DEVELOPMENT OF HIGH – ACCURACY GROUND SYSTEM FOR REGISTRATION OF AIRGLOW

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In the paper “Development of high - accuracy ground system for registration of airglow” features of measurement of intensity of airglow with compensation of background signals are considered.

The method of emission delta spectroscopy allowing full separate compensation of effects of fine – and coarse fractions of aerosol to the results of held measurements is proposed. The possibility of high accuracy ground measurements of anormal emission of atmosphere in fixed wavelengths is also considered. The method of differential optical emission spectroscopy, realization of which allows to carry out such measurements is described.

1. Introduction

Natural or artificial illumination of atmosphere, i.e. gases, existing in upper layers of atmosphere at heights more than 70 – 80 km is important component of total radiation of the sky at night. The night radiation of atmosphere besides continual spectrum also contain the emission lines of oxygen, hydrogen, natrium, and molecular lines of hydroxyl, oxygen, monoxide of carbon, ozone, water, nitrogen oxides.

The illumination of atmosphere is only one part of existing atmospheric light energy, because there are also illuminations of stars, zodiac light and scattering day light of the Sun. The spectrum of atmospheric illumination includes wavelengths beginning from 1000Å as far as 22,5 mcm. The main line of emission of atmosphere – on wavelength - λ 5577Å, appears at heights 90 – 100 km, within layer having width 30 – 40 km. Generation of such illumination is conditioned with Chapman mechanism, based on recombination of oxygen atoms. Emission lines at wavelength 6300Å appear in the case of dissociating recombination of O_2^+. There are also illumination of nitrogen at wavelengths 5198/5201Å and 5890/5896Å. In general, all indications of natural anormal radiation of atmosphere linked with processes of energy transfer and magneto – ionospheric disturbances, being reaction to non – equal entry of energy from top (solar radiation, particles, etc.).

At low and equatorial latitudes the strong electro dynamically related events happen due to unique geometry of magnetic force lines. At upper latitudes the upper atmosphere is electrically linked with magnetospheric currents.

During magnetic storms, links between different latitude sided becomes more indicative and during this period a significant part of energy and moments transfer from upper latitudes to the lower latitudes by the help of moving ionospheric disturbances, gravitation waves, etc. take place [1].

One of important and useful methods for research of dynamics of upper atmosphere is measurement of airglow and auroral illumination of atmosphere. Intensity of emission at various latitudes and heights depends on volume depth of different factors causing these illuminations. In its turn, these factors are situated in dynamic processes effected by such factors as gravitation waves, winds, temperature, etc.

2. Formulation of problem

During last decades a large number of satellite and ground measurements of night illumination of atmosphere was carried out.

As it is noted in [2], the accurate comparison of data, obtained from various platforms frequently may be fulfilled only in cases, if these data is linked with general coordinate system. This task mat be solved using geographic coordinates. Possibility of accurate registration of atmospheric airglow using ground and satellite methods and calculation on this basis the location of source of radiation is of fundamental importance from view – point of general scientific usefulness of data on optical anormal radiation of different origin.

As it is noted in [2], commonly almost half of results of airglow measurements have low quality due to partly or full cloudiness. The direct lunar radiation leads to insignificant losses of information, bit if aerosol exists, the scattered lunar light way cause serious problems, especially during registration of weak illuminations.

But during research of illumination of airglow at coastal regions is should be taken into account, that coarse fractional part of aerosol acting more effectively in UV and visible spectral bands may significantly decrease authenticity and reproducibility of results of triangulation carried on the basis of ground measurements data. Therefore, removal of effect to results of ground measurements of anormal atmospheric radiation is most important and actual task from view – point of global research of airglow.

2.1. Method of emission delta spectroscopy

Now we describe basic principles of suggested method of emission delta spectroscopy for measurements of anormal atmospheric illumination at coastal regions.

