The University of Iowa
College of Public Health

Tornadoes: Trend in Extreme Weather Events in the US Heartland

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Outline

- Introduction
- Data
- Methods
- Results and Conclusion
- Limitations and Future Work

Tornadoes

- Generated from thunderstorms
  - Cloud vortex that is produced from thunderstorm and touches the ground
  - Exact formation still undetermined

- Severity ranges from F0 to F5
  - Fujita Scale
    - Developed by Dr. Fujita in 1971
    - Ranks severity of tornado by damage
  - Enhanced Fujita Scale
    - Standardized damage scale

Effects of Tornadoes

- Damage by tornadoes is caused by strong winds
  - Buildings destroyed
  - Tree branches or whole trees can be picked up
  - Public health hazard
    - Dangerous materials can be released
    - Flying debris can cause injuries

http://www.press-citizen.com/story/news/2016/04/13/then-and-now-photos-2006-iowa-city-tornado/82980036/

http://www.kctv5.com/story/29484550/damage-reported-after-reported-tornadoes-pound-kansas-city-area

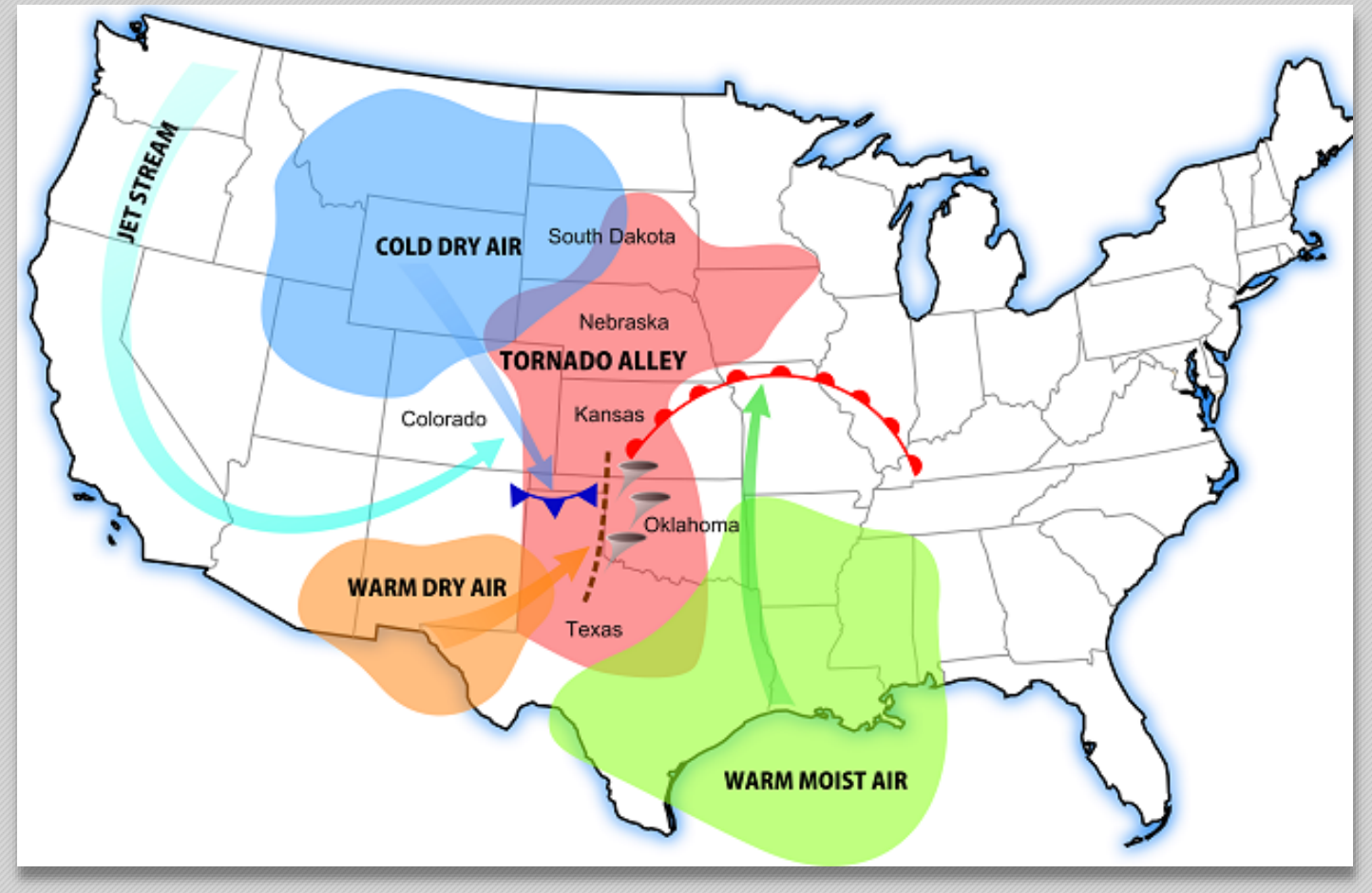
Detecting Tornadoes

- Detection before 1990
  - Doppler radar was not widely used
  - Storm spotters
  - Data is unreliable
- Early 1990s Doppler radar utilized
  - More tornadoes able to be detected

