



Research on the variation characteristics of climatic elements from April to September in China's main grain-producing areas

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Abstract

Climate elements are important indicators of climate change in China's main grain-producing areas during the April–September growth season and affect the growth and yield of crops. This paper combines grain concentration and geographical detector to divide the North and South regions of China's main grain production. The linear trend and Morlet wavelet transform methods are used to analyse the characteristics of climate change based on observational climate data from April to September 1981–2015. The results show that the climate in the North region is warm and dry during the growth season, whereas the climate is warm and humid in the South region. The main periods of the change in temperature in the North and South regions are 3 years, and that in precipitation is 5 years, and that in sunshine hours is 3–4 years. Changes in the climate elements in various provinces show complex, varying and regional characteristics of cold-warm and dry-wet cycles. The changes in climate elements are significant and different climatic conditions and regions have various possible impacts on grain production in China during the growth season. For China's agricultural-economy sustainable development and grain security, the study suggests that governments should place more emphasis on climatic element changes during the growth season and invest more money in disaster prevention and mitigation, especially in the main grain-producing areas.

1 Introduction

China is sensitive to the effects of global climate change (Wu et al. 2012; IPCC 2014). The average annual surface temperature in China has increased by 0.24 °C/10a from 1951 to 2017 (Ding and Wang 2016; CMA 2018). Extreme weather and climate events have increased in strength and the risk of such events has generally increased (Qian et al. 2007; Ren et al. 2010; Sun et al. 2014). These changes in climate will have a major impact on grain production and food security in China (Chavas et al. 2009; Sanchez et al. 2014; Lesk et al. 2016). April–September is a common and important period

for crop growth in different regions. At the same period, China experiences floods in many regions. Most of these regions have experienced high temperature, increased precipitation and stronger radiation, making them more prone to heatwaves and droughts. Such disasters pose a serious threat to crop production. Xu et al. have shown that changes in climatic factors from April to September have potential or significant effects on crop growth and agricultural production (Chou et al. 2006; Yao and Zhang 2009; Xu et al. 2014; Dai et al. 2016). April–September is approximately taken as the grain growth season in China's main grain-producing areas and considered the characteristics of changes in climate elements in different regions in this study.

Many researchers have carried out exploratory work on changes in climate elements and their relationships with food production (Smit and Cai 1996; Dong et al. 2007; Hartmann et al. 2008; Zhang et al. 2009; Piao et al. 2010; Pan et al. 2011; Holst et al. 2013; Shen et al. 2017). They found that the negative impacts of climate change on crop yields are more pronounced. However, there have been few studies targeted on the characteristics of climate change in China's main grain-producing areas and analyses on the time scale of the April–September growing season have rarely been reported. Only by quantitatively and scientifically analysing the characteristics

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of climate change in China's main grain-producing areas can we better adapt agricultural production activities and more fully and rationally use climate resources. Such research will also facilitate the quantitative assessment of the impacts of climate change on grain production and help to sustainably develop future agricultural production.

This paper selects climate data from 1981 to 2015 and divides China's main grain production areas into north and south regions. The research analyses the three climate elements of temperature, precipitation and sunshine hours based on changes in the linear trend and Morlet wavelet transform. The characteristics of climate trends are used to show the variation in the time series of climate elements. The time-frequency characteristics of the wavelet analysis reflect the cyclical changes in climatic elements, showing each trend change characteristic and their timescales. The work is to provide a reference for the analysis of the variation of climatic elements in China's main grain-producing areas on multiple timescales and for impact assessments of climate change. The study can help local relevant departments to "adapt to local conditions" and formulate reasonable and effective policies.

2 Data and methods

The data are derived from the China Earth International Exchange Station monthly climate datasets compiled by the Meteorological Data Center of the China Meteorological Administration. These ground-based climate datasets include the monthly precipitation (unit: mm), average temperature (unit: °C) and sunshine hours (unit: h) during the growth season (April–September) from 1981 to 2015.

The nature and magnitude of climate changes in trend can be expressed by the trend coefficient and propensity rate of each element. The climate trend coefficient is the correlation coefficient between the value of the annual climatic factor (e.g. temperature) and the number of years (Shi et al. 1995).

The correlation coefficient between the sequence of elements is defined as n (years) and the time series (natural sequence) 1, 2, 3, ..., n :

$$r_{xt} = \frac{\sum_{i=1}^n (x_i - \bar{x})(i - \bar{t})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2 \sum_{i=1}^n (i - \bar{t})^2}} \quad (1)$$

where n is the number of years, x_i is the element value of the i th year, \bar{x} is the mean value, and $\bar{t} = (n + 1)/2$. This formula shows that the climatic elements increase (decrease) linearly in the measured time period when r_{xt} is positive (negative).

The climatic tendency rate is equal to the linear regression coefficient of the climate element value and the

time obtained using the least-square method. A multiple of ten is called the tendency rate or rate of change in an element (Ren and Hong 2000; Shi et al. 2001).

$$\hat{x}_t = a_0 + a_1 t, t = 1, 2, \dots, n \text{ (year)} \quad (2)$$

$$\frac{d\hat{x}_t}{dt} = a_1 \quad (3)$$

where $a_1 \cdot 10$ is the climate tendency rate with units of element unit/10a—for example, the unit of precipitation is mm/10a.

The study calculated the trend coefficients and propensity rates for the average temperature, precipitation and sunshine hours in the main grain-producing areas of China during the growth season from 1981 to 2015. The average of growing season is equal to the arithmetic mean over 6 months during the period April–September.

This method has developed rapidly in the field of meteorology since the emergence of the wavelet analysis theory. A large number of Chinese researchers use wavelet analysis theory to study meteorological and climate science issues and have shown that many climate change phenomena are associated with timescales. The application of wavelet analysis theory in atmospheric sciences shows that it can be used effectively to analyse the periodicity in climate data through the continuous exploration of historical datasets and can fully reflect changing trends in the climate system on different timescales. It also provides a qualitative estimate of future climate trends (Dai and Jifan 1995, Dai 2003; Sun and Bingyan 2000; Xu et al. 2004). The principles and details of the wavelet analysis method have been described elsewhere (Wei 2007; Huang et al. 2014) that are not repeated here. This paper analyses the climatic factor anomalies of China's main grain-producing areas from 1981 to 2015.

