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Application of Historical Documentary Records in Reconstruction of the Palaeo-Climate Series in China

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ABSTRACT

Techniques used in reconstruction of the paleo-climate series in China are reviewed. Seasonal and annual mean temperature series have been obtained on the basis of documentary data sources, with decadal resolution for the last 500 years and 50-year resolution for the last millennium. Concerning the precipitation, only the summer rainfall pattern was estimated year by year from 950 AD to the present. Six types of pattern were identified, then changes in the frequency of the types were studied. Finally, general characteristics of climatic change in China for the last millennium are described.

(Key words: Historical records, Paleoclimate, Droughts, Floods, China)

1. INTRODUCTION

Extension of the palaeo-climate series to one thousand years ago has special meaning in studying climate change, for the last millennium included both a colder period than nowadays, the so-called "Little Ice Age" (LIA, 1550-1850 A.D.), and a period warmer than (or at least equal to) the present day, the "Medieval Warm Period" (MWP, 900-1300 A.D.). Anthropogenic effects seem negligible or nearly negligible before 1850 A.D., so climate change in the first 850 years or so of the last millennium could be attributed to the natural variability of the climate. It provides a unique sample of data available for studying the influence of natural forcing on the climate. Understanding of the natural variability of the climate and the impact of the external forcing on the climate will facilitate the detection of the greenhouse effect at the present time, and the prediction of possible climate change in the next century.

Tree-ring and ice core data were extensively used in reconstruction of palaeo-climate series around the world (Crowley and North 1991, Bradley and Jones 1992). Research has also been carried out for the western territory of China (Thompson 1992, Wu 1992). But studies on climate change in East China have long been based on documentary records (Chu 1973, Zhang 1980, Gong *et al.* 1983), for no ice core can be used in this area and old trees are rarely found. However, three problems of the technique used in the reconstruction of

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paleo-climate need to be clarified; calibration of the documentary records; assimilation with the modern observations, and homogeneity of series. For example, documentary records show sometimes only the occurrence of weather phenomena such as frost and the related phenological phenomena or damage to the crop. How can one use them to identify the climate anomaly? The drought or flood as a climate phenomena indicated the deficiency or excess of rainfall. But, how can one transform them to rainfall anomalies? Documentary records are not necessarily consistent throughout the millennium. In particular, records concerning temperature are available only for about 40% of the years examined. How then can one reconstruct a consistent and homogeneous palaeo-climate series? In this paper, these problems are discussed as an example to show the approach in reconstruction of palaeoclimate series in China. Preliminary results of the reconstruction of annual temperature and summer rainfall series of the last millennium in China are given.

2. APPROACH TO THE RECONSTRUCTION OF THE PALAEO-CLIMATE SERIES

Firstly, the relationship between the date of the first frost or last frost and the seasonal mean temperatures (based on the observational data for 1951-1980) was examined. It was found that a delay or lead of ten days of the first frost compared to the normal (average of 1951-1980) corresponds to an autumn temperature anomaly of +0.4°C or -0.4°C (from the average of 1951-1980) for North China (110-120°E, 35-40°N). A lead or delay of ten days in the last frost corresponds to a +0.5°C or -0.5°C spring temperature anomaly. The linear regression coefficient varies from station to station and from autumn to spring. The figures outlined above are the average for the region and rounded to one decimal place.

Secondly, the first or last frost date from documentary records was compared to the normal used above, and the deviation of the date was transformed into a temperature anomaly according to the ratio shown above. However, a correlation coefficient of 0.4 to 0.5 (which was usually found between the date of frost and the temperature) explains only about 20% of the temperature variance. Therefore, documentary records only allow one to make a rough estimate of the temperature anomaly, but not to give an accurate value of the anomaly. Consequently, a severity index rather than temperature anomaly was derived from the documentary records. Then, severity index records were used in reconstruction of the decade mean seasonal temperature series (Wang 1991).

