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Climate of the Past Discussions

Interactive comment on "Physical processes of cooling and megadrought in 4.2 ka BP event: results from TraCE-21ka simulations" *by* Mi Yan et al.

Anonymous Referee #2

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This paper uses a transient model simulation (TraCE-21ka) to explore the possible causes of the 4.2 ka event. While various hypotheses exist regarding the causes of this event, this remains an open and interesting question. The authors find evidence in the transient simulation for climate fluctuations in the middle Holocene that show some of the same temporal and spatial patterns as the 4.2 ka event, and through analysis using several additional single-forcing experiments, argue that the fluctuations likely arose through internal variability of the climate system. The results support some previous hypotheses and work on the causes of this event, and the paper does make a contribution in its use and analysis of the TraCE simulation.

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I had several major concerns with the paper, including the overlap between this paper and another paper by the same authors that is under review in Climate of the Past, as well as how well some of the conclusions are supported by the results. These concerns are described in more detail below.

Major comments

1. The authors have another paper under review in Climate of the Past ("Comparing the spatial patterns of climate change in the 9th and 5th millennia B.P. from TRACE-21 model simulations" by Ning, Liu, Bradley and Yan) that has significant overlap with this manuscript. The Ning et al. paper uses the same model simulation (TraCE-21ka) to analyze the 8.2 ka and 4.2 ka events. Both papers present analysis using the same techniques (anomaly maps, principal component analysis). The Yan et al. paper (this review) provides a more in-depth analysis of the 4.2 ka event, but it is unclear why two papers are necessary. Perhaps even more important, the two papers come to conflicting conclusions about the cause of the 4.2 ka event. In Ning et al., it is stated "We speculate that long term changes in insolation related to precessional forcing led to cooling, which passed a threshold around 4500 years B.P., leading to a reduction in the AMOC and associated teleconnections across the globe. Based on widespread paleoclimatic evidence for the onset of neoglaciation (Solomina et al., 2015), it seems clear that there was a fundamental shift in climate around this time." Whereas, Yan et al. argue that stochastic variability internal to the climate system caused the 4.2 ka event independent of any external climate forcing.

2. It would useful to show on Figure 3 the locations of proxy records discussed in the text that document anomalies at 4.2 ka (perhaps circles color coded according to whether proxy anomalies were cold/warm or wet/dry during the event). This would help to make the point that the model event has the appropriate spatial pattern.

3. The authors need to discuss the implications that their maps show the difference between warm event and cold event – namely, that this approach amplifies the model

anomaly as compared to taking the difference between cold event and long-term average, which is probably what most of the proxy records are showing. Specifically, the authors should also discuss whether differences between cold event and long-term average (say averaged 500-1000 years before the event) are statistically significant. More generally, the authors need to make a point of discussing that the size of the modeled anomalies ARE VERY SMALL. I think it is fine to use the simulations to put forth a hypothesis about processes causing the 4.2 ka event, but given the small size of the modeled changes, it is also very important to be clear that we still might not be modeling events comparable to the 4.2 ka event (e.g., make this point clearer on lines 253-254).

4. Analysis of AMOC: The authors mention several times that simulated patterns are similar to those caused by AMOC, but AMOC is not analyzed. Further, the Ning et al. paper specifically attributes the event to AMOC changes. It is not difficult to generate an AMOC time series from TraCE (e.g., maximum of the meridional overturning streamfunction – the variable 'MOC' – over the North Atlantic avoiding the surface wind-mixed layer) and this would greatly help to clarify what the role of AMOC is.

5. Lines 289-292: The difference between the sum of the single-forcing experiments and the ALL simulation is not strictly internal variability. The difference will also include any interactions between the single forcings. This should be more clearly stated on these lines. Also on Line 295: add "in isolation" to the end of the phrase "the 4.2 ka event might not be triggered by those external forcings" because it is possible that interactions between forcings could be important.

6. Line 202-204, 234-239: Precipitation changes in China are largely insignificant. Recommend deleting these sentences.

Minor comments

Line 20: Change "many" to "several"

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Line 46: “there were warming periods in Holocene induced by natural forcing comparable to current warming.” Current warming, being driven by increased atmospheric greenhouse gas concentrations cannot by definition be comparable to any warming periods in the Holocene. Do you mean comparable in size? Even then, this is debatable.

