Evaluating effects of agricultural drought and flood abrupt alternation on cotton growth

Qian Long, Xiaohong Chen

Center for Water Resources and Environment
Sun Yat-Sen University

Long Qian, Huayue Meng, Xiaohong Chen*, Rong Tang. 2023. Evaluating agricultural drought and flood abrupt alternation: A case study of cotton in the middle-and-lower Yangtze River, China. ***Agricultural Water Management***, 283 (2023) 108313

OUTLINE

I. Background

II. Methodology

III. Results

IV. Conclusion

Background

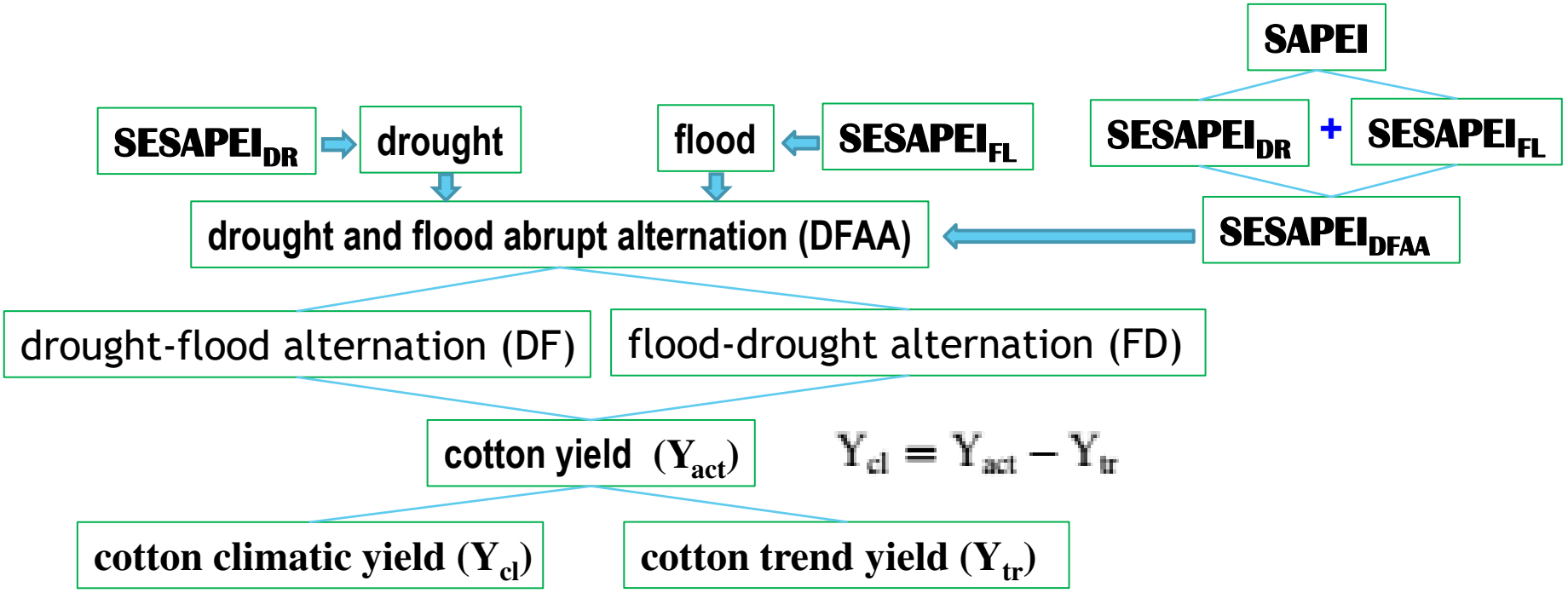
- Both water deficit and excess water in soils, arising from drought and flood disasters, can inhibit crop roots from absorbing water and fertilizer, thus affecting crop growth and yield
- Furthermore, due to increasing climate change, the uneven distribution of precipitation within the year facilitates the occurrence of drought and flood abrupt alternation (DFAA)
- DFAA events occur objectively across the growing period of local crops
- however, their impacts on crop yields differ from those of individual drought and flood stress

- this work provides guidance for monitoring and reducing cotton DFAA disasters by identifying the high-risk regions and periods
- More importantly, by examining the influence of DFAA disasters on cotton responding to drought and flood
- To provide regional-scale evidence for developing comprehensive planning for irrigation and drainage, so as to improve water use efficiency in agriculture

Methodology

technical route

- the middle-and-lower Yangtze River, China is taken as a case study
- to identify and analyze cotton DFAA events
- to further explore the potential influence of DFAA on cotton yield in response to drought and flooding at a regional scale



Methodology

Identification of cotton DFAA events

The standardized antecedent precipitation evapotranspiration index (SAPEI), an improved index from the SPEI, was used to monitor drought and flood disasters

$$APEI_i = \sum_{i=0}^{m} K^i \cdot \Delta W_i \qquad W = P - ET_c \qquad ET_c = K_c \cdot ET_0$$

where *W* is the Water budget, P, ET_c and ET_0 are the daily precipitation, daily cotton potential evapotranspiration, and daily reference crop potential evapotranspiration, respectively. K_c is the crop coefficient of cotton and was calculated with the single crop coefficient method provided by FAO

- **K^i is the decay constant to quantify the contribution fraction of precipitation on Day i, and m is the number of previous days**
- **According to previous research, m and K^i were empirically set to 100 and 0.955, respectively**

The SAPEI is obtained from the APEI series:

- **First, the probability density distribution of a three-parameter log-logistic function F(x) was employed to fit the APEI series over the study period**
- **then, the SPAEI was obtained from the standardized values of F(x)**

