Dear Marit-Solveig Seidenkrantz,

Thank you for your kind attention for our work. We have tried to reply on all your comments. All our responses are as below, changes in text are highlighted in gray. Thank you so much for all your help.

We thank the Referees and you for critically reading the manuscript. We hope that the current version of the manuscript has reached the requested quality standard of CP.

With best wishes, Olga Ukhvatkina and co-authors.

Responses to Editor's Comments

1 Comment: Both reviewer 1 and 2 suggests that you delete the oldest part of the record where only few data series are available. I agree with you that extending the record as far back in time as possible is valuable. However, here it is imperative to make the readers aware about the significant uncertainty for this older part of the record. You may solve this by adding "Although the record from AD 1529 to 1602 is thus less certain, we here report it as it is very important to extend ..." to Line 130 (AR3 version of the ms). Adding this sentence will make it clear to the reader that they need to be more careful when referring to data from the AD 1529-1602 interval.

The authors' response: Comment accepted. We added this phrase in manuscript (lines 131-133).

2 Comment: In relation to this, please also provide information on the uncertainly of the chronology as number of years. E.g., if you mention a cool event from AD 1538-1543, could it for instance be AD 1535-1540 instead? Explaining this will make it easier for non-tree ring specialists to understand the data certainty.

The authors' response: Comment accepted. We corrected these periods in abstract, p. 3.3, p. 4.2, tabl. 3 (lines 215, 216, 296, 615, 617).

2 Comment: Line 369: You state that the 20-year cycle reflects the PDO. You cannot be sure about this despite the arguments that you present in the following sentence, so please add an "likely", "we suggest" or similar to this sentence. Please also explain how the PDO would influence climate at your study site (temperature, precipitation) though comparison to modern conditions. 1-2 sentences should be sufficient.

The authors' response: Comment accepted. We added similar world in lines 372, 376. Also, explanation of PDO influence on region climate was appended too (lines 379-383).

3 Comment: I agree with Reviewer 3 that your correlation to solar irradiation cycles is not strong. It is OK to mention the possibility, but firstly you need to 1) make your statements less categorical, making it clear that you suggest the link between solar irradiation and your record due to the comparable timings; 2) provide a short explanation to the mechanism on how changes in solar irradiation would influence climate at your site. The arguments that your provide line 377 and forward that previous papers have shown a link between solar irradiation and climate (mainly at different time scales) is not sufficient evidence for a similar link in your record.

For the 9 year cycle, it is somewhat different than the 11 year solar cycle, and if your chronology is precise is may be a problem. However, the solar cycle is not fully stable, and it is possible that the link is real. Did you make a direct comparison between the instrumental data of the solar irradiation and your data? If not, there is no way that you can be sure that the 9-year cyclicity is linked to solar irradiation.

Also the 189 years cycle in your data is quite far from the 210-year solar cysle, if your chronology is precise. Furthermore, as you acknowledge yourselves, calculating a multi-centennial cyclicity of a record of 486 years is not convincing. So please moderate and tone down your suggested correlation, both in the discussion and the conclusion/abstract.

The authors' response: Comment accepted. We made our suggestions less categorical (lines 384, 394,395, 399, 423, abstract: lines 21-24). We added explanation of influence of solar activity based on other studies (lines 387-392).

4 Comment: Language: please check the language of the section lines 369-400, where you have added new text.

The authors' response: Comment accepted.

5 Comment: Please make sure that all the sites that you mention in the text are provided on your location figure 1.

The authors' response: Comment accepted.

Response to Referee #1

Dear Referee,

We carefully revised our manuscript according to your comments. We very appreciate your helpful comments on our manuscript. These comments help as to make our reconstruction more perfect and accurate. All detailed revision and response are as below (in yellow in the main text). Thank you so much for all your help.

Sincerely yours,

Olga Ukhvatkina and co-authors

Response to general comments:

Comment: "This biggest problem of this study is that the explained variance of the reconstruction equation is very low. The low explanation means the reliability of the reconstruction equation decreases. In addition, the year to year (high-frequency) variations of the reconstructed series was not in good agreement with the actual minimum temperature series (Fig. 5a). The correlation (0.52) may be caused by the similar trends. Thus, the real correlation coefficient between tree-ring index and autumn-winter minimum temperature might be lower than 0.52, which could be tested by calculating the 1^{st}-order difference correlation coefficient between them. Please try using some methods to increase the amount of the explanation of the reconstruction equation."

The authors' response: We are very grateful to you for this comment. We once again tried to search for available meteorological data and found data on the minimum temperatures from Chuguevka. Then we tried to reconstruct the minimum temperatures (August-December for the previous year) based on these data. This allowed us to significantly increase the explained variance to 39% (our previous result was only 25%). Similar values are often found for reconstruction in the East-Asian region (e.g. Willes et al., 2014). Interestingly, the temperature correlation between Chuguyeva and MP7 for all months is 99%, but the correlation for August-December is only 83%. Compared to the data from Chuguyevka, the data from the MP7 for these months looks a little bit "noisy". We think that this is because on MP7 obtaining data in the winter months was sometimes difficult because this is a weather station on a Research Station without permanent staff of meteorologists.

Comment: "In addition, the greatest advantage of this reconstruction is that it spans a longer time range (more than 500 years), which can capture low-frequency climate variations (as the author said in Lines 40-48, 51). We know it is very important to extend the reconstruction series (or tree- ring chronology), but a generally acceptable threshold of the EPS is greater than 0.85. However, the EPS value from AD 1509 to 1602 is only greater than 0.7 and it contained 3 trees (or cores) (lines 119-124). Please try to find more older trees if you want to make up for this deficiency."

The authors' response: Thank you very much for the suggestion. Indeed, the EPS value becomes greater than 0.85 after 1602. But we think that it is very important to extend the reconstruction as far as possible, since there are few long climate reconstructions in this region. Moreover, the northern Hemisphere temperature series (D'Arrigo et al., 2006) and historical documents very rare for the North-East Asia (and are absent for the Russian Far East), confirmed that the reconstruction temperature from 1529 to 1602 is valuable. Therefore, we kept part of the reconstruction from 1529 to 1602 (EPS>0.75). In order for the reader to understand this, we added some clarifications to the text about the EPS value from 1529 to 1602, and also added lines denoting this part on Fugures 3 and 5.

Response to specific comments:

1. Five main objectives of this study are two much. The objectives (1) and (2) that develop the first (more than 500-year) tree-ring-width chronology in the far eastern region are not the real objectives. Please only list the most important goals and make them less than three.

The authors' response: Comment accepted. We reduced number of objectives from five to three.

2. It's impressive that the authors say "two cores per undamaged old-growth mature tree (50 cores from 25 trees) and one sample from dead trees (20 samples) were extracted from *Pinus koraiensis* trees in the sample plots ......" (lines 98-

99). However, the maximum sample depth of the VUS chronology shown in Figure 3 is nearly 35. It is far less than the actual sample depth. Please check this inconformity or give a reasonable explanation.

The authors' response: It was not a mistake. In fact, we took 2 cores from each living tree, but only one was used for analysis - with a large number of tree rings (we did not mention this in the text). Thus, the total number of samples in the analysis was 45. In addition, we do not have time periods when all 45 samples overlap with each other because some old trees died before new live ones appeared. Therefore, the maximum number of samples on the Figure 3 is less than 40. We made changes to the text, so as not to confuse the reader.

3. The reconstruction period of this study is from 1509 to 1602, which matches the EPS > 0.7, while the authors highlighted the EPS with the value 0.75 in figure 3. Please let them keep consistent.

The authors' response: Comment accepted. We deleted line denoting EPS>0.7 (fig. 3 and fig. 5) and added lines denoting EPS>0.75 and EPS>0.85 on Figures 3 and 5.

4. Some figures (for example, Fig. 3, 5, 8) in the manuscript have no Y-axis title. Please add it.

The authors' response: Comment accepted, titles added.

5. In the manuscript, new plant name should be added with Latin name only if it appears for the first time. Please write the whole Latin name, for example the *P. koraeinsis* in line 20, and the *A. nephrolepis, B. costata, P. jezoensis, P. koraiensis,* and *T. amurensis* (lines 79-80).

The authors' response: Comment accepted. In the text we added whole Latin names (lines 89 and 90): *Abies nephrolepis* (Trautv.) Maxim, *Betula costata* (Trautv.) Regel., *Picea jezoensis* (Siebold et Zucc.) Carr., *Pinus koraeinsis* Siebold et Zucc., and *Tilia amurensis* Rupr.

6. Two climate data sets (Chuguevka and MP7) were used to evaluate the tree growth- climate relationships, but in Figure 2 only the climate (monthly temperature and total precipitation) of MP7 meteorological station were shown. It is better to add the data of another weather station.

The authors' response: Comment accepted. We added climatic parameters of Chuguevka to fig. 2 too.

7. Why there are some big difference in the results of tree growth-climate relationships between long (Chuguevka) and short (MP7) climate data sets? Is it because the tree growth-climate relationships are unstable over time? If it is, the tree-ring data might be not suitable for the climate reconstruction.

The authors' response: After we found the data on the minimum temperatures from Chuguevka, we compared this data with MP7. The results showed that the correlation between the data from Chuguevka and VUS for all months is very high (99%). But the correlation between the data in the winter period is significantly reduced (up to 83%) – see also response to general comment 1. Now Figure 4 clearly shows that the results of the interconnections are very similar for these two weather stations and differ only in the degree of severity.

8. There are some methodological and results sentences in discussion section, please move them into the correct places (method or result section), such as lines 268-269, lines 349-351.

The authors' response: Comment accepted. We added new text to the Methods section (lines 145-148) and also moved and added the comparison results of the reconstruction and CRU TS4.00 in the Results (lines 238-240) and the Discussion (lines 277-283). However, we left the text in Conclusion, as we believe that it is important to repeat this here.

9. There are some Russian in line 275, please change them to English.

The authors' response: Comment accepted.

Response to Referee #2

Dear Referee,

We sincerely thank you for your careful attitude to our manuscript and your help in improving it. We closely analyzed manuscript in accordance with your comments. These help as to make our research more clarify for readers. All detailed response is below (in blue in the ms.). Thank you for your help!

With best wishes, Olga Ukhvatkina and co-authors.

Response to general comments:

1. Comment: I worry that the reconstruction should cut at 1600, where there is more sample depth and a higher EPS value. Generally, the rule is 0.85 and I've seen others use 0.80 but not 0.75 as the authors do. Further, the sample depth during the period prior to 1600 is very small, less than 5 cores.

The authors' response: As we have already responded to the Referee #1, in our opinion it is very important to extend the reconstruction as far as possible, since there are few long climatic reconstructions for this region. Therefore, we would like to keep part of the reconstruction from 1529 to 1602. In order for the reader to better understand that from 1529 to 1602 the EPS value is above 0.75 but less than 0.85, we added some clarifications to the text. We also added lines denoting reconstruction part with 0.75< EPS<0.85 in Figures 3 and 5.

However, if the Editor decides that this part should be excluded, we will make this change (and, accordingly, changes in further results and conclusions).

2. Comment: I also wonder why the authors are comparing their reconstruction with other reconstructions from different seasons. I think there is merit to this paper and think some of my comments could be issues of clarity but would like the C1 authors to consider them to determine if these are methodological concerns or clarity issues.

Specific comments:

Line 219: Why do the authors use Aug-Dec when not all the months are significantly correlated?

The authors' response: Indeed, if we look at individual months, the tree-ring growth is not significantly correlated with the minimum temperature of some of them (in particular, August). However, when we consider combinations of months, the situation changes. We tried all possible combinations of months, before we chose the period from August to December. And if we only consider October-December, the correlation between radial growth and temperature will be 0.56. But if we add August and September, then it rises to 0.62 (new version of manuscript in supplement and the response to Ref.#1).

3. Comment: Line 244: The explanation of KNMI needs to be in the methods.

The authors' response: Comment accepted. (see also response to Ref.#1)

4. Comment: Lines 251: This is a bigger point, why are the authors comparing the Aug-Dec min temperature reconstruction to different seasonal reconstructions? This in itself is not wrong but there needs to be some explanation as to why the signals are different in these reconstructions. I'd be more comfortable with different seasonal comparison with the overall NH reconstructions but wonder why the two reconstructions that are 500km and 430km away are from April to July and Feb. to April. This is especially strange when the authors state that others have found this same Aug-Dec signal but do not compare their reconstruction to those. There could be different reasons for seasonal shifts in climate. Thus, I think this needs to be handled carefully.

The authors' response:

As we understood the Referee's comment can be divided into two questions. The first one is why the climatic signal for the same tree species is different though the distances between the study areas are rather small (500 and 400 km). The second one is why we compare the reconstructions for different seasons despite the fact that seasons can have different climatic shifts.

First, we will answer the second question. There are few reconstructions for the North-East Asia region, so we have to use the available reconstructions. At the same time, the presence of cold and warm periods generally coincides in the compared reconstructions, while the difference between them can be attributed to different seasonal shifts and local climate specifics (but so far, we say this under correction).

We also need to clarify that another two papers which we refer to saying that the other authors have identified similar associations (have revealed the similar correlation) of tree growth and temperature could not be used for comparison.

In the first work ("Temperature signals in tree-ring width and divergent growth of Korean pine response to recent climate warming in northeast Asia", Wang et al., 2016), the authors compared the response of Korean pine radial growth to temperature, precipitation and PDSI in different parts of distribution area. The study points in this work were distributed along a latitudinal gradient along the entire boundary area between the northeastern part of China and Russia. The main conclusion of this work was that in different parts of the range there are various limiting factors for the Korean pine growth. However, the authors did not reconstruct the climatic parameters.

