Hindawi
Advances in Meteorology
Volume 2019, Article ID 1401402, 16 pages
https://doi.org/10.1155/2019/1401402

*Research Article*

# Impact of Climate Change on the Growth of Typical Crops in Karst Areas: A Case Study of Guizhou Province

**Jun Ma [1,2] Baisha Weng [1] Wuxia Bi [1,3] Dan Xu,[4] Ting Xu,[1] and Dengming Yan[1,5]**

[1]*State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research, Beijing 100038, China*
[2]*School of Water Conservancy and Hydroelectric Power, Hebei University of Engineering, Handan 056021, China*
[3]*College of Hydrology and Water Resources, Hohai University, Nanjing 210098, China*
[4]*Guizhou Climate Center, Guiyang 550002, China*
[5]*College of Environmental Science and Engineering, Donghua University, Shanghai 201620, China*

Correspondence should be addressed to Baisha Weng; baishaweng@163.com

Received 22 November 2018; Revised 10 May 2019; Accepted 20 August 2019; Published 3 November 2019

Guest Editor: Dev Niyogi



Climate change has emerged as a significant man-made global environmental challenge marked by rising temperature. The global rising temperature is supposed to alter climatic patterns like floods and droughts, thereby affecting human life supporting system and global food production. In order to clarify the impact of weather events on agricultural production in karst landforms, this study selected the indices of the growth period of crops (start time and duration), growing season precipitation, intense precipitation, number of consecutive rainless days, and number of drought-flood abrupt alternation events to evaluate the variation trend of future weather events and their impact on crop growth in Guizhou Province, China. The results show that (1) the climate is generally getting warmer. From 2019 to 2050, the sowing period of winter wheat and rice tends to be postponed. The duration of maize and rice's growth period will be shortened, and the life cycle of wheat also emerges as having a decreasing tendency except for those from the southern region. Comparing with the mean value during 1961 to 2018, the average crop cycle length of winter wheat, summer maize, and rice was shortened. The rate of shortening of crop cycle length is faster than the value during 1961 to 2018. (2) In the next 30 years, extreme precipitation concentrates in June and mainly falls in the central and southeast parts of Guizhou Province. In addition, summer is the outbreak period of drought events and drought-flood abrupt alternation events, which has a great impact on crop's growth. This study can provide references for the planting system, structure, layout, and management of crops in the karst region.

## 1. Introduction

Climate change has already affected global ecosystems, biodiversity, and social economy [1], and the impacts are likely to be more pronounced in the future [2]. IPCC Fifth Assessment Report has pointed out that global climate change is undoubtable [3]. Climate change has emerged as a significant man-made global environmental challenge marked by rising temperature. Global mean temperature has increased by 0.8°C over the past century and is anticipated to rise from 1.5°C to 4.8°C over the next hundred years [4]. Global warming trends may benefit crop production in cooler regions. Some areas such as northern Europe might benefit from climate change to some extent, in the short and medium terms, e.g., by increasing crop yield, better forest growth, and augmented tourism demand [5]. However, the negative impacts of climate change will be so severe in arid or semiarid areas such as Iran [6]. The agricultural water has been reducing with a steep downward trend in south of the Iran as a result of climate change [7]. Increased temperatures are likely to shorten the crop cycle, thus reducing crop production [8]. Recent increases in climate variability may have affected crop yields in countries across Europe since around the mid-1980s [9]. Global rising temperature is supposed to alter climatic patterns like floods, droughts, and incidents of the El Nino and La Nina, which could also reduce the yield in other regions where optimal temperatures have already existed, thereby affecting human life supporting system and global food production, further leading to food insecurity in terms of food availability, accessibility, utilization, and food system stability [4, 10–13].

The existence of climate change in China is unequivocal. From 1961 to 2017, the average annual surface temperature in China increased by 0.24°C every 10 years, and the heating rate was higher than the global average. From 1961 to 2017, there was no significant increase or decrease in the average annual precipitation in China, but the extreme precipitation events showed an increasing trend [14]. The impact of climate change on Chinese agriculture is evident [15]. Statistics reveal that during a 28-year period from 1980 to 2008 in China, climatic changes led to a crop yield reduction of 1.27%, 1.73%, and 0.41% for wheat, corn, and soybean, respectively, while there was an increment of 0.56% in rice yield [16]. Lv et al. [17] reported a decrease in wheat yield in northern China and an increase in southern China in the future due to the presence of the rain-fed conditions.

Therefore, the study on the climate change impacts on crop growth was mainly in two aspects: one is the impact of normal climatic factors on agriculture, such as, temperature change, precipitation change, and others; the other is the impact of extreme climate events on the agriculture, such as rainstorm and drought. Southwest China is one of the main food producing areas. Guizhou Province has poor surface water storage capacity with karst topography. It has been found that a suitable climate plays a significant role in promoting food production [18]. Therefore, the growth period of crops (start time and duration), growing season precipitation, intense precipitation, number of consecutive rainless days, and number of drought-flood abrupt alternation events were selected as indices. Based on the observation data of 84 meteorological stations and climate model prediction simulation results, the evolution characteristics of extreme weather events and their effects on crop growth were evaluated. It is of great significance to the future agriculture development in Guizhou Province.

## 2. Study Site

Guizhou Province is located in the subtropical monsoon climate zone. The landform type is karst topography, with poor surface water storage capacity. Guizhou is the only province in China without plains. Thus, terrace fields are the main type of farmland. In 2017, the cultivated land area of Guizhou Province accounted for 2.72% of China's total cultivated land area, while the corn production and rice yield accounted for 2.03% and 1.45% of the national total output, respectively [19]. Guizhou has abundant agricultural biological resources, of 207 kinds [20], such as rice, corn, soybean, potato, sorghum, wheat, and so on. However, rice and corn account for about 70% of the total grain output, and winter wheat is responsible for about 50% of the summer harvest [21, 22]. Therefore, rice, corn, winter wheat, and other typical crops were selected to analyze the impact of climate change on crop growth and yield. Figure 1 shows the location of Guizhou Province.

## 3. Data and Methods

*3.1. Research Idea.* This paper conducts research according to the idea of "data sorting-model screening-extreme indices selection-future trend analysis-impact analysis" (details are shown in Figure 2).

*3.2. Climatic Data*

*3.2.1. Measured Meteorological Data.* Daily temperature and precipitation of 84 meteorological stations used in this study (from January 1961 to December 2016) were provided by the Meteorological Bureau of Guizhou Province. And daily temperature and precipitation of meteorological data (from January 2017 to December 2018) were obtained from http://data.cma.cn/site/index.html and https://www.wcrp-climate.org/data-etccdi, respectively. In this paper, the data in the province level were calculated through the Thiessen polygon based on the data of weather stations. The annual average temperature of 58 years in Guizhou was 15.6°C. The annual precipitation was 1183 mm.

*3.2.2. Data Simulated by Model.* The Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) brought together 28 global impact models from five different sectors (water, agriculture, biomes, coastal infrastructure, and malaria). However, models involved in the agricultural component of ISIMIP were GFDL-ESM2M, IPSL-CM5A-LR, HadGEM2-ES, NorESM1-M, and MIROC-ESM-CHEM, with resolution of $0.5^{\circ} \times 0.5^{\circ}$, and were bias-corrected towards an observation-based dataset by using a trend-preserving method which is a common method in climate change studies [23–25]. Therefore, this study predicts the impact of climate change on agriculture based on these five models. Table 1 shows the details of five global climate models [26, 27].

*3.3. Indicators for Evaluating Climate Events.* In order to analyze the impact of climate change on crop growth, five indicators of growth period were selected based on accumulated temperature, growing season precipitation, intense precipitation, number of consecutive rainless days, and number of drought-flood abrupt alternation events.

*3.3.1. Growth Period of Crops (Start Time and Duration).* In order to analyze the impact of climate change on crops, the growth period is calculated based on the accumulated temperature threshold. The average daily temperature between 15°C and 18°C is most suitable for winter wheat sowing. When the daily average temperature is within the abovementioned temperature range (15°C to 18°C) during five consecutive days since late September, the first day of the period is defined as the sowing day of winter wheat [28]. Based on the research performed by Lu and Wang [29], the accumulated temperature ≥10°C (AT10) was chosen as an indicator to identify the stage of winter wheat growth. The AT10 threshold of each stage is given in Table 2 [30]. For

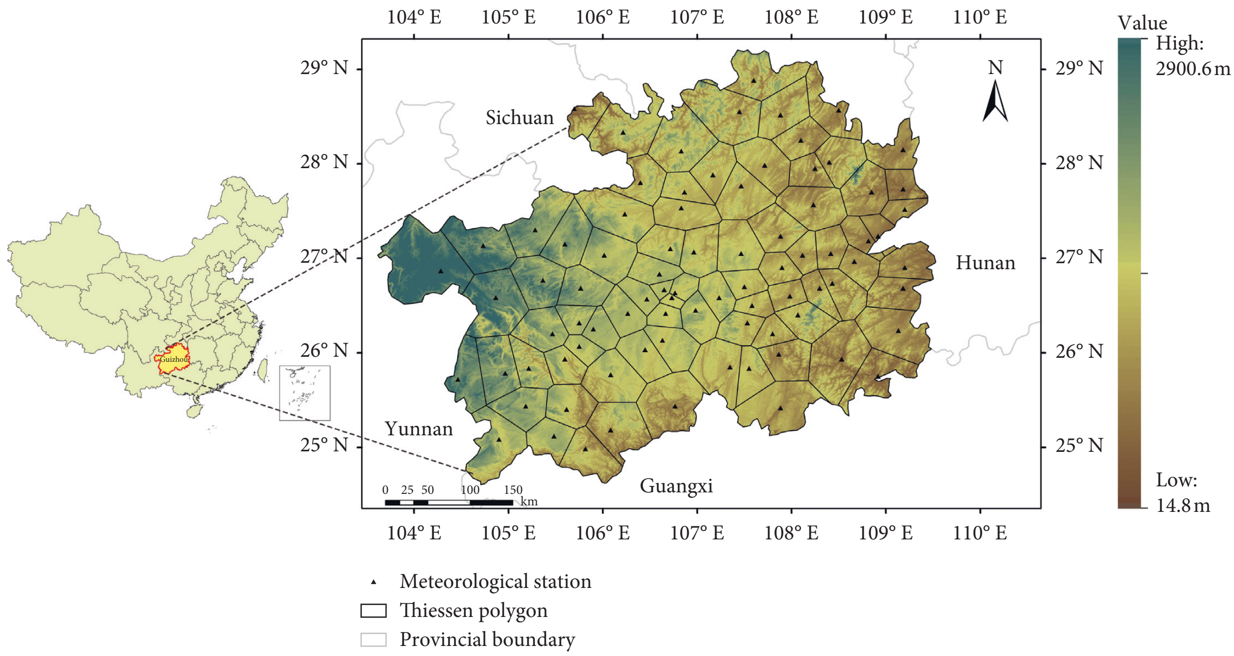


Figure 1: Location and meteorological monitoring points in Guizhou Province. Note: the figure includes the digital elevation model (DEM) data and the Thiessen polygons based on the location of the 84 weather stations.

