

We would like to thank the editor and the reviewer for their constructive comments on our manuscript. We have revised the manuscript, and we believe that all issues raised by the reviewers have been addressed. Please find detailed answers to reviewers' comments below.

Editor: N. Abram (nerilie.abram@anu.edu.au)

Dear Karina Schollaen and co-authors,

The discussion phase of your paper has now ended and two reviewers have provided comments. To continue I need you to prepare a revised manuscript that takes into account the comments and suggestions of the reviewers. Please also provide a response to reviewers file that gives details of your response to all of the points made by the reviewers and any changes that have been made to the revised manuscript to address these comments.

I look forward to receiving your revised paper in due course.

Sincerely, Nerilie Abram

Anonymous Referee #1

General Comments:

This manuscript addresses a relevant scientific question which falls in the scope of CP. None of the concepts, ideas, tools or data can be considered novel, but this research presents the first application of the type of data to the question posed. The conclusions present important information about the El Niño variants. Some of the methods are not specified and a few assumptions may be questionable. I believe the results support the interpretations and conclusions. I believe the experiments and calculations are reproducible. Proper credit is given to related work with clear indications about the origin of research done in this study. The title is adequate as it is. The abstract is very concise and complete. The presentation of the research is easy to follow and clear. There are a few cases where the English is either imprecise or incorrect. The mathematics is adequate. All parts of the paper should be kept as they are. The references are adequate. No supplemental material was provided with this manuscript

Specific Comments:

Lines 12-13 p 3969. I am undecided about the use of alpha-cellulose versus resinextracted wood, not so much because of possible exchange of carbonyl oxygen in some hemi-celluloses, but because of the potential for interannual changes in the proportions of lignin, alpha-cellulose and hemi-cellulose, all of which are recognized to have different d18O values. If the proportions do change interannually, then the climate/ isotope signal will probably be dampened, though I can imagine scenarios where the signal would actually be spuriously enhanced.

Re: Indeed, α -cellulose, hemicelluloses and lignin show different isotope values and changes in relative proportions may dampen or enhance the climate signal. However, we assume that the isotopic differences and annually changing relative contributions of these structural components are not large enough to evoke changes in the statistical climate-isotope relationships that void the reconstruction skills. Resin extraction procedures were applied because we were much more aware of a large variety of potential additional wood extractives such as fats, waxes, alkaloids, proteins, phenolics, simple sugars, pectins, gums, resins, terpenes, starches, glycosides, saponins and essential oils. These substances can

represent as much as 20% (wood dry weight) for tropical trees (e.g. Pettersen 1984). They do have a much higher variability in isotopic signatures and their relative proportions are much more affected by particular non-climatic environmental incidents such as fire, microbial or insect attacks.

Pettersen, R.C., 1984. The chemical composition of wood. In: Rowell, R.M. (Ed.), *The Chemistry of Solid Wood* American Chemical Society, pp. 57–126 (Washington DC).

Line 25 p 3973 to line3 p 3974. It's also possible for the use of stored starch to significantly modify a $\delta^{18}\text{O}$ signal, smoothing the interannual pattern. Did you assess the $\delta^{18}\text{O}$ time series for autocorrelation prior to your analyses?

Re: Indeed, we tested the $\delta^{18}\text{O}_{\text{TR}}$ time series for autocorrelation prior to the analyses and no significant AC1 was detected. This is mentioned in detail in the paper Schollaen et al. 2013.

Lines 13-15 p 3974 Can you be certain land use change was not a factor in the drop in correlation mentioned here?

Re: This study site is a very old forest and for the last few decades, a protected area (included in the manuscript, p8 L27-29). In former times only selected timber were taken from this forest for the construction of palaces and mosques.

Technical Comments

Lines 12-13 p 3966. What does “highest” mean in this context? Is it the longest amount of time represented, the strength of the convection (e.g. punching through the tropopause), or something else. I realize that the meaning is explained in D'Arrigo et al., 2006, but the word “highest” is imprecise.

Line 15 p 3966. Perhaps you mean “essential to ‘the functioning of’ the global climate system”, or something similar.

Re: We have updated this paragraph and its references to better convey the importance of the warm pool. (page 1 L29ff.)

Line 16 p3967. change “in” to “about”

Re: Corrected.

Line 2 p 3969. change “is” to “has been”

Re: Corrected.

Lines 12-13 p 3969. Schollaen et al. (2013) makes it clear that resin-extracted wood, not alpha cellulose, or holo-cellulose was used in this analysis. In that paper you cite studies showing that further extraction is apparently not necessary, but you need to note in this study that “resin-extracted wood” was used, so the reader can decide.

Re: For clarification we added a new sentence: The $\delta^{18}\text{O}_{\text{TR}}$ record is built from resin-extracted wood of 7 teak (*Tectona grandis*) trees, collected from the Donoloyo Cagar Alam (site DNLY in D'Arrigo et al., 2006) shown as green lines in Fig. 2.

Line 13 p 3969. I think this should be “in Schollaen et al. (2013)”, not “in (Schollaen et al., 2013)”, unless CP has different rules.

Re: This has been changed.

Lines 18-19 p 3970. It's not clear from the wording of this sentence if you used the same transform as Ren and Jin (2011), and just extended the transformation back to 1900, or modified the transform in some way. The text in the figure caption for figure 2 is clear about how you used the Ren and Jin (2011) calculation. Reword this sentence to provide the same specific information.

Re: This section has been re-phrased to clarify the calculations.

Anonymous Referee #2

Re: We thank the reviewer for illustrating the confusion that certain parts of our previous manuscript caused. To address the reviewer's concerns, we have revised these parts (also see our detailed answers to the reviewers' comments), and offer below a general comment on the general part of the review:

General comments:

In this manuscript, Schollaen and coauthors compare an existing (and published) d18O tree ring record from teak trees in Java with various ENSO indices. They find a significant –albeit weak – correlation with a Central Pacific ENSO time series, but not with an Eastern Pacific ENSO time series and argue that the d18O time series can thus be used for reconstruction of ENSO flavors. They justify their study based on a presumed influence of ENSO –and its two flavors – on precipitation on Java and thus on (precipitation sensitive) tree-ring series. However, I believe this is the weak spot of this manuscript. For justification of the ENSO-precipitation relationship, the authors only show one map (Fig. 1) that shows the regression of precipitation against the 2 ENSO flavor time series. They claim that these two maps show a clear difference in the influence of the 2 ENSO flavors on Java precipitation, but frankly I don't see that difference: the regression coefficients in Java seem to be equally weak to me. Moreover, the authors do not specify which months (of precipitation and of ENSO indices) are used for the calculation of this map. This turns out to be problematic at the very end of the discussion, where they discuss that the influence of ENSO on precipitation on Java is (1) very weak and (2) strongest during the dry season, whereas tree rings primarily record wet season precipitation. They then use these arguments to explain the weak correlations they find between d18OTR and ENSO. As a reader, I felt deceived at this point (at the very end of the discussion) in the paper: the authors do a lot of armwaving in the introduction and Fig. 1 about the influence of ENSO flavors on precipitation in Java, but lack to come up with concrete evidence. It is not until the very end of the paper that they explain that actually there is not really any influence between ENSO and Java precip and one would thus not expect to find a strong ENSO- d18OTR connection.

We agree with the reviewer that -in its previous version- Fig. 1 failed to properly show the significant differences between WP and CP ENSO influence on Java precipitation. Indeed, the colorscale was overwhelmed by the central Pacific rainfall, which caused the difference over Java to not show properly, as the reviewer points out.

In the revised manuscript we have updated Fig. 1, which now clearly shows the differences over Java, since the central Pacific response does not overwhelm the colorscale. We also report in the text the average regression coefficient over Java for the two flavors: -0.83 for WP and -0.03 for CT (page 5 L1-3). *Note that the regression maps are computed using monthly values.

I believe this is the largest caveat of the paper: why write a paper about the connection between d18OTR and various ENSO flavors, when you would not expect there to be a connection based on what we know? I think this problem could be greatly helped if the authors included an analysis in their paper that concretely (not just in a vague map) showed the link between the various ENSO flavors and Java precipitation. Use the Java precip time series as you use the ENSO time series. As a result, it is not surprising that the correlations the authors find between d18OTR are significant but weak and definitely too weak to use for reconstruction purposes. This should be made much more explicit in the text, particularly in

the conclusion where they state that ‘These results indicate the significant potential for generating reconstructions of different ENSO flavors from the $\delta^{18}\text{O}_{\text{TR}}$ records in Indonesian teak.’ In my opinion, these results show the exact opposite and the weak relationship as a caveat for reconstruction should be discussed.

We believe that Fig. 1 (especially after its update) clearly shows that the two flavors have distinct influence on Java precipitation. Still, without an analysis like the one that we present in this study, one cannot take for granted that $\delta^{18}\text{O}_{\text{TR}}$ is capable of recording these distinct influences. Our quantitative analysis, and Fig. 2 and 3 show that indeed the proxy is able to show the clear differences in ENSO-induced precipitation shown in Fig. 1. We believe that this is the main contribution of our study, i.e. showcasing that a tree-ring proxy clearly captures the distinct teleconnections of Java precipitation and ENSO flavors.

Finally, I find the description of the different indices used for the ENSO flavors confusing and incomplete. The authors do not describe how the La Niña indices are calculated (only how the extreme LN years are calculated, but these are not used in most analyses). Also, they are inconsistent in their use of CT and WP ENSO vs. El Niño, which is very confusing to the reader. If CT and WP El Niño indices are based on SSTas from certain regions, don’t they then reflect El Niño as well as La Niña conditions? How are they an index of El Niños alone? I can see how the extreme (>1 stdev) in these time series indicate a certain flavor of El Niño, but in your analysis you use the entire time series, not just the extreme years. Similarly for the La Niña time series, if this is based on SSTas from region NIÑO4, how is this not an ENSO time series, rather than a La Niña time series alone? Also, given that your La Niña time series and your WP El Niño time series are both based on NIÑO4 and only differ in years when $\text{NIÑO3NIÑO4} > 0$ (sic; equation 1), it does not come as a surprise that they are both correlated to $\delta^{18}\text{O}_{\text{TR}}$. Also, to make a statement as you do in the conclusion (P11 L18-20) that ‘the conclusions of our study call for caution when doing model-proxy comparisons using ENSO indices that are not able to distinguish between the two flavors (e.g. single standard indices such as NIÑO3.4)’, it would be helpful to also include a general ENSO index such as NIÑO3.4 in your analysis in addition to the ENSO flavor indices. All in all, how the different ENSO time series are calculated is crucial to your analysis and discussion and needs to be explained in more detail (see also specific comments).

We also understand that the discussion of the indices caused some confusion, and appreciate the reviewer’s comment on this issue. Of course, the two indices for ENSO flavors -by their construction as anomaly indices- record variants of La Niña events as well. The point of using the Ren & Jin indices is that by their construction they are able to clearly separate the two El Niño flavors. In other words, Equation 1 is a transformation of the phase space of two correlated indices (NINO3 and NINO4) into two new indices (N_{CT} and N_{WP}) which are orthogonal and uncorrelated. During a WP event, NINO4 generally dominates NINO3, therefore N_{CT} will be very small, in contrast to N_{WP} . Consequently, Equation 1 will classify this event as WP. During a CT event, the opposite will occur, and N_{CT} will capture it. The parameter alpha of this transformation is determined by a minimization procedure to better separate the classification of events (for details the reviewer is referred to Ren and Jin 2011).

