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Study on the Temporal and Spatial Characteristics of the Drought in the South of the Yangtze River in China Based on SPI

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Abstract

Using the precipitation data of the sixteen stations in the south of the Yangtze River from 1955 to 2009, this paper calculated the drought index of each month and analyzed the change characteristics of the Station Proportion of Drought Frequency and the Drought Intensity based on the Standardized Precipitation Index (SPI). The results have shown that the drought tendency increased at different degrees in annual scale, and the main drought types are Spring Drought and Autumn Drought with the increasing trends on season scale. Meantime, the Summer Drought trend decreased, and the Winter Drought was considerable variation. As far as the space variation characteristics are concerned, the southwest region is the worst drought area, the southern region comes second, and the central and the eastern part are not so severe. As a drought index, SPI can well reflect a Regional Drought feature.

Keywords: Standardized Precipitation Index (SPI), south of the Yangtze River, Station Proportion of Drought Frequency, Drought Intensity, temporal and spatial characteristics, Drought.

INTRODUCTION

Among many influencing factors of the agricultural development in the south of the Yangtze River, the drought is a natural disaster, which is most common, most pervasive and most massive loss [1, 2]. According to statistical data, crops of 22 million hm2 are stricken by the drought disaster every year in China and accounted for about 60% of the total disaster areas caused by all kinds of meteorological disasters. Simultaneously, 10 billion kilogram grains were lost because of the drought. So, the economic loss is tremendous and affected people's life and social stability.

The south of the Yangtze River is in tropical and subtropical monsoon climate region, so, its precipitation is relatively more than the other areas in China generally. However, this region is also controlled by the subtropical anticyclone, and the rain is less and difference in the region considerably as summer into autumn. So, the seasonal drought weather, such as Summer Drought, always has occurred. This circumstance is extremely disadvantageous to agriculture development, economic development and people's life in the South of Yangtze River. Therefore, it is necessary and vital to study the drought variation characteristics in the South of the Yangtze River.

Based on the precipitation data of the selected sixteen stations from 1955 to 2009 in the south of Yangtze River, this paper analyzed the drought situation in the south of Yangtze River according to the SPI calculation results. The research should be of great significance to assess the drought occurrence condition and trend. It is also beneficial to drought monitor, early warning, engineering construction of disaster prevention and reduction and the government agriculture policy-making [3].

MATERIALS AND METHODS

Research Area Backgrounds

The research areas include each province and region in the south of the Yangtze River, such as Jiangsu, Anhui, Hubei, Shanghai, Zhejiang, Jiangxi, Hunan, Sichuan, Chongqing, Yunnan, Guizhou, Guangxi, Guangdong, Fujian, and Hainan, but not including Hong Kong, Macao, and Taiwan. And sixteen stations in the south of the Yangtze River are selected. The precipitation data from 1955 to 2009 month by month of the selected sixteen stations provided by the China Meteorological Data Sharing Service System [4].

METHODS

Standardized Precipitation Index (SPI) is a precipitation probability index, and it is suitable for the local climate drought monitoring and evaluation. SPI uses Γ distribution probability to describe the precipitation variation, and it makes the precipitation with skewed probability distribution standardization into the normal probability distribution. Drought levels were divided by the standardized precipitation probability distribution eventually [5]. SPI can be calculated with the formula (1):

$$SPI = S\frac{t-(c_2t+c_1)t+c_0}{((d_3t+d_2)t+d_1)t+1.0} \text{ ..... (1)}$$

In equation, $t=\sqrt{\ln\frac{1}{G(x)^2}}$ and the $G(x)$ is precipitation probability distribution relation with Γ function. Here, x is the precipitation sample value, and S is the positive or negative coefficient of the probability density. When $G(x)>0.5$, $G(x)=1.0-G(x)$, S =1 and $G(x)\leq 0.5$, S=-1. $G(x)$ can be calculated with the formula (2):

$$G(x)=\frac{1}{\beta^{\gamma}\Gamma(\gamma)_0}\int_0^x x^{\gamma-1}e^{-x/\beta}dx \quad x>0 \text{ ..... (2)}$$

In equation, γ and β are the shape and dimension parameters of Γ distribute function. c_0, c_1, c_2, d_1, d_2 and d_3 are the simplification approximate calculation parameters of solving formula of the accumulate frequency transformed from the Γ distribute function. It takes the following value [3]: c_0 =2.515517, c_1 =0.802853, c_2 =0.010328, d_1 =1.432788, d_2 =0.189269, d_3 =0.001308. SPI values of different drought levels are detailed to see within Table-1.

