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Emanuele Massetti
Robert Mendelsohn
Shun Chonabayashi

CESIFO WORKING PAPER NO. 5148
CATEGORY 10: ENERGY AND CLIMATE ECONOMICS
DECEMBER 2014

CESifo *Working Paper No. 5148*

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Abstract

Farmland values have traditionally been valued using seasonal temperature and precipitation. A new strand of the literature uses degree days over the growing season to predict farmland value. We find that degree days and daily temperature are interchangeable over the growing season. However, the way that degree days are used in these recent studies is problematic and leads to biased and inaccurate results. These new findings have serious implications for any study that copies this methodology.

JEL-Code: Q120, Q240, Q510, Q540.

Keywords: degree days, climate change impacts, agriculture, land values.

*Emanuele Massetti**
Georgia Institute of Technology
685 Cherry St NW
USA – Atlanta, GA 30332-0345
emanuele.massetti@pubpolicy.gatech.edu

Robert Mendelsohn
Yale University
195 Prospect St.
USA – New Haven, CT 006511
robert.mendelsohn@yale.edu

Shun Chonabayashi
Cornell University
303 Fernow Hall
USA – Ithaca, NY 14853
sc2258@cornell.edu

*corresponding author

December 2014
Massetti gratefully acknowledges funding from the Marie Curie IOF Cli-EMA “Climate change impacts - Economic modeling and analysis”. We would like to thank Wolfram Schlenker and Michael Roberts for sharing his degree day data. The authors would also like to seminar participants at Yale University, the NBER Environmental Economics Spring Institute, the AERE Summer Conference at Banff, and FEEM for useful comments and insights.

1 Introduction

Most cross sectional (Ricardian) studies of farmland values and net revenues (Mendelsohn, Nordhaus, and Shaw 1994; Mendelsohn and Dinar 2003; Schlenker, Hanemann, and Fisher 2005; Massetti and Mendelsohn 2011; Massetti and Mendelsohn 2012) rely on seasonal temperature and precipitation to measure climate.

In a path breaking paper, an alternative measure of climate that depends on degree days is proposed by Schlenker Hanemann and Fisher 2006 (SHF). A number of hypotheses were advanced in SHF concerning how best to apply degree days to study crops. Unfortunately, the degree day data used in SHF was fabricated from monthly measurements. Although actual measurements of degree days were employed in subsequent papers (for example, Schlenker and Roberts 2009 - SR 2009 henceforth), the hypotheses in SHF were never tested with actual degree day data. This paper addresses this omission by testing the hypotheses in SHF with actual measurements of degree days. This is important for several reasons. The fabricated degree day data does not match actual data. The errors in the fabricated data are correlated with temperature. The hypotheses in SHF generally fail statistical tests with actual data. The way that SHF uses degree days leads to biased and inaccurate results. The subsequent literature that has adopted this methodology is likely subject to the same problems.

SHF adopt the standard agronomic base temperature (8°C) for measuring degree days. SHF then make a number of assumptions about how to use degree days to analyze farmland values. Several of these assumptions have been repeated by the subsequent literature relying on degree days to study yields and farmland values (for example, Schlenker and Roberts 2009; Deschênes and Greenstone 2007). 1) Temperatures above 32°C should be treated as though they are 32°C. 2) Cold degree days (days below 8°C) should be omitted. This is what distinguishes degree days from simply measuring daily temperature. 3) Seasonal effects within the growing season do not matter. That is, the impact of a degree day in spring is the same as it is in summer. 4) There is a threshold at 34°C above which temperatures are especially harmful. 5) The only relevant climate occurs between April 1 and September 30 (the growing season). The climate in the remaining six months of the year does not matter.

SHF do not report tests of all of these assumptions. However, they do test whether seasons within the growing season are important and whether there is a threshold at 34°C. They report both hypotheses are statistically valid using the fabricated data. They consequently recommend that degree days be summed across the entire growing season and that thresholds at 34°C be included.

In this paper, we test all of these hypotheses with a geographically and temporally detailed meteorological data set of temperature and precipitation from the North America Regional Reanalysis (NARR) (National Climatic Data Center 2012). This data set was constructed by meteorologists from weather station and other climate measurements. The data contains three hour measures of weather each day from 1979 through 2007 from which accurate measures of degree days can be calculated. We use these measures to reexamine each of the assumptions in SHF. We also test the hypotheses using degree days measured using climate data from SR 2009.

The empirical results using NARR reject all of the hypotheses in SHF. Degree days, modified degree days (assuming temperatures above 32°C are equal to 32°C), and daily temperature over the growing season are interchangeable. It makes no difference which measure one uses. Cold degree days in the growing season have a significant harmful effect. The effect of daily temperature and degree days is the opposite sign depending on whether one is in the first half or the second half of the growing season. One should not add degree days over this 6 month period. The alleged threshold effect at 34°C is peculiar to a single specification of the model. The threshold disappears with a host of alternative specifications. One should not limit degree days to April 1 through September 30. Climate outside of this period has a significant effect on farmland value and is correlated with growing season temperature. Omitting the non-growing season climate variables introduces omitted variable bias and overestimates the damage from warming. These results are robust to a number of alternative model specifications. These results are also evident using the SR 2009 daily data.

The next section of the paper reviews the methodology to test all of these hypotheses. This section also reviews the use of degree days in the agronomic literature. Section 3 examines the NARR weather data in more detail since this data is one important difference between this paper and SHF. Section 4 displays the results using this new data. The paper concludes with a discussion of the limitations of the research, the main conclusions, and the policy implications.

2 Methodology

The first cross-sectional study to examine the relationship between land value and climate (Mendelsohn, Nordhaus, and Shaw 1994) examined all agricultural counties in the United States using the following linear functional form:

$$Y_i = \boldsymbol{\beta}\, h(C_i) + \boldsymbol{\gamma} X_i + \boldsymbol{\theta} Z_i + \epsilon_i \qquad (1)$$

where Y is land value per hectare for observation *i*, $h(\cdot)$ is a generic function of the vector of climate variables, X is a set of socio-economic variables that vary over time, Z is a set of geographic and soil characteristics that are fixed over time, and ε is assumed to be a random component. Subsequent studies found that a loglinear functional form fits agricultural land values more closely than a linear model (Mendelsohn and Dinar 2003; Schlenker, Hanemann, and Fisher 2006; Massetti and Mendelsohn 2011; 2012). This study also uses a loglinear functional form so that Y_i is the log of land value per hectare. Furthermore, this study uses panel data and all time-varying variables are indexed with *t*. In this paper, we follow SHF and limit the data to counties east of the 100th meridian in order to be completely comparable with SHF. Limiting the data, in this way, however, means that the study is no longer representative of the entire agricultural sector of the United States.

Throughout this paper we use climate, the long run average weather, to measure degree days, temperature, and precipitation. The relationship between climate (long term average weather) and land values is assumed to be nonlinear. This nonlinearity has generally been captured using a quadratic model of seasonal temperature and precipitation (Mendelsohn, Nordhaus, and Shaw 1994; Mendelsohn and Dinar 2003; Schlenker, Hanemann, and Fisher 2005; Massetti and Mendelsohn 2011; Massetti and Mendelsohn 2012):

$$Y_{i,t} = \beta_0 + \sum_k \beta_{1,k} T_{i,k} + \sum_k \beta_{2,k} T_{i,k}^2 + \sum_k \beta_{3,k} P_{i,k} + \sum_k \beta_{4,k} P_{i,k}^2 + \boldsymbol{\gamma} X_{i,t} + \boldsymbol{\theta} Z_i + \epsilon_{i,t}\ , \qquad (2)$$

where $k = \{\text{winter}, \text{spring}, \text{summer}, \text{and autumn}\}$. These studies found that the squared terms are generally statistically significant and that seasonal effects are significantly different from each other.

SHF challenge this approach to modeling climate impacts and argue that the sum of degree days over the growing season is a better measure of climate than seasonal temperature. A degree day measures how much mean daily temperature ($t_{i,r}$) in location *i* on day *r* exceeds an assumed baseline. The mean daily temperature is the mean temperature over a 24 hour period starting at midnight.[1] The agronomic convention is that 8°C is the baseline. The annual number of degree days above 8°C is the sum over the year of all the individual degree days. SHF modify this measure and sum degree days over only April 1 through September 30 which they assume is the growing season.

$$dd8_{i,r} = \begin{cases} 0 \text{ if } t_{i,r} \leq \underline{t} \\ t_{i,r} - 8 \text{ if } t_{i,r} > \underline{t} \end{cases},$$

$$DD8_i = \sum\nolimits_{\mathrm{r} \in \{Apr,\ldots,Sep\}} dd8_{i,r}\,. \tag{3}$$

SHF argue that temperature is beneficial to crops from 8°C to 32°C but is harmful thereafter. They make this argument based on a misreading of an agronomy result showing a linear function rising to 32°C and then abruptly falling (Figure 2-3 in Ritchie and NeSmith, 1991). However, the cited figure does not describe yield but rather the inverse of the time it takes a maize plant to develop a fifth leaf. The figure shows how degree days affect timing. A separate figure in the Ritchie and NeSmith paper reveals the traditional hill-shaped relationship between yield and temperature. Based on their reading, however, SHF modify degree days by capping degree days at 32°C.[2] We label this modified degree day as $dd8\text{-}32_{i,r}$.

$$dd8\text{-}32_{i,r} = \begin{cases} 0 \text{ if } t_{i,r} \leq 8 \\ t_{i,r} - 8 \text{ if } 8 < t_{i,r} \leq 32, \\ 24 \text{ if } t_{i,r} > 32 \end{cases}$$

$$DD8\text{-}32_i = \sum\nolimits_{r \in \{Apr,\ldots,Sep\}} dd8\text{-}32_{i,r} \tag{4}$$

SHF also include a threshold variable at 34°C to test whether farmland values fall precipitously at that temperature. They capture this threshold effect by changing the baseline temperature and measuring extreme degrees (D34) as follows:

$$d34_{i,r} = \begin{cases} 0 \text{ if } t_{i,r} \leq 34 \\ t_i - 34 \text{ if } t_{i,r} > 34 \end{cases}, \tag{5}$$

$$D34_i = \sum\nolimits_{r \in \{Apr,\ldots,Sep\}} dd34_{i,r}\,.$$

[1] In the absence of hourly measures, mean daily temperature is calculated as the average of the daily minimum and maximum temperature.

[2] Note that a precise test of Figure 2-3 would include a linear beneficial degree day function between 8°C and 32°C and a harmful linear degree day function above 32°C.

Another way to measure the same threshold is to count the effect of degree days (dd34) above 34°C. This maintains the baseline at 8°C and asks whether very hot days have a different effect from other warm days:

$$dd34_{i,r} = \begin{cases} 0 \text{ if } t_{i,r} \leq 34 \\ t_i - 8 \text{ if } t_{i,r} > 34 \end{cases},$$

$$DD34_i = \sum\nolimits_{r \in \{Apr,\ldots,Sep\}} dd34_{i,r} .$$

The two measurements D34 and DD34 are perfectly correlated but they are not the same after a non-linear transformation.[3]

To measure rainfall, SHF calculate the cumulative precipitation (*TP*) between April 1 and September 30. SHF then introduce degree days and cumulative precipitation into the Ricardian function in a quadratic form. They also include the square root of extreme degrees (D34):

$$Y_{i,t} = \beta_0 + \beta_1 DD8\text{-}32_i + \beta_2 DD8\text{-}32_i^2 + \beta_3 D34_i{}^{1/2} + \beta_4 TP_i + \beta_4 TP_i^2 + \boldsymbol{\gamma} X_{i,t} + \boldsymbol{\theta} Z_i + \epsilon_{i,t} \ . \tag{6}$$

SHF report that degree days summed over the growing season is a better measure of climate than seasonal temperature. They report that the impact of degree days is the same in the first half and second half of the growing season. They consequently argue one can sum degree days over the entire growing season. They report that the coefficient on extreme degrees is negative and significant, implying a threshold at 34°C. Finally, they find that the model with only the growing season generates more accurate out-of-sample predictions than a model that controls for temperature and precipitation in January, April, July and October.

In this paper, we retest the hypotheses in SHF with the actual degree day data measured in NARR. First, we compare degree days, modified degree days, and daily temperature over the growing season.

[3] Degree days are measured using mean daily temperature. Each day is either below or above 34°C. Including only extreme temperatures does not increase the precision of the threshold variable.

Second, we test whether cold degree days have a significant effect on farmland value.[4] Third, we test whether degree days have the same effect in the first half versus second half of the growing season (two season model). Fourth, we test whether there is evidence of a threshold at 34°C by following SHF and including the linear, square root, and squared form of extreme degrees (D34) in the growing season degree day model. But we also try a number of other measures of a threshold including degree days above 34°C (DD34) in linear, square root, and squared forms, a dummy variable for counties that experience any day with temperatures above 34°C (Dummy34), and the square root of extreme degrees (D34) in a two season model. Finally, we test whether omitting climate variables outside the growing season biases the temperature results. We test whether the non-growing season climate coefficients have a significant impact on farmland value. We also compare the predicted optimal temperature and the predicted impact of a uniform 2°C and 4°C warming by the growing season, two season, and four season model.

Throughout the paper we present Eicker-White heteroskedastic-consistent (robust) standard errors and standard errors corrected for spatial correlation as in Conley (1999)[5]. We present bootstrap confidence intervals for estimates of impact of warming on agricultural land values in the Eastern United States, obtained by resampling the 2,406 counties of our panel with repetition, 1,000 times. We weight all counties by the amount of farmland.

As a final test of whether or not the degree day model is superior to the other Ricardian models, we assess each model's ability to forecast out-of-sample using two formal tests. The first test is the Morgan-Granger-Newbold (MGN) forecasting accuracy test (Diebold and Mariano 1995) We select the coldest 80% of counties and we test how well each model predicts the farmland values of the remaining warmest counties. In the second test, we draw 1,000 random samples of 80% of the counties and for each sample we calculate the root mean squared error of predicted land values in the remaining (omitted) counties. We compare the results across alternative models. We then execute pairwise t-tests of whether the RMSE of predicted land values is the same.

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[4] Cold degree days reflect the extent that daily temperature is below a threshold which we assume is 8°C. We label each cold degree day as cdd8 and the sum of the cold degree days as CDD8.

[5] The covariance matrix estimator is obtained using a weighted average of spatial autocovariances that fall within a Bartlett kernel that stretches along the north/south east/west dimensions. We use a constant cutoff point equal to 3 degrees. Observations from counties that fall within the Bartlett kernel, but are of a different Census year, receive a weight equal to zero.

Finally, we conduct a number of robustness checks to confirm the results. We introduce state fixed effects and we explore the use of alternative soil and water measures. We also test the hypotheses using the data in SR2009 which was graciously provided by Wolfram Schlenker and Michael Roberts.

2 Data

It is important to note that the measure of degree days in SHF was not observed but rather was constructed from observed minimum and maximum monthly temperatures using a meteorological smoothing function (Thom 1954; 1966). One of the underlying assumptions of the Thom formula is that daily mean temperatures are symmetrically distributed between monthly minimum and maximum average temperature

In contrast, this paper relies on a data set generated by the National Climatic Data Center (2012) called NARR.[6] The NARR dataset provides high spatial (32 km) and temporal (3 hour) detail of the historic climate of North America and adjacent oceans from October 1978 to the present. The NARR data was constructed by meteorologists using weather station data as well as other measures (such as satellite measures) of North American climate. We rely on the NARR data from 1979 through 2007 (the last economic observation). We utilize the 2 meter temperature measures in NARR which correspond to the height at which weather stations measure temperature. For each grid point we compute degree days from mean daily temperature. We then compute long-run degree days by averaging from 1979 to 2007. Mean daily temperatures are calculated for each grid point using the 3 hour measurements.[7] County climate is interpolated from the four closest grid points to each county's centroid, with weights inverse to distance.

One of the striking results of this analysis is that mean daily temperatures over all months of the growing season are not normally distributed as assumed by the Thom formula.[8] Figure 1 displays the skewness of mean daily temperatures from April through September for every county east of the 100th

[6] The NARR data relies on many measures of weather and has been carefully constructed by climatologists. See http://nomads.ncdc.noaa.gov/docs/ncdc-narrdsi-6175-final.pdf for further information.

[7] As a robustness test, mean daily temperatures is also calculated as the average of daily minimum and maximum temperature, a method commonly used when hourly observations are not available.

[8] We use a 10 percent random sample of grid points of the NARR dataset east of the 100th meridian and for each of them we calculate the skewness of the mean daily temperature, for each month from April to September, for each year from 1979 to 2007. Figure A - 2 in the Appendix shows the distribution of the skewness of mean daily temperature distributions for April to September.

meridian. The distribution is generally skewed to the left (the cold side) in every growing season month. In every month but July, the skewness increases as one moves further south towards warmer locations. Assuming away this skewness consequently introduces an error in the degree day data that is correlated with temperature.[9] The SHF degree day data is not only plagued with measurement error but it is biased as well. All the hypotheses in SHF need to be tested again. In particular, their treatment of seasons needs to be checked to see why it does not matter despite the evidence to the contrary from other economic and agronomic research.