SAPEI < - 0.50 ⇨ daily drought; SAPEI > 0.50 ⇨ daily flood conditions

Methodology

Identification of drought, flood, and DFAA events

The intensity of a DFAA event can be expressed as:

$$SESAPEI_{DFAA} = SESAPEI_{FL} + SESAPEI_{DR}$$

To accurately quantify the intensities of cotton DFAA events over given periods, the accumulative excessive value of the SAPEI over a given period was used. This index was defined as the Sum of Excessive SAPEI (SESAPEI for short):

$$SESAPEI_{FL} = \sum_{j=1}^{n} \sum_{i=1}^{m} (SAPEI_i - 0.5) \qquad SESAPEI_{DR} = \sum_{j=1}^{n} \sum_{i=1}^{m} (|SAPEI_i| - 0.5)$$

where $SESAPEI_{FL}$ and $SESAPEI_{DR}$ indicate the intensity of flood and drought over a given period, respectively. n is the number of flood or drought events during the calculation period; m is the days of the calculation periods

- **0.5 corresponds to the absolute value of thresholds for drought (SAPEI<- 0.50) and flood (SAPEI>0.50).**

- **a cotton drought event was identified when the drought conditions (i.e., SAPEI<- 0.50) lasted for at least 10 days**
- **a cotton flood event was defined as three consecutive days under flood conditions (i.e., SAPEI>0.50)**

Methodology

Cotton climatic yield

- Cotton climatic yield (Y_{cl}) indicates the interannual yield fluctuation that is determined by short-term climate variations, such as drought and flood disasters
- It was calculated as the difference between the collected actual cotton yield (Y_{act}) and the trend yield (Y_{tr}):

