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Exploring new methods to exploit the relationship between cloud spatial structure and their spectral radiative signature in remote sensing and energy budget applications

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In this work, we use 3-dimensional (3-D) radiative transfer modeling to investigate the effects of inhomogeneous cloud spatial structure on spectral signatures of radiative quantities of a cloud field such as irradiance, heating rate and cloud radiative effect. The investigation covers different spectral regions, whose radiative properties are dominated by different effects (e.g., molecular scattering, aerosol scattering and absorption, gas absorption and cloud absorption). We define a number of metrics to describe the 3-D cloud spatial structure, which includes cloud optical thickness, cloud size, cloud-to-cloud distance and spatial pattern of the cloud field. Then we use four inhomogeneous cloud cases, three idealized and one observed, with increasing complexity to access the sensitivities of the spectral radiative signatures in each spectral region on each metric. Thus we are able to discuss how each aspect of the 3-D cloud spatial structure gives rise to the spectral radiative signatures in these different spectral regions.

Specifically, we explore the spectral signature of the net horizontal photon transport for each spectral region and its dependence on each of the metrics. The results suggest that a limited number of metrics may be sufficient to explain the behavior of the net horizontal photon transport for a range of cloud structure. Thus we propose a preliminary parameterization for simplifying the 3-D cloud effects in cloud-aerosol remote sensing applications. Secondly, we investigate the spatial distribution of heating rates when inhomogeneous clouds are present for all these spectral regions. We discuss how the 3-D cloud heating rate differs from the 1-D plane-parallel counterpart and how this difference can be understood in the framework of the previously defined metrics. The results provide insights into how the presence of clouds could change the distribution of energy within the atmosphere and thus influences atmospheric dynamics. Finally, we investigate the cloud radiative effects for realistic cloud scenes and introduce a new spectral parameterization for cloud heterogeneity effect that is applicable for both remote sensing and energy budget studies.