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Historical change

Climatic jumps in the flood/drought historical chronology of central China*

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Abstract. Statistical series of flood/drought (F/D) grades and F/D variabilities were derived for the flood and drought chronology (2700 BC–1980 AD) of central China. Two types of climatic jumps were analyzed. The moving sign-test, T-test and F-test were applied to detect jump signals. A few wet-to-dry jumps for time-scales from decades to thousand years were compared with relevant climatic changes in other regions of the world. Changes in the annual rainfall due to jumps were estimated. Some F/D-deficient-to-F/D-frequent jumps were also found and their significance is discussed.

Introduction

The term "climatic jump" has been employed in climatological analysis in recent years. In this paper, climatic jump is defined simply as a transition during a relatively short period between two climatic regimes persisting relatively longer. In climatological statistics, the climatic jump may be recognized as a significant difference of some statistical characteristics between two successive subseries of one climate series. Specifically, a type I jump is defined as a significant difference in mean value between two subseries and a type II jump is defined as a significant difference of variance between two subseries. Other types of climatic jumps can also be defined if other statistical characteristics, e.g., periodicities in a series, are examined. In a studied series, different types of jumps may not occur simultaneously. For convenience, the time-scale of climatic jump is defined as the length of the subseries used in defining the jump. The points described here were discussed in a few earlier papers (Goossens and Berger 1987; Maasch 1988; Fu and Wang 1991; Ye and Yan 1990).

In fact, people have long noted jump phenomena, such as those during the seasonal transitions (Zhu 1934; Yeh et al. 1959; Zeng et al. 1988) and those during the glacial-interglacial cycles (Morner 1984; An and Liu 1987; Maasch 1988). Recently, with developments and applications of the nonlinear theories and numerical modelling (Lorenz 1968, 1976; Charney and DeVore 1979; Saltzman and Sutera 1987; Zeng et al. 1988), research on climatic jumps received closer attention (Yamamoto et al. 1986; Berger and Labeyrie 1987; Yan et al. 1990). Importantly, more attention was given to jump phenomena on time-scales from decades to centuries. These are time-scales of changes which currently cause global concern and which form the focus of the present paper.

A few papers, most of which were based on instrumental observations, revealed the possibility of decade-scale climatic jump on regional or much larger spatial-scale (Yamamoto et al. 1986; Yan 1991). However, the temporal coverage of the modern observations (~ 100 years) is not long enough to reproduce more rigorous evidence of climatic jumps. How frequently can they occur? How large are their induced changes? Do changes occur independently in some regions as suggested by Hunt and Gordon (1988) or affect much larger areas as in some cases (Fu and Fletcher 1988; Yan 1991)? These questions remain open. Investigations of climatic jumps for the recent past are necessary to provide access to means of jump analyses. The present paper analyses possible decade- and century-scale climatic jumps in the history of central China, to correlate timings to estimate the rates of change and compare results with the other regional events worldwide.

China has a long history with abundant documents, which serve to reconstruct historical climate and environmental changes. Compared with natural archives such as tree-rings and various sediments, historical documents can more directly reflect the climatic changes (Pfister 1984; Zhang 1980). The next section introduces a method of climate reconstruction from historical doc-

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uments. The third section describes methods of jump detection, followed by some results and discussion.

Data basis

Brief overview of central China and the disaster chronology

Central China is an area of almost 300000 km^2 centered in Henan Province, about 34° N and 113° E. It is a humid region with an annual precipitation of about 750 mm/year, in the southeast characterized by pluvial-summer monsoon and the northwest region is characterized as an inland dry area. Such a transitional region may be sensitive to large-scale climatic change.

Central China spreads across the middle to lower reach of the Yellow river, which is known as the cradle of ancient Chinese culture. Many early dynasties founded capitals and cities within central China. Therefore, there remain a great number of historical documents, relics, local chronicles, inscriptions, ballads, and personal diaries, which provide descriptions of the historical climatic events such as floods and droughts. Table 1 gives some examples of literary records of climatic events.

