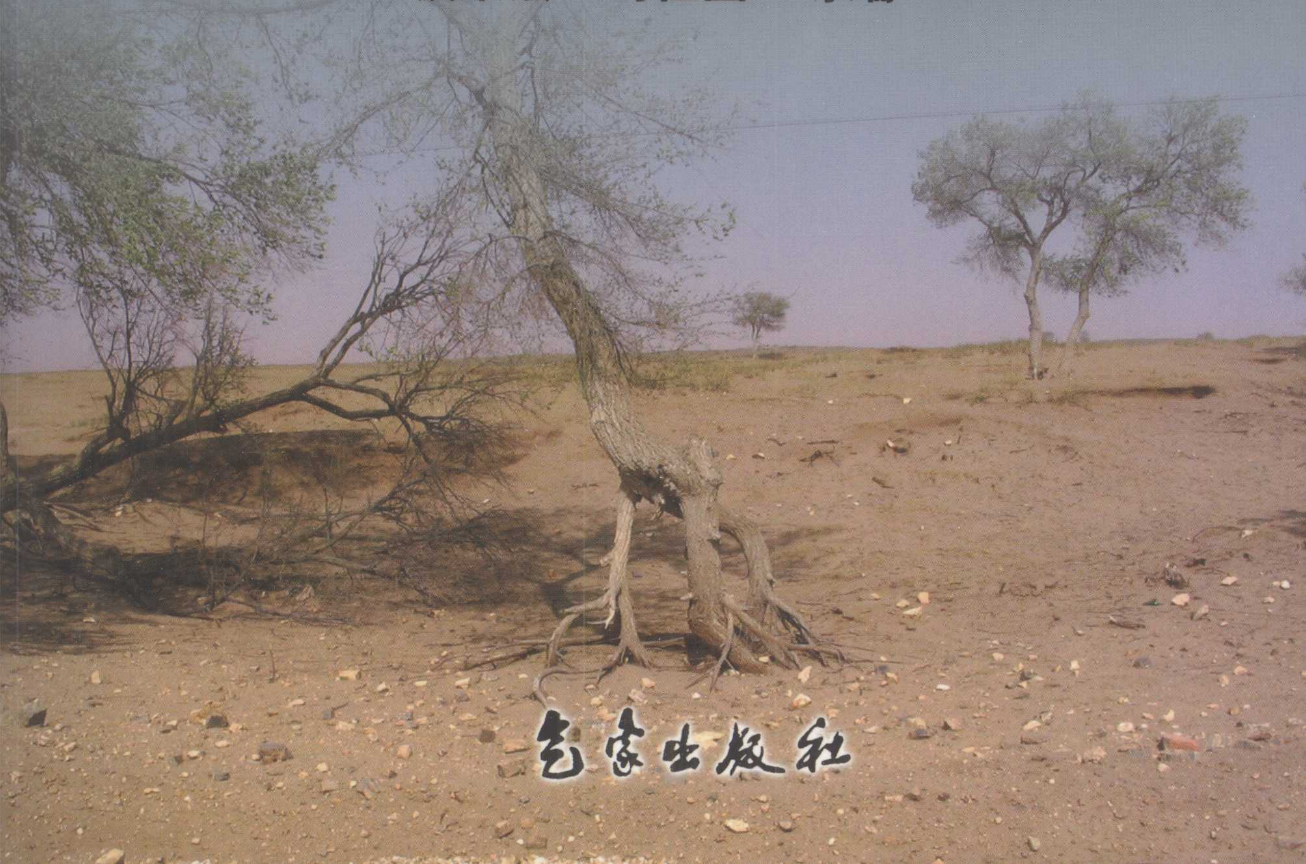
《国家重点基础研究发展规划》项目
我国生存环境演变及北方干旱化趋势预测研究(G1999043400)(二)

北方干旱化的趋势分析和预测研究

钱维宏　马柱国　等编



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内容提要

本集是《国家重点基础研究发展规划》"我国生存环境演变和北方干旱化趋势预测研究"项目论文集的第二集。它集中反映了本项目在我国北方地区近代干湿变化规律及预测方法研究等方面的研究内容。本集共收入有关论文22篇，主要包括了以下几部分的研究成果：

(1) 基于多种气候环境要素，综合分析10～100年时间尺度上北方地区环境干湿演变规律和空间分布格局；

(2) 我国北方极端干湿事件在不同气候背景和不同时间尺度下发生频率和强度的变化规律；

(3) 发展和完善线性和非线性预测模型，开展未来10～50年时间尺度上我国北方干旱化发展趋势的预测试验。

本书可供从事大气科学、环境科学、生态保护、农业科学的有关科研、管理部门和有关院校师生参考，并可供防灾减灾部门和从事全球变化研究的科研人员参考。

Beifang Ganhanhua de Qushi Fenxi he Yuce Yanjiu

北方干旱化的趋势分析和预测研究

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序

北方干旱化是我国最严峻的生存环境问题之一。20世纪90年代中期以来，这一问题进一步加剧，其中1999～2001年的干旱面积超过了北方地区总面积的40%。近5年（1999～2003年）干旱所造成灾害的面积占所有气象灾害面积的60%以上，比前10年平均增长了10个百分点。科学地认识北方干旱化的形成机理及其发展规律、预测其未来发展趋势（继续加剧还是缓解、甚至逆转）并评估其社会经济影响，进而提出合理的适应对策是国家在战略决策层面上的迫切需要。

