P2-12 A New Lidar Method Utilizing the Glory for Measuring Cloud Particle Size

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Introduction

The glory is the phenomenon observed in open air. For example, a person looking down from an airplane and observing the airplane's shadow on water clouds can often see colored rings around the airplane's shadow. This glory phenomenon is explained by the Mie scattering theory for water particles in the cloud.[1] The angular size of the colored ring depends on the cloud particle size. The radius of the ring is smaller for larger particles. This phenomenon, consequently, can be utilized for measuring water cloud particle size.

The measurement of cloud particle size is a current topic concerning the effect of aerosols on the formation of clouds, which is important for estimating the indirect effect of aerosols in the radiative process related to climate change. This paper proposes a new lidar method which utilize the effect of the glory for measuring water cloud particle size.

Glory Lidar

To measure the glory, which is essentially the wavelength and angular dependence of Mie scattering, with a lidar configuration, we require a multicolor laser transmitter. Also, we require either multiple transmitter beams or multiple receivers to observe the angular dependence of scattering. The lidar system considered here employs a five-wavelength laser transmitter and two lidar receiver systems located at scattering angles of 180 degrees and other suitable angle.

The concept of the lidar is shown in Fig. 1. The multicolor transmitter may employ a Nd:YAG laser (1064, 532 and 355 nm), and an optical parametric oscillator (OPO) at 1500 nm as well as its second harmonic at 750 nm. Each lidar receiver is capable of recording lidar signals at the five laser wavelengths. The spectrum of scattering measured at receiver 2 will be normalized by the spectrum at receiver 1, and the normalized spectrum will be analyzed.

Particle Size Measurement

Mie scattering phase functions were calculated for different particle sizes. The size distribution considered here has gamma distribution[2] which is expressed by the following equation.

$$n(r) = C\,(r/r_m)^{\nu_p} \exp(-\nu_p\, r/r_m), \qquad 1)$$

where r_m is the mode radius and C is a normalization constant. We assumed that ν_p=6, and we considered the distributions with mode radii of 4, 6, 8, 12 μm.

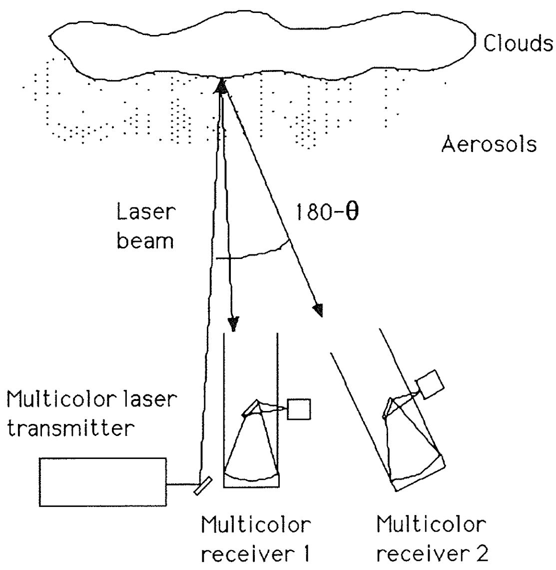

Fig. 1 Concept of the glory lidar.

Figure 2 shows Mie scattering phase functions calculated for a mode radius of 8 μm. The lidar signal intensity at a scattering angle is proportional to the phase function when the polarization of the laser is 45 deg to the scattering plane. The angle at the peak of the phase function next to the peak at 180 deg is dependent on the wavelength, and this causes the colored ring of the glory. The angular diameter of the ring is larger for longer wavelengths, and the angular diameter for the same color becomes larger when the particle size is smaller.

In the lidar configuration of Fig. 1, the scattering angle for receiver 2 is determined by the distance from receiver 1 and the height of the target cloud. Consequently, the scattering angle is not variable during the measurement. We need to select a suitable angle before the measurement.

Figure 3 shows the normalized spectrum (the spectrum relative to that for a scattering angle of 180 deg) for different particle sizes at a fixed scattering angle. We can see from Fig. 3 that we can determine the particle size (mode radius) from the spectrum when the target is observed with a suitable scattering angle.