Tornado Alley

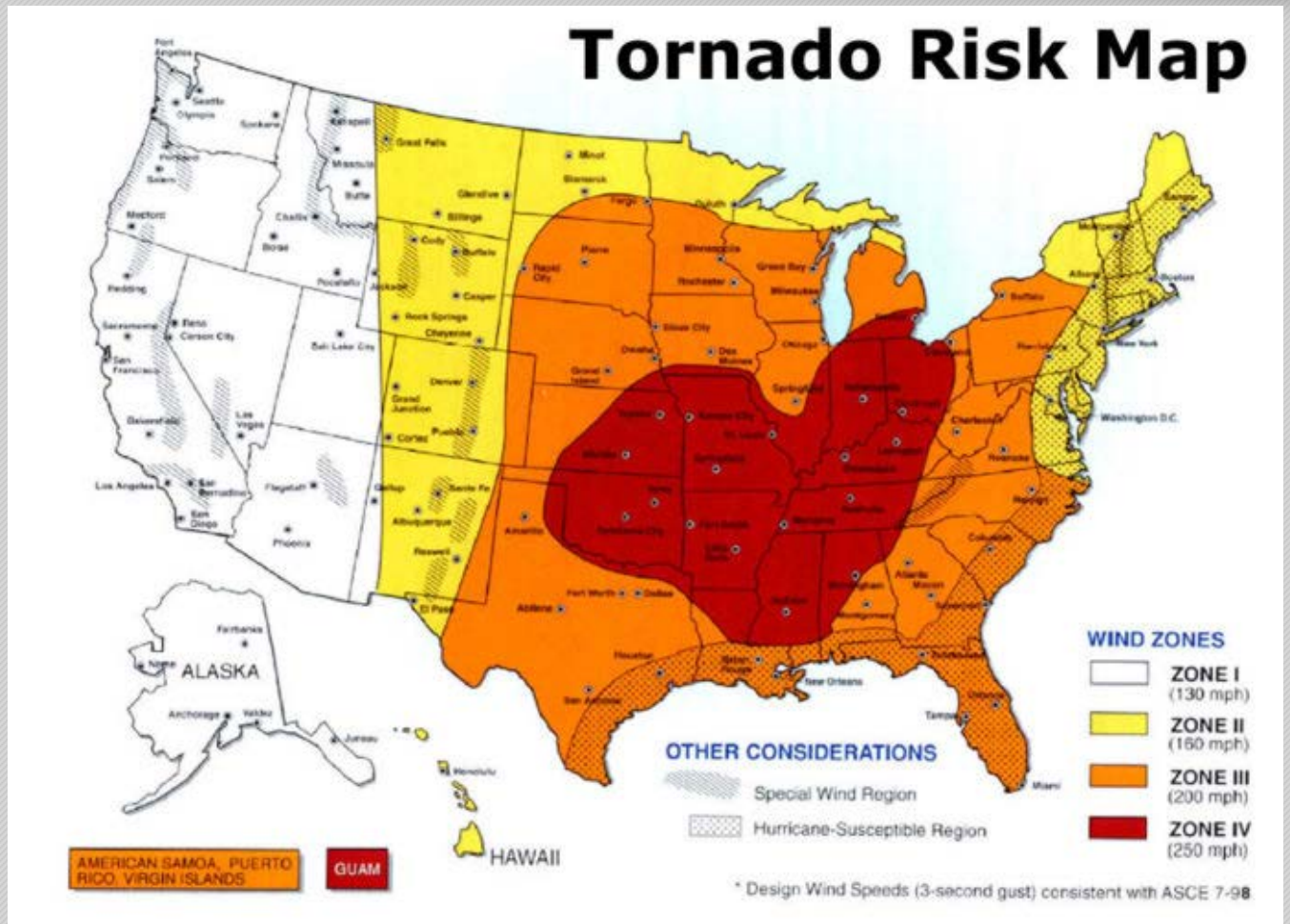
- Area where tornadic activity occurs more frequently.
- No set definition
  - Can refer to Alabama, Arkansas, Iowa, Kansas, Mississippi, Missouri, Nebraska, Oklahoma, and Texas
- Iowa, Kansas, Missouri and Nebraska are the state studied

