ATM S 103

Hurricanes and Thunderstorms

Their Science and Impacts

Announcements

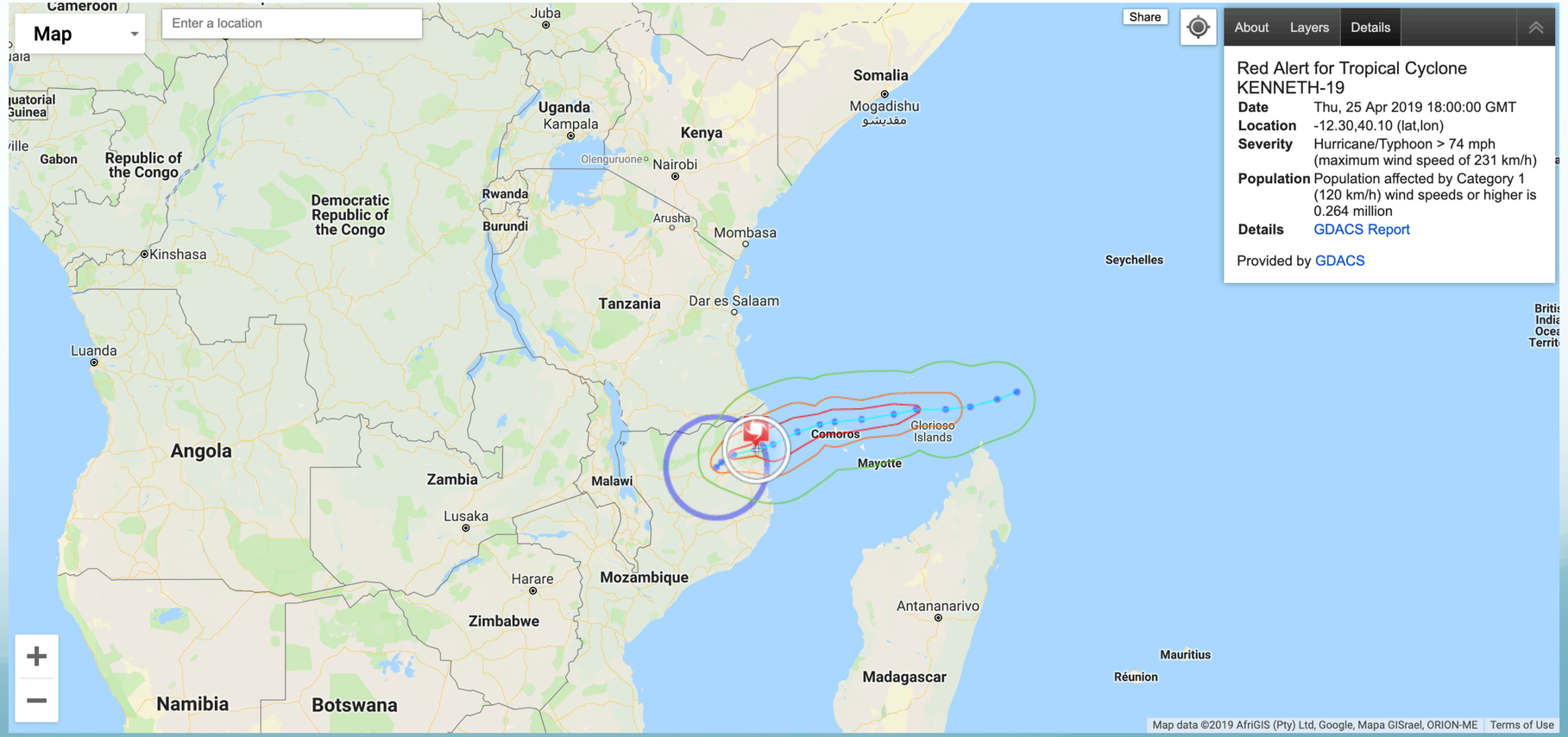
- Homework 3 due 6 PM today
- Pick up the study guide prepared by Litai Kang if you weren't able to attend yesterday's CLUE session

Midterm 1: Wednesday May 1

- Bring a Scantron form
- Closed book, notes, electronics
- 30 multiple choice questions (similar to homework)
- Covers
  - Homeworks 1-3
  - Lectures through April 24
  - Reading weeks 1-4

Kenneth update

- https://www.cnn.com/2019/04/26/africa/cyclone-kenneth-hits-mozambique-intl/index.html



Topics for today

- Formation of rain drops
  - Collision and coalescence
  - Supercooled water
  - Ice crystal process
- Hail
- Multi-cell thunderstorms

Hail

Capital Weather Gang

Hail, not tornadoes, is the most expensive severe storm hazard in Texas. And it could get hit hard Wednesday.

Hail damage to a home in Wylie, Tex., on April 11. (@wyliebear1/Twitter)

Rob Marciano ✓
@RobMarciano

Insane hail stones in Wylie, TX yesterday via Kristin Baxter

♡ 70 4:34 AM - Apr 12, 2016

Paul Dellegatto ⚡FOX ✓
@PaulFox13

Yikes! Softball size hail in Denton, Texas. Not good. per @BryanEnriPineda #severeweather #skytower

♡ 2 2:54 PM - Apr 3, 2014

https://www.washingtonpost.com/weather/2019/04/17/hail-not-tornadoes-is-most-expensive-storm-hazard-texas-it-could-get-hit-hard-wednesday/?utm_term=.d980b112f0c8

Hail in Action

Phoenix, Arizona: Oct 5, 2010

How do the tiny cloud droplets grow into hail stones?

When this is no ice, rain drops grow primarily by

condensation of water vapor molecules nearby on the surface of rain drops.

collision of raindrops of difference sizes, through which small ones are coalesced into large ones.

