

Chapter 19: Tornadoes



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Tornado defined

- **Tornado** – a violently rotating column of air
- What is the typical size of a tornado?
 - 50-800 meters (150 ft to 0.5 mile)
- What range of wind speeds are present in a tornado?
 - 65 mph to over 200 mph
- What kinds of storms do tornadoes form in?
 - Supercells (most common), squall lines, near end of bow echoes, and within landfalling hurricanes

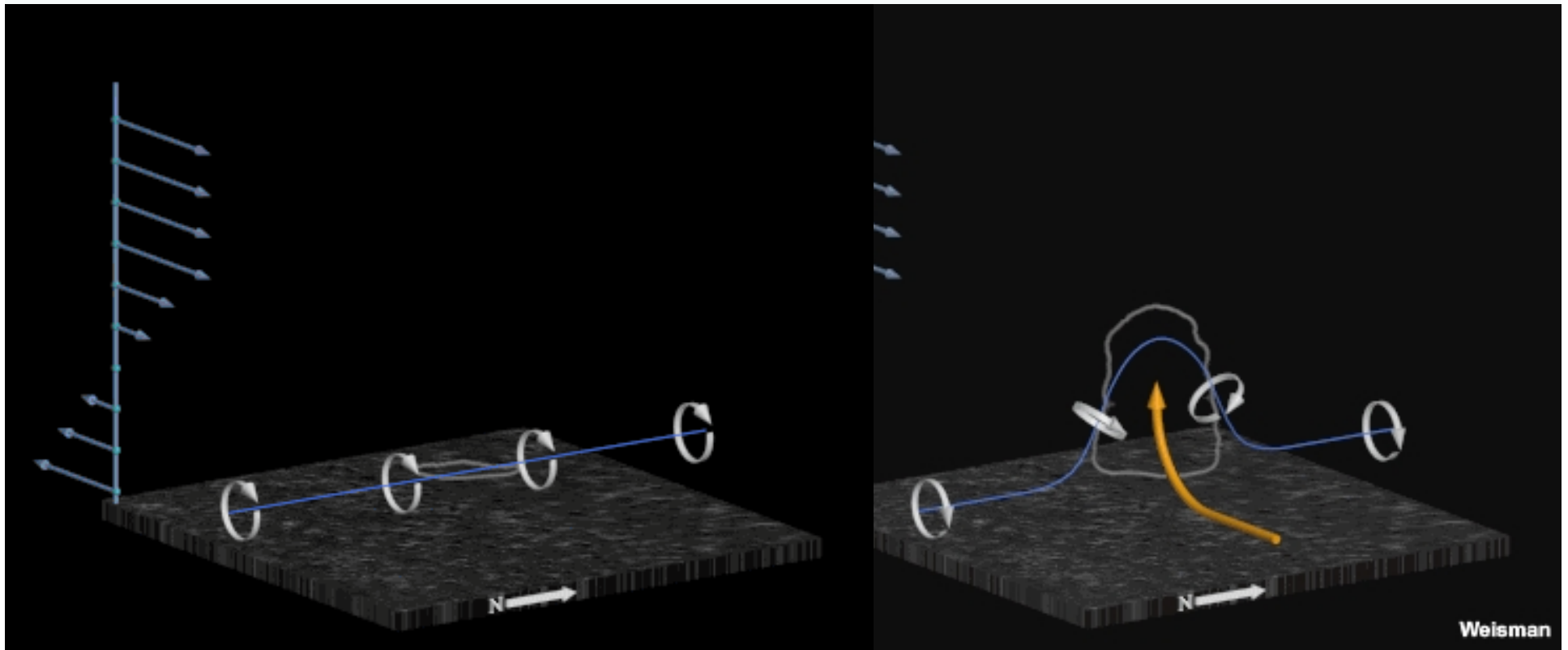
Tornado formation in supercells

- What causes a supercell thunderstorm to rotate?
 - A process called “tilting”
- What is the role of the vertical shear in creating this rotation?
 - Imagine a ball in the wind flow
 - If winds at one level are blowing one direction and winds at an upper level blow the opposite direction, it can create a horizontal “roll” of rotation (the ball would spin)
 - Or likewise if the wind speed changes rapidly with height, it can also create a horizontal “roll” of rotation (the faster wind speeds would make the ball start to spin)
 - The strong southerly winds of the low-level jet can provide this low-level wind shear

Supercell rotation

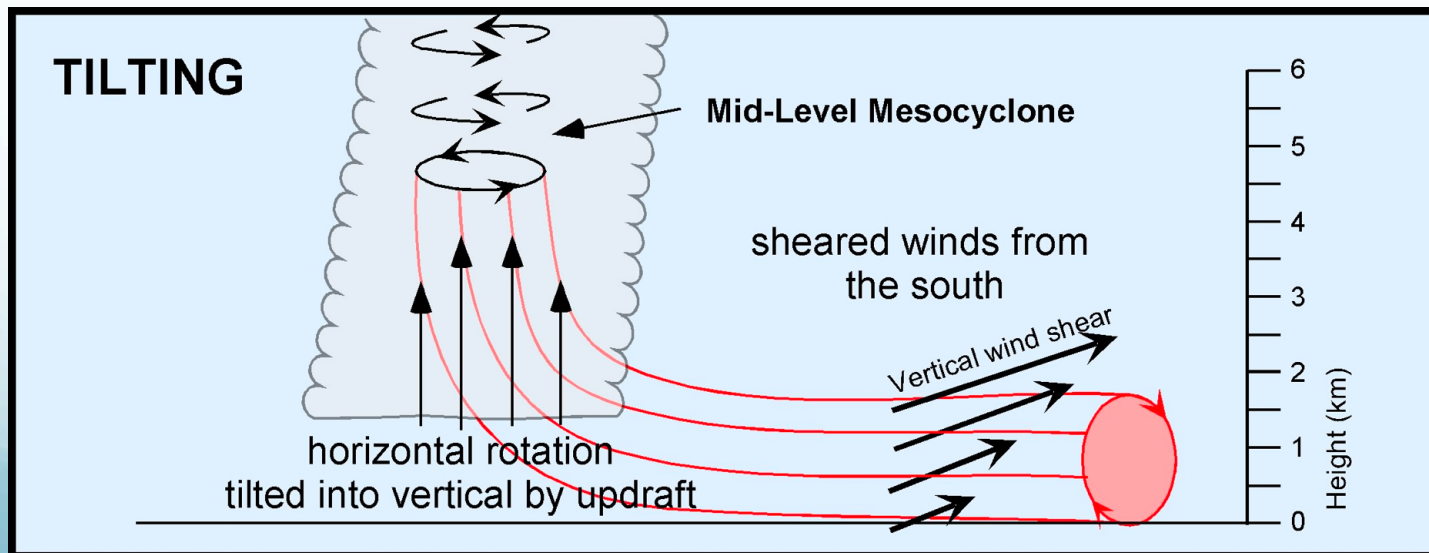
- What happens when you have a vertically sheared environment and an updraft forms?
 - A horizontal “roll” of rotation exists

The “roll” of horizontal rotation gets tilted vertically by the updraft!



