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To
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Revision bg-2016-69

Dear Editor,

Please find enclosed our revised manuscript bg-2016-69 entitled “A sea surface temperature reconstruction for the southern Indian Ocean trade wind belt from corals in Rodrigues Island (19°S, 63°E)”, for consideration as a research article in Biogeosciences.

We thank both reviewers for their constructive comments that helped us to improve the mansucript. You will find our detailed response in the document ‘Point-by-point response to reviewers comments’ that we have added to this letter.

We sincerely hope that our revised mansucript is now suitable for publication in Biogeosciences.

Kind regards,
Jens Zinke

Point by Point response to Reviewers' comments:

Interactive comment on Biogeosciences Discuss., doi:10.5194/bg-2016-69, 2016.

Anonymous Referee #1

Received and published: 6 April 2016

General comments:

The authors have made new high-resolution measurements of the Sr/Ca ratios in two coral cores from Rodrigues Island in southwestern Indian Ocean. They have undertaken screening for diagenesis and detailed mapping of the corallite orientation which they apply to assess the fidelity of the coral-derived sea surface temperature (SST) reconstructions through the length of the two coral time series. They also 'calibrate' the coral Sr/Ca series with a range of available 'observational' SST and air temperature products for the region. I appreciate that available SST/air temperature products for calibration with Sr/Ca may produce different results (Section 5.3) but it is extremely confusing for the reader to distinguish what is important in the detailed dissection of the different calibrations (e.g. Figure 6). It might be more understandable to the reader to present a summary table of the different calibrations and characteristics of the resulting SST reconstruction time series. Can we clearly identify the best 'calibration' data set for this region? At present there is a plethora of detailed descriptions but no overall synthesis or tests of whether the differences using different calibration data sets are statistically significant. Overall, I found this paper extremely hard to follow. It would greatly help if the authors clearly articulated the questions they address and then follow this framework to present the Results, Discussion and Conclusions. There is also a lack to statistical analyses whereby the fidelity/reliability of the two coral records and associated reconstructions can be objectively presented. As a consequence it is hard to determine what the main conclusions are and how well supported they are by the data and analyses presented. A shortened and more straightforward presentation of the findings could be a useful addition to the literature. I strongly recommend that the authors reconsider how they present their findings and also focus on summarising findings rather than give a detailed account of every wiggle in the time series that appears either anomalous and/or does not match the other coral or temperature data sets.

We agree with Reviewer 1 that we could more clearly articulate the main questions to be addressed at the end of the Introduction and present the Results, Discussion and Conclusions following this framework.

The end of the Introduction in the revised version now reads:

“Here, we aim to reconstruct past SSTs from Sr/Ca ratios in two coral cores obtained from Rodrigues Island (19°S, 63°E) located 690 km to the North-East of Mauritius within the trade wind belt of the south-central Indian Ocean. To obtain a robust SST record, we assess the reproducibility of the Sr/Ca proxy, and we provide a rigorous assessment of the potential impacts of diagenesis and corallite orientation on Sr/Ca-SST reconstructions. We calibrate individual Sr/Ca records with *in-situ* SST and various gridded SST products and verify the suitability of SST products for climate studies in the south-central Indian Ocean. Furthermore, we assess relationships between the observed long-term SST and climate fluctuations related to the El Nino-Southern Oscillation (ENSO), the Suptropical Indian Ocean Dipole Mode (SIOD) and the Pacific Decadal Oscillation (PDO) between 1945 and 2006, respectively.”

In addition, the paper has been shortened considerably. Our findings regarding anomalous coral Sr/Ca values and corallite orientation have been summarized in a table, and a large part of the discussion has been moved to the supplementary material. Only our key findings are discussed in the main manuscript (see section 6.1).

Specific comments:

Line 27: ‘over recent decades’ rather than ‘past decades’.

Done.

Lines 29-30: ‘sea surface temperature’.

Done.

Line 30: ‘tropical coral reef ecosystems’.

Done.

Line 38: replace ‘of paramount importance’ with ‘essential’.

Done.

Line 50: give the time period over which this increase was observed rather than ‘the recent 15 years’.

Done.

Line 52: Do you mean the past century or the past 60 years?

The past 60 years as stated

Line 54: ‘major role in the decrease’.

Done.

Line 59:’event causing widespread coral bleaching. . .’. Also provide reference for this statement.

Done, Sheppard, 2003 added.

Done.

Line 61: ‘sustainability of tropical coral reef ecosystems’.

Done.

Line 71: ‘for centuries at a rate of 0.5 and 2 cm.yr-1’.

Done.

Lines71-72: ‘down-core geochemical sampling of massive corals can yield reconstructed SST time series at approximately monthly resolution.’

Done.

Line 74: ‘relative to Ca, in proportion to ambient SSTs’.

Done.
Line 75: ‘have been shown’.

Done.
Line 83: what is meant by ‘need to be excluded by specific analysis’?

Changed to ‘specific petrographic analysis’

Lines 96-97: ‘past variation in salinity associated with’.

Done.
Line 99: ‘sea-level pressure (SLP)’.

Done.
Line 103: ‘significant’ rather than ‘strong’.

Done.
Line 104: Does the Indian air temperature record go back to 1847?

Yes, it's the record from the India Meterological Bureau

Line 106: add (ENSO).

Done.
Line 112: Replace ‘El Nino-Southern Oscillation’ with ‘ENSO’.

Done.
Lines 121-122: ‘continuous fringing reef approximately 90 km in length’.

Done.

Lines 133-135: Confusing.

It is unclear to the authors why this is confusing. The sentences are clear and make sense.

Line 136: ‘in the annual mean’.

Done.
Line 141: what category of tropical cyclone is ‘extreme’?

We added in brackets: “(category 3 and higher)”, strength of extremes also explained at the end of the same sentence: “with winds of 280 km/h and waves that reach 100 m inland and 2 m above sea level. They usually last five to ten days (Turner and Klaus, 2005).”

Line 142: is this referring to waves or a storm surge?

Storm surge, now added
Lines 142-143: is this after they have crossed land and dissipated?

Yes

Line 144: spell out 'CTD'.

Done.

Lines 144-145: what was the sampling resolution of the CTD measurements?

hourly

Line 148: Provide the name and WMO number for the meteorological station.

WMP 61988 added, (name: Rodrigues, Mauritius)

Line 156: 'coral cores'.

Done.

Line 170: 'Annual density bands' rather than 'growth laminae'.

Done.

Line 172: Reorder Figures in appendix as this refers to Figs 7 and 8

Done.

Line 181: 'alteration in the Totor and Cabri cores'.

Done.

Lines 181-185: So were several slabs taken from each core? How many? Is it likely that there would be diagenesis in one slab and not another from the same core?

Only 1 slab for each core were taken

Line 188: What is 'RWTH'? spell out.

Rheinisch-Westfälische Technische Hochschule, now added

Line 204: 'analogous'.

Done.

Lines 212-214: Unclear how the assignment of the Sr/Ca maxima relates to the SST data.

Added 'Sr/Ca-maxima' in brackets

Line 230: 'SST from sparse data'.

Done.

Line 237: 'We also used the United Kingdom Meteorological Office's monthly SST. ..'. Presumably the sea ice data was not relevant to this study.

This is the name of the dataset and correctly stated

Line 246: Is it relevant that this data is used by NOAA's coral reef watch program?

Deleted.

Lines 224-259: Suggest shortening this section and focus on the SST series actually used in the analysis. Also if average statistics of the different data sets are provided in

Appendix Table 1, there is no need to repeat in the text, just provide some general commentary about the differences/or not between the different SST products.

All data are used to show agreement/disagreement with proxy data and between SST products. This is essential because the optimal SST product for use in climate modelling and paleoclimate studies has yet to be determined.

We now refer to Appendix Tab. 1 for actual statistics of SST time series and omitted repetition in text.

Line 264: values here given in mm.yr whereas in Table 1 in cm.yr.

Changed to mm/yr in both

Lines 270-285: Shorten and simplify. Is there a reason to expect long-term trends in the different growth variables.

To our opinion, it is important to provide the growth characteristics. There is no *a-priori* assumption of long-term trends between growth variables.

Line 278: 'the fit is less optimal' – the fit between what and what?

Changed to: "The density banding is obscured between 1877 and 1907 due to the dead surface in Cabri."

Lines 290-292: is the difference in seasonality between the 2 cores significant? Line 293: 'between average Sr/Ca ratios in the two cores. . .. .'.

Changed to: "…yet the difference is statistically not significant (both overlap within 1σ). "

Lines 297-299: Before combining the two records to form a composite series, it would be useful to know whether the two series are correlated. Also, do the SST reconstructions presented here show similar temporal variations to other coral-based climate reconstructions for the western Indian Ocean – do these new reconstructions tell us anything new or just confirm previous findings (which is a useful statement in its own right).

We no longer attempt to composite the two time series. Instead, we focus on core Cabri for evaluating the climatic signals recorded at Rodrigues (section 6.2). Core Cabri shows the SST signature of the PDO. This is a novel finding. Previous coral records from the south-western Indian Ocean recorded PDO-related variations in river runoff (Grove et al., 2013), salinity (Pfeiffer et al., 2004) and sea level pressure (Crüger et al., 2009). Figure 9 compares core Cabri and a coral Sr/Ca record from Madagascar – these two are reasonably well correlated. Please see also our response to the reviewer comments regarding Lines 619-635.

Lines 300-322: In the previous paragraph it was indicated that the Sr/Ca ratios were converted to SST – why not present the SST reconstructions in Figure 3 and use these in the text rather than having to explain that more negative = warming etc? Also suggest simplifying this section as it is hard to determine what the authors are trying to convey apart from identifying wiggles in the time series. How about including some statistics, e.g. are there significant linear trends etc? Also suggest including a weighted filter in the time series graphs to illustrate the decadal variability referred to.

We combined former Fig. 3 with Fig. 6 and show in the new Figure 2 a) the original Sr/Ca time series as routinely required in any such coral proxy study, b) converted SST record for Cabri and c) converted SST record for Totor.

Lines 324-394: I found this section very long and confusing. Why not present the SST:calibrations first in the Results section and then go on to discuss what the SST reconstructions tell us about SST variability in the region? It would be worth considering moving some of the details of the calibration methods to Supplementary Material – as a reader I am getting lost as to what was done and why.

We restructured the Results section.

Line 388: What is meant by ‘slab 7’? Is this s different slice from the coral or is it the section number downcore?

It refers to the section of the core. We now consistently use the term ‘core section’ instead of slab where it is appropriate.

Line 395: I have stopped commenting at this point on writing style and clarification.

Lines 396-424: Should this section on diagentic alterations not come earlier in the Results section?

