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Interactive comment on "On the spatial and temporal variability of ENSO precipitation and drought teleconnection in mainland Southeast Asia" *by* T. A. Räsänen et al.

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Dear editor and referees,

We are pleased to receive such constructive comments. They point out shortcomings in the current version of the manuscript and addressing the comments helps us to improve the manuscript, in particular with regard to clarification of: the seasonal representativeness of the proxy Palmer Drought Severity Index (PDSI) data; the new findings; and the relationship between the precipitation and proxy PDSI analyses. In the following we give a detailed response to all comments from Referee 1 and Referee 2.

Referee 1 comments and author responses

General comments: I enjoyed reading this carefully written and highly relevant manuscript. The authors clearly state their objectives (improving the understanding of the ENSO-MSEA teleconnection by looking into proxy and instrumental record for a long time-span). Their methodology is well structured and they apply state-of-the-art techniques for detecting correlations, synchronized periodic behaviour or frequencies with significant coherence.

I have nonetheless a major comment regarding one of their conclusions and in general the way the authors refer to dry and wet "years". Most of the times they are referring to dry or wet MAM seasons. I explain my concerns below in detail.

Major comment: The authors state in the conclusions that "ENSO has affected the region's hydroclimate over the majority (96 %) of the 355 year study period". Though there is evidence of a recurring monsoon-ENSO link, this statement seems to be a bit abusive in the light of the results of your manuscript. It would seem that the MAM(1)-ENSO correlation is valid for the whole rainy season, which is not true, as you show in e.g. Figure 2. In fact, what would arguably define a year of drought in most part of MSEA is the failure of the monsoon in JJA, not whether it rained more or less in March-April-May. By looking at Figure 2, I would say that ENSO does not correlate strongly with JJA – meaning that it would be irrelevant for the bulk of the water supply to the Tonle Sap, for flooding the rice paddies in the Mekong delta, for bringing water to the flood plains of Laos or even irrigating the rain-fed agriculture of comparatively drier northeast Thailand. By saying that "ENSO has affected the region's hydroclimate over the majority (96 %) of the 355 year study period", you are extrapolating your results to the whole rainy season. Another way how to put it is "how representative is MAM of the rainy season?" I suggest carefully handling this issue throughout the paper before it being considered for publishing. In my view, the paper per se is worth publishing even if the results sound weaker (a dry MAM season vs. a dry year). A more moderate language concerning the results and conclusions won't be as appealing as

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the current version of the manuscript, but it will certainly be truer and still of great value. I encourage you to address this issue not only in the conclusions, but also in the "results" section (section 3)

Response to Referee 1: Thank you for the encouraging and constructive comments! We agree with the referee's major comment and are pleased that the referee brought this up. Our intention was not to claim that the proxy PDSI for MAM season is representative for the whole rainy season, so the framing of our findings and conclusion clearly needs clarification. The referee suggests revising our manuscript so that the text in results and conclusions section better reflect what the analyses truly reveal. In other words, it should be clarified that our results concern the MAM season and not the whole rainy season. We fully agree with the reviewer and we will revise our manuscript accordingly.

The referee also suggests looking at "how representative is MAM of the rainy season. To test this, we now conducted a correlation analysis for MAM and JJA precipitation in the areas of PDSIBDFH and PDSIMCC (see areas in Figure 1 of the manuscript) and did not find a statistically significant correlation between the two seasons. This provides evidence to support our intuition, and the reviewer's argument, that results for MAM do not necessarily apply to the latter part of the rainy season.

However, we do not feel that having results that apply to the whole rainy season would necessarily have strengthened the results – it is MAM that we are in fact interested in when it comes to long-term ENSO teleconnection in Mainland Southeast Asia (MSEA). In the following, we argue that MAM is an appropriate season for analysis scientifically, biophysically and societally.

In terms of hydrology, MAM is the appropriate season for detecting ENSO signal in MSEA. Our analyses revealed that the correlation between ENSO and precipitation in MSEA was strongest and statistically significant over largest area in MSEA during the MAM season compared to other seasons.

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Moreover, the proxy PDSI data is most accurate for the MAM season. The tree-ring data has strongest correlation with instrumental PDSI data and provide best verification results for the MAM season (Buckley et al., 2010;Sano et al., 2008).

Given that precipitation in MAM provides strongest correlation with ENSO and proxy PDSI is most accurate for MAM, we consider that our current approach focusing on the MAM season is the most suitable for detecting and analysing variations in the long-term ENSO teleconnection in MSEA.

