**Climate
of the Past
Discussions**

A 413-year tree-ring based April-July minimum temperature reconstruction and its implications on the extreme climate events, northeast China

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Abstract: A ring-width series was used as a proxy to reconstruct the past 413-year record of April-July minimum

temperature at Laobai Mountain, northeastern China. Chronology was built using standard tree-ring procedures for providing

15   comparable information in this area while preserving low-frequency signals. By analyzing the relationship between the

tree-ring chronology of the Korean pine (*Pinus koraiensis*) and meteorological data, we found that the standard chronology

was significantly correlated with the April-July minimum temperature ($r = 0.76$). Therefore, the April-July minimum

temperature since 1600 was reconstructed by this tree-ring series. The reconstruction equation accounted for 57.3 % of

temperature variation, and it proved reliable by testing with several methods (e.g., sign test, product mean test, reduction of

20   error, and coefficient error). Reconstructed April-July minimum temperature in Laobai Mountains showed five cool periods

(1605-1681, 1684-1690, 1747-1756, 1914-1922, and 1953-1966) and eight warm periods (1697-1704, 1767-1785,

1787-1793, 1795-1801, 1803-1808, 1816-1826, 1835-1878, and 1987-2008) during the past 413 years. The reconstructed

low temperature periods in the 17th and early 18th century were consistent with the Little Ice Age in the Northern Hemisphere,

and the rate of warming in the 19th century was significantly slower than that in late 20th century. In addition, the

25   reconstructed series was fairly consistent with the historical and natural disaster records of extreme climate events (e.g., cold

damage and frost disaster) in this area, and it exhibited 128-60-, 23-22-, 12-10-, 4.0-2.7-, and 2.4-year periods of warm-cool

changes, which may be related to variations in sunspot activity or other large-scale interactions between the ocean and the

atmosphere.

Keywords   Minimum temperature reconstruction; tree-ring width; northeast China; *Pinus koraiensis*; extreme climate

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1 Introduction

Global climate change presents major challenges for the world population. Consequently, it is urgent to understand the climate change and its forcing mechanisms more profoundly. Instrumental records are available for less than 100 years (even less than 50 years) in most areas of the world. It is necessary to put the present climate regime in context with the long-term

5   perspectives, which forces a reliance on natural proxy records to reconstruct the past climate. Tree rings have been widely applied in global climate change studies and paleoclimate reconstructions at both regional and global scales because they offer accurate and continuity temporal record as well as they are widespread and easily replicated (Corona et al., 2010; Bouriaud et al., 2014; Kress et al., 2014). Northeastern China, an area sensitive to global climate change, is located in the ecotone from a temperate to cold temperate zone, belonging to monsoon fringe area. Due to the interannual instability of the

10   monsoon, frequent climate extremes (especially cold damage or frost disaster) seriously affect agriculture and forest ecosystems. In addition, previous studies suggest that climate change in the northeastern China was also linked to the solar activity during certain pre-instrumental periods (Chen et al., 2006; Wang et al., 2012; Liu et al., 2013). It is generally accepted that the climate warms during periods of strong solar activity (e.g., Medieval Warm Period) and cools during periods of low solar activity (e.g., Little Ice Age) (Lean and Rind, 1999; Bond et al., 2001). In addition, the climate in the

15   northeastern China has been significantly affected by the global warming since the 20th century (Ding and Dai, 1994; Wang et al., 2004; Zhao et al., 2009). To understand whether the climate warming in this area is abnormal, we must fully understand the history of climate changes over a long period. However, tree-ring series were rarely used to reconstruct past climate (especially temperature) in this area because of the exceptional hydrothermal conditions. Several temperature-sensitive tree-ring chronologies were developed in the Changbai Mountains (e.g., Shao and Wu, 1997; Zhu et al.,

20   2009; Wang et al., 2012; Li and Wang, 2013) and Xiaoxing'an Mountains (Yin et al., 2009), but almost no results were obtained for the period of over 250 years. Therefore, climate reconstructions are far from adequate and do not satisfy the demands of scientific research in this area. There is a demand for higher-quality climate reconstructions in a greater number of areas over longer periods and a larger group of climatic indicators for verification in this region. For this reason, more information of regional past climate variations registered in a long-term tree-ring series is needed, and it is important to

25   understand the longitudinal impacts of the climate change on forest ecosystems and human production activities in northeastern China.

The main objectives of this study are (1) to develop for the first time a more than 400-year tree-ring width chronology in northeastern China; (2) to analyze the regime of temperature variation during the past four centuries in northeastern China; (3) to identify the recent warming amplitude in a long-term context; (4) and to analyze the extreme low temperature events.

30   Therefore, our new temperature record not only furthers the tree-ring series in northeastern China and provides new evidence for regional impacts of past climate variability and changes, but it can also predict future climate trends in northeast China.

