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## **A Spatio-Temporal Analysis of Climate Change on Corn Yield**

**Zidong Wang, Department of Agricultural Economics, Texas A&M University [markcp9@tamu.edu](mailto:markcp9@tamu.edu)**

**Montalee Kapilakanchana, Department of Agricultural Economics, Texas A&M University**

**Bruce A. McCarl, Regents Professor, Department of Agricultural Economics, Texas A&M University**

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# A Spatio-Temporal Analysis of Climate Change on Corn Yield

Zidong Wang, Montalee Kapilakanchana and Bruce A. McCarl  
Department of Agricultural Economics, Texas A&M University



## Introduction

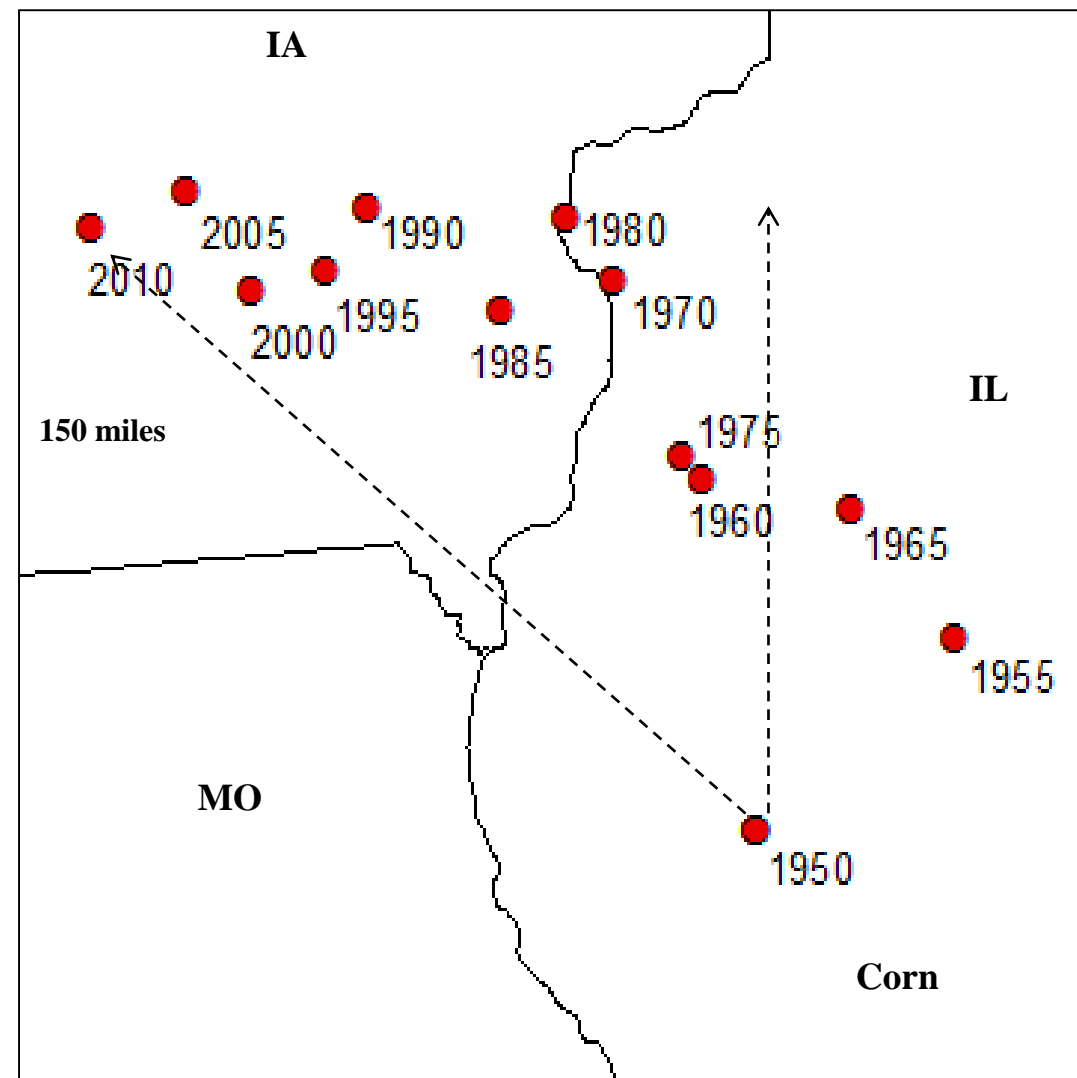


Fig. 1 Shift of corn production weighted centroid 1950-2010

- 1) Climate change alters local weather conditions such as temperature, precipitation and frequency of extreme events, affecting crop yield.
- 2) Crop yields are spatially-correlated due to similar weather and soil conditions in nearby regions.
- 3) Spatial correlation might change over time due to global climate change and adopted technologies.
- 4) Spatial correlations might exhibit localized structure rather than global spatial structure due to following reasons: similar production conditions; natural boundaries; regional weather events.

