

## RC1: 'Comment on egusphere-2024-3483', Anonymous Referee #1, 12 Dec 2024

### General comments

In this paper, Moore and colleagues have thoroughly analyzed the signal of the Holocene 8.2ka event in hydroclimatic proxy records from the tropics. The proxy-based signal is compared to simulation results obtained with the isotope-enabled iCESM global climate model. In the compilation, proxy records from different environments are considered: marine sediment records, lake sediment records and speleothems. As such this work extends the compilation recently published by Parker and Harrison (2022), who focused on the 8.2ka signal in speleothem records. Innovative aspects of this manuscript are the extensive analysis of the impact of age uncertainties and the comparison of the proxy-based hydroclimatic anomaly with a state-of-the-art isotope-enabled model simulation of the 8.2ka event. The paper is well-written, with a clear structure, and includes high-quality figures. The main result is a convincing proxy-based overview of the hydroclimatic response to the 8.2ka event in the tropics, showing clear regional variability. In my view, the manuscript requires some minor revisions, mostly associated with the detection methods used and the climate model experiment. I provide details below.

### Main comments

Introduction, Line 59. “This period occurred during the otherwise stable Holocene epoch (11,700 years ago to present) and was driven by the discharge of around 163,000 km<sup>3</sup> of meltwater from proglacial Lakes Ojibway and Agassiz (remnants of the Laurentide Ice Sheet) into the North Atlantic”. The volume and source of the freshwater perturbation are actually still under discussion. For instance, the volume of the proglacial lakes is under discussion (Törnqvist and Hijma, 2012). In addition, Gregoire et al. (2012) argue that a collapse of the “ice saddle” over Hudson Bay could have played an important role in forcing the 8.2ka event. It is important to make the reader aware of this uncertainty. See also the recent discussion by Aguiar et al. (2021). Besides, it is confusing to refer to Lakes Ojibway and Agassiz as “remnants of the Laurentide Ice Sheet”, so I suggest removing this part of the sentence.

Thank you for this comment. We have updated the wording to better reflect this nuance as follows:

*“This period occurred during the otherwise stable Holocene epoch (11,700 years ago to present) and is thought to have been driven by the discharge of around  $1.63 \times 10^5$  km<sup>3</sup> of meltwater from proglacial Lakes Ojibway and Agassiz into the North Atlantic, triggering a large-scale salinity anomaly and resultant reduction in the strength of the Atlantic Meridional Overturning Circulation (AMOC; e.g., Barber et al., 1999; Ellison et al., 2006). However, the precise source, routing, and strength of the freshwater perturbation are still under discussion (e.g. Törnqvist and Hijma, 2012), ranging from an upper limit of  $27.1 \times 10^5$  km<sup>3</sup> of freshwater released from the retreating Laurentide Ice Sheet (LIS) between 9 ka and 8 ka (Peltier 2004) to a smaller but more abrupt discharge of  $5.3 \times 10^5$  km<sup>3</sup> between 8.31 ka and 8.18 ka (Li et al., 2012). Recent*

*data-model comparisons from Aguiar et al. (2021) suggest that an additional  $8.2 \times 10^5 \text{ km}^3$  of freshwater flowed into the Labrador Sea after the collapse of the Hudson Bay due to the routing of river discharge over the western Canadian Plains (Carlson et al., 2009)."*

Section 2.3.1. MM method. I propose including a schematic figure explaining how the MM method of detection works in practice, using two examples: one example with multiple events of the same sign and one example with multiple events of different signs. I am thinking of an extended version of Morrill's Figure 2. It is not clear to me what the actual modification is to the Morrill method. Please specify. If feasible, including such a schematic for the actR method would also be helpful for readers not familiar with this type of changepoint analysis.

Thank you for this suggestion. We have annotated two such event cases below (Figs. 1a and 1b), which will be included as supplemental figures in the revised manuscript.

Our MM method differs from the method presented in Morrill et al., (2013) in several ways as it serves primarily as a supplement to our actR results. We have updated the wording of that section to clarify that we did not perform the "leave one out" calculation of the standard deviation that Morrill et al. (2013) employed to account for noisy data and outliers in each reference window. Additionally, Morrill et al. (2013) define anomalous events as excursions with at least two adjacent anomalous values of the same sign (three for records with sub-decadal resolution). We modify this by requiring that events "must last at least 10 years and if multiple events are detected within the 7.9-8.5ka window, they are combined into a single event if there are no more than three data points or thirty years separating the different excursions". Finally, we clarify that Morrill et al., 2013 use a moving two-tailed z-test method to define the duration of their detected events, while we only consider the time between the initial and final anomalous data point in our duration calculation.

Per your suggestion, we have also included a schematic summarizing the actR analysis process below (Fig. 2), which will also be added to the Supplementary Material of the manuscript.

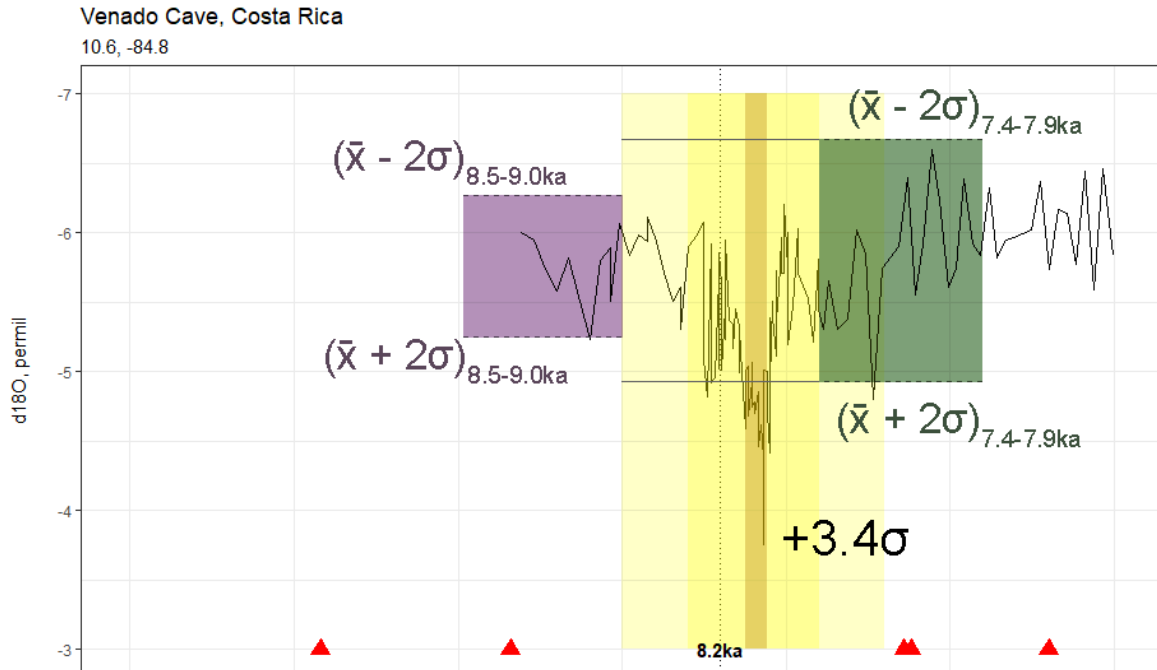


Figure 1a. A schematic illustrating the application of our modified Morrill method to the speleothem record of Lachniet et al., 2004 (V1), corresponding to Fig. A61 in our manuscript. The green and purple rectangles represent the range of values in each reference window, bracketed by the upper and lower bounds of  $\bar{x} \pm 2\sigma$  over each window. The brown rectangle highlights an anomalous isotopic enrichment event (8.124-8.058 ka) which is composed of three separate “events” (separated by 9-19 years of data which do not exceed the event threshold), consolidated into a single 8.2ka Event. The maximum absolute z-score over the event period (+3.4 $\sigma$ ) is taken to represent the magnitude of the event.

