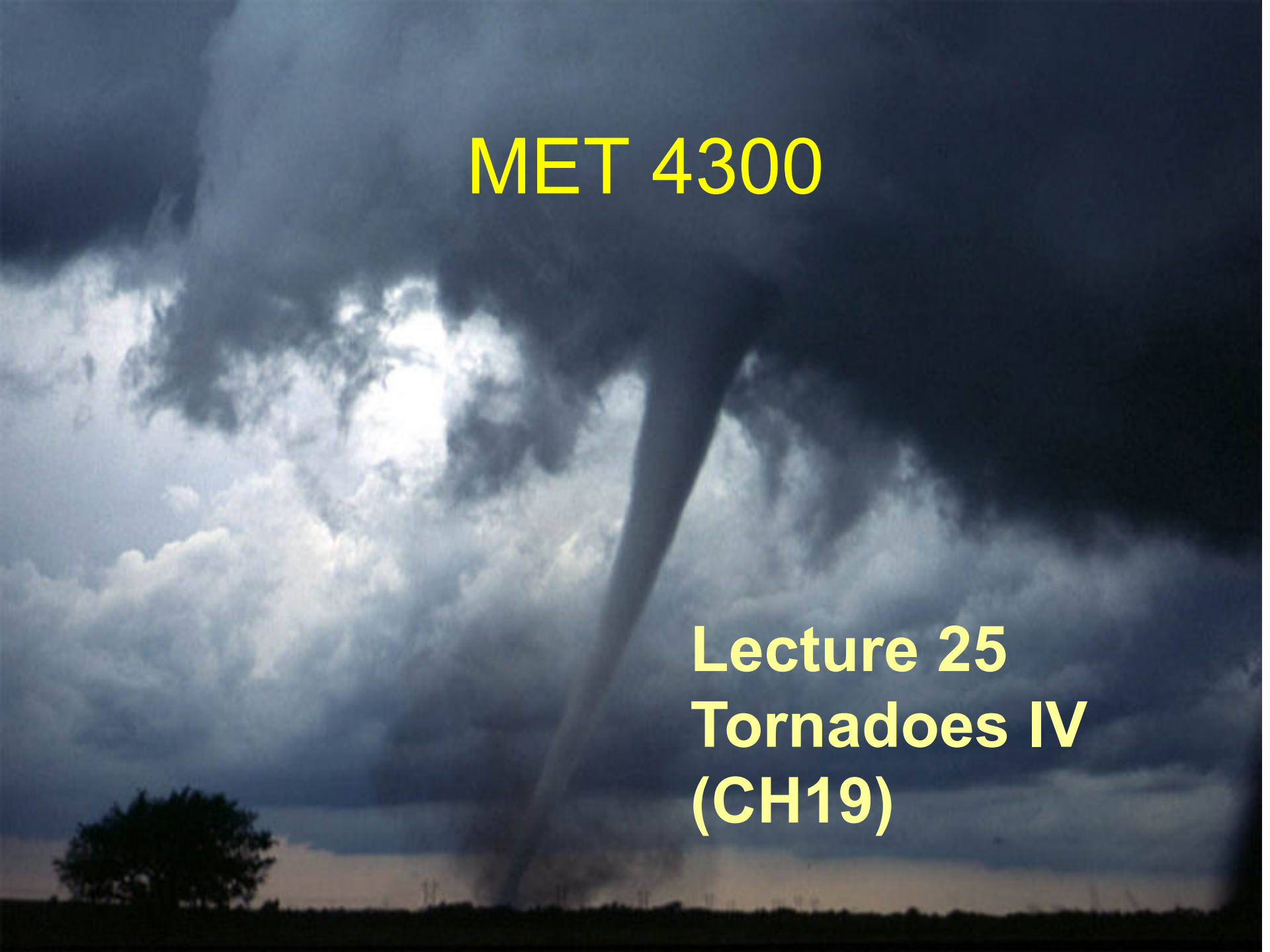


MET 4300

Lecture 25
Tornadoes IV
(CH19)

Outline

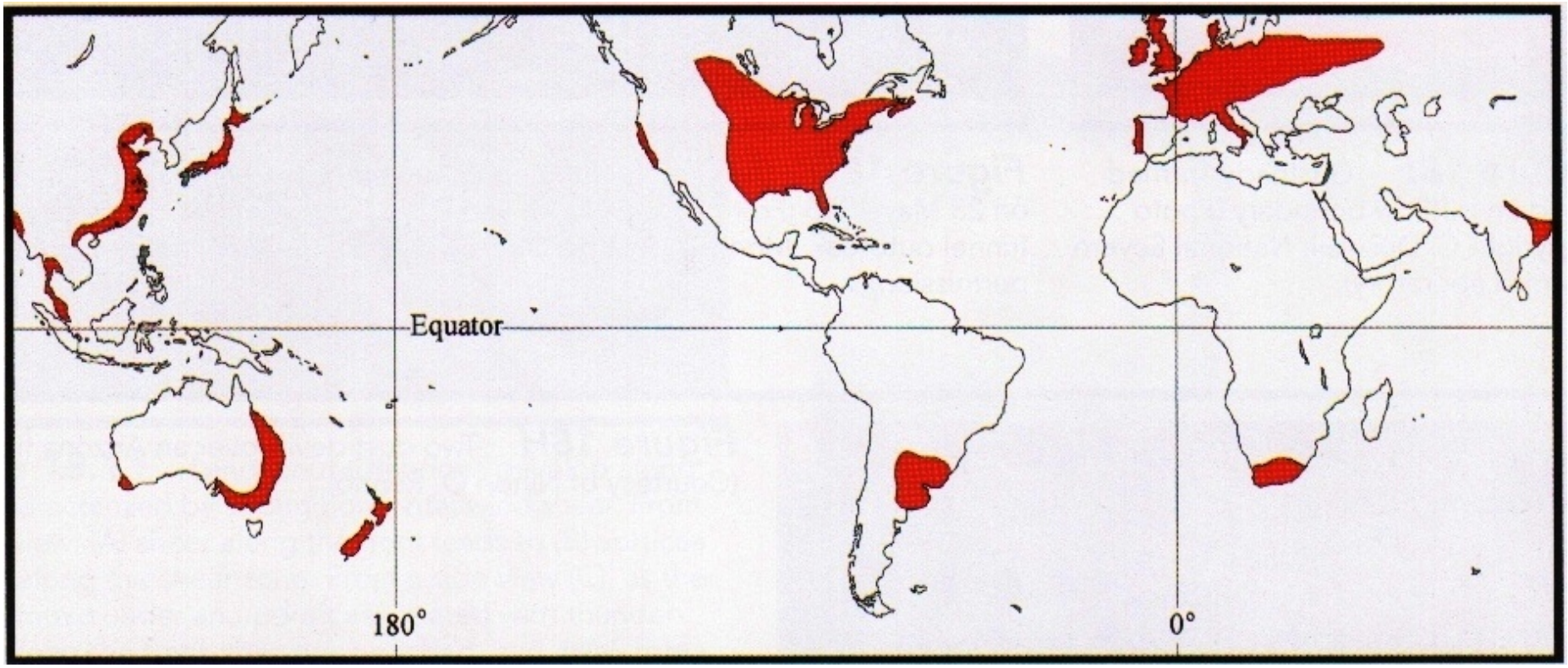
- Definition, life cycle, & climatology of tornadoes
- Tornado formation within supercells
- Tornado formation within non-supercell thunderstorms
- Fujita scale
- Tornado statistics
- Historic cases
- Tornado detection, forecasting, and safety

Tornado Statistics

- East of a mountain range and north of a warm ocean
  - US Great Plains
  - Northern India & Bangladesh
  - Other locales have tornadoes, but not as frequently
- In the US, “Tornado Alley” extends from North Texas to South Dakota
- We now know that 1000-1200 occur each year, compared with 200, the accepted value before the 1940s
- Only ~ 25% of all tornadoes occur outside the US.

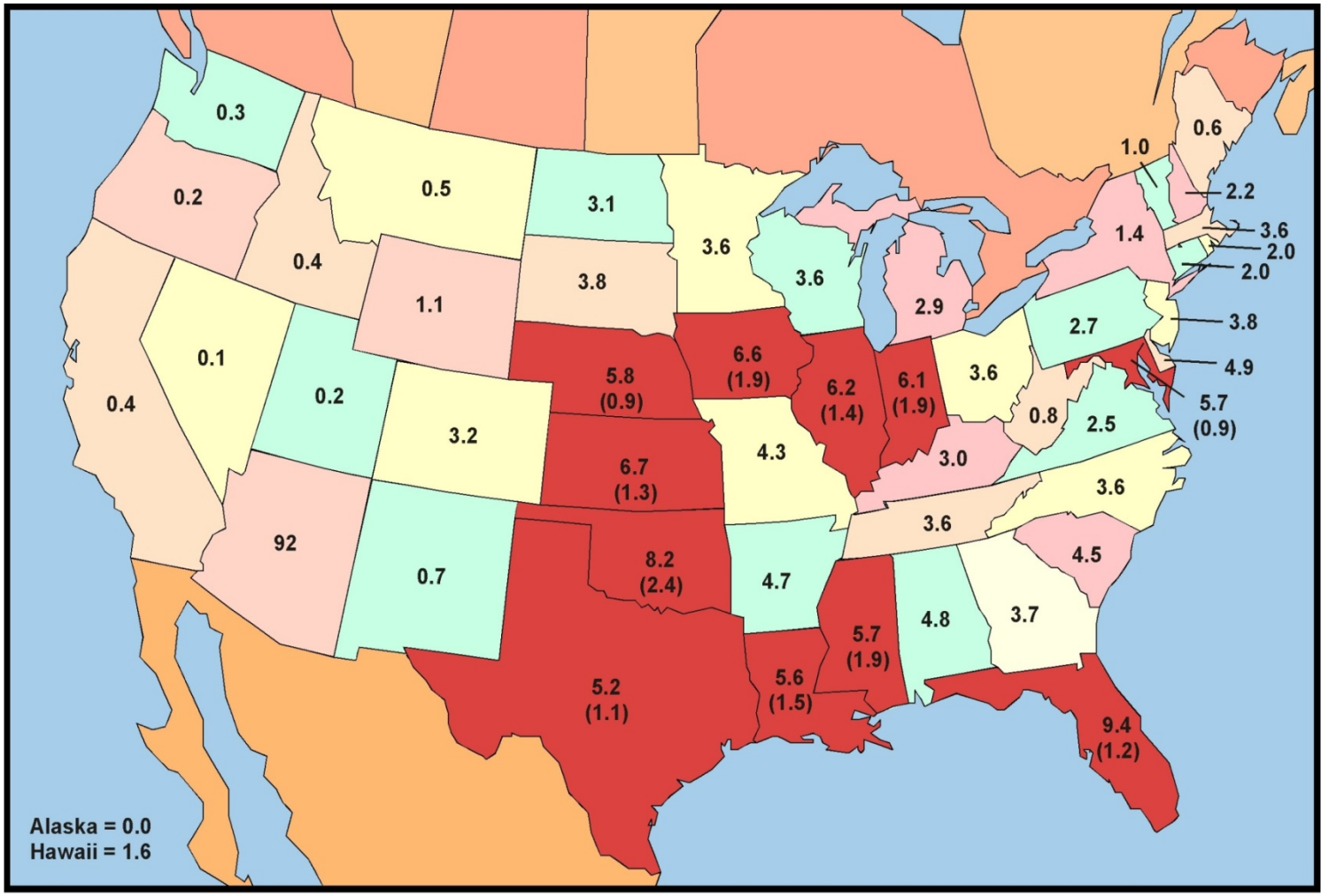
Tornado Occurrence Worldwide:

coincident with agriculturally productive areas of the middle latitudes (the same T-storms that produce tornadoes provide the rain necessary to grow crops).



