The Turbulent Atmosphere (Storms)

Instructor: Doug McCollor
EOSC 114
Wed Sept 18, 2024

Today:

- **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
- **Atmospheric Rivers, heavy precipitation, flooding and landslides**
- **Hail**

(LG: 4a-e)

Today's Learning Goals

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

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

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

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

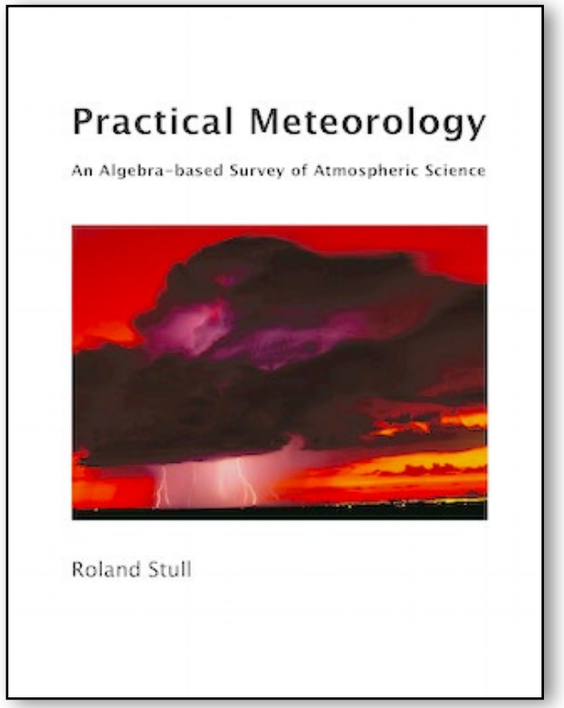
4d) describe atmospheric river hazards, locations of greatest risk, and appropriate safety procedures

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

Good Textbook

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

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



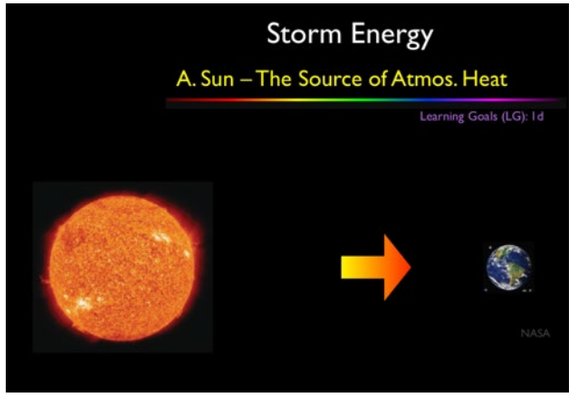
If you like weather and meteorology, consider majoring in Atmospheric Science (ATSC).

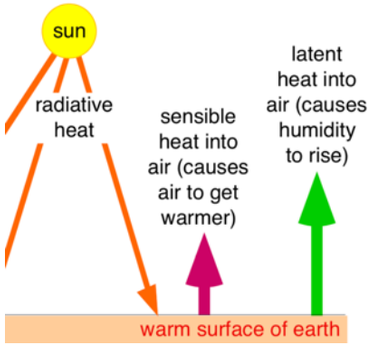
Road-map to Storm topics

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, Flooding	Atmos. rivers	heat to motion, forces, winds
5	Flooding, winds, waves, storm surge	Hurricanes	energy in warm ocean, Coriolis

Review





LG 2e

3. Advection & Adiabatic Cooling

Advection = movement of air by the wind. Water vapour can be advected into a thunderstorm by the wind.

- When a thermal of unsaturated air rises **adiabatically** (with no heat transfer to the surrounding environment), the thermal cools roughly 10°C/km of rise.
- Cooler air can hold less water as vapour
- Therefore, some vapour must condense into liquid droplets.
- But condensation releases latent heat.

WeatherStock, used under license

43

Storm Energy: From Heat to Motion

(LG: 4a)

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 concepts of:

- forces
- acceleration
- buoyancy
- pressure.

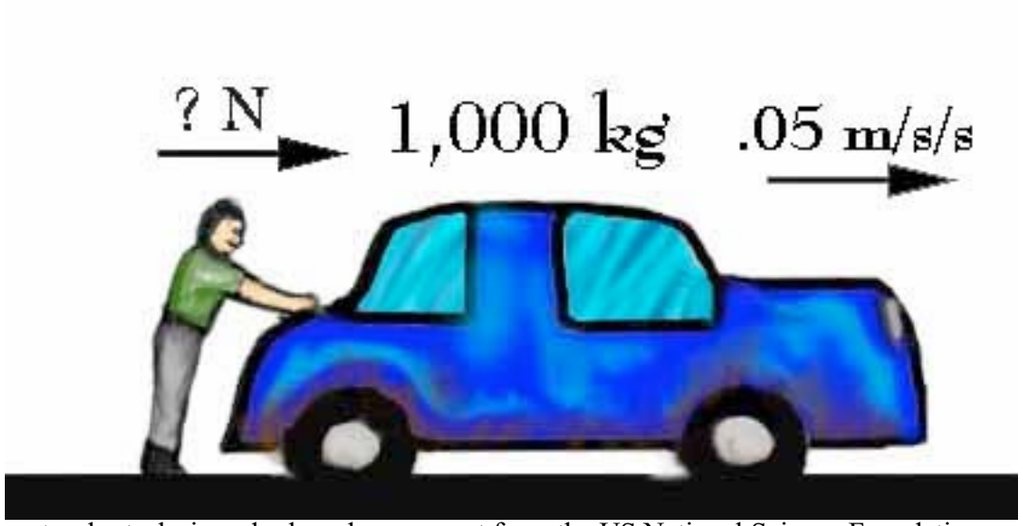
1. Forces create winds

In the atmosphere, forces create winds.
The relationship between forces & motion is described by

Newton's Second Law.

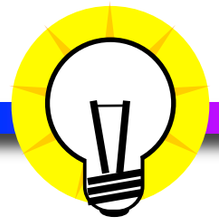
$$F = m \cdot a$$

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



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.

1. Forces create winds

Acceleration (a) = change of velocity (v) during time interval (Δt), 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).

$$a = \frac{v_{new} - v_{old}}{\Delta t}$$

Examples:

- If car increases speed from 50 to 90 km/h during time interval 15 seconds, then it is accelerating (v_{new} = 90, v_{old} = 50)
- If car maintains constant speed of 50 km/h, then acceleration = zero (v_{new} = 50, v_{old} = 50 so $v_{new} - v_{old}$ = 0)

Wikipedia Commons

Forecasting the Winds

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

$$v_{new} = v_{old} + \left(\frac{F}{m}\right)\Delta t \quad \text{(Eq. 1)}$$

(=a)

This equation applies to all objects, including:
cannon balls, cars, and: air parcels!

Wikipedia Commons

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

Air-parcel movement = wind (horizontal or vertical)

So equation (Eq. 1) 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.

2 and 3: 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: 4a,b)

Warm air rises -> updrafts

Cold air sinks -> downdrafts.

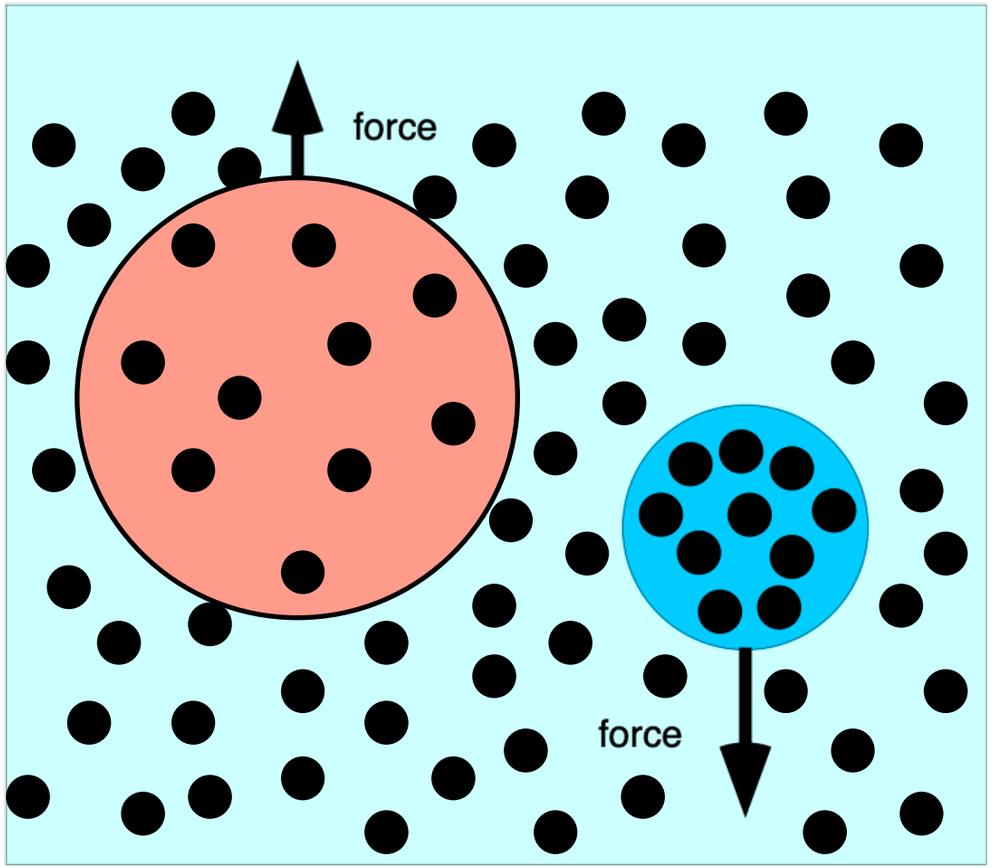
Why?

Temperature affects the **density** of air,

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

Buoyancy

The buoyancy of an air parcel depends on the <u>difference</u> between the
parcel temperature
and the
temperature of the surrounding air.



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.

