Video "Teasers", while students enter the classroom.

Day3-60 Tornadoes of 2016 (16:05) Pecos Hank channel (play 2x or 5x speed) https://www.youtube.com/watch?v=NZmtglWX0N4

Day3-05—Classic tornado in Manitoba 26 June 2007 (2:41)

Search on "tornado" by slair.

https://www.youtube.com/watch?v=xCIIu05KD_s

Watch on your own (not required): 2016 and 2017 tornado videos by Pecos Hank.

https://www.youtube.com/watch?v=a9Y4QulRg_o

https://www.youtube.com/watch?v=acgduoio7-l

https://www.youtube.com/watch?v=Gfr8MExtDYI

2017 tornadoes

9 May 2016 tornadoes

24 May 2016 tornado

Storm Hazards covered in this course

Thunderstorm Hazards

- lightning
- tornado
- hail



- downpours (of rain) / local flooding
- downbursts (of air) / gustfronts

Hurricane Hazards

- contain thunderstorms
- storm surge / coastal flooding
- high waves
- coastal erosion

Road-map to Storm topics

Learning Goals (LG): I-5

	Day	Hazards Risk & Safety	Fundamentals Appearance & Evolution	Energy makes storms
	I	Lightning	Thunderstorm basics	sun, radiation, surface heating
	2	Rain Downpours, Air Downbursts	Supercells, mesocyclone. Observ.: radar, satellite	moisture, condensation, latent heating
	3	Tornadoes	Wall cloud, striations, Doppler radar	
	4	Hail	Clouds at Tstorms: flanking line, mammatus	heat to motion, forces, winds
	5	Flooding, winds, waves, storm surge	Hurricanes	energy in warm ocean, Coriolis

By the end of this period, you should be able to:

- 3a) describe tornado shapes, what makes them visible, and where they form relative to a thunderstorm.
- 3b) use photographs & videos to identify the tornado intensity on the enhanced Fujita scale.
- 3c) describe characteristics of tornado evolution, tornado outbreaks, and mesocyclones.
- 3d) explain tornado hazards and safety procedures, and times and locations of greatest risk.
- 3e) explain the difference between tornado watches and warnings, and appropriate safety responses.

The Turbulent Atmosphere (Storms)

Prof. Roland Stull

Today we will cover:

Tornadoes

- I. Recognizing tornadoes
- 2. Recognizing supercell rotation
- 3. Speeds and disaster scales
- 4. Tornado safety
- 5. Tornado risk
- 6. Tornado outbreaks
- 7. Tornado evolution
- 8. Forecasting tornadoes and public warnings

I. Recognizing Tornadoes

(LG: 3a)



Most tornadoes are made visible by cloud-water droplets

(the funnel cloud) and/or dust and debris from the ground

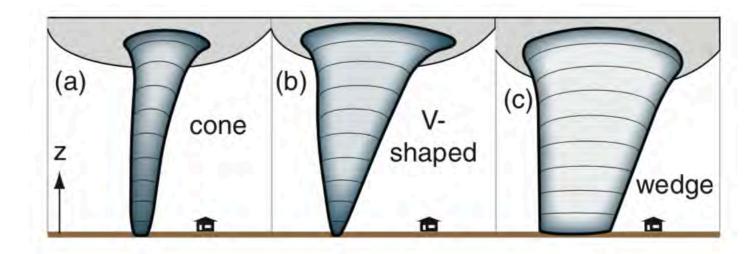
(the debris cloud). Some tornadoes are invisible.

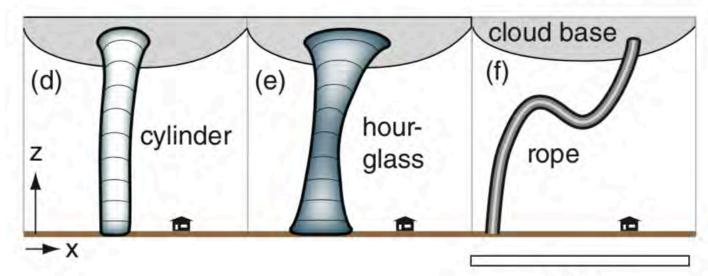


Tornado Shapes

(LG: 3a,b)

- Many shapes are possible for tornadoes from supercell Thunderstorms.
- Shape is independent of intensity classification (i.e., Fujita or Torro scale)





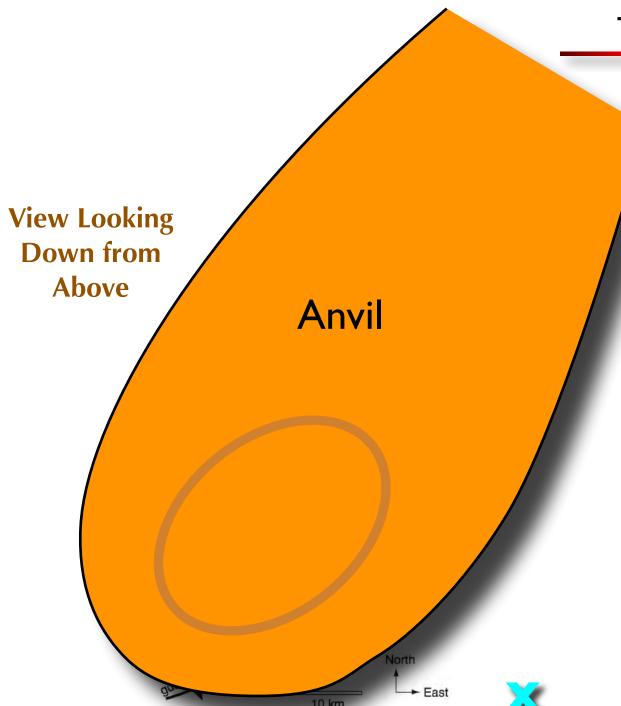
Day3-20 Extreme close-up of tornado near Wray, CO. 2016 (play first 30s at normal speed, skip the middle, then play the last half at 2x speed) Shows separate debris and funnel clouds in first 30 s, becoming 100% debris cloud later.

https://www.youtube.com/watch?v=bjb7QtMEBUg

Watch the remainder of this video on your own.

Tornadoes are Attached to Thunderstorms

(LG: 3a)



Only a small percentage (20-30%) of supercell thunderstorms produce tornadoes.

In N.America, most Thunderstorms move from southwest (SW) toward northeast (NE).

Supercell storms:

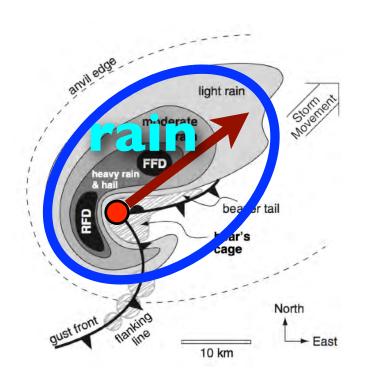
- strongest
- strong tornadoes are most likely associated with supercell storms.

