Heat-risk assessment for winter wheat using long-term weather data

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Abstract
High temperature is one abiotic stress that affects grain filling of winter wheat, and the uncertainty of high temperature will result in the loss of grain yield and quality. In this study, 63 years of daily weather data were obtained from 6 stations in Huaibei plain, Anhui Province, China. The weather data was used to help quantifying the risk of heat stress of wheat growth from anthesis to maturity, and to evaluate the characteristics of highest temperature, lowest temperature and average temperature from anthesis to maturity. By analysing the temperature data from 1955 to 2017, it was found that the average highest temperature increases during the grain filling period. This occurred mainly in the early and middle stages of grain filling whilenight temperature increases during the whole grain filling period. The analysis of high temperature occurrence during grain filling can be used as a reference when we simulate high temperature events.

Keywords
Winter wheat; grain filling stage; high temperature characteristics; China

Introduction
Huaibei plain is an important grain production region in China, playing an important role in ensuring food security. In recent years, the rising of global temperature has caused the frequency and intensity of heat stress episodes. Consequently, wheat may be subjected to more frequent and severe heat stress events. Reducing the impact of heat stress on wheat is essential for food security. Zhao et al. (2017) analysed extreme weather events in Anhui Province, and quantified temperature data with long-term weather records. However, this study did not combine temperature data with local crop phenology, which results were not able to quantify crop development and yield under heat stress. If current knowledge of crop phenology combined with long-term weather data, which will evaluate the likelihood of crop systems being subjected to heat-risk. Quantifying temperature data could help guide the variety selection decisions for wheat producers and reduce the effects of unfavorable weather on crop yield (Teixeira et al. 2013; Zheng et al. 2012). Our primary objective was to quantify temperature data, combining simple crop phenology estimates with long-term weather records to evaluate the likelihood of high temperature for Huaibei plain.

Methods
2.1 Data source
All temperature-related data was obtained from the '*China Meteorological Data Sharing Service System*' which included annual, monthly and daily temperature data. Six representative weather stations were selected in Huaibei plain from 1953 to 2017 which were Bengbu (East), Fuyang (West), Shouxian (South), Dangshan (North), Suzhou (East North), and Bozhou (West North).

2.2 Division of anthesis to maturity period in wheat
In generally, wheat anthesis time from April 20th to April 26th, maturity time from May 25th to May 30th in Huaibei plain. The period of wheat from anthesis to maturity (April 20th to May 30th) was average divided six stages, and the temperature was divided into three sections. First stage was April 20th to April 26th (1-7 days after flowering); Second stage was April 20th to April 26th (8-14 days after flowering); Third stage was May 4th to May 10th (15-21 days after flowering); Fourth stage was May 11th to May 17th (22-28 days after flowering); Fifth stage was May 18th to May 24th (29-35 days after flowering); Sixth stage was May 25th to May 30th (36-42 days after flowering). First section ≥ average temperature value percentage from first stage, second stage, third stage, fourth stage, fifth stage or sixth stage; second section ≥ average temperature value 3°C percentage from first stage, second stage, third stage, fourth stage, fifth stage or sixth stage; third section ≥ average temperature value 5°C percentage from first stage, second stage, third stage, fourth stage, fifth stage or sixth stage.

2.3 Data analysis
In this study, we mainly analysed the temperature characteristics, change in trends in highest and lowest temperature from 63 years in Huaibei plain.

Results

3.1 Analysis of temperature change from anthesis to maturation for the past 63 years

Figure 1 and Figure 2 presents the change from anthesis to maturity of average highest temperature (Tmax) and average lowest temperature (Tmin) in Huaibei Plain from 63 years. The average highest temperature showed a trend of fluctuating increase in the second stage (B1) and the third stage (C1), while, it was not obvious in the other stages. The average lowest temperature showed fluctuating increase trend, the fluctuation trend of temperature showed an obvious increase. By adding the average highest temperature and the average lowest temperature, it can be concluded that the temperature fluctuation presents an obvious increasing trend in the second and third stage. However, the temperature here varies greatly between year and other year, for example, six stage (F1), the average maximum temperature was 35.3°C in 1958, the average maximum temperature was 21.3°C in 1991.