Meteorology of Tornado Alley



http://www.tornadofacts.net/images/tornado-alley.png

Tornado Alley by severity



http://strangesounds.org/wp-content/uploads/2014/04/tornado-risk-map.jpg

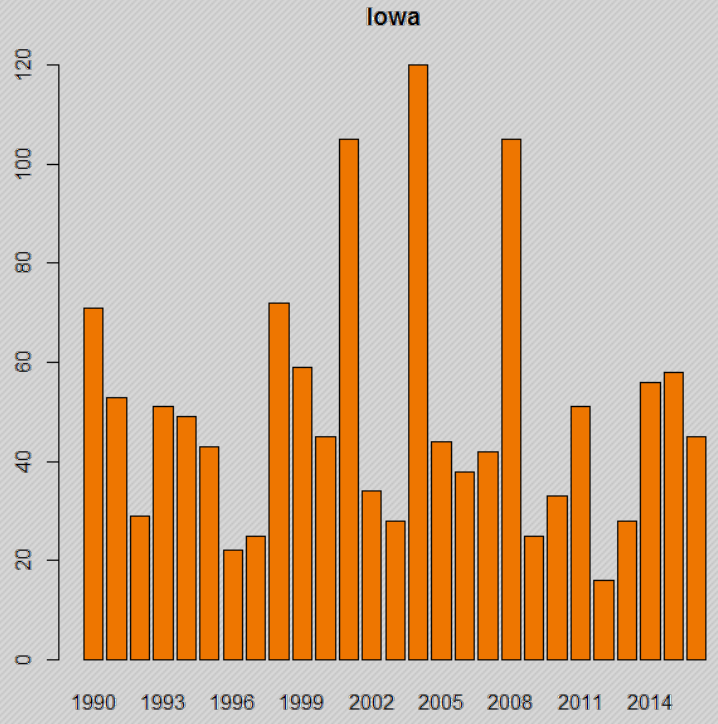
Research Questions

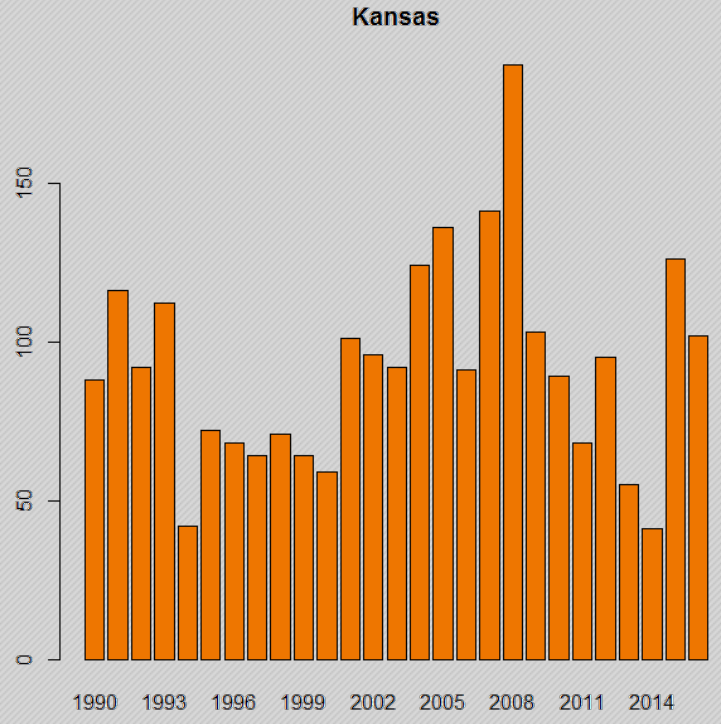
- Is there an increase in the frequency of tornadoes over the 27 year period?
- Is there a correlation between the temperature of a county and the frequency of tornadoes?
- Is there a correlation between the elevation of a county and the frequency of tornadoes?

Data

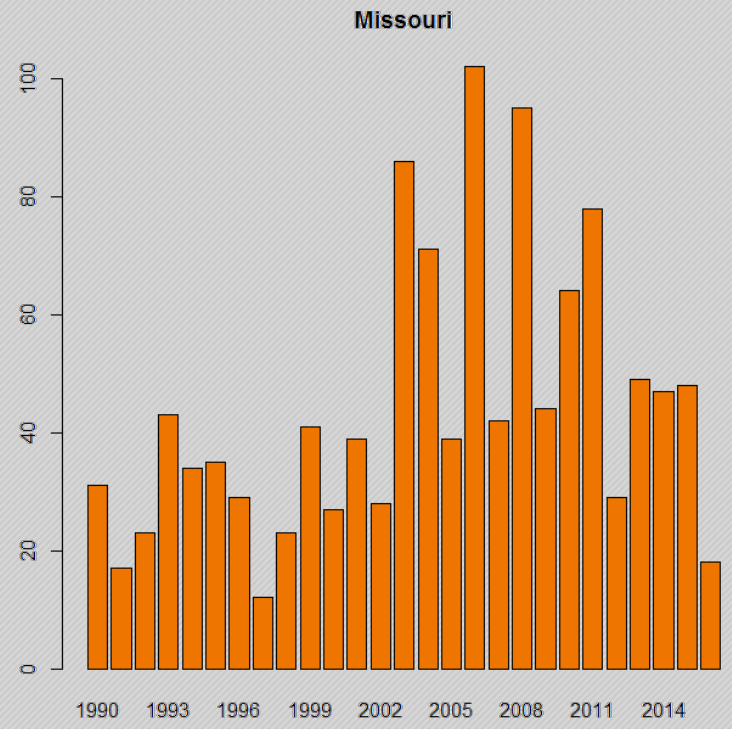
- The data for the tornado counts was obtained from tornadohistoryproject.com.
- The data for elevation and temperature was obtained from the PRISM Climate Group based at Oregon State University.
- The data for temperature is 30 year normal for the month of April.
- The data for land area was a compilation of various government websites.
- The data set covers all counties from states studied.
- Dealing with counties as a unit of observation.

