Reviewer # 2

Precipitation of Inner Mongolia, by Liu et al.

Dendroclimatology in China is worth noting, because China is still underrepresented in the global dendro research world. This research fills a relatively new spot in China, some place other than the Qinghai or Tibet or the Tian Shan of Xinjiang.

The manuscript has a lot of little issues for the authors to take care of I've made many marks on the ms itself, plus I have these follow specific points:

- The entire discussion of the Dunde Ice Cap data (page 20) seems weak. The Dunde Ice Cap is a long ways away from the tree-ring sites (not even included in the map of Figure 1) and at a very different elevation. Furthermore, the ice data are interpreted as a temperature proxy, while these tree-ring chronologies are interpreted as a winter-spring precipitation proxy. It would be miraculous if a strong relationship existed between these two data types. Sure enough, no relationship is found.
- On Figure 1, text is probably too small. It's hard to read as is, and any reduction of the figure will make it even worse.
- Figure 2 is nice, but probably expendable. Unless there is a need to fill a page in the journal, I would drop this.
- For Figure 3, it's often interesting to provide an estimate of variability around monthly mean rainfall totals. Something like a coefficient of variation, which takes into account the different mean values, would be useful. Plus, this kind of precipitation graph is traditionally done as a bar graph. Perhaps a bar graph would be awkward with three stations, but as it is, this figure looks odd as a line graph.
- On Figure 4, it would be helpful to provide some sort of horizontal reference line for each graph, perhaps the meteorological period average, for example.
- In Figure 5, are there no sample depth data for NHL and BYAB? Those bottom graphs are conspicuous compared to the top graphs by not having sample depth lines. This is especially conspicuous since the same authors of this manuscript made those other chronologies. Again, horizontal reference lines would be helpful in this figure.
- In Figure 6, it might be necessary to highlight explicitly the synchronous variation that is touted on page 21. In the figure, the synchrony is not 100% obvious. For example, it says that after 1900, the series are strikingly similar. Does that include a steep increase in LM since 1970 while at the same time BYAB is decreasing? Also, can that temperature curve of Folland et al. (page 22) be included in Figure 6? And one more time: horizontal reference lines.
- Table 1: the statistical characteristics look like just about everything that is reported in the ARSTAN output. But is all of this really necessary? Skewness and kurtosis? All of the various mean correlation values? Seems to be a bit of overkill here.
- Table 2: this information is traditionally given as a bar graph. Monthly and seasonal patterns are hard to see in table form.
- Table 3: the adjusted R^2 is the more conservative indicator of model strength. The unadjusted R^2 is superfluous here and can be dropped. The t values look high, but at what level are they significant? Doesn't regression analysis usually provide an F sta-

tistic with a p value of model significance?

- Table 5: Same comments as for Table 3.
- Table 8: it is perhaps a bit misleading to report p **values** on correlations with hundreds of years of overlap. With such long series, p values are bound to be impressive, even with low correlations. The actual correlations range to as low as 0.15, or about 2% share variance. This hardly seems like a common signal. The only **truly** high correlation is of the two current tree-ring reconstructions, which is expected since they are so close to one another geographically.

TREE-RING PRECIPITATION RECORDS FROM INNER MONGOLIAN, CHINA, AND THE EAST ASIAN SUMMER MONSOON FRONT VARIATION SINCE A. D. 1627

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ABSTRACT

Chinese pine (*Pinus tabulaeformis)* tree ring widths were used to reconstruct rainfall from February to early-July for Wu Dangzhao region and from February to mid-July for La Madong region, Inner Mongolia, China. The predictor variables account for 44.3% and 42.7% of the variance in the precipitation respectively. Both historical records and the other tree-ring rainfall reconstructions from environmentally sensitivity zone, such as northern Helan Mountain range and Baiyinaobao, confirm our results. After applying a 10-year moving average, the trends of four tree-ring reconstructions vary almost synchronously. In general the periods of below normal precipitation could be found over the 1720s~1760s, 1790s, 1840s~1860s, 1890s– 1910s, 1920s–1930s and after the late 1960s–early 1970s and the periods of above normal precipitation occurred over the 1650s–1710s, 1760s~1780s, 1820s– 1830s, 1870s~1880s, 1940s to early 1960s and 1990s.

All curves exhibit striking similarity of variation. Late 1920s was the most severe drought years in a large-scale in north China for the last 374 years. This event was caused by the weak East Asian Summer Monsoon circulation.

Keywords: Inner Mongolia, *Pinus tabulaeformis,* tree ring, precipitation reconstructions, the East Asian Summer Monsoon

INTRODUCTION

An environmentally sensitive zone defined by iso-lines of precipitation, temperature and moisture (Zhou 1996; Fu et al. 1998) stretches from the northeast to the southwest of China (Fig. 1, shaded area in small inset map). This is the transition zone from semi-arid to arid conditions, namely monsoon to non-monsoon, with annual precipitation of 200 mm to 400 mm (70-90% of which is concentrated in the summer) and annual mean temperature of 5.5°C to 8.1°C. In the area north of 30°N the northwesterly wind is strong and dust storms occur 40 times per year on average with 72% occurring during March to May (Wang 1997). Seasonal dry and wet climates alternate due to frequent change of dry-cold air masses from the Arctic or high latitudes in the winter (East Asian Winter Monsoon, EAWM), and warm-humid air masses from the equatorial or low latitude oceans in the summer (East Asian Summer Monsoon, EASM).

Since annual total precipitation is strongly influenced by the Summer Monsoon, the rainfall in this region shows large year-to-year variations that are sensitive to the location, timing and intensity of the Summer Monsoon (Wang 1990). If the sub-tropical high pressure is strong and stable, the Summer Monsoon extends further north (strong EASM) resulting in above normal rainfall. On the other hand, drought years usually occur when the sub-tropical high pressure is weak and stays south (weak EASM).

Agriculture is the traditional primary industry in monsoonal China and the harvest is largely affected by rainfall. Unfortunately, frequent drought and flooding caused by monsoon precipitation can result in loss of lives and tremendous property damage. Therefore, it is very important to recognize the behavior of the EASM in the past in China (Fu and Zeng 1997).

Numerous studies concerning the Asian monsoon, including inter-seasonal and inter-annual variabilities, have been carried out. Recent studies indicate that the Asian Monsoon system is characterized by a high rate of climate change within all time scales (Qian and Lee 2000). These changes are manifested by seasonal fluctuations, high inter-annual and inter-decadal variability and abrupt changes between climate regimes (Fu and Zeng 1997). However, it was impossible to study climate change and annual variation on a long-term scale since there has been a lack of long-term data which could be used to study the **EASM** (Shi ***et*** *al*. 1996).

Abundant Chinese historical documents provide much information for paleo-climate research, especially in Asian monsoon research. **A** five-hundred-year-long series of annual dryness/wetness indices (Academy of Meteorological Science 1982) and cold/warm intervals (Zhang 1996) were generated from analysis of these documents.

Another high-resolution record which could be used in the Asian monsoon study is tree rings. In dry areas where tree growth is limited by precipitation, tree rings can be used to reconstruct rainfall (Touchan ***et*** *al.* 1999) to more accurately portray the dry-wet variations of the past. It has been demonstrated elsewhere that tree rings from the mountains of such regions may contain an accurate record of past variations in precipitation in the variation of their widths, including sites towards the arid limits of tree growth (Fritts 1976, 1991; Hughes ***et*** *al*. 1994). Thus, an opportunity is presented to derive information on the past behavior of certain aspects of the monsoon in the case of this sensitive zone in China. Such information will be of great value in understanding the natural variation of the **EASM** on interannual to multidecadal timescales and so could contribute to the development of an improved capacity to anticipate its future variations.

This paper discusses monsoonal rainfall reconstructed from tree rings in central Inner Mongolia. These reconstructions cast light on the variations of the EASM during the past 350 years.