After selecting the literary records with fidelity proven by cross-correlations with different documents or archaeological evidence, one of the co-authors (Wang) and his collaborators set up a huge data base chronology of disasters in the history of central China (Wang et al. 1981, internal communication). This chronology provides the basis for our reconstruction using a group of digital series. We noted that the records of floods and droughts became more frequent in younger documents. Therefore, we remain cautious in our assessment of results dealing with the earlier data-poor period, particularly prior to the Warring States period (about 475–221 BC).

Table 1. Examples of records of climatic events in central China from literature

2205–2201 BC	Five years of serious floods occured successively in Yu's time. Yu called on his people to pile up earth and wood or to take to the hills to survive.
159 AD	Incessant rain for 50 days led to serious floods in summer.
309 AD	Extremely serious drought caused all the rivers to dry up.
1482 AD	Unprecedented flood ... More than 300000 houses were devastated and more than 11800 people were drowned in Huaiqing and some other regions.

Table 2. Meteorological conditions implied in the literary descriptions and the observation-based estimation of the range of yearly rainfall departure (D) for each grade in the traditional grade system for central China. ([a] from Academy of Meteorological Sciences 1981)

Grade	Implied meteorological conditions[a]	D range
1 serious flood	Heavy rainfall for more than two seasons or almost incessant heavy rainfall for summer that always causes serious disasters such as river-breaks.	150 mm/y or more
2 flood	Heavy rainfall for a single season that may cause local crop failures.	50 to 150 mm/y
3 normal	Few records of flood and drought are found and/or an abundant harvest year is recorded or implied.	−50 to 50 mm/y
4 drought	Rainless for a few months or a single season other than summer that may cause local crop failures.	−150 to −50 mm/y
5 serious drought	Rainless for more than two seasons or throughout the summer that always causes wide-spread agricultural failures.	−150 mm/y or less

Series of F/D-grade and F/D-variability

In China, a five-grade system has long been adopted to reconstruct historical rainfall change (Academy of Meteorological Sciences 1981). In this traditional system, the literal descriptions of climate in historical documents are graded into five categories. The literary descriptions for a given grade may vary from one year to an other. But the implied meteorological conditions are more stable (Table 2). The relationships between the grade and the observational rainfall (in millimeters per year) is designed as:

$$\begin{aligned}
&\text{Grade 1:} && D > a \times S\\
&\text{Grade 2:} && b \times S < D < a \times S\\
&\text{Grade 3:} && -b \times S < D < b \times S\\
&\text{Grade 4:} && -a \times S < D < -b \times S\\
&\text{Grade 5:} && D < -a \times S,
\end{aligned}$$

where D is the observational rainfall departure of one year to the climatological mean; S is the standard deviation of the observation series; and a and b are positive coefficients. The coefficients a and b are chosen so that the frequency of occurrence of each grade during the observation period is approximately equal to that during the whole period concerned. According to the Academy of Meteorological Sciences (1981), the proper values of a and b for China are 1.17 and 0.33, respectively. Table 2 presents the D range for each grade for central China.

Applying the traditional five-grade system, we reconstructed the grade series of 1470–1949 AD for central China as a basis for analysing the decade-scale jumps during the last ca. 500 years.

For earlier times, the literary records of climate are so scarce that it is difficult to reconstruct the climate conditions year by year. Therefore, we designed a new grade-system for estimating mean rainfall conditions of multi-year periods (rather than a year). Dividing the history into a series of periods of equal length (N

years), the Flood/Drought-grade (F/D-grade) of one N-year period is defined as G,

$$G = \begin{cases} -1 & R > \frac{7}{3} \\ 0 \quad \text{if} & \frac{4}{6} < R < \frac{6}{4} \\ 1 & R < \frac{3}{7} \end{cases} \qquad (1)$$

where $R = N_d/N_f$, N_d is the number of years of serious drought in N-year period, N_f is the number of years of serious flood in the N-year period. In order to use as much as possible the information in the historical documents, our definition of the serious disaster is less strict in (1) than that in the traditional grade system. That means some of the cases that are classified into grade 2 and grade 4 in Table 2 may be considered as serious disasters in (1). For example, a year during which some wide-spread drought (or flood) occurs in a single season while few improving conditions occur in the other seasons will be considered a year of serious disaster, though it may be defined as grade 4 (or 2) in the traditional system.