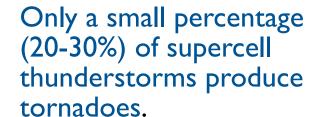
(images by Stull, used with permission)

Tornadoes are Attached to Thunderstorms

(LG: 3a)

View Looking Down from Above





In N.America, most Thunderstorms move from southwest (SW) toward northeast (NE).

Supercell storms:

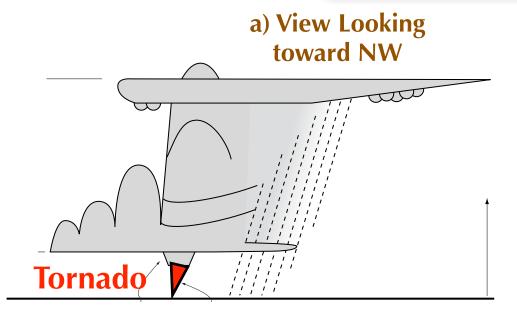
- strongest
- strong tornadoes are most likely associated with supercell storms.



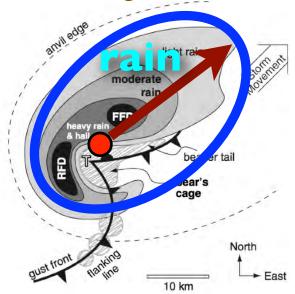
(images by Stull, used with permission)

Tornadoes are Attached to Thunderstorms

(LG: 3a)



b) View Looking Down from Above





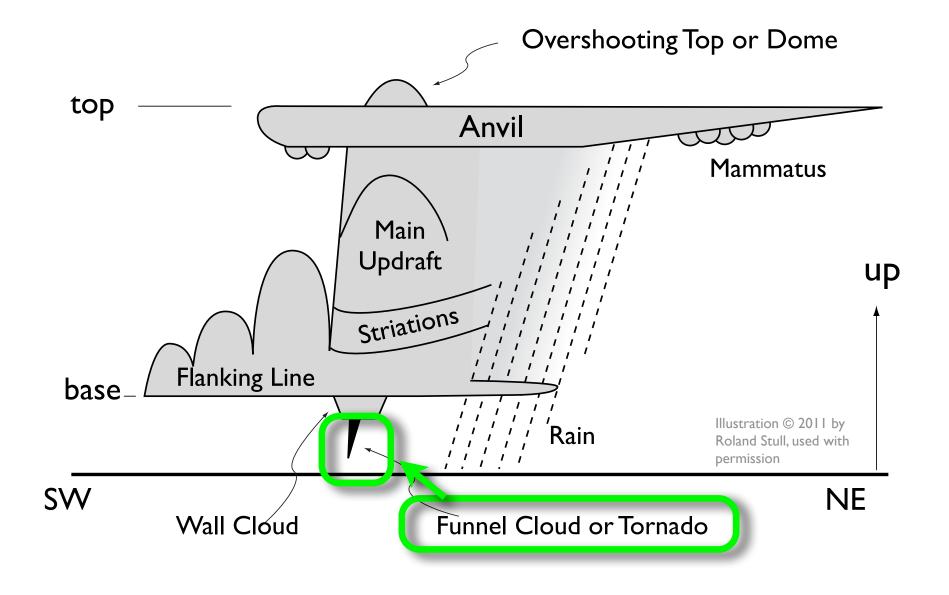
Best thunderstorms viewing is:

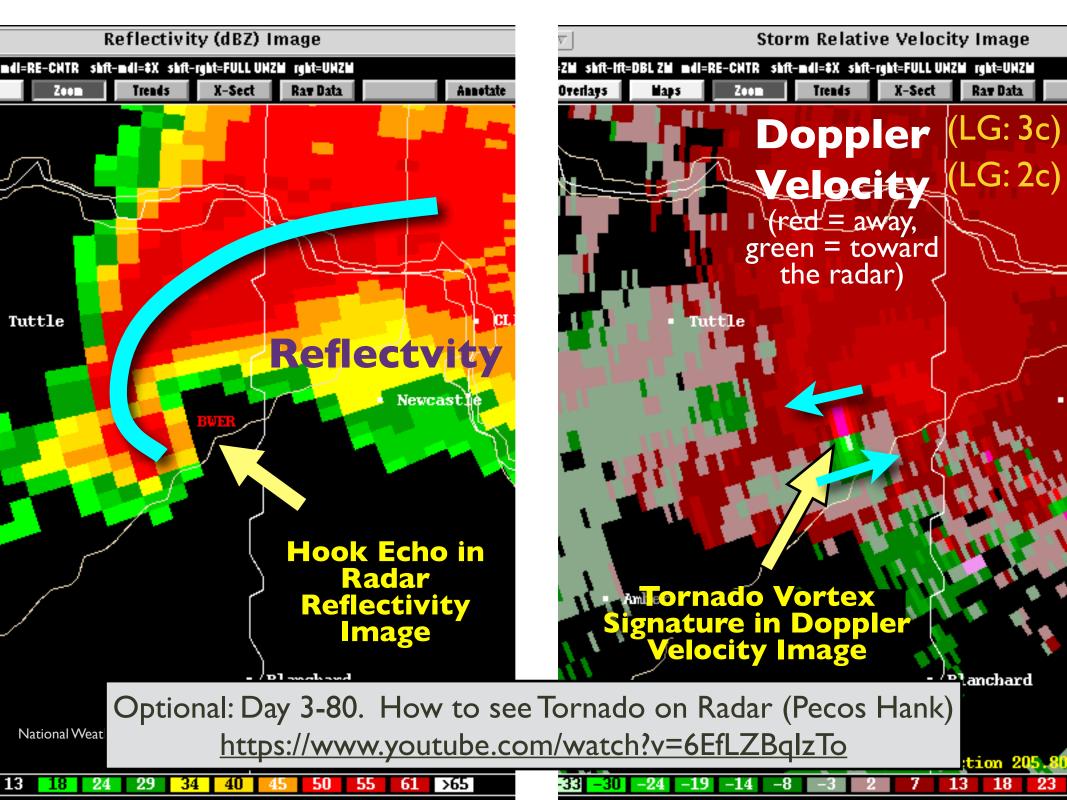
- off to the side of the storm path
- preferred side is to the southeast of the storm (at)
- look at the storm toward northwest
- resulting supercell storm looks like the sketch at upper left

(images by Stull, used with permission)