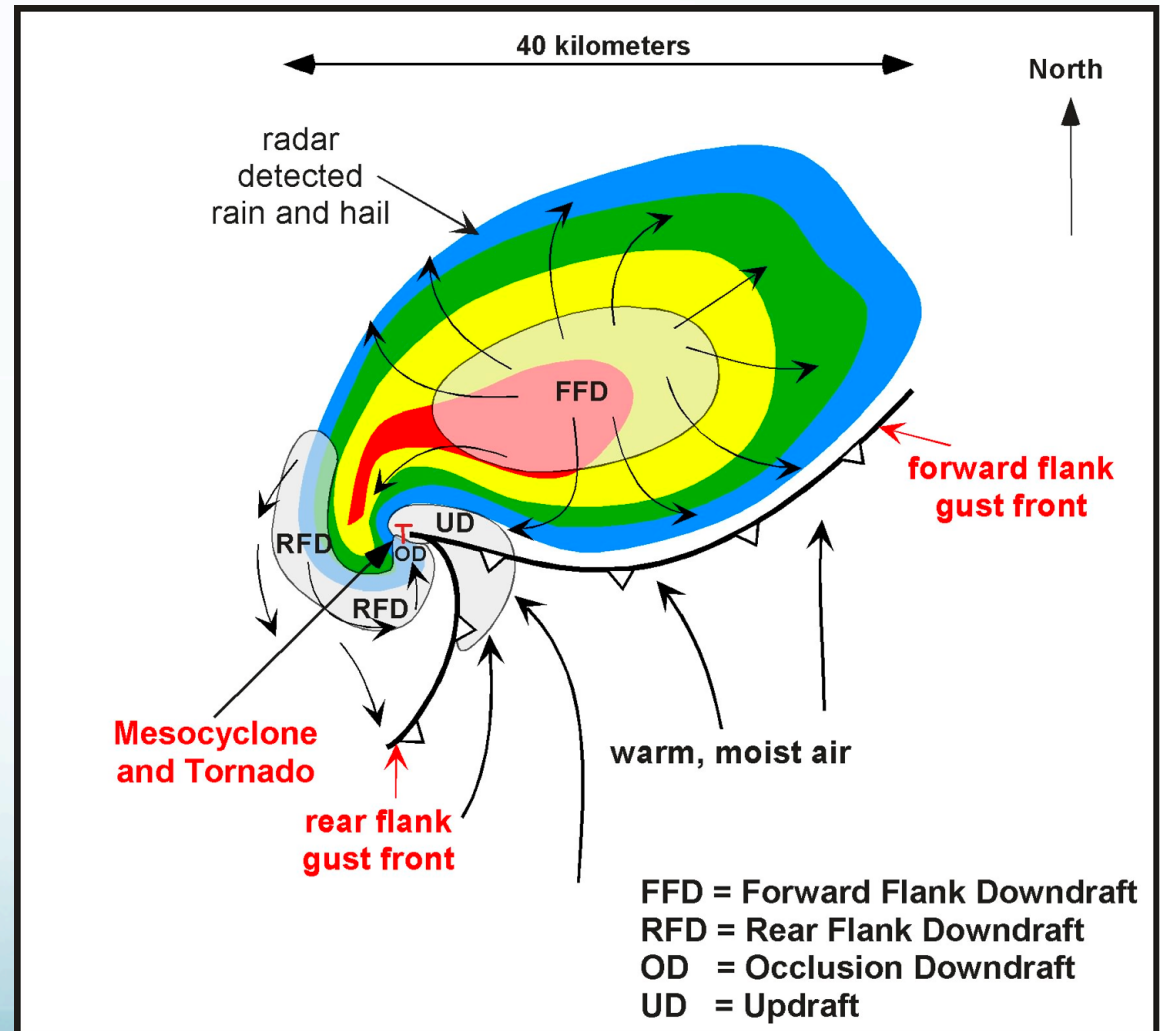
Supercell mesocyclone

- **Mesocyclone** – the rotating circulation in a supercell thunderstorm that is associated with the updraft
 - The mesocyclone is associated with an area of lower pressure.
 - What is the typical size of a mesocyclone? **5 km (3 miles) wide**



Supercells and tornadoes

- Recall the structure and features of a supercell:
 - Rear flank downdraft (RFD)
 - Forward flank downdraft (FFD)
 - Mesocyclone



Clicker Question

- Rotation in a supercell occurs when _____.
 - A. the shear associated with the low-level jet creates rotation about a vertical axis
 - B. the rear flank downdraft forms
 - C. the forward flank downdraft forms
 - D. the rotation created by the shear associated with the low-level jet is tilted into the vertical direction by the updraft

Clicker Question

- What is the typical size of a supercell mesocyclone compared to a tornado?
 - A. Mesocyclones are typically 1 mile wide and tornadoes 3 miles wide
 - B. Mesocyclones are typically 3 miles wide and tornadoes 0.5 mile wide
 - C. Mesocyclones are typically 10 miles wide and tornadoes 3 miles wide
 - D. Mesocyclones are typically 0.5 mile wide and tornadoes 1 mile wide

How does a tornado form?

- **Tornadogenesis** — the formation of a tornado
- The vertical rotation in a supercell (mesocyclone) alone is not enough to produce a tornado
- The mesocyclone rotation needs to be concentrated to form the narrow and fast columns of rotation that we know as tornadoes
- The development of the mesocyclone has been well-studied and is fairly well understood, but the next step that leads to tornadoes is still uncertain.
 - Several theories do exist however
- A key process, called **stretching**, is recognized as one important factor that concentrates the mesocyclone rotation

How would stretching work?

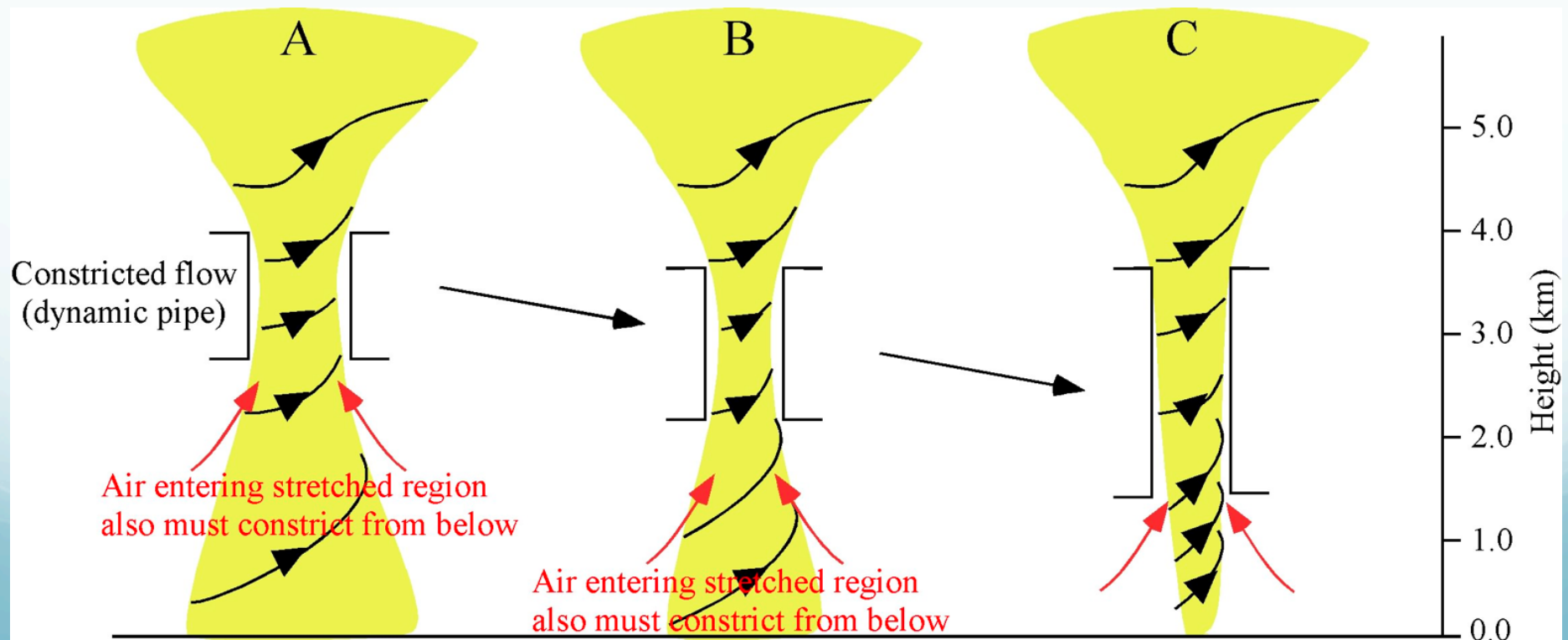
- What happens to an ice skater as he/she draws their arms and legs inward during a spin?
- <http://www.youtube.com/watch?v=AQLtcEAG9v0>
- As the rotation gets stretched vertically, it is more focused into a narrower column and thus should rotate faster
 - Thanks to the conservation of angular momentum

