Connecting tornado and extreme convective weather occurrence to climate variability and change

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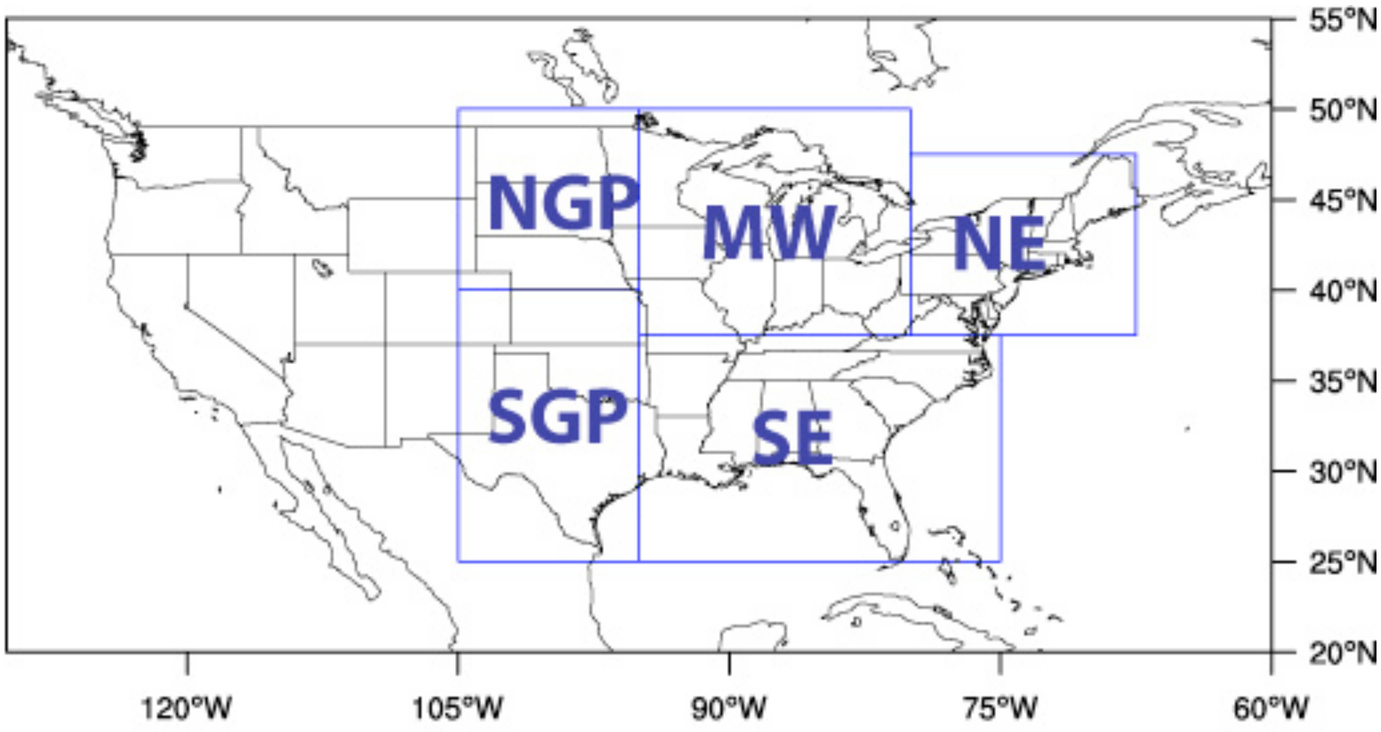
Motivating questions:

1. How will (is) the intensity and frequency of severe *convective-scale* storms respond to changes in human-enhanced *global-scale* radiative forcing?
2. What are the controls of the climate variability of severe thunderstorms/ tornadoes, and how is this variability characterized?

Downscaling via "environmental" parameters

- Individual thunderstorms are unresolved, but we exploit the fact that local storm organization/ intensity is strongly controlled by the wind, temperature, and humidity in the storm's *environment*
  - convective available potential energy (CAPE)
  - vertical wind shear $\left(S06 = \left|\bar{\boldsymbol{V}}_{6km} - \bar{\boldsymbol{V}}_{sfc}\right|\right)$
- NCAR CCSM3, T85, 26 levels
  - 5-member ensemble, A1B emissions scenario
  - continuous integrations from 1950-2100

Trapp et al. (2009, *GRL*)



- **regionally averaged time series**
  - local polynomial regression
  - compute confidence bands at 90% level (Wu and Zhao 2007)

