Impact of Climate Changes on Farmland Conversion in California: Application of Spatial Regression Analysis

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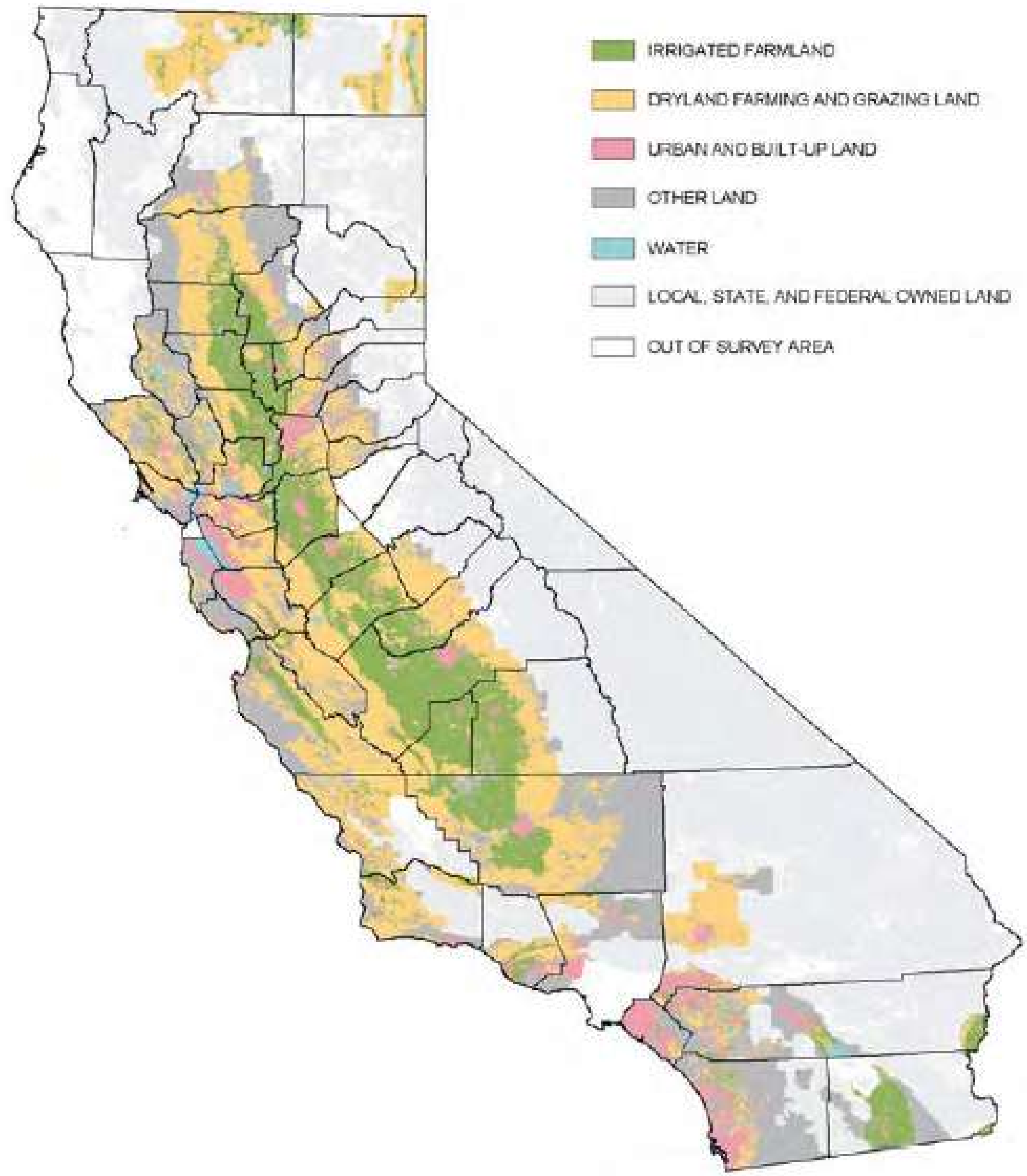
Brief Methodology

- This study combines farmland mapping data with a system vulnerability approach to crop growth and spatial regression technique:
  - Unlike popular urbanization model or LUC model – we look at how climate condition capitalizes into farmland value, and then to land conversion decision (1)
  - System vulnerability: a system being driven to the tipping point. The maximum threshold of crop resistance to heating condition, after which nonlinear damages expected to be overwhelming (2)
- Data
  - state-wide farmland mapping in California: private prime farmland, the most productive farm (3)
  - constructing a climate extreme surface
- Spatial regression and result
  - study using climate extreme can better predict impacts than climate normals
  - for California, moderate increase in the number of heating days may be beneficial, yet significant increase is very harmful

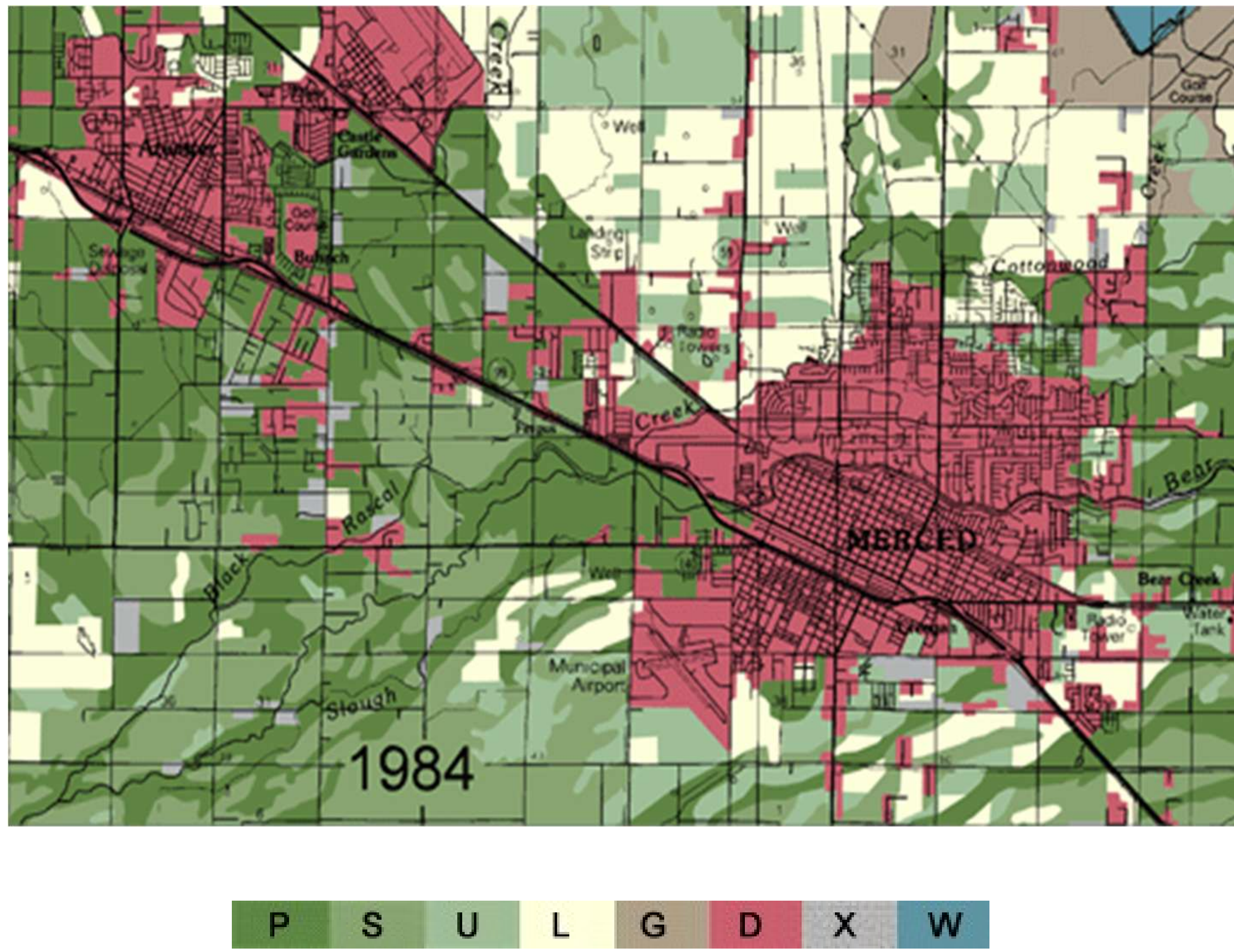
Introduction to Farmland Mapping Program in California

