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QINGHAI SHENG LISHI QIHOU ZILIAO DE CHONGJIAN JI QIHOU BIANHUA YANJIU

青海省历史气候资料的重建及气候变化研究

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内容提要

本文主要内容为利用树木年轮资料恢复和重建青海省百年以上温度和降水资料序列，在此基础上，进一步重建青海省百年以上的其他气候要素序列。利用重建资料，研究和总结青海省历史时期气候变化的基本规律，验证青藏高原是我国东部地区气候变化启动区的结论。

本书可作为研究气候变迁，青藏高原历史气候及相关专业的研究人员、高校师生的工具书和参考书。

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前　言

青藏高原一直是国内外气候变化研究的热点，青藏高原历史气候的研究也是其中至关重要的内容。我国学者曾提出青藏高原东部地区是中国东部气候变化的启动区的观点，青藏高原的环境演变包括气候演变对我国东部环境演变具有明显的指示意义。历史气候资料的恢复和重建工作受到广泛的关注。

本项目是科技部2001年度社会公益研究专项资金项目“青海省历史气候资料的恢复和重建”，项目编号2001DIB10085。主要研究内容为利用树木年轮资料恢复和重建青海省百年以上温度和降水资料序列，在此基础上，进一步重建青海省的百年以上的其他气候要素序列。利用重建资料，研究和总结青海省历史时期气候变化的基本规律，并与我国东部地区和西藏地区历史时期气候研究结果比较，补充青藏高原历史时期气候研究成果，总结青藏高原与我国东部地区气候变化的关系，验证青藏高原是我国东部地区气候变化启动区的结论。为了更好地恢复和重建青海省历史气候资料，课题组广泛收集了青海省境内及周边地区（包括新疆、西藏、宁夏）所采集的树木年轮资料，并于2002年7月份到三江源区的曲麻莱县、治多县采集了具有较长树龄的树木年轮样本，三年来完成并在国内中、英文核心期刊发表有关青海省树木年轮采样、文献史料恢复和重建历史时期气候资料的方法、气候演变规律、气候变化展望、气候变化和环境演变的关系等高质量的研究论文二十多篇，其中SCI文章两篇。“三江源”区树木年轮采样工作弥补了青南高原南部树轮采样相对较少的不足，充实了青海省乃至青藏高原的树木年轮资料库，为今后恢复、重建青藏高原历史气候资料序列、研究高原过去气候变化规律并预测高原未来气候变化趋势提供了重要的资料。利用高原不同区域的多条树木年轮序列重建了青藏高原或区域的气温、降水、地温等气候序列，就利用多条树轮和进行异地重建研究而言是新的尝试和创新。

课题主持人：秦宁生
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目　录

Climate Change over Southern Qinghai Plateau in the Past 500 Years Recorded in *Sabina Tibetica* Tree Rings

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Abstract Two tree ring-width chronologies of *Sabina tibetica* were developed based on cores sampled in Qumalai and Zhiduo, southern Qinghai Plateau. The response function analysis showed that the chronologies were sensitive to temperature and precipitation from April to June in the plateau. Moisture index (*MI*) was defined, reconstructed and extended back to AD 1550. The cross-validation method was used to check the stability of the calibration equation, and the result indicated that the equation was stable. Six severe dry periods were found in this region in the past 453-year reconstruction, which were 1592 to 1610, 1649 to 1665, 1687 to 1697, 1740 to 1750, 1818 to 1829 and 1918 to 1933. Five severe wetting periods were 1669 to 1682, 1700 to 1709, 1800 to 1814, 1898 to 1909 and 1935 to 1950. Spectrum analysis indicated that there existed long-term cycles of 60.4 and 53.4 a, solar cycle of 11 a and short-term cycles of 8, 6 and 4 a in the reconstructed series.

Keywords: southern Qinghai Plateau tree-ring chronology reconstruction moisture index

