How To Build a Seasonal Tornado Model

James B. Elsner (@JBElsner)

Department of Geography, Florida State University
Tallahassee, FL

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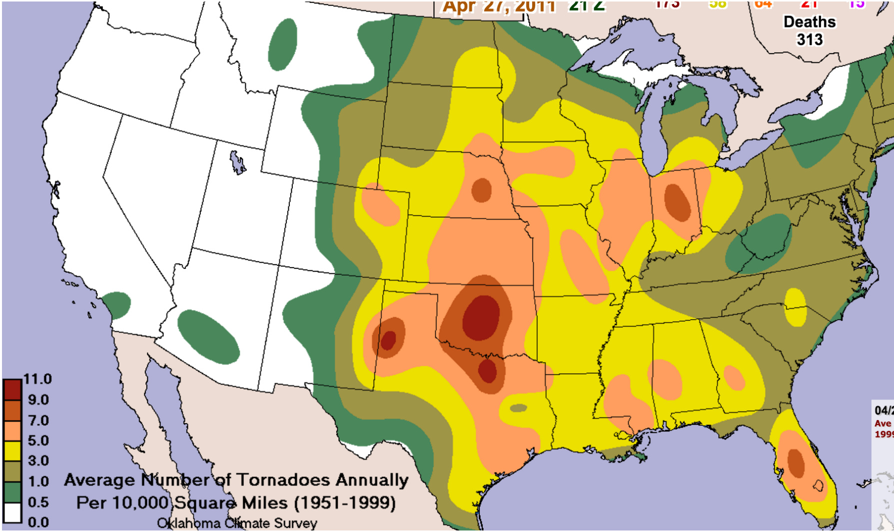
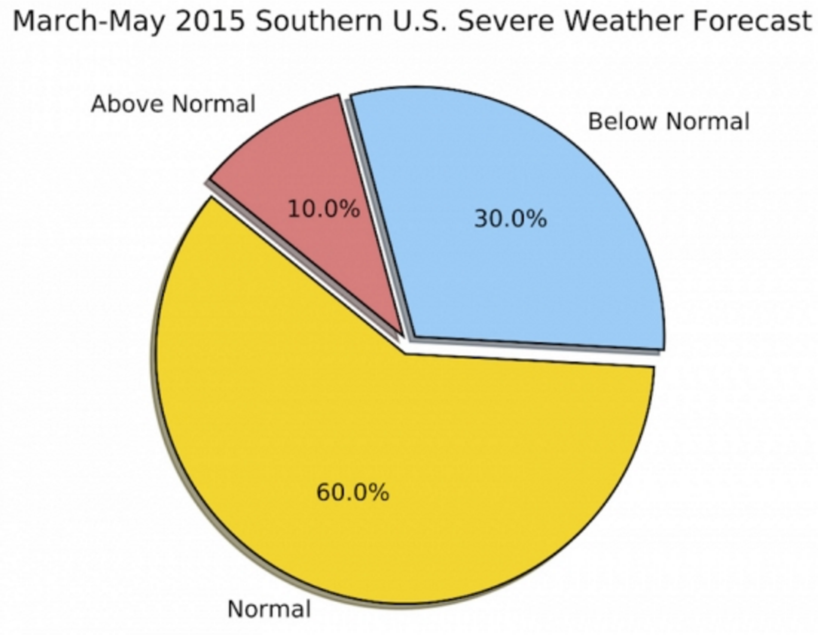
Help: Thomas Jagger, Tyler Fricker, Holly M. Widen
Money: RPI2.0 (Mark Guishard, John Wardman)



Apr 27, 2011 21 Z
Deaths
313
11.0
9.0
7.0
5.0
3.0
1.0
0.5
0.0
Average Number of Tornadoes Annually
Per 10,000 Square Miles (1951-1999)
Oklahoma Climate Survey