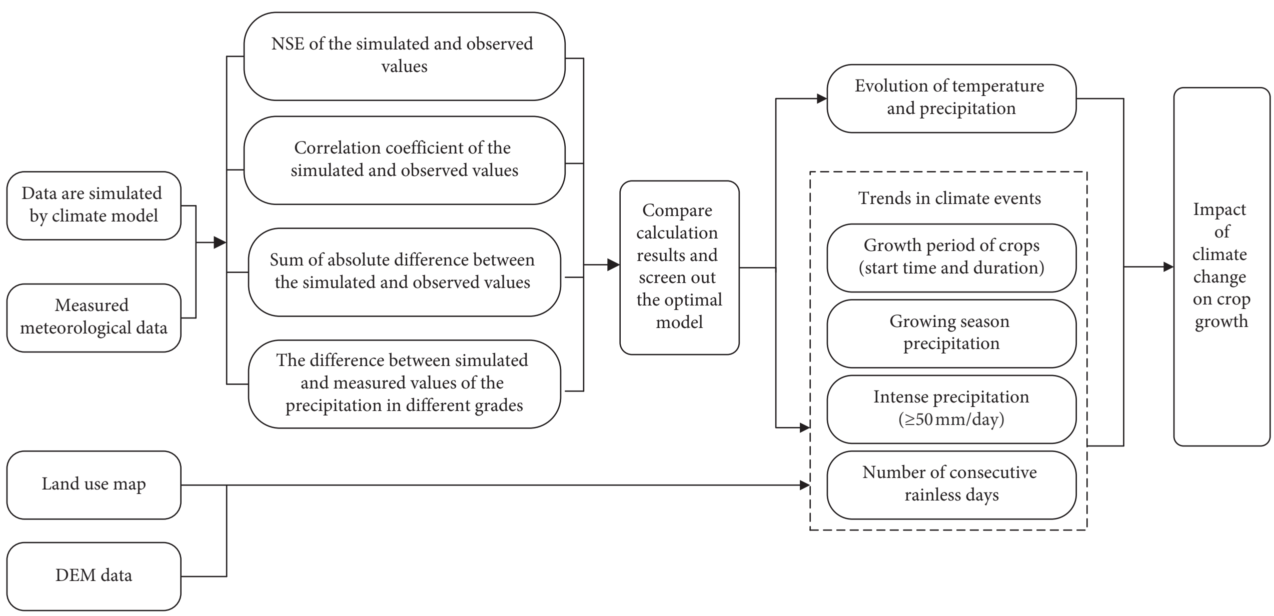


Figure 2: Technical steps for the study. Note: NSE represents the Nash–Sutcliffe efficiency coefficient.

summer maize, suitable sowing temperature ranges from 20°C to 25°C [31, 32]. When the average temperature for 5 consecutive days is within the abovementioned temperature range (20°C to 25°C) for the first time after 5 days before the ripening of winter wheat, the first day of the period is defined as the sowing day of summer maize. Table 3 shows the AT10 threshold of each stage [33]. The minimum temperature for safe seeding of japonica rice is 10°C and that of indica rice is 12°C [34, 35]. In this study, the next day when the average temperature for 5 consecutive days is finally lower than 12°C is selected as the date of rice planting [36]. AT10 thresholds of rice in different growth stages are given in Table 4 [29, 37].

*3.3.2. Growing Season Precipitation.* To study the effects of climate change on agriculture development in Guizhou, the precipitation changes during the crop growing season need to be clarified.

*3.3.3. Intense Precipitation.* Based on the daily precipitation, this study used the criteria in Table 5 to calculate the

Table 1: Details of five global climate models provided by ISIMIP.

| R&D unit (country) | Name | Biogeochemical characteristics of the Earth system | External forcing factors considered in the simulation |
|---|---|---|---|
| Geophysical Fluid Dynamics Laboratory (GFDL) (USA) | GFDL-ESM2M | A (simple), LC, OBGC | GHG, SD, Oz, LU, SI, VI, SS, BC, MD, OC |
| Hadley Centre for Climate Prediction and Research, Met Office (UK) | HADGEM2-ES | A (complex), AC, LC, OBGC | GHG, SA, Oz, LU, SI, VI, BC, OC |
| L'Institut Pierre-Simon Laplace (IPSL) (France) | IPSL-CM5A-LR | A (simple), LC, OBGC | Nat, Ant, GHG, SA, Oz, LU, SS, Ds, BC, MD, OC, AA |
| Technology, Atmosphere and Ocean Research Institute, and National Institute for Environmental Studies (Japan) | MIROC-ESM-CHEM | A (complex), LC, OBGC | GHG, SA, Oz, LU, Sl, Vl, MD, BC, OC |
| Norwegian Climate Centre (Norway) | NORESM1-M | A (complex), AC | GHG, SA, Oz, S1, V1, BC, OC |

*Note*. A: aerosol; AC: atmospheric chemistry; LC: terrestrial carbon cycle; OBGC: marine biogeochemistry; Nat: natural forcing; Ant: artificial forcing; GHG: completely mixed with greenhouse gases; SD: artificial sulphide aerosol (only direct effect); SI: a sulphide aerosol (only indirect effect); SA: a direct and indirect effect of sulphide aerosol; Oz: tropospheric and stratospheric ozone; LU: land use change; Sl: solar radiation; Vl: volcanic aerosol; SS: sea salt; Ds: dust; BC: black carbon; MD: mineral dust; OC: organic carbon; AA: artificial aerosol.

Table 2: AT10 thresholds of winter wheat at different growth stages.

| Growth stage | Sowing-emergence | Emergence-tillering | Tillering-jointing | Jointing-heading | Heading-dough |
|---|---|---|---|---|---|
| AT10 (°C) | 134 | 148 | 179 | 311 | 686 |

Table 3: AT10 thresholds of summer maize at different growth stages.

| Growth stage | Sowing-emergence | Emergence-silking | Silking-dough |
|---|---|---|---|
| AT10 (°C) | 158 | 1086 | 906 |

Table 4: AT10 thresholds of rice at different growth stages.

| Growth stage | Sowing-transplanting | Transplanting-tillering | Tillering-jointing | Jointing-heading | Heading-dough |
|---|---|---|---|---|---|
| Medium japonica rice AT10 (°C) | 800 | 384 | 588 | 557 | 636 |
| Medium indica rice AT10 (°C) | 810 | 584 | 494 | 484 | 590 |

Table 5: Precipitation grade standards.

| Climatic factors | Light rain | Moderate rain | Heavy rain | Rainstorm | Heavy rainstorm | Extraordinary rainstorm |
|---|---|---|---|---|---|---|
| 24 h precipitation (mm/day) | $S < 10$ | $10 \leq S < 25$ | $25 \leq S < 50$ | $50 \leq S < 100$ | $100 \leq S < 200$ | $200 \leq S$ |

*Note*. $S$ represents 24 h precipitation.

precipitation times in different grades and their change rate [38].

*3.3.4. Number of Consecutive Rainless Days.* In order to evaluate the degree of drought, this paper utilized the indicators of consecutive rainless days for analysis and calculation. The number of consecutive rainless days refers to the number of consecutive days without effective precipitation during the crop growth period. According to the Standard of Classification for Drought Severity (SL424-2008) [39], it is considered to be a rainless day when the daily precipitation is less than 3 mm in spring (from March to May), autumn (from September to November), and winter (from December to February) and when the daily precipitation is less than 5 mm in summer (from June to August) (Table 6).

*3.3.5. Number of Drought-Flood Abrupt Alternation Events.* According the analysis of drought-flood abrupt alternation, a drought-flood abrupt alternation event concludes longest consecutive rainless days and following intense precipitaion. The longest consecutive rainless days reach the level of moderate drought. That is, the longest consecutive rainless days are no less than 31 days in spring and autumn and no less than 21 days in summer. The first precipitation after the drought is intense precipitation (with 24 h accumulated precipitation of more than 25 mm). Figure 3 presents an intense precipitation after the summer drought [33].

*3.4. Adaptive Analysis of Climate Models to Simulate Extreme Events.* In order to reduce the impact of model uncertainty on the simulation of Guizhou, four indices were chosen to select the optimal plan: first is the Nash–Sutcliffe efficiency

Table 6: Consecutive rainless days: drought grade standards.

| Season | Region | Number of consecutive rainless days in different drought grades (days) | | | |
|---|---|---|---|---|---|
| | | Light drought | Moderate drought | Severe drought | Extraordinary drought |
| Spring (Mar–May) | North China | 15~30 | 31~50 | 51~75 | >75 |
| | South China | 10~20 | 21~45 | 46~60 | >60 |
| Summer (Jun–Aug) | North China | 15~30 | 31~50 | 51~75 | >75 |
| | South China | 10~20 | 21~45 | 46~60 | >60 |
| Autumn (Sep–Nov) | North China | 10~20 | 21~30 | 31~50 | >50 |
| | South China | 5~10 | 11~15 | 16~30 | >30 |
| Winter (Dec–Feb) | North China | 20~30 | 31~60 | 61~80 | >80 |
| | South China | 15~25 | 26~45 | 46~70 | >70 |

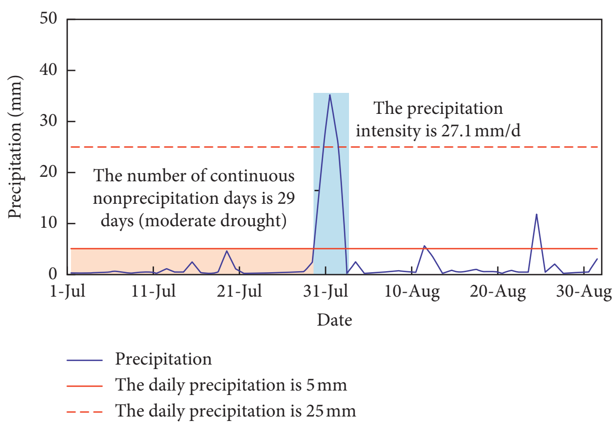


Figure 3: Drought-flood abrupt alternation event.

coefficient (NSE) of daily simulated value and measured value; second is the correlation coefficient of month simulated value and measured value; the third one is the sum of the absolute difference between the simulated value and the measured value of the annual average temperature or precipitation of each mode; and the fourth one is the proportion of precipitation amount of different grades in total precipitation amount.

$$E = 1 - \frac{\sum_{t=1}^{T} \left(Q_0^t - Q_m^t\right)^2}{\sum_{t=1}^{T} \left(Q_0^t - \bar{Q}_0\right)^2}, \quad (1)$$

where $E$ is the value of NSE, $Q_0$ is the measured value, and $Q_m$ is the value of simulation.

$$\rho_{xy} = \frac{\mathrm{Cov}(x, y)}{\sqrt{D(x)}\sqrt{D(y)}}, \quad (2)$$

where $\rho_{xy}$ is the value of correlation coefficient, $\mathrm{Cov}(x, y)$ is the covariance of $x$ and $y$, and $D(x)$ and $D(y)$ are the variances of $x$ and $y$, respectively.