The southern Qinghai Plateau with an average height of 3500 m A. S. L. is located in the northeastern part of the Tibetan Plateau. Being a part of the Tibetan Plateau it is with a huge surface and complex topographic conditions. The climate changes over the plateau play an important role in global change. On one hand, the climate, the eco-environment and the landscape in the plateau are quite sensitive to the global change. On the other hand, the change itself may have an influence on the climate around its vicinity or even far from the plateau areas. It has been shown that the plateau was the start-up region of climate change of East Asia in decadal scale[1]. Therefore, the study of climate change in the plateau in historical period is of importance. Sparse meteorological stations and short periods of the observations, however, limit the researches of climate change and its forcing over the Qinghai-Tibetan Plateau. With the rapid progress of dendroclimatology, tree-ring record has become one of the most important proxy of climate and has been used to study climate change all over the World[2, 3]. There has been also great progress in China using tree-ring data to study the past climate change since the 1930s. Wu Xiangding et al.[4] reconstructed temperature and precipitation in central Tibet using four tree-ring chronologies. The scientists from the Institute of Geography of the Chinese Academy Sciences reconstructed a series dated back to AD 1650 of the anomalies of the mean minimum temperature in winter over westerm Sichuan Plateau[5]. The reconstructions and development of tree-ring chronologies in Qinghai Province began in late 1970s and early 1980s with the research region in the Qilian Mountain[6, 7]. Afterwards, many tree-ring chronologies have been developed such as the 1835-year-long chronology of Dulan[8], the chronology from the Qilian Mountain dated back to AD 1310[9] and several thousand-year-long tree-ring chronologies in eastern Qadamu Basin[10]. However, there is no tree-ring chronology from southern Qinghai Plateau due to its high cold mountain with scare forest distribution. In this paper, based on tree-ring samples collected from Qumalai and Zhiduo, we developed two 500-year ring-width chronologies in the southern Qinghai Plateau and reconstructed a moisture index series for the study area. This will provide basic data for studying the historical climatic change of Qinghai-Tibetan Plateau.

1 Samples and chronology development

Climate in the study area is cool and humid due to the high elevation. The forest there is dominated by *Sabina tibetica* and sparsely distributed along the bank of the lower reaches of the Tongtianhe River and the upper reaches of the Lancang River[11]. Two tree-ring sites sampled are located at Dongfeng township, Qumalai County and Lixin township, Zhiduo County in Yushu State, southern Qinghai Plateau respectively. The distance between the two sites is about 130 kilometers. Table 1 lists the locations, sample depth and time span of the two sites.

Table 1 Sites information in the southern Qinghai Plateau

Site name	Site code	Latitude(N)	Longitude(E)	Elevation(m)	Sample depth (trees/cores)	Time span
Qumalai	QML	33°48′	96°08′	4060	29/57	1480—2002
Zhiduo	ZHD	33°43′	96°17′	3950	27/54	1374—2002

Since the sites are situated in the cold region with high elevation in the southern Qinghai Plateau, the stand condition is poor, the tree growth is slow, and the canopy coverage is generally low. Trees there are affected little by human activities. We sampled long-aged healthy trees and collected more than 100 cores from the two sites. The samples were processed using the standard dendrochronological techniques[12] at the Laboratory of Tree Ring Research in the Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences. After the increment cores were air-dried, glued to wooden mounts, and sanded in the laboratory, they were crossdated, and the ring widths were measured. The oldest tree was 523 years in Qumalai site and 629 years in Zhiduo site respectively.

The preliminary crossdating and measurement of tree-ring samples for each site were checked by the COFECHA program[13] to avoid mistakes. The program calculates the correlations between the single series and the master chronology. Cores that showed low correction coefficients with the master chronology were excluded from the site chronology. Finally there were 52 and 45 cores selected to develop the chronology for Qumalai and Zhiduo respectively.

To reduce low frequency variations due to aging and the competition of trees, 100-year cubic smoothing spline models were used to fit the age trend of each series at each site. The detrended series for a site were then averaged into site chronology. The site chronologies were developed using ARSTAN program[14]. A set of three chronologies—a standard chronology (STD), a residual chronology(RES), and an auto-regressive standard chronology(ARS) were developed for climate reconstructions in order to obtain more information of climate change. The statistical characteristics of the two standard chronologies(STD) and the common interval analysis(1801—1960) are listed in Table 2. The result showed a relative to high agreement between the two tree ring-width chronologies.

Table 2 Statistics of chronologies(STD) and common interval analysis(1801—1960)

Site	MS	SD	AU1	TC	COA	COT	S/N	AP	VPC
Qumalai	0.2678	0.2651	0.2734	19(29)	0.492	0.487	18.013	0.947	52.37
Zhiduo	0.2182	0.2430	0.4002	22(35)	0.415	0.409	15.195	0.938	45.06

MS, Mean sensitivity; SD, standard deviation; AU1, lst-order autocorrelation; TC, trees(cores) used in common interval analysis; COA, correlation among all cores; COT, correlation between trees; S/N: singal-to-noise ratio; AP, Agreement with population; VPC, variance in 1st eigenvector(%).

Figure 1 displays the two STD chronologies with the 31-year running mean and the sample depth for the period 1500 to 2002. It could be seen from Fig. 1 that wide and narrow rings of the two chronologies synchronously occurred. This might be because they were located in the same climate system. It seems that the limiting factor to growth is the same for the two sites.

