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EFFECTS OF RELATIVE CLIMATE CHANGES ON THE GROWTH PERIOD OF WINTER WHEAT IN JIANGSU PROVINCE, CHINA

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ABSTRACT

The trend of the relative climate change during the growth period of winter wheat in Jiangsu, China and its possible impact on the growth period of winter wheat are analyzed, using agro-meteorological experiment, statistical methods and GIS data analysis technology. The main meteorological elements change over time: the temperature rises, while sunshine duration, amount of precipitation and wind speed decrease. The amplitudes of relative change of climate were ranked as follows: wind > temperature > precipitation and sunshine. The relative climate change in Jiangsu is most obvious in the northeast part of North Jiangsu, along the Yangtze river and southeastern part of South Jiangsu. It might cause the increase of vulnerability of winter wheat production, the aggravation of natural disasters such as drought, waterlogging and freezing during the growth of winter wheat. A significant instability of the yield and quality might also be caused. Climate change mainly occurs in the vegetative period of winter wheat, while relatively small changes occur in the reproductive growth stage. The impact of climate change can be mitigated by breeding new cultivars and promotion of new technology, so as to guarantee the ecological, efficient, high-quality development of winter wheat.

Key words: relative climate change, growth period of wheat, meteorological element, winter wheat

INTRODUCTION

The total yield of wheat in China in 2011 was 16.4% of the total yield of wheat in the world. In recent years, the total wheat production in Jiangsu province accounted for about 11% of the total yield in China. Therefore, the effect of climate change on the production of wheat in Jiangsu has aroused great concerns from all circles of society.

Shang et al. (2013) analyzed literatures on climate change and techniques used for evaluating the effect of climate change on wheat production technology at home and abroad. It was found that the main techniques for assessing the impact of climate change on wheat production is trend extrapolation based on facts of climate change and generation of future climate scenarios by climate model. The orientations and conclusions of the previous researches on the effects of climate change on wheat production are as follows.

(1) It was found that the meteorological conditions during wheat production period changed obviously, with a significant temperature rise. For example, the statistical analysis by Wang et al. (2012) showed that the temperatures from March to May (3-5) in Xingtai, China rose extremely significantly in the recent 20 years. The average accumulated temperature in 2000-2009 increased by 231^{o}C.

(2) The total production potential of wheat decreased under climate change (Li, 2013; Tian et al., 2013; Zhou et al., 2013). For example, the suitable growth area and potential yield of crops were calculated with 5 modules using GAEZ 3.0 model by Tian et al. (2013). It is found that the total production potential of rainfed wheat throughout the country decreased by 2.5×108 t in the relative baseline period in the past 20 years (9110s).

(3) The suitable planting area of wheat has changed, and the yield and quality decreased (Kersebaum and Nendel, 2014; Martina et al., 2014; Wilcox and Makowski,

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2014; Chen et al., 2013; Jonathan and Alex, 2013; Li et al., 2013; Lickera et al., 2013; Starr et al., 2013; Tian et al., 2013; Valizadeh et al., 2013; Zhang et al., 2013; Li et al., 2012; Pathak and Wassmann, 2009; Wu et al., 2012). For example, the model for comprehensive climate assessment of winter wheat by area was established by Wu et al. (2012) using grey correlation analysis. It was found that an expansion of planting area for strong gluten wheat and a reduction of weak gluten wheat were suitable for Jiangsu.

(4) The meteorological disasters occurred more frequently and at a higher intensity, which affects the wheat yield and quality (Gu et al., 2013; Zhang et al., 2013; China Meteorological Administration, 1993). For example, the temporal and spatial variation characteristics of disasters in two periods, 2000-2009 and 1990-1999 were compared by Zhang et al. (2013). The results showed that the drought is the type of disaster with the highest frequency of occurrence in wheat. The frequency of occurrence was up to 79.21%.

To sum up, there are very few reports on the comparison of the amplitude of relative change between different meteorological elements. Therefore, the concept of the rate of relative climate change and the calculation model are proposed in this study. In this article, the winter wheat in Jiangsu, China during the growth period was analyzed as a representative example.

MATERIAL AND METHODS

Material and treatment method

(1) The meteorological data of 37 sites representing the climate change of Jiangsu in the meteorological observation station network of China Meteorological Administration were selected to analyze the trend of climate change. The data of the growth period of winter wheat over the years at 10 sites in Jiangsu (Figure 1) in the agricultural meteorological station network of China Meteorological Administration were reviewed for the characteristic analysis of winter wheat in Jiangsu during the growth period. According to the climate and geographical characteristics of Jiangsu, they were divided into 4 major regional types, the whole province (referred to as WP), Subei (abbreviated as SB, also North Jiangsu), Suzhong (abbreviated as SZ, also Middle Jiangsu) and Sunan (abbreviated as SN, also South Jiangsu).

