Project: **1201**

Project title: **Regional Paleoclimate in the EM, the ME and Nile based on COSMO-CLM**

Principal investigator: **Eva Hartmann**

Report period: **2024-11-01 to 2025-10-31**

1. Overview

The Eastern Mediterranean and the Middle East (EMME) and the Nile River basin (Nile) are of profound interest for the study of the relationship between historical events and climate variability and change. Recent studies revealed that paleoclimate modelling with coarse horizontal resolution cannot fully help to understand the complex interactions between the atmospheric circulation, climate variables at the local scale, and connect climate impacts that may trigger or contribute to major social-historical events. Thus, we developed an adjusted paleoclimate version (orbital, solar and volcanic forcings, greenhouse gas concentrations and land use changes) of the RCM COSMO-CLM (CCLM). After several test simulations to identify the appropriate settings and performance of the model in the first phase of the project, the implemented forcings were tested in a sensitivity experiment. The driving MPI-ESM-LR simulation with 1.875° horizontal resolution for the provision of CORDEX-compliant output for the complete period and a second realisation for the common era has been finished. The complete transient RCM simulation until the year 1850 CE is ready and was analysed with a strong focus on large volcanic eruptions.

2. Completion of the transient simulation from 500 BCE to 1850 CE

In 2021, we started a transient CCLM simulation on Mistral with a beginning in the year 500 BCE. For this purpose, we used the output of a CMIP6-compliant MPI-ESM-LR simulation as input and implemented the therein used external forcings (orbital, solar, volcanic, greenhouse gases and land-use change) also in the CCLM. In 2024, after the changeover to Levante, which involved a number of hurdles and many months of apparently infinite simulations, we finally reached the year 1850 with the CCLM simulation. This is the first RCM simulation of its kind, meaning transient for a 2350-year period, without breaks, changes in input, external data, model or any other factor. Results for the temperature and precipitation of the complete domain are shown in Figure 1 as anomalies to the Common Era mean. The largest temperature anomalies can be seen in the 6th century CE and the 5th century BCE, which are both discussed in our sub-projects. Precipitation was remarkably higher in the centuries BCE. After that, there is a large variability with no clear signal.

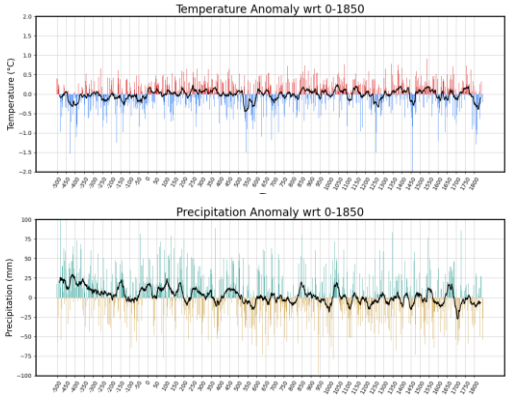

Figure 1. Annual mean temperature (top) and total precipitation (bottom) anomaly wrt the CE 1-1850 for the complete domain

3. Impact of large volcanic eruptions on the climate

In different collaboration projects, we focused on periods with large volcanic eruptions and studied the climatic response shown by the RCM. Those are, for example, the BCE eruptions in 426 and 43 BCE in the Aegean Sea and the Black Sea regions. In Figure 2 are shown the annual mean 2m-temperature (top) and the seasonal temperatures (bottom) as anomalies to the mean of the centuries before the Common Era (500-1BCE). The temperature shows a clear drop after the volcanic eruption. This applies to both sub-domains and all seasons. While the effect is strongest in winter and spring, summer temperature, on the other hand, is less impacted.

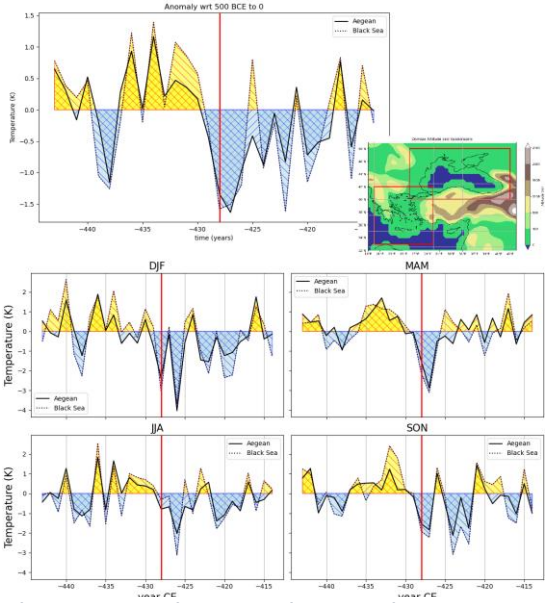

Figure 2. Annual mean and seasonal mean temperatures of the Aegean and the Black Sea for the volcanic eruption in 426 BCE as anomaly wrt 500 - 1 BCE

Other examples are the large volcanic eruptions around the years 540, 1257 and 1458 CE, where in all cases the temperature clearly decreases after the volcanic eruption. Analyses like this are possible for the whole period 500 BCE to 1850 CE and on a very regional scale for the whole EMME-like domain of our simulation.

