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REMOTE SENSING OF ATMOSPHERE, HYDROSPHERE, AND UNDERLYING SURFACE

The Study of Cirrus Clouds with the Polarization Lidar in the South-East China (Hefei)

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Abstract—Results of the study of microphysical characteristics of cirrus clouds in Hefei, China, with a multiwavelength polarization lidar are presented. Measurements were carried out from December 2010, to February 2013. In this work, we consider the only dependable parameter of lidar signals, i.e., the linear depolarization ratio measured at a wavelength of 532 μm. The dependences of depolarization ratios on both the size of ice crystals and the distribution of their distortion angles were calculated in this work for the first time. These results were used for retrieving, with some uncertainty, the microphysical parameters of cirrus clouds observed in Hefei during that period.

Keywords: polarization lidar, cirrus clouds, physical optics approximation, light scattering, ice crystals

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INTRODUCTION

The cirrus clouds located at altitudes of about 10 km and consisting of ice crystals from 10 to 1000 μm in sizes are one of the important climate-forming factors. Their radiation and microphysical properties, necessary for the present-day numerical models for long-term prediction of the weather and global climate change, are still not clearly understood. Therefore, microphysical parameters of cirrus clouds (size, shape, and crystal orientation) are currently under active study with the use of lidar sensing methods from both the ground and space [1–3].

THE COMPARISON BETWEEN THEORETICAL CALCULATIONS AND EXPERIMENTAL MEASUREMENTS

To date, the theoretical problem of light backscattering by ice crystals of cirrus clouds has been solved only for the simplest crystal shapes—hexagonal columns and plates of an ideal shape [4]. In this work, we present the results of calculations for a more realistic model, that is, randomly oriented distorted hexagonal columns, where hexagonal faces of a crystal are skewed relative to rectangular faces at a small angle ξ (distortion angle), similarly to [5]. At such a distortion of the crystal shape, the right angle between crystal faces, which forms the peak of the backscattering, breaks, which, generally speaking, results in the strong dependence of the backscattering on the crystal sizes. However, averaging over the distortion angles ξ, inherent in real clouds, levels the dependence of the depolarization ratio on the crystal sizes. Thus, as our calculations show, the measured values of the depolarization ratio can be meant to weakly depend on crystal sizes. Consequently, the depolarization ratio can be considered as an indicator of only the crystal shape and its spatial orientation in a cloud.

In this work, we calculate for the first time the depolarization ratio as a function of crystal sizes at different distributions of crystal distortion angles for the given model of crystal shape. This allows us to retrieve, with a known uncertainty, microphysical parameters of cirrus clouds, observed at Heifei in the period from December 2010, to February 2013.

The linear depolarization ratio is defined as [4]:

$$\delta = \sigma_{\perp}/\sigma_{\parallel}, \tag{1}$$

where $\sigma_{\parallel}$ and $\sigma_{\perp}$ are the crystal backscattering cross-sections for the normal and parallel components relative to the incident linearly polarized light, averaged over the statistical ensemble of crystals in a cloud. Figure 1 shows the probability distribution of the depolarization ratios in cirrus clouds for the given measurement period.

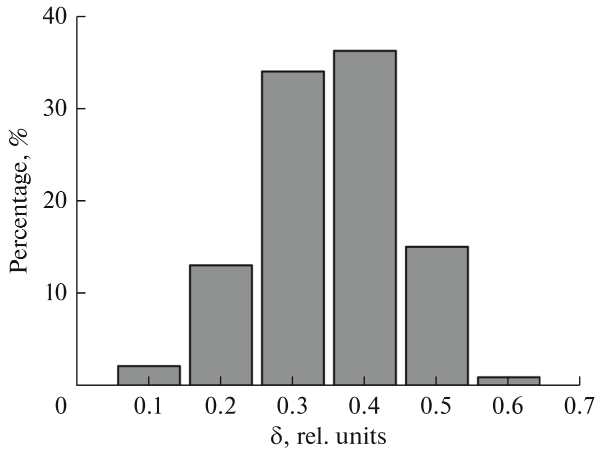

Fig. 1. Probability distribution (in %) of the linear depolarization ratio in cirrus clouds in Hefei.

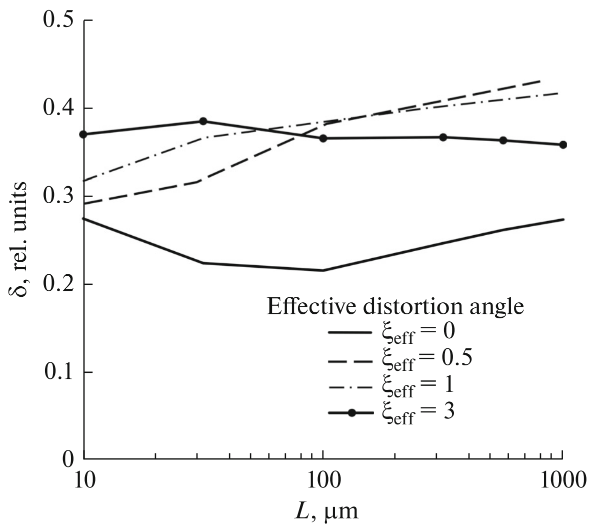

Fig. 2. Linear depolarization ratio calculated for randomly oriented hexagonal columns with effective distortion angles of 0°, 0.5°, 1°, and 3° as a function of the crystal length at an incident light wavelength of 0.532 μm.

Sizes of hexagonal columns are defined by one parameter L (the column length). The diameter D of a hexagonal column in this case is found from the empirical relation [6]:

$$D = \begin{cases} 0.7L, & 10 \le L < 100; \\ 6.96\sqrt{L}, & 100 \le L \le 1000, \end{cases} \tag{2}$$

where L and D are measured in microns.

Figure 2 shows depolarization ratios calculated in our physical optics approximation for randomly oriented hexagonal columns, with the distortion angle ξ distributed by the Gauss law:

$$p(\xi) = (\sqrt{2\pi}\xi_{\text{eff}})^{-1}\exp[-\xi^2/(2\xi_{\text{eff}}^2)], \tag{3}$$

where ξ_{eff} is the effective distortion angle of the crystal faces. As seen in Fig. 2, the sufficiently strong distortion of crystal shape ($\xi_{\text{eff}} > 3°$) levels the dependence of the depolarization ratio on the crystal sizes and increases it from $\delta \approx 0.2$, which is typical for crystals of regular shape, to $\delta \approx 0.35$.

The magnitude of depolarization ratio $\delta \approx 0.2$, as is known [4], is the boundary between quasi-horizontal and chaotic orientations of crystals. Figure 1 allows us to affirm that $\delta \ge 0.3$ in 85% of cases, i.e., crystals in cirrus clouds are chaotically oriented. It is reasonable in this case to attribute high values of depolarization ratio $\delta \ge 0.5$ to complex crystals of aggregate type.

Thus, all the above written and Figs. 1 and 2 allow us to draw a conclusion that in 70% of 85% cases of observation of chaotically oriented particles in the period from December 2010, to February 2013, they had rather simple shapes of the hexagonal column type (bullet or bullet-rosette), and only in 15% of the cases the shape was of aggregate type.

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