## 4. Result

*4.1. Selection of Optimal Climate Model.* Calculation results of four indices are presented in Tables 7–9 and Figures 4 and 5. A comparison and analysis of the four indicators has revealed that the mean of five models is the most accurate in temperature and precipitation simulation. For extreme precipitation, the simulation effect of the HadGEM2-ES model is better. Therefore, we chose the mean value of the five models to predict the future temperature and precipitation data and used the HadGEM2-ES model to predict extreme precipitation events.

### *4.2. Evolution of Temperature and Precipitation*

*4.2.1. The Variation Trend from 1961 to 2018.* Figure 6 shows the evolution trend of the annual average temperature from 1961 to 2018. Figure 7 shows the evolution trend of annual precipitation from 1961 to 2018. Notably, we used linear trends and not some Mann-Kendall-like trend analysis because the linear trends could reflect the evolution trend and rate more directly. It can be seen that the temperature shows an increasing trend, with a rate of 0.14°C per 10 years. However, the precipitation shows a decreasing trend, with a rate of 15.02 mm per 10 years.

*4.2.2. The Variation Trend from 2019 to 2050.* Three RCPs (Representative Concentration Pathways) adopted in the IPCC's Fifth Assessment Report AR5 (RCPs 2.6, 4.5, and 8.5) were applied. For RCP4.5 scenario, the average temperature from 2019 to 2050 will go up, with a rate of 0.29°C per 10 years (Figure 8). The precipitation also shows an increasing tendency, with the rate being 27.9 mm/10 years (Figure 9). Compared with historical data, the increase rate of temperature is about 2 times that in history. The average annual precipitation in the next 30 years is lower than that in the past 60 years. The temperature increases the most in winter (Figure 10). The precipitation decreases in spring, autumn, and winter (Figure 11). In the next 30 years, annual average temperature increases from 1.36°C to 1.5°C compared with baseline period (from 1961 to 2018) (Figure 12).

*4.2.3. Growth Period of Crops (Start Time and Duration).* Climate change has changed the cycle length of crops [37, 40]. Studying the changes in crop growth period can provide a basis for adjusting crop types. A land use map, developed in 2014, was obtained from the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences. The spatial distribution of main crops in Guizhou was from the land use map in Geographic Information System (GIS) using the ArcMap platform (Figure 13(a)). This study chose the same precision as the climate model data and divided Guizhou Province into 65

Table 7: Comparison of simulated and measured values of temperature in Guizhou from 1961 to 2000.

| Indices | GFDL-ESM2M | HadGEM2-ES | IPSL-CM5A-LR | MIROC-ESM-CHEM | NorESM1-M | Mean of 5 models |
|---|---|---|---|---|---|---|
| NSE | 0.63 | 0.70 | 0.67 | 0.67 | 0.69 | 0.81 |
| Correlation coefficient | 0.82 | 0.85 | 0.84 | 0.84 | 0.84 | 0.90 |
| $T$ (°C) | 23.04 | 20.19 | 23.62 | 26.12 | 22.33 | 17.42 |

*Note.* $T$ represents the sum of the absolute difference between the measured value and the simulated value of the annual average temperature of each mode.

Table 8: Comparison of simulated and measured values of precipitation in Guizhou from 1961 to 2000.

| Indices | GFDL-ESM2M | HadGEM2-ES | IPSL-CM5A-LR | MIROC-ESM-CHEM | NorESM1-M | Mean of 5 models |
|---|---|---|---|---|---|---|
| NSE | −0.67 | −0.35 | −0.83 | −0.89 | −0.44 | −0.01 |
| correlation coefficient | 0.14 | 0.20 | 0.14 | 0.13 | 0.20 | 0.27 |
| $P$ (mm) | 6398.98 | 5858.67 | 6854.68 | 7082.90 | 6432.12 | 4768.24 |

*Note.* $P$ represents the sum of the absolute difference between the measured value and the simulated value of the annual average precipitation of each mode.

Table 9: The difference between simulated value of the precipitation of in different grades simulated by each mode and the measured precipitation from 1961 to 2000.

| Prediction schemes | Light rain | Moderate rain | Heavy rain | Rainstorm | Heavy rainstorm | Extraordinary rainstorm |
|---|---|---|---|---|---|---|
| GFDL-ESM2M | −3.86 | 10.03 | −0.54 | −5.90 | −0.20 | 0.30 |
| HadGEM2-ES | 3.86 | 2.91 | −1.93 | −4.71 | −0.11 | −0.18 |
| IPSL-CM5A-LR | −7.44 | 9.14 | 0.43 | −3.35 | 1.24 | −0.18 |
| MIROC-ESM-CHEM | −8.67 | 3.21 | 6.82 | −1.26 | −0.91 | 0.65 |
| NorESM1-M | 0.73 | 9.39 | 0.09 | −7.70 | −2.61 | −0.18 |
| Mean of 5 models | 13.6 | 21.58 | −17.60 | −14.24 | −3.32 | −0.18 |

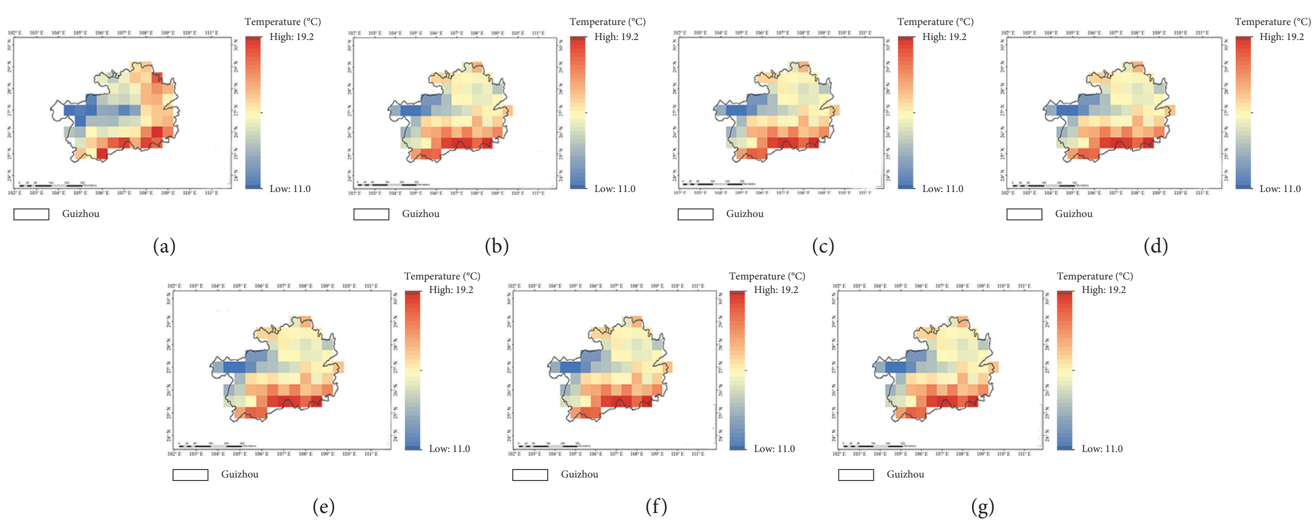


Figure 4: Spatial distribution of temperature. (a)–(g) represent measure, GFDL-ESM2M, IPSL-CM5A-LR, HadGEM2-ES, NorESM1-M, MIROC-ESM-CHEM, and the mean of the five models, respectively.

grid cells each with the size of $0.5^{\circ} \times 0.5^{\circ}$ (Figure 13(b)). The main crops in Guizhou are winter wheat, summer maize, and rice. The varieties of rice mainly include single-cropping medium japonica rice and single-cropping medium indica rice [41, 42]. The spatial distribution of rice species is shown in Figure 13(c). According to the accumulated temperature, the growth period of 1961 to 2018 and 2019 to 2050 crops was analyzed. In the study, there is only one cultivar for each crop, from the past to the future.

From 1961 to 2018, the average winter wheat cycle length was 200 days. The growth period of winter wheat showed a decreasing trend with a rate of −2 days/10 years. The average summer maize cycle length was 98 days. The growth period of summer maize showed a decreasing trend with a rate of −0.9 days/10 years. The average summer maize cycle length was 141 days. The growth period of summer maize showed a decreasing trend with a rate of −1 days/10 years.

From 2019 to 2050, taking the RCP4.5 scenario as an example, the wheat sowing period will be postponed. The average crop cycle length of winter wheat, summer maize, and rice is 177 days, 94 days, and 132 days, respectively. From the spatial analysis (Figure 14(a)), the crop cycle length