Table-1: Drought level based on the Standardized Precipitation Index (SPI)

Grade	Type	Abbreviation in this paper	SPI value
1	No Drought	ND-SPI	-0.5<SPI
2	Light Drought	LD-SPI	-1.0＜SPI≤-0.5
3	Middle Drought	MD-SPI	-1.5＜SPI≤-1.0
4	Heavy Drought	HD-SPI	-2.0＜SPI≤-1.5
5	Serious Drought	SD-SPI	SPI≤-2.0

Drought evaluation index

Drought occurrence frequency (P_i)

Drought occurrence frequency (P_i) is used to evaluate how often the drought occurred during the years which have the record data in a station [6]. Its calculation formula is:

$$P_i=(n/N)\times 100\% \text{ ..... (3)}$$

In equation, N represents the number of years of meteorological data in a station and n represents the total number of years which a drought occurred. Different drought occurrence frequency can be calculated based on drought degrees. To facilitate the analysis and comparison, unless otherwise specified, the Light Drought includes the Light Drought and its above, the Middle Drought consists of the Middle Drought and its above, etc.

Station Proportion of Drought Frequency (P_j)

Station Proportion of Drought Frequency (P_j) represents the range of the drought occurrence area and also represents the drought degree [6]. Its calculation formula is:

$$P_j=m/M\times 100\% \text{ ..... (4)}$$

In equation, M represents the number of meteorological stations and m represents the number of meteorological stations which drought occurred in a particular area. Table 2 lists the drought classification according to the value of P_j.

Table-2: Classification of the size of drought area and the drought degree

P_j	Drought degree level	Abbreviation in this paper
$P_j\geq 50\%$	Whole Regional Drought	DTR-PJ
$50\%>P_j\geq 33\%$	Regional Drought	RD-PJ
$33\%>P_j\geq 25\%$	Partial Drought	PD-PJ
$25\%>P_j\geq 10\%$	Local Drought	LOD-PJ
$P_j<10\%$	No Obvious Drought	NOD-PJ

Drought Intensity

Drought Intensity represents the drought degree. Its calculation formula is:

$$S_{ij} = \frac{1}{m}\sum_{i=1}^{m}\left|SPI_i\right| \quad \text{..... (5)}$$

In equation (5), $\left|SPI_i\right|$ is the absolute value of the SPI while the drought occurred. If the values of the Drought Intensity range from 0.5 to 1.0, the Drought Intensity is defined as a Light Drought. If the values of the Drought Intensity range from 1.0 to 1.5, the Drought Intensity is described as a Middle Drought. If the value of the Drought Intensity is greater than or equal to 1.5, the Drought Intensity is defined as a Serious Drought [7].

ANALYSIS AND RESULTS

Annual Drought Variation Characteristics

Annual Drought Variation

Based on the statistical results of drought occurrence times, the different drought degrees had occurred almost every year from 1955 to 2009 in the south of the Yangtze River. A total of fifty years had occurred the Light Drought and above (Fig-2). Only five years had the No Obvious Drought happened in the whole research areas, and they are 1965, 1970, 1973, 1998 and 1999. During the drought occurrence years, the total years of different drought degrees are not significant. That is to say, the Whole Regional Drought, the Regional Drought, the Partial Drought, and the Local Drought are 13 years, 14 years, 12 years and 11 years respectively from 1955 to 2009.

From the drought occurrence time, the drought almost occurred in all the years. For the drought occurrence trend, its tendency is higher at both ends and lower in the middle. And the Whole Regional Drought in 1966 is most pressing. Among all the stations, the Station Proportion of Drought Frequency above the Light Drought accounted for 75%. As a whole, especially along with coming into the 21st century, the times of the Regional Drought occurrence had a ascend trend. This state reflects the effects of global warming and global change at present. As time goes on, this upward tendency is expected to strengthen in the future [8].

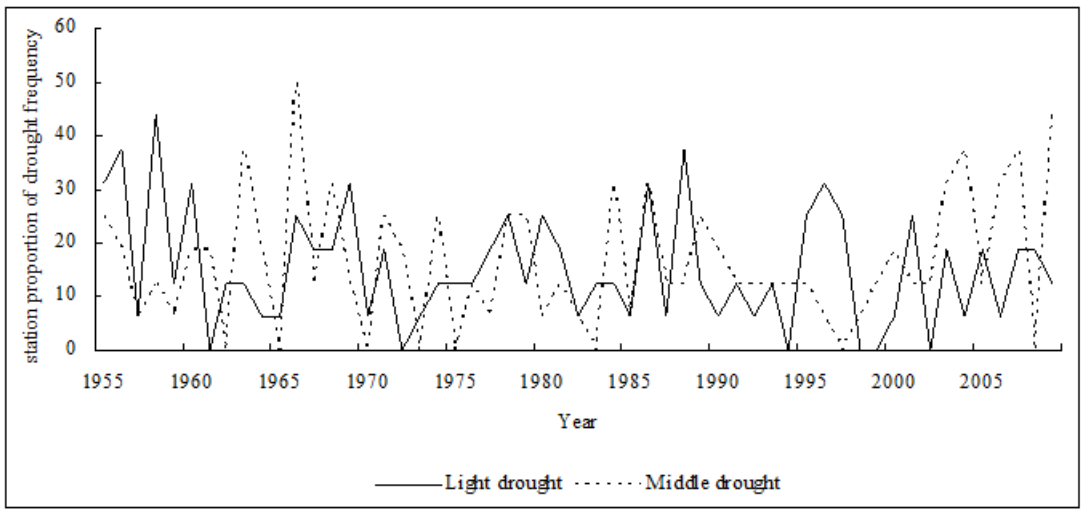

Fig-2: Variation characteristics of the Station Proportion of Drought Frequency in the south of the Yangtze River from 1955 to 2009

