Predicting Seasonal Tornado Activity

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January 11, 2016
AMS Annual Meeting
New Orleans, LA

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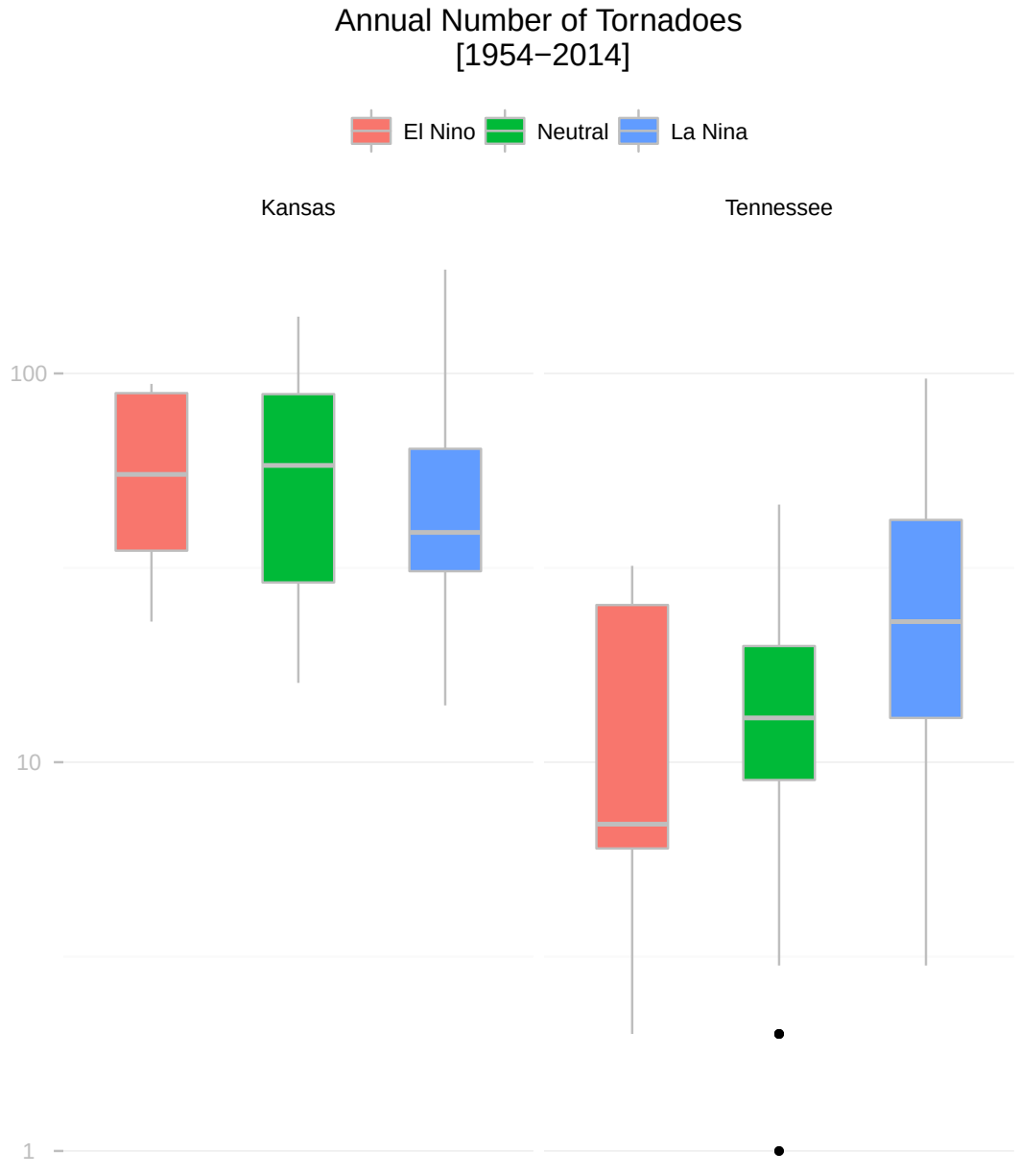
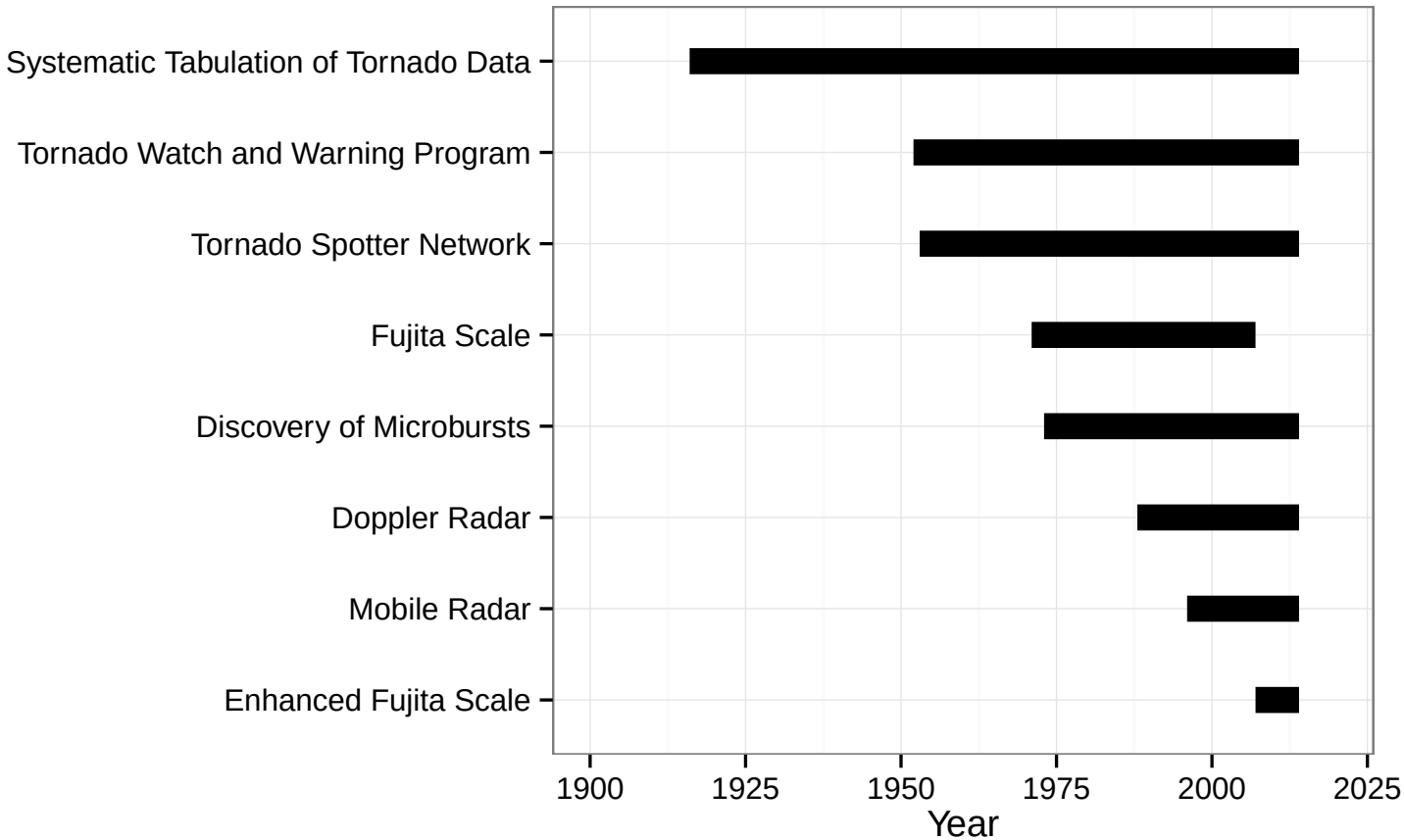
Motivation