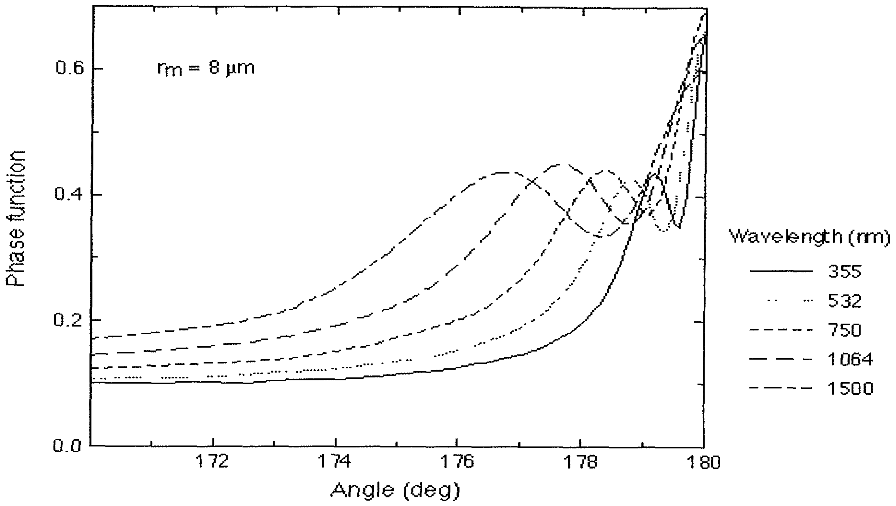

Fig. 2 Mie scattering phase functions for a mode radius of 8 μm.

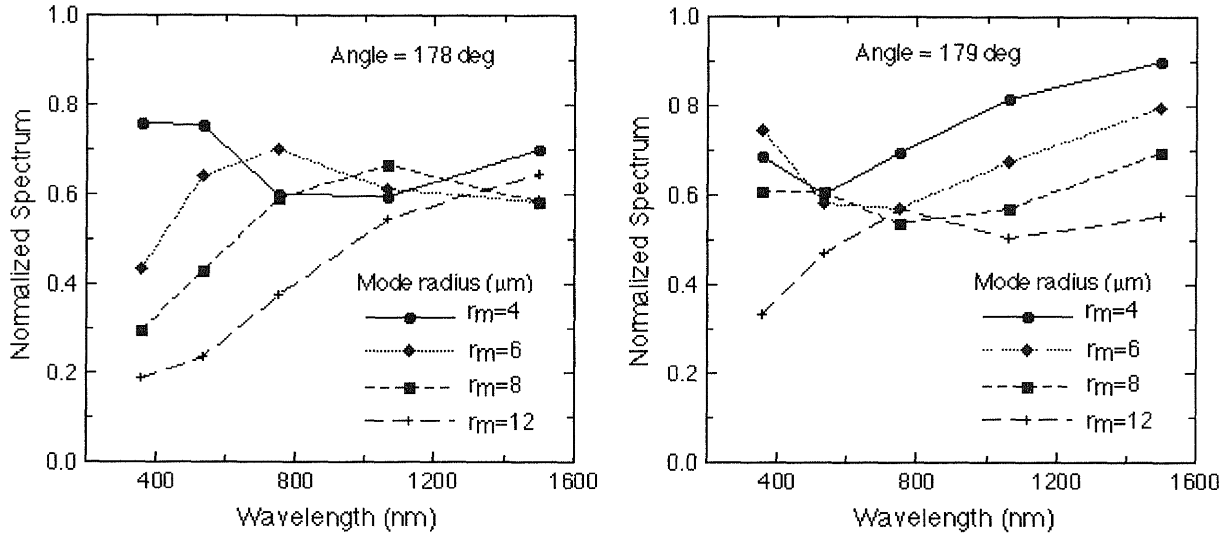

Fig. 3 Normalized spectrum at a scattering angles of 178 deg and 179 deg.

The result shows the suitable angle ranges from 177.5 to 179 deg for a mode radius of 4 to 12 μm. If the height of the target cloud is 1 km and the scattering angle is 178 deg, the distance between receivers 1 and 2 is 35 m. Conversely, if we set the distance between receivers at 35 m, the height range corresponding to an angular range of 177.5 to 179 deg is 800 to 2000 m. Therefore, this height range is covered with the fixed receiver distance of 35 m. To cover this height range with a fixed receiver, receiver 2 must have a field of view exceeding 1.5 deg (26 mrad). Wide field of view is not required for receiver 1.

Figure 3 suggests that we may omit the 1500 nm channel from the lidar system. In this case, we can use the three wavelengths (355, 532, and 1064 nm) from a Nd:YAG laser and 750 nm from an OPO pumped by 532 nm. We may use photomultiplier tubes for signal detection at 355, 532 and 750 nm and a PIN photodiode for detection at 1064 nm.

The major advantage of this lidar method is the capability of measuring aerosol density and wavelength dependence below the cloud at the sametime with the cloud particle size near the cloud base. Because the scattering phase function for aerosols does not have steep angular dependence, it is sufficient to measure aerosol scattering with only receiver 1.

References

1) H. C. van de Hulst, Light Scattering by Small Particles (Wiley, New York, 1957).

2) D. Deimendjian: Scattering and polarization properties of water clouds and hazes in the visible and infrared, Applied Optics, **2**, 187-196 (1964).