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Effects of climatic factors, drought risk and irrigation requirement on maize yield in the northeast farming region of China over 1961 to 2010

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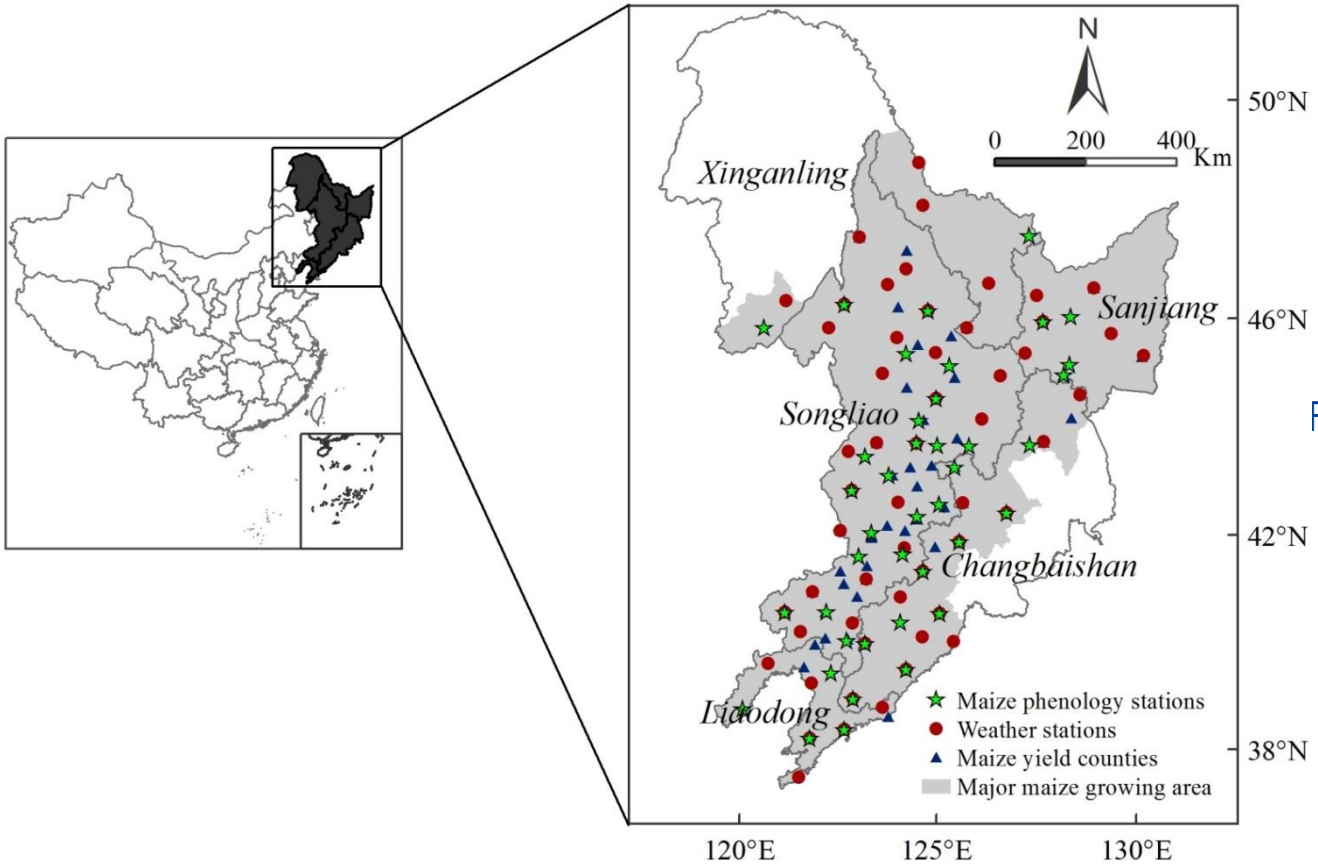


Fig. 1 Locations of Northeast China

Irrigation: 15%
Rain-fed : 85%

- The area includes 304 counties, Crop growing season is from May to September.
- The annual accumulated temperature above 10°C ranges from 1700 to 3600°C d
- The frost free period normally starts at 28th March, and ends on 2nd October.
- The annual mean sunshine duration is 2400~2900 hours.
- Annual precipitation is 500-800 mm, 80%

Table 1
Ratio of maize, rice and soybean in Northeast China to the whole country in 2010

	Crop	NFR	China	Ratio (%)
Crop area	Maize (10^6 ha)	9.5	32.5	29
	Rice (10^6 ha)	4.1	29.9	14
	Soybean (10^6 ha)	4	8.5	47
Crop production	Maize (10^6 ton)	54.8	177.2	31
	Rice (10^6 ton)	28.7	195.8	15
	Soybean (10^6 ton)	7.1	15.1	47

