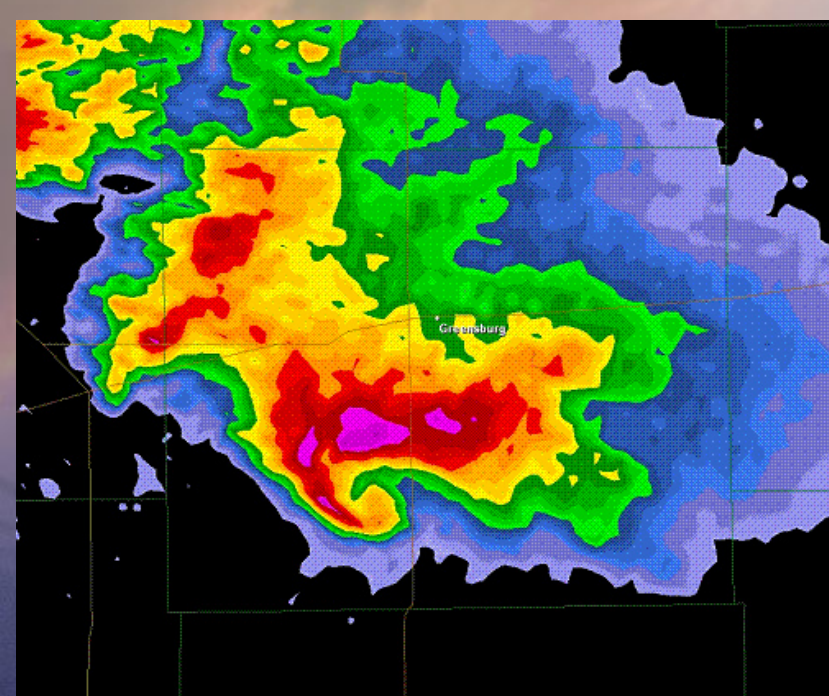


The Science of Tornadoes



Dr. John A. Knox
University of Georgia
Masters of Disaster Workshop
May 23, 2011

Above: Doppler radar reflectivity and aftermath (<http://twitpic.com/51ar69/full>) of 5/22/2011 Joplin, MO tornado ;
reflectivity and aftermath (Ackerman and Knox, 3e) of 5/4/2007 Greensburg, KS EF-5 tornado

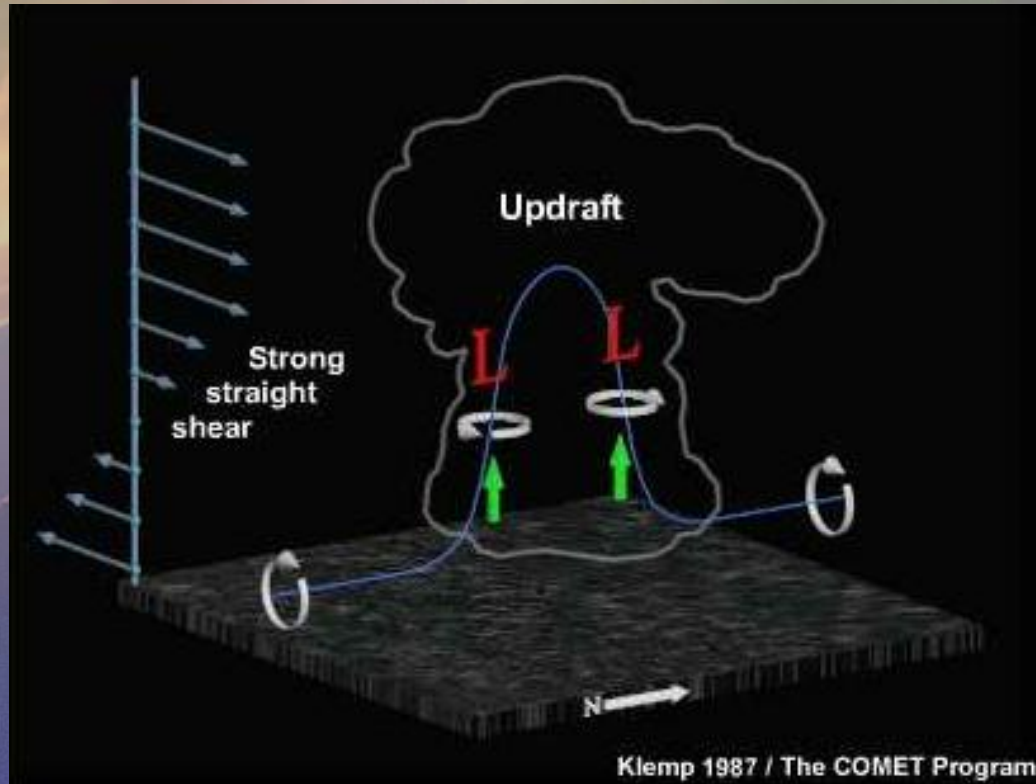
First: the role of vertical wind shear in thunderstorms

- **Vertical wind shear:** change of *horizontal* wind (in both speed and direction) as you go *up*
- Causes of vertical wind shear:
 - Large-scale “environmental” winds (**jet streams**)
 - Small-scale flow around thunderstorm (**downdraft** and outflow from storm, called the “cold pool”)
- Interaction of **vertical wind shear** with thunderstorm **can radically change the character and life cycle of a thunderstorm**

Thunderstorm summary

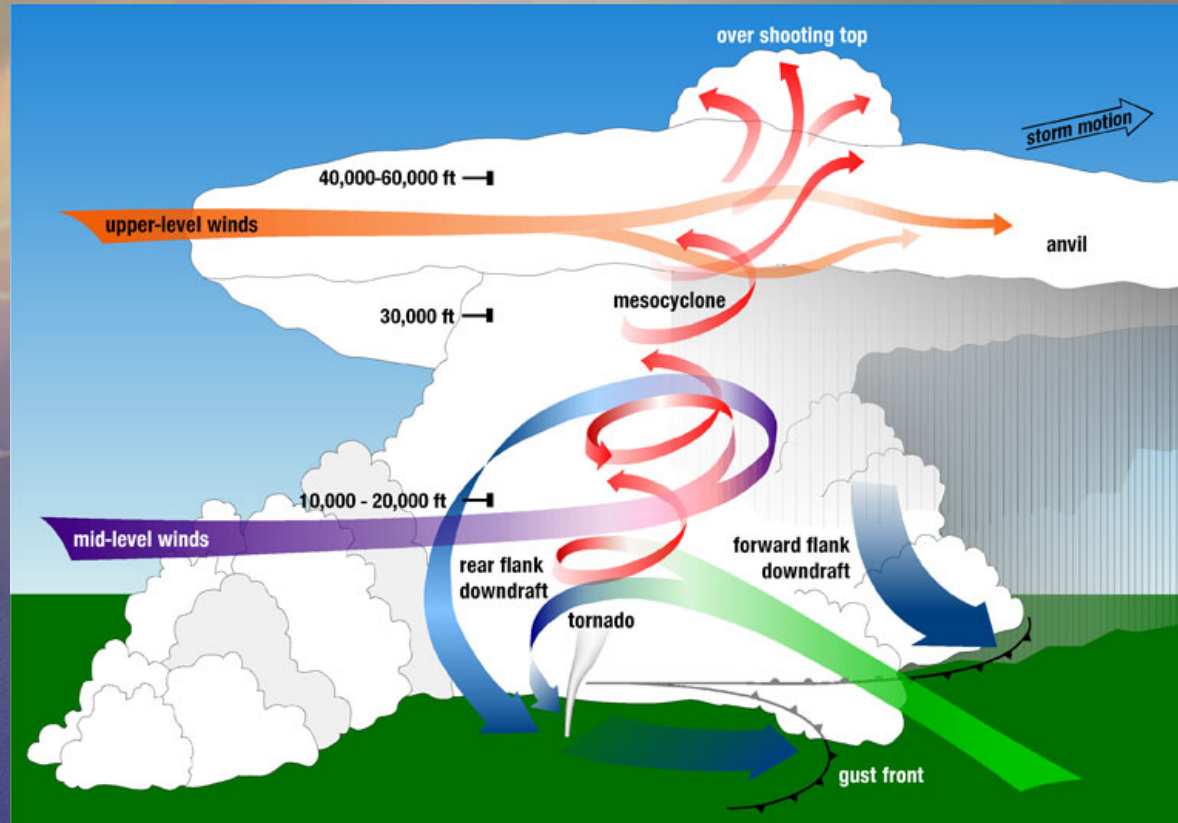
	Amount of vertical wind shear	% of tornadoes caused by
Air mass	Small	Close to 0%
Multicell	Moderate	About 20%
Supercell	Large (especially directional shear)	About 80% (even higher for violent tornadoes)

“Supercell” thunderstorm



- Strong shear at surface is tilted upward by updraft
- Result: oppositely spinning pair of “mesocyclones” inside the thunderstorm (demo)
- **Rotating updraft is signature of supercells**

“Supercell” thunderstorm schematic



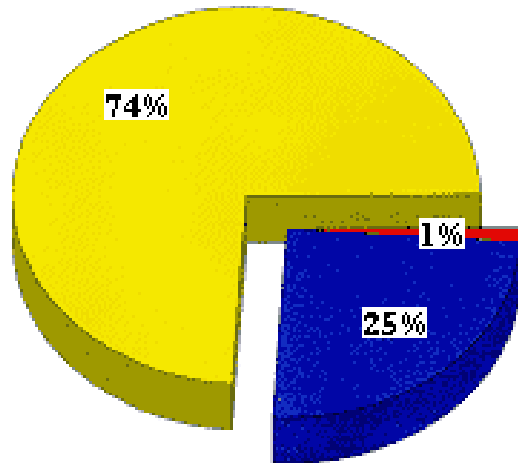
http://www.nssl.noaa.gov/primer/tornado/tor_basics.html

- Low pressure caused by tilted-upward rotation
- Low “sucks in” more air, accelerating rotation and causing storm to move to the *right* of upper-level winds (“*right-movers*”)
- **In only 30% of supercells, tornado forms** (beneath mesocyclone)

A few tornadoes = most of the problem

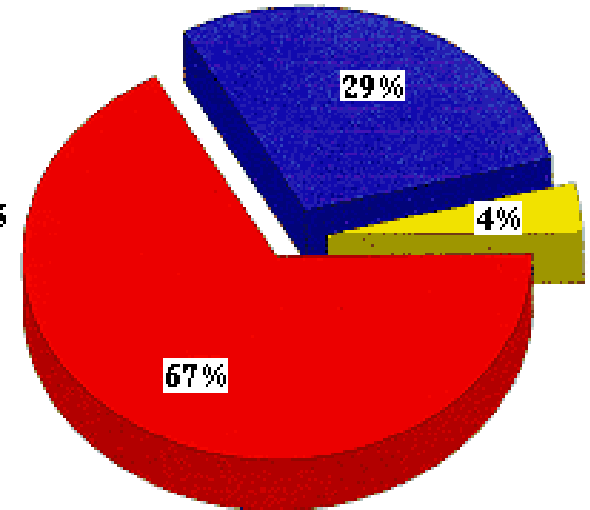
Percent of All Tornadoes 1950-1994
by Fujita Scale Class