- Climate models do not predict tornadoes
- Models can be used to predict necessary conditions
- But necessary does not imply sufficient
- Needed are evidence-based analysis and models
- Establish a baseline level of skill then a forecast model
- Outline:
  Spatial model (county level) $\Rightarrow$ Space-time model (grid level)

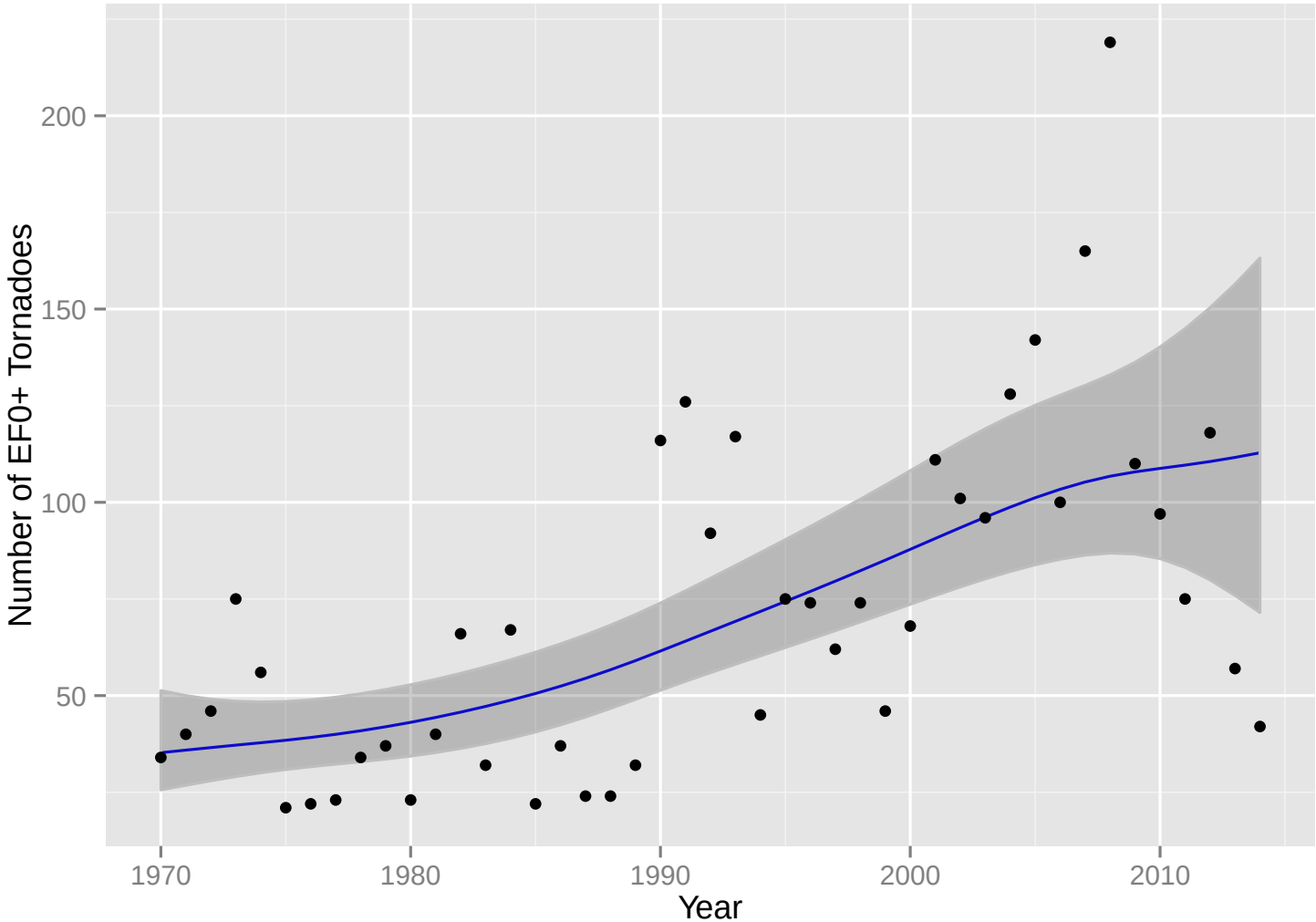
Climate effects on tornadoes vary spatially

