The Journal of Animal & Plant Sciences, 25 (3 Suppl. 1) 2015 Special Issue Page: 260-269
ISSN: 1018-7081

SPATIOTEMPORAL CHANGE OF SPRING DROUGHT IN SOUTHWEST CHINA

Y. B. Yao[1, 2], Q. Zhang[1], J. S. Wang[1], J. L. Shang[2], Y. Wang[1], J. Shi[2] and L. Y. Han[3]

[1]China Meteorological Administration Key Laboratory of Arid Climate Change and Reducing Disaster, Gansu Province Key Laboratory of Arid Climate Change and Reducing Disaster, Lanzhou Institute of Arid Meteorology, China Meteorological Administration, Lanzhou 730020, China; [2]Meteorological Bureau of Dingxi City, Dingxi 743000, China; [3]Northwest Regional Climate Center, Lanzhou 730020, China)

Email address of corresponding author: yaoyubi@163.com

ABSTRACT

A drought index analytical method based on a relative moisture index was used to evaluate meteorological data between 1958 and 2012 and study the temporal variation, spatial distribution, and sub-regional evolution characteristics of spring drought in Southwest China. The results showed a decreasing frequency of spring drought in the West Sichuan Plateau, Southwest Sichuan Upland, and Yunnan Plateau and an increasing frequency in the East Sichuan Basin and Guizhou Plateau from 1958 to 2012. In the first EOF model for spring drought intensity, the load vector fluctuated in equal phases of different areas. The main abnormal areas were the North Yunnan Plateau and Southwest Sichuan Upland. The second EOF model, distributed in opposite phases of the east and west, showed the characteristics of variances influenced by the atmospheric system. Four subregional abnormalities including the Yunnan Plateau, Guizhou Plateau, West Sichuan Plateau, and East Sichuan Basin were divided according to the load vector abnormality in REOF. The intensity of spring drought had a significantly increasing frequency in Jiangcheng and Ganzi, which had its mutation point from weak to strong appear in 1970a and 1975a, respectively. It also showed an increasing but not significant frequency in Anshun and Suining. The temporal fluctuating period was mainly 4 to 6a in the southwest during the recent 55a.

Key words:abnormal distribution; spring drought; subregional evolution; Southwest China

INTRODUCTION

As mentioned in the "Summary for Policymakers in Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation" released by IPCC (Intergovernmental Panel on Climate Change), the frequency and intensity of extreme world drought and high temperature climates is increasing in the background of global warming. Continuously changing climates may lead to the change of extreme weathers and climatic events in frequency, intensity, spatial range, duration, and occurrence time, and further cause unprecedented extreme climate and weather events (IPCC, 2012).

Southwest China is an important agricultural and economic crop production district (Zhu, *et al*., 2006), but rainfall in the district is not uniformly distributed and the variance is very large. Drought occurred frequently in recent years, including the abnormal spring drought in Yunnan during 2005; the extreme summer drought in Sichuan and Chongqing during 2006; the extensive drought around Yunnan and Guizhou from the autumn of 2009 to the spring of 2010; the long, extensive, and serious drought in Southwest China during 2009, which was the most serious meteorological drought since there was a meteorological record for the district; and the summer drought in Chongqing, Sichuan, and Guizhou during 2013. Frequent drought brings serious losses to agricultural production and social economic development in Southwest China. Drought events and characteristics are research hotspots.

Huang Ronghui determined that Southwest China has recently been in a drought in all seasons (Huang, *et al*, 2012). He Jinyun studied the meteorological data from 108 stations in Southwest China from 1960~2009 and found that the frequency of extreme drought in the Southwest Sichuan Basin, South Hengduan Mountainous Area, and North Guizhou had significantly increased in the past 50 years (He, *et al*., 2011). Wang Mingtian discovered that drought frequency was distributed in a belt that was high in the west and low in the east of Southwest China. The drought intensity was significantly enlarged in recent 10 years (Wang, *et al*., 2012). Southwest China is being aridified with different moisture-changing characteristics, aridifying durations, and phases in different areas (Ma, *et al*, 2007). For example, rainfall in Yunnan continuously decreased in recent 46a and significantly decreased in summer, while temperatures in West Yunnan kept rising (Liu, *et al*., 2010; Tao, *et al*., 2009; Duan, *et al*., 2000).

Global scholars have also studied droughts in Africa (Nicholson, 2001), Central Asia (Wang, 2010), North China (Ma, *et al*., 2001; 2005; Zhang, *et al*., 2003), Northwest China (Luo, 2005; Qian, *et al*., 2001; Zhang, 2008; Zhang, *et al*., 2010), and the Loess Plateau Drought

(Yao, *et al*., 2005; Yao, *et al*., 2013; Lu, *et al*., 2009). However, research on seasonal drought was mostly performed on annual distribution characteristics, and they were not thorough enough to examine changes within the seasons. Drought spans time and space, so while an annual scale drought monitor is helpful for comprehending the district drought in the large scale, it is often too broad (Zhang, *et al*., 2011). In light of this gap in research and of global warming, this study examines the temporal variation, spatial distribution, and sub-regional evolution characteristics of spring drought that influence agricultural production in Southwest China. This study was performed with the intent of providing science-based suggestions for regional drought control and disaster reduction.