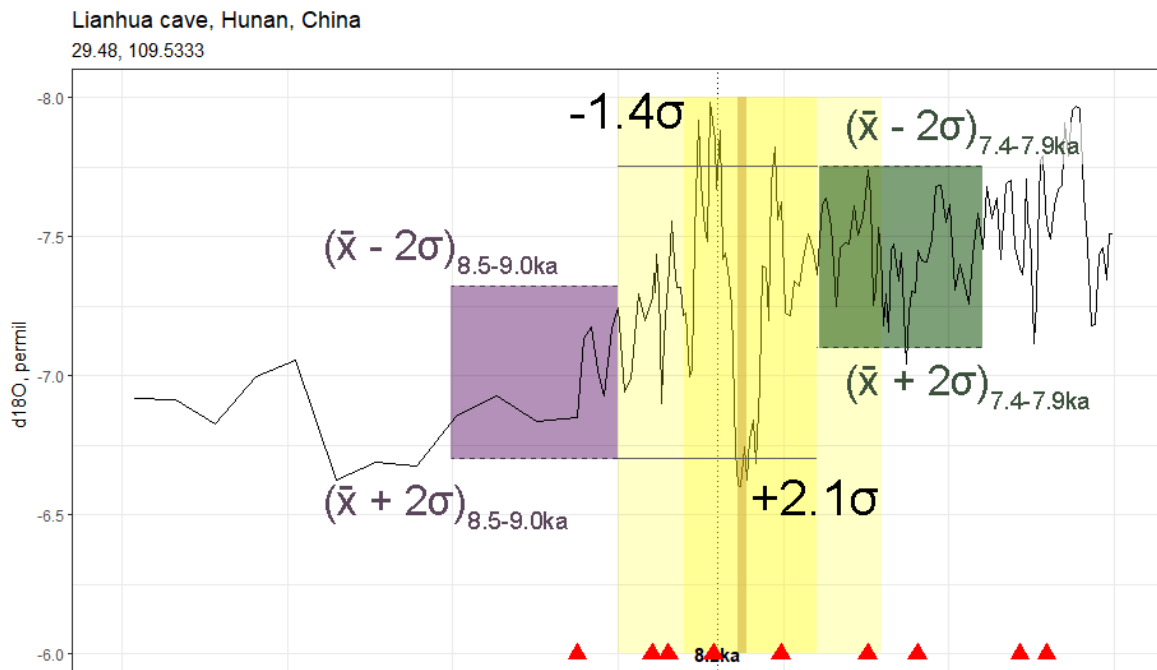


Figure 1b. As for Fig. 1a, but for the record of Zhang et al., 2013 (LH2), corresponding to Fig. A33 in our manuscript. This record shows multiple events of opposing signs within the detection window: an anomalous isotopic depletion ( $-1.4\sigma$ , 8.221-8.208 ka) and an anomalous enrichment ( $+2.1\sigma$ , 8.138-8.129 ka). The event with the larger absolute value z-score is taken to represent the 8.2ka Event.