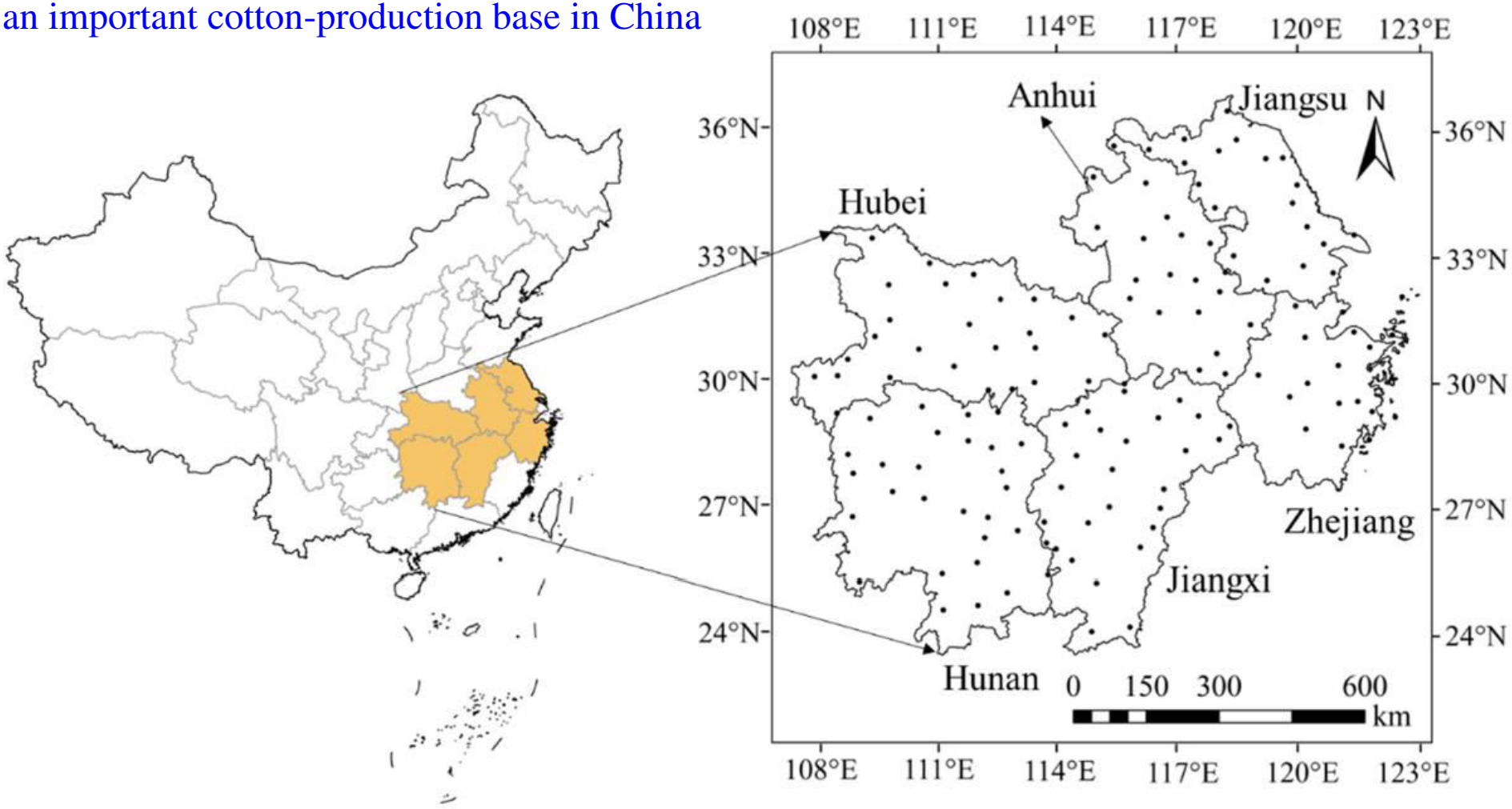
$$Y_{cl} = Y_{act} - Y_{tr}$$

cotton trend yield (Y_{tr}) was obtained by fitting a quadratic polynomial curve

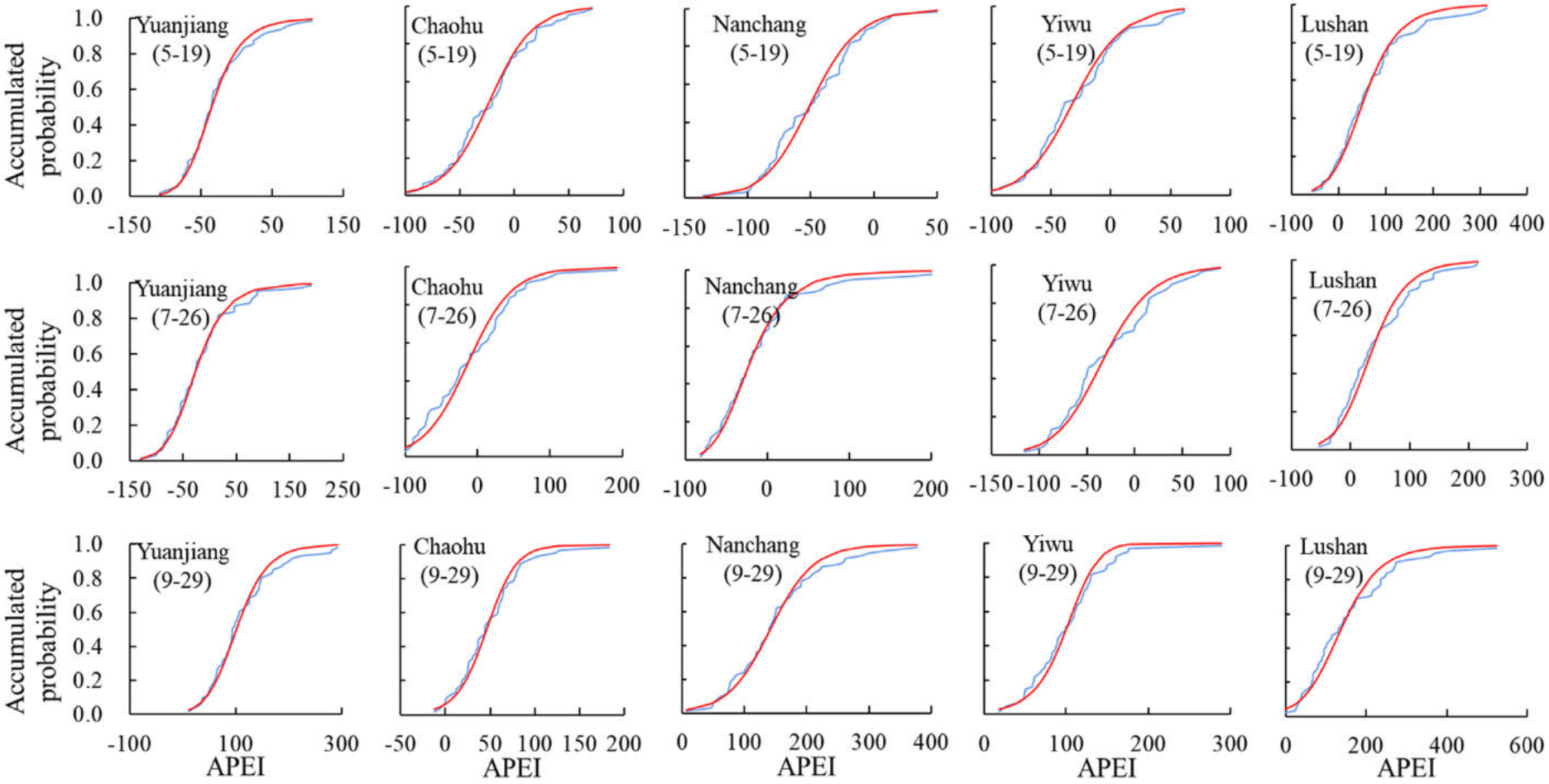
Results

Case study area ---- the middle-and-lower Yangtze River (MLRYR), China
DFAA cotton during 1961–2020

one of the most DFAA-prone areas in China
an important cotton-production base in China



