

Dear Prof. Hans Linderholm and two reviewers,

Thank you very much for giving us a chance to revise our manuscript “**A 424-year tree-ring based PDSI reconstruction of Cedrus deodara D. Don from Chitral HinduKush Range of Pakistan: linkages to the ocean oscillations**” (cp-2019). We greatly appreciate the two reviewers for their valuable and helpful comments. We have revised our manuscript according their comments. The manuscript has been greatly improved after the revision. The point by point response to the reviewers’ comments can be found in the following pages. The reviewer’s comments are listed in black, and our response are in blue. Thank you for all your help in processing our manuscript. We look forward to hearing from you soon.

Best wishes,

Xiaochun Wang

On behalf of all co-authors

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Anonymous Referee #1:

Ahmad et al. contribute a new reconstruction of scPDSI in Northern Pakistan, where Such work is still highly necessary. Generally, the manuscript is well organized and the methods are regular and solid, the main conclusions are largely supported by the Results. I would be happy to see the work published in CP, but only after some of following concerns well addressed.

Response: Thank you for your affirmation. We have revised it carefully according to your comments.

1. The compared reference reconstruction Treydte et al. (2006) are generally in opposite phases in the history, but not well explained. It is also controversial to the statement in the abstract (L28-30).

Response: Fully accepted. We used the raw $\delta^{18}\text{O}$ value in Treydte et al. (2006) to compare with our reconstruction, while the high raw $\delta^{18}\text{O}$ value represents dry and the low value represents wet, just opposite to the PDSI index. Therefore, their results are just the opposite of ours. We have added explained the situation in the manuscript.

2. More explanations should be provided for the linkage between the climate reconstructions with these ocean oscillation indices in the discussion part.

Response: Fully accepted. More explanations have been provided for the linkage between the climate reconstructions with these ocean oscillation indices in the discussion section.

Khan et al. (2014) showed that most of our study area is covered by monsoon shadow, but the Asian monsoon showed an overall weak trend in recent decades (Li and Zeng, 2003; Wang and Ding, 2006; Ding et al., 2008). Therefore, the increase of regional precipitation may be linked to the ENSO. Previous studies (Chen et al., 2019; Shi et al., 2106, Wang et al., 2005) have confirmed that ENSO is an important factor in regulating the hydrological conditions related to the AMO. In the past, sever famine and drought occurred simultaneously with the warm phase of ENSO, and these events were related to the failure of Indian Summer Monsoon (Shi et al., 2014b; Shi et al., 2014a).

2 Material and Methods

The Atlantic Multi-decadal Oscillation (AMO) index was downloaded from KNMI Climate Explorer https://climexp.knmi.nl/data/iamo_hadsst.dat over the period 1890-2016. The reconstructed June-August South Asia Summer Monsoon (JJA-SASM) data was downloaded

from Monsoon Asia Drought Atlas (MADA)

<http://drought.memphis.edu/MADA/TimeSeriesDisplay.aspx> over the period 1300-2005.

3 Results

The spatial correlation analysis between our reconstructed and actual PDSI from May to August shows that our drought reconstruction is a good regional representative (Fig. 8). This shows that our reconstruction is reliable and can reflect the drought situation in the region. In addition, the PDSI of low-frequency (the 31-year moving average) reconstruction had good consistency with AMO ($r = 0.53, p < 0.001, 1890-2001$) and SASM ($r = 0.35, p < 0.001, 1608-1990$), which indicated that these are the potential factors affecting the drought pattern in the region.

