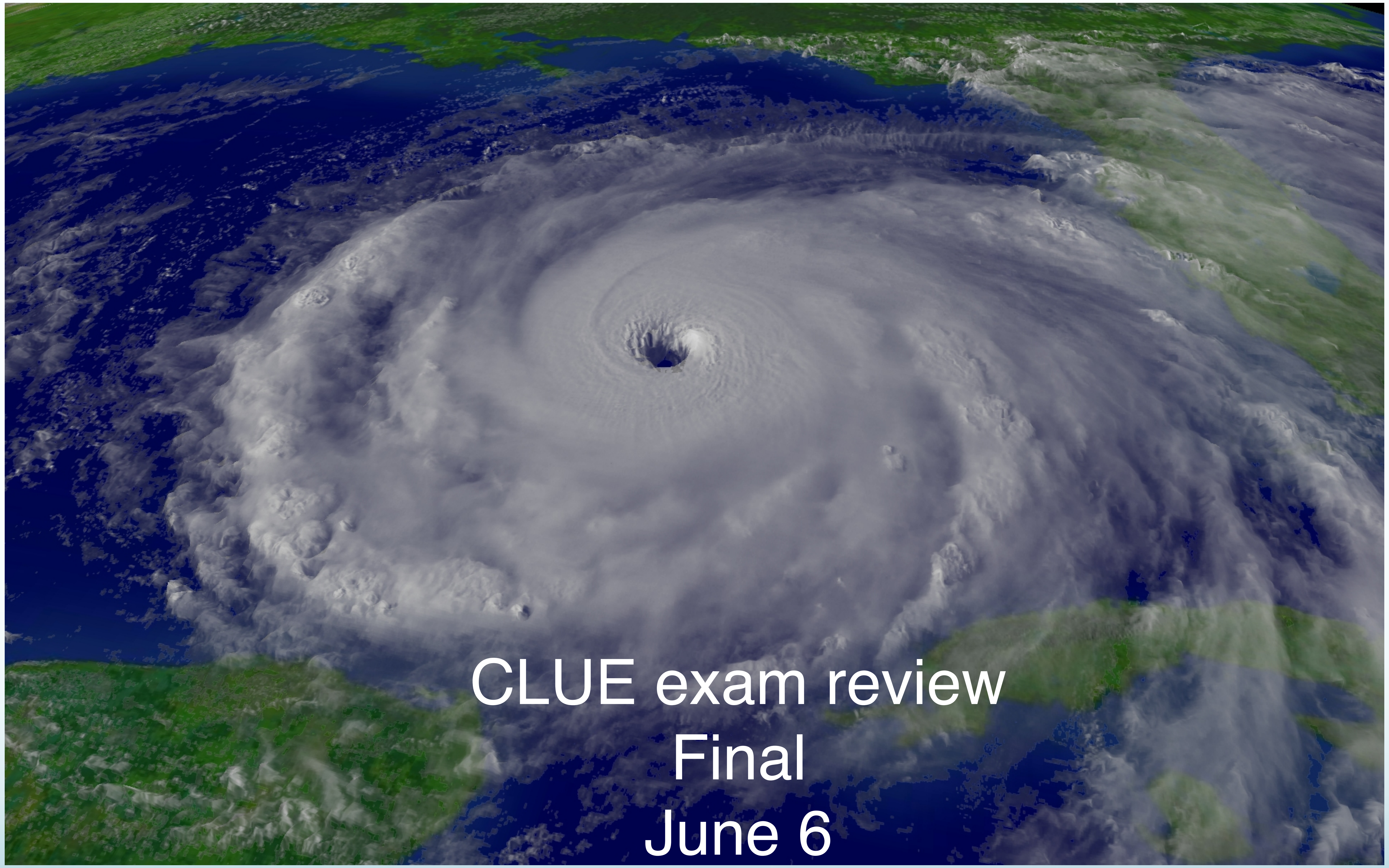
ATM S 103

Hurricanes and Thunderstorms



CLUE exam review

Final

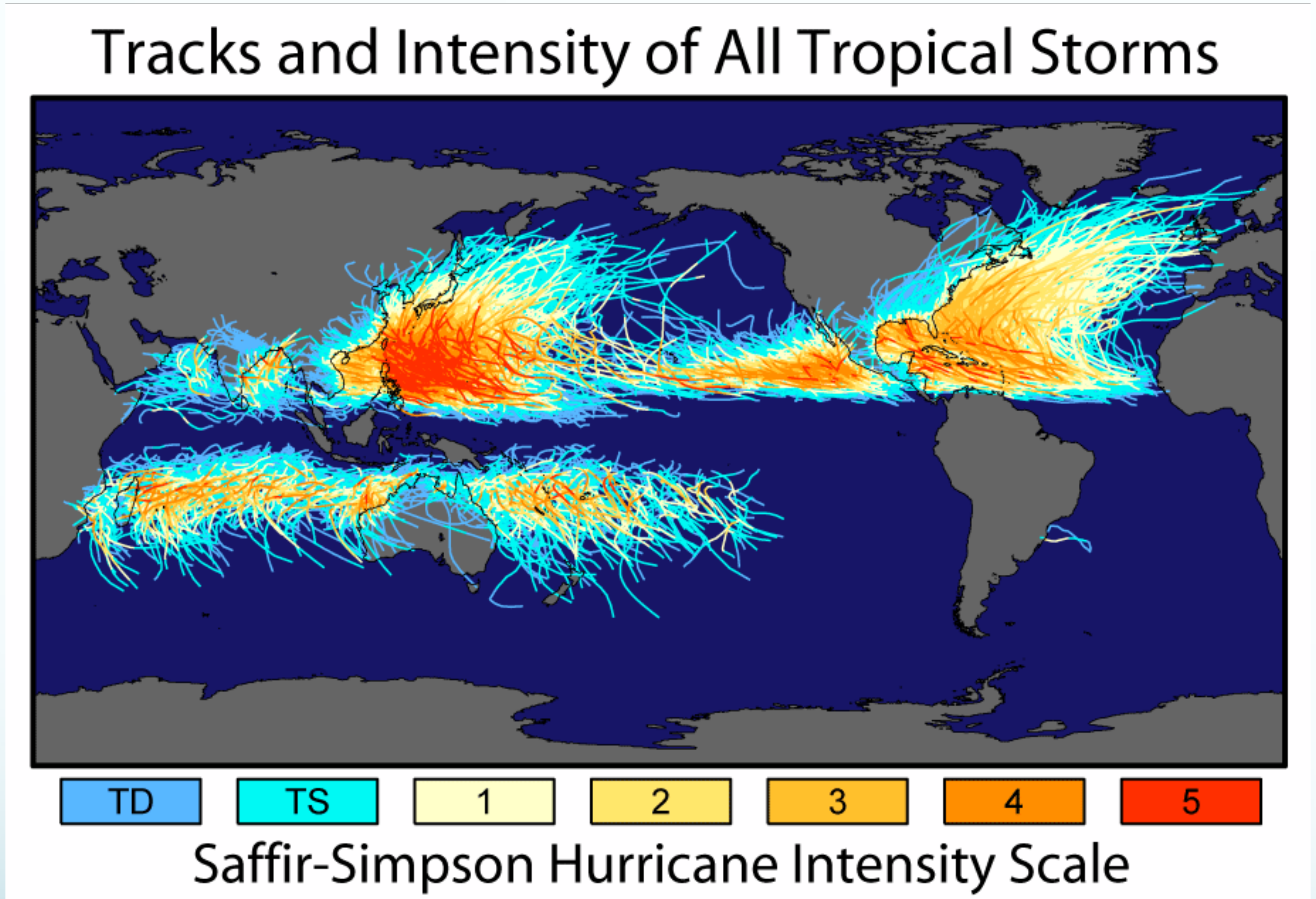
June 6

Today’s outline

- Hurricanes
- Tornado
- Thunderstorm
- Clouds

….Yes, the final is accumulative!

Tropical cyclone (TC) climatology

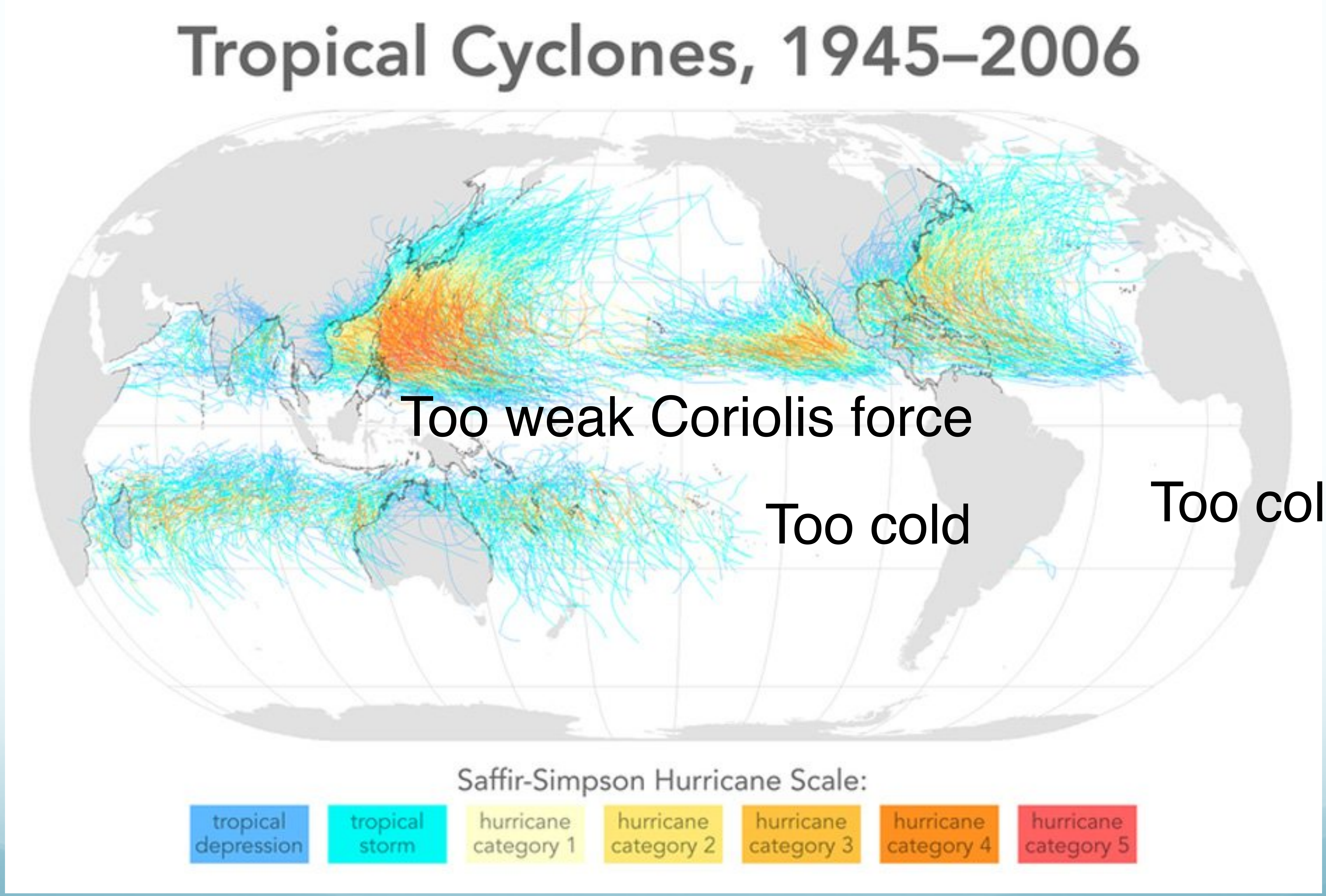


- TC occurs over the very water

(SST > 26.7°C or 80°F)

- Storms occur in all tropical ocean basins except the SE Pacific and SE Atlantic
- Most intense in the W Pacific ( )
- Almost none in SE Pacific & SE Atlantic (too)
- No TC at the equator (very weak)
- Not many tropical cyclones in Western South Atlantic (too much and too few)

Tropical cyclone (TC) climatology

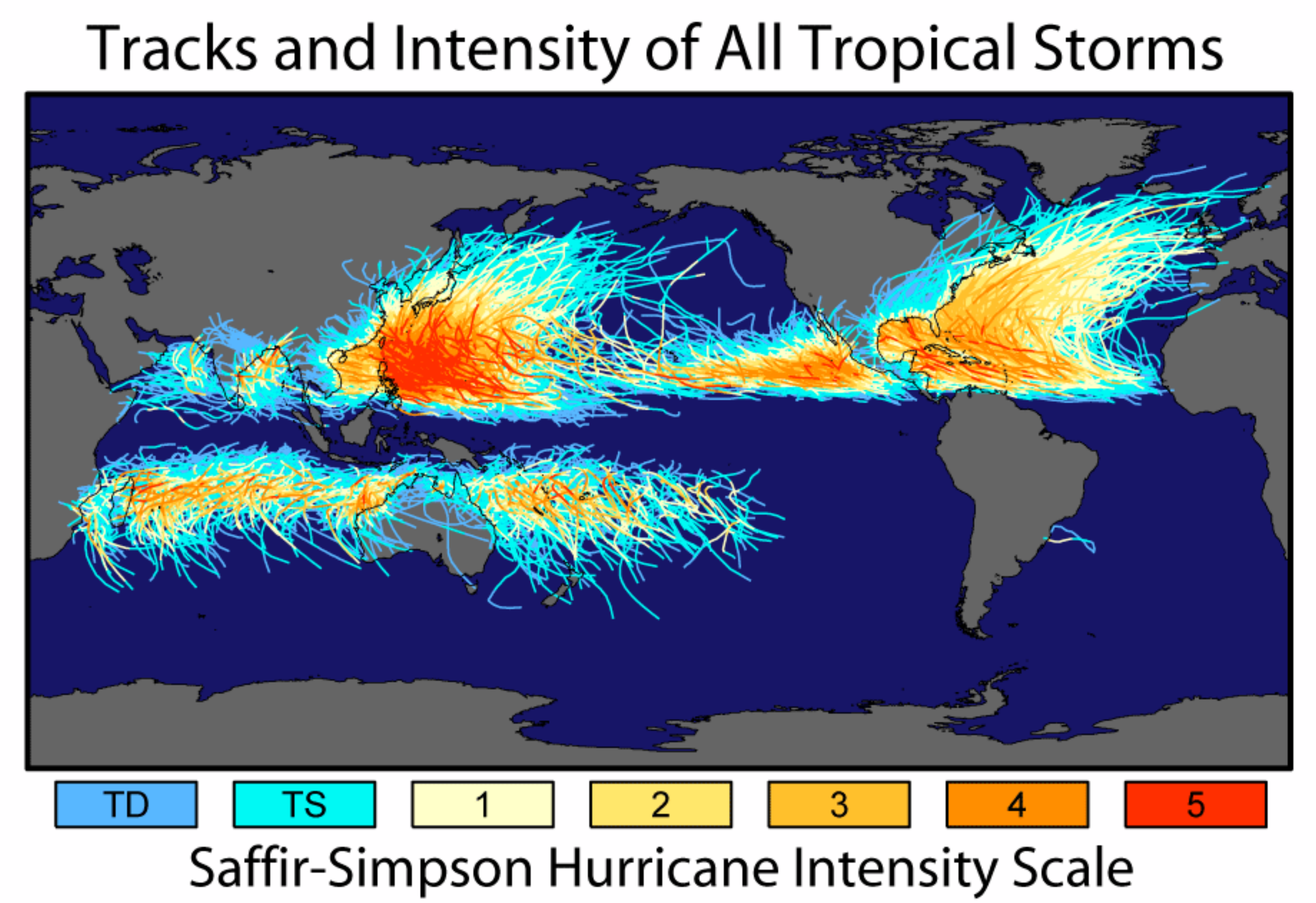


Too weak Coriolis force

Too cold

Too cold

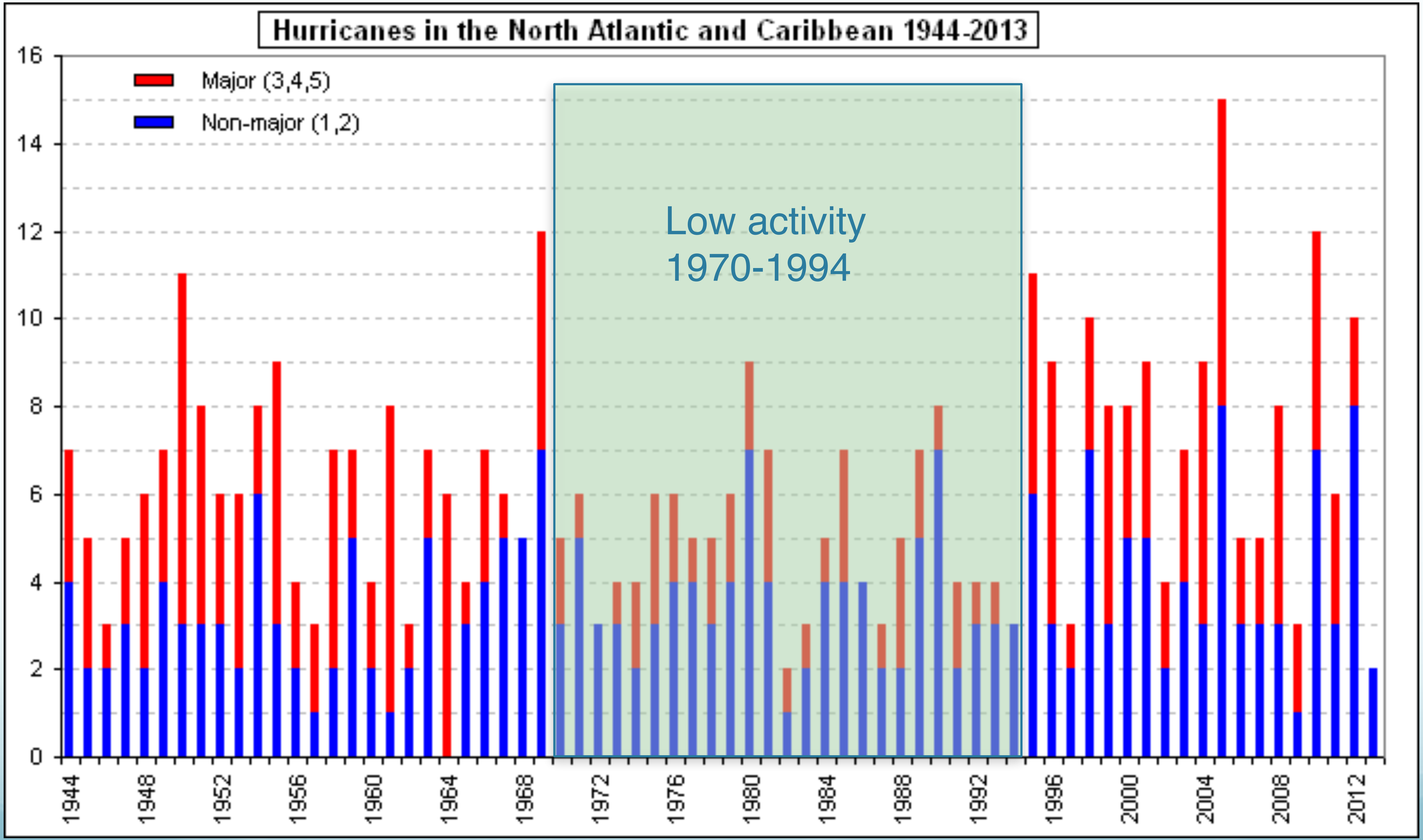
Tropical cyclone (TC) climatology



Tropical Cyclone Seasons

- N Atlantic: June-Nov
- W Pacific: April-Jan.

Decadal Variations in Atlantic hurricane activity



Decadal Variations in Atlantic hurricane activity

- Before 1960s, fewer tropical cyclones

  maybe some TCs were undetected before satellite era]

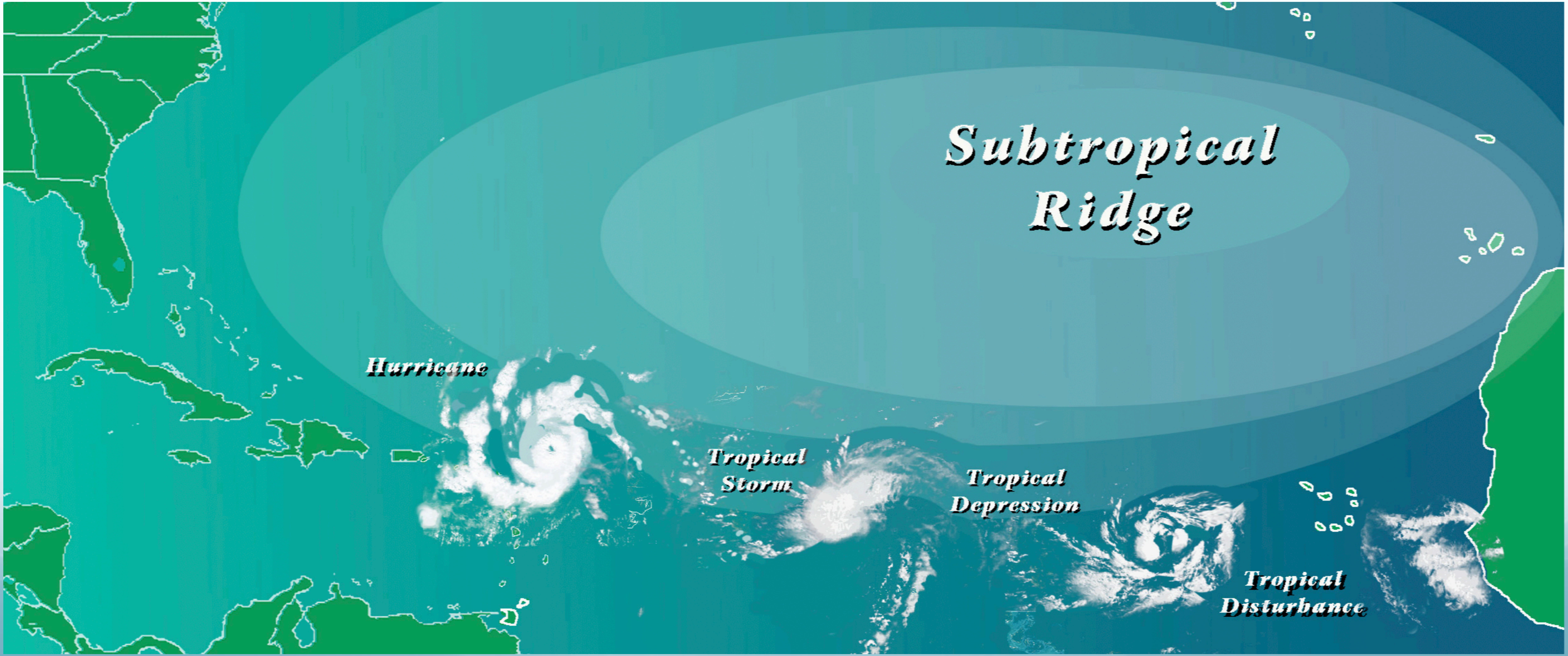
- 1970-1994 [low activity] vs 1995-2013[more active].

  Potential causes:

  •Sea surface temperatures: Atlantic Multi-Decadal Oscillation

  •Vertical shear: El Niño

Tropical cyclone Lifecycle



Tropical cyclone Lifecycle

Life stage

- Tropical disturbance (cluster of thunderstorms with weak winds)
- Tropical depression (Cyclonic circulation evident; winds up tp 38 mph)
- Tropical storm (Storm gets ☐; winds between 39~73 mph)
- Hurricane (winds > 74mph; about 6 per season in Atlantic)

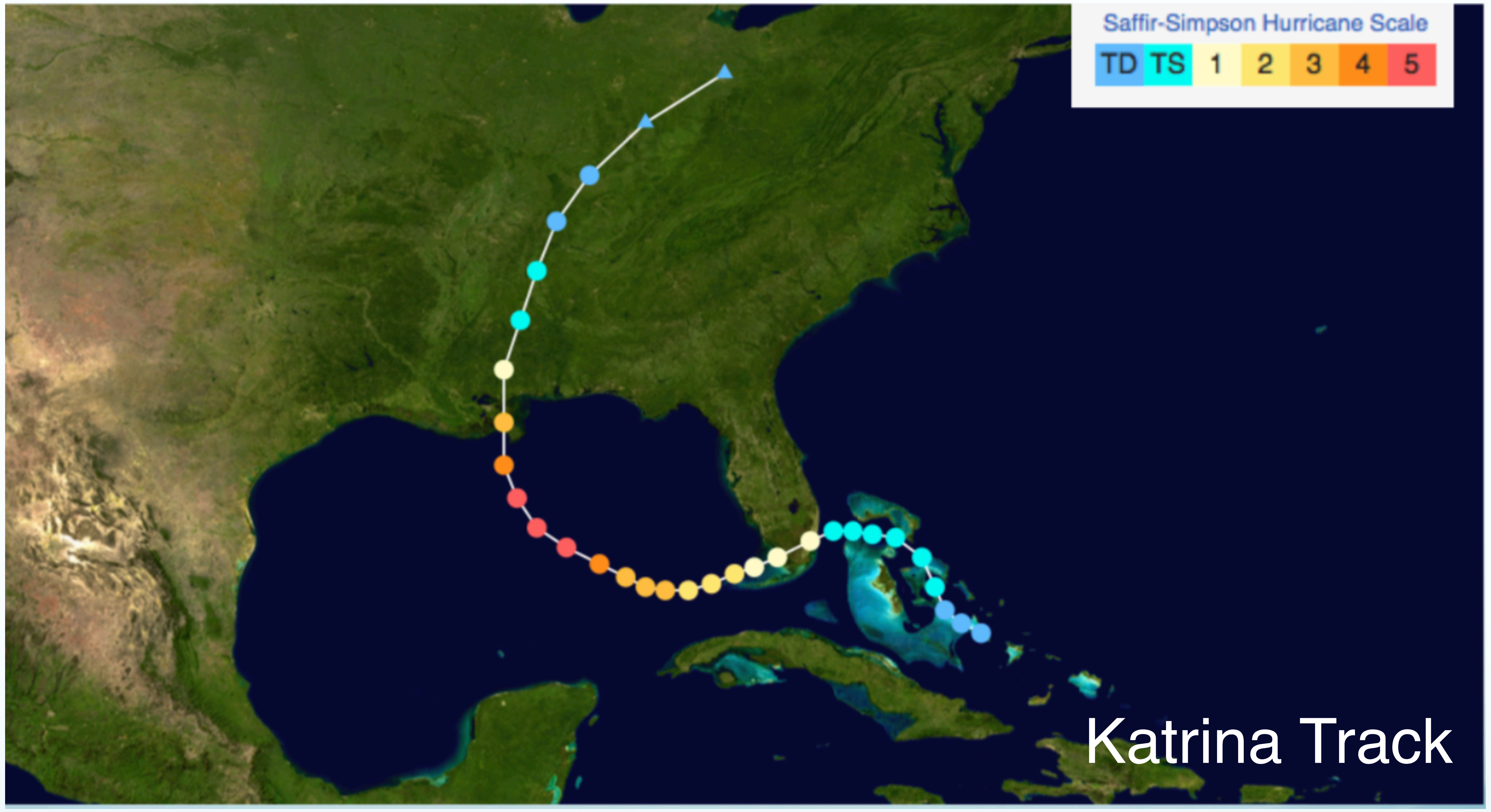
Note: Evolution from a tropical disturbance to a hurricane is not inevitable.

Necessary condition for hurricane development

For a tropical disturbance to develop into a hurricane, it needs:

- Very ☐ water (SST > 26.7°C or 80°F)
- ☐ vertical shear
- Some ☐ (needs to be at least 5° away from the equator)

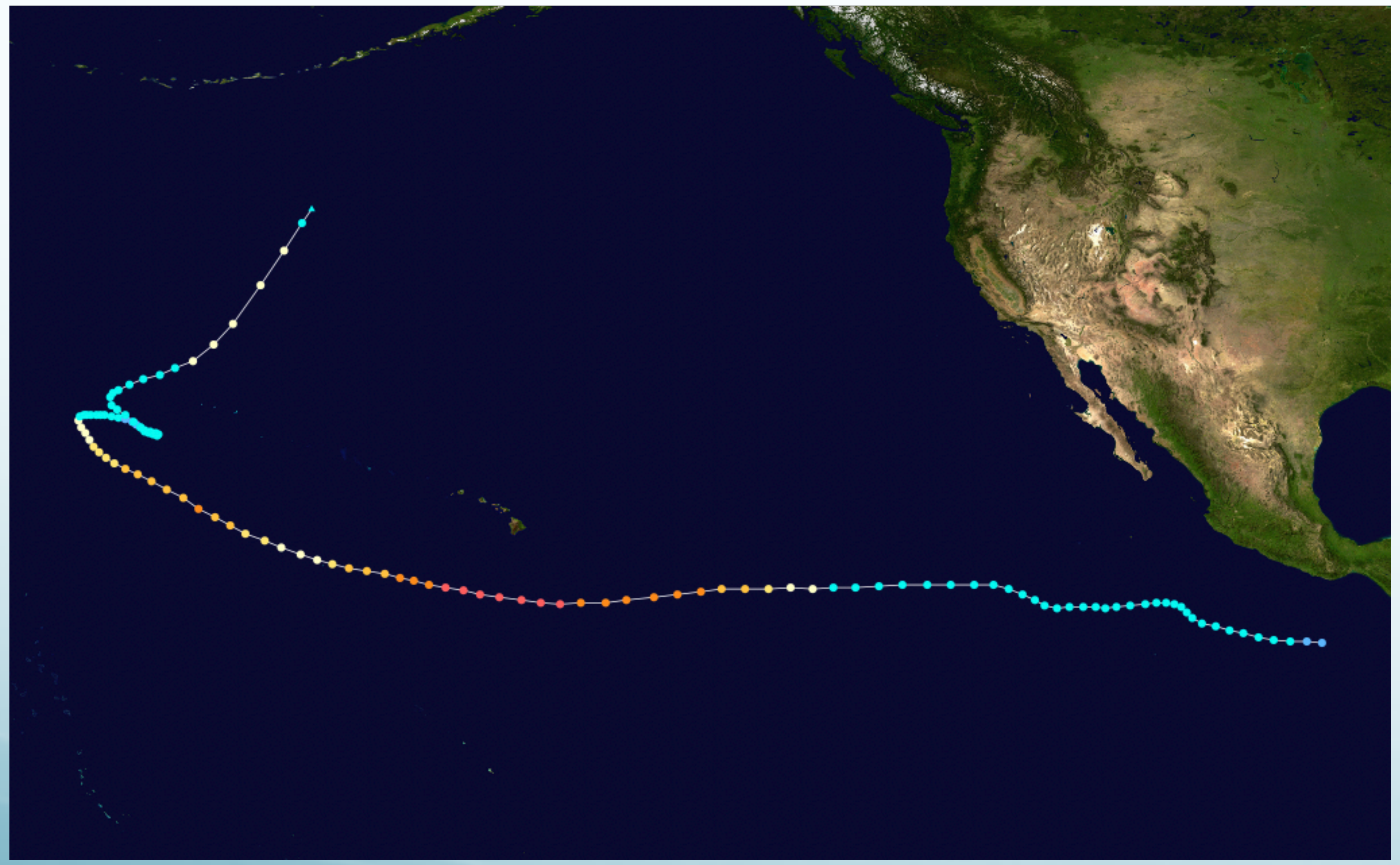
TC weaken over land. Why?



Because they were cut off from warm surface waters, their source of energy

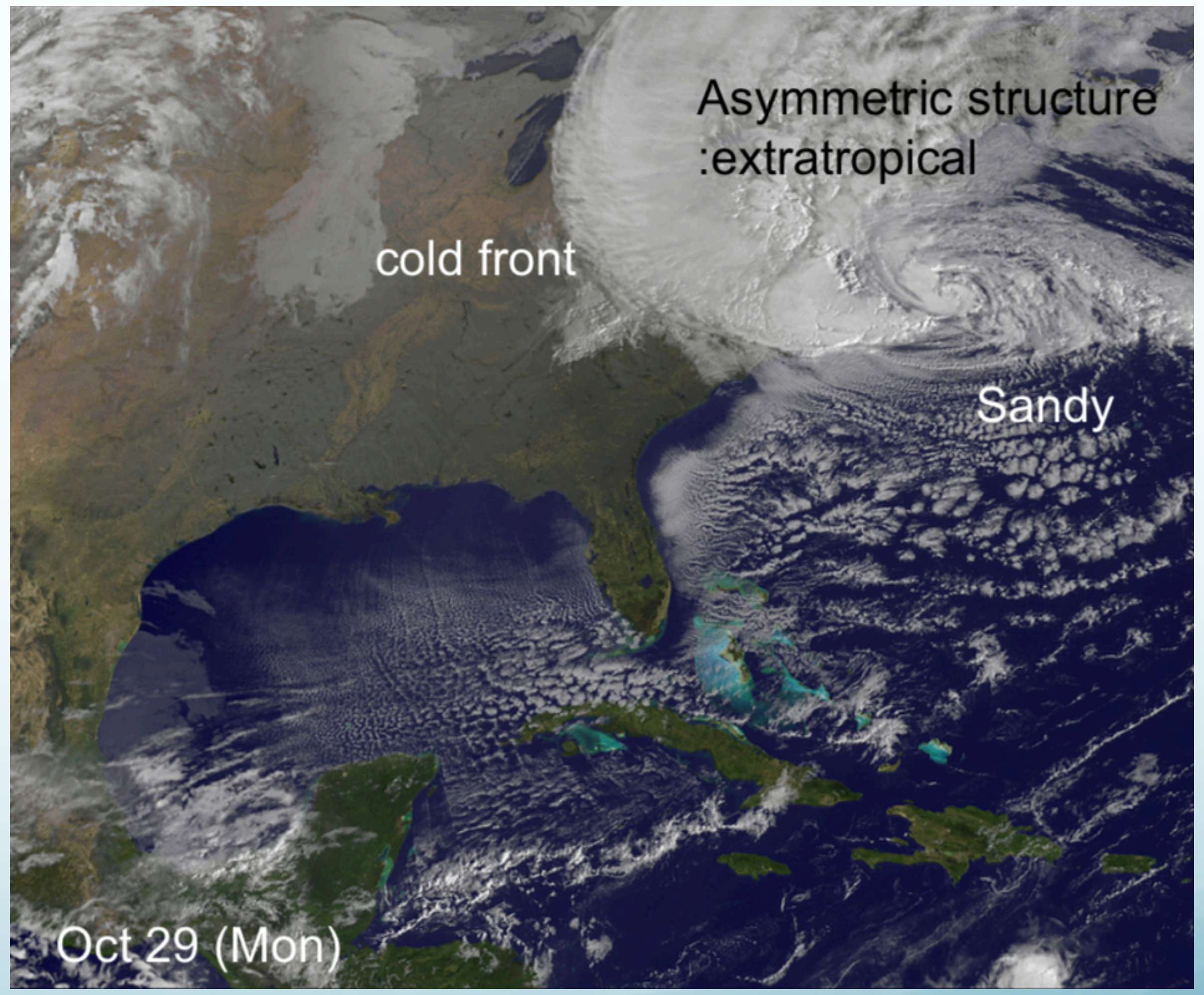
TC death and (maybe) Rebirth as mid-latitude low

- Typically, TC die when they move over land or cold water or into a region of strong vertical shear.
- But TC that recurve over the ocean can change into an



Hurricane John 1994

Hurricane Freda



Sandy's Transition to EC

Tropical Cyclone Motion

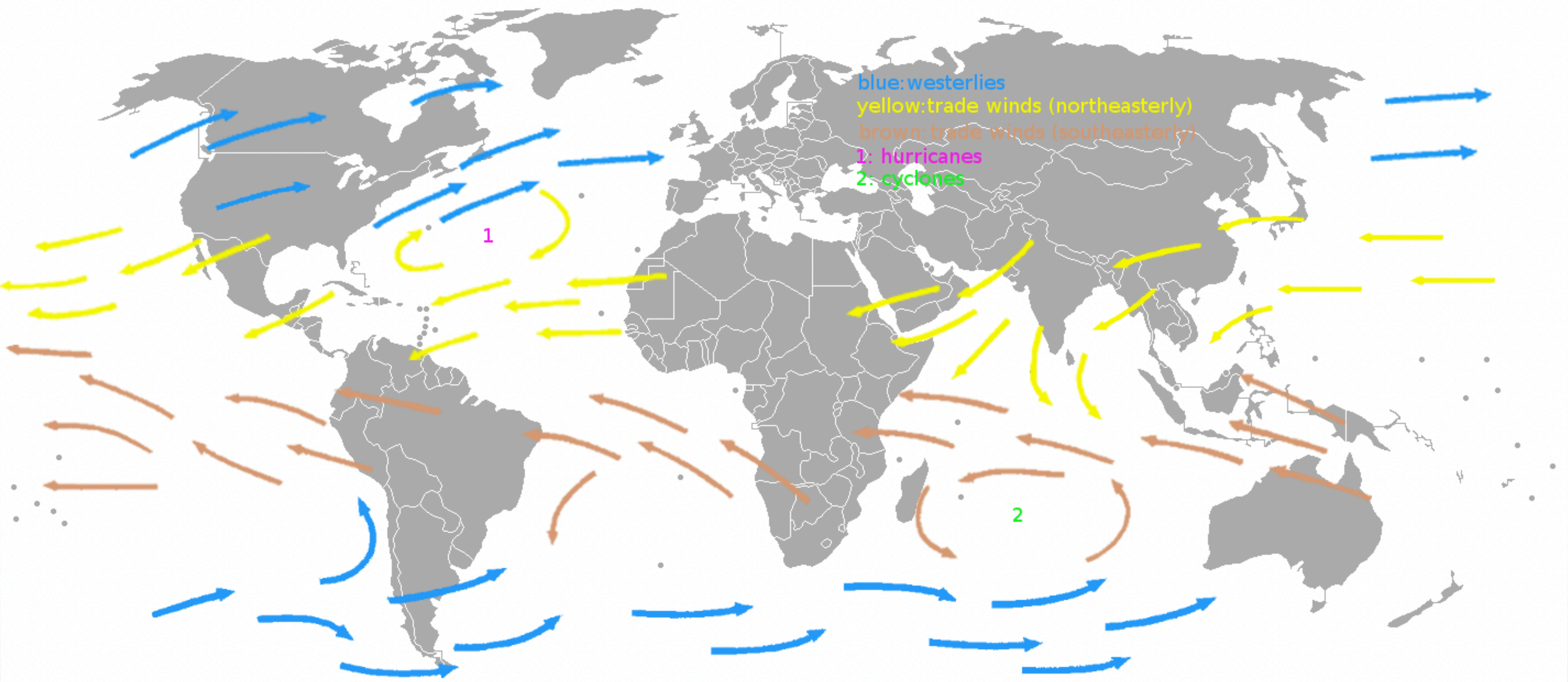
Westerlies (winds from the west) in mid-latitudes

Easterlies (winds from the east) in the deep tropics

Hurricanes tend to move with the flow in

World Tropical Cyclone Track

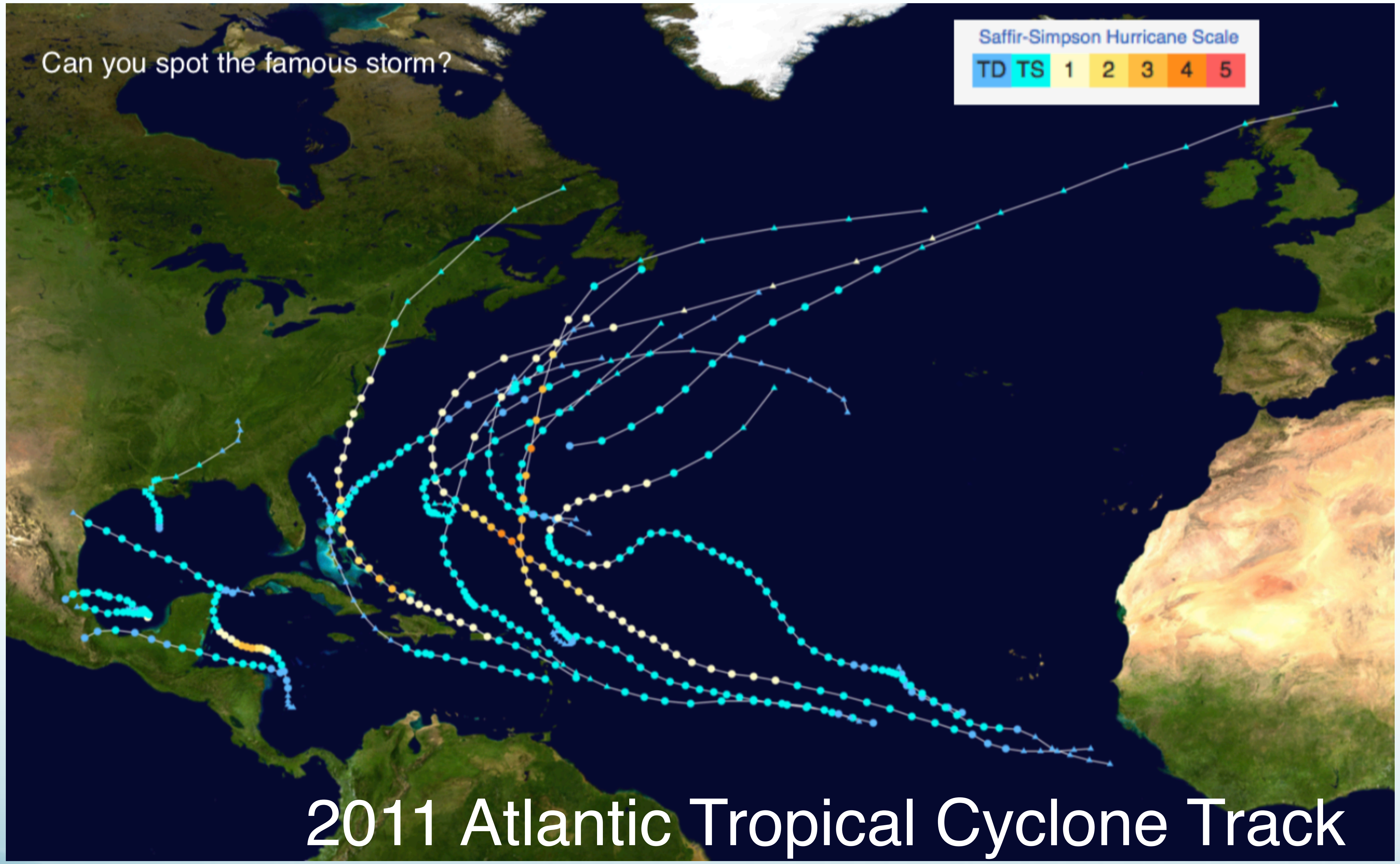
Tropical Cyclone Motion



Hurricanes tend to move with the flow in their surrounding environment:

- Easterlies (winds from the east) in the deep tropics
- Westerlies (winds from the west) in mid-latitudes

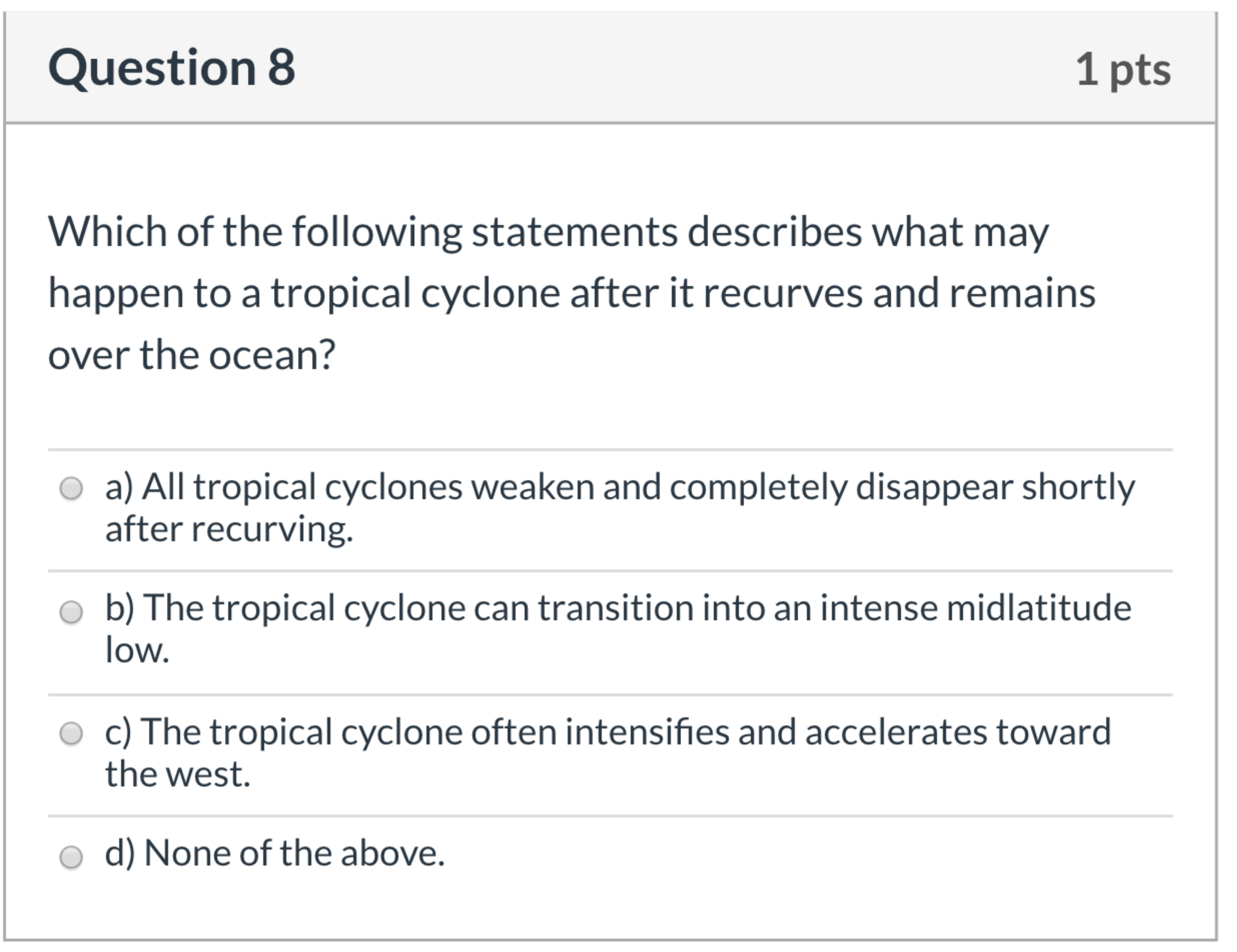
Tropical Cyclone Motion: Recurving



2011 Atlantic Tropical Cyclone Track

Once westward moving storms in the deep tropics drift far enough north, they recurve back to toward the t as they feel the westerly winds in mid-latitudes.