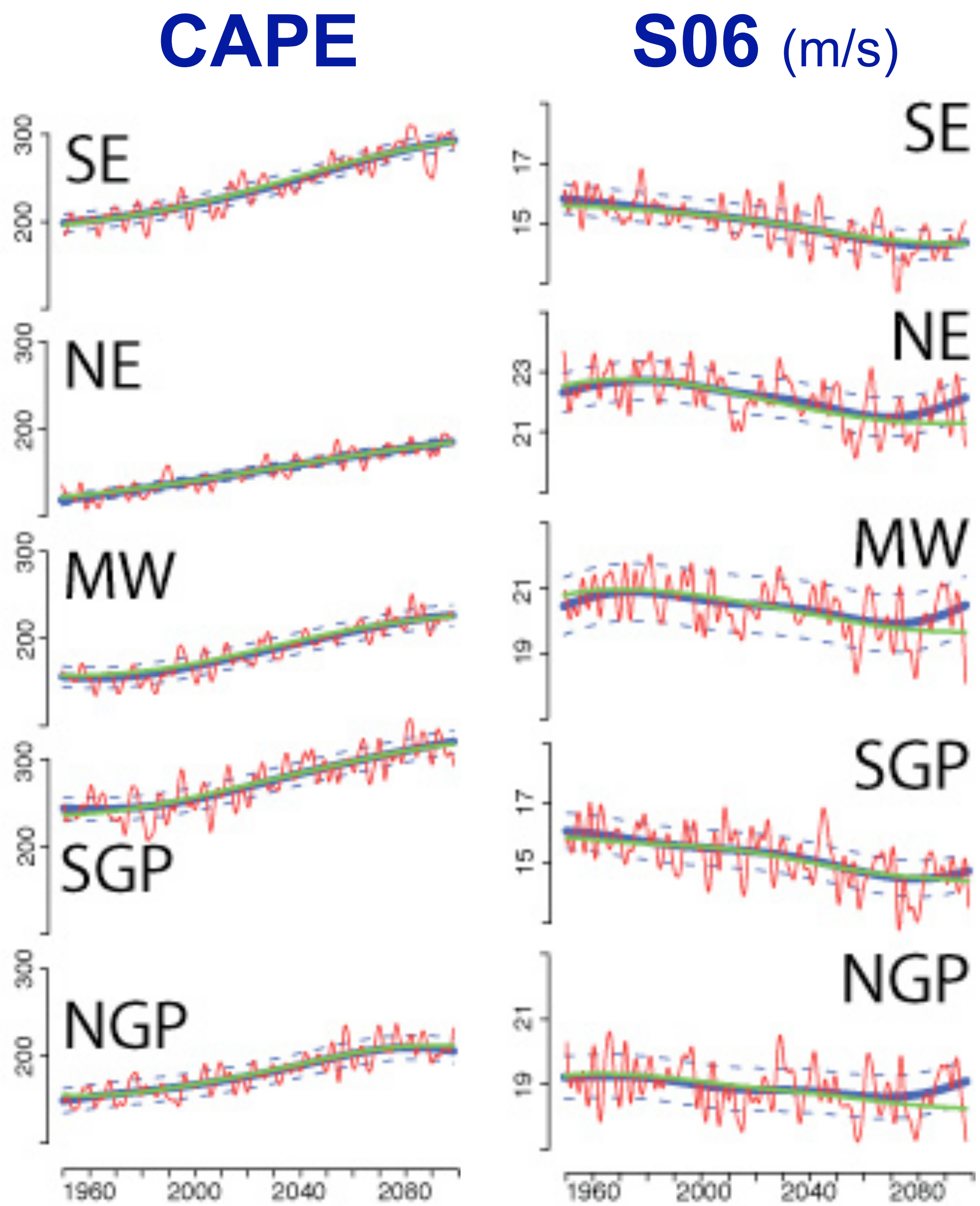
Trapp et al. (2009, *GRL*)

- Positive, statistically significant trends in CAPE

- Generally negative trends in S06

    - *These are consistent with simple physical arguments*

- We need to consider both jointly…



Trapp et al. (2009, *GRL*)

•red line – polynomial fit with12-mth bandwith •blue line – trend •dashed blue – 90% confidence band •green – ensemble mean trend

•Based on the Brooks et al. (2003) LDA results, let occurrences of

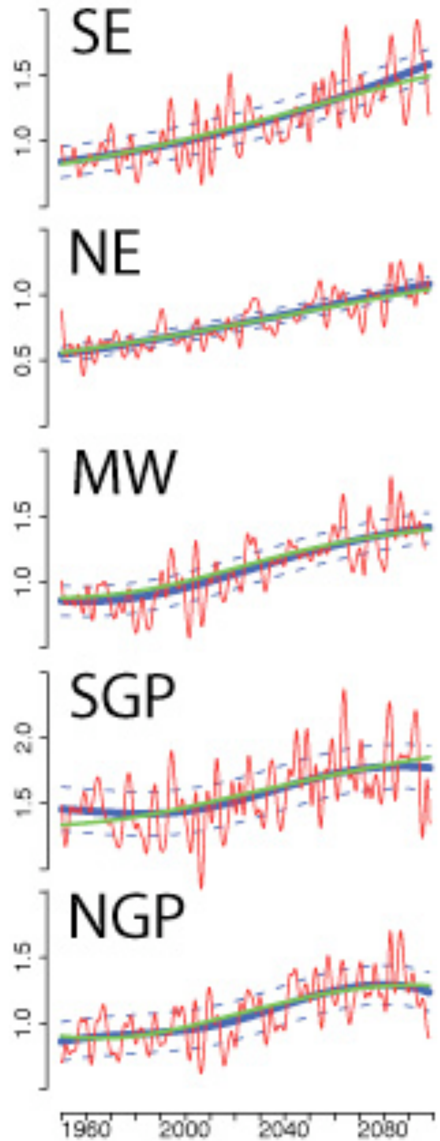
CAPE×S06>10,000

equate to a *severe thunderstorm day* (N_{DSEV})

•The regionally averaged evaluations of N_{DSEV} show positive trends (and large variability)

- *Provides further evidence of the effect of anthropogenic climate change on long-term trends in severe thunderstorm forcing*

N_{DSEV} (days)



Trapp et al. (2009, *GRL*)

Limitation

- Ultimately, coarse resolution allows conclusions only about the forcing, rather than actual convective storms and associated phenomena:
  - the parameters do not quantify *convective initiation*, and convective clouds must first initiate to realize the CAPE and vertical wind shear