Line 57-58: “that inaugurated the “modern” El Nino Southern Oscillation (Fisher et al. 2008).” The record cited is not a direct record of ENSO (it is an ice core in the Yukon) and there are lots of more direct records of ENSO from the tropical Pacific that suggest complexity in how ENSO changed through the middle to late Holocene. Delete this phrase.

Line 70: “Moreover, according to the hydrologic cycle. . .” I’m not sure what this means. Is the point that hydroclimate changes are often regionally specific, and other regions could have had different hydroclimate changes?

Lines 76-80: “For the causes of the event, some reconstruction studies have suggested that orbital forcing played an important role in the early Holocene. . .” Does this refer to abrupt changes in the early Holocene, or longer-scale changes? Please provide references. “. . .; however, no strong evidence has shown that the solar forcing affected glacier fluctuations (cooling events) in the late Holocene. . .” Does “solar forcing” here refer to solar irradiance changes or to orbital forcing? Also, glacier fluctuations are only one indication of cooling, other temperature proxies do seem to be sensitive to solar irradiance changes.

Lines 90-91: For clarity, change “Additionally, there are discrepancies in the circulation pattern during the late Holocene (Finkenbinder et al., 2016)” to something like “However, studies come to differing conclusions on the likely phase of the NAO-like pattern during the late Holocene.”

Line 94: Change “might could be” to “could be”

Line 159: It is important to be very careful about calling a particular event in the model simulations the 4.2 ka event, especially since the variability being described in the model is internally driven. It is likely coincidental that these events described in the TraCE experiment happen around 4.2 ka – particularly if they are the result of internal variability. It is more appropriate to say "which indicates that simulated climate events potentially comparable to the 4.2 ka event" instead of "which indicates that the 4.2 ka BP event has multidecadal to centennial variabilities." Similarly, on the following lines, use "Moreover, the centennial warming periods right before and after the simulated cooling event indicate that this event might be included in a quasi-millennium variation" instead of "Moreover, the centennial warming periods right before and after the 4.2 ka BP event indicate that this event might be included in a quasi-millennium variation."

Figure captions: Specify which of the model simulations (i.e., "ALL") is plotted.

Figure 1: flip x axis so that time matches the sense of the x axis in Figure 2. Also, it seems that June insolation is not the most informative since the climate fluctuation in question is mostly a wintertime response and plots are all showing mean annual.

Figures 3, 4, 5, 7: Plot full globe, 90 degrees south to 90 degrees north.

Line 197: change "most regions" to "many land regions"

Line 198: change "central and southern North America (Intra America)" to "interior North America and central America"

Line 212-213: There are many more citations of relevance here, going back to Vellinga and Wood (2002) Climatic Change 54: 251-267 and Zhang and Delworth (2005) Journal of Climate 18: 1853.

Line 252: Change "The solar irradiance is not included. . ." To "Changes in solar irradiance are not included. . ." Solar irradiance is included in this model, it is just not changing.

Lines 273-276: Clarify here that there was no meltwater flux applied in the model for

the years analyzed (5000-3000 years BP). Why might these correlation coefficients be significant given that there is no meltwater flux? Is this likely due to chance? Please discuss this more in the paper.

Lines 368-369: “We attributed the internal variabilities to be an essential forcing of the 4.2 ka BP event; however, why it occurs at approximately 4400 BP to 4000 BP remains unknown.” If the event is stochastic (as argued), there is nothing more to know about why it occurred when it did.

Acknowledgements: The TraCE-21ka team and funding should be acknowledged. See instructions at: https://www.earthsystemgrid.org/project/trace.html.

References: There are other papers that have hypothesized links between the North Atlantic and the 4.2 ka event and that should be cited. They include: Cullen, H. M., Kaplan, A., Arkin, P. A., and deMenocal, P. B.: Impact of the North Atlantic Oscillation on Middle Eastern climate and streamflow, Climatic Change, 55, 315–338, 2002. Kushnir, Y. and Stein, M.: North Atlantic influence on 19th–20th century rainfall in the Dead Sea watershed, teleconnections with the Sahel, and implication for the Holocene climate fluctuations, Quaternary Sci. Rev., 29, 3843–3860, 2010.

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