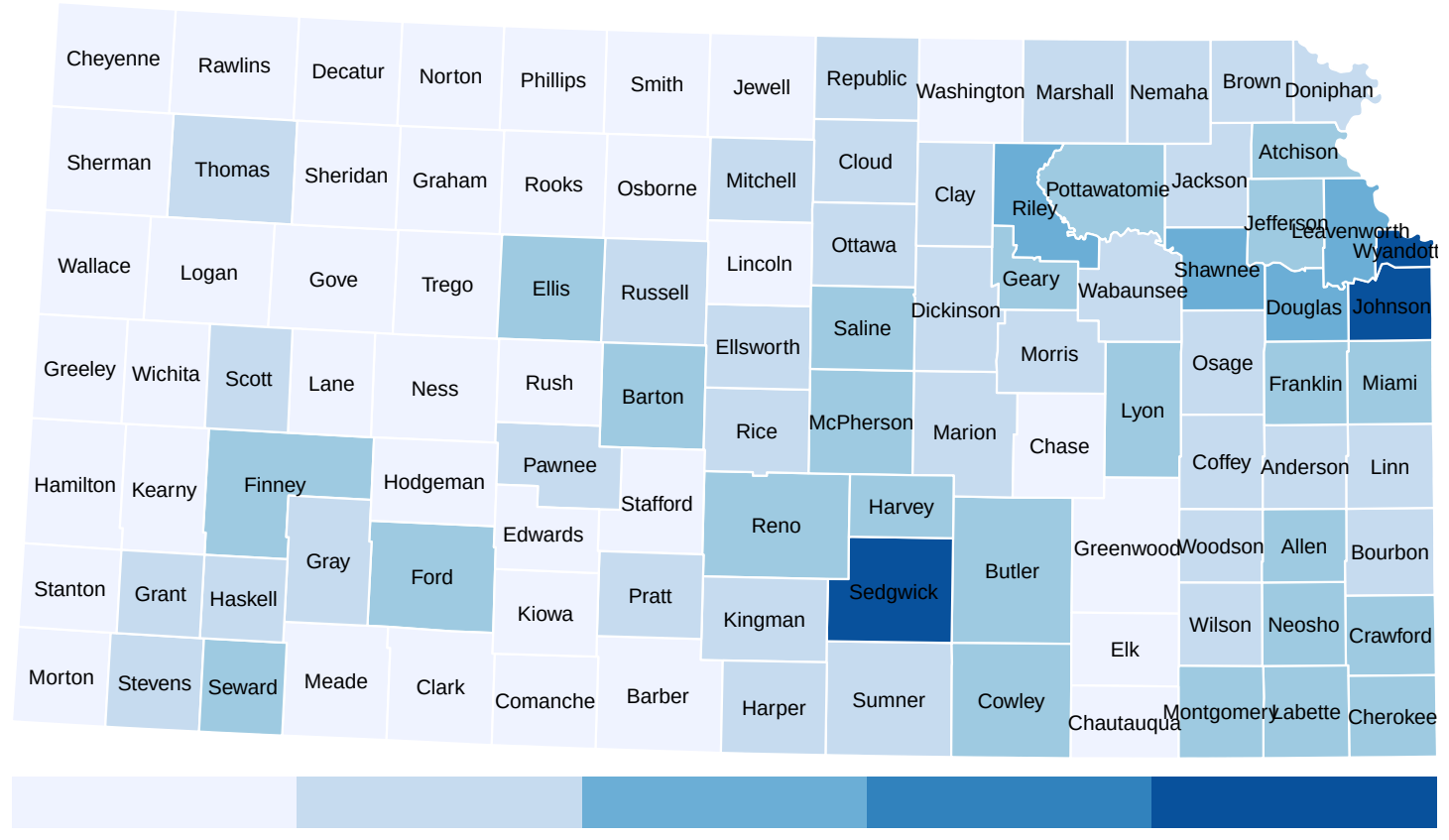


Reliability of tornado records vary over time

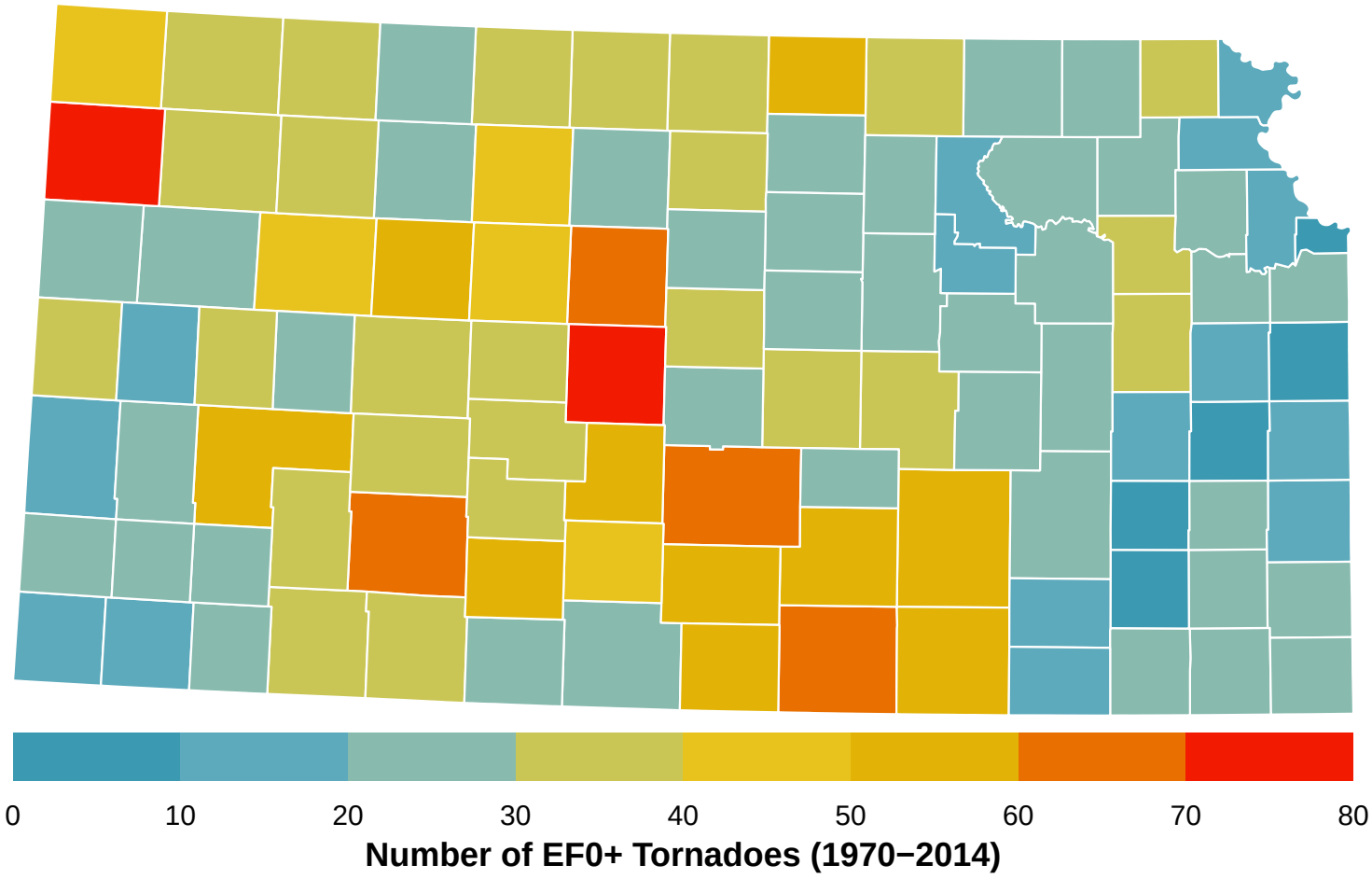


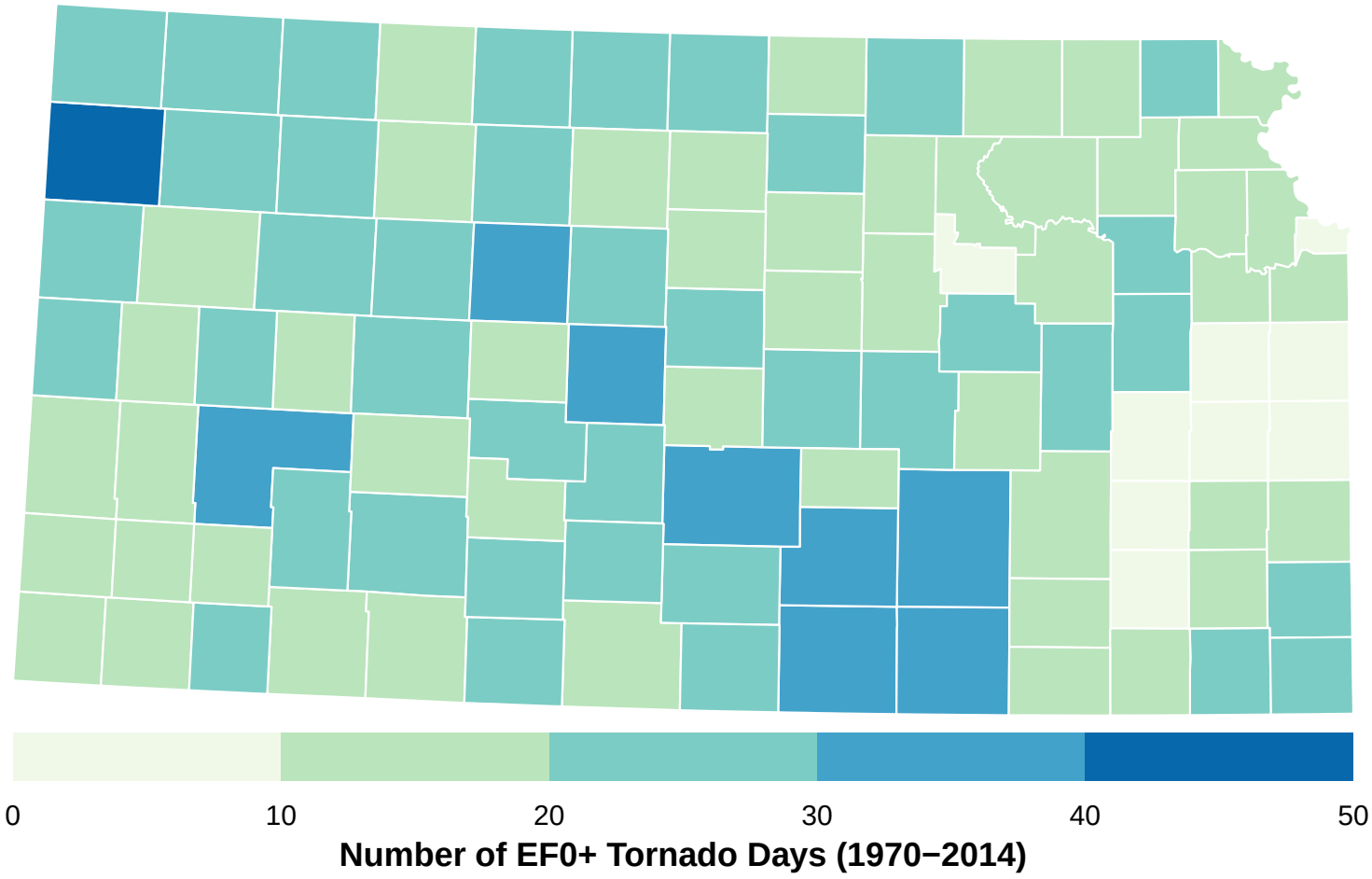
Annual number of tornado reports (Kansas)

