Change in Climate Extremes and Their Impacts on Groundwater Variation and Grain Yield in China over the Past 50 Years

Min Liu, Yanjun Shen, Yongqing Qi, Hongwei Pei, Yanliang Tian

Institute of Hydrogeology and Environmental Geology, Chinese Academy of Geological Sciences
Center for Agricultural Resources Research, Chinese Academy of Sciences

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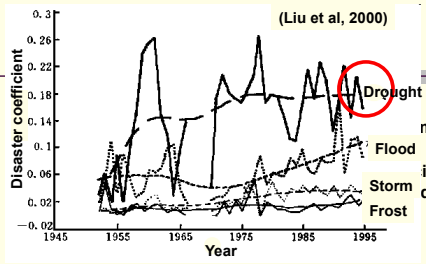
Background

Climate change exacerbate regional extreme precipitations and extreme droughts!



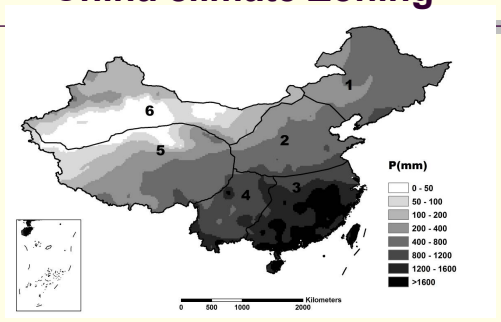
- most events.
- ially which d destructive

- Drought is the most influential factor of the agricultural disasters due to its accumulative effects, elusiveness, durative and extensiveness.
- Groundwater irrigation is an effective way to alleviate drought in water shortage region, but groundwater overexploitation always results in a series of eco-environmental problems. Sustainable groundwater in agricultural faces an unprecedented challenge.

The goal of this study

- Thresholds determination of the extreme precipitations (EP) and extreme droughts (ED).
- Analyze the frequency and intensity trends of the extreme precipitations and extreme droughts.
- the response of groundwater level depth variation to climate extremes in irrigation areas.
- the response of the grain yield to the extreme droughts in rain-fed areas.

China climate Zoning



- 1- Northeast China; 2-North China; 3- Southeastern region; 4-Southwest region; 5- Qing-Tibet region; 6-Northwestern region

Data

- Precipitation and temperature data for this study were provided by China Meteorological Administration from approximately 680 stations across China for the period of January 1 1961 to January 31 2012.
- Grain yield data are from ‘Guangdong statistical yearbook’, ‘Guangdong Rural statistical yearbook’, ‘Guizhou statistical yearbook’, and ‘Shanxi statistical yearbook’ from 1990 to 2008.
- Groundwater level depth data are from Luancheng agro-ecosystem experimental station of the Chinese Academy of Sciences and Center for Hebei environmental monitoring station. groundwater exploitation data are also from the Center for Hebei environmental monitoring station.

Methods

- Thresholds determination of extreme precipitation：Percentile/CDF（95%）
- Threshold model of Extreme droughts

  Three major modules：

  ① the module of agricultural drought index selection ；

  ② the module of the crop type, plantation pattern, growing season and the water critical period determination；

  ③ the module of determination of the invert cumulated distribution function (ICDF)

① the module of agricultural drought index selection

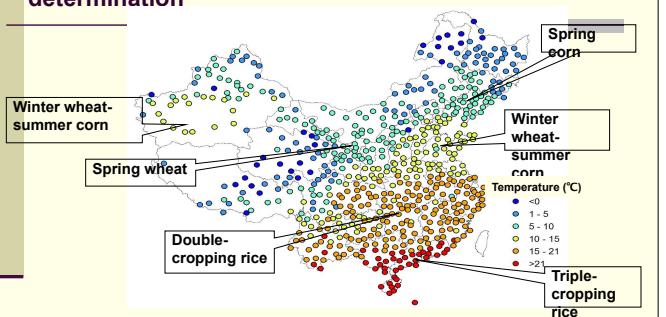
- Index: consecutive days without available precipitation (CDWAP)
- CDWAP is calculated by the equation below:

$$Dnp = \sum_{i=1}^{n} a \cdot Dnp_i \qquad Dnp_i = \begin{cases} 1 & P < P_0 \\ 0 & P \geq P_0 \end{cases}$$

  - a is the season adjustment coefficients, 1 for spring,1.4 for summer, 0.8 for autumn, and 0.2 for winter;
  - P_0 is the daily available precipitation, 3mm for growing season, 5mm for water critical period, and 1mm for the other period.