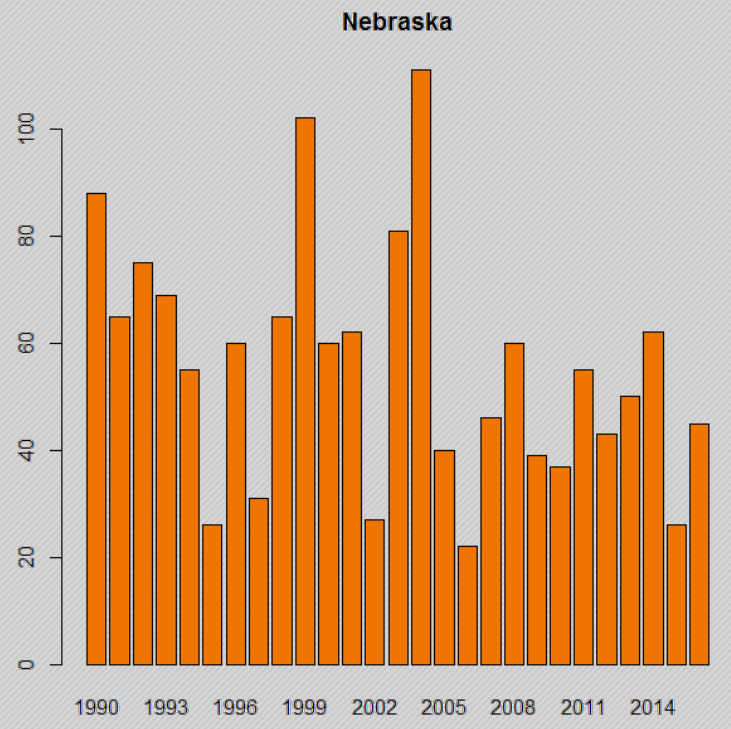
Counts of tornadoes



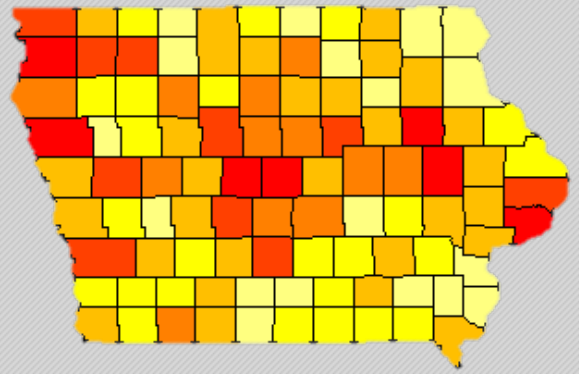


Counts of tornadoes

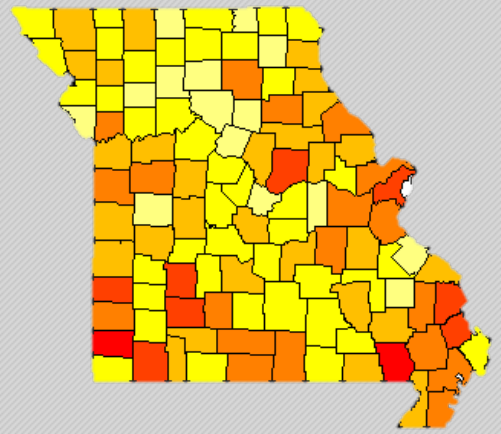




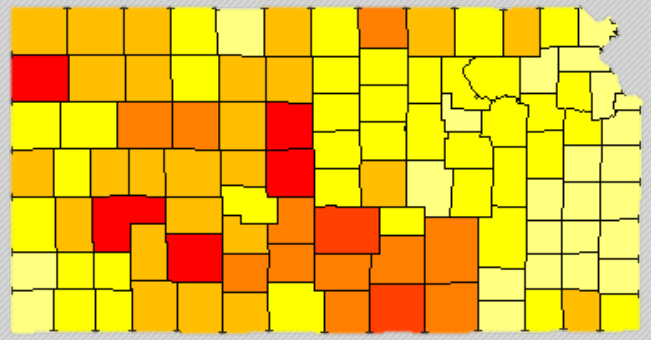
Iowa Total Tornado Frequency



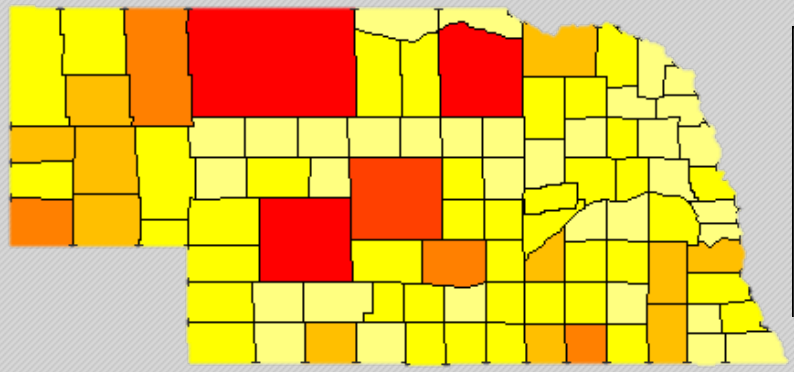
(2.97,7.33]
(7.33,11.7]
(11.7,16]
(16,20.3]
(20.3,24.7]
(24.7,29]



(0,4.67]
(4.67,9.33]
(9.33,14]
(14,18.7]
(18.7,23.3]
(23.3,28]

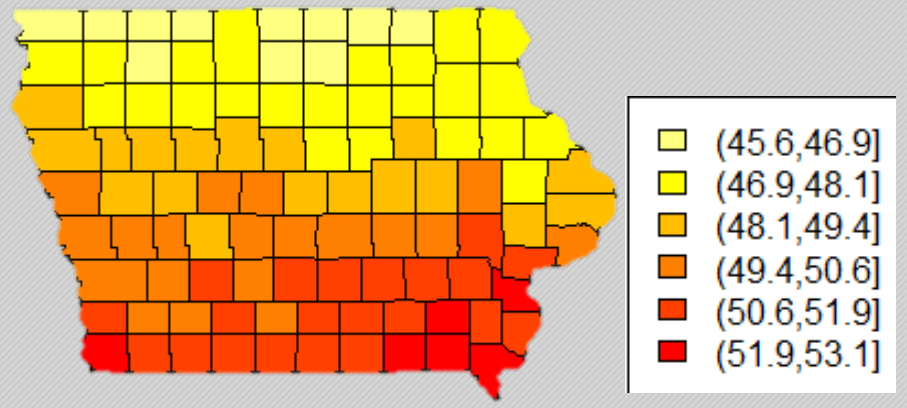


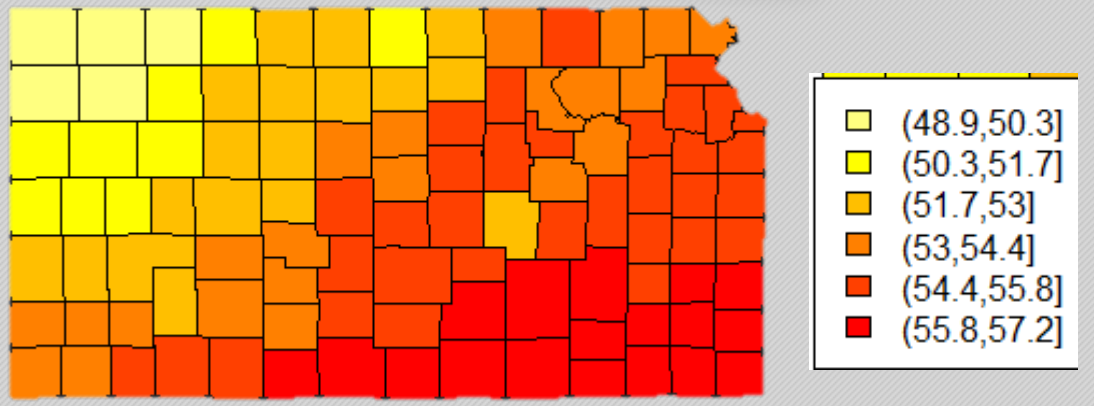
(1.93,13]
(13,24]
(24,35]
(35,46]
(46,57]
(57,68.1]