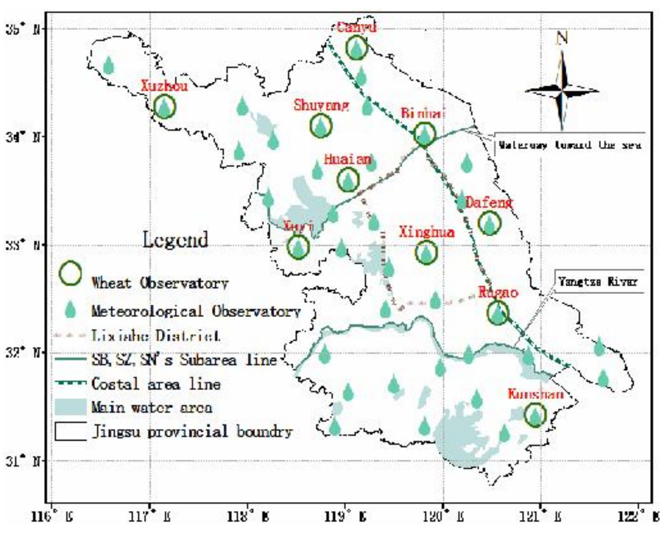


Figure 1. Subarea and distribution of observation stations

(2) The observation data of winter wheat in the growth period from 1980 to 2011 were used in this study. The meteorological observation data in 1960-2011 were selected in this study. A life cycle of wheat was used as the basic time unit in calculation. An average value was taken every 5 years for comparison, which were 1980-1984 to 2010-2011,

respectively. The meteorological data were also divided into groups in the same way since 1960, which were 1960-1984 to 2010-2011.

(3) Meteorological elements (ME) related to wheat growth: The active accumulated air temperature (AAAT), Negative accumulated air temperature (NAAT), active accumulated earth temperature (AAET) and temperature average (TA) were mainly analyzed. Accumulated precipitations (AP), total rainy days (TRD), days of light rain (0.1≤AP<5) (LIR), days of light to moderate rain (5≤AP<10) (LTR), moderate rain days (10≤AP<25) (MOR), days of heavy rain (25≤AP<50) (HER), days of torrential rain (AP≥50) (TOR), Precipitation average → PA, Accumulated sunshine duration (ASD), sunshine average, (SA), Total wind speeds (TWS), wind speed average (WA). All meteorological elements average (AA).

(4) Winter wheat (WW). According to the growth stage (GS), the characteristics of climate change of whole growth stage (WG) and growth stage length (GL) were analyzed. According to the agricultural meteorological observation criteria of China Meteorological Administration (1993), the specific growth period of wheat was divided into sowing (SOW), sprouting (SPR), triphyllous (TRI), tillering (TIL), over-wintering (OWI), regreening (REG), setting (SET), jointing (JOI), booting (BOO), heading (HEA), anthesis (ANT), milk (MIL) and mature (MAT).

(5) "/" between the abbreviations was used to denote simultaneous use, for example, the rate of relative change of mean temperature was represented by "RT/TA".

(6) For the roots of wheat varieties (lines) the maximum values occurred in 0-20 cm soil layer (Yang et al., 2000). Therefore, the ground temperature at the depth of 5-20 cm was chosen as the soil temperature affecting the growth and development of the roots of winter wheat.

Design of calculation model

(1) The unit of the climate trend rate is the specific unit of this element-1 (such as ^{o}C, mm, hr) × (10a). The climate trend rates of different meteorological elements can not be compared due to different dimensions. If the rate of relative climate change is expressed as the ratio of the climate trend rate to the average value, meaning that it is a relative quantity, the dimensions of different meteorological elements all change into $(10a)^{-1}$. Suppose the data series of a certain element (DX) is DXt. The climate trend rate (CTR), statistical model of rate of relative climate change (RT) is shown as follows.

$$RT = \frac{|CTR|}{|\overline{DX_t}|} \tag{1}$$

$$DX_t = a + bt \tag{2}$$

$$CTR = 10b \tag{3}$$

$$\overline{DX_t} = \frac{1}{n}\sum_{t=1}^{n} DX_t \tag{4}$$

(2) The means of rates of relative climate change is divided into temperature, precipitation, sunshine duration, wind etc. The overall means represented the relative change of all meteorological elements.

$$RT\&TA = \frac{RT\&AAAT + \frac{5cmRT\&AAET + 10cmRT\&AAET + 15cmRT\&AAET + 20cmRT\&AAET}{4}}{2} \tag{5}$$

$$RT\&PA = \frac{RT\&AP + \frac{RT\&IR + RT\&LTR + RT\&MOR + RT\&HER + RT\&TOR}{5}}{2} \tag{6}$$

RT&SA=RT&ASD (7)

RT&WA=RT&TWS (8)

$$RT\&AA = \frac{RT\&TA + RT\&PA + RT\&SA + RT\&WA}{4} \tag{9}$$

Analytical method

(1) The meteorological elements and regional means in the growth period of wheat and their relationship were analyzed using the method of mathematical statistics.

