Clim. Past Discuss., 9, C3429–C3440, 2014
www.clim-past-discuss.net/9/C3429/2014/

Climate of the Past Discussions

Interactive comment on "A probabilistic model of chronological errors in layer-counted climate proxies: applications to annually-banded coral archives" *by* M. Comboul et al.

M. Comboul et al.

comboul@usc.edu

Received and published: 11 February 2014

We thank the reviewers for their comments which we address below.

Response to reviewer #1

1. "The effect due to chronological errors is thus not the main cause of loss of coherency among records, high individual variability is an inherent feature of coral archives even on a small oceanic area. However, the coherency shown by multi proxy signals measured on a single sample (Juillet-Leclerc et al., 2006),

thus following identical chronology, could be used to strengthen a timing model. In this context, questions raised by the need to establish a reliable chronology of coral records cannot be only solved by probability. Although De Ridder et al. (2004) method was not based on probability but on the strong periodicity shown by proxies strongly affected by seasonality, I am surprised that these investigations are never mentioned."

When optimal sampling strategies are utilized, DeLong et al. (2013) demonstrated that the records were highly reproducible among cores from the same site. Along with previous studies (Hendy et al., 2002; DeLong et al., 2007), this work also highlighted chronological uncertainties associated with coral reconstructions as a main source of discrepancies among records. We have revised our paper in Sect. 4 to make the point that chronological errors are among the potential causes of loss of coherency across dataseries. The De Ridder et al. (2004) method is concerned with subannual time series and reconstructing periodic variability between (yearly) anchor points. The revised paper includes a citation to this work in the discussion of future work (Sect. 5) where we describe how our approach could be used to study chronological uncertainty on subannual timescales (noting the additional uncertainty associated with interpolation of the data between tie points, as well as the intra-annual timescale uncertainty problem being better-constrained because there is usually a well-defined annual cycle in one or more paleodata streams from the coral (and other annually-layered archives) that mostly "resets" age model uncertainty at some point in the year). Citations to Juillet-Leclerc et al. (2006) and other sources were also added in Sect. 5 after we mention different ways to estimate the error rate parameters (1st limitation point). All mechanisms described by us and Juillet-Leclerc et al. (2006) result in additive ("red") error as the chronology is developed back in time, so we focused on chronological uncertainty using a simple model for its statistical properties. We would also like to point out that our model is not intended to reduce but rather to quantify the uncertainties derived from potential dating errors.

2. "Variability between interannual and multidecadal scales highlighted in the manuscript could be due to the proxy itself and not to age perturbation. For instance, it is assumed but not mentioned that $\delta^{18}O$ is linear during the time. However, Crowley et al. (1999) stressed possible mismatch between inter and intra annual time scales. But this paper remained totally ignored by the paleo-climatologist community."

The Crowley et al. (1999) paper shows a mismatch between the slope of the $\delta^{18}O$-SST between sub-annually and annually resolved coral series, with the annual calibration reducing the early 20th century SST bias observed in the record when a sub-annual calibration is used. The paper points out the potential for local salinity variability to contribute to low-frequency coherence (or lack thereof) among records (see page 612 of Crowley et al., 1999). There is emerging evidence that the calcification process may create resolution-dependent $o^{18} - T$ regression effects (Gagan et al, 2012). These issues would be important to consider in our chronological uncertainty model, if we considered subannual resolution variations. Further, although the GFDL model may not represent low-frequency SSS variability well (particularly because of its overly energetic ENSO), the variability on interannual and multidecadal scales observed in our study holds in the pseudocoral frame-work (i.e., results are independent of model SSS, see references cited in Sect. 3.2 related to the GFDL CM2.0 model of the revised paper). In addition, by solely imposing chronological uncertainty, we can assess the extent to which the observations might arise from this mechanism alone. This doesn't preclude the possibility that other sources of loss of coherency (e.g. undersampling an energetic annual cycle for resolving true interannual-decadal variance) don't exist and/or are important and we acknowledge this in Sect. 4 of the revised manuscript.

3. "Following the relationship (6) the oxygen isotopic ratio is depending on

SST and SSS during the time, SSS being regionally determined versus seawater $\delta^{18}O$. The latter dependence may vary during the time (Delcroix et al., 2011) due to oceanic advection. In addition, the high variability already described is not taken into account, making the forward model poorly realistic."

