# CFSv2 forecasts of a U.S. monthly tornado index

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# Extended range, monthly or seasonal forecasts of tornado activity: A hard problem

- Observations are bad
  - Tornado data is unreliable. Data quality and uncertainty will affect results. Should first work to improve the tornado dataset.
- Numerical models are bad
  - Model have biases in the Central US. Warm season precipitation is poorly represented. Varying bias patterns in tornado-prone regions.
- Forecasts are bad
  - Extending any results based on reanalysis and observations to forecasts is problematic. Forecast biases in the central US.

# A hard problem to ignore

- April and May 2011
  - $22.5 billion total losses
  - 540 fatalities
- March 2012
  - First billion-dollar weather disaster of 2012

# Outline

- The “ingredients” approach
- A new monthly tornado activity index
- Results with NARR environmental parameters
- Results with CFSv2 forecasts

# Connecting climate and tornado activity: **Conditional probabi**lities

- Prob (tornadoes | current initial conditions)?
- Prob (tornadoes | ENSO)?
- Prob (tornadoes | Climate change)?

Two approaches:

- **Statistical** (data)
  - Expectation[tornadoes | something] = regression, composites
- **Dynamical** (model)
  - Tornadoes in mechanistic model forced by something

# The problem with statistical and dynamical approaches

"Tornadoes, the deadliest weather disaster to hit the country this year, present a particularly thorny case."

- "Tornadoes are small and hard to count, and scientists have little confidence in the accuracy of older data."

—

- "The computer programs they use to analyze and forecast the climate do not do a good job of representing events as small as tornadoes."

*Harsh Political Reality Slows Climate Studies Despite Extreme Year* -- NY Times 12/25/2011

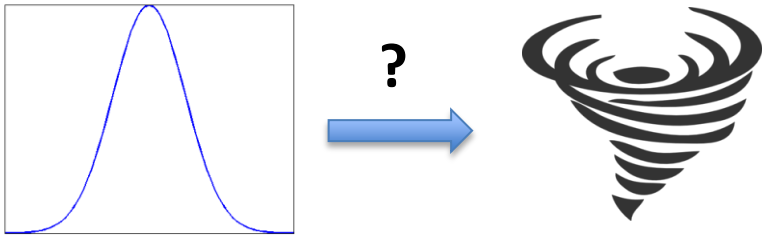
"Tornadoes are not in the least bit 'thorny.'"-- Roger Pielke, Jr

# The “ingredients” approach: Associate environmental factors with likelihood of tornado activity

# Basic Issues

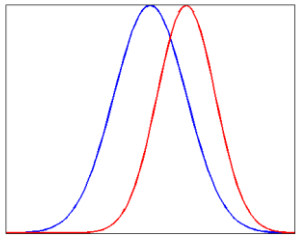
- To what extent do environmental parameters explain tornado activity?

Does the distribution of environmental parameters during a month determine tornado activity?



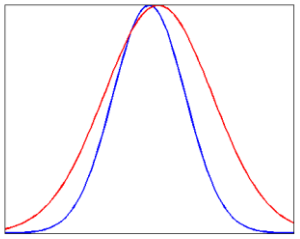

- What makes one month more active than another?

Changes in mean?



Easier?

Changes in spread?



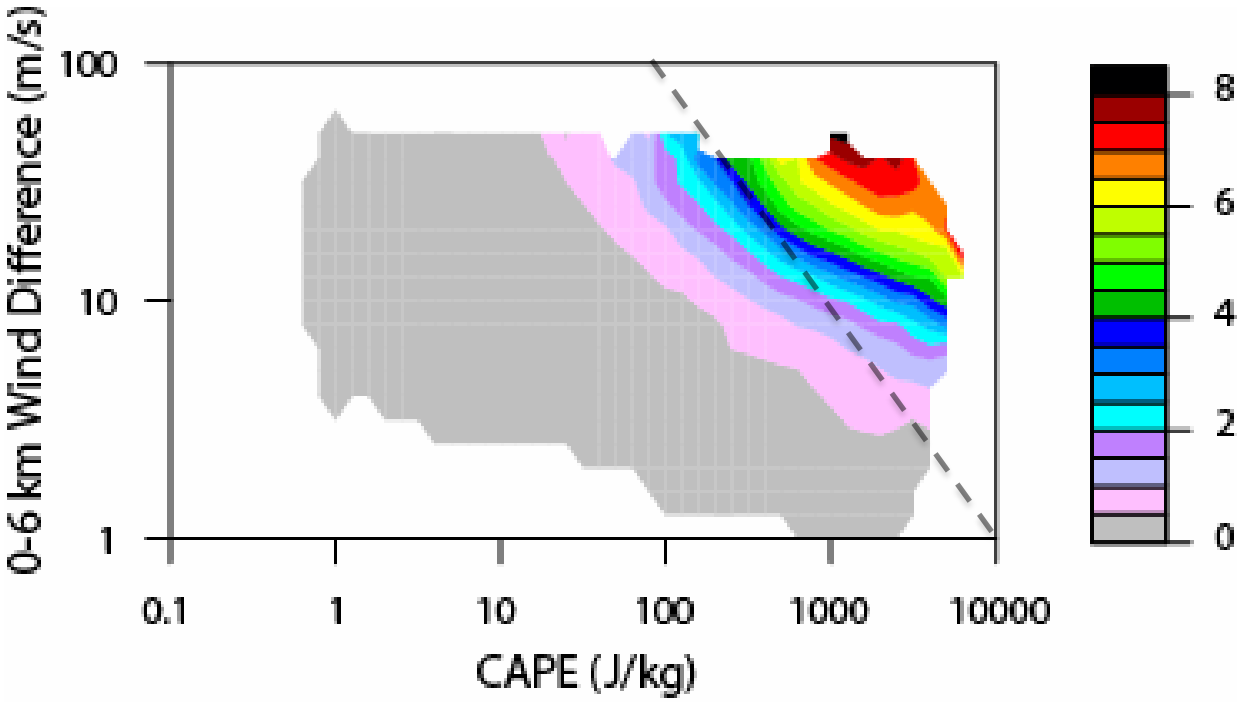
Harder?

- Are the variations predictable?

# Typical environmental parameters associated with tornadoes

- Instability, updrafts, e.g. CAPE
- Shear, e.g., 0-6km shear, Storm Relative Helicity (SRH)
- Convective initiation

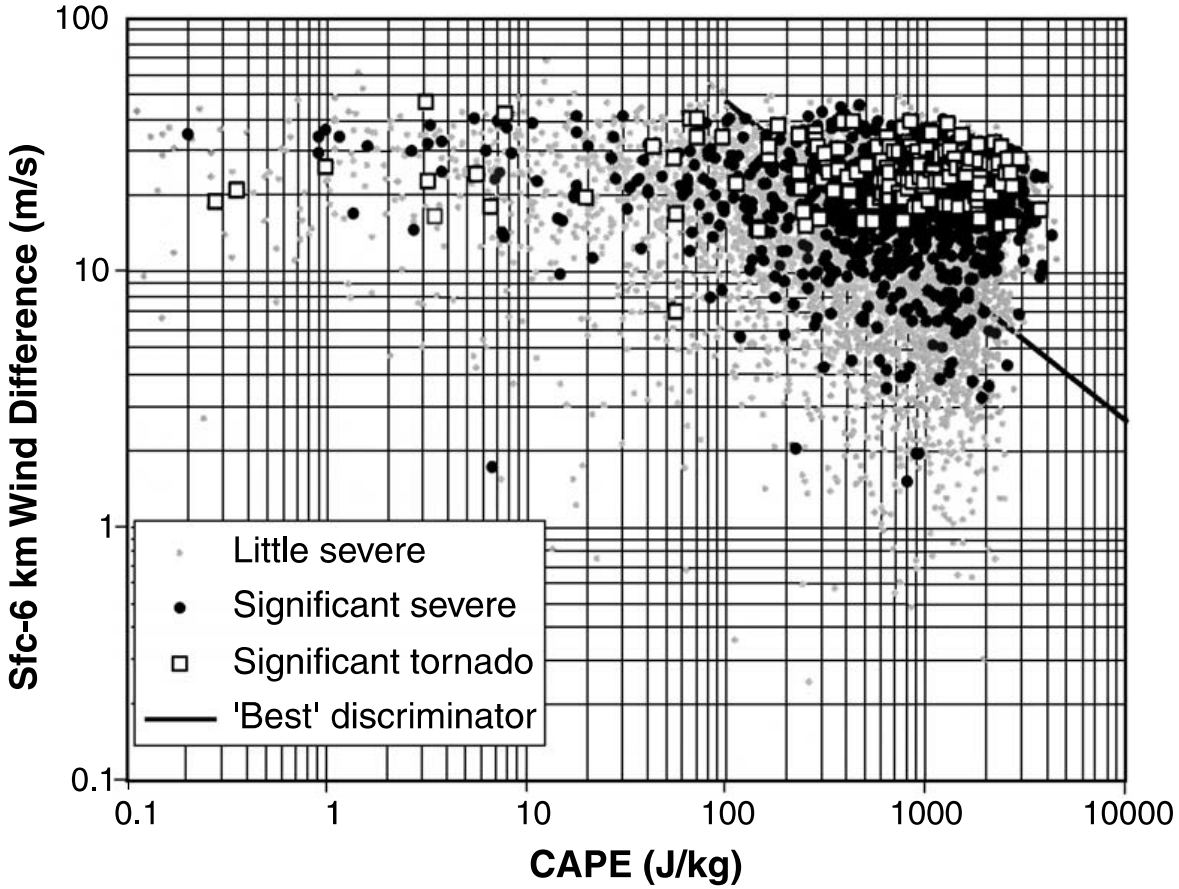
# Probability of severe thunderstorms with F2 tornado, 5cm hail, or 120 km/h wind gusts



