Trend Analysis of Temperature and Precipitation Extremes during Winter Wheat Growth Period in the Major Winter Wheat Planting Area of China*

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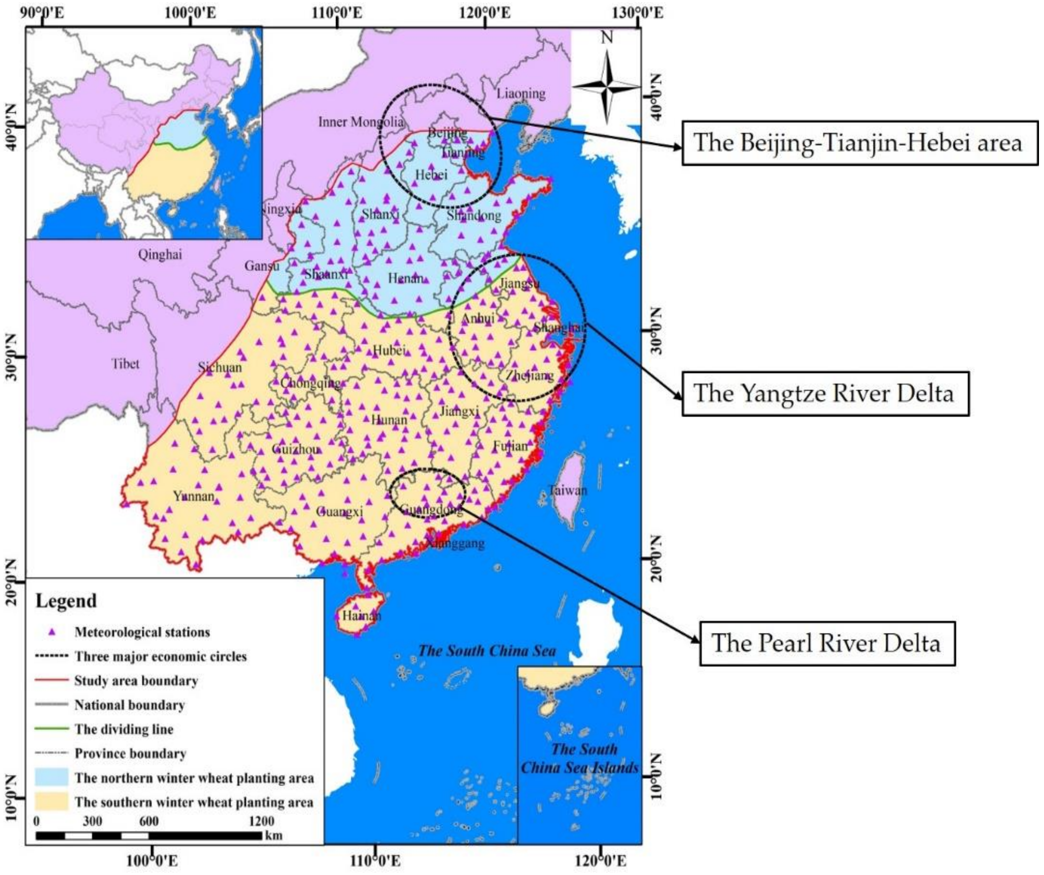
◆ Introduction

1. In the past century, the global climate has shown a significant warming trend, and the mean surface temperature has increased by 0.85 °C during 1880 and 2012.
2. Climate is the major uncontrollable factor in crop yields:
   (1) temperature increasing: accelerating growth of the phenophase, shortening the duration of crop growth and grain filling period, aggravating heat-related water stress and exacerbating pest and disease losses.
   (2) increasing mean annual temperature and extreme high temperature: the potential amount of grains and the number of seeds will be reduced.
   (3) Heavy precipitation → Excessive soil moisture → the root respiration would weaken and even stop.
3. Wheat is the main food crops in the world, and China is the largest producer in the world



* Nie, H.; Qin, T.; Yang, H.; Chen, J.; He, S.; Lv, Z.; Shen, Z. Trend Analysis of Temperature and Precipitation Extremes during Winter Wheat Growth Period in the Major Winter Wheat Planting Area of China. *Atmosphere* 2019, 10, 240.

