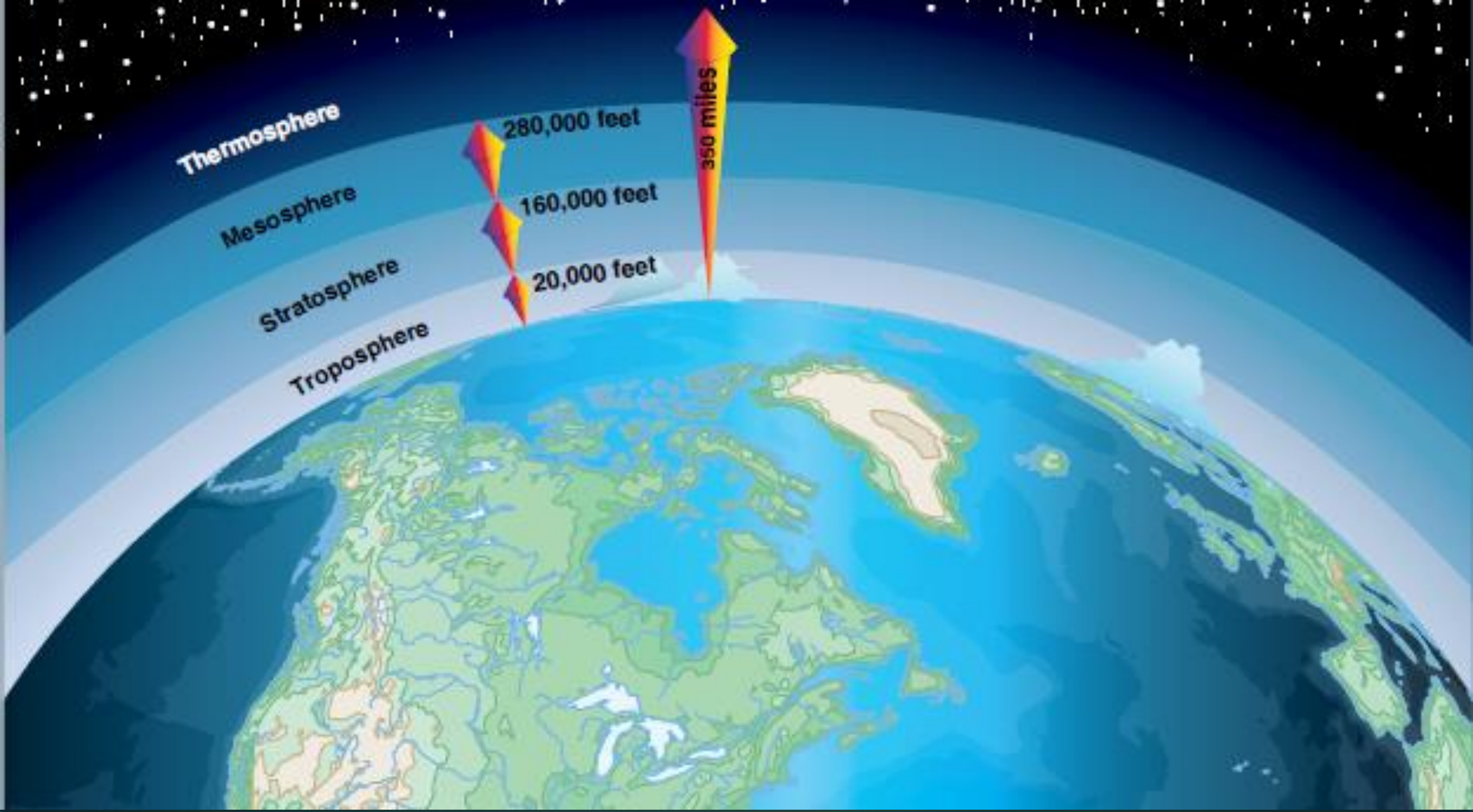
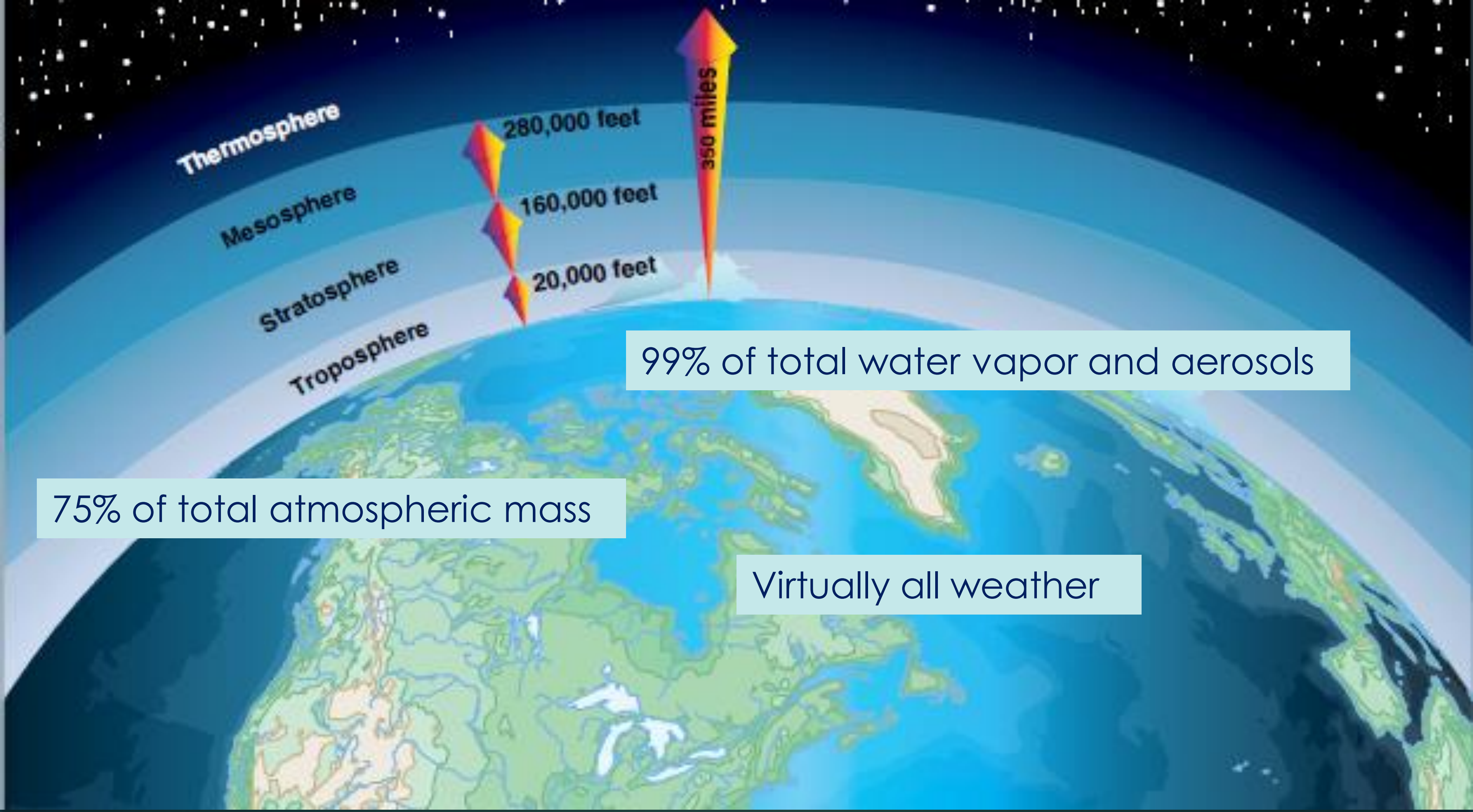
Weather Theory

Topics Covered

- General Principles
- Circulation and Wind
- Air Masses and Fronts
- Vertical Motion of the Atmosphere
- Clouds and Precipitation
- Thunderstorms
- Other Causes of Turbulence
- Obstructions to Visibility
- Icing



All VFR flying occurs in the slice of atmosphere called the “troposphere.”



All VFR flying occurs in the slice of atmosphere called the "troposphere."

Atmospheric Gases

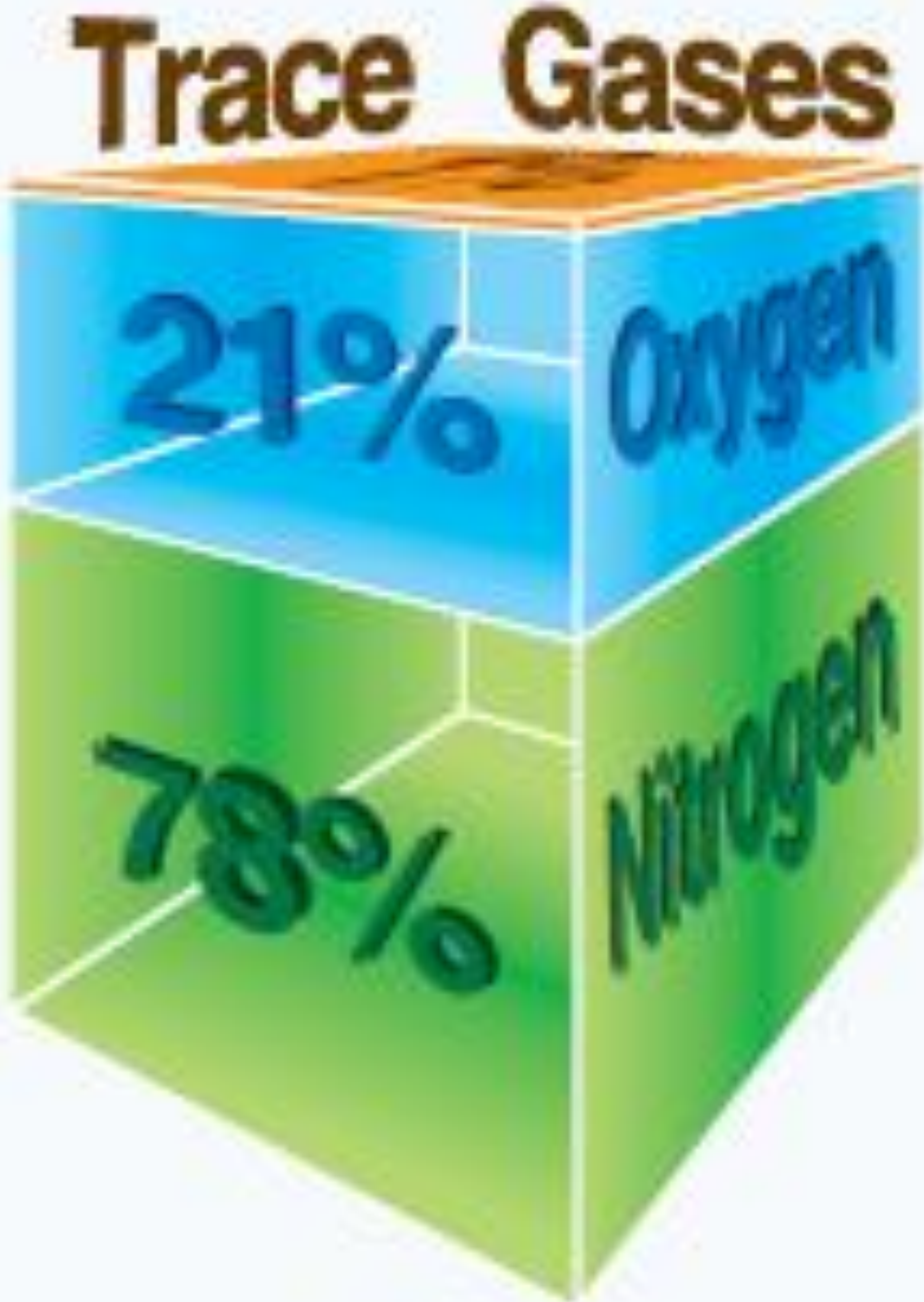
- Nitrogen : 78%
- Oxygen: 21%
- Trace gases: 1%