4. Climate of the 6th (and 7th) century

The climate of the 6th and 7th centuries was influenced by major volcanic eruptions in the years 536, 540, 574, 626, and 682. The cooling effect of the volcanic eruption is highest after the two consecutive eruptions in the years 536 and 540. The impact of those cluster volcanoes amplifies; however, the strength of the signal varies in different areas and seasons. Because this cooling is often discussed in literature, we also take a closer look at the climate of the 6th century and its following years/decades. In Figure 3, this is done for the monthly mean temperature of the EMME domain with two different realisations of both the driving ESM and the RCM. The temperature decreases after each of those eruptions. Since the two eruptions in 536 and 540 occurred very shortly after each other, the effect is amplified and is visible for a longer time of up to 15 years, until about 550. The length of the cooler period is also strongly debated in the literature. The two realisations help to justify that the shown results are not only an artefact of one simulation but are very reasonable. When looking into climatic variables with smaller scale effects as for example precipitation, the advantage of the RCM comes even more into play. While the spatial mean does not show signals after the volcanic eruption, some specific regions do.

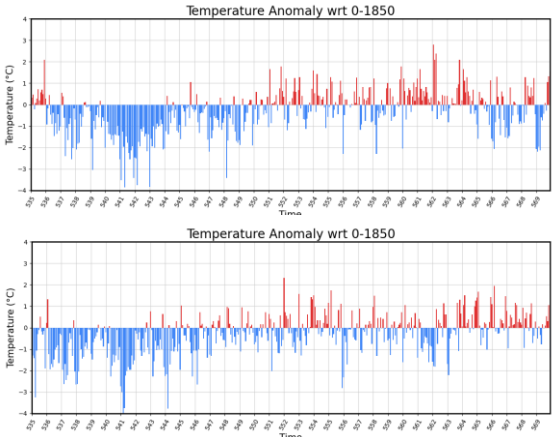

Figure 3. Monthly mean temperature of the EMME in the 6th century wrt the CE 1-1850 in the first and second realization

5. Summary and Outlook

In this project, we have performed so far a) simulations with CCLM to define optimum settings for the paleo-climate simulations b) sensitivity tests for the different forcings c) a transient CCLM simulation from 500 BCE to 1850 CE and d) the driving global MPI-ESM-LR, CMIP6 compliant, simulation as well as an additional second realization of the driving and the RCM model for limited periods. This enables us to study the climate of the last 2500 years on a regional scale. The completed transient run is the first continuous and transient RCM simulation of the last 2500 years that allows for a broad spectrum of studies of the climate of the past. This is imperative for the study of interesting periods with respect to climate, society and history in the EMME and the Nile River basin.

Due to a last-minute change in the people involved in the project, we could not further extend to China. Instead, we expanded the expertise of our project in the direction of statistical methods. To this end, we focus on large-scale mechanisms and employ state-of-the-art dimensionality reduction techniques. Specifically, we apply regularized generalized canonical correlation analysis (Tenenhaus and Tenenhaus et al., 2011), an extension of classical approaches such as empirical orthogonal functions and canonical correlation analysis. This method enables the representation of complex physical phenomena and multivariate interrelationships in a more comprehensive manner.

A manuscript with a focus on the 426 BCE eruption, including results of our simulation, has been submitted by an international collaborator. Manuscripts with a focus on the 6th century CE are in preparation and should soon be ready to publish. The manuscript describing the implementation of the forcings was recently published in Climate of the Past.

In the coming months, we will focus on further analysis of the long transient simulation together with second realisations and nesting of special periods and areas. Additionally, we will start a new collaboration in another international project. For this, we will need new transient simulations and ensembles with the ESM and our modified RCM for different periods in the past for the EURO-CORDEX domain.

6. Literature

Hartmann, E., Zhang, M., Wagner, S., Adakudlu, M., Luterbacher, J., and Xoplaki, E.: On the implementation of external forcings in a regional climate model – a sensitivity study around the Samalas volcanic eruption in the Eastern Mediterranean/Middle East, Clim. Past, 21, 1699–1724, https://doi.org/10.5194/cp-21-1699-2025, 2025