For the Middle Drought and above, the number of the year is up to 48 and accounted for 87.3% of the total years. Notably, the occurrence frequency of the Middle Drought is more frequent. From 2000 to 2009, there were six years, which the Whole Regional Drought or the Regional Drought had occurred during the ten years. Thus, the drought has become a more common natural disaster in the south of the Yangtze River with coming into the 21st century. Without a doubt, this will be very disadvantageous for the agricultural production and development in the south of the Yangtze River in the future.

Drought Intensity

The values of the drought intensities in the south of the Yangtze River maintained at 0.5~2.0 from 1955 to 2009, and the mean value was about 1.0 (Fig-2). Between the drought years, ten years had reached the Serious Drought level, especially in 1986, 2007 and 2009. There were 25 years which their value of the drought intensities ranged from 1.0 to 1.5, and was belong to a Middle Drought. It also can be seen that 15 years are the Light Drought and the other five years have the No Obvious Drought occurred in 1965, 1970, 1973, 1998 and 1999. It's shown that the drought intensities were mainly the Middle Drought and the Light Drought, accounted for 72.8% of the 55 years.

However, the Whole Regional Drought hadn't occurred during the 55 years, and there were differences among different regions in the south of the Yangtze River. Even so, the future drought condition doesn't seem very hopeful. Since 2000, the drought intensities have an upward tendency. Thus, the status of disaster prevention and reduction of the whole areas was still grim.

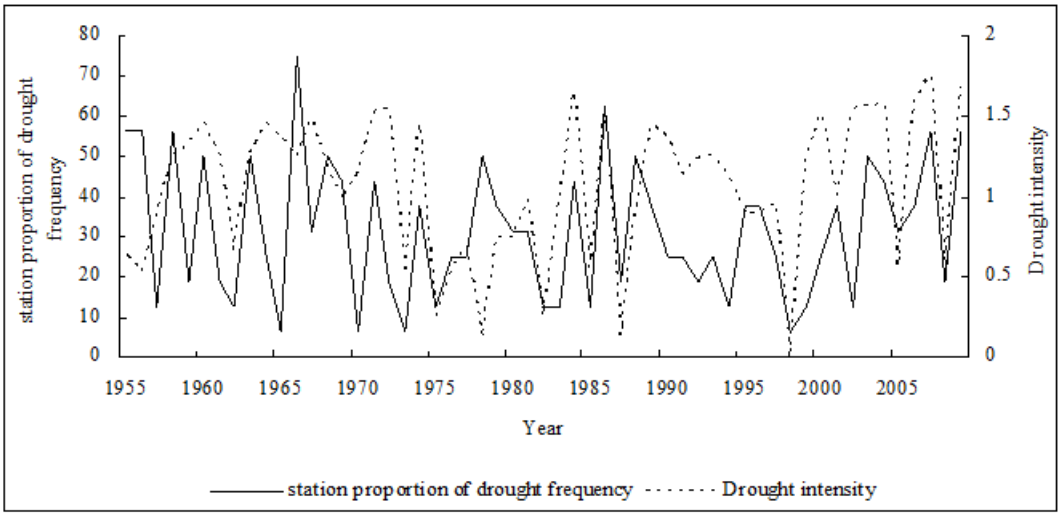

Fig-3: Variation characteristics of the drought intensities in the south of the Yangtze River from 1955 to 2009

Station Proportion of Drought Frequency

As shown in Fig-3, the droughts were mainly the Light Drought in the 1950s, the Station Proportion of Drought Frequency was high and the mean drought occurrence times were very much. However, in the 1960s, the Station Proportion of Drought Frequency decreased, and the increase of the Middle Drought was faster. To say, the drought has intensified. Subsequently, the Station Proportion of Drought Frequency reduced from the 1970s to 1990s on the whole.