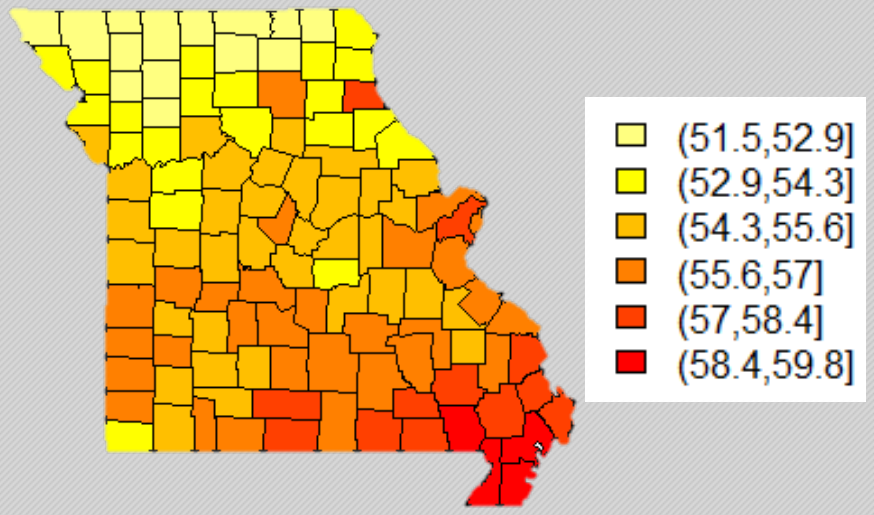


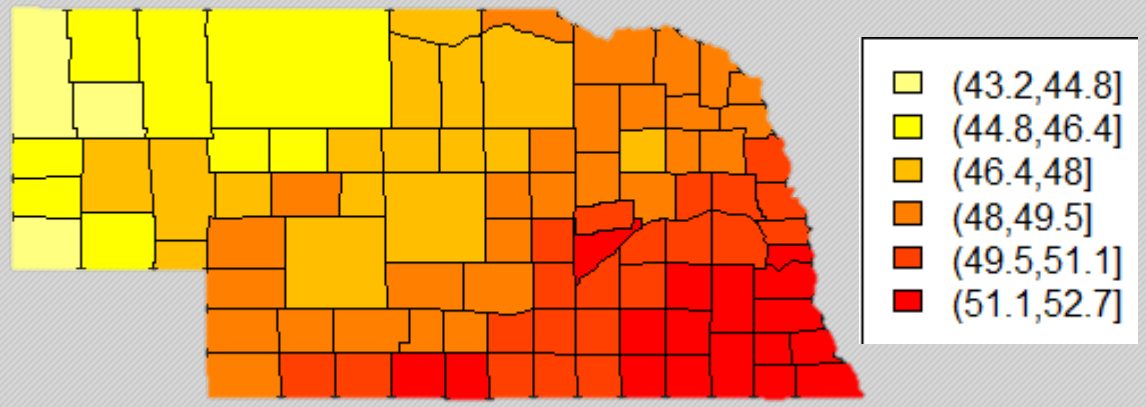
(1.94,11.5]
(11.5,21]
(21,30.5]
(30.5,40]
(40,49.5]
(49.5,59.1]

Temperature Differences between Counties

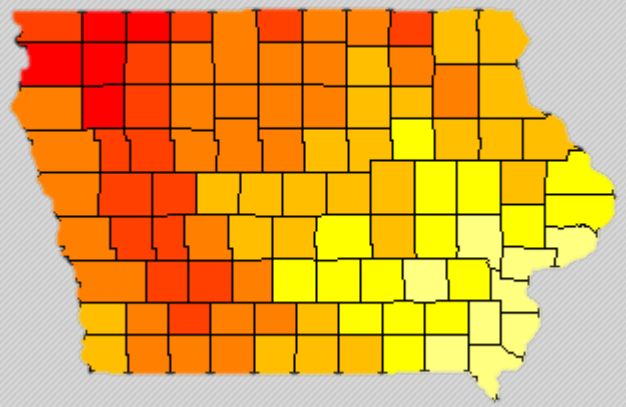




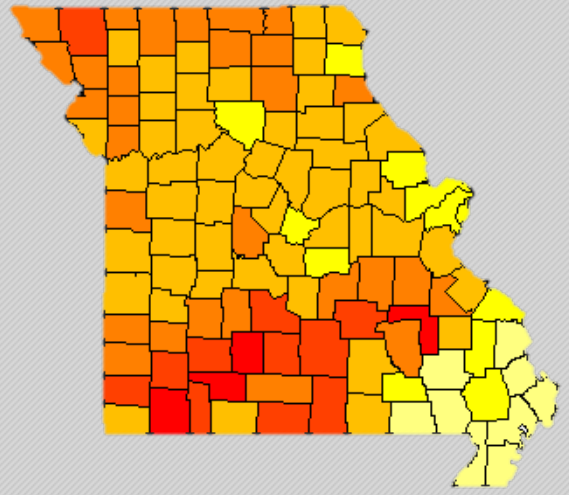




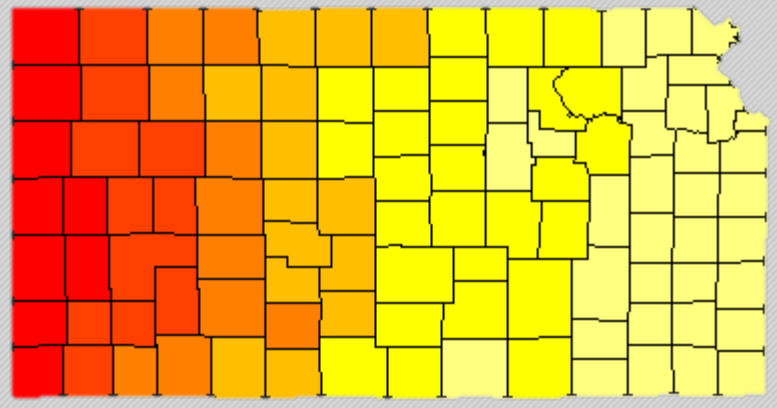
Elevation Differences between Counties



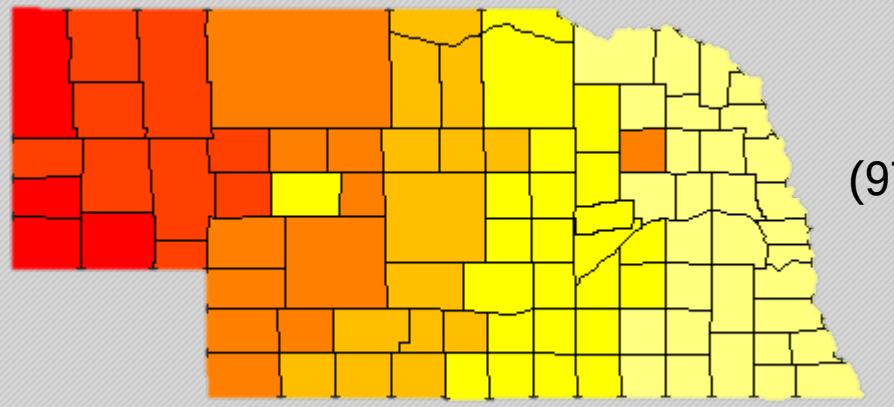
(586ft, 1570ft)