For the period when $6/4 < R < 7/3$, we define $G = -1/2$ if $R' > 6/4$, or $G = 0$ if not. And for the period when $3/7 < R < 4/6$, we define $G = 1/2$ if $R' < 4/6$, or $G = 0$ if not. R' is the ratio of N'_d/N'_f, where N'_d is the number of years of extremely serious drought in the N-year period and N'_f is the number of years of extremely serious flood in the N-year period. The extremely serious floods (or droughts) stand for those serious disasters (Table 2) that are widespread over the whole region of central China and persist almost all the year round. According to Wang and Wang (1987), the frequency of occurrence of the extremely serious flood (or drought) in the history of central China is nearly 4% and its D value is double more (or less) than the criterion value for the serious disaster (Table 2). In fact, there were fewer cases for $G = 1/2$ or $-1/2$.

We note that only the records of serious disasters are employed in the definition of the new grade. The reason is that, in Chinese historical documents, the records of serious disasters are better than those for smaller events. Supposing that the average rainfall of a period is more (or less) if there are much more (or less) serious-flood-years than serious-drought-years in the period, we might infer that the larger G value represents wetter conditions while the smaller G value represents drier conditions. However, it remained conjectural to judge "much more than" by a simple criterion ratio $R = 7/3$ as used in (1). To find a more appropriate ratio, we compared the traditional grade series with the new grade series that were derived under different R criteria (9/1,8/2,7/ and 6/4, for example). As an example take the period length to be 10 years and calculate a group of series with different criteria of R according to (1).

Then, calculate the in-step correlation coefficient between the new series and the traditional series from 1470–1479 AD to 1970–1979 AD. The correlation coefficient reaches its maximum, 0.68, when the R values are chosen as shown in (1). The formula (1) is indeed an empirical definition. It may fall short of making full use of the detail information in the literary records.

To investigate the historical climatic variability of rainfall, we defined a Flood/Drought-variability (F/D-variability) of the N-year period as V,

$$V = (2 - |G|)\frac{(N_d + N_f)}{N} \qquad (2)$$

where $(N_d + N_f)/N$ represents the frequency of F/D disasters in the N-year period. As suggested in some earlier papers (e.g., Zheng and Feng 1985), the frequency of serious flood and serious drought could be adopted to research the historical evolution of rainfall variability. The factor $(2 - |G|)$ implied that the rainfall variability of a period when almost all the disasters are floods (or droughts), i.e., $|G| = 1$, is less than that of an other period when nearly half of the disasters are floods and another half are droughts, i.e., $G = 0$.

A group of series were derived according to (1) and (2), which provided a basis for analyzing the climatic jumps of thousand-year-scale and hundred-year-scale in the rainfall history of central China.

Methods of determining the jump reference point

Although there are a few summaries of methods for detecting jumps in series (Goossens and Berger 1987; Maasch 1988; Ye and Yan 1990), we briefly describe our procedure for the moving sign-test, T-test and F-test applied in this paper, as follows.

Moving sign-test

A sign-test may be applied to the problem such as whether or not the mean values or medians of two groups of stochastic samples are the same. It does not require that the stochastic samples belong to some normal populations as required in many other tests such as T-test and F-test. However, some technical stipulations are necessary to determine jumps in a series using a sign-test. Therefore, we designed the moving sign-test formed by the following procedures.

a. For a grade series $G(i)$, compare L pairs of $G(i+k)$ and $G(i-k)$, $k = 1, 2, \ldots L$. Let p be the number of pairs of $G(i+k) > G(i-k)$ and q be the number of pairs of $G(i+k) < G(i-k)$.

b. Let $n = p + q$, and $S = \min\{p, q\}$. For the given significance level 0.01, compare S with the criterion S_o. The ith point at which $S < S_o$ is called a potential jump reference point (PJRP).