Following SHF, we build a balanced panel using United States Agricultural Census data for 1982, 1987, 1992, 1997, 2002 and 2007. We use the following time varying socio-economic variables: income per capita, population density, population density squared, residential house price index.[10] We also control for a set of geographic, time invariant characteristics at county centroids: latitude, elevation, and distance from major metropolitan areas. We use USGS data to estimate the average annual surface and ground water use per hectare of farmland during 1982-2007. Finally, we control for some important soil characteristics: salinity, percentage of soil subject to flooding, percentage of land with low drainage, soil erodibility, average slope length factor, percentage of sand and of clay, minimum available water capacity, and permeability. We include 2,405 out of the 2,471 counties east of the 100th meridian, covering 99% of agricultural land east of the 100th meridian. A detailed description of all variables is in the Appendix. Descriptive statistics of all variables used in the analysis and in robustness tests are displayed in Appendix (Table A - 1 through Table A - 4).

The results are not restricted to the NARR data set. We also use the SR 2009 data that was interpolated between temporally detailed weather station measurements to generate daily temperatures. Except for summer measures which are consistently lower, the SR 2009 data is quite similar to the NARR temperature data.[11] In the Appendix, we further compare the SHF, NARR and SR2009 data.

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[9] For example, SHF overestimate the number of days with mean temperature above 34°C. With the SHF data, all counties in the eastern US have degree days above 34°C but with the NARR data, only 45% of counties have degree days above 34°C, and with SR 2009, only 12% of counties have degree days above 34°C. The mean number of degree days above 34°C is 2.37 in SHF, 0.19 in NARR and 0.004 in SR 2009.

[10] This is the same set of variables used by Massetti and Mendelsohn (2011; 2012), with the exclusion of the share of sales from agriculture in greenhouses and subsidies to agriculture.

[11] NARR data is available at many elevations. We use 2 meter air temperature because this is the standard in the literature. Schlenker and Roberts (2009) also use 2 meter air temperature as this is the height at which weather station temperature measurements are taken. Alternative measures from NARR such as the surface temperature are not as effective.

3 Results

Degree days (both modified and not) and mean daily temperature are highly correlated in the United States (east of the 100th meridian) over the growing season. Daily temperature explains 99.9% of the variation of degree days. There is not much difference between *T* (the average of the mean daily temperature), DD8, and DD8-32 over the growing season (see Figure A - 3 in the Appendix). This high correlation is due to the fact that most days during the growing season have a temperature between 8°C and 32°C. We introduce T, DD8 and DD8-32 into a Ricardian regression with a quadratic functional form (see Table A - 16 in the Appendix for a complete set of coefficients). The adjusted R squared for each regression is 0.786. Figure 2 reveals that all three measures of temperature predict almost identical marginal impacts. The marginal impact of one additional degree day at the median daily temperature during the growing season (21°C) is equal to -15.9% [-19.2% to -10.9%], -16.3% [-19.5% to -11.4%], and -16.2% [-25.7% to -6.7%], for *T, DD8*, and *DD8-32* respectively.[12] The only notable difference is that modified degree days have slightly wider confidence intervals.

One of the striking results of Figure 2, is that all three of these models predict that farmland value is highest when the growing season temperature is 9°C. This is 3°C colder than the coldest county in the sample. It is not clear one could earn positive net revenues growing crops at this allegedly optimal temperature. Any model that predicts 9°C is the optimal temperature of the growing season is clearly going to give biased estimates of the effect of warming. It is clearly not sufficient to model climate effects with a cumulative growing season model.

We then add cold degree days over the growing season to the three models (see Table A - 17 for a full list of coefficients). Cold degree days consistently have a negative and highly significant effect on farmland values with a coefficients of -.00367, -0.00315 and -0.00289, respectively for the models that uses T, DD8 and DD8-32. Temperatures below 8°C belong in the model of farmland values because they capture one problem with climates that are too cold.

We next test whether DD8-32 in the first half of the growing season (April-June) has the same marginal effect as DD8-32 in the second half (July-September). Figure 3 reveals that the marginal impacts of DD8-32 in the two seasons are significantly different and of the opposite sign (see Table A - 18 for the complete regressions). Similar results are found for T and DD8. Especially given the nonlinear

[12] 95 percent confidence interval adjusted for spatial correlation is shown in brackets.

relationship assumed for degree days, it is not appropriate to sum degree days across the entire growing season. The harmful summer and beneficial spring degree days should be summed separately.

We next test whether there is a threshold effect at 34°C. Table 1 starts with the growing season DD8-32 model and adds different measures of a threshold for 34°C. The threshold measures include the variable D34 used by SHF to measure extreme degrees. We also include DD34, degree days in days with temperature above 34°C. Each of these variables is introduced separately into the regression as a linear, squared, and square root term. The table also includes a dummy variable for counties that experience daily temperatures above 34°C or not (Dummy34). Finally, the table includes one specification where the spring and summer season are separated and a square root term for D34 is added (see Table A - 19 and Table A - 20 for the complete regressions). The only specification with a negative and statistically significant coefficient occurs when one uses the entire growing season and the square root of D34. The majority of specifications suggest a significant positive effect above 34°C which implies the response function is actually flatter (not steeper) than the quadratic model suggests. The square root result with D34 also disappears with a 2 season model of the growing season. It appears that the reported threshold result in SHF is merely an artifact of a single poorly specified model.[13]

Table 1 also reports the resulting impact estimate for a uniform warming of 4°C. Whether or not a threshold is included in the model makes very little difference to the resulting predicted impact of a large warming. The overall harmful impacts reported in Table 1 are largely driven by the linear and squared coefficients of the degree day variable, not the threshold variable.

The next empirical test examines whether the climate before April or after September has a significant effect on farmland value. Figure 4 shows the marginal impact of temperature and precipitation in spring, summer, autumn, and winter (see Table A - 22 for the complete regression results). The coefficients of the non-growing season climate are highly significant and have different effects depending on the season. Chow tests for whether the seasonal coefficients are the same generate *p*-values that are virtually equal to zero. A warmer spring and autumn is beneficial, extending the growing season. A warmer summer is harmful because high temperatures damage crops. A warmer winter is also harmful because cold winters reduce pests. The temperatures in all four seasons have a significant effect on farmland values. The marginal effect of precipitation also varies by season with wetter winter and springs being beneficial and wetter summers and autumns being harmful.

[13] These results hold with the DD8 and daily temperature model as well (results available from authors).

There are many reasons that the climate from October to March significantly affects land values. Many crops and perennials are still in the ground between October and March (see Table A - 8 in the Appendix for planting and harvesting dates of major crops). Climate conditions in the winter and early spring can affect next season's growing conditions (for example soil moisture). Finally, the climate during the non-growing season affects the growth of pests which in turn affects net revenue and land value.

The climate in the growing season is correlated with the climate in the non-growing season. Warmer places in the summer tend to be warmer in the winter. In years when March is warmer, April tends to be warmer. Similarly, when September is warmer, October is also warmer. If studies omit the non-growing season, they are likely introducing omitted variable bias. Including the non-growing season is problematic for degree days because degree days are a very poor proxy for temperature outside the growing season.

In Table 2, we display t-statistics of tests of the ability of different pairs of Ricardian models to predict land values out of sample. We conduct two sets of tests. The Granger Morgan Newbold (GMN) test checks the accuracy of predicting land values in warmer areas. Coefficients are estimated from cooler counties and then are used to predict the farmland values of warmer counties. The RMSE test measures model forecast accuracy. Random counties are selected to estimate the coefficients which are then used to predict the farmland values in the omitted counties. Comparing a single growing season model based on modified degree days against a growing season model based on temperature reveals the degree day model is more accurate than the temperature model but provides a poorer prediction of warming. Making the same comparison with a two season model of the growing season suggests that the degree day version is slightly better at predicting effects in warmer climates. The results confirm our general statement that degree days and temperature are similar within the growing season. The results, however, also show that the two season model is generally preferred over the one season model for both accuracy and its ability to predict outcomes in warmer counties.[14] However, the most important result concerns the comparison with the 4 season model. The 4 season model outperforms both a single growing season and a two season growing season model in all cases. The results show that adding more seasons increases both the accuracy of forecasts and the ability of the model to predict farmland values in warmer counties. The results hold in further tests in which we vary the sample size used for the regressions.

[14] The one exception is with the temperature model where the superior accuracy of the two season model over the one season model is not quite significant at the 5% level.

Our final analysis compares the predicted impacts of nonmarginal warming for the degree day growing season model, the temperature growing season model, the temperature 2 season model, and the temperature 4 season model (Table 3). We calculate the predicted impact of a 2°C and 4°C uniform warming on the sample. The lowest damages are predicted by the four season model. The damages are significantly higher for all the rest of the models. This implies that omitting non-growing seasons from the model not only provides less accurate results but it also biases impact predictions upwards.

There are several possible reasons why the results in this paper may differ from SHF in addition to their problems with climate data. One possibility is that the NARR data set may also be problematic. It is possible that the NARR data is inaccurate. SHF focused on degree days but perhaps should have used degree hours as was done in SR 2009. SHF used different soil variables and failed to control for water at all. We test all of these propositions in a series of robustness tests. To test whether the results are unique to the NARR data set, we use SR 2009 data, a comprehensive and widely used temperature and precipitation dataset, and perform all of the tests again. The Appendix carefully describes both datasets. In general, we find the SR 2009 and NARR data are quite similar. The key regression results using SR2009 are in Table A - 12 to Table A - 13 in the Appendix. Using SR 2009, we find that daily temperature and degree days over the growing season remain interchangeable. They both predict very similar marginal effects as those shown in Table 3. They also both predict the optimal temperature is colder than the observations in the data set. We find that cold degree days are significant and negative. We find that the marginal effects in the first and second half of the growing season are the opposite sign and significantly different. We find evidence of a negative threshold at 34°C using the one season degree day model. However, the effect once again disappears in the two season degree day model. The results continue to imply that the threshold effect in SHF is peculiar to the specification tested. We find that climate in every season is significant. Although the difference is small, a direct comparison of the two datasets reveals that the NARR data leads to more accurate predictions of farmland values than the SR 2009 data (Table A - 9). All the results found in this paper remain with the SR 2009 data.

We also explore what happens if one uses hourly temperatures rather than daily temperatures. Because hourly temperatures capture the wide swing in temperatures within a day, they have more variance than daily temperatures. They also introduce another factor- daytime versus night time temperatures may have different effects. Nonetheless, the results using degree hours from the NARR data set are similar to the degree day results. There is no difference between hourly temperatures versus degree hours for the growing season. The marginal effect of degree hours and hourly temperature is similar.

The marginal effects of spring and summer degree hours are significantly different. The threshold effects at 34°C are negative and significant only when one uses degree days over the entire growing season. In the two-season degree day model, the threshold effect vanishes. The marginal effect of degree hours and hourly temperatures outside the growing season are significant. The growing season degree hour model continues to be overly pessimistic about warming. The degree hour model predicts that the optimal degree hour is 9°C over the growing season. This is below the median hourly temperature during the growing season of the entire sample of counties.

We also test alternative soil data. We drop the water variables. None of these changes alter the results. The results for each of these robustness tests are in the Appendix (see Table A - 10 and Table A - 13). The full set of robustness regression coefficients and impact estimates are available from the authors.

The results are robust. For each robustness test, the coefficients for *T*, *DD8* and *DD8-32* are not statistically different from each other. Cold degree days matter. There is no evidence of a harmful threshold at 34°C. Climate coefficients are not the same in each season.

4 Conclusion

The Ricardian model has been employed to estimate the sensitivity of farmland value and net revenues to climate around the world. SHF seek to improve upon this model by using degree days summed across the growing season rather than seasonal temperature across the year. They report that their degree day model works well. They also report evidence of a threshold at 34°C above which farmland values plummet. Unfortunately, these original tests were based on constructed degree day data from monthly temperature records which were flawed.

Using more accurate temperature measures gathered by NOAA and more recent data collected by Schlenker and Roberts (2009), this paper re-examines the hypotheses in the SHF paper. We find that degree days, modified degree days, and daily temperature are interchangeable. Moving from temperature to degree days provides no new insights. However, aggregating degree days or temperature into a single growing season is problematic. There are two problems: the effect of temperature varies across seasons and omitting nongrowing season temperatures introduces omitted variable bias. The importance of season is evident even within the growing season. The impact of warmer degree days in the first half of the growing season is beneficial but the impact of warmer degree days in the second half of the growing season is harmful. One should not sum degree days across the entire growing season, especially in a nonlinear model. A two season model outperforms a one season model of the growing season. This result extends to the seasons outside the growing season. A four season model of the entire year outperforms a two season model of the growing season. The temperatures during the nongrowing season are correlated with the temperatures during the growing season. All four seasons have a significant effect on land value. When the nongrowing season is omitted, the growing season coefficients become biased predicting optimal temperatures that are far too cold and warming effects that are consequently too high. The importance of including all four seasons is problematic for degree days because degree days do not proxy temperatures in the six months from October to March. These results confirm findings in agronomy that seasons matter.

Finally, there is paltry evidence of a threshold at 34°C. The result is peculiar to looking at the square root of extreme temperatures in a one season growing model. This threshold effect disappears in the two season degree day model and also disappears if one utilizes the number of degree days above 34°C or a dummy variable indicating whether or not a county experiences any temperatures above 34°C. The threshold effect reported in SHF appears to be just a specification error.

In short, this paper confirms the results of the original Ricardian literature. The relationship between farmland value and temperature (or degree days) is hill-shaped. Cold days are important, not just warm days. The threshold effects reported in SHF are likely just a result of a poorly specified model and of imprecise daily temperature measurements. Seasons are terribly important. The impact of degree days is different in the first half of the growing season compared to the second half. In fact, temperature and precipitation have significantly different effects in each of the four seasons of the year. All these results are consistent with agronomic evidence. Temperatures have a concave impact on yields in crop experiments. Frost days cause farmers to lose their crops. What happens to a plant in each phase of its life (each season) is different- a fact built into every crop model. Temperature and precipitation is expected to have different effects in each season. Climate in the non-growing season has important impacts on pests including insect populations, diseases, and weeds. The more pests, the more farmers have to spend on pest control, reducing net revenue.

The results withstand a large set of robustness tests. They are confirmed using degree hours instead of degree days; using alternative methods to aggregate NARR data over time and over space; using different soil characteristics, water variables, and soil data; using alternative model specifications; and using the Schlenker and Roberts (2009) updated data for degree days.

There is another important limitation to this study. Farmland in the Eastern United States is a poor proxy for farmland across the whole country. The study limited the scope of the analysis to just the eastern half of the United States to be comparable with earlier studies of degree days. However, to understand effects across the whole country, it is important to include observations from all the agricultural regions of the country.

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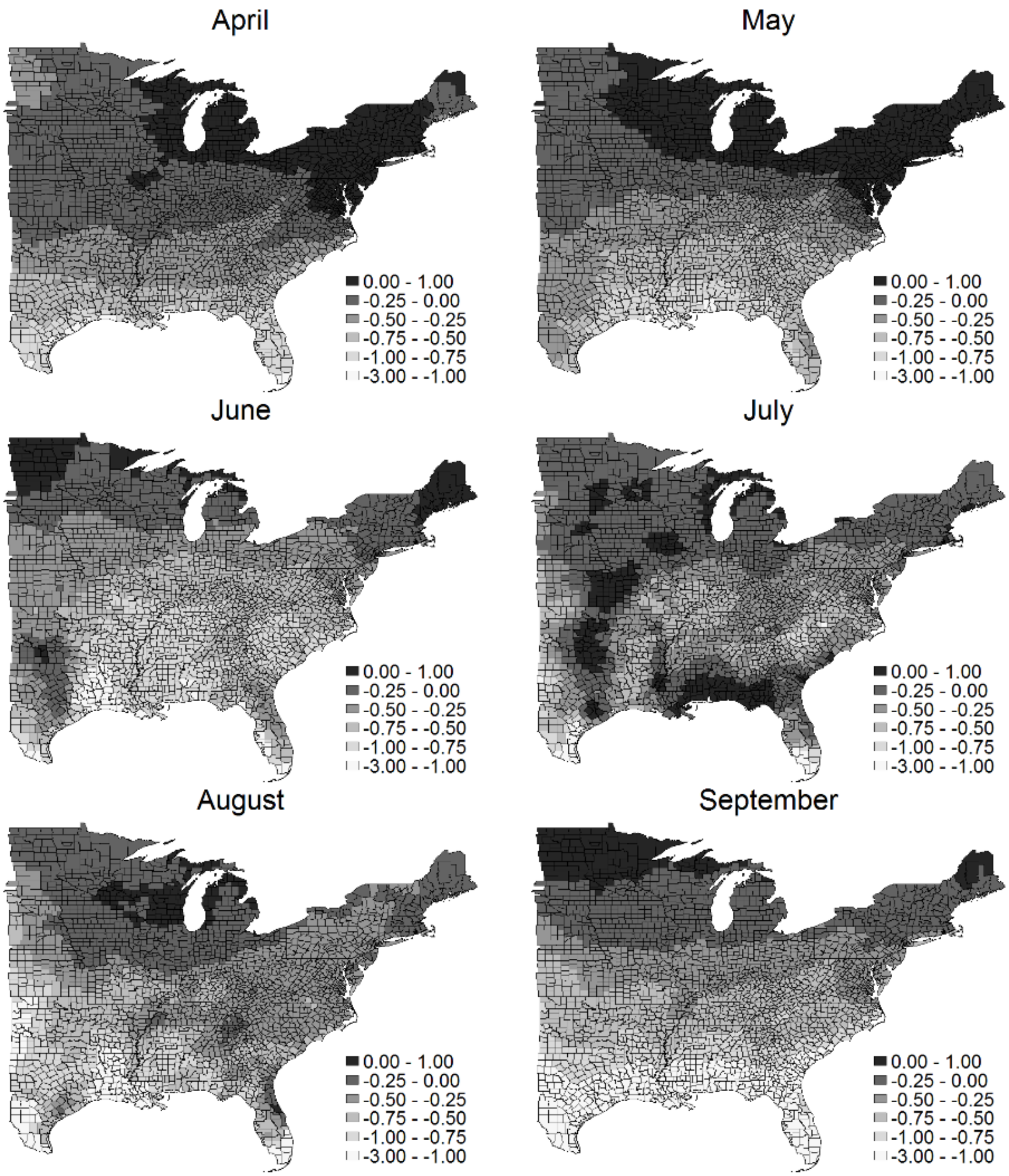
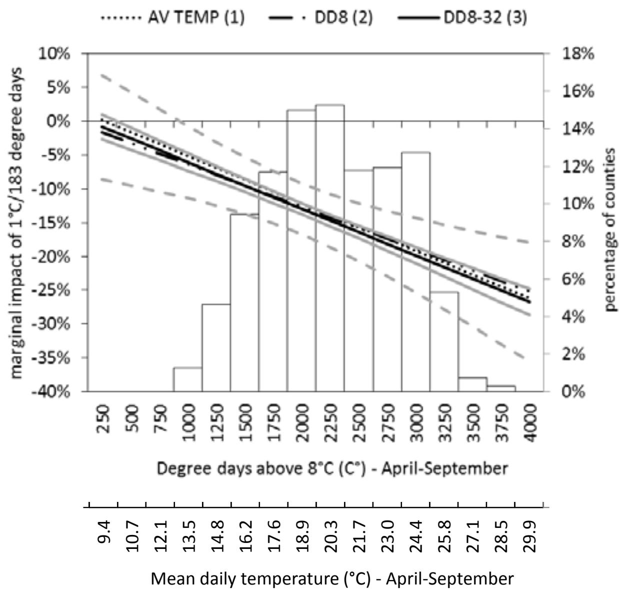
List of Figures