(*National Standard of P.R.C –Agricultural Drought Grades (drafts))

② The module of the crop type, plantation pattern, growing season and the water critical period determination



The spring corn-producing area in Northeast China with the annual average temperature lower than 10℃
The spring wheat-producing area in other regions with the annual average temperature lower than 10℃
The winter wheat – summer corn area with the annual average temperature 10-15℃
Double –cropping rice area with the annual average temperature 15-21℃
Triple-cropping rice area with the annual average temperature higher than 21℃

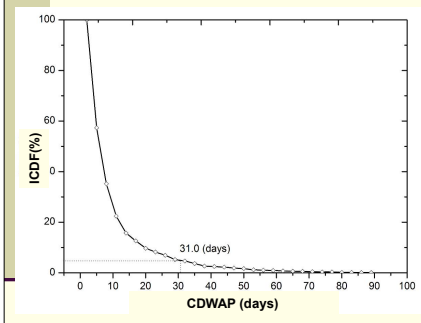
Parameters of crop growing periods and water critical periods in each region

Crop	WCP
Wheat	Booting to heading
Rice	Booting to flowering
Corn	Booting to milky maturity

	Ta<10				10<Ta<15		15<Ta<21		Ta>21	
	Northeast C (Spring corn)		Northwest C (Spring wheat)		Winter wheat Summer corn		Double cropping rice		Triple cropping rice	
	month	day	month	day	month	day	month	day	month	day
Fr of GP	4	15	3	20	4	5	4	5	4	5
Fr of WCP	7	28	5	25	6	1	6	1	6	1
End of WCP	9	3	6	15	6	20	6	20	6	20
Fr of WCP			8	10	9	1	9	1	9	1
End of WCP					9	20	9	20	9	20
Fr of WCP									12	25
End of WCP									2	5
End of GP	9	10			10	20	10	20	3	5

* Ta – temperature; GP – Growing period; WCP – water critical period; Fr – from;

③ The inverted cumulated distribution function



Threshold value determination procedure：

✓Firstly establish a CDWAP arithmetic progression, e.g. 2, 4, 6, ……

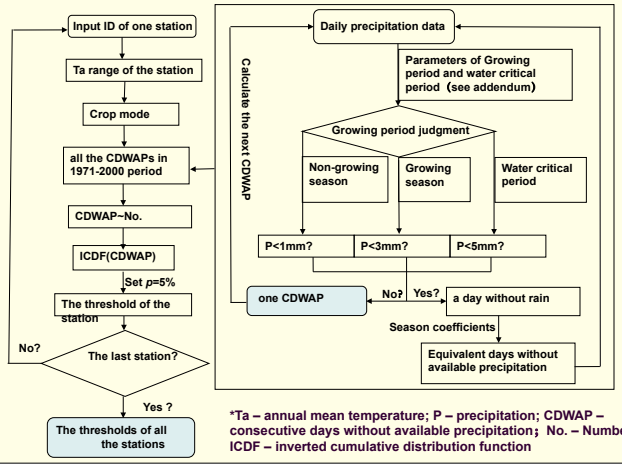
✓Calculate the frequency within 1971-2000 to which each CDWAP corresponds (continuous calculation should be made between two adjacent years);

✓Establish the relationship between CDWAP and the frequency sequence (N), i.e. each N is the cumulative frequency value of the drought events which CDWAP equal to or larger than the corresponding CDWAP;

✓Establish the inverted cumulative distribution function (ICDF) of the CDWAP based on the relationship between N and CDWAP.

- ICDF refers to the proportion of the frequency of extreme agro-climatic droughts whose CDWAP is larger than or equals to a certain CDWAP value to the total frequency.
- We adopted 5% as the threshold value for the extreme agro-climatic droughts in this study, namely, the extreme event probability is 5%.

