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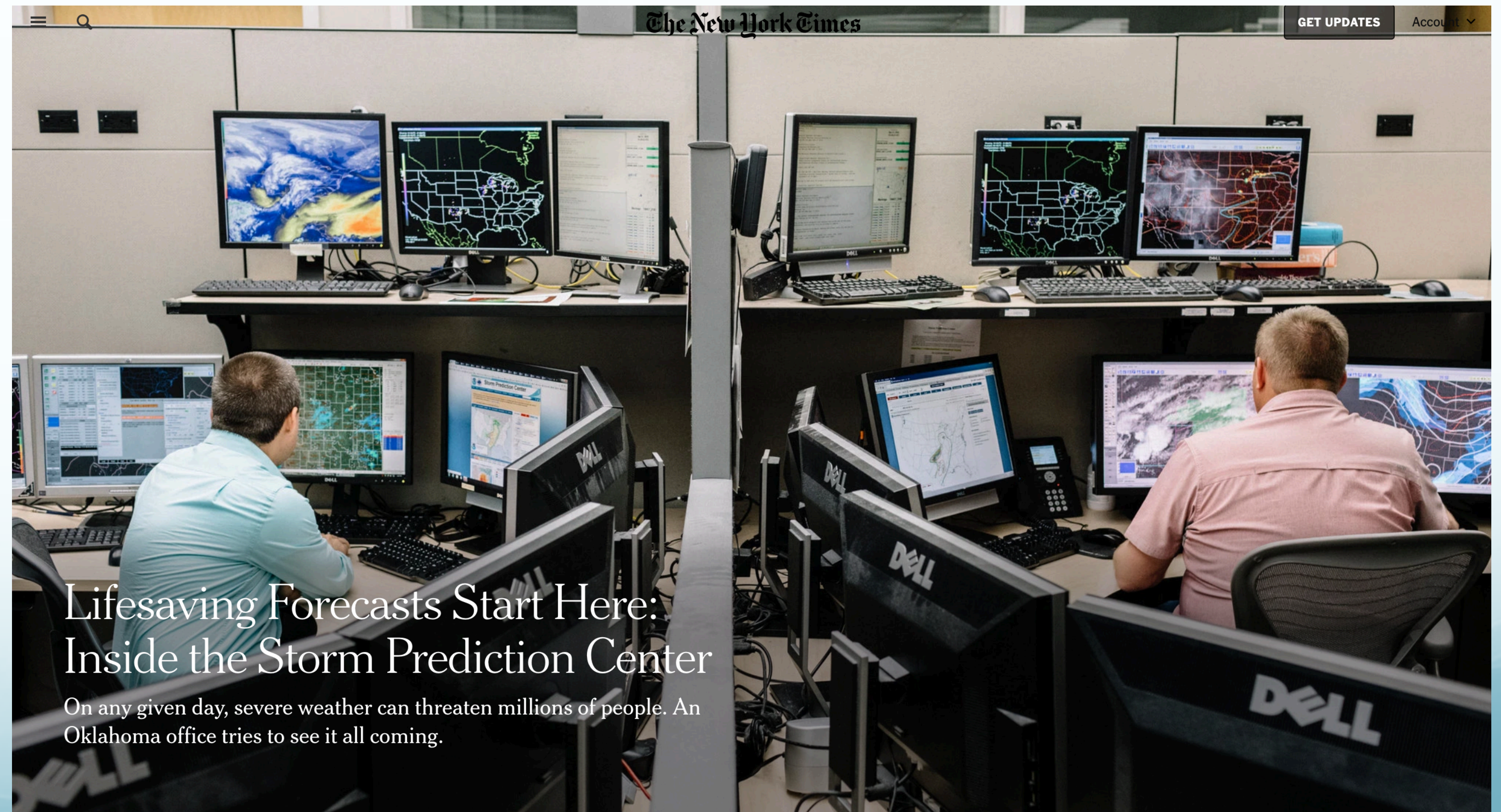
Hurricanes and Thunderstorms

Their Science and Impacts



A New York Times Article about the Storm Prediction Center

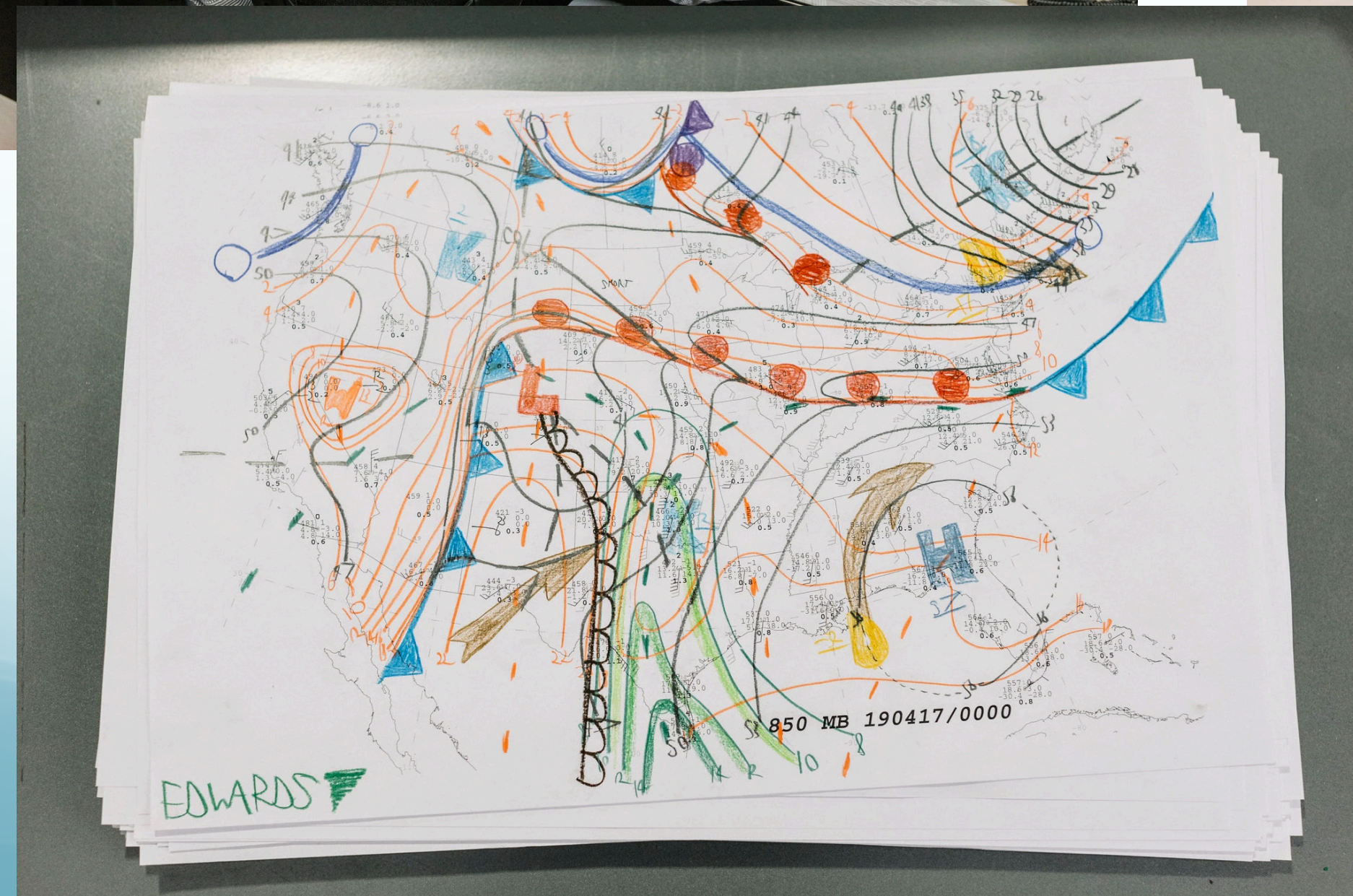
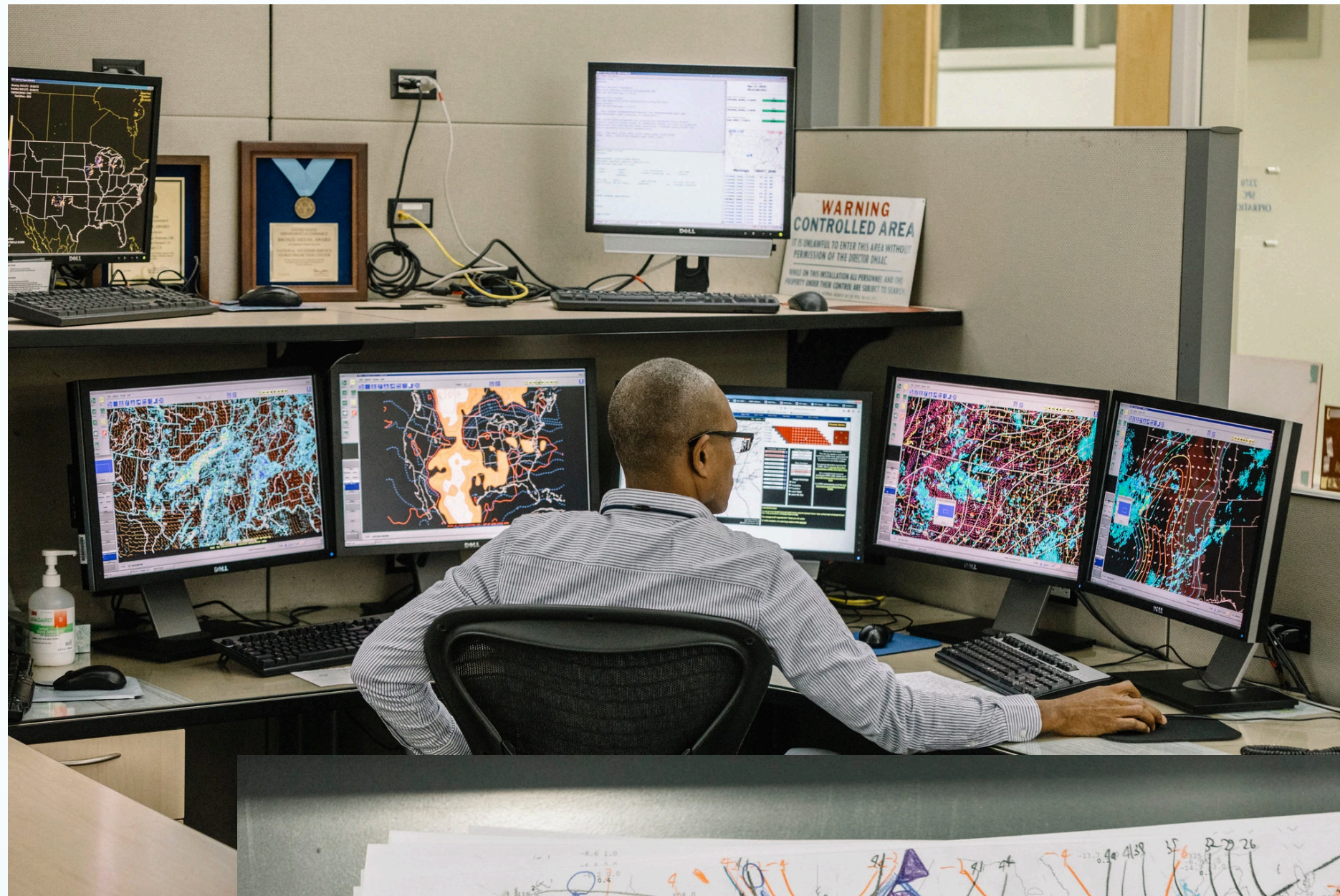
- <https://www.nytimes.com/2019/04/21/us/storms-weather-oklahoma.html>



