N87-10278

LIDAR MEASUREMENTS OF SLANT VISUAL RANGE

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When converting the lidar equation

$$P_z = A_z z^{-2} \beta_z T_{oz}^2 = A_z z^{-2} \beta_z \exp\left\{-2\int_0^z \sigma_{z'}\, dz'\right\} \qquad (1)$$

relative to the extinction coefficient σ_z and, correspondingly, the visual range, one encounters the instability of solution at the increase of the optical density of the sounding path (P_z is the lidar signal from the distance z , T_{oz} is the transmittance of the layer $[0, z]$, β_z is the backscattering coefficient, A_z is the calibration function). The search for a stable solution has resulted in the appearance of a set of inversion algorithms differing mainly in the manner of assigning the a priori information on the profile sought[1]. The paper suggests a stable algorithm of inversion and gives a comparative analysis and experimental verification of some methods of processing the signals at sounding the optically dense atmospheric formations.

The solution of Eq.(1), relative to σ_z , has, as known, the form

$$\sigma_z = \Psi_z \left(\frac{\Psi_{z_k}}{\sigma_{z_k}} - 2\int_{z_k}^{z} \Psi_{z'}\, dz' \right)^{-1} \qquad \Psi_z = \frac{P_z z^2}{A_z g_z T_{oz_0}^2} \qquad (2)$$

$g_z = \beta_z / \sigma_z$ is the lidar ratio, z_k is the reference (calibration) point, which can be chosen randomly along the sounding path $[z_0, z_m]$. The theoretical analysis and model calculations showed that the choice of a reference point z_k determines, in many respects, the stability of the solutions obtained. That is, the stability is the higher, the farther z_k is from the lidar. For $z_k = z_m$ the solution of the form

$$\sigma_z = \Psi_z \left(\frac{\Psi_{z_m}}{\sigma_{z_m}} - 2\int_{z_m}^{z} \Psi_{z'}\, dz' \right)^{-1} = \Psi_z \left(\frac{\Psi_{z_m}}{\sigma_{z_m}} + 2\int_{z}^{z_m} \Psi_{z'}\, dz' \right)^{-1} \qquad (3)$$

is most stable[1]. The similar conclusion has been arrived at by Klett[2]. His algorithm does not in fact differ from (3).

The main difficulty encountered when utilizing Eq.(3) is the necessity of measuring σ_{z_m} by an independent technique. The use, in this case, of logarithmic derivative (determination of σ_{z_m} based on the lidar-signal logarithm slope in the vicinity of z_m) is problematical due to the instability of the method to random variations of the signal. The most admissible is the processing of lidar signals with the use of integral calibration when transmittance of a sufficiently large segment $[\tau_o, \tau_k]$ is considered to be known. When $\tau = \tau_m$ the solution has the form

$$\sigma_\tau = \frac{\Psi_\tau}{2}\left(\varepsilon \int_{\tau_o}^{\tau_m} \Psi_{\tau'} d\tau' + \int_{\tau}^{\tau_m} \Psi_{\tau'} d\tau'\right)^{-1} \qquad \varepsilon = \left(T^{-2}_{\tau_o \tau_m} - 1\right)^{-1} \quad (4)$$

and is absolutely stable [1].

For approximately evaluating the parameter ε, one should use in Eq. (4) the lidar data together with different qualitative assumptions on the optical properties of the atmosphere along the path[1]. The simplest estimate $T^2_{\tau_o \tau_m}$ can be obtained by using the least-square method assuming the statistical homogeneity along the path