Average annual number of tornadoes (EF2-EF5 in parentheses) per 10,000 square miles occurring in each state in the US over the 52-yr period during 1953-2004

- >5 (red): TX, OK, KS, NE, IA, IL, IN, MD, LA, MS and FL
- Mainly over the Gulf states & Tornado Alley
- FL: most tornadoes due to short winter, sea breeze triggering thunderstorm s everyday, & landfalling hurricanes

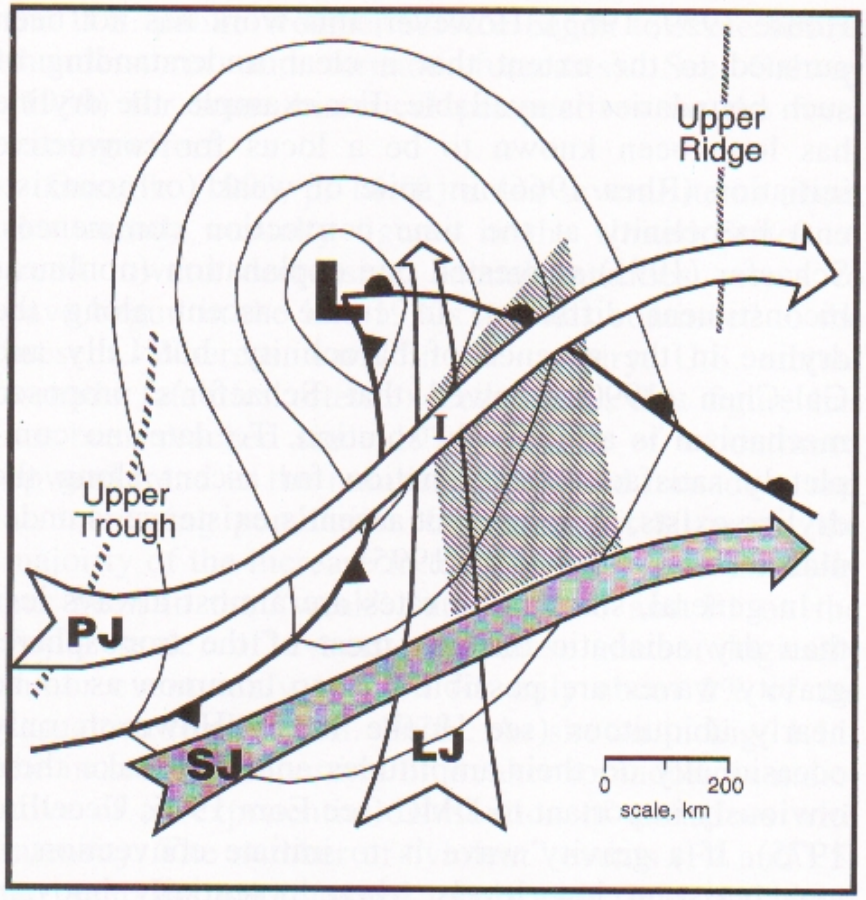


Tornado Alley

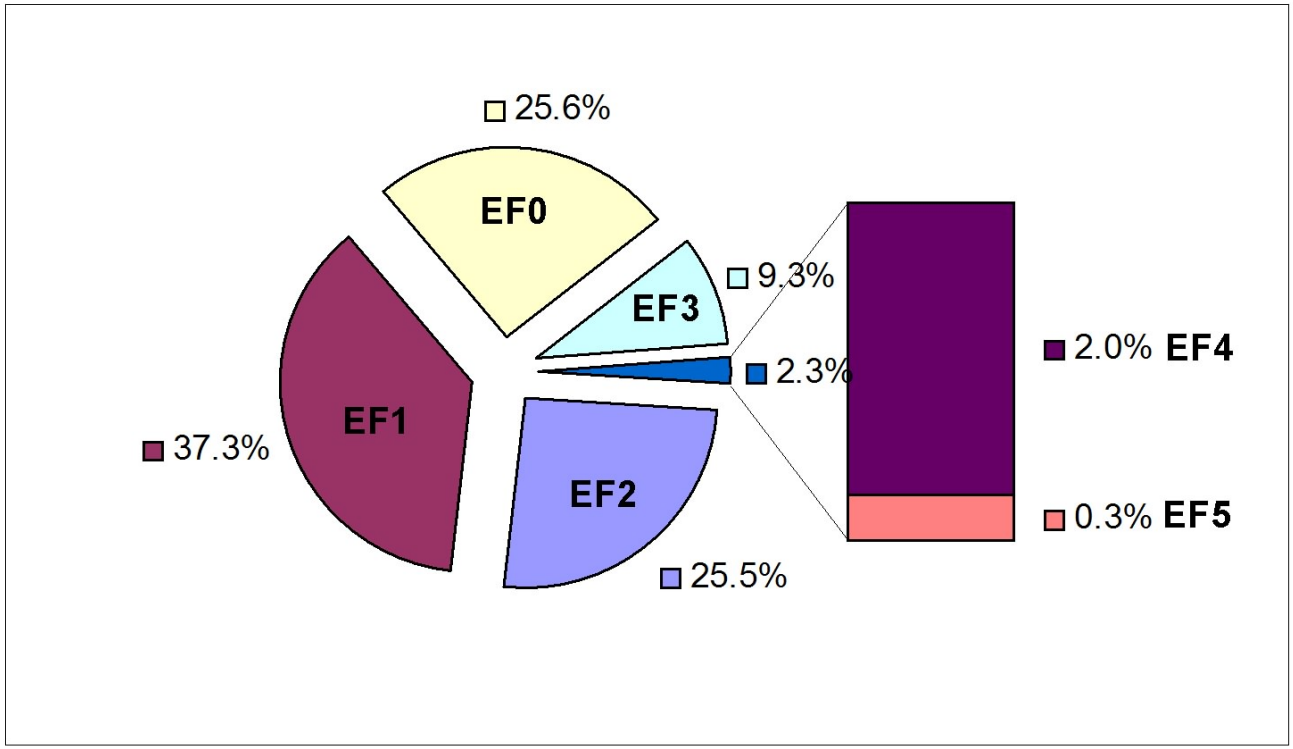
- Great plains and Midwestern states
- These states are oriented along a SW-NE line called Tornado Alley
- Corresponds to typical orientation of strong fronts as they move across central US in the spring and early summer; and to typical orientation of the upper-level jet
- The largest number of violent tornadoes occurs in OK, where very sharp dry lines and cold fronts trigger supercell thunderstorms in spring and early summer.
- Also large instability in this region.

Tornadoes (and Other Severe Weather Events) Like Upper Divergence Over Warm & Moist Low-Level Advection

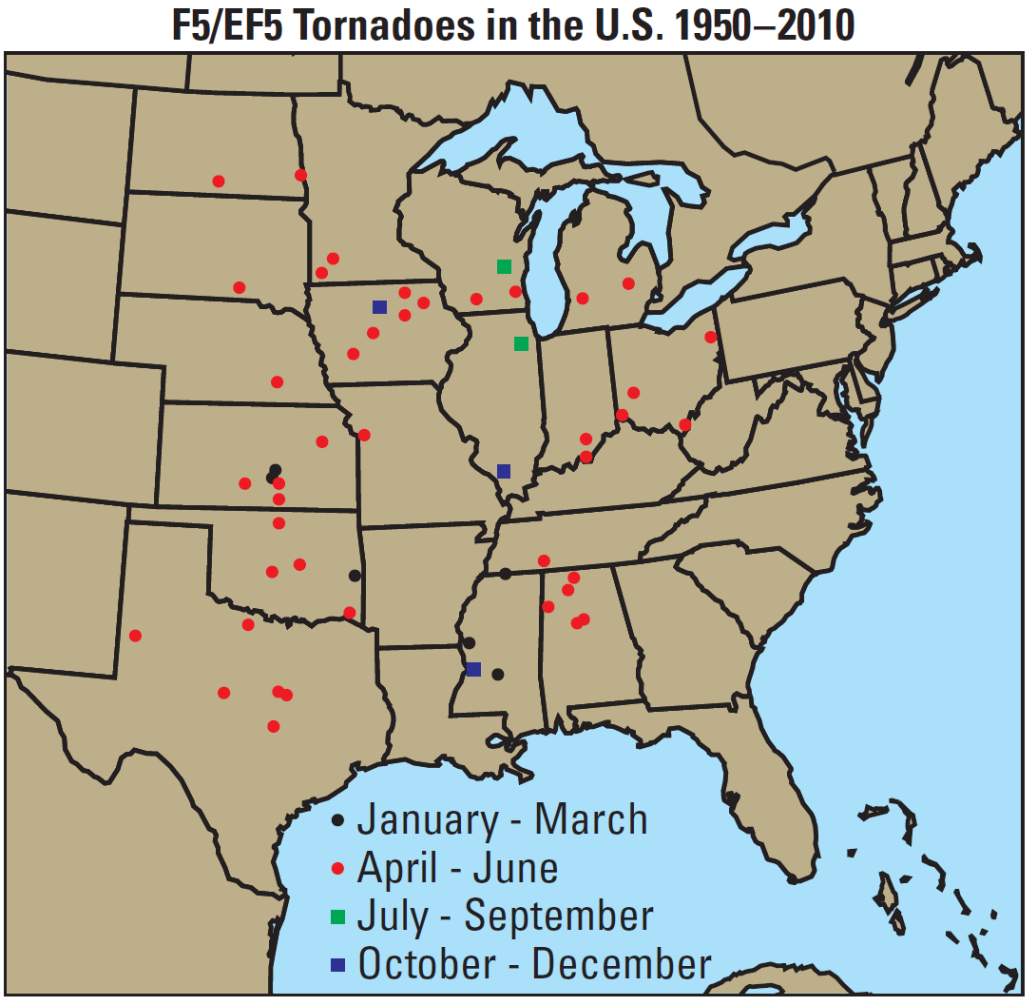
- Low-Level Jet
  - Brings moist air from the Gulf
  - Thermal gradient due to front
  - Or nocturnal cooling on the upslope
- Polar (or sometimes ST) Jet
  - Lifting in right entrance region, or left exit, sometimes.
- Dryline, too



Tornado Occurrence by Enhanced Fujita-Scale Number



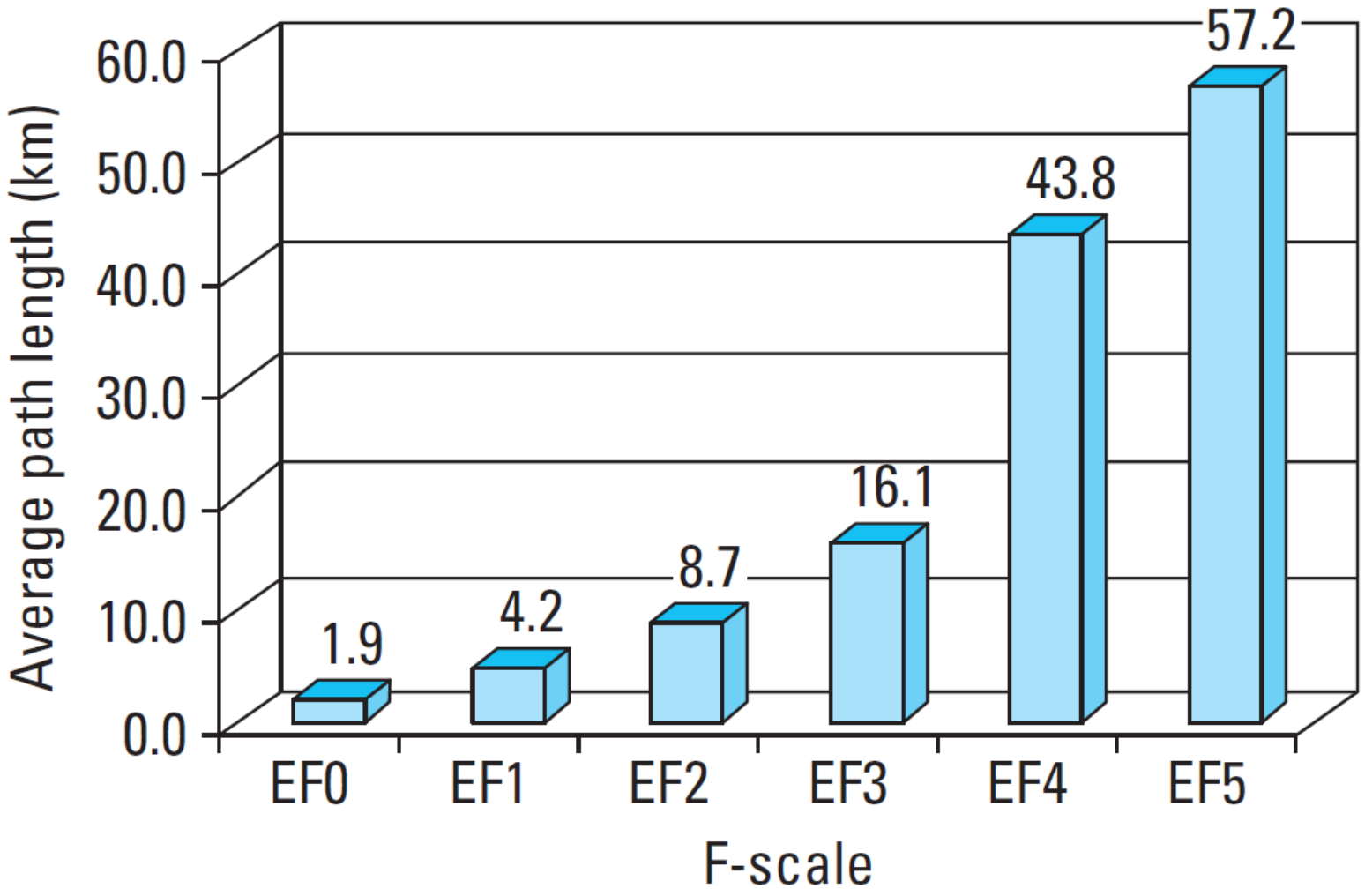
Slightly under 90% of all tornadoes in EF1-2 categories
Only 0.3% achieved EF 5



1) All EF5 tornadoes occurred on the Plains between the Rocky and Appalachian Mountains, with many along a line extending from central Texas northward to Iowa

2) >45% east of the Mississippi River.