DATA AND METHODS

Sites Descriptions and Sampling

Two sampling sites, Wu Dangzhao (WD, 4048- 5UN and 11018.5-20.5E), and La Madong (LM, 4046- 47N and 11116- 17.5E) were located in the south facing slope ot Yin Shan Mountains, the northern margin of EASM (Figure 1). The elevation of the WD site range from 1500 m to 1800 m while the LM site range from 1300 m to 1600 m. The Yin Shan Mountains (2300 m at the peak of Mt. Da Qing) stretch from east to west in central Inner Mongolia. This is an important boundary between temperate grassland and desert scrub and is also the boundary of agriculture-pasture land and pure rangeland. The Ulaanchabu Plateau is north of these mountains and the Tumote-Dalarlte Plains lie to the south. Severe and frequent droughts are the most serious threat to crops and animal husbandry (Wu 1991).

Fig. 1

Figure 1. Location of the sampling sites (A), meteorological stations (•) and other two comparison tree-ring sites, Baiyinaobao) and the north Helan Mountain. The shaded area in the whole China map (inset in

low right) indicates the environmental sensitivity zone.

Because of both natural impacts (such as drought) and human activity (logging and wars) trees rarely exist on the exposed southern slopes of the Yin Shan Mountains but trees are relatively more abundant on the northern slope.

On these sites vegetation is sparse and Chinese pine (*Pinus* tabulaeformis) is the dominant tree species, although a few junipers (Platycladus orientalis and *Juniperus rigida*) and *Betula platyphylla* occur. Most of the Mountains have nutrient-poor soil and are covered by sparse vegetation (Figure 2). The sites are very open, with 30 m to 100 m between trees and a discontinuous canopy. We collected Chinese pine trees from both sites. The WD site has a nutrient-poor soil layer about 5 cm to 10 cm deep. In the LM site most of trees grow on the rocks. Two increment cores from each of 65 trees were collected from WD site. The oldest core sampled has 283 annual rings. Two cores from each of 55 trees were collected from LM site and the oldest core back to 1525 AD. Cores were collected in the summer 1997 and 2001 separately.

Fig. 2

Figure 2. The typical sampling condition in the La Madong site, most of trees we collected grow on the rocks. Photograph by Yu Liu.

Chronology Development

In the laboratory tree-ring samples were prepared, cross-dated and measured following standard practices (Stokes and Smiley 1996; Holmes 1986). Cores with any ambiguities of cross-dating were excluded from further analysis. The rate of absent rings in WD group is 3.13%, and in LM group,

The individual ring-width measurement series were detrended and standardized to ring-width indices by using the ARSTAN (Cook and Kairiukstis 1990; Dendrochronology Program Library, http://www.ltrr.arizona.edu/software.html). Undesirable age- and stand-dynamics-related growth trend, which is not related to climatic variation, was removed from each series during the detrending process. To conserve the maximum common signal at the lowest frequency possibly each ring-width measurement series of each individual core was standardized with only conservative negative-exponential or straight-line fitting. The individual radial series were combined into a single chronology using a bi-weight robust mean. Sub-sample signal strength (SSS) was used to assess the adequacy of replication in the early years of the chronologies (Wigley et al. 1984). In order to extend the tree-ring chronologies longer and to ensure the reliability of the reconstructed climate we restricted our analysis to the period with an SSS of at least 0.75. This threshold corresponds to a minimum sample depth of 2 series (trees) for WD. The ring-width chronology from the WD site extends from 1734 to 2001. Meanwhile a minimum sample depth of 5 series (trees) for LM site extends from 1627 to 2001. The statistical features of standard series are listed in Table 1.

Table 1. The statistical characteristics of both WD and LM chronologies

Table 1

Meteorological Data

Considering that it is the nearest to the sampling site and have no missing data, the Shiguai (1961-1990, 1100 m elevation at 40°46′N and 110°23.5′E) and Hohhot (1951-2001, 1063 m elevation at 40°49′N and 111°41′E) meteorological stations were used in the tree-ring climatic response analysis. Homogeneity was tested by both double-mass analysis, a graphical technique (Kohler 1949) and the Mann-Kendall (Mann 1945) statistical method. Baotou (1951- 2001) station was used as reference. The test was done by using computer programs in the Dendrochronology Program Library (http://web.ngdc.noaa.gov/paleo/softlib.hl). The results show that Shiguai and Hohhot have no inhomogeneity. Figure 3 shows the seasonal distribution of precipitation for three stations. It should be noted that the Shiguai station was removed in 1991.

Fig. 3

Figure 3. Average monthly precipitation values from the Shiguai(●), Hohhot(■) and Baotou(▲) meteorological stations in the region of the sampling sites.

Identification of Climate Response

Ecological site observations and comparison with instrumental rainfall records (see below) indicate that the ring widths in the site are sensitive to precipitation variation. The typical growing season in this area is from late-March to early October (Inner Mongolia Forest Agency 1995).

In this study, we used non-overlapping 10-day mean temperature and total precipitation data from the prior September to current October from both Shiguai and Hohhot stations.

The correlation function analysis results indicated that tree-ring width shows a weak response to temperature and a strong response to precipitation. Tree growth is especially influenced by precipitation from February to early-July (July 10) at WD, and February to mid-July (July 20) at LM (Table 2). The correlation between the chronology from WD and total precipitation from February to early-July (July 10) is significant, with r=0.60 (N=30, p<0.0001, t =3.97). Meanwhile, the correlation between the chronology from LM and total precipitation from February to mid-July (July 20) is also significant with r=0.63 (N=50, p<0.0001, t =5.62) (Table 2).

Table 2. The correlation between observed precipitation and ring width indices

Table 2

The time period from February to July (early or mid) could be acceptable. Beyond the statistical high value of correlation (r=0.60~0.63) there is basis of the physiological explanation. In such an arid region the relationship between tree growth and spring and early summer precipitation can be described the linear correlation before the rainfall increased to a great amount in a short time period (for example, more than 100 mm in one day could be monsoon-related flooding). In the spring and early summer when temperature rises the tree need more water for its fast growing. More water (precipitation), partly attribute to the frontal movement of the East Asia Monsoon, could cause a wide ring; if water decreases tree growth could slow down, producing a narrow ring. In the flood season, however, the correlation between precipitation and ring width becomes less significant and has a non-linear relationship (Shao and Wu 1994). Meteorological research demonstrated that the great amount of rainfall (flooding) occurs during the period of late July to early-August (July 21 to August 10) in Hohhot region (Wang 1997).

Generally speaking, February to early summer rainfall is a crucial factor for the commencement of tree growth, formation of new needles and the effective length of the growing season in the study regions.

RECONSTRUCTIONS

Wu Dangzhao (WD) Rainfall Reconstruction From February to Early- July (R_{27E})

According to the correlation results and also considering that the auto-correlation in the STD-WD chronology is significant with r= 0.381 (N=282), a transfer function between tree-ring width (predictors) and total precipitation of February to early-July (predicted) is designed as follows:

$$R_{27E} = 56.6W_{(t)} - 27.5\, W_{(t+1)} + 74.6 \qquad (1)$$

(N=29 , r=0.666, R^2=44.3%, R^2_{adj}= 40%, F=10.35 , standard error=32.62, $P<0.0001$, $t= 4.2$)

where R_{27E} is total precipitation of February to early-July (to July 10th), $W_{(t)}$ and $W_{(t+1)}$ are the indices of the $STD_{(t)}$-WD and $STD_{(t+1)}$-WD chronologies, separately. For the calibration period of 1962-1990 ($N_1=29$), the equation is highly significant. The predictor variable accounts for 44.3% (and 40% when adjusted for loss of degrees of freedom) of the variance in the precipitation. Fig. 4a shows the comparison of actual and estimated total precipitation of February to early-July (July 10) over WD region for the interval of 1962-1990.