Lifesaving Forecasts Start Here:
Inside the Storm Prediction Center

On any given day, severe weather can threaten millions of people. An Oklahoma office tries to see it all coming.

Storm Prediction Center on April 17, 2019



The scope — and consequences — of the storms they have charted are similarly sharp in their memories. They know the triple-digit death tolls that sometimes come, even when their forecasts are tragically accurate. Just last month, [23 people died in Alabama](#) after a well-warned tornado outbreak. “You just see the injuries, the damages, the fatalities just piling up, and you’re thinking, ‘What’s the point?’” Mr. Thompson said as he considered some of the larger outbreaks on his watch. “It’s like, I did the best I could, and we just had the most people killed in one of these kinds of forecasts on record. I kind of wondered and thought, ‘Is it just the limit of what we can do?’” Indeed, the forecasters know that all they can do from Oklahoma is to come up with predictions and alert the public — and to be as credible as possible, he said, “so that when we jump up and down and yell and wave our arms, people take it seriously.”

Hierarchy of Topics

- Goal: To explore science, history, and impacts of thunderstorms and hurricanes
 - Clouds (Weeks 1-2)
 - **Thunderstorms** (Weeks 3-5)
 - Tornadoes (Weeks 6-7)
 - Hurricanes (Weeks 8-10)

Topics for today

- Triggering thunderstorms
- Life cycle of single-cell thunderstorms
- The downdraft and gust front
- Microbursts

Kinds of Thunderstorms

- **Single cell**
 - “Ordinary” or “air mass” thunderstorm
 - Generates lightning, heavy rain, downbursts.
- **Multi-cell**
 - May be **severe**
 - Severe if hail >1” or winds > 58 mph
 - Seldom makes strong tornadoes
- **Supercell**
 - Relatively long-lived, often **severe**
 - Associated with most strong tornadoes

