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July-August temperature of central Korea since 1700 AD: Reconstruction from tree rings of Korean pine (*Pinus koraiensis*)

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ABSTRACT

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July-August mean temperatures of 1657-1998 AD were reconstructed using two local chronologies of Korean pine (*Pinus koraiensis*) growing in subalpine regions (1500-1600 m) of Sorak Mountain in the central Korean peninsula. Calibration function for the instrumental period (1909-1949 AD) was obtained by using linear regression with the lagged chronology at t-1. The calibration was verified by independent data of 1953-1995 AD. The reconstruction indicates that the 1700-1730 and 1830-1850 periods were coolest in last 340 years. The warming trend was not found in summer temperature during the 20th century.

Key-words—Global warming, Dendroclimatology, Korean pine, Subalpine trees.

मध्य कोरिया के विगत 1700 ई. से आज तक के जुलाई-अगस्त माह का तापमान : कोरियाई चीड़ (*पाइनस कोराइएन्सिस*) के वृक्ष वलयों से तापमान का पुनर्सृजन

वोन-क्यू पार्क, जिओंग-वुक स्यू, योजुंग किम एवं जेइ-हो ओह

सारांश

मध्य प्रायद्वीप के सोराक पर्वत के उपअल्पाइन क्षेत्रों (1500-1600 मीटर) में उगने वाले कोरियाई चीड़ (*पाइनस कोराइएन्सिस*) के दो स्थानीय कालानुक्रमों की सहायता से विगत सन् 1657-1998 ई. के मध्य के जुलाई-अगस्त माह के औसत तापमान का पुनर्सृजन किया गया। टी-1 पर पश्चायित कालानुक्रम से रैखिक समाश्रयण को प्रयुक्त करते हुए प्रमुख अवधि (सन् 1909-1949 ई.) हेतु अनुसंशोधित फलन प्राप्त किया गया। यह अनुसंशोधन सांख्यिकीय रूप से सन् 1953-1995 ई. की अवधि से तुलनीय है। पुनर्सृजन से संकेतित होता है कि विगत 340 वर्षों के दौरान सन् 1700-1730 ई. तथा सन् 1830-1850 ई. की अवधियाँ सर्वाधिक ठण्डी थीं। 20वीं शताब्दी के दौरान उष्णता सम्बन्धी रूझानों के कोई प्रमाण नहीं प्राप्त हुए हैं।

संकेत शब्द—भूमण्डलीय उष्णता, वृक्षजलवायुविकी, कोरियाई चीड़, उपअल्पाइनी वृक्ष.

INTRODUCTION

GREATER understanding of the global changes, particularly recent climate change, so called 'global warming', due to anthropogenic impacts, has become an increasingly important goal of scientific endeavor in the world which is faced with growing population and increasing pressure on energy, water and ecological values. However, the basic problem is that we do not know enough about the climate and its variations in the past, which is key to study the present and future climate. The records of actual instrumental observations of meteorological stations are too short to examine the climate variations in long term. Fortunately, information about climate prior to the beginning of instrumental observation can be obtained from proxy data such as pollen, sediment, ice cores and tree rings. Among proxies, tree rings provide the data with the highest resolution, at least, in yearly and even in seasonal scales (Fritts, 1976; Hughes *et al.*, 1982; Schweingruber, 1988; Cook & Kairiukstis, 1990).