(LG: 4a,b)

Buoyancy causes
hot air balloons to rise.

photos by Prof. Roland Stull

Buoyancy

(LG: 4a,b)

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

(LG: 4a,b)

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 1: $$v_{new} = v_{old} + \left(\frac{F}{m}\right)\Delta t \quad \text{(Eq. 1)}$$

Thus, pressure drives winds !!

Pressure-gradient Force

(LG: 4b)

Pressure differences are what's important**: ΔP**

- pressure at only one place is not important here.
- the **difference** between opposing pressures is important.
- pressure pushing on one side of air parcel

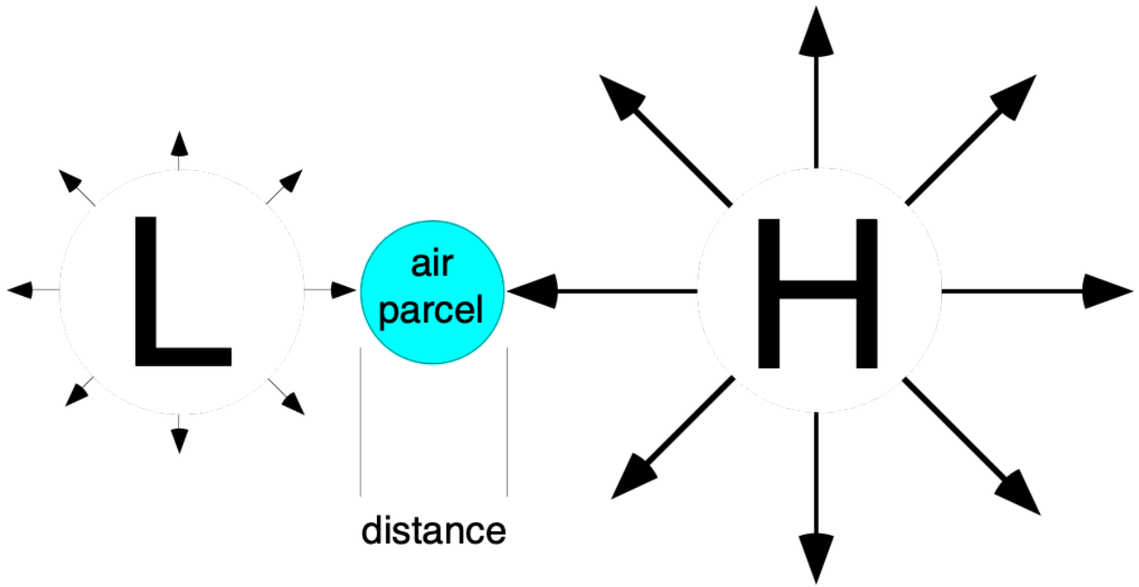
vs.

pressure pushing on other side

- pressure difference across a distance is called a: **pressure gradient.**

Pressure-gradient Force

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.

Pressure-gradient Force

Example: Hurricanes are strengthened by pressure-gradient forces

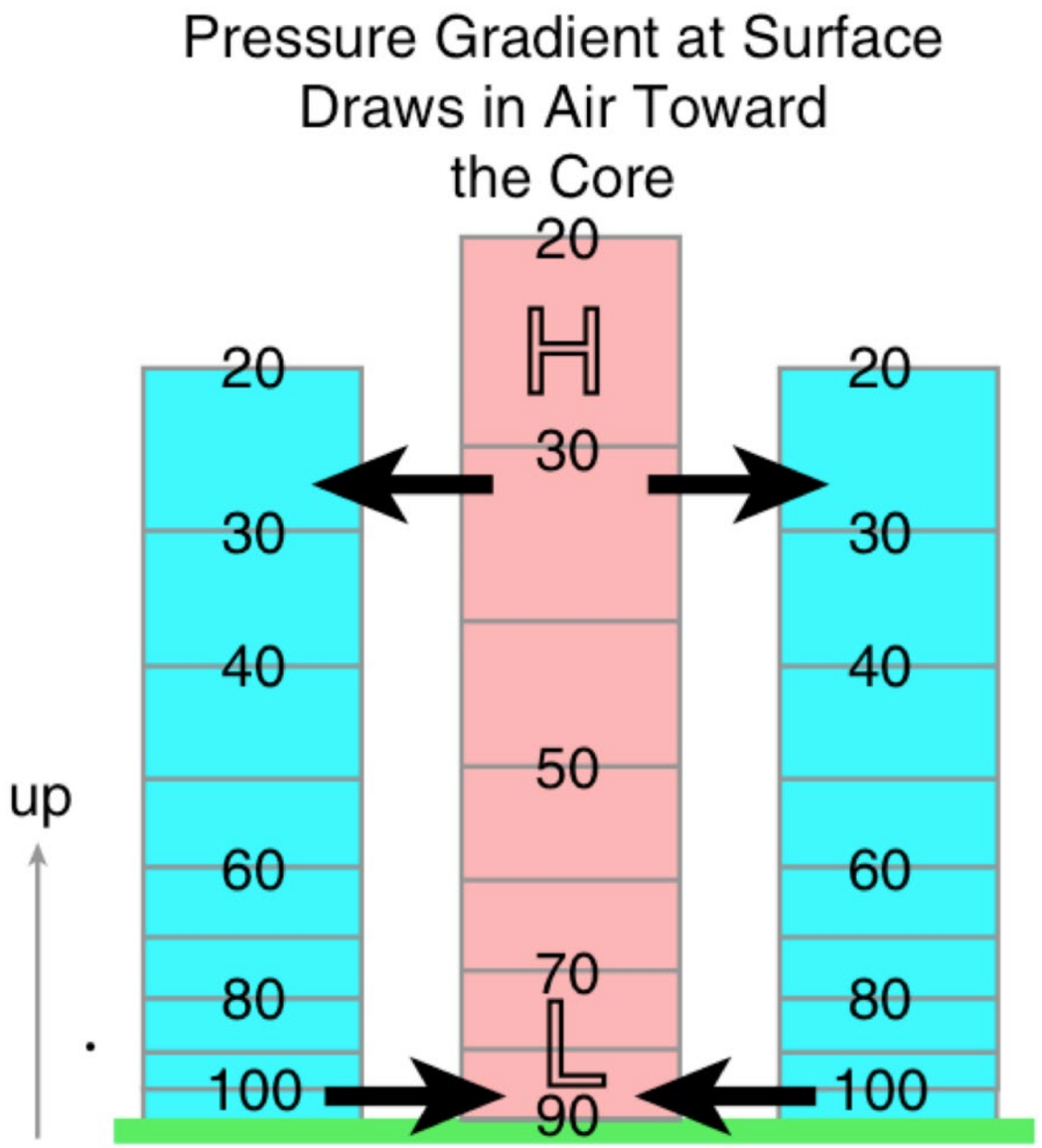
Latent heating from condensation in the centre of the hurricane causes the centre to be warmer.

This warm air expands, creating low pressure near the surface in the centre

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.



3. Temperature alters pressure to 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**.

It also drives **Atmospheric Rivers**.

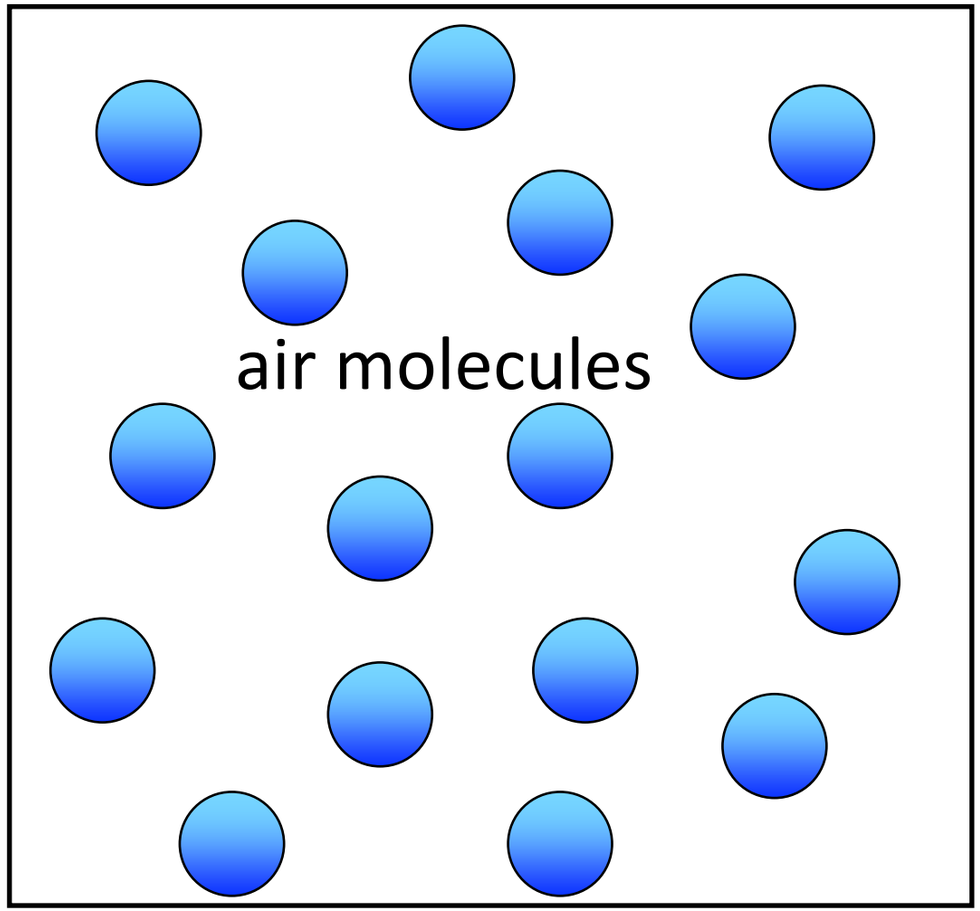
4. Continuity Links Vertical & Horizontal Winds in Circulations

(LG: 4c)

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**.