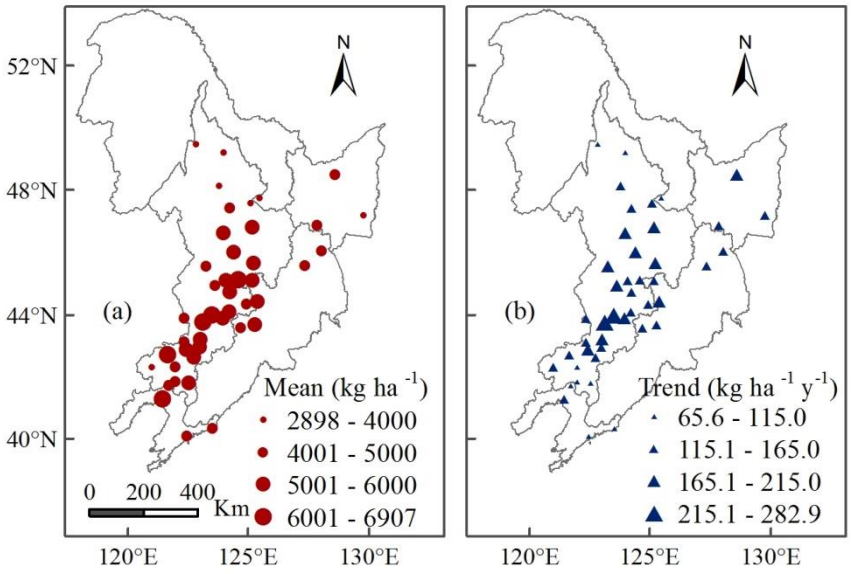


Fig.2 Distributions of maize yield

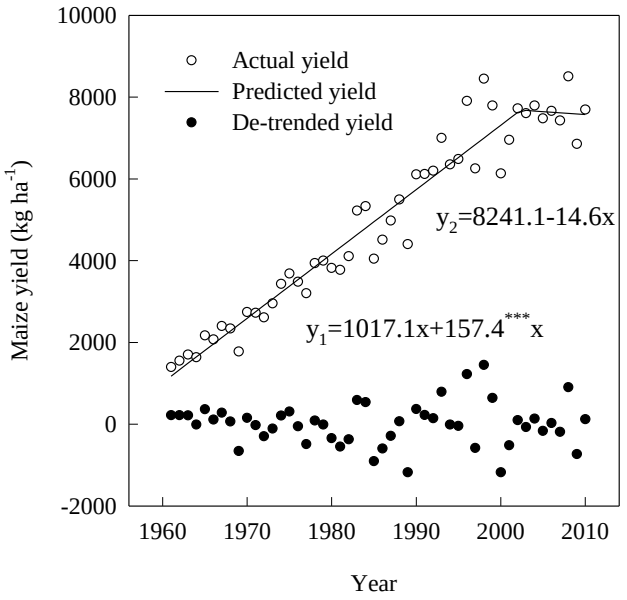


Fig.3 Changes of maize yield

Limitations for maize production

- Large ratio of maize area under rain-fed
- Higher climate risks
- Drought caused large number of yield loss
- Irrigation systems are less developed
- Climatic factors in different phases may have different effects on maize yield

Objectives

- To analyze the spatial variation of climatic factors in different maize growth phases and their influences on maize yield
- To investigate the spatial variation of drought risk in specific growth phase and its impact on maize yield
- To estimate the spatial variation of irrigation water requirement in each growth phase

Data sources and analyses

- Maize phenology data: 40 stations from 1981 to 2010
- Climate data: 54 stations from 1961 to 2010
- Maize yield: 44 stations from 1961 to 2010