- Initiated in 1984 with biennial report
  - Arial photos with soil survey
  - Covering 48 counties and 46 million acres (91% privately owned land) as of 2006
  - 6 main types of farm
- Williamson Act to protect the state farmland since 1965
  - Farm owners get property tax credit by entering 10-year rolling contract with the government
  - Cancelling contract would incur fine of 10% farm value



Status of Farmland Conversion

- Farm conversion is a serious threat to CA agriculture (1)
- Urbanization is often described as the exclusive cause (2)
- Yet, it is complicated that agricultural acreage gains were reported in some place, especially where the microclimate was suitable for some crops (3)
  - adverse weather and climate changes may be a contributing factor, still a matter of heated debates (4)
  - IPCC report (5)



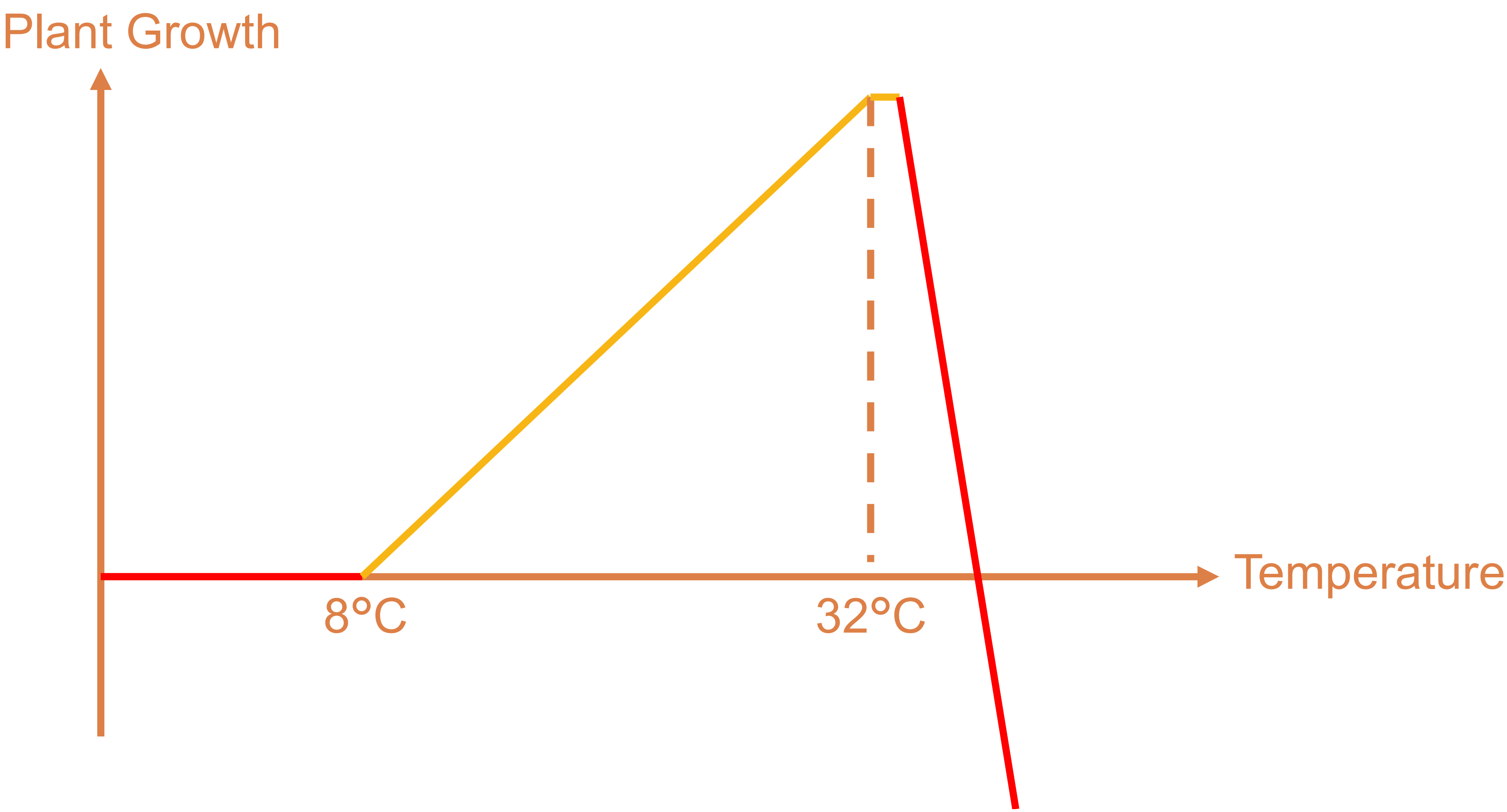
Tracking Farmland Conversion in Merced County – California

How Climate Changes Relate to Farmland Conversion, beside Urban-driven Factors?