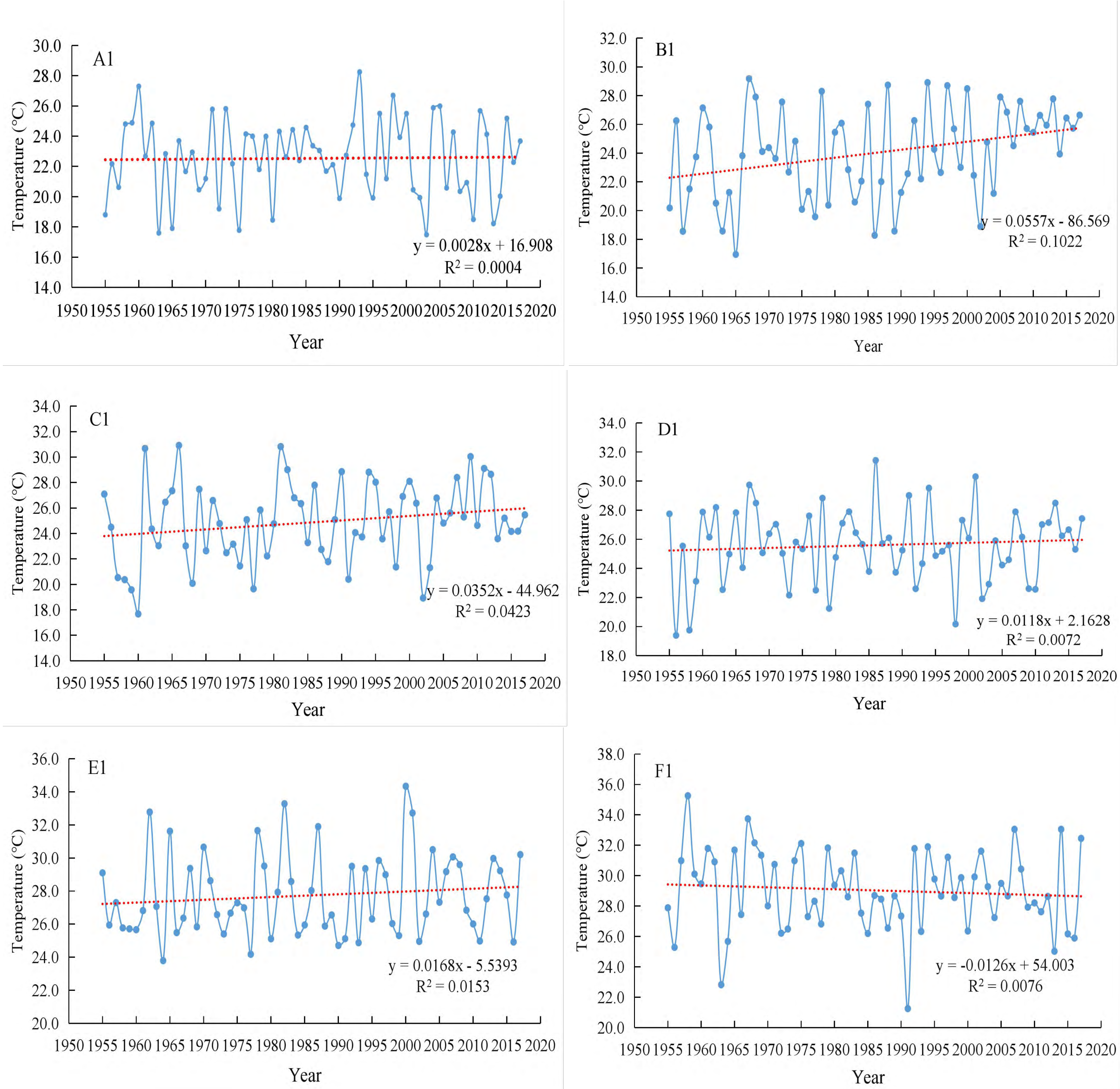

Figure 1. The changes of average highest temperature from anthesis to maturity for 63 years in Huaibei plain
A1 denotes average highest temperature change in first stage; B1 denotes average highest temperature change in second stage; C1 denotes average highest temperature change in third stage; D1 denotes average highest temperature change in fourth stage; E1 denotes average highest temperature change in fifth stage; F1 denotes average highest temperature change in sixth stage.