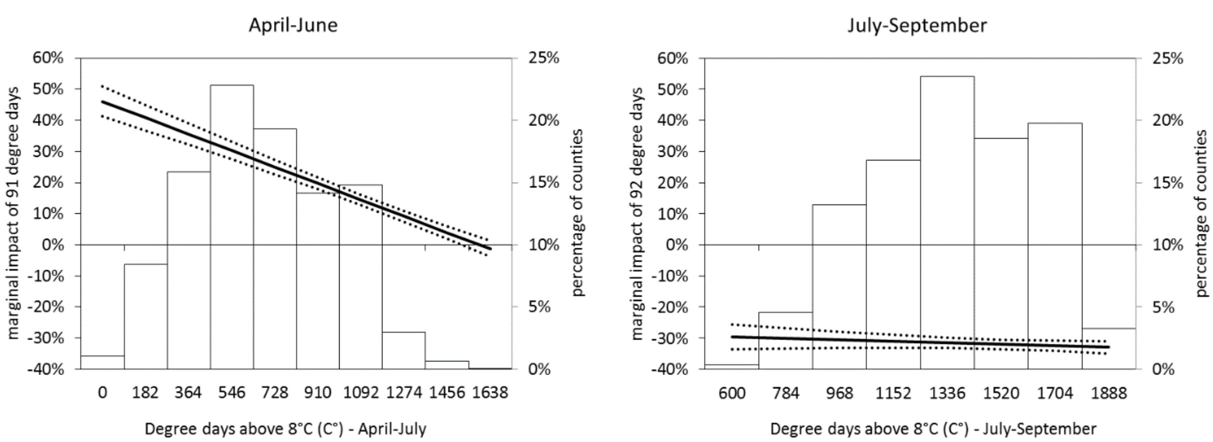
Notes: Daily temperatures in each month, from 1979 to 2007.

Figure 1. Skewness of the distribution of daily mean temperature in different months of the growing season.



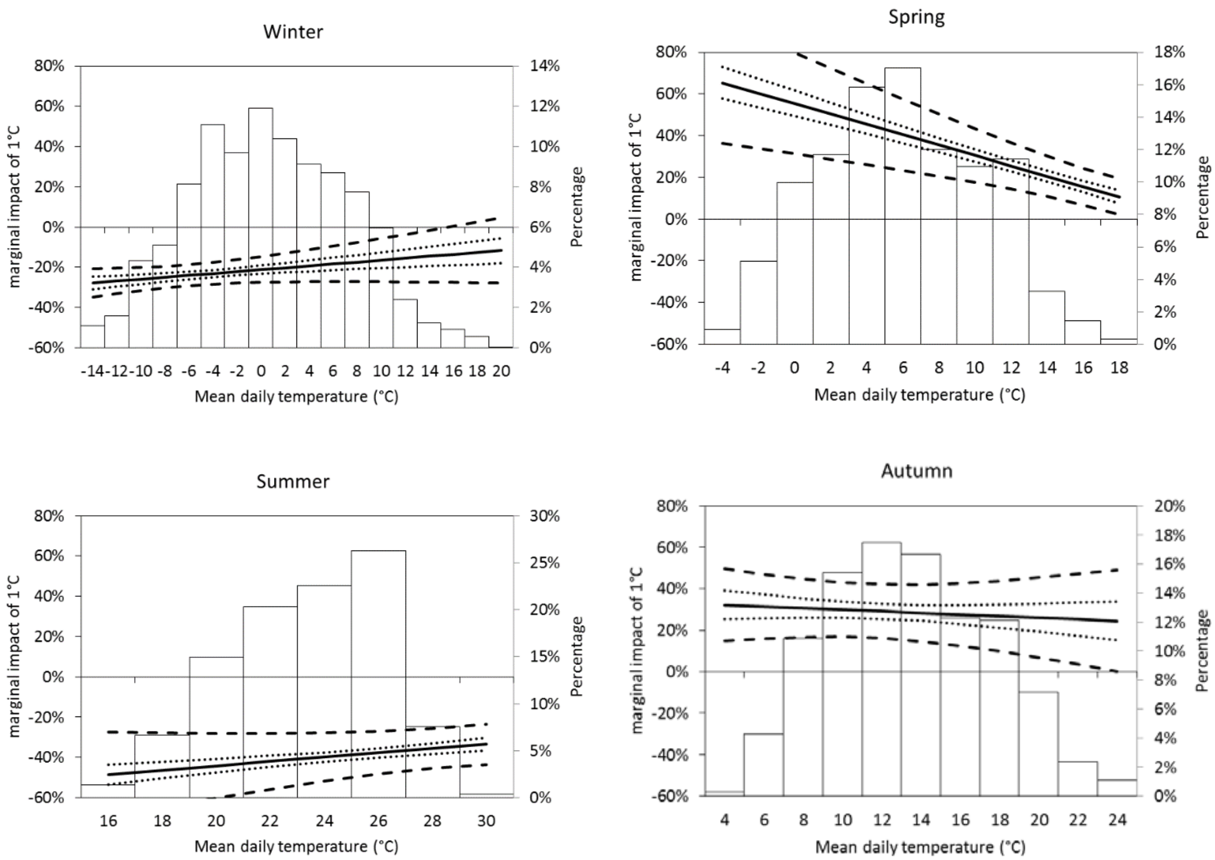
Notes: The figure displays the marginal impact of average temperature, degree days and modified 8 to 32°C degree days from April through September. The underlying histogram depicts the distribution of degree days (and daily temperature). The 95% confidence interval for the modified degree days (DD8-32) model using robust standard errors is in solid gray and using spatial correlation corrected estimates is dashed gray. Full set of regression coefficients in Table A - 16.

Figure 2. Marginal effect of degree days, modified degree days, and temperature during April-September.



Notes: The first figure displays the marginal impact of the 91degree days (˜1°C) from April to June and the second figure the marginal impact of the 92 degree days (˜1°C) from July to September. The dotted lines mark the 95% robust confidence interval. The underlying histogram depicts the distribution of degree days in each season. Analogous results are obtained when using mean temperature and degree days above 8 °C. Full set of regression coefficients in **Error! Reference source not found.**.

Figure 3. Marginal effect of modified degree days in the first versus the second half of the growing season .



Notes: Dotted lines mark the 95% robust confidence interval and the dashed lines mark the 95% confidence interval corrected for spatial correlation. The underlying histogram depicts the distribution of temperature in each season. Winter: December, January, February; Spring: March, April, May; Summer: June, July, August; Autumn: September, October, November. Full set of regression coefficients in Table A - 22.

Figure 4. Marginal effect of temperature in the four seasons.

List of Tables

Base model	Extreme temperature	Coefficient	Impact of +4°C
DD8-32 GS	--	--	-47.8% [-50.6% , -44.6%]
DD8-32 GS	Dummy 34	0.0463*** [0.00875] {0.0427}	-49.1% [-51.9% , -45.9%]
DD8-32 GS	D34	-0.00202 [0.00578] {0.0209}	-48.5% [-53.1% , -34%]
DD8-32 GS	D34 sq	0.00255** [0.00110] {0.00321}	>100% [-52.4% , >100%]
DD8-32 GS	D34 sqrt	-0.0666*** [0.0121] {0.0629}	-48.9% [-51.7% , -45.5%]
DD8-32 GS	DD34	0.00178*** [0.000335] {0.00165}	-48.5% [-51.4% , -45.3%]
DD8-32 GS	DD34 sq	6.81e-05*** [1.28e-05] [6.360E-05]	-44.5% [-48.3% , -35.9%]
DD8-32 GS	DD34 sqrt	0.00907*** [0.00171] {0.00841}	-48.9% [-51.9% , -45.5%]
DD8-32 2 SEASONS	D34 sqrt	0.0418*** [0.0143] {0.05302}	-46.3% [-49.9% , -41.6%]

Notes: All models include a quadratic specification of modified degree days. One specification separates growing degree days into two seasons. Dummy34 is equal to one if the county experiences a daily temperature above 34°C. Impacts measure percentage change in land value of a uniform increase of temperature equal to 4°C with no change in precipitation. Confidence intervals from bootstrapping (1,000 repetitions) and robust standard errors (*** p<0.01, ** p<0.05, * p<0.1) are in brackets. See Table A - 19 and Table A - 21 for a complete set of coefficients.

Table 1. Impact of extreme heat.

model 1	model 2	MGN	RMSE
DD8-32 GS	T GS	-24.9	35.4
DD8-32 2 SEASONS	DD8-32 GS	29.0	12.5
DD8-32 2 SEASONS	T 2 SEASONS	2.81	1.27
T 2 SEASONS	T GS	24.3	1.82
T 4 SEASONS	T GS	28.4	30.5
T 4 SEASONS	DD8-32 GS	29.1	27.7
T 4 SEASONS	DD8-32 2 SEASONS	6.69	34.6
T 4 SEASONS	T 2 SEASONS	8.50	6.53

Notes: Values greater than |1.96| are significant at the 5% level. A positive t suggests model 1 is superior to model 2 and a negative value implies model 2 is superior to model 1. For MGN, estimated coefficients from cooler counties are used to predict farmland values in warmer counties. For RMSE, counties are selected randomly to predict farmland values in omitted counties. Additional tests are available from the Authors.

Table 2. Significance tests of forecasting accuracy; MGN tests ability of model to predict effect of warmer temperatures and RMSE tests the accuracy of model forecasts.

	Marginal	+2°C	+4°C
T GS	-15.9%	-27.0%	-49.0%
	(-15.1% , -14.2%) [-19.2% , -10.9%]	{ -28.9% , -24.7% }	{ -51.8% , -45.5% }
DD8-32 GS	-16.3%	-26.9%	-47.8%
	(-15.5% , -14.6%) [-19.5% , -11.4%]	{ -28.7% , -24.8% }	{ -50.4% , -44.5% }
DD8-32 2 SEASONS	-16.2%	-27.1%	-48.0%
	(-18.5% , -13.9%) [-25.7% , -6.7%]	{ -28.9% , -25.1% }	{ -50.6% , -44.9% }
T 4 SEASONS	-19.4%	-16.2%	-32.1%
	(-21.4% , -17.5%) [-26.6% , -12.3%]	{ -21.3% , -10.9% }	{ -40.2% , -23.1% }

Notes: Percentage loss of land values in all counties included in the analysis. Precipitation is assumed to remain unchanged. Marginal loss at average climate. Average climate calculate using farmland weights. In parenthesis robust 95% confidence interval; in brackets 95% confidence interval corrected for spatial correlation using Conley (1999) routine with a cutoff at 3 degrees of latitude/longitude; in curly brackets bootstrap confidence intervals obtained using 1,000 repetitions. Full set of regression coefficients in Table A - 16, **Error! Reference source not found.** and Table A - 22.

Table 3. Marginal and non-marginal impact of temperature on land values.

Appendix

Data

We have constructed a balanced panel with observations for 2,406 out of the 2,471 counties east of the 100th meridian, covering 99% of agricultural land, over the years 1982, 1987, 1992, 1997, 2002 and 2007. Units of measurement are in the metric system; economic variables are converted to constant 2005 United States Dollars ($) using the Implicit Price Deflators for Gross Domestic Product (Bureau of Economic Analysis Table 1.1.9). If not otherwise stated, variables measure data of interest in years 1982, 1987, 1992, 1997, 2002 and 2007.

<u>Climate data</u>

Temperature and precipitations – Temperature and precipitation data is obtained processing the North American Regional Reanalysis (NARR) dataset. Temperature at 2 meters above ground. Normals over the period 1979-2007. For further information on the NARR dataset see http://nomads.ncdc.noaa.gov/docs/ncdc-narrdsi-6175-final.pdf .

<u>Agriculture data</u>

Farmland value – Estimated value of land and buildings, average per hectare of farmland. Data source is the Agricultural Census.

Farmland – Land in farms as in the Census of Agriculture from 1982 to 2007, hectares. The Census of Agriculture defines 'Land in farms' as agricultural land used for crops, pasture or grazing. It also includes woodland and wasteland not actually under cultivation or used for pasture or grazing, provided it was part of the farm operator's total operation. Large acreages of woodland or wasteland held for non- agricultural purposes were deleted from individual reports. Land in farms includes acres in the Conservation Reserve and Wetlands Reserve Programs. Land in farms is an operating unit concept and includes land owned and operated as well as land rented from others.

Surface or ground water withdrawals – Thousands of liters per day, per hectare, of surface or ground water for irrigation purposes. The 'Estimated use of water in the United States', published every five years by the United States Geological Survey, supplies data on water use at county level starting from 1985. We divided the amount of water used at county level for years 1985, 1990, 1995, 2000, 2005 by the amount of farmland in that county in census years 1987, 1992, 1997, 2002 and 2007, respectively, and we computed the time average of surface water use per hectare of land. We used this variable as a proxy for surface and ground water availability at county level for all time observations of our panel.

Socio-economic data

Income per capita – Per capita personal income, measured in thousands of $; Bureau of Economic Analysis, Regional Economic Accounts, table CA1-3.

Population density – Population from the Bureau of Economic Analysis, Regional Economic Accounts, table CA1-3, measured in hundred persons per squared kilometer. Area estimated from current division of counties boundaries.

Value of owner occupied homes – Median value of owner occupied homes, measured in thousands of $. We use data on the median value of owner occupied homes (SF3 H085) at county level from the 2000 United States Census. Data for other years is obtained using the Home Price Index (HPI) for metropolitan areas or at state level estimated by the Office of Federal Housing Enterprise Oversight (OFHEO). The HPI measures the movement of single-family house prices. It is a repeat-sales index that measures average price changes in repeat sales or refinancing on the same properties (www.fhfa.gov/webfiles/896/hpi_tech.pdf). The HPI was adjusted to reflect inflation using the Implicit Price Deflator of GDP.

Geographic data

Latitude – Latitude of county's centroid, measured in decimal degrees.

Elevation – Elevation of county's centroid, measured in thousands of meters.

Distance from cities – Distance between county's centroid and metropolitan areas with more than 200,000 inhabitants in 2000, measured in kilometers.

Soil characteristics – NRI dataset

Soil data is from the National Resources Inventory (NRI), developed by the United States Department of Agriculture, years 1992 and 1997 (Nusser and Goebel 1997). The NRI is a longitudinal sample survey of natural resource conditions and trends on non-Federal land in the United States based upon scientific statistical principles and procedures. It is conducted by the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS). We consider soil samples classified as: cultivated cropland, noncultivated cropland, pastureland and rangeland. We calculate a sample area weighted average of soil characteristics from all samples that fall within a county. In some cases we reclassify qualitative soil characteristics into numeric indicators, as detailed below.

Salinity – Percentage of agricultural land that has salinity–sodium problems.

Flooding – Percentage of agricultural land occasionally or frequently prone to flooding.

Wet factor – Percentage of agricultural land that has very low drainage (poor and very poor).

k factor – Average soil erodibility factor. It is the average soil loss, measured in tons/hectare. The k factor is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff.

Slope length – Average slope length factor, measured in meters. Slope length is the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins, or the runoff water enters a well-defined channel that may be part of a drainage network or a constructed channel. For the NRI, length of slope is taken through the sample point.

Sand – Percentage of agricultural land classified as sand or coarse- textured soils.

Clay – Percentage of agricultural land that is classified as clay.

