Supercells & Mammatus (LG: 4a)

A video "Teaser", while students enter the classroom.

Examples of mammatus clouds, mesocyclones, gust fronts, lightning and more.

- Day 4-60 — FRACTAL by stormlapse.com (3:23)
  https://www.youtube.com/watch?v=kOIBirvzV5g

Optional: Watch these tornado videos on your own (not testable).

El Reno Lessons from the most deadly tornado to storm chasers.

- Day4-05 — El Reno tornado (start at 00:08:40)
  https://www.youtube.com/watch?v=TBjr-nvA2Jg

- Day4-55 — Heavenly Storms (Pecos Hank, 2:38)
  https://www.youtube.com/watch?v=jyjiFWkUigs

The Turbulent Atmosphere (Storms)

Prof. Roland Stull

Today:

- Clouds associated with Thunderstorms
- Storm Energy --

  From Heat to Motion

  1. Forces Create Winds
  2. Temperature alters buoyancy to drive vertical winds
  3. Temperature alters pressure to drive horizontal winds
  4. Continuity links vertical & horizontal winds in circulations
- Hail & more about precipitation.

Today's Learning Goals

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

4a) identify mammatus clouds, cloud striations, haboobs, arc clouds, and wall clouds, and explain their significance

4b) explain how forces, acceleration, buoyancy, and pressure-gradients relate to winds

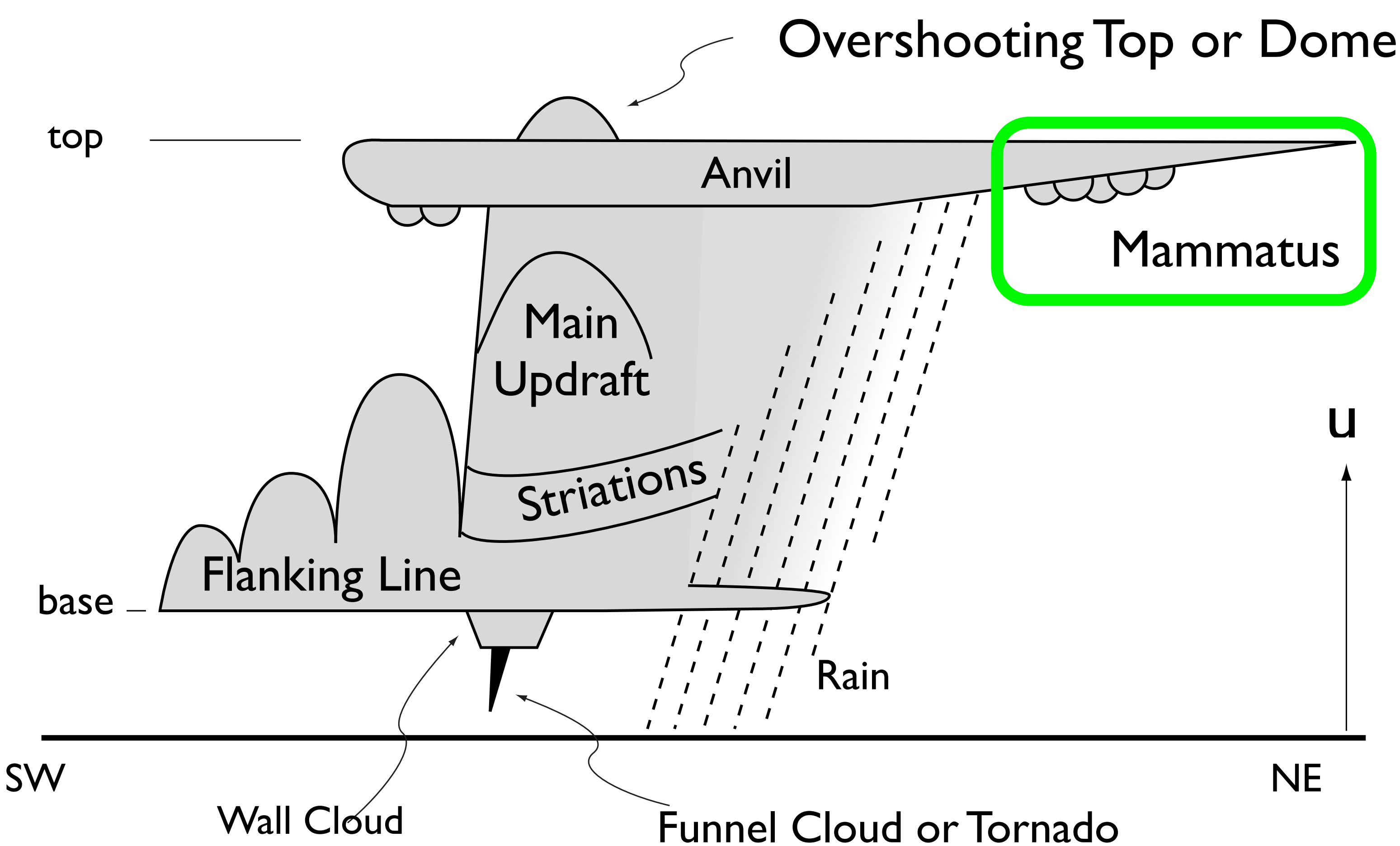
4c) describe how heat released in the atmosphere can create vertical and horizontal winds and atmospheric rivers

4d) explain how the continuity effect ties vertical and horizontal winds into circulations

4e) describe hail hazards, locations and times of greatest risk, and appropriate safety procedures

How to Recognize:
Mammatus Clouds

(LG: 4a)



Mammatus Clouds
(on underside of thunderstorm anvil)

(LG: 4a)

Wikipedia Commons

Mammatus Clouds

(LG: 4a)

YouTube clips (search on "mammatus clouds"):

Day 2 - 07 Storm of Beauty. Pecos Hank.
(view only 3:00 - 4:00)

https://www.youtube.com/watch?v=0jkfnIBJRBQ

Optional: Watch on your own (not testable).

Day 4 - 60 Watch the first 30 seconds of "Fractal", by Stormlapse.com.
https://www.youtube.com/watch?v=AFB1kHoIBK4

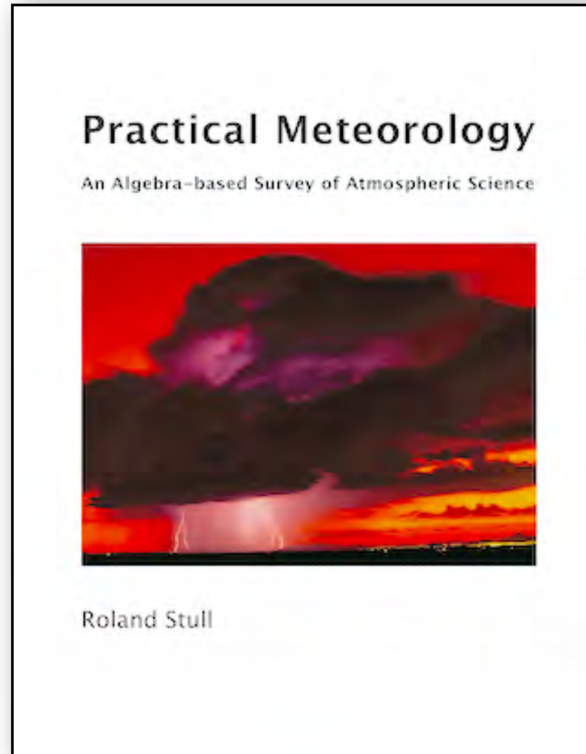
Day4-10 — Mammatus Clouds in Regina 26 June 2012 (1:19)

https://www.youtube.com/watch?v=uIQf3dNnHXM

My Textbook

- ☑ Practical Meteorology: An Algebra-based Survey of Atmospheric Science.
  R. Stull, 2017. 940 pp.

- ☑ FREE online for everyone. Google Search on
  "Practical Meteorology Stull"



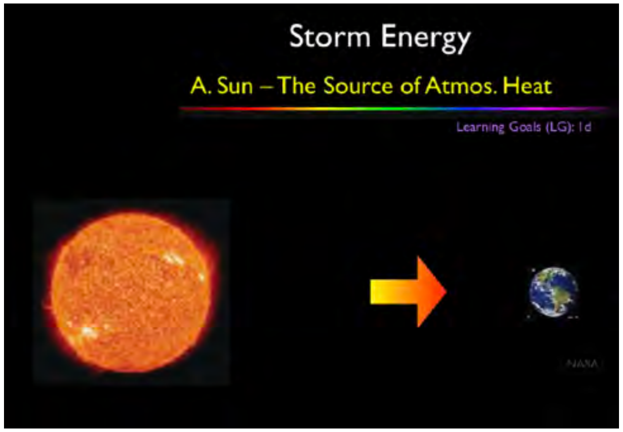
If you like weather and meteorology, consider majoring in Atmospheric Science (ATSC).

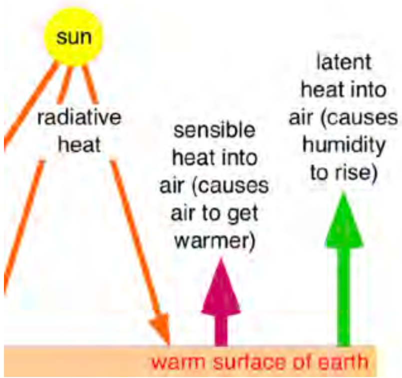
Road-map to Storm topics

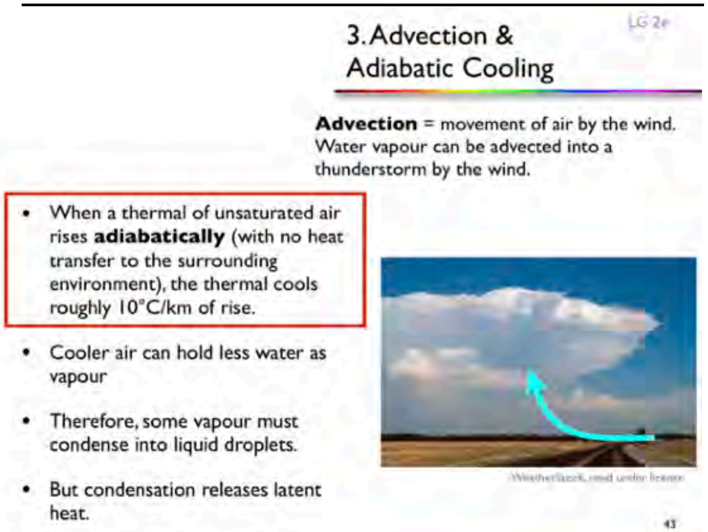
Learning Goals (LG): 1-5

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

Review







From Heat to Motion

Air motions = "**Winds**"

- cause damage directly, and
- blow in more warm, humid air (i.e., storm fuel). This is called "**moisture advection**".