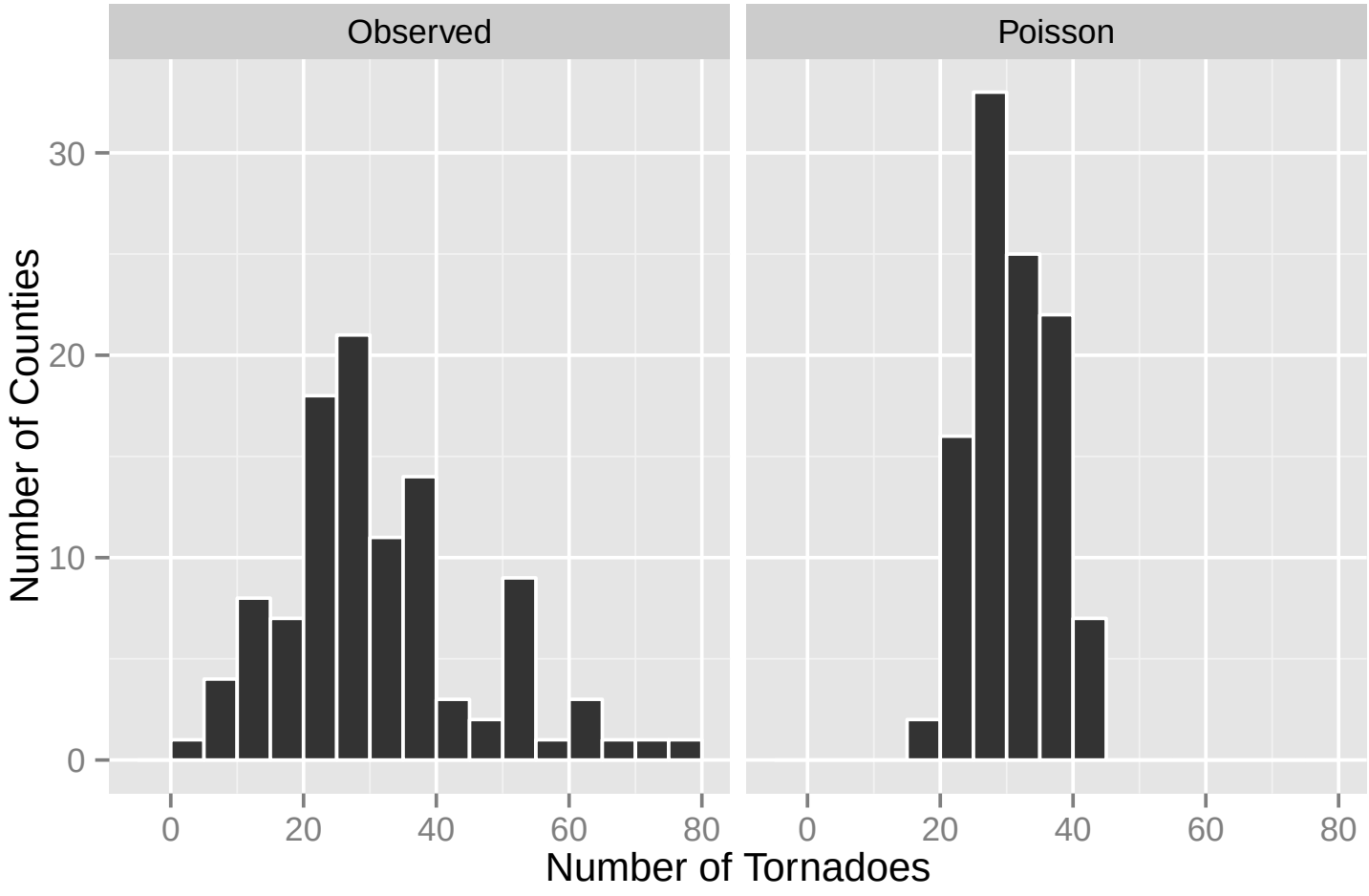




2012 Population Density [persons per square km]


0
10
20
30
40
50
60
70
80
Number of EF0+ Tornadoes (1970−2014)


0
10
20
30
40
50
Number of EF0+ Tornado Days (1970−2014)


Observed
Poisson
Number of Counties
0
10
20
30
0
20
40
60
80
Number of Tornadoes

The number of tornado reports in each cell (T_s) is assumed to follow a negative binomial distribution with mean (μ_s)

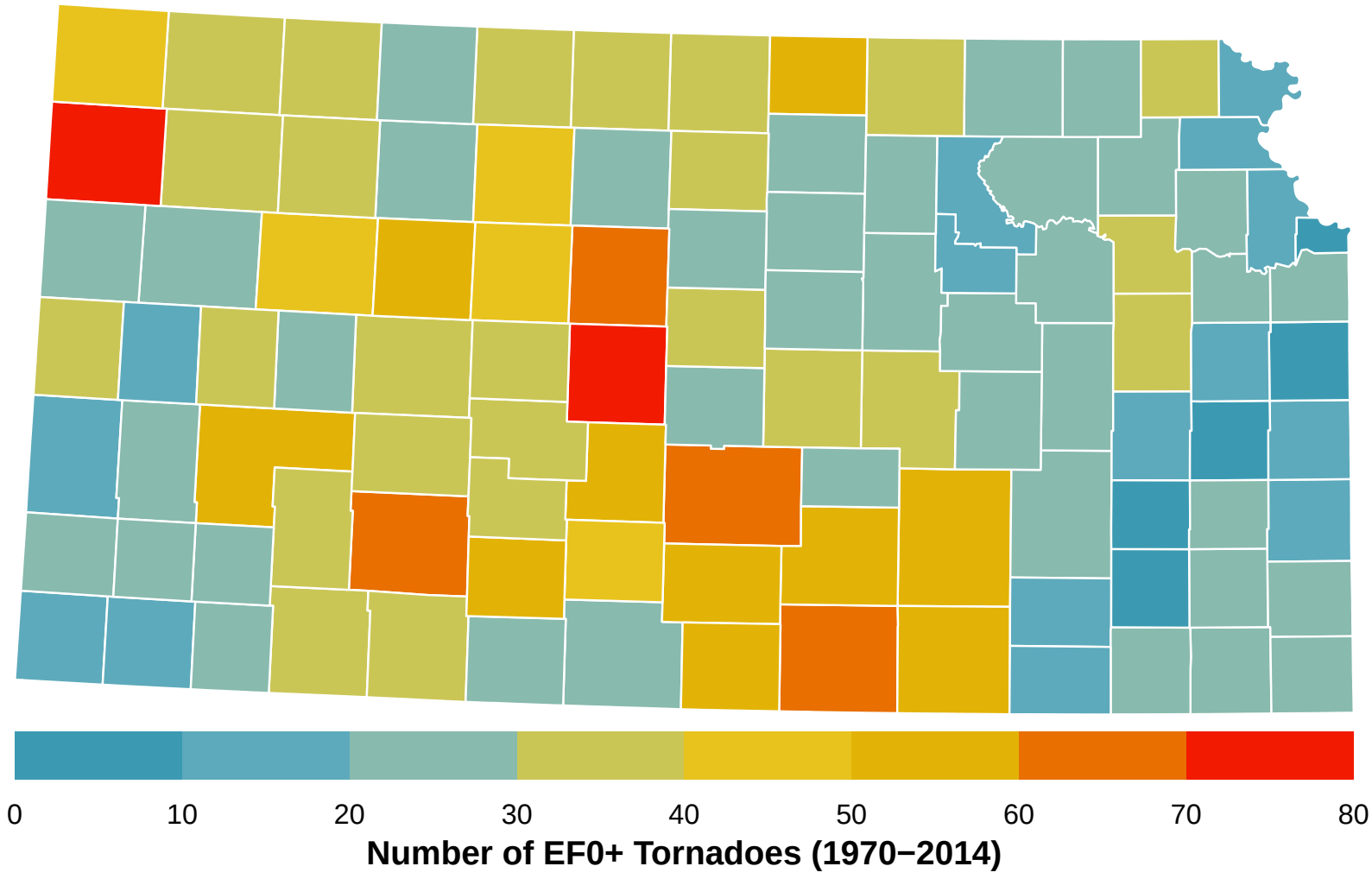
$$
\begin{aligned}
T_s|\mu_s, r_s &\sim \text{NegBin}(\mu_s, r_s) \\
\mu_s &= A_s \exp(\nu_s) \\
\nu_s &= \beta_0 + \beta_1 \,\text{lpd}_s + \beta_2 \,(t - t_0) + \beta_3 \,\text{lpd}_s (t - t_0) + u_s + v_t \\
r_s &= A_s \, n
\end{aligned}
$$