Answer

- Rain drops can grow quickly through collision and coalescence

Ice Crystal Process

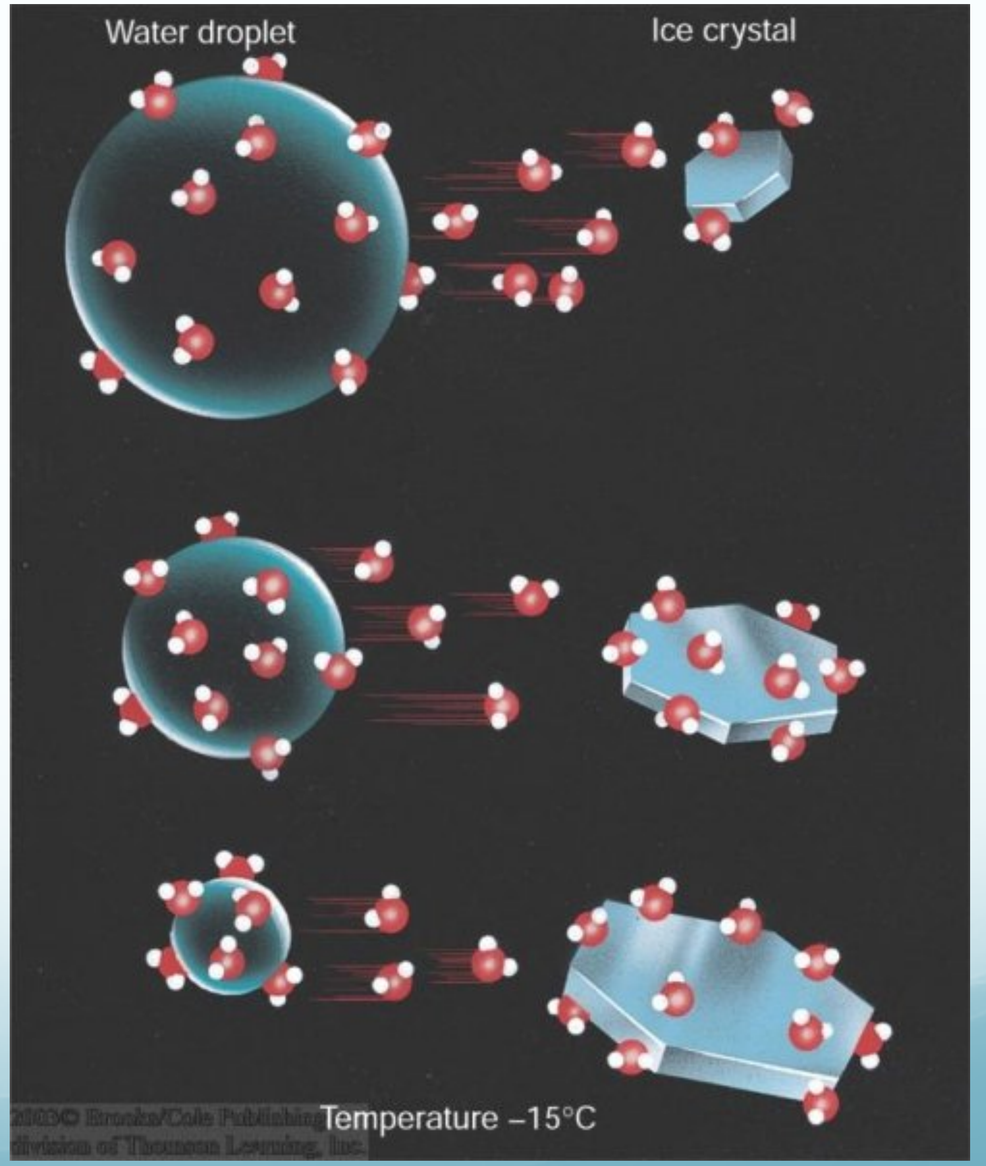
- Another way of growing rain drops quickly

The Ice Crystal Process

Shows the net transfer of water-vapor molecules from liquid droplets to the ice.

- Top is the earliest time.
- Bottom is the latest time.

Wait, water droplet at temperature -15 ^{o}C?



All cloud above the freezing level is not ice

Ice in Clouds

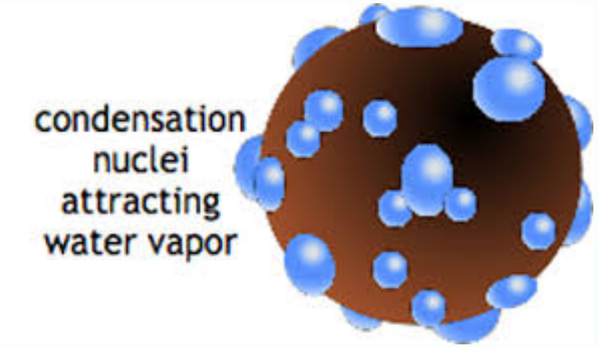
- There are almost no ice crystals in clouds at temperatures warmer than –10 °C.
- Mixed ice and liquid droplets between –10 °C and –40 °C
- All ice at temperatures less than –40 °C

Supercooled Water

- How can liquid water exist below 0°C?
- Freezing at temperatures just below 0°C requires the presence of several low energy molecules at the same point in the water.
- The chance of this is greatly reduced in very small volumes of water.
- The liquid needs to get to –40°C (also –40°F) to ensure freezing will happen rapidly without the help of an ice nucleus.

Ice Nuclei

- Cloud condensation nuclei (CCN) help form liquid droplets from vapor.



- Ice nuclei help form ice crystals from water droplets.
  - Provide a seed to start crystal growth
  - Often clay particles or plant material.
- But compared to CCN, ice nuclei are rare, and most are not active at temperatures warmer than –10 °C.

Aircraft Icing

The wing surface provides locations (microscopic irregularities) for crystals to start growing.

In a Cloud with Super-cooled Water and Ice

- There is a net transfer of water from the liquid to the ice
  - Liquid → Vapor → Ice
  - Saturation vapor pressure over the super-cooled liquid water exceeds the saturation vapor pressure over the ice.
- Equilibrium conditions for the droplets are ones in which the ice must grow.
- Ice grows rapidly because the air is supersaturated (with respect to ice).

