ACCOUNTING FOR AEROSOL EXTINCTION IN THE INTERPRETATION OF DATA ON LIDAR SENSING OF THE STRATOSPHERE

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We propose a method for calculating the ratio R of the indices of the total and the molecular backscattering of the stratosphere from lidar sensing data. The algorithm accounts for aerosol extinction. The algorithm is based on the a priori definition of the lidar ratio profile and does not need large expenditures of computer resources and can be realized a microcomputer. An example of processing of real errors caused by neglecting the experimental data is given. The errors caused by neglecting the aerosol extinction are discussed.

At present lidar measurements have become one of the principal and the most effective means of monitoring the state of the stratospheric aerosol. The qualitative and quantitative data which have been obtained from these measurements find direct use in climatology, meteorology, and in the solution of problems on conservation of the environment. Therefore, the improvement of methods of processing the registered echoes and reconstructing the profiles of optical parameters is of great importance in practical applications.

In the interpretation of the stratospheric sensing data an algorithm is often used which neglects the aerosol extinction of the probing radiation in the investigated range (see, e.g., Ref. 1). One should note that this simplification can adversely affect the qualitative results particularly during volcanic activity. In regard to the problem of lidar sensing of the stratosphere, methods which account for the aerosol extinction were proposed in Refs. 2 and 3. These methods are based on an iterative algorithm of the estimate of the extinction index. However, the application of this algorithm is rather difficult because it requires large expenditures of computing time, when we need rapid data processing and the calculations are carried out by microcomputers, with which lidar stations are usually equipped. The present paper describes another algorithm based on the analytic form of the relation between the corrected values of the ratio $R(z) = \beta(z)/\beta_m(z)$ (where $\beta(z)$ and $\beta_m(z)$ are the indices of the total and the molecular backscattering at the coordinate z, respectively) which characterizes the aerosol distribution in the stratosphere and its zeroth approximation $R_0(z)$ calculated without accounting for the aerosol extinction. The resultant expression naturally complements the conventional data processing scheme of lidar sensing in the stratosphere[1].

Let us assume that the single-scattering approximation is correct and the profile of the molecular scattering is known. The latter is usually calculated from data on weather-balloon measurements. The relation between the number $N(z)$ of single-photon pulses recorded by the receiving lidar system and the optical characteristics of the medium is described by Eq. (1)

$$N(z)=Kz^{-2}\beta(z)Q^2(z), \tag{1}$$

where z is the distance from the lidar to the sounded volume; K is the instrument function; $\beta(z) = \beta_a(z) + \beta_m(z)$, $\beta_a(z)$ is the aerosol backscattering index

$$Q^2(z)=\exp\left[-2\int_0^z \sigma(z')dz'\right];$$

$$\sigma(z)=\sigma_a(z)+\sigma_m(z);$$

and $\sigma_a(z)$ and $\sigma_M(z)$ are the indices of aerosol and the molecular scattering, respectively.

According to the standard scheme[1] we select some point z_0 in which the aerosol concentration is a priori assumed to be minimum and to correspond to $R(z_0) = R_{\min}$.

Then, from Eq. (1) it follows that

$$R(z)=\frac{z^2N(z)Q^2(z_0)\beta_M(z_0)}{z_0^2N(z_0)Q^2(z)\beta_M(z)}R_{\min}. \tag{2}$$

In Eq. (2) $Q^2(z) = Q_a^2(z)Q_M^2(z)$. $Q_M^2(z)$ is assumed to be known and is calculated from the profile of the molecular scattering. Q_a^2 is usually considered to be equal to unity, i.e., the aerosol extinction in the range $[z, z_0]$ is neglected, and the experimental data processing then results in a profile of the following form

$$R_0(z)=\frac{z^2N(z)Q_M^2(z_0)\beta_M(z_0)}{z_0^2N(z_0)Q_M^2(z)\beta_M(z)}R_{\min} \tag{3}$$

From Eqs. (2) and (3) we obtain the following relation

$$R_0(z)=R(z)\exp\left[2\int_z^{z_0}\sigma_a(z')dz'\right] \tag{4}$$

Equation (4) contains two unknown functions $\beta_a(z)$ and $\sigma_a(z)$. Therefore, when solving this expression one needs some additional a priori data. Following the conventional approach, we will assume the profile of the lidar equation $q(z) = \beta_a(z)/\sigma_a(z)$ to be preset.