The second work (Zhang et al., 2015) reveals the response of radial tree growth to the minimum temperatures of August-December of the previous year (as it is in our study), but it was made for the Tibetan plateau. We didn't think it would be correct to compare our results with the results of a study performed on the territory located more than 2.500 km far from the site of our study.

The answer to the first question is more complicated. As we have said, the Wang et al., 2016 study shows that the tree response to climatic factors differs in different parts of the range. At the same time, we see that climate in the Sikhote-Alin and Northeast regions of China is very similar, which is also confirmed by Fig. 7a (new version of manuscript). At present, we cannot give the detailed answer to the question of what determines the difference in limiting factors for the Korean pine growth of in different parts of its range. However, we can make some assumptions. To do this, let's compare each neighboring reconstruction with ours separately.

The first reconstruction was done by Zang et al. (2016) on the minimum temperatures of April-July. As it's explained by the authors of the article, the warming of the last decades was most strongly expressed by increasing the minimum temperatures in their study area. The authors of this article believe that for their territory the most important limiting factor for the Korean pine growth is the absence of spring and early summer frosts, that allows trees to form wider rings. At the same time, their analysis shows the correlation between the Korean pine growth and the minimal temperatures of August-December of the previous year (as it is in our study). But the correlation for that territory is less significant compared with the minimum temperatures of April-July.

We compared the diagram of mean monthly temperature and total precipitation of this article with that one from our study area. The results show that in our study the minimum temperatures are much lower in August-December (especially in October-December), and the minimum temperatures of April-July almost completely coincide in these two points. Probably, that's that affected the differences of limiting factors.

As for the second reconstruction (Zhu et al., 2009), the authors of this study did not analyze the minimum temperatures effect on the Korean pine growth. They based their reconstruction at the average monthly temperature of February-April.

Fig. 4c of our study clearly shows that it also reveals the correlation between the Korean pine growth and the February-April temperature, but it turned to be lower than the temperature influence in August-December of previous year (Fig. 4h). Perhaps, if the authors of the article Zhu et al., 2009 would have analyzed the correlation of the minimal temperature with the growth of the Korean pine, they could also reveal these relationships.

In order for the reader to understand this, we added some clarifications to the text: "Although the spring and summer temperatures have been reconstructed in the last two cases, we use these reconstructions for comparison, because, firstly, there are no other reconstructions for this region, and secondly, despite the possible seasonal shifts, long cold and warm periods should be identified in all seasons". (Lines 289-292).

5. Comment: Figure 5: The relationship between tree growth and instrumental temperature looks a little weak. I would like the authors to discuss what the tree-rings are not getting (i.e., peaks or troughs). I also worry that the higher r-value is more of an artifact of both timeseries trending upward rather than a true correlation.

The authors' response: Comment accepted. According to comment of Referee #1 we improved R-value and R^2-value of our reconstruction using more accurate climate dataset (see: response to Ref.#1 and new version of manuscript in supplement).

6. Comment: Figure 7: I'm not sure why this figure is in here. Are the authors trying to show that region has a strong consistent climate signal? If so, then again why are the other regional reconstructions based off of different seasons? Perhaps I'm missing something due to clarity?

The authors' response: Comment accepted. We changed Fig 7. (see new version of manuscript). Fig. 7a showed that minimal temperature in our territories and neighboring territories is very similar. In spite of different response of Korean pine radial growth on climate, Fig. 7b indicating that our temperature reconstruction is representative of large-scale regional temperature variations. But it suggestion needs further researches. We added next text in the manuscript for readers: "We can conclude that the analysis shows that the reconstructed data is representative for large-scale regional temperature variations (Fig. 7). At the same time, some cold and warm periods in our reconstruction and other neighbored studies do not coincide (Fig. 8), which can be due to the reconstruction of other climatic parameters and differing environmental conditions. So, we believe that these results can characterize regional climate variations and provide reliable data for large-scale reconstructions for the northeastern portion of Eurasia, but their use for large-scale regional reconstructions requires further research." (Lines 352-357, new version)

Response to Referee #23

Dear Referee,

Thank you very much for your attention to our research. We closely analyzed manuscript in accordance with your comments and hope that our answers will be satisfactory to you. Some your comments the same with comments of Ref.#1 and Ref.#2 and we ventured repeat our answers to these comments again.
We express to you our deep appreciation for your help, which has greatly improved our manuscript.

With kind wishes, Olga Ukhvatkina and co-authors.
Changes in the main text highlighted in green.

Response to general comments:

1. Comment: The paper initially discusses potential climatic parameters as the dominant mechanism controlling tree-ring growth, then – in one sentence – concludes that "the most stable correlation appears between the growth and the minimum monthly temperature of August- December of the previous year at MP7, on which we base our subsequent reconstructions". This aspect is critical, because this is where the meaning of the climate reconstruction is defined, and the treatment of this aspect is too superficial and not sufficiently robust. It is unclear what "stable correlations" refer to, and it should be discussed how much of the variance is actually explained by this parameter – that turns out (in the Conclusion section) to be quite a small fraction. Based on Fig. 4, it seems that several of the other climatic parameters correlate with the tree-ring growth almost as well as the August-December temperature. This should be explored – and discussed - in more detail. Also, would it make sense to use principal component analysis and combine some of the climatic parameters to see if it is possible to explain more of the variance in the data – although this will not make it possible to reconstruct more climate parameters back in time, it may still prove helpful for our understanding of the climate parameters driving tree-ring growth.

The authors' response: Comment accepted, "stable correlation" changed to "significant correlation". Analysis of correlation between climatic parameters and tree-ring weight was conduct in specific package for dendroclimatic studies "treeclim" in R (Zang, Biondi, 2014) (reference in main text: Lines 155-156).

This is citation of package authors (Zang, Biondi, 2014): Numerically, treeclim uses the algorithm implemented in DENDROCLIM2002 to calculate response and correlation functions; format of input data is the same as for DENDROCLIM2002 and bootRes. In the case of response functions, the design matrix is orthogonalized so that the regression is performed against principal components of the design matrix, retained according to the PVP criterion (Guiot 1991), which corresponds to the determinant of a correlation matrix of uncorrelated variables. Estimated regression coefficients are then transformed back into the original parameter space (Zang and Biondi 2013). Correlation function analysis uses Pearson's linear correlation computed between the response variable and each subvector of the climate design matrix. Bootstrap resampling (1000 iterations) is used to test for significant correlations.

This citation is showed that significance of revealed correlations is corroborating by bootstrap resampling analysis (1000 iterations). These methods of analysis are common and "classical" in tree-ring studies.

The relatively low value of the explained variance was also noted by Ref.#1 and Ref.#2. According to these comments we improved our reconstruction (see new ver. of manuscript and response to Ref.#1). In additional the R^2 value now indicated not only in Conclusion, but also in the section in 3.2 (line 189) and in Table 2.

Indeed, the principal component analysis could increase the explained variance, but it is practically not used in such studies, because, as you mentioned, it will not possible to reconstruct climatic parameters.

2. Comment: It is also unclear how the bootstrapping method was used for the verification – vital details are missing as this is not explained in the text. It just states that: "The idea that this method is based on indicates that the available data already include all the necessary information for describing the empirical probability for all statistics of interest". It is unclear what this actually means, and it should be explained in more detail how the verification is done.

The authors' response: Comment accepted. Bootstrap method is the one of the most well-known methods of short data analysis in the tree-ring based studies. Since this method is widely used it is well described in the literature. In main text of manuscript (line 196) we added references, so readers can study the features of the method. In Table. 2 it is indicated that 199 iterations have been carried out for the verification, and in the methodology (Section 2.4) there is a reference to the STATISTICA software we used for the analysis.

2. Comment: **Defining warm and cold periods**

The occurrence of warm and cold periods in the new record is defined as when the temperature deviates more than half the standard deviation from the mean. However, it is unclear if this refers to the 21-yr smoothed record, or the annual data – my guess is the annual data, but the text seems to suggests the 21-yr averaged data, and it is impossible to tell from the figure. The problem with the definition and the figure (Fig. 5) is that it is hard to make them match, i.e. the 21-yr smoothed record rarely increase/decrease above/below the dashed lines (or is that because it is the standard deviation on Fig. 5 and not half the standard devation?), whereas the annual data show more variability, briefly extending beyond the standard deviation on many occasions – but in this case the defined periods seem very arbitrary and could as well have been longer or shorter. Also, looking at Fig. 5b, the four warmest years do not occur during the years cited in the text (although it is unclear if this is based on the annual or the 21-yr smoothed data, but neither seem to fit the description in the text).

The authors' response: Comment accepted. It's our omission that we didn't describe the process of defining of cold and warm periods. In order to clarify this in the main text the following explanation was inserted: "If the reconstructed minimum temperatures were above or below the average value by >0.5 SD for three or more years, then we considered this deviation as warm or cold period, respectively. Also, if two warm (or cold) periods were separated by one year, when the temperature sharply decreased (or increased), then such periods merged into one." (lines 211-214).

3. Comment: First of all, it is a bit difficult to follow the discussion of regional climate changes without a map, where the location of some of the other records are indicated (e.g. Fig. 7). Secondly, the discussion is somewhat unclear, because it is concluded that "...these results characterize regional climate variations and provide reliable data for large-scale reconstructions for the northeastern portion of Eurasia". At the same time, there are clearly differences between the record presented in this study and the nearby records shown in Fig. 8c and 8d. The differences between the new climate record presented in this study and those from nearby areas are briefly discussed in lines 308-316, and are attributed to differences in the reconstructed temperature parameters – and the asymmetry between medium, minimum, and maximum temperatures. This is a really important aspect, as the different records reconstruct the temperature during different parts of the year, as it is therefore a little like comparing apples and oranges. I think this aspect deserves much more attention, particularly if we are to understand the regional climate variability. It also raises the question as to how and the extent to which we should understand the new record as representing regional climate variability.

The authors' response: As we understood this comment may be divided on two parts. First of all, it is necessary to understand where the study areas for which reconstructions being compared. For this we added locations points on the Fig. 7.

The next part of the comment concerns the irrelevance of comparing of reconstructions for different seasons. As we answered to Ref.#2 in part this is a fair comment, but we had to use such different reconstructions (see response to com. 4 to Ref.#2) and it is make sense. In addition, we improved the Fig. 7 and now it shows that our reconstruction is representative to the territory of all three reconstructions (for minimum temperature of August - December). Also, despite the fact that the temperature was reconstructed for different seasons, the general trend (cold and warm periods) coincide.

4. Comment: First of all, there is no description of the methods underlying the spectral analysis. The paper just states that "The MTM analysis over the full length...", which means that it is impossible to reproduce the spectral results presented in this paper. The Methods section should provide sufficient details of the method used to enable other people to reproduce the results.

The authors' response: Comment accepted. We added links to the authors of the method and information about used software (lines 157-160).

5. Comment: Secondly, in the Results and Discussion sections a myriad of significant 2-3 year cycles (2.3, 2.5, 2.9, 3.0, 3.3, and 3.7) are reported and discussed. While these periodicities may be real – and potentially reflect the ENSO or quasi-biennial oscillation – they are very close to the Nyquist frequency. With a Nyquist period of 2 years, it is hard to interpret the 2-3 years as direct evidence for climatic oscillations on this time scale. It is thus likely that these high-frequency periods reflect year-to-year scatter, but this aspect is not discussed as all.

The authors' response: We used the additional analysis method (SSA) to confirm the significance of the detected cycles. As a result, we obtained that all 2-3-year cycles are joined in one 3-year cycle. Traditionally, such short-period fluctuations in the region are associated with ENSO or quasi-biennial oscillation and we indicate this in the text. But additional analysis using the KNMI Climate Explorer (http://climexp.knmi.nl) did not reveal a significant correlation between the ENSO indexes and the reconstructed temperatures, but showed a significant correlation with the North Pacific temperature. Therefore, we assume that the Pacific Decadal Oscillation is more important for climate variations. According to the comment and the new results obtained, we made corrections to the main text of the article (lines 141-144, 157-160, 225-237, 367-371, 374-379).

6. Comment: Thirdly, the Abstract and Conclusion mention an 11-year cycle, but the 11-yr cycle is not visible in the power spectrum (Fig. 6), and the Results section only mentions the 8.9-yr cycle, whereas the Discussion section mentions a 8.9-11.5-yr cycle. But where did the 11- or 11.5-yr cycle come from? There is no mention of this and this a confusing.

The authors' response: Comment accepted. We made changes to the manuscript in accordance with this comment, comment #5 and new results obtained. According to an earlier study (Zhu et al., 2016), the 11-year cycle of solar activity in tree-ring reconstructions can be detected as a 8.5-11.5-year.

7. Comment: Finally, a more general criticism of this aspect concerns the discussion of the origin of the periodicities. The main problem is that the periodicities, in particular the 8.9- and 189-yr cycles, uncritically are taken as direct evidence for a strong solar influence on climate on these time scales. While the Sun may have driven climate change on these time scales in the study area, it is simply not enough to infer this based on periodicities that resemble those of the Sun (which on average are 11 and 210 yeas, respectively). In such a record, there will almost always be periodicities that resemble those of the Sun and it therefore takes more to infer causality. In the authors want to establish that the Sun influenced climate in the area, they should engage in much more detailed analysis of the new tree-ring climate record and records of solar activity and calculate correlations, lads, and compare those to red-noise models. It would also be interesting to establish if the cold period indeed corresponds to solar minima – as stated in the abstract – but such an analysis is completely missing.