Geographical detector (Wang and Xu 2017) is a statistical tool to identify spatial stratified heterogeneity (SSH) and to attribute spatial patterns. The factor detector is used in this study and identifies the regional demarcation of China's main grain-producing areas through climate indicators such as temperature, precipitation and sunshine hours. The q -statistic of the factor detector measures the SSH of different climatic factors based on regional division, expressed by q -value (Wang et al. 2016), the expression is

$$q = 1 - \frac{\sum_{h=1}^L N_h \sigma_h^2}{N \sigma^2} \quad (4)$$

where N is the number of units, σ^2 is the variance of Y , Y is composed of L strata ($h = 1, 2, \dots, L$); for example, this study divides China's main grain production areas into two sub-regions, $L = 2$. N_h is the number of units, σ_h^2 is the variance of Y in stratum h . The q -value is within $[0, 1]$ (0 if a spatial stratification of heterogeneity is not significant and 1 if there is a

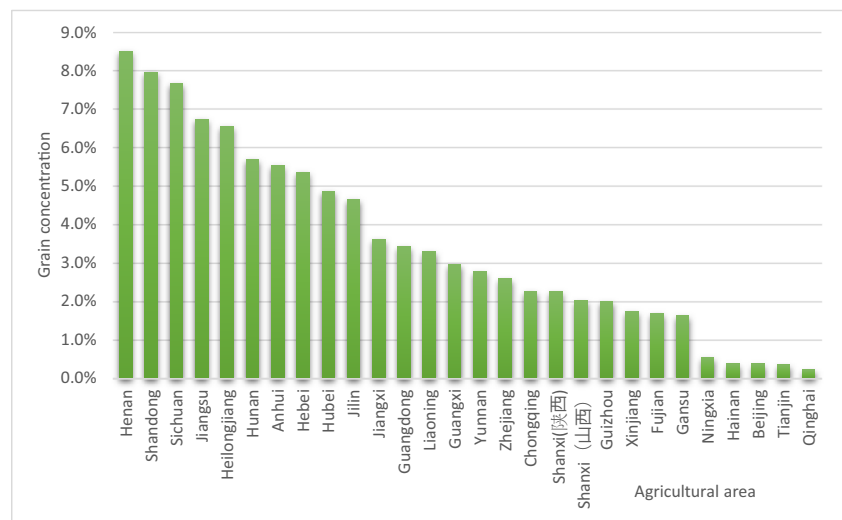
perfect spatial stratification of heterogeneity). The q -value shows that X (climate factors) explains 100% of Y (regional demarcation).

3 Division of the main grain-producing areas

Based on the division of China's grain production areas by Gu and Qinghai (2011), this study statistically analysed the proportion of the annual grain yield in China's 28 provinces to the national annual grain yield in the past 35 years (1981–2015) (Fig. 1). The first 12 provinces are further selected as the main grain-producing areas with a total grain concentration of 70.4%. It is also considered that the Qinling-Huaihe line is a typical north-south boundary line in China. Therefore, 12 main grain-producing areas are classified into two main regions—a South region and a North region—with different climatic factors. The South region includes the provinces of Jiangsu, Anhui, Jiangxi, Henan, Hubei, Hunan and Sichuan. The North region includes the provinces of Heilongjiang, Jilin, Liaoning, Hebei and Shandong (Fig. 2).

Geographical detector is used to identify the North-South regional division based on climate indicators (e.g. average temperature, precipitation and sunshine hours). The paper analyses the influence of different climate indicators on the regional division through q -statistics. The results show that the q -values of precipitation and sunshine hours are higher ($q = 0.71$), while the q -value of average temperature has only 0.23. It shows that the North-South regional division has significant spatial heterogeneity on the characteristics of climate elements.

Fig. 1 Distribution of annual average grain concentration in the provinces (1981–2015) (the ordinate indicates the grain concentration, which refers to the proportion of grain production to the national grain output; the abscissa indicates the agricultural area)



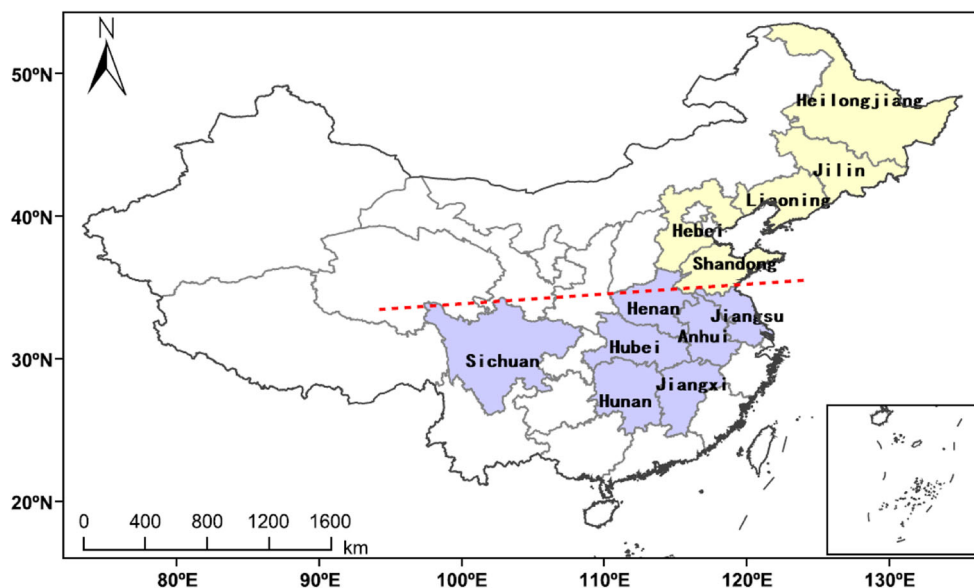
4 Results

4.1 Trend coefficients and propensity rates of climate elements in the past 35 years

It can be seen from Table 1 that the average temperature of all the main grain-producing areas increased during the period 1981–2015, and all areas passed the 95% and 99% significance test, indicating that China's average temperature is increasing with the background of global warming. The change in sunshine hours shows a negative trend and all areas pass the significance test, indicating that the number of sunshine hours in the main grain-producing areas has significantly decreased. By contrast, there are clear regional differences in the precipitation trend and the precipitation trend coefficient; the propensity rates do not pass the significance test in most of the regions, indicating that long-term changes in precipitation can be considered as a naturally fluctuating phenomenon.