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

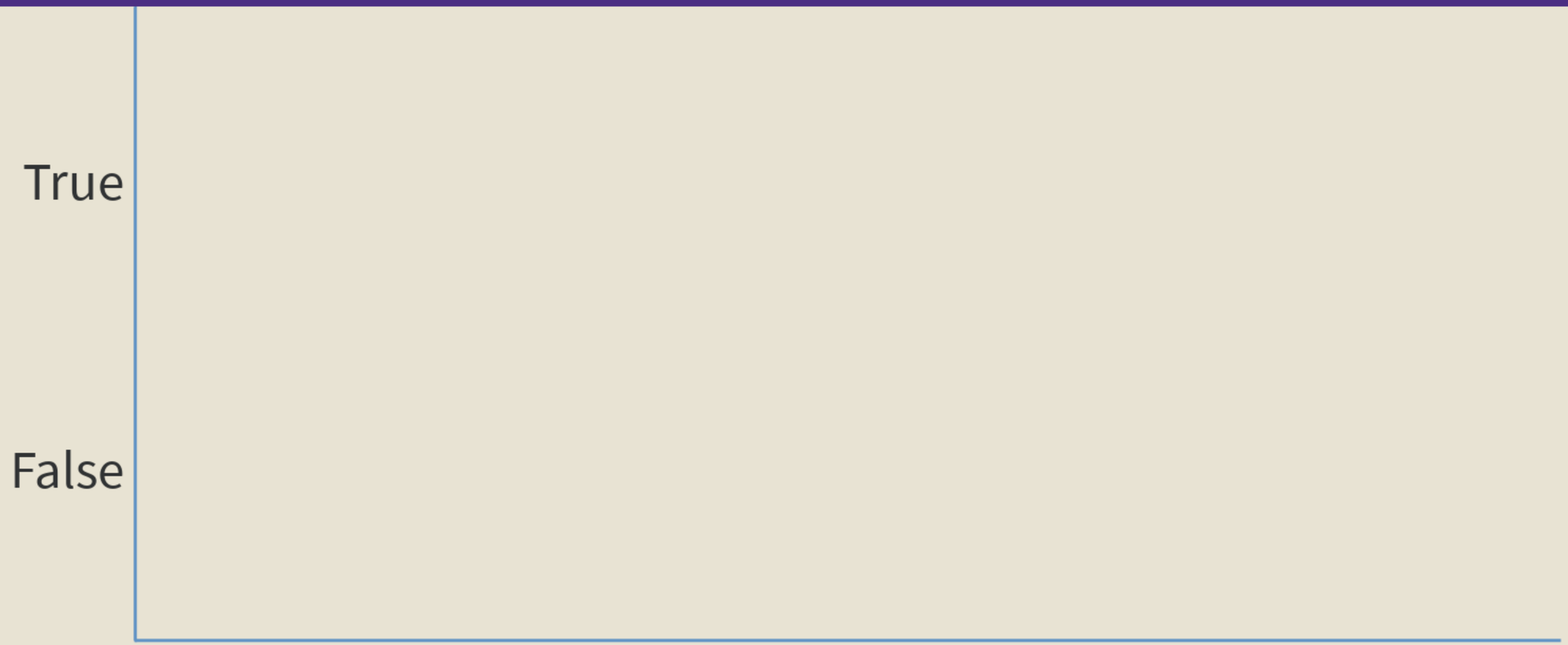
Ice Crystal Process

Bergeron-Findeisen Process

Snow Melts to Form Rain

- When gets large (heavy) enough, the ice crystals or snow falls down.
- Outside the tropics, almost all precipitation starts as ice crystals or snow.
- Mid-latitude raindrops are melted snow.

W Thunderstorms with ice visible in the upper part of the cloud are likely to start raining very soon.



Start the presentation to see live content. Still no live content? Install the app or get help at **PollEv.com/app**

Total Results

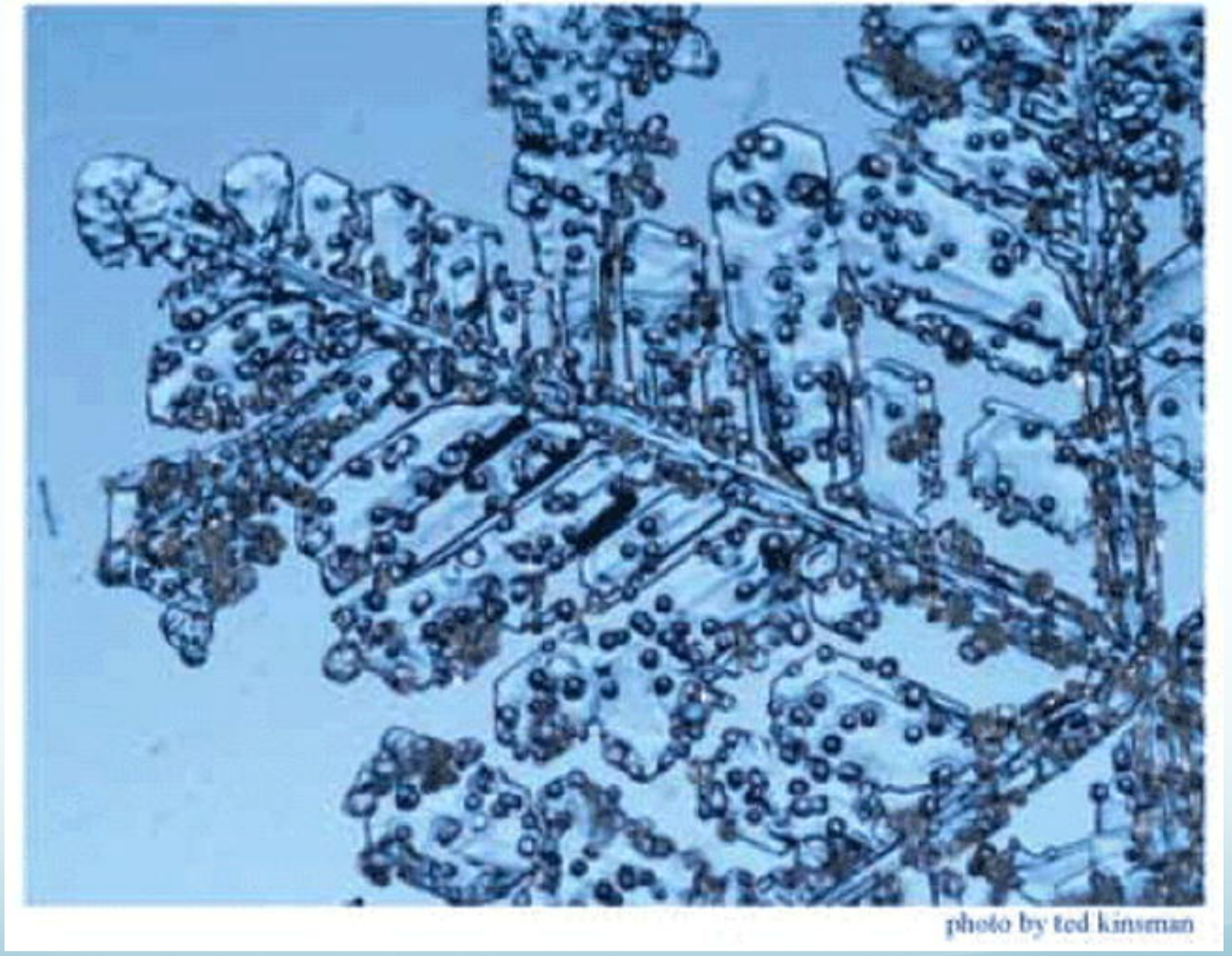
True

- When ice and liquid water are both present in a deep cumulus cloud, the ice-crystal process becomes active.

