Severe Thunderstorms, Tornadoes, and Climate Change: What We Do and Don't Know

HAROLD BROOKS

NOAA/NSSL

HAROLD.BROOKS@NOAA.GOV

Big questions

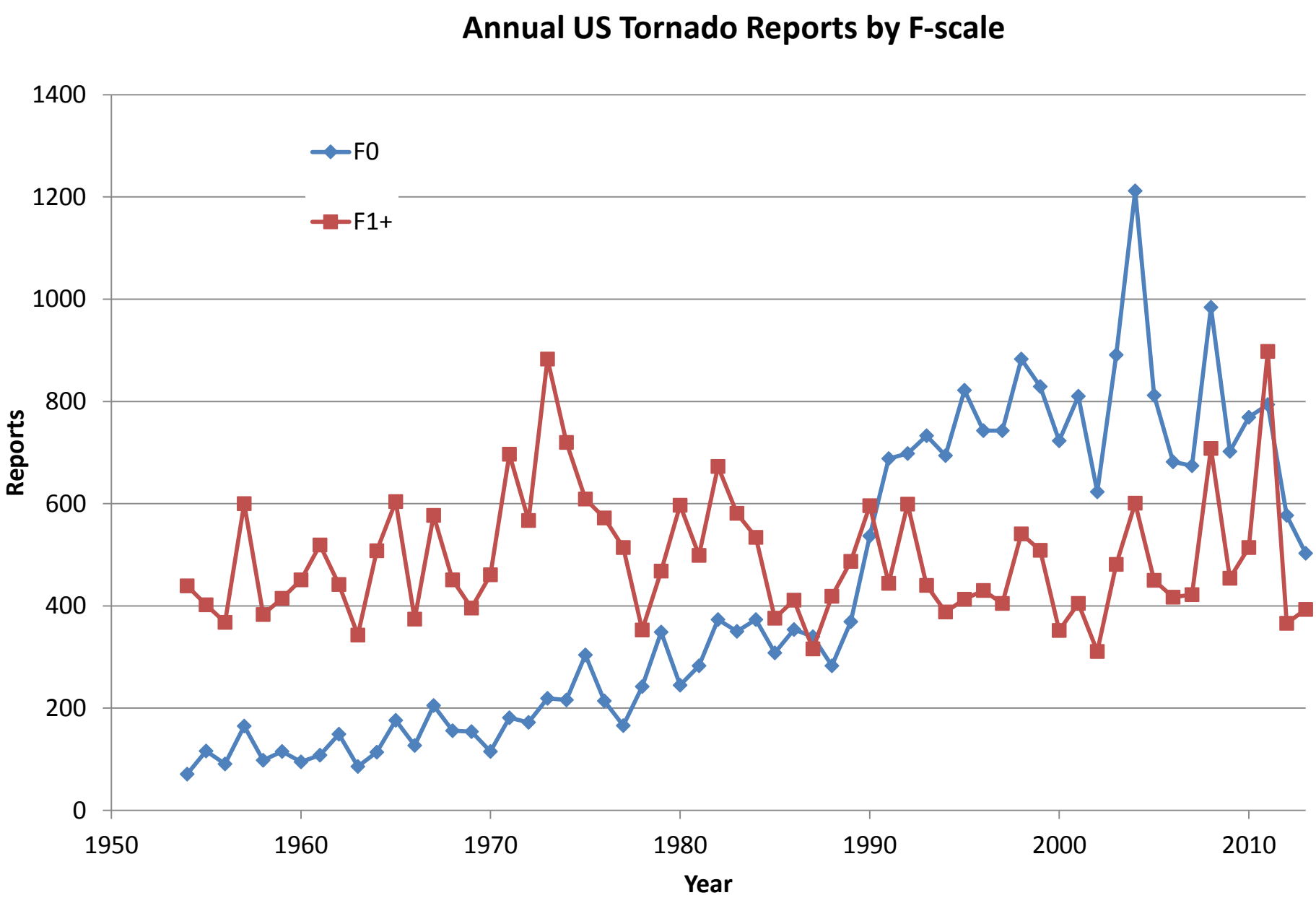
- What do we know about severe thunderstorms?
- Are things changing in time and will they?

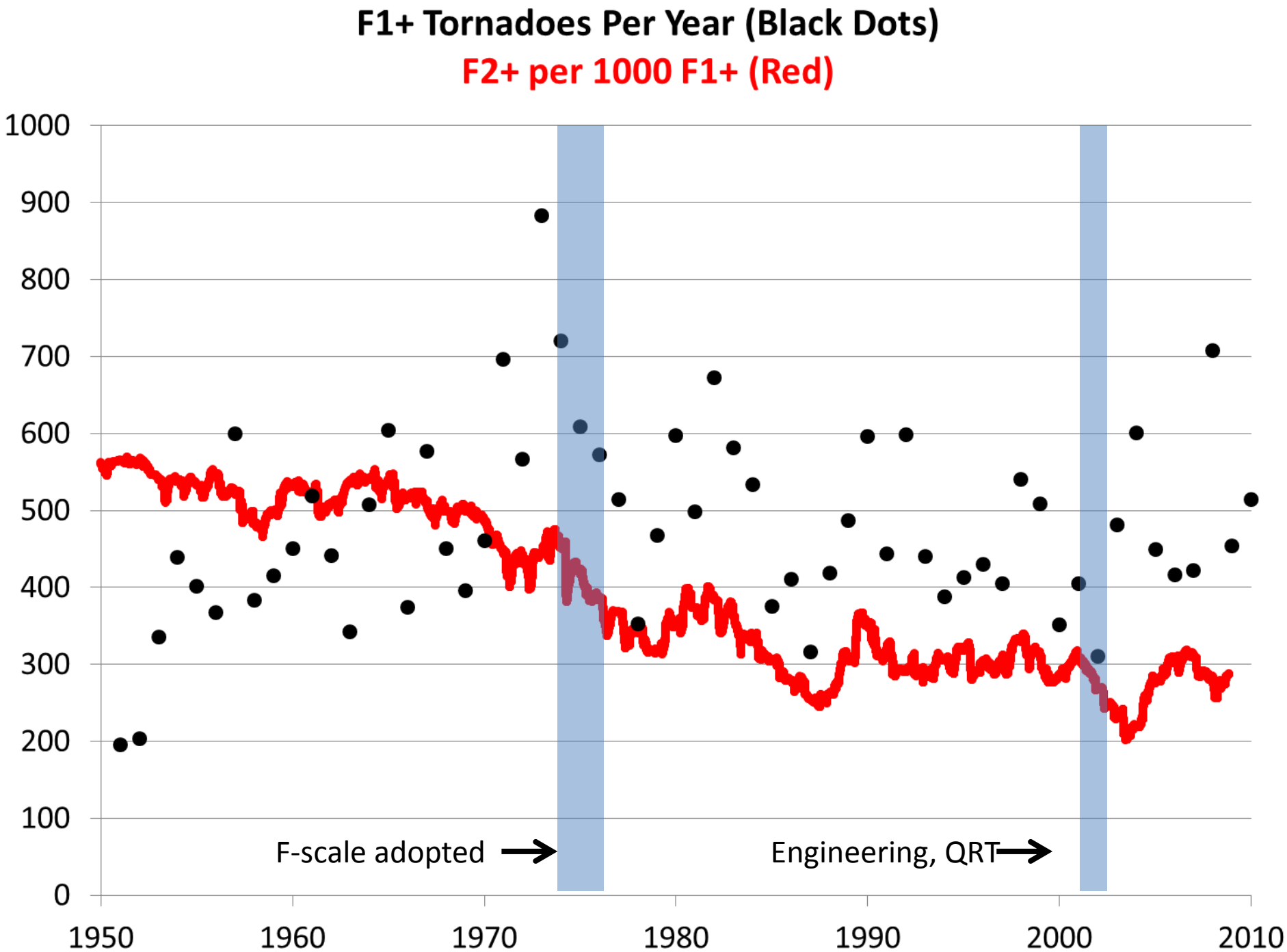
- Look at severe thunderstorms (tornado, winds>=50 kts, hail>=1 inch)

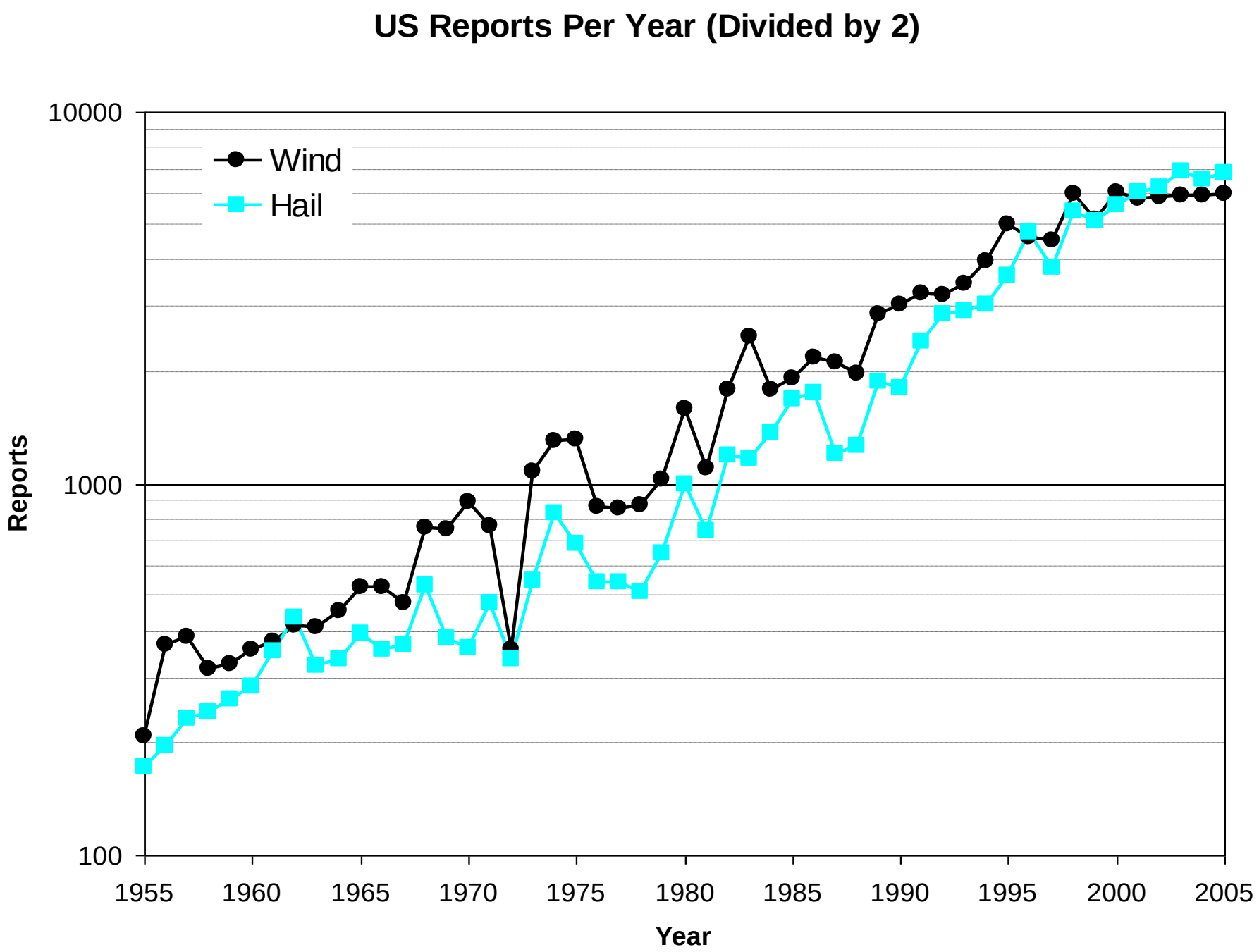
- Good news-lots of new work published in last 2 years

Reports-A logical place to start

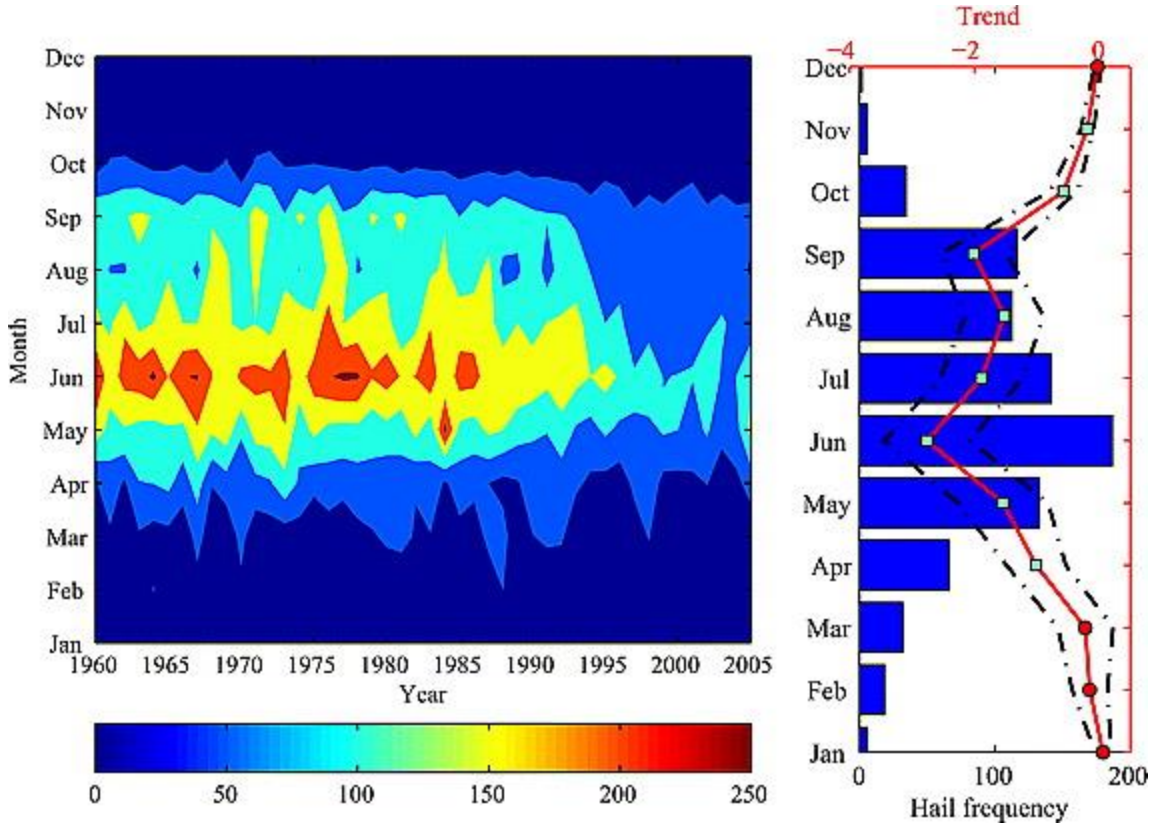
- US reporting database
  - Target of opportunity
  - Changes in *de jure* and *de facto* standards
- Hail in other countries
  - China-yes/no reports available at >500 sites with some size data
  - Italy, France, and Spain-hailpad networks


Annual US Tornado Reports by F-scale
F0
F1+
Reports
Year
0
200
400
600
800
1000
1200
1400
1950
1960
1970
1980
1990
2000
2010


F1+ Tornadoes Per Year (Black Dots)
F2+ per 1000 F1+ (Red)
1000
900
800
700
600
500
400
300
200
100
0
1950
1960
1970
1980
1990
2000
2010
F-scale adopted
Engineering, QRT

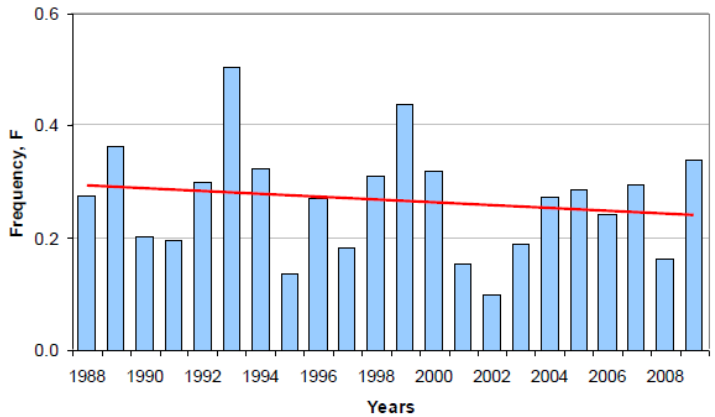

US Reports Per Year (Divided by 2)
Wind
Hail
10000
1000
100
Reports
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
Year