在国家科学技术部的《国家重点基础研究发展规划》“我国生存环境演变和北方干旱化趋势预测研究（G1999043400）”的资助下，来自中国科学院有关研究所、教育部有关院校、中国农业科学院和中国气象局等十九个单位的九十多位专家组成的项目研究队伍针对国家对北方干旱化趋势预测、影响评估和对策问题上的重大需求，围绕“干旱化的发展规律和形成机理”的关键科学问题，以全球变化科学理论为指导，运用多学科交叉的集成分析、生态系统的观测实验和数值模拟方法，重点研究由水、土、气、生组成的生存环境变化的自然规律，揭示全球增暖以及人类活动对干旱化影响的过程和机理。在此基础上发展干旱化趋势预测和影响评估的理论和方法，以及组织有序人类活动、适应和缓解干旱化的科学途径。

5年来，项目组成员围绕以上关键科学问题，通过野外考察和取样、实验室分析、数据的处理和计算分析、生态系统的观测实验、数值模拟等，重建了我国北方生存环境干旱化长期演变历史，为认识干旱化的发展规律和形成机理提供了重要的自然背景；系统地分析了北方干湿变化的规律，检测全球增暖对干旱化的可能影响；发展了区域环境系统集成模式并应用于项目研究，为干旱化趋势预测和有序人类活动的虚拟试验提供了工具；系统分析了土地和水资源利用与干旱化的关系，建立了干旱化对水、土、农影响评估模拟模型，并对未来50年的干旱化影响做出了系统评估，给出了地理分布；系统地开展了北方典型生态系统对干旱化的响应和适应的观测实验和模拟研究（包括植株、种群和生态系统三个层次）并提出了相应的适应对策；开展了人类对干旱化有序适应的观测、数值虚拟试验和生态示范区的建设。另外，围绕项目的科学目标，分别就干旱指数的建立和比较、干旱化发展趋势集成预测、综合影响评估和形成机理进行了项目层次上的跨课题的集成研究，取得了明显效果。

项目执行5年来，科研人员取得了一批重要的研究结果，在国内外产生了重大影响，提高了我国科学家在国际全球变化研究领域的学术地位。为了集中总结和交流本项目的研究成果，项目专家组编辑了这套论文集：

第一集：中国北方干旱化的历史证据和成因研究

第二集：北方干旱化的趋势分析和预测研究

第三集：区域环境系统集成模式的发展和应用研究

第四集：北方干旱化对农业、水资源和自然生态系统影响的研究

第五集：人类对北方干旱化的有序适应——观测、虚拟试验和实验研究

《国家重点基础研究发展规划》项目（G1999043400）

我国生存环境演变和北方干旱化趋势预测研究

项目首席科学家　符淙斌　安芷生

2004年9月15日

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前　言

本集是《国家重点基础研究发展规划》“我国生存环境演变和北方干旱化趋势预测研究”项目论文集的第二集。它集中反映了本项目在我国北方地区近代干湿变化规律及预测方法研究等方面的研究内容。本集共收入有关论文 22 篇，主要包括了以下几部分的研究成果：

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钱维宏　马柱国

2004 年 10 月 10 日

目 录

Centennial-Scale Dry-Wet Variations in East Asia

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Abstract

This study attempts to combine four independent long-term climatic data and modern observations into one cohesive set; to describe the spatial and temporal patterns of variability of dry and wet periods in East Asia over the past one thousand years; and to examine physical causes of the pattern variations. The data include the 220-year observed precipitation in Seoul, South Korea, the dryness-wetness intensity data in eastern China for the last 530 years, and other two independent chronologies of dryness-wetness grades in the past millennium in eastern China based on instrumental observations and historical documents. Various analysis methods including wavelet transform and rotated empirical orthogonal function were used in revealing climate variations from these datasets. Major results show that the dry and wet anomalies initially appeared in the north part of eastern China and then migrated southward to affect south China. This process is repeated about every 70 years. However, in contrast in the last two decades of the twentieth century a dry situation appeared in north China and a wet climate predominated in the south part of the country. The multidecadal variations of the monsoon circulation in East Asia and the thermal contrast between inland Asia and its surrounding oceans may contribute to the dry-wet phase alternation or the migration of dry-wet anomalies. In regional scale variations, a consistent dry or wet pattern was observed spreading from the lower Yangtze River valley to South Korea. Frequencies of severe dry-wet situations were low in the eighteenth and nineteenth century and they were higher in the twentieth century. The recent increasing trend in frequencies of severe dry-wet chances occurred along with global warming and regional climatic changes in China.

1 Introduction

In China, droughts and floods have caused the largest economic losses among all natural disasters in 1949 – 1995 (Damage Report 1995). During these 47 years, there were 12 severe droughts occurring in at least one of the major river basins in China. These droughts seemed clustered in three periods i.e. 1959 – 1961, 1978 – 1982 and 1986 – 1994. In 1986 – 1994, for example, six severe droughts occurred. In the last decade alone, three major floods also occurred in the summers of 1991, 1998, and 1999 in the lower Yangtze River valley and northeastern China, resulting in tremendous losses in human life and property damages. The frequent recurrence of the floods and droughts in recent decades suggests a rise in the frequency of severe droughts/floods in eastern and southern China. It is important to understand such changes in severe droughts/floods in the historical context and identify possible mechanisms for these disastrous climate events. Such an understanding will give us the ability to predict droughts/floods in the future.

