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Experience of noctilucent clouds registering in the near infrared spectrum region

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Some aspects of increasing the efficiency of noctilucent clouds ground-based observations are considered. The study of such objects is highly relevant in connection with the general problems of climate change. It is shown that the limitations on the possibility of registering the phenomenon in the optical range are associated both with the relatively low brightness of clouds of this type against the background of the twilight segment, and with the strong absorption of light by dust aerosol in the surface layer of the atmosphere. The paper substantiates the idea that the transition to observations of noctilucent clouds in the near infrared range will increase the contrast of their images in the twilight segment. This will make it possible to detect noctilucent clouds during civil twilight, including at low altitudes above the horizon. To test this assumption, shooting was carried out during the 2022 season using a CANON 2000 D camera and RG780 and RG830 infrared filters. The images revealed features morphologically similar to noctilucent clouds. An analysis of the images showed that they can hardly be associated with tropospheric clouds or anthropogenic formations. The results obtained were compared with ground-based observation data from other points, as well as with satellite information on the state of noctilucent cloud fields. This comparison showed that noctilucent clouds, which were not detected in visible light images, were highly likely to be detected in near-infrared images. The prospects for the application and development of the proposed method for ground-based registration of noctilucent clouds are also considered.

Key words: noctilucent clouds, ground-based monitoring, twilight segment, light scattering, image contrast, scattering indicatrices, infrared radiation, filters, satellite observations.

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1 Introduction

Research into a wide range of phenomena manifesting itself on the celestial sphere requires obtaining high-quality observational material, including the most informative images. This statement can be fully attributed to the study of noctilucent clouds (NLC) developing in the mesosphere. The recent identification of this phenomenon connection with both large-scale tropospheric processes and, in general, with climatic changes gives special relevance to such works. At the same time, the tasks of synoptic monitoring and morphology of NLC with a further transition to identifying patterns of their genesis and evolution are relevant [1-5].

However, when solving these problems, a number of limitations arise. These limitations are associated both with the sky illumination conditions due to the fact that observations in the visible range are effective only during navigational twilight, and with the low altitude of the object above the horizon. The first limitation is due to the fact that only during navigational twilight the brightness of the dawn segment falls below the brightness of mesospheric NLC still illuminated by the Sun. The second limitation is due to the particularly strong influence of light scattering on aerosols contained in the air near the horizon

In this regard, the task of the images contrast increasing of faintly luminous cloud formations and other extended objects on the celestial sphere appears. As we have shown earlier, one of the promising directions for its solution may be the transition to obtaining images of the studied objects not in the optical range, but in the near infrared region of the spectrum [6]. At the same time, one can expect a decrease in the background brightness of the clear sky and, as a result, a more confident registration of NLC against the background of the twilight segment due to a lower degree of scattering of long-wave radiation in the air [7-9]. Both the ability to detect NLC with minimal immersion of the Sun's disk under the horizon before the beginning of navigation twilight and the time interval for their ground registration will increase.

2 Image contrast increasing as a method for detecting diffuse objects in the sky

One of the most important characteristics of images is optical contrast, which determines the ability to highlight image details from the surrounding background. In this sense, optical contrast determines the informativeness of the image under study. The ratio of the difference in brightness of some detail and background brightness to the sum of their brightnesses is most often taken as a measure of contrast. In this case, we have a dimensionless quantity varying from zero to one. This approach to image quality assessment is currently not the only one. Of the various methods for assessing image contrast, the most convenient one was chosen. In particular, when recording NLC images with their high vertical brightness gradient, it makes sense to talk not about the overall contrast of the picture, but about the local contrast of individual details. With sufficiently high local contrast values, it is not difficult to distinguish not only the presence of details of the cloud structure, but also to classify their type.

Local contrast is determined by the relation of brightness of light and dark adjacent parts of the image under study. Its value is calculated using the formula:

$$K_L = \frac{D_{\max} - D_{\min}}{G-1}, \qquad (1)$$

where D_{max} and D_{min} are the maximum and minimum brightness values of pixels close in position, and G is the maximum possible number of brightness gradations for the bit depth used. For example, with 8 bit pixels, it will be 256.

