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Monsoonal Precipitation Variation in the East Asia: Tree-Ring Evidences from Korea and Inner Mongolia

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ABSTRACT

Three tree-ring monsoon rainfall reconstructions from China and Korea have been used in this paper to investigate the variation of the East Asian summer monsoon over the past 160 years. Statistically, there is no linear correlation on a year-by-year basis between Chinese and Korean monsoon rainfall, but region-wide synchronous variation on decadal-scale was observed. Strong monsoon intervals (more rainfall) were 1860-1890, 1910-1925,1940-1960, and weak monsoon periods (dry or even drought) were 1890-1910, 1925-1940, 1960-present. Reconstructions also display that the East Asian summer monsoon suddenly changed from strong into weak around mid-1920, and the East Asian summer monsoon keeps going weak after 1960.

Introduction

The apparent character of the East Asian climate is the monsoon system. It is well known that Asian monsoon system plays a crucial role in the global system. Asian summer monsoon can be divided into two parts, South Asian (Indian) monsoon and East Asian monsoon [Zhu et al., 1986; Tao and Chen, 1987; Ding 1994]. Numerous studies concerning Asian monsoon, including inter-seasonal and inter-annual variabilities, have been carried out. However, it was impossible to study climate change and annual variation in the long-time scale, since they were still lack of better long-term series which could be used to study East Asian summer monsoon[Shi et al., 1996].

The monsoon has profound influence on the social and economic conditions of Asia which possesses over 60% of the earth's population. In particular, the water resources in the East Asian countries depend largely on the precipitation during the summer monsoon season, for example, from June to late August in South Korea [Kim, 1985; Kim, 1998], and June to August in China [Xu, et al., 1983]. The summer monsoon rainfall over East Asia exhibits regional characteristics which are known by different names in different countries, such as *Mei-yu* in China and *Changma* in Korea [Ho and Kang, 1998]. Agriculture is traditional primary industry in the monsoon areas and the harvest is largely affected by rainfall. The monsoon system, therefore, is an important factor in East Asian countries. Unfortunately, frequent drought and flooding caused by monsoon precipitation result in loss of lives and tremendous property damages. Therefore it is very important to recognize the behavior of East Asian summer in the past and to predicate its variation in the future for these countries [Hahn, 1998].

Recent studies indicate that Asian monsoon system is characterized by the high rate of climate changes at all time scales. These changes are manifested by seasonal jump, high inter-annual and inter-decadal variability and abrupt changes between climate regimes [Fu and Zeng, 1997]

Korea and China are both impacted by the East Asian monsoon. By using traditional multivariate statistical calibration approaches and modeling, the variability of monsoon has been well studied by scientists from the both two countries using instrumental climate data [Ding, 1992; Kang et al, 1999]. After the start of GAME(GEWEX Asian Monsoon Experiment) in 1996, intensive field observations have been conducted in key regions in Asia along with long-term monitoring and modeling studies. However, only few works on the long-term variation of East Asian monsoon have appeared so far, due mainly to the scarcity or unavailability of datasets for longer time periods. There has been no comparison study on monsoon climate between these two countries in long-term basis. This paper will describe the monsoon precipitation variation since 1840 AD based on the tree-ring reconstructions from two countries. Annual dryness/wetness indices from Chinese historical documents, and the instrumental records from traditional Korean rain gauge(scientific rainfall measurement in the ancient time) will be employed to compare the tree-ring results.

Tree-ring and Historical Data

1. Tree-ring data

Three annually-resoluted monsoonal rainfall reconstructions, which were obtained from well replicated tree-ring chronologies in China and Korea, were used in this paper. Among of them, Baotou(BT) is from Inner Mongolia [Liu, et al., 2000], and Baekdam Jang (BJ) and Dae Sum (DS) from Korea peninsula [Park, et al, 2000]

BT site (40°50'N, 110°20.5'E, elevation 1500 m), near Baotou city in west-central Inner Mongolia, China, is in the farthest north-west margin of the East Asian Summer Monsoon. It is a very important Monsoon area and quite sensitive to the monsoon strength variation. Tree-ring reconstruction, from 1738 to 1996, represents June to early August(R_{68E}) monsoon precipitation, account for 32.60% of explained variances. This is the only monsoon precipitation reconstruction, longer than 250 years, available in China currently.

