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The relative importance of horizontal and vertical unresolved cloud variability for solar radiative transfer calculations

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Errors in the radiative transfer calculation due to either horizontal or vertical cloud unresolved structures are examined with the aim of quantifing the relative importance of these two aspects and under which conditions it could be possible to neglect either the one or the other. Using aircraft observations to initialise a statistical cloud model, a three dimensional stratocumulus field with prescribed (observed) variability over a range of horizontal spatial scales, has been generated. From this scene, several other representations are derived by progressively degrading the vertical or horizontal resolution. For each scene a three dimensional SW radiation calculation is performed.

For a given radiative variable (such as reflection or transmission) the bias due to unresolved vertical (horizontal) structure, Δ_{ζ}, is defined as the relative error between a calculation performed using a high vertically (horizontally) resolved representation of the cloud field and the calculation obtained on cloud fields reduces to a vertically (horizonatlly) uniform slabs. For the observed cloud scenes Δ_{ζ} is found of the same magnitude ($\sim 3\%$ for the reflection and $\sim 10\%$ for the transmission) as the biases produced by unresolved horizontal variability, but of opposite sign.

Two opposing mechanisms contribute to the final vertical bias. The increased opacity at cloud top due to the adiabatic liquid water profile renders a vertically resolved cloud much more reflective then a vertically homogeneous slab. On the other hand resolving the wavy cloud top structure acts in opposite direction being a corrugated-bumpy cloud top less reflective then a flat one. When the cloud vertical structures are resolved, Δ_{ζ} is mainly controlled by the cloud aspect ratio as seen from the sun direction. Introducing a non-dimensional scale length Ψ related to ratio between cloud horizontal and vertical dimensions, it is possible to demark two regimes relevant for the radiative properties of the field. In the first the interaction at the top is dominated by direct radiation and therefore the radiative bias with respect to an unresolved cloud is due to the vertical distribution of cloud water. In the second regime the dominant interaction at the cloud-top is due to the diffuse radiation and thus the horizontal variability mainly controls the bias. It is suggested that the definition of Ψ, i.e of a relevant geometrical length scale for cloud system, can help the parametrisation of effects due to unresolved features.