Chapter 19: Tornadoes

Courtesy of Glen Romine

- ❑ Tornadoes formation in supercell thunderstorms
- ❑ Tornadoes formation in non-supercell thunderstorms

Tornadoes

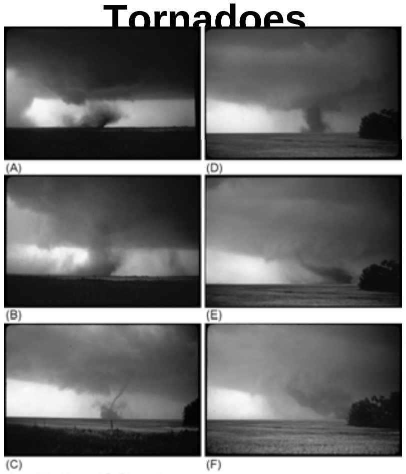
- ❑ Tornadoes are violently rotating columns of air that extend from a thunderstorm cloud to the ground.
- ❑ On average, over 1,000 tornadoes are reported in the US each year.
- ❑ Tornadoes primarily develop within supercell thunderstorms, but also form in thunderstorms along squall lines, near the ends of thunderstorm bow echoes, and within landfall hurricane.
- ❑ Most tornados are short lived.

Life Cycle of Long-lived Tornadoes

Funnel cloud: emerging from the wall cloud

Dust swirl stage: tornadoes make contact with the ground

Organizing stage: funnel cloud descends to the ground and intensify



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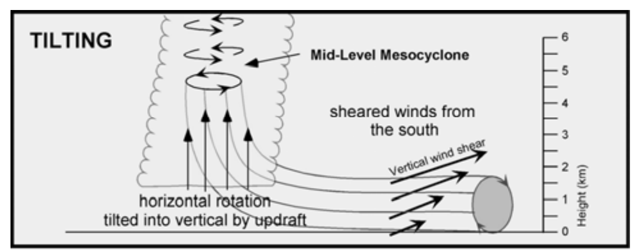
Mature stage: at its peak intensity and largest size

Shrinking stage: vortex tilts over more; rope-like appearance

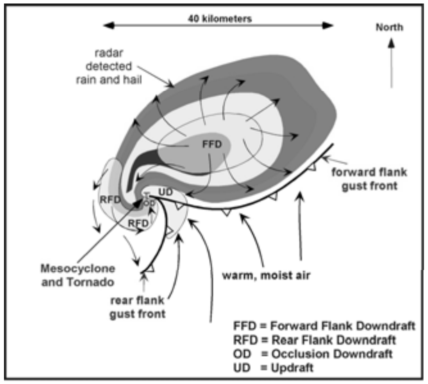
Decay stage

Tilting



- ❑ Supercell thunderstorms rotate about a vertical axis as a result of tiling.
- ❑ Vertical shear associated with the storm produce a rotation tube, whose rotation axis is in parallel to the ground.
- ❑ Warm airs within the tube is drawn into the thunderstorm updraft, which at the same time “tilt” the rotation axis vertical.

Location of Tornado within Supercell Thunderstorm

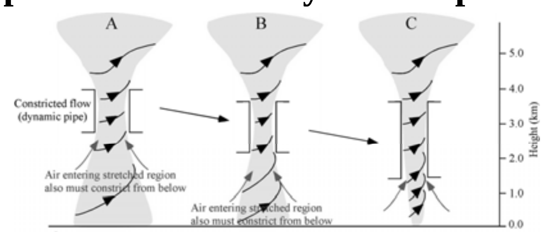


- The rotating updraft that produces the "tilting" is within the ***mesocyclone*** of supercell thunderstorms.

Tornadogenesis

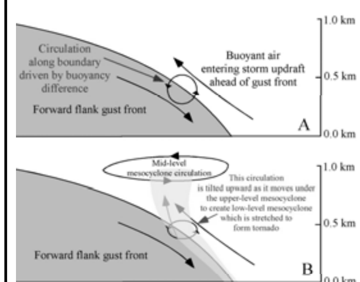
- Tornadogenesis: the formation of tornadoes, whose detail processes are not clear due to limited observations.
- Tornadogenesis appears to occur in one of three ways: (1) top down process (a dynamic pipe effect), (2) bottom up process, and (3) vortex breakdown.