2 Materials and methods

2.1 Study area

The study area is located on the Laobai Mountains (128°03' E, 44°06' N) in the boundary zone between Jilin and Heilongjiang provinces, and it is also a transition area between the Changbai and Xiaoxing'an Mountains, where the flora of the natural ecosystem is best-preserved. The third highest peak in northeastern China rises to 1650 m above sea level (a.s.l.) in this area. Almost no inhabitants live in or near the mountains; thus, the native vegetation remains predominantly intact. The vegetation is mainly affected by the vertical changes of mountain terrain, and the area contains five zones that range from temperate to frigid, with respect to the increase in altitude. The five zones are *Quercus mongolica* broad-leaved forest below 800 m a.s.l., mixed broadleaved Korean pine forest from 800 to 1050 m, dark conifer forest with *Picea jezoensis* from 1050 to 1350 m, *Betula ermanii* forest between 1350 and 1640 m, and *Pinus pumila* forest and subalpine meadow above 1640 m, in which the plant species is a transition from Changbai Mountains to Xiaoxing'an Mountains. Furthermore, the forest ecosystem shows remarkable vertical distribution with elevation changes. The important dominant evergreen species on the sampling site is the Korean Pine (*Pinus koraiensis*). This pine is widely distributed on well-drained wet mountain slopes close to the subalpine timberline. The soils on the site are mainly composed of dark-brown to brown coniferous forest soil, mountain podzoluvisols and marsh (Bu et al., 2003).

This region belongs to temperate continental monsoon climate. The mean annual temperature is -2 ℃, the total annual precipitation is 690 mm, and the annual frost-free period is approximately 90-110 days. The average highest temperature is 18.2 ℃ in July, and the average lowest temperature is -20.5 ℃ in January (Fig. 1).

2.2 Tree-ring chronology development

Tree-ring samples were obtained from the south slope of Laobai Mountains along an elevational gradient from 950 to 1050 m, from an almost pristine area containing well-preserved old forests largely uninfluenced by human activity. One or two cores per undamaged tree (54 cores from 31 trees) were extracted from cross-slope sides of the trunks at breast height using an increment borer. The cores were air dried, glued firmly to groove wooden mounts and sanded with progressively finer grade abrasive paper up to 800 grit. After the samples were cross-dated using a skeleton plot method (Stokes and Smiley, 1968), each tree-ring width was measured with a precision of 0.001 mm using VELMEX tree-ring width equipment. Data were checked for missing rings and dating errors using the quality control program COFECHA (Holmes 1983).

ARSTAN (Cook 1985) was used to standardize cross-dated tree-ring width series into a tree-ring chronology. During this detrending process, biological factors (such as age-related trends) and non-climatic variations were removed by fitting negative exponential curves or straight-lines to each ring-width series. All detrended data from individual tree cores were then averaged using a bi-weight robust mean to form the chronology (Cook and Kairiukstis, 1990). A standard chronology, which preserves more low frequency signals than other chronologies, was used in the subsequent analyses. The full length of

tree-ring series spanned from 1600 to 2013. The expressed population signal (EPS; Wigley et al., 1984) was used to assess the quality of the tree-ring chronology. A generally acceptable threshold of the EPS was consistently greater than 0.85 from AD 1660 to 2013 (five trees) (Fig. 2), which affirmed that this is a reliable period. The statistical characteristics for the standard chronology of *Pinus koraiensis* in Laobai Mountains is shown in Table 1.

2.3 Climate data and statistical methods

Meteorological data were obtained from the National Meteorological Information Center (http://data.cma.cn/). Considering the proximity to the sampling sites and the climate record length, the climate data from the Dunhua meteorological station (43°22′ N, 128°12′ E, elevation 524.9 m a.s.l., 1956-2013) were selected to identify the climate signals in the tree-ring series. Furthermore, the climate data included total monthly precipitation, mean maximum temperature, mean temperature, and mean minimum temperature. Months from current January to current December were selected for the analysis of the relationship between the climatic factors and the Korean pine growth.

To confirm the climate-growth relationships of the Korean Pine in Laobai Mountains, a correlation analysis was performed for the monthly mean maximum temperature, the mean temperature, the mean minimum temperature, and the total precipitation over the current years of tree growth. The stability and reliability of the regression equation was assessed by the split-period calibration and verification analyses (Fritts, 1976; Cook and Kairiukstis, 1990) for the two periods 1956-1984 and 1985-2013. The Pearson correlation coefficient (r), R square (R^2), sign test, and the reduction of error test (RE), and product means test (PMT) are the tools used to verify the results. To test the periodicity of the minimum temperature variation in this area, a spectral analysis was performed using a multi-taper method, a method especially powerful for the time series (Mann and Lees, 1996). All statistical analyses presented in this paper were performed using the commercial software SPSS12.0.