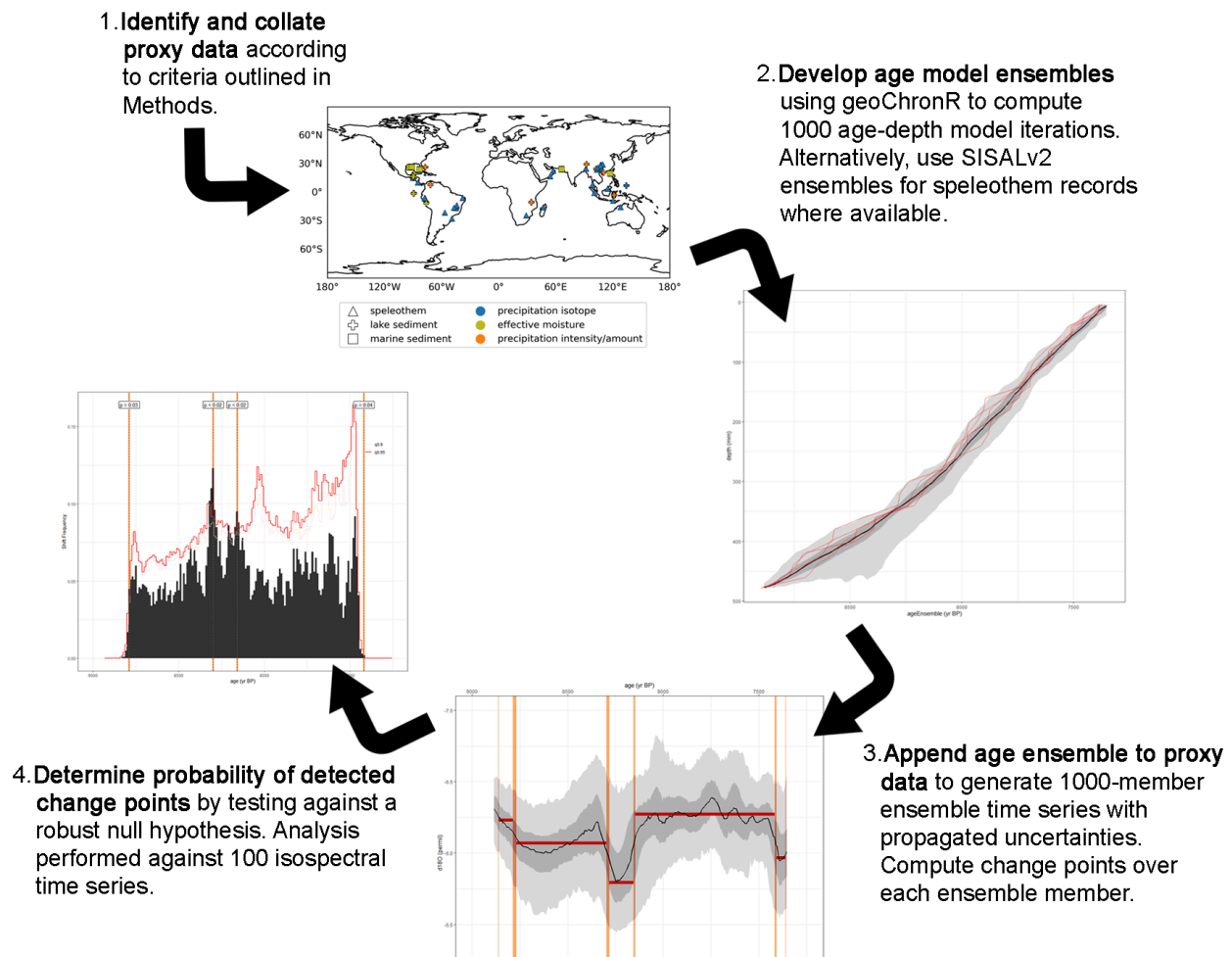


Figure 2. A schematic illustrating the actR analysis process. Step 1: Relevant records are identified and collated into our compilation based on the criteria outlined in the Methods (see Tables 1 and 2 in our manuscript). Records are then converted to the LiPD file format for analysis. Step 2: A 1000-member age model ensemble is developed using the geoChronR library in R, or, where available for our speleothem records, drawn from the ensembles presented in version 2 of the SISAL database. This allows us to propagate age uncertainties through each successive analysis step. Step 3: The age ensemble is appended to the proxy data to generate a 1000-member ensemble time series, including both age and simulated proxy data ( $\sigma/2$ ) uncertainties (represented by the ribbons, where the outermost [lighter] bands represent extreme quantile values and the innermost [darker] bands the central quantile values).

The data are fit to a Gaussian distribution, and the change point analyses are conducted across this ensemble to determine the timing of changes in the proxy data. Step 4: The significance of the detected change points is tested by performing the same change point analyses against 100 isospectral surrogate time series, and the frequency of shifts is plotted as a histogram summarized in 10-year-long bins. The p-value is shown for shifts exceeding the  $\alpha = 0.05$  and  $\alpha = 0.10$  level (95% and 90% confidence intervals, respectively).

Section 2.4. Please make clear that the experimental setup for the iCESM simulation of the 8.2ka event does only partly follow the PMIP4 design reported by Otto-Bliesner et al. (2017). In the PMIP4 design, the 8.2ka simulation starts from an experiment with fixed forcing for 9.5 ka instead of 9 ka as is done here. In addition, in the PMIP4 design the freshwater hosing is applied in the Labrador Sea instead of across the entire northern North Atlantic.

We agree that it is important to specify how our experimental setup otherwise differs. We have updated the wording of that section to clarify that we followed the PMIP4 protocol for the timing and duration of the meltwater events (2.5 Sv for 1 year, followed by 0.13 Sv for 99 years), while the location of the meltwater forcing is notably different. We have also clarified that our hosing experiment branches from 9 ka boundary conditions (instead of 9.5 ka), and thus uses slightly different orbital and GHG configurations.

Discussion. In some regions, for example the Caribbean and SE Asia, there are records without any detected change located close to records with a clear signal for the 8.2ka event (see for instance Figure 2). How to interpret the absence of a signal in these records without significant change? It would be insightful to discuss the possible reasons for the absence of a signal. You raise an important point that we have addressed more explicitly in our revision by adding the text below:

*“In central America and Brazil, records with no detected change are located close to records with a clear signal of the event (Fig. 5, Fig. 6). This could be due to several factors, including localized hydroclimate signals and variable age uncertainty and temporal resolution in the proxy records.”*

Section 4.2. Simulated 8.2ka event. The results of the last 50 years of the “hose” experiment are taken to represent the modelled 8.2ka event. The mapped difference between “hose” and “ctrl” is used, for instance in Figure A2 and in the model-data comparison. It would be informative to know how the climate evolved through time in “hose” relative to “ctrl” (for instance related to detectability in the model result, see next point), so I propose including additional figures with modelled time-series of hydroclimate for the key regions shown in Figures 4 to 7. These additional figures could show 100-year time-series of both “ctrl” and “hose”.

Thank you for the suggestion. We will include the following time series of precipitation  $\delta^{18}\text{O}$  for these regions as supplemental figures (see Figs. 3-5 below).

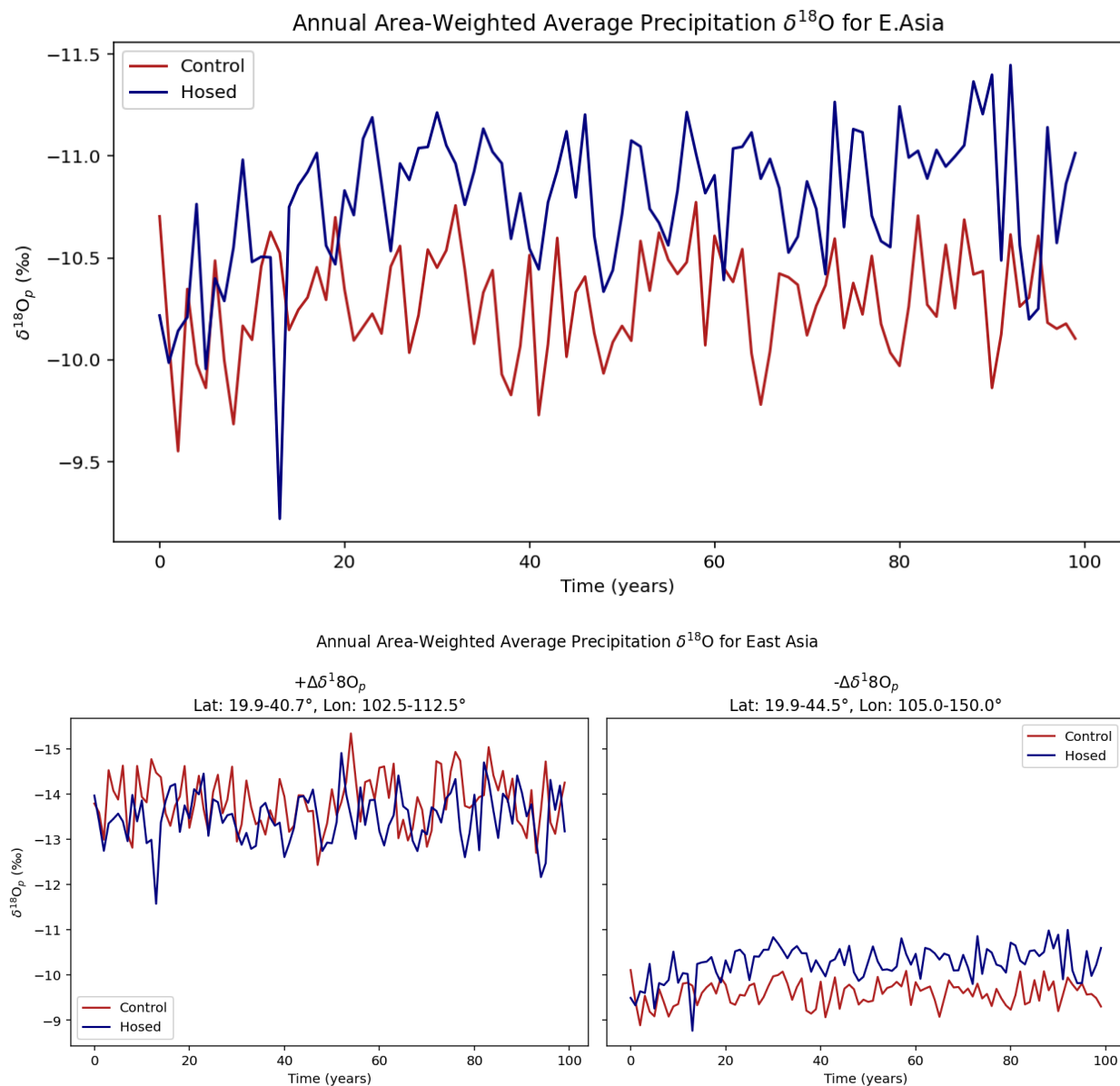


Figure 3. The amount-weighted, area-weighted mean annual precipitation  $\delta^{18}\text{O}$  for the “ctrl” (red) and “hose” (blue) simulations over all of East Asia (manuscript Fig. 4; top panel), the western subregion defined by the  $+\Delta\delta^{18}\text{O}_p$  anomaly in manuscript Fig. 4a (bottom left panel), and the eastern subregion defined by the  $-\Delta\delta^{18}\text{O}_p$  anomaly in Fig. 4a (bottom right panel).

