DROUGHT/FLOOD VARIATIONS IN EASTERN CHINA DURING THE COLDER (1610-1719) AND WARMER (1880-1989) PERIODS AND THEIR RELATIONS WITH THE SOUTHERN OSCILLATION

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Abstract The drought/flood index in eastern China, with five drought/flood grades which are 1 (very wet), 2 (wet), 3 (normal), 4 (dry) and 5 (very dry), is used to explore and compare interannual and decadal drought/flood changes in 1610-1719 and 1880-1989. The period 1610-1719 is the coldest epoch during the Little Ice Age and the period 1880-1989 is a relatively warmer epoch in the recent 400 years.

The annual rates of long-term tendency in 1610-1719 in the middle-upper reaches of the Yellow River, the down reaches of the Yangtze Valley and Huabei (the north part of eastern China) are -0.35%, -0.09% and -0.41% respectively. The annual rates of long-term tendency in 1880-1989 in the three regions are 0.24%, 0.42% and 0.49% respectively. The largest lagged-one auto-correlation for drought/flood index in 1610-1719 was found in the middle-upper reaches of the Yellow River. The interdecadal changes show that the strongest fluctuations can be detected around 1645 in eastern China during 1610-1719 and around 1895 in Huabei and the down reaches of the Yangtze Valley during 1880-1989. The interdecadal changes for drought/flood index in Huabei in the two periods better correspond to large-scale coldness/warmth variability.

The Southern Oscillation Index (SOI) with the upper quartile (SOI-UQ) in summer and autumn (the latter half year) is closely associated with wet conditions in eastern China in 1904-1989, especially in Huabei. While the SOI-UQ occurred in the latter half year, their average drought/flood indices in the middle-upper reaches of the Yellow River, the down reaches of the Yangtze Valley and Huabei are 2.59, 2.73 and 2.31, respectively. The drought/flood variability in Huabei was correlated with seasonal sea level pressure (SLP) at Darwin in March-April-May (MAM). The drought/flood index in the down reaches of the Yangtze Valley is related to the SLP at Darwin in the following September-October-November (SON).

Key words: drought/flood index, eastern China, colder and warmer periods, drought/flood variation, the Southern Oscillation

1. Introduction

Many studies have shown several characteristics of long-term precipitation variations in eastern China (*e.g.*, Wang and Zhao 1978; Wang and Li 1990; Yasunari and Tian 1990; Ding 1994; Yatagai and Yasunari 1994; Liang and Wang 1995). The statistical analyses in nearly 40 years indicate that heavy rainfall all over China occurred in 1954, 1956 and 1991. On the contrary, drought occurred in several years such as in 1959, 1960, 1970 and 1972 (Li 1992). According to the statistics of the impact of dryness/wetness in China for the 2125 year period (from B.C. 206 to A.D. 1949), 1092 cases of relatively severe flood occurred once every two years on a countrywide scale (Ding 1994).

Wang and Zhao (1978, 1981) pointed out that the dominant periodicities for drought/flood in China were 2-3 years, 22 years and 36 years. They have noted that the variation for drought/flood is closely related to 500hPa mean height fields. A 15 to 40 year periodicity of precipitation exists over China in the present century (Zhang and Lin 1992). Zhang (1978) used historical records of coldness/warmth to analyze temperature variation in the south of eastern China for nearly 500 years. Mikami (1987) analyzed the relationship between drought/flood variations in eastern China and Japan in the latter part of the Little Ice Age and considered that there are remarkable associations for drought/flood variations in the two regions.

Climate variations in a 10-100 year scale are the most important to the human life, because much of the planning importance to modern civilization is based on this time span. For example, modern water resource planning is usually conceived in the context of the next 50 to 100 years. Precipitation records rarely exceed 100 years in length, and for most cases, are around 40 years. Therefore, the historical records of drought/flood index can be developed to analyze the long-term drought/flood variations.

The variation of drought/flood occurrence shows both periodic and non-periodic characteristics. External forces with non-periodic random process may cause the abrupt climatic change, which is often associated with unusual changes in temperature, atmosphere and ocean circulation.

Yamamoto and Iwashima (1985, 1986) used the annual average temperature to investigate the abrupt change of coldness/warmth in Japan, and considered that a climatic jump occurred around 1950. Recently, Wei and Cao (1995) also found the abrupt change of annual average temperatures in China in the early 1950s.

Concerning the climate change over the 500-600 years, Wang (1994) considered that the global climate has two remarkable variations. The first one is a colder period in the Little Ice Age, and the other is a warming period in 20th century. So far, the coldness/warmth variations have been studied by many researchers (*e.g.* Jones *et al.* 1986; Domros and Peng 1988; Li 1992; Wang 1994). Further, study of this climatological aspect would help to predict long-term climate variation in the region.

The purpose of this study is to analyze the characteristics of drought/flood for interannual and decadal variation and century trend in 1610-1719 (colder period) and 1880-1989 (warmer period) in eastern China and compare their differences for drought/flood change. Furthermore, the variation of drought/flood index connecting with the Southern Oscillation (SO) in the warmer period will be also discussed.

2. Data and Method

Data

Regional drought/flood index

Historical drought/flood index in eastern China has been used in several studies (*e.g.*, Wang and Zhao 1981; Wang and Li 1990; Liang and Wang 1995). They are classified as five grades from 1 to 5: 1 for very wet, 2 for wet, 3 for normal, 4 for dry and 5 for very dry. The drought/flood index before 1980 is obtained from the records for yearly charts of dryness/wetness in China for the last 500 years (Acad. Meteor. Sci. 1981). The index for the period 1980-1989 is obtained from the drought/flood distribution chart in 1980-1991 (Zhang 1993). 39 stations over eastern China are selected for this study. Two periods of colder (1620-1719) and warmer (1890-1989) and their transition periods of both 1610-1619 and 1880-1889 are used (Domros and Peng 1988).