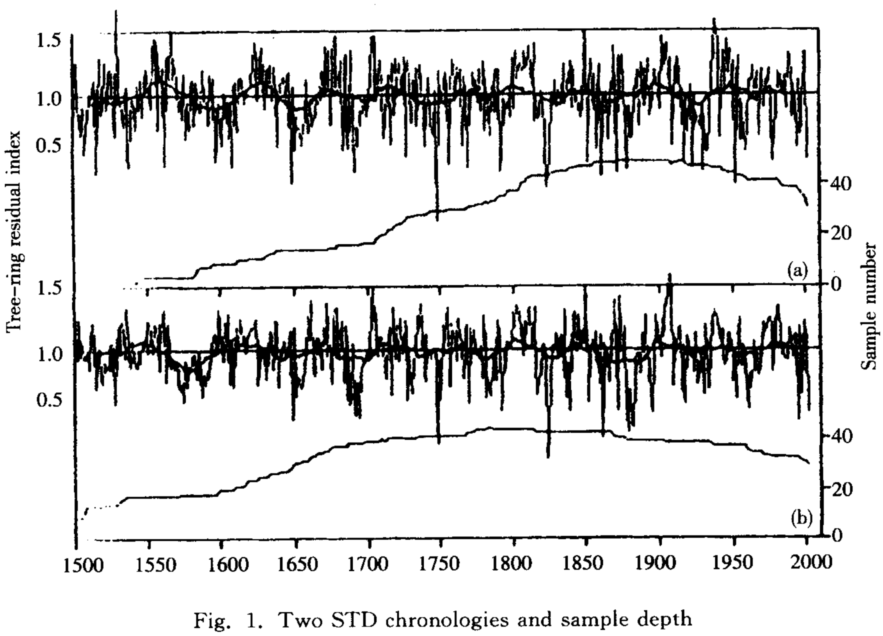

Fig. 1. Two STD chronologies and sample depth

2 Responses of tree-ring indices to climatic factors

Tree growth is limited by climatic factors and the relationships between them can be identified by response-function[15]. The climatic data from the meteorological stations in Qumalai, Zhiduo, Zhaduo, Yushu and Maduo were obtained. Several climate variables were used including monthly mean temperature, monthly mean maximum temperature, monthly mean minimum temperature, monthly precipitation, monthly evaporation, monthly mean relative humidity and monthly mean vapor pressure for 16 months from July of the previous year to October of the current year in the period of 1957—2001. Correlation functions were calculated between the two chronologies and seven climatic factors. The results showed that climatic conditions in spring(April to June) in Qumalai, Zhiduo and Zhaduo regions were most favorable to the growth of *Sabina tibetica*. In order to reduce the inhomogeneities induced by relocation and devices changing of the meteorological stations, regional climatic variables were calculated by averaging monthly mean climatic data of the Qumalai , Zhiduo and Zhaduo meteorological stations. The results of correlation analysis between two standard chronologies (STD) and seven regional climatic variables from previous November to current October are presented in Table 3. Similar results were obtained between the two residual chronologies (RES) and seven regional climate variables. It could be seen that the radial growth of *Sabina tibetica* was significantly and negatively correlated with temperature (monthly mean temperature and monthly mean maximum temperature) and monthly evaporation in April, May and June. A significant positive relationship was found between tree growth and monthly precipitation and monthly mean relative humidity in the same period.

Table 3 Correlation between the two chronologies and mean monthly climatic factors

	Month	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.
	mean temp	−0.11	−0.08	0.04	0.01	−0.13	−0.39**	−0.49**	−0.28*	0.14	−0.06	0.10	0.06
	max. temp	−0.02	−0.04	0.16	−0.05	−0.12	−0.43**	−0.60**	−0.43**	0.14	−0.05	−0.03	−0.09
	min. temp	−0.02	−0.05	−0.04	0.00	−0.18	−0.11	−0.16	−0.07	0.24	−0.13	0.26	0.04
Qumalai	precipitation	0.12	−0.20	0.05	0.17	0.08	0.26	0.52**	0.10	0.07	0.16	0.23	0.05
	evaporation	0.11	−0.00	0.09	0.05	−0.13	−0.30*	−0.55*	−0.57**	−0.21	−0.11	−0.17	0.00
	evop. Press	−0.04	−0.00	−1.01	−0.06	−0.01	0.12	0.12	0.17	0.35*	−0.05	0.20	0.06
	humidity	−0.07	−0.10	−0.14	−0.05	0.13	0.23	0.45**	0.43**	0.20	0.03	0.32*	0.02
	mean temp	0.11	0.02	0.30*	0.14	0.10	−0.15	−0.34*	−0.36*	0.01	0.11	−0.04	0.05
	max. temp	0.22	−0.10	0.29*	0.04	−0.11	−0.10	−0.50**	−0.48**	−0.03	0.21	−0.06	0.08
	min. temp	0.15	0.12	0.29*	0.20	0.09	−0.12	−0.05	−0.08	0.05	−0.04	0.12	−0.04
Zhiduo	precipitation	0.09	−0.05	0.07	0.23	−0.11	0.05	0.35*	0.28*	0.01	−0.04	0.18	−0.09
	evaporation	0.21	−0.07	0.10	0.05	−0.10	−0.00	−0.48**	−0.58**	−0.29*	0.03	−0.39*	0.04
	evop. Press	−0.05	−0.02	0.15	0.14	−0.03	−0.12	0.09	0.13	0.21	0.04	0.13	−0.02
	humidity	−0.23	−0.08	−0.14	0.05	0.03	−0.08	0.34*	0.45**	0.22	−0.07	0.26	−0.05