A warming climate is observed during the growth season of China's main grain-producing areas. The rate of increase in temperature in the North region is 0.21 °C/10a (Table 1a), whereas the rate of temperature increase in the South region is 0.27 °C/10a (Table 1b); both regions pass the 99% significance test. China's main grain-producing areas are generally warming up, which probably caused the high temperature and other weather events. There are differences in precipitation during the growth season in both the South and North regions. The precipitation in the South region shows an upward trend, increasing by 7.81 mm/10a (Table 1b), whereas there is a decrease of 2.15 mm/10a in the North region (Table 1a), and neither pass the significance test. The change in the precipitation trend in the two regions is not significant and can be considered as a natural change. The number of sunshine hours has decreased and both regions show significant negative trends, which decreased of 36.96 and 33.23 h/10a (Table 1)

Fig. 2 Divisions of China’s main grain-producing areas (the yellow area represents the North region, the blue area represents the South region, the white area represents other areas and the dotted line is the dividing line between the North and South regions)



in the South and North regions, respectively. Both regions pass the 99% significance test, indicating a reduction in the time that crops could photosynthesis, which may have affected their growth and development.

Figure 3 clearly shows that the regional differences in the average temperature and sunshine hours of the main grain-producing areas are small in the two regions, whereas the change in precipitation is reversed in the two regions, indicating that the main grain-producing areas are vulnerable to abnormal amounts of precipitation.

A climate warming trend is observed during the growth season for all the main grain-producing provinces. Figure 3a

shows that the temperature trends in Heilongjiang, Sichuan, Jiangsu and Jiangxi provinces are significant. The trend coefficient is > 0.58 and the heating rate is as high as 0.3 °C/10a. However, the positive trends in Hebei and Shandong provinces are weak and the heating rate is < 0.2 °C/10a; all the heating trends pass the significance test.

Precipitation increases from north to south during the growth season in the main grain-producing provinces (Fig. 3b), and there are large regional differences. The positive trend of precipitation is concentrated in Jiangsu, Anhui, Jiangxi and Hunan provinces in the South region. The trend coefficient in Jiangsu is 0.23, and the rate of increase is 30.75 mm/10a.

Table 1 Climate trend coefficient (*r*) and climate trend rate (*b*) of main grain-producing areas from 1981 to 2015

Area		Average temperature (°C/(10 years))				Precipitation (mm/(10 years))				Sunshine hours (h/(10 years))			
		<i>r</i>	<i>P</i>	<i>b</i>	<i>P</i>	<i>r</i>	<i>P</i>	<i>b</i>	<i>P</i>	<i>r</i>	<i>P</i>	<i>b</i>	<i>P</i>
North region	North region	0.46***	0.01	0.21***	0.01	-0.03	0.86	-2.15	0.86	-0.53***	0	-36.96***	0
	Heilongjiang	0.63***	0	0.35***	0	-0.32	0.06	-20.36	0.06	-0.21	0.22	-18.37	0.22
	Jilin	0.45***	0.01	0.24***	0.01	-0.14	0.44	-10.47	0.44	-0.16	0.35	-13.59	0.35
	Liaoning	0.38**	0.03	0.21**	0.03	-0.08	0.65	-9.15	0.65	-0.15	0.4	-13.06	0.4
	Hebei	0.37**	0.03	0.19**	0.03	-0.03	0.86	-2.42	0.86	-0.71***	0	-71.01***	0
	Shandong	0.28	0.11	0.11	0.11	0.25	0.15	31.64	0.15	-0.66***	0	-68.73***	0
South region	South region	0.61***	0	0.27***	0	0.09	0.6	7.81	0.6	-0.47***	0	-33.23***	0
	Jiangsu	0.58***	0	0.32***	0	0.23	0.19	30.75	0.19	-0.38**	0.02	-38.50**	0.02
	Anhui	0.48***	0	0.28***	0	0.15	0.41	19.81	0.41	-0.32	0.06	-30.39	0.06
	Jiangxi	0.60***	0	0.31***	0	0.11	0.52	22.79	0.52	-0.19	0.27	-16.88	0.27
	Henan	0.50***	0	0.25***	0	-0.06	0.74	-8.56	0.74	-0.58***	0	-65.05***	0
	Hubei	0.38**	0.02	0.21**	0.02	-0.12	0.48	-18.53	0.48	-0.43***	0.01	-45.83***	0.01
	Hunan	0.39**	0.02	0.20**	0.02	0.11	0.55	17.27	0.55	-0.37**	0.03	-36.31**	0.03
Sichuan	0.78***	0	0.34***	0	-0.13	0.45	-8.96	0.45	0.01	0.98	0.33	0.98	

Note: *P* is significant in the climate trend coefficient sequence at ****P* ≥ 99%; ***P* ≥ 95%