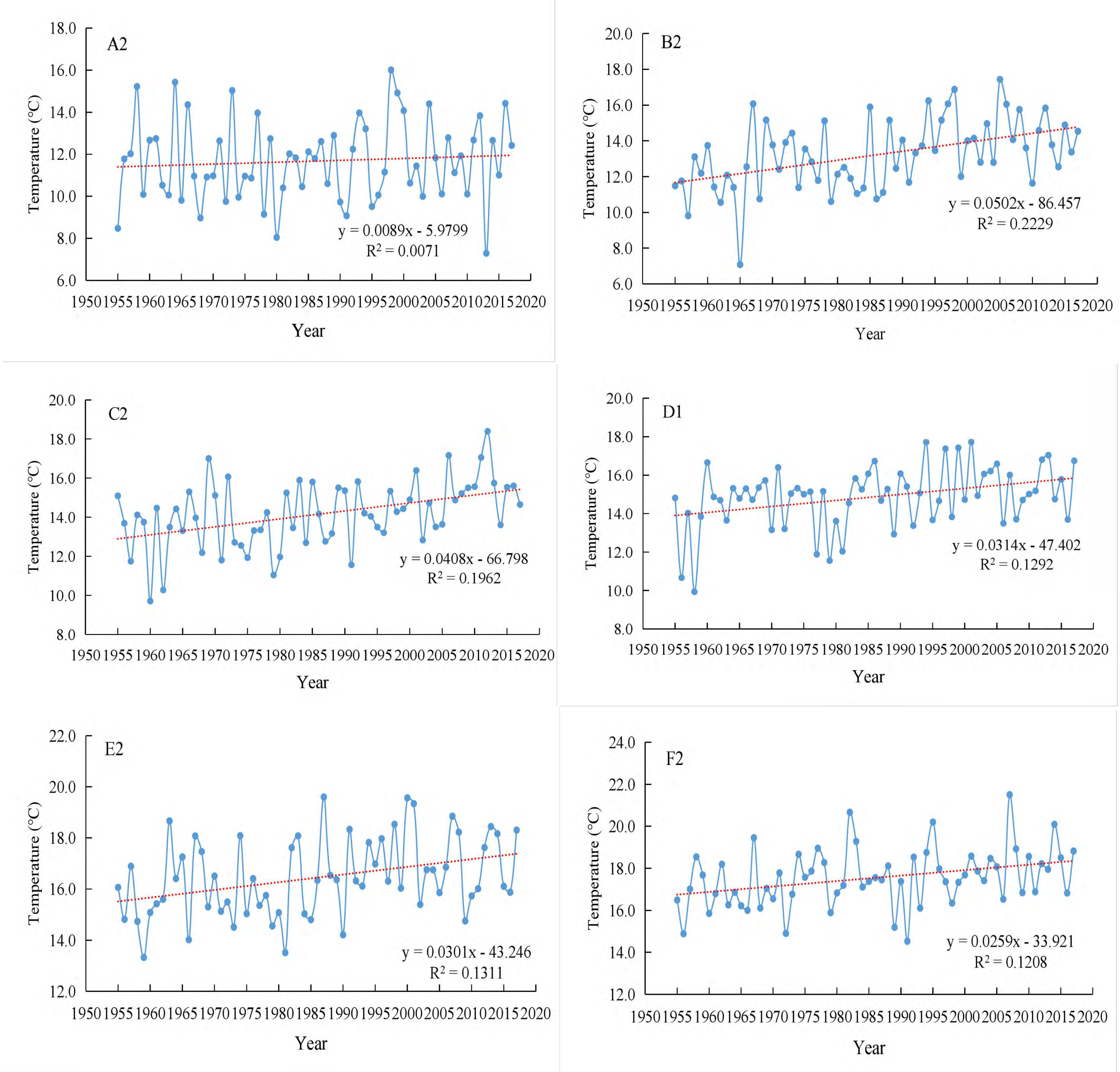

Figure 2. The changes of average lowest temperature from anthesis to maturity for 63 years in Huaibei plain
A2 denotes average lowest temperature change in first stage; B2 denotes average lowest temperature change in second stage stage; C2 denotes average lowest temperature change in third stage; D2 denotes average lowest temperature change in fourth stage; E2 denotes average lowest temperature change in fifth stage; F2 denotes average lowest temperature change in sixth stage.

3.2 Analysis of the probability of high temperature occurrence from anthesis to maturity

We have quantified temperature data from anthesis to maturity (April 20th to May 30th), analysed the possibility of average value from daily highest temperature (Tmax), average value from daily lowest temperature for this period daily highest (Tmin), ≥ average temperature value percentage, ≥ average temperature value 3°C percentage, ≥ average temperature value 5°C percentage were calculated. Average highest temperature values were 22.5°C (First stage), 24.0°C (Second stage), 24.9°C (Third stage), 25.6°C (Fourth stage), 27.8°C (Fifth stage), 29.1°C (Sixth stage), average lowest temperature values were 11.7 °C (First stage)，13.2 (Second stage), 14.2 (Third stage), 14.9 (Fourth stage), 16.5 (Fifth stage), 17.6 (Sixth stage). Tmax and Tmin raised from first stage to six stage; The maximum probability of the average highest temperature ≥ 3°C in the second stage; The maximum probability of the average highest temperature ≥ 5°C in the third stage; The maximum probability of the average lowest temperature ≥ 3°C and 5°C in the second stage (Table 1).