Top-Down Process / Dynamic Pipe Effect



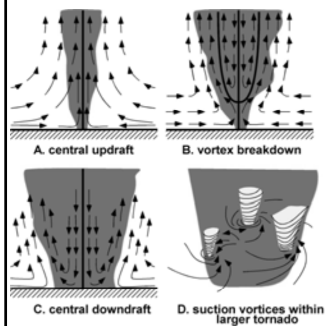
- With this process, tornadoes descend from midlevels within the thunderstorm and then emerge from the base of the wall cloud.
- A narrowly constricted flow in the middle atmosphere that might develop when the mid-level mesocyclone is stretched.
- Air entering this narrow "pipe" from below must itself constrict as it approaches the entry point.
- That constriction in effect lowers the "pipe", and the constriction grows downward.
- When the constricted "pipe" reaches the ground, tornadoes touchdown occur.

Bottom-Up Process



- This process is believed to occur as a result of tilting of the horizontal circulation along the forward frank gust front as it moves under the ascending updraft.
- Air behind the gust front is cool, negatively buoyant, and descending. In the updraft air adjacent to the gust front, air is warm, positively buoyant, and ascending.
- This leads to a sense of rotation along the interface between the gust front and warm air.
- If this region advances under the strong updraft of the mid-level mesocyclone, it can be tilted to the vertical, leading to rapid rotation very close to earth's surface.
- With further vortex stretching, the rotation can spin up to become a "bottom up" tornado.

Vortex Breakdown



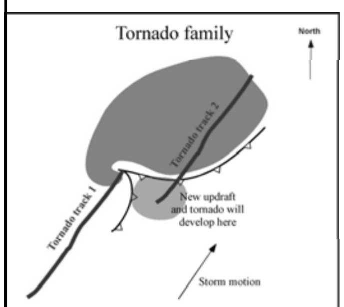
Courtesy of the American Meteorological Society

- Most tornadoes remain as a narrow column of rising rotation air, but vortex breakdown can occur in some tornadoes, which can cause the tornado to expand to a very large size.
- ***A→B***: the tornado vortex transforms from a rotating updraft to a structure with a downdraft at its core.
- ***B→C***: updraft displaced to the outside of the central downdraft.
- C→D: when the central downdraft reaches the ground, strong wind shear between the downdraft and updraft areas lead to the formation of smaller vortices, called suction vortices.
- The strongest winds in tornadoes occur in suction vortices (can be 290mph).

Decay of a Tornado

- A tornado may be on the ground for a few minutes to as long as an hour.
- The typical tornado life cycle concludes as the rear flank downdraft wraps completely around the tornado circulation.
- In this process, cool, denser air encircles the tornado, eventually weakening and finally eliminating the tornado's circulation.
- As a supercell moves, typically northeastward, the upper part of the updraft that contains the tornado is tilted downstream by the mid-level winds relative to the lower part of the tornado.
- As this occurs, the tornado is stretched into a narrow vortex with a rope-like shape.
- Without an updraft to sustain, the tornado spins down.

Tornado Family



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- A tornado supercell may pass through the sequene of growing dying a few times in its lifetime.
- Each cycle is associated with a new updraft that forms just outside and southeast of the previous cell that produced the earlier tornado.
- The tornadoes emerging from the supercell over its lifetime constitutes a tornado family.

Example of a Tornado Family

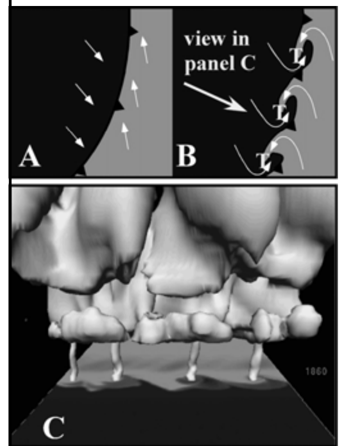
Courtesy of the University of Oklahoma Press

- A supercell thunderstorm produced eight tornadoes within five hours when it moved over Illinois and Indian on 3 April 1974.
- The local time that the mesocyclone (the gray line) passed an area is noted along the track.

