

Referee #1

The authors attempted to reconstruct long-term Indian monsoon rainfall or intensity variations based on tree-ring oxygen isotope chronologies produced from northern part of the Indian subcontinent. They developed two new isotope chronologies spanning the past two centuries or more. Combined with existing tree-ring oxygen isotope records, they produced a so-called regional composite chronology which is regarded as an indicator of the Indian summer monsoon intensity. Further, the authors explored variation characteristics of the regional composite and potential driving mechanism by the way of statistical comparison. One main conclusion is that the intensity of the Indian summer monsoon exhibits a decreasing trend since the early nineteenth century. However, this conclusion is difficult to assess, and it might be subject to large uncertainties since they did not show the comparison of all available five tree-ring oxygen records. Furthermore, observed all Indian rainfall record does not show a decreasing trend according to much longer observational data. It needs much more evidence to validate. At any rate, given that the high-resolution proxy records are still sparse in this region, their effort is expected to add new contribution to the knowledge of regional climate variability. In general the methodology used here is simple and routine in dendrochronological study. This work is worthy of publication in the *Climate of the Past*. However, there are some questions should be clarified or explained before it is ready to go.

Specific comments:

- 1) The main conclusion in this manuscript is that the Indian summer monsoon strength decreased during the last 180 years. To confirm the robustness of this conclusion, much more evidence and discussion are needed to compliment using all available proxy records together with some statistical approach. Furthermore, it is necessary to show a comparison of five isotope chronologies from all five sites. In so doing, one can see how different they are on low-frequency variations, particularly for the time span from 1820 AD till at present. Another concern is why the authors do not use any ring width chronologies into discussion since a large number of chronologies have been published in the study region. It is no problem for ring width to retain century scale climatic signals due to long-lived species used in producing the chronologies.

Answer: In previous manuscript, we compared five isotope chronologies from all five sites in Figure 4a. Based on your helpful suggestion, we added the comparisons among five oxygen isotope chronologies from all sites in new Figure 4. Please see the new Figure 4 in revised manuscript or the following Figure (red line: 31-year running average; black line: mean value

oxygen isotopes from all trees; gray shadows: the 95% ($\pm 1.96\sigma$) confidence limits to show the uncertainty of each chronology and regional tree ring oxygen isotope chronology, respectively (except for tree ring oxygen isotope chronology in Hulma, western Nepal, because the tree ring oxygen isotopes chronology was produced by pooling method, and therefore the uncertainty of this chronology was not able to show.).