Table-3: Comparison of the Station Proportion of Drought Frequency, the number of drought occurrence times, the Drought Intensity at each station in the south of the Yangtze River

	Degree	1955-1959	1960s	1970s	1980s	1990s	2000-2009
Station Proportion of Drought Frequency (%)	Light Drought	26.25	16.25	12.5	16.875	11.875	13.125
	Middle Drought	13.75	18.75	13.75	14.375	10.625	23.75
Occurrence times	Light Drought	4.2	2.7	2.0	2.7	1.9	2.1
	Middle Drought	1.6	2.3	1.1	1.1	0.7	2.0
Drought intensities		0.9289	1.0589	0.7688	0.9207	0.9393	1.3143

The drought intensities varied a little at about 0.9~1.0 in the 1950s, 1960s, 1980s, and 1990s, but the drought intensities were the lowest in 1970s. After 2000, Drought Intensity strengthened rapidly. Notably, the station proportion of the Middle Drought frequency had increased and reached the highest, surpassing 20% for the first time. Moreover, the vast regions were affected by the drought, and the drought situation is hardly optimistic. As time goes on, the Station Proportion of Drought Frequency, drought frequency, drought intensities, drought times and the drought regions are expected to rise further [8].

Seasonal drought variation characteristics

All the year round

Based on the Station Proportion of Drought Frequency all the year round, 15 years of the Whole Regional Drought had occurred in the last 55 years. Moreover, Drought Intensity was heavy. Mainly, after entering the 21st century, the frequency of the Whole Regional Drought increased sharply. This situation may be affected by the globe change. From the drought intensities, there are 18 times of the Middle Drought during the 55 years, and the intensities strengthened on the whole. So, drought situation is very rigorous in the south of the Yangtze River.

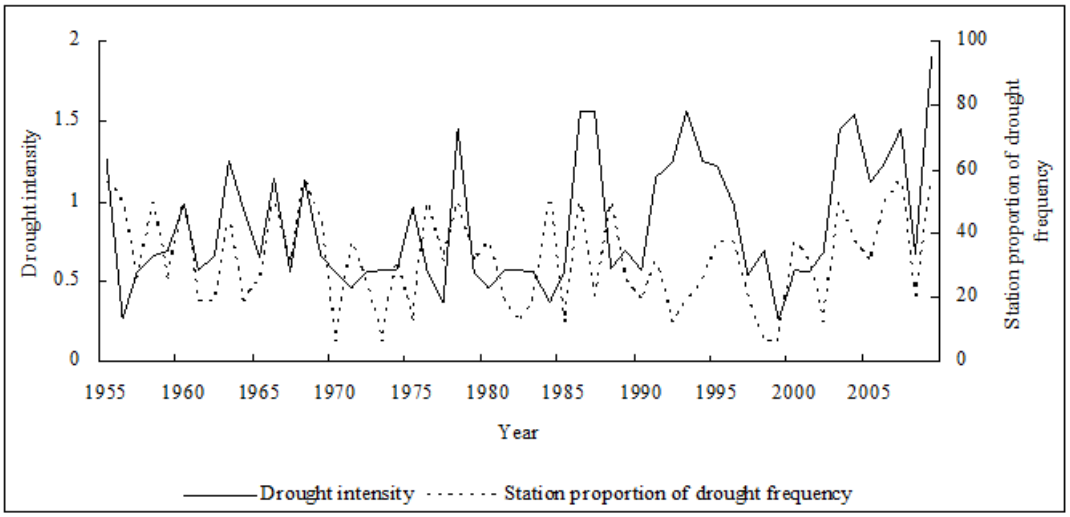

Fig-4: Variation characteristics of the drought in the south of the Yangtze River from 1955 to 2009

Spring Drought

Based on the curve of the station proportion of the drought frequency, the phase characteristic is noticeable (Fig-5). The Spring Drought rose and fell for many times. Eight times of the Spring Drought had occurred in the 1980s. Especially in 1991, the station proportion of the drought frequency was higher than 60%, and the Drought Intensity was close to 1.6, and up to a Serious Drought.

According to the drought intensities, four years (1958, 1960, 1987, 1992) had experienced the Serious Drought. Most of the Spring Drought intensities fluctuated between 0.5 and 1.3. Moreover, in the 1990s later, the Spring Drought intensities maintained at about 1.0 and belonged to the Middle Drought. Consequently, the Spring Drought was more frequent in the south of the Yangtze River. Thus, the situation of the Spring Drought is severe.