To gain such knowledge, we need to first understand how droughts/floods varied in the past. This information may disclose long-term trends and multidecadal and centennial scale climate variations influencing the occurrence of droughts/floods. Further understanding of the processes or causes of these trends and variations, may help us to identify the ones that can be used to project the course of future climate (Bradley and Jones 1992). In this study, we examine historical data for the last 1000 years in the East Asia in order to understand centennial-scale alternations of the region's wet and dry climate and potential causes of the variations.

China, Korea, and Japan are located in East Asia. Previously, rainfall patterns of these three countries have been investigated separately, and little attention has been given to relationships of regional rainfall patterns (Qian et al. 2002). For example, the dry-wet variations can be found from individual studies for different historical periods for Korea (Cho and Na 1979; Kiln 1992; Lim and Jung 1992), Japan (Murata 1992), and eastern China (Wang and Zhao 1979; Ronberg and Wang 1987; Wang 1988; Jiang et al. 1997; Song 1998, 2000; Hu and Feng 2001; Qian and Zhu 2001, 2002). As yet, no cohesive understanding has been developed. In order to understand long-term droughts/floods variations in East Asia a long-term series of wet-dry data needs to be developed from the different data sources.

To develop such a cohesive historical dataset, we use modern observations and several historical dry-wet data series derived from ancient Chinese documents. These historical data series were used in several previous studies, but only a single data series was applied in individual studies. In this study of droughts/floods variations, we construct a cohesive data series from the existing historical data series. These data series are described in the next section, followed by discussion in Sect. 3 on their extension to recent decades using the instrumentation records. In Sect. 4, we use the data and derive the dry-wet principle components and their variations from rotated empirical orthogonal function and wavelet transform calculations. In Sect. 5, previous approaches used to derive frequency of wetness/dryness are reviewed, and dry-wet intensity changes in six regions in China are derived from historical data series. In Sect. 6, indices measuring wetness and dryness in eastern China for the past 1000 years are obtained and their variation relationships in different river basins are analyzed. In Sect. 7, the derived data are used to examine centennial- scale variations in wetness and dryness and their relationship with variations in the East Asian monsoon systems. Multidecadal circulation change and its possible forcing effect on dry/wet anomalies are examined in Sect. 8. Section 9 contains the conclusions.

2 Data Sources

2.1 Dry-Wet Intensity (DWI)

Since the 1970s, Chinese climatologists have collaborated in an effort to extract climatic information from over 2000 historical documentary records for the last 530 years beginning in 1470. These records included the government weather book "Clear and rain records" and local government drought/flood reports and private diaries. A product of this effort is the *Yearly charts of dryness/wetness in China for the last* 500 *years* (Central Meteorological Bureau 1981). In this dataset, the summer season climate (May-September) was categorized into dry and wet intensity (DWI) on a scale of 1 to 5, from very wet (flood, 1), wet (2), normal (3), dry (4), and very dry (drought, 5), for each summer in the 530 years from 1470 to 1999 for 120 sites in China. The DWI records in this dataset for the recent decades after instrumentation observations became available are calculated from measured rainfall in the months of May-September based on methods described in Tang (1988), Zhang (1988), and Zhang and Crowley (1989). Statistical properties, for example, consistency and persistency, of this DWI data series have been carefully examined and established (Yao 1982; Ronberg and Wang 1987).

Recently, this unique historical dataset has been used to understand climate variations in China. For instance, Hu and Feng (2001) analyzed the DWI data (1470 – 1997) from 65 of the 120 sites and found a centennial-scale southward migration of droughts/ floods in eastern China. Song (2000) used data from 100 of the 120 sites (1470 – 1998) and studied changes in dryness/ wetness in different centuries. Zhou et al. (2002) studied chaotic features of floods using data from the sites in the Huaihe River Basin over the time period 1470 – 1991.

In this study, we use the DWI data from 100 sites in eastern China from 1470 to 1999 (Fig. 1). This data length and spatial coverage are similar to that in Song (1998, hereafter S98) but our study subjects and analysis methods are different.