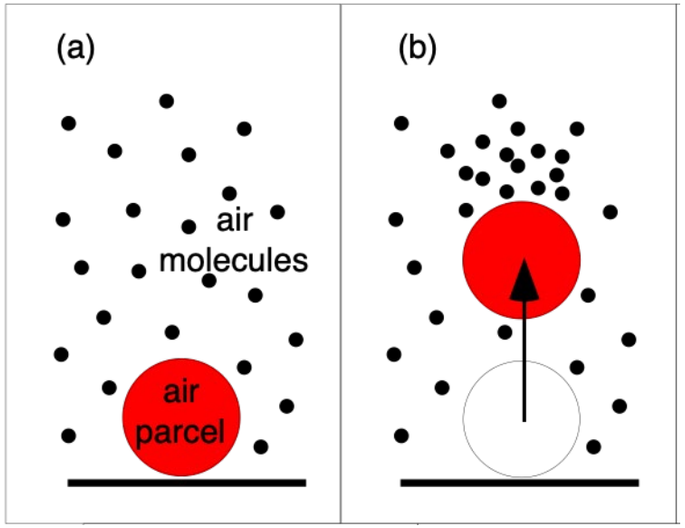


Continuity leads to Circulations

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.

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



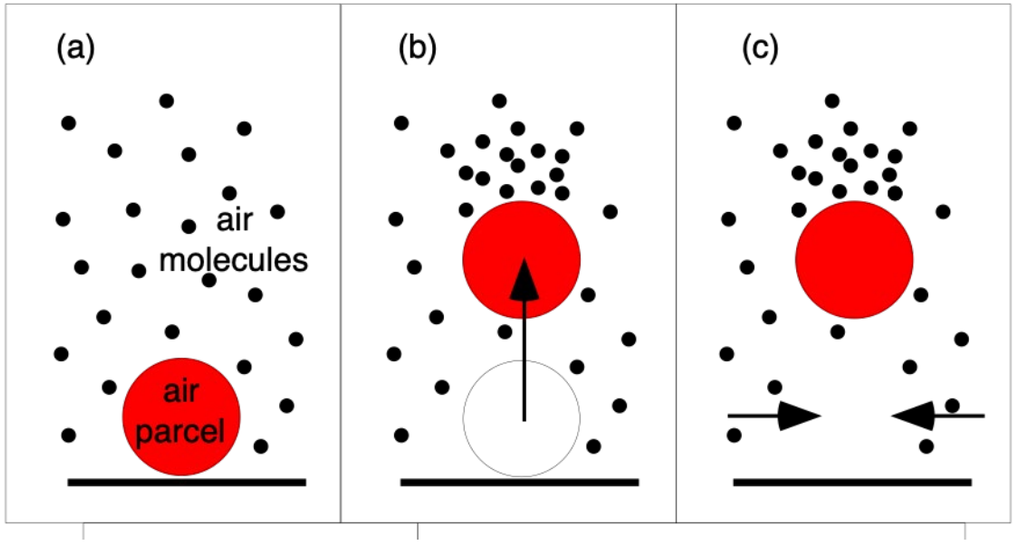
Continuity leads to Circulations

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**

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



Continuity leads to Circulations

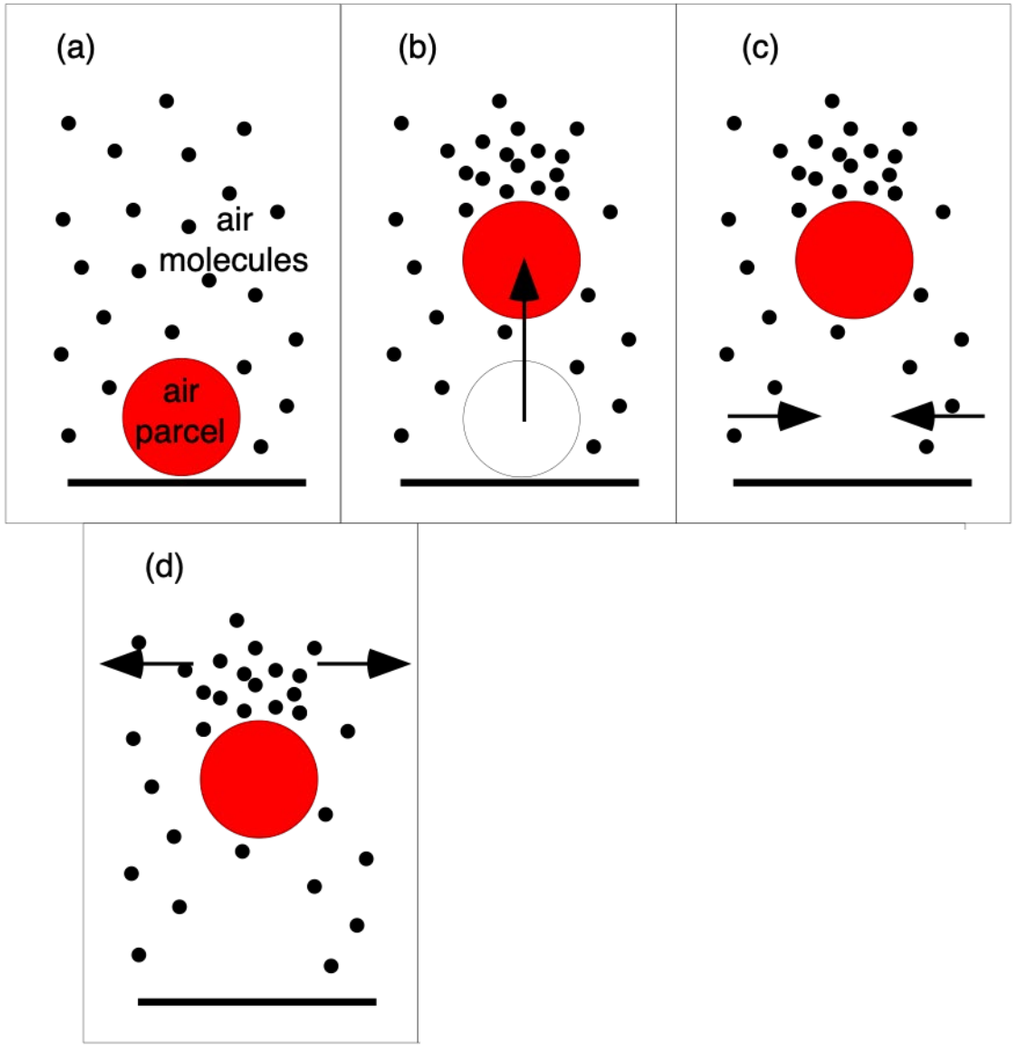
a) Air molecules are **smoothly** and **evenly distributed** in space

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**

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



Continuity leads to Circulations

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

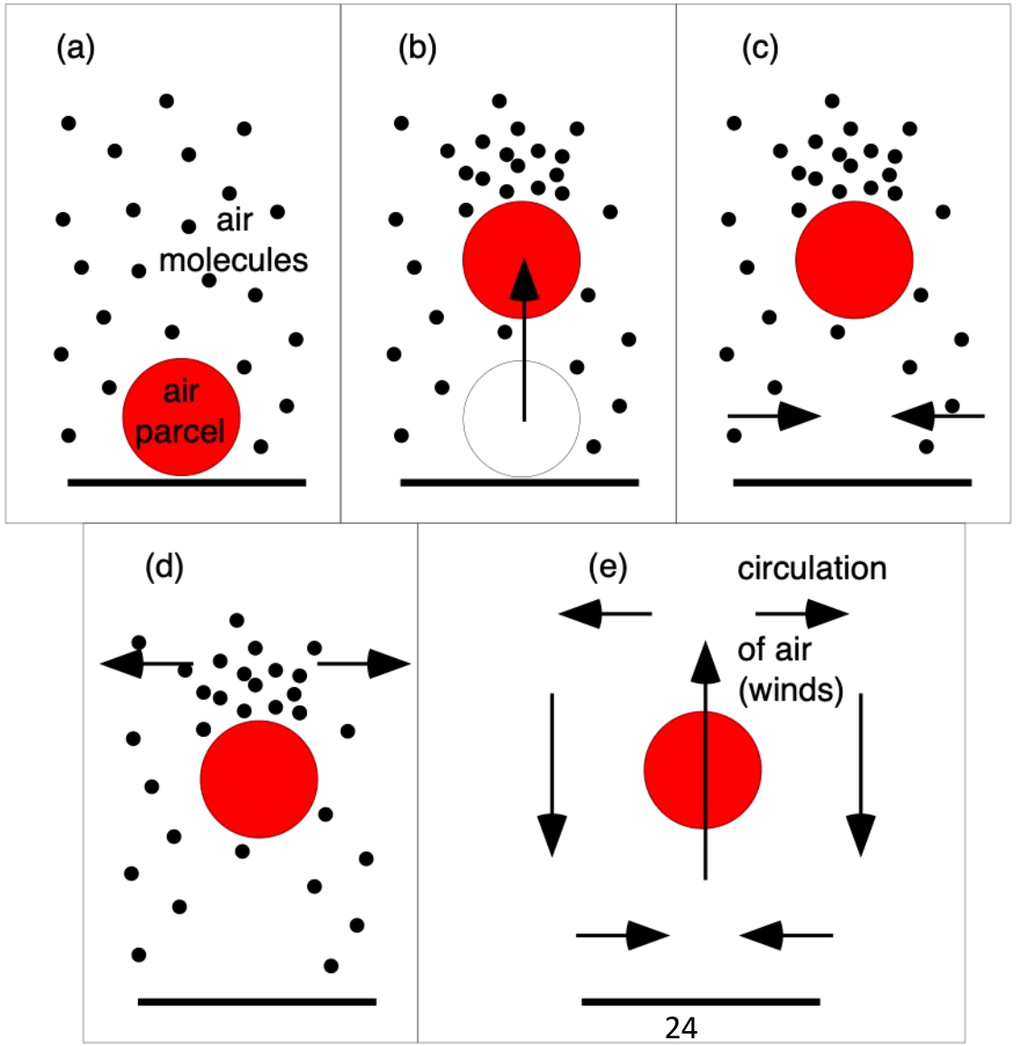
b) Buoyant air parcel rises, leaves hole where it used to be => **a (partial) vacuum**: has **lower pressure** than surrounding air.