Fig. 4

Figure 4. Comparison between observed (thick lines) and tree-ring estimated (thin lines) precipitation (mm). (a) February to early-July (to July 10th) for WD; (b) February to mid-July (to July 20") for LM.

The ***jackknife*** replication technique (Monteller and Tukey 1977) was used to assess the accuracy of the calibrated regression equation since the observation series is short. This procedure could be carried to its limit, where the observations in the calibration period are left out one at a time and calibrations are made on the remainders (Gordon 1980). This is also called a "leave-out-one" procedure. The ***jackknife*** results revel that the all values of r, R^2, R^2_{adj}, standard error of estimate, t-value and Durbin-Watson statistics are close to the values found on the total data set (Table 3). The small difference between each item shows the stability of the calibration function.

We also use powerful bootstrap resampling approach (Efi-on 1979; Young 1994) to do verification. This method is used for that the available observations of a variable contain the necessary information to construct an empirical probability distribution of any statistic of interest. It is often used when the data set is too small (Cook and Kairiukstis 1990). By using bootstrap method, after 50 time iterations, we obtained the equivalent results with those of ***Jackknife*** method. Again, all values of r, R^2, R^2_{adj}, standard error of estimate, t-value and Durbin-Watson statistics are close to the values found on the total data set (Table 3).

Both ***Jackknife*** and bootstrapping results indicate that the calibration regression model for WD site has relatively stable correlation estimates.

Table 3. Calibration and verification statistics for WD regression.

Table 3

Besides the above ***Jackknife*** and bootstrap tests, we also use the sign test **(S_1, S_2)**, reduction of error (RE) and product mean (t) (Fritts, 1991) to verify the precision and reliability of our reconstructions. Table 4 shows the statistical characteristics of the reconstructions. For the precipitation of February to early July in WD, in general, the items in table 4 indicate that the R_{27E} reconstructed data track the independent observation quite well fi-om 1961 to 1990. Only the sign test S_1 (n= 21) does not reach the

99% confidence level (B= 23), but at the 95% level (A=21). Thus, the R_{27E} reconstruction surely contains useful information.

Table 4. The statistical characteristics of verification of WD and LM reconstructions.

Table 4

Therefore, the total precipitation from February to early-July for the WD area was reconstructed based on the model (1) for the period of 1719 to 2001 (Fig. 5a).

La Madong (LM) Precipitation Reconstruction From February to Mid- July (R_{27M})

For the same reason that stated above, we here again use standard chronology from LM. It should be noted that auto-correlation in the STD-LM chronology is significant with r= 0.37 (N=401). Transfer functions were established and the statistical characteristics of model are:

$$P_{27M} = 12.5W'_{(t)} - 3.7\ W'_{(t+1)} + 6.8 \qquad (2)$$

(N=50 , r=0.653, R^2=42.7%, R^2_{adj}= 40.3%, F=17.51 ,

standard error=43.56, P<0.0001, t= 5.9)

where P_{27M} is total precipitation of February to mid-July (July 20), $W'_{(t)}$ and $W'_{(t+1)}$ are the indices of the $STD_{(t)}$-LM and $STD_{(t+1)}$-LM chronologies, separately. For the calibration period of 1952-2001 (N_1=49) the equation is highly significant. The predictor variable accounts for 42.7% (and 40.3% when adjusted for loss of degrees of freedom) of the variance in the precipitation. Fig. 4b shows the comparison between observed and tree-ring estimated total precipitation of February to mid-July (July 20) over LM region for the interval of 1952-2001.

The results of the ***Jackknife*** and bootstrap tests (Table5) show that the calibration regression model for LM site has relatively stable correlation estimates. Statistical characteristics of sign test **(S_1, S_2),** reduction of error (RE) and product mean (t) for LM February to mid-July rainfall reconstruction are in Table 4.

Table 5. Calibration and verification statistics for LM regression.

Table 5

Based on equation (2) the total precipitation from February to mid-July, therefore, was reconstructed for LM area for the period of 1600 (SSS>0.75 from 1648) to 2001 (Figure 5b).

DISCUSSION

Comparison Between Reconstructions and Historical Documents

We have been able to use historical documents to check the reliability of our reconstructions. **A** great volume of Chinese historical writings contains abundant climatic descriptions which are of considerable value for studying climatic fluctuations. During 1970's hundreds of climatologists processed these materials from more than 2200 local annals and many other historical writings nation-wide and abstracted fiom them more than two million and two hundred thousand characters (data). The dryness/wetness (D/W) of each year in the recent 510-year period were classified into 5 grades: grade 1 – wettest, grade 2 – wet, grade 3 – normal, grade 4 – dry, and grade 5 – drought (Academy of Meteorological Science 1982).

Many dry or drought and wet years identified in the historical records emerged also in our reconstructions. Historical records and reconstructions are statistically significantly correlated at the 99% level with Spearman rank correlation r = -0.20 for LM (N_3=379, 1600-1979, p<0.0001, t =3.96) and r = -0.22 for WD (N_4=260, 1719-1979, p<0.0001, t = 3.62).

Both the precision and resolution of series derived from historical documents is likely to be higher after 1900 due to many more records being available than in earlier times (Zhang 1995). The correlations rise to -0.46 for LM (N=80, 1900-1979, p<0.0001, t = 4.6) and -0.28 for WD (N=80, 1900-1979, p<0.001, t = 2.6). This is mainly due to that in the earlier time there were less historical records available (Zhang 1995).

Another approach is that we directly used some local annals fiom the areas nearby (for example Baotou city, 30 km south of WD; and Hohhot city, 20 km east of LM) to test our reconstructions. Some severe drought years in these historical records emerge in the two reconstructions. The years with precipitation of February to early July (or mid July) lower than $R_t \leq R_m - 1.17\sigma$ (see Table 6 for the definition of severe drought) are described as "severe drought" in original documents (Institute of Meteorology of Inner Mongolia

1975; Council of Inner Mongolia 1976). Some examples, just to name a few, are given in Table 7. We should note that many drought years which appear in the reconstructions no records are available in the historical documents, the reason we have stated above.

Table 6. Five wet/dry classes (P-grade) divided from the two precipitation reconstructions

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Table 6

In the Table 7, almost all severe drought years in the historical documents correspond to low precipitation years in the reconstructions.

But one case, the year 1883, is an exception. It was recorded as "severe drought in Baotou and Hohhot". However, in two tree-ring reconstructions, no drought is evident. Rainfall in WD was 100 mm corresponding to precipitation grade 3, which means "normal". Precipitation in LM was 169 mm, correspond to precipitation grade 2, which means "wet". Probably an artificial mistake was placed in the historical document. This feature should be viewed with caution when we use historical documents.

To make a better comparison we divided precipitation reconstructions into five equally probable classes, precipitation-grade (P-grade), based on standard described in Table 4 (Academy of Meteorological Science 1982). Percentage in the Table 4 displays that the frequency of wet (LM: 1 + 2 grade=37.2%; WD: 1 + 2 grade=36.6%) and dry (LM: 4 + 5 grade=36.3%; WD: 4 + 5 grade=38.5%) is larger than the normal ones (LM: 3 grade= 26.5%; WD: 3 grade= 24.9%). In the WD region the frequency of dry years is higher than that of wet and normal years, since WD is 120 km northwest away to LM sites, it is more sensitive to monsoon front related precipitation. In another words, the stronger monsoon the more rainfall and the weaker monsoon the less rainfall. In such an environmentally sensitive transition region, 120 km can make a big difference in response to strong or weak monsoon front variation.

Table 7. The correspondence between reconstructed low precipitation from February to early July (or mid July) and documented drought years

Table 7

From the observation records, we know that the range of precipitation from February to mid-July in LM region is about 50–354 mm, and the average is 154 mm, but in the more west WD area the range of February to early-July precipitation is only 47–180 mm, and mean is 103 mm. WD region receives much less precipitation than LM, since WD site is in the far northwestern margin of the EASM. This is just the major feature of the EASM climate in its margin regions. Despite two curves display similar trend, but the precipitation amount are different.