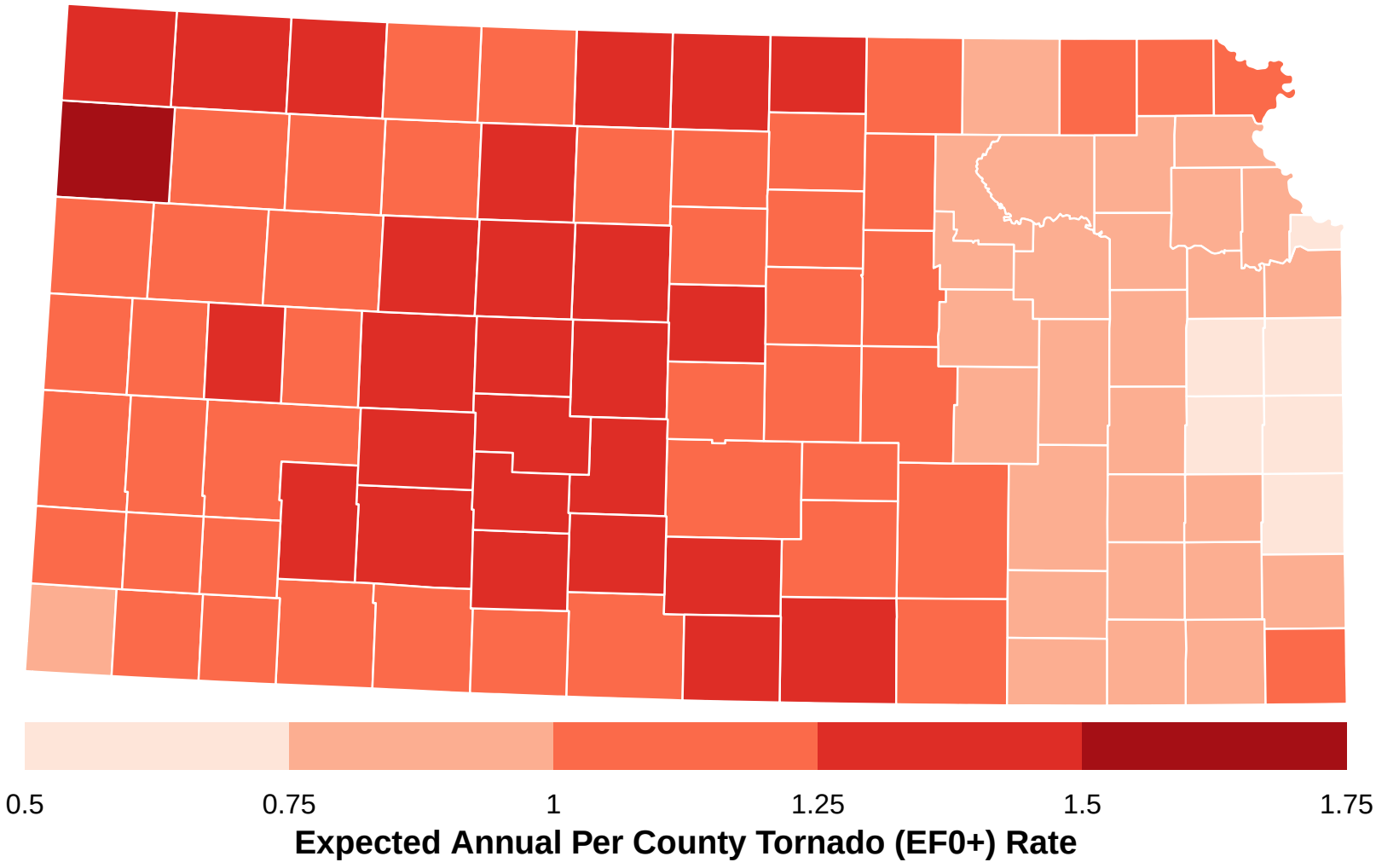
where NegBin(μ_s, r_s) indicates that the conditional tornado counts ($T_s|\mu_s$, r_s) are described by a negative binomial distribution with mean μ_s and size r_s, lpd_s represents the base two logarithm of the population density during 2012 for each county, and t_0 is the base year set to 1991 (middle year of the record).

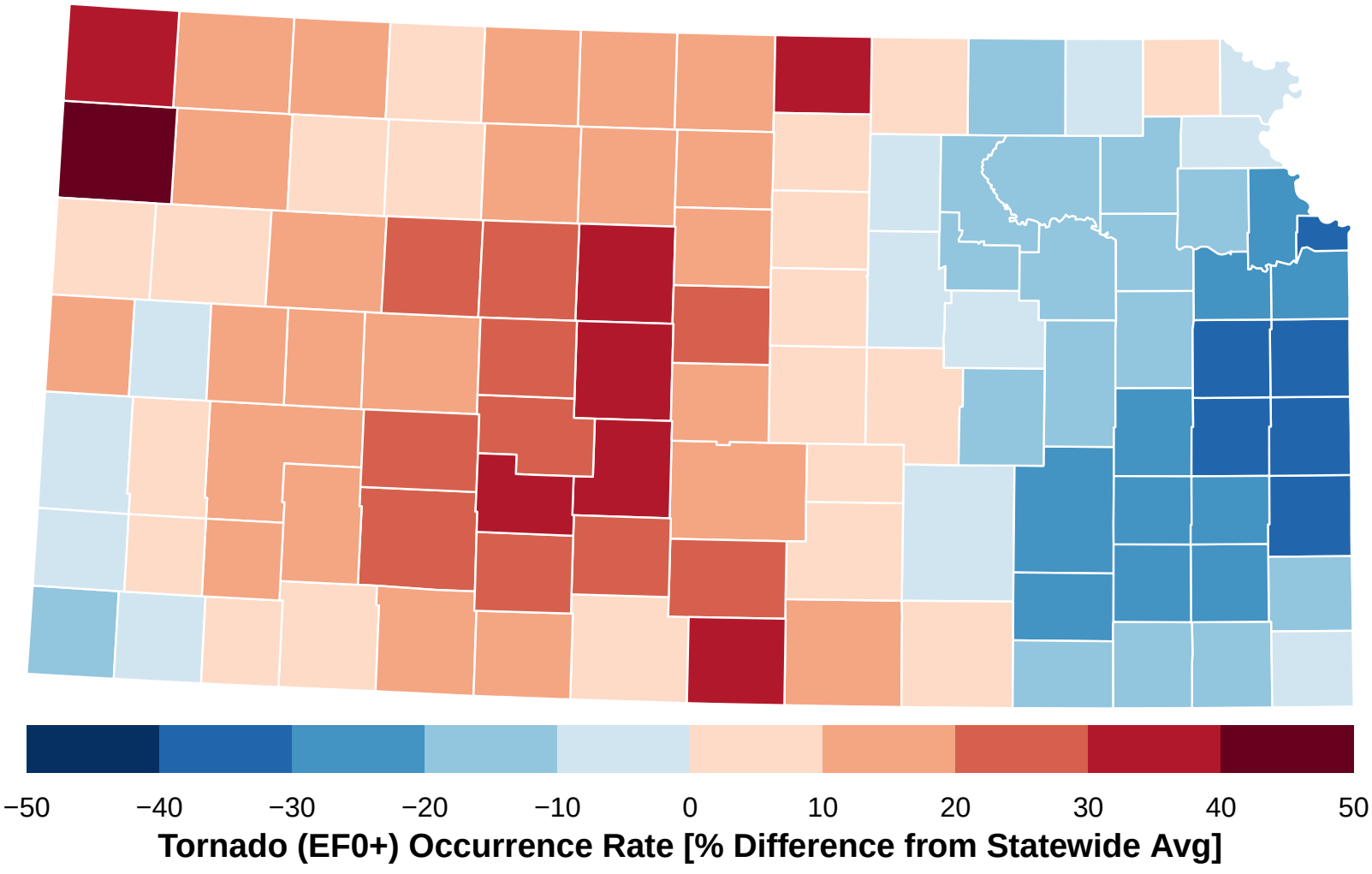
The spatially correlated random effects u_s follows an intrinsic Besag formulation with a sum-to-zero constraint.

