Project: **1053**

Project title: **CRC 1211 - A03: Statistical-dynamical modelling of Aeolian processes in the Atacama Desert over geological time scales and their implications to life at the dry limit**

Principal investigator: **Mark Reyers**

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

In the second phase of the Collaborative Research Centre 1211 (CRC1211 "Earth – Evolution at the dry limit"; funding period 2020-07-01 to 2024-06-30) we focus on paleo-climate simulations with the regional climate model WRF in the sub-project A03, using PMIP4-CMIP6 global climate model output as boundary conditions. The work is motivated by the fact that the hyper-aridity in the Atacama Desert was punctuated by more pluvial phases in the past. However, the processes leading to these climate shifts are still largely unknown. Therefore, we address two scientific questions in our sub-project:

(i) can we identify these paleo-climate episodes of increased rainfall also in climate models, and

(ii) if so, what are the key driver for this increase?

In the report period we have simulated two PMIP4 experiments with the WRF model: the last glacial maximum LGM (21 ka) and the mid-Pliocene (3.2 Ma). To examine paleo-climate changes relative to present day conditions, we additionally downscaled CMIP6 historical experiments with WRF. For each experiment, selected 30-year periods were simulated.

In this report we will focus on the findings for the mid-Pliocene, as this episode is of great interest for researchers from different disciplines. From the GCMs contributing to the mid-Pliocene experiment, we selected the CESM2 model from NCAR, as this model realistically captures the occurrence of mid-tropospheric troughs off the Atacama coast, and as it reveals a particular strong SST warming in the ENSO region and at the north-western coast of South America for the mid-Pliocene, which qualitatively agrees well to PRISM reconstructions. Via a double one-way nesting the CESM2 output is downscaled to a horizontal resolution of 10 x 10 km. Figure 1 shows the climate change signal (mid-Pliocene minus historicals) for mean annual and seasonal rainfall. A general increase of rainfall is simulated for the hyper-arid core of the Atacama Desert (Figure 1a). This is in accordance to climate proxies from several locations in the Atacama Desert, which point to increased rainfall during the Pliocene (e.g. Amundson et al. 2012; Hartley and Chong, 2002). The simulated increase is mostly due to more rainfall in austral winter during the mid-Pliocene (Figure 1d). We will therefore focus on this season in the following.

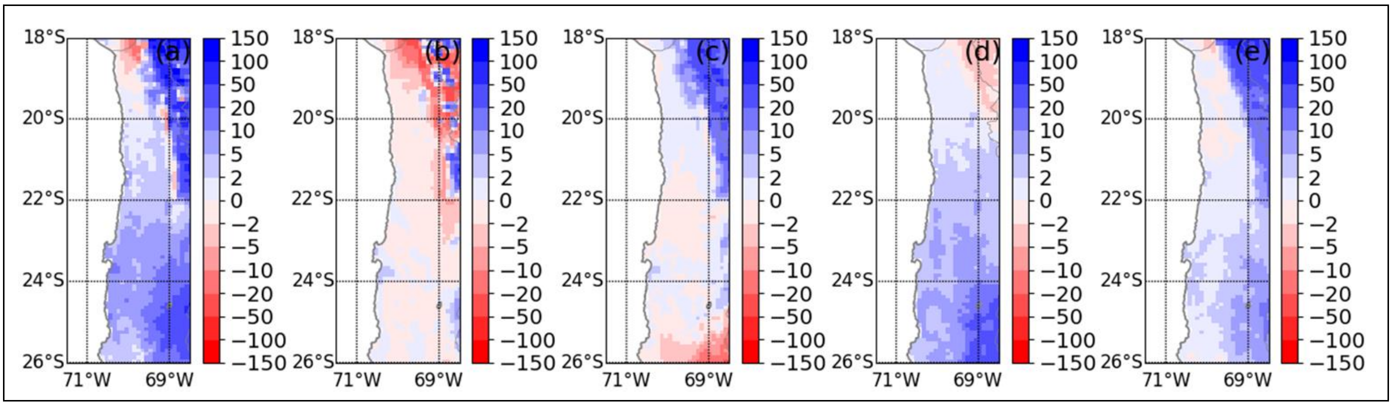

Figure 1: Climate change signal (mid-Pliocene minus historicals) for (a) mean annual rainfall and (b-e) seasonal rainfall. (b) DJF, (c) MAM, (d) JJA, and (e) SON.

It turned out that the rainfall increase in winter is caused by more intense rainfall extremes in the mid-Pliocene (not shown). When analysing the strongest rainfall events in both, the mid-Pliocene and the historicals, we found that the extreme rainfall events in the mid-Pliocene are often associated with so-called moisture conveyer belts (MCBs, elongated bands of strong poleward water vapor fluxes) coming from the tropical Southeast Pacific at the foreside of mid-tropospheric troughs. In contrast, rainfall extremes in the historicals are much weaker and are rather connected to MCBs from the subtropical Pacific. In a recent study we could demonstrate the important role of MCBs for rainfall in the Atacama Desert under present day conditions (Böhm et al. 2021). This leads to the question whether there are systematic differences in the characteristics of MCBs during the mid-Pliocene and under present-day conditions. With this aim, we systematically clustered integrated water vapor fluxes using a combination of self-organizing maps and the K-means clustering. For the mid-Pliocene we found cluster which represent MCBs from the tropical Pacific (Figure 2, see red boxes), and which do not occur in the historicals (not shown).