However, the separation for La Niña variants is not significant, and taken that the La Niña anomalies generally propagate westward, a single index like NINO4 is sufficient to capture them. We agree with the reviewer that N_{WP} and NINO4 are very closely related, and this is

reflected in the correlations reported in Fig.2. Note that the third panel shows NIÑO4*(-1), in order to highlight the La Niña events (we have corrected the label here as well). The reason why we also present an analysis using NINO4 here and plot it in the third panel is to indicate the La Niña events that are selected by our methods and used in Figure 3 without overwhelming the first panel of Figure 2 (Nwp) with La Niña shading. Otherwise, the reviewer is correct, and the third panel is only -to an extent- complementary to the first panel; yet we feel it is useful because it presents a clear identification of La Niña events used in the subsequent Figure 3.

In conclusion, indeed, the two indices record both warm and cold anomalies. We have corrected the y-axes labels in Fig.2 to avoid the confusion that was caused by our previous labels.

With respect to our discussions and conclusions, we believe that this study illustrates that proxies from specific regions (like Java) are ideally located to distinguish between ENSO flavors and help elucidate some of the open questions regarding their past variability. Our conclusion about the caution required for interpreting proxies was not specifically referring to this region (due to its strong teleconnection with La Niña; the latter indeed can be captured using a single ENSO index-- see our answers above and in the comments below). Even in this case of generally low correlations between the flavors and d18O, we show that the correlations with NINO3.4 (which is an index that mixes the signals of the two flavors) are even lower and non-significant statistically (Table 2). Thus, especially in multi-proxy reconstructions, where proxies from different regions are synthesized to reconstruct past ENSO variability it is important to take notice of the distinct (and often of opposite sign) correlations with the two flavors and not convolute their influence by using a single ENSO index. We have updated the conclusions to clarify this point.

Specific comments:

1) P3 L8: I am confused as to whether these are El Niño flavors or ENSO flavors. You only discuss El Niño flavors (positive ENSO phases), yet you keep calling them ENSO flavors. If they were ENSO flavors, shouldn't there be a La Niña equivalent?

Re: "ENSO flavors" typically refers to the two variants of the positive ENSO phase (El Niño); this is the manner in which we use the term in this paper. For our comment on the existence of La Niña flavors, we refer the reviewer to page 5, L27- page 6 L2. The reviewer is correct to point out that when referring to Nwp as "WP El Niño index" and not WP ENSO index one might think that it does not capture cold events. We have updated the manuscript throughout to avoid such confusions. We changed the wording WP El Niño/ CT El Niño index into WP/CT ENSO index, accordingly.

2) P3 L10-11: Fig. 2 does not show an increased frequency in WP ENSO events. How do you explain this?

Re: Given the short length of the record, whether there is indeed increased frequency of CP events in the recent decades and whether it can be attributed to GHG forcing or natural variability is still an open question. We have altered the phrasing of this sentence to better highlight this. Our analysis and our Fig. 2 only depict the two flavor indices up to 2007. It can be seen that after the big El Niño event of 1997, there are only WP events, and this state continues up to 2014, with a possibility of having another CT event only emerging in 2015 (and yet to be confirmed).

3) P3 L17: dampened instead of damped?

Re: The correct word is damped.

4) P3-L25: I don't think Fig. 1 demonstrates this well: Fig. 1 shows that the precipitation in Java (red square) is approximately equally strongly regressed against WP El Niño as it is against CT El Niño. In general, you are going to have to make a much stronger case for differential influences of WP vs. CT ENSOs on Java's precipitation to make the case you want to make.

Re: As noted in our general comments above, the problem with Fig. 1 was that the colorscale was overwhelmed by rainfall in the central Pacific, which is irrelevant for our study, and thus the difference in regression coefficients over Java was not clear. We have updated this figure to better illustrate the difference, and we also report the 2x3 grid-point average regression coefficient for the two indices, which are -0.03 for CT and -0.83 for WP (order of magnitude different) (page 5 L1-3).

5) P5 L10-11: it would be good to mention what time period is covered by the TRW chronology, so that the reader has an idea of how far a potential ENSO reconstruction based on $\delta^{18}O$ could extend back in time.

Re: We added the following sentence: The according TRW chronology goes back in time until AD 1714.

6) P6 L9: it would be nice to see this demonstrated in a more convincing way: what is the concrete correlation between Java precip and ENSO in general and WP and CT ENSO in particular? Again, I find Fig. 1 not very convincing in that respect and I don't see the 'nodal line of influence' that you are talking about.

Re: As noted above, the colorscale was overwhelmed in the previous version of this figure. Please see updated version. We also report the regression coefficients for the two flavors, as requested.

7) P6 L20: - Please give a reference for the 'alternative indices' that you are talking about

Re: We added the following references: No significant differences were found when using alternative indices (e.g. Ashok et al., 2007; Takahashi et al., 2011) for calculating ENSO flavors....

8) It is unclear to me what you mean by 'since the NIÑO3-NIÑO4 SST anomalies are so closely associated with rainfall anomalies in the Java region': - It is exactly these correlations that you are failing to show in this paper. Writing that they are closely correlated is not sufficient. -I also don't understand how this presumed close correlation influences the calculation of CT and WP ENSO indices?

Re: This sentence was re-phrased, and the whole section was edited for clarity.

9) P6 equation 1: - What are NCT and NWP and N3 and N4? I assume SSTas in zone NIÑO3 and NIÑO4, but this has not been defined.

Re: We have added the necessary clarifications.

10) What do you mean by $N3N4 > 0$? I'm assuming this should be $NIÑO3 - NIÑO4 > 0$? - If NCT and NWP are based on SSTas of NIÑO3 and NIÑO4 regions, do they not reflect both positive (El Niño) and negative (La Niña) conditions? How come this is considered an index of El Niño alone? Please explain.

Re: As noted above, we understand the confusion caused by the phrasing, and we thank the reviewer for pointing this out. As anomaly indices, the indices are for both positive and

negative anomalies, however Nct mainly captures the CT events, while Nwp the WP events. We have updated the discussion in this session to clarify (page 5 L14- 27).

Please note that $N3N4 > 0$ refers to the product of the two indices and is used in order to distinguish between the cases when SST anomalies in these two regions are of the same or opposite sign, i.e. to describe whether the anomalies are basin-wide or not. In the latter case, the NINO3 and NINO4 indices are adequate to capture the different ENSO flavors and thus Nct and Nwp are equal to them without any transformation. Also, in this case, the anomalies are mostly small and the conditions are neutral (see Figure 1 in Ren and Jin 2011). Equation 1 and the parameter alpha of this transformation are determined by a minimization procedure to better separate the classification of events (also see Ren and Jin 2011 for details).

We have updated the equation symbols to clarify the above points.

11) P6 L25-26: This is not the case for Table 2, which shows correlation with indices over various combinations of months.

Re: The Ren & Jin indices belong to the ENSO indices. We modified the sentence for clarification:

For subsequent analyses we use the January (Jan_{n+1}) indices for the ENSO flavors, for the timespan 1900–2007.

12) P7 L3-5: please also mention what La Niña index you used to calculate the La Niña time series you used in Figs. 2, 3, 4 and Table 2.

Re: This sentence explains the calculation of the La Niña time series: We classify a year as La Niña (LN) when NINO4 is negative by less than one standard deviation of the monthly NINO4 index (Kaplan et al. 1998).

13) P7 L7-10: this would be a much stronger statement if you showed this for Precip in Java or in a Fig. similar to your Fig. 1, rather than just making a general statement based on the literature.

Re: The attached figure (S1) shows the regression coefficients between precipitation and the two ENSO flavor indices for wet (October to May) and dry (June to September) season.

It shows that most of the signal in the IMC and surrounding oceanic areas is from WP ENSO in wet and dry season (mostly dry), and CT ENSO shows no signal for either season.

The figure shown in the manuscript uses monthly data to perform the regressions, therefore shows the ENSO flavor influence throughout the year. According to our literature review and our previous work on the different isotopic signatures in $\delta^{18}O_{TR}$, the annually-resolved $\delta^{18}O_{TR}$ record that is used here encompasses the influence of both seasons, so it seems more appropriate to show in Fig. 1 the regressions based on the monthly values throughout the year (as we do). If the reviewer and the editor wish, we can include the attached figure in an appendix.

14) P7 L20-22: - How were neutral conditions defined here? - It would be nice to also show this for general El Niño conditions (not separate flavors)

Re: We added the following sentence (page 6 L22-24): We classify neutral conditions when CT or WP are not greater than one standard deviation of the respective monthly index and when LN is negative by more than one standard deviation of the monthly NINO4 index.

15) P8 L2-11: all of the reported correlation coefficients are statistically significant, but none

of them are strong enough for reconstruction purposes. These are really rather low correlation coefficients that weaken the potential of teak d18O for ENSO reconstruction purposes. The results of this study are still of interest, but the weak correlations and what that implies for reconstruction need to at least be discussed in the discussion section.

Re: We agree with the reviewer that it is difficult to make reconstructions based solely on this proxy given the weak correlations. The low correlation is discussed in the last parts of the discussion section.

16) P8 L19: until in stead of till

Re: Corrected.

17) P8 L20 and L28: please define the time period for which this 'overall r' is calculated.

Re: We modified the sentence:

The teleconnection with Jan_{n+1} WP ENSO is strong and significantly positive from the 1950s until present, with running correlations reaching 0.6, and an r of 0.45 for AD 1950-2007 ($p < 0.001$) (Fig. 2a).

18) P9 L26: what do you mean here by 'in cases with no strong signal'? what signal are you talking about?

Re: We modified the sentence:

In contrast, no clear CT El Niño signal is preserved in the $\delta^{18}\text{O}_{\text{TR}}$ record, illustrated by the bimodality.

19) P10 L1: dampened in stead of damped?

Re: The right word is damped.

20) P10 L8-9: this discussion would be greatly helped by showing the seasonality of the influence of WP and CT ENSO on Java precipitation.

Re: We also refer the reviewer to our answer above and the attached figure, which we could include in an appendix if the reviewer and editor believe is need.

21) P10 L16-18: it wouldn't be too hard to test this: add an IOP time series to your analysis and see if you find a stronger correlation with d18OTR in the earlier period. Why not do this?

Re: For the benefit of the discussion, we attach here in Figure 2a (S2) the correlation between the $\delta^{18}\text{O}_{\text{TR}}$ record and the (DJF) DMI index (Kaplan et al. 1998). However, we do not feel it is essential information that should be included in the manuscript, and it might be distracting, since studying the IOD influence is outside the scope of this paper.

22) P10 L20: space missing between the d18OTR

Re: Corrected.

23) P10 L23-29: I find it interesting that you don't mention this until the very end of your discussion. This should be mentioned in your introduction! Also, this begs the question for which months Fig. 1 was calculated then? And also, again, this should be supported by showing correlations between the different ENSO indices and Java precipitation.

Re: This paragraph was moved to the site description (page 4 L22-L27). We also refer the reviewer to our answer above regarding the updated Fig. 1 and the attached figure, which we could include in an appendix if the reviewer and editor believe is need.