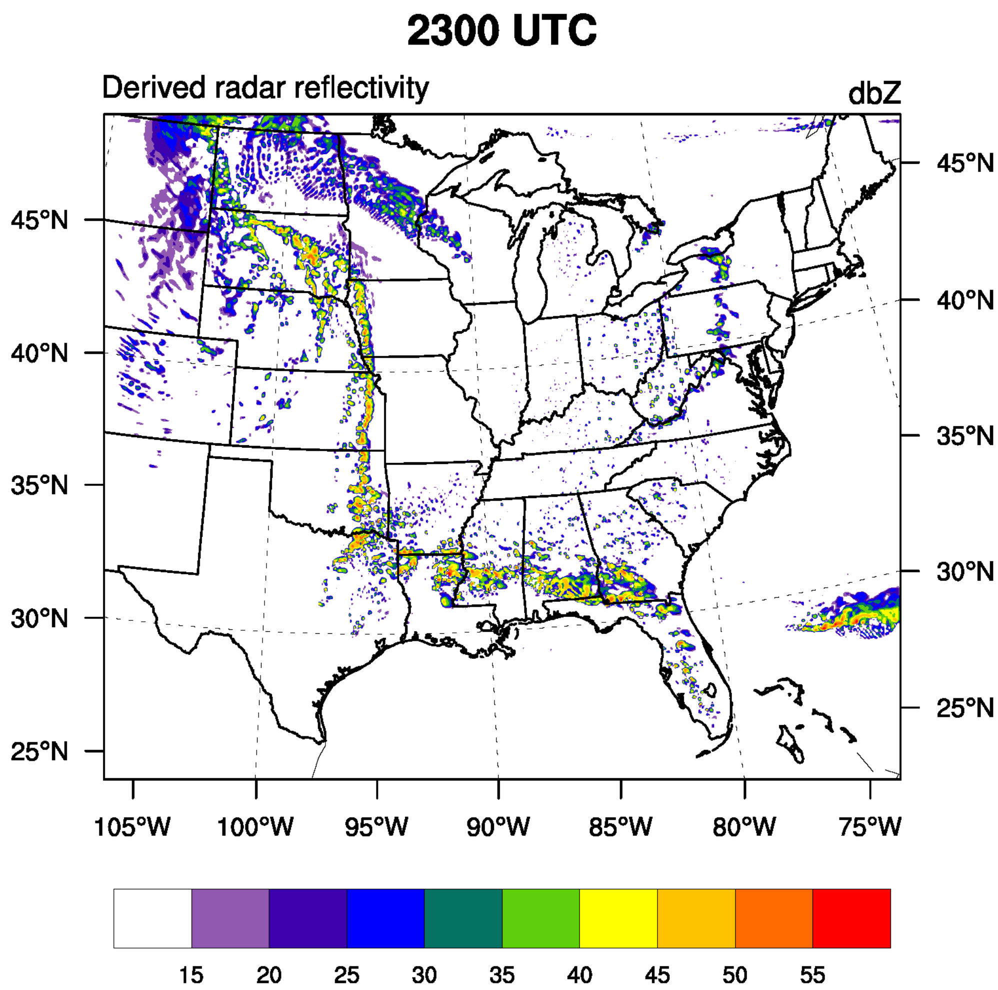
Alternative approach: *High-resolution* dynamical downscaling

- Series of integrations with “advanced research” WRF model, using 4.25-km horizontal gridpoint spacing
  - *convective-storm permitting: no cumulus parameterization*
- Computational domain: continental U.S.
- Initial/boundary conditions from:
  NCEP-NCAR Reanalysis Project (R1) global data

Trapp et al. (2011, *Climate Dynamics*)