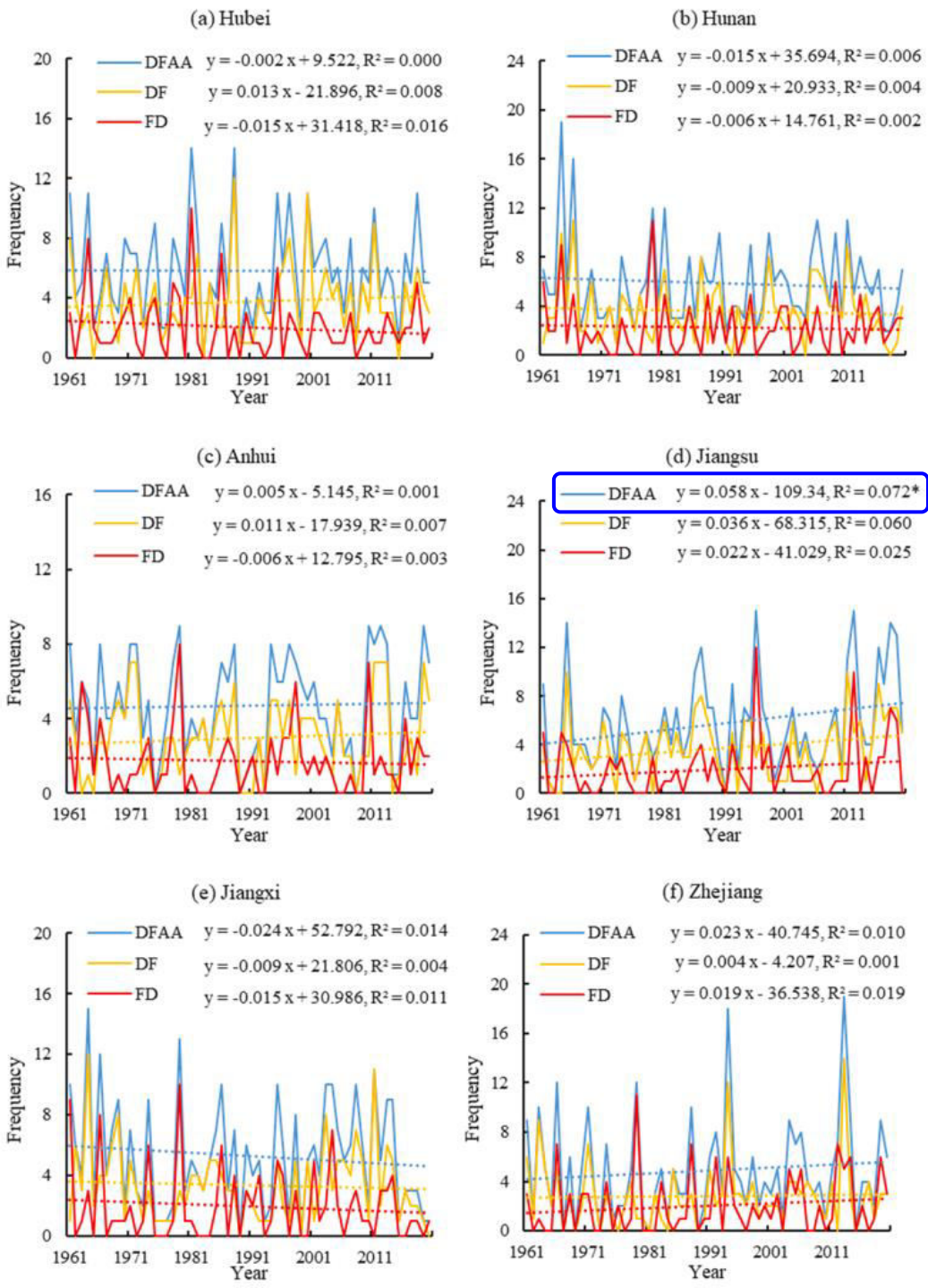
Results



- Comparison between the empirical distribution of the APEI series (blue line) and the theoretical distribution of the log-logistic distribution (red line)
- Five case study districts were selected to examine the assumed probability distribution function ---- they produce large amounts of cotton and are located in different geographic orientations

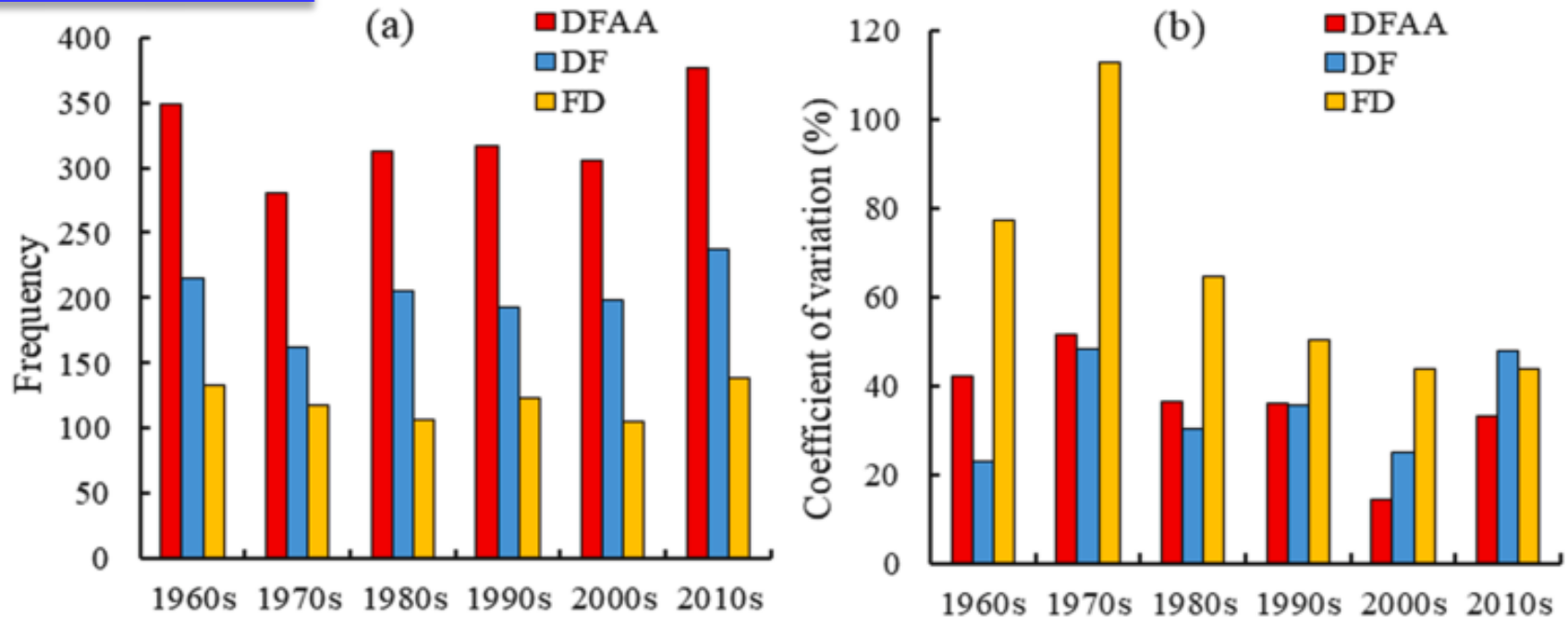
Results

- Temporal trends of the frequencies of drought and flood abrupt alternation (DFAA) during the whole cotton growth period in the MLRYR
- * indicates $p < 0.05$



- the DF frequency was larger than the FD frequency
- the temporal trends of the cotton DFAA, DF, and FD frequencies were not significant in most provinces
- however, a significant upward trend ($p < 0.05$) of cotton DFAA frequency was detected in Jiangsu Province (d)