(2) The relative importance of elements was measured using path analysis.

(3) The interpolation was performed for all types of distribution maps using GIS, and the contours were analyzed (CN).

RESULTS AND DISCUSSION

Relative change of length of the growth period

Relative change of length of the whole growth stage

They present latitudinal distribution in middle and northern part of SB as changes to -0.0023 $(10a)^{-1}/°$, and meridian distribution in other areas as changes to 0.0007 $(10a)^{-1}/°$. The rate of relative climate change is small in middle and western parts, and large in the coastal regions. It can be seen from Table 1 that the mean rate of relative climate change is less than 1% in the whole province. It is indicated that the length of the whole growth stage of winter wheat did not change obviously with the variation of climate.

Relative change of length of each growth stage

It can be seen from Figure 2 that the main peak appears in the stage from REG to JOI, i.e. the stage from vegetative growth to the parallel and transition stage of vegetative and reproductive growth. During the whole growth stage, the rate of relative climate change is only less than half of the minimum value. This indicated that winter wheat has certain adaptability to climate change. It can be relatively stable through self-adjustment during the whole growth stage. The regions with low rate of relative climate change drift from Lixia River area → SB→ coastal region→ SZ → region along the river to SN → Lixia River area with the change of growth period. This indicated that the length of the growth period in the region of Lixia River plain is the most stable, and the stability of rate of relative change in hills and mountains is low.

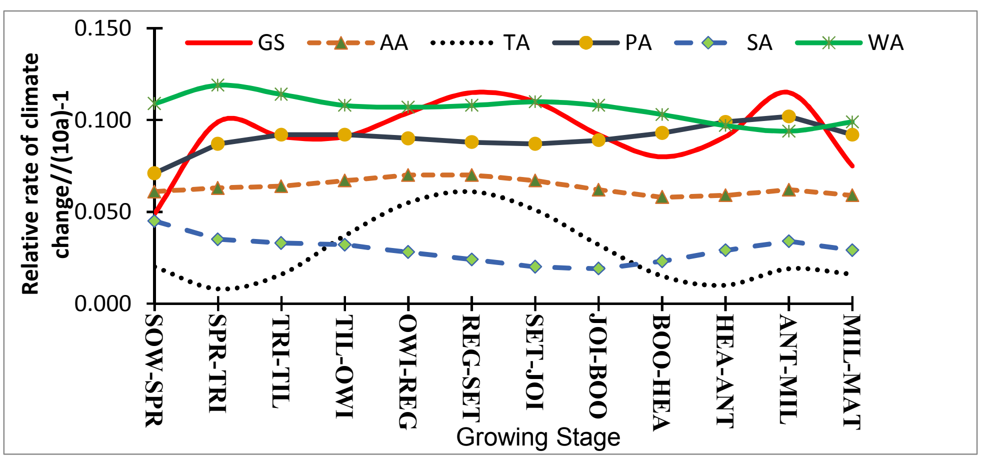


Figure 2. Relative rate of climate change for each growing stage

Relative change of meteorological conditions during the growth period

Relative change of meteorological conditions during the whole growth stage

There is obvious regional distribution in the rate of relative change of temperature, light, water and wind. Three major regions are divided, the Taihu basin in the southern part of SN, the Lixia River area and coastal wetland region in SZ, and the hills and mountains in the northern part of SB. It is known from Table 1 that the mean rate of relative change of meteorological conditions in SN is close to that in SZ, but it is obviously different from that in SB. The mean of the whole province is about 6 times, temperature and sunshine are still 1.6 times, precipitation is about 2.5 times, wind is 12 times than that during the whole growth stage. Therefore, the relative change of the meteorological conditions is more obvious than that of wheat growth period.