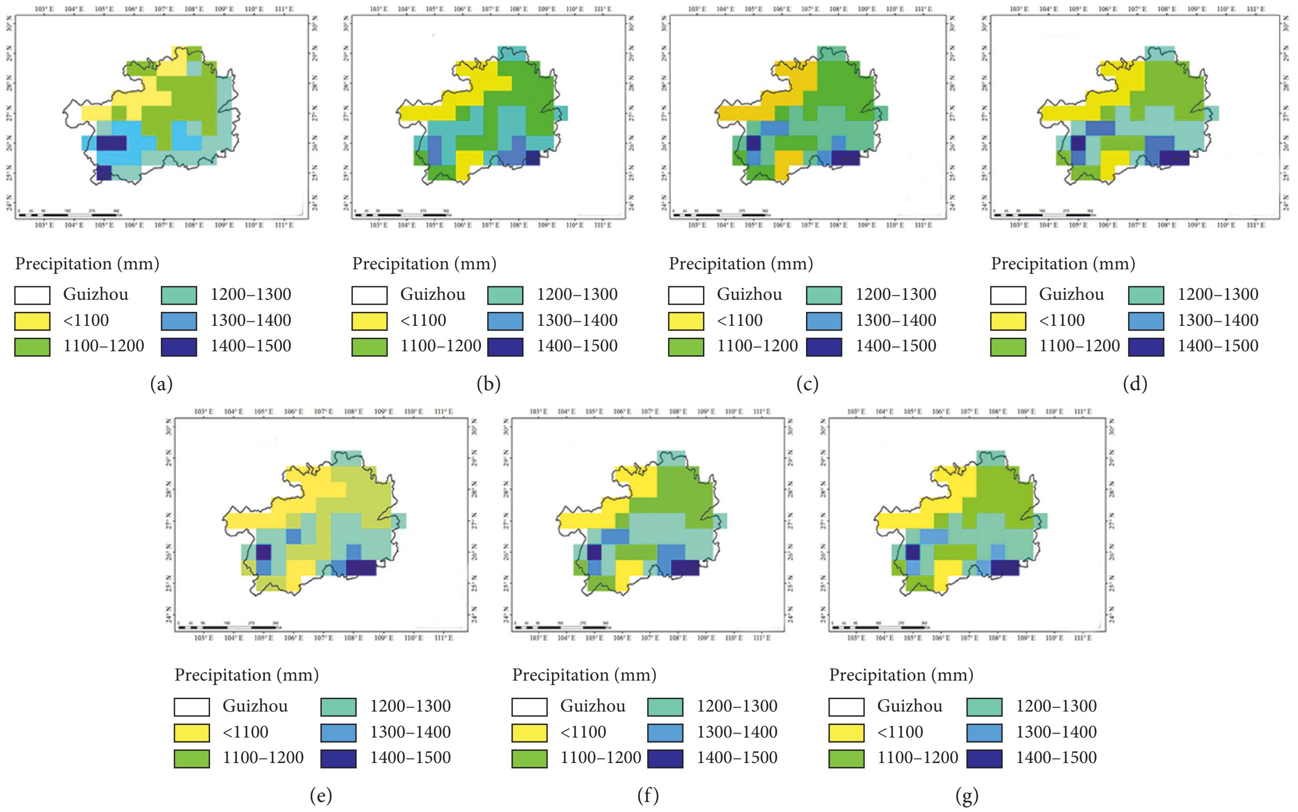


Figure 5: Spatial distribution of precipitation. (a)–(g) represent measure, GFDL-ESM2M, IPSL-CM5A-LR, HadGEM2-ES, NorESM1-M, MIROC-ESM-CHEM, and the mean of the five models, respectively.

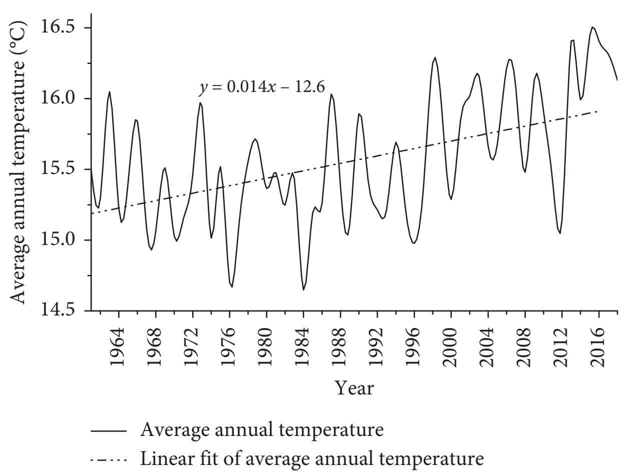


Figure 6: Evolution trends of the average annual temperature from 1961 to 2018.

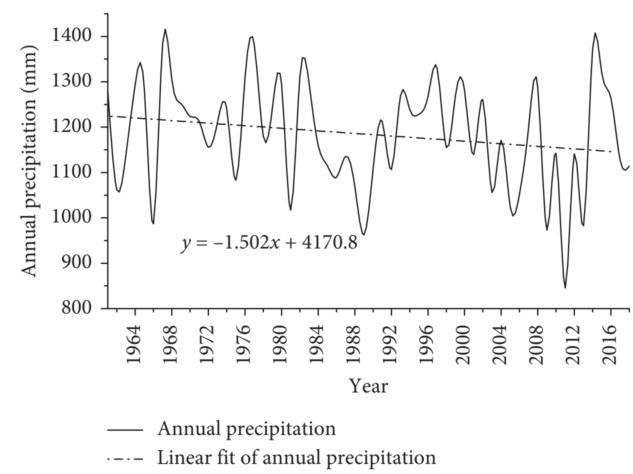


Figure 7: Evolution trends of annual precipitation from 1961 to 2018.

of winter wheat is shortened except for the southern region, with the rate of −2.1 days per 10 years. The linear tendency rate of corn planting date is small. From the spatial analysis (Figure 14(b)), the crop cycle length of summer maize is shortened in most areas of Guizhou, with the rate of −1.2 days per 10 years. The rice sowing period will be postponed in the next 30 years. From the spatial analysis (Figure 14(c)), the total number of days in rice growth period is shortened, with the rate of −1.6 days per 10 years.

*4.2.4. Growing Season Precipitation.* According to the calculation of the growth period of crops, the whole growth period of maize and rice is from April to September, and the growth period of wheat is from October to next April. The yield of wheat is positively correlated with the precipitation from December to March [43, 44].

For RCP4.5 scenario, the linear tendency rate of the precipitation tendency is small in the wheat growing season but large in the interannual variation (Figure 15). The

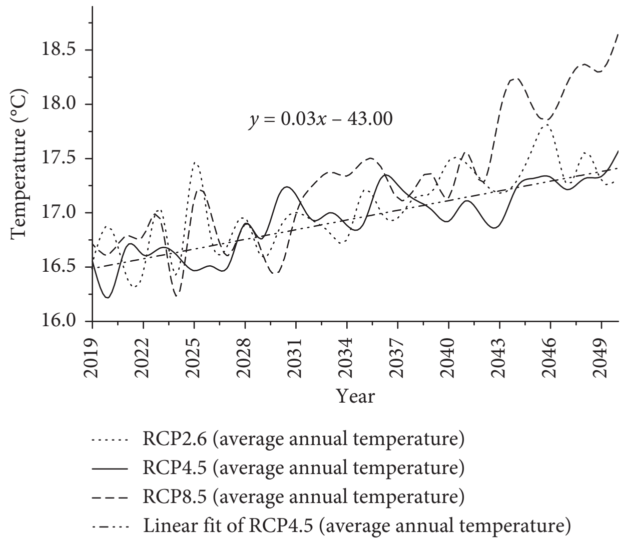


Figure 8: Evolution trends of the average annual temperature from 2019 to 2050.

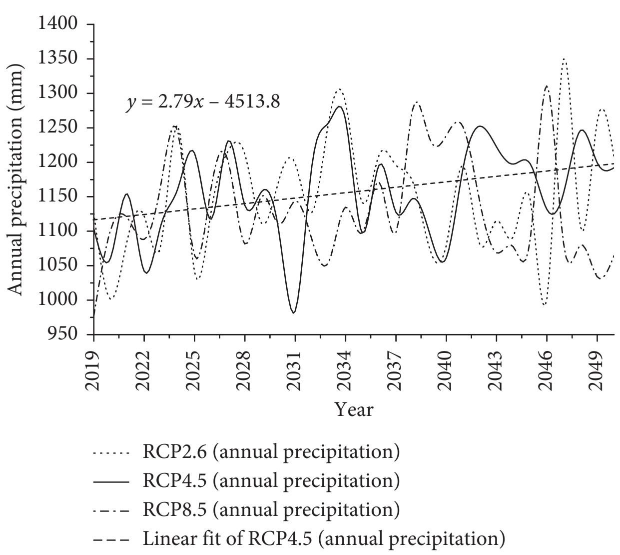


Figure 9: Evolution trends of annual precipitation from 2019 to 2050.

precipitation in the growing season of rice and corn showed an increasing trend, with a rate of 20.2 mm/10 years (Figure 16).

*4.3. Trends in Extreme Events from 2019 to 2050*

*4.3.1. Intense Precipitation.* In the next 30 years, intense precipitation (≥50 mm/day) events occur in April to October under three scenarios, with a difference in spatial distribution. For example, in the RCP4.5 scenario, extreme precipitation is mainly concentrated in the central and southeastern parts of Guizhou (Figure 17). And extreme precipitation accounts for 2.9% of total precipitation, with 1.1%, 0.56%, and 0.43% in June, July, and September, respectively.

*4.3.2. Consecutive Rainless Days.* Figure 18 plots the probabilities of different levels of drought in Guizhou from 2019 to 2050, and Figure 19 shows the probabilities of drought (except light drought) in different seasons from 2019 to 2050.

Drought is considered to be the most serious meteorological disaster affecting agriculture, and the drought in Guizhou Province has obvious seasonality and regionality [45]. Therefore, this paper analyzed the different levels of drought and seasonal drought in Guizhou in the next 30 years. Spring drought and summer drought are the main disaster-causing factors for rice and corn. Autumn and spring droughts are the main hazard factors for wheat and rapeseed [46]. This study mainly analyzed the probability of drought in spring, summer, and autumn.

Under the RCP4.5 scenario, in the next 30 years, the occurrence probability of drought in western Guizhou is higher than that in eastern Guizhou. In eastern Guizhou, drought is frequent in summer, while much less in spring and autumn. A number of droughts (except light drought) might occur most in the summer followed by spring. Therefore, the greatest impact on agriculture in the next 30 years is summer drought, followed by spring drought. Frequent drought events will increase the irrigation water demand and augment the pressure on freshwater resources.

*4.3.3. Drought-Flood Abrupt Alternation Events.* Soil fertility, rice growth period, physiological characteristics, and others will be affected by drought-flood abrupt alternation events, and the latter results in large reduction of production [47]. Figure 20 shows spatial distribution of drought-flood abrupt alternation events in Guizhou.

Low incidence of drought-flood abrupt alternation events is present in the RCP4.5 scenario, but each event has the longest drought duration with severe disasters. In the RCP4.5 scenario, drought-flood alternation change events might occur in spring, summer, and autumn.

## 5. Discussion

*5.1. Effect of Normal Climatic Factors on Crop Growth.* In Guizhou, the whole climate is getting warmer. Compared with historical data, the increase rate of temperature based on model projections is about 2 times that in history.

