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Cold pool vortex rings as the “snow plows” of convective triggering

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New convective cells occur at increased likelihood near cold pool gust fronts – as was shown by observations and high-resolution simulations alike. However, pinning down whether this is due to single gust fronts or collisions of multiple ones is much less settled. Conceptual models show that this very distinction, single vs. multi-CP collisions, may be key to the character of the resulting spatial organization of thunderstorms, and related extreme precipitation events.

We assume that the likelihood of triggering convection scales with the height and strength of the updrafts, generated at the gust front of the CP. The faster the CP, the more vigorous updrafts are generated. However, the relation between the ‘first generation’ rain event, the strength of the resulting CP and the intensity of the triggered ‘second generation’ rain event seems not as straight forward. To understand this feedback, we consider a conceptual model that decomposes CPs into three players: (1) a cold air downburst that determines the initial potential energy, (2) a peripheral rotating torus – often referred to as a vortex ring – and (3) the updrafts generated in the ambient air in front of the CP vortex ring. The vortex ring could be caricatured as a snow plow shoveling air into the vertical due to its key role in the dynamic interaction of and between CPs. The introduction of a vortex ring allows us to relate the understanding of cold pool collisions back to the process of vortex interaction - a well-seasoned branch of classical fluid dynamics.

This theoretical vortex ring model is compared to idealized large-eddy simulations. Preliminary results suggest that not only the initial potential energy from evaporation, but also the geometry of the rain cell plays a role for the dynamics and lifetime of the CP. This most likely is a consequence of the division into linear and rotational kinetic energy during the transfer of potential energy to kinetic energy. The linear kinetic energy is dominated by the spreading velocity of the cold pool gust front, while the rotational energy is stored in the peripheral vortex ring. The higher the initial downbursts from the rain event, the higher fraction of potential energy seems to be turned into rotational energy of the vortex ring. The hypothesized vortex ring further seems to reduce mixing at the CP front, letting the CPs spread as coherent structures over times that exceed the lifetimes predicted by conventional models based on the assumption of cylindrically shaped CPs.
Regarding collisions, the simulations show that the maximum vertical velocities resulting from two colliding CPs are up to a factor three higher than at an undisturbed CP front and extend higher into the atmosphere. This supports the formation of deep convective events in contrast to shallow convection clouds that are often observed near single cold pool gust fronts.