Tornadoes Formed within Non-Supercell Thunderstorms

- Tornadoes sometimes develop within squall line thunderstorm aligned along fronts or along outflows from mesoscale convective systems (MCs).
- These tornadoes are called non-supercell tornadoes, landspout tornadoes, mesovortices, or gustnadoes.
- These tornadoes are generally short-lived and not as intense as their supercell tornado counterparts.

Formation Mechanism for Non-Supercell Tornadoes



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

A: Some fronts are characterized by a very sharp change in wind speed and direction on either side of the front.

B: This strong horizontal wind shear can develop a series of small vortices along the front.

C: When the vortices develop under an updraft, the updraft stretches the vortex into a tighter and tighter circulation until a non-supercell tornado forms.

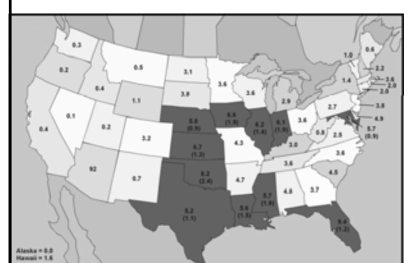
- Nearly all tornadoes in California in wintertime develop along cold fronts by this process

Waterspout Tornadoes

Photo by Joe Golden, Courtesy of NOAA

- Waterspouts are a class of weak tornadoes that are commonly observed off coastlines, particularly in tropical regions such as the Florida Coast and the Gulf of Mexico.
- The formation mechanism of waterspouts is still not well known.

Tornado Alley



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- This figure shows the annual number of tornadoes observed per 10,000 square miles in each of the fifty states during 1953-2004.
- The red states have more than 5 tornadoes annually.
- Florida has the highest numbers.
- Beside the Gulf states, tornadoes occur most frequently over the Great Plains and Midwestern states.
- These states are oriented along a southwest-northwest line called Tornado Alley.

EF-Scale Wind Speed Ranges and corresponding wind speeds from the Fujita scale

Fujita Scale	3-second gust speed (mph)	Operational Enhanced Fujita Scale	3 Second Gust 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

Damage Indicators for establishing EF-Scale ratings

For the structures listed below, damage assessors use detailed tables that describe the degree of damage, together with example photographs from damaged structures to establish the likely wind speed and EF scale rating for a tornado

No.	Damage Indicator
1	Small Barns or Farm Outbuildings
2	One or Two Family Residences
3	Manufactured Home – Single Wide
4	Manufactured Home – Double Wide
5	Apartments, Condos, Townhouses
6	Motel
7	Masonry Apartment or Motel
8	Small Retail Building
9	Small Professional Building
10	Strip Mall
11	Large Shopping Mall
12	Large Isolated Retail Building
13	Automobile Showroom
14	Automobile Service Building
15	Elementary School
16	Junior or Senior High School
17	Low-Rise Building (1-4 stories)
18	Mid-Rise Building (5-20 stories)

No.	Damage Indicator
19	High-Rise Building (> 20 stories)
20	Institutional Building
21	Metal Building System
22	Service Station Canopy
23	Warehouse Building
24	Electrical Transmission Lines
25	Free Standing Towers
26	Free Standing Light Poles, Luminary Poles, Flag Poles
27	Trees (Hardwood)
28	Trees (Softwood)

Estimating the EF scale rating from damage to a one or two family residence (Indicator 2 in Table 19.2)

Degree of Damage	Damage Description	EXPECTED WIND SPEED	LOWE ST WIND SPEED	HIGHEST WIND SPEED
1	Threshold of visible damage	65	53	80
2	Loss of roof covering material (<20%), gutters and/or awning; loss of vinyl or metal siding	79	63	97
3	Broken glass in doors and windows	96	79	114
4	Uplift of roof deck and loss of significant roof covering material (> 20%); collapse of chimney, garage doors collapse inward, failure of porch or carport	97	81	116
5	Entire house shifts off foundation	121	103	141
6	Large sections of roof structure removed; most walls remain standing	122	104	142
7	Exterior walls collapsed	132	113	153
8	Most walls collapsed, except small interior rooms	152	127	178
9	All walls collapsed	170	142	198
10	Destruction of engineered and/or well constructed residence, slab swept clean	200	165	220

Figure 19 G

Courtesy of Nilton O. Rennó

Figure 19 K

Courtesy of John Jarboe, National Weather Service