Quiz 8



Question 8

1 pts

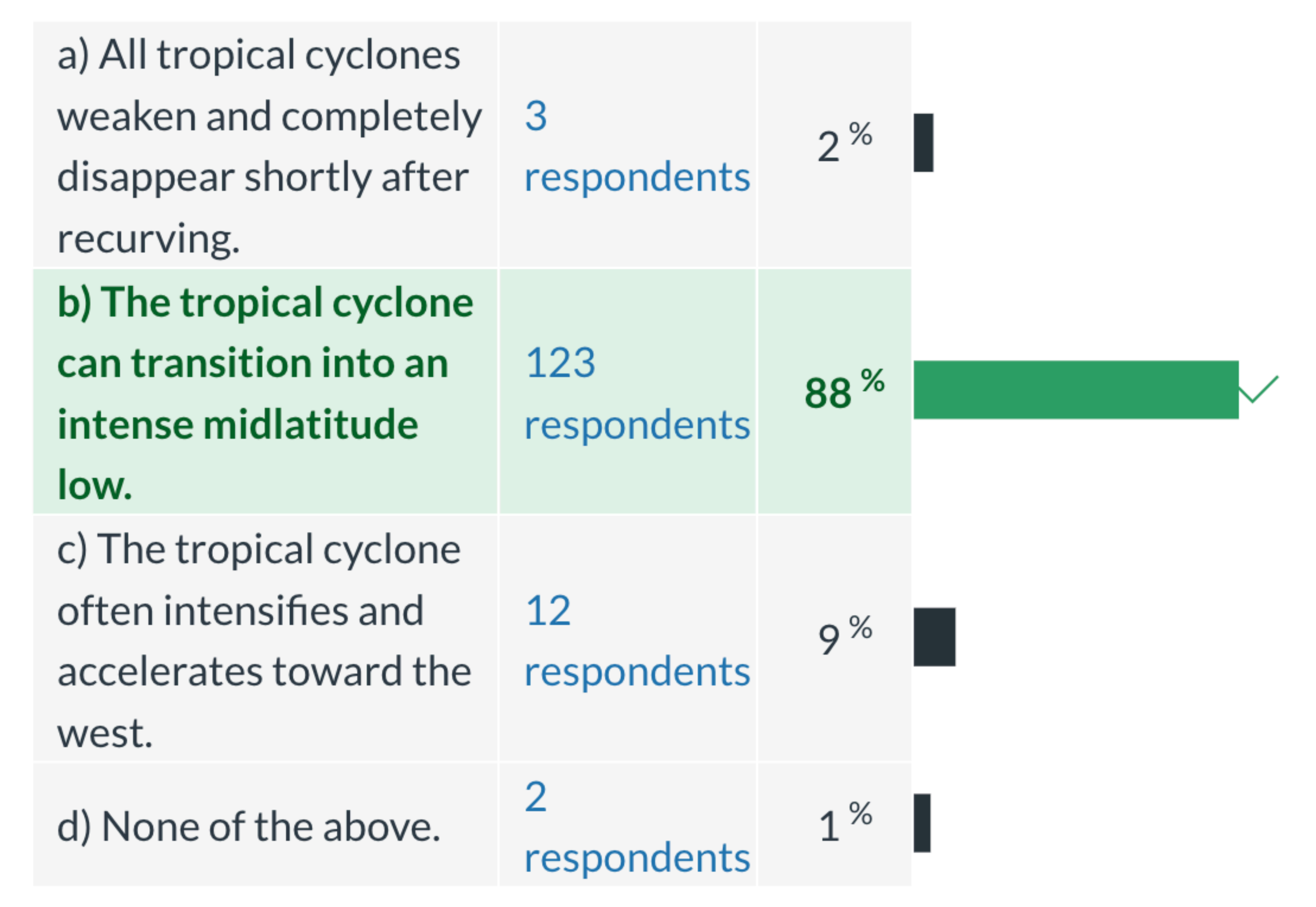
Which of the following statements describes what may happen to a tropical cyclone after it recurves and remains over the ocean?

○ a) All tropical cyclones weaken and completely disappear shortly after recurving.

○ b) The tropical cyclone can transition into an intense midlatitude low.

○ c) The tropical cyclone often intensifies and accelerates toward the west.

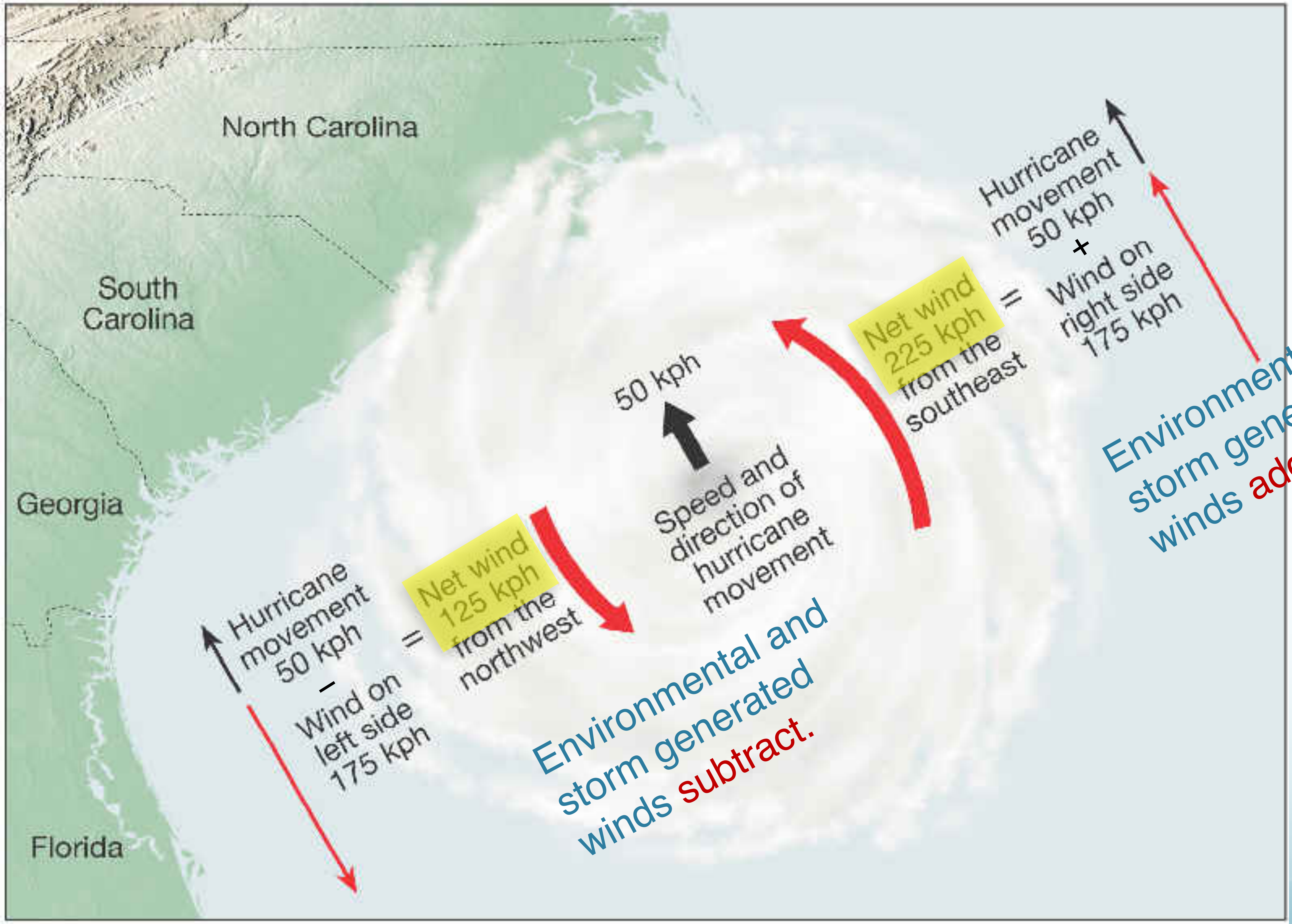
○ d) None of the above.



a) All tropical cyclones weaken and completely disappear shortly after recurving.	3 respondents	2 %	
b) The tropical cyclone can transition into an intense midlatitude low.	123 respondents	**88 %**	✓
c) The tropical cyclone often intensifies and accelerates toward the west.	12 respondents	9 %	
d) None of the above.	2 respondents	1 %	

Storm Surge

In NH, ☐ gets higher winds.

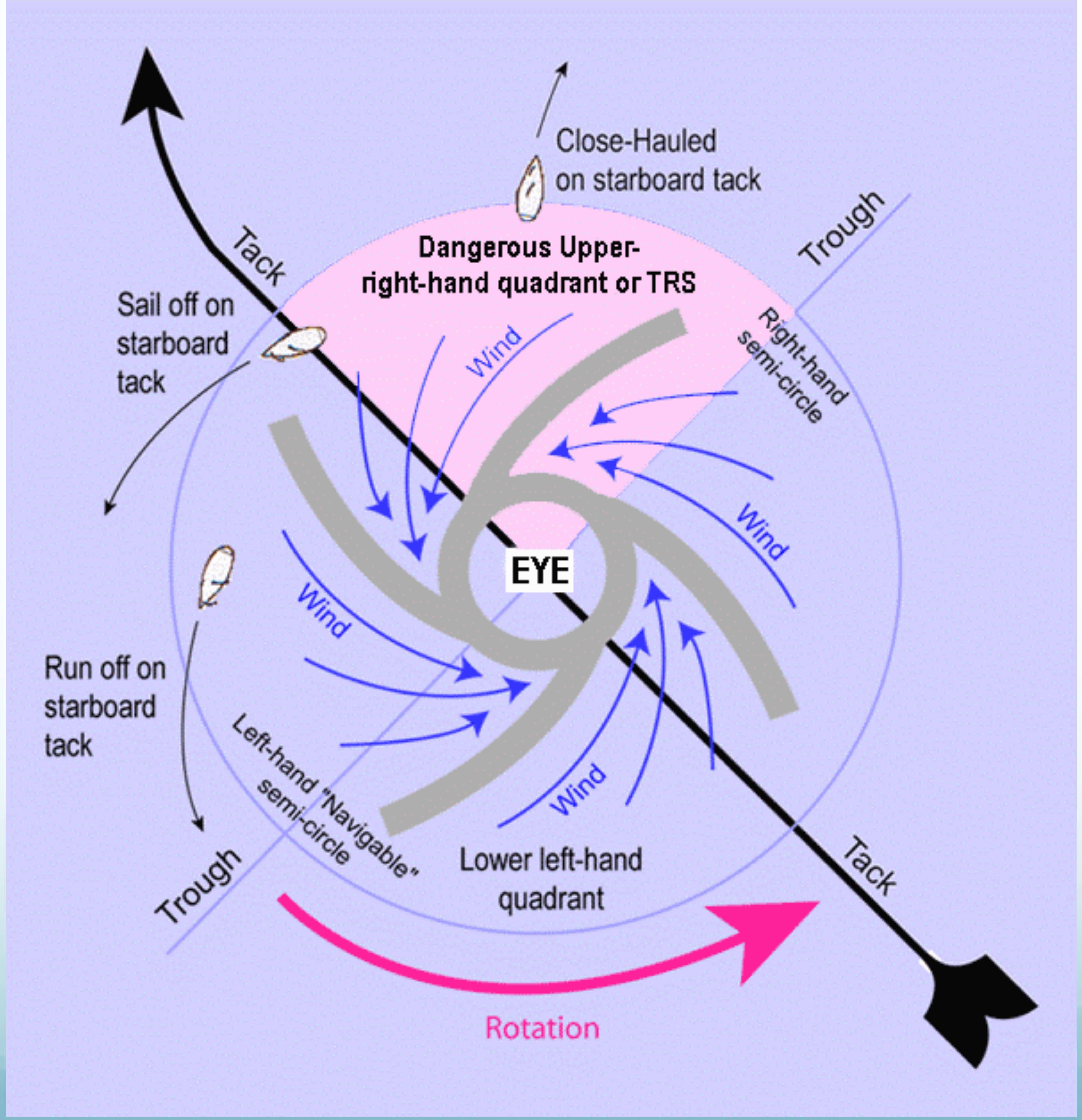


Environmental and storm generated winds add.

Environmental and storm generated winds subtract.

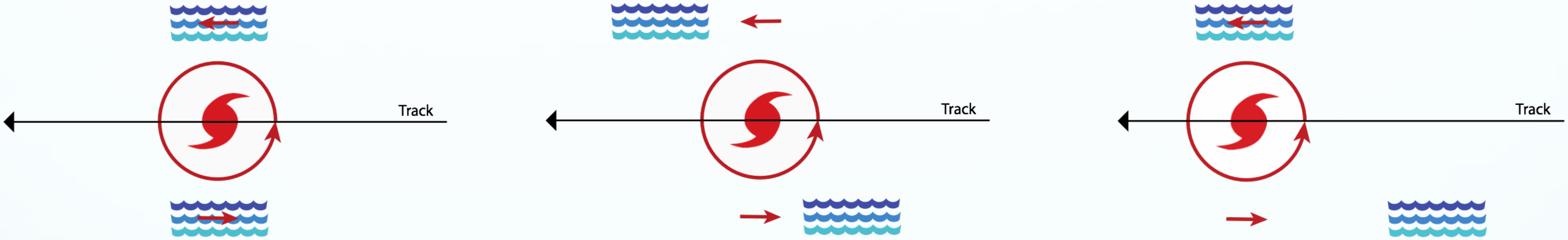
Storm Surge

In NH, higher waves in the [redacted]. Why?



Storm Surge

In NH, Higher waves in the right-front quadrant. Why?



Waves are generated by wind blowing across the sea surface.

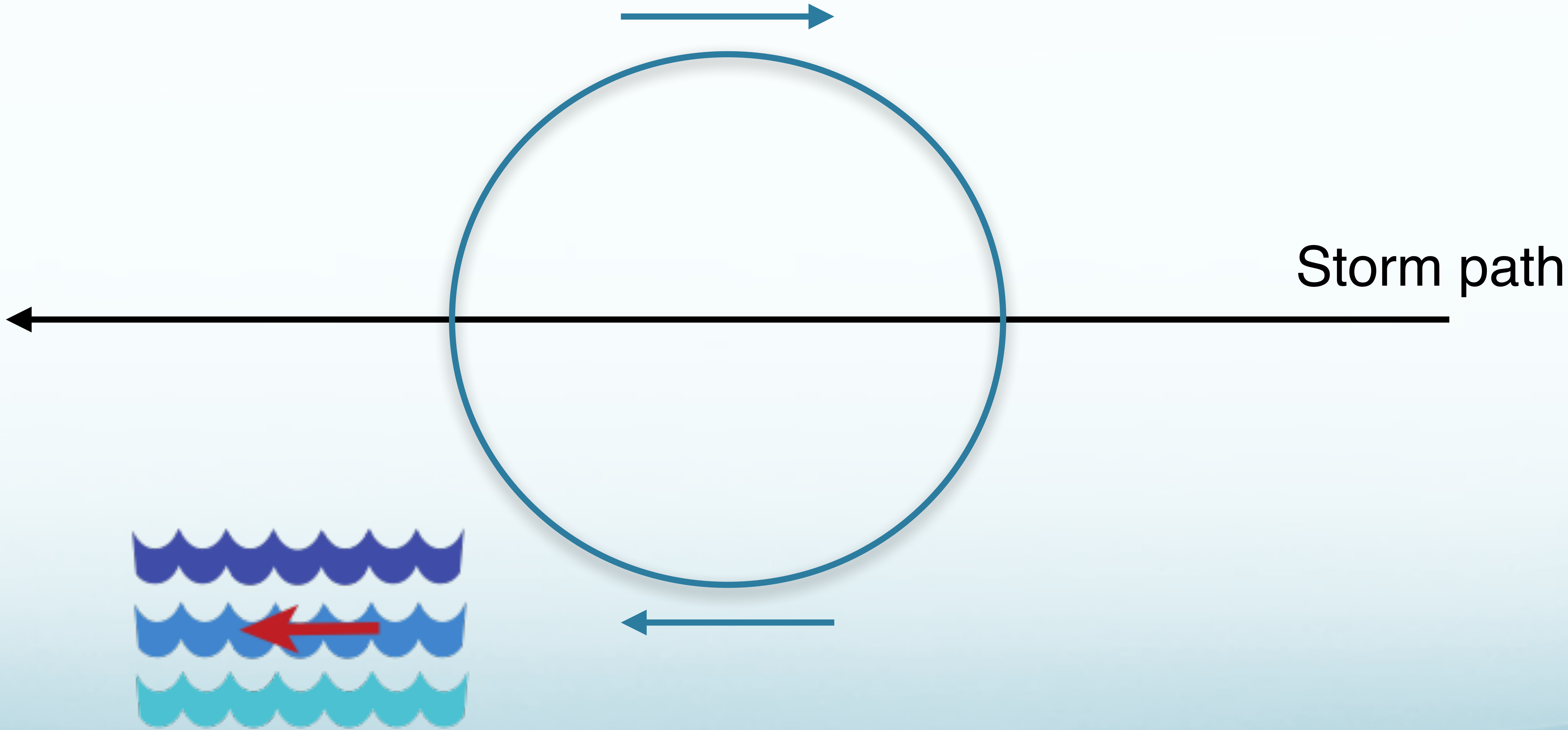
1. The [redacted] the winds, the bigger the waves.
2. The [redacted]e the waves are exposed to the wind, the larger they get.

Waves generated at right-front quadrant of storm continues to be exposed to strong wind when account for hurricane motion as well a wave propagation

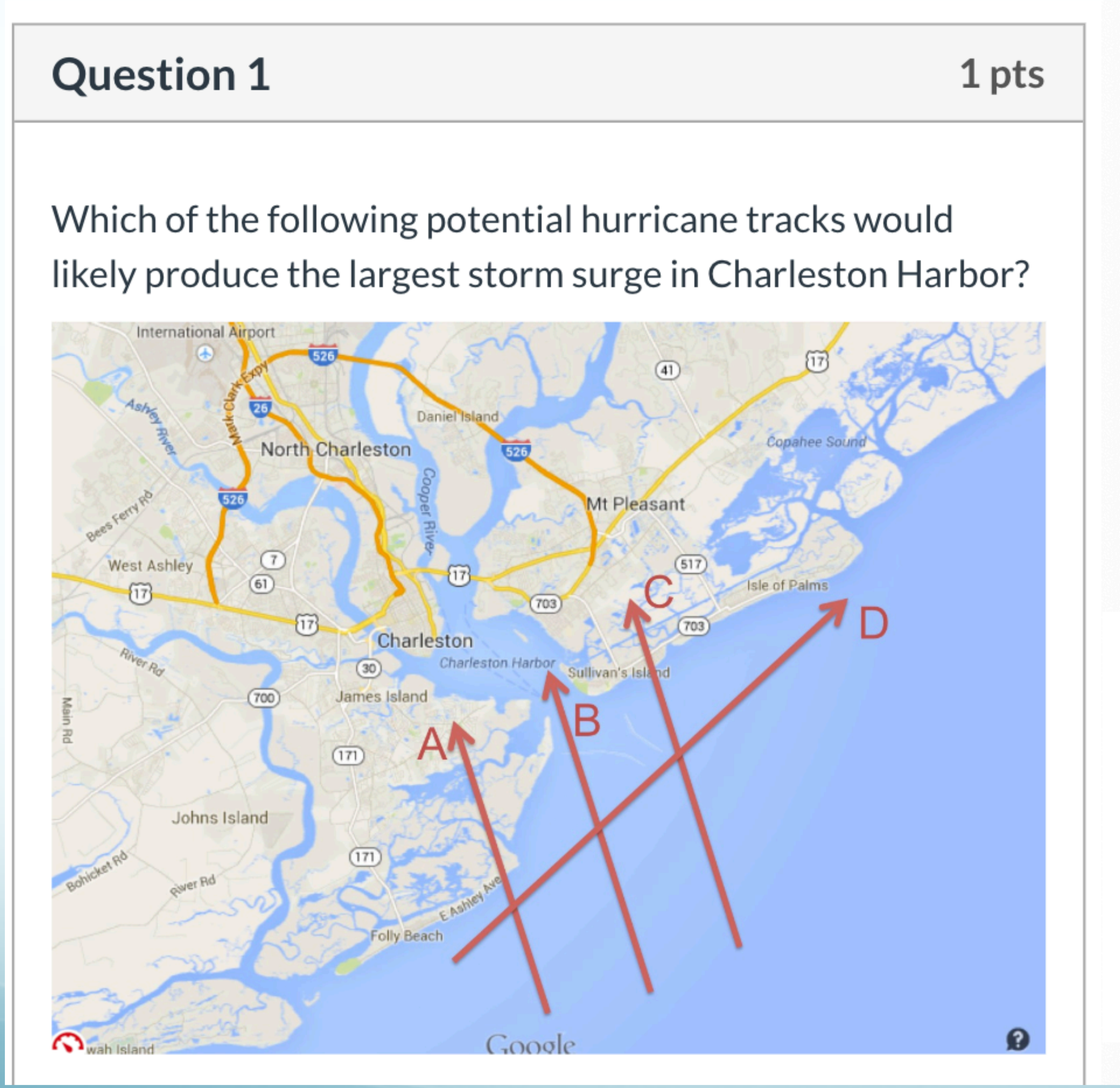
Storm Surge

In SH, higher waves in the left-front quadrant. Why?

- Because cyclones spin the opposite direction in the SH, the most dangerous quadrant is the ☐



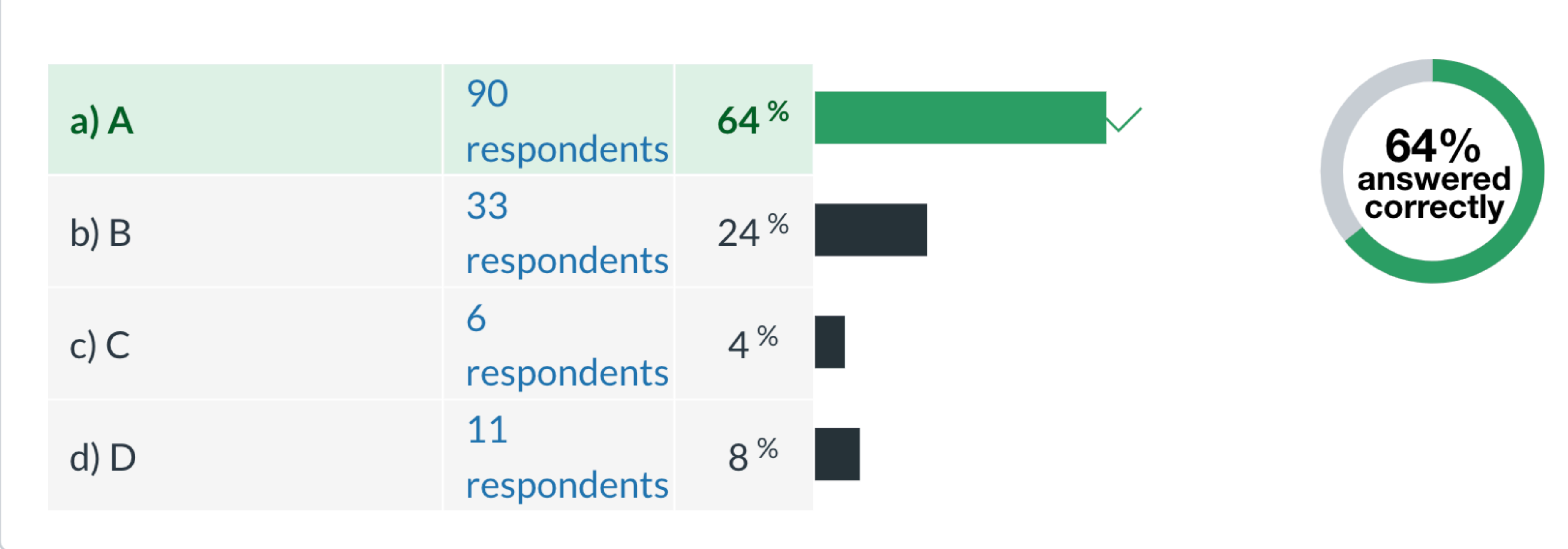
Quiz 8



Question 1

1 pts

Which of the following potential hurricane tracks would likely produce the largest storm surge in Charleston Harbor?

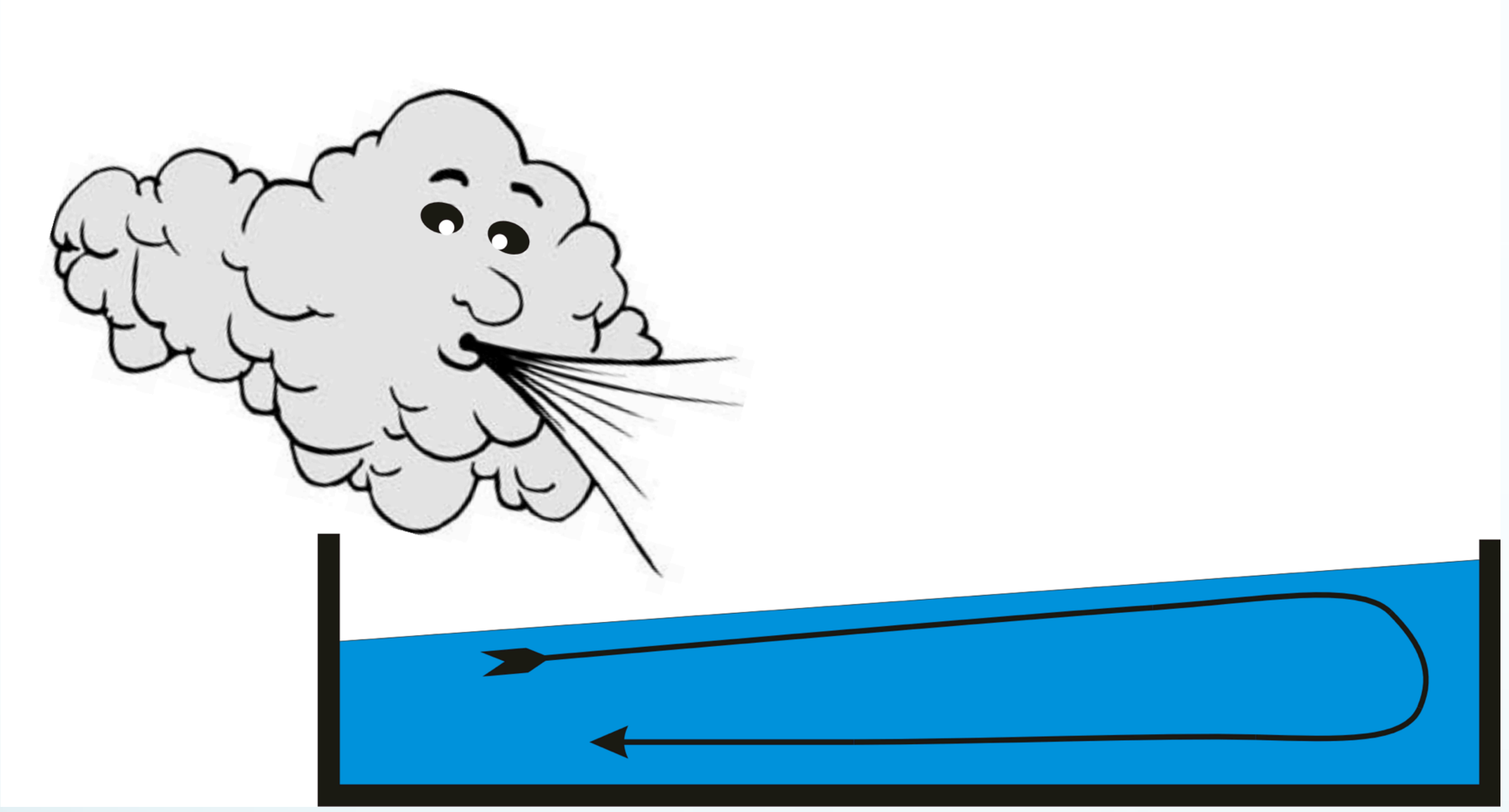


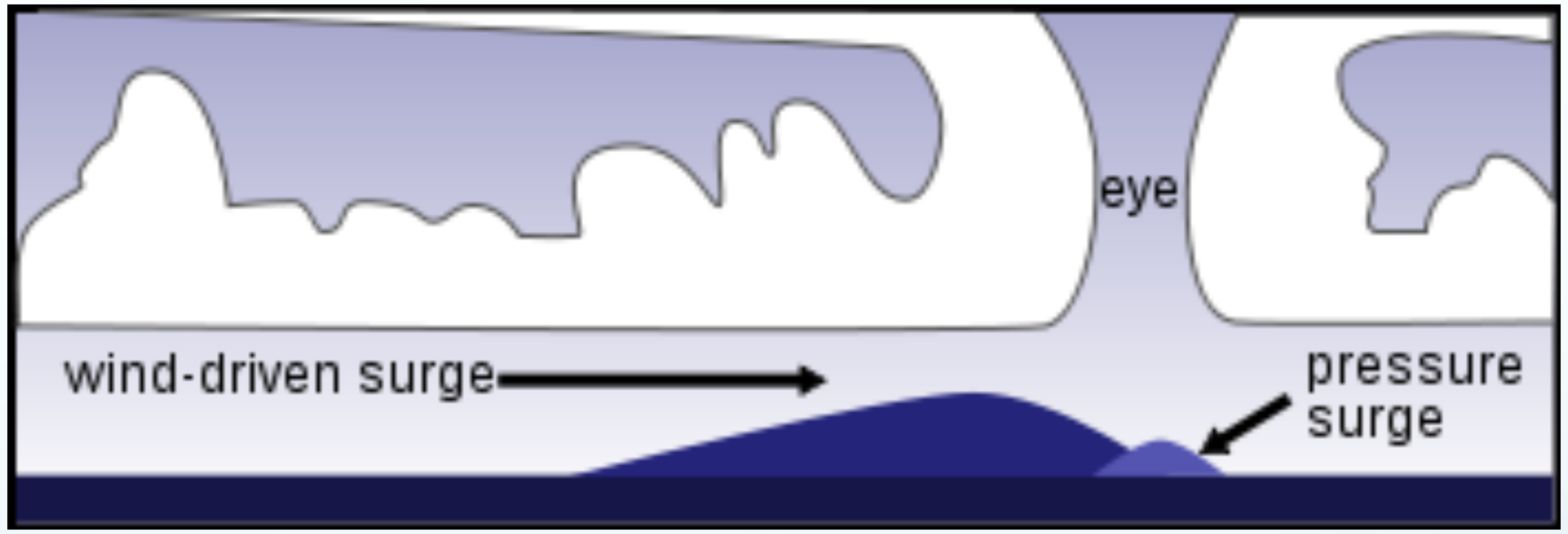
a) A	90 respondents	64 %	✓
b) B	33 respondents	24 %	
c) C	6 respondents	4 %	
d) D	11 respondents	8 %	

64% answered correctly

Storm Surge Causes

- Produced primarily by blowing water against a shore
- Secondarily by the local drop in near the eye.

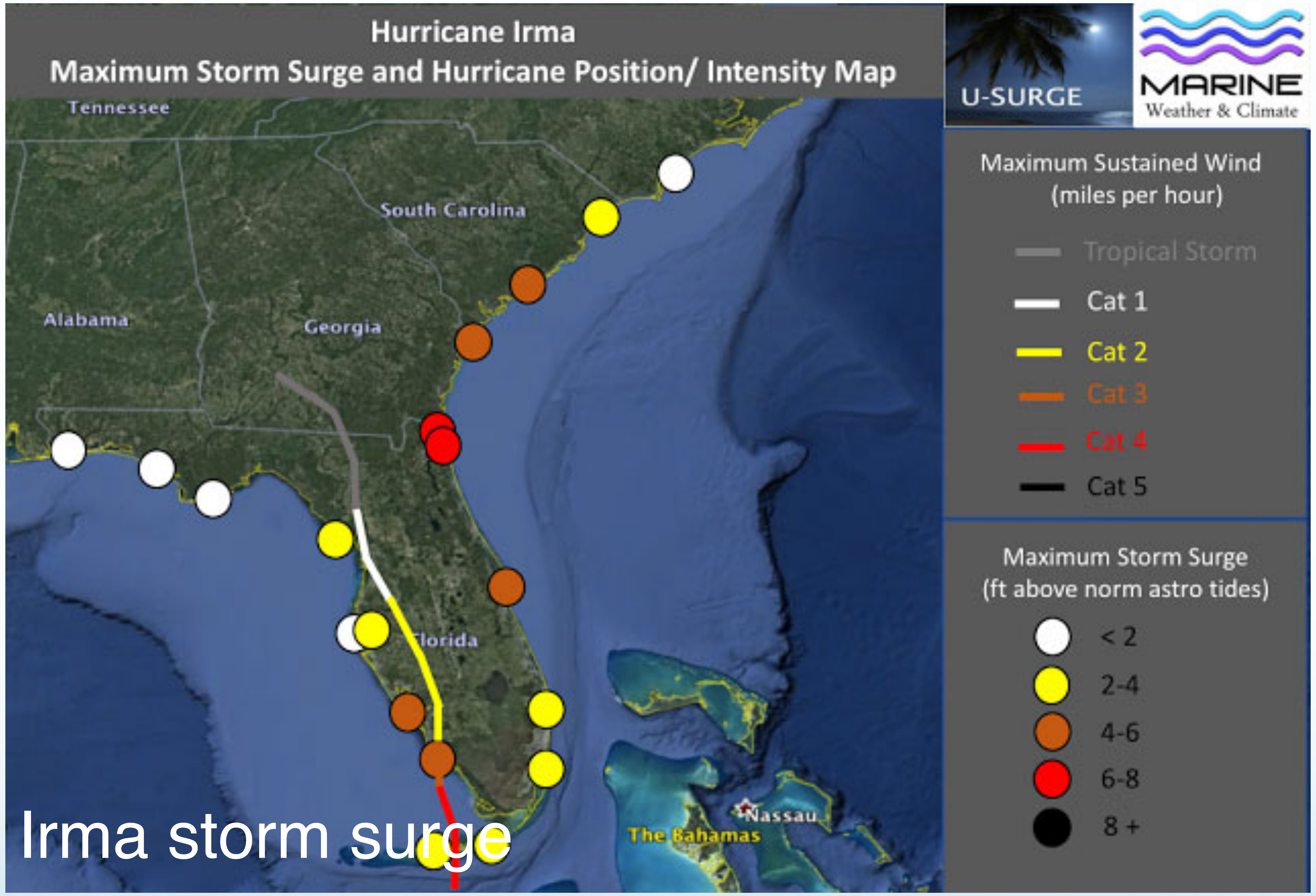




Pressure contribution typically just 5% of total surge.

Storm Surge

Is it possible to get negative storm surge in some places?

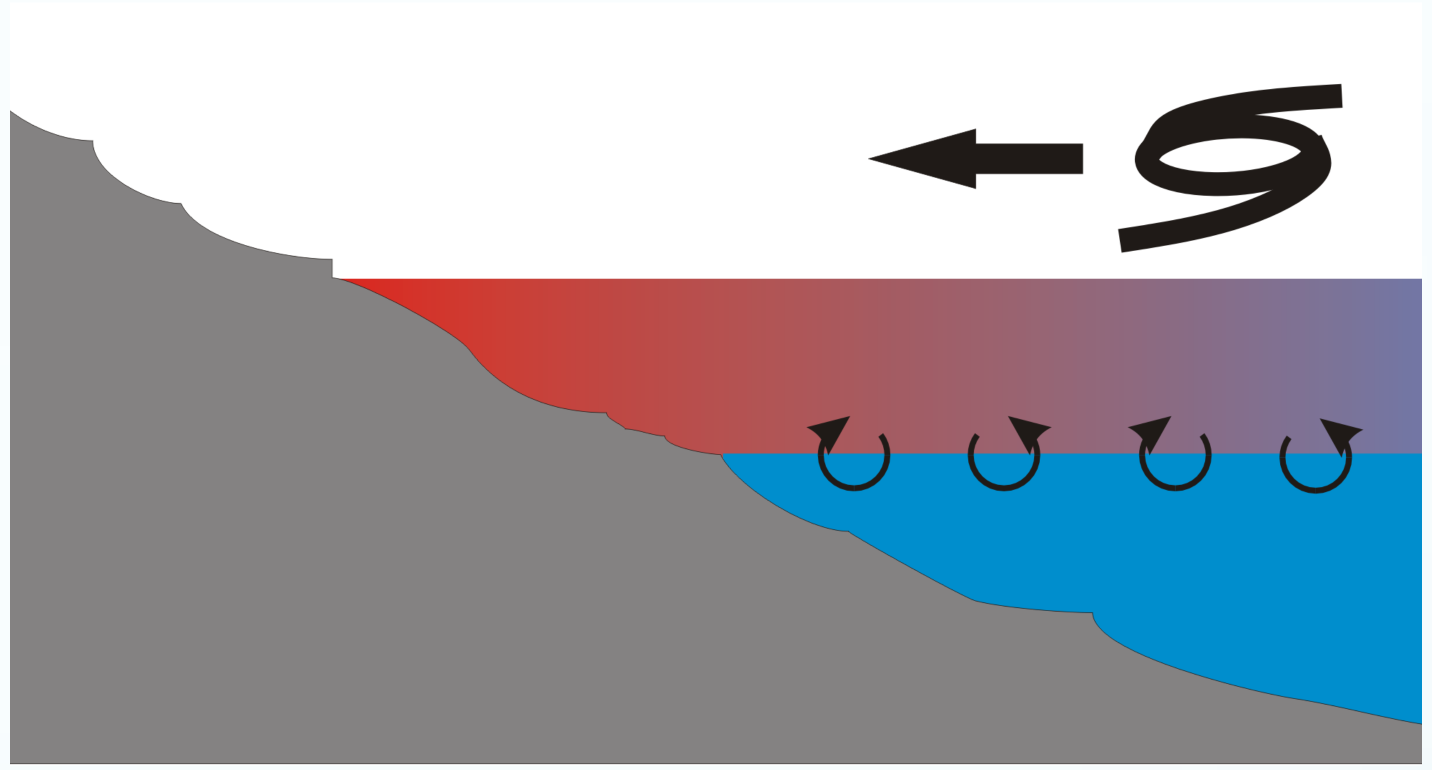


Irma storm surge

Causes:

Storm Surge
Influence by …

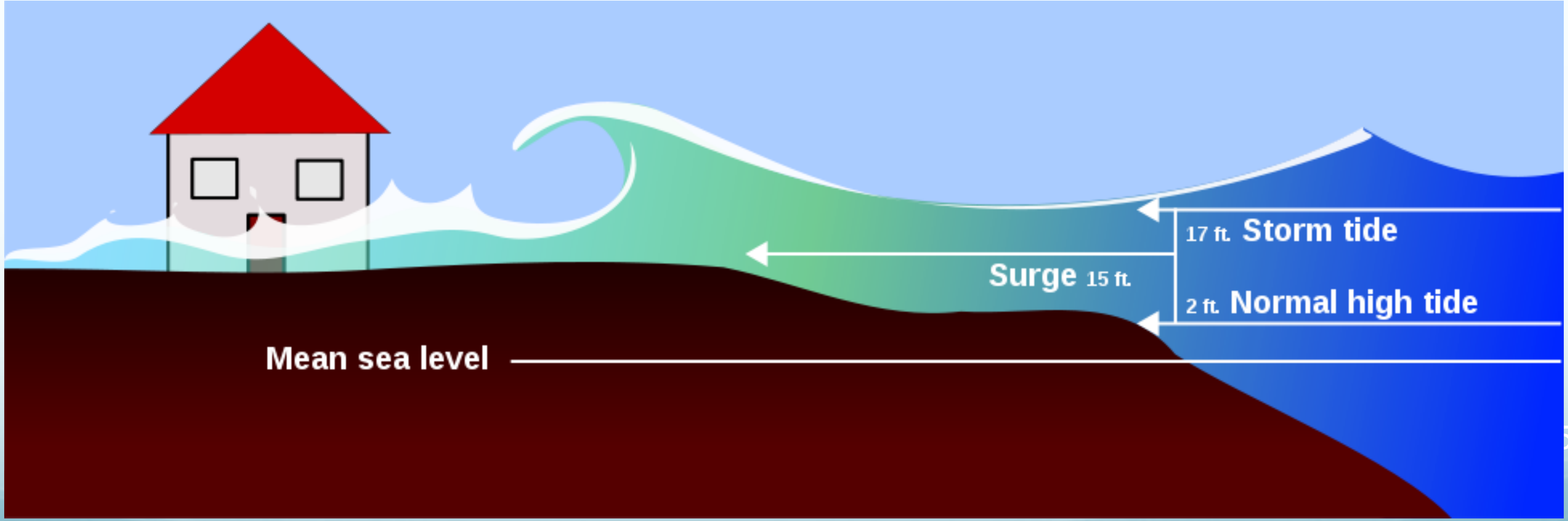
- Wind speed (major factor)
- Drop in atmospheric pressure (minor factor)
- Shape of the sea floor / beach slope
  - ☐ slope is more favorable for storm surge
- Path of the hurricane relative to the coast.
  - Is the storm approaching head-on or almost parallel to the coast.



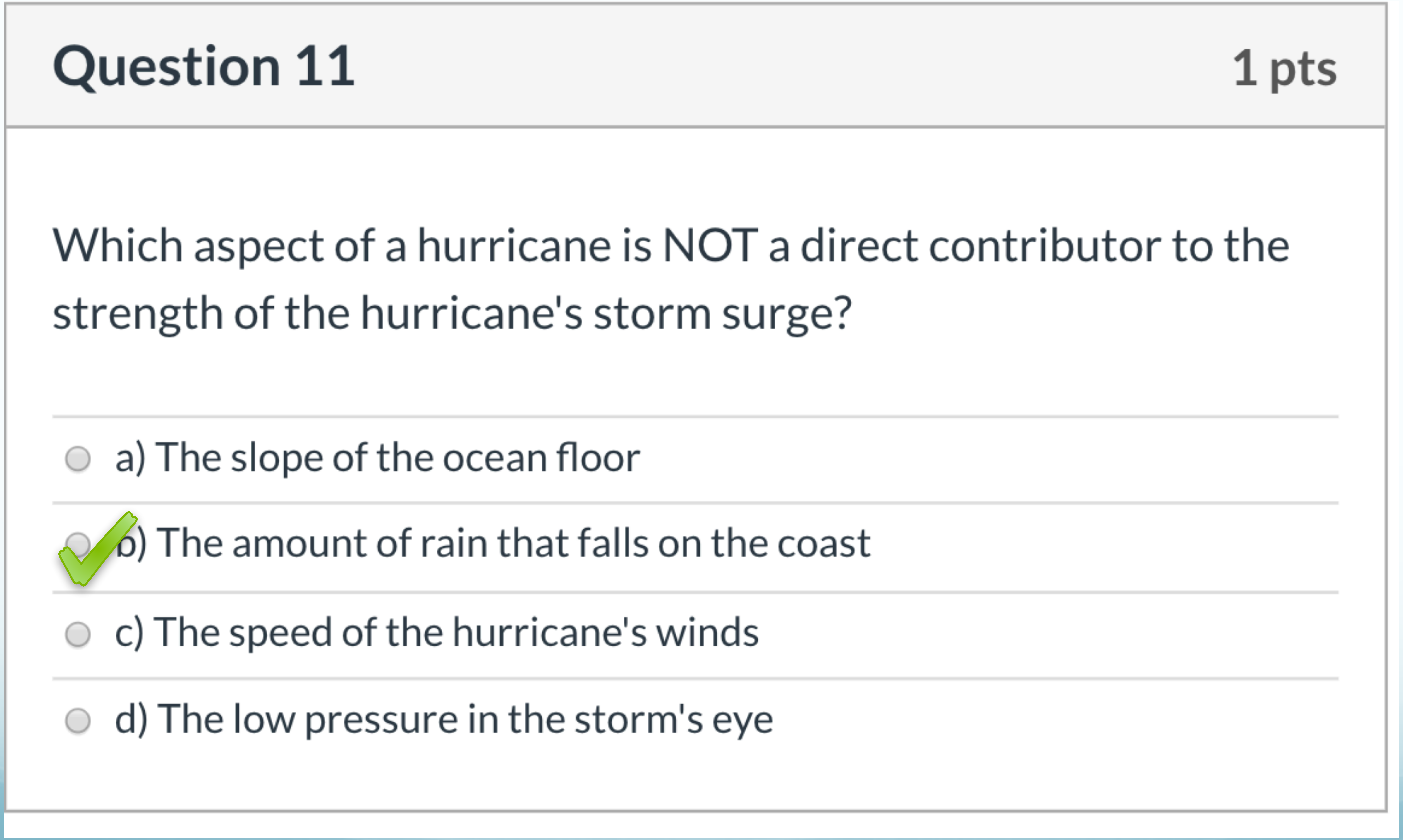
Storm Surge
Factors Determining the Storm Tide

b.