We then calculated the correlation between the historical dryness/wetness (WID) indices and precipitation grade (P-grade) for the different time intervals. The correlation between them is likely to be higher step-by-step. For example LM sites reach 0.47 after

1879 (N=101, 1879-1979, p<0.0001).

Comparison Between Reconstructions and the Other Summer Monsoon Front Related Precipitation Reconstructions in North China and Dunde Ice Cap Accumulation From West China

The movement of the EASM fi-ont, to a certain degree, reflects strong/weak of monsoon in the past. Thus it is very important to determine whether our reconstructions in this paper have regional or local climatic signals. We here compare them to other two annual-resolution reconstructions, which come from environmentally sensitive zone, in another words, monsoon margin as well.

One is from northern Helan Mountain (NHL), 400 km away in the west of our study area. The rainfall reconstruction, May to July precipitation, from this site is based on Chinese pine (*Pinus* tabulaeformis) tree-ring index from 1726 to 1997 (Liu et *al.* 2004).

The other one is from Baiyinaobao (BYAB), 600 km away eastern of **LM,** Inner Mongolia (Liu et al. 2003). The total precipitation fi-om April to early July (July 10) in growing season in this site was constructed using Picea *koraiensis* tree-ring width.

Precipitation changes in all the 4 regions over environmentally sensitive zone in northern China are shown in Fig. 5. Many small#-scale variations can be found in all annual-resolution series. These four original curves are correlated, except the low correlation between WD and BYAB (Table 8), the wet or dry extreme events are well matched in many cases, for example, the severe drought in 1792, 1839, 1867, 1900, 1928~1929, 1966 etc. It looks like that trees we selected responded strongly and quite synchronously to a large-scale climatic change. This means that the same climatic systems, presumably related to the EASM front, affect the precipitation from February to July in a large region in north China. The trees we selected responded positively to this large-scale climatic change.

Fig. 5

Figure 5. Precipitation changes in the four regions over environmental sensitivity zone in Northern China. (a) February to mid-July (to July 20th) for LM region; (b) February to early-July (to July 10th) for WD; (c) May to July precipitation for the North Helan Mountains; (d) April to early July (to July 10th) precipitation for Baiyinaobao. The curves overlapped in (a) and (b) show the changing sample size for each year.

Since these four sites are all located in the margin of the EASM, the reconstructed climatic factor (rainfall from late spring, or spring, to early summer) in these regions should be related to the EASM front rainbelt. This comparison also could indicate a spatial and temporal connection of spring to early summer climatic condition for the northwestern to northeastern along the environmentally sensitive zone (the margin of the EASM).

Table 8. Correlations between rainfall reconstructions from LM, WD, Baiyinaobao, and northern Helan Mountains.

Table 8

We have made a large-scale monsoonal front precipitation comparison in northern China, but these precipitations are all based on the tree-ring data. Beyond the tree-ring data, we use another high-resolution records, ice annual accumulation from Dunde ice cap (Thompson *et al.* 1988), to make comparison. Dunde is the closest ice cap site to our tree-ring sites. As calculated, the correlation between Dunde ice annual accumulation and tree-ring precipitations are very low, not significant. Rotated empirical orthogonal function (REOF) analysis on these five tree-ring based precipitation and ice accumulation revealed that all tree-ring rainfall reconstructions have the same signs, but opposite sign for ice accumulation. That means that there are different variation trends between Dunde ice annual accumulation and tree-ring precipitation. However, there is the same trend within all four precipitations series.

The results .demonstrate the existence of spatially coherent modes of the EASM precipitation variation in the LM, WD, Baiyinaobao, and northern Helan mountains, at least reflect large-scale modes of climate forcing on tree growth. Also it revealed a fact that Dunde ice cap is not strongly influenced by the EASM system. Thus, the reconstruction from Dunde ice cap is not well suited for comparison with our eastern China tree-ring reconstructions, since they seem reflecting the different climatic system.

Decadal to Multi-Decadal Variation Analysis on Reconstructions

In order to recognize the climatic variation at decadal to multi-decadal time scales, four reconstructed precipitation series and dryness-wetness indices were smoothed by a

10-year moving average (Figure 6). The dry and wet periods could be surveyed more clearly. The trends of four tree-ring reconstructions vary almost synchronously, in spite of some low correlations between them (Table 8).

After moving average, correlation between LM and WD and dryness/wetness index, are slightly higher than original series, with value 0.25 to LM (N=369, p<0.01), and 0.24 to WD (N= 250, p<0.01). However during 1860s~1 870s they are controversy. LM and WD display relatively wet, but dry in dryness/wetness series.

In general, in this margin of the EASM the periods of below normal precipitation could be found over the 1720s~1760s, 1790s, 1840s~1860s, 1890s– 1910s, 1920s–1930s and after the late 1960s–early 1970s. The periods of above normal precipitation occurred over the 1650s–1710s, 1760s~1780s, 1820s– 1830s, 1870s~1880s, 1940s to early 1960s and 1990s. These periods were deducted om the smooth curves. Since 1880, the variation trends are quite similar to the precipitation variation in Northeast and Northwest China found by Qian (Qian and Zhu 2001).

Fig. 6

Figure 6. Comparison within dryness/wetness indices, LM, WD, north Helan Mountains, Baiyinaobao on decadal to multi-decadal time scales. All curves were smoothed using a 10-year moving average.

It is worth to note that all five curves exhibit striking similarity of variation after

1900. Precipitation in WD, LM and north Helan Mountains is increasing very clearly since 1970s, which followed the increasing of the northern Hemisphere mean temperature. They, except Baiyinaobao, seem have a quite similar trend to North Hemisphere Temperature curve (Folland *et al.* 2001). Probably the EASM front is becoming stronger as the result of North Hemisphere Temperature increase. The late 1990s is the period with the most precipitation in WD region for the last 270 years (Figure 6).

Another striking feature is the late 1920s severe drought event which is displayed in all smoothed curves. In LM it was the period with the lowest rainfall in the past 400 years, and the lowest precipitation in WD for last 270 years. In north Helan Mountains and Baiyinaobao it was a period with a significant precipitation reduction.

CONCLUSION

The results of this paper show that there is great potential to reconstruct the EASM front related precipitation in environmentally sensitive zone in north China through ring indices over the past 400 years. Using Chinese pine (*Pinus tabulaeformis*) ring-width data, rainfall fiom February to early-July for Wu Dangzhao region and from February to mid-July for La Madong region, Inner Mongolia, China, were reconstructed. The explained variances account for 44.3% and 42.7% in the precipitation. Many dry or drought and wet years in our reconstructions could be identified in the historical records.

The reconstructions also could be compared with other tree-ring seasonal precipitation reconstructions fiom environmentally sensitive zone, such as northern Helan Mountain and Baiyinaobao. Many smaller scale variations can be found in all annual resolution series. Trees we selected responded strongly and quite synchronously to this large-scale climatic change, such as severe drought in 1792, 1839, 1867, 1900, 1928–1929, 1966 etc. This comparison also could indicate a spatial and temporal connection of spring to early summer climatic condition for the northwest to northeast along the environmentally sensitivity zone.

Another striking feature is late 1920s severe drought event which is displayed in all smoothed curves. Late 1920s was the most severe drought event ~~in a large-scale~~ in north China for the last 400 years. This event was most likely caused by the weakest EASM circulation.

The information from this paper will be of value in understanding the natural variation of the EASM on interannual to multidecadal timescales, and so could contribute to the development of an improved capacity to anticipate its future variations.

ACKNOWLEDGMENTS

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REFERENCES CITED

Academy of Meteorological Science

1982 Yearly Charts of *Dryness/Wetness* in China for the Last 500-Year Period.

China Cartographic Publishing House, Beijing; 332 pp.

