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Reconstruction of May—July precipitation in the north Helan Mountain, Inner Mongolia since A.D. 1726 from tree-ring late-wood widths

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Abstract **By analyzing statistical characteristics of five tree-ring standard chronologies, early-wood ring width (EWW), late-wood ring width (LWW), total ring width (TRW), minimum early-wood density (MinD), maximum late-wood density (MaxD) and, their climatic response respectively, we reconstructed the May to July precipitation using late-wood ring width (LWW) over the north Helan Mountain since A.D. 1726. The explained variance is 42% (R^2_{adj} = 41%, F = 31.46, p < 0.000001). After 11-a moving average, the explained variance reaches 82% (F = 156.9, p < 0.05). On the decadal scale, the rainfall reconstruction of the northern Helan Mountain displays a quite similar variation pattern with that of the April to early July precipitation in Baiyinaobao, east of Inner Mongolia for the last 150 years. It may reflect the intensity variation of the East Asia Summer Monsoon front to a certain extent. Spectrum analysis shows 11-a and 22-a periodicities in the May to July precipitation reconstruction at the north Helan Mountain.**

Keywords: Helan Mountain, *pinus tabulaeformis*, late-wood ring width, precipitation reconstruction.

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In recent years, great progress of dendroclimatology study has been made in China, and lots of valuable data have been obtained. The climatic factors, such as temperature, precipitation, etc., have been reconstructed on the basis of tree-ring data for the past several centuries[1−5]. These data have played (or will play) an important role in both regional and global change researches[6]. So far, however, tree-ring data from the boundary of the desert to loess area in northwest China are sparse[7]. This study will use the tree-ring data in terms of the statistical method to reconstruct the May to July precipitation at the north Helan Mountain, which is located in the boundary, since A.D.1726.

The Helan Mountain is situated in China inland, which is at the northwest margin of the East Asia Summer Monsoon. The precipitation in the region, generally speaking, mainly concentrates upon June to August, accounting for annual 50%—60%, and in certain years it reaches 80%—90% (for example, in 1979, 89% in Yinchuan meteorological station, and 81% in A La Shan station, respectively). The summer precipitation in the region is related with the East Asia Summer Monsoon. In fact, after running a long way, the intensity of the Summer Monsoon is weakened when it arrives in the Helan Mountain area. The region, therefore, is quite sensitive to the strong/weak intensity variation of the Summer Monsoon front[8].

1 Materials and methods

The sampling site is located in the south and north braes of Beisi valley (39°05′N, 106°05′E), western slop of northern part of the Helan Mountain (Fig. 1), in Inner Mongolia. The gradient of sampling site is 30°—60° with the elevation of 1500—2000 m. The site is quite open and faces the Tengger desert westward. The preponderant species at the site is Chinese pine (*Pinus tabulaeformis*), although a few junipers (*Juniperus rigida*) and Birch (*Populus davidiana*) grow there also. The soil of the site is thin and the vegetation is scarce. Some samples were taken from isolate trees standing on the gap of rock. During a field trip in April of 1998, 25 Chinese pine trees were selected, named MHL02 Group. Two cores were taken from each tree, and the third core was collected from each of 19 trees among the total for density analysis.

Cross-dating[9] was carried out to ensure that every growing ring has an exact calendar year. Each annual ring

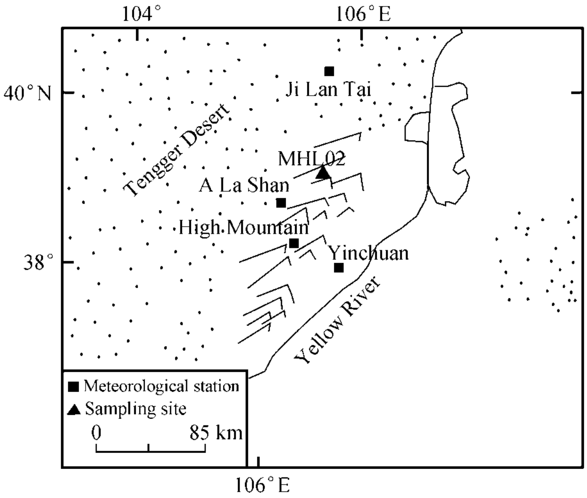

Fig. 1. The location of sampling site and meteorological stations.

was then measured within 0.001 mm. Quality control was done by the COFECHA program[10]. The outcome shows that the average correlation coefficient among the series is 0.817, mean sensitivity 0.617, and the rate of ring-absent 2.818%. These mean that all the trees in the study region are controlled by climatic factors extensively. Tree-ring density was measured in the Laboratory of Tree-ring Research, The University of Arizona, U.S. and the technique procedure can be found in ref. [11]. The turning point of smooth to abrupt rising on the density curve was used to distinguish early wood and late wood. The early- and late-wood ring widths were also measured during the process of density analysis.