This section has been moved into the Results section.

Line 412-413: Any indication that dissolution could explain these discrepancies … ?

Thin sections and SEM are often used to detect dissolution in reef corals (Hendy et al., 2007; McGregor and Abram, 2008; Sayani et al., 2011). The application of both techniques in this study showed that the two coral cores are devoid of dissolution. Hendy et al (2007) showed that dissolution during marine diagenesis leads to an increase in Sr/Ca and therefore an apparently cold temperature anomaly. Dissolution during marine diagenesis therefore would not be able to cause the observed positive temperature anomaly. Decreased Sr/Ca values in diagenetically modified corals have been attributed to aragonite dissolution and concomitant calcite cementation in a meteoric environment (Sayani et al., 2011). With a combination of SEM, thin section microscopy and XRD we demonstrated the lack of dissolution and calcite cementation in the corals and therefore can rule out any influence of dissolution on the proxy record.

Lines 426-453: Again, this is long-winded and confusing for the reader. What questions are being addressed by the authors in this section? How as 'Indian Ocean wide SST' calculated and with what data set of the many used in this study?

Though it is not clear what the reviewer does not understand the text was revised to make the subjects of the sentence clear.

Lines 456-536: Again this section is long-winded and confusing for the reader.

Though it is not clear what the reviewer does not understand the text was revised to make the subjects of the sentence clear.

It is very hard to determine what the main discussion points are.

Lines 538-617: Comments as for the previous sections – confused and confusing and hard to determine what is being done and why.

Though it is not clear what the reviewer does not understand the text was revised to make the subjects of the sentence clear.

Lines 619-635: The main conclusion seems to me to be the need for careful screening of coral samples (for diagenesis and corallite orientation) before measuring and developing climate reconstructions. Do the reconstructions actually tell us anything new about SST variability in the Indian Ocean given the main period is 1945-2006?

The main results (as stated in abstract, discussion and conclusions) from our study is that the Cabri Sr/Ca record provides the first SST reconstruction from the tropical and subtropical Indian Ocean that shows a clear relationship between SST fluctuations and the PDO since 1945. Previous studies have shown only indirect links between the PDO with sea level pressure and salinity (Crueger et al., 2009), hydrological balance (Zinke et al., 2008) and river runoff (Grove et al., 2013) in the western Indian Ocean. In addition, our record includes a Sr/Ca record, which is currently considered the most reliable proxy for SST in corals. The only long record from this region of the Indian Ocean is a stable isotope record from Reunion Island that mainly records salinity variations. Therefore, our

new proxy record from Rodrigues for the period between 1945 and 2006 is a valuable addition to the sparse Indian Ocean coral proxy network. Furthermore, the Cabri records shows statistically significant correlations with the Subtropical Indian Ocean Dipole (SIOD), a fact that we had overlooked in the previous version of the manuscript. We now clearly articulate the climatic link with the SIOD and PDO in the Introduction, Results and Discussion, supported by a number of new references. Our results also demonstrate that records from Rodrigues are well suited when studying climate teleconnections with the SIOD and PDO (as stated in abstract and conclusions). Even the long record might be proven invaluable as a subtropical Indian Ocean record in the near future. We demonstrate that the Totor record does follow grid-SST in the 19th and early 20th century for several decades. Only further replication with Sr/Ca records from the same site or nearby sites can provide further validation of the long Totor Sr/Ca record. We have also included a new Figure 9 that illustrates the agreement with another coral Sr/Ca-SST proxy record from St. Marie Island off east Madagascar (Grove et al., 2103a) and a Supplementary Figure 2 that illustrates the agreement/disagreement of Totor SST with the longest coral SST reconstruction from the tropical western Indian Ocean (MAHE, Seychelles: Pfeiffer and Dullo, 2006).

Crueger, T., Zinke, J. and Pfeiffer, M. 2009. Dominant Pacific SLP and SST variability recorded in Indian Ocean corals. International Journal of Earth Sciences 98, Special Volume. doi:10.007/s00531-008-0324-1.

Grove, C. A., Zinke, J., Peeters, F., Park, W., Scheufen, T., Kasper, S., Randriamanantsoa, B., McCulloch, M. T. and Brummer, GJA 2012. Madagascar

corals reveal Pacific multidecadal modulation of rainfall since 1708. ***Climate of the Past*** **9, 641-656.**

Zinke, J., Timm, O., Pfeiffer, M., Dullo, W.-Chr., Kroon, D. and Thomassin, B. A. 2008. Mayotte coral reveales hydrological changes in the western Indian between 1865 to 1994. Geophysical Research Letters 35, L23707, doi:10.1029/2008GL035634.

Line 864 (Table 1): clarify that depth is of the colony; also provide time periods for the calculations of average growth characteristics.

Done. Time periods now indicated.

Line 882: 'Rodrigues Island'

Done.

Lines 887-889: provide the sampling resolution for these graphs.

Now indicated.

Lines 892-894: Indicate in Figure caption that y-scale for Sr/Ca is inverted.

Done.

Lines 936-939: There are 3 panels to Fig A1 – explain each in caption; also indicate temporal resolution of time series.

Now indicated.

Supplementary Tables 1-26: This is a lot of information that I feel needs to be better synthesised for the reader. Also, in carrying out so many correlations on the same set of time series, has any allowance been made for loss of degrees of freedom? i.e. the number of correlations undertaken increases the probability of obtaining a significant correlation by chance.

In our opinion, it is extremely important to provide the correlation tables with various SST products that all have their own strength' and weaknesses. SST products for the Southern Hemisphere are more strongly affected by measurement biases than Northern hemisphere data, as clearly stated in Jones (2016). We aim to be transparent in showing the individual correlations with

various SST products. The reader can infer which SST products shows statistically significant correlations with our individual coral records. All correlations with the coral composite were omitted since we no longer attempt to composite the two core records.

For our interpretations, we do not 'pick' a few significant correlations from a large set of linear regressions (which would indeed increase the risk of correlations 'by chance'). It is clear from Supplementary Tables 1-21 that our interpretations are solely based on robust correlation results, i.e. for core Cabri, correlations with grid SST are always strong and significant, regardless of the SST product or season, while for core Totor they are not.

Jones, P. The Reliability of Global and Hemispheric Surface Temperature Records. Advances in Atmospheric Sciences, 33, 269-282, 2016.

Anonymous Referee #2

Received and published: 3 May 2016

General comments:

This paper presents two new Sr/Ca-SST reconstructions from Rodrigues Island in the south-central Indian Ocean, which contribute to our understanding of SST variability and trends in this region and their relationship to modes of climate variability (PDO, ENSO). The authors present a very rigorous assessment of the potential impact of diagenesis, corallite orientation, and Sr/Ca-SST calibration on these Sr/Ca-SST recon- structions. The results of this analysis emphasize the importance of corallite orientation and screening for diagenesis in such reconstructions, as suggested in previous work by DeLong et al. (2012), Hendy et al. 2007 (and others). However, a number of warm and cold anomalies may not be completely explained by either corallite angle or diagenesis, and the authors conclude that the SST reconstruction is only reliable back to 1945. This leaves little gained beyond the instrumental record, though additional support for the importance of these issues is still an important contribution on its own.

Nonetheless, I have a number of other major concerns that need to be addressed by the authors before publication:

1) Calculation of the composite: the composite was calculated by taking the arithmetic mean of the coral records from each site, yet the authors do not demonstrate strong agreement between the two coral records before compositing. The authors need to show statistics supporting the agreement

between the records. E.g., what is the correlation between the two records? Based on figure 3, there appears to be disagreement between the two records such that when averaged, the variability of the composite is reduced over the interval that included the two records (relative to that of the earlier period when only 1 record is available). The two records also have opposing trends over the 1951-2005 interval (as discussed on lines 359-363)! The moderate trend of the composite (0.44 degrees) is simply a result of averaging the strong positive (1.38 degrees) and moderate negative trend (-0.49 degrees) and thus isn't physically interpretable. The climate signal also appears to be weakened in the composite (e.g., Figure A5).

We have omitted all correlations using the coral composite since we will no longer attempt to compute a composite record.

2) Selection of Sr/Ca-SST calibration: the authors compute a local calibration with both in situ and gridded SST data, but then use the relationship from Corrège 2006. The justification for this is not clear from the paper. Since local SST data is available, the authors should use this calibration unless they have a valid reason not to use the in situ data.

We compute calibrations with local and regional grid-SST data over a short time interval 2002 to 2006 and with satellite SST/grid-SST back to 1981 (Table A2). The local calibration with *in-situ* SST is based on only four years and it is currently not known if the slope of the short calibration period would be stable over longer periods. The application of the regression slope for the entire record is therefore not robust. We still find a relatively large spread of Sr/Ca-SST relationships depending on the coral core and the SST record. However, the range of this spread is consistent with the results of Correge, 2006, who used a much larger set of coral Sr/Ca records. Therefore, our regression equations are a confirmation of Correge's work. In addition, we consider the mean Sr/Ca-SST slope of Correge (who used more than 30 coral Sr/Ca records from various ocean basins and different coral genera) to be much more reliable than our short in situ calibration. Corrège (2006) provided regression slopes from a greater density of calibrated records across the global tropics and his 'global' slope of ~ -0.06mmol/°C agrees with the range of slopes that

we obtained (Table A2). Most coral records used in Corrège (2006) were calibrated with satellite or grid-SST. Since we are interested in the reconstruction of large-scale southern Indian Ocean SST and their teleconnections with global climate modes, we use of grid-SST. We account for the full spread in regression slopes reported in the literature (-0.4 to -0.084 mmol/°C) and our uncertainty bounds are conservative estimates. In addition, it has been shown by Nurhati et al. (2011) that reconstructions of absolute SST have large errors (up to 7°C) while those of relative SST (anomalies) are lower (<1°C). Therefore, in our study we use SST anomalies calculated with the mean slope from Corrège (2006) for the assessment of interannual climate relationships.

Corrège, T., Sea surface temperature and salinity reconstruction from coral geochemical tracers. Palaeogeo. Palaeoclim. Palaeoeco., 232, 408-428, 2006.

Nurhati, I. S., K. M. Cobb and E. D. Lorenzo (2011). Decadal-Scale SST and Salinity Variations in the Central Tropical Pacific: Signatures of Natural and Anthropogenic Climate Change. Journal of Climate 24: 3294-3308.

3) Sr/Ca-SST calibration methodology: the authors should use a reduced major axis regression instead of simple linear regression to calibrate their Sr/Ca records with SST. RMA takes into account errors in both SST and Sr/Ca, which is critical given that the SST observations themselves are also imperfect (see Solow and Huppert 2004; York et al. 2004; Thirumalai et al. 2011). It is also unclear why the authors use only the max and min to calibrate, rather than the full record of monthly anomalies over the calibration period. Justification for this choice is needed.