Refers to dry air

Constant both

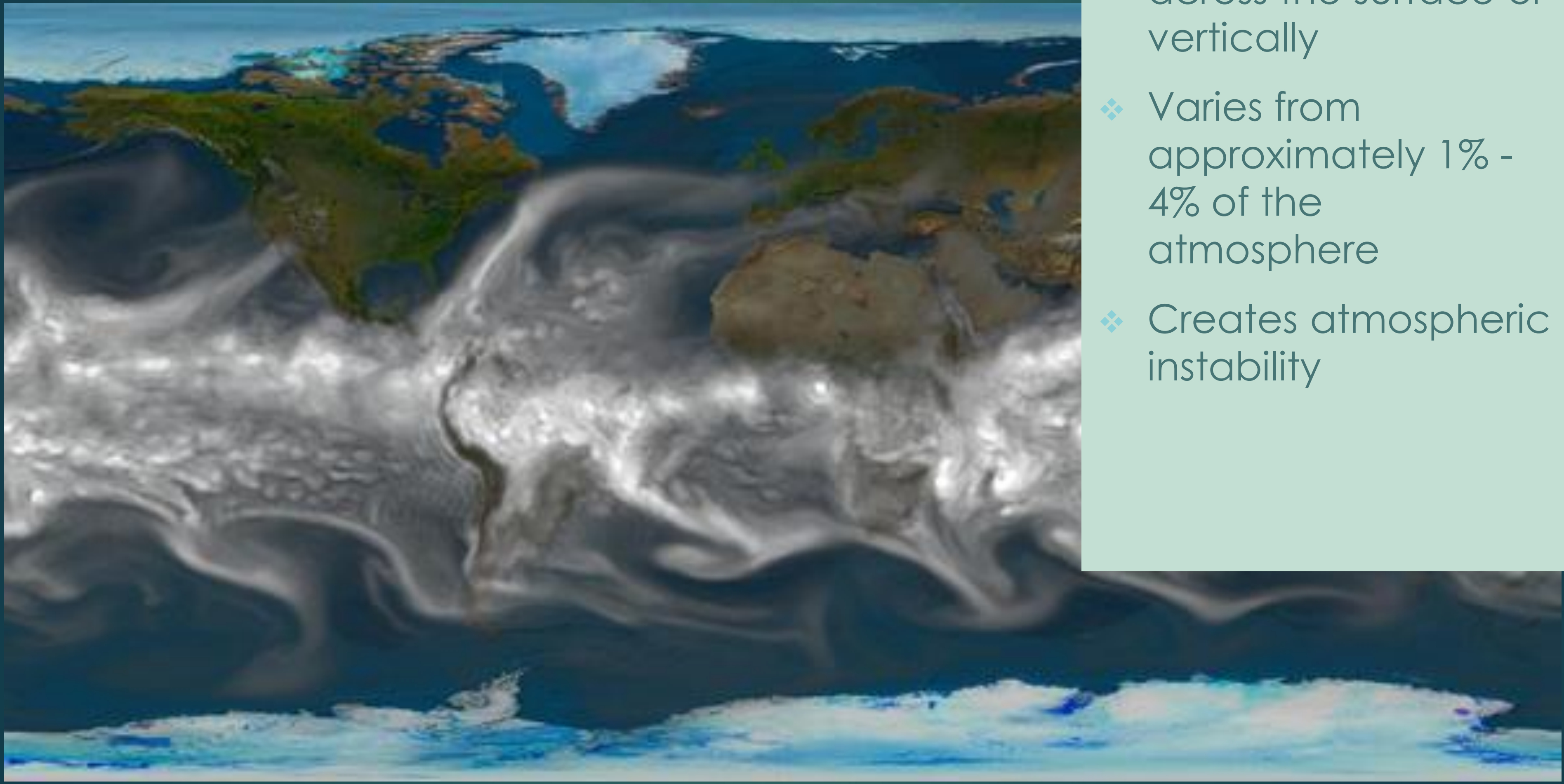
Horizontally

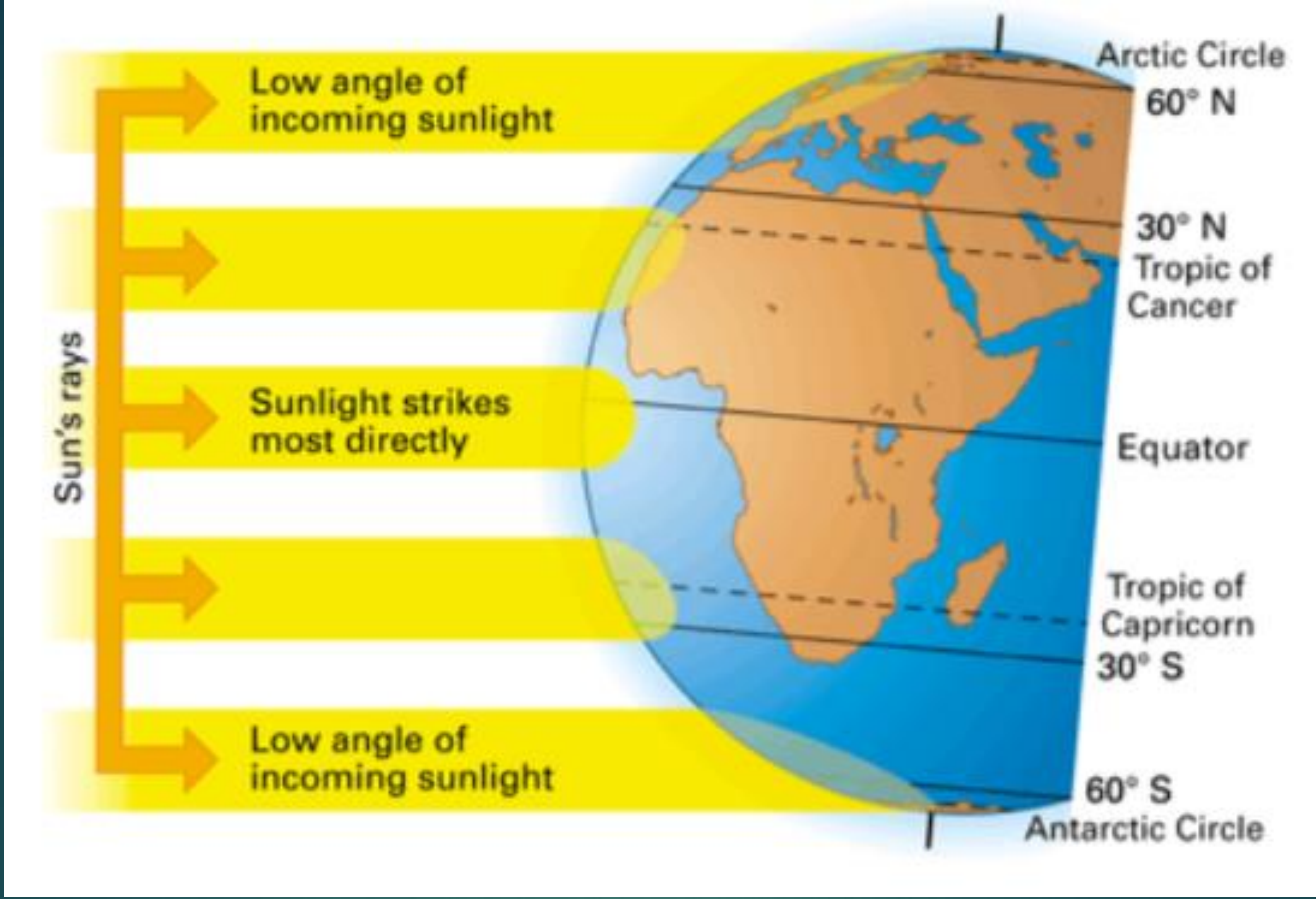
Vertically



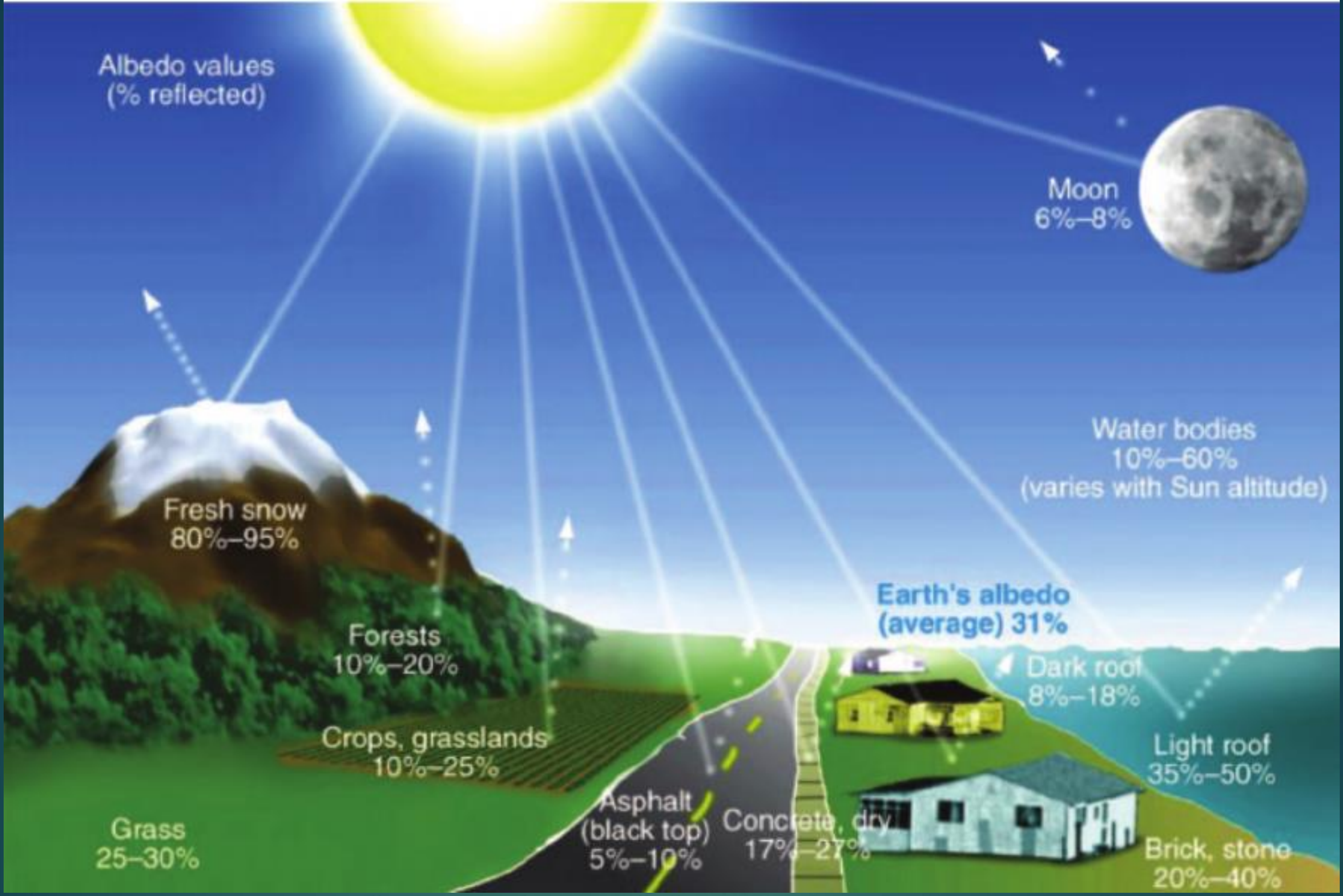
Water vapor

- Is not uniformly distributed either across the surface or vertically
- Varies from approximately 1% - 4% of the atmosphere
- Creates atmospheric instability





Radiation from the sun heats the earth's surface. This heating is uneven and varies on a global scale with the angle of incidence of the sun's rays.



Local heating is also uneven and is caused by different reflective properties of soil, vegetation, manmade surfaces, and water.