- Astronomical tide (2 high tides, 2 low tides per day)
- Storm surge (generated by the hurricane)
- (High waves ride on top of the storm tide.)



Quiz 8



Question 11

1 pts

Which aspect of a hurricane is NOT a direct contributor to the strength of the hurricane's storm surge?

○ a) The slope of the ocean floor

✓ b) The amount of rain that falls on the coast

○ c) The speed of the hurricane's winds

○ d) The low pressure in the storm's eye

Hurricane impacts and adaptation

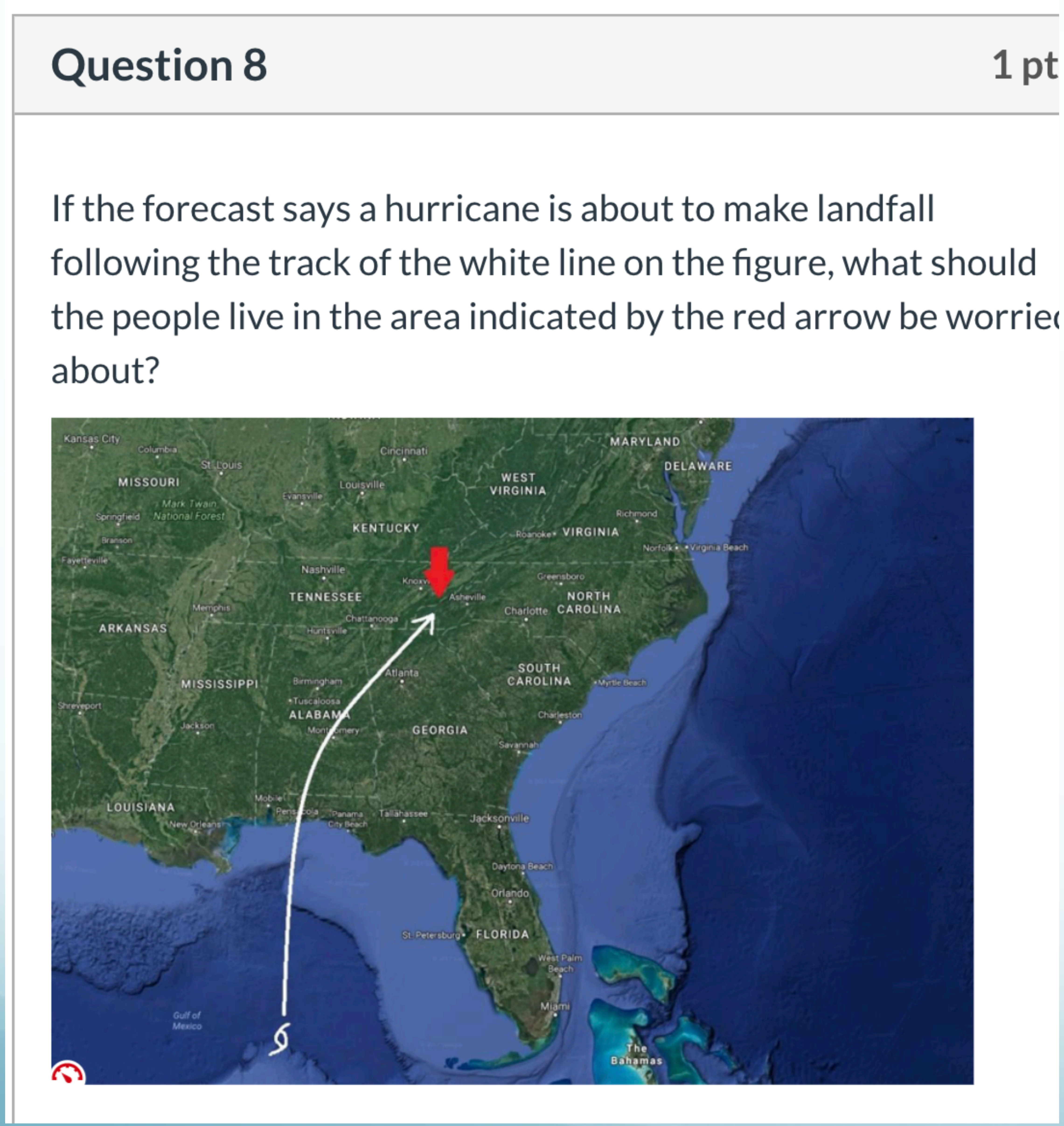
- High winds

  e.g. Hurricane Andrew exposed weaknesses in home construction

Building codes upgraded

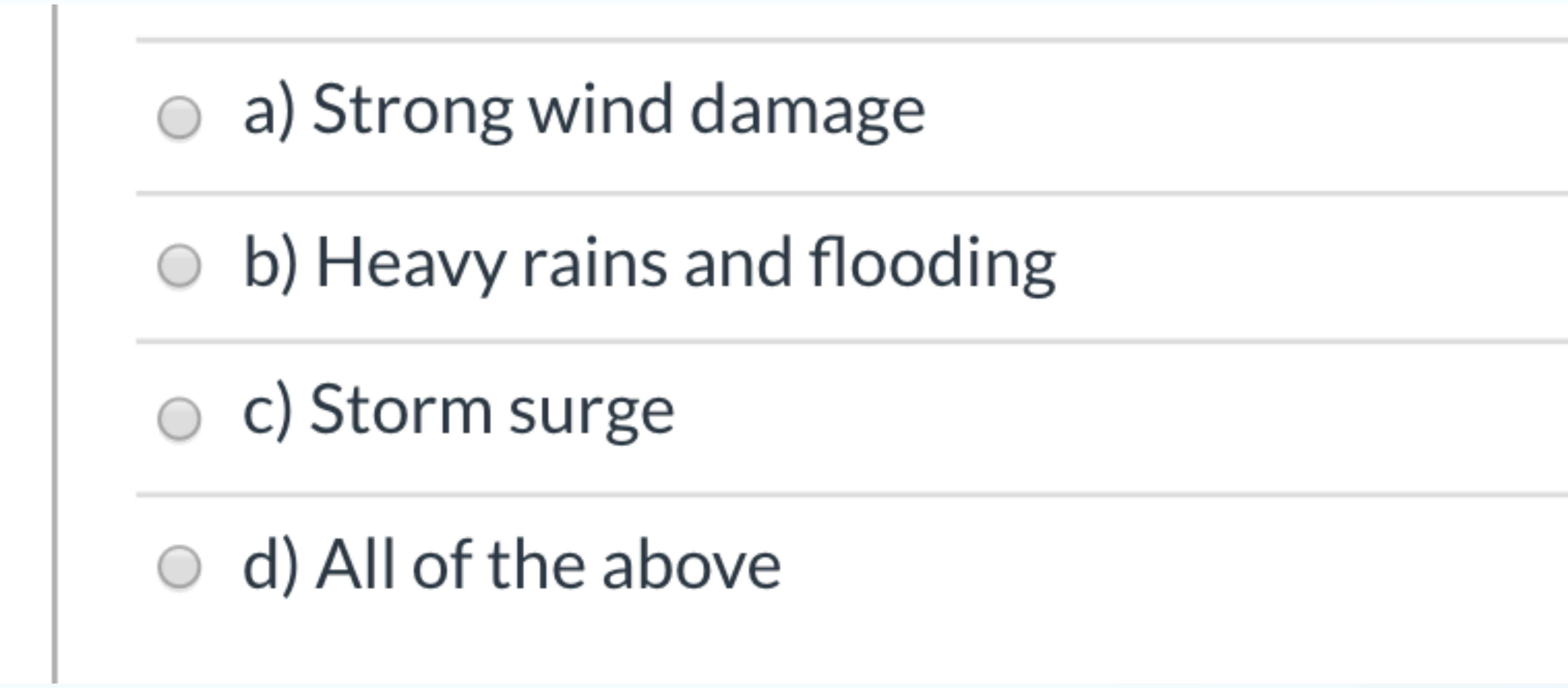
- Storm surge ( )
- Flooding with heavy rainfall (, typically most severe when the storm encounters)

Quiz 9



Question 8 **1 pt**

If the forecast says a hurricane is about to make landfall following the track of the white line on the figure, what should the people live in the area indicated by the red arrow be worrie about?



○ a) Strong wind damage

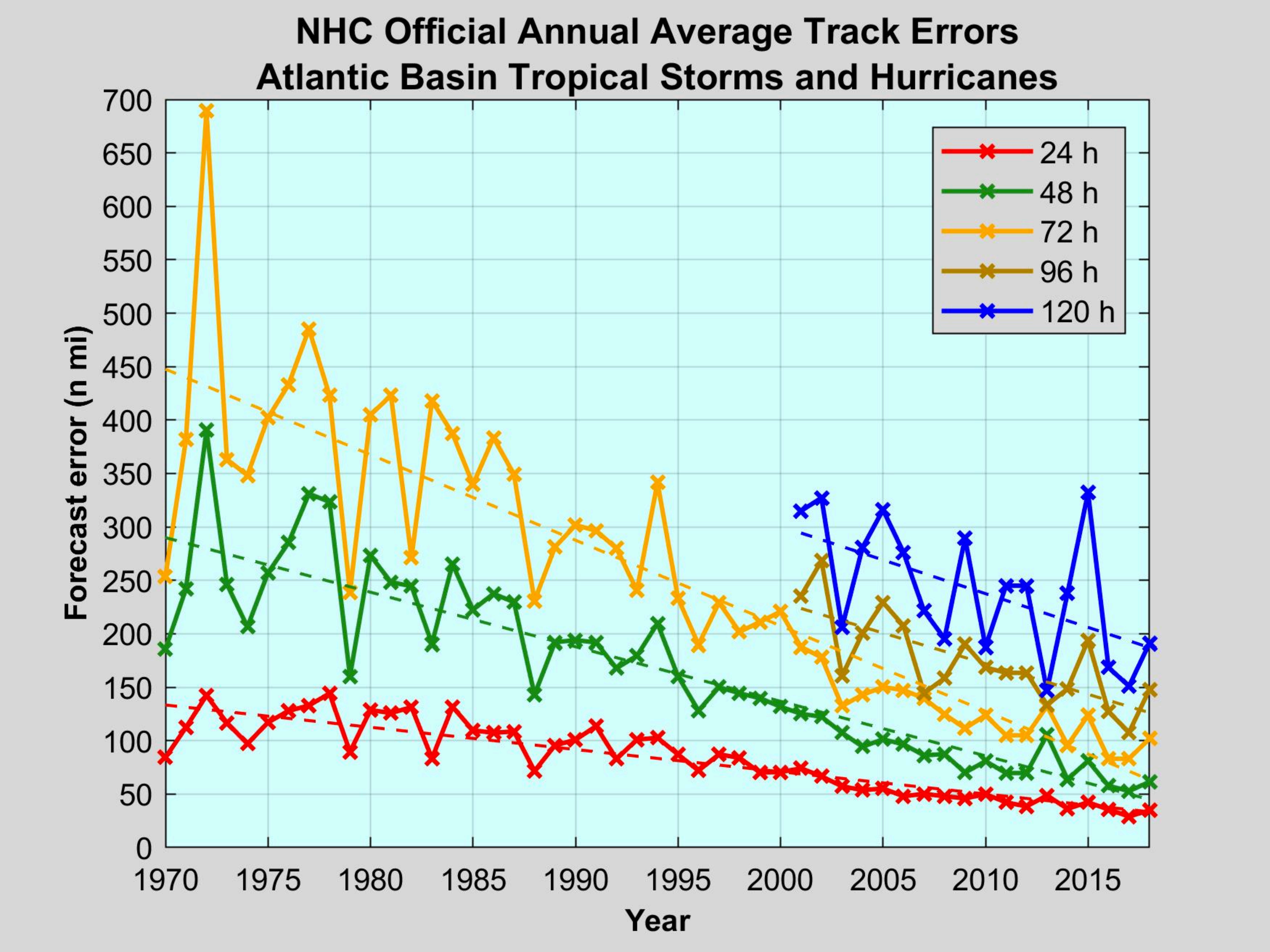
○ b) Heavy rains and flooding

○ c) Storm surge

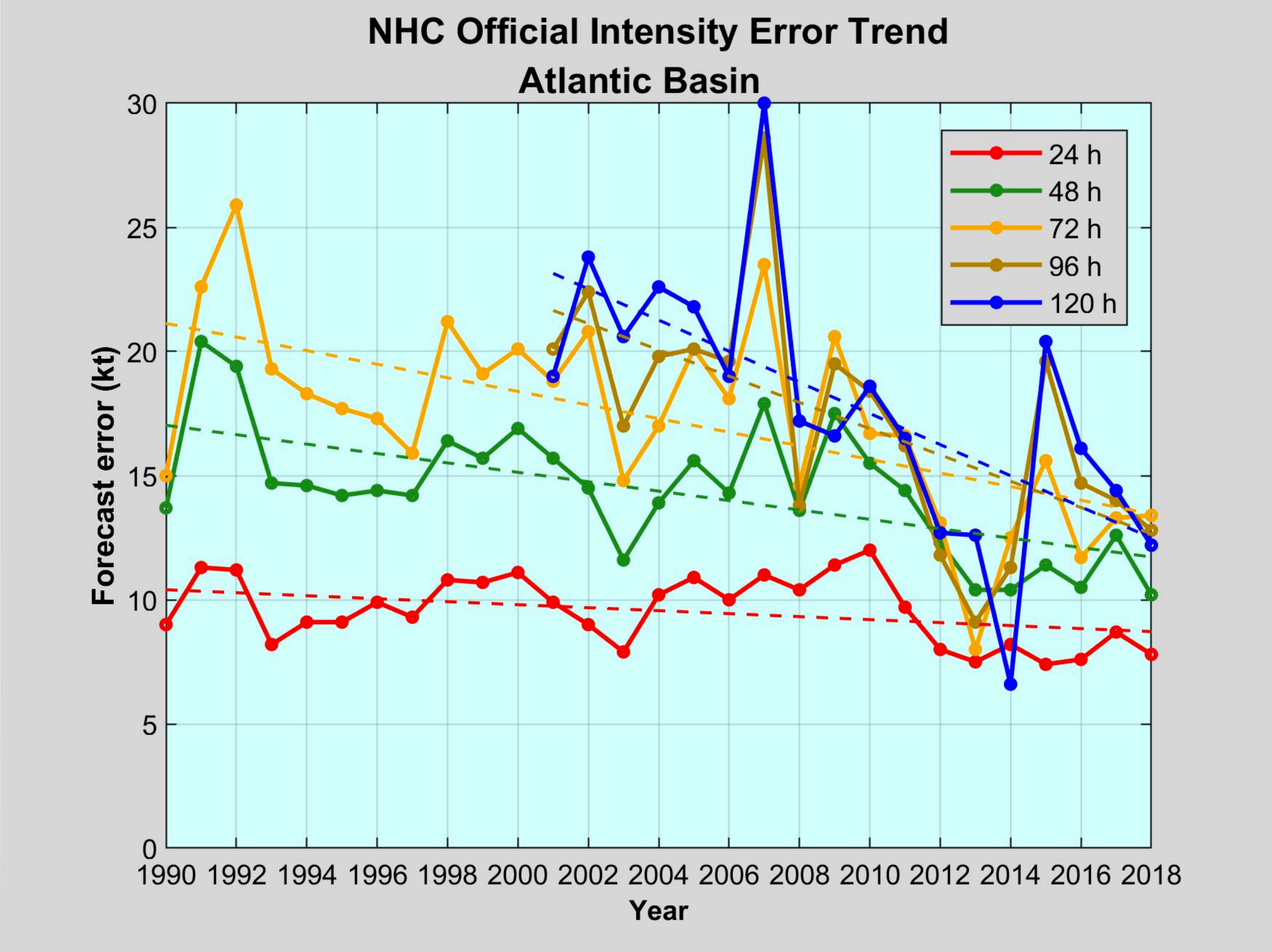
○ d) All of the above

Tropical cyclone forecast
improvements

- Over the past 30 years in the north Atlantic: hurricane ☐ forecasting has improved little while hurricane ☐ forecasting has improved significantly



Track



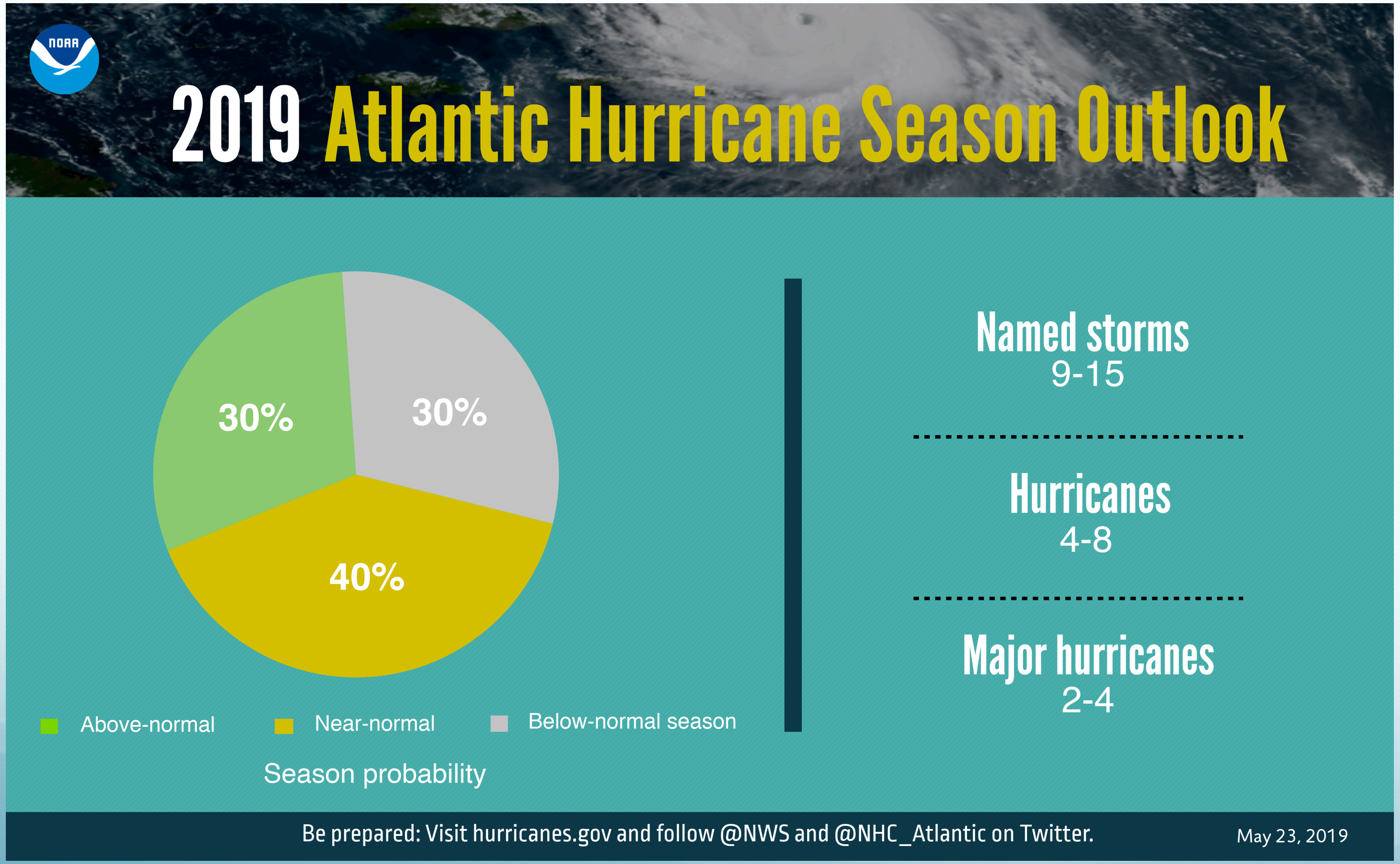
Insensity

Tropical cyclone forecast
Forecast challenges

- Knowing the current state of the atmosphere
- Modeling how the atmosphere will evolve from its current state
- Improvements in track forecasts have come from improvements in both determining the [redacted] and improving [redacted]
- Lack of improvement in 24-hour intensity forecasts may be limited by sensitivity of hurricane development of small, hard to observe properties of the current state

Tropical cyclone forecast
Seasonal Forecast

- Outlook: number of named storms, hurricanes and major hurricanes



2019 Atlantic Hurricane Season Outlook

Named storms
9-15

Hurricanes
4-8

Major hurricanes
2-4

Be prepared: Visit hurricanes.gov and follow @NWS and @NHC_Atlantic on Twitter.

May 23, 2019

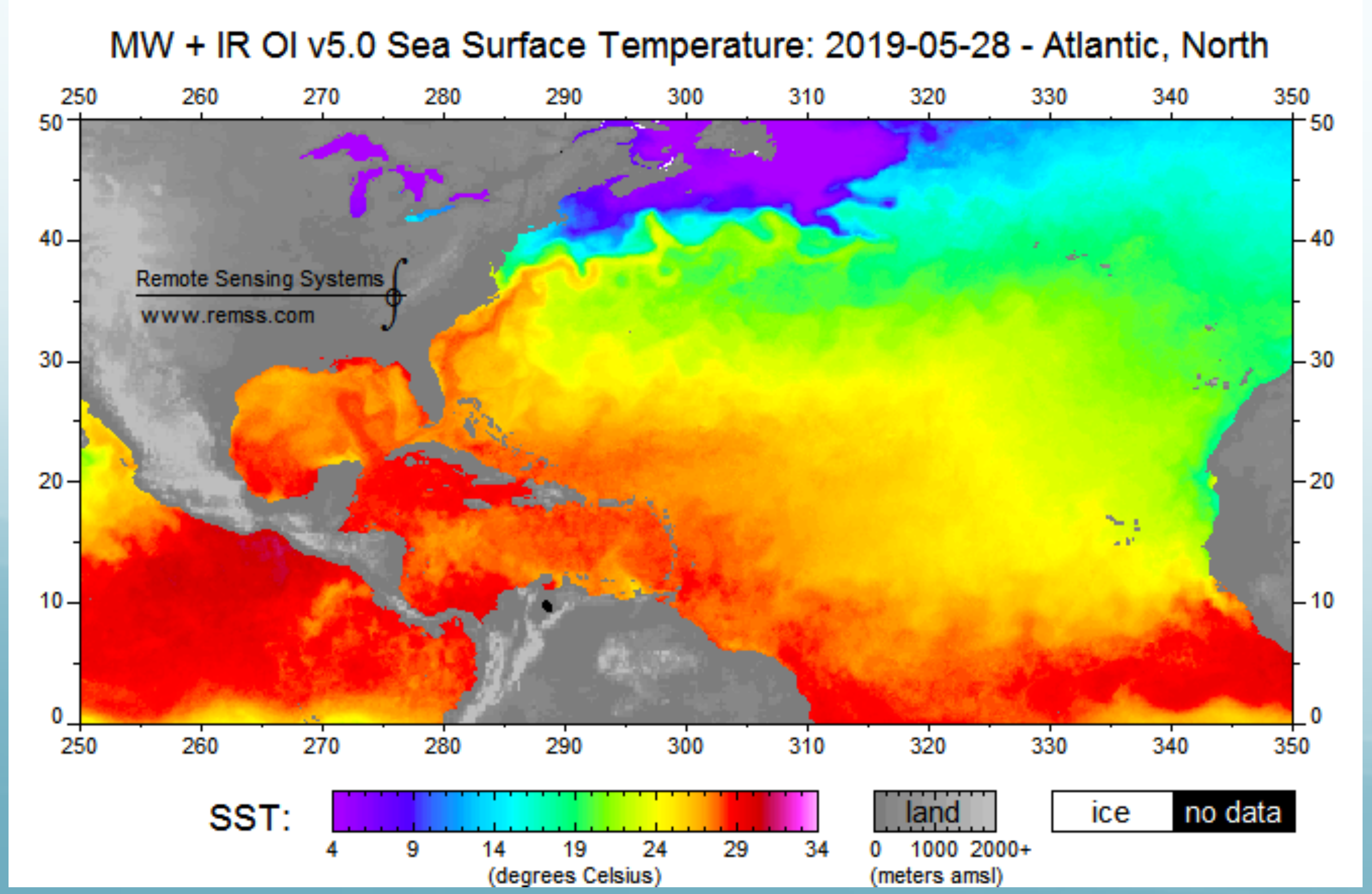
NOAA 2019 Seasonal Forecast: Near Normal

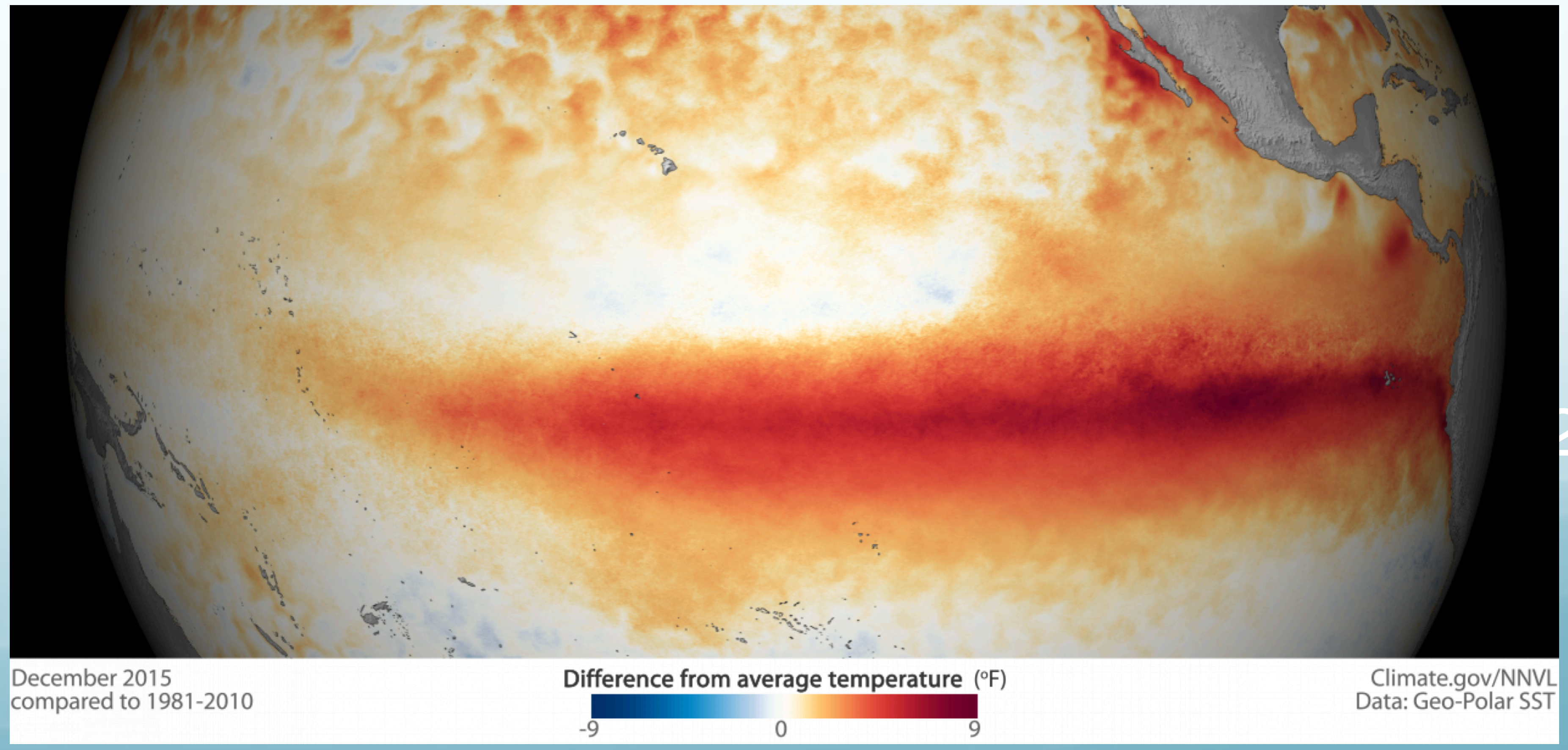
Tropical cyclone forecast
Seasonal Forecast

- Hurricane Seasonal Forecast are largely based on forecast of:
  - Sea surface temperatures (SST) in the tropical north Atlantic

    [Local effect of SST beneath the hurricanes]
  - Presence of El Niño or La Niña

    [Remote influence of SST in the equatorial Pacific Ocean]

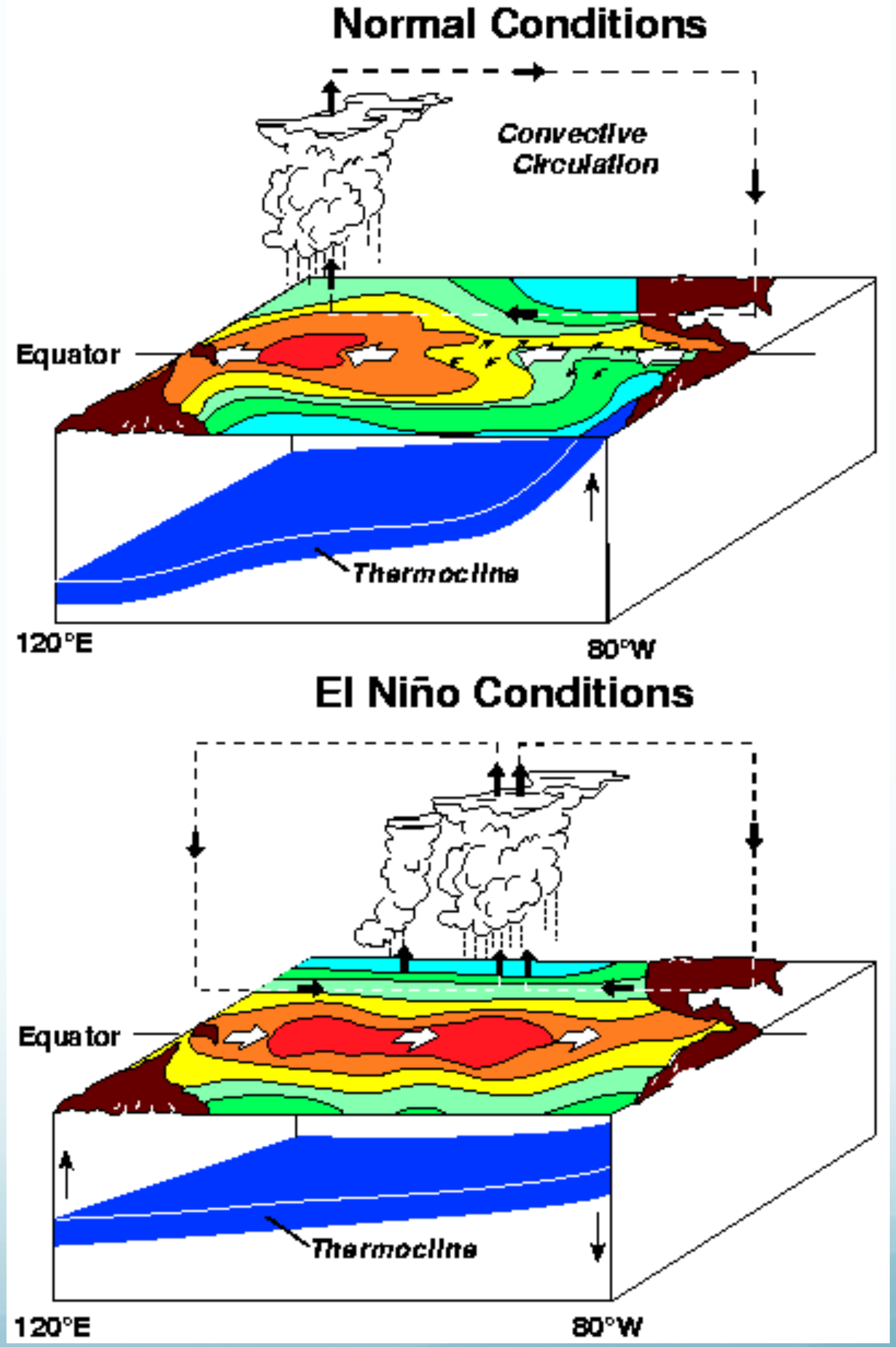




Impacts of El Niño on hurricanes

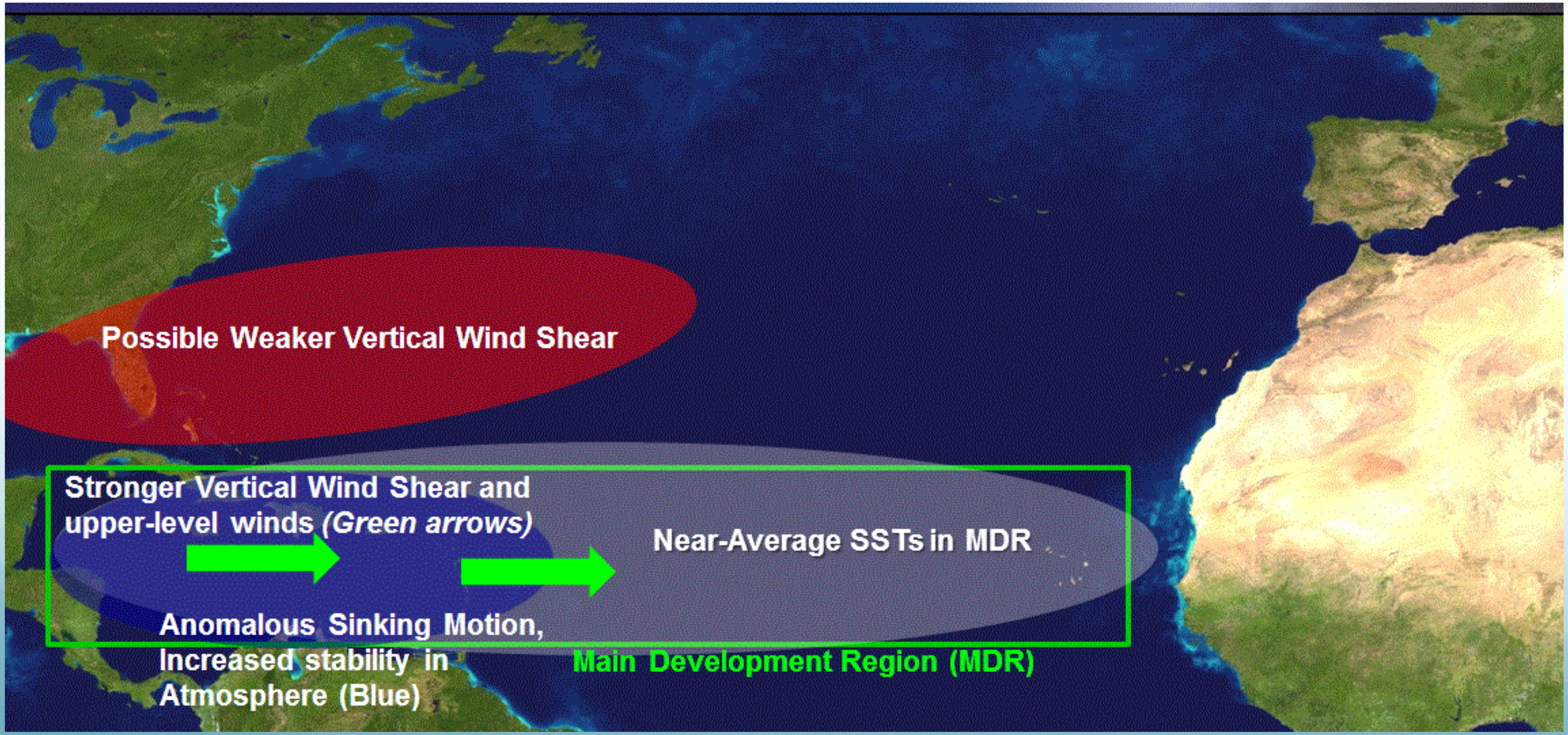
El Niño

- Is the absence of typical cold conditions in the eastern equatorial Pacific
- anomaly (difference from average conditions)
- El Niño is associated with a shift of thunderstorm activity ward along the equator



Impacts of El Niño on hurricanes

- Increases the environmental vertical wind shear in the Tropical Atlantic
- Decreases the environmental vertical wind shear in the Eastern Pacific



El Niño Impacts in Atlantic

Climate Change

- Global warming: Greenhouse gas effect
- What is expected to happen:
    - sea-level rise (may make stronger storm surge)
    - More floods/heavy rainfall (warmer air holds more moisture)
    - More drought (since the air can hold more moisture, surface evaporation will increase)

Climate Change & hurricane

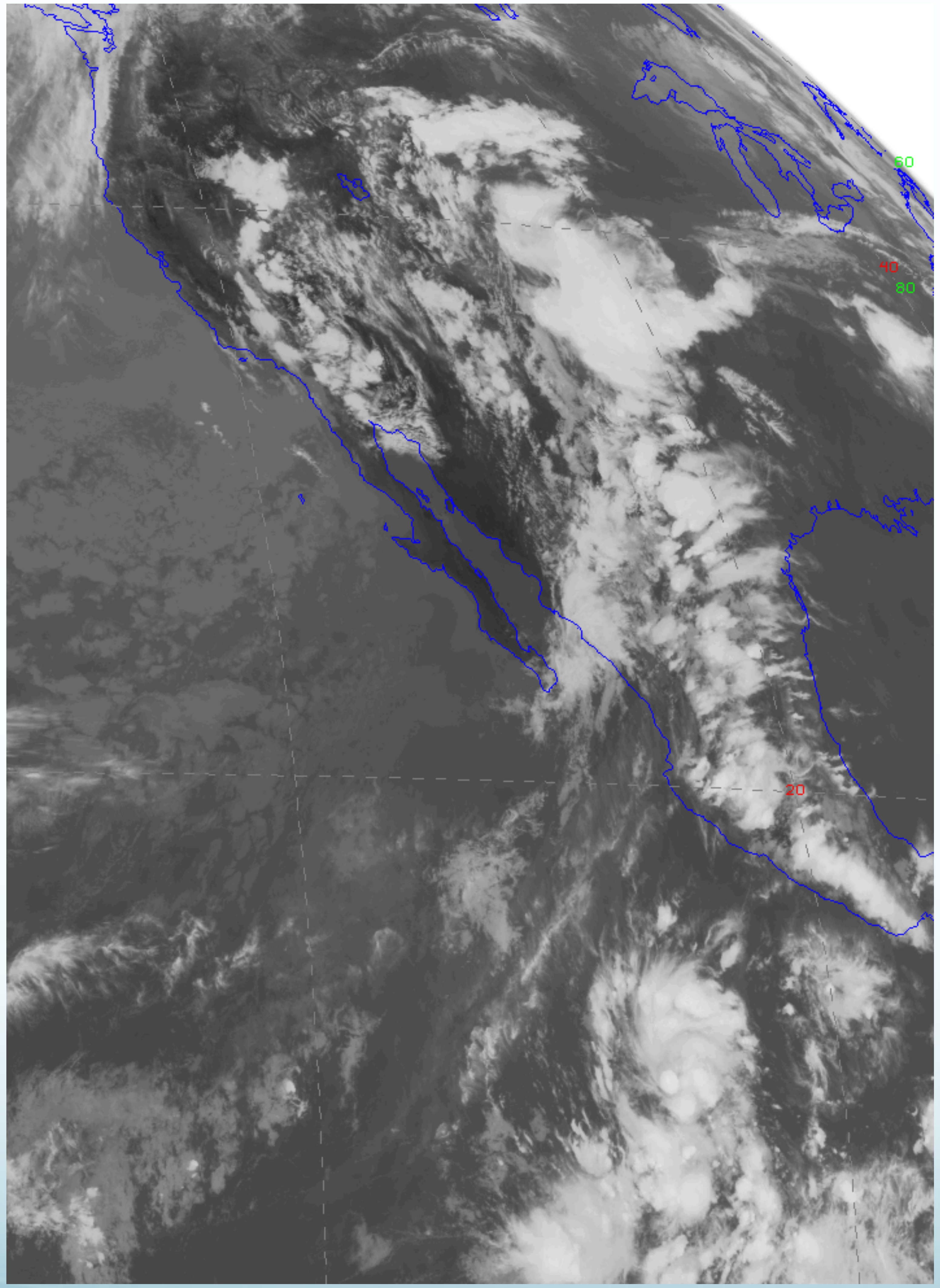
- Warmer temperatures means: Warmer ocean & More water vapor in the air
- But also need to think about wind shears.

  Prediction of increased shear over the Gulf of Mexico could act to weaken hurricanes
- Recent model results are suggesting fewer but more intense storms

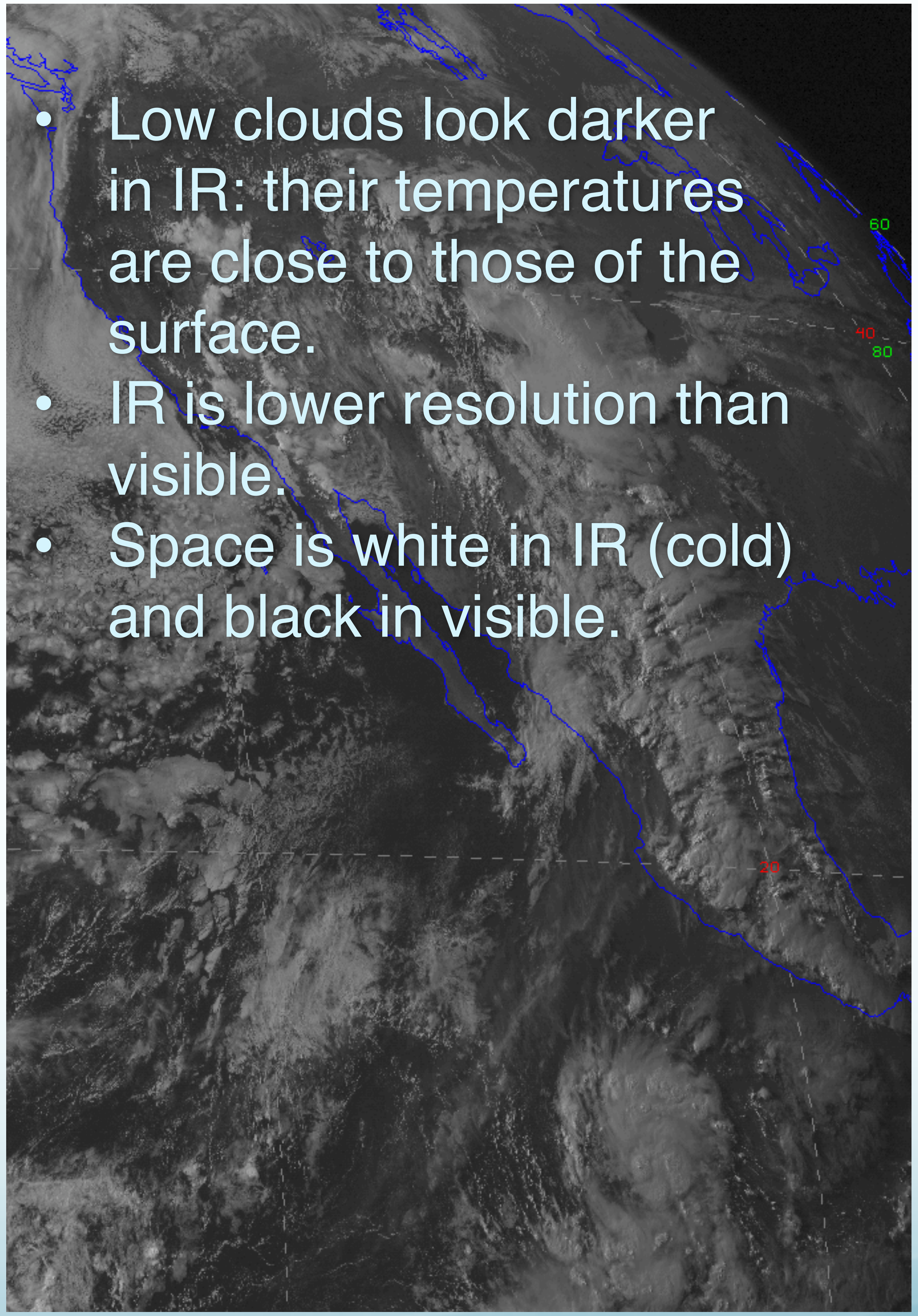
Some historical tropical cyclones…
[More details in the lecture slides]

- Galveston & Ike
- Katrina [2005]
- Superstorm Sandy [2012]
- Harvey, Irma, Maria [2017]
- Cyclone Nargis [2008]

Visible and IR, which is which?



