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Self-organization of tropical convection as a process of coarsening

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Numerical model simulations of the tropical atmosphere in radiative-convective equilibrium have shown simultaneous self-aggregation of convection and humidity, even in the absence of large-scale instabilities or external forcings.

We claim this self-aggregation is a coarsening process of moist and dry regions, driven by a positive feedback between free tropospheric humidity and cumulus convection. Deep convection will form more readily in a moist environment, where the loss of humidity due to entrainment is reduced, and, at the same time, will increase the humidity of the free troposphere by importing moisture from the boundary layer. If horizontal mixing is not rapid enough to overcome this tendency, the atmosphere will tend to separate into increasingly large moist and dry regions through a process of coarsening, where length scales show a power law increase in time.

A simple model for the free tropospheric moisture budget is introduced in terms of a two dimensional Reaction-Diffusion Equation with a global constraint on the average precipitation rate, representing radiative-convective equilibrium. The model includes a subsidence drying, a horizontal transport and a convective moistening term, with the latter representing the positive feedback between convection and humidity. When initialized with a spatially uncorrelated moisture distribution, it depends on the choice of parameter values whether self-organization is observed or a uniform humidity distribution is approached. Using a linear stability analysis we can find critical parameter values separating the two possibilities. In the parameter space leading to self-aggregation, the model shows self-organization of precipitation with two main stages: A coarsening stage where the correlation length grows proportional to time to the power 1/2 and a droplet stage where precipitation is confined to a decreasing number of circular moist regions.

To test the assumptions as well as the predictions made by the simple model, radiative-convective equilibrium simulations over a constant sea surface temperature without large-scale forcing are performed. The numerical model EULAG is used over a 510 km x 510 km domain on an f-plane with periodic boundary conditions and no wind shear. These simulation results are used to test the functional form of each term of the simple model. On the one hand, the subsidence drying and the convective moistening term are in reasonably good agreement with the assumptions. On the other hand, the horizontal transport is not convincingly represented by a simple diffusion term. The idealized simulations show that self-aggregation occurs but only above a critical value of the sea surface temperature, which is in agreement with the prediction made by the simple model that the occurrence of coarsening depends on the choice of parameters. The growth of the correlation length with time in the self-aggregating numerical simulations, suggests that some parts of the evolution can be described by coarsening as they show the predicted dynamical scaling relation.