Collisions also help falling ice crystals grow more massive

- Falling ice crystals can grow by collecting super-cooled cloud droplets
  - The droplets freeze onto the crystal
  - Called Riming (or accretion)

Lightly Rimed Snowflake



Heavily Rimed Snowflake

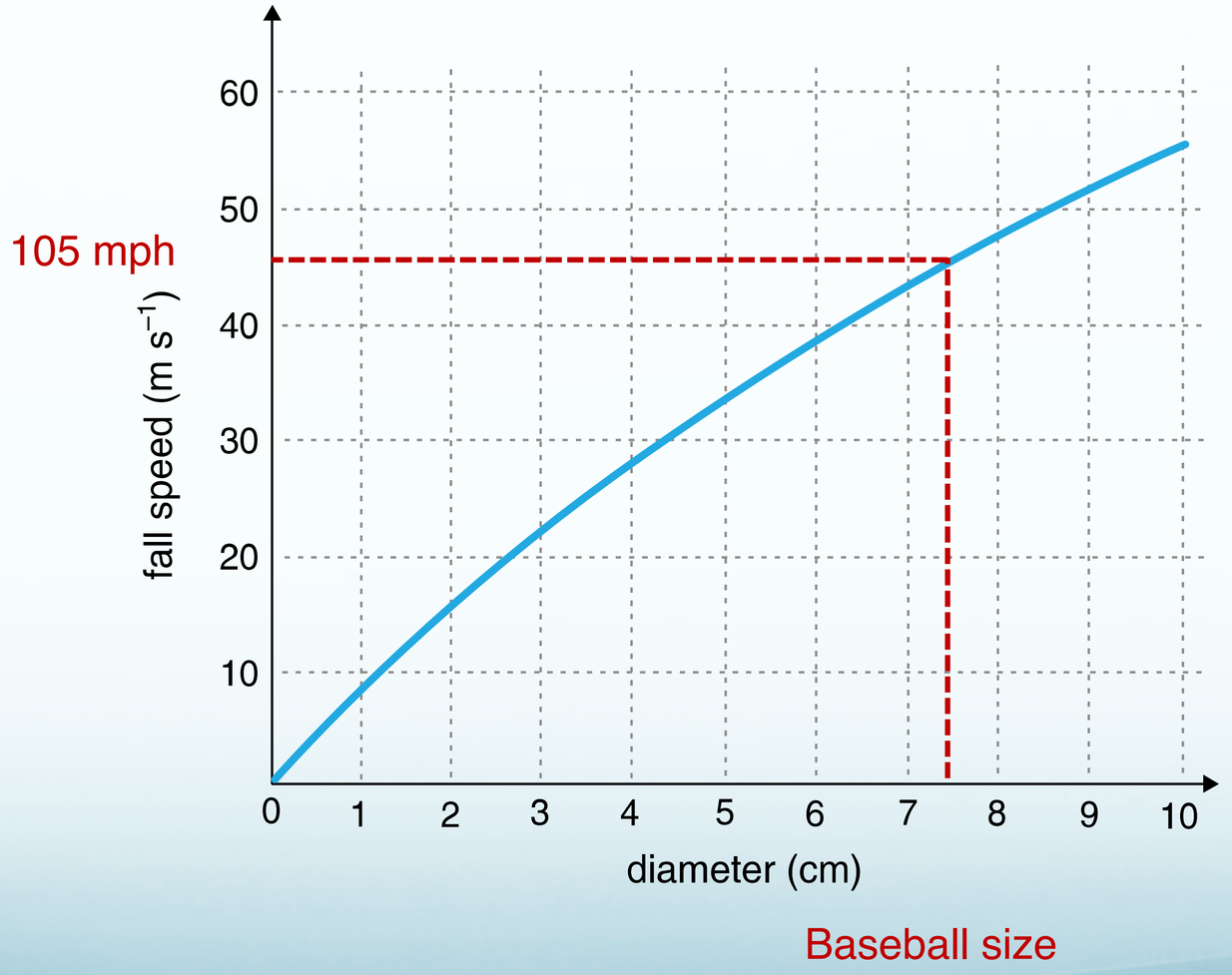
Graupel

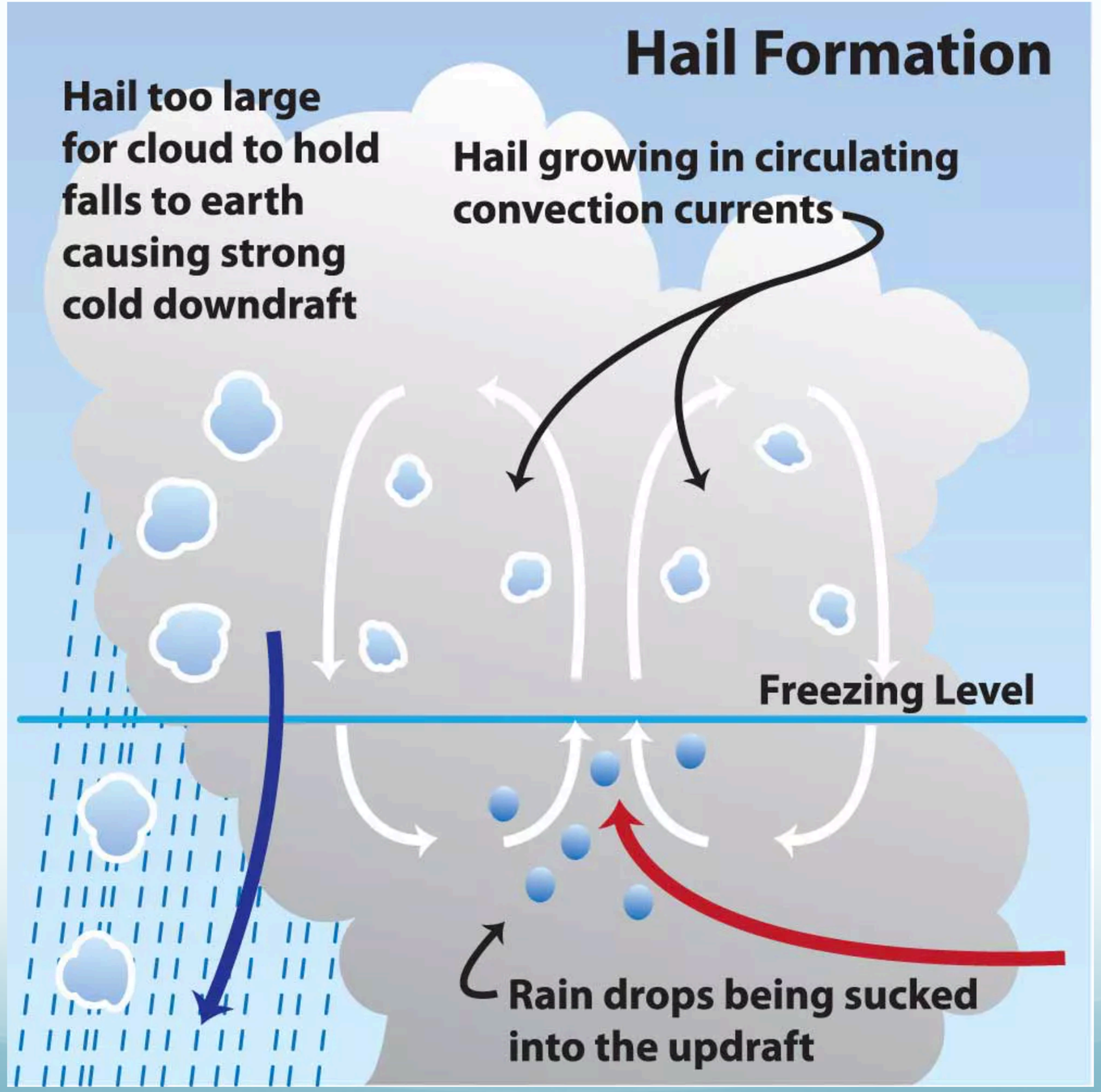
Graupel

- Looks white because lots of air is trapped within the rimed ice
- Lightweight and crunchy because of the trapped air.

Beyond Graupel: Hail

Terminal Falls Speeds for Hail




Hail Formation
Hail too large for cloud to hold falls to earth causing strong cold downdraft
Hail growing in circulating convection currents
Freezing Level