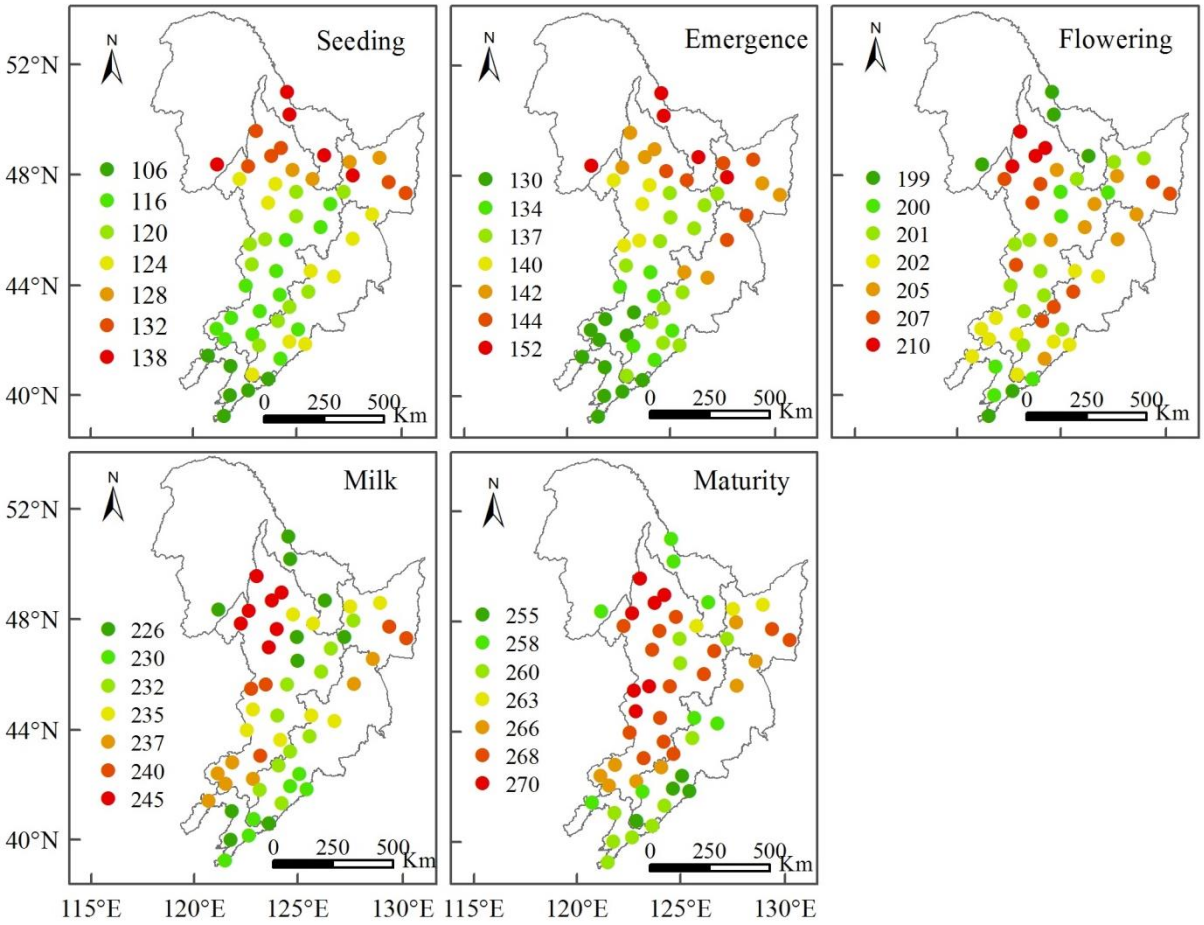


Fig. 4 Spatial distributions of DOY (day of year) for sowing, emergence, flowering, milk and maturity

Maize growth phases

- Seeding phases: sowing to emergence
- Vegetative phases: emergence to flowering
- Flowering phases: flowering to milk
- Maturity phases: milk to maturity

Calculation of water balance

$$D_{r,i} = D_{r,i-1} - P_{eff,i} - I_i - CR_i + ET_{c,i} + DP_i$$

Dual crop coefficient, MABIA model (http://www.mabia-agrosoftware.co/)

