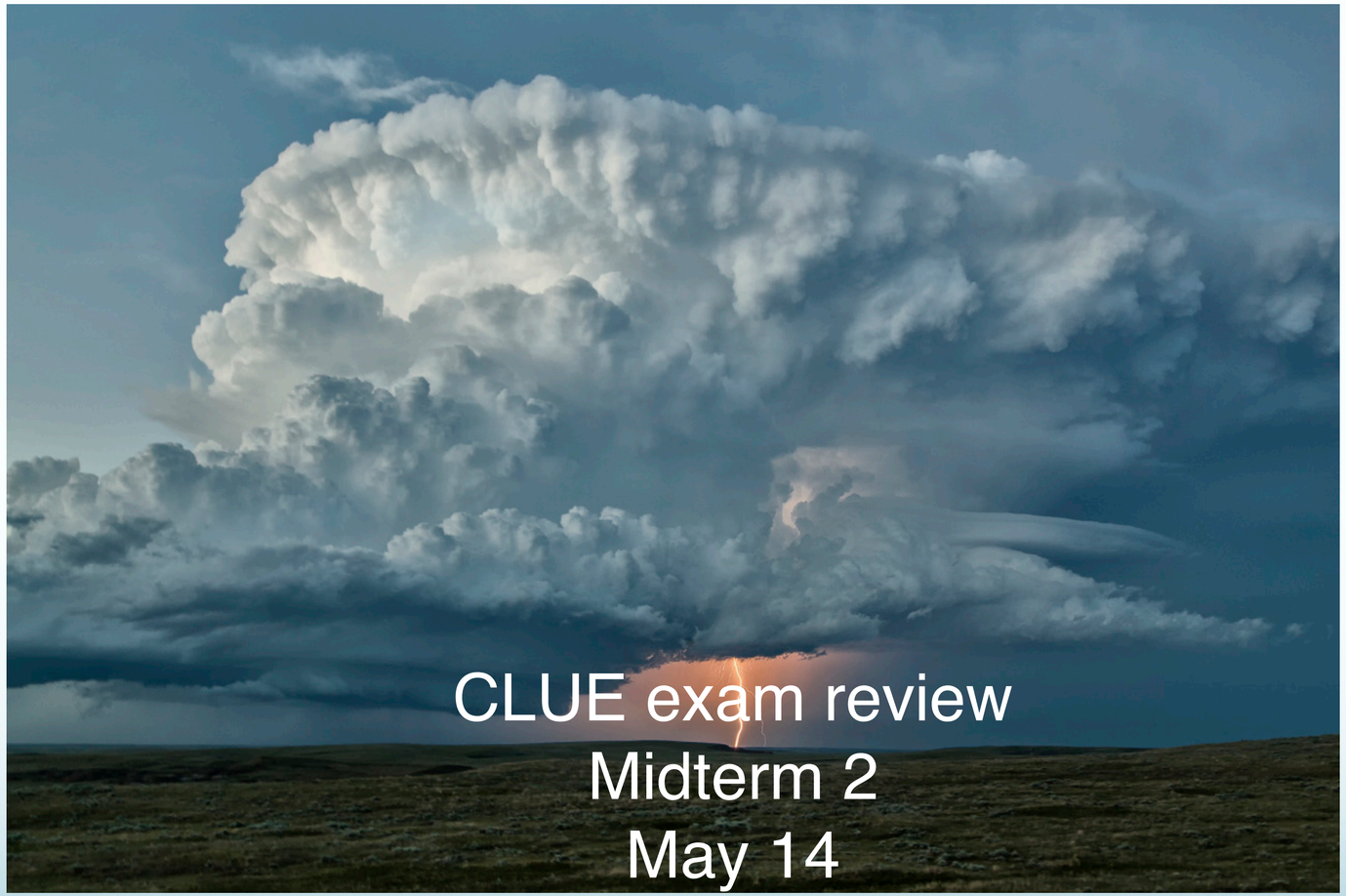
ATM S 103

Hurricanes and Thunderstorms



Midterm 2: Wednesday May 22

- Bring a Scantron form
- Closed book, notes, electronics
- 30 multiple choice questions (similar to homework)
- Covers
  - Homeworks 4-6
  - Lectures from April 26 through today
  - Reading weeks 5-8
  - **No overlap with Midterm 1**

Outline

- Raindrops, Graupel and Hail
  - Ice crystal process of raindrop formation, formation of graupel and hail
- Thunderstorms
  - Muti-cell, supercell, Radar basics
- Tornado
- Hurricane

1. Raindrops, Graupel and Hail

How do raindrops/ice crystals grow?

How do raindrops grow?[continued]

- Condensation

  overall is very slow … at least 2 days!

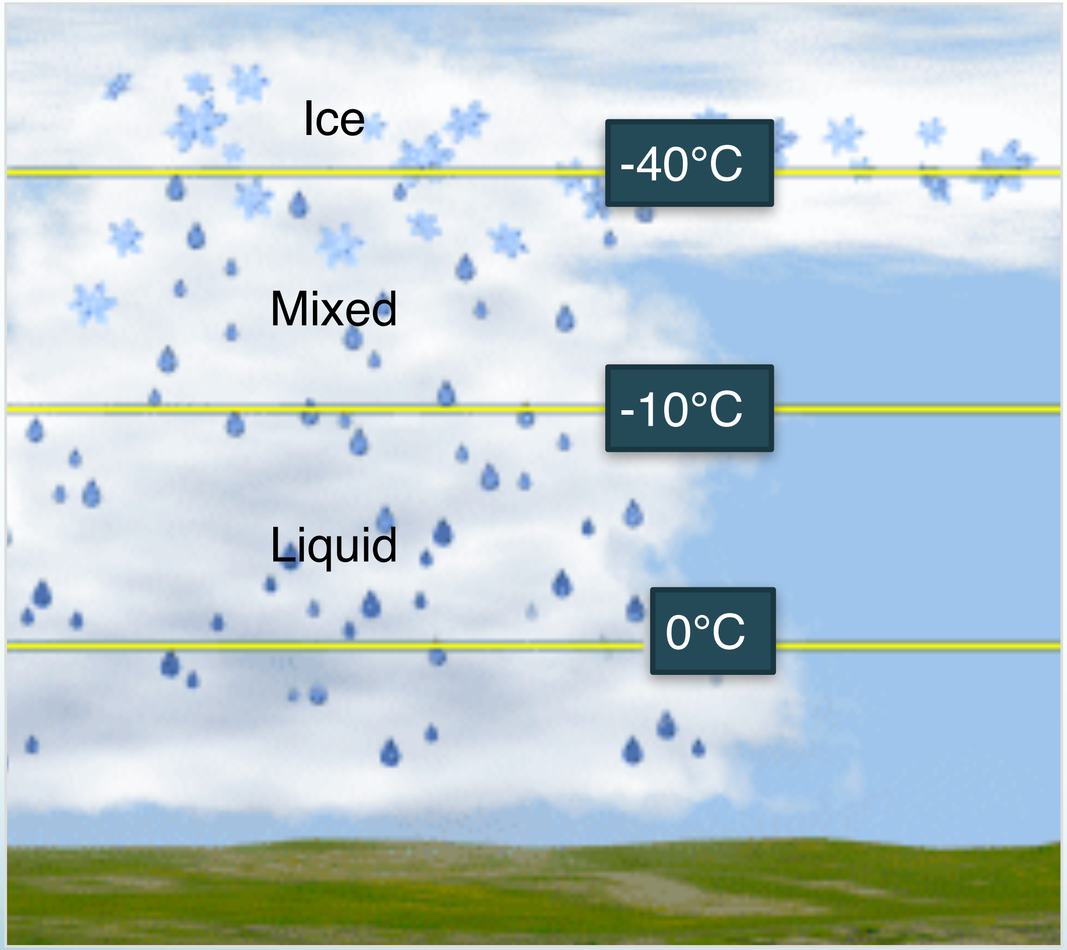
- Collision and coalescence

  Collide and merge with other droplets…

- Ice crystal process

  Another way of growing rain drops quickly

Ice crystals in clouds



1. Almost no ice crystals in clouds at temperatures warmer than –10 °C.

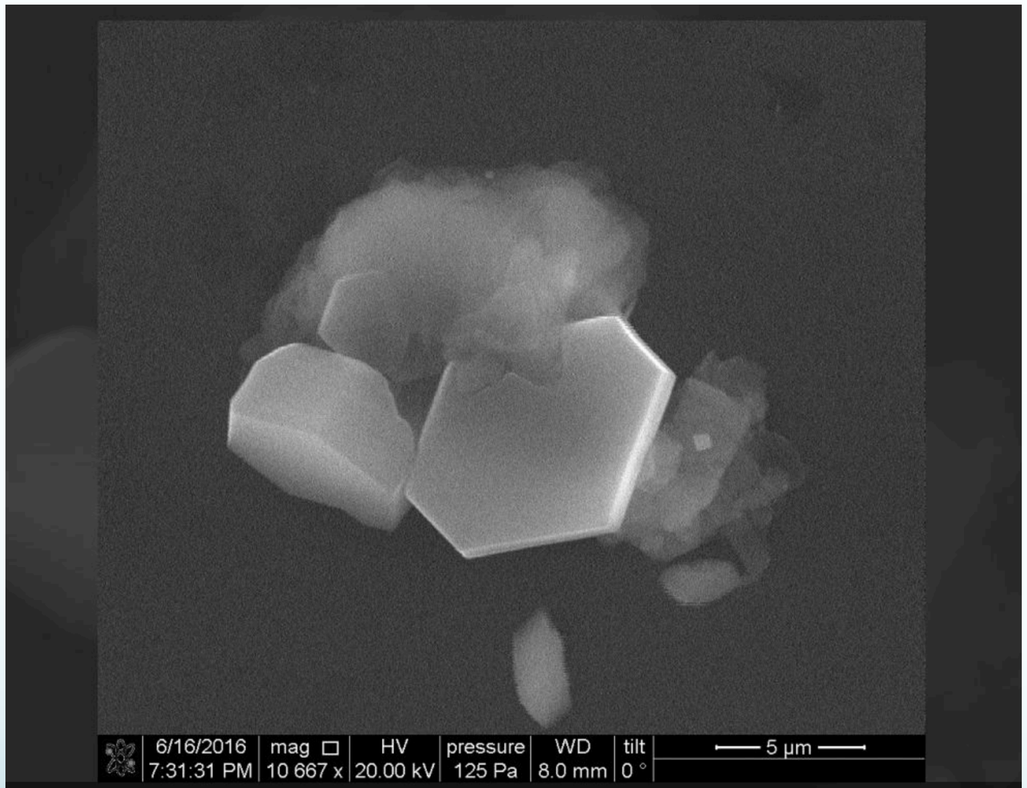
2. Mixed ice and liquid droplets between –10 °C and –40 °C

3. All ice at temperatures less than –40 °C

Supercooled Water

- liquid water that exist below 0 °C. The liquid needs to get to –40°C to ensure freezing will happen rapidly without the help of an ice nucleus.

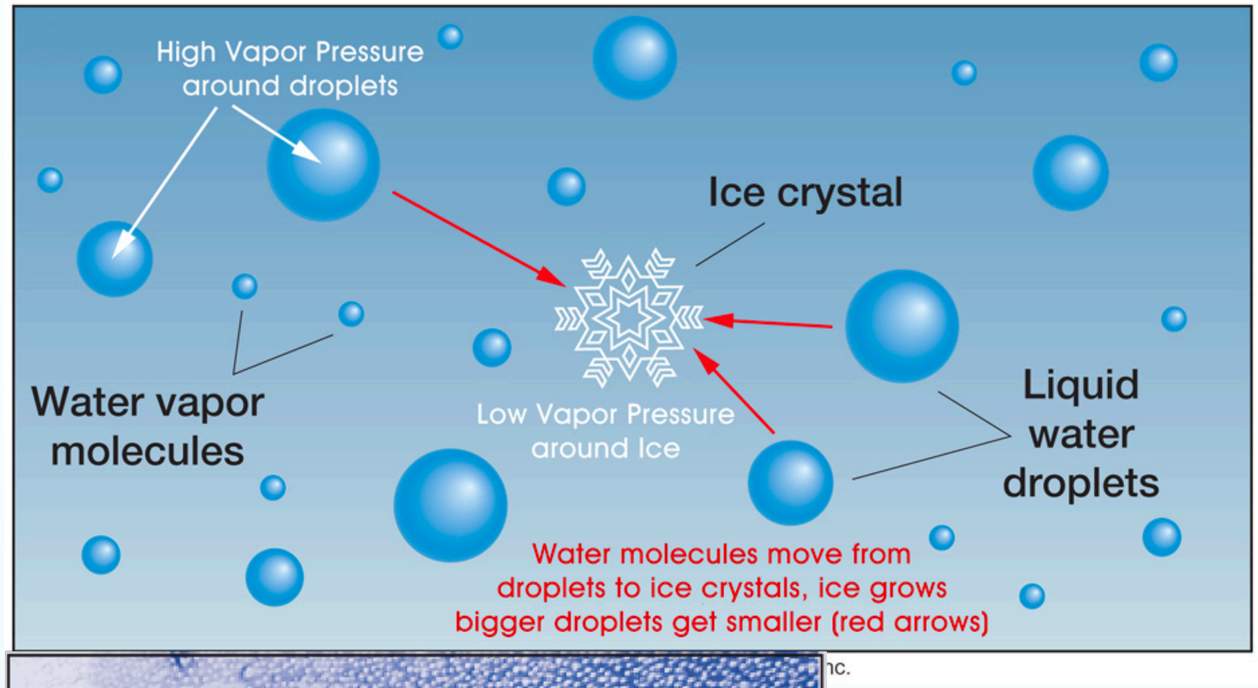
Ice Nuclei



Ice crystals form around a minuscule particle in the very first seconds of the formation of an ice cloud.