The rotated principal component analysis (RPCA) is used to define the drought/flood regions in eastern China. According to the RPCA loading coefficient, three regions could be clearly classified. The variances explained by the RPCA 1-3 for the period 1610-1719 and 1880-1989 are given in Table 1a. The regions are named as the middle-upper reaches of the Yellow River (the Yellow River), the down reaches of the Yangtze Valley (the Yangtze Valley) and Huabei in 1610-1719 (1880-1989) which include 9 (8), 10 (9) and 7 (8) drought/flood stations, respectively (Fig. 1 and Table 1b). Area averaged drought/flood

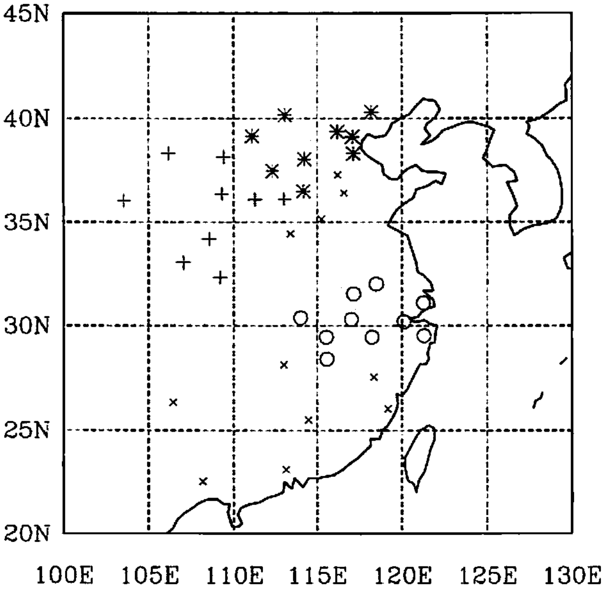

Fig. 1 Thirty-nine stations in eastern China used in this study
Plus signs: the middle-upper reaches of the Yellow River, circle signs: the down reaches of the Yangtze Valley, asteris signs: Huabei, x signs: the other stations in eastern China

Table 1a Variances explained by the first three RPCA and their corresponding areas in this study

RPCA	Period I	(1610–1719)	Period II	(1880–1989)
	Variance %	Corresponding area	Variance %	Corresponding area
1	18.85	Yellow River	17.78	Huabei
2	10.85	Yangtze Valley	11.31	Yangtze Valley
3	7.38	Huabei	8.94	Yellow River

Table 1b The stations in the middle-upper reaches of the Yellow River (A), the down reaches of the Yangtze Valley (B) and Huabei (C) in this study
On the absolute value of RPCA 1-3 spatial loading >0.1, the station numbers in 1610-1719 are 9 (A), 10 (B) and 7 (C), respectively, while the station numbers in 1880-1989 are 8 (A), 9 (B) and 8(C), respectively.

Region	No	Station	Latitude	Longitude	RPCA	spatial loading
					1610–1719	1880–1989
A	1	Yuling	38°14′	109°42′	0.20	0.17
	2	Linfen	36°09′	111°27′	0.15	0.15
	3	Changzi	36°12′	113°07′	0.11	0.07 (<0.1)
	4	Yanan	36°36′	109°30′	0.21	0.22
	5	Xian	34°18′	108°56′	0.17	0.18
	6	Hanzhong	33°04′	107°02′	0.13	0.17
	7	Ankang	32°32′	109°21′	0.14	0.16
	8	Lanzhou	36°03′	103°53′	0.11	0.10
	9	Yinchuan	38°31′	106°16′	0.15	0.21
B	10	Tunqi	29°45′	118°23′	0.20	0.17
	11	Ningbo	29°52′	121°30′	0.11	0.10
	12	Shanghai	31°10′	121°26′	0.21	0.13
	13	Nanjing	32°00′	118°48′	0.11	0.11
	14	Hangzhou	30°19′	120°12′	0.19	0.16
	15	Jiujiang	29°45′	115°55′	0.16	0.17
	16	Anqing	30°31′	117°02′	0.14	0.14
	17	Wuhan	30°38′	114°04′	0.14	0.14
	18	Hefei	31°53′	117°15′	0.13	0.16
	19	Naichang	28°40′	115°58′	0.13	0.06 (<0.1)
C	20	Peking	39°35′	116°19′	0.18	0.17
	21	Tianjing	39°11′	117°08′	0.16	0.15
	22	Tangshan	39°38′	118°10′	0.18	0.12
	23	Baodin	38°50′	115°24′	0.20	0.18
	24	Changzhou	38°20′	116°55′	0.17	0.15
	25	ShijiaZhuang	38°04′	114°26′	0.18	0.17
	26	Hantan	36°48′	114°27′	0.13	0.08 (<0.1)
	27	Danton	40°05′	113°15′	0.08 (<0.1)	0.10
	28	Taiyuan	37°47′	112°33′	0.08 (<0.1)	0.12

index in each region is constructed to indicate the regional drought/flood variability.

The seasonal Southern Oscillation Index (SOI) with the upper and lower quartile

The SOI is expressed as the standardized seasonal sea level pressure from average at Tahiti minus that of Darwin. The El Nino (warm) event corresponds to anomalous low pressure in eastern South Pacific and results in a low SOI. Conversely, the La Nina (cold) event corresponds to high SOI. Seasonal SOI data, from 1904 through 1989, used in this study corresponded to an updated version of the data reported by Ropelewski and Jones (1987) and Guetter and Georgakakos (1996).

Sea level pressure (SLP) at Darwin

The monthly SLP at Darwin from 1882 to 1990 was used in this study to analyze the association of tropical sea level pressure with drought/flood indices in the three regions.