**Objective:** Identify levels of spatial correlation for corn and whether climate is altering them.

## Data

**Study region:** Nine states in North Central US, contributing to more than 70% of US corn production in year 2014.

$Y_{kt}$ : Corn yield (Bushel/Acre) in county k in year t

$X_{kt}$ : Weather data including average temperature (tavgA) and total precipitation (prcpA) as well as squared terms and standard deviation.



Fig. 2 Study region

## Model

- Equations (1)-(2) specify a basic OLS yield model assuming  $\phi_{kt}$ , the latent component, is characterized by a normal distribution with mean zero.
- Equations (1)-(6) contains a spatial-temporal setup for  $\phi_{kt}$  with: a) the conditional mean vector  $\phi_t$  evolves over time over a multivariate AR(1) model with temporal dependence parameter  $\gamma$ ; and b) a variance-covariance matrix  $\mathbf{W}$ , which is a K-by-K neighbor matrix of spatial proximity with 1 representing adjacent areas, 0 representing the other, and  $\rho$ , which is a global spatial dependence parameter.
- Equations (7)-(9) introduced localized spatial structure based on the ST.Global model.  $W^+$  is the vector representation of the non-zero elements in  $\mathbf{W}$  and  $V^+$  is its logit transformation, which is modeled with a multivariable normal prior.

Table 1. Model Specification

OLS	$Y_{kt} \sim \text{Normal}(u_{kt}, \nu^2)$	(1)
	$u_{kt} = X_{kt}^T \beta + \phi_{kt}$	(2)
ST.Global	$\phi_t   \phi_{t-1} \sim \text{MVN}(\gamma \phi_{t-1}, \tau^2 Q(\mathbf{W}, \rho)^{-1})$ for $t = 2, \dots, T$	(3)
	$\phi_1 \sim \text{MVN}(\mathbf{0}, \tau^2 Q(\mathbf{W}, \rho)^{-1})$	(4)
	$\tau^2 \sim \text{IG}(a, b)$	(5)
	$\rho, \gamma \sim \text{Unif}(0, 1)$	(6)
ST.Localised	$w^+ = \{w_{kj}   k \sim j\}$	(7)
	$v^+ = \log\left(\frac{w^+}{1-w^+}\right)$	(8)
	$f(v^+   \zeta^2, \mu) \propto \exp\left[\frac{-1}{2\zeta^2} (\sum_{v_{ik} \in v^+} (v_{ik} - \mu)^2)\right]$	(9)

## Results

- 1) Corn yield benefits from warm conditions and more rain but exhibits a U shape (turning point at 10.59 °C and 913 mm).
- 2) OLS model showed a stronger climate effect, while such effects are smaller in the two spatial models.
- 3) Strong spatial correlation of yields in adjacent regions (both close to 1) and moderate temporal dependence (0.65 and 0.42 respectively) were found in the two ST models.

Table 2. Model Results

	OLS	ST.Global	ST.Localised
(Intercept)	-19.12 *	88.14 *	81.29 *
TMP	18.86 *	3.51 *	3.40 *
TMP <sup>2</sup>	-0.89 *	-0.17 *	-0.16 *
TMP_sd	-13.52 *	-0.08	1.07
PRCP	17.16 *	1.45	2.80 *
PRCP <sup>2</sup>	-0.94 *	-0.04	-0.12 *
PRCP_sd	-15.80 *	-0.96 *	-0.91 *
$\nu^2$	-	423.08	0.25
$\tau^2$	-	11.59	204.39
$\rho$	-	1.00	1.00
$\gamma$	-	0.65	0.42
$\zeta^2$	-	-	220.97
DIC	209,296	131,918	51,453

Note: \* means estimates is significantly different from 0 at 95% quantile-based confidence interval