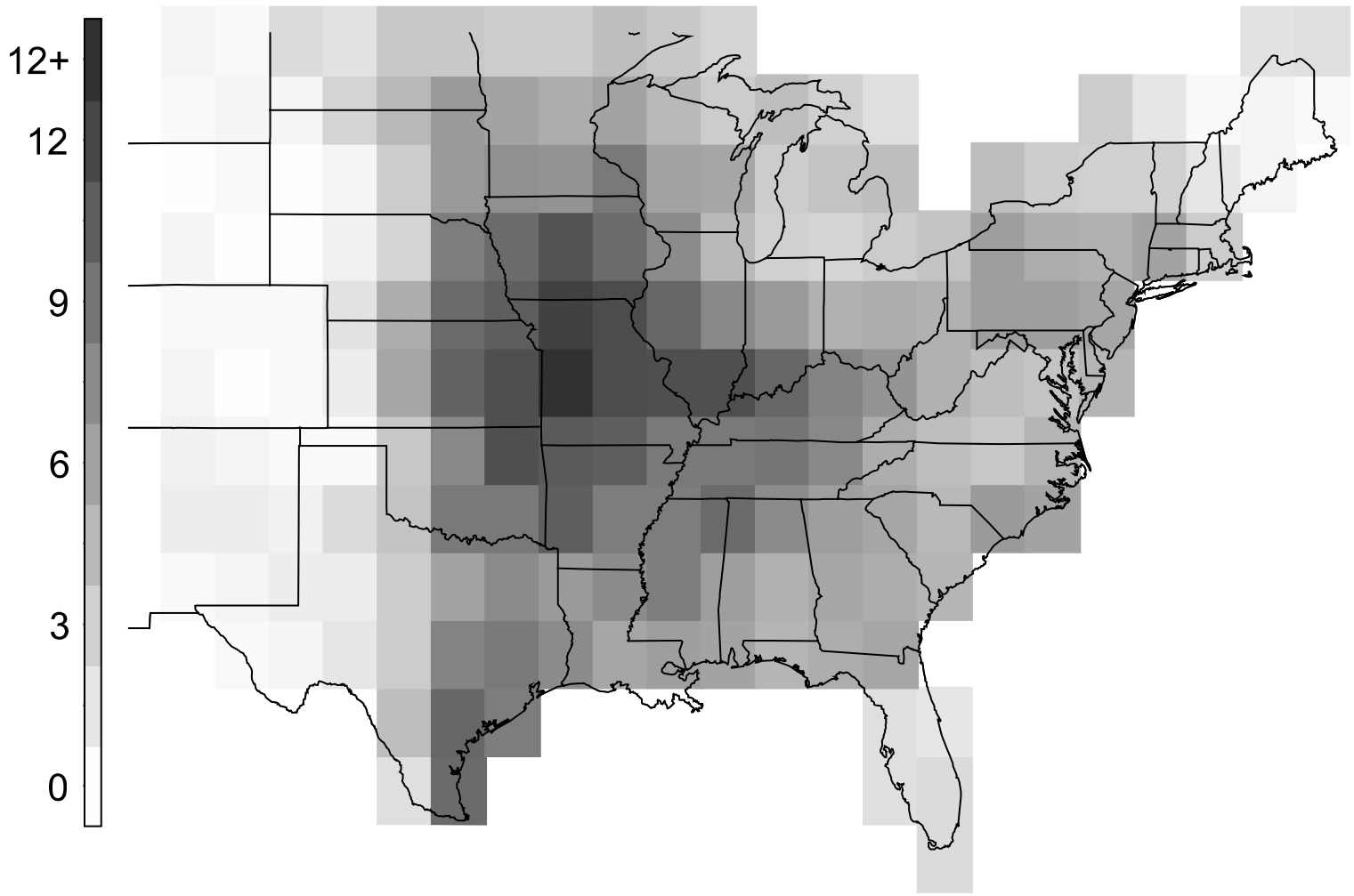

Soundings in the vicinity of severe thunderstorms

Significant severe parameter (Craven and Brooks, 2004)
CAPE x 0-6 km Shear > 10,000 $m^3 s^{-3}$
Figure from Brooks and Dotzek (2008)

# NCEP/NCAR 6-h reanalysis environmental parameters near severe thunderstorms 1997-1999



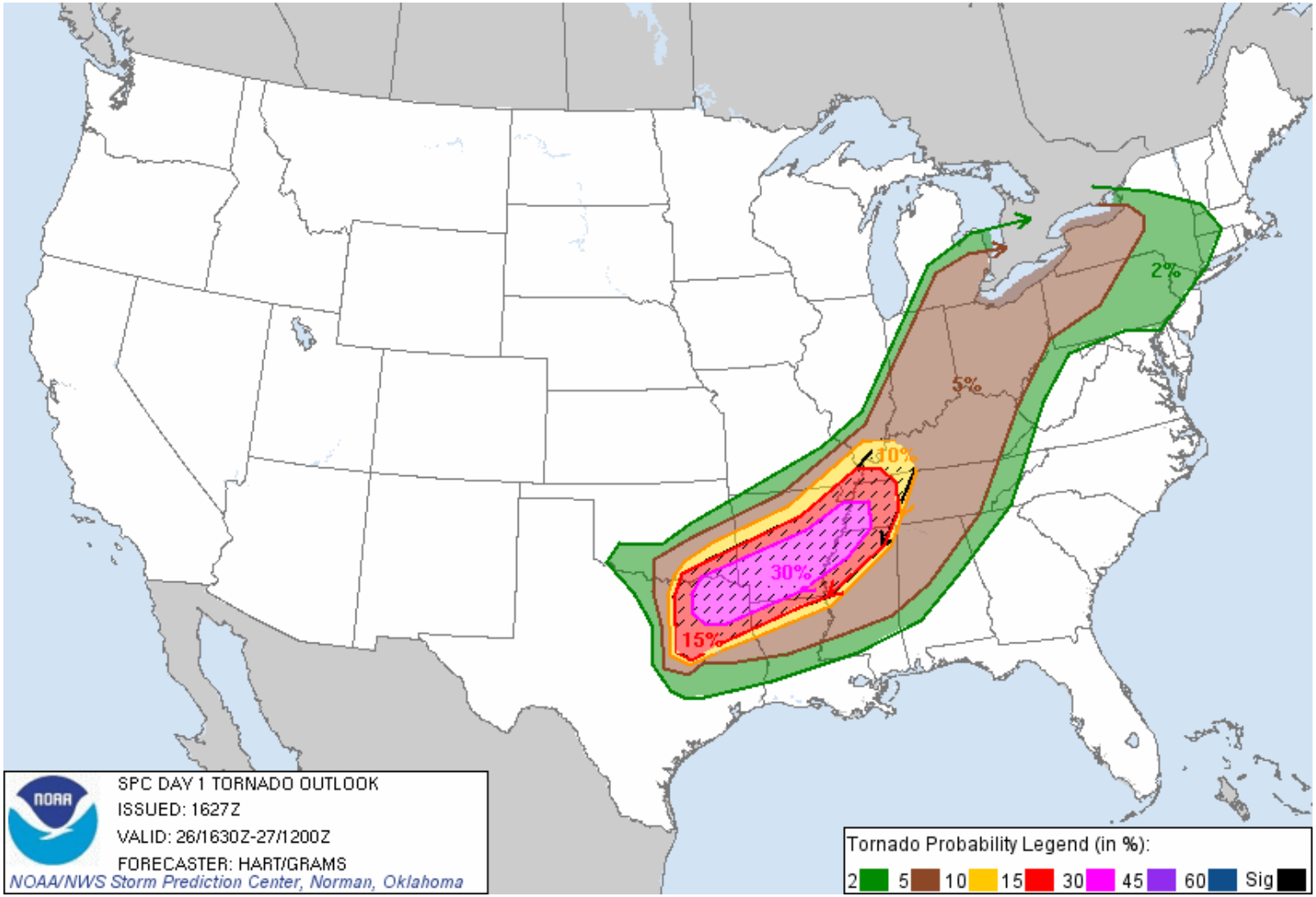

(Brooks et al. 2003)




6-hourly reanalysis

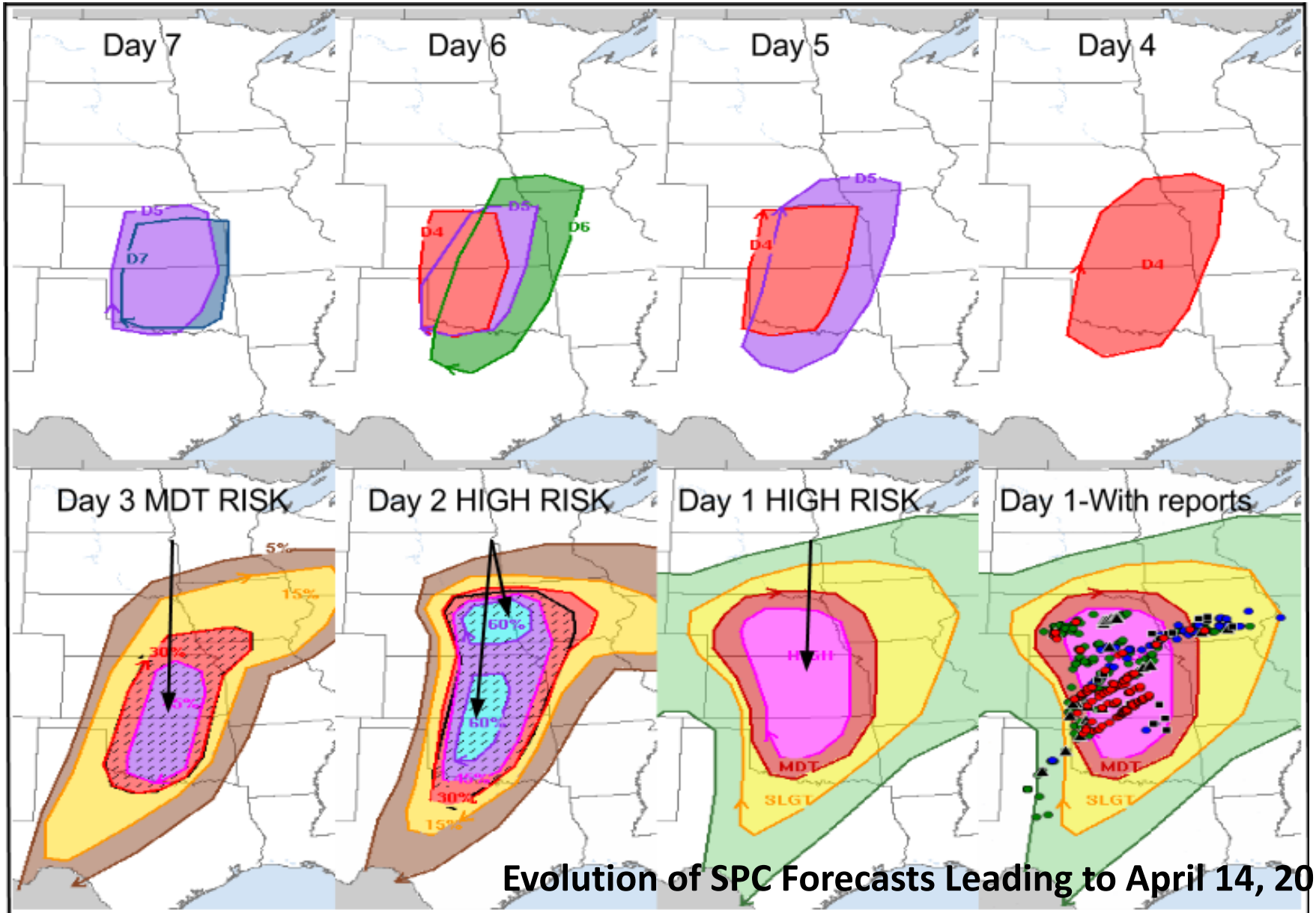
(Brooks et al 2003)