Statistic methods used in the analysis of time series

The methods for detecting the interdecadal fluctuation of drought/flood are as follows:

The Student's t-statistic

This method is applied to analyze the interdecadal fluctuation for drought/flood. This method has been used to analyze the abrupt changes in climatic variables by Karl and Riebsame (1984), Wei and Cao (1995) and Vargas *et al.* (1995). They used this method to study the interdecadal fluctuation of temperature and precipitation variations in different areas. The principle used for detecting the climate variation is to compare adjacent two stages of drought or flood, and to detect the difference between two average stages of dryness/wetness.

The abrupt change index t is defined in the following equation:

$$t=(X_1-X_2)/(S_p(1/M+1/N)^{1/2}). \tag{1}$$

Where, $S_p^2=((M-1)\ S_m^2+(N-1)S_n^2)/(M+N-2)$, X_1 and S_m are the sample means and standard deviations over the time span covering M years before abrupt change point, respectively; X_2 and S_n are the same as X_1 and S_m but after the abrupt change point covering N years. M and N are the sample size of spans before and after the change point, and S_p is the simultaneous sample variance. If the t-value in a point is the maximum comparing adjacent points reaching the significant level at 95%, the point is considered as abrupt change time. Additionally, t-value which is higher (lower) than zero means that the change process is a transition from relatively dry (wet) to wet (dry) conditions in this study.

The signal-to-noise ratio (S/N)

The method for detecting jump-like change in climatic variables is proposed by Yamamoto and Iwashima (1985, 1986). The climatic jump was defined in the following manner. If the time average over a few decades before a jump year is different from the same average after the jump year, discontinuity in the time average can be presumed with a specified confidence limit (95% confidence level). The signal-to-noise ratio is defined as:

$$S/N = |\mu 1 - \mu 2| / (\sigma 1 + \sigma 2). \quad (2)$$

where $\mu 1$ and $\mu 2$ are time means before and after a reference year, respectively, and $\sigma 1$ and $\sigma 2$ are the corresponding standard deviations. If the S/N is greater than 1.0, a jump is detected, and the appearance of a jump is determined with the time of the maximum S/N ratio, among various combinations of $\mu 1$ and $\mu 2$.

Characteristics of climate changes can be identified by these two methods. Karl and Riebsame (1984) used Student's t-statistic to study the fluctuation of temperature and precipitation defining the time span on the scales of 10, 15 and 20 years to compare the characteristics of climatic fluctuations in the United States. Yamamoto and Iwashima (1985, 1986) used the time span length of 10 to 30 years to discuss the occurrence of abrupt climatic changes based on the maximum S/N.

The time span lengths 10, 15 and 20 years are selected as the interdecadal scale to investigate the climatic change for drought/flood occurrence in two periods. The year for abrupt change is determined by $S/N > 1$ and Student's t-value reaching significant at 95% level, simultaneously.

3. Characteristics of Drought/flood Variation in 1610-1719 and 1880-1989 in Eastern China

The time series of regional drought/flood index in 1610-1719 (the period I) is depicted in Fig. 2, which reveals a tendency of drought/flood variation toward wetness. The annual change rates of drought/flood index in the Yellow River, the Yangtze Valley and Huabei are -0.35%, -0.09% and -0.41%, respectively. On the other hand, in 1880-1989 (the period II), the annual rates in the three regions are 0.24%, 0.42% and 0.49%, respectively (Fig. 3). The century drought/flood tendency in the two periods shows consistent trend over the three regions. The annual change rate in Huabei is higher than the other two regions. On the century scale, average drought/flood indices in the Yellow River, the Yangtze Valley and Huabei are 3.09, 2.99 and 3.05 in 1610-1719, respectively. For the period II, these indices are 2.97, 2.93 and 2.96 respectively, which indicates that the average drought/flood index in the Yellow River is the largest (drought), and that in the Yangtze Valley is the lowest (flood). Table 2 shows that the auto-correlation coefficient of drought/flood index in the Yellow River in 1610-1719 was 0.50 (the highest) at significant level of 99%, and it is 0.02 in 1880-1989 (the lowest).

Comparing 30-year correlation between region to region drought/flood indices in the two periods (Table 3), it is found that the correlation coefficient between Huabei and the Yellow River for 1620-1649 is 0.64, which is the highest in 1610-1719. Moreover, the correlation between Huabei and the Yellow River from 1650-1699 is negative. In 1690-1719, the correlation coefficient between Huabei and the Yellow River is 0.47 (significant level of 99%). Domros and Peng (1988) pointed out that the 1620-1720 was the absolutely coldest period during the last 400 years. Within this period, the years from 1650-1700 are the peak of the coldness; snow was often observed in the tropical regions of southern

