DETERMINATION OF THE SECOND TWILIGHT BRIGHTNESS BY THE METHOD OF THE TWILIGHT PROBING OF THE EARTH'S ATMOSPHERE

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Abstract. A new method of 'gradients' for determination of the secondary twilight brightness is proposed, which allows to determine the brightness of secondary twilight directly from the observations.

Key Words: brightness of the sky's nightglow,secondary twilight.

The method of the twilight probing of the Earth's atmosphere was proposed by V.G.Fesenkov in 1923. Let's consider the penetration of the solar rays under the twilight conditions (Fig.1).

Let an observer be on the Earth's surface in the O point and makes measurements of the brightness of the twilight sky B_{obs} in the direction OM, which is determined by the azimuth coordinates Z, A. At the solar depression angle g (g= ξ -90 where ξ - is the angular distance between the Sun and the zenith), the extraterrestrial flux of the solar radiation I_0 is directed along the SM line.

The method of the twilight probing the atmosphere is based on the fact, that under the twilight conditions, the solar radiation is scattered by a thin atmosphere layer (of the order of 20 kms). At Fig. 1, the considered layer is located along the SM line. The atmosphere is located below the SM line, and does not almost scatter the solar radiation, since practically it is not illuminated by the Sun. The atmosphere above this layer is of much smaller density, and scatters the solar radiation much weaker. Instead of the twilight layer, as was proposed by N.M.Staude (1936), the twilight ray (SM) is considered, which determines the mean height of the scattering layer at the fixed solar depression g .

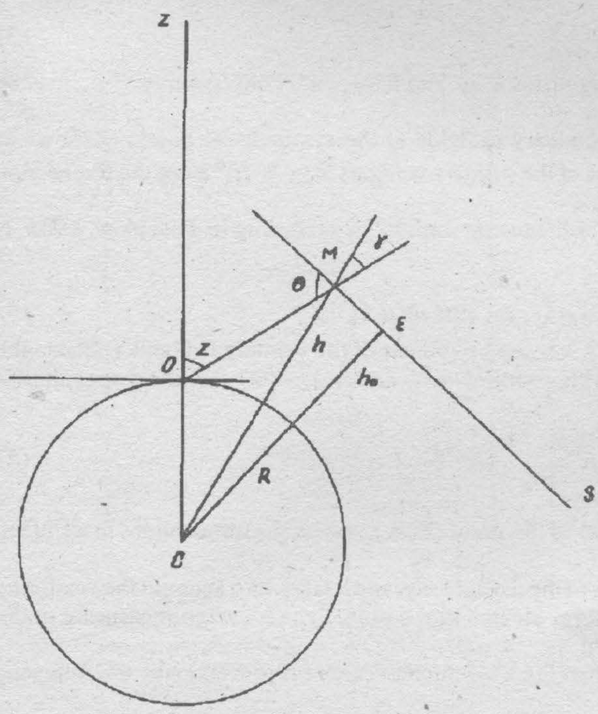

Fig. 1 The solar rays motion under twilight conditions.

As was shown by N.B.Divari (1968), the height of a twilight ray above the Earth's surface depends on the solar depression and on the wavelength of the monochromatic radiation. At the M point, the a twilight ray is intersected with the direction of vision OM. The height above the Earth's surface h of the scattering element, located at the M point, depends on the direction of vision, that is on z and A , on the solar depression and on the wavelength of the monochromatic radiation. The calculations of h for different z, A , g and λ , are presented by N.B.Divari (1968).

Thus some part of the solar radiation, which is scattered at an angle Θ , will be directed to the observer in the M point. Let's designate this sky's twilight brightness as B_1 , and call it the 'brightness of the primary twilights'. Since the atmosphere's density at the heights of 30-120 km (that is, at the heights, where the twilight method is effective) is not large, and decreases rapidly with the height, we may consider that the brightness of the primary twilights is conditioned only by the scattering of the first order, whereas the scattering of higher orders can be neglected.