Table 1. Analysis the probability of average highest temperature (Tmax) and average lowest temperature (Tmin) occurrence at different levels from anthesis to maturation in Huaibei plain

Stages	Tmax (°C)	≥ Tmax percentage (%)	≥ Tmax 3°C percentage (%)	≥ Tmax 5°C percentage (%)
First stage	22.5	49.5	26.2	14.2
Second stage	24.0	49.6	27.9	13.3
Third stage	24.9	50.3	26.7	14.2
Fourth stage	25.6	51.8	24.2	11.1
Fifth stage	27.8	52.1	23.6	9.5
Sixth stage	29.1	52.9	24.1	8.6

Stages	Tmin (°C)	≥ Tmin percentage (%)	≥ Tmin 3°C percentage (%)	≥ Tmin 5°C percentage (%)
First stage	11.7	49.9	17.8	6.2
Second stage	13.2	49.9	19.0	7.1
Third stage	14.2	50.5	18.0	5.9
Fourth stage	14.9	51.7	14.4	4.2
Fifth stage	16.5	51.0	13.8	3.3
Sixth stage	17.6	50.6	11.2	2.0

Tmax denotes average value from daily highest temperature for this period; Tmin denotes average value from daily lowest temperature for this period

Conclusion

This paper analysed temperature data from anthesis to maturity of wheat in Huaibei plain from 63 years. First stage and second stage temperature shown upward trend, both the average highest temperature and the average lowest temperature have similar results. When temperature ≥ average highest temperature value (Tmax) 5°C was frequent occurrence in early and middle stages of grain filling. In future warming scenarios, it's great significance to quantify high temperature occurrence characteristics and frequency to guide wheat management from grain filling stage in Huaibei plain.

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