-> positive feedback

-> longer-lasting storms

(this is how storms can become " **organized** ")

To understand how all this works, we will cover:

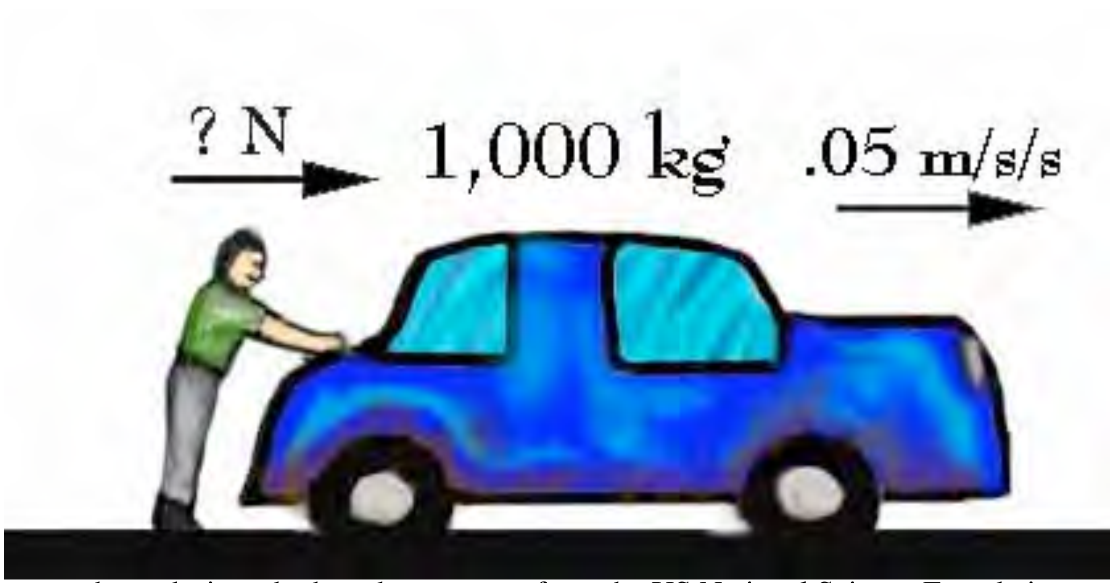
- forces
- acceleration
- buoyancy
- pressure.

1. Forces Create Winds

The relationship between forces & motion is described by **Newton's Second Law.**

$$F = m \cdot a$$

Force (N) = mass (kg) times acceleration (m/s^2)



teachertech.rice.edu, based on support from the US National Science Foundation

In words:
If you push on an object harder (with **greater force**), then it **accelerates** faster in the **direction** you push it.

Insights

- Equations are just a shorthand notation for concepts we can describe in words.

  They are like the sheet-music of science.

Acceleration (a)

a = change of velocity (v) during time interval (Δ *t*), where velocity has both **speed** and **direction**.
Acceleration is measured as velocity (m/s) change per time (s), thus giving acceleration units of (m/s^2).

$$\mathbf{a} = (\mathbf{v}_{new} - \mathbf{v}_{old}) / \Delta \mathbf{t}$$

Examples:

- If car increases speed from 50 to 90 km/h during time interval 15 seconds, then it is accelerating.
- If car maintains constant speed of 50 km/h, then acceleration = zero.

Wikipedia Commons

Forecasting the Winds

Combining these relationships (Newton's Law, & definition of acceleration) gives a "forecast method" (also called a "prognostic equation"):

$$v_{new} = v_{old} + [\ (F / m) \cdot \Delta t\ ] \qquad (C1)$$

applies to objects such as

• cannon balls, • automobiles, • air, etc.


Wikipedia Commons

Air parcel = hypothetical blob of air about the size of a city block.

Air-parcel movement = wind (horizontal or vertical)

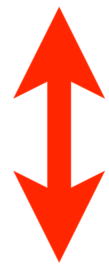
So equation (C1) is a **forecast equation for the wind**.

It tells how winds will increase or decrease or change direction, depending on the forces that act on air parcel.

(LG: 4b)

Forces in the Atmosphere (a partial list):

- **buoyancy force** (vertical)
  ==> causes up & downdrafts



- **pressure-gradient force (PGF)**
  (horiz. or vert.)
  [horizontal PGF -> horizontal winds]

We will see how temperature can affect both buoyancy and pressure to create winds.

2. Temperature alters Buoyancy to Drive Vertical Winds

(LG: 4b,c)

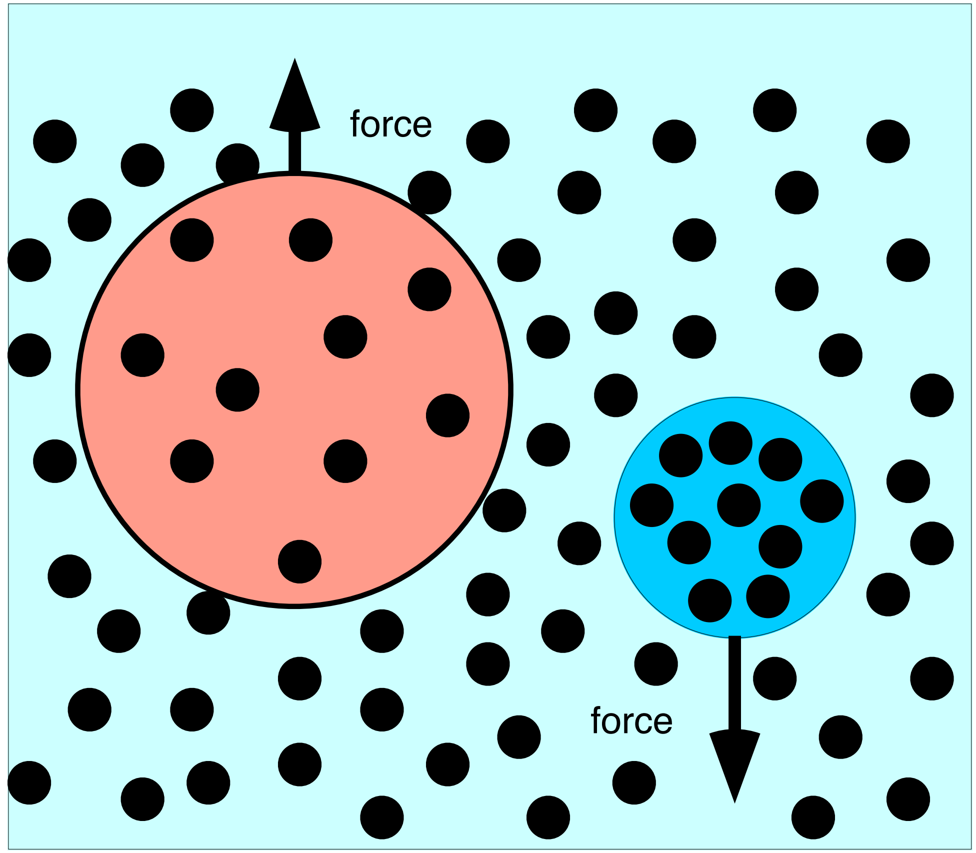
- **Warm air rises** -> updrafts
- **Cold air sinks** -> downdrafts.

Why?

Temperature affects the **density** of air,

and **density** affects **buoyancy**.

Buoyancy



Warmer air is less dense (i.e., the molecules are further apart), resulting in an upward buoyancy force.

Colder air is more dense (molecules are closer together), resulting in a downward buoyancy force.

Buoyancy

The buoyancy of an air parcel depends on the difference between the **parcel temperature** and the **temperature of the surrounding air**.

Buoyancy causes hot air balloons to rise.

photos by Stull

Buoyancy drives Thunderstorms

Condensation in Tstorms releases latent heat.

Latent heat warms the Tstorm air, making it buoyant and causing the air to rise.

This is what drives the violent updrafts in thunderstorms.

3. Temperature alters Pressure to Drive Horizontal Winds

Pressure (*P*) = **force** (*F*) per unit **area** (*A*)

$$P = F / A$$

- where we are concerned only with the component of force **perpendicular** to the surface area
- pressure units: N / m^2 (Newtons per square meter)

But forces can drive winds, from eq. C1.

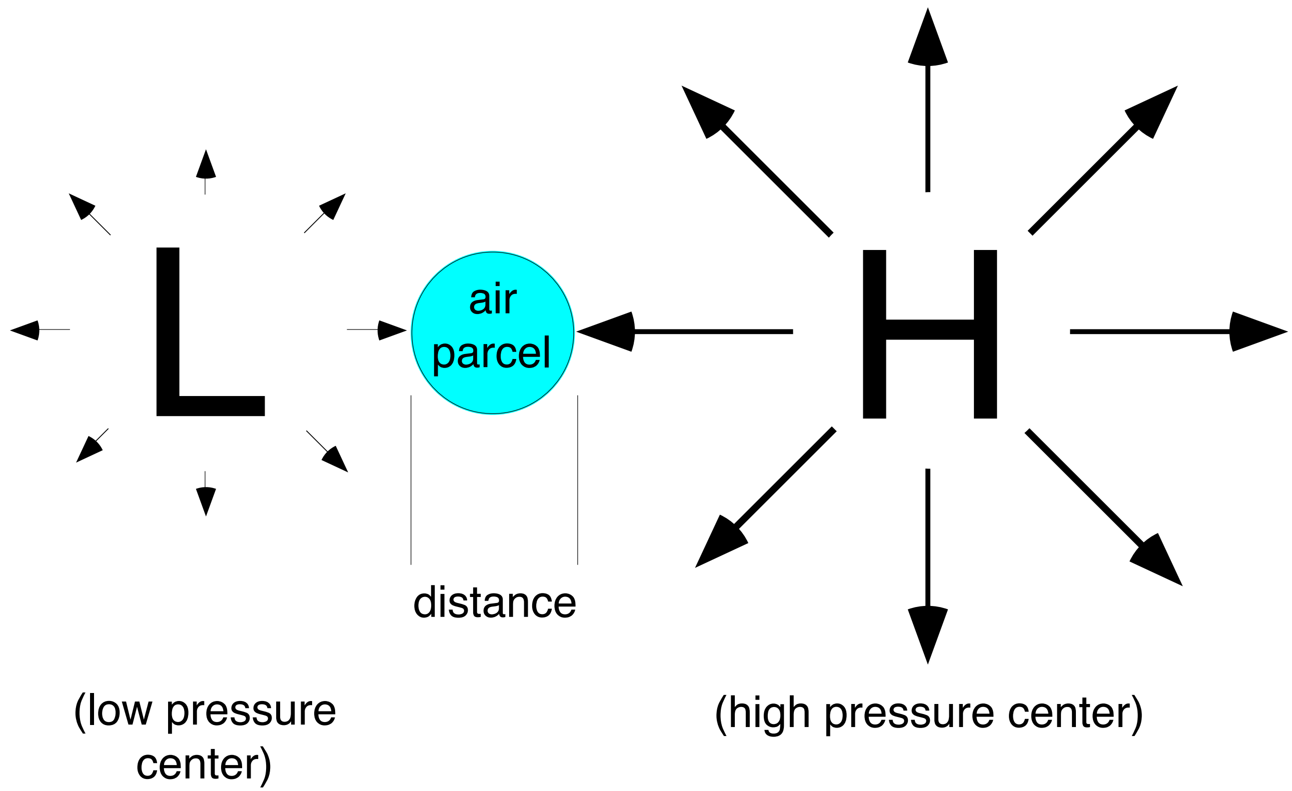
Thus, pressure drives winds !!