Other two sites are from Korea, east side of the East Asian monsoon areas. BJ(40°50'N, 110°20.5'E, elevation 400 m) is at Baekdamsan-jang Valley in the Mountain Sorak in north east of South Korea. Total rainfall from April to August (R_{48}) was reconstructed from ring index for the period of 1890 to 1997, with 41.5% explanation variance.

DS(40°50'N, 110°20.5'E, elevation 800-900 m) is at Daeseung Valley, 10 km of the north of BJ. Earlymonsoon, May to June (R_{56}) precipitation was reconstructed by tree ring for 1840 to 1997. The explanation variance is 42.6%.

2. Historical data

For better understanding the variation pattern of tree-ring reconstructions, Chinese regional dryness/wetness indices and Korean rain gauge data in this paper also are used to support tree-ring results.

Chinese dryness/wetness index is defined as: 1 wettest, 2 wet, 3 normal, 4 dry and 5 drought. These indices were derived from Chinese documentary sources [Academy of Meteorological Science *et al.*, 1981]

Korean rain gauge data: rain gauge was invented by Korean in the year of 1441. It is a very simple device, a copper-cylinder type rain collector and a ruler to measure rainwater depth in it [Hahn, 1998]. The precipitation amount by the traditional Korean rain gauge was recorded with the Korean foot-rule such as *Pun*, *Chi* and *Cha*, which approximately correspond to 2 mm, 20 mm and 200 mm, respectively. The original records were converted to modern ones in mm unit [Jung, 1999; Jung et al, 2000]. After 1907, it has been recorded with modern system.

Results

Correlation between China and Korea monsoon precipitation reconstructions

Statistically, Chinese and Korean monsoon rainfall reconstructions have no significant linear correlation at all in time on a year-by-year basis (Fig. 1). It seems that there is no correlation between west and east, in the large scale, inside the East Asian Summer Monsoon system. However, both Chinese and Korean tree-ring reconstructions reflect the features of regional climate variation, and they are verified by the following: the correspondence between the Chinese BT monsoon precipitation (R_{68E}) and historical dryness/wetness index back to 1738 is significant at the 95% level, with r=-0.27 (degree of freedom; n-1=257). Korean DS rainfall from May to June (back to 1840, d.f.=154) is significantly correlated to rain gauge data at 95% level as well, with r= 0.39. These correlations are much better after 10-year moving average described below. Two reconstructions from Korean are significant at 95% level, with r=0.26 (d.f.=104).

These indicate that both China and Korea regional climate changes, in particular the summer monsoon precipitation were recorded quite accurately in the tree-ring series. But from the Figure 1, we could observe that the inter-annual variability of precipitation

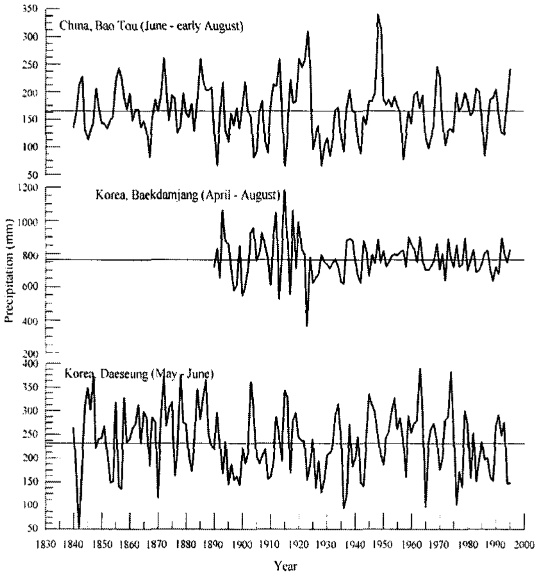

Fig. 1. Chinese (BT) and Korean (BJ and DS) monsoonal rainfall reconstructions

in China is much greater than that in Korea and which is relatively stationary. Because Baotou, a very important monsoon area in China, is in the farthest north-west margin of the East Asian summer monsoon, it has less precipitation, with 166.7 mm mean of June to early August (from 1738-1996). It is more sensitive in response strong or weak monsoon variation during June to early August. But inland western part is not only influenced by summer monsoon in which water comes from the Pacific Ocean, but also receives the moisture from the west, which provides different rainfall characteristics than the summer monsoon [Wang and Li, 1990].