Tornadoes are attached to thunderstorms

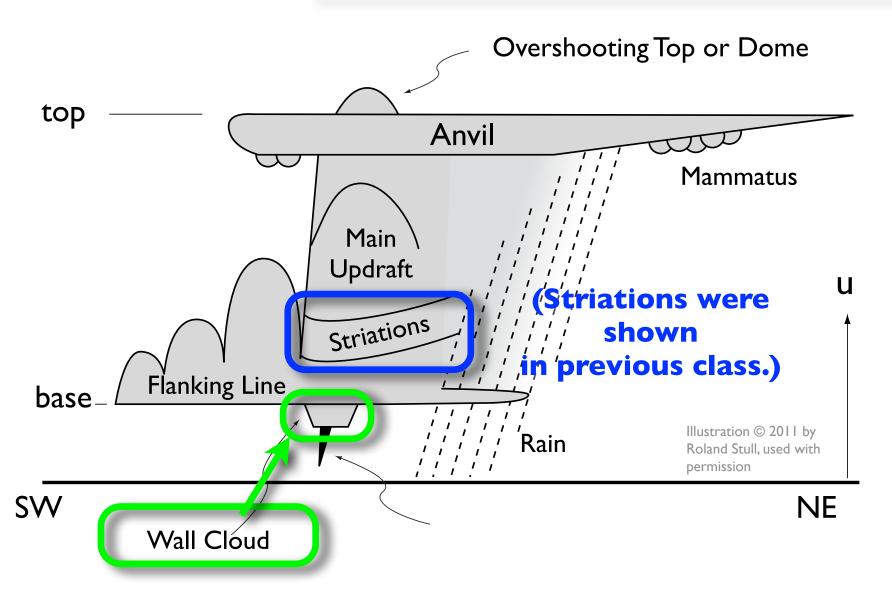
(LG: 3a)





2. Recognizing supercell rotation:

- striations around the mesocyclone
- a rotating wall cloud



Mesocyclone Rotation(LG: 3a, c)

Day2-XZ Nebraska, LP supercell in 2020, by Freddy McKinney (2:38 min) play 2x speed.

https://www.youtube.com/watch?v=zzBylV2Qkul

Watch on your own (not testable):

Day3-23 Kansas, Classic Supercell" by Stephen Locke, 2015.

Time lapse of a mesocyclone (3:02) (play at 2x speed)

https://www.youtube.com/watch?v=Y4EK2r9JJ1k

Day3-24 "Red Cloud, NE, Supercell" by Stephen Locke, 2015.

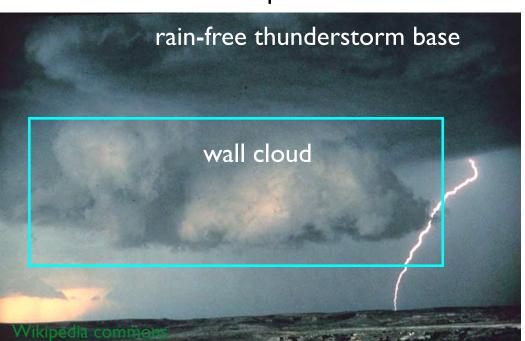
Time lapse of a mesocyclone (3:02) (play at 2x speed)

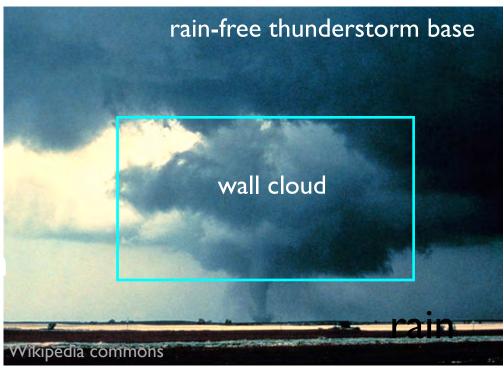
https://www.youtube.com/watch?v=LRrXugg2PBI

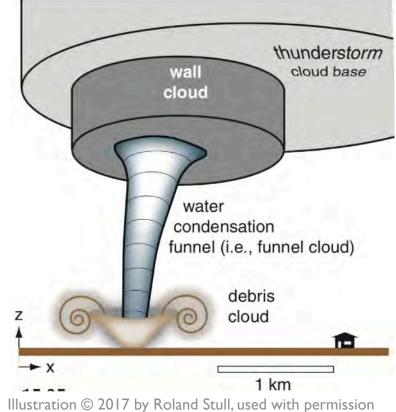
(LG: 3a, c)

Wall Cloud

- A <u>wall cloud</u> is an isolated lowering of cloud base ...
- beneath rising cumulus towers ...
- on SW flank of the storm ...
- outside of (SW of) the precipitation region.
- Tornadoes come from rotating wall clouds in supercells .







18

Excellent Wall Cloud Example

(LG: 3a, c)

Day3-30 Wall cloud near Amber, OK. 2015

Search on "tornado wall cloud Amber gopro". (1.35, show all). (play 2x speed)

https://www.youtube.com/watch?v=KiAqIqDOszg

3. Speeds and Disaster Scales

Horizontal Movement (Translation) of the Center of the Tornado

- usually from SW toward NE in N.America
 (but movement toward any direction has been observed)
- translation speeds of center of tornado = 0 and 100 km/hr
- most move at speeds near middle of that range
- If in your car, you can easily drive away from most tornadoes. (Take a road perpendicular to the tornado path.)

Tornado Rotation Speeds & Disaster Scales

Rotational (tangential) speeds around tornado center are much faster than translation speeds. These rotational winds cause the <u>damage</u>.

Classified by:

• Enhanced Fujita Scale (used in N. America)

determined by amount of damage to buildings.

EF0 = very weak tornado -> might break a few windows.

EF5 = exceptionally strong tornado -> totally destroy whole buildings

TORRO Scale determined by wind speed. (Europe)

FF Rating	Wind Speeds	Review this Expec	https://www.weather.gov/hun/efscale_explanation ted Damage
Li Mating	will opecus	on your own	(LG: 3b)
EF-0	65-85 mph	'Minor' damage: shingles blown off or parts of a roof peeled off, damage to gutters/siding, branches broken off trees, shallow rooted trees toppled.	
EF-1	86-110 mph	'Moderate' damage: more significant roof damage, windows broken, exterior doors damaged or lost, mobile homes overturned or badly damaged.	
EF-2	111-135 mph	'Considerable' damage: roofs torn off well constructed homes, homes shifted off their foundation, mobile homes completely destroyed, large trees snapped or uprooted, cars can be tossed.	
EF-3	136-165 mph	'Severe' damage: entire stories of well constructed homes destroyed, significant damage done to large buildings, homes with weak foundations can be blown away, trees begin to lose their bark.	
EF-4	166-200 mph	'Extreme' damage: Well constructed homes are leveled, cars are thrown significant distances, top story exterior walls of masonry buildings would likely collapse.	
EF-5	> 200 mph	'Massive/incredible' damage: Well constructed homes are swept away, steel-reinforced concrete structures are critically damaged, high-rise buildings sustain severe structural damage, trees are usually completely debarked, stripped of branches and snapped.	23



Effective Apr 2013 in Canada. Speed is max 3-second gust.

