Abstract

The Moderate Resolution Imaging Spectroradiometer (MODIS) cloud product provides three separate 1 km resolution retrievals of cloud particle effective radii (r_e), derived from 1.6, 2.1 and 3.7 µm band observations. In this study, differences among the three size retrievals for maritime water clouds (designated as $r_{e,1.6}$ $r_{e,2.1}$ and $r_{e,3.7}$) were systematically investigated through a series of case studies and global analyses. Substantial differences are found between $r_{e,3.7}$ and $r_{e,2.1}$ retrievals ($\Delta r_{e,3.7\text{-}2.1}$), with a strong dependence on cloud regime. The differences are typically small, within ±2µm, over relatively spatially homogeneous costal stratocumulus cloud regions. However, for trade wind cumulus regimes, $r_{e,3.7}$ was found to be substantially smaller than $r_{e,2.1}$, sometimes by more than 10 µm. The correlation of $\Delta r_{e,3.7\text{-}2.1}$ with key cloud parameters, including the cloud optical thickness (τ), r_e and a cloud horizontal heterogeneity index (H_σ) derived from 250 m resolution MODIS 0.86 µm band observations, were investigated using one month of MODIS Terra data. It was found that differences among the three r_e retrievals for optically thin clouds (τ<5) are highly variable, ranging from -15µm to 10µm, likely due to the large MODIS retrieval uncertainties when the cloud is thin. The $\Delta r_{e,3.7\text{-}2.1}$ exhibited a threshold-like dependence on both $r_{e,2.1}$ and H_σ. The $r_{e,3.7}$ is found to agree reasonably well with $r_{e,2.1}$ when $r_{e,2.1}$ is smaller than about 15µm, but becomes increasingly smaller than $r_{e,2.1}$ once $r_{e,2.1}$ exceeds this size. All three r_e retrievals showed little dependence when $H_\sigma < 0.3$ (defined as standard deviation divided by the mean for the 250 m pixels within a 1 km pixel retrieval). However, for H_σ>0.3, both $r_{e,1.6}$ and $r_{e,2.1}$ were seen to increase quickly with H_σ. On the other hand, $r_{e,3.7}$ statistics showed little dependence on H_σ and remained relatively stable over the whole range of H_σ values. Potential contributing causes to the substantial $r_{e,3.7}$ and $r_{e,2.1}$ differences are discussed. In particular, based on both 1-D and 3-D radiative transfer simulations, we have elucidated mechanisms by which cloud heterogeneity and 3-D radiative effects can cause large differences between $r_{e,3.7}$ and $r_{e,2.1}$ retrievals for highly inhomogeneous clouds.

Our results suggest that the contrast in observed $\Delta r_{e,3.7\text{-}2.1}$ between cloud regimes is correlated with increases in both cloud r_e and H_σ. We also speculate that in some highly inhomogeneous drizzling clouds, vertical structure induced by drizzle and 3-D radiative effects might operate together to cause dramatic differences between $r_{e,3.7}$ and $r_{e,2.1}$ retrievals.