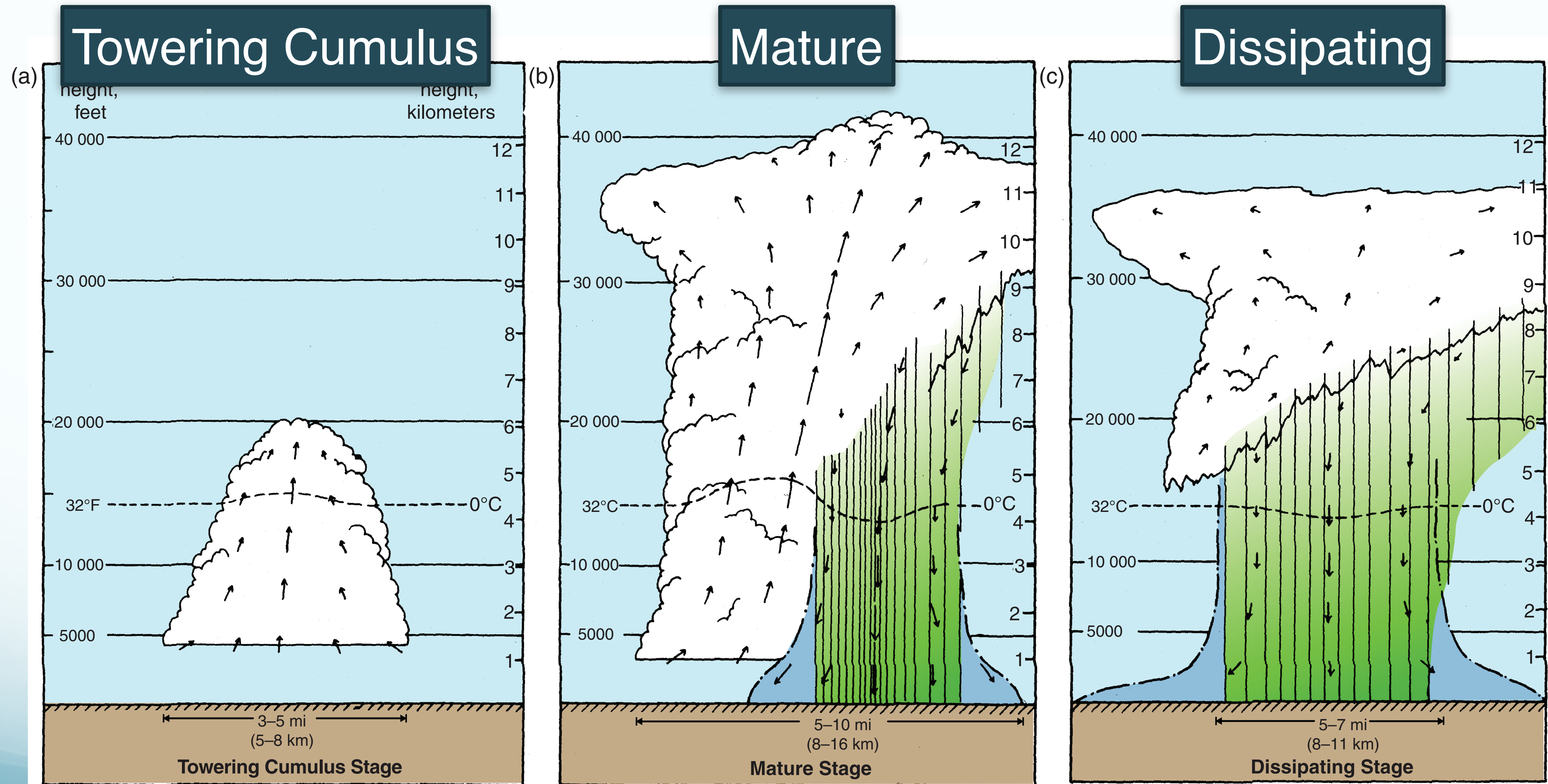
Single Cell Thunderstorms



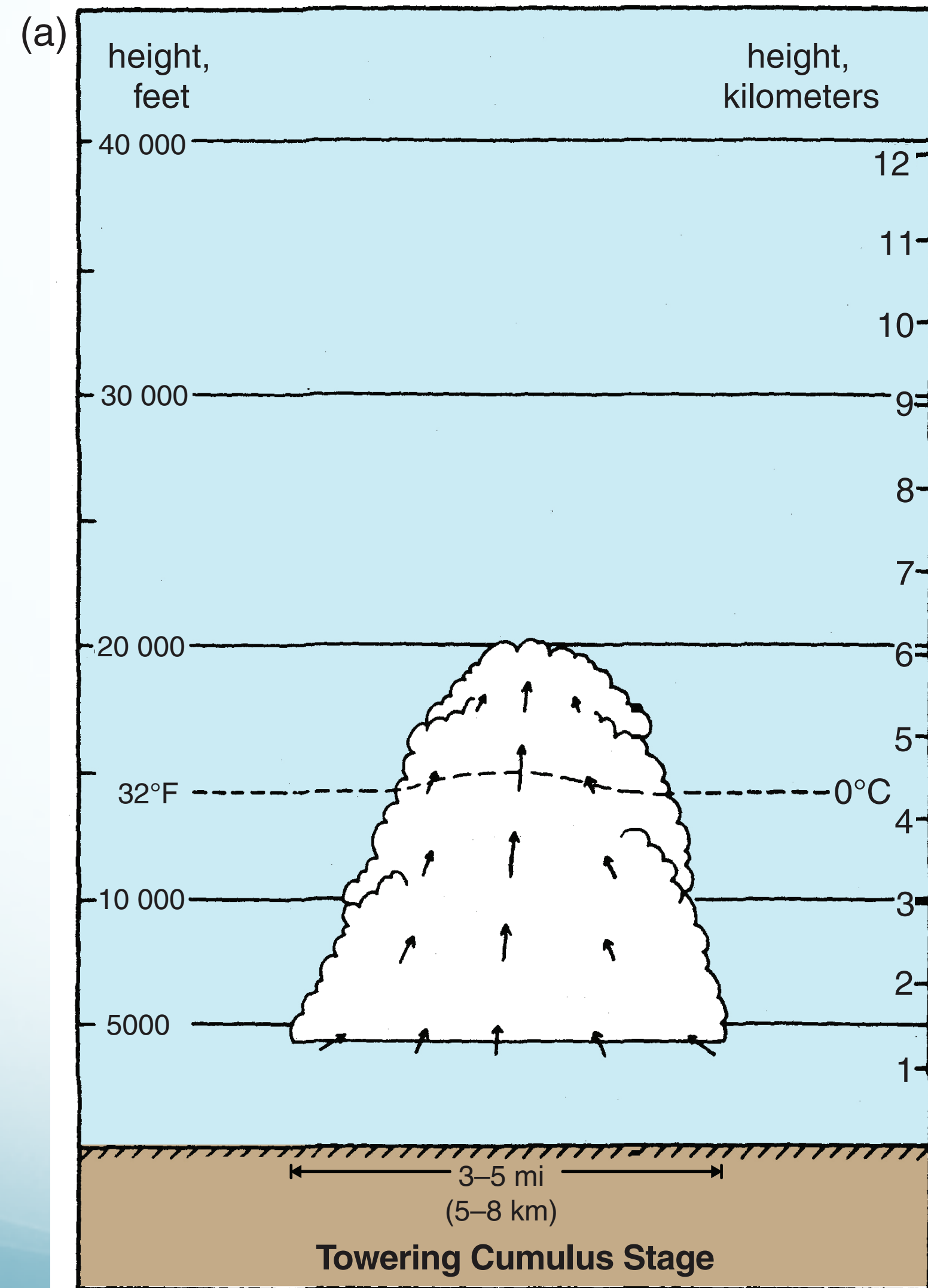
What is this?

- June 24, 1975: Eastern Airlines Flight 66 was on its final approach into New York Kennedy when it encountered *this*.
- The aircraft struck the ground 2,400 feet short of the runway. It skidded along, bursting into flames and scattering the wreckage.
- Of the 124 people on board, 112 died.
- At the time, it was the deadliest single plane crash in United States history.

Life Cycle of a Single Cell



Stage I: Towering Cumulus



Stage I: Towering Cumulus

1. The trigger makes parcels ascend and cool to saturation..
2. The trigger continues to force the cloudy air parcels to rise until they become slightly warmer than their conditionally unstable surroundings.
3. The cloudy air parcels can then ascend freely until reaching some stable layer, such as the stratosphere.
 - Upward growth of the cloud can be explosive.

One More Hurdle: Entrainment

- *Entrainment* occurs when unsaturated air at the edge of the cloud mixes with the rising air.
- We have ignored this in our previous arguments about hypothetical “air parcels”.

W

After unsaturated air mixes with cloud air at the same temperature, the mixture

Contains less liquid water

Becomes colder

Both of the above

Neither of the above

Answer

- **Cloud droplets evaporate** until the mixture is
 - Once again saturated
 - Or no liquid water droplets remain
- After entraining unsaturated air, **the mixture**
 - **Has less liquid water**
 - **Has been cooled** by the evaporation of cloud droplets.