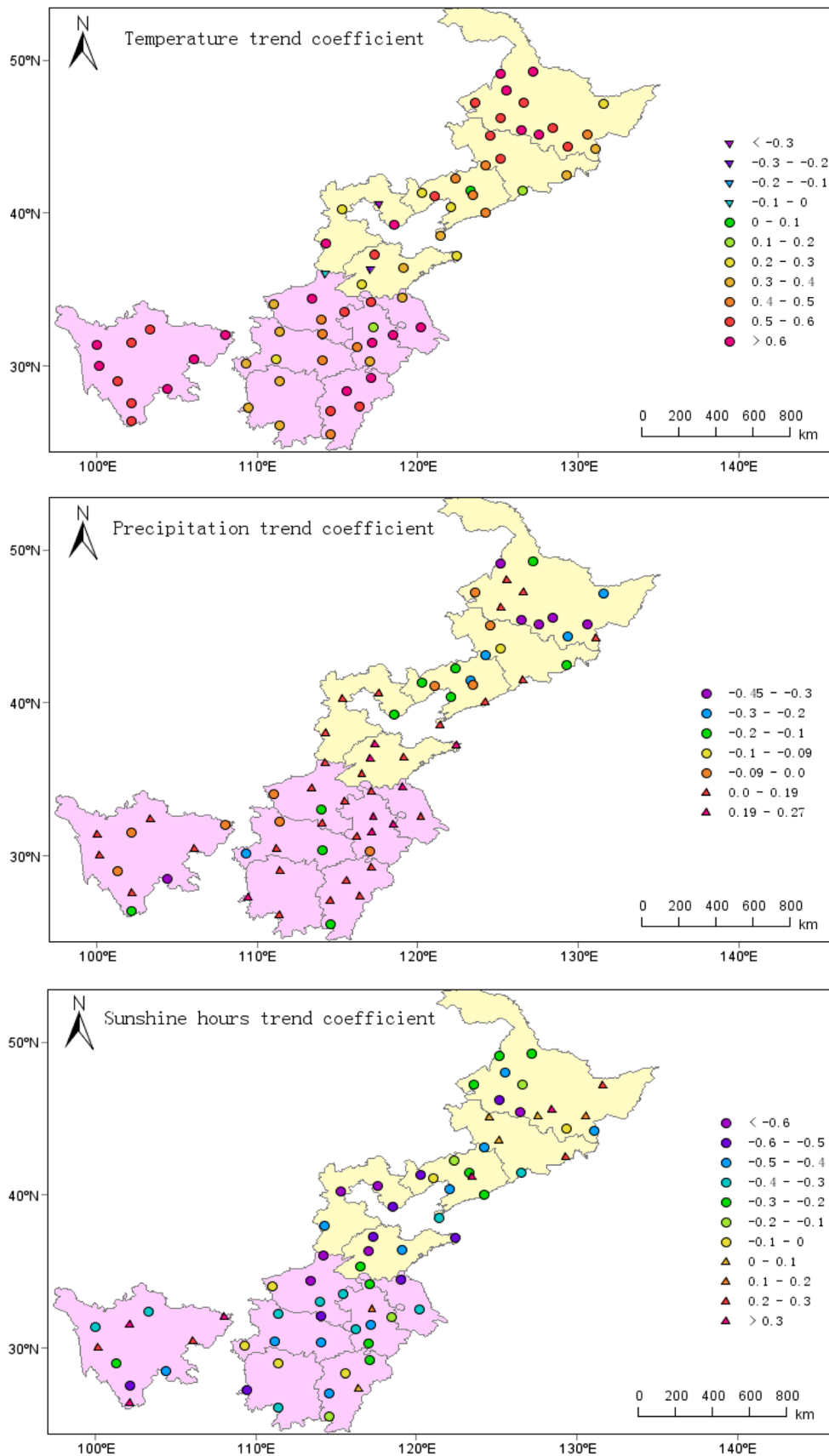


Fig. 3 Distribution of the trend coefficient of climatic elements during the growth season (the yellow area represents the North region, the blue area represents the South region and the colour of the symbols indicates the trend coefficient of the climate element)

Negative trends are concentrated in Heilongjiang, Jilin and Liaoning provinces in the North region. The trend coefficient in Heilongjiang is -0.32 , and the rate of decrease is only $20.36 \text{ mm}/10\text{a}$.

The sunshine hours show a decreasing trend during the growth season in all provinces. The negative trend in sunshine hours is concentrated in Hebei and Shandong in the North region and Henan in the South region. The highest trend coefficient in Hebei is 0.71 with a rate of decrease of $71.01 \text{ h}/10\text{a}$, followed by Shandong; all the provinces pass the significance test. There are also regional differences in sunshine hours. There are increasing sunshine hours in southeastern Heilongjiang and northwestern Jilin in the North region and central Anhui, eastern Sichuan and eastern Jiangxi in the South region, but their changes are weak. This does not affect the overall decreasing trend, and all areas pass the significance test.

The climate in the North region is therefore characterised by high temperatures, with no significant decrease in precipitation and a significant reduction in sunshine hours. This may lead to a dry climate, a lack of precipitation and insufficient photosynthesis in the North region, which may affect the growth of corn and other crops, leading to reduced production or even no harvest. The climate in the South region is characterised by a significant increase in temperature, a significant increase in precipitation and a significant decrease in sunshine hours. An increase in temperature to above the upper limit of the temperature required for the growth and development of crops during the growth season will lead to heat damage. This may make the region prone to flooding and may endanger food production if there is too much precipitation. There have been historical hazards, such as floods, caused by high temperatures in the South region and rice and other grain crops have suffered heavy losses (Zhou et al. 2014).

This paper uses trend analysis to compare this new climate data from 1981 to 2015 with previous studies, taking into consideration social factors and economics. The study uses the time period with the greatest impact on food crops (the growing season, April–September) and obtain the distribution of modern day climate change in China's main grain-producing areas.

The results are similar to those in previous studies (Ma et al. 2005; Qin 2009; Qi et al. 2011; Zhou et al. 2014) and also reveal some new features, including the following:

(1) China's main grain-producing areas are generally warming up. Precipitation is clearly different in the South and North regions. Rainfall in the South region increased by $7.81 \text{ mm}/10\text{a}$, but decreased by $2.15 \text{ mm}/10\text{a}$ in the North region; neither region passes the significance test. The reduction in sunshine hours in the North region is more rapid than that in the South region during the growth season, with a decrease of $36.96 \text{ h}/10\text{a}$.

(2) There are clear regional differences in the trends of the climate elements between provinces within the South and North regions: Jiangsu, Anhui, Jiangxi and Sichuan provinces show warming trends, especially the temperature trend index in Sichuan, which is > 0.7 ; the 99% significance test is passed. Precipitation in Shandong and Jiangsu has a significant increasing trend (up to $30 \text{ mm}/10\text{a}$).

