Software for processing of experimental data on polarization laser sensing of high-level clouds

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ABSTRACT

Methodology for determination of the optical and geometric characteristics of clouds is described. Problems of processing data obtained in experiments on polarization laser sensing of the atmosphere are discussed. Technique for reduction of the phase matrices of cirrus obtained with the high-altitude polarization lidar developed at National Research Tomsk State University to the symmetry plane affixed to the preferred orientation of ice crystals in cirrus is described. The experimental data are compared with the data of numerical modeling of phase matrices in the physical optics approximation and meteorological conditions over the lidar at cirrus altitudes.

Keywords: cirrus, phase matrix, polarization laser sensing, reduction to the proper basis

INTRODUCTION

Modern hardware and software, as well as the methodology for performing experiments and processing their results provide many possibilities for scientists to study the Earth's atmosphere. However, despite the existing instruments, the researchers still do not have a model of the Earths' atmosphere describing completely the phenomena proceeding in it. One of such factors not yet considered is the spatial orientation of non-spherical ice crystals in high-level clouds (HLC) [1]. These clouds play a significant role in climate formation due to their large horizontal extension. Orientation of particles in the HLC affects significantly the Earth's radiation budget and hence it must be considered in models of solar radiation propagation in the atmosphere.

1. EXPERIMENTAL AND THEORETICAL DETERMINATION OF PHASE MATRICES OF HIGH LEVEL CLOUDS

Remote evaluation of the preferred orientation of ice crystals in clouds is possible when the method of polarization laser sensing of the atmosphere (PLSA) is used. This method is based on an analysis of changes in the polarization state of laser radiation after its interaction with the examined medium [2]. This is implemented in the high-altitude lidar developed at the National Research Tomsk State University (NR TSU) that allows full phase matrices of HLCs to be retrieved [3]. This important advantage is provided by 16 measurements of vertical profiles of the lidar return signal intensity in each measurement run. The technique for processing of the experimental data is based on the equation of laser sensing for the signal power derived in the single-scattering approximation [4]. The methodology of estimation of

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the microstructure parameters of clouds is based on the experimental determination of their phase matrices and their comparison with matrices calculated theoretically for the given characteristics of ice crystal particles in clouds.

One example of such theoretical calculation is the database [5] is created by employees of the V. E. Zuev Institute of Atmospheric Optics of the Siberian Branch of the Russian Academy of Sciences (IAO SB RAS). This team of scientists is headed by A. G. Borovoi. The database consists of the phase matrices of monodisperse clouds calculated in the approximation of physical optics depending on the particle size and spatial orientation (Figure 1). In the calculation, the following empirical relationship between the thickness and the effective plate diameter was used: $h \approx 2.02D^{0.449}$ [6].

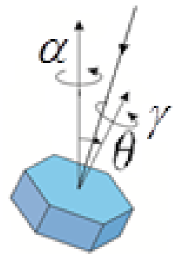

Figure 1. Parameters of the position of a hexagonal ice plate: α is the angle of rotation of the plate about the vertical axis, θ is the angle of inclination of the plate normal relative to the vertical axis, and γ is the angle of rotation of the plate around its normal [7].

To calculate phase matrices of polydisperse clouds, we used functions of hexagonal plate distributions over angles and sizes in cirrus borrowed from experimental works [8–13]. Taking them into account, we calculated the phase matrices of clouds for different preset parameters of these functions using the database described above. The algorithm for calculation of these matrices was developed and implemented in software.

2. REDUCTION OF EXPERIMENTAL PHASE MATRICES TO THE VERTICAL SYMMETRY PLANE

As a rule, theoretical matrices are calculated in the reference plane comprising the zenith direction and the symmetry axis of a crystal particle (hexagonal plate or column). At the same time, the phase matrices obtained experimentally are calculated in the basis related with a particular lidar. A significant problem of comparing matrices obtained experimentally and theoretically is the need to reduce them to a common basis. To do this, it is necessary that during experimental data processing, the plane of mirror symmetry of the ensemble of crystal particles in a cloud coincided with the scattering plane [2]:

$$\mathbf{M}'(h) = R(\varphi)\mathbf{M}(h)R(\varphi), \tag{1}$$

where $\mathbf{M}'(h)$ is the transformed matrix of the cloud at the altitude h, $R(\varphi)$ is the rotation matrix, φ is the azimuthal angle between the plane of mirror symmetry of the ensemble of particles and the reference plane, and $\mathbf{M}(h)$ is the cloud phase matrix determined experimentally and normalized on the element M_{11}. As a result, the phase matrix takes the following form:

$$\mathbf{M}'(h) = \begin{pmatrix} 1 & b & 0 & h \\ b & e+f & 0 & 0 \\ 0 & 0 & -e+f & d \\ h & 0 & -d & c \end{pmatrix}, \tag{2}$$

whose elements take values from –1 to 1. It allows different experimental phase matrices to be compared with each other and with phase matrices calculated theoretically. The condition for the implementation of transformation (1) is the equality to zero of the elements m'_{13}, m'_{23}, and m'_{24} of the block-diagonal matrix $\mathbf{M}'(h)$ [14]. Since the elements of

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the matrix **M**(h) are obtained experimentally, they are determined with errors, this condition is not satisfied. Additional conditions for the correct determination of the angle φ are the inequalities:

$$m'_{12} \le 0, \quad a'_{22} + a'_{33} \ge 0\,. \tag{3}$$

This conditions are not always satisfied due to the same errors in determining the elements of the matrix **M**(h).

