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DRY/WET CLIMATE CHANGE SINCE 960 A. D. IN TAIHU DRAINAGE BASIN OF CHINA

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ABSTRACT: The present study reconstructs an annual dry/wet grade series from 960 A. D. to 1992 A. D. in the Taihu drainage basin of eastern coast, China by collecting historical climatic records, to examine the climate periodicity and climate jumps. Power Spectrum analysis reveals that the dry/wet climate in the study area was a superposed phenomenon with the major period of quasi-100-year, and several other notable periods. These periods were supposed to be closely linked with the celestial activity. Climate jumps are detected using moving t-test. The two abrupt changes around 1247 – 1263 A. D. and 1618 – 1635 A. D. are proved as regional events. The 14th to 15th century appeared as the wettest period during the last 1000 years in the Taihu drainage basin. These are interpreted as the consequence of east Asia climate change.

KEY WORDS: climate periodicity; climate jump; annual dry/wet grade series; Taihu drainage basin

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1 INTRODUCTION

Records of climate disaster have been abundantly found in Chinese historical literature. Previous works have collected such records to study the historical climate change. Distribution of drought and flood hazards in China during the last 500 years has been examined (SMA, 1981; ZHANG and LIU, 1993). ZHANG *et al.* (1994) collected climate literature from 47 sites to study the episodes of climate change during the last 2000 years in China. ZHANG *et al.* (1997) reconstructed quasi-1000-year dry/wet series of eastern China to study the climate abrupt changes. In the Taihu drainage basin, CHEN(1987) collected systematically historical climate events of different sites and established the grade sequence of floods and droughts since the Southern Song Dynasty. He also analyzed the cycles of dry/wet climate change, divided dry/wet periods, and discussed its relationships with cold/warm variation and solar activity (CHEN 1987; 1989).

The present study tends to establish the dry/wet series since 960 A. D. of Taihu drainage basin on the basis of yearly identification of historical records. It is also our purpose to study the characteristic of historical climate change using climate periodic and jump analyses and thus to further understand its controlling factors.

2 RECONSTRUCTION OF ANNUAL DRY/WET GRADE SERIES AND RESEARCH METHOD

2.1 Reconstruction of Annual Dry/Wet Grade Series and Its Evenly Distribution Test

The historical climate records can be traced back to

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as early as the Warring State. However, annual record was not available until the Northern Song Dynasty (960 A. D.). The present study collected climatic information from following literatures (in Chinese): "The Occurrence of Major Natural Disasters by Floods, Droughts, and Tides in the Jiangsu Province during the Last Two Thousand Years"; "Preliminary Study of Historical Climate Records in Jiangsu Province"; "Preliminary Study of Historical Climate Records in Zhejiang Province"; "History of Taihu Lake's Hydraulic Engineering"; and "Yearly Charts of Dryness/Wetness in China for the Last 500-year Period" (SMA, 1981).

A five-grade index of severe flood (1), flood (2), normal (3), drought (4), and severe drought (5) was used to reflect the precipitation feature of the study area. The definition for these five grades is according to SMA (1981). Climate data of Suzhou is the present grade series' major source. Other stations in the drainage basin provide supplemental information. Grades between 1470 A. D. to 1979 A. D. are directly from "Yearly Charts of Dryness/Wetness in China for the Last 500-year Period " (SMA, 1981) and "Preliminary Study of Historical Climate Records in Jiangsu Province". Authors defined the dry/wet grade series between 960 A. D. and 1469 A. D. based on literatures listed above, and the series between 1980 A. D. and 1992 A. D. using the May-September rainfall according to SMA (1981).

To eliminate the unevenness of the dry/wet grade series due to difference of various historical records and subjective judgment, χ^2-test was used to examine if the series of 960 - 1475 A. D. (series Ⅰ) and series of 1476 - 1992 A. D. (series Ⅱ) belong to the same quasi-normal distribution.

Result of χ^2-test demonstrates that each χ^2 is lower than 9. 448 (Table 1), reflecting an evenly distribution of dry/wet grade series in the present study.

Table 1 Result of χ^2-test

($\chi^2_{0.05} = 9.448$, $\chi^2_{0.01} = 13.277$)

Series	Series Ⅰ and Ⅱ	Series Ⅰand the whole series	Series Ⅱ and the whole series
χ^2	5. 561	1. 894	1. 821

2. 2 Method of Statistics

The present study use power spectrum analysis to examine the climate periodicity, use moving t-test to detect the abrupt climate changes. Spectrum analysis has been widely used in previous works. Following is the introduction of moving t-test.