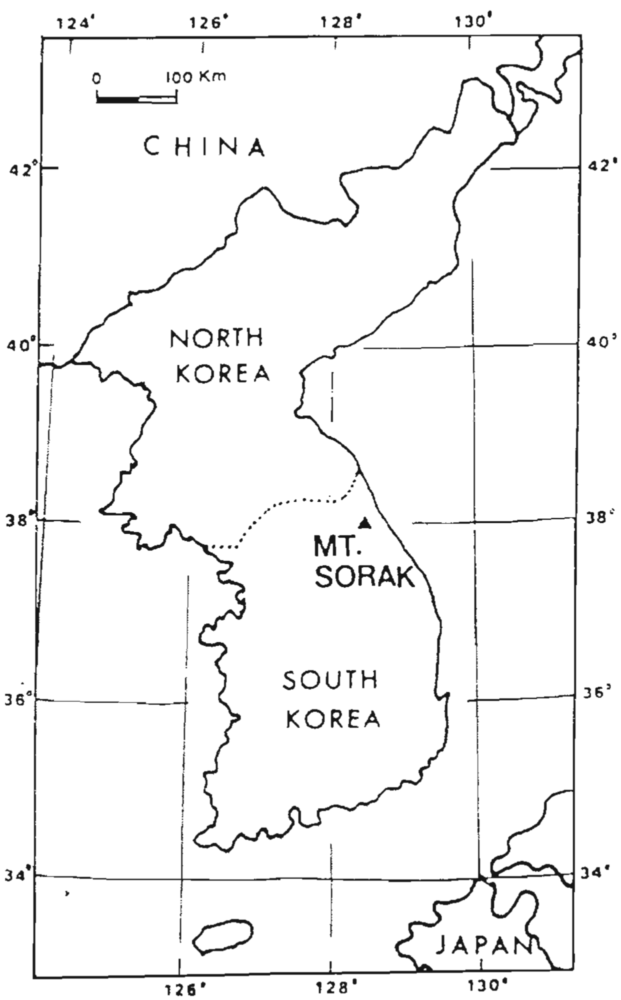

Fig. 1—Location of study site.

Some species reported growing for several centuries in Korea (Kong & Watts, 1993) provide unique opportunities to develop long tree-ring chronologies for climatic reconstructions for this region. Though the area is very important from a climatic view point, only a few high-resolution records of palaeoclimate are available for the Korean region (Park & Yadav, 1998).

The climate of the Korean peninsula within the domain of monsoon system is directly influenced by host of teleconnections with various climatic phenomena operating far remote from the area (Lau, 1992; Dodson & Liu, 1995). Long term high-resolution proxy climate data from such an area where various land-ocean-atmospheric processes interact are very important for assessing the natural variability of Earth's climate system especially in relation to the position of Siberian High, Tibetan High, the Asian monsoon and the western Pacific Warm Pool near Indonesia and New Guinea (Dodson & Liu, 1995).

In the present study, mean July-August temperatures are reconstructed back to the mid 17th century using tree-ring chronologies of Korean pine (*Pinus koraiensis* S. et Z.) growing in subalpine regions (1500-1600 m) of Sorak Mountain in the central Korean peninsula. Korean pine (*Pinus koraiensis*, 5-needle pine) is among the only few trees that live for several hundred years (Kong & Watts, 1993). The objectives of this study are to examine long-term summer temperature variation in central Korea and to compare the 20th century one with that of pre-industry period.

METHODS

Four site chronologies of Korean pine were made from the Sorak Mountain range, which is located in the east coast area of Central Korea (Fig. 1). Two sites (HC & OS) are on the slopes of Taecheongbong, the highest peak of Mt. Sorak and others (HU & HD) on the valley of Hangaerung. The former sites (1500-1600 m) are located at higher elevation than the latter ones (1300-1400 m). Each chronology was made from more than 10 trees. A total of 101 trees were sampled for the present study from dominant ones in each forest site (Fig. 2).

Paired increment cores were taken at breast height using an increment borer from each tree except in a few cases where another side was not approachable due to steep slope. The tree-ring sequences of the mounted and surfaced core samples were crossdated using the graphic method (Schweingruber, 1988). Ring widths were measured to nearest 0·01 mm using a Velmex measuring system. The ring-width plots of each core (log scale) were produced from the ring-width measurements using program TSAP. These plots were used for visual comparison on a light table to date the sample cores within and between the trees. Double-check of dating and measurement accuracies was performed by correlating overlapping 50-years segments of all measured series by using program COFECHA (Holmes, 1983). This helps in identifying segments of a core or group of cores where dating or measurement errors might occur. Thirteen trees could not be crossdated and were not included in further analysis.