* and ** denote correlation significant at the 0.05 and 0.01 confidence level respectively.

We further investigated the relationship between the RES chronologies and the plateau heat (temperature) and moisture (precipitation and relative humidity) conditions by response-function. In this procedure, 33 elements, i.e. monthly mean temperature and monthly precipitation from July of the previous year to September of the current year and indices from three previous years were selected. The climate data cover the period from 1957 to 2001. The results of response-function showed that the multiple correlation coefficients was 0.8284 for Qumalai RES chronology and 65.62% variance could be explained by climate elements. For Zhiduo, the coefficient was 0.6568 and climate variables capture 36.80% variance. The response of tree growth to temperature was negative in the growth season (from March to July) and significant negative correlation (at 0.05 confidence level) was found in May and June. The response of tree growth to precipitation was positive in the same period and significant positive correlation (at 0.05 confidence level) was also found in May and June. This suggested that the tree growth in this region was influenced by both temperature and humid (precipitation) conditions.

The response surface for Qumalai chronology is given in Fig. 2 to display further the relation of tree growth with temperature and moisture. In the figure x-axis is the normalized monthly mean temperature of May-June and y-axis is the normalized monthly precipitation of May-June, z-axis is the normalized residual chronology index for Qumalai site. From Fig. 2 it could be seen that increase in precipitation promoted tree growth when the precipitation was above normal. While increase in temperature could limit tree growth when the precipitation was below normal. In the southern Qinghai Plateau area such as Qumalai, Zhiduo, Zhaduo, Yushu and Maduo, the rainfall was mainly distributed in the months from July to September, the period from May to June was a relatively dry season. Therefore, the precipitation was the limiting factor to tree growth during this period. High temperature will cause severe evapotranspiration, it will limit tree growth when water stress is intensified, so the temperature is likely to have a negative relationship with tree ring width.

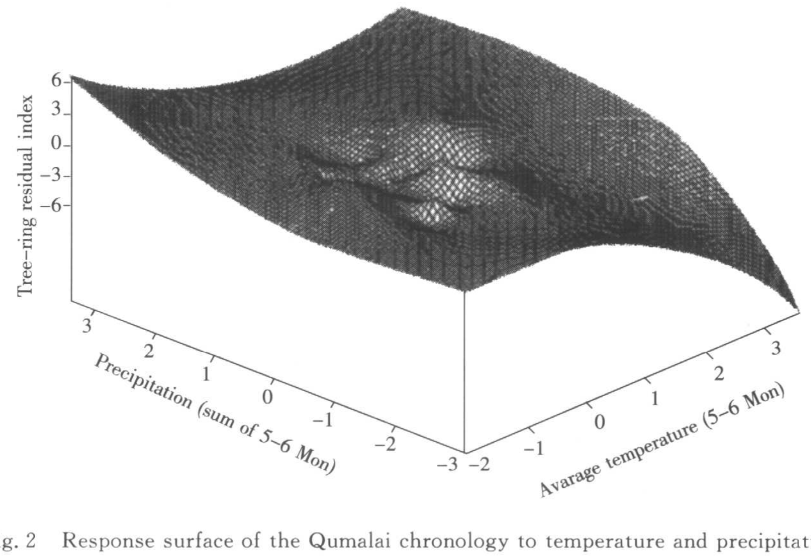

Fig. 2 Response surface of the Qumalai chronology to temperature and precipitation

The annual precipitation was about 449.9 mm based on data from 1957 to 2001 and about 36.3% of the rainfall (163.4 mm) occur in May and June in the southern Qinghai Plateau. In this region, the increase in temperature in May and June will enhance the evaporation and evapotranspiration, which aggravates water stress in tree, so the growth of tree is limited. It is beneficial to tree growth when precipitation increases and temperature is low.

