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Estimating bulk entrainment with aggregated and unaggregated convection

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Entrainment alters both the updraft mass flux and the updraft composition, especially its buoyancy. This study investigates how entrainment depends on the degree of convective aggregation in convection-permitting simulations. This is investigated with the ICON-LEM model with 1 km resolution, using a radiative-convective equilibrium framework that mimics conditions over the tropical ocean in a 600x600 km2 cubic domain with doubly-periodic boundary conditions. Bulk entrainment is quantified with a radioactive tracer, which is injected at the surface and decays in the atmosphere, with an e-folding time scale of 4 days.

Vertically-integrated bulk entrainment estimates show that the entrainment rate is independent of the degree of aggregation, though entrainment rate varies more with height in aggregated conditions. Additionally, the entrainment rate is mostly independent of the updraft location within the aggregated cluster of convection, but entrainment does depend on the number of surrounding updraft grid points. However, the efficiency of entrainment strongly depends on the degree of aggregation. In aggregated conditions, the mean moist static energy in the nearby environment of updraft grid points is closer to the updraft moist static energy than in unaggregated conditions. Thus, when aggregating, the entrainment efficiency decreases by one third, considering all model levels between 850 hPa and 600 hPa. So aggregation does not affect how much mass is exchanged through entrainment, but it affects the constitution of the entrained air, thereby changing how efficient entrainment is in decreasing the updraft buoyancy.

Although the impact of entrainment on updraft mass flux is the same in aggregated and unaggregated conditions, updraft mass flux is twice as large in unaggregated conditions as in aggregated conditions because cloud base mass flux is higher. The reason is that higher subsidence velocities are necessary for balancing the radiative cooling because the atmosphere is much less stable. Less stability also causes higher values of CAPE, leading to higher vertical velocities in the updraft. Bulk detrainment, calculated as residual from bulk entrainment and change of updraft mass flux with height, is similar in aggregated and unaggregated conditions in the upper troposphere, but in the low troposphere it is larger in aggregated conditions due to the higher atmospheric stability.