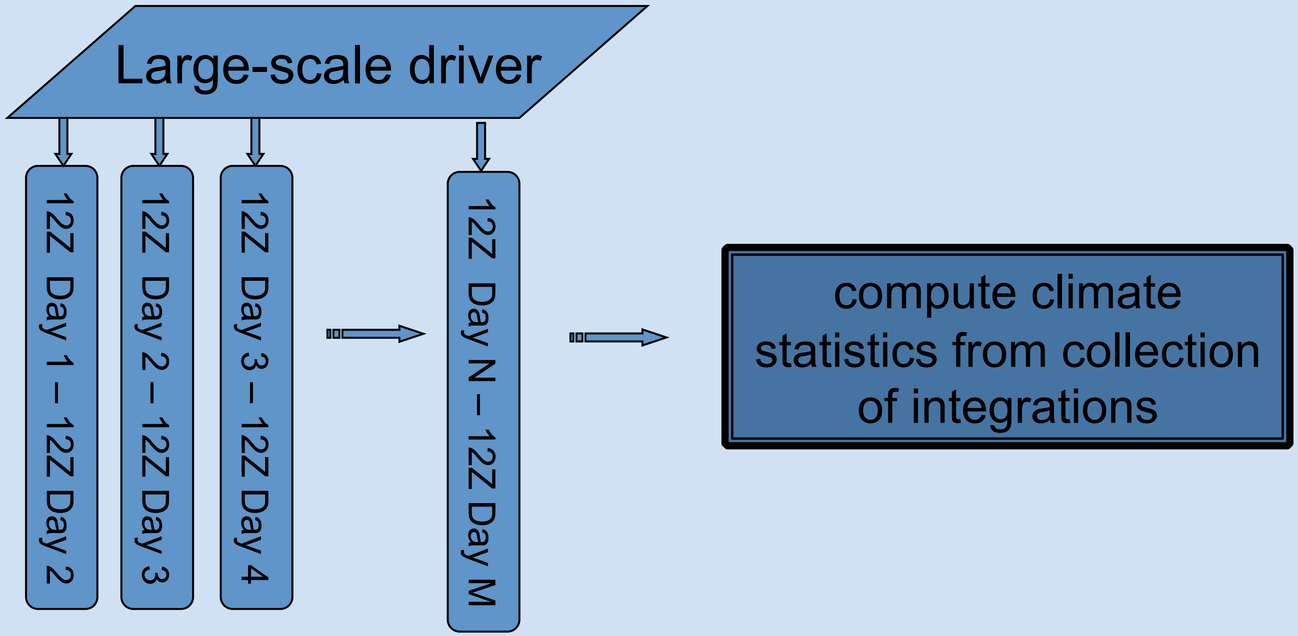
Example of 1-hrly output

IC/BC from R1
global reanalysis



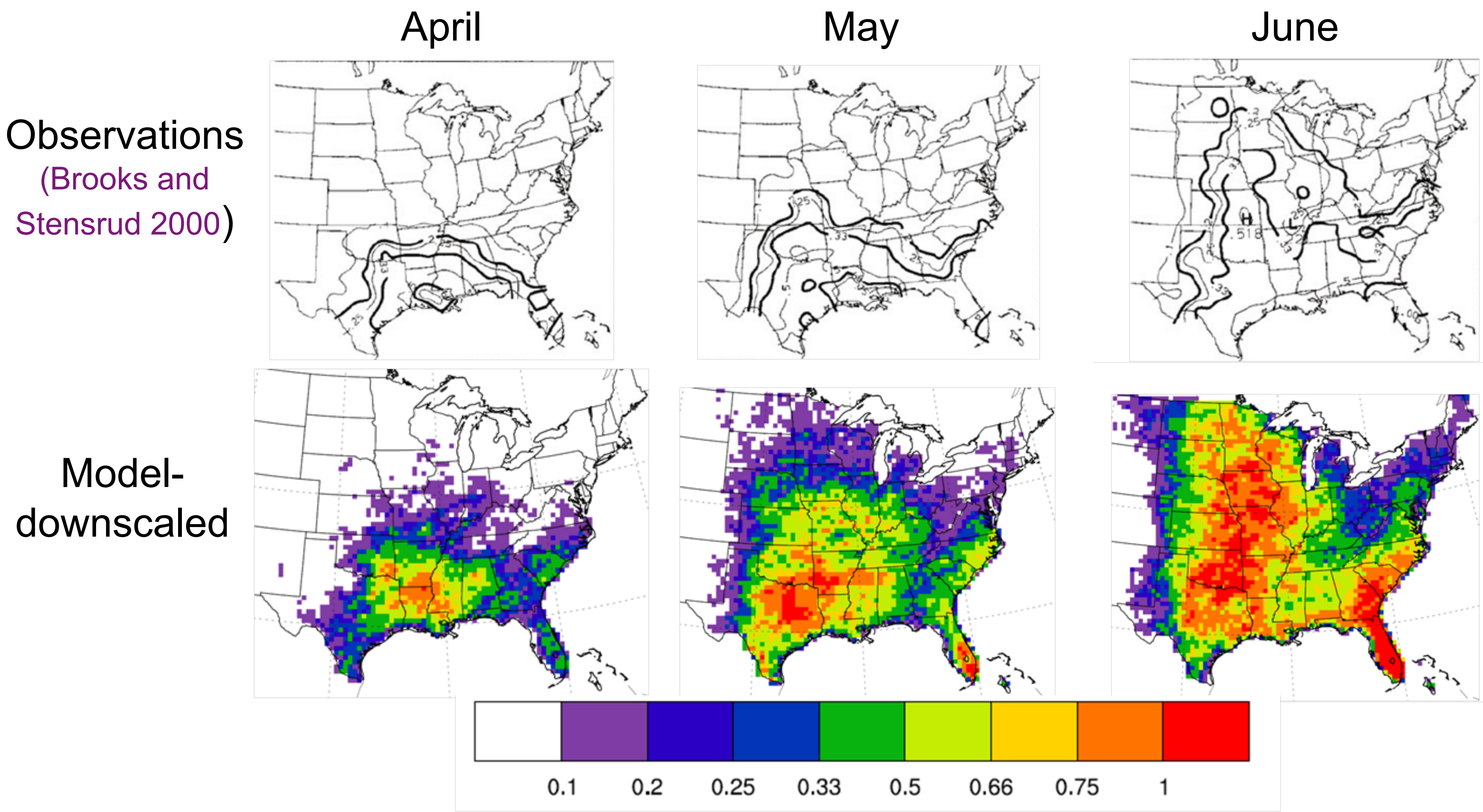
Integration procedure

- *24-h* integrations (12 UTC - 12 UTC) for months of April, May, June, over period 1990-2009
  - daily re-initialization (efficiently use resources, reduce error growth)
  - model "spin-up" within ~6 h: diurnal cycle maintained



Trapp et al. (2011, *Climate Dynamics*)

Mean occurrence frequency of heavy rainfall (> 1 in/hr) (1990-2009)