China-Hail Frequency

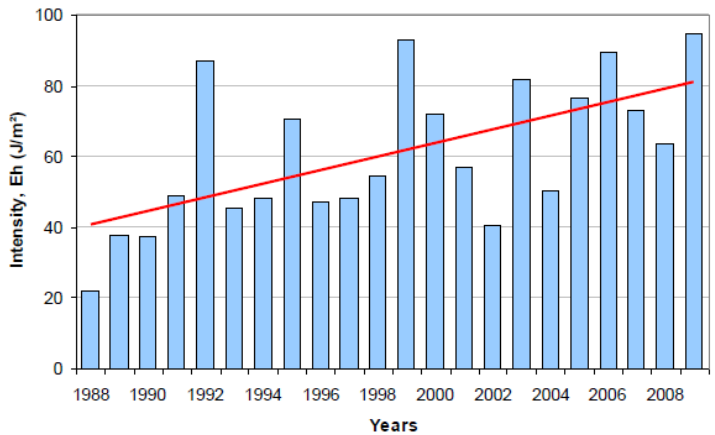


Xie et al. 2008 (*GRL*)

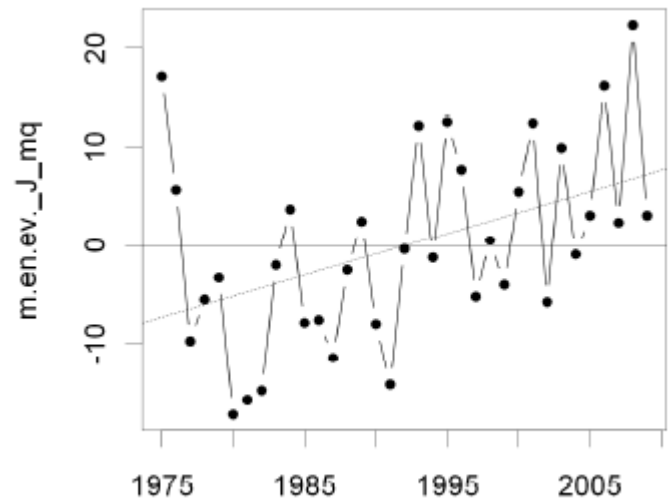
France/Italy Hailpad Data



Occurrence



Kinetic Energy



Berthet et al. (ECSS 2009)

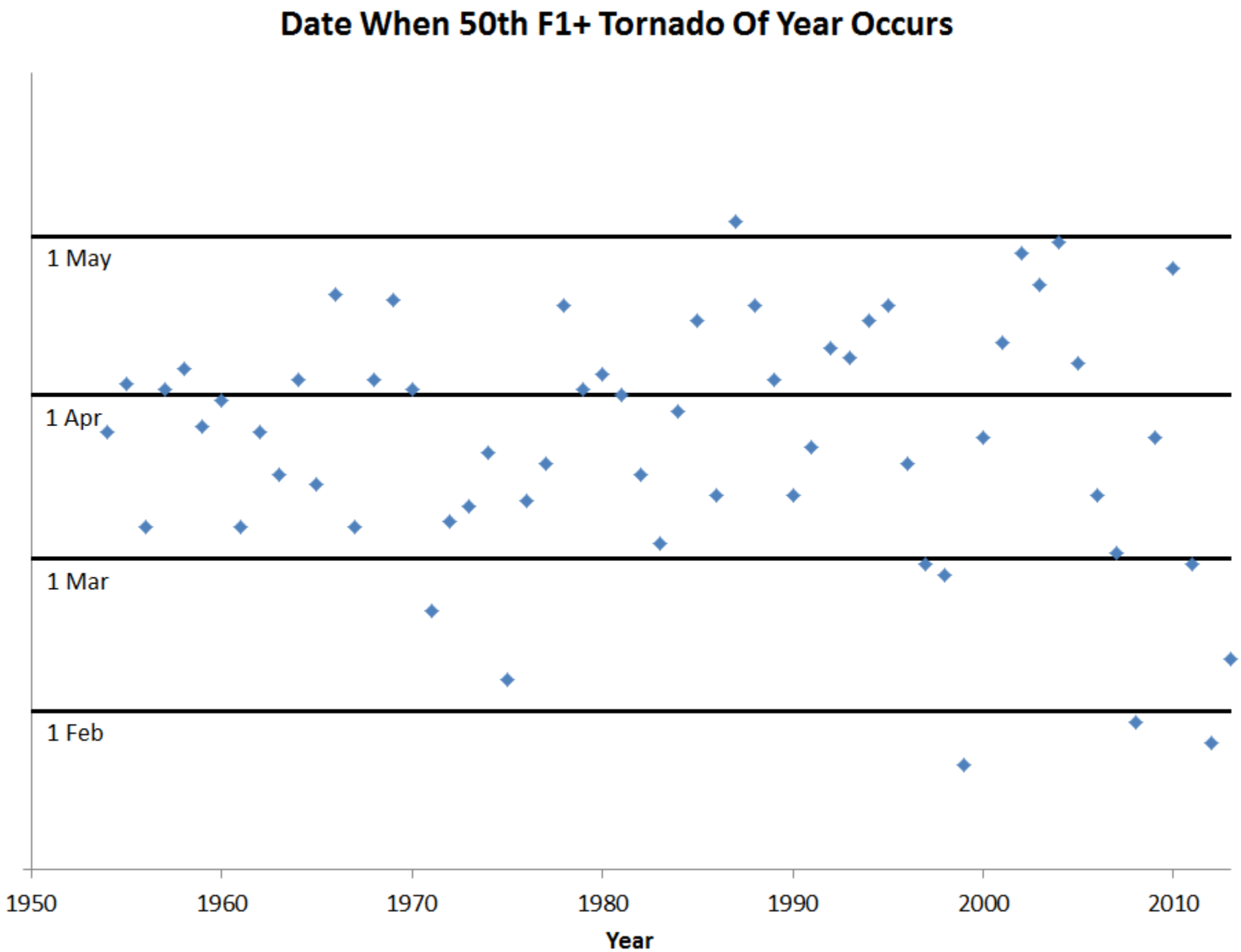
Eccel et al. (2011)

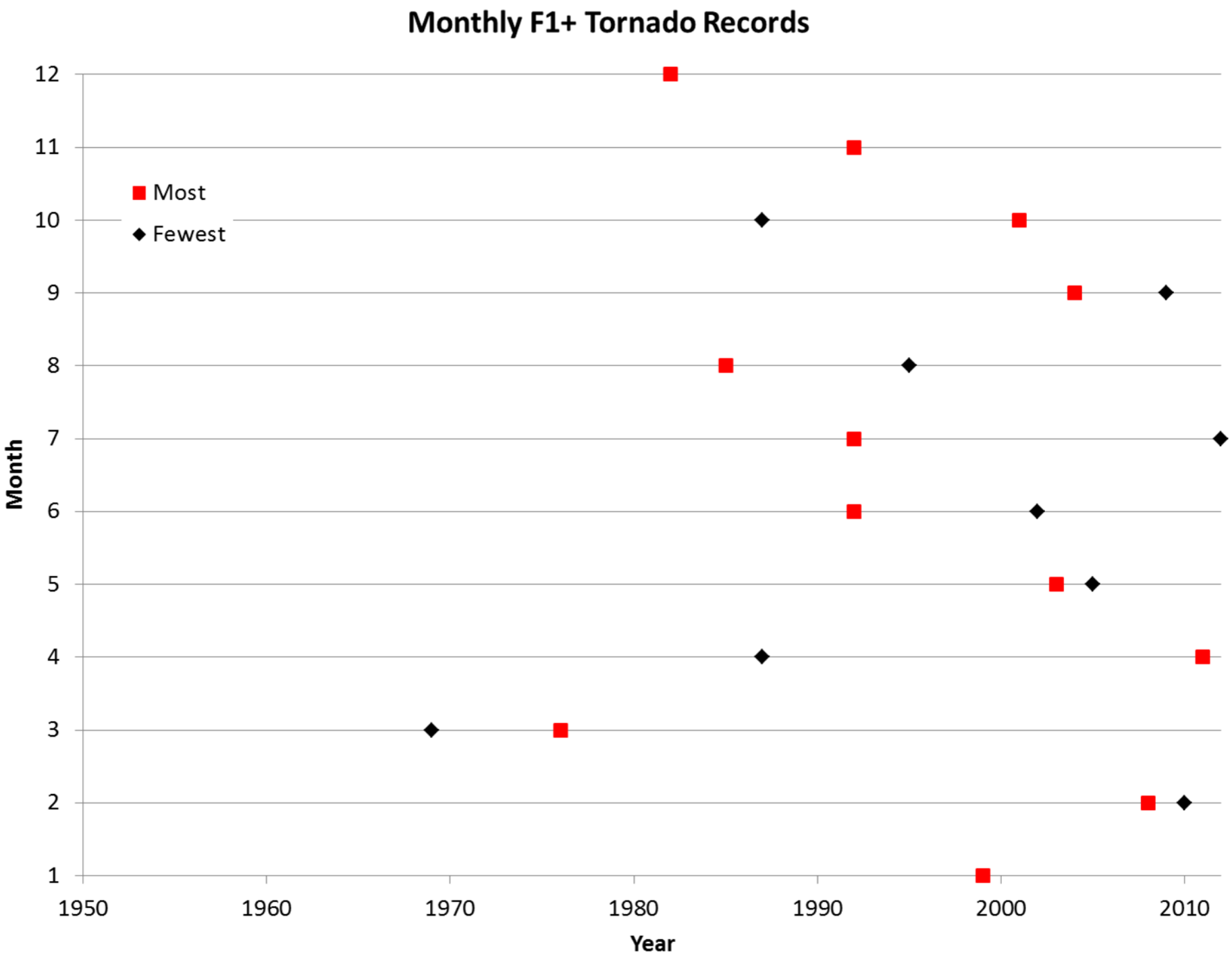
Reports Summary

- Lots of reporting changes make it hard to know
- Big interannual variability
- Small decrease in mean hail size, but increase in kinetic energy of hailfalls
  - Start with slightly larger hail at beginning of fall
  - Melt more because of higher freezing level height, particularly impacting small
  - Leaves distribution shifted to larger stones
- Does it extend to larger sizes?

What might have changed with tornadoes?

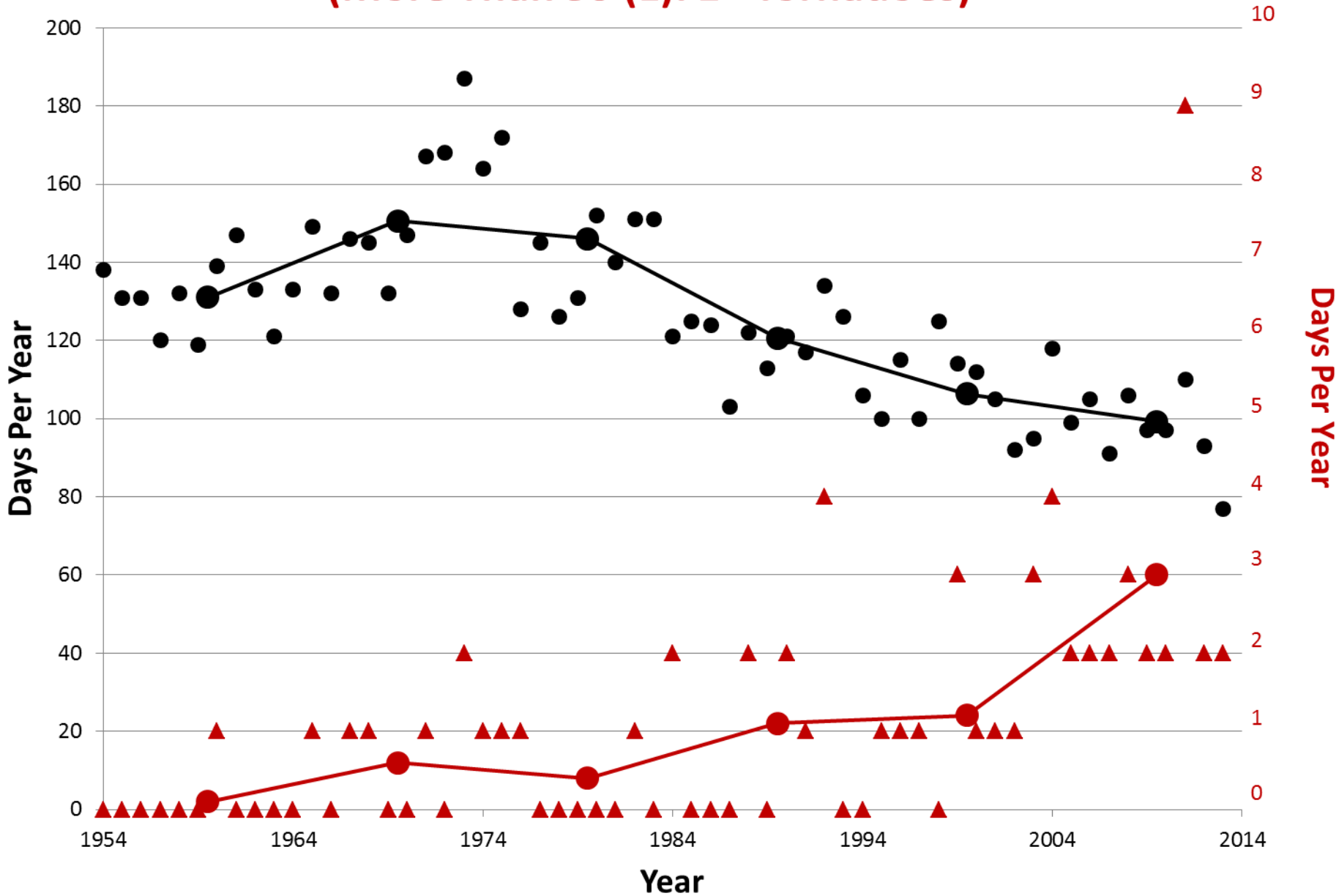
- Impacts of seasonal temperature swings?
- Timing of season
- "As spring moves up a week or two, tornado season will start in February instead of waiting for April”
- When does tornado season start?


Date When 50th F1+ Tornado Of Year Occurs
1 May
1 Apr
1 Mar
1 Feb
1950
1960
1970
1980
1990
2000
2010
Year

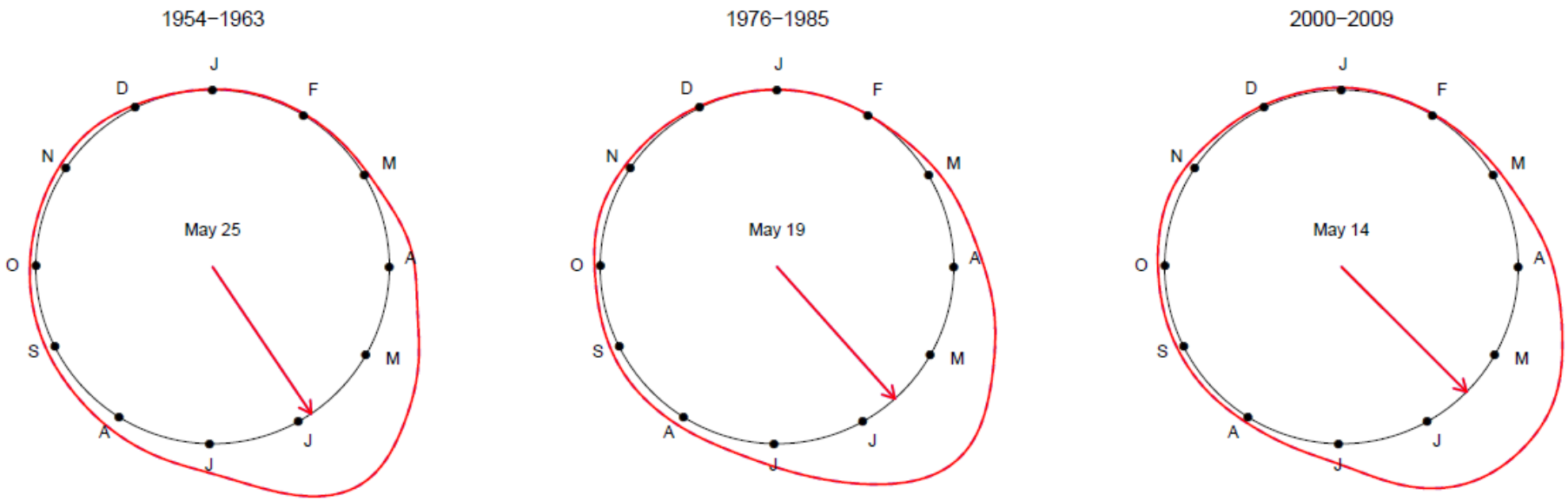

Monthly F1+ Tornado Records
Most
Fewest
Month
Year
12
11
10
9
8
7
6
5
4
3
2
1
1950
1960
1970
1980
1990
2000
2010

