Clim. Past Discuss., 5, 1215–1229, 2009
www.clim-past-discuss.net/5/1215/2009/

Climate of the Past Discussions

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Tree ring-based February–April temperature reconstruction for Changbai Mountain in Northeast China and its implication for East Asian Winter Monsoon

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Received: 27 March 2009 – Accepted: 6 April 2009 – Published: 15 April 2009

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Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

Long-term climatic records are scarce in the northeast Asia for understanding the behavior of the East Asian Winter Monsoon. Here we describe a 250-year February–April temperature reconstruction (TCBM) based on tree-ring widths of Korean Pines from the Changbai Mountain area, Northeast China. The reconstruction can account for 45.7% of the temperature variance in the instrumental period (1953 to 2001). Four cold events including 1784–1815, 1827–1851, 1878–1889 and 1911–1945, and two warm events of 1750–1783 and 1855–1877 were identified before the instrumental period. Four regime shifts were also detected at 1781, 1857, 1878 and 1989. Good agreements between TCBM and other temperature records of East Asia suggest that the reconstruction is of good reliability and captures the regional cold/warm events of East Asia. Moreover, TCBM shows negative correlations with the instrumental or proxy-based EAWM intensity records. The known weakening of the EAWM in the late 1980s is in agreement with the regime shift at 1989 in TCBM. These comparisons suggest that the February–April temperature reconstruction may be a good indicator of the EAWM intensity.

1 Introduction

Long temperature records are critical in studying the long-term behavior of the East Asian Winter Monsoon (EAWM), which is a key climatological feature in the northern hemisphere winter. Tree rings, as a continuously and annually resolved proxy, have been widely used to reconstruct past climate in North America and Europe (e.g. Briffa et al., 2004; Cook et al., 1999). In recent years, there are also several dendroclimatic reconstructions in East Asia (EA), such as in China, Korea and Japan (e.g. Choi et al., 1994; Shao and Wu, 1997; Yonenobu and Eckstein, 2006; Zhu et al., 2008). However, there still remains a lack of long temperature proxies for the northeast Asia, where winter climate is predominantly influenced by the intensity of the East Asian Winter

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Monsoon.

The purpose of this study is to reconstruct temperature record based on tree-ring widths of Korean Pines from the Changbai (also known as Baekdu) Mountain area in Northeast China (Fig. 1). The reconstruction may be used in the study of the long-term behavior of the EAWM.

2 Materials and methods

The study area is located in the Changbai Mountain, a volcano in Northeast China (Fig. 1). Tree-ring increment cores were sampled from four sites of trees in the Changbai Mountain (Fig. 1 and Table 1). The trees sampled were all from the dominant species, Korean Pine (*Pinus koraiensis*), of closed-canopy temperate forest. The cores were mounted, crossdated and measured through traditional process (Fritts, 1976; Stokes and Smiley, 1968). Then we used the COFECHA program to evaluate the accuracy of the crossdating and measurements (Holmes, 1983).

Tree-ring chronologies were developed using the ARSTAN program. A 180-year cubic smoothing spline was used to remove the long-term growth trends of raw ring-width series. The resulting ratio series were then averaged to build the site chronologies. To evaluate the reliability of the chronologies, the 50-year moving Expressed Populational Signal (EPS) with a 25-year lag (Wigley et al., 1984) were calculated (Table 1). Significant correlations from 0.52 to 0.63 exist among all site chronologies over the 1825–2002 common period (EPS>0.85). This allowed us to build a regional chronology (CB) by averaging all the individual ratio series of the four sites. CB is considered to be reliable from 1750 AD, when the sample depth is 20 series, although the EPS is 79.6%, slightly lower than the commonly used level of 0.85.

The relationships between tree-ring indices and climate variables were analyzed using correlation analysis for the period 1953–2002. The climate variables include monthly mean temperature and total precipitation from the Dunhua meteorological station (Fig. 1). The data from previous October to current October were used for the analysis, as the climate conditions of the previous year may have effects on tree-ring growth of the current year (Fritts, 1976).