Ring-width series were detrended to make tree ring indices using program ARSTAN (Cook, 1985). The detrending methods were chosen to remove age and stand dynamics related growth trends while preserving the maximum common signal with century scale. In most of the cases the cubic spline with 50% variance reduction function at 200 years was found suitable. Site chronologies were obtained by taking robust mean of all index series for each site.

Basic statistical qualities of each site chronology were obtained. Cross-correlation analysis (Briffa & Jones 1990) was conducted to examine the degree to which individual index series agreed with each other; the mean of all correlation among different cores, between-tree correlations, within-tree correlations, Expressed Population Signal (EPS) and the ratio of signal to noise (SNR) were obtained (Fig. 4).

The climate data used for calibration and verification are regional monthly temperatures, the average of 8 station data series obtained from Central Meteorological Service, Korea, 1990. To define an optimum season for reconstruction, we carried out the analysis of correlation between ring indices and monthly temperatures. These indicated generally positive correlations during late growing season and previous dormant season with the tree growth. Based on the correlation profiles, July-August mean temperatures were selected for reconstruction. The calibration and verification periods were chosen as 1909-1949 and 1953-1995, respectively. Multiple linear regression was used for calibration. Lagged predictors were tested for the regression. The lagging process used the ring-width indices for years t-2, t-1, t, t+1, t+2 (where the year of growth is year t) to determine if climatic variations in one year can influence growth in subsequent years due to biological persistence (Fritts, 1976). Various statistical comparisons were used for the verification. These are the correlation coefficients, R^2; sign test, and reduction of error (Fritts 1976).

Site I.D.	HC	OS	HU	HD
Mountain range	Taecheongbong		Hangaerung	
Location	Hwachebong	Osaek	Upper Slope	Down Slope
Elevation	1500	1600	1400	1300
Number of trees (cores)	46(96)	13(23)	13(26)	29(58)

Fig. 2—Site Information.

RESULTS AND DISCUSSION

We developed four sites chronologies (216-342 years) of Korean pine from Sorak Mountain in central Korea (Figs. 3 & 4). The plots of chronologies (Fig. 3) illustrate that the fluctuation patterns agree well with each other. Low growth periods in 1840s and 1900s are apparent. The pointer years, such as 1906, 1917 and 1959, are well matched (Fig. 3). Correlations among the chronologies obtained at similar elevation were high (0·706 between HC & OS, 0·812 between HU & HD for the 1900-1990 period), however, low among different elevation ones (0·354 between HC & HD, 0·183 between OS & HD). The mean correlation among site chronologies was 0·499. Chronology statistics and the results of cross-correlation analysis are given in Fig. 4. Mean sensitivities are 0·144-0·168. These data indicate moderate interannual variation of the tree-ring series. The correlation