Moisture level – Minimum value for the range of available water capacity for the soil layer or horizon. Available water capacity is the volume of water retained in 1 cm^3 of whole soil between 1/3-bar and 15-bar tension. It is reported as cm of water per centimeters of soil.

Permeability – The minimum value for the range in permeability rate for the soil layer or horizon, expressed as centimeters/hour.

<u>Soil characteristics – FAO HWSD dataset</u>

Soil data used in the robustness test is from the Harmonized World Soil Database (HWSD).[15] The HWSD database provides a comprehensive map of soil physical and chemical characteristics over the entire globe in GIS format. Soil data at county level is obtained as a weighted average of soil characteristics over the entire area of each county. Data is provided separately for the topsoil (0-30 cm) and subsoil (30-100 cm). The definition of soil characteristics below are valid for both topsoil and subsoil.

[15] FAO/IIASA/ISRIC/ISS-CAS/JRC. 2008. Harmonized World Soil Database (version 1.0). Rome, Italy and Laxenburg, Austria: FAO and IIASA.

AWC class – Available water storage capacity class of the soil unit, measured in mm/m.

Gravel – Percentage of materials in a soil that are larger than 2 mm, measured as percentage of volume (%vol.).

Sand – Percentage of sand in soil, measured as percentage of weight (% wt).

Silt – Percentage of silt in soil, measured as percentage of weight (% wt).

Ref. bulk density - Reference bulk density is a property of particulate materials. It is the mass of many particles of the material divided by the volume they occupy. The volume includes the space between particles as well as the space inside the pores of individual particles. Measured in kg/dm^3.

Organic carbon – Organic carbon in soil, measured as percentage of weight (%wt.). Organic Carbon is together with pH, the best simple indicator of the health status of the soil. Moderate to high amounts of organic carbon are associated with fertile soils with a good structure. Soils with an organic matter content of less than 0.6% are considered poor in organic matter.

pH – pH is a measure for the acidity and alkalinity of the soil, measured in concentration levels (-log(H+)). pH between 5.5. and 7.2 offers the best growing conditions. Agronomic limits are: <4.5 (extremely acid), 4.5-5-5 (very acid), 5.5-7.2 (acid to neutral), 7.2-8.5 (moderately alkaline), >8.5 (strongly alkaline).

CEC – Cation exchange capacity (CEC) of soil, measured in cmol/kg. The CEC measures the total nutrient fixing capacity of a soil. Soils with low CEC cannot build up stores of nutrients. Values in excess of 10 cmol/kg are considered satisfactory for most crops.

$CaCO_3$ – Calcium carbonate (lime) content soil, measured as percentage of total soil weight (%wt.). A small amount of calcium carbonate is good for agriculture. High amounts create iron deficiency and may limit water storage capacity. Agronomic limits are as follows: <2 (very low), 2-5 (low), 5-15 (moderate), 15-40 (high), >40 (very high).

$CaSO_4$ – Calcium sulphate (gypsum) content of soil, measured as percentage of weight (%wt.). Research indicates that excessive calcium sulphate can cause substantial reduction in yields.

ESP – Exchangeable sodium percentage (ESP) in soil, measured as percentage of total soil volume (%vol.). Agronomic limits are as follows: <6 (low), 6-15 (moderate), 15-25 (high), >25 (very high).

ECE – Electrical conductivity of soil, measured in dS/m. The salt content of a soil can be roughly estimated from the Electrical Conductivity of the soil.

NARR and Schlenker and Roberts 2009 weather data.

Schlenker, Hanemann and Fisher (2006) (SHF) examine the impact of temperature on land values using degree days built from mean daily temperatures. Daily temperatures are derived from monthly minimum and maximum temperatures using a meteorological smoothing function (Thom 1960). In this paper we closely follow SHF and therefore we build degree days using daily mean temperature. NARR data is obviously more accurate than SHF2006 data because daily mean temperatures are readily available instead of being obtained by interpolating from monthly minimum and maximum temperature.

Schlenker and Roberts (2009) (SR2009) recognize the limits of using Thom's formula in a model that explains crop yields using weather outcomes (Tables A2-A3, pp. 11-12 of SI), but they argue that Thom's formula is fine to study how climate affects land values (SR2009, SI, p. 2).

In this paper we show instead that Thom's formula is source of bias because it assumes that daily temperatures are symmetrically distributed around the monthly mean temperature. Daily temperatures are instead typically left-skewed during each month of the growing season (Figure 1 in the paper and Figure A - 1 in the Appendix). The National Climatic Data Center suggests using daily observations to build degree days, when available.[16]

SR2009 introduce the use of hourly temperature measurements to count how many hours a crop spends at 3°C-wide temperature intervals.[17] They argue that agricultural productivity reflects very short temperature variations and that temperature effects are perfectly time separable. These two assumptions are best explained with one example. One hour at 30°C on any day of the growing season has a distinct effect on agricultural productivity from an hour at 27°C during the same day. Furthermore, one hour at 30°C has the same impact on crop productivity during the whole growing season. Thus, it is possible to sum all hours spent at or above a give temperature during the growing seasons and group them in bins to study the relationship between temperature and crop yields. SR2009 shorten the time interval over which temperature is observed.

In order to be comprehensive, we repeat the analysis in the paper building degree days using the 3-hour temperature measurements in the NARR dataset. We test all the models estimated in the paper using degree days built from 3-hour temperature measurements from the NARR dataset. For convenience we express the total number of degree hours in days and we call them degree *hours* (DH). For instance, eight three-hour

[16] Document available at http://www.ncdc.noaa.gov/oa/climate/normals/normdegdmeth.pdf, last consulted on December 1st 2014.

[17] The total number of hours is then expressed in days (dividing by 24), but the temperature measurements that form one "day" at a given temperature do not need to be continuous over time. Thus, the underlying assumption is that heat effects are perfectly time separable.

temperature measurements at 20°C correspond to 12 degree *hours* above 8°C. Table A - 7 provides summary statistics of degree hours obtained using NARR data.

It is important to note that shifting the time over which temperature is measured increases the number of days (24 hour time periods) above the 34°C threshold. While it is extremely rare to observe days with mean temperature above 34°C, high afternoon temperature often reach the 34°C thresholds during summer time in many parts of the eastern US. Degree days above 34°C tend to be observed rarely. Degree hours above 34°C are instead frequent in places with high summer temperatures. It is important to note that by shifting from days to hours, one also implicitly lowers the relevant agronomic threshold. Experiments cited by SHF use constant temperature over weeks. The agronomic literature and farmers also typically use mean daily temperature to compute degree days. Therefore, the use of daily temperature measurements seems the most appropriate if one wants to test the effect of a daily temperature threshold. Otherwise the threshold should be raised. Despite these caveats, we estimate our models using degree hours and we continue to reject the main hypothesis in SHF (Table A - 10).

We generate an additional set of robustness tests using SR2009 data instead of NARR data.[18] Both datasets use 2-meter air temperature but they obtain daily and infra-daily temperature measurements differently.[19] NARR data is generated by a weather model run by the NOAA that uses a large variety of weather observations (temperature at different elevations, humidity, cloud coverage, rainfall, pressure, etc.). These observations are obtained from weather stations, satellites and other measurement instruments. NARR data is provided with a 32x32 km resolution. SR2009 data is obtained by interpolating daily temperature observations from weather stations and monthly means from the PRISM dataset. Long time series of daily minimum and maximum temperature observations are available only from a limited set of weather stations. The PRISM dataset provides instead climate data on a very dense, 2.5x2.5 km grid. By combining the strengths of these two sets of data SR2009 generate an accurate set of daily temperature and precipitation data. While infra-daily

[18] We are grateful to Schlenker and Roberts for sharing their weather dataset with us. The dataset in our possession has daily minimum and maximum temperature up to 2005. We use a sine wave function based on daily minimum and maximum temperature to obtain hourly temperature measurement (Reicosky et al. 1989). Each county's climate is obtained by taking the un-weighted average of all grid cells that fall within a county. The climatology is from 1979 to 2005. NARR data is coarser in resolution and each county's climate is obtained by interpolating data from the four closest grid cells to the county centroid. NARR climatologies are from 1979 to 2007. Several tests with alternative spatial aggregation methods and alternative time periods to calculate climatologies confirm our results using. SR2009 have calculated the amount of cropland in each grid cell. A test that uses cropland weighted temperature and precipitation data does not reveal any substantial difference.

[19] When comparing temperature data it is important to select datasets that take temperature measurement at the same height. For example, comparing NARR surface temperature (the temperature of the "skin" of the planet) to SHF (2-meter air temperature) is a mistake. Daily maximum temperature can be very high in the NARR surface temperature dataset.

temperature measurements are directly available from the NARR dataset, SR2009 estimate hourly temperature using a sinusoidal function of the daily minimum and maximum daily temperature.

The construction of infra-daily data from daily data is however problematic. First, the infra-daily temperature distribution is typically asymmetric. It varies over space and over time. Most importantly, the distribution is related to the absolute temperature level. For example, under normal circumstances the distribution of infra-daily temperatures is typically right-skewed in the eastern US. This means that temperatures are usually closer to the daily minimum than to the daily maximum temperature. During heat waves the distribution becomes instead left-skewed as the very high temperature measurements persists during the day and also during the night. Thus, the use of a functional form that is constant over space, time and under normal and rare events does not provide the most accurate measurements.

Furthermore, a spatially and temporally uniform transformation of daily minimum and maximum temperature does not add any particularly useful information because it just reflects the underlying variation of daily minimum, maximum and mean temperature.[20] Some interpolation methods may reveal the presence of a particular threshold while other methods may not detect it. However this is not relevant when the threshold is endogenously determined. When the threshold is exogenously set, one must be careful that the time interval at which the threshold was calculated and the time interval at which temperature is measured correspond. In brief, fabricating hourly data from daily minimum and maximum temperature does not add useful information from an econometric point of view.

NARR data immediately provides 3-hour measurement estimated by a large-scale, professional weather model in which infra-daily temperatures do not follow a uniform pattern. NARR data is thus more accurate than SR2009 data in providing fine scale temporal temperature and precipitation measurements. This hypothesis is confirmed by a formal test in which we compare the forecasting accuracy of the same models estimated using the two different datasets. As Table A - 9 reveals, NARR data is superior to SR2009 data in all models that use degree hours and also in models that use two or four seasons.

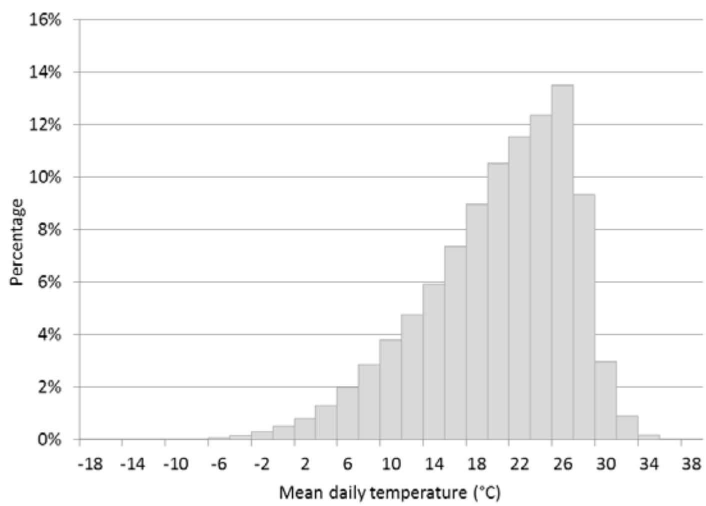
It is important to stress that despite all the methodological differences, SR2009 and NARR data are relatively similar if compared to SHF data (see Table A - 1 and in Table A - 5). In SHF all counties in the eastern US have degree days above 34°C while only 45% of counties in NARR data and only 12% of counties in SR2009 have degree days above 34°C. The mean number of degree days above 34°C is equal to 0.19 in NARR data and 0.004 in SR2009 data, compared to 2.37 in SHF. In order to test whether the NARR data set is consistent with weather

[20] The daily mean temperature is obtained by averaging daily maximum and daily minimum temperature when infra-daily measurements are not available.

station data, we use data from 788 evenly spread weather stations east of the 100th meridian that provide daily maximum and minimum temperatures (GHCN-Daily). We drop data marked as potentially erroneous and we compute daily mean temperatures by averaging daily minimum and maximum temperatures. If we pool all daily temperatures, from all weather stations, from April 1 to September 30, from 1979 to 2007, we find that only 0.023% of days have a temperature above 34°C.

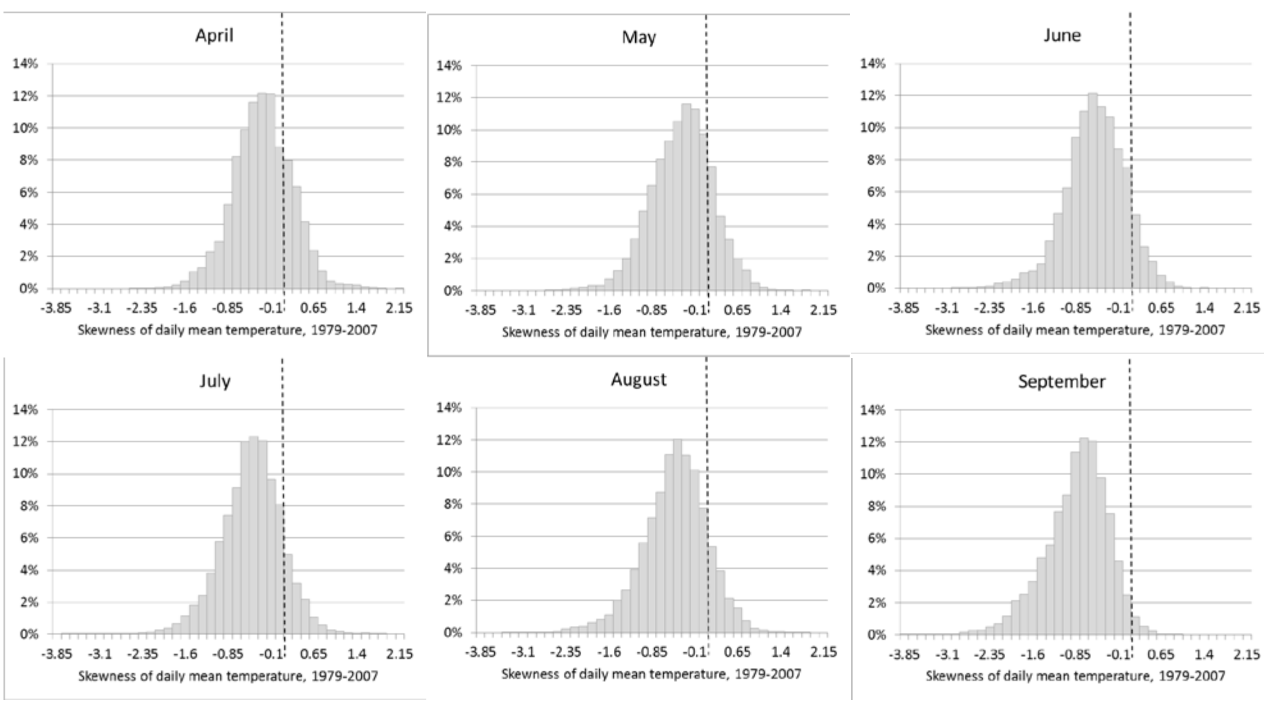
The number of degree hours in NARR is slightly higher than in SR2009 data, as shown in Table A - 1 and in Table A - 5, but the two datasets are similar.

List of Figures



Notes: All grid-cells of NARR dataset east of the 100th meridian, all days from April 1st to September 30th from 1979 to 2007.

Figure A - 1. Distribution of daily mean temperature.



Notes: Skewness of the distribution of mean daily temperature, by month, all years from 1979 to 2007, in a 10 percent random sample of NARR grid cells east of the 100th meridian. The vertical dashed line separates positive from negative values.

Figure A - 2. The distribution of the skewness of mean daily temperature.