Table 1. Relative rate of climate change of winter wheat whole growth stage in different regions

Item	Range	Average
WP&WW&GL	0.005～0.017	0.009
SB&WW&GL	0.006～0.009	0.008
SZ&WW&GL	0.005～0.014	0.010
SN&WW&GL	0.017	0.017
WP&ME&WG&AA	0.016～0.062	0.040
SB&ME&WG&AA	0.039～0.062	0.052
SZ&ME&WG&AA	0.018～0.046	0.034
SN&ME&WG&AA	0.016～0.059	0.035
WP&ME&WG&TA	0.004～0.027	0.014
SB&ME&WG&TA	0.010～0.021	0.015
SZ&ME&WG&TA	0.004～0.023	0.012
SN&ME&WG&TA	0.009～0.027	0.015
WP&ME&WG&PA	0.005～0.055	0.022
SB&ME&WG&PA	0.012～0.055	0.032
SZ&ME&WG&PA	0.011～0.032	0.018
SN&ME&WG&PA	0.005～0.027	0.015
WP&ME&WG&SA	0.000～0.034	0.015
SB&ME&WG&SA	0.004～0.034	0.022
SZ&ME&WG&SA	0.000～0.034	0.012
N&ME&WG&SA	0.000～0.027	0.015
WP&ME&WG&WA	0.023～0.173	0.108
SB&ME&WG&WA	0.098～0.173	0.140
SZ&ME&WG&WA	0.048～0.151	0.095
SN&ME&WG&WA	0.027～0.159	0.094

Relative climate change of meteorological conditions during each growth stage

As seen from Figure 2, the temperature, precipitation, sunshine duration and wind conditions show significant periodic characteristics. The average changes of meteorological conditions, temperature and precipitation are most obvious from REG to JOI stage. The distribution characteristics of the rate of relative change of the length of winter wheat growth period are close to those of wind and precipitation with high values. The influence of the greatest changes of meteorological conditions was the most significant on the length of growth period of winter wheat. There is an obvious regional difference in the rate of relative change of mean meteorological conditions. However, the high and low value regions have a smaller area compared with that of the length of growth period of winter wheat. There is a certain correspondence relationship, but not completely consistent.

Analysis of the impact of climate change on the length of growth stages

The meteorological element was taken as an independent variable X_{ji} (I is the serial number of meteorological element) versus the length GL_j of different growth stages (J is the serial number of growth stage), as shown in the equations:

$$GL_j = a_j + \sum_{i=1}^{14} b_{ji} X_{ji} \tag{10}$$

Suppose the change of meteorological condition caused by climate change is ΔXji, and the change of the length of growth stage is ΔGLj. Thus,

$$\Delta GL_j = \sum_{i=1}^{14} b_{ji} \Delta X_{ji} \tag{11}$$

Then, it is substituted into (11) to calculate the possible impact of climate change on the length of growth stage. The results are analyzed as follows.

(1) According to Figure 3, in the first stage (from SOW-SPR to TRI-TIL), they are positive in SB and SZ. In the second stage (TIL-OWI to BOO-ANT), they are negative in SB except in OWI - REG and JOI-ANT. The values are negative in SZ. They are negative from SET to JOI and BOO-ANT in SN. In the third stage (HEA-ANT to MIL-MAT), they are positive except in HEA-ANT in SB; the values are negative except in MIL-MAT in SZ and SN. The possible influence degree in SOW-SPR, BOO-ANT and MIL-MAT is relatively small. The change from OWI to REG directly affects the frequency of occurrence of freeze injury in early spring. The change of ANT-MIL affects the spike type. Therefore, the obvious change determines the instability of the yield and quality of winter wheat.