Entrainment in Fair Weather Cumulus



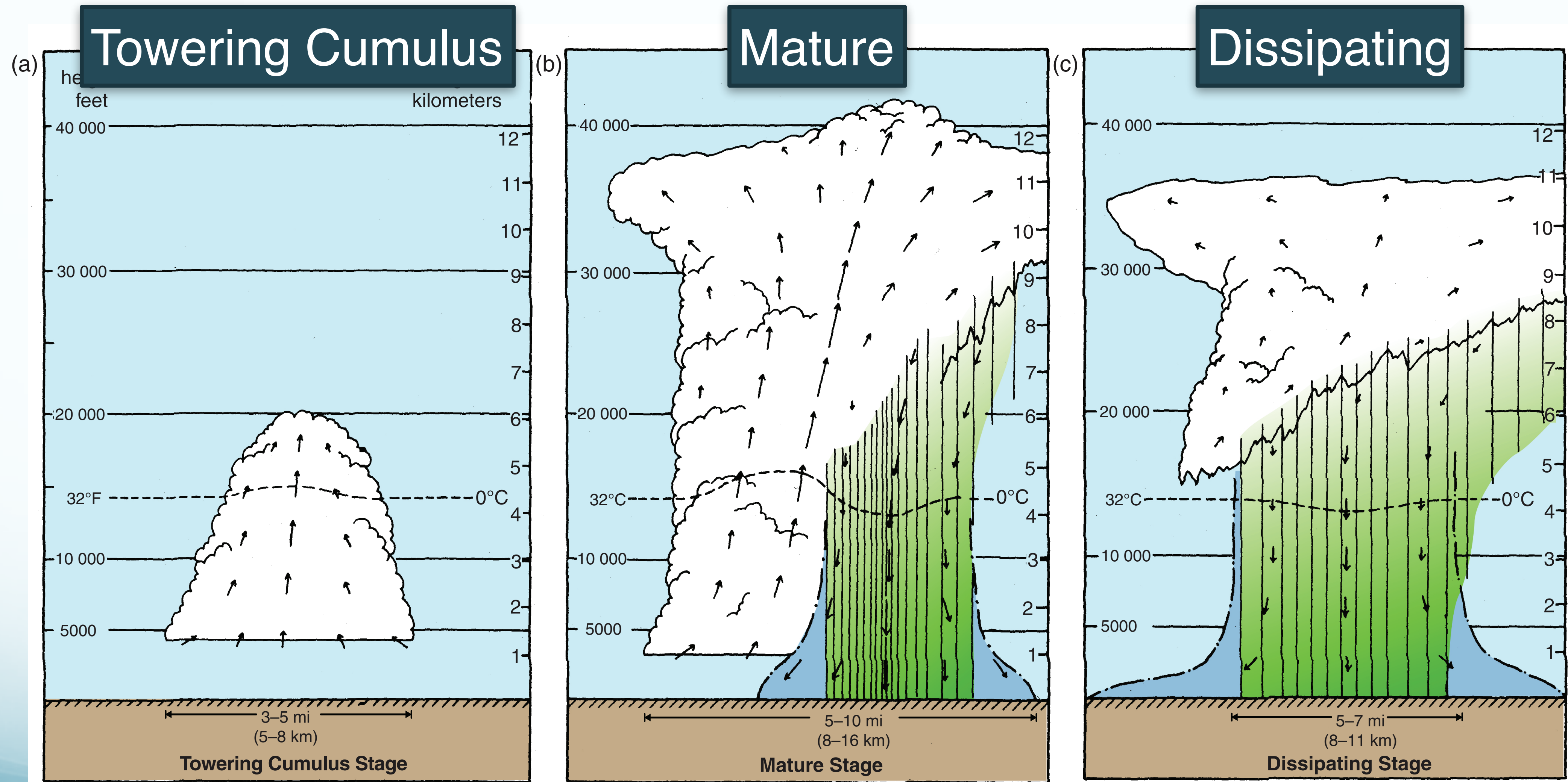
How is this storm dealing with entrainment?



Minimizing the Effects of Entrainment

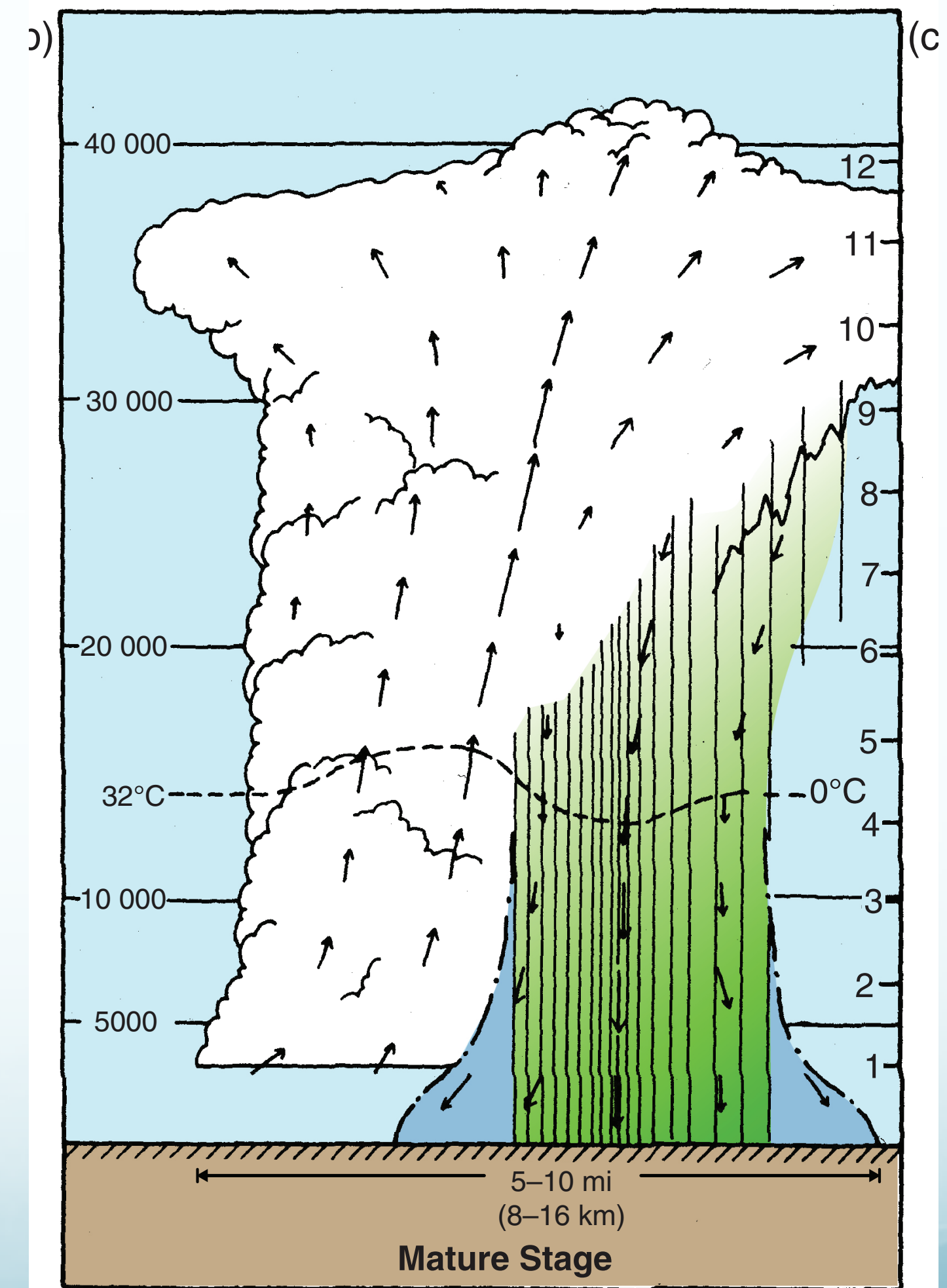
- Each parcel whose rise is stopped by entrainment leaves the surrounding air a little more humid.
- A series of parcels rising in the same place, moistens the air, reducing the evaporative cooling encountered by the next parcel rising into that area.
- Parcels in the core of an active thunderstorm updraft are relatively protected from the entrainment of environmental air.

