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Comment on cp-2021-49

Anonymous Referee #1

Referee comment on "Was there a volcanic-induced long-lasting cooling over the Northern Hemisphere in the mid-6th–7th century?" by Evelien van Dijk et al., Clim. Past Discuss., <https://doi.org/10.5194/cp-2021-49-RC1>, 2021

Summary: The manuscript focuses on the climate response to the strong volcanic eruptions that occurred in the 6th century. The authors analyse an ensemble of climate simulations with the model MPI-ESM, compare their results with other previous simulations and with temperature reconstructions based on dendroclimatological data. The analysis of model data include the atmospheric response (temperature, precipitation, wind) and the response of the ocean circulation in the North Atlantic. One important issue is the duration of the response of these variables, as previous simulations and decollimated reconstructions seem to disagree - at least in some regions.

Recommendation: In my opinion the scope and focus of the article are valuable. There are some knowledge gaps about the response of large volcanic eruptions and the origins of Little Ice Ages in the last millennia, that need to be filled.

However, the manuscript leaves clear room for improvement, and I believe it requires considerable revisions. The structure is sometimes confusing, the language is also not always clear, and the data analysis is not deep enough. This is reflected in the unclear take-home-messages of the manuscript. Disagreements between simulations are explained by general model differences. Disagreements between reconstructions and simulations are explained by possible errors in the volcanic forcing or deficiencies of the proxy data, mainly in the tree-ring data, but the manuscript does not include more specific and solid explanations. Sometimes, the discussion is inconsistent, and some example of this are given in the list of particular points below.

1. ' sea level pressure and a decrease in hydrological variables occur'

The text could be here clearer. Does this sentence mean that both precipitation and evaporation becomes smaller?

2. 'However, most reconstruction data sets go back to about 1200

CE, and the further back in time, the fewer proxy records remain, and the more uncertainties they contain (Masson-Delmotte, 2013; Neukom et al., 2019).

3. The sentence is not clearly formulated (perhaps it is not grammatically correct). Consider an alternative formulation like ' Further back in time the network of proxy data becomes sparser and uncertainties in each individual temperature record also grow.

4. 'The aim of this study is to investigate whether a multidecadal to centennial cooling may have occurred in the mid 6th to 7th century.'

This sentence states the main objective of the study. However, the reader will not be wiser after reading the manuscript. The disagreement between the proxy record that do indicate a centennial cooling do not agree with the model results, but the study does not include a solid explanation for this disagreement (apart from speculating that perhaps the high altitude of the Alp records may be responsible for the long temperature recovery).

This is perhaps my main concern of the manuscript. It is in general too descriptive and does not go deep enough into explaining those disagreements.

5. ' the short term (years), as well as the long term (decadal to centennial)

the short term (annual)...

6. 'sea ice impacts, we also study atmospheric and ocean circulation, hydrology and the ocean-sea ice feedbacks in maintaining the climate signal'

the 'climate signal' is too unspecific. Please, help the reader by being more specific, for instance 'in maintaining the volcanic induced cooling'

7. 'For this study, we ran ten ensemble members for 160 years from 520-680 CE.'

for 160 years, starting in 520 CE. Or alternatively, covering the period 520-680 CE

8. For each ensemble member the atmospheric diffusivity was changed by $1 \cdot 10^{-5}$ to simulate slightly different climate states by the year 536 CE, the year of the first large volcanic eruption.

physical units are missing

9. Historical Land Use Data Set for the Holocene (HYDE3.2, Klein Goldewijk, 2016). Considering several options (e.g. linear ramp-up) we decided to simply let the land-cover data be constant for the first 850 years of the past2k runs.

We prescribed a constant land-cover for the first 850 years of...

10. 'The tree-ring sites are displayed in Fig. A1. For the model-tree-ring comparison a land mask was applied to the model 2m air temperature analyzing the NH extratropics between

40°N and 75°N.'

Here and in other instances in the manuscript, it is not clear whether the reconstructed NH temperature was just calculated as the to be the simple average of the local temperature reconstructions at the tree-ring sites or whether there was a more sophisticated reconstructions method, for instance by calibrating a statistical model to replicate the NH mean temperature (as in Stoffel et al. 2015). The present manuscript lists in Table 2 just 6 records. Is the NH temperature the average of only these 6 records or is it the temperature reconstructed by Stoffel et al. ? I think that the simple average of these 6 records cannot meaningfully be considered a Northern Hemisphere average.

