

IMPACT OF CLIMATE ON GRAIN YIELD PER UNIT AREA IN CHINA DURING THE YEARS OF 1949– 1992^①

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(Received 8 May 1998)

ABSTRACT: The grain yield per unit area in China has been increasing from 1949 to 1992 with annual fluctuations, which was caused by both policies and monsoon climate. The total grain yield is divided into trend yield, which reflects the influence of economic factors, and climate yield, which reflects the impact of climate factors. The results of grain and climate yield by EOF (empirical orthogonal function) method show that the grain yield in the eastern China is higher and more fluctuating than that in the western region. The spatial and temporal distributions of climate yield were divided into four patterns. Regional unanimity of climate-yield variation is the first and main spatial pattern, and then there are the spatial patterns of north– south difference and east– west difference in some years. Generally, climate conditions are good for grain yield during the 1950s and 1980s all over the country.

KEY WORDS: grain yield, climate yield, empirical orthogonal function, spatial and temporal distribution

Since the year of 1949, the production of grain in China has experienced a great increase, which indicates that not only the food problem of 1/5 of the world population has been solved, but also China can export grain into the world grain market. However, it should be seen that, at present, production of agriculture in China depends on natural conditions greatly, especially climate. The climate in China is monsoon climate, which is characterized by the great annual variation of precipitation and severe natural disaster such as flood and draught and makes grain production more unstable. A lot of researches have focused on analysis of the impact of climate change in the future on China's agriculture production, which includes planting system, change of quantity and quality of crops, change of the length of the growing season, etc (Guo *et*

① Supported by the National Natural Science Foundation of China.

al., 1993; Guo *et al.*, 1996). As regard to the impact of modern climate on agriculture, there have been many regional researches. This paper attempts to research the effects of climate factors on the fluctuations of the grain yield and its regional variance through analyzing the temporal and spatial variation of the grain yield per unit area in China and climate change for more than 40 years. It is important for the sustainable development of Chinese agriculture.

I. DATA AND METHOD

State Statistic Bureau's data of grain yield of 1949– 1992 for each province, municipality, and autonomous region were used. Because the data in Tianjin and the Xizang Autonomous Region are incomplete and there are no data from Taiwan Province, they are not included in this study, and the data of new province Hainan is still included in Guangdong Province.

The production is the result of both social economic and natural factors. The grain yield has been increasing continuously with annual fluctuations. So it can be divided into two parts: trend yield and climate yield. The former was determined by social economic input and the development of technology. The latter was mainly reflects the influence of climate factors which are still out of man's control. This can be expressed as follows:

$$Y = Y_t + Y_c$$

where Y is actual grain yield per unit area; Y_t is the trend yield, represents time tendency; Y_c is climate yield, which refers to the fluctuation of grain yield. This paper analyzes the climate yield mainly. According to our research we use a polynomial equation to simulate the trend yield as follows:

$$Y_t = b_0 + \sum b_i t^i$$

where t is time sequence; b is coefficient; and i is power which equal to 4 in this study. The regression result of the selected equation is at 1% significant level. Then

$$Y_c = Y - Y_t$$

In order to eliminate the influence caused by great difference of numbers scale among different regions and make the yields comparable, climate yields in each province, municipality, autonomous region have been normalized. Normalized climate yield data was disintegrated by empirical orthogonal function (EOF), the results were used to analyze the spatial distribution and temporal change of climate yields and the impacts of climate on grain production in China.

II. TEMPORAL AND SPATIAL CHARACTERISTIC OF GRAIN YIELD

The level of grain yield per unit area indicates a region's agriculture production level, especially in China, which has a large amount of population but insufficient land resource. The food supply mainly depends on the increase of grain yield per unit area. In China, the grain

yield has been increasing gradually during more than 40 years, from 1020 kg/ ha in 1949 to 4005 kg/ ha in 1992. The average increase rate was about 67. 5 kg/ ha per year, but it was different in different periods (Table 1).

Table 1 The change of grain yields in different periods

Years	1950s	1960s	1970s	1980s	1949– 1992
Increase(kg/ ha)	39	79. 5	81	111	67. 5

The levels of grain yield per unit area demonstrate strong regional difference. The areas with higher productivity of grain production are mostly located in east China. They are North-east Plain, North China Plain, Changjiang River Middle and Lower Reaches Plain and Pearl River Delta and the grain yields in these regions are above 4500 kg/ ha. The grain yields in most of provinces in northwest China, such as Shanxi, Shannxi, Inner Mongolia, Gansu, Ningxia, Qinghai provinces(regions), are just below 3000 kg/ ha. The grain yields of other places in China are between 3000– 4500 kg/ ha. Generally speaking, the fluctuation range in east China with higher productivity is greater than that in other regions with comparably lower productivity (Table 2). This is because east China is impacted by monsoon climate with a great annual variation of climate and frequent climate disasters.

