Point-by-point response

We thank both reviewers for their constructive comments which we address briefly in this response.

Reviewer 1

1) …why we used annual resolution Sr/Ca record and how to explain relatively low correlation with SST…

Answer: We opted for multi-core records in this study at annual resolution complemented by short decadal periods of bimonthly data (published previously in Zinke et al., 2004) in order to build a long record of $\delta^{18}O_{seawater}$. Our main focus in this study is to assess the interannual to decadal salinity changes of the greater Agulhas region which have so far not been possible due to the lack of coupled Sr/Ca and $\delta^{18}O$ data. Unfortunately, a higher resolution Sr/Ca analysis is not possible at this stage.

Furthermore, instrumental SST is extremely sparse in the region and will by definition not represent SST at the reef site very well (see Figure 1 of this response). There is no data close to the reef site for many decades pre-dating the 1970's. The low correlation of Sr/Ca-SST with ERSST or HadISST may therefore imply that instrumental data coverage precludes us from making a better judgement. We have illustrated the HadSST4 dataset which has not been infilled as other SST data products to highlight the number of observations and uncertainties. We believe that Sr/Ca-SST does reflect local SST well, otherwise the $\delta^{18}O_{seawater}$ reconstructions would not agree with SODA salinity. As such, the $\delta^{18}O_{seawater}$ reconstruction provides independent proof for the quality of the Sr/Ca-SST data as a local SST record. However, local SST may be less informative to assess large-scale SST changes in the region. Note that SST adjusts faster to local atmospheric conditions than $\delta^{18}O_{seawater}$ and salinity, and thus has a stronger signature of local variability. Nevertheless, it is essential to capture local SST in order to correctly reconstruct local $\delta^{18}O_{seawater}$. Our relatively low, yet significant correlation in the Sr/Ca-SST with regional SST is reflected in our Monte Carlo error propagation approach. Therefore, we have taken this low correlation into account and treated our resulting reconstruction more conservatively.