In turn, the overall contrast across the entire image field can be estimated as follows:

$$K_S = \frac{2\sigma_D}{G-1}, \qquad (2)$$

where σ_D is the standard deviation of brightness across all pixels of the picture. Thus, formulas (1) and (2) allow us to calculate dimensionless indicators characterizing the quality of the resulting picture [10-12].

In astronomical practice, the contrast of images is determined not only by the parameters of the receiving equipment, but also by the features of the shooting objects. Thus, when taking NLC images, the ratio of the brightness of cloud details (determined by the concentration of aerosol in the cloud) and the background of the twilight segment of the sky (the brightness of which can vary widely) becomes critical. Then, to highlight an object in a picture, it can be useful to reduce the brightness of the background, leading to an increase in image contrast and the overall informativity of the resulting picture.

3 Technique for increasing the contrast of cloud images due to the transition to the IR region of the spectrum

As noted, one of the problems in identifying the presence of NLC in images of the dawn sky segment is the slight difference in their brightness from the background brightness of the sky. Therefore, increasing the contrast of images, primarily by reducing the background brightness of the sky, becomes an urgent task. Theoretically, here we can rely on the Rayleigh law of light scattering on air molecules, namely, the inverse proportionality of the intensity of light scattering to the fourth power of the wavelength [13-15]. Based on the fact that the detectors of most cameras are most sensitive to radiation with a wavelength of about 400 nm, it is easy to determine that in order to reduce the brightness of the sky background by at least 10-15 times, it is desirable to switch to shooting the sky in the wavelength range of at least 800 nm (near infrared range) [14-16].

It is also necessary, along with the scattering of light, to take into account its absorption. The fact is that NLC, as a rule, are observed at low altitudes above the horizon, and for the most distant cloud fields the altitude can be a few degrees. In this case, the absorption of light by dust aerosols in the region located between the object of study and the observer, that is, in the troposphere, begins to play a significant role, complicating the registration of NLC. The role of dust aerosols in the formation of the twilight segment is well studied. It is important to note here that as the wavelength of radiation increases, the transparency of the surface layer of the atmosphere increases rapidly. If the transparency of the surface layer in the visible range is maximum for red rays, then it will be even more pronounced in the near infrared range [17]. That is, it should be easier to detect NLC near the horizon in the IR range than in the optical range.

When analyzing the possibility of using the IR range to detect NLC, along with taking into account the scattering of light on air density fluctuations, it is necessary to consider the mechanisms of scattering of light radiation on the NLC particles themselves. In this case, it was necessary to make a choice between several scattering theories. Based on classical works, preference should be given to the Mie theory, and as the results of calculations and measurements have shown, the indicatrix of light scattering by NLC particles is strongly extended forward (Figure 1) [18].

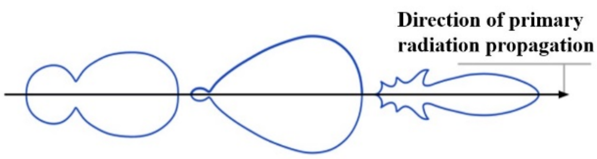

Figure 1 – Graphic representation of Mie scattering indicatrices for particles of size: a) 1/3 λ, b) 1.0 λ, c) more than 1.0 λ [17].

Confirmation of the importance of taking into account the influence of the light scattering indicatrix type when studying NLC is the fact that the maximum albedo of NLC particles is observed at altitudes of about 2 degrees. This corresponds to a light beam deflection angle no more than 10 degrees. Such deviation is described by elongated indicatrices, both in the Mie and Henyi-Gristein theories. At the same time, observations in the IR range make it possible to sharply reduce both the influence of the background of the twilight segment and the dust content of the tropospheric layer. Thus, there is reason to expect that recording the pattern of the twilight segment in the near-infrared region of the spectrum will make it possible to increase the difference in the brightness of high-altitude cloud formations and the sky background and to detail the type of cloudiness distribution in the sky.

To implement this approach in NLC photography experiments, we used RG780 and RG830 filters. The filters were standardly attached with a threaded connection to the wide-angle lens CANON EF-S LENS of the CANON 2000 D camera [19]. The general view of the camera with a filter and the transmission curves of the filters are shown in Figure 2.