Vortex stretching

- The mesocyclone occlusion forms when the RFD gust front catches up to the FFD gust front.
 - When this occurs the updraft is weakened in the lower part of the supercell, but remains strong aloft.
 - This leads to vertical stretching of the rotating updraft (vortex stretching), and a strengthening of the rotation.
- **Vortex stretching occurs in nearly all supercells, but is not sufficient to create a tornado (only 30% of supercells produce tornadoes).**
 - Thus, other theories must still be invoked to completely explain tornadogenesis
 - Scientists have identified three possible methods for tornadoes to form in supercell thunderstorms.

Theory 1: Dynamic Pipe Effect

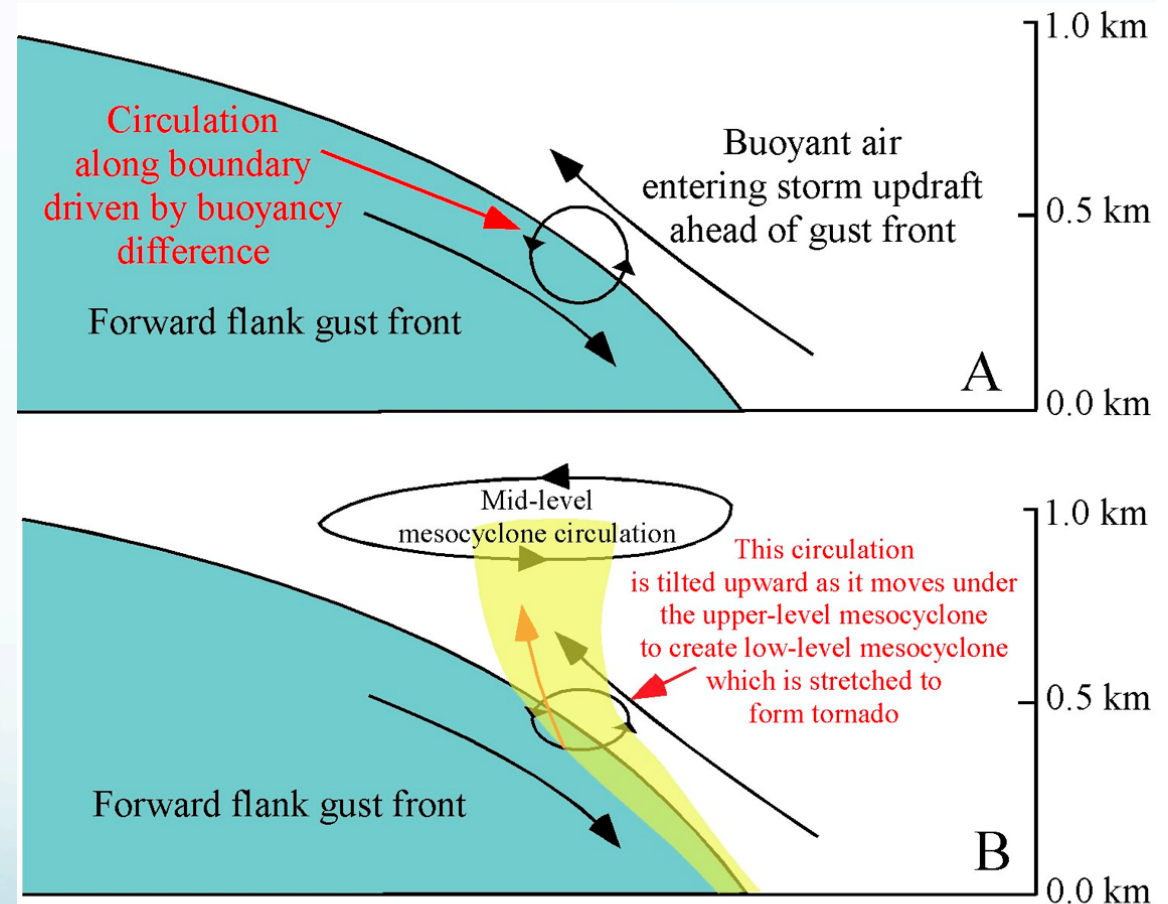
- Constricted flow at mid-levels can result from vortex stretching.



Theory 2:

Bottom up approach

- The generation of rotation in a tornado, in the bottom-up approach, is similar to how the rotation of a mesocyclone is created due to tilting.



Theory 3:

Vortex breakdown

- Vortex breakdown can occur in many types of vortices such as mesocyclones and tornadoes.

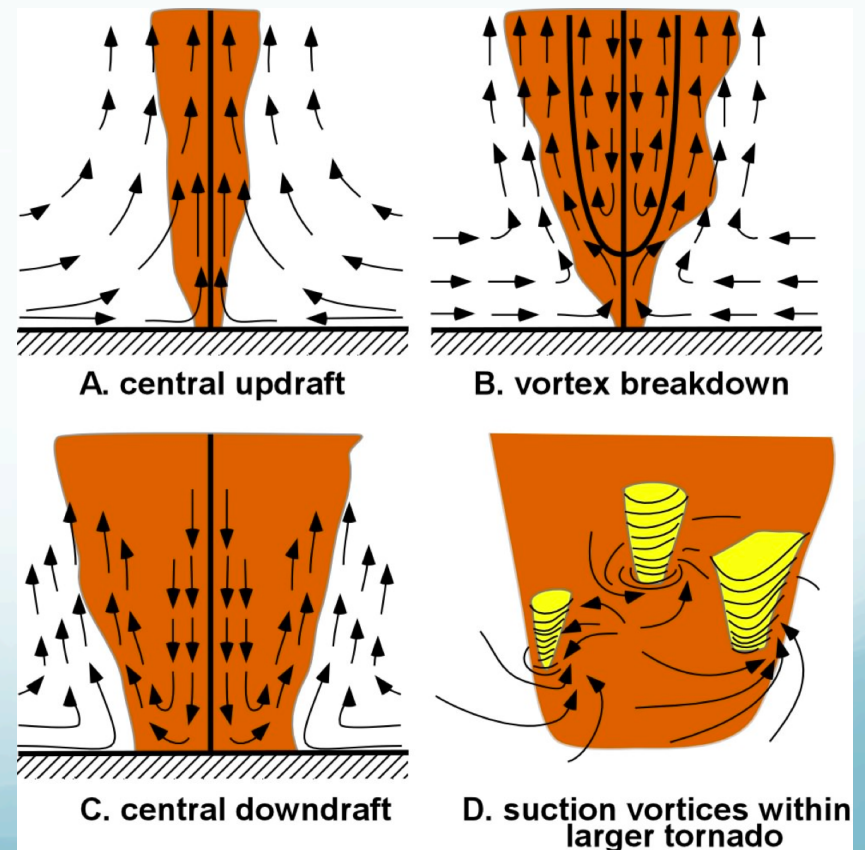
A. Initially the tornado consists of only an updraft, with low pressure at the center near the surface.