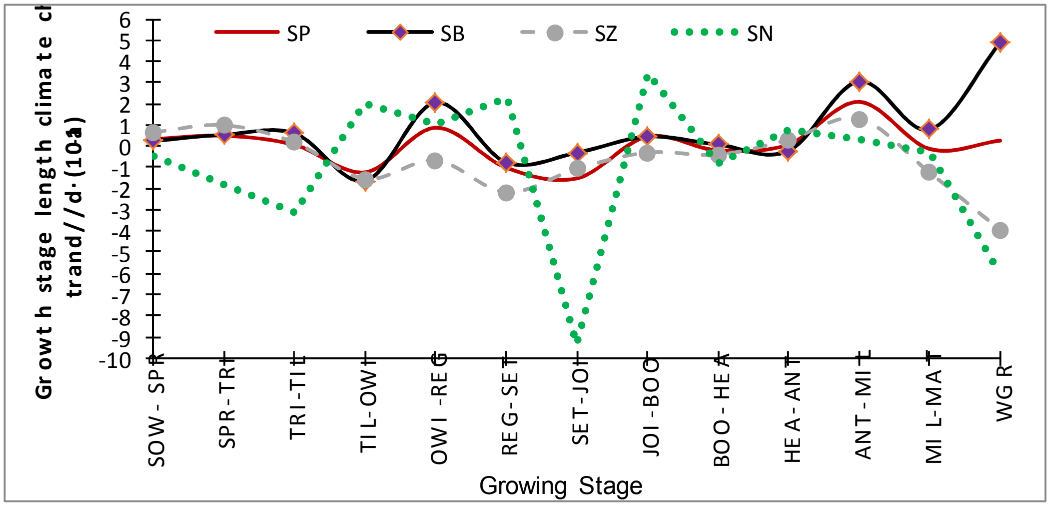


Figure 3. Influence of climate change on the length of different growth stages

As seen from Figure 4 (a), the decreases mainly occur in the northern part of SB and southeastern part of SN. For other areas, increasing trend is mostly found. The impact on the length of whole growth stage is in the range of -5.98~39.25 d•(10a)$^{-1}$ in the whole province. The mean impact in the whole province is 0.26d•(10a^{-1}; 4.89 d•(10a)$^{-1}$ in SB, -3.96 d•(10a)$^{-1}$ in SZ, -5.98 d•(10a)$^{-1}$ is SN. The growth period in SB is prolonged, while that in SZ and SN is shortened obviously.

(2) For the stage SOW-SPR, according to Figure 4 (b), the values were negative in the northwestern of SB and southeastern part of SN. They approach 0 from the Lixia River area to the central part of SB. For other regions, the values are positive. The possible impact of climate change on the length of growth period of winter wheat is -0.43~1.52 d•(10a)$^{-1}$. The mean impact in the whole province is 0.34 d•(10a)$^{-1}$; 0.26 d•(10a)$^{-1}$ in SB, 0.66 d•(10a)$^{-1}$ in SZ, and -0.43 d•(10a)$^{-1}$ in SN.

(3) For the growth stage SPR-TRI, we found from Figure 4 (c) that the values are negative in the north and central part of SB and in the south and central part of SN. They are positive in other areas with small values. The impact of climate change on the length of growth period of winter wheat is -1.80~1.31 d•(10a)$^{-1}$. The mean impact in the whole province is 0.49 d•(10a)$^{-1}$; 0.54 d•(10a)$^{-1}$ in SB, 0.99 d•(10a)$^{-1}$ in SZ, and -1.80 d•(10a)$^{-1}$ in SN.

(4) For the growth stage TRI-IL, as seen from Figure 4 (d), the values are negative in a strip-like region from the southern part of SN to Lixia River area of SZ and to the central part of SB. They are positive in other areas. The values from Lixia River to the western part of SZ are relatively small. The impact of climate change on the length of growth period of winter wheat is -3.15~2.42 d•(10a)$^{-1}$. The mean impact in the whole province is 0.06 d•(10a)$^{-1}$; 0.60 d•(10a)$^{-1}$ in SB, 0.18 d•(10a)$^{-1}$ in SZ, and -3.15 d•(10a)$^{-1}$ in SN.

(5) For the growth stage TIL-OWI, as seen from Figure 4 (e), the values are positive in a strip-like region from the northeastern part of SB to Southwest of SN. They are negative in other areas. The strong negative values are in the northwestern part of SB. The impact of climate change on the length of growth period of winter wheat is -8.54~1.90 d•(10a)$^{-1}$. The mean impact in the whole province is -1.23 d•(10a)$^{-1}$; -1.64 d•(10a)$^{-1}$ in SB, -1.54 d•(10a)$^{-1}$ in SZ, and -2.04 d•(10a)$^{-1}$ in SN.

(6) For the growth stage OWI-REG, as seen from Figure 4 (f), the values are negative in the northwestern part of SB and southeast of coastal region. They are positive in other areas. The values in northwestern and southeastern parts of SB and the western part of SN are relatively large, and those in Lixia River are close to 0. The impact of climate change on the length of growth period of winter wheat is -5.37~10.22 d•(10a)$^{-1}$. The

mean impact in the whole province is 0.87 d•(10a)$^{-1}$; 2.06 d•(10a)$^{-1}$ in SB; -0.67 d•(10a)$^{-1}$ in SZ, and 1.02 d•(10a)$^{-1}$ in SN.

(7) For the growth stage REG-SET, according to Figure 4 (g), the values are positive in a strip-like region from SN to the southeast of SB. The values in Lixia River are relatively small, and are negative in other areas. The lowest negative value occurs in the northwestern part of SB. The impact of climate change on the length of growth period of winter wheat is -5.24~4.26 d• (10a)$^{-1}$. The mean impact in the whole province is -1.02 d•(10a)$^{-1}$; -0.77 d•(10a)$^{-1}$ in SB; -2.18 d•(10a)$^{-1}$ in SZ, and 2.31 d•(10a)$^{-1}$ in SN.