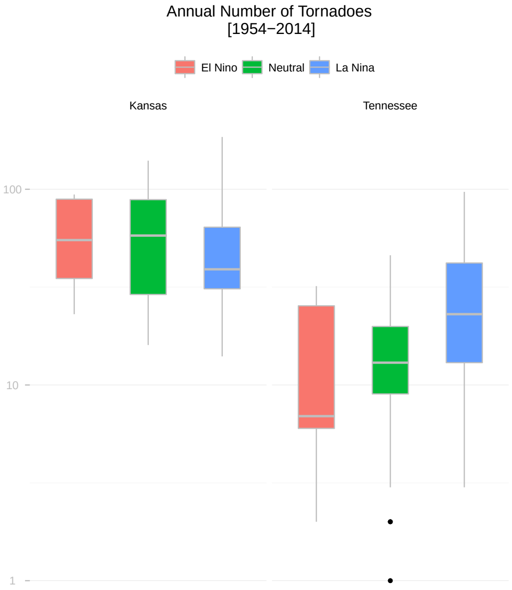
The experimental outlook for the 2015 spring tornado season released by Columbia University researchers.
Credit: John Allen

Why are we doing this?

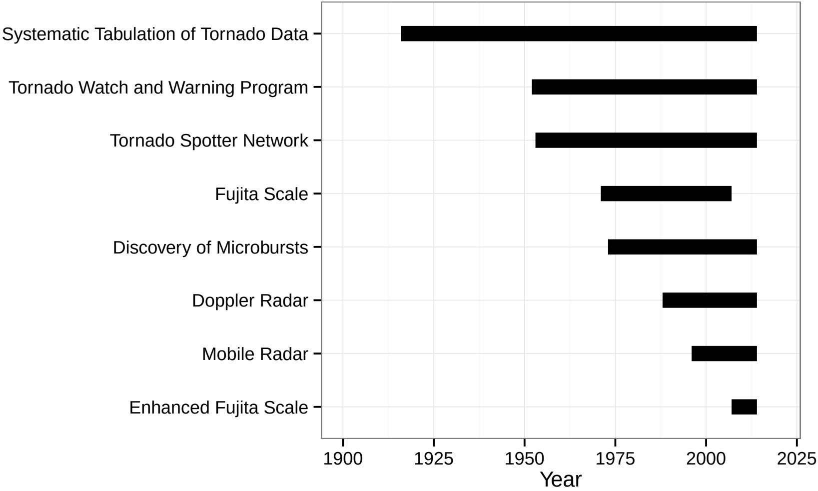
- Dynamical models can't predict tornadoes
- They can predict conditions necessary
- But necessary does not imply sufficient
- Statistical models are needed, but how should they be made?
- Here I show you a way that is quite flexible

Spatial model (county level) $\Rightarrow$ Space-time model (grid level)