$$u_i | \{u_{j,j \neq i}, \tau\} \sim N\left(\frac{1}{m_i}\sum_{i \sim j} u_j, \frac{1}{m_i}\tau\right),$$

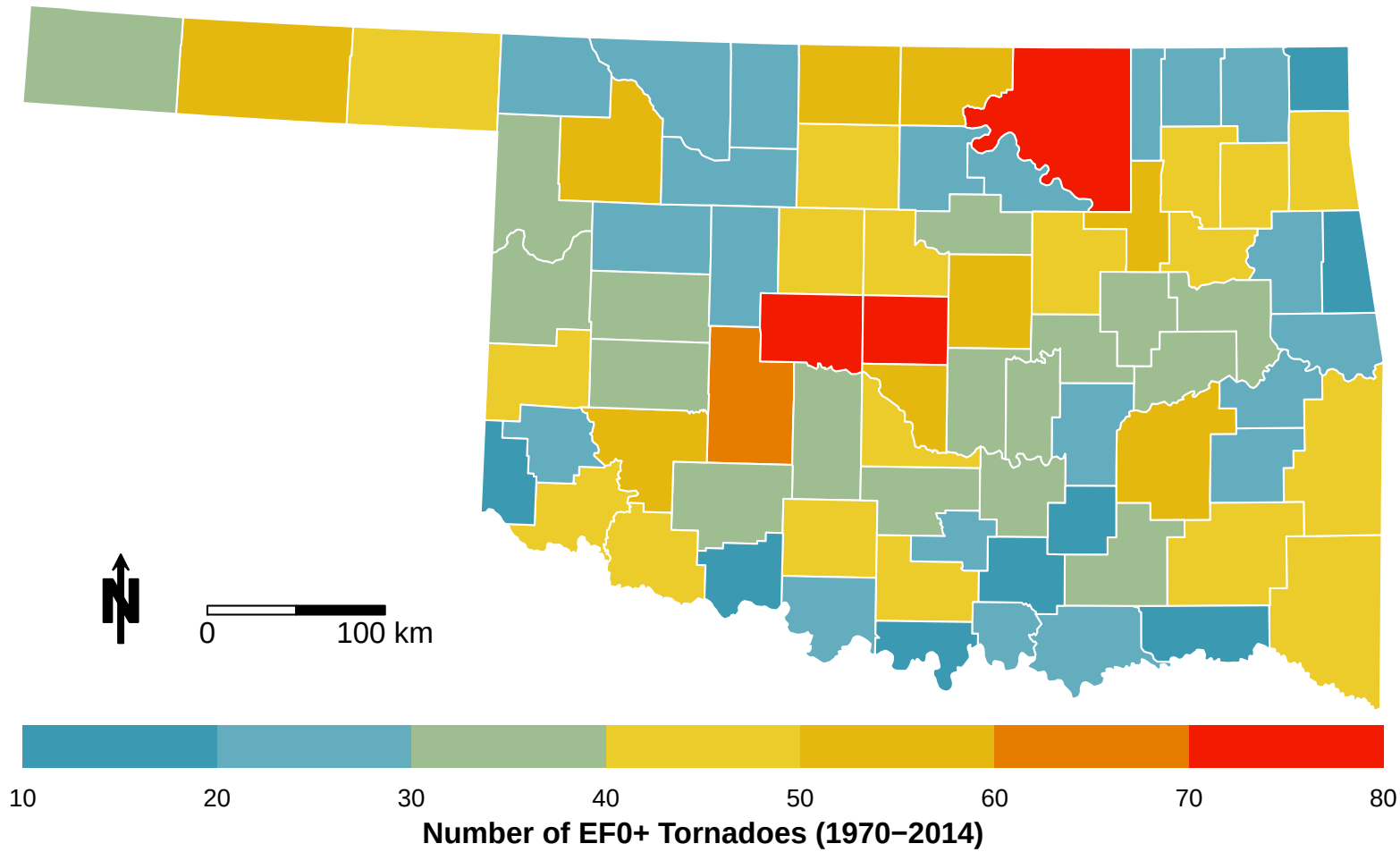
where N is the normal distribution with mean $1/m_i \cdot \sum_{i \sim j} u_j$ and variance $1/m_i \cdot 1/\tau$ where m_i is the number of neighbors of cell i and τ is the precision; $i \sim j$ indicates cells i and j are neighbors. Neighboring cells are determined by contiguity (queen's rule). The annual uncorrelated random effect, v_t, is modeled as a sequence of normally distributed random variables, with mean zero and variance $1/\tau'$.