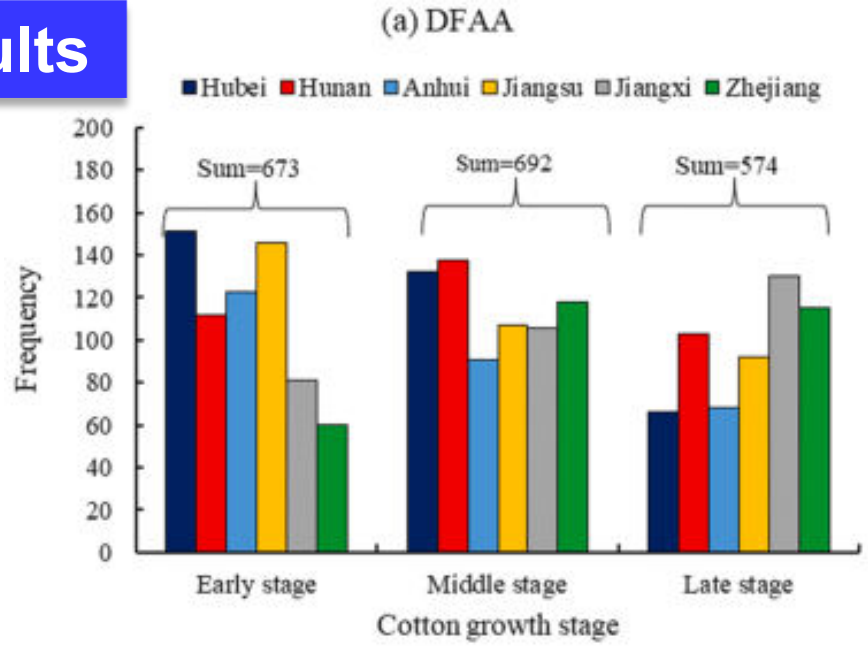
Results

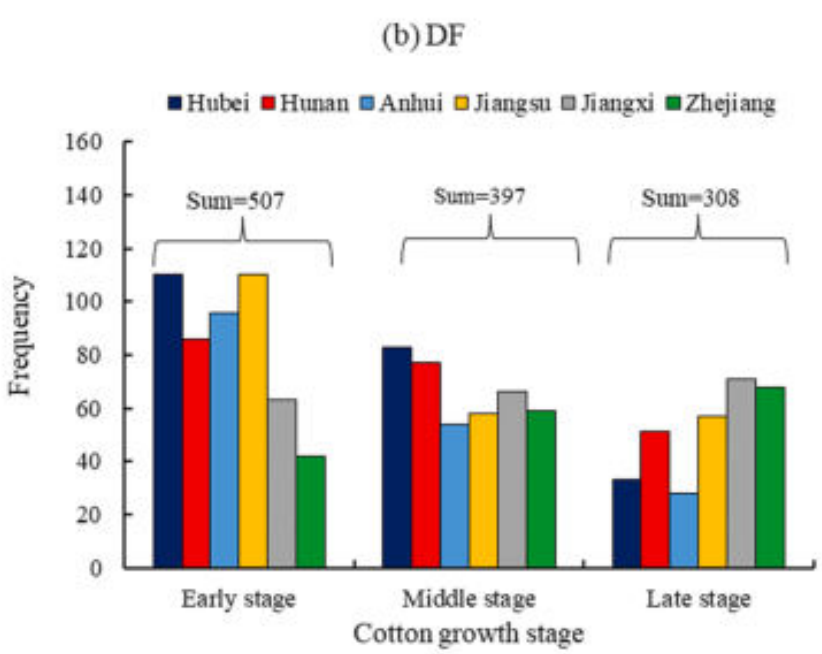


- **The frequencies (a) and coefficient of variation (b) of the drought and flood abrupt alternation (DFAA) in different decades during the whole cotton growth period in the MLRYR**

- **the most recent decade (2010s) had seen the greatest number of cotton DFAA, DF and FD events**
- **the interdecadal fluctuations of cotton DFAA and DF frequencies peaked in the 1970s (b)**
- **the frequency of cotton DF was higher than that of cotton FD in all decades**
- **the variability of cotton FD was greater than that of cotton DF in all decades except the 2010 s**