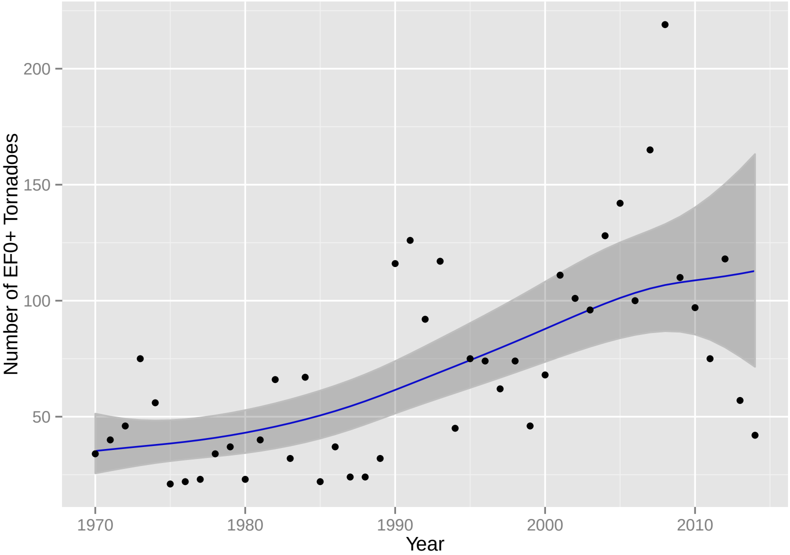
Model must be spatial

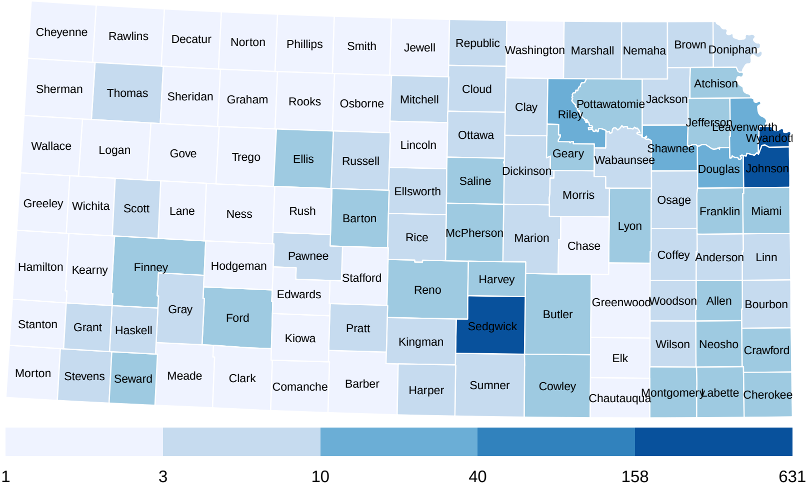


Model must deal with pathological tornado records

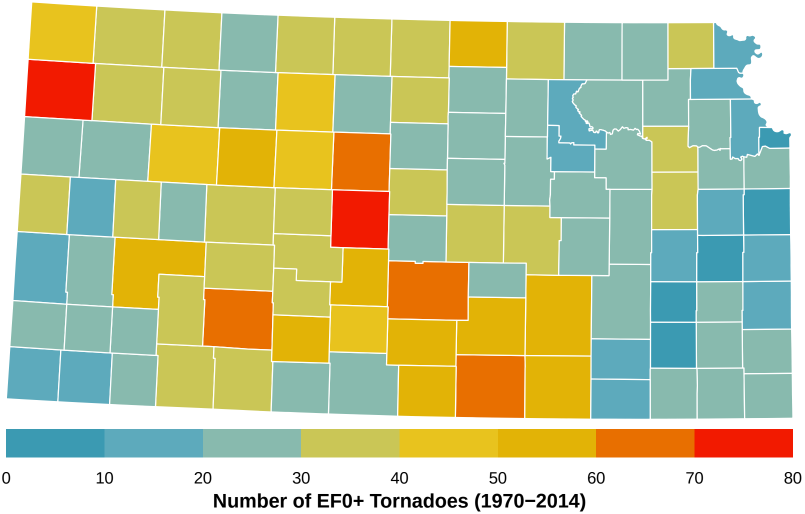


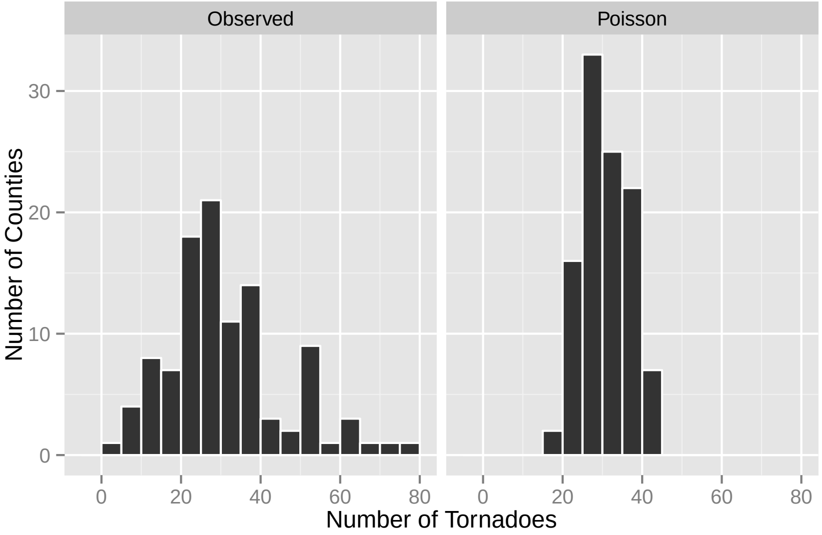
Annual number of tornado reports (Kansas)





