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NIGHT SKY BACKGROUND BRIGHTNESS ESTIMATION BY THE EXAMPLE OF THE ST. PETERSBURG CITY

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ABSTRACT

Within the big city boundaries, artificial component of the sky glow increases every year. The main reasons are the expansion of the cities, the rapid growth of technical capabilities, inefficient lighting design without master-planning and lack of quality control of lighting projects. The data of astronomical observations confirm a significant brightness increasing in the lower atmosphere due to factors of terrestrial origin. The problem is mostly acute for observatories are located near major cities, which are struggling for the possibility of further research. Night sky background glow estimation is an actual direction for research in the modern world. The paper considers a model for calculating the sky brightness for the St. Petersburg city. According to the developed model observation position is located near the Pulkovo Observatory. The model is based on the Garstang's method with use of Python programming language.

Keywords: sky glow, sky brightness, background brightness

1. INTRODUCTION

Night sky artificial glow increases due to the diffuse scattering of artificial light on the components of the lower atmosphere: the vapours of water and particles of dust.

For the first time, the brightness of the lower atmosphere was assessed by the staff of the Department of Physics and Astronomy at the Padua University of Italy. P. Cinzano, F. Falchi and C.D. Elvidge, being concerned about the growth rates of the night sky glow, developed the first atlas using data obtained via satellites intended for meteorological research [1].

In addition to experimental astronomical studies, modelling of the corresponding conditions is used to estimate the artificial component of the sky glow. The most simplified model for estimating sky glow is the Walker's model [2], which takes into account the population size and remoteness of the observer from the city centre.

More complicated model, taking into account the approximation for small angles with allowance for the particle scattering mechanisms, was proposed by Bertiau and Treanor [3]. The assumptions adopted in the model are homogeneity of the atmosphere composition; directivity of scattering of aerosol particles in the visible part of the spectrum.

The Treanor's model was modified by Garstang [4], taking into account the heterogeneity of the atmosphere. In the modified methodology was taken into account the exponential characteristic curve of particles density depending on the height.

The Garstang model has been responsive to several thousand American observatories, such as Mount Wilson, the Lick Observatory, the Palomar Observatory, Kitt Peak National Observatory, Sacramento Peak, Mauna Kea, McDonald Observatory [5] and still widely uses in different research studies [6,7,8].

The aim of the study was night sky background glow estimation with use of the Garstang's model, modified for the St. Petersburg city, taking into account the population of 18 districts of the city accor-

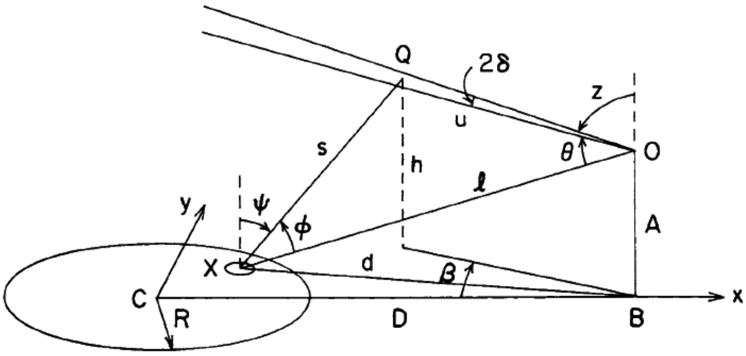

Fig. 1. Schematic representation of the light propagation from the side of the city to the observer; radiation from the element $dx \cdot dy$ in point X with coordinates (x, y) reaches the observer in point O, [4]

ding to Petrostat data and taking into account technical data about the luminaries according to State Unitary Enterprise "Lensvet".

2. METHODOLOGY

The model was developed using the programming language Python 3 with connecting libraries *numpy, sympy, sympy.plotting* in the Jupiter Notebook development environment. *NumPy* is a library of high-level mathematical functions with the ability to support large multidimensional arrays. *SymPy* is an actively developing library for character calculations.

According to developed model, the observation point (p.O) was considered near the oldest Russian observatory called Pulkovo, which is located at Pulkovo Heights, 75 metres above sea level. The distance from each of the city district to the point of observation does not exceed 50 km, so the curvature of the Earth's surface was not taken into account, Fig 1.

The value of the natural glow contribution for clear sky was taken into account in case of the artificial light absence with minimal solar activity, about 0.00017 cd/m^2.

The model includes Rayleigh scattering characteristic of atmospheric molecules with a cross section $\sigma_R = 4{,}6 \times 10^{-27}\,\mathrm{sm}^2$ at a wavelength 550 nm, multiple scattering of molecules and aerosol particles, absorption in the lower layers of the atmosphere for the vertical propagation of particles in accordance with the Beer–Lambert Law, Fig.2.

The model contains the following assumptions:

- The molecules are in hydrostatic equilibrium,
- The aerosol density is an exponential function,
- The atmosphere is uniform horizontally.