3 Climatic reconstruction

The moisture index (*MI*) was selected as the variable of reconstruction since the tree growth was influenced by both the temperature and the precipitation. The *MI* was defined as follows: $MI = R/T$, where R and T were the total precipitation of May to June and the mean monthly temperature in the same period, respectively. From the definition we can see that *MI* is a composite index that can indicate the variations of temperature and precipitation at the same time. When precipitation increases and temperature decreases, the *MI* increases. When the precipitation and temperature both increase or decrease, the *MI* changes little. Hence, the *MI* can be used as an index to signify the cool-wet and warm-dry patterns of climate. Two ring-width chronologies of Qumalai (QML) and Zhiduo (ZHD) were used in the reconstruction of the *MI*. The reconstruction period was from 1550 to 2002 when there were enough samples. The final regression equation is

$$MI = 2.5532 + 0.052\ \text{QML} + 0.051\ \text{ZHD}$$

This equation accounts for 30.32% of the variance in the observed climatic data ($F = 9.1345$, $p \leqslant 0.001$).

To test the stability of the reconstruction equation. cross-validation method[16] was performed. The sign test of original series, the sign test of the first-order difference series and the reduction of error were calculated. The results indicated that in the period from 1957 to 2001 there were 34 years in which the signs were the same, significant at 0.01 confidence level. The sign test for the first-order difference series was also significant at 0.01 confidence level. The reduction of error was 0.1969. The Pearson correlation coefficient between the reconstructed and the observed data was 0.5506, significant at 0.01 confidence level. Those results suggested that the reconstructes series were reliable. Fig. 3 shows the reconstructed *MI* (May—June) and the observed *MI* calculated by the observations of precipitation and temperature in the southern Qinghai Plateau in the period of 1957—2001.

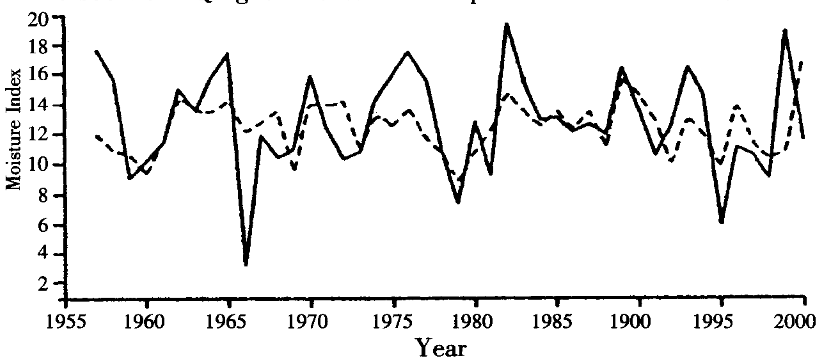

Fig. 3 Reconstructed *MI* and observed *MI* (May—June) in the southern Qinghai Plateau in the period of 1957—2001

With the reconstruction equation, we calculated the normalized series of *MI* in the past 453 years (1550—2002). The mean of *MI* series was zero and the variance was 1 respectively (Fig. 4).

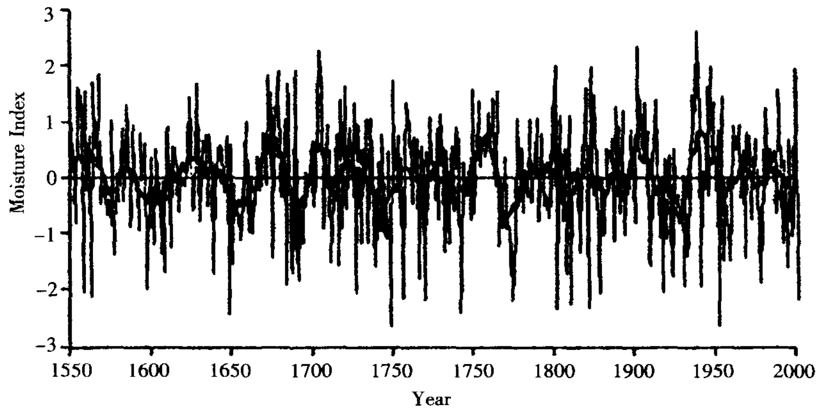

Fig. 4 Interannual variations of reconstructed *MI* (May—June) in the southern Qinghai Plateau (heavy solid line denotes 11-year smoothing)

To describe quantitatively the characteristics of *MI*, the series was smoothed by 11-year running mean and then classified into grades using the method of ref. [9]. We defined the relatively wet or dry period when the absolute values of *MI* was greater than 0. 2. Table 4 shows the reconstructed wet-dry period of the southern Qinghai Plateau.