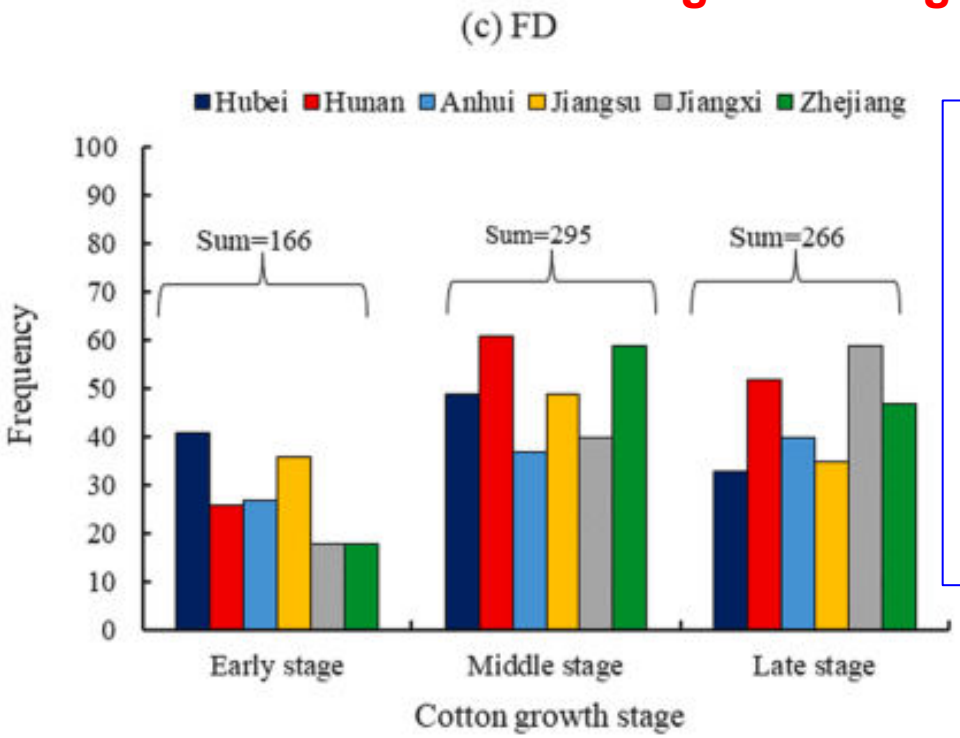
Results





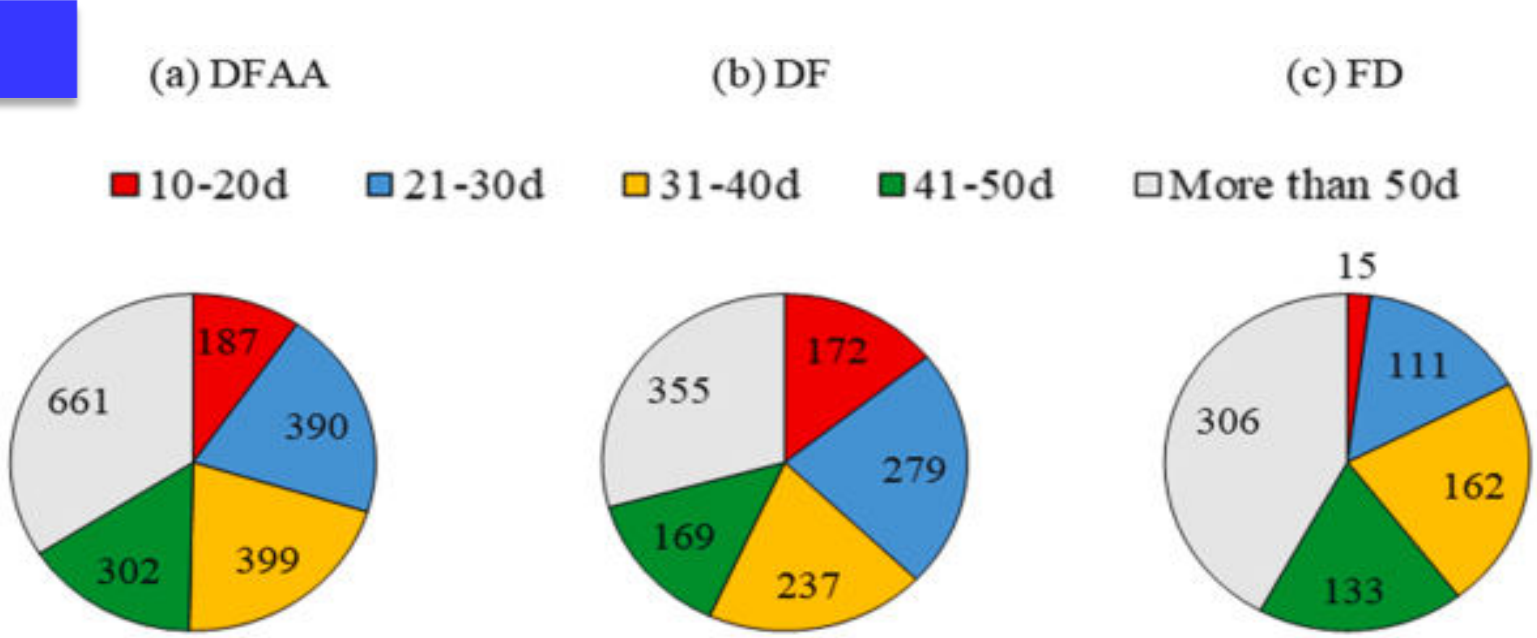
frequencies of DFAA at different cotton growth stages

- **cotton DFAA events are more likely to occur during the early and middle stages than during the late stage**
- **cotton at the early stage was more likely to suffer DF events than at the two later stages**



- **it is interesting that the cotton DF and FD events had adverse intergrowth-stage distributions**

Results



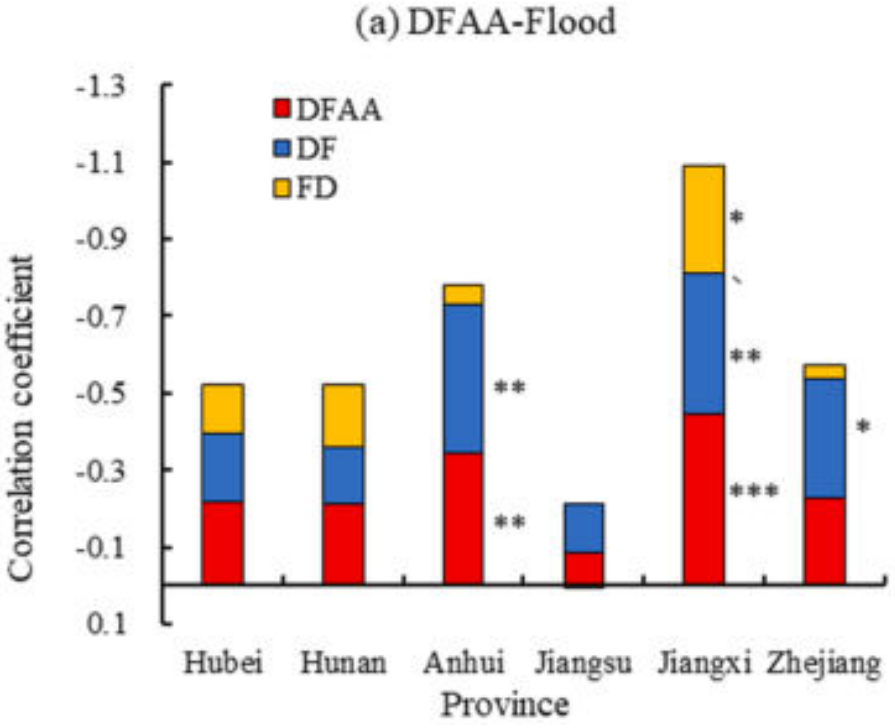
Distribution proportions of the duration of drought and flood abrupt alternation (DFAA) during the whole cotton growth period in the MLRYR. DFAA includes drought-flood alternation (DF) and flood-drought alternation (FD)