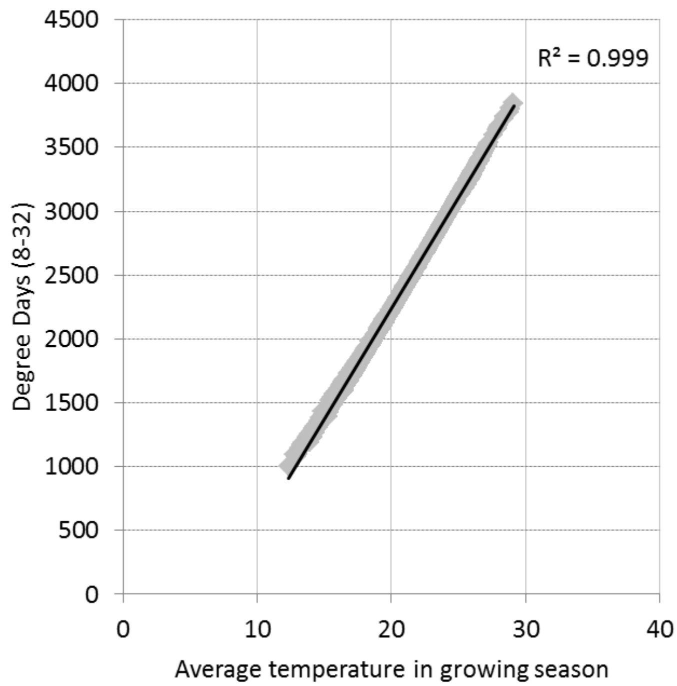
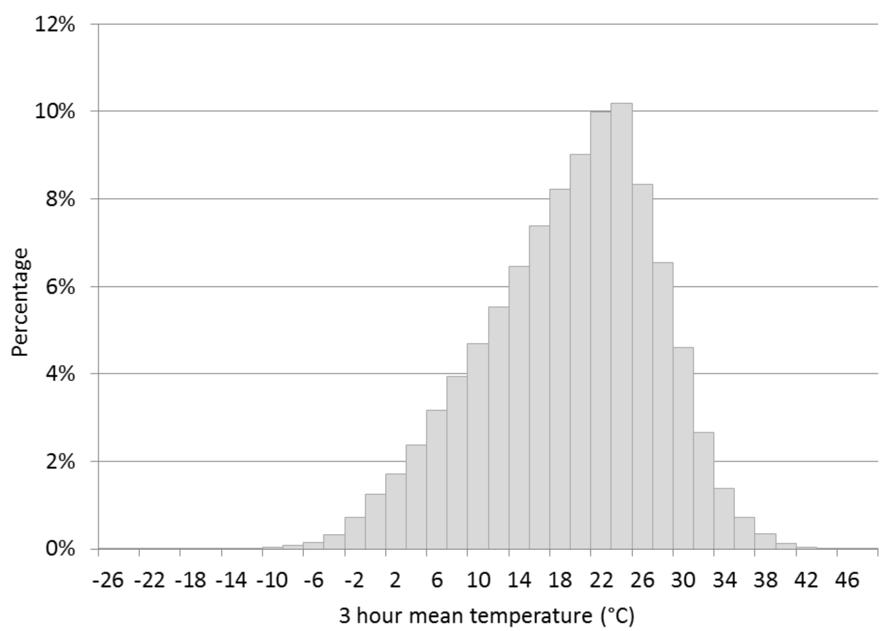


Figure A - 3. Plot of degree days 8-32°C against mean daily temperature (1979-2007 climatologies), April 1 to September 30.



Notes: All grid-cells of NARR dataset east of the 100th meridian, all three hour time intervals from April 1st to September 30th from 1979 to 2007.

Figure A - 4. Distribution of 3-hour temperature intervals

List of Tables

April-September	Mean	Std. Dev.	Min	Max
DD8 (°C)	2,394	576	1,001	3,886
DD8-32 (°C)	2,392	574	1,001	3,850
CDD8 (°C)	28.1	35.8	0	219.6
Dummy 34	0.45	0.50	0	1.00
DD34 (°C)	0.19	0.6	0	8
T Apr-Sep	20.9	3.32	12.3	29.2

July-September	Mean	Std. Dev.	Min	Max
DD8 (°C)	1,443	278	691	2,086
DD8-32 (°C)	1,442	276	691	2,055
CDD8 (°C)	0.47	1.03	0	12.9
Dummy 34	0.45	0.50	0	1.00
DD34 (°C)	0.17	0.6	0	6.6
T Jul-Sep	23.7	3.03	15.3	30.7

April-June	Mean	Std. Dev.	Min	Max
DD8 (°C)	950	301	300	1,835
DD8-32 (°C)	950	301	300	1,825
CDD8 (°C)	27.6	34.9	0	216.8
Dummy 34	0.20	0.40	0	1.00
DD34 (°C)	0.02	0.10	0	1.6
T Apr-Jun	18.1	3.63	8.95	28.2

Four seasons	Mean	Std. Dev.	Min	Max
T Dec-Feb	1.7	6.5	-13.7	20.1
T Mar-May	12.9	4.5	2.8	25.3
T Jun-Aug	24.4	2.9	16.1	31.2
T Sep-Nov	14.5	4.2	5.0	25.4

Table A - 1. Temperature data.

Precipitation (cm/month)	Mean	Std. Dev.	Min	Max
P Apr-Sep	9.7	1.5	4.4	16.2
P Apr-Jun	10.0	1.6	4.1	14.3
P Jul-Sep	9.4	2.0	3.9	19.6
P Dec-Feb	6.9	3.3	0.9	14.2
P Mar-May	9.3	2.0	3.3	13.6
P Jun-Aug	10.1	2.0	4.1	20.8
P Sep-Nov	8.0	1.7	2.8	13.1

Table A - 2. Precipitation data.

	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
		1982				1997		
Value of land ($/ha)	5,119	2,943	998	39,732	4,750	3,765	573	67,576
Farmland ('000 ha)	35.8	28.6	0.26	269	33.8	29.0	0.28	356
Pop. Density ('00 persons/sq. km)	0.47	1.07	0.0029	21.3	0.54	1.20	0.0029	21.7
Income per capita ('000 $)	17.1	3.48	7.48	34.8	24.1	4.96	7.67	56.8
Residential houses price ('000 $)	74.0	25.3	25.5	204	78.5	30.0	24.6	281
		1987				2002		
Value of land ($/ha)	3,950	2,998	682	40,859	6,020	5,525	645	85,049
Farmland ('000 ha)	34.7	28.9	0.24	331	34.6	29.3	0.18	335
Pop. Density ('00 persons/sq. km)	0.48	1.10	0.0030	21.1	0.56	1.24	0.0028	21.8
Income per capita ('000 $)	19.4	4.18	6.51	42.4	26.7	5.68	11.90	65.0
Residential houses price ('000 $)	79.7	33.8	26.0	372	92.7	39.1	29.0	432
		1992				2007		
Value of land ($/ha)	4,158	3,954	516	57,012	7,600	5,871	1,045	74,001
Farmland ('000 ha)	33.8	28.7	0.23	280	34.1	29.5	0.16	304
Pop. Density ('00 persons/sq. km)	0.51	1.15	0.0028	21.2	0.59	1.27	0.0025	21.0
Income per capita ('000 $)	21.4	4.29	8.77	49.2	28.9	6.39	13.99	75.4
Residential houses price ('000 $)	74.7	31.5	24.6	316	105.9	53.4	31.0	494

Table A - 3. Summary statistics of time-varying variables.

	Mean	Std. Dev.	Min	Max
Latitude (degrees)	37.7	4.62	26.1	48.8
Elevation ('000 meters)	0.25	0.17	0.001	1.22
Distance from met. Areas (km)	149	89.5	0	664
Surface water withdrawals ('000 l/day/ha)	0.14	0.73	0	16.16
Ground water withdrawals ('000 l/day/ha)	0.26	0.99	0	14.22
Salinity (%)	10.8	15.4	0	100
Flooding (%)	9.8	11.0	0	82.9
Wet factor (%)	12.1	18.7	0	100
k factor (t/ha)	0.73	0.18	0.25	1.20
Length of slope (m)	47.5	24.5	0.19	242
Sand (%)	11.8	24.6	0	100
Clay (%)	5.22	13.4	0	92.4
Moisture level (cm/cm^3)	0.14	0.04	0.02	0.23
Permeability (cm/hour)	3.44	3.40	0.08	29.1

Table A - 4. NRI (National Resources Inventory) soil variables.

April-September	Mean	Std. Dev.	Min	Max	July-September	Mean	Std. Dev.	Min	Max
DD8 (°C)	2,294	555	977	3,817	DD8 (°C)	1,378	269	684	2,043
DD8-32 (°C)	2,294	555	977	3,806	DD8-32 (°C)	1,378	269	684	2,035
CDD8 (°C)	28.6	37.3	0	206.5	CDD8 (°C)	0.68	1.53	0	12.8
Dummy 34	0.12	0.33	0	1.00	Dummy 34	0.12	0.32	0	1.00
DD34 (°C)	0.004	0.022	0.000	0.360	DD34 (°C)	0.00	0.0	0	0.2
T Apr-Sep	20.3	3.21	12.2	28.8	T Jul-Sep	22.9	2.94	15.3	30.2
April-June	Mean	Std. Dev.	Min	Max	Four seasons	Mean	Std. Dev.	Min	Max
DD8 (°C)	916	288	286	1,774	T Dec-Feb	1.7	6.2	-13.6	19.6
DD8-32 (°C)	916	288	286	1,771	T Mar-May	12.7	4.4	2.6	24.2
CDD8 (°C)	27.9	36.0	0	197.7	T Jun-Aug	23.7	2.8	16.2	30.8
Dummy 34	0.03	0.18	0	1.00	T Sep-Nov	14.0	4.1	4.3	25.4
DD34 (°C)	0.00	0.01	0	0.2					
T Apr-Jun	17.8	3.50	8.96	27.5					

Table A - 5. Temperature data, SR2009 data.

Precipitation (cm/month)	Mean	Std. Dev.	Min	Max
P Apr-Sep	10.0	1.6	5.3	16.9
P Apr-Jun	10.3	1.7	5.1	15.5
P Jul-Sep	9.8	2.2	4.7	21.4
P Dec-Feb	7.3	3.7	1.0	16.1
P Mar-May	9.7	2.3	3.3	16.0
P Jun-Aug	10.4	2.1	4.5	21.9
P Sep-Nov	8.7	2.0	3.1	15.8

Table A - 6. Precipitation data, SR2009 data.

	NARR					SR2009			
April-September					April-September				
	Mean	Std. Dev.	Min	Max		Mean	Std. Dev.	Min	Max
DH8 (°C)	2,406	567	1,028	3,880	DH8 (°C)	2,320	537	1,058	3,817
DH8-32 (°C)	2,385	549	1,028	3,680	DH8-32 (°C)	2,303	522	1,058	3,617
CDH8 (°C)	43.0	44.2	0	242	CDH8 (°C)	54.5	54.5	0	287
DH34 (°C)	8.67	15.02	0	118	DH34 (°C)	5.45	8.98	0	101
April-June					April-June				
	Mean	Std. Dev.	Min	Max		Mean	Std. Dev.	Min	Max
DH8 (°C)	41.0	41.8	0	236	DH8 (°C)	50.2	48.9	0	252
DH8-32 (°C)	1.35	4.13	0	51	DH8-32 (°C)	0.7	1.7	0	31.0
CDH8 (°C)	0	0	0	0	CDH8 (°C)	0	0	0	0
DH34 (°C)	1,446	276	700	2,085	DH34 (°C)	1,381	265	708	2,043

Table A - 7. Degree hours, NARR and SR2009 data.

			Usual Planting dates			Usual Harvesting dates		
Crop	State	% of total harvest acres	Begin	Peak	End	Begin	Peak	End
Corn	Iowa	17%	19-Apr	Apr 25 - May 18	26-May	21-Sep	Oct 5 - Nov 9	21-Nov
	Illinois	15%	14-Apr	Apr 21 - May 23	5-Jun	14-Sep	Sep 23 - Nov 5	20-Nov
Cotton	Texas	47%	22-Mar	Apr 8 - Jun 7	20-Jun	10-Aug	Sep 13 - Dec 21	11-Jan
	Georgia	13%	23-Apr	May 2 - May 31	11-Jun	23-Sep	Oct 10 - Dec 2	18-Dec
Sorghum	Kansas	46%	5-May	May 15 - Jun 20	15-Jul	10-Sep	Sep 25 - Nov 10	25-Nov
	Texas	37%	1-Mar	Mar 11 - Jun 15	5-Jul	25-Jun	Jul 8 - Nov 16	6-Dec
Soybeans	Iowa	12%	2-May	May 8 - Jun 2	16-Jun	21-Sep	Sep 28 - Oct 20	31-Oct
	Illinois	12%	2-May	May 8 - Jun 12	24-Jun	19-Sep	Sep 26 - Oct 26	7-Nov
Spring Wheat	North Dakota	49%	16-Apr	Apr 24 - May 25	3-Jun	1-Aug	Aug 8 - Sep 13	25-Sep
	Montana	18%	6-Apr	Apr 14 - May 12	18-May	30-Jul	Aug 7 - Sep 6	13-Sep
Winter Wheat	Kansas	26%	10-Sep	Sep 15 - Oct 20	1-Nov	15-Jun	Jun 20 - Jul 5	15-Jul
	Oklahoma	10%	3-Sep	Sep 15 - Oct 22	6-Nov	1-Jun	Jun 6 - Jun 27	3-Jul

Table A - 8. Planting and harvesting dates for major crops in the eastern US.

NARR	SR2009	MGN	RMSE
T GS	T GS	-8.5	11.5
DD8-32 GS	DD8-32 GS	-7.6	13.9
DD8-32 GS + CDD8	DD8-32 GS + CDD8	7.7	3.9
DD8-32 GS + D34sqrt	DD8-32 GS + D34sqrt	2.8	8.2
DD8-32 2 SEASONS	DD8-32 2 SEASONS	13.4	21.8
T 4 SEASONS	T 4 SEASONS	21.1	65.0
DH8-32 GS	DH8-32 GS	-7.4	12.98
DH8-32 GS + CDH8	DH8-32 GS + CDH8	2.3	-26.41
DH8-32 GS + DH34sqrt	DH8-32 GS + DH34sqrt	-9.2	4.32
DH8-32 2 SEASONS	DH8-32 2 SEASONS	-4.5	17.55

Table A - 9. Test of whether NARR data leads to lower out-of-sample forecasting accuracy than SR2009 data.

MODEL	No state fixed effects	State fixed effects	Hourly temperature	HWSD Top-soil data	HWSD Sub-soil data	Without water usage
DD8-32 GS + CDD8	-0.00493***	-0.00367***	-0.00493***	-0.00704***	-0.00524***	-0.00497***
	[0.000553]	[0.000741]	[0.000553]	[0.000587]	[0.000627]	[0.000551]
DD8-32 GS + Dummy 34	0.0463***	0.0356***		0.0496***	0.0320***	0.0485***
	[0.00875]	[0.00863]		[0.0100]	[0.00952]	[0.00879]
DD8-32 GS + D34	-0.00202	-0.00939	-0.00114***	-0.0415***	-0.0278***	-0.00628
	[0.00578]	[0.00656]	[0.000422]	[0.00556]	[0.00549]	[0.00571]
DD8-32 GS + D34 sq	0.00255**	-0.00304***	1.08e-05***	-0.00167*	0.000774	0.00196*
	[0.00110]	[0.00111]	[4.19e-06]	[0.000882]	[0.000898]	[0.00108]
DD8-32 GS + D34 sqrt	-0.0666***	0.000911	-0.0267***	-0.186***	-0.164***	-0.0724***
	[0.0121]	[0.0142]	[0.00405]	[0.0130]	[0.0127]	[0.0122]
DD8-32 GS + DD34	0.00178***	0.00131***	-0.000772*	0.00166***	0.00107***	0.00184***
	[0.000335]	[0.000332]	[0.000396]	[0.000386]	[0.000367]	[0.000337]
DD8-32 GS + DD34 sq	6.81e-05***	4.64e-05***	2.80e-06	5.31e-05***	3.44e-05**	6.93e-05***
	[1.28e-05]	[1.29e-05]	[2.87e-06]	[1.48e-05]	[1.41e-05]	[1.29e-05]
DD8-32 GS + DD34 sqrt	0.00907***	0.00686***	-0.00936**	0.00913***	0.00587***	0.00944***
	[0.00171]	[0.00169]	[0.00400]	[0.00197]	[0.00187]	[0.00172]
DD8-32 2 SEASONS + D34 sqrt	0.0418***	0.0266	0.00659	0.0548***	0.0376**	0.0356**
	[0.0143]	[0.0166]	[0.00446]	[0.0160]	[0.0151]	[0.0143]
DD8-32 2 SEASONS + DD34 sqrt	0.0138***	0.00686***	0.00609	0.0161***	0.0125***	0.0140***
	[0.00162]	[0.00169]	[0.00405]	[0.00167]	[0.00162]	[0.00163]
T 2 SEASONS + D34 sqrt	0.0170	0.00613	0.0299***	0.0238	0.000560	0.0134
	[0.0149]	[0.0168]	[0.00530]	[0.0165]	[0.0159]	[0.0149]
T 2 SEASONS + DD34 sqrt	0.0119***	0.00620***	0.0165***	0.0143***	0.0109***	0.0122***
	[0.00161]	[0.00162]	[0.00427]	[0.00165]	[0.00161]	[0.00163]

Standard errors in brackets. *** p<0.01, ** p<0.05, * p<0.10.

Table A - 10. Robustness test: replication of main findings in the paper using alternative data.

