Project: **1201**

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

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Report period: **2022-11-01 to 2023-10-31**

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, owing to the broad-spectrum instrumental time series, documentary information and natural archives available in the area. 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, the RCM COSMO-CLM (CCLM), in an adjusted paleoclimate version (orbital, solar and volcanic forcings are adjusted), and accordingly greenhouse gas concentrations and land use changes, is used in this project. After several test simulations for the implementation of the forcings and present-day simulations to identify the appropriate settings and testing the 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 reaslisation for the common era are finished. The transient RCM simulation has reached the year 1500 CE. Completed experiments details can be seen in Table 1.

Table 1. Overview of the performed simulations

Experiments	*Model*	*Description*	*Resolution*	*Simulation years*
Samalas sensitivity	*CCLM*	*Individual forcings, full forcing, standard conf.*	*0.44*	*1255-1264 (7*10)*
mythos500bc	*MPI-ESM*	*transient (CMIP6)*	*1.875*	*500 BCE – 1850 CE (2350)*
r2_mythos500bc	*MPI-ESM*	*transient (CMIP6)*	*1.875*	*1 CE – 1850 CE (1850)*
mythos500bc_cclm	*CCLM*	*transient*	*0.44*	*500 BCE – 1500 CE (2000)*
r2_mythos500bc_cclm	*CCLM*	*transient*	*0.44*	*500 CE – 700 CE (200)*

2. Samalas sensitivity experiment

In Figure 1 the 2m annual air temperature of the EMME region (domain after Zittis et al., 2022) is shown for the 10-years sensitivity experiment for the Samalas volcanic eruption. The simulated temperature decreases after the eruption in September 1257. The differently forced CCLM simulations all show a similar order of decrease. After some colder years, the temperature returns to values comparable to those prior the eruption. After the volcanic eruption the volcanic forcing has, as expected, the largest impact which is also shown in the fully forced simulation. Both show the coolest temperatures of the sensitivity study in the year of the eruption and the four following years.

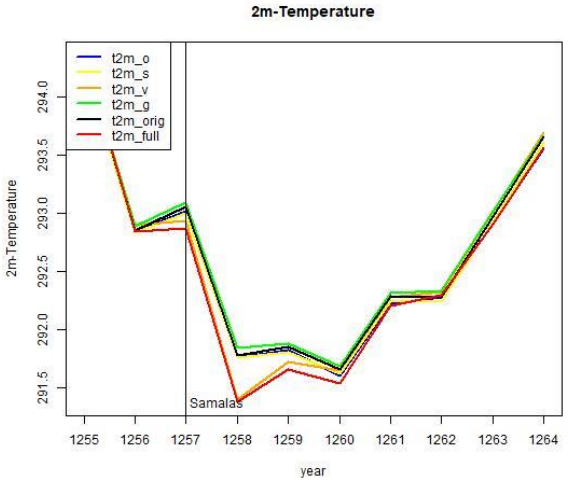

Figure 1. EMME annual 2m air temperature ('_orig'=no, '_o'=orbital, '_s'=solar, '_v'=volcanic, '_g'= greenhouse gas, '_full'=full forcing).

3. Differences between the pre-industrial (PI, 1800-1850 CE) climate and the climate of the early roman period (ERP, 400-362 BCE)

Differences between the ERP (400-362 AD) and pre-industrial (1800-1850 CE) climate conditions are evaluated in terms of mean and variance for both precipitation and temperature of the CCLM reconstruction data. The Student's t-test at each grid point and the 95% significance level is used to assess differences between the two periods. In Figure 2, we are showing the mean and standard deviation differences of the

2m air temperature and the total precipitation between the ERP and PI. Mean air temperature statistically significant differences for winter (DJF) and summer (JJA) characterize larger areas in the Sahara and the Tropics, respectively. Summer temperature variability appears slightly decreased for the PI climate, whereas CCLM simulates overall higher variability for winter. The precipitation differences are mainly not statistically significant but the standard deviation is differently distributed especially in summer.

