

DRY-WET EVOLUTION IN GUANGDONG PROVINCE DURING LAST 500 YEARS

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ABSTRACT: Based on the historical records in Guangdong Province during the last 500a, the moist index sequence was reconstructed and analyzed by the correlation analysis, wavelet analysis and the power spectrum analysis. The results indicate that: 1) The El Niño events have evident correlations with the droughts happened in the west and north of Guangdong Province, which intensified the dryness and wetness distribution patterns in these areas in a certain degree. 2) Good correspondence relations exist among the moist index sequence, Greenland ice core oxygen isotope record and the winter-half-year temperature sequence in the eastern China, which showed an apparent monsoonal disposal pattern of moisture and temperature. 3) By applying the wavelet analysis to deal with the data, several apparent periodicities are revealed, among which some can be attributed to the solar activities. At the same time, the ENSO event, monsoon (especially the East Asian monsoon) activity and the human activity may also have some influences on the periodicities of the climatic changes in Guangdong Province. 4) Guangdong will persist in dry period before 2040 (± 5 years) though some little waterlogged period will also exist in this interval, and after that great floods maybe take place in Guangdong. We think that the variety range of the dryness and wetness has increasing tendency in Guangdong Province in future several even hundred years.

KEY WORDS: dry-wet evolution; El Niño; monsoon; solar activity; Guangdong Province

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1 INTRODUCTION

The global warming change has already become one of the focuses that many scientists pay attention to, and the precipitation change of China is also one part of the questions under the whole world changes today. According to the actual material analysis, the climate in China had a warm-dry tendency in a wide spread range during the past one hundred years (ZHAO, 1993), and it could not draw a verdict as for future tendency at present. Following the thought of Prof. HUANG Bing-wei's "how to treat the questions of the global warming change, taking hold of the things which may have not much possibility" (CHEN, 1996), looking for some other materials and methods to study the above questions still has great significances even it may have much uncertainty.

An abundance of historical records in China make us have superiorities and characteristics on the study of historical climate, and it may have great contributions to the study on dry-wet possibility under the current conditions in China only if we sufficiently use these materials and

study the dry-wet evolution seriously. Guangdong Province is located in Southeast China, which abuts the Pacific Ocean. The natural disasters especially the floods and droughts occurred frequently in Guangdong Province since ancient time. Up to now, the tremendous damages and potential threatens of natural disasters to society and economy of this area should not be neglected absolutely. The authors have done one preliminary study on the distribution features of the dryness and wetness of Guangdong Province in different stages of the historical period, and some significance conclusions have also been obtained (XUE et al., 2005). Based on the former foundation, possible relations among the moist index sequence, El Niño events, monsoon circulation and the solar activity during the last 500a are studied in this paper.

2 MATERIALS AND METHOD

The original data used to reconstruct the moist index in this paper are according to former studies (TRILHGP, 1961; QIAO and TANG, 1993; LIANG and YE, 1993).

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We choose and collect the historical records of flood and drought disasters of 34 counties and cities in Guangdong (Fig. 1) during the period of 1480- 1940 (equivalent to the Little Ice Age, LIA) with temporal resolution of 5 years and set up the moist index sequence with the same way introduced in the XUE's literature (XUE et al., 2005). The calculation formula of the moist index (I) used in this paper is as follows:

$$I=F*2/(F+D)$$

where I is moist index that lies between 0 and 2; F represents the times of the floods disasters of a certain area in some year; D represents the times of the corresponding

droughts disasters. When the times of the floods is equal to that of the droughts, I=1. So we can reconstruct the moist index of Guangdong during 1480- 1940 (Fig. 2).