Since the work of Solow and Huppert has been cited incorrectly in a couple of coral papers, we report below their original text which discusses the problems of RMA regression (which, according to Solow and Huppert, cannot be solved!).

We decided to use ordinary least squares (OLS) regression for the calibration of our coral records, as this is the method best suited for asymmetric relationships. The coral Sr/Ca-SST

relationship is clearly asymmetric (SST influences coral Sr/Ca, coral Sr/Ca has no influence on SST). A potential error in the instrumental data does not justify the use of RMA. See Smith (2009): Use and misuse of the reduced major axis for line-fitting (DOI: 10.1002/ajpa.21090) for a discussion.

Solow and Huppert (2004) (incorrectly cited by the reviewer as suggesting RMA regression for coral calibrations) also advocate the use of OLS for the calibration of coral proxies. They do not recommend RMA regression:

The biggest problems with the application of RMA for coral-Sr/Ca calibrations are the unknown errors. RMA assumes that the error variance in the SST observations equals the error variance of the Sr/Ca determinations. There is no reason to believe that this assumption is warranted. The RMA method can be extended to allow for differences in the error variances. To do so, it is necessary to have an estimate of both the SST and Sr/Ca error variance. However, it is practically impossible to determine the error variance of coral Sr/Ca determinations, as these include not only the analytical error but also other factors such as vital effects or skeletal heterogeneities.

Nevertheless, we do not reconstruct absolute SST for the entire time series. Instead we reconstruct relative SST changes or SST anomalies, which have a much lower error than absolute SST estimates (see Nurhati et al., 2011). The calibration exercise is reported in order to give the reader an idea how well absolute SST is recorded for the 4 years of *in-situ* SST measurements. We report the various calibrations since this is now standard procedure.

4) Potential warm and cool biases in the coral records: It is unclear which of the warm and cool biases (highlighted in figure 6 and discussed on lines 414-424) were included in the composite, and which were removed. From the composite of figure 6, it looks like many of them were averaged in. Clearer justification of their inclusion is needed. Given the magnitude of these

anomalies and the fact that their source is unclear (in the cases where no clear diagenesis was identified), the authors should investigate whether removing these events from the record changes their results.

We have now focused our climate interpretation on the Cabri record and no longer attempt to compute a composite record.

Specific comments:

Lines 289-292: it is difficult to see this comparison of seasonality from figure 3. I suggest showing the period of overlap separately to demonstrate the agreement between the records

The period of overlap was illustrated in former Figure 7. Here, in our new Figure 2 we aim to show the entire records.

Lines 301-303: Figure 3 does not effectively portray the trends discussed here

We have removed the trends from the text and discuss SST later in the validation section.

Lines 325-327: Discuss these calibration methods earlier (when discussing the calibration approach in the methods section)

We have restructured the Results section. We now present the calibration results after the diagenesis section.

Line 329: This validation period includes part of the calibration period. Stop in 2002 to have independent calibration/validation periods.

The validation was performed with long term SST and air temperature products only, while the *in-situ* calibration was made with local SST and other products between 2002 and 2006 only. Since we do not reconstruct absolute SST, a strict calibration/validation exercise has not been undertaken. We performed the calibration in order to obtain the spread in regression slopes for the Sr/Ca-SST relationship for the short period of *in-situ* observations. However, we decided to use the mean slope of the Sr/Ca-SST relationship from Corrège (2006) who provided regression slopes from a greater density of calibrated records across the entire tropics.

Lines 374-394: This comparison with SST over the past 150 years is not a very useful exercise given the paucity of data at this site (as shown in figure A2). The authors seem to be using the agreement with the instrumental data over the full record to support their reconstruction, but this reasoning is circular (we need a coral reconstruction because there aren't enough observations, but then we use the observations to validate our record). Stick to the well observed period for the calibration/validation exercise. It is very possible that some of these discrepancies between the Sr/Ca-SST and SST are due to biases in the SST record.

We agree with reviewer 2 that that discrepancies between proxy and SST data simply arise from a lack of SST observations. At present, it is not clear which gridded SST data are most suited for the Indian Ocean and tropical oceans in general. The use of multiple SST products is now a standard procedure in almost all meteorological studies. We have adopted this approach in our manuscript. In our opinion it is therefore extremely important to assess/illustrate the agreement between various SST products for our region with our proxy data. Currently, this is the only independent method to assess which SST products might perform better in specific ocean basins. We have also included a new Figure 9 that illustrates the agreement with another coral Sr/Ca-SST proxy record from St. Marie Island off east Madagascar (Grove et al., 2103a).

Line 412: see also Sayani et al. 2011

Lines 412-413: What about dissolution, any indication that dissolution could explain these discrepancies (e.g., see Sayani et al. 2011) who show that dissolution is associated with low Sr/Ca anomalies/warm biases)?

Thin sections and SEM studies are often used to detected dissolution in reef corals (Hendy et al., 2007; McGregor and Abram, 2008; Sayani et al., 2011). The application of both techniques in this study showed that the two coral cores are devoid of dissolution. Hendy et al (2007) showed that dissolution during marine diagenesis leads to an increase in Sr/Ca and therefore an apparently cold temperature anomaly. Dissolution during marine diagenesis therefore would not be able to cause the observed positive temperature anomaly. Decreased Sr/Ca values in diagenetically modified corals have been attributed to aragonite

dissolution and concomitant calcite cementation in a meteoric environment (Sayani et al., 2011). With a combination of SEM, thin section microscopy and XRD we demonstrated the lack of dissolution and calcite cementation in the corals and therefore can rule out any influence of dissolution on the proxy record.

Hendy, E. J., Gagan, M. K., Lough, J. M., McCulloch, M., and deMenocal P. B.: Impact of skeletal dissolution and secondary aragonite on trace element and isotopic climate proxies in Porites corals, Paleoceanography, 22, PA4101, doi:10.1029/2007PA001462, 2007.

McGregor, H. V. and Abram, N. J.: Images of diagenetic textures in Porites corals from Papua New Guinea and Indonesia, Geochemistry, Geophysics, Geosystems 9(10), doi:10.1029/2008GC002093, 2008.

Sayani, H. R., Cobb, K. M., Cohen, A. L., Crawford Elliott, W., Nurhati, I. S., Dunbar, R. B., Rose, K. A., Zaunbrecher, L. K.: Effects of diagenesis on paleoclimate reconstructions from modern and young fossil corals, Geochimica et Cosmochimica Acta, 75, 6361–6373, 2011.

Lines 434-436: Recommend performing a running correlation analysis to test this.

No longer applicable. The section in question referred to non-stationary relationships between the coral composite and large-scale SST. We no longer use the composite as requested by the reviewers. Instead, we now focus our climate interpretation on the Cabri record that extends from 1945 to 2006.

Lines 522-526: other potential drivers of these discrepancies? E.g., see Alpert et al. 2015

We mentioned unknown vital effects as a potential driver of the discrepancies.

Line 602-607: corals may have acclimatized or adapted to the high temperature variability. A number of studies have shown that corals in sites that have high temperature variability may be less susceptible to bleaching (e.g., Thompson and van Woesik 2009, Donner 2011). This variability is now usually taken into account when calculating the thermal stress thresholds to predict bleaching (e.g., Kleypas et al. 2015), as this approach has been shown to better predict observed bleaching patterns (e.g., Logan et al. 2012); this should be used instead of the conventional degree heating weeks threshold on lines 605-607.

We have deleted this section.

Figure 8 caption: this caption needs to be reworded. It is hard to follow what is in each panel.

Done.

Figure 9: why divide the analysis into these periods? This needs to be justified some- where. If the goal was to compare among different phases of the PDO & ENSO (which from the text appears to be the goal), then the authors should select periods that line up with the phases of these modes.

We divided the analysis into different periods in order to test for differences in spatial correlation patterns and their stability over different time series length. We used the full overlap period with grid-SST of the Cabri dataset and two multi-decadal sub-periods. For instance, the 1961-1990 period is chosen to use SST data from a period that includes pre- and post-satellite era observations, yet does not include the most recent years between 1991 and 2006.

Figure 2: change the color scheme so that the lines in 2a are differentiable

We changed the color scheme.

Figure 7: the markings denoting corallite angle are not clear, where do the transitions occur, at the end of the lines? May be clearer if brackets are used to denote the sections with different corallite angles

We now use brackets instead of colors.

Figure A1: change the color scheme so that the black lines are differentiable

We changed the color scheme.

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Technical corrections:

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Line 548: closest agreement to Table A1 caption, line 977: change “in brackets” to “in parentheses”

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A sea surface temperature reconstruction for the southern Indian Ocean trade wind belt from corals in Rodrigues Island (19°S, 63°E)

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Abstract

The western Indian Ocean has been warming rapidly over recent decades causing a greater number of extreme climatic events. It is therefore of paramount importance to improve our understanding of links between Indian Ocean sea surface temperature (SST) variability, climate change, and sustainability of tropical coral reef ecosystems. Here we present monthly-resolved coral Sr/Ca records from two different locations from Rodrigues Island (63°E, 19°S) in the south-central Indian Ocean trade wind belt. We reconstruct SST based on a linear relationship with the Sr/Ca proxy with records starting from 1781 and 1945, respectively. We assess relationships between the observed long-term SST and climate fluctuations related to the El Nino-Southern Oscillation (ENSO), the Subtropical Indian Ocean Dipole Mode (SIOD) and the Pacific Decadal Oscillation (PDO) between 1945 and 2006, respectively. The reproducibility of the Sr/Ca records are assessed as are the potential impacts of diagenesis and corallite orientation on Sr/Ca-SST reconstructions. We calibrate individual robust Sr/Ca records with *in-situ* SST and various gridded SST products. The results show that the SST record from Cabri provides the first Indian Ocean coral proxy time series that records the SST signature of the PDO in the south-central Indian Ocean since 1945. We suggest that additional records from Rodrigues Island can provide excellent records of SST variations in the southern Indian Ocean trade wind belt to unravel teleconnections with the SIOD/ENSO/PDO on longer time scales.