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** !

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



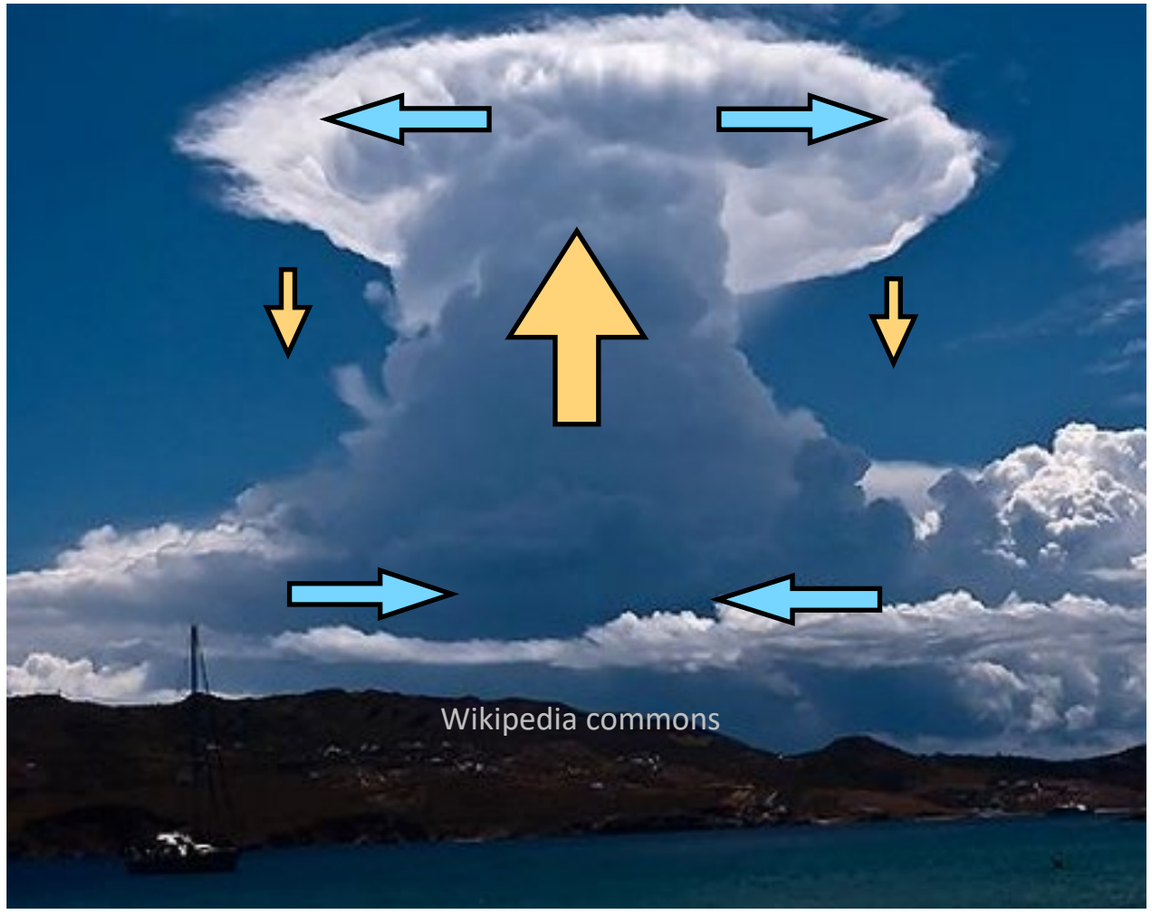
Circulations

(LG: 4c)

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 <u>linked</u>
by the effect of **continuity**.



(LG: 4a-c)

Storm Energy: 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.**

WeatherStock.com, used under license

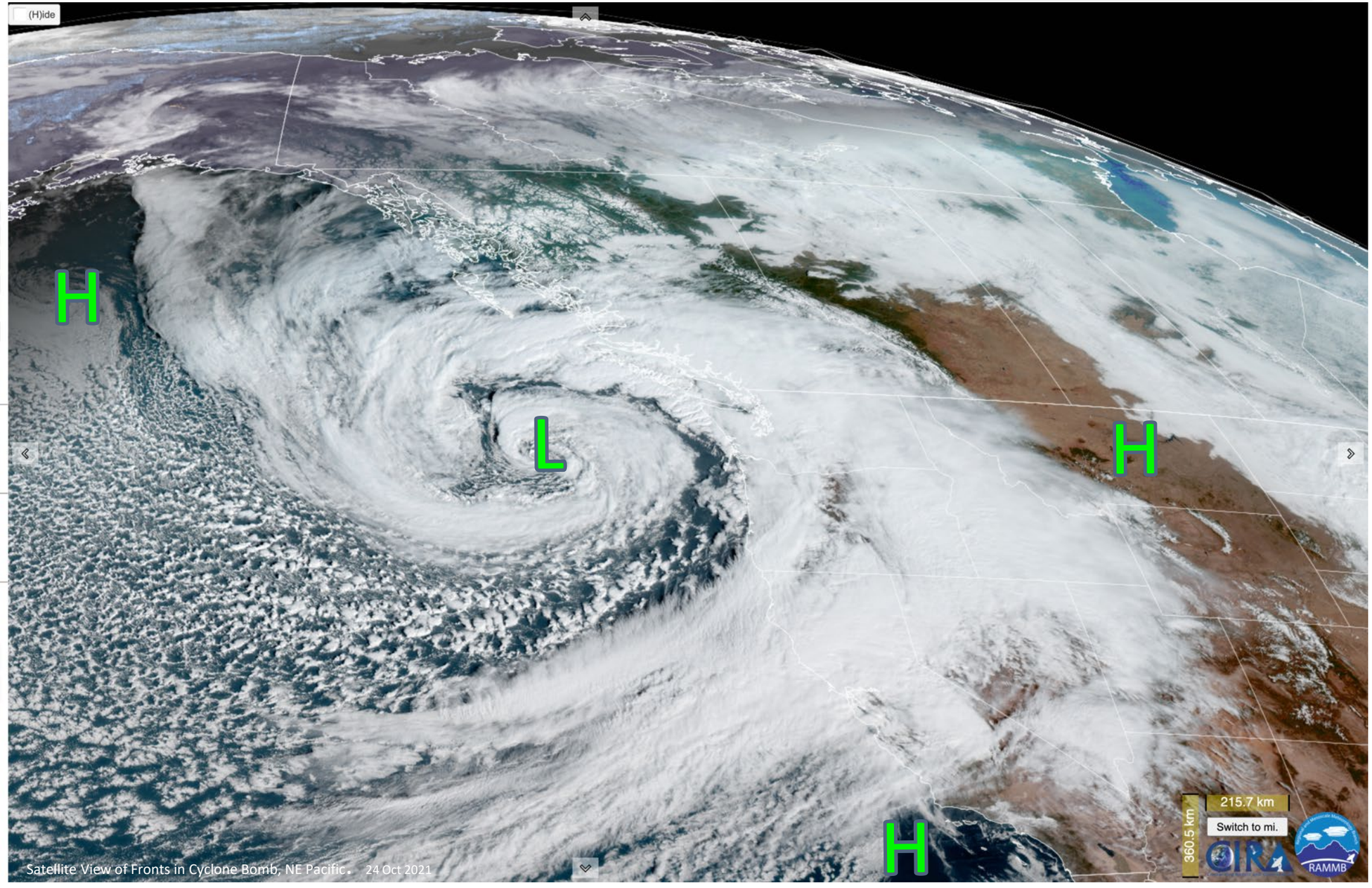
Road-map to Storm topics

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, Flooding	 Atmos. rivers	heat to motion, forces, winds
5	Flooding, winds, waves, storm surge	Hurricanes	energy in warm ocean, Coriolis