Favorable comparison is observed after simply filtering the raw data with 10-year moving average. The decadal trends in the three reconstructed precipitation series are quite similar (Fig. 2), showing that there were the same wet and dry intervals between west and east sides of Asian monsoon region. The correlation between BT and DS is 0.43 from 1840 to1990, and even higher with 0.49 from 1890 to 1990. The correlations within three reconstructions are listed in Table 1. It presents a

Table 1. Correlation matrix for the tree-ring reconstructions and historical records and rain gauge data (correlation coefficients *r* and *p-values*) (data were smoothed by 10-year moving average, 1890-1990)

	BT	D/W	DS	BJ	RG56
BT	1.00				
D/W	-0.61, <0.0001	1.00			
DS	0.49, <0.001	-0.34, <0.023	1.00		
BJ	0.34, <0.021	-0.43, <0.001	0.64, <0.0001	1.00	
RG46	0.42, <0.0001	-0.38, <0.005	0.50, <0.0001	0.18, <1.000	1.000

· BT: Baotou tree-ring reconstruction from China, and BJ: Baekdam Jang and DS: Dae Sum from
· Korea. D/W: dryness/wetness indices in China and RG_{16}: ancient rain gauge data from Korea.

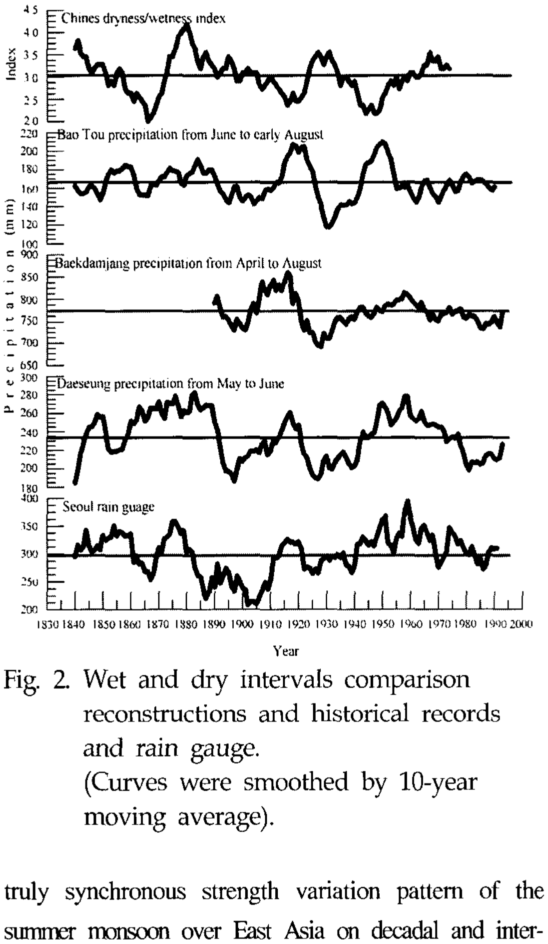

Fig. 2. Wet and dry intervals comparison reconstructions and historical records and rain gauge.
(Curves were smoothed by 10-year moving average).

truly synchronous strength variation pattern of the summer monsoon over East Asia on decadal and inter-decadal scales.

In Figure 2, both Chinese and Korean reconstructions display the large-scale precipitation patterns, with most notable increases from 1910 to 1920, and decreases during the period 1920-1940. These indicate the strong and weak periods of the East Asian summer monsoon, respectively. Quite anomalous drought events, e.g. four years severe drought starting from 1926 and ending in 1929 (extreme drought) in north China on large scale which were known from historical documentaries[Shaanxi Meteorological Station, 1976; Institute of Meteorology of Inner Mongolia, 1975], were illustrated in the curves as well. In 1929, it was no rain for spring and summer, nothing grew, and livestock were killed because of no food in BT region. This event also has been observed at other tree-ring sites, such as Hua Shan [Hughes et al., 1994] and Huangling [Liu, et al., 1996; Liu et al., 1997]. In Korea, the time series of rain gauge data also show a relatively dry interval around 19201940, although it is not distinguished as strong as the tree-ring reconstructions. It is notable that there is extremely dry period around 1880-1910, which is also appeared in the time series of annual rain gauge data (Jung, 1999, Jung et al., 2000).