(265ft, 1510ft)



(784ft, 3690ft)



(974ft, 4910ft)

Methods

- Why are we using a Bayesian approach
  - Multiple Data (spatial structure)
- Used R-package CARBayesST
  - (MCMC)
- Poisson Regression
  - Counts

$$Log(E(Y_{it})) = (Intercept + \Phi_{0i}) + Log(area_i) + (\alpha + \Phi_{1i})T_t + \beta_1 Elevation_i + \beta_2 Temperature_i$$

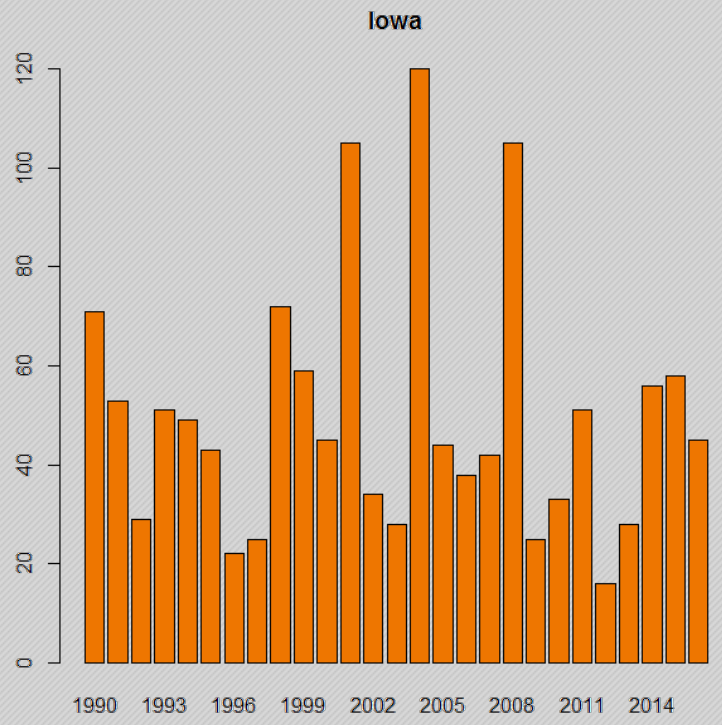
Results

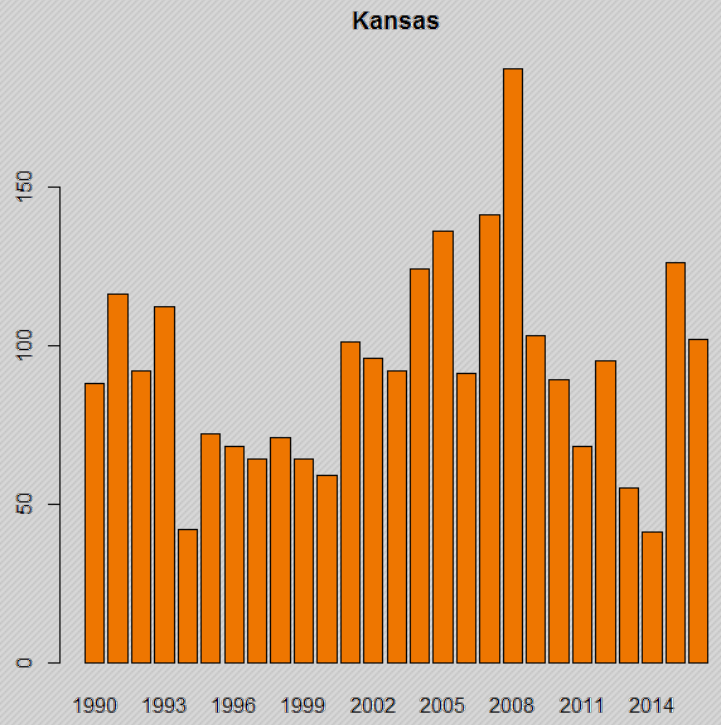
	Iowa	Kansas	Missouri	Nebraska
Intercept Point Estimate	-5.7292	-5.1431	-13.1713	-12.0725
Intercept	(-9.6829, -1.7896)	(-10.1284,-0.4187)	(-17.4427, -9.2847)	(-15.9422, -8.1249)
Temperature Point Estimate	-0.0274	-0.0333	0.1039*	0.0985*
Temperature	(-0.1071, 0.0529)	(-0.1210, 0.0590)	(0.0335, 0.1811)*	(0.0175, 0.1776)*
Alpha Point Estimate	-0.1081	0.1678*	0.7032*	-0.5609*
Alpha	(-0.2923, 0.0802)	(0.0132, 0.3230)*	(0.4985, 0.9100)*	(-0.7568, -0.3712)*