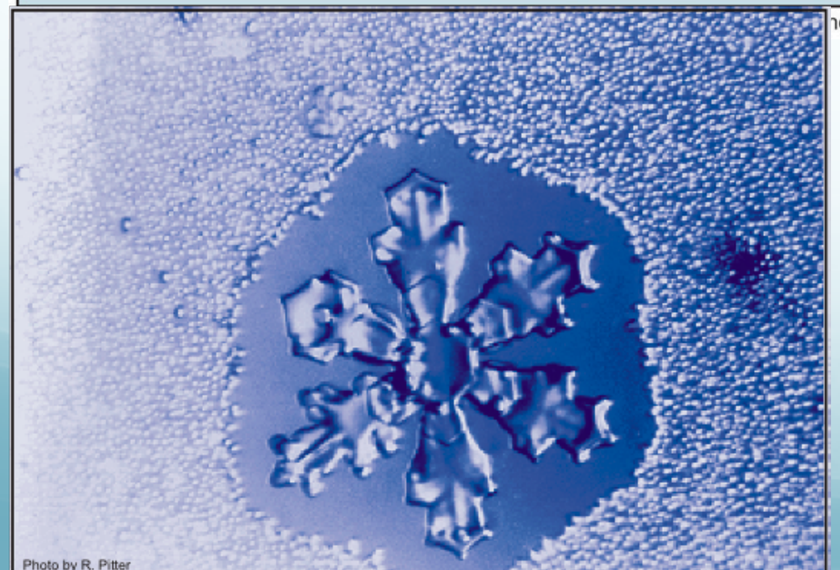
- Ice Nuclei (IN): particles (e.g. clay particles, plant material) help form ice crystals from water droplets by providing seed to start crystal growth.
- But compared to CCN, ice nuclei are rare, and most are not active at temperatures warmer than –10 °C.
- Example: aircraft icing

Ice Crystal Process (Bergeron-Findeisen)

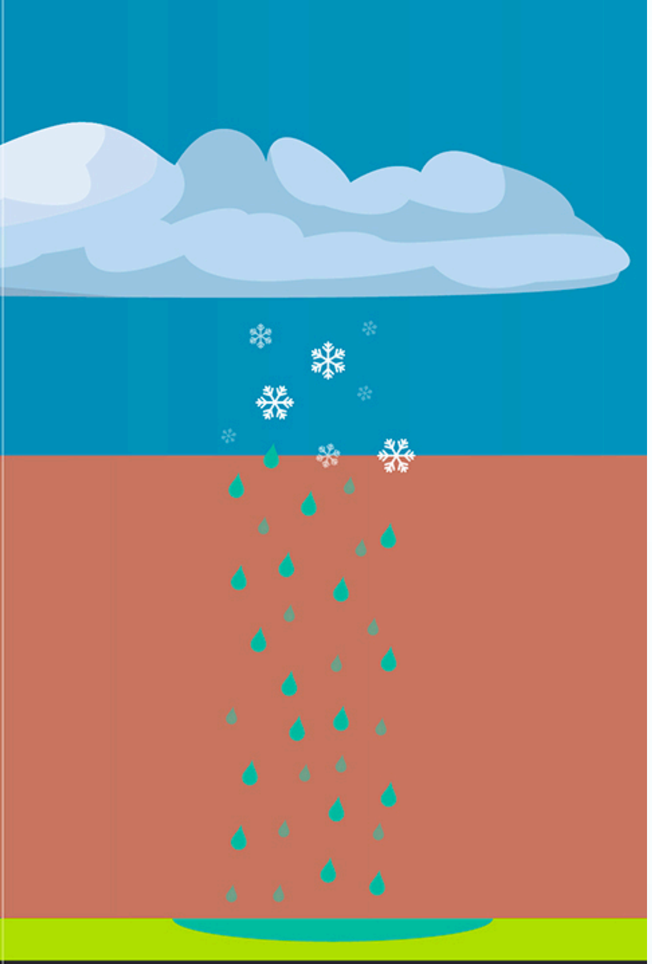


- Saturation vapor pressure over the super-cooled liquid water exceeds the saturation vapor pressure over the ice.
- There is a net transfer of water from the liquid to the ice

  Liquid ➔ Vapor ➔ Ice



- Ice grows rapidly because the air is supersaturated with respect to ice.



Snow melts to form rain

- When ice crystals or snow get large(heavy) enough, they fall down and form rain.
- Outside the tropics, almost all precipitation starts as ice crystals or snow.

Collisions help falling ice crystals grow large…

Graupel

Hail

Graupel

- Formed by riming

  riming: falling ice crystals grow by collecting super-cooled cloud droplets

- Looks white, wightweight and crunchy because air is trapped inside

Hail

- Layered Growth:

White layers: new ice froze instantly when it contacted the stone (air trapped, light)

Clear ice: water freezes slowly when it contacted the stone (dense ice)

- Terminal Fall speeds of hail depends on the its size

2. Thunderstorm

Continued from last time….
Focus on Muti-cell, supercell, Radar basics

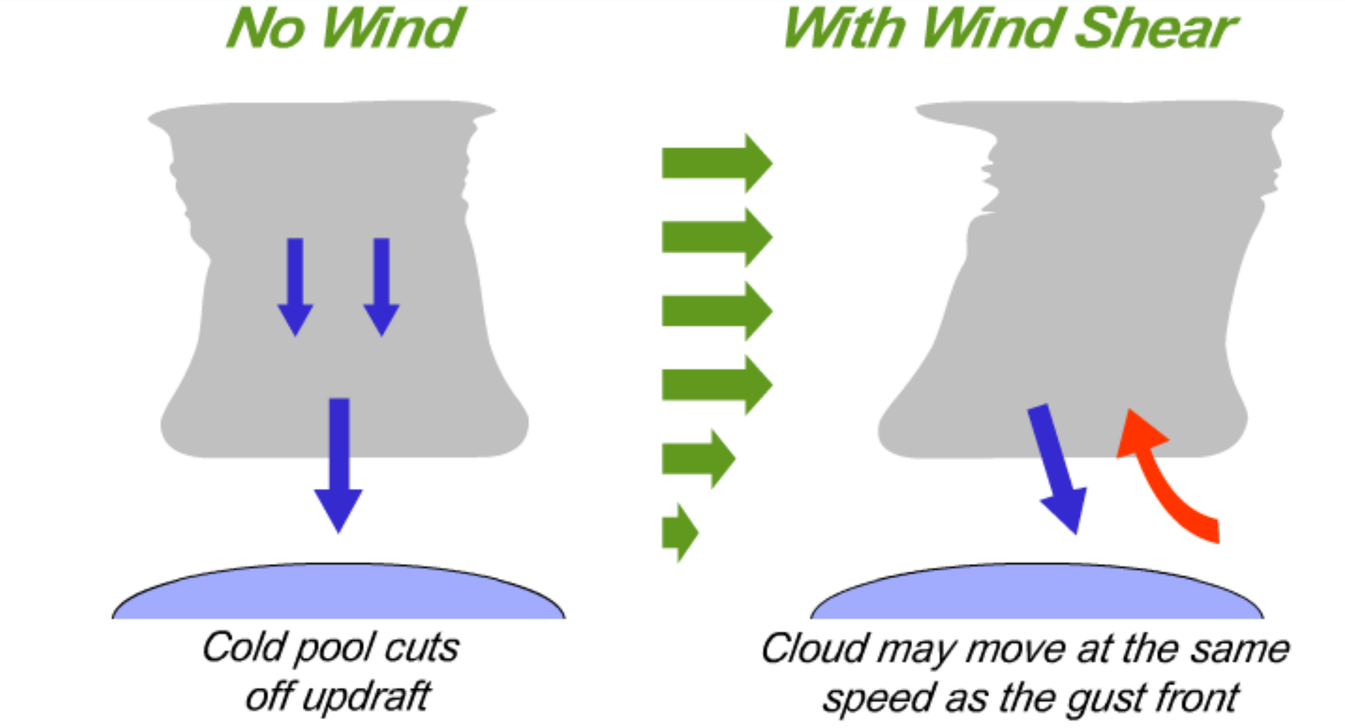
Recall 3 kinds of thunderstorm

- Single cell (weak low-level wind shear)
  - “Ordinary” or “air mass” thunderstorm
  - Generates lightning.
- Multi-cell (moderate low-level wind shear)
  - May be severe (>1” hail, winds > 58 mph)
  - Seldom makes strong tornadoes
- Supercell (strong low-level wind shear)
  - Relatively long-lived
  - Associated with most strong tornadoes

Why might wind shear matter?

- Low level wind shear may extend the lifetime beyond that of a single cell storm
- Type of thunderstorm is determined by …
  - How much warmer rising air parcels become in comparison to their environment (the CAPE)
  - the low-level wind shear.

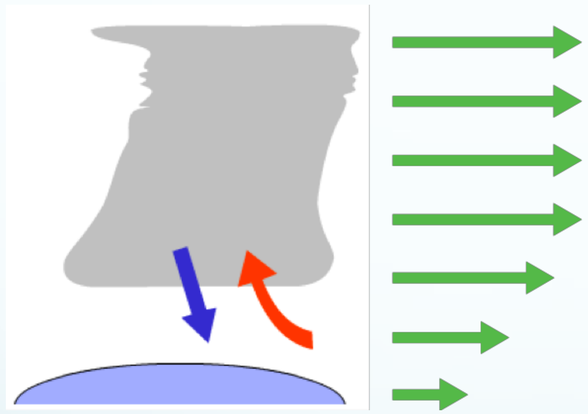
How wind shear affects thunderstorm



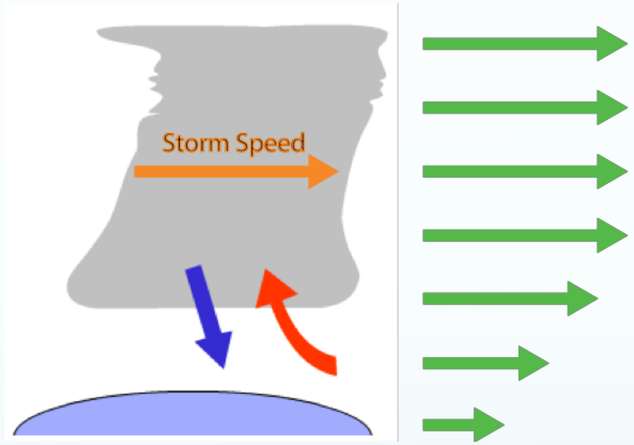
- Tilts the thunderstorm
- Keep the cold pool/gust front from cutting off the updraft

How wind shear affects thunderstorm

Environment with Low-Level Shear

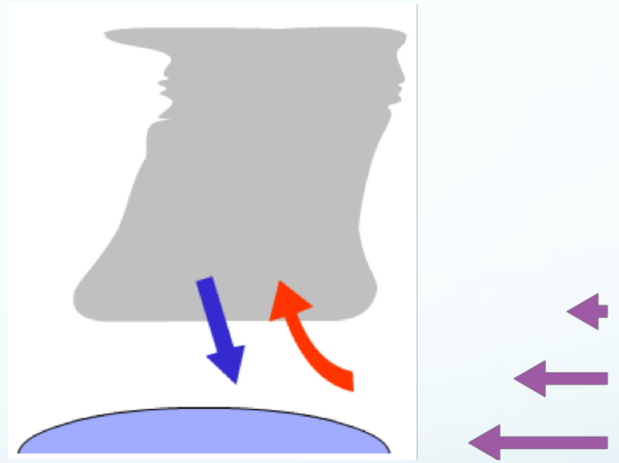


Shift to Storm-Relative View Point



Subtract (remove) the storm speed from the environmental winds.

Storm-Relative Winds



Low-level shear holds back the gust front.

lti-cell storms last longer than single-cells because

Multi-cell storms live longer because low-level wind shear keeps the cold pool from surging out to cutoff the updraft

Start the presentation to activate live content

If you see this message in presentation mode, install the add-in or get help at PollEv.com/app

APE, i.e., more energy available to power the storm. | Low-level wind shear keeps the cold pool from surging out to cutoff the updraft. | The surface temperatures and dew point

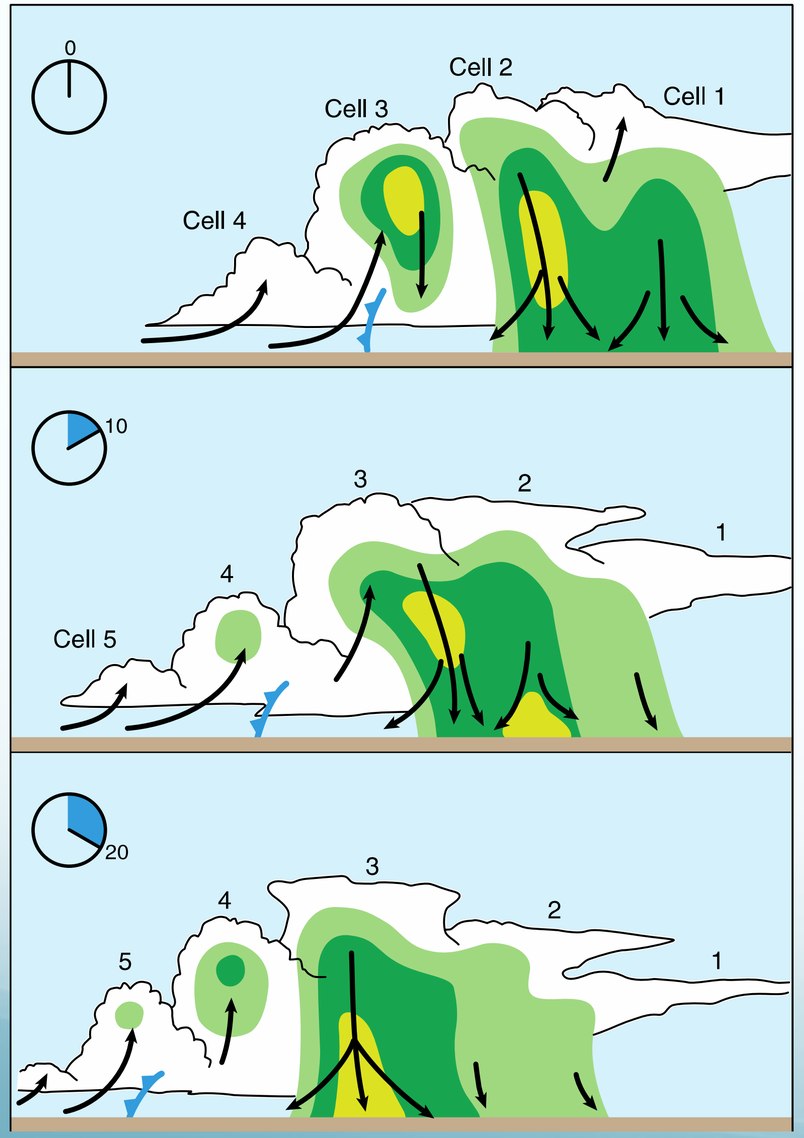
Total Results: 0

Multi-cell Thunderstorm

- Multicell thunderstorms are a "group" or "family" of single cells at various stages of their life cycles.
- Multi-cell storms live longer because low-level wind shear keeps the cold pool from surging out to cutoff the updraft
- Low level wind shear is able to keep the gust front near to the storm updraft by moving the thunderstorm clouds with the cold pool.

  This triggers new convection close enough to the old cells that they can interact each other and form a multicell thunderstorm.

Multi-cell Thunderstorm



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Supercell

- Account for almost all
  - Instances of hail > 2” diameter
  - Violent tornadoes (>111 mph 3 s gusts)
  - High lightning flash rates (200 per min)
- Long-lived
  - 1– 4 hours common
  - As long as 8 hours
  - because wind shear separates the cold pool and the updrafts

- Distinguishing property: significant rotation (mesocyclone)

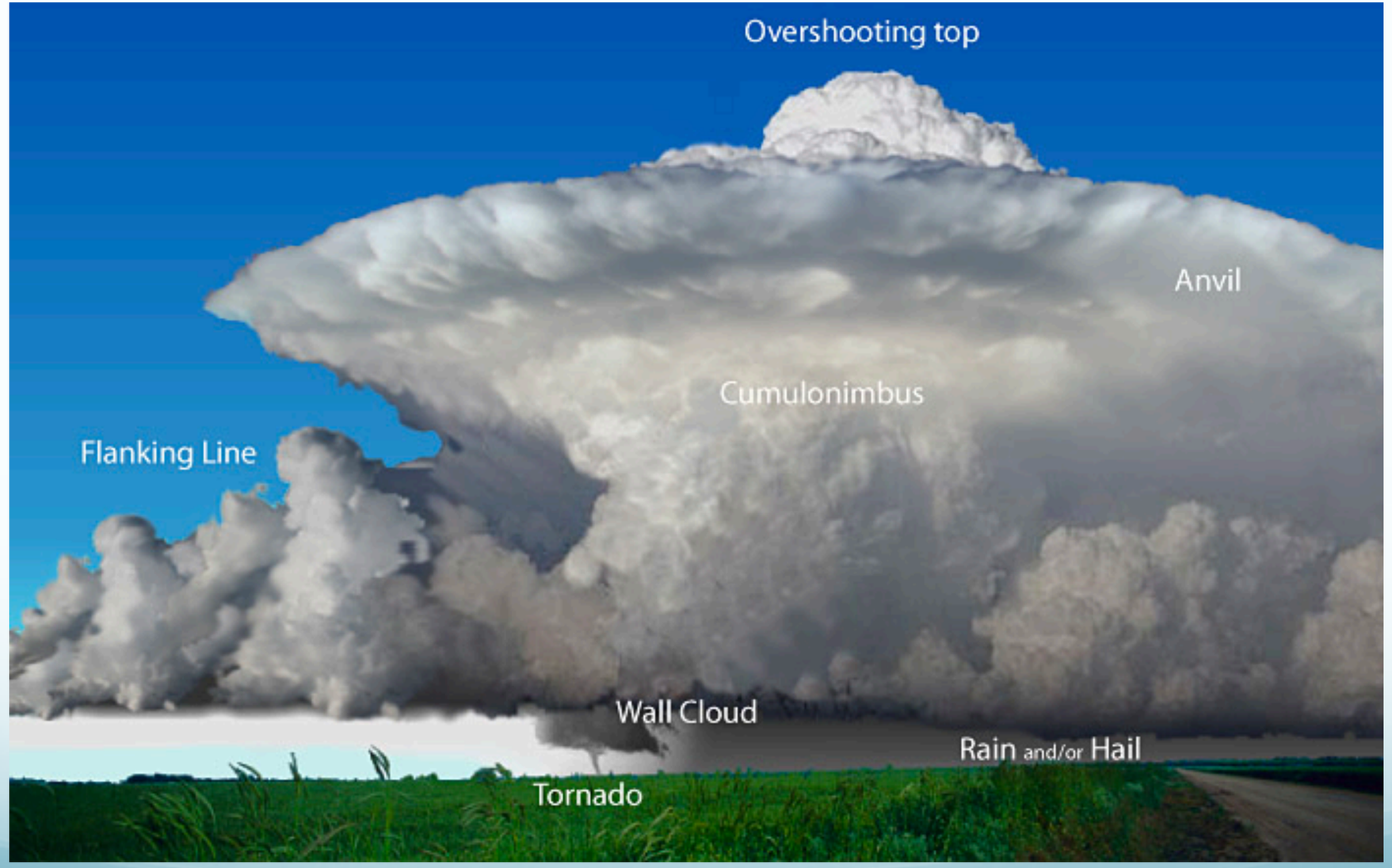
Supercell environment

- Decent but not unusually large CAPE
  - But the amount of CAPE is not necessarily higher than for multi-cell storms.
- Wind shear is strong and is significant through a much deeper layer than for multi-cells.