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EGU General Assembly 2020 Vienna | Austria | 3-8 May 2020

◆ Methods

1. Indices of Extremes

8 extreme temperature indices and 7 extreme precipitation indices.

Indices	Name	Definitions	Units
Temperature			
FD0	Frost days	WWGP (winter wheat growth period) count when TN (daily minimum) < 0 °C	days
GSL	Growing season length	WWGP (1st Jan to 31st Dec in NH, 1st July to 30th June in SH) count between the first span of at least six days with TG (daily average) > 5 °C and first span after July 1 (January 1 in SH) of six days with TG < 5 °C	days
TXx	Max Tmax	Monthly maximum value of daily maximum temp	°C
TNn	Min Tmin	Monthly minimum value of daily minimum temp	°C
TN10p	Cool nights	Percentage of days when TN < 10th percentile of October 1971 to May 2001 [1]	%
TX10p	Cool days	Percentage of days when TX (daily maximum) < 10th percentile of October 1971 to May 2001	%
TN90p	Warm nights	Percentage of days when TN > 90th percentile of October 1971 to May 2001	%
TX90p	Warm days	Percentage of days when TX > 90th percentile of October 1971 to May 2001	%
Precipitation			
Rx1day	Max one-day precipitation amount	Monthly maximum one-day precipitation	mm
Rx5day	Max five-day precipitation amount	Monthly maximum consecutive five-day precipitation	mm
SDII	Simple daily intensity index	WWGP total precipitation divided by the number of wet days (defined as RR (daily precipitation) >= 1.0mm) in the year	mm/day
R20mm	Number of days above 20 mm	WWGP count of days when RR > = 20mm	days
CDD	Consecutive dry days	Maximum number of consecutive days with RR < 1mm	days
R95pTOT	Very wet days	WWGP total PRCP when RR > 95th percentile	mm
PRCPTOT	WWGP total wet day precipitation	WWGP total PRCP in wet days	mm

[1] The period of October 1971 to May 2001 is the base period.

2. The M–K test was applied to analyze the trend strengths in extremes indices.

Positive trends ($p \leq 0.05$)
Positive trends ($0.05 < p \leq 0.1$)
Positive trends ($0.1 < p \leq 0.2$)
Negative trend ($p \leq 0.05$)
Negative trends ($0.05 < p \leq 0.1$)
Negative trends ($0.1 < p \leq 0.2$)
Insignificant trends ($p > 0.2$)

⇨

↑ Very strong upward trends
↑ Strong upward trends
↑ Weak upward trends
↓ Very strong downward trends
↓ Strong downward trends
↓ Weak downward trends
◆ Insignificant trends

3. Trend Percentage and Stability

Positive ($S \geq 60\%$)
Positive ($25\% \leq S < 60\%$)
Positive ($0\% \leq S < 25\%$)

Negative ($S \geq 60\%$)
Negative ($25\% \leq S < 60\%$)
Negative ($0\% \leq S < 25\%$)