Pressure-gradient Force

Use **pressure differences** **Δ P**

- pressure at only one place is not important here.
- the **difference** between opposing pressures is important.
- like a "push of war".
- pressure pushing on one side of air parcel vs.
  pressure pushing on other side
- pressure difference across a distance is called a **pressure gradient.**

Pressure Gradient
(change in pressure across a distance)



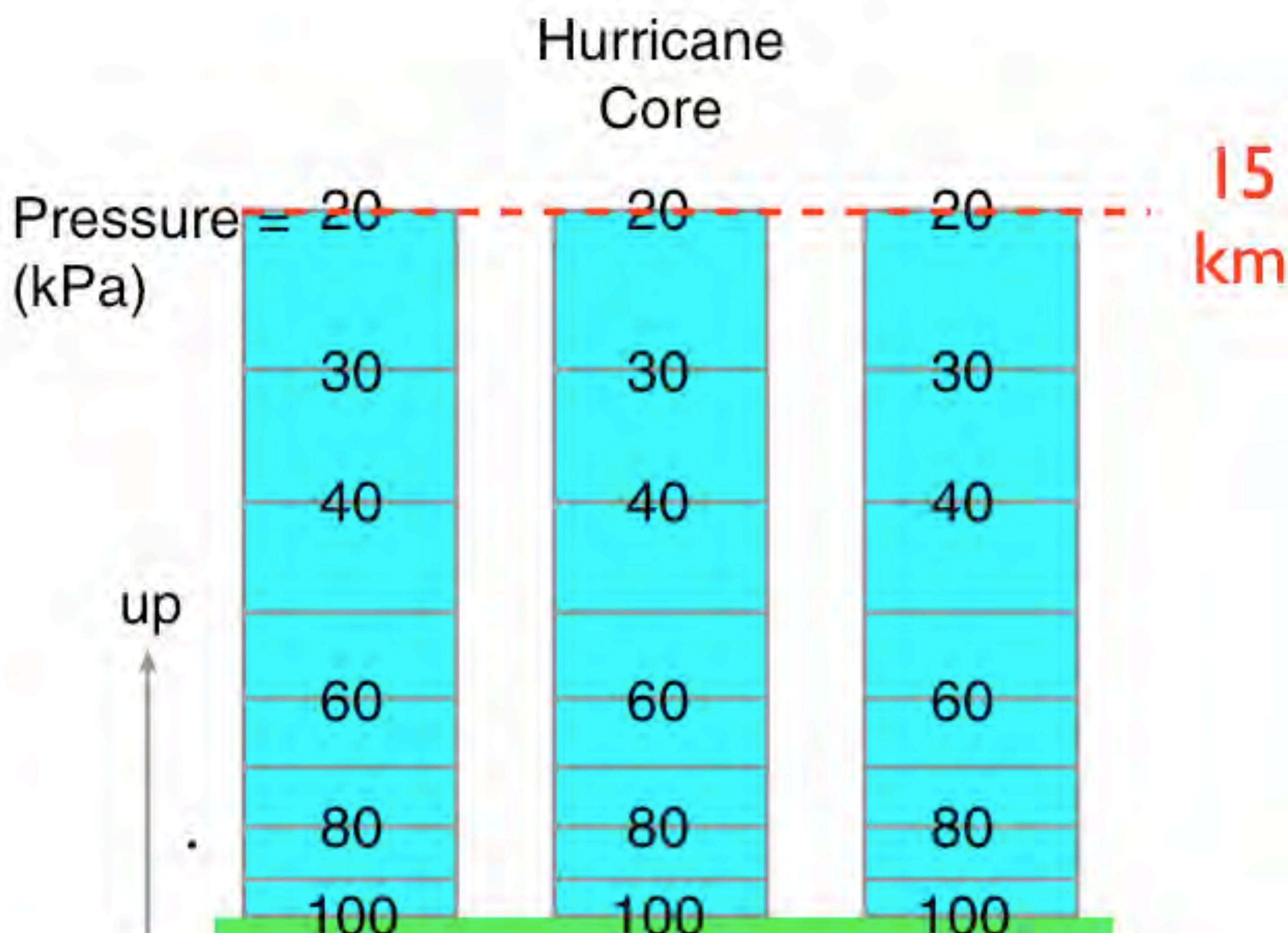
Pressure-gradient force (per unit mass)
is caused by the difference between
two pressures across a distance.

(LG: 4b,c)

How do pressure gradients form in Hurricanes?

Lets do a "thought experiment."

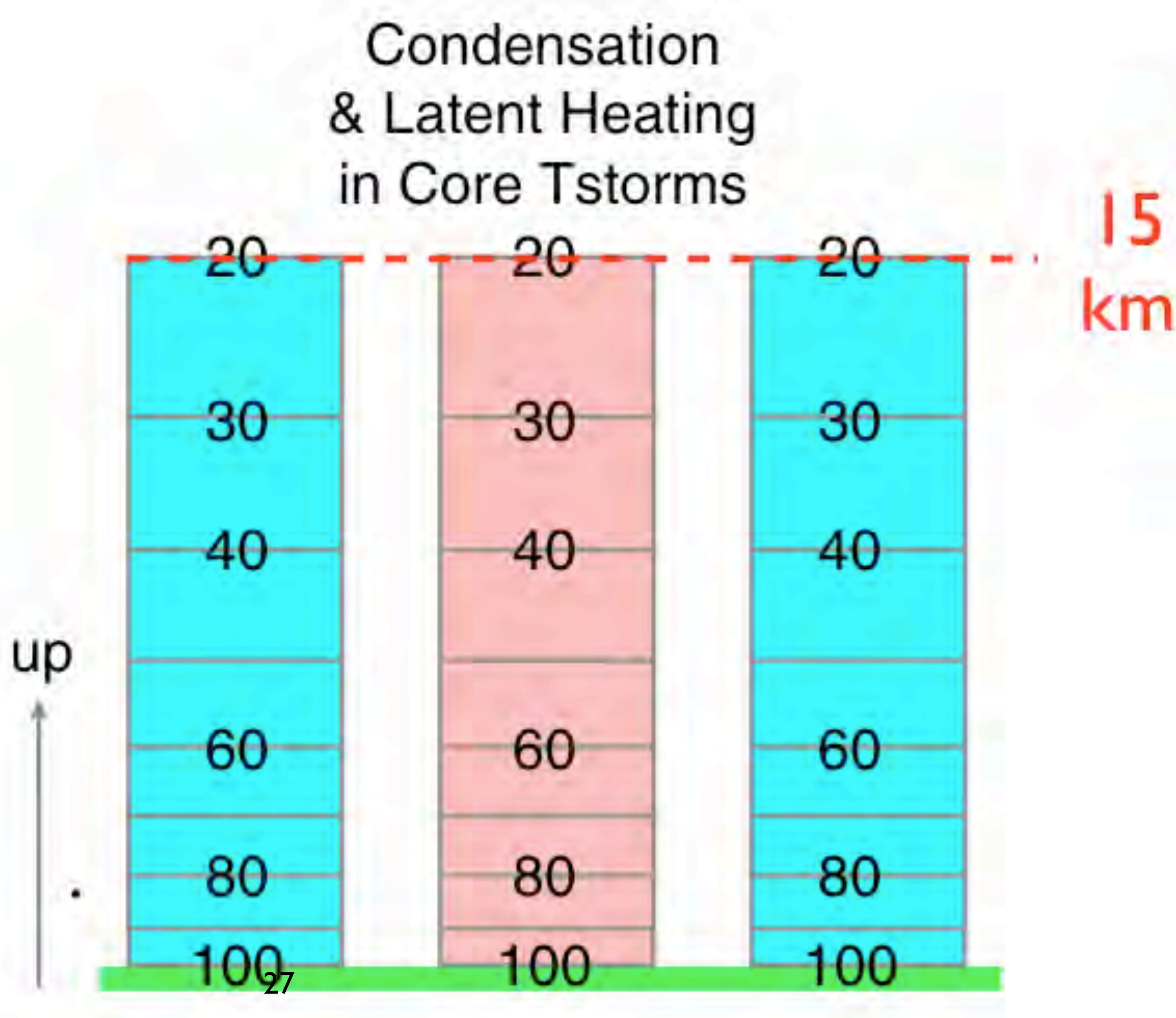
Consider a vertical slice through a hurricane, but with air initially cool everywhere.



How do pressure gradients form in Hurricanes?

In the center (core) of a hurricane are lots of thunderstorms.

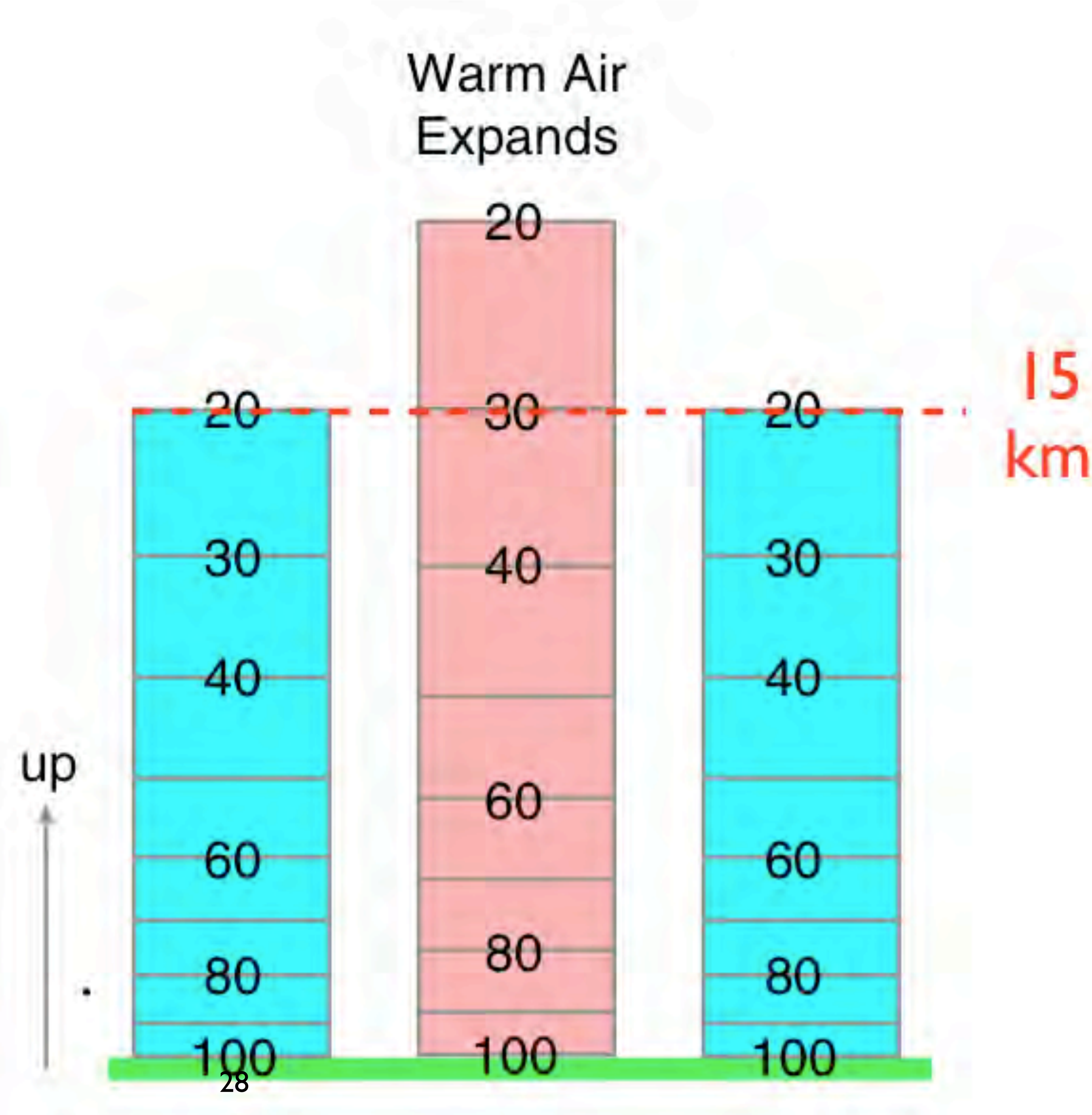
Condensation in these storms makes the core warmer.



