Project: **1166**

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

Principal investigator: **Jan Haerter**

Report period: **2021-05-01 to 2022-04-30**

Text: Maximum of two pages including figures. Reports for joint projects may be longer.

During the report period (2021-05-01 to 2022-04-30) a number of computational research projects have been accomplished:

Nissen & Haerter (JGR, 2021) addresses “convective self-aggregation”, a large-scale self-organization phenomenon found for radiative-convective equilibrium simulations. There, the atmosphere spontaneously organizes into segregated cloudy and cloud-free regions. Some evidence exists for how CSA is stabilized, but it had until then not been known how it arises favorably for large domain size, whereas smaller domains do not show the phenomenon. The authors used large-eddy simulations (UCLA-LES) and drew a connection between spatial organization and the interactions between convectively-generated cold pools (CPs). To study this, the authors systematically reduced the simulated rain evaporation to achieve smaller and smaller CP radii. They found that CSA occurs earlier under these changes. A typical rain cell generation time and a minimum radius were detected, within which the formation of subsequent rain cells is suppressed. The authors finally proposed a toy model that describes how CSA arises earlier on large domains: when two CPs of given radii collide, they form a new convective event, which then can again cause further collisions. These findings imply that interactions between CPs may explain the initial stages of CSA.

The paper provides a new perspective on the mechanism that gives rise to convective self-aggregation and explains model grid resolution and domain sizes affect CSA through cold pool interaction.

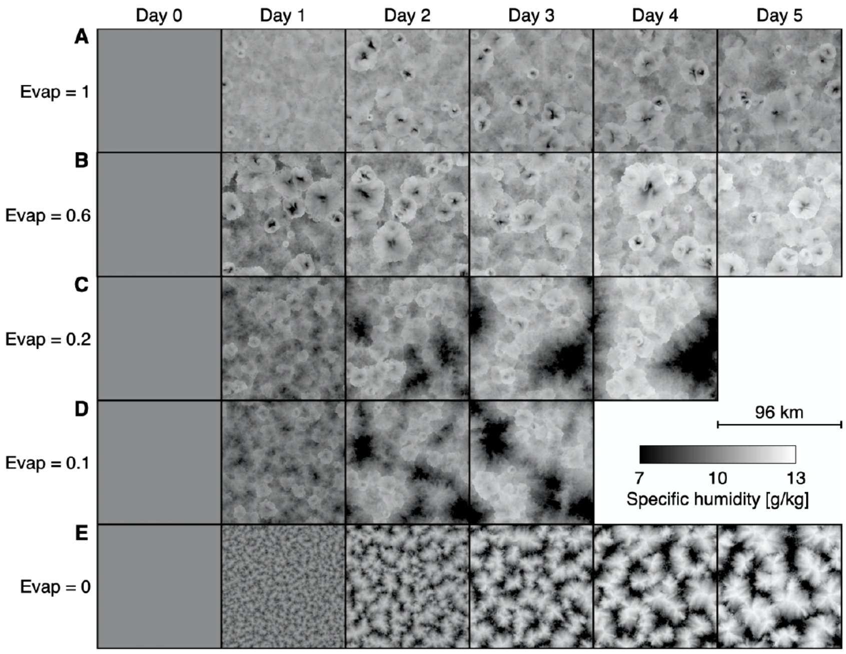

Fig. 1, ***Formation of convective self-aggregation in large-eddy simulations.*** *Panels show near-surface humidity for a suite of simulations with varying rain evaporation rates (rows) for different days (columns) after the start of the simulation. Notably, rain evaporation, thus cold pool formation, has a strong effect on the organizational pattern and reduced rain evaporation gives rise to more rapid segregation into moist and dry patches (e.g., panel D). Notably, complete removal of rain evaporation (E) leads to a qualitatively different pattern, which is now studied further.*

In an accepted study (**Jensen, Fiévet, Haerter, JAMES, 2022**) the authors study the connection between periodically-forced convection, which is typically observed over tropical continental areas under diurnal heating of the land surface, and more constant-temperature sea surfaces. To this end, a substantial suite of numerical simulations, carried out using UCLA-LES, was employed to study a range of questions. In short, it was found that the diurnally forced simulations gave rise to strong organizational effects, where so-called mesoscale convective systems (MCS) emerge spontaneously (see also:

Haerter, Meyer, Nissen, npj Climate and Atmospheric Science, 2020). These MCS show a nearly checkerboard-like pattern on any given day. However, from one day to the next the pattern is spatially anticorrelated, such that checkerboards alternate at a one-day time lag. Moreover, when giving the system approximately 10 days to organize, areas of overall reduced moisture emerge, where rainfall is suppressed indefinitely - much like the dry patches that are typical for convective self-aggregation (CSA). The effect described is enhanced for high spatial model resolution but disappears at lower resolution. Conversely, when shifting to oceanic boundary conditions, the effect also disappears. Additionally, a form of hysteresis effect was detected, where patterns formed under the diurnal cycle persist, when the entire system is shifted over a sea surface.

