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Effects of climatic variation and warming on rice development across South China

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ABSTRACT: Rice *Oryza sativa* L. development — and also its response to climatic change — is mainly determined by temperature and photoperiod. An experiment was conducted to study the influence of meteorological factors on growth and development of hybrid rice in South China, in which seeds were sown at different sites at different dates in the spring. The 29 experimental sites were spread over a large area, with latitudes from 21° 39′ to 34° 16′ N and altitudes from 1 to 1862 m above sea level. It was found that the length of the growth period at low latitudes (21 to 25° N) was mainly determined by temperature and showed a single-peaked curve with an optimum temperature at about 25.7°C. The temperature response of development is almost linear at high latitudes (25 to 35° N), but the dependence is not as close and significant as that at low latitude, due to longer daylength and its higher variation. A phenological-simulation model with a biological basis was used to simulate the developmental stages of rice in South China. It described both thermal sensitivity and photoperiodism using nonlinear equations. The model was validated by data of sowing-date experiments carried out at different geographical sites, and then was applied to evaluate changes in the length of the rice-growth period in response to climate warming during the period from 1951 to 2006. Because there was significant warming, and the length of the growth period was sensitive to this change over the Yunnan-Guizhou Plateau, the length of the growth period was narrowed by 6 to 14 d (comparing 1990 to 2006 with 1951 to 1989), whereas it was shortened by 1 to 2 d in most low plain areas in South China. The probability of serious temperature related crop failure will increase if planting of a late-maturity variety is adopted in high altitude areas.

KEY WORDS: Climatic variation · Temperature · Photoperiod · Rice · Development · Model · South China

1. INRODUCTION

Rice *Oryza sativa* is a dominant crop in China, and its regional distribution and production are strongly influenced by climate. Rice is widely distributed from 45° N in the northeast to 19° N in the south of China. It has been planted up to an altitude of 2600 m on the Yunnan-Guizhou Plateau (YGP) in southwest China, but is sparsely cultivated in north and northwest inland areas that have a continental climate. More than 85% of the planting area is located in South China, which has a warm and humid climate. Such a regional distribution reflects the impact of temperature, daylength and rainfall as governed by latitude, longitude and altitude. Temperature and daylength are the 2 main climate factors influencing rice phenological development, and in turn regional distribution, and productivity (Huang et al. 1998).

The climate in the east part of China is influenced predominantly by monsoons controlled by interactions between oceanic and continental air masses. The seasonal variations in temperature, precipitation and solar radiation are much greater there than those at the same latitude on the American and West Eurasian continents (Domros & Peng 1988). The marked interannual climate variability causes significant interannual

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variations in rice production. At the regional level, the spatial difference in temperature in winter is much greater than that in summer. While the maximum monthly mean temperature in July has a difference of only a few degrees from north to south (26 to 30°C), the minimum monthly mean temperature in January decreases to a much larger extent from south to north, ranging from 7 to –12°C. Such a spatiotemporal pattern of temperature difference, together with that of rainfall and photoperiod length, has shaped the rice production distribution in China for centuries. In the last 5 decades, a clear warming trend has been observed in South China (Zhai et al. 1999, He & Zhang 2005, Lu et al. 2006, Wu et al. 2006). The impact of this warming trend on the phenological development of rice has not been carefully studied. Knowledge gained from such study would be essential in the assessment of the impact of climatic variation and changes on rice production in South China.

China launched a national project to study the dependence of rice production on climate between 1979 and 1981 in South China, which focused on 3 aspects of hybrid rice production: indices of low temperature damage, matching of flowering dates of parent varieties and overall climate suitability of rice growth. It was the most comprehensive experiment focussed on the rice–climate relationship, with the largest spatial extent, ever carried out in China. Experimental results on the relationship between rice development and meteorological conditions have been reported (GMCHR 1985, Yu et al. 2002); however, the relationships were derived only from data collected from 3 yr of experimentation. Some simulation research has been carried out across Asia, including South China, to study the variability of rice production due to climatic variations (Kropff et al. 1994, Mall & Aggarwal 2002, Yao et al. 2007). But some of these studies were restricted to specific locations, and some failed to provide insight into the processes of crop grow and development (Peiris et al. 1996). Thus, a region-wide view of how rice phenological development is influenced by climatic variations is still lacking.

For a regional assessment of the impact of past climatic variations and the warming trend on rice phenologies, a modelling approach is needed. Physiologically based phenological simulation models are useful tools to analyze the crop developmental response to climatic variations (Matthews 1995). The objective of the present paper was to develop a rice phenological simulation model including the effects of both temperature and photoperiod based on the experimental data collected during the national project and then to use the model to evaluate the impact of past climatic variations and the warming trend in South China on the phenological development of rice.

2. MATERIALS AND METHODS

2.1. Rice-climate experiments 1979–1981

A detailed description of the experimental area, management and observation method for the South China rice experiment from 1979 to 1981 was given by Yu et al. (2002). Here, only a summary of the observations and data used in the present paper is given.

Serial planting experiments were conducted from 1980 to 1981 at different geographic sites by sowing seeds and transplanting rice seedlings into field conditions. The experimental sites were distributed over 12 provinces of South China (Fig. 1), with latitudes ranging from 21° 39′ N (Zhanjiang) to 34° 15′ N (Xuzhou) and with longitudes from 102° 50′ E (Jianshui) to 121° 26′ E (Ningbo, near the shore). The altitudes at experimental sites ranged from 1 m above sea level at Nanhai to 1862 m at Qujing on the YGP.