MODEL	Baseline	State fixed effects	Degree Hours	HWSD Top-soil data	HWSD Sub-soil data	Without water usage
T GS	-15.1%	-10.7%		-16.4%	-16.7%	-14.7%
	[-15.9% , -14.2%]	[-12.1% , -9.3%]		[-17.5% , -15.4%]	[-17.7% , -15.8%]	[-15.6% , -13.9%]
DD8 GS	-15.4%	-11.1%	-15.7%	-17.0%	-17.3%	-15.1%
	[-16.3% , -14.6%]	[-12.6% , -9.7%]	[-16.6% , -14.8%]	[-18.1% , -15.9%]	[-18.3% , -16.3%]	[-16% , -14.2%]
DD8-32 GS	-16.0%	-11.8%	-18.4%	-17.5%	-17.8%	-15.7%
	[-16.9% , -15.1%]	[-13.3% , -10.4%]	[-19.4% , -17.5%]	[-18.6% , -16.4%]	[-18.8% , -16.9%]	[-16.6% , -14.8%]
DD8-32 2 SEASONS						
April-June	18.1%	13.7%	20.2%	26.3%	23.4%	17.8%
	[16.2% , 19.9%]	[11.2% , 16.2%]	[18.2% , 22.2%]	[24.4% , 28.1%]	[21.5% , 25.4%]	[15.9% , 19.7%]
June-September	-31.5%	-25.8%	-38.2%	-38.0%	-35.8%	-31.3%
	[-33% , -30.1%]	[-28.2% , -23.4%]	[-40% , -36.4%]	[-39.6% , -36.4%]	[-37.4% , -34.1%]	[-32.8% , -29.8%]
Growing season	-13.5%	-12.1%	-18.0%	-11.7%	-12.3%	-13.5%
	[-14.4% , -12.6%]	[-13.5% , -10.7%]	[-19% , -17%]	[-12.8% , -10.6%]	[-13.3% , -11.3%]	[-14.5% , -12.6%]
T 4 SEASONS						
Winter	-20.8%	-20.4%		-25.9%	-22.2%	-18.7%
	[-22.9% , -18.6%]	[-23.1% , -17.8%]		[-28.1% , -23.8%]	[-24.3% , -20.1%]	[-21.1% , -16.4%]
Spring	23.2%	10.3%		29.7%	26.7%	23.2%
	[20.6% , 25.7%]	[7.3% , 13.3%]		[27% , 32.4%]	[24.2% , 29.3%]	[20.7% , 25.8%]
Summer	-39.0%	-30.8%		-47.4%	-44.3%	-38.0%
	[-41.3% , -36.6%]	[-33.6% , -28.1%]		[-49.5% , -45.3%]	[-46.4% , -42.2%]	[-40.3% , -35.6%]
Autumn	28.3%	34.0%		35.9%	32.6%	25.0%
	[24.4% , 32.2%]	[29.8% , 38.3%]		[32.3% , 39.5%]	[29.1% , 36.2%]	[21% , 29.1%]
Annual	-8.3%	-6.9%		-7.7%	-7.1%	-8.4%
	[-10.2% , -6.3%]	[-8.8% , -5%]		[-9.8% , -5.6%]	[-9.1% , -5.1%]	[-10.4% , -6.4%]

Notes: Percentage loss of land values in all counties included in the analysis. Precipitation is assumed to remain unchanged. In brackets bootstrap confidence intervals obtained using 1,000 repetitions.

Table A - 11. Robustness test: impact of temperature on land values.

MODEL	No state fixed effects	State fixed effects	Hourly temperature	HWSD Top-soil data	HWSD Sub-soil data	Without water usage
DD8-32 GS + CDD8	-0.00221***	-0.00192***	-0.00378***	-0.00302***	-0.00181***	-0.00213***
	[0.000599]	[0.000733]	[0.000525]	[0.000618]	[0.000632]	[0.000598]
DD8-32 GS + Dummy 34	-0.101***	0.0134		-0.137***	-0.143***	-0.107***
	[0.0103]	[0.0102]		[0.0105]	[0.0102]	[0.0104]
DD8-32 GS + D34	-0.631***	-0.894***	-0.00429***	-0.810***	-0.746***	-0.707***
	[0.122]	[0.138]	[0.000692]	[0.128]	[0.121]	[0.121]
DD8-32 GS + D34 sq	-1.827***	-4.462***	-1.35e-05	-2.475***	-2.087***	-2.064***
	[0.540]	[0.618]	[8.96e-06]	[0.549]	[0.521]	[0.537]
DD8-32 GS + D34 sqrt	-0.410***	-0.293***	-0.0861***	-0.508***	-0.499***	-0.447***
	[0.0506]	[0.0565]	[0.00643]	[0.0533]	[0.0521]	[0.0502]
DD8-32 GS + DD34	-0.00389***	0.000503	-0.00429***	-0.00525***	-0.00550***	-0.00411***
	[0.000396]	[0.000391]	[0.000692]	[0.000405]	[0.000393]	[0.000401]
DD8-32 GS + DD34 sq	-0.000150***	1.88e-05	-1.81e-05***	-0.000202***	-0.000211***	-0.000158***
	[1.52e-05]	[1.51e-05]	[5.61e-06]	[1.56e-05]	[1.51e-05]	[1.54e-05]
DD8-32 GS + DD34 sqrt	-0.0198***	0.00260	-0.0820***	-0.0268***	-0.0280***	-0.0210***
	[0.00202]	[0.00200]	[0.0100]	[0.00206]	[0.00201]	[0.00205]
DD8-32 2 SEASONS + D34 sqrt	-0.0725	-0.225***	-0.0213***	-0.0432	-0.0899	-0.0861
	[0.0540]	[0.0555]	[0.00738]	[0.0565]	[0.0557]	[0.0539]
DD8-32 2 SEASONS + DD34 sqrt	-0.00162	0.00378*	0.00146	0.00244	-0.00391*	-0.00191
	[0.00204]	[0.00200]	[0.0110]	[0.00204]	[0.00204]	[0.00206]
T 2 SEASONS + D34 sqrt	-0.145***	-0.266***	0.00106	-0.158***	-0.207***	-0.156***
	[0.0546]	[0.0562]	[0.00926]	[0.0559]	[0.0557]	[0.0546]
T 2 SEASONS + DD34 sqrt	-0.00302	0.00325	0.0455***	-0.000165	-0.00638***	-0.00326
	[0.00203]	[0.00199]	[0.0131]	[0.00199]	[0.00201]	[0.00206]

Standard errors in brackets. *** p<0.01, ** p<0.05, * p<0.10.

Table A - 12. Robustness test: replication of threshold tests using alternative data and SR2009 data.

MODEL	Baseline	State fixed effects	Degree Hours	HWSD Top-soil data	HWSD Sub-soil data	Without water usage
T GS	-19.5%	-13.3%		-22.5%	-22.5%	-19.3%
	[-20.5% , -18.5%]	[-15.1% , -11.5%]		[-23.7% , -21.3%]	[-23.6% , -21.3%]	[-20.3% , -18.3%]
DD8 GS	-19.9%	-13.8%	-20.7%	-23.1%	-23.1%	-19.8%
	[-21% , -18.9%]	[-15.7% , -11.9%]	[-21.7% , -19.6%]	[-24.4% , -21.8%]	[-24.3% , -21.9%]	[-20.8% , -18.7%]
DD8-32 GS	-20.0%	-13.9%	-22.2%	-23.2%	-23.1%	-19.8%
	[-21% , -19%]	[-15.7% , -12%]	[-23.4% , -21.1%]	[-24.4% , -21.9%]	[-24.3% , -22%]	[-20.9% , -18.8%]
DD8-32 2 SEASONS						
April-June	15.8%	9.3%	22.8%	28.6%	25.5%	16.3%
	[13.8% , 17.8%]	[6.2% , 12.4%]	[20.4% , 25.1%]	[26.3% , 30.9%]	[22.9% , 28%]	[14.3% , 18.3%]
June-September	-29.8%	-21.7%	-39.1%	-41.2%	-38.2%	-30.1%
	[-31.6% , -28.1%]	[-24.7% , -18.7%]	[-41% , -37.2%]	[-43.3% , -39.1%]	[-40.5% , -36%]	[-31.9% , -28.4%]
Growing season	-14.0%	-12.4%	-16.3%	-12.6%	-12.8%	-13.9%
	[-15.2% , -12.9%]	[-14.2% , -10.5%]	[-17.5% , -15.2%]	[-13.9% , -11.4%]	[-14% , -11.6%]	[-15% , -12.7%]
T 4 SEASONS						
Winter	-17.9%	-17.5%		-24.6%	-20.9%	-16.5%
	[-20.1% , -15.6%]	[-20.3% , -14.6%]		[-26.6% , -22.5%]	[-23% , -18.8%]	[-19.1% , -13.9%]
Spring	16.0%	-5.8%		21.7%	15.2%	17.3%
	[12.7% , 19.2%]	[-9.5% , -2%]		[18.2% , 25.1%]	[11.8% , 18.6%]	[14.1% , 20.5%]
Summer	-33.2%	-14.9%		-44.2%	-38.9%	-32.7%
	[-36.4% , -30%]	[-18.5% , -11.2%]		[-47.6% , -40.9%]	[-42.2% , -35.6%]	[-35.9% , -29.5%]
Autumn	15.9%	25.2%		25.8%	23.7%	12.9%
	[11.9% , 19.9%]	[20.6% , 29.9%]		[21.9% , 29.7%]	[19.7% , 27.6%]	[8.7% , 17%]
Annual	-19.2%	-12.9%		-21.4%	-20.9%	-19.0%
	[-21.1% , -17.3%]	[-14.8% , -11%]		[-23.2% , -19.6%]	[-22.7% , -19.2%]	[-20.9% , -17.1%]

Notes: Percentage loss of land values in all counties included in the analysis. Precipitation is assumed to remain unchanged. In brackets bootstrap confidence intervals obtained using 1,000 repetitions.

Table A - 13. Robustness test: impact of temperature on land values, using SR2009 data.

model 1	model 2	MGN	RMSE
DH8-32 GS	T GS	-15.0	38.6
DH8-32 GS	DH8-32 GS + CDH8	-42.7	19.2
DH8-32 GS + DH34sqrt	DH8-32 GS	11.3	8.4
DH8-32 GS + DH34sqrt	T GS	5.9	35.1
DH8-32 2 SEASONS	DH8-32 GS	17.1	11.0
DH8-32 2 SEASONS	DH8-32 GS + DH34sqrt	14.7	9.1
T 4 SEASONS	DH8-32 GS	29.1	21.6
T 4 SEASONS	DH8-32 GS + DH34sqrt	28.6	19.8
T 4 SEASONS	DH8-32 2 SEASONS	15.3	23.9

Table A - 14. Test of forecasting accuracy, degree hours with NARR data.

model 1	model 2	MGN	RMSE
DD8-32 GS	T GS	-38.7	31.7
DD8-32 2 SEASONS	DD8-32 GS	25.9	-1.84
DD8-32 2 SEASONS	T 2 SEASONS	-21.2	1.03
T 2 SEASONS	T GS	27.5	-1.01
T 4 SEASONS	T GS	13.1	0.65
T 4 SEASONS	DD8-32 GS	15.0	-0.20
T 4 SEASONS	DD8-32 2 SEASONS	-3.84	4.85
T 4 SEASONS	T 2 SEASONS	-15.1	-0.63

Table A - 15. Test of forecasting accuracy, SR 2009 data.

Estimated coefficients for regressions in the paper

	T GS	DD8	DD8-32	T GS	DD8	DD8-32
Temp. Apr-Sep (°C -8)*183	0.000104**			0.000266***		
	[4.96e-05]			[7.64e-05]		
Temp. Apr-Sep sq. (°C - 8)*183	-1.92e-07***			-1.76e-07***		
	[1.16e-08]			[1.73e-08]		
DD8 Apr-Sep (°C)		-4.02e-06			0.000206**	
		[5.70e-05]			[8.82e-05]	
DD8 Apr-Sep sq. (°C)		-1.71e-07***			-1.66e-07***	
		[1.27e-08]			[1.89e-08]	
DD8-32 Apr-Sep (°C)			4.72e-05			0.000248***
			[5.72e-05]			[8.91e-05]
DD8-32 Apr-Sep sq. (°C)			-1.89e-07***			-1.83e-07***
			[1.28e-08]			[1.93e-08]
Precip. Apr-Sep (cm/month)	0.191***	0.193***	0.185***	0.252***	0.253***	0.248***
	[0.0237]	[0.0238]	[0.0238]	[0.0276]	[0.0276]	[0.0275]
Precip. Apr-Sep sq. (cm/month)	-0.0110***	-0.0111***	-0.0107***	-0.0130***	-0.0131***	-0.0129***
	[0.00122]	[0.00122]	[0.00122]	[0.00143]	[0.00143]	[0.00143]
Income per capita ('000 $)	0.0113***	0.0115***	0.0116***	0.0103***	0.0104***	0.0104***
	[0.00133]	[0.00133]	[0.00133]	[0.00128]	[0.00128]	[0.00128]
Pop. density ('00 persons/km^2)	0.143***	0.143***	0.142***	0.148***	0.148***	0.148***
	[0.00940]	[0.00939]	[0.00934]	[0.00890]	[0.00891]	[0.00889]
Pop density sq. ('00 persons/km^2)	-0.00744***	-0.00742***	-0.00735***	-0.00786***	-0.00787***	-0.00785***
	[0.00116]	[0.00116]	[0.00115]	[0.00110]	[0.00110]	[0.00109]
Res. houses price ('000 $)	0.00529***	0.00526***	0.00524***	0.00505***	0.00504***	0.00504***
	[0.000196]	[0.000197]	[0.000196]	[0.000188]	[0.000189]	[0.000188]
Dummy 1987	-0.418***	-0.419***	-0.419***	-0.416***	-0.417***	-0.417***
	[0.0114]	[0.0114]	[0.0114]	[0.0105]	[0.0105]	[0.0105]
Dummy 1992	-0.448***	-0.449***	-0.449***	-0.445***	-0.446***	-0.446***
	[0.0124]	[0.0124]	[0.0124]	[0.0115]	[0.0115]	[0.0115]
Dummy 1997	-0.351***	-0.353***	-0.353***	-0.345***	-0.346***	-0.346***
	[0.0141]	[0.0142]	[0.0141]	[0.0133]	[0.0133]	[0.0133]
Dummy 2002	-0.283***	-0.284***	-0.285***	-0.271***	-0.272***	-0.272***
	[0.0155]	[0.0155]	[0.0155]	[0.0148]	[0.0148]	[0.0148]
Dummy 2007	-0.0484***	-0.0500***	-0.0503***	-0.0307*	-0.0320**	-0.0320**
	[0.0169]	[0.0169]	[0.0169]	[0.0161]	[0.0161]	[0.0161]
Salinity (% of farmland)	-0.000145	-0.000151	-0.000108	-0.000882***	-0.000884***	-0.000857***
	[0.000311]	[0.000311]	[0.000309]	[0.000307]	[0.000307]	[0.000307]
Flooding (% of farmland)	-0.000822***	-0.000829***	-0.000838***	-0.00117***	-0.00119***	-0.00121***
	[0.000311]	[0.000311]	[0.000311]	[0.000296]	[0.000296]	[0.000297]
Wet factor (% of farmland)	0.00317***	0.00317***	0.00319***	0.000813***	0.000819***	0.000840***
	[0.000244]	[0.000244]	[0.000244]	[0.000250]	[0.000250]	[0.000250]
k factor (t/ha)	-0.938***	-0.934***	-0.942***	-0.493***	-0.491***	-0.495***
	[0.0372]	[0.0372]	[0.0372]	[0.0420]	[0.0420]	[0.0420]
Slope length (m)	0.00225***	0.00225***	0.00223***	0.00231***	0.00231***	0.00232***
	[0.000147]	[0.000147]	[0.000147]	[0.000153]	[0.000153]	[0.000153]
Sand (% of farmland)	-0.00133*	-0.00138*	-0.00121*	-0.00202***	-0.00202***	-0.00192***
	[0.000705]	[0.000707]	[0.000706]	[0.000628]	[0.000629]	[0.000629]
Clay (% of farmland)	-0.00197***	-0.00193***	-0.00190***	-0.00213***	-0.00211***	-0.00211***
	[0.000338]	[0.000338]	[0.000336]	[0.000309]	[0.000309]	[0.000309]
Moisture level (cm/cm^3)	3.106***	3.145***	3.194***	0.937***	0.943***	0.980***
	[0.201]	[0.201]	[0.201]	[0.250]	[0.251]	[0.251]
Permeability (cm/h)	-0.00517	-0.00426	-0.00509	-0.00888*	-0.00869	-0.00893*
	[0.00590]	[0.00591]	[0.00591]	[0.00533]	[0.00533]	[0.00533]
Latitude (degrees)	-0.106***	-0.104***	-0.107***	-0.0705***	-0.0698***	-0.0743***
	[0.00337]	[0.00329]	[0.00329]	[0.00567]	[0.00559]	[0.00566]
Elevation (km)	-0.957***	-0.951***	-0.967***	-0.546***	-0.546***	-0.562***
	[0.0280]	[0.0279]	[0.0279]	[0.0359]	[0.0359]	[0.0359]
Distance from cities (km)	-0.000970***	-0.000953***	-0.000936***	-0.000826***	-0.000826***	-0.000819***
	[4.60e-05]	[4.62e-05]	[4.61e-05]	[5.04e-05]	[5.04e-05]	[5.03e-05]
Surface water use ('000 l/ha/day)	-0.0151	-0.0154	-0.0149	-0.00155	-0.00169	-0.00170
	[0.0111]	[0.0111]	[0.0112]	[0.0103]	[0.0103]	[0.0103]
Ground water use ('000 l/ha/day)	0.0265***	0.0265***	0.0270***	0.0380***	0.0378***	0.0380***
	[0.00319]	[0.00320]	[0.00321]	[0.00361]	[0.00360]	[0.00361]
Constant	12.46***	12.50***	12.66***	10.11***	10.17***	10.37***
	[0.210]	[0.212]	[0.211]	[0.319]	[0.325]	[0.325]
State fixed effects	No	No	No	Yes	Yes	Yes
Adjusted R-squared	0.786	0.786	0.787	0.836	0.836	0.836

Standard errors in brackets. *** p<0.01, ** p<0.05, * p<0.1

Table A - 16. T, DD8 and DD8-32.