But as air warms in the core, the air expands.

Namely, warm air is less dense than cool air, hence it takes up more space.

This causes pressure at the top of the core to be greater than surrounding pressures.

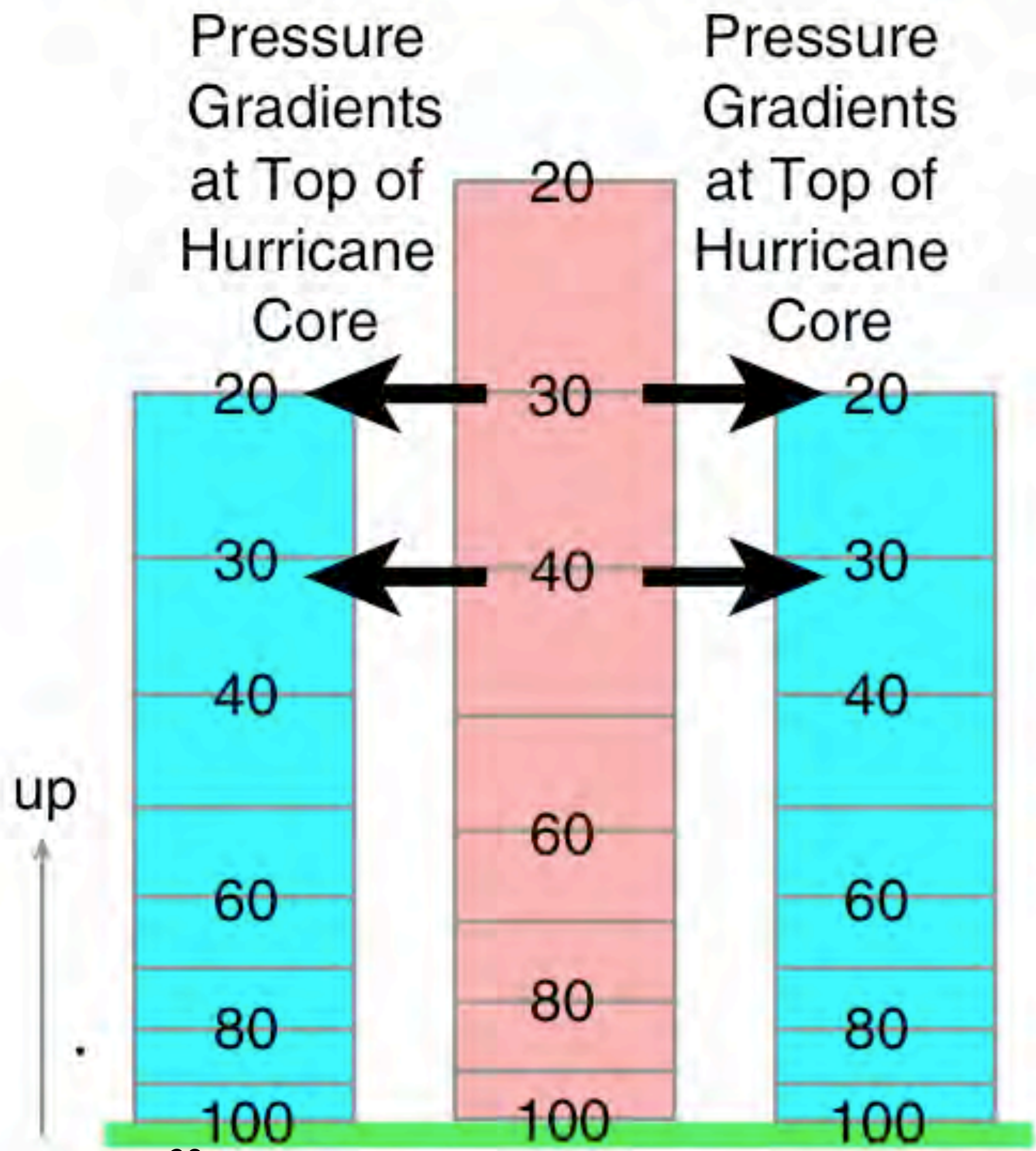


The pressure gradient drives horizontal winds.

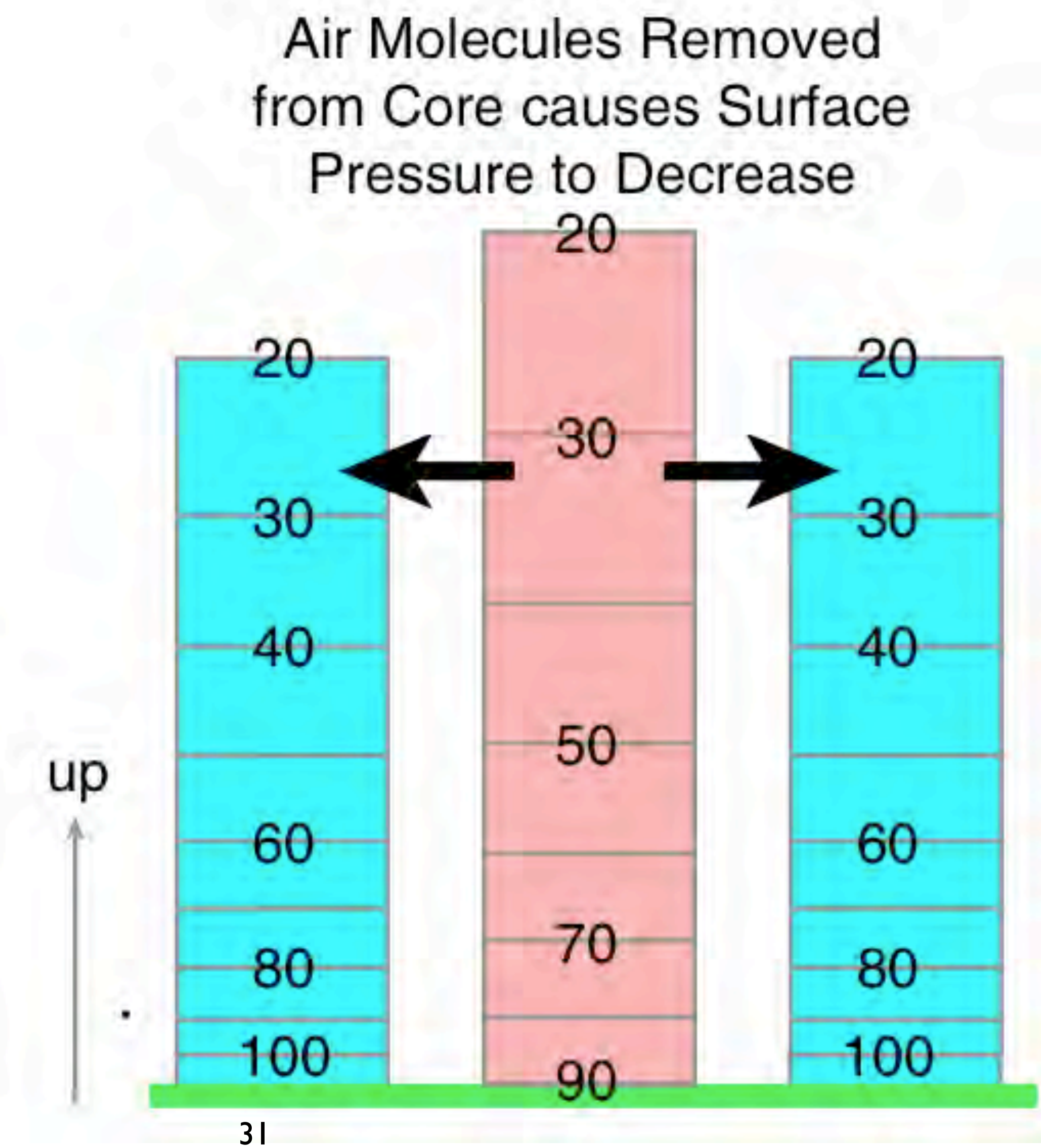
(LG: 4b,c)

The horizontal pressure gradient at the top of the hurricane creates outward spiraling winds.

These winds remove air molecules from the core.



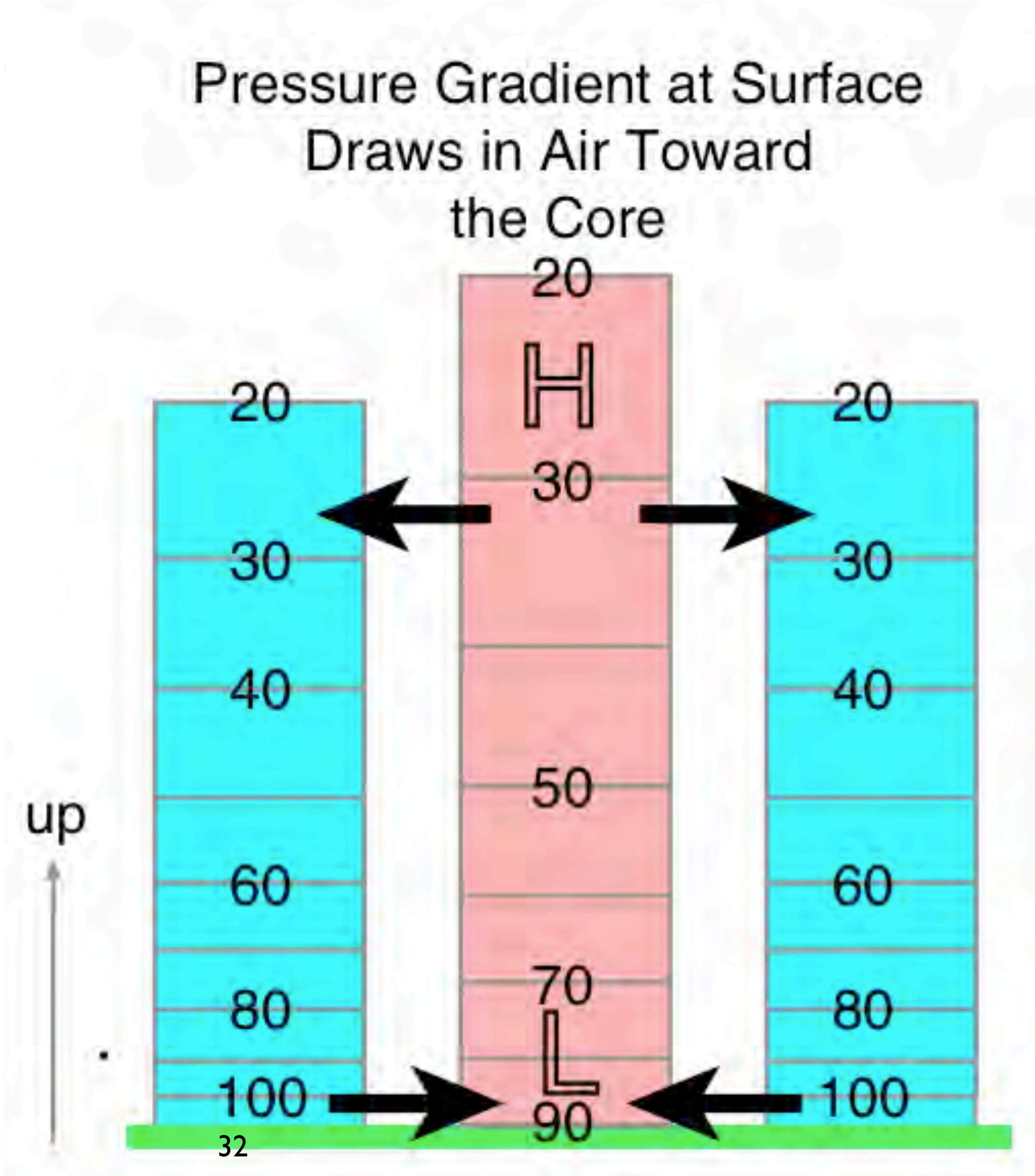
Fewer molecules in the core causes lower pressure at the surface, because pressure is the weight of all the overlying air.