# Useful relation between large-scale environmental parameters and tornado activity on short time-scales




April 26, 2011 16:30Z

# Useful relation between large-scale environmental parameters and tornado activity on short time-scales




**Evolution of SPC Forecasts Leading to April 14, 2012**

# A new monthly tornado activity index

# A monthly index for the number of U.S. tornadoes

- Index = exp(constants x environmental parameters)
- Constants estimated by Poisson regression
- Potential parameters = CAPE, CIN, lifted index, lapse rate, mixing ratio, **SRH**, vertical shear, precipitation, **convective precipitation** and elevation
- Estimate constants from observed *climatology*
  - Avoids issues with changing technology and reporting practice
  - Same constants at all (U.S.) locations, all months of year
- Data
  - NARR data 1x1 degree grid. 1979-2010.
  - SPC Tornado, Hail, and Wind Database. 1979-2010.
  - ***All*** tornadoes (>F0). [F1 and greater gives smaller values, similar sensitivities]

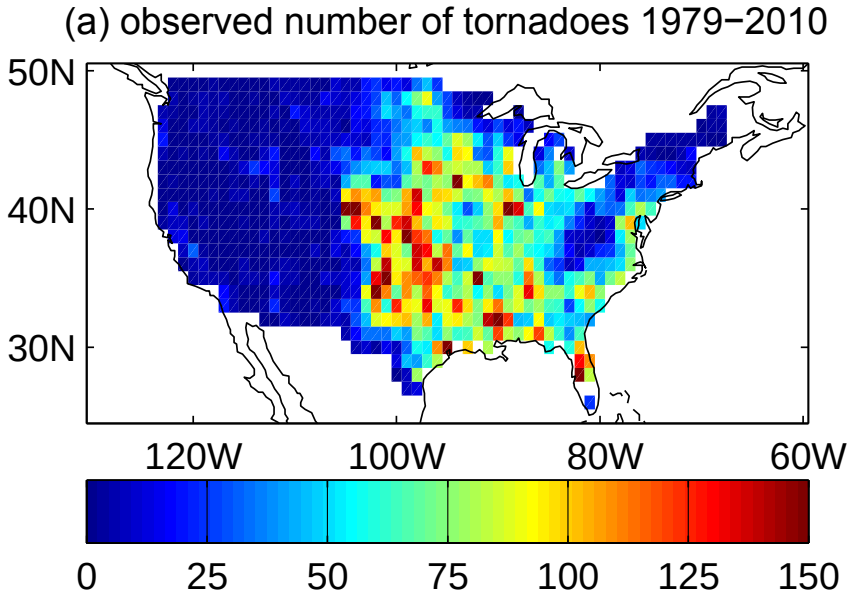
# A monthly index for the number of U.S. tornadoes

- Index = exp(c0 + c1 x SRH + c2 x cPrcp )
  - Monthly averages
- Estimate 3 constants from **annual cycle** data
  - No annually varying data used to select parameters or fit constants
  - No forecast data used. “Prefect prognosis”
- Index = Expected number of tornadoes/month
  - 1x1 degree grid
  - ***All*** tornadoes (>F0).

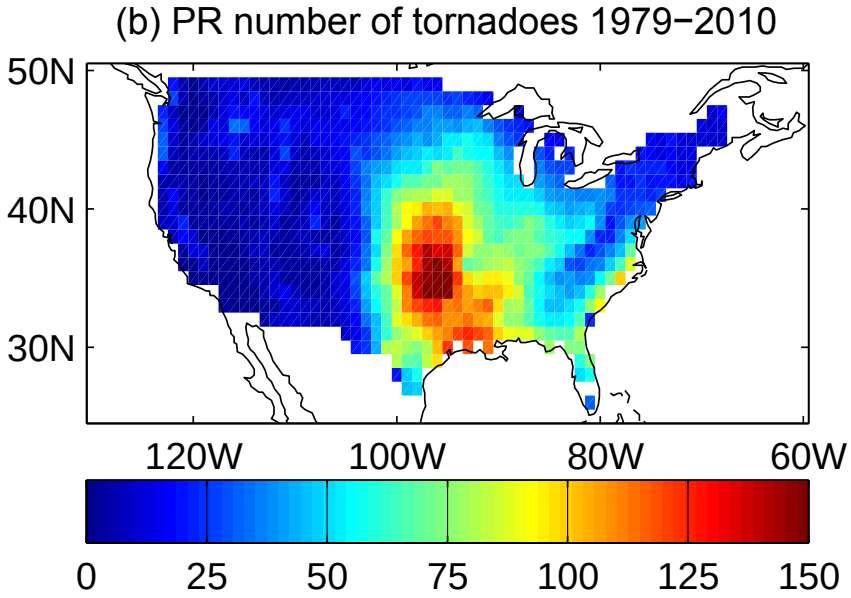
# Results with NARR environmental parameters