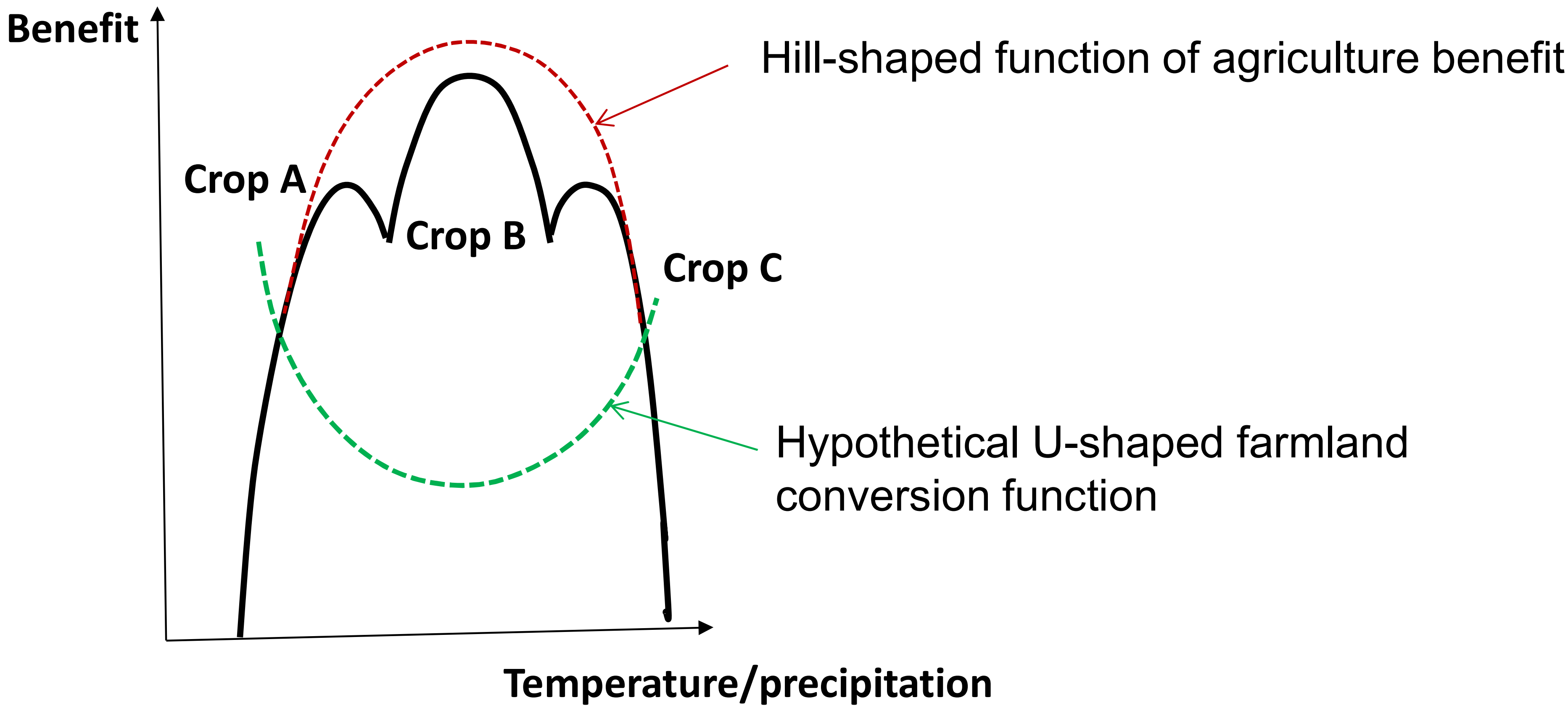
- Climate changes may affect farmland value, thus the possibility of conversion. Expectedly, farmland with depreciated value would be more likely converted to other higher-value usage.
  - Adverse impact: may accelerate farmland conversion, *ceteris paribus*
  - Places with more favorable growing condition: expect gain in agricultural acreage

Agronomic Fundamentals

- Agronomic field experiments have shown that plant growth is non-linear in temperature



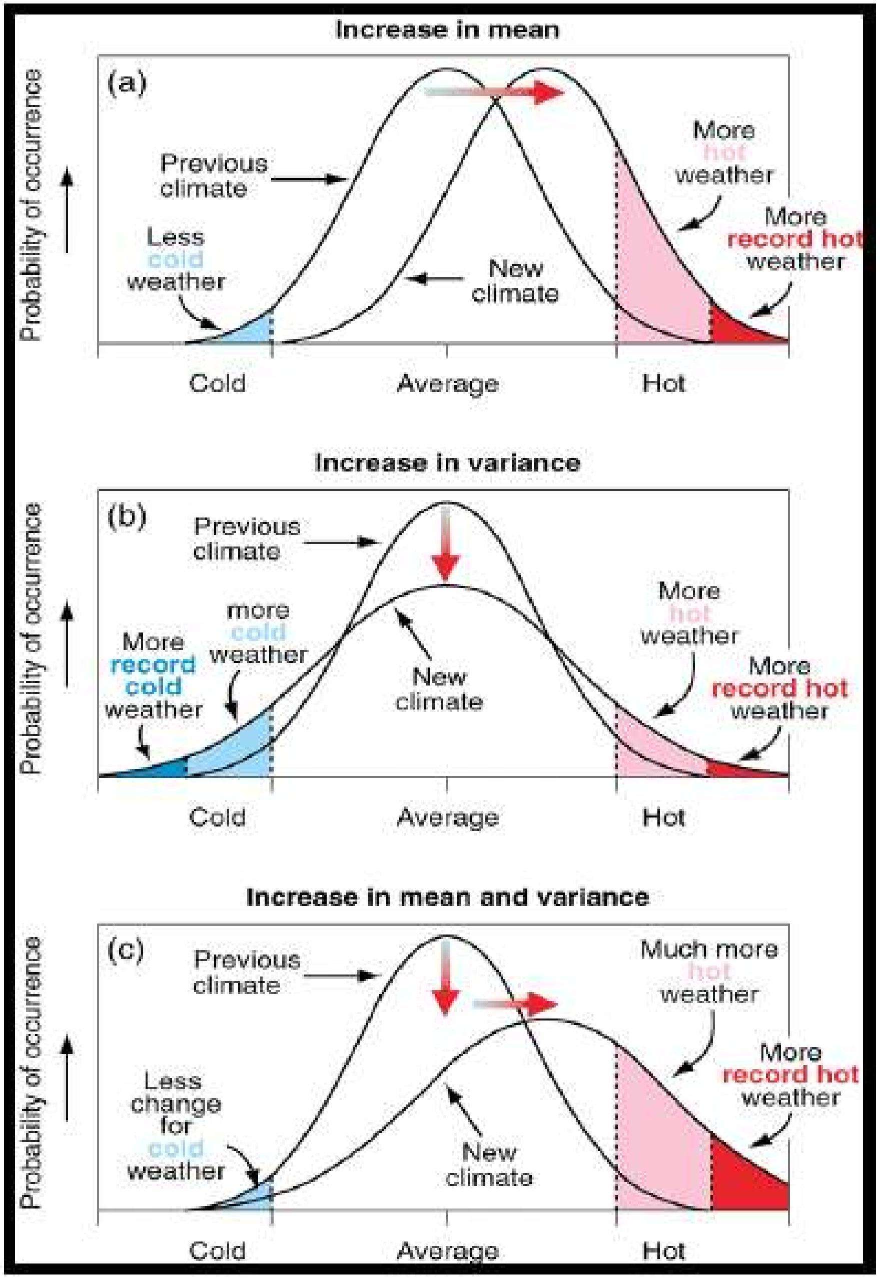
A simple model of farmland conversion accounting for farmer adaptation to climate condition (1, 2, 3)



- Farmers' choice of crop reflects adaptation to different climate condition

How to identify climate change signal and problem with many existing studies

- The two most observable climate signal is temperature and precipitation. What we are observing is a distribution of the heat/precipitation
- Weather vs Climate (1)
- Climate changes may come with little change in mean condition (2)
- Fluctuations in climate and the extreme events have the most serious consequence (3)
- Studies using mean condition alone will vastly underestimate the impact (4)



Caution!