It is of both theoretical and practical importance to understand the characteristics of these climate elements to allow us to determine the patterns of climate change in China's main grain-producing areas and to plan for relevant disaster prevention and mitigation work based on the local conditions.

4.2 Analysis of periodic changes in meteorological elements

4.2.1 North region

Figure 4 shows the average temperature of the growth season as a time series function with wavelet transform in the North region from 1981 to 2015, with the size of the wavelet coefficient indicated by the depth of the colour. The main period of the average temperature is about 3 years, passed the 95% significance test and the temperature increases by $0.21 \text{ }^\circ\text{C}/10\text{a}$ during the growth season in the North region. The average temperature experiences a cycle of the cold period-the warm period-the cold period between 1990 and 2002 in the North region. Following the trend of wavelet structure after 2015, it is expected that the temperature will be mainly showed by a 3-year cycle of the cold period-the warm period-the cold period during the growth season in the North region.

Figure 5 shows that the main period of the change in precipitation is about 5 years and passed the 95% significance test, and it decreases by $2.15 \text{ mm}/10\text{a}$ during the growth season in the North region. Precipitation experiences an increasing–decreasing cycle from 1985 to 2000. Following the trend of wavelet structure after 2015, it is expected that precipitation will be mainly showed a 5-year cycle of increasing–decreasing during the growth season in the North region.

There is a clear cycle change of 4 years in sunshine hours during the growth season in the North region (Fig. 6) and passed the 95% significance test. Sunshine hours experience an increasing–decreasing cycle from 1995 to 2005. According to the 4-year scale, the wavelet coefficient is positive in 2015, and there is a trend of continued development. It is expected that the sunshine hours will be mainly showed a 4-year cycle of increasing–decreasing during the growth season in the North region.

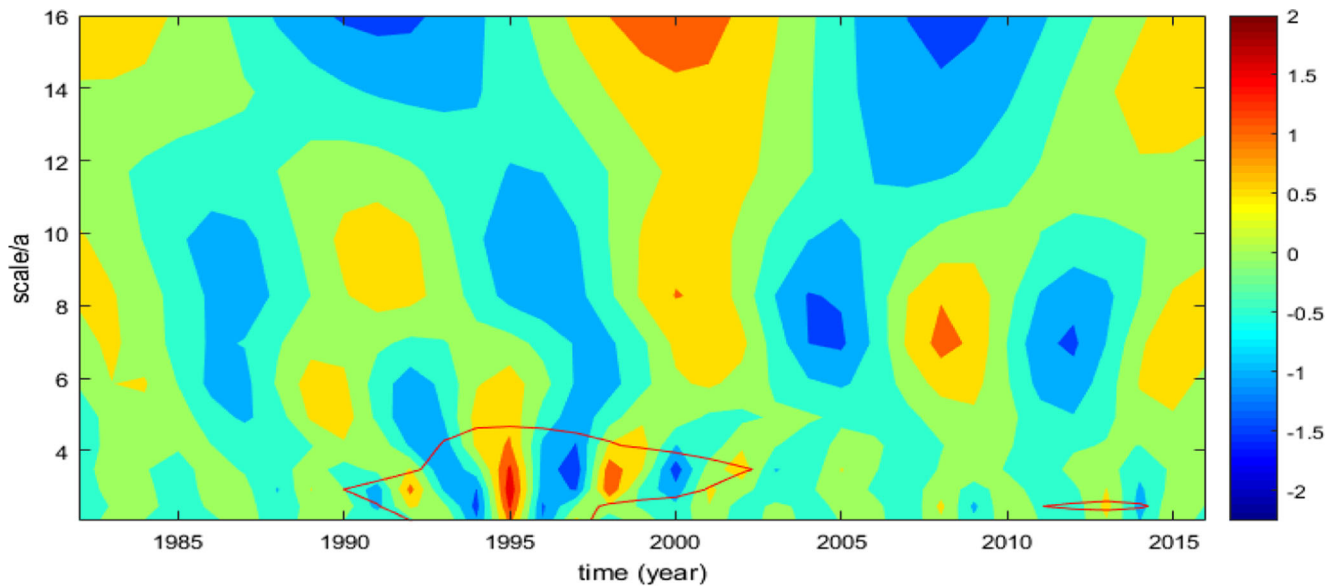


Fig. 4 Wavelet transformation of the mean temperature in the growth season in the North region. The horizontal coordinates represent the time series (unit: year) from 1981 to 2015 and the ordinate represents

the annual scale (unit: year) at intervals of 5 years. The colour indicates the size of the wavelet coefficient. The range enclosed by the red solid line indicates the 95% significance test

4.2.2 South region

Figure 7 shows that the average period of temperature is about 3 years and passed the 95% significance test; the temperature increases by 0.27 °C/10a during the growth season in the South region. The average temperature experiences a cycle of the warm period-the cold period-the warm period in 1990–2002 and 2010–2015 in the South region. The wavelet coefficients were negative in 3 years in 2015, and there was a trend of continued development. It is expected that temperature will be mainly showed by

a 3-year cycle of the cold period-the warm period-the cold period during the growth season in the South region.

Figure 8 shows that the main period of precipitation change is about 5 years during the growth season in the South region and passed the 95% significance test. Precipitation experiences an increasing–decreasing cycle from 1995 to 2005. On a 5-year timescale, the wavelet coefficient is positive in 2015, and there will be a trend of continued development. It is expected that precipitation will be mainly showed a 5-year cycle of increasing–decreasing during the growth season in the South region.