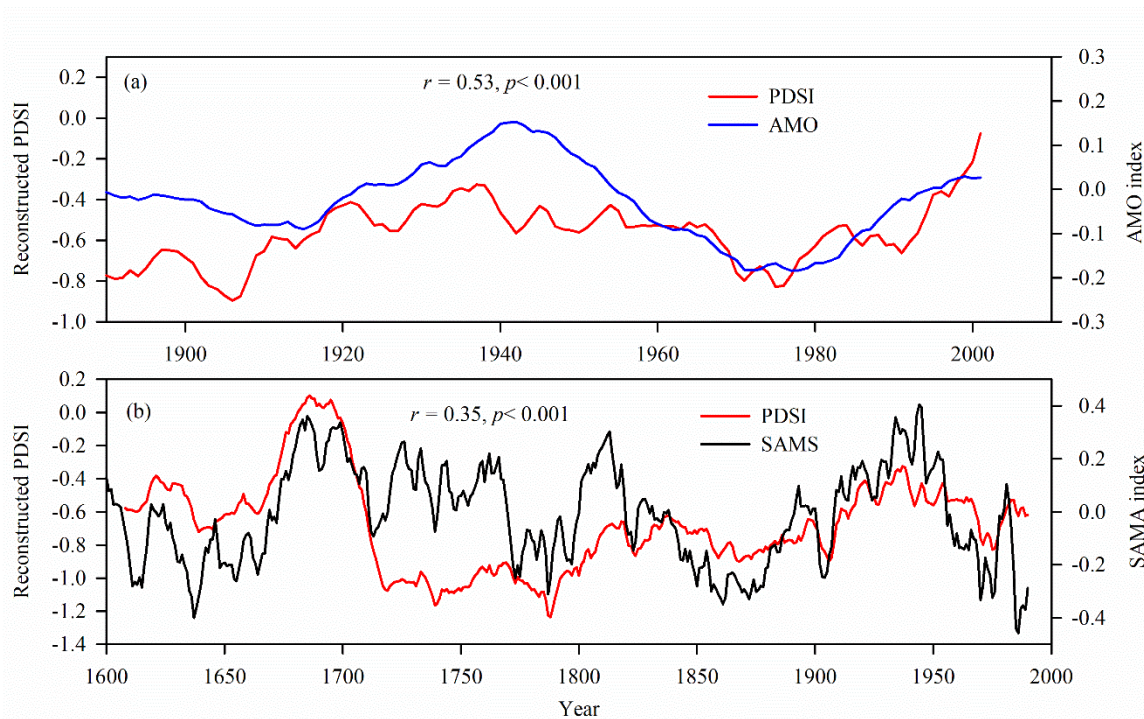


Fig. 9 (a) Comparison of the 31-year moving average series between the reconstructed Mar-Aug scPDSI and the AMO index during the common period (1890-2001); (b) Comparison of the 31-year moving average series between the reconstructed Mar-Aug scPDSI and the JJA-SAMS during the common period (1608-1990).

4 Discussions

The middle-frequency cycle (16 years) may be related to the solar cycle, which is similar to other studies in South Asia (Panthi et al., 2017; Shekhar et al., 2018; Chen et al., 2019). Solar activity may affect climate fluctuations in the Chitral, Hindukush ranges, northern Pakistan (Gaire

et al., 2017). The low-frequency (36-38 years) may be caused by the Atlantic Multi-decadal Oscillation (AMO), which is the anomalies of sea surface temperatures (SST) in the North Atlantic basin. Previous studies have shown that the AMO may alter drought or precipitation patterns in North America (McCabe et al., 2004; Nigam et al., 2011) and Europe (Vicente-Serrano and López-Moreno, 2008). Although our study area is far from the Atlantic Ocean, it may also be affected by AMO (Lu et al., 2006; Wang et al., 2011; Yadav, 2013). Lu et al. (2006) found that the SST anomalies in the North Atlantic (such as AMO) can affect the Asian summer monsoon. Goswami et al. (2006) reported the mechanism for the AMO influence on the Indian monsoon precipitation. The warm AMO appears to cause a late withdrawal of the Indian monsoon through strengthening the meridional gradient of tropospheric temperature in autumn (Goswami et al., 2006; Lu et al., 2006). Yadav (2013) suggested that the role of AMO in modulating winter droughts over the western Himalaya through the tropical Pacific Ocean. Wang et al. (2009) pointed out that the AMO heats the Eurasian middle and upper troposphere in all four seasons, resulting in weakened Asian winter monsoons but enhanced summer monsoons. This is consistent with the findings that the AMO affects climate in China, which is made possible by the Atlantic-Eurasia wave train from the North Atlantic and increased due to global warming (Qian et al., 2014). Further work is still needed to unravel the links between the Pacific and Atlantic Oceans and how the two are coupled through the atmosphere and oceans to affect drought in Asia.