Weather Extremes or Climate Changes: Some Easily Confused Concept

- Weather system is chaotic ("butterfly effects"):
  - A few warmer-than-usual years (even if happened continuously) aren't unusual, may not be a consequence of climate changes.
  - Neither any single catastrophic event (Katrina, for example) could be a definite evidence of climate changes.

- But there is a long-term pattern (or statistically different from what is normal): either increasing in trend or more fluctuation at the extremes, or both. That's why we will look at a 25-year climate extremes surface:
  - Short-term fluctuation will not produce bias on long-term trend.
  - Overreaction to short-term gain/loss should not be considered a result of climate changes (1, 2)

Climate Extremes Surface

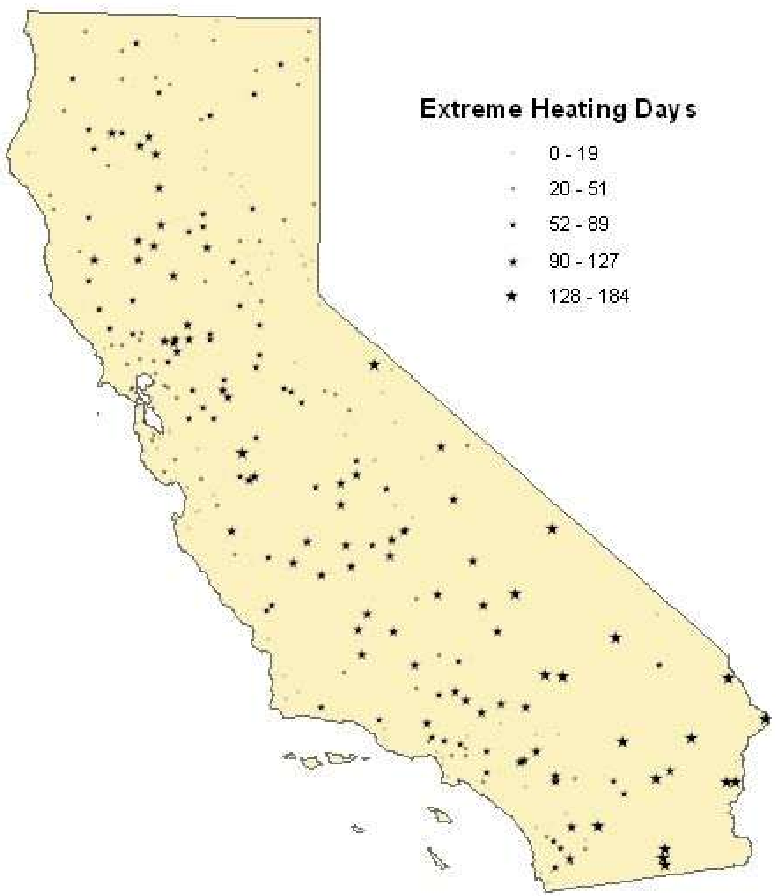
- Focus on the use of climate extremes, or observations at the tail of the distribution, especially extreme heating condition, thought most harmful to crops

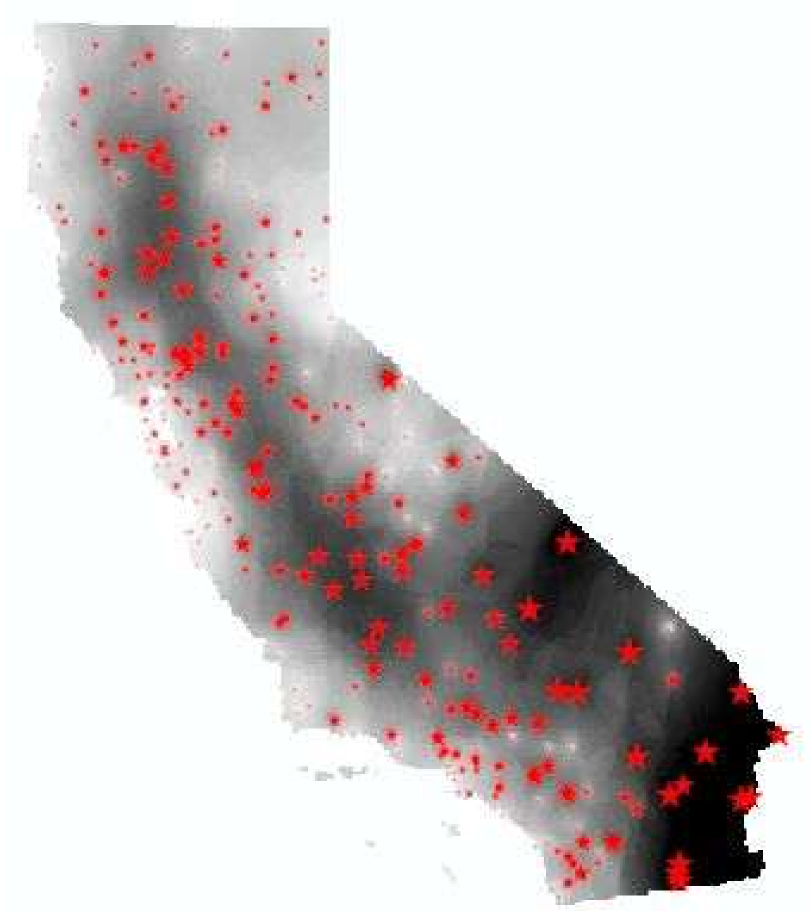
- Advantage: adaptation to climate extremes is less evident, even with 50 year of data there is no evidence to suggest that crops have become more heat resistant (Schlenker and Robert, 2008)

- Comprehensive historical records of daily observation over the past 25 years from 350 weather stations in California:
  - The number of days with recorded temperature reached 90 Fahrenheit (32.2 Celsius) – close to the field experiment of optimal crop growth temperature