Let is consider the case of anormal atmospheric illumination at wavelength λ_2 (fig. 1). At the considered wavelength band (UV or visible part of Solar spectrum) the total optical depth of atmosphere consist of such components as molecular scattering, molecular absorption, and aerosol absorption. As it was shown above, the temporal non – stability of coastal aerosol leads to non – accuracy and losses of reproducibility of measurements results, which in its turn leads to errors of spatial localization of illuminated zones, and also places of reasons caused them both on the Earth and Atmosphere. We can show, that when estimating the intermediate parameter $ln Z$, where Z - conditional dimensionless value of ratio of three signals, determined on following formula, the appropriate choosing of wavelength λ_1 may lead to compensation of effect of non – stability of aerosol to accuracy of localization.

$$ln Z = ln I(\lambda_2) - \frac{ln I(\lambda_1) + ln I(\lambda_3)}{k}. \tag{1}$$

It should be noted, that $I(\lambda_2), I(\lambda_1), I(\lambda_3)$ are to be determined on the basis of Bouger – Beer law as follows:

$$I(\lambda_i) = I_0(\lambda_i) \cdot e^{-m\tau_\Sigma(\lambda_i)},\ i = \overline{1,3}, \tag{2}$$

where $I_0(\lambda_i)$ - value of Solar constant at wavelengths (λ_i), $i = \overline{1,3}$; m - optical mass; $\tau_\Sigma(\lambda_i)$ - total optical depth of atmosphere, determined as follows:

$$\tau_\Sigma = \tau_\Sigma^* + \tau_c + \tau_f, \tag{3}$$

where τ_Σ^* - partial optical depth of atmosphere, indicating such effects as molecular scattering, molecular absorption and aerosol scattering; τ_c - optical depth of coarse component of atmospheric aerosol; τ_f - optical depth of fine component of atmospheric aerosol.

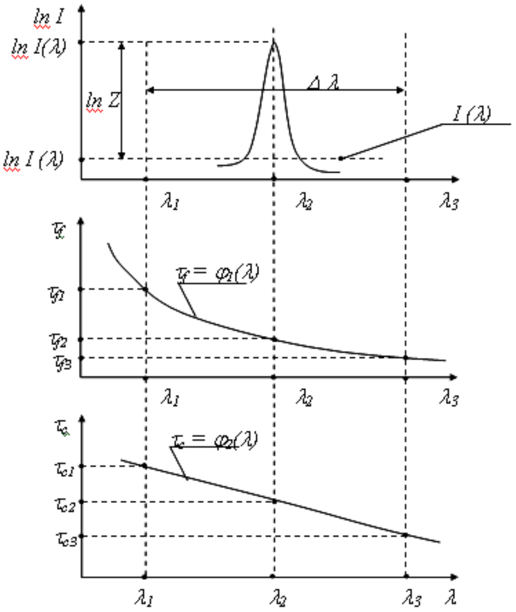

Fig. 1. Main parameters effected to accuracy of measurements of illuminations at wavelength λ_1, $\lambda_{12}$and λ_3.

Functions $\tau_f = \varphi_1(\lambda)$ and $\tau_c = \varphi_2(\lambda)$ are conditionally shown in fig. 1. In this case the task of research may be formulated as follows: Upon given functions $\tau_f = \varphi_1(\lambda)$; $\tau_c = \varphi_2(\lambda)$, and known values of λ_2 and λ_3 we should find out such a value of λ_1, upon which the value of z would not depend from parameters τ_f and τ_c, i.e. full compensation of aerosol error were achieved.

To solve the above formulated task, first of all we should transform the formula (1) as follows:

$$Z = \frac{I(\lambda_2)}{\sqrt[k]{I_\phi(\lambda_1) \cdot I_\phi(\lambda_3)}}. \tag{4}$$

Taking into consideration of equations (2), (3) and (4) we can find out the condition of full separate compensation of τ_c and τ_f.

$$\frac{\tau_f(\lambda_1) + \tau_f(\lambda_3)}{k} = \tau_f(\lambda_2), \tag{5}$$

$$\frac{\tau_c(\lambda_1) + \tau_c(\lambda_3)}{k} = \tau_c(\lambda_2). \tag{6}$$

Here we note, that the basic principle of aerosol's physics used as basis for formulas (5) and (6) is that fine and coarse fractions of aerosol have different origins and practically zero inters fractional correlation.

Using formulas (5) and (6) we can obtain following equation:

$$\frac{\tau_f(\lambda_1) + \tau_f(\lambda_3)}{\tau_c(\lambda_1) + \tau_c(\lambda_3)} = \frac{\tau_f(\lambda_2)}{\tau_c(\lambda_2)}. \tag{7}$$

From equation (7) we can find out the formula calculation value of $\tau_c(\lambda_1)$, which would provide full separate parametric compensation:

$$\tau_{c\,cal}(\lambda_1) = \frac{\tau_c(\lambda_2)\left[\tau_f(\lambda_1) + \tau_f(\lambda_3)\right]}{\tau_f(\lambda_2)} - \tau_c(\lambda_3). \tag{8}$$

Therefore, the formula (8) makes it possible to calculate $\tau_{c\,cal}(\lambda_1)$, which would provide compensation of aerosol errors. But in real case the coarse fraction has its own real function $\tau_{c\,re}(\lambda)$ and within context of this article this function cannot be changed. As a result, the value of wavelength λ_1 may be calculated using following equation:

$$\tau_{c\,cal}(\lambda) = \tau_{c\,pre}(\lambda). \tag{9}$$

Solution of equation (9) in regard of λ_1 is illustrated in fig. 2. Results of experimental measurements of $\tau_{f\,re}$ and $\tau_{c\,re}$ are given in Table 1.