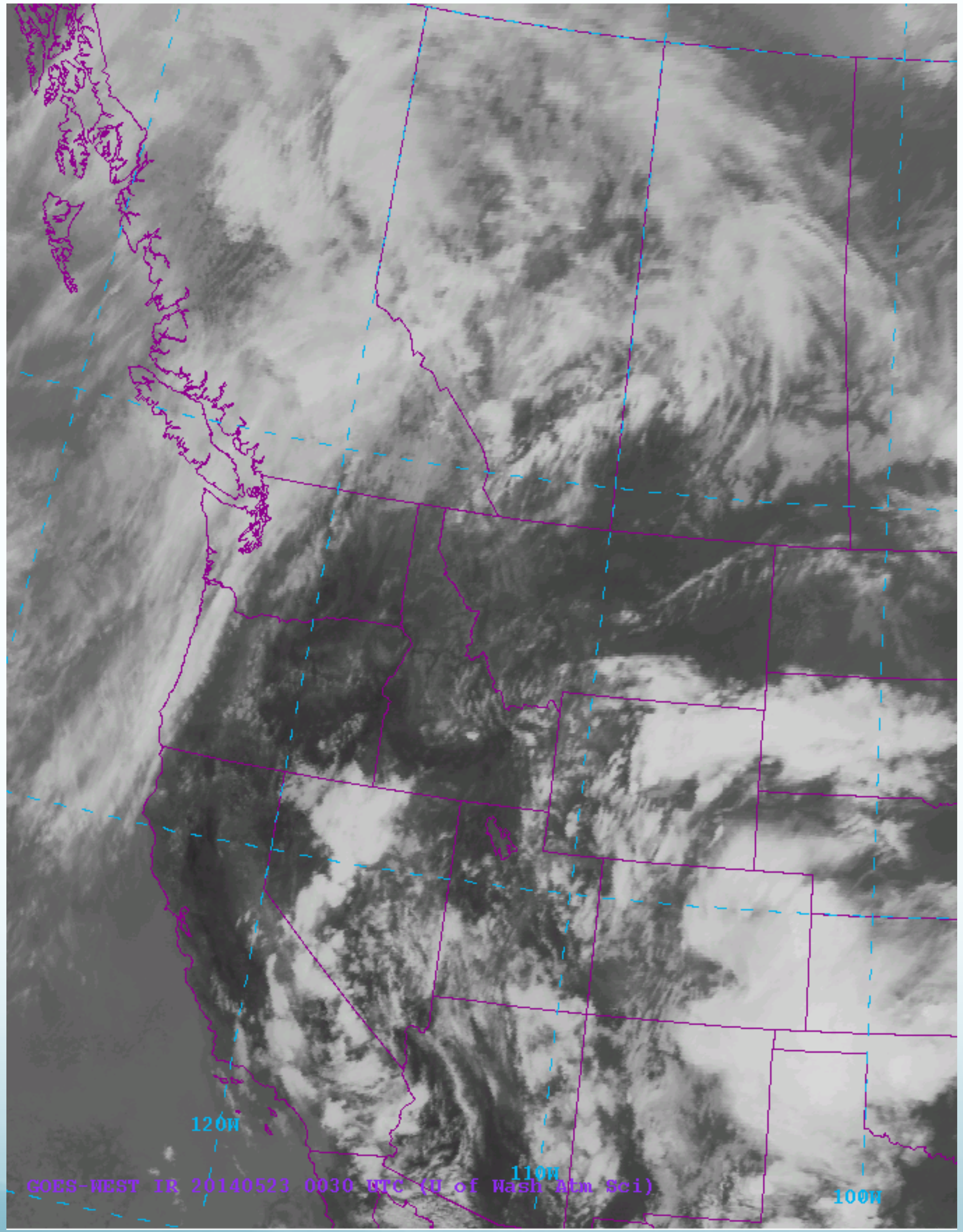
IR



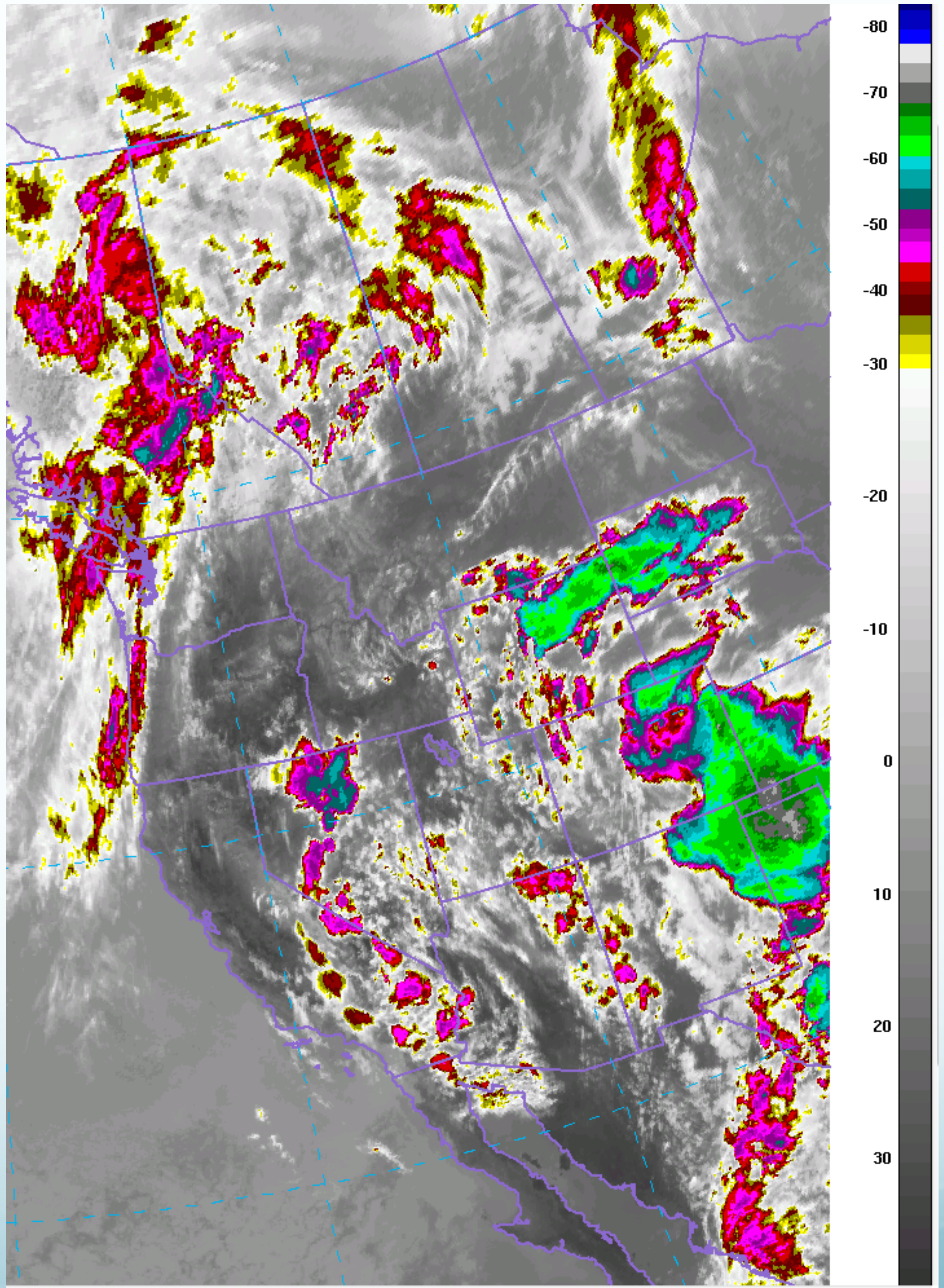
- Low clouds look darker in IR: their temperatures are close to those of the surface.
- IR is lower resolution than visible.
- Space is white in IR (cold) and black in visible.

Visible

Color can be added to IR images to highlight the coldest (highest) clouds.



Standard IR



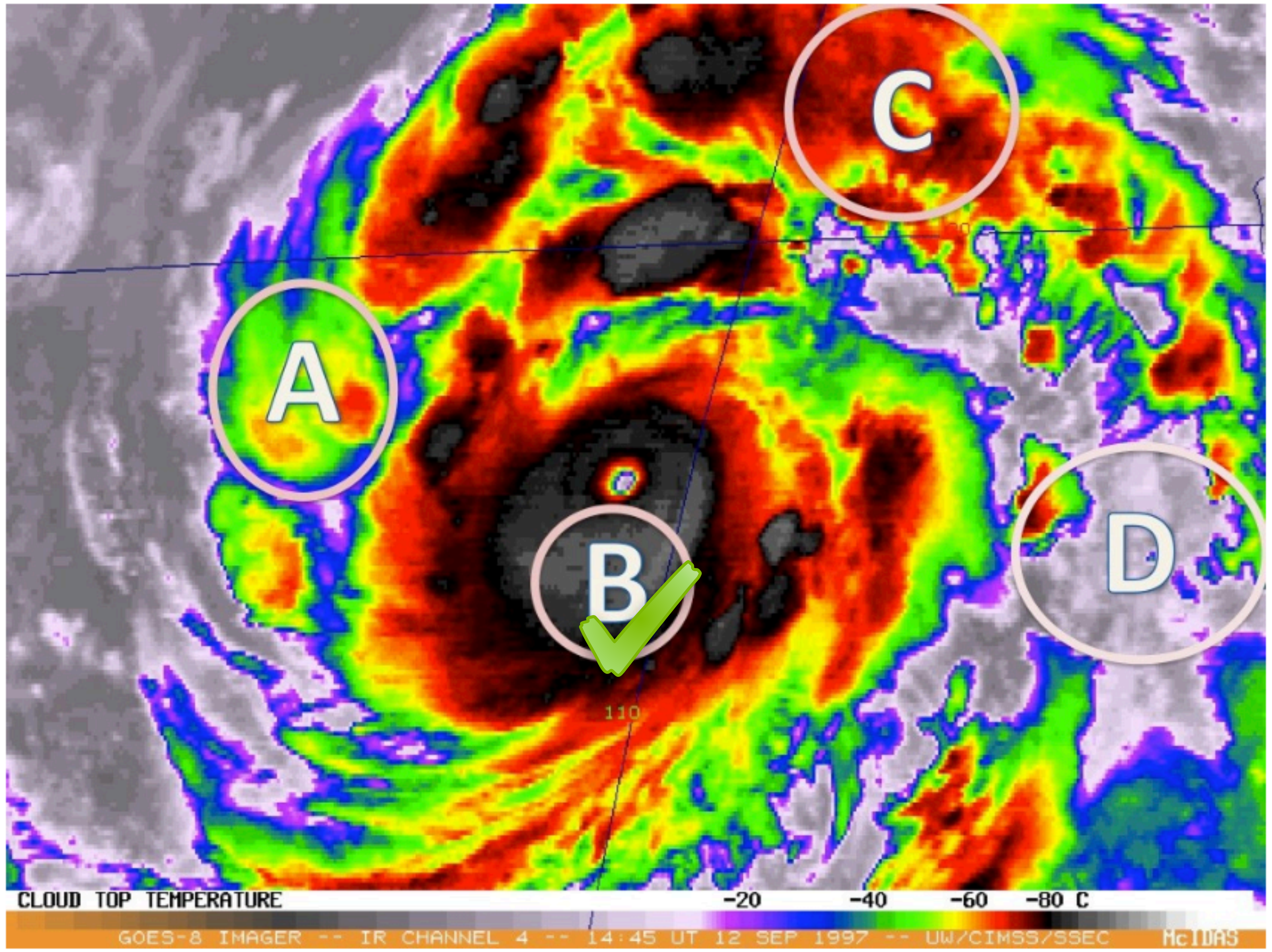
Enhanced IR

Satellite Imagery

Visible images	IR images
The visible images display the earth very similar to how humans see it with their eyes or how typical cameras view it.	Infrared satellites are measuring the of the clouds. The higher the cloud tops are, the colder they will be. They can display multi-colors to highlight temperatures.
Not useful at night Cannot loop images for long periods.	Images available night and day.
On visible satellites, clouds are thicker when they looks brighter. In Visible, you may see cloud texture. Space is black in visible image.	Low clouds (warmer) are , high clouds (colder) are IR is lower resolution than visible. Space is white in IR (cold)

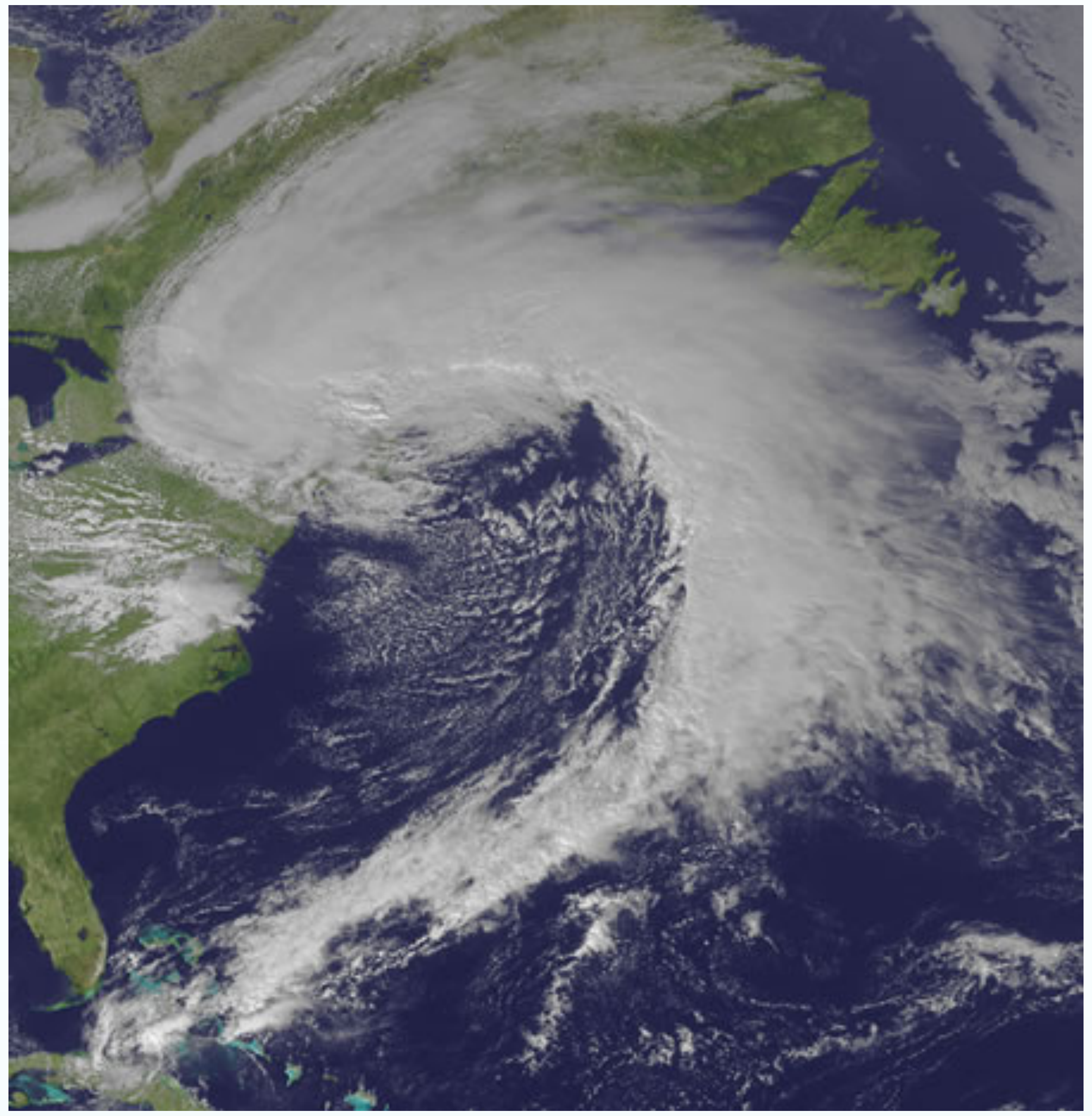
Quiz 8

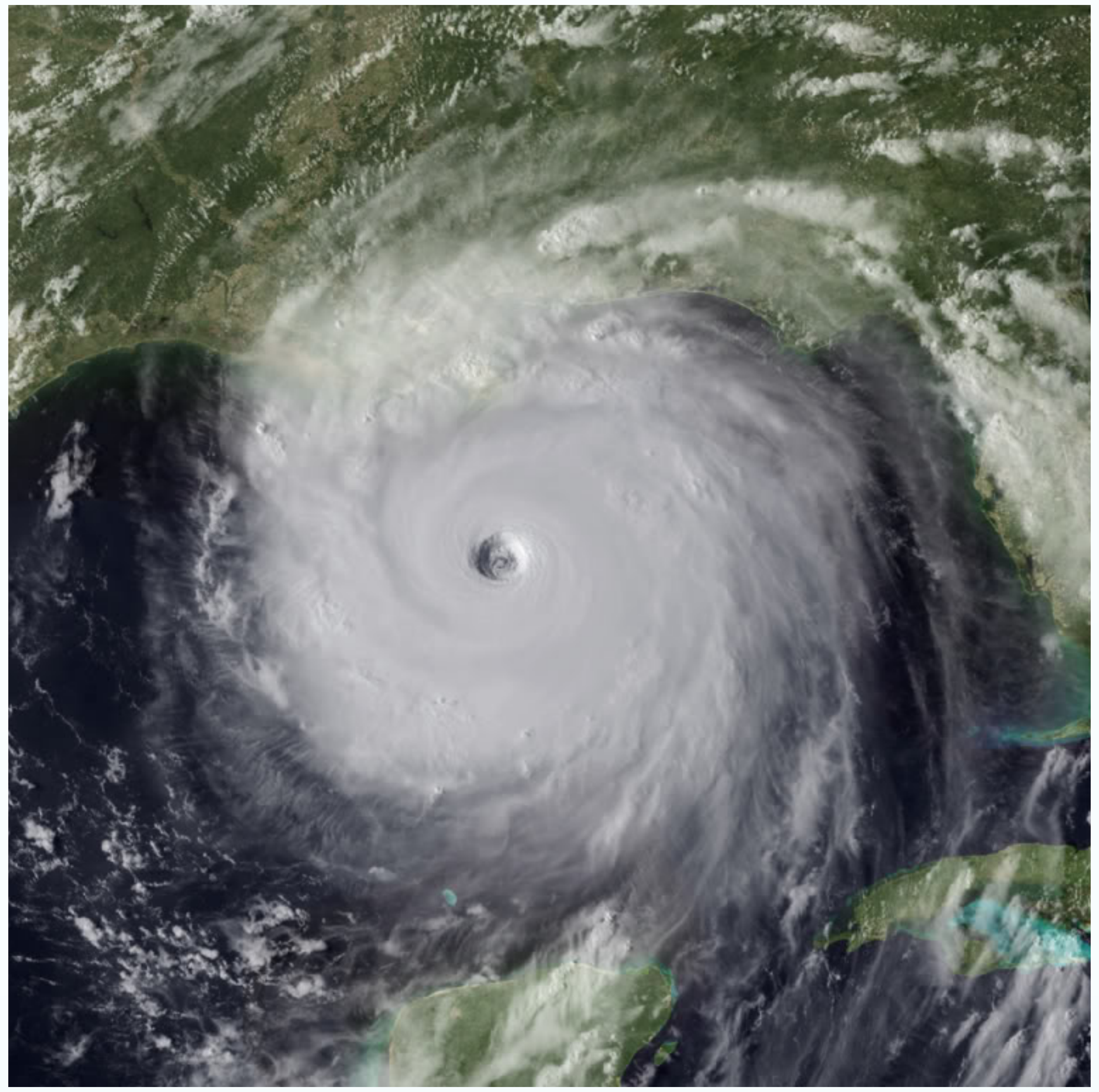
The image below depicts an enhanced infrared (IR) image of a tropical cyclone with the color-temperature scale located at the bottom of the image. In which region are the cloud tops the highest? (Higher clouds are colder because their temperature is similar to that in their environment, which decreases with height.)



Hurricanes [more]

Tropical Cyclone or Midlatitude-Cyclone?

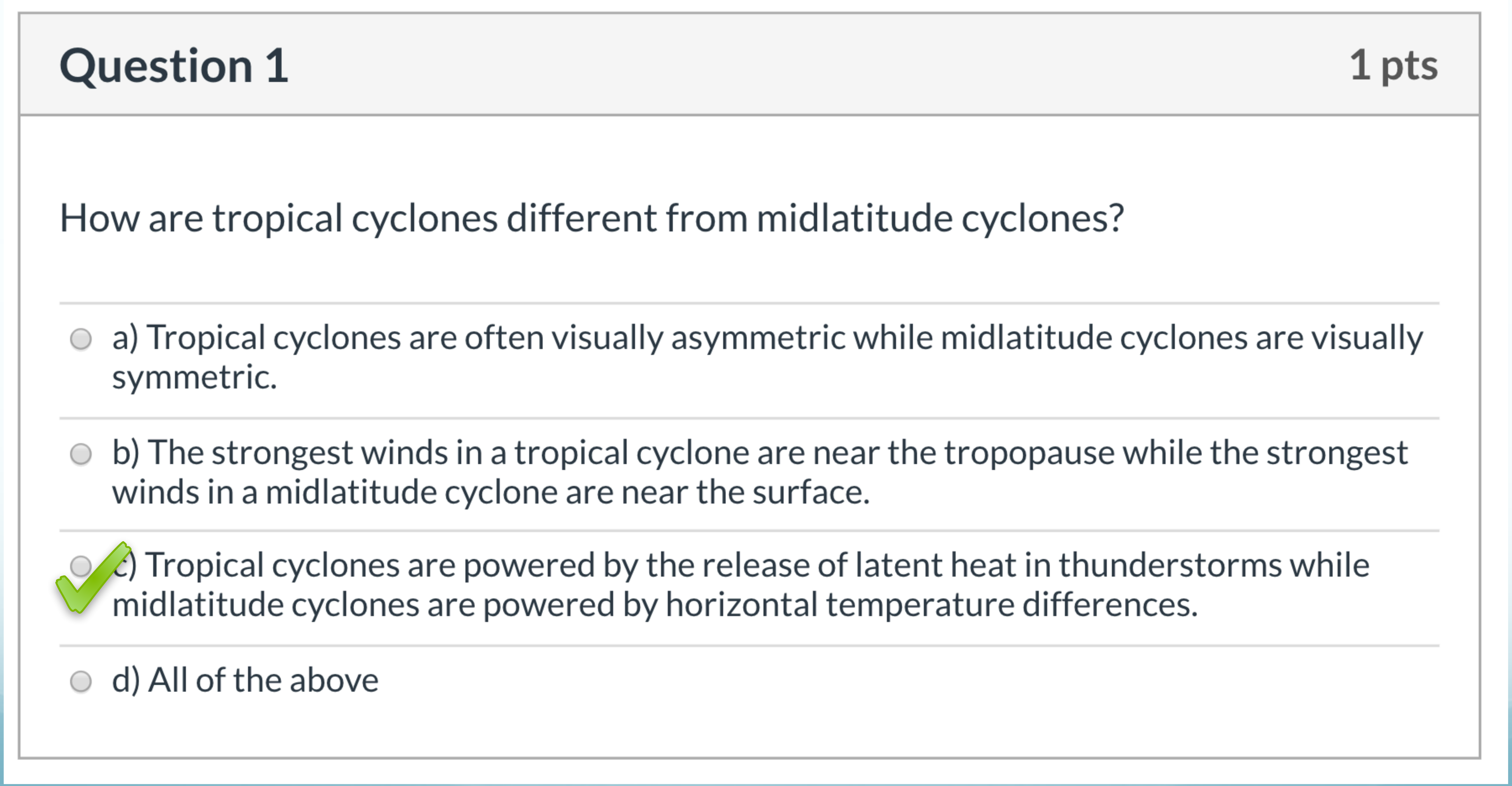




Symmetry? eye? fronts?

Powered by?

Quiz 7



Question 1 **1 pts**

How are tropical cyclones different from midlatitude cyclones?

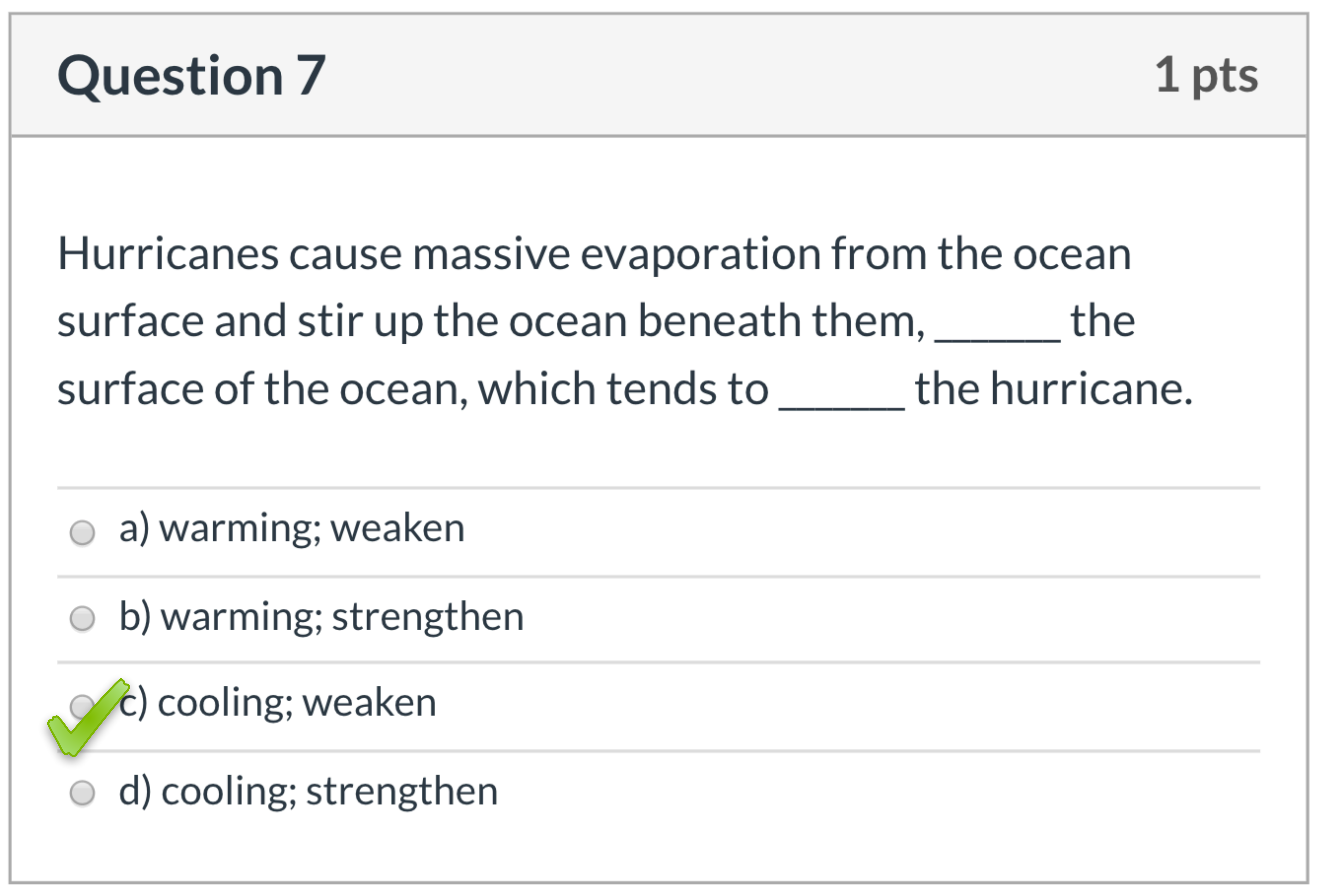
○ a) Tropical cyclones are often visually asymmetric while midlatitude cyclones are visually symmetric.

○ b) The strongest winds in a tropical cyclone are near the tropopause while the strongest winds in a midlatitude cyclone are near the surface.

○ ✓ c) Tropical cyclones are powered by the release of latent heat in thunderstorms while midlatitude cyclones are powered by horizontal temperature differences.

○ d) All of the above

Quiz 7

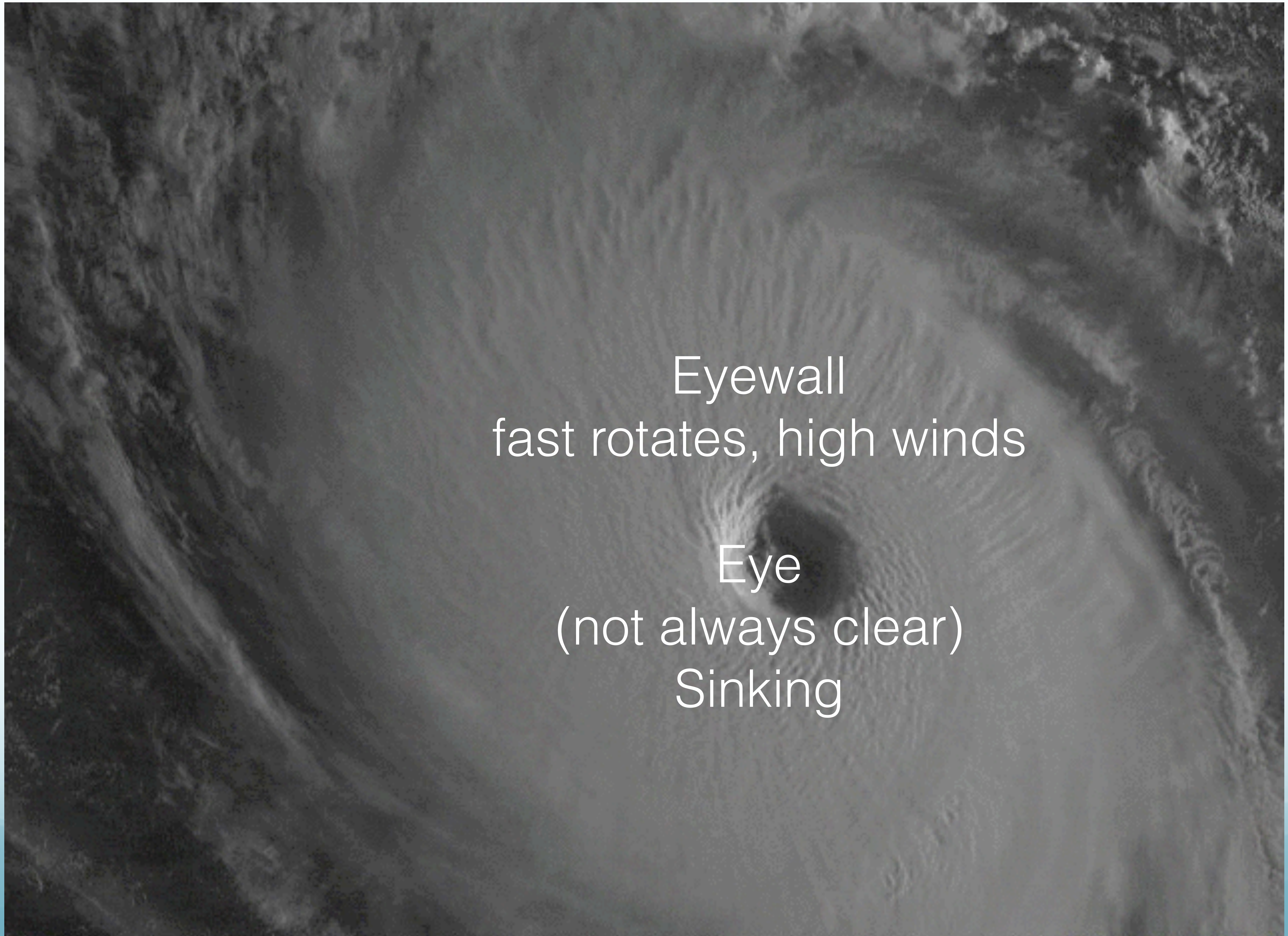


Question 7 **1 pts**

Hurricanes cause massive evaporation from the ocean surface and stir up the ocean beneath them, ______ the surface of the ocean, which tends to ______ the hurricane.

- ○ a) warming; weaken
- ○ b) warming; strengthen
- [✓ c) cooling; weaken]
- ○ d) cooling; strengthen

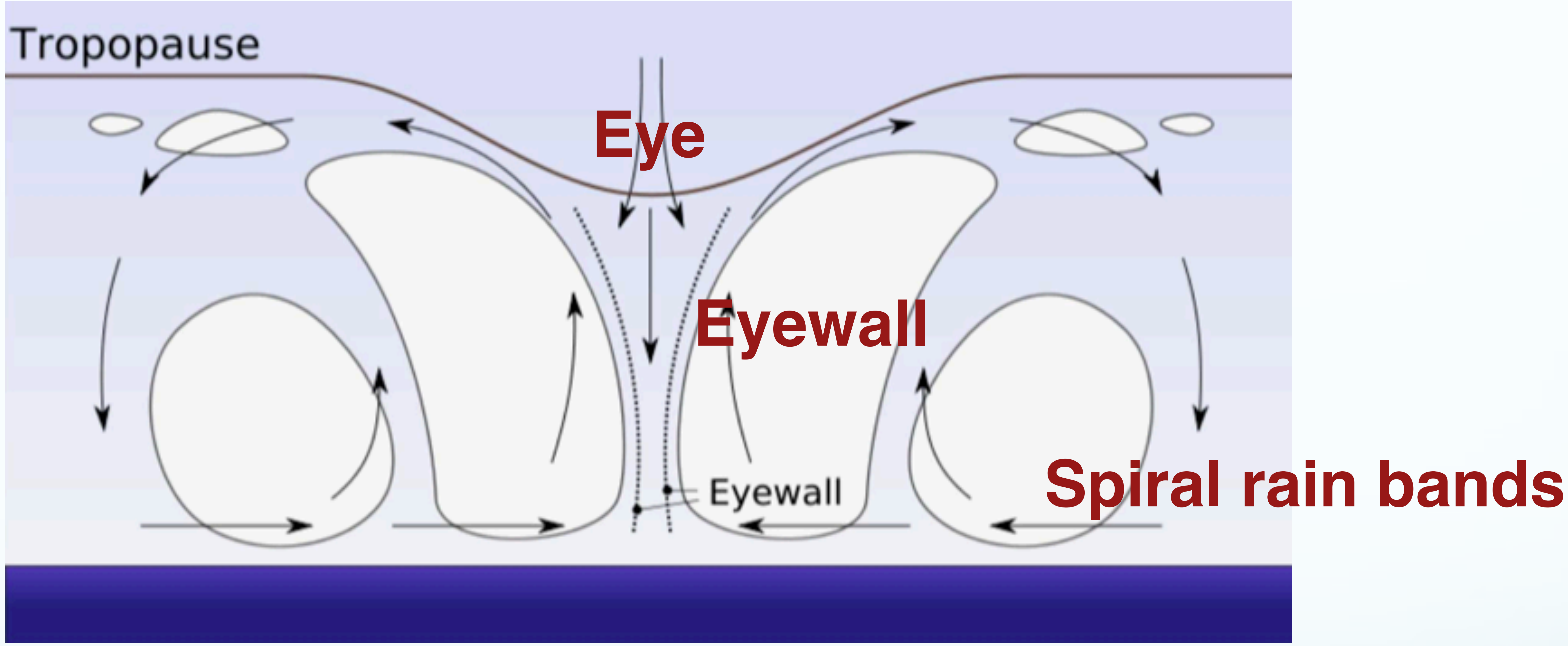
Basic structure



Eyewall
fast rotates, high winds

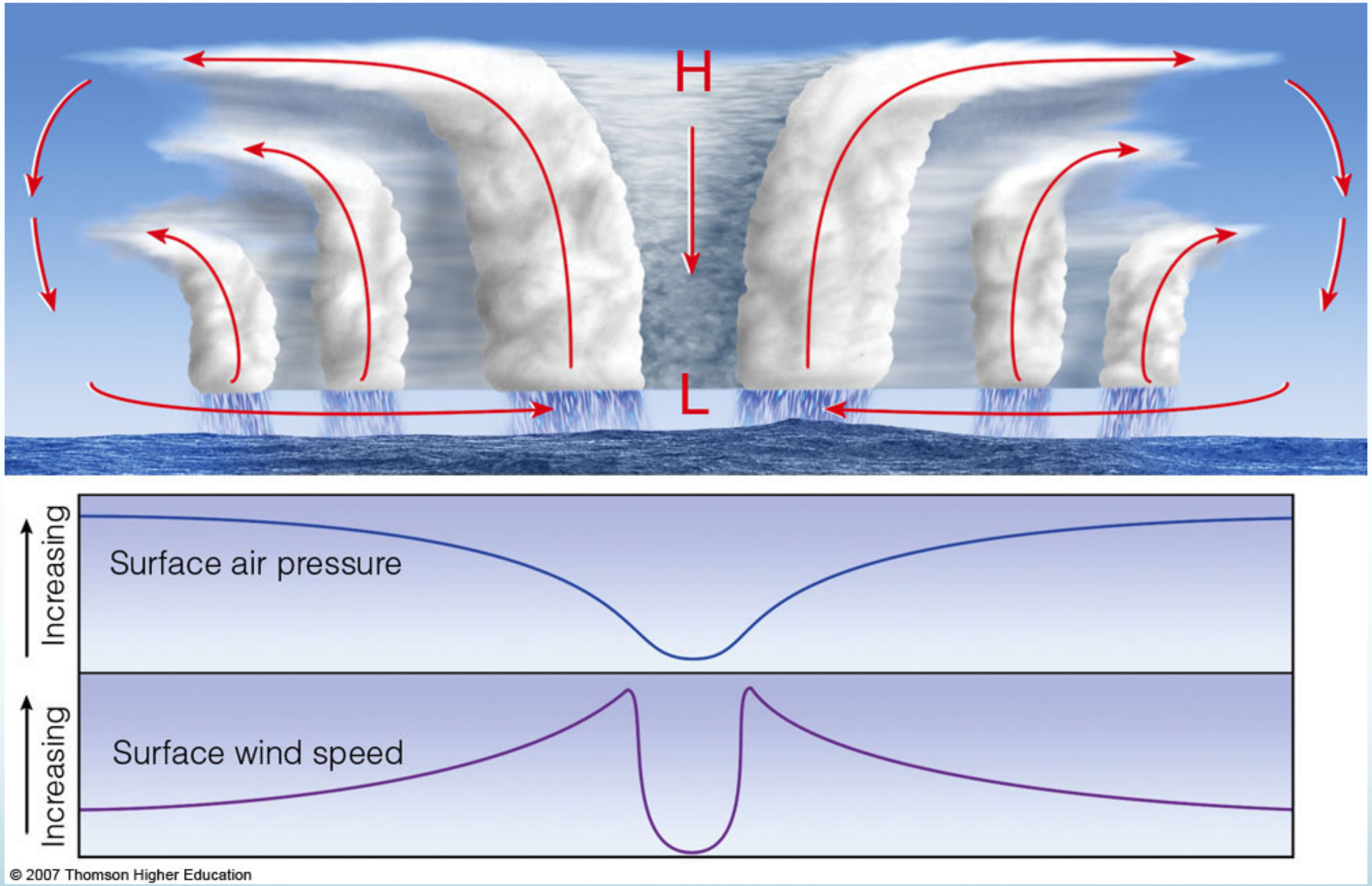
Eye
(not always clear)
Sinking

Basic structure



Where is maximum surface speed?
Where is minimum air pressure?
At the same level, which place is wamer?

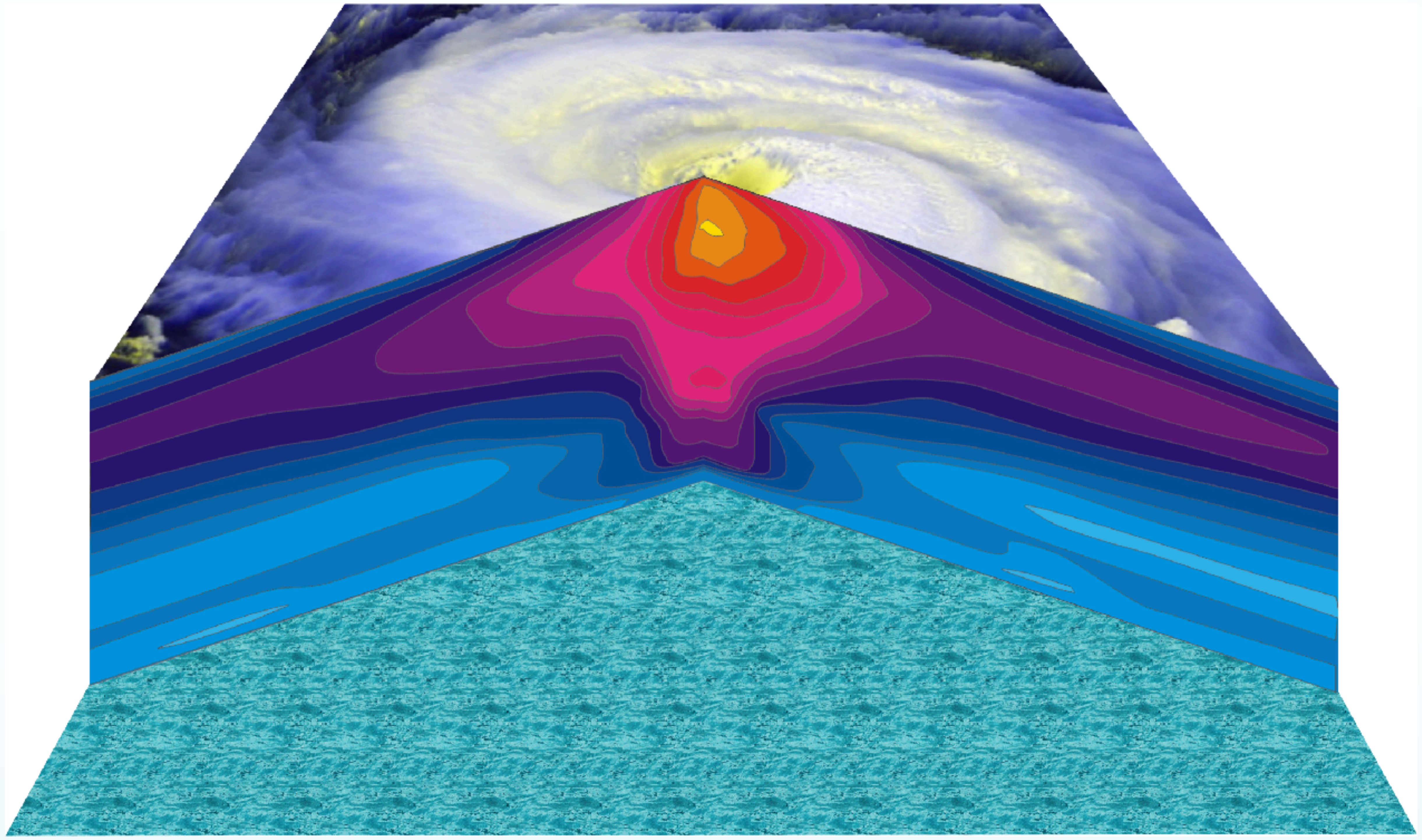
pressure and wind profile



© 2007 Thomson Higher Education

Quiz 7

Temperature profile



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

Mid-term2

Which of the following is a feature associated with tropical cyclones?

