Project: **1166**

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

Principal investigator: **Jan Haerter**

Report period: **2022-05-01 to 2023-04-30**

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

Jensen, Fiévet, Haerter (JAMES, 2022) addresses diurnally induced convective self-aggregation. In this work we show that an imposed surface temperature diurnal cycle can cause the spontaneous self-organization of mesoscale convective systems (MCS). Over the course of several model days, these MCS act to redistribute near-surface moisture, and thus buoyancy, in ways that at first appear as a day-to-day anticorrelation in moisture patterns. However, eventually sub-regions appear that remain continuously dry (precipitation is absent here) and do not recover, even for extended periods of several weeks. Conversely, other regions show pronounced rainfall and do not dry out. This effect is reminiscent of convective self-aggregation, which however is normally found for constant SST set-ups and coarse horizontal resolution. When switching to a constant SST set-up, we find in our case convective self-aggregation does not occur, and can only be recovered for much coarser resolution. Thus, in the limit of fairly high horizontal resolution (the realistic limit), the diurnal cycle seems important in bringing about persistent moisture pattern formation. This is a new effect which may be relevant for the transition from tropical continent to ocean, and possibly the formation of tropical cyclones (Fig. 1).

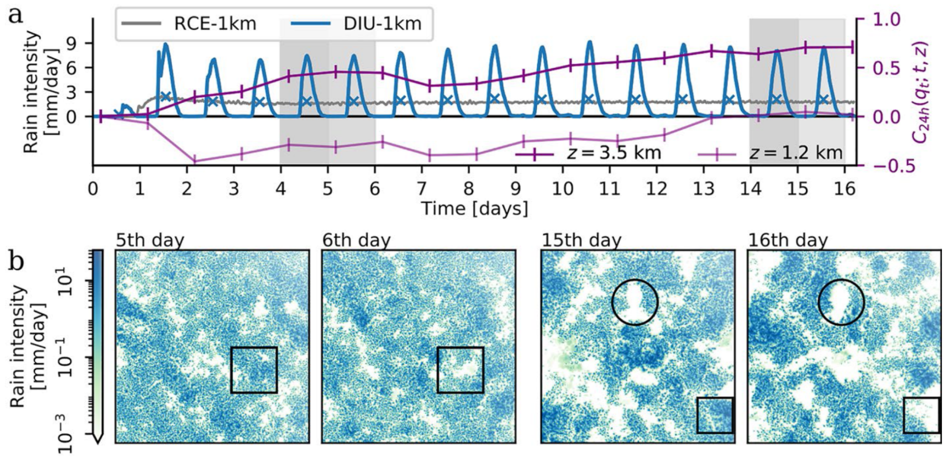

Fig. 1, **Spatio-temporal organization by diurnal surface temperature oscillations.** All data correspond to the DIU-1 km experiment, except panel e and the gray curve in panel a which represent the radiative–convective equilibrium RCE-1 km experiment for comparison. (a) Time series of domain-mean rain intensity in DIU-1 km (blue curve) and RCE-1 km (gray curve). Blue ×-symbols indicate daily-average rain intensity in DIU-1 km. Dark and faint purple curves show time series of 24-hr Pearson correlations, C24h(qt; t, z), for total water mixing ratio, qt, for z = 3.5 km and z = 1.2 km, respectively, with t taken at 4 hr on any given day (Details: Methods). (b) Daily surface rainfall intensity for DIU-1 km, temporally averaged over the 5th, 6th, 15th, and 16th day. Corresponding averaging periods indicated by gray shades in (a).

Wave-convection interaction (Haerter & Fiévet). In a preprint *(under peer review)*, we investigate the interaction between the diurnal cycle and the large-scale circulation. To idealize, a double periodic model domain is supplied with a surface temperature gradient, such that a line-like area (mimicking the equator) has a peak in surface temperature. A persistent large scale circulation builds up, but notably shows intrinsic oscillations, e.g., in domain-mean precipitation rate. We find the oscillation frequency to scale with linear system size. We then impose a diurnal cycle by allowing each grid box surface temperature boundary condition to oscillate at a 1-day period, which also influences the formation of precipitation (Fig. 2). Thus, the two frequencies (intrinsic vs. forced) interact, however, they do so in initially non-obvious ways, with certain domain sizes displaying stronger influence of the diurnal cycle than others. To better understand the interaction we build a simple forced and kicked harmonic oscillator model, which is able to reproduce various aspects of the actual cloud resolution simulations. Our results may have implications for the understanding of large-scale climate modes and occurrence of oscillations.

