Response to Reviewer #1 comments by Leupold et al.

We are grateful for the feedback provided by an anonymous reviewer. The reviewer raises seventeen (RC1 –1 to RC1 – 17) specific comments, which are addressed in detail below. Additionally, technical corrections are provided by the reviewer, which are addressed below, as well. In the following, we will repeat the reviewer's statements (in bold font) and our reply to it. Below the responses to these specific comments, we respond to the technical corrections except for cases where e.g. typos are highlighted.

Specific comments

RC1 - 1

- l104: "ENSO Indices" There is in my opinion more recent ENSO time series that you coul have. Why did you chose to use only "old" reconstructions?

We wanted to use as few indices as possible, and the same indices for all coral time windows shown in our study, for consistency. However, we did not only rely on the Quinn record from 1993. We compared Quinn 1993 with the list of ENSO events compiled in Brönnimann et al., 2007 (https://doi.org/10.1007/s00382-006-0175-z). We believe that this gives some indication of the sensitivity of our results with respect to different ENSO reconstructions. Both records cover all our coral time windows, including our 17th century coral record. Brönnimann et al. (2007) combined several reconstructed ENSO indices (ERSST NINO3 by Smith and Reynolds, 2004 (https://doi.org/10.1175/1520-0442(2004)017<2466:IEROS>2.0.CO;2); Mann NINO3 by Mann et al., 2000 (https://doi.org/10.1175/1087-3562(2000)004<0001:GTPIPC>2.3.CO;2); Cook/D'Arrigo NINO3 by Cook, 2000 (https://www.ncdc.noaa.gov/paleo-search/study/6250) and D'Arrigo et al., 2005 (https://doi.org/10.1029/2004GL022055); Stahle SOI by Stahle et al., 1998 (https://doi.org/10.1175/1520-0477(1998)079<2137:EDROTS>2.0.CO;2), climate field reconstructions and early instrumental data and also assessed the data for consistency.

RC1 - 2

- l137: "concentration of approximately 8ppm Calcium". I'm a bit surprised by this value. Usually with 0.6 mg of carbonate powder in 6mL you are getting 50ppm of Calcium. Additionally, Villiers et al. (2002) that you are citing above recommend analyzing between 40 to 60 ppm of Ca.

The concentration of Ca in the measuring solution is determined by the concentration of the trace element to be analyzed:

For Mg (Mg/Ca) in foraminifers which is the target analyte of the de Villiers et al. (2002) and Schrag (1999) papers we use Ca at 40-50 mg/L giving best response of the Mg 279 line in our instrument at given conditions.

For Sr (Sr/Ca) in corals we use the Sr-407 (or Sr-421) emission line with very high sensitivity in our instrument so that we had to reduce the Ca concentration to 8 mg/L. This also allows for reduced sample weights and, therefore, for higher time resolution in the coral.

It is the concentration and response of the trace element that defines the required concentrations in solution for getting best counting statistics. The Ca concentrations are, as a consequence, determined by the trace element response and the Mg/Ca and Sr/Ca ratio of the sample, and not vice versa.

RC1 - 3

- l140: Can you, please, indicate why you did not use any CRM such as JCp-1? Can you, please, be more specific and give the mean % of recovery ± SD and the N values

In total, 5 different standards were used, including the international standards JC-p-1 and JC-t-1. They were measured before and after the entire measurement sequence. We will explain this in more

detail in the methods section in a revised version. Furthermore, we will add error bars on all coral Sr/Ca graphs and will give precision values.

RC1 - 4

- l149: "We assigned the highest Sr/Ca value to the SST minimum of each year and interpolated linearly between these anchor points to obtain a time series with equidistant time steps" Which software did you use? Why only interpolate between two consecutive high values? Why not between two lows or between one high and one low as it is usually the case?

We developed the age model following the pioneering work of Charles et al., 1997 (https://science.sciencemag.org/content/277/5328/925), who has proposed to use the month of August as one single anchor point in any given year at the Seychelles, a site located slightly further west than Chagos with a similar monsoon-dominated SST seasonality. Charles et al. have demonstrated that with their approach, monthly anomalies can be computed from coral proxy data, and that these monthly anomalies can be correlated (calibrated, in fact) with instrumental SST anomalies. See Charles et al., 1997, Figure 2 B.

Due to the strong cooling of the western and central Indian Ocean following the onset of the Indian summer monsoon in boreal summer, which is seasonally phase-locked, this age model is very precise (the non-cumulative age model error is +/-1 month in any given year). Each additional anchor point would introduce an additional error which, in the Indian Ocean, tends to be larger during the other seasons of the year.