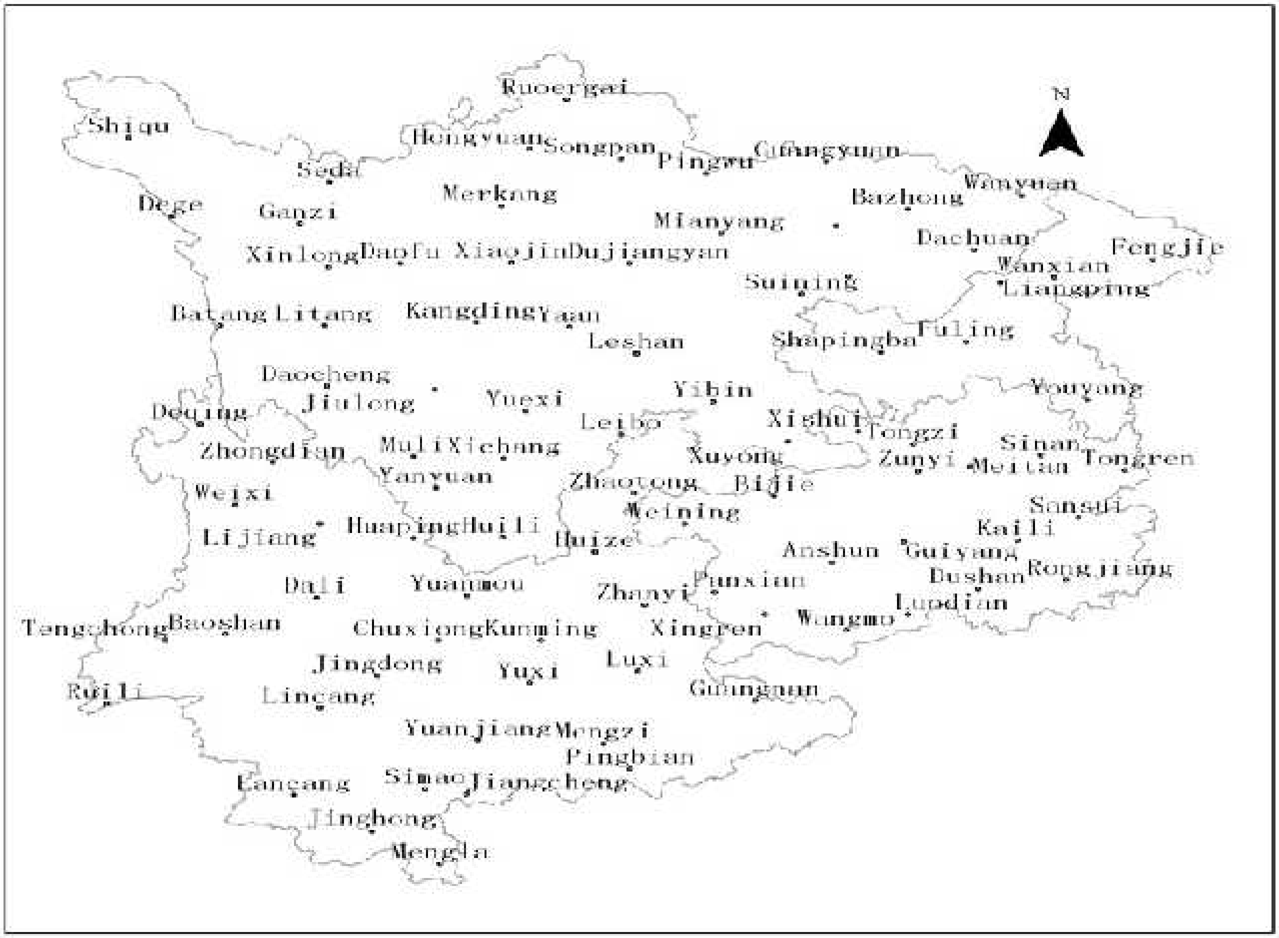

Fig. 1. The weather stations distribution of Southwest China

MATERIALS AND METHODS

Target regions: The target regions cover Sichuan Province, Guizhou Province, Yunnan Province, and Chongqing City in Southwest China. These have the geographic coordinates of 97.4°E~110.2°E and 21.2°N~34.4°N, a land area of 1,150,000km^2, a farmland area of 19,000,000hm^2, an asl of 150~5000m, a mean annual precipitation of 303.7～1924.2mm, and a mean annual temperature of -0.9～20.6℃. From 1958 to 2012, there was a declining trend of precipitation in the experimental regions. The temperature in the experimental region shows a clear ascending trend. The target regions include various and complicated land forms, including plateaus, mountains, hills, plains, valleys, and basins, which cover the East Qinghai-Tibet Plateau, Yunnan-Guizhou Plateau, and Sichuan Basin. The regions also have diverse climates in unique geological locations.

Data: From 1958 to 2012, meteorological data were acquired from basic meteorological data daily measured in basic meteorological stations of 89 countries. The data were spatially typical and measured continuously for years without many faults. The data that were analyzed included mean temperature, maximum temperature, minimum temperature, precipitation amount, wind speed, relative humidity, and sunshine duration.

Drought index: The relative moisture index is the ratio of difference between rainfall and possible evapotranspirated amount to the possible evapotranspirated amount in the same period. It is a drought monitor index based on the soil moisture balance that reflects the moisture balance characteristics of crops in different growing periods. The index is suitable for monitoring droughts and evaluating the crop growing period in a scale of ten days. Table 1 shows the classification of drought based on relative moisture index.

Tab. 1 Classification of drought based on relative moisture index

$$PE = \frac{0.408\Delta(R_n - G_i) + \gamma \dfrac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (2)$$

Class	Definition	Relative moisture index
1	No drought	-0.40＜M
2	Light drought	-0.65＜M≤-0.40
3	Medium drought	-0.80＜M≤-0.65
4	Serious drought	-0.95＜M≤-0.80
5	Extreme drought	M≤-0.95

The relative moisture index (M) is calculated as per:

$$M = \frac{R - PE}{PE} \quad (1)$$

Where R is the rainfall in a period, and PE is the possible evapotranspirated amount (mm) (Zhang, *et al.*, 2006).

PE can be obtained from the Penman-Monteith model recommended by FAO, according to the following formula (Allen, *et al*., 1998; Walter, *et al*., 2000):

Where Rn is the net radiation on the earth's surface (MJ $m^{-2}d^{-1}$); G_i is the soil net flux (MJ $m^{-2}d^{-1}$); γ is the psychrometer constant (kPa°C^{-1}); Δ is the saturation vapor pressure curve slope (kPa°C^{-1}); T is the mean air temperature (°C); U_2 is the mean wind speed 2m above ground (ms^{-1}), calculated from the mean wind speed at 10m above the ground; e_s is the saturation vapor pressure (kPa); and e_a is the actual vapor pressure (kPa).

Analyzing method: The tendency coefficient change of climatic elements is expressed by a linear equation, and the change of slope in 10a is the climate tendency rate that can be obtained by the climate tendency coefficient (Wei, 2007).

In the Mann-Kendall (M-K) mutation method (Wei, 2007), it is originally assumed that H_0 is that the climate sequence, if unchanged, is assumed into x_1, x_2, … and x_n; m_i is the accumulated number of the i^{th} sample and x_i is larger than x_j ($1 \le j \le i$). A statistic is defined and a significance level α_0 is given. When $\alpha_1 > \alpha_0$, the original assumption H_0 is accepted, and when $\alpha_1 < \alpha_0$, the original assumption is refused.