This low pressure at the bottom of the core creates a pressure gradient that sucks in air.

This gives the spiral inflow into the bottom of a hurricane.

This inflow advects in more fuel (warm humid air), making the hurricane stronger.



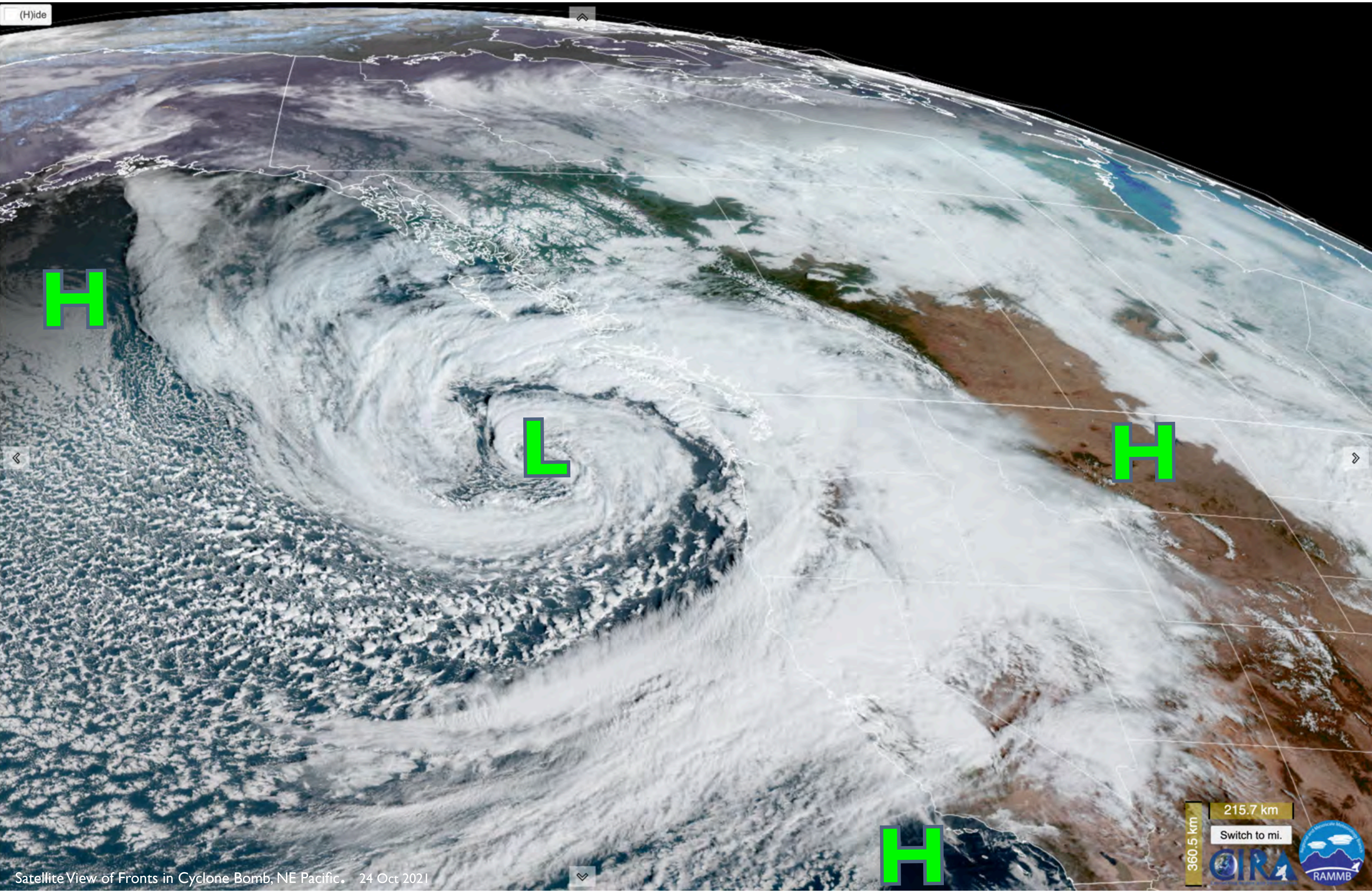
Pressure Gradients drive Horizontal Winds

Summary of How it works:

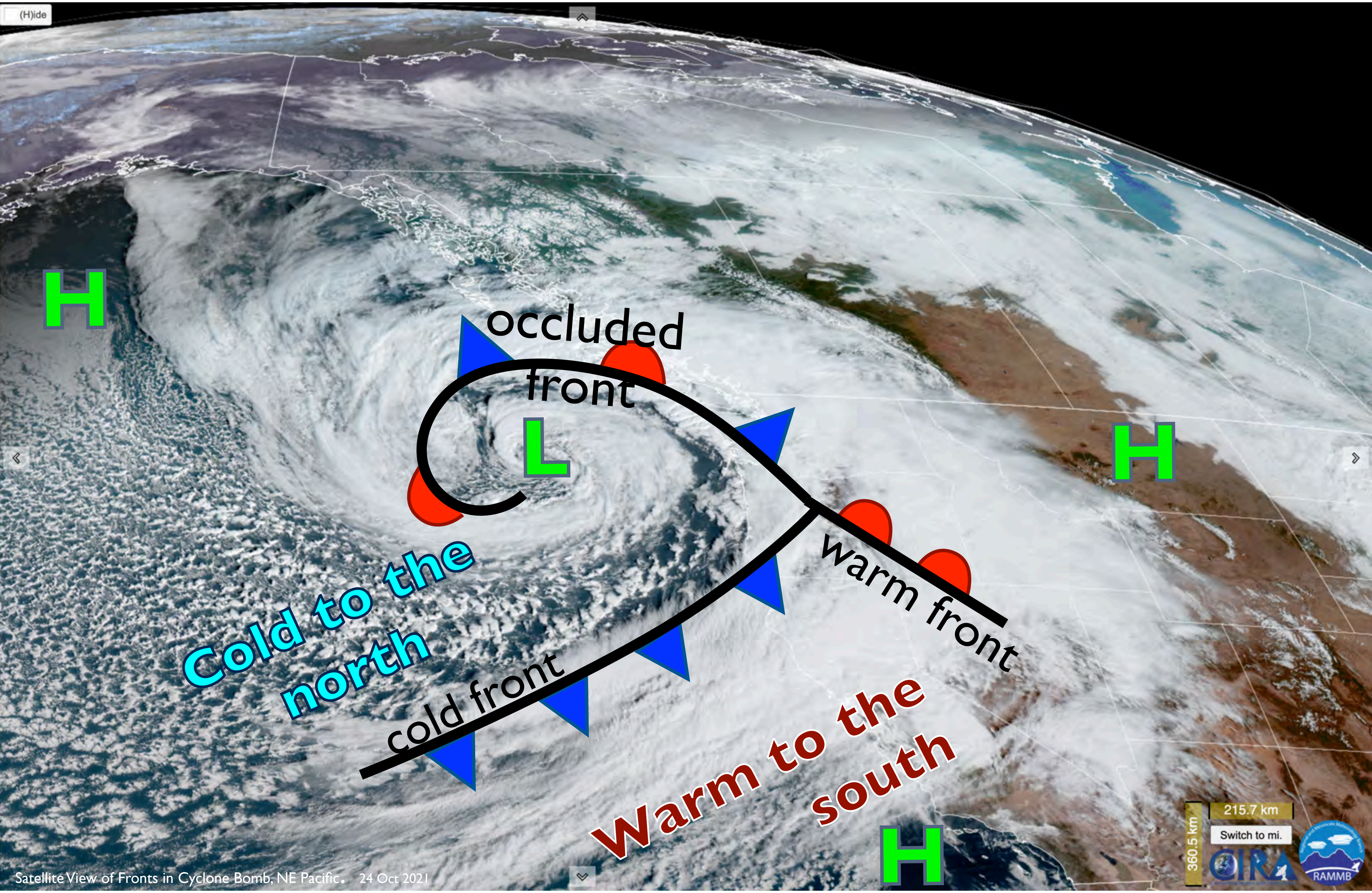
- horizontal changes in temperature ==>
- horizontal changes in pressure that increase with height ==>
- pressure gradient increasing at higher altitudes ==>
- drives faster winds at higher altitudes.

This type of pressure-gradient force drives the violent winds in **hurricanes**.