Weak F0-F1*
Strong F2-F3
Violent F4-F5



Percent of Tornado Related Deaths 1950-1994
by Fujita Scale Class

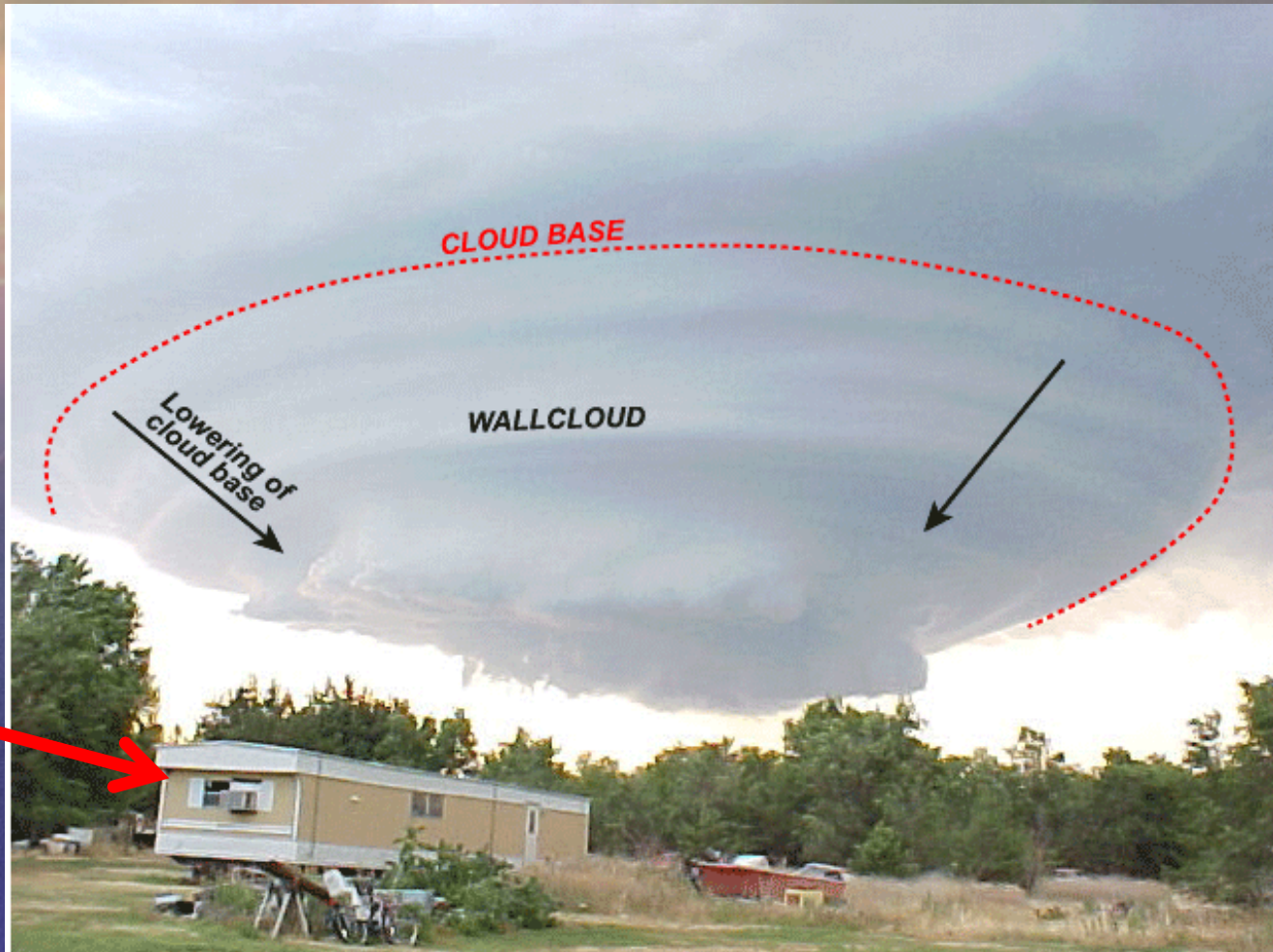
Weak F0-F1*
Strong F2-F3
Violent F4-F5



Graphs from www.tornadoproject.com

- **1% of all tornadoes cause 2/3rds of all the deaths**
- Nearly all of 1% are from supercell thunderstorms
- And so: **focus mostly on tornadic supercells!**

Rotating thunderstorm wall cloud



Bad
place
to be!

From Ackerman and Knox,
Meteorology: Understanding the Atmosphere, 2nd edition (2e)

Tornado

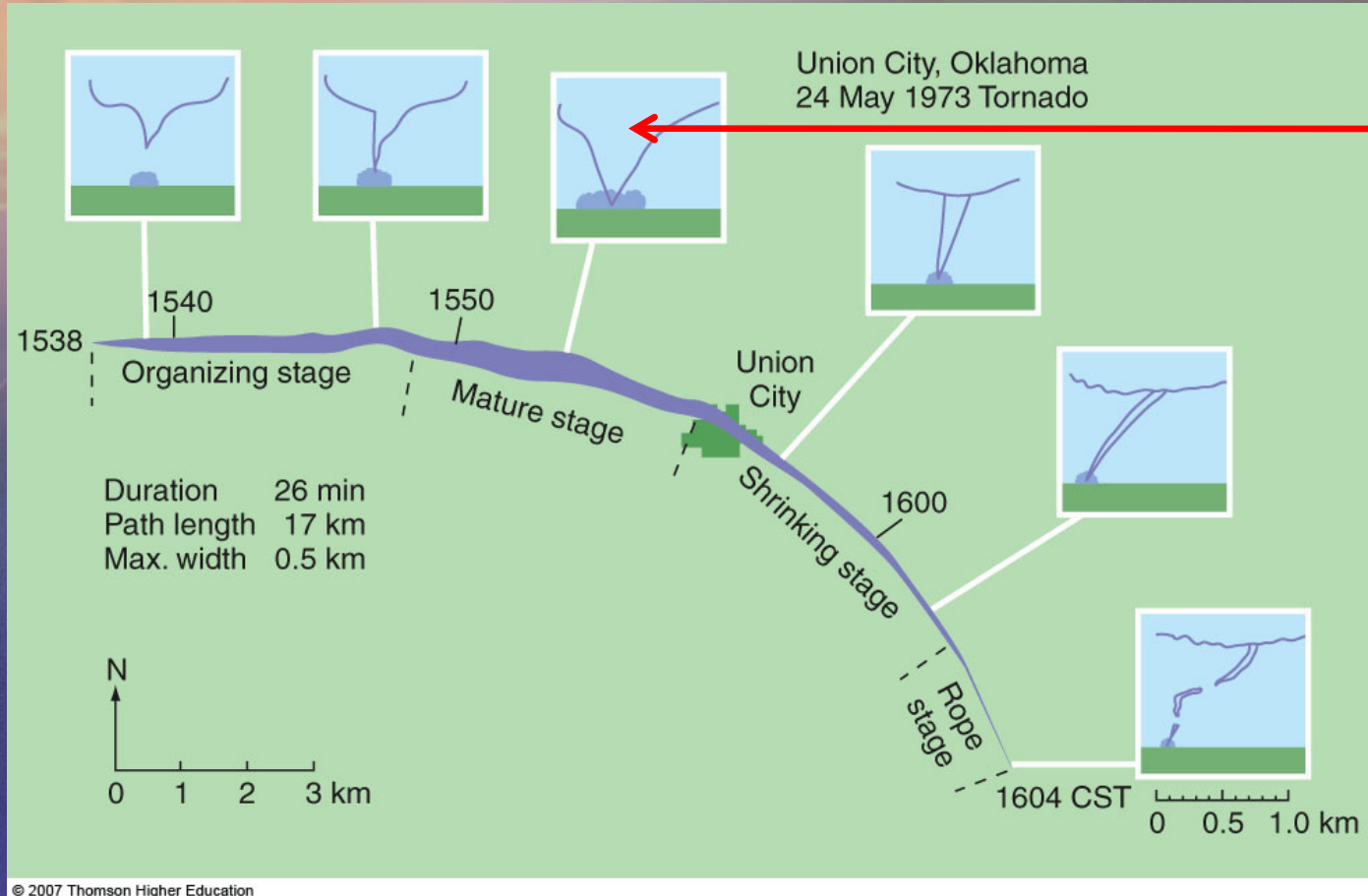
- **Most violent winds on Earth** (over 200 mph; 318 mph radar-measured above ground)
- Funnel caused by condensation of water vapor rising in low pressure; dust, debris, too
- At worst, tornadoes can be **1-2 miles wide, last 1-2 hours, and travel over 100 miles** (4/27/2011 outbreak pushed these limits)
- Worst place on Earth for tornadoes: **central U.S.** (all ingredients for supercells exist there)



*Another bad
place to be!*

Tornado life cycle

If fat part of funnel down to near ground, called “**wedge** tornado”

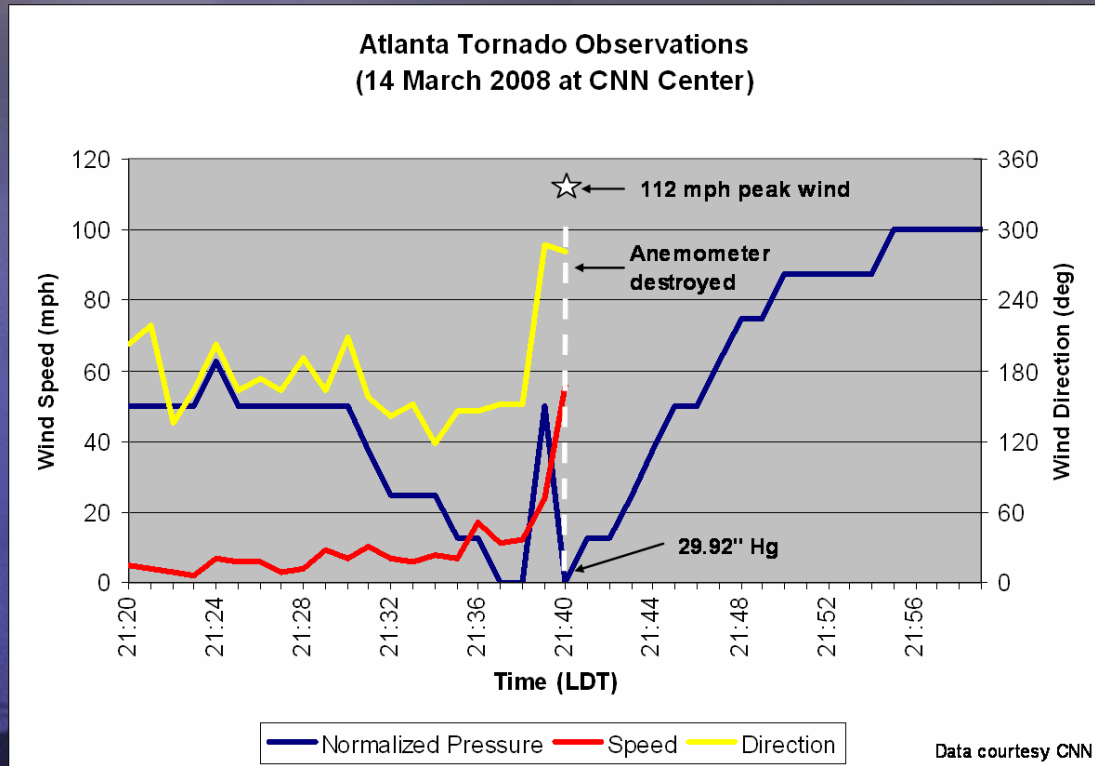


Q: Which stage do you think the tornado on the previous slide was in?

From Ackerman and Knox, 2e

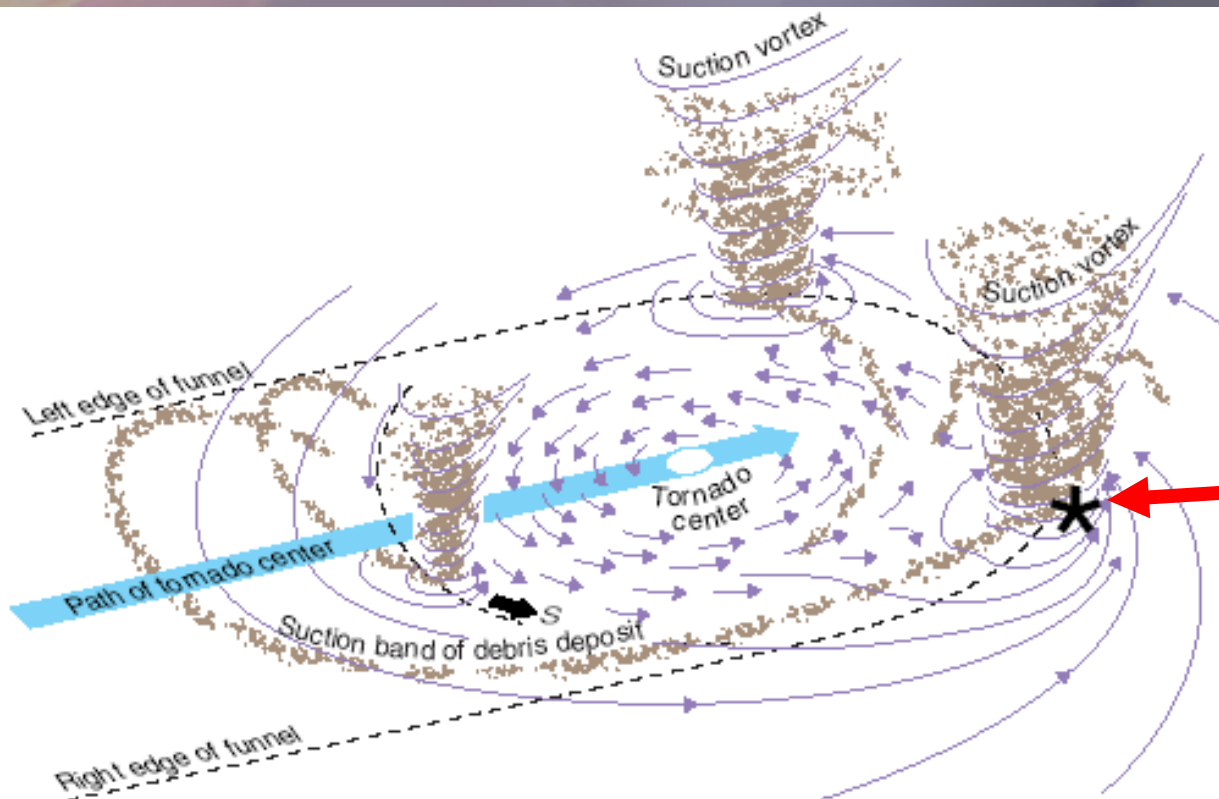
Tornado winds

- **Extreme wind speeds because of large, rapid change in pressure over distance** (“horizontal pressure gradient”)
- Winds usually (not always) counter-clockwise in NH
- At center of funnel, pressure drops about 10% vs. outside of funnel
- Funnel is NOT a vacuum!