If the observed brightness of the twilight sky consisted only of that of the primary twilights B_1, then, taking into account the absorption of the solar radiation on the way to the scattering element (that is, on the SM way), and on the way from the scattering element to the observer (i.e., on the MO way), one may determine the scattering capacity of the atmosphere in the M point immediately.

However, the picture of the observed brightness of the twilight sky is complicated by the fact, that at the solar depression angle $g \geq 6^0$, the twilight layer has already been separated from the troposphere rather well, and has become an independent brightness source, that is the radiation of each element of a twilight layer is scattered by the dense troposphere layers lying below it.

Let's denote by B_2 the part of radiation of a twilight layer scattered by troposphere which reaches the observer along the OM-line, and let's call it the brightness of the secondary twilights.

Thus, the observed brightness of the twilight layer B_{obs} may be expressed in the form

$$B_{obs} = B_1 + B_2 + B_{sky} + B_{em} , \qquad (1)$$

where B_1 and B_2 - are the brightnesses of the primary and secondary twilights, respectively; B_{sky} is the brightness of the stellar component, which may be determined from the observations; B_{em} is the brightness of the sky's nightglow. It is eliminated by using the narrow-band filters centered in those spectral bands, which are free from the emission lines.

While using the method of the twilight probing of the atmosphere, the account of the brightness of the secondary twilights is the most difficult procedure.

There are some methods (Fesenkov, 1962, 1972; Divari and Zaginailo, 1971), which allow to take into account the brightness of the secondary twilight B_2, that is they enable us to determine the brightness of the primary twilights B_1 from the observed brightness of the twilight sky B_{obs}.

Now we will discuss the most commonly used methods among them.

The first method is the V.G.Fesenkov's (1962) method of measuring the brightness of the twilight sky in two symmetrical points of the solar meridian.

Let the measurements be carried out in the solar meridian before the nightfall in two symmetrical points with the zenith distance z equal to 70^0. Let us designate by z_1 the zenith distance of the observed point on the solar side of the solar meridian and by z_2 - that on the antisolar side of the meridian.

The observed brightness of the twilight sky B_{obs} at the point located on the solar side of the meridian can be expressed in the form

$$B_{obs} = B_1 + B_2 + B_{sky}, \tag{2}$$

where B_1, B_2 and B_{sky} are the brightness of the primary, secondary twilights and of the night sky, respectively, in the point with the zenith distance z_1.

As has been shown by V.G.Fesenkov (1962), at the solar depression angle $g \geq 6^0$, the Earth's shadow is raised above the $z = 70^0$, that is the twilight layer proves to be above the point of the observations $z_2 = 70^0$, and the observed brightness consists only of that of the secondary twilights B_2' and that of the night sky B_{sky}'

$$B_{obs}' = B_2' + B_{sky}'. \tag{3}$$

As the measurements are carried out before the nightfall, the brightness B_{sky} and B_{sky}', and, consequently, B_2', may be determined directly from the observations.

If we calculate the theoretical ratio of the brightness of the secondary twilights at the symmetrical points of the solar meridian $k = B_2/B_2'$, then it is possible to determine the brightness of the primary twilights at $z_1 = 70^0$ from the Expression (2).

The brightness of the secondary twilights at the point with the coordinates z_0 and A_0, according to Fesenkov, 1955, is determined by the expression

$$B_2(z_0, A_0) = \int\int B_1(z, A) f(\Phi) \varphi(z, z_0) \sin z \, dz \, dA, \tag{4}$$

where the integral is taken from all over the sky. In Ex.(4), $B_1(z, A)$ - is the brightness of the primary twilights (outside the troposphere, that is, the brightness of a twilight layer in the point with coordinates z and A); $f(\Phi)$ is the troposphere's indicatrix of scattering, where Φ - is the scattering angle, and

$$\varphi(z, z_0) = \frac{p^{m_0} - p^{m}}{m - m_0} m_0, \tag{5}$$

where p - is the transparency coefficient, m -is the atmosphere mass of the point (z, A), m_0 is the atmosphere mass of the point (z_0, A_0).