Pressure Gradients also drive Atmospheric Rivers

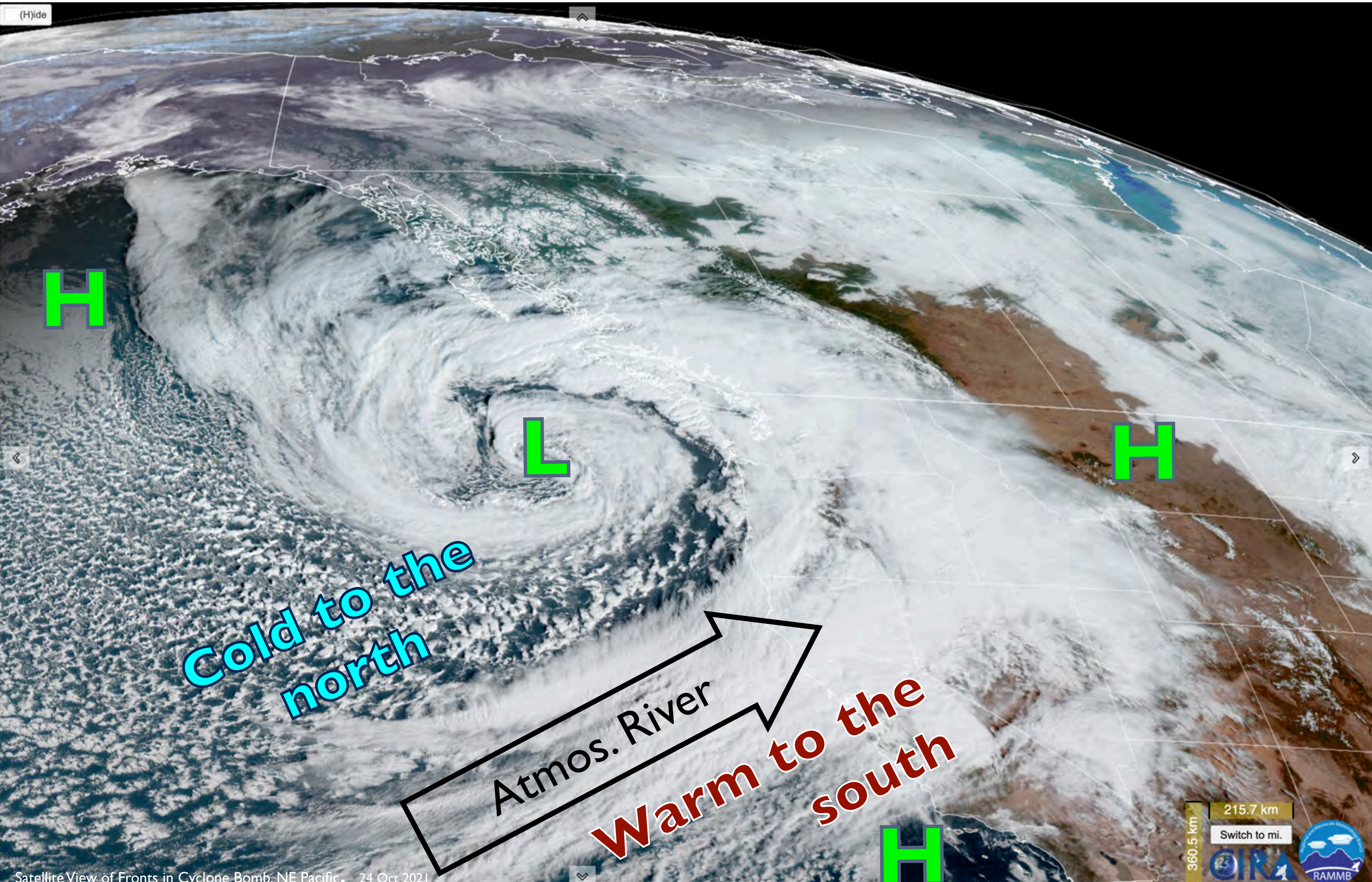


Pressure Gradients also drive Atmospheric Rivers



Satellite View of Fronts in Cyclone Bomb, NE Pacific. 24 Oct 2021

Pressure Gradients also drive Atmospheric Rivers



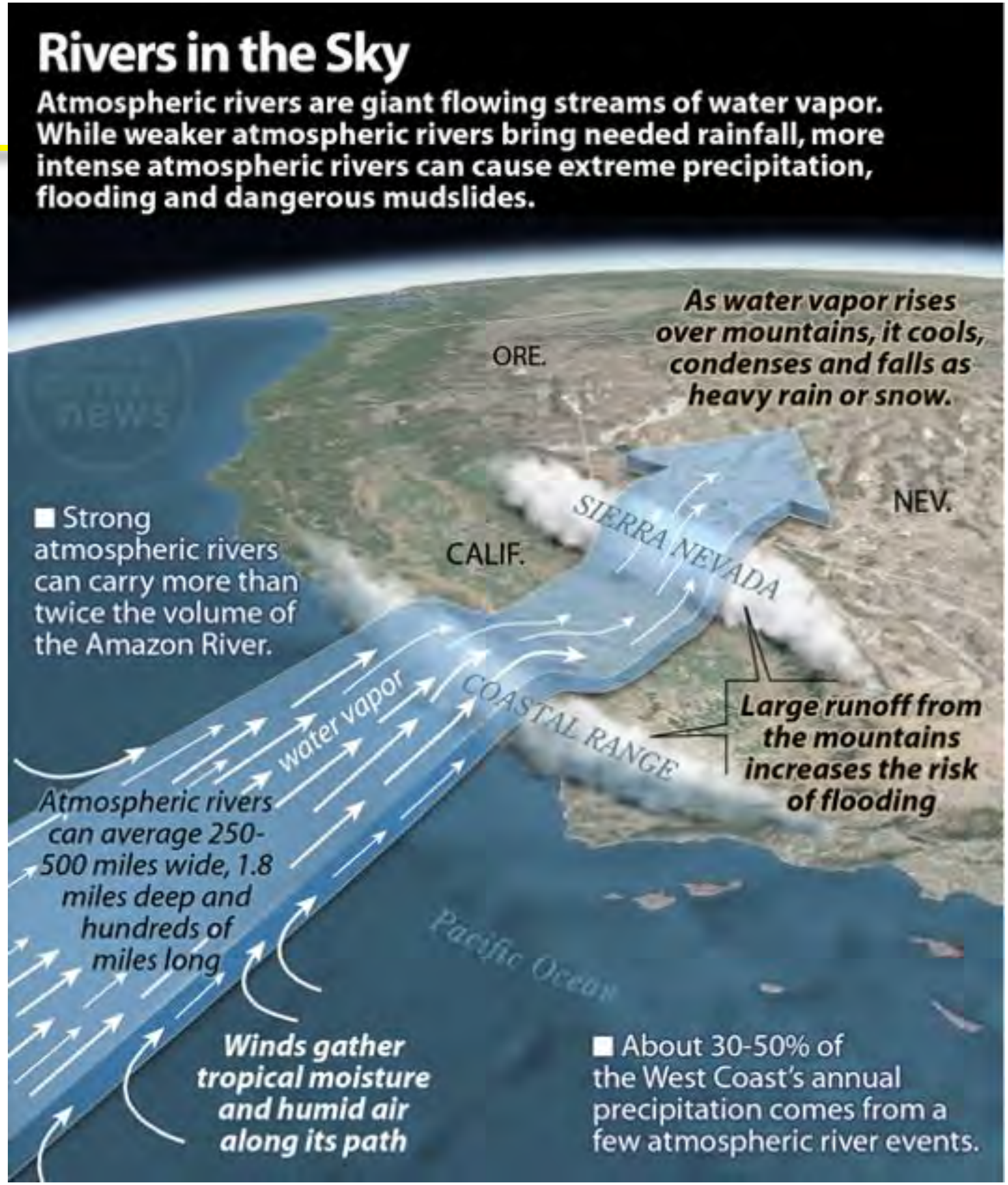
Satellite View of Fronts in Cyclone Bomb, NE Pacific. 24 Oct 2021

Pressure Gradients also drive Atmospheric Rivers

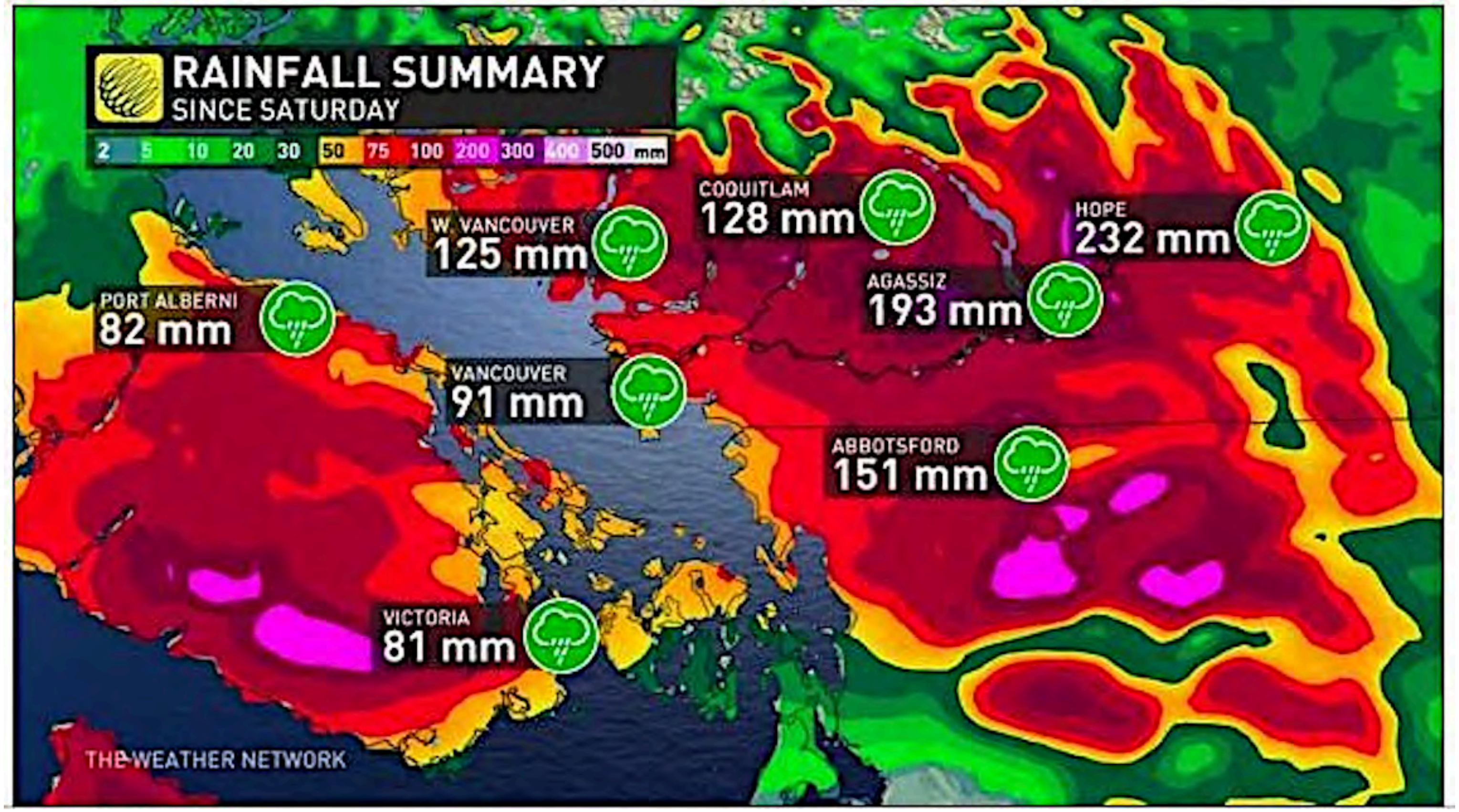
When the air hits mountain ranges and is forced to rise,

the air cools at the adiabatic lapse rate (10°C/km),

causing water vapour to condense, and rain to form.