Tornado Path Length by F-Number

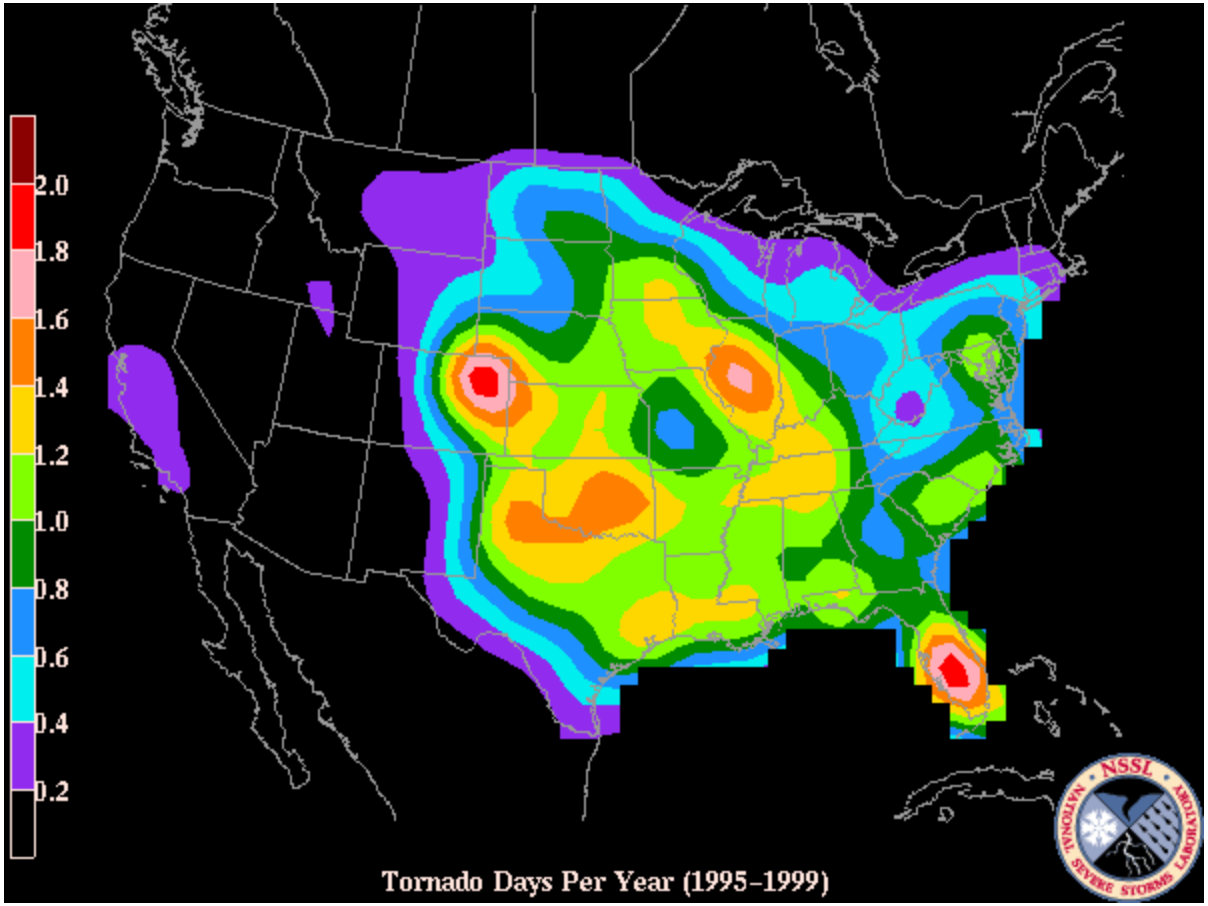


Significant Tornado Alley

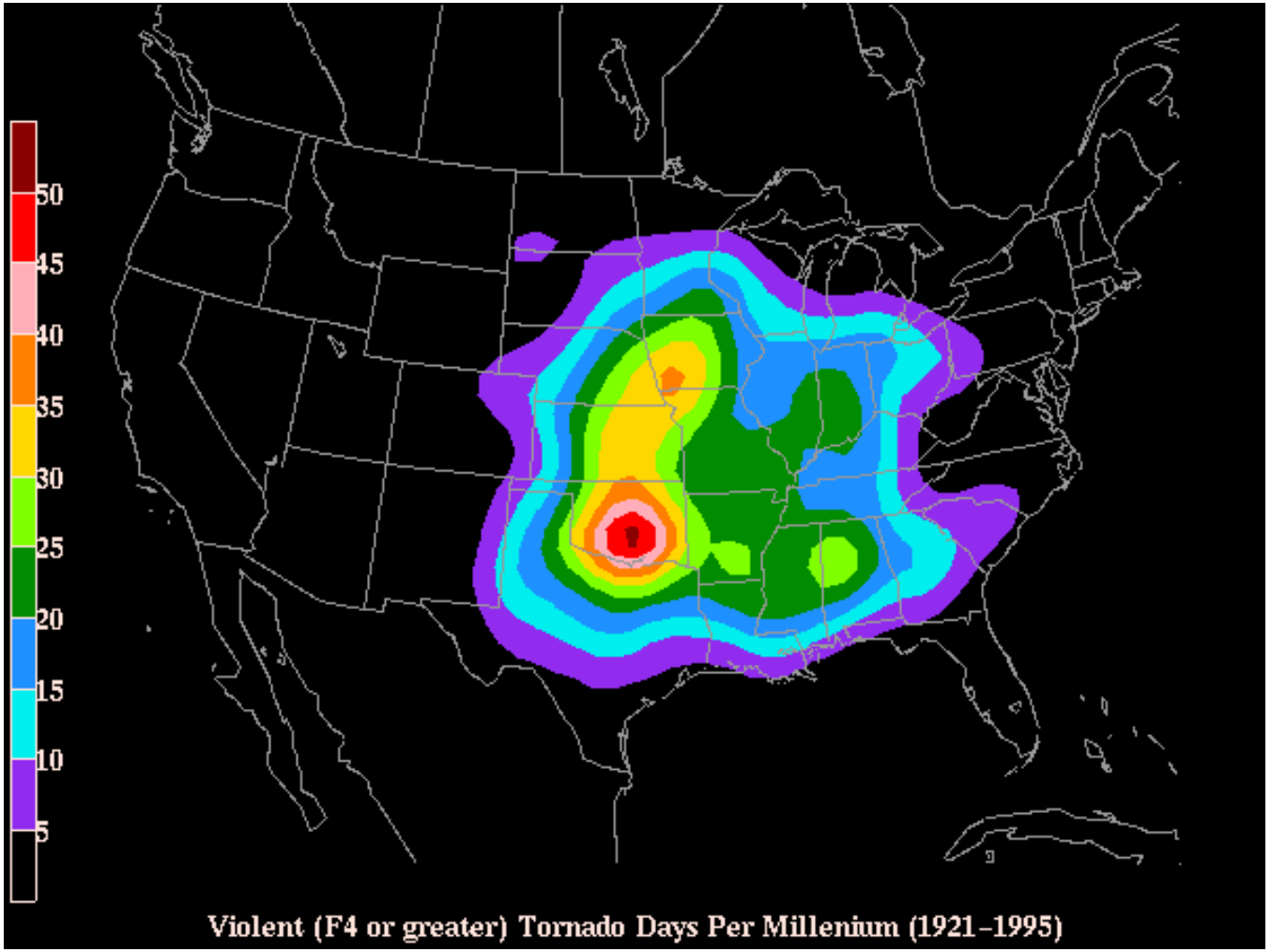
(1 day/decade, 60% near peak)

l., 2000

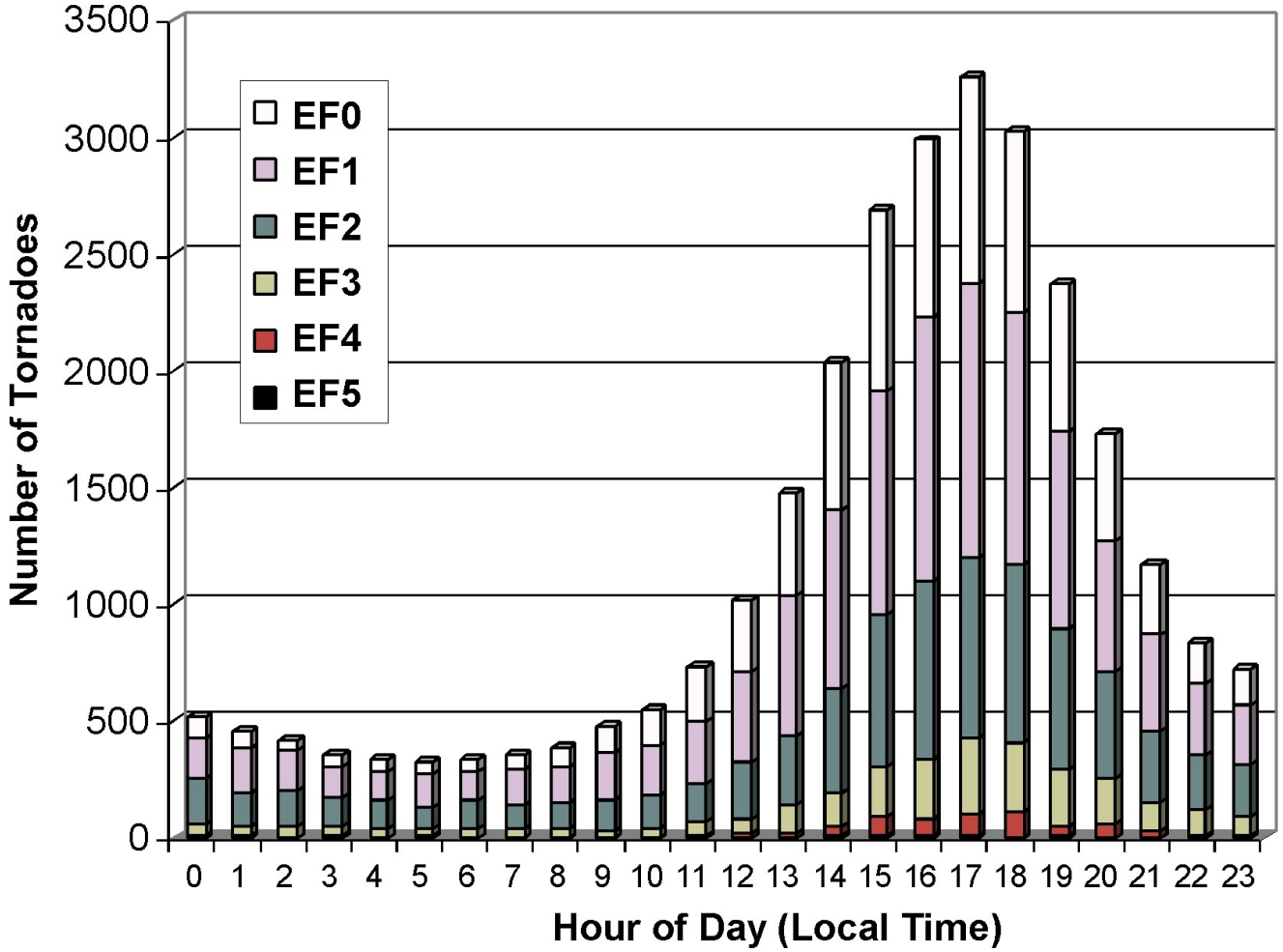
Where Do Tornadoes Occur in the US?



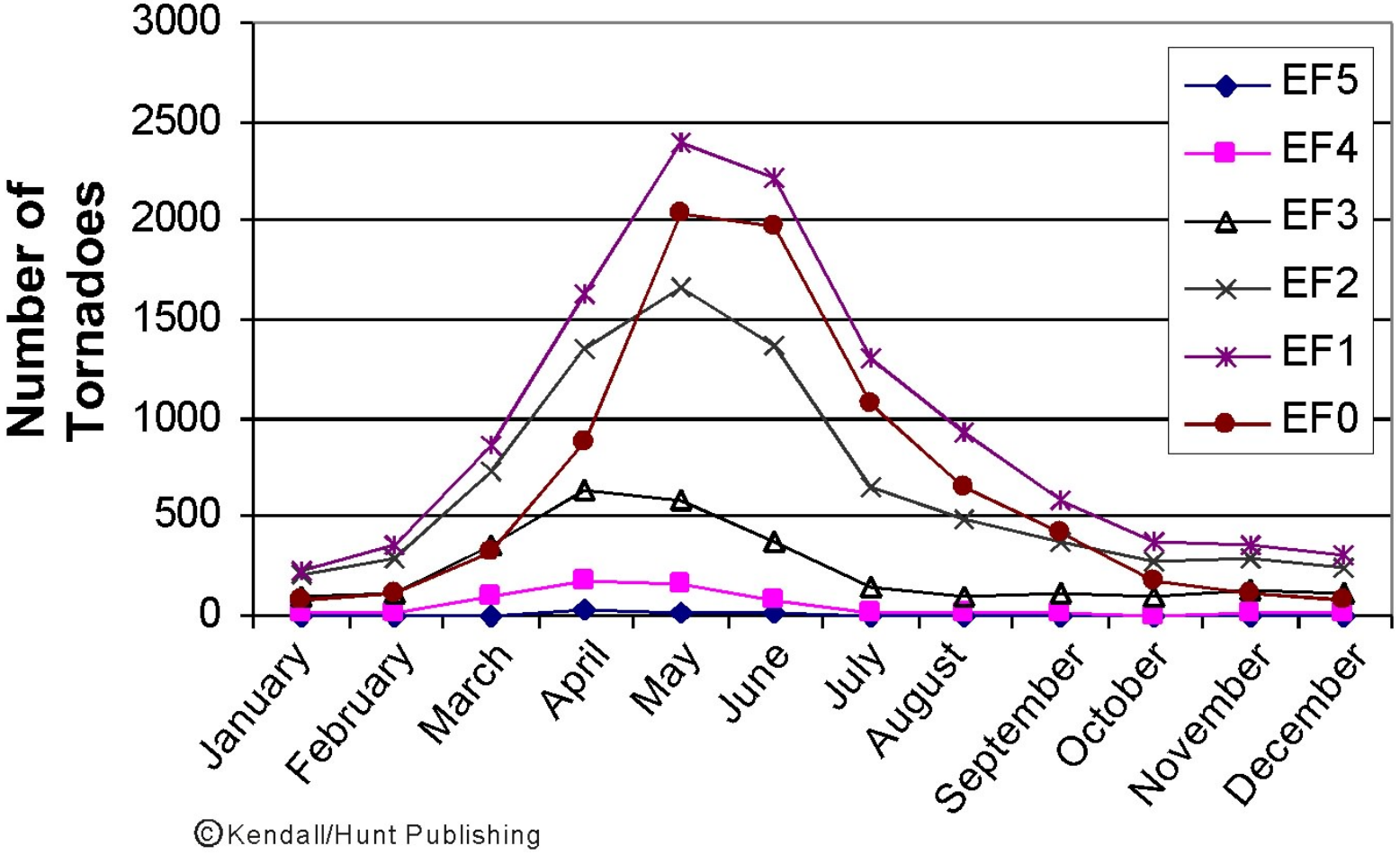
Where Do Severe Tornadoes Occur?