2 Establishment of chronologies and their relationships

Standardizing each series (i.e. detrending) is a key step in dendroclimatology study. The purpose is to eliminate tree-age related growing trends and inconsistent disturbances among trees. During the process of standardization, in order to minimize the removal of any long-term climatic variance, we selected conservatively negative exponential functions or straight-line to fit each individual ring-width or ring-density measurement series. The detrended index series were then prewhitened using an autoregressive model selected on the basis of the minimum Akaike Information Criterion (AIC) to remove the persistence not related to climate variation, and combined into a single chronology using a biweight robust estimate of the mean. Thus, three kinds of chronologies were obtained, standard (STD), residual (RES) and ‘ARSTAN’ (ARS). The residual chronology mainly express high-frequency signals, and the low-frequency signals attenuate severely. In order to extract low-frequency signals, which will be used in another climate prediction paper, we use standard chronology to do reconstruction in this paper. The longest series is from 1721 to 1997. Because there are few samples in the early years, our precipitation reconstruction is from 1726 to 1997. The chronologies described above were established by using the program CRONOL1).

The five standard chronologies, early-wood ring width (EWW), late-wood ring width (LWW), total ring width (TRW), minimum early-wood density (MinD) and maximum late-wood density (MaxD) have been obtained in the studying site. Correlation analysis indicates that there is significant correlation between TRW and EWW ($r = 0.75$, $p < 0.001$), TRW and LWW ($r = 0.63$, $p < 0.001$), LWW and MaxD ($r = 0.51$, $p < 0.001$). The MinD is relatively independent. PC1 and PC2 can explain 74% of total variance. PC1, PC2 and PC3 explain 87%.

The following statistical analysis shows that the LWW is more suitable for seasonal precipitation reconstruction (Table 1).

Table 1 The statistics of LWW, MinD, MaxD standard chronologies

Statistical item	LWW	MinD	MaxD
Mean	1	1	1
Mean sensitivity	0.45	0.11	0.22
Standard deviation	0.44	0.12	0.22
Skewness	0.49	–2.33	–0.42
Kurtosis	–0.10	18.23	0.75
First order autocorrelation (AR1)	0.26	0.15	0.32
Mean correlation between all series	0.55	0.12	0.56
Mean correlation between trees	0.55	0.12	0.56
Mean correlation within a tree	0.71	0.19	0.68
Signal/noise ratio	10.85	1.18	11.35
% Variance in 1st PC	59.43	26.88	60.18
Expressed population signal (EPS)	0.92	0.54	0.92

3 Climatic data, response function and transfer function

There are four meteorological stations around the sampling site: A La Shan (38°50′N,105°40′E, elevation 1561.4 m, record period 1953—1997), Ji Lan Tai (39°47′N, 105°45′E, elevation 1031.8 m, 1955—1997), Yinchuan (38°29′N, 105°13′E, elevation 1111.5 m, 1951—1997) and High Mountain (38°46′N, 105°54′E, elevation 2901 m, 1961—1990).

Before using the data, Man-Kendall statistic and double-mass analysis methods were applied to testing homogeneity and randomness against trend of climatic data[12,13]. The results show that the temperature and precipitation data from these four stations do not display quite evident inhomogeneity and can be used for further analysis.

The response function analyses indicate that the tree’s growth negatively correlates with the temperature of late spring to early summer in three meteorological stations, and positively correlates with the precipitation of spring to summer (Fig. 2). In other words, the tree’s growth positively correlates with the total precipitation of May to July in three stations, and negatively correlates with the mean temperature of June to July. More rainfall in May to July leads to wider late-wood ring width and higher density value due to lag effect, and *vice versa*.

After calculating and comparing, we found that the tree-ring chronologies are better correlated with the climatic data from A La Shan station. This station, the nearest and similar elevation to the sampling site, is located in the western slop of the Helan Mountain. The data from A La Shan station, thus, will be used in the following calibration.