The variety of rice used was the hybrid Shanyou 6, which is moderately sensitive to temperature and photoperiod. Seeds were sown every 10 d in spring so that rice plants grew under different meteorological conditions. The number of different sowing times ranged from 2 to 6, depending on the length of the growing season at each site. Seed quantity, number of basic seedlings, times and amounts of fertilizers applied were unified across all the sites, and pests and diseases were controlled using insecticides and pesticides. The area of each sowing plot was 20 m^2, with 3 replications at each site.

The observations noted were calendar dates of different developmental stages, grain yield and yield components, burliness ratio, above-ground dry matter, leaf area index and nutrient contents of grains. Only the observational data on dates of phenological developmental stages were used in this study.

2.2. Climate data

Temperature records were obtained from national meteorological stations, and compiled and released by the National Meteorological Bureau. Data from weather stations that are close by or representative of the experiment sites were used. On average, the distance between the selected weather stations and the experimental sites was about 15 km.

The daylength (DL in hours) is calculated as a function of latitude and time of the year:

$$DL = 15 \arccos(-\tan\varphi \times \tan\delta)/\pi \quad (1)$$

in which φ is the latitude and δ is the solar declination, which is calculated by the calendar day.

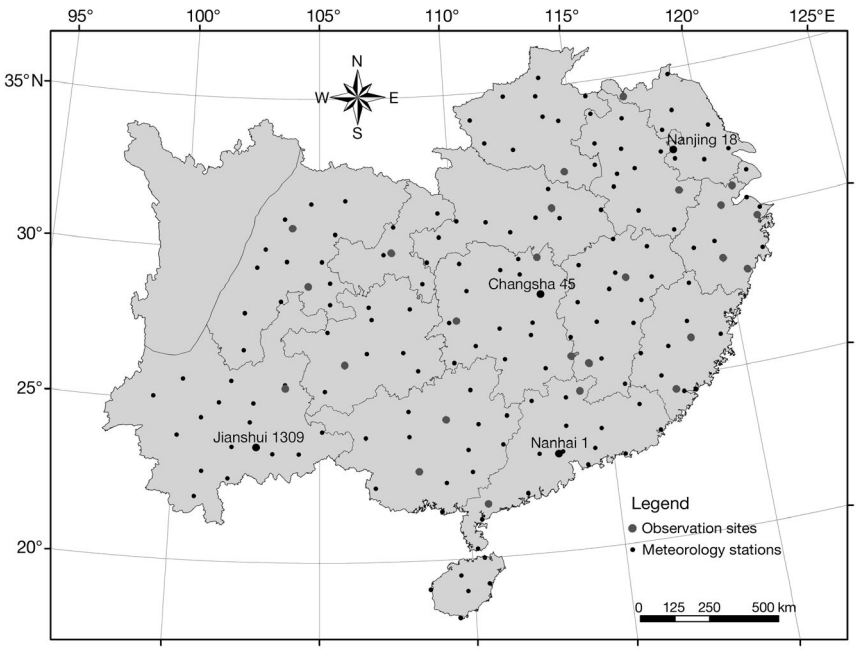

Fig. 1. Geographical distribution of the 29 experimental sites in South China (number after each station is altitude, m). Nanjing, Changsha, Nanhai and Jianshui represent the north, middle and south subtropical zones, and the Yunnan-Guizhou Plateau (YGP), respectively

2.3. Spatial variation of temperature and daylength

The rice growing region in South China can be divided into 4 areas: the north, middle and south subtropical zones, and the YGP. There is also a large rice growing area in the Sichuan basin in the southwest, where the climate is warm and humid; this area belongs to the mid-subtropical zone. In South China, although there are some seasonal droughts when the weather patterns are dominated by subtropical anticyclones in summer, the influence of rainfall on growth and development was not considered in this study because there was ample water supply for irrigation in the rice fields covered by the experiments.

The 4 experimental sites Nanjing, Changsha, Nanhai and Jianshui represent the north, middle and south subtropical zones, and the YGP, respectively (Fig. 1). Fig. 2 shows the 10 d average temperatures (1 to 10, 11 to 20, and 21 to end of the month) at the 4 representative sites in 1980. At Nanhai, the 10 d average temperatures ranged from 11.6°C in winter to 29.7°C in summer. The winter and spring temperatures were much higher than those in areas to the north. Therefore, rice can be cultivated 3 times a year in the same plot in the south, but only 1 to 2 times in the northern part of the region. The temperature ranges at Nanjing and Changsha were from −0.1 to 28.6°C and from 1.6 to 30.8°C, respectively, where the summer temperature may exceed that in the south because of subtropical anticyclones, which bring with them many clear and hot days. The climate at Jianshui is characterized by small variations of temperature with relatively high spring temperatures and relatively low summer temperatures, with a temperature range of 9.5 to 23.7°C in 1980.

Natural daylength changes with both latitude and time of year, which is deterministic in contrast to other climatic variables. Fig. 3 illustrates the seasonal changes in daylength at latitudes of 20, 25, 30 and 35°N. At higher latitudes, daylength is very much longer in summer, which may delay the rice developmental stages, and the seasonal variation in daylength has a larger range.