Table 1

	$\tau_{f\,re}$	$\tau_{c\,re}$
λ_1	0,85	0,31
λ_2	0,44	0,23
λ_3	0,3	0,21
λ_4	0,53	0,27

Taking into consideration the data given in table 1, the equation (8) allows to carry out following calculations

$$\tau_{c\,cal}(\lambda_1)=\frac{0{,}23\left[\tau_f(\lambda_1)+0{,}3\right]}{0{,}44}-0{,}21=0{,}523\left[\tau_f(\lambda_1)+0{,}3\right]-0{,}21\,.$$

If $\tau_f(\lambda_1)=0{,}85$ we have $\tau_{c\,cal}(\lambda_1)=0{,}39$.

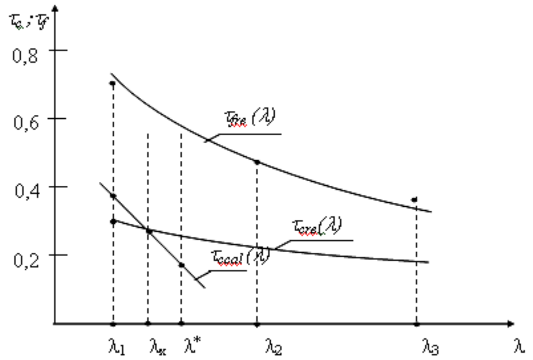

Fig. 2. Solution of equations (9).

Similar calculation may be carried out for wavelength λ^* determined as

$$\lambda^*=\frac{\lambda_1+\lambda_2}{2}\,.$$

As a result of calculations we have

$$\tau_{c\,c\,a\,l}(\lambda^*)=0{,}21\,.$$

Approximating the function $\tau_{c\,cal}=\tau_{c\,cal}(\lambda)$ with a line function using calculated values at the points λ_1 and λ^* we can find out the point of crossing of curves of functions $\tau_{c\,cal}=\tau_{c\,cal}(\lambda)$ and $\tau_{c\,re}=\tau_{c\,re}(\lambda)$. The searched for crossing point is λ_1 (fig. 1). As a result, we obtain possibility to calculate accurately such a value of $\lambda_1=\lambda_x$, upon which the full separate compensation of two fractions of aerosol may be achieved.

2.2 Method of differential emission spectroscopy

The non – stability of optical depth of atmosphere in UV band is mainly caused by temporal variability of optical depths of ozone, atmospheric aerosol and Rayleigh scattering. Next in this paper we shall describe an original method making it possible to carry out the accurate measurements of intensity of anormal illumination of atmosphere with full statistical compensation of non – stability of separate components of total optical depth of atmosphere.

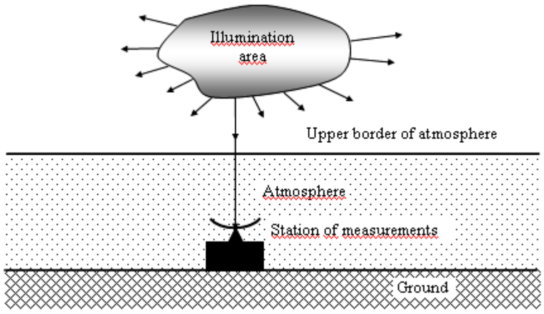

Fig 3. Schematic illustration of procedure of measurement of intensity of anormal illumination.

Procedure of one station measurements of intensity of anormal illumination of atmosphere is given in fig. 3.