The dry-wet evolution and the latest changing tendency are analyzed by correlation analysis, wavelet analysis and the power spectrum analysis methods. Compared to the correlation analysis and the power spectrum analysis, the wavelet analysis has yet obtained more and more widespread application in scientific researches during recent years (YANG and SHI, 2001; SUN and AN, 2002; LIU et al., 2005; LIN and DENG, 1999). Based on different strong points of each wavelet, the Morlet wavelet is

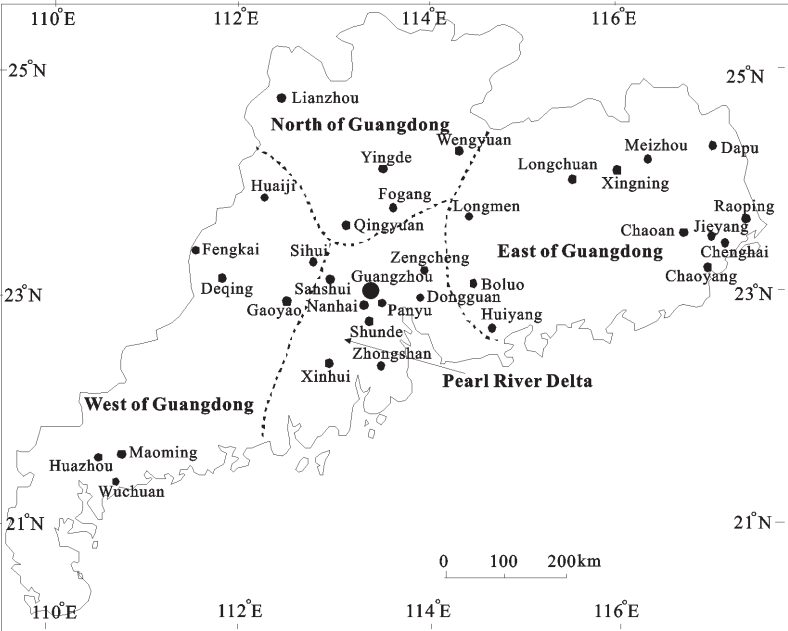


Fig. 1 Distribution of data-collecting sites and sub-areas in Guangdong Province

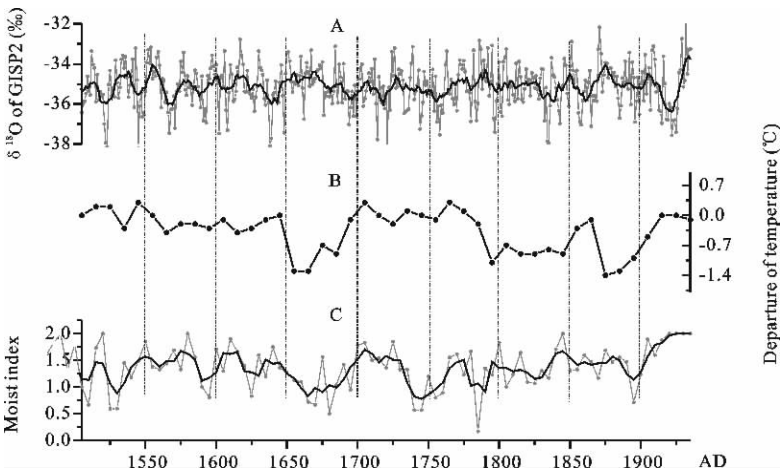


Fig. 2 Comparison of $\delta^{18}\text{O}$ of GISP2 (A, GROOTESPM et al., 1993), winter-half-year temperature sequence in East China (B, GE et al., 2002), the moist index serial in Guangdong (C)

used to do the cyclical analysis and the MHAT wavelet to do the multi-scale analysis to the moist index sequence.

3 RESULTS AND ANALYSIS

3.1 Characteristics of Drought and Flood in Historical Period

Guangdong Province is located in the coastal area of the southern China, which suffered from the natural disasters frequently since ancient times. In the 1990s, there once existed a popular viewpoint in academic circles, which considered it a general phenomenon that "the floods took place less than the droughts in each province" during the 16th-17th centuries in China (CHEN and GAO, 1991), but perhaps this conclusion could not accord with the actual conditions of Guangdong Province. According to the materials, the floods were the main natural disasters in any period and its times were much more than that of the droughts disasters. Generally speaking, the floods and the droughts excluded each other, though this kind of situation existed to a certain extent in Guangdong, it seemed a more general phenomenon that the droughts and the floods happened jointly. Fig. 2 shows the changing tendency of the moist index (I) during 15th-19th centuries in Guangdong Province, and it can be found from the figure that the moist index (I) is greater than 1 during the most periods studied in this paper, and this also proved that the flood was the main natural disaster.