24) P11 L15-18: given what you describe in the last paragraph of the discussion, the predominantly wet season signal in d18OTR vs. the predominantly dry season teleconnection between Precip and ENSO, and the resulting low correlation coefficients between d18OTR and ENSO, I think this statement is not justified. I don't think, based on your results, that whole-ring d18OTR has potential for ENSO (flavor) reconstructions. I think you've just demonstrated that.

Re: The sentence has been modified (page 9 L16-18):

These results indicate the potential for generating reconstructions of different ENSO flavors from high-resolution intra-annual $\delta^{18}\text{O}$ records from appropriately selected regions, such as Java.

We have also edited this discussion to clarify the potential for reconstructions.

25) P11 L18-20: you would have a stronger argument for this statement if you had actually compared d18OTR to e.g. NIÑO3.4 and found weaker correlations than WP ENSO. - Table 2: also here, it would be good to see results for a general El Niño index (e.g. SOI, Niño3.4) for comparison. Does divvying the El Niño up in flavors increase your correlation coefficients? –

Re: As discussed in previous answers, one of the main foci of our study is to illustrate that proxies, such as $\delta^{18}\text{O}_{\text{TR}}$, do record different flavors in a clear way (as seen in Figure 1 and Figure 3), and can potentially be used in a synthesis with other proxies with higher correlations for reconstruction of past ENSO flavor variability. We have edited our discussion in order to clarify this point.

In addition, the conclusions of our study call for caution when doing model-proxy comparisons using ENSO indices that are not able to distinguish between the two flavors (e.g. single standard indices such as NINO3.4).

We have also added NINO3.4 in Table 2, which shows insignificant correlations, due to the mixing of the signal of the two flavors when using a single ENSO index.

26) Fig. 1: What months (precipitation and ENSO indices) are these maps calculated for?

Re: The figure shown in the manuscript uses monthly data to perform the regressions, therefore shows the ENSO flavor influence throughout the year.

27) Fig. 2 caption: - 75% confidence level: that seems fairly irrelevant to me, why not show 95% as usual? L6: analysis in stead of anaylsis

Re: The Figure 2 shows the 95% confidence levels. This was a spelling error, and we thank the reviewer for pointing this out.

28) Fig. 4: - Why not also show for CT El Niño? - To me, Fig. 4B and C don't mean/show much. The fact that you don't really interpret the results (P9 L13-16) confirms this to me. I suggest leaving these panels out.

Re: We modified Figure 4. Instead of showing La Niña index in Figure 4c we show now the CT ENSO index.

1 ENSO flavors in a tree-ring $\delta^{18}\text{O}$ record of *Tectona grandis* 2 from Indonesia

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15

16 **Abstract**

17 Indonesia's climate is dominated by the equatorial monsoon system, and has been linked to El
18 Niño-Southern Oscillation (ENSO) events that often result in extensive droughts and floods
19 over the Indonesian archipelago. In this study we investigate ENSO-related signals in a tree-
20 ring $\delta^{18}\text{O}$ record (1900-2007) of Javanese teak. Our results reveal a clear influence of Warm
21 Pool (central Pacific) El Niño events on Javanese tree-ring $\delta^{18}\text{O}$, and no clear signal of Cold
22 Tongue (eastern Pacific) El Niño events. These results are consistent with the distinct impacts
23 of the two ENSO flavors on Javanese precipitation, and illustrate the importance of
24 considering ENSO flavors when interpreting palaeoclimate proxy records in the tropics, [as
25 well as the potential of palaeoclimate proxy records from appropriately selected tropical
26 regions for reconstructing past variability of ENSO flavors.](#)

27

28 **1 Introduction**

29 [The tropical warm pool surrounding the Indonesian maritime continent \(IMC\) is a region of
30 homogenous sea surface temperatures where atmospheric deep convection occurs, and plays a
31 key role in the regulation of the global tropical climate \(Clement et al., 2005; Pierrehumbert,
32 1995\).](#)

Karina Schollaen 14/8/2015 20:32

Gelöscht: The tropical warm pool waters surrounding the Indonesian maritime continent (IMC) are the region of the highest convective activity in the world (D'Arrigo et al., 2006). The IMC is known for its exceptionally high rainfall throughout the year and is a center of heat flux essential to the global climate system (Yulihastin et al., 2010).

1 Indonesia's regional climate is governed by the Australian-Indonesian Monsoon (Wheeler and
2 McBride, 2005) and the associated seasonal movement of the Inter Tropical Convergence
3 Zone (ITCZ). Variations of the equatorial monsoon system significantly impact the livelihood
4 of over 230 million people living in the world's fourth most populated country.

5 The El Niño-Southern Oscillation (ENSO) phenomenon contributes to the rainfall pattern of
6 the IMC and has been thought to interact with the monsoons (e.g. Hendon, 2003; Lau and
7 Nath, 2000). Recent studies have drawn attention to the existence of more than one variant or
8 'flavors' of El Niño ([the warm phase of ENSO](#)) (Ashok et al., 2007; Kug et al., 2009; Larkin
9 and Harrison, 2005; Ren and Jin, 2011; Takahashi et al., 2011). The canonical [El Niño](#)
10 (Sarachik and Cane, 2010), also referred to as eastern Pacific (EP) El Niño (Kao and Yu,
11 2009) or Cold Tongue El Niño (Kug et al., 2009; Ren and Jin, 2011), exhibits SST anomalies
12 localized in the eastern equatorial Pacific. The El Niño variant with maximum SST anomalies
13 located in the central equatorial Pacific is referred to as the central Pacific (CP) El Niño (Kao
14 and Yu, 2009), Warm Pool (WP) El Niño (Kug et al., 2009; Ren and Jin, 2011), date line El
15 Niño (Larkin and Harrison, 2005) or El Niño Modoki (Ashok et al., 2007; Takahashi et al.,
16 2011). In this study we use the terms Cold Tongue (CT), and Warm Pool (WP) El Niño (Ren
17 and Jin, 2011) to describe these two ENSO flavors.

18 Identifying the mechanisms responsible for the CT and WP ENSO flavors is an active field of
19 research. At present, there is no consensus on whether [a reported increase in the frequency](#)
20 [and intensity](#) of WP ENSO events in recent decades (Ashok et al., 2007; Kao and Yu, 2009;
21 Kug et al., 2009; Lee and McPhaden, 2010) [is](#) a result of anthropogenic greenhouse gas
22 forcing (Yeh et al., 2009), or natural variability (McPhaden et al., 2011; Newman et al.,
23 2011). In addition, the simulation of ENSO flavors in Global Climate Models (GCMs) is still
24 subject to limitations in our understanding of the phenomenon. Consequently, there is much
25 uncertainty [about](#) whether ENSO activity will be enhanced or damped in the future, or if the
26 relative frequency of ENSO flavors will change (Collins et al., 2010). Long records of ENSO
27 activity are essential for identifying trends and multidecadal changes in the patterns of sea
28 surface temperature associated with ENSO, making palaeoclimate reconstructions particularly
29 attractive for shedding light onto the past and future of ENSO flavors.

30 Recent research on ENSO-proxy teleconnections recommends, that when interpreting proxy
31 data, [differences in the influence of the two ENSO flavors on SST, precipitation and salinity](#)
32 [should be taken into account](#) (Karamperidou et al., 2015). Certain regions like Java lie in key
33 locations where interannual precipitation variability is significantly correlated to one ENSO
34 flavor but not the other (see [Fig. 1](#)). Thus, long-term rainfall proxies from Java can be useful

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Gelöscht: ENSO

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Gelöscht: details in the differences between ENSO flavors, with regards to SST's, precipitation and salinity, should be taken into account (Karamperidou et al., submitted).

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Gelöscht: Figure

1 for distinguishing between ENSO flavors, and for studying their relation to monsoon
2 variability.

3 Over the last decade there have been several attempts to reconstruct continuous time series of
4 ENSO variability using different proxy archives such as corals (e.g. Abram et al., 2008;
5 Charles et al., 2003; Cobb et al., 2013; Evans et al., 2002; Linsley et al., 2004; Pfeiffer et al.,
6 2009; Quinn et al., 2006; Wilson et al., 2006), tree-ring widths (e.g. D'Arrigo et al., 2005;
7 Fowler et al., 2012; Stahle et al., 1998) or tree-ring stable isotopes (Sano et al., 2012).
8 Furthermore, several multi-proxy reconstructions of ENSO variability are available (e.g.
9 Braganza et al., 2009; D'Arrigo et al., 2006; Emile-Geay et al., 2013; Mann et al., 2000;
10 Wilson et al., 2010). However, many of these reconstructions are based on extratropical proxy
11 records, particularly from tree-ring widths, and thus do not represent ENSO activity directly.

12 Tree-ring stable isotopes often provide additional climate information where the more
13 commonly used tree-ring proxies (e.g., ring width and maximum latewood density) do not, or
14 where the teleconnection signal is weak. In tropical regions, oxygen isotope data from tree
15 rings ($\delta^{18}\text{O}_{\text{TR}}$) are often more sensitive to precipitation than ring width (e.g. Brienen et al.,
16 2012; Schollaen et al., 2013). $\delta^{18}\text{O}_{\text{TR}}$ data are primarily controlled by the isotopic composition
17 of precipitation, i.e. the source water, and relative humidity (e.g. Barbour, 2007; McCarroll
18 and Loader, 2004). The isotopic composition of precipitation ($\delta^{18}\text{O}_{\text{Pre}}$) depends on a number
19 of factors, the so-called 'kinetic isotope effects' (Araguás-Araguás et al., 2000). One of these
20 effects, 'the amount effect', is the inverse correlation between rainfall amount and $\delta^{18}\text{O}_{\text{Pre}}$
21 values, and a crucial driver in determining $\delta^{18}\text{O}_{\text{Pre}}$ values in the tropics (e.g. Brienen et al.,
22 2012; Zhu et al., 2012). Thus $\delta^{18}\text{O}_{\text{TR}}$ records offer a promising approach to examine monsoon
23 activity, and large-scale climate variations such as ENSO.

24 In previous studies we investigated relationships between seasonal rainfall variability and
25 tree-ring stable isotope records from Javanese teak trees on inter- to intra-annual time scales
26 (Schollaen et al., 2014; Schollaen et al., 2013). In this study we explore the signal strength of
27 ENSO flavors in our annually resolved $\delta^{18}\text{O}_{\text{TR}}$ record from Java, the only well replicated,
28 centennial $\delta^{18}\text{O}$ record from Javanese teak in existence. We place particular emphasis on the
29 time stability of the teleconnected $\delta^{18}\text{O}$ /ENSO relationship. To the best of our knowledge this
30 is the first time the relationship between tree-ring proxies and the two ENSO flavors **has been**
31 tested. We find a unique WP El Niño signal in the $\delta^{18}\text{O}_{\text{TR}}$ record from Java, supporting the
32 notion that proxies from carefully selected regions are valuable for answering questions of
33 past and present ENSO variability, and for constructing reliable ENSO reconstructions.