Reduction of the HLC phase matrices during experimental data processing consists in finding the angle at which the basis must be rotated in order that the matrix became block-diagonal one. This transformation is nontrivial, because the above-described angle is determined in terms of the elements of the phase matrix by the following expression:

$$\varphi = arctg\left(-\frac{M_{21}}{M_{31}} \pm \sqrt{\left(\frac{M_{21}}{M_{31}}\right)^2 + 1} \right). \tag{4}$$

The software for reducing experimental phase matrices of clouds to the plane of vertical symmetry was developed by S. N. Volkov [15]. This software allows the lidar return signal to be corrected for afterpulsing and erroneous signals of photomultipliers of the lidar receiving system statistical in character as well as to reduce the statistical noise level of the signal caused by the regime of PMT operation in the photon counting mode and to subtract the background noise. In addition, the signal can be programmatically calibrated against the molecular benchmark in the given altitude range. The complexity of application of the above-described software for processing of experimental data obtained with the polarization lidar developed at the NR TSU is that it was intended for processing of the data obtained with the lidar developed at the Hanbat National University [16]. This lidar performs only 9 measurements, because it has no half-wave plates rotating the reference plane through 90° in its polarization attachments in the transmitting and receiving channels, unlike the NR TSU lidar which performs 16 measurements. In the present work, the software was adapted for processing of the experimental data obtained with the NR TSU lidar. Figure 2 shows the user interface of the adapted version of the software.

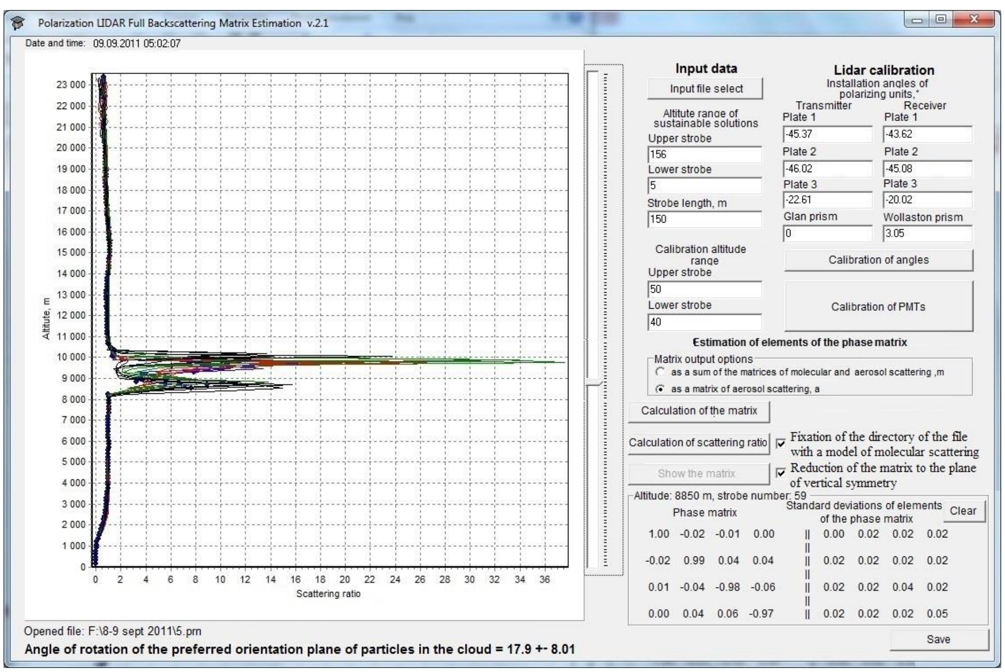

Figure 2. The user interface of the software adapted for processing of the data obtained with the NR TSU lidar.

The adaptation made it possible to compare the phase matrices obtained using this lidar with each other and with the theoretical matrices.

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CONCLUSION

The methodology for experimental retrieval of the phase matrices of high-level clouds with the high-altitude polarization lidar developed at National Research Tomsk State University and the methodology for obtaining the theoretical phase matrices of polydisperse clouds have been described. Calculations were performed for the given parameters of the functions of the angular and size distributions of hexagonal ice plates in clouds. The methodology of reducing the matrices obtained experimentally and theoretically to the uniform basis for their further comparison was described.

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