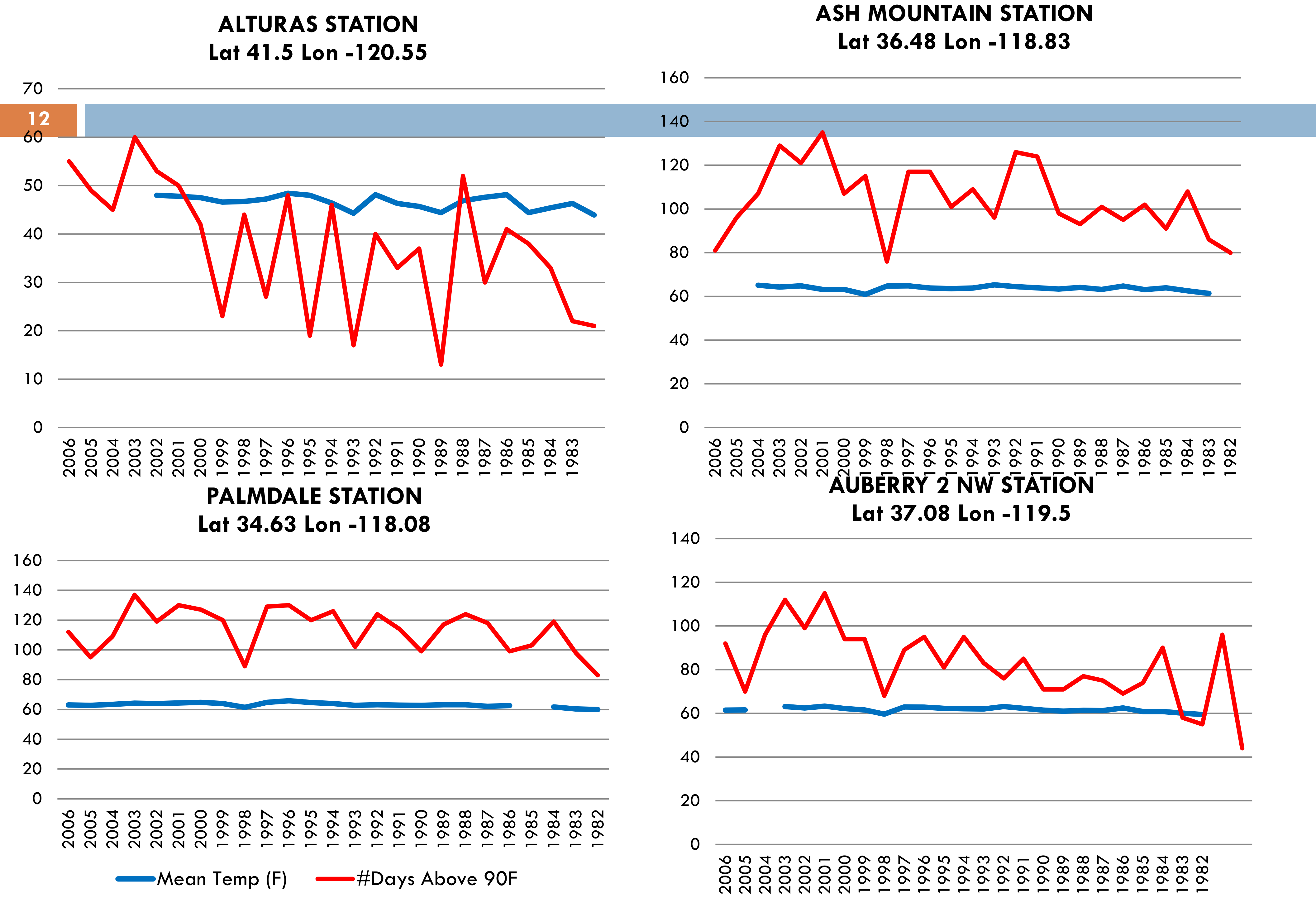
Constructing a Climate Extremes Surface

- Climate extreme surface is interpolated from the station positions by inverse distance weighting