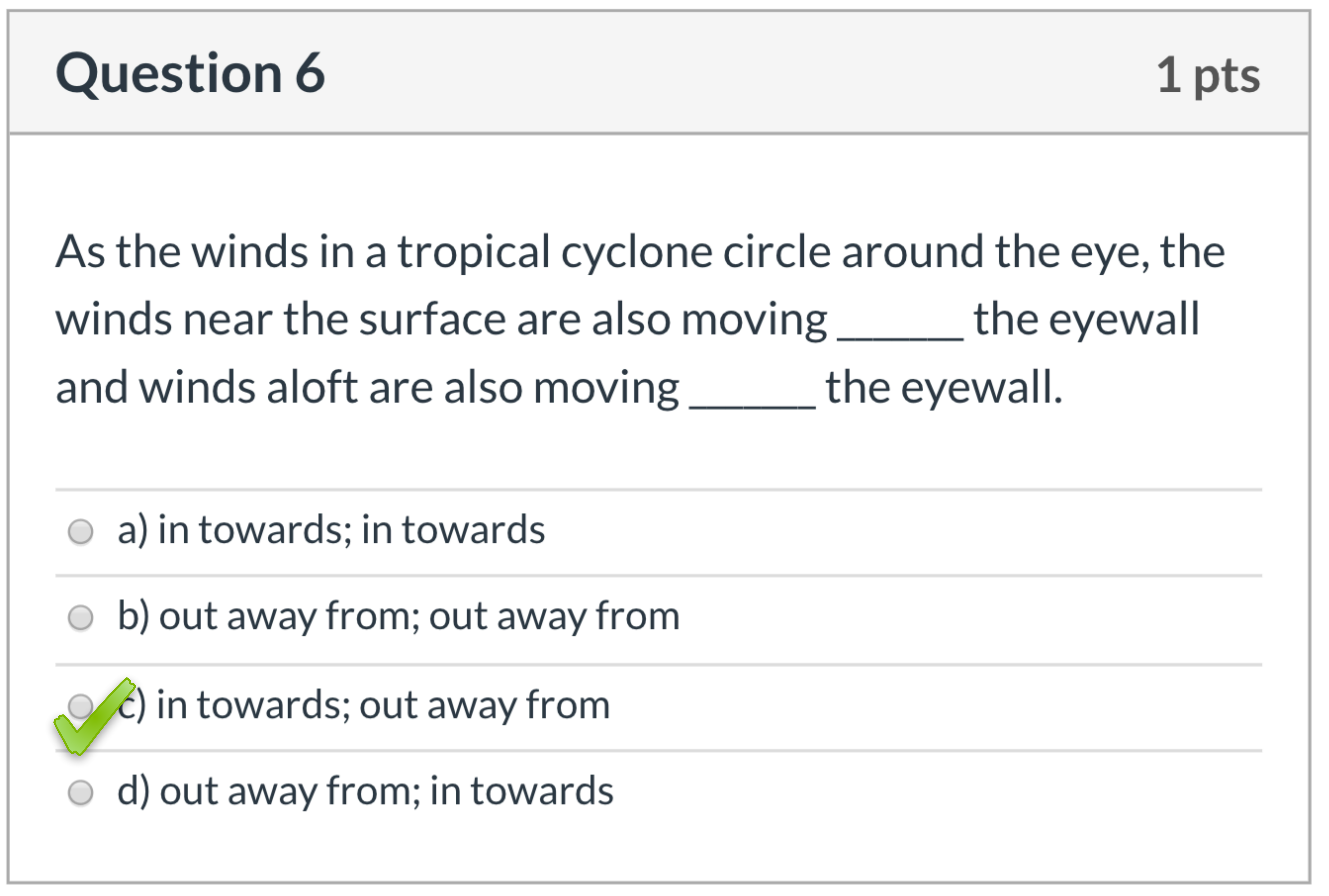
A) Their cloud pattern, viewed from above, is distributed very asymmetrically

B) They are powered by north-south differences in temperature

[✓ C) Their winds are strongest near the surface and weaken near the top of the storm]

D) All of the above are features of tropical cyclones

Quiz 7



Question 6

1 pts

As the winds in a tropical cyclone circle around the eye, the winds near the surface are also moving ______ the eyewall and winds aloft are also moving ______ the eyewall.

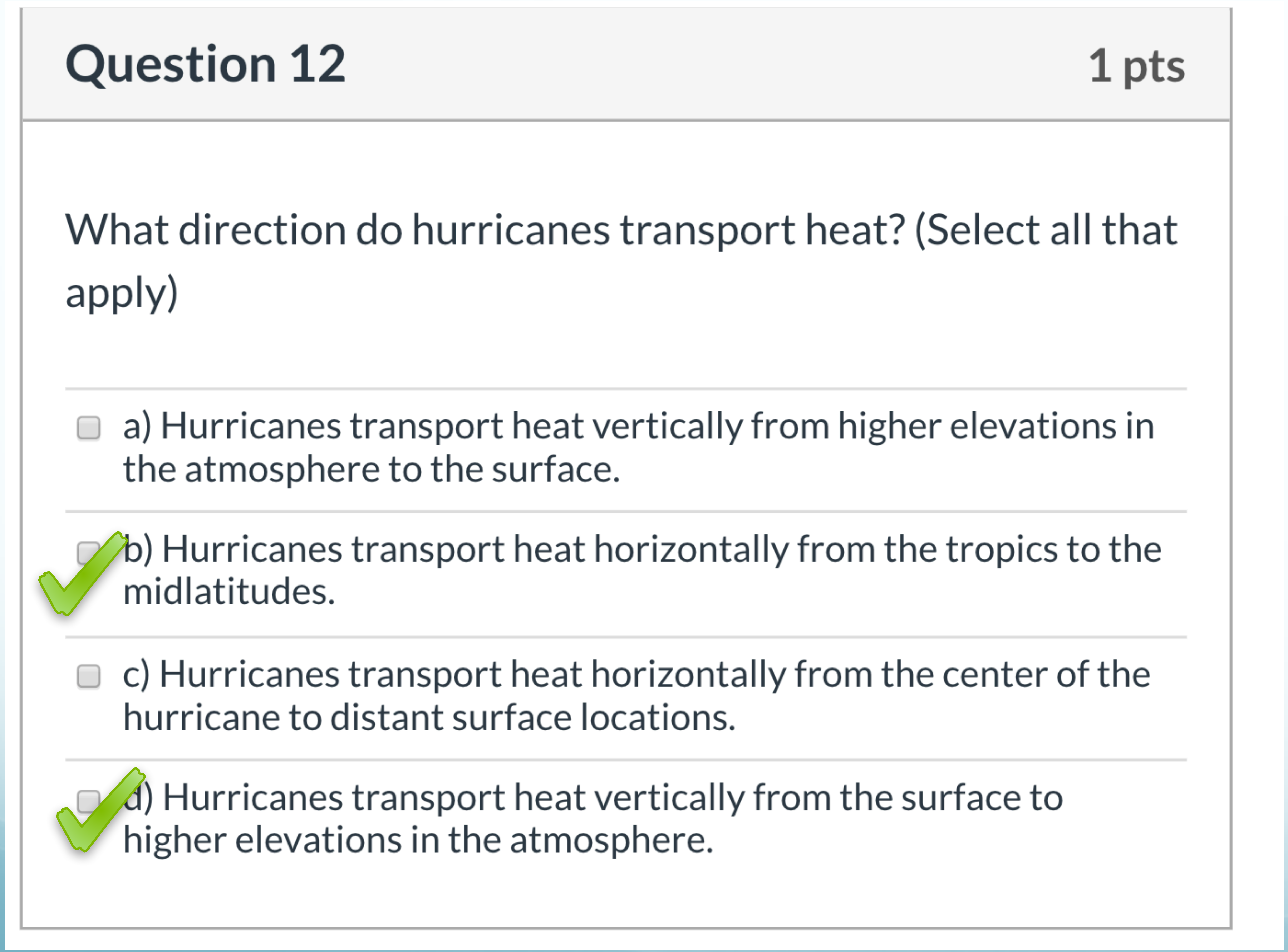
○ a) in towards; in towards

○ b) out away from; out away from

○ ✓ c) in towards; out away from

○ d) out away from; in towards

Quiz 7



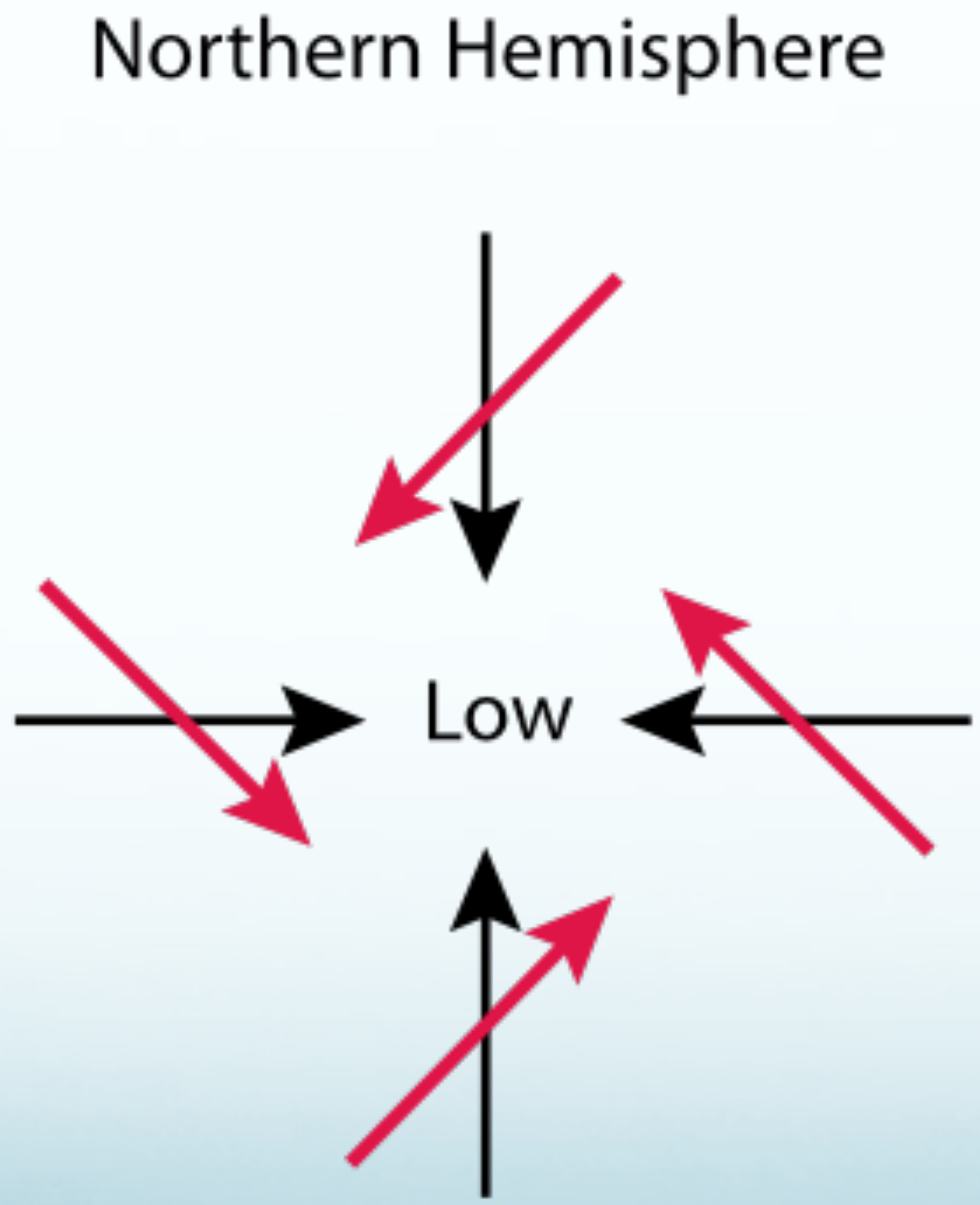
Question 12 **1 pts**

What direction do hurricanes transport heat? (Select all that apply)

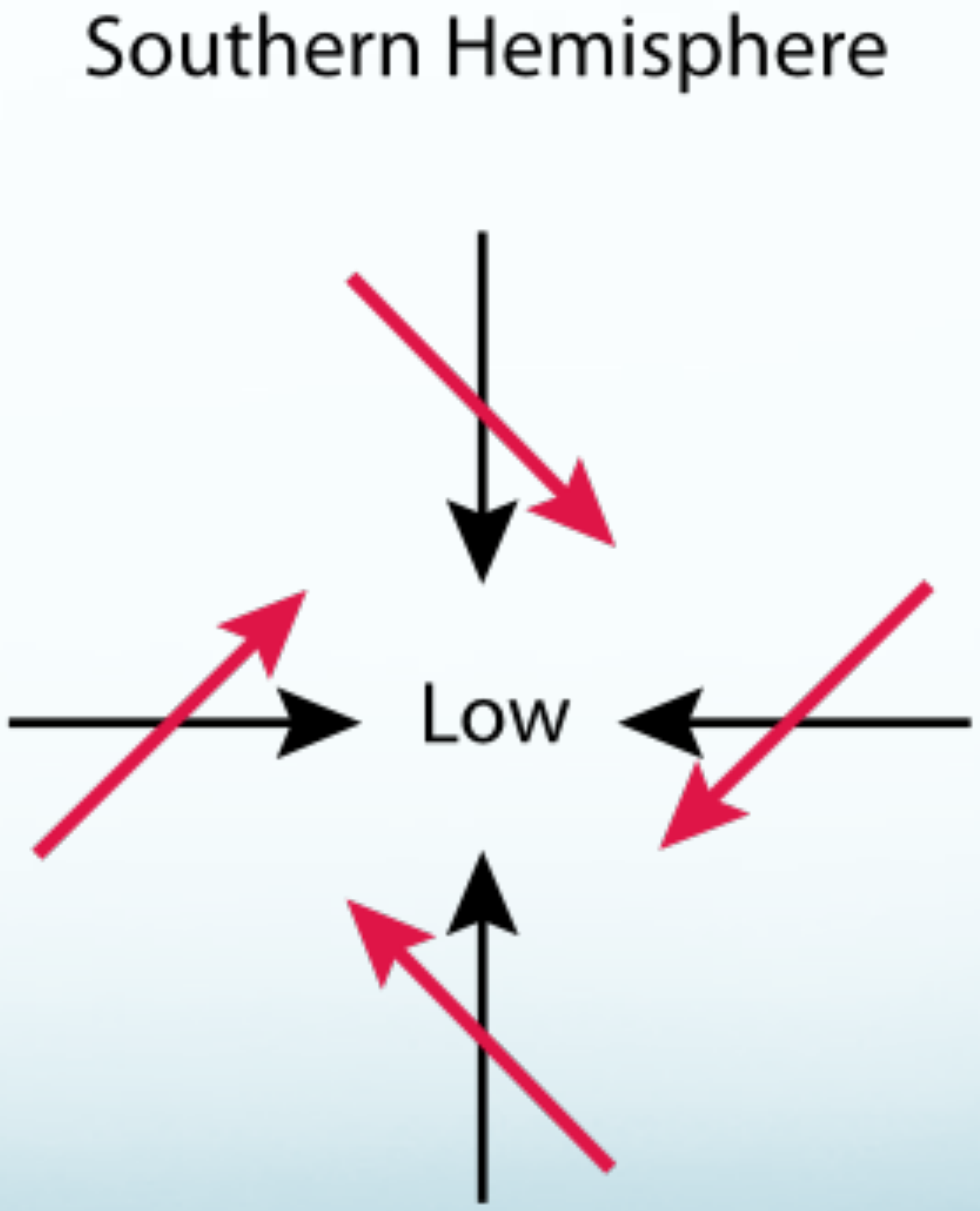
- ☐ a) Hurricanes transport heat vertically from higher elevations in the atmosphere to the surface.
- ☑ b) Hurricanes transport heat horizontally from the tropics to the midlatitudes.
- ☐ c) Hurricanes transport heat horizontally from the center of the hurricane to distant surface locations.
- ☑ d) Hurricanes transport heat vertically from the surface to higher elevations in the atmosphere.

Rotation direction of hurricanes

- Caused by Coriolis force



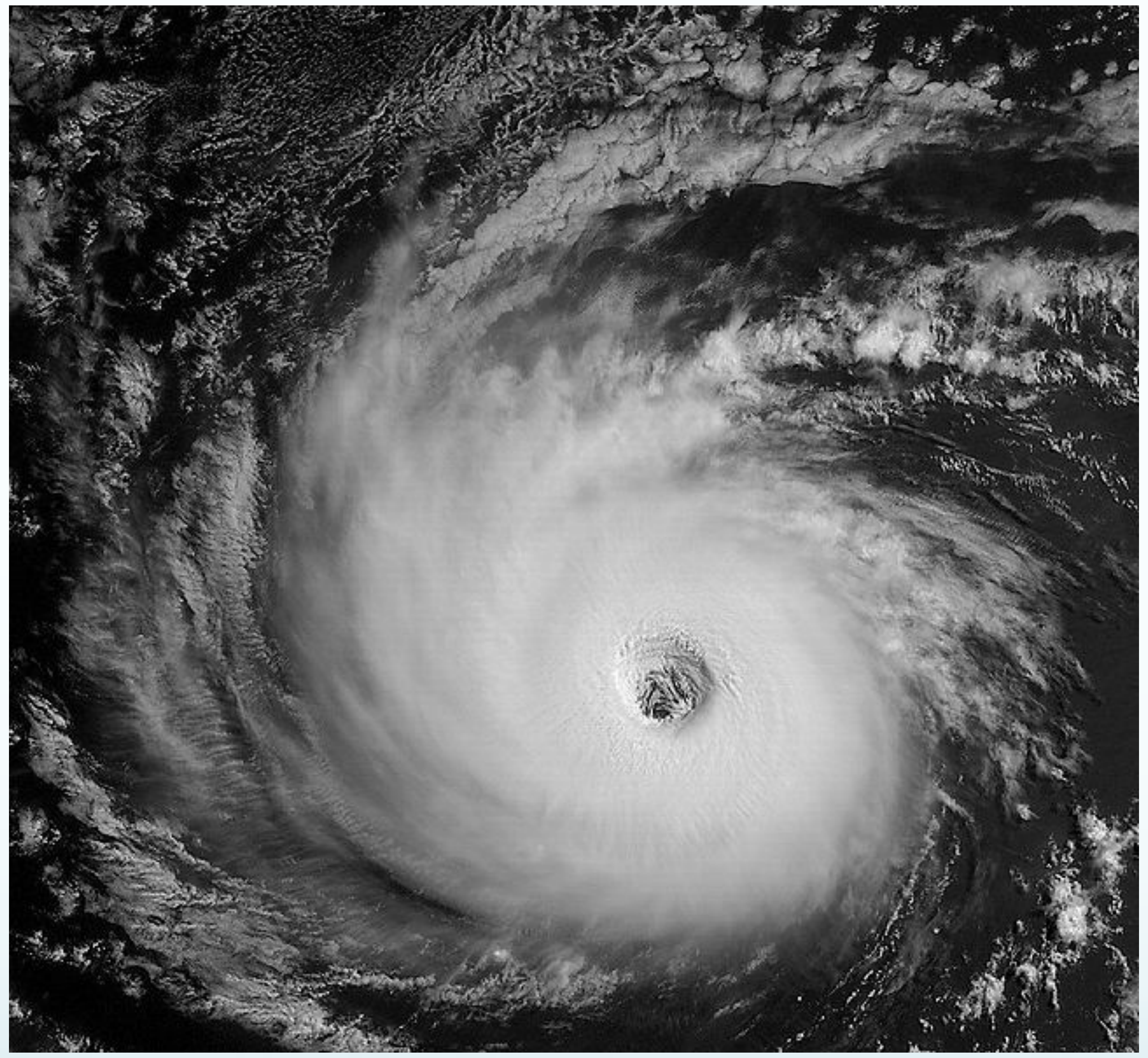
Winds turned to the right (red)



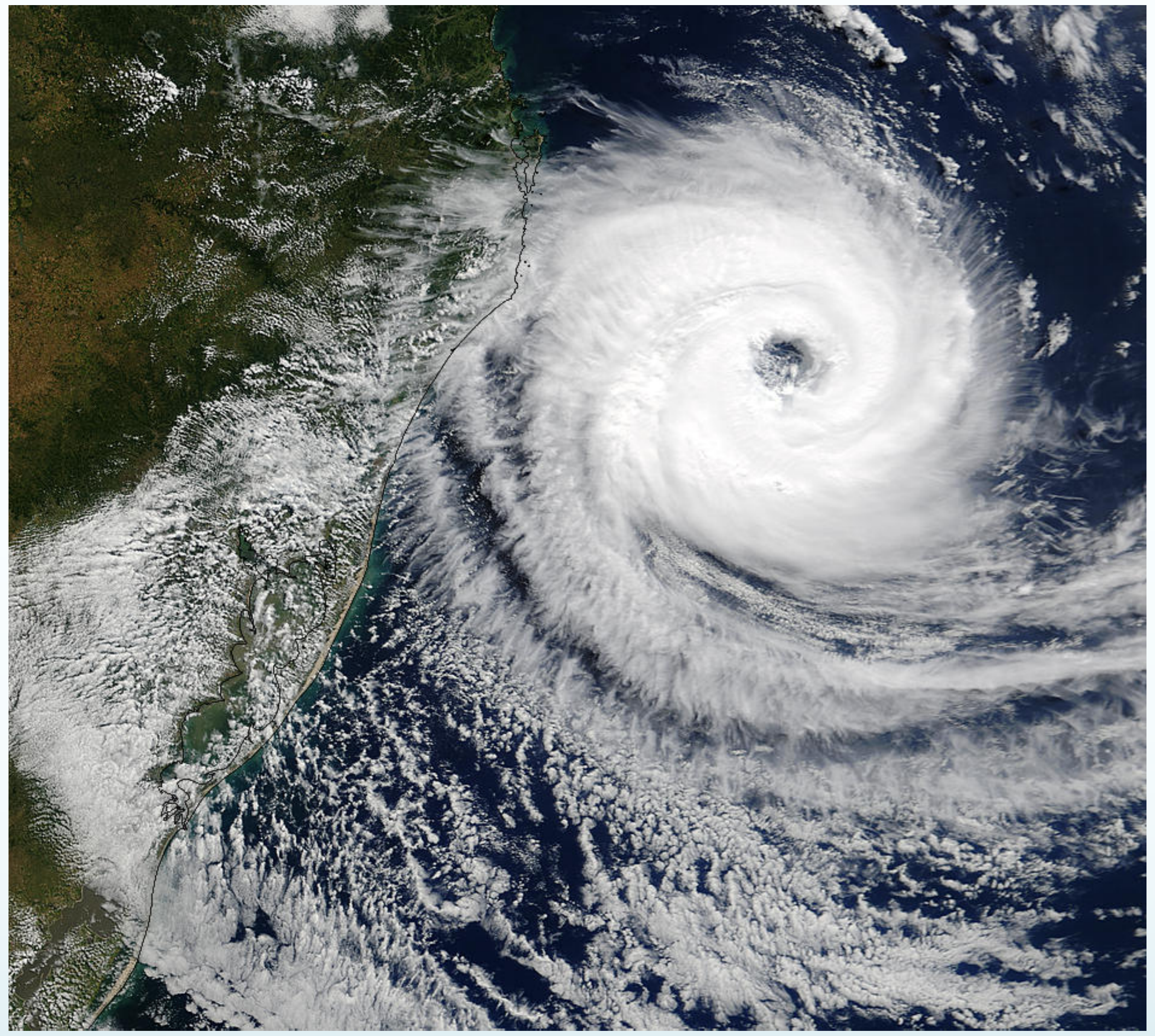
Winds turned to the left

Rotation direction of hurricanes

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



Northern Hemisphere
(Counterclockwise)



Southern Hemisphere
(Clockwise)

Mid-term2

The key reason that tornadoes and hurricanes are affected differently by the Coriolis force is their

A) Wind speed

B) Number of hailstones

[✓ C) Time scale]

D) They are affected similarly by the Coriolis force

Tornado

What is tornado?

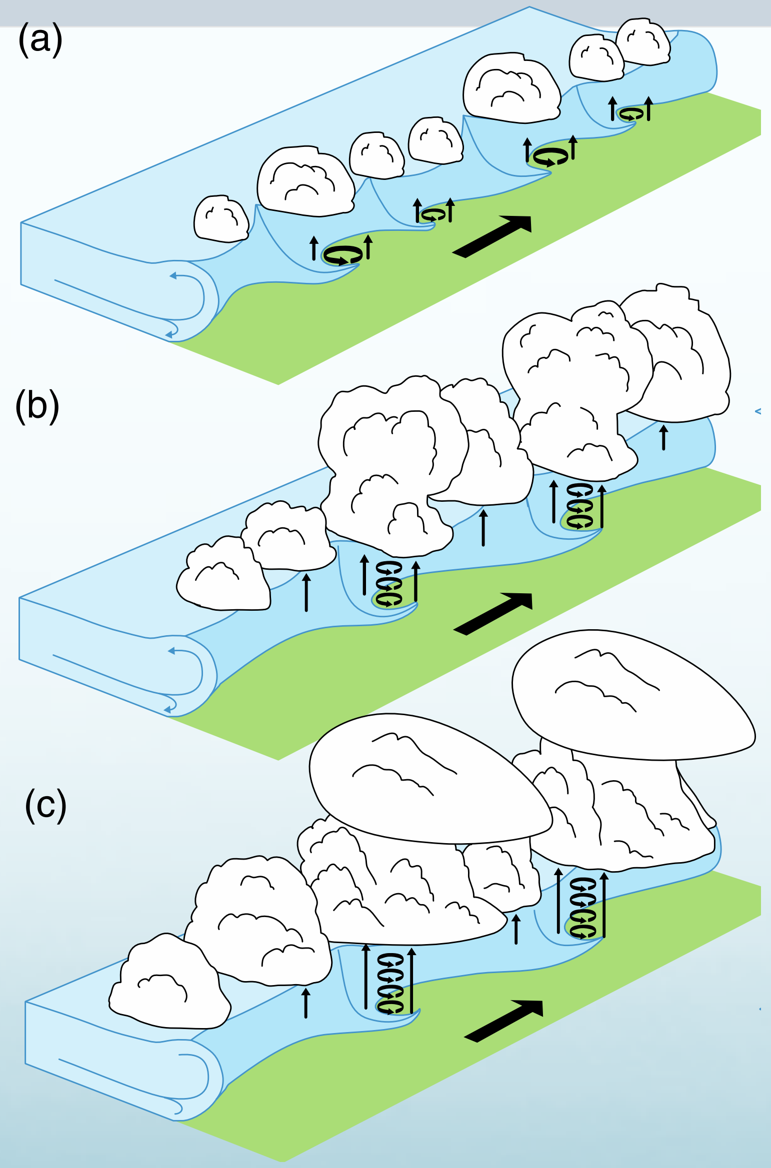
- Definition of a tornado:
  - A violently rotating column of air
  - In contact with the ground
  - Connecting up to a cumulus cloud
  - Often (not always) visible as a funnel cloud

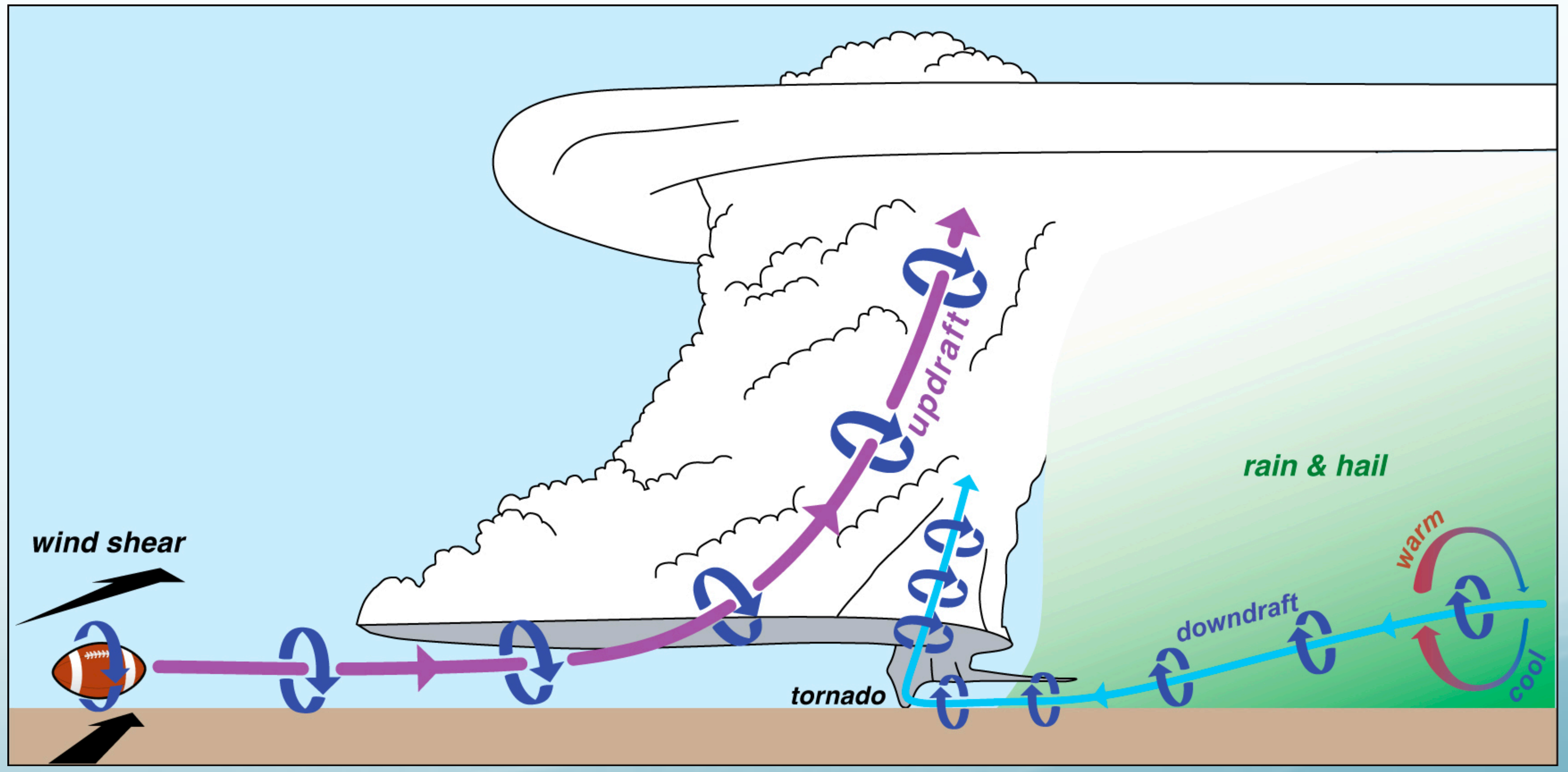
What makes a tornado?

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

Two types of tornadoes

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





along a shear line!

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	

Waterspouts

Landspouts

Mid-term2

What important formation mechanism do all types of tornadoes have in common?

A) The tilting of horizontal wind shear into the vertical

B) The deflection of air rushing into a surface low pressure center by the Coriolis force, which creates the intense swirling winds

C) Very strong downdrafts within the rotating core

[✓ D) The intensification of rotation about a vertical axis by an updraft]

Tornado safety…

Thunderstorms

Key points:

- Ingredients for thunderstorm
- Different types of thunderstorm: single cell, muticell, supercell

(characteristics, environment, development, hazards)

- Radar basics

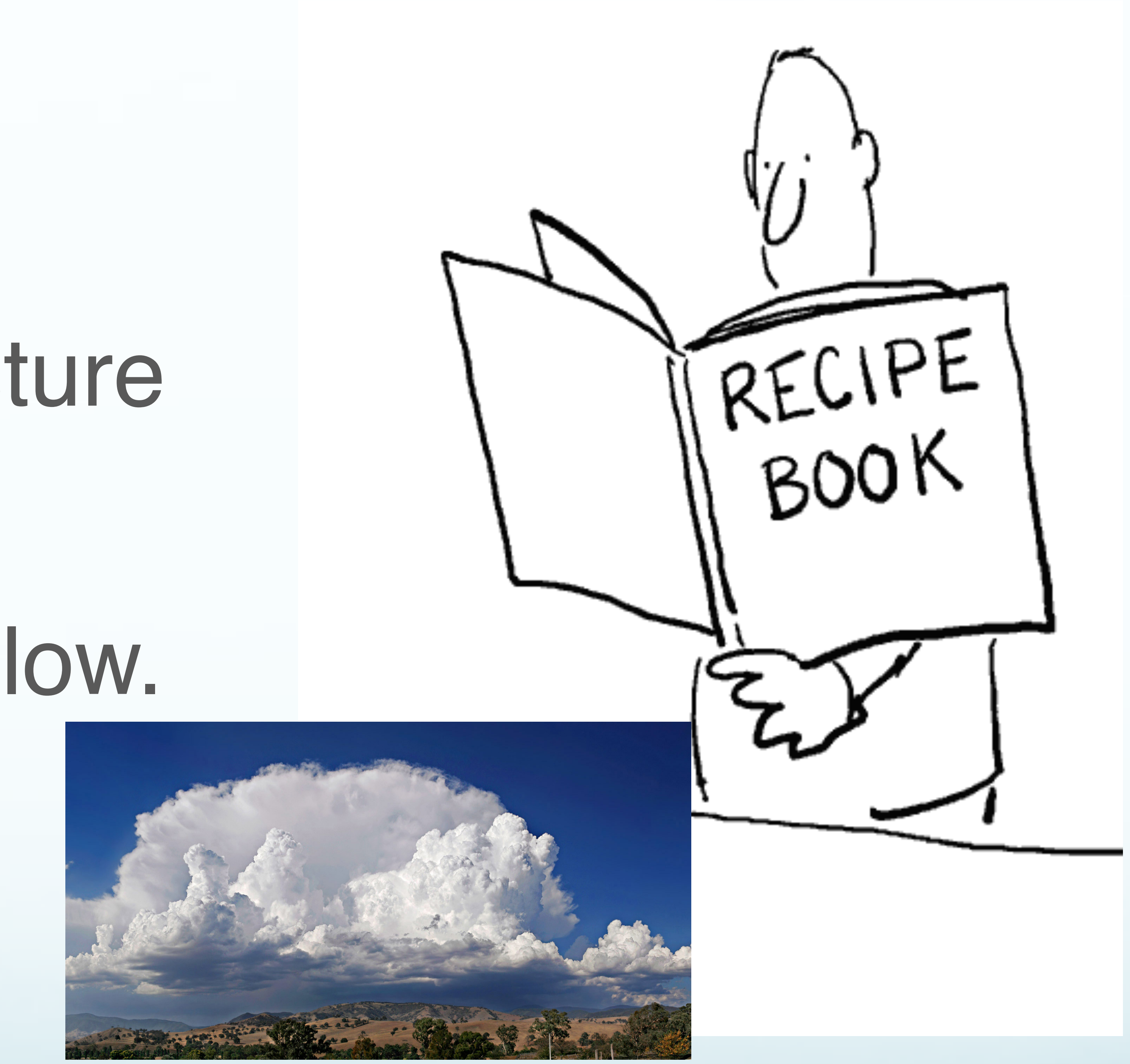
Thunderstorm ingredients

- 1. A suitable lapse rate

conditional instability

- 2. Adequate low-level moisture
  - RH can’t be too low.
  - Dew points can’t be too low.
- 3. Trigger

Lifts the low-level air



Thunderstorm ingredients

- 1. A suitable lapse rate

conditional instability

- 2. Adequate low-level moisture
  - RH can’t be too low.
  - Dew points can’t be too low.
- 3. Trigger

Lifts the low-level air

1 + 2 determines

CAPE
CIN

Thunderstorm ingredients

- CAPE (Convective Available Potential Energy)
  - The total energy that can be released while a rising air parcel is warmer than its environment.

- CIN (Convective InhibitioN)
  - The cap that allows lots of CAPE to build up until conditions are ripe for a thunderstorm.

- A trigger that lifts the low-level air (overcomes the CIN)
  - Surface Heating
  - Lifting at a weather front
  - Lifting of ascending air by mountains

What determines type of thunderstorm?

- CAPE:

The amount by which rising air parcels become warmer than their environment

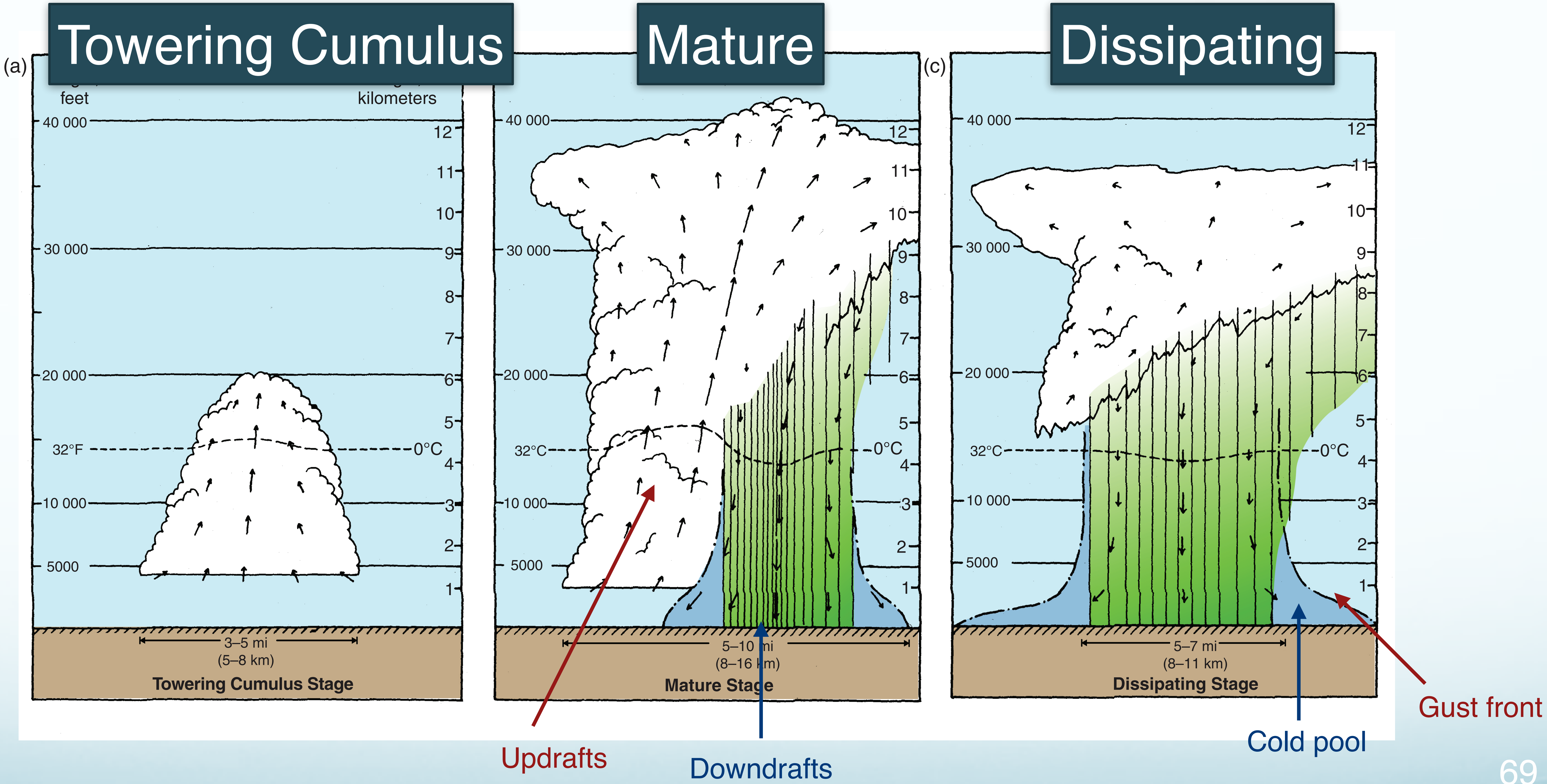
- Low-level Wind Shear

The change with height in the wind’s speed and direction in the lowest 5 km above the ground.

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

Single Cell: Life Cycle

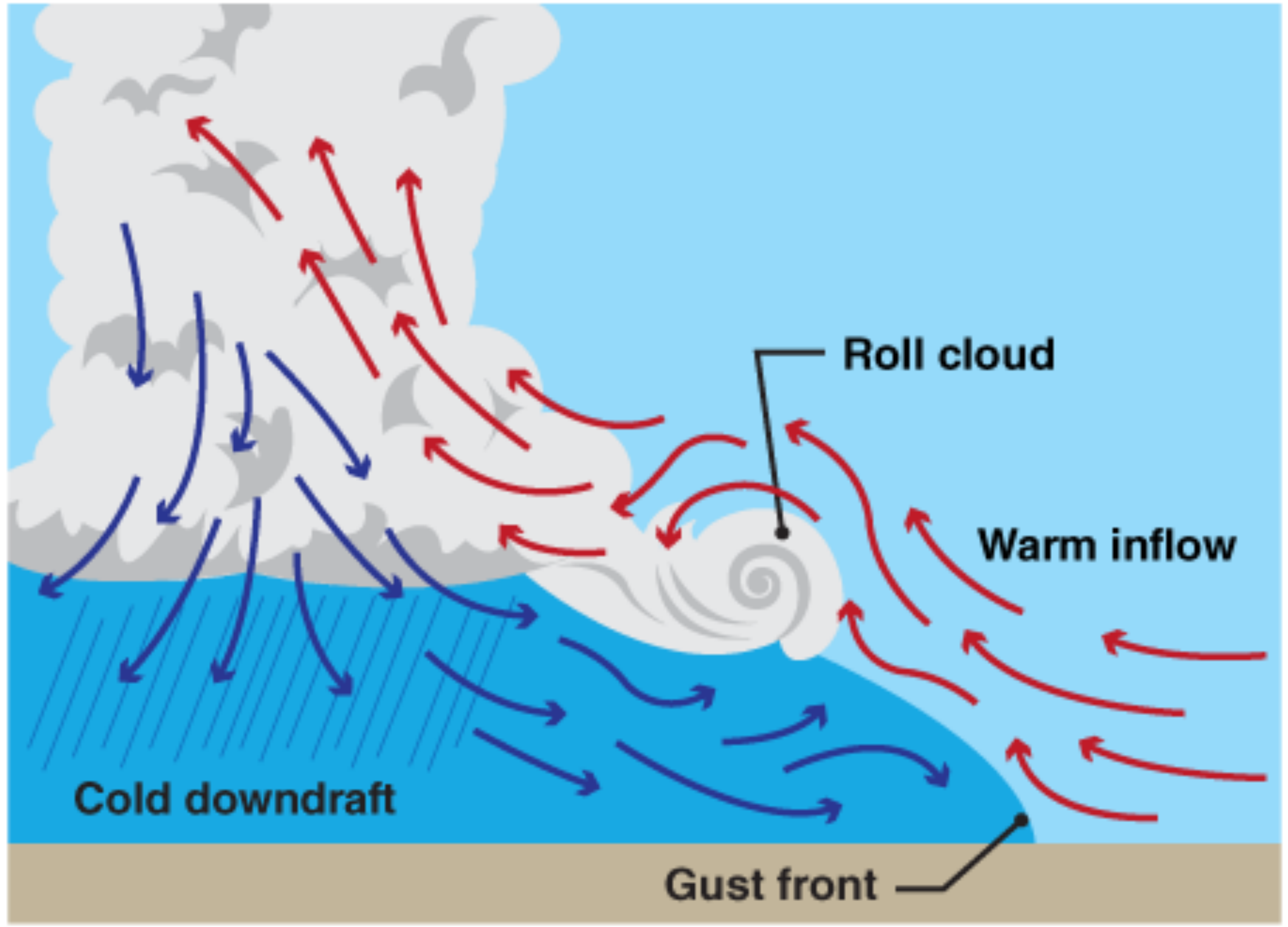


Updrafts updraft & downdraft downdraft

cutoff by the spreading cold pool.