How does strong wind shear fuel supercell?

- Both Low-level and deep-layer wind shear help separate the rain and the updrafts
- The deep-layer wind shear also interacts with the updrafts to add upward-directed pressure forces to the updraft
  - Upward force is not exclusively due to buoyancy of warm air rising

Supercell Thunderstorm



Question 5 — 1 pts

Which of the following characteristic of supercell makes the distinctive difference from other types of thunderstorm?

- Significant amount of CAPE.
- The rotation in the updraft.
- Extremely warm and moist air at the surface.
- Gust fronts.

Question 7 — 1 pts

Which of the following properties distinguishes environments that produce supercell thunderstorms from environments that produce other types of thunderstorms?

- the presence of high, thin clouds
- an unusually unstable atmosphere
- strong environmental wind shear between the surface and the tropopause
- high surface dew points

Useful tool to detect mesocyclone
Doppler Radar

- Reflectivity measures the strength of the reflection
  - stronger signals imply bigger drops
- The Doppler velocity measures the speed of the target along the line back to the radar
  - Toward to away from the radar

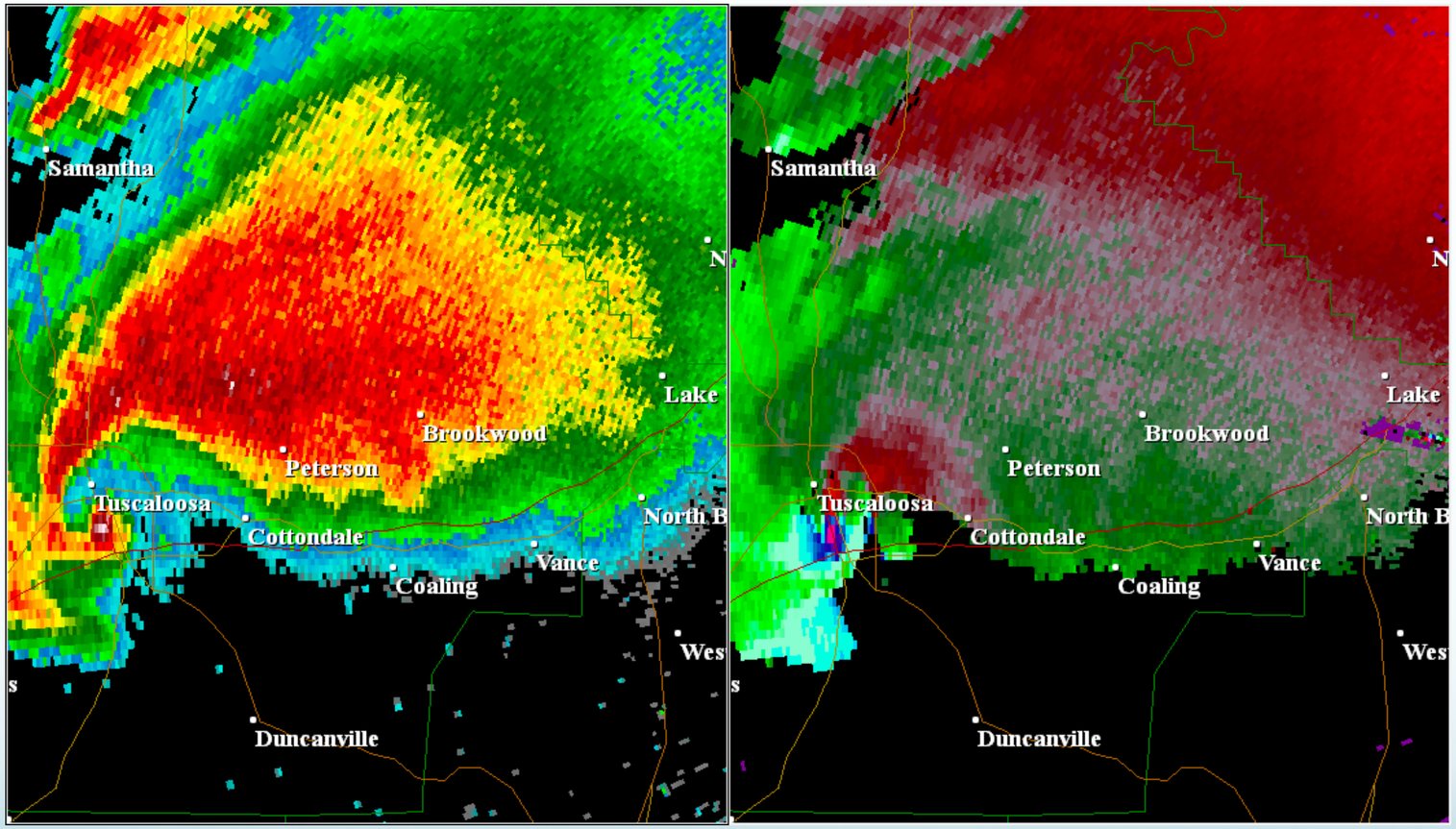
Question 2 — 1 pts

Which of the following will appear in a radar echo (reflectivity)?

- Lightning
- Water vapor
- Raindrops and hail
- All of the above

Radar features

Where is hook echo, velocity couplet, debris ball?

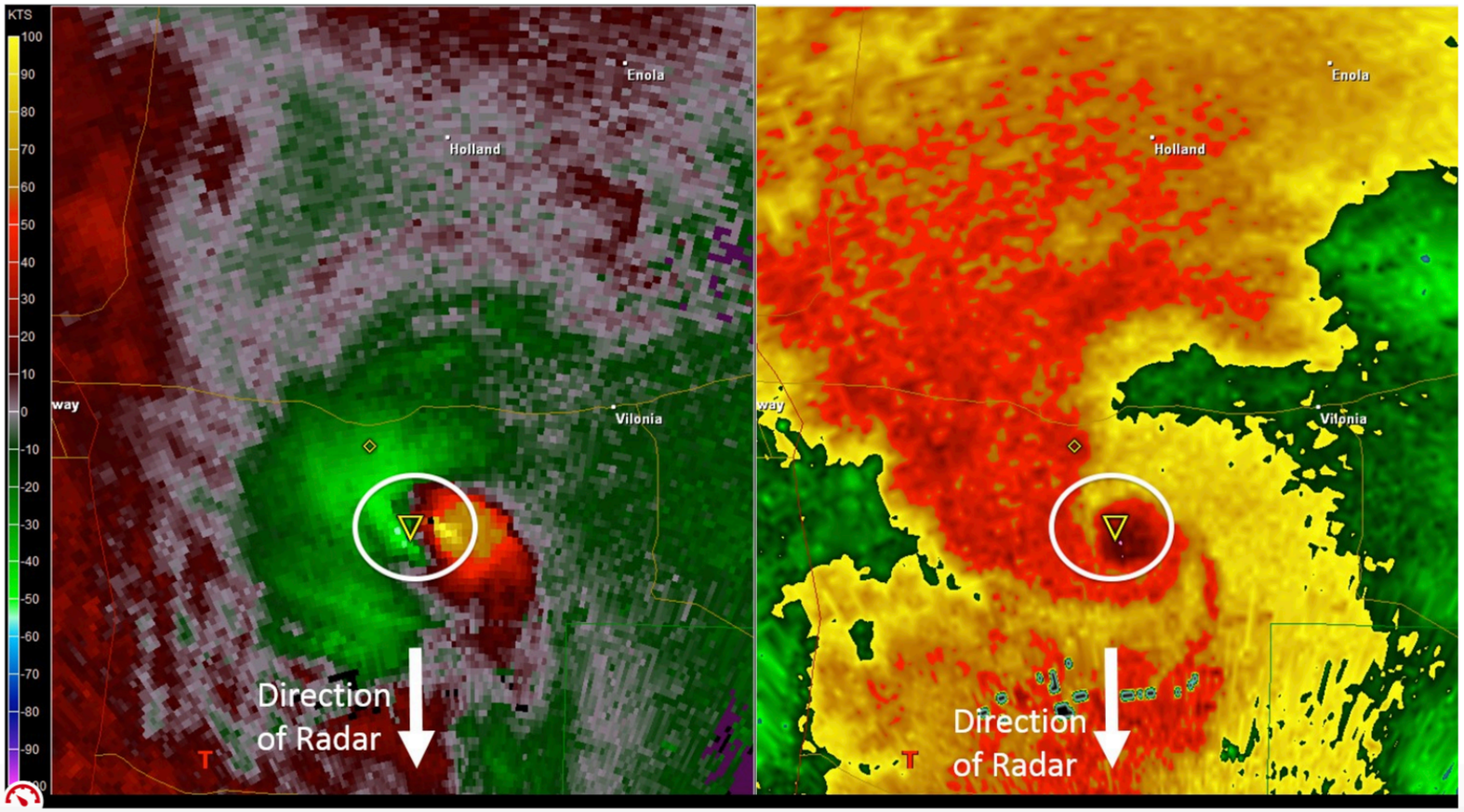


What caused the weak echo region inside the hook?

Question 9

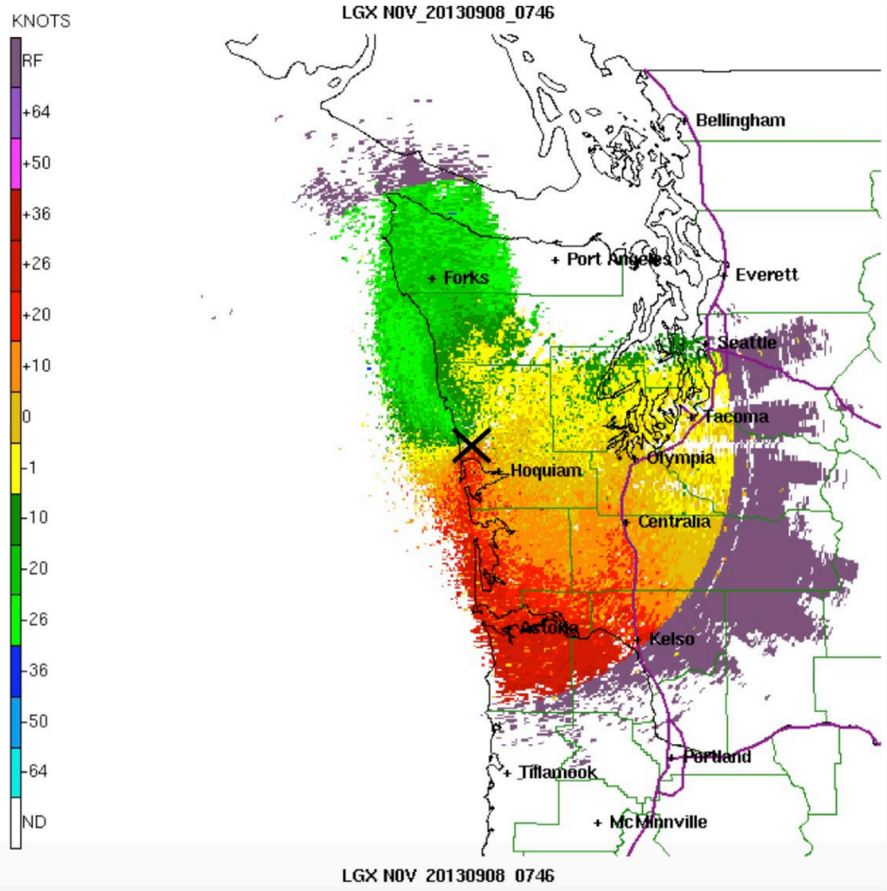
1 pts

The image below shows radar information for radial velocity (left, velocities away from the radar are reds, toward the radar are greens) and reflectivity (right). Over the region inside the circle, which of the following options best describes what the radar is observing?



- a gust front
- a microburst
- a tornado
- a mesocyclone

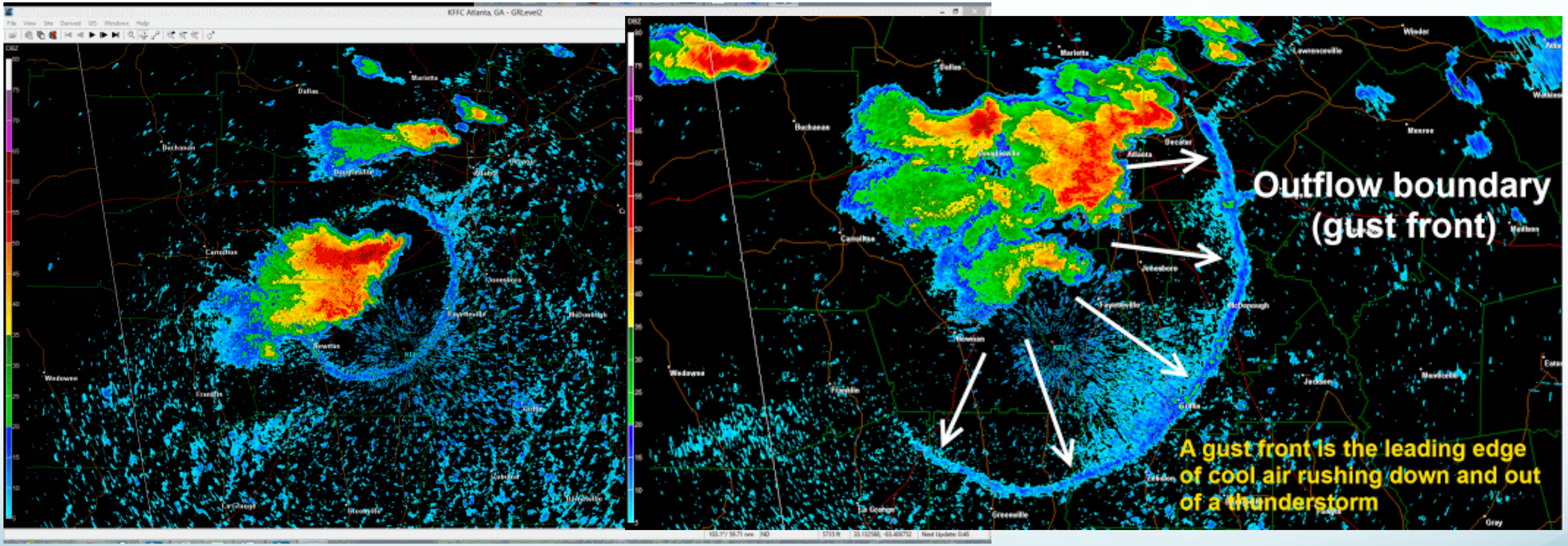
The Doppler radar image below comes from the Langley Hil on the Washington coast (the location marked with the blac X). The picture shows the radial velocity of birds flying at night, relative to the radar location. Negative values, indicated by greens, are towards the radar. Which way are the birds flying?