The authors' response: Comment accepted. We agree that the identification of similar cycles cannot be a direct evidence of the influence of solar activity on the tree growth. Also, the correlation of solar activity indicators with reconstructed temperatures is also not a direct evidence of this. For a full answer to this question, more in-depth studies are needed that, to our opinion, go beyond the scope of this article. However, studies by other authors (e.g., Raspopov et al., 2008) indicate that both short-period and long-period solar activity cycles are directly tracked in tree-ring records and we base our research on these studies.

As for comparison of the reconstructed temperatures with the solar activity minimums, we performed an analysis of relationship between our reconstruction and TSI using the KNMI Climate Explorer (http://climexp.knmi.nl). As a result, we obtained a significant correlation with this indicator. In addition, there is analysis of individual cold periods at the end of the 17th century and historical records for neighboring regions in the main text of the manuscript (lines 294-298).

Minor comments

L. 19. Abstract: It is unclear what you mean by "de-Vier quasi-200 quazi-200 solar activity cycle." Presumably this refers to the de Vries (or Suess) 210-year solar cycle. The word "year" is also missing.

The authors' response: Comment accepted.

L. 47. "It is well known that warming of the climate is correlated with solar activity". This sentence and the following sentence suggest that solar activity is the only source of warming, including global warming. You need to be much more precise with respect to what you mean here. Also, solar activity is a driver of climate change, but it is not strong driver a temperature changes compared to changes in greenhouse gases.

The authors' response: Comment accepted. Line 49.

L. 128-129. Maybe spell out what is meant by “...it matches a minimum sample depth of 3 trees in this segment”.

The authors’ response: This is common expression that mean a number of samples in this part of tree-ring chronology. Usually this expression doesn’t need explanation.

L. 133. Where is the Chuguevka meteorological station relative to the sample site? This is really an import aspect.

The authors’ response: Comment accepted. Line 135.

L. 175. There is no “Y” in the equation – guess this refers to “VUSr”?

The authors’ response: Comment accepted. Line 188.

L. 297. “The period of landscape formation......during the transition”. This is unclear, as the landscape formation occurred long before the Little Ice Age – do you refer to vegetation changes?

The authors’ response: Comment accepted. Line 330.

L. 326-327. This sentence makes no sense to me – how is this related to the sentences above (which it refers to)?

The authors’ response: Comment accepted. We rewrote the sentence (L380-382).

Figures Figure 3

It is unclear what the sample depth refers to. Is it he number of tree records?

The authors’ response: Indeed, this is the common designation of the number of samples.

Figure 7

It is the correlation coefficient that is plotted here – this is not clear to me? It is also unclear if the signifance refers to all colours, so that for white areas there is no correlation at the 10% signifaince level? It would be very helpful if the geographical position of the record from this study (Fig. 8a) and the two nearby records in Figs. 8c and 8d could be indicated in this plot.

The authors’ response: Comment accepted. In according to Editor’s recommend we added locations on the Fig 1. As indicated in the caption to this figure, it shows the significant value of the correlation coefficient between our data (instrumental observations - Fig. 7a, reconstruction - Fig. 7b) and model calculated temperatures of the earth's surface (CRU TS 4.00).

Autumn – winter minimum temperature changes in the southern Sikhote-Alin mountain range of northeast Asia since 1529 AD

Olga N. Ukhvatkina, Alexander M. Omelko, Alexander A. Zhmerenetsky, Tatyana Y. Petrenko.

Federal Scientific center of the East Asia terrestrial biodiversity Far Eastern Branch of Russian Academy of Sciences, Vladivostok 690022 RUSSIA

Correspondence to: Olga Ukhvatkina (ukhvatkina@gmail.com)

Abstract. The aim of our research was to reconstruct climatic parameters (for the first time for the Sikhote-Alin mountain range) and to compare them with global climate fluctuations. As a result, we have found that one of the most important limiting factors for the study area is the minimum temperatures of the previous autumn-winter season (August-December), and this finding perfectly conforms to that in other territories. We reconstructed the previous August-December minimum temperature for 485 years, from 1529 to 2014. We found twelve cold periods (1535-1540, 1550-1555, 1643-1649, 1659-1667, 1675-1689, 1722-1735, 1791-1803, 1807-1818, 1822-1827, 1836-1852, 1868-1887, 1911-1925) and seven warm periods (1560-1585, 1600-1610, 1614-1618, 1738-1743, 1756-1759, 1776-1781, 1944-2014). These periods correlate well with reconstructed data for the Northern Hemisphere and the neighboring territories of China and Japan. Our reconstruction has 3, 9, 20 and 200-year periods, which are may be in line with high-frequency fluctuations in ENSO, the short-term solar cycle, PDO fluctuations and the 200-year solar activity cycle, respectively. We suppose that the temperature of North Pacific, expressed by Pacific Decadal Oscillation may make a major contribution to regional climate variations. We also assume that the regional climatic response to solar activity becomes apparent in the temperature changes in the northern part of Pacific Ocean and corresponds to cold periods during the solar minimum. These comparisons show that our climatic reconstruction based on tree-ring chronology for this area may potentially provide a proxy record for long-term, large-scale past temperature patterns for northeast Asia. The reconstruction reflects the global traits and local variations in the climatic processes of the southern territory of the Russian Far East for more than the past 450 years.

1 Introduction

Global climate change is the main challenge for human life and natural systems, which is why we should clearly understand climatic changes and their mechanisms. A retrospective review of climatic events is necessary for understanding the climatic conditions from a long-term perspective. At the same time, instrumental climate observations rarely cover more than a 100-year period and are often restricted to 50-70 years. This restriction forces the researchers to continuously find new ways and methods to reconstruct climatic fluctuations. Dendrochronology has been widely applied in climatic reconstruction for local territories and at the global scale for both climatic reconstructions of the past few centuries and paleoclimatic reconstructions because it is rather precise, extensively used and a replicable instrument (Corona et al.; Popa and Bouriaund, 2014; Kress et al., 2014; Lyu et al., 2016).

A great number of studies have focused on climatic change reconstruction for the northeastern parts of China based on *P. koraeinsis* radial growth studies (e.g., Zhu et al., 2009; Wang et al., 2013; Wang et al., 2016; Zhu et al., 2015; Lyu et al. 2016). Climatic parameters were reconstructed for the whole Northern Hemisphere (Wilson et al., 2016), China (Ge et al., 2016), and temperature characteristics were reconstructed for northeastern Asia (Ohyama et al., 2013). Despite this, there are very few studies of Russian Far East climate (e.g., Willes et al., 2014; Jacoby et al., 2004; Shan et al., 2015); moreover, there is an absence of dendrochronological studies for the continental part of Russian Far East. Meanwhile, most of species present in northeastern China, the Korean peninsula and Japan grow in this region. In addition, the distribution areas of these trees often end in the south of the Russian Far East, which increases the climatic sensitivity of plants. Additionally, some parts of the forests in the Russian Far Eastern have not been subjected to human activity for the last 2000-4000 years. This makes it possible to forests extend the studied timespan. In addition, the southern territory of the Russian Far East is sensitive to global climatic changes as it is under the influence of cold air flow from northeastern Asia during the winter and summer monsoons. All of the factors listed above create favorable conditions for dendroclimatic studies.

It is well-known that cold and warm periods of the climate is correlated with intensive solar activity (e.g., the Medieval Warm Period), while decreases in temperature occurs during periods of low solar activity (e.g., the Little Ice Age; Lean and Rind, 1999; Bond et al., 2001). According to findings from an area of China neighboring the territory studied here, the registered warming has been significantly affected by global warming since the 20th century (Ding and Dai, 1994; Wang et al., 2004; Zhao et al., 2009), which is often indicated by a faster rise in night or minimum temperatures (Karl et al., 1993; Ren and Zhai, 1998; Tang et al., 2005). To better understand and evaluate future temperature change trends, we should study the long-term history of climatic changes.

However, using tree-ring series for northeastern Asia (particularly temperature) is rather complicated due to the unique hydrothermal conditions of the region. Most reconstructions cover periods of less than 250 years (e.g., Shao and Wu, 1997; Zhu et al., 2009; Wang et al., 2012; Li and Wang, 2013; Yin et al., 2009; Zhu et al., 2015), except for a few with periods up to 400 years (Lyu et al., 2016; Wiles et al., 2014). The short period of reconstructions is the reason why such reconstructions cannot capture low-frequency climate variations.

The warming of the climate (particularly minimum temperature increase) is registered across the whole territory of northeastern Asia (Lyu et al., 2016). In the Russian Far-East, such warming has been recorded for more than 40 past years (Kozhevnikova, 2009). However, the lack of detailed climatic reconstructions for the last few centuries makes it difficult to capture long-period climatic events for this territory and interpret the temperature conditions for the last 500-1000 years.

Therefore, the main objectives of this study were (1) to develop the first three-ring-width chronology for the southern part of the Russian Far East; (2) to analyze the regime of temperature variation over the past centuries in the southern part of the Russian Far East; (3) to identify the recent warming amplitude in context of long-term changes and to analyze the periodicity of climatic events and their driving forces. Our new minimum temperature record supplements the existing data for northeast Asia and provides new evidence of past climate variability. There is the potential to better understand future climatic trajectories from these data in northeast Asia.

2 Materials and methods

2.1 Study area

We studied the western macroslope of the southern part of the Sikhote-Alin mountain range (Southeastern Russia) at the Verkhneussuriysky Research Station of the Federal Scientific Center of the East Asia terrestrial biodiversity Far East Branch of the Russian Academy of Sciences (4400 ha; N 44°01’35.3’’, E 134°12’59.8’’, Fig. 1).

The territory is characterized by a monsoon climate with relatively long, cold winters and warm, rainy summers. The average annual air temperature is 0.9 °C; January is the coldest month (–32 °C average temperature), and July is the warmest month (27 °C average temperature). The average annual precipitation is 832 mm (Kozhevnikova, 2009). Southerly and southeasterly winds predominate during the spring and summer, while northerly and northwesterly winds predominate in autumn and winter. The terrain includes mountain slopes with an average angle of ~ 20°, and the study area is characterized by brown mountain forest soils (Ivanov, 1964) (Fig. 2).

Mixed forests with Korean pine (*Pinus koraeinsis* Siebold et Zucc.) are the main vegetation type in the study area, and they form an altitudinal belt up to 800 m above sea level. These trees are gradually replaced by coniferous fir-spruce forests at high altitudes (Kolesnikov, 1956). Korean pine-broadleaved forests are formed by up to 30 tree species, with *Abies nephrolepis* (Trautv.) Maxim, *Betula costata* (Trautv.) Regel., *Picea jezoensis* (Siebold et Zucc.) Carr., *P. koraeinsis* and *Tilia amurensis* Rupr. being dominant.

Korean pine-broadleaved forests are the main forest vegetation type in the Sikhote-Alin mountain range in the southern part of the Russian Far East. This area is the northeastern limit of the range of Korean pine-broadleaved forests, which are also found in northeastern China (the central part of the range), on the Korean peninsula, and in Japan. The Sikhote-Alin mountain range is one of the few places where significant areas of old-growth Korean pine-broadleaved forest remain. In the absence of volcanic activity, which is a source of strong natural disturbances in the central part of the range (Liu, 1997; Ishikava, 1999; Dai et al., 2011), wind is the primary disturbance factor on this territory. Wind causes a wide range of disturbance events, from individual treefalls to large blowdowns (Dai et al., 2011).

Approximately 60% of the Research Station area had been subjected to selective clear-cutting before the station was established in 1972. The remaining 40% of its area has never been clear-cut and is covered by unique old-growth forest.

2.2 Tree-ring chronology development

Our study is based on data collected in a 10.5-ha permanent plot (Omelko and Ukhvatkina, 2012; Omelko et al., 2016), which was located in the middle portion of a west-facing slope with an angle of 22° at a gradient altitude 750-950 m above sea level. The forest in the plot was a late-successional stand belonging to the middle type of Korean pine-broadleaved forests at the upper bound of the distribution of Korean pine, where it forms mixed stands of Korean pine-spruce and spruce-broadleaved forests (Kolesnikov, 1956).

One core per undamaged old-growth mature tree (25 cores from 25 trees) and one sample from dead trees (20 samples) were extracted from *P. koraiensis* trees in the sample plots from the trunks at breast height. In the laboratory, all tree-ring samples were mounted, dried and progressively sanded to a fine polish until individual tracheids within annual rings were visible under an anatomical microscope according to standard dendrochronological procedures (Fritts, 1976; Cook and Kairiukstis, 1990). Preliminary calendar years were assigned to each growth ring, and possible errors in measurement due to false or locally absent rings were identified using the Skeleton-plot cross-dating method (Stokes and Smiley, 1968). The cores were measured using the semi-automatic Velmex measuring system (Velmex, Inc., Bloomfield, NY, USA) with a precision of 0.01 mm. Then, the COFECHA program was used to check the accuracy of the cross-dated measurements (Holmes, 1983). To mitigate the potential trend distortion problem in traditionally detrended chronology (Melvin and Briffa, 2008; Anchukaitis et al., 2013), we used a signal-free method (Melvin and Briffa, 2008) to detrend the tree-ring series using the RCSigFree program (http://www.ldeo.columbia.edu/tree-ring-laboratory/resources/software).