Days Per Year With At Least 1 (E)F1+ Tornado in US

(More Than 30 (E)F1+ Tornadoes)



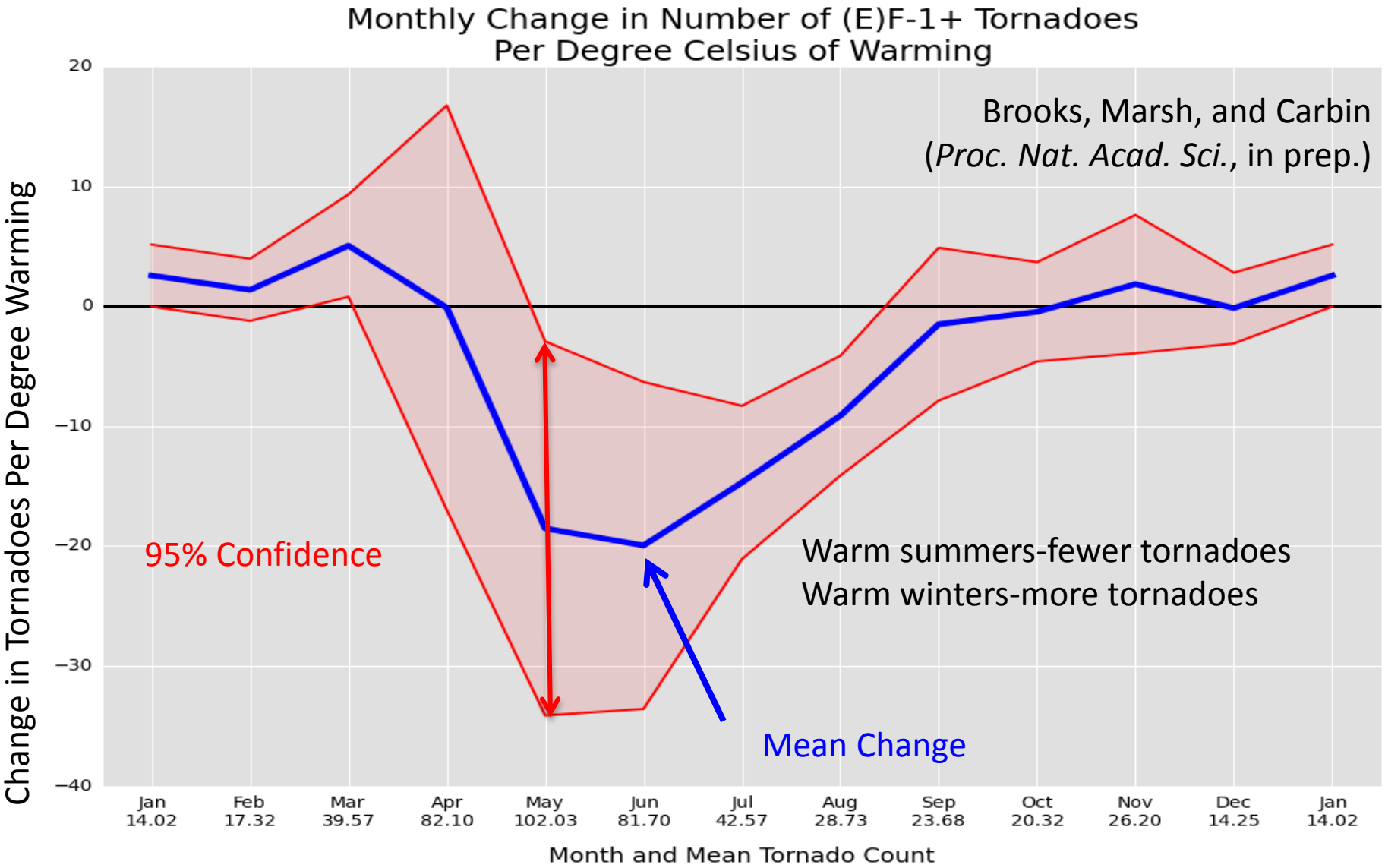
Timing of tornadoes in Plains (TX/OK/KS/NE)

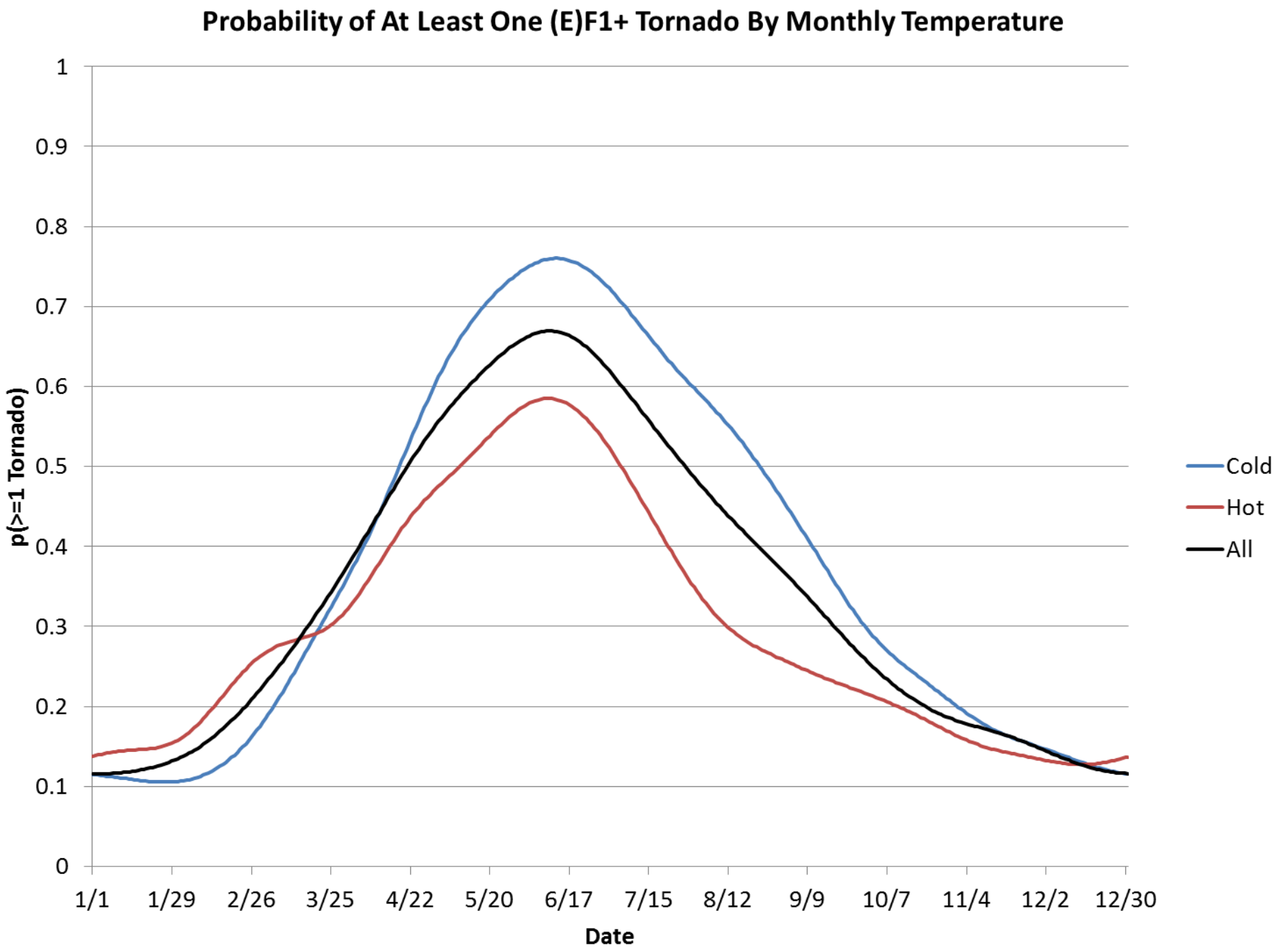


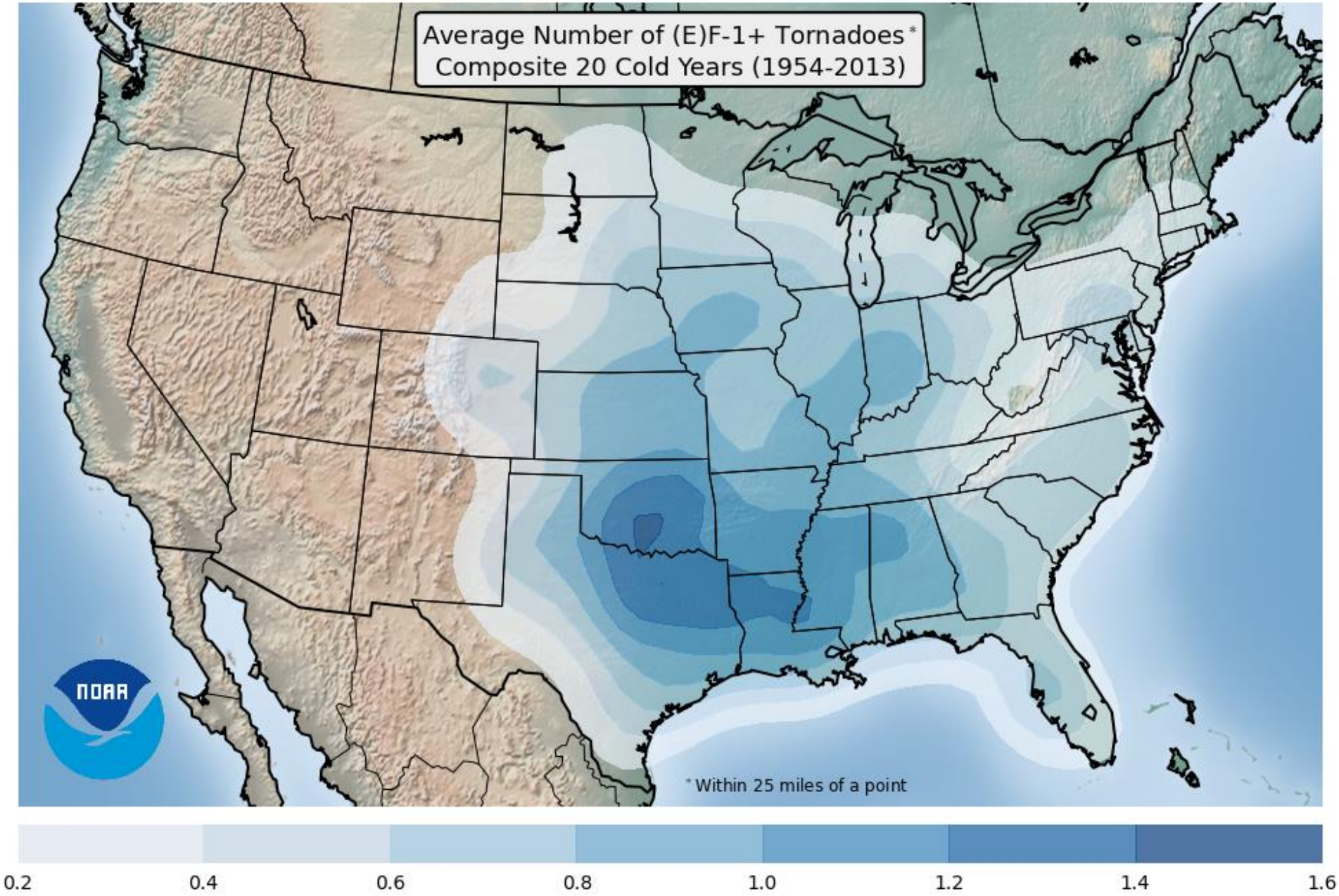
Long and Stoy (2014)