The temperature increase can lead to the northward shifting of suitable cropping areas of rice, maize, and wheat [48]. In the past 30 years, the north boundary of the double cropping rice growing area in southern China has been pushed northward for nearly 300 km [49]. Growth period is advanced and shortened [50]. The decomposition of soil organic matter is accelerated, and the soil fertility is reduced [51, 52]. It may also expand the activity scope of some pests subjected to temperature restrictions, further shorten the growth period of most pests, and increase the number of reproductive generations [53]. In the next 30 years, annual average temperature may increase from 1.36°C to 1.5°C compared with baseline period (from 1961 to 2018). It may change the suitable cropping areas in Guizhou and increase

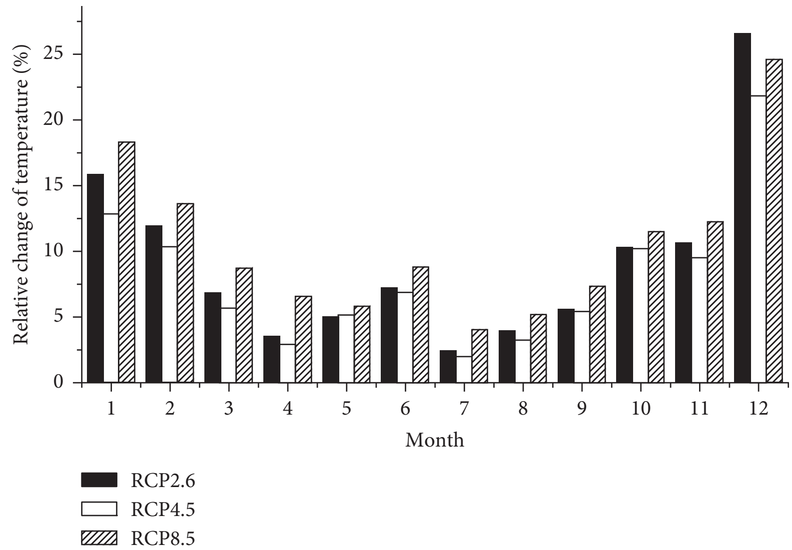


Figure 10: Relative changes of monthly average temperature between 2019–2050 and 1961–2018.

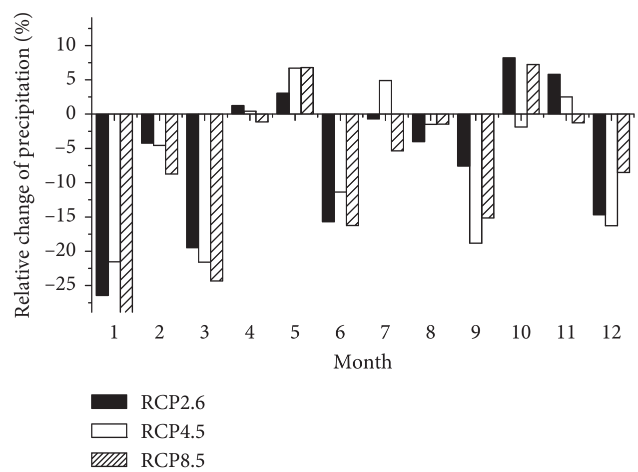


Figure 11: Relative change of monthly average precipitation between 2019–2050 and 1961–2018.

pests and diseases. Ao [54] also obtained this conclusion when she studied the Liupanshui area in Guizhou. It may also reduce crop yield while increasing utilization of fertilizers and pesticides, which will pollute the environment and water resources.

From 2019 to 2050, under RCP4.5 scenario, the sowing period of winter wheat and rice tends to be postponed. The duration of maize and rice's growth period will be shortened, and the life cycle of wheat also emerges as having a decreasing tendency except for those from the southern region. The average crop cycle length of winter wheat, summer maize, and rice was shortened by 23 days, 4 days, and 9 days, respectively, compared with the mean value of 1961 to 2018. Meanwhile, the rate of shortening of crop cycle length is faster than the value of 1961 to 2018. Changes in food quality are to be expected, e.g., decreased protein and mineral nutrient concentrations, as well as altered lipid composition [55]. The linear tendency rate of the precipitation tendency is small in the wheat growing season but large in the interannual variation, which increases the uncertainty of the irrigation amount of water resources. While most parts of Guizhou are rain-fed agricultural areas, the yield of wheat is positively correlated with the precipitation. Thus, the adverse effects will affect the wheat growth.

*5.2. Effect of Extreme Events on Crop Growth.* Extreme precipitation can affect soil fertility, and storm floods can cause sudden increase in diseases [56, 57]. The main stage of rice tillering in Guizhou is in June, which is the key period for rice growing [43]. Extreme precipitation in the next 30 years is mainly concentrated in June and July, which will increase the incidence of diseases. This phenomenon is more evident in central and southeastern Guizhou. In the future, the rice planting layout can be adjusted according to the distribution of extreme precipitation.

Rapeseed is also one of the crops in Guizhou. It blooms in March and matures in the end of April and early May. From the spatial distribution of extreme precipitation, it can

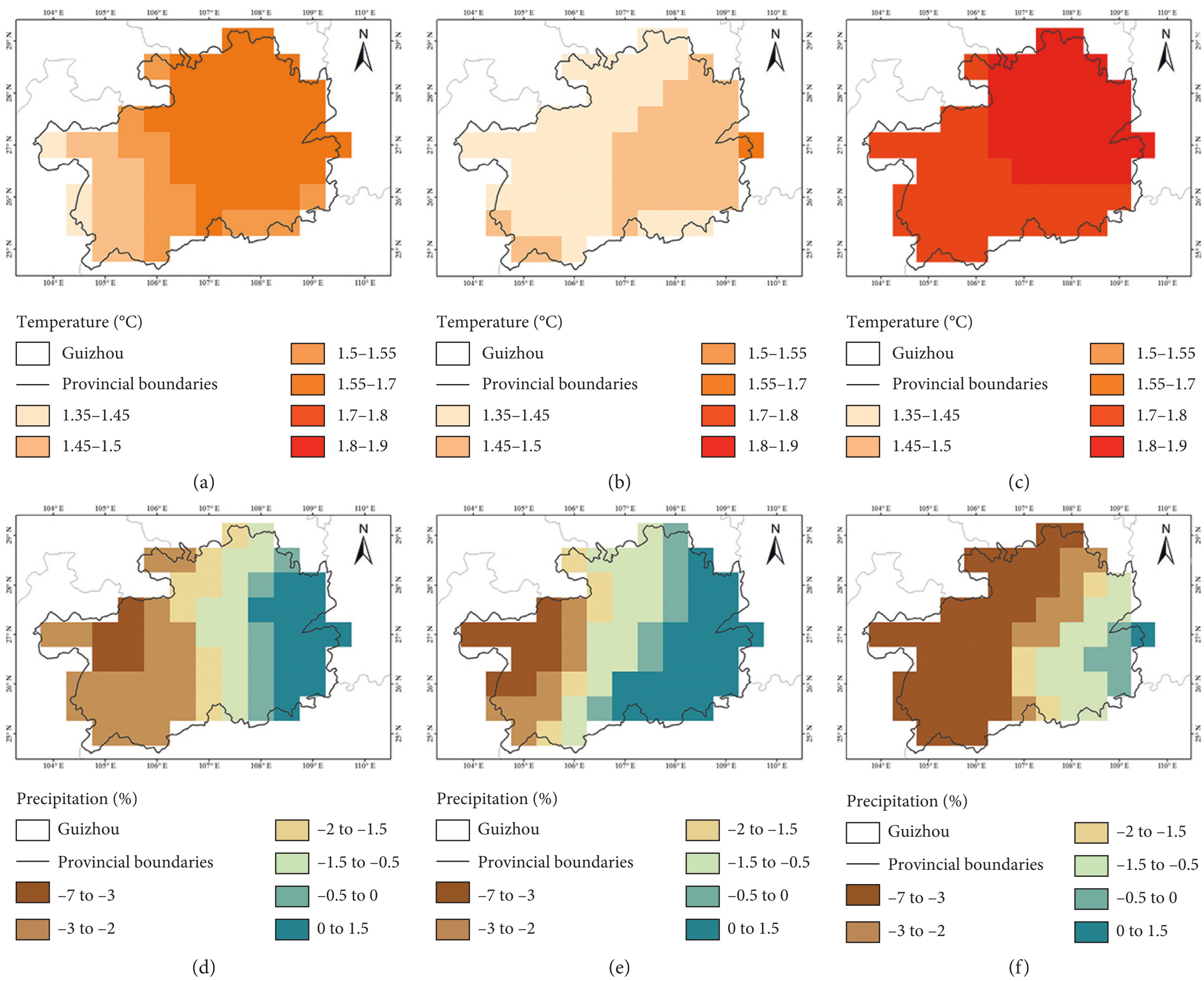


Figure 12: Change of annual average temperature and annual precipitation from 2019 to 2050 compared with the baseline period in Guizhou. (a) RCP2.6. (b) RCP4.5. (c) RCP8.5.

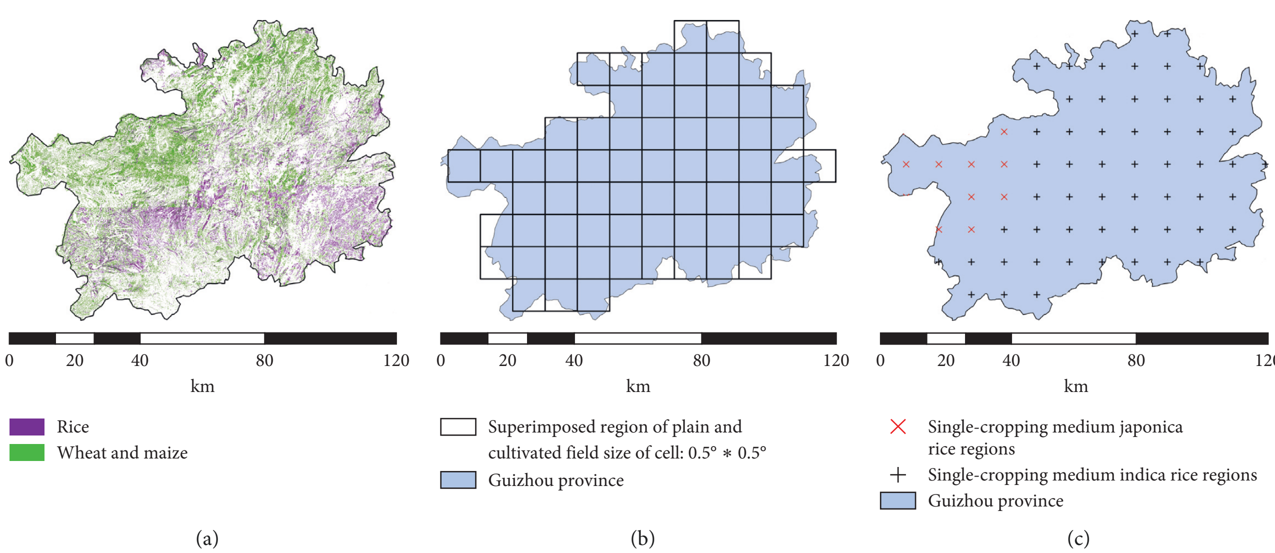


Figure 13: Cultivated field and grid map of superimposed area in Guizhou.