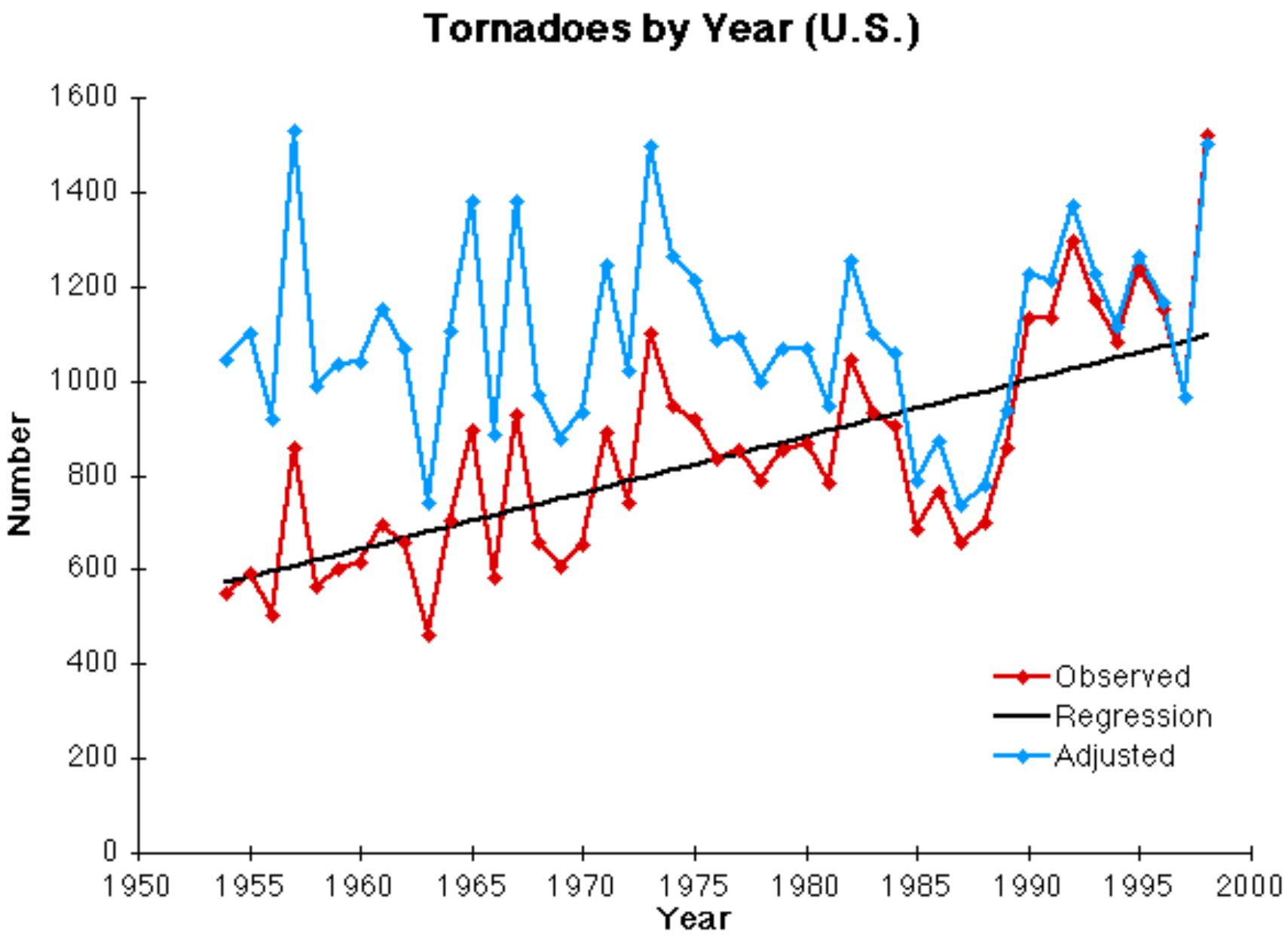


When do Tornadoes Occur During the Day? (peak at 5pm, min at 5am)

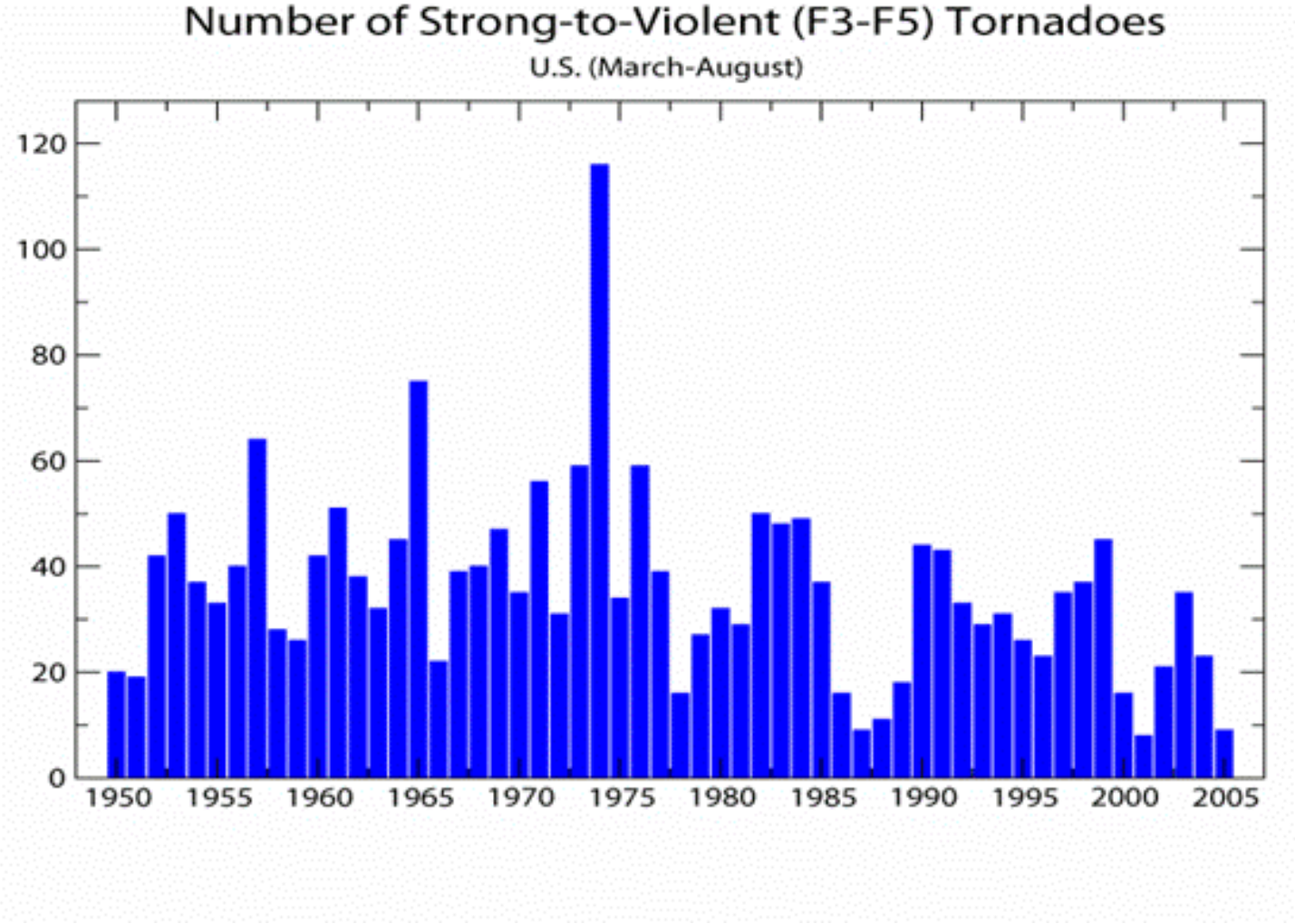


When Do Tornadoes Occur During the Year (Apr, *May*, Jun)



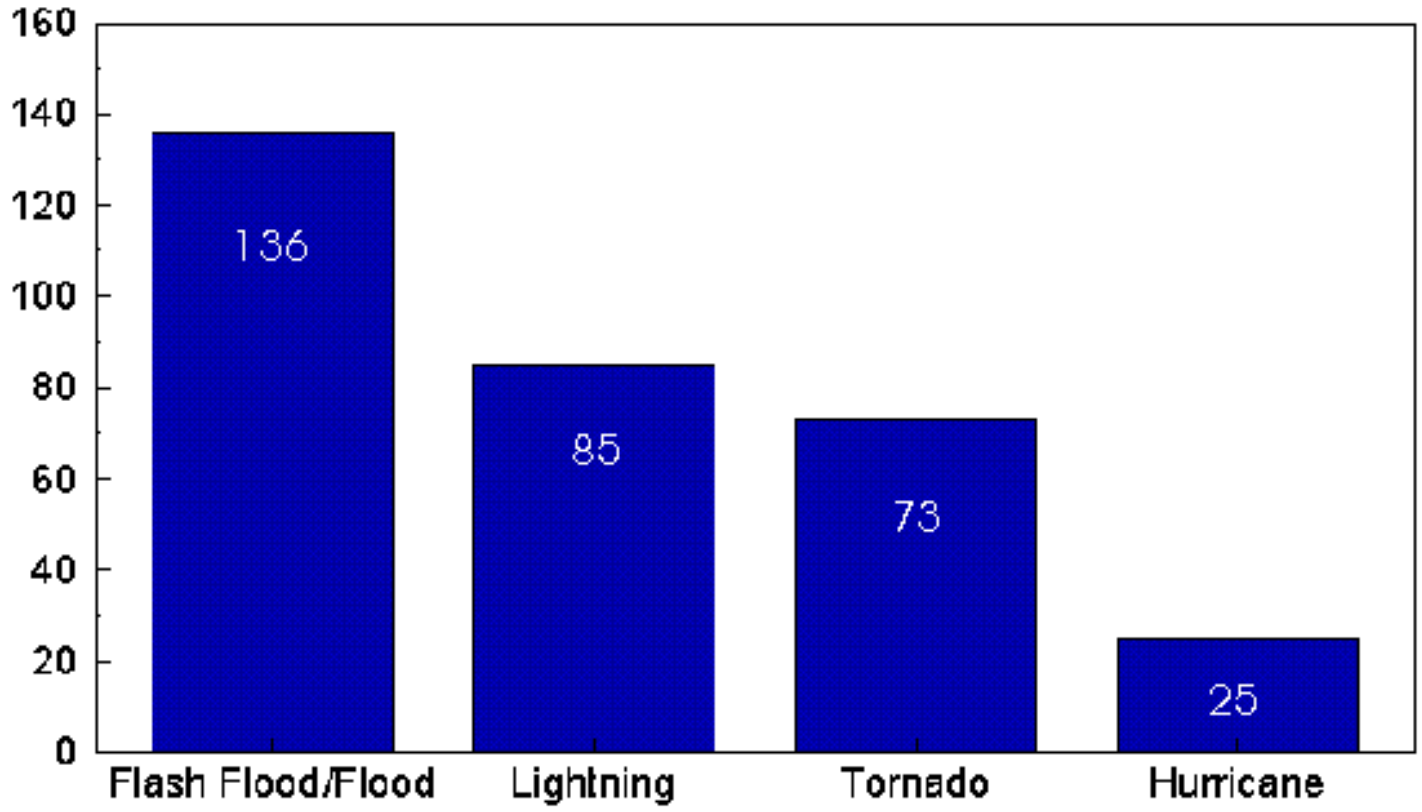

Tornadoes by Year (U.S.)
Number
1600
1400
1200
1000
800
600
400
200
0
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
Year
Observed
Regression
Adjusted

Is the Number of Strong to Violent Tornadoes Changing?



