Reviewer #1

Review of the manuscript

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

1. Importance and interest to the Tree-Ring Research' readers

The paper addresses the attempt to reconstruct summer rainfall in the semi-arid belt of northwest China from tree rings. This is an important aspect of regional climate variability and of general interest for the readership of Tree-Ring Research

2. Scientific soundness of the methods

The standardization of the raw data was carried out by fitting straight lines or exponential functions which is probably appropriate for the kind of data used. Obviously, no adjustment of the variance according to changing sample depth was performed, although the tree-ring index series or the reconstructions derived seem to be heteroscedastic (Fig. 5a, b).

3. Originality of the work

The study contains new data in the form of quite extensive collections of ***Pinus tabulaeformis*** from two locations in the Yinshan Mountains of north China covering the last ca. 380 and 280 years, respectively. Additional data (two more tree-ring sites, ice accumulation data and historical documentary data) for comparison were taken from former publications of the first author or from the literature.

4. Degree to which conclusions are supported bv the data

The ecological interpretation of the resulting correlations make sense, but the explanations on p. 10 are partly trivial ("if water decreases tree growth could slow down, producing a narrow ring" – this is logical for a linear correlation!). On the other hand, only correlations with rainfall are considered and correlations with temperature are not even mentioned. Therefore the interpretation of the tree-growth reactions must be incomplete, although they seem to be plausible.

Another problem I see is the main title where the authors claim to reconstruct "Asian Summer Monsoon Front Variation". Although there is very probably a relationship between the depth that the Asian monsoon air masses could penetrate into the continent and the amount of rainfall, the title seems misleading to me. In very dry years on may assume that the monsoon did not reach the study sites, but in humid years it is not clear from this study where the monsoon front really was located. There is for sure no linear relationship between the rainfall amount at the study site and the inland position of the monsoon, as the authors state quite vaguely on p. 18: "The movement of the EASM front, to a certain degree, reflects strong weak of monsoon in the past" (I did not correct typing errors here!). So it is implied that in very humid years the monsoon was very strong and probably reached further inland, but what the authors finally provide is a reconstruction of rainfall amount and not of the spatial variation of the monsoon front. This might be done once, when the temporal discrepancies in dry and wet years in the local rainfall reconstructions are mapped through time. This intention is probably indicated in the following sentence (p. 18):"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)". However, the meaning of the sentence is not really clear.

5. Organization and clarity of the text and data presentation

There is problematic use of some technical terms:

a) The "environmentally sensitive zone" (ESZ, sometimes also misspelled as 'environmental sensitivity zone') seems to be defined in the literature; nevertheless I have some difficulties with this term since it somehow implies that regions outside this belt between 200-400 mm annual rainfall are not or less sensitive. However, this is certainly not the case for various environmental factors. An annual mean temperature between 5.5°C-8.1°C, as mentioned in the definition is certainly not an indication of environmental sensitivity but just a statistical value representing the temperature conditions within the precipitation belt between 200-400 mm annual rainfall. This region is semi-arid and interannual rainfall variability is naturally high.

b) "Climate change" is sometimes used when actually natural climate variability of precipitation is meant (e.g. p.4. 1.3; p.19, 1.2., p. 23). However, variations in summer rainfall should be clearly differentiated from recent trends in climate that are probably anthropogenically caused.

c) Odd terms like "tree-ring precipitation" should be replaced. Sometimes, tree-ring index curves are meant, sometimes the tree-ring based precipitation reconstructions.

d) In many headlines and in the text, only the term "reconstruction" is used, but for clarity, "precipitation reconstruction" should be preferred.

e) On p. 3, "the sub-tropical high pressure" is mentioned. Please explain more clearly where this high-pressure system is located.

f) "The time period from February to July (early or mid) could be acceptable (p.9)." This sentence is not clear to me.

g) "The correlation between them is likely to be higher step-by-step (p. 18)". This sentence is not clear to me.

h) p.18: "smaller-scale variations": do you mean "local", "individual" or "short-term"?

