PROPAGATION OF A LASER PULSE OVER A ROUTE WITH A CLOUDY LAYER UNDER CONDITIONS OF KINETIC COOLING

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In [1, 2] an analysis was performed of the propagation of a continuous laser beam (λ = I0.6 μm) on a vertical atmospheric route containing a cloudy layer with the lower limit at a height of 1 km. In the present paper we consider the propagation of a laser pulse at λ = I0.6 μm along a vertical atmospheric route containing a cloudy layer up to a height of 20 km. The basic effects that influence the process of propagation in the free atmosphere are the following: the molecular absorption by the water vapor and by the carbon dioxide, the kinetic cooling, the thermal self-action, the diffraction divergence. In a cloudy layer there are added to them the absorption by water vapor and the bleaching effect. With allowance for the foregoing effects, the propagation of a pulse on a vertical route can be described by an equation whose dimensionless form is

$$2i\frac{\partial E'}{\partial \bar{z}} = \varepsilon \Delta_\perp E' - \frac{2E'}{\varepsilon}\Big\{\exp(-\tau)\Big[\nu(\bar{z})\int_0^{\bar{t}}|E'|^2dt' + \mu(\bar{z})\int_0^{\bar{t}}|E'|^2dt'\Big(1-2{,}44\exp\Big(\frac{t'-\bar{t}}{\bar{t}_c(\bar{z})}\Big)\Big)\Big] +$$

$$+ c\xi\Big[1-\exp\Big(-\exp(-\tau)\int_0^{\bar{t}}\frac{|E'|^2dt'}{(\tau_{\text{att}}(w_0,T_0)/t_p)}\Big)\Big]\Big\} - ic\tau_1E' - ic\tau_2E'\exp\Big[-\frac{\exp(-\tau)}{(\tau_{\text{att}}(w_0,T_0)/t_p)}\int_0^{\bar{t}}|E'|^2dt'\Big]. \tag{1}$$

Here $\bar{z} = z/L_{H_2O}(0)$; $\bar{t} = t/t_p$; $\bar{t}_c = t_c/t_p$; $E' = (E/E_0)\exp(\tau/2)$; z, height; t, time; t_p, pulse duration; t_c, duration of the cooling effect; E, complex amplitude of the field; $E_0 = \sqrt{w_0 z_B}$; w_0, radiation intensity on the beam axis; z_B, wave resistance of the medium; τ, optical depth of the free atmosphere;

$L_{H_2O}(z) = \pi c_p \rho a^4/(|dn/dT|\alpha_{H_2O}E_p)$;

$L_{CO_2}(z) = \pi c_p \rho a^4/(|dn/dT|\alpha_{CO_2}E_p)$;

$\nu(z) = (L_{H_2O}(0)/L_{H_2O}(z))^2$;

$\mu(z) = (L_{H_2O}(0)/L_{CO_2}(z))^2$;

$\varepsilon = L_{H_2O}(0)/(ka^2)$;

$\tau_1 = \overset{0}{\alpha}_{H_2O} L_{H_2O}(0)$;

$\tau_2 = \overset{0}{\gamma}_{\text{att}} L_{H_2O}(0)$;

$\xi = (L_{H_2O}(0)/L^0)^2$;

$L_0 = (a^2/(\Delta T|dn/dT|))^{1/2}$;

ρ, density of the air; C_p, heat capacity of the air at constant pressure; T, temperature; α_{H_2O} and α_{CO_2}, molecular coefficients of absorption of water vapor and carbon dioxide; n, refractive index; a, radius of the beam; E_p pulse energy; k, wave number;

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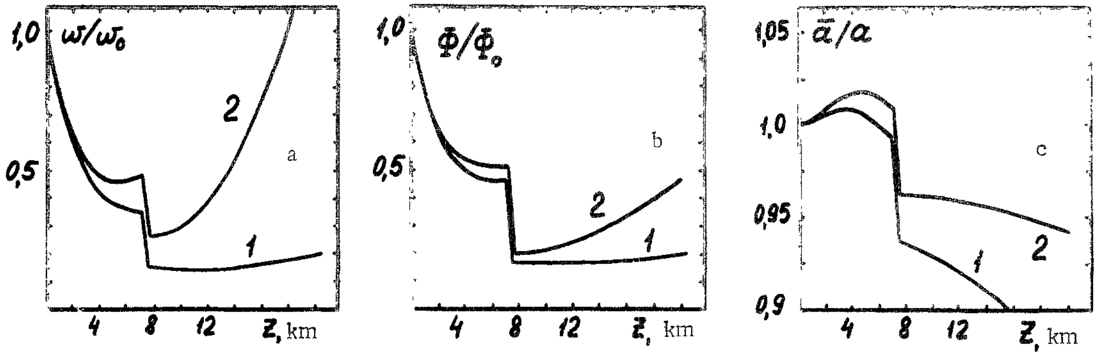