Then, multiplying both parts of Eq. (4) by $2\beta_M(z)q^{-1}(z)M(z)$, where

$$M(z)=\exp\left[2\int_z^{z_0}\beta_M(z')q^{-1}(z')dz'\right], \tag{5}$$

we obtain the expression

$$2R_0(z)\beta_M(z)q^{-1}(z)M(z)=2[\sigma_a(z)+\beta_M(z)q^{-1}(z)]\times$$

$$\times\exp\left\{2\int_z^{z_0}[\sigma_a(z')+\beta_M(z')q^{-1}(z')]dz'\right\}. \tag{6}$$

Replacing z by z' and integrating both sides of Eq. (6) with respect to z' in the range $[z,\ z_0]$, we obtain

$$2\int_z^{z_0}R_0(z')\beta_M(z')q^{-1}(z')M(z')dz'+1=$$

$$=\exp\left\{2\int_z^{z_0}[\sigma_a(z')+\beta_M(z')q^{-1}(z')]dz'\right\}. \tag{7}$$

Substituting Eq. (7) into Eq. (6), after some transformations we arrive at the final formula

$$R(z)=\frac{R_0(z)M(z)}{1+2\int_z^{z_0}R_0(z')\beta_M(z')q^{-1}(z')M(z')dz'}. \tag{8}$$

Obviously, at $z = z_0$ $R(z_0) = R_0(z_0) = R_{\min}$ and $R(z) \to R_0(z)$ as $q^{-1}(z) \to 0$. In processing the experimental data it is desirable to select the point z_0 near the remote part of the interval, where $R(z)$, i.e., the coefficient of amplification of the relative errors of the measurements, is calculated and the value $\gamma = Q^2(z_0)/Q^2(z)$ is proportional to the a priori information.

To illustrate the effect of taking the aerosol extinction into account, we can use Fig. 1, where there is an example of the processing of the experimental stratospheric sensing data at the wavelength $\lambda = 532$ nm. These data were obtained by the lidar system "ANB-314" (Ref. 4). The position of the tropopause is marked by an arrow. We assume a priori that $R_0 = 1.01$ at $z_0 = 27.75$ km. Curve 1 is the profile $R_0(z)$, i.e., the ratio $\beta(z)/\beta_M(z)$, calculated assuming the neglect of the aerosol extinction. Curve 2 is the profile $R(z)$ calculated according to Eqs. (8)and (5) for $q(z) = 0.015 = \text{const}$. The farther one is from z_0, the greater is the difference between curves 1 and 2. In this case the relative deviation $\delta_R = [R_0(z) - R_z]/R_z$ reaches 7.8%. Neglect of the aerosol extinction is manifested to an even greater extent in an immediate scaling of the optical characteristics of the scatterers. The relative deviation of the value of the aerosol backscattering index in the height range 8 to 18 km exceeds 10% and has the mean level of 20%.

Curve 3 in Fig. 1 represents the dependence of the parameter $I(z)=\int_0^{z_0}\beta_a(z')dz'$, and curve 4 is the relative deviation, $\delta_I = [I_0(z) - I(z)]/I(z)$, where $I_0(z)$ is calculated on the basis of $R_0(z)$, and $I(z)$ is calculated from $R(z)$. $I(z)$ characterizes, to some extent, the optical depth τ of stratospheric aerosol in the height range $[z,\ z_0]$. It is evident that the neglect of the aerosol extinction leads to a substantial error In the estimation of τ.

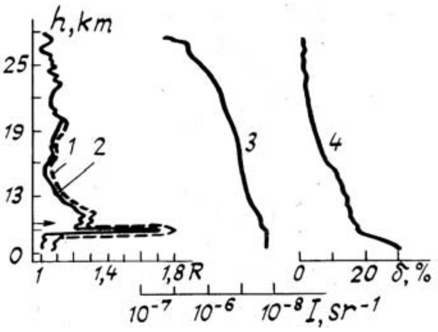

FIG. 1.

In conclusion we note that algorithms note that algorithms (8) and (5) were computed in PASCAL on the "Electronika-60". Using this language the data processing was realized practically in the real-time regime.

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