To reconstruct the past climate variations, the instrumental records were regressed against the regional chronology (CB). In consideration of the lag effects of climate on tree growth, concurrent chronologies (at t) and those lagged at $t+1$ were used as independent variables. Several seasonal mean temperature subsets were examined from previous October to current September according to results of correlation analysis (Fig. 2). February–April mean temperature was chosen for reconstruction for its highest variance explained by CB_t and CB_{t+1}. The leave-one-out cross-validation method (Michaelsen, 1987) was used to verify the reconstruction since the instrumental data set from 1953–2002 was too short to be divided into two subsets for independent calibration and verification tests. The testing statistics include variance explained, adjusted variance explained, sign test of the first difference (SN1), sign test of the raw data (SN2), the reduction of error (RE) and Pearson's correlation coefficient (Fritts, 1976; Cook and Kairiukstis, 1990).

3 Results

Figure 2 illustrates the correlation coefficients between the regional chronology (CB) and the monthly climate data. The ring width has significantly ($p<0.01$) positive correlations with the temperature in previous October, current February to April, and September. However, there were no significant correlations between CB and precipitation at the 0.01 significance level.

The transfer function between February–April temperature and tree-ring chronologies (t and $t+1$) passed most of the calibration and cross-validation statistics. The final calibration model ($Tem=-10.9+0.00235CB_t+0.00412CB_{t+1}$) explained 45.7% ($p<0.001$) of the total variance of the instrumental records during 1953–2002 (Fig. 3). In the cross-validation test, the leave-one-out derived estimates accounted for 37.6% ($p<0.001$) of the recorded data. The positive RE (0.371) indicates good predictive skill of the regression model. Statistically significant SN2 (41+, 8−, $p<0.001$) is also an indication of the reconstruction's validity. The relatively low SN1 (30+, 19−, $p<0.15$) suggests that the strength of the calibration lies more in the lower-frequency agreement between the reconstruction and the instrumental records.

Figure 4a shows the interannual to multi-decadal variations of the reconstructed February–April temperature (TCBM) for the Changbai Mountain area since 1750. Several extended warm and cold events (>11 years) were identified before the instrumental period (1953–2002) according to the 11-year moving averages of the reconstruction and the long-term mean (1750–2002, -4.05°). The warm periods occurred around 1750–1783 (W1) and 1855–1877 (W2), while the cold periods mainly around 1784–1815 (C1), 1827–1851 (C2), 1878–1889 (C3), and 1911–1945 (C4) (Fig. 4a). Intervention analysis (Rodionov, 2004), with the mean values of 15-year periods being compared with values on either side of each year, was also applied to the TCBM to identify any significant shifts ($p<0.05$) (Fig. 4a). Four regime shifts were identified at 1781, 1857, 1878 and 1989.

4 Discussion

The results of correlation analysis (Fig. 2) suggest that the radial growth of Korean pine in Changbai Mountain is mainly limited by the pre-growth season temperature. The positive effect of February–April temperature on tree growth was also reported for other temperate coniferous forests, such as central Japan and Hudson River Valley (Pederson et al., 2004; Yonenobu and Eckstein, 2006). The warm winter may mean less damage to the roots and positive carbon gains for conifer trees when their leaves are not frozen (Chabot and Hicks, 1982; Havranek and Tranquillini, 1995; Pederson et al., 2004). In addition, the warmer temperature of previous October may allow an extended period of food accumulation for the growth of next year. However, the positive effect of current September is difficult to interpret because the cell division and enlargement may have ceased in the end of the growing season (April–September).