B. If the low pressure at the surface becomes strong enough a downdraft forms in the center of the tornado.

C. As the downdraft descends the tornado widens.

D. Smaller vortices can form on the edge of the original tornado (these are called suction vortices).

Example: for a tornado



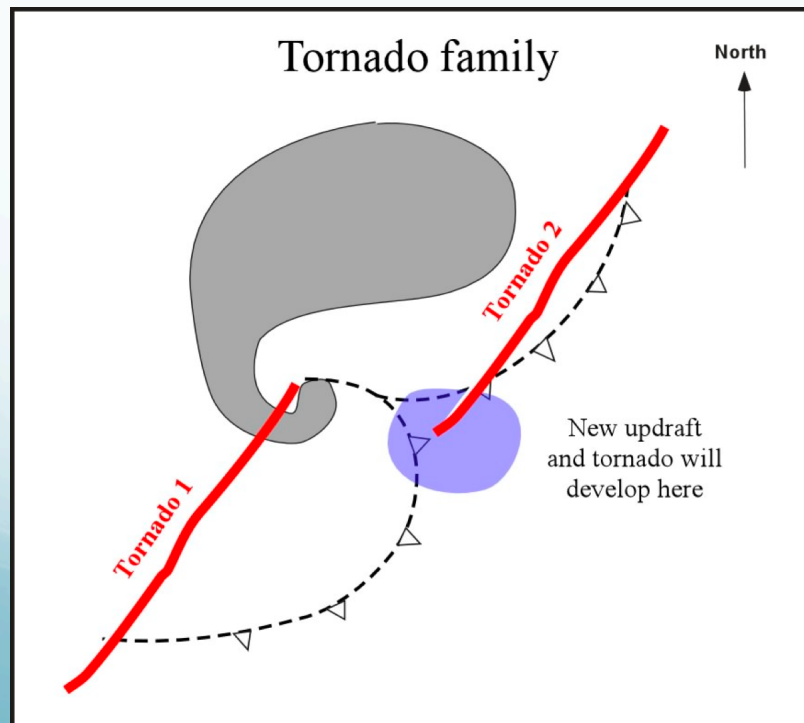
Courtesy of the American Meteorological Society

Vortex breakdown in a supercell

- How does vortex breakdown lead to tornado formation in a supercell?
 - A process similar to vortex breakdown in a tornado can occur in the mesocyclone updraft of a supercell thunderstorm.
- **Occlusion downdraft** (OD) – the central downdraft that can form in the mesocyclone
- Tornadoes can form in the region between the occlusion downdraft and the mesocyclone updraft, similar to suction vortices forming in a tornado.
- This is one way that tornadoes may form in a supercell thunderstorm, but other processes may also cause tornadoes to form in supercells.

Tornado dissipation

- A tornado may be on the ground for a few minutes to as long as an hour
- What causes the tornado to dissipate?
 - The RFD wraps completely around the tornadic circulation



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Tornado Families

Can multiple tornadoes form from the same mesocyclone?

Where will a new tornado form in relation to the features of a supercell?

Clicker Question

- When the rear flank downdraft gust front catches up to the forward flank downdraft gust front this is referred to as the _____ and leads to _____.
 - A. mesocyclone occlusion, vortex stretching
 - B. occlusion downdraft, vortex stretching
 - C. mesocyclone occlusion, the formation of hail
 - D. occlusion downdraft, the formation of hail

Clicker Question

- Vortex stretching _____ the rotation in a supercell.
 - A. weakens
 - B. does not change
 - C. strengthens

Clicker Question

- When the rear flank downdraft completely wraps around the tornadic circulation, what would you expect to happen?
 - A. Vortex stretching
 - B. Tilting of horizontal rotation into the vertical
 - C. Tornadogenesis
 - D. Tornado dissipation

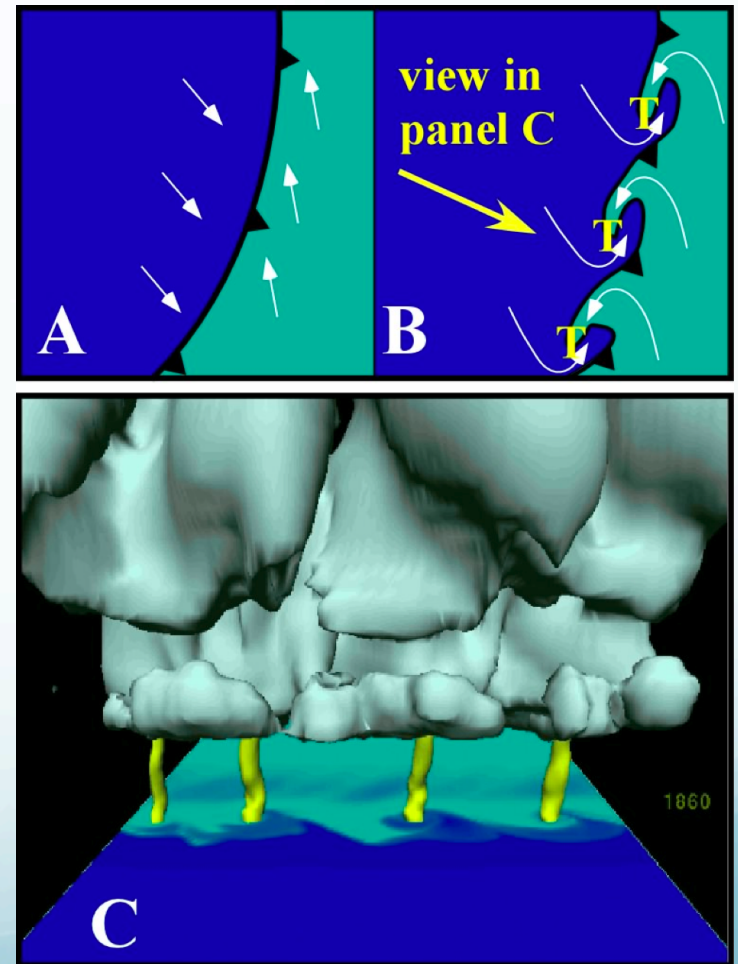
Clicker Question

- A tornado family refers to multiple tornadoes that form _____.
 - A. on the same day
 - B. from the same supercell
 - C. in a squall line
 - D. in multicell thunderstorm complex

Tornadoes in non-supercell storms

Landspout – a tornado that forms in a non-supercell thunderstorm

- What causes a landspout tornado to form?
 - Large horizontal shear across a front can result in the formation of small vortices.
 - These vortices can be stretched, and intensify, if they form underneath a thunderstorm updraft.
- How does the lifetime and strength of a landspout compare to that of a supercell created tornado?



A, B ©2002 Kendall/Hunt Publishing
C. Courtesy of Bruce Lee

Other non-supercell tornadoes

- **Waterspout** – a weak tornado (similar to a landspout) that occurs over water
 - Waterspouts form when cold air moves over warm water.
- **Gustnadoes** – a weak tornado that forms in a manner similar to a landspout, except the formation is associated with shear across a gust front
- Non-supercell tornadoes also form in the NE quadrant of landfalling hurricanes, but the mechanisms responsible for the formation of these tornadoes is still unknown.