Rain drops being sucked into the updraft

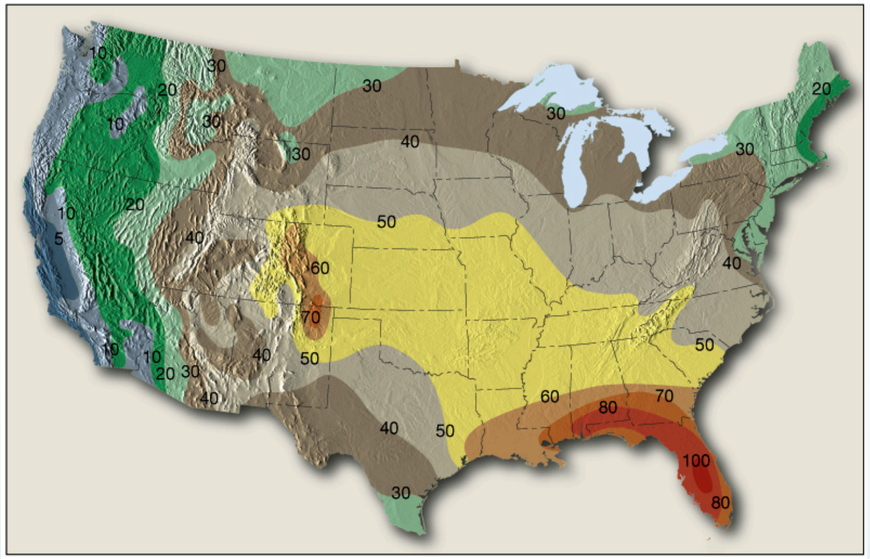
Layered Growth

Clear/Milky Ice Layers

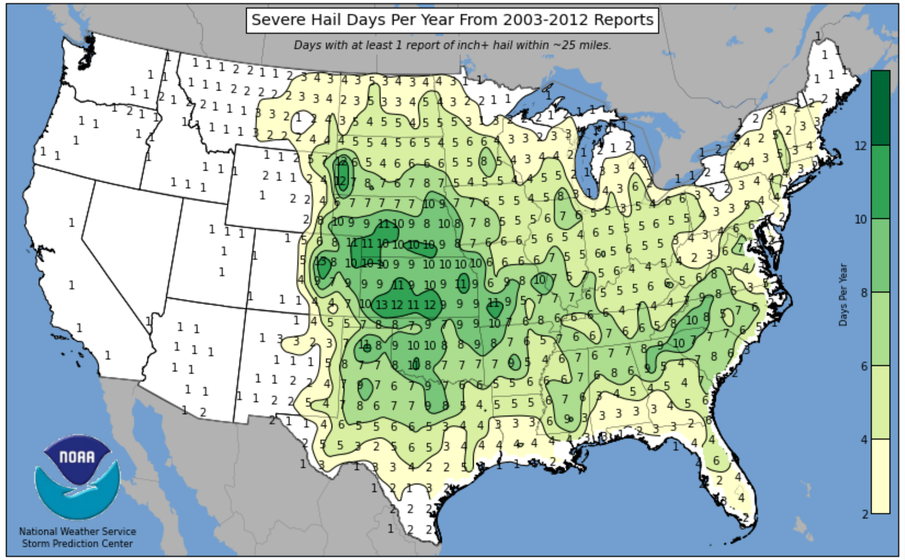
- White layers are where the new ice froze instantly when it contacted the stone.
  - Air get's trapped in the ice
- Clear ice forms in layers when the water freezes more slowly after contacting the stone.
  - Liquid water spreads out before freezing
  - Creates almost clear, dense ice
- Large hailstones recirculate through different parts of the thunderstorm.
  - Encountering droplets with different sizes and temperatures.

Many more thunderstorms in Florida than in Kansas, but more severe hail in Kansas. Why?