The cold/warm periods in our reconstruction (TCBM) (Fig. 4a) are generally consistent with other temperature reconstructions in East Asia. The warm period of W1 and cold periods of C1 and C2 were all indicated by the historical documented winter-half year temperature of East China (EC: Ge et al., 2003) (Fig. 4c) and the tree ring-based February–April temperature reconstruction of central Japan (CJ: Yonenobu and Eckstein, 2006) (Fig. 4b), although they are more than 1000 km away. Moreover, there are evidences from historical documents to suggest that cold climate occurred in the neighboring Heilongjiang Province during 1806–1810 and 1821–1850 (Gong et al., 1979), and cold winters or episodes of heavy snowfall in Japan during 1807–1819 and 1826–1836 (Fukaishi and Tagami, 1992). Despite their differences in lengths and magnitudes, the warm period W1 agrees well with the EC record. In addition, C3 is detected in both EC and CJ records, although it is not as long as in those studies. The cold period of 1910–1940s (C4) is consistent with the low February–April temperature in CJ. Overall, these agreements suggest that our reconstruction is of good reliability, and captures the regional cold/warm variations of EA on the decadal scale. There was a reconstruction of January–April maximum temperature based mainly on *Larix olgensis* and *Picea jezoen* for the Changbai area (Shao and Wu, 1997). However, due to the removing of persistence by autoregressive modeling (Cook and Kairiukstis, 1990) of their tree-ring data, little low-frequency variations were retained in the record for a comparison with the current reconstruction.

We correlated the reconstructed temperature against the EAWM index (EAWMI), which is based on the sum of zonal SLP differences (110–160° E) computed at 10 degree intervals over 10–60° N (Guo, 1994). The reconstructed temperature correlates with the winter (December–February) EAWMI at $r=-0.342$ ($p<0.001$) in 1874–2000, and at -0.503 ($p<0.001$) in 1951–2000 (Fig. 4d). The correlations between their 11-year moving averages are -0.573 and -0.903, respectively. The relatively lower correlations of the whole time span may be due to the scarcity of the earlier pressure data, which introduced uncertainties in the EAWMI. Strong EAWM years are characterized by frequent occurrence of cold surges that brings cold air from the Siberian/Mongolian

High (SH), thus producing the below-normal temperatures in the study area (Ding, 1990; Guo, 1994; Jhun and Lee, 2004; Yin, 1999). In addition, the regime shift identified at 1989 in our reconstruction is also consistent with the weakening of EAWM in the late 1980s (D'Arrigo et al., 2005; Nakamura et al., 2002; Tsunoda et al., 2006; Wang and Jiang, 2006). Therefore, our reconstruction should be a good indicator of the EAWM intensity.

The relationship between the reconstructed February–April temperature in the Changbai Mountain area and the EAWM is also verified by other proxy records. The SH is the source area of EAWM, and it intensity has significant positive correlation with the EAWM intensity, thus the intensity of SH can also be used to indicate the intensity of EAWM (Guo, 1994; Jhun and Lee, 2004; Wu and Wang, 2002). The non-seasalt potassium (NSSK) in the ice core from central Greenland was suggested to be transported from central Asia, and has been used to reconstruct the spring (March–May) SH intensity (Meeker and Mayewski, 2002). The high/low NSSK content variations are in good match with periods of the cold/warm periods in our reconstruction (Fig. 4e). The correlation between their 11-year moving averages is -0.48 for the common period of 1750–1985. Moreover, D'Arrigo et al. (2005) has developed a difference index between the normalized SH index and North Pacific index based on the tree-ring records from a broad Eurasia and northwest America. Although the index provides more information on the interannual variability of EAWM, it also demonstrates stronger Winter Monsoon during ~1825–1851 and 1920–1940s, which is in agreement with the cold events (C1 and C4) of our reconstruction. In addition, C2 is consistent with a culmination of the EAWM from ~1825 to 1841 recorded by historical documents in Japan (Hirano and Mikami, 2008).

5 Conclusions

In this study, we reconstructed a new February–April temperature record based on tree-ring widths of Korean Pines from the Changbai Mountain in Northeast China, which

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revealed variations at the interannual to multi-decadal scales over the past 250 years. The cold/warm events identified in the reconstruction are in good agreement with other reconstructions in East Asia, suggesting that these are significant events with regional implications. In addition, our reconstruction shows negative correlations with instrumental or proxy-based EAWM intensity records. The known regime shift of EAWM in the late 1980s is captured in the reconstruction, and similar shifts have occurred over the past 250 years. On the whole, these comparisons suggest that our reconstruction is of good reliability and may also be used as an indicator of the EAWM intensity. Hence, more efforts should be paid to extend the reconstruction by collecting more old trees or excavated wood samples buried under the volcanic ashes.