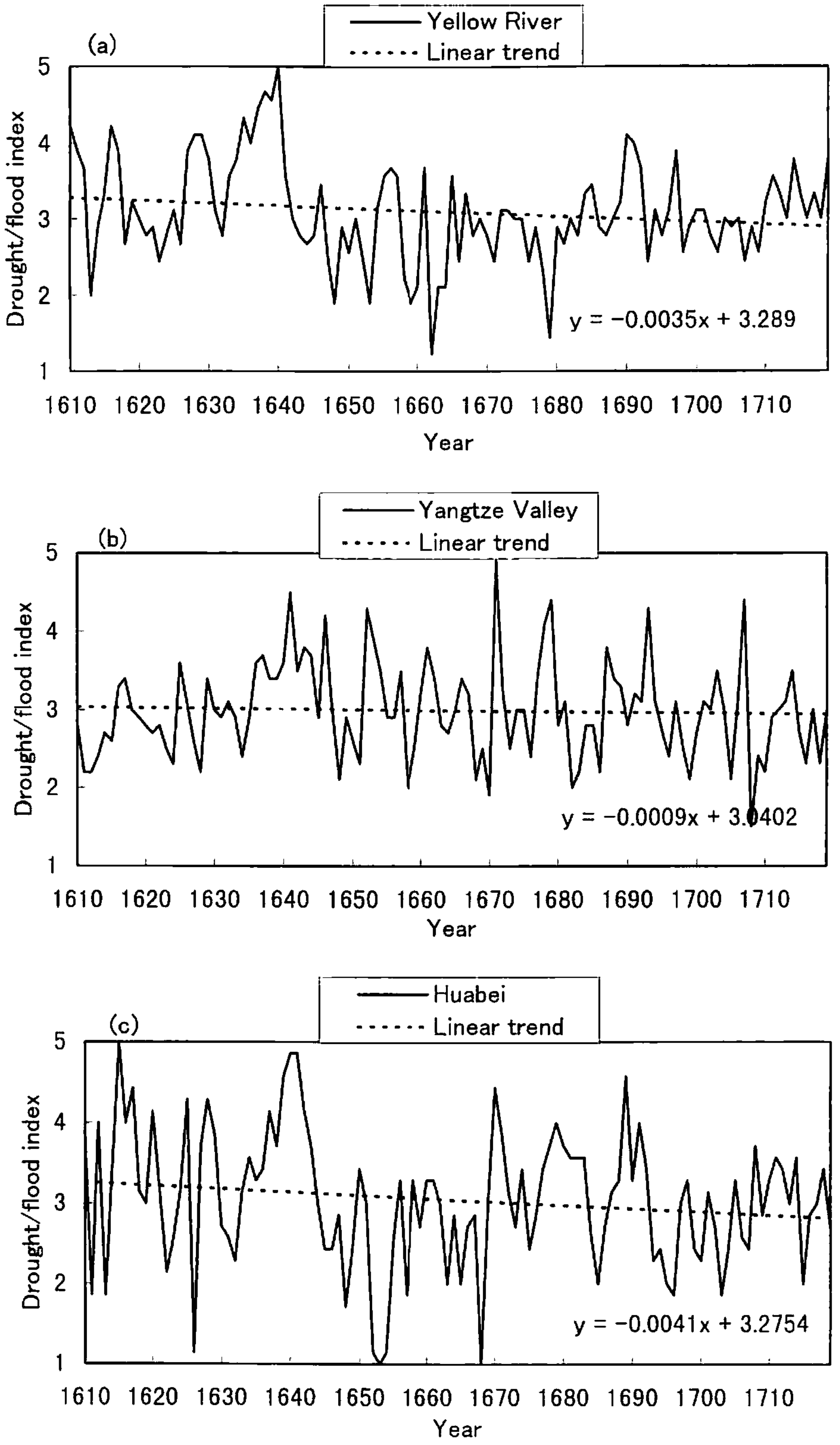

Fig. 2 The interannual variation of drought/flood index and its tendency from 1610 to 1719 (a): the middle-upper reaches of the Yellow River, (b): the down reaches of the Yangtze Valley, (c): Huabei

