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A refined cloud parameterization based on double-Gaussian probability density functions

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The choice of the cloud parameterization in a large scale model like a numerical weather prediction model or a global circulation model is known to have a large impact on microphysical and radiative processes which in turn determine, e.g., the formation of precipitation or the energy balance. Cloud properties like cloud fraction and average liquid water in a large scale model grid box depend on the subgrid variability of temperature and moisture as characterized by their probability density function (PDF). Therefore PDF-based parameterizations of boundary layer clouds are often used in numerical weather prediction or global circulation models. In recent years closures using a 5-parameter double-Gaussian PDF have become increasingly popular because the double-Gaussian distribution can provide very accurate fits to observed or simulated empirical PDFs. Even if we assume that the first three moments of the subgrid PDF can be predicted in the large scale model, the number of parameters still has to be reduced from five to three, i.e., two closure equations are necessary.

Considering cases of different cloud regimes, i.e., trade wind cumulus, stratocumulus and stratocumulus-to-cumulus transition, from large-eddy simulations as well as direct numerical simulations and observational data, a new parameterization based on double-Gaussian PDFs is proposed. A priori testing in large-eddy simulations suggests that the reduced 3-parameter double-Gaussian is an appropriate approximation, especially when the differences between stratocumulus and shallow convection are taken into account. In contrast to previous work, we do not find a perfectly anti-symmetric shape of negatively and positively skewed subgrid PDFs. Instead the PDFs differ in the shape of their tails, with the tail of a positively skewed PDF in a shallow cumulus regime being heavier than the tail of a negatively skewed PDF in a stratocumulus regime. This is consistent with the physical understanding that cloudy updrafts in shallow cumulus are more vigorous than non-cloudy downdrafts in stratocumulus. When taking this difference into account in the closure equations, the new parameterization is able to reproduce profiles of cloud fraction and average liquid water properly. Additionally, we show that the error of the parameterization is smallest for a horizontal resolution of 5 – 20 km and also depends on whether of not the cloud field self-organizes, e.g., in cloud clusters and mesoscale arcs.