c. Supposing the ith point is a PJRP, $G(i+)$ and $G(i-)$ are the non-zero-departure elements nearest after and before the ith element $G(i)$, respectively, the ith point is defined as a jump reference point (JRP) if $G(i+)$ has a departure sign identical to that of the mean of the subseries $G(i+k)$, $k = 1, 2, \ldots L$ while $G(i-)$ has a departure sign identical to that of the mean of the subseries $G(i-k)$, $k=1,2,\dots L$. Here the departure is calculated against the mean of two subseries around the concerned point. This condition ensures a relatively sharp change around the JRP.

d. For different values of L, repeat a, b and c for all the possible i so that a few of JRPs are determined. If the JRPs for different L values occur near the same time, we take the larger L to measure the time-scale of the possible jump event around the JRP.

We found that the moving sign-test is an efficient means of recognizing possible jumps in a time series. In some cases, when data does not cover the time-axis well, other test such as T-test may fail. The moving sign-test remains efficient providing a good indication for a jump signal. The moving sign-test was therefore adopted for the thousand-year-scale analyses and hundred-year-scale jumps in the F/D-grade series derived according to (1).

Moving T-test and moving F-test

In the T-test and F-test, the statistics T and F are calculated respectively, as

$$T(i)=\frac{(M_1-M_2)}{\sqrt{\left(\frac{1}{L_1}+\frac{1}{L_2}\right)\left(\frac{L_1S_1^2+L_2S_2^2}{L_1+L_2-2}\right)}} \tag{3}$$

$$F(i)=\frac{S_1^2}{S_2^2}\cdot\frac{L_1}{L_2}\cdot\frac{L_2-1}{L_1-1} \tag{4}$$

where i denotes the ith point in the series, L_1, M_1 and S_1 are the length, mean value and variance, respectively, of the subseries before the ith point and L_2, M_2 and S_2 are those of the subseries after the ith point.

For the given significance level 0.01, we define the ith point as a JRP if the ith point is a extreme point and $T(i)$ [or $F(i)$] exceeds the significance limits. As classified in the first Section, the jumps detected by moving T-test and moving F-test will be recognized as type I and type II jumps, respectively.

Applying the T-test and F-test to the temporal 5-grade-series would seem to fall short of a reliable measure. However, we found that results of the moving T-test and moving F-test analyses still offer good indications of climatic jumps.

Results

Jumps of thousand-year-scale

Considering the sparseness of data in earlier periods, we took 50 years as the time-resolution of the series for the long-term climatic change on a thousand-year-scale. Let the period length in (1) and (2) be 50 years and the total period be from 2700 BC to 1950 AD. Thus, a F/D-grade series $G(i)$ and a F/D-variability series $V(i)$, $i=1,2,\dots 93$, are obtained. The first point of the series

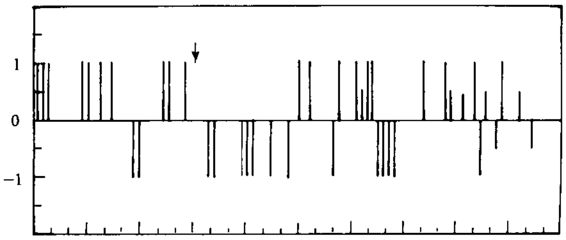

Fig. 1. The 93-point-series of F/D-grades of central China, from 2700–2650 BC to 1900–1950 AD, derived according to (1) with $N=50$ years. The *arrow* indicates the jump reference point around 1300–1250 BC, which is detected by moving sign-test. The significance-level of the test is 0.01 and the subseries length is 1250 years, i.e., $L=25$

represents the mean climatic condition of the period 2700–2650 BC. Fig. 1 shows the resulting $G(i)$ series.

A moving sign-test was applied to the jump analysis of the series in Fig. 1, with the subseries length $L=25$. The result showed a jump reference point at circa 1300–1250 BC as indicated by the arrow in Fig. 1. This implies a significant difference between the rainfall conditions of two above-1000-year periods before and after the time around 1300–1250 BC.