Table 2 The level and change of grain yields(kg/ ha)

Grain yield(kg/ ha)	< 3000	3000– 4500	≥4500
Absolute variation of grain yield(kg/ ha)	595. 5	798. 0	1219. 5
Relative variation of grain yield(%)	21. 9	21. 2	22. 6

III. THE TEMPORAL AND SPATIAL VARIATION OF CLIMATE YIELD

1. Basic Characteristics

Climate yield changed from year to year and the change scale was different among different regions. The smallest change of climate yield was 552 kg/ ha while the largest was 2850 kg/ ha. Liaoning, Jilin and Shandong provinces have the greatest range of change, which is beyond 1500 kg/ ha. Average national climate yield was 37. 5 kg/ ha during the 1950s, it was decreased during the 1960s and 1970s, and then tended to increase during the 1980s (Table 3). The data of climate yield shows three different patterns in temporal variation (Fig. 1).

Table 3 Climate yield in different periods

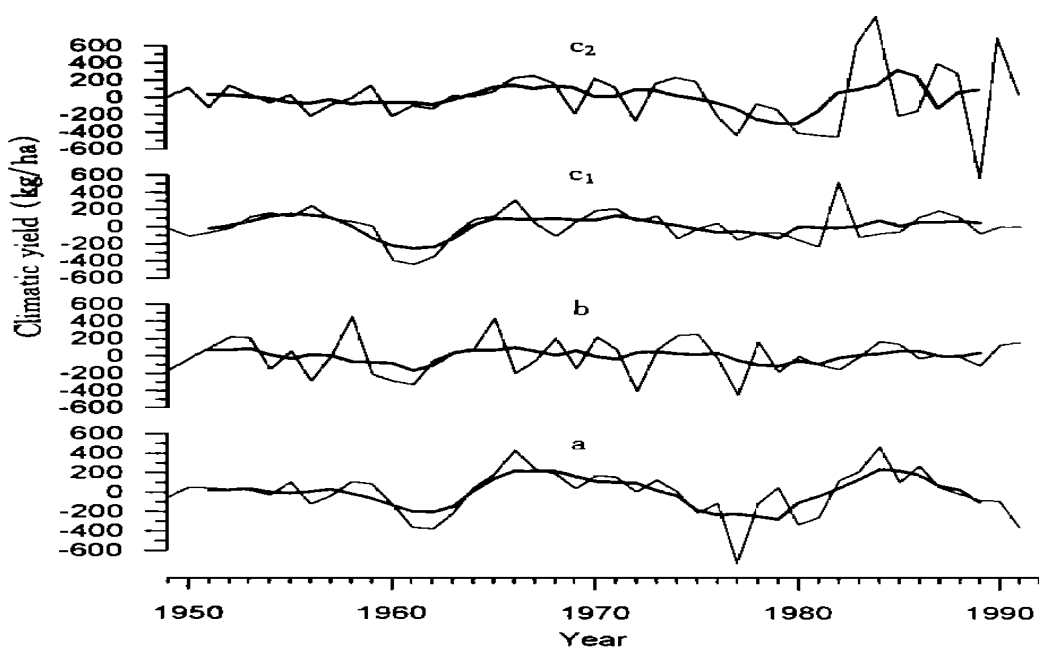
Decades	1950s	1960s	1970s	1980s
Climatic yield(kg/ ha)	37. 5	– 12. 6	– 27. 6	6. 1

(1) Double peak wave type, which is mainly represented by Hebei, Shandong, Henan,

Anhui in Huang-Huai Plain; Middle and lower reaches of the Changjiang River including Shanghai, Jiangsu, Zhejiang, Jiangxi, Hubei, Hunan, Sichuan, Fujian, Guangdong, Guangxi provinces (regions) in south China (Fig. 1a) .

(2) Gentle type, with less change, which includes Beijing, Inner Mongolia, Shanxi, Shaanxi, Ningxia.