Every physical process of weather is

accompanied by

or

is a result of

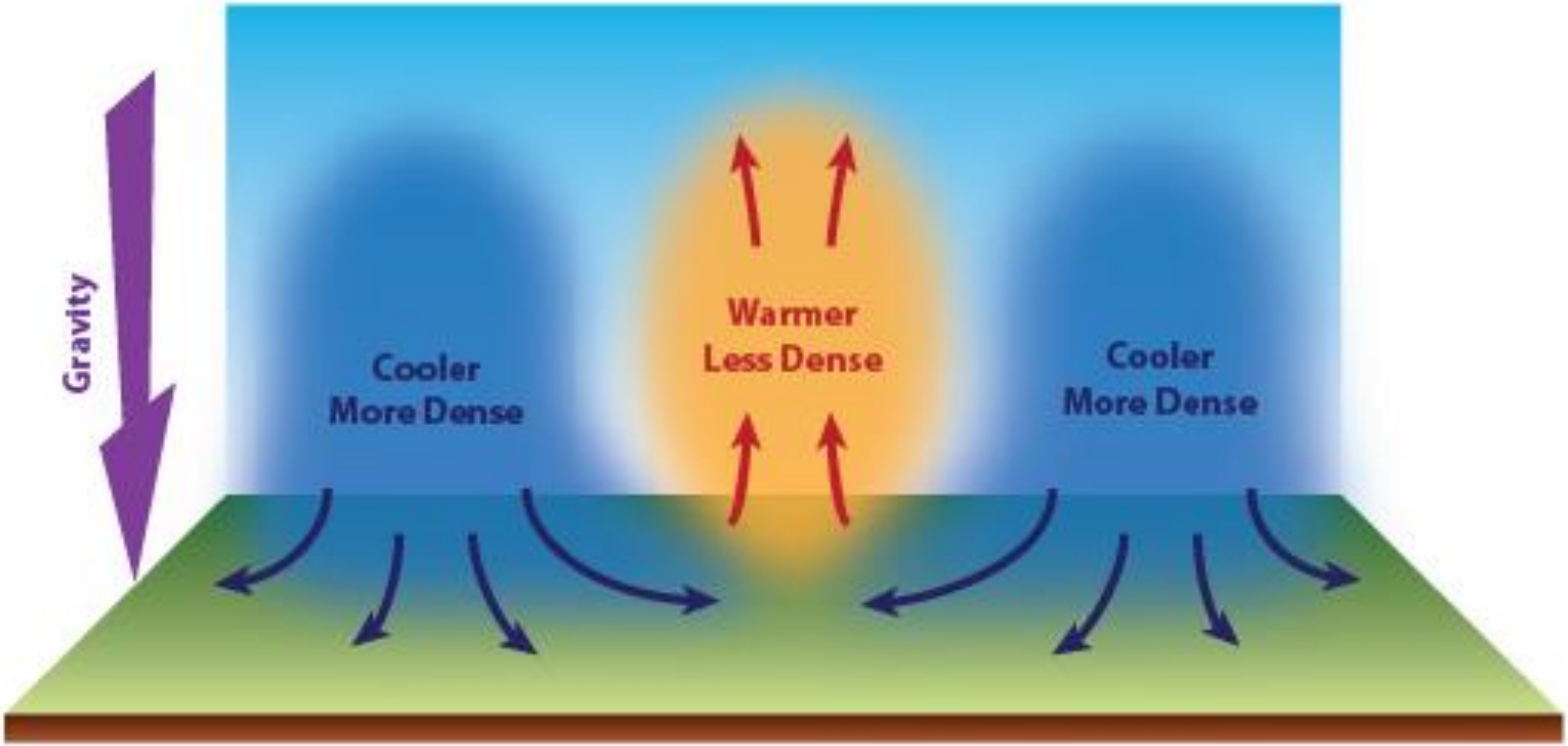
unequal heating of the Earth's surface

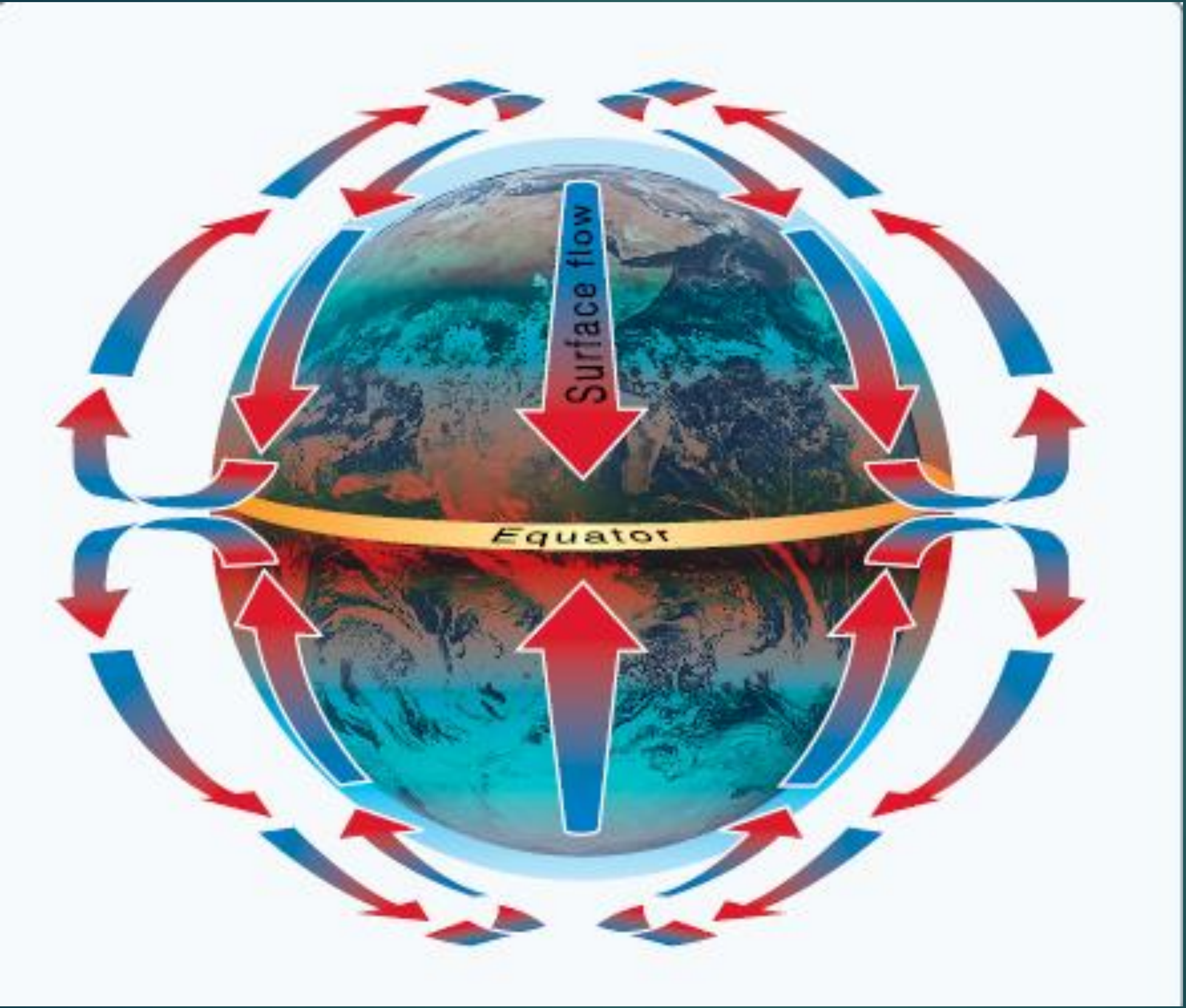
Rises

Warm Air

Cool Air

Falls

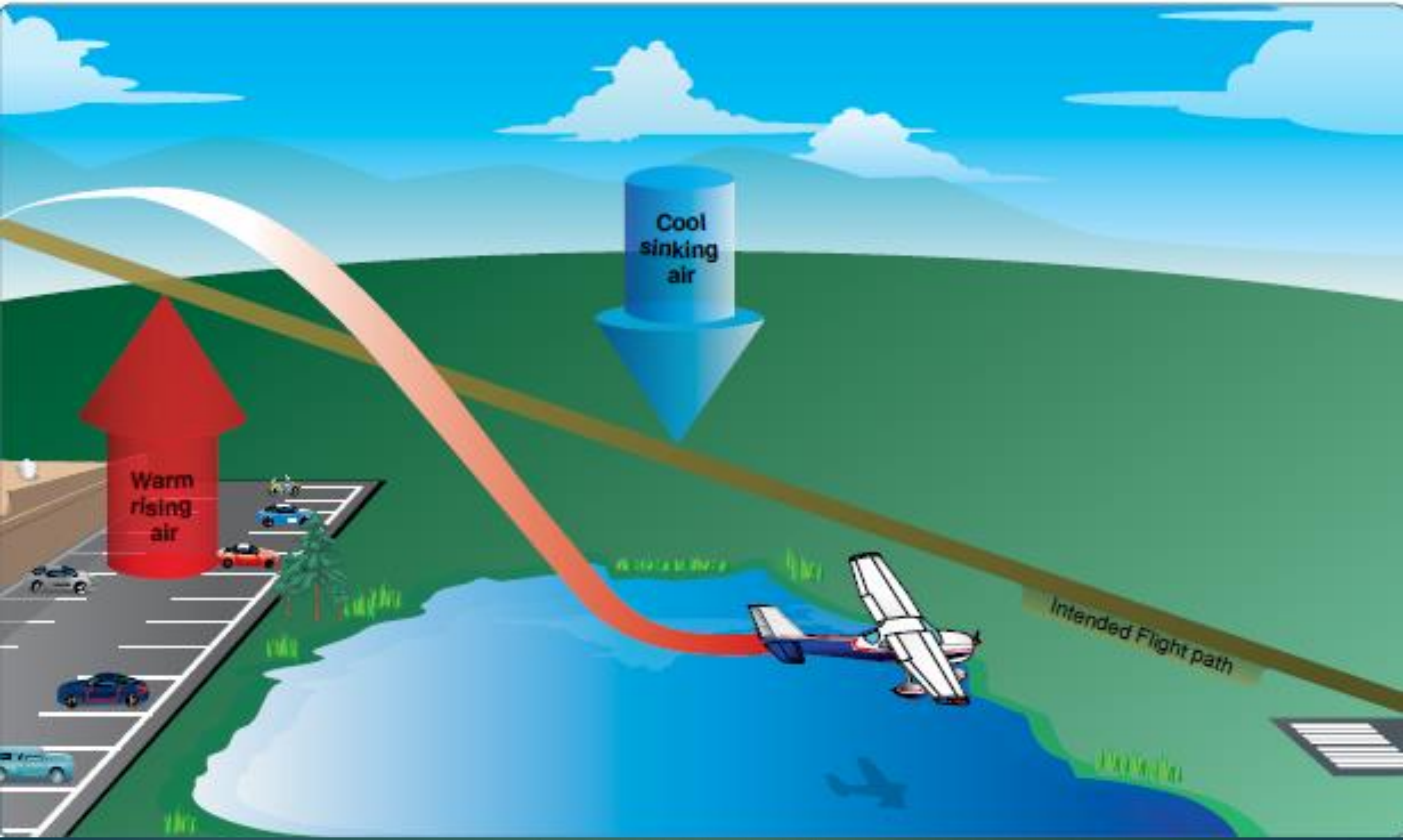

Gravity
Cooler
More Dense
Warmer
Less Dense
Cooler
More Dense



Global scale:

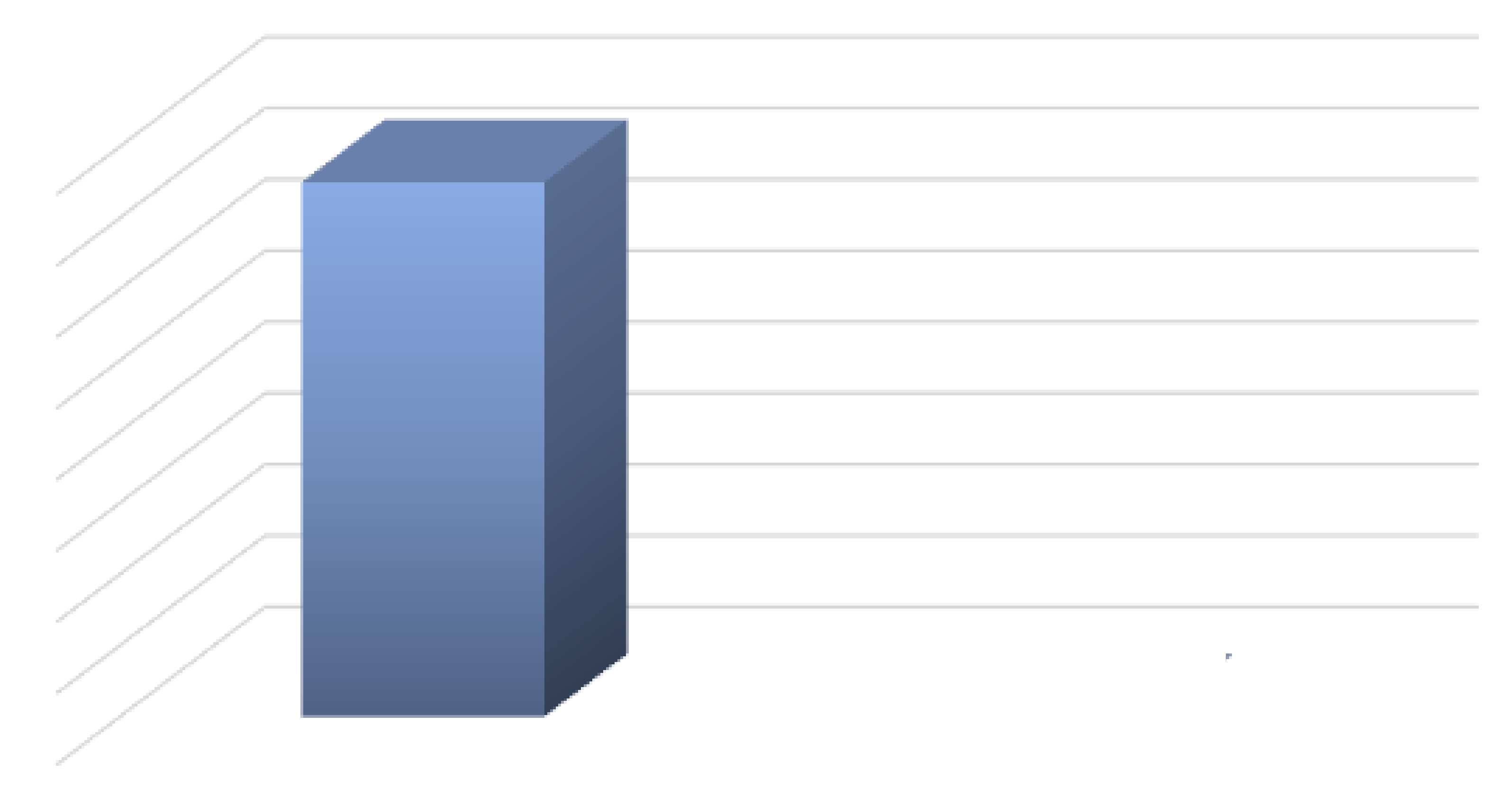
air warmed at lower latitudes rises

cold air from the poles falls to replace it…

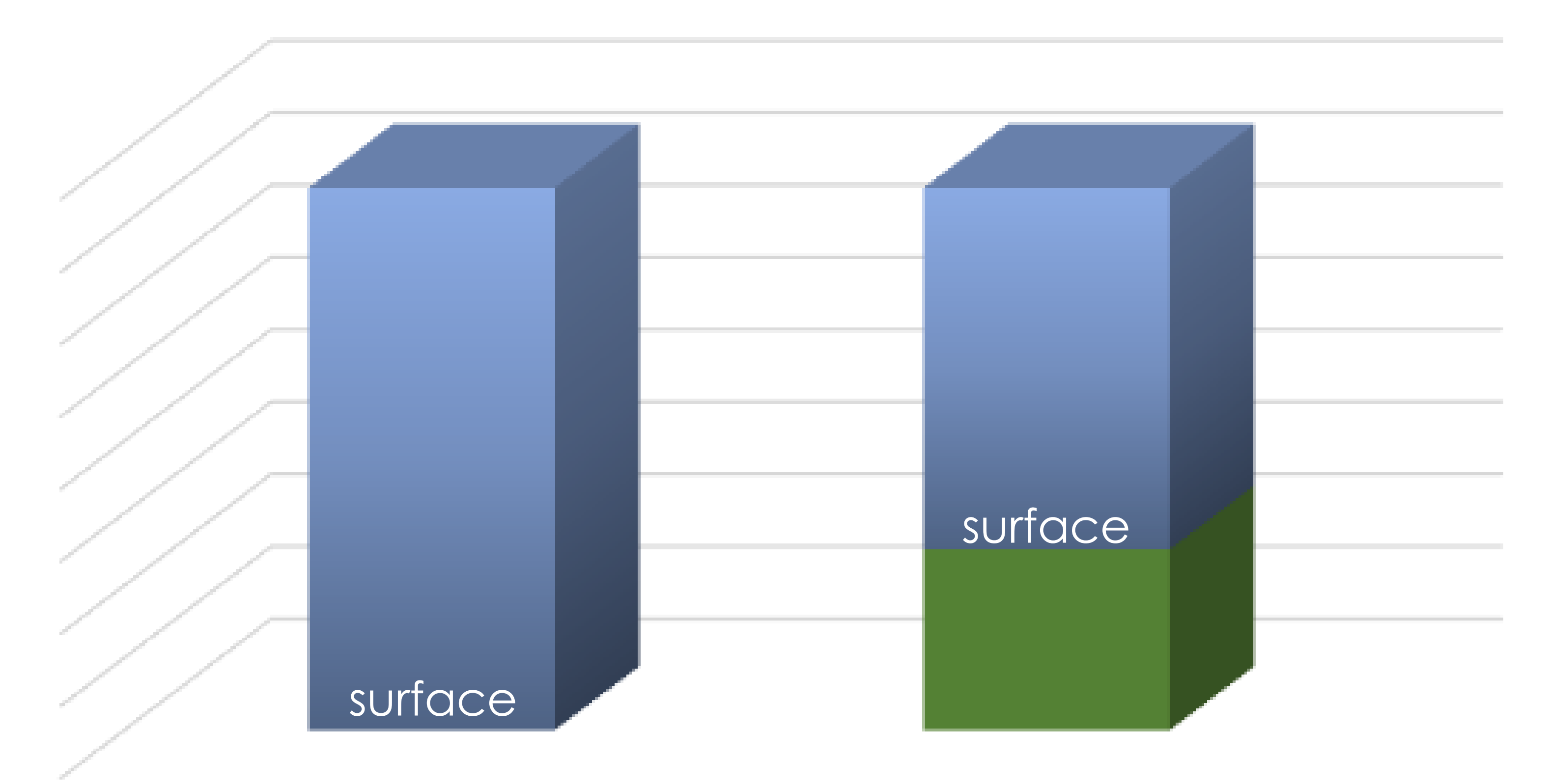


Local Scale: surfaces of varying reflectivity produce areas of faster-rising air.

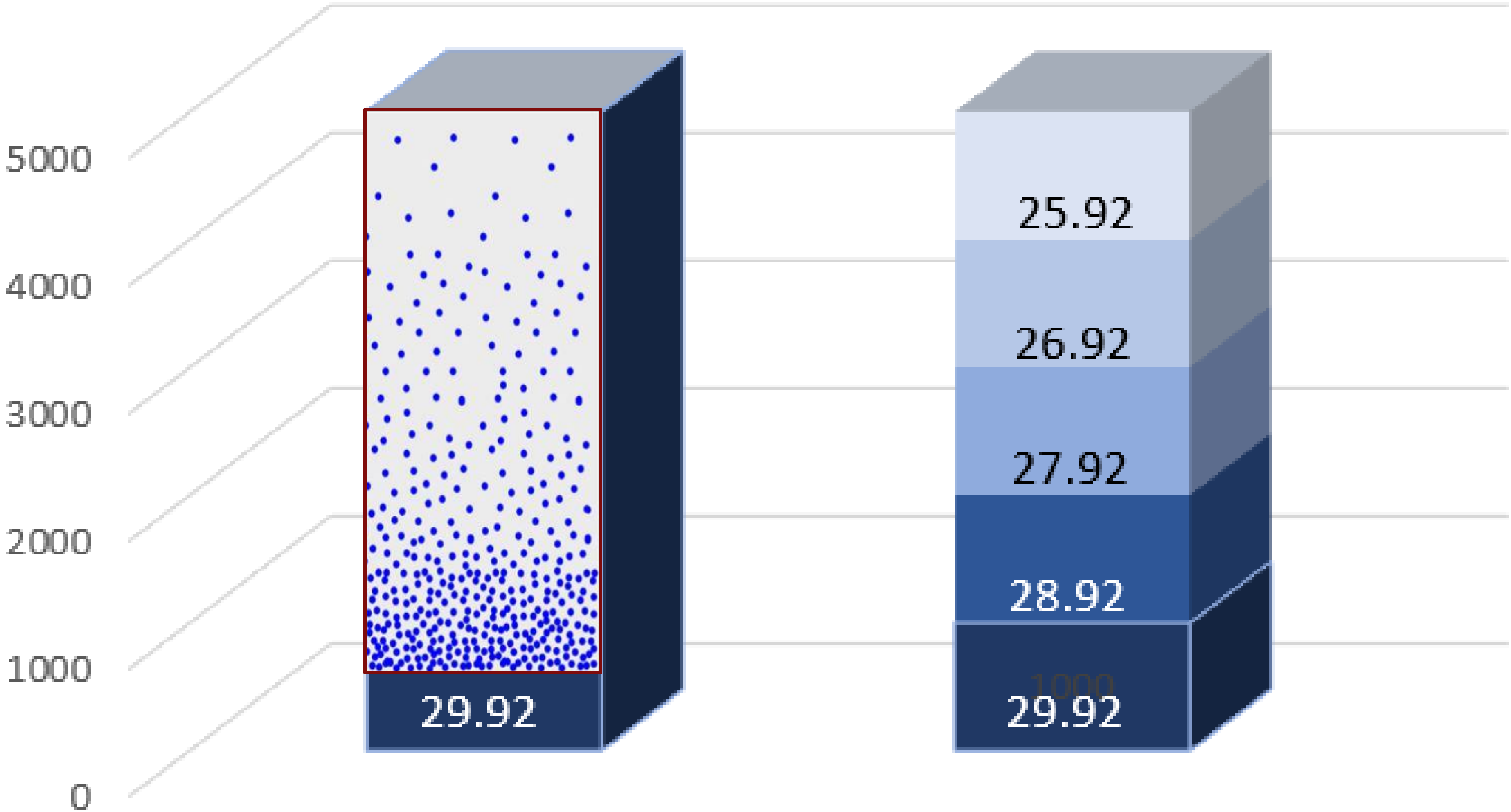
Atmospheric Pressure
<u>and</u>
Temperature
Decrease
with
Altitude