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1 Introduction

The Indian Ocean has been warming steadily over the past century with the western portion of the basin having experienced an increase in SST of up to 1.2°C over the past 60 years (Koll Roxy et al., 2014). The Indian Ocean has also taken up a large amount of heat in its interior between 1999 and 2016 when global SST increased at a smaller rate compared to previous decades (Lee et al., 2015). The strong Indian Ocean warming over the past century is thought to have contributed to a decreasing land-sea thermal contrast with the Indian subcontinent affecting monsoon rainfall and potentially playing a major role in the decrease in East African rainfall between March to May in recent decades (Funk et al., 2008; Koll Roxy et al., 2015). The western Indian Ocean warming has also been shown to follow closely anthropogenic radiative forcing over the past century (Funk et al., 2008; Alory et al., 2009; Koll Roxy et al., 2015). Furthermore, the western Indian Ocean warmed significantly during past El Niño events with the 1997/98 event causing widespread coral bleaching and mortality (Sheppard, 2003). Synchrously, intrinsic climate modes to the Indian Ocean, like the Subtropical Indian Ocean Dipole Mode during austral summer (SIOD; Behera and Yamagata, 2001; Reason, 2001), can interfere with the Indian Ocean-wide teleconnections in SST and rainfall caused by the El Niño-Southern Oscillation (ENSO) or behave independently (Hoell et al., 2016). Mounting evidence indicates that the Pacific Decadal Oscillation (PDO) or Pacific Decadal Variability (PDV) has teleconnections extending to the western Indian Ocean (Cole et al., 2000; Crueger et al., 2009). The positive PDO phase corresponds to warm western Indian Ocean SST anomalies (Deser et al., 2004), thought to exceed SST anomalies associated with ENSO (Krishnan and Sugi, 2003), particularly in the southwestern Indian Ocean

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(Meehl and Hu, 2006). It is therefore of paramount importance to improve our understanding of links between Indian Ocean SST variability, global climate change, and sustainability of tropical coral reef ecosystems. Yet, long-term observational records of Indian Ocean SST are sparse and are thought to be only reliable after the 1960's (Tokinaga et al., 2012).

Paleoclimate reconstructions of SST from massive corals have provided invaluable records for past SST trends and interannual to decadal variability in the western Indian Ocean (Charles et al., 1997; Cole et al., 2000; Cobb et al., 2001; Pfeiffer et al., 2004, 2009; Pfeiffer & Dullo, 2006; Nakamura et al., 2009; Crueger et al., 2009; Grove et al., 2013a, b; Zinke et al. 2008, 2009, 2014). Massive corals, such as *Porites* spp., can grow for centuries at a rate of 0.5 and 2 $cm.yr^{-1}$. Therefore, down-core geochemical sampling of massive corals can yield reconstructed SST time series at approximately monthly resolution. As the coral precipitates its skeleton, trace elements and stable isotopes are incorporated in proportion to ambient SSTs (Felis and Pätzold, 2003). Both, the Sr/Ca ratio and $\delta^{18}O$ composition of the coral aragonite have been shown to be reliable paleo-thermometers with a negative relationship with SST (Alibert and McCulloch, 1997; Pfeiffer & Dullo, 2006; DeLong et al., 2012). A compilation of Sr/Ca-SST calibrations for Porites *spp.* revealed a mean Sr/Ca relationship with SST of -0.061mmol/mol/1°C SST increase (Corrège, 2006). Since Sr has a long oceanic residence time, skeletal Sr/Ca is assumed to mainly reflect SST variability. The quality and accuracy of paleo-thermometers strongly depends on optimal sampling of the major growth axes (De Long et al., 2012). Furthermore, diagenetic alterations of coral aragonite can lead to errors in SST reconstructions and it is important that this effect is identified

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and excluded based on petrographic analysis (McGregor and Gagan, 2003; Hendy et al., 2007; McGregor and Abram, 2008; Sayani et al., 2011; Smodej et al., 2015).

Currently, none of the coral proxy records from the western Indian Ocean cover the south-central Indian Ocean basin in the heart of the trade wind system and Suptropical Indian Ocean Dipole Mode. Furthermore, all proxy records of interest for the trade wind belt are based on oxygen isotopes with the exception of two Sr/Ca ratio records covering 1955 to 2008 from St. Marie Island off East Madagascar (Grove et al., 2013a). The latter provided mixed results with discrepancies in terms of the long-term SST trend estimates due to the effects of coral calcification in at least one core (Grove et al., 2013a). A coral oxygen isotope record from Reunion Island (21°S, 55°E; Mascarene Islands), located approximately 230km to the southwest of Mauritius, spans the period 1832 to 1994 and is the longest for the subtropical region off East Madagascar (Pfeiffer et al., 2004). Pfeiffer et al. (2004) showed evidence that the La Reunion coral dominantly recorded past variation in salinity associated with transport changes of the South Equatorial Current. The proxy record records decadal anomalies that were opposite to those of SST. Crueger et al. (2009) reported close linkages of the salinity, sea-level pressure (SLP) and SST signal associated with the Pacific Decadal Oscillation (Mantua et al., 1997) in coral records from Reunion and Ifaty (SW Madagascar), respectively. Two coral oxygen isotope records from the Seychelles located in the tropical western Indian Ocean (5°S, 54°E) were interpreted as an excellent record of past Southwest Monsoon SST changes and showed significant correlations with air temperatures over India between 1847 to 1994 (Charles et al., 1997; Pfeiffer & Dullo, 2006). Both, the Reunion and Seychelles records record strong correlations with the El Nino-Southern Oscillation

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(ENSO) on interannual and decadal time scales (Pfeiffer & Dullo, 2006). Although the PDO also has a strong impact on the SST in the southwest Indian Ocean (Krishnan and Sugi, 2003; Deser et al., 2004), the SST signature of the PDO has not been reported in coral records from this region to date.

Here, we aim to reconstruct past SSTs from Sr/Ca ratios in two coral cores obtained from Rodrigues Island (19°S, 63°E) located 690 km to the North-East of Mauritius within the trade wind belt of the south-central Indian Ocean. To obtain a robust SST record, we assess the reproducibility of the Sr/Ca proxy, and provide a rigorous assessment of the potential impacts of diagenesis and corallite orientation on Sr/Ca-SST reconstructions. We calibrate individual Sr/Ca records with *in-situ* SST and various gridded SST products and verify the suitability of SST products for climate studies in the south-central Indian Ocean. Furthermore, we assess relationships between the observed long-term SST and climate fluctuations related to the El Nino-Southern Oscillation (ENSO), the Suptropical Indian Ocean Dipole Mode (SIOD) and the Pacific Decadal Oscillation (PDO) between 1945 and 2006, respectively.

2 Regional setting and climate

Rodrigues (63°E, 19°S) is a small volcanic island in the southern Indian Ocean, about 619 km east of Mauritius (Fig. 1). It is part of the eastern edge of the Mascarene Plateau that comprises Lower Tertiary basalts (Mart 1988) formed by a seaward flow of lava, which has been eroded by hydrodynamic forces, and biological and chemical processes (Turner and Klaus, 2005). Rodrigues has a surface area of about 119 km^2, with a maximum altitude of 396 meter above sea level and is surrounded by a nearly continuous

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fringing reef approximately 90 km in length (Turner and Klaus, 2005; Lynch et al. 2002). The reef encloses a shallow lagoon, which, at 240km^2, is twice the area of the island itself. The maximum tidal range is approximately 1.5m, and since the average water depth in the lagoon is less than 2m, some areas are exposed at low spring tides. The water depth immediately beyond the reef slopes is usually within the range of 10m to 30m. The island has three major channels, one dredged for the main harbour at Port Mathurin in the north, and natural channels in the south near Port Sud Est and in the East at St Francois. Several small passes are also found around the reef (Turner and Klaus, 2005).

The water surrounding Rodrigues is supplied by the South Equatorial Current (SEC) (New et al., 2005, 2007), a broad east to west current between 10º and 20º S in the Indian Ocean driven by the southeast trade winds (Schott and McCreary, 2001). The southern part of the SEC water flows in several directions past Rodrigues in southwest and southeast direction, and westward to Mauritius (New et al., 2005, 2007).

Rodrigues has a relatively dry climate and annual mean evaporation exceeds precipitation. Yearly precipitation is ~1000 mm mostly from January to April related to the position of the Inter Tropical Convergent Zone (ITCZ). Between November and March, the Southern Indian Ocean is affected by tropical cyclones, as a result of warm SSTs and a strong convergence between northeast and southeast trades. Rodrigues experiences two to sixteen cyclones per year, of which 2.5 are extreme (category 3 and higher) with winds of 280 km/h and storm surges that reach 100 m inland and 2 m above sea level. They usually last five to ten days (Turner and Klaus, 2005).

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SST was monitored hourly *in situ* by a conductivity, temperature and depth (CTD) device 150m offshore from the northern fringing reefs at Totor between 2002 to 2006 (Hardman et al., 2004, 2008). Maximum SST are recorded between December to March (28.6 ± 0.5ºC) and minimum SST between July to September (22.4 ± 0.27ºC). Annual mean SST is 25.49 ± 0.24ºC with a seasonal amplitude of 6.22 ± 0.68ºC.

Air temperatures have been recorded by the WMO weather station 61988 (name: Rodrigues, Mauritius) located at the northern coast of Rodrigues since 1951 and are available at http://climexp.knmi.nl/. The most recent years between 1997 and 2007 have been provided by the Rodrigues Meteorological Office. The warmest months are December to March (31.2 ± 0.3º), the coldest months are July to September (24.2 ± 0.3º). Yearly average air temperature is 27.49ºC ± 0.31ºC with a yearly amplitude of about 7 ± 0.79ºC.

3 Materials and Methods

Two coral cores were drilled from massive, dome-shaped *Porites* sp. and *Porites lobata* at the northern reef sites Totor and Cabri, respectively (Fig. 1; Table 1). The size of the coral colonies at Totor is ~2.5m and that of Cabri is ~4m in height. Both colonies were healthy and showed no signs of disease or dead surfaces at the time of drilling. The 220cm long Totor core was obtained in August 2005 from the forereef slope of the northern fringing reef facing the open ocean with the top of the colony at 4m water depth. The 180cm long Cabri core was obtained in March 2007 growing in 3m water depth about 1km to the northeast of Totor from the outer fringing reef. The site Cabri is more exposed to trade winds compared to Totor that is more sheltered (Hardman et al., 2004,

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2008).

A commercially available pneumatic drill driven by scuba tanks was used to extract cores along the central growth axis, with a diameter measuring 4 cm. Cores were sectioned into 7 mm thick slabs, rinsed several times with demineralised water, cleaned with compressed air to remove any surficial particles and dried for more than 24 hours in a laminar flow hood. Annual density bands were visualised by X-radiograph-positive prints, and the growth axis of the coral slab was defined as the line normal to these laminae (Figs. A4 and A5). Coral densities (g/cm^3) were calculated by analysing digital X-rays using the program CoralXDS and densitometry (Fig. S1; Helmle et al., 2011; Carricart-Ganivet et al., 2007), calcification rate ($g/cm^2\ yr^{-1}$) by multiplying density with extension rate. The annual extension rates ($cm\ yr^{-1}$) were calculated by measuring the distance (cm) between density minima using the program CoralXDS (Fig. S1). With a diamond coated drill mounted on top of a movable support frame, samples were taken every 1 mm parallel to the growth axis, equivalent to approximately monthly resolution.

