SCIENCE BRIEFS

Jet Contrail Studies Using Polarization Lidar

By Michael Mishchenko — February 1998

Cirrus clouds affect Earth's climate by reflecting incoming sunlight and inhibiting heat loss from the surface. Ordinarily, cirrus clouds are only weakly influenced by most ground-based human activities, because of their high altitude. However, increasing levels of high-altitude jet air traffic may alter the regional climatic effects of cirrus because aircraft condensation trails (contrails) often produce new cirrus, which could differ in their radiative properties. Therefore, it is important to study how contrails form, as well as their radiative properties, using experimental and modeling techniques.

Figure 1. Dissipating jet contrail. (Photograph by Ronald L. Halle, from the University of Illinois WW2010 Project)

Polarization lidar is a promising tool for characterizing contrail particles. It consists of a laser and a receiver. The laser transmits a narrow, fully polarized beam of light in which light waves all oscillate in the same plane. The receiver measures the polarization of light scattered in the backward direction by cloud particles. For a cloud of spherical water droplets, the backscattered light is fully polarized in the same direction as the transmitted beam; i.e., it has only a "co-polarized" component. However, for a cloud composed of non-spherical ice crystals, the backscattered light can be partially depolarized; i.e., it can have a "cross-polarized" component which vibrates perpendicularly to the transmitted polarization.

The ratio of the cross-polarized to the co-polarized components of the backscattered light is called the depolarization ratio. A non-zero depolarization ratio indicates the presence of non-spherical ice crystals. Lidar observations of regular cirrus and contrails often show large depolarization ratios. In order to interpret these measurements quantitatively, in terms of particle size and shape, the scattering of light by non-spherical ice crystals has to be calculated in a computer model. Until recently, such calculations could only be made for large crystals, and it was believed that the observed large depolarization ratios always indicated the dominance of large and thus old ice particles. However, recent lidar measurements fc very young contrails, that are likely to consist of much smaller ice crystals, showed even higher depolariza ratios. These large depolarization ratios raise questions concerning our understanding of the rate of contra particle growth with age and the optical mechanism of depolarization.

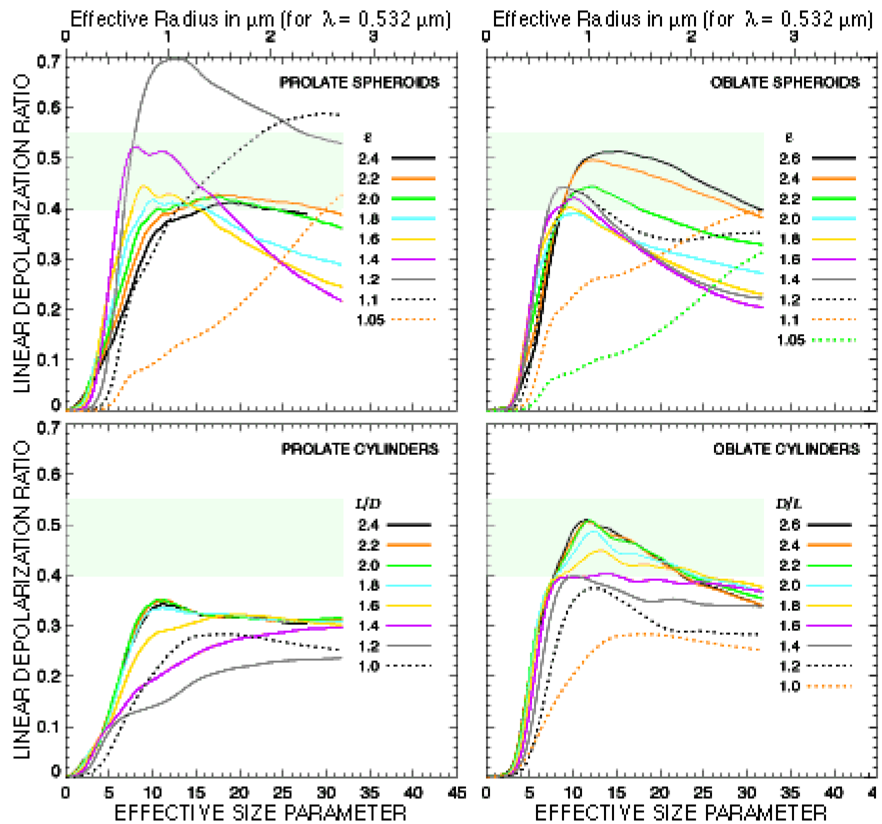

Figure 2. The depolarization ratio as a function of the ice crystal effective size parameter (defined as the average particle circumference divided by the wavelength of light). The upper horizontal axes convert the effective size parameter into the effective radius assuming a lidar wavelength of 0.532 µm. Non-spherical ice crystals are modeled as spheroids with varying axial ratios ε and cylinders with different length-to-diameter (L/D) and diameter-to-length (D/L) ratios. The light green area shows the highest range of depolarization measured for contrails.

can be produced by ice crystals with radii as small as several tenths of a µm. These results explain the frequent occurrence of strong depolarization for young contrails with age less than 20 seconds. Thus it becomes increasingly clear that contrails can often consist of small ice crystals and may therefore have substantially different radiative properties than regular cirrus clouds.

Our findings agree with results of microphysical and chemical modeling of contrail evolution and demonstrate that depolarization measurements can be successfully employed to determine the physical characteristics of contrail particles. In view of the strong dependence of depolarization on the ice particle size apparent in the figure, dual-wavelength lidar systems may be especially useful for studying how contrail ice crystals grow with age.

References

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