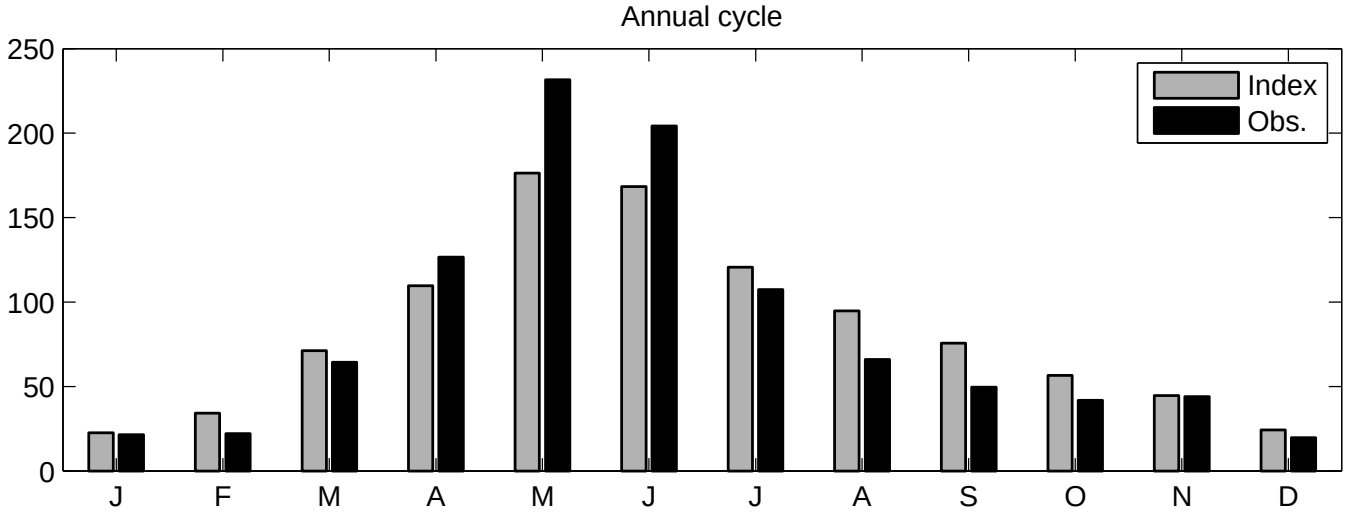
# Climatology

## Observations

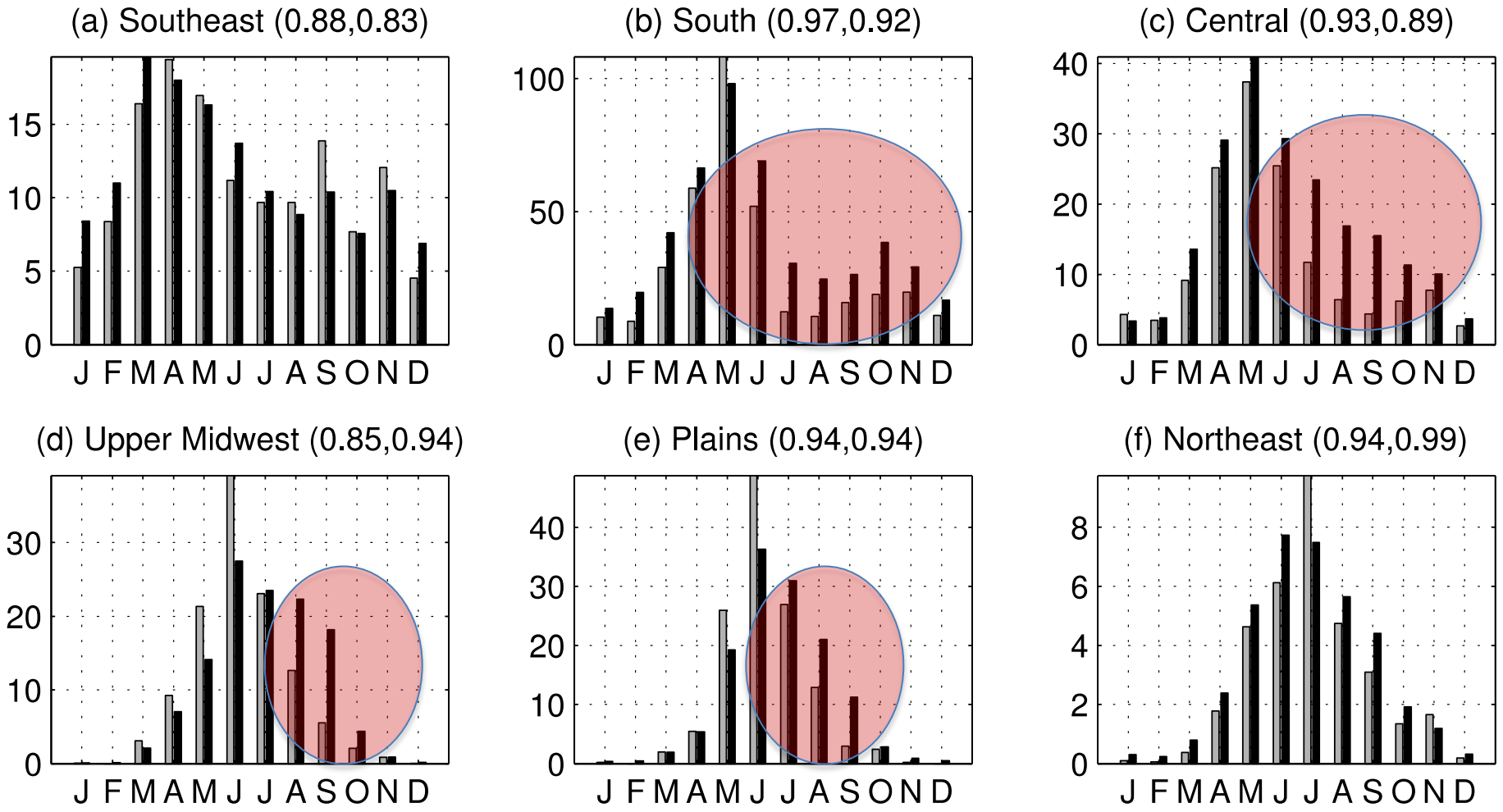



## Index

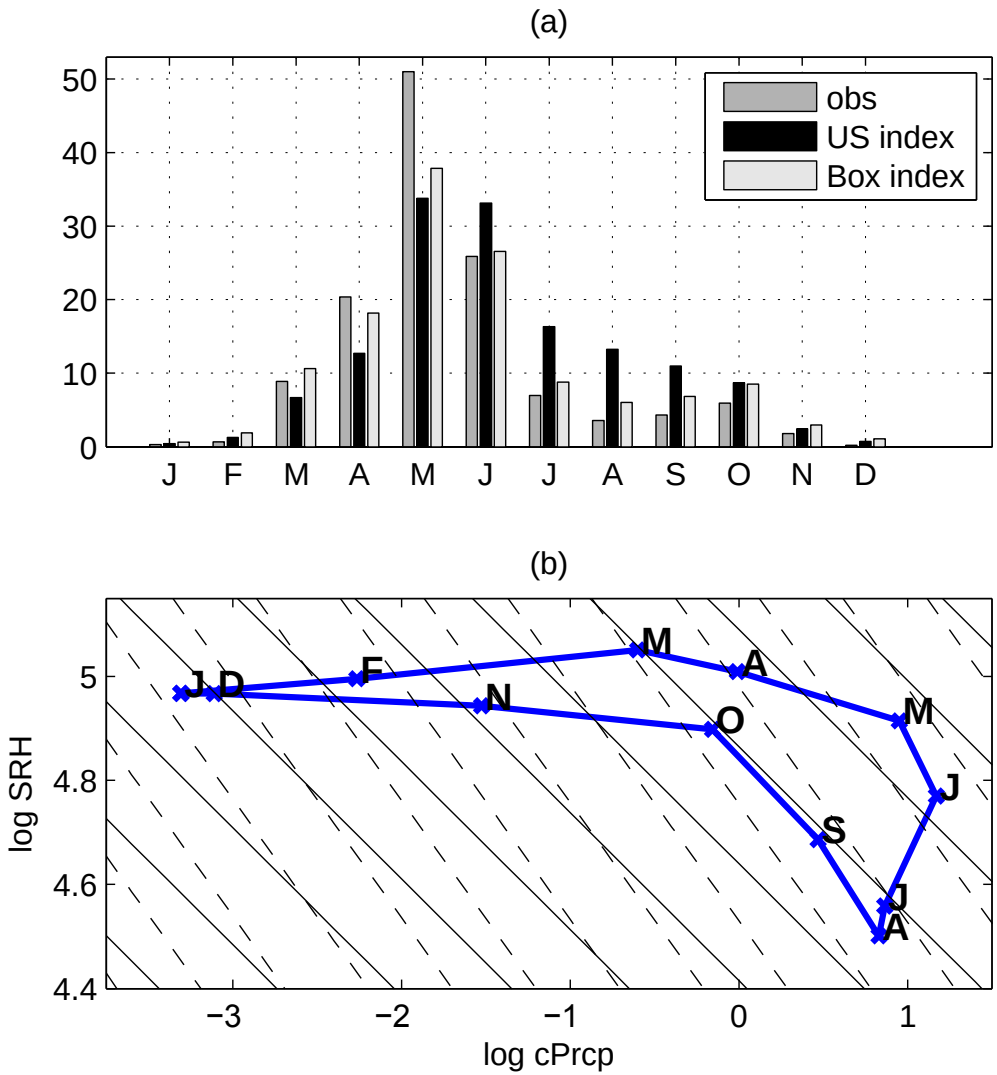


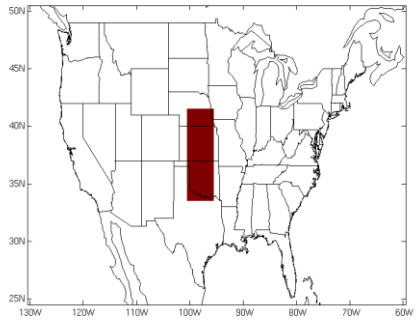



# Regional climatology



# A single index based on monthly averages does not work well everywhere



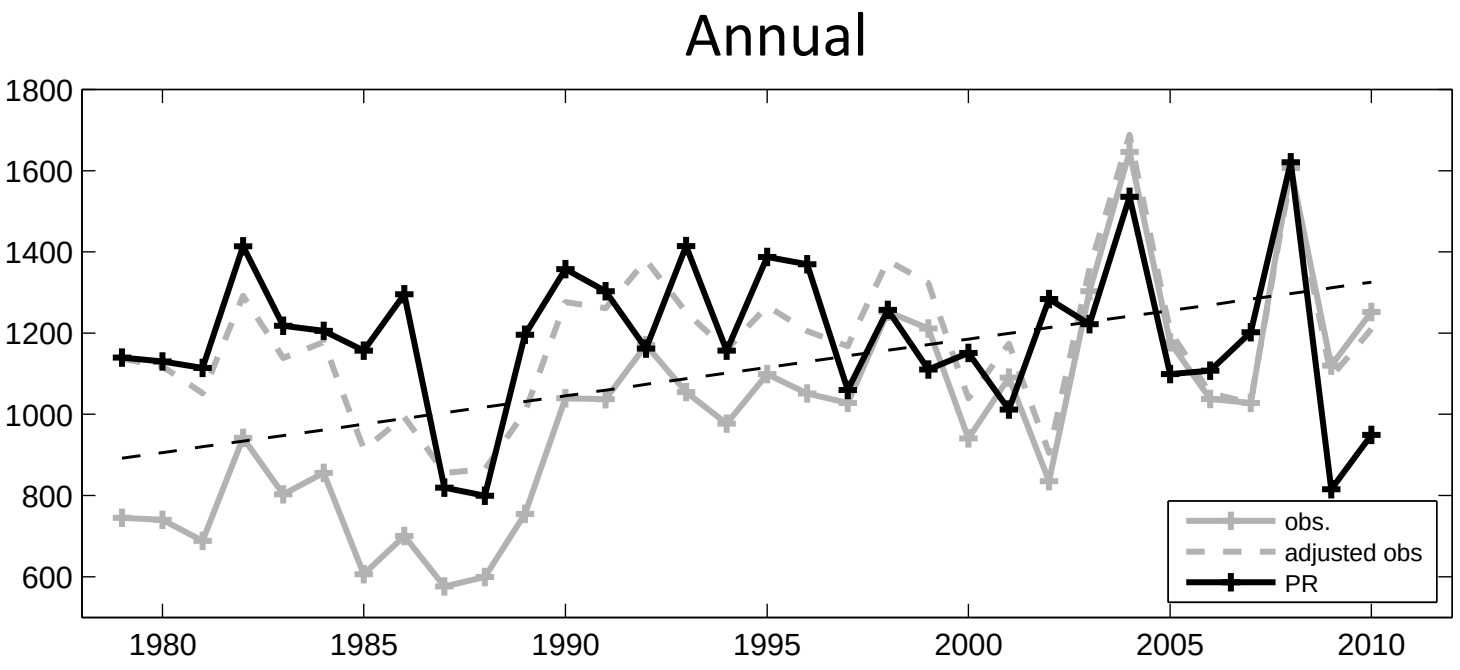



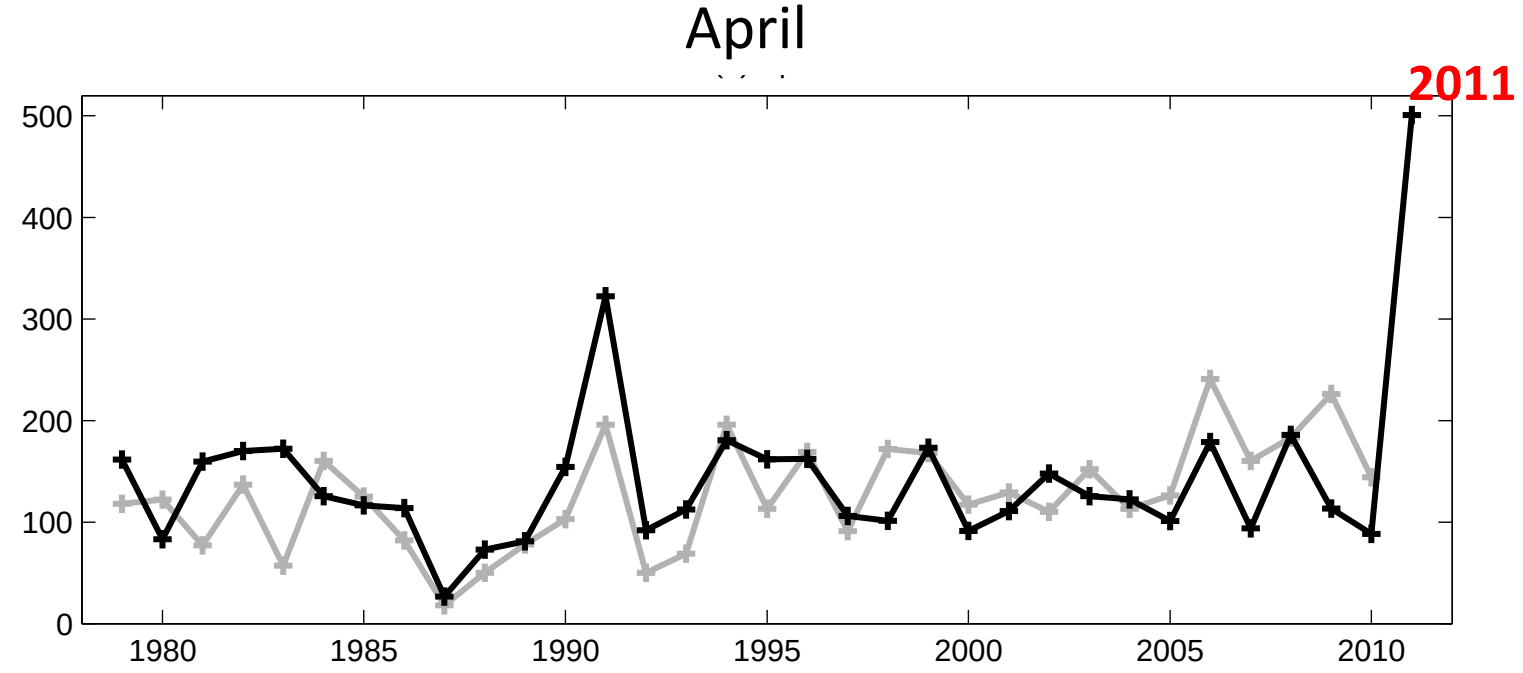
# Interannual variability

CONUS Totals:

Reports

Index



# Interannual variability

Correlation between index and observed number CONUS

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Index | **0.75** | **0.64** | **0.54** | **0.50** | **0.60** | **0.67** | **0.75** | 0.40 | 0.15 | 0.25 | **0.48** | **0.74** |
| SRH only | 0.24 | 0.12 | 0.14 | 0.34 | **0.41** | 0.39 | **0.51** | 0.31 | -0.16 | 0.13 | 0.21 | 0.37 |
| cPrcp only | **0.76** | **0.58** | **0.68** | **0.60** | **0.30** | **0.54** | **0.60** | 0.33 | 0.15 | 0.28 | 0.53 | **0.74** |

What is the relative importance of the factors?