It should not be forgotten that hydrologically MAM is also an important season, not just the monsoon season proper (JJA). MAM is the transition period from dry to wet season when the monsoon precipitation gradually starts (Adamson and Bird, 2010). The increase in the rainfall after the dry season is observed already in April, but it is commonly considered that the wet monsoon starts in early- to mid-May. In addition, our analyses showed that, in the area of PDSIBDFH, the MAM precipitation is 17% of the annual precipitation while for the area of PDSIMCC this is 22%. A dry MAM contributes to moisture deficit that has accumulated during the dry season and thus extends the length of the dry season. This can lead to a drought situation, especially if the monsoon rains of the previous year end early. Räsänen and Kummu (2013) also shows for the Mekong River that during the decay year of the El Niño the flood period is delayed, and during La Niña, advanced.

MAM is also the beginning of the sowing season of rainfed rice in many areas (see e.g. Sawano et al., 2008) and the conditions of the early monsoon affect the transplanting of rice and thus the productivity of the crops (Fukai et al., 1998).

We will include the preceding justification for focusing on MAM season in our revised manuscript. We thank the referee again for pointing out this important framing issue.

Referee 2 comments and author responses

General comment: It is quite important to understand the linkages between ENSO

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and regional climates, which can shed lights on projection of future climate changes. This paper used both of the observational and reconstructed data to study the spatial and temporal linkages between them. The results are sound. I agree with publication after major revision.

Response to general comment: Thank you for the constructive review comments! They help us to improve the manuscript.

Major comment 1: It is very important to highlight the new findings from this study, as you also mentioned that several analyses have been done. For example, there are studies on the seasonal responses ENSO for this area. It is better clearly state the new findings in the Abstract and conclusions. I am feeling that you sometimes try to outline all the results or previous findings, which makes me confusing on the key results and your new findings. Please condense your paper and highlight your new findings.

Response to major comment 1: We agree that the new findings could be highlighted better. Thank you for the comment. We will clarify our new findings clearly in the conclusions section and we will revise the introduction section to explain better the existing knowledge together with research gaps that we aim to fill. We will also revise the abstract to highlight better the new findings.

The research gaps are:

- Understanding of the temporal evolution of ENSO related precipitation anomalies during ENSO events in Mainland Southeast Asia (MSEA).
- Understanding of the spatial variation in the effects between individual ENSO events on precipitation over MSEA.
- Understanding of the long-term variability of the linkage between ENSO and hydroclimate in MSEA

The new findings are:

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- We describe an evolving pattern of ENSO related rainfall anomalies in MSEA and show that the effect of ENSO is strongest and most wide spread in March-May of the year when ENSO events decay. The analysis period was 1980-2013.
- We show variation in the spatial patterns of precipitation anomalies between individual ENSO events over MSEA. The analysis period was 1980-2013.
- We analysed the hydroclimate of the monsoon transition period from dry to wet season (March-May) over the period 1650-2004. This period is important as the failure in the arrival of the monsoon rain extends the dry season conditions and leads potentially to drought. We found that ENSO has affected the region's hydroclimate over these months during the majority (96%) of the study period and during half (56%) of the time this effect was strong.
- Periods with ENSO activity and no response in the March-April hydroclimate in MSEA were also observed suggesting variability or non-stationarity in ENSO-teleconnection.
- During the period of 1650-2004 majority of the extreme wet and dry March-May seasons were found to have occurred during ENSO events, particularly in the southern parts of the study area.

Major comment 2: This paper has studied the seasonal patterns using the observational data and the long term changes using reconstructions. But the reconstructions do not have seasonal distribution. What are the relationships between the two parts?

Response to major comment 2: It is correct that the reconstructions do not have seasonal distributions. The reconstructions represent only the MAM season and the seasonal patterns are analysed only in the precipitation analysis. Given that the reconstruction only reflects one season, the precipitation analysis 1) provides justification for the reconstruction, 2) provides context for interpretation of results, 3) provides a

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more comprehensive picture of ENSO across temporal scales. We elaborate on these contributions in the following:

The precipitation analyses provides verification that the reconstructions for the MAM season are appropriate for detecting ENSO signal in MSEA. The precipitation analysis showed that MAM season has strongest correlation with ENSO and the statistically significant correlations covered largest areas in MSEA during MAM. The reconstructions are located within the areas that showed statistically significant correlation between precipitation and ENSO during MAM.

The precipitation analysis provides important information for the interpretation of the results from the long-term analysis of reconstructions and ENSO. The precipitation analysis revealed that the spatial patterns of rainfall anomalies varied considerably between individual ENSO events. This means that there is a certain degree of uncertainty whether the reconstructions contain the effects of every ENSO events. It is possible that some ENSO events did not affect the area of a reconstruction.

In addition, together the precipitation and reconstruction analyses provide a more comprehensive picture of the spatio-temporal effects of ENSO in MSEA. The precipitation analyses provide understanding of the seasonal evolution of the effects of ENSO and the spatial variation in the effects of individual ENSO events. The reconstructions provide long-term inter-annual analysis of the effects of ENSO on the MAM season and to some extent comparison spatial variations in the long-term effects of ENSO. The reconstructions are for two different areas and thus they also provide indication on the spatial variations in the effect of ENSO in MSEA in long-term.