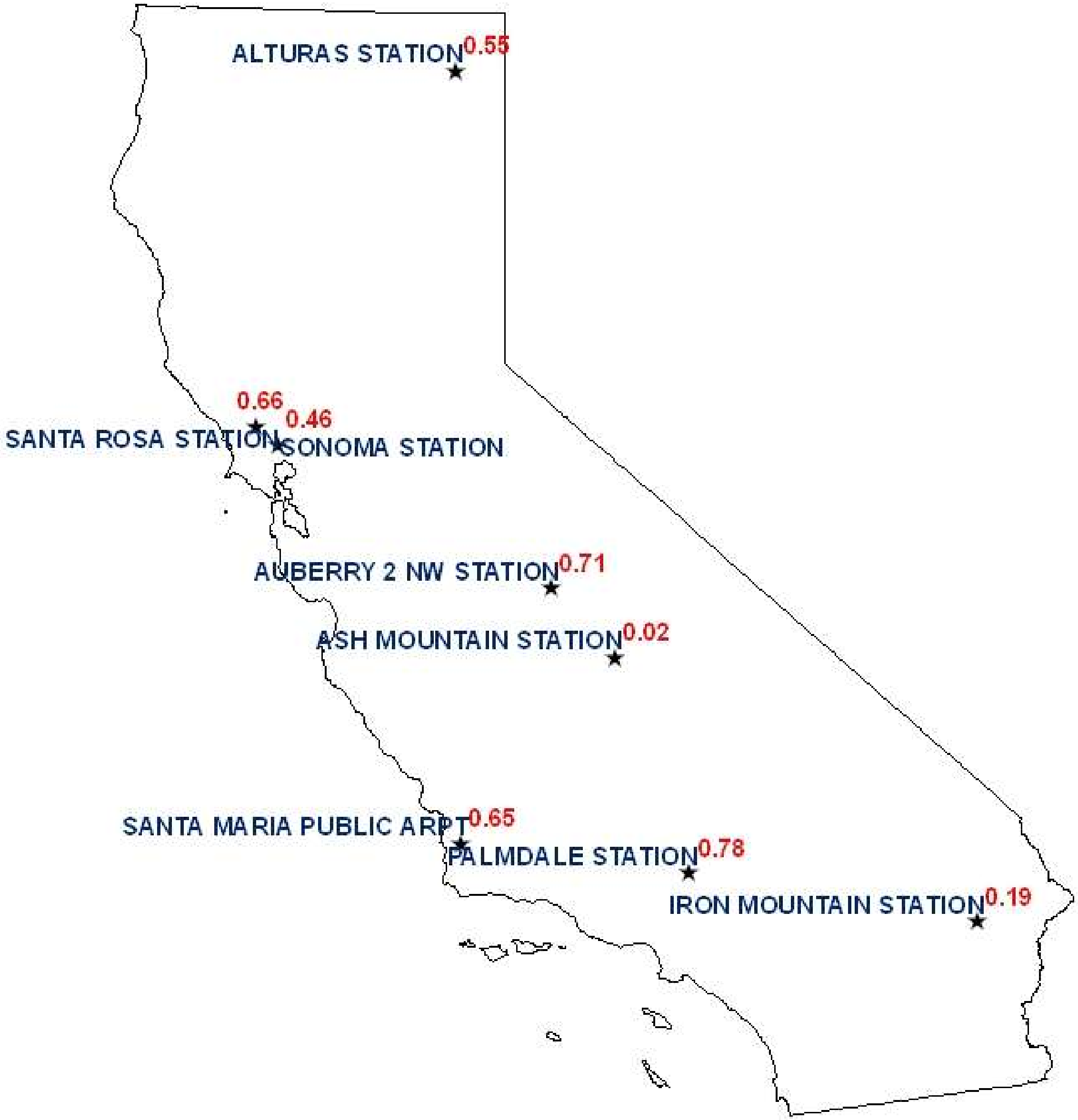




Extreme Heating Condition vs Mean Temperature

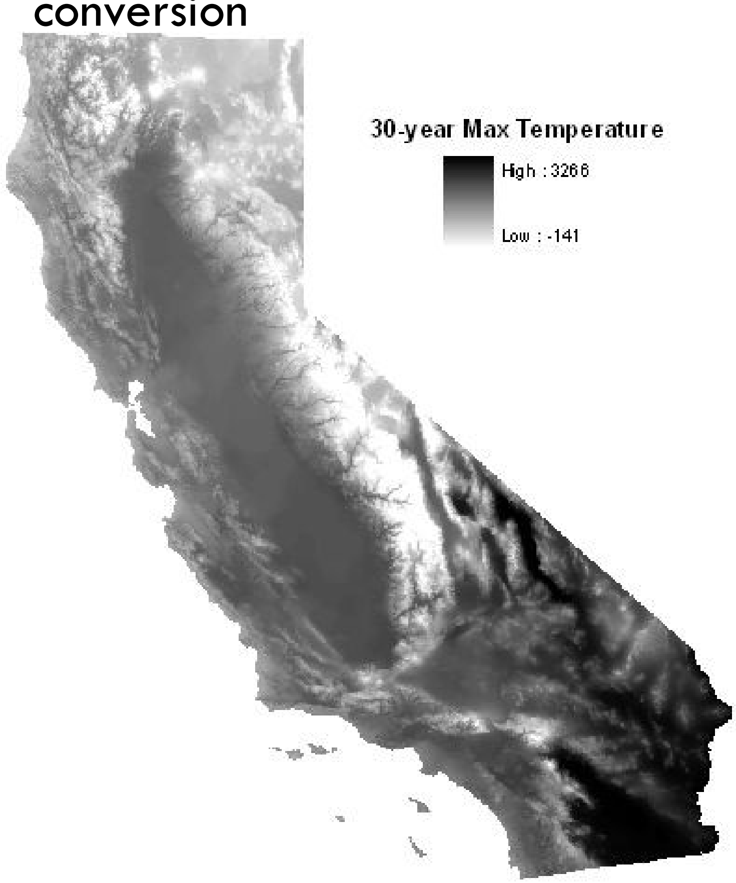


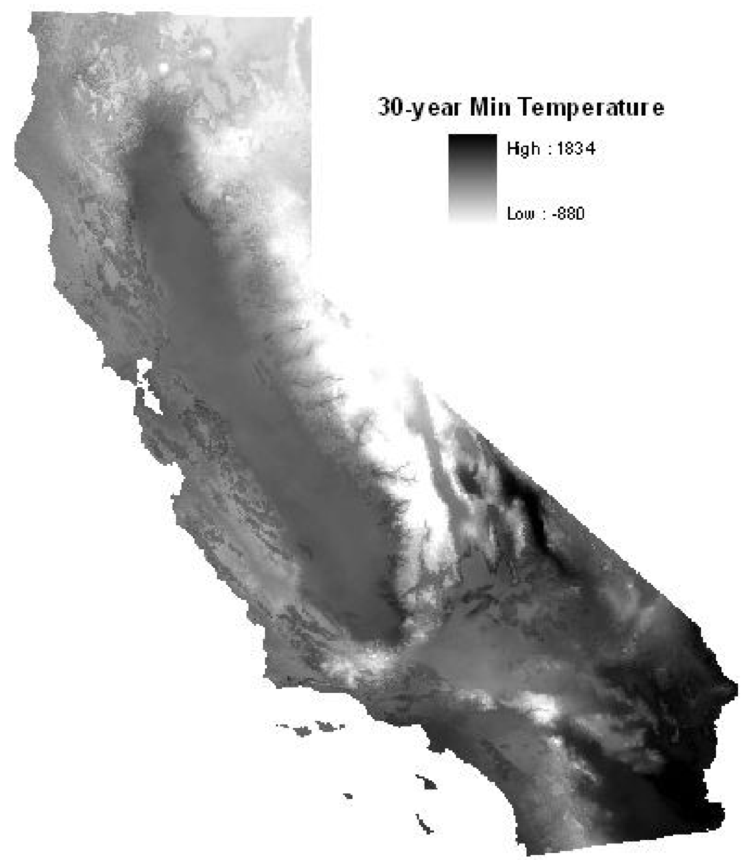
Examine Mean-Extreme Correlation Coefficient



Climate Normals: PRISM 30 Year Min and Max Temperature

- Parameter Regression on Independent Slope Model
  - Widely used in climate study
  - Downscaled data available at 800m resolution
  - 30-year average for 1971-2000 period, 30 year preceding the reported conversion





