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 $\mu$m 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 ($\Delta r_{e,3.7-2.1}$), with a strong dependence on cloud regime. The differences are typically small, within ±2 $\mu$m, over relatively spatially homogeneous coastal 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 $\mu$m. The correlation of $\Delta r_{e,3.7-2.1}$ with key cloud parameters, including the cloud optical thickness ($\tau$), $r_e$ and a cloud horizontal heterogeneity index ($H_\sigma$) derived from 250 m resolution MODIS 0.86 $\mu$m 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 ($\tau<5$) are highly variable, ranging from -15 $\mu$m to 10 $\mu$m, likely due to the large MODIS retrieval uncertainties when the cloud is thin. The $\Delta r_{e,3.7-2.1}$ exhibited a threshold-like dependence on both $r_{e,2.1}$ and $H_\sigma$. 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 15 $\mu$m, 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 $H_\sigma>0.3$, both $r_{e,1.6}$ and $r_{e,2.1}$ were seen to increase quickly with $H_\sigma$. On the other hand, $r_{e,3.7}$ statistics showed little dependence on $H_\sigma$ and remained relatively stable over the whole range of $H_\sigma$ 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 $\Delta r_e, 3.7 - 2.1$ between cloud regimes is correlated with increases in both cloud $r_e$ and $H_a$. 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.