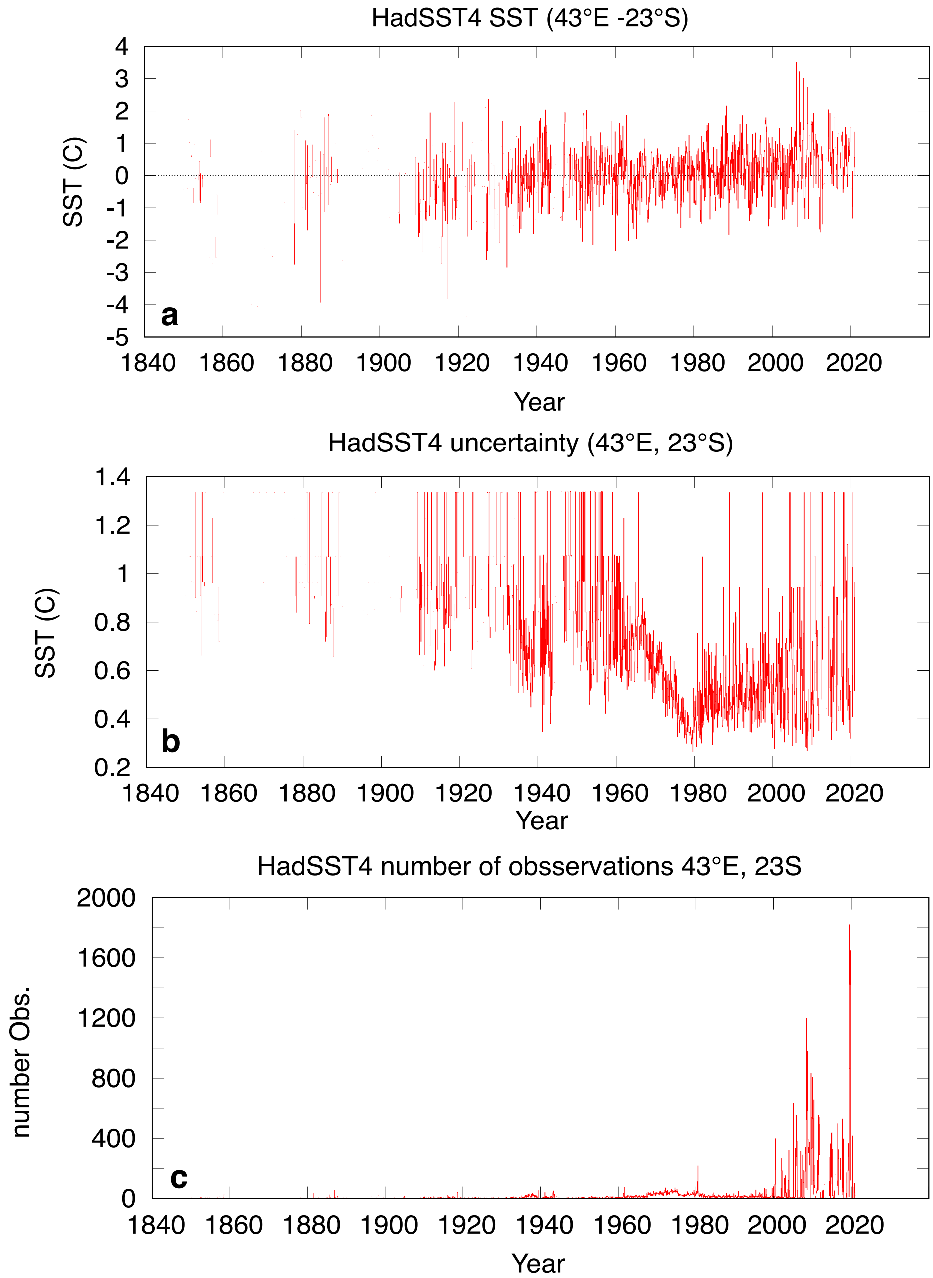

Figure 1 – HadSST4 data for the grid box of Ifaty-Tulear (43°E, 23°S). a) SST anomalies, b) uncertainty of SST and c) number of observations in SST.

2) Agreement/disagreement between $\delta^{18}O_{seawater}$ based on Sr/Ca-SST vs. using HadISST…

Answer: We have indicated the highly significant correlations and significance levels for the detrended $\delta^{18}O_{seawater}$ time series with salinity based on Sr/Ca-SST. In fact, the correlations between $\delta^{18}O_{seawater}$ based on HadISST and salinity are lower, yet still significant. Therefore, despite some year to year variability not being exactly matched in $\delta^{18}O_{seawater}$ based on Sr/Ca-SST, the overall agreement with salinity is statistically robust. Furthermore, HadISST is very sparse for the region as is ERSST5. Hence, we cannot assume that instrumental SST reflect SST at the coral site without significant uncertainties (see comments above). We also like to stress that the $\delta^{18}O_{seawater}$ records based on HadISST or ERSST5 falls within the uncertainty range of our Sr/Ca-SST based $\delta^{18}O_{seawater}$ reconstruction (see Figure 2 of this response). This adds credibility to the Sr/Ca-SST and our $\delta^{18}O_{seawater}$ reconstruction which are truly independent realisations from the instrumental SST and salinity data. We now show ERSST5 in Figure 3a to be consistent in choice of SST dataset for the main figures.

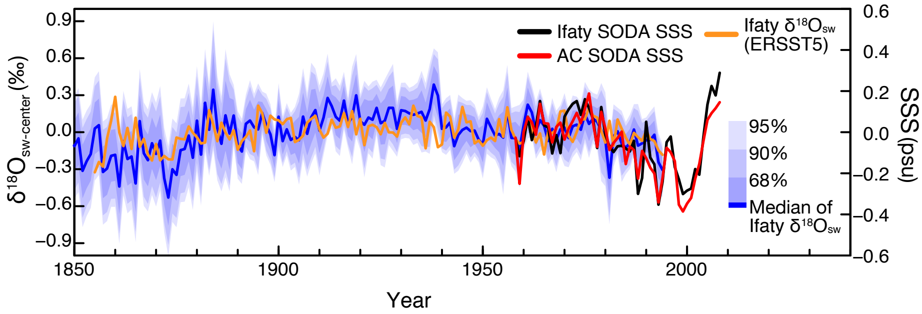

Figure 2 – Ifaty-Tulear $\delta^{18}O_{seawater}$ reconstruction using Sr/Ca-SST (blue), ERSST5 instead of Sr/Ca-SST (orange) compared to SODA salinity for Ifaty (black) and Agulhas Current (AC; red).

3) Manuscript could benefit form more detailed description of model results and potentially re-framing of the aims for the model study…

Answer: We agree with the reviewer that we can reframe the model analysis to better align with our goals. Our study benefits from the inclusion of the model results for mainly two reasons. On the one hand it shows that SST and SSS variability at Ifaty is representative for interannual to decadal variability in the wider AC region. On the other hand it supports the idea that surface fluxes are not the main driver of the that variability. Currently, in the main text, this information is kind of hidden in section 3.1 under the headline "Reconstructed SST and d18O seawater validation with instrumental and ocean model data". This headline is also misleading, since we do not use the model data for a validation of the reconstructions in a traditional sense. During our revision we subdivide the respective old section 3.1 into two new sections 3.1 and 3.2. The new section 3.1 "Validation of reconstructed Sr/Ca-SST and d18Oseawater at Ifaty" is focusing on a comparison of the coral reconstructions for SST and SSS variability at Ifaty with available gridded observation-based products and model data in the Ifaty-Tulear region. It includes a discussion of the discrepancy between the different products regarding the exact temporal evolution of SST and SSS caused by limited number of observations and highlights the best agreement of the coral data with ERSST and SODA. To simplify this discussion, throughout the whole paper we now only analyse variability based on annual means averaged from March to February (in the first version of the manuscript the model part was based on standard January to December means). The new section 3.2 "Representativeness of SST and SSS variability at Ifaty for variability in the wider Agulhas Current region" then focuses on potential co-variability between SST and SSS at Ifaty and other locations in the wider Agulhas region. Here, independent of the mentioned disagreements in the exact temporal evolution, all observational products as well as the model agree that variability at Ifaty is indeed representative for variability in the AC core region (Figure 3). The fact that co-variability is not only found in observation-based products but also in the simulated NST and NSS from an ocean model without data assimilation, supports the idea that this relation is of dynamical nature. This section is further complemented by a new Figure showing spatial maps of correlations between the local NST/NSS variability and NST/NSS variability at Ifaty as inferred from the model. These maps emphasize that co-variability is not only restricted to the AC core region but occurs for the wider AC region.