$$PCT_i = \frac{N_{pi}}{N_T \times M} \times 100\%$$

⇨

$$S_{ij} = \frac{M_{1ij} + M_{2ij}}{M} \times 100\%$$

Upward trends
↑ Strongly stable
↑ Stable
◆ Unstable

Downward trends
↓ Strongly stable
↓ Stable
◆ Unstable

4. Sen's Slope Estimator was used to estimate the trend magnitudes in the extreme index series.

$$Sen_k = \frac{x_z + x_y}{z - y}$$

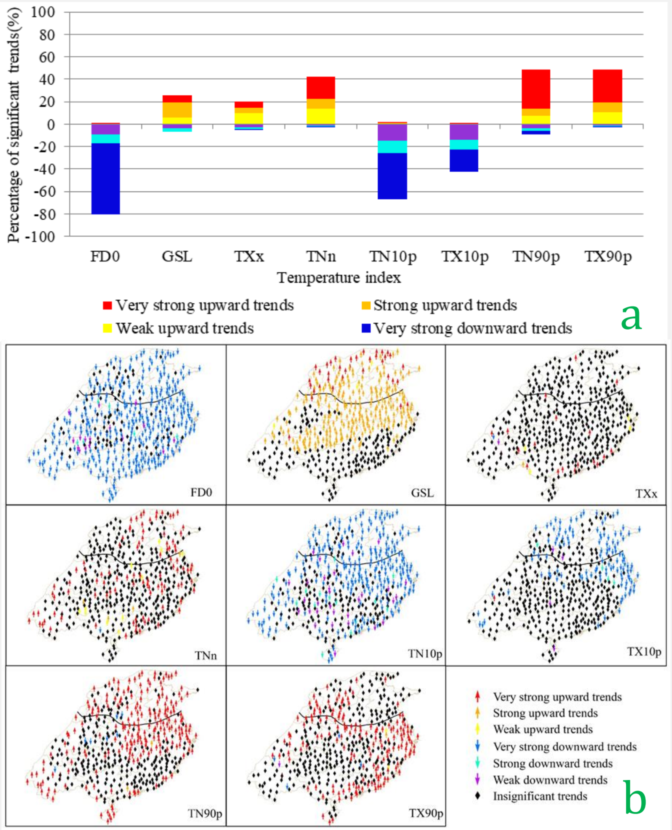
$$Sen = Sen_{[(N+1)/2]}, \text{if } N \text{ is odd}$$

$$Sen = \left(Sen_{[N/2]} + Sen_{[(N+2)/2]}\right)/2, \text{if } N \text{ is even}$$

◆ Results—Trend Strengths

✓ Extreme temperature index

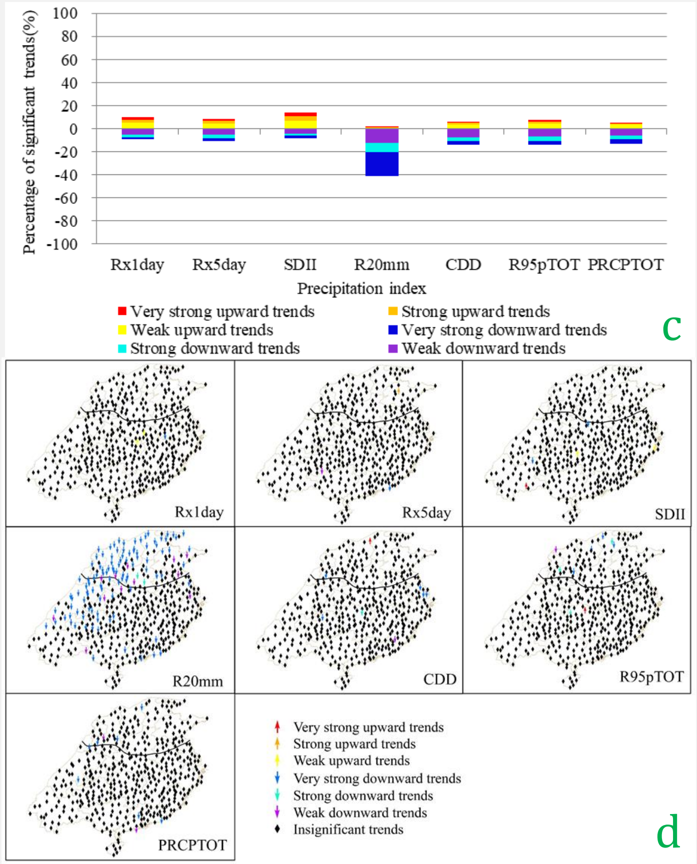
1) Cold extreme indices ↓ : FD0(80%), TN10p(67%), and TX10p(43%); TNn ↑ (42%);
2) Hot extreme indices ↑ : TXx(21%), Tn90p(48%), and Tx90p(49%) ;
3) GSL ↑ (26%);
4) Stations with significant change trend are mainly distributed in the northern winter wheat planting areas and the north of the southern winter wheat planting areas.



