Climate of the Past Discussions

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Review of the manuscript by by Ram Singh et al.

Anonymous Referee #2

Referee comment on "Investigating hydroclimatic impacts of the 168–158□BCE volcanic quartet and their relevance to the Nile River basin and Egyptian history" by Ram Singh et al., Clim. Past Discuss., https://doi.org/10.5194/cp-2022-25-RC2, 2022

Review of the manuscript

Investigating hydroclimatic impacts of the 168-158 BCE volcanic quartet and their relevance to the Nile River basin and Egyptian history

by Ram Singh et al.

Submitted for publication in *Climate of the Past*

General:

The manuscript investigates the hydrological response of a series of volcanic eruptions during the 2nd century BC, focusing also on the societal impacts of the eruptions in the context on the Egyptian history. In addition to empirical evidence, authors use the output of an ensemble of simulations with a comprehensive Earth System Model, simulating potential trajectories of plausible climatic scenarios in the aftermath of the volcanic eruptions.

The manuscript is very well written, material and methods are comprehensively presented and results are discussed within the context of present literature. Therefore, I think the manuscript should be published with some minor comments addressed below. Most specifically, the comments relate to the modeling and statistical part, including a more nuanced discussion and interpretation of model results in the context of past civilizations. Moreover, I would encourage the authors to reduce the overall length of the manuscript by summarizing dedicated paragraphs or moving parts into the supplementary material whenever possible.

Specific comments:

1 Introduction:

l. 114: Linking volcanic eruptions directly to revolts or warfare might be afflicted with high degree of uncertainty: In past societies single upheavals or riots always happened – likewise, a close inspection of ice core records will typically also yield one or two eruptions per decade. Linking both just because of their synchronicity might be co-incidental. The processes of both, the impact of the volcanic eruption on climate and the prerequisites leading to riots or revolts during the period previous to the volcanic eruption can have multiple drivers and causes. Therefore this line of evidence in terms of wiggle matching single historical events with volcanic outbreaks should be handled with care.

l. 118: "hydroclimatic shocks" should be replaced by "pronounced changes in hydrology"

l. 120: The hydrological cycle after very large explosive tropical eruptions is not only driven by the north-south contrast of the monsoon (the African monsoon system is far more complex in this respect), rather than less evaporation caused by lower temperatures according to the Clausius-Clapeyron equation.

ll. 134–170: This whole section should be shortened/summarized and focus on the very area of research, as outlined in the section ll. 171–186.

ll. 190–205: This section should also be shortened to the most relevant information introducing the content of the subsections.

In addition to the points mentioned above there are two additional points that should be mentioned already in the introduction:

1) The importance of natural climatic/hydrological variability in the occurrence of Nile floods and their counterparts. This is important to put the proposed "hydrological shocks"

in the aftermath of volcanic eruptions into context of externally undisturbed periods.

2) A more differentiated introduction of the impact of large explosive tropical volcanic eruptions vs. medium-to-small sized high latitude northern/southern hemisphere eruptions. This relates for instance to the overall amount of cooling, the potential for a dynamical response on natural modes of climate variability (cf. North Atlantic Oscillation/El Nino). Introducing this difference in location and magnitude will also help to better explain the different climatic and hydrological response of the initial tropical eruption E1 and the following high-latitude eruptions E2 – E4 that are presented and discussed further down in the manuscript.

2.1 Model Description

l. 226: How is the impact of volcanic eruptions implemented ?

2.2 Experiment Design

l. 233: What s the rationale using the PMIP4 mid-Holocene protocol ? – maybe the authors could explore in one or two sentences why especially the vegetation is closer to mid-Holocene conditions rather than the one representing the situation during pre-industrial times.

l. 272: The authors could add some effects on the timing of the eruption, i.e. when the eruption date is set to a summer date, especially for the potential effects on monsoon and the northern hemispheric winter atmospheric circulation. It could also be explicitly stated that it is not possible to decipher the exact timing of the eruption in the annual cycle because of dating uncertainties involved in the ice core reconstructions.

l. 273: I suggest to move the following section on the implementation of the volcanic forcing at the end of the model description paragraph – also some words on the uncertainties of the sulfate reconstructions based on ice cores would be helpful to indicate that modeling results on the subsequent simulations are dependent on the magnitude of the reconstructed sulfate injected into the stratosphere.

3. Results

– The header for paragraph 3.1 is missing –

3.1.1 2.5Ka GHG+ORB climate

Changes in orbital forcing – the supposedly most important factor between 2.5 and 6k – were already considerable different at 2.5 k. Therefore I guess that also the classical mid-Holocene pattern is different, even without dynamic vegetation. It would be good to at least indicate those implications when interpreting the 2.5 k pattern in the context of the mid-Holocene 6k climate and vegetation changes.

Another note: Changes due to orbital forcing are mostly effective on a seasonal basis on Holocene timescales, because changes in the inclination of the earth axes do not change the annual amount of radiation received by the sun. An alternative in structuring Fig 1 and Fig 2 is to omit the mean climate states in the upper and middle panel (also for section 3.1.2) and replace them by the patterns for the winter and summer season for the different experiments (together with the annual). This would also show better the impact of the (orbitally induced) background climate conditions between 2.5 k and PI.