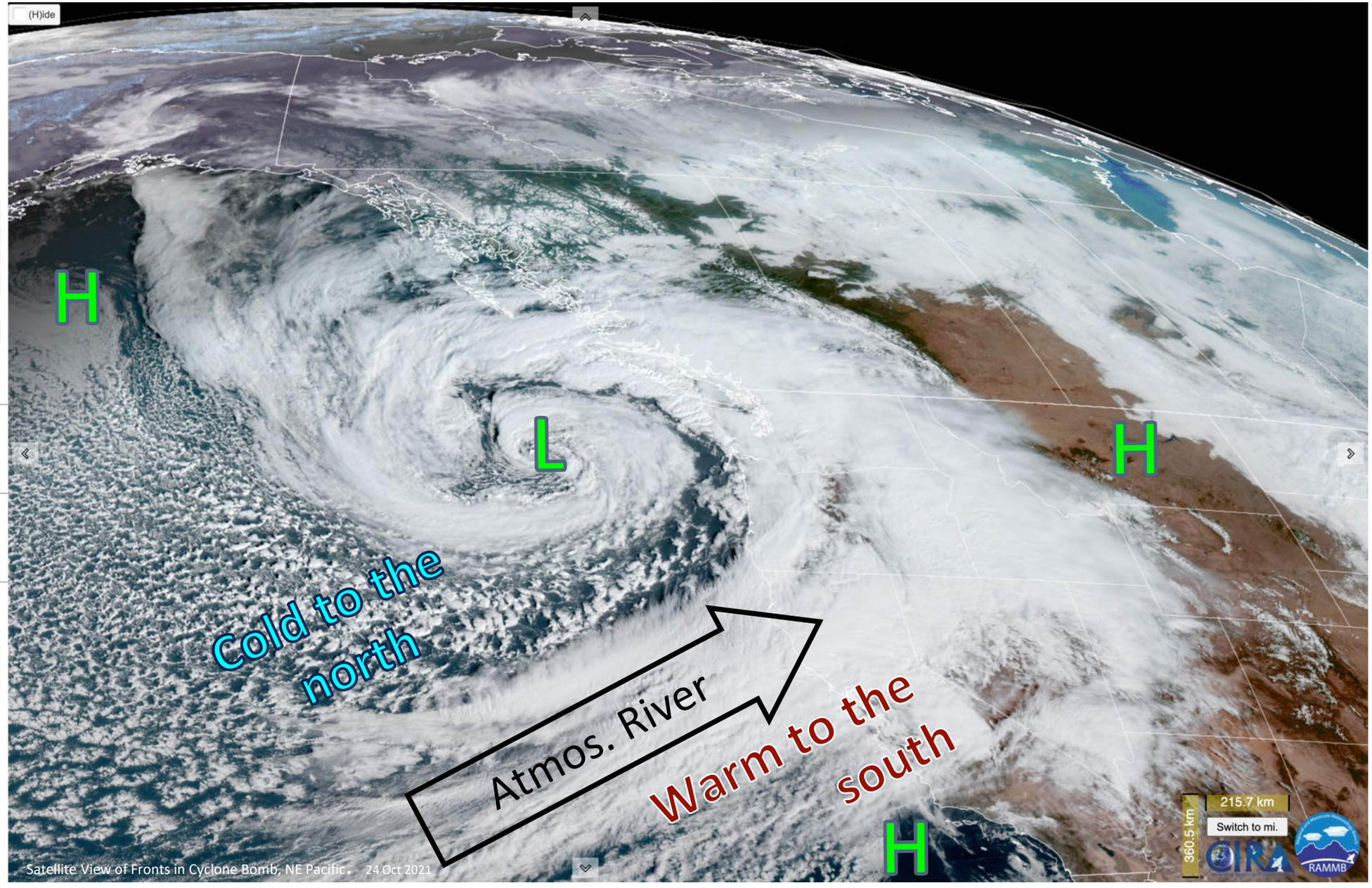
Pressure Gradients also drive Atmospheric Rivers

(LG: 4b, d)



Pressure Gradients also drive Atmospheric Rivers

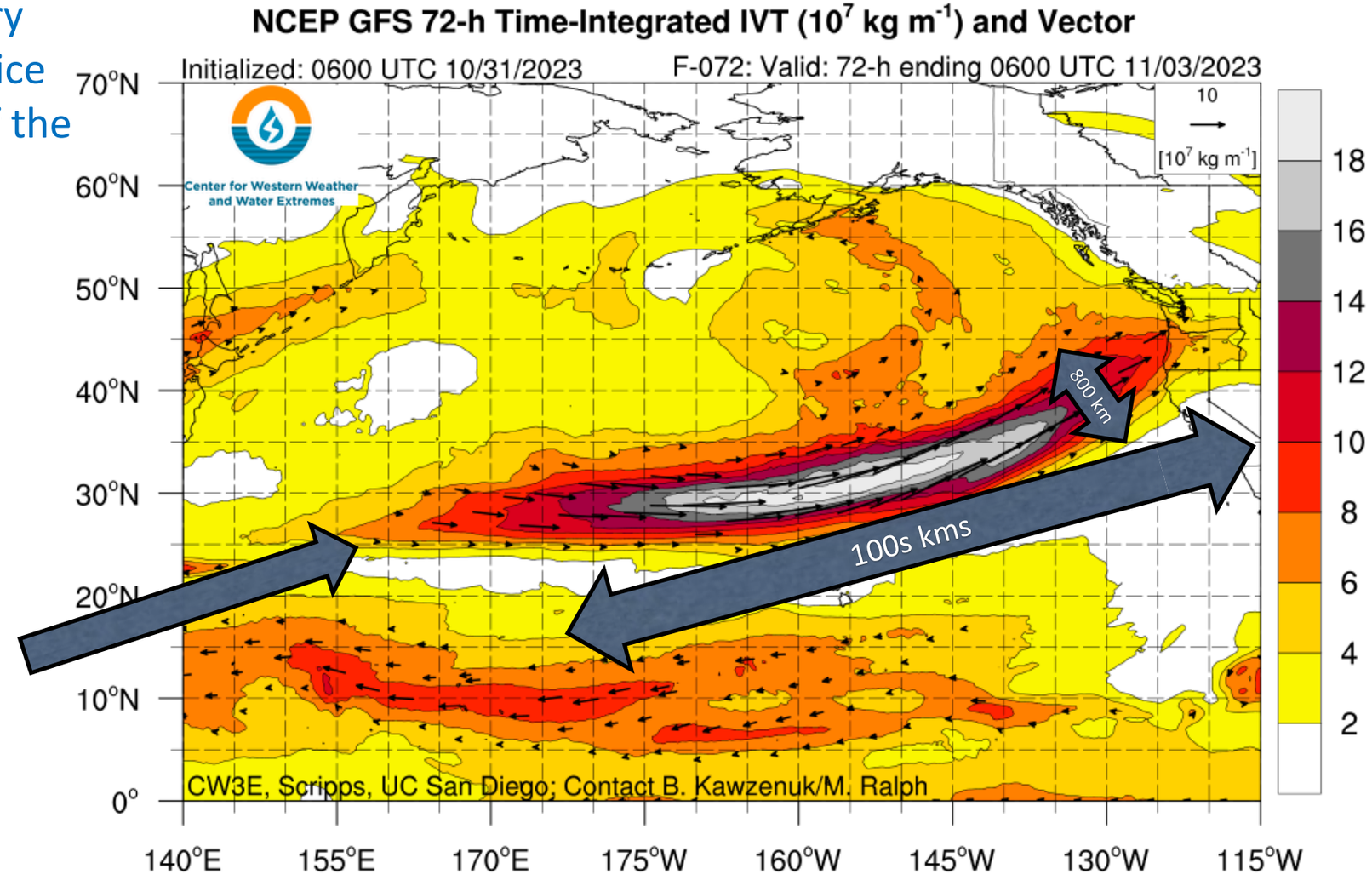
(LG: 4b, d)



Pressure Gradients also drive Atmospheric Rivers

(LG: 4b, d)

Atmospheric rivers can carry more than twice the volume of the Amazon River

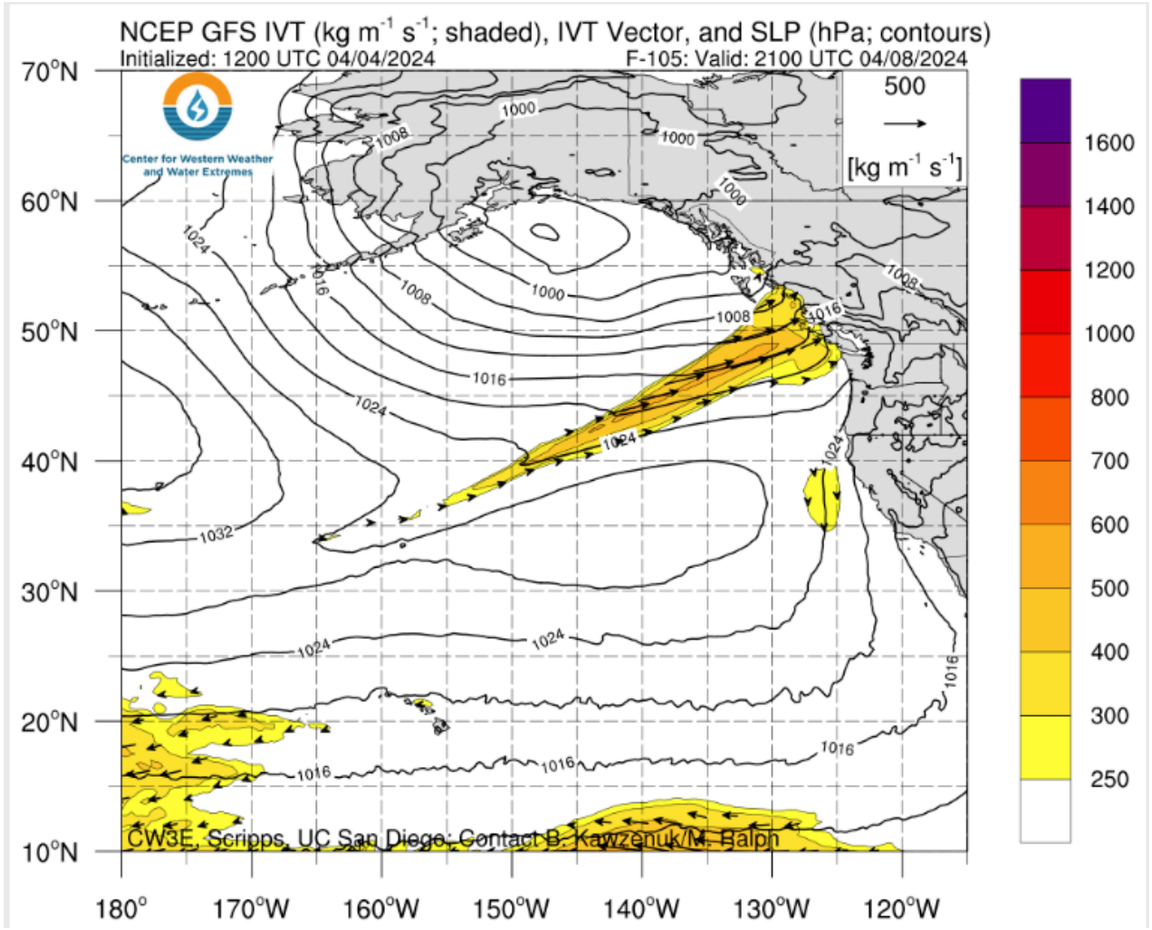


The originate in the tropics/sub-tropical regions

Atmospheric rivers are about 400-800km wide, 3km deep and 100s of km long

Pressure Gradients also drive Atmospheric Rivers

(LG: 4b, d)



Watch atmospheric river forecasts for the US west coast:

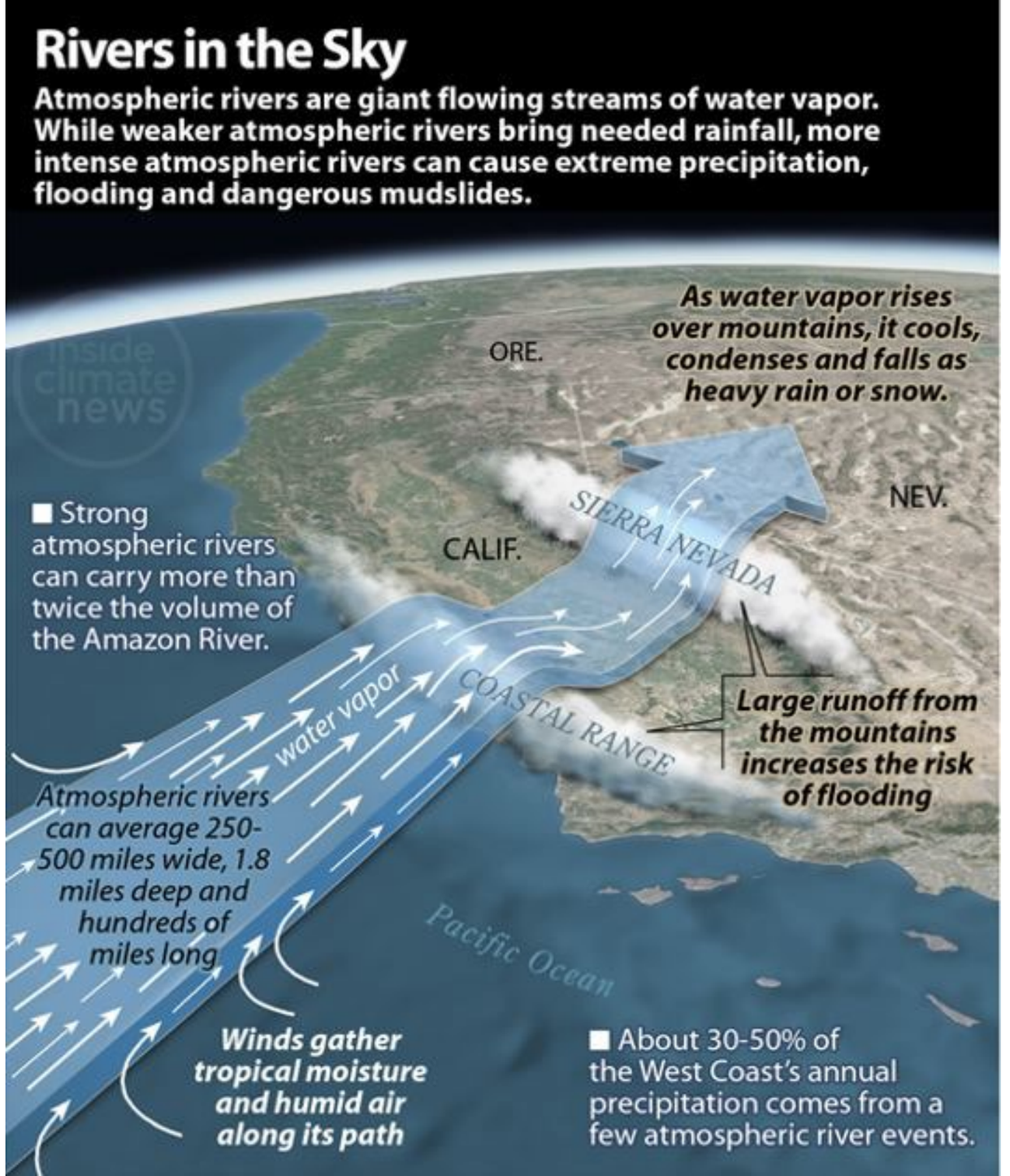
https://cw3e.ucsd.edu/ivt_iwv_npacific/

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.



(LG: 4b, d)

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, Flooding	Atmos. rivers	heat to motion, forces, winds
5	Flooding, winds, waves, storm surge	Hurricanes	energy in warm ocean, Coriolis

(LG: 4b, d)

Pressure Gradients also drive Atmospheric Rivers

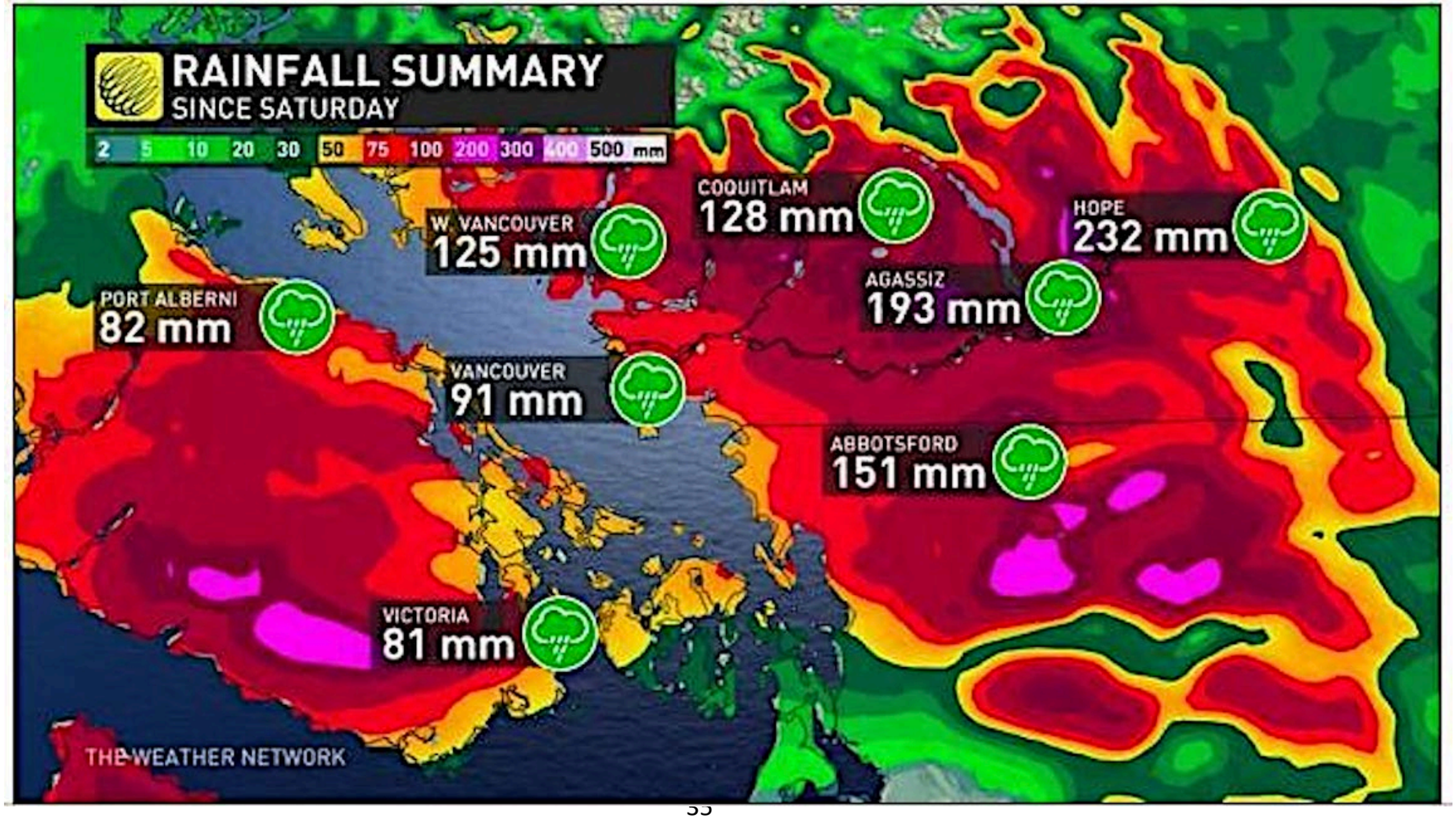
Video - atmospheric rivers of Nov 2021:

https://gpm.nasa.gov/applications/weather/atmospheric-river-brings-severe-flooding-and-landslides-british-columbia

Pressure Gradients also drive Atmospheric Rivers

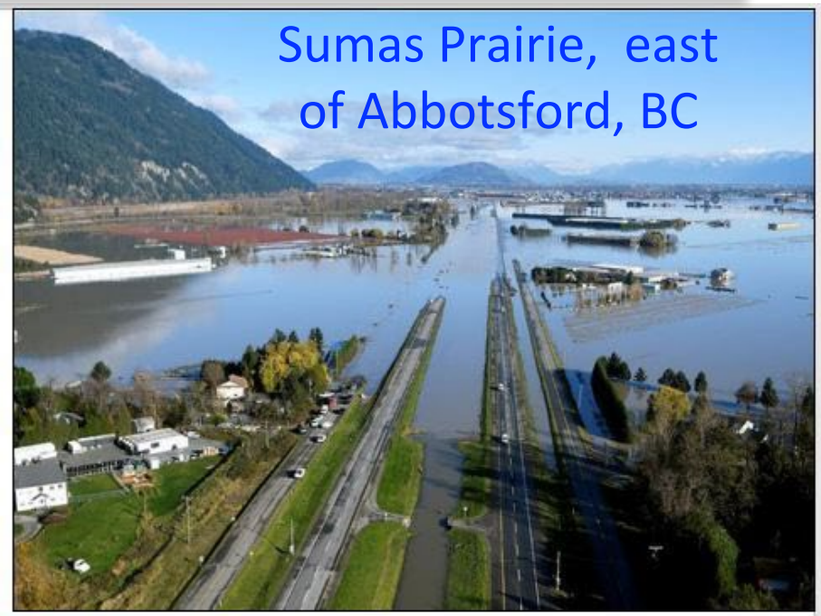
(LG: 4d)

In Nov 2021, a series of Atmospheric Rivers brought very heavy rains that caused flooding and landslides in southern BC.