Life Cycle of a Single Cell

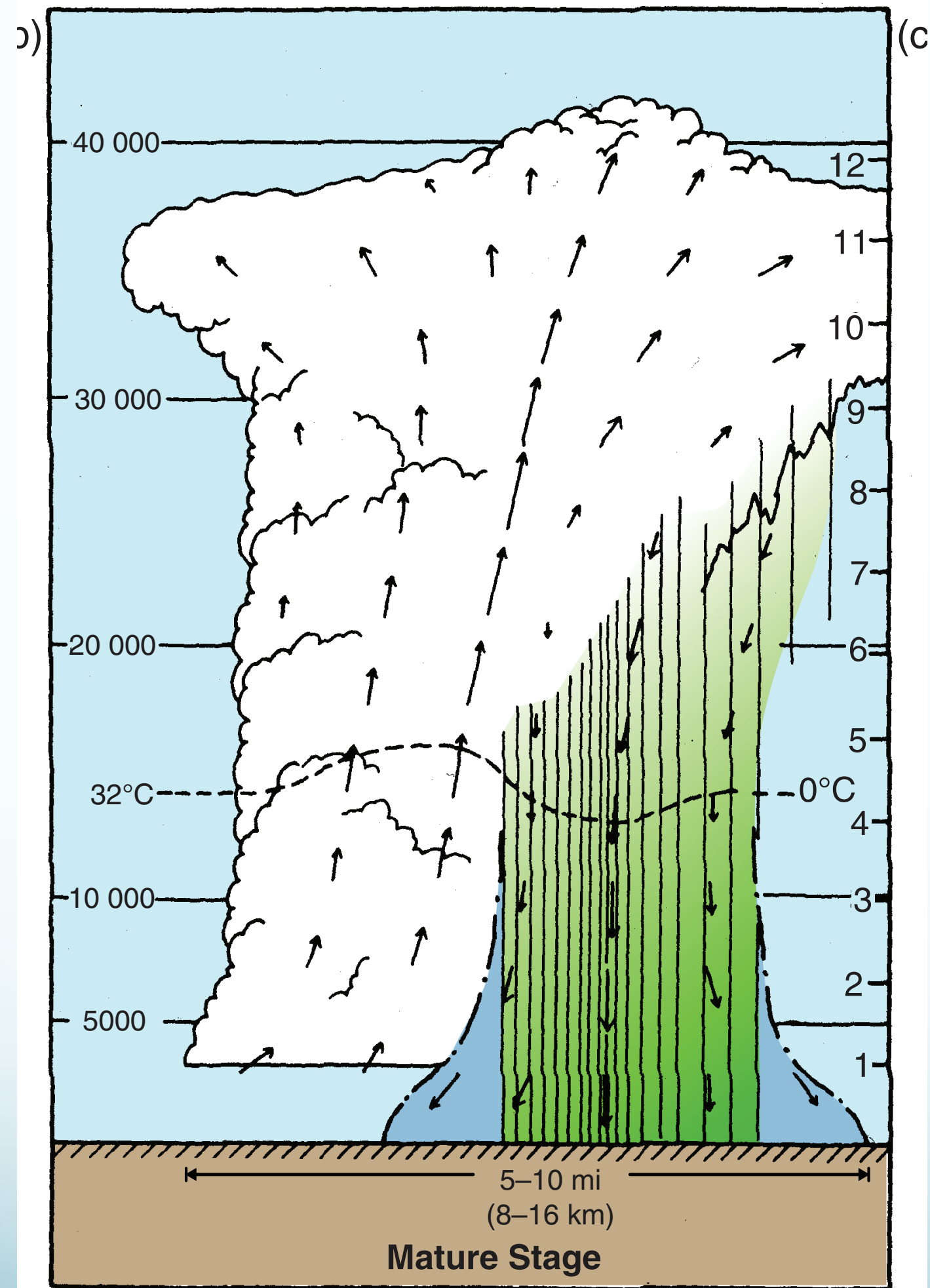


Stage II: Mature Stage

- Updrafts are still significant
- Rain, thunder and lightning (maybe hail, too) have developed
- **Downdrafts** have also developed



Downdraft



Precipitation mixed with descending air

W What happens when the rain-cooled air hits the ground?

It bounces back up
and spreads out well
above the ground.

It spreads out
horizontally along
the ground.

Answer

- The rain-cooled air spreads out horizontally along the ground.
 - It stays at the ground because it is negatively buoyant.

Downdraft



Why are there downdrafts

- What goes up comes down?
 - The upward transport of air needs to be balanced by an equal downward transport.
- Most of the compensating subsidence (descent) actually happens in the clear air around the cloud.
- Downdrafts are produced by
 - Aerodynamic drag from falling precipitation
 - The entrainment of dry air through the sides of the cloud, which is cooled as cloud droplets evaporate.
 - Evaporation of precipitation also cools downdrafts **below** cloud base.

W Downdraft speeds would be increased by

Increasing the environmental humidity
around the sides of the storm

Increasing the lightning flash rate

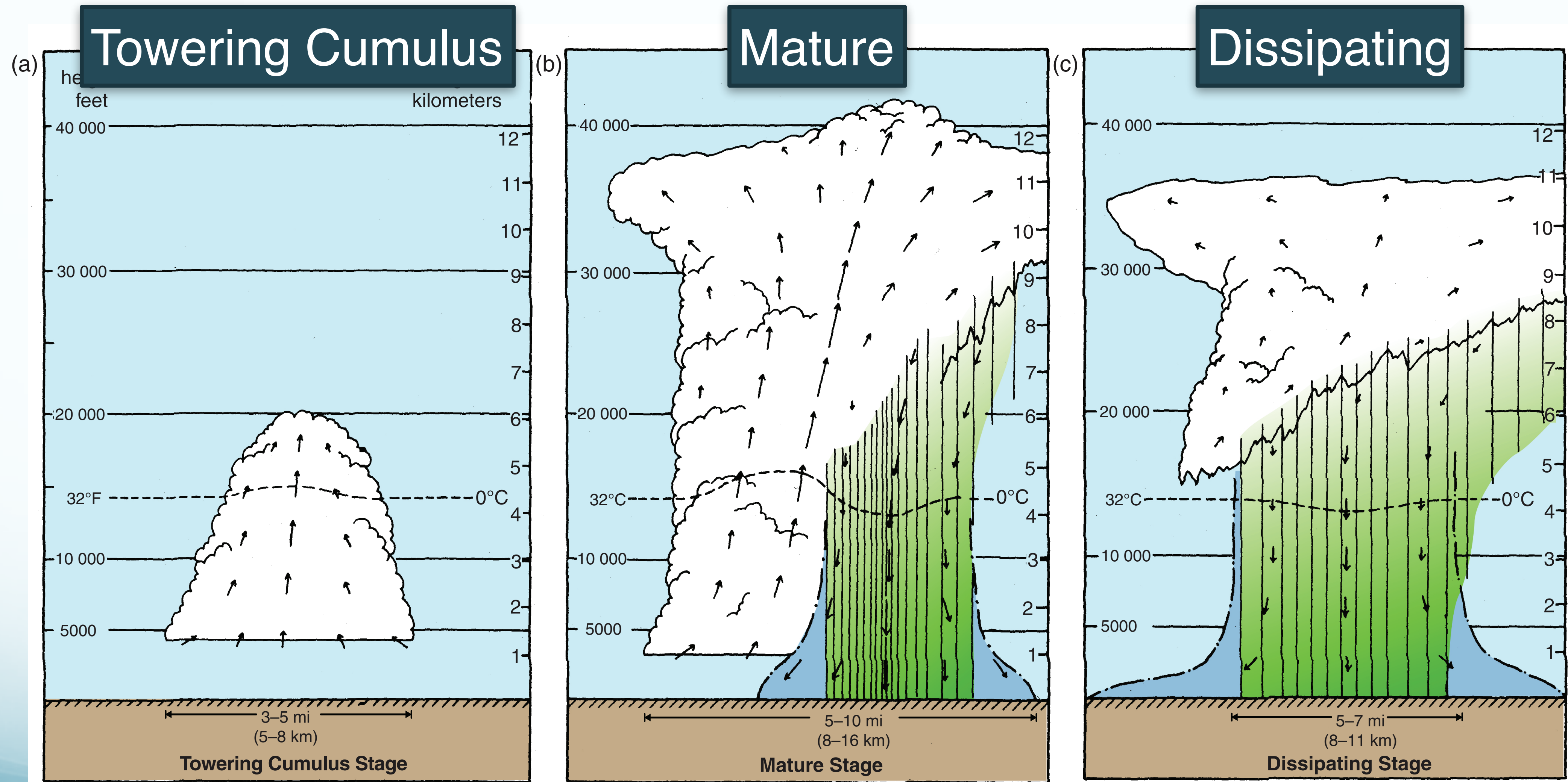
Increasing the number of falling
raindrops