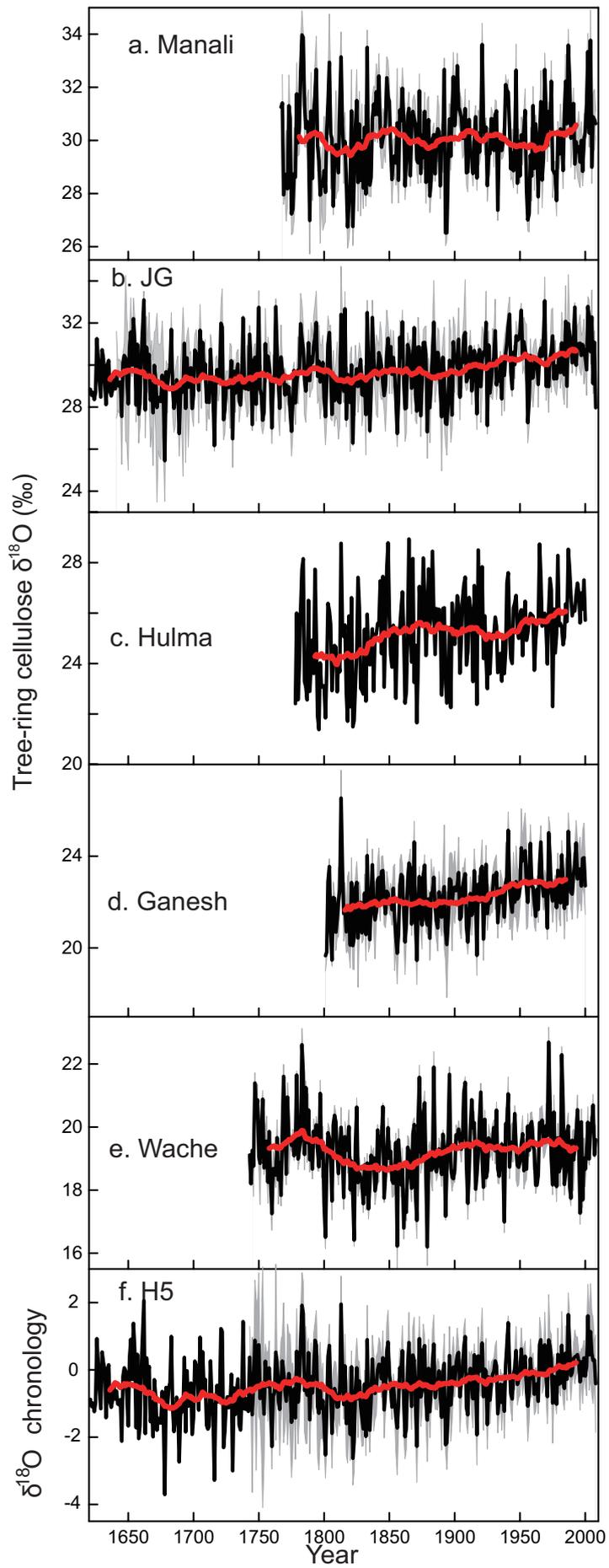


Figure Caption: Figure 4: Tree ring oxygen isotope chronologies from five sites (a-e) and the regional tree ring oxygen isotope chronology (f). (black line: mean values for all samples; red line: 31-year running average for the chronology; gray shadows: the 95% ($\pm 1.96\sigma$) confidence limits)

Yes, there are many ring width chronologies in the study area. There are two reasons that we do not use these ring width chronologies for reconstructing Indian summer monsoon history. 1) Most of ring width chronologies in the study area mainly reflected the climate in spring rather than summer. For example, Cook et al., (2003, International Journal of climatology) reconstructed Kathmandu Temperature based on ring width chronologies. Although Yadav et al., (2014, Quaternary International) reconstructed February-May precipitation using tree-ring width data of Himalayan cedar. Trees throughout the region do not show any direct responses to summer monsoon rainfall (June–September). 2) Teak from Kerala, Southern India reveals that low growth years (narrow rings) are significantly associated with deficient Indian rainfall (DIR). However, normal or above normal rainfall is not consistently reflected as higher tree growth, possibly due to a moisture threshold being reached, above which trees can no longer respond (Borgaonkar et al., 2010, Paleo3). Because the higher tree growth cannot record the signal of strong rainfall, ring width chronology of teak in Southern India was not used for Indian summer monsoon reconstruction.

Borgaonkar H, Sikder A, Ram S, et al. El Nino and related monsoon drought signals in 523-year-long ring width records of teak (*Tectona grandis* LF) trees from south India. *Palaeogeography Palaeoclimatology Palaeoecology*, 2010, 285(1):74-84.

Cook E R, Krusic P J, Jones P D. Dendroclimatic signals in long tree-ring chronologies from the Himalayas of Nepal. *International Journal of Climatology*, 2003, 23(7):707-732.

Yadav R R, Misra K G, Kotlia B S, et al. Premonsoon precipitation variability in Kumaon Himalaya, India over a perspective of ~300 years. *Quaternary International*, 2014, 325:213-219.

2) The overall length of the record is approximately 300 yr or so, so it is impossible to locate a cycle of 350 yr in the composite record.

Answer: Thanks for your helpful comments. We checked the codes that were used to calculate the Power Spectra based on the multi-taper method in previous manuscript. The confidence level in low frequency have some problems. We recalculate power spectra based on the multi-taper method using the Software “kSpectra Toolkit”(v3.4). The results show that the H5 regional tree ring $\delta^{18}\text{O}$ record contains several high-frequency periodicities (4 and 5 years), as well as lower frequency periodicities (~ 133 years). Please see new Figure 7 in revised manuscript or the following Figure.