Wavelet analysis is realized by boundary Morlet wavelet energy spectral analysis (Wu, 2005).

$$\Psi(t) = e^{-2\pi i t} \exp[-(2\pi/k\psi)^2 |t|^2] \quad (3)$$

The wavelet conversion factor is:

$$\xi(t',a) = a^{-1/2} \int f(t)\Psi^*(t/a - t'/a)dt \quad (4)$$

$\xi(t',a)$ is the wavelet coefficient, $f(t)$ is data sequence, and Ψ^* is the conjugate function of Ψ.

EOF (empirical orthogonal function) and REOF (rotated empirical orthogonal functions) analyzed the abnormity distribution characteristics (Wu, 2005). The calculation characteristic error range proposed by North, *et al*. (1982) made the significance check.

RESULTS AND DISCUSSION

Spring drought spatiotemporal distribution: According to the definition of the relative moisture index, there is a direct relationship between the negative absolute value of relative moisture index and drought intensity. The spring relative moisture index spatial distribution map for Southwest China during 1958~2012 (Fig. 2) shows that the negative absolute value of the relative moisture index in Southwest China gradually increased from northeast to southwest, which means that drought intensity gradually increased from northeast to southwest. The spring drought mainly occurred in the Yunnan Plateau, West Sichuan Plateau, and Southwest Sichuan Mountains. The drought area represented about 43% of the total area researched. The medium drought area, which represented about 20% of the area researched, included the north of the Yunnan Plateau, south of the West Sichuan Plateau, and the Southwest Sichuan Mountainous area. The serious drought area, which represented about 5% of the area researched, was in the northwest-southeast belt around the Southwest Sichuan Mountains.

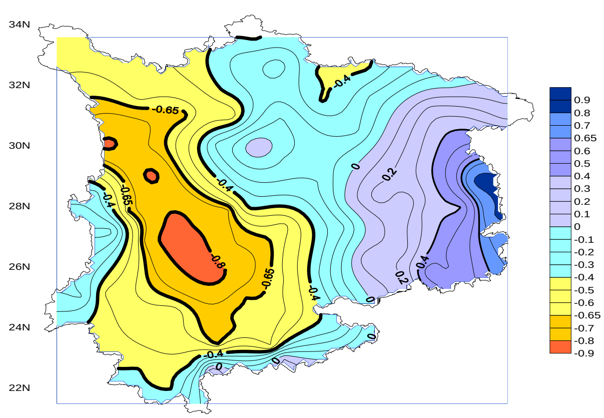

Fig.2 Spatial distribution of the spring droughts index in Southwest China

The linear fitting trend coefficient (Fig. 3a) and (Fig. 3b) of the spring drought index changing curve showed that the drought index linear fitting tendency rates for the west Sichuan Plateau, Southwest Sichuan Mountains, and west Yunnan Plateau were positive; thus the relative moisture index increased, and the spring drought intensity decreased. The tendency rates for most areas were 0.01~0.03/10a, and several were 0.031~0.068/10a. Figure 2a shows the tendency rate r≥0.261 in most areas of the west Sichuan Plateau and northwest Yunnan Plateau that passed the significance check (P<0.05). The spring drought linear fitting tendency rates for the east Sichuan Basin and east Guizhou Plateau were negative; thus, the relative moisture index decreased, and the spring drought intensity increased. The tendency rates for most areas were -0.06~-0.01/10a, and only several stations passed the significance check.

The trend of moisture increase and spring drought intensity decrease in the west Sichuan Plateau, Southwest Sichuan Mountains, and Yunnan Plateau has been established, and this information has passed the significance check. There was a trend of moisture decrease in the east Sichuan Basin and Guizhou Plateau; the spring drought increased, but did not pass the significance check.

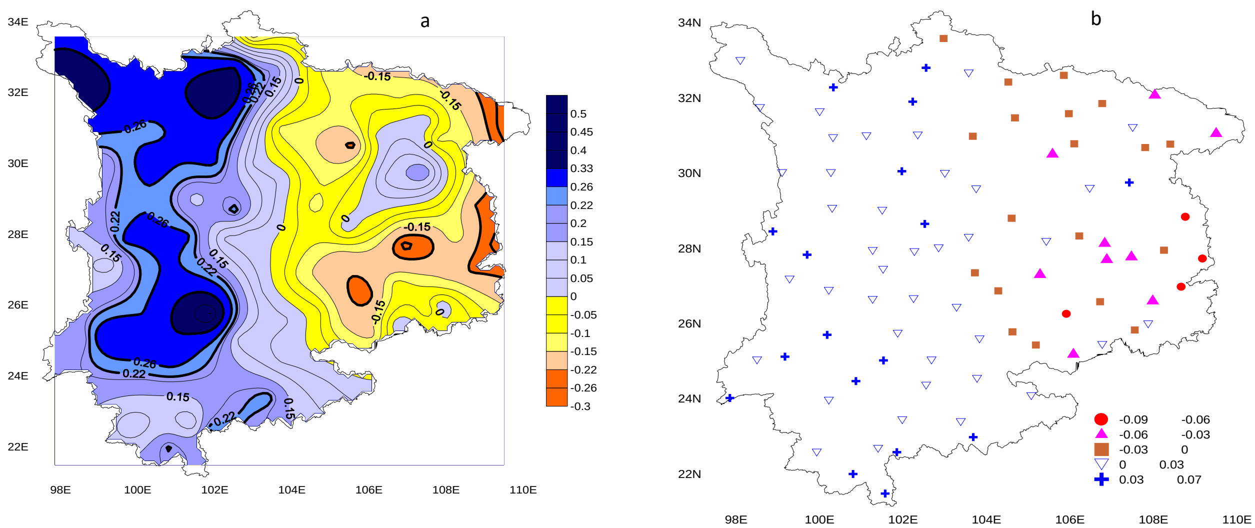

Fig.3 Spatial distribution of spring droughts index trend coefficient and tendency rate in Southwest China from 1958 to 2012 (a:The trend coefficient; b:The tendency rate)

Spring drought abnormity distribution: To thoroughly analyze the spring drought spatiotemporal abnormity distribution, EOF and REOF analyzed spring drought indexes from 89 typical stations in Southwest China, covering principal component analysis and rotated principal component analysis. The LV (loading vector) of PC (principal component), RLV (rotated loading vector) of RPC (rotated principal component), and corresponding time coefficients effectively reflected the spring drought abnormity distribution characteristics in the Loess Plateau.

Percentage of contribution to variance of principal component characteristic value: The percentages of contribution to variance of the first 10 PC and RPC characteristic values were all approximately 71.4% (Tab. 1). The percentages of contribution to variance of the first two model characteristic RPC values, 26.04% and 10.62% respectively, were one order of magnitude larger than other values; the first two model loading vectors were the most important spatial abnormity distributions. This could reflect the spatial abnormity characteristics of the spring drought index in Southwest China.

