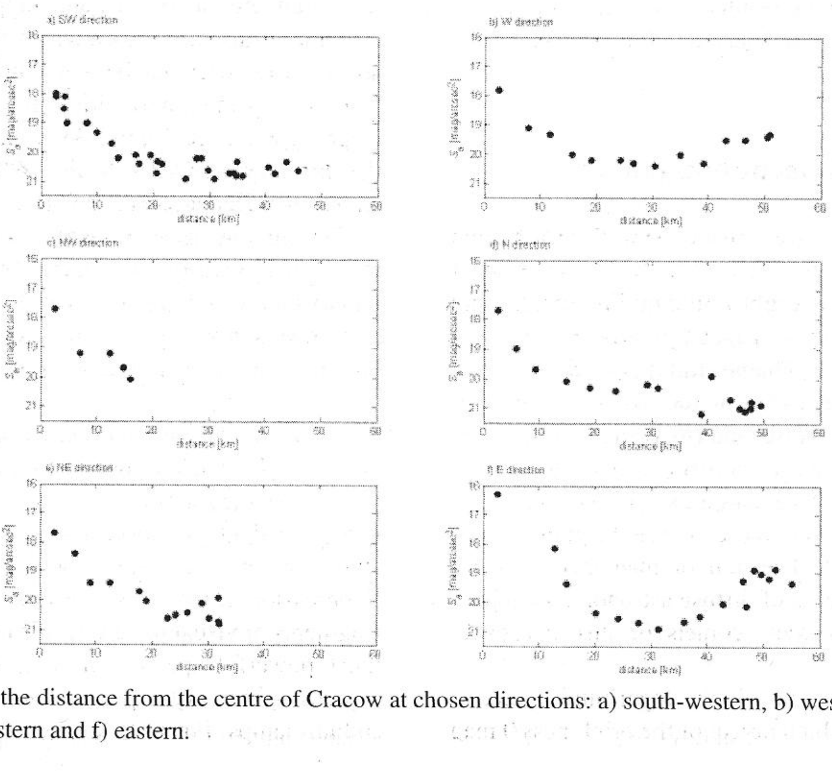

Fig. 1. The S_a value vs. the distance from the centre of Cracow at chosen directions: a) south-western, b) western, c) north-western, d) northern, e) north-eastern and f) eastern.

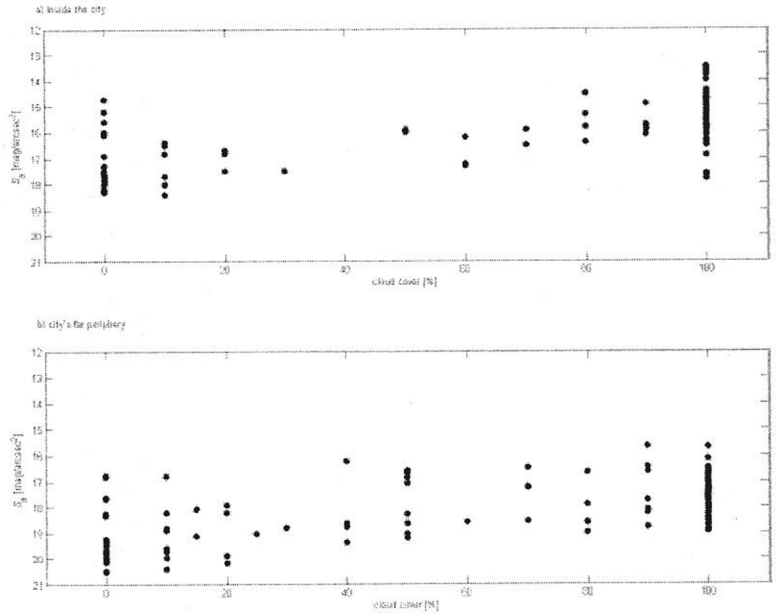

Fig. 2. The S_a value vs. the cloud cover for two chosen measurement points: a) inside the city (Podwawelskie estate) and b) at it's far periphery (Mogilany village).