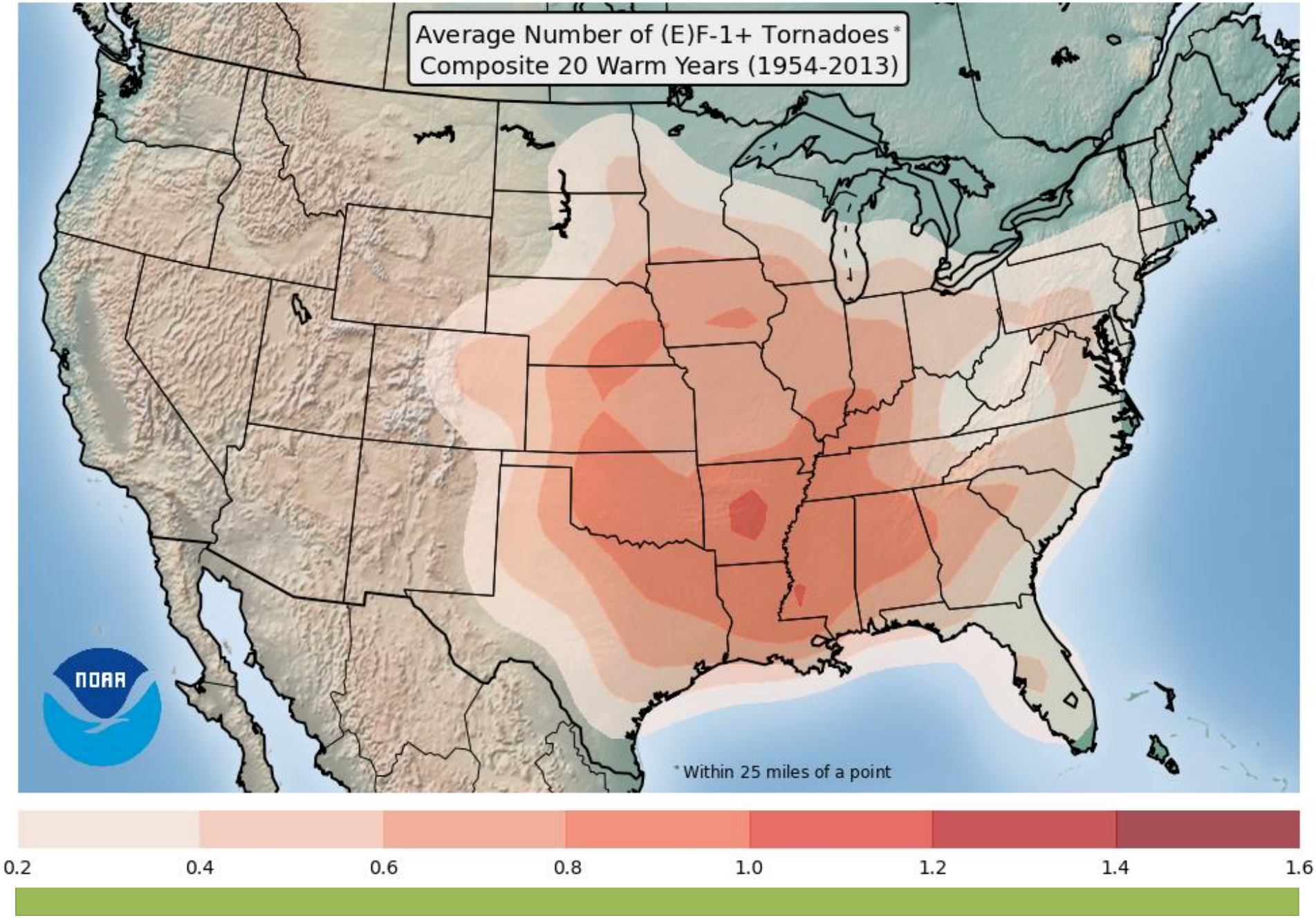
Temperature Impacts on Tornadoes

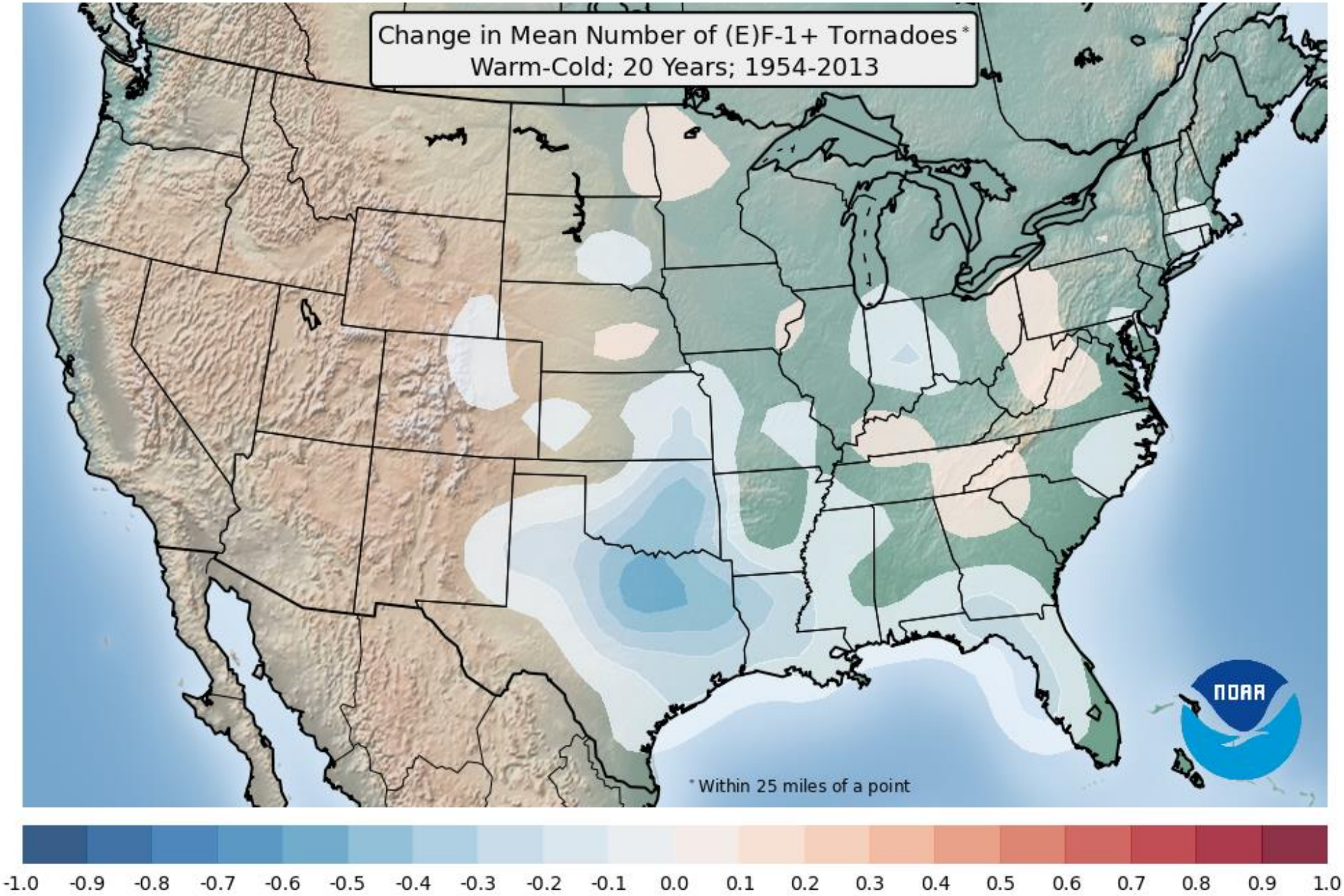
- Use warm and cold historical periods as proxy for change
- Implicit assumption-future patterns look like recent warm
- Look at monthly temps (NCDC US 48 states)
- (E)F1+ counts


Monthly Change in Number of (E)F-1+ Tornadoes
Per Degree Celsius of Warming
Brooks, Marsh, and Carbin
(*Proc. Nat. Acad. Sci.*, in prep.)
95% Confidence
Warm summers-fewer tornadoes
Warm winters-more tornadoes
Mean Change
Change in Tornadoes Per Degree Warming
20
10
0
−10
−20
−30
−40
Jan 14.02
Feb 17.32
Mar 39.57
Apr 82.10
May 102.03
Jun 81.70
Jul 42.57
Aug 28.73
Sep 23.68
Oct 20.32
Nov 26.20
Dec 14.25
Jan 14.02
Month and Mean Tornado Count

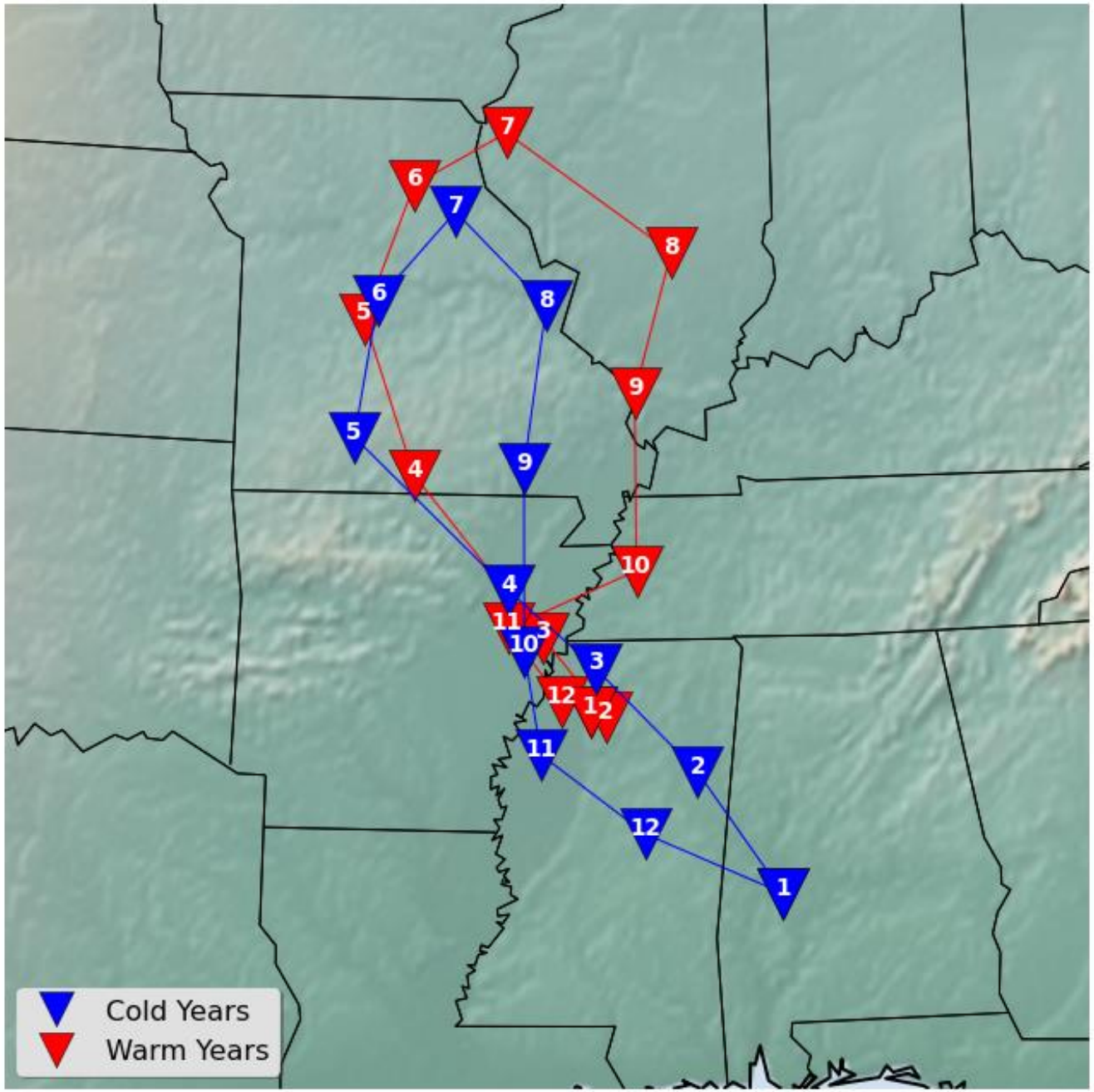

Probability of At Least One (E)F1+ Tornado By Monthly Temperature
p(>=1 Tornado)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1/1
1/29
2/26
3/25
4/22
5/20
6/17
7/15
8/12
9/9
10/7
11/4
12/2
12/30
Date
Cold
Hot
All


Average Number of (E)F-1+ Tornadoes*
Composite 20 Cold Years (1954-2013)
NOAA
*Within 25 miles of a point
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6


Average Number of (E)F-1+ Tornadoes*
Composite 20 Warm Years (1954-2013)
NOAA
*Within 25 miles of a point
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6


Change in Mean Number of (E)F-1+ Tornadoes*
Warm-Cold; 20 Years; 1954-2013
*Within 25 miles of a point
NOAA
-1.0 -0.9 -0.8 -0.7 -0.6 -0.5 -0.4 -0.3 -0.2 -0.1 0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

20 Composite Years
3 Month Smoother

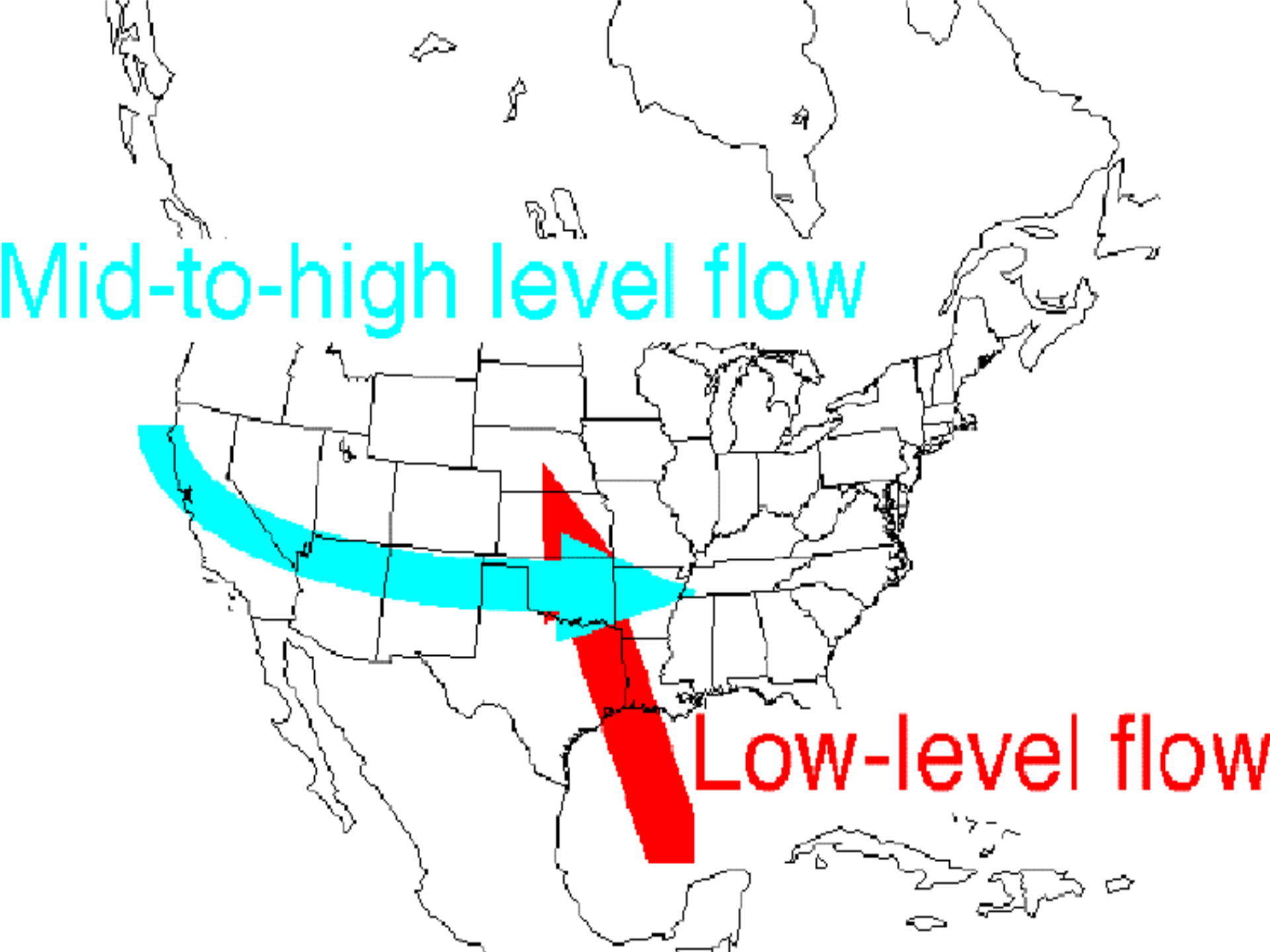


Summary of tornado observations

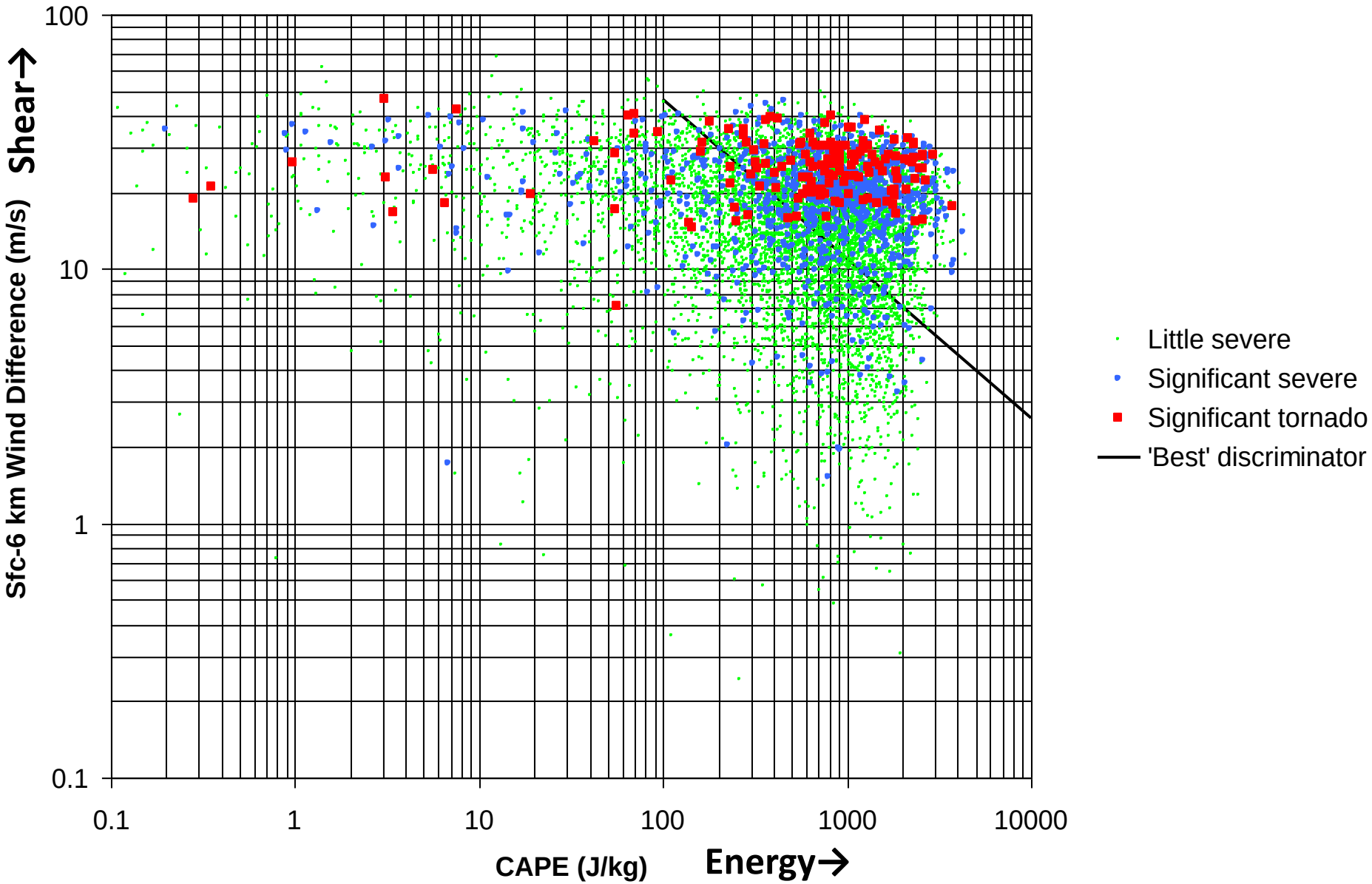
- Increased variability in recent years
- Possible temperature impacts (more in warm winters, fewer in warm summers)
- Change in location??