3 Results and discussion

3.1 Climate-radial growth relationship

Climate-growth response function analysis showed that the standard chronology was positively correlated with the mean minimum temperatures from January to December in current year. Meanwhile, no significant relationship with precipitation was found (Fig. 3). This means that cool or warm conditions are favored for the Korean Pine growth in this area. April-July mean minimum temperature (MMT) shows significant positive correlation with the standard chronology, suggesting that the April-July MMT was the main limiting factor for the radial growth of the Korean Pine on Laobai Mountain. This could result from the two following reasons. First, the sampled site was located at higher elevation close to the upper limit of the Korean pine distribution, which may have caused more sensitive tree growth in relation to temperature (Szeicz and MacDonald, 1995; D'Arrigo et al., 2009; Li et al., 2011; Yu et al., 2011; Flower and Smith, 2012). In the early growing season, higher

mean minimum temperature inhibits the tree respiration and prevents the excessive loss of nutrients, thus providing more advantages for the growth allowing them to form a wider ring (Wu, 1990; Akkemik, 2000; Makinen et al., 2003). Second, a crucial growth period of the Korean pine is from April to July. During this period, the temperature could have direct effects on the growth rate, duration of cambium, and the photosynthetic efficiency, all of which affect tree-ring width (Li et al., 2000;

5   Yu et al., 2011). Moreover, the photosynthesis still occurred during autumn, when it is generally the end of growing season; the lower mean minimum temperature reduced the tree respiration, allowing for more photosynthetic products to be stored, thus creating favorable conditions for subsequent tree growth (Gao et al., 2011; Wang et al., 2011).

3.2 Minimum temperature reconstruction

Based on above analysis, a nonlinear regression model was established to reconstruct the April-July MMT. The transfer

10   function is as follows:

$Y = 2.728\ln(X_t) + 7.812$

($N = 58$, $R = 0.757$， $R^2 = 0.573$, $R^2_{adj} = 0.566$, $F = 75.223$, $P < 0.0001$)

where Y is the April-July MMT and X is the ring-width index of the standard chronology at year t. As shown in Fig. 4a, the reconstructed values closely tracked the observed temperature. The calibration and verification statistics are shown in Table

15   2. The correlation coefficients for the split-sample validation periods indicated a strong relationship between the Korean pine growth and the minimum temperature. The positive RE for this equation revealed useful paleoclimatic information in this reconstruction (Cook et al., 1999). The significant results of ST and PMT indicated good agreement between the actual and the reconstructed data. The final calibration model accounted for 57.3 % of the total variance ($p < 0.01$) and passed all calibration and verification statistical requirements. Therefore, this equation was reliable and allowed for the accurate

20   reconstruction of the April-July MMT in Laobai Mountain.

3.3 Temperature variations from 1600 to 2013 AD

Figure. 4b shows the reconstructed average April-July MMT variations since AD 1600 and its 11-year moving average. The 11-year moving average of the reconstructed series was used to obtain low-frequency information and to analyze the warm/cold variability in this region. The mean value of the 413-year reconstructed temperature was 7.5 ℃, with a standard

25   deviation of ± 0.52 ℃. The warm and cold periods were defined when temperatures exceeded the mean value plus and minus 0.5 times standard deviation, respectively (Fig. 4b). The reconstructed April-July MMT series exhibited obvious stage changes with eight warmer periods and five colder periods during the past 413 years. The longest cold period lasted from 1605 to 1681 AD (77 years), with an average temperature of 1.04 ℃ below the mean value. The longest warm period lasted from 1835 to 1878 AD (44 years), and the average temperature was 0.30 ℃ above the mean value (Table 3). The two cold

30   periods (1605-1681 and 1953-1966) and four warm periods (1795-1801, 1803-1808, 1835-1878, and 1987-2008) were also consistent with other results of the tree-ring reconstructions in northeastern China (Shao and Wu, 1997; Yin et al., 2009;

Wang et al., 2012). In addition, the two cold periods of 1605-1681 and 1684-1690 were fully consistent with the Maunder minimum (1620-1710), an interval of decreased solar irradiance (Bard et al., 2000). The long cooling period of 1605-1681 was also indicated in other proxy records of reconstructed temperatures, which coincides with the Little Ice Age in the northern hemisphere (Lin et al., 2004; Wang et al., 2006; Hong et al., 2009). The Little Ice Age in the 17th century and the

5   rapid warming during the mid-19th and late 20th century in northeastern China had been well recorded in this series, suggesting that this series had a good regional representativeness of temperature variations in northeastern China.