34

2 Data and Methods

2.1 Proxy data and site description

We use a tree-ring $\delta^{18}\text{O}$ chronology from a lowland rainforest in the eastern part of Central Java, Indonesia (07°52'S, 111°11'E; 380 m a.s.l.), spanning the period 1900-2007. The $\delta^{18}\text{O}_{\text{TR}}$ record is built from resin-extracted wood of 7 teak (*Tectona grandis*) trees, collected from the Donoloyo Cagar Alam (site DNLY in D'Arrigo et al., 2006) shown as green lines in Fig. 2.

The according TRW chronology dates back to AD 1714. This $\delta^{18}\text{O}_{\text{TR}}$ chronology and its dendroclimatological potential as a rainfall indicator has been described in detail in Schollaen et al. (2013). Indonesia receives significant rainfall year-round but experiences a distinct wet and dry season. The wet season (approx. October/November to April/May) coincides with movement of the Inter-Tropical Convergence Zone to the Southern Hemisphere, while the dry season (June to September) corresponds with a predominance of dry southeasterly winds from Australia (Aldrian et al., 2007). The isotopic composition of precipitation ($\delta^{18}\text{O}_{\text{Pre}}$) over Java shows that distinct seasonal changes are linked to rainfall amount resulting in high $\delta^{18}\text{O}_{\text{Pre}}$ values during the dry season, and low $\delta^{18}\text{O}_{\text{Pre}}$ values during the rainy season (Fig. 5b, Schollaen et al., 2014). Instrumental records (e.g. Aldrian and Susanto, 2003; Allan, 2000; Haylock and McBride, 2001) and reanalysis products (Aldrian et al., 2007; Jourdain et al., 2013) show rainfall anomalies in Indonesia are affected by ENSO: During a warm ENSO phase (El Niño events) the tropospheric air flow (Walker Circulation) weakens and the Indonesian Low pressure system migrates eastward into the tropical Pacific, resulting in drought over much of the country. Conversely, a cold ENSO phase (La Niña events) brings excess rain to the region (Sarachik and Cane, 2010). Several analyses of Indonesian rain gauge data show that Indonesian rainfall is poorly correlated with ENSO events during the wet monsoon season, but reveal highest coherence during the dry season and transition months prior to the wet season (June to November) (Haylock and McBride, 2001; Hendon, 2003). However, taking the IMC and surrounding oceanic rainfall into account, rainfall during the wet season is also related to ENSO (Fig. 8a, Jourdain et al., 2013).

In this study, we further show that precipitation anomalies in Java are sensitive to ENSO flavors. Fig. 1 shows the relationship between precipitation data and the WP and CT ENSO indices (see Sect. 2.2 for definition of the indices) for the IMC and Pacific region. WP El Niños are associated with drought over Java (Fig. 1, upper panel), and have a strong influence on the Australian-Indonesian monsoon system (e.g. Kumar et al., 2006; Taschetto and England, 2009). On the other hand, Java lies on the nodal line of influence of CT El Niños (Fig. 1, lower panel), which makes it a key location for obtaining records able to distinguish

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Gelöscht: This $\delta^{18}\text{O}_{\text{TR}}$ chronology and its dendroclimatological potential as a rainfall indicator has been described in detail in (Schollaen et al., 2013)

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[1] verschoben (Einfügung)

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Gelöscht: El Niño

1 between the two ENSO flavors. The average regression coefficient between monthly
2 precipitation anomalies over Java and the WP ENSO index is -0.83 mm/day, while for CT
3 ENSO it is -0.03 mm/day (non-significant).

4 The growing season for teak in Central and Eastern Java occurs mostly during the wet season,
5 from October to May (Coster, 1928, 1927; Geiger, 1915; Schollaen et al., 2013). In all
6 subsequent analysis, we use the southern hemisphere convention, which assigns to each tree
7 ring the year in which radial growth begins (Schulman, 1956). Thus lag-0 refers to the year n
8 where tree growth starts: Oct_n-Sep_{n+1}. Lag-1 refers to Oct_{n-1}-Sep_n.

9 2.2 Definition of ENSO flavors

10 In the following, we use the global SST dataset of Kaplan et al. (1998). To calculate indices,
11 for the two ENSO flavors we use the coordinate transform of the NINO3-NINO4 phase space
12 proposed by Ren and Jin (2011) and shown in Equation 1.

$$13 \begin{aligned} N_{CT} &= N_3 - \alpha N_4 \\ N_{WP} &= N_4 - \alpha N_3, \quad \alpha = \begin{cases} 2/5 & \text{if } N_3 \cdot N_4 > 0 \\ 0 & \text{otherwise} \end{cases} \end{aligned} \quad (1)$$

14
15 where N_{CT} , N_{WP} are the indices for CT and WP ENSO , and N_3 , N_4 are the NINO3 and
16 NINO4 indices, i.e. the SST anomaly averaged over the regions [5N-5S, 150W-90W] and
17 [5N-5S, 160E-150W] respectively. The timeseries of the two indices N_{CT} , N_{WP} are shown in
18 Figure 2a and b (January values). When a Warm Pool event occurs (e.g. 1994-95), SST
19 anomalies are mostly concentrated in the NINO4 region, and therefore the N_{CT} index resulting
20 from Equation 1 is very small. In contrast, the N_{WP} index, which is dominated by the NINO4
21 anomalies, is large and, thus, the event is classified as a Warm Pool event. The opposite
22 occurs during large Cold Tongue events (e.g. 1976-77, 1982-83, and 1997-98): NINO3
23 anomalies dominate NINO4, and thus the N_{WP} index is very small compared to N_{CT} , and the
24 event is classified by Equation 1 as a Cold Tongue event. As shown in detail in Ren and Jin
25 (2011), the two indices are able to capture the SST anomaly patterns that characterize the two
26 ENSO flavors, as well and their variability in the 20th century. No significant differences were
27 found when using alternative indices (Ashok et al., 2007; Takahashi et al., 2011) for
28 calculating ENSO flavors (not shown here). Distinguishing between the two corresponding
29 types of La Niña events, as advocated by Kao and Yu (2009) and Ashok and Yamagata
30 (2009), may not be necessary because the SST and precipitation patterns of the two La Niña
31 types are not very distinctive (Kug and Ham, 2011) and the SST anomalies during La Niña

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Gelösch: ENSO-flavor indices are averaged over Jan_{n+1}Feb_{n+1}.

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Gelösch: ENSO

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Gelösch: to define the two ENSO flavors (Equation 1). No significant differences were found when using alternative indices for calculating ENSO flavors (not shown here) since the NINO3-NINO4 SST anomalies are so closely associated with rainfall anomalies in the Java region.

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[2] nach unten verschoben: We classify each year as CT, or WP when N_{CT} , or N_{WP} are greater than one standard deviation of the respective monthly index. We classify a year as La Niña (LN) when NINO4 is negative by less than one standard deviation of the monthly NINO4 index. Table 1 shows the list of years classified as CT, WP, and LN according to the above criteria.

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Gelösch: For subsequent analyses we use the Jan-Feb (JF) time-averaged indices for years 1900-2007. We focus on the JF period which represents the maximum rainy season in Java, when our $\delta^{18}\text{O}_{\text{TR}}$ record correlates the best with regional rainfall data (Schollaen et al., 2013)

1 events generally tend to propagate westward. Therefore a single index (NINO4) suffices to
2 capture La Niña events, as shown in Figure 2c, and a coordinate transform of two indices (as
3 in equation 1 above) is not necessary.

4 For subsequent analyses we use the January (Jan_{n+1}) indices for the ENSO flavors, for the
5 timespan 1900–2007. We focus on the month January as that represents the month with
6 highest precipitation during the rainy season at the study site. Here, our $\delta^{18}O_{TR}$ record
7 correlates the best with regional rainfall data (Schollaen et al., 2013). We classify each year as
8 CT, or WP when N_{CT} , or N_{WP} are greater than one standard deviation of the respective
9 monthly index. We classify a year as La Niña (LN) when NINO4 is negative by less than one
10 standard deviation of the monthly NINO4 index. Table 1 shows the list of years classified as
11 CT, WP, and LN according to the above criteria.

12 2.3 ENSO signal assessment

13 To assess the long-term temporal stability of the ENSO signal, running 31-year correlations
14 were calculated between the $\delta^{18}O_{TR}$ record and the varying ENSO flavors. A Kalman filter
15 analysis was also used as a time-dependent regression-modeling tool to test the temporal
16 stability of the relationship between the $\delta^{18}O_{TR}$ record and the two ENSO flavors. In contrast
17 to the running correlation procedure, the Kalman filter method uses maximum likelihood
18 estimation to objectively test for the identification of time-dependence between predictor and
19 predicted variables (see Visser and Molenaar (1988) for details, and Cook et al. (2002), Cook
20 et al. (2013) or Wilson et al. (2013) for examples).

21 Furthermore, probability density functions of the correlation between $\delta^{18}O_{TR}$ variability and
22 the different ENSO phases (WP, CT and LN), as well as during neutral conditions, were
23 calculated. We classify neutral conditions when CT or WP are not greater than one standard
24 deviation of the respective monthly index and when LN is negative by more than one standard
25 deviation of the monthly NINO4 index. Finally, the spectral properties of the $\delta^{18}O_{TR}$ proxy
26 time series were analyzed (Schulz and Mudelsee, 2002) and wavelet coherency analysis
27 performed (Grinsted et al., 2004; Torrence and Compo, 1998).

28 3 Results

29 Monthly and seasonal correlations between the Javanese $\delta^{18}O_{TR}$ record (Fig. 2, green line in
30 all plots) and ENSO flavors (see section 2.2) were computed for both the concurrent year
31 (lag-0) and the year prior to tree growth (lag-1) (Table 2). Statistically significant (95% level
32 or higher) positive correlations were found between WP El Niño and the concurrent rainy
33 season (Oct_n-May_{n+1}, $r=0.26$). Correlations are strongest with Jan_{n+1} ($r=0.35$), the period of

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[2] verschoben (Einfügung)

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Gelöscht: modelling

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Gelöscht: Cook et al. (2002)

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Gelöscht: when averaged over

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Gelöscht: ,Feb_{n+}

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Gelöscht: 33

1 maximum rainy season precipitation. Furthermore, there is a significant correlation with lag-1
2 January precipitation (Jan_n , $r=0.22$), indicating a WP El Niño influence on tree growth in the
3 following year. Statistically significant negative correlations were found for La Niña events in
4 January (Jan_{n+1} , $r=-0.25$) (Table 2). No positive correlation was found between the tree-ring
5 proxy and the CT ENSO index (Table 2). As noted, the CT ENSO flavor has a weaker
6 influence over Java (Fig. 1), therefore we expected the lag-0 correlation to be insignificant.
7 For reference, we also present the correlation with the standard ENSO index NINO3.4, which
8 shows no significance.

9 Although the $\delta^{18}\text{O}_{\text{TR}}$ record correlates significantly ($p<0.05$) with ENSO flavors, the response
10 is not stationary. Fig. 2 presents the running 31-year correlation and Kalman filter analysis
11 between the varying ENSO flavors and the tree-ring proxy for the period of highest
12 correlation (see Table 2). The teleconnection with Jan_{n+1} WP ENSO is strong and significantly
13 positive from the 1950s until present, with running correlations reaching 0.6, and an r of 0.45
14 for AD 1950-2007 ($p<0.001$) (Fig. 2a). However, before 1950 the correlation falls to zero,
15 and even becomes negative. The Kalman filter time-varying regression coefficients (beta
16 weights) follow the same trend as the correlation values and reinforce the time dependency of
17 the teleconnection. From 1950 onwards, the lower limits do not cross zero, which means that
18 the beta weights are considered statistically significant. However, the correlation weakens
19 slightly again in the beginning of the 21st century. The relationship with Jan_{n+1} NINO4 (used
20 here to primarily capture La Niña events) (Fig. 2c) is also time dependent with weak
21 correlations before 1950 and after 2000, but a significant negative relationship in the second
22 half of the century with $r=-0.37$ ($p<0.01$).