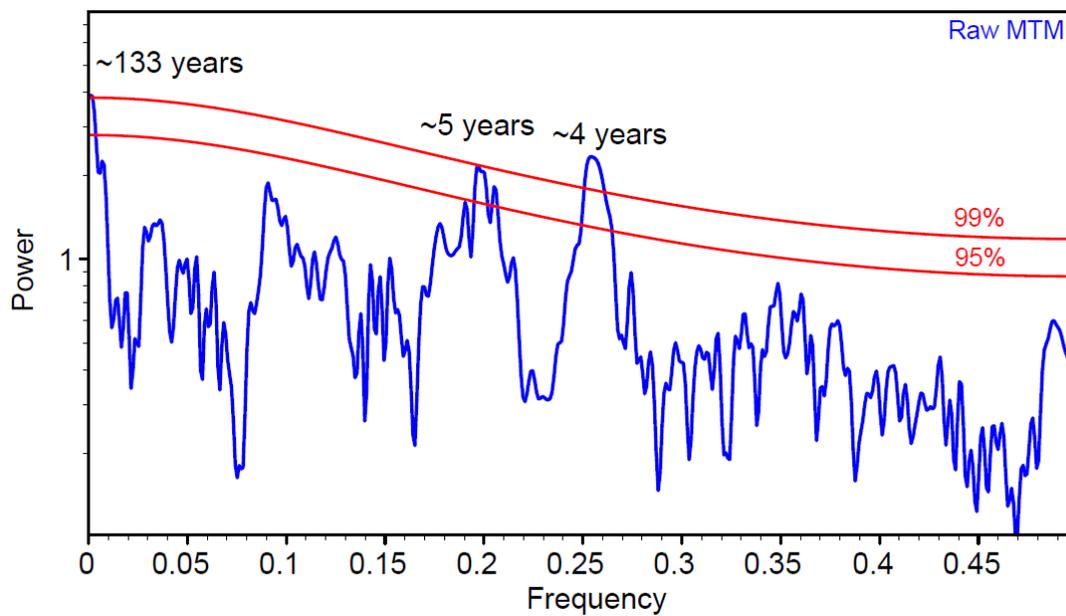


Figure Caption: **Figure 7: Multi-taper power spectra for the H5 regional tree ring $\delta^{18}\text{O}$ record.**

3.3 Interannual variability of the ISM inferred from the regional tree ring $\delta^{18}\text{O}$ record

The results of spectral analysis using the multi-taper method (Mann and Lees, 1996) indicates that the H5 regional tree ring $\delta^{18}\text{O}$ record contains several high-frequency quasi-periodicities (**4 and 5 years**), as well as lower frequency periodicities (**~ 133 years**) at a confidence level greater than 99% (Figure 7).

- 3) ENSO has the strongest power in wave length or cycles 2-7 yr, so 31-yr moving correlations are not suitable in this case.

Answer: Maybe our explanation on 31-year moving correlation is not so clear. ENSO-Monsoon teleconnection is known to be a nonstationary process. We need to evaluate how the

relationships between ENSO and monsoon changed in the past. Because ENSO has the strongest power in wave length or cycles 2-7 yr, 31-year or 21-year window moving correlations between ENSO and precipitation were used to evaluate the stability of relationship between ENSO and climate. The 31-year and 21-year window can cover the main cycles (2-7 years) of ENSO. For example, Camberlin et al., (2004, *Climate Dynamics*) used 31-year moving correlations between NINO3 SST and seasonal rainfall anomalies over a few regions to see ENSO/rainfall teleconnections. 21-year moving window correlation analysis between ENSO and climate was used to investigate the relationship between ENSO and East Asian winter monsoon/precipitation and flood pulse in the Mekong River Basin (Kim et al., 2016; Räsänen and Kummu, 2013)

Camberlin P, Chauvin F, Douville H, et al. Simulated ENSO-tropical rainfall teleconnections in present-day and under enhanced greenhouse gases conditions. *Climate Dynamics*, 2004, 23(6):641-657.

Kim J W, An S I, Jun S Y, et al. ENSO and East Asian winter monsoon relationship modulation associated with the anomalous northwest Pacific anticyclone. *Climate Dynamics*, 2016:1-23.

Räsänen T A, Kummu M. Spatiotemporal influences of ENSO on precipitation and flood pulse in the Mekong River Basin. *Journal of Hydrology*, 2013, 476(1):154-168.

- 4) Shi et al. (2015) temperature reconstruction represents a 10-year moving average rather than a yearly time resolution. It is suggested that the authors also use other summer season temperature reconstructions (see Cook et al., 2013, CD; Wang et al., 2015, JC). In so doing, it can be regarded as a sensitivity experiment.