The paper has implications for the formation of tropical cyclones, which may emerge over continents (as MCS) and are then advected westward over the sea, where they grow into tropical cyclones.

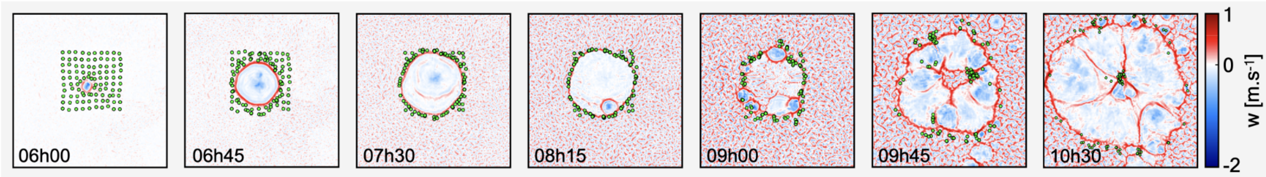

Fig. 2, ***Emergence of a mesoscale convective system (MCS) in diurnal cycle simulations, mimicking a tropical land surface.*** *The heat map shows the near-surface vertical velocity field. Red line structures indicate cold pool gust fronts. The green points represent tracer particles to track the dynamics of an evolving MCS. Initially, a single cold pool emerges (06h45) which eventually triggers several additional cold pools near its gust front. In a second stage, another generation of cold pools appears, building the resultant MCS further.*

The study by Jensen et al. has already prompted a theoretical modeling study (**Niehues, Jensen, Haerter, Physical Review E, 2022**) where a simple toy model for fixed-energy sandpiles is proposed to explain the redistribution of moisture in a spatiotemporal cellular automaton. The model envisions that each site of a 2D square lattice is populated by an initially random "energy," which the authors take to represent moist static energy. When the energy at a given site exceeds a threshold, toppling of the energy on this site to the four nearest neighbors occurs. To incorporate that the diurnal cycle synchronized activity at a fixed one-day period, the toy model allows all possible topplings to take place at once. The energy is thus redistributed and another update timestep may occur. The updating is repeated many times until a steady state or limit cycle self-organizes. A rich phase diagram evolves as a function of the mean energy per site. The authors discuss possible implications for atmospheric self-organization.

publications in preparation:

(i) A substantial suite of cloud-resolving simulations have been carried out using the System for Atmospheric Modeling (SAM) to capture the cross talk between diurnal convective triggering and a model Hadley circulation. These simulations employ a spatially varying surface temperature to mimic the temperature gradient between the equatorial and the sub-tropical regions. Additionally, temporal variation is supplied to mimic the diurnal cycle. The resultant set of simulations shows a complex interplay between periodic convective forcing (24h-period) and a system-intrinsic eigenfrequency, which is determined by the system size.

(ii) slab-surface simulations have been carried out using SAM to study the effect of surface feedbacks on convective organization. Additionally, a spatial interpolation scheme allows for restarting simulations at a given time using a range of grid resolutions. The aim is to gain insight into the effect of model resolution on the formation of mesoscale convective systems and larger-scale convective self-organization.

References

Jensen, Gorm Gruner, Romain Fiévet, Jan O. Haerter. "The diurnal path to persistent convective self-aggregation", Journal of Advances in Modeling Earth Systems, *in press*.

Nissen, Silas Boye, and Jan O. Haerter. "Circling in on Convective Self-Aggregation." *Journal of Geophysical Research: Atmospheres* 126.20 (2021): e2021JD035331.

Haerter, Jan O., Bettina Meyer, and Silas Boye Nissen. "Diurnal self-aggregation." *npj Climate and Atmospheric Science* 3.1 (2020): 1-11.

Niehues, Jakob, Gorm Gruner Jensen, and Jan O. Haerter. "Self-organized quantization and oscillations on continuous fixed-energy sandpiles." *Physical Review E* 105.3 (2022): 034314.