(3) Single depress type which can be found in Gansu, Qinghai, Xinjiang in northwest China and Yunnan, Guizhou in southwest China and Heilongjiang in northeast China. The lowest value appeared in the 1960s and after that the fluctuation became minor (Fig. 1 C₁) . In Jilin and Liaoning the lowest value appeared in the 1980s and there had minor fluctuation before (Fig. 1 C₂) .



a. double peak wave type b. gentle type c. single valley type

Fig. 1 Different types of climate yield change

2. Empirical Orthogonal Function Analysis for Climate Yield

The contribution of accumulated variance of the first 4 special vectors of the EOF is 62.9%. They show the main spatial variation of climate yield (Fig. 2).

The first special vector's contribution is 35.0%, which is the most important spatial variation pattern. All first vector values are greater than zero, and it reflects the uniform feature all over the country in the variation of the climate yield. When its corresponding time coefficient is greater than zero, climate yield all over the country increases, such as the years of 1958, 1966, 1970 and 1984. Otherwise, climate yield decreases, such as 1961, 1977 and 1989. The higher values of this pattern are in south China lying to the south of the Qinling Mountain and the

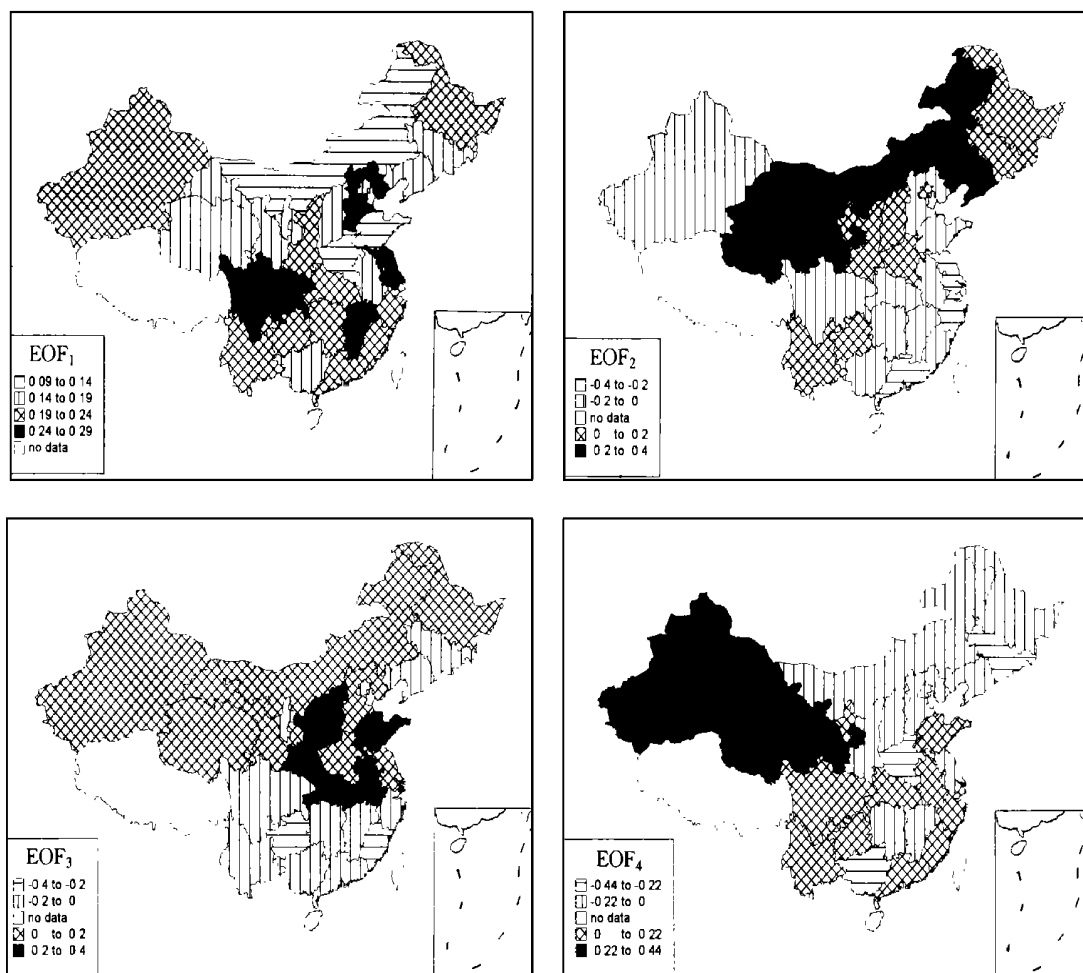


Fig. 2 Distribution of the first 4 EOFs (EOF₁– EOF₄)