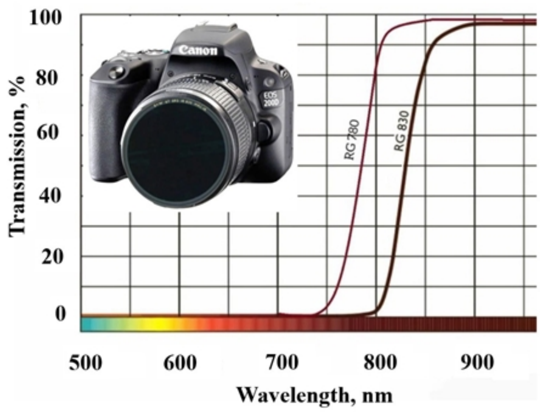

Figure 2 – General view of CANON 2000 D camera with filter and the transmission curve s of the RG780 and RG830 filters.

The assumption about the contrast increasing of the sky extended objects images when shooting in the IR range was verified by repeatedly shooting cirrus clouds in daytime conditions. The fact is that cirrus clouds are structurally closest to NLC, while they are characterized by a thin structure that is detected only on high-contrast images. Therefore, at first, the technique of shooting NLC in the IR range was practiced precisely on cirrus clouds. Examples of shooting results are shown in Figure 3.

Here, the image a) was obtained when shooting without a filter, the image b) was obtained when using a filter with a transmission boundary of 780 nm and the image c) – when using a filter with a transmission boundary of 830 nm. It is noticeable that during normal shooting, details in the lower part of the image are poorly distinguished. And in the near-infrared region of the spectrum, the detail of the picture is noticeably improved. However, it is not the overall impression of the painting that is significant, but the changes in the contrast coefficient. For the picture in the visible region of the spectrum, the local contrast K_L was 0.48, and for filter images 0.74 and 0.75, respectively. Thus, the assumption of the cloud fields images contrast increasing with the transition from their registration in the visible range to the near-IR region of the spectrum can be considered justified.

Figure 3 - Images of the cirrus cloud field obtained in the visible range – a) and using infrared filters – b) and c), respectively.

4 The results of the experiment on the registration of noctilucent clouds in the near-infrared region of the spectrum

Images of the twilight segment in the near infrared region of the spectrum were obtained near the maximum frequency of NLC appearance in the sky of temperate latitudes in the 2022 season. In this case, a CANON 2000 D camera with an RG830 filter, installed on the south-eastern outskirts of Petropavlovsk, was used. Days with clear weather were selected, and the presence of NLC visible to the eye was not required. The shooting was carried out during civil twilight, when NLC are not yet visually observed. Of course, shooting in visible light was also carried out for control. Note that if the exposures were tenths of a second when shooting in visible light, then when using a filter the exposures increased to hundreds of seconds. The most interesting fragments of the images are shown in Figure 4 – the images in visible light are on the left, the images in the near IR range are on the right.

Note that the direction to the north is indicated in the figure. The most interesting and important details of the images are the light formations near the horizon in the images in the IR range. But are they noctilucent clouds? To answer this question, it is necessary to consider in turn the possible effects of light scattering on smoke and cloud aerosols. To do this, the heights of the Sun below the horizon were calculated for all pairs of images and the height of the atmosphere layer that is illuminated by the Sun. The calculation was carried out according to the method adopted in atmospheric optics [17]. The results are shown in table 1.

Based on the data in the table, it is easy to see that smoke aerosols could not play the role of particles scattering IR radiation, since the heights of their distribution are much lower than the layer of the atmosphere illuminated by the Sun. For the date July 10, at heights above 5 km, cirrus or altocumulus clouds could be a possible cause of radiation scattering, but according to the weather station of Petropavlovsk and the city of Ishim located to the north, their absence was noted. Also, on the dates of July 12 and 18, this type of cloudiness was not observed. According to meteorological data, during the specified time interval, episodic appearance of low-cumulus clouds was noted at altitudes of less than 2000 meters [20]. Thus, the influence of tropospheric clouds on the appearance of bright features in infrared images should most likely be excluded.