On p. 20 it is mentioned that Rotated Empirical Orthogonal Function Analysis was performed between five (why five and not four?) tree-ring based precipitation reconstructions and the ice accumulation record of Dunde. This sentence must be relocated into the method section and must be made clearer.

Then, some results about long-term trends and opposing signs are discussed. Finally, the comparison with the Dunde ice accumulation record did not yield any result. This is not really surprising since beside the many climatic factors beside early summer rainfall that probably influence the accumulation rate at Dunde, the record might also have dating problems. However, since there are no graphs about this comparison, the description of this finding (p. 20) is not satisfying. I would suggest that either the Dunde record is included in on of the comparative Figures 5 or 6 and discussed more thoroughly or the paragraph should be deleted.

6. Cohesiveness of the arguments

One open question is the high correlation with rainfall during February to April (Table 2), since this is the pre-monsoon season and rainfall is generally very low during this period (see Fig. 3). Thus, the rainfall reconstruction derived from the correlation during the season February to July includes correlations with rainfall data outside of the summer monsoon season However, the rainfall reconstruction is interpreted as a proxy for the East Asian Summer Monsoon. Some comment of this discrepancy is required.

7. Length

The paper includes 8 tables and 6 figures. I suggest that table 2 should be replaced by a bar graph and that tables 3 and 5 are combined in one table.

8. Conciseness and writing style

The English usage is often odd and unclear. There are many errors concerning grammar, style and typing. I tried to make suggestions for corrections which I indicate with yellow marks in the text, since there are too many of them to indicate them individually.

Specific comments

1. Presentation

The Introduction starts with a definition of a technical term ("environmentally sensitive zone" I which is not very elegant. It would be better to start with a general description of the scientific problem and the scientific or practical relevance of the study.

In the first paragraph of the discussion, the derived rainfall reconstructions are compared with historical weather records. The data were taken from the literature (Academy of Meteorological Sciences 1982). This is of course justified, but better write instead of 'We have been able to use historical documents to check the reliability of our reconstruction" (p. 15) that a dryness/wetness index derived from historical documentary data was available.

Parts of the conclusion paragraph are repetitions of results.

2. Length

See comments on point 7 in 'general comments'

3. Methods

See comments on point 2 in 'general comments'

4. Data presentation

Table 1 contains many data (like MS, AC1) that are not discussed in the text. Are they in this case relevant to show?

5. Statistical design and analyses

On p. 9 it is said that non-overlapping 10-day mean meteorological data were used. However, in Table 2 correlation coefficients with monthly climatic data are presented except for the seasonal averages from February to early-July and February to mid-July.

6. Errors

The text contains many typing errors and grammar mistakes.

7. Citations

The work of Stokes and Smiley is cited with the year of publication 19%. I guess this is just a reprint of the original work dating from 1968.
The paper of Holmes is referred to the year of publication 1983 in the reference list, but 1986 in the text (p.6, bottom line)
The reference Monteller & Tukey 1977 (p.11) is referred to as Mosteller & Tukey 1977 in the reference list
Reference Gordon et al.: The book "Climate from Tree Rings" edited by Hughes et al. was published 1982, not 1980

8. Overlap

Discussion: the authors mention the drought period in the 1920s. This was already found in some other tree-ring data and therefore some references should be added to the discussion:
Liang, E., Shao, X., Kong, Z., Lin, J. (2003): The extreme drought in the 1920s and its effect on tree growth deduced from tree ring analysis: a case study in North China Annals of Forest Sciences 60: 145-152

Liang, E., X. Shao and L. Huang, The tree-ring recorded drought in 20th 20s in middle and west China. Progress in Natural Science, 2004,4 (4) 469-474.

TREE-RING DERIVED PRECIPITATION RECORDS FROM INNER MONGOLIA, CHINA, 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 to 8.1 . In the area north of 30°N, ~~the~~ **northwesterly winds are** 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**~~ **changes** 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 **system** 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 **strongly varying** 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 its inter-seasonal and inter-annual variability, have been carried out. Recent studies indicate that the Asian Monsoon system is characterized by a high range of variability on 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 series reconstructed from tree rings in central Inner Mongolia. These reconstructions shed some light on the variations of the EASM during the past 350 years.