References

- McCabe, G.J., Palecki, M.A., Betancourt, J.L.: Pacific and Atlantic Ocean influences on multidecadal drought frequency in the United States, *Proceedings of the National Academy of Sciences of the United States of America* 101, 4136-4141, 2004.
- Nigam, S., Guan, B., Ruiz-Barradas, A.: Key role of the Atlantic Multidecadal Oscillation in 20th century drought and wet periods over the Great Plains, *Geophysical Research Letters*, 38, 239-255, 2011.
- Vicente-Serrano, S.M., López-Moreno, J.I.: Nonstationary influence of the North Atlantic Oscillation on European precipitation. *Journal of Geophysical Research-Atmospheres*, 113, D20120, 2008.
- Lu, R., Dong, B., Ding, H.: Impact of the Atlantic Multidecadal Oscillation on the Asian summer monsoon, *Geophysical Research Letters*, 33, 194-199, 2006.
- Wang, X., Brown, P.M., Zhang, Y., Song, L.: Imprint of the Atlantic multidecadal oscillation on

tree-ring widths in northeastern Asia since 1568, Plos One, 6, e22740, 2011.

Yadav, R. R.: Tree ring - based seven - century drought records for the Western Himalaya, India, Journal of Geophysical Research: Atmospheres, 118, 4318-4325, 2013.

Goswami, B.N., Madhusoodanan, M.S., Neema, C.P., Sengupta, D.: A physical mechanism for North Atlantic SST influence on the Indian summer monsoon, Geophysical Research Letters, 33, L02706, 2006.

Wang, Y., Li, S., Luo, D.: Seasonal response of Asian monsoonal climate to the Atlantic Mutidecadal Oscillation, Journal of Geophysical Research-Atmospheres 114, D02112, 2009.

Qian, C., Yu, J., Chen, G.: Decadal summer drought frequency in China: the increasing influence of the Atlantic Multi-decadal Oscillation, Environmental Research Letters 9, 124004, 2014.

L57: What kind of production? Food?

Response: Fully accepted. Agricultural production has been added.

The long-term drought from 1998 to 2002 reduced agricultural production, with the largest reduction in wheat, barley and sorghum (from 60% to 80%) (Ahmad et al., 2004).

L64: “an essential archive of dendroclimatic research” A lot of tree-ring work done there? Do you really mean this?

Response: The sentence has been removed.

L117-119: The drought index described here is not consistent with the results in the Fig. 8a.

Response: It is the same PDSI data. The PDSI in the Fig. 8a was also the CRU self-calibrating PDSI.

L169-170: It is not clear why not comparing with reconstructions in the study area but with that outside of the study region. Please add more explanations.

Response: Treydte et al. (2006) are the closest reconstructions to our research site, almost in our research area. We didn't find any more nearby drought (or precipitation) reconstruction to compare.

L181-2: Not clear which criterion was used? EPS or tree No.?

Response: Fully accepted. Corrected.

According to the threshold of EPS ($EPS > 0.85$), 1593-2016 was selected as the reconstruction period to truncate the period 1537-1593 of the chronology (Fig. 3).

L236: What do you mean by the “point years”? Not mentioned before

Response: It means the narrow years of tree rings and has been confirmed as dry year by previous studies. We added the explanation of point years. The point years (narrow rings), 2002, 2001, 2000, 1999, 1985, 1971, 1962, 1952, 1945, 1921, 1917, 1902 and 1892, were recorded in our tree-ring record. The narrow ring formation occurs when extreme drought stress reduces cell division (Shi et al., 2014b; Fritts et al., 1976). Therefore, the narrow rings are also consistent with the extreme drought years.