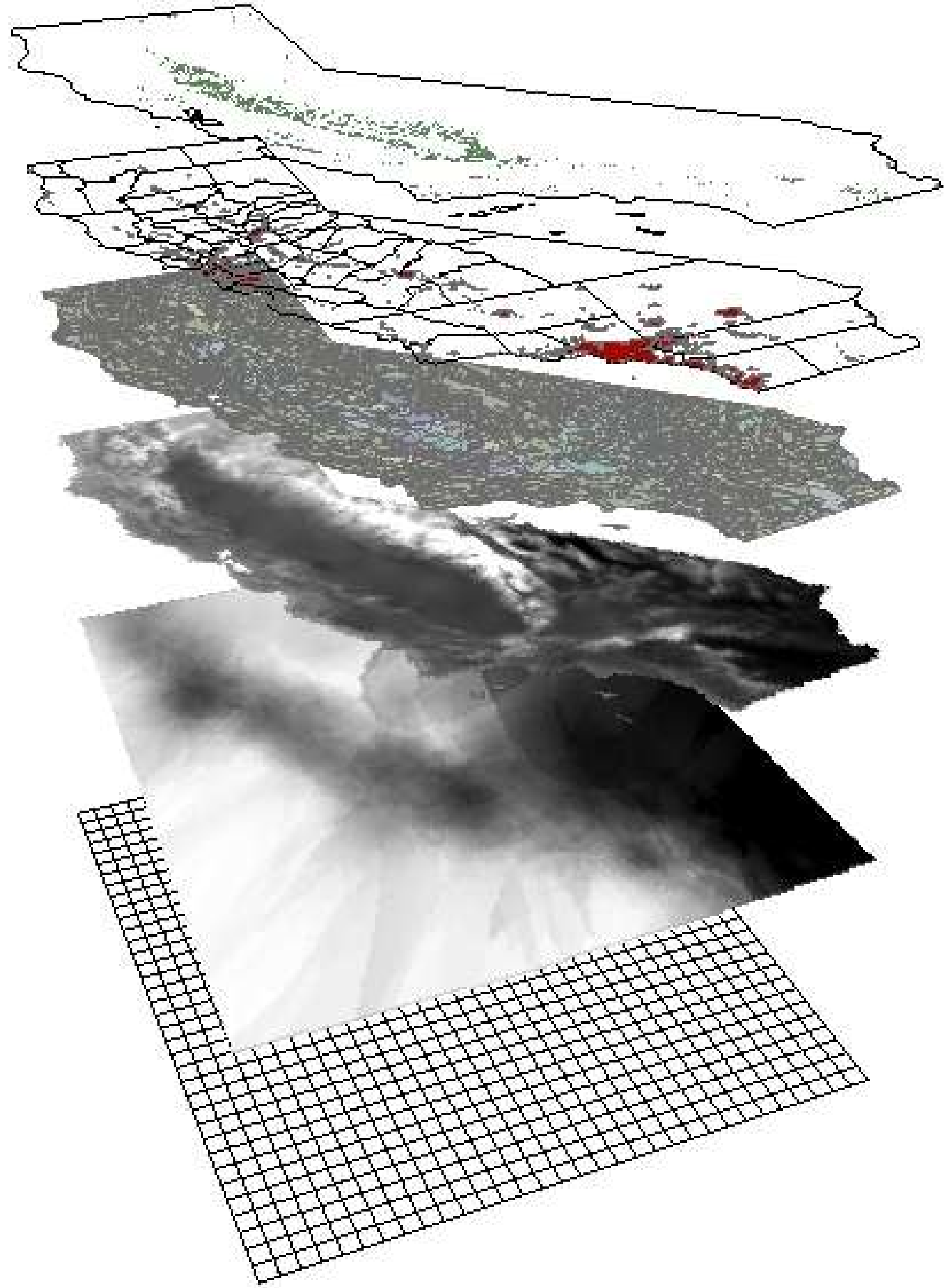
Constructing a Spatial Database

Location of Study Samples

Constructing a Spatial Database

From Top Layer

- Farmland Mapping (FMMP)
- Socio-economic data (Census Bureau) – Tiger/Line
- Soil map (USDA)
- PRISM 30-year climate normals (PRISM)
- Climate extremes surface (Interpolated from NCDC observations)
- Geo-referencing layer

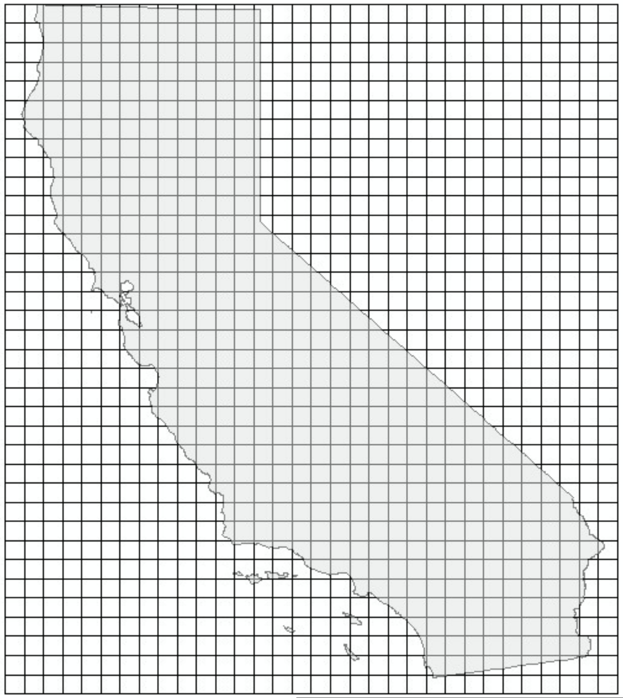


Constructing a Spatial Database

- Farm data is not parceled (farm polygons of different size and shape)

- Generate a cell grid at 4x4 km resolution. Each cell completes with ID, lon and lat address – this information will be utilized in a spatial regression model

- Use the geo-referencing layer to reference to each attribute layer



Non overlapped areas are converted acreage

Spatial Regression Model

Hedonic Regression Model of Farmland Conversion

- Model the conversion as a function of climate extreme index and a set of control variables such as soil and other socio-economic factors (1, 2)

- Econometric specification

$$y_i = \beta_o + X_i\beta + Z_i\gamma + \varepsilon_i$$

y is the fraction of prime farmland converted in each cell over the two report periods

X is vector of interested variables: climate normal or extremes

Z is vector of control variables: : Perimeter, Median Family Income, Population Density, Water Capacity, K-Saturation, Percent Clay, K-factor, Irrigation Class, Water Depth

County fixed effects may be included

Spatial Regression

- Problem with Spatial Data
  - Observations are spatially dependent: first law of geography (1)
  - Moran's I test for spatial dependence confirms the problem

$$Y_i = X_i\beta + \varepsilon_i$$

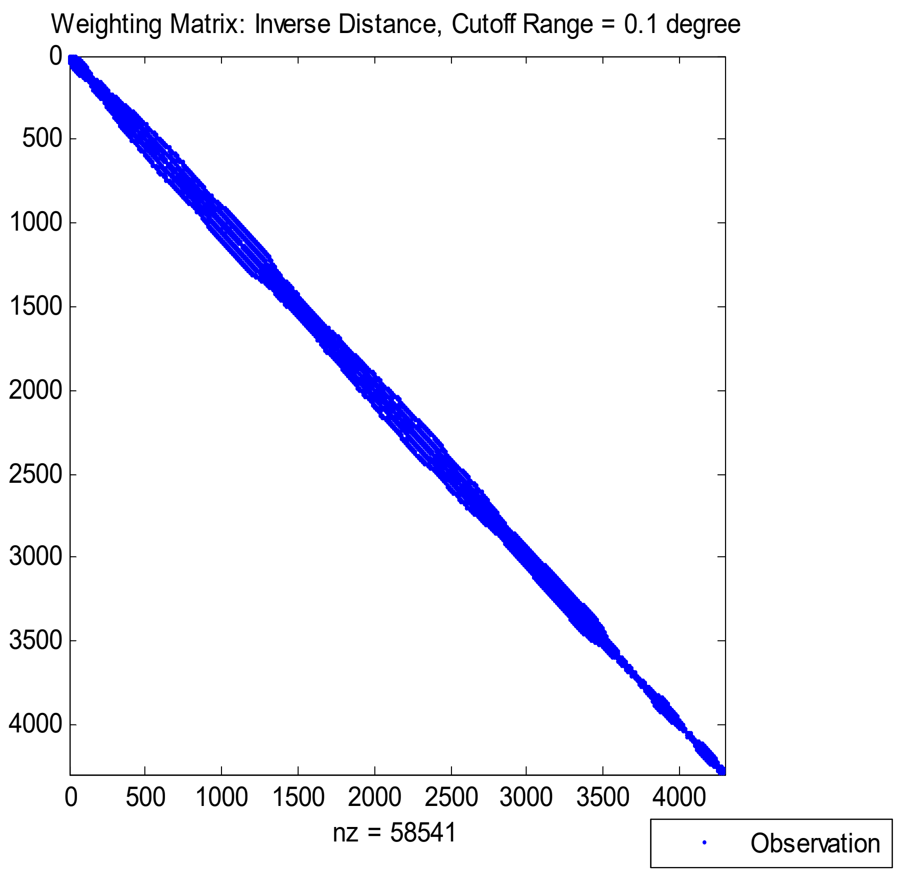
$$\varepsilon_i = \rho W\varepsilon + \nu_i$$