Cook, E. R., and L. A. Kairiukstis

1990 *Methods of Dendrochronology*. Kluwer Academic Publishers, Dordrecht; 394 pp.

Council of Inner Mongolia

1976 ***The history of calamity in Inner Mongolia.*** Unpublished report. Hohhot.

Efron, B.

1979 Bootstrap methods: another look at the jackknife. ***Annals Statistics*** 7: 1-26.

Folland, C.K., T.R. Karl, J.R. Christy, R.A. Clarke, G.V. Gruza, J. Jouzel, M.E. Mann, J. Oerlemans, M.J. Salinger, S.W. Wang

2001 Observed climate variability and change. In ***Climate Change,*** edited by J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. Van der Linden, X. Dai, K. Maskell, and C.A. Johnson, pp. 99-181. Cambridge University Press, Cambridge; 881 pp.

Fritts, H.C.

1976 ***Tree Rings and Climate.*** Academic Press, New York; 567 pp.

Fritts, H.C.

1991 ***Reconstructing large-scale climatic patterns from tree-ring data.*** The University of Arizona Press, Tucson; 286 pp.

Fu, C.B., and Z.M. Zeng

1997 Monsoon regions: The areas with the largest precipitation variability in the world. ***Chinese Science Bulletin*** 42(21): 2306 - 2309.

Fu, C.B., H.L. Wei, and M. Chen

1998 Evolution of summer monsoon rainblets over East China in a regional climate model. *Atmospherica Sinica* 22: 522-534.

Gordon, G. A.

1980 Verification of dendroclimatic reconstructions. In ***Climate from tree rings,*** edited by M. K. Hughes, P. M. Kelly, J. R. Pilcher, V. C. Lamarche Jr, pp 58-61. Cambridge University Press, Cambridge, UK

Holmes, R.L.

1983 Computer-assisted quality control in tree-ring dating and measurement. ***Tree-Ring Bulletin*** 43: 69-78.

Hughes, M.K., X.D. Wu, X.M. Shao, and G. M. Garfin

1994 A preliminary reconstruction of rainfall in north-central China since A. D. 1600 from tree-ring density and width. ***Quaternary Research*** 42(1): 88-99.

Inner Mongolia Forest Agency

1995 ***Annual report of Inner Mongolia Forest.*** 608 pp, unpublished material, Hohhot; 608 pp.

Institute of Meteorology of Inner Mongolia

1975 ***Chronology of meteorological calamity for Inner Mongolia and its adjacent regions.*** unpublished report, Hohhot.

Kohler, M. A.

1949 On the use of double-mass analysis for testing the consistency of meteorological records and for making required adjustments. ***Bulletin of American Meteorological Society*** 30: 188-189.

Liu, Y., Q.F. Cai, W.K. Park, Z.S. An, and L.M. Ma

2003 Tree-ring Precipitation Records from Baiyinaobao, Inner Mongolia since A.D. 1838. ***Chinese Science Bulletin*** 48(11): 1140-1145.

Liu, Y., J.F. Shi, V. Shishov, E. Vaganov, Y.K. Yang, Q.F. Cai, J.Y. Sun, L. Wang, and I. Djanseitov

2004 Reconstruction of May-July precipitation in the north Helan Mountain, Inner Mongolia since A.D. 1726 from tree-ring late-wood widths. ***Chinese Science Bulletin*** 49(4): 405-409.

Mann, H.B.

1945 Non-parametric test against trend. ***Econometrika*** 13: 245-259.

Mosteller, F., and J.W. Tukey

1977 ***Data Analysis and Regression.*** Addison-Wesley Publishing Campany, Massachusetts; 588 pp.

Qian, W.H., and D.K. Lee

2000 Seasonal march of Asian Summer Monsoon. ***International Journal Of Climatology*** 20: 1371–1386.

Qian, W.H., and Y.F. Zhu

2001 Climate change in China from1880 to 1998 and its impact on the environmental condition. ***Climatic Change*** 50: 419–444.

Shao, X.M., and X.D. Wu

1994 Radial growth of Huashan pine and its response to climate. ***The Journal of Chinese Geography*** 4(3/4): 88-102.

Shi, N., Q.G. Zhu, and B.G. Wu

1996 The East Asian Summer Monsoon in relation to summer large scale weather-climate anomaly in China for last 40 years. *Scientia Atmospherica Sinica* 20(5): 575 - 583.

Stokes, M.A., and T.L. Smiley

1996 *An Introduction to Tree-Ring Dating.* University of Arizona Press, Tucson;73 pp...

Thompson, L.G., X. Wu, E.M. Thompson, and Z. Xie

1988 Climaticrecords from the Dunde ice cap, China. *Annals of Glaciology* 10: 178-182.

Touchan, R., D.M. Meko, and M.K. Hughes

1999 A 396-year reconstruction of precipitation in southern Jordan. *Journal of the American Water Resources Association* 35(1): 49-59.

Wang, C.G.

1997 *Important Climatic Changes in Inner Mongolia.* China Meteorological Press, Beijing, 168pp.

Wang, W.H.

1990 *Climate in Inner Mongolia.* China Meteorological Press, Beijing; 273pp.

Wigley, T.M.L., K.R. Briffa, and P.D. Jones

1984 On the average value of correlation time series, with applications in dendroclimatology and hydrometeorology. *Journal of Climate and Applied Meteorology* 23: 201-213.

Wu, H.B.

1991 *Major Climatic Disaster in Inner Mongolia, China* (1947-1987). China Meteorological Press, Beijing; 219 pp.

Young, G. A.

1994 Bootstrap: More than a stab in the dark. ***Statistical Science*** **9(3)**: 382-415.

Zhang, D.E.

1995 High resolution records available from Chinese historical documents. ***Quaternary Sciences*** 1: 75-81.

Zhang, P.Y.

1996 ***Climate of China and Sea-Level Variation and Their Trends and Influences.*** Pp. 345-351. Shandong Science and Technology Press, Ji'nan.

Zhou, W.J.

1996 ***Monsoon variation in environmental sensitivity zone in China and*** ^{14}C ***chronology.*** Ph.D. dissertation, Northwest University, Xi'an.

Table:

Table 1 The statistical characteristics of both **WD** and LM chronologies.

Statistic	LM	WD
Mean sensitivity	**0.29**	0.47
Standard deviation	**0.44**	0.52
Skewness	**0.44**	**1.12**
Kurtosis	**2.77**	**2.91**
First order autocorrelation	0.51	0.46
Mean correlation between all series	0.33	0.62
Mean correlation between trees	0.32	0.62
Mean correlation within a tree	0.41	0.63
Expressed population signal (EPS)	0.82	0.97
% Variance in 1st PC	36.6%	63.37%
SSS period (>0.75)	1627-2001	1734-2001
% missing rings	**1.16**	**3.13**

1.62
1.18

The **WD** chronology based on **69** cores from **40** trees covering the period **AD 1719** to **2001.** Common interval analyses were performed on **45** series from **33** trees for the period **1880** to **1987.** LM chronology based on **60** cores from **50** trees covering the period **AD 1525** to **2001.** Common interval analyses were performed on **38** series from **33** trees for the period **1837** to **1988.**

Table 2 The correlation between observed precipitation and ring width indices.

Month	LM	WD
Prior August	0.15	0.32*
Prior September	0.15	0.5*
Prior October	0.18	0.22
Prior November	-0.15	-0.12
Prior December	-0.10	-0.1
January	-0.14	-0.05
February	0.44*	0.4*
March	0.33*	0.03
April	0.38*	0.31
May	0.26	0.17
June	0.29	0.4*
July	0.24	0.31
August	0.13	-0.01
February to early-July	0.55*	0.60*
February to mid-July	0.63*	0.50*

*--exceeds the 95% significant confidence level. WD: 1961-1990. LM: 1951-2001.

Table 3. Calibration and verification statistics for WD regression.