To further evaluate the reliability of this reconstruction, we compared our data series with the tree-ring based reconstruction temperature data from the Dunhua and the Changbai Mountains (Zhu et al., 2009; Li and Wang, 2013) and the reconstructed Northern Hemisphere temperature data (Wilson et al., 2007) (Fig. 5a-c). The reconstructed April-July MMT showed very

10   similar variation regimes with February-April temperature regimes in the Changbai Mountains (Zhu et al., 2009), April-September temperature regimes in Dunhua (Li and Wang, 2013), and with the northern hemisphere temperature data (Wilson et al., 2007). All of the temperature series exhibited significantly low temperatures during the 1950s-1970s, which coincided with a slight decrease in sun activity from AD 1940-1970 (Beer et al., 2000) (Fig. 5). Another notable feature was that all of the curves showed a sharp increase from 1980, and the peak values appeared in the late 1990s and early 2000s,

15   which was consistent with the reports from the Intergovernmental Panel on Climate Change (IPCC, 2007). These series displayed similar patterns of variations at high- and low-frequency, suggesting that the northeastern temperature was consistent over large-scale variations. Additionally, three northeastern temperature reconstruction series showed that some cold/warm years were not analogous due to the differences in the reconstruction parameters (e.g., temperature subdivisions into average temperature, minimum temperature, maximum temperature, etc.) and habitat conditions in different sampling

20   areas. The sampled site was located at a junction zone between Jilin and Heilongjiang provinces, further to the north than the Changbai Mountain. Meanwhile, some differences of the reconstructed temperature series were explained reasonably well from the comparison with analogous regions. Consequently, these findings could reveal more characteristics of the regional climate variations and provide reliable data for larger-scale climate reconstructions in northeastern China.

3.4 Detection of Northeast-wide cold damage or frost disaster events

25   As the minimum temperatures approach or fall below the freezing point, they may limit the biological activity and growth. Therefore, the low temperature years were often accompanied by the cold damage or frost disaster to some extent. The evidence from historical documents shows that cold damage or frost disaster events have been occurring in Heilongjiang Province since 1675 (Sun et al., 2007). Extremely cold damage or frost disaster events were in good agreement with the four low temperature years (1675, 1682, 1749, and 1755 in Fig. 4b) in reconstructed April-July MMT series during the

30   1600s-1700s. Since the beginning of the 20th century, three severe freezing periods that occurred from 1909-1918, 1934-1945, and 1956-1972 in Heilongjiang Province (Sun et al., 2007) were represented in our reconstruction. In addition, some low temperature years in the reconstructed April-July MMT series corresponded to extremely cold damage or frost

disaster events that occurred in 1915, 1917, 1920, 1932, 1936, 1953, 1954, 1957, and 1969 (Fig. 4b). These results revealed that 11 out of 15 cold damage or frost disaster events corresponded to an April-July MMT lower than the 11 year moving average, while the remaining four events corresponded to higher than April-July MMT values. In contrast, with the climate warming since the 1980s, the decreasing trend of the annual extreme low temperature frequency was more notable, thereby

5   the extremely cold damage or frost disaster events decreased greatly in this region. According to our results, we showed that the MMT of April-July in Laobai Mountain had a strong correlation with cold damage or frost disaster.

3.5 Periodicity analysis of the reconstructed April-July MMT

The reconstructed April-July MMT during the past 413 years showed 128-60-, 23-22-, 12-10-, 4.0-2.7-, and 2.4-year quasi-cycles at a 95 % confidence level (Fig. 6). The 128-60a cycle was close to the Gleissberg cycle (Eddy, 1977;

10   Nagovitsyn, 2001) of solar activity, which had been widely recorded in previous geological series (Ogurtsov et al., 2011). In addition, multi-century cycles related to the solar activity have had a significant effect in research on large-scale climate systems (Rind, 2002; Raspopov et al., 2004). The 23-22a and 12-10a cycles also corresponded to typical of the quasi-11 years of sunspot activity cycle (Shindell et al., 1999). These cycles widely appeared in the tree-ring records in northeastern China (Chen et al., 2006; Wang et al., 2011; Wang et al., 2012; Yao and Wang, 2013). The above results indicated that the

15   solar forcing likely played a crucial role in past climate change in the Laobai Mountain region.

4 Conclusions

A significant positive correlation between the tree-ring widths of the Korean pine and the April-July MMT was found on the Laobai Mountain, northeastern China, and the April-July MMT was reconstructed. The reconstructed and the observed mean minimum temperature series exhibited good coherence during the common periods. The reconstructed series showed

20   interannual to multidecadal temperature variation during the past 413 years. The warm/cold periods of the reconstructed minimum temperature record were validated by the historical documents and several proxy temperature records in northeastern China and Northern Hemisphere. The most notable feature of the reconstructed series was obviously the rapid warming trend since the 1980s, which was also confirmed by other reconstructed temperature series. Additionally, the correspondence between the low-temperature years and the historical cold damage or frost disaster years demonstrate the

25   potential relationship between April-July MMT and cold damage or frost disaster events. In addition, this mean minimum temperature variability in northeastern China might be modulated by solar activity. It may provide new and valuable information for the longest temperature variations period in northeastern China.

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5   **References**

Akkemik, Ü.: Dendroclimatology of umbrella pine (*Pinus pinea* L.) in Istanbul, Turkey, Tree-Ring Bulletin., 56, 17-20, 2000.

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

10   Beer, J., Mende, W., and Stellmacher R.: The role of the sun in climatic forcing, Quaternary Science Reviews., 19, 403-415, 2000.