(Not testable): For more details, see www.spc.ncep.noaa.gov/efscale/ef-scale.html

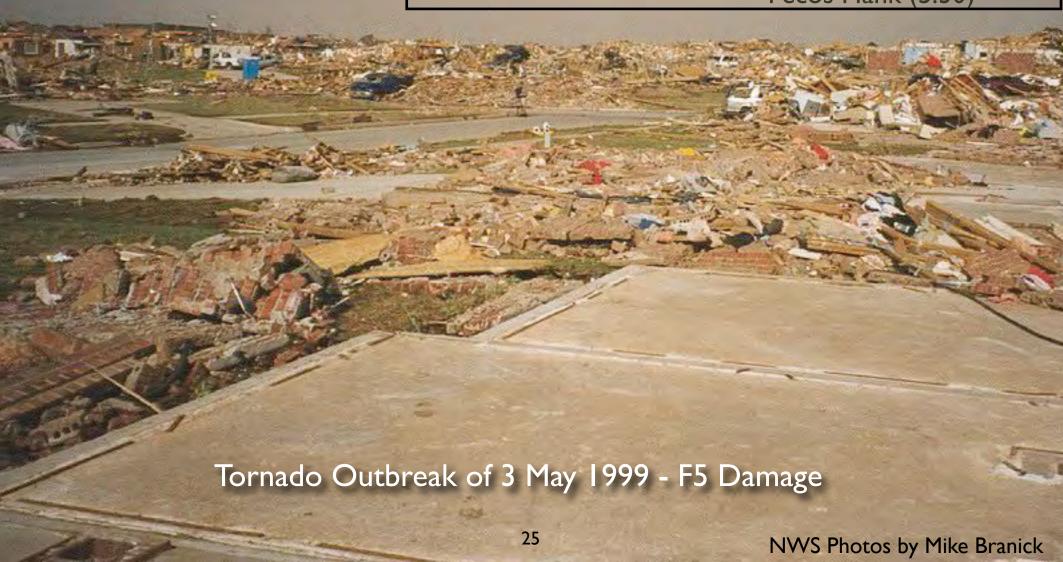
(LG: 3b)

Enhanced Fujita tornado damage scale.			(stats updated 2014)	
Scale	Rotation (mph)	Rotation (km/hr)	Damage	% of torn. in Canada
EF0	65 - 85	105 - 137	Light or Gale	66%
EFI	86-110	138 - 177	Moderate	26%
EF2	111 - 135	178 - 217	Significant	6.5%
EF3	136 - 165	218 - 266	Severe	1.3%
EF4	166 - 200	267 - 322	Devastating	0.3%
EF5	> 200	> 322	Incredible	0.05%

Day3-50. Video showing examples EF0-EF5 damage.

https://www.youtube.com/watch?v=c-uFdoi6DEA

Pecos Hank (5:30)



(old) Fujita Scale for Tornadoes

Scale	МРН	Expected Damage	F-1
F-1	73-112	Moderate Damage	
F-2	113-157	Considerable Damage	
F-3	158-206	Severe Damage	
F-4	207-260	Devastating Damage	
F-5	261-318	Incredible Damage	
F-3			F-4

Chased by Tornadoes

Tornadoes vs. Cars & Trains

Day3-40 Car sucked into tornado. (1:00)
https://www.youtube.com/watch?v=nddkiXuM4Ag
(1:00)

Day3-45 Tornado derails train in Illinois in 2008 https://www.youtube.com/watch?v=LYubpule3cw



We tailor our weather forecast products to suit your needs...









Services and Research





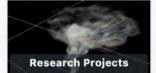














Prof. Stull's Research

Weather Forecast Research Team



Numerical Weather Prediction (Using big computers to forecast the weather for W. Canada.)

- Clean Energy
- Transportation
- Weather Disasters & forest fires
- Special Projects
- Climate forecast downscaling

https://wfrt.eoas.ubc.ca/

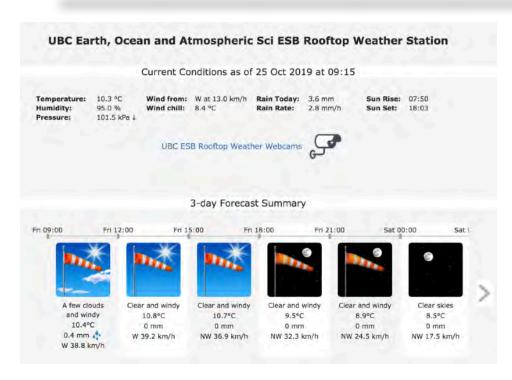


We produce forecasts for many locations:

http://weather.eos.ubc.ca/wxfcst/

(see example on next screen for UBC)

Stull's Research



- Weather forecasts for UBC. (do Google search on **ubc eoas weather forecasts**) https://weather.eoas.ubc.ca/ubcforecast
- We produce weather forecasts for Whistler.

 http://weather.eos.ubc.ca/wxfcst/users/

 Guest/ubcrs_withicons/index.php?

 location=554





ATSC 313 - Renewable Energy Meteorology. (3 cr)