L247-266: I suggest providing the compared reconstructions in the figure if possible.

Response: Fully accepted. However, in this region, the reconstruction of temperature, precipitation and PDSI in the past is less, and the existing reconstruction data in other regions are difficult to obtain. Therefore, we didn't draw such a comparative picture.

4.2 The linkage of drought variation with the ocean oscillations: It is a bit stretching to relate the periodicity results to the ocean oscillation indices, more direct proof should be provided, such as direct comparison or, at least, previous work on the actual connections between local climates and these synoptic indices.

Response: Fully accepted. This discussion was added. The spatial correlation exhibited the significant similarity of El Niño-Southern Oscillation (ENSO) in the region (Figure 8). The intensity of India monsoon in this area was modulated by ENSO patterns. The high frequency of drought cycle (2.1-3.3 years) may be related to the ENSO (Van Oldenborgh and Burgers, 2005). Previous researches (Chen et al., 2019; Shi et al., 2016, Wang et al., 2005) further proved that ENSO is the responsible factor for regulating the hydrological conditions in our study area related to AMO. In the past, severe famines and droughts occurred simultaneously with the El Niño (ENSO warm phase), and these events were related to the failure of Indian Summer Monsoon (Shi et al., 2014b; Shi et al., 2014a).

Fig 1: This is a very nice figure but the statement on the copyright is quite confusing.

Please consider remove or revise it properly.

Response: Fully accepted. The copyright has been removed.

Fig 2: I suggest provided error bars for the mean values of the climate variables.

Response: Fully accepted. Done.

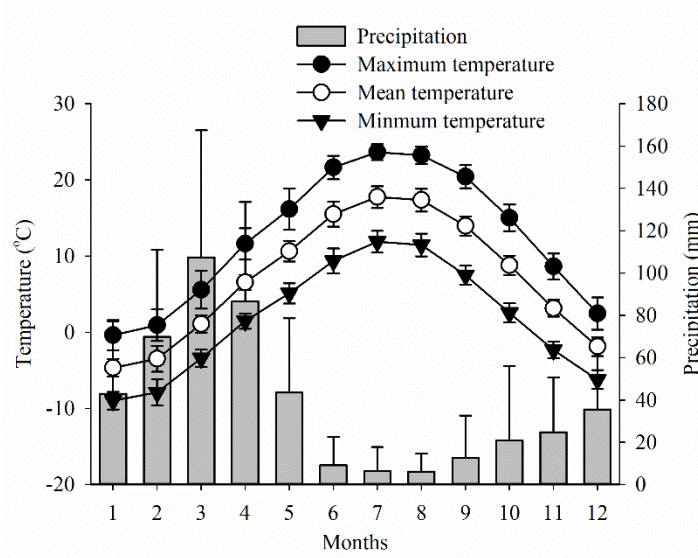


Fig 3: I suggest switching the Y-coordinates of the chronology and the sample depth.

Besides, I suggest replacing “Tree number” by “The number of trees”.

Response: Fully accepted. Done.