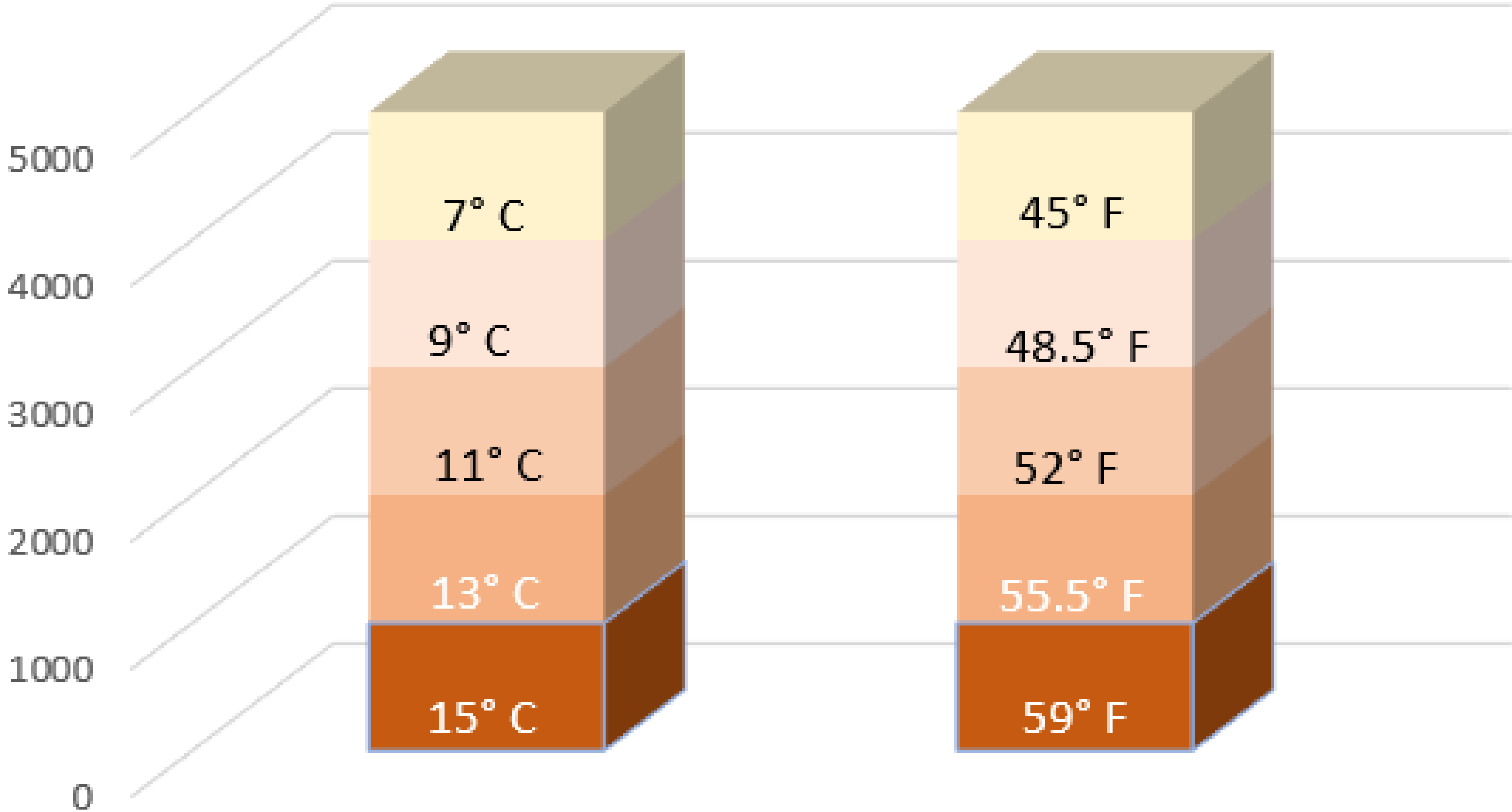
Imagine a column of air one foot square, rising from sea level to the top of the atmosphere. The weight of the entire column of air presses on anything located at the bottom of the column.



Compare this with a column of air reaching from 7,500 feet to the top of the atmosphere. There is less mass pressing on objects located at this surface. The air at the bottom of this column is **less dense**.

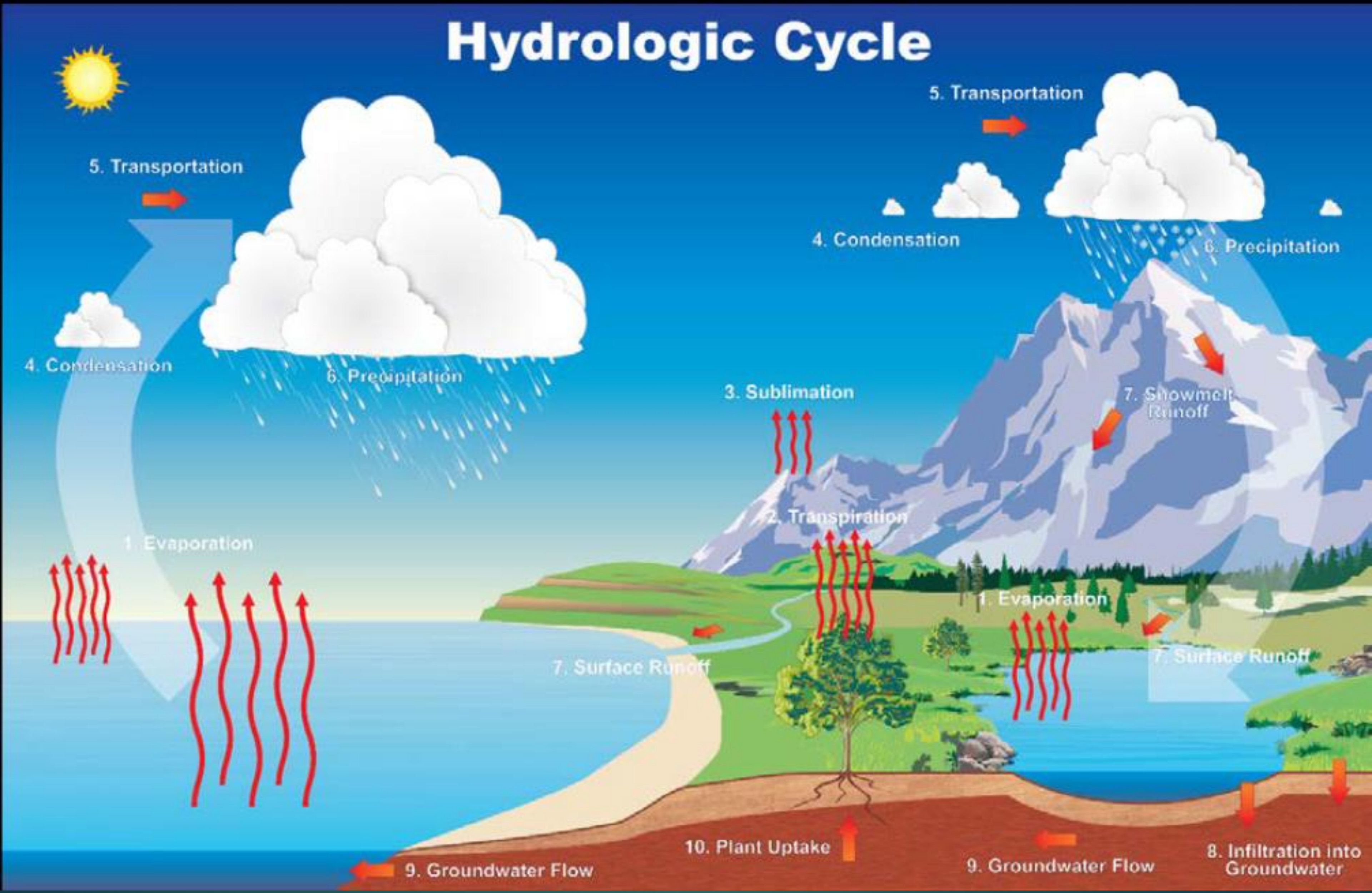


Standard pressure decreases about 1 inch of mercury for every 1000 foot gain in altitude.



In the troposphere, temperature also decreases as altitude increases. The average lapse rate of temperature with altitude is 3.5° F or 2 ° C per 1000 feet. (It is greater for dry air, less for moist air.)

Warm air
can hold more
water vapor
than
cold air



Water enters and leaves the atmosphere through a variety of processes.

Atmosphere contains moisture in the form of water vapor.

Amount of moisture present in the atmosphere is dependent upon the temperature of the air.

Every 20 °F increase in temperature doubles the amount of moisture the air can hold.

Conversely, a decrease of 20 °F cuts the capacity in half."

Temperature largely determines the maximum amount of water vapor air can hold

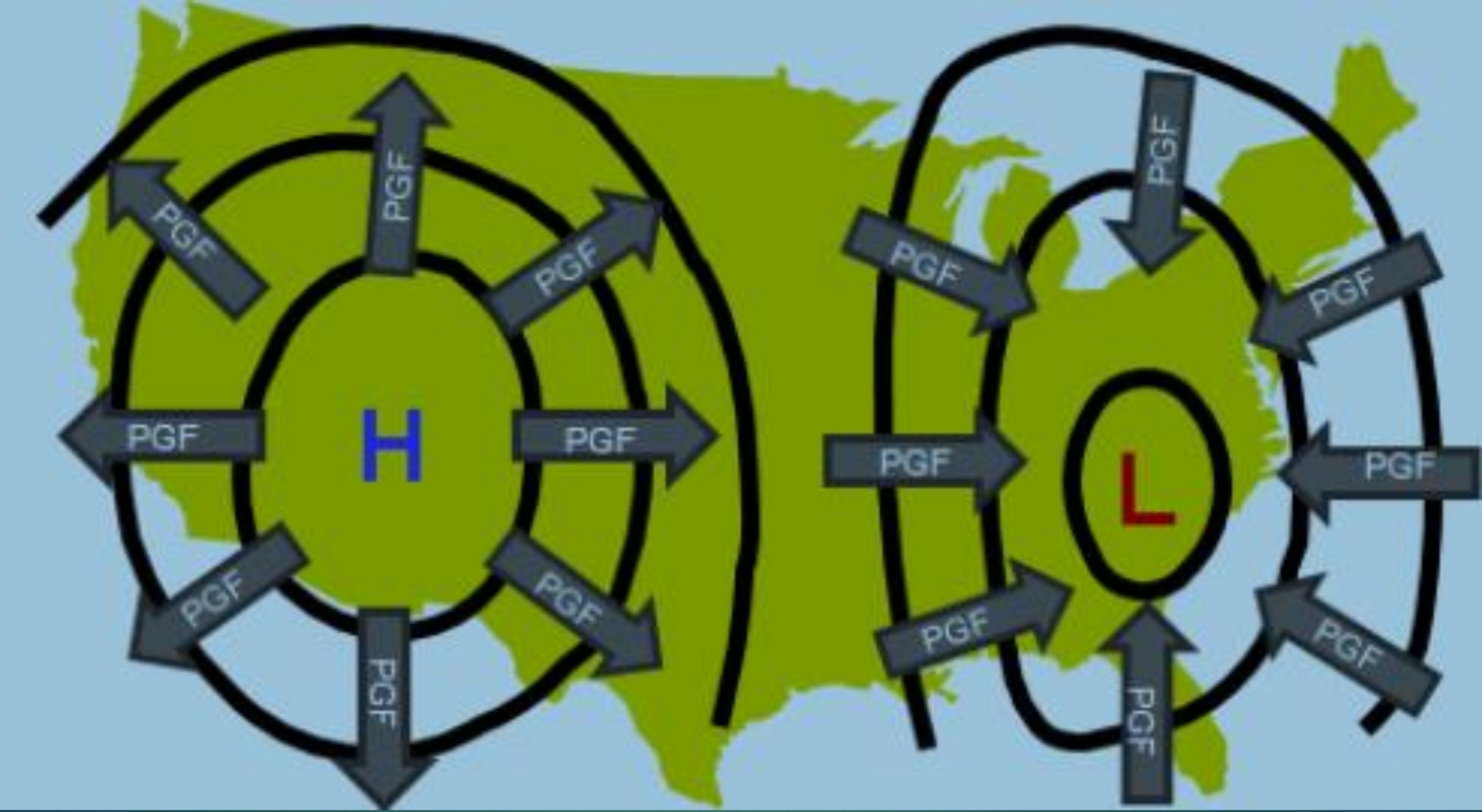
Areas of
high pressure
will move to occupy
areas of
low pressure