2.4. The rice phenology model

Temperature and daylength are the 2 main factors determining rice development. The early, middle and late varieties of rice in China are all sensitive to variations in temperature, but varieties of late rice are the most sensitive and those of early rice are the least (GMCHR 1985). The ability of plants to respond to daylength, i.e. photoperiodism, is linked to an inner circadian rhythm. Rice is generally classified as a short-day plant (Vergara & Chang 1985). The rice growth cycle can be divided into the vegetative, reproductive and maturity stages. The vegetative stage consists of a juvenile phase followed by a photoperiod-sensitive phase, in which rice development is accelerated by short daylength. Under long daylength, heading and flowering stages are delayed (Matthews 1995).

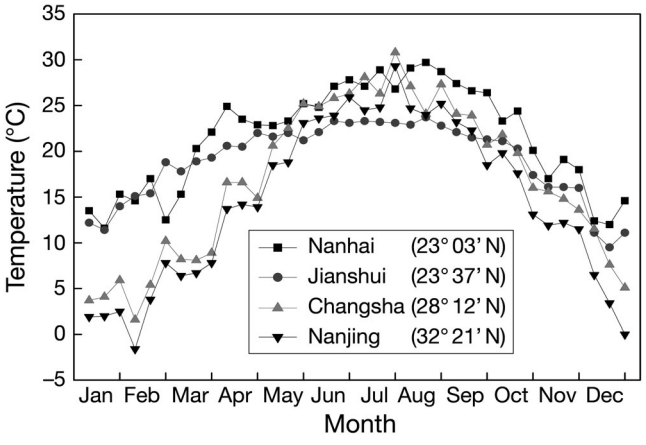

Fig. 2. Seasonal variation of average temperatures at 4 representative sites, 1981

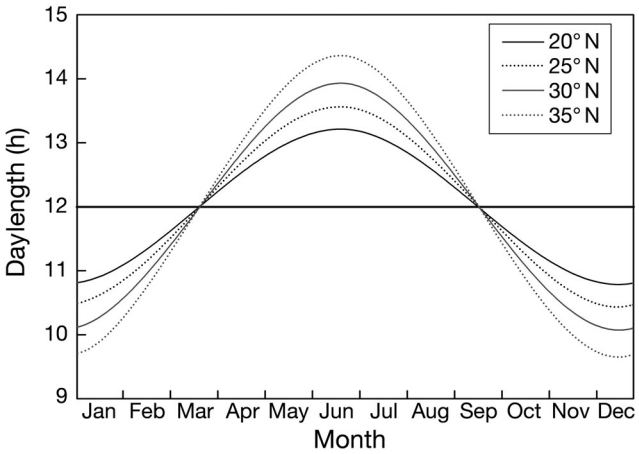

Fig. 3. Seasonal changes in daylength at latitudes 20, 25, 30 and 35° N

The response of crop development to temperature and daylength was expressed by an additive model:

$$V = K_0 + f(T) + f(\mathrm{DL}) \quad (2)$$

in which V is the developmental rate (d^{-1}), $f(T)$ and $f(\mathrm{DL})$ are functions of temperature (T) and daylength (DL), respectively, and K_0, is a model parameter.

For $f(T)$, linear and non-linear functions have been used to describe the response of crop development to temperature. Linear functions have been used in several crop models such as SWHEAT (van Keulen & Seligman 1987) and APSIM (Wang et al. 2002, Keating et al. 2003). Curvilinear functions are used in Shen (1980) and Gao et al. (1992), Yin et al. (1995) and Wang & Engel (1998). The one used by Shen (1980) and Yin et al. (1995) is given as Eq. (3):

$$\frac{1}{n} = \frac{1}{\mathrm{k}}(T - \mathrm{T_{min}})^{1+\mathrm{p}}(\mathrm{T_{max}} - T)^{1+\mathrm{q}} \quad (3)$$

in which $\mathrm{T_{min}}$ and $\mathrm{T_{max}}$ are minimum and maximum temperatures for development, respectively; n is the length of the growth period in days; k, p and q are model parameters determining the shape of the temperature response curve; and T is temperature averaged by daily temperature over a growth period of n days.

For $f(\mathrm{DL})$, both linear and exponential functions have been used. Robertson (1968) used a quadratic equation to describe the response of development rate. Angus et al. (1981), Gao et al. (1992) and Wang & Engel (1998) used an exponential function, while Yin & Kropff (1996) used the beta function to describe the effects of photoperiod on development towards flowering. A general type of the exponential function is given as Eq. (4):

$$\frac{1}{n} = \mathrm{a} \times \exp[-\mathrm{b} \times (\mathrm{DL} - \mathrm{DL_0})] \quad (4)$$

in which $\mathrm{DL_0}$ is the critical daylength below which no developmental process occurs, and a and b (>0) are parameters. The sign of the exponent in the exponential function relates development rate to daylength; it is negative for short-day plants like rice and positive for long-day plants such as wheat.