(8) For the growth stage SET to JOI, as seen from Figure 4(h), the values are positive in the northwest corner of SB, the coastal region of the boundary between SB and SZ, and regions from SZ to the western part of SN. They are negative in other areas. The center with the strong negative value is located in the southeastern part of SN. The possible impact of climate change is -9.35~2.52 d•(10a)$^{-1}$. The mean impact in the whole province is -1.52 d•(10a)$^{-1}$; -0.31 d•(10a)$^{-1}$ in SB, -1.07 d•(10a)$^{-1}$ in SZ, and -9.35 d•(10a)$^{-1}$ in SN.

(9) For the growth stage JOI-BOO, as seen from Figure 4(i), the values are positive in the northwestern and northeastern parts of SB, southeast of coastal regions and the southern part of SN. They are negative in other areas. The possible impact of climate change is -3.27~3.42 d•(10a)$^{-1}$. The mean impact in the whole province is 0.45 d• (10a)$^{-1}$; 0.45 d•(10a)$^{-1}$ in SB; -0.30 d•(10a)$^{-1}$ in SZ, and 3.42 d•(10a)$^{-1}$ in SN.

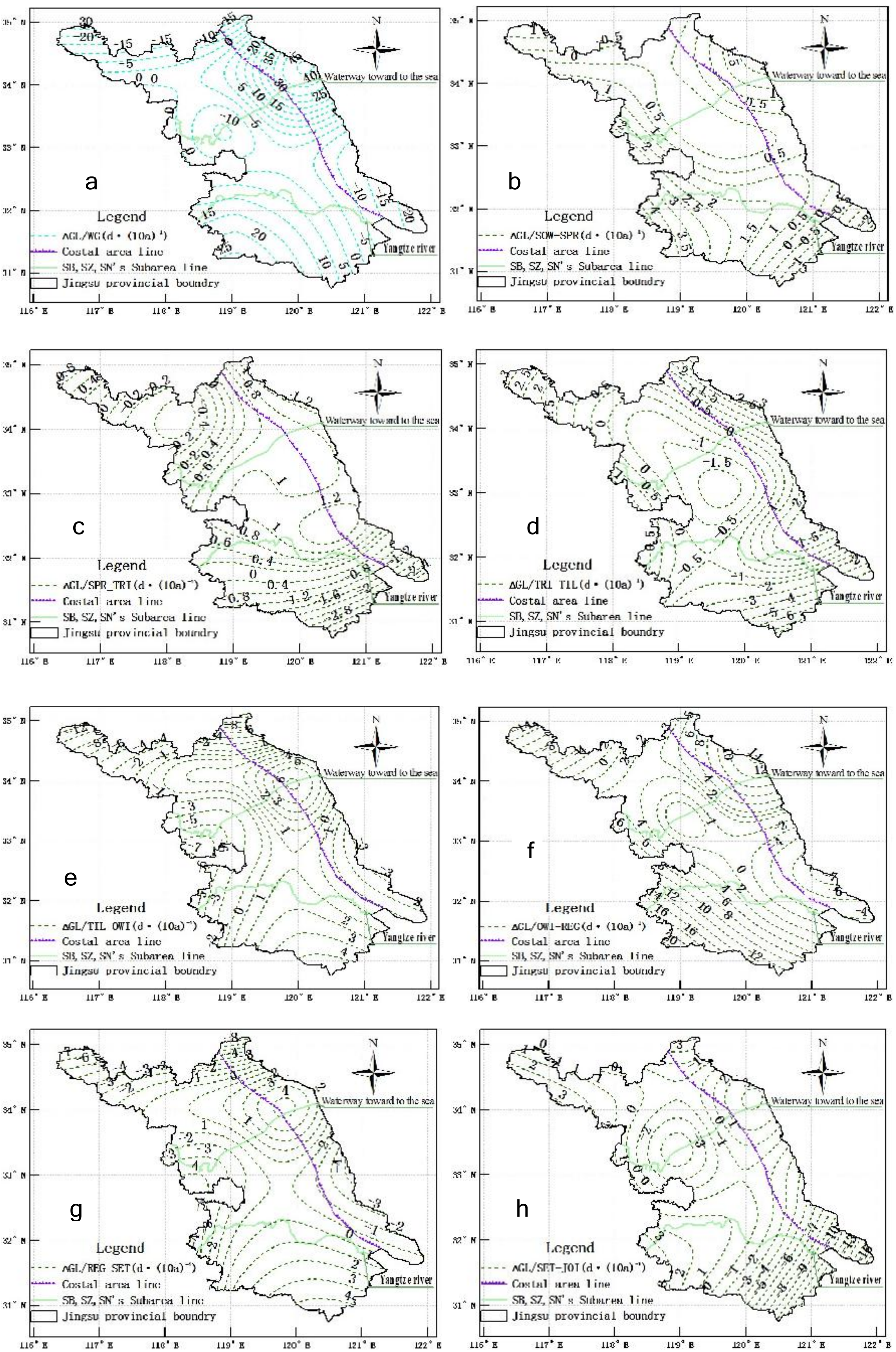
(10) For the stage BOO-HEA, according to Figure 4 (j), the values are positive in a strip-like region from the coastal region of SB to the southwestern part of SN. They are negative in other areas. The possible impact of climate change is -1.46~0.78 d•(10a)$^{-1}$. The mean impact in the whole province is -0.20 d•(10a)$^{-1}$; 0.07 d•(10a)$^{-1}$ in SB, -0.40 d•(10a)$^{-1}$ in SZ, and -0.80 d•(10a)$^{-1}$ in SN.