Age-related trends were removed from the raw tree-ring series using an age-dependent spline smoothing method. The ratio method was used to calculate tree-ring indices, and the age-dependent spline was selected to stabilize the variance caused by core numbers. Finally, the stabilized signal-free chronology was used for the subsequent analysis (Fig. 3). The mean correlations between trees (*R*bt), mean sensitivity (MS) and expressed population signal (EPS) were calculated to evaluate the quality of the chronology (Fritts, 1976). *R*bt reflects the high-frequency variance, and MS describes the mean percentage change from each measured annual ring value to the next (Fritts, 1976; Cook and Kairiukstis, 1990). EPS indicates the extent to which the sample size is representative of a theoretical population with an infinite number of individuals. A level of 0.85 in the EPS is considered to indicate a chronology of satisfactory quality (Wigley *et al.*, 1984). The statistical characteristics of the chronology are listed in Table 1.

The full length of the chronology spans (VUS chronology) from 1451 to 2015. A generally acceptable threshold of the EPS was consistently greater than 0.85 from AD 1602 to 2015 (9 trees; Fig. 3b), which affirmed that this is a reliable period. However, although the EPS value from AD 1529 to 1602 was less than 0.85, it matches a minimum sample depth of 4 trees in this segment (EPS>0.75). Although the record from AD 1529 to 1602 is thus less certain, we here report it as it is very important to extend the tree-ring chronology as much as possible because there are only a few long climate reconstructions in this area. Therefore, we retained the part from 1529 to 1602 in the reconstruction.

2.3 Climate data and statistical methods

Monthly precipitation, monthly mean and minimum temperature data were obtained from the Chuguevka meteorological station (44.151462 N, 133.869530 E, about 30 km from Verkhneussuriisky research station) and the meteorological post at the Verkhneussuriisky research station of the Federal Scientific Center of the East Asia terrestrial biodiversity FEB RAS (Meteostation 7 – MP7) as well. The periods of monthly data available from the Chuguevka and Verkhneussuriisky stations are 1936-2004 and 1969-2004, respectively (1971-2003 for minimum temperature data from the Chuguevka).

The data of large-scale climate conditions, such as the Northern Hemisphere temperature (NH), North Atlantic Oscillation (AMO), Pacific Decadal Oscillation (PDO) and Nino3 reconstruction (Mann et al., 2009), and also indicators of solar activity, such as reconstructed solar constant (TSI, Lean, 2000) and sun spot number (SSN) were downloaded and analyzed in Royal Netherlands Meteorological Institute climate explorer (http://climexp.knmi.nl).

To demonstrate that our reconstruction representative and reflect temperature variations, we conduced spatial correlation between our temperature reconstruction and gridded temperature dataset of the Climate Research Unit (CRU TS4.00) for the period 1960-2003, by using the Royal Netherlands Meteorological Institute climate explorer (http://climexp.knmi.nl).

2.4 Statistical analyses

A correlation analysis was used to evaluate the relationships between the ring-width index and observed monthly climate records from the previous June to the current September. To identify the climate-growth relationships of Korean pine in the southern Sikhote-Alin mountain range, a Pearson's correlation was performed between climate variables and tree-width index. We used a traditional split-period calibration/verification method to explore the temporal stability and reliability of the reconstruction model (Fritts, 1976; Cook and Kairiukstis, 1990). The Pearson's correlation coefficient (r), R-squared (R^2), the redaction of the error (RE) the coefficient of efficiency (CE), and the product means test (PMT) were used to verify the results. Analyses were carried out in R using the treeclim package (Zang and Biondi, 2015) and STATISTICA software (StatSoft®). Analyses of reconstruction included multi-taper method (MTM) (Mann & Lees, 1996) and Monte Carlo Singular Spectrum Analysis (SSA; Allen and Smith, 1996). Analysis was carried out in SSA-MTM Toolkit for Spectral Analysis software (Ghil et al., 2001; Dettinger et al., 1995).

3 Results

3.1 Climate-radial growth relationship

Relationships between the VUS chronology and monthly climate data are shown in Fig 4. To reveal the correlation between climatic parameters and radial growth change of *P. koraiensis,* we had three data sets: the first-time series had a length of 68 years (1936-2004, Chuguevka), the second had a length of 34 years (1966-2000, MP7), and the third had a length of 33 years (1971-2003, Chuguevka, minimum temperature). To select the appropriate parameters, we analyzed all datasets. As a result, we revealed a reliable but slight positive correlation between *P. koraiensis* growth and precipitation in May and June of the current year and September of the previous year in the territory of Chuguevka village (Fig. 4a). There is also a slight positive correlation with precipitation in September of the previous year and May of the current year at Metheostation 7 (MP7) (Fig. 4b). In addition, we revealed a slight negative correlation with precipitation in February-March of the current year.

As for the correlation between temperature and *P. koraiensis* growth, the analysis reveals a weak positive correlation with the average monthly temperature in June of the previous year and in February-April of the current year in the Chuguevka settlement and a slight negative correlation with the average monthly temperature in June-July as well (Fig. 4c). The analysis of the correlation with the average monthly temperature at Metheostation 7 (MP7) shows us a weak positive correlation with temperature in August and December of the preceding year and a negative correlation with temperature in July of the current year (Fig. 4d). In addition, we analyzed the correlation with minimum average monthly temperatures at MP7 and Chuguevka. The revealed correlation with minimum temperature is reliable but weak (Fig. 4e,f).

Moreover, based on the weak interaction that was revealed, we analyzed the correlation with climatic parameters for selected ranges of months (Fig. 4h,g). The highest significant correlation appears between growth and the minimum monthly temperature of August-December of the previous year at Chuguevka (Fig. 4h), on which we base our subsequent reconstructions.

3.2 Minimum temperature reconstruction

Basing on analysis of the correlation between climatic parameters and Korean pine growth, we constructed a linear regression equation to reconstruct the minimum monthly temperature of August-December of the previous year (VUSr). The transfer function was as follows:

$$VUSr = 7.189X_t - 15.161$$

$$(N=32,\ R=0.620,\ R^2=0.385,\ R^2_{adj}=0.364,\ F=18.76,\ p < 0.001)$$

where *VUSr* is the August-December minimum temperature at Chuguevka and *X* is the tree-ring index of the Korean pine RSC chronology in year *t*. The comparison between the reconstructed and observed mean growing season temperatures during the calibration period is shown in Fig. 5(a). The cross-validation test for the calibration period (1971-1997, R=0.624) yielded a positive RE of 0.334, a CE of 0.284, and the cross-validation test for calibration period 1977-2003 (R=0.542) a positive RE of 0.654, a CE 0f 0.644, confirming the predictive ability of the model. Although during the study period, the model shows the observed values very well, the short observation period (1971-2003) does not allow using split-sampling calibration and verification methods in full for evaluating quality and model stability. This limitation is why we used a bootstrapping resampling approach (Efron, 1979; Young, 1994) for stability evaluation and transfer function precision. The idea that this method is based on indicates that the available data already include all the necessary information for describing the empirical probability for all statistics of interest. Bootstrapping can provide the standard errors of statistical estimators even when no theory exists (Lui et al., 2009). The calibration and verification statistics are shown in Table 2. The statistical parameters used in bootstrapping are very similar to those from the original regression model, and this proves that the model is quite stable and reliable and that it can be used for temperature reconstruction.

3.3 Temperature variations from AD 1529 to 2014 and temperature periodicity

Variations in the reconstructed average minimum temperature of the previous August-December (VUSr) since AD 1529 and its 21-year moving average are shown in Fig. 5b. The 21-year moving average of the reconstructed series was used to obtain low-frequency information and analyze temperature variability in this region. The mean value of the 486-year reconstructed temperature was -7.93° C with a standard deviation of ±1.40° C. We defined warm and cold periods as when temperature deviated from the mean value plus or minus 0.5 times the standard deviation, respectively (Fig. 5b). If the reconstructed minimum temperatures were above or below the average value by >0.5 SD for three or more years, then we considered this deviation as warm or cold period, respectively. Also, if two warm (or cold) periods were separated by one year, when the temperature sharply decreased (or increased), then such periods merged into one.

Hence, warm periods occurred in 1560-1585, 1600-1610, 1614-1618, 1738-1743, 1756-1759, 1776-1781, 1944-2014, and cold periods appeared in 1535-1540, 1550-1555, 1643-1649, 1659-1667, 1675-1689, 1722-1735, 1791-1803, 1807-1818, 1822-1827, 1836-1852, 1868-1887, 1911-1925. Among them, the four warmest years were in 1574 (-4.35° C), 1606 (-5.35° C), 1615 (-5.71° C), 1741 (-5.36° C), 1757 (-6.16° C), 1779 (-5.21° C), 2008 (-2.72° C), while the three coldest year were in 1543 (-9.84° C), 1551 (-9.88° C), 1647 (-10.77° C), 1662 (-11.10° C), 1685 (-9.45° C), 1728 (-10.08° C), 1799 (-10.70° C), 1815 (-10.13° C), 1825 (-9.87° C), 1843 (-10.55° C), 1883 (-10.73° C), 1913 (-10.29° C). The longest cold period extended from 1868 to 1887, and the longest warm period extended from 1944 to present day. The coldest year is 1662 (-11.10° C) and the warmest year is 2008 (-2.72° C).

The MTM spectral analysis over the full length of our reconstruction revealed significant ($p < 0.05$) cycle peaks at 2.3-year (95%), 2.5-year (99%), 2.9-year (99%), 3.0-year (99%), 3.3-year (95%), 3.7-year (95%), 8.9-year (99%) short periods and 20.4-year (95%), 47.6-year (95%), 188.7-year (99%) long periods (Fig. 6). Singular spectrum analysis (SSA) reveals 8 leading temporal modes that significant at the 95% confidence level (Allen & Smith, 1996). Of these, SSA analysis reveals a single significant low order mode variability near 200 years, but there is little evidence in the reconstruction variability at the 40-50 years. Also 3 significant power periods were reveals: 20.4-year, 9-year and near 3-year periods. Comparison of the reconstruction and global temperature for oceans of Northern Hemisphere (NH), North Atlantic Oscillation (AMO), Pacific Decadal Oscillation (PDO) and Nino3 reconstruction (Mann et al., 2009) show significant correlation between reconstruction and NH (r=0.67, p<0.0001), AMO (r=0.49, p<0.001), and PDO (r=0.68, p<0.0001), and non-significant correlation between reconstruction and Nino3 reconstruction (r=0.27, p=0.08). Comparison of the reconstruction and indicators of solar activity shows significant correlation of the minimum temperature with the TSI (r=0.52, p<0.0001) and non-significant correlation with SSN (r=0.26, p<0.1). Comparison of the instrumental climate data and instrumental indicators of solar activity shows significant correlation of the minimum temperature with the TSI (r=0.52, p<0.0001) and non-significant correlation with SSN (r=0.26, p<0.1).

Spatial correlations between our reconstruction and the CRU TS4.00 temperature dataset reveal our record's geographical representation (Fig. 7). The results show that the reconstruction of mean minimum temperature of previous August – December is significantly positively correlated with the CRU TS4.00 (r=0.568, p<0.0001).

4 Discussion

4.1 Climate-growth relationships

The results of our analysis suggest that the radial growth of Korean pine in the southern part of the Sikhote-Alin mountain range is mainly limited by the pre-growth autumn-winter season temperatures, in particular the minimum temperatures of August-December (Fig. 4). It is widely known that tree-ring growth in cold and wet ecotopes, situated on sufficiently high elevation in the Northern Hemisphere, strongly correlate with temperature variability in large areas of Asia, Eurasia, North America (Zhu et al., 2009; Anchukaitis et al., 2013; Thapa et al., 2015; Wiles et al., 2014). The limiting influence of temperature on *P. koraiensis* growth has been mentioned in many studies (Wang et al., 2016; Yin et al., 2009; Wang et al., 2013; Zhu et al., 2009). However, the temperature has various limiting effects in different conditions, and these limiting effects manifest in different ways (Wang et al., 2016). For example, Zhu et al., 2016 indicates that in more northern and arid conditions of the Zhangguangcai Mountains, while precipitation is not the main limiting factor, precipitation is considerably below evaporation during the growth season. This finding is why a stable correlation between *P. koraiensis* growth and the growth season temperature is revealed. This finding is also why moisture availability in soil might be the main limiting factor for Korean pine growth (Zhu et al., 2016), but the emergence of this circumstance can be different in different conditions.

The correlation between growth and minimum temperatures in August-December of the previous year, as revealed in our research, was also mentioned for Korean pine in other works (Wang et al., 2016; Zhang et al., 2015). This finding may be explained by the following circumstances. Extreme temperatures limit the growth of trees at the tree line or in high-latitude forests (Wilson and Luckman, 2002; Körner and Paulsen, 2004; Porter et al., 2013; Yin et al., 2015). Taking into consideration the fact that the study area is situated at the altitudinal limit of Korean pine forest distributions, in particular the Korean pine (Kolesnikov, 1956), these findings seem to be reliable.

In addition, in the conditions close to extreme for this species, low temperatures in autumn-winter may lead to thicker snow cover, which melts far more slowly in spring (Zhang et al., 2015). The study area is notable for its dry spring, and the amount of precipitation is minimal during the most important period of tree-growth in April-May (Kozhevnikova, 2009). If the vegetation period of the plant cannot begin at the end of March and packed snow cover melting is impeded up until the beginning of May, plant growth may be reduced. Moreover, although cambial activity stops in the winter, organic components are still synthesized by photosynthesis. Low temperatures (in the territory of the VUSr it can reach -48°C in certain years) may induce to loss of accumulated materials, which adversely affects growth (Zhang et al., 2015). The study area is in the center of the vegetated area, where the conditions for Korean pine growth are optimal during the growing season, and only minimum temperature is regarded as an extreme factor.