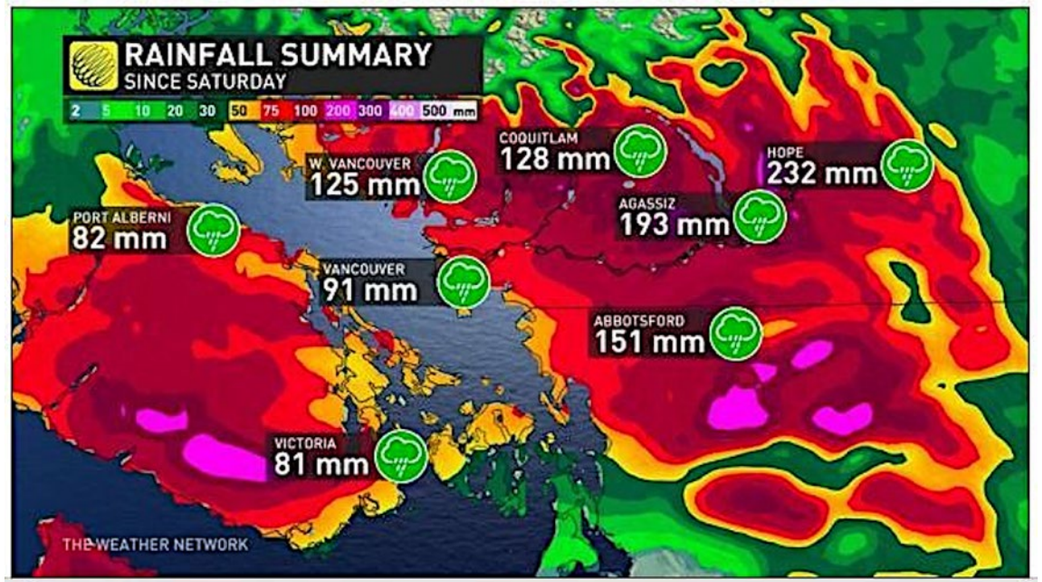


Pressure Gradients also drive Atmospheric Rivers

(LG: 4d)



(LG: 4d)



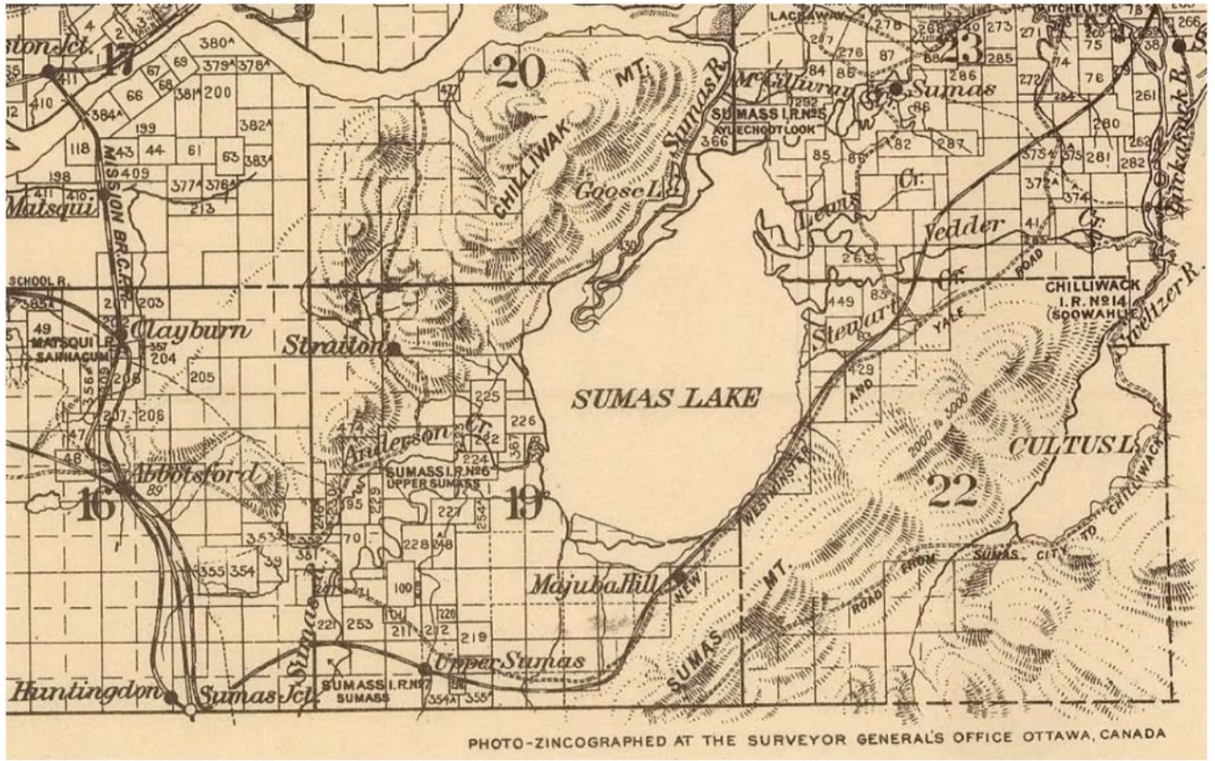
Abbotsford Flooding 2021

- Heavy, prolonged precipitation from a series of atmospheric rivers
- Led to severe and disastrous flooding in the Sumas Prairie
- Could we have been better prepared for the impacts?

(LG: 4d)

Abbotsford Flooding Nov 2021

- Before European colonization of these lands, Sumas Lake existed, which was drained by settlers to create the Sumas Prairie for farmland
- Elders of the Sumas First Nations intentionally built their houses on ground higher than where the Sumas lake was as they believed there was a chance the lake would come back.



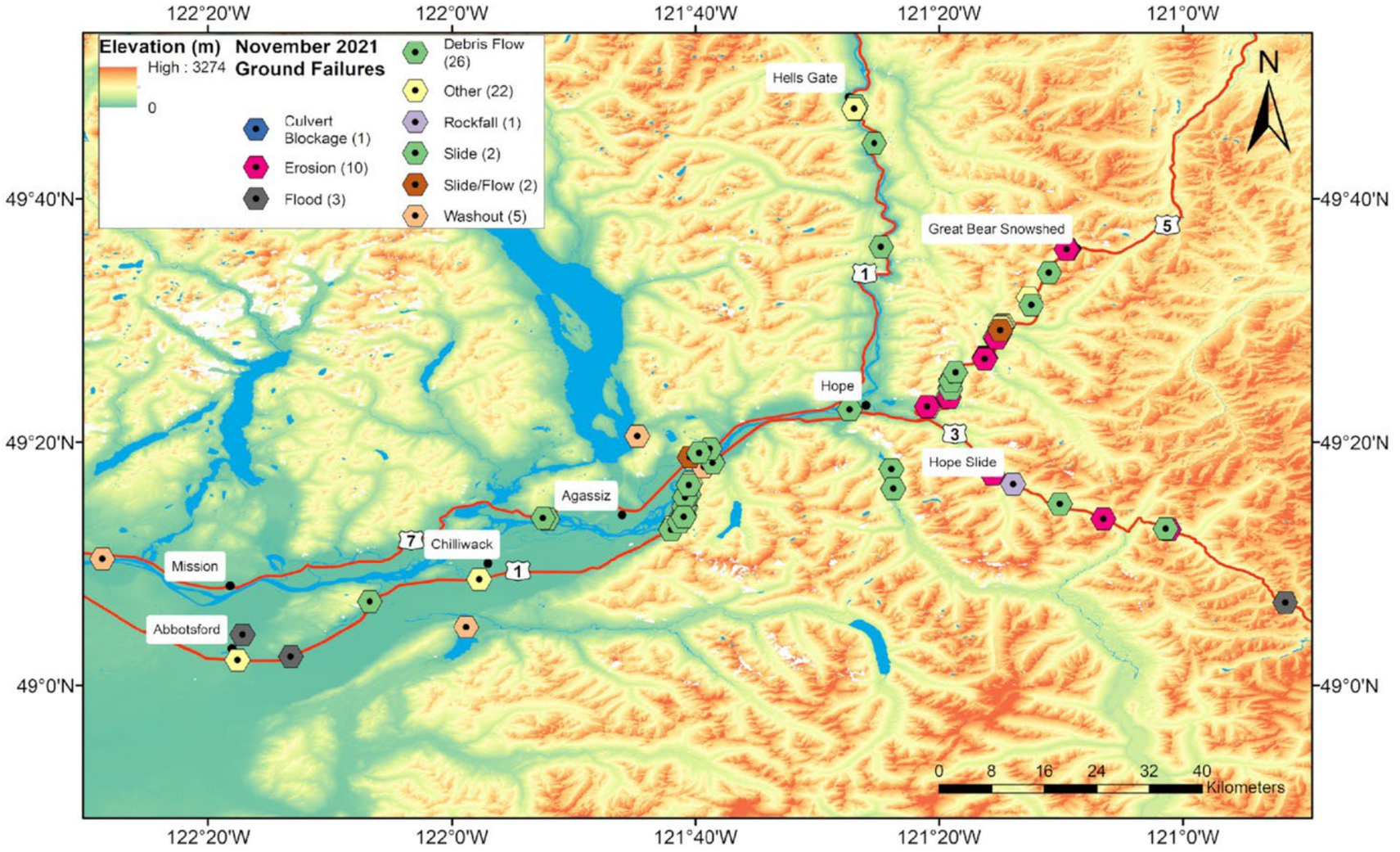
Government map from 1913 showing the location of Sumas Lake which was later drained to become Sumas Prairie. (City of Vancouver Archives, Map 77)

Reconstruction of the Sumas Lake location on a modern map. Solid blue area shows permanent lake. Blue dashed line shows the region that would typically flood each year during snowmelt season

(LG: 4d)

Atmospheric river Hazards: Landslides

The Nov 2021 atmospheric rivers also resulted in a series of landslides, including some impacting major roads in BC:



Sepúlveda et al. 2023

Storm Hazards

Thunderstorm Hazards

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

today

Hurricane Hazards

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

Hail

YouTube clips:

- Day4-25 Pecos Hank hail. Great overview of hail storms 2015. (watch the first 3:30)

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

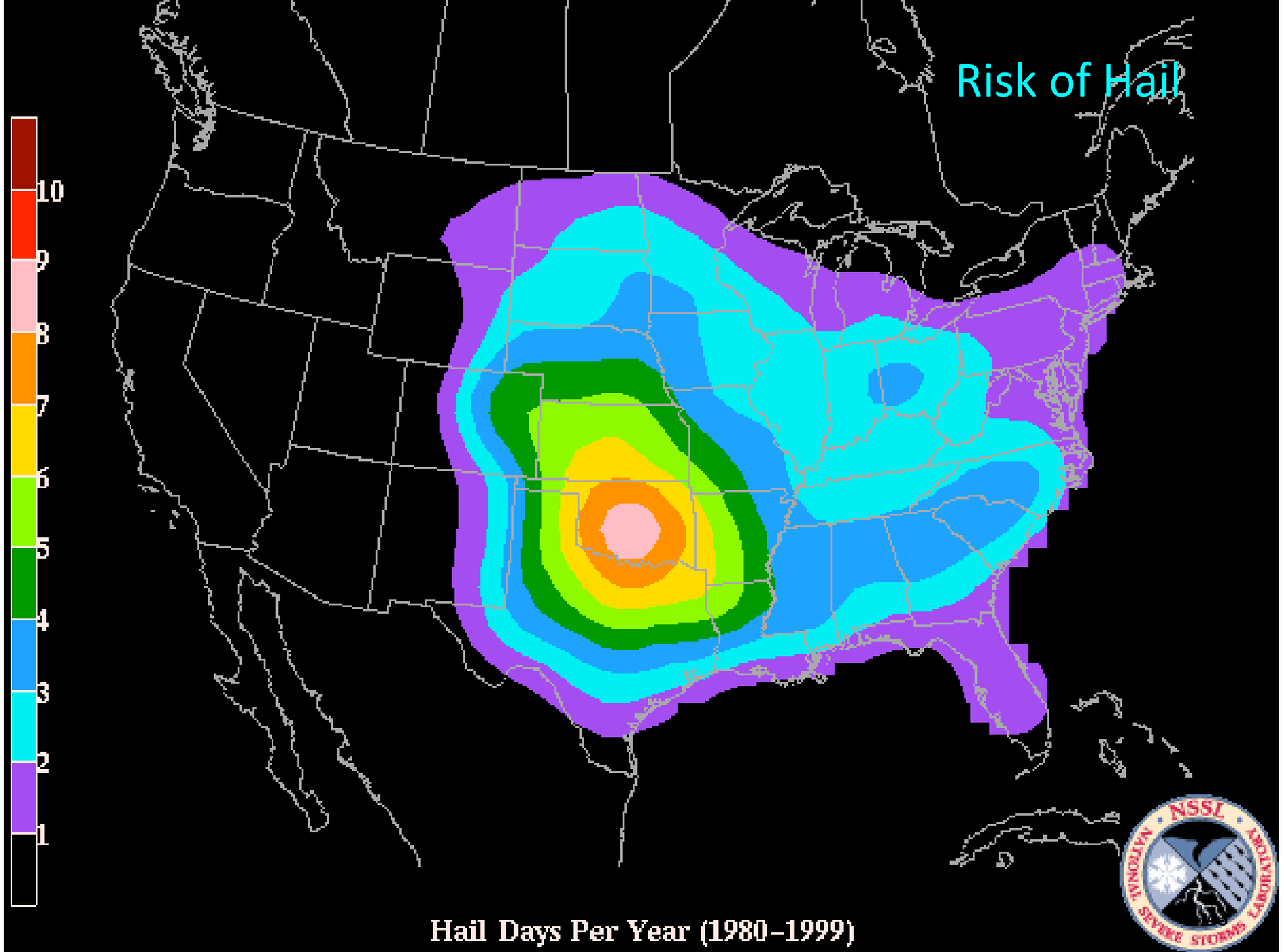
(View middle minute.)

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

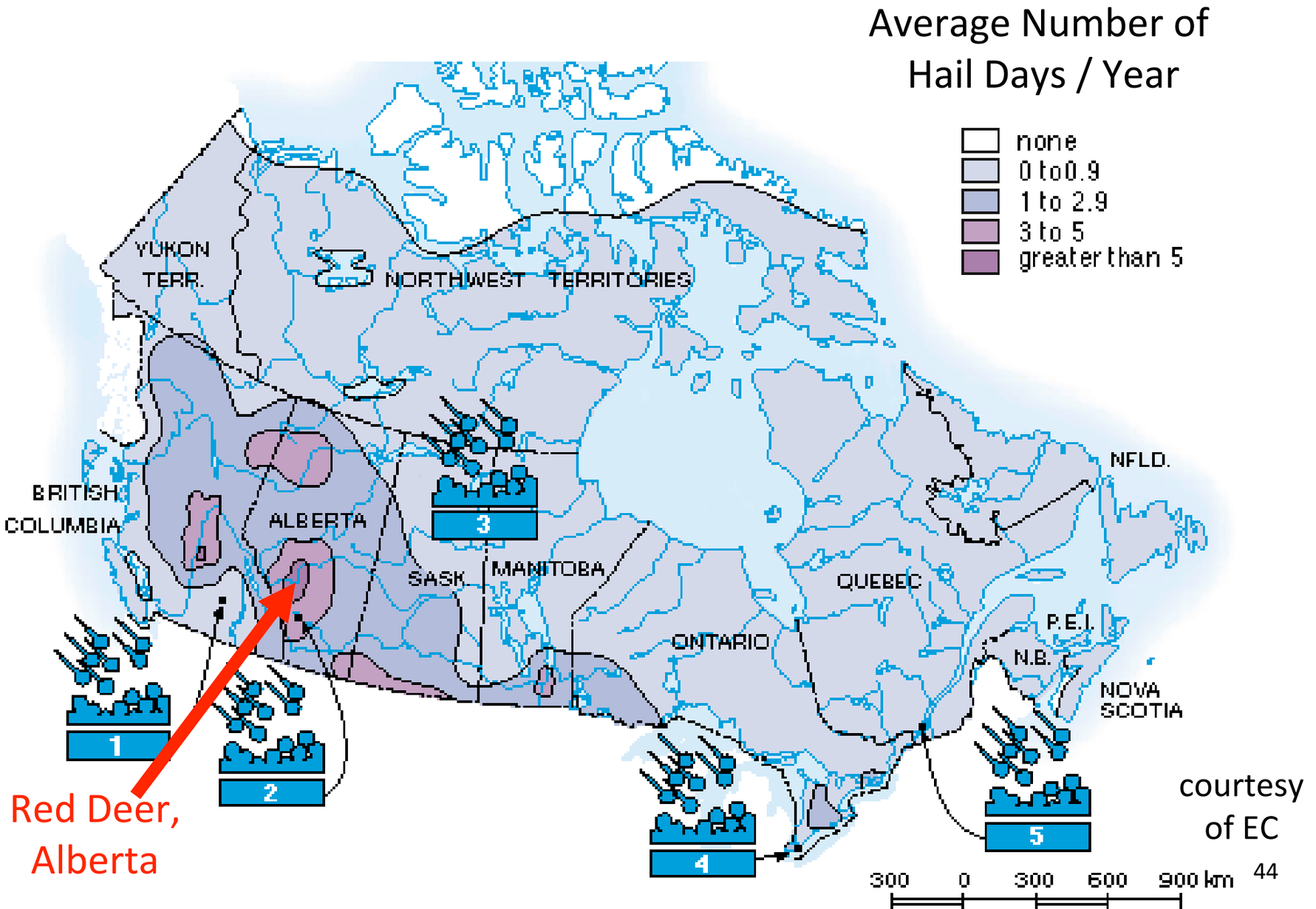
Hail Safety

- Bring or wear safety glasses, in case hail breaks the windows in your car.
- 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
NSSL
NATIONAL SEVERE STORMS LABORATORY
Hail Days Per Year (1980–1999)

Risk of Hail (Canada)



Hail Crop Damage

(LG: 4e)

Manitoba

Also impacts Alberta

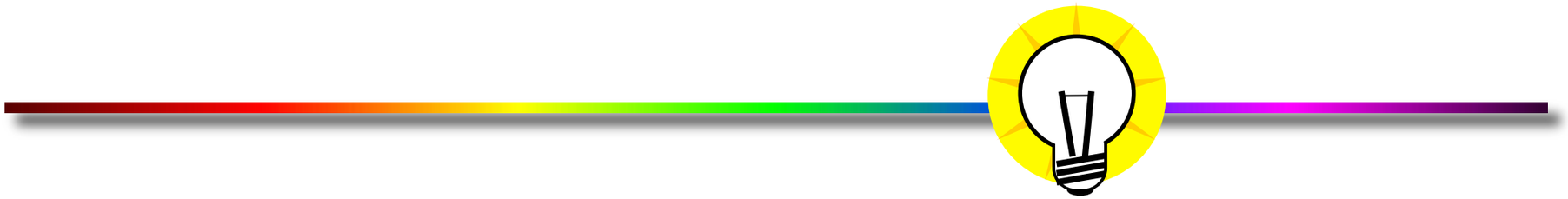
Summary of Rain & Hail Hazards

(LG: 4e)

- **Rain**: Tstorm rain can be heavy, covering small area, very large raindrops, very transient, moving with storm. Atmospheric river rain can cover a large area for a prolonged time.
- 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 (creating shards of glass), 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.

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

Instructor Doug McCollor

Summary of Day 4

- **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**
- **Atmospheric Rivers, heavy precipitation, flooding and landslides**
- **Hail**

Next Class:

Hurricanes, Typhoons & Tropical Cyclones