11. 'Towards the end of the simulation period the ensemble shows a larger spread than at the beginning of the simulations, which corresponds to the ocean heat content state being more different between members in the end than at the beginning of the simulations.'

Could this be an indication that the ensemble set-up is not adequate to investigate the main objective of the study, and that the spread of ocean initial conditions is too narrow ?

12. The results section includes several paragraphs that actually would belong to a (missing) Discussion section. An example is this paragraph:

'Zhong et al. (2011), and Miller et al. (2012) argued that the ocean - sea-ice feedback could play a major role in sustaining a century long cooling after a cluster of four volcanic eruptions in the mid 13th century. In contrast to these studies, we simulate a multi-decadal sea ice response in the mid 6th to 7th century. '

Consider also this reformulation: In contrast to these studies, our simulated cooling is shorter and lasts only for a few decades.

13. After the 536/540 CE double event, the ensemble mean of the model simulations does

not return to zero sea-ice cover anomalies before 560 CE.

the ice-cover in the ensemble mean takes longer to recover and only reaches the climatological mean value by year xxxx.

14. 'Fig 3 (TRW) and triangles (MXD) in the 2 m air temperature maps. The 2σ (1σ) standard deviations for 2m air temperature SLP, evaporation (and precipitation) are stippled (hatched). '

The ensemble standard deviation sigma (2σ) ...are stippled (hatched)

15. 'there is a land-sea contrast present for evaporation in summer, where the signal is opposite over the ocean.'

In summer, the sign of the evaporation anomalies over ocean and land is opposite.

16. 'the north side of the climatological high pressure systems reflecting an atmospheric circulation separation at around 45° N.'

this sentence is unclear. Does it mean that the sign of the anomalies is opposite north and south of 45 N?

17. 'The long term response is shown in the right side of Figure 3.'

on the right side or in the right half of the picture. Better still is to label all the panels and refer to them accordingly.

18. 'The increase in precipitation over the Mediterranean in boreal summer in the model simulations in this study are related to the shifting of the inter tropical convergence zone (ITCZ) into the Southern Hemisphere (SH) after the eruptions (not shown here), as well as a weakening of the high and low SLP over the North Atlantic (Figure 3b). After a large volcanic eruption, the ITCZ shifts away from the cooler hemisphere, in this case the NH (Schneider et al., 2009). '

I guess that during the boreal summer summer , the Northern Hemisphere is the warmer hemisphere, not the cooler hemisphere. Perhaps the authors mean that the negative temperature anomalies are stronger in the NH?.

19. 'appeared to be opposite, with a drying over Southern Europe and a wettening over Northern Europe. They accounted this to the models not capturing the winter NAO well and therefore simulating a different response.'

The reference to Iles and Hegerl to discuss precipitation response in boreal summer over Europe is misplaced. Iles and Hegerl refer to the winter precipitation response, so it is not correct to state that Iles and Hegerl agree with the results obtained here for summer precipitation. It would also strange to claim that a wrong simulation of the winter NAO response can explain the wrong sign of summer precipitation anomalies in Europe.

20. 'The significance was calculated from the 1200 year control run by

taking the 2 to 20 year means of the 1200 years, and then taking 4 random time steps from that time series for the 4 large eruptions. This was done 1000 times for each variable, and the standard deviation was then calculated from those new random time series. 1 time or 2 times the standard deviation (1 and 2σ) were then used to calculate the significance.'

I cannot understand how the standard deviations were calculated. This paragraph seems to me rather unclear

21. 'In boreal winter, there is a see-saw pattern visible in the 2 year SLP response with an increased low pressure over Greenland and a decreased low pressure over Northern Europe, corresponding to the seesaw winter temperature pattern between Greenland and Scandinavia, as described by Van Loon and Rogers (1978). The changes in boreal winter reflects a positive Arctic....'

This whole paragraph is rather unclear. I think there is an error in the first sentence (increased low pressure in both Greenland and Northern Europe?) , but in general it is difficult to follow. It contains a mixture of own results and previous results, and it is difficult to disentangle which is which. After reading the paragraph, it is unclear whether the model does produce a NAO response or not.