The classification of drought/flood records was used here to illustrate the assimilation of the documentary records with the modern observations. In the section of the disasters in a local gazetteer usually drought, severe drought, flood, and severe flood were recorded. But, what does the term drought or flood mean? Is it possible to find a quantitative estimation of rainfall anomaly for droughts or floods? Studies show that it can be done by considering the occurrence frequency of drought or flood. The following classification of summer rainfall anomaly by the occurrence frequency has long been applied in long range weather forecasting studies in China (Table 1). Experience indicated that the classification by occurrence frequency is nearly equal to that by the percentage of rainfall anomaly, which was often used in climatological studies. Thus, documentary records of drought or flood were classified into five grades for key stations according to the occurrence frequency, considering the severity and geographical coverage of the events. One key station usually consisted of 10 to 15 counties in which the climatic characteristics were almost identical. There are 5 to 6 key stations in one province. All together 120 key station series were reconstructed. For the limitation of the space, definition of the drought and flood by documentary data sources has been omitted.

However, the reconstructed summer rainfall anomaly closely correlates with observations for the period when both documentary data and observational data are available. (Wang *et al.*, 1981). This proves the rationality of calibration. Once the drought/flood grades were identified for historical time, the grade series was joined together with the grades estimated according to Table 1. This kind of assimilation ensures homogeneity of the series, for the occurrence frequency of the grade was considered in definition of the grade by documentary records, and it was almost identical to that for the recent period in which the grades were identified according to the rainfall anomalies. Finally, drought/flood maps were drawn for 1470-1979 A.D. (MSRI 1981) and these provide a good basis for studies of climate change in China.

Table 1: Definition of summer drought/flood grades.

grades	drought/flood	percentage total rainfall anomaly	occurrence of the grade
1	severe flood	≥50%	12.5%
2	flood	≥25%,<50%	25.0%
3	normal	≥-25%,<25%	25.0%
4	drought	≥-50%,-25%	25.0%
5	severe drought	≤-50%	12.5%

Another problem often encountered in the application of historical documents concerns the consistency and homogeneity of the records. Documentary records were never consistent. The gazetteers were issued for each of the counties. In a volume of the gazetteer, usually relevant records are available only for about 30% to 40% of the years covered by the gazetteer. The availability of the records of a key station, which consisted of 10 to 15 counties, increased to about 60% to 70% of the years examined. Gaps in the other 30-40% of the years are either interpolated from the grades of neighboring stations (about 5%) or treated as normal conditions (grade 3). The drought/flood grades were estimated according to the predominance of drought or flood in the area of a key station. Therefore, the classification of the records of drought and flood ensured success in the compilation of the drought/flood map series. However, the available documentary records concerning temperature make up only about 10% (or less) for a county. The availability of records increased only to 40% for a region, which consists of 20 to 25 key stations (Table 2). It seems a maximum synthesis of original data for a region consists about 200 to 250 counties. Eighty percent of the available documentary records concerned cold events. The other 20% of the records deal with the extremely warm events. Generally, no ordinary warm events were recorded for they were not important to the crop yields and daily living. Of course, one should not regard all of the gaps (which make up 60% of the total years) as having been normal. Obviously, a lot of warm (but not extremely warm) events were included in that 60% of the years, but one cannot assess which were the normal or the ordinary warm events. In this case, cold events were classified into four grades, which correspond to -1.0°C, -1.5°C, -2.0°C, and -3.0°C or lower, seasonal temperature anomalies. They were denoted as -0.5, -1.0,-2.0, and -3.0 in terms of a "severity index." The severity index was integrated for each of the decades. Statistics show that -1.0 of the integrated severity index corresponds to -0.2°C of the decade mean seasonal temperature anomaly. This ratio varies between -0.15°C to -0.25°C with seasons and regions. So, the average ratio of -0.2°C was accepted and used in reconstruction of seasonal temperature series of East (115-123°E, 27-33°N) China from the 1380's to the 1980's. Of course, there is still a lot of work to be done in the analysis of the documentary records. In this paper, only some possibilities are shown, but this by no means provides a comprehensive description of all potential applications.