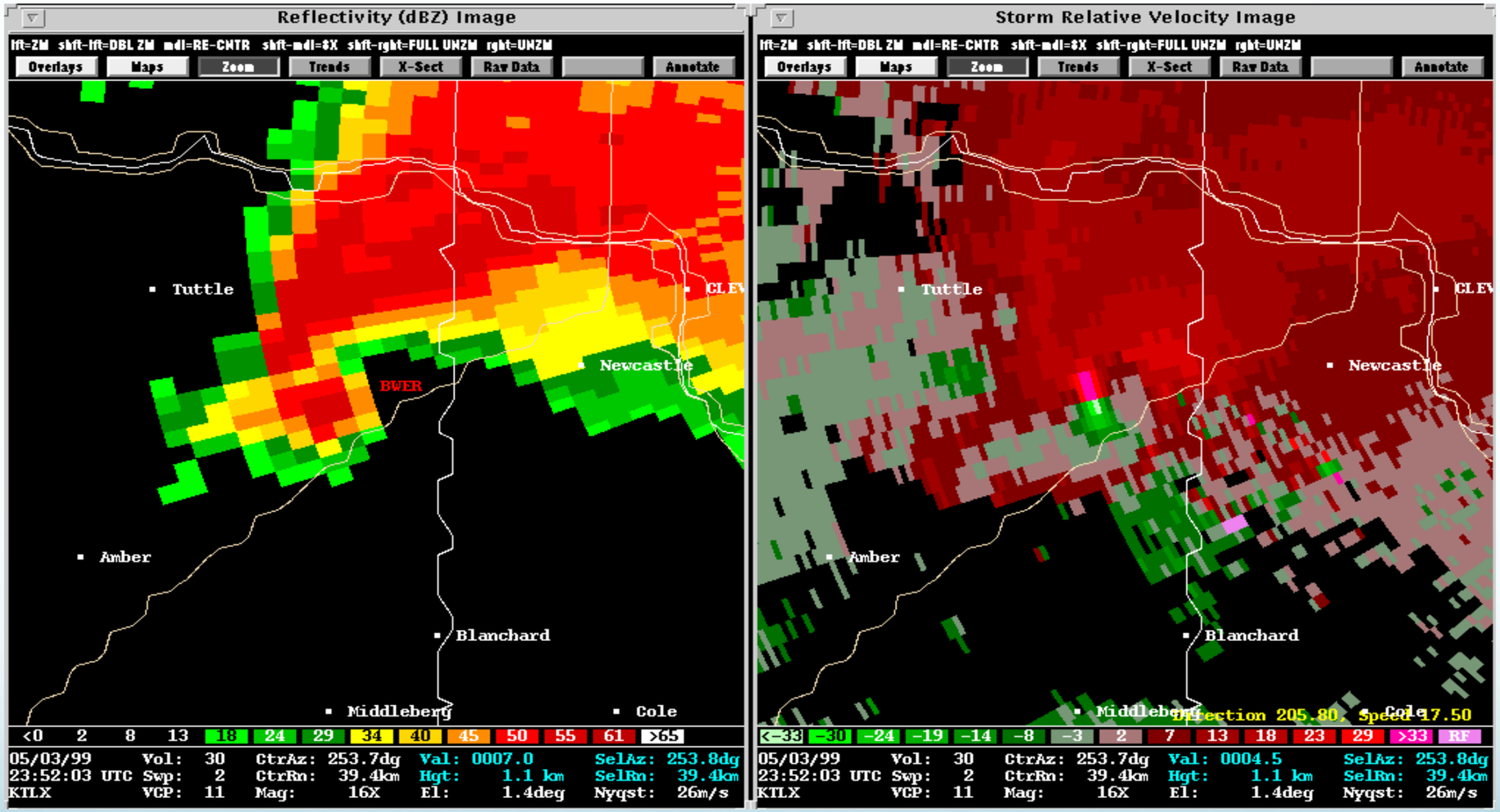
- North
- East
- South
- All directions

North	17 respondents	12 %
East	8 respondents	6 %
South	103 respondents	**74 %**
All directions	12 respondents	9 %

Positive values. Indicated by red are away from the radar.
Negative values. Indicated by greens are towards the radar


KFFC Atlanta, GA - GRLevel2
Outflow boundary
(gust front)
A gust front is the leading edge
of cool air rushing down and out
of a thunderstorm

Hook echo (reflectivity) and Doppler (velocity) couplet



Here Radar is not seeing Tornadoes

- Too big to be the tornado
- Quite high above the ground
- Too slow to be the tornado (50 knots ~ 58 mph)
- The radar is picking up the larger rotating updraft, the mesocyclone
  - 2-5 miles wide
  - Extends at least halfway to the tropopause (where the storm top flattens out).
  - We've been looking at the bottom of mesocyclones in the previous videos.

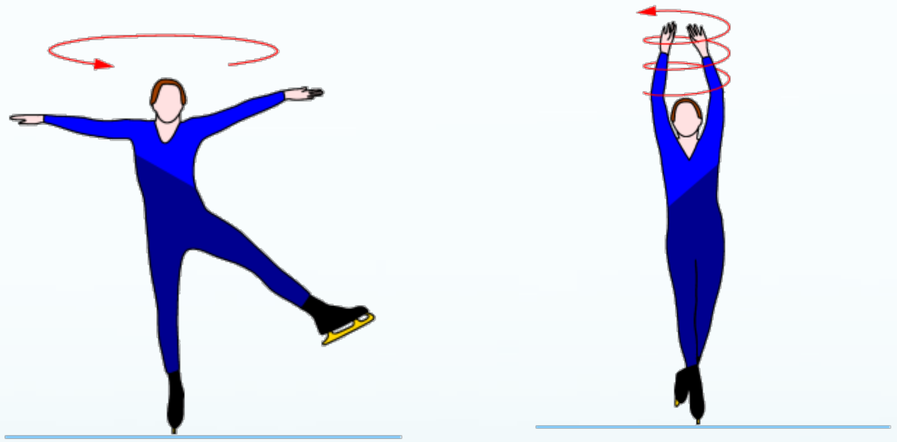
3. Tornado

What is tornado?

- Definition of a tornado:
  - A violently rotating column of air
  - In contact with the ground
  - Connecting up to a cumulus cloud
  - Often (not always) visible as a funnel cloud

What makes a tornado?

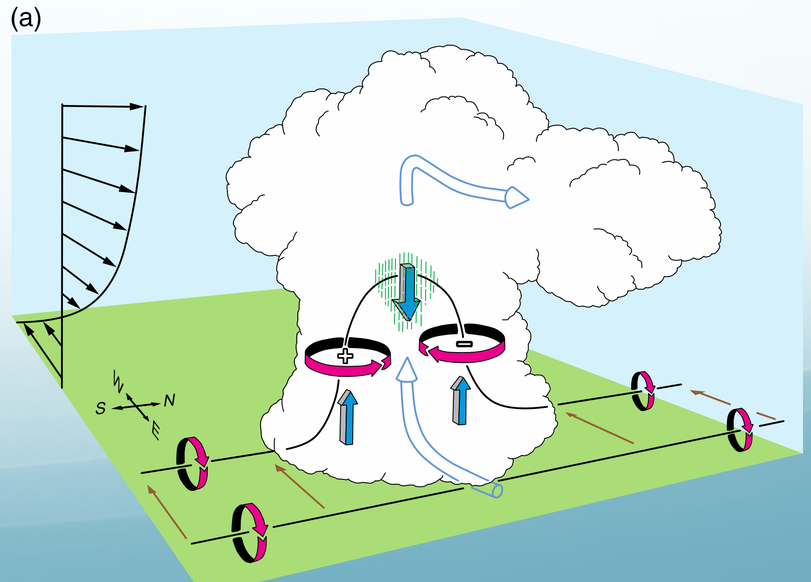
- In brief: initial rotation air gets sucked into updraft rotation speeds up
- wind shear provides initial rotation — air gets sucked into updraft (vertically stretched)—rotation speeds up



- This is due to conservation of angular momentum
- Other example: Dust Devil

Two types of tornadoes

Types	**Non-mesocyclonic tornadoes**	**Mesocyclonic tornadoes**
Requirement	Any thunderstorm (or even deep cumulus) may generate	supercells (mesocyclone)
Strength	weaker	Strong and violent
Initial rotation	Horizontal wind shear	Vertical wind shear
	Waterspouts, landspouts	



The type of tornadoes pictured below are _____.

- mesocyclonic
- non-mesocyclonic
- dust devils

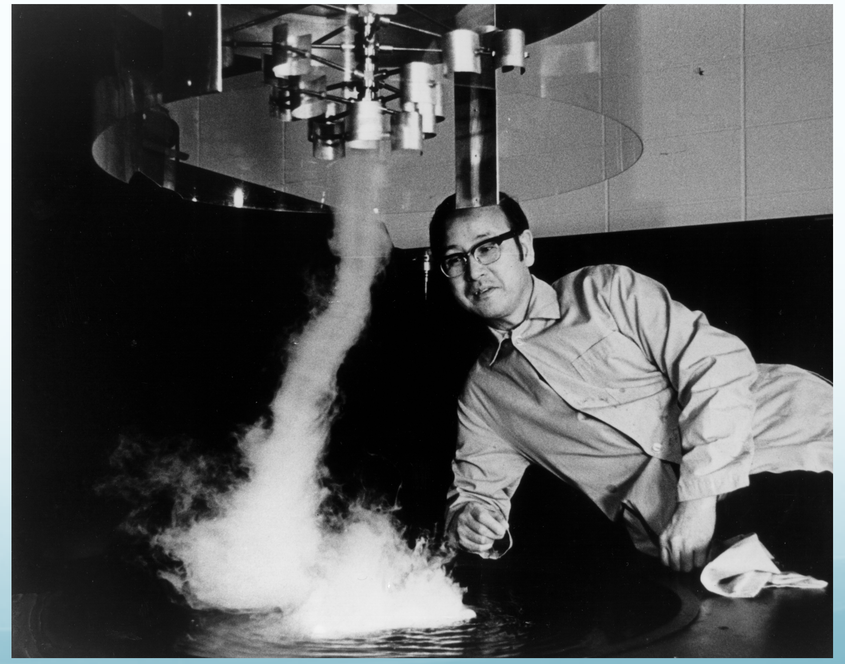
Question 9 1 pts

Which of the tornadoes in the images below is/are associated with a mesocyclone?

How to quantify tornado intensity

Enhanced Fujita (EF) scale

- Based on the damage to estimate winds (because there no practical way to measure the wind speed in most tornados)
- EF 0 (weak) --- EF5 (strong)



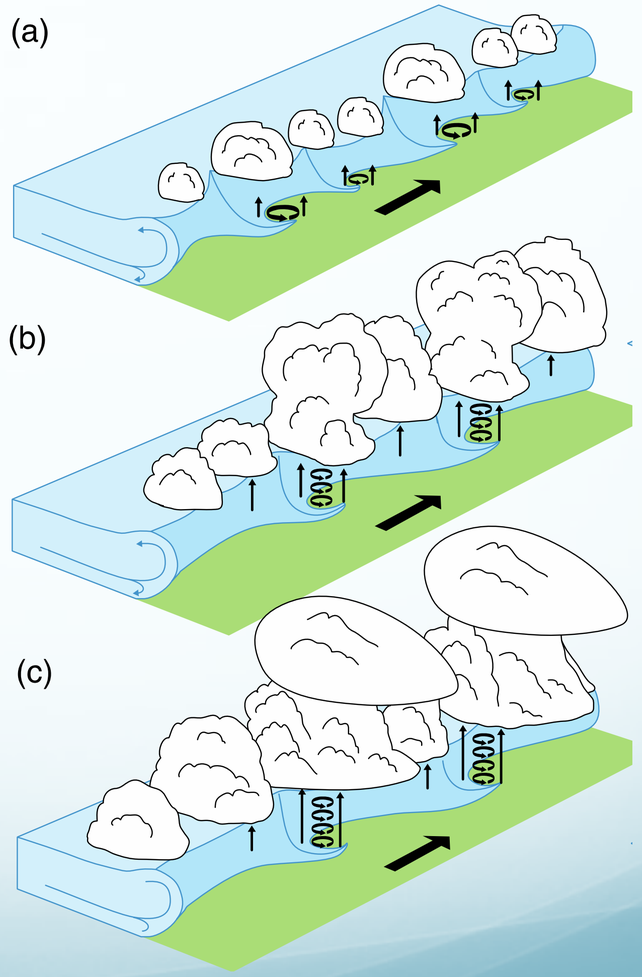
EF Rating	Wind Speeds
EF-0	65-85 mph
EF-1	86-110 mph
EF-2	111-135 mph
EF-3	136-165 mph
EF-4	166-200 mph
EF-5	> 200 mph

Non-mesocyclone tornadoes

Waterspouts

along a shear line!