DATA AND METHODS

Sites Descriptions and Sampling

The two sampling sites, Wu Dangzhao (WD, 40°48′- 50′N and 110°18.5′-20.5′E), and La Madong (LM, 40°46′- 47N and 111°16′- 17.5′E) are located in the south facing slope of Yin Shan Mountains, at the northern margin of EASM (Figure 1). The elevation of the WD site ranges from 1500 m to 1800 m while the LM site ranges 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 and forms an important boundary between temperate grassland which is agriculture-pasture land and desert scrub used as 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 environmentally sensitive zone.

Because of both natural impacts (such as drought) and human activity (logging and fire) 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 also some Cupressaceae (*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 dates back to 1525 AD. Cores were collected in the summers 1997 and 2001 separately.

Fig. 2

Figure 2. The typical sampling condition in the La Madong site, most of trees we collected grow on rocky soils. 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 average rates of absent rings in the samples at WD and LM are 3.13% and 1.16%, respectively

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 trends, **which** are not related to climatic variation, were 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 by computing 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 the** WD and LM chronologies

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Table 1

Meteorological 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 since they are located nearest to the sampling sites and have no missing data. **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.html). 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 **variations**. **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 indicate 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 coefficient 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

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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 as a linear correlation before the rainfall increases to a great amount in a short time period (for example, more than 100 mm rainfall could fall in one day during monsoon-related flooding). In the spring and early summer when temperature rises, the trees need more water. Higher precipitation amounts, partly attribute to the frontal movement of the East Asia Monsoon, could cause a wide ring. On the contrary, 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.

PRECIPITATION 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:

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

$$\square N=29 \square r=0.666,\ R^2=44.3\%,\ R^2_{adj}=40\%,\ F=10.35\square$$

$$\text{standard error}=32.62,\ P<0.0001,\ t=4.20$$

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 data. 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 20th) 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 **reveal** 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 used **the powerful** bootstrap resampling approach (**Efron** 1979; Young 1994) **for verification tests**. **This** method is used **in cases when** 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). **After 50 time iterations of the bootstrap method we obtained** equivalent results with those of ***Jackknife*** method. Again, all values of r, R^2, $\mathbf{R^2_{adj}}$, 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 used 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 $\mathbf{R_{27E}}$ reconstructed data track the independent observation quite well **from** 1961 to 1990. Only the sign test S_1 (n= 21) does not reach the 99% confidence level (B= 23), but **still is significant** at the 95% level (A–21). Thus, the $\mathbf{R_{27E}}$ reconstruction **confidently contains useful paleoclimatic** information.

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

Table 4

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 as stated above, we here again use the 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:

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

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

$$\text{standard error}=43.56,\ P<0.0001,\ t= 5.9□$$

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 **given** 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 f~~or~~ **the** LM area for the period of 1600 (**SSS>0.75** from 1648) to 2001 (Figure 5b).

DISCUSSION

Comparison Between **Precipitation** Reconstructions and Historical Documents

Fortunately, historical documents on rainfall were available for an independent verification to test the reliability of our precipitation 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 **from** 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 a **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).

In another approach ~~is that~~ **we** ~~directly~~ **used** some local annals **from** 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 **for reasons stated above, for** many drought years which appear in the **reconstructions** no records are available in the historical documents.

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 possibility should be viewed with caution when using historical documents.

To make a better comparison we divided our precipitation reconstructions into five equally probable classes of precipitation-grades (P-grades), based on the standard described in Table 4 (Academy of Meteorological Science 1982). Percentages shown in the Table 4 displays that the fiequency of wet (LM: I + 2 grade=37.2%; WD: I + 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 of the LM sites d thus 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 fiom February to early July (or mid July) and documented drought years

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Table 7

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

We then calculated the correlation coefficients between the historical dryness/wetness (W/D) indices and precipitation grades (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 tree-ring derived Precipitation Reconstructions and ~~the Other Summer Monsoon Front Related Precipitation Reconstructions in North China and~~ [redacted] Dunde Ice Cap Accumulation series

The movement of the EASM front, to a certain degree, reflects periods of strong and weak intensities of the Asian Summer Monsoon in the past. Thus it is very important to determine whether our reconstructions presented in this paper contain regional or local climatic signals. Therefore we compared them to two other annually resolved precipitation reconstructions, which originate ~~come~~ from the environmentally sensitive ~~zone, in another words,~~ monsoon margin zone as well.