Most months, cPrcp variability is more important

# Regional variability

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| South | **0.66** | **0.51** | **0.52** | **0.69** | **0.50** | **0.47** | **0.57** | 0.31 | 0.12 | **0.46** | **0.60** | **0.71** | **0.53** |
| Southeast | **0.53** | **0.54** | **0.36** | **0.47** | **0.68** | **0.46** | **0.54** | **0.42** | **0.67** | **0.41** | **0.57** | **0.69** | 0.30 |
| Central | **0.68** | **0.69** | **0.65** | **0.53** | **0.56** | **0.73** | **0.65** | 0.35 | **0.42** | 0.26 | 0.28 | **0.73** | **0.51** |
| Upper Midwest | - | - | **0.60** | **0.55** | **0.71** | **0.57** | **0.56** | 0.14 | **0.54** | **0.56** | - | - | **0.45** |
| Plains | - | - | **0.63** | **0.58** | **0.80** | **0.53** | **0.81** | **0.49** | **0.55** | 0.23 | - | - | **0.51** |
| Northeast | - | - | - | **0.38** | 0.13 | **0.61** | **0.50** | **0.41** | **0.37** | **0.71** | 0.29 | - | **0.36** |
| Southwest | - | - | - | 0.21 | 0.13 | **0.37** | 0.32 | **0.40** | 0.02 | 0.31 | - | - | 0.22 |
| Northwest | - | - | - | 0.03 | **0.44** | **0.36** | - | 0.07 | - | - | - | - | 0.15 |
| West | - | **0.49** | **0.60** | - | - | - | - | - | - | - | - | - | 0.34 |

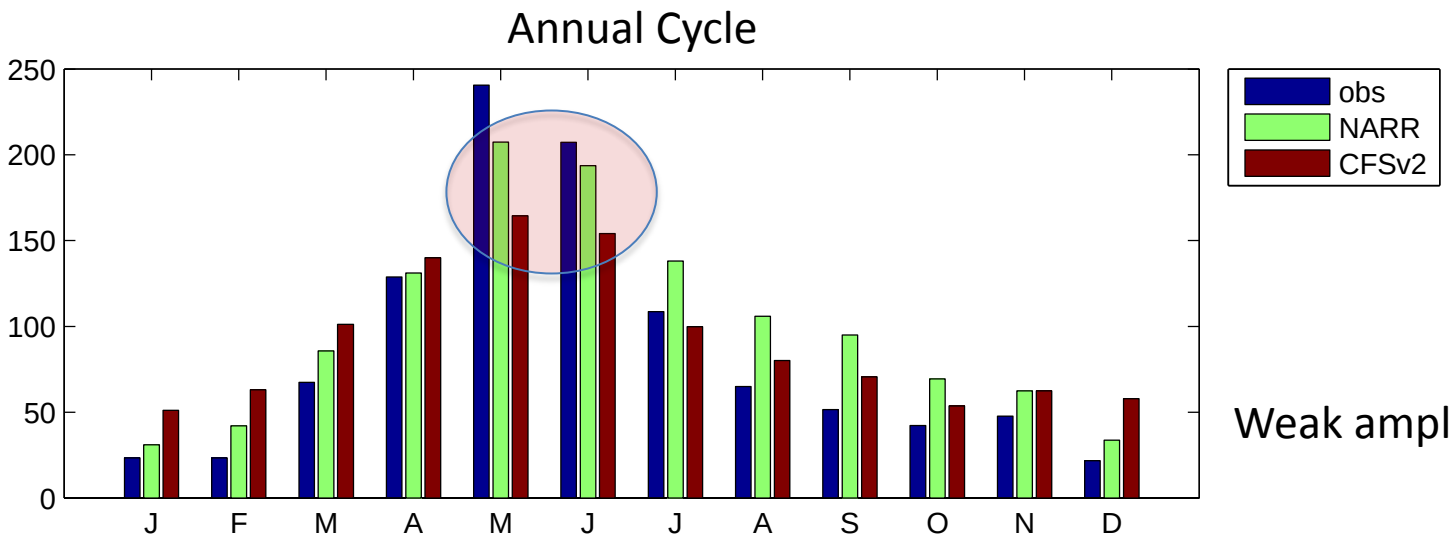
# Monthly CFSv2 forecasts

# CFSv2 hindcasts

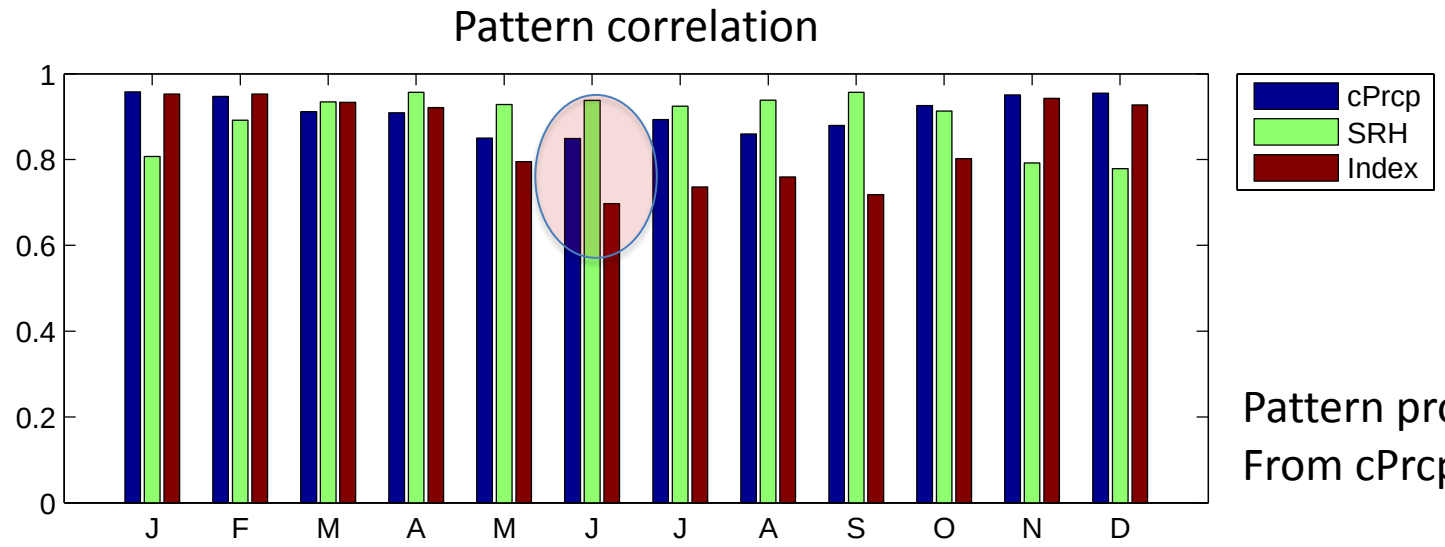
- 1982-2010
- First month lead
- 16 ensemble members (9-24)
- Forecast June average = start from May 21, May 26, May 31 and June 5
- Same index constants (perfect prognosis, no MOS)