From Table 4 it was clear that there were six longterm dry periods and five long-term wet

Table 4 The reconstructed wet-dry period of southern Qinghai Plateau

Climatic Characteristics	Period (the year of absolute value of normalized *MI* greater 30% is in the backet)	Duration(a)
Dry period	1574—1577(1576)	~4(1)
	1592—1610(1596—1598)	~19(3)
	1649—1665(1650—1661)	~17(12)
	1687—1697(1688—1697)	~11(10)
	1740—1750(1740—1749)	~11(10)
	1818—1829(1818—1829)	~12(12)
	1881—1884(1882—1883)	~4(2)
	1913—1915(1914)	~3(1)
	1918—1933(1918—1932)	~16(15)
	1955—1958(1955—1958)	~4(4)
Wet period	1555—1557(1555—1557)	~3(3)
	1624—1630(1624—1630)	~7(7)
	1669—1682(1670—1682)	~14(13)
	1700—1709(1700—1708)	~10(9)
	1800—1814(1800—1812)	~15(13)
	1870—1873(1872)	~4(1)
	1898—1909(1900—1904;1907—1909)	~12(5;3)
	1935—1950(1936—1947)	~16(12)
	1966—1968(1967)	~3(1)
	1985—1988(1985—1987)	~4a(3)

periods that lasted over 10 years respectively since 1550. The number of year when the absolute value of MI was greater than or equal to 20% and 30% was counted. There were 44 and 10 years (wet) when MI was greater than or equal to 20% and 30%, respectively. While 55 and 20 years (dry) when MI was less than or equal to −20% and −30%. The results suggested that the period of warm-dry cool-wet in the past 500 years in the southern Qinghai Plateau. The climate in the Little Ice Age (LIA) (1550—1850) undergone 4 extended warm-dry lasted longer than the cool-wet periods, suggesting that the climate was not always cold even in the LIA. Our reconstruction of the recent warm-dry period in 1918—1932 and the cool-wet period in 1935—1950 were validated by other climate data[17,18], particularly in the 1940s it agreed with the value of spring maximum rain days in the Tianshan region, Xinjiang, China, suggesting that the wet period in 1935—1950 that likely occurred in larger spatial scale. Power spectrum analysis of the reconstructed MI showed that there existed the solar cycle of 11 a and quasi-periodicities of 8 and 4 a significant at 0.01 confidence level and 50.3, 60.4, 15, 6 a quasi-periodicities significant at 0.05 confidence level.

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青南高原树轮年表的建立及与气候要素的关系

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提要 根据青海南部曲麻莱、治多地区树木年轮样本,建立了青海南部高原(下称青南高原)树木年轮年表序列,系统地与所在地区气候资料进行了综合分析。通过响应函数,计算得出该年表对青南高原春季(4～6 月)的最高温度和蒸发量的反映更为敏感。并重建了青南高原春季最高温度序列。

关键词 青南高原 树轮年表 气候重建 最高温度

1 引言

青海南部高原位于青藏高原东部,平均海拔 3 500 m 以上,地域辽阔、地形复杂,是青藏高原大地形的一部分。高原气候变化在全球变化中具有重要作用,一方面高原气候及其生态环境和地表特征对全球变化非常敏感;另一方面高原本身的变化反过来又作用于高原邻近地区,甚至是远离高原的地区。研究表明[1,2],在几十年时间尺度上青藏高原往往表现为东亚地区气候变化的启动区,因此对青藏高原历史时期气候变化的研究具有十分重要的意义,并受到高度重视。但是由于高原气象台站稀少、观测资料时间较短,故用器测资料研究高原气候变化及成因受到限制,不足以使人们了解高原气候变化的全貌。随着树木年轮气候学的迅速发展,利用树木年轮宽度变异对气候变化的响应,获取某些气候要素的代用资料,已经在全球范围内成为研究历史时期气候变化的重要途径之一[3~5]。吴祥定等[6]利用西藏中部四个树木年轮年表对过去的气温和降水变化进行了重建;冯松等[7]利用卫星反演资料和树轮等代用资料分析了青藏高原 600 年的温度变化;中国科学院地理所用川西高原的四个树轮资料重建了 1650 年以来冬季平均最低气温的距平序列[8];1980 年代王玉玺等[9]利用青海祁连圆柏探讨了树轮宽度与我国近千年气候变化和冰川进展的关系,之后,研究人员利用树轮资料建立了青海都兰地区 1835 年的树轮序列[10]、青海祁连山地区 1310 年以来的树轮序列[11]、青海柴达木盆地东缘山区千年长度的树轮宽度序列[12]。在青海南部高原由于地处高寒山区,森林分布较少,目前还没有建立树轮序列。本文利用在曲麻莱、治多等地采集的树轮资料,建立了青海南部高原五百多年的树轮序列,并重建了青南高原的气候序列,这也是迄今为止采集到的距离青藏铁路线最近的树木年轮序列,对研究青藏铁路沿线气候变化具有重要意义,并为青藏高原历史气候研究打下了基础。