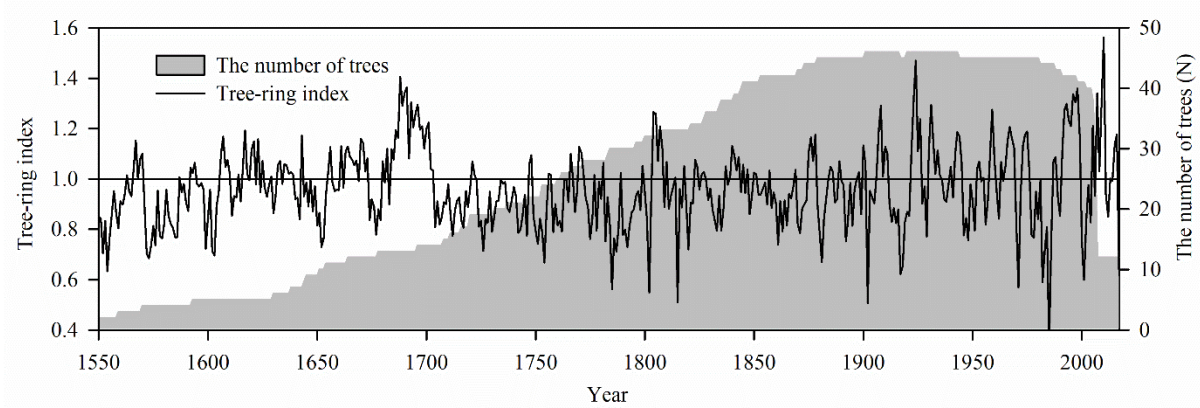


Fig 4: You should explain the meaning of the “previous” and “current” because it is not that self-explaining for every reader. The colors of the two types of the columns are too close, please consider change into other colors.

Response: Fully accepted. The figure caption was modified. Also, the bar colors were changed.

Fig. 4 Pearson correlation coefficients between the tree-ring index of *C. deodara* and monthly total precipitation (1965-2013) and scPDSI (1960-2013) (a) and monthly maximum and minimum temperature (1965-2013) (b) from June of the previous year to September of the current year. Significant correlations ($p < 0.05$) are denoted by asterisks.

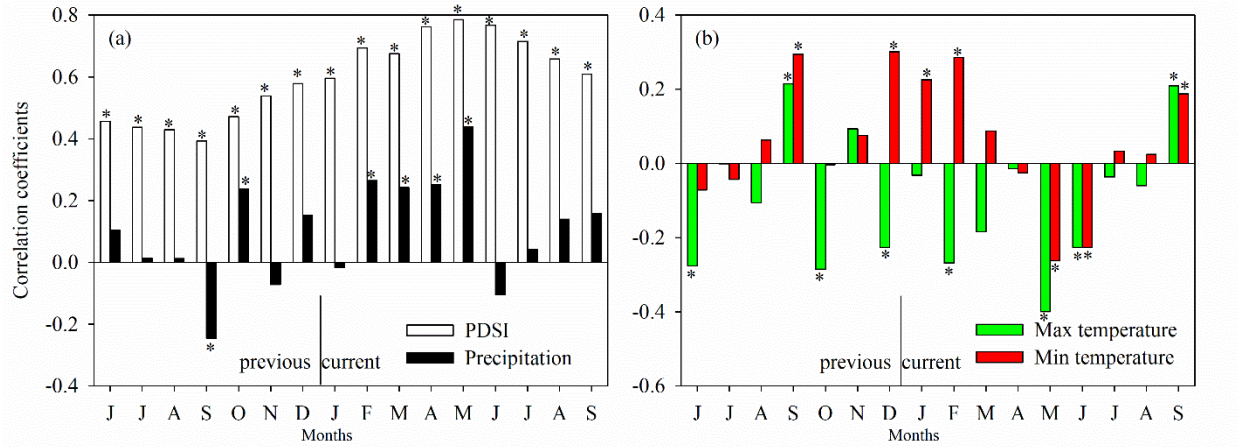


Fig 6: The location of the Treydte et al. (2006) should be provided in the Fig.1.

Response: Fully accepted. The location of the Treydte et al. (2006) was added in the Fig. 1.

Fig 7: The “MTM” should be referred as the full name.

Response: Fully accepted. The full name was added.

Fig. 7 The Multi-taper method spectrums of the reconstructed scPDSI from 1593 to 2016. Red and green line represents the 95% and 99% confidence level, respectively. The figures above the significant line represents the significant periods of drought at 95% confidence level.

Fig 8: The sentence “The value for $p > 0.05$ were masked out” should be clearly pointed to the Fig. 8a. Again, it is very confusing about the copyright statement.

Response: Fully accepted. The figure caption was modified.

Fig. 8 (a) Spatial correlation between the actual May-August scPDSI and the reconstructed May-August scPDSI (1901-2017). (b) The wavelet analysis of the reconstructed scPDSI in the Chitral HinduKush Ranges, Pakistan. The 95% significance level against red noise was shown as a black contour.