Results

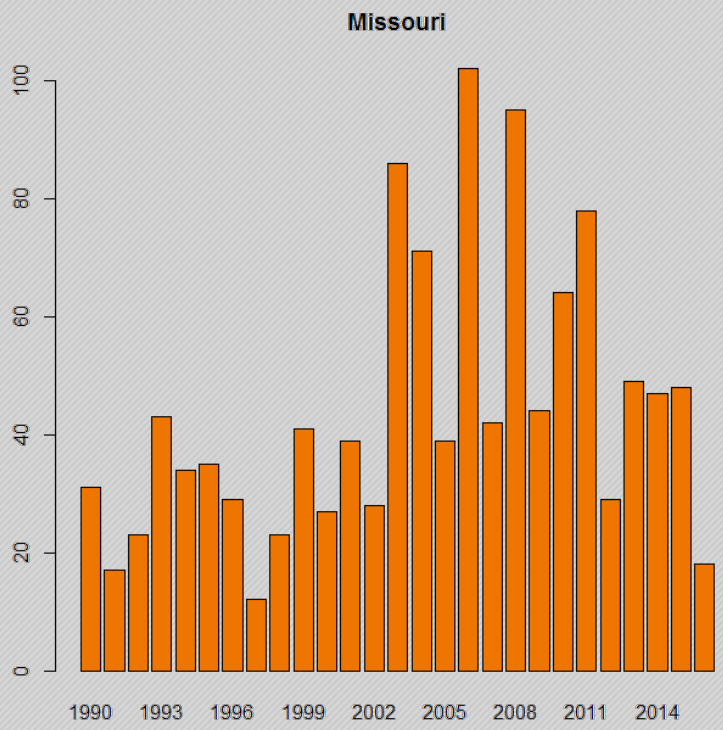
	All States
Intercept Point Estimate	-8.2184
Intercept	(-10.8102, -5.4658)
Temperature Point Estimate	0.0197
Temperature	(-0.0333, 0.696)
Alpha Point Estimate	0.0729
Alpha	(-0.0220, 0.1689)

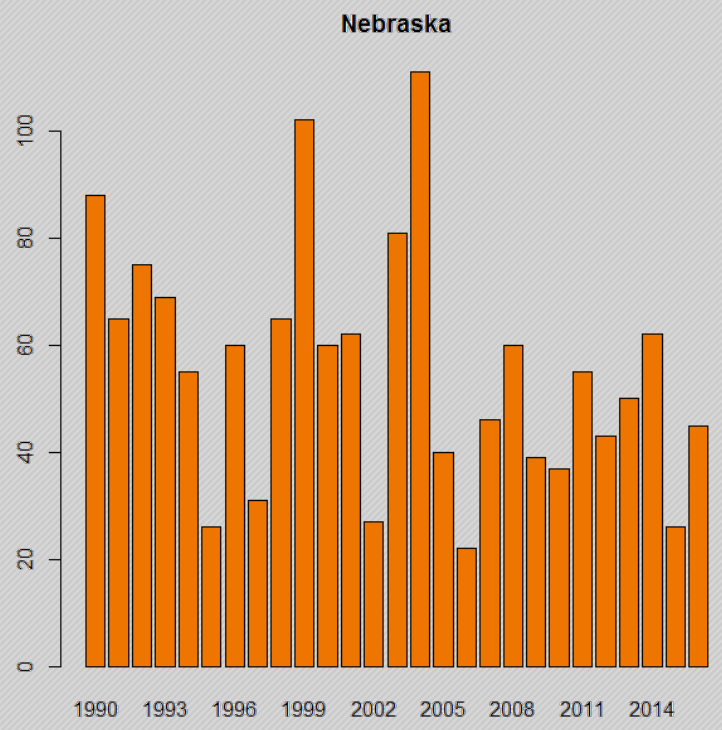
Results


Iowa
0
20
40
60
80
100
120
1990
1993
1996
1999
2002
2005
2008
2011
2014


Kansas
0
50
100
150
1990
1993
1996
1999
2002
2005
2008
2011
2014

Results


Missouri
0
20
40
60
80
100
1990
1993
1996
1999
2002
2005
2008
2011
2014


Nebraska
0
20
40
60
80
100
1990
1993
1996
1999
2002
2005
2008
2011
2014

Conclusions

- The two states that were further south had a meaningful increase in tornado frequency over time, the other two states had a decreasing trend or no change.
- When all four states were combined we found a trend toward increase in tornado frequency.
- In some states we observed the expected positive relationship between temperature and tornado frequency.
- After controlling for the effect of temperature, elevation was not useful for predicting.

Limitations and Future Work

Limitations

- Only 27 years of data
- Not all tornadoes can be detected by the Doppler radar

Future Work

- Analyze data from 1950 –1989 to see if same trends are observed
- Analyze severity of tornado occurrences
- Use all of the states in Tornado Alley for analysis
- Repeat the analysis in the future

R Citations

- R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.
- Original S code by Richard A. Becker, Allan R. Wilks. R version by Ray Brownrigg. Enhancements by Thomas P Minka and Alex Deckmyn. (2017). maps: Draw Geographical Maps. R package version 3.2.0. https://CRAN.R-project.org/package=maps
- Duncan Lee, Alastair Rushworth and Gary Napier (2017). CARBayesST: Spatio-Temporal Generalised Linear Mixed Models for Areal Unit Data. R package version 2.5. https://CRAN.R-project.org/package=CARBayesST

R Citations

- Reinhard Furrer, Stephan R. Sain (2010). spam: A Sparse Matrix R Package with Emphasis on MCMC Methods for Gaussian Markov Random Fields. Journal of Statistical Software, 36(10), 1-25. URL http://www.jstatsoft.org/v36/i10/.
- Florian Gerber, Reinhard Furrer (2015). Pitfalls in the Implementation of Bayesian Hierarchical Modeling of Areal Count Data: An Illustration Using BYM and Leroux Models. Journal of Statistical Software, Code Snippets, 63(1), 1-32. URL http://www.jstatsoft.org/v63/c01/.

R Citations

- John Hughes and Xiaohui Cui. (2017). ngspatial: Fitting the Centered Autologistic and Sparse Spatial Generalized Linear Mixed Models for Areal Data. R package version 1.2. Denver, CO.