A continuous random variable X is divided into two sub-sample X_1 and X_2. U_i, S_i^2 and n_i represent the sample average, variance, and number of sub-sample of X_i ($i = 1, 2$), respectively.

Hypothesis H_0: $U_1 - U_2 = 0$. Define a statistic:

$$t_0 = \frac{\bar{x}_1 - \bar{x}_2}{S_p(\frac{1}{n_1} + \frac{1}{n_2})^{1/2}}$$

In the above equation,

$$S_p^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}$$

Obtain t_α at the significance of α. Compare t_o with t_α. If $|t_0| \geqslant t_\alpha$, the hypothesis H_0 is denied, indicating there exist significant difference between X_1 and X_2. . If $|t_0| < t_\alpha$, the hypothesis H_0 is accepted. Change the value of n_i when using the moving t-test so that the result could be more believable.

3 RESULT

3. 1 Periodicity

Power spectrum analysis was made for the present 1033-year dry/wet grade series with different lagging of 280, 200, and 150. Process of "Red Noise" was applied to make the significance test ($\alpha = 0.05$).

The Result of power spectrum analysis shows that periodicity of the dry/wet climate in the study area is quite complex. The major period is about 100 year. Other periods are 36 years, 26 - 27 years, 11 years, 22 years, 15 years, 19 years, 2 - 3 years, 8 years, and 5 - 6 years (Table 2). Most periods are identical with those revealed by CHEN (1989).

3. 2 Abrupt Change

In the present moving t-test, n_i was taken as 15, 20, 25, 30, 35, 40, 50, 60, 70, 75, and 80. A

Table 2 Periods of the dry/wet climate change resulted from power spectrum analysis

Lagging	Major periods (year)												
280	93	35	26	11	22	15	19	3.6	2.4	8.5	6.5	5.5	5.1
200	100	36	26	11	22	15	19	3.6	2.4	8.5	6.6	5.6	5.1
150	100	37	27	11	22	15	19	3.6	2.4	8.5	6.5	5.6	5.2

variable r_i is calculated as $r_j = | t_j | / t_{0.01}$, so that $r_{0.01} = 1.0$ is used to detect the climate jump informaton (Fig. 1).

The 11-year and 30-year moving average curves and their 6-degree polynomial regression curves are also presented in Fig. 1 to help the detection of climate jump. Two abrupt changes around 1247 – 1263 A. D. and 1618 – 1635 A. D. are generally examined when taking different n_i. As it could be found in Fig. 1e and 1f, these two jumps occurred at the joint points of the polynomial regression curves and the line of averaged value. The climate changed from a dry period to a wet period after 1247 – 1263 A. D., and to dry again after 1618 – 1635 A. D. When the number of sub-sample (n_i) is bigger, less jump years are detected. It mainly occured around 1250 A. D. and 1635 A. D. (Table 3, Fig. 1), reflecting abrupt climate changes of century scale. When the n_i is smaller, there are more decade-scale jump years, 983 A. D., 1170 A. D., around 1215 A. D., around 1284 A. D., around 1522 A. D., and around 1559 A. D. (Table 3, Fig. 1).

4 DISCUSSION

4.1 Periodicity

Spectrum analysis demonstrates that the dry/wet climate change of last 1000 years in the study area was the superposition of multiple periods. We propose that the planetary wind system and east Asia monsoon circulation controlled by celestial activity play the key role in the climate change of the study area.

The periods of Taihu drainage basin are compared with those of celestial activity and climate change collected by CHEN and ZHANG (1995). It is found that quasi-100-year period may be linked with solar activity of century scale. Solar diameter changed with the cycle of 100 years. The 35 – 36-year period was in agreement with the 34.5-year period of the earth rotation velocity, terrestrial poles activity, and the common 35-year period of the moon, Jupiter, Mercury, Saturn, and Uranus. The 35 – 36-year period of dry/wet climate change existed widely in the eastern China as controlled by the celestial factors. Previous works showed that the 35-year period was also the period of precipitation during May to August in the middle and lower Changjiang (Yangtze) drainage basin, precipitation of July in China, flood and drought of the Changjiang and Huanghe (Yellow) River, and annual precipitation of Shanghai. Quasi-26 – 27-year period and quasi-15-year period were close to the period of solar activity. The precipitation of Shanghai and Yichang, and the flood/drought in the lower Changjiang drainage basin also had the period of quasi-26 – 27-year

