C | A | U Christian-Albrechts-Universität zu Kiel
Mathematisch-Naturwissenschaftliche Fakultät

Prof. Dr. Miriam Pfeiffer | Inst. f. Geow. | Ludewig-Meyn-Str. 10 | 24118 Kiel

Nerilie Abram,
Editor
Climate of the Past

Prof. Dr. Miriam Pfeiffer
Paläontologie und
Historische Geologie

Institut für Geowissenschaften
Ludewig-Meyn-Str. 10
24118 Kiel
Tel.: 0431/880 2855
Fax: 0431/880 5557
e-mail:
miriam.pfeiffer@ifg.uni-kiel.de

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Second revision of manuscript titled 'A sub-fossil coral Sr/Ca record documents northward shifts of the Tropical Convergence Zone in the eastern Indian Ocean' by Pfeiffer et al., https://doi.org/10.5194/cp-2024-25

Dear Editor,

Thank you very much for your helpful comments to clarify a key aspect of the KNFa record relating to the signature of the 1877 pIOD event.

Below are your comments (in bold) and our replies in normal font.

***U-Th dating: Can you please consider whether the intial Th230/Th232 ratio that is used (4 (+/- 2) x 10-6) is appropriate for this location.**

In extensive U/Th dating in the Mentawai and Pagai region more conservative values of 5.7(+/- 3.1) x 10-6 or 6.5 (+/- 6.5) x 10-6 have been found to be more appropriate. See Methods section of Abram et al (2020) Nature for a description and references.

We thank the editor for this comment. We used the global ocean mean of 230Th/232Th as the initial value to calculate ages. This reviewer was correct. For the eastern Indian Ocean around the Sumatran islands, regional-specific 230Th/232Th should be used. Chiang et al. (2023) summarized all previous studies and their work to give an 230Th/232Th atomic ratio of 4.3 +-2.5 x 10-6. In the revised MS, we used this value to re-calculate the coral ages, which are within errors comparing to the previous reported ages. We updated our age model and the reference list.

The chronology of KNFa shifts to 1824-1918, and the age model uncertainty increases from ±2.4 to ±3 years (2σ) (see Figure A7). All figures are updated accordingly.

***1877 event: The specific reason that I ask this is because I find it hard to reconcile that you don't reconstruct a strong cooling event in 1877 at Enganno. I can't figure out why such a strong event would be recorded further north at the Mentawai site, but not at Enganno – particularly seeing how well other more recent extreme pIOD events are captured in the KN2 coral. There does look to be an extreme pIOD event in the slab 7 section of KNFa that is omitted due to diagenesis. Could the floating chronology shift enough for this to be the 1877 event if the U/Th dates were calculated with more conservative (but justifiable) initial Th230/Th232 values? And are there any other indicators (e.g. prominent warm events associated with strong El Nino events, or multidecadal variability) that could be used as further checks on the floating chronology?**

In the original version of the manuscript, we tried to explain why we cannot clearly identify the extreme 1877 pIOD event in the Enggano record although it is so clearly seen at Mentawai. However, these sentences appeared to be confusing, and we omitted them in the first revision. We now decided to add a new Figure to illustrate this problem (Fig. A12). A short discussion is added in lines 494-502.

Between 1856-1918, SST variability at Enggano is comparable to SST variability seen today off the coast of Java. Modern SSTs off Java cool during pIOD events, but upwelling and cooling is seen in almost all years. Upwelling causes cooling to ~25°C. However, it does not get much colder than that in any of the upwelling areas off Java and Sumatra. As a result, extreme pIOD events are not seen as clearly in modern SST records off Java (shown in blue colors in Figure A12) as they are seen off Sumatra (shown in red colors in Figure A12): compare the magnitude of the cooling seen off Java in 1994, 1997, 2006 or 2019 with the cooling seen in other, non-IOD years. Furthermore, compare that with the strong cooling (relative to the climatologically much warmer September-November SSTs) during extreme pIOD years seen today off Sumatra, e.g. at Enggano and the Northern Mentawai Islands, where only these events cause strong coastal upwelling. Off Sumatra, extreme pIOD events are seen as large cold spikes. In contrast, it is much harder to identify individual extreme pIOD events in SST records off Java.

Between 1856-1918, SST variability at Enggano is comparable to SST variability seen today off Java. There must have been upwelling and cooling in 1877 at Enggano Island, but given the age uncertainty of the U/Th dating coupled with the change in upwelling frequency seen at Enggano between 1856-1918, it is difficult to unequivocally identify the event at this site. It should be reflected in one of the many cold spikes seen in the KNFa record in the interval ~1880.

In general, the intensity of pIOD events in coral records is better captured by the northward extend of IOD-induced cooling. The magnitude of upwelling-related cooling off Java and Sumatra appears to be limited to 24-25°C (probably by the temperature of the upwelled water) (see Figure A12). This is also seen in Figure A3, which shows the strongest cold anomalies during extreme pIOD events off Sumatra, not off Java.