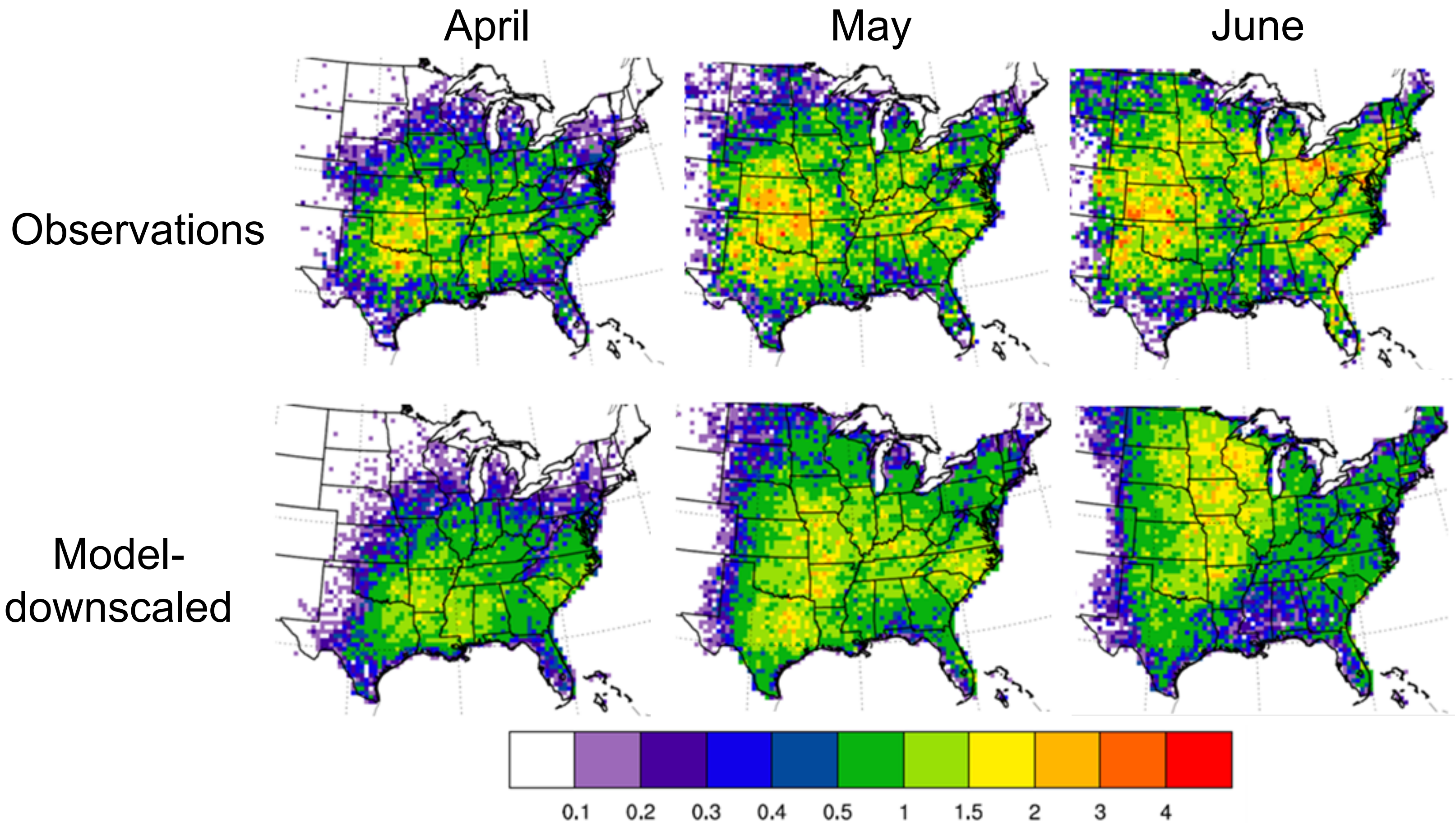


Trapp et al. (2011, *Climate Dynamics*),
and Robinson et al. (2011, *in prep*)

Grid-resolved proxy for severe convective weather occurrence

- Exploits the fact that most hazardous convective storms (i.e., those that produce hail, damaging winds, tornadoes) have rotating updraft cores
- This is quantified using
  1. "updraft helicity," which is a measure of rotation in a convective updraft
  2. simulated radar reflectivity factor, *Z*

Mean occurrence frequency of severe convective weather (1990-2009)



Trapp et al. (2011, *Climate Dynamics*),
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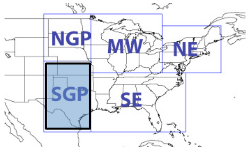
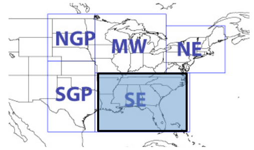
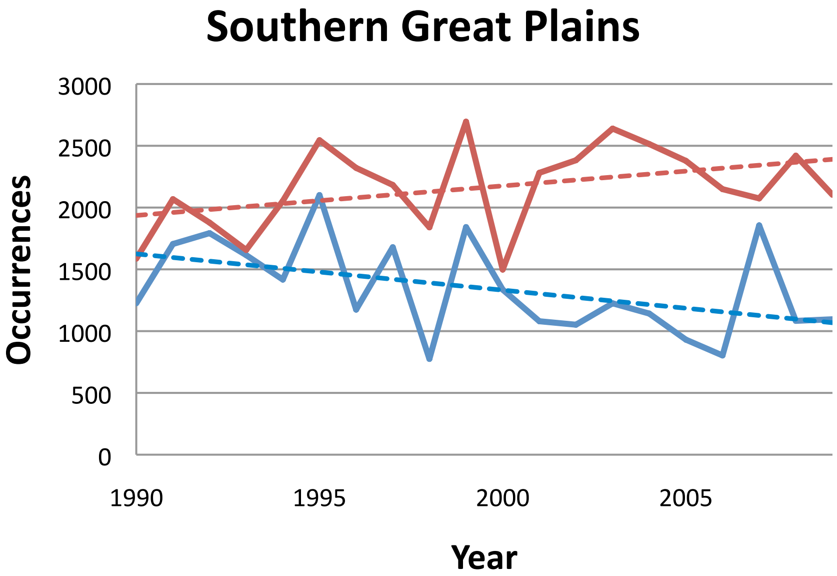
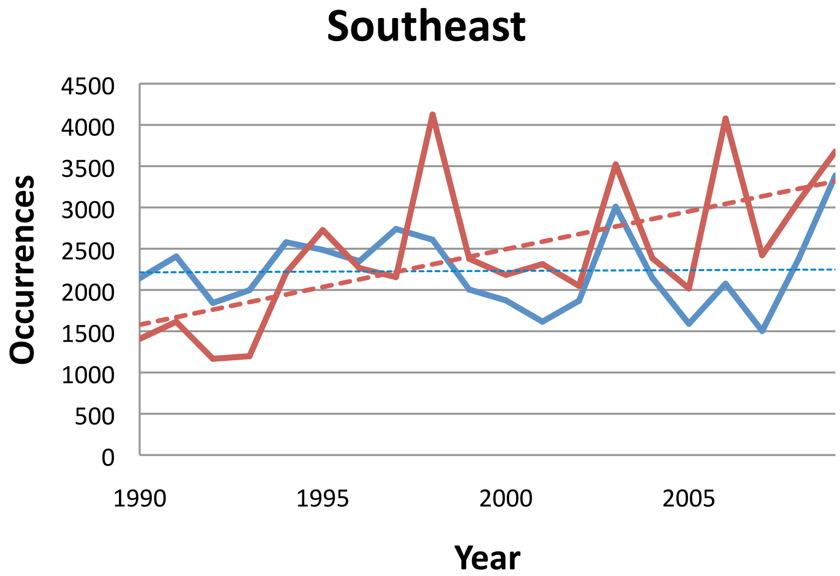
Regionally averaged time series of <u>warm-season</u> occurrences