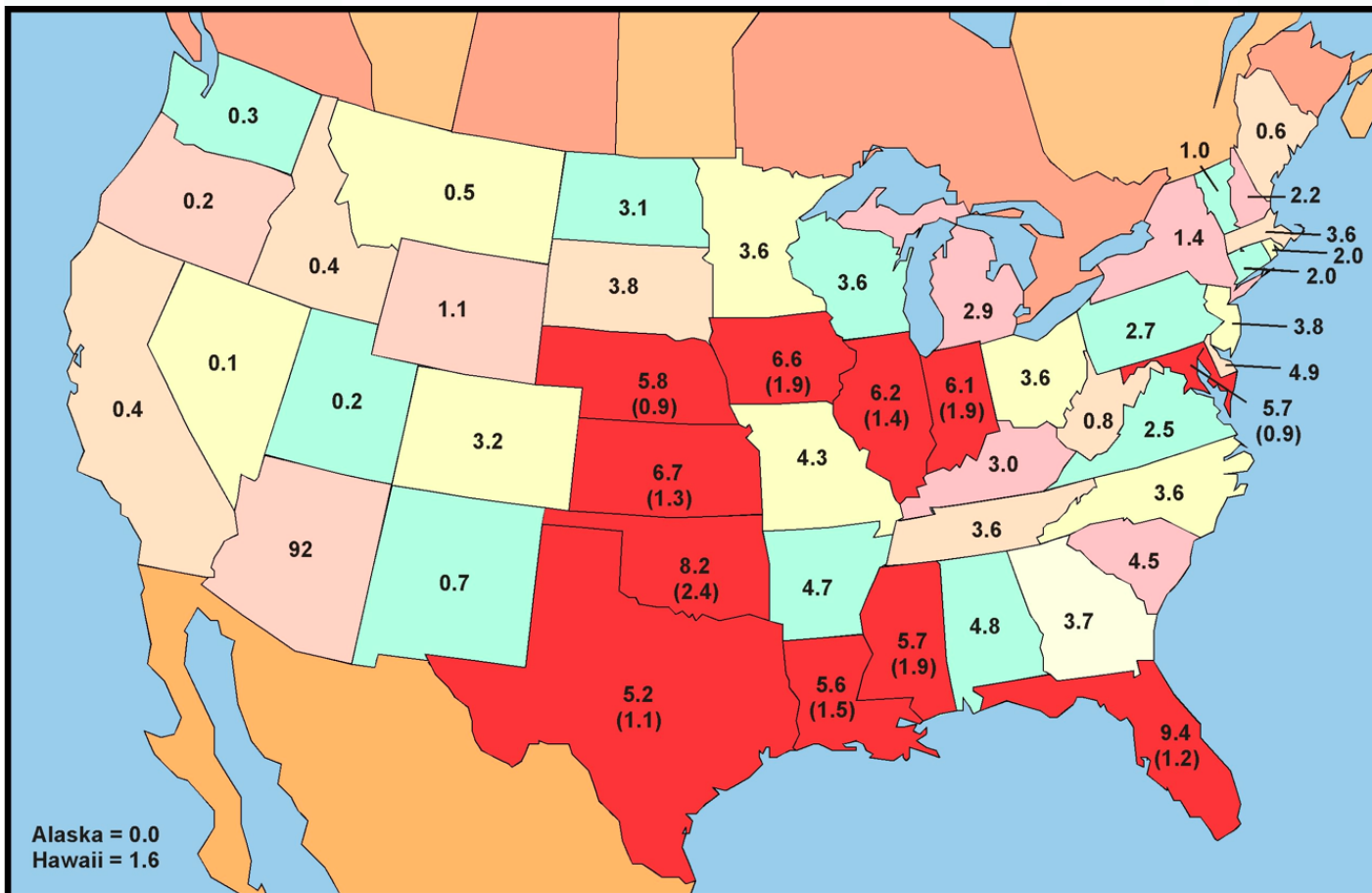


Photo of a waterspout

Photo by Joe Golden, Courtesy of NOAA

Tornado Statistics

- Where are tornadoes most common?

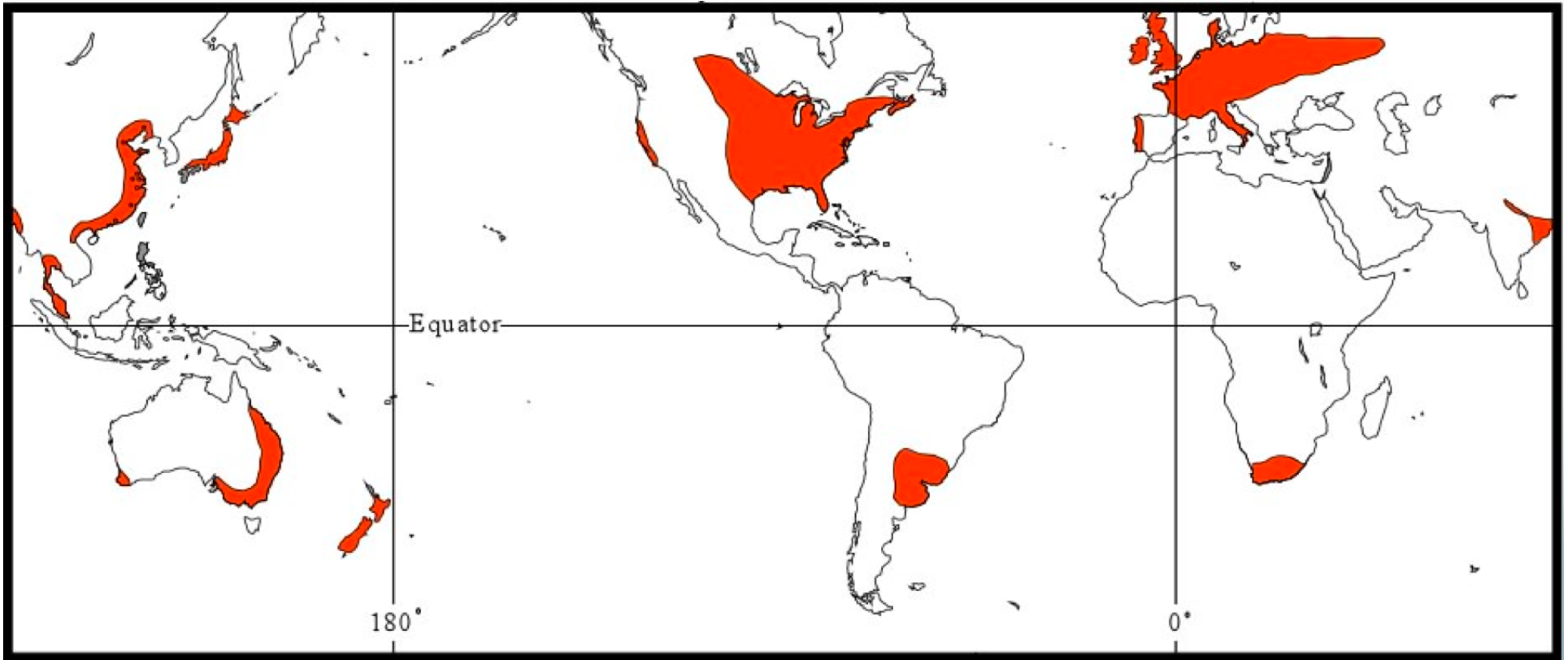


Tornado alley – the area of most frequent tornado occurrence in the United States

Extends from Texas to Illinois

Tornadoes worldwide

- 75% of all tornadoes worldwide occur in the United States.



Tornado Intensity

- **Fujita Scale (F-scale) of tornado intensity** – based on the estimated maximum wind speed in a tornado
 - The Fujita scale was used from 1971 until 2007.
- The Fujita scale has now been replaced by the **enhanced Fujita scale (EF-scale)**.
- Both the F-scale and EF-scale rating of a tornado is based on the damage done by the tornado since it is difficult to measure the wind speed in a tornado.