Extreme temperature index

✓ Extreme precipitation index

1) The percentage of insignificant trends in all extreme precipitation indices are dominate;
2) Only 41% of the sites in R20mm show a significant downward trend, mainly in the northern winter wheat growing area and the northwest of the southern winter wheat planting areas.

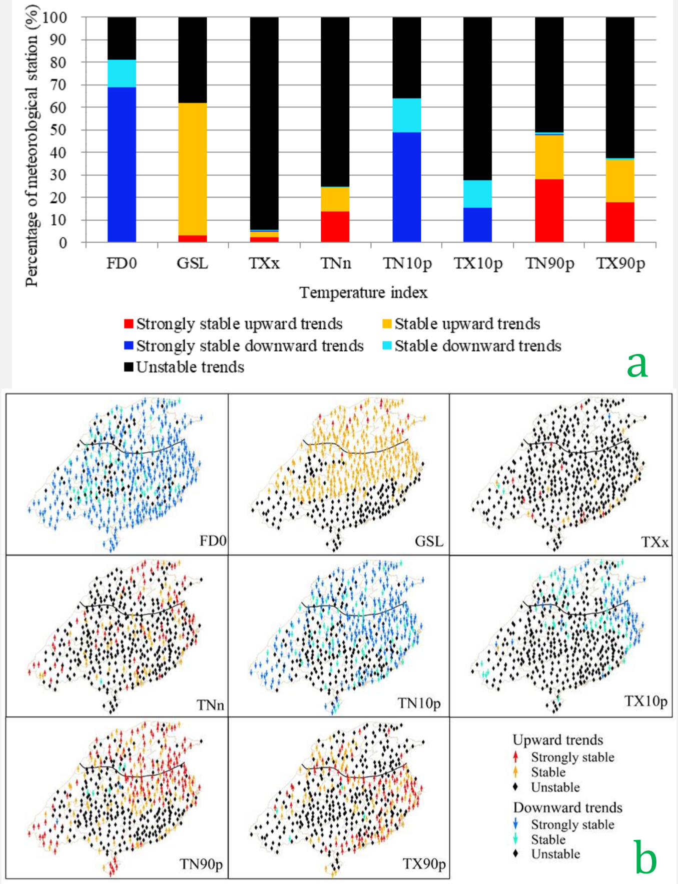


Extreme precipitation index

◆ Results—Stability of Trends

✓ Extreme temperature index

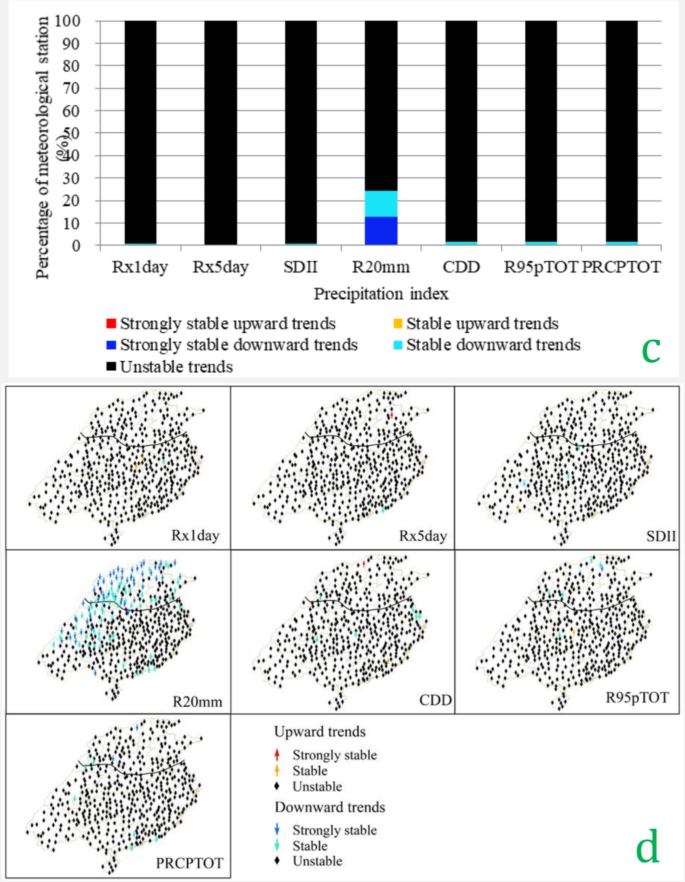
1) Cold extreme indices ↓ : FD0(81%), TN10p(64%), and TX10p(27%); TNn ↑ (25%);
2) Hot extreme indices ↑ : TXx(5%), Tn90p(47%), and Tx90p(36%) ;
3) GSL ↑ (62%);
4) Stations with stable change trend are mainly distributed in the northern winter wheat planting areas and the northeast of the southern winter wheat planting areas.