Guangdong lies in the south of China, and its climate is not only influenced by the monsoon strongly but also influenced by some other factors such as the landform, the longitude, latitude position, etc., and the droughts and the floods were affected unavoidably by these factors, therefore its dry-wet distribution must have different features in different periods. Study (XUE et al., 2005) has shown that: 1) The 113 °E longitude seems to be regarded as an important climate characteristic boundary in Guangdong, east of which the demarcation lines of the droughty areas, the waterlogged areas and the comparatively waterlogged areas are distributed approximately along the direction of the longitude namely north-south, and west of which they are distributed approximately along the direction of the latitude namely east-west. Guangdong is mainly influenced by the East Asian monsoon, at the same time it also receives certain influences of the Indian monsoon, and the different characteristics that these two kinds of monsoon have in the water vapor transport may be the main reason that form the above-mentioned boundary line. 2) According to the his-

torical course, the areas with great regional differentiations of the droughts and the floods were mainly distributed in the west and the north of Guangdong. The Zhujiang (Pearl) River Delta is the comparatively steady waterlogged area; Wengyuan and its surrounding areas in the north of Guangdong, Huaiji and its surrounding areas in the west of Guangdong, Xingning-Jieyang-Chaoyang and its surrounding areas in the east of Guangdong, Wuchuan and its surrounding areas in Leizhou Peninsula were the droughty areas in the history.

3.2 Future Tendency of Dry-wet Evolution

By applying the Morlet wavelet transformation we can obtain the major effect cycles in each time intervals (LIN and DENG, 1999), but the power spectrum analysis can only display the major effect periodicities existed in the entire research time and it is unable to manifest the major periodicities in different time intervals. From Fig. 3 we can find that the moist index sequence mainly includes some periodicities such as 7a, 11-15a, about 23a and so on. By applying the Morlet wavelet transform method to deal with the drought and flood disaster sequences respectively (Fig. 4), several evident periodicities are revealed. In Table 1, the principal periodicities of various sequences are listed. The droughts sequence (Fig. 4A) shows that before 1730, the cycles of 7a, 11a and 23a prevailed, and afterwards, it was dominated by periodicities of 8a and 20a, in addition to the periodicity of 46a prevailing in all the periodicity. As for the floods sequence, in addition to the periodicity of 50a prevailing in 1480-1940 (Fig. 4B), prior to about 1830, it was dominated by the periodicities of 6a, 11-15a and, from then onwards, principal periodicities were characterized by 6a.

Table 1 Principal sequential periodicity of each sequence

Serial	Principal sequential periodicity
Drought disaster	7-8a, 11a, 20a, 23a, 46a
Flood disaster	6a, 11-15a, 50a
Moist index	7a, 11a, 13a, 15a, 23a

As we know that the MHAT wavelet transformation has rigorous principle significances that any other statistical methods do not have (LIN and DENG, 1999). Fig. 5 shows the results of the MHAT wavelet analysis of the moist index sequence of Guangdong on various time-scales during 1480-1940. It can be seen, on 120-a time scale, there were two sudden change points occurred at 1540 and 1840. On 30-a time scale, the sudden change points increased, occurring at about 1495, 1545, 1635, 1695, 1750 and 1845. But on 15-a time scale,