The general conception of suggested method of differential emission spectroscopy is as follows. Assume that illumination of atmosphere at wavelength λ_2 exists (fig. 4). We should determine the intensity of illumination at the external border of atmosphere assuming that values of intensities of normal illumination at the border of atmosphere at wavelengths λ_1 and λ_3 i.e. $I_0(\lambda_1)$ and $I(\lambda_3)$ are known. The main condition of held measurements is ensuring statistical fullness of compensation of random changes of atmospheric optical depth. Briefly, this requirement may be explained as follows. The total optical depth of atmosphere τ_Σ is determined as a sum of separate components τ_i, i.e.

$$\tau_\Sigma=\sum_{i=1}^{n}\tau_i\,.$$

Measurements are held at wavelengths $\lambda_j,\ j=\overline{1,\,n}$.

Here we should take into account, that coefficients of correlation of components of optical depth τ_i are significantly different. It is well known, that some components of optical depth of atmosphere is characterized with more strong correlation on wavelength than between these components in fixed value of wavelength [4]. From another side, as it is known [5], for any two random parameters, the variance of sum or difference of these random parameters may be determined as follows:

$$D(x_1\pm x_2)=\sigma_1^2+\sigma_2^2\pm 2\,\rho_{12}\,\sigma_1\sigma_2\,,$$

where $\sigma_1,\sigma_2,\rho_{12}$ - is root – mean – square deviations and coefficient of mutual correlation of x_1 and x_2, Therefore, if $\rho_{1,2}\approx 1$ we have

$$\sigma(x_1+x_2)=\sigma_1\pm\sigma_2\,,$$

if $\rho_{1,2}\approx 0$, we have

$$\sigma(x_1+x_2)=\sqrt{\sigma_1^2+\sigma_2^2}\,.$$

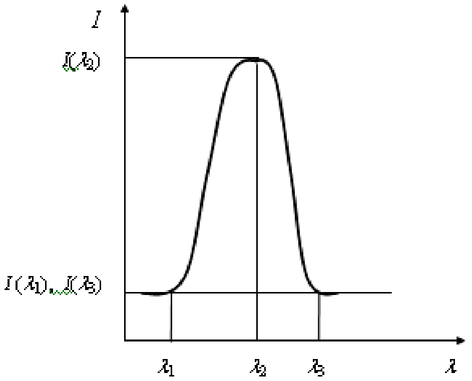

Fig. 4. For explanation of method of differential spectroscopy.

Now we can conclude, that mutual compensation of random parameters x_1 and x_2 is possible only upon presence of strong correlation between them. On the basis of this condition of correlation theory it may be concluded, that the statistically full compensation of effects of components of τ_Σ is possible by separate homogenic compensation of latter's. Now we should find out the mathematical condition for such a compensation and deduce the main equation of suggested method of DOAS. Let us consider two – component model of optical depth of atmosphere and measurements held at three wavelengths λ_1, λ_2 and λ_3. As a result of held measurements we shall have following system of equations:

$$I(\lambda_1) = I_0(\lambda_1) \cdot e^{-m\tau_\Sigma(\lambda_1)} \tag{10}$$

$$I(\lambda_2) = I_0(\lambda_2) \cdot e^{-m\tau_\Sigma(\lambda_2)} \tag{11}$$

$$I(\lambda_3) = I_0(\lambda_3) \cdot e^{-m\tau_\Sigma(\lambda_3)} \quad .(12)$$

Taking logarithms from both sides of (10) – (12), we have

$$ln \frac{I_0(\lambda_1)}{I(\lambda_1)} = m\,\tau_\Sigma(\lambda_1) \tag{13}$$

$$ln \frac{I_0(\lambda_2)}{I(\lambda_2)} = m\,\tau_\Sigma(\lambda_2) \tag{14}$$

$$ln \frac{I_0(\lambda_3)}{I(\lambda_3)} = m\,\tau_\Sigma(\lambda_3). \tag{15}$$

Multiplying both sides of equations (13) – (15) accordingly to variable coefficients k_1 and k_3, we carry out following operation:

formula (13) + formula (15) – formula (14).

As a result of aforesaid transformations we can obtain following equation:

$$k_1 m\,\tau_\Sigma(\lambda_1) + k_3 m\,\tau_\Sigma(\lambda_3) - m\,\tau_\Sigma(\lambda_2) = k_1 ln \frac{I_0(\lambda_1)}{I(\lambda_1)} + k_3 ln \frac{I_0(\lambda_3)}{I(\lambda_3)} - ln \frac{I_0(\lambda_2)}{I(\lambda_2)}. \tag{16}$$

Representing the total optical depth τ_Σ as a following sum of two components,

$$\tau_\Sigma = \alpha + \beta \,,$$

From equation (16) we can deduce following system of equations, describing the condition of full separate compensation of components α and β

$$\begin{Bmatrix} k_1 m\,\alpha(\lambda_1) + k_3 m\,\alpha(\lambda_3) - m\,\alpha(\lambda_2) = 0 \\ k_1 m\,\beta(\lambda_1) + k_3 m\,\beta(\lambda_3) - m\,\beta(\lambda_2) = 0 \end{Bmatrix}. \tag{17}$$

Solution of the system (17) using classic Kramer's method gives us searched for values k_{10}, k_{30}.