Wind

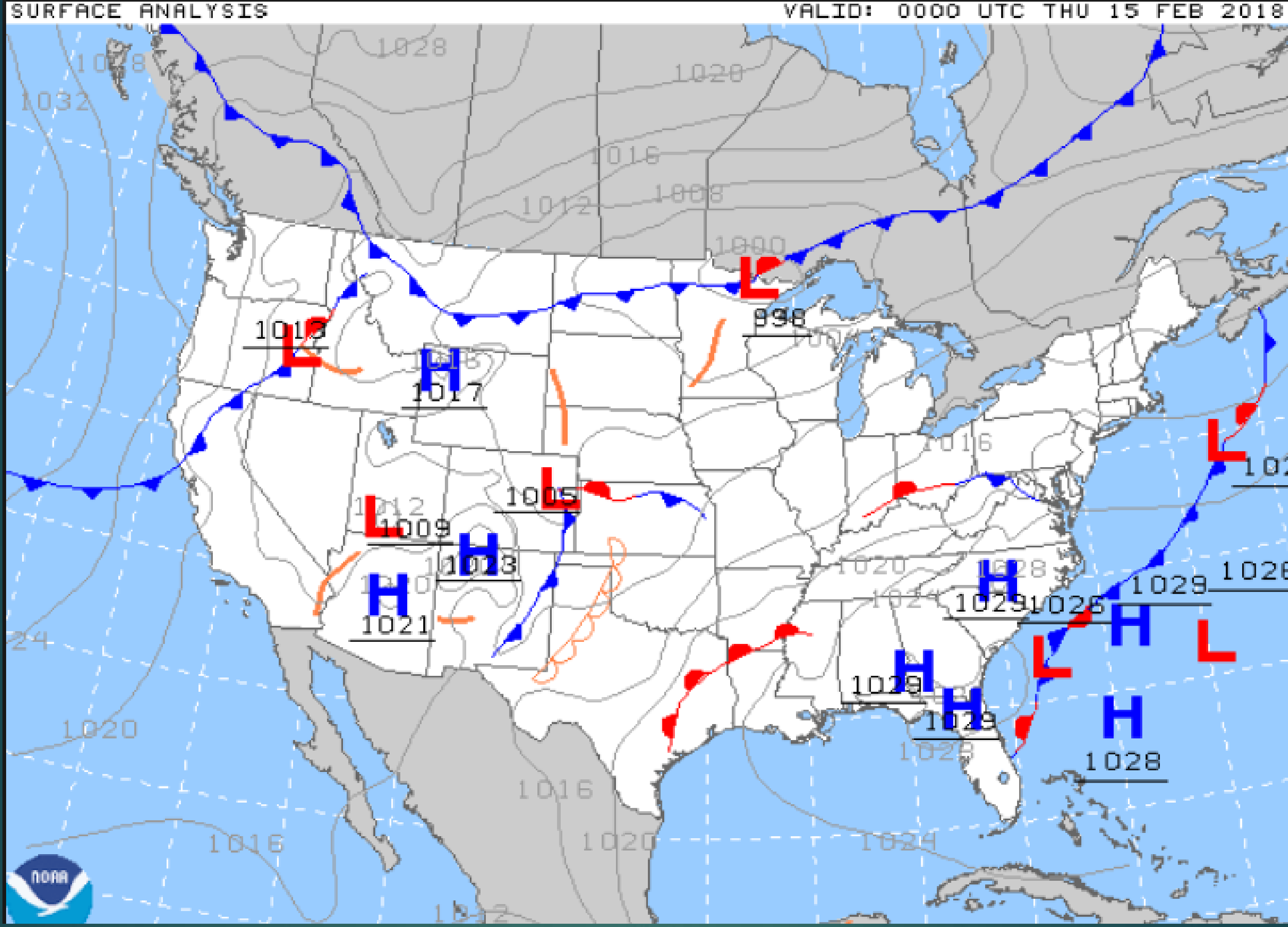
- Wind is the air in motion relative to the surface of the Earth
- Winds cause the formation, dissipation, and redistribution of weather.
- Winds affect aircraft during all phases of flight

Three primary forces affect the flow of wind on a large scale:

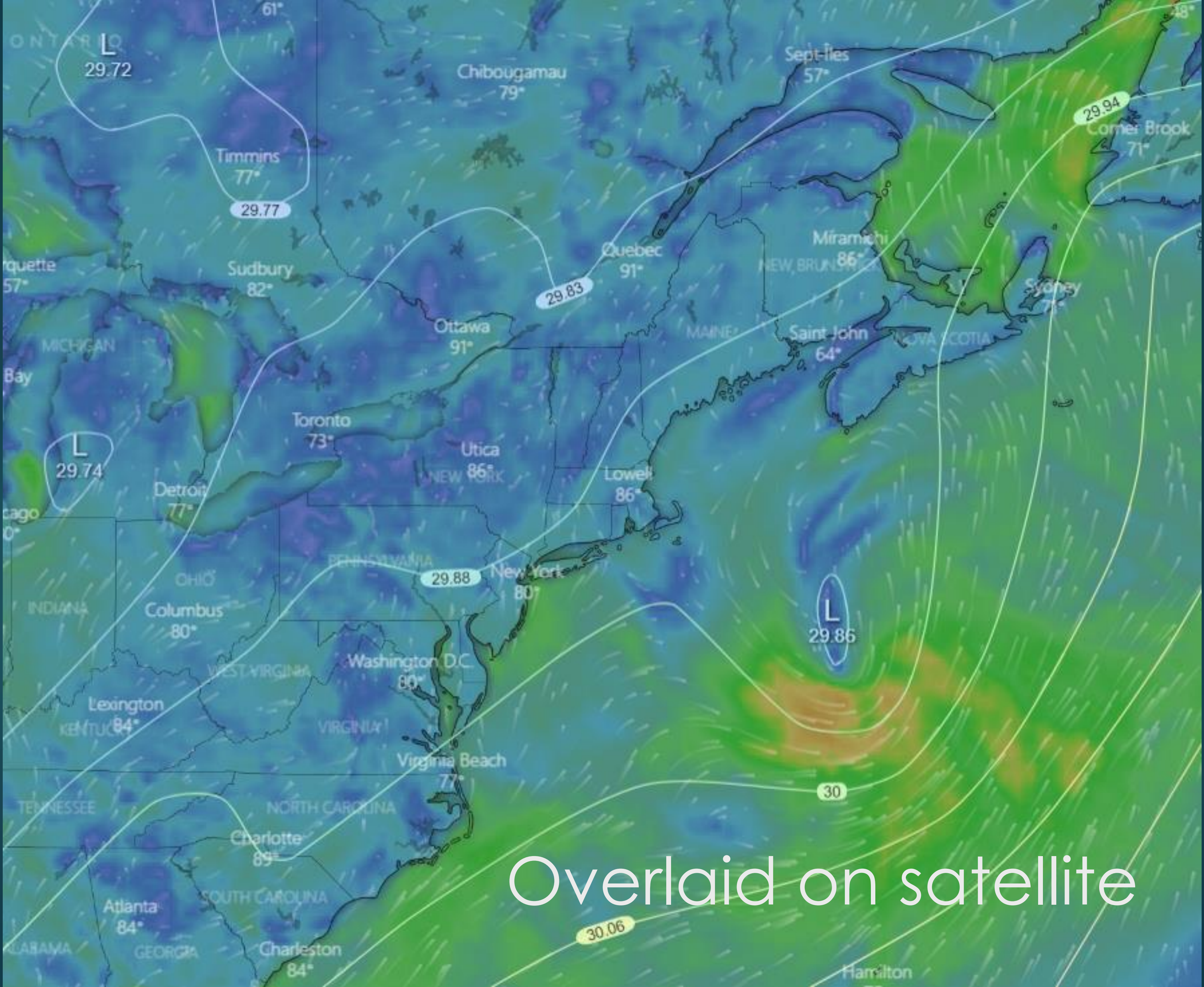
- Pressure gradient force
- Coriolis force
- Friction



Wind is driven by pressure differences which create a force called the Pressure Gradient Force. This force causes the wind to blow in an attempt to equalize pressure differences.



Areas of equal pressure are depicted with lines called “isobars” on this surface analysis chart.