All of the above

Answer

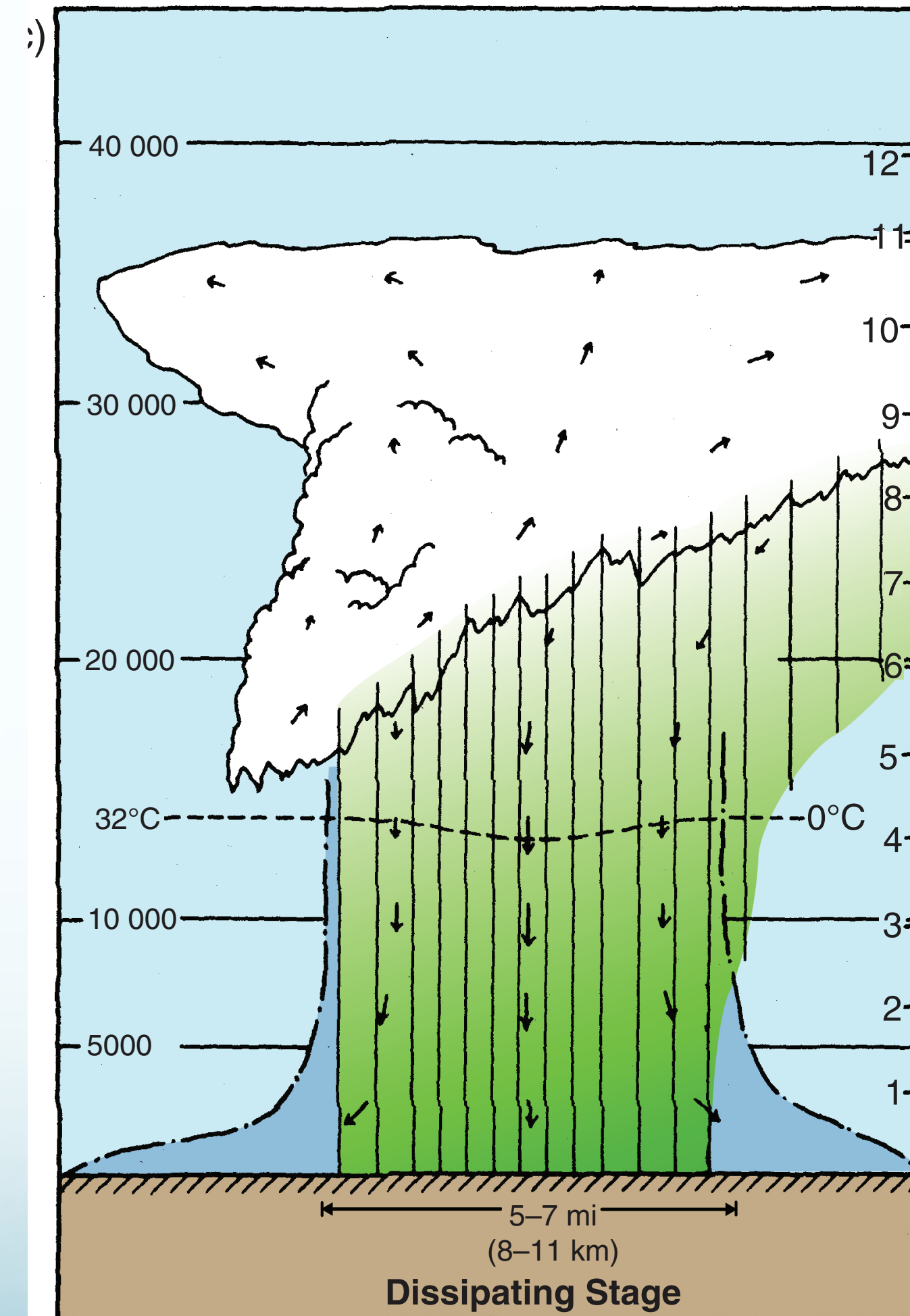
- More raindrops will produce more aerodynamic drag, pulling the air downward.
- **Decreasing** (not increasing) the humidity aloft around the sides of the thunderstorm
 - Will increase the evaporative cooling of air entrained into the thunderstorm.
 - The downdraft air gets colder and sinks faster.

Life Cycle of a Single Cell



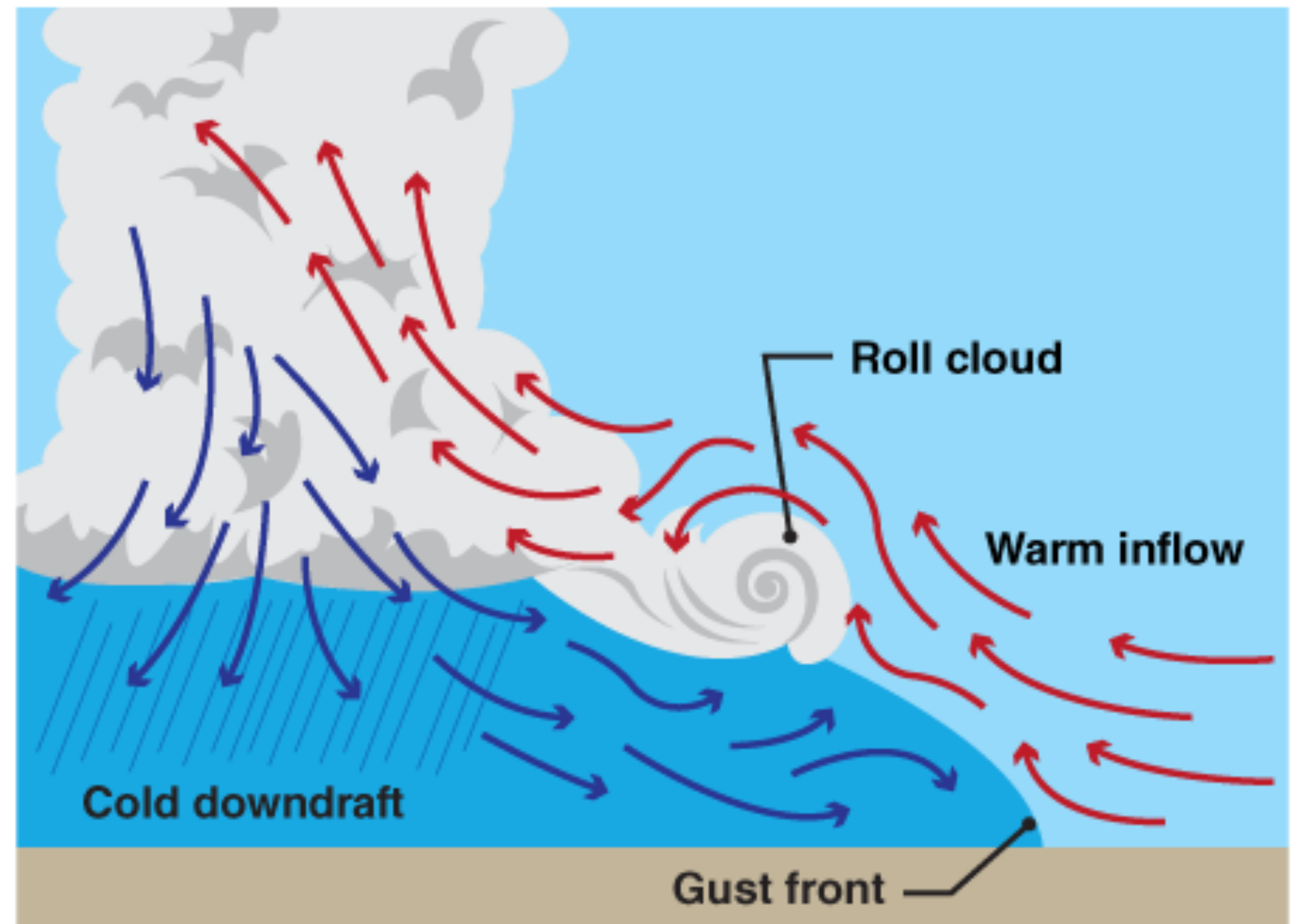
Stage III: Dissipating Stage

- The updrafts are gone.
 - They have been cutoff by the spreading cold pool.
 - Warm moist air is no longer flowing into the cloud.
- Rain, thunder and lightning may continue for a while, but the end is near.