One is from the northern Helan Mountain (NHL), 400 km to the west of our study area. The ~~rainfall reconstruction,~~ May to July precipitation reconstruction from this site is based on ring-width indices of Chinese pine (*Pinus tabulaeformis*) ~~tree-ring index~~ and covers the period 1726 to 1997 (Liu et al. 2004). The other series is from Baiyinaobao (BYAB), 600 km east of LM in Inner Mongolia (Liu et al. 2003). The total precipitation from April to early July (July 10) in the growing season at this site was constructed using Picea koraiensis tree-ring width data.

Precipitation changes in the four study regions ~~over environmentally sensitive zone in~~ northern China are shown in Fig. 5. Many smaller-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). Extreme wet and dry ~~extreme~~ events correspond in many cases, like the severe droughts 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 indicates that the same climatic event, 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 awes 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** **rain belt**. 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 precipitation **reconstructions** are **all** based on the tree-ring data. **Therefore~~Beyond the tree-ring data,~~ we compared another high-resolution paleoclimate proxy record, i.e. the annual ice** 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 the Dunde annual ice accumulation and tree-ring precipitation reconstructions are very low and statistically 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 annual ice accumulation and tree-ring ~~precipitation~~ indices. However, there is the same trend within all four precipitation series.

The results demonstrate the existence of spatially coherent modes of the **EASM** precipitation variations in the LM, WD, Baiyinaobao, and northern Helan Mountains that 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 annual ice accumulation record from Dunde ice cap is not well suited for a comparison with our ~~eastern China~~ tree-ring reconstructions; since they seem ~~reflecting to~~ reflect the influence of different climatic circulation systems.

Decadal to Multi-Decadal Variations of Summer Precipitation Reconstructions

In order to ~~recognize~~ examine the climatic variations at decadal to multi-decadal time scales, the four reconstructed precipitation series and the dryness-wetness index were smoothed with a 10-year moving average (Figure 6). The dry and wet periods could be surveyed more clearly. The resulting long-term trends of the four tree-ring reconstructions vary almost synchronously, in spite of ~~some~~ low correlations between them (Table 8).

After ~~moving average~~ smoothing the original time series, the correlation coefficients between LM and WD and the dryness/wetness index become slightly higher than those comparing the original series, with, $r = 0.25$ for LM (N=369, $p<0.01$), and $r = 0.24$ for WD (N= 250, $p<0.01$). However during the 1860s–1870s the trends are controversy. LM and WD display relatively wet conditions, but ~~dry in~~ the dryness/wetness series indicates a dry period.

In general, ~~in this~~ at the margin of the EASM ~~the~~ periods of below normal precipitation occurred during the 1720s–1760s, 1790s, 1840s–1860s, 1890s– 1910s, 1920s–1930s and during 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 from the smooth precipitation reconstruction curves. Since 1880, the variation trends are quite similar to the precipitation variation in ortheast and orthwest China ~~found by Qian~~ (Qian and Zhu 2001).

Fig. 6

Figure 6. **Comparison of dryness/wetness indices at study sites 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 1970d~~, which followed the increase of the northern Hemisphere mean temperature.~~ ~~They,~~ Except Baiyinaobao, they display a ~~seem have a quite~~ similar trend as the Northern

Hemisphere **emperature** 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 **highest** precipitation in **the** WD **region during** 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** ~~**envi**~~ ~~**ntally sensitive**~~ **the semiarid** zone in north China **by using** ring indices ~~**over the past 400 years**~~. Using Chinese pine (*Pinus tabulaeformis*) ring-width data, rainfall **from** 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** ~~**from environmentally sensitive zone**~~, such as **from the** northern Helan Mountain and Baiyinaobao. Many smaller **scale** variations can be found in all annual resolution series. **The trees** we selected responded strongly and quite synchronously to this large-~cael ~~**climatic change**~~, **precipitation fluctuations,** such as severe drought in 1792,1839,1867,1900,1928–1929,1966 etc. This comparison also could indicate spatial and temporal ~~connection~~ patterns of spring to early summer rainfall variations along southwest to northeast gradient in the semi-arid zone of China.