The distribution of EOF PC and REOF PC showed that the convergence rates of PC characteristic values and RPC characteristic values decreased as the sequence temporal scale was extended and the number of stations increased. This means that the region researched was extensive and included a wide variance of geographical environments and climate states. The variance of the spatiotemporal index of spring drought in Southwest China was significant.

The EOF PC analysis before rotation was balanced to centralize the variance contribution of the characteristic value in the whole calculation scale on the first several PCs. This ensured that the contribution of characteristic values to the whole variance was not uniform, and the contribution to the variance of the first several characteristic values was large. REOF PC analysis was balanced for correlativity distribution characterization, so the contribution of characteristic values to the whole variance was uniform, and the contribution to the variance of each characteristic value was in a varying order.

Tab. 2. Percentage of contribution to whole variance of the first ten PCs and RPCs for the spring droughts index in Southwest China

Sequence	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Accumulated contribution %**
PC contribution %	26.04	10.62	8.33	6.64	4.6	3.71	3.51	2.83	2.77	2.34	71.39
RPC contribution %	16.97	11.72	7.96	5.79	4.04	4.30	4.18	6.03	6.06	4.34	71.40

EOF PC LV and time coefficient: The EOF characteristic value significance check proposed by North, *et al*. was carried out. The first and second PC model characteristic values passed the significance check, which meant the EOF was a valuable signal. The percentages of contribution to the whole variance from the first two model characteristic values were 26.14% and 10.62%, respectively. The first two model PC loading vectors were the most important spatial abnormities in reflecting the variance distribution structure of spring drought in Southwest China. The spatial distribution structure was the typical distribution model of the spring drought index variable field in Southwest China.

The first model LV spatial distribution of EOF showed that the LV for most areas in the southwest was concordantly positive (Fig. 4a), except for several stations in the Daba Mountain in Northeast Sichuan. The spring drought intensity was characterized by fluctuation in equal phases in Southwest China; the changing trend of spring drought in Southwest China was basically concordant, and the fluctuation in equal phases showed that Southwest China and most other regions of China are in the two subsystems of the "East Asia Tropical Monsoon" (South Sea monsoon) and "East Asia Subtropical Monsoon." These regions are usually controlled by the same large-scale weather system, so the spring drought index in Southwest China fluctuated in equal phases. The first model LV absolute value of EOF was ≥0.15 in the north of the Yunnan Plateau and the Southeast Sichuan Mountains; the central maximum absolute value was 0.17, which indicates that the area was the center of spring drought. The spring drought fluctuated intensively, and the drought indexes frequently appeared with abnormities.

The linear fitting tendency rate of the time coefficient corresponding to the first model LV of EOF was 0.648/10a (r=0.214, P>0.10). Although it did not pass the significance check, the time coefficient increased (figure omitted), indicating that the relative moisture index increased and the spring drought intensity decreased. A larger absolute value of year time efficiency indicated a more typical distribution that year. According to the year time coefficients, 1958 and 1969 were typically concordant serious drought years, with the serious drought area representing 29%~32% of the land; 1963 and 1987 were typically concordant medium drought years, with the medium drought area representing 42%~45% of the land; and 1990 was a typically no drought year, with the drought area representing 20% or less of the land.

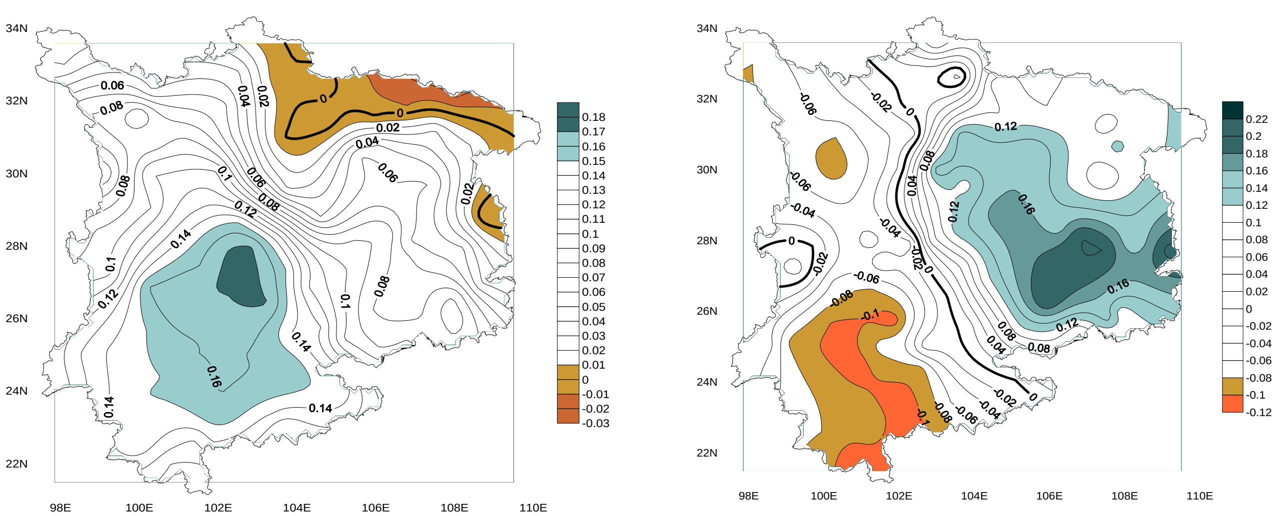

Fig.4 The curve of spatial distribution of the first two main modes for EOFeigenvector (a:The first EOF; b:The second EOF)

The second model LV of EOF was distributed in opposite phases between the east and west (Fig. 4b). The zero line of the LV conversion divided the regions researched into an eastern and western part. The LV for the East Sichuan Basin and Guizhou Plateau was larger than 0 in the east and smaller than 0 in the west, Southeast Sichuan Mountains and Yunnan Plateau. The west Sichuan Plateau, at the border of Qinghai-Tibet Plateau, was influenced by the Qinghai-Tibet Plateau monsoon; the Yunnan Plateau was influenced by the South Asia monsoon; the east was mainly influenced by the East Asia summer monsoon. As a result, the spring drought was distributed in opposite phases, so the east was wet while the west was dry. The west LV was negative, with the larger absolute values in the Yunnan Plateau, and the central maximum value at -0.12. The east LV was positive, with the larger absolute values in the Guizhou Plateau, and the central maximum value was 0.21.

