On applicability of neural network technique to determination of single-scattering particle albedo from clear sky diffuse brightness

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The applicability of neural network techniques to the problem of retrieval of the aerosol particle single-scattering albedo from calculations of the clear sky brightness in a spectral range 0.675 μm is under analysis. A homogeneous neural network consisting of three latent layers, each of 10 neurons, has been considered. A complex of optical parameters covering their actual variations under different atmospheric conditions was used in learning the network. The network was tested in accordance with many samples under learning. A histogram of deviations of the found albedo values from model ones is presented. It follows from the histogram that deviations within 3% are observed in 96.8% of cases.

The progress in computation technologies stimulates a search for new approaches to solution of the problems of atmospheric optics. In the present paper, a possibility to apply the artificial neural network to determining the single scattering albedo of aerosol particles ω_a from the data of almucantar cloudless sky brightness measurements is considered.

The classic way of solving such a problem, based on the use of results of the numerical solution of the radiative transfer equation, includes two approaches. The first, very intricate, is based on the application of the iterative algorithms, and consists of an approximate estimation of the aerosol microstructure from observations of the spectral optical thickness, albedo of the underlying surface, and clear-sky brightness. Each of progressive approximations is formed on the base of the results of solving the radiative transfer equation with data of previous iteration used as input parameters. On comparing the calculated values with experimental data, the decision is taken to continue or to stop the iterative process.[1–3]

The second approach consists of the approximate formulae, derived from the solution of the radiative transfer equation,[4–6] which together with the total optical thickness, determined by Bouger's method and including components of scattering and absorption, allows one to compute ω_a. In the latter case, the researcher meets a need to take into account the asymmetry of the aerosol phase function.[7] This can be realized through the iterative procedure. At such an approach, one must handle with intricate expressions, especially at second and subsequent approximations.

In this work, a possibility is analyzed of development of one more approach to determine ω_a in the framework of a mathematical apparatus, specially designated to solve similar problems: neural networks. The method of the neural network utilizes different ways to solution of physical problems: the method of inversion of the neural network, the method of hybrid fuzzy system, and the method of the stratified network with the algorithm of back propagation.[8,9] It should be noted that information on the use of the neural network for determination of the optical parameters of scattering media is available in scientific literature.[10–12]

The single scattering albedo of aerosol particles can be calculated by the following ways:

1) the set of the geometric and optical parameters of the atmosphere and corresponding data on diffuse irradiance, entered into neural network, is determined. The latter are computed by solving the radiative transfer equation;

2) the learning sample is separated from the initial data, followed by subsequent teaching of the neural networks on its base; as well as the test sample is determined, with the help of which the testing of the trained neural networks is realized;

3) the type and structure of the neural network are found, and the approximate number of neurons used is calculated;

4) the training and following testing of the neural network are carried out, accompanied by possible modification of its structure provided the results of the training or testing do not satisfy the preassigned criteria.

The Monte Carlo method was used to solve the radiative transfer equation in scalar form.[13,14] In the considered case, the values of the sky brightness in the solar almucantar in clear sky atmosphere in the red spectral range (λ = 0.675 μm), computed for the aerosol atmosphere were used as the initial data. The model included three groups of particle with lognormal size distributions: Aitken nuclei, submicrometer and coarse fractions.

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Elongation of the aerosol scattering phase function $f_a(\varphi)$ was varied by changing the number of particles in modes,[15] and the corresponding coefficients of asymmetry of the radiative fluxes for aerosol particles

$$\Gamma_a = \int_0^{\pi/2} f_a(\varphi)\sin\varphi\, d\varphi \Big/ \int_{\pi/2}^{\pi} f_a(\varphi)\sin\varphi\, d\varphi \qquad (1)$$

were set to be equal to 6.00, 7.03, 9.66, and 11.55. Optical thickness due to the Rayleigh scattering τ_{ms} was equal to 0.0427. Aerosol optical thickness varied in interval $0.1 \le \tau_a \le 0.7$ with a step of $\Delta\tau_a = 0.05$, which covered the absolute majority of the optical situations in the cloudless atmosphere. The values of the single scattering albedo ω_a were changed within the limits $0.7 \le \omega_a \le 1.0$ with a step of $\Delta\omega_a = 0.1$. The zenith angles of the Sun were equal to 60; 70.5; 75.5; and 78.5°, while the scattering angle varied between 0 and 157°. The underlying surface albedo was assumed equal to 0.15, which was equivalent to the summer conditions for majority of the types of the land cover. The absorption of air molecules was considered negligibly small.