The Ex.(5) was obtained from the measurements of the brightness of the daylight sky, and it takes into account the scattering by the troposphere of the radiation of each element of the twilight layer located at the point (z, A) when measuring in the direction of the (z_0, A_0) point.

If we consider, that the twilight layer radiation is not polarized, then the k-coefficient can be represented by the following theoretical expression

$$K = \frac{\int\int B_1(z, A) f(\Phi_1) \varphi(z_1, z) \sin z \, dz \, dA}{\int\int B_1(z, A) f(\Phi_2) \varphi(z_2, z) \sin z \, dz \, dA}, \tag{6}$$

where the brightness of the secondary twilight are determined from the Ex.(4).

Having determined from the theoretical considerations the approximate expression for $B_1(z, A)$, V.G.Fesenkov obtained from the Ex.(6) the following values for the k-coefficient:

g^0	6^0	8^0	10^0	.....	12^0	14^0
k	2,02	1,94	1,86	.....	1,78	1,77

(7)

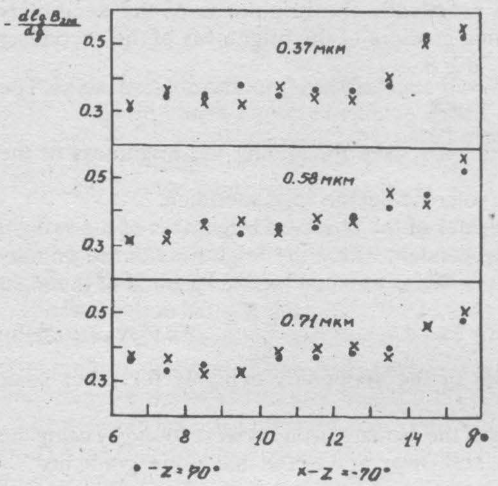

Fig. 2 The brightnesses of secondary twilights computed for the Rayleigh's atmosphere model.

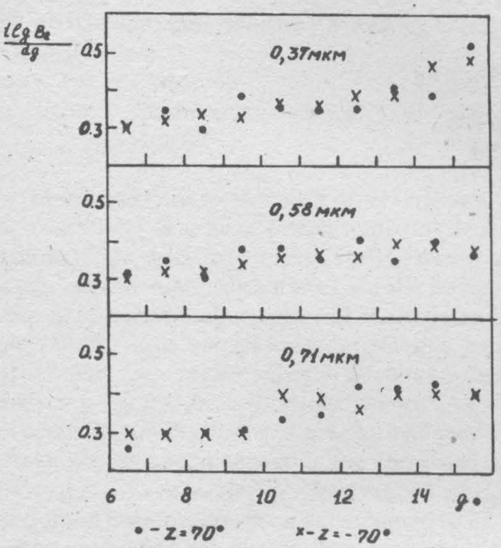

Fig. 3 Brightnesses of secondary twilights for atmosphere model which takes into account the ozone and the atmosphere dust component.

The second method was proposed by N.B.Divari (Divari and Zaginailo, 1971). The primary twilight brightness can be determined by this method from the observed ones in any point of the celestial sphere.

Let the brightness of the twilight sky B_{obs}, and that of the night sky B_{sky} be measured in some point of the celestial sphere. Then the brightness of the primary twilights in this point may be determined by the expression

$$B_1 = k_1 (B_{obs} - B_{sky}), \qquad (8)$$

where k_1 is the theoretically calculated ratio of the brightness of the primary twilights to the sum of those of the primary and secondary twilights $(k_1 = B_1/(B_1 + B_2))$.

The values of k_1 have been calculated by N.B.Divari for different points of the celestial sphere, for the different wavelengths, or for the different values of the transparency coefficient.

The most essential disadvantage of the methods for account of the secondary twilights results from the fact, that they are based upon these or those model atmospheres. But the real dust particles in lower atmosphere's layers are rather variable, causing the considerable variations in the brightness of the secondary twilights and, consequently, in the observed ones of the twilight sky.

It would be desirable to have the method of account of the brightness of the secondary twilights, which would be independent on the model calculations and would be based only on the observational data. Such a method is proposed below and we will call it as the method of 'gradients'.