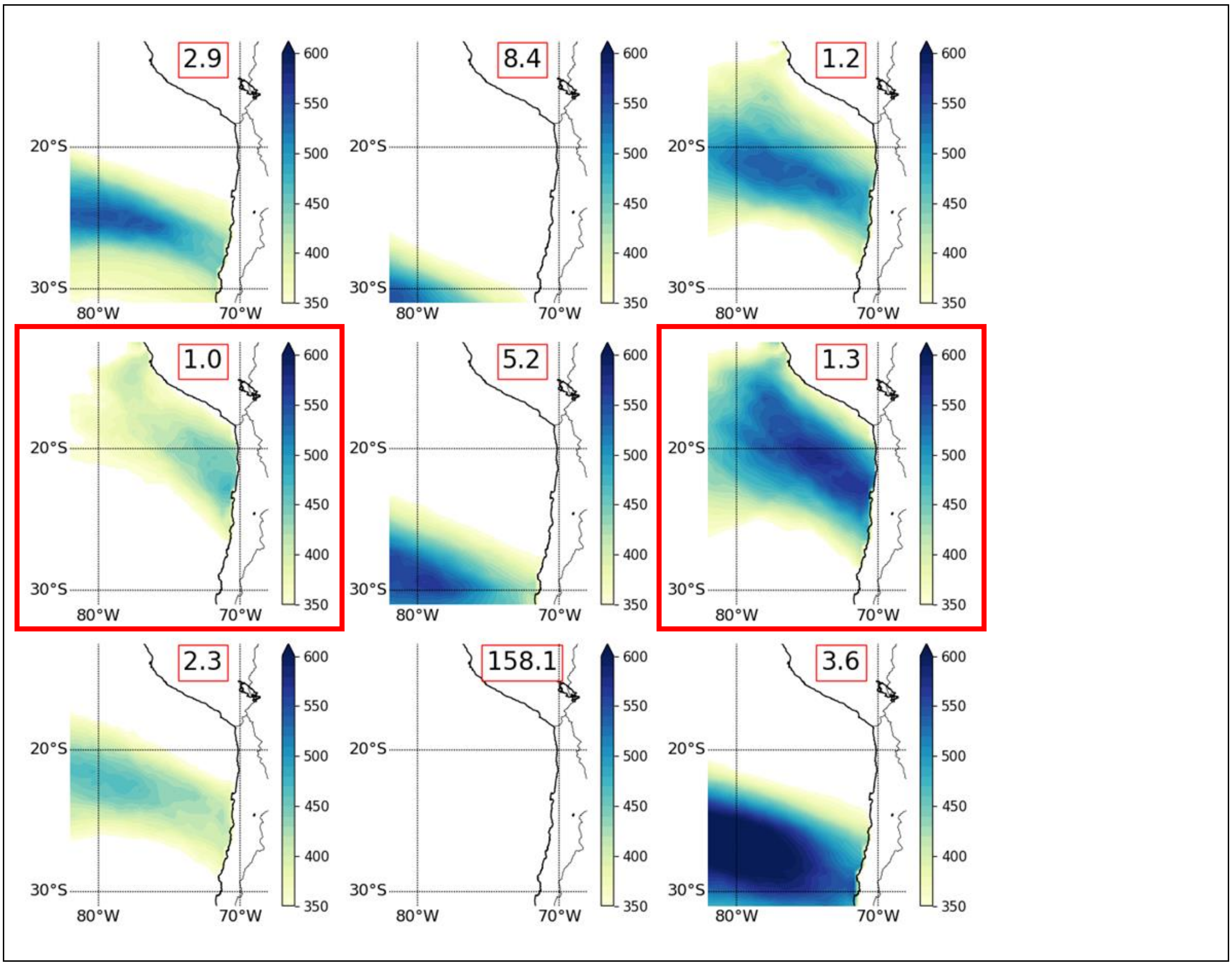

Figure 2: Clusters for integrated water vapor fluxes JJA in the mid-Pliocene as obtained from a methodology combining self-organizing maps and K-means. MCBs from the tropical Pacific are marked with red boxes (cluster 4 and cluster 6). Numbers show the mean frequency of occurrence per winter.

This is due to stronger troughs off the Atacama Desert paired with warmer sea-surface temperatures in the tropical Eastern Pacific and along the northwest coast of South America during the mid-Pliocene, which are favourable for the development of MCBs. The winter rainfall amount associated with MCB cluster 4 and 6 (red boxes in Figure 2) in the mid-Pliocene far exceeds the present-day total rainfall amount (not shown). We therefore conclude that tropical MCBs are a key driver for increased rainfall in the Atacama Desert and should be assessed for future climate. Further, our results clearly demonstrate the benefit of using high-resolution simulations for the paleo-climate in this complex region. A joint paper showing the most important results for the mid-Pliocene is currently in process and will be submitted in summer 2022.

References:

Amundson R, Dietrich W, Bellugi D, Ewing S, Nishiizumi K, Chong G, Owen J, Finkel R, Heimsath A, Stewart B, Caffee M, 2012: Geomorphologic evidence for the late Pliocene onset of hyperaridity in the Atacama Desert, *GSA Bulletin*, **124**, 1048–1070. doi: 10.1130/B30445.1

Böhm C, Reyers M, Knarr L, Crewell S, 2021: The role of moisture conveyor belts for precipitation in the Atacama Desert. Geophysical Research Letters, 48, e2021GL094372. doi:10.1029/2021GL094372

Hartley A, Chong G, 2002: Late Pliocene age for the Atacama Desert: Implications for the desertification of western South America, Geology, 30, 43-46. doi: 10.1130/0091-7613(2002)030<0043:LPAFTA>2.0.CO;2