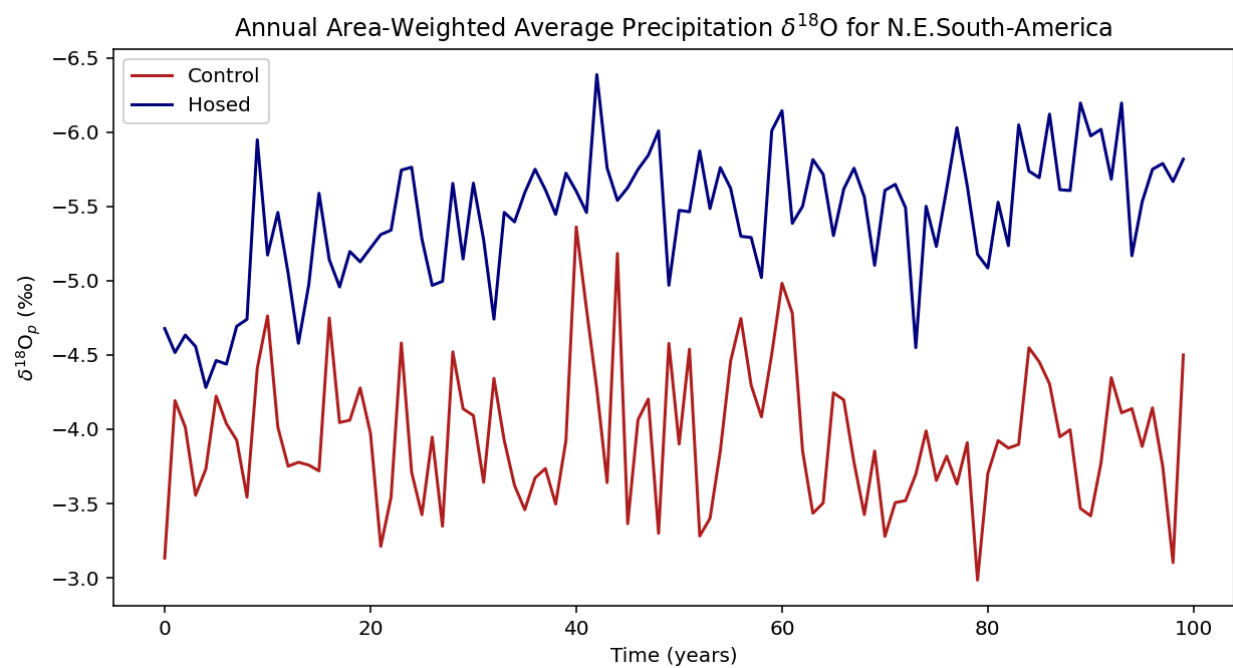


Figure 4. As in Fig. 3, but for NE South America (manuscript Fig. 5).

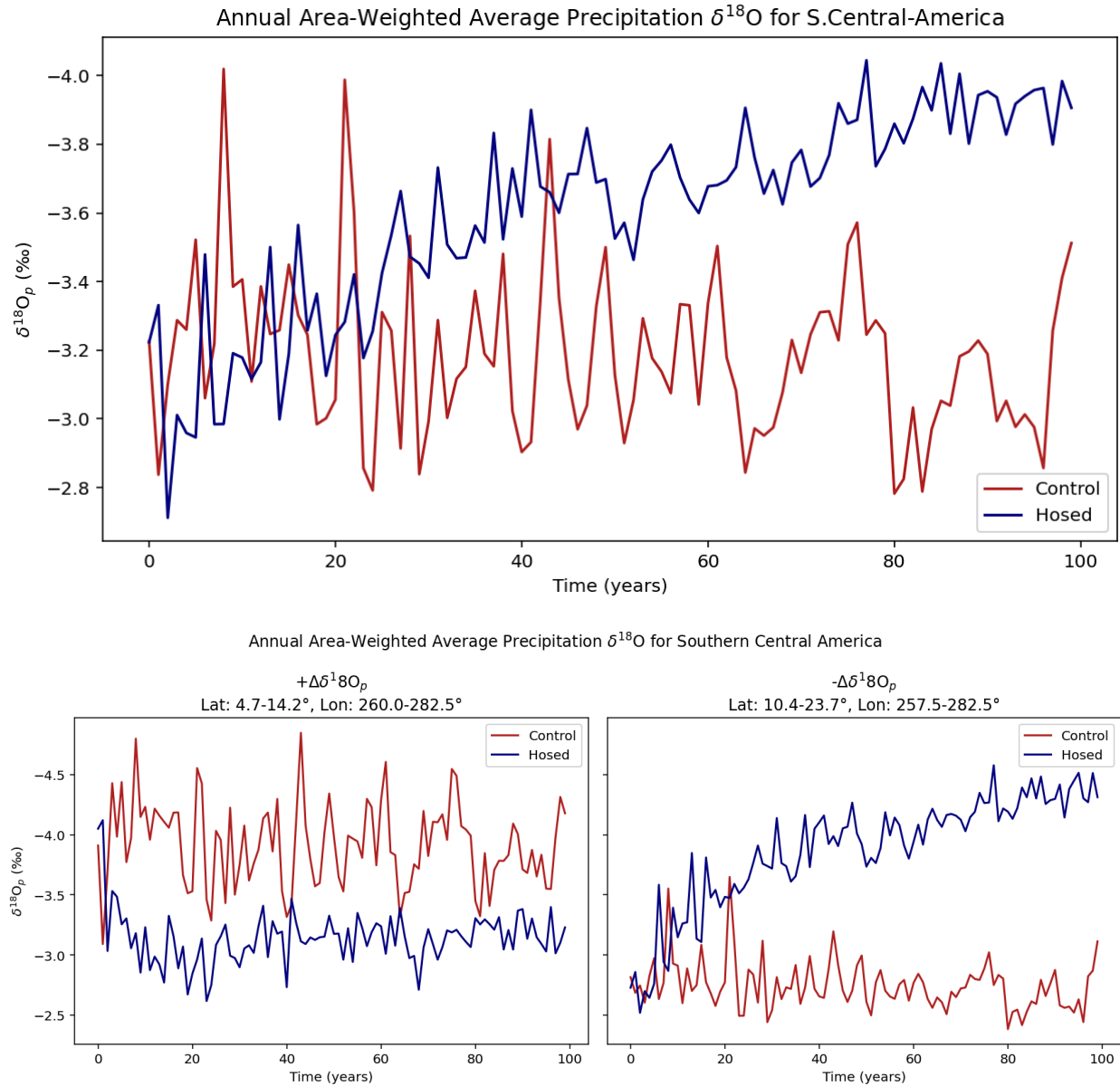


Figure 5. As in Fig. 3, but averaged over all of Southern Central America (top panel), the southern subregion defined by the + $\Delta\delta^{18}\text{O}_p$  anomaly in manuscript Fig. 6a (bottom left panel), and the northern subregion defined by the - $\Delta\delta^{18}\text{O}_p$  anomaly in Fig. 6a (bottom right panel).