4) Question on lines 246 onwards: Reviewer asked if correlations between model SST and observations were done for the Ifaty coral site, the AC region or the SW Indian Ocean more broadly

Answer: The answer to this question can be found in lines 230-235 where we have defined the regions used, it reads: "To further validate our hypothesis that the Sr/Ca and $\delta^{18}O_{seawater}$ records from the Ifaty-Tulear reef complex are representative for temperature and salinity in the wider AC region, we analysed the relationship between the temporal evolution of annual mean (January to December, changed in the revised version to "March to February") **salinity and temperature at the location of Ifaty (43°E, 23°S) and within the AC (30°E, 32°S) in a hindcast simulation** with the mesoscale eddy-rich ocean/sea-ice model configuration INALT20 (Schwarzkopf et al., 2019), as well as in SODA and additional reanalysis and observation-based products (EN4 and HadISST; Good et al., 2013; Rayner et al., 2003)."

5) More detailed description of interannual and decadal variability…explore links with ENSO, PDO etc.

Answer:

We will explore further the links with ENSO and PDO via EOF and running correlation analysis. Regarding ENSO's influence on the region, it has been shown that only 10-20% of variability in SST or current transport is explained by ENSO (Paris et al., 2018). Our analysis and discussion had, therefore, mainly focused on the suggestion by earlier studies on Agulhas Current and leakage SST and salinity showing a lagged response to ENSO up to 24 month. Those results were based on short instrumental observations. Our results provide a long-term assessment far beyond previous assessments. As such, we focused on the lag to ENSO in $\delta^{18}O_{seawater}$, hence salinity. We could confirm that this lag is also observed with the $\delta^{18}O_{seawater}$ data between 1958 and 1995. Now, we can confirm that this lagged response is also observed with the Nino3.4 record based on ERSST5 back to 1880 (see Figure 2 below; $r= -0.37$, $p=0.01$). The lagged response is also reproduced with Nino3.4 paleoclimate reconstructions back to 1750, yet only significant at the 90% level ($r= -0.2$, $p=0.1$).

We avoided overinterpretation of ENSO's influence in our discussion mainly focusing on comparison of the interannual frequencies in our record and how that compares to previous studies for the Indo-Pacific Ocean to draw some careful conclusions regarding potential influences of ENSO in the pre-industrial period. Earlier work by Zinke et al. (2004) already concluded that the relationship between coral $\delta^{18}O$ and ENSO was non-stationary. Thus, drawing conclusions on ENSO's influence beyond the instrumental era is difficult. The latter is mainly due to Last Millennium ENSO reconstructions still not agreeing on the sign and variability (Emile-Geay et al., 2013; Steiger et al., 2018). We had, therefore, opted to tone down the discussion of ENSO's role in the region.

Now, we have tested band pass filtering of the Ifaty-Tulear $\delta^{18}O_{seawater}$ and palaeo-ENSO reconstructions for interannual to multi-decadal periodicities as well as running correlations (see Figure 3 below; Emile-Geay et al., 2013; Steiger et al., 2018). The ENSO reconstructions do not agree with each other for large parts of the record since 1661. The best agreement is found for the period where both ENSO reconstructions were calibrated with instrumental data (1870-1995) for the 3.3 to 4 year frequency band. Consequently, our band pass filtered $\delta^{18}O_{seawater}$ record showed various levels of agreement and disagreement with individual ENSO reconstructions. Running correlations (31-year) revealed a highly non-stationary relationship between Ifaty $\delta^{18}O_{seawater}$ and ENSO, switching between negative and positive correlations (see Figure 4 below). Yet, spectral coherence analysis suggests that Ifaty-Tulear $\delta^{18}O_{seawater}$ is coherent with the Nino3.4 index for observations and paleo reconstructions at frequencies between 3.3 and 4 years, as well as decadal bands ranging between 13-30 years. We will include this analysis in the Supplements. Further results on the lagged correlations are discussed below and explored in Figures 5 and 6 of this response. The results show that the 24-month lagged correlation between $\delta^{18}O_{seawater}$ and Nino3.4 is persistent for the majority of the record. Uncertainties in ENSO reconstructions and/or in our $\delta^{18}O_{seawater}$ record may have affected the lagged correlations beyond 1750. Nevertheless, the consistent lagged response to ENSO is most likely the most important finding of this study.