# Climatology

# Climatology



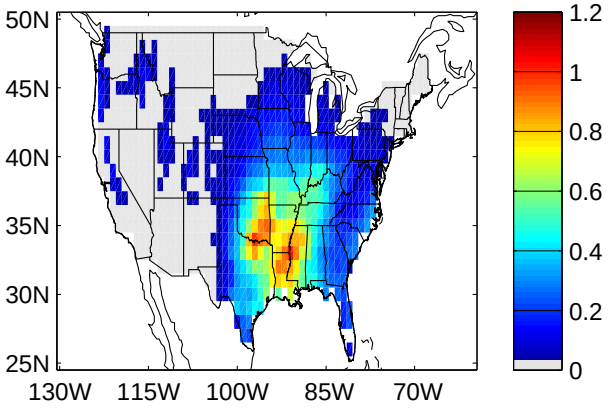

Weak amplitude



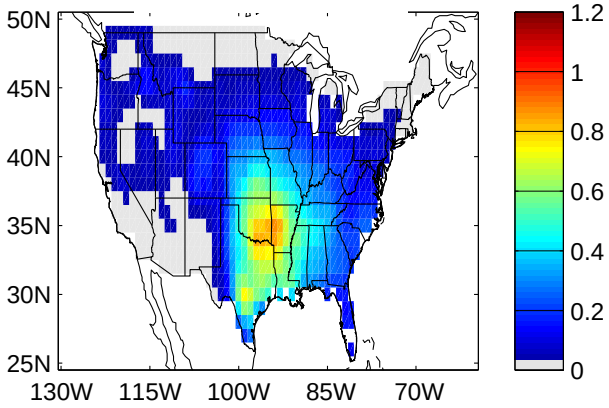

Pattern problems
From cPrcp

# April indices

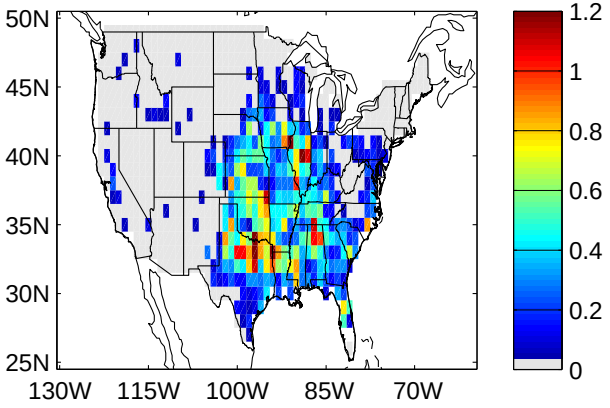
NARR index




CFSv2 index

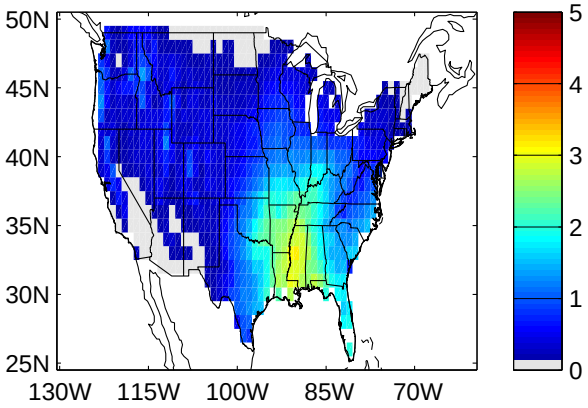



Reports

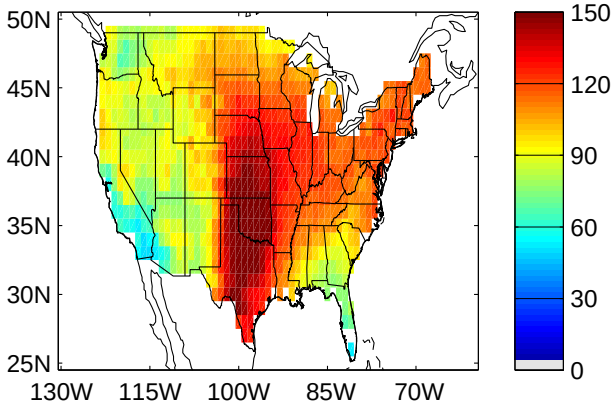


# April parameters

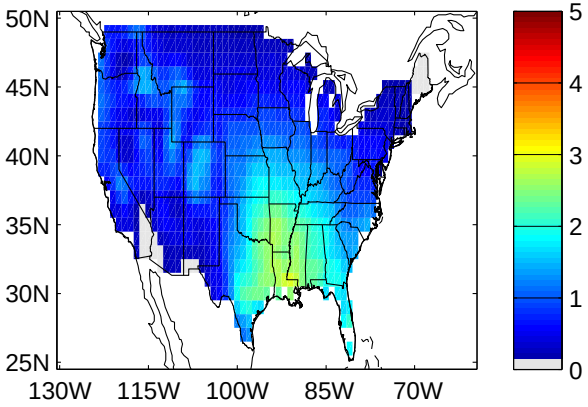
NARR cPrcp



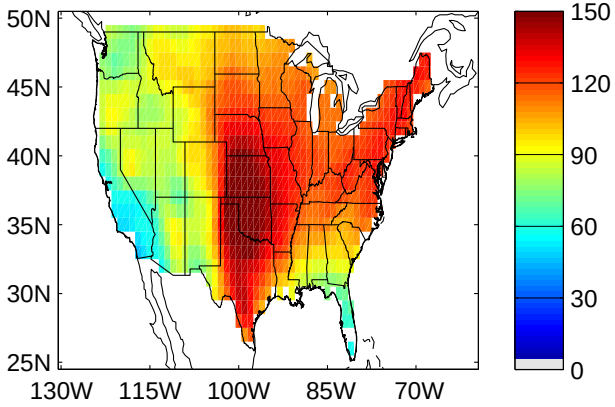

NARR SRH




CFSv2 cPrcp

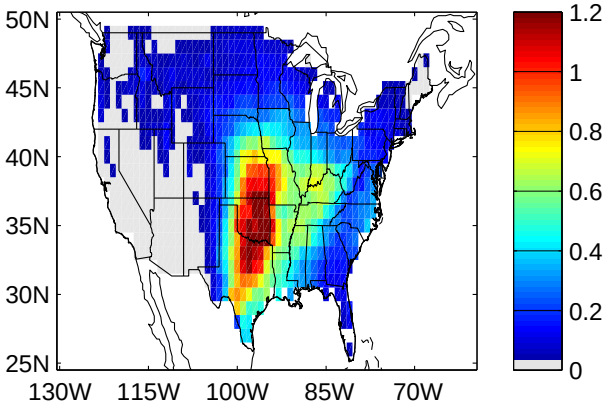



CFSv2 SRH

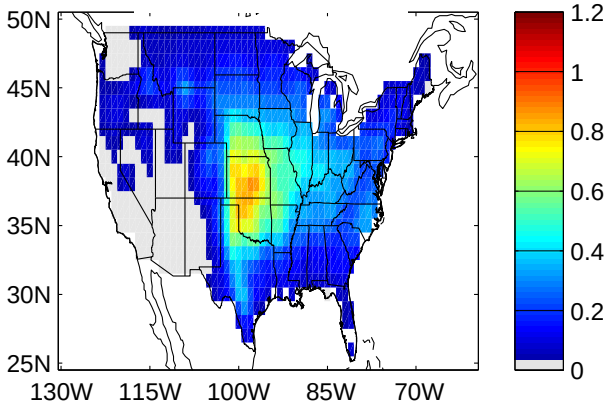


# May indices

NARR index




CFSv2 index

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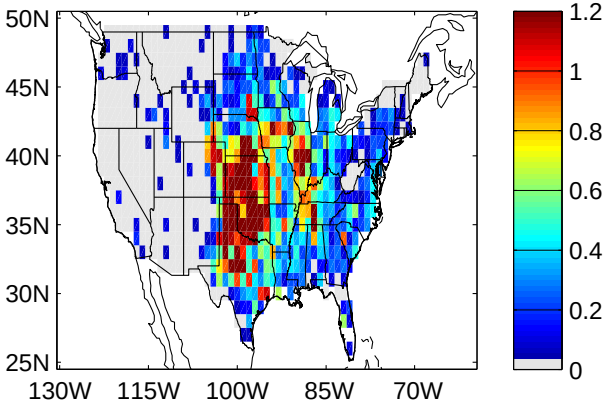
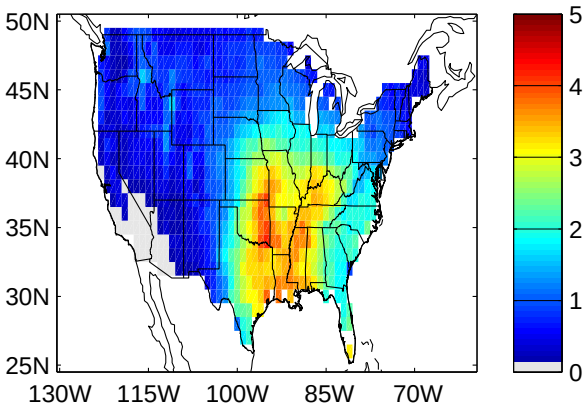
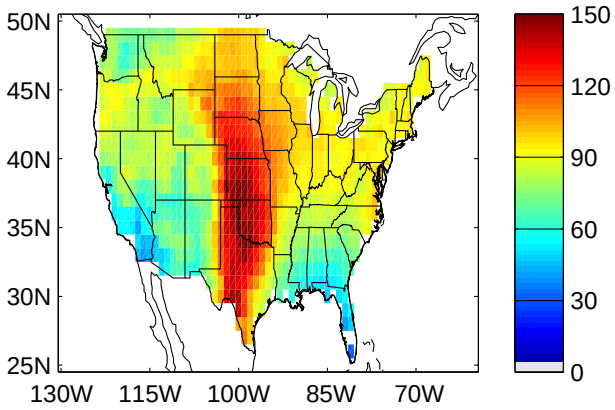