4.2 Comparison with other tree-ring-based temperature reconstructions

At present, temperature reconstructions are uncommon for the Russian Far East, and research sites are located for thousands of kilometers away from one another. For example, Wiles et al. undertook a study of summer temperatures on Sakhalin Island (Wiles et al., 2014). Unfortunately, it is impossible to compare our findings with theirs because Sakhalin Island is climatically far more similar to Japanese islands than to the Sikhote-Alin mountains, and temperature variations in their study area are mainly caused by oceanic currents.

In addition, instrumental observations from the study area rarely encompass a period longer than 50 years (and studies have only been conducted for large settlements). Consequently, the tree-ring record serves as a good indicator of the past cold-warm fluctuations in the Russian Far East. The analysis of spatial correlations between our reconstruction and the CRU TS4.00 temperature dataset reveal spatial correlations between the observed and reconstruction minimum temperatures from the CRU TS4.00 gridded T_{min} dataset during the baseline period of 1960-2003 (Fig. 7). It's indicating that our temperature reconstruction is representative of large-scale regional temperature variations and can be taken as representative of southeastern of the Russian Far East and northeastern of the China.

To identify the regional representativeness of our reconstruction, we compared it with two temperature reconstructions for surroundings areas (Fig. 1) and a reconstruction for the Northern Hemisphere (Fig. 8). The first reconstruction was for summer temperatures in the Northern Hemisphere (Wilson et al., 2016; Fig. 1). The second reconstruction was an April-July tree-ring-based minimum temperature reconstruction for Laobai Mountain (northeast China), which is approximately 500 km northwest of our site. The third was a February-April temperature reconstruction for the Changbai Mountain (Zhu et al., 2009; Fig. 1), which are approximately 430 km southwest of our site. Although the spring and summer temperatures have been reconstructed in the last two cases, we use these reconstructions for comparison, because, firstly, there are no other reconstructions for this region, and secondly, despite the possible seasonal shifts, long cold and warm periods should be identified in all seasons.

Cold and warm periods are shown in table 3 (the duration is given by the authors of the article). The reconstructions show that practically all cold and warm periods coincide but have different durations and intensities. The data on Northern Hemisphere show considerable overlaps of cold and warm periods, and the correlation between reconstructions is 0.45 ($p > 0.001$). At the same time, we found the warm period 1560-1585, which is not clearly shown in reconstruction for the Northern Hemisphere, though the general trend of temperature change is maintained during this period (Fig. 8). Long cold periods from 1643 to 1667 and 1675-1690 that were revealed for another territory (Lyu et al., 2016; Wilson et al., 2016) coincided with the Maunder Minimum (1645–1715), an interval of decreased solar irradiance (Bard et al., 2000). The coldest year in this study (1662) revealed in this period too. The Dalton minimum period centered in 1810 is also notable. Interestingly that cold periods of 1807-1818, 1822-1827, 1836-1852 and 1868-1887 is also registered in reconstructions for Asia (Ohayama et al., 2013) and by Japanese researchers (Fukaishi & Tagami, 1992; Hirano & Mikami, 2007). Moreover, instrumental observations reconstructed for western Japanese territories (the nearest to the study area) provide evidence of a cold period in the 1830s-1880s with a short warm spell in the 1850s (Zaiki et al., 2006), which is in agreement with our data (not reliably period 1855-1865, Tabl. 3). For this period, there are contemporaneous records of severe hunger in Japan in 1832 and 1839, which was the result of a summer temperature decrease and rice crop failure (Nishimura & Yoshikawa, 1936).

In this case, the longer cold period for the study area can be explained by the relatively lower influence of the warm current and monsoon and generally colder climate in the south of the Russian Far East compared with Japanese islands. The differing opinion about the three cold periods in China in the 17th, 18th and 19th centuries (Wang et al., 2003) is also corroborated by our reconstruction. The cold period in the 19th century is even more pronounced than that reported by Lyu et al., 2016. Moreover, Lyu et al., 2016 corroborate that the ascertained cold period in 19th century is more evident in South China, but it is less clear in the northern territories or has inverse trend. Although the Russian Far East is further north than the southern Chinese provinces and is closer to the northern part of the country, the marked monsoon climate likely made it possible to reflect the general cold trend in 19th century, which was typical both for China and the entire Northern Hemisphere. Because of this possible explanation, the cold period in the 19th century for the Changbai Mountains shows up more distinctly than for the northern and western territory of Laobai Mountain (Fig. 8).

Apparently, this discrepancy in regional climate flow is the reason that our reconstruction agrees well with the general reconstruction for the whole hemisphere ($r = 0.45$, $p<0.001$) and to a lesser extent agrees with the regional curves for Laobai Mountain ($r = 0.23$, $p<0.001$) and Changbai Mountain ($r = 0.32$, $p<0.001$).

The changing dynamics of the 20th century temperature is also interesting to watch. The comparison of the minimum annual temperatures for the territory and the reconstructed data for the period of 1960-2003 shows significant data correlation (Fig. 7), including the northeast part of China. At the same time, for Chinese territory (both for southwest regions and for more northwestern regions), the warming is apparent only in the last quarter century (Zhu et al., 2009) or at the end of the 20th century (Lyu et al., 2016) (Fig. 8 c,d). This trend, revealed for the southern Sikhote-Alin mountains (a warm spell since 1944), is corroborated for the whole Northern Hemisphere (Wison et al., 2016) (Fig. 8a,b). The maximum cold period is also corroborated, which we note for the 19th century (Fig. 8a,b).

The probable explanation is in the regional climate flow differences in the compared data. The territory of northeastern China is more continental, though the influence of the Pacific Ocean is also notable. At the same time, the southern part of the Sikhote-Alin mountains is more prone to the influence of monsoons, as are the Japanese islands. According to paleoreconstructions, the Little Ice Age occurred in the Northern Hemisphere 600-150 years ago (Borisova, 2014). The period of landscape formation (vegetation types and altitudinal zonation) for the Sikhote-Alin range during the transition from the Little Ice Age to contemporary conditions occurred within the last 230 years (Razzhigaeva et al., 2016). The timeframe of the Little Ice Age is generally recognized as varying considerably depending on the region (Bazarova et al., 2014). However, it is certain that the Little Ice Age is accompanied by an increase in humidity in coastal areas of northeast Asia (Bazarova et al., 2014). Thus, in similar conditions on the Japanese islands, the Little Ice Age was accompanied by lingering and intensive rains (Sakaguchi, 1983), and the last typhoon activity was registered for the Japanese islands from the middle of the 17th century to the end of the 19th century (Woodruff et al., 2009). At the same time, the reconstruction of climatic changes for the whole territory of China for the last 2000 years (Ge et al., 2016) shows that the cold period lasted until 1920, which correlates with the data we obtained. This timespan wholly coincides with our data, and we can draw the conclusion that in the southern region of the Sikhote-Alin mountains, the Little Ice Age ended at the turn of the 19th century.

Unfortunately, when comparing temperature, different changes were also observed for some cold and warm years (Fig. 8). This finding may be attributed to differences in the reconstructed temperature parameters (such as average value, minimum temperature and maximum temperature) and environmental conditions in different sampling regions. Recent studies show that the oscillations in the medium, minimum and maximum temperature are often asymmetrical (Karl et al., 1993; Xie and Cao, 1996; Wilson and Luckman, 2002, 2003; Gou et al., 2008). The global warming over the past few decades has been mainly caused by the rapid growth of night or minimum temperatures but not maximum temperatures. Meanwhile, some differences between the reconstructed temperature values were well explained by a comparison with similar areas.

We can conclude that the analysis shows that the reconstructed data is representative for large-scale regional temperature variations (Fig. 7). At the same time, some cold and warm periods in our reconstruction and other neighbored studies do not coincide (Fig. 8), which can be due to the reconstruction of other climatic parameters and differing environmental conditions. So, we believe that these results can characterize regional climate variations and provide reliable data for large-scale reconstructions for the northeastern portion of Eurasia, but their use for large-scale regional reconstructions requires further research.

4.3 Periodicity of climatic changes and their links to global climate processes

Among the significant periodicities in the reconstructed temperature detected by the MTM analysis (Fig. 7), some peaks were singled out: 2.3-year (95%), 2.5-year (99%), 2.9-year (99%), 3.0-year (99%), 3.3-year (95%), 3.7-year (95%), 8.9-year (99%) short periods and 20.4-year (95%), 47.6-year (95%), and 188.7-year (99%) long periods. SSA analysis shows significant near 3-year, 9-year, 20.4-year and 200-year periods.

The 3-year cycle may be linked with the El Niño-Southern Oscillation (ENSO). These high-frequency (2-7-year) cycles (Bradley *et al.*, 1987) have also been found in other tree-ring-based temperature reconstructions in northeast Asia (Zhu *et al.*, 2009; Li and Wang, 2013; Zhu et al., 2016; Gao et al., 2015). The 2–3-year quasi-cycles may also correspond to the quasi-biennial oscillation (Labitzke and van Loon, 1999) and the tropospheric biennial oscillation (Meehl, 1987). Despite the fact that many authors establish linkage between 2-7-year cycles and El Niño-Southern Oscillation (ENSO) or quasi-biennial oscillation in northeastern Asia, we couldn't find significant correlation between the August-December minimum temperature reconstruction and Nino3, but the analysis showed significant correlation between the reconstruction and the temperature of Northern Hemisphere oceans. It probably mean that the temperature variations are more associated with the influence of PDO than ENSO.

On the decadal timescale analysis showed 20-year cycles which may reflect processes influenced by Pacific Decadal Oscillation (PDO, Mantua and Hare 2002) variability, which has been found at 15-25-yr and 50-70-yr cycles (Ma, 2007). Our analysis shows a significant correlation (r=0.68, p<0.0001) between reconstruction and the mean annual PDO index of Mann et al. (2009) from 1900-2000. Taking into account that many researchers, who studied on the territory of northeast Asia have also revealed these cycles in relation to the Korean pine, we hypothesize that the Korean pine tree-ring series support the concept of long-term, multidecadal variations in the Pacific (e.g., D'Arrigo et al., 2001; Cook, 2002; Jacoby et al., 2004; Liu et al., 2009; Li, Wang, 2013; Willes et al., 2014; Lu, 2016) and that such variation or shifts have been present in the Pacific for several centuries. The PDO is a main index of major variations in the North Pacific climate and ocean productivity (Mantua et al., 1997; Jacoby et al., 2004). In particular, according to instrumental data analysis (Shatilina, Anzhina, 2008), the last warming of the northern part of the Pacific Ocean (since 1970s) resulted in the intensive temperature increase and precipitation decrease in the southern part of the Russian Far East.

We suppose that 9-year cycle may be related to solar activity, as, first of all, many authors showed influence of solar activity on the climate variability (Bond et al., 2001; Lean et al., 1999; Lean, 2000; Mann et al., 2009; Zhu et al., 2016). Secondly, the significant correlation between of the August-December minimum temperature reconstruction and TSI can be regarded as an additional evidence of this assumption. And, finally, there is a coincidence of the reconstructed cold periods with the Maunder Minimum (1645–1715) and the Dalton minimum period centered in 1810. The solar activity influence in the region is traditionally associated with an indirect effect on the circulation of the atmosphere (Erlykin et al., 2009; Fedorov et al., 2015). In the second half of the 20th century the solar radiation intensity changes contributed to more intensive warming of the equatorial part of the Pacific Ocean and more active inflow of warm air masses to the north (Fedorov et al., 2015).

In spite, the fact that it is quite difficult to reveal for certain long-period cycles in a 486-year chronology, we nonetheless revealed the 189-year cycle (MTM) or 200-year cycle (SSA analysis), which probably may possibly be linked to the solar activity. Close periodicity is revealed in long-term climate reconstructions and is linked to the quasi-200-year solar activity cycle in other study (Raspopov et al., 2008; Raspopov et al., 2009). Raspopov et al. (2008) showed that in tree-ring based reconstructions the cycle varies from 180 to 230 years. Moreover, the high correlation between the minimum temperatures reconstruction and TSI and also the revealed link between the reconstructed temperatures and solar activity minima lead to suppose that the solar activity may be the driver of the 200-year cycle. Such climate cycling, linked not only to temperature but also to precipitation, is revealed for the territories of Asia, North America, Australia, Arctic and Antarctic (Raspopov et al., 2008). At the same time, the 200-year cycle (*de-Vries* cycle) may often have a phase shift from some years to decades and correlates not only positively but also negatively with climatic fluctuations depending on the character of the nonlinear response of the atmosphere-ocean system within the scope of the region (Raspopov et al., 2009). According to Raspopov et al. (2009), the study area is in the zone that reacts with a positive correlation to solar activity, though the authors note that we should not expect a direct response because of the nonlinear character of the atmosphere-ocean system reaction to variability in solar activity (Raspopov et al., 2009). Taking into consideration this fact and that the cold and warm periods shown in our reconstruction are slightly shifted compared with more continental areas and the whole Northern Hemisphere, we can say that the reconstruction of minimum August-December temperatures reflects the global climate change process in aggregate with the regional characteristics of the study area.

Conclusions

Using the tree-ring width of *Pinus koraiensis,* the mean minimum temperature of the previous August-December has been reconstructed for the southern part of Sikhote-Alin Mountain Range, northeastern Asia, Russia, for the past 486 years. This dataset is the first climate reconstruction for this region, and for the first time for northeast Asia, we present a reconstruction with a length exceeding 486 years.