A combination of X-ray images, X-ray diffraction (XRD), light and scanning electron microscopy (SEM) with Energy Dispersive X-Ray Spectrometer (EDS) was used to investigate possible diagenetic alteration in the Totor and Cabri cores. All core sections from both Totor and Cabri were initially screened for diagenetic alterations using X-ray images (Appendix Figs. 4 and 5). Corals that showed an annual density banding without anomalous high or low density patches were selected for further study and considered free from obvious diagenetic alteration. Representative samples were selected from both cores based on the X-ray images for SEM, thin-section and XRD analysis. Additional samples were selected after geochemical analysis targeting intervals with unusually high

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or low Sr/Ca ratios. The powder-XRD diffractometer at Rheinisch-Westfaelische Technische Hochschule (RWTH) Aachen University was calibrated to detect and quantify calcite contents above ~ 0.2% following the method of Smodej et al. (2015). In addition, the 2D-XRD system Bruker D8 ADVANCE GADDS was used for XRD point-measurements directly on the coral slab with a spatial resolution of ~ 4 mm and a calcite detection limit of ~ 0.2% (Smodej et al., 2015). A 2-dimensional detector allows the simultaneous data collection over a large 2 θ range, which reduces the counting time to 10 min for each sampling spot. The coral is mounted on a motorized XYZ-stage and the position of each sample spot is controlled by an automated laser-video alignment system. Multiple sample points can be predefined and measured automatically. This method was used to test for the presence of secondary calcite along the sampling traces of both corals.

Sr/Ca ratios were measured at the University of Kiel with a simultaneous inductively coupled plasma optical emission spectrometer (ICP-OES, Spectro Ciros CCD SOP; Zinke et al., 2014). Approximately 0.5mg of coral powder are dissolved in 1.00 ml 0.2M HNO_3. Prior to analysis, the solution is diluted with 0.2M HNO_3 to a final concentration of ~8ppm Ca. An analogue in-house coral powder standard (Mayotte) was analyzed after every six samples. The international reference material JCp-1 (coral powder) was analyzed with every sample batch. All calibration solutions are matrix-matched to 8 ppm Ca. Strontium and Ca are measured at their 407 and 317 nm emission lines. Our intensity ratio calibration strategy combines the techniques described by de Villiers et al. (2002) and Schrag (1999). Analytical precision of Sr/Ca determinations as estimated from replicate measurements of unknown samples is 0.15% or 0.01 mmol/mol (1sigma).

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The coral core chronologies were developed based on the seasonal cycle of Sr/Ca. We assigned the coldest month (either August or September) to the highest measured Sr/Ca ratio (Sr/Ca maxima) in any given year, according to both *in situ* SST and grid-SST (Extended reconstructed SST; Smith et al., 2008). We then interpolated linearly between these anchor points to obtain age assignments for all other Sr/Ca measurements. In a second step, the Sr/Ca data were interpolated to 12 equidistant points per year to obtain monthly time series using AnalySeries 2.0 (Paillard et al., 1996). This approach creates a non-cumulative time scale error of 1 - 2 month in any given year, due to interannual differences in the exact timing of peak SST. The monthly interpolated Sr/Ca time series were cross-checked with the chronologies from coral XDS to reveal the timing of high and low density banding. High density bands in both corals formed in summer (low Sr/Ca) of any given year.

4 Historical SST data

Historical SST data collected primarily by ships-of-opportunity have been summarised in the comprehensive ocean atmosphere data set (ICOADS) to produce monthly averages on a 2°x 2° grid basis (Woodruff et al., 2005). In the grid that includes Rodrigues Island the data are sparse (Fig. A1). Since the uncertainty in SST bias adjustments due to measurement errors is much larger for Southern Hemisphere than the Northern Hemisphere (Jones, 2016) data, we therefore extracted a large number of SST and marine air temperature datasets for our region in comaprison to our coral proxy data. We extracted SST from extended reconstructed SST (ERSST version 3b/version 4; Smith et al., 2008), also based on ICOADS data, which uses sophisticated statistical methods to

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reconstruct SST from sparse data. From ERSST, we extracted data in the 2x2° grid centred at 61-63°E, 19-21°S (Table A1). Furthermore, we used Met Office Hadley Centre's sea ice and sea surface temperature (HadISST) data for the grid 62-63°E, 19-20°S (Rayner et al., 2003; Kennedy et al., 2011; Table A1). HadISST temperatures were reconstructed using a two-stage reduced-space optimal interpolation procedure, followed by superposition of quality-improved gridded observations onto the reconstructions to restore local detail. Since January 1982, SST time series for HadISST use the optimal interpolation SST (OISST; 1x1°), version 2 (Reynolds et al., 2002) that includes continuous time series of satellite-based SST measurements. We also extracted Advanced Very High Resolution Radiometer (AVHRR) SST at 0.25x0.25° resolution (Reynolds et al., 2007) from 1985 to 2006 . SST from the 5x5° HadSST3, the most sophisticated bias-corrected SST data to date, were downloaded for the region 60-65°E, 15-20°S (Kennedy et al., 2011; Appendix Table 1) but contains data gaps throughout the record due to strict quality control. SST is reported as anomalies relative to the 1961 to 1990 mean climatology. In addition, we extracted 5x5° nigh-time marine air temperature data from HadMAT1 and HadNMAT2 datasets (Kent et al., 2013). HadNMAT2 also contains data gaps throughout the record due to strict quality control. Night-time marine surface air temperature is highly correlated with SST but free of the biases introduced by changes in SST measurement techniques (Tokinaga et al., 2012).

5 Results

5.1 Coral Sr/Ca seasonality, variability and trends

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The average growth rate of the corals Totor (224 years) and Cabri (130 years) were 9.82±0.19mm y^{-1} and 11.79±0.25mm y^{-1}, respectively (Table 1; Fig. S1). The Cabri core shows a growth disturbance at 1907 that led to partial colony mortality (see Suppl. Information). This lower core section is overprinted by diagenesis and it is therefore not suitable for climate studies or to determine density and calcification rates.

For the period of overlap between both cores (1945 to 2005) there is a offset in mean Sr/Ca of 0.0242 mmol/mol between the colonies. Both cores show a distinct seasonality in Sr/Ca throughout their record length (Fig. 2a). The seasonality in the Totor core (0.283±0.049 mmol/mol) is on average slightly higher compared to the Cabri core (0.238±0.055 mmol/mol), yet the difference is not statistically significant (both overlap within 1σ). To eliminate the offset between Sr/Ca time series we calculated Sr/Ca anomalies by subtracting their mean relative to the 1961 to 1990 reference period (Figure 2a).

Between 1945 and 2006 both cores record higher Sr/Ca anomalies (a period of cooling) that started in the mid 1950's and lasted until the early 1970's. Both cores show a pronounced trend to more negative Sr/Ca values (warming) starting in the 1970's and reduced seasonality in that period (Fig. 2a). After 1984 Sr/Ca in the Cabri core further decreases (warms) while core Sr/Ca in the Totor core records no trend. This highlights that the long-term trend estimates after 1984 need to be viewed with caution.

The Sr/Ca time series in the Totor core extends to 1781 (Fig. 2a). Marked negative Sr/Ca anomalies (warmer) are observed during the first half of the 20th century centered at 1918/19, 1936-41 and in the period 1947-1951 that exceed anomalies in the 1961 to 1990 reference period. Sr/Ca anomalies between 1850 and1900 are higher

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(cooler), while decadal periods with lower (warmer) Sr/Ca are observed between 1781 and 1850 relative to 1961 to 1990.

5.2 Diagenetic tests for alterations of Sr/Ca profiles

Representative samples for diagenetic screening with XRD, SEM and light microscopy were identified on the coral slabs using the X-radiographs. Additionally, intervals with presumably anomalous proxy values (warm or cold anomalies) were analyzed with the same methods. Ten thin-sections, six SEM samples, ten powder-XRD and thirteen spot-2D-XRD samples were analyzed from coral core Totor (Fig. 3). For coral core Cabri, seven thin-sections, one powder-XRD and six 2D-XRD samples were analyzed. Neither powder nor spot-XRD analysis detected any calcite. Thin-section analysis indicates a growth break within core section 12 of Totor that is also apparent in the radiograph (Fig. 4; Appendix Fig. 5). Close to this break the coral is strongly affected by bioerosion and encrustation by red algae (Fig. 3e). The sampling transect for geochemical analysis, however, excluded this area and is therefore the reported data are not affected by diagenesis (Fig. 8e). Combined SEM, EDS and XRD analysis shows low amounts of patchy distributed isopachous (~2µm) fibrous aragonite cement in Totor core section 6 (1916-1921), 7 (1882-1887) and 11 (~ 1809).

Aragonite cement should lead to higher Sr/Ca values and lower reconstructed temperatures (Hendy et al., 2007). An interesting outcome is that the observed diagenesis is not able to explain changes in the Sr/Ca ratios except for the Totor core section 7. Here the observed aragonite cement is associated with relatively high Sr/Ca values resulting in an apparent cold anomaly. No anomalously high Sr/Ca ratios are associated with the

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patchy aragonite cements in Totor core sections 6 and 11. Instead core sections 6 and 11 are characterized by low Sr/Ca ratios resulting in apparent relatively warm reconstructed temperatures. All other samples from the core sections Totor 3, 4, 8, 9 and 10 are devoid of diagenetic alteration. In summary, a diagenetic influence on the proxy record and resulting SST reconstructions are only evident for Totor core section 7 (years 1882-1887). Core Cabri showed only localized (single month) positive Sr/Ca anomalies (cool SST bias; Fig. 3f). Thin-section and XRD analysis did not establish any diagenetic alteration, but the coral locally contained aragonitic sediment partially filling pore spaces (Fig. 3f). This aragonitic sediment potentially could have caused the isolated Sr/Ca peaks in the record. These individual data points were omitted from further analysis.