Landspouts

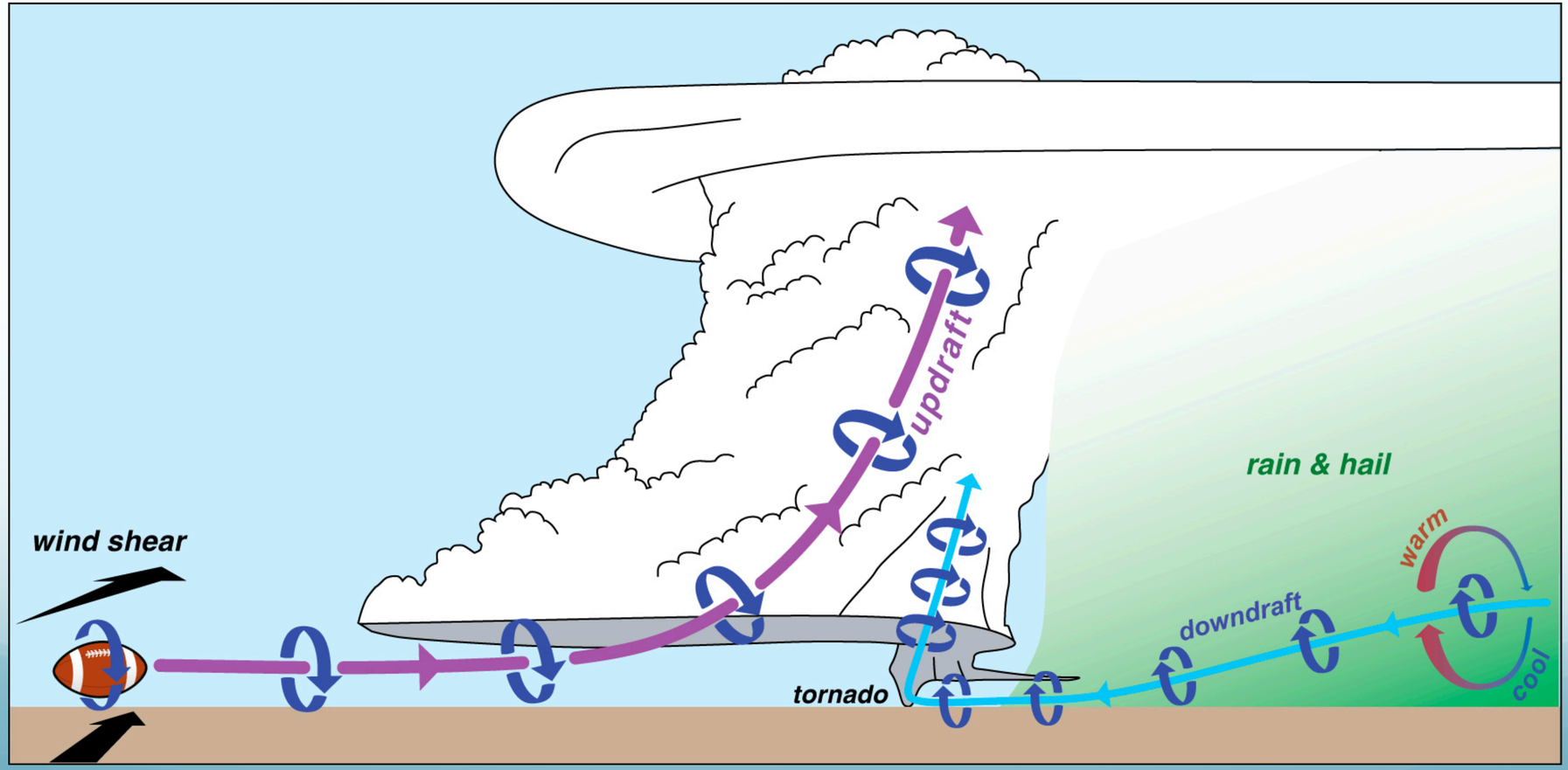


Mesocyclonic tornadoes

- Supercells are associated with strong tornadoes, multi-cell and single cell rarely make tornadoes
- Tornadoes are relatively infrequent, even in supercells.
- Not all mesocyclones produce tornadoes

Mesocyclonic tornadoes

- Vertical wind shear creates rotation about a horizontal axis
- the initial rotation is tilted (about a vertical axis) by strong updrafts



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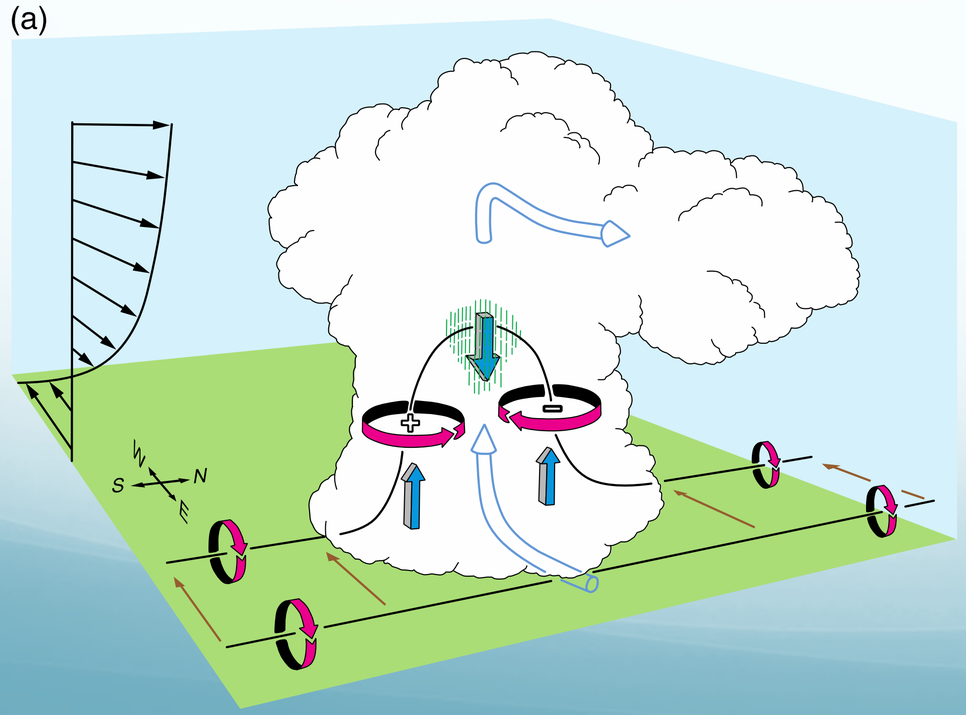
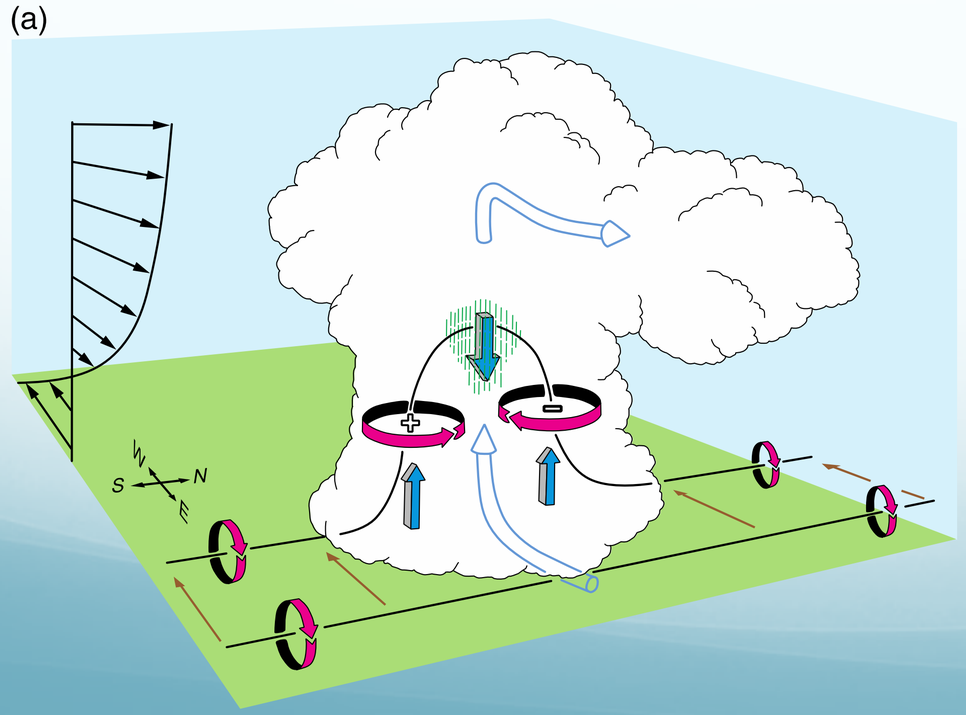
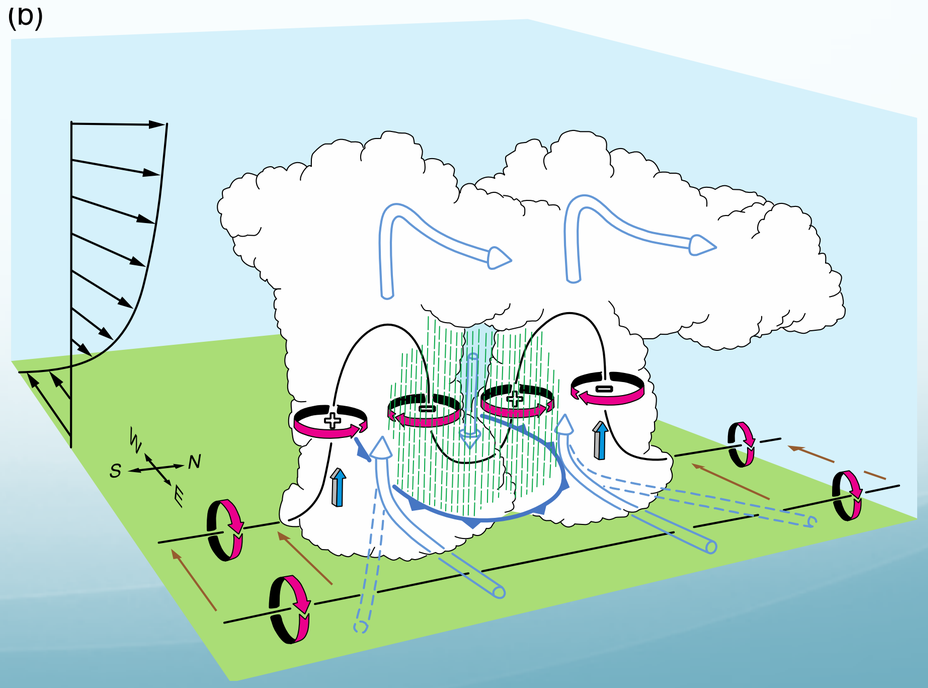


Mesocyclonic tornadoes

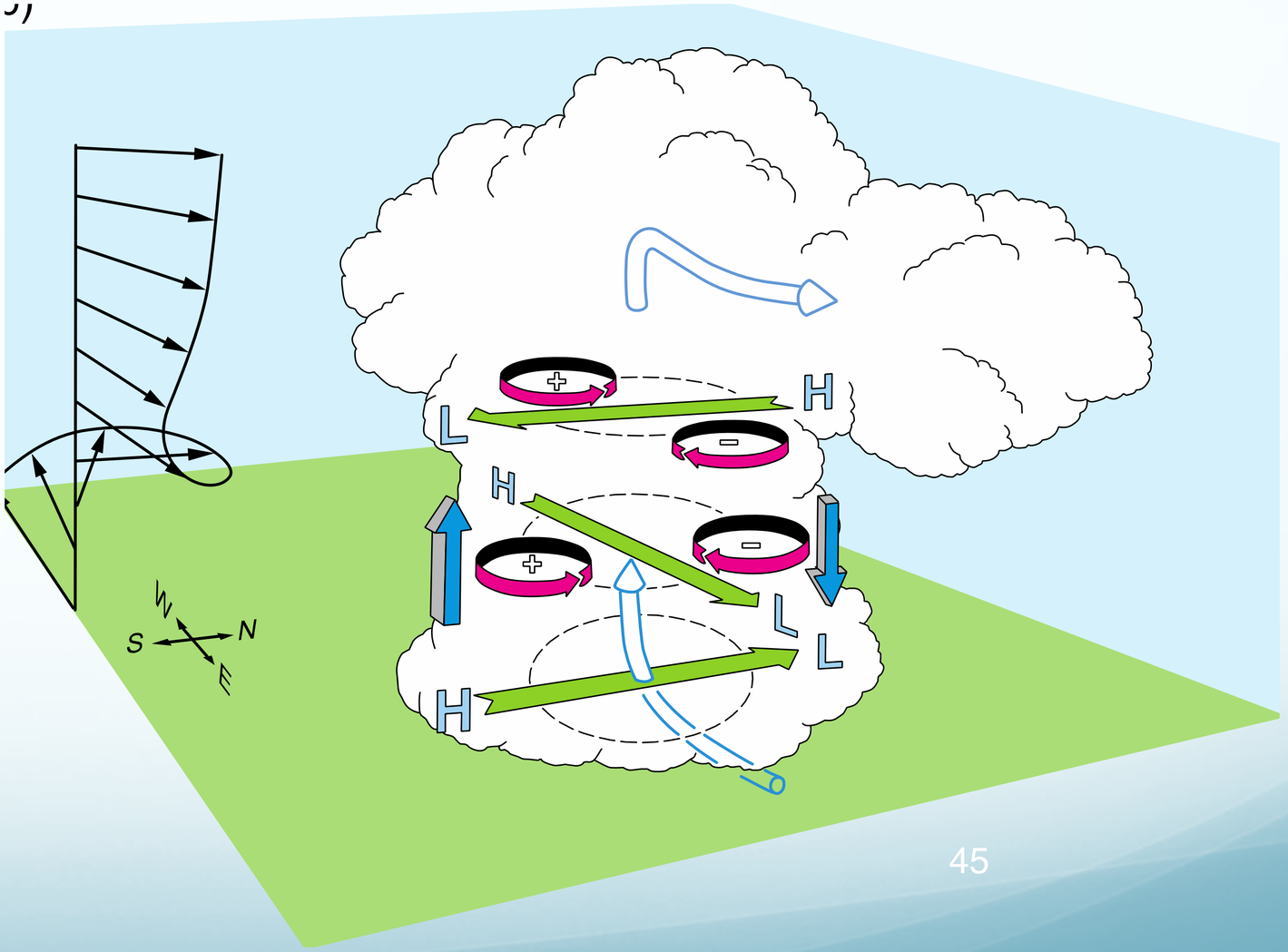
- Vertical wind shear creates rotation about a horizontal axis
- the initial rotation is tilted (about a vertical axis) by strong updrafts
- Rainfall splits the storm





Rotation direction of tornado

- Cyclonic = counterclockwise, in NH
- Cyclonic tornados dominate
  - simply because wind shear create a pressure force that favors cyclonically rotating storm
- Compare to hurricanes?…



Question 19

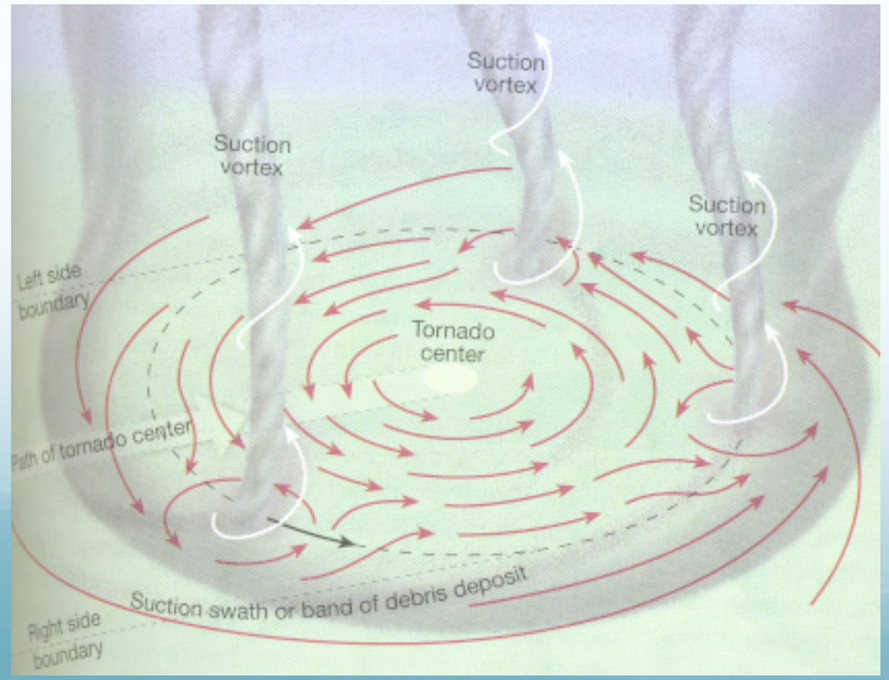
1 pts

Following a storm split, why is the right-moving (and cyclonically-rotating) supercell usually much stronger than the left-moving storm?

- its rotation is enhanced by the Coriolis force acting in the same orientation
- the environmental wind shear produces an upward pressure force that enhances its updraft
- the difference happens randomly

Damage and Safety

- The most intense damage: suction vortices
- “Watch”: conditions are expected but not imminent
- “Warning”: conditions are occurring or imminent
- The biggest danger is flying debris (how to avoid the damage?)