I would recommend to first describe the new results, and then briefly compare them with previous results. In a discussion section this comparison can be then deeper and more detailed.

22. 'The summer cooling over the continents can have a serious effect on the vegetation and society summer can lead to crop failure and famine in areas that are close to the temperature limit for grow....'

This paragraph on the impacts of low temperatures is misplaced here. It is not related with the previous or the following paragraphs. This could go to a Discussion section or be deleted without any loss.

23. From Fig. 4b and c can be seen that the subpolar gyre (south of it can be seen...

24. I found the following two paragraphs to be inconsistent with the ensemble set-up:

'The studies from Zhong et al. (2011) about the onset of the LIA also concluded the response to be depended on the initial state of the North Atlantic, as only 2 out of 4 simulations (one warm and one normal NA state) lead to a cooling long enough to resemble the LIA. Compared to their study, our NA state is relatively warm, but it is hard to compare as a different model and set up were used.'

'be the initial state of the ocean when the volcanic eruptions occur. This is less likely, as 10 ensemble members were run, which showed a range of variability in the same range as the 0-1850 CE variability, where the response to the volcanic eruptions'

The first paragraph states that the initial ocean state is important for a successful simulation of the LIA. The second paragraph indicates that the ocean initial conditions in the ensemble are wide enough separated. However, the initial conditions were prepared by just perturbing one single parameter in the atmosphere submodel, and else where the manuscript states that the spread of the ensemble at the end of the simulations is clearly larger than at the beginning, indicating that the initial ocean states are not that much separated. This requires a deeper discussion.

25. 'For the model - tree-ring comparison, the model temperature anomalies were taken for grid cells corresponding to the latitude/longitude range for the tree-ring locations. In

Fig. 5 the comparison for the NH, the Alps, Altai and Northern Scandinavia are shown.'

Again, it is unclear how the reconstructed NH temperature has been calculated.

26. 'The temperature anomalies from the model simulations and the 2 sigma variability range fall within the 2 sigma variability of the NH of the model simulations and the timing of the peak cooling after the four large volcanic eruptions agree very well.'

I guess the authors mean that the reconstructed NH temperature fall within the model ensemble spread ?

27. 'Figure 5b shows the model - tree-ring comparison for Northern Scandinavia (NScan). Just as for the NH, the variability of the model simulations fall within the variability of the tree-ring temperatures.'

see previous comment

28. 'agree very well both in timing and in signal. This could be because the tree-ring data for Fennoscandinavia consists of MXD data, so there is less time lag and smoothing in the signal (Esper et al., 2015). More deviation is visible for the ensemble mean peak cooling for the 574 and 626 CE eruptions.'

This is an example of, in my opinion, cherry-picking results. It seems that for some of the eruptions the MXD data agree better with the model because the wood density proxies better represent the true temperature. However, this is not the case for the other two eruptions. Why?

29. 'because the volcanic forcing in the model is overestimating the cooling in the mid-latitudes.'

because the prescribed volcanic forcing is too strong

30. 'The concept of a LALIA period was raised by Büntgen et al. (2016), based on tree-ring data. There is a good agreement between the tree-ring temperatures and the model temperatures after normalization. This was done with regard to the time'

In my understanding, there is no normalization involved here. The records have just been re-aligned to a common mean, but they have not been re-scaled to a common standard deviation.

31. 'Perhaps the century long lasting cooling may be only apparent in the Alps and Altai tree-ring records, as the cooling is a local feature occurring at high altitude of the mid-latitudes. Our model resolution is too coarse to fully capture the topography'

This is speculation. It needs to be more strongly supported.

32. This comment may be more a matter of taste but I find that the Summary and Conclusion section is rather repetitive of what has been just exposed in the Results sections. The summary, if the authors wish to keep one, can be considerably shortened - there is no need to repeat all results in detail again. On the other hand, the real conclusions, starting in line 443, could be more sharply written e.g. that none of the simulations of the ensemble reproduce a century-long cooling, but that this could be due to a too narrow choice of ocean initial conditions, that the most important feedback mechanisms for multidecadal cooling involve sea-ice cover. and that the findings here do not agree with some of the palaeoclimatological data, but do agree with other dendro data

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