Acknowledgement. We thank H. Yonenobu, R. D'Arrigo and P. A. Mayewski for providing their data for comparison. We also thank D.-F. Qiao, L. Huang, Y. Xu and Y.-X. Zhang for their assistance. This research was funded by the Chinese Academy of Sciences (KZCX2-YW-315) and the National Natural Science Foundation of China (40771211 and 40890051).

References

Briffa, K. R., Osborn, T. J., and Schweingruber, F. H.: Large-scale temperature inferences from tree rings: a review, Global. Planet. Change, 40, 11–26, 2004.

Chabot, B. F. and Hicks, D. J.: The ecology of leaf life spans, Annu. Rev. Ecol. Syst., 13, 229–259, 1982.

Choi, J. N., Park, W. K., and Yu, K. B.: Central Korea temperature changes reconstructed from tree rings of subalpine conifers: A.D. 1635 to 1990, Dendrochronologia, 12, 33–43, 1994.

Cook, E. R. and Kairiukstis, L. A.: Methods of dendrochronology: applications in the environmental sciences, Kluwer Academic Publishers, Dordrecht, p. 394, 1990.

Cook, E. R., Meko, D. M., Stahle, D. W., and Cleaveland, M. K.: Drought reconstructions for the continental United States, J. Clim., 12, 1145–1162, 1999.

D'Arrigo, R., Wilson, R., Panagiotopoulos, F., and Wu, B. Y.: On the long-term interannual variability of the east Asian Winter Monsoon, Geophys. Res. Lett., 32, L21706, doi:10.1029/2004GL022271, 2005.

Ding, Y.: Build up, airmass transformation and propagation of the Siberian High and its relation to cold surge in east Asia, Meteor. Atmos. Phys., 44, 281–292, 1990.
Fritts, H. C.: Tree Rings and Climate, Academic Press, London, p. 567, 1976.
Fukaishi, K. and Tagami, Y.: An attempt of reconstructing the winter weather situations from 1720–1869 by the use of historical documents, Proceedings of the International Symposium on the Little Ice Age Climate, Tokyo Metropolitan University, Tokyo, 1992.
Ge, Q. S., Zheng, J. Y., Fang, X. Q., Man, Z. M., Zhang, X. Q., Zhang, P. Y., and Wang, W. C.: Winter half-year temperature reconstruction for the middle and lower reaches of the Yellow River and Yangtze River, China, during the past 2000 years, Holocene, 13, 933–940, 2003.
Gong, G. F., Chen, E. J., and Wen, H. R.: The climatic fluctuations in the Heilongjiang province, China, Acta. Geogr. Sin., 34, 129–138, 1979.
Guo, Q.: Relationship between the variations of East Asian Winter Monsoon and temperature anomalies in China, Q. J. Appl. Meteorol., 5, 218–225, 1994.
Havranek, M. and Tranquillini, W.: Physiological processes during their winter dormancy and their ecological significance, in: Ecophysiology of coniferous forest, edited by: Smith, W. K., and Hinkley, T. M., Academic Press, New York, 95–124, 1995.
Hirano, J. and Mikami, T.: Reconstruction of winter climate variations during the 19th century in Japan, Int. J. Climatol., 28, 1423–1434, 2008.
Holmes, R. L.: Computer-assisted quality control in tree-ring dating and measurement, Tree-Ring Bull., 43, 69–78, 1983.
Jhun, J. G. and Lee, E. J.: A new East Asian Winter Monsoon index and associated characteristics of the Winter Monsoon, J. Clim., 17, 711–726, 2004.
Meeker, L. D. and Mayewski, P. A.: A 1400-year high-resolution record of atmospheric circulation over the North Atlantic and Asia, Holocene, 12, 257–266, 2002.
Michaelsen, J.: Cross-validation in statistical climate forecast models, J. Clim. Appl. Meteor., 26, 1589–1600, 1987.
Nakamura, H., Izumi, T., and Sampe, T.: Interannual and decadal modulations recently observed in the Pacific storm track activity and east Asian Winter Monsoon, J. Clim., 15, 1855–1874, 2002.
Pederson, N., Cook, E. C., Jacoby, G., Peteet, D. M., and Griffin, K. L.: The influence of winter temperatures on the annual radial growth of six northern range margin tree species, Dendrochronologia, 22, 7–29, 2004.
Rodionov, S. N.: A sequential algorithm for testing climate regime shifts, Geophys. Res. Lett.,

