A polarization-sensitive imaging lidar based on the division-of-focal-plane scheme for atmospheric remote sensing

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Lidar, as an active remote sensing tool, has been widely employed in atmospheric environmental monitoring. As a branch of atmospheric lidar, polarization lidar plays a significant role in characterizing the properties of cirrus clouds, classifying aerosol types, retrieving aerosol microphysical properties, etc. However, the retrieval reliability and accuracy of the depolarization ratio of atmospheric particles rely on the ratio between the responsivities of the two photodetectors (gain ratio), the cross-talk of the polarization beam splitter (PBS), the misalignment between the laser's polarization plane and the incident plane of the PBS (offset angle), and the polarization purity of the laser beam, etc., which requires extensive calibrations and careful evaluations.

A polarization-sensitive imaging lidar (PSI-Lidar), employing a linearly polarized continuous-wave 450-nm laser diode and a polarization image sensor has been proposed and demonstrated for atmospheric polarization studies. The polarization image sensor, fabricated with four-directional on-ship polarizers at 0°, 45°, 90° and 135°, is able to capture a four-directional polarized image of the transmitted laser beam, from which four polarized atmospheric backscattering signals with 0°, 45°, 90°, and 135° polarization angles can be simultaneously measured. A theoretical model based on the Stokes–Mueller formalism has been established. The systematic errors introduced by the degree of linear polarization (DoLP) of the emitted laser beam, the offset angle, and the quantum efficiencies (QEs) and polarization extinction ratios (PERs) of the polarization image sensor, were evaluated in detail. Validation measurements have been carried out on a near horizontal path. The linear volume depolarization ratio (LVDR) as well as its measurement uncertainty has been theoretically and experimentally evaluated without employing additional optical components and sophisticated online calibrations. The offset angle can also be accurately retrieved (i.e., -0.06°) from the four-directional polarized lidar profiles during the whole measurement period, which contributes negligible influence on the retrieval of the LVDR. It has been found out that the uncertainty of the LVDR was mainly originated from the random noise, which was below 0.004 at nighttime and may reach up to 0.008 during daytime owing to the increasing sunlight background. The performance of the polarization lidar system has been further examined through atmospheric vertical measurements. The low-cost low-maintenance portable polarization lidar system, capable of detecting four-directional polarized lidar signals simultaneously, opens up many possibilities for all-day field measurements of dust, cloud, urban aerosol, oriented particles, etc.