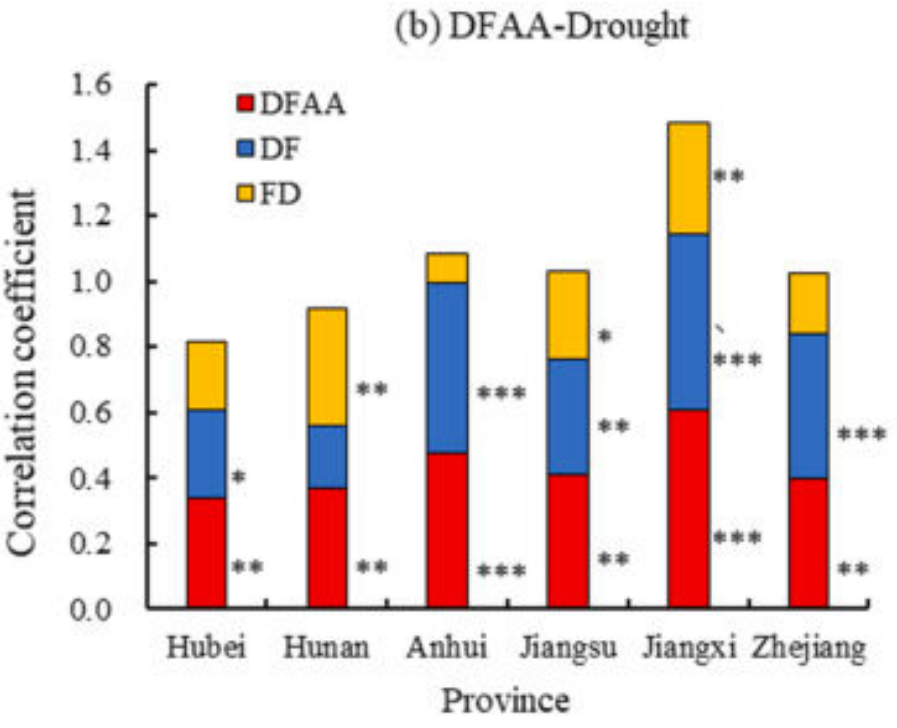
The numbers displayed in the figure indicate the frequencies of cotton DFAA, DF, and FD events

long-term events were still the major embodied form for cotton DFAA events

the DF frequency exceeded the FD frequency in each duration category, reconfirming the previous result that cotton in the MLRYR was much more prone to DF than to FD

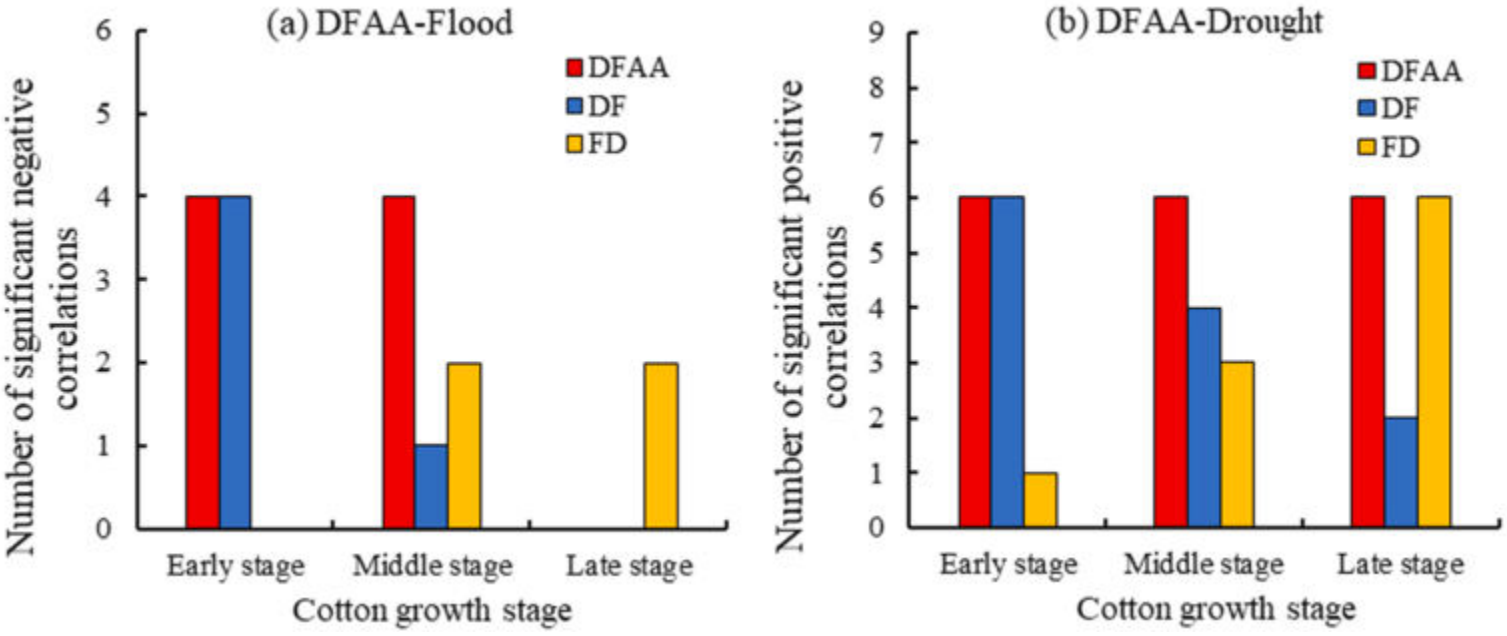
Results





- when cotton drought occurred more frequently, cotton DFAA events would be more likely to occur
- * , * *, and * ** indicate $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively

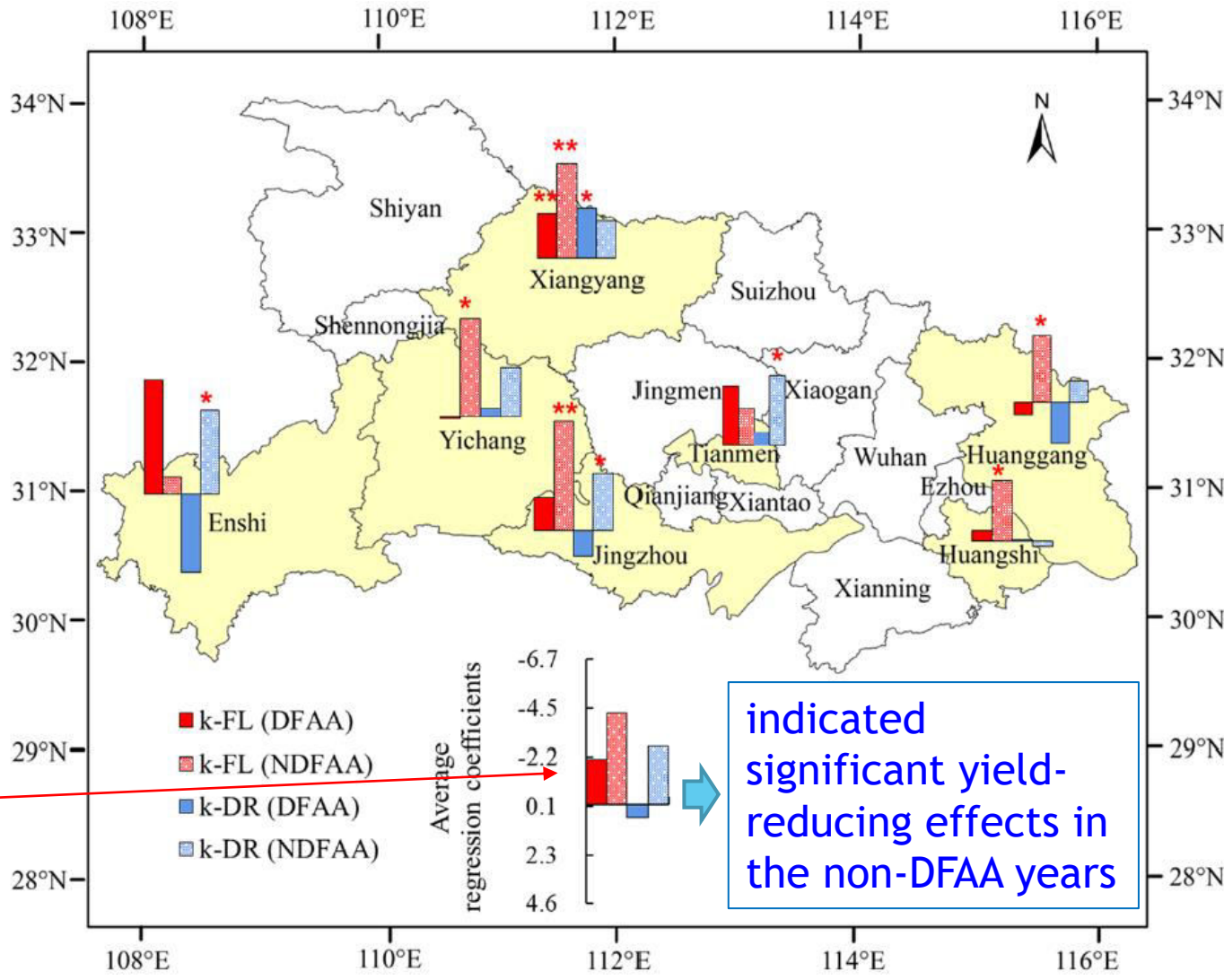
Results



- the “DFAA-Flood” and “DFAA-Drought” relations varied with growth stages
- this is probably because that cotton DF events occurred frequently in the early stage
- but FD events occurred frequently in the late stage

The effects of drought and flooding on cotton yield as affected by DFAA

- the significance of the regression models was much greater in the non-DFAA years than in the DFAA years, as demonstrated by the much higher R^2 value and the significance level
- the values of averaged regression coefficients of the flood variable (X_{FL}) and drought variable (X_{DR}) were negative and low in the non-DFAA years (k-FL= - 4.209, k-DR= -2.674)



non-DFAA years: $Y_{cl} = -7.660^{***}X_{FL} - 2.448X_{DR} + 392.362^{**}$ $(R^2 = 0.714, n = 16, p < 0.001)$

DFAA years: $Y_{cl} = -1.305X_{FL} + 2.001X_{DR} - 1.362$ $(R^2 = 0.145, n = 15, p = 0.391)$

Conclusions

- The SAPEI is applicable for simulating cotton drought and flood and is efficient in capturing the effects of drought and flood on cotton yield
- the SAPEI-based approach well characterized cotton DFAA events, especially capturing numerous short term events (<20 d)
- In the most recent decade over the past six decades, the frequency of cotton DFAA events in the MLRYR, including both cotton DF and FD events, reached a historic high
- the only significant ($p < 0.05$) trend of cotton DFAA events was found in Jiangsu Province and it was an upward trend
- These results imply a near-term high risk of cotton DFAA disasters in the MLRYR.
- although cotton DF and FD events differed greatly in their high-risk regions, the northeastern MLRYR was considered the most cotton DFAA-prone region
- The early and late growth stages of cotton had relatively low risks of cotton FD and DF, respectively
- the middle growth stage was generally the period most affected by DFAA events. cotton DF events occurred more frequently than FD events
- relations between the cotton DFAA frequency and the drought frequency were very significant and positive in all the areas in the MLRYR, demonstrating that more cotton drought events tend to result in more cotton DFAA events
- effects of drought and flooding on cotton climatic yield were significantly stronger in the non-DFAA years than in the DFAA years

Hence, at a regional scale, it is confirmed that the occurrence of cotton DFAA can reduce the yield-reducing effects of cotton drought and flood events, which is fairly in accord with previous field experimental reports

Thanks for your attention!