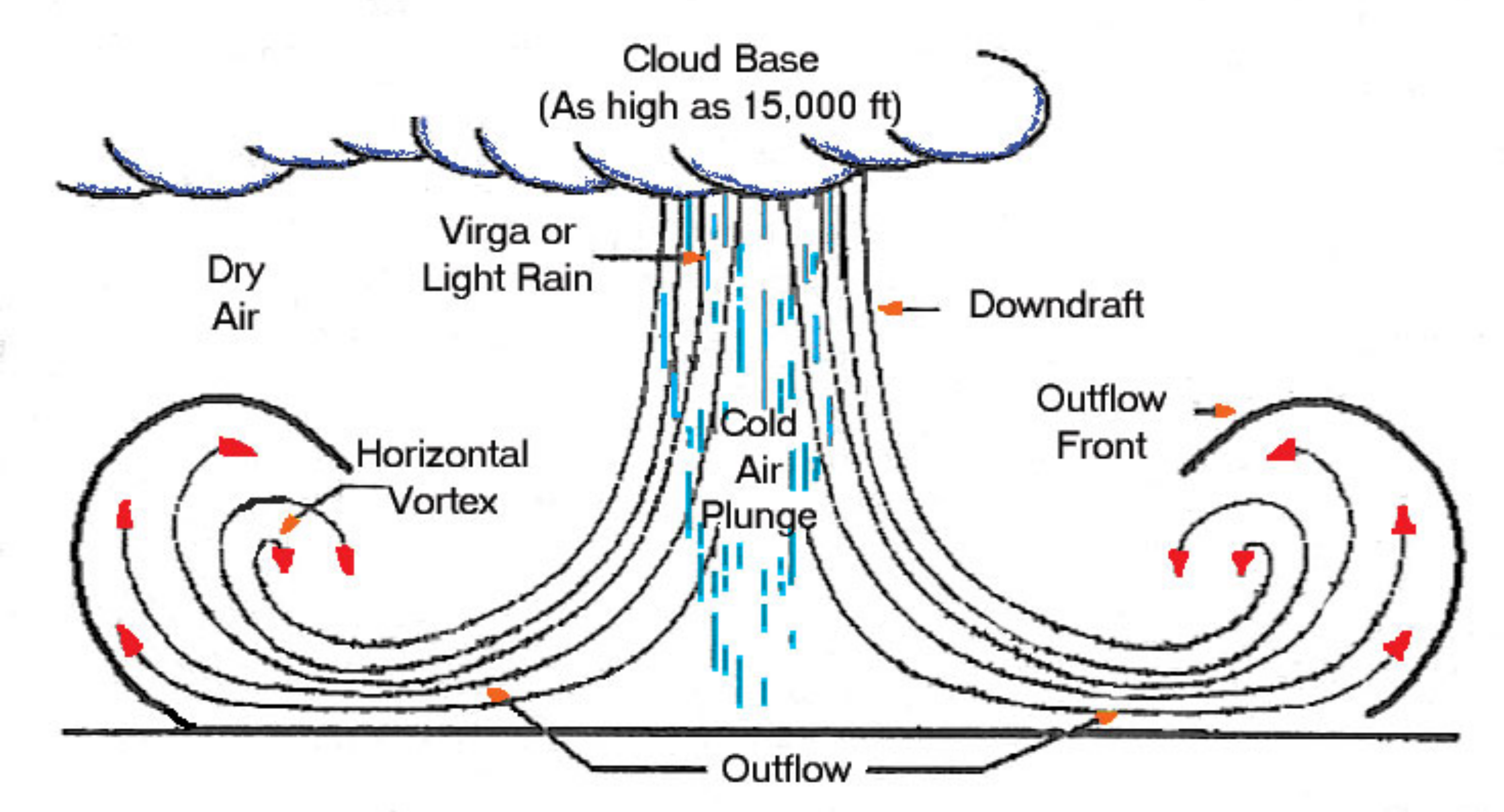
Gust Front

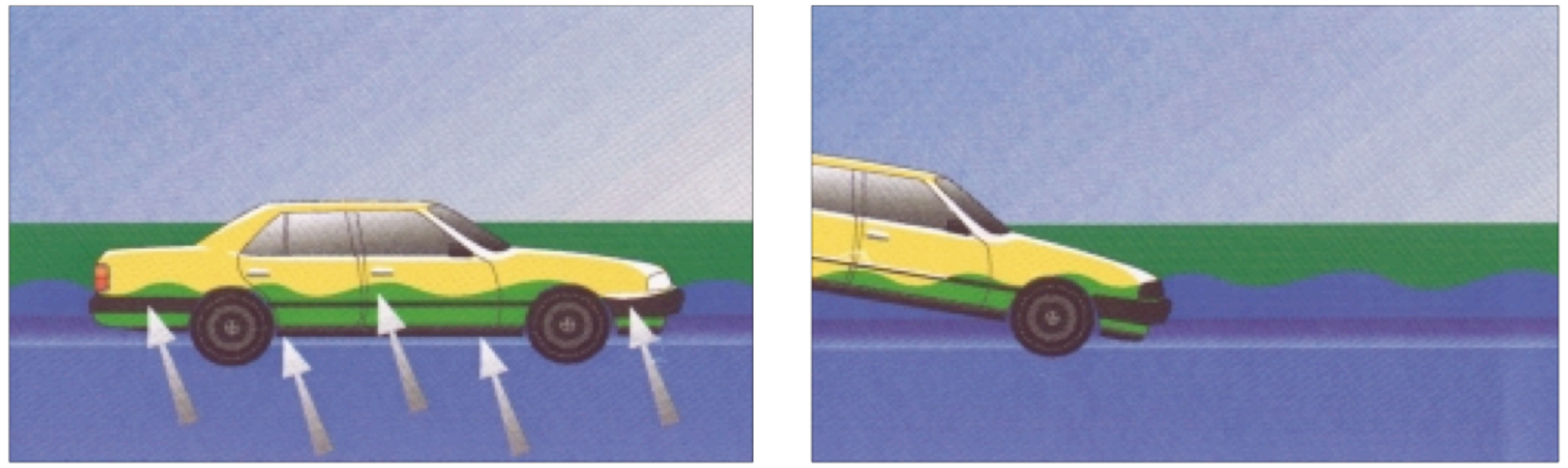
- Downdraft air spreads out along the surface, producing
  - a under the thunderstorm
  - a at the edge of the spreading cold pool



Single Cell: Hazards

- Lightning
- Downdrafts and the spreading gust front create microbursts, an aviation hazard.
- Flash floods (very fast)





But the biggest factor is buoyancy. For each foot the water rises up the side of the car, the car displaces 1,500 lbs. of water. In effect, the car weighs 1,500 lbs. less for each foot the water rises.

Two feet of water will carry away most automobiles.

- June 24, 1975: Eastern Airlines Flight 66 was on its final approach into New York Kennedy when it encountered microbursts.

Mid-term1

Which of the following statements is true about single-cell thunderstorms?

[✓ a) they are relatively short-lived]

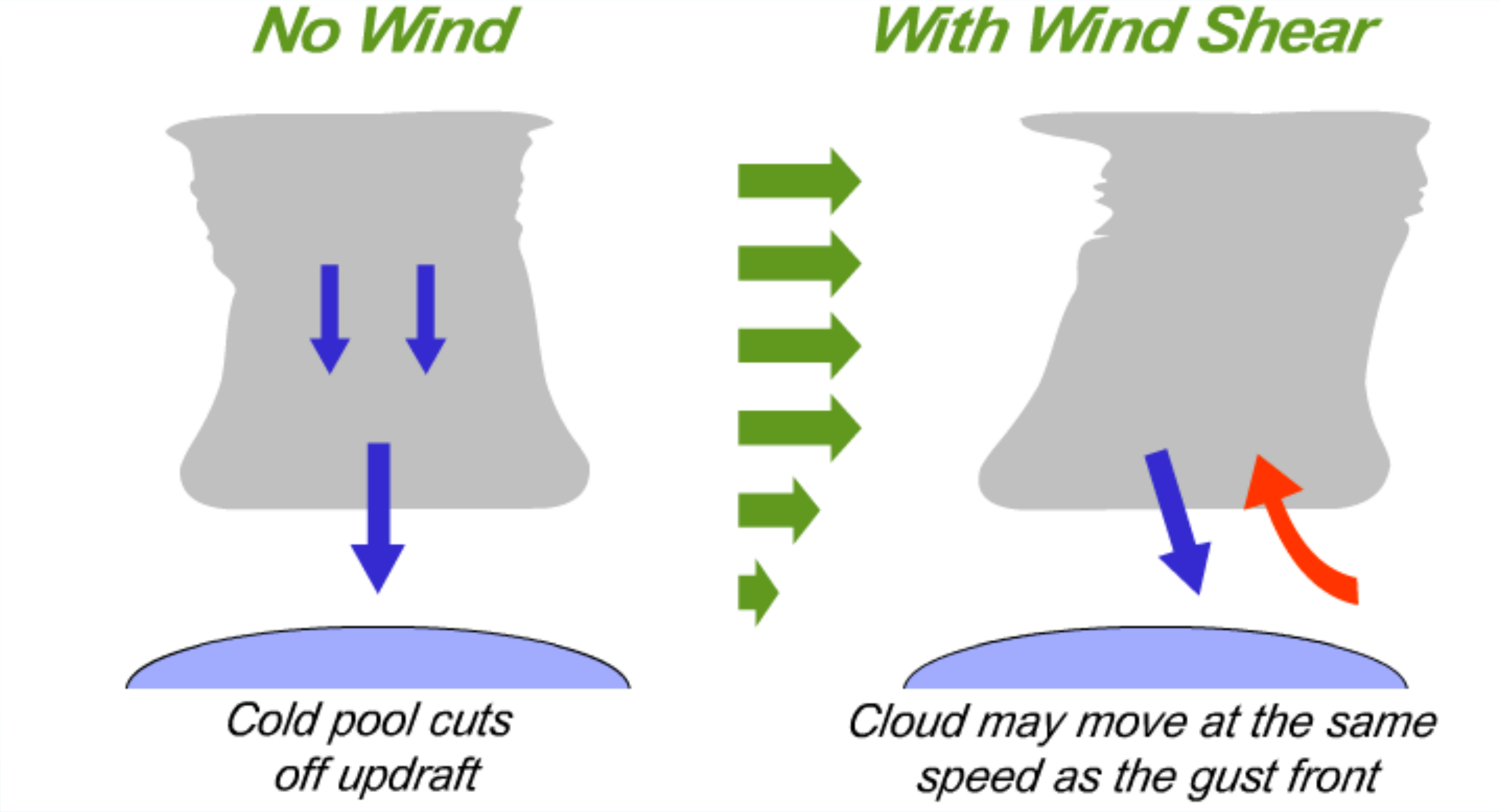
b) low-level vertical wind shear is essential, because it helps maintain the updraft

c) they tend to be most common at dawn

d) they create the most dangerous weather conditions out of all the thunderstorm types

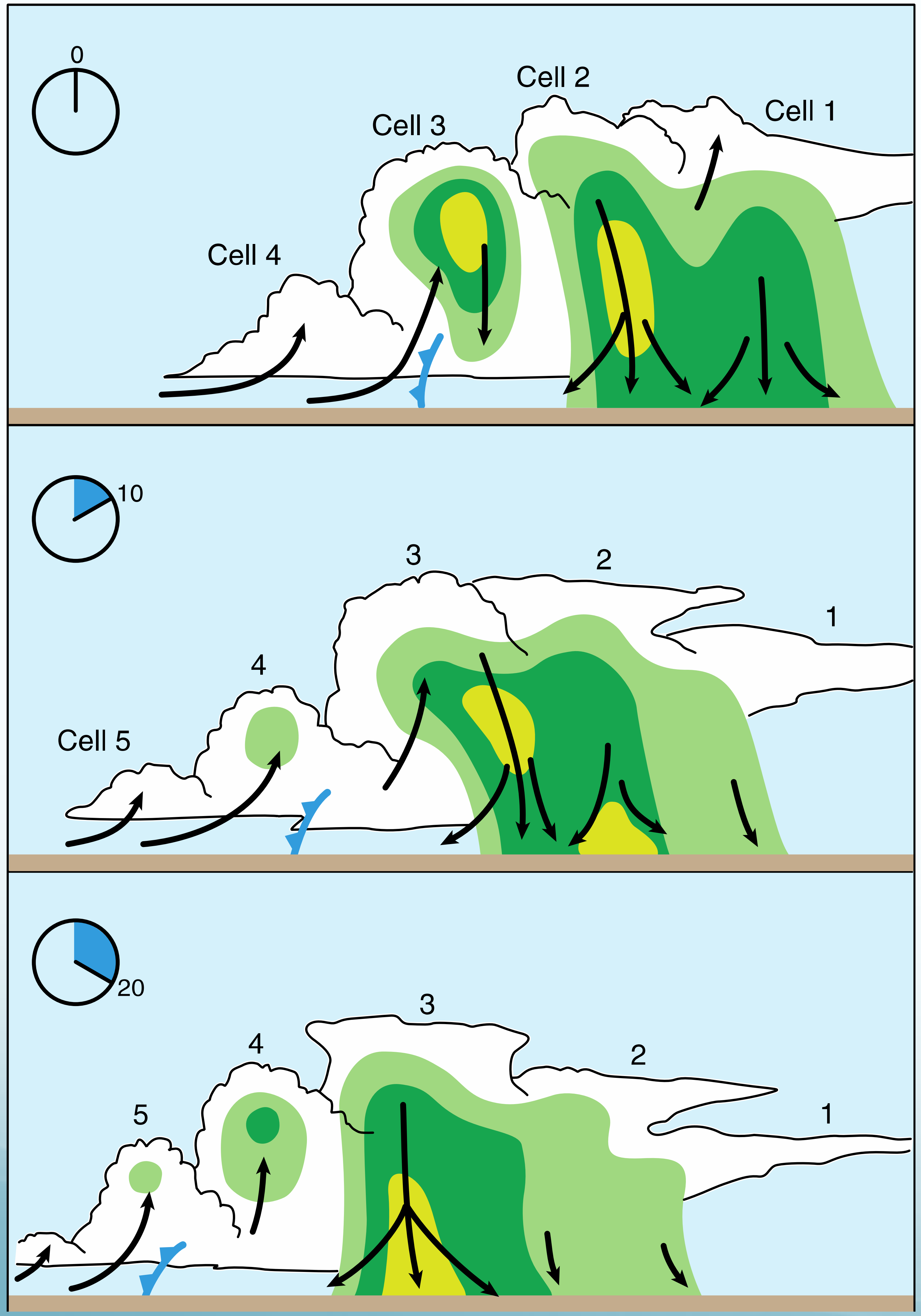
Why might wind shear matter?

- Low level wind shear may extend the lifetime beyond that of a single cell storm



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

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 keeps the cold pool from surging out to cutoff the updraft

Supercell

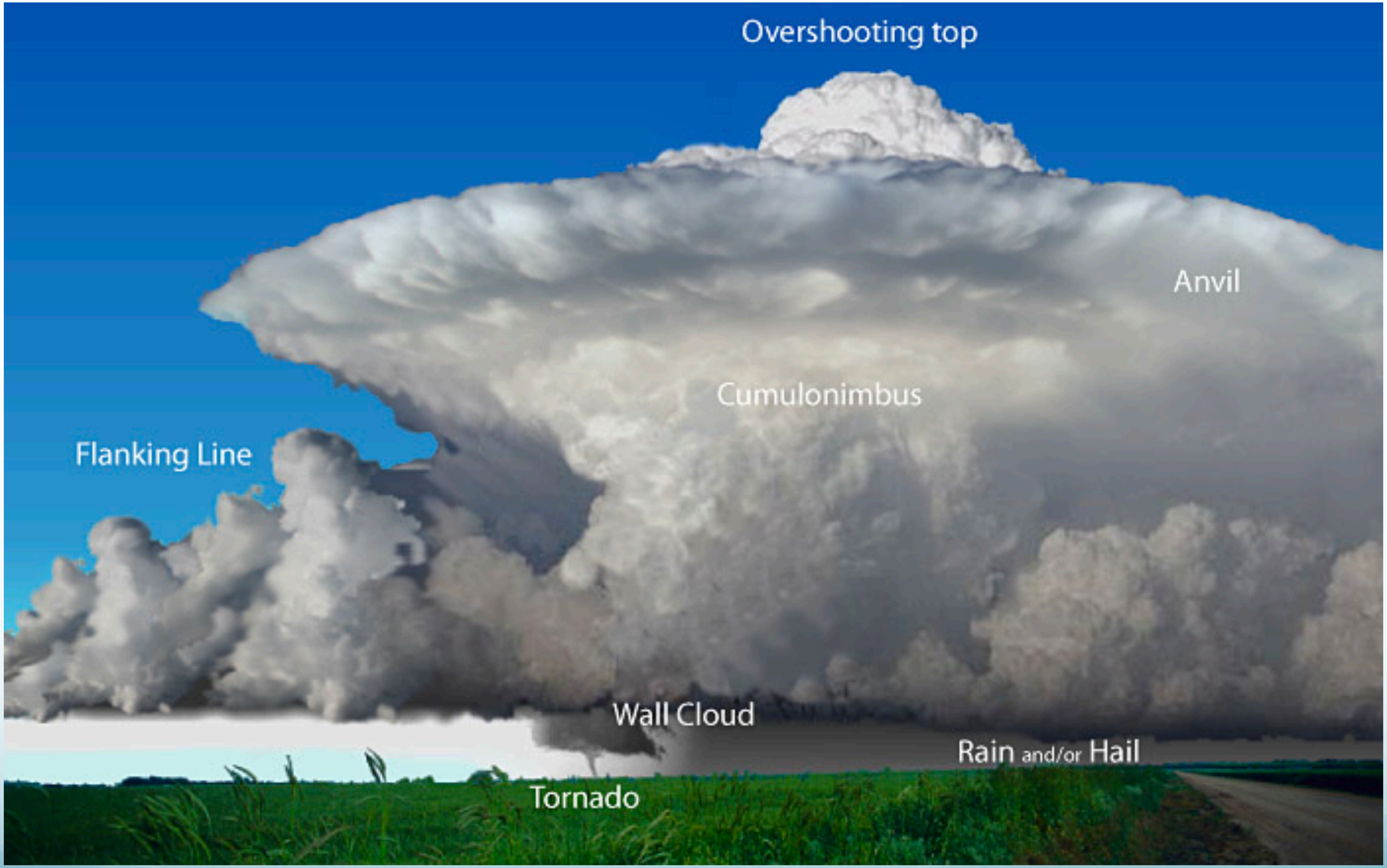
- Supercell (strong low-level wind shear)
  - Relatively long-lived
  - Associated with most strong tornadoes

Distinguishing property:

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



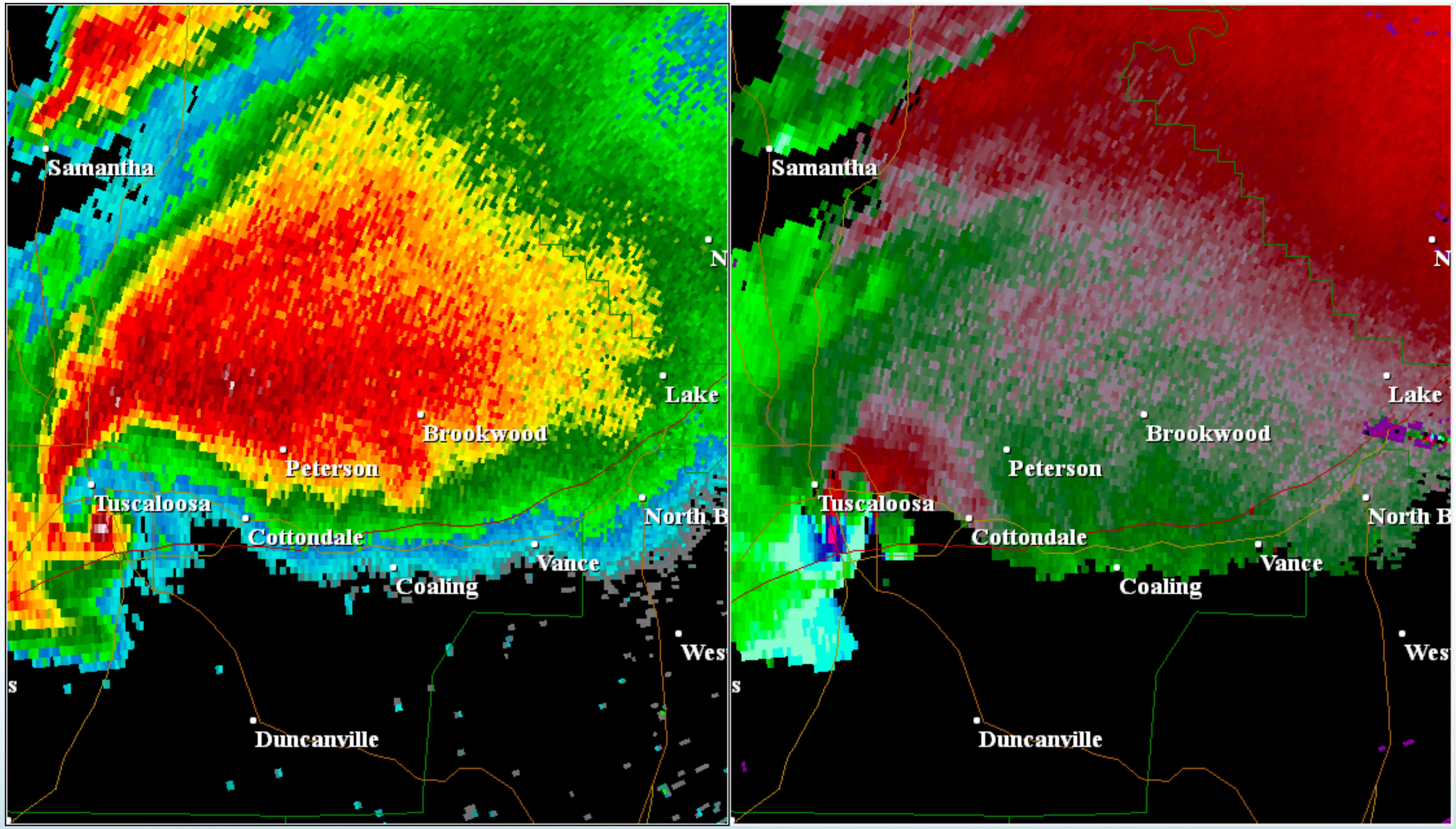
Supercell Thunderstorm

Radar Basics

- 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

Radar features

Where is hook echo, velocity couplet, debris ball?



What caused the weak echo region inside the hook?

Lightning

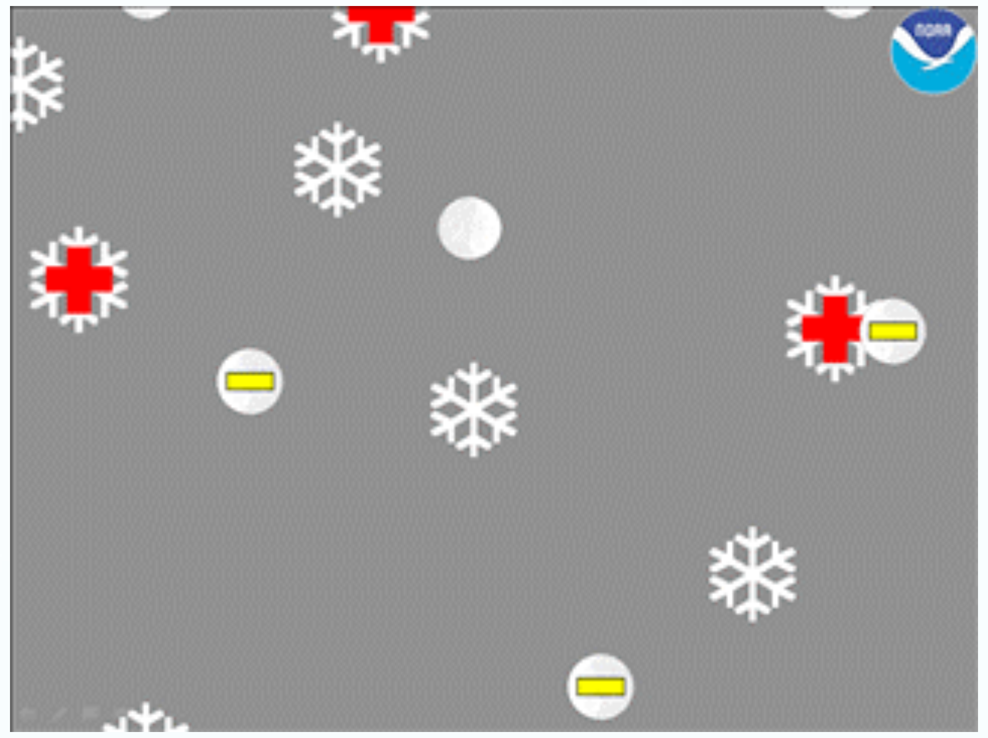
Lightning Ingredients

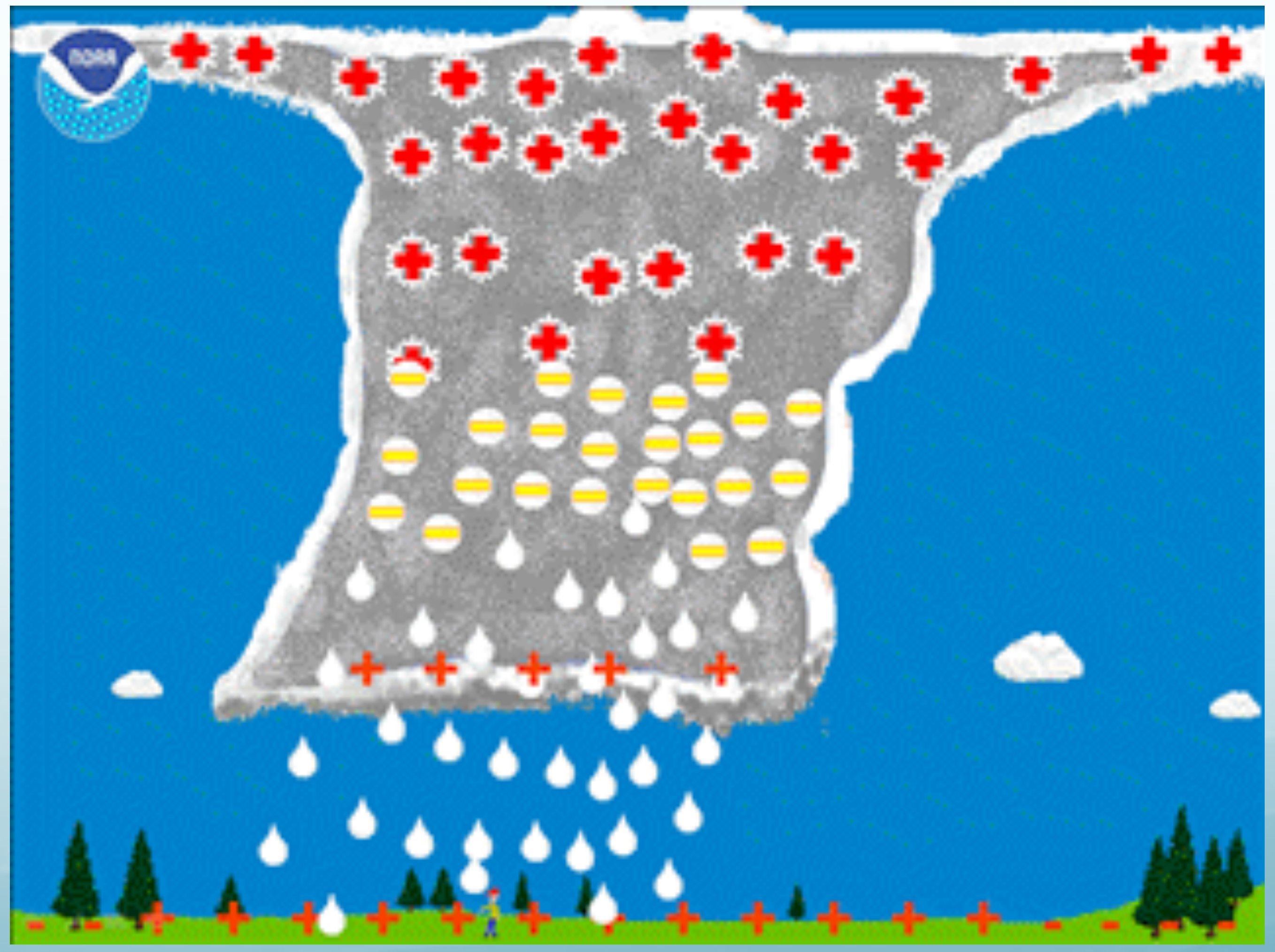
- Generate separate regions of positive and negative charge.
- Trigger a bolt … still an area of research

How to create and separate the charges?

- Falling graupel and hail collide with rising ice crystals
  - Graupel and hail become negative
  - Ice crystals become positive

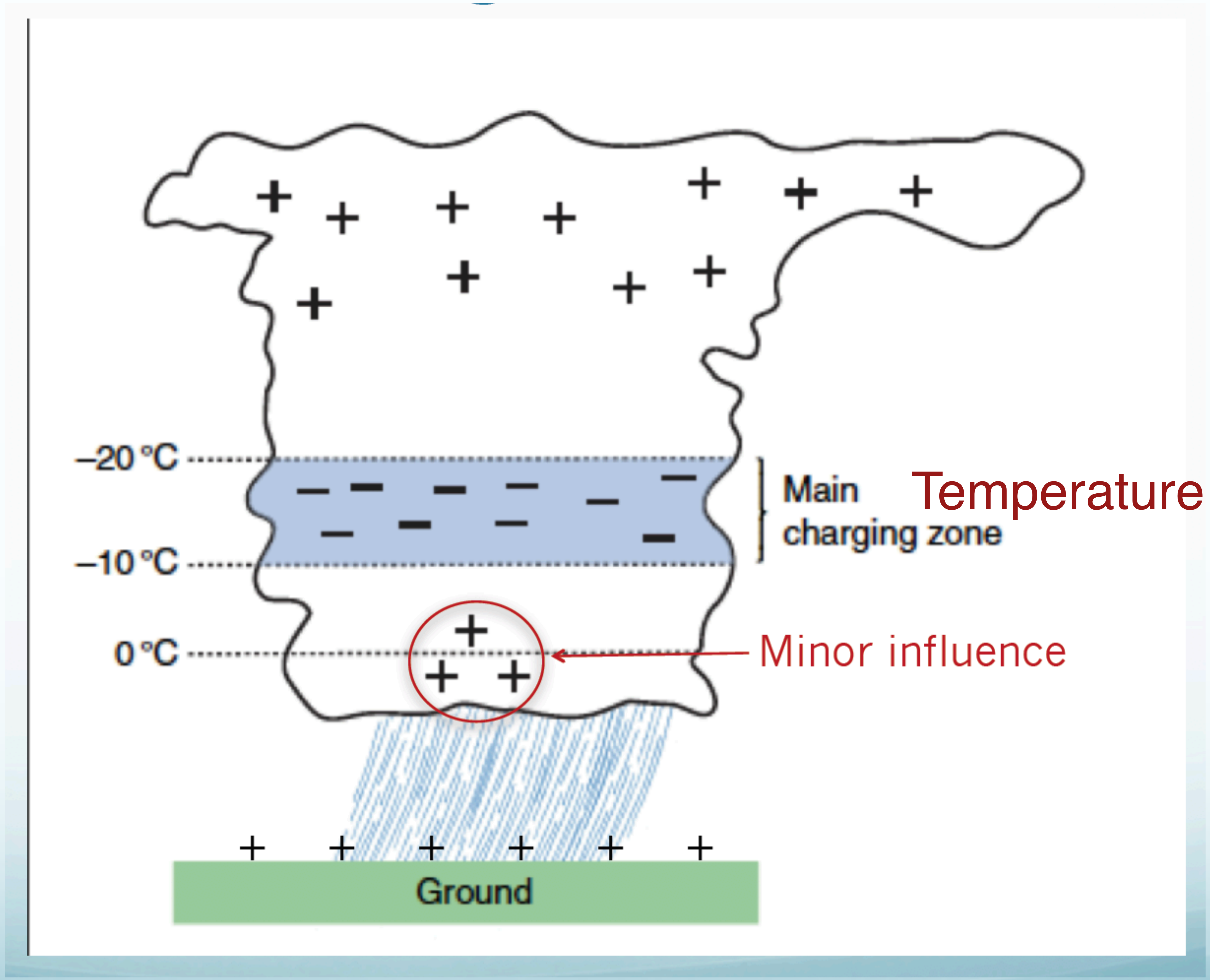
ice plays a key role in electrification.





- [redacted] charge) keep rising and accumulate in the top of the cloud.
- [redacted] (– charge) remain lower in the cloud

Basic Charge Distribution

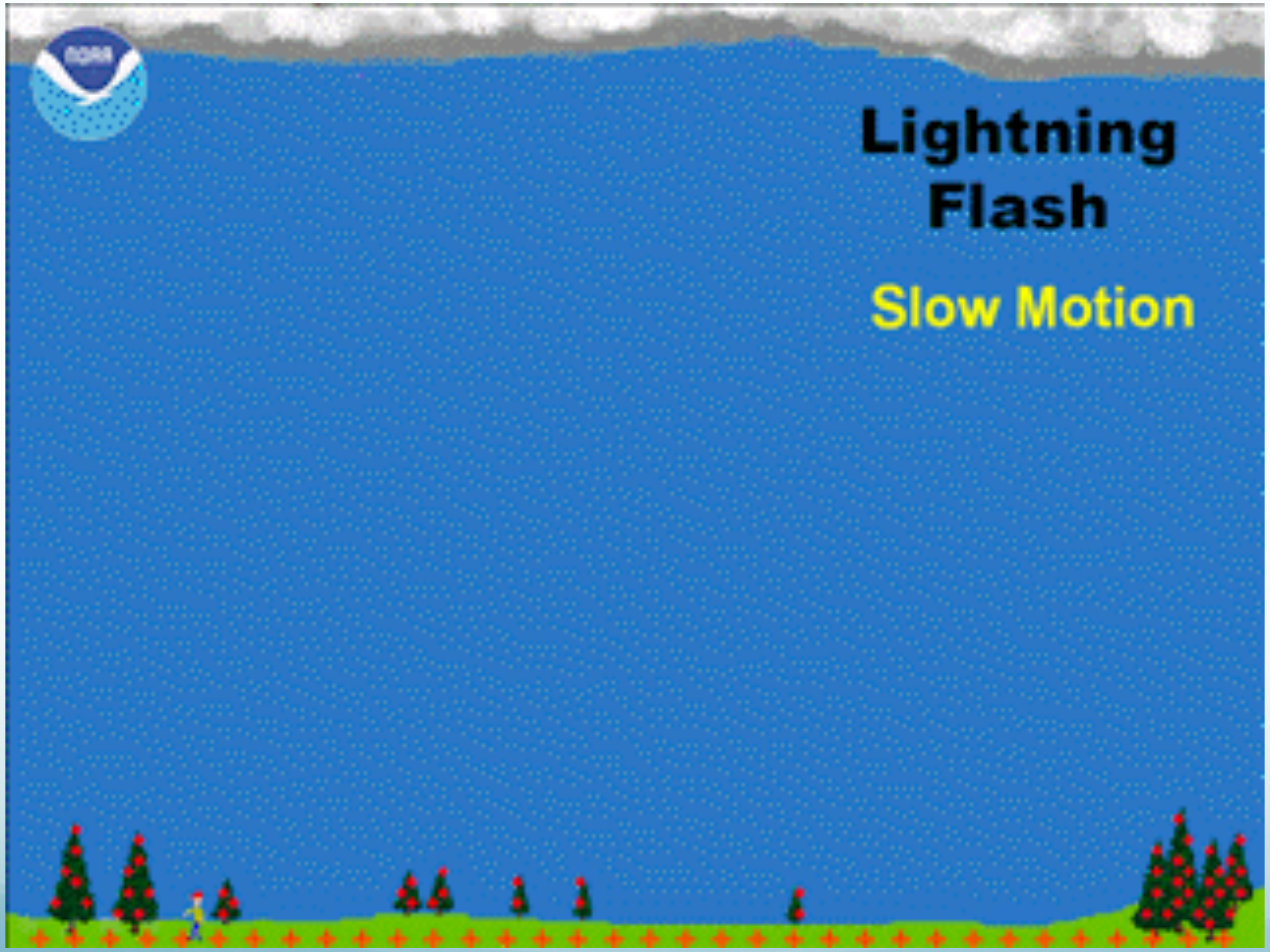


Temperature = -15 C

Minor influence

A Cloud-to-ground Lightning Event

Complete Event – Slow Motion



- Stepped Leader
- Streamers
- Return stroke
- Dart Leader

Lightning Safety?

Clouds

Key points:

- Three states of water, phase change and energy
- Saturation vapor pressure, relative humidity, dew point
- Cloud condensation nuclei(CCN) and Ice nuclei(IN)
- Cloud formation
- Adiabatic cooling and buoyancy
- Cloud shapes and stability
- Raindrops, graupel and hail

Three states of water

Water vapor is invisible!

Vapor (gas): all bonds between molecules are broken

Liquid: some broken bonds between molecules

Ice (solid): almost no bonds broken between molecules

Change in temperature and energy between different states

Vapor

No bonds

Latent heat is released
Condensation

→

←

Evaporation
(Latent heat is absorbed)

Liquid

Some bonds

Latent Heat

- The heat input required to break molecular bonds
- If bonds reform, the same amount of heat is released.

- Condensation occurs when the air parcel is “**saturated**”
- What do we mean by an air parcel is **saturated**?

Saturation

- An air parcel is saturated when its vapor pressure exceeds its saturation vapor pressure.
- Or, its becomes greater than 100%.
  - the ratio of actual vapor pressure to saturation vapor pressure (times 100%)
  - the ratio of water vapor content to water vapor capacity (expressed in percent)

$$\text{Relative humidity} = \frac{\text{(actual) Vapor pressure}}{\text{Saturation vapor pressure}} \times 100$$

- Or, its temperature reaches

Measures of Humidity

Comparing two equal-sized volumes of air, we use

- *Relative humidity (in %)* to determine which is closer to saturation

  It depends on both v and

$$\text{Relative humidity} = \frac{\text{(actual) Vapor pressure}}{\text{Saturation vapor pressure}} \times 100$$

- *Dew point (in ^{o}C or ^{o}F)* to determine which holds more water vapor molecules

  It only depends on the a

Mid-term1

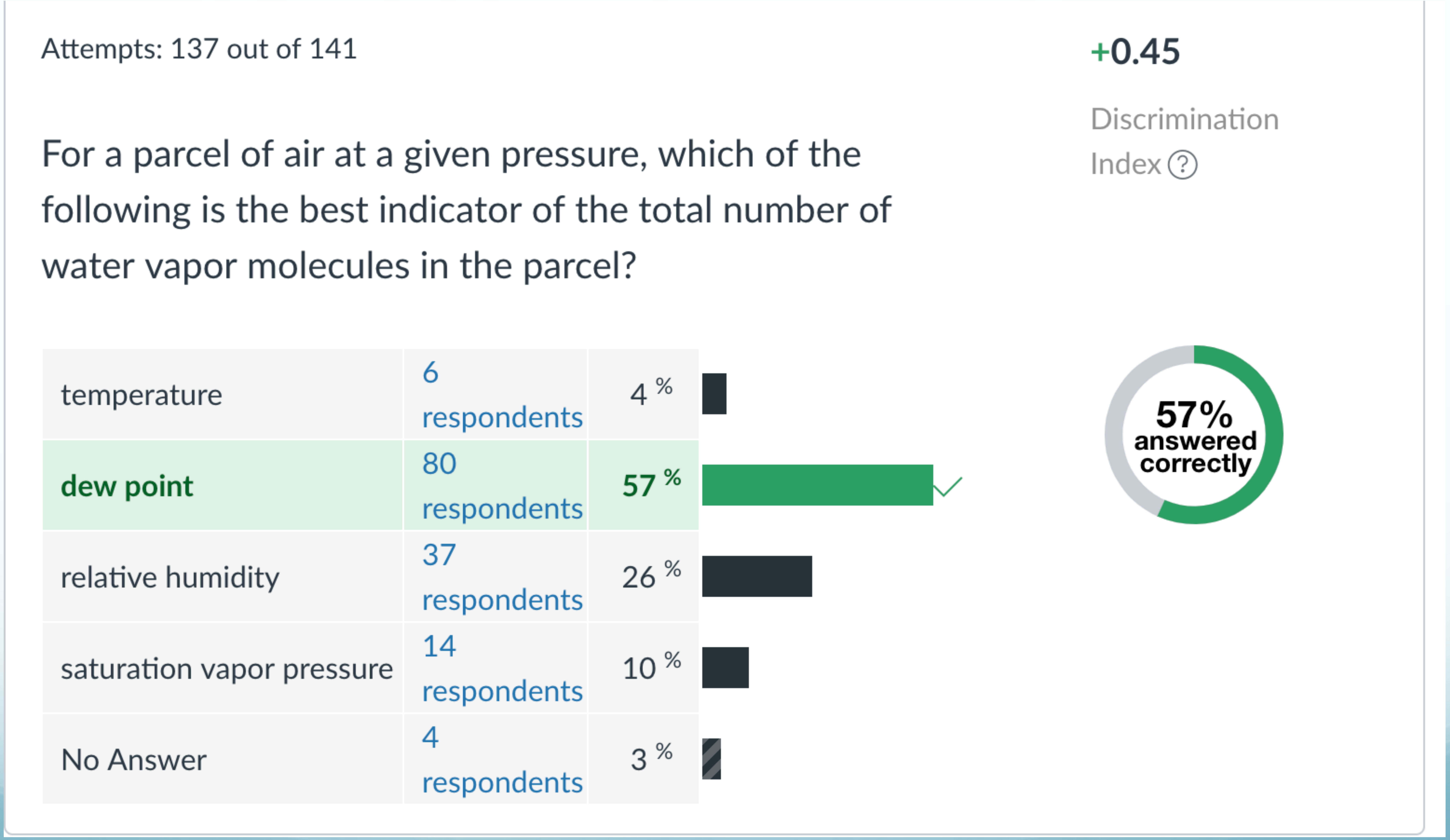
Two air parcels are located near sea level. These parcels contain the same mass of moist air (i.e., the same total number of air and water vapor molecules). Which of the following properties can, by itself, be used to identify the parcel containing the largest number of water vapor molecules.

a) temperature

[✓ b) dew point]

c) relative humidity

d) saturation vapor pressure



Attempts: 137 out of 141

+0.45

Discrimination Index (?)

For a parcel of air at a given pressure, which of the following is the best indicator of the total number of water vapor molecules in the parcel?

temperature	6 respondents	4 %
dew point ✓	80 respondents	**57 %**
relative humidity	37 respondents	26 %
saturation vapor pressure	14 respondents	10 %
No Answer	4 respondents	3 %

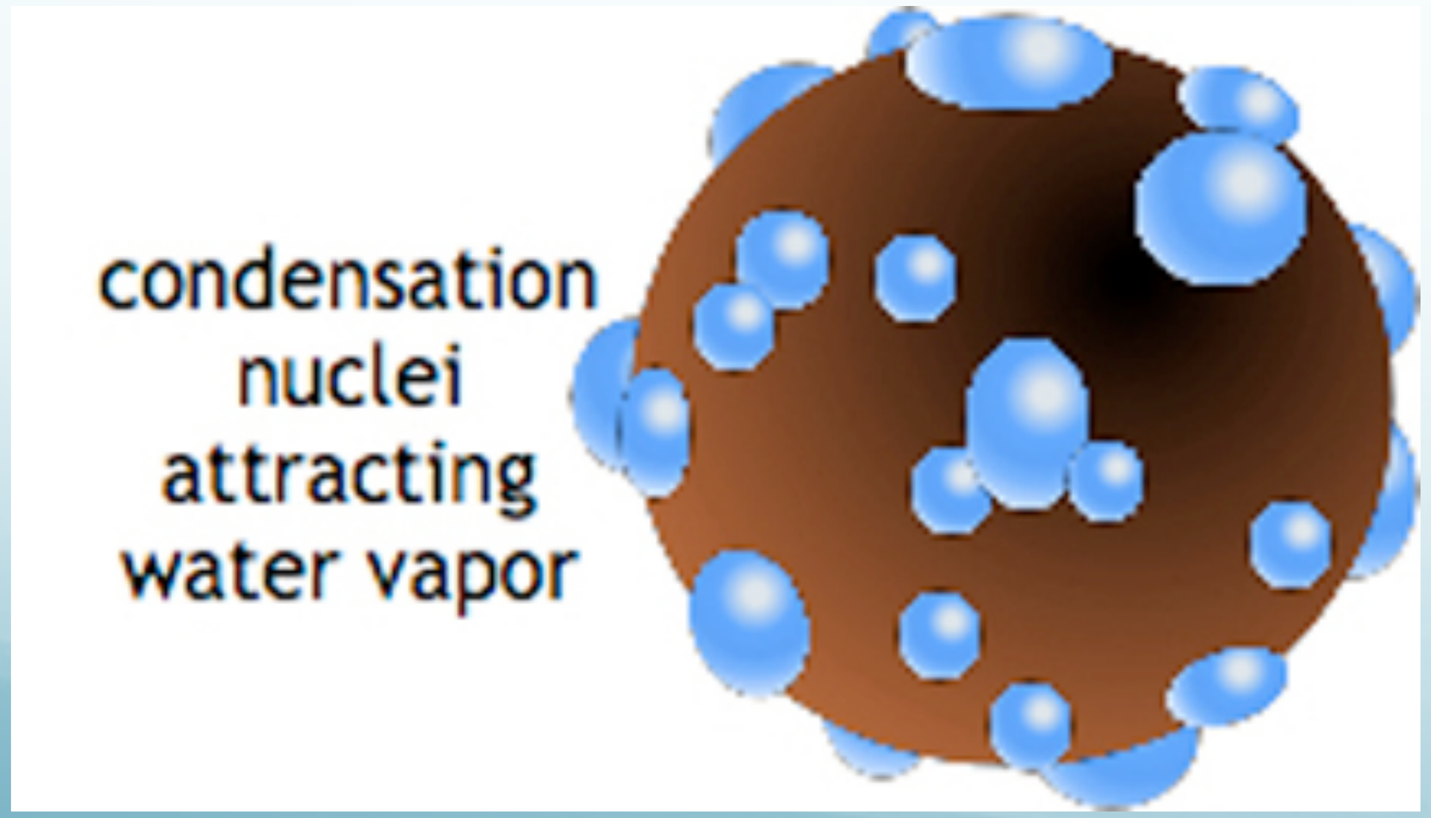
57% answered correctly

Ingredients for making a cloud

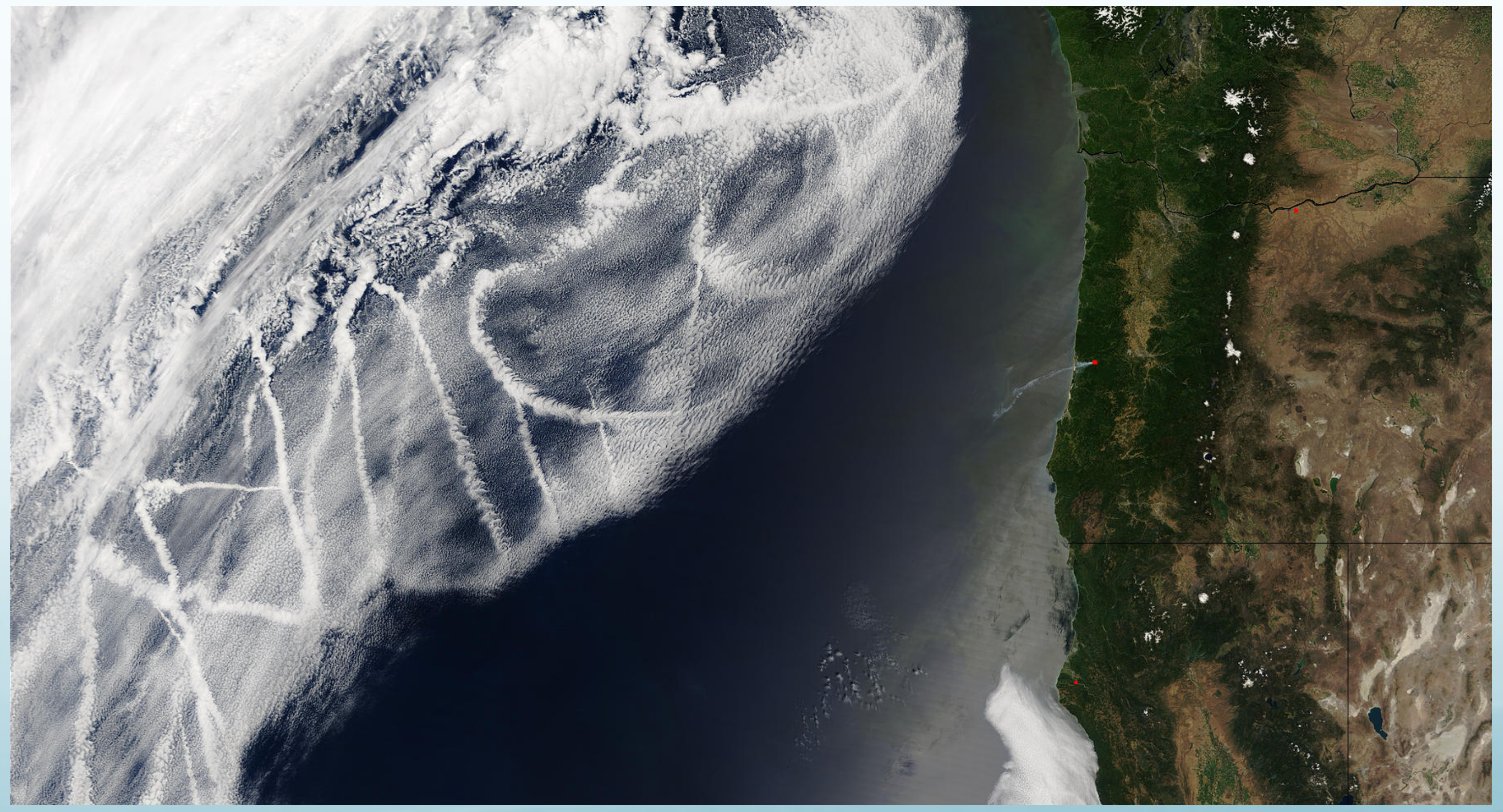
- Water vapor
  - High humidity means high dew point
- Cooling
  - Cooling air down to the dew point means the relative humidity is 100%
- **Cloud condensation nuclei**
  - It helps if the water has something to stick to
  - Makes the cloud more visible too

Cloud Condensation Nuclei

- Water vapor condenses into liquid more easily if the droplet is larger than a few molecules.
- Water vapor condenses on tiny particles of sand, dust, smoke, sea salt, …
    - These are cloud condensation nuclei (CCN)
- CCN is abundant in the atmosphere… (how about IN?)