Table 1: The table caption should be expanded with more information input to make it be able to stand alone. The stats, such as RE and CE, should be explained in detail here too.

Response: Fully accepted. The table caption was modified. The statistical parameters were explained using notes under the table.

Table 1. Statistical test for the tree-ring reconstruction of March-August PDSI in Chitral HinduKush Range of northern Pakistan based on a split calibration-verification procedure.

Calibrations	r	R^2	Verification	RE	CE	ST	DW	RMSE	PMT
1960-2016	0.70	0.49	—	0.49	—	(43, 14)*	1.06*	1.21	10.0*
1989-2016	0.82	0.67	1960-1988	0.61	0.62	(23, 6)*	1.0*	1.72	5.80*
1960-1988	0.73	0.53	1989-2016	0.64	0.62	(24, 4)*	0.98*	1.56	7.42*

Notes: RE-Reduction of error, CE-Coefficient of efficiency, ST-Sign test, DW-Durbin-Watson test, RMSE-Root mean square error, PMT-Product means test.

Anonymous Referee #2

Ahmad et al. presented a reconstructed PDSI time series from tree-ring record for the HinduKush Range of Pakistan where such record is limited. This study will be valuable for understanding long-term drought dynamics in these regions. The method is typical for this type of research, statistical analyses are sound, and results are checked with existing studies. Overall, I find this study is publishable after addressing the following concerns.

Response: Thank you for your affirmation of our manuscript. We have revised the manuscript comprehensively according to your comments and suggestions.

The logic flow of introduction section is very unclear.

Response: Fully accepted. We have deleted some unclear paragraph and revised the introduction.

Numerous studies have shown that the intensity and frequency of drought events have increased due to rapid climate warming (IPCC, 2013; Trenberth et al., 2014). The apparent drought has had serious adverse effects on social, natural, and economic systems (Ficklin et al., 2015; Yao and Chen, 2015; Tejedor et al., 2017; Yu et al., 2018). Global drought is considered to be the most destructive climate disaster that has caused billions of dollars in worldwide loss (van der Schrier et al., 2013; Lesk et al., 2016).

Pakistan has a semi-arid climate, and its agriculture economy is most vulnerable to drought

(Kazmi et al., 2015; Miyan, 2015). The long-term drought from 1998 to 2002 reduced agricultural production, with the largest reduction in wheat, barley and sorghum (from 60% to 80%) (Ahmad et al., 2004). The northern Pakistan is considered to be the world's largest area of irrigation network (Treydte et al., 2006). The production and life of local residents are strongly dependent on monsoon precipitation brought by the mighty ocean and atmospheric circulation system, including El Niño Southern Oscillation (ENSO), Atlantic Multi-decadal Oscillation (AMO), Pacific Decadal Oscillation (PDO) and others (Treydte et al., 2006; Cook et al., 2010; Miyan, 2015; Zhu et al., 2017). However, the current warming rate has changed the regional hydrological conditions, leading to an unsustainable water supply (Hellmann et al., 2016; Wang et al., 2017). It is not only critical for agricultural production but also leads to forest mortality, vegetation loss (Martínez-Vilalta and Lloret, 2016) and increases the risk of wildfires (Turner et al. 2015; Abatzoglou and Williams 2016). The degradation of grassland and loss of livestock caused by drought eventually affect the lifestyle of nomadic peoples, especially in high-altitude forested areas (Pepin et al., 2015; Shi et al., 2019).