Model calculation procedure



*Ta – annual mean temperature; P – precipitation; CDWAP – consecutive days without available precipitation; No. – Number; ICDF – inverted cumulative distribution function

Trend analysis methods

Trend analysis Index of frequency and intensity

- Frequency analysis index:
  - Annual occurrence times of extreme agro-climatic droughts
- Intensity analysis index:
  - Annual maximum consecutive days without available precipitation (MCDWAP)

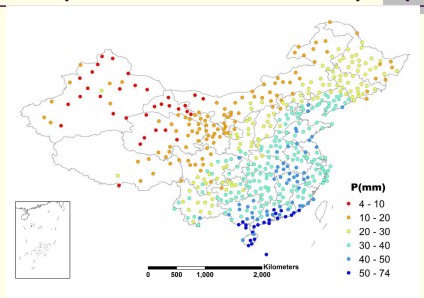
Relative change rate ratio

$$R_{cm} = 100\% \times \frac{\overline{x_2} - \overline{x_1}}{\overline{x_1}}$$

In which, R_{cm} is the ratio of the annual change magnitude in the first period (the reference period) to that in the second period (the target period). $\overline{x_1}$ is the annual mean frequencies/intensities of EAD in the reference period, and $\overline{x_2}$ that of the target period.

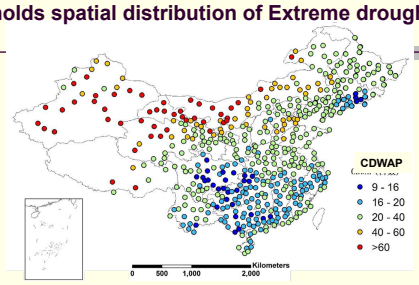
Result and analysis

Thresholds spatial distribution of extreme precipitations



Increased from northwest to southeastern
Less than 10mm in the desert region of Northwest China;
Greater than 50mm in parts of South China;
In semi-humid/ semi-arid region: 10-30mm,
In the humid region: >30mm.

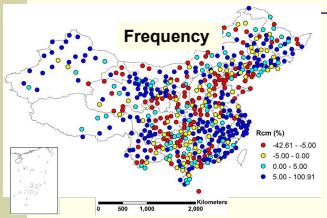
Thresholds spatial distribution of Extreme droughts



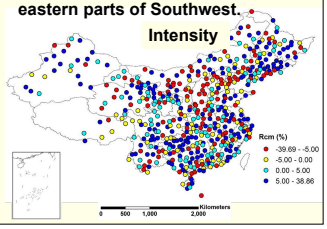
Generally, threshold values decreased from northwest to southeast.
✓Thresholds in most of the stations in northwest region were greater than 60 days;
✓Less than 16 days in middle reaches of Yangtze River;
✓Thresholds range from 20-40 days in North China.
✓Thresholds in humid region less than 20 days

Relative change rate ratio R_{cm} spatial distribution of EP

(annual change magnitude ratio of 1985-2007 to 1961-1984)



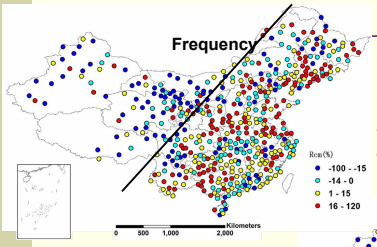
✓Stations with increasing trends in frequency: Northeast C, Southeast C, Qing-Tibet and Northwest. Accounts for the total 59.8%.
✓Decreasing trends in frequency: were mainly distributed in North China and eastern parts of Southwest.



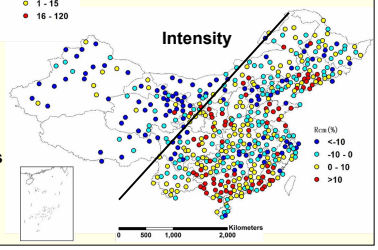
Spatial distribution of EP intensity has a higher heterogeneity, stations with increasing tendency accounts for 58.4% of the total. North China showed a decreasing trend.

Relative change rate ratio R_{cm} spatial distribution of ED

(annual change magnitude ratio of 1985-2007 to 1961-1984)



Stations with increasing frequency mainly distributed in Liaoning-Shandong-Shanxi-Sha'anxi-Chuandong-Guizhou-Guangxi-Yunan line and Huai River basin, in which parts of their R_{cm} exceeded 15%。



Intensity increased in Liaoning, Shandong, Sha'anxi, Yunguichuan area and most of South China, parts of Liaoning and South China Rcm exceeded 10%.