31, L09204, doi:10.1029/2004GL019448, 2004.
Shao, X. M. and Wu, X. D.: Reconstruction of climate change on Changbai Mountain, northeast China using tree-ring data, Q. Sci., 76–85, 1997.
Stokes, M. A. and Smiley, T. L.: An Introduction to Tree Ring Dating, University of Chicago Press, Chicago, p. 73, 1968.
Tsunoda, T., Kawahata, H., Suzuki, A., Minoshima, K., and Shikazono, N.: Winter sea surface temperature variations based on coral oxygen isotope record from Ishigaki Island, the Ryukyus, Japan and transition of its dominant climate factor with 1988/1989 climate regime shift, Geochim. Cosmochim. Ac., 70, A657–A657, 2006.
Wang, H. and Jiang, D.: A new East Asian Winter Monsoon intensity index and atmospheric circulation comparison between strong and weak composite, Q. Sci., 24, 19–27, 2006.
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. Meteor., 23, 201–213, 1984.
Wu, B. Y. and Wang, J.: Winter Arctic Oscillation, Siberian High and East Asian Winter Monsoon, Geophys. Res. Lett., 29, 1897, doi:10.1029/2002GL015373, 2002.
Yin, Z. Y.: Winter temperature anomalies of the North China Plain and macroscale extratropical circulation, Int. J. Climatol., 19, 291–308, 1999.
Yonenobu, H. and Eckstein, D.: Reconstruction of early spring temperature for central Japan from the tree-ring widths of Hinoki cypress and its verification by other proxy records, Geophys. Res. Lett., 33, L10701, doi:10.1029/2006GL026170, 2006.
Zhu, H. F., Zheng, Y. H., Shao, X. M., Liu, X. H., Xu, Y., and Liang, E. Y.: Millennial temperature reconstruction based on tree-ring widths of Qilian juniper from Wulan, Qinghai Province, China, Chin. Sci. Bull., 53, 3914–3920, doi:10.1007/s11434-008-0400-8, 2008.

Table 1. Site information and tree-ring chronology statistics[a].

Site	Lat	Lon	Elev	TS	MSL	C/T	Ac1	Rbt	$Y_{EPS>0.85}$
CB4	37°02′	128°15′	1188	1651–2002	229	27/14	0.461	0.260	1810
LSH	47°27′	127°53′	870	1743–2002	180	40/21	0.349	0.338	1825
FA	42°22′	127°46′	940	1689–2002	206	40/27	0.444	0.251	1765
SMZ	43°11′	127°47′	765	1742–2002	199	57/29	0.531	0.232	1800

[a] Lat=site latitude; Lon=site longtitude; Elev=site elevation in meters; TS=time span; MSL=median segment length; C/T=number of cores/trees; Ac1=first order autocorrelation; Rbt=correlation between trees; $Y_{EPS>0.85}$=year of EPS>0.85.