Because explained variance of our reconstruction is about 39%, we believe that the result is noteworthy as it displays the respective temperature fluctuations for the whole region, including northeast China, the Korean peninsula and the Japanese archipelago. Our reconstruction is also in good agreement with the climatic reconstruction for the whole Northern Hemisphere. The reconstruction shows good agreement with the cold periods described by documentary notes in eastern China and Japan. All these comparisons prove that for this region, the climatic reconstruction based on tree-ring chronology has a good potential to provide a proxy record for long-term, large-scale past temperature patterns for northeast Asia. The results show the cold and warm periods in the region, which are conditional on global climatic processes (PDO), and may reflect the influence of solar activity (the 9-11-year and 200-year solar activity cycles). At the same time, the reconstruction highlights the peculiarities of the flows of global process in the study area and helps in understanding the processes in the southern territory of the Russian Far East for more than the past 450 years. Undoubtedly, the results of our research are important for studying the climatic processes that have occurred in the study region and in all of northeastern Asia and for situating them within the scope of global climatic change.

Acknowledgements This work was funded by Russian Foundation for Basic Research, Project 15-04-02185.

References

Anchukaitis K.J., D'Arrigo R.D., Andreu-Hayles L., Frank D., Verstege A., Curtis A., Buckley B.M., Jacoby G.C., and Cook E.R.: Tree-ring-reconstructed summer temperatures from Northwestern North America during the last nine centuries. J Clim. 26, 3001-3012, doi: 10.1175/JCLI-D-11-00139.1, 2013.

Bard E., Raisbeck G., Yiou F. and Jouzel J.: Solar irradiance during the last 1200 years based on cosmogenic nuclides. Tellus B., 52, 985-992, 2000.

Bazarova V.B., Grebennikova T.A., and Orlova L.A.: Natural-environment dynamic within the Amur basin during the neoglacial. Geogr. Nat. Resour., 35(3), 275-283, doi: 10.1134/S1875372814030111, 2014.

Bond G., Kromer B., Beer J., Muscheler R., Evans M.N., Showers W., Hoffmann S., Lotti-Bond R., Hajdas I., Bonani G.: Persistent solar influence on north Atlantic climate during the Holocene. Sci., 294, 2130–2136, 2001.

Borisova O.K.: Landscape-climatic changes in Holocene. Reg. Res. Rus., 2, 5-20, 2014.

Bradley R.S., Diaz H.F., Kiladis G.N., Eischeid J.K.: ENSO signal in continental temperature and precipitation records. Nat. 327, 497-501, 1987.

Dettinger M.D., Ghil M., Strong C.M., Weibel W., and Yiou, P.: Software expedites singular-spectrum analysis of noisy time series, Eos, Trans. American Geophysical Union 76(2), 12, 14, 21, 1995.

Cook E.R., Kairiukstis L.A.: Methods of dendrochronology: applications in the environmental sciences. Kluwer Academic Publishers, Dordrecht, 1990.

Cook E.R.: Reconstructions of Pacific decadal variability from long tree-ring records. Eos Trans. 83 (19) Spring Meet. Suppl., Abstract GC42A-04, 2002.

Corona C., Guiot J., Edouard J.L., Chalié F., Büntgen U., Nola P. and Urbinati C.: Millennium-long summer temperature variations in the European Alps as reconstructed from tree rings. Clim. Past., 6, 379-400, doi:10.5194/cp-6-379-2010, 2012.

Dai L.M., Qi L., Su D.K., Wang Q.W., Ye Y.J. and Wang Y.: Changes in forest structure and composition on Changbai Mountain in Northeast China. Ann. For. Sci., 68, 889-897, 2011.

Ding Y., Dai X.: Temperature Variation in China during the Last 100 years. Meteorology, 20, 19-26, 1994.

Durbin J. and Watson G.S.: Testing for serial correlation in least squares regression. Biometrika, 38, 159-178, 1951.

Efron B.: The jackknife, the bootstrap, and other resampling plans. Pa. Soc. for Industrial and Appl. Mathem., Philadelphia, 1982.

Efron B.: Bootstrap methods: another look at the jackknife. Annals Statistics, 7, 1-26, 1979.

Erlykin A.D., Sloan T. and Wolfendale W.: Solar activity and the mean global temperature. Environ. Res. Lett., 4, 014006 (5pp), doi:10.1088/1748-9326/4/1/014006, 2009.

Fedorov V.M., Kononova N.K., Gorbunov R.V. and Gorbunova T.Yu.: Solar radiation and circulation processes in the atmosphere of the Northern Hemisphere. The complex systems, 1(2), 58-71, 2015.

Fritts H.C.: Tree rings and climate. Academic Press Inc., London, 1976.

Fukaishi K. and Tagami Y.: An attempt of reconstructing the winter weather situations from 1720–1869 by the use of historical documents. In: Proceedings of the International Symposium on the Little Ice Age Climate, Department of Geography, Tokyo Metropolitan University, Tokyo, 194-201, 1992.

Ge Q., Zheng J., Hao Z., Liu Y. and Li M.: Recent advances on reconstruction of climate and extreme events in China for the past 2000 years. J Geogr Sci 26(7), 827-854, doi: 10.1007/s11442-016-1301-4, 2016.

Ghil M., Allen R.M., Dettinger M.D., Ide K., Kondrashov D., Mann M.E., Robertson A., Saunders A., Tian Y., Varadi F. and Yiou P.: Advanced spectral methods for climatic time series. Rev Geophys 40(1), 3.1-3.41, 10.1029/2000RG000092, 2002.

Gou X., Chen F., Yang M., Gordon J., Fang K., Tian Q. and Zhang Y.: Asymmetric variability between maximum and minimum temperatures in Northeastern Tibetan Plateau: evidence from tree rings. Sci. China. Ser. D. 51, 41-55, 2008.

Hirano J. and Mikami T.: Reconstruction of winter climate variations during the 19th century in Japan. Int J Climatol 28, 1423-1434, doi:10.1002/joc.1632, 2007.

Holmes R.L.: Computer-assisted quality control in tree-ring dating and measurement. Tree-ring Bull. 43, 69-78, 1983.

Ishikawa Y., Krestov P.V. and Namikawa K.: Disturbance history and tree establishment in old-growth *Pinus koraiensis*-hardwood forests in the Russian Far East. J. Veg. Sci. 10, 439-448, 1999.

Jacoby G., Solomina O., Frank D., Eremenko N. and D’Arrigo R.D.: Kunashir (Kuriles) Oak 400-year reconstruction of the temperature and relation to the Pacific Decadal Oscillation. Palaeogeogr Palaeoclimatol Palaeoecol, 2009, 303-311, doi: 10.1016/j.paleo.2004.02.015, 2004.

Karl T.R., Jones P.D., Knight R.W., Kulas G., Plummer N., Razuvayev V., Gallo K.P., Lindseay J., Charlson R.J., and Peterson T.C.: A new perspective on recent global warming: asymmetric trends of daily maximum and minimum temperature. B. Am. Meteorol. Soc., 74, 1007-1023, 1993.

Kolesnikov B.P.: Korean pine forests of the [Russian] Far East. Trudy DVF AN SSSR. 2, 1-264, 1956 (In Russian).

Körner C. and Paulsen J.: A world-wide study of high altitude treeline temperatures. J. Biogeogr., 31, 713-732, doi:10.1111/j.1365-2699.2003.01043.x, 2004.

Kozhevnikova N.K.: Dynamics of weather-climatic characteristics and ecological function of small river basin. Sib. Ecol. J., 5, 93-703, 2009 (In Russian).

Kress A., Hangartner S., Bugmann H., Büntgen U., Frank D.C., Leuenberger M., Siegwolf R.T.W. and Saurer M.: Swiss tree rings reveal warm and wet summers during medieval times. Geophys. Res. Lett., 41, 1732-1737, doi: 10.1002/2013GL059081, 2014.

Labitzke K.G. and van Loon H.: The Stratosphere: Phenomena, History and Relevance. Springer, Berlin, 1999.

Lean J.: Evolution of the Sun's spectral irradiance since the Maunder Minimum. Geophys. Res. L., 27(16), 2425-2428, doi: 10.1029/2000GL000043, 2000.

Lean J. and Rind D.: Evaluating sun-climate relationships since the Little Ice Age. J. Atmos. Sol. Terr. Phys., 61, 25-36, 1999.

Li M. and Wang X.: Climate-growth relationships of three hard- wood species and Korean pine and minimum temperature reconstruction in growing season in Dunhua, China. J. Nanjing. For. Univ., 37, 29-34, 2013.

Liu Y., Bao G., Song H., Cai Q. and Sun J.: Precipitation reconstruction from Hailar pine (*Pinus koraiensis* var. *mongolica*) tree rings in the Hailar region, Inner Mongolia, China back to 1865 AD. Paleogeogr Paleoclimatol Paleoecol, 282, 81-87, doi:10.1016/j.palaeo.2009.08.012, 2009.

Liu Q.J.: Structure and dynamics of the subalpine coniferous forest on Changbai mountain, China. Plant. Ecol. 132, 97-105, 1997.

Lu R., Jia F., Gao S., Shang Y. and Chen Y.: Tree-ring reconstruction of January-March minimum temperatures since 1804 on Hasi Mountain, northwestern China. J. Arid. Environ., 127, 66-73, doi:10.1016/j.jaridenv.2015.10.020, 2016.

Lyu S., Li Z., Zhang Y. and Wang X.: A 414-year tree-ring-based April–July minimum temperature reconstruction and its implications for the extreme climate events, northeast China. Clim. Past. 12, 1879-1888, doi:10.5194/cp-12-1879-2016, 2016.

Ma Z.G.: The interdecadal trend and shift of dry/wet over the central part of north China and their relationship to the Pacific Decadal Oscillation (PDO). Chin. Sci. Bull., 52(12), 2130-2139, 2007.

Mann M.E. and Lees J.M.: Robust estimation of background noise and signal detection in climatic time series. Clim. Change, 33, 409-445, 1996.

Mann M.E., Zhang Z., Rutherford S., Bradley R.S., Hughes M., Shindell D., Amman C., Faluvegi G. and Ni F.: Global Signatures and Dinamical Origins of the Little Ice Age and Medieval Climate Anomaly. Science, 326, 1256-1260, doi:10.1126/science.1177303, 2009.

Mantua N., Hare S.: The Pacific decadal oscillation. J. Oceanogr. 58(1), 35-44, 2002.

Meehl G.A.: The annual cycle and interannual variability in the tropical Pacific and Indian Ocean regions. Mon. Weather. Rev., 115, 27-50, 1987.

Melvin T.M. and Briffa K.R.: A 'signal-free' approach to dendroclimatic standardisation. Dendrochronologia, 26, 71-86, doi: 10.1016/j.dendro.2007.12.001, 2008.

Nishimura M. and Yoshikawa I.: Nippon Kyokoshi Ko, Maruzen, Tokyo, an archival collection of disasters in Japan, 1936 (in Japanese)

Ohayama M., Yonenobu H., Choi J.N., Park W.K., Hanzawa M. and Suzuki M.: Reconstruction of northeast Asia spring temperature 1784-1990. Clim. Past., 9, 261-266, doi:10.5194/cp-9-261-2013, 2013.

Omelko A., Ukhvatkina O. and Zmerenetsky A.: Disturbance history and natural regeneration of an old-growth Korean pine-broadleaved forest in the Sikhote-Alin mountain range, Southeastern Russia. For. Ecol. Manag. 360, 221-234, doi: 10.1016/j. foreco.2015.10.036, 2016.

Omelko A.M. and Ukhvatkina, O.N.: Characteristics of gap-dynamics of conifer-broadleaved forest of Southen Sikhote-Alin (Russia). Plant World Asian Russ., 1, 106-113, 2012.

Popa I. and Bouriaud O.: Reconstruction of summer temperatures in Eastern Carpathian Mountain (Rodna Mts, Romania) back to AD 1460 from tree-rings. Int. J. Climatol., 34, 871-880, doi: 10.1002/joc.3730, 2014.

Porter T.J., Pisaric M.F., Kokelj S.V. and DeMontigny P.: A ring-width-based reconstruction of June-July minimum temperatures since AD 1245 from white spruce stands in the Mackenzie Delta region, northwestern Canada. Quaternary. Res., 80, 167-179, doi: 10.1016/j.yqres.2013.05.004, 2013.

Raspopov OM, Dergachev VA, Esper J, Kozyreva OV, Frank D, Ogurtsov M, Kolström T, Shao X (2008) The influence of the de Vries (~200-year) solar cycle on climate variations: Results from the Central Asian Mountains and their global link. Palaeogeogr Palaeoclimatol Palaeoecol, 259, 6-16. doi: 10.1016/j.palaeo.2006.12.017

Raspopov O.M., Dergachev V.A., Kozyreva O.V., Kolström T., Lopatin E.V. andLuckman B.: Geography of 200-year climate periodicity and Lon-Term Variations of Solar activity. Reg. Res. Russ., 2, 17-27, 2009.

Razzhigaeva N.G., Ganzei L.A., Mokhova L.M., Makarova T.R., Panichev A.M., Kudryavtseva E.P., Arslanov Kh.A., Maksimov F.E. and Starikova A.A.: The Development of Landscapes of the Shkotovo Plateau of Sikhote-Alin in the Late Holocene. Reg. Res. Russ., 3, 65-80, doi:10.15356/0373-2444-2016-3-65-80, 2016.