23 The fingerprints of the ENSO flavors in the $\delta^{18}\text{O}_{\text{TR}}$ record can be seen in the probability
24 density function (PDF) of $\delta^{18}\text{O}_{\text{TR}}$ anomalies (Fig. 3) conditioned on ENSO phase. The $\delta^{18}\text{O}_{\text{TR}}$
25 probability mass for WP El Niño is skewed towards positive anomalies associated with dry
26 conditions. By contrast, the PDF for CT El Niño events exhibits bimodality with peaks in
27 both positive and negative $\delta^{18}\text{O}_{\text{TR}}$ anomalies, suggesting this record is not a good proxy for
28 CT El Niño variability.

29 To further investigate expressions of ENSO variability in the $\delta^{18}\text{O}_{\text{TR}}$ record we performed
30 spectral analysis (Fig. 4a). Spectral analysis of the $\delta^{18}\text{O}_{\text{TR}}$ record reveals a broad peak at 2–4
31 years, falling within the classic ENSO bandwidth (Sarachik and Cane, 2010) as well as
32 significant, decadal-to-multidecadal variability (12.5 years). Wavelet coherence analysis
33 between the proxy record and the WP ENSO and CT ENSO index (Fig. 4b,c) indicates that
34 the coherence varies in time across most spectral bands. The periods of greatest coherence in

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Gelösch: and February

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Gelösch: Feb_{n+}

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Gelösch: 24

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Gelösch: El Niño flavor

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Gelösch: this El Niño

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Gelösch: JF

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Gelösch: El Niño

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Gelösch: till

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Gelösch: overall

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Gelösch: 43

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Gelösch: teleconnection

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Gelösch: JF

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Gelösch: index

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Gelösch: 38

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Gelösch:)

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Gelösch: WP

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Gelösch: The PDF for the previous (lag-1) rainy season CT El Niño (dashed line) is also skewed towards negative $\delta^{18}\text{O}_{\text{TR}}$ anomalies, similar to that of lag-0 La Niña events (blue line), supporting the idea that the lag-1 correlation reflects subsequent La Niña events.

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Gelösch: El Niño

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Gelösch:) and La Niña (Fig. 4c

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Gelösch: their

1 time occur on inter-annual timescales (2-4 years), again spanning the classic ENSO
2 bandwidth. We found no significant coherence with CT ENSO index as expected.

3

4 **4 Discussion**

5 The positive correlation pattern between the $\delta^{18}\text{O}_{\text{TR}}$ record and the WP ENSO index, as well
6 as the negative correlation with La Niña events, supports the conclusion in Schollaen et al.
7 (2013) that the formation of annual $\delta^{18}\text{O}$ in Javanese teak trees is dominated by precipitation
8 patterns. El Niño events are linked to drought conditions over the IMC coinciding with
9 increased $\delta^{18}\text{O}$ values in the tree-ring proxy (Figs 2, 3). The opposite occurs during La Niña
10 events.

11 The PDFs illustrate a clear WP El Niño and a less strong La Niña signal, with really dry years
12 linked to WP El Niños. In contrast, no clear CT El Niño signal is preserved in the $\delta^{18}\text{O}_{\text{TR}}$
13 record, as indicated by the bimodality in the corresponding PDF. The different seasonal
14 rainfall signals (wet and dry season rainfall) in the $\delta^{18}\text{O}_{\text{TR}}$ record are damped in the annually
15 resolved proxy due to seasonally alternating isotope signatures in $\delta^{18}\text{O}$ of precipitation
16 (Schollaen et al., 2013). Thus, CT El Niño signals seem to be obscured when followed by a
17 La Niña event. This is the case for the strong CT El Niño event in 1982/83 that was followed
18 by a La Niña, resulting in a low $\delta^{18}\text{O}_{\text{TR}}$ value (Fig. 2b, 2c). High-resolution intra-annual
19 $\delta^{18}\text{O}_{\text{TR}}$ analyses help to disentangle the contrasting isotope effects of dry and rainy season
20 rainfall patterns, as demonstrated in Schollaen et al. (2014). We conclude that the annually
21 resolved tree-ring proxy is suitable for distinguishing between WP El Niño and La Niña, but
22 not for CT El Niños. Correlation tests (Table 2) with a standard ENSO index (such as
23 NINO3.4) show no correlation with the tree-ring record, as this index captures mixed signals
24 from both ENSO flavors. Overall, the strongest and most significant ENSO signal in the tree-
25 ring proxy data is that of WP El Niño.

26 Our analysis shows that the teleconnections described above are not stationary (Figs 2, 4).
27 There is a drop in correlation in the first half of the 20th century. Land use change is not an
28 influencing factor as this study site is a very old forest and for the last few decades, a
29 protected area. One can speculate this weakening teleconnection is related to the pattern of
30 relatively weak and irregular ENSO activity in the middle of the 20th century (Tudhope et al.,
31 2001). Arguably, there may be other factors (e.g. Indian Ocean Dipole Mode) determining
32 wetter or drier conditions in this period and the ENSO phenomenon may play a secondary
33 role. In recent decades, a climate regime transition has preceded periods of strong and

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Gelöscht: El Niño flavor

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Gelöscht: illustrates the uncertainty in cases with no strong signal

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Gelöscht: experiments show

1 sustained ENSO events (e.g. O'Kane et al., 2014), leading to a stronger ENSO fingerprint in
2 the $\delta^{18}\text{O}_{\text{TR}}$ record. Furthermore, Chang et al. (2004) reveal an interdecadal trend of increasing
3 correlations between Indonesian monsoon rainfall and ENSO beginning in the late 1970s.

4 The $\delta^{18}\text{O}_{\text{TR}}$ record is a rainfall indicator for wet and dry season rainfall, albeit largely
5 dominated by the wet season signal (Schollaen et al., 2013). Note, that the "amount effect"
6 leads to different isotopic signatures in $\delta^{18}\text{O}_{\text{TR}}$ values during wet and dry season. Thus, the
7 dry season rainfall signal, which tends to have the highest coherence with ENSO, is damped
8 in the annually resolved $\delta^{18}\text{O}_{\text{TR}}$ record by the following wet season signal. This may explain
9 the low correlation between the tree-ring proxy and June to November ENSO indices. To
10 distinguish the causes of inter-annual rainfall variability across Java future work needs to
11 focus on high-resolution $\delta^{18}\text{O}_{\text{TR}}$ records.

12 5 Conclusions

13 In this study we used a $\delta^{18}\text{O}_{\text{TR}}$ chronology from teak (*Tectona grandis*) that correlates
14 significantly with regional precipitation over Java (Schollaen et al., 2013) to examine various
15 manifestations of ENSO. This is the first time a high-resolution $\delta^{18}\text{O}_{\text{TR}}$ record is used to
16 detect signals of ENSO flavors in palaeoclimatic data as argued by Karamperidou et al.
17 (2015). These results indicate the potential for generating reconstructions of different ENSO
18 flavors from high-resolution intra-annual $\delta^{18}\text{O}$ records from appropriately selected regions,
19 such as Java. Such palaeoclimatic records may help answer the many remaining questions
20 surrounding the diversity of ENSO activity and past ENSO variability. In addition, the
21 conclusions of our study call for caution when attempting to interpret proxy records using
22 ENSO indices that are not able to distinguish between the two flavors (e.g. single standard
23 indices such as NINO3.4). As shown here, single ENSO indices may capture mixed signals
24 from both flavors, resulting in lower correlations with proxies and thus confounding
25 paleoclimate reconstruction attempts. Furthermore, performing model-proxy comparisons
26 using single ENSO indices may be misleading. For example, in multi-proxy reconstructions
27 where proxies from different regions can be synthesized to reconstruct past ENSO variability
28 it is important to account for the distinct (and often of opposite sign) influence of two flavors:
29 convoluting their signals by using a single ENSO index can lead to potential misinterpretation
30 of significant changes in past ENSO variability, as in the case of mid-Holocene (6ka BP)
31 coral proxies from the central Pacific (Karamperidou et al., 2015).

32 Last, our study calls for more

33 6

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[3] verschoben (Einfügung)

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[4] verschoben (Einfügung)

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[1] nach oben verschoben: Several analyses of Indonesian rain gauge data show that Indonesian rainfall is poorly correlated with ENSO events during the wet monsoon season, but reveal highest coherence during the dry season and transition months prior to the wet season (June to November) (Haylock and McBride, 2001; Hendon, 2003).

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Gelöscht: This is especially true for January, which has consistently insignificant correlations over Indonesia (1979–2002) (Chang et al., 2004). However, taking the IMC and surrounding oceanic rainfall into account, rainfall during the wet season is related to ENSO (see Fig. 8a in Jourdain et al. (2013) and Fig. 1 of this study). The $\delta^{18}\text{O}_{\text{TR}}$ record is a rainfall indicator for wet and dry season rainfall, albeit largely dominated by the wet season signal (Schollaen et al., 2013)

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[3] nach oben verschoben: . Note, that the "amount effect" leads to different isotopic signatures in $\delta^{18}\text{O}_{\text{TR}}$ values during wet and dry season. Thus, the dry season rainfall signal, which tends to have the highest coherence with ENSO, is damped in the annually resolved $\delta^{18}\text{O}_{\text{TR}}$ record by the following wet season signal. This may explain the low correlation between the tree-ring proxy and June to November ENSO indices. To distinguish the causes of inter-annual rainfall variability across Java future work needs to focus on high-resolution $\delta^{18}\text{O}_{\text{TR}}$ records.

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[4] nach oben verschoben: Conclusions
In this study we used a $\delta^{18}\text{O}_{\text{TR}}$ chronology from teak (*Tectona grandis*) that correlates significantly with regional precipitation over Java

1 emphasis on sampling long-term terrestrial $\delta^{18}\text{O}_{\text{TR}}$ records at seasonal and monthly resolution
2 from selected regions such as northern or eastern Indonesia. Such high-resolution terrestrial
3 $\delta^{18}\text{O}_{\text{TR}}$ records may have stronger correlations with ENSO flavors, and thus be appropriate for
4 robust reconstructions of wet and dry season rainfall and of past variability of the two ENSO
5 flavors.