Now let us examine significant differences between two periods around the jump reference point with the original data, the flood and drought chronology. It is found that:

1. between 2700 BC–1300 BC, there were 38 years of disasters, 76% floods and 24% droughts,
2. between 1250 BC–300 BC, there were 55 years of disasters, 29% floods and 71% droughts,
3. between 1250 BC–1950 AD, there were 626 years of disasters, 54% floods and 46% droughts.

Therefore, we may conclude that there was a thousand-year-scale wetter-to-drier jump around 1300–1250 BC. However, frequencies of flood and drought during the last 3000 years are comparable, implying that the present climate has gradually shifted out of the drier phase which started around 1300 BC.

Two jump reference points are determined in the F/D-variability series by the moving T-test with the subseries lengths $L_1=L_2=20$. The T value reached 5.8 and 6.3 around 700 BC and 200 BC, respectively, implying rapid increases in disaster frequency around the jump reference points. The mean flood and drought disaster frequencies of three periods separated by the jump reference points are listed.

2300 BC–700 BC: total 47 disasters, about 1 disaster/34.0 years

700 BC–200 BC: total 37 disasters, about 1 disaster/13.5 years

200 BC–1950 AD: total 566 disasters, about 1 disaster/3.8 years

Disaster frequency appears much greater since 200 BC than in the earlier periods. This may also be due to the incompleteness of the historical records. Note that there was a cultural flowering at this time, i.e., the Spring and Autumn Period (about 770–476 BC) and that the First Emperor of Qin unified China around 221 BC, after which documents became more abundant. However, it is interesting to find that during the last 2000 year period the disaster frequency of central China reached one disaster every 3-4 years, which is near to the frequency of El Niño and Southern Oscillation, a strong signal of variability in our earth climate system.

Jumps of hundred-year-scale

The changes of F/D-grade and F/D-variability during 50 BC–1980 AD are concerned with a temporal resolution of 10 years. The series is composed of 203 elements. Figure 2 shows the $G(i)$ series, $i=1, 2, \dots 203$.

As indicated in Fig. 2, two jump reference points are determined by the moving sign-test with the subseries length $L=20$. One is near 290-300 AD and another near 670-680 AD. According to the original F/D chronology, we found that:

1. between 30 AD-290 AD, there were 48 years of disasters, 69% floods and 31% droughts,
2. between 290 AD-500 AD, there were 41 years of disasters, 20% floods and 80% droughts,
3. between 500 AD-680 AD, there were 36 years of disasters, 53% floods and 47% droughts,
4. between 680 AD-1130 AD, there were 102 years of disasters, 71% floods and 29% droughts.

Droughts seldom occurred in the history of central China, where flood was more serious in general, but as many as 80% of the total disasters were serious droughts during the more-than-200 years, 290-500 AD. The jump reference point near 290-300 AD indicated indeed a sharp change from a pluvial period to an extremely dry period. With the jump near 680 AD, however, the climate of central China reverted back into a pluvial phase.

Applying the moving T-test ($L_1=L_2=20$) to the F/D-variability series, we find three jump reference points near 1280, 1420 and 1710 AD, respectively (figure omitted). The T value reached 4.1, 4.9 and −3.6 at the three points, respectively. The mean disaster frequencies of several periods divided by the jump reference points are listed as follows:

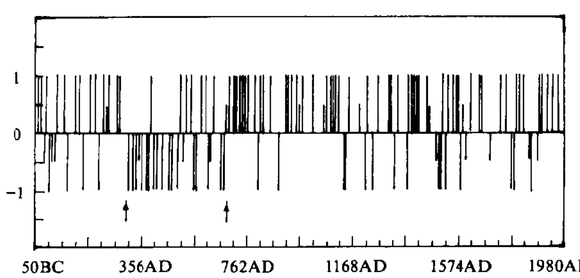

Fig. 2. The 203-point-series of F/D-grades of central China, from 50-40 BC to 1970-1980 AD, derived according to (1) with $N=10$ years. The *arrows* indicate the jump reference points around 290-300 AD and 670-680 AD, which are detected by moving sign-test. The significance-level of the test is 0.01 and the subseries length is 200 years, i.e., $L=20$

50 BC–1100 AD: total 234 disasters, about 1 disaster/4.9 years
1100–1280 AD: total 15 disasters, about 1 disaster/12 years
1280–1420 AD: total 39 disasters, about 1 disaster/3.6 years
1420–1710 AD: total 154 disasters, about 1 disaster/1.9 years
1710–1870 AD: total 44 disasters, about 1 disaster/3.6 years.