It is also interesting that the low angular height of the light details is very close to the conditions for observing the NLC “from the edge”, for example, from spacecraft. In addition, the total angle of the light rays deflection in this case fully corresponds to the elongation of the scattering indicatrix, both in the Mie and Henyi-Gristain approximations.

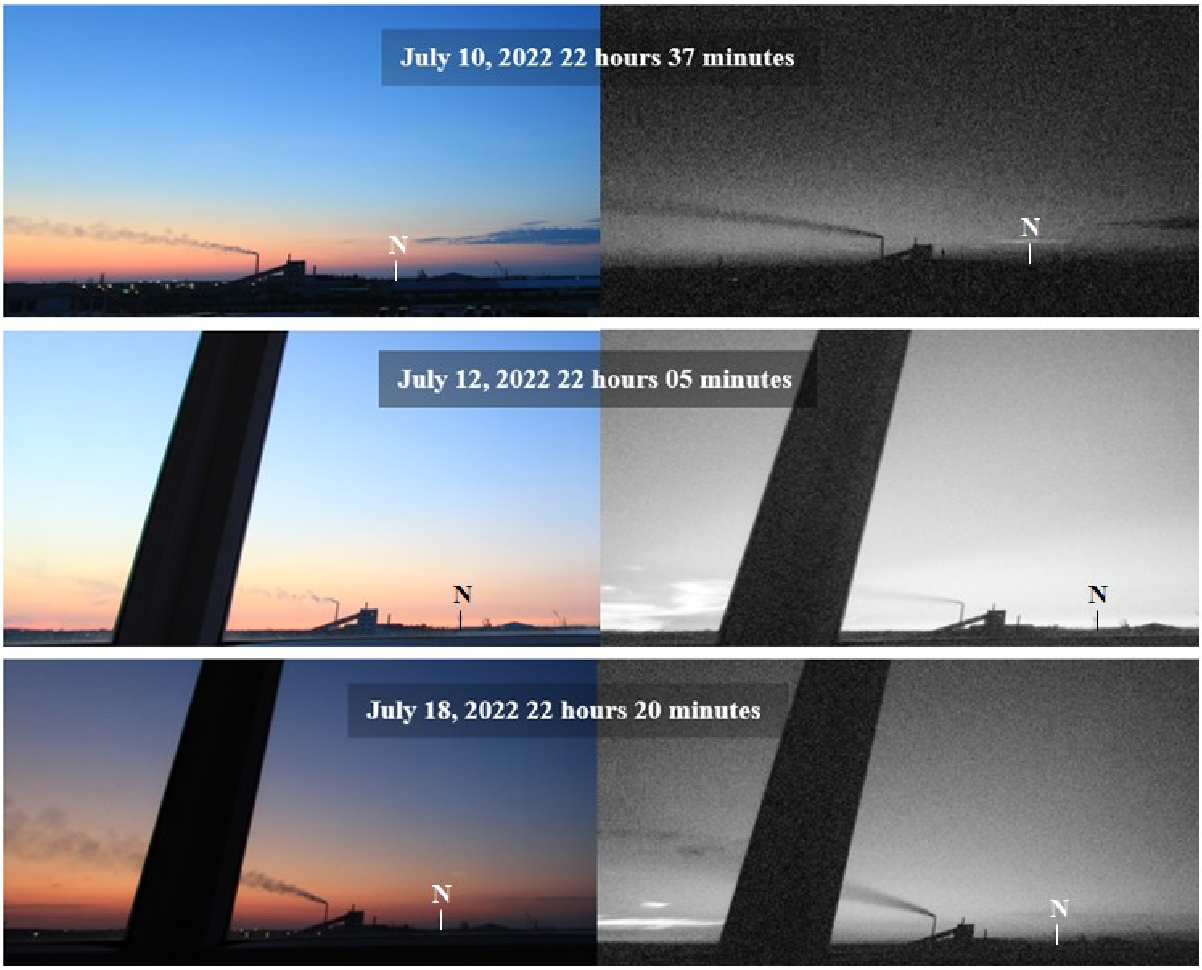

Figure 4 - Fragments of images of the twilight segment in visible light and in the near-infrared region of the spectrum.

Table 1 - Angular heights of the Sun at the time of shooting тand extremely low heights of atmospheric illumination.