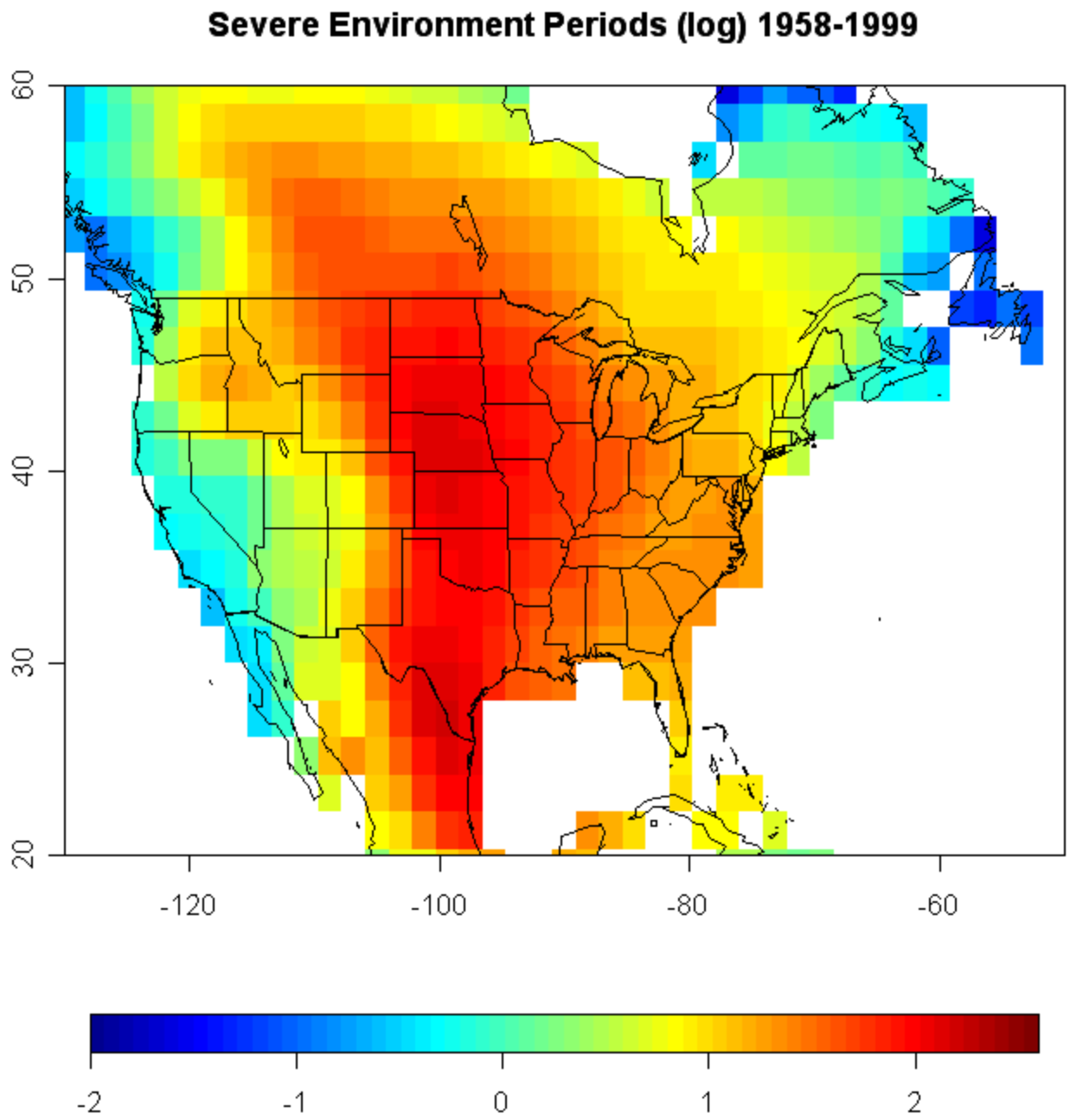
“Ingredients” for severe thunderstorms-the supercell

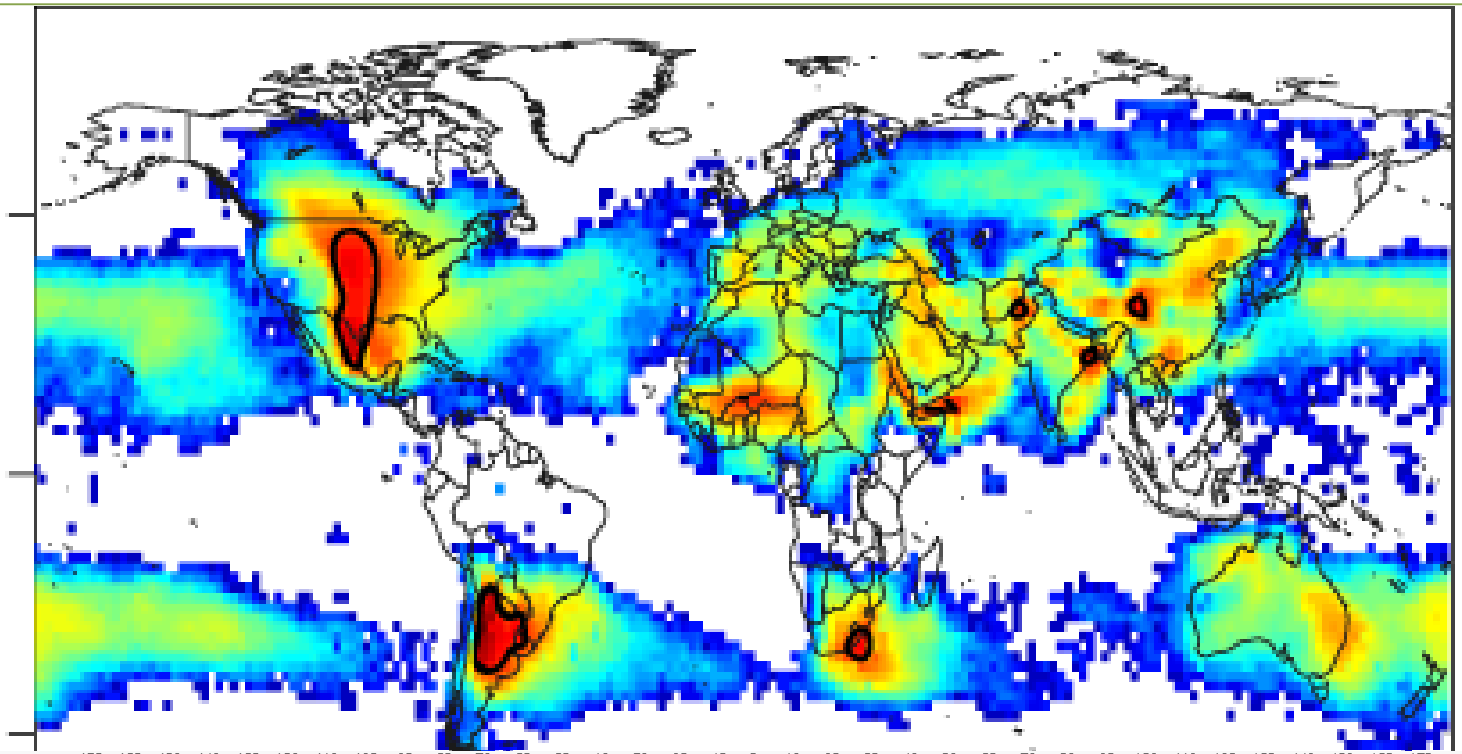
- Thunderstorms
  - Low-level warm, moist air
  - Mid-level (~2-10 km) relatively cold, dry air
  - Something to lift the warm, moist air
  - Combine first two to get energy available for storm (CAPE or Wmax)
- Organization
  - Winds that increase and change direction with height over lowest few km
  - From equator at surface, west aloft

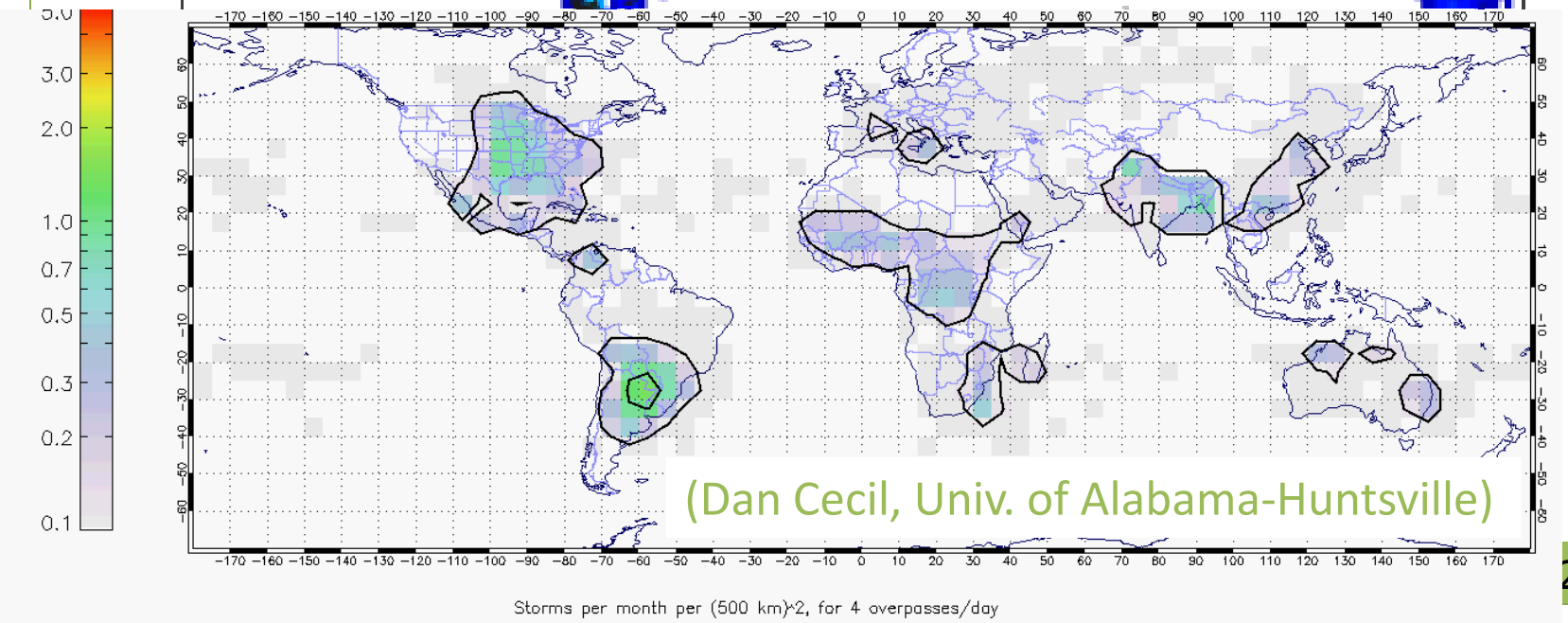

Mid-to-high level flow
Low-level flow

Reanalysis Proximity Soundings (1997-9)



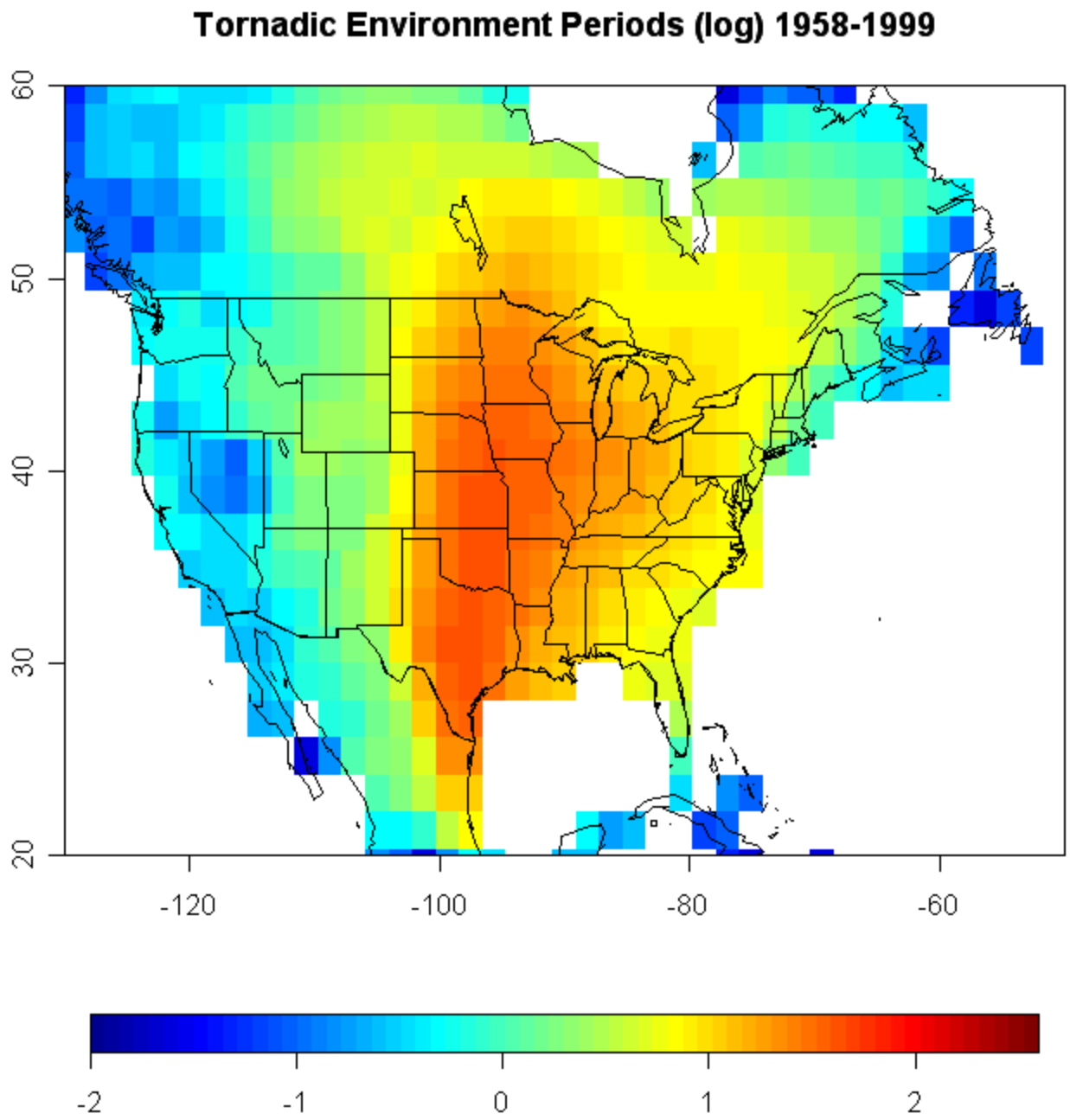

Severe Environment Periods (log) 1958-1999
60
50
40
30
20
-120
-100
-80
-60
-2
-1
0
1
2