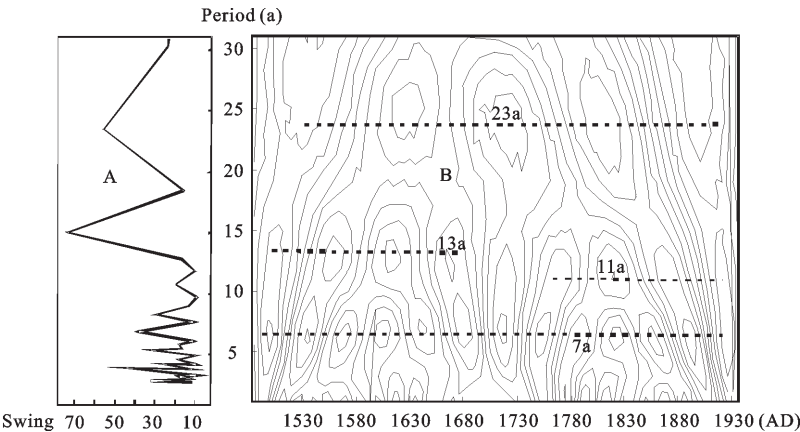


Fig. 3 Cycle analysis of sequence of moist index in Guangdong Province
(A: power spectrum analysis; B: Morlet wavelet transformation)

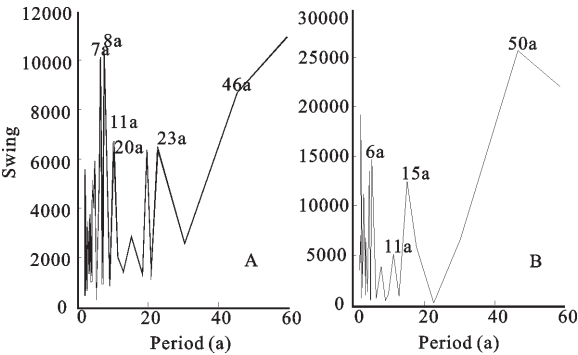


Fig. 4 Cycle analysis of drought (A) and flood (B) serials in Guangdong Province

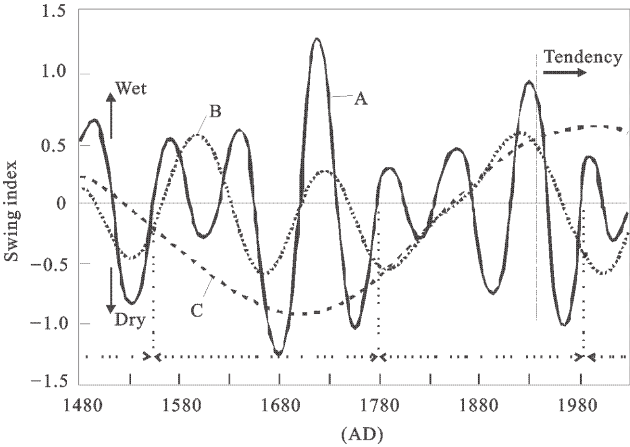


Fig. 5 Analysis result of wet index sequence on different time-scales in Guangdong
(Time-scale: A- 15a; B- 30a; C- 120a)

there were 12 sudden change points at 1510, 1550, 1590, 1620, 1650, 1695, 1740, 1775, 1805, 1840, 1870 and 1910. Two high rainfall periodicities at about the 1920s, and the 1970s, together with two dry periodicities appeared at the 1950s- 1960s and the 1980s identified from the monthly rainfall record of Guangzhou City (LIN and WU, 1996) are also reflected in Fig. 5, showing that our results is credible and accurate. Moreover, from the 15a time-scale we can find that the dry-wet evolvements in Guangdong also have an evident periodicity (Fig. 5) embodied by a 210a cycle.

In a word we can believe that waterlogged period will exist in Guangdong in the 21th century on the above 120a time-scale analysis. From 2000 (± 5 years) it has been in the drought stage, which will reach the most drought level at about 2010 (± 5 years). The drought conditions will continue to 2040 (± 5 years) or so and before that low intensity waterlogged period will also appear. After 2040 (± 5 years) great intensity waterlogged period will appear in Guangdong. Moreover in future several even hundred years, the changing tenden-

cy of dryness-wetness in Guangdong will increase greatly.