Huaihe River, which indicates climate yield has greater fluctuation there. The lower values are in north China where the fluctuation of climate yield is relatively minor. The time coefficient (Fig. 3) fluctuates around zero, which is positive in the 1950s, later 1960s, earlier 1970s, and middle of 1980s, in the other times the values are negative. The lowest and highest values appear in the beginning of the 1960s and the middle of the 1980s respectively, which corresponded to the most severe natural disaster year and the most favorable weather year since 1949. During the 44 years from 1949 to 1992, the climate yield increased for 25 years but decreased for 19 years.

The second special vector of EOF contributes 10.4% variance. Two obviously different regions can be indicated according to the line of west or north boundaries of Hebei, Shandong, Anhui, Hubei, Hunan and Guangxi provinces. The vector value is negative in southeast region with the lowest center in south China coast area, while the northwest region has a positive value with the highest center of Inner Mongolia, Gansu, and Qinghai provinces. When its

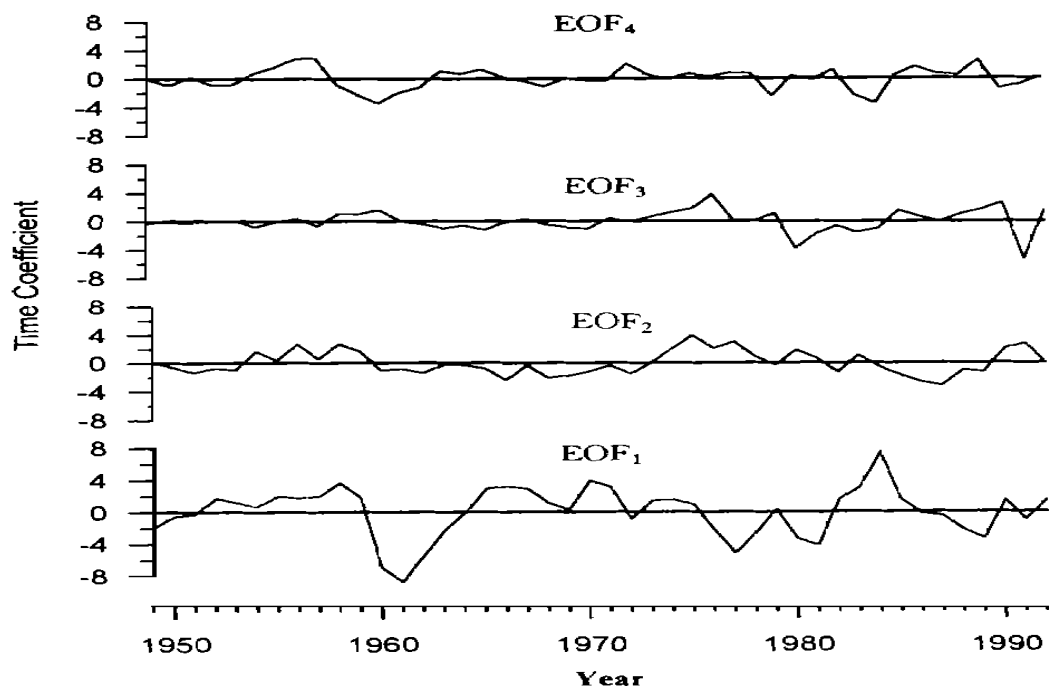


Fig. 3 Time coefficient of the first 4 EOFs (EOF₁ – EOF₄)

corresponding time coefficient is greater than zero, the climate yield decreases in the region where the vector value is negative but increases in the region where the vector is positive. When time coefficient is below zero, the situation is opposite. For example, during the 1950s and 1970s the time coefficient was positive, so the climate yield increased in northwest China but decreased in southeast China. Oppositely, during the 1960s and 1980s, the climate yield increased in southeast China but decreased in northwest China. During the 1990s the situation was the same as that in the 1950s and 1970s (Fig. 3). What is noticeable is that southeast area with the negative vector value is the main area of the grain production, so the change of grain yield in this area will strongly influence the yield of the whole country. In short, the change tendency of the southeast showed by EOF₂ is similar to that showed by EOF₁ for the whole country: when yield was increased in southeast China during the 1960s and 1980s, it was the same as the whole country. The symbol of EOF₂ is value of southeast area is opposite to that of EOF₁ is, and the change of their time coefficients is opposite to each other either.