2012 Population Density [persons per square km]


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


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

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

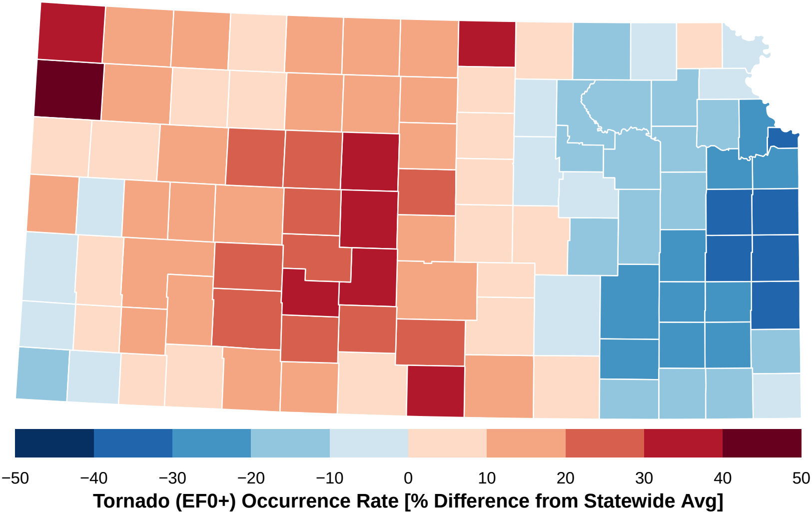
$$
\begin{aligned}
T_s|\mu_s, r_s &\sim \text{NegBin}(\mu_s, r_s) \\
\mu_s &= \exp(A_s \nu_s) \\
\nu_s &= \beta_0 + \beta_1 \,\text{lpd}_s + \beta_2 \,(t - t_0) + \beta_3 \,\text{lpd}_s (t - t_0) + u_s \\
r_s &= A_s \, n
\end{aligned}
$$

where the mean of the distribution is linked to a structured additive response ν_s and the county area (A_s). The base-two log of county population density is lpd_s, t is the year, t_0 is the base year set to 1991 (middle year of the record), n is the dispersion parameter, and u_s is the random effects term.

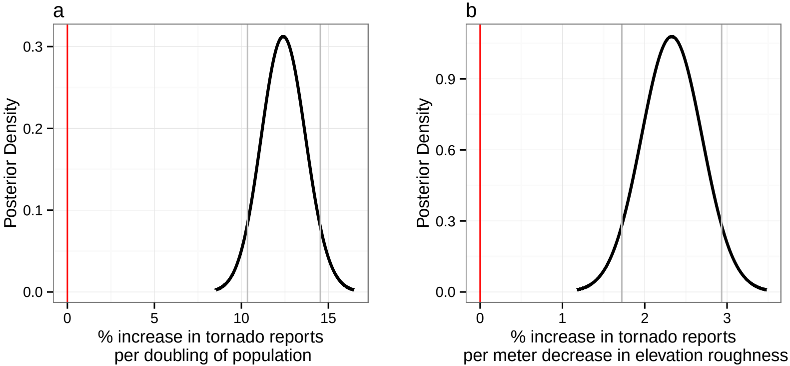
To account for spatial correlation the random effects term follows an intrinsic Besag formulation with a sum-to-zero constraint.