5.3. Calibration of coral Sr/Ca-SST with in-situ and gridded SST

The coral Sr/Ca from both cores was calibrated with *in situ* SST, ERSSTv.3b and AVHRR SST for the period 2002 to 2006 using the minima and maxima in any given year, as well as monthly values with AVHRR SST for 1981 to 2006 (Fig. 4; Tab. A2). There is a relatively large variance in the Sr/Ca-SST relationships depending on the coral core and the SST record. The slopes of the ordinary least squares regressions vary between -0.0384 to -0.0638 mmol/mol per 1°C (Tab. A2). The lowest slopes are obtained with *in situ* SST and the highest with ERSSTv.3b (Tab. A2). The range of this variance is consistent with the results of Corrège (2006), who used a set of more than 30 coral Sr/Ca records from various ocean basins and different coral genera. We reconstructed absolute SST for the period of overlap with *in situ* SST from 2002 to 2006 from both coral cores (Fig. 4). The Sr/Ca-SST in the Totor core shows the best fit with *in situ* SST in terms of

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the seasonal amplitude. The Sr/Ca-SST in the Cabri core overestimates the winter SST of 2002 and 2005, yet agrees well for 2003 and 2004 (Fig. 4). Taking into account the uncertainties (measurement error, regression error) in absolute SST from Sr/Ca for Cabri and Totor of 1.23°C and 1.05°C (1σ), respectively, the coral data agree with *in situ* SST within the 1σ uncertainty.

5.4. Validation of Sr/Ca-SST anomalies with gridded SST products

To eliminate errors associated with absolute SST reconstructions from coral Sr/Ca we calculated relative changes in SST for the composite coral temperature record relative to the 1961 to 1990 mean based on the established empirical relationship of -0.0607 mmol/mol per 1°C derived from >30 published Sr/Ca calibrations (Corrège, 2006; Nurhati et al., 2011). This slope is well within the range of our regressions based on a variety of SST datasets and consistent with the results of Corrège (2006). (Appendix Tab. 2). We consider the mean Sr/Ca-SST slope of Corrège (2006) to be much more reliable than our short *in situ* calibration. We use a conservative estimate of the uncertainty around relative SST changes based on the difference between lower (-0.04) and upper slope (-0.084) estimates from these regression equations, thus ± 0.02 mmol per 1°C or ±0.33°C (following Gagan et al., 2012; Tab. A2).

We validated the coral derived annual mean SST reconstruction against local Air Temperature (AT), ERSSTv3b, ERSST4, HadISST, HadSST3, HadMAT1 and HadNMAT2 for the period 1951 to 2006 (Figure 5; See Supplementary Tables 1-16 for mean annual correlations). The Cabri coral SST record records the highest correlations with HadISST and HadMAT1 in the grid box surrounding Rodrigues Island while the

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overall best fit is obtained with local Rodrigues AT. Core Totor has no significant correlations with both ERSST products and HadISST, yet shows significant correlations with HadSST3, HadMAT1 and HadNMAT2 (Suppl. Tabs. 11, 15, 16). Discrepancies between AT and gridded SST products are observed between 1951 and 1955 with AT indicating significantly warmer temperatures. Cabri tracks grid-SST between 1951 and 1955 while Totor shows warm anomalies similar to AT. Taking into account the uncertainty of ±0.33°C based on the regression error, however, Cabri SST agrees with gridded SST and AT within 1σ while Totor shows less agreement.

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For the period 1951 to 2005, we used AT, ERSSTv3b, ERSST4, HadISST, HadSST3, HadMAT1 and HadNMAT2 to validate trends in annual mean coral Sr/Ca-SST anomalies (Fig. 5). The uncertainty for the trend estimates in coral Sr/Ca SST is calculated from the square root of the sum of squares of the regression error and the error in the slope of the Sr/Ca-SST relationship. The long-term trends in Sr/Ca-derived SST anomalies for the period 1951 to 2005 for Cabri and Totor converted to SST, using the published Sr/Ca-SST relationship of -0.0607mmol/mol per 1°C, indicate a warming of 1.38±0.39°C and cooling of -0.49±0.41°C, respectively. Instrumental SST indicate a warming trend of 0.61±0.13°C for HadISST, 0.72±0.11°C for ERSST3b (0.86±0.12°C for ERSST4) and 0.78±0.12°C for HadSST3. Air Temperature at Rodrigues weather station recorded a warming trend of 0.46±0.17°C. All trends are significant at the 2% level with the exception of the negative trend in Sr/Ca SST anomalies in the Totor core.

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For the pre-1945 period we used ERSSTv3b, HadISST, HadSST3 HadMAT1 and HadNMAT2 to validate annual mean coral Sr/Ca-SST from core Totor (Fig. 2). We stress that the number of SST observations in the ICOADS SST and marine AT database is extremely sparse for our region (Fig. A1). In general, the Totor SST record is a valid reconstruction for the region surrounding Rodrigues Island for several decades with the possible exception of 1854-1860, 1916-1921, 1936-1941 and 1948-1951 (Fig. 2). The Totor coral SST time series displays significantly higher SST anomalies compared to all gridded SST reconstructions in the 1850's, between 1916-1921, 1936-1941 and 1948-1951 and lower SST anomalies for brief periods between 1850 and 1890. Interestingly, the Totor Sr/Ca-SST has significant correlations with HadSST3, HadMAT1 and HadNMAT2 observational time series only (Suppl. Tabs. 11, 15, 16). The cool bias in coral derived SST between 1882 and 1887 (core section 7) is related to diagenetic alterations, but none of the anomalously warm periods can be explained by diagenesis (see next section). We assessed the orientation of corallites relative to the coral slab surface to test for sampling artifacts that might have altered our Sr/Ca data which we summarized in Tables 2 and 3, illustrate in Figure 2 and discuss in section 6.1. Most anomalous warm periods show sub-optimal orientation of sampling path with corallites at an angle to the slab surface (see 6.1).

5.5 Large scale teleconnections between 1945 and 2006

The large-scale teleconnections with SST are significant for the Cabri Sr/Ca-SST time series starting in 1945 (Figs. 7 and 8), while core Totor has statistically insignificant correlations in that period. This indicates that the Cabri time series is more reliable for the recent 60 years for monthly averages and annual means and shows the strongest correlations across the Indo-Pacific (Figs. 7 and 8). Therefore, we assess the large-scale climate teleconnections only for the period between 1945 and 2006.

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The detrended Cabri Sr/Ca-SST records shows positive correlations for austral summer and annual means with Indian Ocean wide SST, a positive correlation with the central and eastern Pacific SST and negative correlations with North Pacific SST typical for the spatial ENSO and PDO pattern (Figure 7; Supplementary Tables 17-19). The detrended mean annual time scales (July-June) and austral summer (JFM) record for the Cabri SST shows a positive correlation with southern Indian Ocean SST along a southeast to northwest band stretching along the trade wind belt (Figure 7d-f). The correlation with the southern Indian Ocean trade wind belt remains stable over different record length and is most pronounced post 1971. We find positive correlations with the eastern Pacific SST and negative correlations with the northern Pacific along 40°N and stretching between 160°E and 150°W. The SST pattern mimics part of the typical spatial ENSO and PDO pattern across the Indo-Pacific (Mantua et al., 1997; McPhaden et al., 2006). Stratifying the correlations into negative and positive PDO phases between 1950-1975 and 1976 to 1999 reveals the PDO-like spatial SST pattern (Fig. 8). The detrended Cabri record shows negative correlations (r= -0.39; p<0.001; N=48) with the SIOD index for austral summer month. This agrees with similar sign and strength of correlations of HadISST for Rodrigues with the SIOD (r= -0.43; p<0.001; N=48; Fig. A3; Tab. S19-21).

Comparison with available coral proxy records from the wider trade wind belt region in the SWIO between 12 to 21°S and 50 to 63°E reveals that the Cabri record agrees best with the Sr/Ca-SST from St. Marie Island (core STM2 in Grove et al., 2013a; r=0.25; N=50, p=0.08) on mean annual time scales, yet not with the La Reunion record (Fig. 9). Cabri shows the highest correlation of the three coral records from SWIO with HadISST for the larger grid-box between 12 to 21°S and 50 to 63°E (r=0.49, p=0.001,

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N=60) while both St. Marie and La Reunion corals show no statistically significant correlations.

6 Discussion

6.1 Diagenesis, orientation of corallites and potential biases in Sr/Ca derived SST

Generally diagenesis could be excluded as a major cause of discrepancies between coral SST and grid-SST. For core Totor, only for the period between 1882 and 1887 is diagenesis a potential cause of a cool bias on our coral SST reconstruction (Figure 3d). Core Cabri showed only localized positive Sr/Ca anomalies (cool SST bias) caused by aragonitic sediment trapped within growth framework pores (Fig. 3f). These specific samples have been removed before interpolation. Having excluded diagenesis for almost all of the record, we assessed sampling biases due to changes in the orientation of growth axes and positioning of corallites to the slab surface (Tab. 2 & 3). De Long et al. (2012) showed clear evidence for warm or cool biases in coral Sr/Ca-SST reconstructions caused by suboptimal orientation of corallites in corals from New Caledonia. We have adopted a similar approach to test for sampling biases in our two cores (summarized in Table 2 & 3). We found that core Totor contained areas where a sampling bias could explain anomalous Sr/Ca-derived SST (1781-1797, 1825-1835, 1854-1860, 1916-1921, 1936-1941 and 1948-1951, 1984-2001). We provide a detailed explanation of the potential biases in core Totor in the Supplementary Information that is of particular importance for coral paleoclimatologists.

De Long et al. (2012) showed that warm biases were often caused by corallites orientated at an angle or oblong to the slab surface and where growth orientation had

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changed. Sampling of these suboptimal intervals will have seasonal cycles with more summer Sr/Ca values than winter values causing an apparent warm bias. Such a relationship could not be identified for core Totor, for instance for the largest single warm anomaly in the years 1916 to 1921. Nevertheless, the extreme warm anomaly between 1916 to 1921 could be associated with an unidentified vital effect (Alpert et al., 2015). Interestingly, despite the potential influence of vital effects on the trend, the seasonality in this core section was well preserved. This implies that seasonality can be captured robustly while absolute values and trends are potentially biased by vital effects. This adds confidence for the study of seasonality from fossil corals where vital effects are harder to distinguish from true variability due to the lack of SST data for verification.