4 DISCUSSION

4.1 Influence of El Niño Event on Drought and Flood For what relations actually existed in the sequences of the El Niño events and the drought and flood disasters, we think it a valid way to find out the correlative relations between the disasters and the El Niño events by referring them from the historical literatures. As no consolidated conclusions to the division of the El Niño events at present, previous studies (ZHANG and XUE, 1994; GONG and WANG, 1998) coming down to the influence of the El Niño events mainly took the "El Niño year" as an unit, but the "El Niño year" determined by different scholars was always different from each other, the El Niño year sequence we used in this paper was only deter-

mined by WANG (1990), in order to avoid the differences that different sequences may have as far as possible.

Up to now, there were few studies focusing on the relations between the El Niño events and the natural disasters happened in historical period in Guangdong Province. Some studies (XUE et al., 2004; XU et al., 1998) indicated that looking Guangdong Province as a whole, the El Niño events had few influence on the occurrences of the drought and flood disasters from the viewpoint of the historical course. But the authors here discovered an interesting phenomenon that if we divide the whole Guangdong Province into four regions (Fig. 1) according to the traditional terrain region division, we can find that the El Niño events have remarkable correlations (Person correlation coefficients are respectively 0.337, 0.391, $\alpha = 0.05$) with the drought disasters happened in the north and west of Guangdong Province, but no remarkable relations between the El Niño events and the flood disasters took place in the whole Guangdong Province. As we have mentioned before (XUE et al., 2005), the areas with great droughts and floods distribution changes were mainly distributed in the west and the north of Guangdong according to the historical course. The authors thought it should not be only one kind of accidental phenomenon that may have its inevitability and the El Niño events actually intensified the regional differentiations of the drought and flood disasters in a certain extent.

4.2 Influence of Monsoon on Dry-wet Evolution

Obviously, the fluctuation of the moist index sequence can reflect the processes and characteristic of regional climatic dry-wet changes. From Fig. 2, the fluctuations of the moist index during 1480–1940 in Guangdong Province are identical with the ^{18}O record of the GISP2 ice core in Greenland that is usually used to indicate temperature and the winter temperature series of east China (GE et al., 2002). In general, lower I (indicating dry climate) corresponds to lighter ^{18}O (indicating cold climate) and high I (indicating wet climate) corresponds to heavier ^{18}O (indicating warm climate). This kind of evident monsoonal disposal pattern of moisture and temperature indicates that the dry-wet changes in Guangdong with low latitude are of extensive regional similarities, and is deeply influenced by the East Asian monsoon circulation.

Studies have shown that among the terrestrial summer precipitation in China, 56% comes from the South China Sea, 33% from Indian Ocean southwest vapor current, and the vapor taken by east-south monsoon that is driven

by west Pacific sub-tropic high only accounts for 11% (CHEN et al., 1991). Due to specific geographic location of Guangdong, it is sure that the vapor from different sources mentioned above is able to affect this area. But up to now, we do not know the extents of their individual influence. From a 30Ma record revealed by the tropic deep sea sediment taken in the South China Sea, East Asian monsoon evolution has been undergone the influence of both orbital and ice volume forcing and shows distinct tropic process (WANG et al., 2003). From Fig. 2, the visually significant correlation between the moist index and ^{18}O record of GISP2 ice core reflects consistency between the high latitude polar climate and low latitude continental monsoon climate change on decadal-to centennial-scale. The dynamic mechanism analysis of modern East Asian monsoon shows that high frequency oscillations of East Asian monsoon closely relate to the frequent intrusions of high latitude cold air mass (ZHANG, 1984). The East Asian winter monsoon is the most active factor of East Asian monsoon system (DING et al., 1995). In LIA, the Siberia Cold High and polar front shifted southward evidently, and resulted in the East Asian winter monsoon circulation being strengthened apparently (YOSHINO, 1978). The decrease of moist index in cold intervals during LIA in Guangdong closely relates to these processes. So the fluctuation of moist index sequence during LIA in Guangdong can be considered a good reflection of East Asian monsoon evolution.