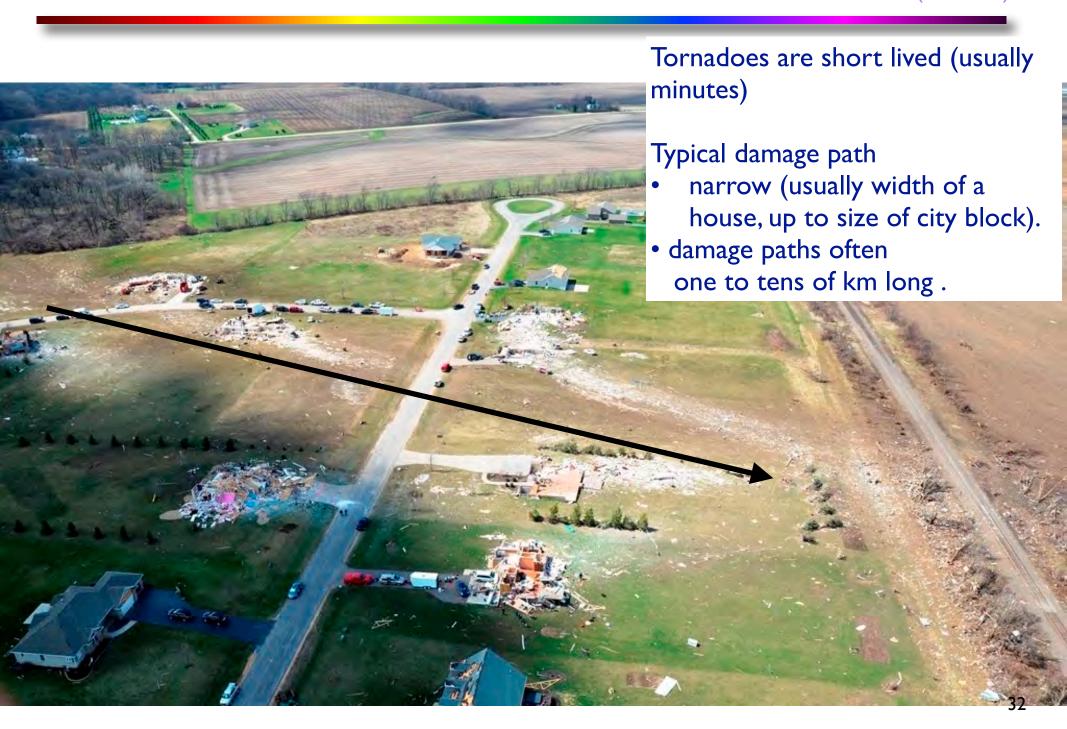
Weather for Hydro, Wind & Solar Power

Designed for STEM students in their 3rd or 4th year.

Prereqs: first year math, physics, computing

Offered every January term.

https://www.eoas.ubc.ca/courses/atsc313/



Rarely last for hours, or have damage paths I km or more wide, or have paths of a 100 of km long.



(LG: 3d,e)

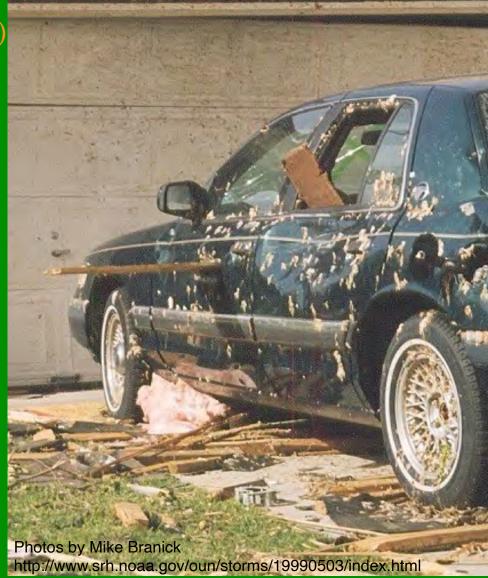
Safest places to be:

If indoors:

- <u>below ground</u>, in a basement or storm cellar
- get out of mobile homes (worse place to be in tornado)

If outdoors on foot:

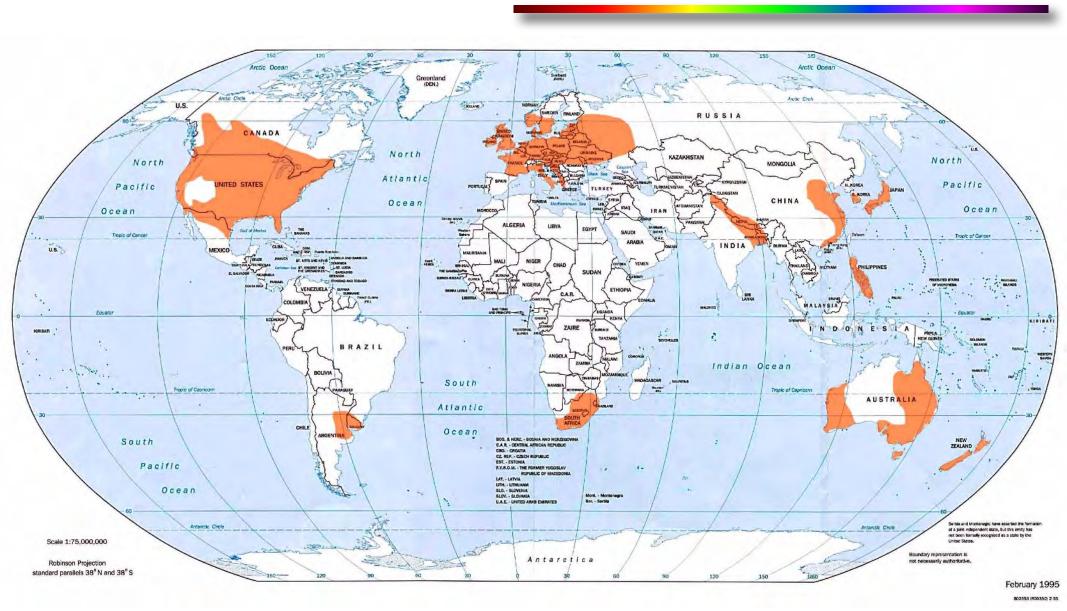
- get into a ditch or hole
- place your body <u>below "line of fire"</u> of fast moving debris



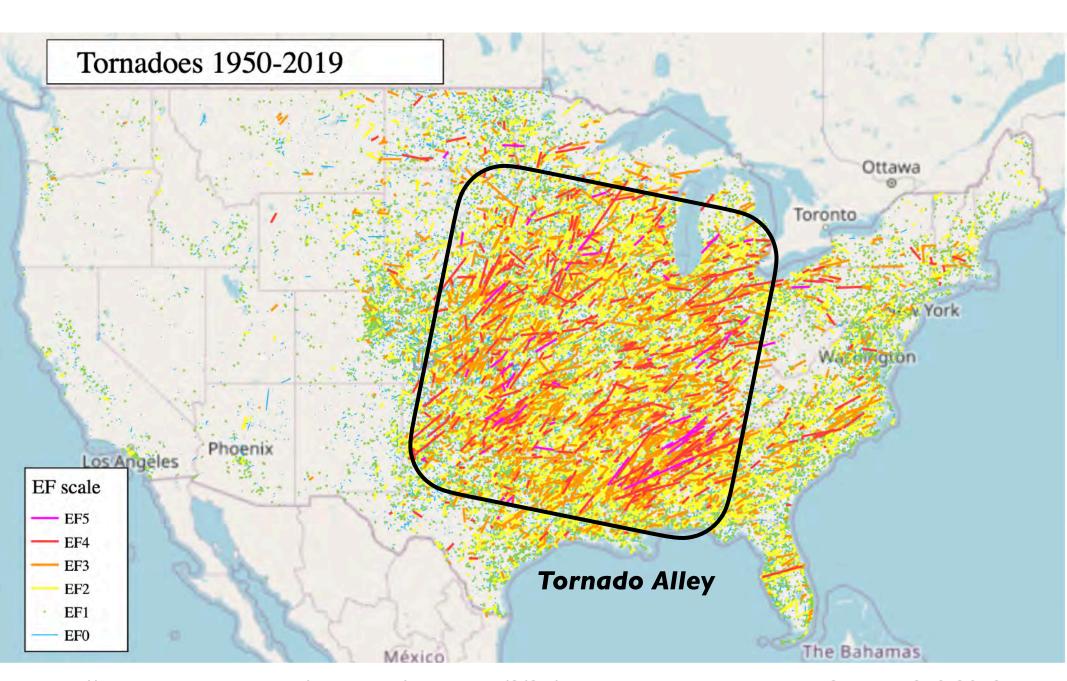
If in car:

- drive away from tornado on best convenient road
- preferably to right or left of translation direction of tornado.
- Do NOT hide under highway bridge or overpass.