# May parameters

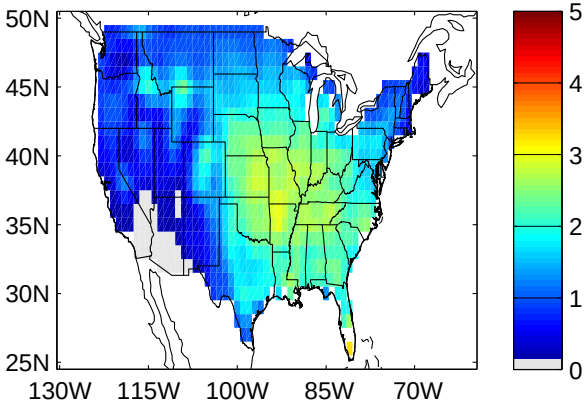
NARR cPrcp



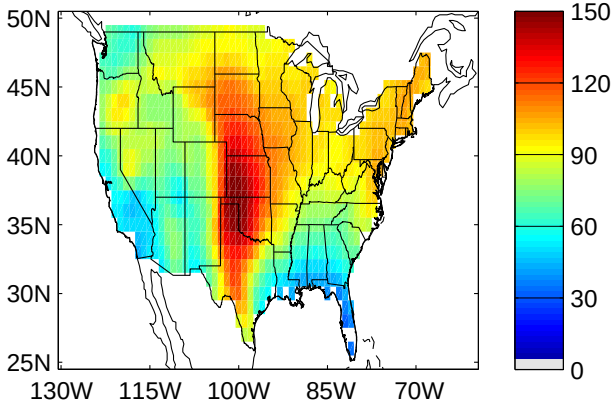

NARR SRH




CFSv2 cPrcp

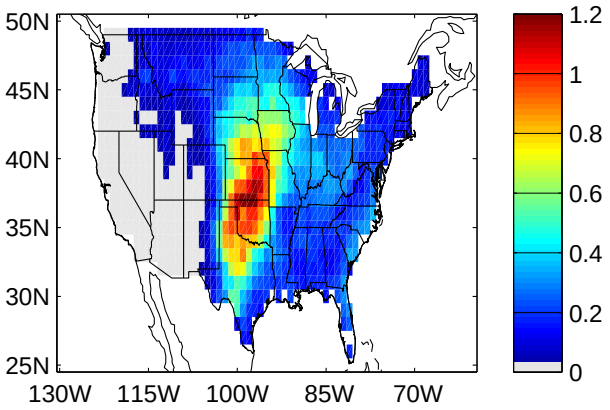



CFSv2 SRH

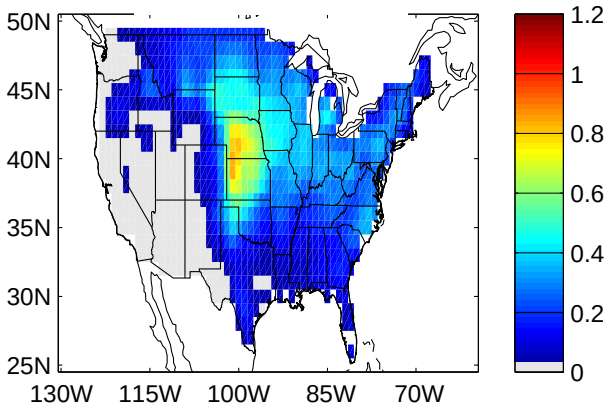


# June indices

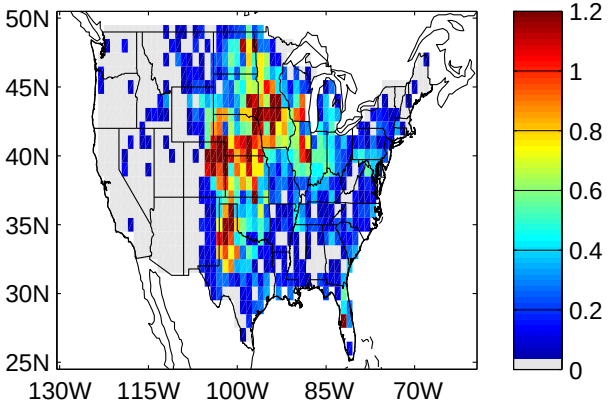
NARR index




CFSv2 index

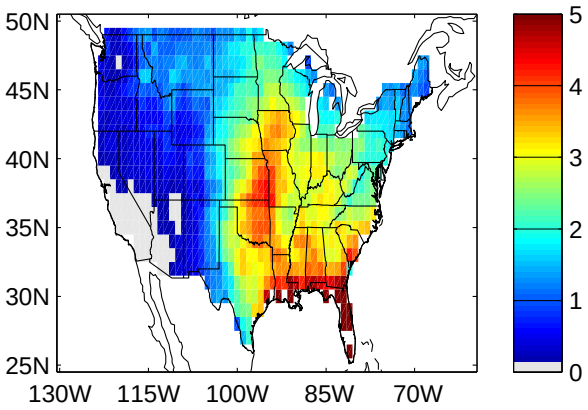



Reports

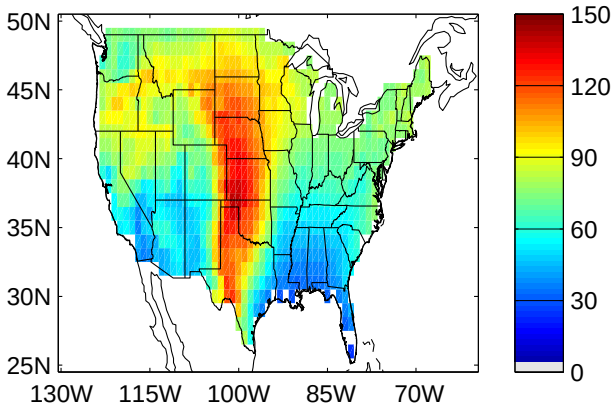


# June parameters

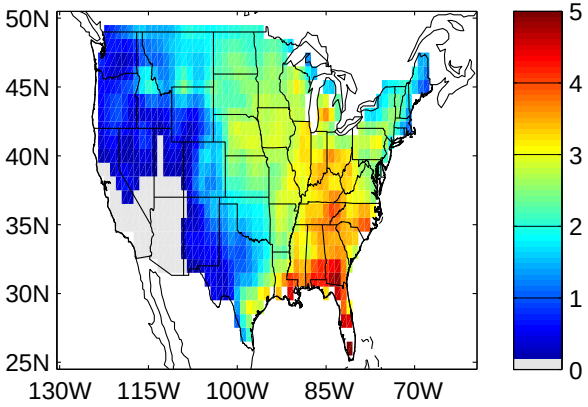
NARR cPrcp




NARR SRH




CFSv2 cPrcp

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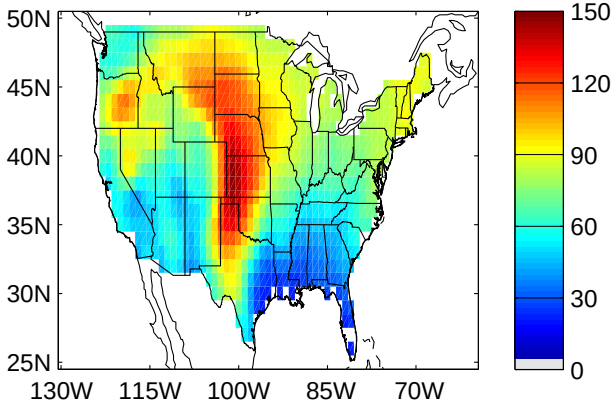
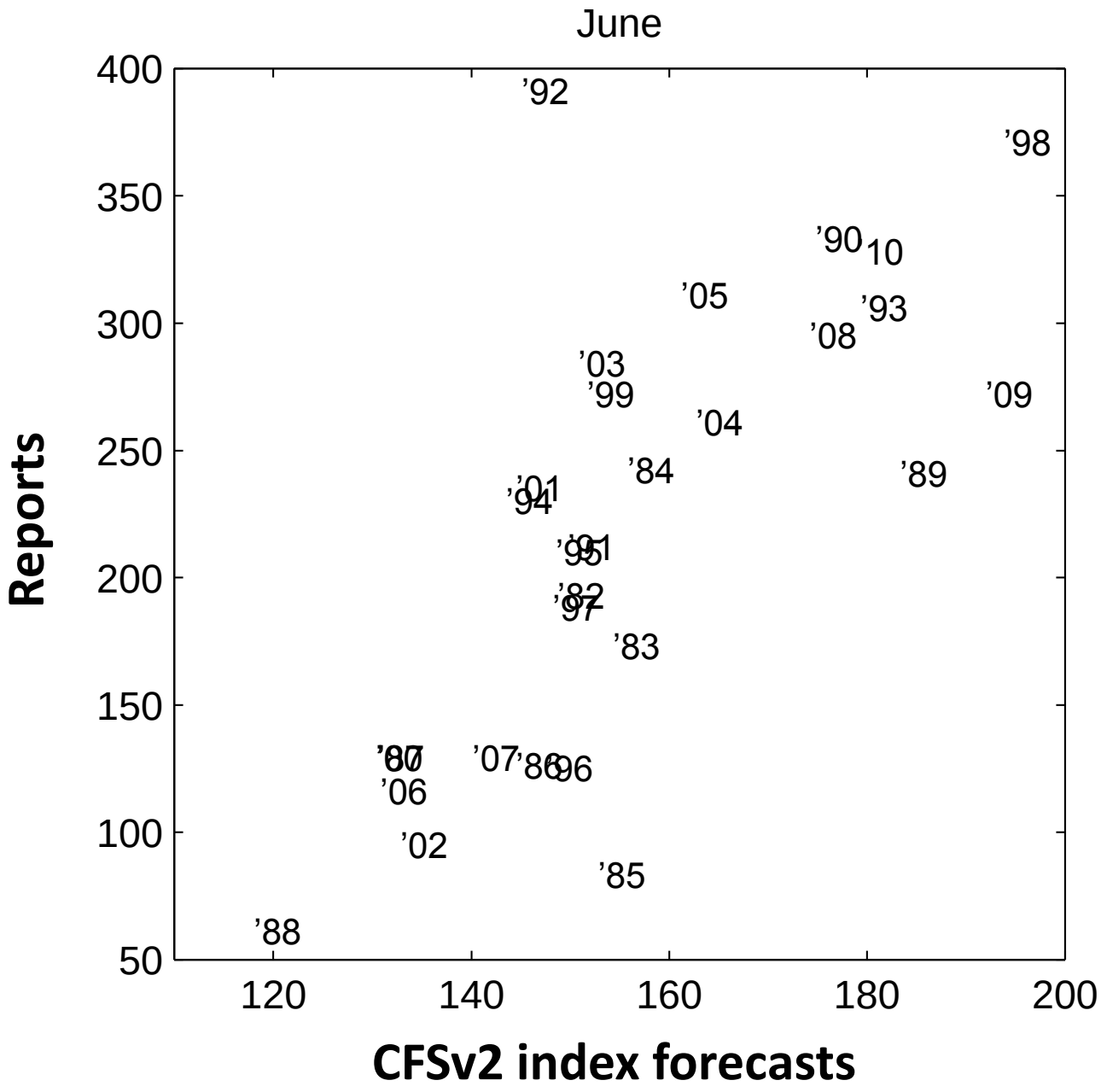


# Monthly Forecasts

# Correlation between index and observed number CONUS

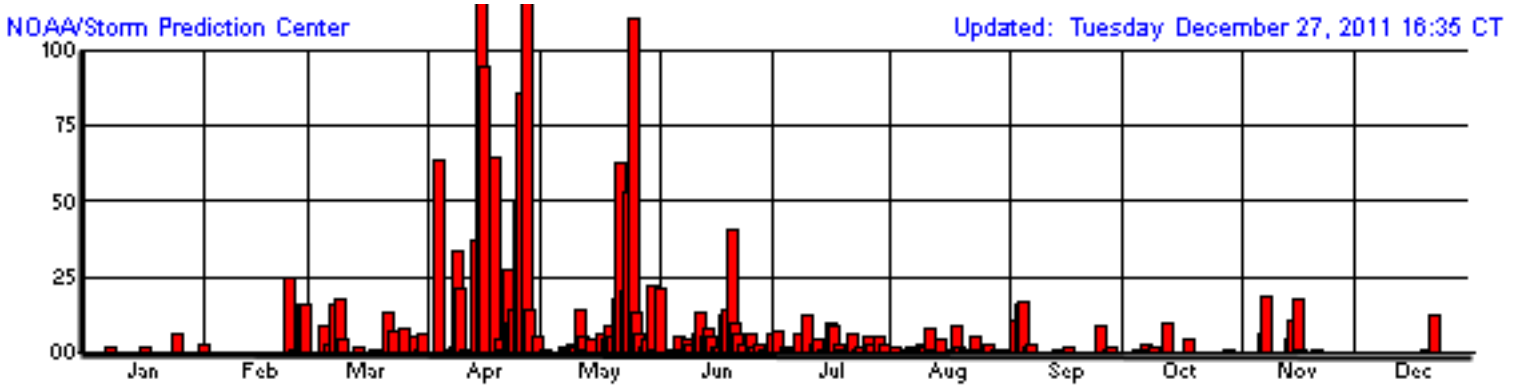
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NARR | **0.75** | **0.64** | **0.54** | **0.50** | **0.60** | **0.67** | **0.75** | **0.40** | 0.15 | 0.25 | **0.48** | **0.74** |
| CFSv2 | 0.36 | **0.38** | 0.30 | 0.35 | 0.31 | **0.72** | **0.59** | **0.41** | -0.25 | 0.18 | **0.41** | **0.37** |