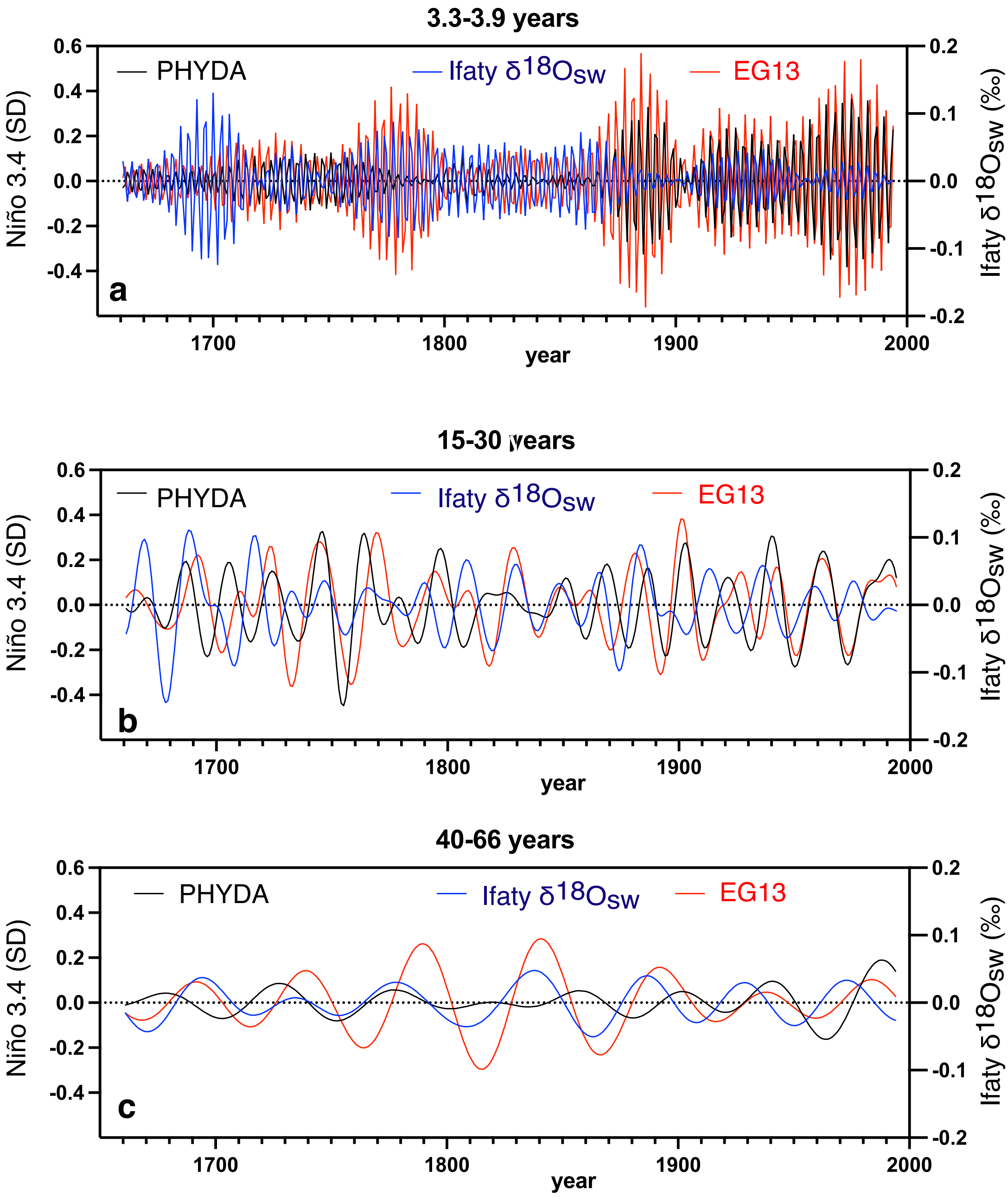

Figure 3 – Band pass filtered data for Ifaty-Tulear $\delta^{18}O_{seawater}$ (blue), Nino3.4 index from Emile-Geay et al. (2013; EG13; red) and Nino3.4 index from Steiger et al. (2018; black; PHYDA) for a) interannual (3.3 to 3.9 years), b) interdecadal (15-30 years) and c) multidecadal (40-66 years) frequency bands.