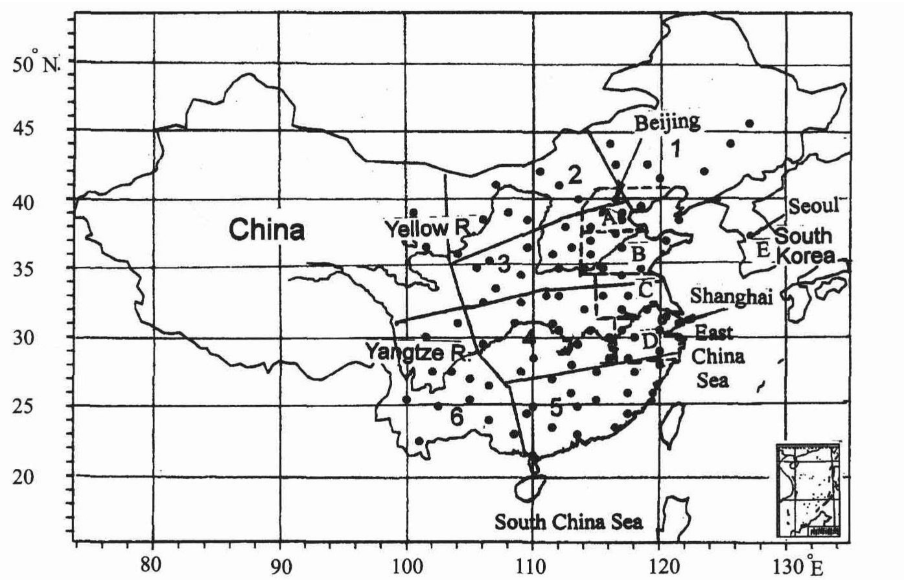

Fig. 1. Geographic distribution of the 100 sites selected in eastern China. Geographical location of the six study regions: 1 is northeast China, 2 is northern north China, 3 is the mid- and lower Yellow River, 4 is the mid- and lower Yangtze River, 5 is south China, and 6 is southwest China. The lettered regions, *A*, *B*, *C*, *D* indicated four regions divided by the *dashed lines* in east China and *E* is South Korea. The Yellow River and the Yangtze River are *labeled*

2.2 Wang's Type (WT) and Derived Wang Indices (WI)

In a comparison analysis, Wang (1988) examined the empirical orthogonal function (EOF) derived from the data in *Yearly charts of dryness/wetness in China for the last* 500 *years*, and from instrumental data for the recent decades. His EOF results confirmed that the two data sets are nearly identical in spatial variations, confirming that the conversion from the instrumentation data to the wet/dry intensity scale is reliable. While examining the data consistency, Wang et al. (1987) explored additional historical sources of rainfall information and were able to extend the historical rainfall records from 1470 back to AD 950. With this data consistency, Wang (1988) extended his series to the last 1000 years, and found six wet-dry anomaly patterns in eastern China. He named them pattern A through F (Fig. 2) and used them to describe annual rainfall anomaly in eastern China from AD 950 to 1980. His result was a series of letters A to F for each year in the period. This chronology of rainfall anomaly patterns has been referred to as Wang's type (WT).

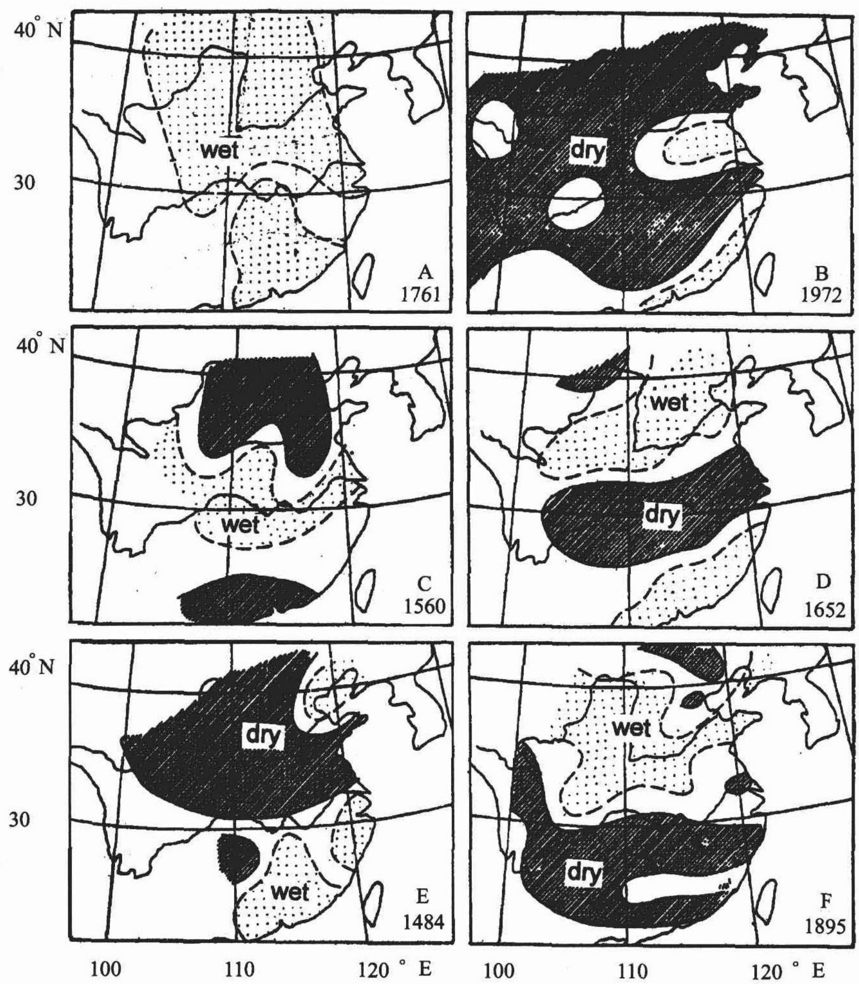

Fig. 2. Examples of the six different types in WT. The *shaded area* indicates dry and the *stippled area* denotes wet conditions in the specific years