Answer: Thanks for your suggestions. We added two summer temperature reconstructions (Cook et al., 2013 and Wang et al., 2015) to calculate the land-sea thermal contrasts (New Figure 10 in revised manuscript). Three land-sea temperature anomaly time series (Land temperature: Cook et al., 2013; Shi et al., 2015; Wang et al., 2015; Sea temperature: Tierney et al., 2015) showed similar lower frequency variations. A decreasing trend of land-sea temperature anomaly during the last 200 years were shown by three land-sea temperature anomaly time series. In addition, our regional tree ring $\delta^{18}\text{O}$ chronology showed an increasing trend (reduced intensity of Indian summer monsoon) since 1820 CE.

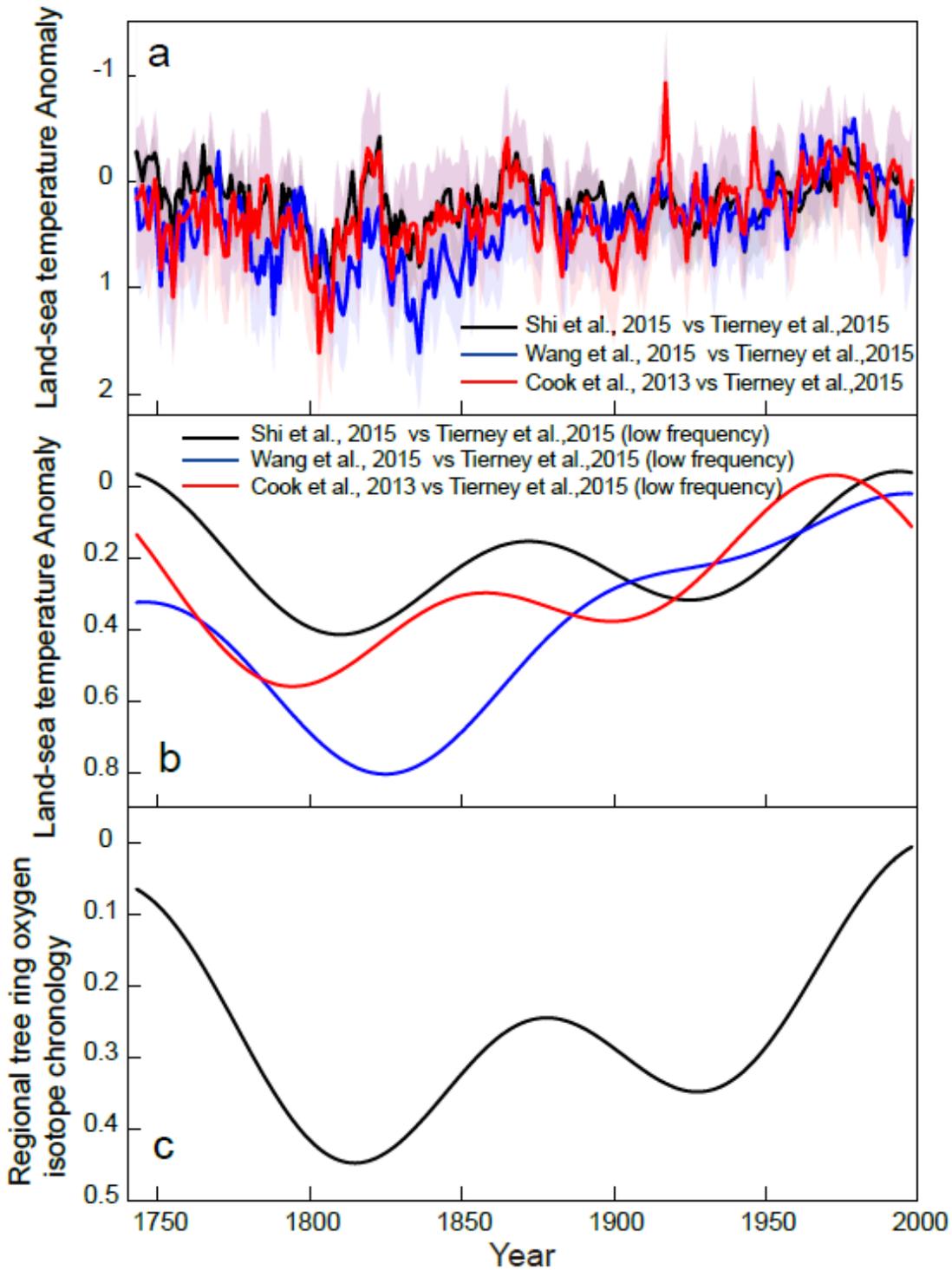


Figure Caption: Figure 10. a: Land-sea Temperature Anomaly based on three summer temperature reconstruction for the Tibetan Plateau and one Indian Ocean SST reconstruction; b and c: centennial variations of land-sea thermal contrasts and the H5 regional tree ring $\delta^{18}\text{O}$ chronology.