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Gelöscht: (Schollaen et al., 2013) to examine various manifestations of ENSO. This is the first time a high-resolution $\delta^{18}\text{O}_{\text{TR}}$ record is used to detect signals of ENSO flavors in palaeoclimatic data as argued by Karamperidou et al. (submitted). These results indicate the significant potential for generating reconstructions of different ENSO flavors from the $\delta^{18}\text{O}_{\text{TR}}$ records in Indonesian teak. Such palaeoclimatic records may help answering the many remaining questions surrounding the diversity of ENSO activity. In addition, the conclusions of our study call for caution when doing model-proxy comparisons using ENSO indices that are not able to distinguish between the two flavors (e.g. single standard indices such as NINO3.4). Performing such comparisons may confound attempts to reconcile models with proxy ... [1]

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Gelöscht: is needed

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Gelöscht: to reveal a

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Gelöscht: reconstruction

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Gelöscht: with its teleconnection to

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Gelöscht: different

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[5] verschoben (Einfügung)

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[5] nach oben verschoben: We acknowledge the Bolin Centre's, Climate Research Summer School during which this project and collaboration was conceived.

1 **References**

- 2 Abram, N. J., Gagan, M. K., Cole, J. E., Hantoro, W. S., and Mudelsee, M.: Recent
3 intensification of tropical climate variability in the Indian Ocean, *Nature Geosci*, 1, 849-853,
4 2008.
- 5 Adler, R. F., Huffman, G. J., Chang, A., Ferraro, R., Xie, P.-P., Janowiak, J., Rudolf, B.,
6 Schneider, U., Curtis, S., Bolvin, D., Gruber, A., Susskind, J., Arkin, P., and Nelkin, E.: The
7 Version-2 Global Precipitation Climatology Project (GPCP) Monthly Precipitation Analysis
8 (1979–Present), *Journal of Hydrometeorology*, 4, 1147-1167, 2003.
- 9 Aldrian, E., Dümenil Gates, L., and Widodo, F. H.: Seasonal variability of Indonesian rainfall
10 in ECHAM4 simulations and in the reanalyses: The role of ENSO, *Theoretical and Applied
11 Climatology*, 87, 41-59, 2007.
- 12 Aldrian, E. and Susanto, R. D.: Identification of three dominant rainfall regions within
13 Indonesia and their relationship to sea surface temperature, *International Journal of
14 Climatology*, 23, 1435-1452, 2003.
- 15 Allan, J. R.: ENSO and Climatic Variability in the Past 150 Years. In: *El Niño and the
16 Southern Oscillation: Multiscale Variability and Global and Regional Impacts*, Diaz, H. F.
17 and Markgraf, V. (Eds.), Cambridge University Press, 2000.
- 18 Araguás-Araguás, L., Froehlich, K., and Rozanski, K.: Deuterium and oxygen-18 isotope
19 composition of precipitation and atmospheric moisture, *Hydrological Processes*, 14, 1341-
20 1355, 2000.
- 21 Ashok, K., Behera, S. K., Rao, S. A., Weng, H., and Yamagata, T.: El Niño Modoki and its
22 possible teleconnection, *Journal of Geophysical Research: Oceans*, 112, C11007, 2007.
- 23 Ashok, K. and Yamagata, T.: Climate change: The El Niño with a difference, *Nature*, 461,
24 481-484, 2009.
- 25 Barbour, M. M.: Stable oxygen isotope composition of plant tissue: a review, *Functional Plant
26 Biology*, 34, 83-94, 2007.
- 27 Braganza, K., Gergis, J. L., Power, S. B., Risbey, J. S., and Fowler, A. M.: A multiproxy
28 index of the El Niño–Southern Oscillation, A.D. 1525–1982, *Journal of Geophysical
29 Research: Atmospheres*, 114, D05106, 2009.
- 30 Brienen, R. J. W., Helle, G., Pons, T. L., Guyot, J. L., and Gloor, M.: Oxygen isotopes in tree
31 rings are a good proxy for Amazon precipitation and El Niño–Southern Oscillation variability,
32 *Proceedings of the National Academy of Sciences*, 109, 16957-16962, 2012.
- 33 Chang, C. P., Wang, Z., Ju, J., and Li, T.: On the Relationship between Western Maritime
34 Continent Monsoon Rainfall and ENSO during Northern Winter, *J. Clim.*, 17, 665-672, 2004.
- 35 Charles, C. D., Cobb, K., Moore, M. D., and Fairbanks, R. G.: Monsoon–tropical ocean
36 interaction in a network of coral records spanning the 20th century, *Marine Geology*, 201,
37 207-222, 2003.
- 38 [Clement, A. C., Seager, R., and Murtugudde, R.: Why Are There Tropical Warm Pools?, *J.*
39 *Clim.*, 18, 5294-5311, 2005.](#)
- 40 Cobb, K. M., Westphal, N., Sayani, H. R., Watson, J. T., Di Lorenzo, E., Cheng, H., Edwards,
41 R. L., and Charles, C. D.: Highly Variable El Niño–Southern Oscillation Throughout the
42 Holocene, *Science*, 339, 67-70, 2013.
- 43 Collins, M., An, S.-I., Cai, W., Ganachaud, A., Guilyardi, E., Jin, F.-F., Jochum, M.,
44 Lengaigne, M., Power, S., Timmermann, A., Vecchi, G., and Wittenberg, A.: The impact of
45 global warming on the tropical Pacific Ocean and El Niño, *Nature Geosci*, 3, 391-397, 2010.
- 46 Cook, E. R., D'Arrigo, R. D., and Mann, M. E.: A Well-Verified, Multiproxy Reconstruction
47 of the Winter North Atlantic Oscillation Index since A.D. 1400*, *J. Clim.*, 15, 1754-1764,
48 2002.
- 49 Cook, E. R., Palmer, J. G., Ahmed, M., Woodhouse, C. A., Fenwick, P., Zafar, M. U., Wahab,
50 M., and Khan, N.: Five centuries of Upper Indus River flow from tree rings, *Journal of
51 Hydrology*, 486, 365-375, 2013.

1 Coster, C.: Zur Anatomie und Physiologie der Zuwachszonen- und Jahresringbildung in den
2 Tropen, *Ann. Jard. Bot. Buitenzong*, 38, 1-114, 1928.
3 Coster, C.: Zur Anatomie und Physiologie der Zuwachszonen- und Jahresringbildung in den
4 Tropen, *Ann. Jard. Bot. Buitenzong*, 37, 49-160, 1927.
5 D'Arrigo, R., Cook, E. R., Wilson, R. J., Allan, R., and Mann, M. E.: On the variability of
6 ENSO over the past six centuries, *Geophys. Res. Lett.*, 32, L03711, 2005.
7 D'Arrigo, R., Wilson, R., Palmer, J., Krusic, P., Curtis, A., Sakulich, J., Bijaksana, S.,
8 Zulaikah, S., Ngkoimani, L. O., and Tudhope, A.: The reconstructed Indonesian warm pool
9 sea surface temperatures from tree rings and corals: Linkages to Asian monsoon drought and
10 El Niño–Southern Oscillation, *Paleoceanography*, 21, PA3005, 2006.
11 Emile-Geay, J., Cobb, K. M., Mann, M. E., and Wittenberg, A. T.: Estimating Central
12 Equatorial Pacific SST Variability over the Past Millennium. Part II: Reconstructions and
13 Implications, *J. Clim.*, 26, 2329-2352, 2013.
14 Evans, M. N., Kaplan, A., and Cane, M. A.: Pacific sea surface temperature field
15 reconstruction from coral $d^{18}O$ data using reduced space objective analysis,
16 *Paleoceanography*, 17, 7-1-7-13, 2002.
17 Fowler, A. M., Boswijk, G., Lorrey, A. M., Gergis, J., Pirie, M., McCloskey, S. P. J., Palmer,
18 J. G., and Wunder, J.: Multi-centennial tree-ring record of ENSO-related activity in New
19 Zealand, *Nature Clim. Change*, 2, 172-176, 2012.
20 Geiger, F.: Anatomische Untersuchungen über die Jahresringbildung von *Tectona grandis*. In:
21 *Jahrbücher für wissenschaftliche Botanik*, Pfeffer, W. (Ed.), 1915.
22 Grinsted, A., Moore, J. C., and Jevrejeva, S.: Application of the cross wavelet transform and
23 wavelet coherence to geophysical time series, *Nonlin. Processes Geophys.*, 11, 561-566,
24 2004.
25 Haylock, M. and McBride, J.: Spatial Coherence and Predictability of Indonesian Wet Season
26 Rainfall, *J. Clim.*, 14, 3882-3887, 2001.
27 Hendon, H. H.: Indonesian Rainfall Variability: Impacts of ENSO and Local Air-Sea
28 Interaction, *J. Clim.*, 16, 1775-1790, 2003.
29 Jourdain, N., Gupta, A., Taschetto, A., Ummenhofer, C., Moise, A., and Ashok, K.: The Indo-
30 Australian monsoon and its relationship to ENSO and IOD in reanalysis data and the
31 CMIP3/CMIP5 simulations, *Climate Dynamics*, 41, 3073-3102, 2013.
32 Kao, H.-Y. and Yu, J.-Y.: Contrasting Eastern-Pacific and Central-Pacific Types of ENSO, *J.*
33 *Clim.*, 22, 615-632, 2009.
34 Kaplan, A., Cane, M., Kushnir, Y., Clement, A., Blumenthal, M., and Rajagopalan, B.:
35 Analyses of global sea surface temperature 1856–1991, *Journal of Geophysical Research-*
36 *Oceans*, 103, 18567-18589, 1998.
37 Karamperidou, C., Di Nezio, P. N., Timmermann, A., Jin, F.-F., and Cobb, K. M.: The
38 response of ENSO flavors to mid-Holocene climate: Implications for proxy interpretation,
39 [Paleoceanography](#), 30, 527-547, 2015.
40 Kug, J.-S. and Ham, Y.-G.: Are there two types of La Nina?, *Geophysical Research Letters*,
41 38, L16704, 2011.
42 Kug, J.-S., Jin, F.-F., and An, S.-I.: Two Types of El Niño Events: Cold Tongue El Niño and
43 Warm Pool El Niño, *J. Clim.*, 22, 1499-1515, 2009.
44 Kumar, K. K., Rajagopalan, B., Hoerling, M., Bates, G., and Cane, M.: Unraveling the
45 Mystery of Indian Monsoon Failure During El Niño, *Science*, 314, 115-119, 2006.
46 Larkin, N. K. and Harrison, D. E.: On the definition of El Niño and associated seasonal
47 average U.S. weather anomalies, *Geophysical Research Letters*, 32, L13705, 2005.
48 Lau, N.-C. and Nath, M. J.: Impact of ENSO on the Variability of the Asian–Australian
49 Monsoons as Simulated in GCM Experiments, *J. Clim.*, 13, 4287-4309, 2000.
50 Lee, T. and McPhaden, M. J.: Increasing intensity of El Niño in the central-equatorial Pacific,
51 *Geophys. Res. Lett.*, 37, L14603, 2010.

Karina Schollaen 14/8/2015 20:32

Gelöscht: Palaeoceanography, submitted.
submitted

1 Linsley, B. K., Wellington, G. M., Schrag, D. P., Ren, L., Salinger, M. J., and Tudhope, A.
2 W.: Geochemical evidence from corals for changes in the amplitude and spatial pattern of
3 South Pacific interdecadal climate variability over the last 300 years, *Climate Dynamics*, 22,
4 1-11, 2004.

5 Mann, M. E., Gille, E., Overpeck, J., Gross, W., Bradley, R. S., Keimig, F. T., and Hughes,
6 M. K.: Global Temperature Patterns in Past Centuries: An Interactive Presentation, *Earth
7 Interactions*, 4, 1-1, 2000.