In the present paper, a comprehensive model combining Eqs. (3) & (4) is used to simulate the phenological development of rice plants. The model is given in Eq. (5):

$$V = \mathrm{a_0} + \mathrm{a_1} \times \exp[-\mathrm{b} \times (\mathrm{DL} - \mathrm{DL_0})] + \mathrm{a_2} \times (T - \mathrm{T_{min}})^{1+\mathrm{p}} \times (\mathrm{T_{max}} - T)^{1+\mathrm{q}} \quad (5)$$

in which $\mathrm{a_0}$, $\mathrm{a_1}$, $\mathrm{a_2}$, b, p and q are parameters. The model is then calibrated and validated against the observational data and used to analyze the impact of climatic variation and warming on rice development.

2.5. Model parameterization

The development stage (DVS, a dimensionless variable) is expressed as the integration of development rate with respect to time t, i.e. the number of days from the start of growth. The DVS has the following form:

$$\mathrm{DVS}(t) = \int_1^t V(t)\,\mathrm{d}t \quad (6)$$

or

$$\mathrm{DVS} = \sum_{t=1}^{t} V(t) \quad (7)$$

Assuming $t = 0$ and DVS = 0 to be the day of sowing, the integration of the development rate over the entire period under consideration represents development from transplantation to maturity (DVS = 1), which is given the value of unity. For any given sowing date, if the total number of days from sowing to maturity is n_j, then:

$$\mathrm{DVS} = \sum_{t=1}^{n_j} V(t) = 1.0 \quad (8)$$

$$n_j \mathrm{a_0} + \mathrm{a_1} \times \sum_{i=1}^{n_j} \exp[-\mathrm{b} \times (\mathrm{DL_i} - \mathrm{DL_0})] + \mathrm{a_2} \times \sum_{i=1}^{n_j} [(T_i - \mathrm{T_{min}})^{1+p} \times (\mathrm{T_{max}} - T_i)^{1+\mathrm{q}}] = 1 \quad (9)$$

The DVS consists of the period from sowing to heading and from heading to maturity. Since rice development is sensitive to photoperiod only from transplanting to heading, in model calibration, daylength was fixed to 12 h for the period from heading to maturity to eliminate the photoperiod impact on the development rate.

There were a large number of data from sowing experiments over wide areas, with a total of 29 sites and 221 sowing dates. Data from 29 sites in 1980 and 1981 were used to calibrate the model. These sites were representative of the wide distribution of rice growing in

South China. Linear regression was used to determine the values of parameters in the model. Some initial values of parameters b, p and q were given at first. Then the model was fitted by progressive regression to calculate the values of parameters a_0, a_1, a_2, and b. Subsequently the values of parameters b, p and q were adjusted in the second round of fitting until the best fit of the equation to the observed dates was achieved.

By differentiating Eq. (5) with respect to temperature, and setting $dV/dT = 0$, the optimal temperature (T_{op}) is obtained as:

$$T_{op} = \frac{(1+p)T_{max} + (1+q)T_{min}}{2+p+q} \quad (10)$$

Validation of the model is conducted by using the parameterized model to simulate length of rice growth period for all the observational sites. The simulated lengths of growing periods were then compared with the observed lengths.

2.6. Simulation of warming impacts and spatial interpolation

The phenological simulation model, together with the climatic data from 1951 to 2006, was then used to simulate the impact of climatic variations and the warming trend on the length of the rice growing period. The temporal variations in the length of the growing period in 4 climate zones in South China, i.e. the north, middle, and south subtropical zones, and the YGP in the southwest are shown (see Fig. 7). The spatial distribution of simulated average lengths of the growth period is shown spatially (see Fig. 8), and the temporal variation is calculated as the standard deviation of annual lengths of the growth period (see Fig. 9).

The inverse distance weighting (IDW) method was applied in spatial interpolation. IDW interpolation explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart. A value for any grid can be calculated using the measured values of the surrounding sites. Those measured values closest to the prediction location will have more influence on the predicted value than those farther away. Thus, IDW assumes that each measured point has a local influence that diminishes with distance. For the predicted value $Z(x_0)$:

$$Z(x_0) = \sum_{i=0}^{m} \lambda_i Z(x_i) \quad (11)$$

where $Z(x_i)$ is the measured value at the ith location, λ_i is an unknown weight for the measured value at the ith location, x_0 is the prediction location, and m is the number of measured values. The value λ_i is expressed by:

$$\lambda_i = d_{i0}^{-r} / \sum_{i=1}^{m} d_{i0}^{-r} \quad (12)$$

where r is the exponential coefficient and d_{i0} is the distance between x_0 and x_i. It is obvious that the weight is affected by r, and r is usually equal to 2.

3. RESULTS

3.1. Influence of temperature and daylength on growth period

To separate the impact of temperature and daylength, the whole region under study is divided into 3 zones according to latitude; within each zone, the differences in daylength are small. There are 11 sites in the south zone, with latitudes from 21 to 27° N; 10 sites in the middle zone, from 27 to 31° N; and 8 sites in the north zone, from 31 to 35° N. The relationship between the lengths of the growth periods and their corresponding average temperatures are shown in Fig. 4.

As temperature increased with decreasing latitude and decreasing altitude, the average length of the growing period increased with latitude and altitude (Fig. 4a–c). In the north zone, the growing period ranged from 118 to 157 d, and from 112 to 144 d in the middle. In the south zone, the growing period of 105 d was the shortest in the low plain, but reached 159 d on the YGP (Fig. 4c).

