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Numerical study on the self-aggregation of moist convection in radiative-convective equilibrium

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Deep convective clouds in the tropospheric atmosphere are often organized into large cluster systems (e.g., typhoons or mesoscale convective systems). They play significant roles in the atmospheric energy balance through the redistribution of heat. Idealized numerical simulations of radiative-convective equilibrium atmosphere have shown that clouds spontaneously aggregate despite horizontally uniform boundary conditions and forcings (Fig. 1).[1] This phenomenon referred to as convective self-aggregation (CSA) has received growing attention as a key to understanding the nature and roles of clouds in the climate system. In this study, we investigated (1) the existence of characteristic length for the CSA onset, (2) the CSA onset mechanism, and (3) the characteristic form and distance in high-level hierarchical structure of self-aggregated clouds.

We conducted a series of cloud-resolving numerical simulations with various horizontal domain sizes and horizontal grid spacings using a non-hydrostatic fully compressible 3D atmospheric model SCALE-RM version.[2,3] The lower boundary condition was sea surface with a uniform temperature of 300 K. Physical parameterization schemes were used for cloud microphysics, radiation, subgrid-scale turbulence, and surface flux processes. The simulated atmosphere evolved toward a statistical equilibrium state where radiative cooling and moist convective heating balanced.

While previous studies reported that CSA occurred only when the horizontal grid spacing was larger than ~2 km and the domain size was larger than ~200 km, we showed that CSA occurred even when the horizontal grid spacing was smaller than ~2 km if the domain size was sufficiently large. The critical domain size existed on ~500 km for the CSA onset with small grid spacings.[4]

Next, we investigated the reason for the upgradient moisture transport associated with the CSA onset. In the aggregated cases, the horizontal gradient of buoyancy was generated by the enhanced radiative cooling in the dry region, which drove the low-level circulation.[5]

Finally, to understand the natural behavior of CSA unaffected by the computational domain, we drastically extended the horizontal domain size up to ~25,000 km with a relatively coarse horizontal grid spacing of 8 km. We discovered that the high-level hierarchical structure exhibited a mesh-like horizontal pattern with a characteristic horizontal length of ~3,000–4,000 km.[6]

Although the simulations were performed under idealized conditions, these discoveries will provide new insights into the fundamental mechanisms for the spatial scale and pattern of cloud clusters in the real atmosphere.

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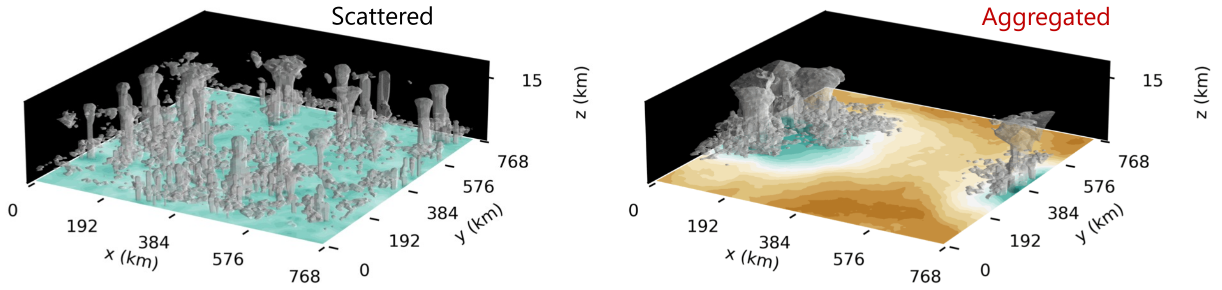

Figure 1. An example of an idealized numerical simulation of moist convection. While randomly scattered convection occurs initially (left), an aggregated cloud cluster spontaneously forms after several days (right). Gray 3D objects indicate isosurfaces of hydrometeors. The 2D shading indicates the vertically-integrated water vapor content.