Detectability of the simulated 8.2ka event. The question of detectability of the 8.2ka event is not only relevant for proxy records, but also for the model results. The difference between “hose” and “ctrl” includes anomalies produced by both internal variability and forced variability (i.e. by hosing). Ideally, one should not perform just one simulation for the 8.2ka event as is done here, but rather an ensemble experiment in which the members differ only in initial conditions and have identical freshwater forcing (hosing). The ensemble mean allows then to analyze the forced response and to separate it from the internal variability. I refer to Wiersma et al. (2011),



who performed this analysis for the temperature response associated with the 8.2ka event. I realize that it is probably not feasible within the framework of this study to perform several additional ensemble members with iCESM, but in my view the aspect of detectability in the model results should also be discussed in the paper. In addition, I suggest performing a statistical test to determine what results of “hose” are significantly different from the “ctrl” climate, and to include only those significantly different results in the model-data comparison.

Thank you for this comment. We agree that it is important to highlight the statistically significant changes in the model simulations. While running additional ensemble members to separate the forced response from internal variability is outside the scope of this study, to address the issue of significance, we have performed an unpaired two sample Student’s t-test on the precipitation, effective moisture, and amount-weighted precipitation  $\delta^{18}\text{O}$  fields from the hosed and control model runs. In our revised figures showing the changes in precipitation and precipitation  $\delta^{18}\text{O}$  under hosing (see below), we now only plot those changes that exceed the 95% confidence level ( $p < 0.05$ ).

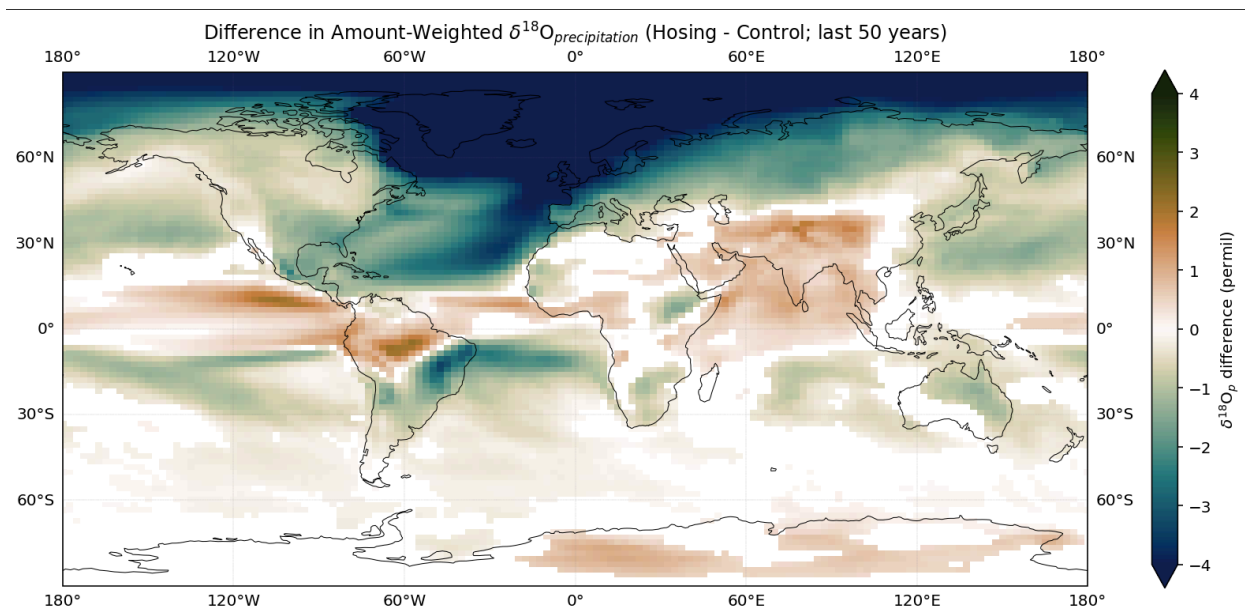


Figure 6. The difference in amount-weighted  $\delta^{18}\text{O}_p$  between the last 50 model years of the “hose” and “ctrl” simulations. Shading indicates anomalous changes that exceed the 95% confidence level ( $p < 0.05$ ).

#### Other comments

Line 87. Why is it a critical tool? Please elaborate.

This sentence was removed and the paragraph was modified to more explicitly indicate how model data can complement proxy data to provide a more comprehensive understanding of the response of the climate system to the 8.2ka Event:

*“We further assess how well the proxy reconstructions compare to a new isotope-enabled model simulation of the 8.2ka Event. Such model simulations provide dynamical context to the sparse*

*proxy data and, by tracking water isotopes through the hydrologic cycle, facilitate more direct comparisons between proxy and model data than conventional climate models.”*

Line 104. How is this sensitivity to hydroclimate determined?

The passage in question: “To assess the tropical hydroclimate response to the 8.2ka Event, we developed an updated compilation of published, high-resolution, continuous, well-dated proxy datasets, collating records that span the period 7ka-10ka, cover latitudes from 30°N to 30°S, and which are sensitive to some aspect of hydroclimate variability.”

We address this in point (ii) of the subsequent paragraph: *“To constrain the timing and duration of the abrupt hydroclimate anomaly associated with the 8.2ka Event, the datasets in this compilation were screened to meet the following criteria: (i) data resolution of 50 years or better over the period of 7ka-10ka; (ii) **based on hydroclimate-sensitive proxy data interpreted by authors as reflecting precipitation amount or intensity, the isotopic compositions of environmental water (including precipitation, lake water, and seawater), effective moisture, lake level, fluvial discharge, or sea surface salinity (SSS);** and (iii) contain at least three radiometric dates over the 7ka-10ka interval. Emphasis was placed on collecting water isotope-based records to enable more direct comparison with isotope-enabled climate model simulations.”*

Line 151. Why 10 years? On what is this based?

The actR parameter in question (summary.bin.step) controls how the shift detection information is summarized in the output, and has no bearing on the change point calculation itself. Because the majority of our records are decadal resolved, and because we wanted to constrain the timing of significant shifts as precisely as possible, this value was chosen for our data processing.

Line 166. Why 50 or 100 years? Why not taking just 50 years?