The linear fitting tendency rate of the time coefficient corresponding to the second model LV of EOF was -0.754/10a ($r=0.396$, $P<0.01$). In the east, the time coefficient decreased (figure omitted), indicating that the relative moisture index decreased and spring drought intensity increased, while in the west, the relative moisture index increased and the drought intensity decreased. 1992 was typically dry in west but not in east, while 2011 was typically mildly dry in the west and somewhat dry in the east.

REOF PC LV and time coefficient change: The REOF analyzing method was used to study the subregional changing characteristics of spring drought. Then the first 10 PCs and corresponding LVs of EOF were rotated, and RLV were obtained.

Percentages of contribution to the whole variance from the four model characteristic values after rotation were 19.76%, 11.72%, 7.96%, and 5.79% respectively (Tab. 2). The percentage of accumulated contribution from the first four was 42.45%. The first four RLVs were the most important spatial abnormity models reflecting the regional distribution of spring drought in Southwest China; they were divided into corresponding subregional models. Figure 4 shows the spatial distribution characteristics of the first 4 RLVs.

Figure 5a shows the first model spatial distribution of REOF. The larger absolute values of RLV appeared in South Yunnan, as a result of abnormalities in the Yunnan Plateau. RLV>0 and a maximum absolute value of 0.89 appeared in South Yunnan. The typical station was at Jiangcheng (101.85°N, 22.58°E), which was mainly influenced by the South Asia Monsoon. The time coefficient of the first model LV of REOF fluctuated and increased, but it did not pass the significance check (figure omitted). 1958, 1992 and 1995 were typical Yunnan Plateau abnormal drought years, and 1990 was a typical Yunnan Plateau no-drought year.

Figure 5b shows the second model spatial distribution of REOF. The larger absolute values of RLV appeared in Central and Northwest Guizhou, as a result of abnormalities in the Guizhou Plateau. RLV>0 and a maximum absolute value of 0.77 appeared in Central and Northwest Guizhou. The typical station was at Anshun (105.92°N, 26.25°E), which was mainly influenced by the East Asia Monsoon and then by the South Asia Monsoon. The LV time coefficient fluctuated and decreased, but it did not pass the significance check (figure omitted). 1991 was a typical Guizhou Plateau abnormal drought year, and 1984 and 2008 were typical Guizhou Plateau no-drought years.

Figure 5c shows the third model spatial distribution of REOF. The larger absolute values of RLV appeared in central and north West Sichuan Plateau, as a result of abnormalities in the West Sichuan Plateau. RLV<0 and a maximum absolute value of -0.85 appeared in central and north West Sichuan Plateau. The typical station was at Ganzi (100.00°N, 31.62°E), which was mainly influenced by the Qinghai-Tibet Plateau Monsoon. The time coefficient corresponding to the first model LV of REOF significantly decreased, and the linear fitting tendency rate was -0.184/10a ($r=0.288$, $P<0.05$). The RLV was negative in the West Sichuan Plateau, so the relative moisture index increased and the drought intensity decreased. 1986 was a typical West Sichuan Plateau abnormal drought year and 1999 was a typical West Sichuan Plateau no-drought year.

Figure 5d shows the fourth model spatial distribution of REOF. The larger absolute values of RLV appeared in central East Sichuan Basin, as a result of the abnormalities in the East Sichuan Basin. RLV>0 and a maximum absolute value of 0.76 appeared in Central and Northwest Guizhou. The typical station was at Suining (105.58°N, 30.5°E), which was mainly influenced by the East Asia Monsoon and then by the Qinghai-Tibet Plateau Monsoon. The LV time coefficient fluctuated and decreased, but did not pass the significance check (figure omitted). 1961, 1965, and 2000 were typical East Sichuan Basin abnormal drought years, and 1963 was a typical East Sichuan Basin no-drought year.

The abnormal spatial distribution of REOF LV model shows that the spring droughts in Southwest China can be divided into four subregional abnormities: the Yunnan Plateau, Guizhou Plateau, West Sichuan Plateau, and East Sichuan Basin.