The Hindu Kush Himalayan region (HKH) is the source of ten major rivers in Asia, which provides water resources for one fifth of the world's population (Rasul, 2014; Bajracharya et al., 2018). The region is particularly prone to drought, floods, avalanches and landslides, with more than 1 billion people exposed to increasing frequency and serious risks of natural disasters (Immerzeel et al., 2010; Immerzeel et al., 2013). The extent of climate change in this area is significantly higher than the world average, which has seriously threatened the safety of life and property, traffic and other infrastructure in the downstream and surrounding areas (Lutz et al., 2014). Dry conditions are exacerbated by an increase in the frequency of heatwaves in recent decades (Immerzeel et al., 2010; IPCC, 2013). The intensity and frequency of drought trend are very complex in HKH, and there is no manifest measuring tool to compute how long the drought period might persist. Climate uncertainty complicates the situation, for example, whether the drought trend is increasing or decreasing (Chen et al., 2019). Most studies believe that the wetting trend in HKH is going to increase in current decades (Treydte et al., 2006). However, some extreme drought events in the region are very serious and persistent (Gaire et al., 2017). Little has been done to examine the linkage between drought trend and large-scale ocean climate drivers (Cook et al., 2003; Gaire et al., 2017). Besides in northern Pakistan, there is little research on the dendroclimatology and instrumental climate records are inadequate in terms of quality and

longevity (Treydte et al., 2006; Khan et al., 2019). In high altitude, arid and semi-arid areas, forest growth more sensitive to climate change, so dare need to understand more about the long-term drought regimes of the past (Wang et al., 2008). Climate reconstruction is the best way to understand long-term climate change and expand climate record to develop forest management strategies. Researchers used multiple proxies, including ice cores, speleothems, lake sediments, and historical documents and tree rings to reconstruct past short-term or long-term climate change. Meanwhile, tree rings were widely used in long-term paleoclimatic reconstructions and forecasting future climate because of their accurate dating, high resolution, wide distribution, easy access, long time series, and abundant environmental information recorded (Esper et al., 2016; Zhang et al., 2015; Klippel et al., 2017; Shi et al., 2018; Chen et al., 2019)

In this study, we collected drought-sensitive tree-ring cores of *Cedrus deodar* from the upper and lower HKH region of Pakistan. These tree rings have a good potential for dendroclimatic study (Yadav, 2013). Then, the March-August Palmer Drought Sensitivity Index (PDSI) was reconstructed for the past 424 years to examine the climatic variability and driving forces. To verify its reliability, we compared our reconstructed PDSI with other available paleoclimatic records (Treydte et al., 2006; Treydte et al., 2009) near our research area. The intensity and drought mechanism in this area were also discussed. This will be the first time that the drought index has been reconstructed in northern Pakistan and is considered to be a baseline for more tree-ring reconstruction in Pakistan.

The second paragraph is hard to follow. From line#58-61, It is hard to follow why “their distinct and complex topography, and unique precipitations seasonality” makes tress in HKH “important”? In addition, what is the purpose of mentioning the hydroelectric reservoir? What is the purpose of comparing 4% from government and 2% from FAO?

Response: Fully accepted. The second paragraph and the whole the introduction section has been revised.

Pakistan has a semi-arid climate, and its agriculture economy is most vulnerable to drought (Kazmi et al., 2015; Miyan, 2015). The long-term drought from 1998 to 2002 reduced agricultural production, with the largest reduction in wheat, barley and sorghum (from 60% to 80%) (Ahmad et al., 2004). The northern Pakistan is considered to be the world's largest area of irrigation network (Treydte et al., 2006). The production and life of local residents are strongly dependent

on monsoon precipitation brought by the mighty ocean and atmospheric circulation system, including El-Nino Southern Oscillation (ENSO), Atlantic Multi-decadal Oscillation (AMO), Pacific Decadal Oscillation (PDO) and others (Treydte et al., 2006; Cook et al., 2010; Miyan, 2015; Zhu et al., 2017). However, the current warming rate has changed the regional hydrological conditions, leading to an unsustainable water supply (Hellmann et al., 2016; Wang et al., 2017). It is not only critical for agricultural production but also leads to forest mortality, vegetation loss (Martínez-Vilalta and Lloret, 2016) and increases the risk of wildfires (Turner et al. 2015; Abatzoglou and Williams 2016). The degradation of grassland and loss of livestock caused by drought eventually affect the lifestyle of nomadic peoples, especially in high-altitude forested areas (Pepin et al., 2015; Shi et al., 2019).