Regression analyses between tree-ring standard

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1) Dendrochronology Programm Library, http://www.ltrr.arizona.edu/software.html

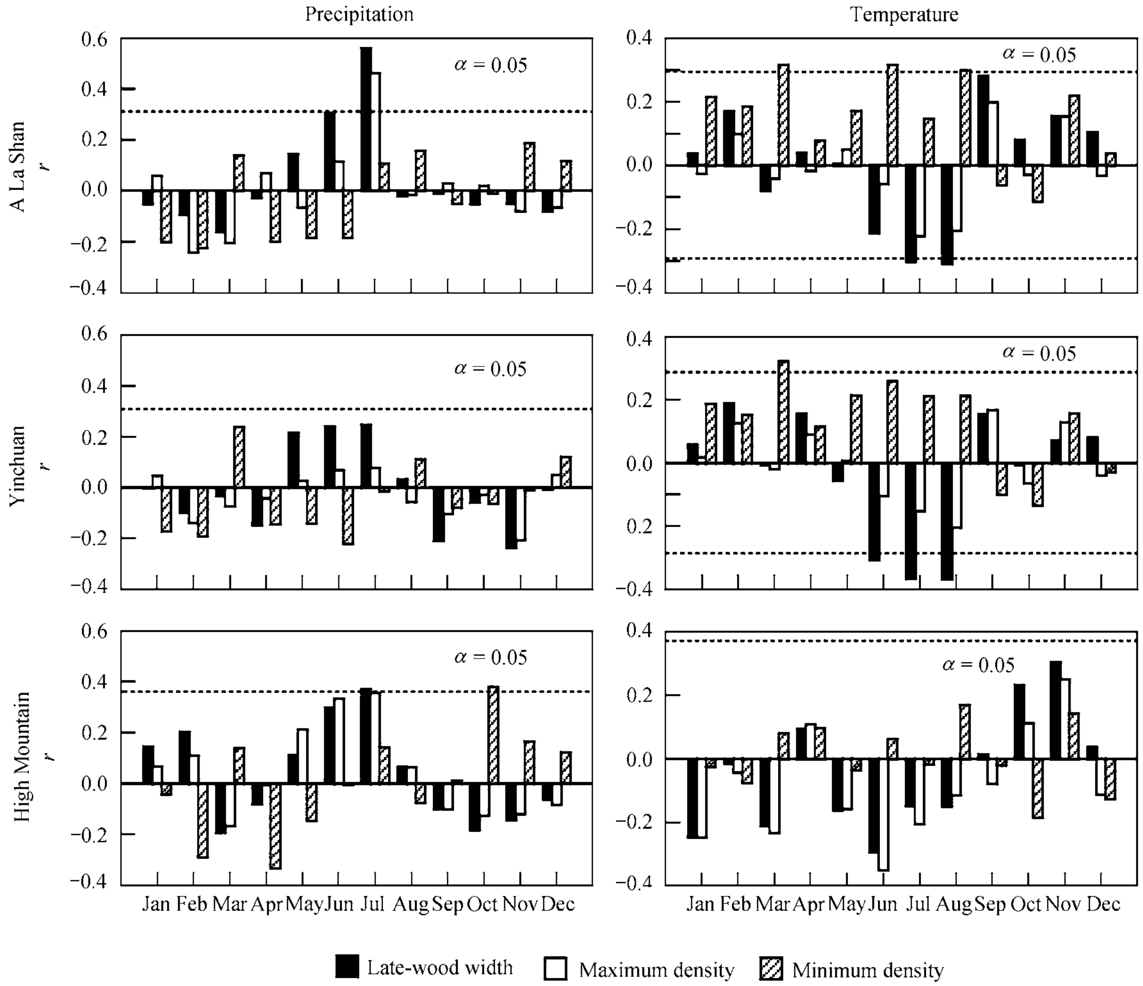

Fig. 2. The response function analyses of the standard chronologies (LWW, MinD and MaxD).

chronologies (including EWW, LWW, TRW, MinD, MaxD) and the total precipitation from May to July (P57) suggest that the late-wood maximum density (MaxD) and the late-wood ring width (LWW) are more sensitive to the precipitation change. MaxD and LWW are therefore used to do multi-regression, and the multiple correlation of the model is significant with r=0.66, the explained variance R^2 is 0.44, the F value 16.4, $p < 0.0001$.

The partial correlation analysis shows that when the MaxD is fixed, the correlation between P57 and LWW is closer ($r_{\text{partial}} = 0.57$, $p < 0.001$), between P57 and MaxD is very weak ($r_{\text{partial}} = -0.16$, $p < 0.05$). This result indicates that the late-wood maximum density (MaxD) could be excluded in the following study.