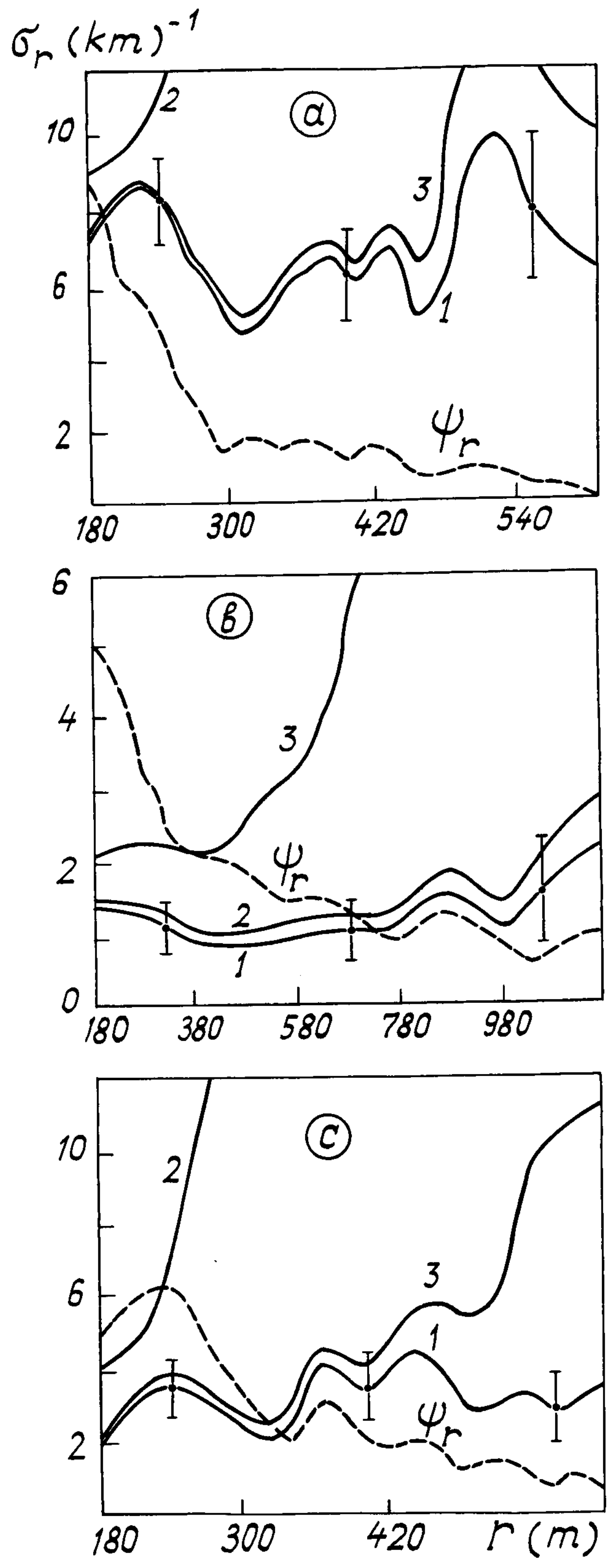
$$T^{-2}_{\tau_o \tau_m} = exp\left\{-\frac{3}{(\tau_m - \tau_o)^2}\int_{\tau_o}^{\tau_m} (\tau - \tau_o)\, \ell n \frac{\Psi_{\tau_o}}{\Psi_\tau} d\tau\right\} \quad (5)$$

Such an approximation is sufficient for the sounding paths close to horizontal.

The data on sounding fogs obtained with the use of lidar "LOZA-3" developed at the Institute of Atmospheric Optics was used to experimentally verify the algorithms (4,5). The sounding at λ = 0.53 um was carried out in the horizontal direction with simultaneous monitoring for the optical state of the atmosphere with the photometer placed at the beginning of the path. Some results of these measurements are given in figures where the signals Ψ_τ and the profiles σ_τ restituted with the use of the algorithm described (curves 1) are shown in relative units. The profiles σ_τ restituted using Eq.(2) with the photometer calibration at the beginning of the path (curves 2) and using Eq.(3) in which σ_{τ_m} value is determined using the method of logarithmic derivative (curves 3) are presented for comparison

$$\sigma_{\tau_m} = \frac{1}{2(\tau^* - \tau_m)} \ell n \frac{\Psi_{\tau_m}}{\Psi_{\tau^*}} \quad (6)$$

In many cases the use of photometer calibration at the beginning of the path resulted, as it should be expected, in the solution divergence (Figs. a-c). The use of the value σ_{τ_m} from (6) for calibration does not allow one to carry out stable processing, since in this case σ_{τ_m} strongly depends on choice of the point τ^* corresponding to the assumption on homogeneity σ_τ at the segment $[\tau^*, \tau_m]$. If in Figs. a, c the value σ_{τ_m} obtained from (6) can be considered valid, then the inhomogeneity at the end of the path for the case b leads to a negative value σ_{τ_m} and divergence of the profile σ_τ. The necessity in choosing a homogeneous segment of the path makes the automated processing of the results difficult. It should be noted that the use of some model value σ_{τ_m} for calibration, as the calibrations showed, gives sufficient accuracy for large optical depths of the path $\tau \gtrsim 2$ only. In the range $0.5 \lesssim \tau \lesssim 2$, the most probable



at sounding fogs, the solution is quite critical to the accuracy of evaluation σ_{r_m}. The algorithms(4,5) gave stable results for all signal ψ_r realizations. Thus, the use of functional limitations to the type of the solution sought (in this case, the assumption on statistical homogeneity of the path) allows one to construct stable algorithms for processing the results. The use of the more detailed information on solution and noises [1] gives the possibility of obtaining optimal algorithms with wider application limits than those of algorithms (4,5).

References

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