Bouriaud, O. and Popa, I.: Reconstruction of summer temperatures in Eastern Carpathian Mountains (Rodna Mts, Romania) back to AD 1460 from tree-rings, International Journal of Climatology., 34, 871-880, 2014.

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

15   Bu, Z. J., Wang, S. Z., Lang, H. Q., and Guo, K.Q.: Vegetation vertical zone spectrum and its features on southern slope of Laobai Mountain in Huangnihe Nature Reserve, Journal of Mountain Science., 21, 80-84, 2003.

Cook, E. R.: A time series analysis approach to tree-ring standardization, University of Arizona Press, Tucson, 1985.

Corona, C., Guiot, J., Edouard, J. L., and Chalié, F.: Millennium-long summer temperature variations in the European Alps 20   as reconstructed from tree rings, Clim. Past., 6, 379-400, 2010.

Chen, Z. J., He, X. Y., Chen, W., Shao,X. M., Sun,Y., Tao, D. L.: Solar activity, global surface air temperature anomaly and Pacific Decadal Oscillation signals observed in urban outskirts tree ring records from Shenyang, China, Advances in Space Research., 38, 2272-2284, 2006.

Cook, E. R., Kairiukstis, L. A.: Methods of dendrochronology: applications in the environmental sciences, Kluwer Academic 25   Publishers, Dordrecht, 1990.

Cook, E. R., Meko, D. M., Stahle, D. W., and Cleaveland, M. K.: Drought reconstruction for the continental United States, Journal of Climate., 12, 1145-1162, 1999.

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

D'Arrigo, R., Jacoby, G., Buckley, B., Sakulich, J., Frank, D., Wilson, R., Curtis, A., Anchukaitis, K.: Tree growth and 30   inferred temperature variability at the North American arctic treeline, Global and Planetary Change., 65, 71-82, 2009.

Eddy, J. A.: Climate and the changing sun, Climate Change., 1: 173-190, 1977.

Fritts, H. C.: Tree rings and climate, Academic Press, London, 567 pp., 1976.

Flower, A., Smith, D. J.: A dendroclimatic reconstruction of June-July mean temperature in the northern Canadian Rocky

Mountains, Dendrochronologia., 29, 55-63, 2012.

Gao, L. S., Wang, X. M., and Zhao, X. H.: Response of Pinus koraiensis and *Picea jezoensis* var. *komarovii* to climate in the transition zone of Changbai Mountain, China, Chinese Journal of Plant Ecology., 35, 27-34, 2011.

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

Hong, B., Liu, C. Q., Lin, Q. H., Yasuyuki, S., Ling, X. T., Wang, Y., Zhu, Y. X., and Hong, Y. T.: Temperature evolution of the last 14000 years of the Hani peat δ^{18}O, Science China Earth Sciences., 39, 626-637, 2009.

IPCC: Climate Change 2007: The Physical Science Basis, Cambridge University Press, Cambridge, UK and New York, USA, 2007.

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, Geophysical Research Letters., 41, 1732-1737, 2014.

Li, G.Q., Bai, F., and Sang, W. G.: Different responses of radial growth to climate warming in Pinus koraiensis and Picea jezoen-sis var. komarovii at their upper elevational limits in Changbai Mountain, China, Chinese Journal of Plant Ecology., 35, 500-511, 2011.

Lin, Q. H., Leng, X. T., and Hong, B.: The Peat Record of1ka of Climate Change in Daxing Anling, Bulletin of Mineralogy, Petrology and Geochemistry., 3, 15-18, 2004.

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. C.: Climate-growth relationships of three hardwood species and Korean pine and minimum temperature reconstruction in growing season in Dunhua, China, Journal of Nanjing Forestry University (Natural Sciences Edition), 37, 29-34, 2013.

Liu, Y., Wang, Y. C., Li, Q., Sun, J. Y., Song, H. M., Cai, Q. F., Zhang, Y. H., Yuan, Z. L., Wang, Z. Y.: Reconstructed May-July mean maximum temperature since 1745 AD based on tree-ring width of Pinus tabulaeformis in Qianshan Mountain, China, Palaeogeogr. Palaeocl., 388, 145-152, 2013.

Li, J. F., Yuan, Y. J., and You, X. R.: Research and application of dendrohydrology, Science Press, BeiJing, 2000.

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

Mäkinen, H., Nöjd, P., Kahle, H. P., Neumann, U., Tveite, B., Mielikäinen, K., Röhle, H., and Spiecker, H.: Large-scale climatic variability and radial increment variation of *Picea abies* (L.) Karst. in central and northern Europe, Trees., 17, 173-184, 2003.

Nagovitsyn, Y. A.: Solar activity during the last two millennia: solar patrol in ancient and medieval China, Geomagnetism and Aeronomy., 41, 680–688, 2001.

Ogurtsov, M., Sonninen, E., Hilasvuori, E., Kourdriavtsev, I., Dergachev, V., and Jungner, H.: Variations in tree ring stable

isotope records from northern Finland and their possible connection to solar activity, Journal of Atmospheric Solar-Terrestrial Physics., 73, 383-387, 2011.

