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Abstract

Full Text

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ON THE LIMITS OF APPLICABILITY OF BOUGUER' S LAW AND ON THE EFFECTS OF REVERSAL, ANOMALOUS, AND "SELECTIVE" TRANSPARENCY OF THE ATMOSPHERE

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1. If a nearly parallel light beam of intensity I_0 from a distant source, having small angular dimensions ω_0, is incident (in the direction $\mathbf{r}_0$) at an angle ζ on a plane layer of a scattering medium with optical thickness τ, then it can be shown that an instrument placed at the bottom of the layer and having direction $\mathbf{r}$, entrance-pupil area S, and angular dimensions of the field of view ω, will receive a luminous flux

$$\Phi = SI_0\omega_0\frac{\omega}{\pi}\,g(-\mathbf{r}_0)g(\mathbf{r})\cos\zeta\,\frac{l}{(1-A)\tau+l} + \begin{cases} SI_0\omega_0 e^{-\tau\sec\zeta}\delta_{r,\mathbf{r}_0} & (\omega\gg\omega_0),\\ SI_0\omega e^{-\tau\sec\zeta}\delta_{r,\mathbf{r}_0} & (\omega\ll\omega_0),\end{cases} \tag{1}$$

where A is the albedo of the underlying surface; $g(\mathbf{r})$ is an unknown function of order 1; l is a constant depending on the scattering matrix (for molecular scattering $l = 4/3$); and $\delta_{r,\mathbf{r}_0}$ is the Kronecker symbol. (It is assumed that $\tau\sec\zeta \gtrsim$ 4-5 and that the specific absorption in the layer is small.) The first term accounts for light multiply scattered in the layer, and the second for direct light from the source. For not very large $\tau\sec\zeta$, the second term dominates, i.e., Bouguer' s law holds. As $\tau\sec\zeta$ increases, the leading role passes to the first term, which entails a violation of Bouguer' s law, and the sooner, the larger ω or A is. If $\omega \simeq \omega_0$, Bouguer' s law is appreciably violated at approximately $\tau\sec\zeta$ = 8-10 (the deviations are about 1% at $\tau\sec\zeta \simeq 8$, about 10% at 10, and about 100% at 13).

Fig. 1. Experimental reversal curves (1). The arrows indicate the minima of the O_2 band for an ozone content of 3 mm.

2. Let us suppose that the atmosphere has a three-layer structure: above a practically nonabsorbing layer of optical thickness τ there is an ozone layer with optical thickness τ_0, and above it again a nonabsorbing atmosphere

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with optical thickness τ' (since the height of the ozone layer is about 30 km, $\tau' \simeq \tau \cdot 10^{-2}$).

In the spectral region $\lambda \simeq$ 0.23-0.32 μ, $\tau \simeq 1.2$, while τ_0 varies from tenths to several units. Taking, for definiteness, $A = 0.8$ (snow) and directing the instrument in the solar meridian at zenith angle z, we obtain approximately, instead of (1):

$$\Phi \simeq SI_0\omega_0\frac{\omega}{4}\left(\frac{e^{-\tau_0 m_0}}{m} + 10^{-2}e^{-\tau_0}\right) + SI_0\omega_0 e^{-\tau_0 m_0 - \tau m}\delta_{z,\zeta}, \tag{2}$$

where $m_0(\zeta)$ and $m(\zeta)$ are the air masses for the ozone layer and the sub-ozone layer of air, respectively.

3. For $z \neq \zeta$ (for example, $z = 0$, which corresponds to the usual conditions for observing the reversal effect—see, for example, ([1])) and small m_0, the first term decreases almost exponentially with increasing m_0, but when

$$\exp\left[(1 - m_0)\tau_0\right] \simeq m \cdot 10^{-2}$$

the first term gives way to the second, and the decrease of Φ with increasing m_0 ceases (owing to the sphericity of the Earth' s atmosphere, a weak decrease of Φ with increasing m_0 is retained). The larger τ_0, the earlier the change of dependences occurs; the reversal effect sets in near the inflection point of the curve $\lg \Phi(m_0)$ for the wavelength with larger τ_0 (Fig. 1). In contrast to Goetz' s interpretation ([2]), multiple scattering in the sub-ozone layer of the atmosphere plays an important role, which requires a revision of the method for interpreting the reversal curves.

Fig. 2. Experimental curves of anomalous transparency ([2]). The arrows indicate the position of the minimum according to (2) for an ozone content of 3 mm. The crosses are an extrapolation of (2) to $\zeta = 90^\circ$.

4. If $z = \zeta$, then for small ζ the principal role is played by the direct light of the Sun, for which Bouguer' s law is fulfilled.

But when

$$\exp\left[(1 - m_0)\tau_0 - m\tau\right] \simeq 2.5 \cdot 10^{-3}\,\omega$$

Bouguer's law is violated, and the principal role passes to the light first scattered above the ozone layer and then multiply scattered beneath it. Again an almost exponential decline is replaced by a slower one, and a reversal effect arises. For the Sun, reversal occurs at $\zeta = 75$–85°, depending on τ_0 (with increasing τ_0 the reversal effect shifts to smaller ζ). The picture obtained (Fig. 2) corresponds not only qualitatively but also quantitatively to the anomalous-transparency effect discovered by S. F. Rodionov and co-workers ([2]).

Thus this effect, as S. F. Rodionov ([2]) supposed, has the same nature as the reversal effect; however, they are explained not by peculiarities of scattering on aerosol, but by the effects of multiple scattering of light. The anomalous-transparency effect should be observed at $\tau \gtrsim 0.5$ and at ζ close to 90°, and also in the absence of ozone, owing to the violations of Bouguer' s law considered in item 1.

5. S. F. Rodionov ([3]) based the explanation of anomalous transparency on the effect of so-called selective transparency ([3,4]), consisting in a sharp decrease of the aerosol component of atmospheric extinction when the wavelength is decreased in the ultraviolet region of the spectrum. Since the authors of ([3,4]) did not take into account the very strong background of multiply scattered light, there are grounds for considering this effect apparent. In any case, a careful experimental check using a point light source is necessary.

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