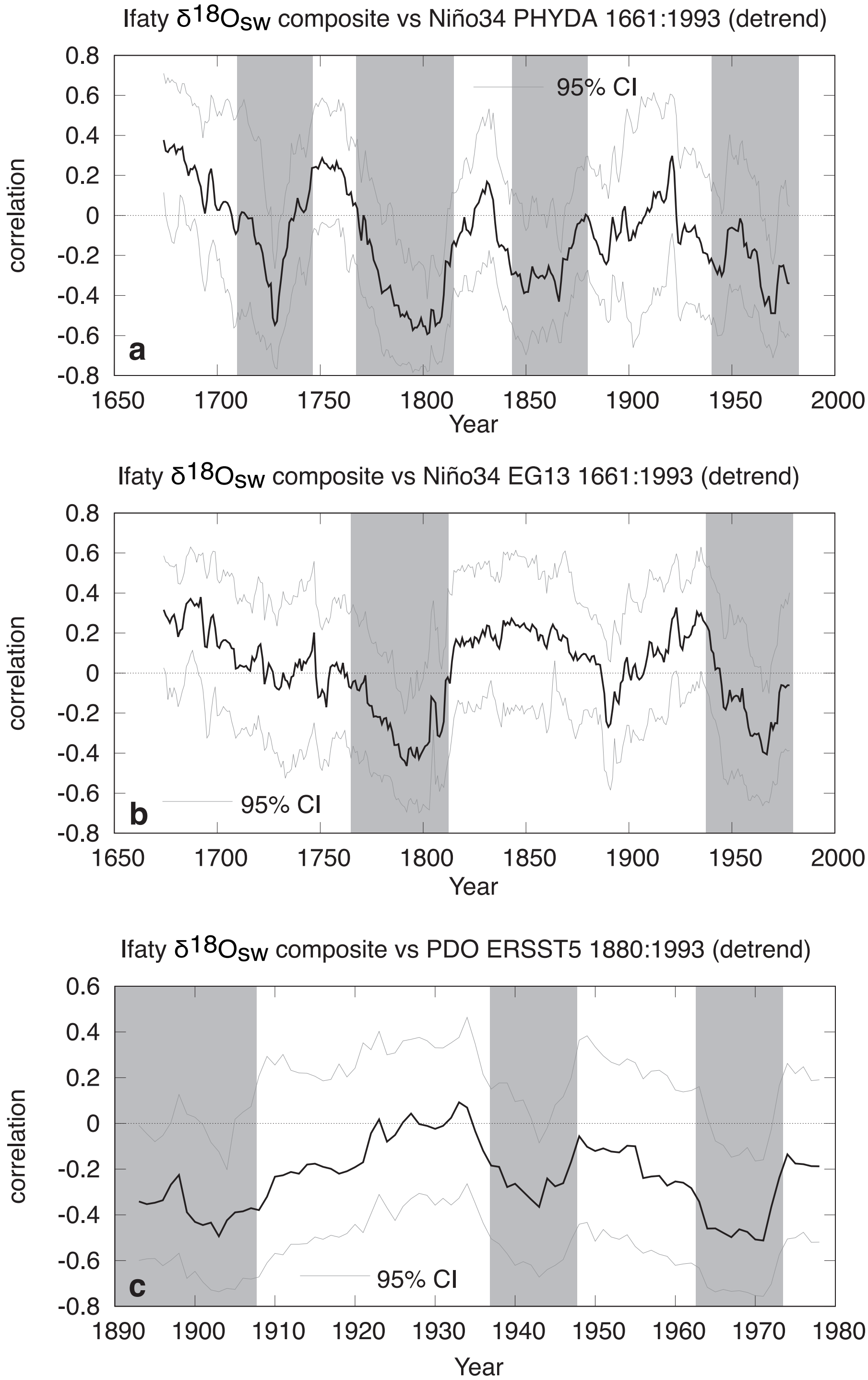

Figure 4 – 31-year running correlations (black line) between Ifaty-Tulear $\delta^{18}O_{seawater}$ composite and a) Nino3.4 reconstructions of Steiger et al. (2018; PHYDA), b) Nino3.4 reconstruction of Emile-Geay et al. (2013; EG13) and c) PDO reconstruction from instrumental ERSST5 data (1880-1995). Grey lines mark 95% confidence interval. Grey shaded bars highlight period of significant negative correlations. Overall, the relationships are highly non-stationary.

The PDO has been suggested to play a small, yet important role in SW Indian Ocean SST and rainfall on interdecadal time scales (Crueger et al., 2009; Grove et al., 2013).) The same holds for correlations between the PDO and Ifaty-Tulear ERSST5 (r=0.26, p=0.003). Crüger et al. (2009) showed that the combined SST and SLP patterns related to Pacific Decadal Variability has some influence on the Ifaty coral δ^{18}O-SST by influencing trade winds and the South Equatorial Current. A 31-year running correlation between the PDO index based in ERSST5 and $\delta^{18}O_{seawater}$ revealed a non-stationary relationship (see Figure 4c above). The correlation coefficient for the entire record between 1880 and 1995 is r= -0.28 (p=0.01), thus relatively weak. Negative correlations ranging between -0.4 and -0.6 were observed for 31-year periods centered around 1900, 1940 and 1970. In these periods, a negative PDO was associated with positive $\delta^{18}O_{seawater}$ anomalies (more saline conditions). In the revised version we will further investigate the PDO influence during the instrumental data period to assess if further conclusions can be drawn with regard to decadal variability observed in our Ifaty $\delta^{18}O_{seawater}$ record.
We plan to include the figures in this response as Supplementary Figures in the revised manuscript.

6) Question about the comparison of regional $\delta^{18}O_{seawater}$ reconstructions across the western Indian Ocean and why correlations are not significant.

Answer:
We agree with the reviewer that we could have pointed out that while long-term changes agree, year to year variability does differ between reef sites. We will amend the text accordingly. The caption of Fig. S9 does show the correlation and p-value for Antongil Bay with Mayotte and indicates that other correlations between sites are not significant.

We added to caption of Fig. 10: "Only the correlation between Mayotte and Antongil Bay reconstructed $\delta^{18}O_{seawater}$ is statistically significant."

<u>Technical comments:</u>

Line 184: Are these GPS coordinates for coral sites?

Answer: No, there are the grid-box GPS coordinates which include our coral sites.

Lines 191-192: Why was the MEI index used?