3.1.2 2.5Ka ORB+GHG+VEG climate

l. 344: The authors should provide some implications the linear interpolation of vegetation might have on their results (e.g. it is also likely that vegetation changed considerably earlier to preindustrial-like conditions, resulting in a higher albedo due to less forest over the high northern latitudes.)

3.3 Volcanic aerosol properties

Concerning the overall length of the manuscript, I suggest to move this section into the supplementary information, as the general content of the manuscript is for an interdisciplinary readership.

3.4. Latitudinal temperature response to volcanic aerosol forcing

l. 483: How did the authors estimate their level of significance ? A few words in the supplementary or within the section would be helpful to assess the robustness of the test, using only a limited number of ensemble simulations for the estimation of the level of statistical significance.

3.5 Latitudinal precipitation response to volcanic aerosols ll. 506: The authors should add one or two sentences on the potential complications investigating the direct output of global and coarsely resolved earth system models. For instance, the simplified parameterizations used for the simulation of precipitation in global models which impact a realistic simulation of tropical convection.

l. 514: This section is one of my critique zones, especially in the context of interpreting climatic trajectories in the context of past societies: The ensemble mean never happens in the real world – if any, a single trajectory compares best to a real world manifestation. Therefore it would also be imperative to show trajectories for single ensembles. This also reflects the bandwidth of potential hydrological changes in the aftermath of volcanic eruptions.

l. 540: Here again, a more detailed information on the evaluation of the statistical significance would be helpful.

3.6 African monsoon and Nile River response

l. 581: The already mentioned information that a more consistent comparison between model and empirical evidence can only happen at the single simulation level can again picked up here, because in the real world one could not expect a mean response of different simulated trajectories for single events in history.

l. 584: Results for the E1 eruption seem convincing and also have a large-scale character that can be attributed to an external event – However, eruptions E2 – E4 show a very inconsistent pattern (even in the ensemble mean). This is also reflected in the statistical test (that presumably uses standard testing techniques that are not taking account the small sample size of n=10 samples). This heterogeneity in the response of the northern hemisphere E2 – E4 eruptions should be more emphasized, also in the subsequent interpretation in the context of their sustained effects on Nile floods.

l. 614 incl. Table 2: Interpreting the Table and the calculation of the according values correctly, the standard deviation is based on the volcanically forced ensemble members and the difference on the mean over all ensemble members minus the climatological mean of the 100 year control ?

An alternative is to calculate the annual standard deviation of the 100 year control run and include it as the 1.95*std = 95% confidence interval. This will give an indication how the mean discharge value is outside the natural range. In the present form it gives the bandwidth of the volcanically forced simulations, not taking into account the natural undisturbed variability. The interpretation of the 95% confidence interval based on the control will give an indication how exceptional the respective year after eruption E1 – E4 was in the context of the natural variability.

Fig 12: This figure contains basically very good information – Similar to Table 2, and to show the exceptional behavior of the different metrics, it would be better to illustrate the 1.95*std of the natural 100 y control run as two lines parallel to the x-axis, together with the individual trajectories of the 10 volcanically forced simulations. When a considerable number of trajectories falls above or below the 95% confidence levels for an individual year, one can speak of a robust response – according to the hypothesis proposed, the discharge trajectories should then fall below the lower boundary for the years after the volcanic eruptions.

In addition, without the green vertical lines it is difficult to decipher the volcanic eruptions based on the evolution of precipitation and discharge, because also other sub-periods with considerable reductions in stream flow appear that are unaffected by volcanic forcing (e.g. year 159). An alternative interpretation that could be hypothesized relates to an increased intra-ensemble variability after volcanic eruptions compared to undisturbed conditions.

4. Discussion and Conclusions

ll. 712: This paragraph also relates to the interpretation of empirical evidence in the context of earth system and climate model simulation: It is important also taking into account the natural or stochastic nature of historical processes that are not always determined by external environmental forcings. Otherwise a state in the interpretation and explanation of historical events will be reached, where numerous single historical events are only interpreted within the climate-determinism concept, which can be true for severe events, but might be misleading for most medium-to-small size events, especially in the context of volcanic eruptions.

l. 731: For producing a basis for "historical realization" it is again of utmost important to look and investigate the trajectories of individual realizations of ensemble simulations from climate models and not (only) their mean response.

l. 791: As the authors state correctly, from a conceptual point of view there is no "best" member, because all members are equal probable under the same set of external forcings implemented. What might be more important is the notion that the combination of external AND internal forcings shape the exact evolution in both, the real and the model world.

Figures and Tables:

In general, Figures and Tables are presented with high quality and an appropriate level of information included. Below just a few minor suggestions how to improve or modify selected items:

Fig 1: As already stated in the main text, Fig 1 and 2 might be combined into one single Figure by representing only the differences for annual, winter and summer (alternative JJAS) mean.

Fig 5 center panel: The style of the presentation of the single trajectories could be used as template for the precipitation and discharge Figure 12 to show the variability of the different ensemble simulations together with the 95% confidence level of natural variability of the 100 yr control simulation.

Table TS1: The authors might include also the volcanically forced simulations as and additional column and highlight those simulations that are presented in the manuscript.