	T GS & CDD8	DD8 & CDD8	DD8-32 & CDD8	T GS & CDD8	DD8 & CDD8	DD8-32 & CDD8
Temp. Apr-Sep (°C -8)*183	-0.00113***			-0.000477***		
	[0.000139]			[0.000173]		
Temp. Apr-Sep sq. (°C - 8)*183	3.23e-08			-5.61e-08*		
	[2.65e-08]			[3.24e-08]		
DD8 Apr-Sep (°C)		-0.00118***			-0.000494***	
		[0.000139]			[0.000171]	
DD8 Apr-Sep sq. (°C)		4.29e-08			-5.31e-08*	
		[2.66e-08]			[3.21e-08]	
DD8-32 Apr-Sep (°C)			-0.00107***			-0.000407**
			[0.000142]			[0.000175]
DD8-32 Apr-Sep sq. (°C)			1.67e-08			-7.49e-08**
			[2.73e-08]			[3.33e-08]
CDD8 Apr-Sep (°C)	-0.00617***	-0.00528***	-0.00493***	-0.00367***	-0.00315***	-0.00289***
	[0.000628]	[0.000546]	[0.000553]	[0.000741]	[0.000630]	[0.000640]
Precip. Apr-Sep (cm/month)	0.177***	0.181***	0.176***	0.243***	0.242***	0.240***
	[0.0244]	[0.0244]	[0.0244]	[0.0282]	[0.0282]	[0.0281]
Precip. Apr-Sep sq. (cm/month)	-0.0101***	-0.0102***	-0.0100***	-0.0127***	-0.0127***	-0.0126***
	[0.00126]	[0.00126]	[0.00125]	[0.00146]	[0.00146]	[0.00145]
Income per capita ('000 $)	0.0121***	0.0122***	0.0121***	0.0110***	0.0110***	0.0110***
	[0.00133]	[0.00133]	[0.00133]	[0.00128]	[0.00128]	[0.00128]
Pop. density ('00 persons/km^2)	0.139***	0.139***	0.139***	0.147***	0.147***	0.147***
	[0.00920]	[0.00920]	[0.00917]	[0.00881]	[0.00881]	[0.00880]
Pop density sq. ('00 persons/km^2)	-0.00716***	-0.00716***	-0.00713***	-0.00777***	-0.00778***	-0.00776***
	[0.00114]	[0.00114]	[0.00113]	[0.00108]	[0.00108]	[0.00108]
Res. houses price ('000 $)	0.00518***	0.00518***	0.00518***	0.00500***	0.00499***	0.00499***
	[0.000197]	[0.000197]	[0.000196]	[0.000189]	[0.000189]	[0.000189]
Dummy 1987	-0.420***	-0.420***	-0.420***	-0.418***	-0.418***	-0.418***
	[0.0114]	[0.0114]	[0.0114]	[0.0105]	[0.0105]	[0.0105]
Dummy 1992	-0.452***	-0.452***	-0.452***	-0.448***	-0.448***	-0.448***
	[0.0124]	[0.0124]	[0.0124]	[0.0115]	[0.0115]	[0.0115]
Dummy 1997	-0.357***	-0.357***	-0.357***	-0.350***	-0.350***	-0.350***
	[0.0142]	[0.0143]	[0.0142]	[0.0133]	[0.0133]	[0.0133]
Dummy 2002	-0.289***	-0.290***	-0.289***	-0.276***	-0.277***	-0.276***
	[0.0155]	[0.0155]	[0.0155]	[0.0148]	[0.0148]	[0.0148]
Dummy 2007	-0.0559***	-0.0563***	-0.0556***	-0.0376**	-0.0379**	-0.0374**
	[0.0169]	[0.0169]	[0.0169]	[0.0161]	[0.0161]	[0.0161]
Salinity (% of farmland)	6.43e-05	7.22e-05	8.56e-05	-0.000722**	-0.000723**	-0.000710**
	[0.000305]	[0.000305]	[0.000304]	[0.000305]	[0.000305]	[0.000305]
Flooding (% of farmland)	-0.00103***	-0.00103***	-0.00102***	-0.00128***	-0.00129***	-0.00130***
	[0.000306]	[0.000306]	[0.000307]	[0.000293]	[0.000293]	[0.000294]
Wet factor (% of farmland)	0.00327***	0.00327***	0.00328***	0.000916***	0.000917***	0.000929***
	[0.000239]	[0.000240]	[0.000240]	[0.000247]	[0.000247]	[0.000247]
k factor (t/ha)	-0.875***	-0.870***	-0.882***	-0.456***	-0.455***	-0.461***
	[0.0361]	[0.0361]	[0.0361]	[0.0420]	[0.0421]	[0.0421]
Slope length (m)	0.00222***	0.00222***	0.00221***	0.00235***	0.00235***	0.00235***
	[0.000148]	[0.000148]	[0.000148]	[0.000154]	[0.000154]	[0.000154]
Sand (% of farmland)	-0.00170**	-0.00175**	-0.00161**	-0.00206***	-0.00206***	-0.00197***
	[0.000704]	[0.000704]	[0.000702]	[0.000628]	[0.000628]	[0.000628]
Clay (% of farmland)	-0.00151***	-0.00151***	-0.00152***	-0.00197***	-0.00196***	-0.00197***
	[0.000323]	[0.000323]	[0.000322]	[0.000305]	[0.000305]	[0.000305]
Moisture level (cm/cm^3)	3.019***	3.007***	3.058***	0.931***	0.931***	0.964***
	[0.198]	[0.198]	[0.198]	[0.250]	[0.250]	[0.250]
Permeability (cm/h)	0.00156	0.00203	0.00104	-0.00682	-0.00676	-0.00709
	[0.00586]	[0.00585]	[0.00585]	[0.00532]	[0.00532]	[0.00532]
Latitude (degrees)	-0.0850***	-0.0838***	-0.0877***	-0.0629***	-0.0622***	-0.0668***
	[0.00401]	[0.00389]	[0.00396]	[0.00613]	[0.00606]	[0.00620]
Elevation (km)	-0.973***	-0.971***	-0.982***	-0.574***	-0.573***	-0.585***
	[0.0280]	[0.0280]	[0.0279]	[0.0359]	[0.0359]	[0.0358]
Distance from cities (km)	-0.000756***	-0.000746***	-0.000747***	-0.000735***	-0.000733***	-0.000734***
	[4.75e-05]	[4.75e-05]	[4.74e-05]	[5.05e-05]	[5.06e-05]	[5.05e-05]
Surface water use ('000 l/ha/day)	-0.0139	-0.0140	-0.0138	-0.00105	-0.00104	-0.00111
	[0.0109]	[0.0109]	[0.0109]	[0.0102]	[0.0102]	[0.0103]
Ground water use ('000 l/ha/day)	0.0263***	0.0263***	0.0267***	0.0376***	0.0375***	0.0376***
	[0.00319]	[0.00318]	[0.00319]	[0.00361]	[0.00360]	[0.00361]
Constant	13.38***	13.38***	13.45***	11.01***	11.02***	11.12***
	[0.245]	[0.246]	[0.244]	[0.358]	[0.357]	[0.355]
State fixed effects	No	No	No	Yes	Yes	Yes
Adjusted R-squared	0.789	0.789	0.789	0.836	0.836	0.836

Standard errors in brackets. *** p<0.01, ** p<0.05, * p<0.1

Table A - 17. Cold degree days.

	DD8-32 2 SEASONS	DD8-32 2 SEASONS & DD34 SQRT	DD8-32 2 SEASONS	DD8-32 2 SEASONS & DD34 SQRT
DD8-32 Apr-Jun (°C)	0.00506***	0.00524***	0.00500***	0.00514***
	[0.000268]	[0.000273]	[0.000402]	[0.000415]
DD8-32 Apr-Jun sq. (°C)	-1.59e-06***	-1.62e-06***	-1.80e-06***	-1.84e-06***
	[1.09e-07]	[1.09e-07]	[1.64e-07]	[1.67e-07]
DD8-32 Jul-Sep (°C)	-0.00304***	-0.00294***	-0.00420***	-0.00409***
	[0.000342]	[0.000344]	[0.000481]	[0.000480]
DD8-32 Jul-Sep sq. (°C)	-1.43e-07	-2.53e-07**	4.63e-07***	3.75e-07**
	[1.09e-07]	[1.15e-07]	[1.53e-07]	[1.55e-07]
DD34 Apr-Sep sq. root (°C)		0.0418***		0.0266
		[0.0143]		[0.0166]
Precip. Apr-Jun (cm/month)	0.422***	0.416***	0.205***	0.204***
	[0.0259]	[0.0259]	[0.0331]	[0.0333]
Precip. Apr-Jun sq. (cm/month)	-0.0202***	-0.0200***	-0.00917***	-0.00926***
	[0.00124]	[0.00124]	[0.00152]	[0.00152]
Precip Jul-Sep (cm/month)	-0.206***	-0.204***	-0.147***	-0.147***
	[0.0146]	[0.0146]	[0.0200]	[0.0200]
Precip Jul-Sep sq (cm/month)	0.00736***	0.00724***	0.00450***	0.00448***
	[0.000693]	[0.000690]	[0.000933]	[0.000932]
Income per capita ('000 $)	0.0101***	0.0103***	0.00946***	0.00954***
	[0.00129]	[0.00129]	[0.00128]	[0.00128]
Pop. density ('00 persons/km^2)	0.169***	0.169***	0.164***	0.164***
	[0.00971]	[0.00967]	[0.00925]	[0.00923]
Pop density sq. ('00 persons/km^2)	-0.00875***	-0.00871***	-0.00863***	-0.00861***
	[0.00127]	[0.00127]	[0.00122]	[0.00122]
Res. houses price ('000 $)	0.00524***	0.00525***	0.00504***	0.00505***
	[0.000184]	[0.000184]	[0.000184]	[0.000184]
Dummy 1987	-0.417***	-0.417***	-0.415***	-0.415***
	[0.0109]	[0.0109]	[0.0103]	[0.0103]
Dummy 1992	-0.445***	-0.445***	-0.443***	-0.443***
	[0.0119]	[0.0119]	[0.0113]	[0.0113]
Dummy 1997	-0.345***	-0.346***	-0.341***	-0.341***
	[0.0134]	[0.0135]	[0.0130]	[0.0130]
Dummy 2002	-0.274***	-0.275***	-0.264***	-0.265***
	[0.0150]	[0.0150]	[0.0146]	[0.0146]
Dummy 2007	-0.0356**	-0.0377**	-0.0224	-0.0235
	[0.0167]	[0.0167]	[0.0161]	[0.0162]
Salinity (% of farmland)	-0.000870***	-0.000842***	-0.00132***	-0.00130***
	[0.000297]	[0.000294]	[0.000304]	[0.000303]
Flooding (% of farmland)	-0.00216***	-0.00221***	-0.00202***	-0.00205***
	[0.000279]	[0.000278]	[0.000284]	[0.000282]
Wet factor (% of farmland)	0.000359	0.000359	-0.000442*	-0.000455*
	[0.000240]	[0.000239]	[0.000252]	[0.000251]
k factor (t/ha)	-0.695***	-0.681***	-0.448***	-0.438***
	[0.0443]	[0.0441]	[0.0470]	[0.0473]
Slope length (m)	0.00201***	0.00199***	0.00222***	0.00224***
	[0.000137]	[0.000137]	[0.000144]	[0.000145]
Sand (% of farmland)	-0.000215	-0.000178	-0.000812	-0.000788
	[0.000667]	[0.000669]	[0.000614]	[0.000614]
Clay (% of farmland)	-0.00273***	-0.00272***	-0.00232***	-0.00232***
	[0.000312]	[0.000310]	[0.000297]	[0.000297]
Moisture level (cm/cm^3)	2.255***	2.246***	1.036***	1.016***
	[0.201]	[0.201]	[0.265]	[0.266]
Permeability (cm/h)	-0.00886	-0.00789	-0.0123**	-0.0117**
	[0.00557]	[0.00560]	[0.00530]	[0.00533]
Latitude (degrees)	-0.0653***	-0.0694***	-0.0671***	-0.0713***
	[0.00344]	[0.00363]	[0.00545]	[0.00547]
Elevation (km)	-1.114***	-1.132***	-0.887***	-0.900***
	[0.0285]	[0.0294]	[0.0378]	[0.0371]
Distance from cities (km)	-0.000733***	-0.000697***	-0.000718***	-0.000696***
	[4.43e-05]	[4.58e-05]	[5.10e-05]	[5.19e-05]
Surface water use ('000 l/ha/day)	0.0115	0.0113	0.0106	0.0104
	[0.0127]	[0.0127]	[0.0110]	[0.0110]
Ground water use ('000 l/ha/day)	0.0182***	0.0190***	0.0256***	0.0255***
	[0.00340]	[0.00341]	[0.00380]	[0.00380]
State fixed effects	No	No	No	No
Constant	11.43***	11.55***	12.74***	12.85***
	[0.309]	[0.311]	[0.461]	[0.461]
Adjusted R-squared	0.815	0.816	0.844	0.844

Standard errors in brackets. *** p<0.01, ** p<0.05, * p<0.1

Table A - 18. Spring and summer.

	DD8-32 & DUMMY D34>0	DD8-32 & D34	DD8-32 & D34 SQ	DD8-32 & D34 SQRT
DD8-32 Apr-Sep (°C)	-1.38e-05	4.38e-05	6.85e-05	2.50e-05
	[5.87e-05]	[5.80e-05]	[5.77e-05]	[5.74e-05]
DD8-32 Apr-Sep sq. (°C)	-1.90e-07***	-1.87e-07***	-1.98e-07***	-1.57e-07***
	[1.28e-08]	[1.34e-08]	[1.31e-08]	[1.35e-08]
Dummy 34 °C Apr-Sep (°C)	0.0463***			
	[0.00875]			
D34 Apr-Sep (°C)		-0.00202		
		[0.00578]		
D34 Apr-Sep sq. (°C)			0.00255**	
			[0.00110]	
D34 Apr-Sep sq. root (°C)				-0.0666***
				[0.0121]
Precip. Apr-Sep (cm/month)	0.186***	0.180***	0.205***	0.163***
	[0.0239]	[0.0238]	[0.0240]	[0.0245]
Precip. Apr-Sep sq. (cm/month)	-0.0108***	-0.0105***	-0.0115***	-0.00958***
	[0.00122]	[0.00122]	[0.00123]	[0.00126]
Income per capita ('000 $)	0.0116***	0.0114***	0.0119***	0.0112***
	[0.00133]	[0.00133]	[0.00133]	[0.00134]
Pop. density ('00 persons/km^2)	0.142***	0.141***	0.143***	0.144***
	[0.00936]	[0.00931]	[0.00949]	[0.00946]
Pop density sq. ('00 persons/km^2)	-0.00736***	-0.00732***	-0.00747***	-0.00748***
	[0.00115]	[0.00115]	[0.00117]	[0.00118]
Res. houses price ('000 $)	0.00524***	0.00523***	0.00523***	0.00529***
	[0.000196]	[0.000195]	[0.000197]	[0.000197]
Dummy 1987	-0.419***	-0.419***	-0.419***	-0.418***
	[0.0114]	[0.0114]	[0.0113]	[0.0114]
Dummy 1992	-0.449***	-0.449***	-0.450***	-0.448***
	[0.0124]	[0.0125]	[0.0124]	[0.0124]
Dummy 1997	-0.353***	-0.352***	-0.355***	-0.351***
	[0.0142]	[0.0142]	[0.0141]	[0.0142]
Dummy 2002	-0.285***	-0.283***	-0.287***	-0.282***
	[0.0156]	[0.0156]	[0.0155]	[0.0156]
Dummy 2007	-0.0506***	-0.0478***	-0.0538***	-0.0476***
	[0.0169]	[0.0169]	[0.0169]	[0.0170]
Salinity (% of farmland)	-0.000113	-8.42e-05	-0.000196	-9.50e-05
	[0.000309]	[0.000308]	[0.000311]	[0.000311]
Flooding (% of farmland)	-0.000836***	-0.000890***	-0.000853***	-0.000987***
	[0.000310]	[0.000310]	[0.000309]	[0.000310]
Wet factor (% of farmland)	0.00318***	0.00319***	0.00304***	0.00318***
	[0.000244]	[0.000243]	[0.000242]	[0.000242]
k factor (t/ha)	-0.940***	-0.955***	-0.903***	-0.932***
	[0.0380]	[0.0376]	[0.0383]	[0.0368]
Slope length (m)	0.00223***	0.00222***	0.00221***	0.00223***
	[0.000147]	[0.000147]	[0.000146]	[0.000149]
Sand (% of farmland)	-0.00124*	-0.00105	-0.00148**	-0.00139*
	[0.000701]	[0.000705]	[0.000694]	[0.000708]
Clay (% of farmland)	-0.00190***	-0.00190***	-0.00192***	-0.00185***
	[0.000336]	[0.000335]	[0.000343]	[0.000336]
Moisture level (cm/cm^3)	3.180***	3.266***	2.958***	3.176***
	[0.203]	[0.201]	[0.205]	[0.201]
Permeability (cm/h)	-0.00497	-0.00611	-0.00462	-0.00339
	[0.00588]	[0.00591]	[0.00585]	[0.00591]
Latitude (degrees)	-0.106***	-0.110***	-0.0934***	-0.113***
	[0.00342]	[0.00331]	[0.00364]	[0.00355]
Elevation (km)	-0.964***	-0.976***	-0.905***	-0.990***
	[0.0283]	[0.0279]	[0.0296]	[0.0284]
Distance from cities (km)	-0.000940***	-0.000921***	-0.00100***	-0.000934***
	[4.68e-05]	[4.63e-05]	[4.66e-05]	[4.62e-05]
Surface water use ('000 l/ha/day)	-0.0149	-0.0148	-0.0145	-0.0155
	[0.0112]	[0.0112]	[0.0110]	[0.0111]
Ground water use ('000 l/ha/day)	0.0268***	0.0278***	0.0256***	0.0266***
	[0.00324]	[0.00324]	[0.00316]	[0.00321]
Constant	12.62***	12.79***	11.90***	13.14***
	[0.216]	[0.212]	[0.229]	[0.236]
State fixed effects	No	No	No	No
Adjusted R-squared	0.787	0.787	0.787	0.787

Standard errors in brackets. *** p<0.01, ** p<0.05, * p<0.1

Table A - 19. Extreme degree days above 34°C.