Table 3 Years of abrupt climate change during the last 1000 years in Taihu drainage basin

$n_1 = n_2 = 15$	$n_1 = n_2 = 20$	$n_1 = n_2 = 25$	$n_1 = n_2 = 30$	$n_1 = n_2 = 35$	$n_1 = n_2 = 40$	$n_1 = n_2 = 50$	$n_1 = n_2 = 60$	$n_1 = n_2 = 70$	$n_1 = n_2 = 75$	$n_1 = n_2 = 80$
983	983									
1170										
1215										1221
	1250	1253		1262	1263	1250	1260	1250	1253	1247
1285						1282	1284	1284		
		1403								
		1522	1522	1522	1522	1518	1519			
1559	1559		1554	1559	1559	1568	1559			
1635	1627		1635	1613	1633	1618	1620	1635	1635	1634

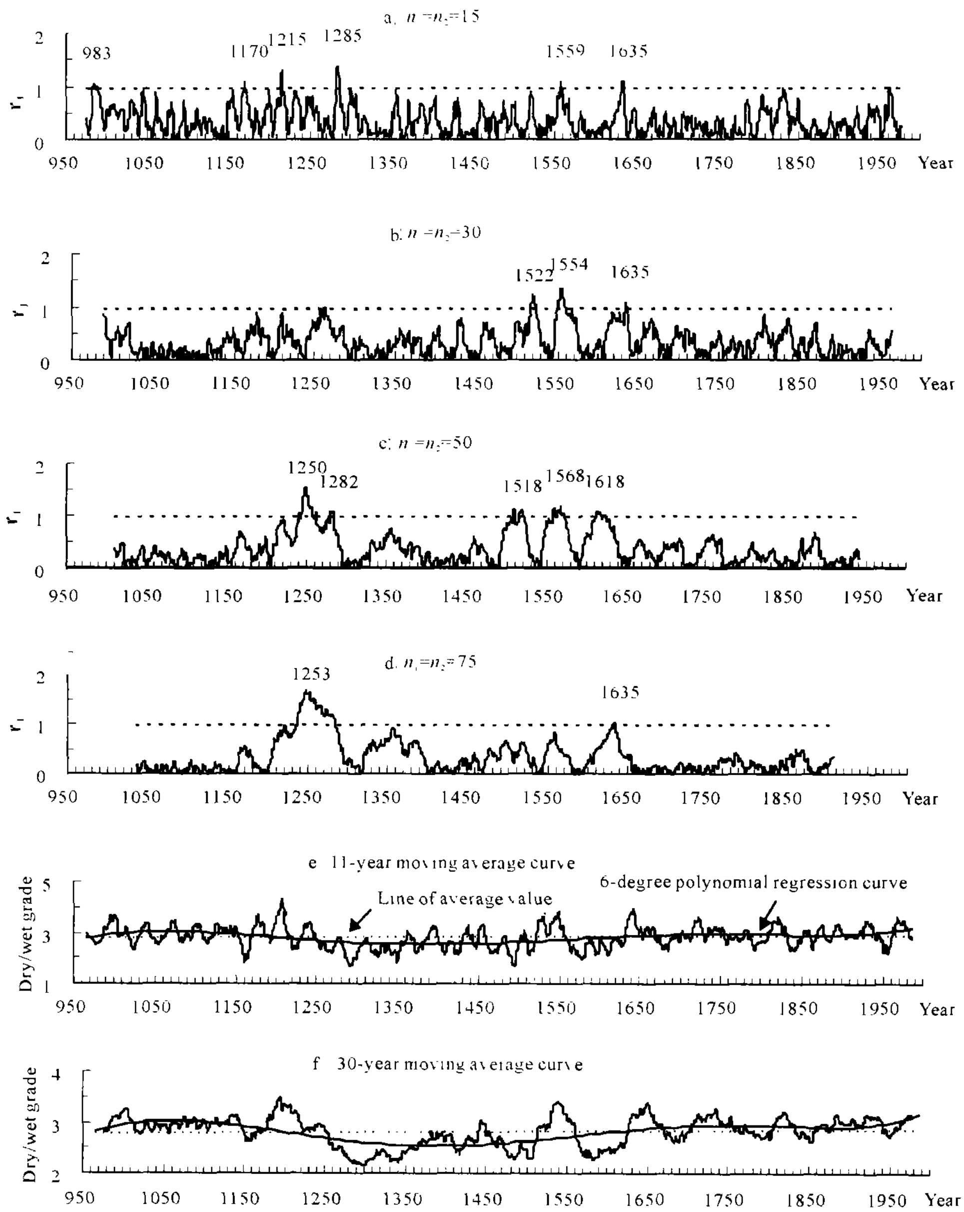

Fig. 1 Moving t-test curves and moving average curves of last 1000 years of the dry/wet grade series in Taihu drainage basin

and 15-years. The quasi-19-year period was close to the 18.61-year period of the tide generating force. The 22-year, 11-year, and 5 – 6-year periods corresponded to the Hale cycle, sunspot cycle, and bi-oscillation cycle of solar activity, respectively. The 11-year and 22-year periods were both the period of flood/drought around Shanghai. Eleven-year period was the same as the period of plum rains in the middle and lower Changjiang drainage basin. Twenty-two-year period was the same as the period of the start of plum rains in the middle and lower Changjiang drainage basin. The quasi-8-year period can correspond with the period of Venus's inferior conjunction. It was also seen in the annual precipitation of Shanghai and the May – August precipitation of the middle and lower Changjiang drainage basin. The quasi-3-year period was probably related to the ENSO event controlled by the ocean-atmosphere interaction.

From above comparison, it can be found that the climate change was closely linked with celestial activity. Especially the Sun, which is the most important provider of energy for the earth surface system, its activity influences deeply the dry/wet climate change on earth. CHEN(1989) found that several wet periods since the Southern Song Dynasty in Taihu drainage basin were almost contemporary with that of the strong solar activity. Statistic method demonstrated that the dry/wet grade series and the 1 - 3-year advancing relative number of sunspot were significantly correlated ($p < 0.01$) (CHEN, 1989).