Question 13

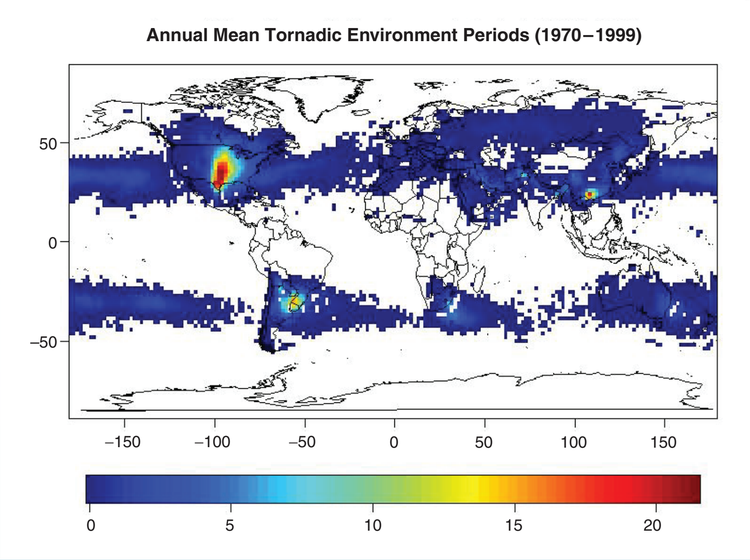
1 pts

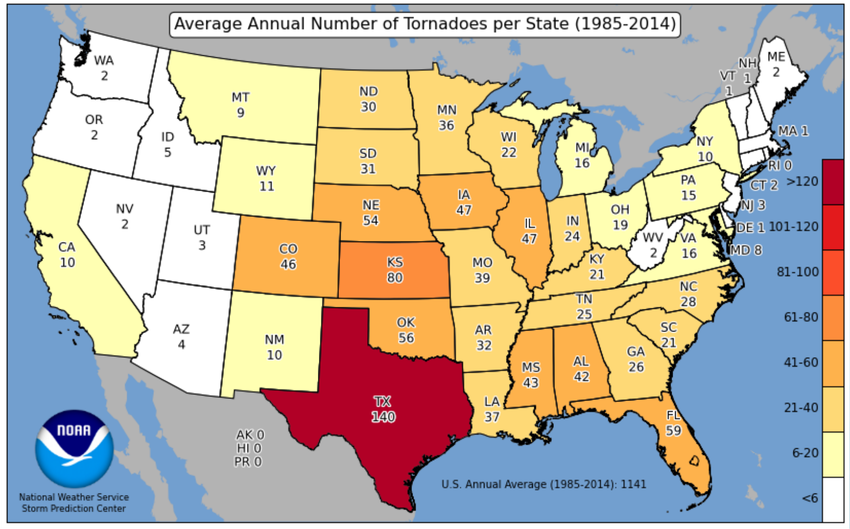
Tornadoes can completely destroy one house while leaving the neighboring one almost untouched because

- tornadoes often lift houses and set them back down in the same place.
- there is no wind immediately outside of a visible funnel.
- all the windows were opened before the storm in the untouched house
- powerful suction vortices within the main funnel can cause severe isolated damage.

Tornado Climatology

- Global distribution --- hot spots in US, South America, Southern China
- US Distribution per state: Texas, Oklahoma, Kansas, Nebraska, Colorado…
- Time of day: e.g. late-afternoon in Kansas due to max. low-level heating
- Nocturnal Tornadoes Distribution
- Seasonal Distribution: spring, autumn



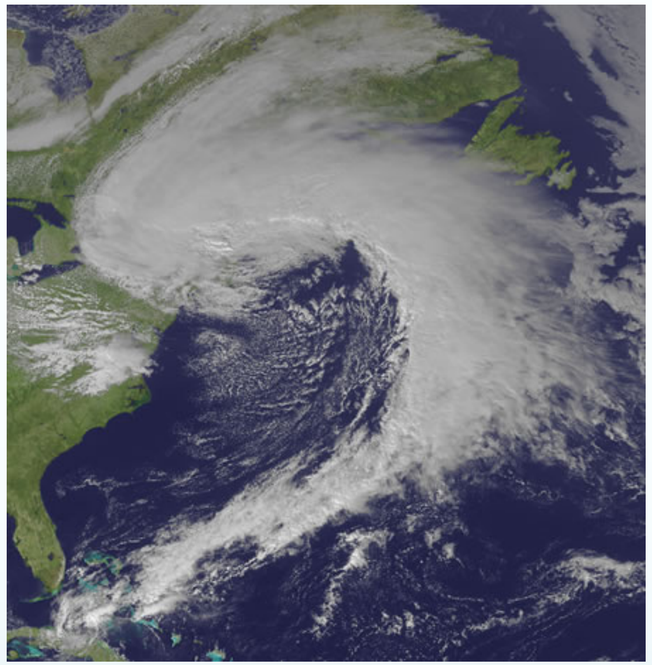


4. Hurricanes

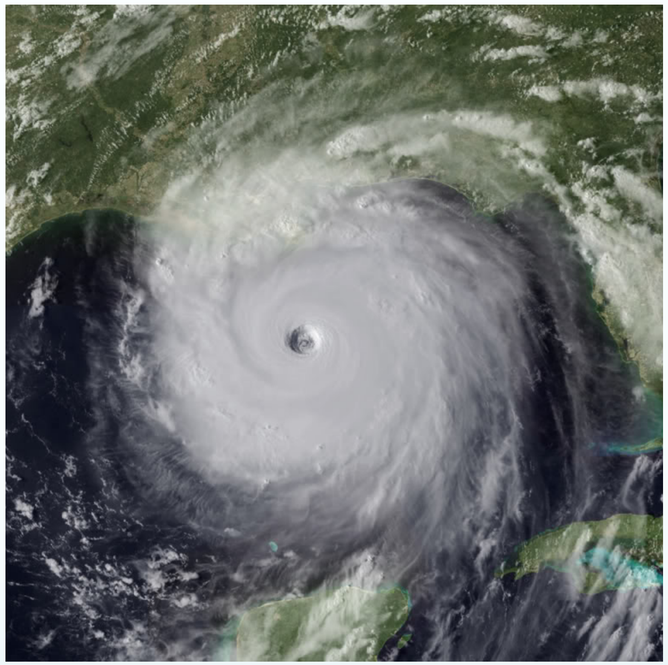
Hurricanes are much bigger scale phenomenon.

“Hurricane”, “typhoon”, “cyclone” all refer to ***Tropical cyclones***

Midlatitude-Cyclone



Tropical Cyclone
“Hurricane”

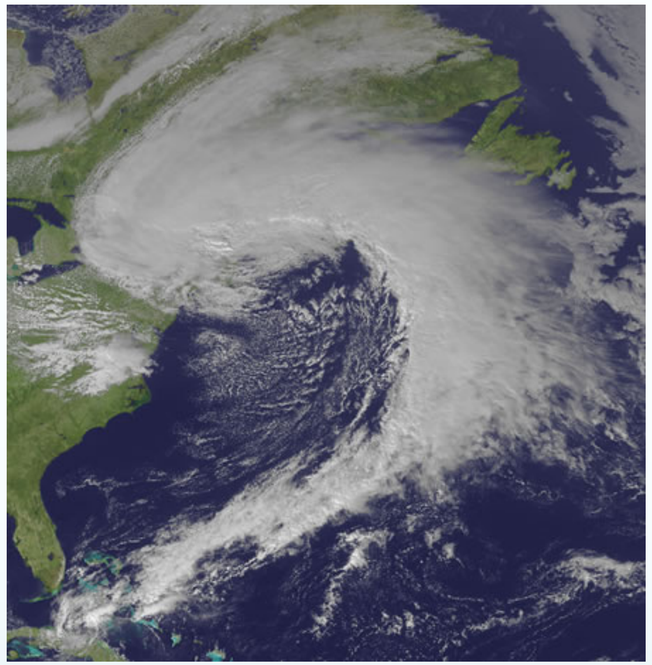


- Shape

circular symmetry? eye? fronts?

- Wind (strong winds aloft or at surface?)

Midlatitude-Cyclone



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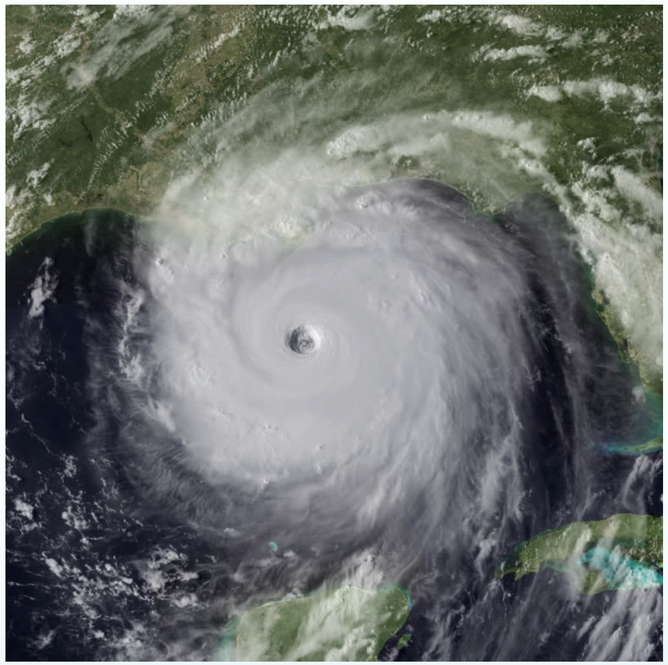

- Powered by
  - Mid-lat: by north-south horizontal temperature different
  - Hurricane: by latent heat released in thunderstorm

How to quantify hurricane intensity

Saffir-Simpson Scale

Scale from 1 to 5 based on measured/estimated wind speed
Wind values are averaged over 1 minute, at a height 10 m above the surface.

Saffir-Simpson Hurricane Scale

Category	*Winds (MPH)*	*Damage*	*Storm Surge*
1	74 - 95	**Minimal**: Damage to unanchored mobile homes, vegetation & signs. Coastal road flooding. Some shallow flooding of susceptible homes.	4 - 5 feet
2	96 - 110	**Moderate**: Significant damage to mobile homes & trees. Significant flooding of roads near the coast & bay.	6 - 8 feet
3	111 - 130	**Extensive**: Structural damage to small buildings. Large trees down. Mobile homes largely destroyed. Widespread flooding near the coast & bay.	9 - 12 feet
4	131 - 155	**Extreme**: Most trees blown down. Structural damage to many buildings. Roof failure on small structures. Flooding extends far inland. Major damage to structures near shore.	13 - 18 feet
5	More than 155	**Catastrophic**: All trees blown down. Some complete building failures. Widespread roof failures. Flood damage to lower floors less than 15 feet above sea level.	Greater than 18 feet

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EF-1	86-110 mph
EF-2	111-135 mph
EF-3	136-165 mph
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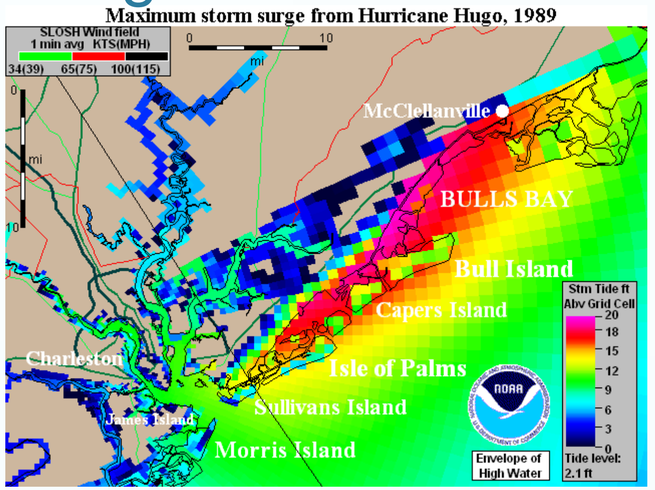
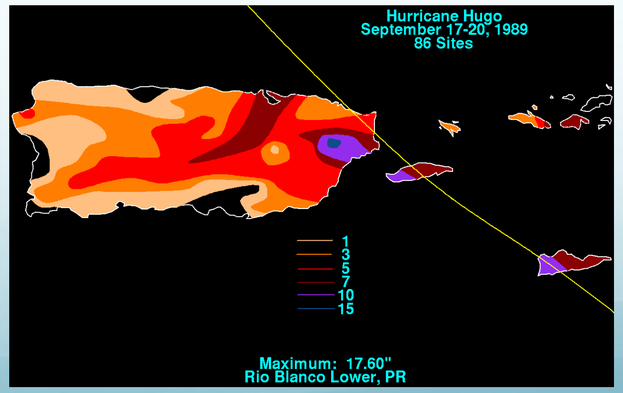
Hurricane Damage