8 McCarroll, D. and Loader, N. J.: Stable isotopes in tree rings, *Quaternary Science Reviews*,
9 23, 771-801, 2004.

10 McPhaden, M. J., Lee, T., and McClurg, D.: El Niño and its relationship to changing
11 background conditions in the tropical Pacific Ocean, *Geophysical Research Letters*, 38,
12 L15709, 2011.

13 Newman, M., Shin, S.-I., and Alexander, M. A.: Natural variation in ENSO flavors,
14 *Geophysical Research Letters*, 38, L14705, 2011.

15 O'Kane, T. J., Matear, R. J., Chamberlain, M. A., and Oke, P. R.: ENSO regimes and the late
16 1970's climate shift: The role of synoptic weather and South Pacific ocean spiciness, *Journal
17 of Computational Physics*, 271, 19-38, 2014.

18 Pfeiffer, M., Dullo, W.-C., Zinke, J., and Garbe-Schönberg, D.: Three monthly coral Sr/Ca
19 records from the Chagos Archipelago covering the period of 1950–1995 A.D.: reproducibility
20 and implications for quantitative reconstructions of sea surface temperature variations,
21 *International Journal of Earth Sciences*, 98, 53-66, 2009.

22 [Pierrehumbert, R. T.: Thermostats, Radiator Fins, and the Local Runaway Greenhouse,
23 *Journal of the Atmospheric Sciences*, 52, 1784-1806, 1995.](#)

24 Quinn, T. M., Taylor, F. W., and Crowley, T. J.: Coral-based climate variability in the
25 Western Pacific Warm Pool since 1867, *Journal of Geophysical Research: Oceans*, 111,
26 C11006, 2006.

27 Ren, H.-L. and Jin, F.-F.: Niño indices for two types of ENSO, *Geophysical Research Letters*,
28 38, L04704, 2011.

29 Sano, M., Xu, C., and Nakatsuka, T.: A 300-year Vietnam hydroclimate and ENSO variability
30 record reconstructed from tree ring $\delta^{18}\text{O}$, *Journal of Geophysical Research*, 117, D12115,
31 2012.

32 Sarachik, E. S. and Cane, M. A.: *The El Niño-Southern Oscillation Phenomenon*, Cambridge
33 University Press, London, 2010.

34 Schollaen, K., Heinrich, I., and Helle, G.: UV-laser-based microscopic dissection of tree rings
35 – a novel sampling tool for $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ studies, *New Phytologist*, 201, 1045-1055, 2014.

36 Schollaen, K., Heinrich, I., Neuwirth, B., Krusic, P. J., D'Arrigo, R. D., Karyanto, O., and
37 Helle, G.: Multiple tree-ring chronologies (ring width, $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$) reveal dry and rainy
38 season signals of rainfall in Indonesia, *Quaternary Science Reviews*, 73, 170-181, 2013.

39 Schulman, E.: *Dendroclimatic Change in Semiarid America*, University of Arizona Press,
40 Tuscon, Arizona, 1956.

41 Schulz, M. and Mudelsee, M.: REDFIT: estimating red-noise spectra directly from unevenly
42 spaced paleoclimatic time series, *Computers & Geosciences*, 28, 421-426, 2002.

43 Stahle, D. W., Cleaveland, M. K., Therrell, M. D., Gay, D. A., D'Arrigo, R. D., Krusic, P. J.,
44 Cook, E. R., Allan, R. J., Cole, J. E., Dunbar, R. B., Moore, M. D., Stokes, M. A., Burns, B.
45 T., Villanueva-Diaz, J., and Thompson, L. G.: Experimental Dendroclimatic Reconstruction
46 of the Southern Oscillation, *Bulletin of the American Meteorological Society*, 79, 2137–2152,
47 1998.

48 Takahashi, K., Montecinos, A., Goubanova, K., and Dewitte, B.: ENSO regimes:
49 Reinterpreting the canonical and Modoki El Niño, *Geophysical Research Letters*, 38, L10704,
50 2011.

51 Taschetto, A. S. and England, M. H.: El Niño Modoki impacts on Australian rainfall, *J. Clim.*,
52 22, 3167-3174, 2009.

1 Torrence, C. and Compo, G. P.: A Practical Guide to Wavelet Analysis, Bulletin of the
2 American Meteorological Society, 79, 61-78, 1998.
3 Tudhope, A. W., Chilcott, C. P., McCulloch, M. T., Cook, E. R., Chappell, J., Ellam, R. M.,
4 Lea, D. W., Lough, J. M., and Shimmield, G. B.: Variability in the El Niño - Southern
5 oscillation through a glacial-interglacial cycle, Science, 291, 1511-1517, 2001.
6 Visser, H. and Molenaar, J.: Kalman Filter Analysis in Dendroclimatology, Biometrics, 44,
7 929-940, 1988.
8 Wheeler, M. C. and McBride, J. L.: Australian-Indonesian monsoon. In: Intraseasonal
9 Variability in the Atmosphere-Ocean Climate System, Springer Praxis Books, Springer Berlin
10 Heidelberg, 2005.
11 Wilson, R., Cook, E., D'Arrigo, R., Riedwyl, N., Evans, M. N., Tudhope, A., and Allan, R.:
12 Reconstructing ENSO: the influence of method, proxy data, climate forcing and
13 teleconnections, Journal of Quaternary Science, 25, 62-78, 2010.
14 Wilson, R., Miles, D., Loader, N., Melvin, T., Cunningham, L., Cooper, R., and Briffa, K.: A
15 millennial long March-July precipitation reconstruction for southern-central England,
16 Climate Dynamics, 40, 997-1017, 2013.
17 Wilson, R., Tudhope, A., Brohan, P., Briffa, K., Osborn, T., and Tett, S.: Two-hundred-fifty
18 years of reconstructed and modeled tropical temperatures, Journal of Geophysical Research:
19 Oceans, 111, C10007, 2006.
20 Yeh, S.-W., Kug, J.-S., Dewitte, B., Kwon, M.-H., Kirtman, B. P., and Jin, F.-F.: El Niño in a
21 changing climate, Nature, 461, 511-514, 2009.
22 | Zhu, M., Stott, L., Buckley, B., Yoshimura, K., and Ra, K.: Indo-Pacific Warm Pool
23 convection and ENSO since 1867 derived from Cambodian pine tree cellulose oxygen
24 isotopes, Journal of Geophysical Research, 117, D11307, 2012.
25

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Gelösch: Yulihastin, E., Febrianti, N., and Trismidianto: Impact of El Niño and IOD on the Indonesian Climate, National Institute of Aeronautics and Space (Lapan), Indonesia, 2010. -

- 1 | Table 1. Classification into ENSO flavors and phase based on Jan_{n+1} values (see section 2.2).
 2 | Note the use of the southern hemisphere convention (Schulman, 1956), i.e. year n refers to
 3 | Jan_{n+1} .

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 Gelöscht: JF

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 Gelöscht: Feb_{n+1}

ENSO classification	Years										
WP	1900	1902	1904	1907	1913	1927	1929	1939	1941	1957	1958
	1968	1978	1979	1987	1990	1994	2001	2002	2003	2004	
CT	1905	1911	1914	1918	1919	1923	1925	1930	1940	1965	1972
	1976	1982	1986	1991	1997						
LN	1909	1916	1917	1920	1924	1933	1938	1942	1949	1955	1970
	1973	1975	1983	1988	1998	1999	2000	2005	2007		

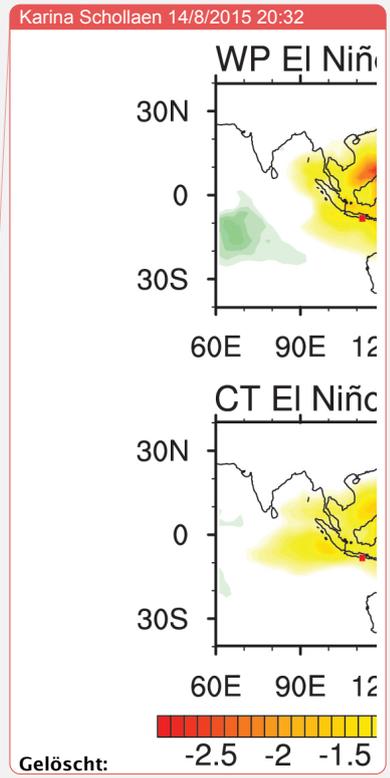
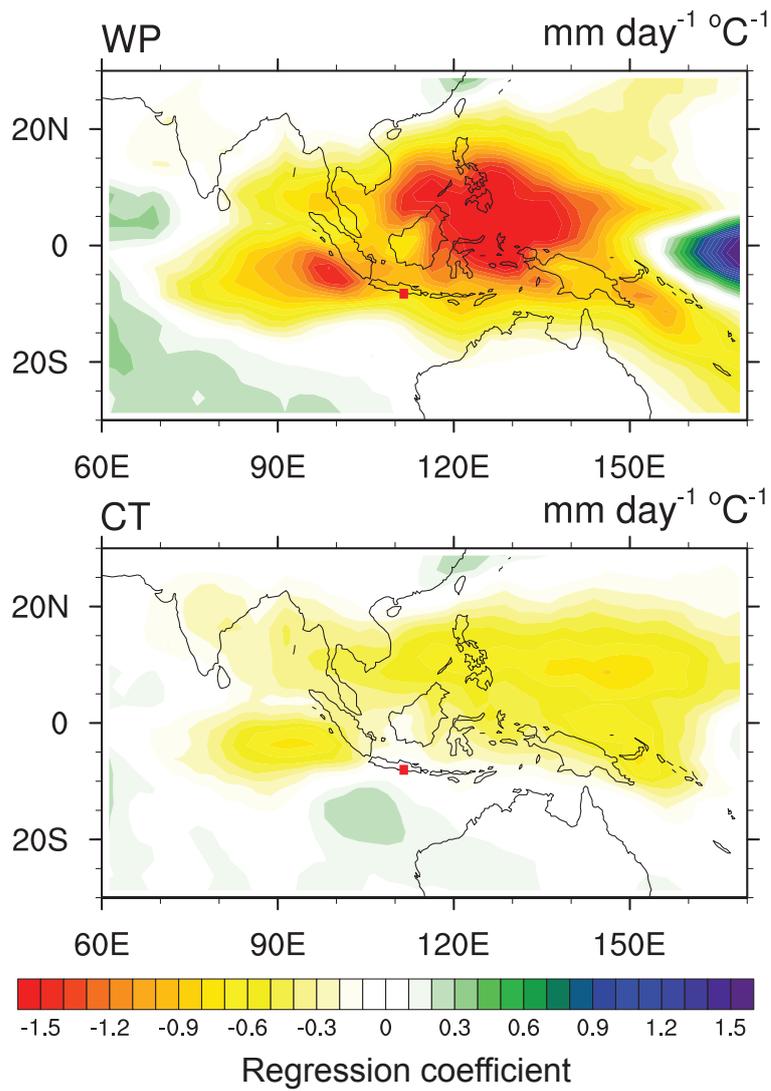
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1 Table 2. Correlation values between the annually resolved $\delta^{18}\text{O}_{\text{TR}}$ record and climate months
 2 of different ENSO flavors and the standard NINO3.4 and La Niña index (NINO4*(-1)) for the
 3 period from the year prior to growth (lag-1) to the current year (lag-0) and seasonal means
 4 (calculated over the 1900-2007 period). (**: $p < 0.001$, *: $p < 0.01$, bold: $p < 0.05$).