Measurements Inside the City

At the ideal weather conditions (cloudless sky, absence of mist and snow mantle) the worst values (S_a between 18.3 and 18.4 mag/arcsec^2) are reached at big multifamily housing estates (Nowa Huta) and in the city centre, although differences can be seen. At some housing estates (Nowy Bieżanów and Bronowice) these values are higher (19.1 and 18.8 respectively), thus sky is darker. This is probably due to the less air pollution by dust and aerosols. At the residential housing areas, located outside city centre, Sa reaches 19.2 mag/arcsec^2, whereas outside agglomeration or at urban fringe Sa reaches: 19.8 mag/arcsec^2 (Wieliczka, 13 km to east from Cracow centre), 20.4 mag/arcsec^2 (Jerzmanowice, 22 km to north-west), 20.5 mag/arcsec^2 (Mogilany, 14 km to south) and 20.6 mag/arcsec^2 (Łuczyce, 15 km to north).

Weather Conditions

It is worth to examine the spread of S_a values in relation to weather conditions. As one should expect, the lowest S_a values (the brightest sky) we have got for big multifamily housing estates during overcastted sky, with low-level snow clouds and earth covered by fresh snow mantle. The worst values we have got at city centre (at neighborhood of Vistula River bend near Wawel Hill) – 13.5 mag/arcsec^2, and a little better at big housing estates – 13.6-14.1 mag/arcsec^2. With such values the sky is brighter the one at the start of civil twilight (15 mag/arcsec^2), i.e. about 30 min after sunset! In winter we noticed periods of several days (e.g. January 5-7 and January 28-31; data for Nowa Huta quarter) when without any problem one could read a text without any additional light.

Influence of Cloud Cover

The dependence of the S_a value on cloud cover is depicted at Fig. 2a (Podwawelskie estate, 2.5 km to Cracow centre) and Fig. 2b (Mogilany, 14 km to Cracow centre, just beyond administrative boundary of Cracow). In both cases one can see (expected anyway) plain decrease in the S_a value (i.e. increase in sky brightness) with increase in cloudiness. One can see also, that beyond the city changes of S_a are smaller than inside, what should be expected (for the sake of smaller light pollution in that region). Furthermore, in both cases one can see very big scatter of measured S_a values for the same value of cloudiness. This scatter seems to be constant for urban fringe, whereas for measurements inside city it grows both with full overcast and with cloudless sky. For values of the cloud cover near to 100% this phenomenon could be explained by different levels of clouds, which return light toward earth. On the other hand, increase in scatter of the S_a values with cloudless sky gives rather evidence of even more factors influence, such as suspended dust and other air pollutants.

Influence of Snow Cover

Evaluation of degree of snow cover was made at the measurement point in Mogilany (14 km to the Cracow

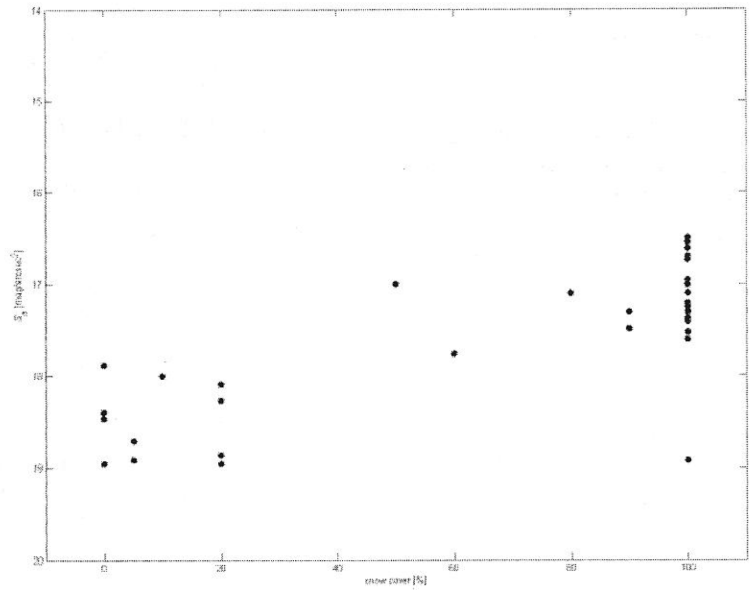

Fig. 3. The Sa value vs. the snow-cover for measurement point located at the far periphery of the city (Mogilany village).

