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Heating-insensitive scale increase caused by convective precipitation

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The origin of intense convective extremes and their unusual temperature dependence has recently challenged traditional thermodynamic arguments, based on the Clausius-Clapeyron relation. In a sequence of studies (Lenderink and v. Mejgaard, Nat Geosc, 2008; Berg, Haerter, Moseley, Nat Geosc, 2013; and Moseley, Hohenegger, Berg, Haerter, Nat Geosc, 2016) the argument of convective-type precipitation overcoming the 7%/K increase in extremes by dynamical, rather than thermodynamic, processes has been promoted. How can the role of dynamical processes be approached for precipitating convective cloud? One-phase, non-precipitating Rayleigh-Bénard convection is a classical problem in complex systems science. When a fluid between two horizontal plates is sufficiently heated from below, convective rolls spontaneously form. In shallow, non-precipitating atmospheric convection, rolls are also known to form under specific conditions, with horizontal scales roughly proportional to the boundary layer height.

Here we explore within idealized large-eddy simulations, how the scale of convection is modified, when precipitation sets in and intensifies in the course of diurnal solar heating. Before onset of precipitation, Bénard cells with relatively constant diameter form, roughly on the scale of the atmospheric boundary layer. We find that the onset of precipitation then signals an approximately linear (in time) increase in horizontal scale. This scale increase progresses at a speed which is rather insensitive to changes in surface temperature or changes in the rate at which boundary conditions change, hinting at spatial characteristics, rather than temperature, as a possible control on spatial scales of convection. When exploring the depth of spatial correlations, we find that precipitation onset causes a sudden disruption of order and a subsequent complete disintegration of organization —until precipitation eventually ceases.

Returning to the initial question of convective extremes, we conclude that the formation of extreme events is a highly nonlinear process. However, our results suggest that crucial features of convective organization throughout the day may be independent of temperature – with possible implications for large-scale model parameterizations. Yet, the timing of the onset of initial precipitation depends strongly on the temperature boundary conditions, where higher temperatures, or earlier, moderate heating, lead to earlier initiation of convection and hence allow for more time for development and the production of extremes.