The multiple-vortex tornado

- Worst tornadoes tend to exhibit moving “whirls inside of whirls,” i.e. multiple vortices
- Discovered by tornado pioneer Ted Fujita



Where forward speed of storm, funnel's winds *and* suction vortex winds all add together, **winds can be significantly stronger than just a few feet away**

Tornado wind estimation

- **Enhanced Fujita (EF) scale:** uses careful examination (28 damage indicators) of tornado damage to provide after-the-fact estimate of winds
- Scale: EF-0 (light damage) to EF-5 (incredible damage)
- Use our **fun applet** (updated) to learn about the EF scale:
<http://profhorn.meteor.wisc.edu/wxwise/tornado/t.html>

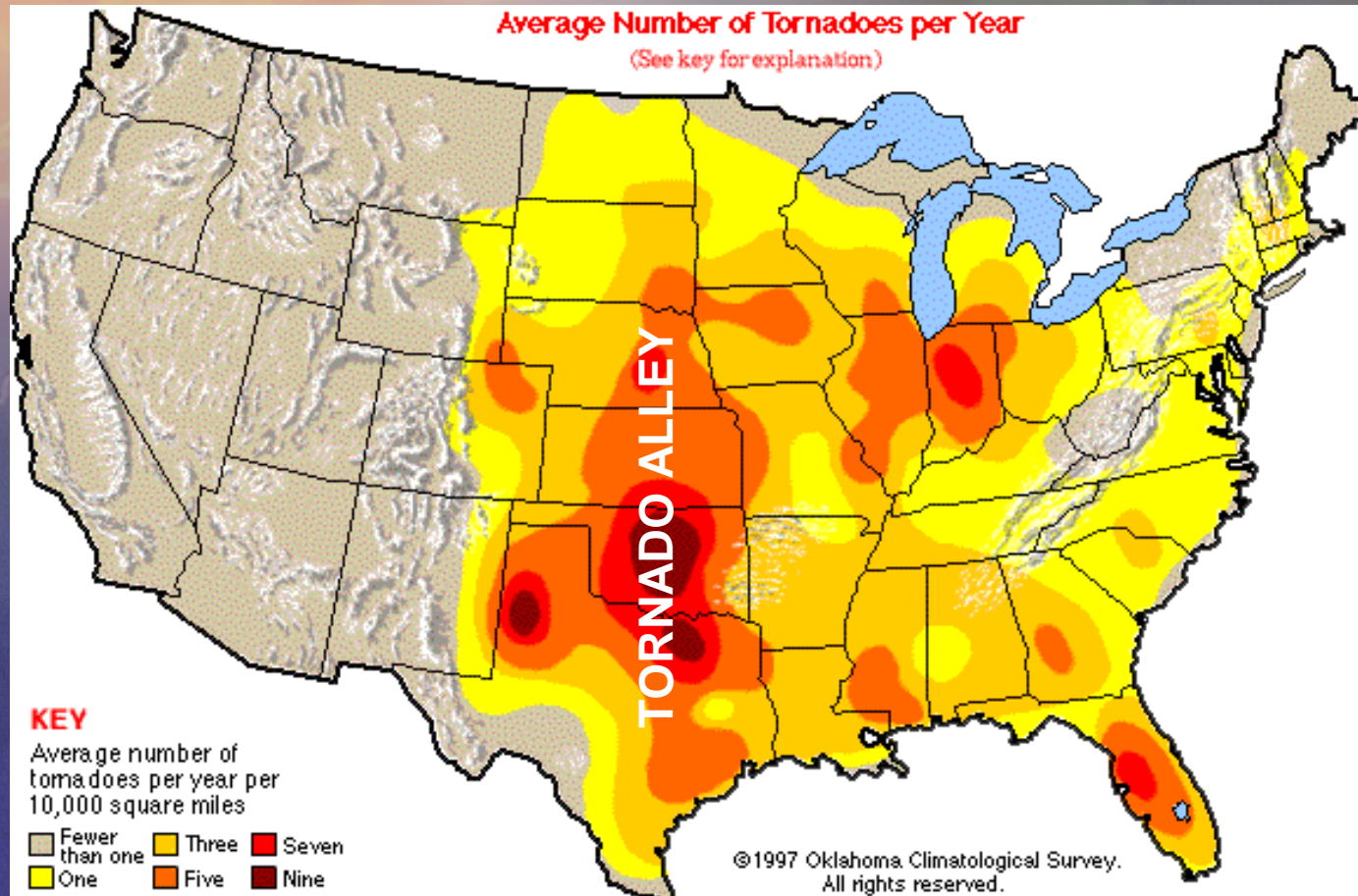


EF scale winds

EF scale	Estimated 3-second wind (mph)
EF-0	65-85
EF-1	86-110
EF-2	111-135
EF-3	136-165
EF-4	166-200
EF-5	Over 200

<http://www.spc.noaa.gov/efscale/ef-scale.html>

National tornado climatology



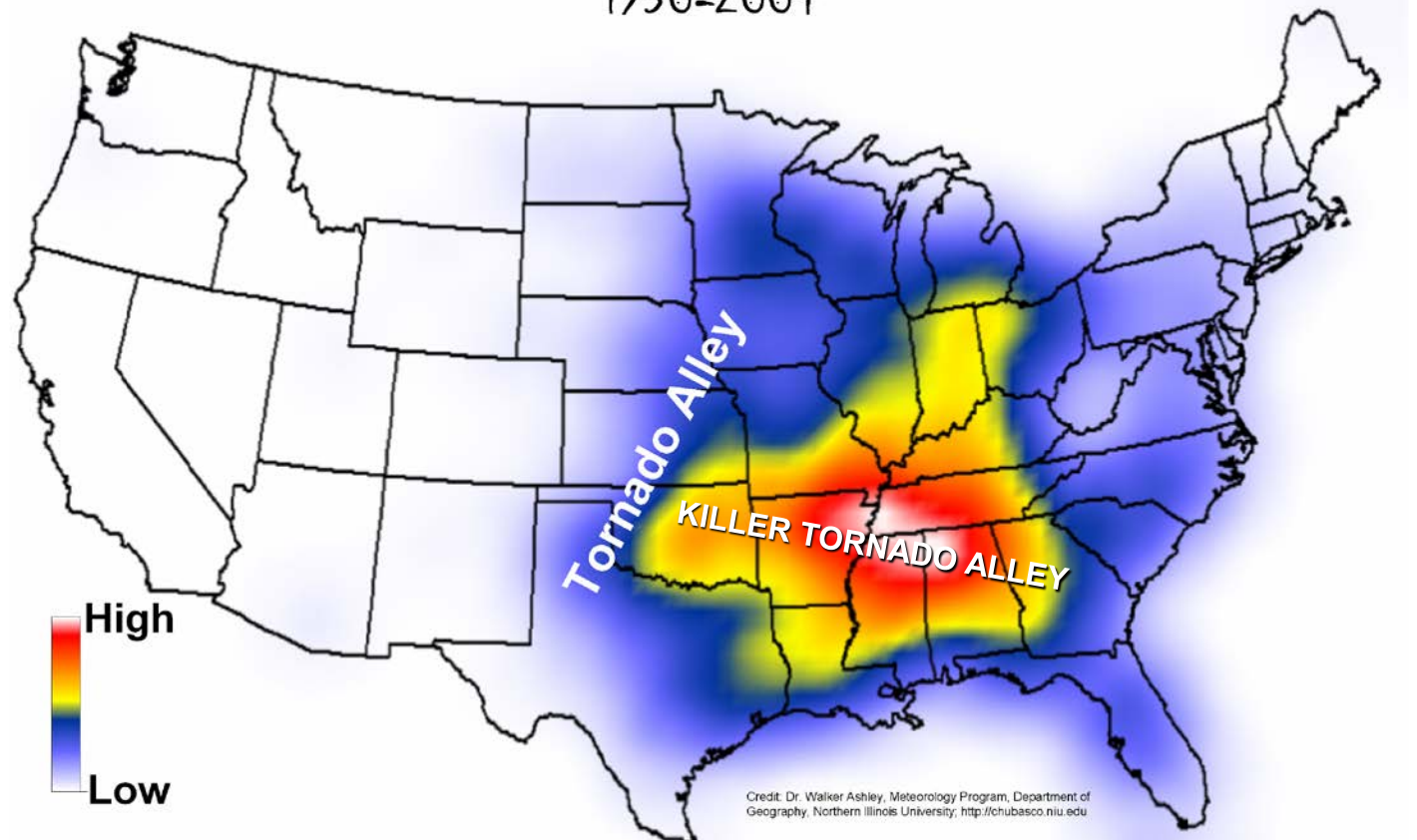
Killer tornado climatology for U.S.

(research by UGA Ph.D. Walker Ashley, Northern Illinois University)

Q: Why do you think many killer tornadoes occur more frequently outside of the typical “Tornado Alley”?

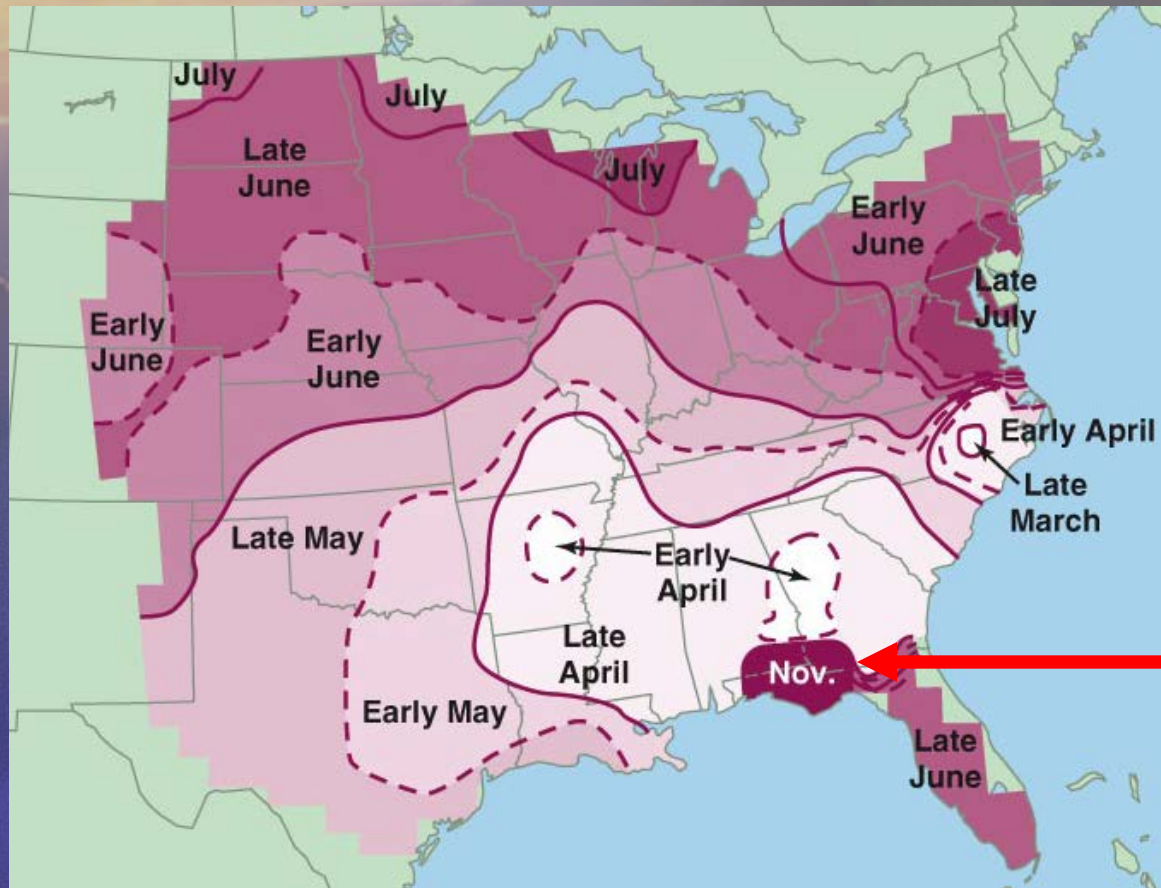
Relative Frequency of Killer Tornadoes

1950-2004



National “maximum tornado threat” climatology

Risk generally moves northward during the year, along with warm moist air and the jet stream