Calibration		Verification	
		Jackknife Mean (range)	Bootstrap (50 iterations) Mean (range)
r	0.666	0.666 (0.635-0.71)	0.649 (0.366-0.802)
R^2	0.443	0.444 (0.403-0.504)	0.429 (0.134-0.643)
R^2_{adj}	0.40	0.422 (0.38-0.485)	0.409 (0.103-0.63)
Standard error of estimate	32.617	32.0066 (30.516-32.615)	30.32 (24.031-35.653)
t	4.21	4.485 (2.277-5.141)	4.665 (2.083-7.096)
Durbin-Watson	2.297	2.289 (1.921-2.478)	2.268 (2.077-2.36)

Table 4 The statistical characteristics of verification of WD and LM reconstructions.

	S_1 (a, *b*)	S_2 (*a*, *b*)	*t*	*RE*
LM	37(30,32)	39(31, 33)	5.9	0.39
WD	21(21, 23)	23(21,22)	4.2	0.42

a=95% significant confidence level; *b*= 99% level. *RE* -- reduction of error ; S_1, S_2-- sign test. S_1 is the general sign test between observation and reconstruction that measures the associations at all frequencies. S_2, which reflects the high-frequency climatic variations, is a similar test to that mentioned above, and it is made for the first differences; *t*--product mean (Fritts 1991).

Table 5 Calibration and verification statistics for LM regression.

Calibration		Verification	
		Jackknife Mean (range)	Bootstrap (50 iterations) Mean (range)
r	0.653	0.653 (0.593-0.688)	0.637 (0.319-0.786)
R^2	0.427	0.427 (0.352-0.473)	0.416 (0.102-0.618)
R^2_{adj}	0.403	0.415 (0.338-0.462)	0.403 (0.083-0.61)
Standard error of estimate	43.554	43.088 (40.105-43.553)	41.495 (30.445-50.734)
t	5.901	5.919 (5.051-6.493)	5.946 (2.33-8.086)
Durbin-Watson	1.996	2.006 (1.826-2.186)	1.974 (1.857-2.108)

Table ***6*** Five wet/dry classes (P-grade) divided from the two precipitation reconstructions

			Years		Percentage of the total (%)	
P-grade	Wet/Dry	Range	LM	WD	LM	WD
I	wettest	$R_t > R_m + 1.170$	47	33	11.7	11.7
II	wet	$R_m + 0.33\sigma < R_t \leq R_m + 1.17\sigma$	102	70	25.5	24.9
III	normal	$R_m - 0.33\sigma < R_t \leq R_m + 0.33\sigma$	106	70	26.5	24.9
IV	dry	$R_m - 1.17\sigma < R_t \leq R_m - 0.33\sigma$	100	71	25	25.3
V	drought	$R_t \leq R_m - 1.17\sigma$	45	37	11.3	13.2

R_m is the precipitation mean, and σ is standard deviation. R_t is the precipitation at *t* year.

For LM February to mid-July precipitation, R, = 154 mm and σ = 31 mm (1601 to 2001).

For WD February to early-July precipitation, R, = 103 mm, and σ = 24 mm (1720 to

2001).

Table 7 The correspondence between reconstructed low precipitation from February to early July (or mid July) and documented drought years

Year	Wu Dangzhao		La Madong		
	WD Rconstruct-ed rainfall (mm)	WD P-grade	LM Rconstr-ucted rainfall (mm)	LM P-grade	Documents descriptions
1750	93	4	**109**	5	severe drought in Baotou;
1758	70	5	92	5	severe drought in Baotou and Hohhot, no rainfall for the whole year, nothing could be eaten except bark and grass roots, people even ate each other;
1777	92	4	118	4	severe drought;
1800	75	4	119	4	severe drought in Baotou;

1877	99	3	144	4	severe drought in Baotou and
1878	74	5	158	3	Hohhot for two years, wheat was as precious as pearls;
1883	100	3	169	2	severe drought in Baotou and Hohhot;
1891	55	5	93	5	severe drought in Baotou and Hohhot for several years, no rainfall, cannot plant, no harvest, nothing left in the food bank, countless people died;
1905	80	4	110	5	severe drought in Baotou;
1926	65	5	132	4	severe drought in Inner Mongolia on large scale
1928	53	5	86	5	severe drought in Inner Mongolia on large scale
1929	75	5	54	5	severe drought in Inner Mongolia on large scale for four years (in north China), nothing in the field; especial in 1928, it has no rain for spring and summer, nothing grew, livestock were killed because of no food;
1941	95	4	135	4	severe drought in Baotou;

1942	60	5	133	severe drought in Baotou.

Table 8 Correlations between rainfall reconstructions from LM, WD, Baiyinaobao (BYAB), and northern Helan Mountains (NHL).

	Original series r (N, p)			After 10-year moving average r		
	LM	WD	BYAB	LM	WD	BYAB
WD	0.62 (282, 0.0001),			0.60		
BYAB	0.28 (163, 0.0001)	0.15 (163, 0.06)		0.14	0.13	
NHL	0.29 (277, 0.0001)	0.37 (277, 0.0001)	0.28 (161, 0.0001)	0.24	0.32	0.11

Figure Captions:

Figure 1 Location of the sampling sites (▲), meteorological stations (●) and other two comparison tree-ring sites, Baiyinaobao) and the north Helan Mountain. The shaded area in the whole China map (inset in low right) indicates the environmental sensitivity zone.

Figure 2 The typical sampling condition in the La Madong site, most of trees we collected grow on the rocks. Photograph by Yu Liu.

Figure 3 Average monthly precipitation values from the Shiguai(●), Hohhot(■) and Baotou(▲) meteorological stations in the region of the sampling sites.

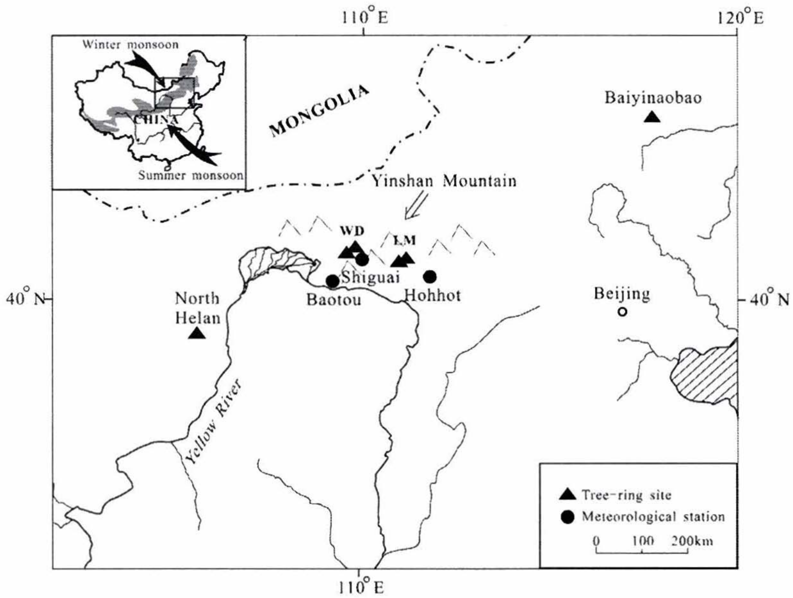
Figure 4 Comparison between observed (thick lines) and tree-ring estimated (thin lines) precipitation (mm). (a) February to early-July (to July 10th) for WD; (b) February to mid-July (to July 20th) for LM.

Figure 5 Precipitation changes in the four regions over environmental sensitivity zone in Northern China. (a) February to mid-July (to July 20th) for LM region; (b) February to early-July (to July 10th) for WD; (c) May to July precipitation for the North Helan Mountains; (d) April to early July (to July 10th) precipitation for Baiyinaobao. The curves overlapped in (a) and (b) show the changing sample size for each year.

Figure 6 Comparison within dryness/wetness indices, LM, WD, north Helan Mountains, Baiyinaobao on decadal to multi-decadal time scales. All curves were smoothed using a 10-year moving average.