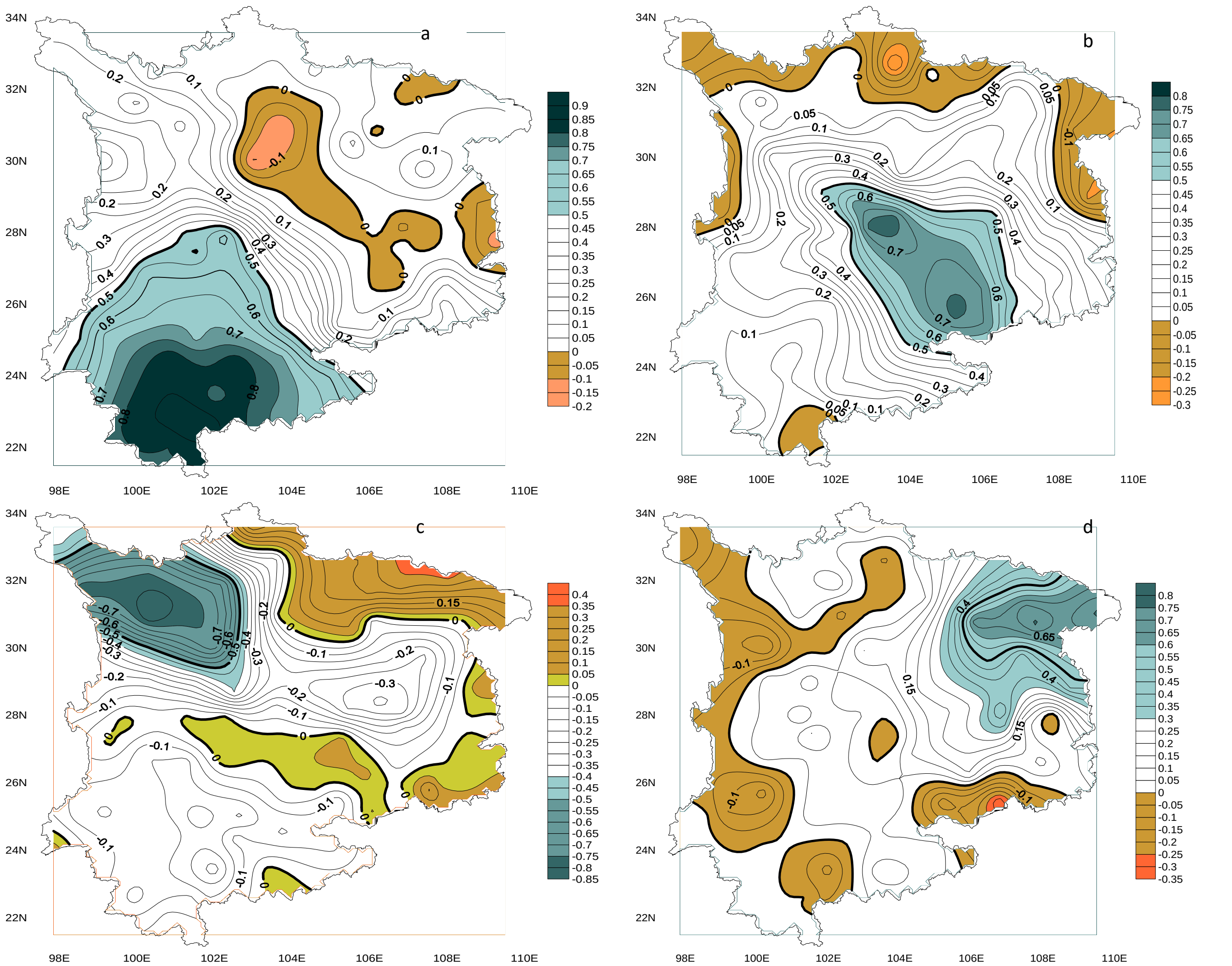

Fig.5 The chart of spatial distribution of the first four main modes for REOF
(a:The first REOF; b:The second REOF:c:The third REOF d:The fourth REOF)

Spring drought subregional temporal evolving characteristics

Subregional trend change: The four spatial abnormity models of REOF LV suggest that spring drought at the typical stations with the maximum absolute value of LV in the corresponding area may reflect characteristic changes in the area. Subsequently, the time sequence of spring drought in each typical station was used to analyze the change of temporal subregional trend.

Table 3 shows the trend coefficient and tendency rate of the subregional spring drought index in Southwest China. The typical station Jiangcheng for Yunnan Plateau showed an increasing trend, a tendency rate of 0.068/10a, and a trend coefficient of r=0.226; it passed the significance check by P<0.10. This indicates that the relative moisture in Yunnan Plateau increased and spring drought intensity decreased. The typical station Anshun for the Guizhou Plateau showed a decreasing spring drought index. The climate tendency rate was -0.07/10a, and the climate trend coefficient r=0.258; it passed the significance check by P<0.10. This indicates that the relative moisture in Guizhou Plateau decreased and spring drought intensity increased. The typical station Ganzi for West Sichuan Plateau displayed an increasing spring drought index. The climate tendency rate was 0.029/10, and the climate trend coefficient r=0.291; it passed the significance check by P<0.05. This indicates that the relative humidity in West Sichuan Plateau increased and the spring drought decreased. The typical station Suining for East Sichuan Basin showed a decreasing spring drought index. The climate tendency rate was -0.36/10a, and the climate trend coefficient r=0.241; it passed the significance check by P<0.10. This indicates that the relative moisture in East Sichuan Basin decreased, and spring drought intensity significantly increased.

Tab. 3 Trend coefficient and tendency rate of the subregional spring droughts index in Southwest China

Typical station	**Jiangcheng**	**Anshun**	**Ganzi**	**Suining**
Climate trend coefficient	0.226△	-0.258△	0.291▲	-0.241△
Climate tendency rate $(10a)^{-1}$	0. 068△	-0.07△	0.029▲	-0.036△

△P<0.10， ▲P<0.05, ★P<0.01

Subregional sudden change analysis: The Mann-Kendall sudden change check method was used to verify the time sequence of the spring drought index in subregional typical stations in Southwest China. It was also used to analyze the subregional sudden change of spring drought intensity in recent 55a. Figure 5 shows the M-K check curve of the spring drought indexes in subregional typical stations, where UF (full line) was the positive time sequence statistic curve, UB (dotted line) was the negative time sequence statistic curve, the significance check level was α=0.05, and the critical line was U_{α}=1.96. If UF crossed U_{α}, it passed the trend change significance check. If UF and UB crossed at the critical line, the cross point was the starting point of sudden change.

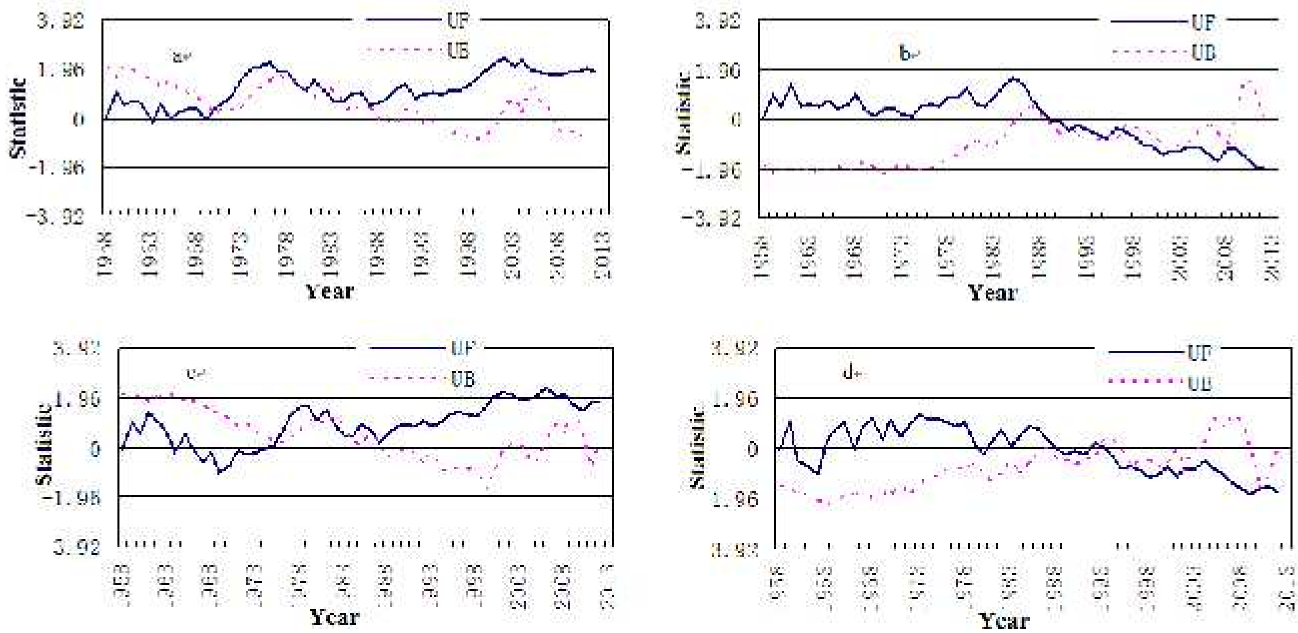

Fig. 6 Suddenly check curve of the subregional spring droughts index on southwest in China (a:Jiangcheng; b:Anshun:c:Ganzi; d:Suining)