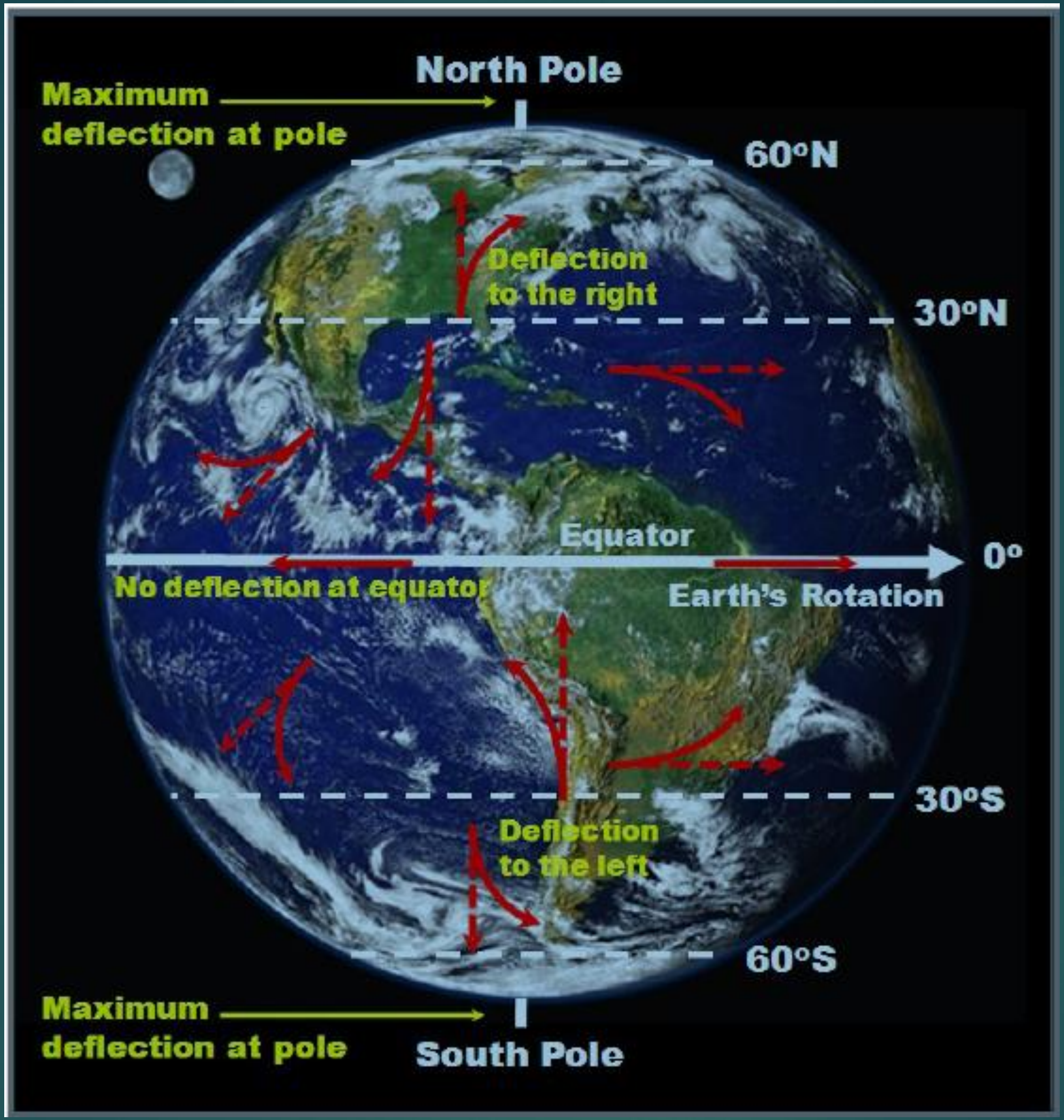


Overlaid on satellite

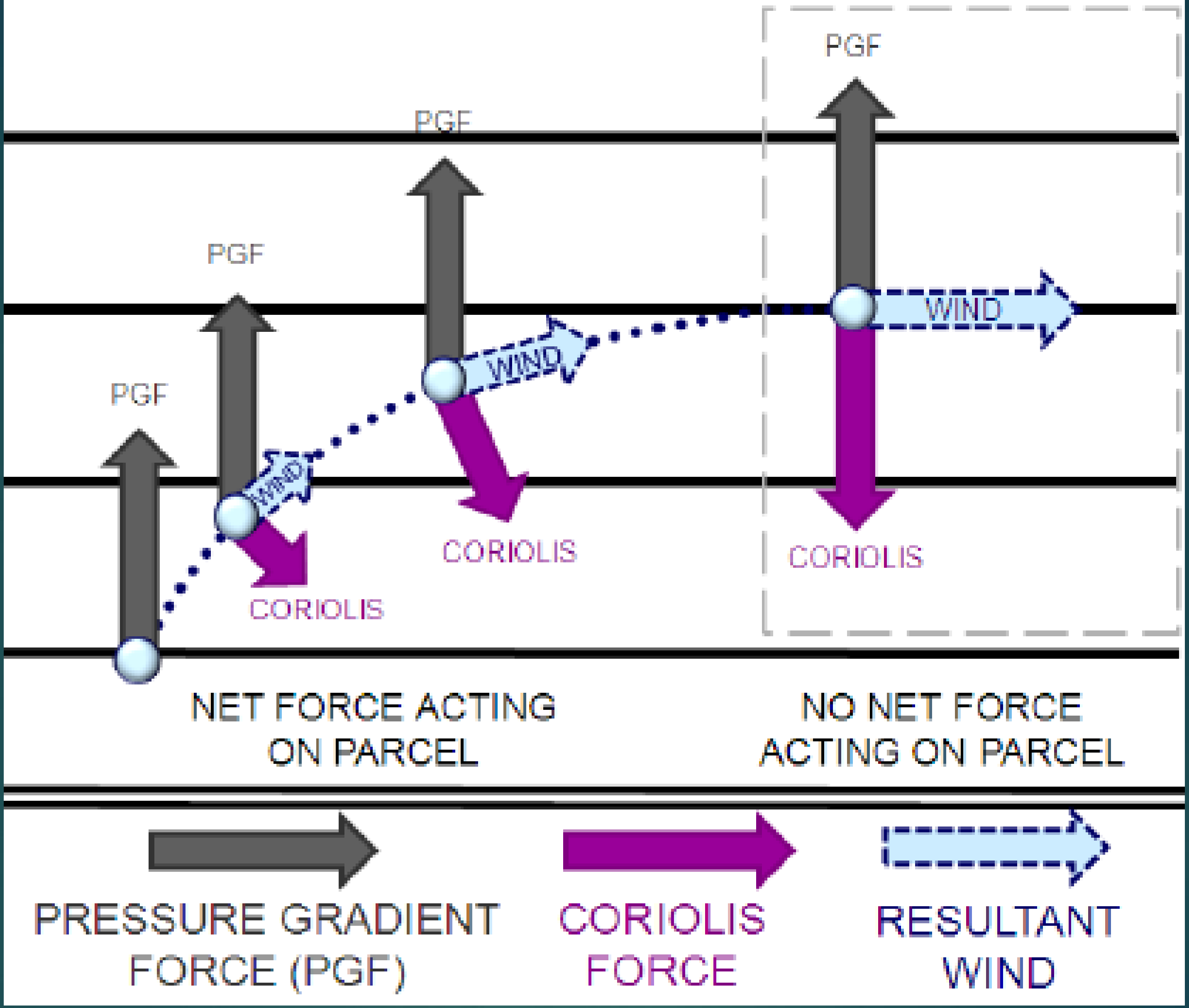
Coriolis Force

A moving mass travels in a straight line until acted on by some outside force.

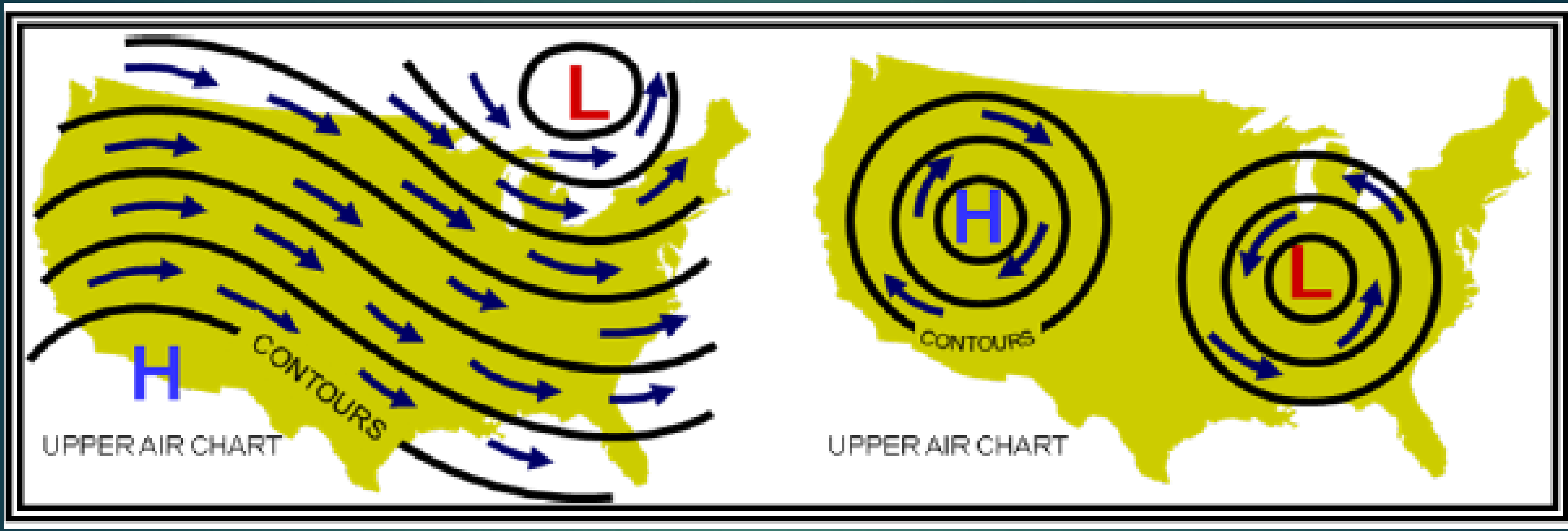
If one views the moving mass from a rotating platform, the path of the moving mass relative to his platform appears to be deflected or curved.



The Coriolis force is greatest at the poles and least at the equator. It is proportional to the speed of the wind

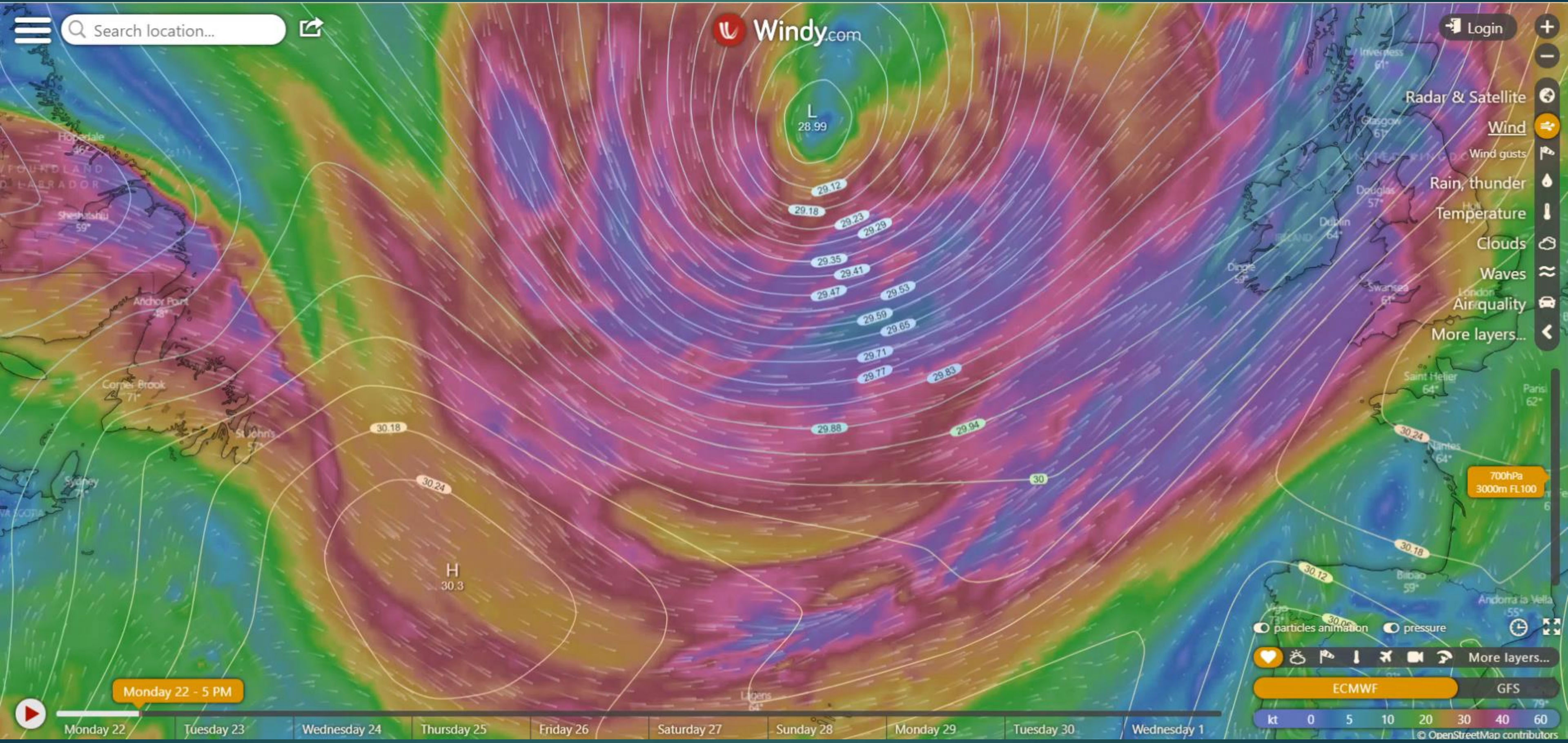


In the upper air, friction is not a factor. The wind starts moving initially from high to low pressure, but as soon as it starts moving, Coriolis force turns it to the right.



When PGF and Coriolis force are in balance, the wind now moves parallel to the contours. Air flows clockwise around areas of high pressure and counter-clockwise around areas of low pressure.