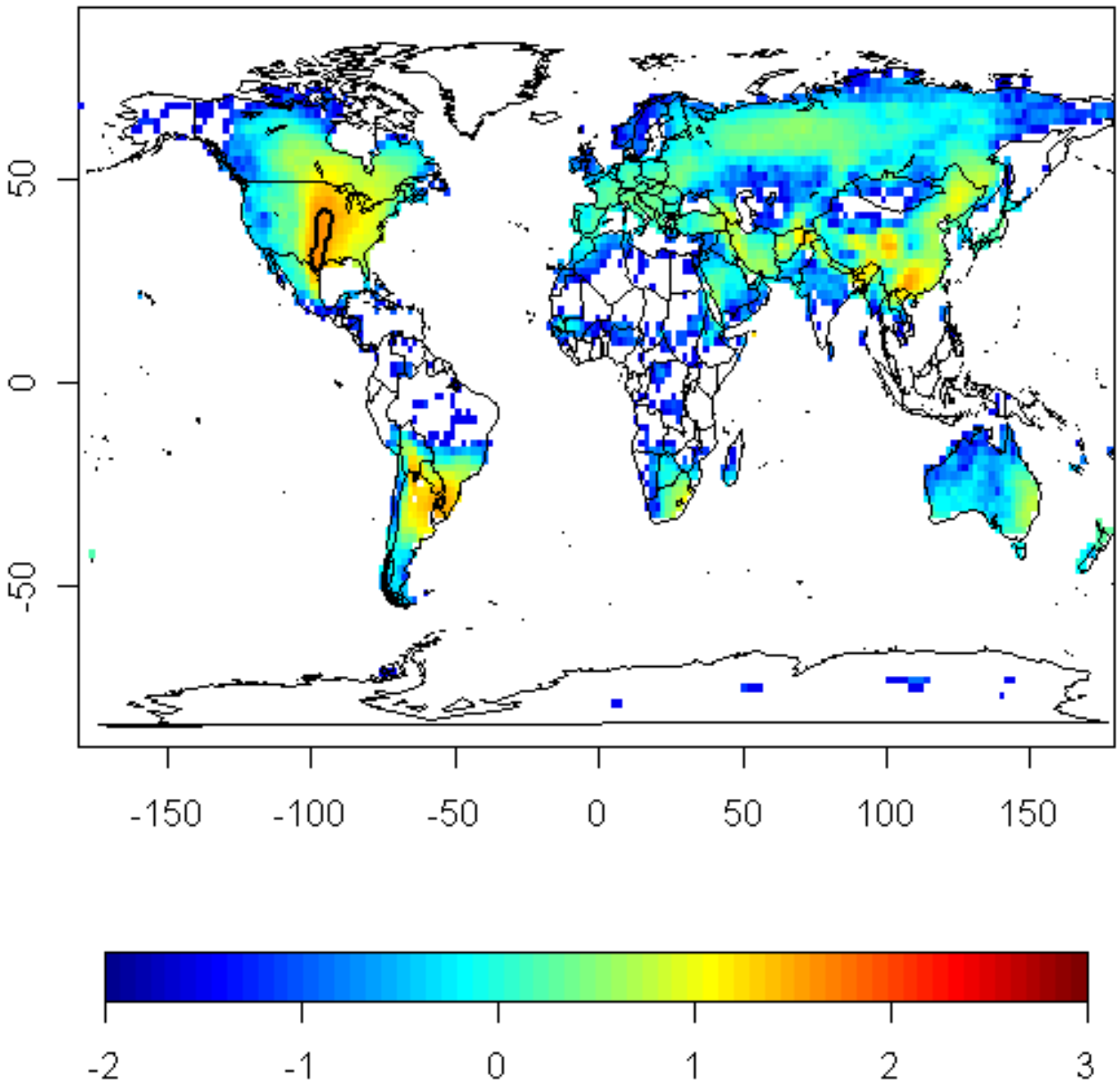


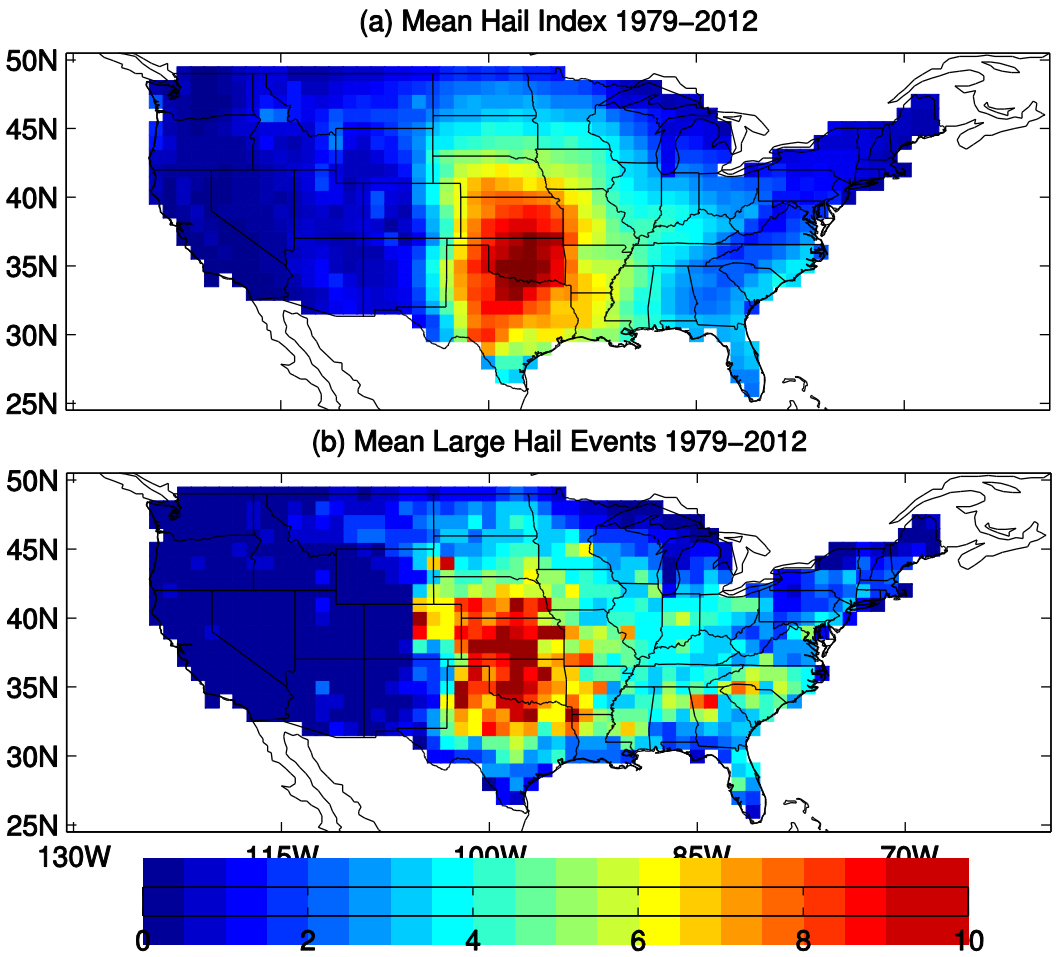
(Dan Cecil, Univ. of Alabama-Huntsville)

2003)

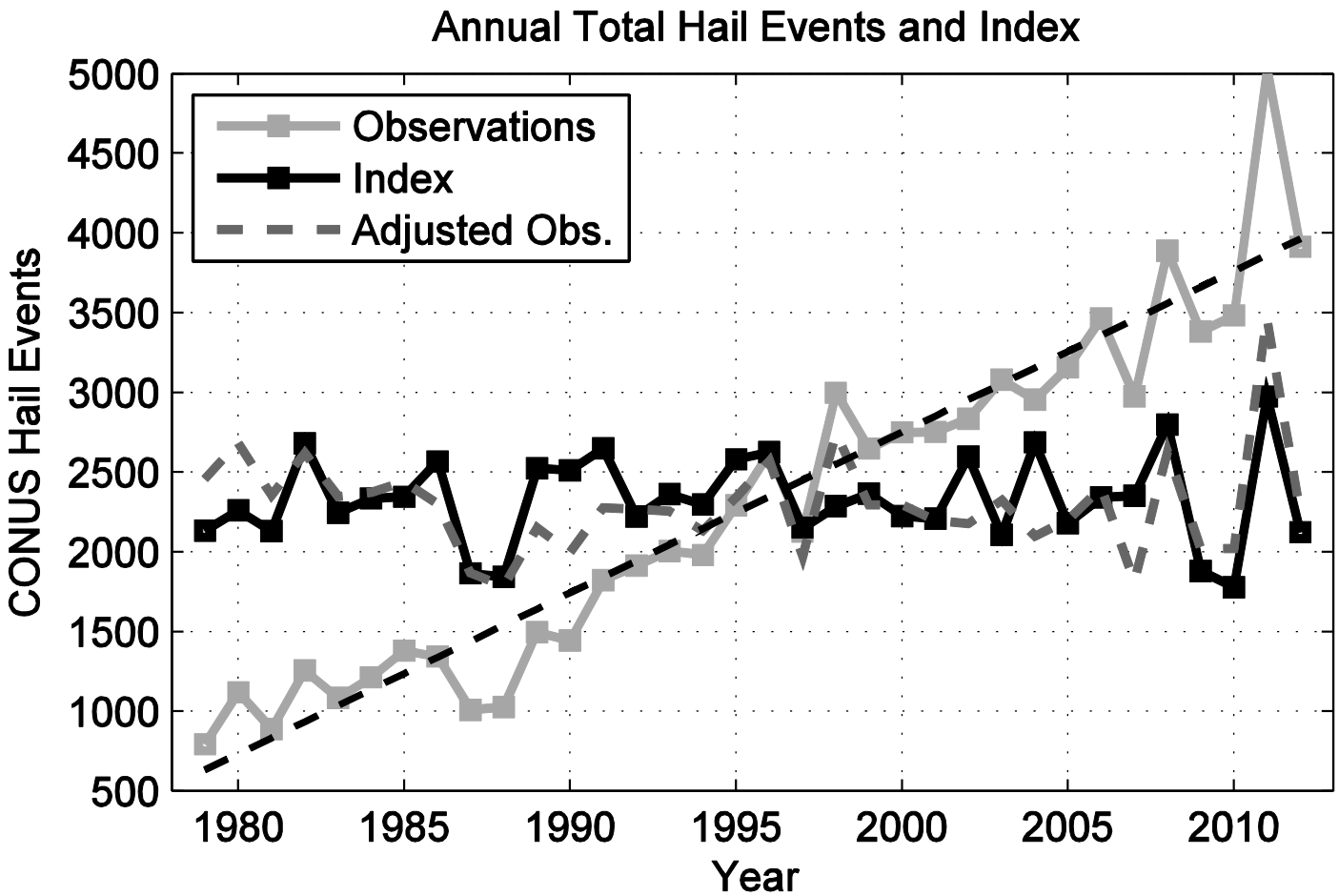

Tornadic Environment Periods (log) 1958-1999
60
50
40
30
20
-120
-100
-80
-60
-2
-1
0
1
2

Annual Tornadic Environment Periods (log) (1970-1999)





Allen et al. 2015

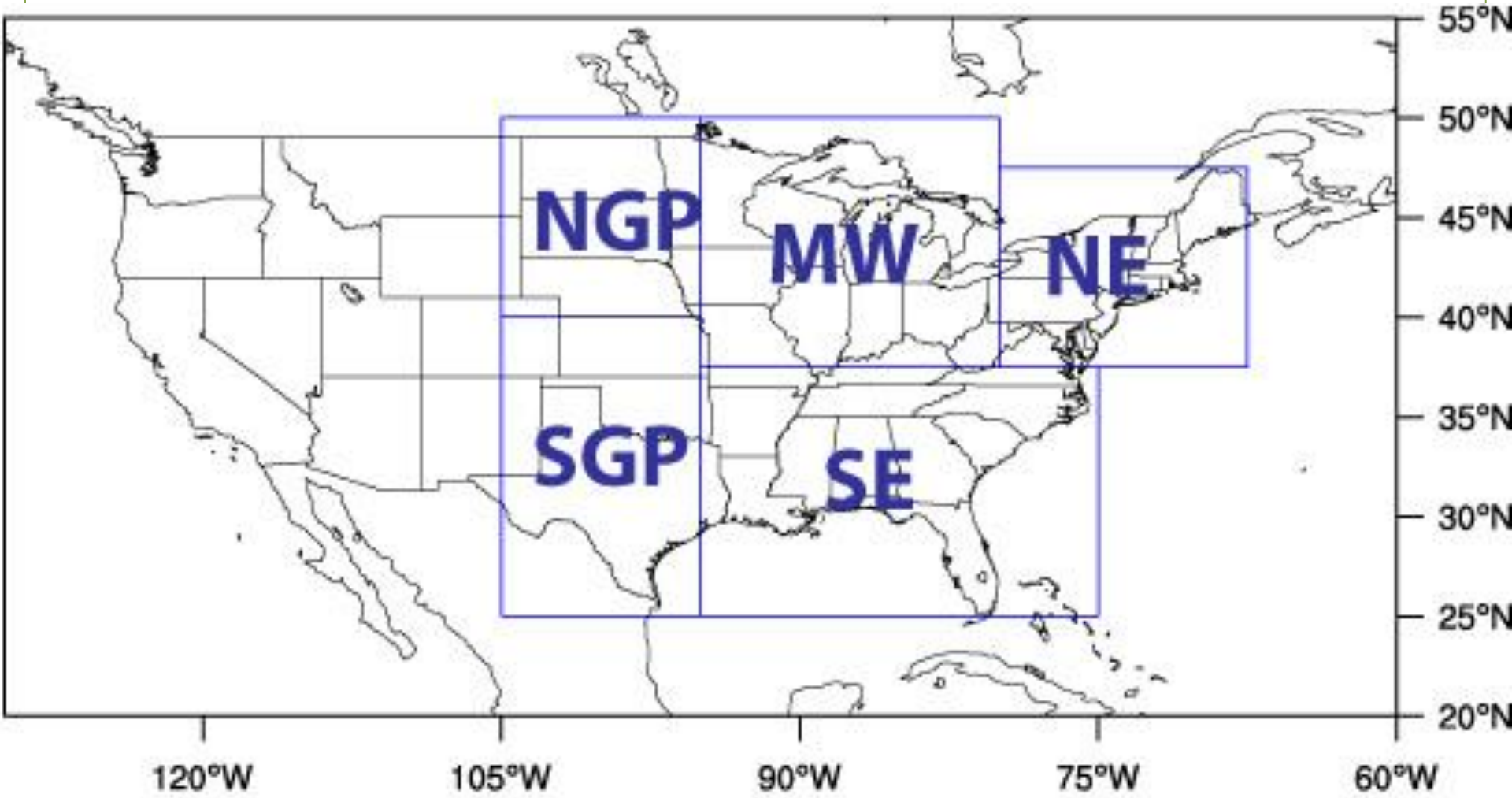


Allen et al. 2015

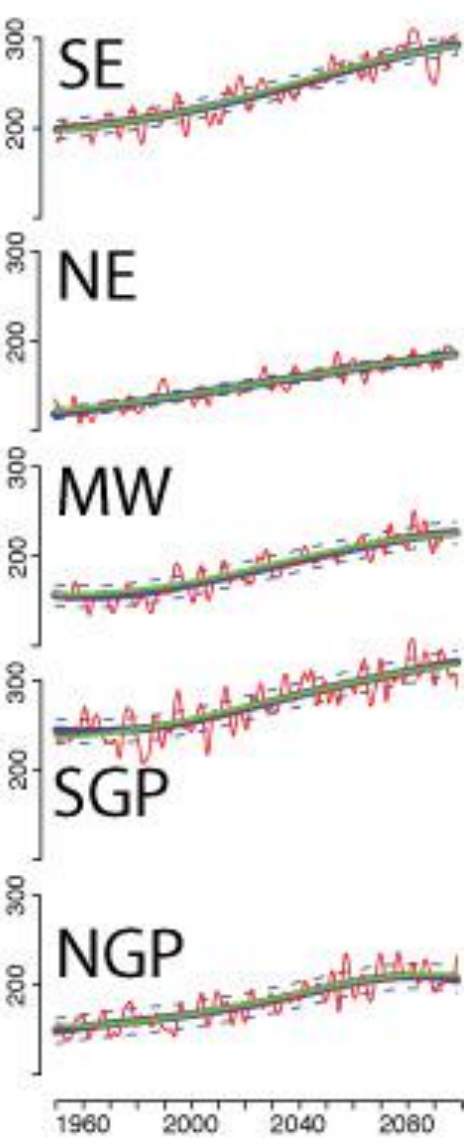
What will happen in the future

- Mean expected changes
  - CAPE goes up (related to moisture increase)
  - Shear goes down (decrease in equator-to-pole gradient)
- We care about combinations
  - Climate model simulations
  - “Dynamical downscaling”