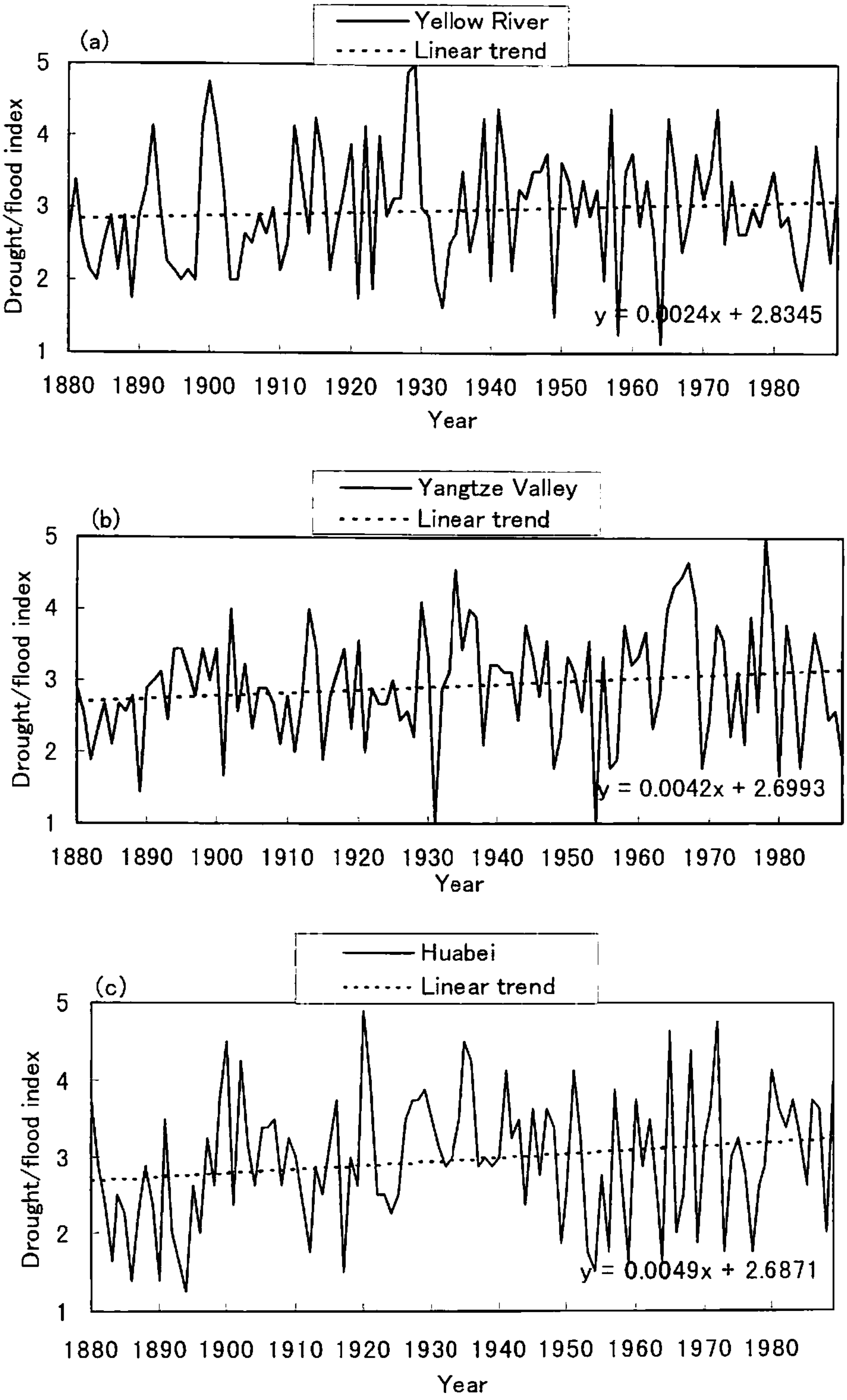

Fig. 3 The interannual variation of drought/flood index and its tendency from 1880 to 1989 (a): the middle-upper reaches of the Yellow River, (b): the down reaches of the Yangtze Valley, (c): Huabei

Table 2 The statistical characteristics about drought/flood index in the middle-upper reaches of the Yellow River (A), the down reaches of the Yangtze Valley (B) and Huabei (C) in the period I (1610-1719) and the period II (1880-1989)
Mean: average drought/flood index, SD: standard deviation, and Auto-corr: lagged-one auto-correlation coefficient

	Period I			Period II		
Region	Mean	SD	Auto-corr	Mean	SD	Auto-corr
A	3.09	0.67	0.50	2.97	0.80	0.02
B	2.99	0.62	0.20	2.93	0.77	0.04
C	3.05	0.85	0.37	2.96	0.84	0.09
Average	3.04	0.71	0.36	2.95	0.80	0.05

Table 3 Correlation coefficients of drought/flood indices in two regions in 30 years for 1610-1719 and 1880-1989
A: the middle-upper reaches of the Yellow River, B: the down reaches of the Yangtze Valley and C: Huabei The significance at 99% confidence level is 0.46.

No	Period	Corr-			Period	Corr-		
		A and B	B and C	C and A		A and B	B and C	C and A
1	1610-1639	0.36	0.25	0.56	1880-1909	0.12	0.28	0.36
2	1620-1649	0.30	0.38	0.64	1890-1919	-0.17	0.11	0.29
3	1630-1659	0.26	0.07	0.60	1900-1929	0.12	0.24	0.27
4	1640-1669	0.29	0.16	0.36	1910-1939	0.03	0.20	0.17
5	1650-1679	-0.17	-0.02	-0.10	1920-1949	0.15	0.23	0.28
6	1660-1689	-0.27	0.32	-0.15	1930-1959	0.00	0.26	0.27
7	1670-1699	-0.33	0.22	-0.12	1940-1969	-0.06	0.18	0.43
8	1680-1709	-0.08	-0.16	0.26	1950-1979	-0.07	0.23	0.48
9	1690-1719	-0.02	-0.23	0.47	1960-1989	-0.02	-0.03	0.53

China during that time. The coldest climate during 1650-1700 changed the correlation between drought/flood indices in Huabei and the Yellow River.

In the period II, there is a positive correlation between drought/flood indices in Huabei and the Yellow River, however, significant correlation in the two regions existed in 1940-1969, 1950-1979 and 1960-1989, with the correlation exceeding 99% significant level. The correlation between drought/flood indices in the Yangtze Valley and the two other regions is not significant in the recent years.

4. Interdecadal Changes for Drought/flood in 1610-1719 and 1880-1989

Table 4(a) shows the strong abrupt changes for drought/flood in eastern China occurred in the period 1631-1643. The strongest interdecadal change in the Yellow River and Huabei occurred in the middle of 17th century. Figure 4a depicted the five drought/flood changes in the Yellow River in the period I. The similar changes also appeared in Huabei during that period. In the period I, the first dry interdecadal change occurred in 1627 in the Yellow River. The analysis of signal-to-noise ratio (*S*/*N*) indicates that dry interdecadal change for drought/flood in the Yangtze Valley in 1631 is larger than that in the Yellow River in 1627 and Huabei in 1633. In the Yangtze Valley, the change for

Table 4 Occurrence year of abrupt change on the value of single-to-noise ratio (*S*/*N*) in 1610-1719 and 1880-1989
Tables 4(a) and 4(b) indicate the characteristics of abrupt change in the period 1610-1719 and 1880-1989, respectively. Mb denotes span length (unit: year) before a jump year, Ma denotes span length (unit: year) after the jump year. D(F) represents that average interdecadal drought/flood index after a jump year is relatively drier (wetter) than that before the jump year. A: the middle-upper reaches of the Yellow River, B: the down reaches of the Yangtze Valley and C: Huabei

(a)

Region	Jump year	Drought(D)/Flood(F)	S/N	Mb	Ma
A	1627	D	1.79	10	15
	1642	F	2.57	10	10
	1682	D	1.23	10	10
	1697	F	1.17	10	10
	1709	D	1.74	10	10
B	1631	D	1.88	10	10
	1646	F	1.05	10	10
C	1633	D	1.12	10	15
	1643	F	2.27	10	10
	1668	D	1.22	15	10
	1692	F	1.35	10	15
	1704	D	1.31	10	10

(b)

Region	Jump year	Drought(D)/Flood(F)	S/N	Mb	Ma
A	1974	F	1.05	10	10
B	1889	D	1.74	10	10
	1957	D	1.40	10	10
C	1896	D	1.59	15	10