Another striking feature is late 1920s severe drought event which is displayed in all smoothed curves. The late 1920s were 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.

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Figure Captions:

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.

Figure 2 The typical sampling condition in the La Madong site, most of trees we collected grow on rocky soils. 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 study 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 superimposed curves ~~overlapped~~ in (a) and (b) show the changing sample size ~~for each year~~.

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

Tables:

Table 1 Basis statistical characteristics of the WD and LM standard 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 trees	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**

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 Correlation coefficients between observed precipitation data 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 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) derived 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	$R_m + 0.33\sigma < R_t \leq R_m + 1.170$	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	$R_t \leq R_m - 1.170$	45	37	11.3	13.2

R_m is the precipitation mean, and σ is the standard deviation. R_t is the precipitation at *t* year. For LM February to mid-July precipitation, $R_m = 154$ mm and $\sigma = 31$ mm (1601 to 2001). For WD February to early-July precipitation, $R_m = 103$ mm, and $\sigma = 24$ mm (1720 to 2001).

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

Year	Wu Dangzhao		La Madong		
	WD Rconstructed rainfall (mm)	WD P-grade	LM Rconstructed 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 Hohhot for two years, wheat was as precious as pearls;
1878	74	5	158	3	
1883	100	3	169	2	severe drought in Baotou and Hohhot;

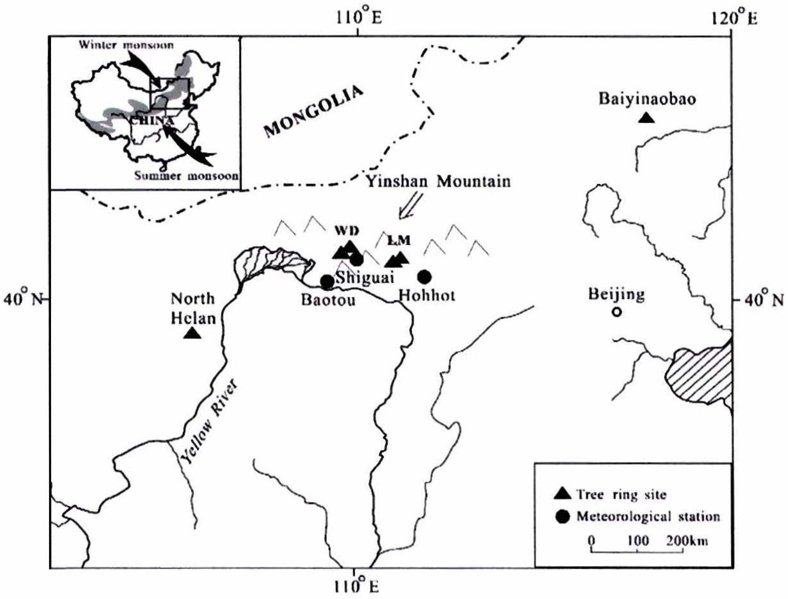
1891	55	5	93	5	severe drought in Baotou and Hohhot for several years, no rainfall, cannot plant, no harvest, nothing left in the food bank, countless people died;
1905	80	4	110	5	severe drought in Baotou;
1926	65	5	132	4	severe drought in Inner Mongolia on large scale
1928	53	5	86	5	severe drought in 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	4	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

Figures:

FIGURE 1



Figure

FIGURE 2

FIGURE 3

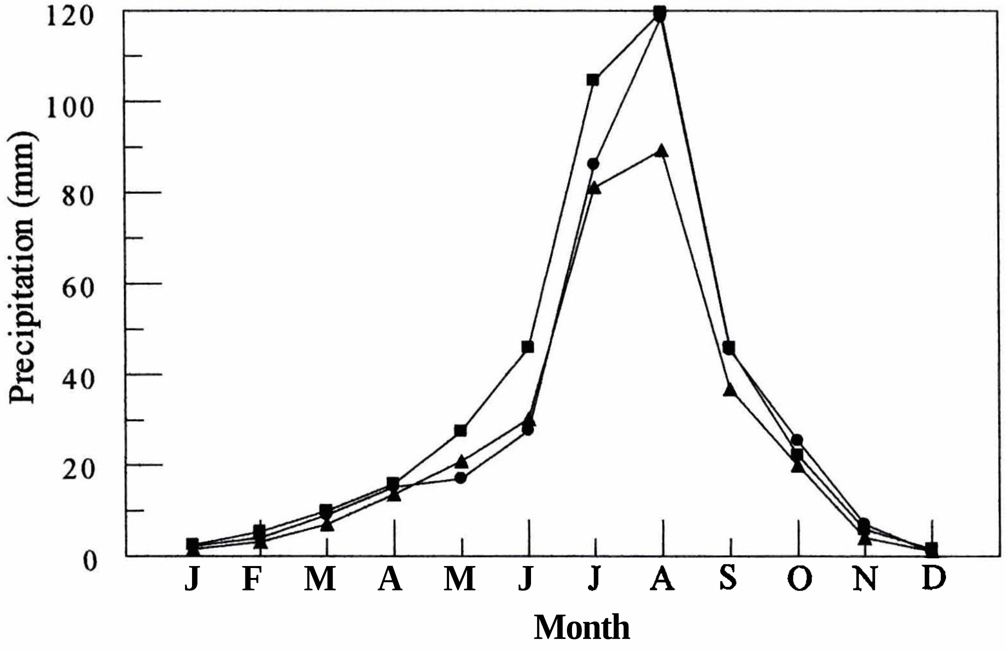


Figure 3