EOF₃ is contribution ratio of variance is 8.6%. The spatial pattern of EOF₃ shows the difference from south to north divided by the Changjiang (Yangtze) River. The vector value in the south is negative but positive in the north. When the time coefficient is larger than zero, the climate yield decreases in the south but increases in the north. The spatial pattern of EOF₃ is not remarkable before the 1970s, but remarkable since the 1970s, and this shows that the difference of climate yield between south and north has increased.

EOF₄ is contribution rate of variance accounts for 8.0%. It shows the different change be-

tween east and west. The vector value in the east region is negative but positive in the west region. When the time coefficient is larger than zero, the climate yield decreases in the east but increases in the west. The different change of climate yield between east and west region was remarkable in the 1960s.

The typical years of each EOF during 1949– 1992 is given in Table 4.

Table 4 Change of the first 4 EOFs from 1949 to 1992

EOF	Years (time coefficient > 0)	Pattern	Years (time coefficient < 0)	Pattern
EOF ₁	1952, 1953, 1955, 1958 1965, 1966, 1967, 1970, 1971 1973, 1982, 1983, 1984, 1992	Increase of climate yield in the whole country	1949, 1960, 1961, 1962 1963, 1977, 1978, 1981 1988, 1989	Decrease of climate yield in the whole country
EOF ₂	1954, 1974, 1975	Decrease of climate yield in the southeast but increase in the northwest	1951, 1968, 1969, 1985 1986, 1987	Increase of climate yield in the southeast but decrease in the northwest
EOF ₃	1976, 1990	Decrease of climate yield in the south but increase in the north	1980, 1991	Increase of climate yield in the south but decrease in the north
EOF ₄	1956, 1957, 1964, 1972	Decrease of climate yield in the east but increase in the west	1950, 1959, 1979	Increase of climate yield in the east but decrease in the west

3. Analysis of the Impact of Climate Change on Climate Yield

Compared to the studies of the temporal and spatial variation of temperature and precipitation in China(Chen *et al.*, 1996), the relationship between the change of climate and climate yield is obvious. The result of EOF₁, which shows the great increase during the 1950s and 1960s but decrease during the 1970s and 1980s in the whole country, is consistent to the decrease tendency of precipitation in China from the 1970s to 1980s (Wang, 1996). This shows the important role of precipitation change in climate yield change in China. The pattern of EOF₁ mainly reflects the role of precipitation in climate yield. The decrease tendency of precipitation in China from the 1970s will be harmful to grain yield. Although the precipitation increases since the 1980s, it is still much lower than that in the 1950s. The result of EOF₂ mainly reflects the impact of regional precipitation change on climate yield. In the 1950s and the late of the 1970s, the climate yield increased with the increasing of precipitation in north China, but in the 1960s and 1980s, the same phenomenon happened in the southern China. The result of EOF₃ mainly reflects the impact of the temperature change on grain yield. During last 40 years, temperature tends to rise in the north, but in the south it did not increase or even a little decrease (Tang, 1996). So the climate yield increased in north China but decreased in the south. It is noticeable that the pattern of EOF₃ is more typical since the 1970s with the temper-

ature rising, this shows that the impact of temperature change on climate yield will be greater when the climate becomes warmer and warmer.

IV. CONCLUSIONS AND DISCUSSIONS

Several conclusions could be drawn based on the above analysis:

(1) The climate yield, taking out the trend yield from the total grain yield, will indicate clearly the influence of the climate change on grain yield. In the most of the cases the impact of climate change on grain yield is the uniform in the whole country, the grain yield increases some years but decrease in some other years all over the country. Some years it is different from different regions, climate yield increase in some regions but decrease in the others.

(2) The first 4 EOF accumulated variance is 62.9%, which basically reflects the main temporal and spatial variation of the climate yield change.

(3) The climate yield change is mainly affected by the change of precipitation for the more than 40 years, however, after the 1980s, the influence of temperature change on climate yield was greater because of the temperature rising. EOF₁ and EOF₂ show the effects of the change of precipitation, and EOF₃ indicates the effect of the change of temperature.

(4) The grain yield is the result of both social economic and natural conditions. It can be divided into trend yield and climate yield. The trend yield is caused by the social and economic factors, which is also influenced by temperature rising, and the climate yield reflects the fluctuation of climate, which could be also influenced by policy change.

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