As a test sample, the values of sky brightness and single scattering albedo were used, calculated for the following optical parameters of the atmosphere: aerosol scattering optical thickness τ_a equal to 0.15; 0.23; 0.37; 0.41; 0.54; 0.66; and 0.69; secants of the solar zenith angle Z: 2; 2.2; 2.9; 3.2; 3.3; 3.5; 4.1; 4.2; 4.5; and 4.9; single scattering albedo of the aerosol particles ω_a: 0.73; 0.84; and 0.96.

The stratified neuron networks were used to solve the problem of ω_a retrieval. The widely known Back propagation algorithm was used in their training. This is an iterative gradient algorithm of training, which is used to minimize the root mean square deviation of the actual current output from the desired output of the multi-layer neural networks.[8,9]

Several structures of neural network – from single-layer to ten-layer – with different number of neurons in the layer were analyzed. The most reasonable results were shown by the homogeneous neuron network with three latent layers and 10 neurons in each. In the network chosen, maximum and mean absolute errors in ω_a estimation made 0.013 and 0.043, when testing at the learning set, and 0.012 and 0.043, respectively, when testing at the examples, not belonging to the learning set. That was essentially better than for other networks considered. In the construction of the neural networks, the program product NeuroPro, version 0.25 was used. Their training was carried out with 1008 teaching examples. The network was tested at 280 examples with variation of the basic optical characteristics in the limit of values, specified for the learning sample.

The results of neural network testing are presented in the form of histogram shown in Figure, where the deviations δ of the single scattering albedo of particles $\omega_{a,test}$ from $\omega_{a,0}$ are presented:

$$\delta = \frac{\omega_{a,test} - \omega_{a,0}}{\omega_{a,0}} \cdot 100\%. \qquad (2)$$

Here $\omega_{a,test}$ are the values of the single scattering albedo at the output of the neural network, and $\omega_{a,0}$ are the values of albedo, used in solving the radiative transfer equation.

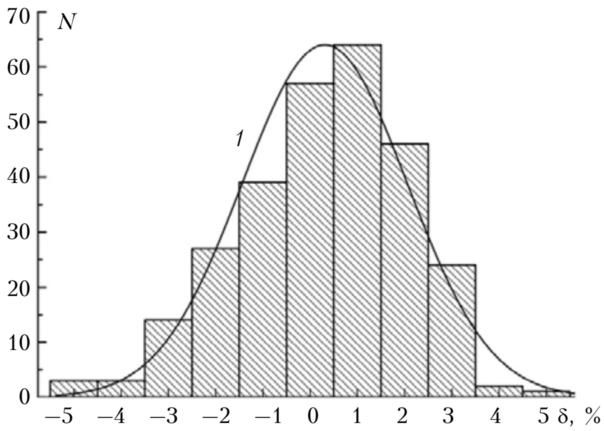

Fig. Histogram of results of testing of the neural network. N is the number of examples, δ is the relative deviation, *1* is the curve of the stochastic distribution of deviations.

For considered 280 examples of ω_a retrieval, in 160 cases (57%) relative deviations are within ± 1% and in 257 cases (91.8%) they do not exceed ± 3%. On the whole, the errors in retrieval of all 280 ω_a values do not exceed ± 5.5%. The deviations are not of systematical character for different input parameters of the testing sample. Although, it should be noted that negative deviations are observed mainly for small values of the aerosol optical thickness and positive – for thickness exceeding 0.5. The least number of deviations, exceeding 3%, arise at the asymmetry coefficient of radiative fluxes equal to 9.66. These facts require a more detailed analysis.

Thus, the first attempt of using the neural network technologies for the retrieval of the single scattering albedo of the aerosol particles from the data on the model sky brightness gave the positive result: it has shown the principal possibility of their practical application for solution of highly complicated multi-parameter problems of the atmospheric optics.

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