Calculation of water dificit

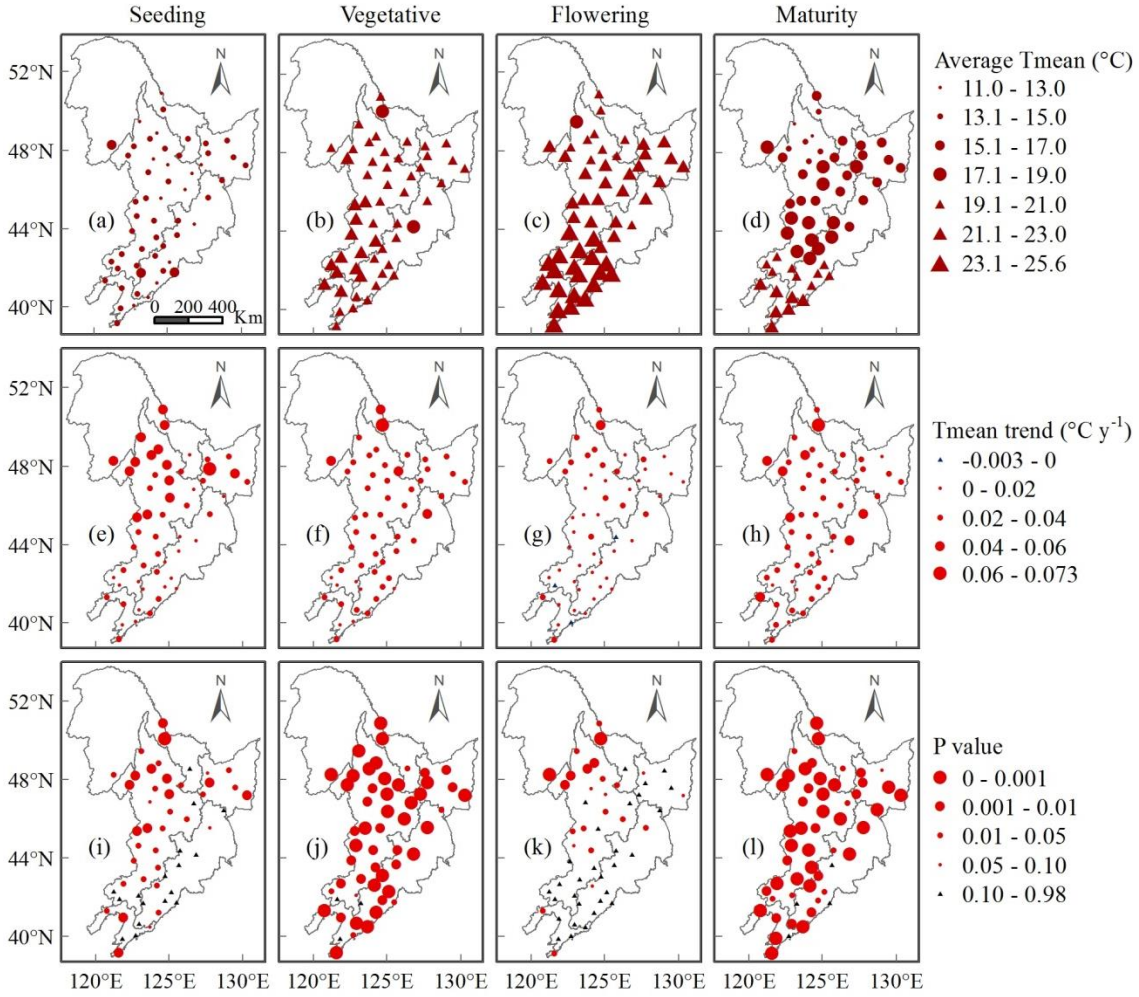
$$W_{di} = 1\text{-}ETa/ETc$$

Drought stress days

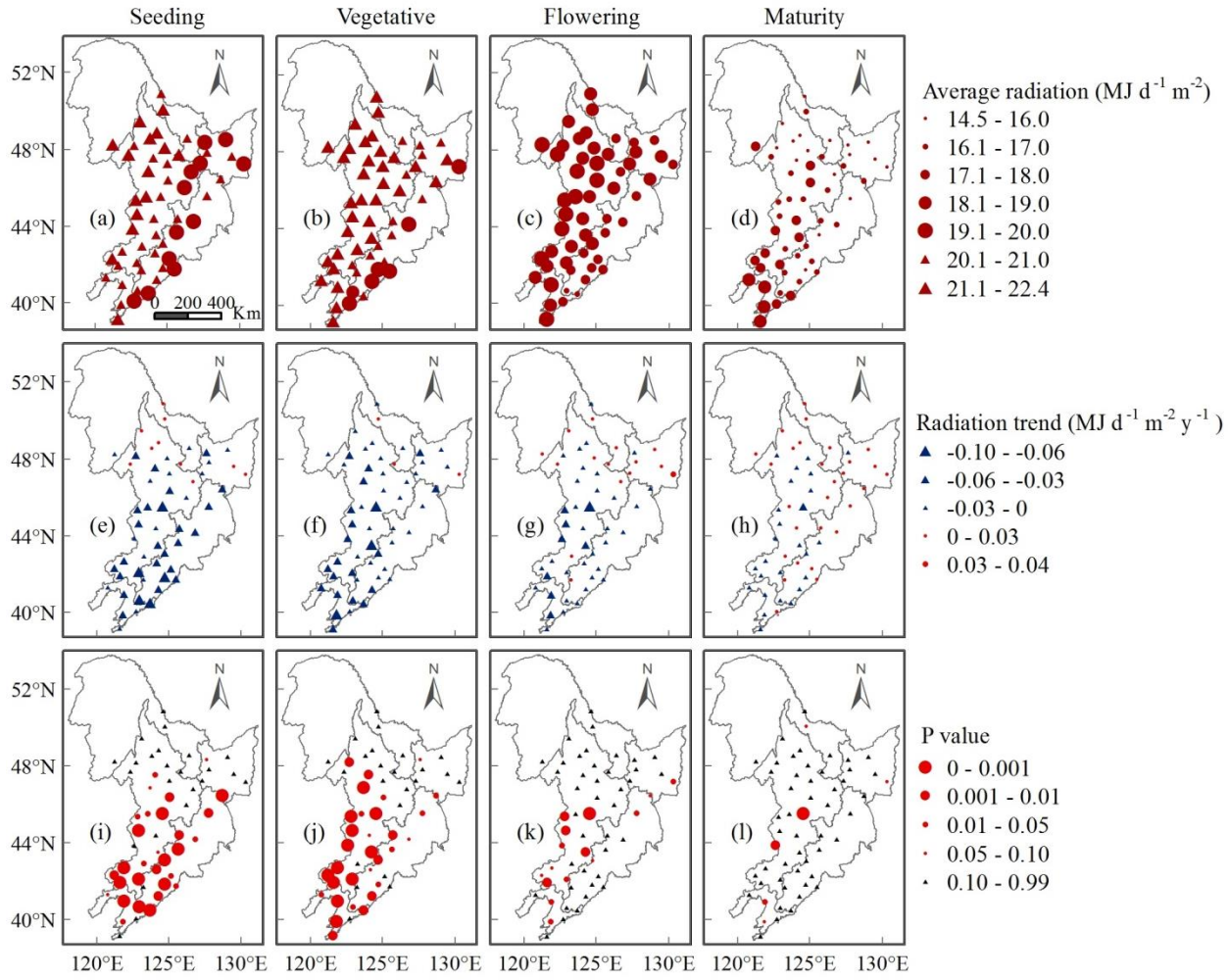
$ETa/Etc < 0.4$

1. Changes of climatic factors, drought risk and irrigation

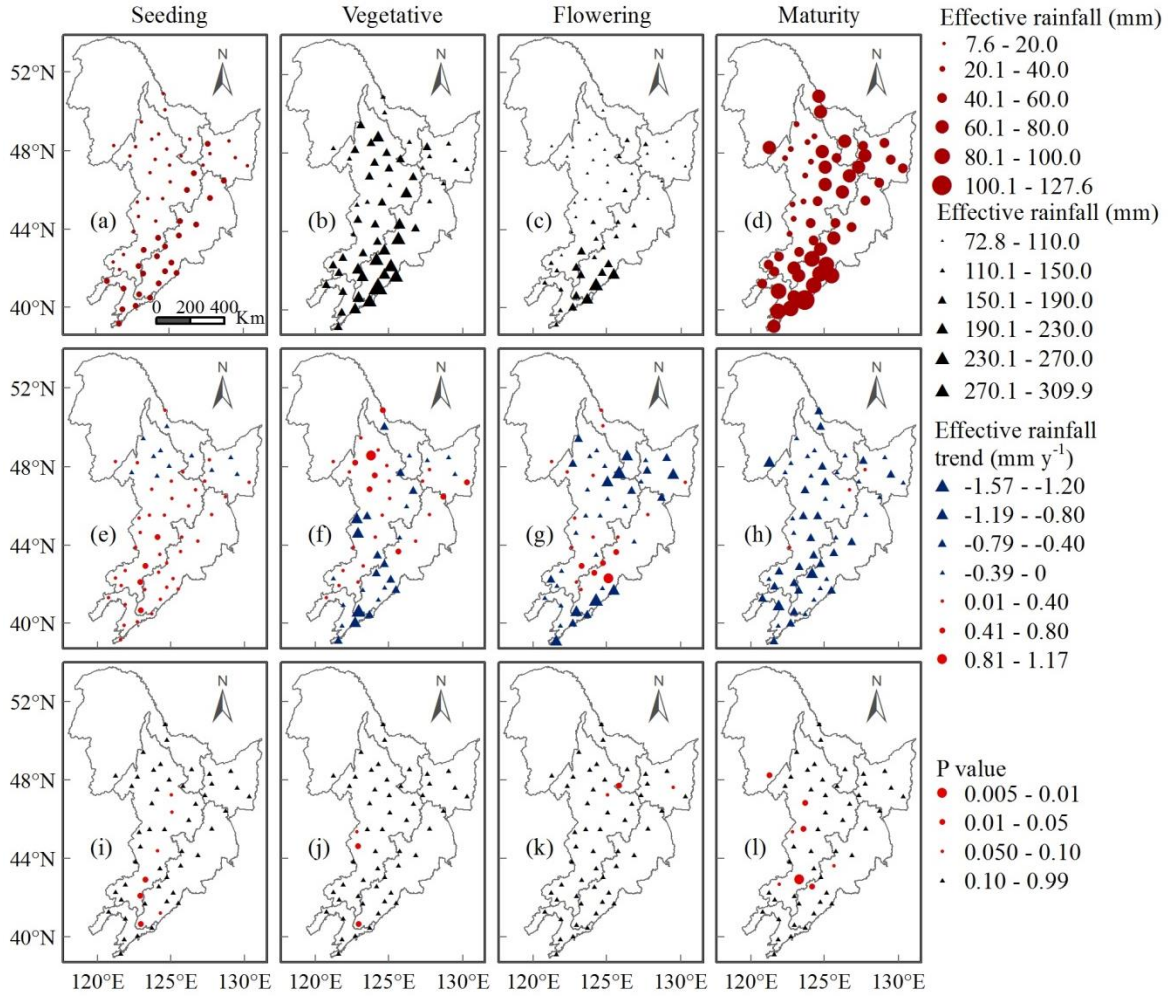
1.1 Mean temperature



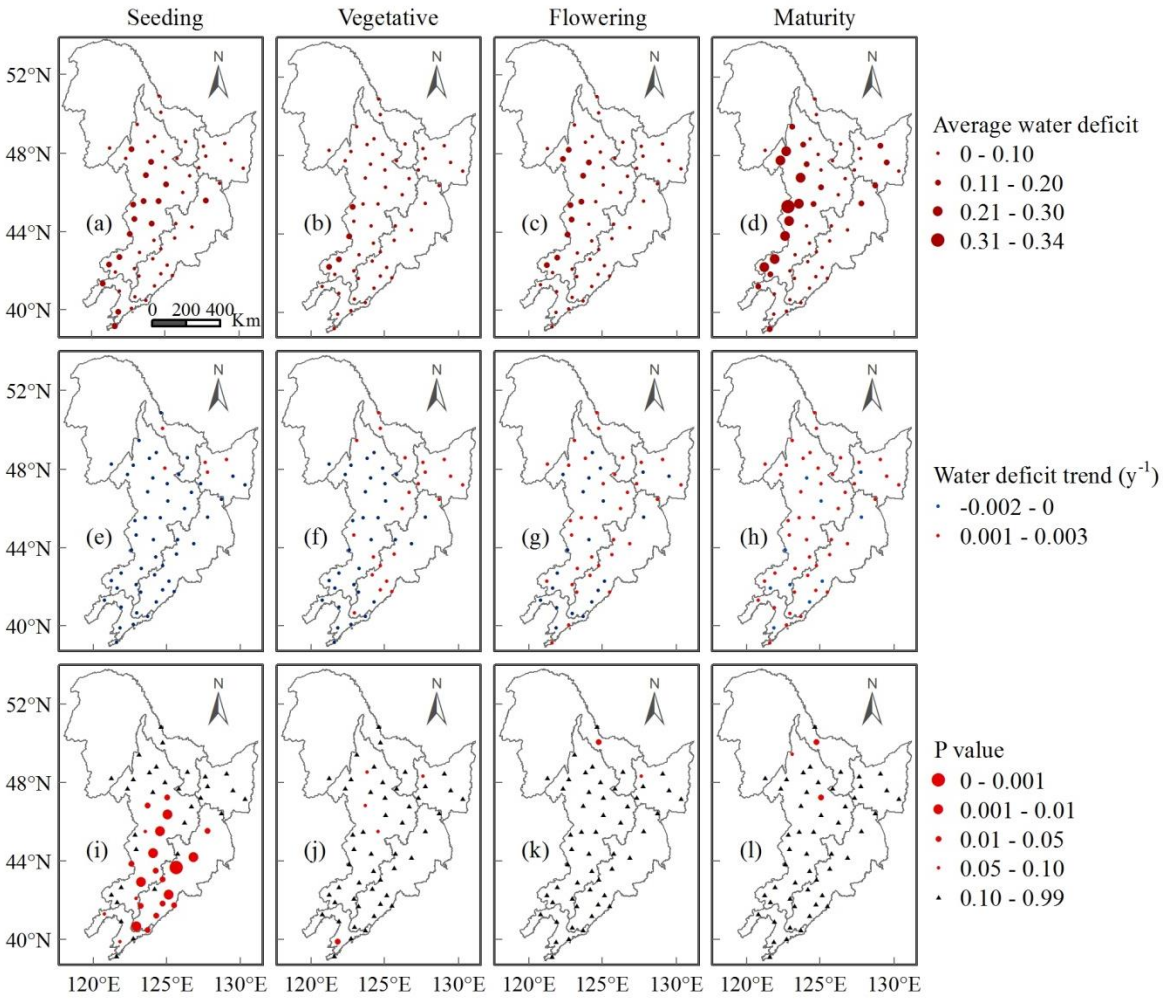
1.2 Radiation



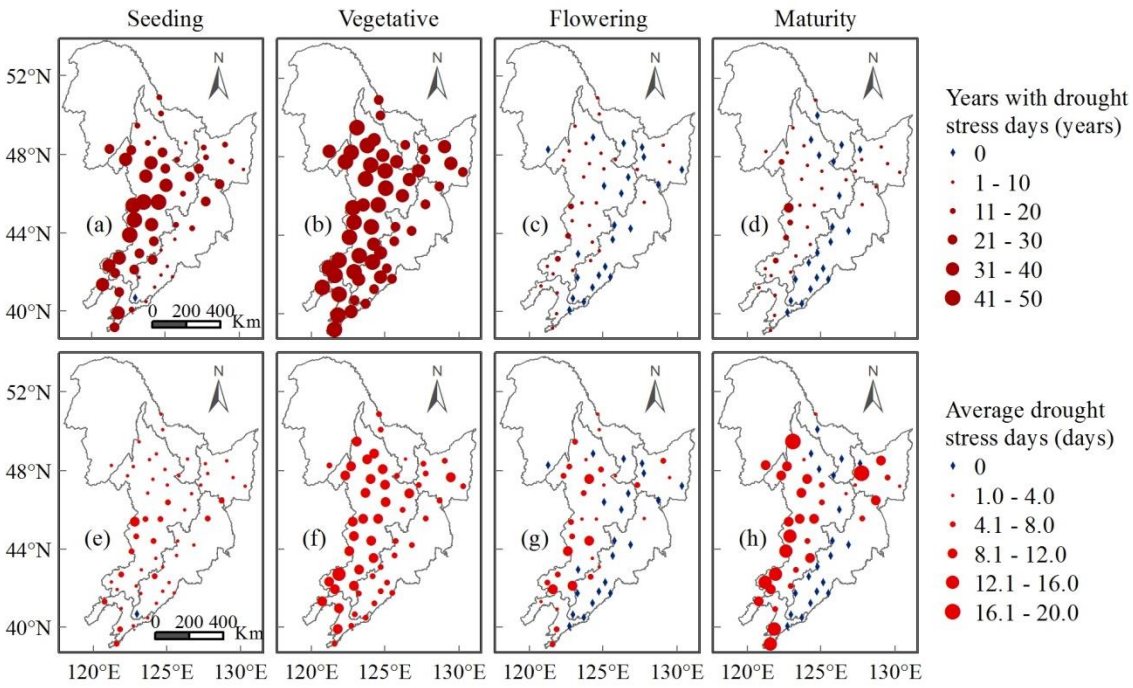
1.3 Effective rainfall



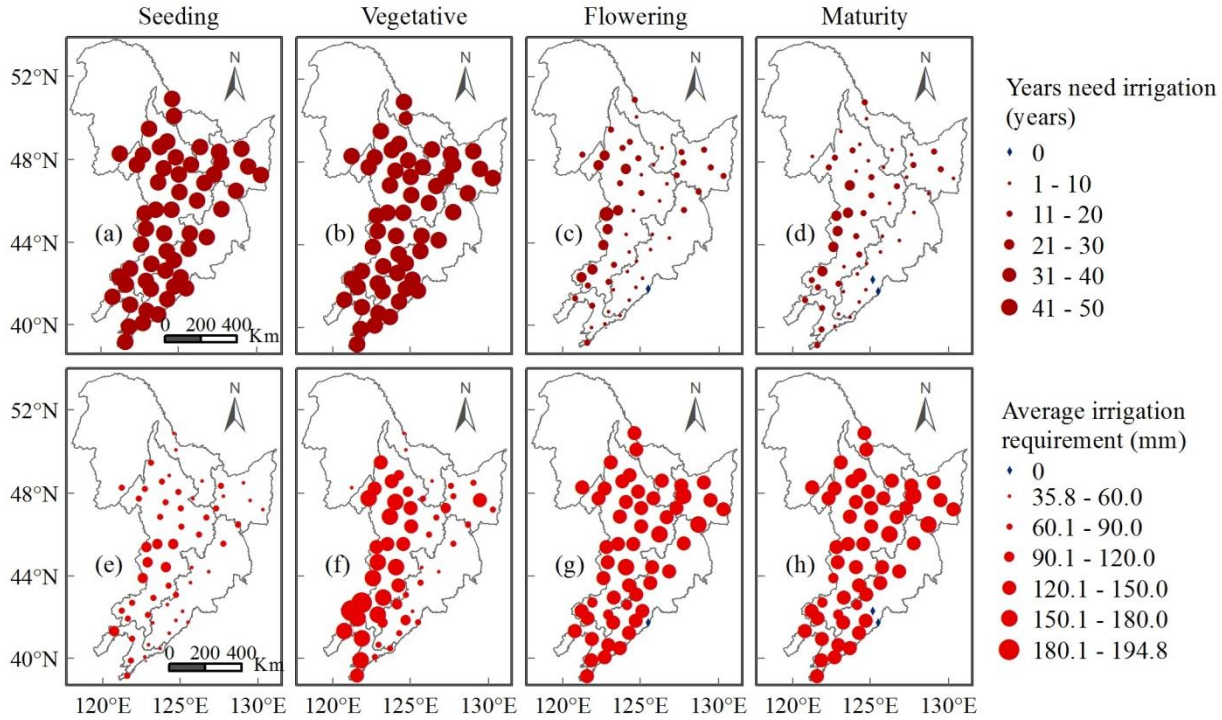
1.4 Water deficit



1.5 Drought stress days



1.6 Irrigation requirement



Impacts of climatic factors, drought risk and irrigation requirement on maize yield