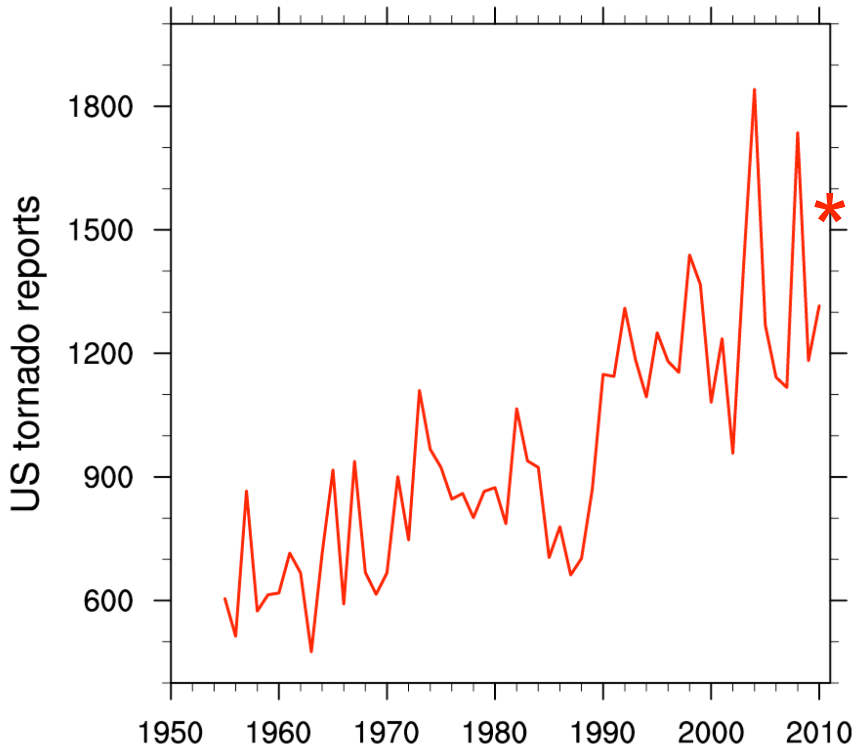




- Interannual agreement between model and observations
- Decrease, or no trend, in the *model-downscaled* occurrences
  consistent with previous work over this short period
- Significant increase in *observed* occurrences

Observed Severe Convective Weather Occurrence: *Temporal*

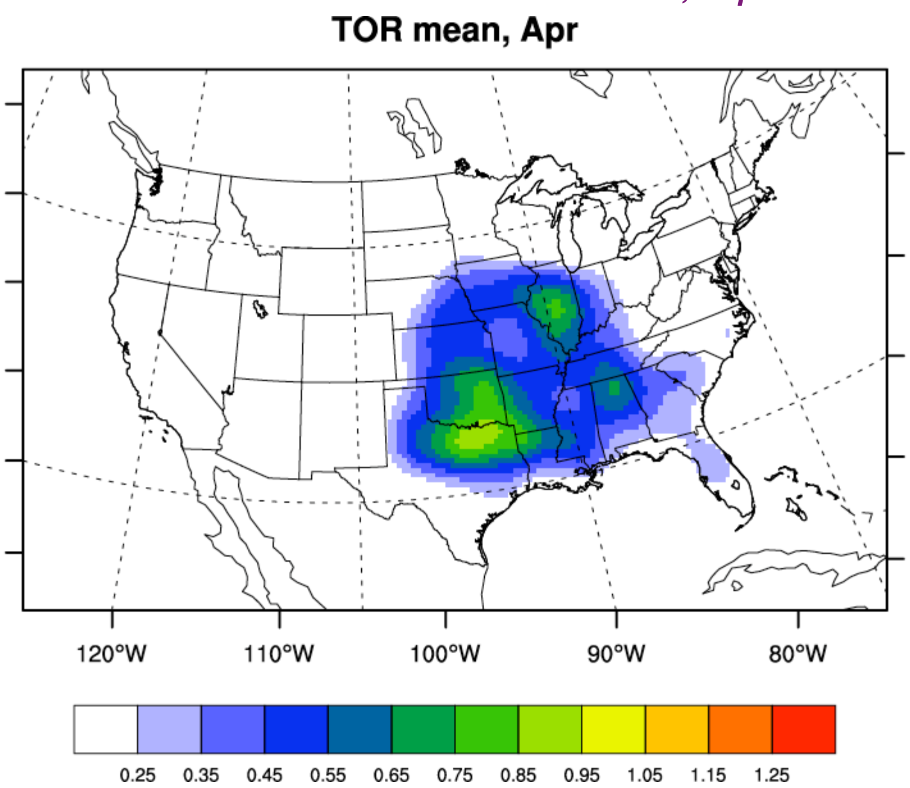
- Derives from eyewitness reports and damage
  - *trend is biased*: true signal in long-term time series is convolved with population growth, reporting procedures, etc.
- Total reports in U.S. is the typical means of characterizing the activity of a given year.
  - Do characterizations by *region* tell the same story?



Observed Severe Convective Weather Occurrence: *Spatial*

- Following Brooks et al. (2003, *WAF*), we consider *tornado days* within grid boxes
  - NARR (221) grid (~32 km)
  - 1980-2009 (*N*=30)
- apply temporal and spatial smoothing (Gaussian Kernel)