F-scale vs EF-scale

Fujita Scale	Wind Speed (mph)	Enhanced Fujita Scale	Wind Speed (mph)
F0	45 – 78	EF0	65 – 85
F1	79 - 117	EF1	86 – 110
F2	118 - 161	EF2	111 – 135
F3	162 - 209	EF3	136 – 165
F4	210 - 261	EF4	166 – 200
F5	262 - 317	EF5	> 200

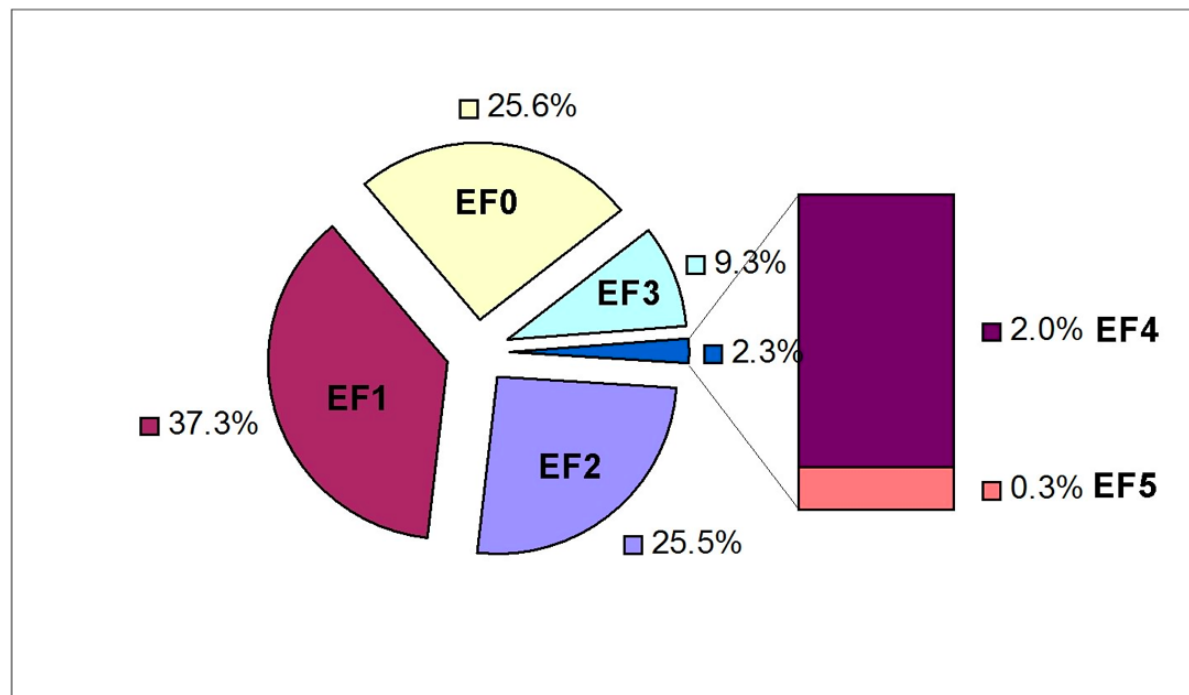
Remember these are estimates based on the damage done by the tornado!

Frequency of tornado intensity

- What intensity tornadoes are most common? **EF1**
 - Does that make sense? Why might EF0 tornadoes not be as common?

They may not be reported as much since they are weakest

- Which are least common? **EF5**

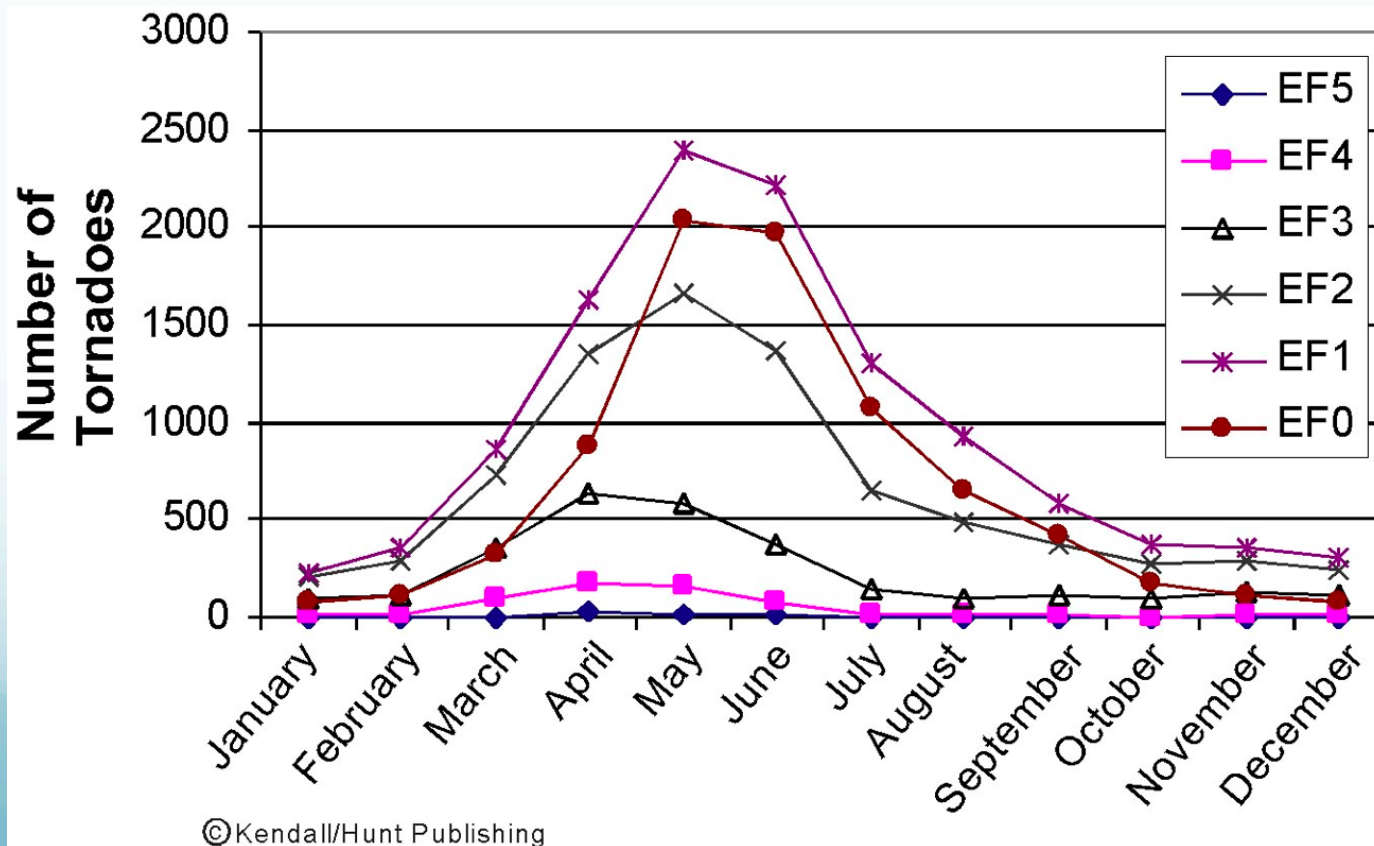


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EF5 tornadoes account for only 0.3% of all tornadoes in the United States.