XU (1985), XU and JIN (1986) revealed that the location of subtropics high of western Pacific has close correlation with the 1 - 3 year advancing sunspot numbers, and its 11-year and 22-year cycles couple well with the same periods of solar activity. This may indicate that the sunspot influences the east Asia monsoon through the subtropics high of the western Pacific.

4. 2 Episode of Climate Change

The dry/wet climate showed a series of abrupt changes due to the function of various periods. The most significant climate jumps occurred around 1247 - 1263 A. D. and 1618 - 1635 A. D. It was a relatively wet period between these two jumps (Fig. 1e, 1f). These two abrupt changes were regional events as comparing with the results of previous works. ZHANG *et al.* (1994) revealed that the most obvious climate change during the last 2000 years in China happened around 1230 - 1260 A. D., which is the beginning of modern monsoon. ZHANG *et al.* (1997) examined the dry/wet climate in Su(Suzhou)-Hang(Hangzhou) area. They found it changed from a dry episode to a wet episode around 1216 A. D and from the wet episode to a dry one around 1636 A. D. The abrupt change in 17th century was also detected in the Haihe drainage basin, and Central Plains (YAN *et al.*, 1991; 1993). Besides, these two abrupt changes corresponded well with the warmest 13th century and the coolest 17th century (ZHANG, 1991; 1994).

The dry/wet grade series of the present study is compared with the moisture index of the Southeastern China (ZHENG *et al.*, 1977), variation of precipitation in the Central Plains(SHI, 1993), and the percentage of lake water-area status in China(FANG, 1993, Fig. 2). It is demonstrated that the humid period during the 14th and the 15th centuries occurred widely as a large-scale climate event. In Taihu drainage basin the the 14th to the the 15th century was the wettest period during the last 1000 years(Fig. 2a). The moisture index of the Southeastern China indicates two humid peaks during the early 14th century and 15th century (Fig. 2b). In the Central Plains, the late 14th century to the 15th century was a significant wet period (Fig. 2c). Lake expansion occurred during 1250 A. D. to 1650 A. D. (Fig. 2d), and reached the peak in the 14th to the 15th century, indicating the humid climate. Besides, the temperature index(SHEN and CHEN, 1991) of the Taihu drainage basin since the Southern Song Dynasty was collected. It could be found that the climate in the study area was a kind of warm / wet and cool/dry pattern (Fig. 2e), reflecting the characteristics of the east Asia monsoon.