Thunderstorm frequency



Severe Hail Frequency

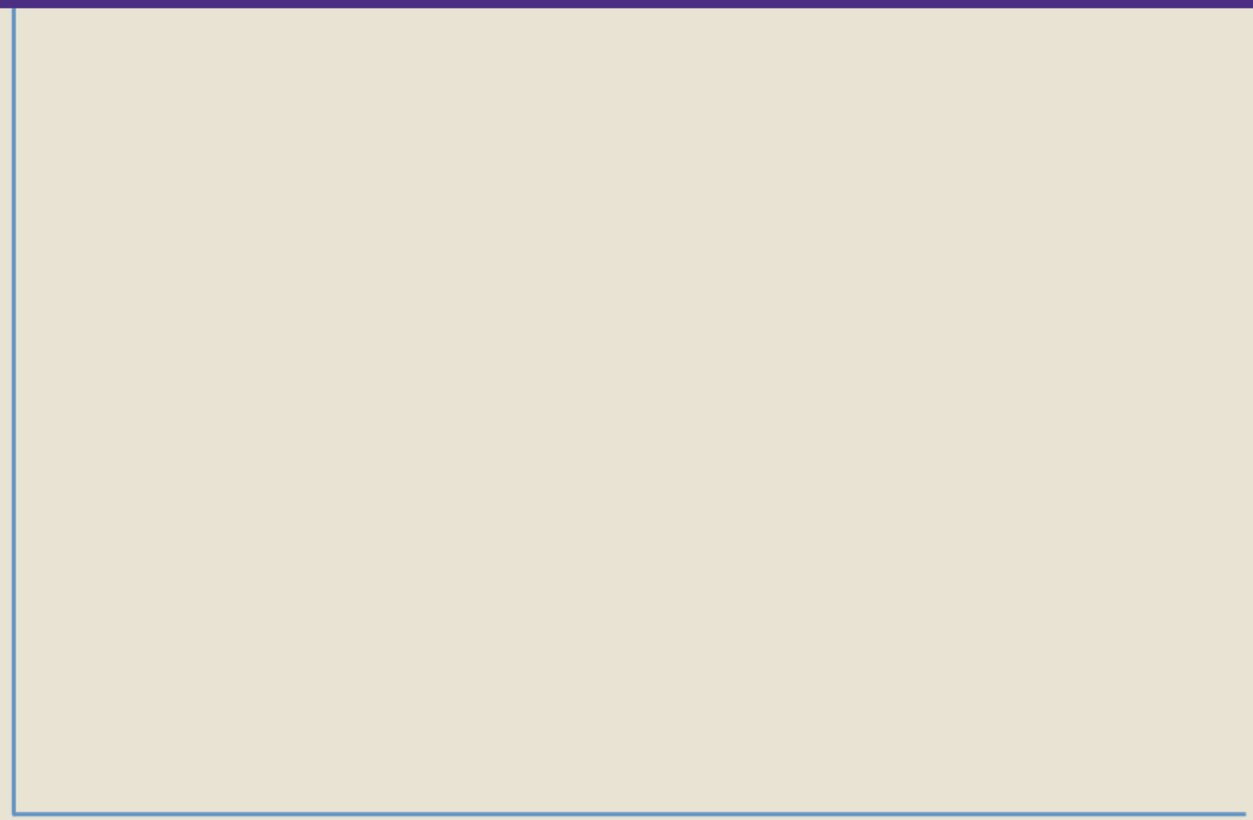


There are many more thunderstorms in Florida than in Kansas, but more severe hail in Kansas. Why?

Because the air below cloud base is DRIER in Florida.

Because the height where the air temperature drops to 0 C is HIGHER in Florida.

Both of the above.



Answer: The higher melting level makes severe hail less common in Florida

- Hailstones have more time to melt before hitting the ground in Florida because the melting level is higher.
- The air below cloud base is drier in Kansas than in Florida. (Lower dewpoints …)
- If a hailstone is falling though dry air at temperatures above freezing:
  - Melted water on the outside of the stone evaporates rapidly.
  - This evaporation cools the stone, slowing the melting.

Hail in Action

Grandbury, Texas: May 15, 2013

Windshield trouble

US Record Holder

July 23, 2010, Vivian, South Dakota: 8.0” diameter, 1 lb, 15 oz

World-Wide Hail Records

- Heaviest: 2 ¼ lbs in Bangladesh, April 14, 1986
- Deadliest: April 30, 1888: 246 killed in India
- Costliest: $3 billion in Sydney, Australia
  - 3 ½ inch stones fell for almost one hour
  - April 14, 1999

Roop Kund, India

RoopKund, India

- 1942: British forest guard discovers hundreds of human skeletons around frozen lake
- 2004 scientific analysis: all of the people died from blows to the head.
  - The short, deep cracks in the skulls appeared to be the result not of weapons but of something round.
  - Only had wounds on their heads and shoulders, indicating the blows came from directly above.
  - Conclusion: The hundreds of travelers all died from a sudden and severe freak hailstorm.

Kinds of Thunderstorms

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

Single-cell thunderstorms dissipate when

They grow high enough for their tops to hit the tropopause.

Ice starts to develop in the top of the cloud.

The gust front spreads out cutting off the supply of warm low-level air.

Answer

- The storm dies when the gust front at the edge of the expanding pool of rain-cooled air, cuts of the supply of warm moist air feeding the updraft.