Annual trends

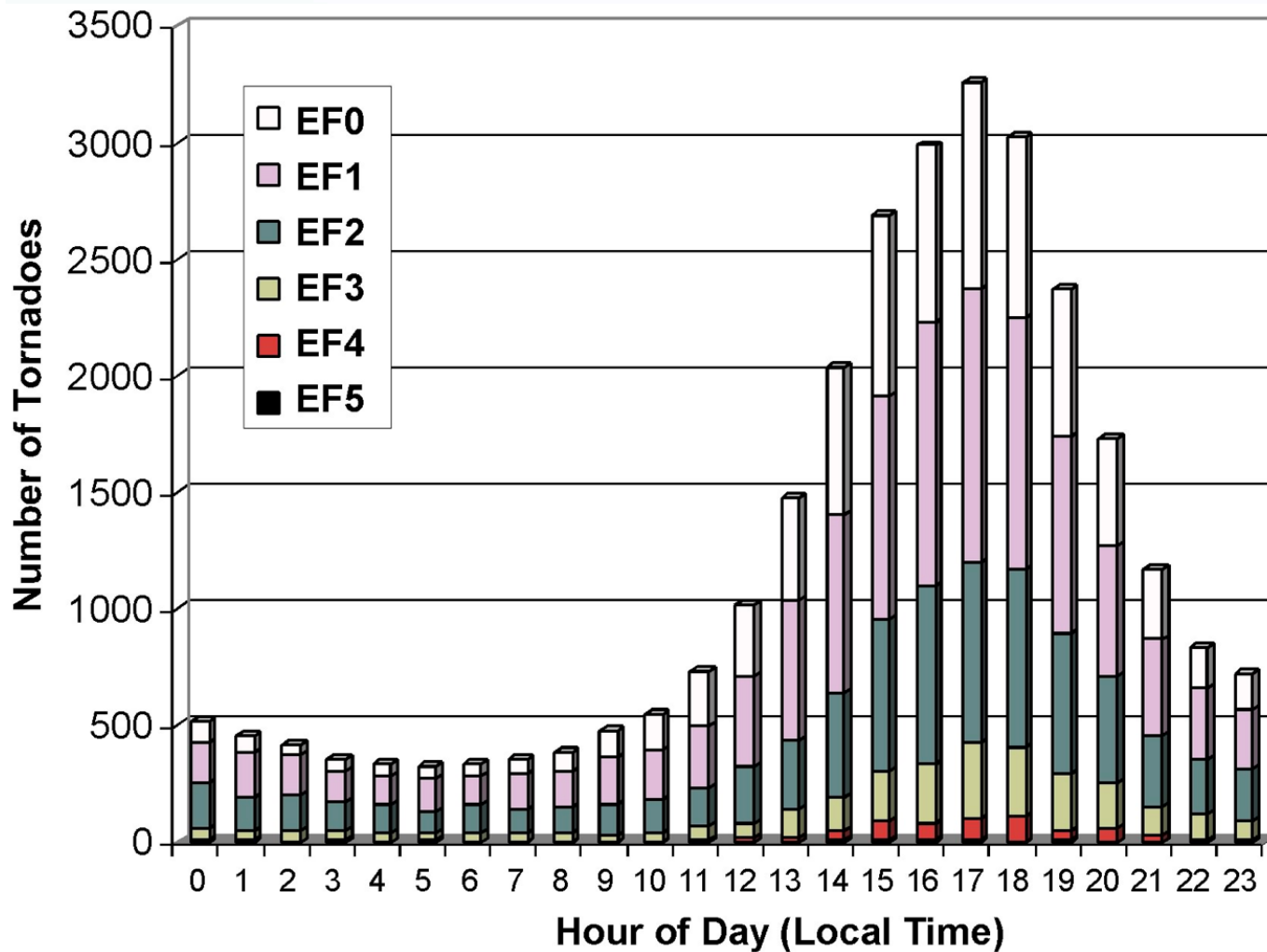
- What time of year are tornadoes most common?
 - Tornadoes occur year-round, but are most common from April through June.
 - Why are tornadoes most common at this time of year?



Where do they occur each month?

- <http://severewx.atmos.uiuc.edu/18/tornado.freq.html>
- What trends do you see in where tornadoes occur as you go from Jan through to Dec?

What time of day do they occur most often?



Why do tornadoes form most often during the late afternoon or early evening?

Time of max surface heating!

Clicker Question

- Landspout tornadoes form in _____ thunderstorms as a result of _____.
 - A. supercell, vortex stretching followed by vortex breakdown
 - B. non-supercell, vortex stretching by vortex breakdown
 - C. supercell, stretching of small vortices that form due to shear across a front
 - D. non-supercell, stretching of small vortices that form due to shear across a front

Clicker Question

- A gustnado forms in a manner similar to a _____, but is associated with shear _____.
- A. supercell tornado, across a gust front
- B. landspout, across a gust front
- C. supercell tornado, in an occlusion downdraft
- D. landspout, in an occlusion downdraft

Clicker Question

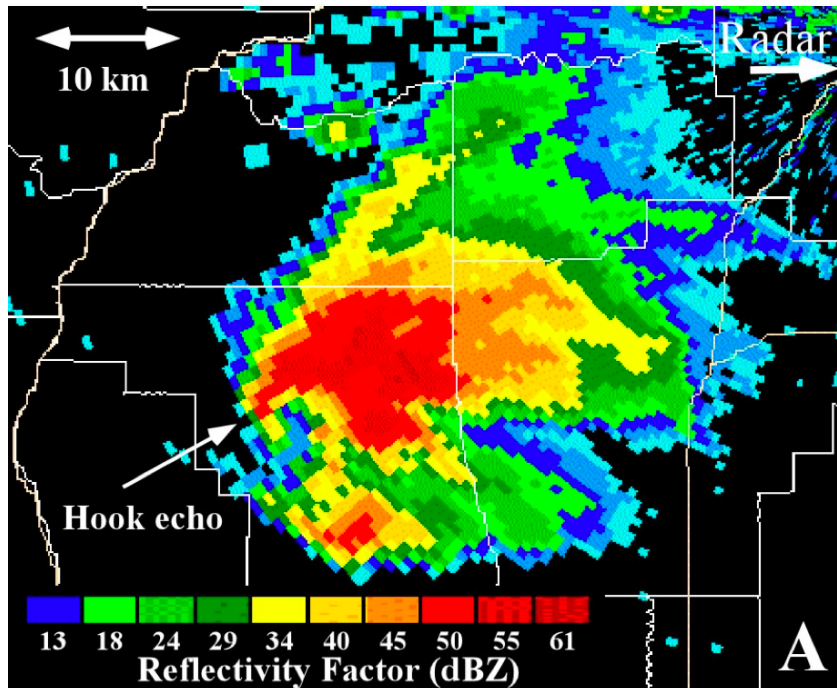
- True or false: Tornadoes only occur in the United States.
 - A. True
 - B. False

Clicker Question

- What intensity tornadoes occur most frequently in the United States?
 - A. EF0
 - B. EF1
 - C. EF2
 - D. EF4
 - E. EF5

Tornado Detection

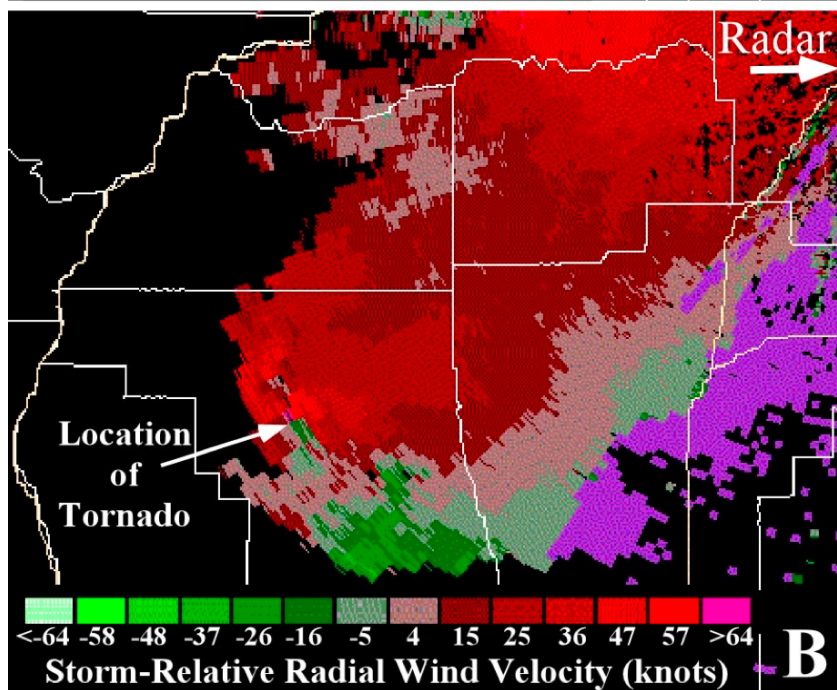
- How do we know when a tornado is occurring?
 - Observations by people
 - Storm spotters, police reports, reports from the public
 - Doppler radar