The forward model used in our work is an anomaly model for $\delta^{18}O$ of coral aragonite, with a priori, not tuned, coefficients. We have revised the text in Sect. 3.2 (after Eq. 2) to say that the coral model coefficients are constant over time. Thompson et al. (2013) investigated the stability of the $\delta^{18}O_{sw}$-SSS relationship through time using an isotope enabled version of the GISS model. They found that the relationship within regions was consistent over monthly to decadal timescales, suggesting that the use of $\delta^{18}O_{sw}$-SSS relationship (for $\delta^{18}O_{sw}$) may be appropriate for simulating tropical variability during the past century (although the relationship may vary at the millennial timescale, e.g. LeGrande and Schmidt, 2013). Similar results were seen with the HadCM3 model by Russon et al. (2013), who concluded that the range of slopes observed is "not inconsistent with regression noise in a stationary system.". Further, Thompson et al. (2011) compared the 1st and 2nd eofs of the modeled and observed coral records, and found that this forward model was able to capture the dominant modes of variability observed in corals, supporting the utility of this simple model of $\delta^{18}O_{coral}$.

Response to reviewer #2

1. "I fear the technical language may alienate some readers, especially those who really need to read this paper and to consider the findings in their own work."

In order to reach a broader audience, we eliminated symbolic notations as much as possible and used the simple sine signal example of Fig. 2 to describe how our age model works in sections 2.1 and 3.1 of the revised paper. We have also added Fig. 1 to illustrate our notation.

2. "My other suggestion for the paper is to include in the discussion the influence of linearly interpolating the data to constant time steps. Linear interpolation tends to alter the higher frequencies depending on the level resampling, over sampling produces a stepper spectral slope whereas undersampling a flatter spectral slope, see Schulz and Stattegger (1997). I have experimented with this in coral data and I did not find an influence for periodicities > two years. Granted, if the coral worker is using a constant sampling interval and the linear growth rates have variations or trends, this could produce artificial shifts in the record but I am not sure what the sensitivity would be."

Looking at annual scale records was a first pass of experiments. Sub-annual scales might require much more thought, especially in the types of age error to consider, because of the increased inhomogeneities in coral growth rates and will be left for future study. A discussion on this issue was added in the discussion section (4th limitation point).

3. Page 6080 item #2 Line 12: "It would be useful to mention here that tree-ring reconstructions are many replicated records whereas varve sediments, ice cores, and corals are not. Another item is mention, perhaps in the discussion, is that corals are not layered as in sediments or ice cores, but are biological origins with a 'sclerochronometer' in their skeleton, as are trees. Trees are easier to sample because they have concentric growth along a main axis. Corals do not; they grow in three-directions and have complex morphologies such

as branching corals. Massive corals grow slower than branch- ing corals and essentially fill in the space between branches. Growth direction can change quickly and coring the colony to achieve the best core with the representative 'sclerochronometer' takes experience and luck. Some cores are better than others, and looking at the x-rays can quickly tell you if you will have a good chronology, see Alibert and Kinsley (2008). Look at the x-rays and figures in the supplemental material with the multiple paths."

Thank you for pointing this out, we have added this information in the revised manuscript (introduction and Sect. 4). We have also added image (in Fig. 1) of different coral cores, illustrating the complexity of coral growth. In this work, we also assume that the records are derived from optimal sampling strategies (assumption added in the introduction).

4. Page 6081 line 20 "Other papers to consider for banded records: Breitenbach, S. F. Climate of the Past, 8, 2012, 1765-1779 doi:10.5194/cp-8-1765-2012. Carre et al., Clim. Past, 8, 433?450, 2012 www.clim-past.net/8/433/2012/ doi:10.5194/cp-8-433-2012."

Thank you for the interesting readings. We added Breitenbach et al. (2012) in the literature review. Though we do not believe that the Carre et al. reading is relevant to our paper since they do not address chronological uncertainties.

5. Page 6083 line 18 "Another item that is prevalent in coral x-rays are stress bands (Hudson et al., 1976) or apparent secondary bands (Barnes and Lough, 1990; Barnes and Taylor, 1993) that are artifacts of slab depth and growth orientation. The geochemistry is typically not altered with the so called stress

bands or apparent secondary bands but studies that use density banding or luminescent banding as the proxy would have greater occurrences of these false years. Coral cores with x-rays revealing continuous 'horizontal' layers down core will have less dating error than cores with the growth direction changing direction, see previously mention Alibert's x-rays. More core breaks and discontinuous sampling paths lead to more dating error."

This information was also added to the revised manuscript in section 2.1 where we describe the different sources of errors.

6. "Page 6084 line 8 This is confusing, the initial date, (t1) is the known or youngest data of the coral, if collected live (as stated in page 6083, line 6), how can t1 be off by 10 years? I think you have the initial and final dates (at 100 years) mixed up. Be clear on which direction time is moving i.e., youngest and oldest, instead of ?initial?."

Yes, thank you for pointing that out, this was definitely a mistake and we clarified this issue in the revisions.