Some studies also indicate that in the cold intervals, lower temperature, hyper-unstable climatic conditions and the essential changes in Asian monsoon system (SU, 1999) probably resulted in drastic change in the distribution of the dryness and wetness in Guangdong. Another study shows that during various climatic periods during LIA, the influences of westerly force on East Asian summer monsoon were different (BRYAN and MURRAY, 1977; ZHENG and FENG, 1985), which can probably be considered another cause, leading to changes in the distribution of the dryness and wetness in Guangdong.

4.3 Possible Relationship Between Dry-wet Evolution and Solar Activity

The quasi 2a to 7–8a climatic cycle is often considered to result from the inter-oscillations of climate system, and other longer cycles of climate change are regarded as result of external forcing, such as solar forcing (YAN, 1994). The basic cycle of sunspot, which is often used to represent solar activities, is about 11a (varying between 11 to 16a). The distinct periodicities of 11a, 22a exhibit in the dust record of GISP2 ice core (RAM et al., 1997),

believed to be associated with the Schwabe, Hale solar cycles respectively. The cycle of 11.8a was found in reconstructed sequence in the middle and lower reaches of the Changjiang (Yangtze) River in China (JIANG et al., 2004). Climatic changes of dryness-wetness in the past 300 years in the western China show quasi cycle of 30a (LI et al., 2003). Spectral analysis of the 87-a rainfall record of Guangzhou City (from 1903 to 1990AD) revealed pronounced 7a, 11a and 30a peaks (LIN and WU, 1996). In this paper, our results obtained from the moist index sequence and the other two sequences match these periodicities in surprising well. ZHONG Wei's research (2004) indicated that the similarity of periodicities and phase correlations of climatic changes indicated a possible teleconnection of decadal and centennial scale global climate fluctuations through common solar forcing. LEAN and RIND (1999) think that during the LIA, prior to 1850, solar forcing played major influence in climate variation, but since 1900 then, with the strengthening of artificial influences, solar forcing became less gradually. So, we think that the forcing of the historic dry-wet change and occurrence of drought-flood disasters in Guangdong relates to multi-causes, including the solar forcing.

5 CONCLUSIONS

Based on the historical records in Guangdong Province during the historical period, the moist index sequence was reconstructed and analyzed by the correlation analysis, wavelet analysis and power spectrum analysis. From the analysis above, we can primarily draw some conclusions as follows:

(1) The moist index sequence mainly includes some periodicities such as 7a, 11- 15a and 23a. The multi-scale analysis indicates that Guangdong will persist in the dry periodicity before 2040 (± 5 years) though some little waterlogged periodicity will also exist, and after that great waterlogged disasters maybe take place in Guangdong Province. We think that in several even hundred years, the variety range of the dryness and wetness has the increasing tendency in Guangdong Province.

(2) From the viewpoint of the historical course, the El Niño events had evident correlations with the droughts that happened in the west and north of Guangdong Province, which in a certain degree intensified the dryness and wetness distribution patterns in these areas.

(3) Good correspondence relations existed among the moisture index sequence, GISP2 ice core oxygen isotope record and the winter-half-year temperature sequence in East China, which shows an apparent monsoonal dispos-

al pattern of moisture and temperature. This kind of evident monsoonal disposal pattern of moisture and temperature indicates that the dry-wet changes of the low latitude Guangdong Province are of extensive regional similarities, and are deeply influenced by the East Asian monsoon circulation.

(4) By applying the wavelet analysis to dealing with the data, several apparent periodicities are revealed, among which some can be attributed to the solar forcing. At the same time, the ENSO events, the monsoon (especially the East Asian monsoon) activity and the human activity may also have some influences on the periodicities of the climatic changes in Guangdong Province.

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