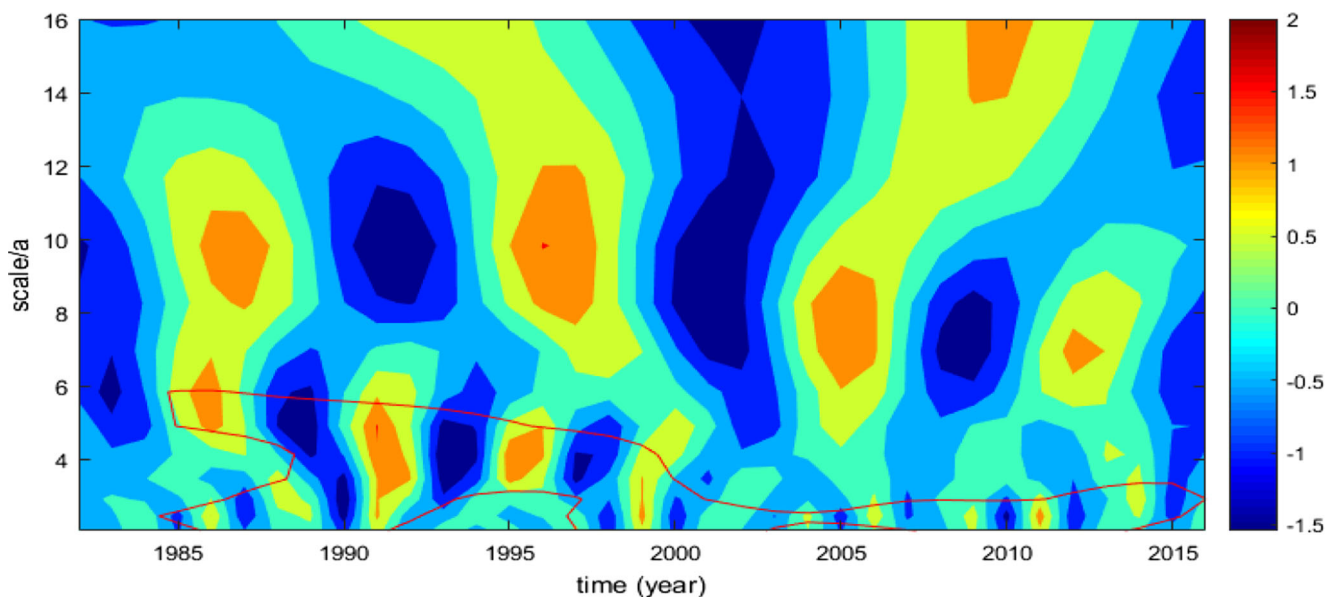


Fig. 5 Wavelet transformation of precipitation during the growth season in the North region

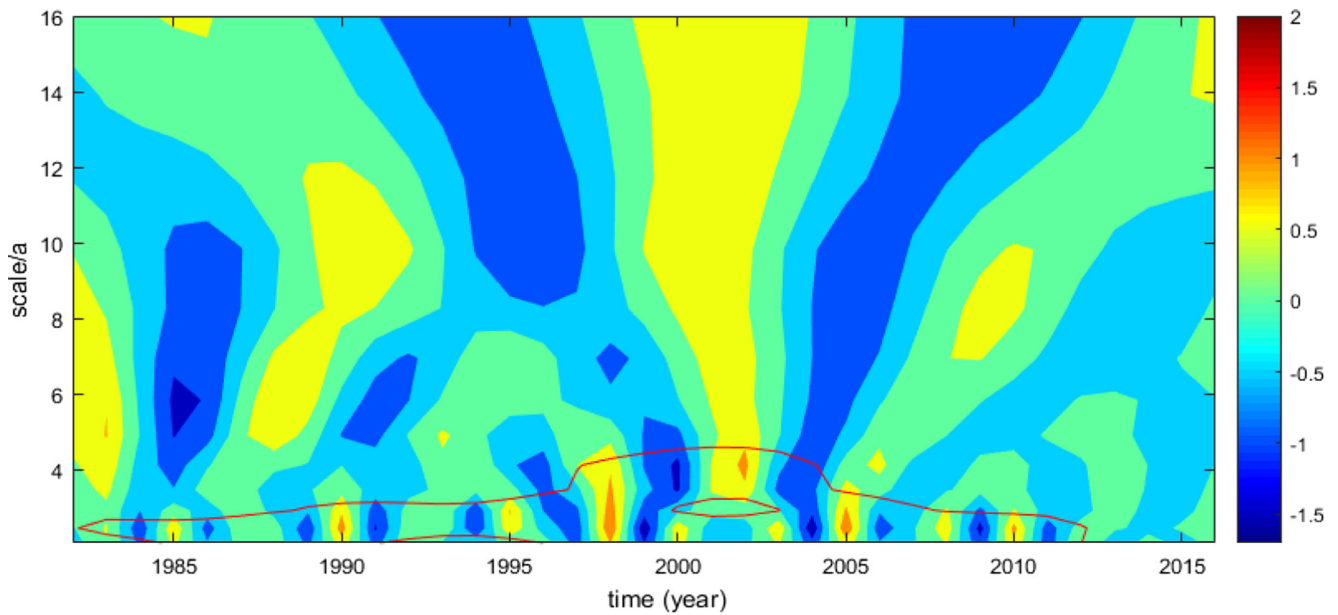


Fig. 6 Wavelet transformation of sunshine duration during the growth season in the North region

There is a clear cycle change of 3 years in sunshine hours during the growth season in the South region (Fig. 9) and passed the 95% significance test. Sunshine hours experience a decreasing–increasing cycle from 1990 to 2005. According to the 3-year timescale, the wavelet coefficient is negative in 2015, and there is a trend of continued development. It is expected that the sunshine hours will be mainly showed a 3-year cycle of decreasing–increasing during the growth season in the South region.

The cyclical changes in climate elements therefore show important regional differences in China's main grain-producing areas. The climate elements have a cyclical change of 3–5 years during the growth season in China's main grain-producing areas. This paper suggests that relevant government departments should do a good job in preventing the impact of climate change on crops in advance, strengthen the intensity of disaster prevention and mitigation, reduce future climate risks and agricultural economic losses.