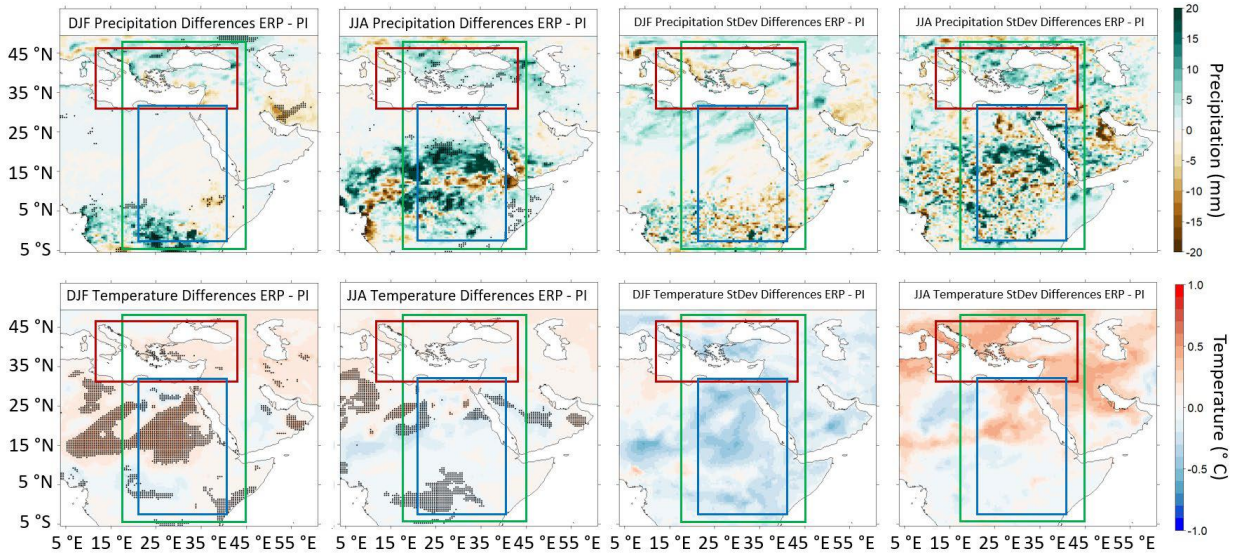

Figure 2. Mean temperature and total precipitation and standard deviation differences between ERP and PI climate for winter (DJF) and summer (JJA) in the EM (red), NR (blue) and EMNR (green) with black dots indicating statistical significance at the 95% confidence in students t-test.

4. Climate of the 6th and 7th century

The climate of the 6th and 7th century was influenced by major volcanic eruptions in the years 536, 540, 574, 626, 682. As can be seen in the timeseries of both realisations of the models in Figure 3, the annual mean 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 precipitation which is not shown here does not have such a clear effect on the whole domain but is visible more on the regional scale.

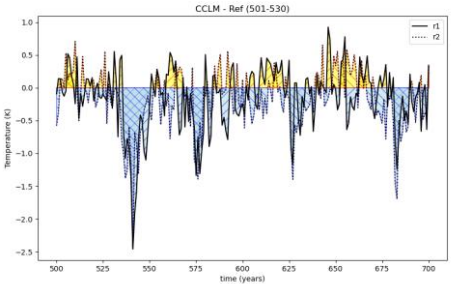

Figure 3. Annual mean temperature of the EMME in the first and second realisation of simulations as anomaly wrt 501-530

5. Summary and Outlook

In this project, we 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 1500 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 continuation of the transient simulation in the next months is imperative for the study of interesting periods with respect to climate, society and history in the EMME and the Nile River basin. The completed run will be 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.

6. Literature

Zittis, G., Almazroui, M., Alpert, P., Ciais, P., Cramer, W., Dahdal, Y., et al. (2022). Climate change and weather extremes in the Eastern Mediterranean and Middle East. *Reviews of Geophysics*, 60, e2021RG000762. https://doi.org/10.1029/2021RG000762

Hartmann, E., Zhang, M., Adakudlu, M., Wagner, S., Xoplaki, E., Implementing External Climate Forcings into the COSMO-CLM~5.0 - A Sensitivity Study around the Decade of the Samalas Volcanic Eruption in the Eastern Mediterranean and Middle East. In prep.

Zhang, M., Hartmann, E., Wagner S., Adakudlu, M., Luther, N., Zerefos C., Xoplaki, E., The climate of the Eastern Mediterranean and the Nile River basin 2000 years ago using the fully forced COSMO-CLM simulation., Clim. Past Discuss. [preprint], https://doi.org/10.5194/cp-2023-77, in review, 2023.