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Evaluating 3D effects in 1D VIS-NIR cloud retrievals using LES cloud fields and 3D radiative transfer

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Liquid water path (LWP) is a crucial cloud parameter playing an important role in both atmospheric radiation and hydrology. Unfortunately, the various observational datasets (microwave and VIS-NIR) show considerable and as yet not fully explained discrepancies in the global distribution of this quantity. Operational VIS-NIR retrieval algorithms have to reduce natural complexity by treating clouds as plane-parallel, homogeneous layers in order to be practical. These simplifications might work well for extensive Sc sheets but are less suitable for broken, heterogeneous cloud fields. Due to the complex 3D structure of clouds, 1D retrievals can significantly underestimate or overestimate true LWP at certain view geometries (e.g., shadowed vs. illuminated cloud sides). These 3D effects are generally larger in broken clouds and at oblique solar and view angles. In addition, the relationship between cloud optical thickness and reflectance is non-linear; therefore, sub-pixel-scale variability can also introduce large errors in retrieved cloud properties (plane-parallel bias). This study is a contribution to the long-term effort of fully quantifying such 3D retrieval biases. Our approach was to combine Large Eddy Simulation (LES) cloud fields with the Spherical Harmonic Discrete Ordinate Method (SHDOM) Radiative Transfer (RT) model.

We have implemented a 2-channel retrieval technique similar to the operational MODIS algorithm to estimate cloud optical thickness and droplet effective radius from 0.86 μm and 2.13 μm radiances. The 3D SHDOM RT model was used to calculate accurate radiances for LES cloud fields. These radiances were then inverted for optical thickness and effective radius with the help of 1D look-up tables generated by the plane-parallel SHDOMPP RT model. Our retrieval implementation was tested on homogeneous and near-homogeneous cloud fields with known properties and was found to have 1D retrieval errors typically below 2%, similarly to the operational MODIS algorithm.

In this study, we investigated 3D radiative effects as a function of solar zenith angle in 72 LES scenes of 8x8 km2 ranging from Sc to more broken trade Cu. The LES liquid water content and droplet effective radius fields had a 70 m horizontal and 30 m vertical resolution and cloud property retrievals were done at 70 m horizontal resolution. In general, the spatial distribution of retrieved LWP agreed well with that of the true LES LWP at high Sun and nadir view; however, the agreement somewhat broke down at low Sun and oblique view. The retrieved domain mean optical thickness and effective radius showed $\sim$20% underestimation and $\sim$20-30% overestimation, respectively, compared to the LES truth. Due to such compensating errors in optical thickness and effective radius, the LWP retrieval was in much better agreement with the true LES LWP. The results also revealed a significant increase in optical thickness at solar zenith angles above 55º. The increase was only $\sim$20% in the more homogeneous Sc fields, however, for the broken trade Cu clouds optical thickness more than doubled. Qualitatively similar discrepancies were observed in our previous comparison of MODIS VIS-NIR and AMSR-E microwave LWPs.