Figures:

FIGURE 1



Figure

41

FIGURE 2

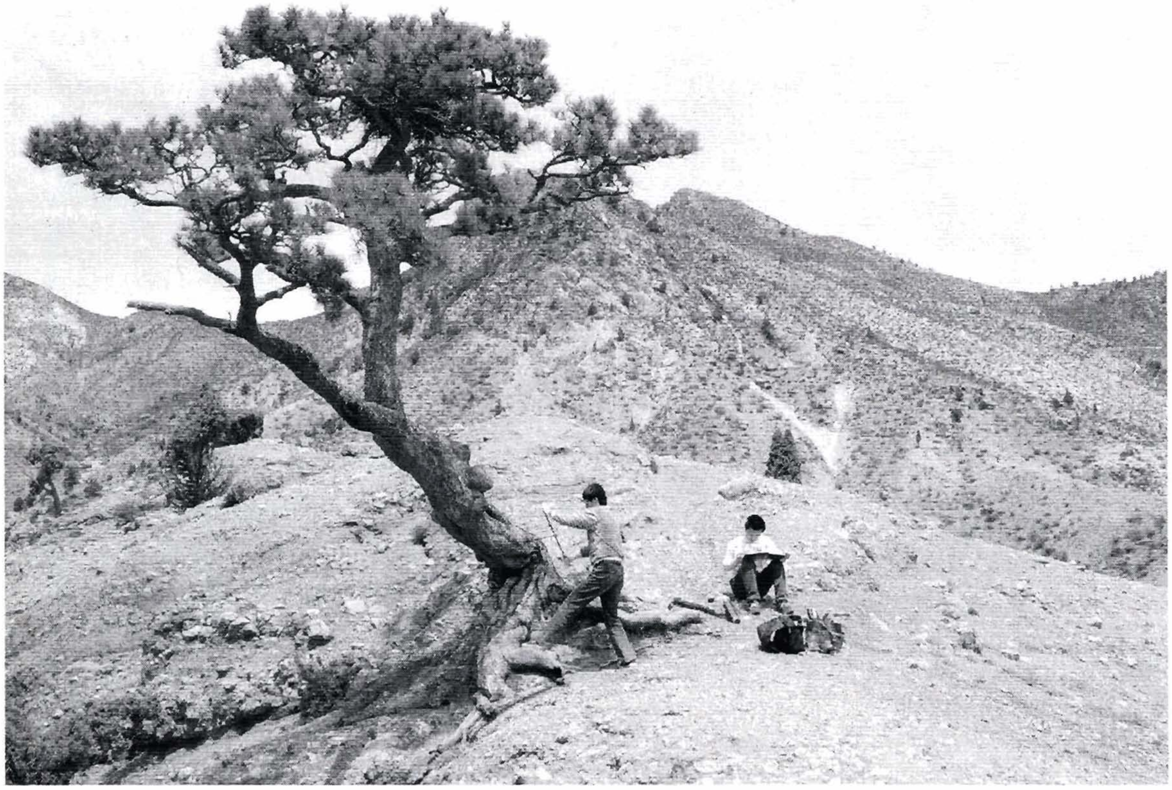


FIGURE 3

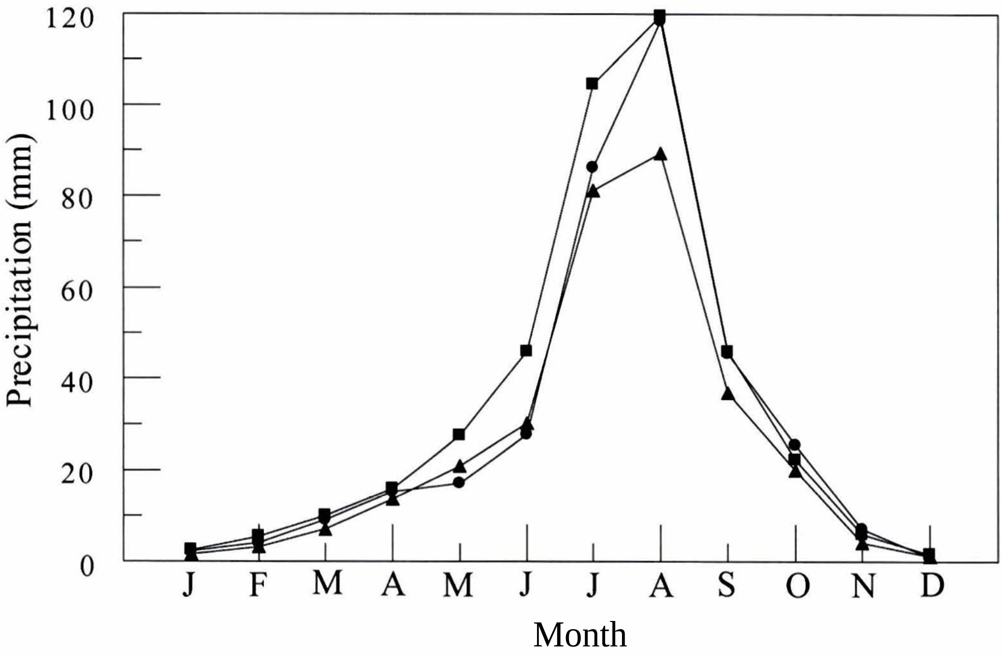


Figure 3

FIGURE 4

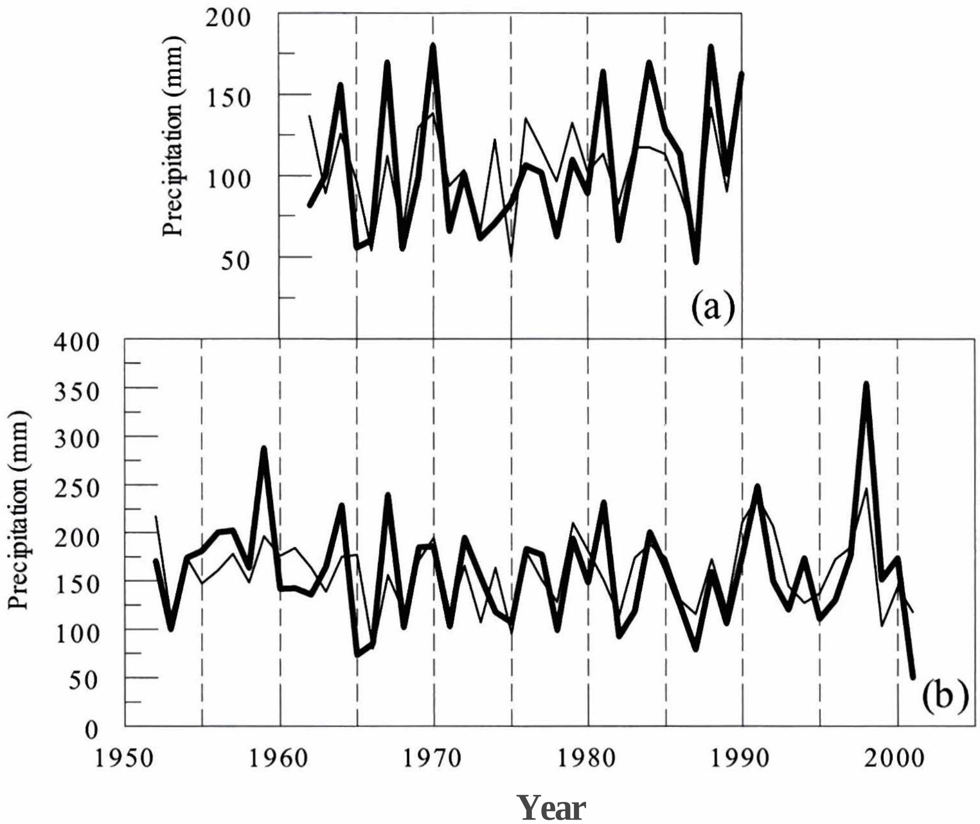


Figure 4

FIGURE *5*

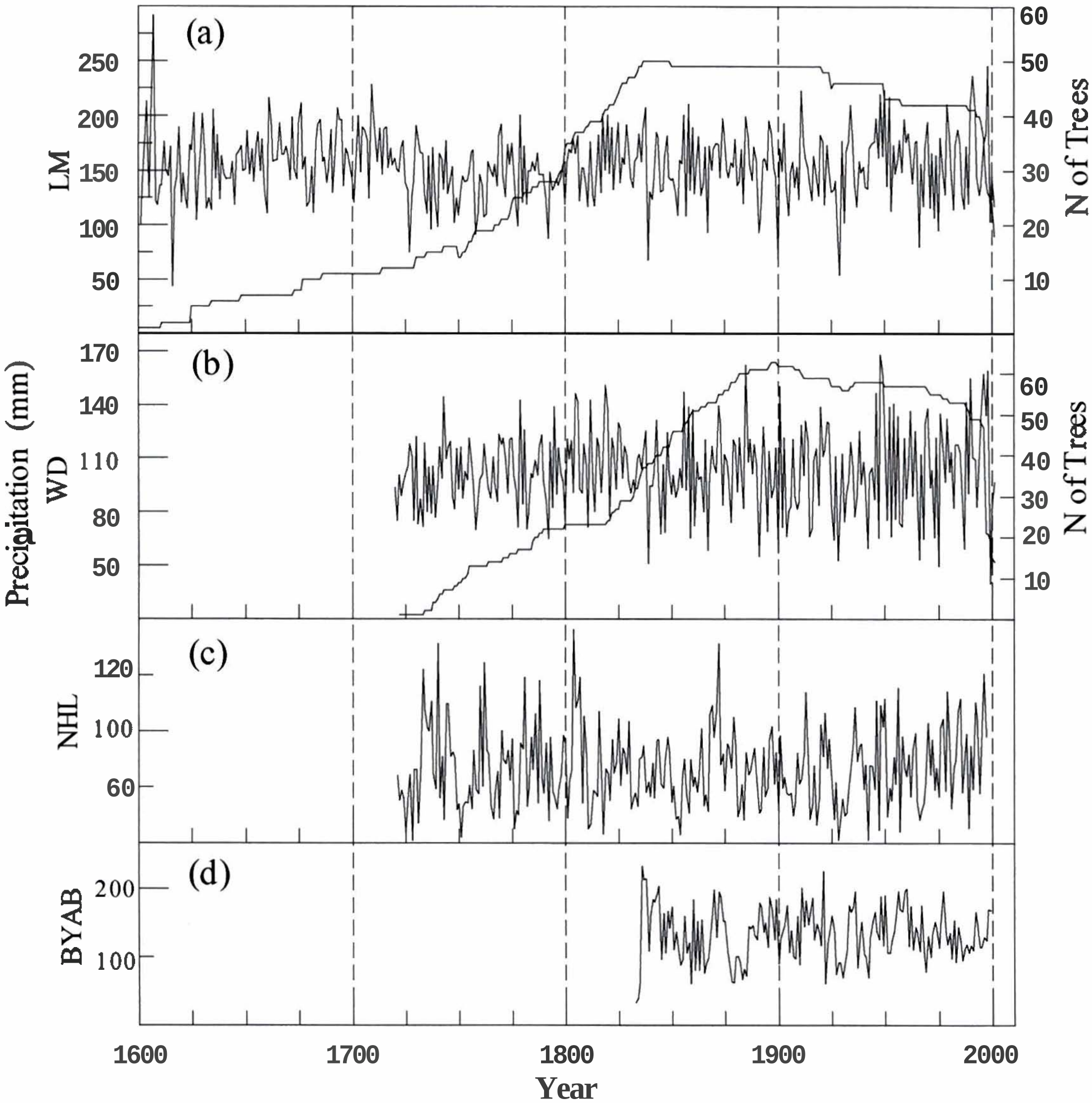