2 资料获取

青南高原由于海拔高、气温低,属于高寒湿润型气候。在海拔 3 900～4 500 m 以上有一些

散生的原始圆柏疏林，树种以大果圆柏（*Sabina tibetica*）为主，是青海省分布最高的森林群落，主要分布在通天河下段和澜沧江上游的扎曲河及其支流两岸[13]，采样点选在青南高原的玉树州曲麻莱县东风乡和治多县立新乡（表 1）。采样点地处高寒，土壤类型是疏林草甸土，处在年青的发育阶段，树木立地条件较差，生长缓慢，郁闭度较小，树木受人类活动影响较少，取样的树木为树龄较长的健康活树，两个采样点共采集样本 100 多个，树轮样本在中国科学院地理科学与资源研究所树轮实验室进行了干燥、固定、磨光、定年和树轮宽度量测。曲麻莱采样点树龄最长为 523 年，治多采样点树龄最长达 629 年。

表 1　青南高原树轮采样点概况

采样点名称	采样点代号	纬度（°N）	经度（°E）	海拔高度（m）	采集样本量	样本长度
曲麻莱	QML	33°48′	96°08′	4060	57	1480—2002 年
治　多	ZHD	33°43′	96°17′	3950	54	1374—2002 年

3　建立树轮年表

为了确保年轮资料的可靠性和适用性，根据国际上通用的树木年轮分析的基本程序[14~16]，对经初步定年和宽度量测的树轮样本进行交叉定年的检验，剔除奇异点过多或与主序列相关性较差的样本，在曲麻莱采样点和治多采样点分别筛选出 52 个和 45 个样本序列。用样条函数对两个采样点每个样本的轮宽序列进行了树木生长趋势的拟合，去除了树木的生长趋势和树木间竞争导致的低频变化，得到了三种树轮年表（即：标准化年表（STD）、差值年表（RES）及自回归年表（ARS）），以增加在气候重建时年表的可选择性，获得更多的气候变化信息。表 2 给出了两个采样点共同区间（1801—1960 年）的分析结果。从表 2 中可看出，两个采样点树木年轮宽度在同期变化上表现出很好的一致性。图 1 给出了两个采样点 1801—1960 年的标准化年表的逐年变化曲线。从图 1 中可看出，窄轮和宽轮出现的时间基本一致，这和两个采样点同处于通天河流域，受相同的气候因素影响有关，说明控制树木生长的限制因子基本相同。

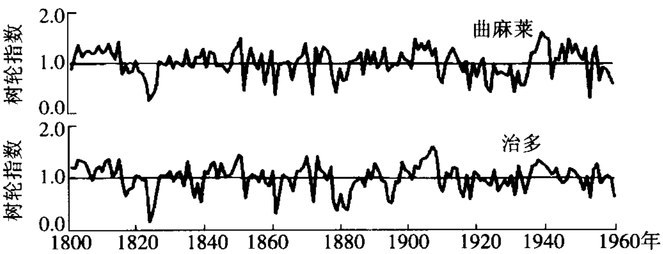

图 1　两个采样点 1801—1960 年标准化年表的逐年变化

4　树轮指数对气候因子的响应

树木生长在很大程度上受到气候因子的制约，气候因子对树木生长贡献的大小一般通过响应函数的计算获得[17,18]，响应函数是通过对标准化气候资料的主分量分析，定量地表示出所选各月的气候因子对树木生长的贡献，在以树轮指数与气候因子进行响应函数计算时，需要考虑