5. Tornado Risk

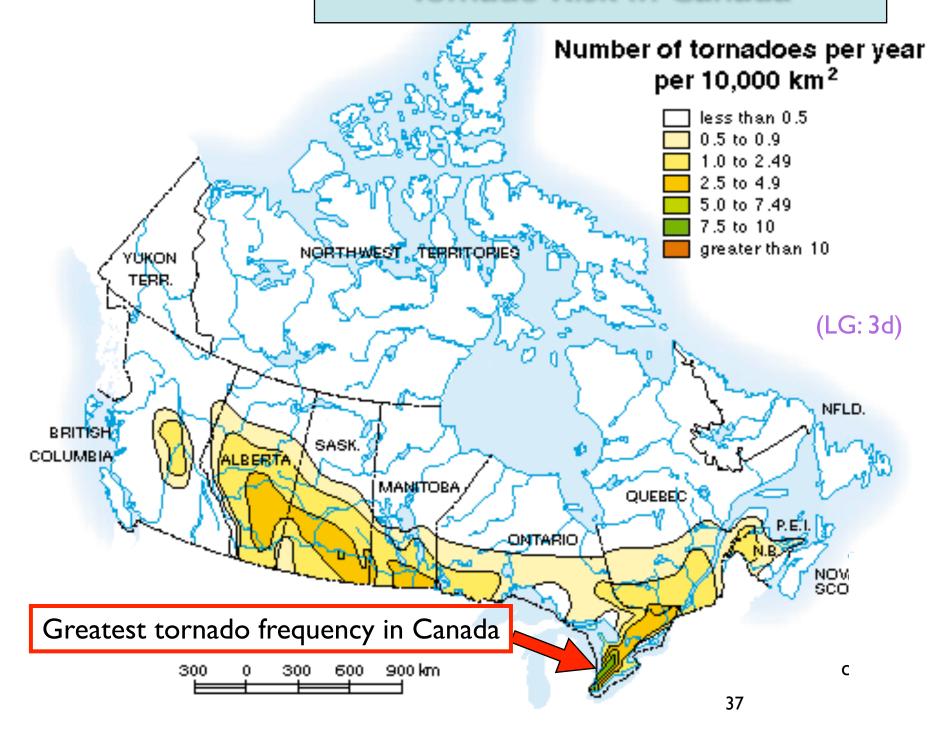


About 75% of the world's tornadoes happen in North America

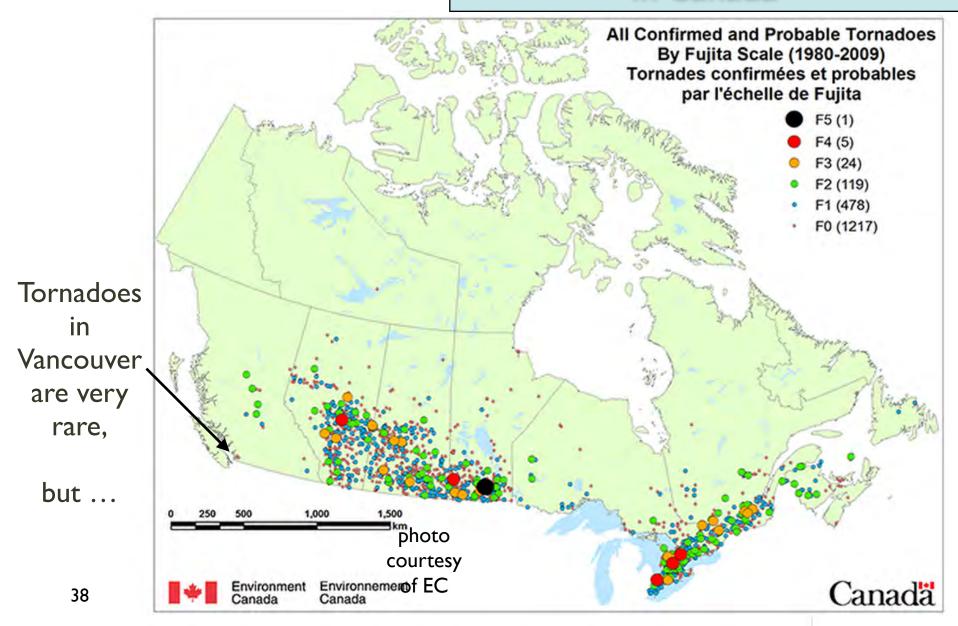


https://upload.wikimedia.org/wikipedia/commons/9/9e/Tornadoes_in_the_United_States_1950-2019.svg

Tornado Risk in Canada



Tornado Frequency vs. Intensity in Canada



EFO TORNADO hit UBC on 6 Nov 2021!!

Small hail (graupel)







EFO TORNADO hit UBC on 6 Nov 2021!!

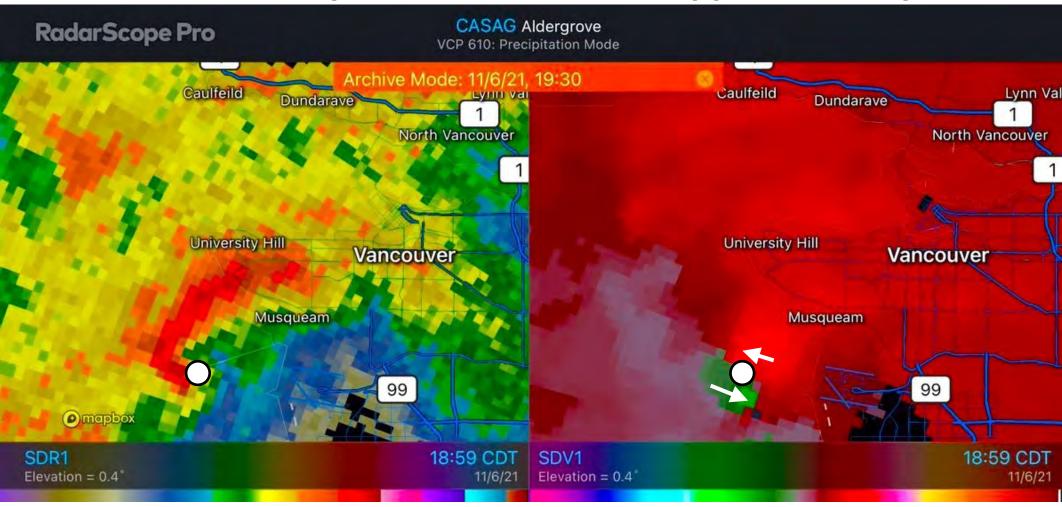
Mesocyclone rotation visible when viewed 20x speed.