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

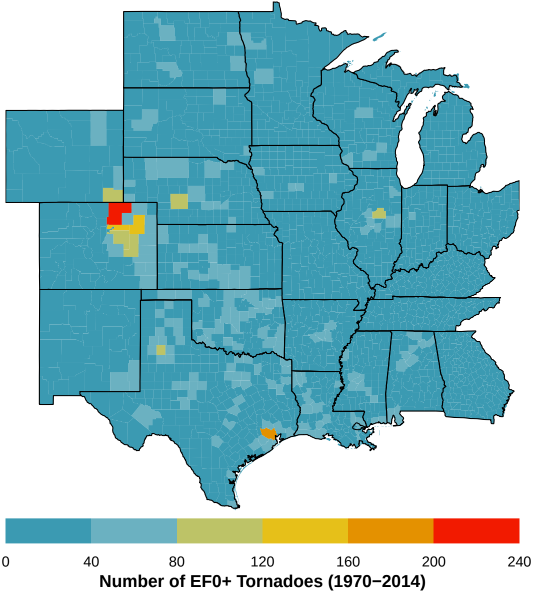
where N is the normal distribution with mean $1/m_i \cdot \sum_{i \sim j} u_j$ and variance $1/m_i \cdot 1/\tau$ where m_i is the number of neighbors of cell i and τ is the precision; $i \sim j$ indicates cells i and j are neighbors. Neighboring cells are determined by contiguity (queen's rule).


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

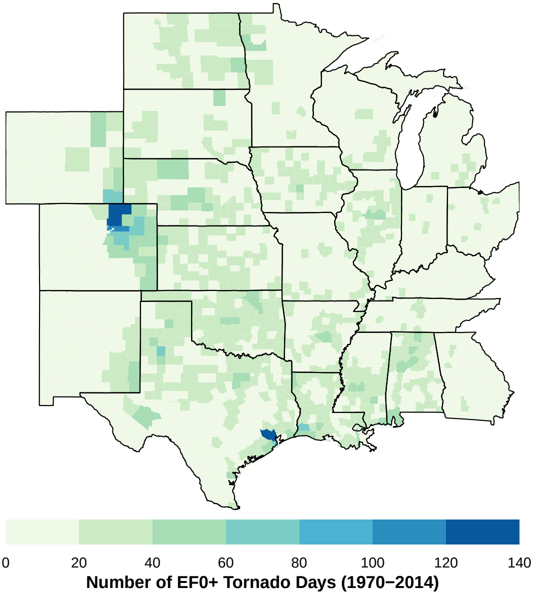
The model was used to show that tornadoes are significantly more likely to occur over smooth terrain at a rate of 23%/10 m decrease in roughness.[1]

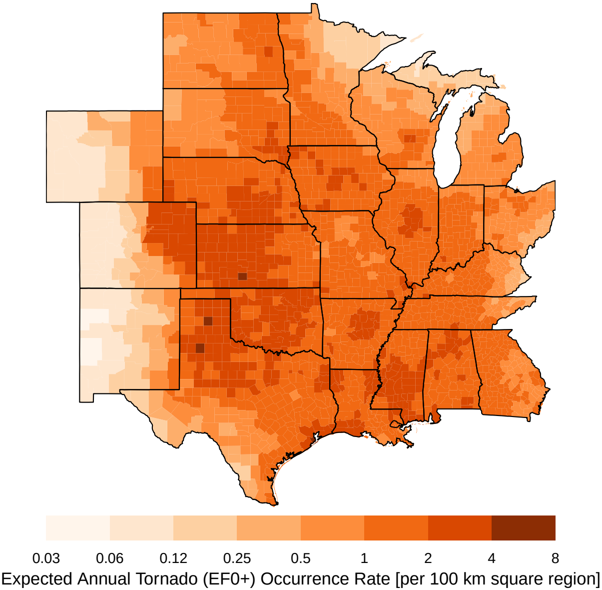


[1] Elsner, J. B., T. Fricker, H. M. Widen, et al., The relationship between elevation roughness and tornado activity: A spatial statistical model fit to data from the central Great Plains, *Journal of Applied Meteorology and Climatology*, in the press.