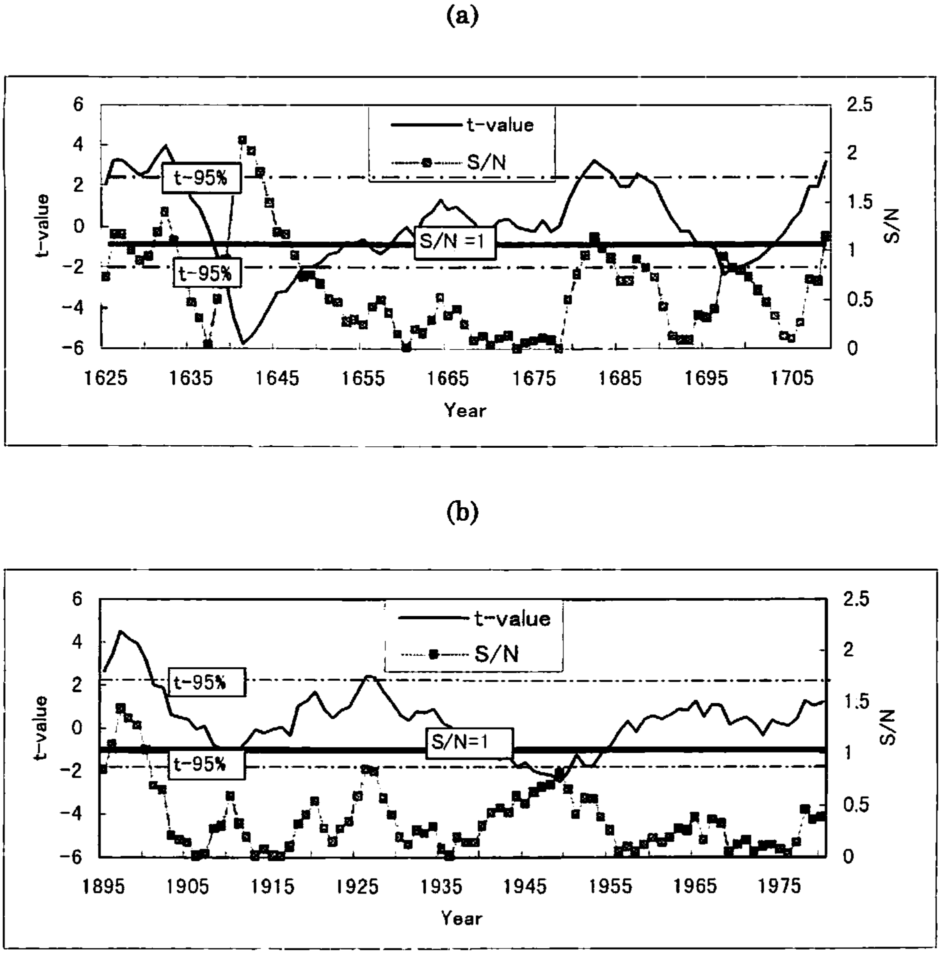

Fig. 4 The analysis of Student's-t value and Signal-to-Noise(S/N) ratio for drought/flood index
The span length before and after a reference point is 15 and 10 years, respectively. Here, (a) and (b) indicate the fluctuation in the middle-upper reaches of the Yellow River in the period 1610-1719 and in Huabei in the period 1880-1989, respectively. Thick solid line indicates Student's-t value reaching significant level at 95%.

drought/flood in 1631 is more distinct than the wet change in 1646.

For the period II, remarkable dry interdecadal changes in Huabei and the Yangtze Valley occurred in 1889-1896 (Table 4b), which was associated with global warming in the Little Ice Age of 19th century (Domros and Peng 1988; Li 1992). Besides that, there was the other dry change in the Yangtze Valley in the mid-1950s. The dry interdecadal change in the Yangtze Valley in 1957 is related to the strong East Asian monsoon in 1960's. Li (1992) pointed out that there were three different stages of the East Asian summer monsoon in the period from 1951 to 1980. The first period was normal variation for summer monsoon in 1951-1959, the second was the stronger variation in 1960-1966 and the third was the weaker variation in 1967-1980. Chen *et al.* (1992) showed that a strong summer monsoon is accompanied by wet condition in Huabei and dry condition in the Yangtze Valley. While summer monsoon became stronger during 1960-1966, rainfall in the Yangtze Valley decreased and the interdecadal transition from wet to dry condition occurred in 1957. The wet interdecadal change in 1974 occurred in the Yellow River.

It should be noted that the stronger changes for drought/flood in Huabei in 1643 and 1896 were accompanied by global temperature change (Wang 1994). The former change corresponded to the transition of the coldest period in the Little Ice Age and the latter change corresponded to the beginning of warmer period and the end of the Little Ice Age. The other two weaker changes for drought/flood index in Huabei, occurred in 1926 and 1949 (Fig. 4b). In these years, t-values are significant at 95%, but *S/N* ratios are not. Wang (1994) showed that average temperature in the Northern Hemisphere in 1924 apparently increased. The change for drought/flood in the middle of 1920's corresponded to the annual temperature jump in the Northern Hemisphere. The other change for drought/flood in the end of 1940's agreed relatively well with apparent temperature jump in Japan and China (Yamamoto and Iwashima 1986; Wei and Cao 1995). These analyses show that the interdecadal changes for drought/flood in Huabei correspond to the large-scale temperature jump.

Zhang and Crowley (1989) pointed out that an apparent difference is found in the past and present East Asian monsoon. Due to a modified development of the different phases of summer monsoon in both 17th and 20th centuries, the first phases of summer monsoon (rainfall in southern China) appeared to have been normal. However, the second (Meiyu) and the third (northern China) phases during 17th century were weaker than present situation. In this analysis, the drought/flood indices in Huabei in 1610-1719 were higher (drier) than those in 1880-1989, which corresponds to the result obtained by Chen *et al.* (1992) who considered that weaker monsoon caused dry condition in Huabei. It is noteworthy that the number of interdecadal changes for drought/flood index in Huabei in 17th century (weaker East Asian monsoon) is more than that in the 20th century.