Increasing daylength with latitude leads to longer growing period from south to north. An ANOVA indicates that a change in daylength of 1 h caused variations in the length of the growth period of 8 to 9 d, whereas a temperature variation of 1°C resulted in variations in the length of the growth period of 4 to 5 d for the cultivar under study. The variations are nearly the same in different zones, which implies that the influence of daylength is independent of temperature; thus, an additive model is adequate to simulate the impact of temperature and daylength. Greater variations in daylength between sowing-date treatments in the north zone led to more scattered points in the temperature response relations in Fig. 4a.

As temperature in the south zone varied significantly with altitude from 1 to 1862 m above sea level, the response of development rate (1/L) being the reciprocal of the length of the growth period (L) to temperature is a single-peaked curve with a temperature optimum slightly closer to T_{max} than to T_{min} (Fig. 5). Fig. 5 shows a fitted curve to the data points. Development rate is highest at an average temperature of 25.7°C over the growth period.

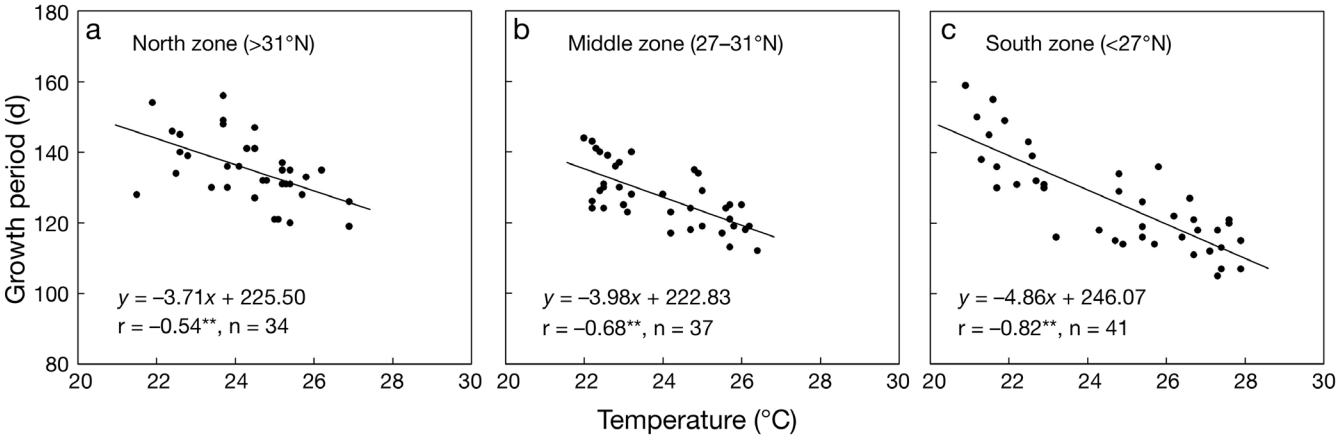

Fig. 4. Changes in the length of the rice growth period in 3 zones: (a) north, (b) middle and (c) south. **p < 0.01

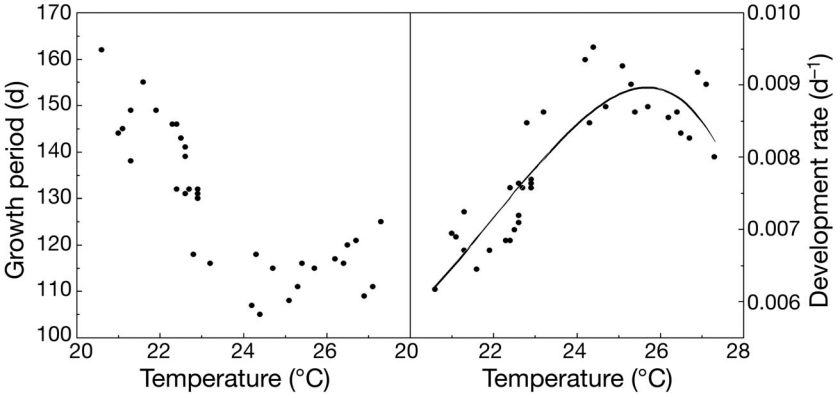

Fig. 5. Dependence of the rice growth period (L) and development rate (1/L) on average temperature of the corresponding periods of growth and development in the south zone of South China (1980 to 1981)

as T_{op} = 28.8°C. The optimal temperature for rice development may change with step length of simulations from a day to a growing season. The daily T_{op} is 28.8°C (Eq. 10), and 25.7°C is the average temperature over the growing season (Fig. 5). This difference of 3.1°C may be attributed to temperature variation over the growing season. For example, when the development rate was highest at 28.8°C, the mean temperature over the growing season may be averaged from 12 to 30.6°C. This may lower the value of the optimum temperature.

3.2. The phenology model

The minimum temperature for development (T_{min}) was found to be 12°C, and the maximum temperature (T_{max}) was found to be 41°C by maximizing the value of correlation coefficient.

The parameters in the model derived from progressive regression are shown in the following equation:

$$V = 6.0\times10^{-4} + 4.2\times10^{-3}\exp[-0.3(\mathrm{DL}-\mathrm{DL}_0)] + 1.63\times10^{-6}(T-\mathrm{T}_{min})^{1+0.8}(\mathrm{T}_{max}-T)^{1+0.3} \quad (13)$$

(n = 106, R^2 = 0.79, p < 0.01)

The results show that 79% of the variations in the observed lengths of the growth period can be explained by the model (Fig. 6). Of the average deviation from the simulated values 80% is <5.0 d, and the average deviation is 3.6 d.