It is noted that through the successive jumps around 1280 and 1420 AD, the disaster frequency of central China increased from the earlier 1 disaster every 12 years to a much higher value, about 1 disaster every 2 years. After a period of lower values, during 1710–1870 AD, the disaster frequency increased again. However, there were no jumps detected for the last over 200-year period.

Jumps of decade-scale

Two types of jumps in the traditional 5-grade-series of central China of 1470–1949 AD are analyzed with the moving T-test (MTT) and moving F-test (MFT), respectively. In anticipation of sensitivity of the results of MTT and MFT, we combine the figures of the original series and the Moving T-test (or F-test) curves.

Figure 3 shows the MTT curves with different subseries length [refer to the expression in (3)] and the 11-point-running mean curve of the original 5-grade-series. The adoption of a running mean is to make the features of the curve easily visible. The T-test is made

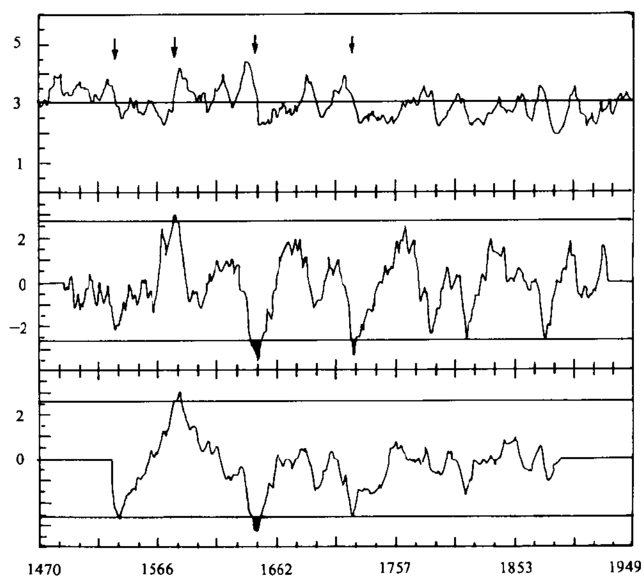

Fig. 3. The 11-point-running mean curve of the traditional grade series, 1470–1949 AD (*upper*) and the moving T-test curves with different subseries lengths (*middle:* $L=20$ and *lower:* $L=60$, with same coordinations). The *arrows* indicate the jump reference points around 1534, 1583, 1647 and 1725 AD. The significance-level of the test is 0.01. The significance-limits are shown in the figure

on the original series. Four jump reference points of type I jump are determined as indicated by arrows in Fig. 3, which are near 1534, 1583, 1647 and 1725, respectively. Note that the earlier three events are detected by the MTT with longer subseries length ($L=60$) but the last one is detected only by the MTT with $L=20$. This implies the difference between their time-scales. The mean situations of several periods divided by the jump reference points are surveyed as follows:

1483–1533 AD: $G_m=3.5$, total 7 disasters, 0% floods, 100% droughts
1535–1583 AD: $G_m=2.7$, total 7 disasters, 100% floods, 0% droughts
1584–1645 AD: $G_m=3.6$, total 21 disasters, 29% floods, 71% droughts
1647–1681 AD: $G_m=2.5$, total 8 disasters, 100% floods, 0% droughts
1686–1723 AD: $G_m=3.4$, total 10 disasters, 20% floods, 80% droughts
1725–1761 AD: $G_m=2.4$, total 8 disasters, 88% floods, 22% droughts
1765–1949 AD: $G_m=2.8$, total 34 disasters, 62% floods, 38% droughts,

where G_m denotes the mean of the annual grades during the period. It is noted that the difference between the mean grades of two periods around the jump is nearly one. The differences among the different periods are clear. For example, all 7 disasters were serious floods between 1535–1583 AD while the most of the disasters were serious droughts between 1584–1645 AD. No jumps are found after the mid-18th century. The mean grade of the recent approximately 300 years is 2.8, implying a slightly pluvial period.