Fig. 1

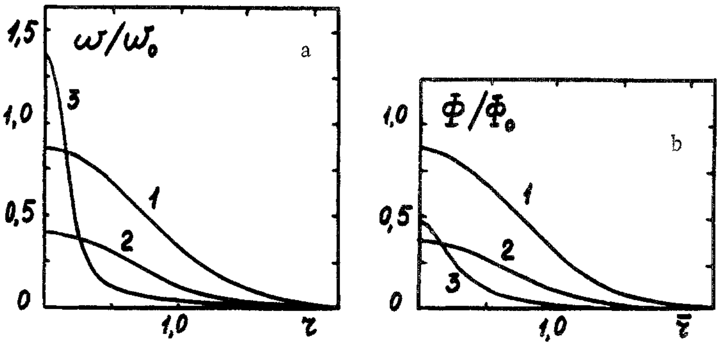

Fig. 2

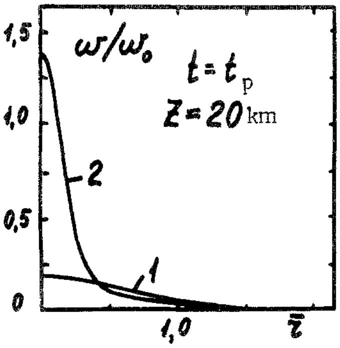

Fig. 3

ΔT , maximum possible overheating of the medium on account of the evaporation of the drops [3]; $\alpha^0_{H_2O}$, molecular coefficient of absorption of water vapor in the cloudy layer; γ^0_{att} , attenuation coefficient of aqueous aerosol; τ_{att} , characteristic time of change of the value of γ^0_{att} due to the evaporation of the drops [3]; T_0 , initial temperature of the cloud layer; $C = 0$ at $0 \leq z < z_1$, $z_2 < z \leq$ 20 km and $C = I$ at $z_1 \leq z \leq z_2$; z_I and z_2 are the lower and upper limits of the cloud layer. The distributions of the quantities ρ , n , α_{H_2O} , α_{CO_2} , and T were taken for the standard model of the summer atmosphere from [4]. The effect of cooling is taken into account in (1) in accordance with [5, 6], and the dependence of the quantity t_p on the height was taken from [7]. A cloud layer with temperature 253°K is assumed to be located at heights from 7.0 to 7.5 km. The solution of (1) was obtained numerically by a method described in [8].

A number of calculation results for the case of a Gaussian beam and a water content of the layer $W_0 = I0^{-2}$ g/m^3 are given in Figs. 1-3. For convenience, the vertical axes are calibrated in quantities normalized to their initial values. Figure 1 illustrate the change, along the route, of the radiation intensity $W(r, z, t)$, of the energy density $\Phi(r,z,t) = \int_0^t W dt'$ and of the effective radius of the beam $\bar{a} = \int_0^\infty r \Phi r dr / \int_0^\infty \Phi r dr$ on the beam axis ($r = 0$) at the end of the pulse /$t = t_p$/ for $L_{H_2O}/0/ =$ 3.6 km and $\varepsilon = 0.0243$. Curves 1 and 2 of Fig. 1 correspond to the values of the parameter $\bar{t}_c/0/ = 2$ and 6. The cloud layer leads to a noticeable deterioration of the energy characteristics of the beam and, in particular, to a decrease of the paraxial focusing of the beam. Nonetheless, at the end of the route at $\bar{t}_c/0/=6$, owing to the kinetic cooling, the intensity of the radiation on the beam axis exceeds its initial value. Figures 2 and 3 show the distributions of W and Φ, corresponding to the data of Fig. 1, in the beam cross section ($\bar{r} = r/a$). Curves 1, 2 and 3 in Fig. 2 pertain to heights 0.5, 7.2, and 20 km and are plotted for $\bar{t}_c/0/=6$. Figure 3 illustrates the influence of the contraction of the pulse on the degree of its focusing in the atmosphere. On going from $\bar{t}_c/0/=2$ (curve 1) to $\bar{t}_c/0/=6$ (curve 2) the intensity on the beam axis at the end of the pulse increases by ~6,7 times while the pulse energy reaching the level $z = 20$ km remains practically unchanged.

Also discussed in the paper is the influence of the water content of the cloud layer on the characteristics of the pulse propagation.

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