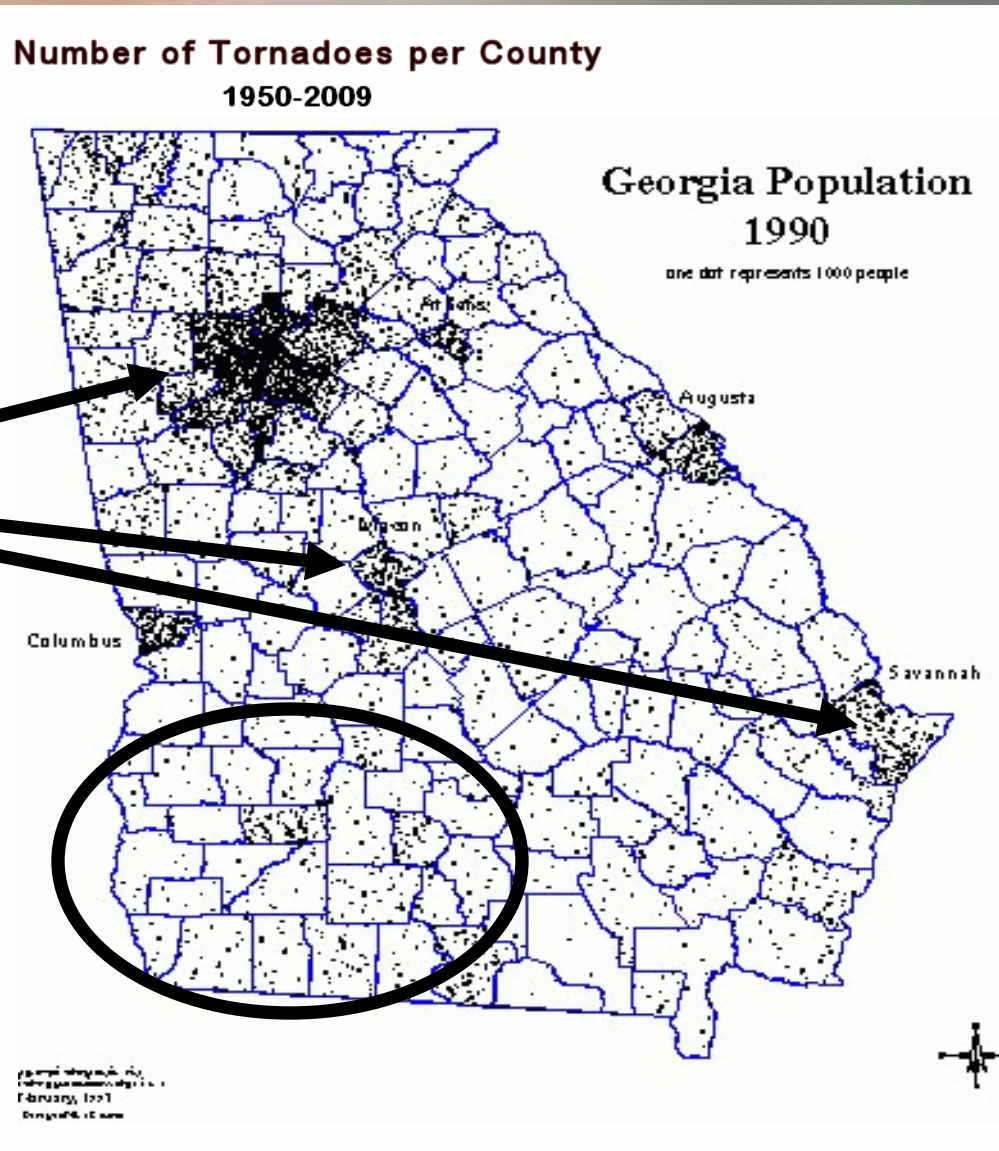


Q: Do recent outbreaks (AL, MO) fit this climatology?

SW Georgia is a unique fall anomaly!

From Ackerman and Knox, 2e

Georgia tornado climatology

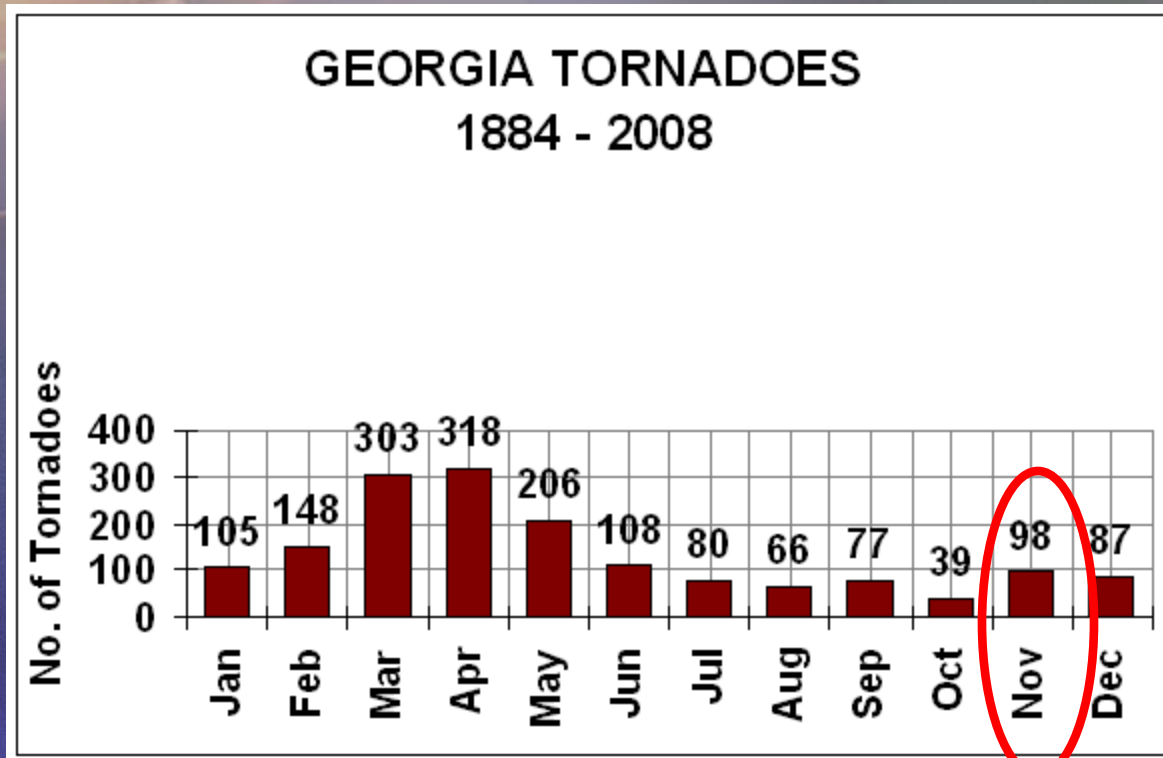


<http://www.srh.noaa.gov/images/ffc/tornado.gif>

<http://climate.engr.uga.edu/tornado/population.gif>

Georgia tornado climatology by month

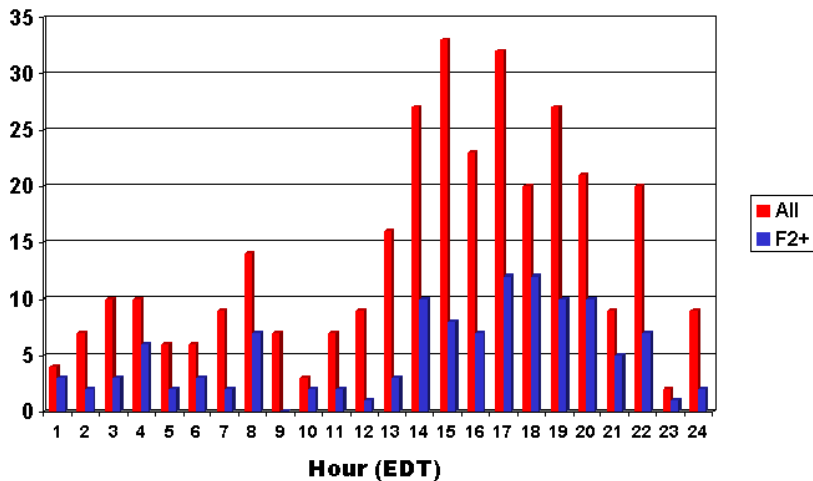
Note the secondary maximum in November!



<http://www.srh.noaa.gov/images/ffc/torntotal1.PNG>

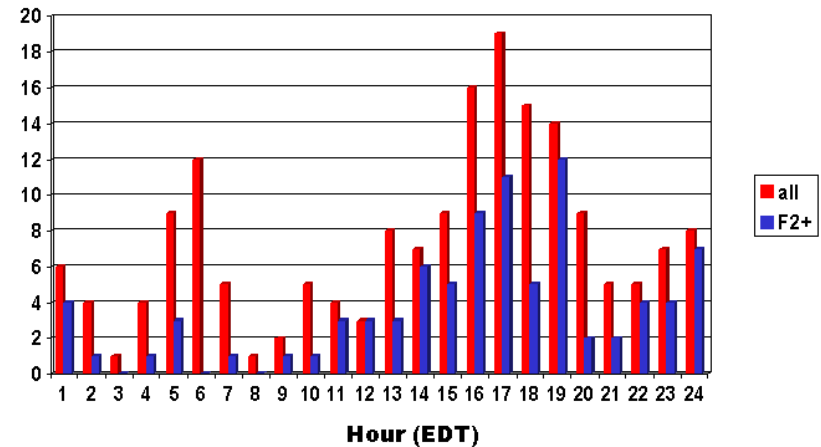
Georgia tornado climatology by hour of the day

Tornado Frequency (by hour)
March - May



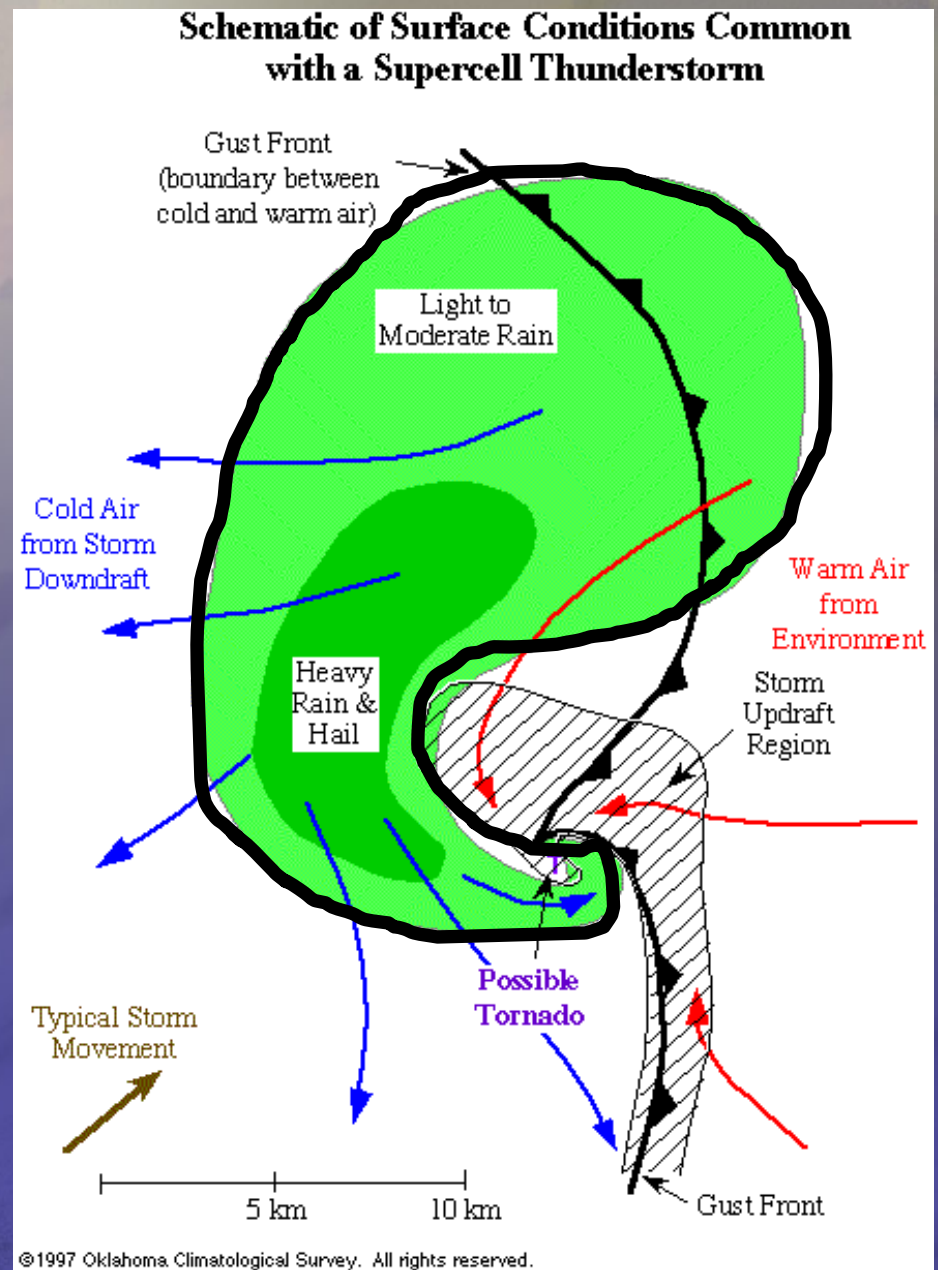
Springtime: late afternoon/
early evening max