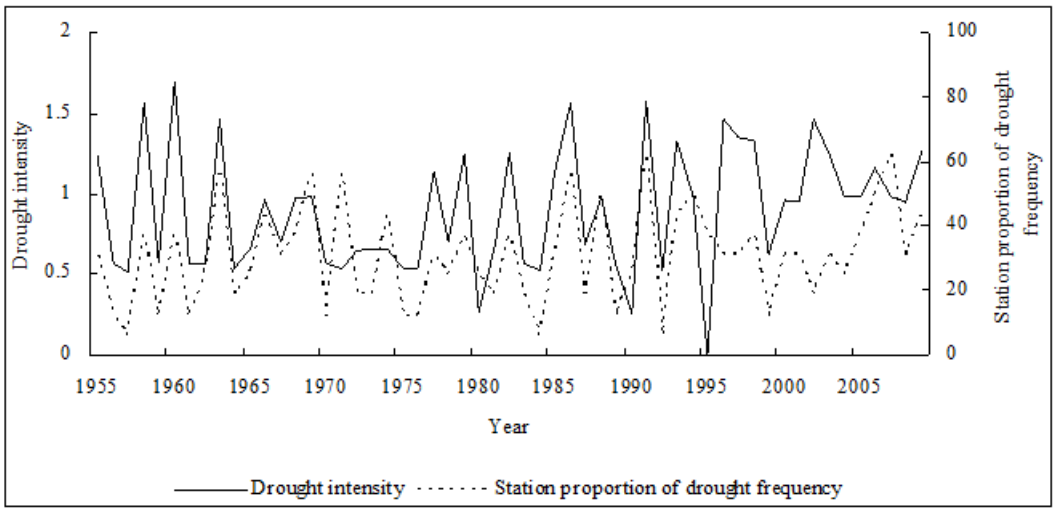

Fig-5: Characteristics of the drought change in the south of the Yangtze River in spring from 1955 to 2009

Summer Drought

Summer Drought in the entire region was few. Four years, such as 1973, 1991, 1998 and 2008, had no apparent Summer Drought from 1955 to 2009. Most of the Summer Drought was mainly the Local Drought, and their station proportion of the drought frequency ranged from 25% to 33% (Fig-6). Concerning the drought intensities, most of them ranged from 0.5 to 1.3 and inclined toward the Light Drought. Only in 1973, the Summer Drought approached the highest value at about 1.8. On the whole, the Summer Drought was not apparent in the south of Yangtze River.

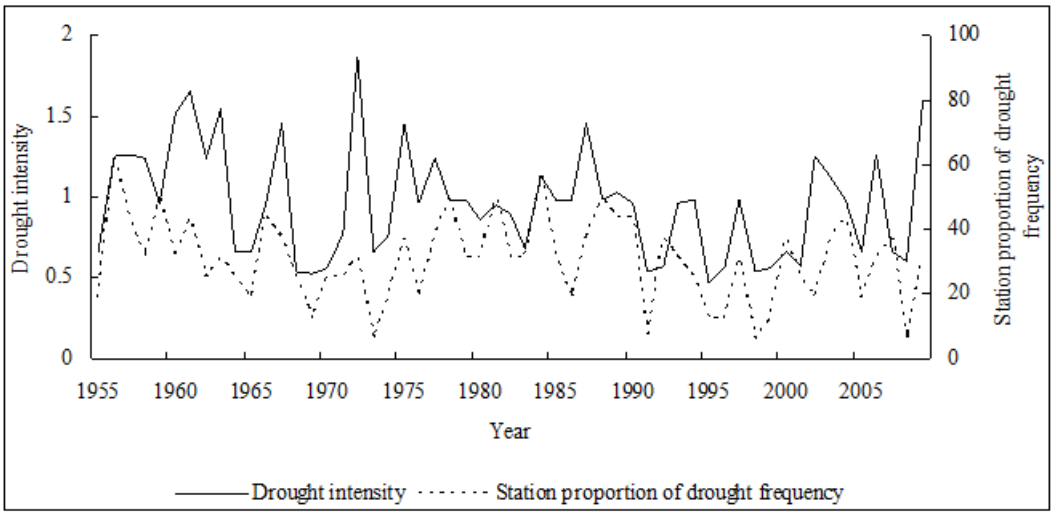

Fig-6: Characteristics of the drought change in the south of the Yangtze River in summer from 1955 to 2009

Autumn Drought

The overall trend of the Autumn Drought descended in first and ascended at last. During the 55 years, the times of the Autumn Drought were relatively more and 14 years were the Whole Regional Drought, exceeding a quarter of the whole 55 years (Fig-7). It was not hard to find five times of the Whole Regional Drought occurred, and the station proportion of the drought frequency maintained at about 50% in the mid-1960s and the early 1970s. There were five times of Whole Regional Drought occurred, and their station proportion of the drought frequency maintained at about 50%. And it also can be seen that nine times of the Regional Drought occurred and most years had occurred local Autumn Drought except 1961, 1970 and 1990. After entering the 21st century, the drought scope has ascended as a whole. Moreover, six times of the regional Autumn Drought had occurred just in the ten years from 2000 to 2009. The drought occurrence frequency is considerably higher. On the other hand, there were 13 years of middle Autumn Drought. So, it was clear that the situation of the Autumn Drought is critical in the south of the Yangtze River.