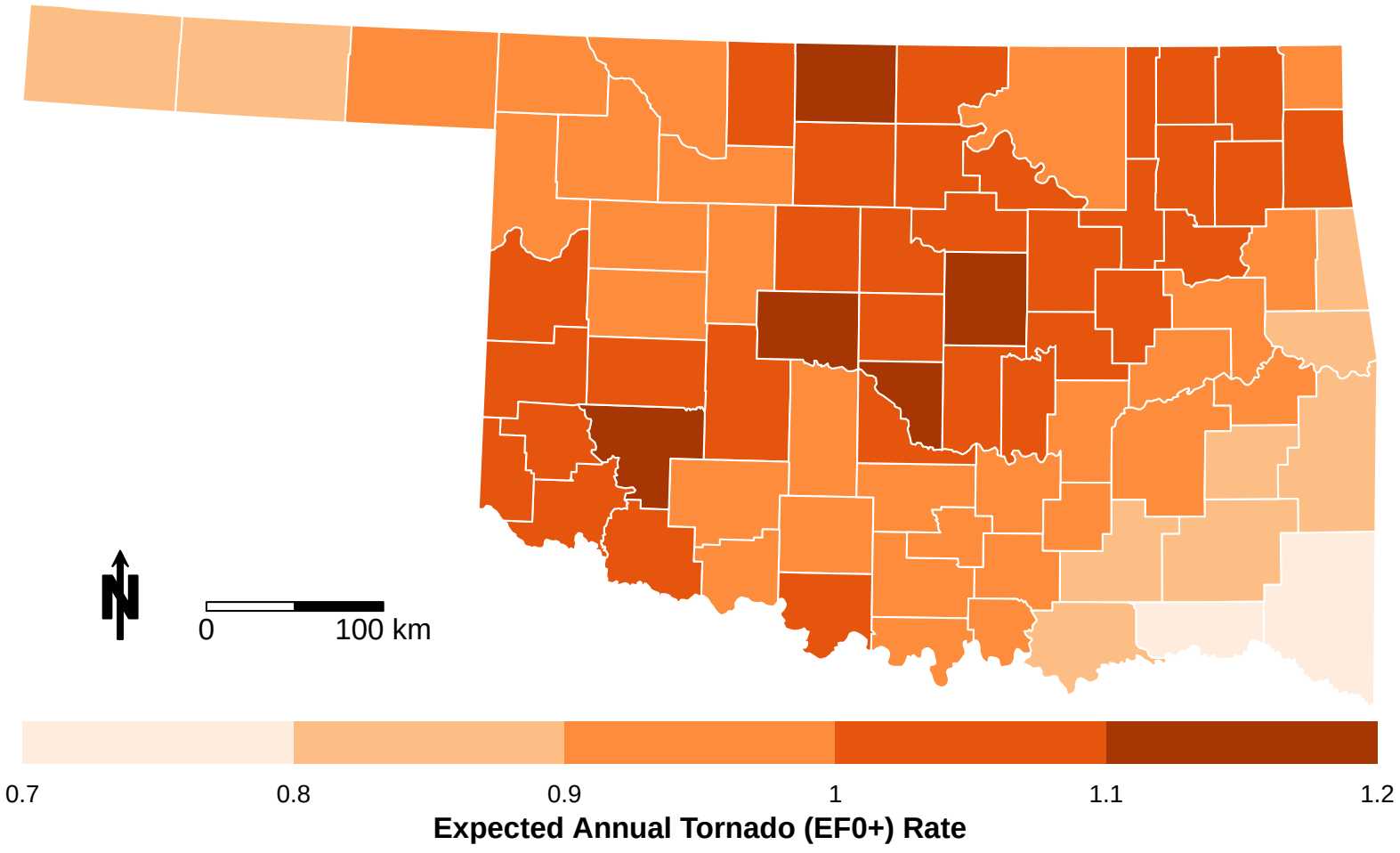

0
10
20
30
40
50
60
70
80
Number of EF0+ Tornadoes (1970−2014)


0.5
0.75
1
1.25
1.5
1.75
Expected Annual Per County Tornado (EF0+) Rate

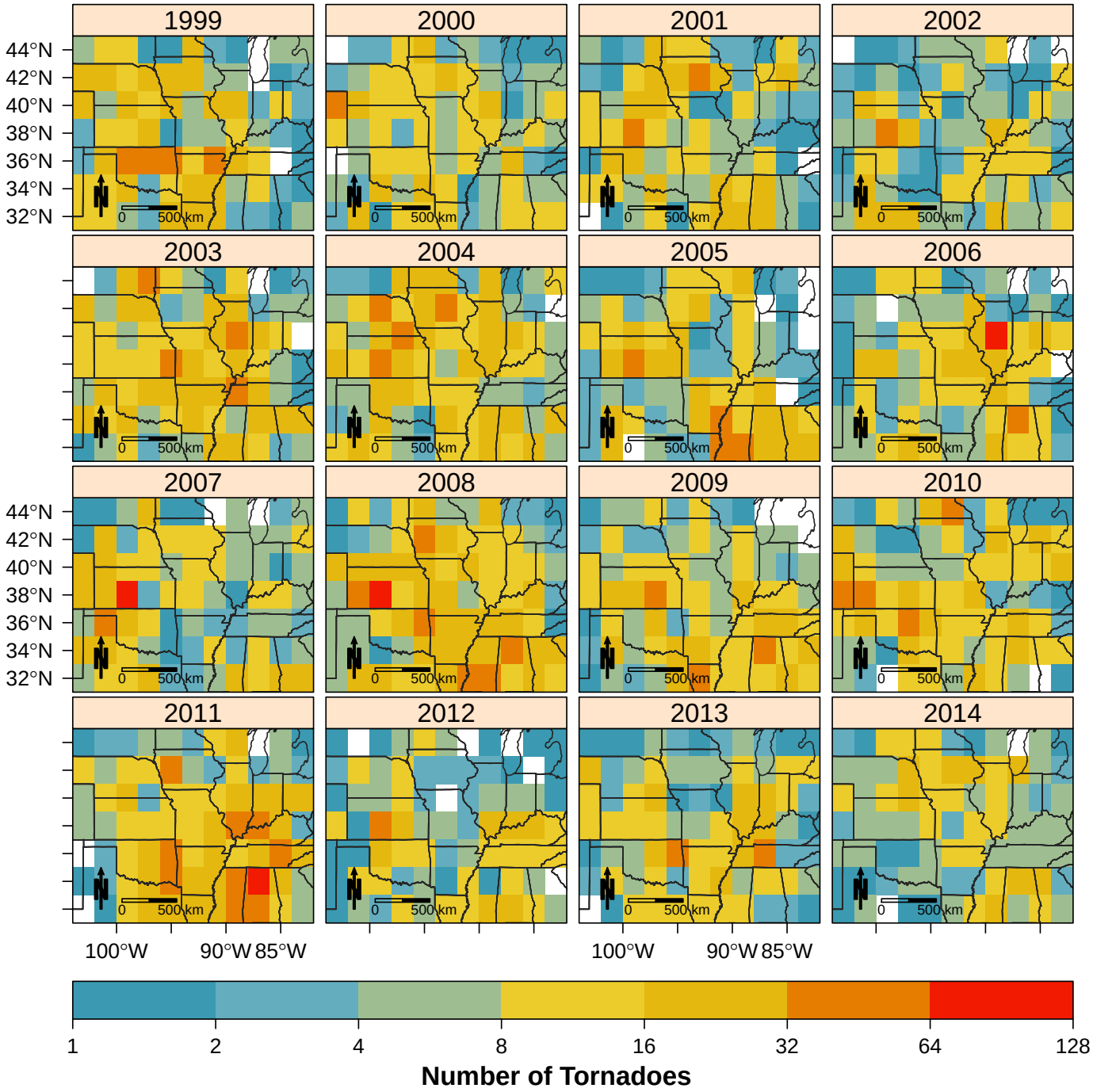

−50
−40
−30
−20
−10
0
10
20
30
40
50
Tornado (EF0+) Occurrence Rate [% Difference from Statewide Avg]