The distribution of lighting intensity in the upper hemisphere, according to the model, was estimated by the formula [11]:

$$I_{up} = \frac{LP}{2\pi} \times \\ \times \left\{2G(1-F)\cdot cos\psi + 0{,}554\cdot F\cdot\psi\right\}, \tag{1}$$

where G is the albedo of the surface, F is the fraction of the luminous flux emitted by the luminaires in the upper hemisphere, P is the population, L is the luminous flux per capita.

The basic equation of the sky brightness model [9]:

$$b = \pi\cdot I_{up}(\psi)\cdot S^{-2} \times \\ \times \int du\cdot e^{-\tau(s)}\cdot(1+SAA)\cdot e^{-\tau(s)}. \tag{2}$$

Based on the statistical data of the State Unitary Enterprise "Lensvet" and on data of the population of Petrostat [10], the average luminous flux per capita was estimated as 670 lm. For each region, the total average luminous flux was calculated taking into account the population. The albedo of the earth's surface was taken equal to 0.15, luminous flux fraction emitted by the luminaires to the upper hemisphere was taken equal to 0.13. Based on the Garstang's model, night sky luminance was estimated with the natural glow considered as 0.00017 cd/m^2.

For each of the 18 city regions, there was estimated the intensity of the radiation to the upper hemisphere for different values of the zenith angle, z = 0 ° and z = 45 °.

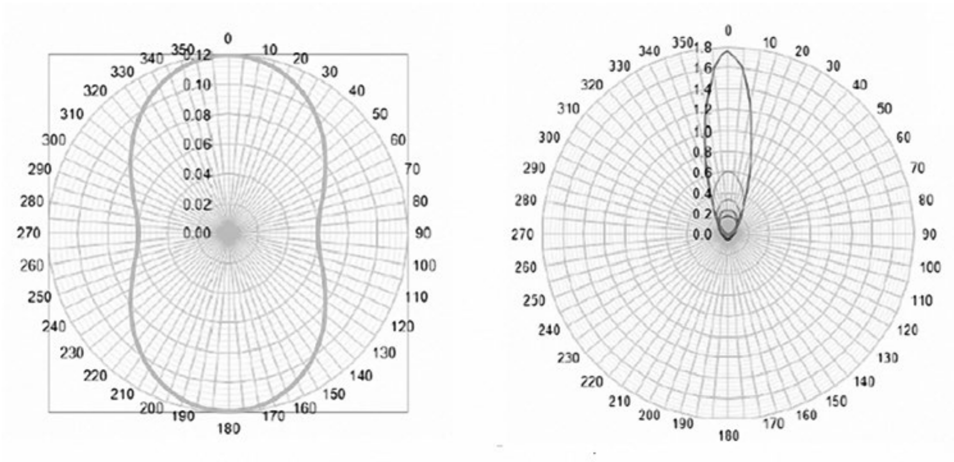

Fig. 2. Scattering diagrams of the molecular components of the atmosphere (left) and aerosol particles (right)

The value of average luminance, taking into account 18 regions: for observing direction 45 ° towards the city is equal to 0.17 cd/m^2; while observing 0 ° toward the city – 0.21 cd cd/m^2, which correlates with the data of ground-based experiments provided by Pulkovo Observatory for a clear sky on a moonless night with low solar activity.

3. ANALYSIS

According to the data of the Pulkovo Observatory, luminance of the objects under study varies from 0.017 to 43000 cd/m^2 in the transition from the astronomical system of magnitudes to lighting units. At the same time, luminance of 1700 objects of observation is relatively low and amounts to (0.0017–1.7) cd/m^2. Thus, 15 % of the objects are in potential danger from the point of view of the possibility of carrying out measurements. There are satellites of Uranus, asteroids, parallaxes, stars with a suspected invisible component among the objects in the risk zone.

Researches of further interest taking into account obtained results:

• Finalization of the model and program code, taking into account the forecasting of the impact of new construction near the observatory;

• Modification of the model and program code taking into account the influence of different weather conditions;

• The more detailed accounting of changes in the natural glow of the sky during the year;

• Analysis of the spectral composition of the radiation influence;

• Comparison of results obtained by modelling with experimental data;

• Exploring the possibilities of night sky glow decrement by implementing control systems.

4. DISCUSSION

The issue of reducing the background component of night sky glow and assessing the degree of its influence both on human life and on the accuracy of astronomical observations is topical, but in Russia at the moment is not sufficiently studied. Currently, environmental laws that affect on the night sky glow decrement exist only in five countries around the world. In a number of countries, there were developed recommendations for lighting designers, aimed at rationalizing of lighting solutions.

From the point of view of lighting design to reduce the dynamics of sky glow increasing, it is necessary to take into account the patterns of light propagation in the lower atmosphere and the nature of scattering by various particles in its composition, as well as the introduction of control systems for outdoor lighting to reduce the brightness levels of illuminated surfaces at night.

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