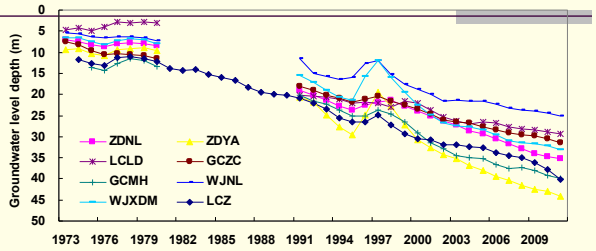
Comparison of regional station mean R_{cm} between extreme precipitations and extreme droughts

	R_{cm} of extreme precipitations		R_{cm} of extreme droughts	
	Frequency(%)	Intensity(%)	Frequency(%)	Intensity(%)
Northeast C	5	4	5	-1
North C	-3	-3	26	3
Southeast C	6	4	64	15
Southwest C	1	4	98	26
Qing-Tibet P	8	1	-2	-11
Northwest C	16	4	-9	-5

Case study of groundwater response to climate extremes in irrigation area

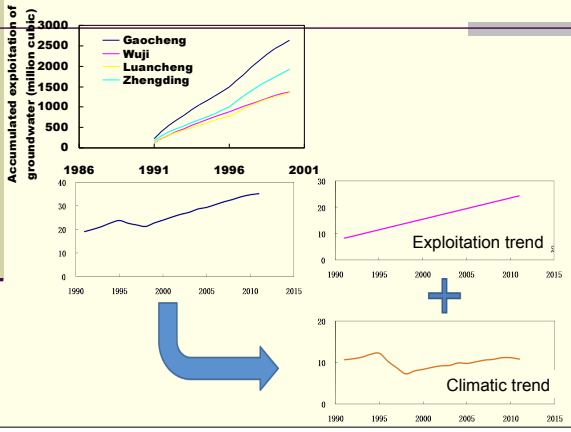
- 8 monitoring wells over 4 counties in Shijiazhuang;
- Locates in NCP, one of the top three major groundwater depletion areas of the world;
- Annual precipitation 558mm;
- High agricultural output depends predominantly on groundwater irrigation.

Trends of groundwater level depth in Shijiazhuang

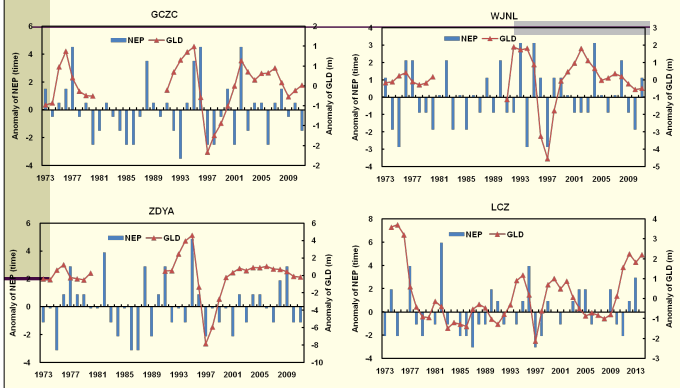


Change Rate	ZDNL	ZDYA	LCLD	GCZC	GCMH	WJNL	WJXDM	LCZ
Before 1980	0.12	-0.05	-0.29	0.51	-0.29	0.21	0.09	-0.12
After 1990	0.80	1.21	0.49	0.66	1.05	0.65	0.96	0.89