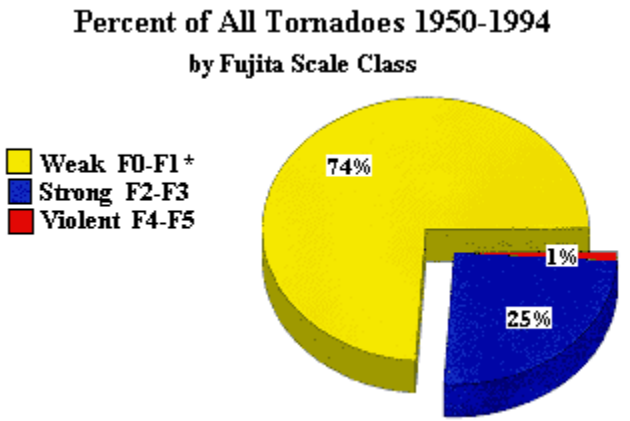
Weather Fatalities

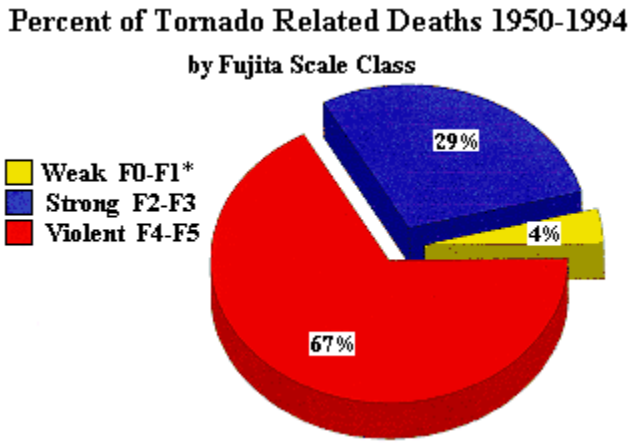
1966-1995 (30 year average)

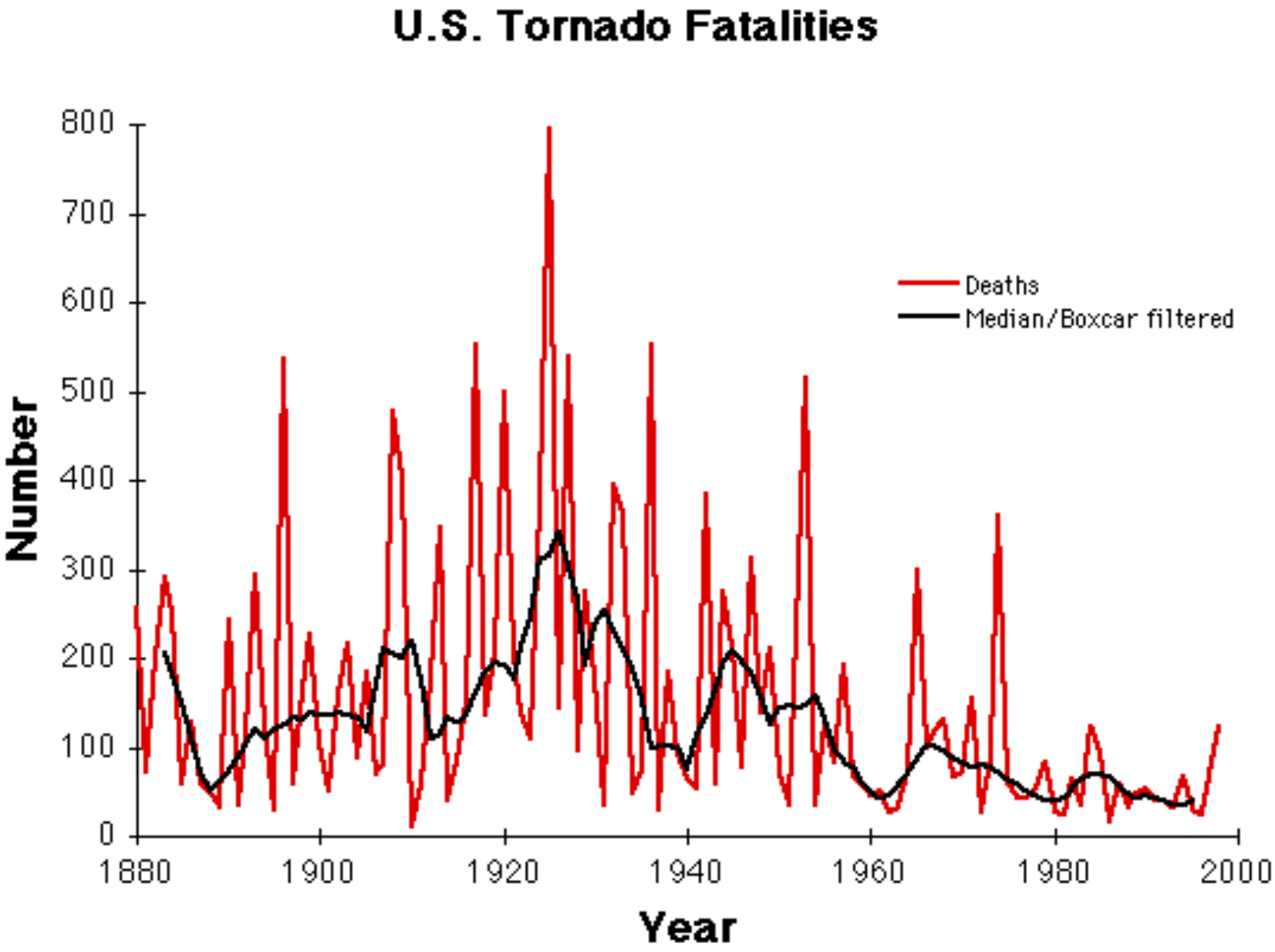


Tornados and Loss of Life

- Damage increases rapidly with strength
- Weak (F0-F1)
  - 74% of occurrences 4% of deaths
- Strong (F2-F3)
  - 25% of occurrences 29% of deaths
- Violent (F4-F5)
  - 1% of occurrences
  - 67% of deaths






U.S. Tornado Fatalities
800
700
600
500
400
300
200
100
0
Number
1880
1900
1920
1940
1960
1980
2000
Year
Deaths
Median/Boxcar filtered

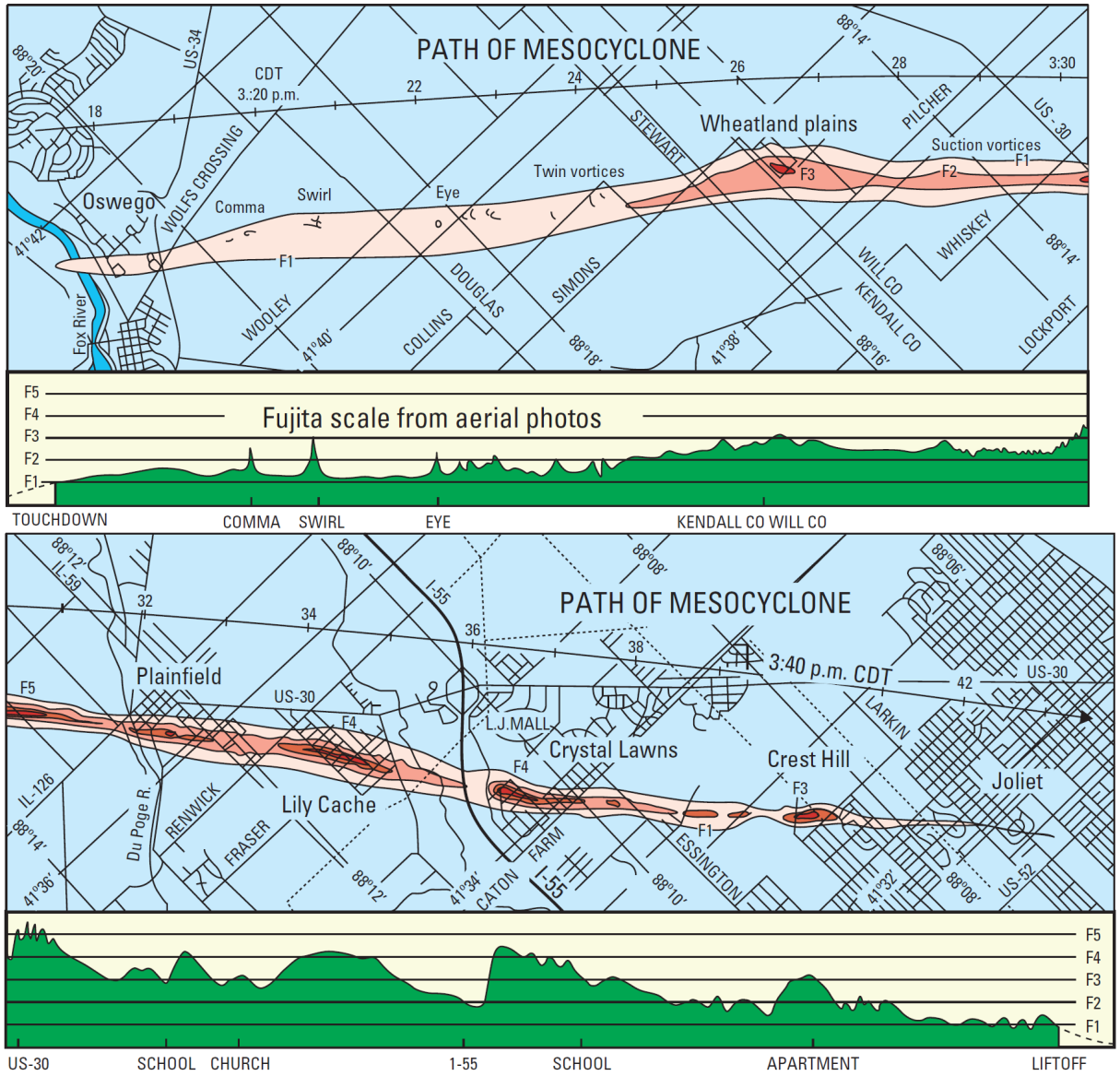
Tornado Impacts

- Economic damage, corrected for…
  - Inflation
  - Population
  - Personal Wealth
  - Totals $1B per decade, or $100M per year
  - Compared with ~$10B per year from hurricanes
  - Constant apart from economic scaling
- Loss of life--- 20-30 per year by 2006