The Gust Front

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



Gust Front



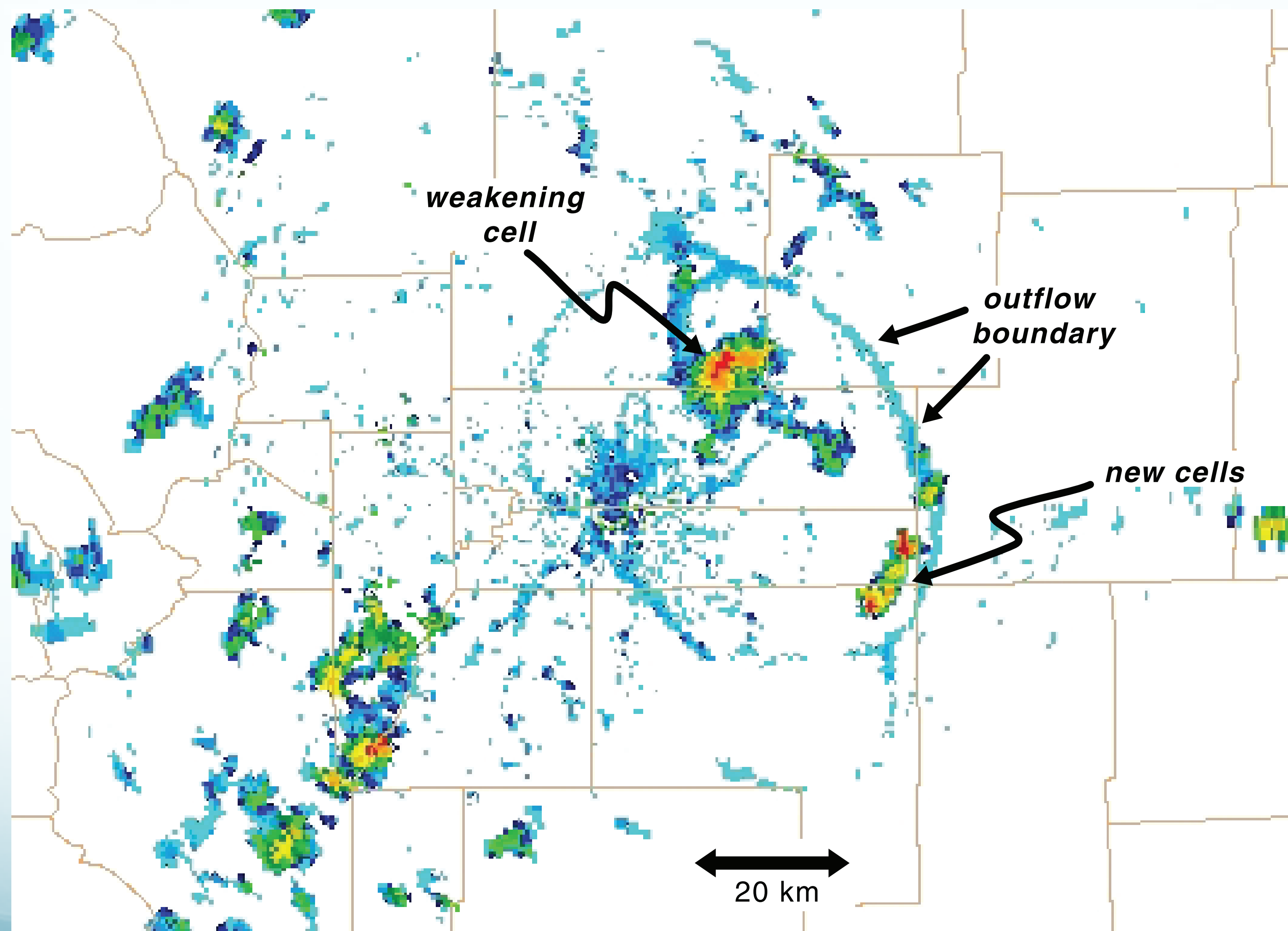
‘Shelf’ Cloud Above Gust Front



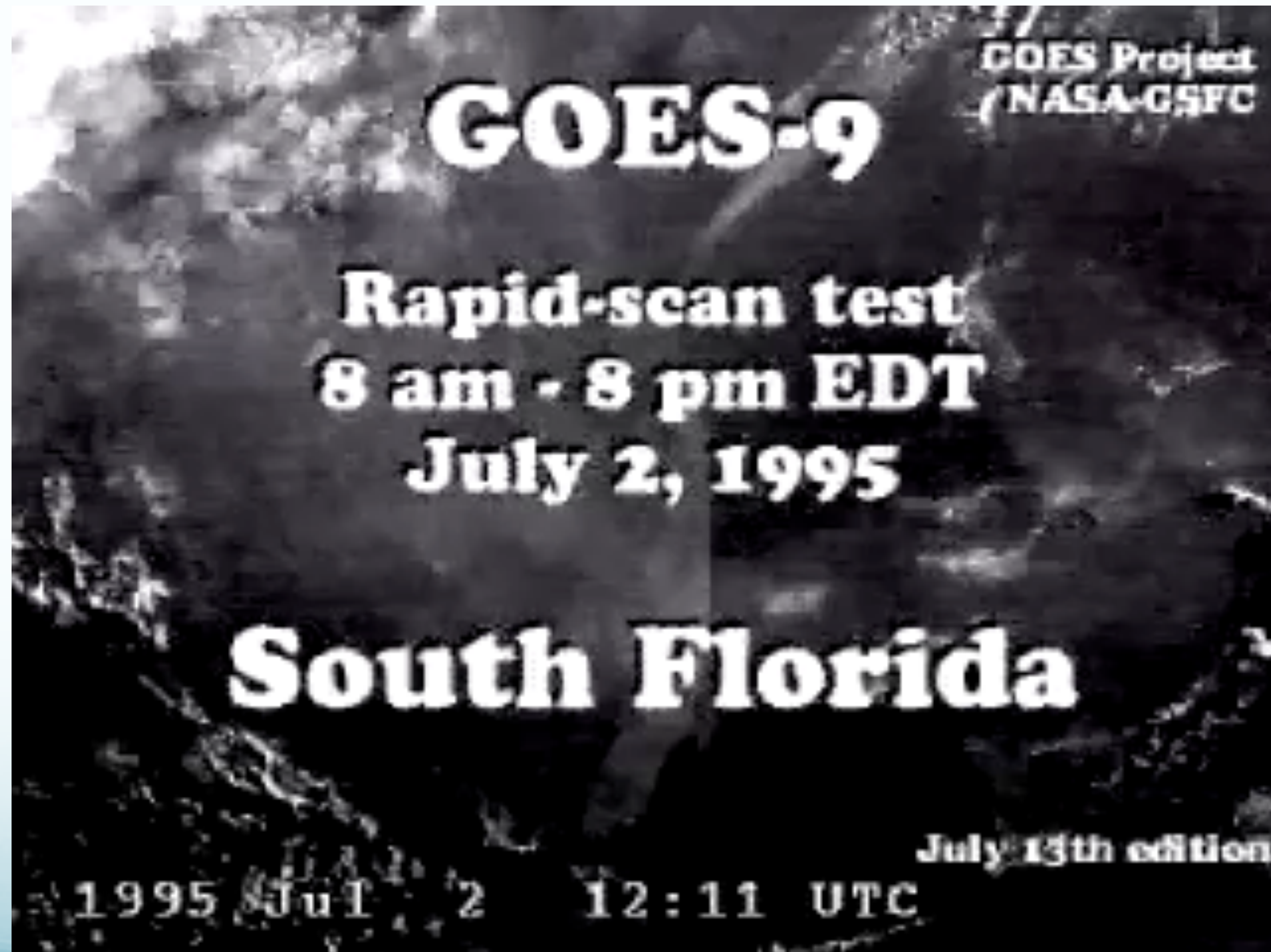
Cloud Above Gust Front



Gust Front in Radar



South Florida Viewed from Space



W Why does a line of cloud often form above the gust front?

The air is cooled by contact with the cold air behind the gust front.

Warm moist air is lifted as cold air spreads outward at the gust front.

The air is moistened by the high relative humidity behind the gust front.

Answer

- Cloud forms above the leading edge of the gust front because warm moist air is forced to rise over the spreading current of cold dense air.