Although the WT series described variations of summer rainfall anomaly patterns, its letter series made it difficult for quantitative evaluation of multidecadal and centennial scale variations of wet-dry conditions in eastern China. To resolve this problem, we examined the six patterns and found that they can be paired in three groups, each of which has two patterns. In each pair, one pattern is a nearly reverse of the other as shown in Fig. 2. The top two panels in Fig. 2 are examples of a pair that has a wet summer in the eastern half of China, pattern A, and a nearly reversed pattern, pattern B, corresponding to a dry summer in the region. The middle pair in Fig. 2 has one pattern with wet summer in the mid and lower Yangtze River regions and dry conditions in both the north and south of the river basin, pattern C, has a reversed pattern,

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pattern D. Patterns E and F in the third pair in Fig. 2 have rainfall anomalies of opposite signs in northern and southern China with near average rainfall along the corridor of the Yangtze River.

These features in the WT allow us to define a scale to represent rainfall anomaly intensity in different regions in China. In particular, for the Yangtze River basin, pattern C with very wet conditions in the basin is assigned + 2 and pattern D with very dry conditions in the area is assigned − 2. In patterns A and B, the area has moderately wet and dry conditions and is assigned values + 1 and − 1, respectively. Because both patterns E and F correspond to nearly normal rainfall in the area, a 0 is assigned for the area. As a result, we have transformed the WT into a series of numerical indices describing intensity of summer rainfall anomalies. We named this index series Wang indices (WI). The WI for the Yellow River basin and southern China are defined in a similar manner and their scales and corresponding WT are given in Table 1.

Table 1. Characteristics and typical years of WT, and corresponding WI in the Yellow River valley, the Yangtze River valley, and south China

WT Characteristics	Typical year	WI		
		Yellow River	Yangtze River	South China
(A) Wet larger part	1761	+1	+1	+1
(B) Dry all China	1972	−1	−1	−1
(C) Wet in the Yangtze River	1560	0	+2	0
(D) Dry in the Yangtze River	1652	0	−2	0
(E) Wet south and dry north	1484	−2	0	+2
(F) Wet north and dry south	1895	+2	0	−2

2.3 Zhang's Indices (ZI)

In addition to the WT, another series of indices describing dry-wet condition also were developed for a six regions in eastern China but only the four smaller coastal areas, A, B, C, and D have been used here (see Fig. 1). Region A covers the Hebei Province, including Beijing and Tianjin districts. Region B is in the lower part of the Yellow River and Shandong Province. Region C is in the Huaihe River Basin north of the lower Yangtze River. Region D is from south Jiangsu Province to Zhejiang Province south of the lower Yangtze River. Both the "Clear and rain record" of the eighteenth and the nineteenth centuries, which described primarily the dry-wet conditions in regions A and D, and additional documentary records discovered by Zhang and his colleagues, e.g. Jiang et al. (1997), describing the dry-wet conditions in Regions B and C were used to derive a 5-scale dry-wet intensity series for each of the four regions. These series have been referred to as Zhang's indices. In this study, we use Zhang's indices from 1777 to 1992 and analyze the dry-wet variations in the east coastal areas in China to compare them with variations in rainfall anomalies in Korea whose longest wet-dry records start from 1777 (see Sect. 2.5).

2.4 A Comparison of the Indices

To summarize the four dry-wet indices, i.e. DWI, WT, WI, and ZI, and their differences, we prepared Table 2. This shows that DWI has the largest spatial coverage and a total of 120 sites in China. It has a shorter time length from 1470 to 1999, however. The other three indices, particularly the ZI, are for relatively smaller regions but have a longer record length starting in AD 960. The indices, except for WT, have five similar numerical scales measuring intensity from very wet to very dry although WI uses a different numbering method. WI has three series for the Yellow River basin, Yangtze River basin, and south China from AD 950 to 1999. Indices ZI have four series for four regions along the east coasts of China from AD 960 to 1992.

Table 2. Similarities and Differences of China Dry-Wet Indices (DWI), Wang's Type (WT), Wang Indices (WI), and Zhang's Indices (ZI)

Index name	DWI	WT	WI	ZI
Index value	5 classes	1 type/year	5 classes	5 classes
Data series	120	1	3	4
Spatial coverage	120 sites in China	Eastern China (3 river valleys)	Eastern China (3 river valleys)	4 regions in eastern China
Record length	1470 - 1999	950 - 1999	950 - 1999	960 - 1992

The quality of the data series is similar because they were derived using similar data sources although ZI and WI (WT) may have used additional sources of historical documents from regional collections. Various evaluations of these indices for different historical periods have shown their consistency.

2.5 Korean Rainfall (KR)

Korean rainfall (KR) data are used in our comparison of the rainfall variations with that in eastern China. The data are from instrumental records for the last century from a few sites in Korea. In addition, historical rainfall data in Seoul, Korea are used, and these data were produced from traditional Korean rain gauge measurements in Seoul from 1777 to the beginning of the last century (1907) (Lim and Jhun 1992; Jung et al. 2000). In the Korean rain gauge measurements, the precipitation amount was measured using Korean measurements such as "Pun", "Chi", and "Cha", which correspond approximately to 2, 20, and 200 mm, respectively. These early notations of rainfall were converted into modern numerical values with consistent accuracy (Cho and Na 1979; Lim and Jhun 1996).