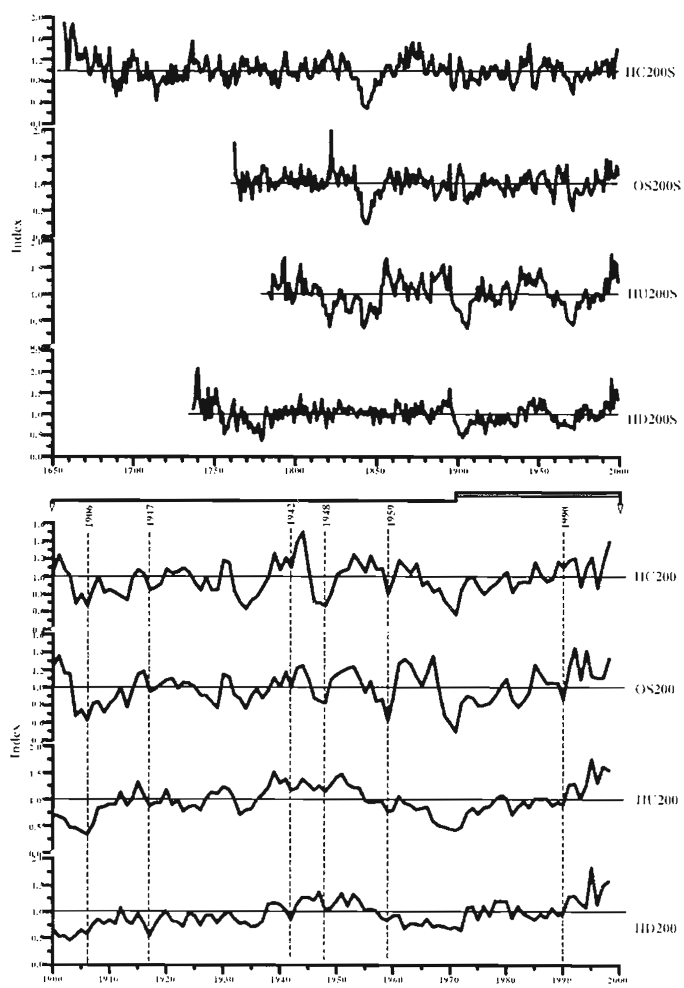

Fig. 3—Tree-ring chronologies of *Pinus koraiensis* of four sites at Sorak Mountain (see Fig. 2 for the chronology abbreviations: The numbers of 200 after site ID indicate the lengths of spline functions used for detrending raw ring-width series)

Site I.D.	HC	OS	HU	HD
Number of trees (cores) analyzed	43(86)	11(20)	13(26)	21(43)
Period (years)	1657-1998 (342)	1762-1998 (237)	1783-1998 (216)	1737-1998 (263)
Mean sensitivity	0·146	0·153	0·144	0·168
Correlation (91 years: 1900-1990)				
Among all radii	0·239	0·216	0·343	0·282
Between trees	0·233	0·206	0·330	0·276
Within trees	0·542	0·411	0·609	0·668
Signal-to-Noise Ratio	11·95	2·59	5·41	6·21
Expressed population signal (EPS)	0·92	0·72	0·84	0·86

Fig. 4—Summary statistics of four sites chronologies.

between trees (0·206-0·330) and the signal-to-noise ratio (2·59-11·95), which provide measures of the strength of common signal in the samples, are rather low. The EPS of three chronologies are higher than the EPS limit (0·85) of acceptable statistical quality suggested by Wigley *et al.* (1984). It implies that the chronologies developed in this study possess common signals.

We obtained mean chronology by taking arithmetic average of two index chronologies obtained at higher elevation sites (HC & OS) to maximize climatic signal. From correlation between climate variables and chronology, July-August mean temperature were chosen for calibration. Five lagged chronologies of t-2, t-1, t, t+1, t+2 years were tried first for the predictors in the stepwise regression, but only one predictor (chronology at t-1) was finally entered into the regression. The lagged predictor results from high autoregression in the chronology. We did not prewhiten the chronology in order to preserve low-frequency variation as much as possible. Final calibration equation for the reconstructions was as follows.

$$T_{J\text{-}A} = 21{\cdot}814 + 2{\cdot}980\ ALL_{t-1}$$

Calibration		Verification				
Period	R^2	Period	r	RE	Sign Test	PMt
1909-1949	0·23*	1953-1995	0·299*	0·05	27/14*	0·267

*R^2 is the square of the correlation coefficient calculated between actual and estimated data; r is the actual/estimated correlation over the verification period; RE is the reduction of error; Sign-test is the sign of paired observed and estimated departures from the mean on the basis of the number of agreements/disagreements; PMt is the t value derived using the product mean test (Fritts, 1976). * $p<0{\cdot}05$, ** $p<0{\cdot}01$.