Line#73-75, why susceptible to ET, soil and air temperature, air humidity, and soil moisture makes tree ring highly recommended for dendroclimatic studies?

Response: Fully accepted. This sentence has been removed.

2. Line#153. Do you have a reason for reconstructing March-August PDSI rather than other period or for the annual mean PDSI? This should be explained in the main text.

Response: Fully accepted. The period of March-August has been removed, and why reconstructed the period of March-August was explained in the main text.

The correlation between and TRI was the highest from March to August, indicating that the growth of *C. deodara* was most strongly affected by the drought before and during the growing season. Based on the above correlation analysis results, the March-August PDSI was the most suitable for seasonal reconstruction.

3. Line#166-168.

Do you have a reason for choosing 1 standard deviation to identify drought/wet periods? Please explain. In addition, the purpose of the second sentence “We assessed the dry and wet periods for many years based on strength and intensity” is not clear to me.

Response: Fully accepted. According to the reference of Chen et al. (2019), we defined the periods are above or low the mean ± 1 standard deviation of PDSI as the wet or drought periods.

Chen, F., Zhang, T., Seim, A., Yu, S., Zhang, R., Linderholm, H. W., Kobuliev, Z. V., Ahmadov, A., and Kodirov, A.: Juniper tree-ring data from the Kuramin Range (northern Tajikistan), reveals changing summer drought signals in western Central Asia. *Forests*, 10(6), 505, 2019.

4. In Fig. 5, the 1960-2016 is relatively dry. This could bias your regression equation at Line#198 towards the dry end. I think this is the reason why the mean of your reconstructed PDSI before 1960 is negative rather than zero. How did you correct this dry bias? Please explain and add discussions on how this dry bias would affect your drought identification and conclusions.

Response: Fully accepted. The explanation was added in the discussion section.

In Fig. 5, the mean of our reconstructed PDSI is below zero. There are two possible reasons for this phenomenon. First, tree growth is more sensitive to drying than to wetting. As a result, more drought information is recorded in ring widths. This leads to a drier (less than zero) PDSI reconstructed with tree rings. This phenomenon exists in many tree-ring PDSI reconstructions (Hartl-Meier et al., 2017; Wang et al., 2008). Second, the period (1960-2016) used to reconstruct the equation is relatively dry. This cause the mean of the reconstruction equation to be lower than zero (dry), resulting in lower values for the whole reconstructions. Therefore, when applying the PDSI data reconstructed by tree rings, its relative value is relatively reliable, and the absolute value data can only be used after adjustment. The adjustment method of the absolute value needs to be further studied.

5. Figs. 6 and 8 are unreferenced in the main text. Please correct. In addition, please consider add more explanations for these two figures. Currently, it is unclear how these two figures support the flow of your discussions.

Response: Fully accepted. The figure has been texted and explained to support the flow of our discussion part. The results were compared with adjacent studies for validation and reliability (Treydte et al., 2006), they used annually resolved oxygen isotope ($\delta^{18}\text{O}$) record from tree rings (Fig. 6). The spatial correlation analysis between our reconstructed and actual PDSI from May to August shows that our drought reconstruction is a good regional representative (Fig. 8). This shows that our reconstruction is reliable and can reflect the drought situation in the region.

The spatial correlation between Actual May-August scPDSI (1901-2017) and Actual May-August reconstructed scPDSI (1901-2017) exhibit a significance effect of El Niño-Southern Oscillation (ENSO) exist in the region (Fig. 8).

The English of this manuscript needs to be polished. The following are a list of errors that I caught.
• Line 48, lacking an “and” before “increases risk of wildfires”.
• Line 57, 80% to 60% of what?
• Line 63, replace “in the form of” with “from”
• Line 169, remove “a” before “few”, remove “still”.
• Line 185-187, please consider decompose this long sentence into smaller ones.
• Line 308, is “weather” a good word for climate-related studies?

Response: Fully accepted. Done. The English of the whole manuscript was also polished by the AJE English editing service company.