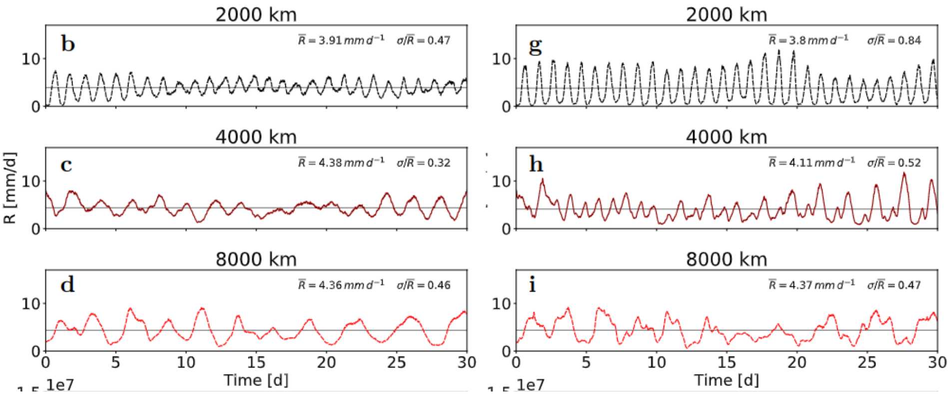

Fig. 2, **The effect of the diurnal cycle on precipitation variability.** Timeseries of horizontal-mean surface precipitation intensity for variable meridional domain sizes Ly as labeled on top of each panel for the 30-day analysis period. The latitudinal temperature difference $\Delta Ts,lat$=10 K in all simulations shown. b—d, Simulations corresponding to constant SST. g—i, Simulations corresponding to the diurnal case.

publications in preparation:

Land-to-ocean advection (Kruse). A substantial suite of cloud-resolving simulations were carried out using the System for Atmospheric Modeling (SAM): Idealized experiments in the report period were focused on the transition of MCSs from a land to ocean, specifically in tropical Africa and the adjacent Atlantic during hurricane season (July-Aug-Sept), when there is a constant westward advection of deep convection generated over land and moved onto the sea. This helped understand factors necessary for the maintenance of an aggregated deep convective structure in the transition from a favorable environment for clustered deep convection (land) to a less favorable environment (ocean).

Land-atmosphere coupling (Engelbrecht). We found that in an idealized, checkerboard framework of dry/wet soil moisture: (i) There is an increased probability of CP collisions due to specific vegetation/soil moisture patterns; (ii) Mesoscale sized dry soil moisture or "deforested" areas focus convection (by thermal mesoscale circulations) which promotes the formation of very large and strongly negatively buoyant CPs that can travel further, extending its range of influence. Simultaneously, increased interaction between CPs and thermal mesoscale circulations occur such that CPs develop at the breeze front which accelerate the propagation speed (Rieck et al., 2015) toward the center of deforested 'islands', increasing the likelihood of heavy precipitation there.

Idealized monsoons and island convection (Colin). We conducted three series of idealized monsoon simulations over an aquapatch. In the first, we ran equilibrium simulations of the monsoon forced by a permanent solstice situation. We varied the position of the SST peak, the use (or not) of convective parameterization, and various other domain and simulation options. In the second series, we generated sensitivity tests by varying the intensity of the SST gradient with latitude. In the third series, we ran simulations of monsoon as forced by an idealized seasonal cycle. We varied the boundary conditions (ocean or land), and the use or not of convective parameterization.

European MCS dynamics (Da Silva). In the previous allocation period we performed two high resolution (600 m) case study simulations of European MCS (manuscript in preparation). In one of them, we found thunderstorm development a few tens of kilometers ahead of the MCS which then merged the MCS in a later stage due to the development of a mesoscale surface low-pressure, in accordance with what was observed and which led to local floods.

References

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