Fig. 5—Calibration and verification statistics computed for tree-ring and the mean temperature of July to August for two sub-periods. The sub-periods 1909-1949 and 1953-1995 were used for calibration and verification, respectively.

where $T_{J\text{-}A}$ is the mean July-August temperatures; ALL_{t-1} is the ring-width index data at year t-1 for the mean chronology of Mt. Sorak Korean pine.

The calibration and verification statistics are summarized in Fig. 5. Despite the relatively low quality of the calibration (R^2 = 0·23), all verification tests were significant. The RE (reduction of error), considered as the most rigorous test (Fritts *et al.*, 1990), was larger than zero, which is roughly equivalent to a 95 confidence level for n=20. The verification results indicated the reliability of the reconstruction.

The complete reconstruction is plotted in Fig. 6. Though the reconstruction was made since 1657 AD, the plot was truncated at 1700 AD prior to which sample depth is low. The reconstructed summer temperature (Fig. 1) shows that alternating periods of generally cool and generally warm conditions are typical in summer in central Korea. It indicates also that the 1700-1730 and 1830-1850 were coolest in the last 300 years.

The ancient rain-gauge data in Seoul (1770-1910 AD) records the period 1830-1840 as the wettest period during the last two centuries (Wada, 1917). Highest annual precipitations in the ancient and modern records in Seoul were found in 1839 (3220 mm), 1879 (3148 mm), 1821 (3186 mm) and 1832 (2744 mm). The heavy rains in July brought major floods in 1821 (1410 mm) and in 1832 (1426 mm), which were even much higher than annual mean precipitation (about 1300 mm) (Wada, 1917). In Japan, also very heavy rainfalls brought floods in 1830s (Mikami, 1992). Late 1830s was found one of coolest and wettest summer periods in Northeastern and Central Japan in a study based on the daily weather records in old diaries (Kim, 1992; Mikami, 1992). The present reconstruction indicates that 1840, 1841 and 1842 were the coolest years in the central Korea in the last 300 years. Previous dendroclimatic study also indicated that the years of 1841 and 1842 were coolest years in the same region. We conclude that the 1830-40s cool anomaly is not local but regional aspect, at least in east central Korea.

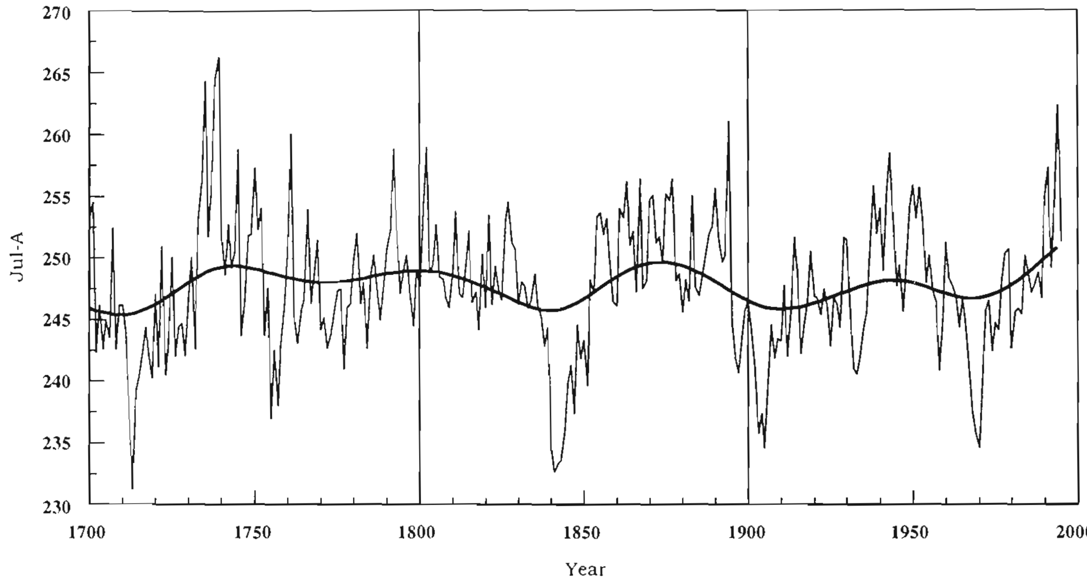

Fig. 6—Reconstructed July-August mean temperature variation. (Y-axis: x 10 celsius degree, bold line is 80-year spline filter)