№	Date and time the image was taken	Angular height of the Sun, degrees	Height of the layer illuminated by the Sun, km
1	10.07.2022 22.37	- 4.7	5.4
2	12.07.2022 22.05	- 1.8	0.8
3	12.07.2022 22.19	- 3.2	2.5
4	12.07.2022 22.33	- 4.5	4.9
5	18.07.2022 22.07	- 2.8	1.9
6	18.07.2022 22.20	- 4.1	4.1

Using the map, it is not difficult to estimate the distance from the observation site to the thermal power station chimney, which has a height of 150 meters. The distance is 2800 meters. Therefore, the angular height of the chimney top is close to 3 degrees. At the same time, luminous formations, if they are NLC (average height 82 km), should be removed from the place of observation (latitude 54.85, longitude 69.2 degrees) for distances of about 1400 km to the north on July 10 and for distances from 1000 to 1500 km to the north-northwest on July 12. Similarly, on July 18, 2022, the NLC should be expected to be removed from the observation point within the range of 1000 to 1400 km. It is possible to verify the presence or absence of NLC in the appropriate locations and at close points in time based on the analysis of data from the AIM mission [21] and synoptic observations of NLC on the specified dates from points in the Urals and Western Siberia. Information from the online journal meteoweb.ru [22], which noted the presence of NLC north of Petropavlovsk on July 12 and 18, was very useful.

5 Discussion

The absence of NLC in images taken in the visible range is explained, on the one hand, by the fact that during civil twilight NLC, as a rule, do not stand out against the background of the bright twilight segment. On the other hand, observation experience in Petropavlovsk showed that low-brightness NLC are often not recorded on images even in nautical twilight conditions when they are located at altitudes less than 4-5 degrees above the horizon. The reason is the strong absorption of light by dust in the ground layer of the atmosphere. As noted above, the possibility of the NLC presence above the horizon of the observation point at the time of shooting can be associated with the results of ground-based observations from other points. Another source of information about the parameters and structure of the NLC field in the northern hemisphere is satellite images [23]. Using these images, it is possible to estimate the position of the southern boundary of the cloud field, the distance and azimuth of the sight line from the observation point to the clouds and make a general agreement on the results of ground and space observations. Following this logic, an analysis of the NLC presence possibility in the IR images for the required dates using satellite images was carried out.

Fragments of NLC field images projections onto the Earth's surface on the specified dates are shown in Figure 5. The position of our observation point is also indicated here. The places that correspond to the position of the light formations in the images shown in Figure 4 are highlighted here with circles.

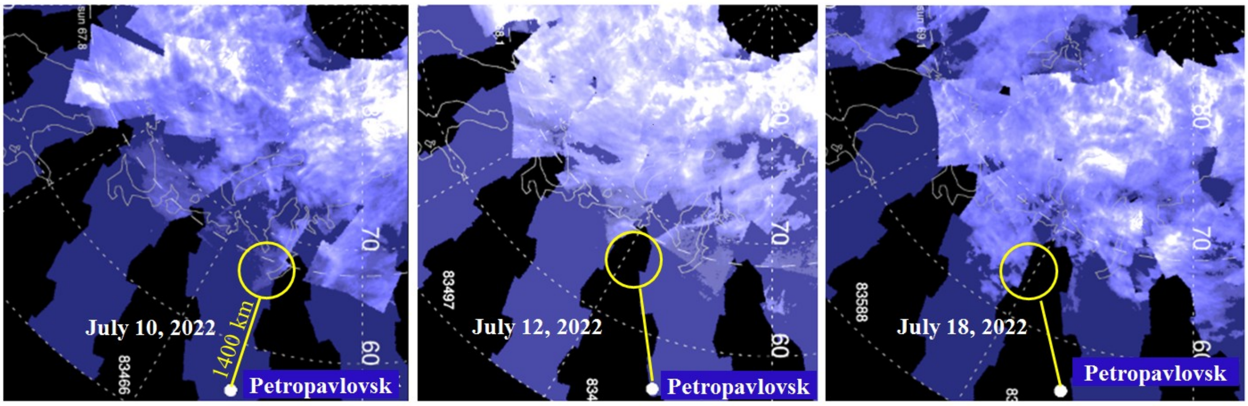

Figure 5 - To assess the possibility of observing NLC from Petropavlovsk on July 10, 12 and 18 (according to AIM satellite shooting)

As can be seen in Figure 5, the position of the cloud field southern boundary is such that NLC could well have been present in the selected locations during the acquisition of ground-based images. The results of the image analysis are shown in Table 2, which shows the estimated distances from the observation point to the boundaries of cloud fields and the time of obtaining the corresponding satellite images. The shooting times are given for two adjacent orbital bands. The table shows the numbers of these bands. The first indicates the time of shooting the eastern band of orbital images, the second the western.