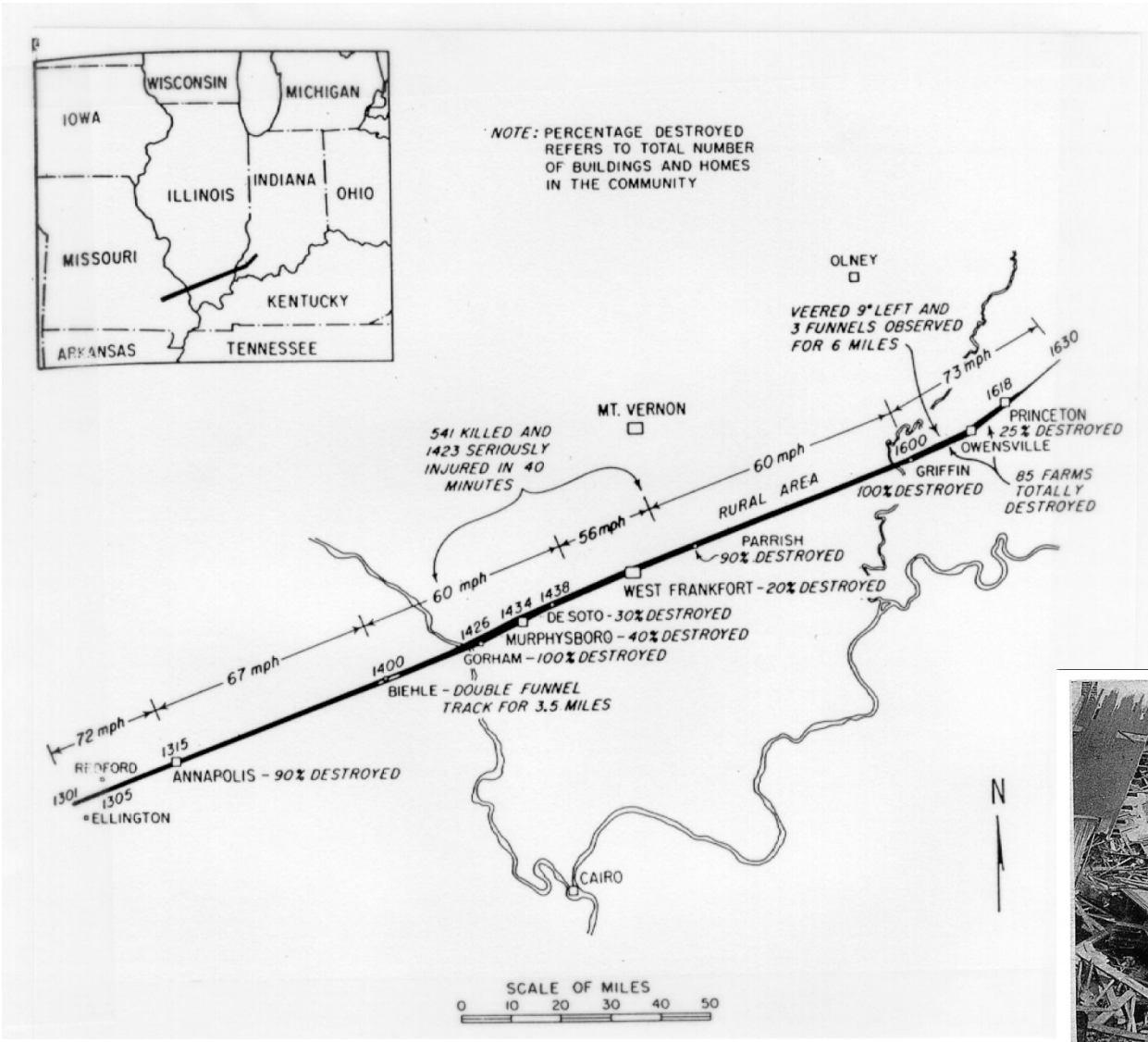
Historic Tornado Cases

Plainfield-Crest Hill, IL Tornado

28 August 1990
Killed 30
Injured 350
16.4 mile track
F5 only W of Plainfield



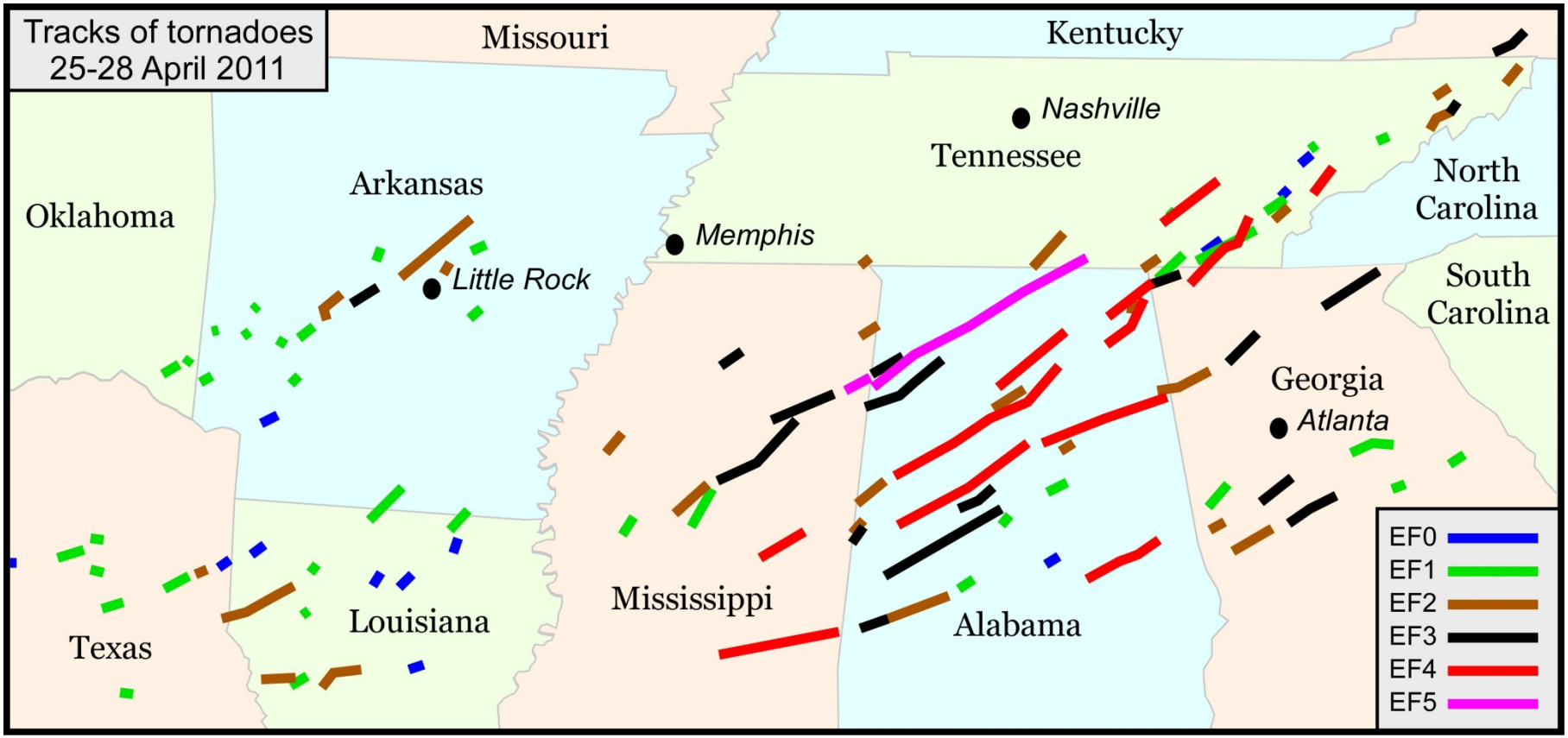
Tri-State (Missouri, Illinois, and Indiana) Tornado of 18 MAR 1925



Was the deadliest tornado in US history
Killed 695
Injured 2027
$16.5 M in damage
Path 294 km long
0.4 km width in MO, 0.8-1.6 km in IL
Unbroken damage path; Must have been a tornado family?

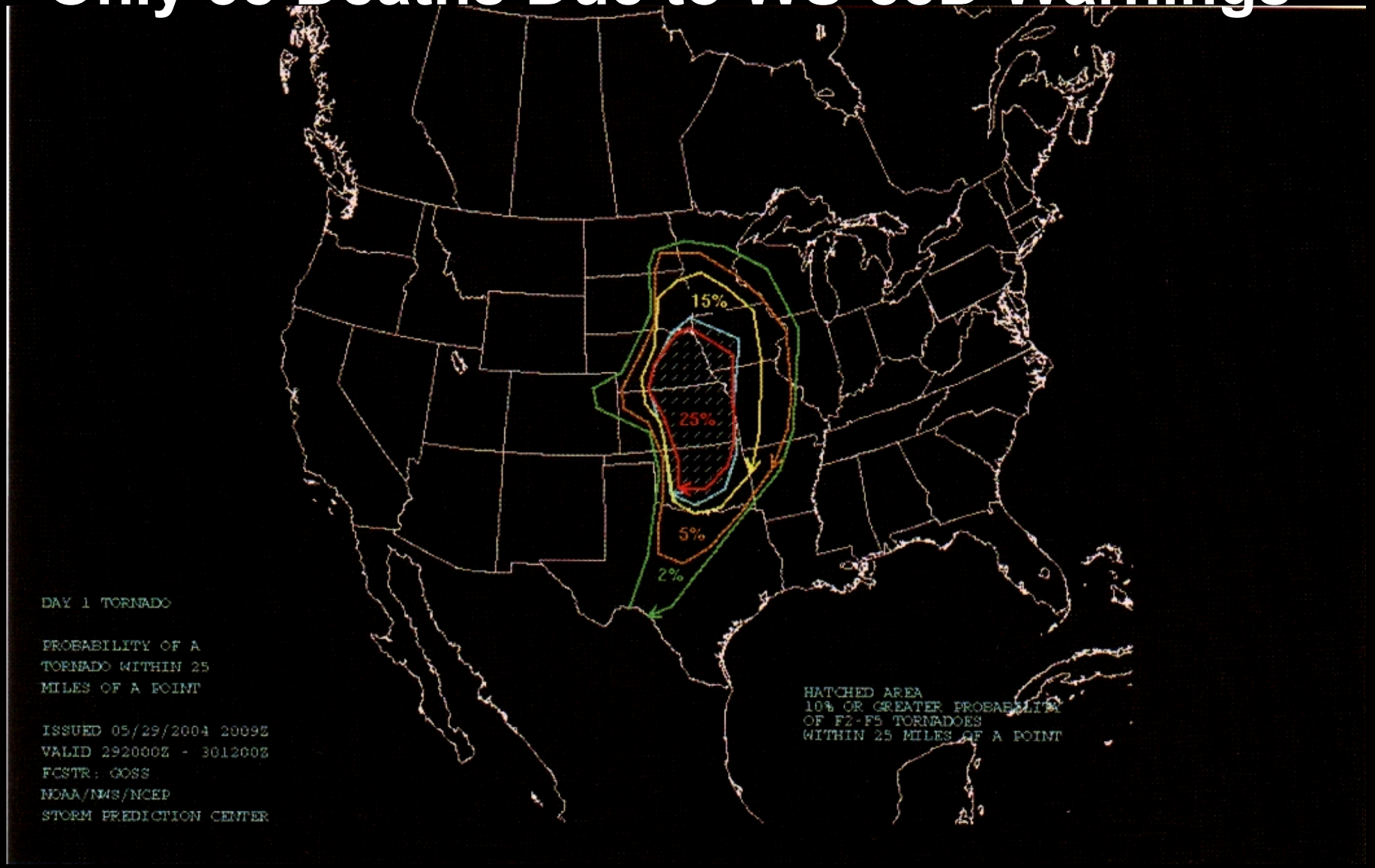
HOMES SHATTERED TO PIECES AT MURPHYSBORO, ILL., IN TORNADO OF MAR. 18, 1925, WHICH RENDERED HOMELESS HALF THE POPULATION OF THE CITY. ABOUT 1200 HOMES WERE COMPLETELY DESTROYED IN AN AREA 1 MILE WIDE AND 2½ MILES LONG.

Tornado Outbreak of 27 April 2011 in the SE US: total 353 tornadoes, 4 EF5, 11 EF4, 23 EF3 (over 300 fatalities)



- Well forecast by NWS: 6 day in advance; >90% of the tornadoes had warnings (resulted from Doppler radar mesocyclone signatures); average lead time of specific tornado warnings was 24 mins.
- Still 353 fatalities occurred due to some tornadoes' very large size (1.5 miles wide, 80 miles long)

May 2003: Record 516 Tornadoes, But Only 38 Deaths Due to WS-88D Warnings

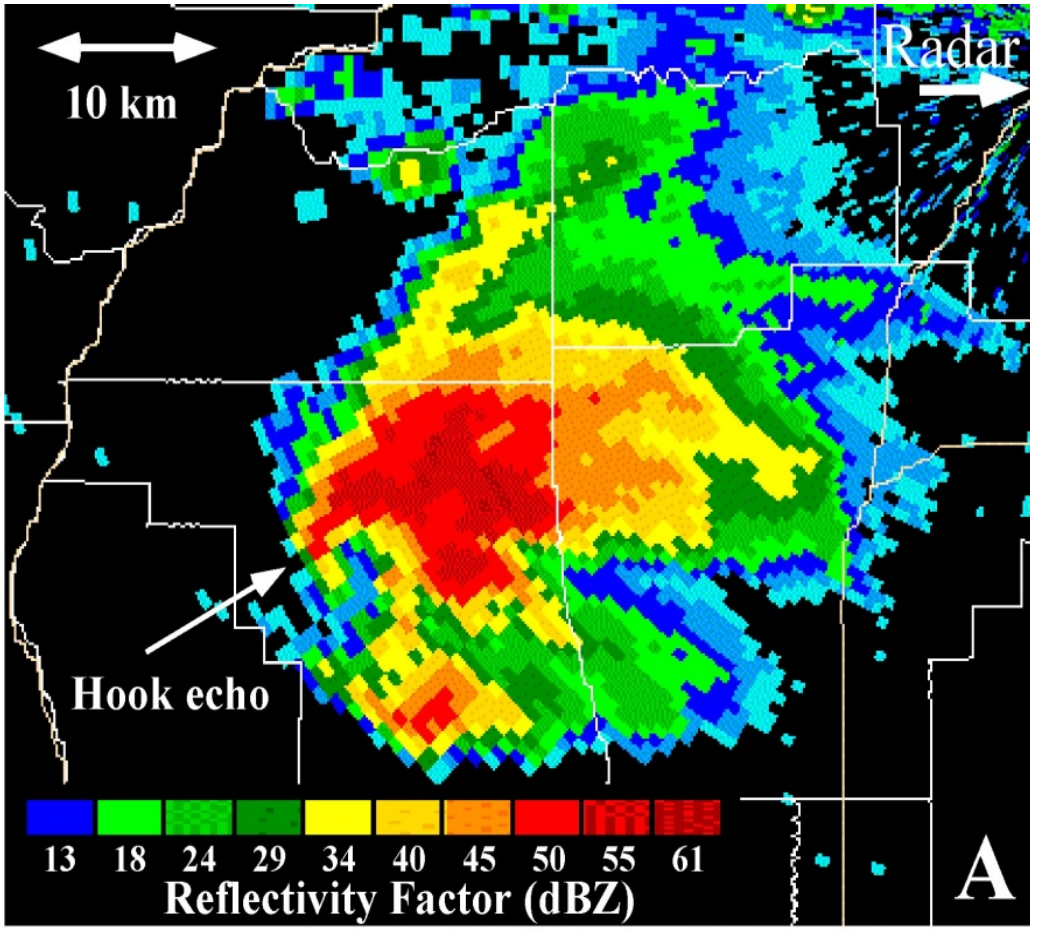


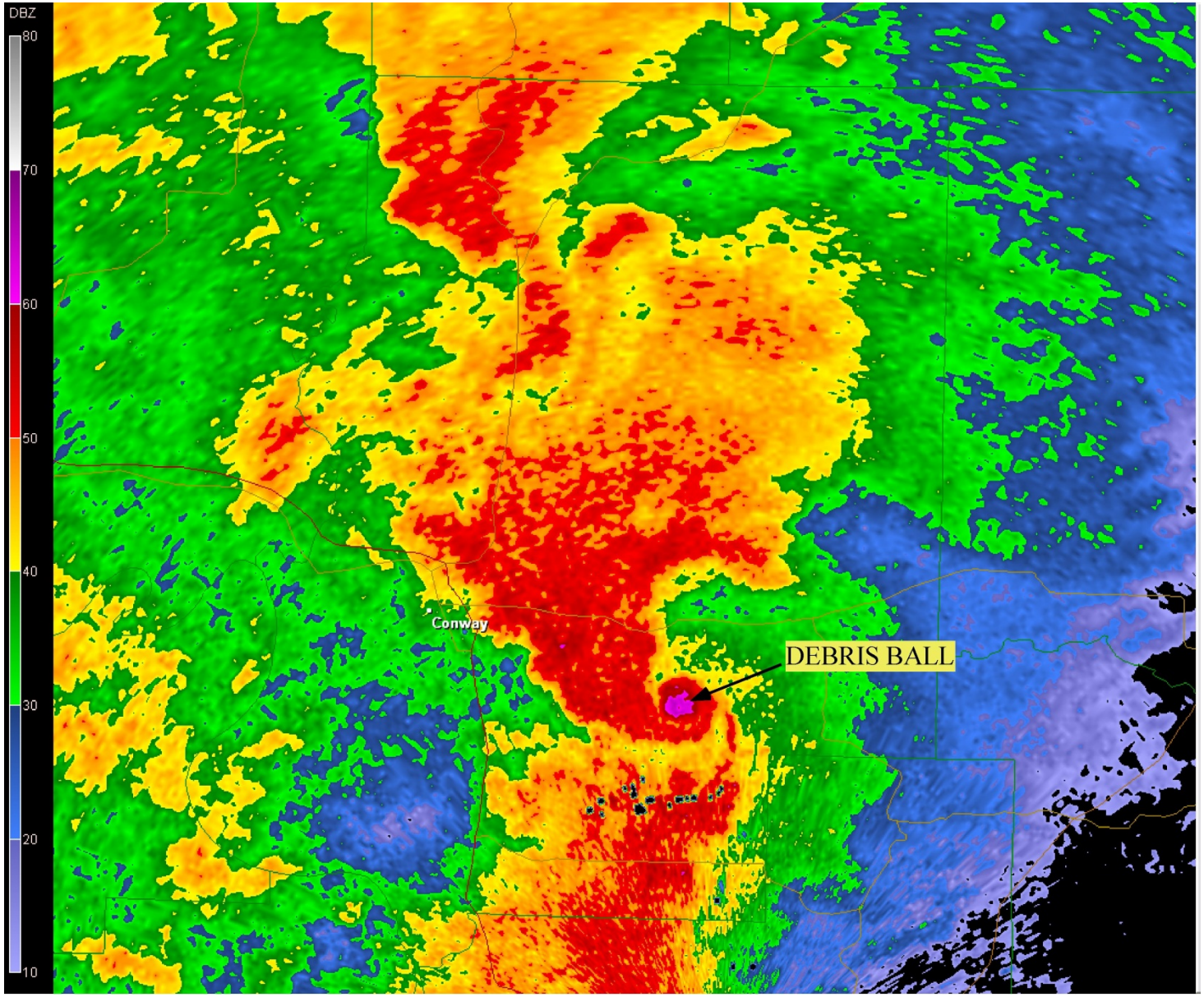
Tornado Detection

- Traditionally, trained networks of storm spotters report tornadoes
- WSR-88D Doppler radar network in 1990s: allow advanced warnings (several minutes before an actual tornado) to be issued.
- Hook echo in reflectivity field: RFD wraps around the echo-free base of the updraft
- Doppler Radar can detect mesocylone.