Climate months	WP El Niño	CT El Niño	NINO3.4	La Niña
<i>lag-1 lag-0</i>				
Oct _{n-1} Oct _n	0.12 0.21	-0.18 -0.03	-0.10 0.08	0.00 -0.14
Nov _{n-1} Nov _n	0.17 0.17	-0.23 -0.01	-0.13 0.05	0.00 -0.12
Dec _{n-1} Dec _n	0.18 0.18	-0.20 0.04	-0.11 0.10	-0.01 -0.15
Jan _n Jan _{n+1}	0.22 0.35**	-0.19 -0.01	-0.07 0.12	-0.06 -0.25*
Feb _n Feb _{n+1}	0.15 0.29*	-0.15 -0.06	-0.07 0.09	-0.05 -0.21
Mar _n Mar _{n+1}	0.05 0.21	-0.17 -0.12	-0.10 0.02	0.03 -0.12
Apr _n Apr _{n+1}	0.14 0.21	-0.21 -0.09	-0.12 0.01	-0.02 -0.15
May _n May _{n+1}	0.12 0.20	-0.14 -0.11	-0.06 -0.01	-0.03 -0.12
Jun _n Jun _{n+1}	0.14 0.08	-0.07 -0.06	0.00 -0.03	-0.08 -0.03
Jul _n Jul _{n+1}	0.12 0.16	-0.02 -0.08	0.05 -0.03	-0.09 -0.10
Aug _n Aug _{n+1}	0.11 0.10	-0.02 -0.07	0.07 -0.03	-0.10 -0.05
Sep _n Sep _{n+1}	0.17 0.01	-0.05 -0.05	0.03 -0.06	-0.11 0.02
peak wet season (Jan _{n-4})	0.35**			-0.25*
Dec _n -Feb _{n+1}	0.27*			-0.21
wet season (Oct _n -May _{n+1})	0.26*			

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Eingefügte Zellen
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Gelöscht: lag-1 lag-0
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Eingefügte Zellen
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Eingefügte Zellen
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Gelöscht: Feb_n
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Gelöscht: 33**
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Gelöscht: -0.24
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Eingefügte Zellen

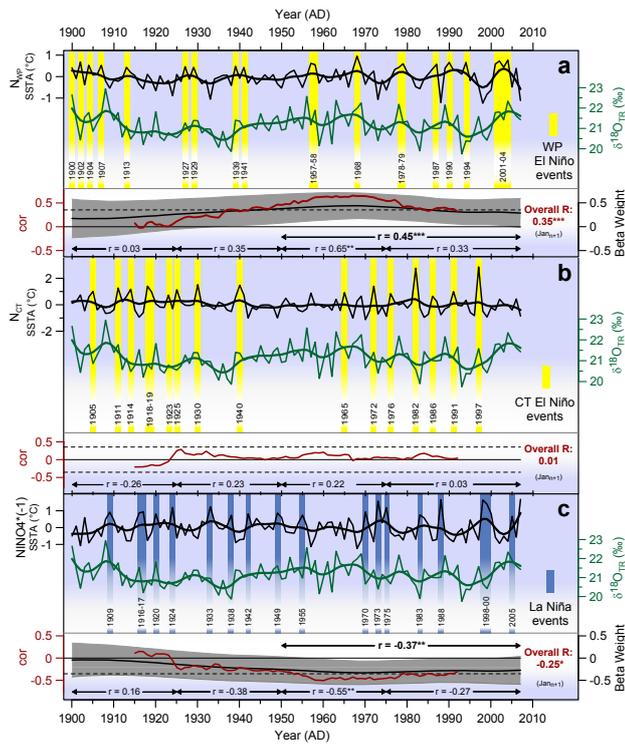


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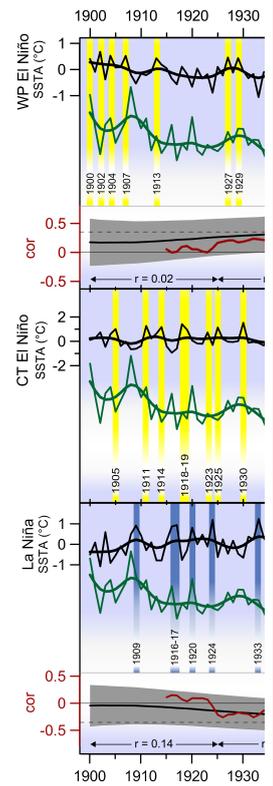
Figure 1. Regression coefficients ($\text{mm day}^{-1} \text{ } ^\circ\text{C}^{-1}$) of monthly precipitation on the Warm Pool (WP) and the Cold Tongue (CT) ENSO index. The two indices are computed as per Ren and Jin (2011) (1). Precipitation data are from the GPCP (Adler et al., 2003), for the period 1987-2010. The tree-ring site is marked with a red square.

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Gelöscht: El Niño

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Gelöscht: squared



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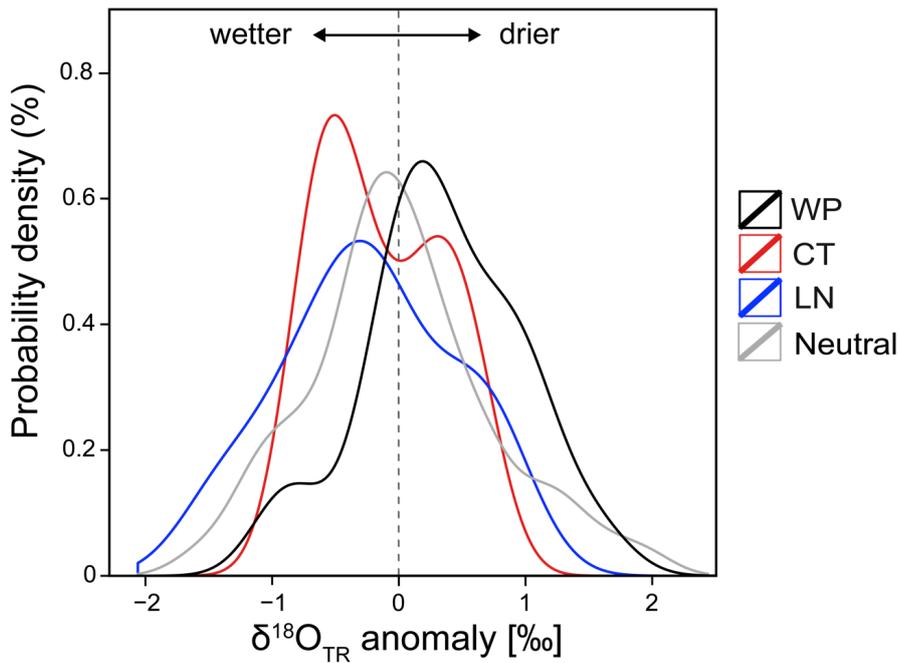
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Gelösch: to February ...Jan_{n+1}Feb_{n+1}... [2]

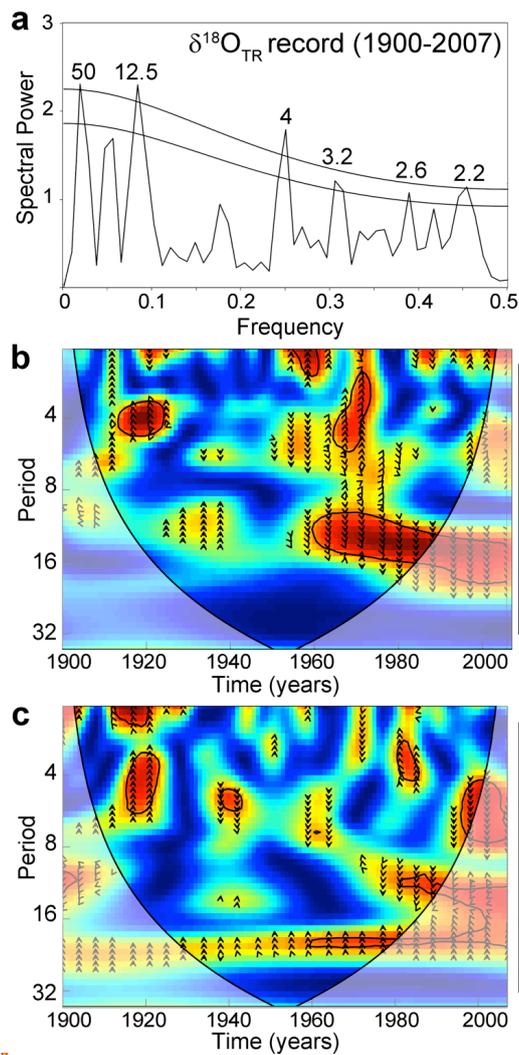
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Figure 2. Time series of the $\delta^{18}\text{O}_{\text{TR}}$ chronology (green) and the January (Jan_{n+1}) indices of (a) Warm Pool ENSO (N_{WP}), (b) Cold Tongue ENSO (N_{CT}), and (c) negative NINO4 index ($\text{NINO4}^*(-1)$, used here as a La Niña index). The WP and CT ENSO indices are computed as per Ren and Jin (2011) (1). Thick lines denote 10-year cubic smoothing spline. In the lower part of each figure the running 31-year correlation (red) is shown. Dashed horizontal line indicates the 95% confidence level. Also shown are the results from a Kalman filter analysis (black line) used as a dynamic regression modeling tool. Grey shading denotes ± 2 standard error limits of the beta weights. Where the limits do not cross zero, the regression relationship are considered statistically significant ($p=95\%$). ENSO events based on classification of Table 1 are highlighted in yellow (El Niño) and blue (La Niña), respectively. (** $p < 0.01$, *** $p < 0.001$, * $p < 0.05$).



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 2 Figure 3. Probability density function of tree-ring $\delta^{18}\text{O}$ variability conditional on different
 3 ENSO phases: Warm Pool El Niño (WP, black line), Cold Tongue El Niño (CT, red line), La
 4 Niña (LN, blue line) and neutral conditions (grey line). For the construction of the PDF, we
 5 use January-February ($\text{Jan}_{n+1}\text{Feb}_{n+1}$) time-averaged values; the events considered for each
 6 conditional PDF are shown in Table 1.

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Figure 4. (a) Spectral analysis (Schulz and Mudelsee, 2002) of the $\delta^{18}\text{O}_{\text{TR}}$ chronology from 1900 to 2007. 90% and 95% confidence levels are indicated. (b) Wavelet coherence transform comparing shared variance as a function of frequency between $\delta^{18}\text{O}_{\text{TR}}$ record and Warm Pool (WP) ENSO index (Jan_{n+1}) and (c) Cold Tongue (CT) ENSO index (Jan_{n+1}) for 1900 to 2007. The wavelet coherence illustrating temporal frequency coherence between the time series at given periods. The thick black contour designates where time series share significant coherence ($p=95\%$) and the cone of influence where edge effects might distort the picture is shown as a lighter shade. Arrows indicate the phase relationship between series with in-phase pointing right and antiphase pointing left.

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