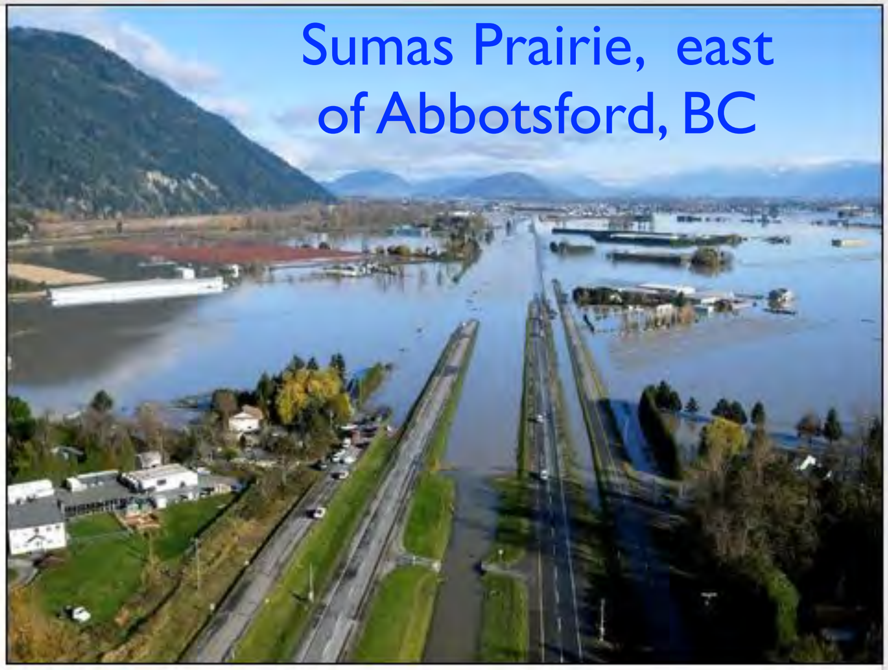


Pressure Gradients also drive Atmospheric Rivers



In Nov 2021, an Atmospheric River brought very heavy rains that caused flooding in southern BC.

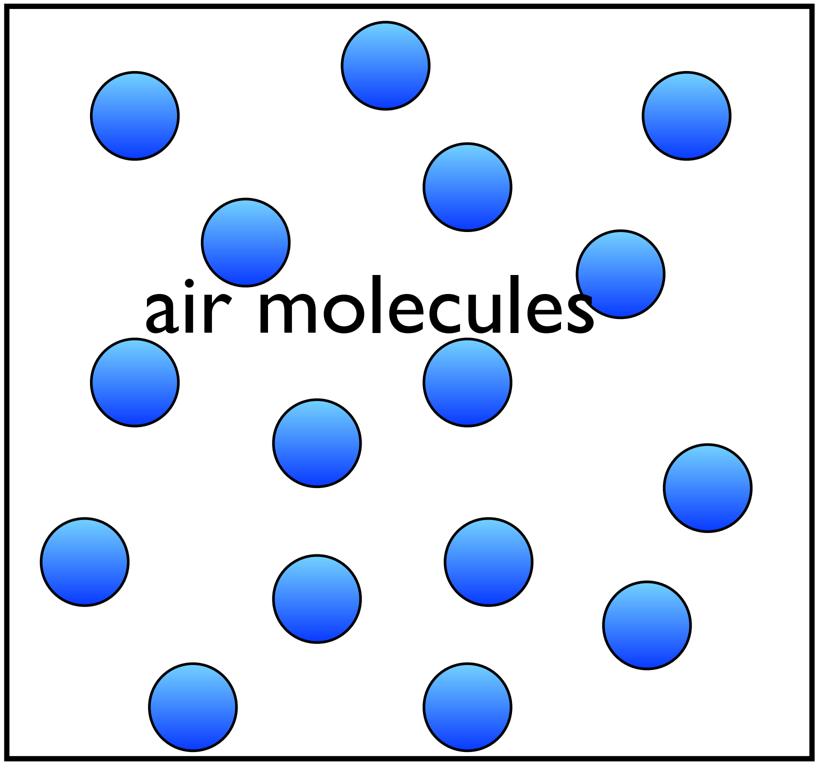
Pressure Gradients also drive Atmospheric Rivers



4. Continuity Links Vertical & Horizontal Winds in Circulations

Continuity concept:

- Air molecules tend to spread themselves smoothly and evenly
- They don't leave any gaps (i.e., they don't leave a vacuum)
- They don't get bunched together.
- Namely, air is **spread relatively evenly**.



Continuity causes Circulations

(LG: 4d)

Vertical Motions cause Horizontal Motions to create a Circulation, because of Continuity

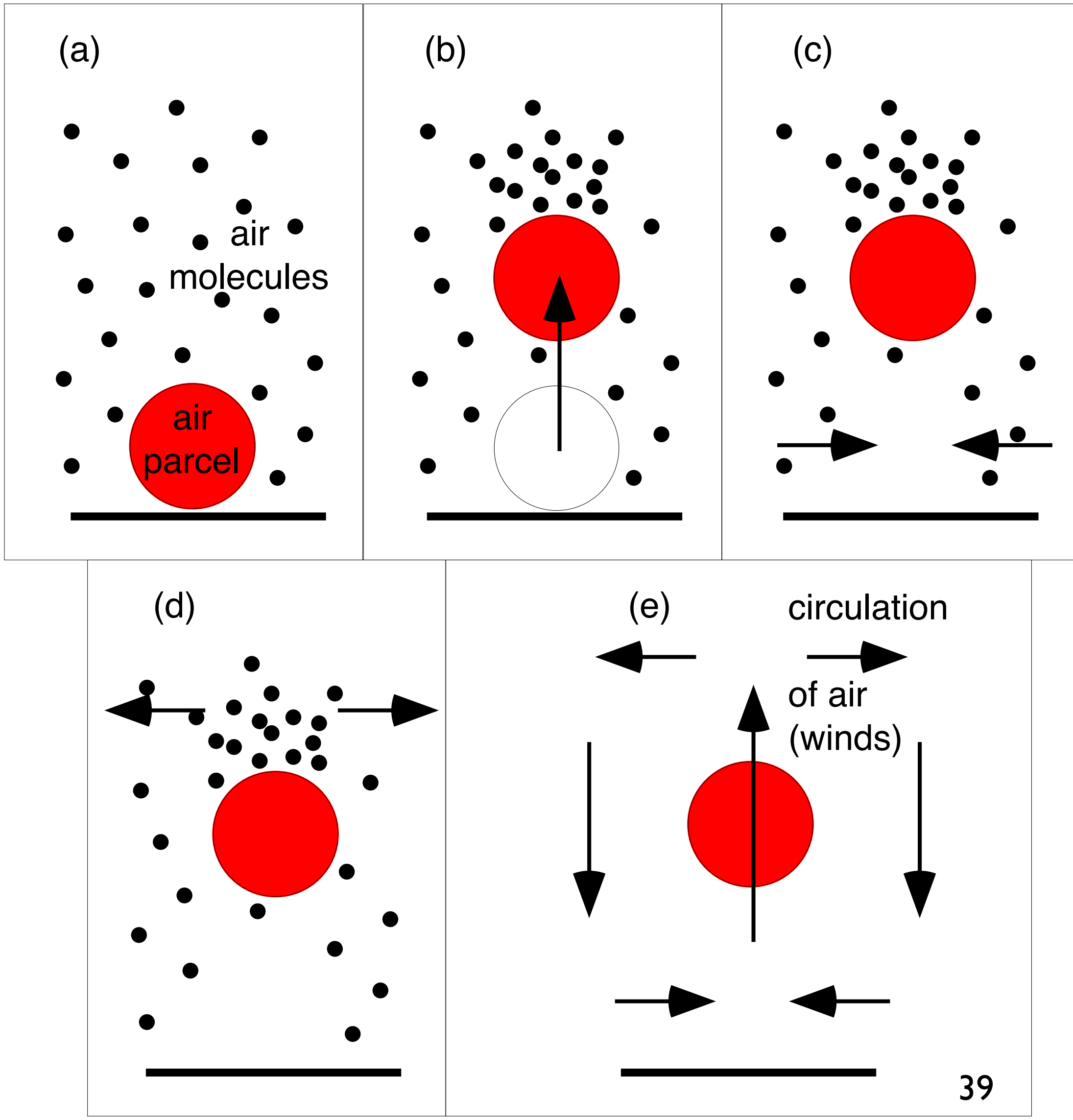
a) Air molecules are **smoothly** and **evenly distributed** in space

b) Buoyant air parcel rises, leaves hole where it used to be => **a (partial) vacuum**: has **lower pressure** than surrounding air.

c) Surrounding air sucked in to fill hole: **maintain continuity**

d) Air above the rising parcel is **compressed**: has **higher pressure**, expands **laterally**

e) Net result: initial **VERTICAL MOTION** due to buoyancy generates **HORIZONTAL MOTION** in surrounding air ==> **CIRCULATION** !

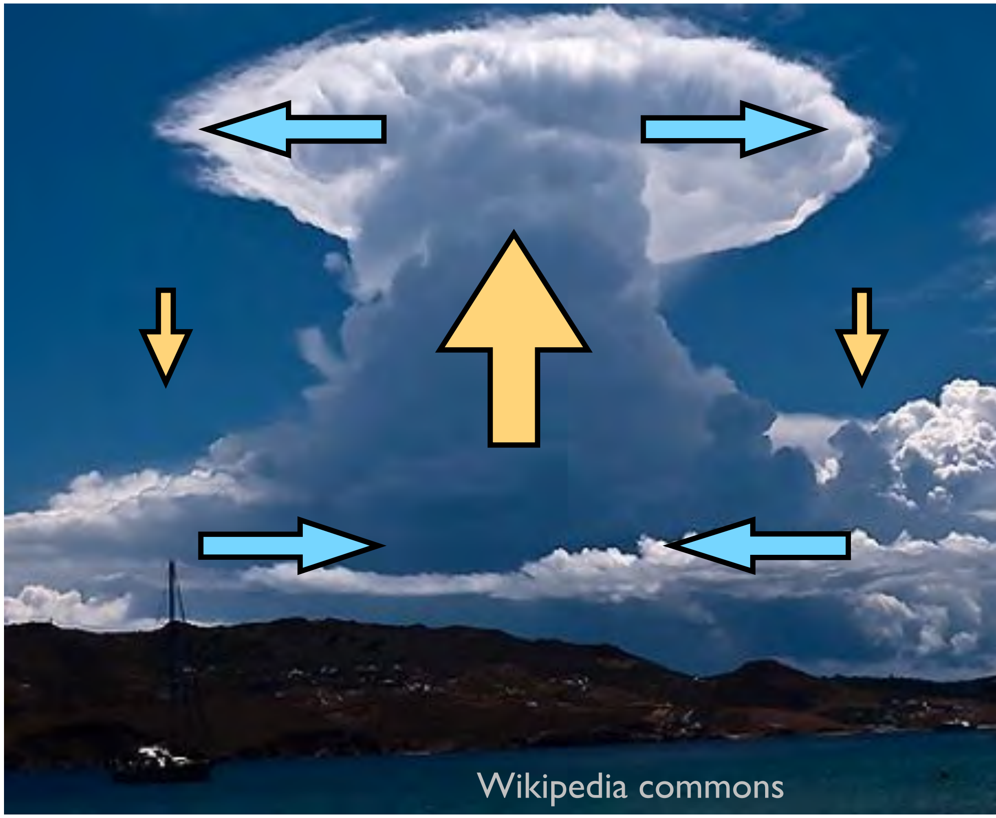


Circulations

In real life, circulations develop smoothly and continuously to try to maintain continuity as air parcels start to move.