Answer: The MEI index is a superior index to Nino3.4 because it reflects the combined atmosphere-ocean (multivariate) signature of ENSO which influences the Indian Ocean. Furthermore, the MEI index has been used by previous studies which assessed the salinity-ENSO relationship of the Agulhas Current and leakage region, so for optimal comparison we opted for the MEI index as well. However, using Niño3.4 index instead of the MEI index leads to the same conclusion (see figure 3 below for detrended data). The Niño3.4 data show a lead of 20-24 month to $\delta^{18}O_{seawater}$ with a negative correlation in agreement with earlier studies for the Agulhas leakage region salinity between 1880 and 1995 (see figure 5 below). For the period 1950 to 1995, the 20-24 month lagged correlation is even higher (r= -0.42, p=0.006).
We also tested the relationship with two Nino3.4 paleo-reconstructions of Emile-Geay et al. (2013) and Steiger et al. (2018) (see Fig. 5b, c and Fig. 6 below). The lagged correlation of 24 month is confirmed back to 1880 in all Nino3.4 indices and back to 1750 with the Steiger et al. (2018) and Emile-Geay et al. (2013) reconstructions (Fig. 6a, b). However, the lagged

correlation is stronger between 1880 and 1995 then pre-1880. We plan to include the figures as Supplementary Figures in the revised manuscript.

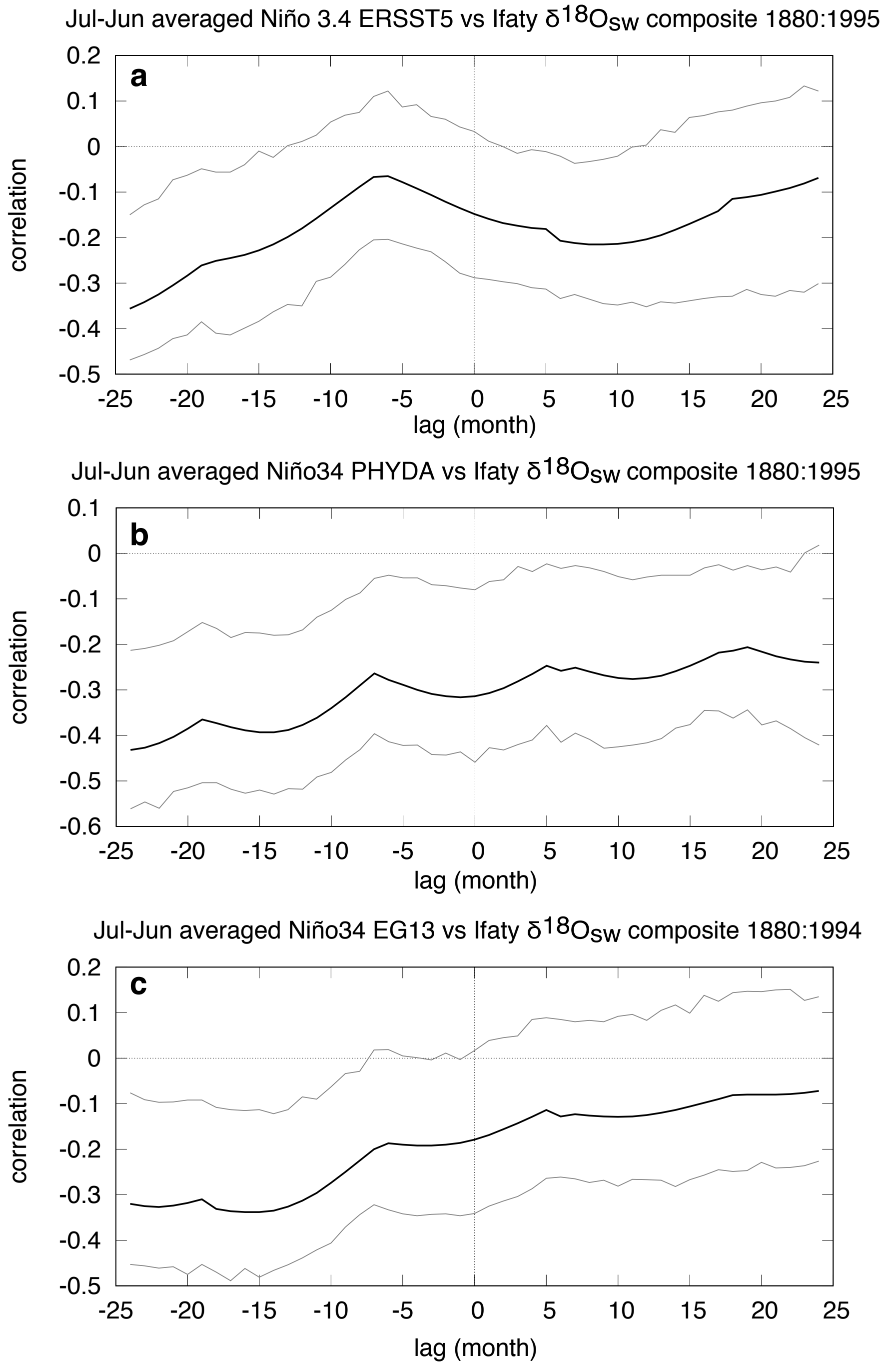

Figure 5 – Lagged correlation between annual mean Ifaty-Tulear $\delta^{18}O_{seawater}$ composite with Nino3.4 index between 1880 and 1995 from a) based on ERSST5, B) from Steiger et al. (2018; PHYDA) and c) from Emile-Geay et al. (2013: EG13). Negative lag means Nino3.4 is leading. The analysis confirms the lag of 15-24 month between Nino3.4 and Ifaty-Tulear $\delta^{18}O_{seawater}$ beyond 1958.