We now consider a number of values $k(g)$ (7), determined by V.G.Fesenkov. What is their physical sense?

1. The logarithmic gradient of the brightness of the secondary twilights $-\frac{d \lg B_2}{dg}$ at the symmetric points of the solar meridian is the same.

2. The ratio of the brightness of the secondary twilights at the symmetric points of the solar meridian is always constant for the fixed solar depression.

The second assumption is apparently inconsistent with the reality, and we can neglect it.

We now consider in what way the model calculated by N.B.Divari is related to the first assumption. At figures 2 and 3, the depen- dencies are shown for two symmetric points of the solar meridian $z = 70^0$ of the logarithmic gradient of the brightness of the secondary twilights upon the solar depression for three spectral bands.

The brightness of the secondary twilights have been calculated for the Rayleigh's model atmosphere (Fig.2) and for that taking into account the ozone and dust particles (Fig.3).

As one may see from the figures, the logarithmic gradients of the secondary twilight brightness at the symmetric points of the solar meridian $z = 70^0$ are the same for both model atmospheres. Some scatter of the points can be accounted for the fact, that the models have been calculated for several solar depressions, whereas in the logarithmic gradients' calculation, the values of the brightness of the secondary twilights have been obtained for each depression by the graphic interpolation.

For other symmetric points of the solar meridian, the analogous results were obtained. Thus, the considered methods of the account of the brightness of the secondary twilights are consistent with the fact, that the logarithmic gradient of the brightness of the secondary twilights is the same at the symmetric points of the solar meridian.

Then the procedure of separating the brightness of the secondary twilights won't take much effort.

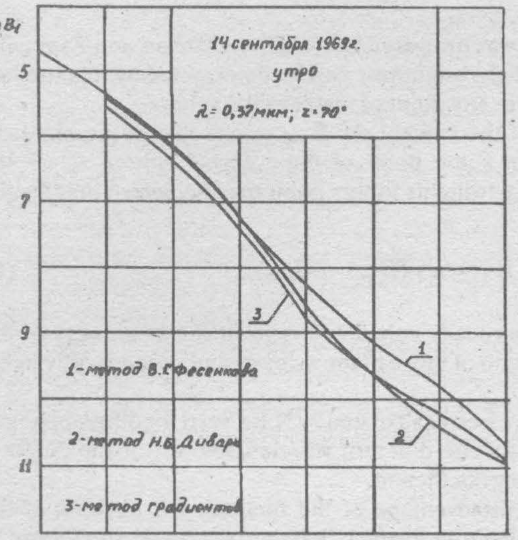

Fig. 4 Brightnesses of the primary twilights computed with different methods in September 14th, 1969 morning (R=0,37 mcm, Z=70^{o};
1 - the method of V.G.Fesenkov;
2 - the method of N.B.Divari;
3 - the gradients' method).

__Method of 'Gradients'.__ The observed brightness of the twilight sky on the antisolar side of the solar meridian at the points, which are occulted by the Earth's shadow, are practically the brightness of the secondary twilights. So, the logarithmic gradient of the brightness of the secondary twilights for these points $-\frac{d \lg B_2}{dg}$ is found from the observa- tions. The obtained values $-\frac{d \lg B_2}{dg}$ are used for finding the brightness of the secondary twilights on the solar side of the solar meridian.

For this, we used the values of the observed brightness of the twilight sky at rather large solar depression, where the brightness of the primary twilights is practically absent. We subtracted the background of the night sky and, using the previously found values $-\frac{d \lg B_2}{dg}$, we may restore the changes of the brightness of the secondary twilights for other solar depressions.

At Fig.4, the brightness of the primary twilights were found by using the methods of V.G.Fesenkov, N.B.Divari and by the that of the 'gradients'.

The usage of the method of 'gradients' for taking into account the secondary twilights and of the method of N.B.Divari (1970,1972) of solving the research problem of the twilights' allows the reliable determination of the optical characteristics of the atmospheric aerosol in twilight probing of the Earth's atmosphere.

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