Circulations can be driven:
by **buoyancy** in the vertical,
or by horizontal **pressure gradients**.

Vertical & horizontal motions are linked by the effect of **continuity**.



(LG: 4b-d)

From Heat to Motion

Overall Summary

- **Forces** create **winds**
- **Temperature** alters **buoyancy**

  => vertical forces => vertical winds
- **Temperature** alters **pressure**

  => horizontal forces => horizontal winds
- **Continuity** links **vertical** and **horizontal** winds into **circulations.**

Storm Hazards

(LG: 4e)

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Thunderstorm Hazards

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

today

Hurricane Hazards

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

(LG: 4e)

Hail

YouTube clips:

- Day4-25 Pecos Hank hail. Great overview of hail storms 2015. (7:00)

https://www.youtube.com/watch?v=6JbU0dIq70E

Optional, watch on your own (not testable):

YouTube clips (search on "hail"):

- Day4-30 - Hail in Carson, AB 2012
(View middle minute.)

https://www.youtube.com/watch?v=gB6lvmxCYLs

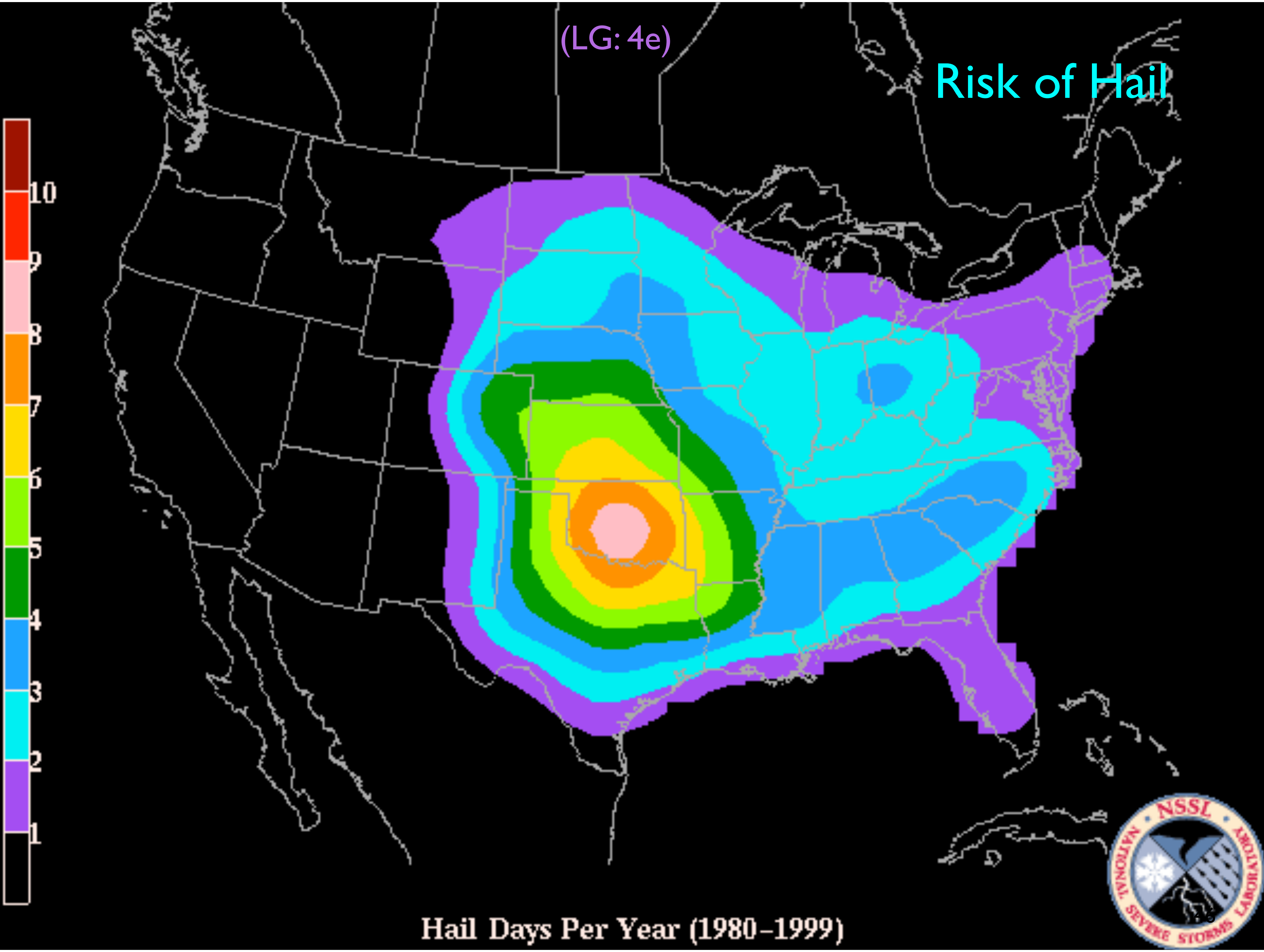
- Day4-40 Hail breaking windshields. (4:00)
https://www.youtube.com/watch?v=-rXEzXZY7No

Hail Safety

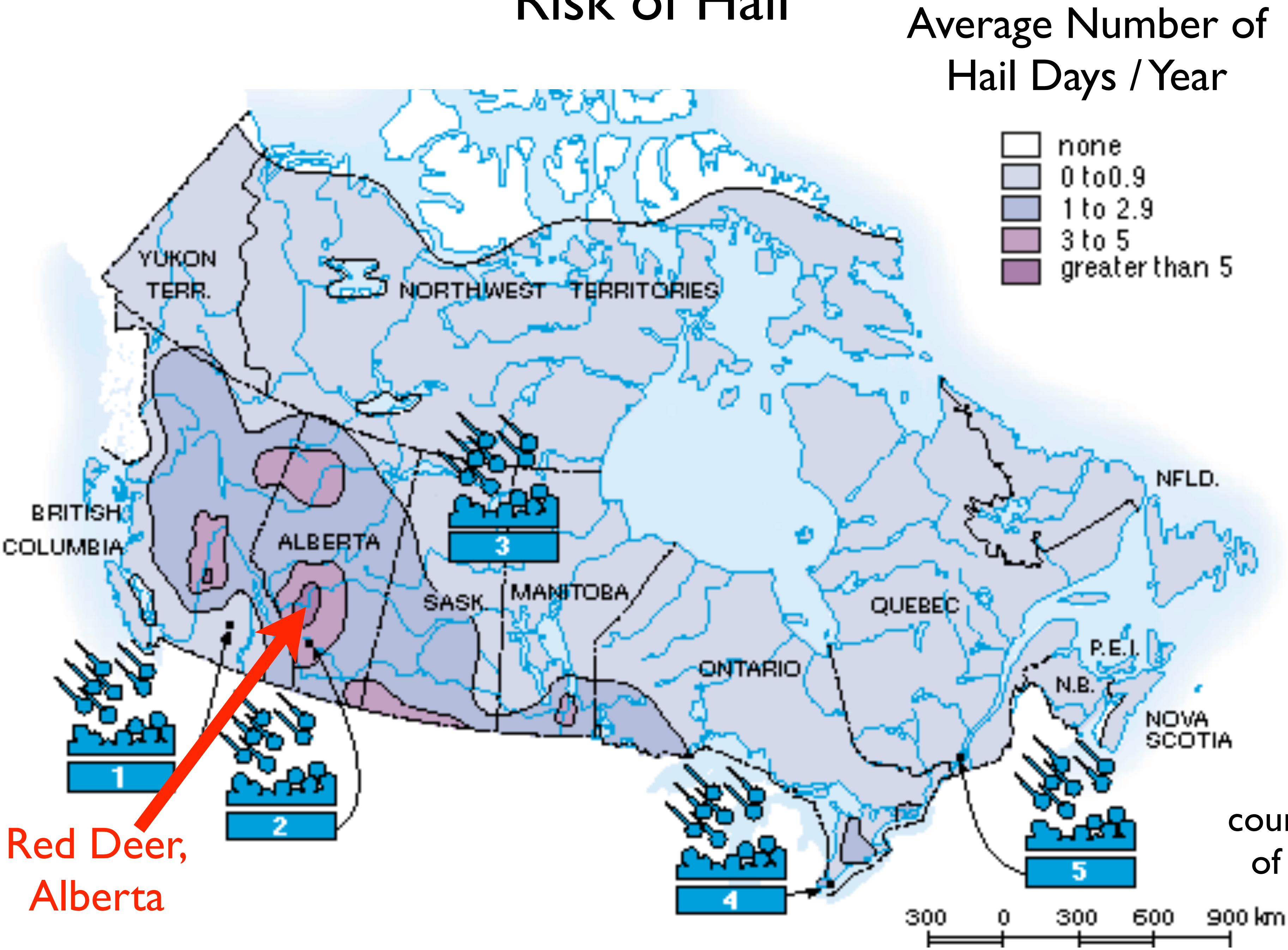
- Bring or wear safety glasses, in case hail breaks the windows in your car.

Stull vs. Auto Glass

- If possible, turn away from the storm and drive away.
- Stay under a roof, inside a car, under a farm tractor, etc. to protect yourself from falling hail.


(LG: 4e)
Risk of Hail
10
9
8
7
6
5
4
3
2
1
Hail Days Per Year (1980–1999)
NSSL
NATIONAL SEVERE STORMS LABORATORY

Risk of Hail



courtesy of EC

Hail Crop Damage

(LG: 4e)

Manitoba

Alberta

...and what about cloud seeding near Red Deer, Alberta.

(LG: 4e)

Summary of Rain & Hail Hazards

- **Rain**: Tstorm rain can be heavy, covering small area, very large raindrops, very transient, moving with storm.
- Hazards: Downpours can cause flash floods, and reduced visibility while driving. (& can trigger landslides)
- Safety: Move to high ground. Don't drive through water of unknown depth.

- **Hail**: can come from any large Tstorm, but are most common with supercells (low precip.)
- Hazards: injury or death, dent metal cars, break windows (sending shards of glass to your eyes), flatten crops, kill livestock
- Safety: get indoors. If in a car, U-turn to leave hail area, or park under a roof. If car is exposed to strong hail, pull over to the side of the road and park, and close your eyes to keep glass shards out.

(LG: 1-5)

Insights

- Different storms behave differently -- they don't all have the same hazards.

  When threatened with an approaching storm, look at its behavior and characteristics to anticipate the worst hazards, and take appropriate action.

The Turbulent Atmosphere

Prof. Roland Stull

Summary of Day 4

- Clouds associated with Tstorms
- Storm Energy
  - C. From Heat to Motion
    1. Forces Create Winds
    2. Temperature alters buoyancy to drive vertical winds
    3. Temperature alters pressure to drive horizontal winds
    4. Continuity links vertical & horiz. winds in circulations
- Hail & more about Precipitation

Next Storm-lecture Class

- Hurricanes