With the values of parameters in the model and Eq. (10), the optimal temperature (T_{op}) is estimated

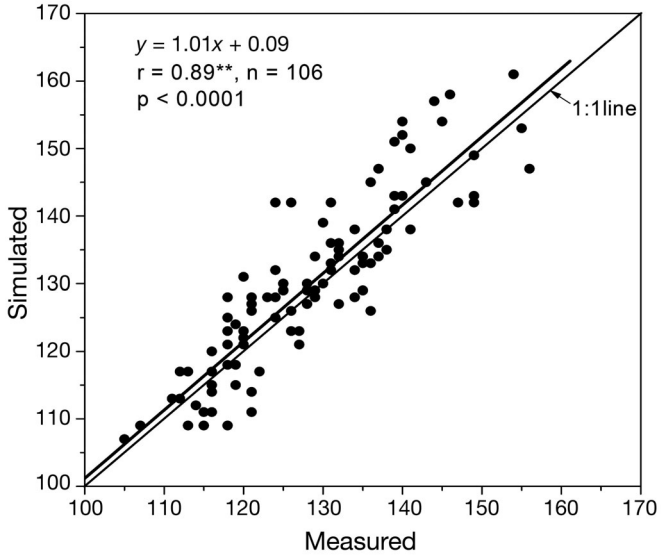

Fig. 6. Simulated and observed rice growth period for 29 sites in South China (1980 and 1981). **p<0.01

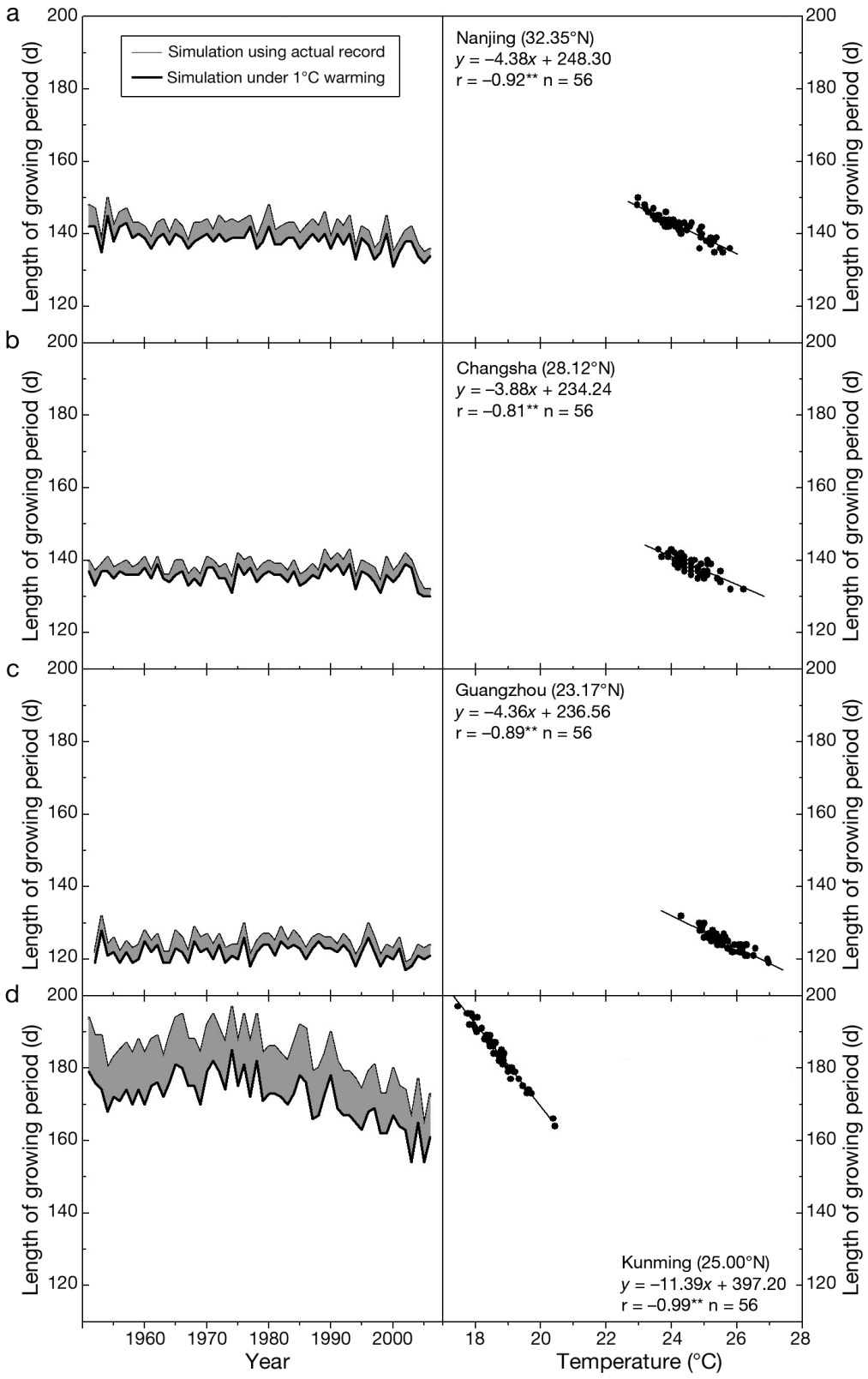

Fig. 7. *Oryza sativa.* Evaluation of changes in the length of the rice growth period according to year (1951–2006) and temperature at 4 representative sites: (a) south, (b) middle and (c) north subtropical zones, and (d) the Yunnan-Guizhou Plateau. Lefthand panels: grey line: simulated growth in length during 1951 to 2006; black line: simulated length of the growth period under the 1°C warming scenario. Note different axis scales. Difference in length of the rice growing period (grey shaded area) is sensitivity of growing period response to climate change. $^{**}p<0.01$