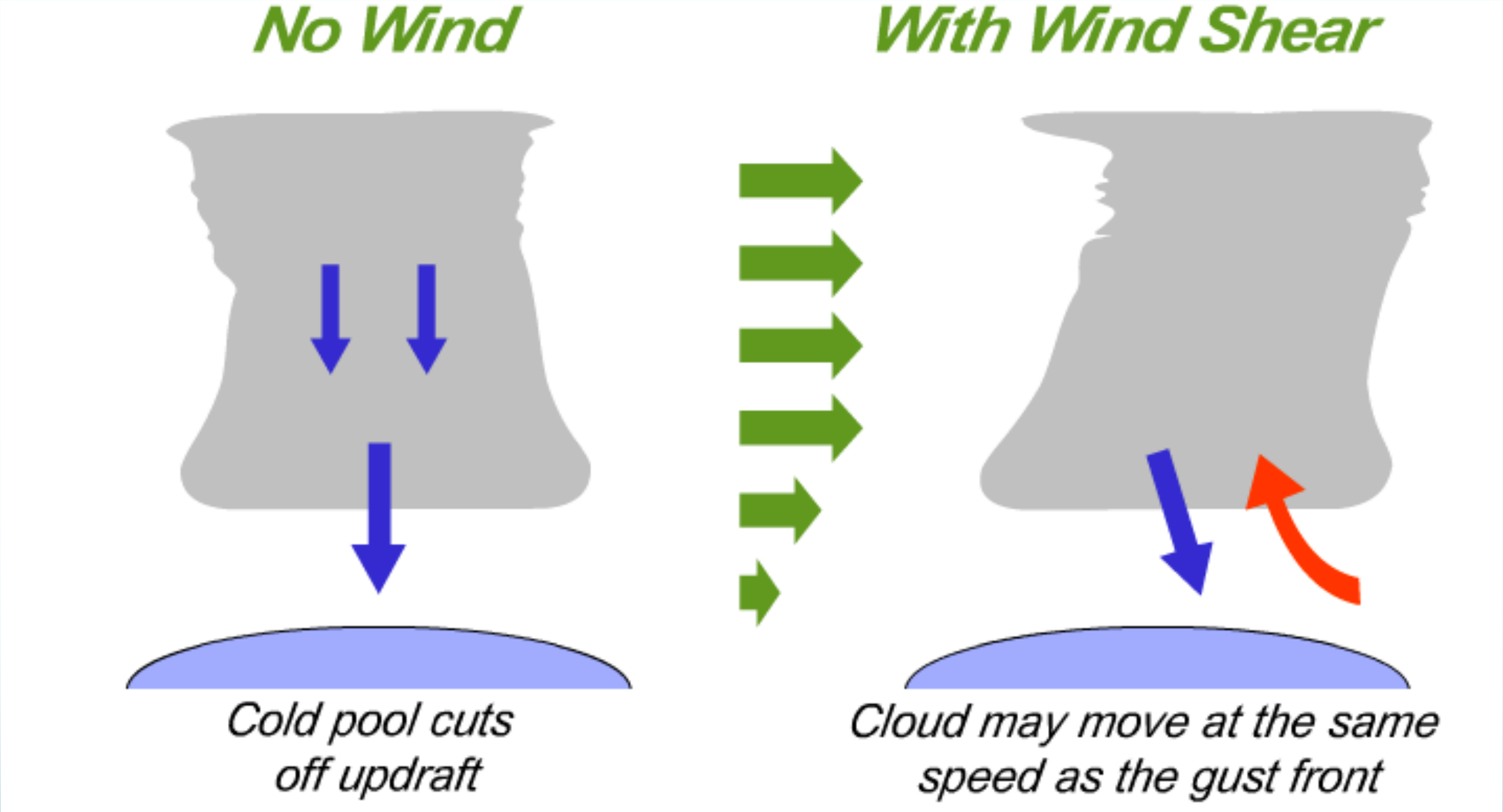
Type of Thunderstorm Is Determined By

- How much warmer rising air parcels become in comparison to their environment (the CAPE)
- The change with height in the wind speed and direction in the lowest 5 km of the atmosphere.
  - This is the low-level wind shear.

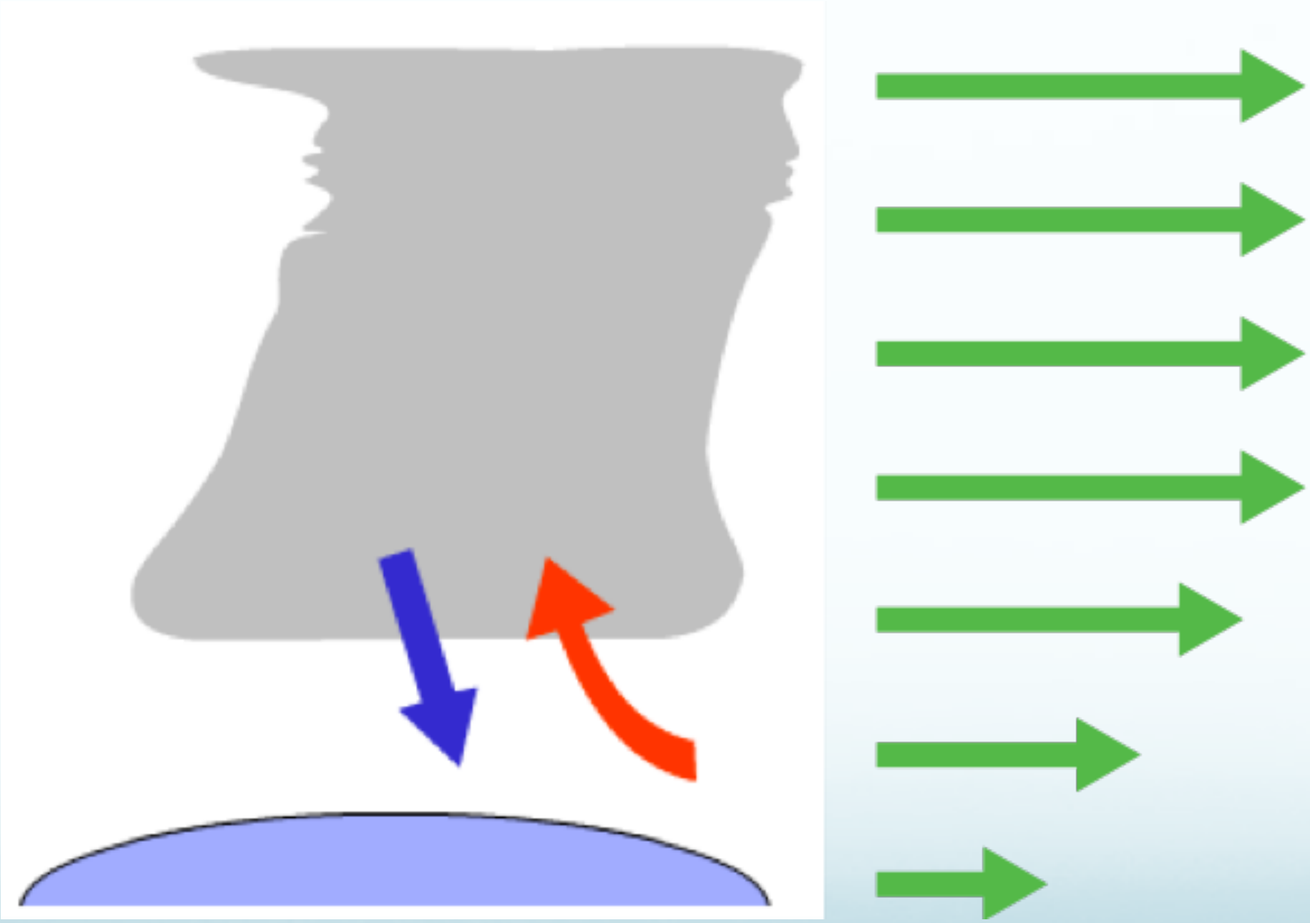
Extending the Lifetime Beyond that of a Single Cell Storm

- Need to keep the cold pool/gust front from cutting off the updraft.
- This can be accomplished by low-level wind shear.