7. "Section 2.2 There are coral records based on every other sample or annual samples (Dassié et al., 2013; Linsley et al., 2006; Linsley et al., 2008; Wu et al., 2013) or 5-year sampling intervals (Calvo et al., 2007; Hendy et al., 2002). Skipping every other sample (to save analytical cost) could potential alias the time series analysis or lead to more missing years. More people are using these methods to save money (and program managers think it OK to do so) but there is a potential to add more dating error to records. Could you perform simulations that addressing these sampling methodologies and whether are not

they are good practices."

The Hendy et al. (2002) and Calvo et al. (2007) studies were measurements on 5-year bulk samples; not every fifth year. 5 year bulk averages should be much less problematic than sampling every fifth year. To address this question, we repeated the simulations on the Havannah record (the longest one), except with 5-year averages of annual data. The comparison with the results from annual resolution simulations are in the figure shown in this response letter and we can see that the spectrum isn't deformed by this practice (besides the resulting lower Nyquist frequency). This problem is perhaps, in combination with the subannual extension rate problem, a subject in itself, in which case this is the basis for another paper. However in the revisions, we mention in the model development (Sect. 2.1 after Eq. 1) and in the discussion comment (4th limitation point), that in this work we neglect such effects, but they may be important for the reasons noted by the reviewer, and should be studied further.

8. "Page 6091 This is interesting finding. Could this explain why PDO reconstructions do not agree with each other before 1900, even the tree-ring records?"

This is an interesting thought, but we would probably need more evidence in order to make that statement.

9. "Check order of figures and first mention in the text. Fig 4 in mentioned in the text before Fig 3.

The order of figures was fixed, thank you!

10. “Page 6099 second item This can be quantified by looking at x-rays and the sampling paths. Most studies now include x-rays at least as supplementary material. The # of breaks between cores = possible missing time, # of paths = increase in the # of double counted years or missing years between paths, Intervals with uncertain growth structures = distance is approximates time missing or duplicated (this is difficult to assign a ±years). Some cores will be very good with little time missing whereas others are very messy, thus more dating error.”

Thank you for the remark, we added those details in the discussion section (1st limitation point) along with some references.

11. “Figure 1 panels c and d This is a fossil coral with U-Th date. It looks like the U-Th dating uncertainty is not included since the top (?1703) does not show accumulated error. I understand this exercise was to look at cumulative dating errors, but this coral is shown with the calendar age and those dates with vary as well. Additionally, did Kim date the top of coral and is there just one U-Th date or more than one? Add a marker to indicate where the U-Th date was taken from (assuming it is from a single annual density band). This is important for reconstructions using dead corals to extend the chronology back in time by splicing records together.”

Correct, we did not include the U/Th dating uncertainties in this experiment because we are interested in the effects on the power spectrum of the modeled chronological errors alone, noting that there shouldn't be any spectral deformation arising from sliding the whole sequence across the U/Th error window. The U/Th dating model was, however, included in the Palmyra maximum correlation to NADA PC1 study of section 2.3.

12. “Fig. 4 It took me a little bit to understand this figure. You have missing intervals in (b) but no additional years or double counted years. I think the y-axes on panel a) and b) should have the number dropped since it appears they are not meant to be mean shifted time series (most coral records have the means removed for multi-record reconstructions). Panel (c) is still not clear to me, you are starting a 0 or 50 on the x-axis?”

We modified this figure (now Fig. 2 in the revised paper) by shifting all the series vertically and by reformulating the labels.

References

Alibert, C. and Kinsley, L.: A 170-year Sr/Ca and Ba/Ca coral record from the western Pacific warm pool: 2. A window into variability of the New Ireland Coastal Undercurrent, Journal of Geophysical Research, 113, 1–10, doi:10.1029/2007JC004263, http://www.agu.org/pubs/crossref/2008/2007JC004263.shtml, 2008.

Breitenbach, S. F. M., Rehfeld, K., Goswami, B., Baldini, J. U. L., Ridley, H. E., Kennett, D. J., Prufer, K. M., Aquino, V. V., Asmerom, Y., Polyak, V. J., Cheng, H., Kurths, J., and Marwan, N.: COnstructing Proxy Records from Age models (COPRA, Climate of the Past, 8, 1765–1779, doi:10.5194/cp-8-1765-2012, 2012.

Calvo, E., Marshall, J. F., Pelejero, C., McCulloch, M. T., Lough, J. M., and Isdale, P. J.: Interdecadal climate variability in the Coral Sea since 1708 A.D., Palaeogeography, Palaeoclimatology, Palaeoecology, 248, 190–201, 2007.

Crowley, T. J., Quinn, T. M., and Hyde, W. T.: Validation of coral temperature calibrations, Paleoceanography, 14, 605–615, doi:10.1029/1999PA900032, 1999.

De Ridder, F., Pintelon, R., Schoukens, J., Gillikin, D. P., André, L., Baeyens, W., de Brauwere, A., and Dehairs, F.: Decoding nonlinear growth rates in biogenic environmental archives, Geochemistry, Geophysics, Geosystems, 5, doi:10.1029/2004GC000771, 2004.