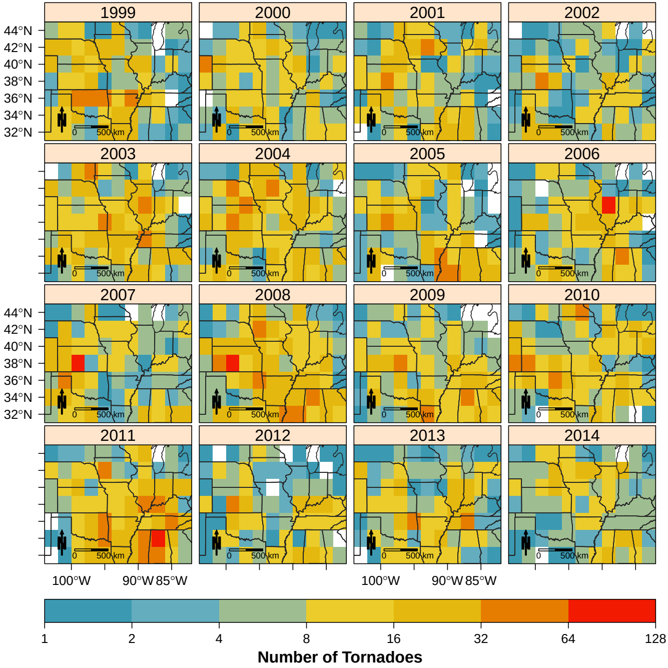


0
40
80
120
160
200
240
Number of EF0+ Tornadoes (1970−2014)

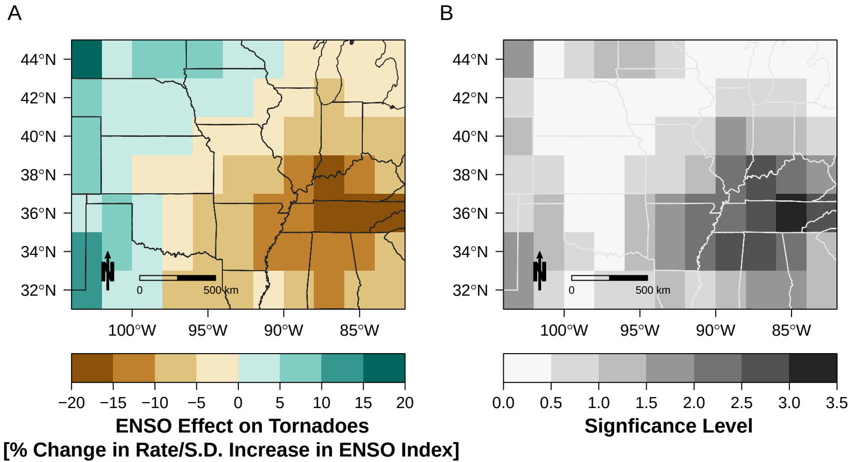

0
20
40
60
80
100
120
140
Number of EF0+ Tornado Days (1970−2014)

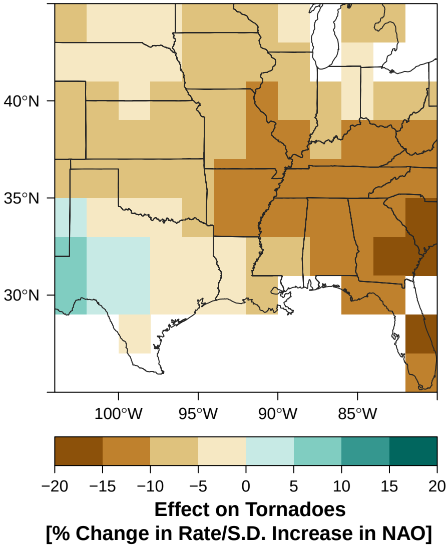

0.03
0.06
0.12
0.25
0.5
1
2
4
8
Expected Annual Tornado (EF0+) Occurrence Rate [per 100 km square region]