Groundwater trend decomposition

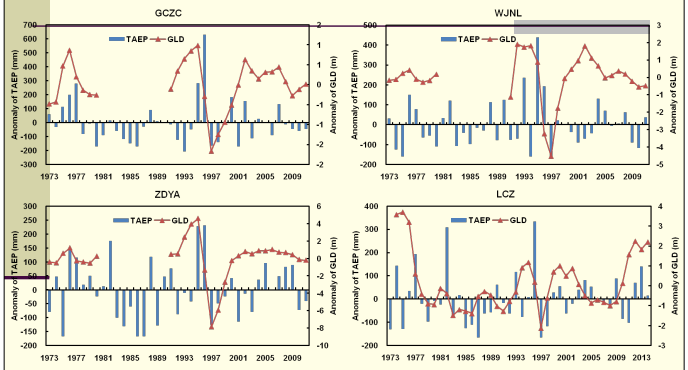


Relationship of NEP and GLD



NEP = number of extreme precipitation; GLD = groundwater level depth

Relationship of TAEP and GLD



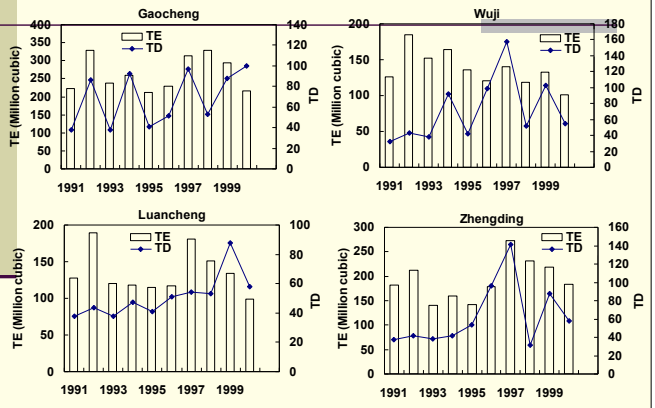
TAEP = total amount of extreme precipitation; GLD = groundwater level depth

Grey relation degree of GLD and EP index

Station	NEP	IEP	MDP	TAEP
LCZ	**0.533**	**0.557**	**0.585**	**0.547**
LCLD	**0.518**	**0.453**	**0.467**	**0.537**
GCZC	**0.534**	**0.514**	**0.514**	**0.515**
GCMH	**0.522**	**0.484**	**0.497**	**0.504**
WJNL	**0.487**	**0.577**	**0.638**	**0.557**
WJXDM	**0.525**	**0.601**	**0.685**	**0.610**
ZDNL	**0.542**	**0.533**	**0.559**	**0.538**
ZDYA	**0.540**	**0.573**	**0.611**	**0.553**

GLD = groundwater level depth; NEP = number of extreme precipitation; IEP = intensity of extreme precipitation; MDP = maximum daily precipitation; TAEP = total amount of extreme precipitation

Relationship between total groundwater exploitation amounts and total extreme drought days



* TE - total groundwater exploitation amounts, TD - total extreme drought days

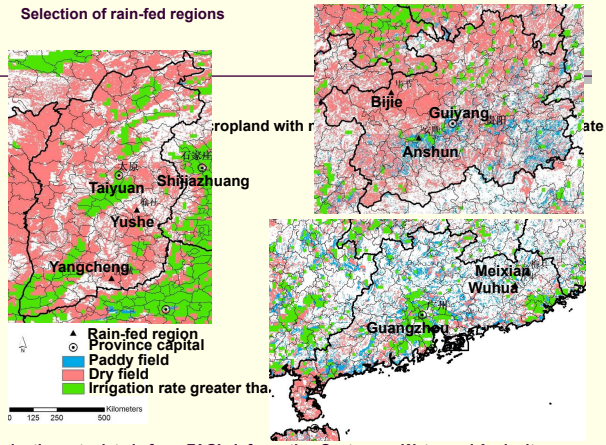
Grey relation degree of groundwater exploitation and the index of extreme droughts

Station	Frequency	Intensity	MCDWAP	TD
Gaocheng	0.53	0.55	0.55	0.60
Wuji	0.52	0.51	0.52	0.55
Luancheng	0.60	0.54	0.52	0.62
Zhengding	0.57	0.52	0.52	0.57

Grain yield variation in rain-fed region response to extreme droughts - case study

- Rain-fed region selection:
  - Shanxi：Yushe (annual precipitation 535mm),Yangcheng (annual precipitation 584mm)
  - Guizhou：Bijie (annual precipitation 900mm), Anshun (annual precipitation 1376mm)
  - Guangdong：Meixian (annual precipitation 1528mm), Wuhua (annual precipitation 1539mm)
- Calculation of climatic yield
- Climatic yield variation response to extreme droughts

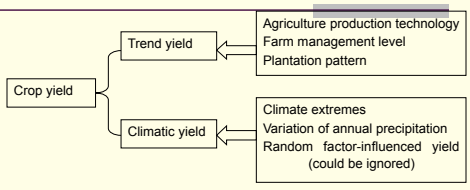
Selection of rain-fed regions



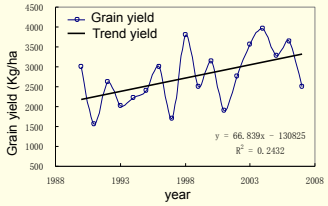
Irrigation rate data is from FAO's Information System on Water and Agriculture "Global Map of Irrigation Areas" version 4.0.1