References

- **Official Nebraska Government Website. (2009, February 4). Retrieved June 21, 2017, from https://opportunity.nebraska.gov/files/research/stathand/asect1.htm**
- PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, created 29 June 2017- 3 July 2017.
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- **Tornado History Project: Maps and Statistics. Retrieved June 23rd, 2017, from http://www.tornadohistoryproject.com/**
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- https://www.census.gov/prod/cen2010/cph-2-17.pdf
- https://www.census.gov/prod/cen2010/cph-2-27.pdf

Acknowledgments

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1. Our mentor: Dr. Mary Kathryn Cowles
2. Dr. Gideon Zamba

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Iowa Output

```
[[1]] IOWA TEMP

#################
#### Model fitted
#################
Likelihood model - Poisson (log link function)
Latent structure model - Spatially autocorrelated linear time trends
Regression equation - newCounts[[i]]$Freq ~ temp + offset(offsetst)

############
#### Results
############
Posterior quantities for selected parameters and DIC

            Median    2.5%   97.5% n.sample % accept n.effective Geweke.diag
(Intercept) -5.7292 -9.6829 -1.7895    10000     35.6      1426.8          0.0
temp        -0.0274 -0.1071  0.0529    10000     35.6      1425.8          0.0
alpha       -0.1081 -0.2923  0.0802    10000     35.4      9792.2         -1.2
tau2.int     0.2441  0.1229  0.4627    10000    100.0      4579.8          0.7
tau2.slo     0.0090  0.0021  0.5960    10000    100.0       128.4          0.8
rho.int      0.5524  0.1966  0.9067    10000     44.0      5007.8          0.7
rho.slo      0.4413  0.0357  0.9137    10000     43.3      1651.1         -0.9

DIC =  5287.932       p.d =  -7.444599       LMPL =  -2621.492
```

Kansas Output

```
[[2]] KANSAS TEMP

#################
#### Model fitted
#################
Likelihood model - Poisson (log link function)
Latent structure model - Spatially autocorrelated linear time trends
Regression equation - newCounts[[i]]$Freq ~ temp + offset(offsetst)

############
#### Results
############
Posterior quantities for selected parameters and DIC

            Median     2.5%   97.5% n.sample % accept n.effective Geweke.diag
(Intercept) -5.1431 -10.1284 -0.4187    10000     35.5       314.3         0.4
temp        -0.0333  -0.1210  0.0590    10000     35.5       314.2        -0.4
alpha        0.1678   0.0132  0.3230    10000     35.2     10000.0        -1.5
tau2.int     0.3778   0.2361  0.5965    10000    100.0      5159.8         2.0
tau2.slo     1.8779   1.0154  3.3379    10000    100.0      4300.9         1.1
rho.int      0.6993   0.3610  0.9536    10000     44.5      4003.3         0.8
rho.slo      0.5106   0.1638  0.8886    10000     44.2      4480.6        -0.4

DIC =  8019.702       p.d =  41.82688       LMPL =  -3925.996
```

Missouri Output

```
[[3]] MISSOURI TEMP

#################
#### Model fitted
#################
Likelihood model - Poisson (log link function)
Latent structure model - Spatially autocorrelated linear time trends
Regression equation - newCounts[[i]]$Freq ~ temp + offset(offsetst)

############
#### Results
############
Posterior quantities for selected parameters and DIC

             Median     2.5%   97.5% n.sample % accept n.effective Geweke.diag
(Intercept) -13.1713 -17.4427 -9.2847    10000     35.6      1420.5        -0.5
temp          0.1039   0.0335  0.1811    10000     35.6      1422.3         0.5
alpha         0.7032   0.4985  0.9100    10000     35.3      7345.2        -0.8
tau2.int      0.2503   0.1284  0.4580    10000    100.0      3670.3         0.8
tau2.slo      0.0155   0.0023  1.9354    10000    100.0        42.4        -0.1
rho.int       0.5166   0.1581  0.8794    10000     44.2      4076.6        -0.6
rho.slo       0.4285   0.0381  0.8853    10000     43.7      1819.8        -0.6

DIC =  5078.863       p.d =  -1.804016       LMPL =  -2505.872
```

Nebraska Output

```
[[4]] NEBRASKA TEMP

#################
#### Model fitted
#################
Likelihood model - Poisson (log link function)
Latent structure model - Spatially autocorrelated linear time trends
Regression equation - newCounts[[i]]$Freq ~ temp + offset(offsetst)

############
#### Results
############
Posterior quantities for selected parameters and DIC

             Median     2.5%   97.5% n.sample % accept n.effective Geweke.diag
(Intercept) -12.0725 -15.9422 -8.1249    10000     35.7       598.5        -0.3
temp          0.0985   0.0175  0.1776    10000     35.7       581.7         0.2
alpha        -0.5609  -0.7568 -0.3712    10000     35.4      9163.3        -0.6
tau2.int      0.2995   0.1581  0.5387    10000    100.0      4112.2         0.2
tau2.slo      1.1592   0.4876  2.7220    10000    100.0      1894.1         1.6
rho.int       0.5445   0.1756  0.9107    10000     44.0      4123.8        -1.5
rho.slo       0.1738   0.0090  0.6275    10000     43.6      2163.2         0.3

DIC =  5346.888       p.d =  8.853861       LMPL =  -2622.372
```

All States Output

```
##################
#### Model fitted
##################
Likelihood model - Poisson (log link function)
Latent structure model - Spatially autocorrelated linear time trends
Regression equation - state4countsv ~ tempcombo + offset(state4offset)

############
#### Results
############
Posterior quantities for selected parameters and DIC

             Median     2.5%    97.5% n.sample % accept n.effective Geweke.diag
(Intercept) -8.2184 -10.8102 -5.4658    20000     35.2       149.9        -0.2
tempcombo    0.0197  -0.0333  0.0696    20000     35.2       149.7         0.2
alpha        0.0729  -0.0220  0.1689    20000     35.1     18992.1         0.9
tau2.int     0.4572   0.3599  0.5809    20000    100.0      7124.6        -0.9
tau2.slo     2.3579   1.7162  3.1906    20000    100.0      8867.4         0.9
rho.int      0.9157   0.7678  0.9889    20000     43.8      3261.2        -0.4
rho.slo      0.7555   0.5046  0.9399    20000     43.8      9556.8        -1.0

DIC =  23728.61       p.d =  148.5       LMPL =  -11593.93
```