5 CONCLUSION

The present study, on the basis of collected historical climate records, reconstructs the annual dry/wet grade series from 960 A. D. to 1992 A. D., in the Taihu drainage basin of eastern China coast. Power spectrum analysis and moving t-test are applied to examine the climate periods and abrupt changes.

The power spectrum analysis shows that the dry/wet climate in the study area was a kind of superimposed oscillation. The major period was quasi-100-year. Others were 35 - 36 years, 26 - 27 years, 11 years, 22 years, 15 years, 19 years, 3 years, 8 years, and 5 - 6 years. It is proposed that such periodicity was the reflection of celestial activity on the planetary wind system and east Asia monsoon circulation.

The moving t-test detected two large-scale abrupt changes, i. e., 1247 - 1263 A. D. and 1618 - 1635 A. D. The climate between these two abrupt changes

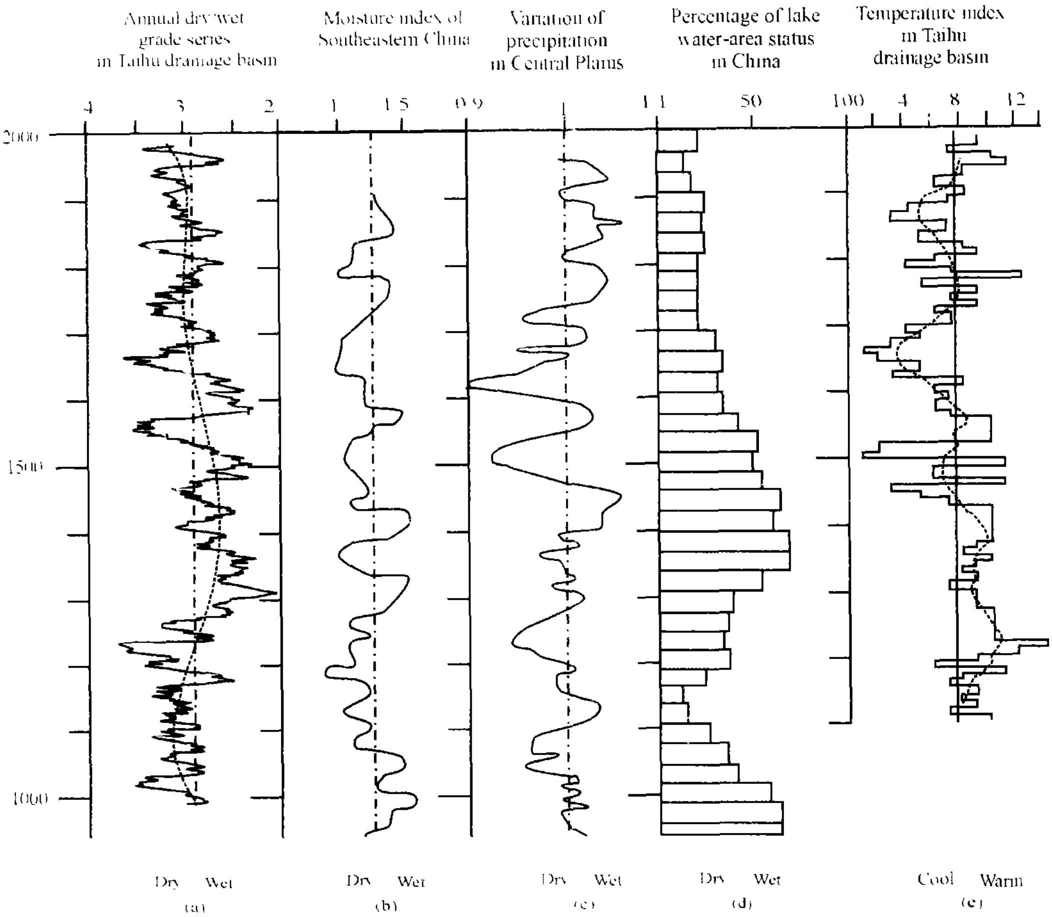

Fig. 2 Comparison of dry/wet climate changes in east Asia and temperature variation of Taihu drainage basin during the last 1000 years

was relative humid. Before 1247 A. D. and after 1635 A. D. it was relative dry. The 14th to the 15th century was the wettest episode during the last 1000 years in the study area. This getting-humid event occurred widely in east Asia.

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