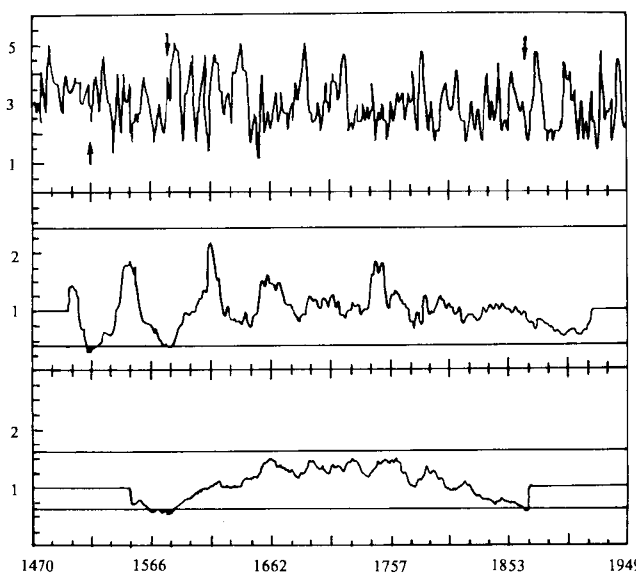

Fig. 4. The 3-point-running mean curve of the traditional grade series, 1470–1949 AD (*upper*) and the moving F-test curves with different subseries lengths (*middle:* $L=30$ and *lower:* $L=80$, with same coordinations). The *arrows* indicate the jump reference points around 1527, 1582 and 1869 AD. The significance-level of the test is 0.01. The significance-limits are shown in the figure

Figure 4 shows the MFT curves of different subseries length and the 3-point-running mean curve of the original 5-grade-series. Three jump reference points of type II jump are determined as indicated in Fig. 4, which are near 1520, 1582 and 1869, respectively. All three events represent a jump from smaller variability to larger variability (the corresponding F values are smaller than 1). This implies that the climate may change rapidly from a state of few disasters to a state of frequent disasters but not in the opposite direction. We note the abundance of historical chronicles for the last 500 years in China.

According to some authors (e.g., Zheng and Feng 1985), the frequency of flood and drought disaster might be used to represent the variability of rainfall climate. Here the 'disaster' denotes the year of serious flood or serious drought (grade 1 or 5 in the traditional grade system). In such a sense, we summed up the disaster frequencies of the periods divided by the jump reference points, in order to understand further the results of the moving F-test.

1486–1520 AD: 1 years of disasters, about 1 disaster/35 years
1521–1553 AD: 8 years of disasters, about 1 disaster/4 years
1554–1582 AD: 1 years of disasters, about 1 disaster/28 years
1583–1613 AD: 15 years of disasters, about 1 disaster/2 years
1820–1869 AD: 3 years of disasters, about 1 disaster/16 years
1870–1949 AD: 25 years of disasters, about 1 disaster/3 years

It is obvious that the variabilities of rainfall of the different periods are very different. Particularly, we note the low frequency about 1 disaster/28 years during 1554–1582 AD and the highest frequency about 1 disaster/2 years during 1583–1613 AD, which reflects the significant transition between two climatic regimes around the early 1580s.

Discussion and summary

Although the statistical analyses in this paper provide new implications, their significance should be assessed cautiously. The most serious problem in the application of historical documents to climate change research arises from the human effect on the documents, which may misrepresent the real climatic conditions to various extents. This problem remains unresolvable at present. It is proper to compare the results of different analyses so that some more reasonable conclusions may be reached. The historical chronicles can, however, form the basis for comparative tests with other proxy records (tree-rings, lake varves).