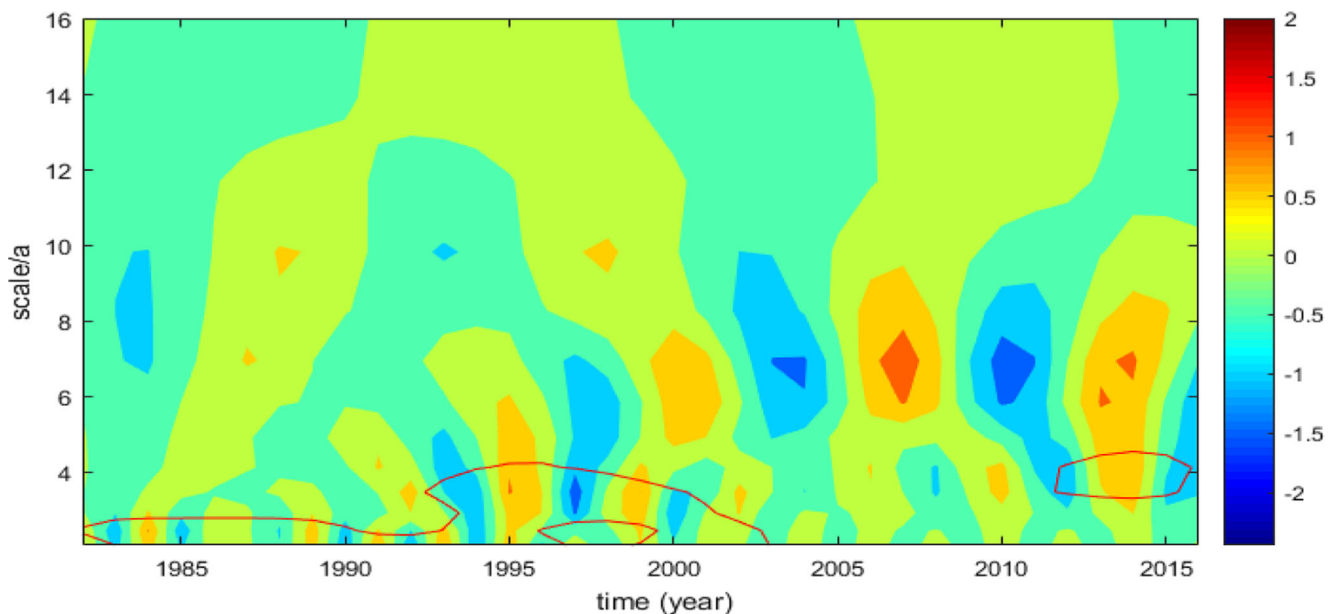


Fig. 7 Wavelet transformation of the mean temperature during the growth season in the South region

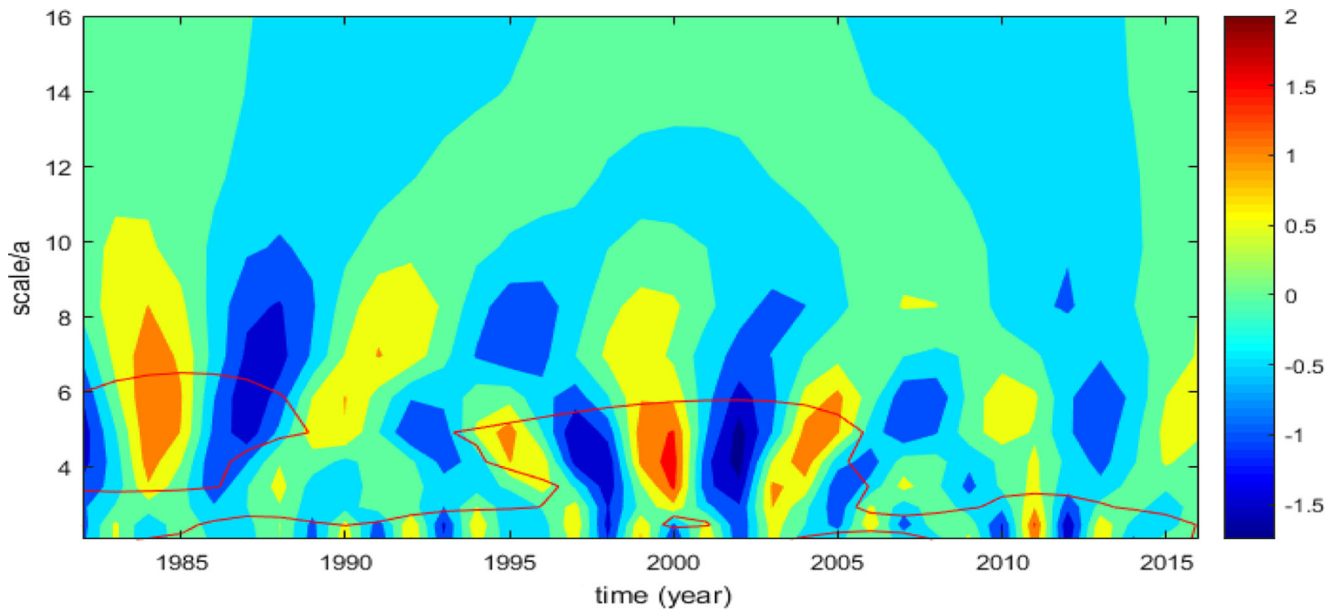


Fig. 8 Wavelet transformation of precipitation during the growth season in the South region

4.3 Possible impacts of climatic factors on the agriculture in the main grain-producing areas of China

It can be clearly seen that the average temperature has a warming trend of 3-year cycle changes in both the South and North regions (Table 2). The precipitation has a downward trend, with a significant 5-year cycle change in the North region, whereas precipitation in the South region shows an increasing trend with a 5-year cycle change. The sunshine hours have a decreasing trend of 3–4-year cycle changes in both the North and South regions. In general, the climate

characteristic is showed by warm-dry with high temperature, less precipitation and weak sunshine in North region, whereas the climate in South region is showed by warm-humid with higher temperature, more precipitation and weak sunshine. These complex regional structures of climate enhance the uncertainty in climate change and increase the difficulty of forecasting weather and climate; further research is needed.

The analysis shows that the climatic factors are complex and variable, the regional distribution is uneven and the inter-annual changes are large during the growth season in China’s main grain-producing areas, which will have direct effects on the agricultural production.