Table 2. Documentary records used in reconstruction of paleo-climate in China.

climate element	Number of key stations	Number of counties	Number of items of documentary records
summer rainfall	120	1,500	90,000
seasonal temperature in North China	20	200	2,500
seasonal temperature in East China	25	250	3,000

3. CLIMATE CHANGE IN CHINA DURING THE LAST MILLENNIUM

A decade mean annual temperature anomaly series was reconstructed for East and North China from the 1380's to the 1980's. Anomalies were the departures from the normal of the 1880's-1970's. Three cold periods (I, II, III) were identified; each of them consists of two cold phases (1,2). The average temperature anomaly and the number of coldest decades in each cold phase is given in Table 3. The numerators in Table 3 show the numbers of decades with -0.5°C or lower temperature anomaly. The denominators give the numbers of decades of the phase. The figures for the twentieth century warm period (1920's-1940's) are shown too in Table 3 for comparison. The total number of the coldest decades from the 1380's to the 1980's was 16 and 14 for East and North China, that is 26.2% and 23.0% respectively. Only two of the coldest decades did not occur in the cold period. The first of the three cold periods was weak, especially phase I2 in North China. Mean temperature anomalies averaged by phase vary from -0.3°C to -0.6°C. It suggests that temperature anomalies averaged for 30 years or more had increased more than 1.0°C from the coldest phase (II2) to the warm period in twentieth century in China. The generally acknowledged LIA (1550-1850) is more or less synchronous with the II and III cold periods in China.

Table 3. Annual temperature anomalies from the 1880–1970 mean and numbers of coldest decades in cold phases of the Little Ice Age and in the warm period of the twentieth century.

period		East China		North China	
		temperature anomaly	number of coldest decades	temperature anomaly	number of coldest decades
I1	1450's-1470's	-0.30°C	1/3	-0.29°C	1/3
I2	1490's-1510's	-0.60°C	2/3	-0.05°C	0/3
II1	1560's-1600's	-0.47°C	2/5	-0.47°C	3/5
II2	1620's-1690's	-0.57°C	5/8	-0.63°C	6/8
III1	1790's-1810's	-0.41°C	0/3	-0.45°C	1/3
III2	1830's-1890's	-0.57°C	4/7	-0.32°C	1/7
	1920's-1940's	0.43°C	0/3	0.49°C	0/3

Table 4. Number of extremely cold and extremely warm seasons in China, by century.

century	winter		summer	
	extremely cold	extremely warm	extremely cold	extremely warm
9	5	4	3	4
10	3	10	3	5
11	6	6	5	5
12	13	8	7	7
13	4	6	7	6
14	11	6	9	9
15	10	7	8	5
16	18	12	11	3
17	19	8	17	5
18	13	5	7	6
19	21	7	6	2
20	5	9	3	8
mean	10.7	7.3	7.2	5.4

Before 1380 A.D., there were not enough documentary records to reconstruct the decade mean temperature series. An estimation was made for the century means. East and North China was combined into one region, because EOF analysis of seasonal temperature anomalies showed the predominance of identical character of temperature changes in these two regions. Extremely cold or extremely warm events were considered, for only this kind of record are available in the early time (Table 4). Only summer (June to August) and winter (December to February) seasons were examined. Close correlation was found between the numbers of the extremely cold and extremely warm seasons in each century and the century mean temperature anomalies, by using the reconstructed decade mean temperature anomalies from the 1380's to the 1980's. Then, century mean temperature anomalies were reconstructed from A.D. 800 to 1990. Anomalies are referred to the normal of the 1880's-1970's. The last century consisted of 90 years, in which observational data were used. The number of stations used in estimation of the average temperature from the 1880's-1970's varied from four in the 1880's to 160 in the 1980's. However, the numbers increased to about 60 in the 1920's. It was the maximum number of stations which could be used in calculation of the average. Figure 1 shows 100 year anomalies of 50 year overlapping intervals. The year indicated on the abscissa shows the middle of 100 years, for example 1900 means the average for the period 1850-1949 A.D., 1850 the average of 1800-1899 A.D., etc. The anomalies which are significant at a 95% confidence interval (t-test) were cross-shaded or shaded. Winter temperatures were higher than the normal from A.D. 800 to 1100 A.D. and form A.D. 1200 to 1350. Summer temperatures were higher than the normal from A.D. 900 to 1050 and from A.D. 1150 to 1250. Therefore, the MWP in China may have consisted of two warm periods; A.D. 900-1050 and A.D. 1150-1300.