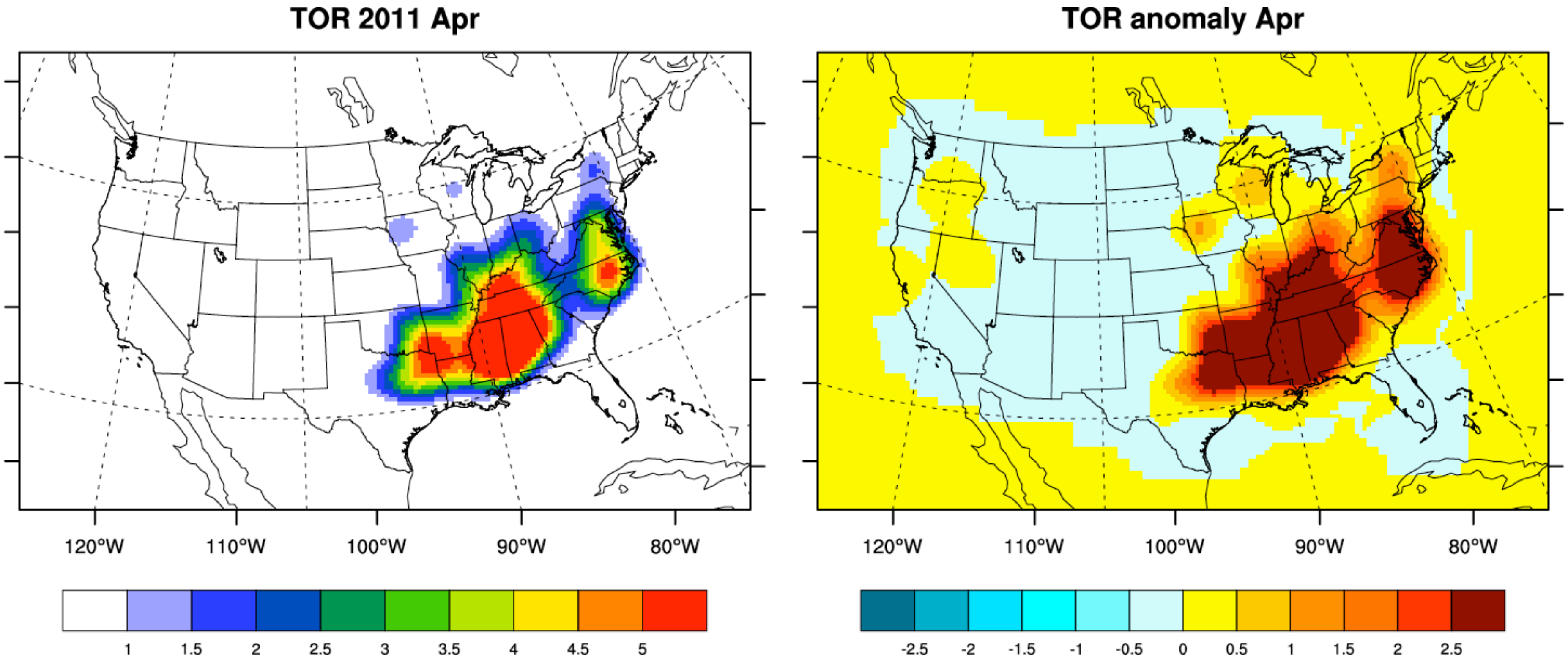
Mean tornado occurrence, April



0.25 0.75 1.25

Trapp and Brooks (2011, *in prep*)

Apply same procedure to individual years, and then compute anomalies ($x' = x_{yr} - x_{mean}$)

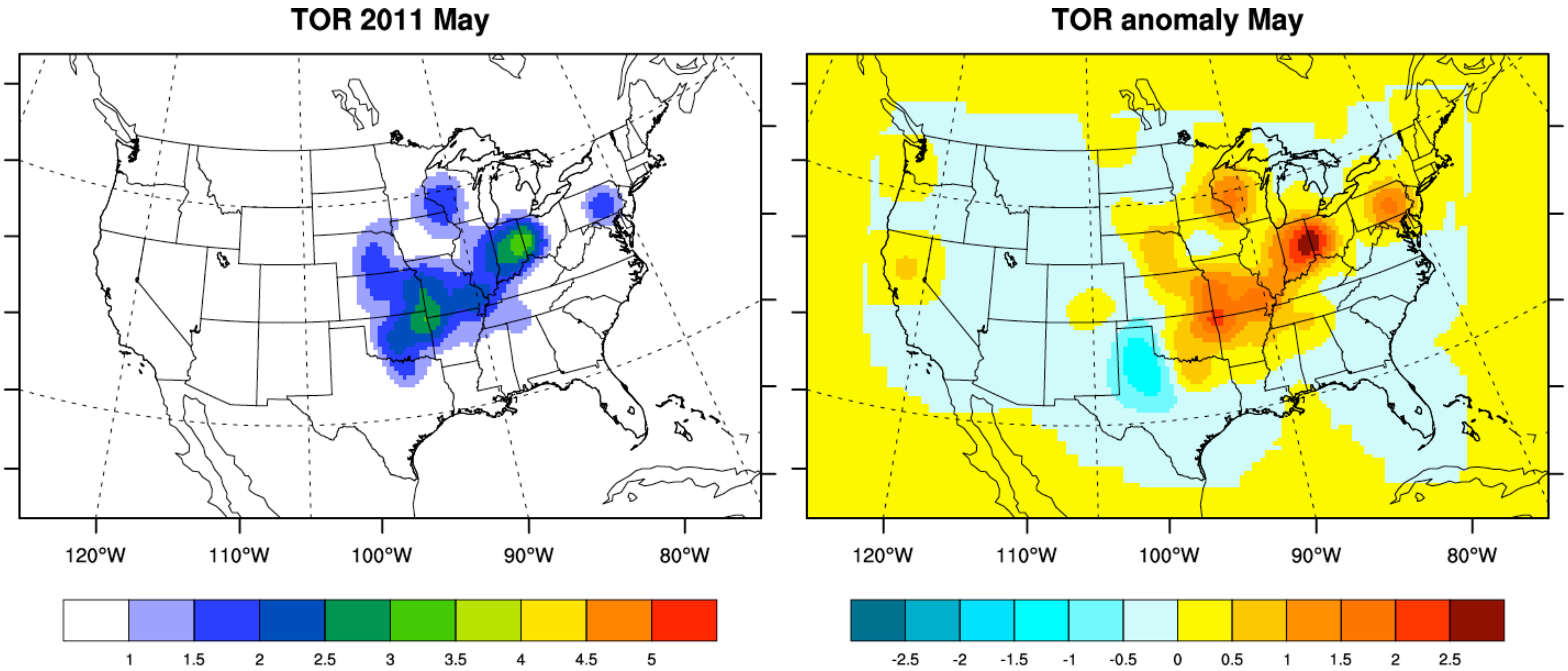


1.0 3.0 5.0

-2.5 0.0 2.5

Trapp and Brooks (2011, *in prep*)