The warm trend in summer temperature was not found in the last 20th century. In a dendroclimatic study, the warm trend found in the 20th century was less pronounced than the cool periods in the previous centuries. Both studies confirm that the summer-temperature warming trend in central Korea during the 20th century is not obvious.

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REFERENCES

Briffa KR & Jones PD 1990. Basic chronology statistics and assessment. *In* : Cook ER & Kairiukstis LA (Editors)—Methods of Dendrochronology: Applications in the Environmental Sciences : 137-152. Kluwer Academic Publisher, Dordrecht.

Cook ER 1985. A time series analysis approach to tree ring standardization. Unpublished Ph.D. dissertation. University of Arizona, Tucson, Arizona, 175 p.

Cook ER & Kairiukstis LA (Editors) 1990. Methods of Dendrochronology: Applications in Environmental Sciences. Kluwer Academic Publisher, Dordrecht, 394p.

Dodson J & Liu T 1995. The Austral-Asian transact. chapter III, Palaeoclimates of the northern and southern Hemispheres- The Pole-Equator-Pole Transacts: science and implementation plan, PAGES, 95-1: 43-64.

Fritts HC 1976. Tree Ring and Climate. Academic Press Inc., New York, 565 p.

Holmes RL 1983. A computer-assisted quality control program. Tree-Ring Bulletin 43: 69-78.

Hughes MK, Kelly PM, Pilcher JR & LaMarche VC (Editors) 1982. Climate from Tree Rings. Cambridge University Press, Cambridge, U.K, 223p.

Kim YO 1992. The Little Ice Age in Korea: An approach to historical climatology. *In*: Mikami T (Editor)—Proceedings of the International Symposium on the Little Ice Age Climate : 170-175. Department of Geography, Tokyo Metropolitan University.

Kong WS & Watts D 1993. The Plant Geography of Korea with an Emphasis on the Alpine Zones. Kluwer Academic Publisher, Dordrecht, 229 p.

Mikami T 1992. Climate variations in Japan during the Little Ice Age-Summer temperature reconstructions since 1771. *In*: Mikami T. (Editor)—Proceedings of the International Symposium on the Little Ice Age Climate : 176-181. Department of Geography, Tokyo Metropolitan University.

Lau KM 1992. East Asian summer monsoon rainfall variability and climate teleconnection. Journal of Meteorological Society of Japan 70 : 211-242.

Park W-K 1993. Increasing atmospheric carbon dioxide and growth trends of Korean subalpine conifers. Journal of Korean Forestry Society 82 : 17-25 (in Korean).

Park W-K & Yadav RR 1998. Reconstruction of May precipitation (A.D. 1731-1995) in West-Central Korea from tree rings of Korean red pine. Journal of Korean Meteorological Society 34 : 459-465.

Schweingruber FH 1988. Tree Rings. Kluwer Acad. Pub., Dordrecht, Netherlands, 276p.

Wada Y 1917. Chosen Kodai kansoku kiroku chosa hokoku (reports on the survey of the ancient records of observation in Korea), Government-General of Chosen Weather Bureau, Seoul, Korea, 200p (in Japanese).

Wigley TML, Briffa KR & Jones PD 1984. On the average value of correlated time series, with applications in dendroclimatology and hydrometeology. Journal of Climate and Applied Meteorology 23:201-213.