- High winds
- Storm surge
- Floods

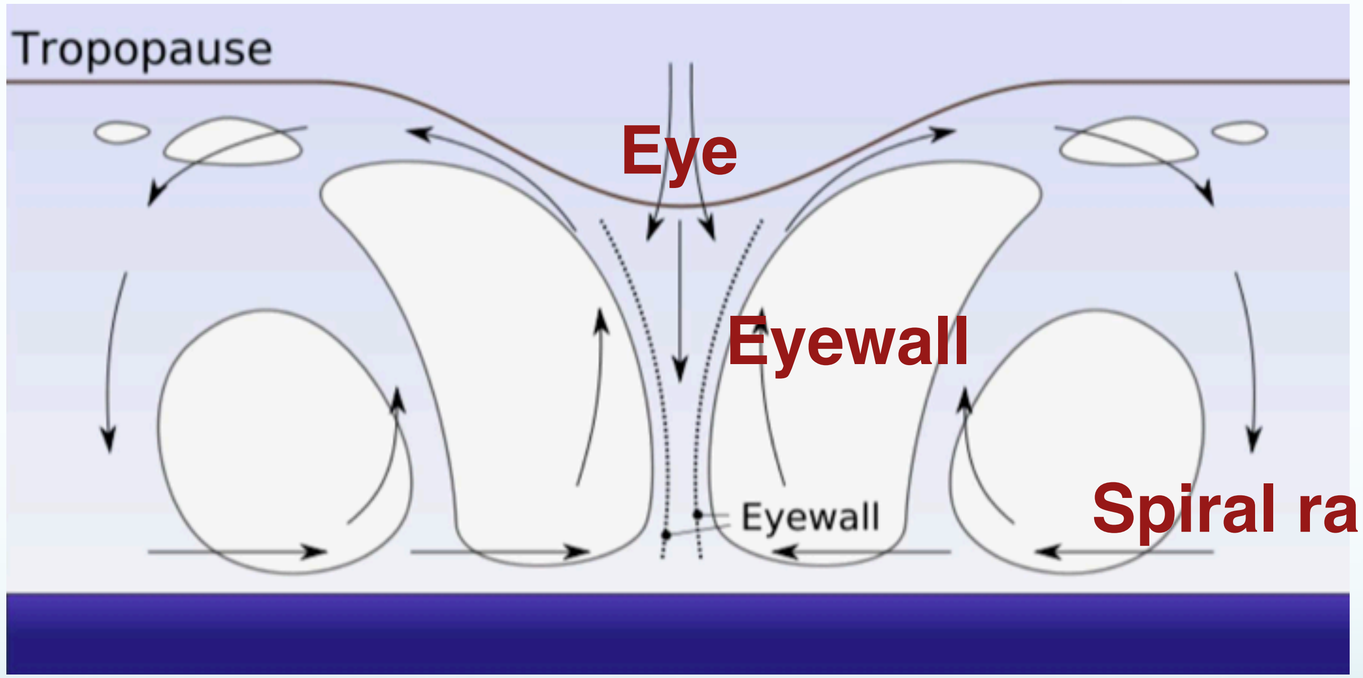
Storm Surge Maximum about 20 ft



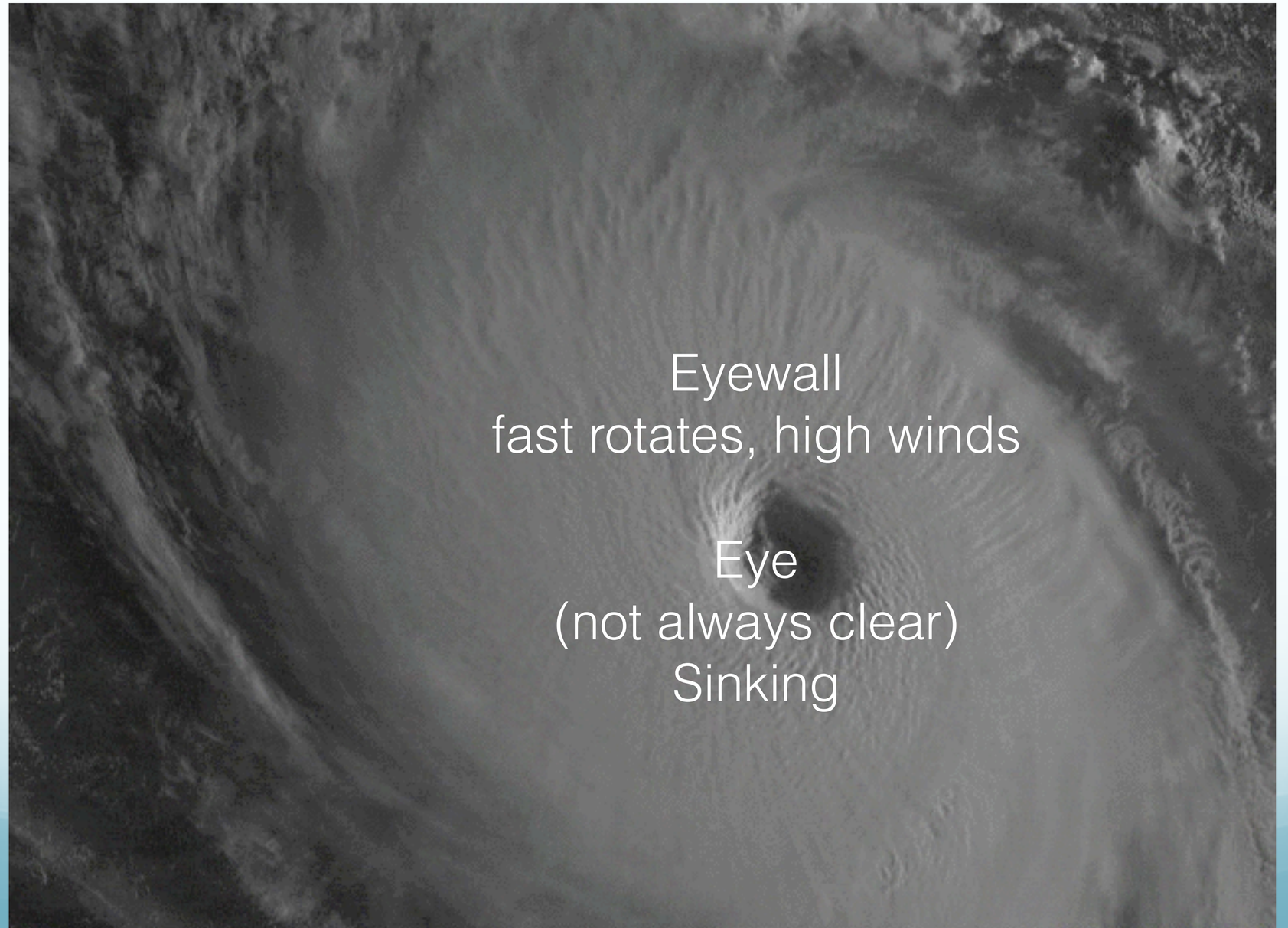
Rainfall in Puerto Rico



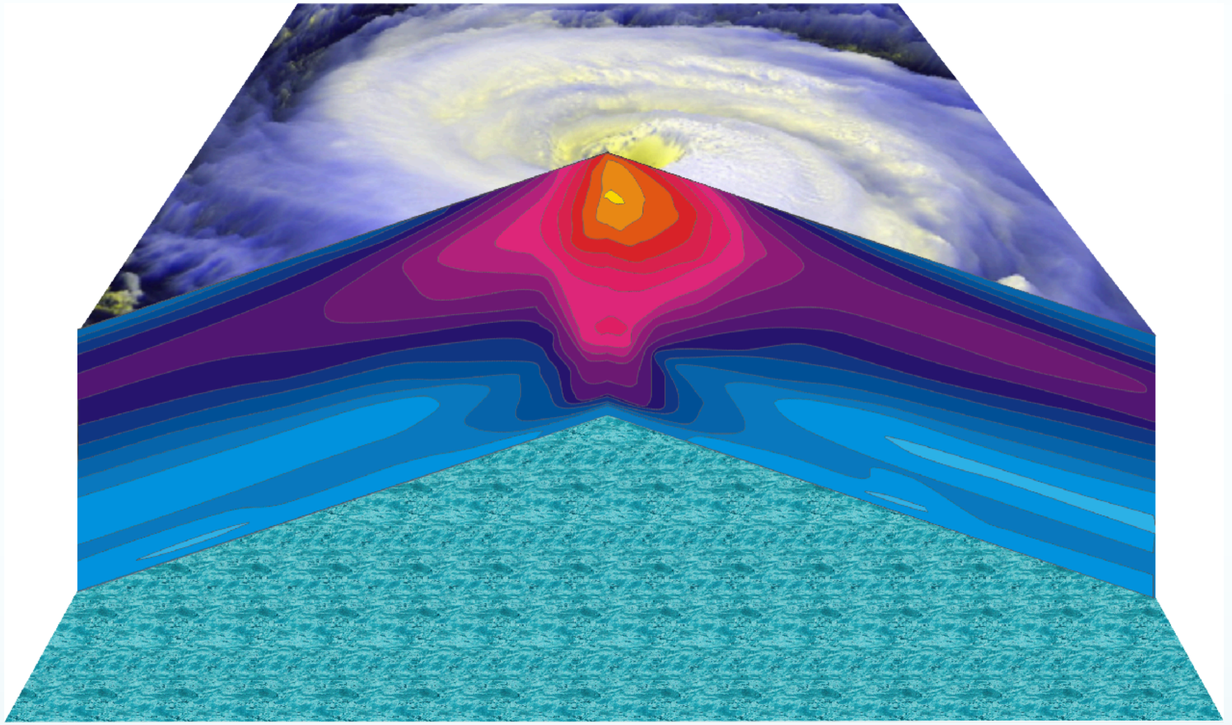
Basic structure



Basic structure

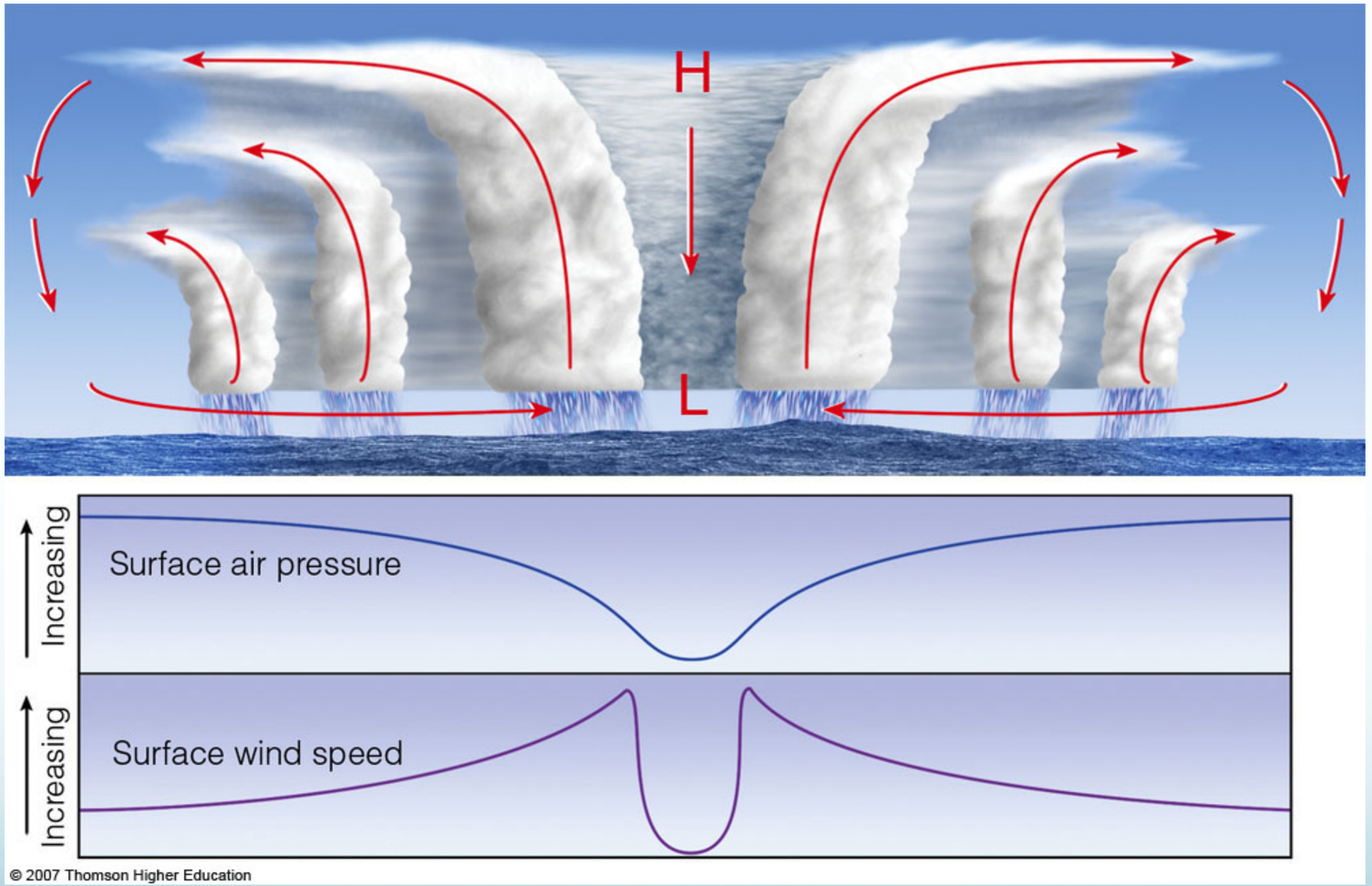


Temperature profile



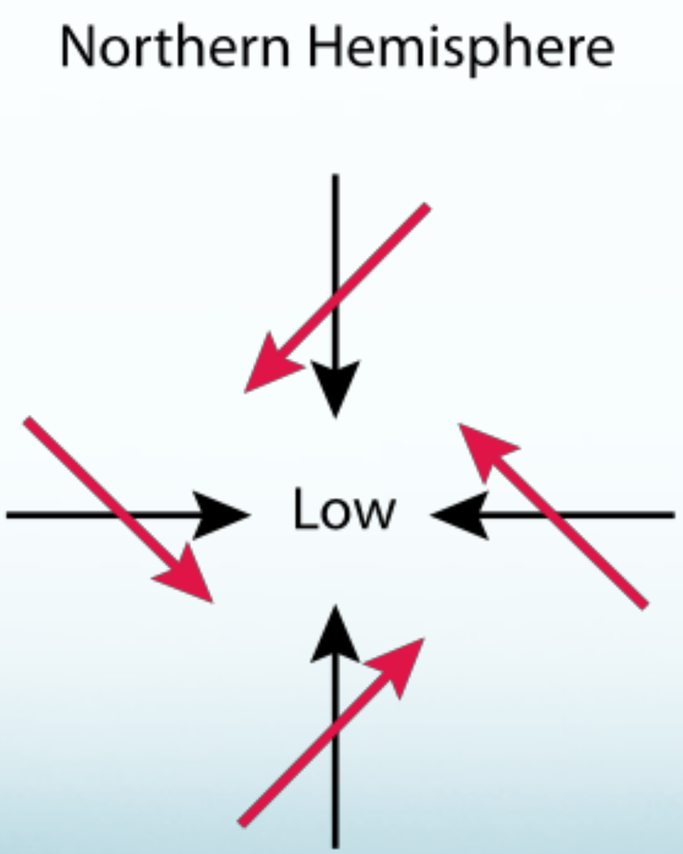
At the same level, eye is warmer than the surrounding environment, except surface

pressure and wind profile

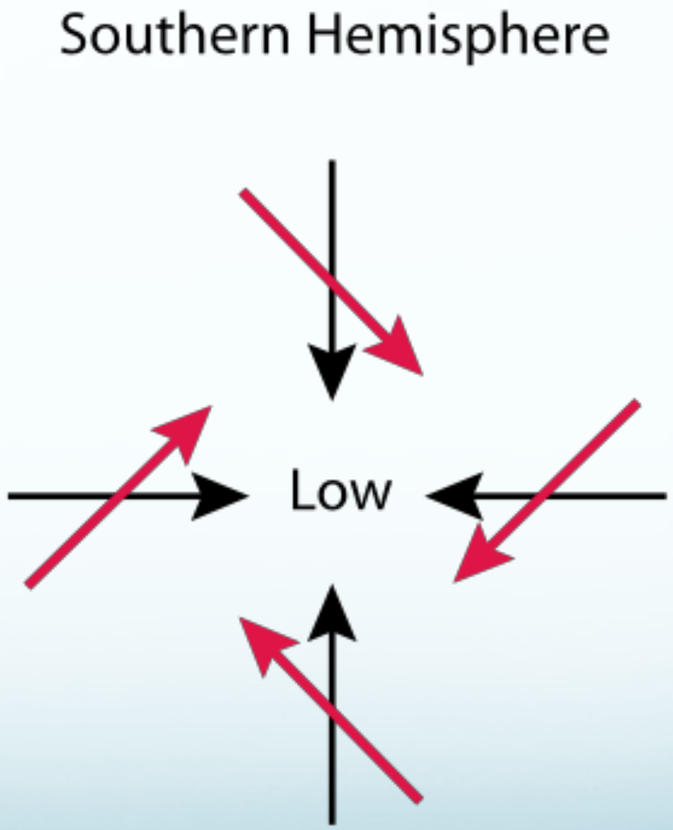


Rotation direction of hurricanes

- Caused by Coriolis force



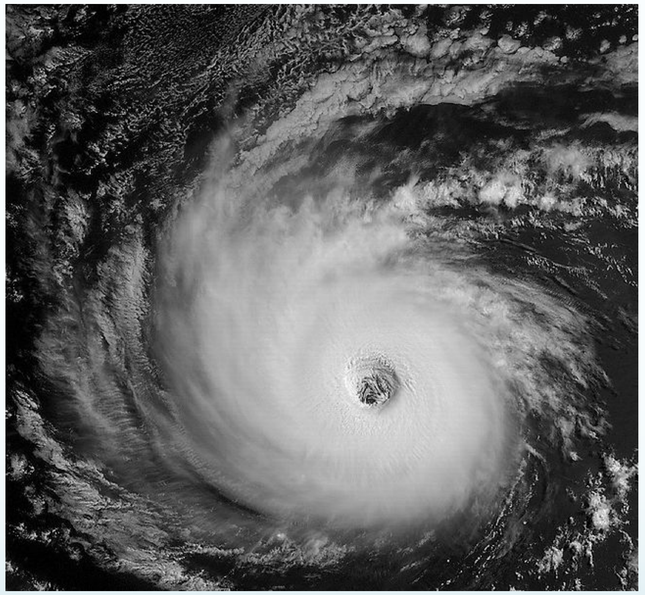
Winds turned to the right (red)