Thank you for this question. Our parameter choices were based on the following considerations: The large dataset required parameters that would effectively accommodate most time series in our compilation while minimizing spurious shift detections. For all but one record in our compilation, the 100-year minimum segment length optimally captured abrupt changes without detecting broader climatic trends or less significant (spurious) shifts. For the PAD07 speleothem record of Cheng et al. (2009; Fig. A43 in our manuscript), it was necessary to reduce the minimum segment length to 50 years to capture the clear isotopic depletion near 8.2 ka that was otherwise smoothed over when employing our longer 100-year minimum segment length (see Fig. 7 below). This was the only record in our compilation that necessitated such an adjustment, and we have clarified this in the manuscript. A comprehensive sensitivity analysis of this parameter would be valuable to systematically determine the optimal minimum segment lengths across different types of paleoclimate records. However, this was outside the scope of our current study.

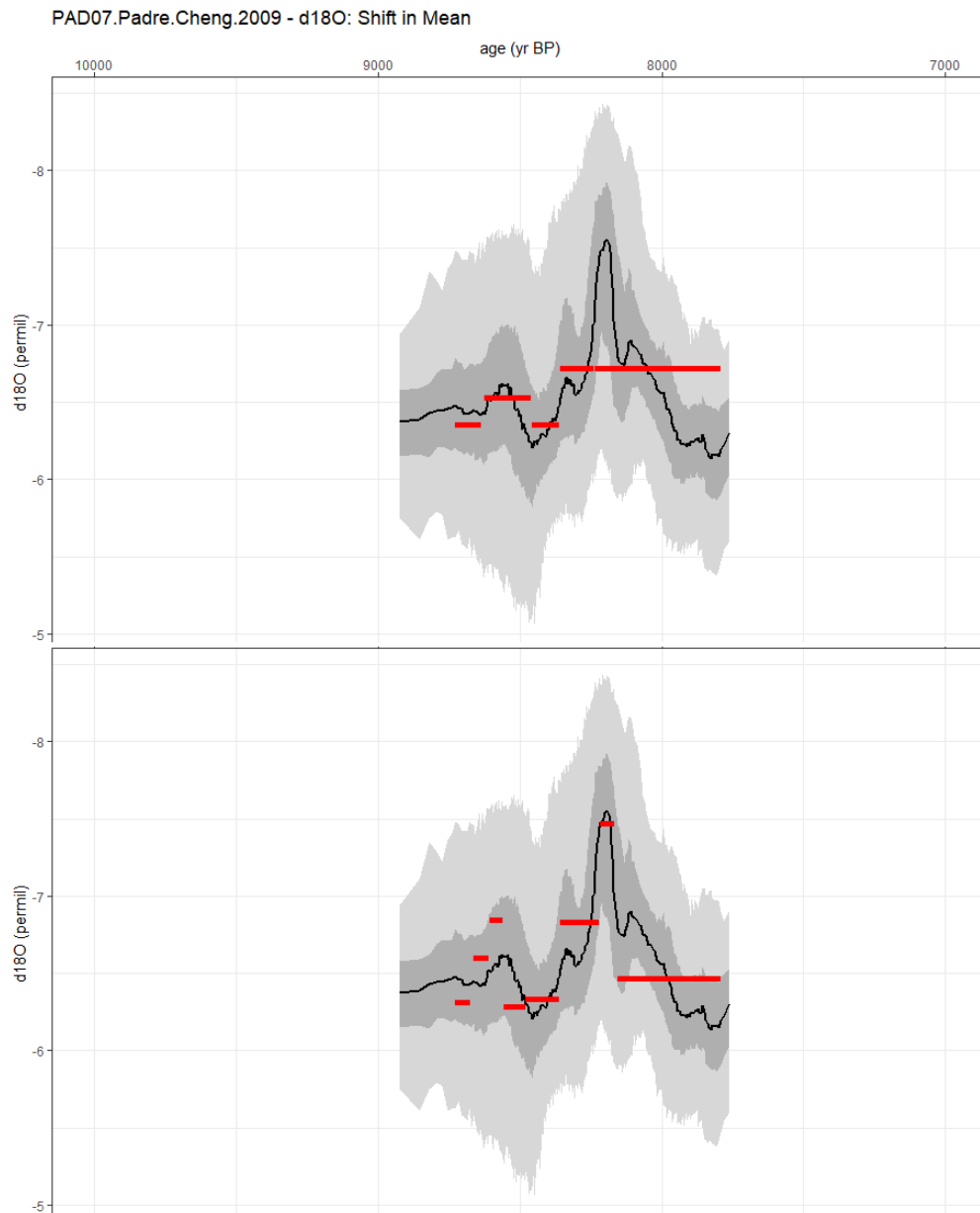


Figure 7. A comparison of shifts in mean (red horizontal lines, thickened for visibility) detected in the ensemble time series for PAD07 (Cheng et al., 2009) using a minimum segment length parameter of 100 (top panel) and 50 (bottom panel).

Line 183. In the actR method, the time window for detection (7.9 to 8.3 ka) is different from the window used in the MM method (7.9 to 8.5 ka). Why this difference and what is the consequence? In addition, is there also a minimum duration for detection in the actR method? The analysis window used in the MM method is the same as the window defined in Morrill et al. (2013), maintained here for some degree of parity with their original analysis, which they chose “to bracket the [8.2ka] event, while accommodating errors in the age models of several hundred years”. The tighter (“significant”) window that we employed in our actR method (7.9-8.3ka) is based on the duration of the 8.2ka Event in Greenland ice core data within age uncertainties

(8.25ka to 8.09ka; Thomas et al., 2007). Additionally, we define a second, broader actR window from 7.7-8.5ka to further account for age uncertainty across which we define our “tentative” events. The actR method allows us to leverage new, robust age modeling tools and the propagation of age uncertainties through our changepoint analyses to better estimate the timing and duration of abrupt events, like the 8.2ka Event, while the MM method adds supporting evidence to our interpretation of the sign and magnitude of the detected changes.

To your second question, the minimum event duration length using the actR method is 20 years. We have added this to our Methods section in our revision, and we thank you for bringing this omission to our attention.

Line 212. Are the forcings for the “ctrl” simulation identical to the 400-year-long 9ka simulation? If not, what are the differences? And is the climate stable in “ctrl” or is there still a trend in the surface conditions, signifying adjustment to the different forcings?

Yes, the preindustrial control simulation is branched from the 9 ka simulation and all forcings and boundary conditions are identical to the 400-yr 9 ka simulation. Quasi-equilibrium has indeed been reached in the last 100 years of the control run (analyzed in this study), based on the lack of a trend in the global average surface air temperature (see Fig. 8 below).