Tornado Frequency (by hour)
October - February

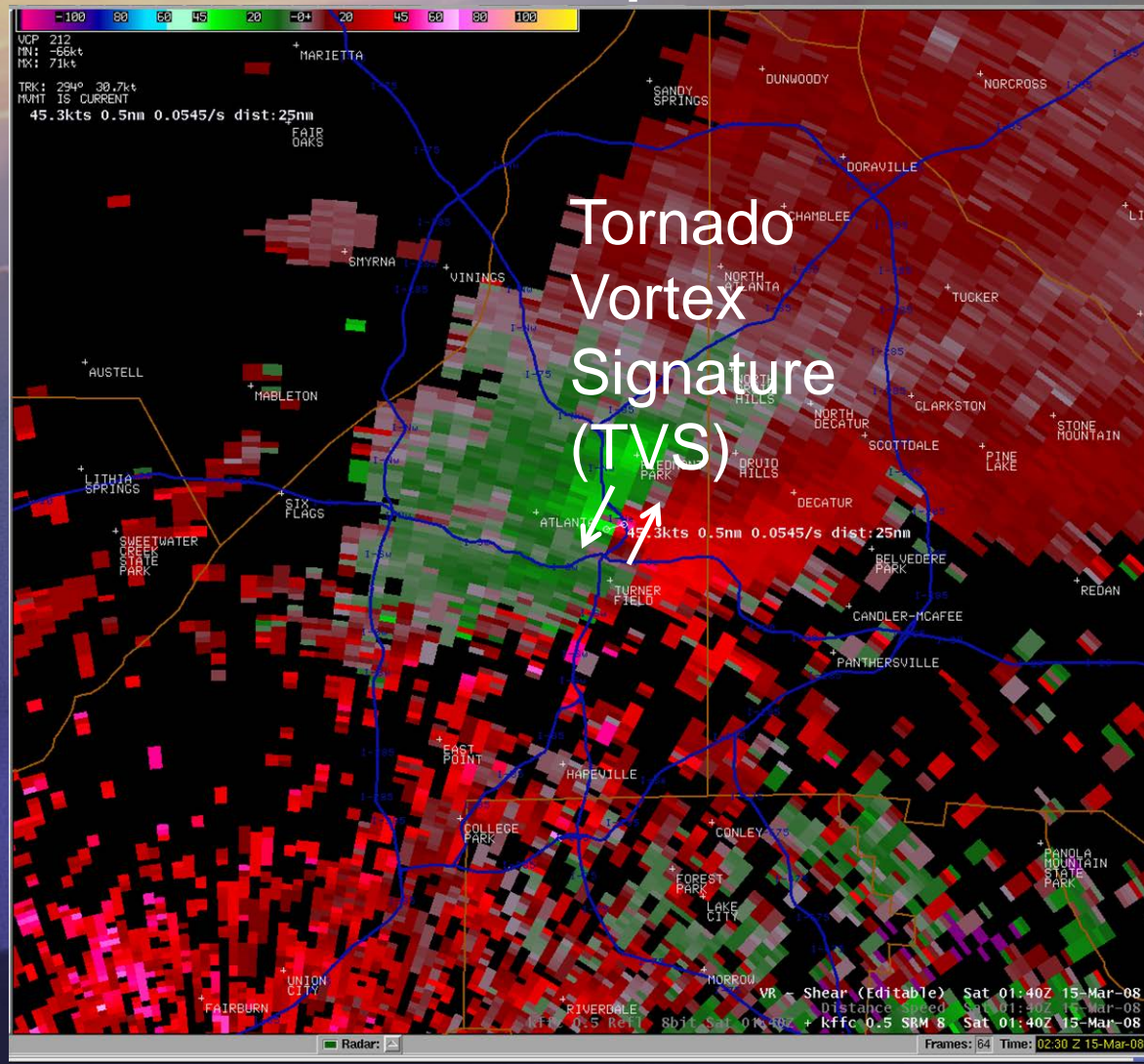


Fall/winter: late afternoon/
early evening max, *but also*
midnight and dawn, too (a
problem for getting warnings out to the public)

Tornado
schematic:
Radar
reflectivity
“hook echo”

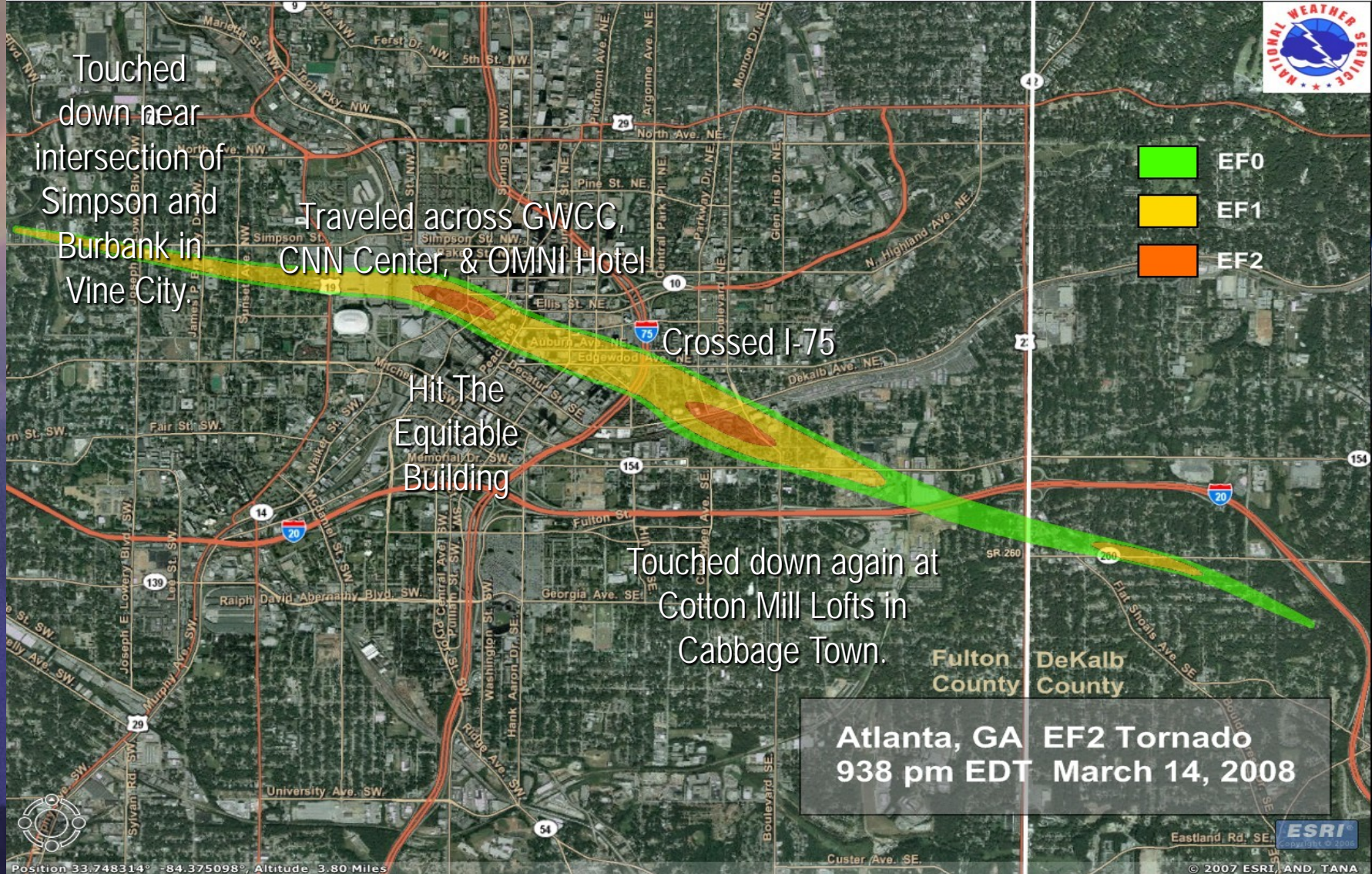


Tornado visualizations: NWS Doppler radar velocity Atlanta, 9:40 pm 3/14/08



Tornado visualizations: EF path in ATL

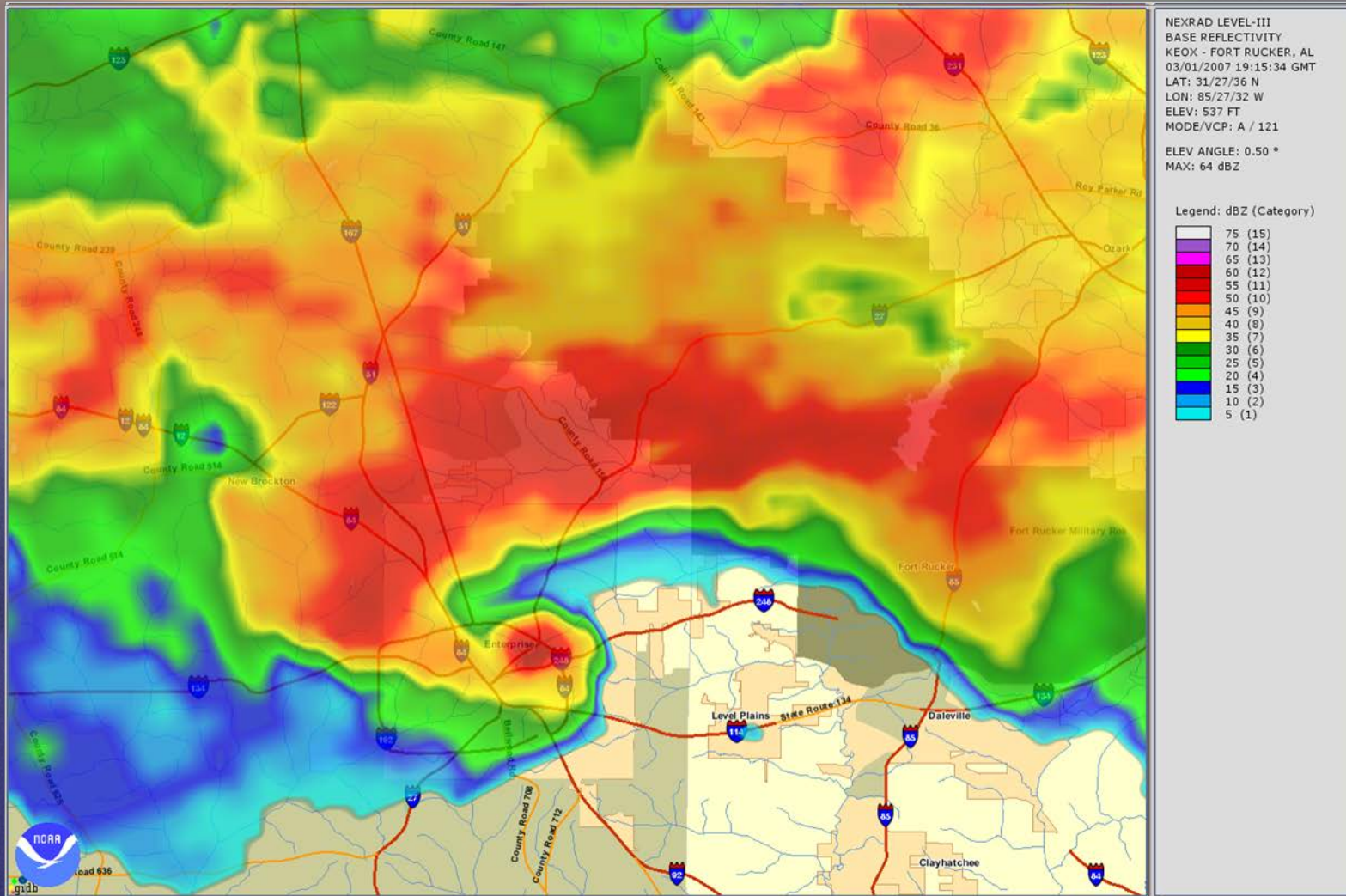
Knoxes were here!
14th floor of the Four Seasons Hotel in downtown ATL, looking south at transformer flashes



More tornado visualizations:

Enterprise, AL EF-4 on 3/1/2007 (9 dead, 8 in high school)