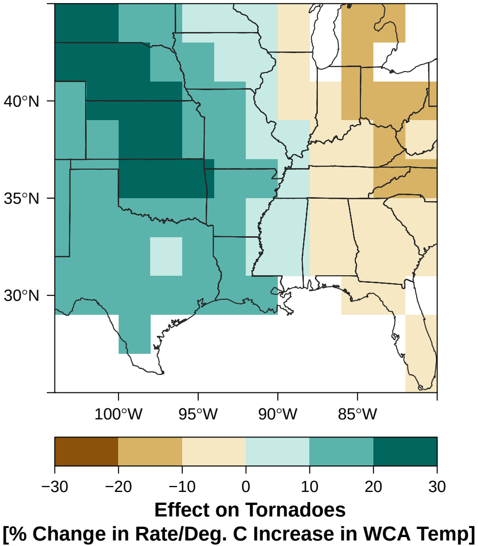
A space-time model



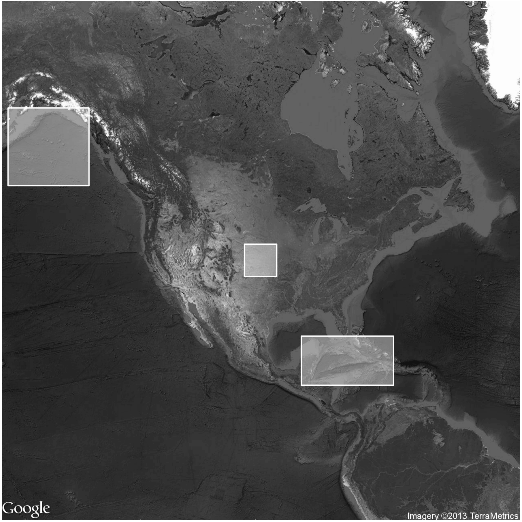
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
44°N
42°N
40°N
38°N
36°N
34°N
32°N
0 500 km
100°W
90°W 85°W
1
2
4
8
16
32
64
128
Number of Tornadoes


A
B
44°N
42°N
40°N
38°N
36°N
34°N
32°N
100°W
95°W
90°W
85°W
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

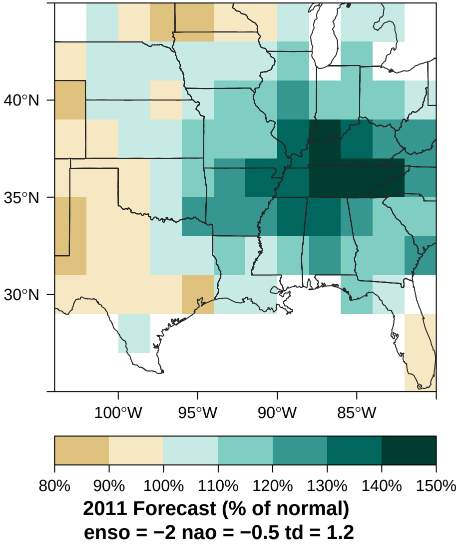

40°N
35°N
30°N
100°W
95°W
90°W
85°W
−20
−15
−10
−5
0
5
10
15
20
Effect on Tornadoes
[% Change in Rate/S.D. Increase in NAO]

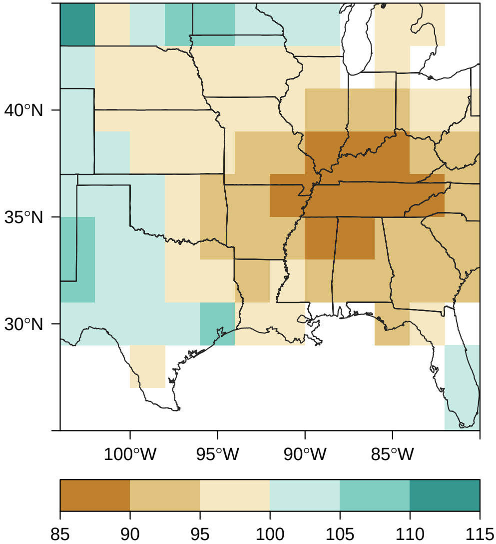

40°N
35°N
30°N
100°W
95°W
90°W
85°W
−30
−20
−10
0
10
20
30
Effect on Tornadoes
[% Change in Rate/Deg. C Increase in WCA Temp]

Elsner, J. B., and H. M. Widen, 2014: Predicting spring tornado activity in the central Great Plains by March 1st. *Monthly Weather Review*, **142**, 259–267.