For the core tops between 1984 and 2005, Sr/Ca trends in cores Totor and Cabri deviate with Totor showing a statistically insignificant cooling trend while Cabri shows a strong warming trend (Fig. 2). Our analysis of polyp growth revealed a change in growth pattern near the top of core Totor: the corallites form parallel, elongated rods of septa for the entire period 1984 to 2005 (Fig. 6). Cabri shows a normal growth pattern, with an optimal orientation of corallites at the core top between 1984 and 2006 (Fig. A5), with the exception of sub-optimal corallites in the period 2000 to 2006. The core top of the Totor coral skeleton has very low overall density. The Sr/Ca ratios show an increased seasonality, with colder winter values compared to core Cabri, while summer values are not affected. At first glance, the peculiar structure of the corallites in Totor would suggest optimal vertical growth of the corallites with the polyps clearly visible from the apex of the core slab. This structure is, however, clearly associated with high Sr/Ca ratios and artificially cold SST anomalies. A similar growth pattern was found in a *Porites lutea*

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from St. Marie Island off East Madagascar (core STM4 in Grove et al. 2013a). Grove et al. (2013a) ascribed the Sr/Ca trend difference between cores STM2 and STM4 to changes in coral growth and calcification, yet their results were not conclusive. Re-examination of core STM4 revealed that it also forms the parallel-elongated rods of septa in the core top, which was biased towards high Sr/Ca ratios and therefore cold SST anomalies. STM4 also showed low densities in this core top section that agrees with low density in Totor. Inspection of various core sections in Totor and other coral cores revealed that similar elongated rods of septa (not sampled down core) are formed between neighboring growth fans of septa. We propose that these parallel septa grow very fast in summer and winter, therefore show weak density contrast with overall low skeletal density. Similar anomalously high Sr/Ca values between adjacent fans of corallites were reported for Great Barrier Reef corals (see Figure 4 in Alibert and McCulloch, 1997). Alibert and McCulloch (1997) suggested that less optimal growth conditions may results in smaller corallites and overall low skeletal density affecting Sr/Ca ratios. We suggest that core tops from *Porites* sp. with similar parallel septa should be avoided for sampling since it can cause a cold bias in Sr/Ca-based SST reconstructions.

Overall, our test for sampling biases to a large extend confirms the findings of De Long et al. (2012) and indicates that such analysis should accompany climate reconstructions from coral cores. Our results suggest that a new core needs to be obtained from the Totor colony or other large *Porites* sp. in order to overcome the SST biases identified in the current record. The Cabri coral (>3.5m in height) would be an ideal site since it provided an excellent and largely un-biased record of SST for the period 1945 to

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2006. The 1907 dead surface was present, however, in three long cores drilled from the Cabri coral at different angles, which could undermine the SST reconstruction for a few decades below the mortality event. The reason for the mortality event could not be determined.

6.2 Trends and large-scale climate teleconnections since 1945 from core Cabri

Based on our analysis of corallite orientations and diagenesis, we conclude that core Cabri provides a largely un-biased record to assess SST trends and interannual variability since 1945. The Cabri time series recorded a higher SST rise (1.38±0.41°C) than instrumental data between 1945 and 2006, which ranged between 0.61 to 0.86±0.15°C,. The trend in Cabri agrees with all SST datasets within 2σ, whereby the lower range of uncertainty for the Cabri trend estimates (~1°C) and the upper range for the coral composite (~0.8°C) is in closes agreements to trends from gridded SST datasets. Most of the accelerated warming trend in Cabri resulted from the recent 6 years where the orientation of the corallites was sub-optimal. We conclude that the SST trend in Cabri and the coral composite closely follows open ocean grid-SST, which both indicate strong warming (~0.68-1°C) of the south-central Indian Ocean over the past 60 years. Roxy et al. (2014) reported that during 1901–2012, the Indian Ocean warm pool warmed by 0.78°C while the western Indian Ocean (5°S–10°N, 50°–65°E) experienced anomalous warming of 1.28°C in summer SSTs. Our results for Cabri are therefore not unusual and within the range of observed Indian Ocean SST trends (Annamalei et al., 2005; Alory et al., 2007; Koll Roxy et al., 2014). The strong warming in the southern Indian Ocean trade wind belt could potentially alter the monsoon circulation, especially during the monsoon

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onset phase in austral autumn (March to May; Annamalei et al., 2005). Both, our Cabri coral SST time series and SST products indicate the strongest warming for the March to May season (not shown). Rodrigues station precipitation is strongly positively correlated with SST between March and May. When precipitation is anchored over a warmer SWIO between March and May it can prevent the movements of the ITCZ towards the North and potentially disrupt the Asian monsoon onset (Annamalei et al., 2005).

The Cabri record also indicated that Rodrigues Island has negative correlations with the SIOD. Rodrigues Island is located at the westernmost edge of the northeastern flank of the SIOD that stretches from the south-central western Indian Ocean to the coast of Western Australia. There is no other coral reef between Rodrigues Island and the West Australian coast that is able to track the SIOD. Rodrigues is therefore the only coral reef at which SST variability tracks the SIOD at its northeastern flank. The Ifaty corals off southwest Madagascar was shown to track the southwestern flank of the SIOD (Zinke et al., 2004). Our results suggest that a combination of corals off southwest Madagascar with longer records from Rodrigues could provide valuable records of past SIOD variability.

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The Cabri coral SST reconstructions revealed a clear ENSO/PDO teleconnection pattern for mean annual and austral summer averages with positive correlations across the Indian Ocean in response to ENSO and PDO (Xie et al., 2016; Fig. 7 and 8; Suppl. Tabs. 17-19). The ENSO/PDO teleconnection was stable for the recent 60 years, yet appears strongest between 1971 and 2006 (Fig. 7c,f). The latter period is known for increased occurrence of El Niño events and a switch to a positive PDO phase up to 1999 (McPhaden et al., 2006). These results are in agreement with ENSO/PDO pattern correlations observed in other coral records from the southwestern Indian Ocean (Pfeiffer et al., 2004; Crueger et al., 2009). This is the first Indian Ocean coral SST reconstruction, however, that shows a clear Indian Ocean SST relationship with the PDO. Previous studies have shown only indirect links between the PDO with southwestern Indian Ocean sea level pressure and salinity (Crueger et al., 2009), hydrological balance (Zinke et al., 2008) and river runoff (Grove et al., 2013b). In addition, our record is the first Sr/Ca record for the south-central Indian Ocean, which is currently the most reliable proxy for SST in corals. The only long record from this region of the Indian Ocean is a stable isotope record from La Reunion Island that mainly records salinity variations (Pfeiffer et al., 2004). The lack of correlation between the La Reunion and Cabri record is therefore not surprising and points to the need to develop Sr/Ca time series for La Reunion (Fig. 9). The St. Marie Island Sr/Ca coral record shows reasonable agreement with Cabri, with the SST shift in the 1970's especially apparent in both records (Fig. 9). The St. Marie Island record is, however, not well suited to track the wider trade wind belt variations. Therefore, our new proxy record from Rodrigues for the period between 1945 and 2006 is a valuable addition to the sparse Indian Ocean coral proxy network. It also provides establishes that records from Rodrigues are well suited to study decadal climate teleconnections with the (extra)tropical Pacific.

7 Acknowledgements

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Western Indian Ocean Marine Science Association through the Marine Science for Management program under grant MASMA/CC/2010/02. We thank the team of SHOALS Rodrigues for their excellent support in fieldwork logistics and in the organization of the research and CITES permits. We would also like to thank the Rodrigues Assembly and the Ministry for Fisheries for granting the research and CITES permits. A Senior Curtin Fellowship in Western Australia, and an Honorary Fellowship with the University of the Witwatersrand, South Africa, supported JZ. Bouke Lacet and Wynanda Koot (VUA) helped cut the core slabs and prepared the thin sections. Janice Lough and Eric Matson (AIMS) provided skilled technical support for coral core densitometry measurements and data processing. We thank Dieter Garbe-Schoenberg for assistance with the ICP-OES measurements.

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Appendix A –Instrumental sea surface temperature (SST) records and linear regression equations of coral Sr/Ca with SST.

Tables

Core name	GPS position	Species	Water depth	Mean growth	Mean density	Mean Calcification

			(m)	rate mm year^{-1}	g/cm^3	rate g/cm^2 year^{-1}
Totor	S19º40.237; E63º25.754	*Porites sp.*	4.0	9.2 (±0.19)	1.128 (±0.11)	1.07 (±0.18)
Cabri	S19°40.030, E63°26.065	*Porites lobata*	3.0	11.8 (±0.25)	1.36 (±0.12)	1.60 (±0.16)

Table 1 - Coral cores with their GPS co-ordinates and colony depths at low tide, with mean rates of extension, densities and calcification over the complete length of the individual records (1907 to 2006 for Cabri; 1781 to 2005 for Totor).

Section	Year	Orientation	Bias	Notes
1	2005-1987	Sub-optimal	cool	Corallites parallel to surface, yet straight angle; probably like a valley
2	1987-1982	Sub-optimal	cool	Corallites parallel to surface, yet straight angle; probably like a valley

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2	**1981-1977**	**Sub-optimal**	**none**	**Corallites at an angle to the surface; no bias**
3	**1978-1975**	**Sub-optimal**	**none**	**Corallites at an angle to the surface; no bias**
3	**1974-1958**	**Optimal**	**none**	**Corallites parallel to surface; no bias**
4A	1958-1952	Sub-optimal	warm	Corallites at an angle to the surface; scallop texture from angles of corallites
4A	1951-1945	Sub-optimal	warm	Corallites at an angle to the surface; 1947-1952 low growth rate; reduced seasonality
4B	**1947-1936**	**Optimal**	**none**	**Corallites parallel to surface, 1945-1947 better orientation than in slab 4A**
4B	**1938-1933**	**Sub-optimal**	**none**	**Corallites at an angle to the surface; 1936-1941 warm anomaly years show normal seasonality and high growth rate**
5	**1933-1922**	**Optimal**	**none**	**Corallites parallel to surface; 1922-1928 reduced seasonality**
6	1921-1915	Sub-optimal	warm	1915-21 warm spikes shows slightly oblong corallites, yet normal seasonality; switch from optimal to sub-optimal orientation
6	**1915-1896**	**Optimal to Sub-optimal**	**none**	**Corallites mostly parallel to surface, small section with corallites at slight angle;;**
7	**1897-1890**	**Optimal**	**none**	**Corallites parallel to surface**
7	1887-1882	Optimal	cool	Diagenesis detected between years 1882-1887
7	**1881-1872**	**Sub-optimal**	**none**	**Corallites at an angle to the surface; 1872 close to bioerosion track; 1878-1880 low seasonality, yet no effect**
8	1872-1868	Sub-optimal	cool	Corallites at an angle to the surface; some corallites at almost 90° angle; 1868-1872 below bioerosion track; 1867-1871 low seasonality
9	1860-1854	Sub-optimal	warm	Corallites at an angle to the surface; 1854-1858 low seasonality, less winter samples
9	1856-1845	Sub-optimal	warm	Corallites parallel to surface; low seasonality with relatively warm winter samples
9	**1844-1831**	**Optimal**	**none**	**Corallites parallel to surface; only 1831-1832 corallites at an angle to surface**
10	1830-1827	Sub-optimal	warm	Corallites at an angle to the surface; oblong orientation
10	1826-1823	Disorganised	warm	Corallites rotating at 90° angle; low growth rate, seasonality reduced 1823-1825 with relatively warm winter samples
10	**1822-1815**	**Optimal**	**none**	**Corallites parallel to surface; low growth rate; reduced seasonality 1818-1822, yet no effect on SST anomalies**
11	**1816-1806**	**Sub-optimal**	**none**	**Corallites at an angle to the surface, yet no effect on SST anomalies**
11	**1807-1798**	**Sub-optimal**	**none**	**Corallites at an angle to the surface in sub-optimal parts; Corallites rotating at 90° angle near terminating fans (not sampled); 3 growth axes with terminating fans in between (not sampled); 1799-1807 regular seasonality**
11	1797-1792	Sub-optimal	warm	Corallites at an angle to the surface
12	1795-1792	Disorganised	warm	Corallites rotating at 90° angle; 1792-1791 long year, more summer samples
12	1791-1784	Sub-optimal	warm	Corallites parallel to surface; 1784-1787 Corallites at an angle to the surface; 1789-1794 seasonality distorted
12	1781-1783	Disorganised	warm	Corallites rotating at 90° angle; seasonality slightly distorted, apparently more summer samples

Table 2 – Summary of sampling issues detected in core Totor. Unbiased sampling tracks indicated in bold.