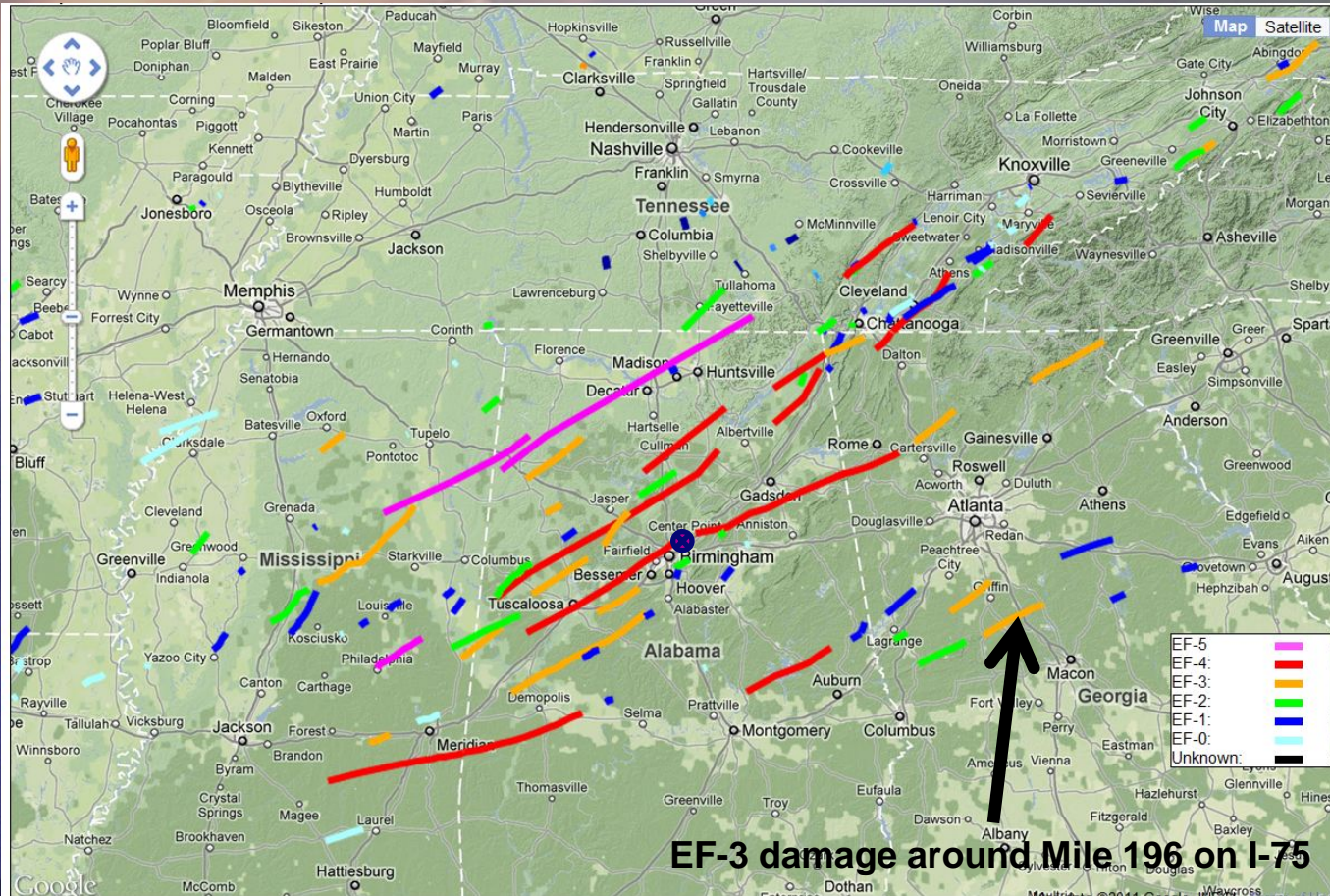
Hook echo with “debris ball”; TVS



Q:
Where's
the
tornado?
How do
you
know?

Applying your knowledge to the April 25-28, 2011 Tornado Outbreak

Over 200 tornadoes, 326+ deaths (236 in AL; 15 in GA)
Note my family's house in Birmingham (in crosshairs below)



EF-5	3
EF-4	11
EF-3	21
EF-2	47
EF-1	62
EF-0	57
Total:	201

Compare to 1974
Superoutbreak
(148 tornadoes,
315 deaths):

F5:	6
F4:	24
F3:	35
F2:	30
F1:	31
F0:	21

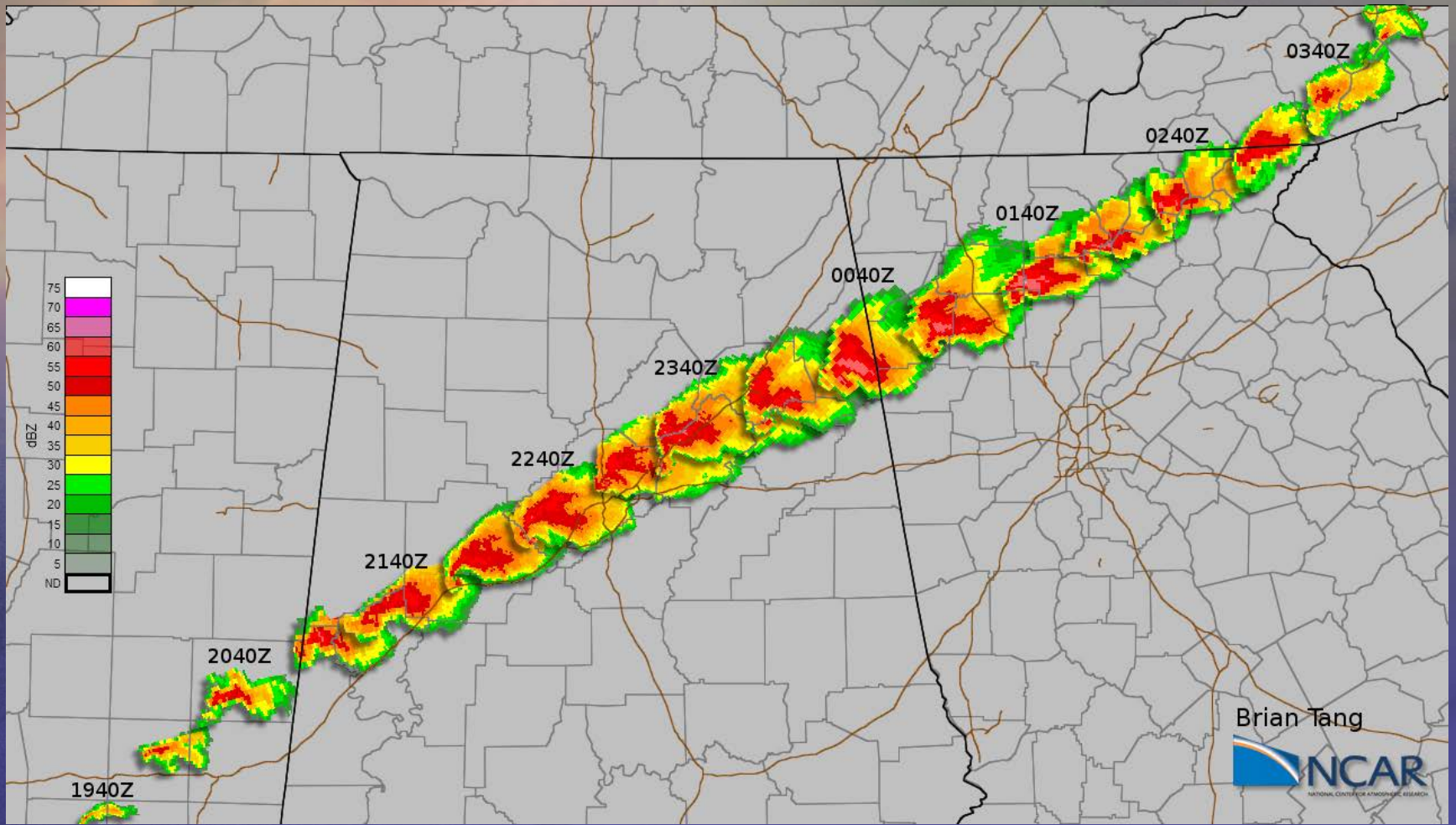
EF-3 damage around Mile 196 on I-75

From <http://www.srh.noaa.gov/srh/ssd/mapping/>

From <http://www.noaa.gov/news.noaa.gov/>
april 2011 tornado information.html

From <http://www.rms.com/Publications/1974SuperTornadoReport.pdf>

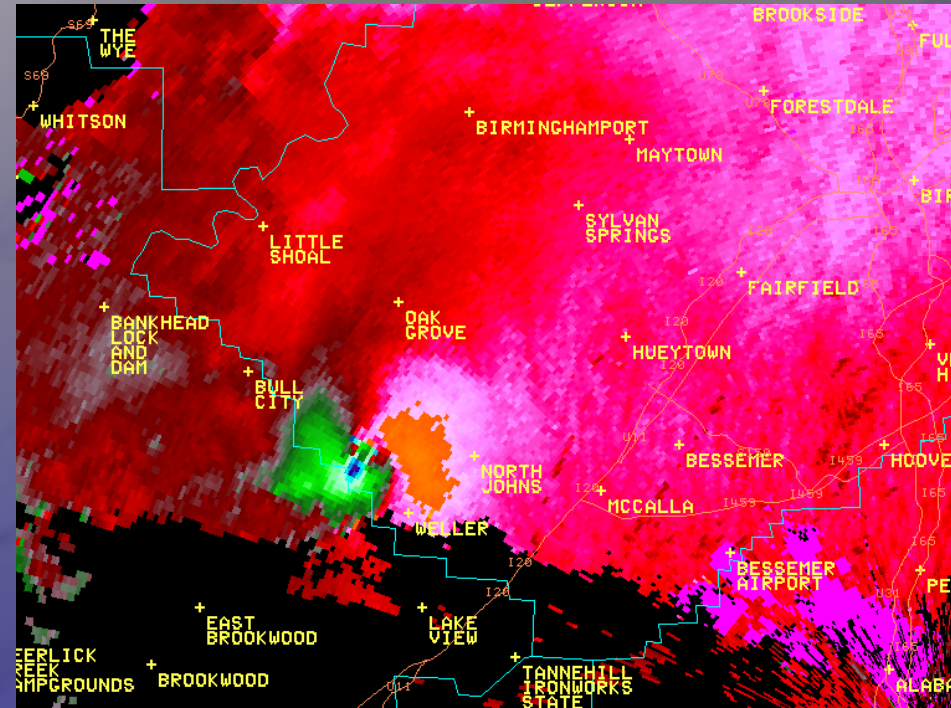
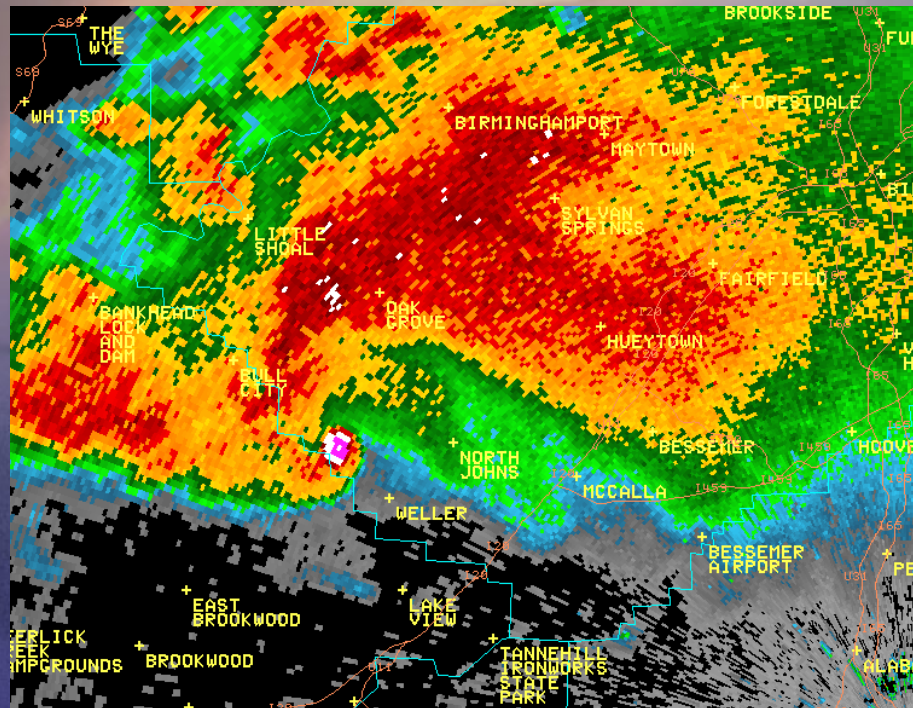
Applying your knowledge to the April 25-28, 2011 Tornado Outbreak



Q: Can you find hook echo(es) in this radar reflectivity composite of “The Supercell from Hell”? (traveled 380 miles in 7 hours 24 minutes)

Applying your knowledge some more...