$$Y = Y_0 + \alpha_{st} Y_r + \beta_s T_s + \beta_v T_v + \beta_f T_f + \beta_m T_m + \chi_s R_s + \chi_v R_v + \chi_f R_f + \chi_m R_m$$
$$+ \delta_s P_s + \delta_v P_v + \delta_f P_f + \delta_m P_m + \gamma_s A_s + \gamma_v A_v + \gamma_f A_f + \gamma_m A_m + X_s + \varepsilon$$

- A linear mixed model was used to estimate the effects of climatic variables on crop yield, and there are 2200 observations in each mixed model,
- To investigate the effect of drought stress, four configurations of the mixed model were considered
- Mean temperature, radiation and effective rainfall were the three basic climatic factors included, while water deficit, drought stress days, ETa and irrigation requirement were used separately each time with the three basic climatic factors. Year was included to represent variety, Station was used as random effects.
- The correlation analysis and the variance inflation factor (VIF) test were performed for each mixed model including all the variables to test the multicollinearity

Table 2 Regression models of maize yield for mean temperature (Tmean), radiation (R), effective rainfall (Peff) and either water deficit (Wd), drought stress days (Dsd), actual evapotranspiration (ETa) or irrigation requirement (Ir) in different maize phases.

	Seeding	Vegetative	Flowering	Maturity	Intercept	year	R^2	RMSE
Tmean (°C)	82.0***	-0.9	-8.8	53.8†	-322.6	143.9***	0.80	1216.7