The approach proposed by the Reviewer (interpolating between two lows or between one high and one low) would only be applicable at sites that have large-amplitude, sinusoidal seasonal cycles, where age model errors become a problem in the transitional seasons in fall and spring due to the rapid change in SST during a short time period.

RC1 - 5

- l193: I would have liked to see how you determine the annual mean (average between two max Sr/Ca) ? and how did you determine the standard error?

The annual means were generated by averaging every values of one year (Jan-Dec). When averaging different values, you can determine a standard deviation for this calculation what we did with Excel. With the standard deviation, we calculated the standard error with the formula below.

The standard error (SE) were used and calculated as follows:

SE = (standard deviation (σ))/$\sqrt{}$ (Number of values (n))

RC1 - 6

- l218: Can you please explain how and especially why you decided to detrend the record?

For detrending we used published methods by Mudelsee, 2000 (https://doi.org/10.1016/s0098-3004(99)00141-7) and Mudelsee, 2009 (https://doi.org/10.1140/epjst/e2009-01089-3). As it can be seen in figure S6 in the Supplementary Material, the long-term trend was subtracted and not, e.g., the annual cycle. Detrending was necessary for time series analysis (singular spectrum and power spectrum analysis) and to compile the composite records. With the long-term trend being subtracted out, the anomaly events could be detected (see also figure S6).

RC1 - 7

- l223: You should not cite Figure 7-9 while talking about ENSO event frequency, those figures are not at all giving information on frequencies.

We agree, that figures 7-9 do not say anything about ENSO frequency. We will change the reference in the revised version.

RC1 - 8

- l228: I'm confused l226 you indicate that El Nino events occurs every 5 years between 1965 and 1995 and l228 you mention a recurrence time of 3.6 years ...

We agree that this might lead to confusion. The recurrence time of 3.6 years between 1965-1995 mentioned in l228 is taken from the list of events in Quinn 1993 (as mention one sentence before in l227). We wanted to compare the recurrence times calculated from our coral records with that calculated from published data. We will adjust this paragraph in a revised version so that it will not lead to any confusion anymore.

RC1 - 9

- l229: Can you please indicate here which threshold you used when considering an anomaly and therefore considering that it is an El Nino or La Nina year?

The events described in this paragraph are the same listed in Tables 4, 5 and 6. They were picked as described in section 4.5 in the manuscript: "…Positive SST anomalies in the coral records were interpreted as positive ENSO events when the year of occurrence was listed as one with large-scale ENSO event in Quinn (1993) and Brönnimann et al. (2007) within the error of each coral age model and **when the anomaly exceeds 1.5 standard deviations of the mean of each coral record** (Fig. S6). In addition to the strong La Niña events listed in Brönnimann et al. (2007), we added negative SST anomalies occurring in years after the El Niño years to the composite."

RC1 - 10

- l240: Using data from Quinn (1993). I do believe that there is more up to date studies on ENSO events... I would feel more confident in your results if you had compared to multiple studies.

As also mentioned in l240, we not only used data from Quinn (1993), but also from Brönnimann et al., 2007 (https://doi.org/10.1007/s00382-006-0175-z), who provides a synthesis of multiple ENSO reconstructions. For an extended explanation why we used these lists/indices, see our comment below reviewer comment RC1 - 1 in this document.

RC1 - 11

- l241: "error of each coral age model". What values did you use as a bracket for the age model uncertainty?

As mentioned in section 3.3 Chronology (in l152), the uncertainties of the age models are approximately ±1.9 years (E5), ±2.2 years (B8) and ±2.4 years (E3).

RC1 - 12

- l242: "we added negative SST anomalies occurring in years after the El Niño years to the composite." I do not understand - are those considered La Niña-like events?

As La Niña events tend to occur after El Niño events, e.g. Cai et al., 2015 (https://doi.org/10.1038/nclimate2492), we interpreted negative anomaly events exceeding 1.5 standard deviations of the mean of each coral record (Fig. S6) and occurring after El Niño events as La Niña events.

RC1 - 13

- l266: "the greater sensitivity of the corals to reef-scale". Can it reflect also issues with the calibration you used to convert Sr/Ca to SST?

A detailed calibration for modern corals from the same site (Chagos Archipelago) was presented in Leupold et al., 2019 (https://doi.org/10.1029/2018GC007796). In this study, the regression of coral Sr/Ca with satellite data indicates a significant correlation (r-squared: 0.62, p<<0.01, n=265). As we used the slope of this regression in our study, it probably does not reflect issues with the calibration we used to convert Sr/Ca to SST.

RC1 - 14

- l301-032: "However, … "Something is wrong with this sentence. How could differences between means are not significantly different with one p value of 0.9 and one of 0.07 …. Additionally, does that mean that the decrease in amplitude of the negative anomalies are not statistically significative?