The correlation between the LWW standard chronology and the precipitation of June and July exceeds the confidence level at 95% (r = 0.30 and 0.56 respectively). The correlation with the rainfall of May is 0.14. Combine the 3 months: the correlation between the LWW and the total precipitation from May to July is 0.65 and it has evident tree physiological bases.

In terms of analysis mentioned above, we finally only use the LWW index to reconstruct May—July precipitation for the north Helan Mountain. A transfer function is designed as

$$\text{P57} = 53.558\ \text{LWW} + 31.378, \tag{1}$$

$$(N = 45,\ r = 0.65,\ R^2 = 0.42,\ R^2_{\text{adj}} = 0.41,\ F = 31.46,\ p < 0.000001)$$

where P57 presents the total precipitation from May to July, LWW is the standard chronology (STD) of late-wood ring width.

Figure 3 shows the comparison between the reconstructed May—July precipitation and the actual instrumental data for the period of 1953—1997. They have shown well coincidence. Leave-one-out[14] test suggests that the regression model (1) is unstable due to the existence of 1993. Climatic records show that the precipitation of 1993 from May to July is in the normal range (Fig. 4), but the rainfall of March is 0.6 mm (only 1/10 of the 45-a average), and in April is 2.6 mm (the 45-a average 10.9 mm). Obviously, the precipitation less than normal in March and April caused a great negative effect on the tree's growth in the year 1993. If the year 1993 is eliminated, the quality of regression model will be higher than before (r = 0.7, R^2 = 0.49, R^2_{adj} = 0.48, F = 40.45, p < 0.000001). However, considering the needs of long-term climatic variation trend and prediction, the year 1993 is still kept in the model.

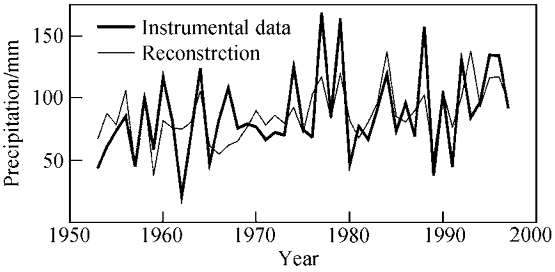

Fig. 3. The comparison between the reconstructed May—July rainfall and the actual instrumental data.

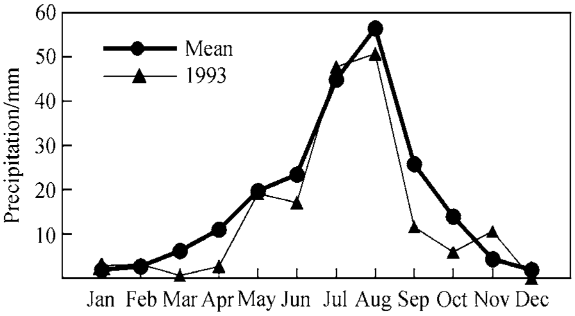

Fig. 4. The precipitation comparison between each month in 1993 and the mean values of multiple years

It is possible to improve the regression quality by a filtration of high-frequency components as random white noise. The dynamic quality of the model becomes much higher after 11-a moving average both for precipitation and LWW (r = 0.91, R^2 = 0.82, F = 156.9, p < 0.05) (Fig. 5).

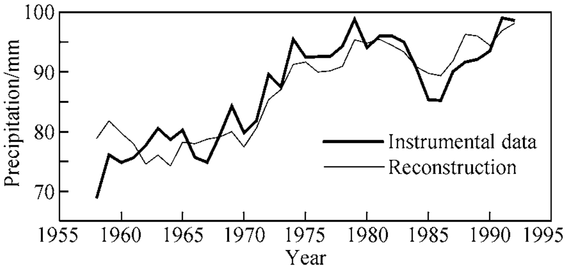

Fig. 5. Dynamic comparison between May—July precipitation reconstruction based on the LWW and the actual instrumental data after 11-a moving average.