FIGURE 4

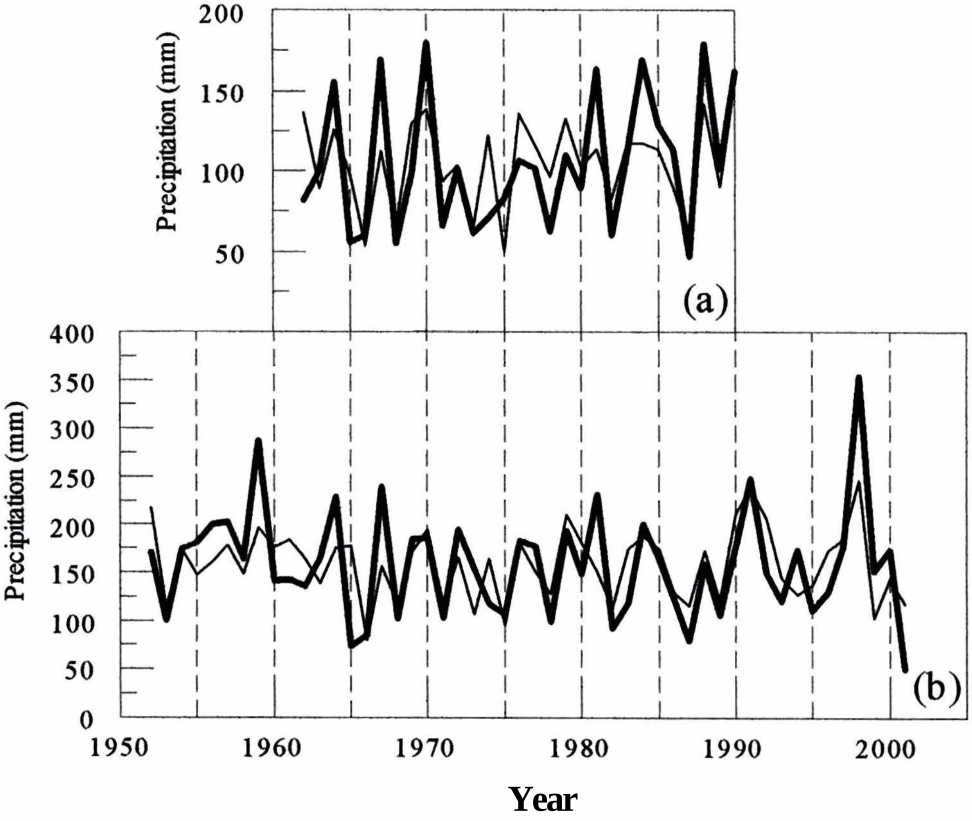


Figure 4

FIGURE 5

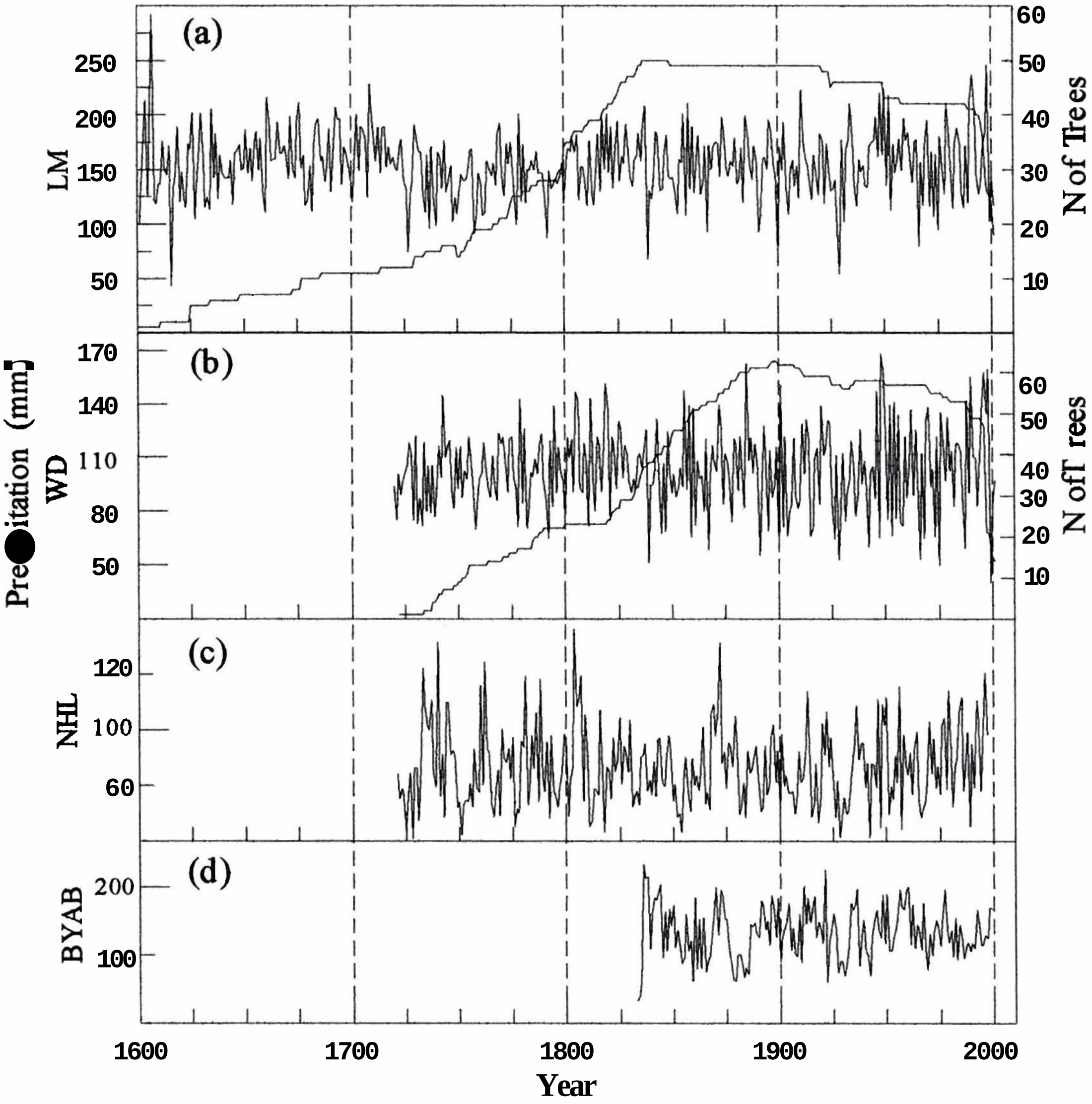