气候上的一致性，在选择气候资料时，力求气象站点和树轮采样点同属一个气候区[19]。为了探讨青海南部高原树木生长状况对气候要素变化的响应，我们选取了采样点附近的曲麻莱、治多、扎多、玉树、玛多五个气象站的月平均温度、月平均最高(最低)温度、月降水量、月蒸发量、月水汽压和月相对湿度，通过相关分析，发现曲麻莱、治多、扎多三站的气候要素与两个采样点的相关较好。我们用三站的各要素平均值代表区域气候要素，表 3 给出了区域内各要素从 1957—2001 年前一年 11 月到当年 10 月与两个采样点的相关。由表 3 可以看出，两个采样点树轮宽度和 4～6 月的平均温度、平均最高温度、降水量、蒸发量、相对湿度有很好的相关。并且用各气候要素的组合进行了响应函数分析，结果表明，气候要素的变化可解释 50.6%～73.3%的树轮宽度指数序列的方差，其中月平均最高温度和月蒸发量的组合所解释的方差较高。从表 3 中还可看到，研究区域月平均最高温度和月蒸发量与两个采样点的树轮宽度指数序列的相关最好，说明月平均最高气温和月蒸发量对树木生长影响较大。侯爱敏等[20]的研究表明，温度、湿度对树木生长的影响较为复杂，在生长季开始时温度的升高有利于延长生长季，故与年轮宽度成正相关；而在生长旺季，温度往往不再是限制因子，这时温度的升高会导致蒸散加剧，在水分不足时往往限制了树木的生长，故多表现为与年轮宽度的负相关。在青南高原地区，春季最高温度的升高和蒸发量的增大，有可能加剧本已存在的水分不足，从而限制树木的生长。

表 2　青南高原树轮采样点树轮指数序列统计特征及共同区间分析结果

采样点	平均敏感度	序列均方差	一阶自相关系数	共同区间样本量 P 株(样芯)	样芯间平均相关系数	树间平均相关系数	信噪比	样本量总体代表性	第一主成分方差(%)
曲麻莱	0.2678	0.2651	0.2734	19(29)	0.492	0.487	18.013	0.947	52.37
治多	0.2182	0.2430	0.4002	22(35)	0.415	0.409	15.195	0.938	45.06

表 3　两个采样点树轮宽度指数和青南高原气候要素序列间的相关

采样点		月份											
		11	12	1	2	3	4	5	6	7	8	9	10
曲麻莱	平均温度(℃)	-0.11	-0.08	0.04	0.01	-0.13	-0.39**	-0.49	-0.28*	0.14	-0.06	0.10	0.06
	最高温度(℃)	-0.02	-0.04	0.16	-0.05	-0.12	-0.43**	-0.60**	-0.43**	0.14	-0.05	-0.03	-0.09
	最低温度(℃)	-0.02	-0.05	-0.04	0.00	-0.18	-0.11	-0.16	-0.07	0.24	-0.13	0.26	0.04
	降水量(mm)	0.12	-0.20	0.05	0.17	0.08	0.26	0.52**	0.10	0.07	0.16	0.23	-0.05
	蒸发量(mm)	0.11	-0.00	0.09	0.05	-0.13	-0.30	-0.55**	-0.57**	-0.21	-0.11	-0.17	0.00
	水汽压(hPa)	-0.04	-0.00	-0.01	-0.06	-0.01	0.12	0.12	0.17	0.35	-0.05	0.20	0.06
	相对湿度(%)	-0.07	-0.10	-0.14	-0.05	0.13	0.23	0.45**	0.43*	0.20	0.03	0.32	0.02
治多	平均温度(℃)	0.11	0.02	0.30*	0.14	0.10	-0.15	-0.34*	-0.36*	-0.01	0.11	-0.04	0.05
	最高温度(℃)	0.22	-0.01	0.29*	0.04	-0.11	-0.10	-0.50**	-0.48**	0.03	-0.21	-0.06	-0.08
	最低温度(℃)	0.15	0.12	0.29*	0.20	0.09	-0.12	-0.05	-0.08	0.05	-0.04	0.12	-0.04
	降水量(mm)	0.09	-0.05	0.07	0.23	-0.11	0.05	0.35*	0.28*	0.01	-0.04	0.18	-0.09
	蒸发量(mm)	0.21	-0.07	0.10	0.05	-0.10	-0.00	-0.48**	-0.58**	-0.29*	0.03	-0.39*	0.04
	水汽压(hPa)	-0.04	-0.02	-0.15	-0.14	-0.03	-0.12	0.09	0.13	0.21	-0.04	0.13	-0.02
	相对湿度(%)	-0.23	-0.08	-0.14	0.05	0.03	-0.08	0.34*	0.45**	0.22	-0.07	0.26	-0.05

注：表中 * 和 ** 分别表示通过 0.05 和 0.01 的显著性水平检验。

5　气候重建

根据响应函数分析，我们选择对青南高原春季最高温度进行重建，考虑到复本原理，重建时段选为 1550—2002 年，这样既保证了两个树轮宽度序列有足够的样本量，又保证了定年的准确和量测宽度的总体代表性。根据曲麻莱和治多两个树轮宽度序列，利用回归方程[12,17]重建了青南高原春季的平均最高温度序列。重建方程为：