Gust Front in Action

Charleston, WV

Gust Front: Lake Michigan

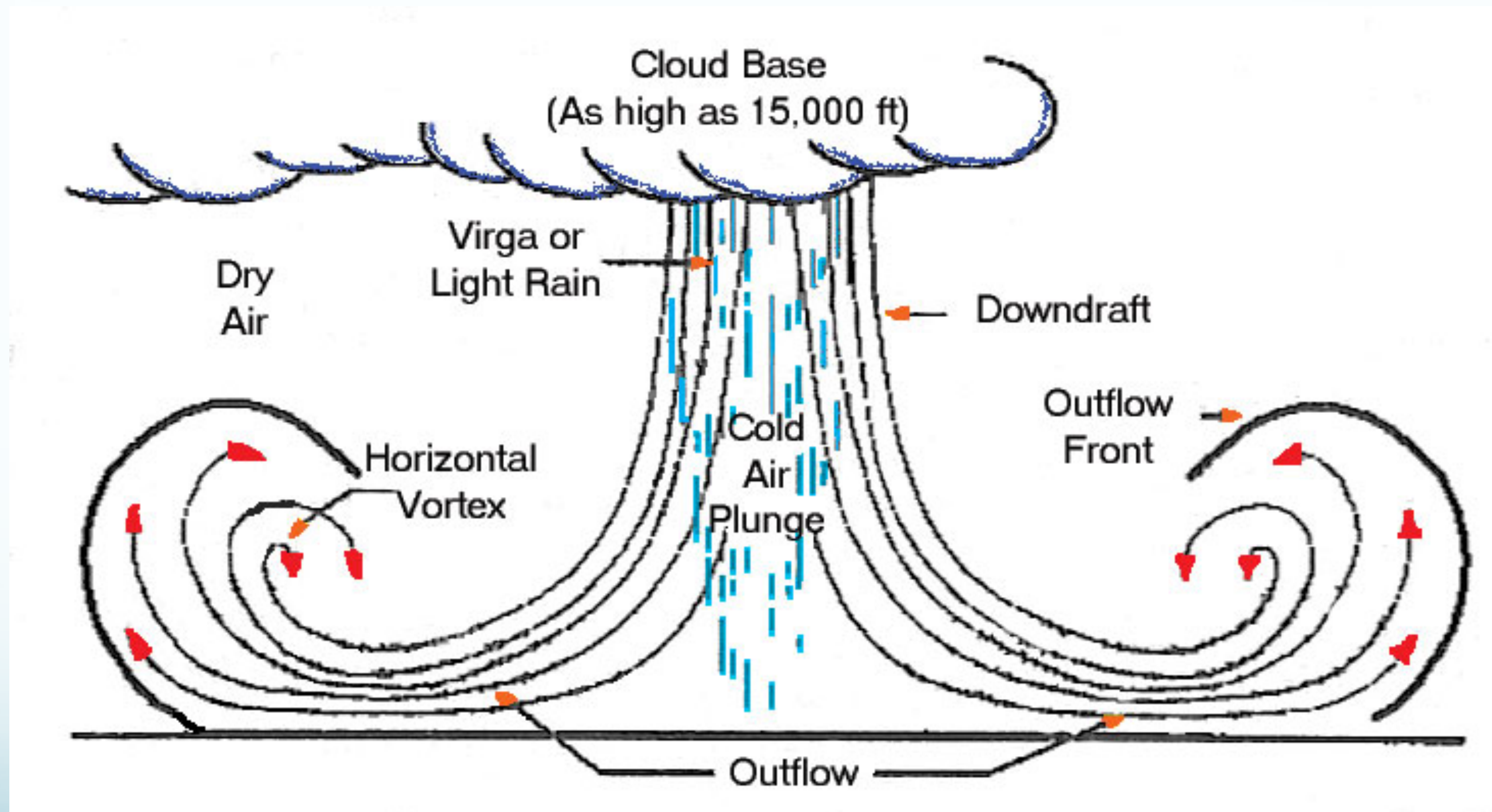


[Time-lapse video](#)

Hazards from single-cell thunderstorms

- Lightning
- Downdrafts and the spreading gust front create **microbursts**, an aviation hazard.
- Flash floods

Microbursts



Microburst Showing C " " " "

Ed



3-frame animation



Microburst Damage Pattern



Microburst in Phoenix



Lake Millstatt, Austria



<https://twistedifter.com/videos/cloudburst-over-lake-millstatt-austria/>

Near Phoenix Airport

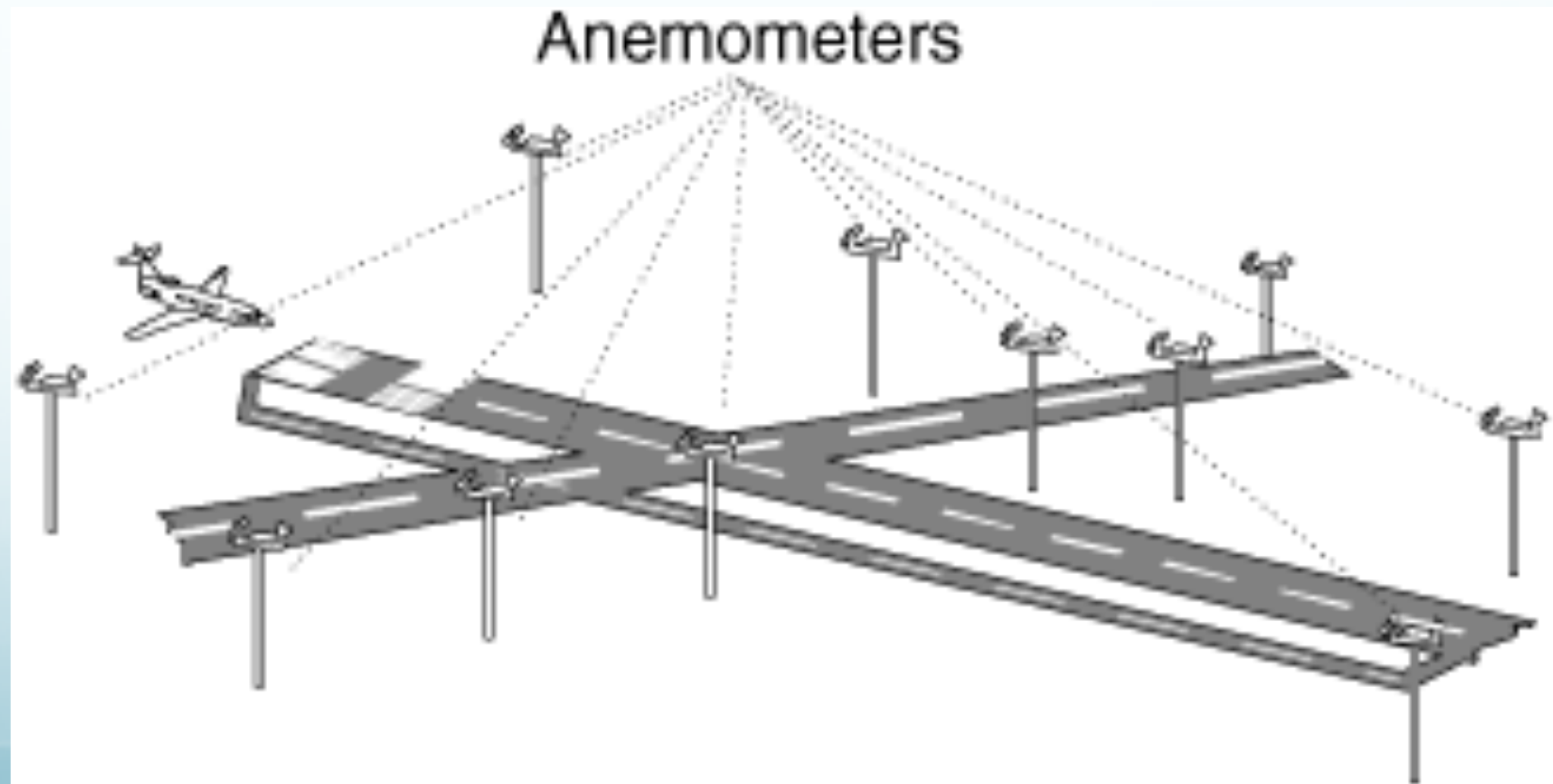
Video July 18, 2016

Microbursts

- June 24, 1975: Eastern Airlines Flight 66 was on its final approach into New York Kennedy when it encountered a **microburst**.
- The aircraft struck the ground 2,400 feet short of the runway. It skidded along, bursting into flames and scattering the wreckage.
- Of the 124 people on board, 112 died.
- At the time, it was the deadliest single plane crash in United States history.

Eastern Airlines 66 Aftermath

- This accident led to the development of the original low level windshear alert system by the U.S. Federal Aviation Administration in 1976.
- This system was installed at 110 FAA towered airports between 1977 and 1987



August 2, 1985 DFW

video

Delta Airlines Flight 191

- Crashed while on approach to Dallas-Fort Worth International Airport during a thunderstorm, killing 136 of the 163 people aboard and one on the ground.
- In 1988 the U.S. Federal Aviation Administration mandated that all turbine-powered commercial aircraft must have on-board windshear detection systems by 1993.

Terminal Doppler Weather Radar

(Optimized to detect wind shear, not precipitation.)