Next, drought/flood type variations were examined in relation to the MWP and the LIA. Six types have been identified (Table 5) based on the 500 year drought/flood map series (Wang and Zhao 1981). Then, the drought/flood type chronology was extended to A.D. 950 (Wang *et al.* 1987). As mentioned above, type 1a, 1b, and 2 are characterized by floods anywhere in central and south China, and type 4 and 5 indicate droughts in that area. Therefore, an increase (decrease) in the frequency of type 1a, 1b, and 2, and a decrease (increase) of the

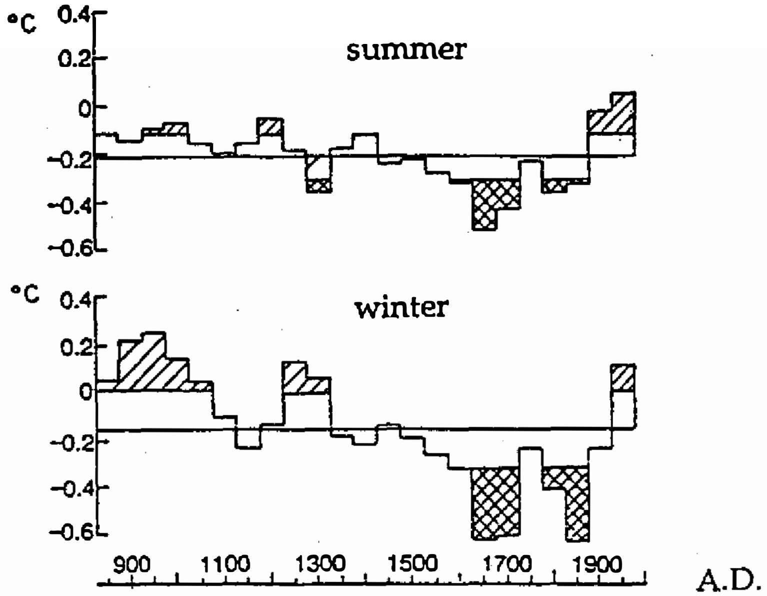

Fig. 1. Century mean temperature anomalies in China since A.D. 800, expressed as departures from the normal of the 1880's-1970's.

frequency of type 4 and 5 indicates the prevalence of floods (droughts). Figure 2 shows the frequency of types (4+5) and types (1a+1b+2), and the difference between them for each century period. The droughts in the first half of 12th century and in the 20th century, and the floods in the second half of 15th and second half of 16th century are prominent. Two periods of three hundred years were compared to study the climate change in summer wetness from the LIA to the MWP. Table 6 shows that the floods (type 1a) predominated in the LIA, but drought (type 5) increased in the MWP. The frequency of type 2 was also higher in the MWP. It is of interest to note that the frequency of type 5 (and type 2 also) increased in the warm period in twentieth century. Eight years with type 5 and nine years with type 2 make 26.6% and 30.0% of the thirty years from 1920's to 1940's. It is much greater than the long-term normal frequency of 10.5% and 22.5% respectively.