We will clarify these three aspects better in the manuscript following the explanations given here.

Minor comment 1: There is still room to polish the language to make it clearer. For example, you mentioned “in northern regions in DJF.” It is better than you clearly state which region. You can also condense some sections to make it clearer. For example,

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for your analyses of the results, there is no need to detailed descript each correlation, it is better to summarize the correlation patterns that make readers to comprehend the changes in response patterns easily.

Response to minor comment 1: We will polish the text. When we discuss certain areas or regions we will refer more accurately to countries or their parts (e.g. Southern Vietnam). We agree that it is clearer in this way. We will also improve the flow of the text in results section regarding the description of the correlations. We agree that that these changes improve readability.

Minor comment 2: The spatial coverage of Figure 1 and 2 are different. It would be better to make them consistent

Response to minor comment 2: We are not sure what the referee means here. The spatial coverage in terms of latitude and longitude coverage are same in all figures (maps).

Minor comment 3: Please explain MEI when you first mention it. What is the difference for this index?

Response to minor comment 3: We use the acronym MEI for the first time in Section 2. Methodology and we will explain it there. In addition, in Section 2.1 we will explain from which data the MEI is calculated from.

Minor comment 4: Page 5317, you write “early 90th century”. It is difficult to say how climate would like then.

Response to minor comment 4: This is a typo. Will be corrected.

Minor comment 5: You also mentioned other proxies sensitive to ENSO, such as the study by Xu et al., why you did not consider these series. It is better to use more than one series to study the relationships with ENSO for the whole Southeastern Asia.

Response to minor comment 5: We have already used two proxy series from differ-

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ent locations instead of one and together they provide better understanding of ENSO teleconnection in MSEA. We did not use the data from Xu et al. (2013) simply because the data was not available for us. In addition, the PDSI data and the location of the reconstruction of Xu et al. (2013) overlap with ours and therefore the use of data from Xu et al. (2013) would have resulted in some degree of redundancy. The comparison of two different reconstructions for partially same location would have been interesting but we consider it to be outside the scope of this manuscript.

Minor comment 6: Page5320, you mentioned "During the development phase of ENSO events in SON(1)" and "During the peaking months of ENSO events in DJF(1),". Do you mean SON (0) and DJF (0)?

Response to minor comment 6: This comment helped us to spot two mistakes: SON(1) should be SON(0) and DJF(1) should be DJF(0/1). Thank you for noticing these. We intentionally use (0/1) for DJF as the season spans the years 0 (development) and 1 (decay). This is consistent with earlier literature (Juneng and Tangang, 2005;Räsänen and Kummu, 2013).

Minor comment 7: The first paragraph of the Discussion section contains many results, which should be merged in the results section. Some of the results can be condensed as this paragraph, which are clearer.

Response to minor comment 7: We understand the referee comment but we consider this to be a style issue. It is common to summarise the key results in the beginning of discussion section before discussing the results in other contexts. We would prefer to keep the structure of the manuscript as it is. In addition, we consider that it is important in the results section to accurately state the detailed findings, which we use as premises to build our conclusions. This approach naturally leads to more technical description of the result in the results section, but a less technical explanation is therefore given in the beginning of discussion section. We considered this while writing the manuscript and found this style to work for this manuscript. In addition, the guidelines

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of Climate of the Past permit the current style of the manuscript.

Minor comment 8: Page5320, it is not good to state "These results point to a need for further research" at the beginning of the Discussion section. Implications for future studies can be shown at the end of the Discussion.

Response to minor comment 8: The sentence that referee refers will be removed.

Minor comment 9: Page5321, The moving correlation and wavelet analyses are widely used in paleoclimate studies. I think it is not necessary to highlight these methods.

Response to minor comment 9: We will reduce the discussion on the methods in the beginning part of the section. However, we prefer to keep the discussion on the limitations of the methods as they are important for the interpretation of the results. Not all readers may be aware of the methods used and their limitations.

Minor comment 10: Page5321, "annual dating" should be revised.

Response to minor comment 10: "annual dating" will be changed into "years"

Minor comment 11: Page5322, at the end of the page, you mentioned "that allows regional and seasonal comparison", please more detailed write the regional and seasonal comparison. It is very important to indicate the improvements of this paper. It appears to me that you have mainly used two previous reconstructions and season comparisons for the reconstructed data do not appear evident to me. Please indicate your improvements in the Abstract also.

Response to minor comment 11: The sentence that the referee refers to will be revised to be clearer. We will state clearly the improvements of our manuscript for the understanding of ENSO in MSEA in the abstract and the conclusion section. The research gaps that the paper aims to fill will also be explained more clearly in the introduction section. The question about improvements, or contributions of our paper, are already addressed in our response to Major comment 1 from the Referee 2.

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