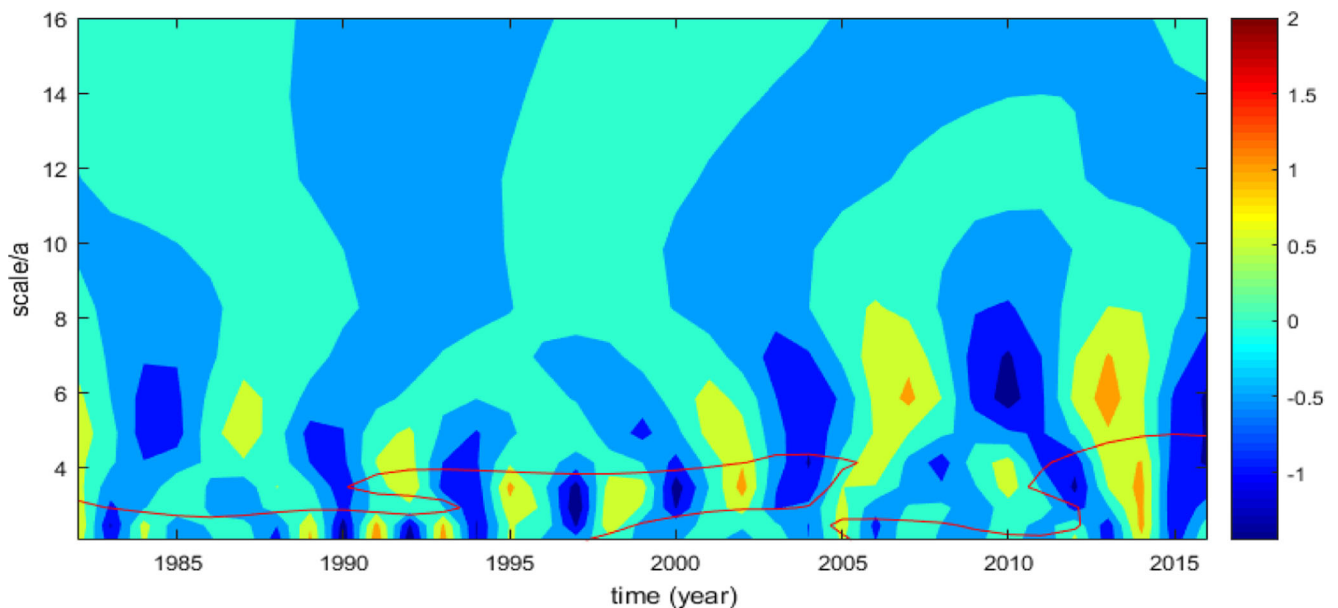


Fig. 9 Wavelet transformation of sunshine duration during the growth season in the South region

Table 2 Climatic elements during the growing season in the main grain-producing areas of China

Area	T	Period(a)	P	Period(a)	S	Period(a)
North region	North region	+ 3	- 5	- 4		
	Heilongjiang	+ 3	- 4	- 3		
	Jilin	+ 3	- 4	- /		
	Liaoning	+ 3	- 4, 8	- /		
	Hebei	+ 3, 7	- 4, 8	- 5		
	Shandong	+ 3	+ 3, 6	- 4		
South region	South region	+ 3	+ 5	- 3		
	Jiangsu	+ 3	+ 4, 7	- 5		
	Anhui	+ 3, 6	+ 4, 7	- 3, 6		
	Jiangxi	+ 3	+ 5	- 4		
	Henan	+ 3, 8	- /	- 3, 6		
	Hubei	+ 3, 6	- 5	- 3, 6		
	Hunan	+ 3	+ 5	- 2, 5		
	Sichuan	+ 3	- 5	+ 4		

Note: “T”, “P” and “S” represent the linear trend changes of average temperature, precipitation and sunshine hours, respectively. “+”, increase in climatic elements; “-”, decrease in climatic elements; “/”, no trend

Climate change may have positive effects on agricultural production. A warmer climate may extend the growth season and facilitate the production of food crops (such as corn) in the North region. The occurrence of low temperatures and cold damage has reduced in the North region (e.g. in Heilongjiang province), which favours high and/or stable yields of food crops. Precipitation over the North region currently leads to water shortages, but a predicted increase in precipitation of 31.64 mm/10a in Shandong province in the North region may favour the growth of grain crops.

Climate change may also have negative effects on crop growth and yields. The climate is characterised by elevated temperature, reduced precipitation and reduced sunshine hours in the North region (such as Hebei) during the growth season, which may affect the growth and yield of some crops (e.g. corn). Precipitation is increasing in most provinces in the South region (e.g. Jiangsu, Anhui, Jiangxi and Hunan provinces). Excessive precipitation may cause hypoxia or even the drowning of food crops (e.g. rice) in the South region. The sunshine duration shows a significant decreasing trend in the South and North regions, with a rate decrease of up to 30 h/10a, which may seriously affect photosynthesis and the growth of crops.

Climate change may affect agricultural climate resources, such as sunshine, heat and water. The agricultural production process will be affected by changes in climate, which will, in turn, affect the growth and production of crops. Major climate disasters that have had a major impact on China’s historical production of grain include droughts, floods, low-temperature disasters and winds. Among these, drought disasters have

been the most severe, followed by floods. Based on the characteristics of previous climate change and statistics for extreme climate events in China’s main grain-production areas, it can be shown that China’s main grain-producing areas experience extreme weather events (e.g. frequent droughts, heavy rains, winds and high temperatures) during the period of April–September. There are many windstorms in the North region, and storms and floods in the South region, which increase the vulnerability of food crops and may lead to huge losses in agricultural production.

5 Discussion and conclusions

The climate in the North region is characterised by the trend of warm and dry, with increased temperature, reduced precipitation and reduced sunshine during the growth season. The climate is characterised by the trend of warm and humid with increased temperature, increased precipitation and reduced sunshine in the South region.

The climatic elements have different historical and future cyclical characteristics in the South and North regions of the grain-producing areas during the growth season.

The climate changes have different characteristics in the different grain-producing regions, which affect and may even jeopardise the growth and production of the three major crops in China.

The characteristics of climatic elements in China’s main grain production areas can be reflected by the three major climatic elements of temperature, precipitation and sunshine duration. These elements are the basic factors used to research the impact of climate change on agricultural production, but specific economic assessments and response measures need further research.

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Compliance with ethical standards

Competing interests The authors declare that they have no competing interests.

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