EFO TORNADO hit UBC on 6 Nov 2021!!

Reflectivity

Doppler Velocity



hook echo

tornado vortex signature

6. Tornado "Outbreaks"

Tornado Outbreak = 6 tornadoes in one day and one region, or many tornadoes during about a week.

Outbreaks occur almost every year in N. America. Some recent examples:

- Apr & May 2011: 2 outbreaks: <u>336</u> & <u>180</u> tornadoes, killed 523.
- 30 Aug 2 Sep 2021: Hurricane Ida: 37 tornadoes in E. USA.
- 10-11 & 15 Dec 2021: 2 outbreaks: 70 & 117 tornadoes, killed 90 in USA.

... and they continue.

Don't memorize all these. Just note that there are many tornado outbreaks.

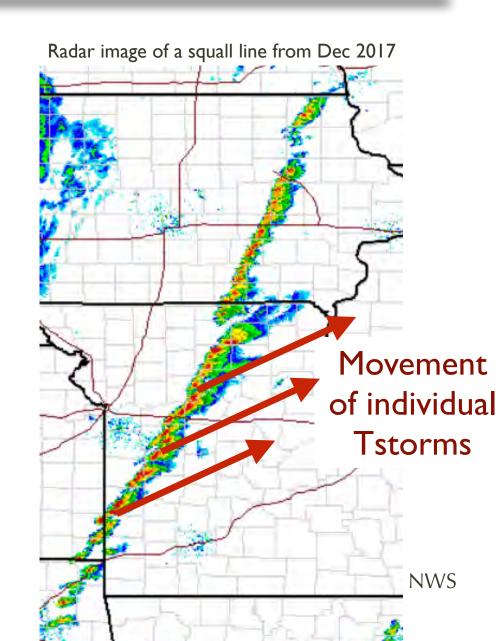
(LG: 3a-e)

Recall that a Squall Line is a line of thunderstorms

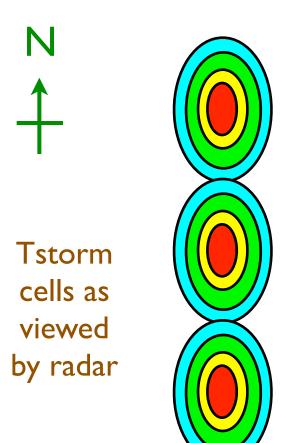
Tornado outbreaks are often associated with squall lines.

Squall lines often form along cold fronts.

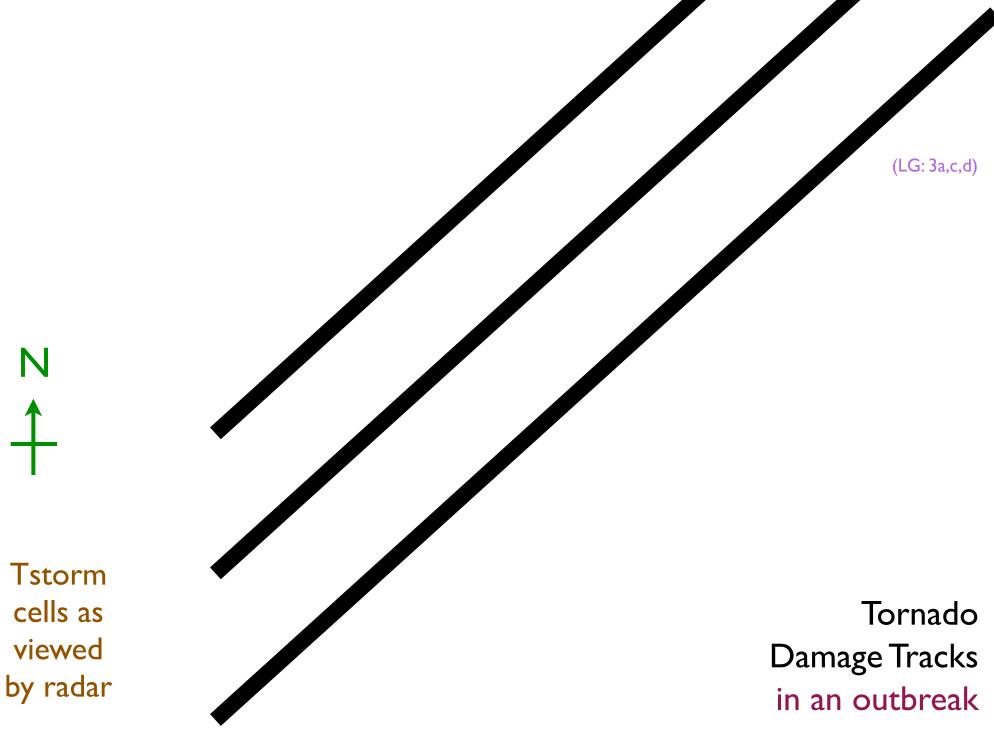
As the cold front moves toward the southeast, the thunderstorms along the front move toward the northeast.



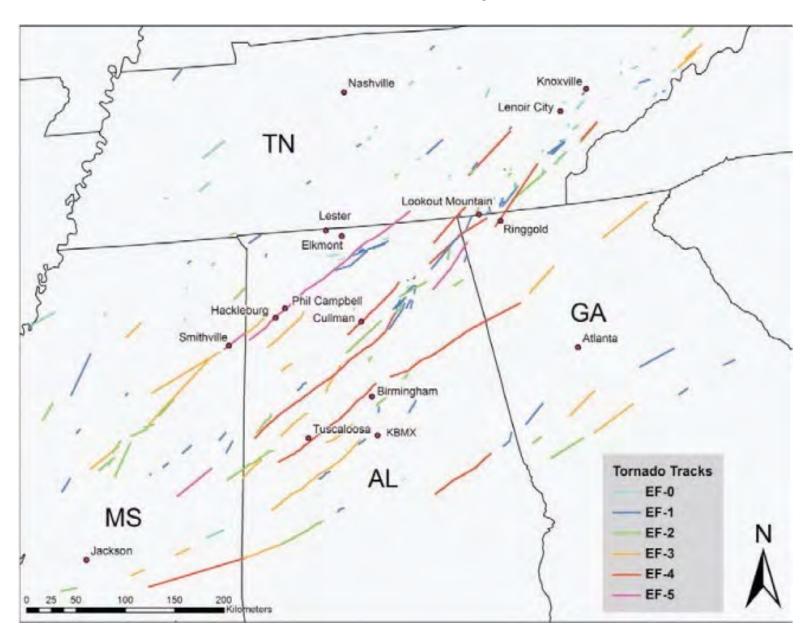
(LG: 3a,c,d)