- 5) It is strange why the best spatial correlations between the regional tree ring $\delta^{18}\text{O}$ record with May-September SST during 1871-2008 CE (Fig. 8) center around the central tropical ocean rather than in the eastern tropical ocean due to a close association between the ENSO and the Indian monsoon.

Answer: Historical rainfall record and atmospheric general circulation model experiments showed that El Nino events with the warmest sea surface temperature (SST) anomalies in the central equatorial Pacific are more effective in weakening the Indian monsoon severely than events with the warmest SSTs in the eastern equatorial Pacific (Kumar et al., 2006, Science). Kumar K K, Rajagopalan B, Hoerling M, et al. Unraveling the mystery of Indian monsoon failure during El Nino. Science, 2006, 314(5796):115-119.

- 6) Fig. 10 is not helpful due to poor agreement between the two curves.

Answer: We have added uncertainty of age for stalagmite samples and more discussion on the similarities and dissimilarities between regional tree ring oxygen isotope chronology and stalagmite oxygen isotope time series in northern India. Please see the revised Figure 11 and Section 3.5 in the revised manuscript.

3.5 Comparison of regional tree ring $\delta^{18}\text{O}$ record with speleothem $\delta^{18}\text{O}$ record in northern India

The H5 regional tree ring $\delta^{18}\text{O}$ record does not exhibit significant decadal to multi-decadal periodicities (Figure 7), while the main spectral component of high-resolution speleothem $\delta^{18}\text{O}$ records (a proxy of ISM rainfall in northern and central India) consists of multi-decadal periodicities (~15, 20, 30, 60 and 70 years) (Sinha et al., 2011; Sinha et al., 2015). This inconsistency may be the result of the different types of proxy record used together with micro-environmental differences between the sampling sites. Although decadal to multi-decadal variability of the H5 tree ring $\delta^{18}\text{O}$ record is not strongly developed, the record does contain decadal to multi-decadal changes. Decadal to multi-decadal variability was extracted using bandpass filters (15-80 years) (Figure 11, red line). **From the perspective of decadal to multi-decadal changes, the H5 record shares similarities with the speleothem record, while the H5 record are out-of-phase with speleothem $\delta^{18}\text{O}$ records during several intervals (Figure 11).**

Based on the oxygen isotope fractionation theory, tree ring $\delta^{18}\text{O}$ and speleothem $\delta^{18}\text{O}$ should share similar changes (Managave, 2014) if both of them inherit a common source water $\delta^{18}\text{O}$ signal, as shown by Ramesh, et al (2013). The following reasons may cause incoherence between regional tree ring $\delta^{18}\text{O}$ and speleothem $\delta^{18}\text{O}$. Other controlling factors differentially affect tree ring $\delta^{18}\text{O}$ and speleothem $\delta^{18}\text{O}$ values. Relative humidity has an important impact on tree ring $\delta^{18}\text{O}$ in regions where the variation of relative humidity during the growing season exceeds 1% (Managave, 2014), while the cave epikarst dynamics affect speleothems $\delta^{18}\text{O}$ significantly (Lachniet, 2009). The infiltrating water from different rainfall events may be stored and mixed in the epikarst. Lag times of $\delta^{18}\text{O}$ values in drip waters relative to rainfall are several years or decades in some locations (Lachniet, 2009), and a slow transit time smoothed climate signal. In addition, limited three ^{230}Th dates points (3 control points) and relative large age uncertainty (9-31 years) of speleothems $\delta^{18}\text{O}$ time series during the common period of 1743-2000 may result in the incoherence between tree ring and speleothems $\delta^{18}\text{O}$. Long-term process-based study on tree ring $\delta^{18}\text{O}$ and speleothem $\delta^{18}\text{O}$ variations in future study are needed for a better understanding for climatic implication of two proxies.