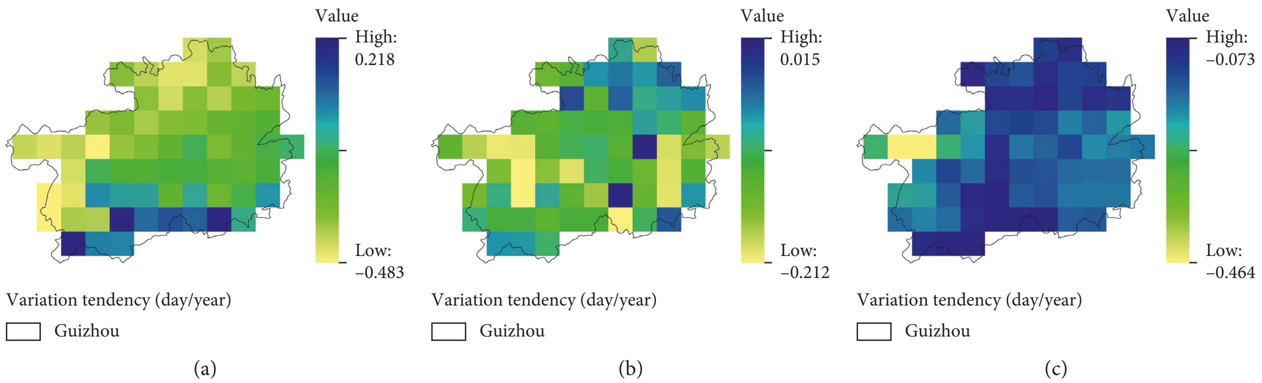


FIGURE 14: Distribution of the change rate of total days in crop growth period: (a) winter wheat, (b) summer maize, and (c) rice.

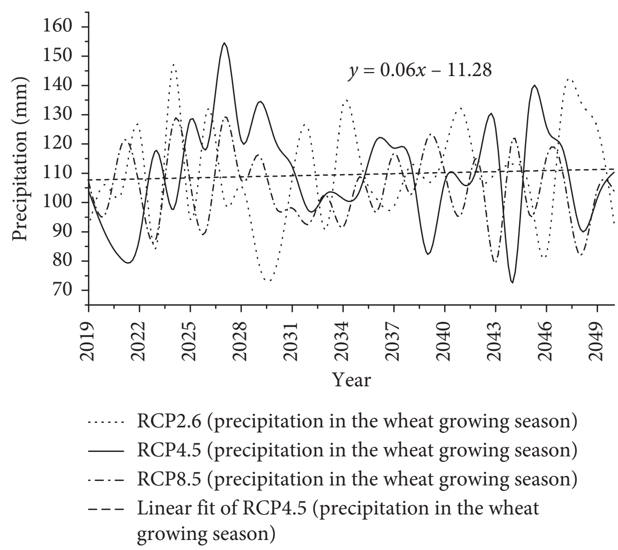


FIGURE 15: Precipitation trends during the wheat growing season (December to March) from 2019 to 2050.

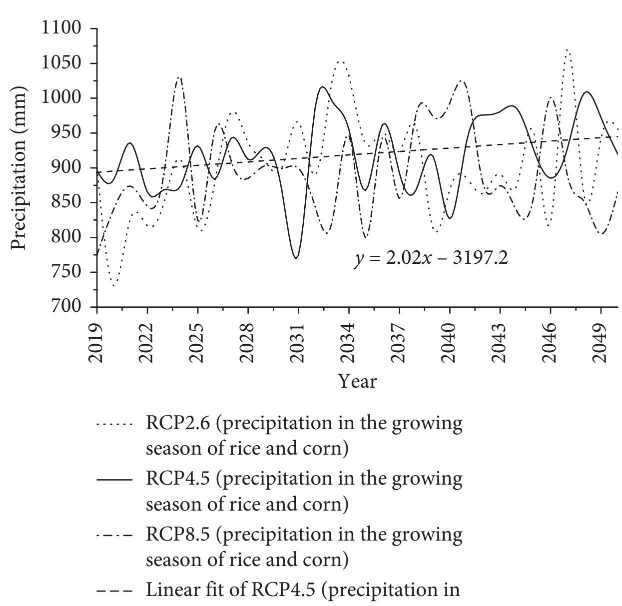


FIGURE 16: Precipitation trends during the growing season of rice and corn (April to September) from 2019 to 2050.

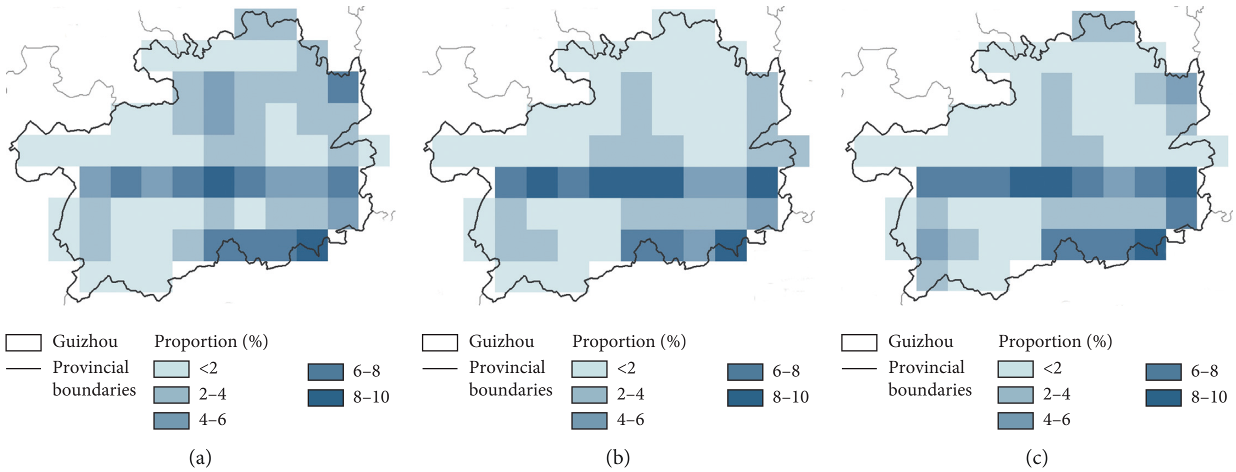


Figure 17: Spatial distribution of the proportion of extreme precipitation to total precipitation. (a) RCP2.6. (b) RCP4.5. (c) RCP8.5.

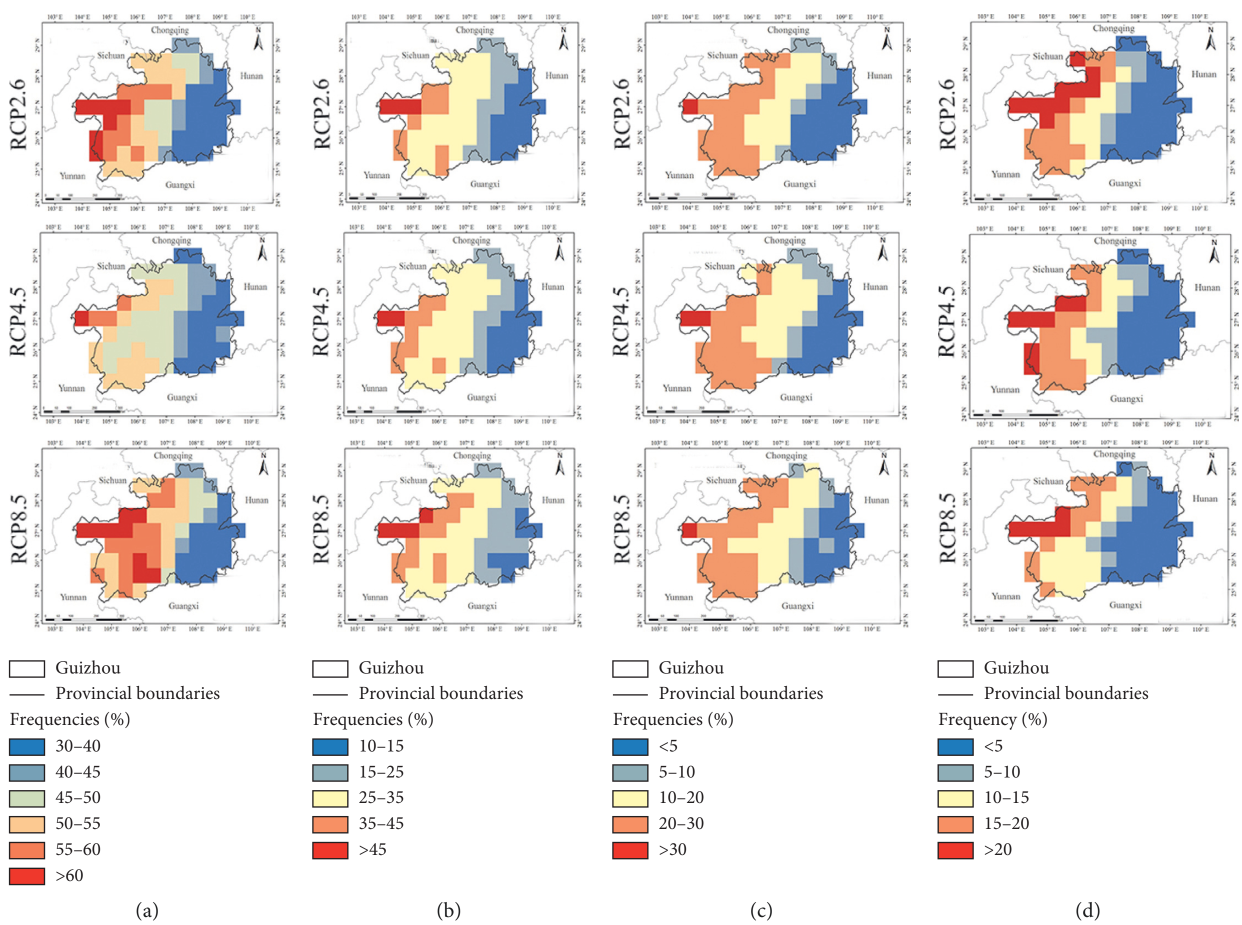


Figure 18: The probabilities of different levels of drought in Guizhou from 2019 to 2050. (a) Light drought. (b) Moderate drought. (c) Severe drought. (d) Extraordinary drought.

be explored that the occurrence probability of extreme precipitation is relatively high in the two major rapeseed producing areas, Buyei and Miao Autonomous Prefecture of QianNan and Guiyang. In April, extreme precipitation accounted for 0.16% of the annual precipitation.