2.6 Atmospheric Circulation Data

It is perceived that dry-wet alternations in China, Korea, and Japan will be connected and affected by variations in various summer monsoon systems in East Asia. Several recent studies have shown that the seasonal shifts of the East Asia rainfall zones are linked to the movement of the monsoon fronts and the subtropical high in the northwest North Pacific (Lu 2001; Qian et al. 2002; Kim et al. 2002). Depending on the shift, the northward extension and intensity of the monsoon circulation in the summer months, moisture processes in the atmosphere and rainfall develop differently in eastern and northern China. Because the moisture advection is the largest near the 850 hPa level, moisture processes in the atmosphere associated with monsoon have often been evaluated using 850 hPa circulation. In this study, we examine summer season (June - August) atmospheric circulation changes and their relationship with the dry-wet conditions in China, using 850 hPa wind data and the 1000 hPa air temperature analyzed from the NCEP/NCAR Reanalysis Model (Kalnay et al. 1996; Kistler et al. 2001). The Reanalysis data have a spatial resolution of 2.5° × 2.5° and are for the period 1948 – 2000. To reveal the anomalous features of summer rainfall in China for the recent times, meteorological data for the last 50 years from 160 stations in mainland China are used.

3 Analysis Methods

Spectral analyses and wavelet transform methods are used in this study to reveal various variation components in the historical data series. Wavelet transform has been widely applied in signal detection from climate data series (e.g. Lau and Weng 1995; Jiang et al. 1997). The method is a powerful way to characterize the frequency, intensity, time position, and duration of variations in a climate data series. As a unique feature, the transform reveals localized time and frequency information without requiring the time series to be stationary as required by the Fourier transform and other spectral methods. Two kinds of function different in their symmetry are widely used in wavelet transform. A symmetric wavelet is the second derivative of a smoothing function and is optimal for finding maximum curvature in variations. The 'Mexican hat' wavelet is the second derivative of the Gaussian function, and is able to localize unstationary frequencies (Brunet and Collinean 1994).

We adopted the 'Mexican hat' wavelet in this study to analyze each dry-wet series and rainfall dataset. Details of the wavelet transform formulae and 'Mexican hat' functions are described in Jiang et al. (1997). According to the definition of the wavelet function, the scale parameter a represents the time-scale of the function. A smaller a value refers to a shorter scale or a higher frequency. The location parameter b corresponds to the time points in a year-to-year sequence. In order to detect climatic variations on decadal and centennial scales, we ran computations on the normalized time series (intensity indices) with the following time scale parameters: $a = 2, 3, \ldots, N/2$, through all data points, and $b = 1, 2, \ldots, N$ (N is the length of the series). Edge effects may occur originating at both the start and end point of a data series, magnifying or reducing values of the wavelet coefficients in an area near the end points, but the sign and other essential properties of the transform remain unchanged. The wavelet coefficients, $W(a, b)$, with positive or negative anomalies may represent the transitions between dry and wet condition on various time scales, a, and at different time points, b. $W(a, b) > 0$ corresponds to the dry condition while $W(a, b) < 0$ indicates a wet condition. A close pair of minimum and maximum centres of $W(a, b)$ may, show an abrupt change from one persistent spell of anomaly to another anomaly of the opposite sign, leaving the required significance threshold as an open question (Brunet and Collinean 1994). If a frequency appears at a specific time scale, regular oscillation at the time scale exists.

Another method used in this study is the empirical orthogonal function (EOF) analysis. EOF provides a convenient method for studying the spatial and temporal variabilities. Because this method splits the spatial-temporal field into a set of orthogonal modes, it allows us to examine the spatial patterns and their temporal variations separately. If the modes are ordered, each successive mode explains the maximum amount of the remaining variance in the original field. Therefore, EOF is an effective method to compress the spatial-temporal field in both space and time. This feature, related to the data-adaptive nature of EOF, does not exist in other spectral analysis methods, such as Fourier analysis.

To seek physical modes with attractive properties, we also applied the rotated EOF (REOF) analysis (Richman 1981). REOF yields a new set of principle components (PCs, or modes) after we rotate the vector space of the initial EOFs to improve physical interpretations of the original field. Some details of the EOF have been reported in several studies (e.g. Richman 1981, 1986; Kelly and Jones 1999) and will not be repeated here.

4 Dry-Wet Modes and Their Variations

We first examine the variations of the precipitation in China in recent decades. Fig.3 shows the total May – September precipitation averaged from 1950 to 1999 and its standard deviation based on 160-station data in China (Zhao et al. 1999). More precipitation is found in southern China and less in northern and western China. The standard deviation distribution reveals three large centres (hatched areas) in the lower Yellow River, the lower Yangtze River, and south China. In the rest of this study, we will focus on dry-wet alternations in these three centres.