In this case, from right side of equation (16) we can obtain following main equation of suggested method of differential optical emission spectroscopy (DOES)

$$\frac{I_0(\lambda_2)}{I(\lambda_2)} = \left[\frac{I_0(\lambda_1)}{I(\lambda_1)}\right]^{k_{10}} \cdot \left[\frac{I_0(\lambda_3)}{I(\lambda_3)}\right]^{k_{30}} \quad . \tag{18}$$

As a result, the obtained equation (18) allows to find out the accurate value of intensity of atmospheric illumination using results of measurements of intensity at wavelength λ_2 at the Earth surface, multiplied to following correcting coefficient

$$\left[\frac{I_0(\lambda_1)}{I(\lambda_1)}\right]^{k_{10}} \cdot \left[\frac{I_0(\lambda_3)}{I(\lambda_3)}\right]^{k_{30}} .$$

It should be noted, that two – component model of total optical depth is characteristic for UV band. If the measurement are held out of UV band, then three – and more component model of optical depth of atmosphere should be considered. The number of fixed wavelengths of measurements in this case should be more than number of components by one. Naturally, there would be necessary to find out appropriate number of coefficients k_i by solving system of linear equations by order more than that system (10).

Conclusion

It should be noted that combination of suggested multi – wavelengths method with well – known triangulation procedures may lead to increase of effectiveness of triangulation procedures, used for detection of source of illumination.

In this case the relevant methods of multi wave triangulation, taking into consideration different optical masses of beams trajectory should be developed.

It should be noted, that such a compensated methods of measurements have an universal feature and after some modifications may be easily used for solution of tasks of localization of absorbing medium.

The method described here may be used both in district stations designated for monitoring of anormal illumination of atmosphere and in multi station networks. In the second case, the procedure of calculation described here should be repeated for each station separately, because one cannot expect equality of mean values of optical parameters relevant for various places installation of such stations.

In conclusion we should stress out the utmost importance of proper solution of accurate localization task of illumination area of atmosphere, because solution of it commonly link with task of localization of reason of such an illumination, which may exists both on the surface or inside the Earth.

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ATMOSFERİN ANOMAL İŞIQLANMASINI QEYD ETMƏK ÜÇÜN YÜKSƏK DƏQİQLİKLİ YERÜSTÜ SİSTEMLƏRİNİN İŞLƏNİB HAZIRLANMASI

Məqalədə atmosferin anomal işıqlanma intensivliyinin fon siqnallarının kompensasiyası ilə ölçülməsi xüsusiyyətləri nəzərdən keçirilmişdir. Emission delta spektroskopiya metodu təklif edilimişdir ki, bu metod xırda dispers və iri dispers aerozolun aparılan ölçmələrin nəticələrinə təsirini ayrı-ayrılıqda tam kompensasiya etməyə imkan verir. Həmçinin, atmosferdəki anomal işıqlanmaların fiksə edilmiş dalğa uzunluqlarında yüksək dəqiqlikli yerüstüölçmələrinin aparılması imkanı nəzərdən keçirilmişdir. Bu cür ölçmələrə imkan verən differensial optik emission spektroskopiya metodu təsvir edilmişdir.

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РАЗРАБОТКА НАЗЕМНОЙ ВЫСОКОТОЧНОЙ СИСТЕМЫ ДЛЯ РЕГИСТРАЦИИ АНОМАЛЬНОГО СВЕЧЕНИЯ АТМОСФЕРЫ

В статье рассмотрены особенности измерения интенсивности аномального свечения атмосферы с компенсацией фоновых сигналов.

Предложен метод эмиссионной дельта спектроскопии, позволяющий полную раздельную компенсацию эффекта мелкодисперсионного и грубодисперсионного аэрозоля на результат проводимых измерений. Также рассмотрена возможность проведения высокоточных наземных измерений аномального излучения атмосферы на фиксированных длинах волн. Изложен предлагаемый метод дифференциальной оптической эмиссионной спектроскопии, реализация которого позволяет проводить такие измерения.

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