Project: **1166**

Project title: **Cloud-cloud interaction in convective precipitation (INTERACTION)**

Principal investigator: **Jan Haerter**

Report period: **2023-05-01 to 2024-04-30 (INTERACTION) [2024-07-01 to 2025-12-31 (DakE continuation)]**

During the report period above a number of computational research projects have been accomplished:

Hoeller et al., (2024) employs a U-Net neural network approach to automate the detection of convective cold pools from satellite-observable fields that are in this study provided by model output from SAM. Thus, this study sets the stage for a subsequent satellite based detection of cold pools for realistic observed data. Convective cold pools (CPs) mediate interactions between convective rain cells and help organize thunderstorm clusters, in particular mesoscale convective systems and extreme rainfall events. Unfortunately, the observational detection of CPs on a large scale has been hampered by the lack of relevant near-surface data. Unlike numerical studies, where fields, such as virtual temperature or wind, are available at high resolution and frequently used to detect CPs, observational studies mainly identify CPs based on surface time series, for example, from weather stations or research vessels—thus limiting studies to a regional scope. To expand to a global scope, we here develop and evaluate a methodology for CP detection that relies exclusively on data with (a) global availability and (b) high spatiotemporal resolution. We trained convolutional neural networks to segment CPs in high-resolution cloud-resolving simulation output by deliberately restricting ourselves to only cloud top temperature and rainfall fields. Apart from simulations, such data are readily available from geostationary satellites that fulfill both (a) and (b). The networks employ a U-Net architecture, popular with image segmentation, where spatial correlations at various scales must be learned. Despite the restriction imposed, the trained networks systematically identify CP pixels. Looking ahead, our methodology aims to reliably detect CPs over tropical land from space-borne sensors on a global scale. As it also provides information on the spatial extent and the relative positioning of CPs over time, our method may unveil the role of CPs in convective organization.

The paper by **Hoeller, Haerter, Da Silva (2024)** provides additional back-up for the assumptions on specific satellite features, such as disruptions of the continuity in the brightness temperature field during the passage of cold pool gust fronts.

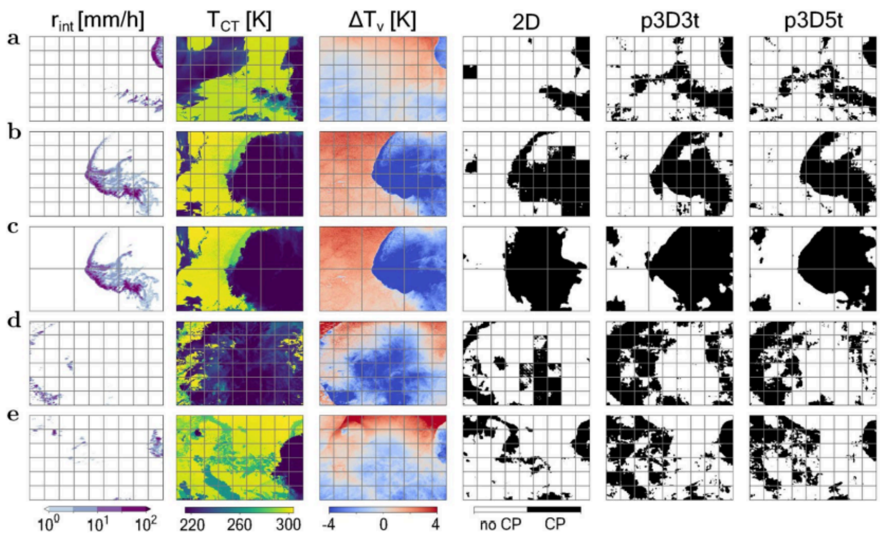

Fig. 1 U-Net based segmentation of cold pools using satellite-observable measurables in SAM simulation data.

Hoeller, Fiévet, Haerter (2024) addresses the tracking of cold pools and the family trees formed by them within high-resolution cloud resolving simulations using the System for Atmospheric Modeling (SAM). The paper employs a k-means and watershed approach to detect the cold pools in simulated near-surface moisture and temperature fields. It provides the ground truth data needed for the U-Net based paper on neural network segmentation of cold pools (Hoeller et al., 2024, see above). Observations and modeling increasingly reveal the key role of cold pools in organizing the convective cloud field. Several methods for detecting cold pools in simulations exist, but are usually based on buoyancy fields and fall short of reliably identifying the active gust front. The current cold pool (CP) detection and tracking algorithm (CoolDeTA), aims to identify cold pools and follow them in time, thereby distinguishing their active gust fronts and the "offspring" rain cells generated nearby. To accomplish these tasks, CoolDeTA utilizes a combination of thermodynamic and dynamical variables and examines the spatial and temporal relationships between cold pools and rain events. We demonstrate that CoolDeTA can reconstruct CP family trees. Using CoolDeTA we can contrast radiative convective equilibrium (RCE) and diurnal cycle CP dynamics, as well as cases with vertical wind shear and without. We show that the results obtained are consistent with a conceptual model where CP triggering of children rain cells follows a simple birth rate, proportional to a CP's gust front length.

The proportionality factor depends on the ambient atmospheric stability and is lower for RCE, in line with marginal stability as traditionally ascribed to the moist adiabat. In the diurnal case, where ambient stability is lower, the birth rate thus becomes substantially higher, in line with periodic insolation forcing—resulting in essentially run-away mesoscale excitations generated by a single parent rain cell and its CP.

The paper by **Da Silva and Haerter (2023)** studies the statistics of mesoscale convective systems over Europe using the IMERG satellite-based dataset. This paper is supported by extensive numerical simulations using WRF to further dissect processes involved in the occurrence of extreme MCS events in Europe.

Vraciu et al., 2024 addresses the temporal evolution of convection as it emerges within the diurnal cycle. It specifically studies a pre-moistening effect caused by previous shallow convection that is found to enable deeper and deeper clouds that eventually penetrate the troposphere depth by forming deep convection. Regions with less pre-moistening do not see as many deep convective events. Properly capturing the transition from shallow to deep convection remains a major shortcoming of numerical weather and climate models due to poor understanding of the physical processes controlling this transition. Although recent studies suggest shallow preconditioning and cold pool feedbacks to be important, these studies are unable to explain the initial phase of the transition. We identify an additional mechanism, namely the interaction between passive cloud volumes (PCV)—old cumulus cloud volumes in the decaying stage—and updrafts, and discuss the potential role of this mechanism in the transition from shallow to deep convection. We show that the number of updrafts interacting with PCV is very large during the transition and the updrafts better preserve their buoyancy due to entrainment of much moister air. We argue that PCV might play an important role in the transition and cumulus parameterizations could therefore benefit from including them.

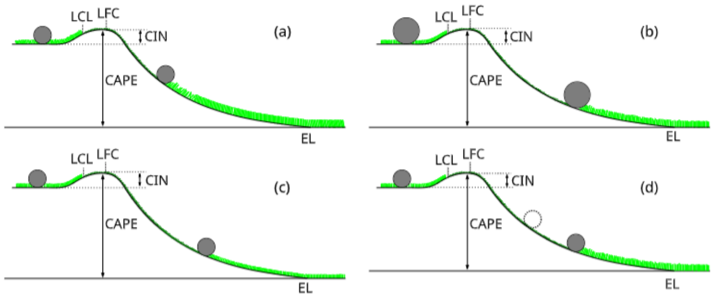

Fig. 2. Conceptual model for the preconditioning of the atmospheric moisture field from passive cloud volumes.

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