Hook Echo & Debris Ball

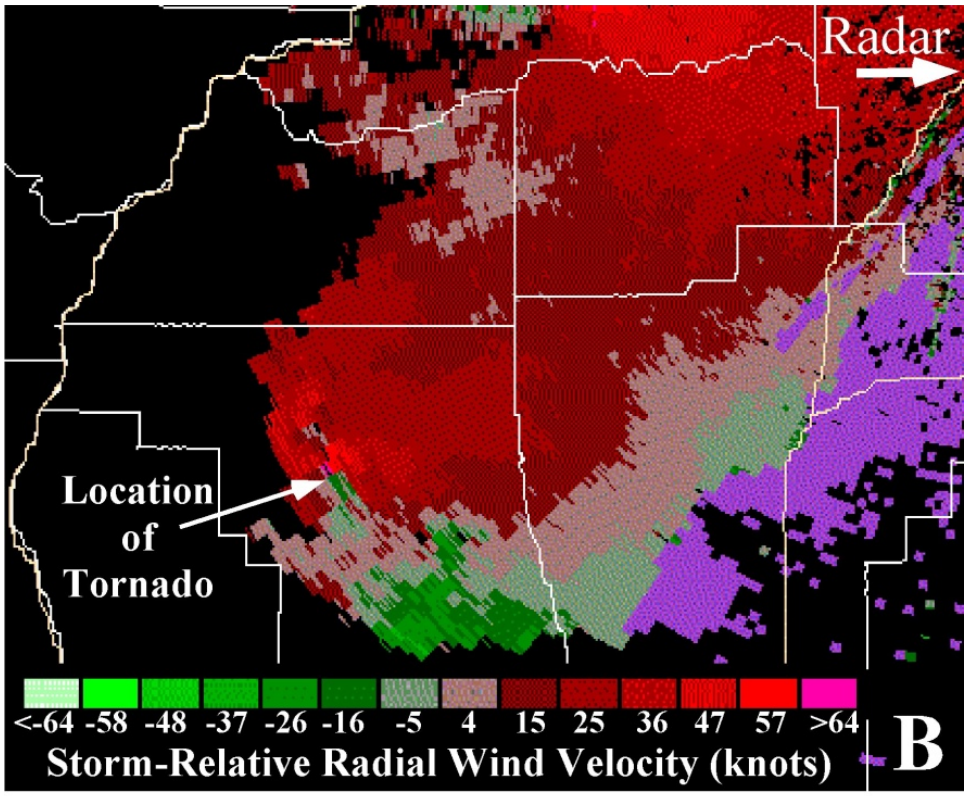
- Tornado is usually near the tip of the hook.
- Debris ball sometimes occur right in the tip of the hook echo, pinpointing the tornado
- Debris ball doesn't occur when no debris, or radar beam is too high
- Hook echoes do not appear in all supercells (RFD air sometimes precipitation free), and do not occur in non-supercell tornadoes.




DBZ
80
70
60
50
40
30
20
10
Conway
DEBRIS BALL

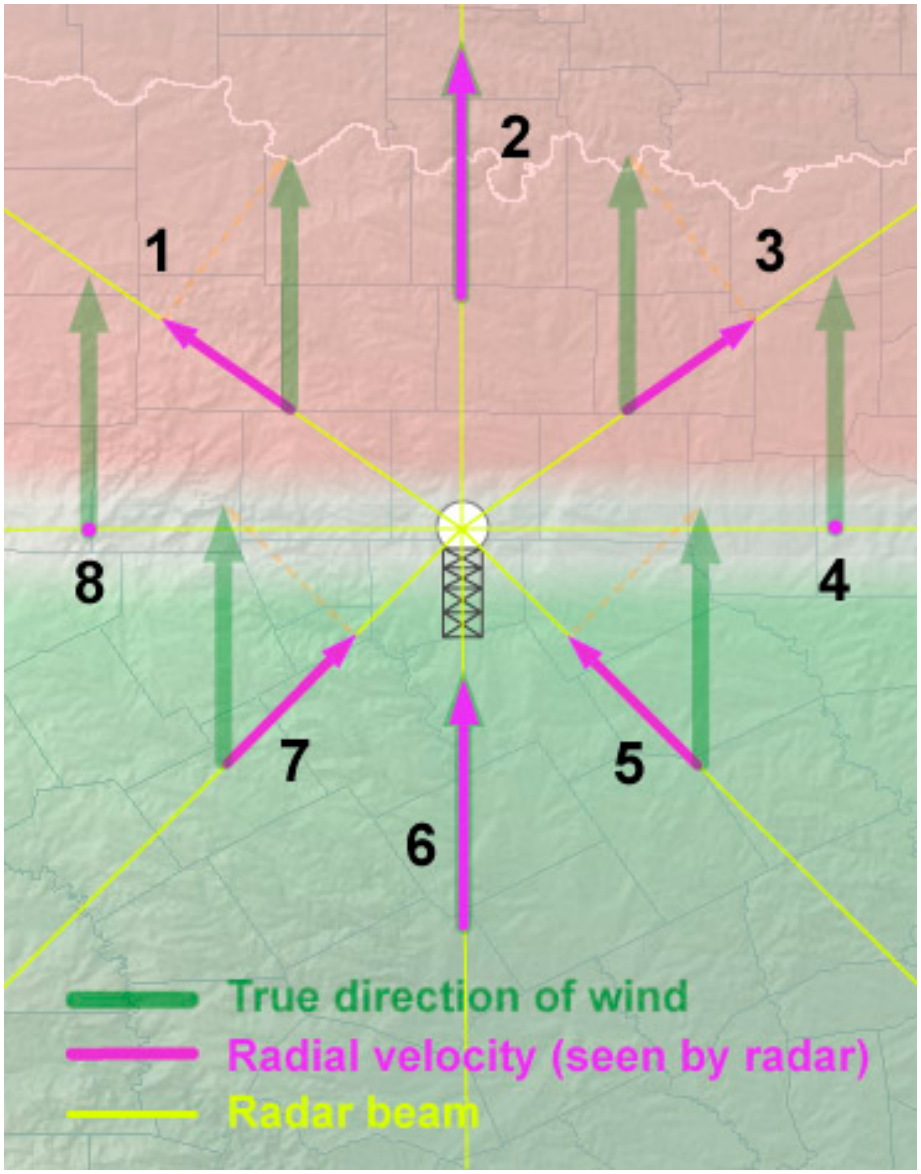
Mesocyclone signature & tornado vortex signature in Doppler radial velocity fields

- Doppler radar can provide clear evidence of rotation in thunderstorms long before a tornado occurs.
- Mesocyclone signature is a precursor of tornado formation.
- Forecasters can track the path of mesocyclone and extrapolate forward to estimate future tornado location
- Tornado vortex signature (a tiny area, only one sample volume) can occasionally be seen in Doppler wind fields.
- Doppler radar increased the warning lead time from 6 min to 12 min on average .



Doppler Radial Velocity

A measure of the component of the wind along the direction of the radar beam



- Doppler velocity is negative for toward radar, positive for away from radar
- Zero value zone means that the wind direction is perpendicular to the radar beam.

Patterns associated with nonuniform horizontal wind fields (difluent)

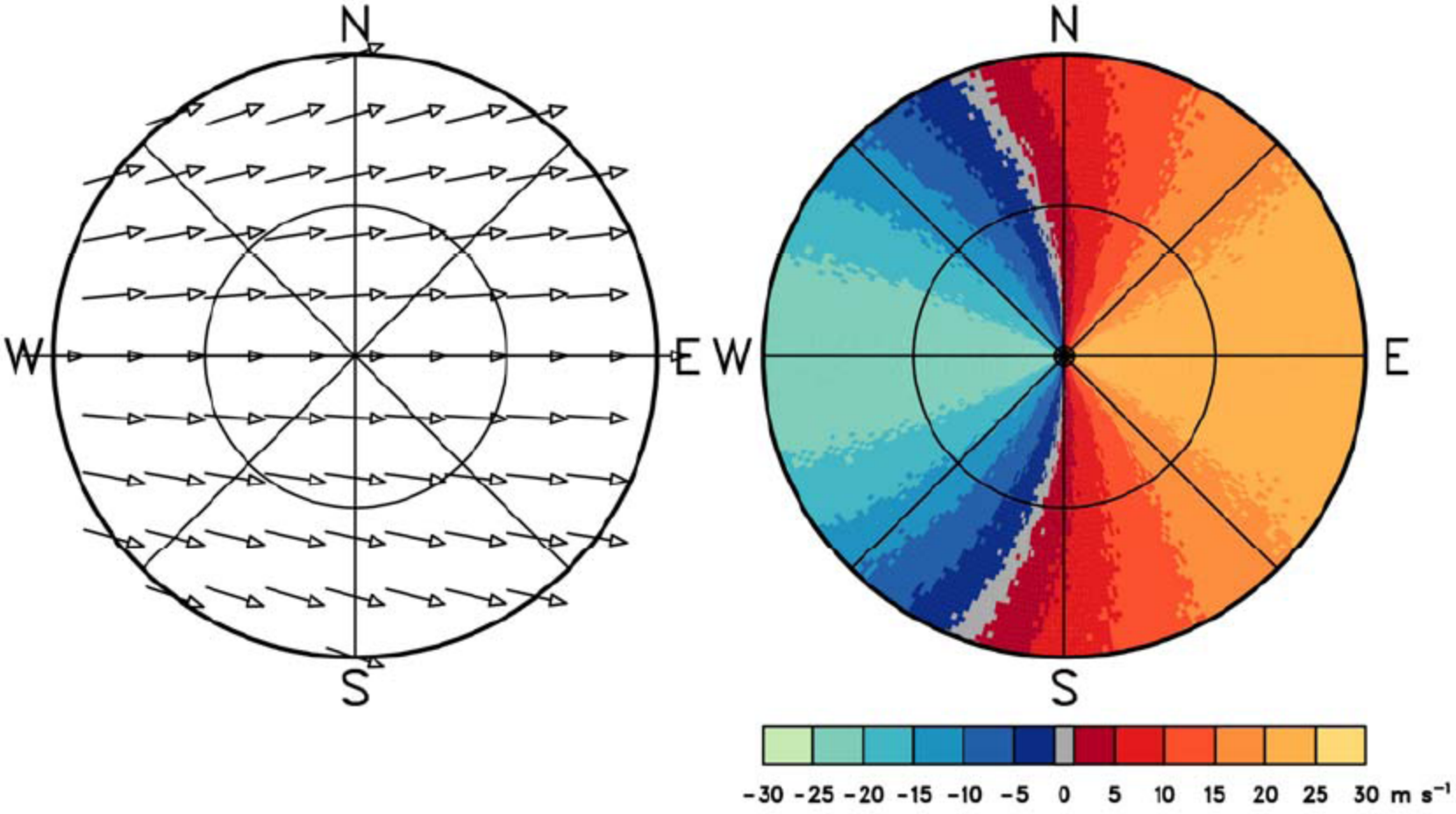


Fig. 2.3.1. *Doppler velocity pattern (right) corresponding to a horizontal flow field that is difluent with the same speed (23 m s^{-1} or 45 kt) at all heights (left). Negative (positive) Doppler velocities represent flow toward (away from) the radar. Radar location is at the center of the display.*

Patterns associated with nonuniform horizontal wind fields (confluent)