DeLong, K. L., Quinn, T. M., and Taylor, F. W.: Reconstructing twentieth-century sea surface temperature variability in the southwest Pacific: A replication study using multiple coral Sr/Ca records from New Caledonia, Paleoceanography, 22, 2007.

DeLong, K. L., Quinn, T. M., Taylor, F. W., Shen, C.-C., and Lin, K.: Improving coral-base paleoclimate reconstructions by replicating 350 years of coral Sr/Ca variations, Palaeogeography, Palaeoclimatology, Palaeoecology, 373, 6 – 24, 2013.

Hendy, E. J., Gagan, M. K., Alibert, C. A., McCulloch, M. T., Lough, J. M., and Isdale, P. J.: Abrupt Decrease in Tropical Pacific Sea Surface Salinity at End of Little Ice Age, Science, 295, 1511–1514, doi:10.1126/science.1067693, 2002.

Juillet-Leclerc, A., Thiria, S., Naveau, P., Delcroix, T., Le Bec, N., Blamart, D., and Corrège, T.: SPCZ migration and ENSO events during the 20th century as revealed by climate proxies from a Fiji coral, Geophys, Res. Lett., 33, doi:10.1029/2006GL025950, 2006.

LeGrande, A. N. and Schmidt, G. A.: Water isotopologues as a quantitative paleosalinity proxy, Paleoceanography, 26, PA3225, doi:10.1029/2010PA002043, 2013.

Russon, T., Tudhope, A. W., Hegerl, G. C., Collins, M., and Tindall, J. C.: Inter-annual tropical Pacific climate variability in an isotope-enabled CGCM: implications for interpreting coral stable oxygen isotope records of ENSO, Climate of the Past, 9, 1543–1557, doi:10.5194/cp-9-1543-2013, 2013.

Thompson, D. M., Ault, T. R., Evans, M. N., Cole, J. E., and Emile-Geay, J.: Comparison of observed and simulated tropical climate trends using a forward model of coral of , Geophys. Res. Lett., 38, doi:10.1029/2011GL048224, 2011.

Thompson, D. M., Ault, T. R., Cole, J. E., Emile-Geay, J., and LeGrande, A. N.: Coral-model comparison highlighting the role of salinity in long-term trends, PAGES news, 21, 2013.

Interactive comment on Clim. Past Discuss., 9, 6077, 2013.

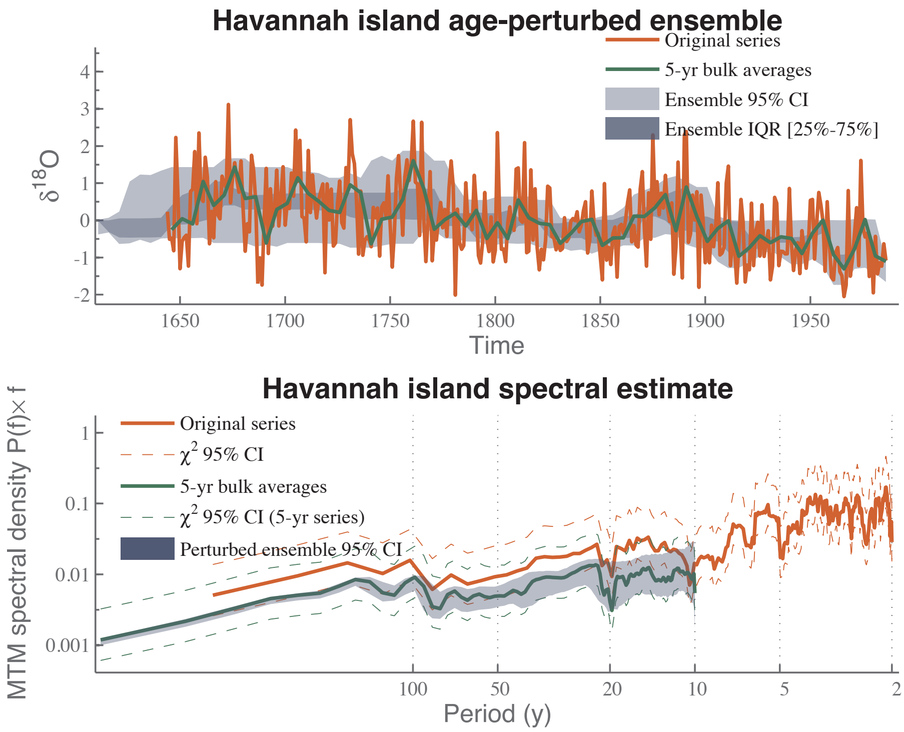

Fig. 1.