More CCN means visually ☐r clouds



Ingredients for making a cloud

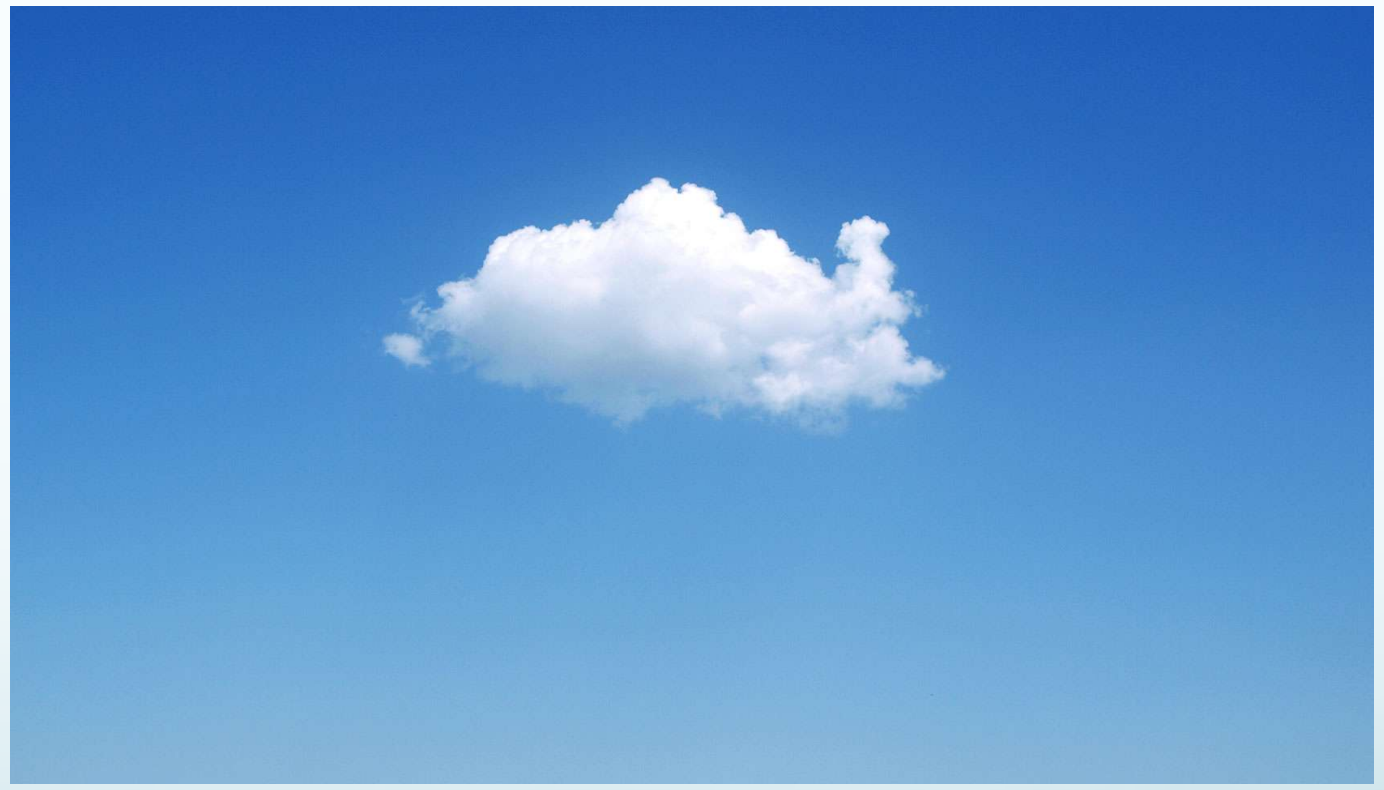
- Water vapor
  - High humidity means high dew point
- **Cooling**
  - Cooling air down to the dew point means the relative humidity is 100%
- Cloud condensation nuclei
  - It helps if the water has something to stick to
  - Makes the cloud more visible too

When do clouds form?

Most clouds form when air is ☐ without adding water vapor and condensation start to happen

Condensation

- Clouds from when air is cooled to saturation (RH = 100%)
- The cooling occurs as the air rises

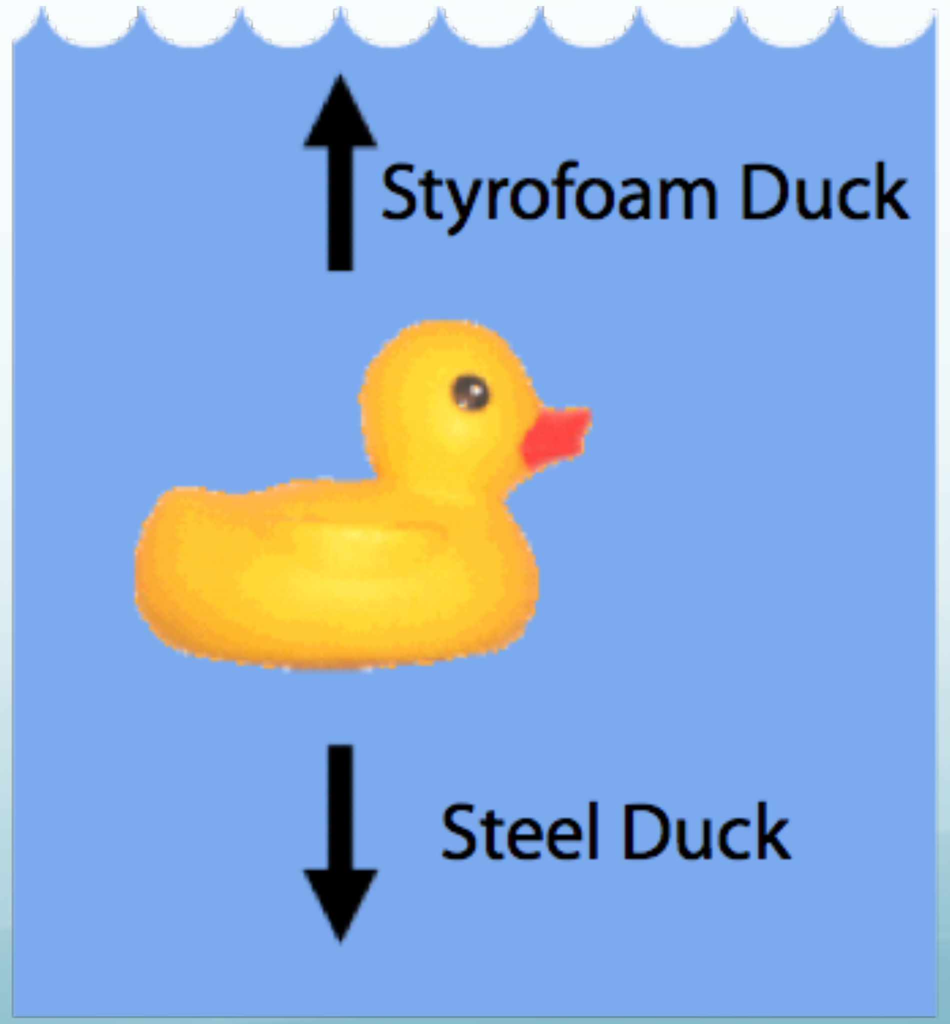


When does an air parcel rise?

when its density is lower than the surrounding air

- *Density* and *Buoyancy*

- Objects (or fluid parcels)
  - *Less dense* than surrounding fluid *float upward*.
  - *More dense* than surrounding fluid *sink downward*



How is temperature related with density and buoyancy?

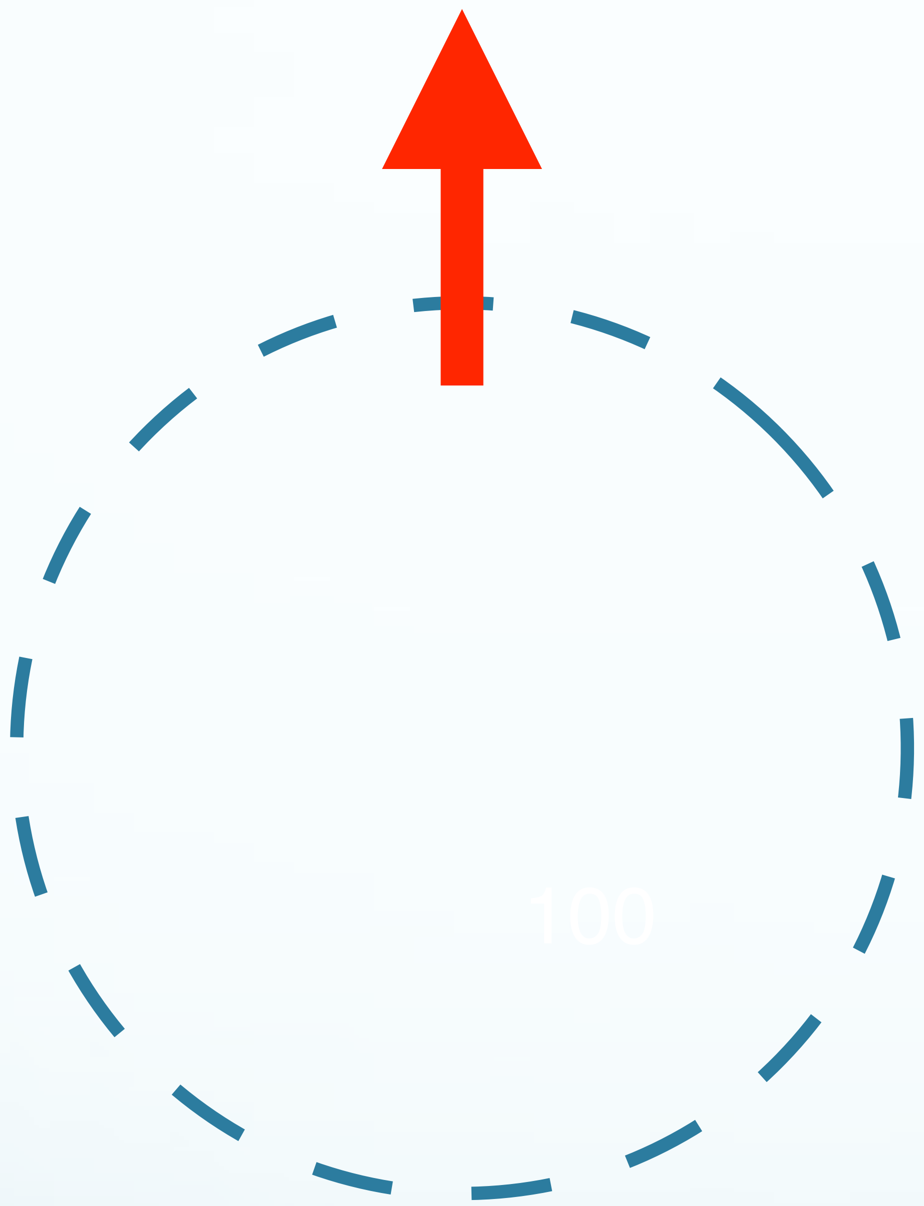
- *Warmer, Less dense, positively buoyant*
- *Colder, more dense, negatively buoyant*

- Gas law

$$\underset{\text{pressure}}{p} = \underset{\text{density}}{\rho} R \underset{\text{temperature}}{T}$$

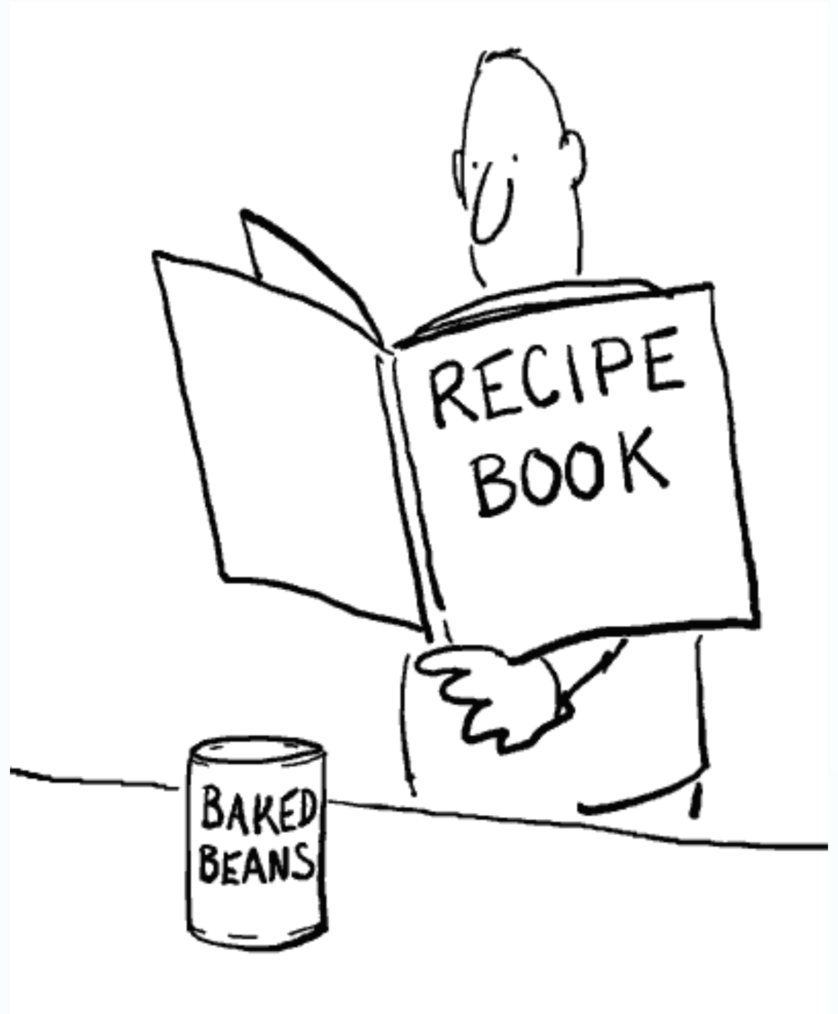
- When pressure of an air parcel matches that of the surrounding air, the air parcel is positively buoyant when its temperature is $\boxed{}$ than the surrounding air

A story for a rising air parcel



- An air parcel rises when it is lighter than the surrounding air
- A rising air parcel expands and cools down
- The cooling from expansion alone will push the parcel back down
- If the parcel contains enough moisture, the latent heat from condensation counteracts the cooling and help the parcel keep rising

What Shapes the Clouds?

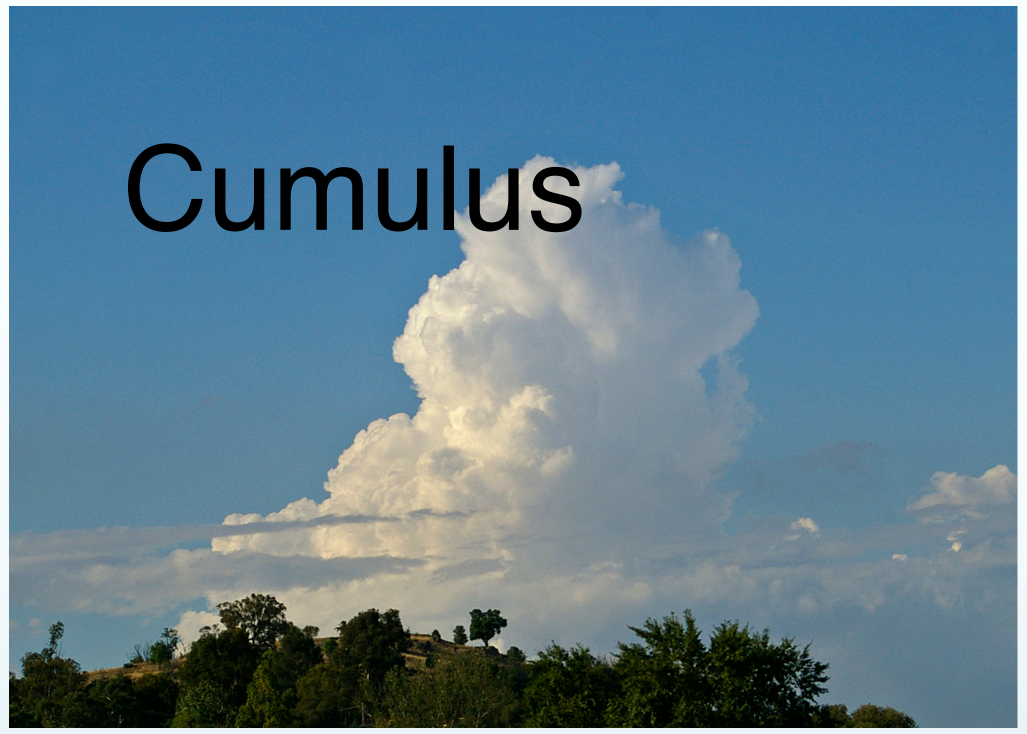


- Key factor: [redacted]
  - *Stable: Stratus clouds* form
  - *Unstable: Cumulus clouds*
  - *Conditional Unstable: Thunderstorm*

Ingredients for making a cloud

- Water vapor
- Cooling
- CCN

All the air rises at the same rate.



Some air goes up very fast

Some air goes down

How do we measure atmospheric stability?

Compare the environmental lapse rate with

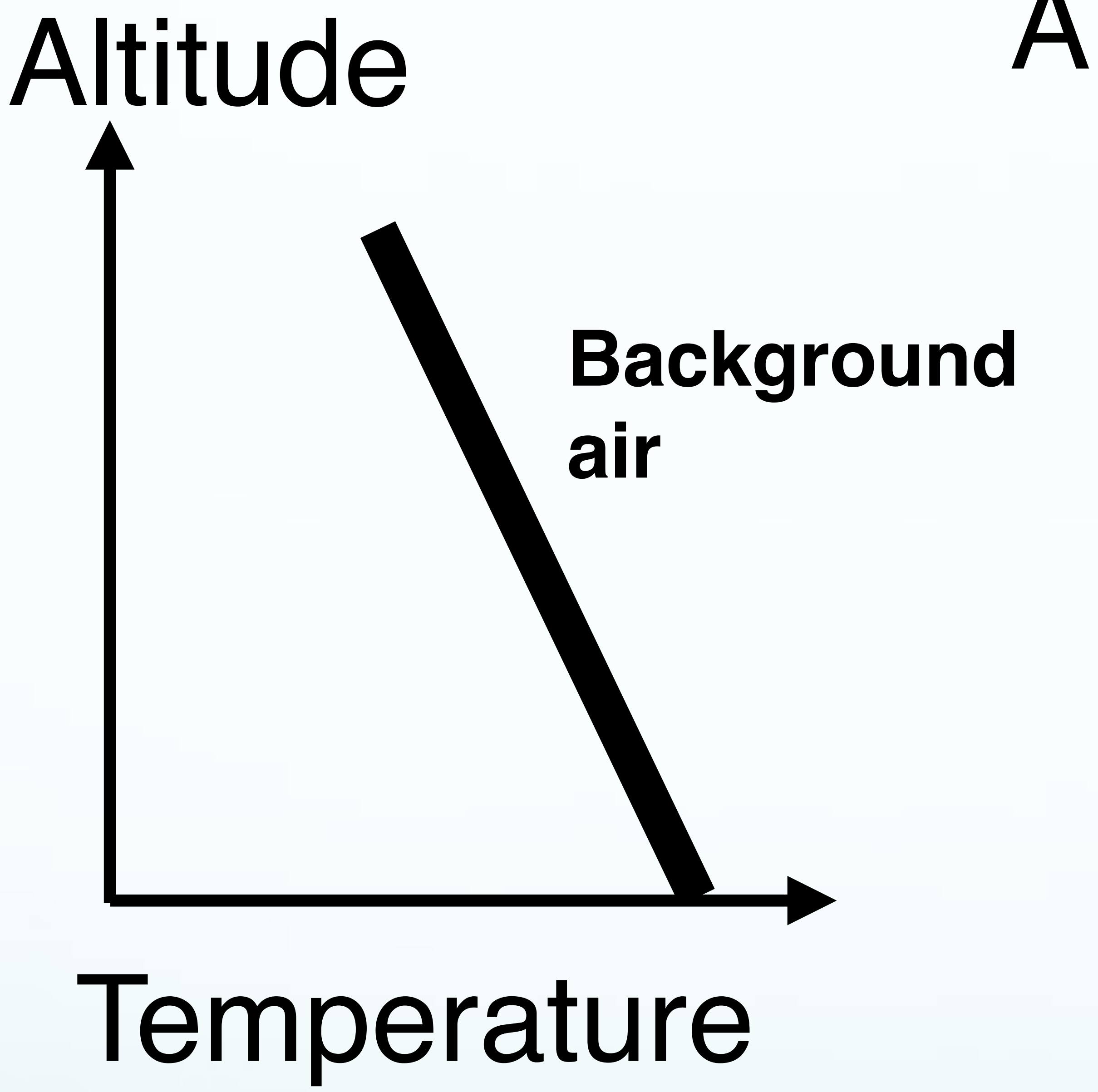
Lapse rate: the rate at which temperature drops with height

- Environmental (or background) lapse rate
- Dry adiabatic lapse rate
- Moist adiabatic lapse rate

Note:
adiabatic means no heat is added or removed from the air parcel

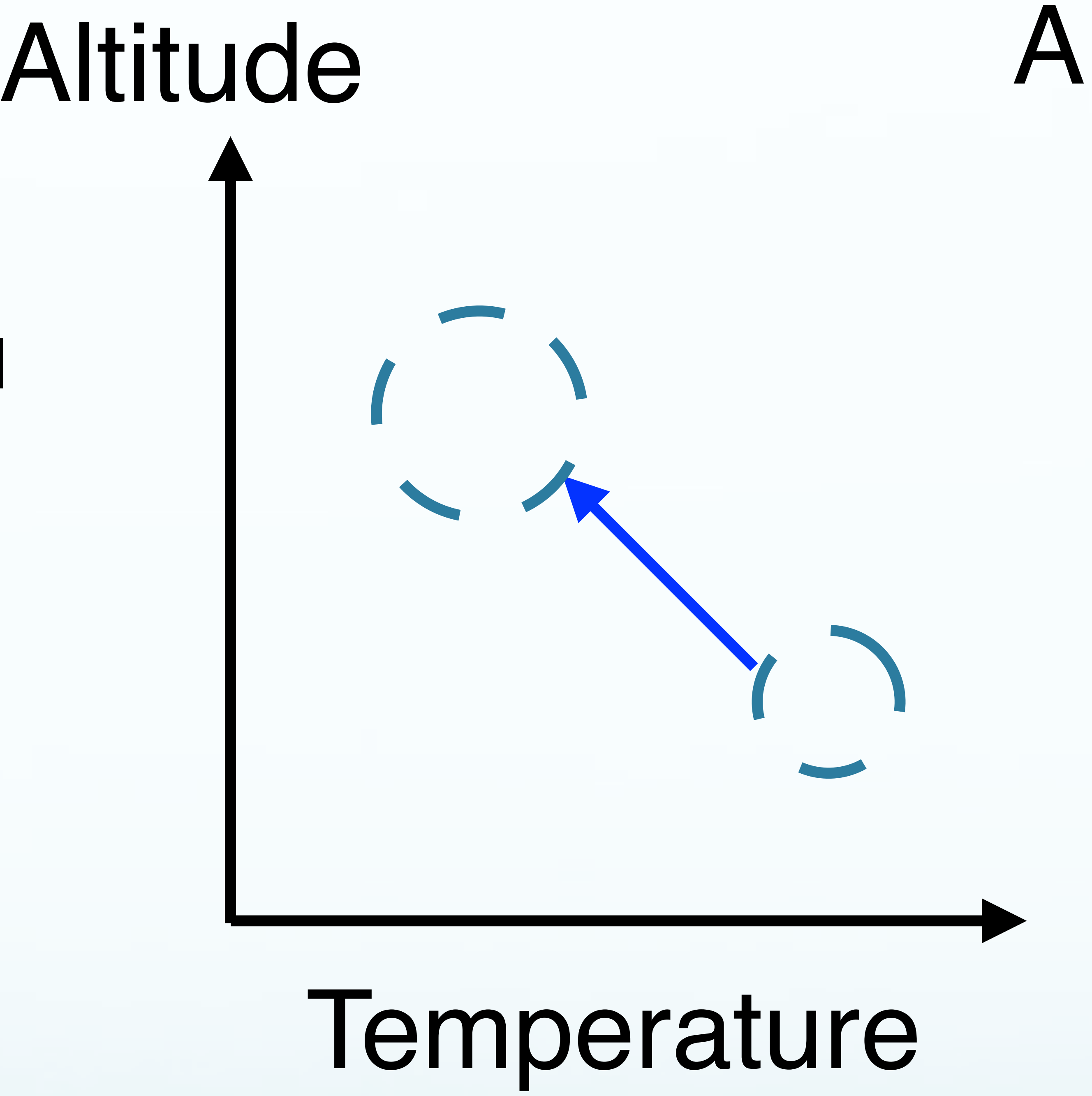
Lapse rate

Environmental lapse rate(varies)



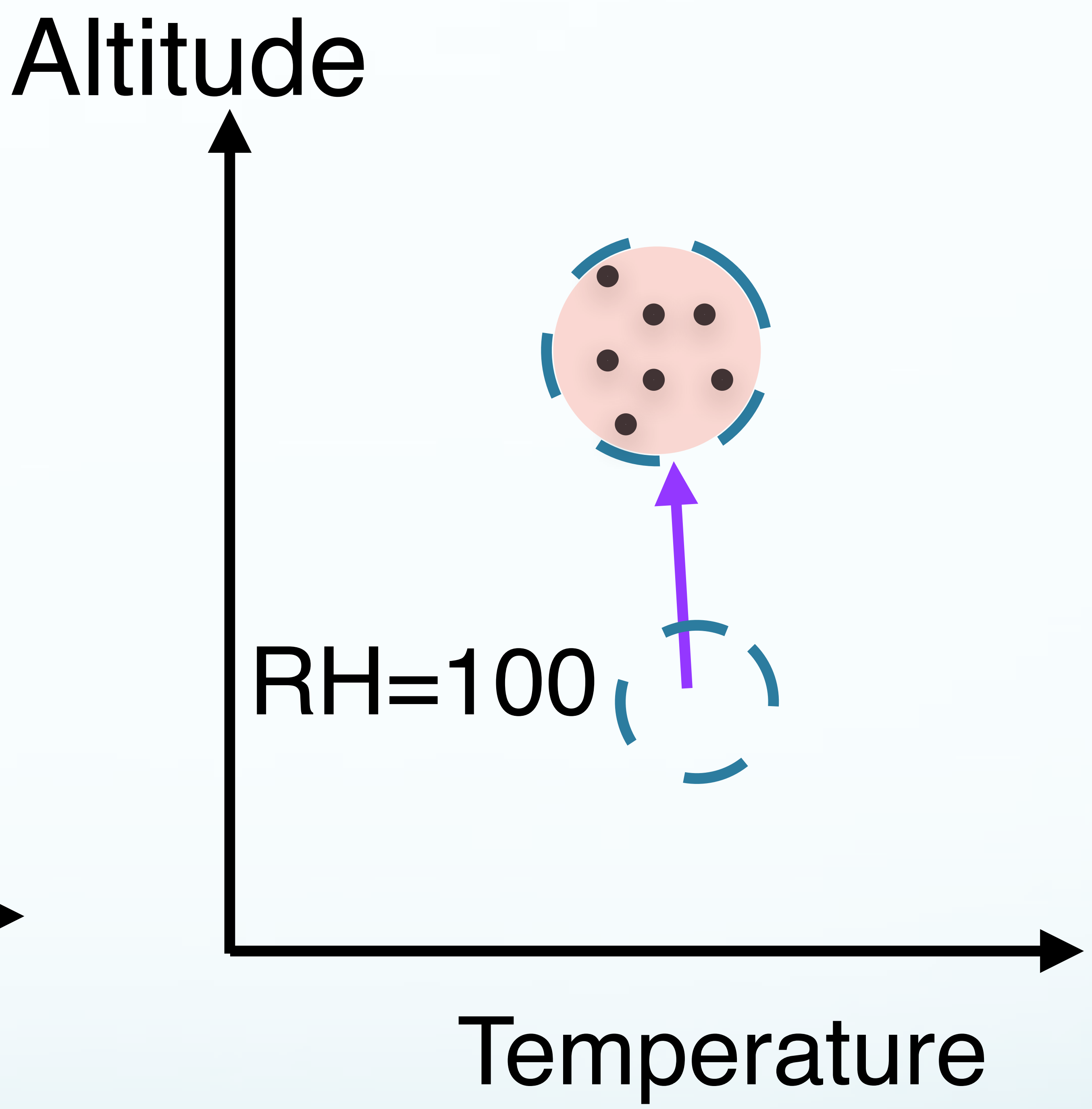
Environmental lapse rate: the rate at which background air temperature drops with height (varies depending on where you are)

Dry adiabatic lapse rate(10 ^{o}C/km)



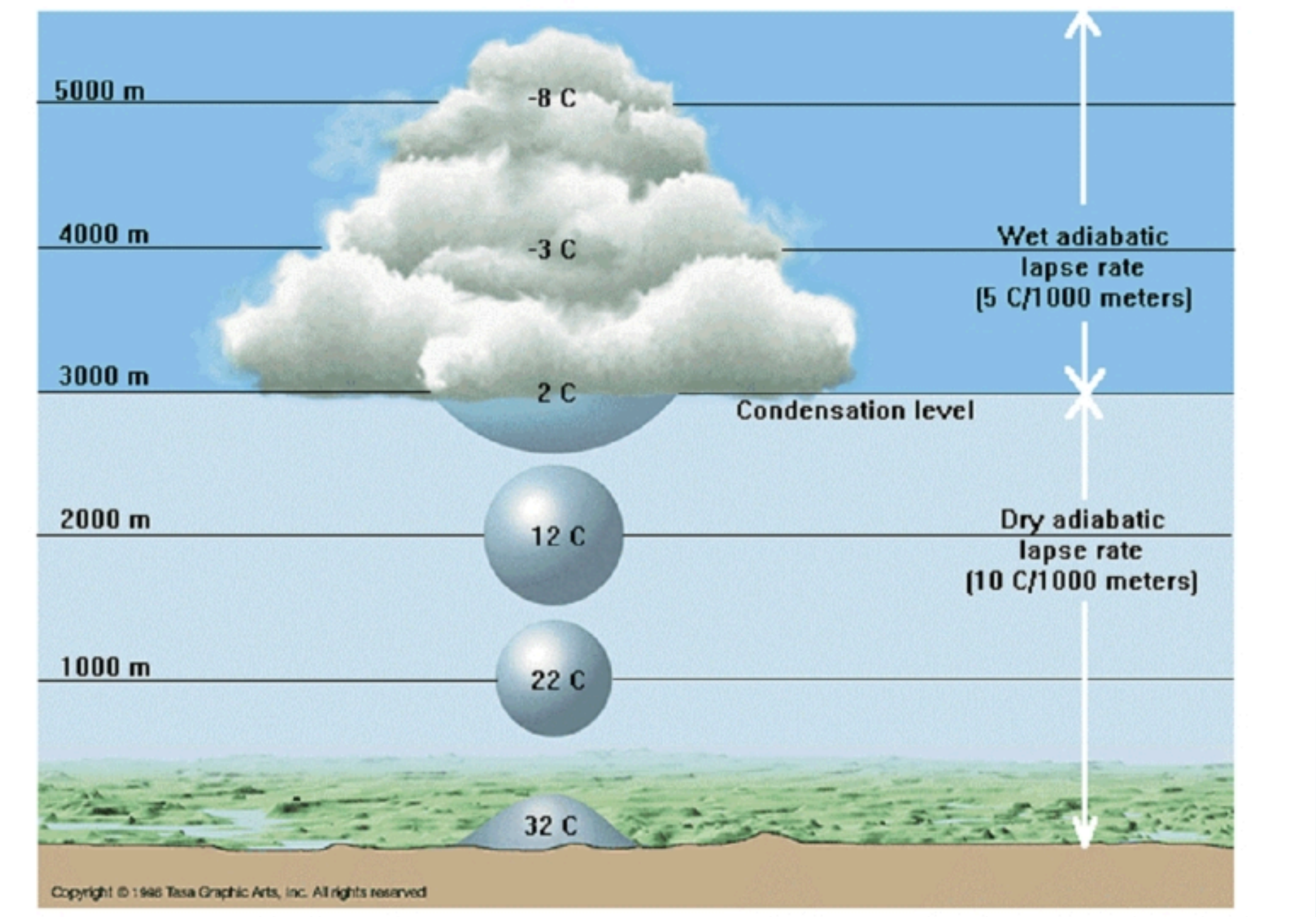
Dry adiabatic lapse rate: the rate at which temperature drops in an air parcel as it is adiabatically raised up (always 10 ^{o}C/km)

Moist adiabatic lapse rate(varies)



Moist adiabatic lapse rate: the rate at which temperature drops in a saturated parcel as it is adiabatically raised up (varies depending on the amount of water vapor, less than 10 oC/km)

Dry vs. moist adiabatic lapse rate



- *Latent heat is released* as the vapor condenses.
- Latent heat partially offsets the cooling accompanying the parcel's expansion as it encounters lower pressures aloft.

Moist adiabatic lapse rate ☐ Dry adiabatic lapse rate

Mid-term1

Unsaturated air parcels cool at the dry adiabatic lapse rate. Saturated air parcels cool at the moist adiabatic lapse rate. Why is the moist adiabatic lapse rate less than the dry adiabatic lapse rate?

a) Saturated parcels have a higher pressure than unsaturated parcels when they rise, so they cool less.

b) Saturated air parcels have a lower vapor pressure than unsaturated air parcels.

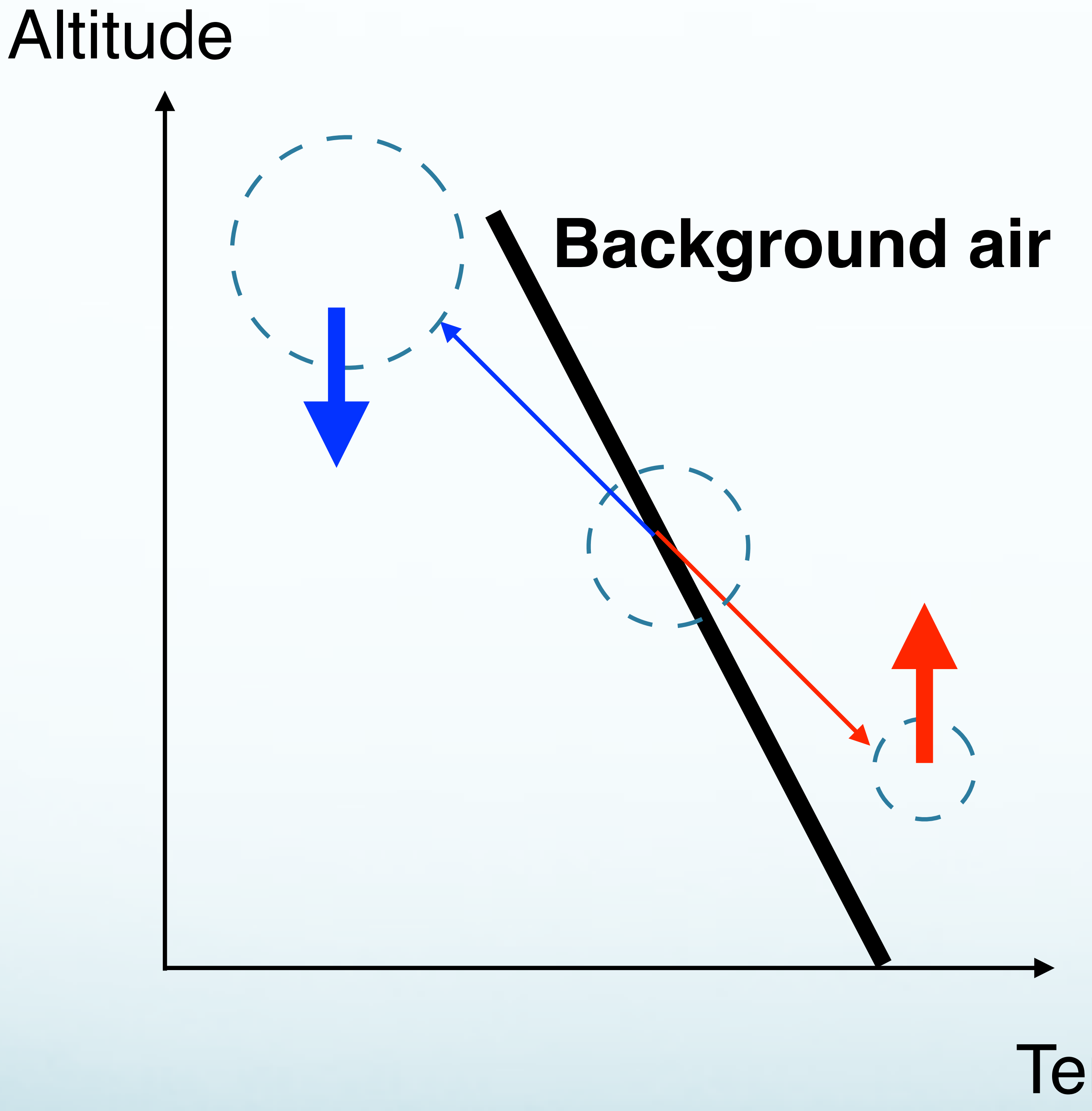
c) Saturated air parcels are cooled less by entrainment than unsaturated parcels.

[✓ d)] Condensation occurs as a saturated parcel rises; this releases latent heat and prevents the saturated air from cooling as rapidly as an unsaturated parcel.

How do we measure atmospheric stability?

Compare the environmental lapse rate with dry/moist lapse rate

“Stable”



Very Stable Air

Thunderstorm anvil from space

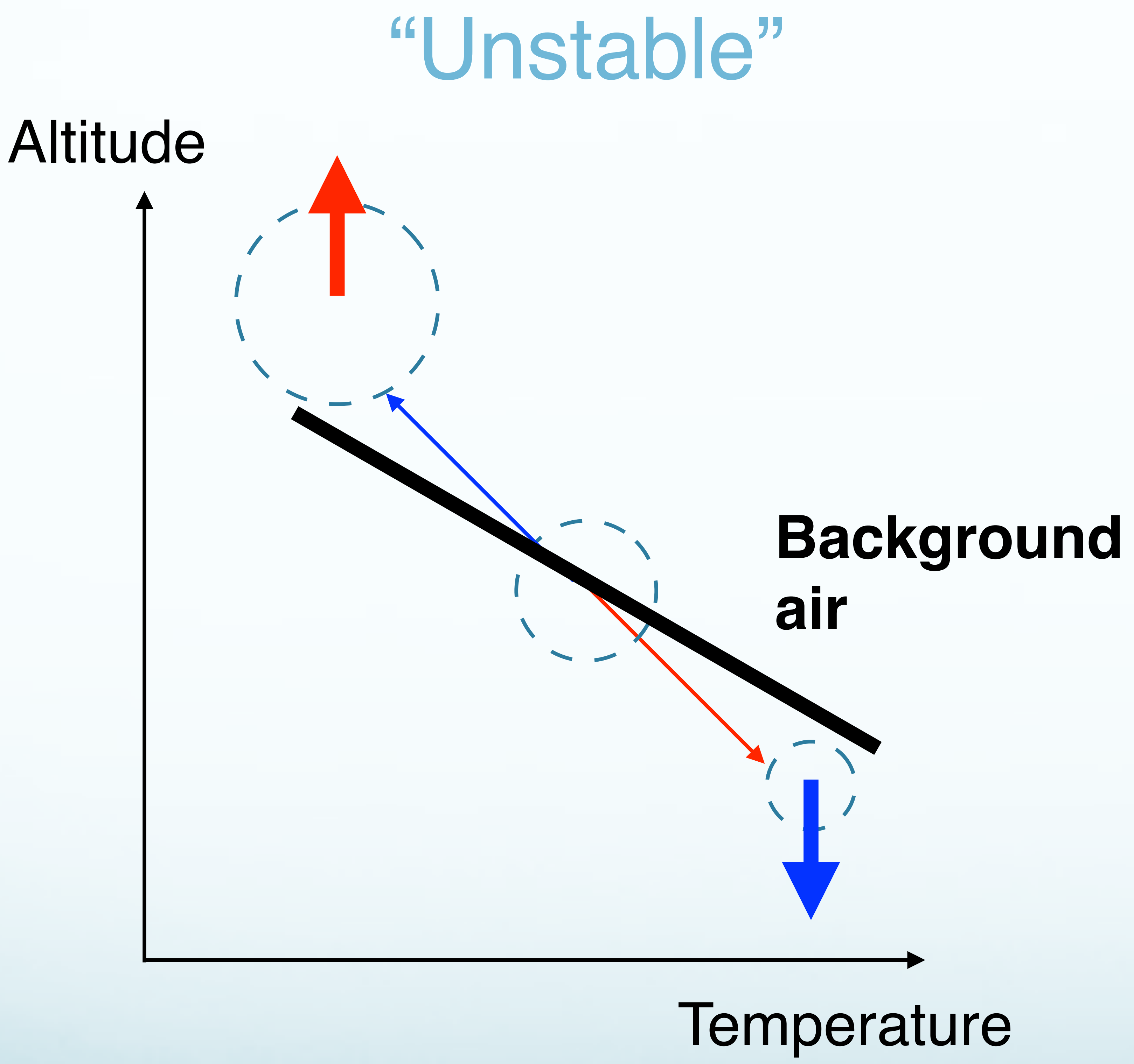
thunderstorms “stop rising” when they reach the tropopause because stratosphere is stable

When the parcel is pushed *up* a bit, it becomes slightly *colder* than its surrounding & *sinks* back down (and oscillates about its original position).

Environmental lapse rate < Dry adiabatic lapse rate

How do we measure atmospheric stability?