Rind, D.: The Suns role in climate variations, Science, 296: 673-677, 2002.

Raspopov, O. M., Dergachev, V. A., and Kolstrom, T.: Periodicity of climate conditions and solar variability derived from dendrochronological and other palaeoclimatic data in high latitudes, Palaeogeography, Palaeoclimatology, Palaeoecology., 209, 127-139, 2004.

Sun, Y. G.: Grand dictionary of China meteorological disasters: Volume Heilongjiang, China Meteorological Press, Beijing, 2007.

Szeicz, J.M., MacDonald, G.M.: Dendroclimatic reconstruction of summer temperatures in northwestern Canada since A.D. 1638 based on age-dependent modelling, Quaternary Research., 44, 257-266, 1995.

Shindell, D., Rind, D., Balachandran, N., Lean, J., and Lonergan, P.: Solar cycle variability, ozone, and climate, Science, 284, 305-308, 1999.

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

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

Wu, X. D.: Tree-rings and climate change, China Meteorological Press, Beijing, 1990.

Wigley T. M. L., Briffa K. R., 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.

Wang, X. C., Brown, P. M., Zhang, Y. N., and Song L.: Imprint of the Atlantic Multidecadal Oscillation on tree-ring widths in Northeastern Asia since 1568, PLoS One, 6: e22740, 2011.

Wang, J. S., Chen, F. H., Yang, B., and Chen, J. H.: New advances in research on the Little Ice Age climate change, Advances in Climate Change Research., 2, 21-27, 2006.

Wilson, R., D'Arrigo, R., Buckley, B., Büntgen, U., Esper, J., Frank, D., Luckman, B., Payette, S., Vose, R., and Youngblut, D.: A matter of divergence: Tracking recent warming at hemispheric scales using tree ring data, J. Geophys. Res., 112, D17103, doi:10.1029/2006JD008318, 2007.

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

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

Wang, X. M., Zhao, X. H., Gao, L S., and Jiang, Q. B.: Age-dependent growth responses of Pinus koraiensis to climate in the north slope of Changbai Mountain, North-Eastern China, Acta Ecologica Sinica., 31, 6378-6387, 2011.

Yin, H., Guo, P. W., Liu, H. B., Huang, L., Yu, H. M., Guo, S. Y., and Wang, F.: Reconstruction of the October mean

temperature since 1796 at Wuying from tree ring data, Advances in Climate Change Research., 5, 18-23, 2009.

Yao, Q. C. and Wang, X. C.: Climate-growth relationships of Abies nephrolepis and its connection with large-scale climate change in Xiaoxing'an Mountains, northeastern China, Journal of Beijing Forestry University., 35, 30-38, 2013.

Yu, D. P., Wang, Q. W., Wang, Y., Zhou, W. M., Ding, H., Fang, X. M., Jiang, S. W., and Dai, L. M.: Climatic effects on radial growth of major tree species on Changbai Mountain, Annals of Forest Science., 68, 921-933, 2011.

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

Zhao, C. Y., Ren, G. Y., Zhang, Y. F., and Wang, Y. F.: Climate change of the Northeast China over the past 50 years, Journal of Arid Land Resources and Environment., 23, 25-30, 2009.

Tables

Table 1. Major statistical characteristics for the chronology of *Pinus koraiensis* in the Laobai Mountains.

	STD
Number of cores	54
Time span	1600-2014
Mean sensitivity	0.13
Standard deviation	0.22
Correlations between trees	0.25
Correlations within trees	0.64
Signal-to-noise ratio	8.67
Autocorrelation order1	0.75
Agreement with population chronology	0.90
Variance in first eigenvector	32.96%
First year where EPS>0.85 (No. of trees)	1660(5)

Table 2. Calibration and verification statistics of the reconstruction equation for the common period of 1956-2013

Calibration	R	R^2	Verification	R	Reduction of Error	Sign Test	Product Mean Test
whole Section （1956-2013）	0.757[**]	0.573	-	-	-	-	-
Front Section (1956-1984)	0.443[**]	0.196	Back Section (1985-2013)	0.638[**]	0.568	(21,8)[**]	4.683[**]
Back Section (1985-2013)	0.638[**]	0.407	Front Section (1956-1984)	0.443[**]	0.805	(21,8)[**]	6.116[**]

* Significant at the 0.05 level (two-tailed). ** Significant at the 0.01 level (two-tailed).

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Table 3. Cold and warm periods based on the 11-year moving average for the Laobai Mountain region April-July mean

minimum temperature during AD 1600–2013.