On the thousand-year-scale

As Fig. 1 shows, a wet-to-dry jump might have occurred 1250–1300 BC in central China. Although only few earlier authors adopted the term "jump", a few authors proposed a climate transition around 3000 BP. For example, Zhu (1972) noted a warm and wet period before 3000 BP at the famous Banpo Ruins and Anyang Ruins, which are located within central China. Wu and Lin (1981) found a warm and wet period before 3000 BP in Tibetan Plateau with natural evidence other than historical records. In north Africa the formal *Saharization* started around 3000 BP as reviewed by Petit-Maire (1987). Based on instrumental observations, Yan et al. (1990) found that during cooling periods in the Northern Hemisphere, north Africa, Tibet and Sino-Japanese areas became abruptly drier. All of these results may help us to understand the present results. The time around 3000 BP was supposed to be an end part of the well-known middle-Holocene optimum (Zhu 1972), when climate cooling began.

It is interesting to note that the mean flood and drought frequency during the last 2000 years is about 1 disaster per 3-4 years, which is of the order of El Niño/Southern Oscillation (ENSO) events. A few investigators used instrumental observations to propose a close relationship between ENSO and climatic anomalies in some Chinese regions (e.g., Wang 1989). Therefore, our results may imply that Chinese historical documents of the last 2000 years are quite reliable for an ENSO analysis.

On the hundred-year-scale

The most notable jump of century-scale happened around 290-300 AD, when a severe dry period began in central China. Recently, Yan et al. (1991) found that the jump around 300 AD influenced most of northern China. Zhu (1979) wrote that many regions over the world such as north Africa and north Europe also experienced the severe droughts around 300 AD. The in-phase relationship in rainfall changes among north Europe, north Africa and north China on a decade-to-century-scale may reflect some systematic changes in large-scale atmospheric circulation (Yan et al. 1990, 1990a).

There were two jump-type increases in flood and drought frequency near 1280 AD and 1420 AD, respectively, and one decrease in the early 18th century, which thus led to a maximum disaster frequency during the 15-17th century. Note that the Little Ice Age reached its acme during 15-17th century (Grove 1988). Based on this fact, Zheng and Feng (1985) argued that climate behaved more variably during cold periods. The mechanism behind this interesting phenomenon remains unexplained.

On the decadal-scale

More cases with two types of jumps on decadal-scale are detected for the last 500 years in central China. The difference of mean value between two decade-scale periods around the type I jump point is about one grade. Implied in the grade definitions (Academy of Meteorological Sciences 1981), one grade is equivalent to a difference of about 100 mm/year in annual precipitation for central China.

The early 1580s might be a turning period during which the climate of central China changed from a pluvial and disaster-deficient period to a dry and disaster-frequent period. Both of the periods were of three or more decades. The 1570s-1580s seems also an important transition period for Europe (Grove 1988). At present, however, the various proxy data may not be dated accurately enough for us to make proper comparison between the regional changes on decade-scale. It is possible that the decade-scale climatic jump may happen in some sensitive regions. More regional cases are needed in order to obtain a more thorough view.

Summary

The flood/drought-grade series for the past 4000 years is derived from the historical documents of central China. Two types of climatic jumps, the jump of mean condition and the jump of climatic variability, in the history of central China are surveyed, with regard to their timing and the changes induced in annual rainfall. We especially note the wet-to-dry jump around the early 1580s, which is of decade-scale and had regional impact, and the wet-to-dry jump around the end of the 3rd century, which is of century-scale and of much larger spatial-scale.

The paper cannot offer direct digital rate estimates for climatic change during a jump, due to limitations in the written documents. The difficulty of the rate estimation also arises from the fact that the climatic jumps take place in a "noisy" environment with strong yearly variations and other short-term climate fluctuations. At present, a more feasible research approach may be to investigate the spatial patterns of climatic jumps (as done by Yan et al. 1990, for example), as helping to get into the essence of complicated climatic phenomena.

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