Tornado activity during May 2011

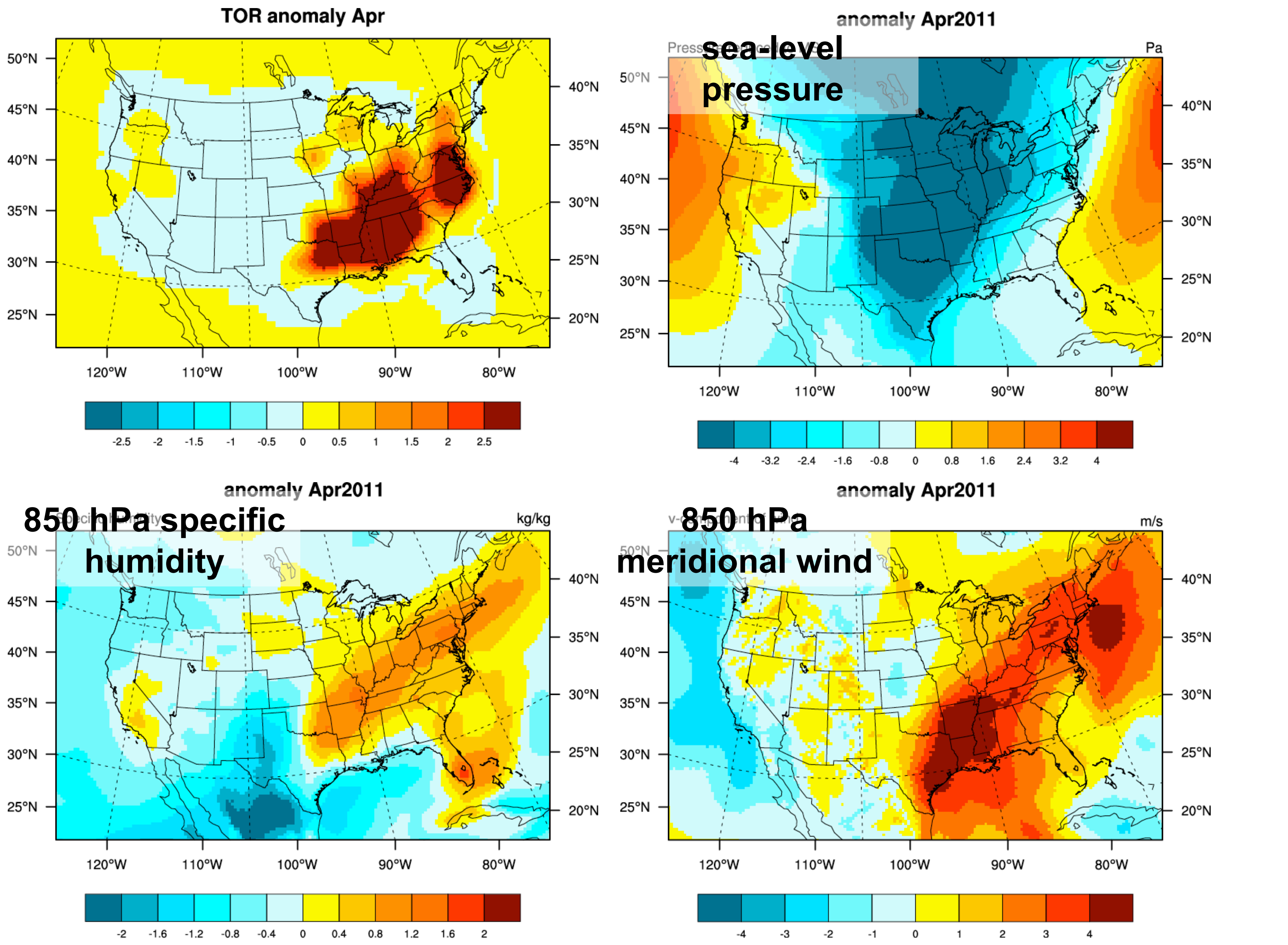


1.0 3.0 5.0 -2.5 0.0 2.5

Trapp and Brooks (2011, *in prep*)

Conclusions

- The regional contributions to the total U.S. tornado activity varies substantially from year-to-year and month-to-month
  - An active year for the U.S. could be relatively inactive for specific regions
  - April 2011 was an anomalously active year in the southeast U.S.
    - …not just reported tornadoes, but number of days of tornado activity
- Occurrence anomalies relate well to anomalies in atmospheric variables (NARR)


TOR anomaly Apr
-2.5 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 2.5
anomaly Apr2011
sea-level pressure
Pa
-4 -3.2 -2.4 -1.6 -0.8 0 0.8 1.6 2.4 3.2 4
anomaly Apr2011
850 hPa specific humidity
kg/kg
-2 -1.6 -1.2 -0.8 -0.4 0 0.4 0.8 1.2 1.6 2
anomaly Apr2011
850 hPa meridional wind
m/s
-4 -3 -2 -1 0 1 2 3 4
50°N 45°N 40°N 35°N 30°N 25°N
40°N 35°N 30°N 25°N 20°N
120°W 110°W 100°W 90°W 80°W

Ongoing work, future directions

- Relate occurrence anomalies to anomalies in atmospheric variables (NARR)
  - framework for attribution, seasonal predictions

Acknowledgments:

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NCAR ASD

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Model setup: similar to forecast-model applications

Parameterization	Scheme
Microphysics	WSM6
Radiation (SW/LW)	Dudhia / RRTM
Land Surface Model	Noah
Planetary Boundary Layer	MYJ
Model Parameters	
time step	25 s
vertical (Eta) levels	35
horizontal gridpoints	n_x = 790, n_y = 660, $delta_{x,y}$ = 4.25 km