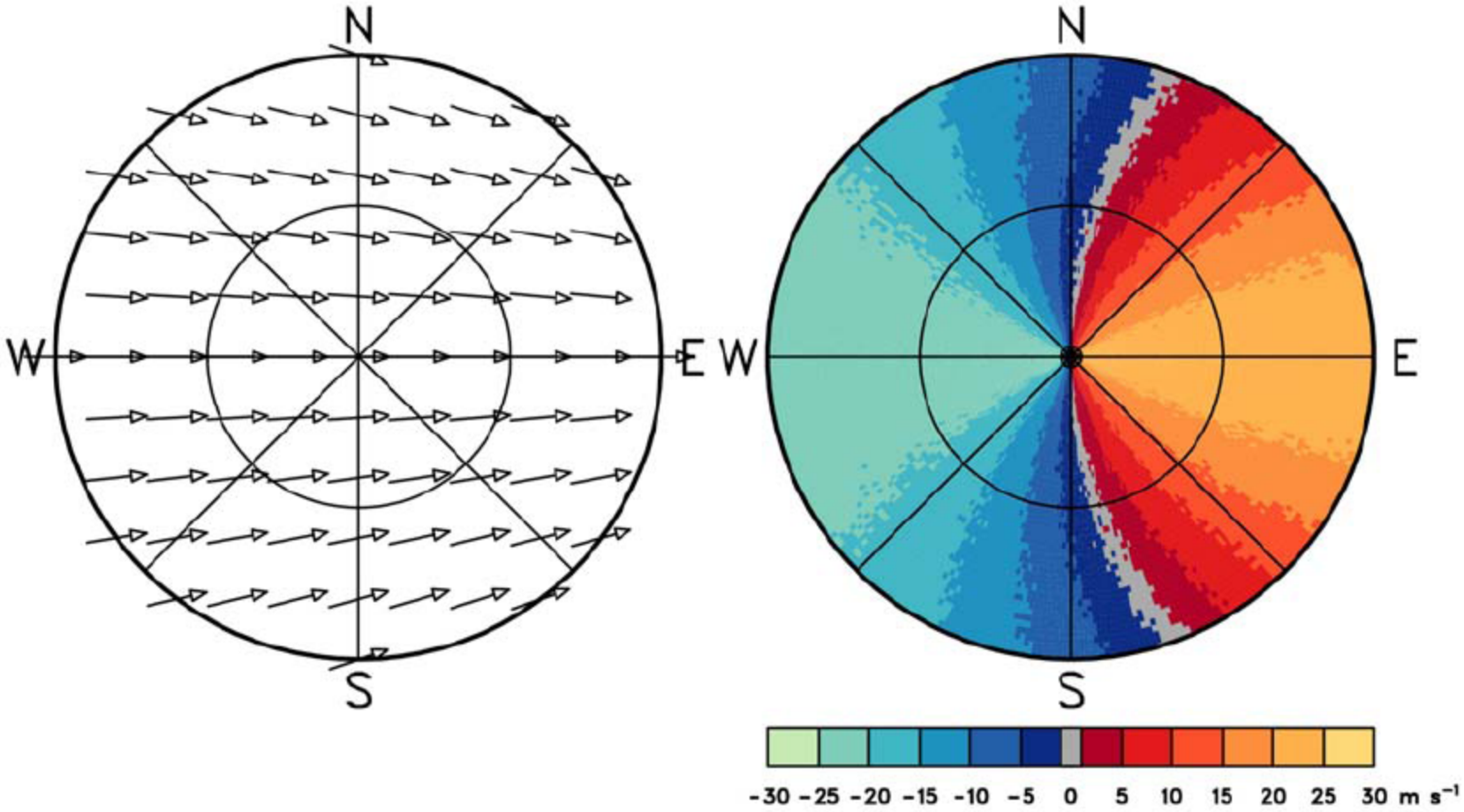


Fig. 2.3.2. *Same as Fig. 2.3.1, except that the horizontal flow field is confluent with the same speed (23 m s^{-1} or 45 kt) at all heights.*

Patterns associated with a mesocyclone

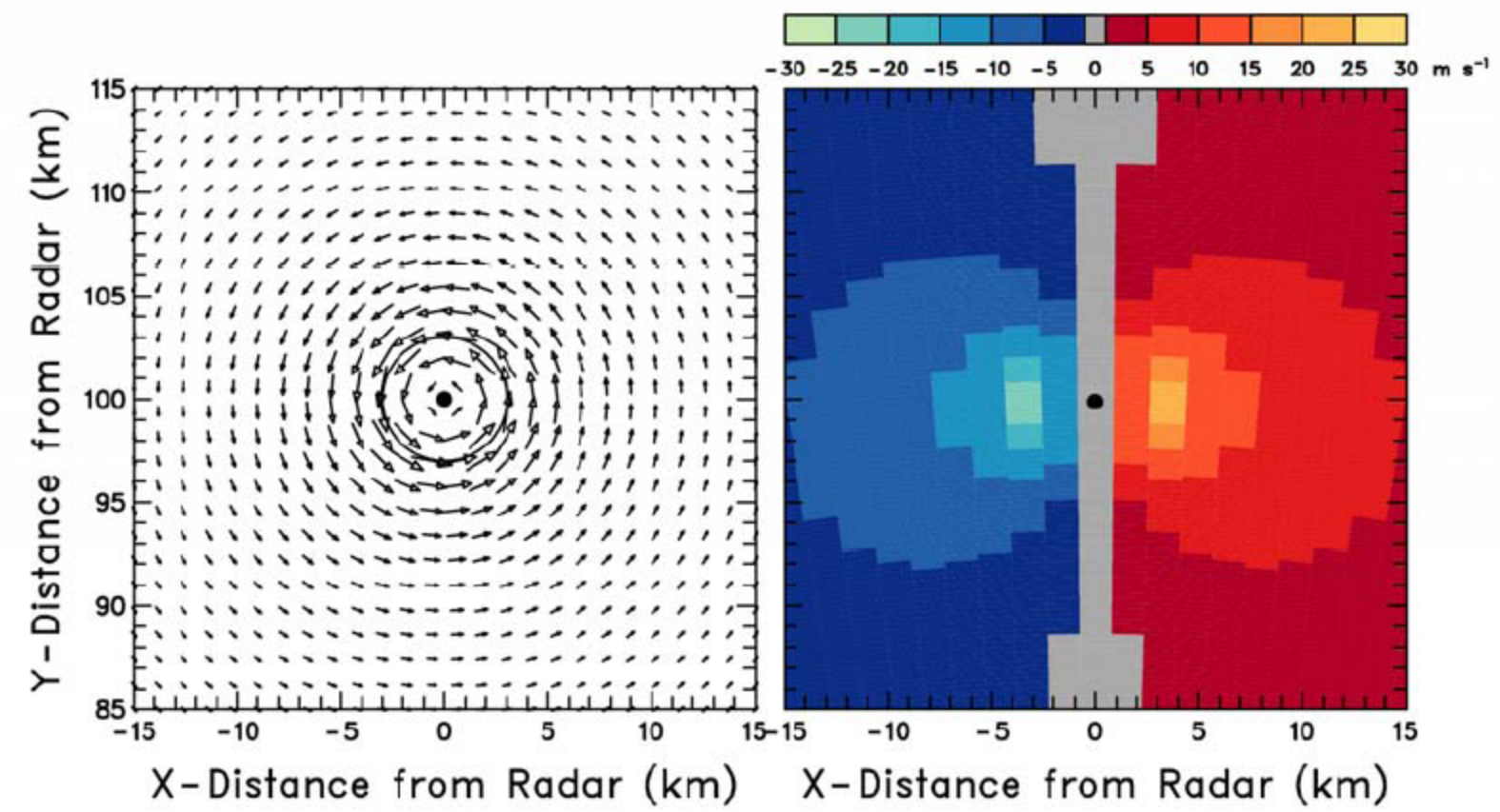


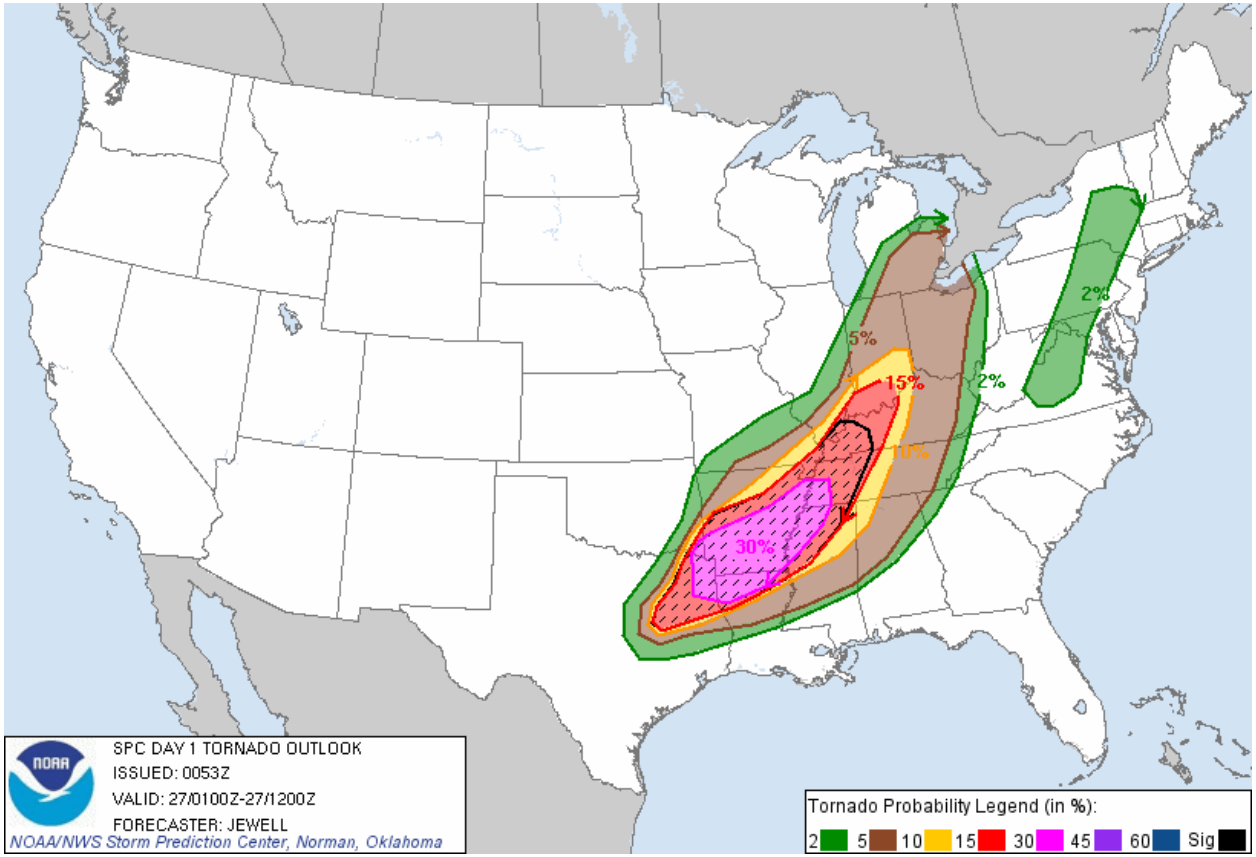
Fig. 4.3.2. *Same as Fig. 4.3.1, except that the Doppler velocity pattern (right) corresponds to a mesocyclonic (left) that has peak tangential velocities of 25 m s^{-1} (49 kt) at a radius of 3 km (1.6 n mi) from the circulation center (black dot).*

Tornado Forecasting

- Model soundings are used to estimate atmosphere instability indices
- Model soundings can be used to analyze for future conditions; provide data for locations without actual sounding observations.
- CAPE: a measure of instability; range between 0 and 5000 J/kg. CAPE > 2000 j/kg is necessary for strong T-storms
- Storm-Relative Helicity (SRH): measure the horizontal rotation in the lowest 1-3km, related to shear. Larger values are more favorable for tornadoes.
- Energy-Helicty Index (EHI)=CAPExSRH /16,000: a combination of shear and instibility.

Tornado Forecasting at SPC

- Forecasters at SPC identify possible regions of severe storms using CAPE, SRH, EHI, and lifted index
- Within regions where severe storms are possible, forecaster look for fronts, other boundaries , cloud cover, inversion, availability of moisture, and jetstreams



- 12hr to 3-day potential severe weather area forecasts
- **Day 1 product (left)**: The probability of a tornado occurring within 25 miles of a point

Tornado Watches & Warnings by NWS

- **Watches** are issued by NWS to inform the public of the potential severe weather threat.
  - **Severe thunderstorm watch**: means that the conditions are favorable for the development of thunderstorms containing strong winds, hail, and possible tornadoes.
  - **Tornado watch**: indicates that conditions are particularly favorable for tornado formation and are usually conducive for other types of severe weather as well.
- **Warnings** are issuded by NWS when the storms are in progress
  - **Severe thunderstorm warning**: a severe thnderstorm is occurring in or near the warned area. The warning can be based on radar, reports from local officials such as state police and spotters, or information from the public
  - **Tornado warning**: a tornado is believed to be present in the warning area (based on radar hook echo or tornado vortex signature, or on sightings by the police, storm spotters, or the public)

Tornado Safety

- When threatening weather is imminent: Do Minute-by-minute tracking, pay attention to watches and warnings on **NOAA All Hazards Radio** (alarm) and local broadcast media
- Go to shelter---Underground (basement) or interior room or hallway on the lowest floor (bathroom); windows should be avoided.
- If caught outdoors, move as far away from potential airborne objects as possible and lie in the lowest spot available.
- If in a car, abandon the car and seek a sturdy shelter. If not available, lie in a ditch and cover your head and neck.

Summary

- 88% of tornados are EF0-EF2, 9% are EF3, 2% are F4, and 0.3% are EF5
- Tornado Alley: Texas to South Dakota
- Worst month: MAY; Worst time of day 4:00 PM
- Better monitoring has led to more detection (~1000 /year, up from 200 in early 1900s), but fewer F4 and F5s (~1%)
- F4 & F5 account for ~1% of tornados, but 67% of deaths
- Impact ~$100M and 20-30 deaths per year
- Much less than hurricanes for damage, but similar loss of life
- Watch—Tornados likely based upon CAPE, etc
- Warning ----Tornado on the ground
- WSR-88D provides minute-by-minute situation awareness
- Shelter underground or in interior windowless rooms