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OPTIMAL FILTRATION OF THE ATMOSPHERIC PARAMETERS PROFILES

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The earlier suggested approach [1] for extracting the fluctuating profiles of temperature T(z), density $\rho(z)$, pressure p(z) and other atmospheric parameters related to a single-frequency lidar sounding did not take into account the contribution of aerosol scattering. Due to this fact it was only applicable to sounding based on either Raman scattering of nitrogen with a small cross section or Rayleigh scattering of air in the atmospheric regions with low aerosol content.

The present paper develops the same idea of optimal Marcovian filtration of fluctuating profiles from lidar signals but as applied to a double-frequency sounding which allows one to make use of large cross sections of elastic scattering and to correctly separate out the contributions due to aerosol and Rayleigh scatterings from the total lidar return.

In accordance with the lidar equation, a signal power component received from the altitude z is proportional to the smoothed backscattering coefficient

$$\beta_i(z)=2(cE_i)^{-1}\int_0^z \beta_i^n(z')P_i\left[2(z-z')/c\right]dz' \tag{1}$$

where c is the speed of light, E_i is the energy of a radiated pulse with the power function $P_i(t)$, where $\beta_i^n(z)=\beta_{\alpha i}^n(z)+\beta_{mi}^n(z)$ is the sum of natural nonsmoothed coefficients of aerosol and Rayleigh scatterings.

Let us assume the profiles of aerosol backscattering and transmittance to be determined during a single sounding, although unknown functions of altitude, and the relation g_α of backward and total coefficients of aerosol scattering to be constant in the interval of sounding altitudes. When the spectral dependence of aerosol scattering volume coefficients is used, it is sufficient to evaluate one of aerosol profiles, e.g., $Y_{\alpha 1}(z)$ being aerosol transmittance at one of the sounding wavelengths λ_1.

Under the assumptions made the smoothing (1) at the constant intervals of smoothing $L_i=c\tau_i/2$, where τ_i is the pulse duration, i = 1,2, significantly changes only the profiles $\beta_{mi}^n(z)$ and connected with them T(z), $\rho(z)$, p(z). Under the conditions of laser sounding, if $L \gg z_{KT}^n$, where z_{KT}^n is the spatial correlation radius of nonsmoothed temperature fluctuations along the sounding path, these profiles are fully determined by the Marcovian vector-process $\vec{\eta}(t)$ satisfying the stochastic differential equation [1]

$$\dot{\vec{\eta}}(t)=A(t)\vec{\eta}(t)+\vec{w}(t)$$

where $\vec{\eta}(t)=\{\eta_1,\eta_2\}$, $\vec{\omega}^T(t)=\{\omega_1(t),0\}$, $\omega_1(t)$ is the white Gaussian noise: $\langle\omega_1(t)\rangle=0$, $\langle\omega_1(t)\omega_1(t')\rangle=2\alpha\delta(t-t')$, $\alpha=\tau^{-1}$, $\tau=\min\{\tau_i\}$, $A=\|A_{ij}\|$, $A_{11}=-\alpha$, $A_{12}=A_{22}=0$, $A_{21}=\bar{T}^2(z_0)/\bar{T}^2(z)$: the bar above the symbols denotes the averaging over the ensemble of the temperature fluctuations.

For the data of realization $\vec{\eta}(t)$ and $Y_{\alpha 1}(z)$ the photodetector current of the i-th channel $y_i(t)$ is the sum of the signal component $s_i(t;\vec{\eta},Y_{\alpha 1})$ averaged over the ensemble of shot fluctuations and white Gaussian noises $n_i(t)$, if $\Pi_i\tau_i >> 1$, where Π_i is the band of the postdetection filter of the i-th channel. The equations of quasioptimal filtration $\vec{\eta}(t)$ and simultaneous estimate of $Y_{\alpha 1}(z)$ using "the method of maximum probability" have the following forms:

$$\dot{\vec{\eta}}^*=A\vec{\eta}^*+KF_1(Y_{\alpha 1}^*)$$

$$\dot{K}=AK+KA^T+b+KF_2(Y_{\alpha 1}^*)K$$

$$\dot{Y}_{\alpha 1}^*=-\bar{\beta}_{m1}(z)\cdot c/g_a\{[y_1(t)-s_{m1}(t;\vec{\eta}^*,Y_{\alpha 1}^*)]/\bar{s}_{m1}(t)\}$$

where F_1,F_2 are the first and second derivatives with respect to $\vec{\eta}$ of the function F, which is the derivative of probability-functional logarithm with respect to time; $b=\|b_{ij}\|$ is the matrix of diffusion coefficients $\vec{\eta}$, whose elements $b_{11}=-2\alpha$, $b_{ij}=0$ at $(i,j)\neq(1,1)$; $s_{m1}(t;\vec{\eta}^*;Y_{\alpha 1}^*)$ is the estimate of the photocurrent component s_1 taking no account of the aerosol scattering, whose mean value is $\bar{s}_{m1}(t)$; $\beta_{m1}(z)$ is the mean profile of Rayleigh scattering.

The paper shows the filtration efficiency under different conditions of sounding using a computer modeling. The accuracy of restituted profiles T(z), $\rho(z)$, p(z) is determined by the elements of a posteriori matrix $K=\langle(\vec{\eta}-\vec{\eta}^*)(\vec{\eta}-\vec{\eta}^*)^T\rangle$ of the vector $\vec{\eta}^*$. Therefore the profiles of K, of the atmospheric parameters filtration variances and the effect of aerosol on their altitude dependence. The results obtained allow one to determine the lidar power required for providing the necessary accuracy of restitution of the atmospheric parameters profiles at chosen wavelengths of sounding in the ultraviolet and visible ranges.

References

1. G.N.Glazov, G.M.Igonin. Optimal lidar filtration of the atmospheric parameters profiles: theory and numerical experiment. 12-th I.L.R.C., August, 1984.