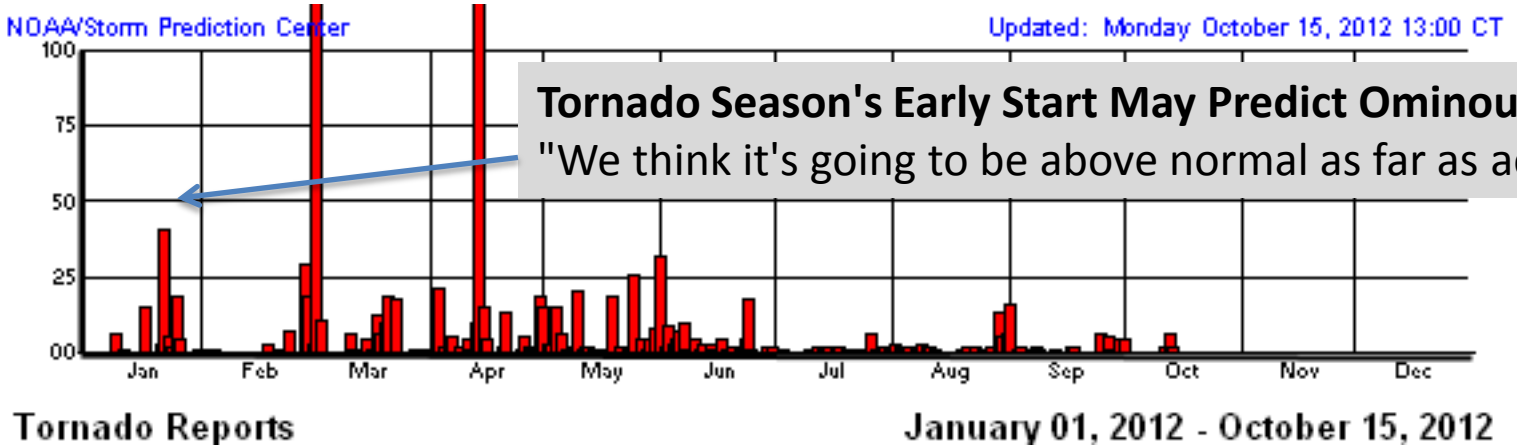

June
Reports
CFSv2 index forecasts
400
350
300
250
200
150
100
50
120
140
160
180
200
’92
’98
’90
10
’05
’93
’08
’03
’99
’09
’04
’84
’89
’01
’94
’95
’97
’83
’07
’86
’96
’06
’02
’85
’88

# Regional correlations

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| South | 0.16 | 0.36 | 0.29 | 0.05 | 0.28 | **0.51** | 0.09 | 0.34 | 0.05 | 0.30 | 0.29 | 0.33 |
| Southeast | 0.22 | 0.24 | 0.00 | **0.41** | **0.66** | 0.25 | -0.01 | 0.00 | **0.49** | 0.26 | **0.45** | **0.47** |
| Central | **0.47** | **0.50** | **0.64** | 0.23 | 0.37 | **0.45** | **0.42** | 0.05 | 0.19 | 0.03 | 0.24 | **0.42** |
| Midwest | | | -0.12 | **0.58** | 0.15 | **0.67** | **0.39** | **0.42** | 0.02 | 0.39 | -0.04 | |
| Plains | | | 0.12 | 0.37 | **0.40** | **0.50** | **0.53** | 0.27 | -0.03 | 0.03 | | |
| Northeast | | | | 0.15 | 0.05 | 0.15 | **0.41** | 0.18 | 0.70 | 0.15 | -0.02 | |
| Southwest | | | | 0.02 | -0.10 | 0.32 | 0.04 | -0.01 | -0.44 | 0.30 | | |
| Northwest | | | | -0.14 | 0.15 | 0.30 | | 0.19 | | | | |
| West | | 0.21 | 0.34 | 0.13 | | | | | | | | |

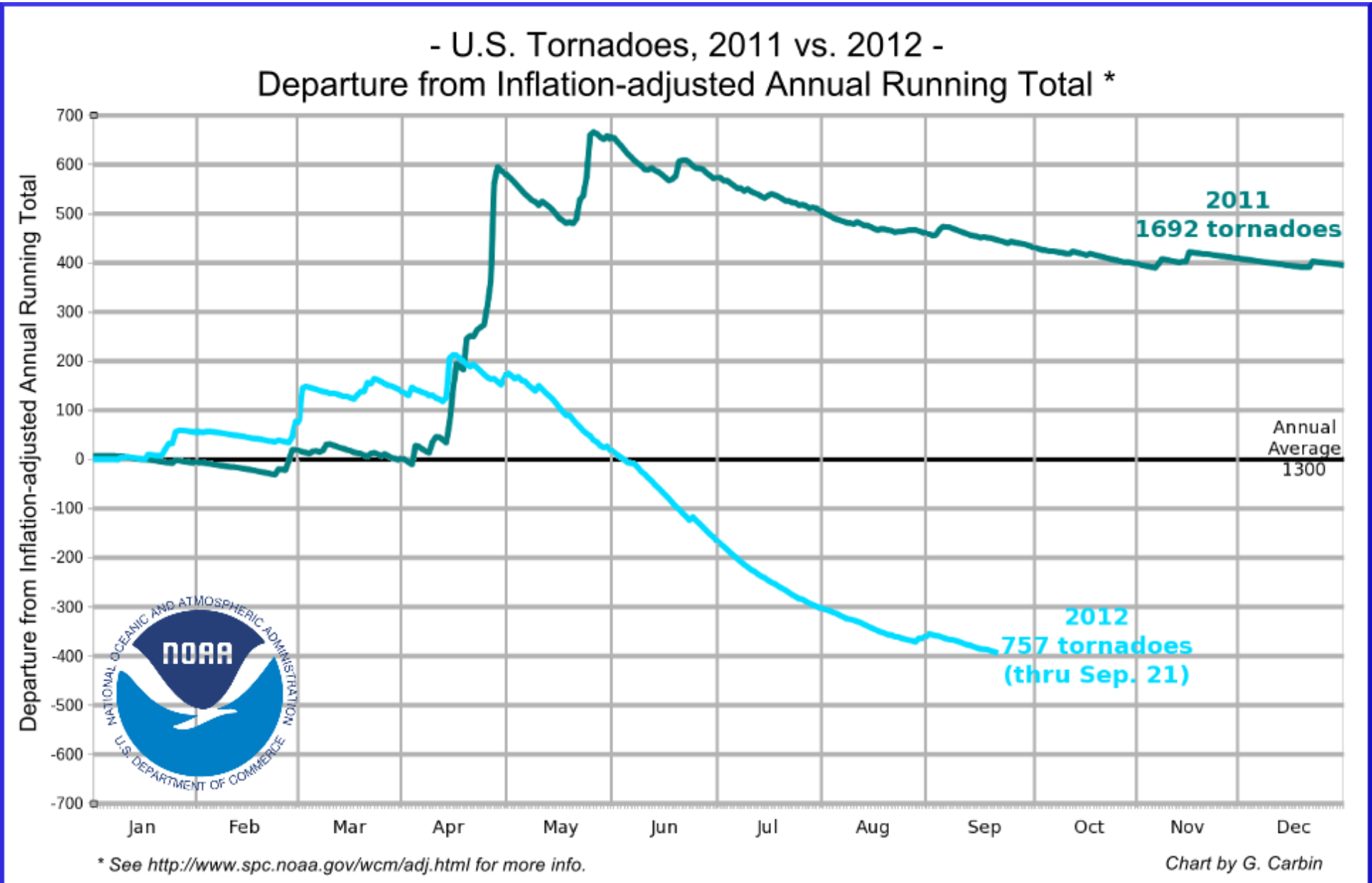
# 2011 and 2012?



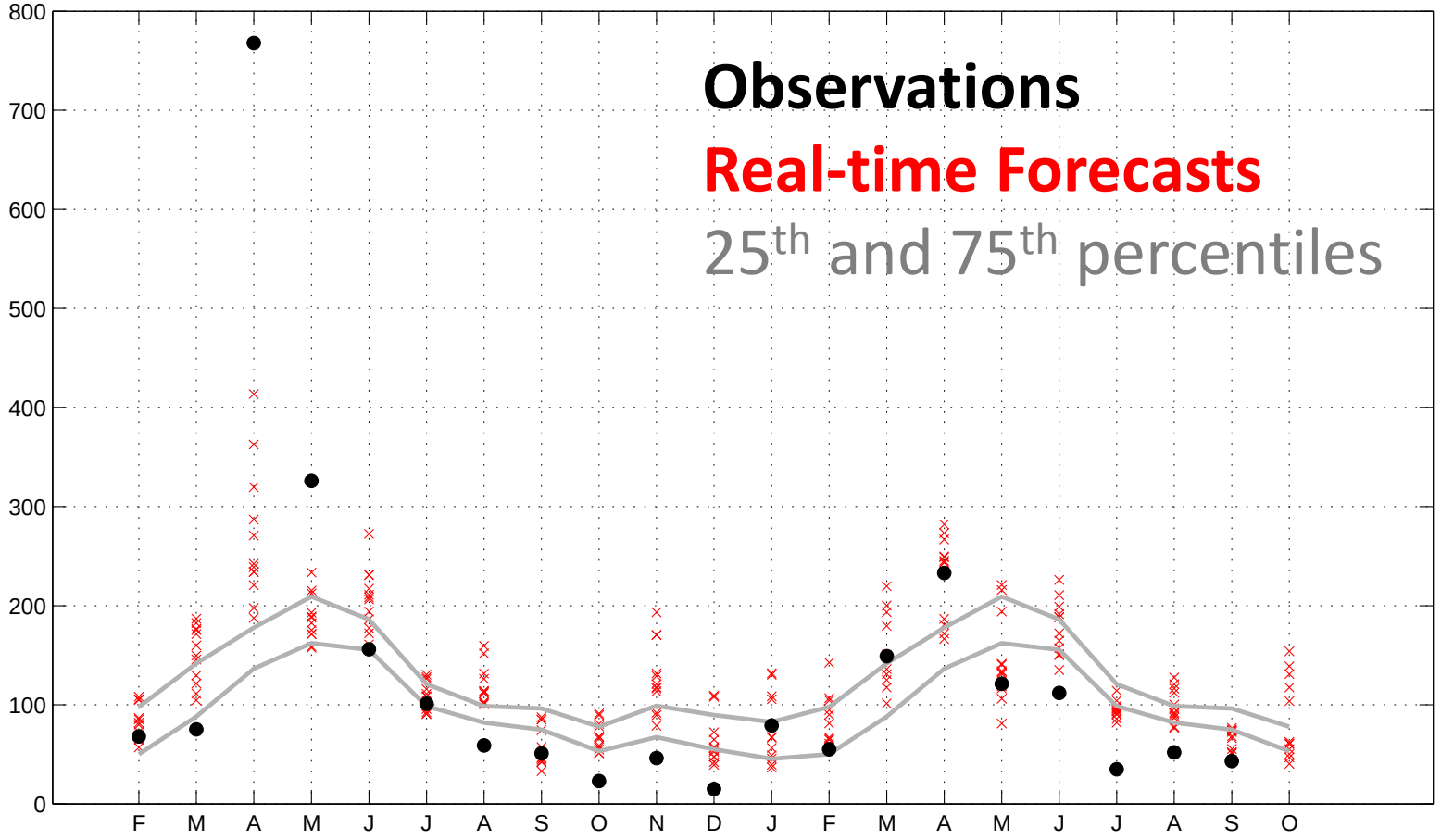

**Tornado Season's Early Start May Predict Ominous Year**
"We think it's going to be above normal as far as activity"

# 2011 and 2012?



# 2011 and 2012?

Daily data?




**2011** **2012** **2013**

# Summary

- A new index associating environmental variables and US tornado activity
  - Explains aspects of annual cycle and interannual variability
- Systematic differences between NARR and CFSv2, especially convective precipitation.
- Monthly CFSv2 forecasts of index show some skill on continental and regional scales
- MOS could be beneficial