Ren F. and Zhai P.: Study on Changes of China's Extreme Temperatures During 1951–1990. Sci. Atmos. Sin., 22, 217-227, 1998.

Sakaguchi Y.: Warm and cold stages in the past 7600 years in Japan and their global correlation. Bull. Dep. Geogr. 15, 1-31, 1983.

Shao X. and Wu X.: Reconstruction of climate change on Changbai Mountain, Northeast China using tree-ring data. Quaternary. Sci., 1, 76-83, 1997.

Shatilina T.A. and Anzhina G.I.: Features of atmospheric circulation and climate in the Far East (Russia) in the beginning of 21 Century. Izv. TINRO, 152, 225-239, 2008 (In Russian).

Stokes M.A. and Smiley T.L.: Tree-ring dating. The University of Chicago Press, Chicago, London, 1968.

Tang H., Zhai P. and Wang Z.: On Change in Mean Maximum Temperature, Minimum Temperature and Diurnal Range in China During 1951–2002. Climatic Environ Res., 10, 728-735, 2005.

Thapa U.K., Shan S.K., Gaire N.P. and Bhuju D.R.: Spring temperatures in the far-western Nepal Himalaya since 1640 reconstructed from *Picea smithiana* tree-ring widths. Clim dyn, 45(7), 2069-2081, doi: 10.1007/s00382-014-2457-1, 2015.

Wang H., Shao X.M., Jiang Y., Fang X.Q. and Wu S.W.: The impacts of climate change on the radial growth of *Pinus koraiensis* along elevations of Changbai Mountain in northeastern China. For. Ecol. Manag., 289, 333-340, doi:10.1016/j.foreco.2012.10.023, 2013.

Wang X., Zhang M., Ji Y., Li Z., Li M. and Zhang Y.: Temperature signals in tree-ring width and divergent growth of Korean pine response to recent climate warming in northeast Asia. Trees 31(2), 415-427, doi: 10.1007/s00468-015-1341-x, 2016.

Wang S., Liu J. and Zhou J.: The Climate of Little Ice Age Maximum in China. J. Lake. Sci., 15, 369-379, 2003.

Wang W., Zhang J., Dai G., Wang X., Han S., Zhang H. and Wang Y.: Variation of autumn temperature over the past 240 years in Changbai Mountain of Northeast China: A reconstruction with tree-ring records. China. J. Ecol., 31, 787-793, 2012.

Wang Z., Ding Y., He J. and Yu J.: An updating analysis of the climate change in China in recent 50 years. Ac Meteorol Sin, 62, 228-236, 2004.

Wigley T.M.L., Briffa K.R. and Jones P.D.: On the average value of correlated time series, with applications in dendroclimatology and hydrometeorology. J. Clim. Appl. Meteorol., 23, 201-213, 1984.

Wiles G.C., Solomina O., D’Arrigo R., Anchukaitis K.J., Gensiarovsky Y.V. and Wiesenberg N.: Reconstructed summer temperatures over the last 400 year a based on larch ring widths: Sakhalin Island, Russian Far East. Clim. Dyn., 45, 397-405, doi: 10.1007/s00382-014-2209-2, 2014.

Wilson R.J.S. and Luckman B.H.: Tree-ring reconstruction of maximum and minimum temperatures and the diurnal temperature range in British Columbia, Canada. Dendrochronologia, 20, 1-12, 2002.

Wilson R.J.S., Luckman B.H.: Dendroclimatic reconstruction of maximum summer temperatures from upper treeline sites in Interior British Columbia, Canada. Holocene, 13, 851-861, doi:10.1191/0959683603hl663rp, 2003.

Xie Z. and Cao H.: Asymmetric changes in maximum and mini- mum temperature in Beijing. Theor Appl Climatol, 55, 151-56, 1996.

Yin H., Guo P., Liu H., Huang L., Yu H., Guo S. and Wang F.: Reconstruction of the October mean temperature since 1796 at Wuying from tree ring data. Adv. Clim. Change. Res., 5, 18-23, 2009.

Yin H., Liu H., Linderholm H.W. and Sun Y.: Tree ring density-based warm-season temperature reconstruction since AD 1610 in the eastern Tibetan Plateau. Palaeogeogr, Palaeoclimatol, Palaeoecol, 426, 112-120, doi: 10.1016/j.palaeo.2015.03.003, 2015.

Young G.A.: Bootstrap: more than a stab in the dark. Statistical. Sci. 9, 382-415, 1994.

Zaiki M., Können G., Tsukahara T., Jones P., Mikami T. and Matsumoto K.: Recovery of nineteenth-century Tokyo/Osaka meteorological data in Japan. Int J Climatol, 26, 399-423, doi:10.1002/joc.1253, 2006.

Zang C. and Biondi F.: Treeclim: an R package for the numerical calibration of proxy-climate relationships. Ecogr. 38, 001-006, doi: 10.1111/ecog.01335, 2015.

Zhang R.B., Yuan Y.J., Wei W.S., Gou X.H., Yu S.L., Shang H.M., Chen F., Zhang T.W. and Qin L.: Dendroclimatic reconstruction of autumn-winter mean minimum temperature in the eastern Tibetan Plateau since 1600 AD. Dendrochronologia, 33, 1-7, doi: 10.1016/j.dendro.2014.09.001, 2015.

Zhao C., Ring G., Zhang Y., Wang Y.: Climate change of the Northeast China over the past 50 years. J. Arid. Land. Resour. Environ., 23, 25-30, 2009.

Zhu H.F., Fang X.Q., Shao X.M. and Yin Z.: Tree-ring-based February-April temperature reconstruction for Changbai Mountain in Northeast China and its implication for East Asia winter monsoon. Clim Past., 5, 661-666, 2009.

Zhu L., Li Z., Zhang Y. and Wanga X.: A 211-year growing season temperature reconstruction using tree-ring width in Zhangguangcai Mountains, Northeast China: linkages to the Pacific and Atlantic Oceans. Int. J. Climatol., doi: 10.1002/joc.4906, 2016.

Zhu L., Li S., Wang X.: Tree-ring reconstruction of February-March mean minimum temperature back to 1790 AD in Yichun, Northeast China. Quaternary. Sci., 35, 1175-1184, doi: 10.11928/j.issn.1001-7410.2015.05.13, 2015.

Tables

Table 1. The sampling information and statistics of the signal-free chronology

	VUSr
Elevation (m a.s.l.)	700-900
Latitude (N), Lingitude (E)	44°01’32’’, E 134°13’15’’
Core (live trees) / sample (dead trees)	25/20
Time period / length (year)	1451-2014 / 563
MS	0.253
SD	0.387
AC1	0.601
R	0.691
EPS	0.952
Period with EPS>0.85 / length (year)	1602-2014 / 412
Period with EPS>0.75 / length (year)	1529-2014 / 485
Skew/Kurtosis	0.982/5.204

MS – mean sensitivity, SD – standard deviation, AC1 – first-order autocorrelation, EPS – expressed population signal

Table 2. Calibration and verification statistics of the reconstruction equation for the common period 1971-2003 of Bootstrap

Statistical item	Calibration	Verification (Bootstrap, 199 iterations)
r	0.62	0.62 (0.54-0.70)
R^2	0.39	0.39 (0.37-0.41)
R^2_{adj}	0.36	0.37 (0.37-0.40)
Standard error of estimate	1.20	1.11
F	18.76	18.54
P	0.0001	0.0001
Durbin-Watson	1.73	1.80

Table 3. Cold and warm periods based on the results of this study compared with other researches

Period	Southern Sikhote-Alin (this study)	Laobai Mountain (Lyu et al., 2016)	Changbai Mountain (Zhu et al., 2009)
Cold	1535-1540[1]; 1550-1555[1]	*	*
	—	1605-1616	
	1643-1649; 1659-1667	1645-1677	*
	1675-1689	1684-1691	*
	1791-1801; 1807-1818	—	1784-1815
	1822-1827; 1836-1852		1827-1851
	1868-1887	—	1878-1889
	1911-1925	1911-1924; 1930-1942; 1951-1969	1911-1945
Warm	1560-1585[1]	*	*

1600-1610[1]; 1614-1618	—	*
1738-1743	—	—
1756-1759; 1776-1781	1767-1785	1750-1783
*1787-1793***	1787-1793	—
*1795-1807***	1795-1807	—
*1855-1865***	—	1855-1877
1944-2014	1991-2008	1969-2009

Note: *italic* ** – the periods which agreement with VUSr but not reliably for VUSr; * - the reconstruction not covering this period; [1] – uncertain periods, when chronology has EPS> 0.75 (AD 1529-1609).

Figure captions

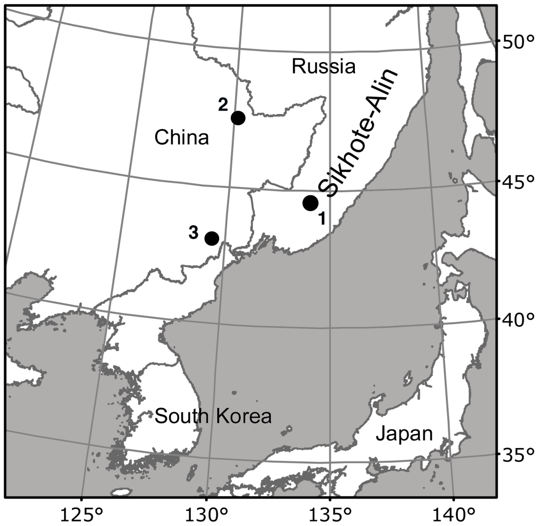

Figure 1: Location of the study area on the Sikhote-Alin Mountains, Southeastern Russia (1) and sites of compared temperature reconstructions: April – July minimum temperature on Laobai Mountain by Lyu et al., 2016 (2), and February – April temperature established by Zhu et al. (2009) on Changbai Mountain (3).

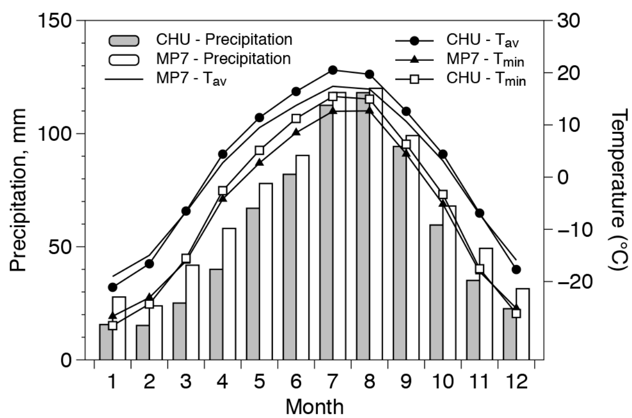

Figure 2: Mean monthly (1936-2004), minimum temperature (1971-2003) and total precipitation (1936-2004) at Chuguevka and mean monthly, minimum temperature and total precipitation for VUS meteorological station (MP7) (1966-2000)

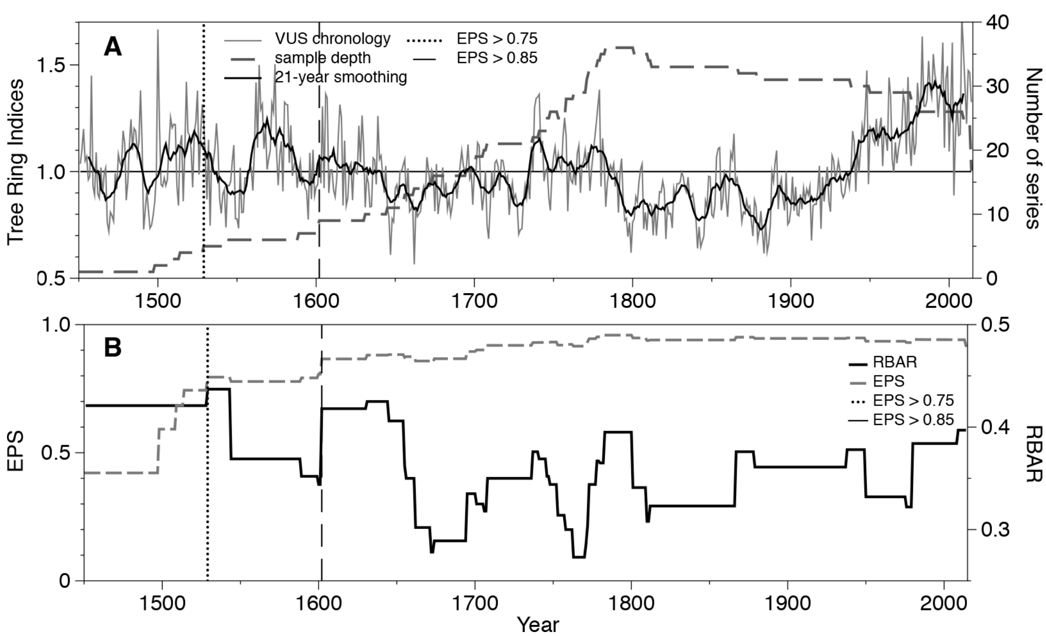

Figure 3: Variations of the VUS chronology and sample depth (a) and the expressed population signal (EPS) and average correlation between all series (Rbar) VUS chronology from AD 1451 to 2014 (b)