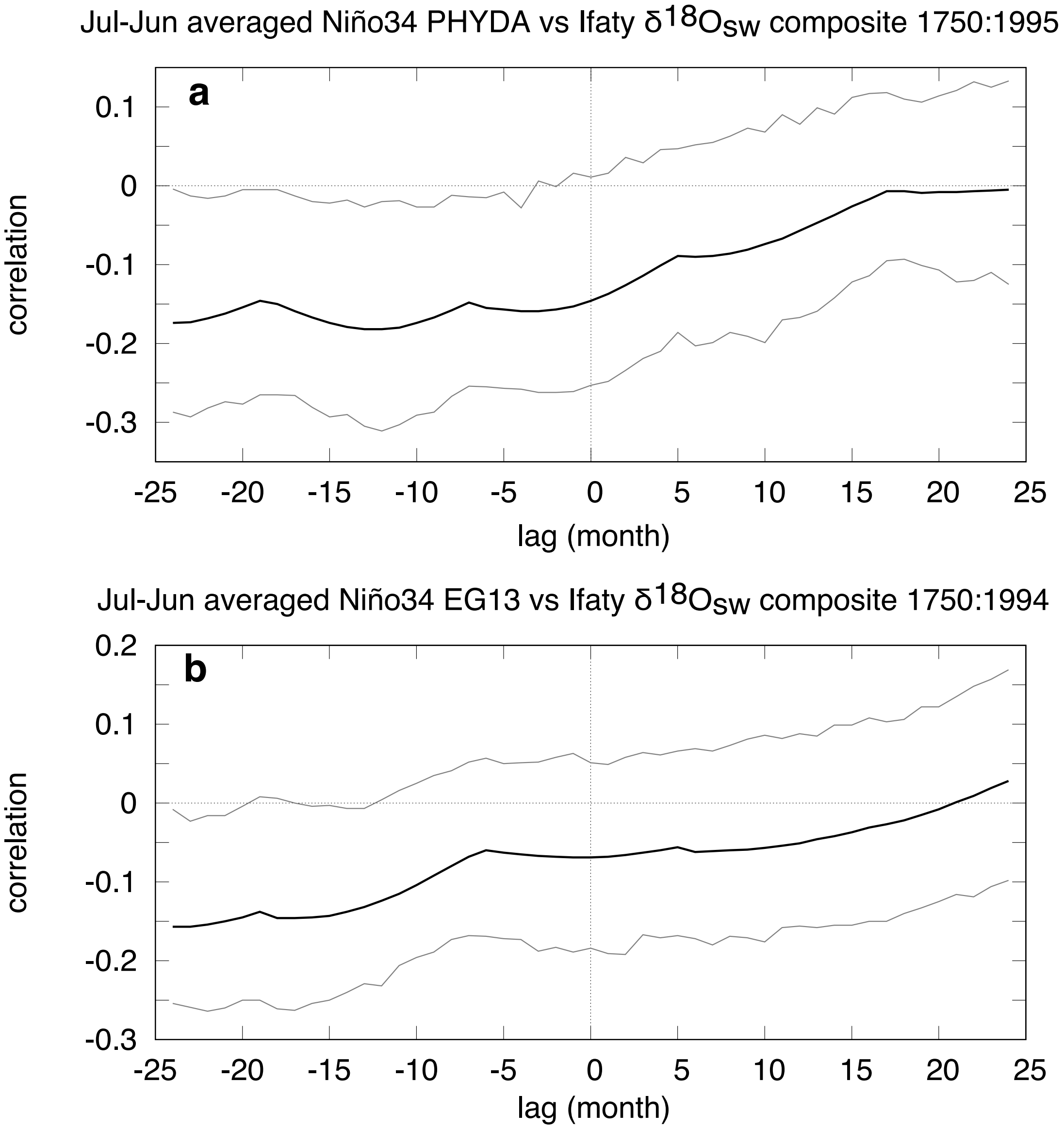

Figure 6 - Lagged correlation between annual mean Ifaty-Tulear $\delta^{18}O_{seawater}$ composite with Nino3.4 index between 1750 and 1995 from a) Steiger et al. (2018; PHYDA) and b) Emile-Geay et al. (2013; EG13). For this period, correlations are significant at 90% level or higher. Beyond 1750, the 15-24-month lagged correlation is no longer significant.

Other comments:

Lines 202-203: Difficult to see how well ERSST5 compares to Sr/Ca-SST in Fig. 2.

Answer: We have illustrated the 1850-1995 record in Fig. S1 in the Supplements to enable a direct visual comparison for the instrumental era. Figure 2 in the paper is to show the long-term coral record with the instrumental data overlaid (*e.g.* ERSST, SODA salinity). We refer the reader to Fig. S1 to get a better idea of the match and mismatch periods for the instrumental era. In addition, Tab. S1 shows all correlation coefficients and significance levels. As stated earlier, we cannot expect a close agreement between ERSST5 and Sr/Ca-SST for all data periods pre-1970 due to very sparse observations.

