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 \( \pm 2 \mu m \), 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 \((H_o)\) 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 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 \( H_o \). 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 \( H_o < 0.3 \) (defined as standard deviation divided by the mean for the 250 m pixels within a 1 km pixel retrieval). However, for \( H_o > 0.3 \), both \( r_{e,1.6} \) and \( r_{e,2.1} \) were seen to increase quickly with \( H_o \). On the other hand, \( r_{e,3.7} \) statistics showed little dependence on \( H_o \) and remained relatively stable over the whole range of \( H_o \) 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.