Extreme temperature index

✓ Extreme precipitation index

1) The percentage of unstable trends in all extreme precipitation indices are dominate;
2) Only 24% of the sites in R20mm show a stable downward trend, mainly in the northern winter wheat growing area and the northwest of the southern winter wheat planting areas.

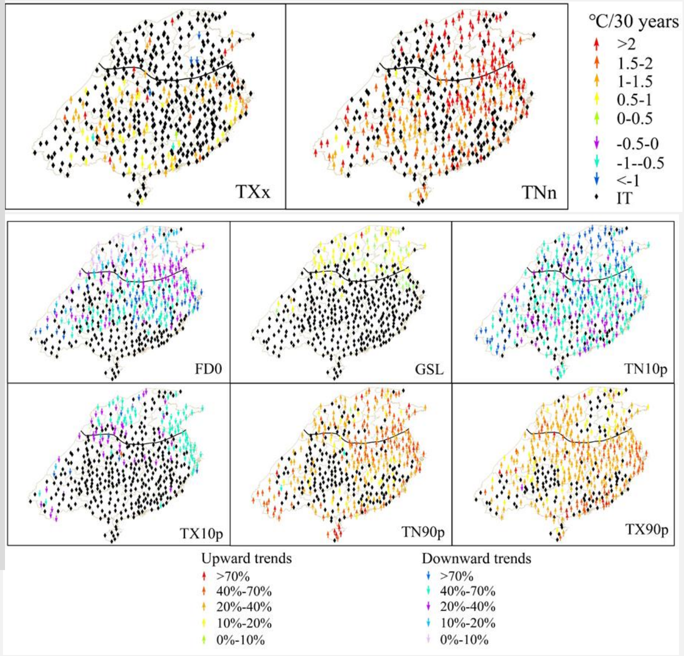


Extreme precipitation index

Results—Trend Magnitude

✓ Extreme temperature index

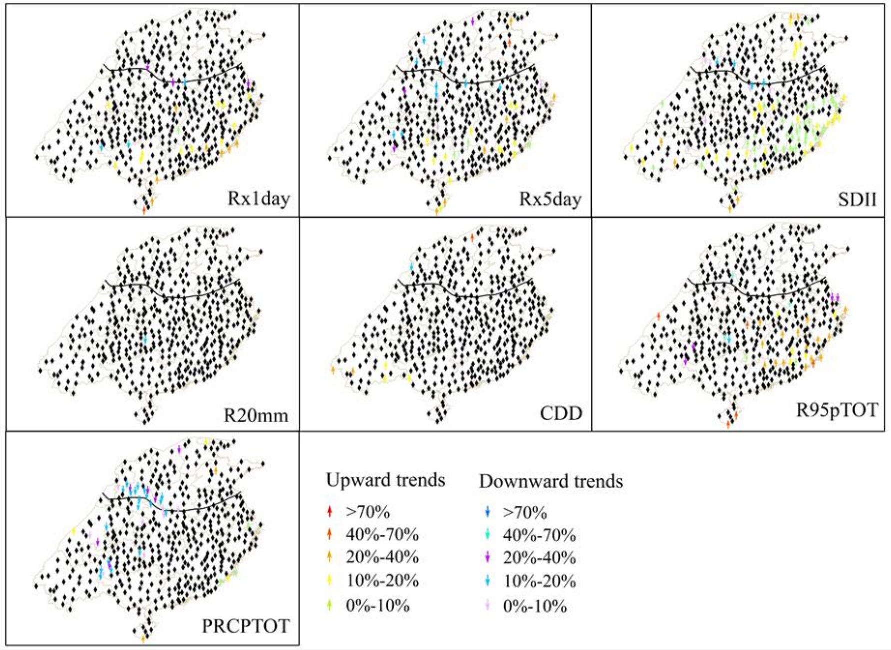
1) Cold extreme indices ↓ >20%: FD0(45%), TN10p(77 %), and TX10p(26%); TNn ↑ (49% ↑ >1°C/30 years);
