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ON HIGHER-ORDER SCATTERING IN THE ZENITH OF THE TWILIGHT SKY

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Abstract

Full Text

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GEOPHYSICS

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ON HIGHER-ORDER SCATTERING IN THE ZENITH OF THE TWILIGHT SKY

In sounding the optical properties of the upper atmosphere by the twilight method, higher-order scattering of light is usually underestimated; in the zenith region of the sky it cannot be isolated from the observations themselves. We have therefore made a theoretical calculation of this effect, assuming that the scattering of light (produced by the Earth's atmosphere) follows an exponential law for heights of a homogeneous atmosphere of, respectively, 10 and 20 km. As is known, when the sun is sufficiently far below the horizon, namely by not less than 6°, the primary twilight segment is separated from the troposphere above the observer by a large distance and can therefore be regarded as a certain external source of light. In this case, which is of greatest interest, the illumination produced by this partially polarized segment at the zenith may be represented by the expression

$$I(0, 0) = \frac{\mu}{\tau} \iint B(z, A) f(\vartheta) \varphi(z, 0) (1 + PP_0 \cos 2\alpha) \sin z \, dz \, dA,$$

where $B(z, A)$, P_0 are the brightness and polarization of the primary segment at the point with coordinates z, A ; $f(\vartheta)$ is the tropospheric scattering indicatrix, found directly from observations with its polarization components f_1 and f_2 (¹); α is the angle at (z, A) between the directions toward the sun and toward the zenith; τ/μ is a dimensionless quantity equal to $2\pi \int_0^\pi f(\vartheta) \sin \vartheta \, d\vartheta$, and, finally,

$$\varphi(z, 0) = \frac{p - p^{\sec z}}{\sec z - 1}, \quad P = \frac{f_1 - f_2}{f_1 + f_2} \quad (p \text{ is the transparency index}).$$

A rigorous expression for $B(z, A)$ should take into account the refraction of light rays in the atmosphere—the so-called refraction dispersion—and the finite dimensions of the solar disk, as well as the scattering indicatrix peculiar specifically to the high atmospheric layers and characteristic of aerosols, but not of the ordinary gaseous component. For the calculations indicated, we used a simpler expression without allowance for refraction, namely

$$B(z, A) \sim \frac{f(\vartheta)}{\sin \vartheta} \int_{h_{0\min}}^{\infty} \mu(h) [1 - e^{-K(h_0-B)^2}] dh_0,$$

where the expression in square brackets under the integral sign approximately takes into account the extinction, produced by the lower atmospheric layers, of the solar rays passing above the Earth's surface at the least distance h_0 , while $\mu(h)$ is the scattering function, dependent on height and taken, as indicated above, in the form $\mu(h) = e^{-h/H}$, where $H = 10$ km, $H = 20$ km. Empirically it has been found that $K = 0.004$ and $B = 9$ km.

For any point of the sky (z, A) and for any zenith distance of the sun ζ , one can find the relation between the parameter h_0 and the height h of the scattering element of the atmosphere along the entire path of the ray of vision and then, using the aerosol component of the scattering indicatrix, calculate the brightness of the primary twilight segment. For brevity we give here the intensity distribution only for different points of the solar vertical in arbitrary units (see Table 1).

Table 1

$\log B(z, A)$

| | $\zeta = 96^\circ,$ $H = 10$ km | $\zeta = 96^\circ,$ $H = 20$ km | $\zeta = 98^\circ,$ $H = 10$ km | $\zeta = 98^\circ,$ $H = 20$ km | $\zeta = 100^\circ,$ $H = 10$ km | $\zeta = 100^\circ,$ $H = 20$ km | $\zeta = 102^\circ,$ $H = 10$ km | $\zeta = 102^\circ,$ $H = 20$ km | $\zeta = 104^\circ,$ $H = 10$ km | $\zeta = 104^\circ,$ $H = 20$ km |
|----------|---------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|--|--|--|--|--|--|
| tg z | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 0 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 1 | 0.636 | 0.520 | 0.799 | 0.595 | 1.112 | 0.729 | 1.545 | 0.922 | 2.090 | 1.256 |
| 2 | 1.249 | 1.022 | 1.510 | 1.154 | 2.010 | 1.374 | 2.629 | 1.695 | 3.532 | 2.160 |
| 4 | 1.929 | 1.608 | 2.363 | 1.805 | 3.062 | 2.115 | 3.927 | 2.549 | 5.498 | 3.147 |
| 10 | 2.780 | 2.290 | 3.374 | 2.538 | 4.268 | 2.929 | 5.369 | 3.464 | 6.830 | 4.183 |
| ∞ | 3.716 | 2.963 | 4.482 | 3.276 | 5.598 | 3.770 | 6.892 | 4.385 | 8.549 | 5.185 |

For an approximate calculation of scattering of higher orders, we note that, as trial computations showed, allowance for the polarization P_0 changes the result by only a few percent and therefore is not obligatory. Using the usual tropospheric scattering indicatrix, taking the atmospheric transparency coefficient $p = 0.835$, and finding for the ratio $\tau/\mu = 17.78$, we obtain for the zenith point the following ratio of scattering of higher orders (tropospheric component) $I(0, 0)$ to the intensity of primary twilight at the same point $B(0, 0)$ (see Table 2).

Table 2

$$-I(0,0)/B(0,0) \quad (z = 0)$$

| ζ | $H = 10 \text{ km}$ | $H = 20 \text{ km}$ |
|---------|---------------------|---------------------|
| 96° | 0.96 | 0.31 |
| 98° | — | 0.50 |
| 100° | 32.7 | 1.08 |
| 102° | — | 3.81 |
| 104° | 13 000 | 13.44 |

As can be seen, the influence of higher-order scattering in the zenith of the twilight sky, in comparison with the brightness of primary twilight at the same point, can be very considerable and depends to a high degree on the assumed structure of the atmosphere. It follows from this that observations of the twilight sky at the zenith for judging the optical properties of the atmosphere on the basis of the quantity $B(0,0)$ are entirely unpromising.

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References Cited

1. E. V. Pyaskovskaya-Fesenkova, *Investigation of Light Scattering in the Earth's Atmosphere*, Moscow, 1957, p. 106.

Note: Figure translations are in progress. See original paper for figures.

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