Tuscaloosa-Birmingham tornado: high-end EF-4 (190 mph); 80.3 miles long; up to 1.5 mile wide, as it crossed I-65 just N of Birmingham; > 1000 injuries, at least 65 fatalities (deadliest single U.S. tornado since 1955)



From http://www.srh.noaa.gov/bmx/?n=event_04272011tuscobirm

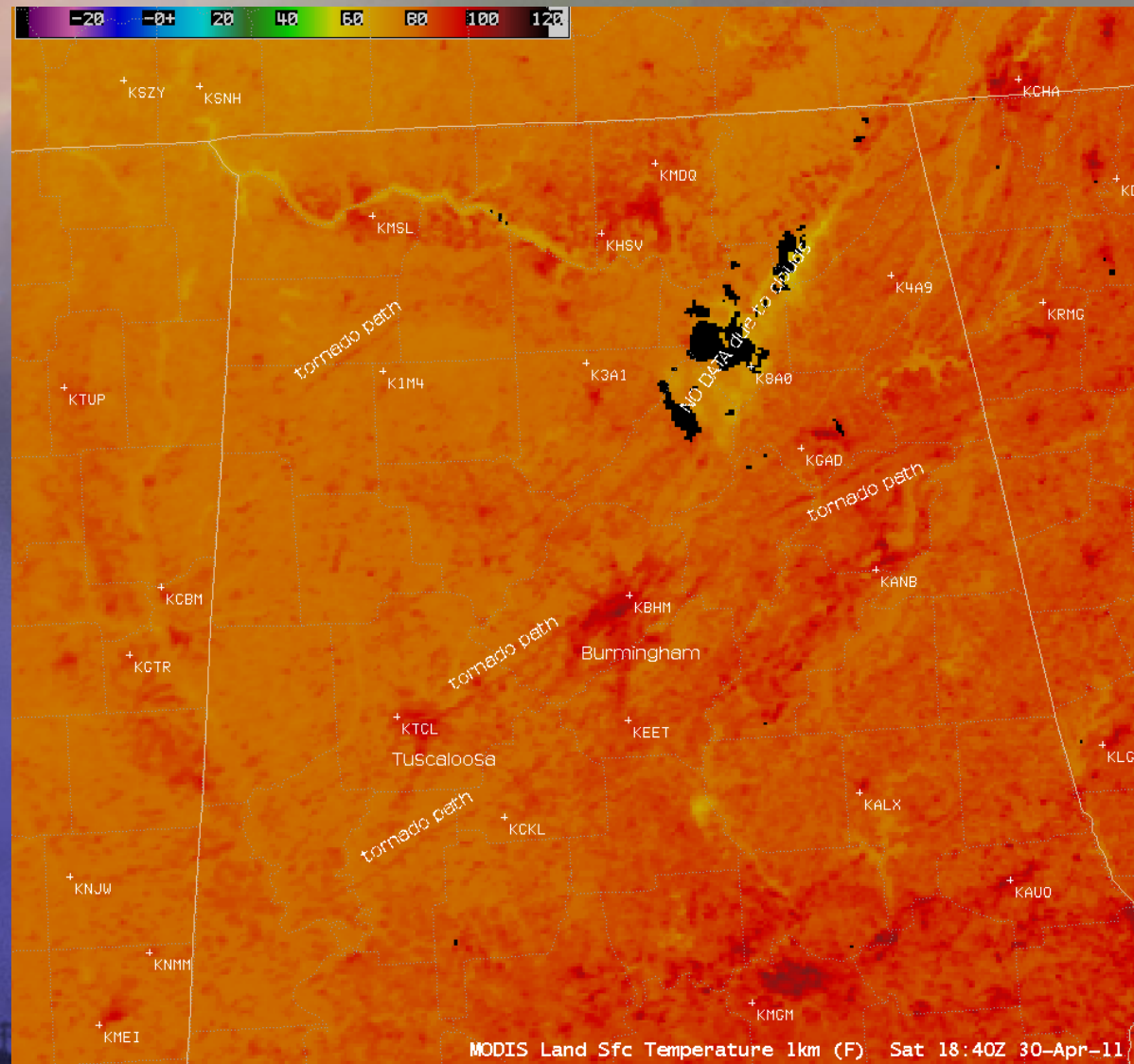
Q: Where's the hook echo? What is the highly reflective bulge at the end of it called? Why does it exist? Where's the TVS?

Live coverage of Tuscaloosa tornado: <http://www.cbs42.com/content/localnews/story/Tuscaloosa-tornado-caught-on-tape-wreaking-havoc/hsK7dFmlUku5YlvteTFy6A.csp>

Applying your knowledge to satellite imagery...

Q: Look for the damage paths from tornadoes in this satellite image of surface temperature.

Q: Why do you think tornado damage paths would be **warmer** than the surrounding area, as seen in this satellite image?



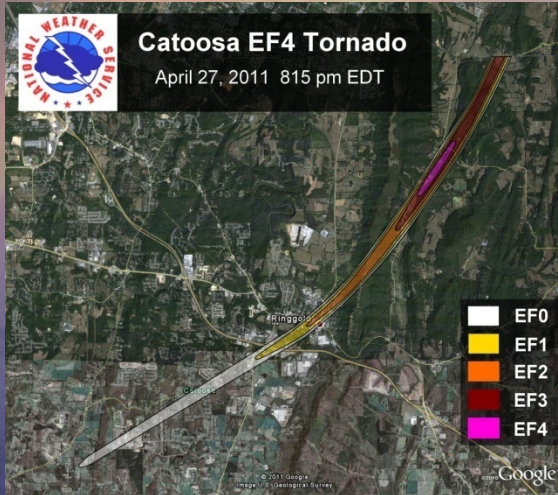
From
<http://cimss.ssec.wisc.edu/goes/blog>
and
http://profhorn.aos.wisc.edu/wxwise/AckermanKnox/chap11/April_27_2011.htm

Satellite loop of entire storm found at: <http://www.nasa.gov/topics/earth/features/severe-storms-20110429.html>

More on the April 25-28, 2011 Tornado Outbreak: GA connection

From http://www.srh.noaa.gov/ffc/?n=20110427_svrstorms

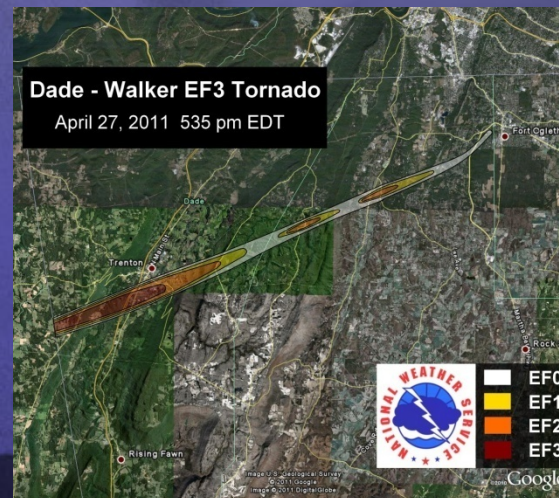
15 tornadoes: 1 EF-4, 4 EF-3, 4 EF-2, 6 EF-1



EF-4 damage just NE of Ringgold

Ringgold/Catoosa Co. tornado (left):
13 miles long, 1/3 mile wide, at least 7 fatalities (NWS)

Dade-Walker Co. tornado (right): 18 miles long in GA, 6/10ths mile wide, 2 fatalities



Up to EF-3 damage just S of Trenton

Tornado forecasting, in a nutshell

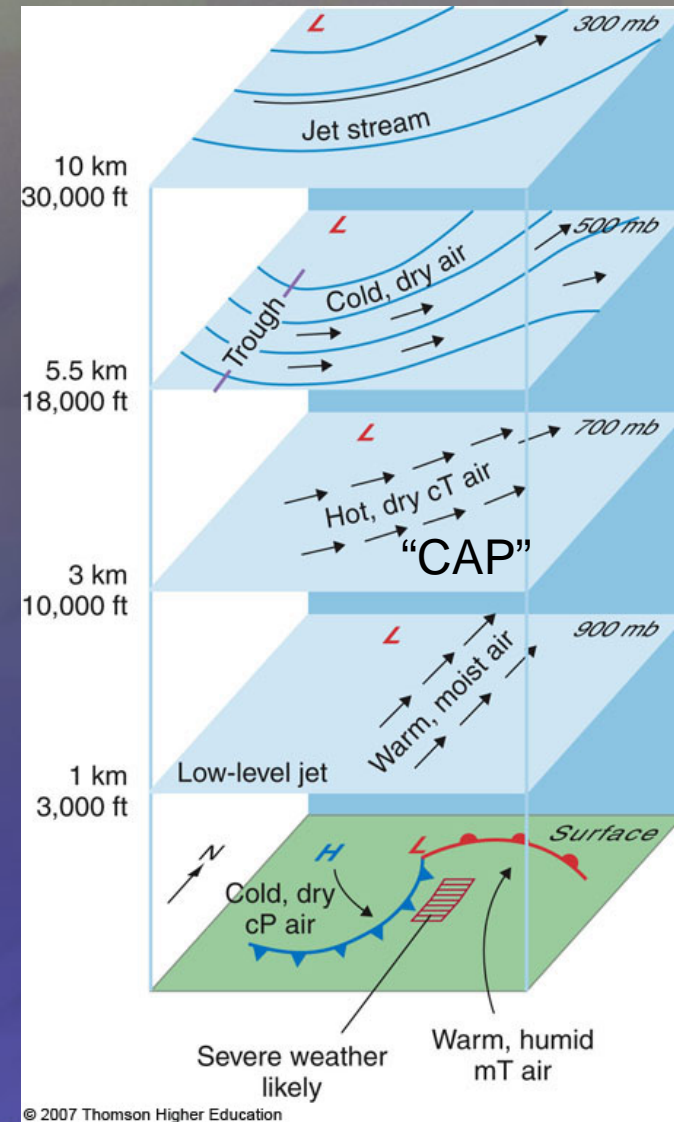
- **First-ever forecast: March 25, 1948**

<http://www.nssl.noaa.gov/goldenanniversary/millerposter.pdf>

- Tinker AFB, OK, hit by tornado on 3/20/48 (\$10 million damage)
- Major Fawbush and Captain Miller charged with creating forecast method
- They predict a tornado on 3/25/48
- Incredibly enough, another tornado hits Tinker AFB on 3/25!
- Thus begins military tornado forecasting; U.S. Weather Bureau starts in 1952

- **Tornado forecast approach today:**

- Identify likely locations for supercell development (trigger, buoyancy, shear)
- More likely with more buoyancy + shear
- Mid-level “cap” (inversion) can create even stronger updraft *if* cap “broken”



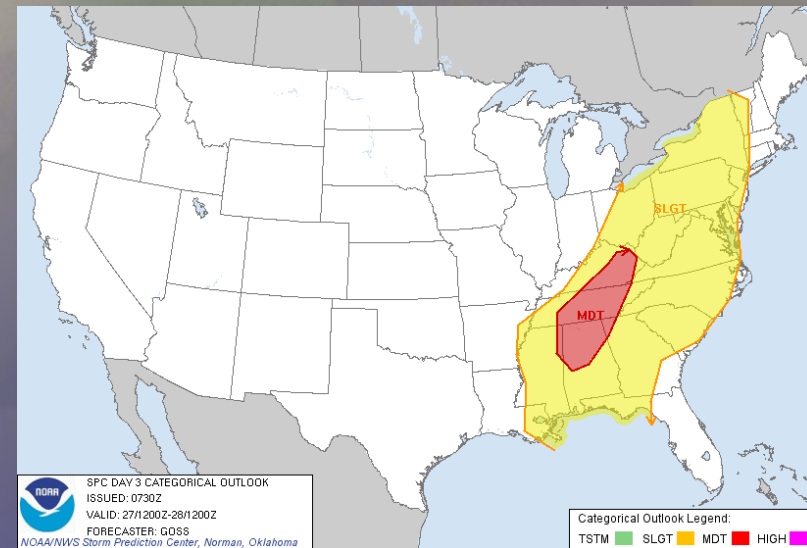
From Ackerman and Knox, 2e

Tornado forecasts: outlooks

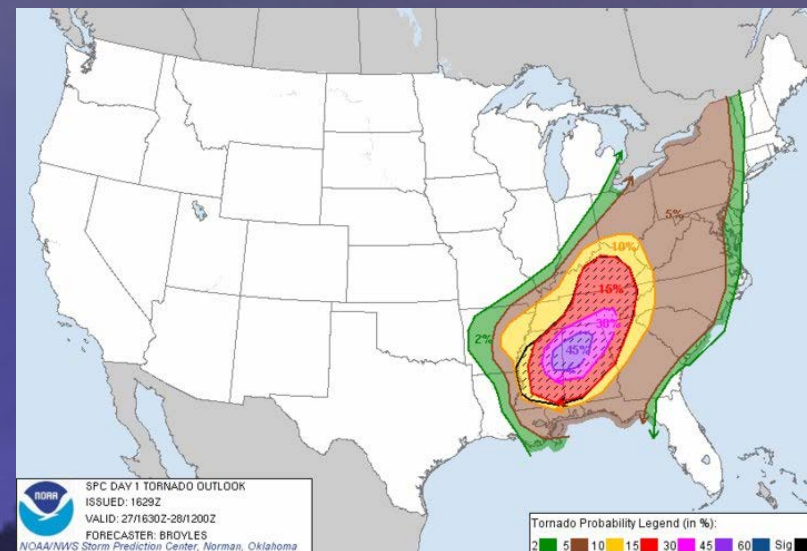
• SPC Convective Outlooks

- Storm Prediction Center:
<http://www.spc.noaa.gov/products/outlook/>
- Issued day(s) ahead of event
- Risk categories:
“Slight/moderate/high”
- Upper right: Day 3 risk outlook;
moderate risk 3 days ahead!
- **Lower right: % chance of
tornado within 25 miles on
4/27/2011, issued 11:29 am
CDT on the fateful day (10% =
moderate risk; 30% = high risk)**

Q: How accurately did these outlooks identify areas that were hit by tornadoes on April 27?