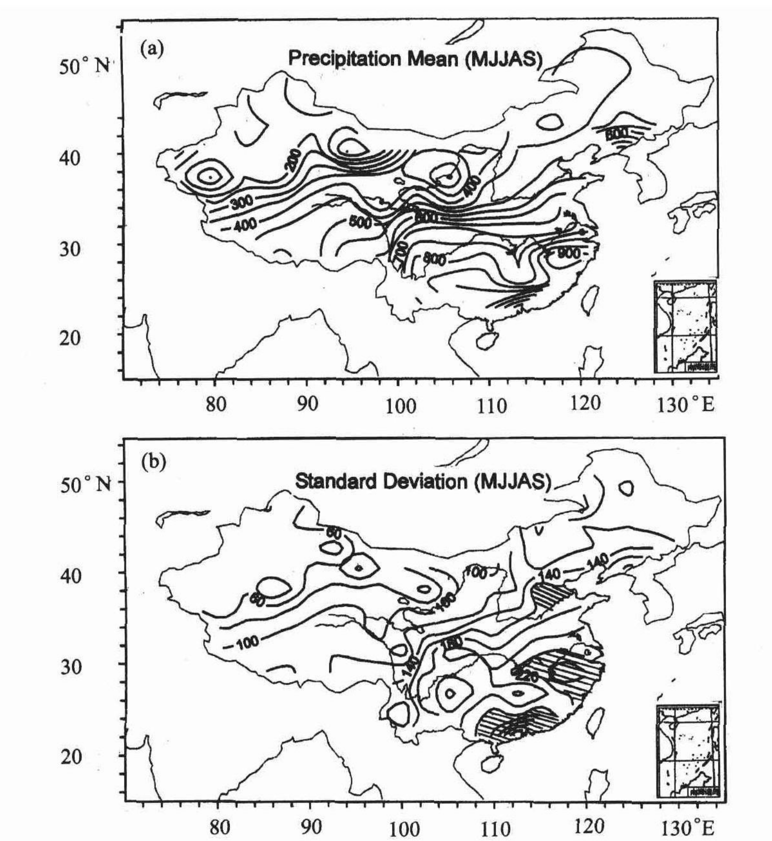

Fig.3. (a) The averaged May – September total rainfall, and (b) May – September rainfall standard deviation from 1950 to 1999. Units are mm. In (b), the *shaded areas* denote the relatively large standard deviations in the lower Yellow River, the lower Yangtze River, and south China

REOF analysis on the 100-site DWI series for 530 years in China revealed six leading principal components (PCs) (Fig. 4). A five-year running mean was applied to the data series before the REOF calculation, in order to filter out high frequency variations. The first six PCs (or modes) explain a total of 64% (12%, 11%, 11%, 10%, 10%, and 10% for mode 1 to 6, respectively) of the variances of DWI. Six centres were found and marked by A, B, C, D, E, and F in the mid-reaches of the Yellow River and the Yangtze River, the lower-reaches of the Yellow River (similar to the eigenvector 2 of the EOF results in S98), the lower-reaches of the Yangtze River (similar to the eigenvector 3 in S98), south China, northern north China (similar to the eigenvector 4 in S98), and in the south central Yangtze River basin.

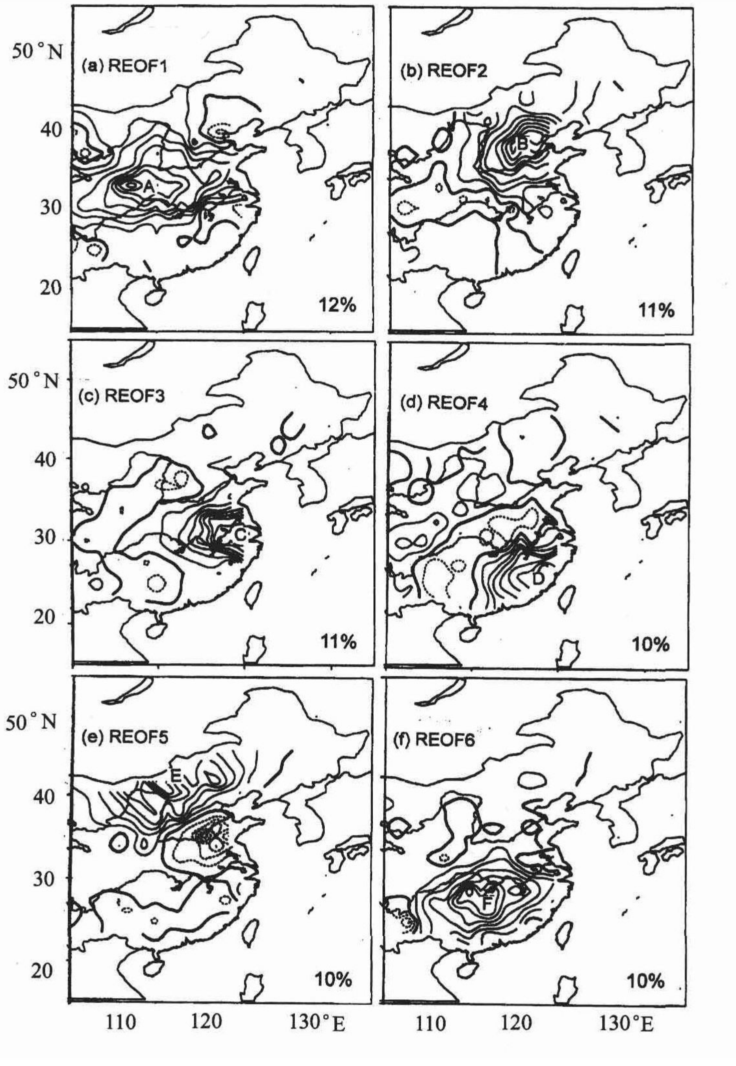

Fig.4. The first six principal components of REOF for DWI in eastern China (see text for details). The interval is 0.1. The letters, A, B, C, D, E, and F, indicate the centres of modes. *Solid lines* denote positive REOF coefficients