In most field of scientific work, it is common to apply a confidence level of 99%. In this case, the corresponding significance level is 0.01. Both p values (0.9 and 0.07) are larger than our significance level of 0.01, i.e. that the difference between the means is not statistically significant. So, yes, this means that the decrease in amplitude of the negative anomalies between the period 1830-1929 and the period 1965-1995 is not statistically significant.

RC1 - 15

- l322-323: Can you please develop a bit more on this idea.

We are not sure what idea is exactly meant. We described larger anomaly amplitudes during a period of general cooler mean temperatures, which is consistent with results shown in Pfeiffer et al., 2017 (https://doi.org/10.1038/s41598-017-14352-6) and Zinke et al. 2004 (https://doi.org/10.1016/j.epsl.2004.09.028).

RC1 - 16

- l325: "comparable". Comparable to what? You also need to be consistent, you have been using the term "coral composite" and know you are using "Chacos coral"… it is a bit confusing, we are wondering if you are not referring to something else …

With this sentence we want to say that El Niño magnitudes are comparable to La Niña magnitudes. We used Chagos coral records in this sentence, because the El Niño and La Niña events are recorded in the corals from Chagos, they are not recorded in the "Composites". The composites were then generated by selecting the El Niño and La Niña event anomalies recorded in the Chagos corals.

RC1 - 17

- l344: You mean the frequency because the strength of the events are different, there is no change in strength of ENSO events in your study during the 20th century (Figure 9).

We are not sure what the reviewer wants to point at with this comment, because in l344 we did not write anything about the strength of events.

Technical corrections

- l51: "The modern core was included in a composite reconstruction of large-scale SST (Pfeiffer et al., 2017) and the core top (1950-1995) was shown to record SST variability at Chagos on grid-SST scale (Pfeiffer et al., 2009)." I'm a bit confused by sentence. Maybe should explain a bit more what you had in mind while writing it. One core records more global scale SST variability while the other more the local variability? Is that it?

We simply wanted to say that core GIM has been calibrated with SST in a previous study. In addition, it has been part of a composite coral record for the western equatorial Indian Ocean (together with corals from the Seychelles). We will revise this sentence.

- l55: "We identify past warm and cold events in each record and use these events to compile composites to evaluate the symmetry of positive and negative ENSO-driven SST anomaly events in the tropical Indian Ocean." This paragraph seems out of context here.

With this sentence we explain what we will focus on in this study. We think, it is essential to have it in the introduction. However, we will add more text on ENSO asymmetry in the introduction of a revised version of our manuscript and revise this sentence to better convey the main aims of our study.

- **l62: "… water exchange with the open ocean is substantial." Do you specify that because your coral core is from inside the lagoon?**

We specified it to give a better idea of the setting. We do not know where the coral lived exactly as they were found as boulders at the beach or in derelict buildings.

- **l98: "Averaged over the entire area of the Chagos (70-74° E; 4-8° S), SST is similar…" It would be interesting to add the mean values for both sites.**

We will mention the mean SST for both sites in the revised version. We do not interpret the mean values of our Sr/Ca data. In corals, these are influenced by vital effects, see e.g. Sayani et al., 2019 (https://doi.org/10.1029/2019GC008420).

- **l104: "ENSO Indices" You might want to introduce this paragraph as the time series you will compare your records to? Or something in this line.**

We agree, we will add to this paragraph that the indices presented here are the ones we use for comparison with our coral data.

- **l125: "The core top (1950-1995) was shown to record SST variability at Chagos on a grid-SST scale (Pfeiffer et al., 2009). The entire record was included in a composite reconstruction of large-scale western Indian Ocean SST (Pfeiffer et al., 2017)." Those sentences are similar to the ones l51 that I did not understand. The top core was comapred to grid-SST data and it maches perfectly and then the entire record was used in a coral composite but with which other corals? Can you, please, add more information here.**

The GIM core was included in the coral composite of the Seychelles-Chagos thermocline ridge. This composite comprises cores from the Seychelles and Chagos. We will add this in a revised version of this manuscript.

- **l128: "From the slabs of the sub-fossil corals, powder samples were drilled at 1 mm increments using a micro-milling machine (type PROXXON FF 500 CNC). This depth resolution can be translated to monthly temporal resolution with average growth rates being 12 mm/yr. The subsampling paths were always set along the optimal growth axis that was determined based on x-ray images (Fig. S2)." Can you please add some information on the sampling over laps that you had to do when switching sampling paths? How did you determine the temporal resolution, by looking at the density band or by looking at the seasonal cycles in Sr/Ca data? You might want to move this paragraph up right below where you talk about your new coral core samples.**

All sampling paths were selected so that we get a continuous record for each coral sample. This includes, e.g., both sampling paths on coral slab E3. For this sample, there is an overlap of 10 mm, which means 10 subsamples, for each sampling path, i.e. there is around one year of overlap. We determined the temporal resolution by combining the interpretation of the annual bands visible in the x-rays and the seasonal cycles recorded in the Sr/Ca data.