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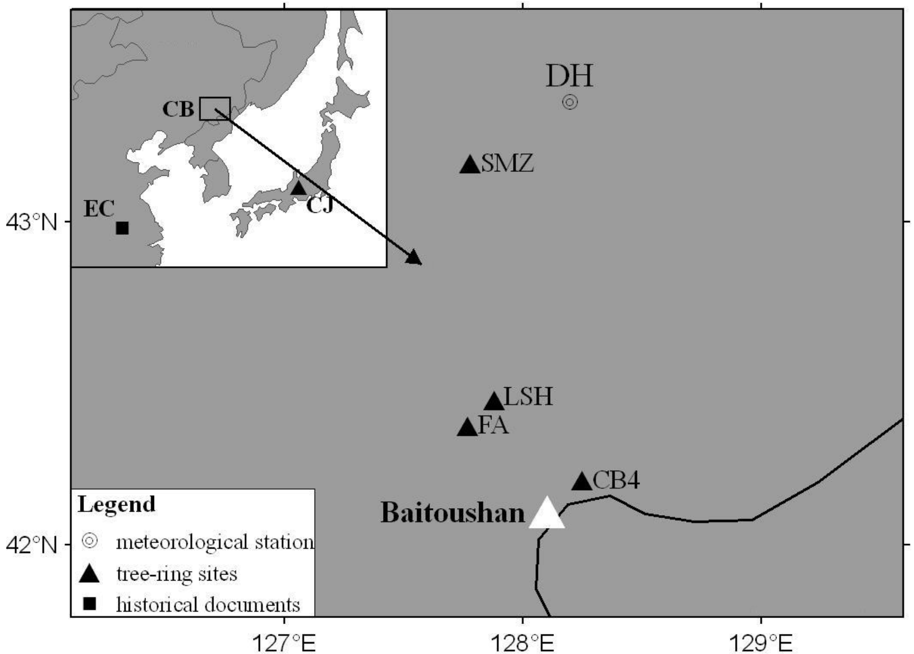

Fig. 1. Map showing the tree-ring sites, meteorological station, and other locations mentioned in text. CJ: Feburary–April temperature (Yonenobu and Eckstein, 2006); EC: Winter-half year temperature (Ge et al., 2003). Baitoushan is the main peak of Changbai Mountain.

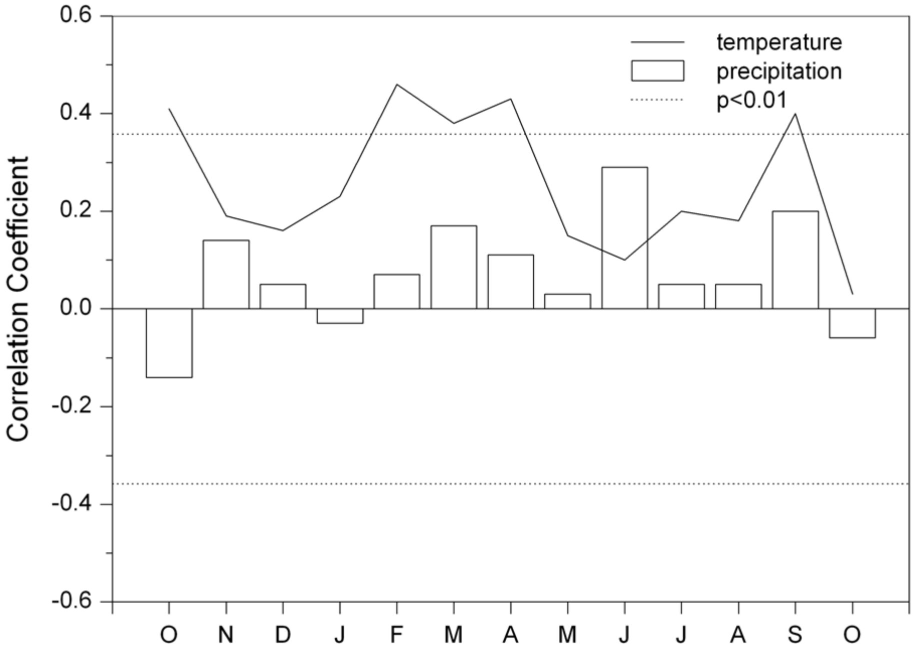

Fig. 2. Correlations between the regional chronology (CB) and monthly temperature and precipitation from previous October to current September at Dunhua station (1953–2002).