(11) For the stage HEA-ANT, as seen from Figure 4 (k), the values are positive in a strip-like region from the northeastern part of SZ to southeastern part of SN. The high value center is in the coastal region of the middle of SZ. They are negative in other areas. The possible impact of climate change on the length of growth period of winter wheat is -1.37~2.02 d• (10a)$^{-1}$. The mean impact in the whole province is 0.08 d•(10a)$^{-1}$; -0.22 d•(10a)$^{-1}$ in SB, 0.30 d•(10a)$^{-1}$ in SZ, and 0.74 d•(10a)$^{-1}$ in SN.

(12) For the growth stage ANT-MIL, as seen from Figure 4 (l), the values are negative in the middle part of SB and the southwestern part to the south of state-owned enterprise. They are positive in other areas. The strong positive value center is located in the coastal region from the middle part of SB to the northern part of SZ. The possible impact of climate change on the length of growth period of winter wheat is -6.00~7.17 d•(10a)$^{-1}$. The mean impact in the whole province is 2.09 d•(10a)$^{-1}$; 3.06 d•(10a)$^{-1}$ in SB, 1.30 d•(10a)$^{-1}$ in SZ, and 0.34 d•(10a)$^{-1}$ in SN.

(13) Regarding the growth stage MIL-MAT, as seen from Figure 4 (m), the values are positive in the coastal region from the middle part of SB to the northern part of SZ. They are negative in the northern part of SB and southeastern part of the coastal region. The values are positive in other areas. The possible impact of climate change on the length of growth period of winter wheat is -2.27~4.90 d•(10a)$^{-1}$. The mean impact in the whole province is -0.13 d•(10a)$^{-1}$; 0.79 d•(10a)$^{-1}$ in SB, -1.24 d•(10a)$^{-1}$ in SZ, and -0.32 d•(10a)$^{-1}$ in SN.

To sum up, the most significant effect of climate changes on the length of growth stages was found from OWI to REG and from ANT to MIL. SZ, especially the wetland regions of Lixia River plain was affected the least, followed by the wetland in coastal regions and along the river. The northern part of SB and hilly and mountain terrain were the most affected.


a
Legend
ΔGL/WG(d • (10a)⁻¹)
Costal area line
SB, SZ, SN's Subarea line
Jingsu provincial boundry
Waterway toward to the sea
Yangtze river
b
Legend
ΔGL/SOW-SPR(d • (10a)⁻¹)
Costal area line
SB, SZ, SN's Subarea line
Jingsu provincial boundry
Waterway toward to the sea
Yangtze river
c
Legend
ΔGL/SPR_TRI(d • (10a)⁻¹)
Costal area line
SB, SZ, SN's Subarea line
Jingsu provincial boundry
Waterway toward to the sea
Yangtze river
d
Legend
ΔGL/TRI TIL(d • (10a)⁻¹)
Costal area line
SB, SZ, SN's Subarea line
Jingsu provincial boundry
Waterway toward to the sea
Yangtze river
e
Legend
ΔGL/TIL OWI(d • (10a)⁻¹)
Costal area line
SB, SZ, SN's Subarea line
Jingsu provincial boundry
Waterway toward to the sea
Yangtze river
f
Legend
ΔGL/OWI-REG(d • (10a)⁻¹)
Costal area line
SB, SZ, SN's Subarea line
Jingsu provincial boundry
Waterway toward to the sea
Yangtze river
g
Legend
ΔGL/REG SET(d • (10a)⁻¹)
Costal area line
SB, SZ, SN's Subarea line
Jingsu provincial boundry
Waterway toward to the sea
Yangtze river
h
Legend
ΔGL/SET-JOI(d • (10a)⁻¹)
Costal area line
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Jingsu provincial boundry
Waterway toward to the sea
Yangtze river