Rank	Cold period			Warm period		
	period	Year	Mean (℃)	period	Year	Mean (℃)
1	1605-1681	77	6.77	1697-1704	8	7.79
2	1684-1690	7	7.19	1767-1785	19	8.12
3	1747-1756	10	7.17	1787-1793	7	7.82
4	1914-1922	9	7.04	1795-1801	7	7.82
5	1953-1966	14	6.98	1803-1808	6	7.85
6				1816-1826	11	7.89
7				1835-1878	44	8.09
8				1987-2008	22	8.31

Figure captions

Fig. 1 Mean monthly temperature (℃) and total precipitation (mm) at the Dunhua meteorological station for the period 1956 to 2013

Fig. 2 Plot showing the Laobai Mountains STD chronology and sample depth

Fig. 3 Correlation between the ring width index and the average monthly meteorological data (including mean temperature, mean maximum temperature, mean minimum temperature, and precipitation) from Dunhua station (1956-2013). The dashed horizontal line represents the 95 % confidence limit.

Fig. 4 (a) Plots of actual (black line) and reconstructed (blue line) April-July minimum temperature for the common period of 1956-2013; (b) Reconstruction of April-July minimum temperature in Laobai Mountains for the last 413 years (the smoothed line indicates the 11-year moving average and blue dots represent minimum freezing events).

Fig. 5 (a) April-September mean minimum temperature reconstructed by Li and Wang (2013) in Dunhu, (b) February-April temperature established by Zhu et al. (2009) in Changbai Mountains, (c) Northern Hemisphere extratropical temperature (Wilson et at., 2007), and (d) April-July minimum temperature in Laobai Mountains (black lines denote temperature reconstruction values, red color lines indicate the 11-year moving average).