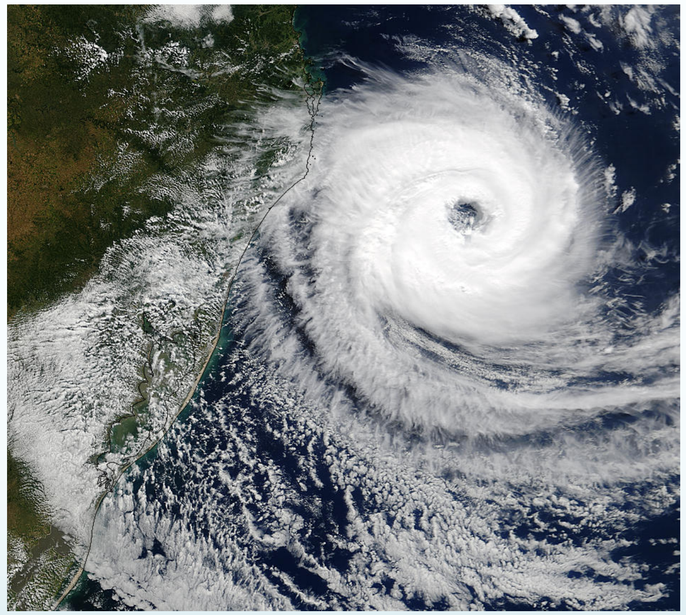
Winds turned to the left

Rotation direction of hurricanes

- Recall Coriolis force …
- Opposite on different sides of the equator



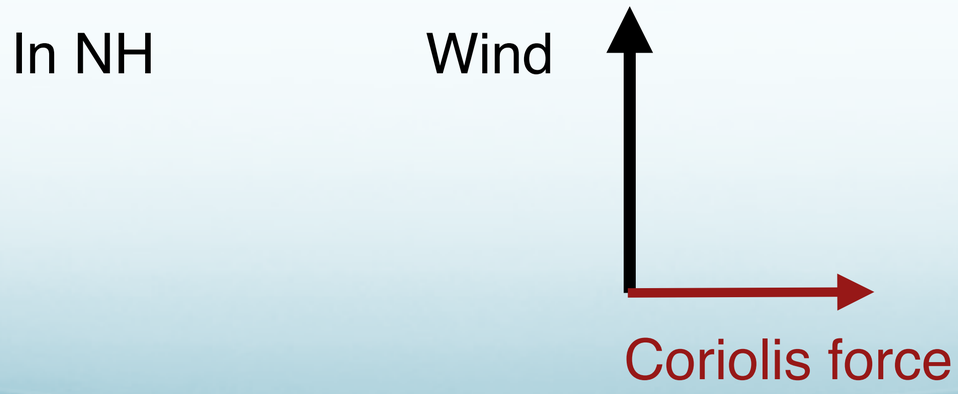
Northern Hemisphere
(Counterclockwise)



Southern Hemisphere
(Clockwise)

Coriolis force

- Arises because we are looking at motions in a rotating frame of reference.
- Turns winds to the right/left in the northern/southern hemisphere.



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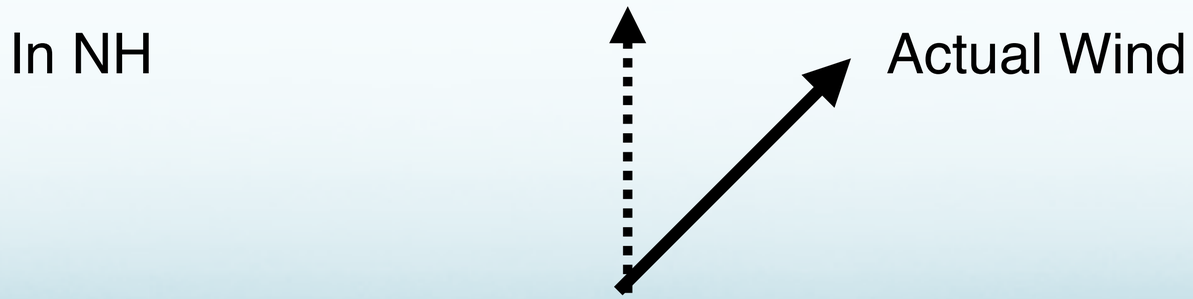
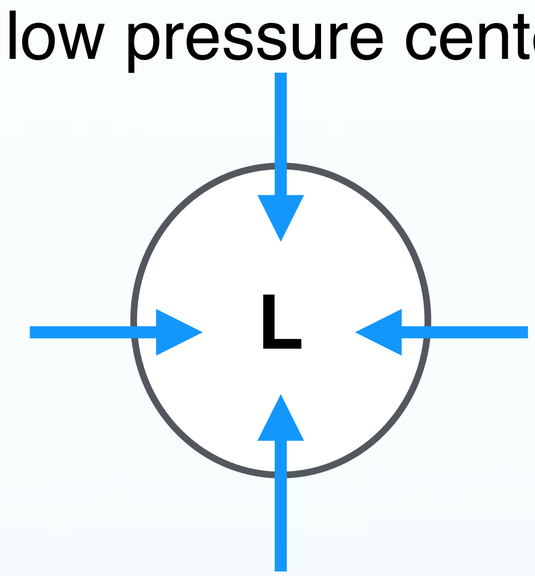
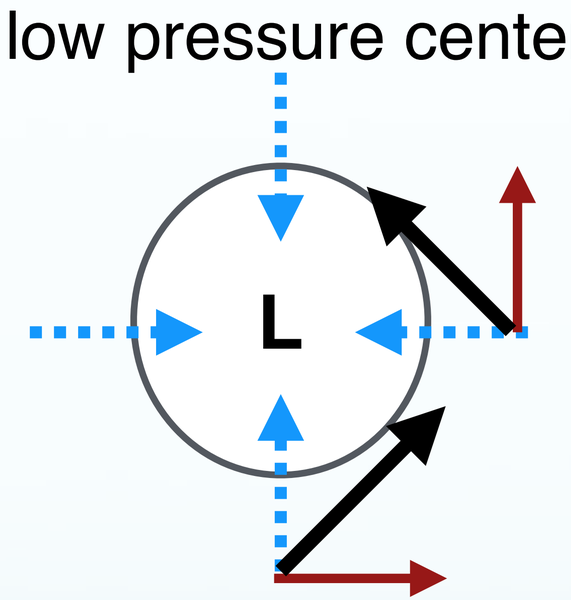


Back to the previous exercise



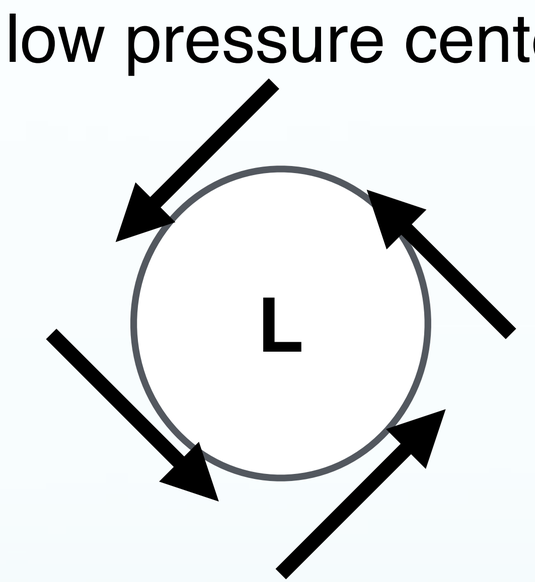
In NH, what is the actual wind direction around a low pressure center?

Back to the previous exercise



In NH, what is the actual wind direction around a low pressure center?

Back to the previous exercise



In NH Counterclockwise
(cyclonic)

Rotation direction of hurricanes

- All hurricanes are cyclonic
- But NOT ALL tornadoes are cyclonic, because tornadoes are not affected by Coriolis force (too fast compared to ration of the Earth)

Why do hurricanes exist?

- To keep the tropics from getting too warm as a result of the solar heating
- Hurricanes cool the tropics by cooling tropical ocean surface via evaporation
- Hurricanes warm the extratropics via releasing latent heat there

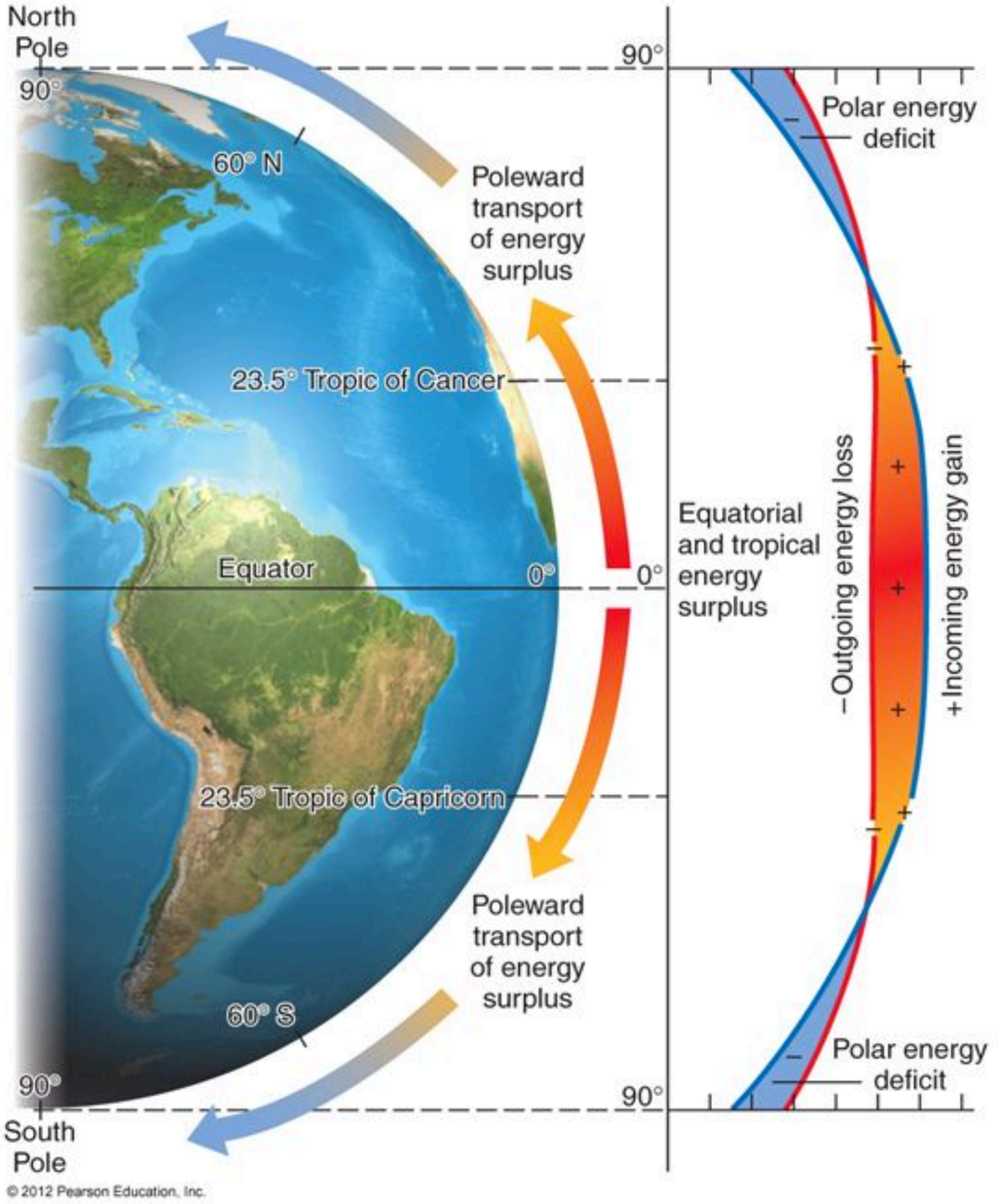
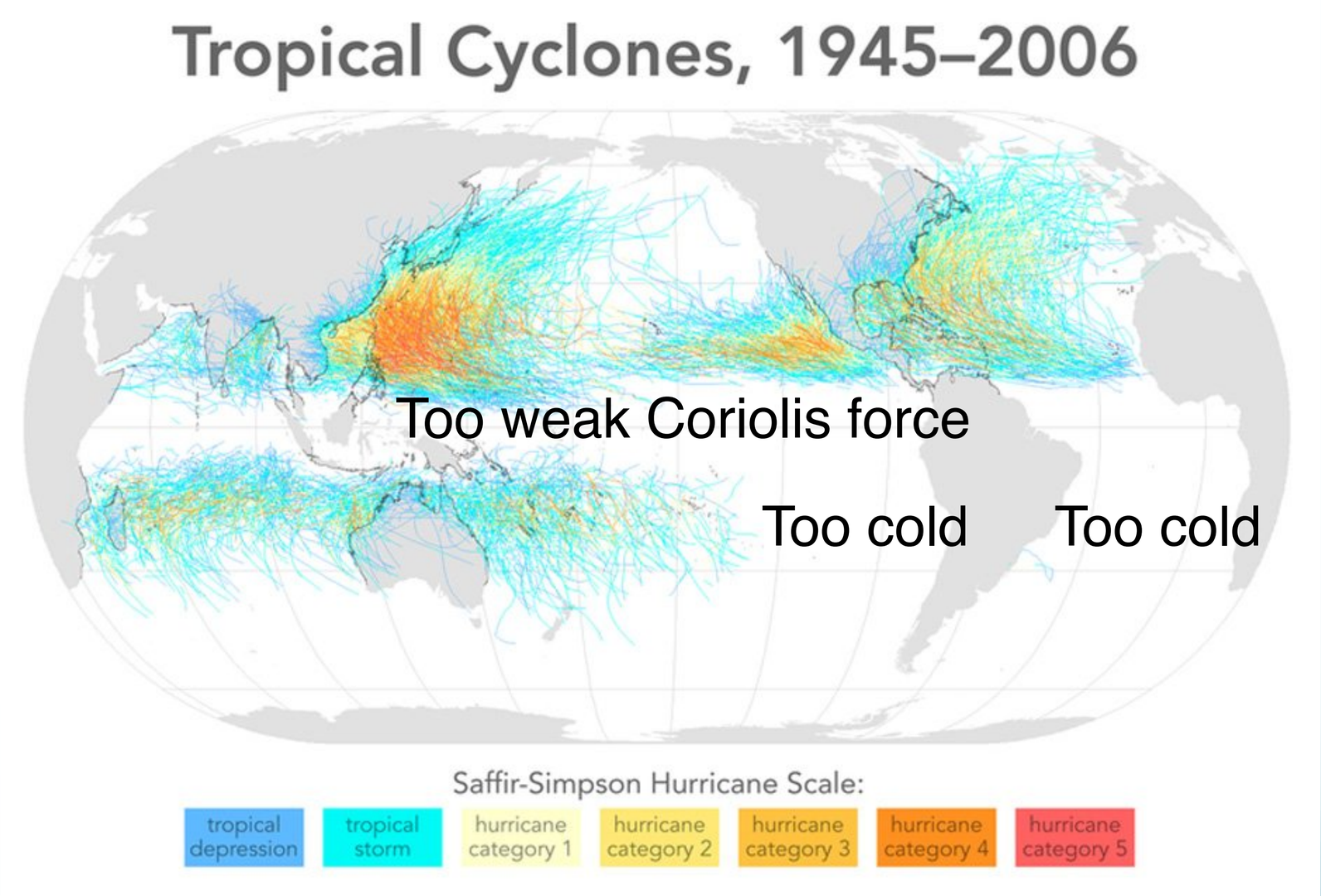


Figure 4.12

Hurricane climatology



Tornado VS Hurricane

Type	**Tornado**	**Hurricane**
Where they form	Mostly over land	Over tropical warm ocean water
Spatial scale	No more than ¼ mile wide	Up to several hundred miles
Time scale	No more than an hour	Can last up to 3 weeks
Source of Rotation	Wind shear (horizontal or vertical)	Coriolis force
Rotation direction	Cyclonic rotation dominates Sometimes anticyclonic	Counterclockwise in NH Clockwise in SH
Intensity	Enhanced Fujida scale (use damage to estimate winds)	Saffir-Simpson scale (use winds to estimate damage)

Hurricanes and Thunderstorms