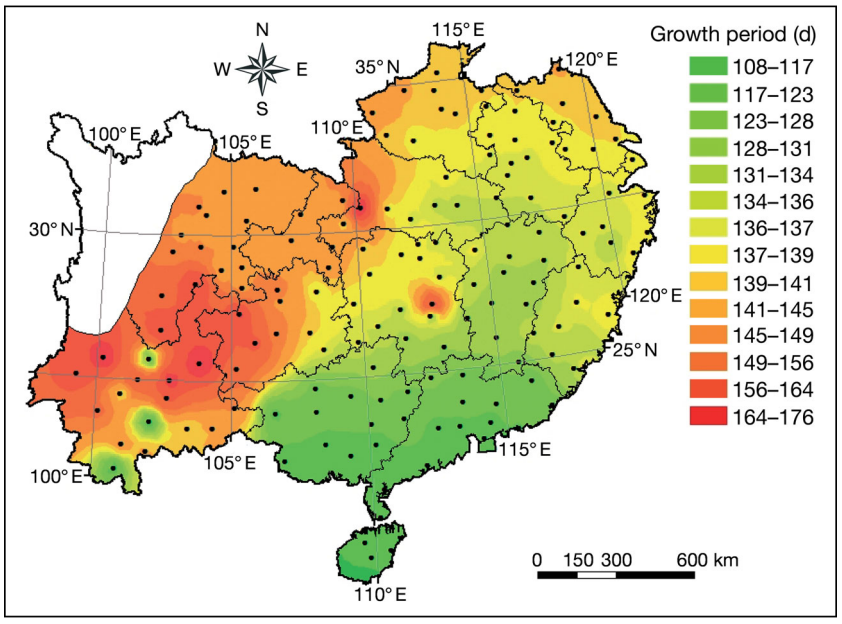

Fig. 8. Average length of the rice growth period in South China from 1951 to 2006

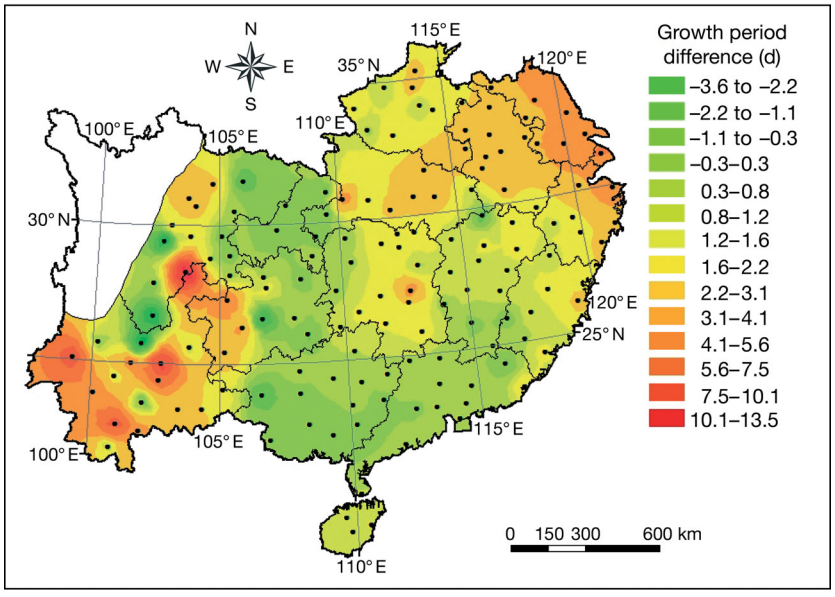

Fig. 9. Shortening of rice growth period in 1990–2006 as compared to 1951–1989 in South China

3.3. Effects of climate on growth period

Fig. 7 shows the simulated length of the growth period in 4 climate zones in South China. The simulated length of the growth period is shortened with increasing temperature, but to different rates in different zones. With every 1°C increase in temperature, the length of the growth period is shortened by about 11.4 d on the plateau, whereas it is shortened by 3.8 to 4.4 d in other zones. The significant reduction in the length of the growth period from the late 1970s to 2006 shows the impact of warming on the plateau (Fig. 7d).

The spatial distribution of the average simulated growth period from 1951 to 2006 is shown in Fig. 8. The length of the growth period on the plateau ranges from 145 to 176 d, which is much longer than that in other areas. This can be attributed to low temperature and low latitude or short daylength. Rice is a short-day plant, higher temperatures and shorter daylength in the south in summer may decrease the growth period. Therefore, the growth period increases from 108 d on Hainan Island to 140 d in Huaihe River in the north.