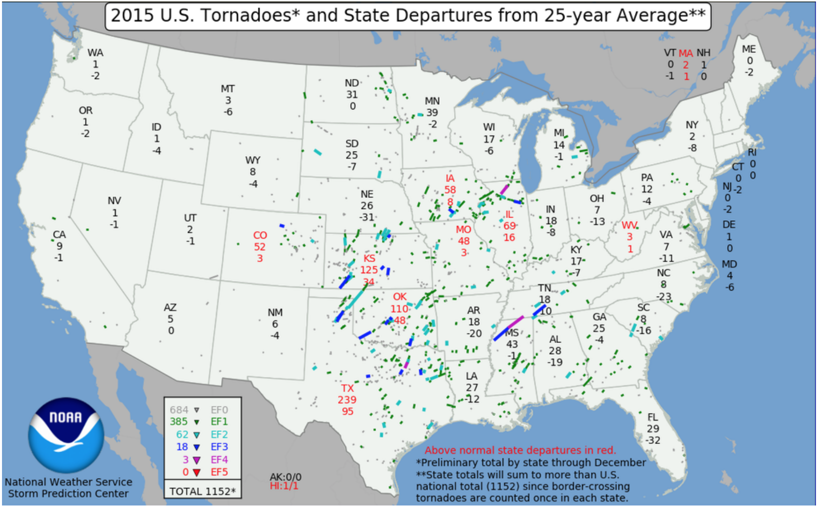


According to Aon, the costliest U.S. thunderstorm outbreak on record occurred in late April 2011 across the Lower Mississippi Valley and cost insurers $7.7 bn in today's dollars.

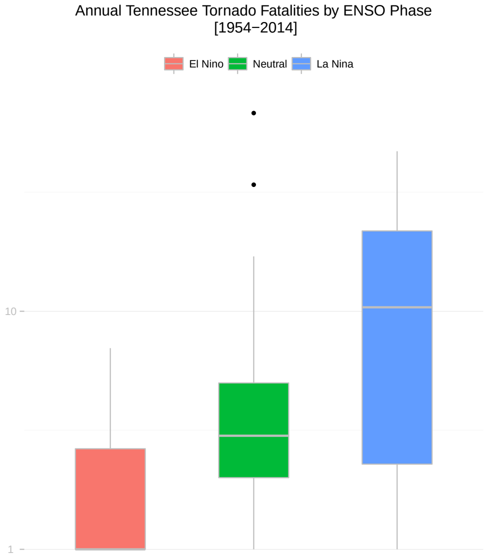




2015 Hindcast (% of normal)
enso = 0.8 nao = 0.25 td = −0.56



2015 U.S. Tornadoes* and State Departures from 25-year Average**
WA 1 -2
OR 1 -2
CA 9 -1
ID 1 -4
NV 1 -1
MT 3 -6
WY 8 -4
UT 2 -1
AZ 5 0
CO 52 3
NM 6 -4
ND 31 0
SD 25 -7
NE 26 -31
KS 125 34
OK 110 48
TX 239 95
MN 39 -2
IA 58 8
MO 48 3
AR 18 -20
LA 27 -12
WI 17 -6
IL 69 16
MI 14 -1
IN 18 -8
OH 7 -13
KY 17 -7
TN 18 10
MS 43 -1
AL 28 -19
GA 25 -4
FL 29 -32
SC 8 -16
NC 8 -23
VA 7 -11
WV 3 1
PA 12 -4
NY 2 -8
VT 0 -1
MA 2 1
NH 1 0
ME 0 -2
RI 0 0
CT 0 0
NJ 0 -2
DE 1 0
MD 4 -6
684 EF0
385 EF1
62 EF2
18 EF3
3 EF4
0 EF5
TOTAL 1152*
AK:0/0
HI:1/1
NOAA
National Weather Service
Storm Prediction Center
Above normal state departures in red.
*Preliminary total by state through December
**State totals will sum to more than U.S. national total (1152) since border-crossing tornadoes are counted once in each state.


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

Preliminary forecast for 2016