Table 5. Characters of droughts and floods by types.

type	characters of droughts and floods
1a	floods over the whole east China, but mainly in the Changjiang and Huai Rivers
1b	floods in the Changjiang and Huai rivers, droughts to the north and south of then
2	floods in the south and droughts in the north China
3	droughts in the Changjiang and Huai rivers, floods to the north and south of them
4	floods in the north and droughts in the south China
5	droughts predominate the whole east China

Table 6. Frequency of drought/flood types during the Medieval Warm Period (MWP) and the Little Ice Age (LIA).

period	1a	1b	2	3	4	5	total
MWP(A.D. 950-1249)	39	46	73	56	50	36	300
LIA(A.D. 1550-1849)	57	48	61	56	51	27	300

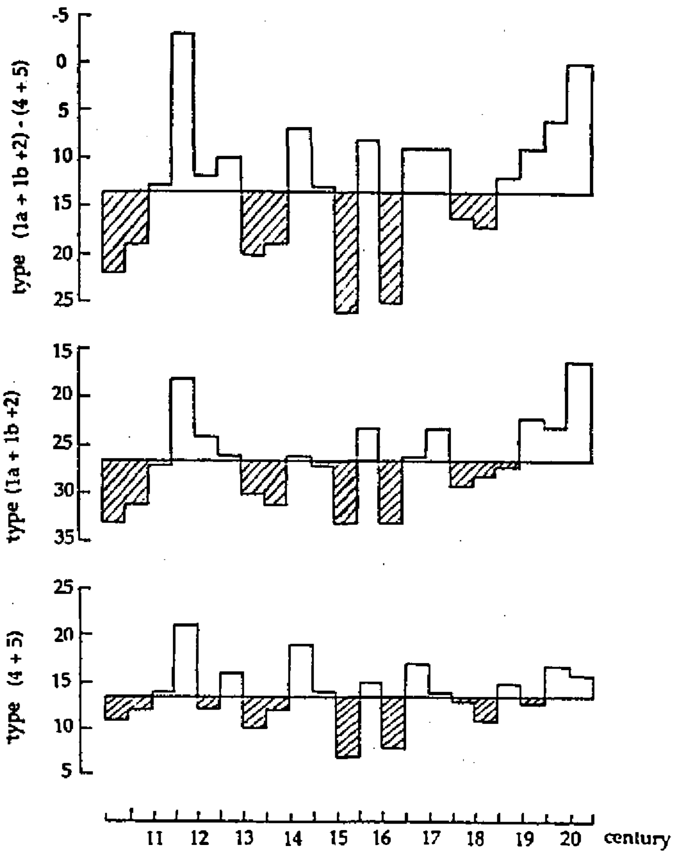

Fig. 2. Frequency of drought/flood types in each half century since A.D. 950; horizontal lines show the average for the last millennium. Lower panel shows the frequency of types 4 & 5 (see Table 5). Middle panel shows the frequency of types 1a, 1b, and 2. Upper panel shows the difference in frequency of (types 1a, 1b, and 2) and (types 4 and 5).

4. SOME IMPLICATIONS FOR THE GREENHOUSE EFFECT

The 0.5°C of warming on the global scale since A.D. 1850 is often attributed to the greenhouse effect (Houghton *et al.* 1992). However, paleo-temperature series of China indicate that the summer temperature in the MWP was, maybe, as high as in the 20th century, and that in the LIA it was much colder than the 20th century. It indicates that the natural change of climate has a greater amplitude than the 20th century warming. Meanwhile, the latter has begun from a cold period of the LIA. Therefore, one can hardly attribute the modern warming only to the greenhouse effect. On the other hand, the local climate characteristics of the warming scenario in the next century remains ambiguous in many aspects (Wang *et al.* 1992). Studies on the impact of greenhouse gases other than CO2 on the climate show different patterns of warming (Wang *et al.* 1991). The general ability of the simulation to predict the local climate remains relatively low. Therefore, care must be taken in estimating the possible warming in the future in a local area as in China. Great complexity was encountered when the possible rainfall change in a warm scenario was examined. No significant difference was found in the frequency of types 1b, 2, 3, and 4 between the MWP and LIA. The only thing one can mention was the greater (lower) frequency of type 1a (type 5) in the MWP than in the LIA. Recently, simulations showed that the summer rainfall will increase in South China when the greenhouse gases are doubled whereas North China will suffer from drought. This is at least partly in accordance with the climate change in the MWP and in the warm period of the twentieth century. Of course, more research should be done, before a robust conclusion can be made.

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