Three reconstructions from different sites are quite synchronously reflecting that the East Asian summer monsoon suddenly varied from strong into weak around 1925. This notable abrupt climate change, characterized precipitation decrease obviously from the peak of 309.55 mm of 1923 and 241.97 of 1924 to 96.06 of 1925 in Baotou China, has been noted elsewhere, and meanwhile the Indian Monsoon apparently increased

[Fu, and Zeng, 1997]. However, in Korea the change was little earlier, around 1920, and not so sharply, although two curves display the same trend.

All tree-ring reconstructions show that the variation patterns of the East Asian summer monsoon during the past 160 years as follows:

Strong monsoon intervals(more rainfall): 1860-1890, 1910-1925,1940-1960.

Weak monsoon periods (dry or even drought, shaded): 1890-1910, 1925-1940, 1960-present.

It is worthwhile to note that 1925 to 1942 is the weakest period of summer monsoon during the last 160 years. Meanwhile the mean precipitation in BT, China was 127.18 mm (1738-1995 mean is 166.17 mm), 730.13 mm in BJ (1890 to 1995 mean is 772.25 mm) and 200.81 mm DS (1840 to 1995 mean is 234.75 mm) in Korea.

During 1960 (in China after 1955) to present, the East Asian summer monsoon keep going weak, and it is more pronounced in Korea. It is known that the variation of Mei-yu in eastern China is closely linked to that of the summer monsoon in the South China Sea. Fu and Fletcher (1988) showed that the accumulated curves of the zonal wind component of the monsoon over the South China Sea increased since 1958. This implies dry monsoon after 1958.

By analyzing the observed data from 135 meteorological stations in northwest China, it was found that precipitation in semi-arid regions of China displays a decreasing trend during the last 40 years, particularly in northwest China [Xu, et al., 1997]. This again demonstrates our tree-ring results. The interesting thing is that the maximum precipitation decreasing was observed in Sahara and the Middle East for the same time period[Hulme et al., 1992]. Some relationships may exist between the north East Asian monsoon region and Sahara and Middle East.

In China BT, tree-ring monsoon precipitation(R_{68E}) shows 12.63-, 7.5-, 5.11- to 5.22-, 4.53- to 4.62- and 3.16- to 3.53-yr (p<0.05) cycles [Liu, et al., 2000]. In Korea, BJ displays 4.14- and 3.16-yr (p<0.05) cycles, and 3.18- and 3.12-yr for DS. Among of them, quasi-3-year cycle is common. This periodicity, actually, is an important one in semi-arid region in west China, and it also was found both in the modern observation and historical dryness/wetness indices [Xu, et al., 1997].

Conclusions

Three valuable tree-ring monsoon rainfall reconstructions have been used in this paper to investigate the variation of the East Asian summer monsoon over the past 160 years. The results show a region-wide, between western and eastern inside of the East Asian summer monsoon system, similar variation on decadal and inter-decadal scale. Three reconstructions are quite synchronously reflecting that the EASM suddenly shifted from strong into weak around 1925. The East Asian summer monsoon keep going weak after 1960, and it is more pronounced in Korea.

A principal difference between major droughts of the twentieth century and those of the more distant past is the duration, which is an order of seasons to years compared to decade to centuries [*Woodhouse and Overpeck*, 1998]. The reconstructions in this study are advantageous for the study of natural modes of climate variability and extremely important for examining the full range of past drought variability in magnitude and duration.

In order to better understanding of past climate variability for the whole East Asia, more samples are needed from other sites, for example, west and east of China, Southern Korea and Japan to extend the length of the reconstructions.

Nevertheless, the evidence for a plausible large-scale monsoon influence on the East Asia has implications for monsoon precipitation forecasting.

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