Calculation of climatic yield

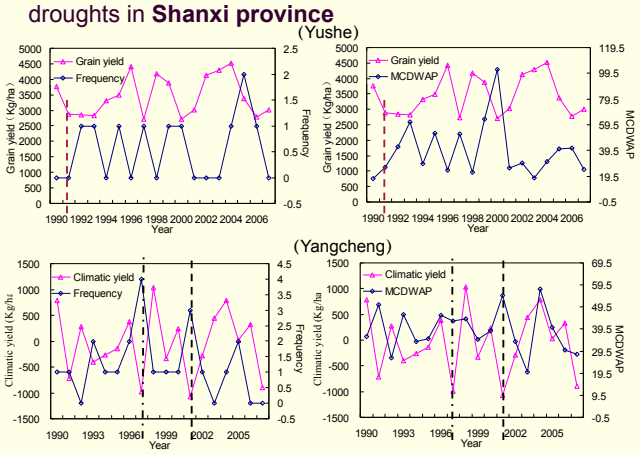
- Crop yield decomposition



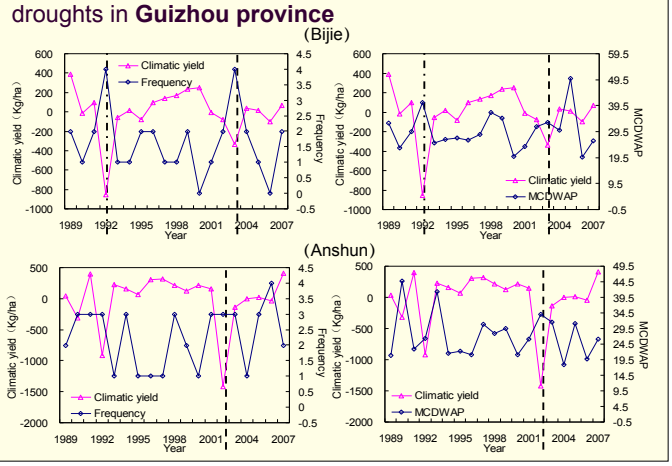
- Calculation of climatic yield:
  Climatic yield=crop yield-trend yiel



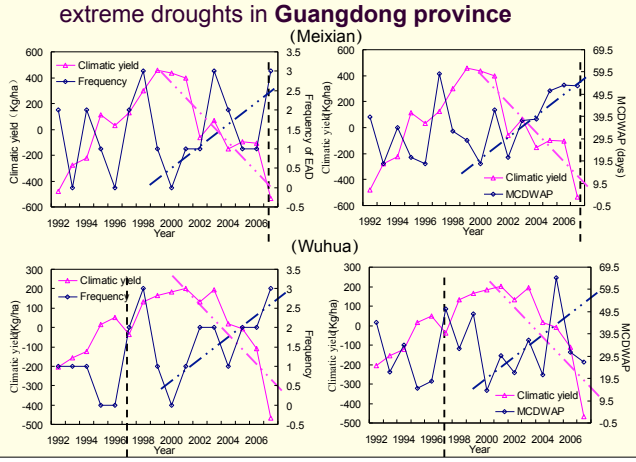
Climatic influenced yield variation response to extreme droughts in **Shanxi province**



Climatic influenced yield variation response to extreme droughts in **Guizhou province**



Climatic influenced yield variation response to extreme droughts in **Guangdong province**



Conclusions

1) EP showed increasing trend in almost all the climatic zones except North China, while ED increasing trends were popularly detected in all the climatic zones except Northwest China and Qing-Tibet Platen.

2) Groundwater showed a declining trend since the end of 1970s in Shijiazhuang, the average declining rate was about 0.8 m/ decade.

3) Groundwater level depth decreased in the year with higher frequency and intensity of extreme precipitations, and vise verse.

4) groundwater exploitation had a strong relationship with the extreme droughts. In the years with a higher extreme droughts frequency and intensity, the exploitation were usually larger correspondingly.

5) The anti-phase relationship was detected between the grain yield in the rain-fed areas and the frequency and intensity of the extreme droughts. Higher frequency and intensity of the extreme droughts would lead to higher probability of the yield reduction.

6) The anti-phase response relationship of the climatic yield to the extreme droughts was more significant in areas with higher precipitation-supplying degree and higher proportion of the plantation of staple crops (wheat, rice, and corn)

Thanks for your attention!