Drought is considered to be the most serious meteorological disaster affecting agriculture. Under the RCP4.5 scenario, in the next 30 years, a number of droughts (except light drought) might occur most in the summer followed by spring. Therefore, the greatest impact on agriculture in the

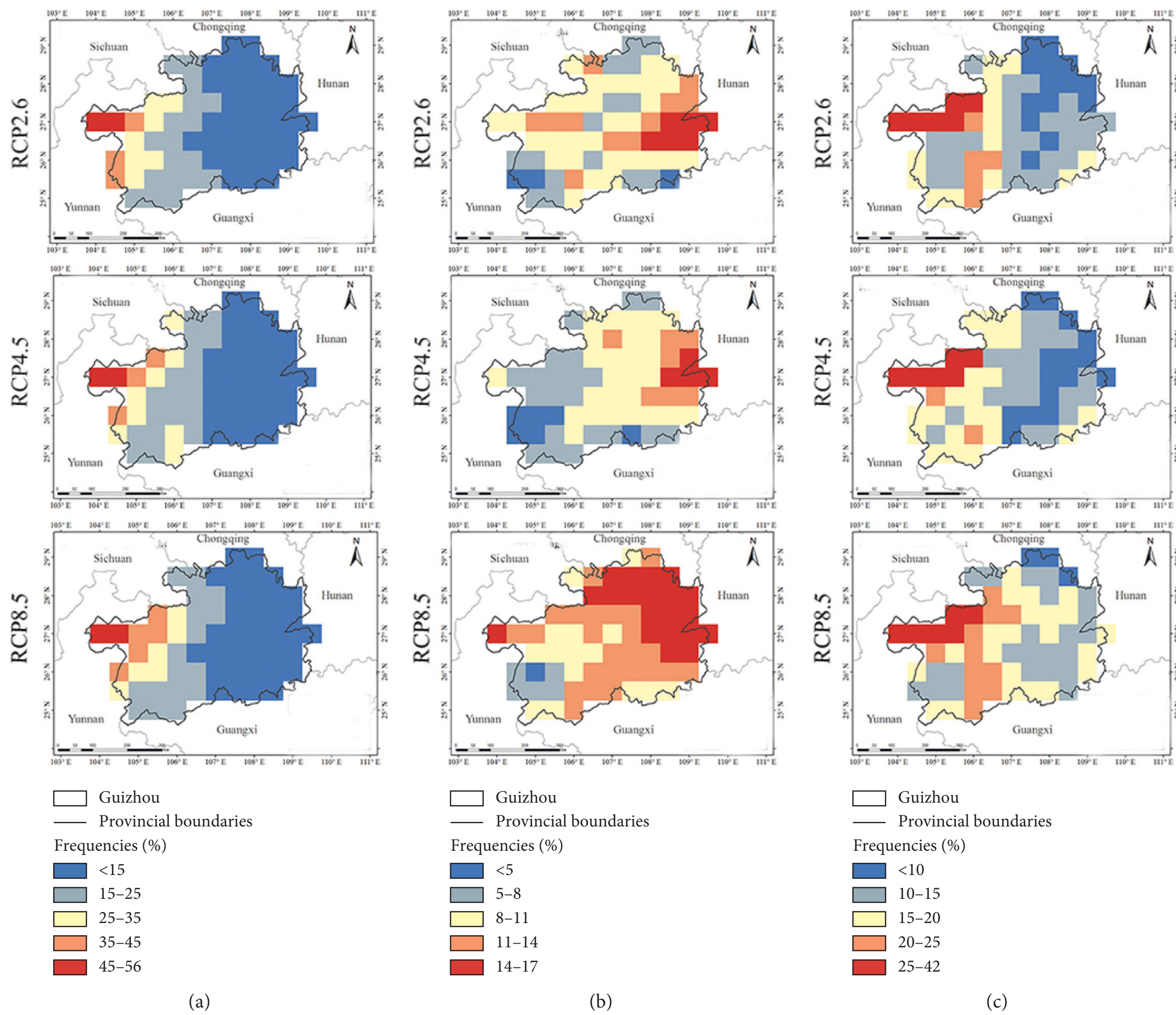


Figure 19: The probabilities of drought (except mild drought) in different seasons from 2019 to 2050. (a) Spring. (b) Summer. (c) Autumn.

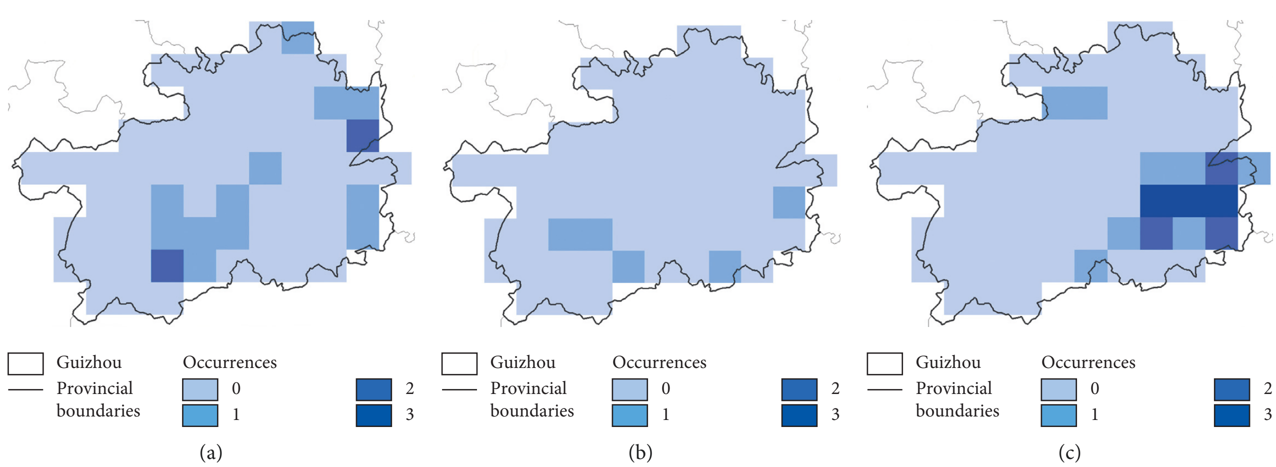


Figure 20: Spatial distribution of the frequency of drought-flood abrupt alternation events in Guizhou from 2019 to 2050. (a) RCP2.6. (b) RCP4.5. (c) RCP8.5.

next 30 years is summer drought, followed by spring drought. Frequent drought events will increase the irrigation water demand and augment the pressure on freshwater resources. In the RCP4.5 scenario, drought-flood abrupt alternation events might occur in spring, summer, and autumn, which will seriously affect soil quality and increase fertilizers.

## 6. Conclusions

(1) From 1961 to 2018, the temperature showed an increasing trend, with a rate of 0.14°C per 10 years. The precipitation showed a decreasing trend, with a rate of −15.02 mm per 10 years. Compared with historical data, under RCP4.5 scenario, the increase rate of temperature is about 2 times that in history.

(2) The growth period of crops has been influenced by climate change. The average crop cycle length of winter wheat, summer maize, and rice was shortened by 23 days, 4 days, and 9 days, respectively, compared with the mean value of 1961–2018. The sowing period of wheat and rice will be postponed in the next 30 years. The winter wheat cycle length is shortened except for the southern region, with the rate from −4.83 to 2.18 (days/10 years). The life cycle of corn also emerges as having a decreasing tendency in most areas of Guizhou, with the rate from −2.12 to 0.15 (days/10 years). The rice sowing period will be postponed in the next 30 years. The rice cycle length is shortened, with the rate from −4.65 to −0.07 (days/10 years). In the next 30 years. The precipitation tendency is low in the wheat growing season but large in the interannual variation, which increases the uncertainty of the irrigation amount of water resources. The precipitation in the growing season of rice and corn shows an increasing trend, with a rate of 16.6 mm/10 years.

(3) In the next 30 years, intense precipitation (≥50 mm/day) events might occur during April to October under three scenarios. Under the RCP4.5 scenario, extreme precipitation is mainly concentrated in the central and southeastern parts of Guizhou. And extreme precipitation accounts for 2.9% of total precipitation, 1.1% in June. The occurrence probability of extreme precipitation is relatively high in the two major rapeseed producing areas, Buyei and Miao Autonomous Prefecture of QianNan and Guiyang.

(4) Under the RCP4.5 scenario, in the next 30 years, the occurrence probability of drought in western Guizhou is higher than that in eastern Guizhou. In eastern Guizhou, drought is frequent in summer, while much less in spring and autumn. A number of droughts (except mild drought) might occur most in the summer followed by spring. Therefore, the greatest impact on agriculture in the next 30 years is summer drought, followed by spring drought. In the RCP4.5 scenario, drought-flood abrupt alternation events might occur in spring, summer, and autumn, which will seriously affect soil quality and increase fertilizers.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that there are no conflicts of interests regarding the publication of this article.

## Acknowledgments

This research was supported by the National Key Research and Development Project (no. 2016YFA0601503), the Chinese National Natural Science Foundation (no. 51725905), the Research Fund of the State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin (no. SKL2018TS02), and the Science and Technology Project in Guizhou Province (SY (2014) no. 3066). The authors would like to thank the Guizhou Climate Center for providing the basic data and full support during this study.

## References

[1] J. H. Kotir, "Climate change and variability in Sub-Saharan Africa: a review of current and future trends and impacts on agriculture and food security," *Environment, Development and Sustainability*, vol. 13, no. 3, pp. 587–605, 2011.

[2] J.-M. Montaud, N. Pecastaing, and M. Tankari, "Potential socio-economic implications of future climate change and variability for Nigerien agriculture: a countrywide dynamic CGE-Microsimulation analysis," *Economic Modelling*, vol. 63, pp. 128–142, 2017.

[3] IPCC, *Working Group I Contribution to the IPCC Fifth Assessment Report Climate Change 2013: The Physical Science Basis: Headline Statements from the Summary for Policymakers*, Cambridge University Press, Cambridge, UK, 2014.

[4] S. Shankar and Shikha, "Chapter 7—impacts of climate change on agriculture and food security," in *Biotechnology for Sustainable Agriculture: Emerging Approaches and Strategies*, R. L. Singh and S. Mondal, Eds., pp. 207–234, Woodhead Publishing, Sawston, UK, 2018.

[5] S. Isoard, *Perspectives on Adaptation to Climate Change in Europe*, Springer, Dordrecht, The Netherlands, 2011.

[6] V. Karimi, E. Karami, and M. Keshavarz, "Climate change and agriculture: impacts and adaptive responses in Iran," *Journal of Integrative Agriculture*, vol. 17, no. 1, pp. 1–15, 2018.

[7] S. Jamshidi, S. Zand-parsa1, M. Pakparvar, and D. Niyogi, "Evaluation of evapotranspiration over a semi-arid region using multi-resolution data sources," *Journal of Hydrometeorology*, vol. 20, no. 5, pp. 1–50, 2015.