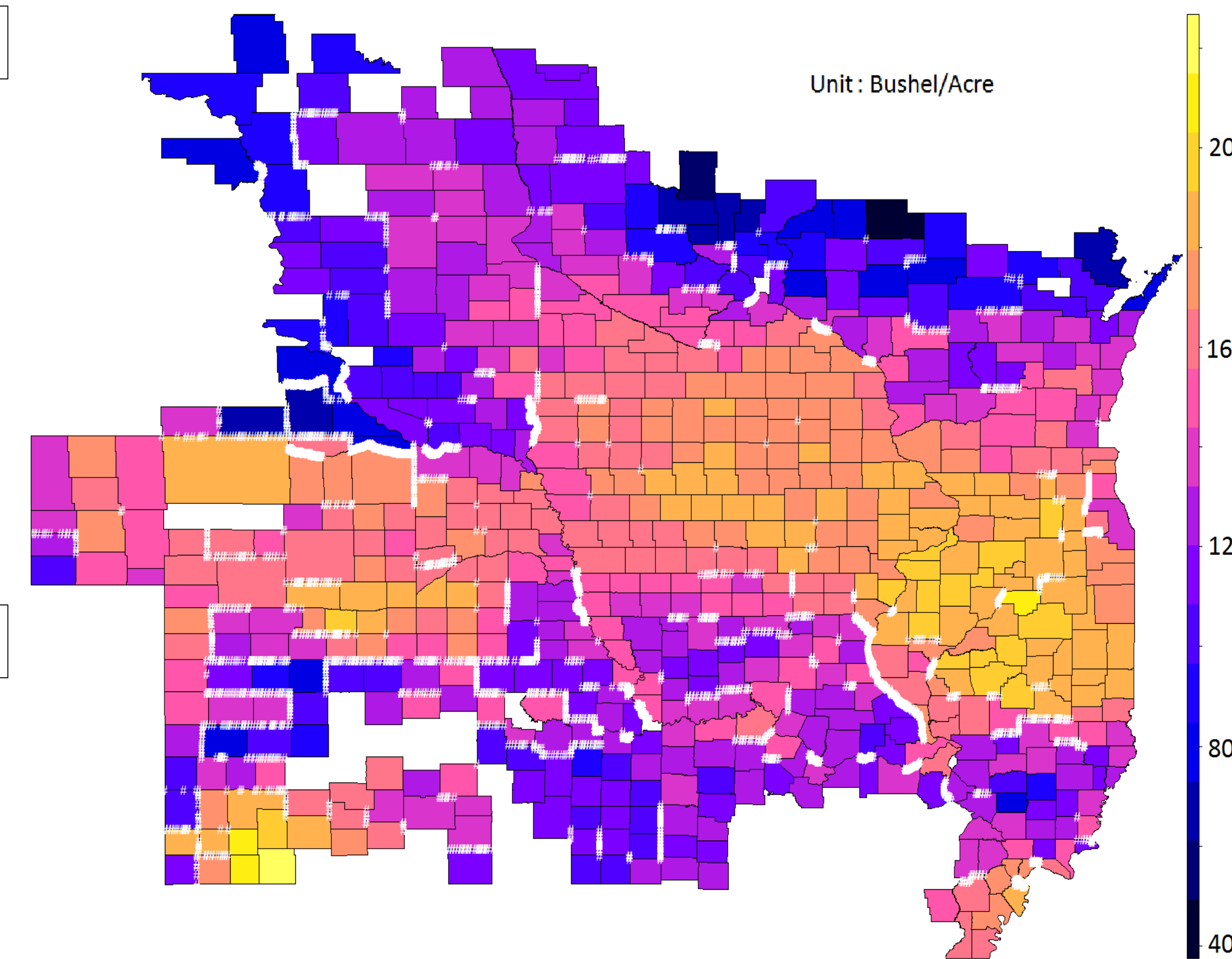


Fig. 3 Predicted localized structure with corn yield in 2007

## Discussion

- Variation in climate variables and localized spatial structure
  - Continuing from the OLS estimates in result (2), one explanation was that large variations in rain or temperature indicated for appearance of extreme weather events such as drought, flood or heat waves, reducing crop yield.
  - Goodwin et al. (2015) argued that extreme weather events were more likely to be regional in scale, contributing to the spatial correlation of the crop yield. This explained why the negative impact of climate variable variation faded away once spatial structure was allowed to correct the spatial correlation in  $\phi_{kt}$  in model ST.Global and ST.Localised
- $\zeta^2$  is the variance parameter for  $V^+$ , the logit transformation of the non-zero elements in  $\mathbf{W}$ . As  $\zeta^2 \rightarrow 0$  the distribution of  $V^+$  degenerates to its mean  $\mu$  and ST.Localised becomes ST.Global. In this study estimated  $\widehat{\zeta^2}$  is significantly different from zero, providing strong evidence for localized spatial structure.
- A majority of the dividing lines were horizontal, indicating a larger yield variation in south-north (or potentially from the heat constraint).