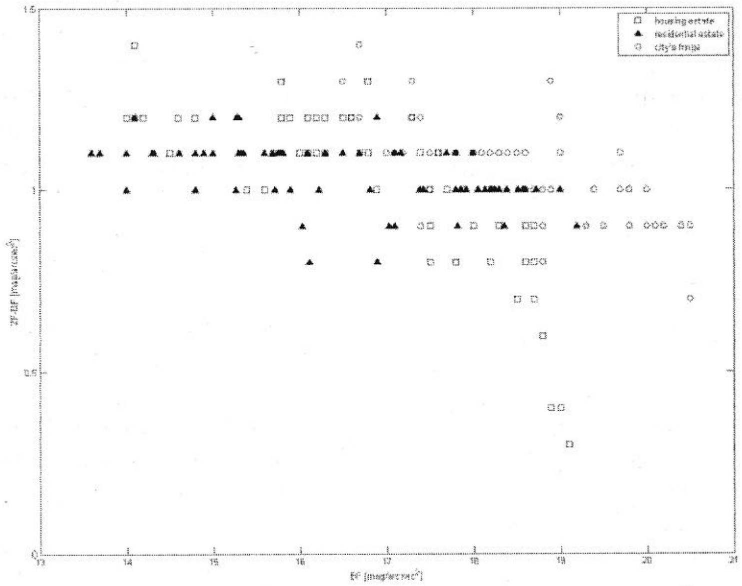

Fig. 4. The composite plot of difference between not filtered and filtered measurements (BF-ZF) vs. not filtered ones (BF).

centre). The dependence of S_a value on the snow-cover depicts Fig. 3. In order to separate effect of snow cover, only measurements with full overcast are taken into account. In spite of big scatter of S_a values, probably related to clouds type and level, one can clearly see that the brightness of sky increases with the increase in snow cover. This effect must be related to the additional illuminating sky factor. This is the reflection of artificial lighting of the earth surface by snow toward the sky.

Measurements with LPS Filter

LPS filter suppress part of spectrum of light, before it reaches SQM. It causes, of course, that the measurements with filter (ZF) give bigger S_a values than ones without the filter (BF), what is the consequence of inverse scale of magnitudo. Mean differences are equal to 0.9-1.1 mag/arcsec^2. More information one can get from the analysis of difference between not filtered and filtered measurements (BF-ZF) vs. the S_a value measured without filter (BF). Fig. 4 depicts collective plot for several measurement points. It is clear, that for low Sa values (brighter sky), due to the full overcast, value of ZF-BF is constant and comes to about 1.1 mag/arcsec^2. It gives evidence, due to the logarithmic scale of S_a, that filter decreases intensity of light with constant proportion. It is striking, however, that for the measurements points at big multifamily housing estates the value of ZF-BF begins to decrease with higher values of BF (i.e. for darker sky), commonly achieved with clear sky. This effect becomes noticeable inside the city for S_a values above 17 mag/arcsec^2, and at the city's fringe only above 20 mag/arcsec^2. One should exclude the instrumental effect, because the same instruments were used during the measurements of „city light island" boundaries far from the city and also were controlled in the dark room. In both cases we have not noticed such effect. Undoubtly this effect is related to the characteristic of artificial sky glow in the city. Nowadays we could not find a good explanation of this effect. We hope for explanation it by the measurements of spectra of artificial sky glow in different weather conditions at different measurement points.

Conclusions

Presented here the preliminary results of measurements ensures us, that even such small means, as used by us, give very interesting information about the artificial sky glow phenomenon. First of all, we succeeded in determination of the „city light island" of Cracow agglomeration. The boundaries of the „city light island" are clearly visible. Mobility of the equipment enables making of the map of light pollution of the city. The only problem is to find appropriate location of measurement point (free of side lights).

Measurements confirmed relation to the air conditions, and the dependence of S_a value on cloud cover turns attention to taking into account the state of atmosphere. The very interesting effect is the decrease in difference of S_a values between not filtered and filtered measurements, with increase in Sa value of not filtered measurement beyond certain value. This effect needs further research and we suppose that the measurements of sky glow spectra at the various localizations and with various weather conditions will bring us explanation.

Acknowledgements

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