2) Hot extreme indices ↑ >20% : TXx(14% ↑ >1°C/30 years), Tn90p(52%), and Tx90p(62%) ;
3)GSL: 81% insignificant trends;
4) Stations with stable change trend are mainly distributed in the northern winter wheat planting areas and the northeast of the southern winter wheat planting areas.



Extreme temperature index

✓ Extreme precipitation index

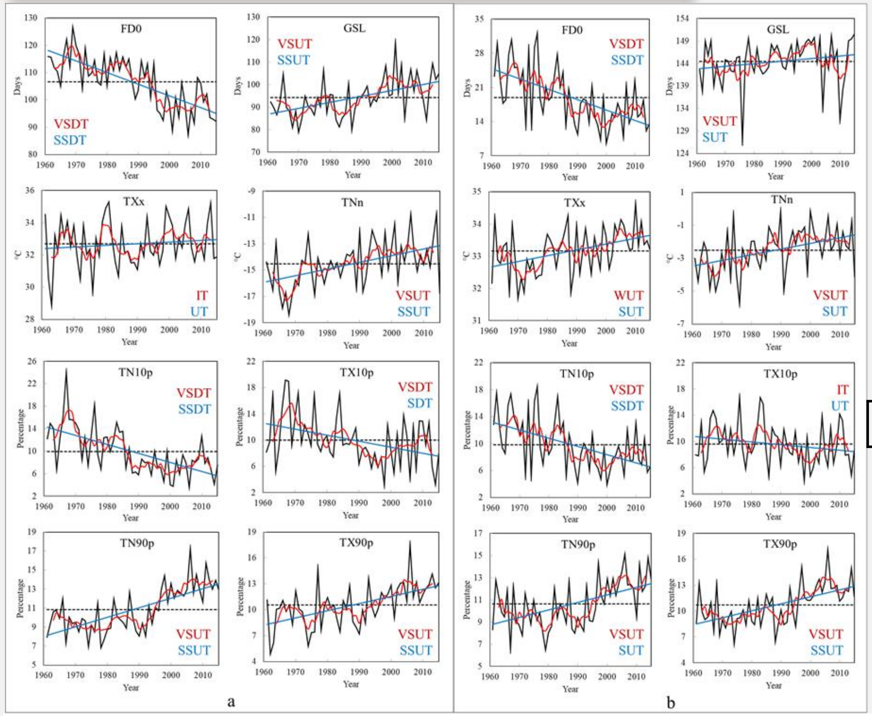
1) More than 82% of the stations do not pass the significance test (p=0.05);
2) In general, the trend magnitude of extreme precipitation indices in the study area is not significant.



