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Interactive comment on "A sea surface temperature reconstruction for the southern Indian Ocean trade wind belt from corals in Rodrigues Island (19° S, 63° E)" *by* J. Zinke et al.

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Response to Reviewer comments on Biogeosciences Discuss., doi:10.5194/bg-2016-69, 2016 by Zinke et al.

We would like to thank both reviewers for their assessment of our research article. We are particularly grateful for the constructive suggestions provided. Below, we address the major concerns and suggestions of both reviewers. We hope that our response merits revision of our manuscript for publication in Biogeosciences.

1) Response to Reviewer 1 in terms of clarity of manuscript

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.

Abstract of revised version:

“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 East of Mauritius within the trade wind belt of the south-central Indian Ocean. We assess relationships between the observed long-term SST and climate fluctuations related to the El Nino-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) between 1945 and 2006, respectively. To obtain a robust SST record, we assess the reproducibility of the Sr/Ca proxy from two different locations, and we provide a rigorous assessment of 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 our reliable SST record from Carbi provides the first Indian Ocean coral proxy time series that records the SST signature of the PDO in the SW subtropical Indian Ocean since 1945.”

Response to Reviewer 1 and 2: Use of coral composites

We agree with both Reviewers that the calculation of the coral composite needs to be verified by showing agreement between the individual records. We have therefore decided to omit the calculation of a composite record since the climate signals also appear to be weakened as compared to our record from Cabri (based on agreement on annual, interannual time scales with SST, ENSO and PDO). Instead, we will focus the climatic interpretation on the Cabri record that extends from 1945 to 2006 and will adjust the Figures accordingly.

Response to Reviewer 1 and 2: Statistical analysis

We will omit all correlations using the coral composite since we will no longer attempt to compute a composite record. We have performed a number of correlations illustrated in Table S1 to S26. All significance levels of the correlations take into account the loss of degrees of freedom. A 95% confidence interval based on a Monte Carlo simulation is also indicated in the Tables that shows the upper and lower bound of correlation coefficients (see knmi website and reference Trouet, V. and van Oldenborgh, G.J. KNMI Climate Explorer: a web-based research tool for high-resolution paleoclimatology. Tree Ring Research 69, 1, 3-13 (2013). We will perform the running correlation analysis as requested by reviewer 2 to support lines 434-436 and show them as Supplementary Figure.

Corallite orientation

Reviewer 1 found our rigorous assessment of effects of corallite orientation on SSTs rather long-winded and confusing. This is in contrast to Reviewer 2 who emphasized the importance of such a ‘rigorous assessment’ to provide reliable SST reconstructions. We agree with DeLong et al. (2012), who were the first to make such an assessment, that examining effects of corallite orientation proves useful and makes the SST series more robust. We focused on our long SST record from Totor, pre-1945. It illustrates the importance of having multiple Sr/Ca records from nearby regions as corallite orientation from one record may bias the SST reconstruction. We will archive the data for both cores on the NOAA WDC paleodata webarchive which will enable comparison of the Totor Sr/Ca record with future records. Our rigorous assessment of potential reconstruction biases will therefore provide the user with important information which otherwise would be lost to the proxy community when performing larger scale analysis based on multiple records.

Use of multiple instrumental data products

As mentioned by reviewer 2, SST observations from gridded products are extremely sparse for our region and one could argue that discrepancies between proxy and SST data simply arise from a lack of observations. At present, it is not clear which gridded SST data are best 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. We do, however, agree with Reviewer 1 that we should summarize which SST dataset appears to agree best with our reconstruction.

Response to Reviewer 1 and 2 comments on information gained by new proxy record

Reviewer 1 asked if the reconstructions tell us ‘anything new about SST variability in the Indian Ocean” and reviewer 2 asked what climate information we gain from the proxy record beyond the instrumental record. 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 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. It also provides us with the knowledge that records from Rodrigues are well suited when studying climate teleconnections with the 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. 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.

Response to Reviewer 2 point 2) on Selection of Sr/Ca-SST calibration

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 four years only 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. 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 rather 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.

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Response to Reviewer 2 point 3) on Sr/Ca-SST calibration method

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 provided 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.

Response to Reviewer 1 and 2: questions about diagenesis section

Reviewer 1: Line 83/181-185/388: We now consistently use core section instead of slab. Line 412-413: Reviewer 2 asks: “Any indication that dissolution could explain these discrepancies?” 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.

Modified caption to Fig. 8: Thin-section and SEM images of pristine coral skeleton and diagenetic alteration in cores Totor and Capri. A and B: Excellent preservation of the primary coral aragonite (PA) in core Totor. Trace amounts of aragonite cements (AC) 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 is well preserved. F (right): The pristine coral skeleton of core Capri locally contains aragonitic sediment (S) partially filling pore spaces. Thin section photographs are shown in plane- (left) and cross-polarized light (middle).

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