Section	Year	Orientation	Bias	Notes
1	2007-2000	Sub-optimal	warm	Corallites parallel to surface; yet no clear growth fans
1	**1999-1992**	**Optimal**	**none**	**Corallites parallel to surface**
2	**1984-1992**	**Sub-optimal**	**none**	**Corallites at an angle to the surface; oblong corallites**

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3	**1983-1968**	**Sub-optimal**	**none**	**Corallites parallel to surface; yet no clear growth fan**
4	**1967-1964**	**Sub-optimal**	**none**	**Corallites at an angle to the surface**
5	**1963-1958**	**Optimal**	**none**	**Corallites parallel to surface**
5	**1957-1954**	**Sub-optimal**	**none**	**Corallites at an angle to the surface**
5	**1953-1945**	**Optimal**	**none**	**Corallites parallel to surface**

Table 3 – Summary of sampling issues detected in core Cabri. Unbiased sampling tracks indicated in bold.

Figure captions

Figure 1 – a) Map of Rodrigues Island with the position of the two corals cores at Totor and Cabri indicated. The star shows the position of the CTD that collects SST and salinity data. Polygon indicates the location of the Meteorological Station which records air temperature, sunshine hours, wind speed and rainfall. b) Spatial correlation between January-March averaged SIOD index (Behera and Yamagata, 2001) with HadISST for Rodrigues Island (Rayner et al., 2003). c) Spatial correlation between July-June mean annual averaged PDO index (Mantua et al., 1997) with HadISST (Rayner et al., 2003). All correlations with detrended data. Only correlation with $p<0.05$ are coloured. Computed at KNMI climate explorer (van Oldenborgh and Burgers, 2005). Yellow star in b) and c) marks the location of Rodrigues Island.

Figure 2 – a) Time series of monthly (thin solid lines) Sr/Ca anomalies (right Y-axis converted) relative to the 1961 to 1990 climatological mean for coral cores Cabri (top), Totor (middle) for the period 1781 to 2006. Annual mean time series of individual cores (red line) b) Cabri and c) Totor compared to SST reconstructions: ERSSTv3b, ERSSTv4, HadISST, HadSST3, HadMAT1 and HadNMAT2. See legend in b) and c) for colour code. For all time series we computed anomalies relative to 1961 to 1990. The

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uncertainty of mean annual coral Sr/Ca-SST anomalies are indicated by the grey envelope. Potential warm bias in coral SST is indicated in parathenses, pointing up for warm and down for potential cool biases, respectively. In parathenses with inset D marks core interval with diagenesis.

Figure 3 - Thin-section and SEM images of primary coral aragonite (PA) and aragonite cement (AC) in cores Totor and Cabri. A and B: Excellent preservation of the primary coral aragonite in core Totor. Trace amounts of aragonite cements occur as isolated patches in core sections 6 (C), 7 (D) and 11 (E) of Totor. F (left): A prominent growth break (stippled line) in core section 12 of Totor is encrusted by coralline red algae (CRA). F (middle): The section above the growth break shows well preserved primary coral aragonite. F (right): The pristine coral skeleton of core Cabri contains locally aragonitic sediment (S) partially filling growth-framework pores. A to E: Thin section photographs are shown in plane- (left) and cross-polarized light (middle). F: All thin section photographs are shown in plane-polarized light.

Figure 4 – a) Climatology at Rodrigues between 1997 to 2007. Monthly averaged SST *in situ* (red), ERSSTv.3 (grey; Smith et al., 2008) and AVHRR SST (blue stippled; Reynolds et al., 2007); b) Reconstructed absolute SST from coral Sr/Ca from cores Totor (dark grey with triangle) and Cabri (light grey with diamond) for 2002 to 2006 based on calibration with in situ SST from Rodrigues (red). The uncertainty for single month absolute SST for individual cores Cabri and Totor is 1.23°C and 1.05°C (1σ), respectively. The coral data agree with *in situ* SST within the 1σ uncertainty.

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Deleted: Figure 3 - Thin-section and SEM images of primary coral aragonite (PA) and aragonite cement (AC) in cores Totor and Capri. A and B: Excellent preservation of the primary coral aragonite in core Totor. Trace amounts of aragonite cements occur as isolated patches in core sections 6 (C), 7 (D) and 11 (E) of Totor. F (left): A prominent growth break (stippled line) in core section 12 of Totor is encrusted by coralline red algae (CRA). F (middle): The section above the growth break shows well preserved primary coral aragonite. F (right): The pristine coral skeleton of core Capri contains locally aragonitic sediment (S) partially filling growth-framework pores. A to E: Thin section photographs are shown in plane- (left) and cross-polarized light (middle). F: All thin section photographs are shown in plane-polarized light.

Figure 5 – Time series of annual mean temperatures anomalies relative to the 1961-1990 mean for the coral Cabri SST reconstruction, Rodrigues weather station air temperature (AT), ERSSTv3b, ERSSTv4, HadISST, HadSST3, HadMAT1 and HadNMAT2 for the period 1950 to 2006. The uncertainty of mean annual coral Sr/Ca-SST anomalies is indicated by the grey envelope.

Figure 6 – a) Monthly interpolated Sr/Ca profiles for cores Cabri (red) and Totor (grey). B) Images of core Totor (coloured blue) with orientation of corallites indicated. Years for core sections indicated on coral slab and grey arrow points to major change in orientation of corallites in core top section of Totor around 1983/84.

Figure 7 – Spatial correlation of Cabri Sr/Ca-SST anomalies (relative to 1961-1990) with HadISST (Rayner et al., 2003). January to March austral summer in a) between 1945-2006, b) 1961-1990 and c) 1971-2006. Annual mean correlations in d) between 1945-2006, e) 1961-1990 and f) 1971-2006. Only correlation with $p<0.05$ are coloured. Computed at KNMI climate explorer (van Oldenborgh and Burgers, 2005). Yellow star in a) marks location of Rodrigues Island.

Figure 8 – Spatial correlations of Left) Cabri coral SST and Right) HadISST grid for Rodrigues Island with global austral summer HadISST for a-c) 1950 to 1975 (February to May) negative PDO phase (Mantua et al., 1997) and c-d) 1976 to 1999 (January to April) positive PDO phase. Only correlations with $p<0.05$ coloured. Computed at KNMI climate

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Comment [39]: Instead of composite we show only Cabri

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explorer (van Oldenborgh and Burgers, 2005). Yellow star in a) marks location of Rodrigues Island.

Figure 9 – Comparison of southwestern Indian Ocean (SWIO) coral records from St. Marie Island (black; Grove et al., 2013) with the Cabri record from Rodrigues (red). An SST time series for the grid-box in the SWIO averaged between 12-20°S and 50-63°E is also illustrated (light blue). All time were annualized and converted to SST anomalies relative to 1961-1990. The uncertainty of mean annual Cabri Sr/Ca-SST anomalies are indicated by the grey envelope.

Figure A1 –Number of SST observations in the grid box surrounding Rodrigues in the ICOADS database. Note the extremely sparse observations even in recent years (van Oldenborgh and Burgers, 2005).

Figure A2 – Spatial correlations of mean annual HadMAT1 air temperature anomalies between 1945 to 2001 relative to 1961-1990 with a) HadISST for Rodrigues, and b) Cabri SST. Only correlations with $p<0.05$ coloured. Computed at KNMI climate explorer (van Oldenborgh and Burgers, 2005). Y-axis Latitude, X-axis Longitude.

Figure A3 – Correlation of the Subtropical Indian Ocean Dipole Mode with global HadISST between 1958 and 2006 for austral summer January to March averages (Behera and Yamagata, 2001; Rayner et al., 2003). Note the location of Rodrigues Island (marked by yellow star) at the northeastern flank of the SIOD and the negative correlations there.

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Comment [40]: New Figure 9, as suggested by reviewer

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Comment [41]: New Apendix figure to show SIOD and its global signature next to Indian Ocean pattern

Only correlations with p<0.05 coloured. Computed at KNMI climate explorer (van Oldenborgh and Burgers, 2005).

Figure A4 – X-ray positive print for core sections of core Totor with sampling lines indicated. Blue lines indicate high resolution sampling tracks. Yellow lines superimposed on blue lines indicate sampling at annual resolution for other purposes. Start or end years for each core section indicated.

Figure A5 - -ray positive print for core sections of core Cabri with sampling lines (milling holes) indicated. Start or end years for each core section indicated. Note the dead surface before 1907 that is most probably related to a past coral bleaching event.

Table A1 – Statistics of various sea surface temperature (SST) products and air temperature for Rodrigues with 1σ standard deviations in brackets for the period 2002 to 2006 (period with *in situ* SST data). STDV = 1σ standard deviation over all years. All units in °C.

Table A2 - Linear regression of coral Sr/Ca with a) *in situ* SST 2002-2005/6, b) ERSSTv.3 (Smith et al., 2008) 1997-2005/6, c) AVHRR SST NOAA Coral Reef watch data 2000-2005/6 and d) monthly Sr/Ca with AVHRR SST (Reynolds et al., 2007) for the period 1982 to 2005.

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Deleted: X-ray positive print for slabs of core Totor with sampling lines indicated. Blue lines indicate high resolution sampling tracks. Yellow lines superimposed on blue lines indicate sampling at annual resolution for other purposes. Start or end years for each slab indicated.

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