Fig. 6 Multi-taper method power spectra of the reconstructed minimum temperature (AD 1600-2013). Peaks above the dotted line represent significant periods at the 5 % level.
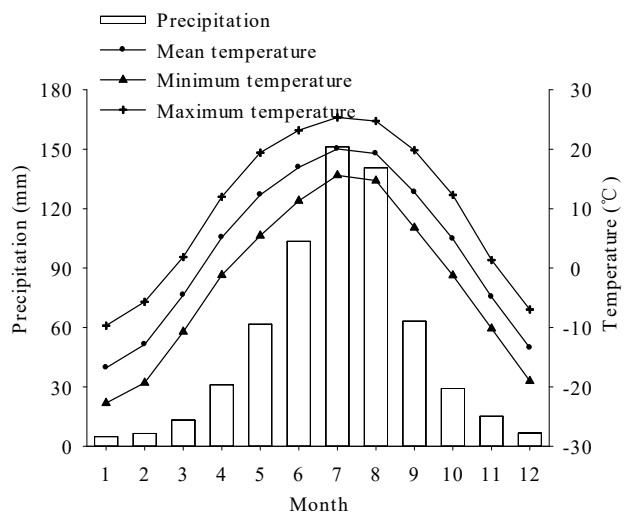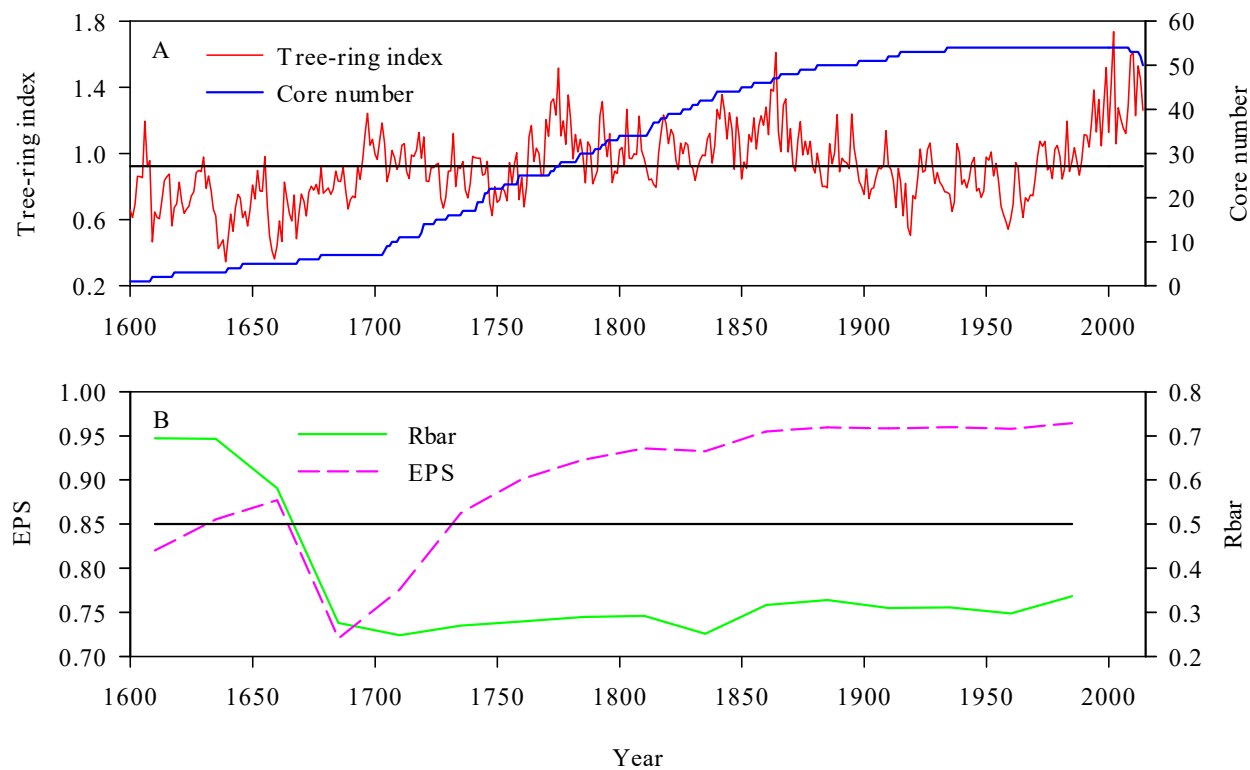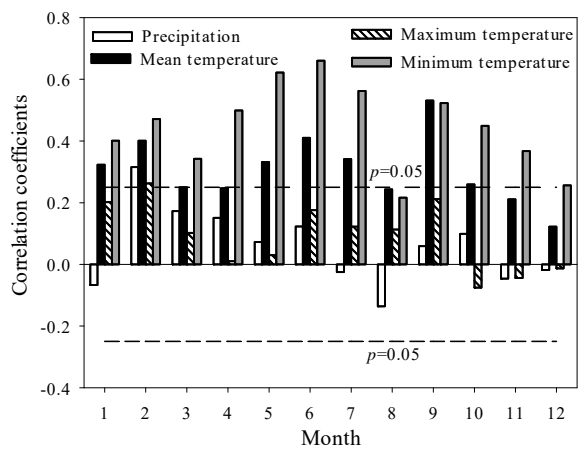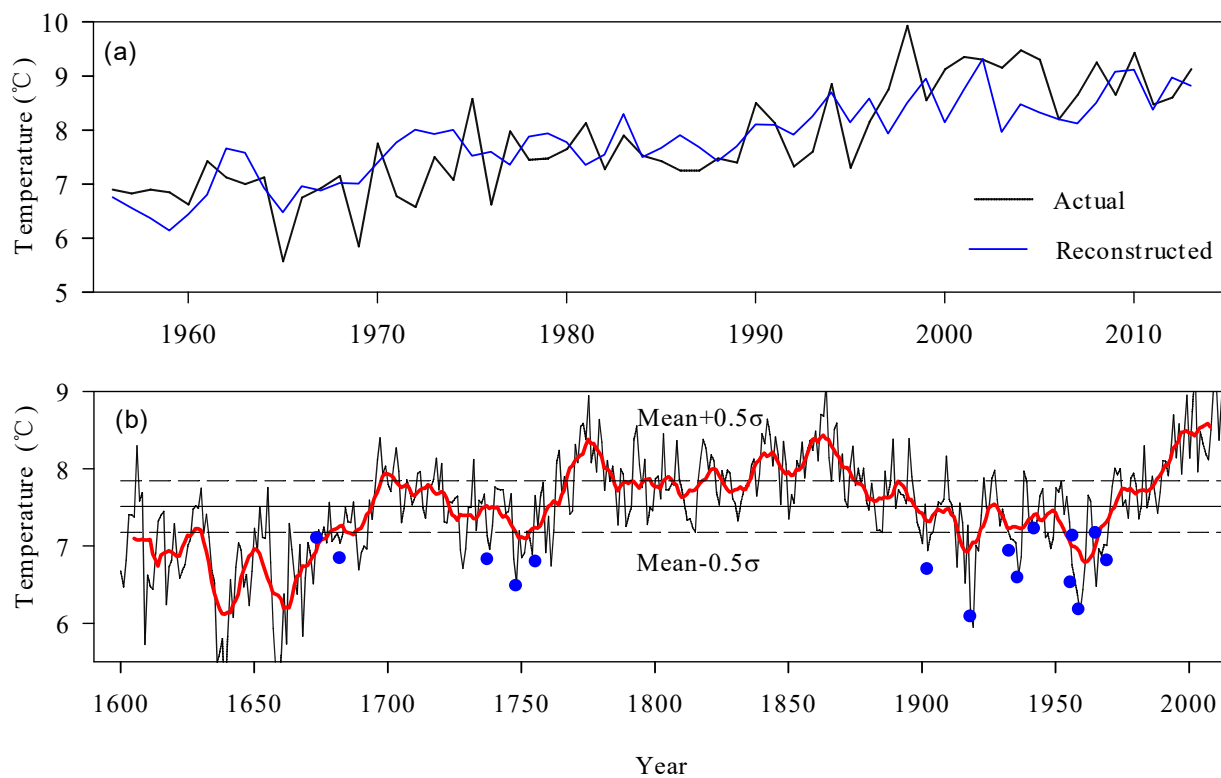
Fig. 1

Fig. 2

Fig. 3

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Fig. 4

Fig. 5

Fig. 6