Standard deviations, reflecting fluctuations from the means of time series, vary from 3.7 to 9.2 d on the plateau and are <3.7 d in the low plain (data not shown). The high standard deviation of the growing period on the plateau and in the northern part of the region reflects the large inter-annual variation in temperatures.

The simulated impact of climate warming from 1951 to 2006 on the length of the rice growing period is shown in Fig. 9. As temperature increase on the plateau is faster than in other areas, the length of the growth period was shortened by 6 to 14 d between 1951 to 1989 and 1990 to 2006, compared to 1 to 2 d in the low plain (Fig. 9). But increases in the length of the growth period are also found in individual areas on the plateau, due to complex climate variability or complex topography. For example, the temperature is very high at a station located in a valley on the plateau, and its simulated length of the growth period is similar to that in the low plain (Fig. 8).

4. DISCUSSION

4.1. The modelling approach

The present study uses the historical climatic data from 1951 to 2006 and a modelling approach to investigate the impact of climatic variations and the warming trend on rice phenology. Here, the area under study covers the main cultivation regions of rice in South China, with latitudes from 21° 39′ to 34° 16′ N.

For a study involving such a large geographic region and to estimate the impact of long-term climate variability, an experimental approach is impractical. A phenological simulation model developed on the basis of experimental data enables the assessment of the impact of both temporal and spatial climate variability. The model captures the effects of both temperature and photoperiod on rice phenological development.

There is wide variation in the rice varieties cultivated in the area under study, but only 1 representative variety with moderate sensitivity to temperature and daylength, i.e. Shanyou 6, was used in the simulation. This method of examination is useful for finding the unique impact of temperature on spatial and temporal variation. The model parameters were obtained on the basis of the experiments from 1979 to 1981. Rice varieties have been improved to obtain higher production since then. However, the lengths of the growth period of current varieties fell well within the range of those found in the 1979 to 1981 experiment (Table 1). This shows that rice development in response to temperature and light is quite stable. It is difficult to assess whether the current varieties have a longer growth period due to the lack of comparative experiments under the same climatic conditions. A long-term monitoring study of crop growth and development is much needed. The China Climate Observatory launched such a study 2 yr ago.

4.2. Effect of climate on rice production

Rice production is reported to be sensitive to climate variability and change in Southeast Asia (Bachelet et al. 1992, Buan et al. 1996, Matthews et al. 1997, Amien et al. 1999, Mall & Aggarwal 2002, Naylor et al. 2007), as well as in South China (Yao et al. 2007). In the present study, we only demonstrated a change in the length of growth in response to a temperature increase and its spatial difference from the low plain to plateau. Climatic warming affects rice production in 2 ways: growth and development, which both shape yield components, i.e. stem number, spikelet number and 1000-grain weight (i.e. weight of 1000 grains). There may be other diverse responses of yield components to temperature change and atmospheric CO_2 increase that need further investigation. As climatic change and variability have impacts on the physiological processes of crops, temperature may influence photosynthetic rate, pollination and development rate. Lansigan et al. (2000) found that the degree of vulnerability of crops to climate variability depends mainly on the developmental stage of the crops at the time of weather aberration. Tao et al. (2003) assessed the impacts of climatic change on the agricultural water cycle and the implications of those impacts for agricultural production in the croplands of China. Further investigation is needed to show other yield responses to climate warming besides crop phenology.

An extension of the growing season as a result of global warming has been widely reported. For example, the average annual growing season has lengthened, on average, by 10.8 d in Europe between 1951 and 1996 (Menzel & Fabian 1999). However, in the case of rice, a shortened life period resulting from global warming, has meant that cultivars with a longer life period are being recommended by agricultural extension institutions to take advantage of the longer growing season. As late-maturing cultivars have a longer life period, they have been extended to high altitudes in recent years. But the considerable climate variability on the plateau (Fig. 8) may result in reduced production of late-maturing cultivars. For example, the cold season on the plateau in 2002 resulted in a 50% reduction of rice yield. A more comprehensive analysis of the impact of the climatic warming trend on the productivity of different rice cultivars across the region is necessary.

Table 1. *Oryza sativa.* Length of the growth period and production of previous and current rice varieties at 4 representative sites: north, middle and south zones, and a plateau. Superscripts — a: early rice; b: second rice; c: midseason rice (data for current varieties are from NCVE 2007a,b,c,d)

Site	Sowing date		Length of growing period (d^{-1})		Variety		Average yield ($kg\ ha^{-1}$)	
	1979–1981	Current	1979–1981	Current	1979–1981	Current	1979–1981	Current
Nanhai	Jan 30–Aug 7	End of Feb–early Mar[a]; Early July[b]	95–149	125[a]; 115[b]	Shanyou 6	Fengmeizhan; Zhengyou 998	5250–8752	6950[a]; 6942[b]
Jianshui	Mar 25–Jun 15	Mar–end of Apr[b]	131–159	151[c]	Shanyou 6	Yinong 1	7522–11587	8355[c]
Changsha	Mar 25–Jul 6	End of Mar[a]	107–144	114[a]	Shanyou 6	Zhunliangyou 2	5055–8310	8287[a]
Nanjing	Apr 25–Jun 15	End of Apr[a]	118–134	113[a]	Shanyou 6	Xiannong 1	5677–11767	8092[a]

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