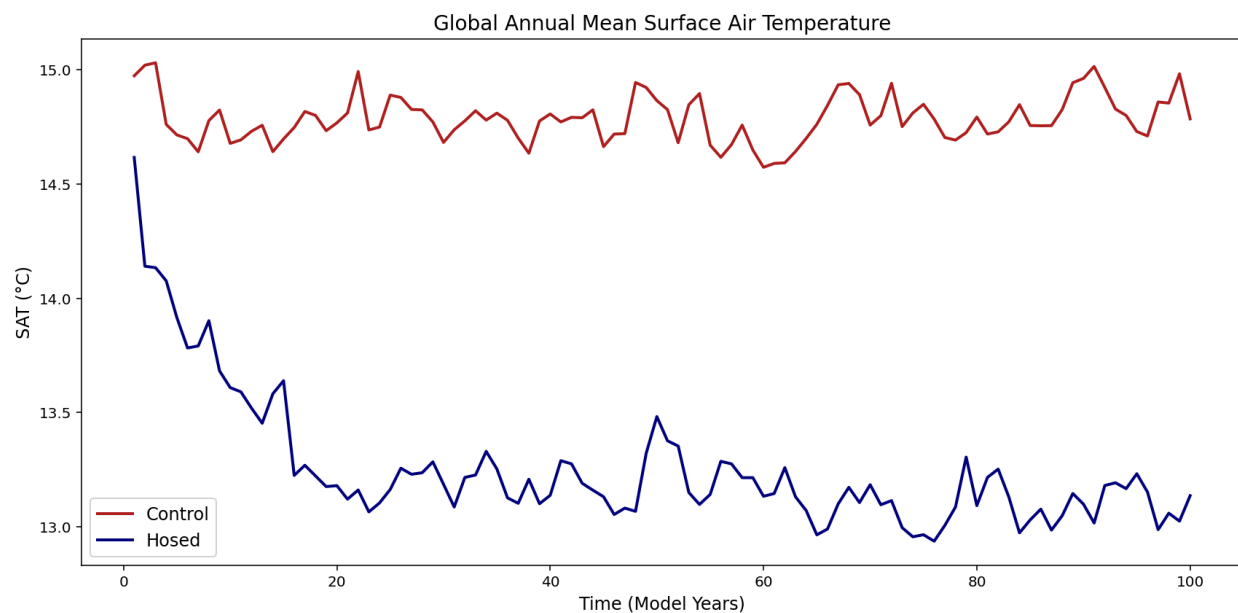


Figure 8. Time series of simulated global mean surface air temperature (SAT) for the last 100 years of the control run (red) and all 100 years of the hosed run (blue).

4.3 Data-Model comparisons. It is noteworthy that the regional structure of the 8.2ka event found in this study resembles the hydroclimatic anomaly in a simulation of the Younger Dryas cold event in which freshwater forcing applied in the North Atlantic also plays an important role (Renssen et al. 2018). The hydroclimatic response for the Younger Dryas shows wetter conditions in the Caribbean, SE South America, Southern Africa and Madagascar, but drier

conditions in S Central America, the Arabian Peninsula and SE Asia, broadly consistent with the proxy-based signal of the 8.2ka event provided in the present paper in Figure 2.

Thank you for pointing this out. There are indeed some interesting similarities between these two data sets and thus, we have added the following sentence to our Results in 3.5 Data-Model Comparisons:

*“Similar hydroclimate features also appear in simulations of the Younger Dryas cold event from Renssen et al (2018).”*

However, we don't emphasize the comparisons between our proxy compilation and this study beyond this for several reasons: (1) the Younger Dryas cold event had differing boundary conditions and a much larger amplitude than the 8.2ka event, (2) the majority of the proxy records in Fig. 2 are speleothem  $\delta^{18}\text{O}$  records, a proxy for precipitation  $\delta^{18}\text{O}$ , while the modeling results of Renssen et al. (2018) show the change in soil moisture, and (3) the fact that the most robust signature in our proxy records is the drying/isotopic enrichment event in East Asia, which does not agree with the simulated increase in soil moisture in that region in Renssen et al. (2018).

Line 238. "... a lack of agreement of the sign or presence of an event". Do you mean a lack of agreement between the two detection methods? Please clarify.

Yes, thank you for the suggestion. The sentence has been updated to make this explicit: "The remaining 31 records in our compilation displayed a lack of agreement between the two detection methods in the sign or presence of an event and are thus excluded from further analysis."

Figures 2-7. The grey symbols are very hard to see, so I suggest improving their visibility.

Thank you for this suggestion. Because the size of the symbols scales with the magnitude of the Z-scores to emphasize the most prominent signals in the records, the grey symbols (indicating no change) are typically small. However, we agree that it is important to identify these records, and so we have added black outlines to the grey symbols in our revised figures, which we believe has made them more visible (e.g. see Fig. 9 below).

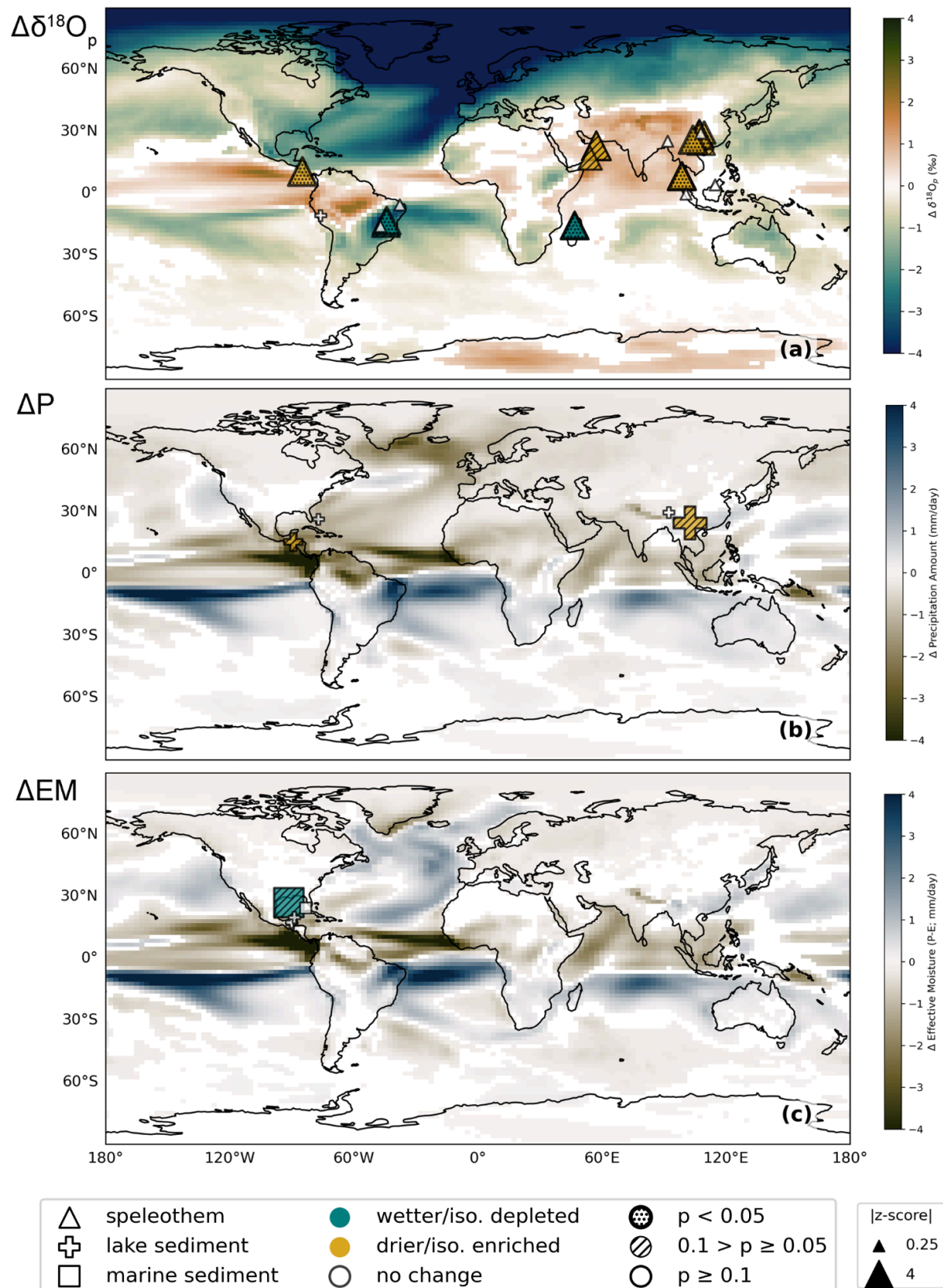


Figure 9. Summary of the 8.2ka Events detected using our actR method for the paleoclimate records included in this study. Records with drier and/or isotopically enriched events are shown