Interestingly, each of the six modes falls in one of the six divisions in Fig. 1, indicating different variation characteristics in each of the divisions. We pay special attention to those divisions along the east coast of China. Figure 5 shows the time series of the three modes centred in the lower Yellow River (division 3), the lower Yangtze River (division 4), and south China (division 5). The thick solid line for each mode indicates the 19-year running mean of the time series. In these time series, positive values denote dry conditions and negative values wet situations.

In our previous work (Qian and Zhu 2001), an analysis of annual precipitation for the last 120 years in seven sub-regions in eastern China showed that opposite signs of long-lasting or persistent precipitation anomalies were noted between north and south China with a secular variation starting from north China. Using the DWI series, Hu and Feng (2001) found a southward migration of centennial variations of dryness or wetness in the last 500 years in eastern China as well as in the western United States. Consistent with the migration result, the dashed-lines in Fig. 5, connecting the low points of the running curves, indicate similar migration of the wet maximum from one region to the next one south of it. A quasi-70-year oscillation can be

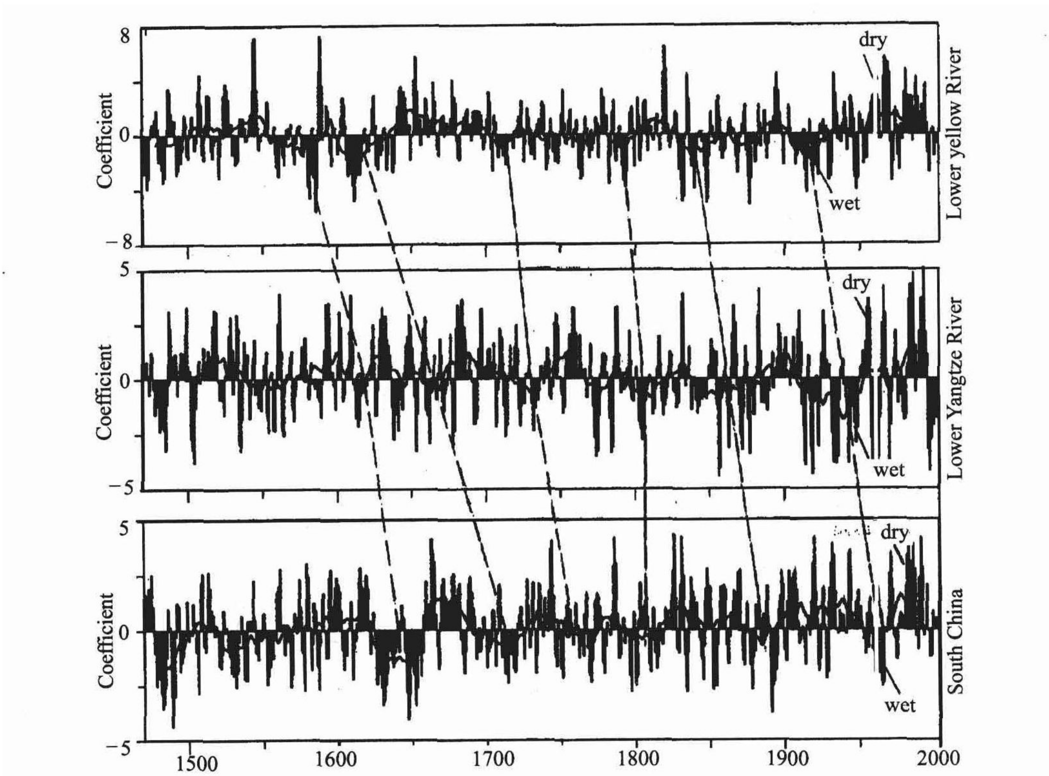

Fig. 5. Time series of three modes along (*upper*) the lower Yellow River (*B*), (*middle*) the lower Yangtze River (*C*) and (*lower*) south China (*D*) in Fig. 4, calculated from REOF. The *heavy line* denotes the 19-year running mean and the *dashed lines* join the wet maximum across the different valleys. A positive coefficient denotes dry climate

inferred from the running curves. The last dashed-line indicates a similar southward migration with a wet maximum from the lower Yellow River in the early twentieth century, crossing the lower Yangtze River by 1940s, to south China in the 1950s and 1960s. It is interesting to notice that after the eighteenth century relatively regular oscillation and phase relations are found from these variations.

Zhu and Wang (2001) also showed an 80-year oscillation of summer rainfall in eastern China. By performing the wavelet transform from the third mode in the lower Yangtze River, a major dry-wet alternation at the time scale of about 70 years persisted since 1750s but an 80 – 90-year oscillation was noted in the earlier years (Qian and Zhu 2002). In the 70-year variation, two wet periods occurred in the last century, one in 1920s – 1940s and another one staring since mid

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