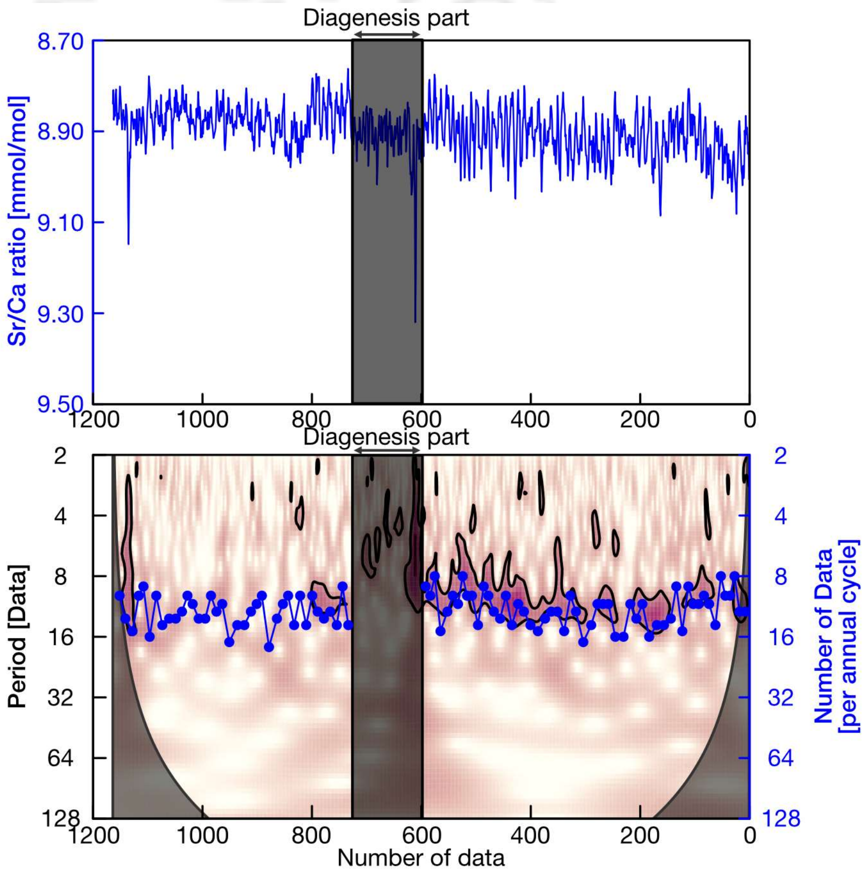
Similar relationships have been illustrated and described in a comparison of modern coral d18O records from Java and Sumatra (Figure 5 of Abram et al. (2015), and related discussion). In fact, this Figure helped us to understand what we see in the sub-fossil record from Enggano. Coral cores from various sites along the coast of Java and Sumatra can therefore help to constrain the magnitude of past IOD events. The Mentawai record tells us that the 1877 pIOD event was among the most extreme events ever recorded (comparable to

1997), while the Enggano record suggests that this event occurred in a mean climate with stronger SE monsoon winds associated with a northward shift of the Tropical Convergence Zone.

***Wavelet analysis: In Figure 6, should the analysis for KNFa be run prior to omitting the slab 7 section with diagenesis, and then this part of the wavelets masked out. By running the analysis this way you would be able to more accurately represent the longer wavelength power which should still be able to be accurately pulled out of the coral record without being affected by the short section of the coral that is affected by diagenesis.**

The wavelet in Figure 6 was run after interpolating the data to monthly resolution. It is not possible to interpolate the data of Slab 7, as diagenesis has distorted the seasonal cycle too much. We have run a wavelet analysis on all the Sr/Ca data of core KNFa prior to interpolation (see Figure below). This is possible as core KNFa has fairly stable growth rates. The results are consistent with Figure 6 in the manuscript (a strong seasonal cycle after 1856, a weak seasonal cycle from 1824-1855). We do not see any significant low-frequency variability, so we decided not to this wavelet analysis in the manuscript.

In the interval affected by diagenesis, we see one extremely large spike that would exceed any pIOD event seen in the modern corals (where we can clearly see long aragonitic fibers in the drill holes in the SEM images). In the remaining sections of this interval, we see low-amplitude variability that would be 'sub-seasonal' if it were climate related.



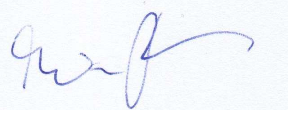
Top panel: Sr/Ca data of core KNFa versus sample number (=mm downcore). The top of the core is on the left. The interval affected by diagenesis is masked out in grey.
Bottom panel: Wavelet power spectrum of KNFa Sr/Ca data vs. sample number. Blue dots/ line indicate number of Sr/Ca measurements per annual cycle. Note significant power at annual frequencies

(corresponding to ~8-16 datapoints per year) that appears after 1856, while the number of samples per year remains stable from 1824-1918. Interval affected by diagenesis is masked out in grey and does not show any periodic oscillations.

Other changes:

We have added one additional affiliation for Hideko Takayanagi (Advanced Institute for Marine Ecosystem Change (WPI-AIMEC), Tohoku University, Sendai, Japan).

Sincerely,



Miriam Pfeiffer