Tornado
Damage Tracks
in an outbreak

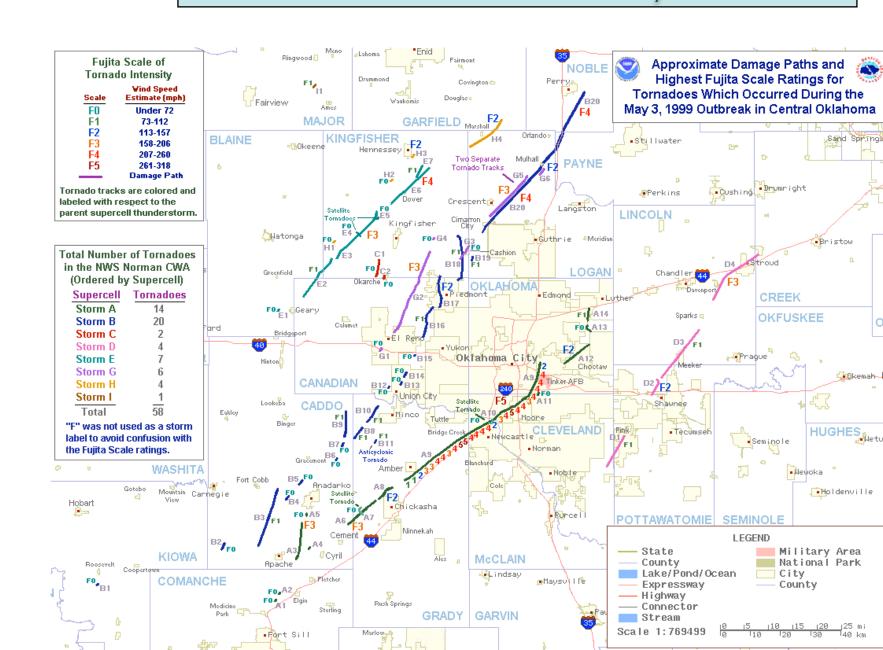


Damage Paths from the Tornado Outbreak of 27-28 Apr 2011



Damage Paths from the

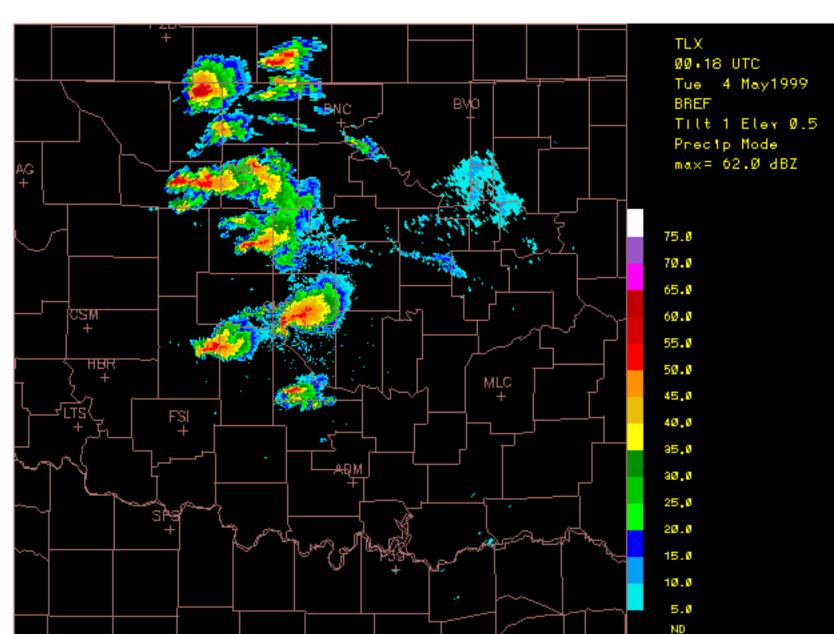
Tornado Outbreak of 3 May 1999



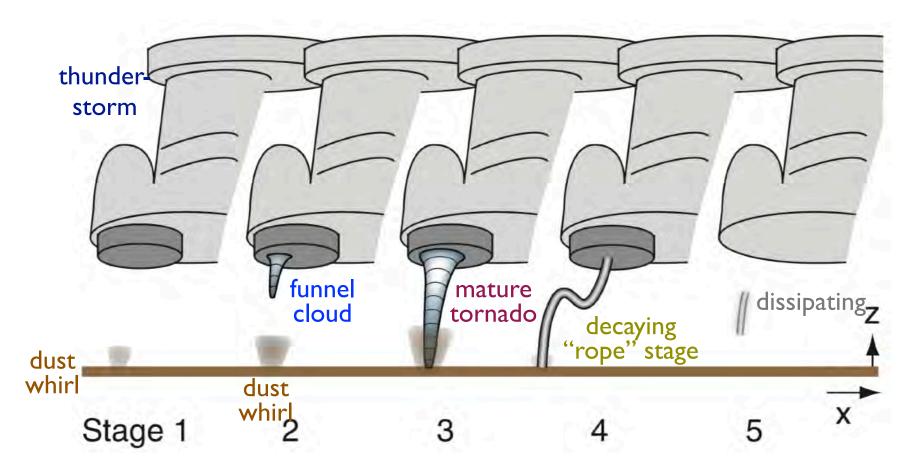
(LG: 2c)

(LG: 3c)

Tornado Outbreak of 3 May 1999 - Radar



7. Tornado Evolution (from supercells)



8. Forecasting Tornadoes is Very Difficult

Tornado Watch

- 6 to 12 hour forecast
- a broad region within which tornadoes are favorable or likely later in day
- you can continue your normal activities
- you should monitor emergency announcements on news or weather radio.

Stull & wife vs. Tornado

Tornado Warning

- tornado actually detected now ("nowcast"), by either
 - Doppler radar sees tornado vortex signature or TVS, or
 - human spotter or other government official actually sees a tornado
- nowcast warning tells you:
 - where tornado is
 - where it is moving
 - warning is for specific towns or counties within the expected path
 - tornado sirens activated in those towns
- warnings come only 15 minutes or less prior to a tornado hitting you, so you MUST immediately terminate normal activities and go to tornado shelter or other area of refuge.

The Turbulent Atmosphere

Day4-50—One last YouTube recommendation to watch on your own if you plan to chase storms: Pecos Hank **Tornado Death Traps**. (11:40)

https://www.youtube.com/watch?v=VsxFwIUlp2A

Summary of Day 3

Tornadoes

Prof. Roland Stull

- I. Recognizing tornadoes
- 2. Recognizing supercell rotation
- 3. Speeds and disaster scales
- 4. Tornado safety
- 5. Tornado risk
- 6. Tornado outbreaks
- 7. Tornado evolution
- 8. Forecasting tornadoes and public warnings

Next Class:

From Heat to Motion Hail