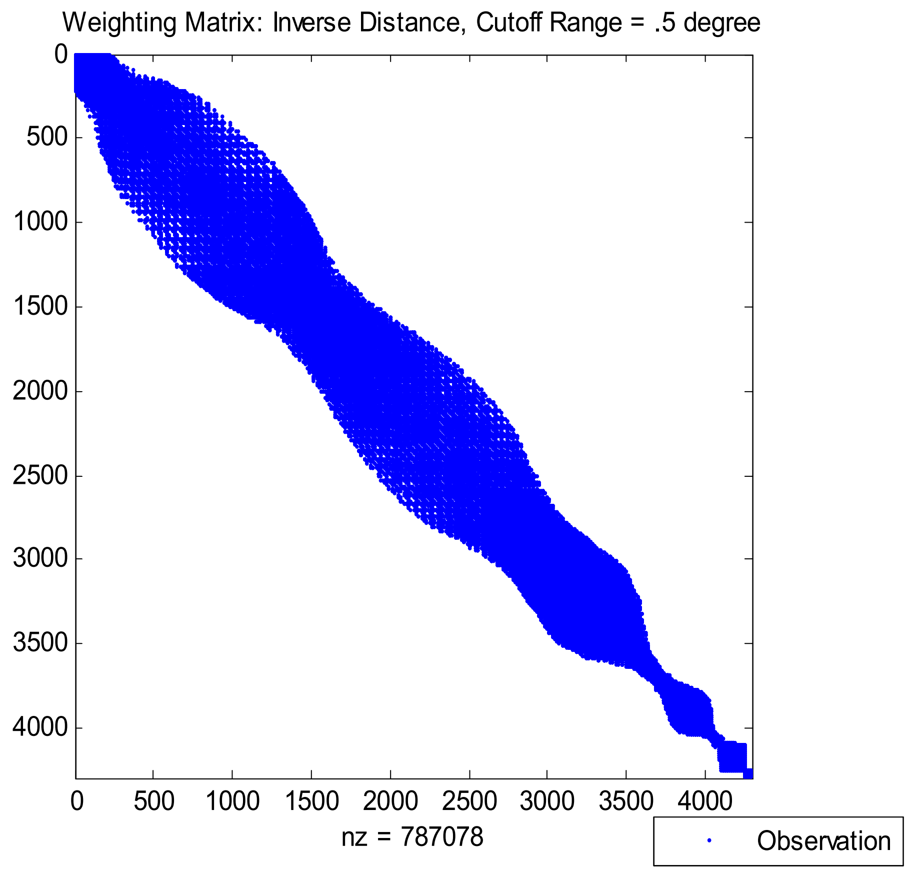
$$\nu_i \sim N(0,\sigma^2)$$

- Solution: GMM (Conley, 1999) or MLE (Elhorst, 2003) (2)
  - Spatial filtering (I-pW): extract what is not due to spatial dependence
  - W weighting matrix: to weight the observation based on distance and location (cutoff range)
  - Tradeoff between cutoff range and significance of the estimator

Weighting Matrixes

- Increasing cutoff range will allow for more observations to be spatially autocorrelated





Compare the Results

Based on 4220 cells covering all conversion in 2000-2006 period

(***, **, * denotes significant at 1, 5 and 10% level, respectively)

	Variable	OLS (Robust STD)	t-statistics, Corrected for Spatial Dependence		With County Fixed Effects
			Cutoff Range = .1	Cutoff Range = .5	
Climate Extremes	Number of Days above 90F	-7344.3***	(2.45)**	(1.59)	-3007.2
	Number of Days above 90F, squared	52.33***	(2.57)**	(1.69)*	20.80*
	Min Temperature	225.86**	(1.82)*	(1.10)	208.67
	Precipitation	-8.46**	(1.71)*	(1.05)	-3.88
	Precipitation, squared	.0000582***	(-1.94)*	(-1.19)	.0000186
Climate Normals	Mean Temperature	-1566.23***	(2.24)**	(1.54)	-969.94
	Mean Temperature, squared	.48***	(2.06)**	(1.40)	.20
	Precipitation	-8.26**	(1.72)*	(1.07)	-4.99
	Precipitation, squared	.0000584***	(2.05)**	(1.27)	.0000237

Some Significant Results

- Confirmation of the U-shaped conversion function
  - Moderate heating is beneficial: longer growing season, warmer night may help some crops
  - Squared term negative, meaning that too much increase is harmful.
- Most importantly, <u>using climate extremes can predict negative consequence, unlike mean temperature only</u> :
  - Especially look at the squared term (harmful effects): using mean temperature won't be able to predict harmful consequence
  - Same result for model with county fixed effects
- Bottom out at 70 days (no FE) or 72 days with FE
  - Implication: Where are we now? Left or right of the curve (1)

Other Control Variables

- <u>Precipitation not significant</u>: as expected, as very limited rainfall from April-September (growing season). CA agriculture is heavily dependent on irrigated water, unlike East coast region.

- <u>All soil variables</u> have the expected sign
  - Negative: water capacity, permeability (K-sat), percent clay (higher capacity to keep water than sand), irrigation class (unsuitable for other purpose)
  - Positive: erodibility (K-factor), depth to water table

- <u>Socio-economic and other controls:</u>
  - Edge length: positive, meaning that more fragmented or position closer to the farm polygon border more likely get converted first
  - Median family income: positive and highly significant

Conclusions

- Model of farmland conversion as a function of climate, soil, and socio-economic variables
  - Emphasize the use of climate extremes, or extreme heating condition, instead of climate normals
  - Confirm that although the effect is minimal, but present and significant
  - Nonlinear effect of climate condition: moderate gain may be possible, yet excessive heating is harmful
- Future works: projection under different climate change scenarios