in brown, records with wetter and/or isotopically depleted events are shown in green, and records in which no event was detected are shown in white. Stippling indicates that a “significant” event was detected in a given record by actR with event “start” and “end” times within the 7.9-8.3ka interval at the  $p < 0.05$  significance level. Slashed hatching indicates the presence of a “tentative” hydroclimate anomaly, with either a “significant” event detected outside of the 7.9-8.3ka window (between 7.7-8.5ka) or an event within that window where  $0.1 > p \geq 0.05$ . Symbol size is scaled by  $250\ln(1+|z|)$ , calculated from the per-record mean and standard deviation over the 7ka-10ka interval. Symbols are mapped over the simulated anomalous (a) amount-weighted oxygen isotopic composition of precipitation, (b) precipitation amount, (c) and effective moisture calculated from difference between the last 50 years of the iCESM “hose” and “ctrl” experiments at the 95% confidence level ( $p < 0.05$ ).

Figures 3-7. What do the grey isolines represent? Please explain.

The grey isolines represent the average oxygen isotopic composition of precipitation from the control simulation, however, they are extraneous and so have now been removed from the revised figures.

Figures 4-7. In several cases, there are no proxy records of a specific type in a region (for example marine records in East Asia, Figures 4c and f). It is not very meaningful to show the simulation results in these cases, as there is no data-model comparison possible. So, I propose to only show the maps of key regions if there are proxy records available for the data-model comparison.

Thank you for the suggestion. We agree that the panels lacking proxy data are unnecessary. These extraneous panels have been removed from the revised figures.

Figure 5. Legend is missing.

Thank you for finding this. We have corrected it in Fig. 10 (see below), and have incorporated your suggestion from the previous comment as well. The MM results will be moved to the Supplemental Material.

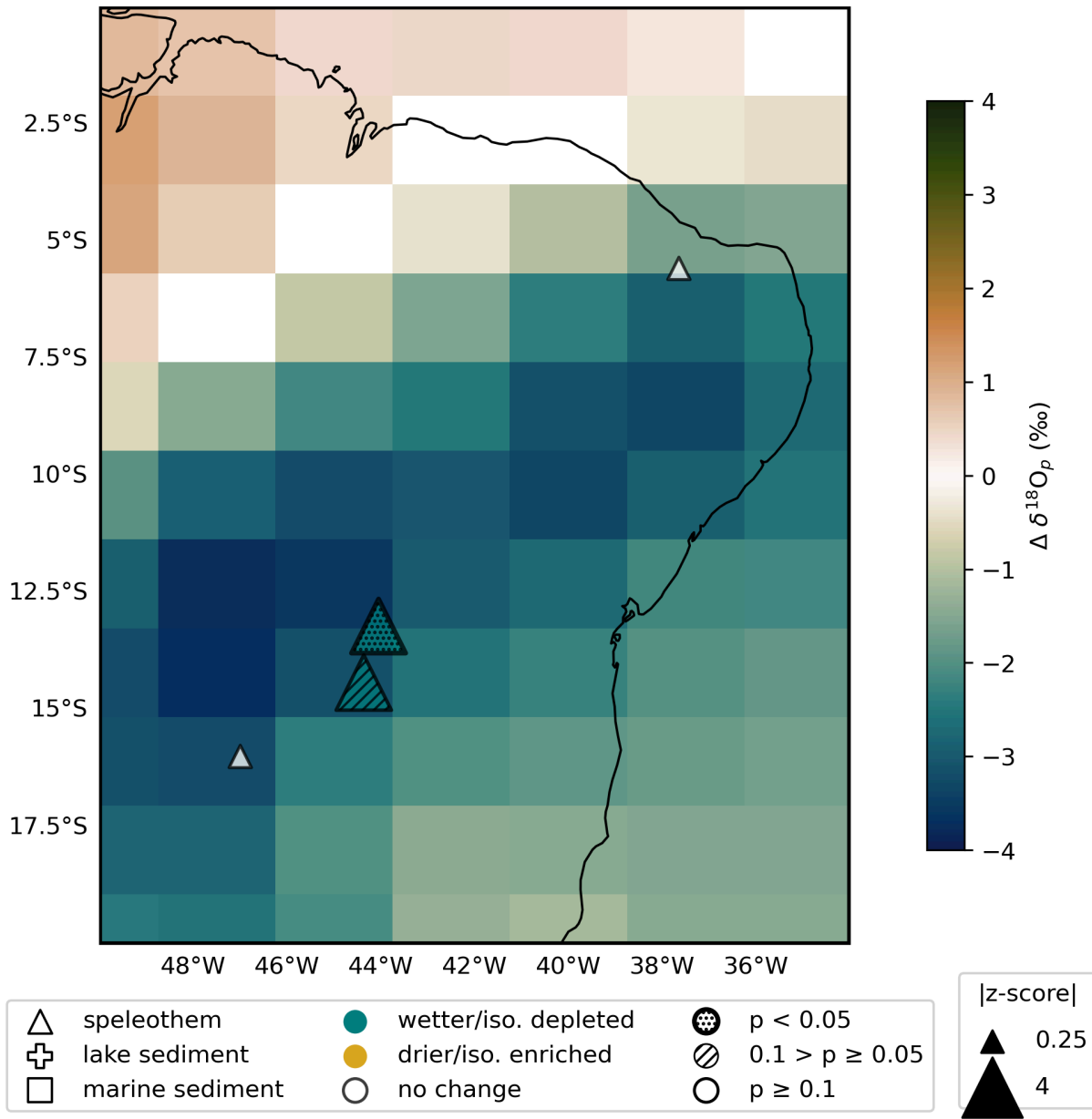


Figure 10. Data-model comparison of IPCC region 11: northeastern South America. Symbols are scaled to  $400\ln(1+|z|)$  for visibility.

Figure A2a and b. According to the figure caption, the contours in these figures indicate the “range of temperatures in the “ctrl” simulation over the full 100 years”. It is not clear what temperatures these isotherms represent, so I do not see how these contours are useful, and I suggest removing them from the figure.

Thank you for the suggestion. The unfilled contours representing the isotherms in the control simulation have been removed.

Additional references



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