4 Seasonal precipitation reconstruction and discussion

The rainfall from May to July is reconstructed for the period of 1726 to 1997 at the north Helan Mountain based on transfer equation (1) (Fig. 6). The horizontal line is the mean from 1726 to 1997, and the standard deviation (σ) is 9 mm. In this paper, we define dry: less than mean −1σ, and wet more than mean + 1σ. So the annual dryness/wetness changes are clearly shown in Fig. 4. As calculated, the dry season (May to July) presents 101 years, 37% of the total years in the reconstruction, and the wet one is 90 years, 33.1% of the total. It is obvious that dry (or drought) May—July occurred frequently in this region. The drought

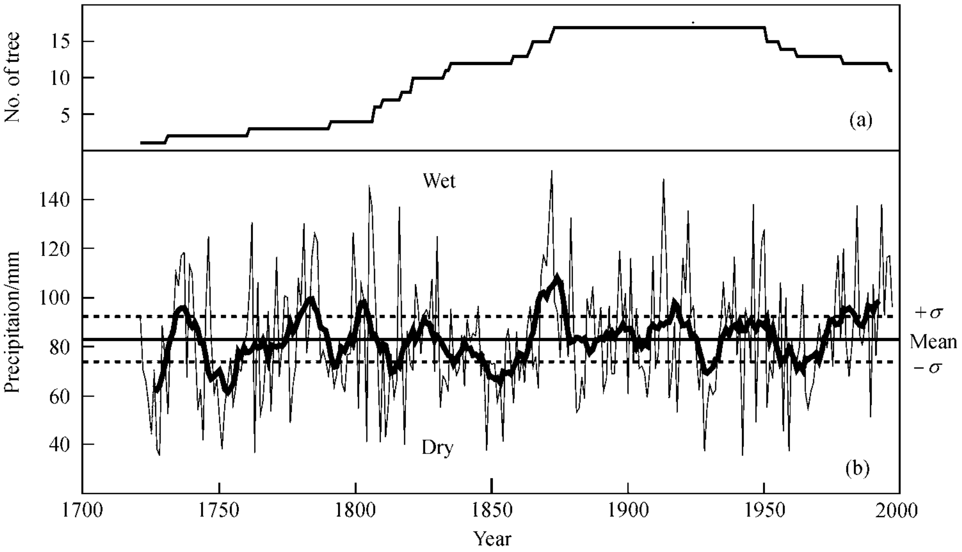

Fig. 6. The precipitation reconstruction based on the LWW from May to July during 1726 to 1997 for the north Helan Mountain. The horizontal line is the mean (83 mm) of 1726—1997, the standard deviation σ = 9 mm, the smooth line is the 11-a moving average.

event around 1929 is very clear in the reconstruction, which again confirms that it is a severe and wide range drought event[6,15,16].

After 11-a moving average (the smooth line in Fig. 6), the precipitation has clear changing rhythm on decadal scale, and it is quite similar to the precipitation from April to early July in Baiyinaobao, located in eastern Inner Mongolia[3] (Fig. 7). Although there is a long distance more than 1000 km between the Helan Mountain and the Baiyinaobao region, the two places are both located in the margin of the East Asia Summer Monsoon. The reconstructed climatic factor (rainfall from the late spring to early summer) in both regions is related with the East Asia Summer Monsoon, and displays the common variation trend. Therefore, to a certain degree the two curves reflect the strong/weak variation of the East Asia Summer Monsoon front.

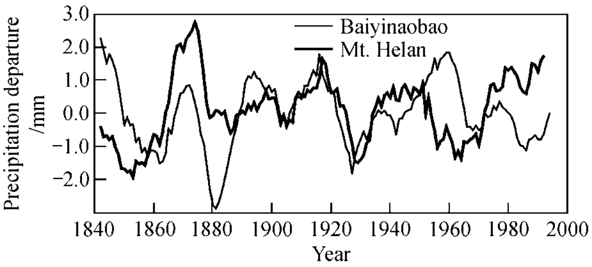

Fig. 7. The precipitation comparison between the north Helan Mountain (May to July) and the Baiyinaobao (April to July 10th) during 1840 to 1992 (two curves are smoothed by 11-a moving average).

In general, the reconstruction shows six periods with the precipitation lower than mean: 1743—1774, 1790—1799, 1809—1819, 1831—1863, 1926—1934, 1954—1971; and eight intervals with the precipitation higher than mean: 1732—1742, 1775—1789, 1800—1807, 1820—1830, 1864—1878, 1908—1925, 1935—1953, 1972—1992. Among them 1879—1907 is a stable period with more precipitation. It is worth noting that the three dry periods of 1831—1863, 1926—1934, 1954—1971, and the three wet intervals of 1864—1878, 1908—1925, 1935—1953 correspond to the dry/wet intervals in Baotou (in Inner Mongolia) and Korea very well at the same time[6]. It reflects the regional variation of climatic characteristics.

The singular spectrum, power spectrum analysis and Fourier transform all found that the precipitation from May to July in the north Helan Mountain mainly exists 11-a and 22-a cycles, which is the same as the precipitation in Baiyinaobao (April to July 10th)[3].

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