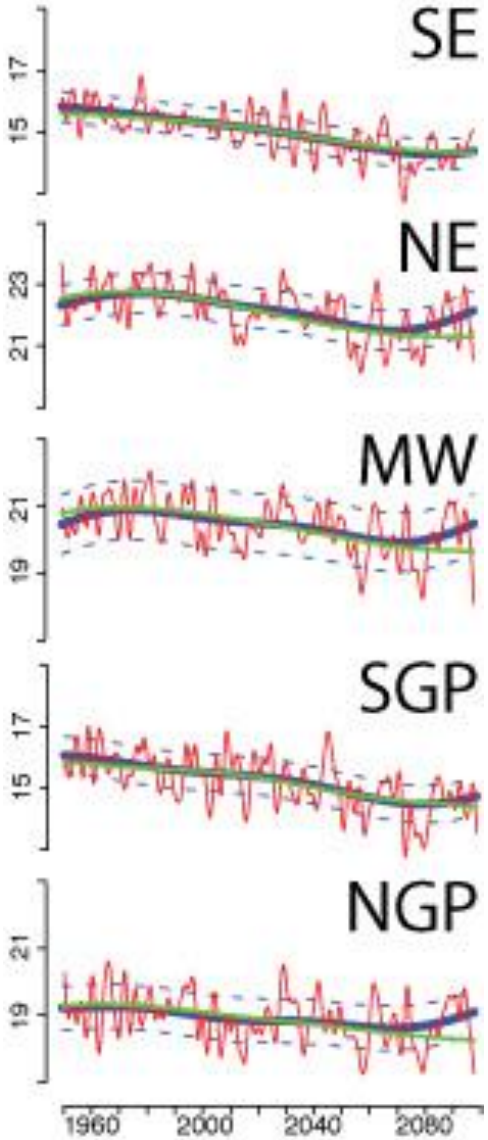
Trapp et al. (2009) Regional Analyses



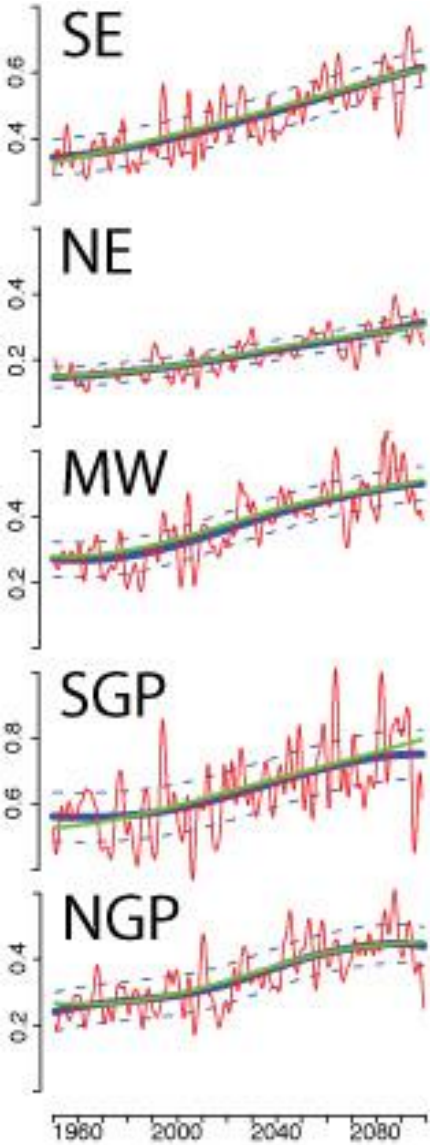
Updraft

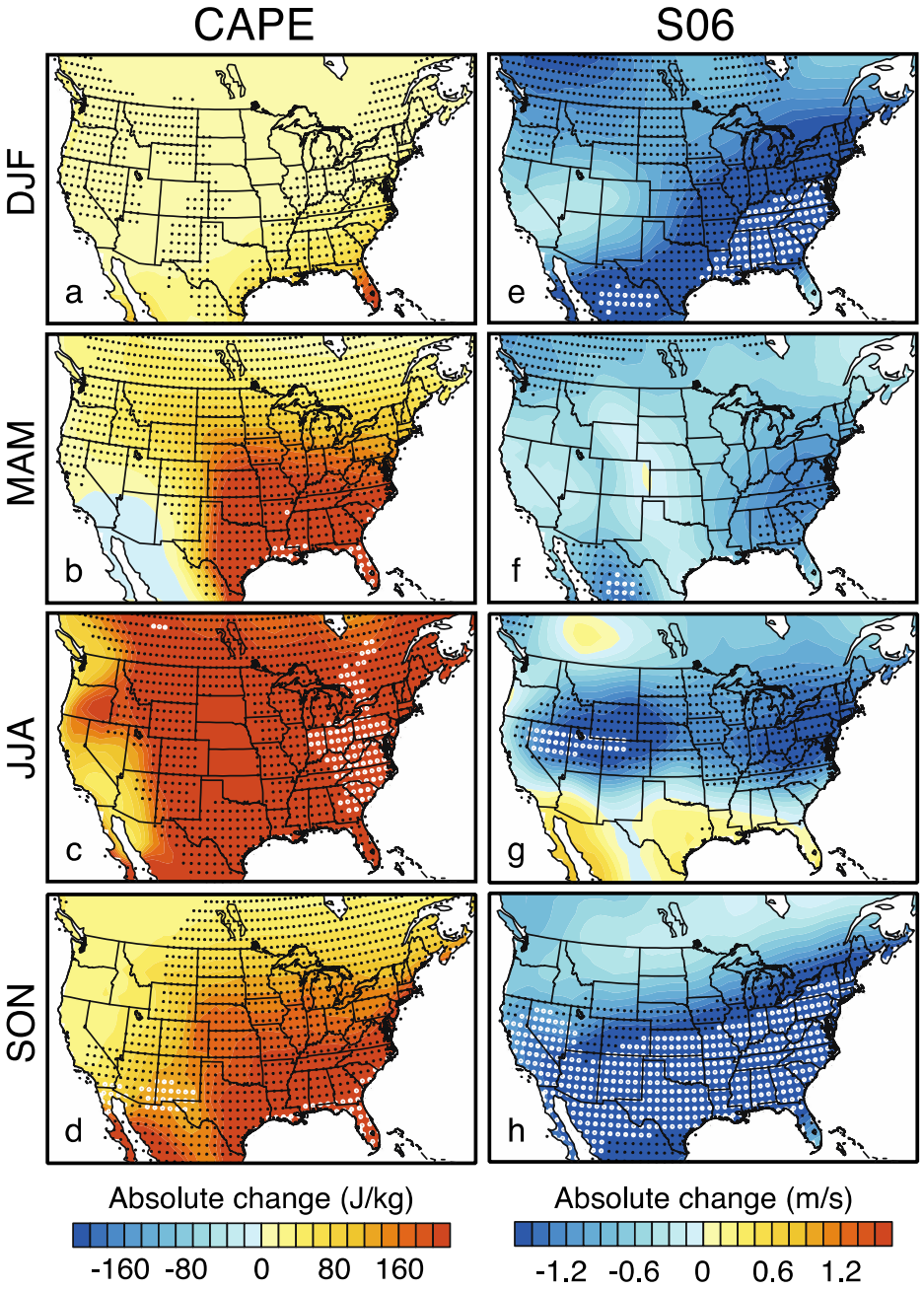


Shear



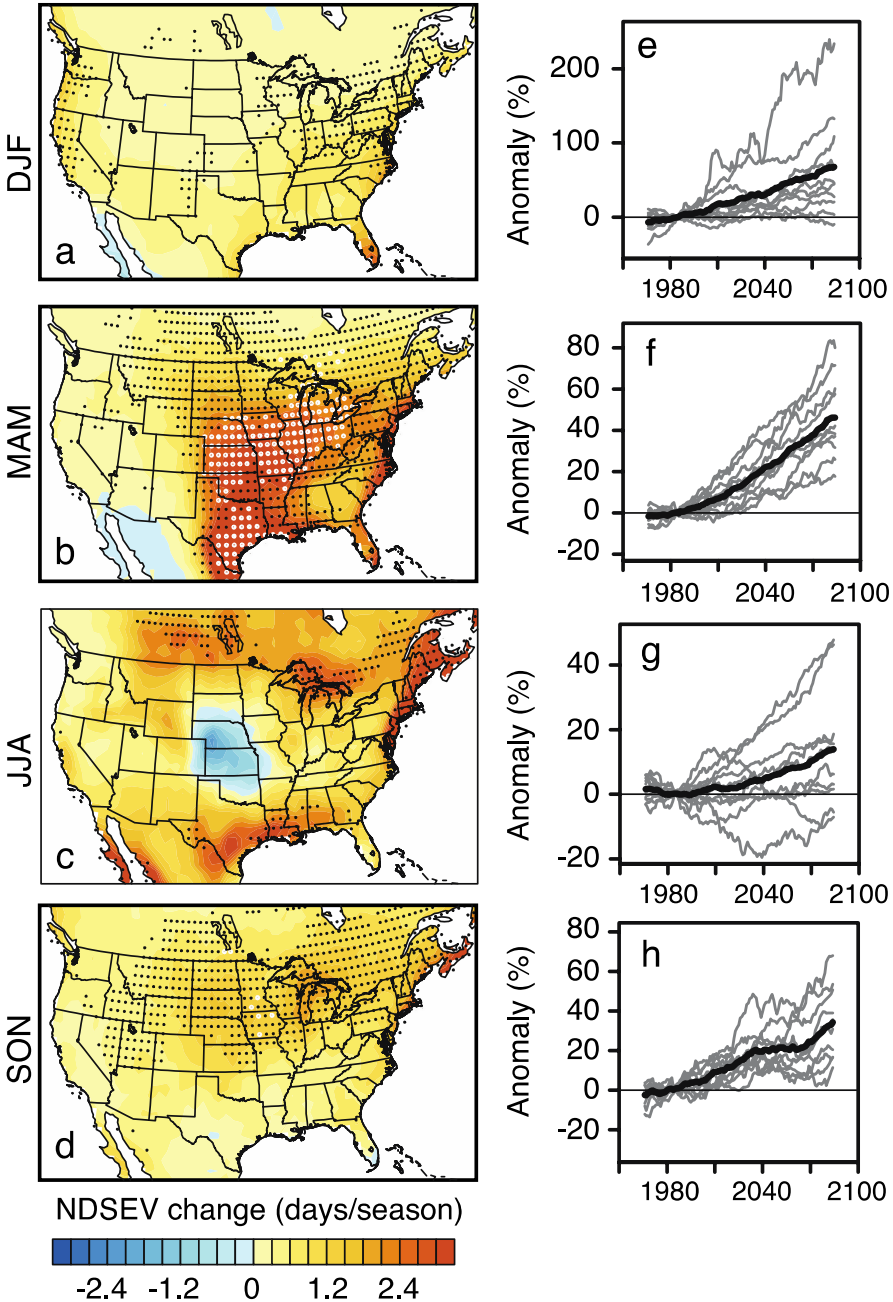
Combination





Climate model projections for ingredients

Diffenbaugh et al. (2013)



Favorable
Severe Storm
Environments

Black dots:

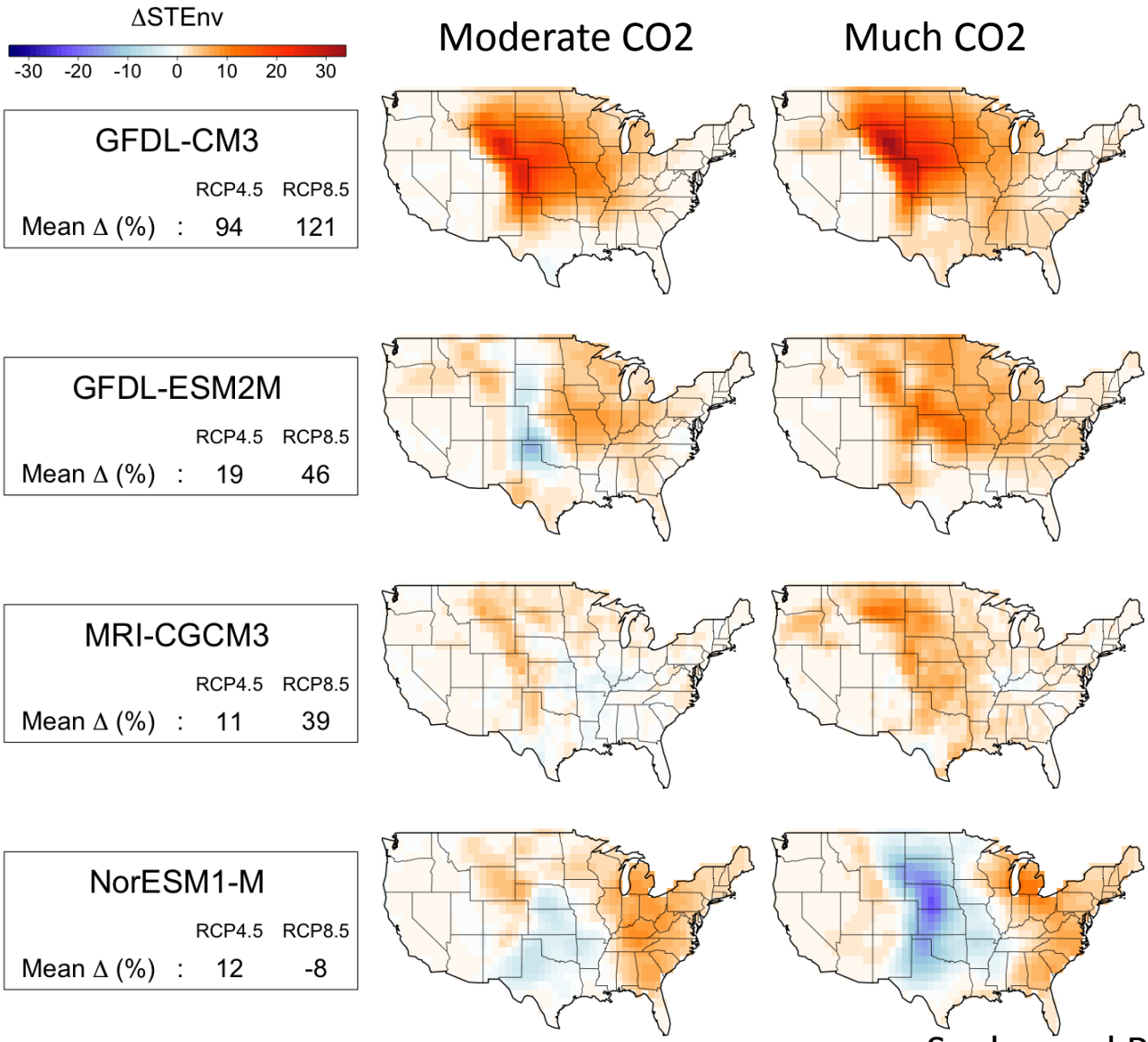
Ensemble S/N > 1

White dots:

Ensemble S/N > 2

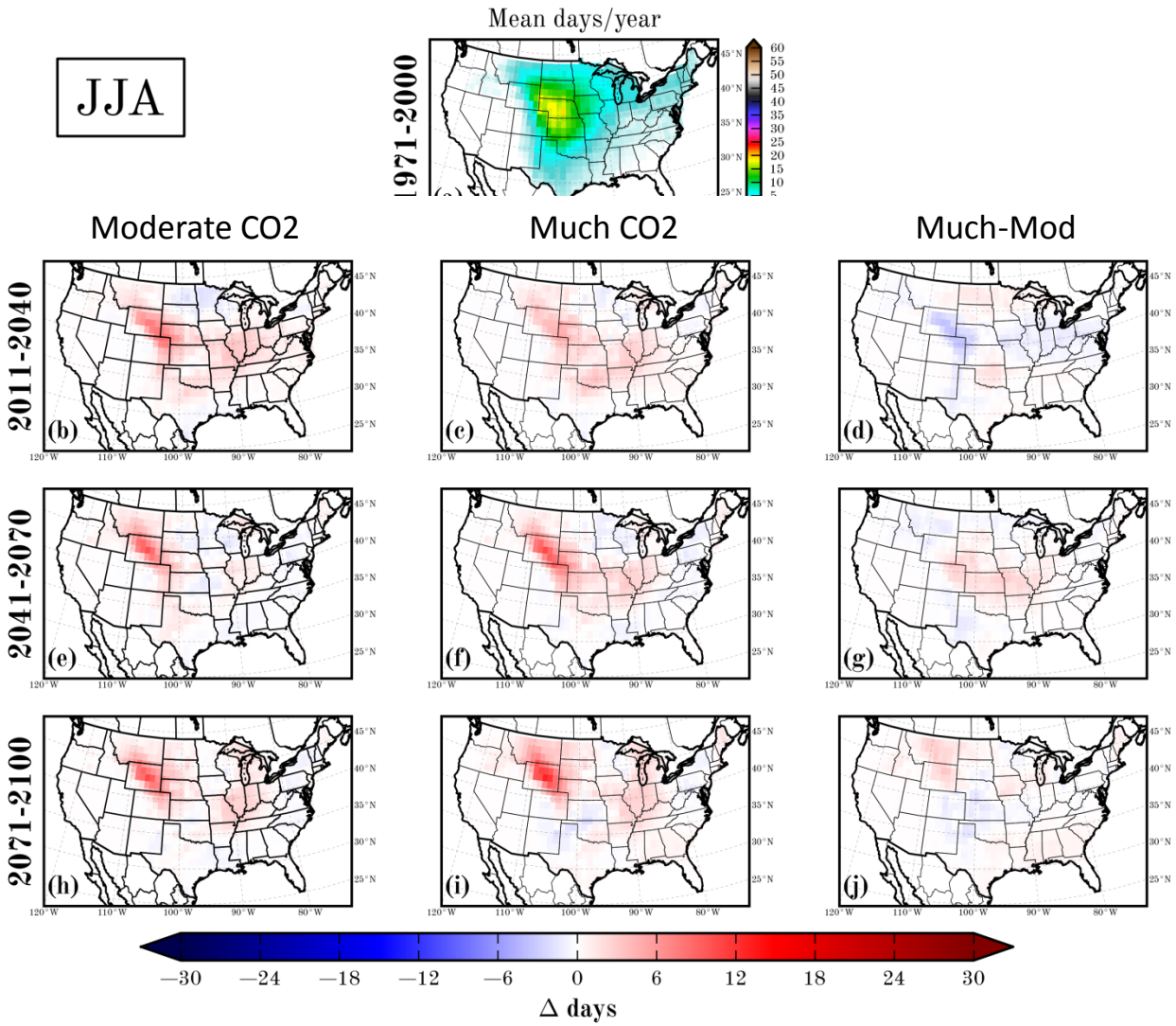
Diffenbaugh et al. (2013)