The positive time sequence statistic curve UF of the spring drought in Jiangcheng fluctuated and increased (Fig. 6a). It exceeded the critical line U_{α} twice. In 1970, UF and UB crossed at U_{α} for the first time. The relative moisture in Jiangcheng started to increase in 1969. The spring drought intensity significantly decreased and suddenly changed in 1970. The spring drought index for Anshun started to decrease in 1986 (Fig. 6b). Drought intensity increased and approached the critical line U_{α} without exceeding it at 2011. The drought index UF for Ganzi started to increase in 1969 (Fig.6c); it exceeded the critical line U_{α} at 2001. UF and UB first crossed at U_{α} at 1975, so relative moisture started to increase from 1969 and reached the significant level at 2001. In 1975, the spring drought intensity decreased significantly and suddenly. The spring drought index for Suining decreased (Fig. 6d), while the drought intensity increased. It approached the critical line U_{α} at 2009 without exceeding it.

Subregional cycle characteristics: A Morlet wavelet energy spectrum with set borders was used to distinguish the cycle characteristics of spring drought temporal change. Characteristics of temporal spring drought index change in Southwest China during the recent 55a were studied. The isoline analysis of wavelet energy spectrum showed a significant fluctuating cycle of 4-5a (Fig. 7a); the cycle was fluctuated most during the 1980s. The spring drought index for Anshun in recent 55a fluctuated in a cycle of 6~7a (Fig. 7b). It also fluctuated most during the 1980s. The spring drought index for Ganzi in recent 55a fluctuated in a cycle of 4~6a (Fig. 7c), mostly during the 1980s and around 2000. The spring drought index for Suining in recent 55a fluctuated in a cycle of 3~4a (Fig. 7d), mostly around 1970 and during the 1980s. In sum, the spring drought in Southwest China during the recent 55a mainly fluctuated in a cycle of 4~6a.

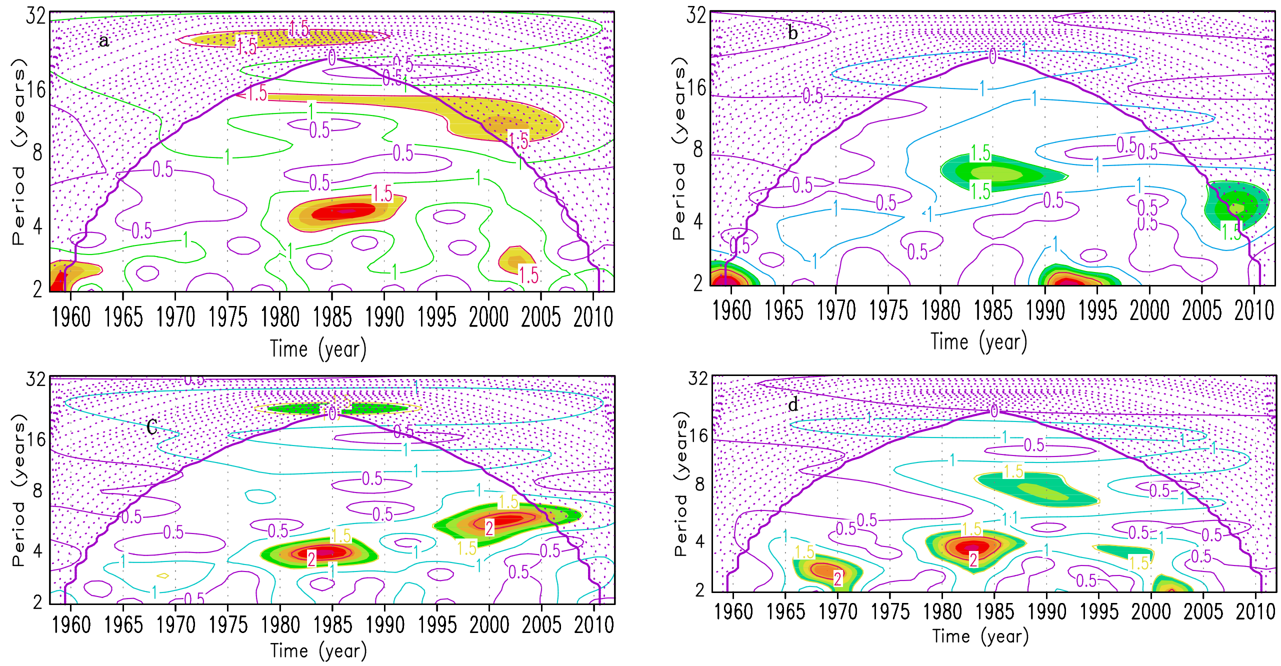

Fig. 7 Isoline chart of Morlet wavelet energy spectrum for the subregional spring droughts index on southwest in China (a:Jiangcheng; b:Anshun; c:Ganzi; d:Suining)

Conclusion: During the recent 55a, the mean spring drought area in Southwest China was nearly 43% of the total area. The medium drought was distributed in the north of Yunnan Plateau and south of West Sichuan Plateau, about 20% of the total area; the serious drought area was distributed in the northwest-southeast belt around the Southwest Sichuan Mountains, about 5% of the total area. The drought intensity increased from northeast to southwest. In recent 55a, the temporal characteristics of spring drought intensity showed a decrease in West Sichuan Plateau, Southwest Sichuan Mountains, and Yunnan Plateau. There was an increase in East Sichuan Basin and the Guizhou Plateau.

The first model loading vectors of EOF for most areas in Southwest China were positive; spring drought intensities fluctuated in equal phases. In the northern part of the Yunnan Plateau and the Southwest Sichuan Mountainous Area, the drought intensity was abnormal in the central area of spring drought. The second model loading vectors of EOF were distributed in opposite phases between the east and the west. This indicated that the Qinghai-Tibet Plateau Monsoon, South Asia Monsoon, and East Asia Summer Monsoon variably influenced the two regions.