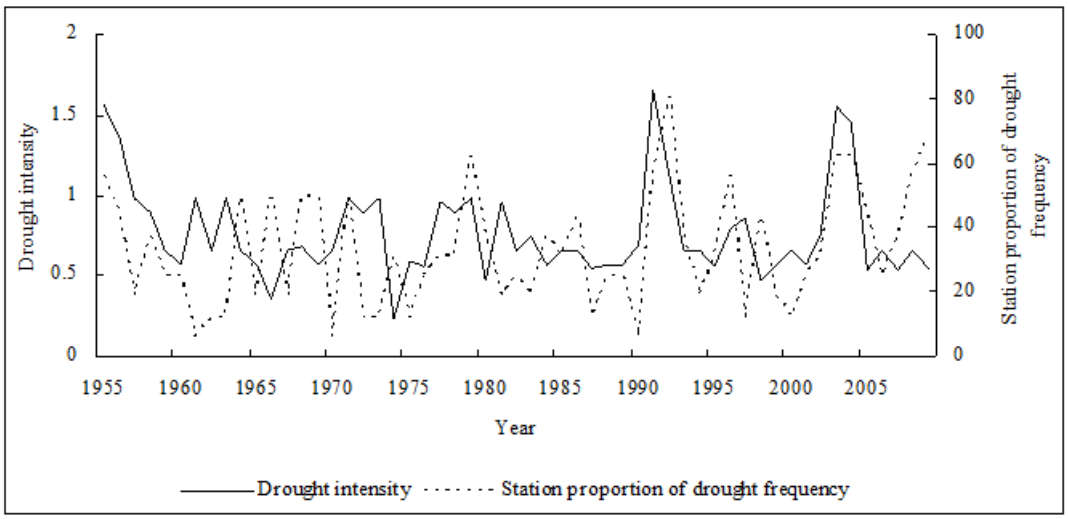

Fig-7: Characteristics of the drought change in the south of the Yangtze River in autumn from 1955 to 2009

Winter Drought

The Winter Drought was very different in time based on the station proportion of the drought frequency. According to Fig-8, the curves rose and fell very much. During the 55 years, the Whole Regional Drought had occurred 14 times, and their drought intensities were also very high and almost above the Middle Drought. Especially in 1964, the Drought Intensity was close to 2.0 and nearly reached the Serious Drought. However, this circumstance was unsteady. Actually, there were ten years without the drought among the 55 years.

Difference analysis on the drought in each area in the south of the Yangtze River

According to the climate characteristics and regional contacts, the south of the Yangtze River can be divided into four different parts: the eastern region, the

southern region, the central region, and the southwestern area. Here, the variation of the Station Proportion of Drought Frequency and SPI in different parts is analyzed to find their difference.

Eastern Region

As shown in Fig-9, the total years of the Whole Regional Drought were 19 in the eastern area, according to the Station Proportion of Drought Frequency, including three years in the 1950s, eight years in the 1960s, three years in the 1970s, two years in the 1990s and four years after 2000. At the same time, the times of the Partial Drought and above were 21, especially 14 years since 1990 and amounting to two-thirds of the total 21 years. However, there were also 15 years of the No Obvious Drought and concentrated in the 1970s ~1990s.

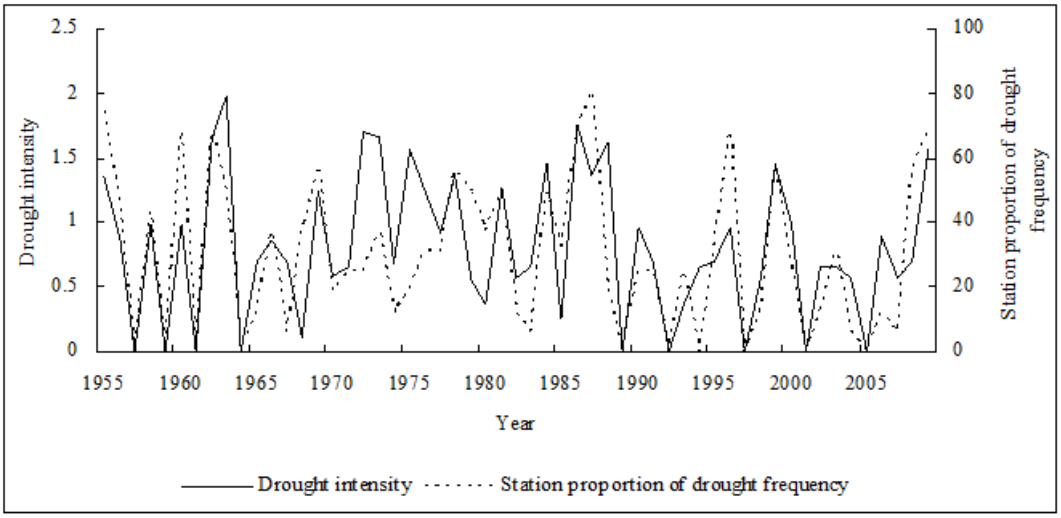

Fig-8: Characteristics of the drought change in the south of the Yangtze River in autumn from 1955 to 2009

Based on the SPI value, three years had reached the Middle Drought level, ten years had reached the Light Drought level and other years were the No Obvious Drought. It should be pointed out that no drought had occurred since the 1980s and the intensities were very low. And compared with the 1950s ~ 1960s, the drought situation had already eased.

