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Changes in cloudiness, precipitation and trade-wind layer structure as shallow convection deepens to congestus

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Cloudiness near the tops of shallow cumulus clouds forms the major component of variability in observed low cloud cover in the downstream trades. For example, the frequent occurrence of stratiform outflow layers near the trade inversion contributes to enhanced cloud cover in winter. The summer season with frequent deep convection has overall less cloud cover, but more precipitation. Here we use large-eddy simulation (LES) to examine how the interplay of convection, its organization and the large-scale environment control changes in cloudiness and the trade-wind layer structure as shallow convection deepens and precipitates more.

Across the different numerical experiments performed, we find that the deepening of convection exerts a dominant influence on the structure of the trade-wind layer and the distribution of cloudiness. In those simulations where the trade-wind layer remains shallow and capped by a strong inversion, cloud cover increases strongly due to stratiform outflow layers located near 2 km. The thin stratiform layers develop from condensate-detrainment of larger and deeper precipitating cloud clusters, which help strengthen the inversion. Furthermore, interactive radiation is crucial to form and maintain the outflow layers. In simulations where sustained deeper convection weakens the inversion—for example in response to stronger winds, horizontal advective cooling, or under a drier free troposphere—, the outflow layers cease to develop, but precipitation increases. By building up relative humidity during intermittent periods or in confined regions, stronger winds and horizontal advective cooling can enhance cloud fractions between 1 and 2 km despite the cloud layer being deep and the inversion weak.

An analysis of the statistics of spatial organization as identified by cold pools is performed to test with observations the simulated relationships between shallow-convective organization, cloudiness and the vertical humidity structure. We find that the LES captures the observed relationships at Barbados reasonably well, but simulated cloud cover is overall underestimated. In the observations, cloud cover in the hour after the cold-pool front is strongly enhanced compared to the long-term mean. Because of the important implications shallow-convective organization might have for the albedo in the trades, it is important to understand how these relationships translate to longer temporal and spatial scales.