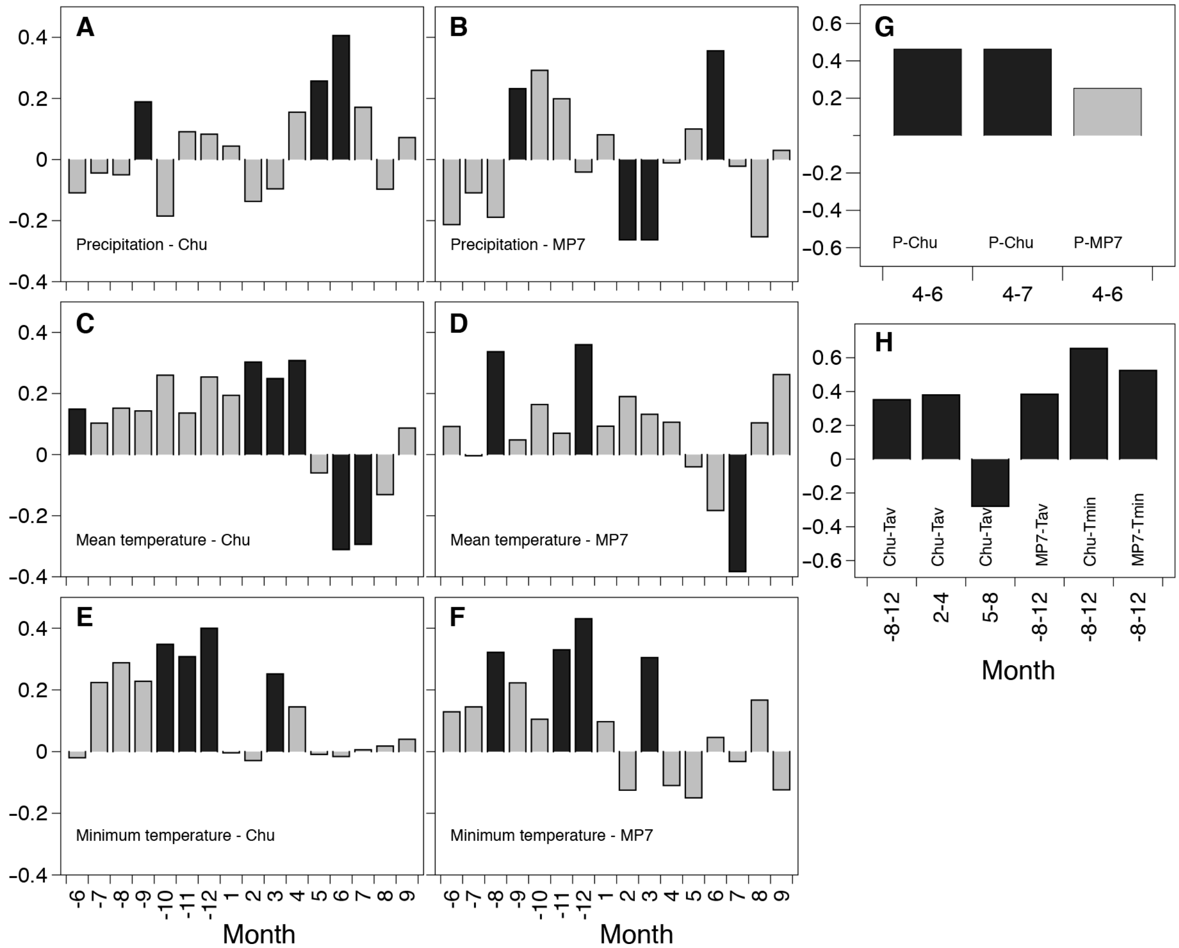

Figure 4: Correlations between the monthly mean meteorological data and VUS chronology A, C, E – Chuguevka (Chu) and VUS chronology; B, D, F - VUS meteorological station (MP7) and VUS chronology; G – correlation coefficients between VUS chronology and the precipitation of different month combinations; H – correlation coefficients between VUS chronology and the temperature of different month combinations. The black bars are significant value.

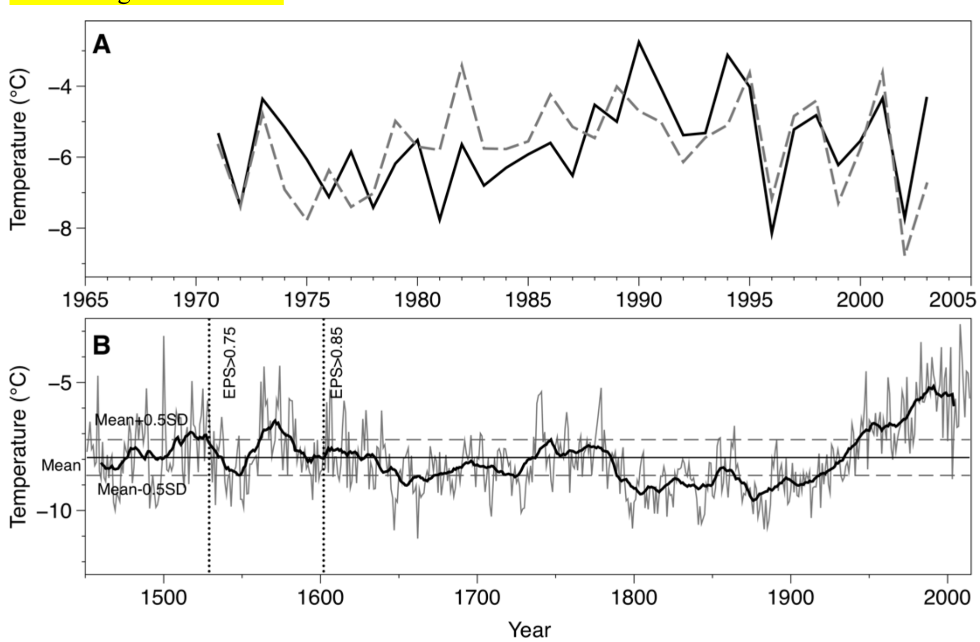

Figure 5: (a) Actual (black line) and reconstructed (dash line) August – December minimum temperature for the common period of 1971-2003; (b) reconstruction of August – December minimum temperature (VUSr) to Southern part of Sikhote-Alin for the last 563 years. The smoothed line indicates the 21-year moving average.

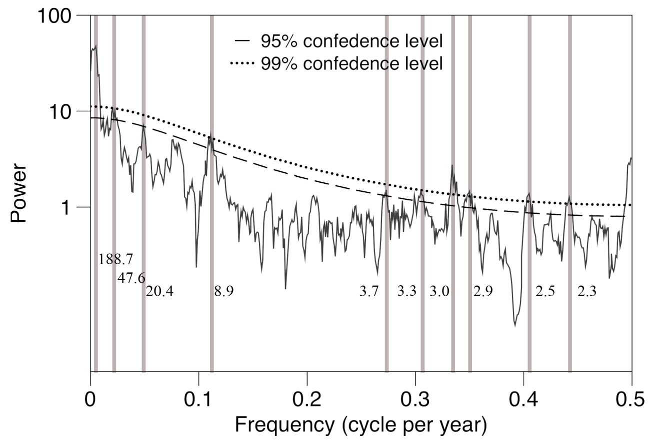

Figure 6: The MTM power spectrum of the reconstructed August – December minimum temperature (VUSr) from 1529 to 2014

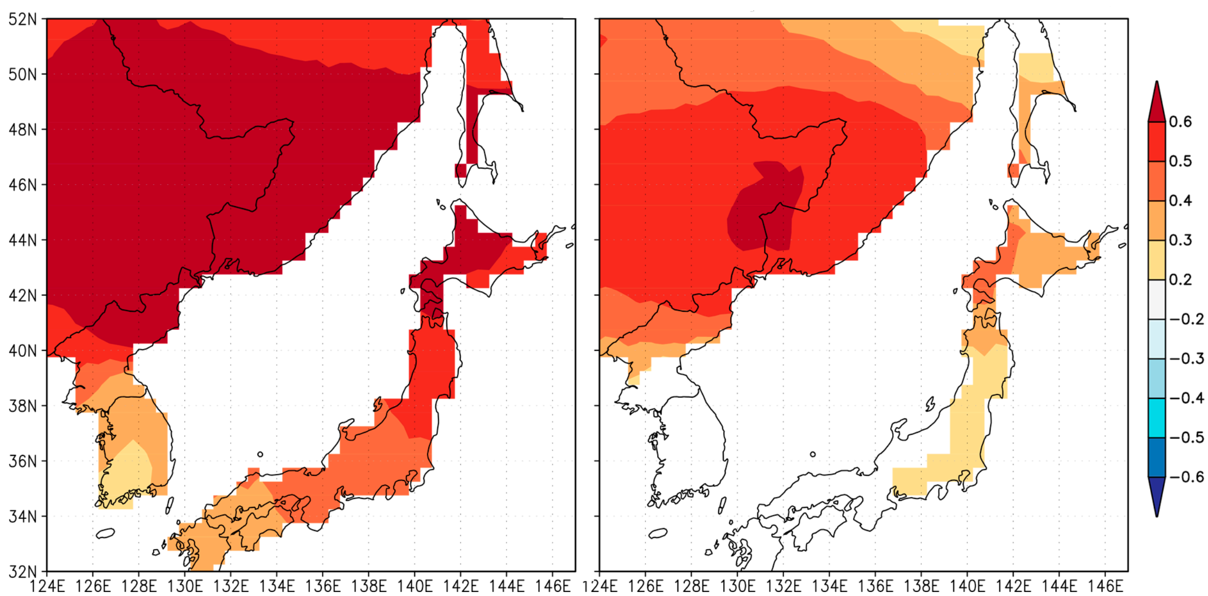

Figure 7: Spatial correlations between the observed (a) and reconstructed (b) August – December minimum temperature (VUS) in this study and regional gridded annual minimum temperature from CRU TS 4.00 over their common period 1960–2003 (p < 10%).

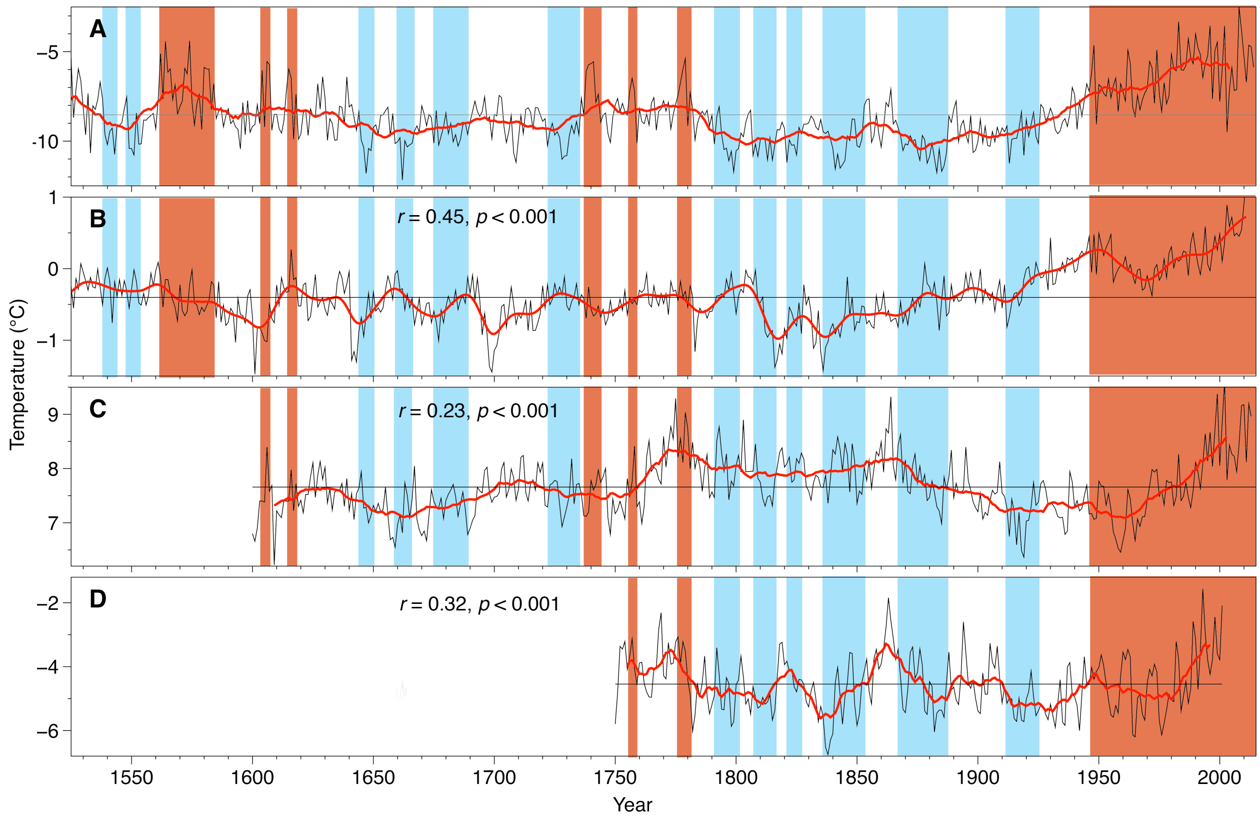

Figure 8: (a) August-December mean minimum temperature reconstructed (VUSr) on southern part of Sikhote-Alin, (b) Northern Hemisphere extratropical temperature (Willes et al., 2016), (c) April – July minimum temperature on Laobai Mountain by Lyu et al., 2016, and (d) February – April temperature established by Zhu et al. (2009) on Changbai Mountain. Black lines denote temperature reconstruction values, and red color lines indicate the 21-year moving average; red and blue fields – warm and cold period consequently (in this study)