JJA



Seeley and Romps 2015

Favorable Tornado Environments



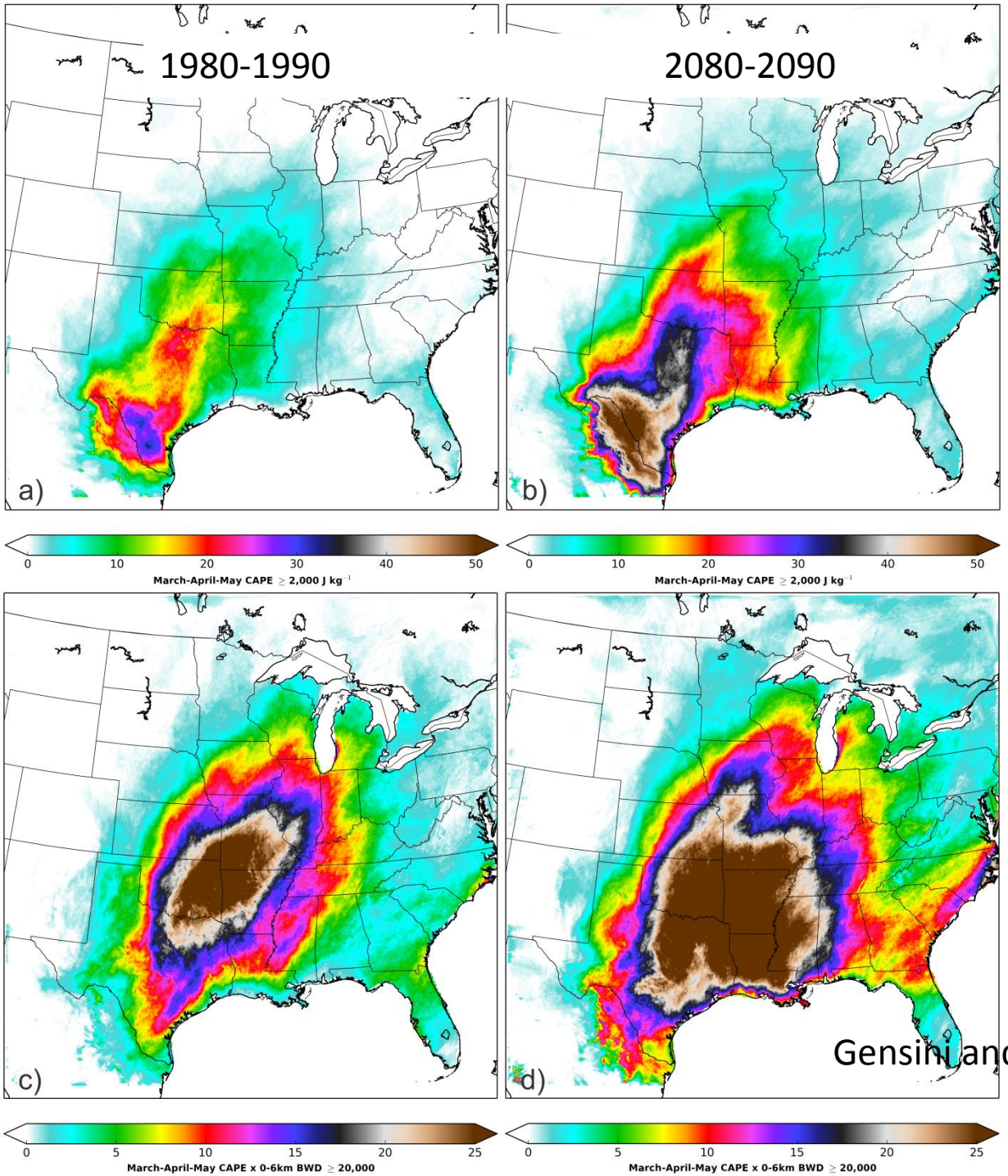
Courtesy K. Hoogewind

Gensini and Mote 2015

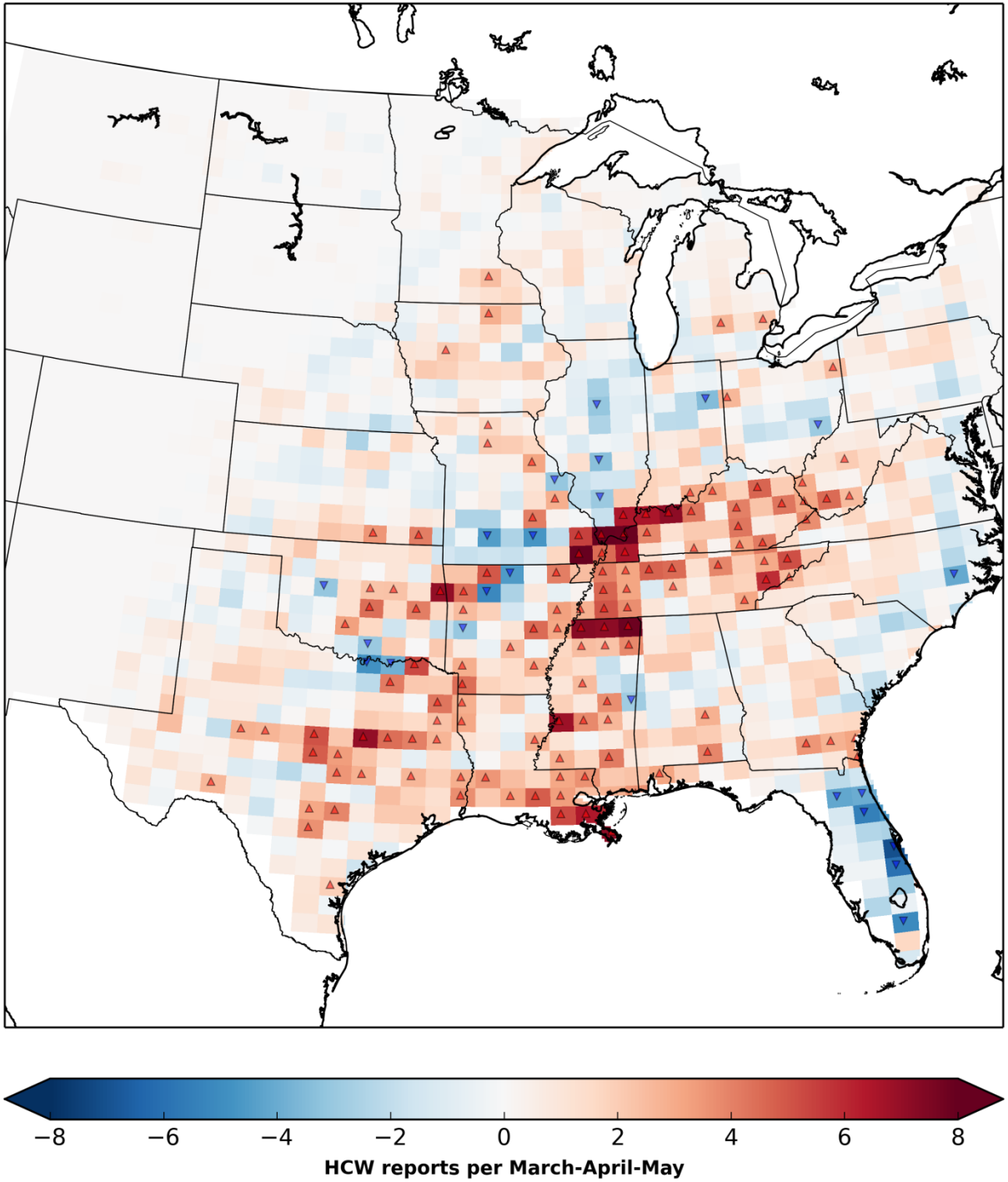
- Used GCM to drive 4-km grid spacing model
  - Looks like experimental weather prediction models
  - Sees many features of storms
  - Run for March-May for 11 years in late 20th, late 21st century
- Lets us look at environments and storms

Energy

Favorable Environments

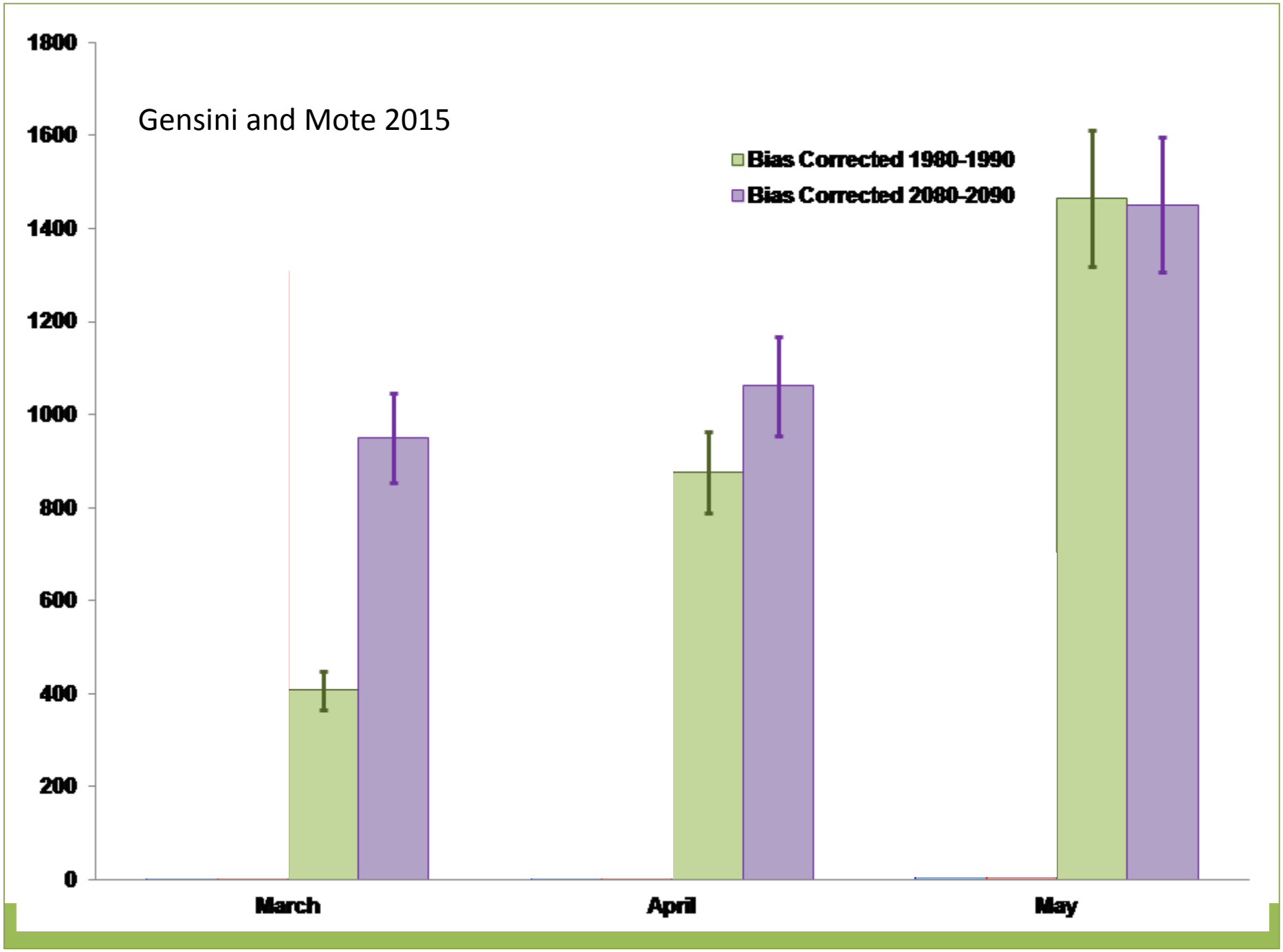


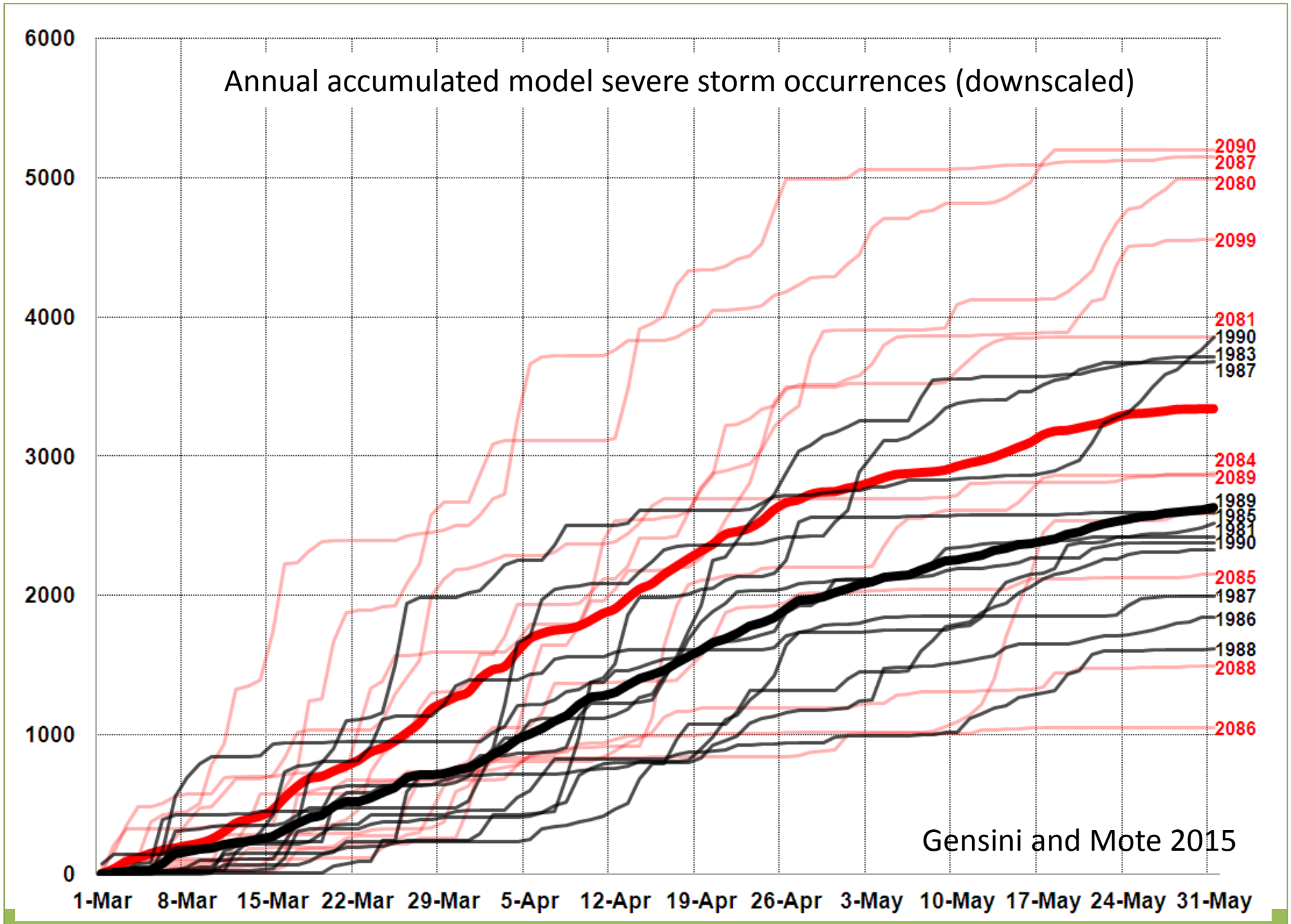
Gensini and Mote 2015



Projected increase (red), decrease (blue) in severe storms (downscaled)

Gensini and Mote 2015


Gensini and Mote 2015
Bias Corrected 1980-1990
Bias Corrected 2080-2090
1800
1600
1400
1200
1000
800
600
400
200
0
March
April
May


Annual accumulated model severe storm occurrences (downscaled)
6000
5000
4000
3000
2000
1000
0
1-Mar
8-Mar
15-Mar
22-Mar
29-Mar
5-Apr
12-Apr
19-Apr
26-Apr
3-May
10-May
17-May
24-May
31-May
2090
2087
2080
2099
2081
1990
1983
1987
2084
2089
1989
1985
1981
1980
1990
2085
1987
1986
1988
2088
2086
Gensini and Mote 2015

Model summary

- Environments
  - Energy term increases
  - Shear term decreases
  - Overall, more environments favorable for severe storms
    - Tendency to increase non-tornadic wind events
    - Weaker evidence for long-term increase in tornadoes
  - But…

Closing thoughts

- Increase in favorable environments for severe
- Increased variability
  - Tornadoes on fewer days, more on outbreak days
  - Models increase variability in future
- Timing of season?
- What does variability mean for risk management?