Line 207: What are the slopes for the calibration equations used in Tab. S1?

Answer: As specified in the methods section, we did not perform a calibration. We applied the mean slope for Sr/Ca vs. SST of -0.06mmol/mol/°C following Correge (2006) and Pfeiffer et al. (2017) on Sr/Ca and $\delta^{18}O$ anomalies (relative to 1961 to 1990) and we randomly propagated the slope errors (±0.01mmol/mol $°C^{-1}$) based on literature estimates in our Monte Carlo reconstruction. It is specified in the methods section.

Lines 215-217: Equations for $\delta^{18}O_{seawater}$ reconstruction should be presented…

Answer: The equations are now included in the methods section 2.3.

Lines 228-230: "I'm having a hard time understanding the sentence…"

Answer: Here we mean that the interannual and decadal variations between fresher and saltier periods pre-1970 indicated by $\delta^{18}O_{seawater}$ are mostly positively correlated (not significant) with Sr/Ca-SST and instrumental SST. Yet, statistically no clear causal relationship could be established. We have clarified this in the text. It now reads: "For the record between 1854 and 1995, it appears as if decreasing (increasing) Ifaty-Tulear $\delta^{18}O_{seawater}$, i.e., freshening (salinification), coincides with decreasing (increasing) Sr/Ca-SST and ERSST5, i.e., cooling (warming). Yet, the relationship is weak and interannual to decadal variability is not statistically significant correlated. Hence, no robust correlation or causality could be established between the temporal evolution of regional temperature and salinity."

Lines 225: "What's the correlation and significance between SODA salinity and the $\delta^{18}O_{seawater}$ record?

Answer: Table 1 shows all correlations and significance levels, and the 95% confidence intervals for these correlations. The correlation is 0.63 (0.50 for detrended data) with significance ranging between p=0.008 and 0.001. The correlations with AC region salinity are higher at r= 0.7, p<0.001 (r= 0.57 and p=0.002 for detrended data).

Lines 264-267: explain what positive correlation between d18Osw and rainfall means etc.

Answer: Now added: "Rainfall and salinity or $\delta^{18}O_{seawater}$ should be negatively correlated when rainfall or freshwater runoff influences the signal."

Lines 282-282: …what a positive correlation means in terms of how changes in zonal wind stress impact $\delta^{18}O_{seawater}$ …

Answer: It now reads: "Our low-pass filtered reconstructed $\delta^{18}O_{seawater}$ record indicates a positive correlation (r= 0.67, p= 0.0063) with the southern Indian Ocean (10-40°S, 50-100°E) ICOADS zonal wind stress, pointing to easterly wind anomalies driving ocean advection of the salinity signal across southern Indian Ocean."

Lines 285-287: It would be helpful to indicate the region you are referring to in Fig. S7

Answer: That region is already specified in the text. The regions we mean are highlighted in colour, they represent the regions with significant correlations. We have now added rectangles for the regions we refer to.

Lines 313-315: "I don't agree that Fig. S8 demonstrates that $\delta^{18}O_{seawater}$" covaries with regional rainfall.

Answer: With regional rainfall we mean the rainfall around the coral site or nearby land regions. We do not imply a large-scale correlation here. We now clarified that in the text.

Figure 2: Make dark red line darker

Answer: Done.

Figure 4: Caption difficult to understand

Answer: We reformulated the caption and hope it reads better now: "**Reconstructed and simulated co-variability of temperature and salinity in the Ifaty-Tulear and AC core regions**. (a-c) SST at Ifaty reconstructed from coral Sr/Ca (red), simulated with INALT20 (black), and obtained from ERSST5 (dark yellow), as well as SST in AC core region simulated with INALT20 (grey) and obtained from ERSST5 (light yellow); (d-f) SSS at Ifaty reconstructed from coral d18Osw (blue), simulated with INALT20 (black), and obtained from SODA (dark cyan), as well as SSS in AC core region simulated with INALT20 (grey), and obtained from SODA (light cyan). Shown are annual mean (thin lines) and sub-decadally filtered (7-year Hamming filter) anomalies (referenced to 1961-1990 mean), whereby annual means in ocean model and instrumental data are calculated as March to February averages for better comparison with the coral record."

Figure 5: Please use colour.

Answer: We increased the contrast of black and grey lines in Figure 5. It is consistent with Figure 4.

Figure 7: Use same Y-axis on all panels, explain green lines.

Answer: Done. Green lines changed to grey and mean correlation to black line. Grey line legend now included stating that it shows the 95% confidence interval of the correlation.

Figure S1: add a, b, c and d

Answer: Done.

Figure S2: It seems that annual $\delta^{18}O_{seawater}$ record underestimates seasonal extremes….

Answer: We dont have high-resolution data here, so we need to rely on the annual record at hand. This figure is to illustrate that the annual record captured the year to year variability for the majority of the bimonthly record data. We do not attempt to capture all seasonal extremes by annual data, rather focus on the interannual to decadal changes and agreements on long-term trends.

Figure S3: Please use colour in panel b

Answer: Done.

Figure S8: Can't read any of the small text at top of panels.

Answer: Done.