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+

Year

Reports
China-Hail Frequency

Xie et al. 2008 (GRL)
France/Italy Hailpad Data

Berthet et al. (ECSS 2009)

Occurrence

Eccel et al. (2011)

Kinetic Energy
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

Year

What has changed about tornado distributions?

- Appearance of increased variability
- Starting date
- Most monthly records (max/min) are recent
- Days per year (F1) decreased
- More tornadoes on biggest days
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
Mean Change

Brooks, Marsh, and Carbin
(*Proc. Nat. Acad. Sci.*, in prep.)

95% Confidence

Warm summers - fewer tornadoes
Warm winters - more tornadoes

Monthly Change in Number of (E)F-1+ Tornadoes Per Degree Celsius of Warming

Change in Tornadoes Per Degree Warming

Month and Mean Tornado Count
Change in Mean Number of (E)F-1+ Tornadoes
Warm-Cold; 20 Years; 1954-2013

* Within 25 miles of a point
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)

Sfc-6 km Wind Difference (m/s)

CAPE (J/kg)

Little severe
Significant severe
Significant tornado
'Best' discriminator

Energy →

Shear →
(Dan Cecil, Univ. of Alabama-Huntsville)
(a) Mean Hail Index 1979–2012

(b) Mean Large Hail Events 1979–2012

Allen et al. 2015
Annual Total Hail Events and Index

CONUS Hail Events

Year

Observations
Index
Adjusted Obs.


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
Climate model projections for ingredients

Diffenbaugh et al. (2013)
Ensemble S/N > 1

White dots:
Ensemble S/N > 2

Favorable Severe Storm Environments

Diffenbaugh et al. (2013)
Seeley and Romps 2015

JJA

Moderate CO2

Much CO2

GFDL-CM3

RCP4.5  RCP8.5
Mean Δ (%) : 94   121

GFDL-ESM2M

RCP4.5  RCP8.5
Mean Δ (%) : 19   46

MRI-CGCM3

RCP4.5  RCP8.5
Mean Δ (%) : 11   39

NorESM1-M

RCP4.5  RCP8.5
Mean Δ (%) : 12   -8

Seeley and Romps 2015
Favorable Tornado Environments

Moderate CO2

Much CO2

Much-Mod

Mean days/year

Δ days

-30 -24 -18 -12 -6 0 6 12 18 24 30

1971-2000

JJA

2011-2040

2041-2070

2071-2100

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
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?