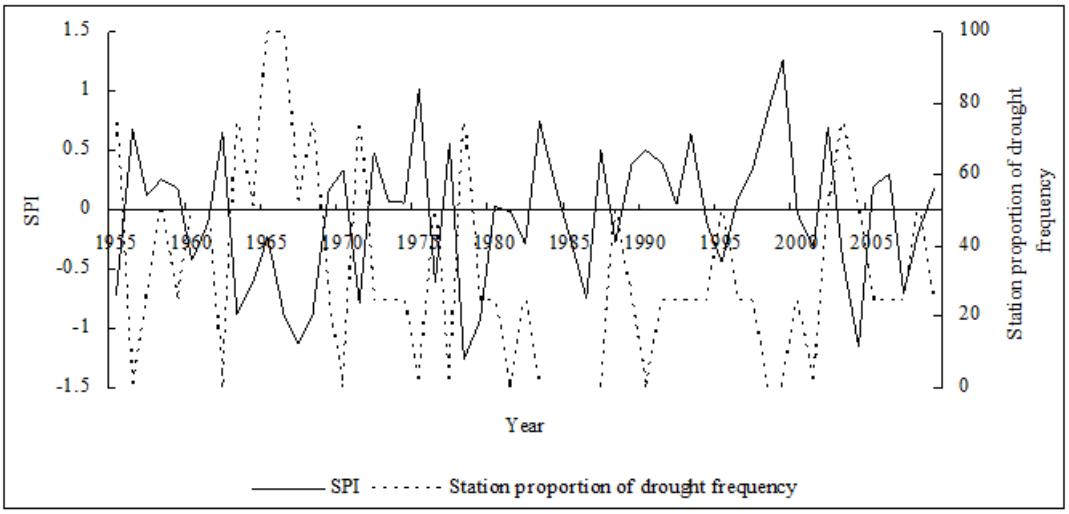

Fig-9: Variation Characteristics of drought in eastern region from 1955 to 2009 Southern region

As shown in Fig-10, the total 20 years had occurred the whole region drought based on the Station Proportion of Drought Frequency, including 4 years in the 1950s, 5 years in the 1960s, one year in the 1970s, 3 years in the 1980s, 2 years in the 1990s, and 5 years after 2000. At the same time, the Partial Drought and above was 19 years, but there were 17 years without drought either. Moreover, the drought was mainly in the 1960s ~ 1990s. On the other hand, based on the SPI value, five years had reached the Middle Drought, seven years had reached a mild drought level and other years were the No Obvious Drought. In a word, the drought situation is severe.

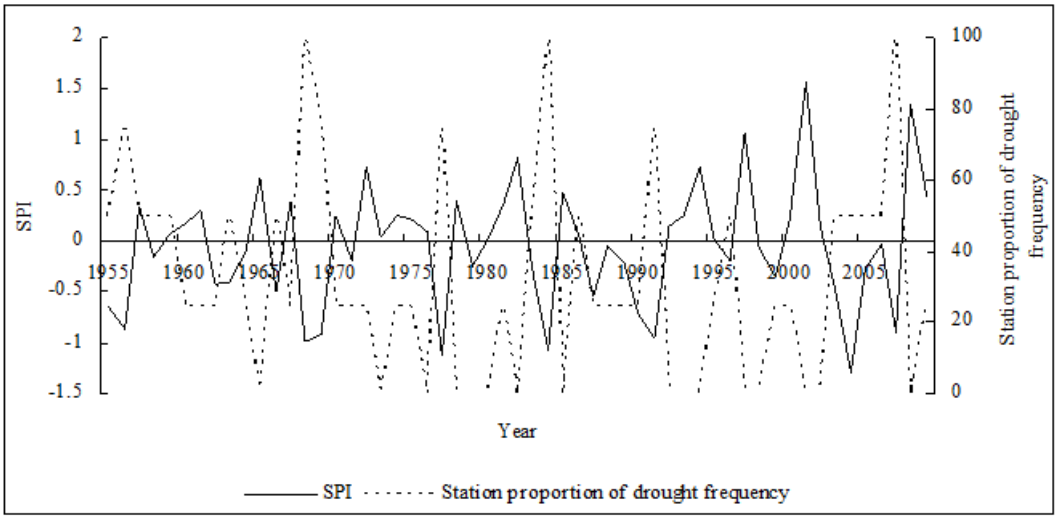

Fig-10: Variation Characteristics of drought in the southern region from 1955 to 2009 Central region

In the central area, the Whole Regional Drought had occurred 21 years based on the Station Proportion of Drought Frequency and accounted for 38% of the whole years. Meantime, the Partial Drought and the No Obvious Drought were all 17 respectively. But based on the SPI value, three had reached the Middle Drought, nine years had reached the Light Drought and other years were the No Obvious Drought. Just for this index, the Drought Intensity isn't heavy.