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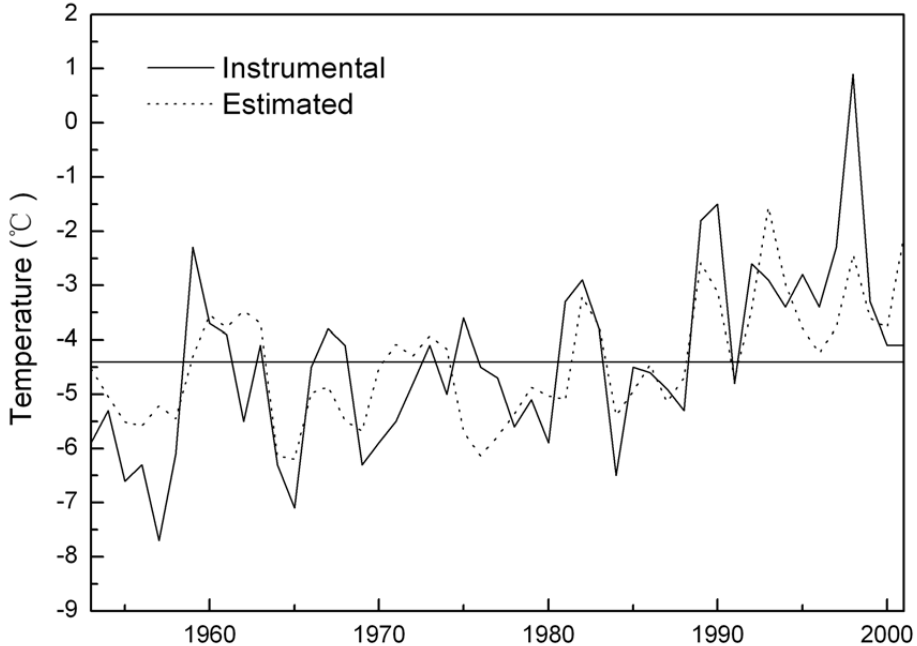

Fig. 3. Comparison between the instrumental and reconstructed February–April temperatures at Dunhua Station.

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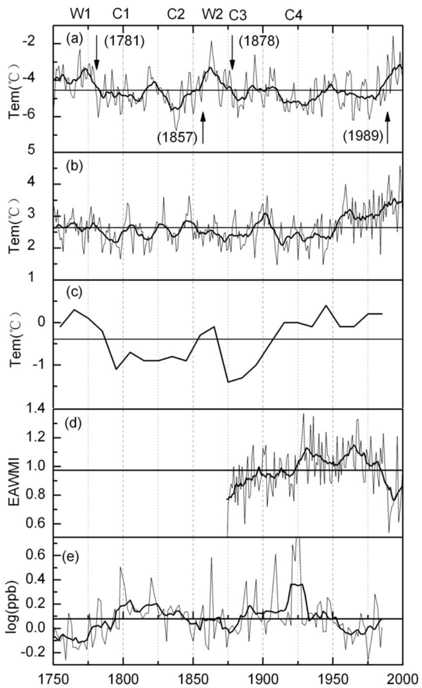

Fig. 4. Comparisons of the February–April temperature reconstruction in this study with other temperature reconstructions and East Asian Winter Monsoon (EAWM) records. **(a)** February–April temperature reconstruction of this study; **(b)** February–April temperature reconstruction in central Japan (Yonenobu and Eckstein, 2006); **(c)** winter-half year temperature reconstruction in East China (Ge et al., 2003); **(d)** East Asian Winter Monsoon (EAWM) index (Guo, 1994); **(e)** Non-seasalt potassium concentration (NSSK) in ice core from central Greenland (Meeker and Mayewski, 2002). The thick black curves are the 11-year moving averages and the horizontal lines are the long-term means. The years identified as regime shifts of the temperature reconstruction in this study are marked by arrows in (a).

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