Figure 5

FIGURE *6*

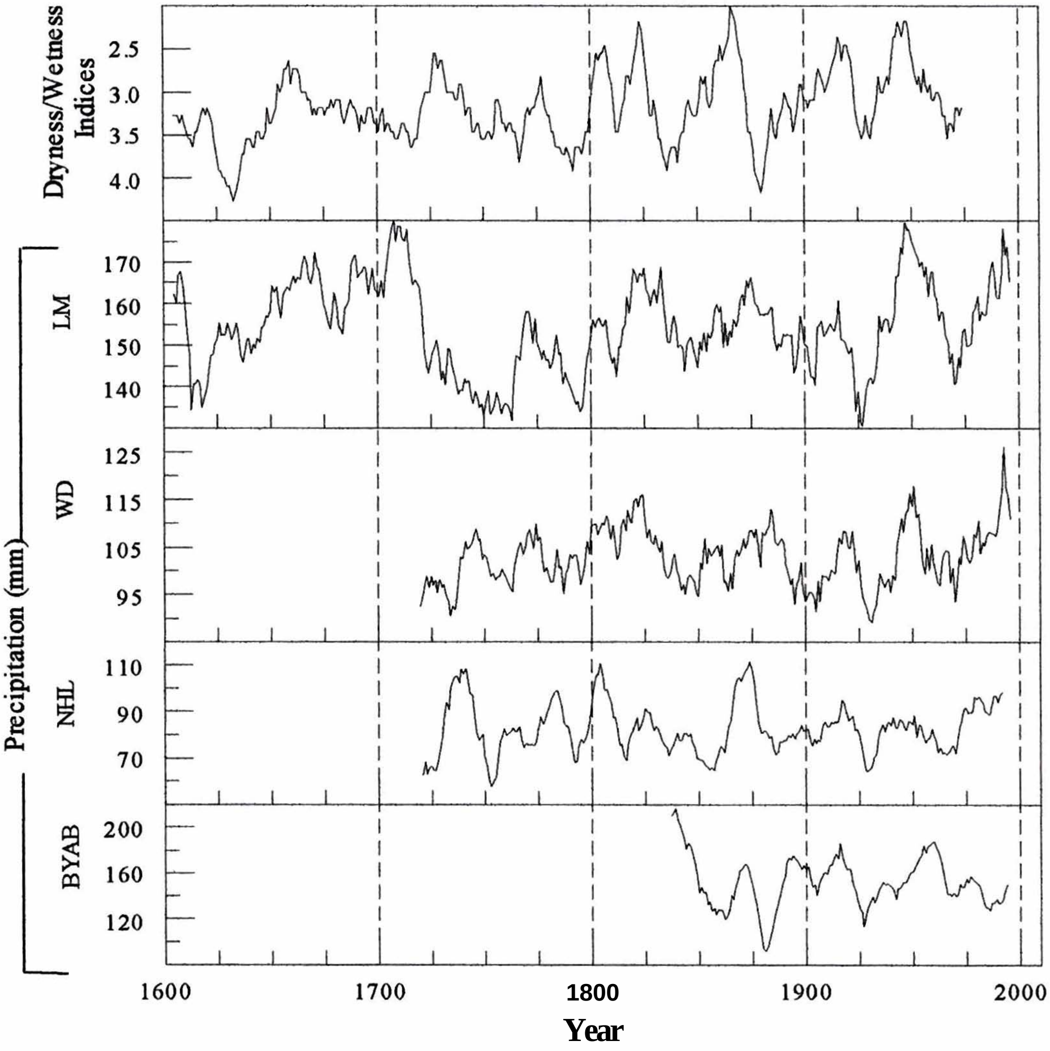


Figure 6