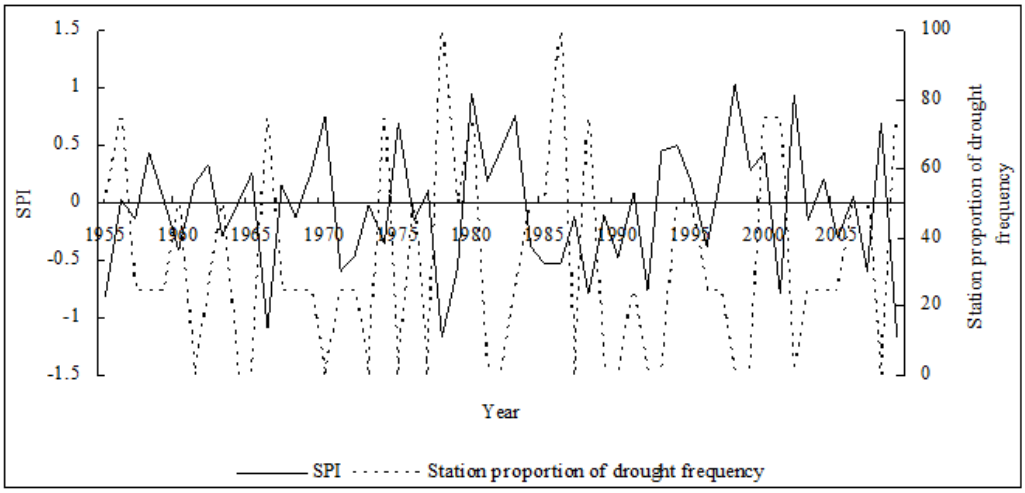

Fig-11: Variation Characteristics of drought in the central region from 1955 to 2009 Southwest area

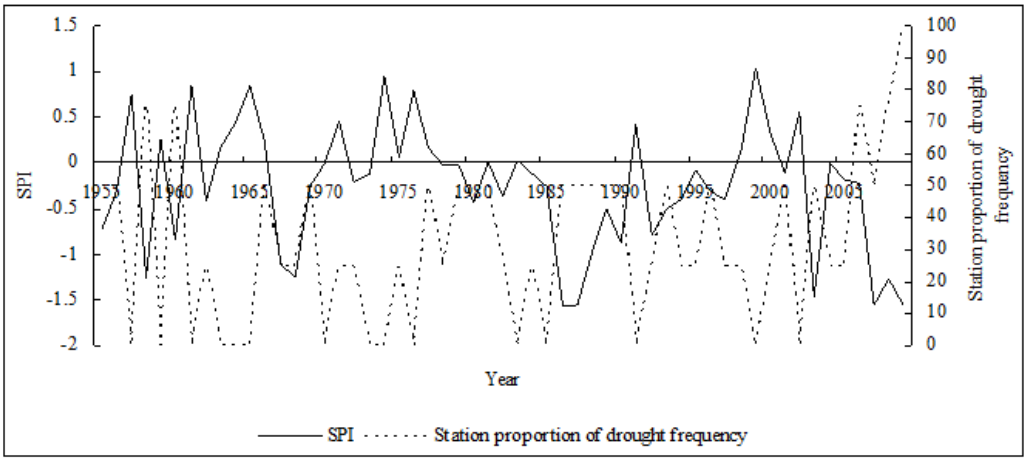

Fig-12: Variation Characteristics of drought in the southwest region from 1955 to 2009

From a Station Proportion of Drought Frequency point view, during the 55 years, the Whole Regional Drought had occurred 21 years, and the Partial Drought was 18 years. After the 21st century, the drought frequency and strength have all increased. For the SPI value, nine years had reached the Middle Drought, and 11 years had reached the Light Drought. So, the drought situation in the southwest region is most relative severe to the other areas.

CONCLUSION

The research results of the annual, seasonal and spatial drought variation characteristics in the south of the Yangtze River region and its different regions in recent 55 years showed that:

The Station Proportion of Drought Frequency and drought intensities of the south of the Yangtze River have stage distribution characteristics. For the year scale, the drought variation characteristics are different in a different period. For the seasonal scale, the Spring Drought and the Autumn Drought are the major drought types with an aggravating tendency on the whole.

According to the Station Proportion of Drought Frequency and SPI, the drought variation trend of different interior regions was consistent with that of the south of the Yangtze River. However, the drought conditions vary significantly between regions. The study showed that the drought was most serious in the southwest, followed by the south, and relatively minor in the central and eastern regions. This article analyzed the drought developing principles with time in the south of the Yangtze River systematically and illustrated the seasonal drought characteristics. At the same time, based on the SPI index, the research also discussed the drought characteristics of each different region [10]. Of course, because SPI is only considering precipitation elements and exists shortcomings, more deep research will be carried out in the future to establish a suitable drought index for the south of the Yangtze River [11].

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