Extreme precipitation index

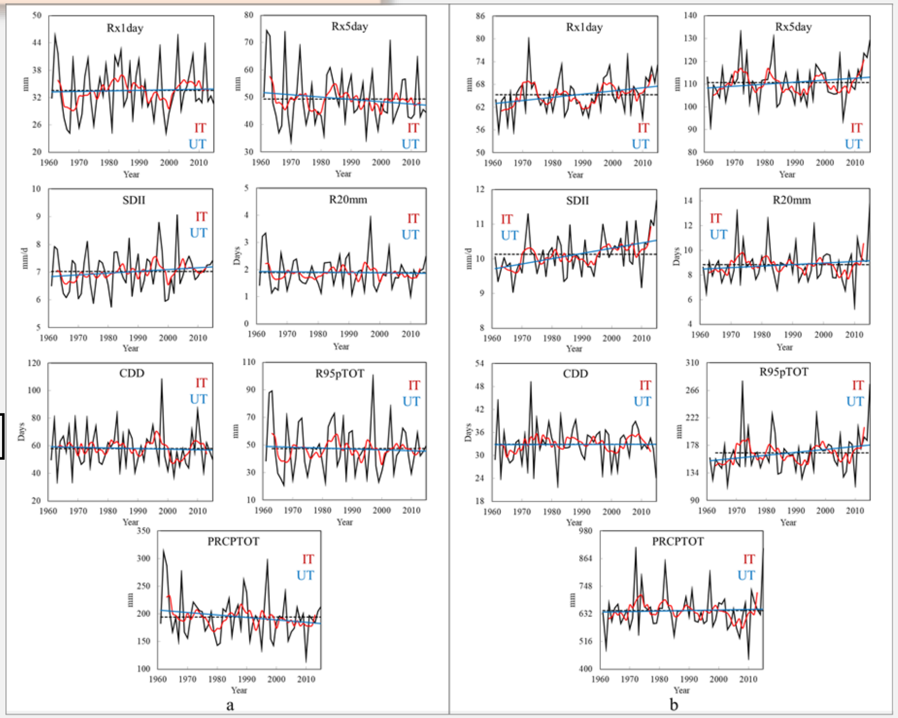
◆ Results—Average Index Time Series

✓ Extreme temperature index



a: the northern China winter wheat region;
b: the southern China winter wheat region.

✓ Extreme precipitation index



Type of test	Area	Extreme temperature indices							
		FD0	GSL	TXx	TNn	TN10p	TX10p	TN90p	TX90p
Trend strengths	a	VSDT	VSUT	IT	VSUT	VSDT	VSDT	VSUT	VSUT
	b	VSDT	VSUT	WUT	VSUT	VSDT	IT	VSUT	VSUT
Stability of trends	a	SSDT	SSUT	UT	SSUT	SSDT	SDT	SSUT	SSUT
	b	SSDT	SUT	SUT	SUT	SSDT	UT	SUT	SSUT

Type of test	Area	Extreme precipitation indices						
		Rx1day	Rx5day	SDII	R20mm	CDD	R95pTOT	PRCPTOT
Trend strengths	a	IT	IT	IT	IT	IT	IT	IT
	b	IT	IT	IT	IT	IT	IT	IT
Stability of trends	a	UT	UT	UT	UT	UT	UT	UT
	b	UT	UT	UT	UT	UT	UT	UT

VSDT: very strong downward trends. VSUT: very strong upward trends. WUT: weak upward trends. IT: insignificant trends. SSDT: strongly stable downward trends. SSUT: strongly stable upward trends. UT: unstable trends. SDT: stable downward trends. SUT: stable upward trends.

Conclusions

Trends of extreme climatic indices

Extreme temperature index

Time: the winter wheat growth period is undergoing a warming process with a decrease in extreme cold events and an increase in extreme hot events.

Space: the warming trends in the northern winter wheat planting area and north of the southern winter wheat planting area are more significant, especially in the three major economic circles.

Extreme precipitation index

The change trends of most extreme precipitation indices are insignificant and unstable in the winter wheat growth period in the study area.

The response of extreme indices to climate change

The extreme temperature index can well reflect the temperature change of the growth period of winter wheat, while extreme precipitation indices are not suitable for evaluating climate change during the growth period of winter wheat in this region (the events and amounts of the precipitation in China mostly occur in flood season with heavy rainfall intensity and long rainfall duration).