Figure 5

FIGURE 6

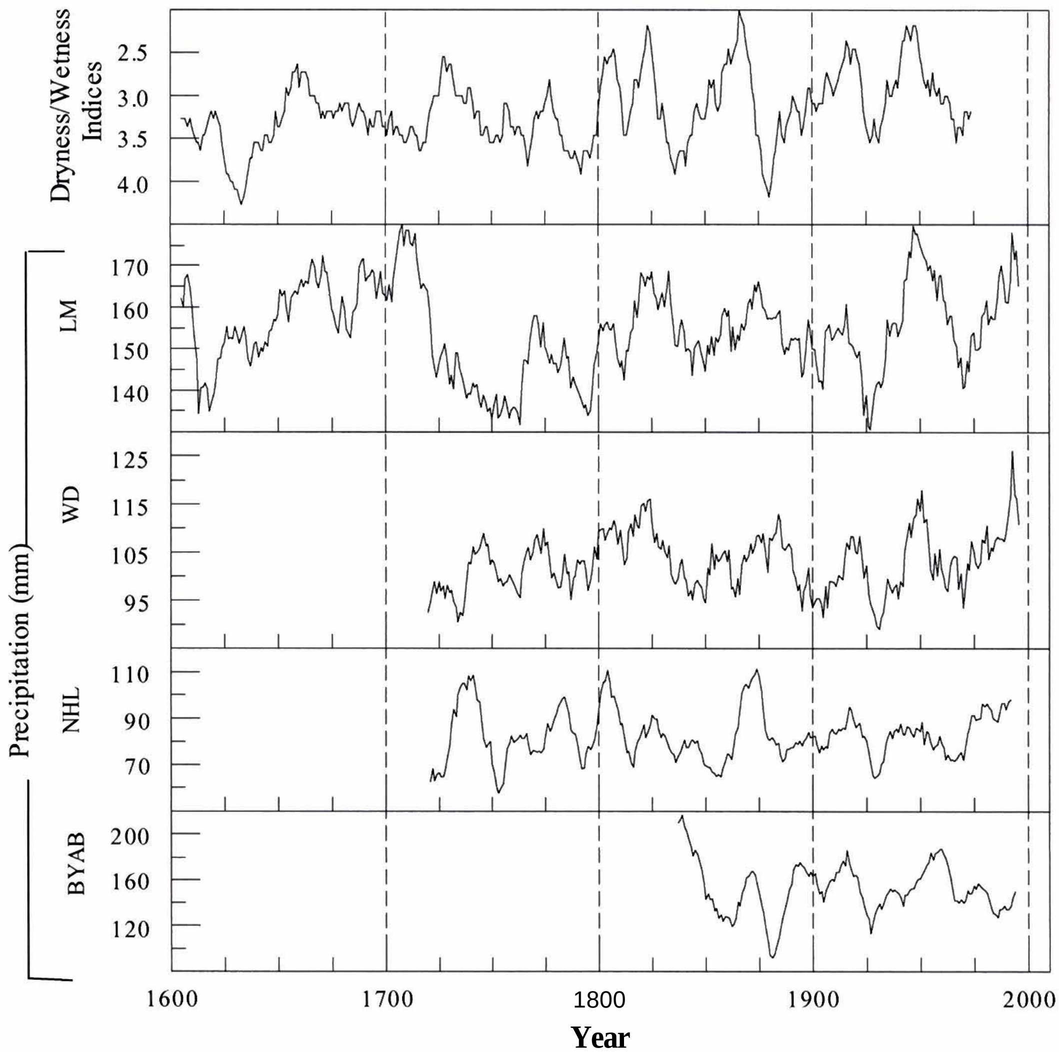

Dryness/Wetness Indices
2.5
3.0
3.5
4.0
Precipitation (mm)
LM
170
160
150
140
WD
125
115
105
95
NHL
110
90
70
BYAB
200
160
120
1600
1700
1800
1900
2000
Year

Figure 6