[8] M. A. Martins, J. Tomasella, and C. G. Dias, "Maize yield under a changing climate in the Brazilian Northeast: impacts and adaptation," *Agricultural Water Management*, vol. 216, pp. 339–350, 2019.

[9] J. R. Porter and M. A. Semenov, "Crop responses to climatic variation," *Philosophical Transactions of the Royal Society B: Biological Sciences*, vol. 360, no. 1463, pp. 2021–2035, 2005.

[10] W. N. Smith, B. B. Grant, R. L. Desjardins et al., "Assessing the effects of climate change on crop production and GHG emissions in Canada," *Agriculture, Ecosystems & Environment*, vol. 179, no. 5, pp. 139–150, 2013.
[11] R. Ortiz, K. D. Sayre, B. Govaerts et al., "Climate change: can wheat beat the heat?," *Agriculture, Ecosystems & Environment*, vol. 126, no. 1-2, pp. 46–58, 2008.
[12] A. Bhattacharya, *Changing Climate and Resource Use Efficiency in Plants*, Academic Press, Cambridge, MA, USA, 2019.
[13] D. Bocchiola, L. Brunetti, A. Soncini, F. Polinelli, and M. Gianinetto, "Impact of climate change on agricultural productivity and food security in the Himalayas: a case study in Nepal," *Agricultural Systems*, vol. 171, pp. 113–125, 2019.
[14] CMA, *China Blue Book on Climate Change*, Science Press, Beijing, China, 2018.
[15] R.-l. Li and S. Geng, "Impacts of climate change on agriculture and adaptive strategies in China," *Journal of Integrative Agriculture*, vol. 12, no. 8, pp. 1402–1408, 2013.
[16] F. Tao, Z. Zhang, S. Zhang, Z. Zhu, and W. Shi, "Response of crop yields to climate trends since 1980 in China," *Climate Research*, vol. 54, no. 3, pp. 233–247, 2012.
[17] Z. Lv, X. Liu, W. Cao, and Y. Zhu, "Climate change impacts on regional winter wheat production in main wheat production regions of China," *Agricultural and Forest Meteorology*, vol. 171-172, pp. 234–248, 2013.
[18] T. Dai, J. Wang, D. He, and N. Wang, "Impact simulation of climate change on potential and rainfed yields of winter wheat in Southwest China from 1961 to 2010," *Chinese Journal of Eco-Agriculture*, vol. 24, no. 3, pp. 293–305, 2016.
[19] NBS Statistical Communique of the National Economic and Social Development of Guizhou Province, 2017, http://www.gzgov.gov.cn/zfsj/tjgb/201805/P020180528542634287622.pdf.
[20] D. Zheng, W. Fang, R. Ruan et al., "Diversity of agro-biological resources in Guizhou province," *Journal of Plant Genetic Resources*, vol. 18, no. 2, pp. 367–371, 2017.
[21] L. Liu, J. Wu, and Y. Xu, "Study on the relationship between wheat growth and solar energy resources in Guizhou," *Journal of Guizhou Meteorology*, vol. 5, pp. 8–12, 2003.
[22] X. Chen, H. Lei, J. Xu et al., "Spatial and temporal distribution characteristics of drought during crop growth period in Guizhou province from climate change perspectives," *Journal of Natural Resources*, vol. 30, no. 10, pp. 1735–1749, 2015.
[23] L. Warszawski, K. Frieler, V. Huber, F. Piontek, O. Serdeczny, and J. Schewe, "The inter-sectoral impact model intercomparison Project (ISI-MIP): project framework," *Proceedings of the National Academy of Sciences*, vol. 111, no. 9, pp. 3228–3232, 2013.
[24] C. Piani, G. P. Weedon, M. Best et al., "Statistical bias correction of global simulated daily precipitation and temperature for the application of hydrological models," *Journal of Hydrology*, vol. 395, no. 3-4, pp. 199–215, 2010.
[25] S. Hagemann, C. Chen, J. O. Haerter et al., "Impact of a statistical bias correction on the projected hydrological changes obtained from three GCMs and two hydrology models," *Journal of Hydrometeorology*, vol. 12, no. 4, pp. 556–578, 2011.
[26] Z. Zhao, Y. Luo, and J. Huang, "The detection of the CMIP5 climate model to see the development of CMIP6 earth system models," *Climate Change Research*, vol. 14, no. 6, pp. 643–648, 2018.
[27] B. D. Santer, J. C. Fyfe, G. Pallotta et al., "Causes of differences in model and satellite tropospheric warming rates," *Nature Geoscience*, vol. 10, no. 7, pp. 478–485, 2017.
[28] Y. Wu and R. Wang, *Practical Techniques for Wheat Cultivation*, China Agricultural Science and Technology Press, Beijing, China, 2014.
[29] Q. Lu and L. Wang, "Accumulated temperature of the main varieties of rice, cotton and cotton in China," *Acta Agronomica Sinica*, vol. 4, no. 2, pp. 157–170, 1965.
[30] Z. Yuan, D. Yan, Z. Yang, J. Yin, P. Breach, and D. Wang, "Impacts of climate change on winter wheat water requirement in Haihe River Basin," *Mitigation and Adaptation Strategies for Global Change*, vol. 21, no. 5, pp. 677–697, 2016.
[31] X. Xi, Z. Guo, X. Hai et al., *High-yield Cultivation Techniques for Maize*, China Agricultural Science and Technology Press, Beijing, China, 2017.
[32] X. Wang, *Corn Cultivation Technology*, Northeastern University Press, Shenyang, China, 2014.
[33] Z. Yuan, "Drought risk assessment and its coping strategies under changing environments: a case study in Luanhe River Basin," Ph. D. thesis, China Institute of Water Resource and Hydropower Research, Beijing, China, 2016.
[34] Y. Zhang, "Planting upper limit and temperature conditions of different climate ecotype rice varieties in China," *Resources Science*, vol. 5, no. 2, pp. 65–72, 1983.
[35] Q. Yu, P. Lu, J. Liu et al., "Crop photo 2 temperature productivity model and numerical analysis of suitable growth season of rice in southern China," *Journal of Natural Resources*, vol. 14, no. 2, pp. 163–168, 1999.
[36] Y. Yang, *High-yield Cultivation Techniques for Rice*, China Agricultural Science and Technology Press, Beijing, China, 2017.
[37] Q. Ao, X. Gu, Y. Yao et al., "Yixiangyou1108': growth and yield under temperatures of different sowing dates," *ChineseAgricultural Science Bulletin*, vol. 32, no. 36, pp. 11–15, 2016.
[38] J. Xiao, B. Mu, and F. Hu, *Agrometeorology*, Vol. 2, Higher Education Press, Beijing, China, 2009.
[39] Ministry of Water Resources, *Standard of Classification for Drought Severity (SL424–2008)*, Ministry of Water Resources, Beijing, China, 2008.
[40] Y. Liu, Q. Chen, Q. Ge et al., "Modelling the impacts of climate change and crop management on phenological trends of spring and winter wheat in China," *Agricultural & Forest Meteorology*, vol. 248, pp. 518–526, 2018.
[41] J. Wu, "Guizhou major rice cultivation climate type area and variety distribution," *Rural Economy and Technology*, vol. 4, p. 41, 2002.
[42] J. Duan and G. Zhou, "Climatic suitability of double rice planting regions in China," *Scientia Agricultura Sinica*, vol. 45, no. 2, pp. 218–227, 2012.
[43] X. Gao, J. Xu, S. Yang et al., "Water requirement pattern and crop coefficient of main crops in Guizhou province," *China Rural Water and Hydropower*, vol. 1, pp. 11–19, 2015.
[44] S. Zhong, "Analysis of the relationship between meteorological factors and wheat yield in bijie," *Tillage and Cultivation*, vol. 1, no. 1, pp. 8–10, 1996.
[45] Y. Feng, N. B. Cui, Y. Xu, Z. P. Zhang, and J. P. Wang, "Temporal and spatial distribution characteristics of meteorological drought in Guizhou Province," *Journal of Arid Land Resources and Environment*, vol. 29, no. 8, pp. 82–86, 2015.
[46] J. Liao, Y. Su, Z. Feng et al., "Analysis on the effects of agricultural natural disasters on the agricultural economy in Guizhou in the past 54 years," *Journal of Anhui Agricultural Sciences*, vol. 25, pp. 11114–11117, 2008.
[47] X. Cheng, "Research on rice response regularity and water production function under drought-floods abrupt alternation

condition," Ph. D. thesis, Wuhan University, Wuhan, China, 2017.

[48] L. Xu and J.-j. Liu, "Climate change and issues of Chinese agricultural development," *Acta Agriculturae Zhejiangensis*, vol. 25, no. 1, pp. 192–199, 2013.

[49] Y. Song, B. Liu, and H. Zhong, "Impact of global warming on the rice cultivable area in southern China in 1961–2009," *Progressus Inquisitiones DE Mutatione Climatis*, vol. 7, no. 4, p. 259, 2011.

[50] Y. Liu and F. Tao, "Probabilistic change of wheat productivity and water use in China for global mean temperature changes of 1°, 2°, and 3°C," *Journal of Applied Meteorology and Climatology*, vol. 52, no. 1, pp. 114–129, 2013.

[51] D. Li, J. Fan, X. Zhang et al., "Hydrolase kinetics to detect temperature-related changes in the rates of soil organic matter decomposition," *European Journal of Soil Biology*, vol. 81, pp. 108–115, 2017.

[52] G. Ondrasek, H. Bakić Begić, M. Zovko et al., "Biogeochemistry of soil organic matter in agroecosystems & environmental implications," *Science of The Total Environment*, vol. 658, pp. 1559–1573, 2019.

[53] P. P. Reddy, *Climate Resilient Agriculture for Ensuring Food Security*, Springer, Delhi, India, 2015.

[54] X.-H. Ao, "Impact and adaptive strategies of climate change on agriculture in karst areas: a case study of Liupanshui city in western Guizhou," *Journal of Guiyang University*, vol. 11, no. 1, pp. 58–62, 2016.

[55] F. M. DaMatta, A. Grandis, B. C. Arenque, and M. S. Buckeridge, "Impacts of climate changes on crop physiology and food quality," *Food Research International*, vol. 43, no. 7, pp. 1814–1823, 2010.

[56] C. Gao, J. Zhu, J. Zhu et al., "Effect of extreme rainfall on the export of nutrients from agricultural land," *Acta Geographica Sinica*, vol. 6, pp. 113–119, 2005.

[57] Z.-g. Huo, M.-s. Li, L. Wang, J.-j. Xiao, D-p. Huang, and C.-y. Wang, "Impacts of precipitation variations on crop diseases and pests in China," *Scientia Agricultura Sinica*, vol. 45, no. 10, pp. 1935–1945, 2012.