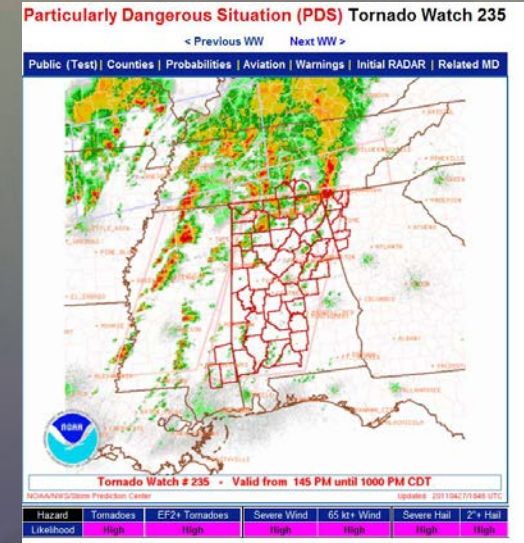
SPC Day 3 categorical outlook issued 2:30 am CDT, 4/25/2011



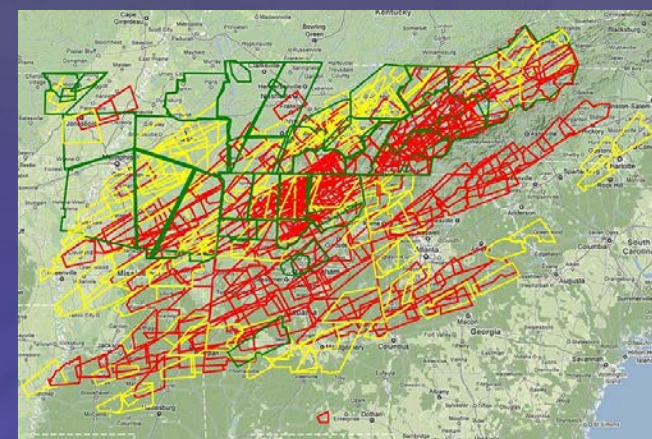
SPC Day 1 tornado outlook issued 11:29 am CDT, 4/27/2011

Tornado forecasts: watches and warnings

- **Tornado Watch: tornado could happen soon; prepare**
 - Issued by National Weather Service
 - Issued hours ahead of bad weather
 - Watch box covers **region** (~ a state)
 - **“PDS”**: Particularly Dangerous Situation (a few times a year)
 - Top right: PDS watch for north Alabama, issued at 1:45 pm
(Tuscaloosa hit at 4 pm, Birmingham at 5 pm)



Q: Why would a tornado watch be issued for locations that weren't currently experiencing storms?



Warnings on April 27, 2011:
Red = Tornado, Yellow = Severe Thunderstorm, Green = Flood

- **Tornado Warning: tornado is coming now, take action now**
 - Issued by NWS, for an hour or so
 - Warning area is **local** (~ a county)

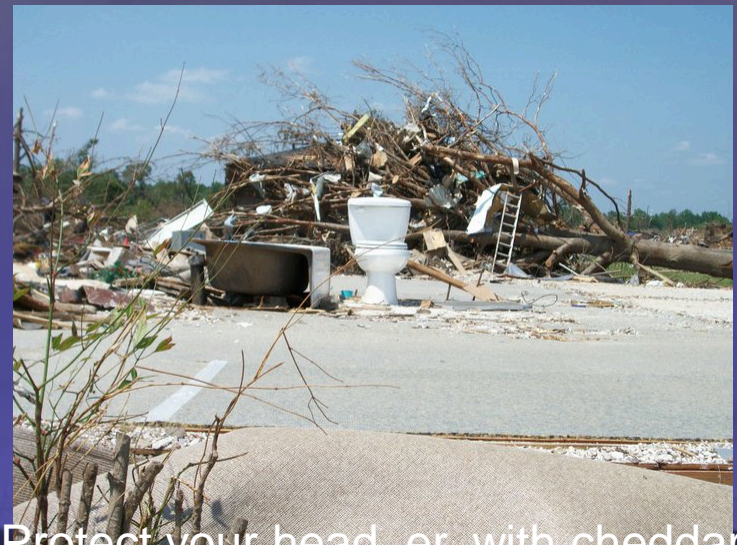
Tornado safety: what to do in a...

- **Frame house: go to basement**

- Only 20-30 deaths in basement out of 11,000 tornado-related deaths from 1880-2000 (Grazulis)
- Parkersburg, IA 5/25/08 tornado at top right: even basements not safe from EF-5
- **Small windowless room with strong walls best** (pipes in bathrooms help); photo from Birmingham area at right
- Put as many walls between you and the tornado as possible
- Hide under a table
- **Avoid head injuries**



[http://www.crh.noaa.gov/Image/dmx/Parkersburg Tornado/IMG_2006.JPG](http://www.crh.noaa.gov/Image/dmx/Parkersburg_Tornado/IMG_2006.JPG)



“Protect your head, er, with cheddar!”
Photo of 4/27/2011 damage in Pleasant Grove/
Concord, AL by UGA alumnus Matt Daniel

Tornado safety: what to do in a...

- **School/church/workplace: follow severe weather plan**

- Avoid large free-span roofs
- Go to hallways without windows
- Avoid glass
- Crouch, protect your head
- Buses: don't outrun storm



- **At right: F4 destroys metal fabrication plant in Illinois in 2004, no deaths and no injuries** thanks to planning; **150 employees evacuated to shelters (yellow) in just 3 minutes**



Figure 3. Overhead picture of the damage at the Parsons Company, looking southeast. The yellow circles indicate the locations of the storm shelters. The center of the 0.4 KM wide tornado tracked through the building in the lower left of the picture. Photo courtesy of the Peoria Journal-Star.

http://www.crh.noaa.gov/images/ilx/pdf/Miller_Abstract.pdf

Also:

Video of 2006 tornado hitting MO school:

<http://www.youtube.com/watch?v=UdSjzWVevl8>

Video of 2011 tornado hitting STL airport:

http://www.washingtonpost.com/blogs/capital-weather-gang/post/despite-warning-st-louis-tornado-caught-airport-passengers-off-guard/2011/05/13/AFYkhX2G_blog.html

Tornado safety: what to do in a...

- **Vehicle: get out**

- Some debate about this, but definitely do it for violent tornadoes
- Lie in a ditch
- **DON'T hide under an overpass** (channels winds and makes them stronger)
<http://www.srh.noaa.gov/ou/n/?n=safety-overpass>
- Don't sightsee, don't try to become a YouTube sensation, etc.



Vehicles pulverized in April 27, 2011

Phil Campbell, AL EF-5 tornado

http://www.srh.noaa.gov/hun/?n=franklin-al_lawrence_limestone_madison_franklin-tn_counties

Asphalt pavement was scoured from the ground and landed 1/3 of a mile away in Phil Campbell.

A Corvette sailed **641 feet** through the air in nearby Oak Grove, AL!

Tornado safety: what to do in a...

- **Mobile home: get out**
 - Take shelter nearby, preferably in steel-reinforced surroundings and/or underground
 - **Tornadoes are NOT attracted to mobile homes**
 - Instead, low-income *people* in relatively poor “tornado alleys” who can’t afford frame homes *are attracted to mobile homes*



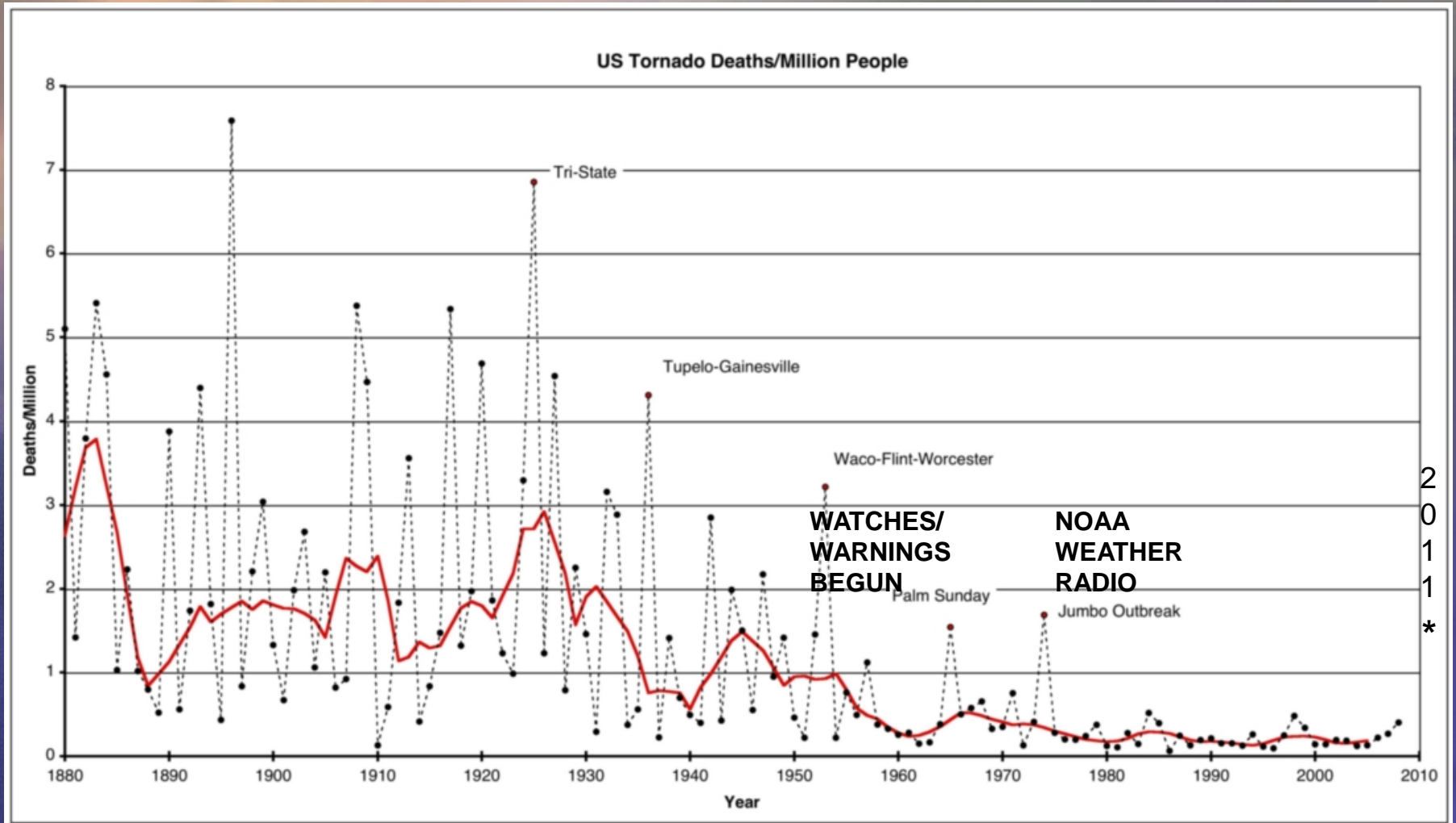
<http://www.texastech.edu/images/story-photos/tornado-path-large.jpg>

Tornado safety: what to do in a...

- **Arena or skyscraper**
 - Stay away from windows!
 - Follow instructions, if any
 - Go to lower floors (wind speed increases with height)
 - **Westin Peachtree Plaza tower swayed 2' during ATL tornado!**



Tornado safety: *We are getting safer*, because of better warnings and better safety precautions



http://www.flame.org/~cdoswell/images/UStordeaths_1880-2008b.jpg

Main sources of information

- Ackerman, S.A., and J.A. Knox, *Meteorology: Understanding the Atmosphere* (2nd edition), Brooks/Cole, 2007. (Some material from the just-released 3rd edition!)
- Grazulis, T.P., *The Tornado*, University of Oklahoma Press, 2001.
- <http://www.meted.ucar.edu> (requires registration)
- <http://www.spc.noaa.gov/faq/tornado/>

A dramatic sky with a sunset or sunrise, a large dark storm cloud, and a dark silhouette of a landscape with power lines.

Questions?

What is/isn't/sort of is a tornado

- **Tornado:** narrow, violently rotating column of low pressure that extends from the lowered base (wall cloud) of a **thunderstorm** to the ground
- Tornado funnel caused by condensation of water vapor in rising air and lower pressure; also by debris
- Not tornadoes (although there's debate):
 - **Funnel cloud:** not a tornado until it affects the ground
 - **Waterspout:** out of cumulus, not cumulonimbus; not as violent, not associated with mesocyclone
 - **Landspout:** similar to waterspout, over land
 - **Gustnado:** thunderstorm-outflow tornado
 - **Dust devil:** caused by Sun's heat, sunny day