The researched region was divided into four sub-regions according to the different spatial models for REOF loading vector, i.e., the Yunnan Plateau was mainly influenced by the South Asia Monsoon, the Guizhou Plateau was jointly influenced by the East Asia Summer Monsoon and the South Asia Monsoon, the West Sichuan Plateau was mainly influenced by the Qinghai-Tibet Plateau Monsoon, and the East Sichuan Basin was jointly influenced by the East Asia Summer Monsoon and the Qinghai-Tibet Plateau Monsoon.Of the four subregional typical stations, the spring drought intensities in Jiangcheng and Ganzi decreased significantly and suddenly changed in 1970a and 1975a, respectively. The spring intensities in Anshun and Suining increased but did not pass the significance check. The temporal fluctuation of spring drought in Southwest China during the recent 55a was characterized by a cycle of 4~6a.

Acknowledgements: This work was financially supported by the National Key Basic Research & Development Program (Program 973) (2013CB430200 (2013CB430206), 2012CB955304); the Special Fund for Commonweal (Meteorological) Scientific Research (GYHY201106029, GYHY201006023), and the National Natural Science Fund (41175081, 41275118)

Brief about the author: Yao Yubi (1962~), Tongwei County, Gansu Province, China, Researcher Grade Senior Engineer, mainly engaged in research on climate change's influence on agriculture and ecology;
E-mail: yaoyubi@163.com

REFERENCES

Allen, R. G., L. S. Pereira, D. Raes and M. Smith (1998). Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56.FAO, Rome,300 (9), D05109.

Duan, X., W H. You and J M. Zheng (2000). The drought and flood feature in Yunnan. Plateau Meteorol, 19 (1): 84-90.

He, J., M. Zhang, P. Wang, S. Wang, and X. Wang (2011).Climate Characteristics of the Extreme Drought Events in Southwest China during Recent 50 Years [J].Acta Geographica Sinica, *9:* 006.

Huang, R H ., Liu Y , Wang L and Wang L (2012). Analyses of causes of severe drought occurring in Southwest of China from the fall of 2009 to the spring of 2010. Chinese J Atmos Sci, 36 (3), 443-457.

IPCC (2012). Summary for policymakers in managing the risks of extreme events and disasters to advance climate change adaptation. A special report of working groups I and II of the intergovernmental panel on climate change. Cambridge university press, Cambridge, UK, and New York, NY, USA, 1-19.

Lu, A. G. (2009). Spatial and temporal precipitation variation on the Loess Plateau in the past half century. Ecol Environ Sci, 18 (3): 957-959.

Luo, Z. X. (2005). Introduction arid climate dynamics in northwest China. Beijing:Meteorological Press, 90-168.

Ma, Z. G. and C. B. Fu (2001). Trend of surface humid index in the arid area of northern China. Acta Meteorol Sin, 59(6): 737-746.

Ma, Z. G. and X. B. Ren (2007). Drying trend over China from 1951 to 2006. Adv Clim Change Res, 3 (4): 195-201.

Ma, Zhuguo. (2005). Dry/wet variation and its relationship with regional warming in arid-regions of northern China. Chinese J Geophys, 48 (5):1011-1018.

Nicholson, S. E. (2001). Climatic and environmental change in Africa during the last two centuries. Clim. Res., 17: 123-144.

North, G. R., T. L. Bell, R. F. Cahalan, and F. J.Moeng, (1982).Sampling errors in the estimation of empirical orthogonal functions. Monthly Weather Review,110(7), 699-706.

Qiang, Z. A., T. W. Wu, M. H. Song, X. B. Ma, Y. Cai, and X. Y. Liang (2001). Arid disaster and advances in arid climate researches over Northwest China. Adv Earth Sci,6(01), 28-38.

Tao, Y., J.M. Zheng, W. Huang and Y. Liu (2009). Climatic characteristics of Yunnan's drought in later spring and early summer J. Natural Disasters,1, 019.

Walter, I. A., R. G.Allen, R. Elliott, M. E. Jensen, D. Itenfisu, B. Mecham, and D. Martin (2000), November). ASCE’s standardized reference evapotranspiration equation. In Proc. of the Watershed Management 2000 Conference, June.

Wang, J., F. Chen, L. Jin, and H. Bai (2010). Characteristics of the dry/wet trend over arid central Asia over the past 100 years. Climate research 41(1): 51.

Wang, M., X.Wang, W. Huang, Y. Zhang, and J. Ma (2012). Temporal and spatial distribution of seasonal drought in Southwest of China based on relative moisture index.Transactions of the Chinese Society of Agricultural Engineering, 28(19), 85-92.

Wei, F. Y. (2007). Statistic Diagnose and Foreshadow Technology in Present Climate. Beijing: Meteorological Press, 115-131.

Wu, H. B. and Wu L. (2005). Methods for Diagnosing and Forecasting Climate Variability [M]. Beijing: Meteorological Press, 208-244.

Yao, Y. B., R. Y. Wang, J. H. Yang and P. Yue (2013). Changes in terrestrial surface dry and wet conditions on the Loess Plateau (China) during the last half century [J]. J Arid Land, 5 (1): 15−24

Yao, Y. B., Y. R. Wang , Y. H. Li and X. Y. Zhang (2005). Climate warming and drying and its environmental effects in the loess plateau. Resour Sci, 27 (5): 146-152.

Yu, L., Z. Erxu, H. Wei, Z. Jianqin and J. Jianhua, (2010). Characteristic Analysis of Precipitation and Temperature Trend in Yunnan Province in Recent 46 Years J. Catastrophology,1, 010.

Zhang Q Y, J. Wei and S. Y. Tao (2003). The decadal and interannual variations of drought in the northern China and association with the circulations. Climatic Environ Res, 8 (3): 307-318.

Zhang, Q., C. J. Zhang and H. Z. Bai (2010). New development of climate change in northwest china and its impact on arid environment. J Arid Meteorol, 28 (1): 1-7.

Zhang, Q., L. Zhang, X. H. Cui and J. Zeng (2011). Progresses and challenges in drought assessment and monitoring. Adv Earth Sci, 26 (7): 763-778.

Zhang, Q., X. K. Zhou, and F. J. Xiao (2006). Classification arid meteorological drought. Beijing:Standards Press of China, 17.

Zhang, S. Y. (2008). Arid meteorological. Beijing: Meteorological Press, 29-152

Zhu, Z. L., X. J. Zhao and C. T. Wang (2006). Rules of drought and the development of water-saving agriculture in southwest China . Ecol Env, 15 (4): 876-880.