Compare the environmental lapse rate with dry/moist lapse rate



Fair-weather cumulus

Clouds formed by rising motions in an unstable environment near the ground created by solar heating.

When the parcel is pushed *up* a bit, it becomes slightly *warmer* than its surrounding & continues to *rise.* It becomes even warmer than its surrounding. And rising even faster.

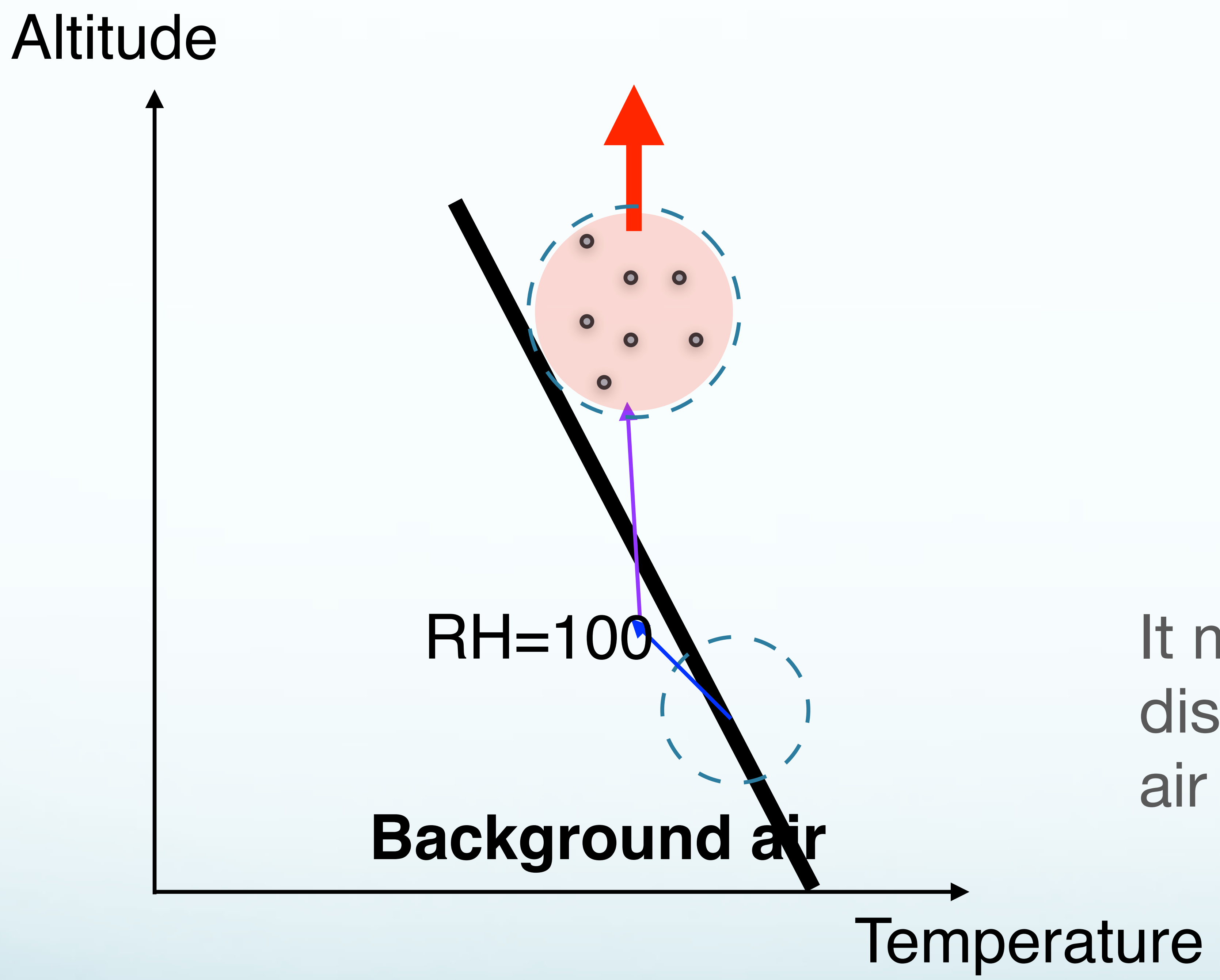
Environmental lapse rate > Dry adiabatic lapse rate

How do we measure atmospheric stability?

Compare the environmental lapse rate with dry/moist lapse rate

“Conditionally unstable”

(thunderstorms develop under this condition!)

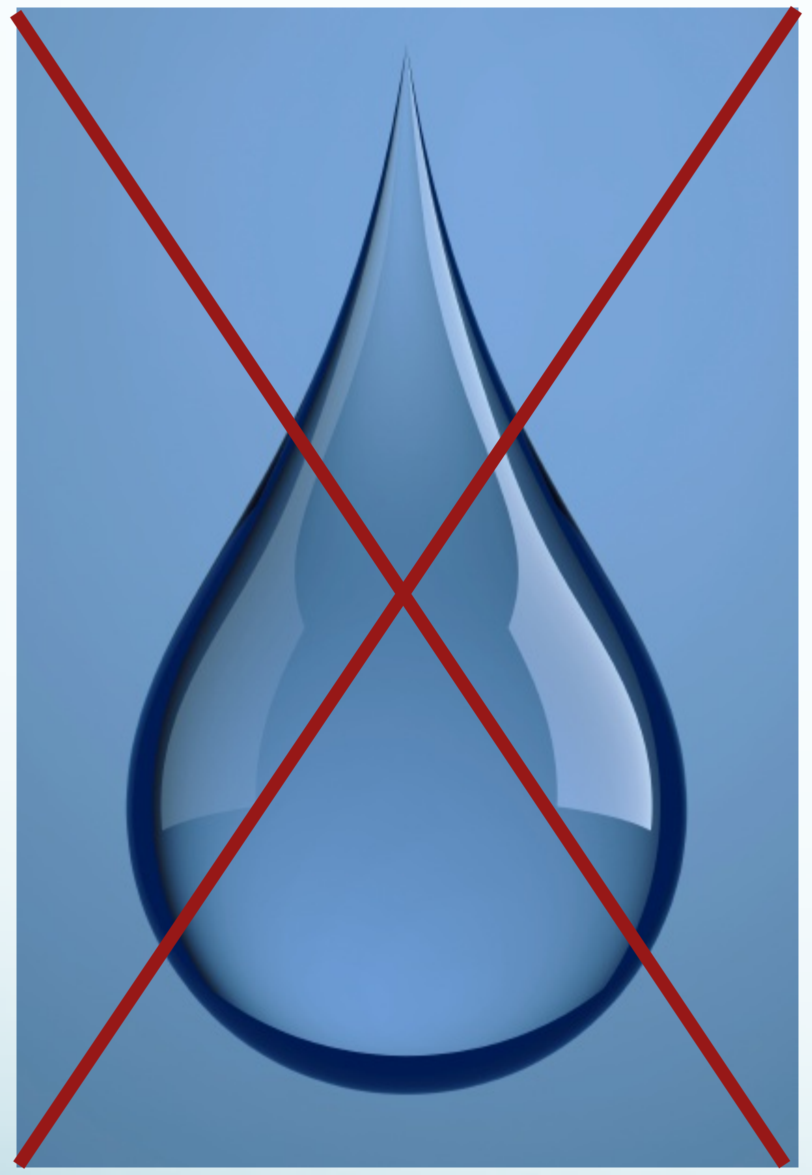


Thunderstorm

It means stable for dry air with small vertical displacement, but unstable for saturated/humid air with large vertical movement

Moist adiabatic lapse rate < Environmental lapse rate < Dry adiabatic lapse rate

Raindrops



Surface tension
Aerodynamics

How do raindrops grow?

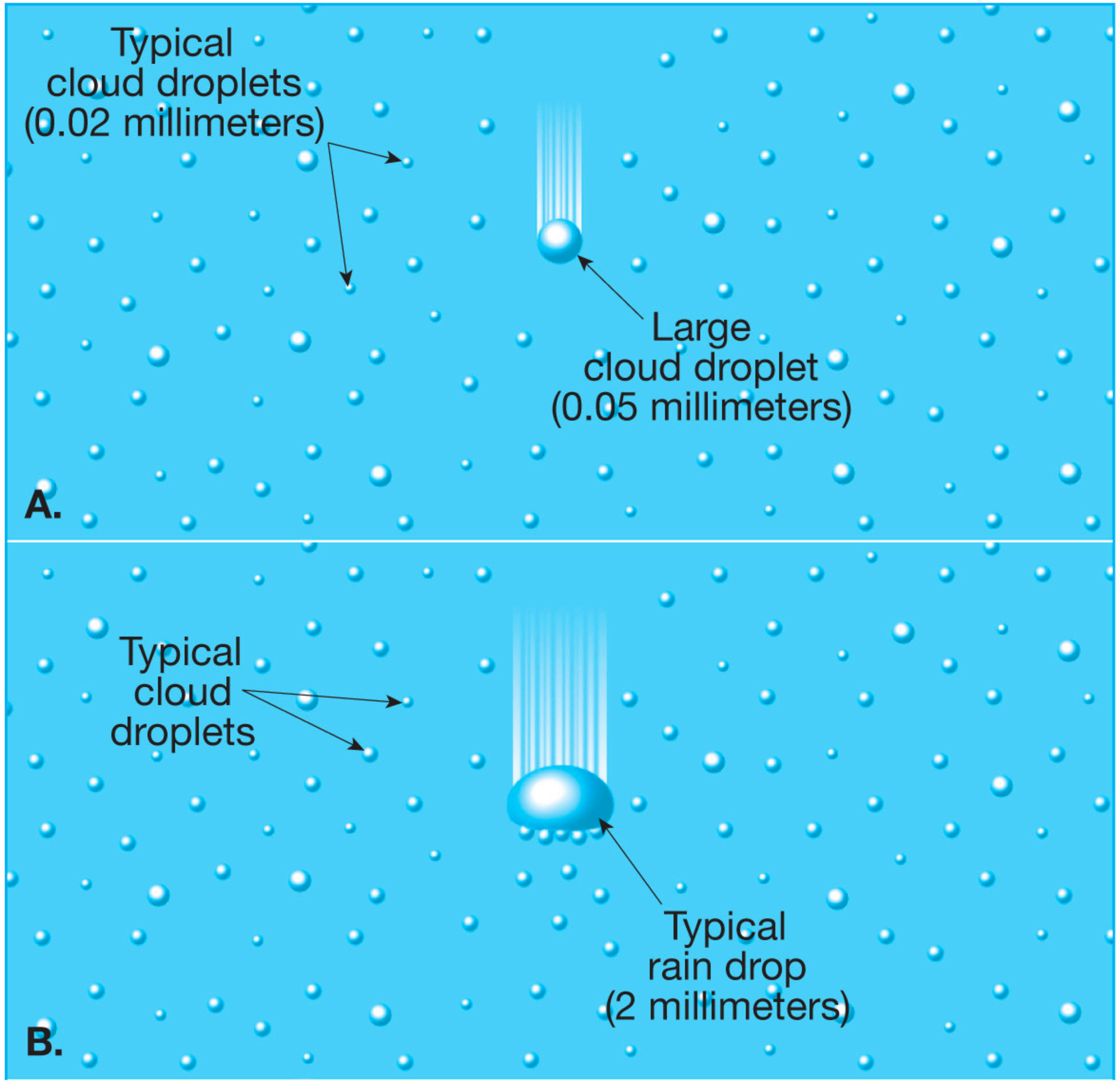
- Condensation

overall is very slow … at least 2 days!

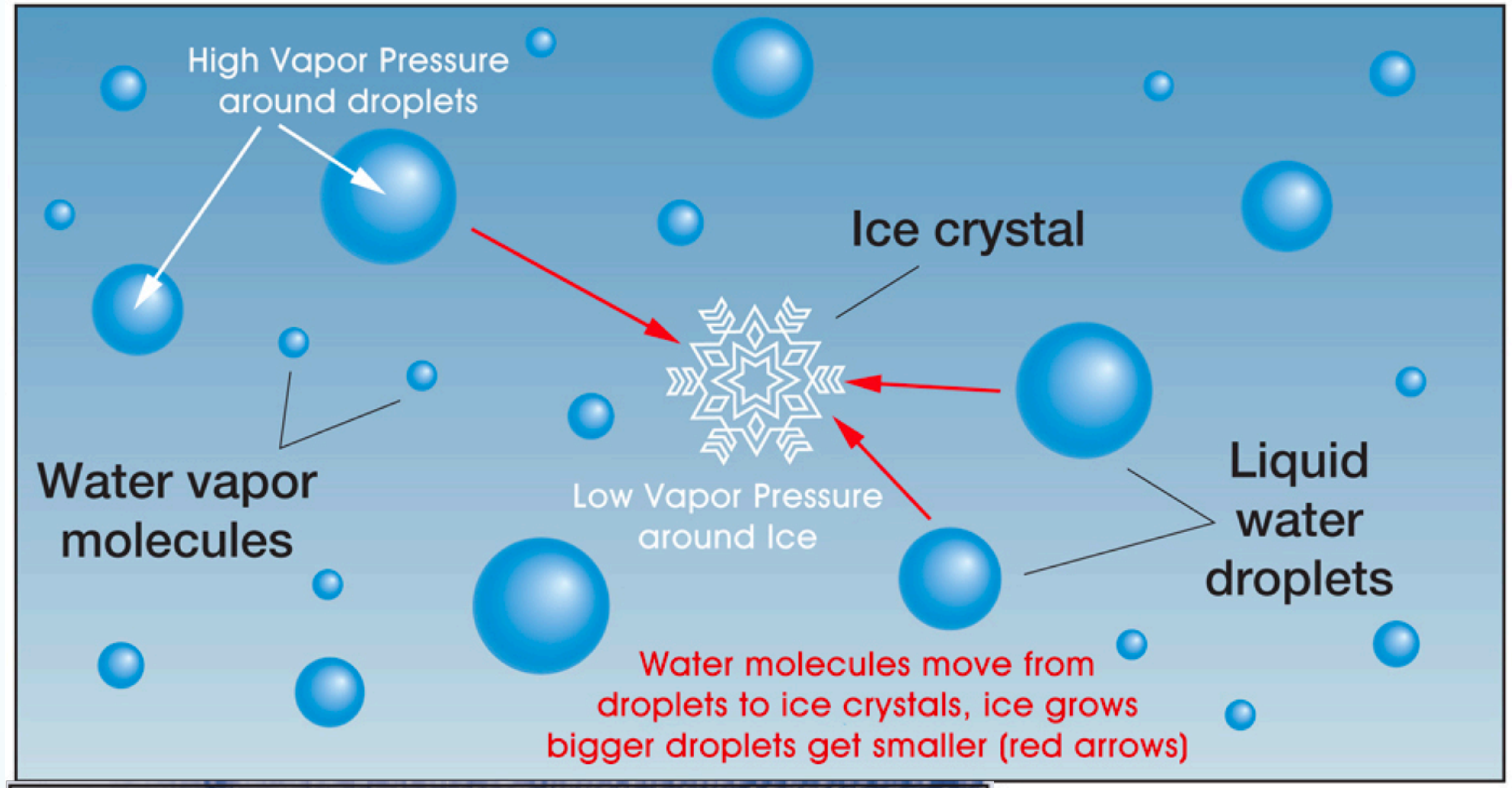
- Collision and coalescence
- ice crystals process

Collision and coalescence

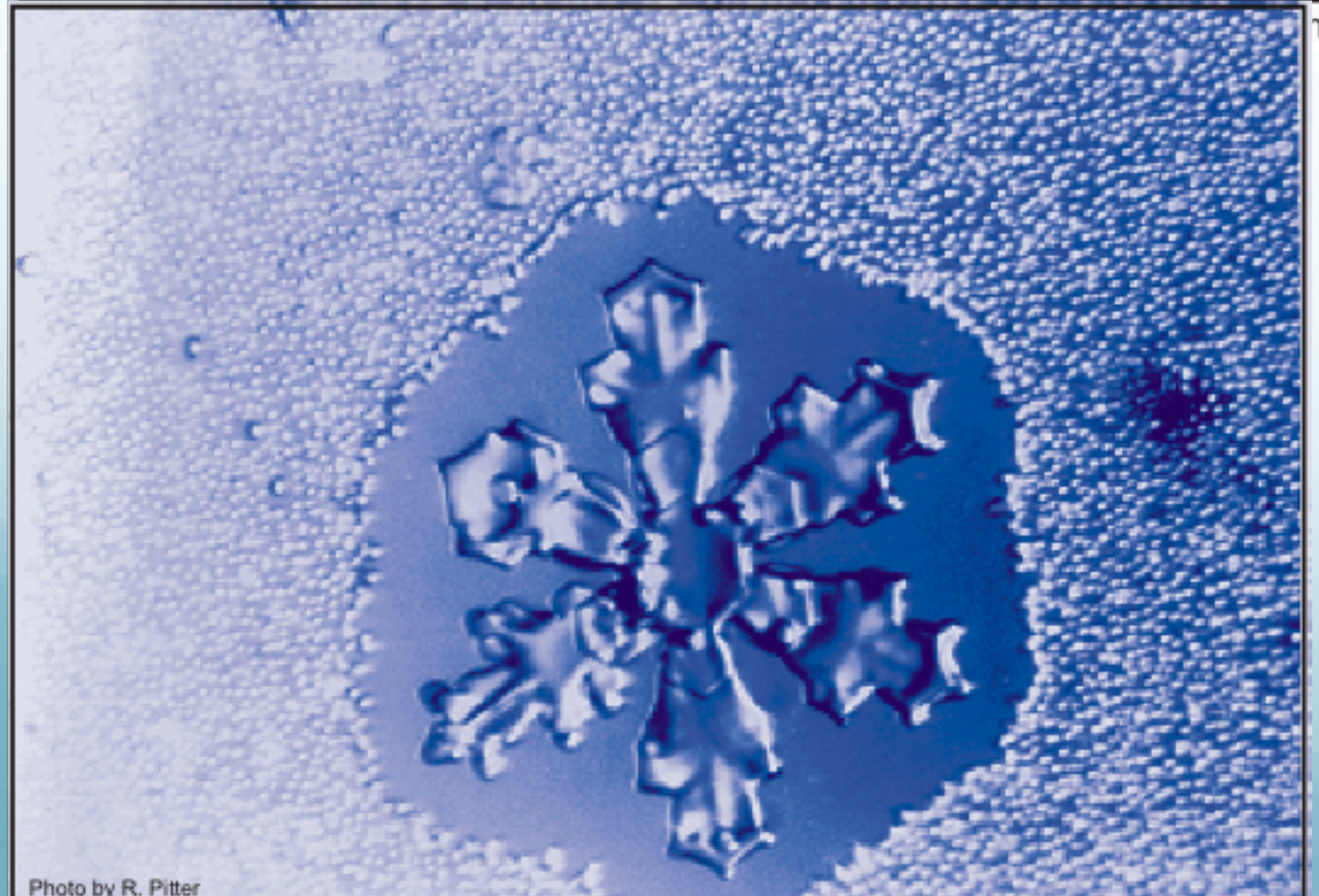
- Large droplets fall faster than small droplets
- The large droplets may collide with smaller droplets in their path
- If collisions result in a merger: the drops coalesce



Ice Crystal Process (Bergeron-Findeisen)



nc.



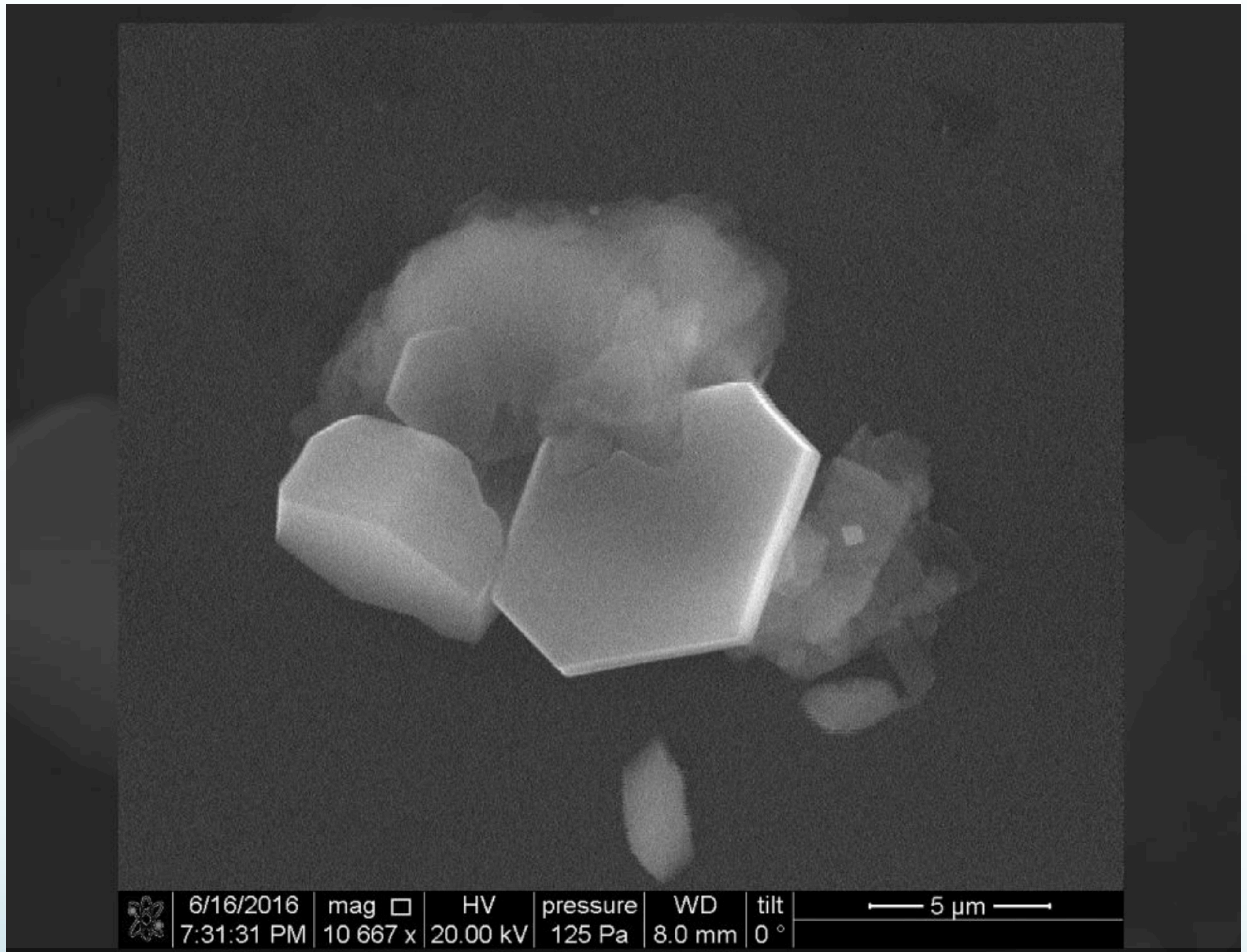
- Saturation vapor pressure over the super-cooled liquid water exceeds the saturation vapor pressure over the ice.

- There is a net transfer of water from the to the

  Liquid ➔ Vapor ➔ Ice

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

Ice Nuclei

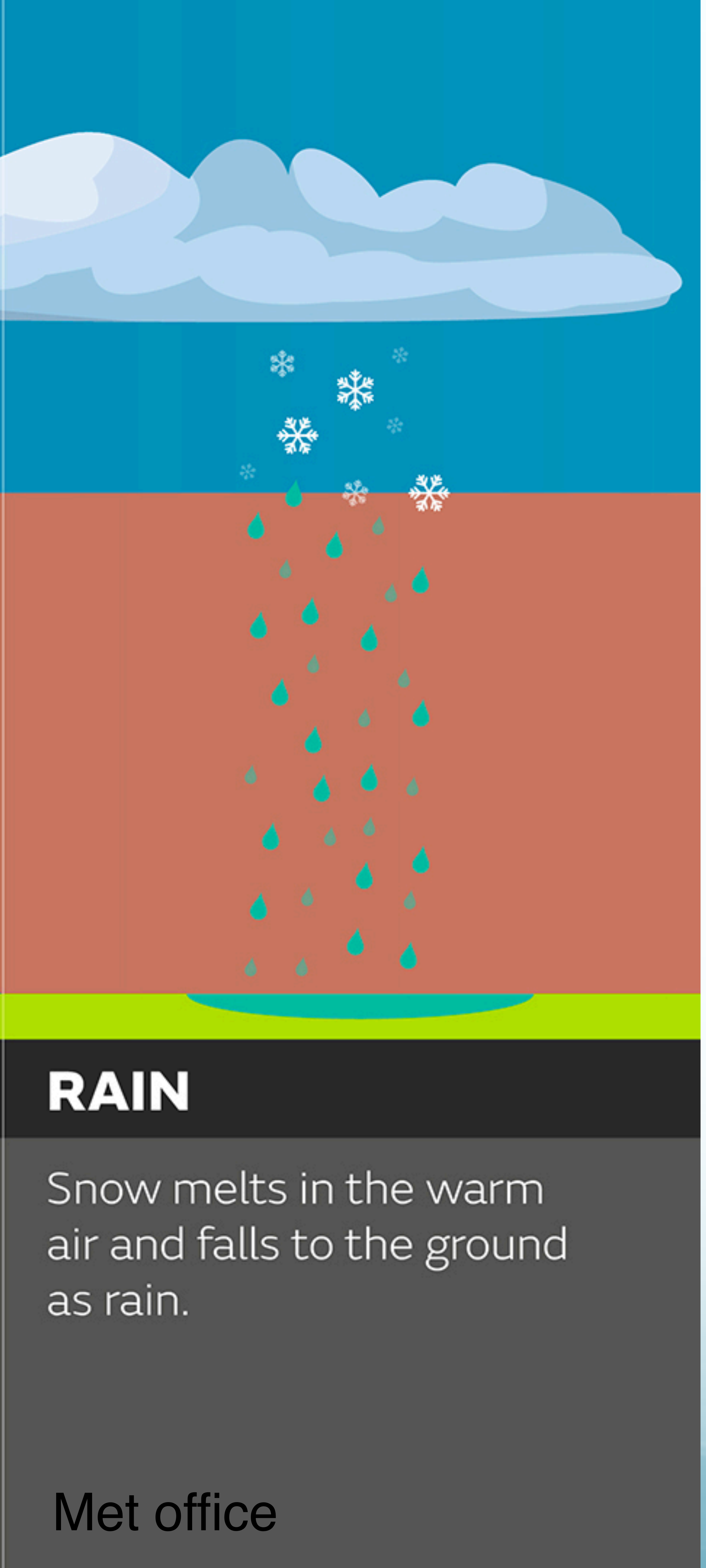


Ice crystals form around a minuscule particle in the very first seconds of the formation of an ice cloud.

- 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 ☐ and most are not active at temperatures warmer than –10 °C.

- Example: aircraft icing



Snow melts in the warm air and falls to the ground as rain.

Met office

Snow melts to form rain

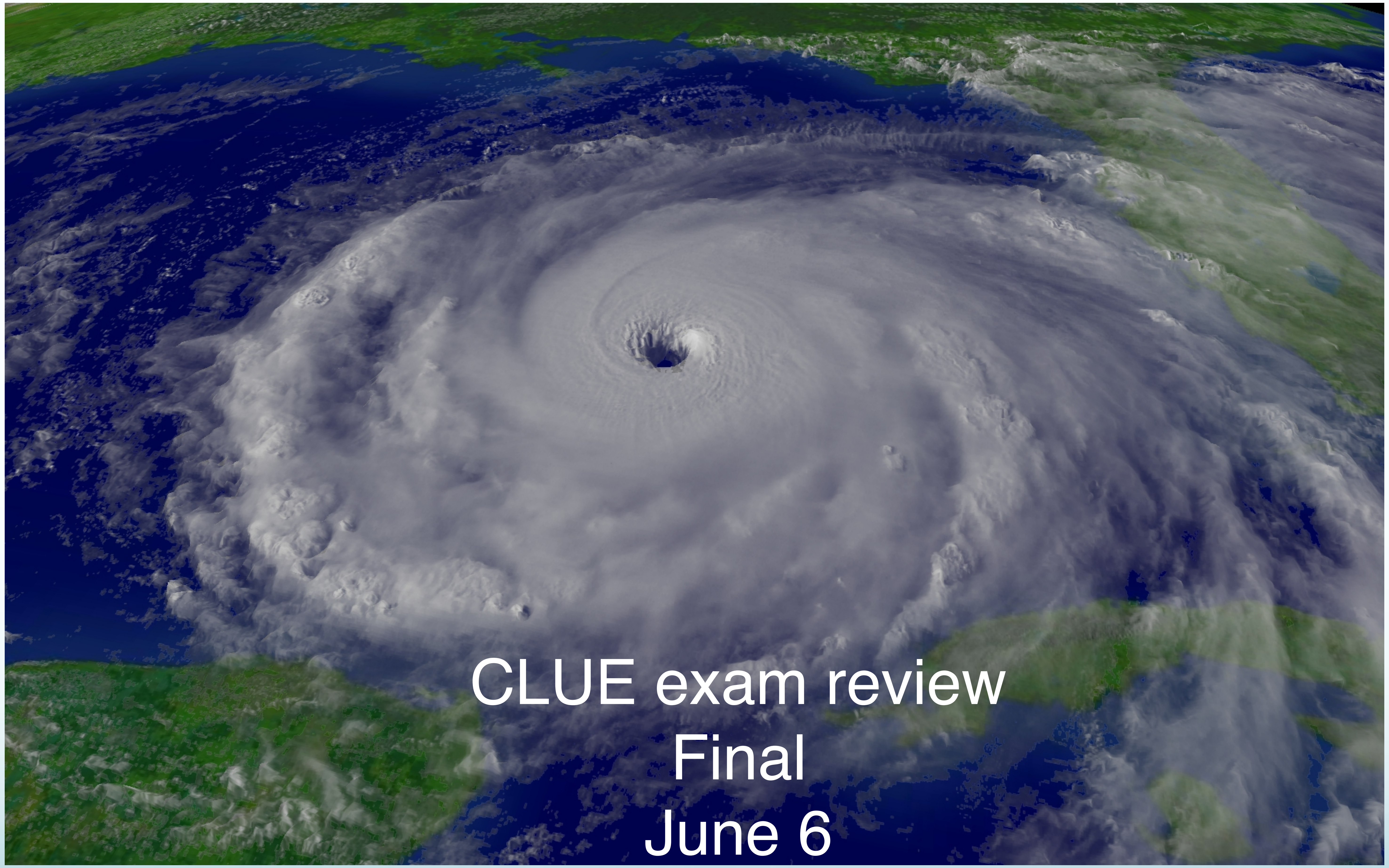
- When ice crystals or snow get large(heavy) enough, they fall down and form rain.
- Outside the tropics, almost all precipitation starts as ice crystals or snow.

Collisions help falling ice crystals grow large…

Graupel

Hail

Hurricanes and Thunderstorms



CLUE exam review
Final
June 6

Mid-term1

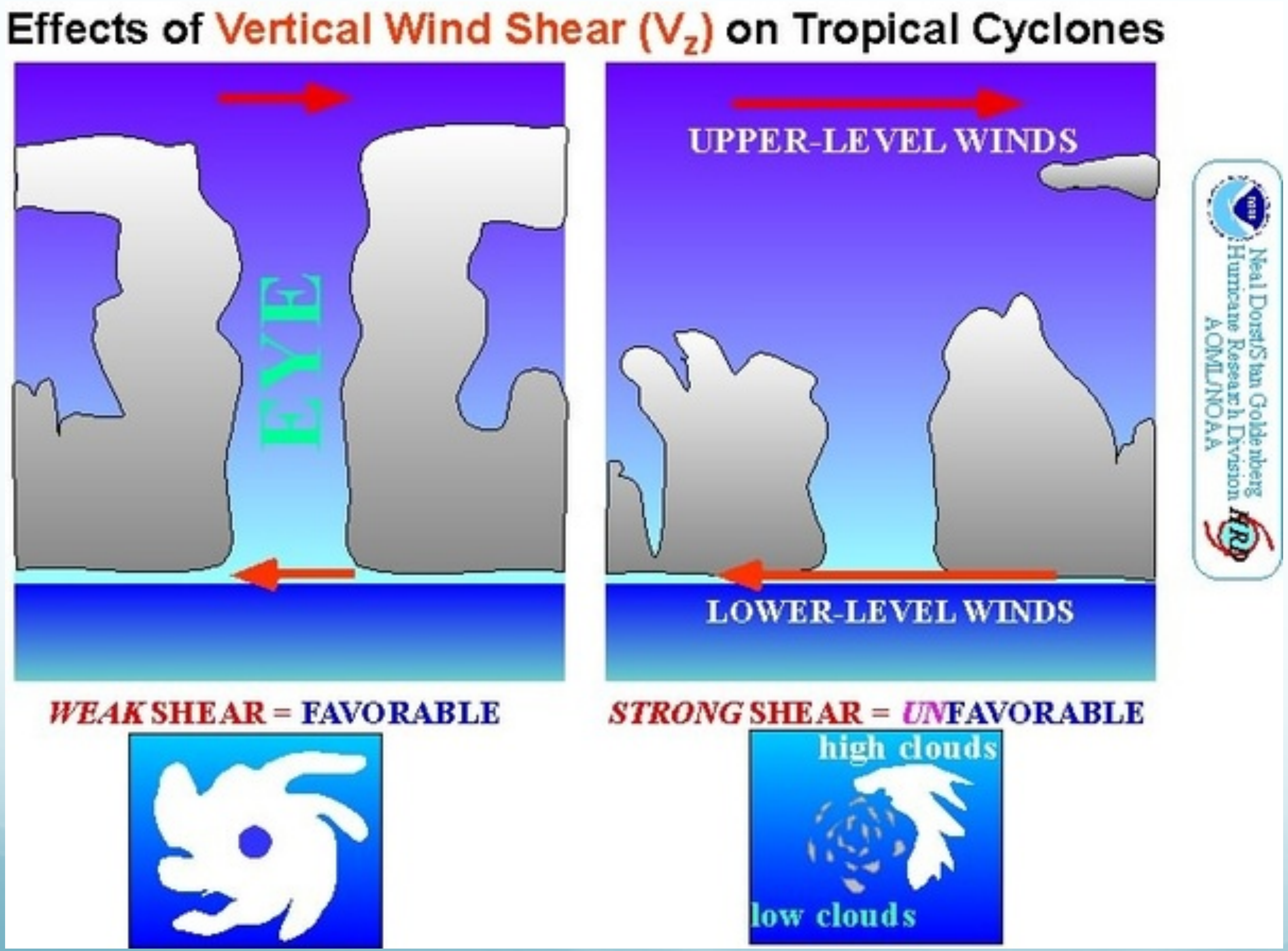
If a saturated air parcel containing a cloud is forced to descend,

[✓ a)] the cloud will tend to disappear because the air in the parcel is compressed and its temperature rises.

b) the cloud will tend to disappear because the pressure in the parcel decreases.

c) the cloud will tend to thicken because the surrounding temperature increases and there is more moisture available.

d) the cloud will not be affected.

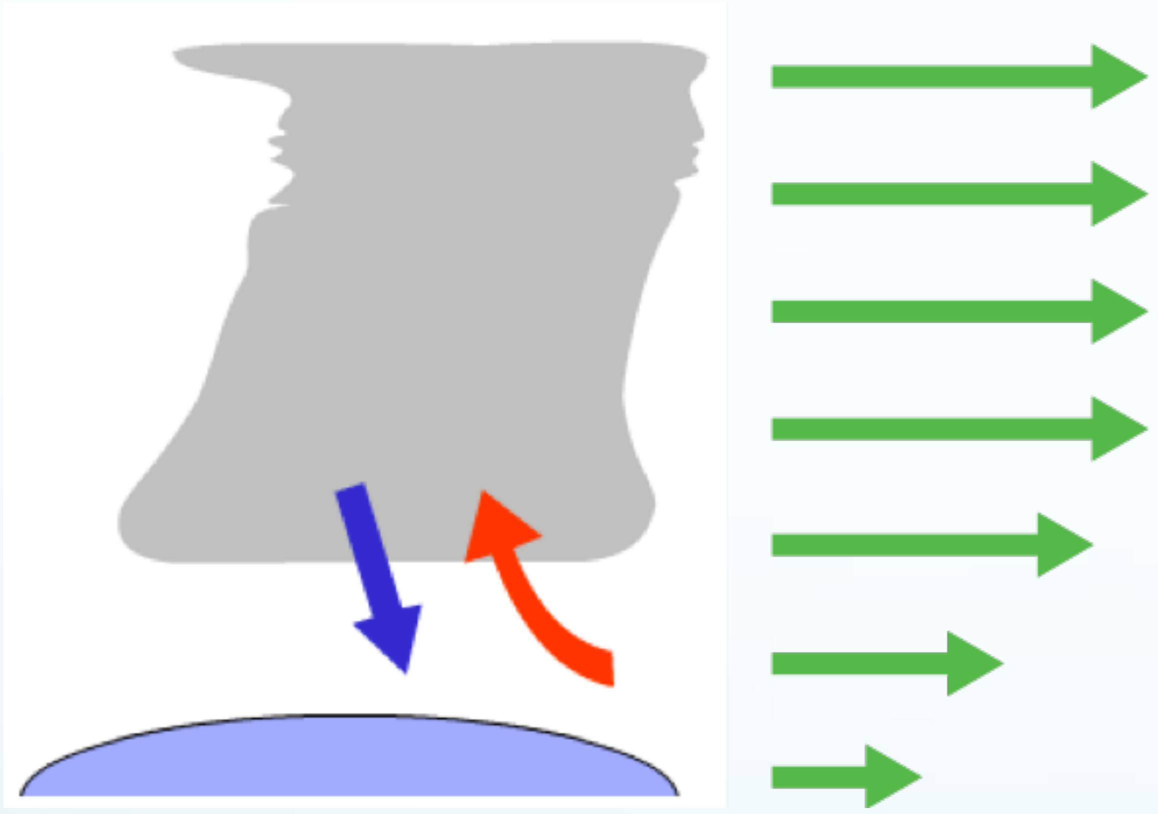


Effects of Vertical Wind Shear (V_z) on Tropical Cyclones

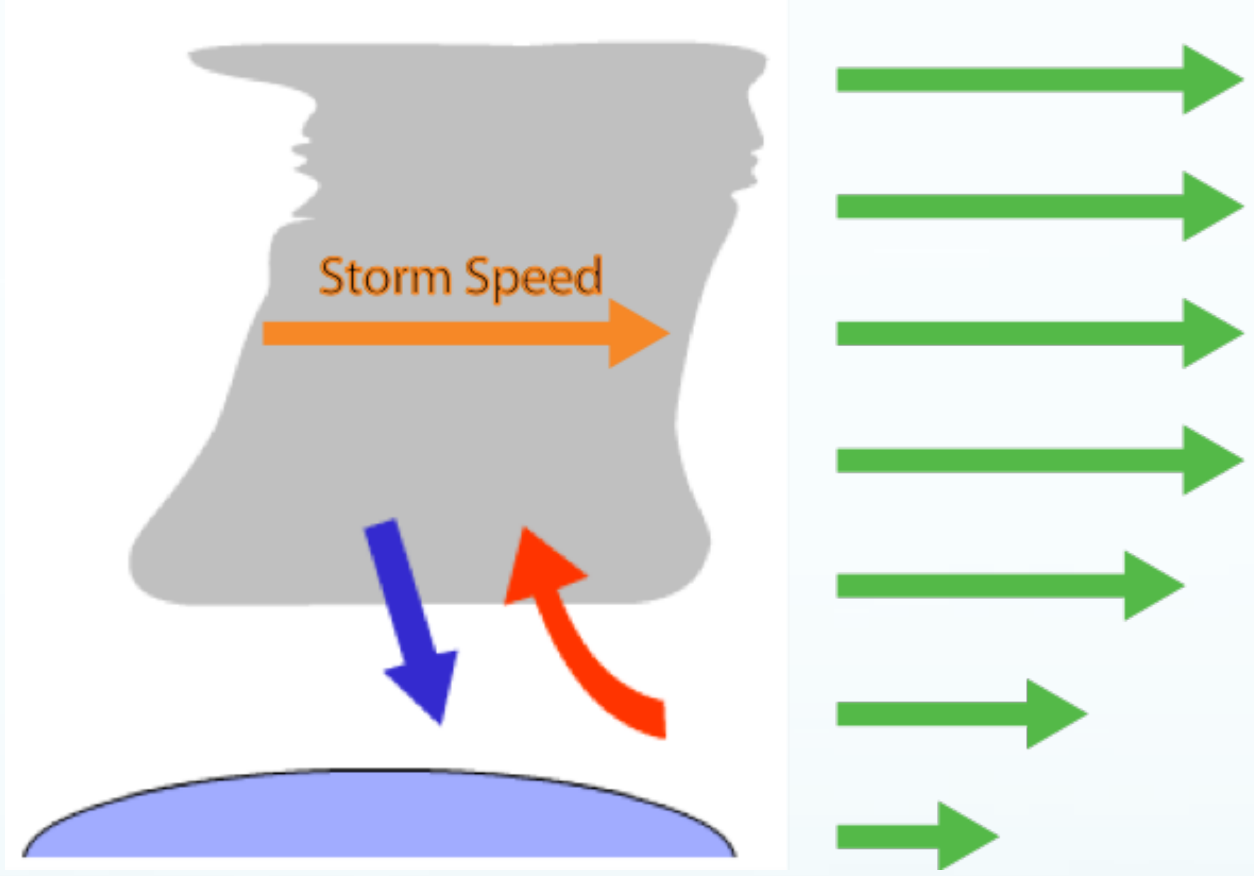
Neal Dorst/Stan Goldenberg
Hurricane Research Division
AOML/NOAA

How wind shear affects thunderstorm

Environment with Low-Level Shear

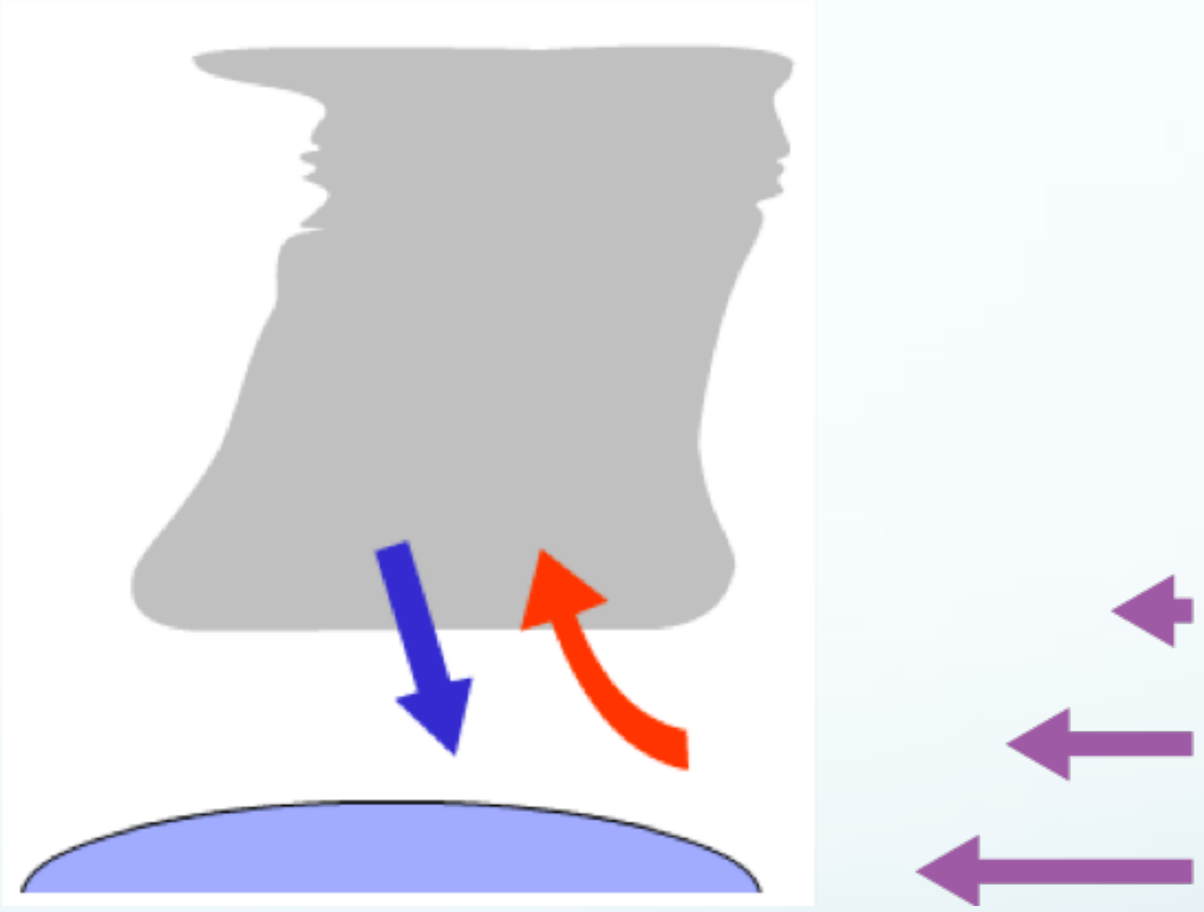


Shift to Storm-Relative View Point



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

Storm-Relative Winds



Low-level shear holds back the gust front.