- Doppler Radar reflectivity
 - **Hook echo** – area of weaker reflectivity near mesocyclone updraft (figure A)

- Doppler Radar Radial Velocity

- **Mesocyclone signature** – small area where radial winds rapidly switch from outbound to inbound (figure B)
 - This is an indication of the circulation associated with the mesocyclone
- **Tornado vortex signature (TVS)** – one pulse of a radar radial velocity image that has an unusually large velocity



3 May 1999 Oklahoma outbreak

- This tornado outbreak killed 44 people and injured over 800 people, and damaged or destroyed 11,000 structures.
 - The supercell passing through Moore, OK produced an F5 tornado
- Loop of radar reflectivity (look for hook echoes)
 - <http://severewx.atmos.uiuc.edu/18/050399.reflectivity.html>
- Loop of radial velocity (look for couplets of inbound and outbound radial winds to see signatures of mesocyclonic rotation)
 - <http://severewx.atmos.uiuc.edu/18/050399.velocity.html>

Severe weather watches

- Severe weather watches are issued by the Storm Prediction Center, and typically cover large portions of one or more states
- **Severe thunderstorm watch** – conditions are favorable for the development of thunderstorms that contain strong winds, hail, frequent lightning, heavy rain, and possible tornadoes in and near the watch area
- **Tornado watch** – conditions are favorable for the formation of tornadoes in and near the watch area
- Severe weather watches are based on the probability in the forecast that conditions that would favor severe weather

Severe weather warnings

- Severe weather warnings are issued by local National Weather Service offices and cover one or more counties
 - **When a warning is issued for your area seek shelter immediately!**
- **Severe thunderstorm warning** – a severe thunderstorm is occurring or is imminent in or near the warning area
- **Tornado warning** – a tornado is present or imminent in or near the warning area
- Severe thunderstorm and tornado warnings are issued based on recent/current observations:
 - Doppler radar indications of a severe thunderstorm or tornado
 - Police or storm spotter reports of a severe thunderstorm or tornado
 - Reports from the public

Tornado Safety

- Information on watches and warnings are broadcast by TV and radio stations and on NOAA Weather radio.
 - If a watch is issued for your area, stay tuned to radio and TV throughout the day to get updates on the situation
- In the event of a tornado:
 - Seek shelter in a basement or underground shelter
 - If no basement is available go to an interior room or hallway (stay away from windows and abandon mobile homes)
 - If caught outside move as far away as possible from potential airborne objects and lie in the lowest spot available
 - Do not try to outrun a tornado in a car. Instead abandon the car and seek shelter in a low-lying area.
 - Do not seek shelter under highway overpasses, as wind speeds can be increased underneath the overpass

Clicker Question

- A hook echo would be visible on a _____.
 - A. infrared satellite image
 - B. visible satellite image
 - C. Doppler radar reflectivity image
 - D. Doppler radar radial velocity image

Clicker Question

- On a Doppler radar radial velocity image a small area where radial winds rapidly switch from outbound to inbound is a _____.
 - A. hook echo
 - B. mesocyclone signature
 - C. tornado vortex signature
 - D. gust front

Clicker Question

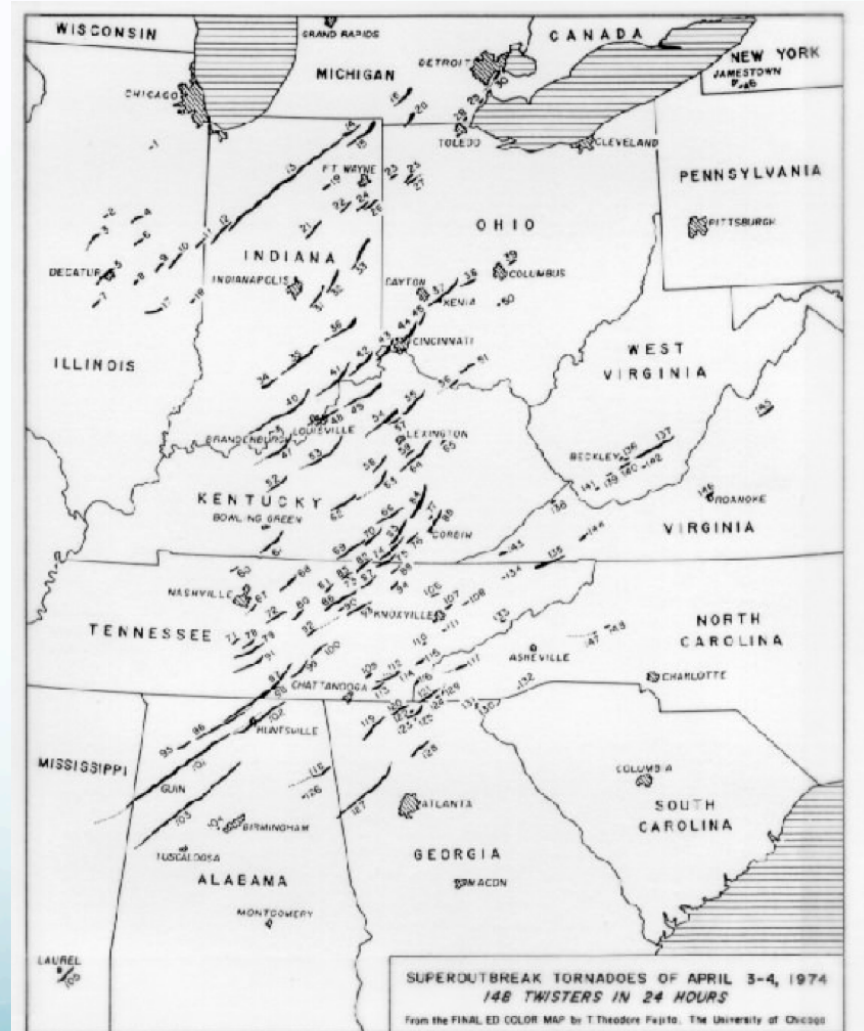
- The Storm Prediction Center would issue a _____ when conditions are favorable for the development of thunderstorms that contain strong winds, hail, frequent lightning, heavy rain, and possible tornadoes.
 - A. severe thunderstorm watch
 - B. tornado watch
 - C. severe thunderstorm warning
 - D. tornado warning

Ex. Tornado passing an overpass

- Winds from a tornado can easily suck a person out from under an overpass
- This storm chasing video is unfortunately what got people started thinking they could hide under an overpass and not be hurt
 - However, this was not a very strong tornado (luckily for these people)
- <http://www.youtube.com/watch?v=IHBZylcxlvw>

The Superoutbreak of 3-4 April 1974

- Several supercell thunderstorms formed ahead of a cold front
- This was the largest tornado outbreak recorded in the US
- 335 people were killed, and 5500 people were injured
- A total of 148 tornadoes formed during this outbreak
- 76% of the tornadoes that formed in this outbreak occurred in tornado families



Courtesy of the Theodore Fujita Family