We will move this paragraph below the paragraph in which we talk about our new coral core samples. In a revised version of this manuscript, we will show the raw data, including the overlaps, as requested by reviewer 2.

- **l138: "The intensities of Strontium and Calcium were converted into Sr/Ca ratios in mmol/mol." Which method did you use to convert the instrument output in intensity to concentration values 1) the calibration given to you by the instrument? or 2) the deVillier et al., 2002 ratio method?**

We convert the intensities of Sr and Ca into Sr/Ca ratios following the methodology proposed by deVillier et al., 2002.

- **l165: Statistic Section : I would like to see this section a bit above as you use statistics in above paragraphs**

We do not see why we should put the statistic section above the other sections in the methods section, because it only introduces statistics used and described in the results and discussion part of the manuscript.

- l189: In my opinion you do not need subsections, but instead a big paragraph labelled Sr/Ca data description, where you describe the results core by core
We think that subsections give a better overview as we have coral samples from different time windows.

- l196: "The range …" Is that the mean range or the maximum range?
It is the range between the maximum and minimum Sr/Ca value (see also table 2).

- l206: Can you please describe how you determine the mean annual cycle?
The mean annual cycles were calculated by averaging interpolated Sr/Ca values for every month over the given time period covered by each coral record. For example, B8 covers 31 years from 1836-1867. For this period, all Sr/Ca values for January were averaged, all Sr/Ca values for February were averaged, all Sr/Ca values for March were averaged, and so on.

- l209: I do believe you should spend a little more time describing Figure 4.
We will add a more detailed description of Figure 4 in the revised version.

- l224: "Our results show that,…" I'm guessing that these conclusions derived from Table 4-6: you might want to refer to it as well as indicate some stats about this change of frequency. Maybe the percentage of increased frequency?
Yes, these conclusions derived from Tables 4-6. We indicated this with an introducing sentence that included the reference to Tables 4-6 at the beginning of the paragraph. However, we can include it once again at the end of the follow-up sentence. We do not see how percentage of increased frequency could help to better illustrates the results described in this paragraph.

- l241: "referring to Figure S6". Figure S6 correspond to the detcoral Sr/Ca records after detrending. Which Figure are you referring to here?
We are referring to Figure S6. In the lower plot, 1.5x of the standard deviation is plotted as dashed lines. Peaks above this standard deviation were considered as anomaly events when listed in Quinn (1993) or Brönnimann et al. (2007). Detrending was necessary for compiling the composite records. With the long-term trend being subtracted out, the anomaly events could be detected. That is why we indicated the standard deviation in this figure and that is why we referred to this figure in this paragraph.

- l245 – 251: This paragraph should be in the method section.
We did not put this in the methods section, because it already consists of our interpretation. We interpret the anomaly events to be El Niño and La Niña events. We think, putting this paragraph in the method section would confuse the reader as it requires information which is provided only later in the manuscript.

- l259: "we compared". I do not think "compare" is the right word. You do not compare, you use the same technique to discriminates El Nino from La Nina from negative events other than La Nina years, right?
That is correct, we also selected the events recorded in the satellite data using the same techniques. But in the end, we compared the results of the satellite data (how many events and the amplitudes) with our coral data.

- l263: "All SST anomalies were … of -0.06 mmol/mol per 1°C (see Leupold et al., 2019)." This section looks more like a material and method section. You do not talk at all about what you found.

This paragraph primarily focusses on the anomaly events we interpreted. However, we agree that we should put sentences like this, regarding the calculation of the SST anomalies, in the methods section.

- l265: "Coral SST proxy". What is that? Is it your so-called ENSO composite?

It is the coral Sr/Ca data, which is used as an SST proxy. We used this expression here, because the ENSO composite is the result of calculations we did with our coral data. We will improve the wording in the revision.

- l288: "On average … (p=0,75)". This sentence is a bit similar to the first sentence of the paragraph, no? You might want to regroup them.

Thank you for pointing that out. We will adjust it in a revised version.

- Figure S1 : Can you please add an arrow to actually point at the boulder you sampled? Can you please add a symbol of the lagoon of Peros Banhos site location on your Map

In figure S1a, a saw can be seen. Above this saw there is pile of boulders. Two of these boulders are E3 and E5. We will add arrows marking E3 and E5. In figure 1 (location of our study area), the lagoon of Peros Banhos is already labeled.