	DD8-32 & DUMMY D34>0	DD8-32 & D34	DD8-32 & D34 SQ	DD8-32 & D34 SQRT
DD8-32 Apr-Sep (°C)	0.000199**	0.000234**	0.000241***	0.000249***
	[8.86e-05]	[9.09e-05]	[8.96e-05]	[9.06e-05]
DD8-32 Apr-Sep sq. (°C)	-1.78e-07***	-1.72e-07***	-1.71e-07***	-1.83e-07***
	[1.93e-08]	[2.05e-08]	[1.98e-08]	[2.04e-08]
Dummy 34 °C Apr-Sep (°C)	0.0356***			
	[0.00863]			
D34 Apr-Sep (°C)		-0.00939		
		[0.00656]		
D34 Apr-Sep sq. (°C)			-0.00304***	
			[0.00111]	
D34 Apr-Sep sq. root (°C)				0.000911
				[0.0142]
Precip. Apr-Sep (cm/month)	0.240***	0.252***	0.254***	0.248***
	[0.0277]	[0.0276]	[0.0276]	[0.0276]
Precip. Apr-Sep sq. (cm/month)	-0.0125***	-0.0130***	-0.0131***	-0.0129***
	[0.00144]	[0.00143]	[0.00143]	[0.00143]
Income per capita ('000 $)	0.0103***	0.0104***	0.0106***	0.0104***
	[0.00129]	[0.00128]	[0.00128]	[0.00128]
Pop. density ('00 persons/km^2)	0.149***	0.148***	0.149***	0.148***
	[0.00896]	[0.00893]	[0.00892]	[0.00890]
Pop density sq. ('00 persons/km^2)	-0.00792***	-0.00787***	-0.00788***	-0.00785***
	[0.00111]	[0.00110]	[0.00109]	[0.00109]
Res. houses price ('000 $)	0.00507***	0.00504***	0.00504***	0.00504***
	[0.000189]	[0.000189]	[0.000189]	[0.000188]
Dummy 1987	-0.417***	-0.417***	-0.417***	-0.417***
	[0.0105]	[0.0105]	[0.0105]	[0.0105]
Dummy 1992	-0.446***	-0.446***	-0.446***	-0.446***
	[0.0115]	[0.0115]	[0.0115]	[0.0115]
Dummy 1997	-0.346***	-0.346***	-0.347***	-0.346***
	[0.0133]	[0.0133]	[0.0133]	[0.0133]
Dummy 2002	-0.271***	-0.272***	-0.273***	-0.272***
	[0.0148]	[0.0148]	[0.0148]	[0.0148]
Dummy 2007	-0.0316**	-0.0323**	-0.0337**	-0.0320**
	[0.0161]	[0.0161]	[0.0160]	[0.0161]
Salinity (% of farmland)	-0.000853***	-0.000888***	-0.000903***	-0.000855***
	[0.000307]	[0.000307]	[0.000306]	[0.000305]
Flooding (% of farmland)	-0.00127***	-0.00118***	-0.00113***	-0.00121***
	[0.000296]	[0.000293]	[0.000292]	[0.000294]
Wet factor (% of farmland)	0.000792***	0.000810***	0.000813***	0.000841***
	[0.000249]	[0.000251]	[0.000250]	[0.000250]
k factor (t/ha)	-0.493***	-0.488***	-0.481***	-0.495***
	[0.0420]	[0.0420]	[0.0420]	[0.0422]
Slope length (m)	0.00231***	0.00231***	0.00231***	0.00232***
	[0.000156]	[0.000153]	[0.000153]	[0.000154]
Sand (% of farmland)	-0.00205***	-0.00203***	-0.00210***	-0.00191***
	[0.000631]	[0.000628]	[0.000631]	[0.000625]
Clay (% of farmland)	-0.00211***	-0.00210***	-0.00213***	-0.00211***
	[0.000308]	[0.000310]	[0.000307]	[0.000311]
Moisture level (cm/cm^3)	0.922***	0.935***	0.901***	0.982***
	[0.251]	[0.250]	[0.250]	[0.250]
Permeability (cm/h)	-0.00870	-0.00864	-0.00818	-0.00893*
	[0.00533]	[0.00532]	[0.00533]	[0.00533]
Latitude (degrees)	-0.0760***	-0.0689***	-0.0667***	-0.0746***
	[0.00568]	[0.00556]	[0.00560]	[0.00541]
Elevation (km)	-0.566***	-0.548***	-0.540***	-0.563***
	[0.0358]	[0.0350]	[0.0356]	[0.0345]
Distance from cities (km)	-0.000798***	-0.000827***	-0.000824***	-0.000818***
	[5.00e-05]	[5.05e-05]	[5.04e-05]	[5.08e-05]
Surface water use ('000 l/ha/day)	-0.00128	-0.00133	-0.000910	-0.00171
	[0.0103]	[0.0103]	[0.0104]	[0.0103]
Ground water use ('000 l/ha/day)	0.0383***	0.0378***	0.0377***	0.0380***
Constant	10.56***	10.11***	9.990***	10.38***
	[0.329]	[0.314]	[0.321]	[0.307]
State fixed effects	Yes	Yes	Yes	Yes
Adjusted R-squared	0.836	0.836	0.836	0.836

Standard errors in brackets. *** p<0.01, ** p<0.05, * p<0.1

Table A - 20. Extreme degree days above 34°C, with state fixed effects.

	DD8-32 & DD34	DD8-32 & DD34 SQ	DD8-32 & DD34 SQRT	DD8-32 & DD34	DD8-32 & DD34 SQ	DD8-32 & DD34 SQRT
DD8-32 Apr-Sep (°C)	-1.07e-05	-6.90e-06	-1.24e-05	0.240***	0.240***	0.240***
	[5.85e-05]	[5.84e-05]	[5.86e-05]	[0.0277]	[0.0277]	[0.0277]
DD8-32 Apr-Sep sq. (°C)	-1.91e-07***	-1.93e-07***	-1.91e-07***	-0.0125***	-0.0125***	-0.0125***
	[1.28e-08]	[1.28e-08]	[1.28e-08]	[0.00144]	[0.00144]	[0.00144]
DD34 Apr-Sep (°C)	0.00178***			0.00131***		
	[0.000335]			[0.000332]		
DD34 Apr-Sep sq. (°C)		6.81e-05***			4.64e-05***	
		[1.28e-05]			[1.29e-05]	
DD34 Apr-Sep sq. root (°C)			0.00907***			0.00686***
			[0.00171]			[0.00169]
Precip. Apr-Sep (cm/month)	0.163***	0.162***	0.163***	0.240***	0.240***	0.240***
	[0.0245]	[0.0245]	[0.0245]	[0.0277]	[0.0277]	[0.0277]
Precip. Apr-Sep sq. (cm/month)	-0.00958***	-0.00954***	-0.00959***	-0.0125***	-0.0125***	-0.0125***
	[0.00126]	[0.00126]	[0.00126]	[0.00144]	[0.00144]	[0.00144]
Income per capita ('000 $)	0.0112***	0.0112***	0.0112***	0.0103***	0.0103***	0.0103***
	[0.00134]	[0.00134]	[0.00134]	[0.00129]	[0.00129]	[0.00129]
Pop. density ('00 persons/km^2)	0.144***	0.144***	0.144***	0.149***	0.149***	0.149***
	[0.00946]	[0.00945]	[0.00947]	[0.00896]	[0.00895]	[0.00896]
Pop density sq. ('00 persons/km^2)	-0.00748***	-0.00748***	-0.00749***	-0.00792***	-0.00791***	-0.00792***
	[0.00118]	[0.00118]	[0.00118]	[0.00111]	[0.00111]	[0.00111]
Res. houses price ('000 $)	0.00529***	0.00529***	0.00529***	0.00507***	0.00506***	0.00507***
	[0.000197]	[0.000197]	[0.000197]	[0.000189]	[0.000189]	[0.000189]
Dummy 1987	-0.418***	-0.418***	-0.418***	#REF!	#REF!	#REF!
	[0.0114]	[0.0114]	[0.0114]	#REF!	#REF!	#REF!
Dummy 1992	-0.448***	-0.448***	-0.448***	-0.417***	-0.417***	-0.417***
	[0.0124]	[0.0125]	[0.0124]	[0.0105]	[0.0105]	[0.0105]
Dummy 1997	-0.351***	-0.351***	-0.351***	-0.446***	-0.446***	-0.446***
	[0.0142]	[0.0142]	[0.0142]	[0.0116]	[0.0116]	[0.0115]
Dummy 2002	-0.282***	-0.282***	-0.283***	-0.346***	-0.346***	-0.346***
	[0.0156]	[0.0156]	[0.0156]	[0.0133]	[0.0133]	[0.0133]
Dummy 2007	-0.0476***	-0.0473***	-0.0477***	-0.271***	-0.271***	-0.271***
	[0.0170]	[0.0170]	[0.0170]	[0.0148]	[0.0148]	[0.0148]
Salinity (% of farmland)	-9.50e-05	-9.01e-05	-9.73e-05	-0.0316**	-0.0316*	-0.0316**
	[0.000311]	[0.000311]	[0.000311]	[0.0161]	[0.0161]	[0.0161]
Flooding (% of farmland)	-0.000987***	-0.000989***	-0.000986***	-0.000849***	-0.000845***	-0.000851***
	[0.000310]	[0.000310]	[0.000310]	[0.000306]	[0.000306]	[0.000307]
Wet factor (% of farmland)	0.00318***	0.00318***	0.00317***	-0.00127***	-0.00128***	-0.00127***
	[0.000242]	[0.000242]	[0.000242]	[0.000296]	[0.000296]	[0.000296]
k factor (t/ha)	-0.932***	-0.935***	-0.931***	0.000798***	0.000805***	0.000795***
	[0.0368]	[0.0369]	[0.0368]	[0.000249]	[0.000249]	[0.000249]
Slope length (m)	0.00223***	0.00223***	0.00223***	-0.494***	-0.495***	-0.493***
	[0.000149]	[0.000149]	[0.000149]	[0.0420]	[0.0421]	[0.0420]
Sand (% of farmland)	-0.00139*	-0.00136*	-0.00140**	0.00231***	0.00231***	0.00231***
	[0.000708]	[0.000708]	[0.000708]	[0.000155]	[0.000155]	[0.000156]
Clay (% of farmland)	-0.00185***	-0.00186***	-0.00185***	-0.00203***	-0.00200***	-0.00204***
	[0.000336]	[0.000336]	[0.000336]	[0.000631]	[0.000631]	[0.000631]
Moisture level (cm/cm^3)	3.176***	3.190***	3.170***	-0.00211***	-0.00211***	-0.00211***
	[0.201]	[0.201]	[0.200]	[0.000308]	[0.000309]	[0.000308]
Permeability (cm/h)	-0.00339	-0.00353	-0.00334	0.931***	0.942***	0.927***
	[0.00591]	[0.00591]	[0.00591]	[0.251]	[0.251]	[0.251]
Latitude (degrees)	-0.113***	-0.114***	-0.113***	-0.00875	-0.00882*	-0.00873
	[0.00355]	[0.00356]	[0.00354]	[0.00533]	[0.00533]	[0.00533]
Elevation (km)	-0.990***	-0.992***	-0.988***	-0.0767***	-0.0773***	-0.0764***
	[0.0284]	[0.0284]	[0.0284]	[0.00569]	[0.00569]	[0.00569]
Distance from cities (km)	-0.000934***	-0.000931***	-0.000936***	-0.568***	-0.570***	-0.567***
	[4.62e-05]	[4.62e-05]	[4.62e-05]	[0.0358]	[0.0358]	[0.0358]
Surface water use ('000 l/ha/day)	-0.0155	-0.0155	-0.0155	-0.000798***	-0.000798***	-0.000798***
	[0.0111]	[0.0111]	[0.0111]	[5.00e-05]	[5.00e-05]	[5.00e-05]
Ground water use ('000 l/ha/day)	0.0266***	0.0267***	0.0265***	-0.00135	-0.00144	-0.00132
Constant	13.14***	13.17***	13.12***	10.59***	10.61***	10.57***
	[0.236]	[0.237]	[0.236]	[0.329]	[0.329]	[0.329]
State fixed effects	No	No	No	Yes	Yes	Yes
Adjusted R-squared	0.787	0.787	0.787	0.836	0.836	0.836

Standard errors in brackets. *** p<0.01, ** p<0.05, * p<0.1

Table A - 21. Degree days above 34°C.

	T 4 SEASONS	T 4 SEASONS		T 4 SEASONS	T 4 SEASONS
Temp. Dec-Feb (°C - 8)*90	-0.212***	-0.212***	1992.year	-0.439***	-0.437***
	[0.0105]	[0.0127]		[0.0115]	[0.0109]
Temp. Dec-Feb sq.	0.00237***	0.00457***	1997.year	-0.336***	-0.332***
	[0.000642]	[0.000701]		[0.0131]	[0.0126]
Temp. Mar-May (°C -8)*92	0.554***	0.326***	2002.year	-0.262***	-0.253***
	[0.0312]	[0.0357]		[0.0147]	[0.0142]
Temp. Mar-May sq.	-0.0124***	-0.00860***	2007.year	-0.0207	-0.00732
	[0.00104]	[0.00118]		[0.0165]	[0.0159]
Temp. Jun-Aug (°C - 8)*92	-0.655***	-0.668***	Salinity (% of farmland)	-0.00107***	-0.00128***
	[0.0611]	[0.0760]		[0.000301]	[0.000314]
Temp. Jun-Aug sq.	0.00534***	0.00723***	Flooding (% of farmland)	-0.00178***	-0.00161***
	[0.00118]	[0.00150]		[0.000281]	[0.000276]
Temp. Sep-Nov (°C - 8)*91	0.338***	0.565***	Wet factor (% of farmland)	0.000261	-0.000884***
	[0.0493]	[0.0504]		[0.000233]	[0.000238]
Temp. Sep-Nov sq.	-0.00195	-0.00787***	k factor (t/ha)	-0.500***	-0.304***
	[0.00188]	[0.00204]		[0.0432]	[0.0467]
Precip. Dec-Feb (cm/month)	-0.00221	-0.00559	Slope length (m)	0.00193***	0.00200***
	[0.00924]	[0.0137]		[0.000145]	[0.000147]
Precip. Dec-Feb sq. (cm/month)	0.00353***	0.00193**	Sand (% of farmland)	-0.000834	-0.000498
	[0.000544]	[0.000773]		[0.000585]	[0.000600]
Precip. Mar-May (cm/month)	0.312***	0.301***	Clay (% of farmland)	-0.00202***	-0.00178***
	[0.0278]	[0.0332]		[0.000293]	[0.000278]
Precip. Mar-May sq. (cm/month)	-0.0169***	-0.0131***	Moisture level (cm/cm^3)	2.019***	0.769***
	[0.00136]	[0.00162]		[0.220]	[0.251]
Precip. Jun-Aug (cm/month)	-0.294***	-0.188***	Permeability (cm/h)	0.00704	-0.00718
	[0.0178]	[0.0247]		[0.00478]	[0.00508]
Precip. Jun-Aug sq. (cm/month)	0.0115***	0.00669***	Latitude (degrees)	-0.0202*	-0.0484***
	[0.000808]	[0.00110]		[0.0114]	[0.0121]
Precip. Sep-Nov (cm/month)	0.132***	-0.0188	Elevation (km)	-0.526***	-0.260***
	[0.0220]	[0.0250]		[0.0475]	[0.0466]
Precip. Sep-Nov sq. (cm/month)	-0.00973***	-0.000997	Distance from cities (km)	-0.000608***	-0.000597***
	[0.00126]	[0.00142]		[4.48e-05]	[4.88e-05]
Income per capita ('000 $)	0.00855***	0.00799***	Surface water use ('000 l/ha/day)	0.0216**	0.0160
	[0.00125]	[0.00123]		[0.0103]	[0.0104]
Pop. density ('00 persons/km^2)	0.183***	0.177***	Ground water use ('000 l/ha/day)	0.0229***	0.0276***
	[0.00970]	[0.00923]		[0.00329]	[0.00367]
Pop density sq. ('00 persons/km^2)	-0.00960***	-0.00937***			
	[0.00135]	[0.00127]	State fixed effects	No	Yes
Res. houses price ('000 $)	0.00533***	0.00508***			
	[0.000178]	[0.000178]	Constant	12.36***	12.66***
1987.year	-0.414***	-0.412***		[0.772]	[0.840]
	[0.0106]	[0.0100]			
			Adjusted R^2	0.828	0.854

Standard errors in brackets. *** p<0.01, ** p<0.05, * p<0.1

Table A - 22. Four seasons.