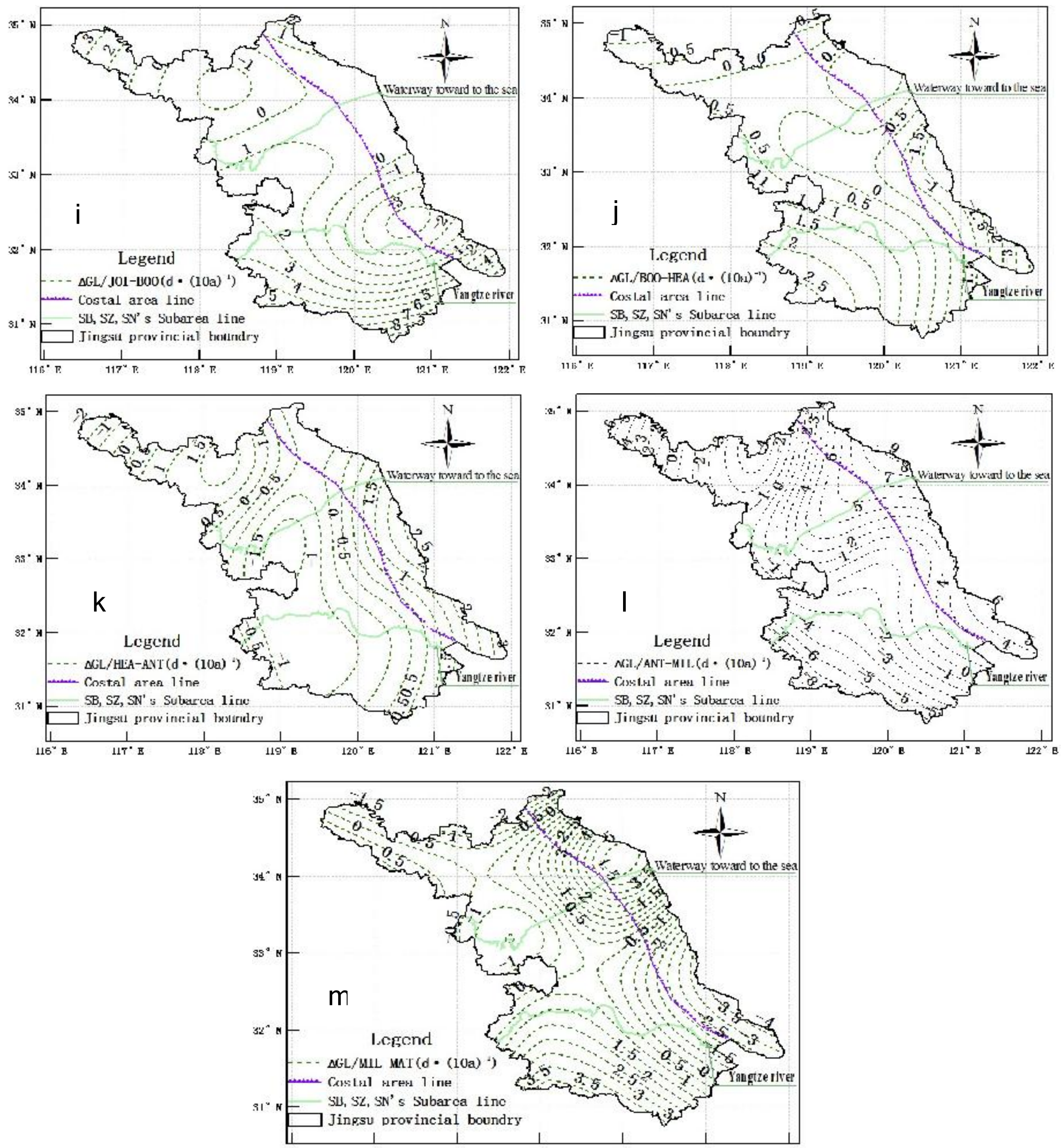

Figure 4. Influence trend of climate change on growth stage lengt

CONCLUSIONS

The temperature variation is the most significant in winter, with sunshine duration and wind speed decreasing interannually and consistently across the regions. Generally, the mean rate of relative change of meteorological elements during the growth period are ranked as wind speed > precipitation > temperature > sunshine duration, which may contribute to the escalation of minor disaster to major disaster. Therefore, the subsequent problems of lodging and heat-forced maturity should be given sufficient attention.

The length of growth period of winter wheat and the meteorological elements during the growth period exhibit large regional variation. This indicates that wetland protection plays an important role in alleviating climate change and its effect on the production of winter wheat.

The breeding and popularization of temperature-insensitive, drought-tolerant and waterlogging-tolerant varieties should be enhanced. The weather disaster emergency defence system should be constructed, in order to increase the monitoring and early warning ability in case of serious weather disasters during the growth period of winter wheat.

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