R (MJ d^{-1} m^{-2})	0.8	106.1***	-100.8***	72.9**				
Peff (mm)	-10.6***	-1.3*	-3.0***	-0.6				
Wd	-5287***	-3978***	-1453***	-784*				
Tmean (°C)	55.5*	-59.0	-47.1	83.3**	1459.0	144.1***	0.79	1237.7
R (MJ d^{-1} m^{-2})	-9.4	61.1*	-121.1***	81.0**				
Peff (mm)	-4.5*	0.9†	-2.1***	-0.1				
Dsd (days)	-56.1***	5.1	-58.7**	-21.2*				
Tmean (°C)	38.0†	-66.4	-56.1	77.5*	1134.0	149.3***	0.79	1235.2
R (MJ d^{-1} m^{-2})	-25.6	76.6*	-178.6***	60.6*				
Peff (mm)	-7.0**	-0.1	-2.6***	- 0.9				
ETa (mm)	12.7**	1.3	10.5***	5.1*				
Tmean (°C)	80.0***	16.0	-33.6	49.7	-314.4	140.3***	0.79	1223.9
R (MJ d^{-1} m^{-2})	15.7	101.3***	-97.0***	93.7***				
Peff (mm)	-6.4***	-0.9	-3.2***	-0.3				
Ir (mm)	-9.3***	-3.9***	-4.1***	-2.1***				

Significance levels: ***P <0.001, **0.001 ≤ P <0.01, * 0.01 ≤ P <0.05, † 0.05≤ P <0.1

Conclusions and perspectives

- Higher mean temperature in the seeding and maturity phases would be beneficial for maize yield
- Excessive rainfall would damage maize yield, in particular in the seeding and flowering phases
- Water deficit in all growth phases would reduce maize yield, the effect of drought stress was particularly strong in the seeding and flowering phases
- Irrigation and drainage systems construction is highly needed in future maize production in Northeast China

Thank you for your attention!