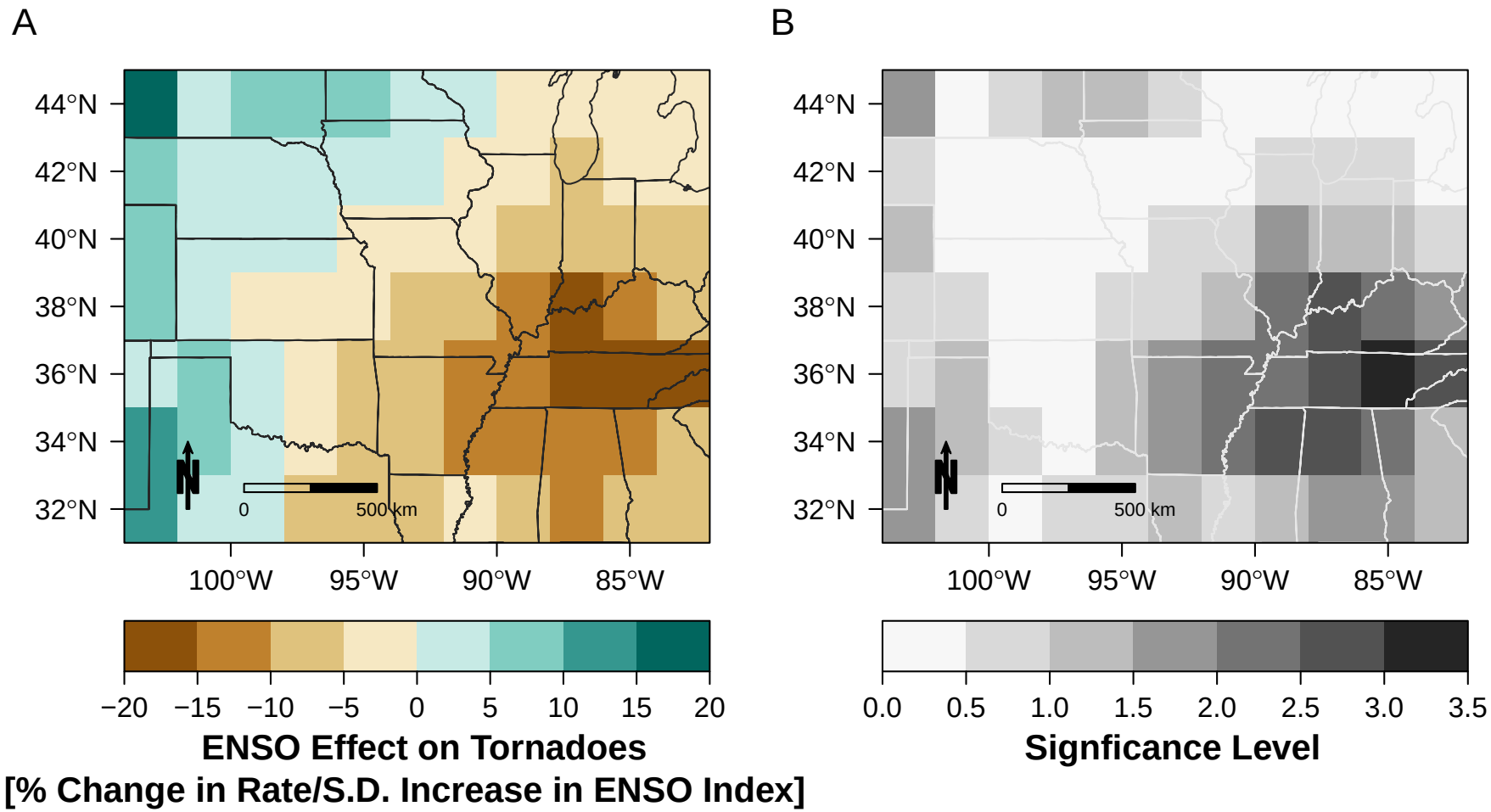
Oklahoma

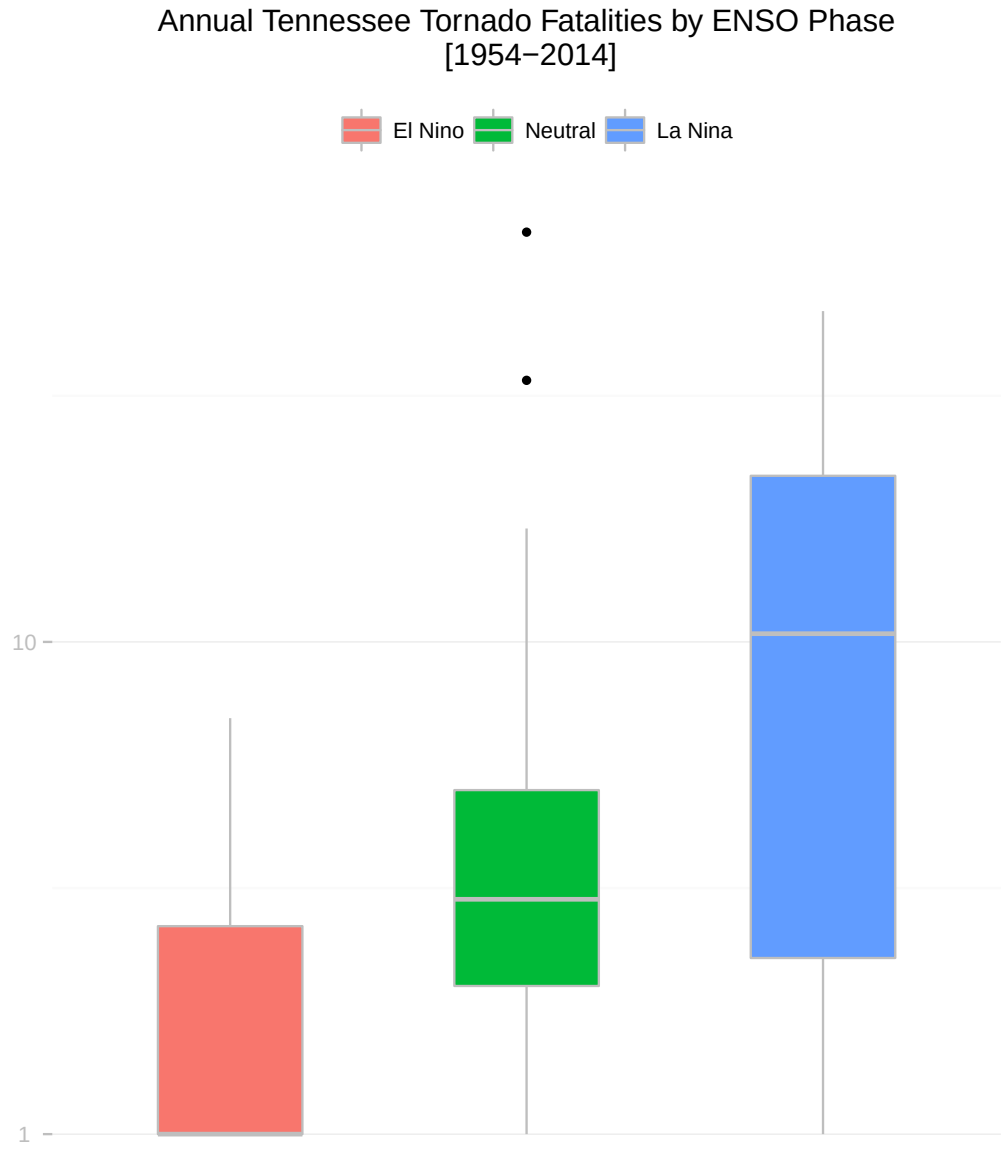

N
0
100 km
10
20
30
40
50
60
70
80
Number of EF0+ Tornadoes (1970−2014)


N
0
100 km
0.7
0.8
0.9
1
1.1
1.2
Expected Annual Tornado (EF0+) Rate

A space-time model


1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
44°N
42°N
40°N
38°N
36°N
34°N
32°N
0
500 km
100°W
90°W
85°W
1
2
4
8
16
32
64
128
Number of Tornadoes


A
B
44°N
42°N
40°N
38°N
36°N
34°N
32°N
100°W
95°W
90°W
85°W
N
0
500 km
−20 −15 −10 −5 0 5 10 15 20
ENSO Effect on Tornadoes
[% Change in Rate/S.D. Increase in ENSO Index]
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5
Signficance Level


Annual Tennessee Tornado Fatalities by ENSO Phase
[1954−2014]
El Nino
Neutral
La Nina
10
1

Other predictors

- PNA
- Global wind oscillation
- NAO

Government efforts toward seasonal prediction of severe weather in the United States

Last March scientists held a workshop in D.C. to assess the feasibility of developing severe weather outlooks on sub-seasonal & seasonal timescales. Two notable recommendations were made:

1. Experimental seasonal weather outlook will be issued sometime this spring, and
2. Research activities for improving outlooks should be supported.