5. The Long-term Variation for Drought/flood in Eastern China and the Southern Oscillation (SO) during 1880-1989

El Nino/Southern Oscillation (ENSO) event is one of the most remarkable impacts of warming in tropical central eastern Pacific on the whole global climate (Bjerknes 1969; Chen 1982). The close relationship between SOI and Indian monsoon rainfall has been documented by many previous studies (*e.g.*, Shukla and Misra 1977; Weare 1979: Rasmusson and Thomas 1983).

There exists close correlation between SLP at Darwin and the SOI (Trenberth 1976; Rasmusson and Carpenter 1982). The correlation between drought/flood indices in the three regions in eastern China and the SO is investigated by using various phases of the SOI and SLP at Darwin for the period II.

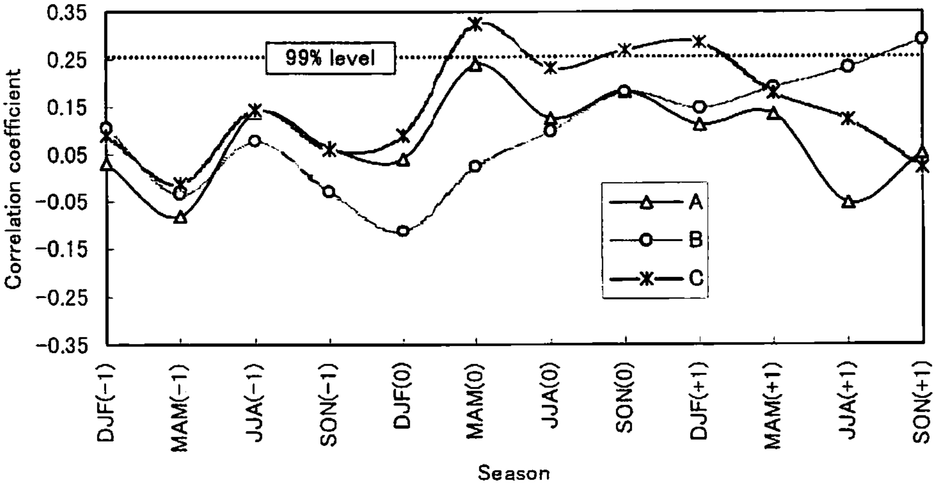

Fig. 5 Correlation analysis between drought/flood index in the three regions in 1884-1989 and seasonal sea-level pressure (SLP) in Drawin in the period 1883-1988 (−1), 1884-1989 (0) and 1885-1990 (+1)
A indicates the middle-upper reaches of the Yellow River, B indicates the down reaches of the Yangtze Valley and C indicates Huabei. Dashed line denotes 99% significance level.

Firstly, the correlation coefficients between drought/flood in three regions in the period 1884-1989 and seasonal SLP at Darwin in the three periods 1883-1988 (-1), 1884-1989 (0) and 1885-1990 (+1) have been calculated and depicted in Fig.5. It is found that the drought/flood indices in Huabei and the Yellow River are positively correlated with SLP in Darwin in March-April-May (MAM) in the same period. The positive relationship between drought/flood in Huabei and SLP at Darwin is the best. Their correlation coefficient is 0.34 which is significant at 99% confidence level. Li (1992) showed that summer precipitation in Huabei and India in June-September during 1951-1980 is associated with the SOI in April. On the other hand, the correlation coefficient between drought/flood index in the Yangtze Valley and SLP at Darwin in the following September-October-November (SON) is 0.29, which is significant at 99% confidence level. However, its physical mechanism for the lagged correlation is not clear.

To analyze the relationship between drought/flood in the three regions in eastern China and the various phases of the SOI, the average drought/flood indices in the Yellow River, the Yangtze Valley and Huabei are investigated during extreme phases of the SOI. According to the records for the seasonal SOI with the lower and upper quartiles (Guetter and Georgakakos 1996), the drought/flood index corresponding to the SOI with the low quartile (SOI-LQ) and the SOI with the high quartile (SOI-HQ) have been analyzed. It is found that the drought/flood index in the Yellow River during the SOI-LQ was 3.27 (Table 5), which is higher than its climatic average value 2.97 (Table 2). On the other hand, the wet condition in the three regions corresponds to the SOI with the upper quartile (SOI-UQ) in autumn. During the SOI-UQ in summer and autumn, the drought/

Table 5 Average drought/flood indices in the three regions during SOI with lower quartile (LQ) and SOI with upper quartile (UQ) in every season from 1900 to 1990 (Guetter and Georgakakos 1996)
A: the middle-upper reaches of the Yellow River, B: the down reaches of the Yangtze Valley and C: Huabei

Region	SOI(LQ)				SOI(UQ)			
	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
A	3.06	3.27	3.13	3.20	2.97	2.89	2.75	2.63
B	2.85	2.86	3.00	3.01	3.09	2.82	2.88	2.74
C	2.89	3.15	3.13	3.14	3.09	2.92	2.75	2.64
Mean	2.93	3.09	3.09	3.12	3.05	2.88	2.79	2.67

Table 6a Drought/flood indices in the middle-upper reaches of the Yellow River (A), the down reaches of the Yangtze Valley (B) and Huabei (C) during SOI with the upper quartile in the latter half year (summer and autumn) (Guetter and Georgakakos 1996)

No	Year	A	B	C
1	1910	2.13	2.78	3.00
2	1917	2.13	3.11	1.50
3	1924	4.00	2.67	2.25
4	1938	2.88	2.11	3.00
5	1950	2.63	3.33	2.50
6	1955	3.25	3.33	2.75
7	1956	2.00	1.78	1.75
8	1964	1.13	4.00	1.63
9	1973	2.50	2.22	1.75
10	1975	2.63	2.11	3.25
11	1988	2.25	2.56	2.00
Average		2.59	2.73	2.31

flood indices in the Yellow River, the Yangtze Valley and Huabei are 2.59, 2.73 and 2.31 respectively, which are lower than their climatic average values in the period II (Table 6a). The wet condition in Huabei is the most apparent characteristic.