Table 2 - Comparison of conditions for obtaining IR and satellite images.

№	Date	Time of obtaining ground-based images, UT	Time of obtaining satellite images, UT	Distance from the observation point to the cloud field, km
1	10.07.2022	16 h 37 m	83465 06 h 30 m 83466 08 h 05 m	1200
2	12.07.2022	From 16 h 05 m to 16 h 33 m	83495 05 h 58 m 83496 07 h 33 m	1200
3	18.07.2022	From 16 h 07 m to 16 h 20 m	83586 05 h 55 m 83587 07 h 30 m	1000

Of course, attention should be paid to the difference in the time of receipt of ground images and images obtained during the flight over the relevant area of the AIM satellite. However, despite the fact that the difference was noticeable, it must be taken into account that NLC fields in most cases evolve rather slowly. In our case, this demonstrates approximately the same location of the southern cloud boundary in the images obtained over an hour and a half time interval. Therefore, the assessment of the distance between the observation point and the boundary of the cloud field, determined from satellite images, has a right to exist. The close correspondence of the distances obtained from ground-based and space-based observations indicates with a high degree of probability that it is NLC that are recorded in the images of the twilight segment taken in the near-IR range during civil twilight.

6 Conclusions

The results obtained are interesting, but, of course, further verification and improvement of the NLC registration method in the near infrared region is necessary. First of all, in our opinion, improvement of the recording equipment is required. As is known, matrix receivers of digital cameras are sensitive to radiation with a wavelength up to 1200 nm with a maximum sensitivity of about 800 nm (Fig. 6a). However, to achieve sharper images, camera manufacturers usually place a glass filter in front of the sensor, which almost completely cuts off radiation with a wavelength greater than 720-740 nm (Fig. 6b). In this case, the lens optics does not prevent the shooting in the IR range (Fig. 6c).

Thus, restoring the sensitivity of the sensor of CANON cameras to radiation in the near infrared range is possible by removing such a filter. If this is done, the sensitivity of cameras in the range under consideration can be increased by at least an order of magnitude. Due to this, it is possible to reduce the exposure to acceptable values and extend the experiment on obtaining NLC infrared images not only to civil, but also to nautical twilight. This will further confirm the effectiveness of recording NLC fields in the near-infrared region of the spectrum.

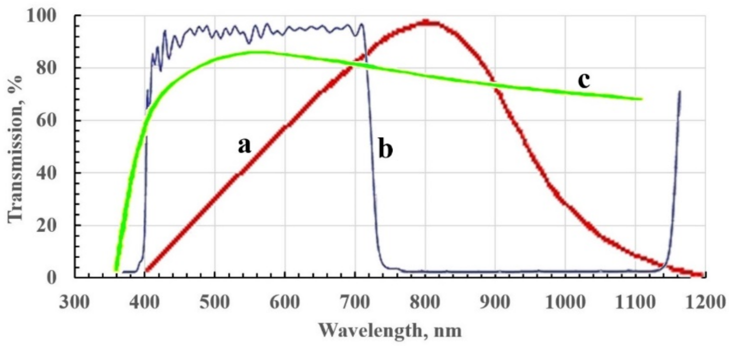

Figure 6 – Dependence of the transmission coefficient on the wavelength of light for a) the matrix of a digital camera; b) the glass filter of the camera; c) the camera lens [24]

Increasing the long-wavelength sensitivity of cameras will allow us to move on to experiments with filters tuned to longer wavelengths. Success in this direction promises to significantly expand the possibilities of ground-based observations of NLC fields, which fully justifies the efforts being made.

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