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Heterogeneity Effects in Optical Cloud Liquid Water Path Retrievals

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Optical estimates of cloud liquid water path (CLWP) are parameterized from 1D, plane-parallel retrievals of cloud optical thickness and droplet effective radius, which neglect horizontal photon transport and 3D cloud structure. It has long been recognized by numerous theoretical studies that such simplifications in 1D radiative transfer can lead to significant biases in retrieved cloud properties. In this work, we investigated the impact of 3D radiative effects specifically on liquid water path retrievals by comparing Moderate Resolution Imaging Spectroradiometer (MODIS) CLWPs with independent microwave estimates from the Advanced Microwave Scanning Radiometer for Earth Observing System (AMSR-E), which are much less susceptible to such errors. The consistency of optical and microwave estimates in warm oceanic clouds was analyzed as a function of scene heterogeneity and solar/view geometry in one year of observations at the native 0.25º scale of AMSR-E retrievals. Two different metrics of cloud heterogeneity were considered. The first was based on brightness temperature variations and measured cloud top variability. The second, Cahalan's inhomogeneity parameter, that is, the ratio of the logarithmic and linear average of cloud optical thicknesses, characterized horizontal variations in liquid water.

Both heterogeneity metrics showed similar geographical and seasonal variations with the most homogeneous scenes occurring in marine stratus/stratocumulus regions and cloud heterogeneity being overall weaker in summer than in winter. Contrary to expectations from theoretical studies, we found the Cahalan inhomogeneity parameter more effective than cloud top variability in separating scenes with or without significant 3D effects on CLWP. The overall relationship between microwave and optical CLWPs was much tighter, with considerably larger correlations and smaller rms differences, for homogeneous than for heterogeneous scenes, especially at lower cloud fractions.

While microwave and optical zonal means were in relatively good agreement in the summer hemisphere, in the winter hemisphere MODIS CLWP sharply increased toward the poles in contrast to AMSR-E. Our analysis suggested that this discrepancy was mainly due to 3D effects in MODIS retrievals over heterogeneous scenes at large solar zenith angles. We found that AMSR-E CLWPs showed similar and generally small solar zenith angle dependence for both homogeneous and heterogeneous scenes, indicating their relative insensitivity to 3D effects. However, while the solar zenith angle dependence of MODIS CLWP in homogeneous scenes was similar to that of AMSR-E CLWP, in heterogeneous scenes MODIS CLWP increased by 40% in the solar zenith angle range of 60º to 80º.

In addition, the view angle dependence of microwave retrievals and that of optical retrievals were also strikingly different. Microwave retrievals in general and optical retrievals in homogeneous clouds were remarkably consistent at all view directions, but optical CLWPs in heterogeneous scenes were considerably larger for oblique views than for overhead views when the Sun was fairly oblique. This U-shaped behavior of MODIS CLWP at low Sun is characteristic of the increased viewing of illuminated cloud sides from oblique directions; a 3D effect missing in 1D models and causing enhanced optical thickness retrievals. As a final note, however, we caution that the heterogeneity parameters themselves exhibited a similar U-shaped view angle dependence due to limb darkening and filling of cloud gaps at oblique views, a factor that has to be considered when interpreting the above results.