Furthermore, while examining the drought/flood index for each station in three regions during the SOI-UQ in summer and autumn, it is found that the drought/flood index in Baodin is 2.0 which is the wettest condition occurred in Huabei (Table 6b). The drought/flood indices in Linfen and Ankang in the Yellow River are lower (wetter) than those in the other stations located in the region. Wang and Li (1990) pointed out that

Table 6b The average drought/flood index during SOI with the upper quartile (UQ) in the latter half year (summer and autumn) from 1910 to 1988 (Guetter and Georgakakos 1996)
The stations with asterisk sign (*) denotes the points used by Wang and Li (1990). A: the middle-upper reaches of the Yellow River, B: the down reaches of the Yangtze Valley and C: Huabei

Region	No	Station	Drought/Flood index
A	1*	Yulin	3.00
	2	Linfen	2.27
	4*	Yanan	2.64
	5*	Xian	2.36
	6	Hanzhong	2.36
	7	Ankang	2.27
	8*	Lanzhou	3.00
	9*	Yinchuan	2.81
B	10	Tunqi	2.64
	11	Ningbo	2.82
	12	Shanghai	2.82
	13	Nanjing	2.91
	14	Hangzhou	2.55
	15	Jiujiang	2.91
	16	Anqing	2.46
	17	Wuhan	2.82
	18	Hefei	2.64
C	20	Peking	2.36
	21	Tianjing	2.19
	22	Tangshan	2.09
	23	Baodin	2.00
	24	Changzhou	2.56
	25	ShijianZhuang	2.36
	27	Danton	2.46
	28	Tiayuan	2.46

summer rainfall in the Yellow River decreased when El Nino occurred. In this study, it is found that the wet conditions in Huabei and the Yellow River are sensitive to the SOI-UQ in summer and autumn. Relatively, the dry condition in the Yellow River corresponds to the SOI-LQ in spring.

6. Conclusions

This study has made an attempt to investigate the considerable variability for drought/flood in eastern China in the colder and warmer periods with a century time scale for the last past 400 years. The analysis of this comparison for drought/flood in eastern China in the two periods has important implications for studying the century and interdecadal drought/flood variations in the Yellow River, the Yangtze Valley and Huabei.

In this study, we obtained the following results:

(a) The positive correlation between regional drought/flood indices in Huabei and the Yellow River on 30-year time scales was very significant in 1610-1649. However, while the coldest period (1650-1699) was approaching over, their relationship was rapidly weakened and became negative. The auto-correlation coefficients in Huabei and the Yellow River in 1610-1719 was significant at confidence level of 99%, and the auto-correlation in 1880-1989 was much weaker than that in 1610-1719. On the other hand, the long-term tendencies in 1610-1719 and 1880-1989 in three regions have consistent wet and dry trends, respectively. The annual rates for drought/flood tendency in Huabei in the two periods were the largest.

(b) By using the long-term drought/flood index in Huabei, we found that the two stronger interdecadal changes for drought/flood in 1643 and 1896 which are related to apparent cold and warm changes with global scale. Moreover, the other two weak changes in 1920's and 1950's in Huabei correspond to average temperature jumps in the Northern Hemisphere and in East Asia, respectively. It is indicated that interdecadal changes for drought/flood in Huabei are sensitive to the temperature jump with large-scale. The drought/flood change in Huabei associated with temperature jump can be explained as follows. The large-scale temperature variation will change heat contrast in Eurasian continent and sea surface temperature (SST) in the northwest Pacific. This heat contrast variation will directly impact on the variations of SLP in these regions. Recent studies show that the difference between SLP in Eurasian continent and the northwest Pacific is a better indicator for East Asian monsoon (Hanawa *et al.* 1988; Shi *et al.* 1996). Chen *et al.* (1992) pointed out that summer rainfall variation in Huabei is closely related to the variation of East Asian monsoon. Therefore, the large-scale temperature adjustment will cause abnormal summer East Asian monsoon, and finally, will change summer rainfall in Huabei.

(c) The relationship between drought/flood index and the seasonal SLP at Darwin provides valuable insights to examine associations for drought/flood in the middle latitude with tropical atmospheric variation. It is found that drought/flood in Huabei and the Yellow River are closely correlated with the SLP at Darwin in spring (March-April-May) in 1884-1989. This result corresponds to the analysis by Li (1992) who showed that summer rainfall in Huabei from 1951-1980 was correlated with SOI in April. On the other hand, the drought/flood index in the Yangtze Valley was weakly associated with concurrent SLP in Darwin but significantly correlated with the SLP in the following autumn. It implies that impacts of SLP in Darwin on the drought/flood in the Yangtze Valley are different from those in the Yellow River and Huabei.

(d) Based on the analysis for drought/flood in eastern China associated with the SOI-LQ and SOI-UQ in different season, it is found that the SOI-UQ in summer and autumn corresponds to wet conditions in the three regions. Moreover, the wet condition in Huabei is the largest. For the seasonal SOI-LQ associated with drought/flood in the three regions, we found that the dry condition in the Yellow River corresponds to the SOI-LQ in spring.

Several characteristics of interannual and decadal drought/flood climate in eastern China have been discussed for the periods 1610-1719 and 1880-1989. This is only a partial work on temporal variation of drought/flood in the regions. Further, more findings can be suggested on this aspect using the longer historical data to analyze the drought/flood variation in relation to extreme events of volcanic eruptions, snow cover and the variation of sunspot numbers.

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