Influence of Low-Level Wind Shear

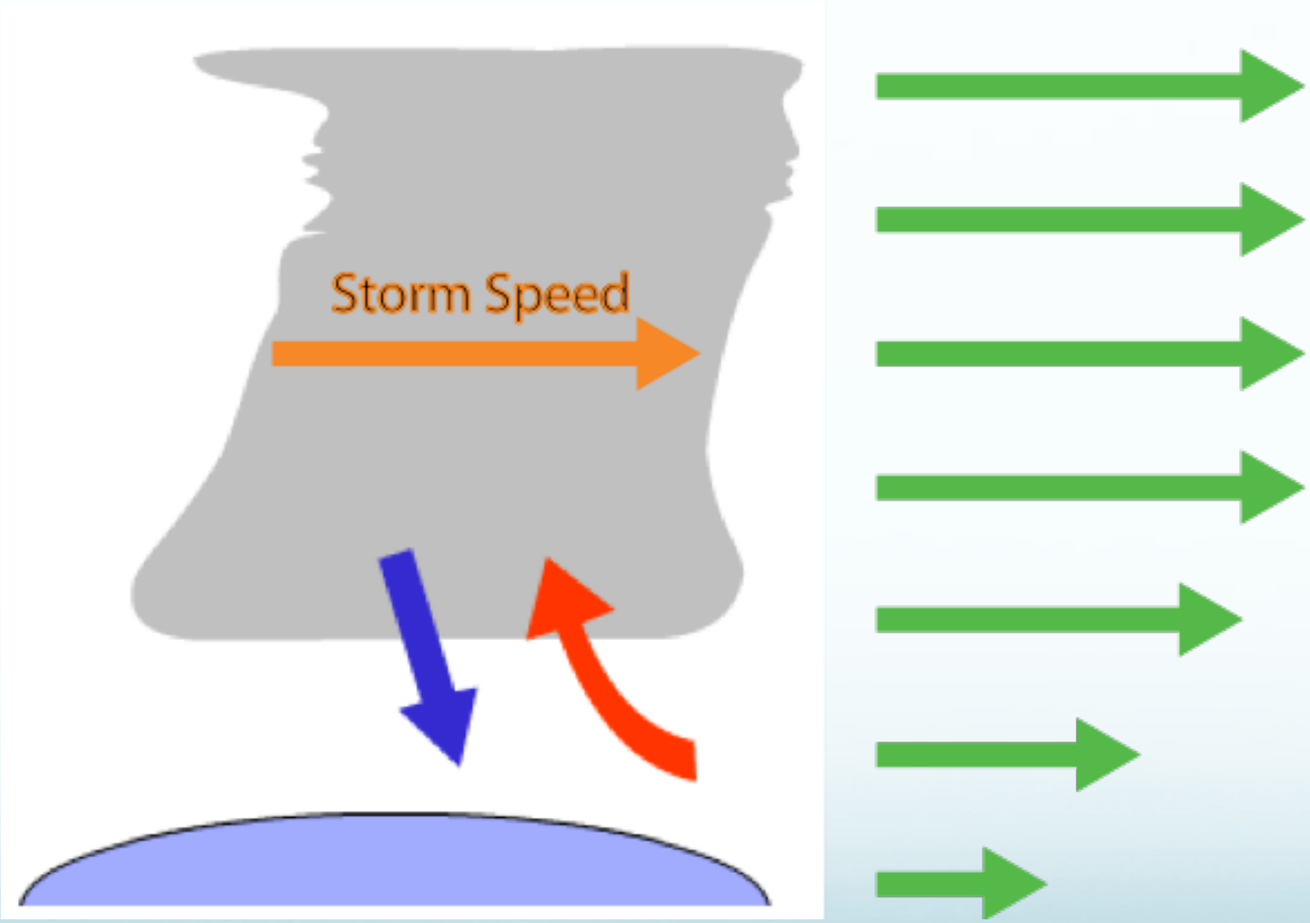


Environment with Low-Level Shear



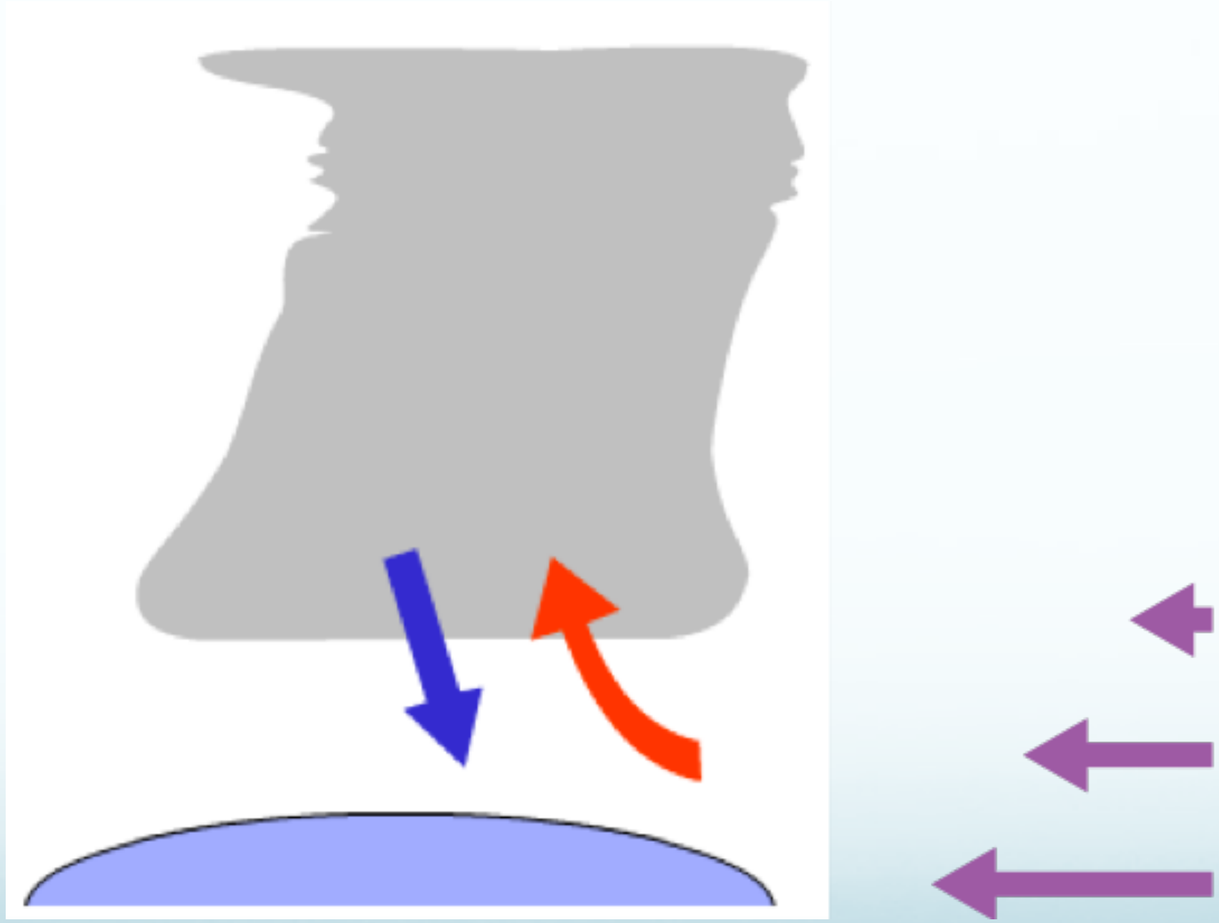
Shift to Storm-Relative View Point

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



Storm-Relative Winds

Low-level shear holds back the gust front.



Influence of wind shear on thunderstorm structure

- 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
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Multi-cell Thunderstorm

Multi-cell Schematic