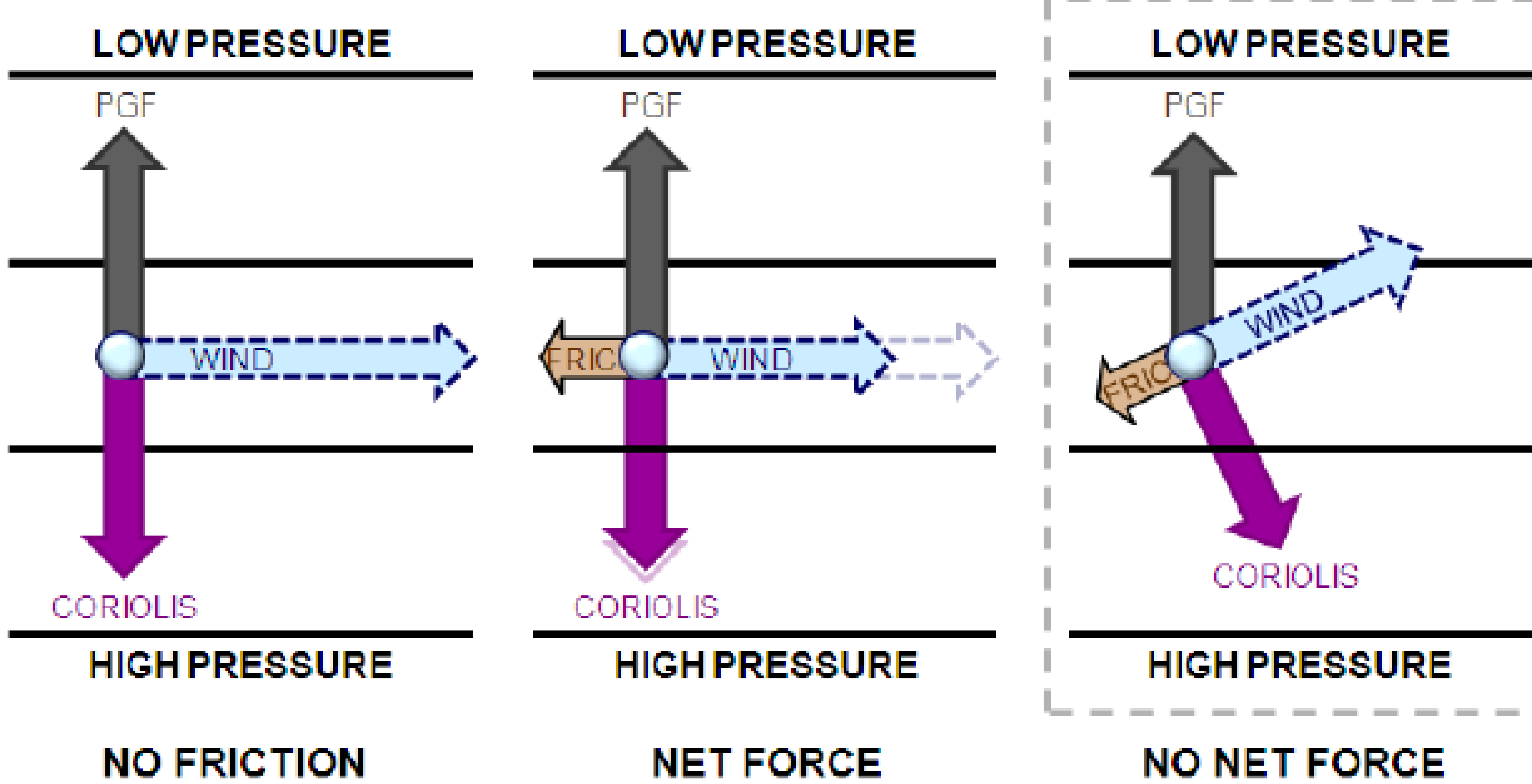
Windy.com


Search location...
Windy.com
Login
L
28.99
H
30.3
Radar & Satellite
Wind
Wind gusts
Rain, thunder
Temperature
Clouds
Waves
Air quality
More layers...
700hPa
3000m FL100
particles animation
pressure
More layers...
ECMWF
GFS
Monday 22 - 5 PM
Monday 22
Tuesday 23
Wednesday 24
Thursday 25
Friday 26
Saturday 27
Sunday 28
Monday 29
Tuesday 30
Wednesday 1
kt 0 5 10 20 30 40 60
© OpenStreetMap contributors

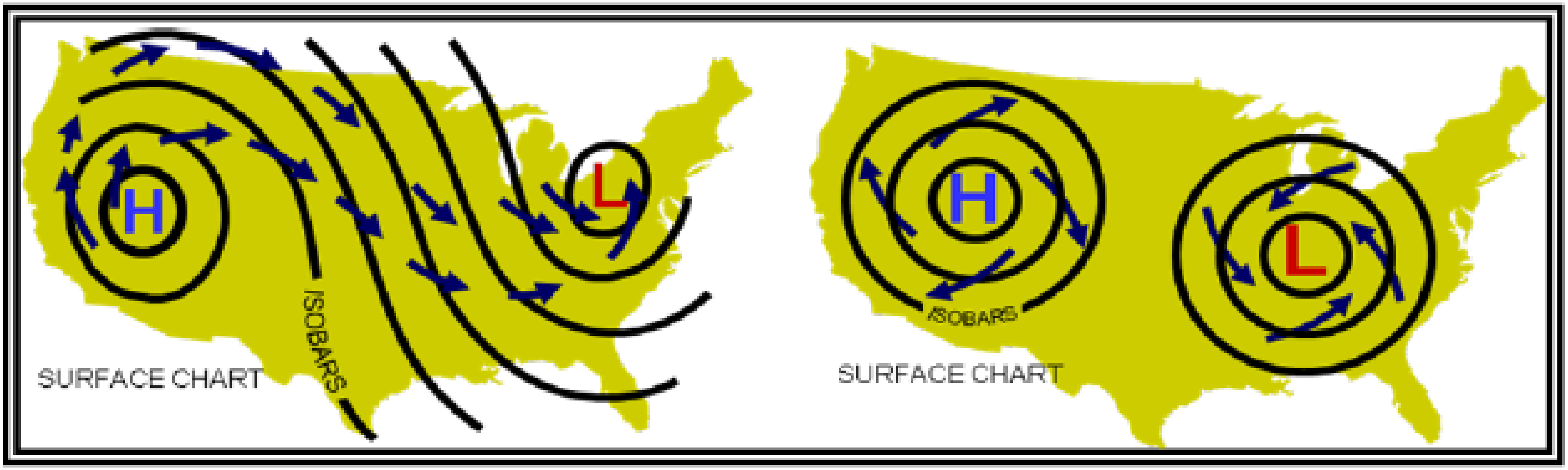
Friction

Within in the friction layer (from the surface to 2,000-3,000 feet AGL) friction between the molecules of air and the terrain surface slows the wind.

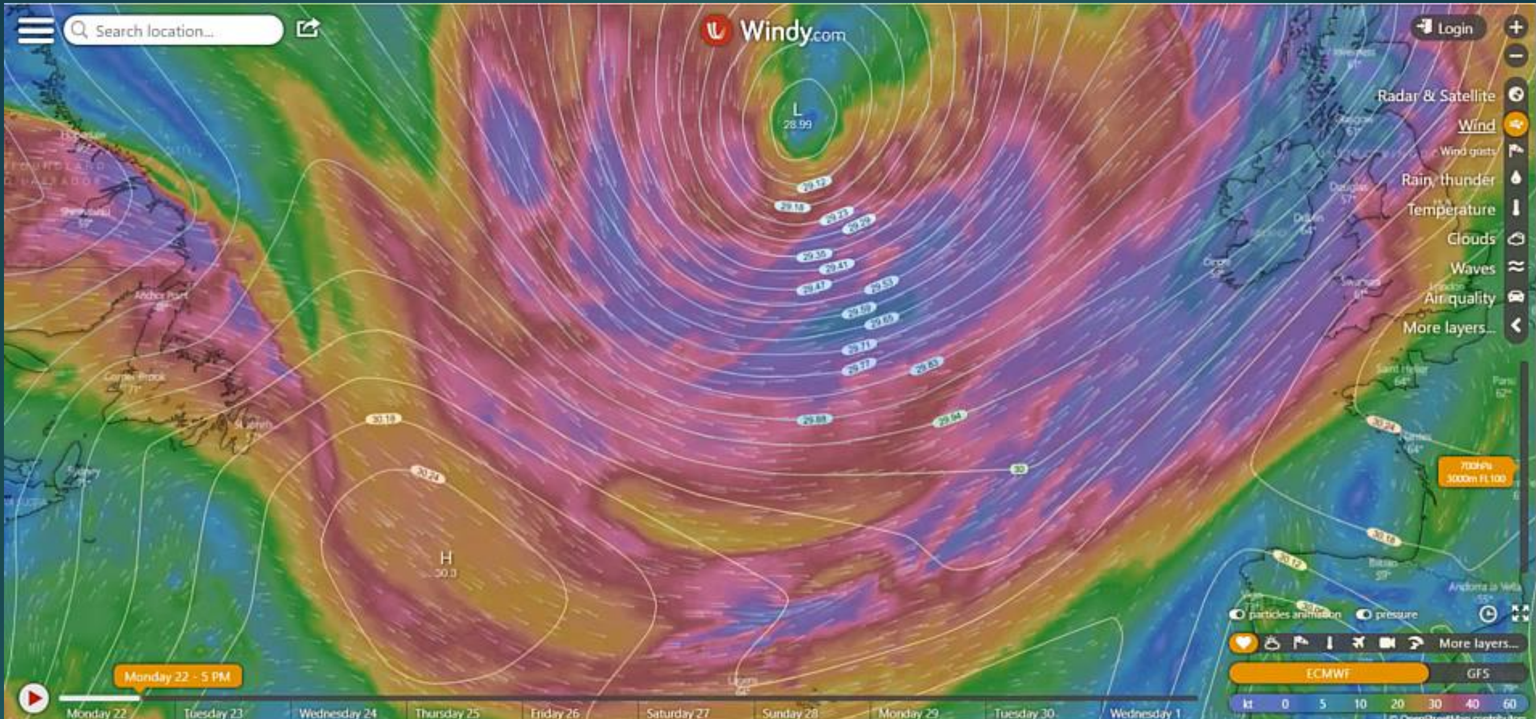
The direction of the friction force is 180 degrees from the direction of the wind.

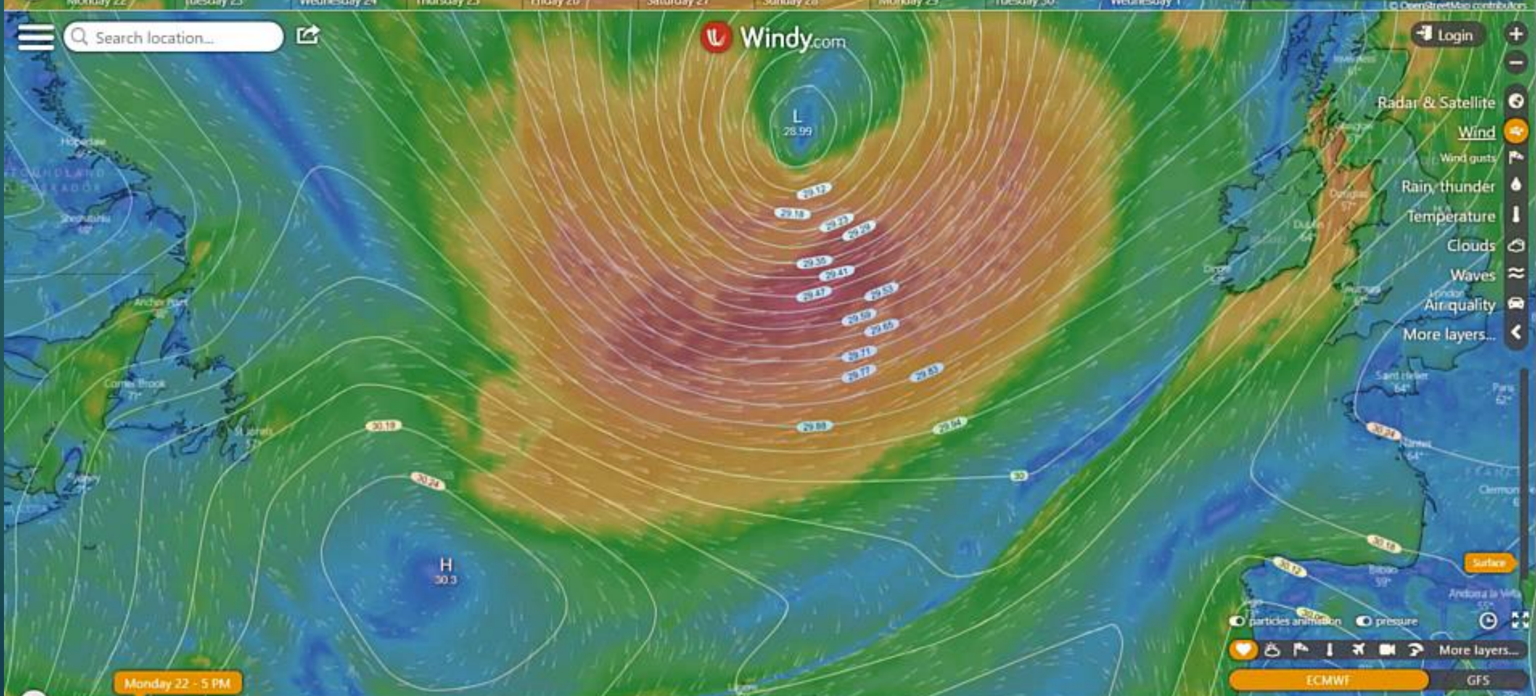


When friction is added to the PGF and Coriolis force, it slows the wind. Since Coriolis force is directly proportional to wind speed, it also slows, and the wind is no longer being pulled quite so strongly to the right.

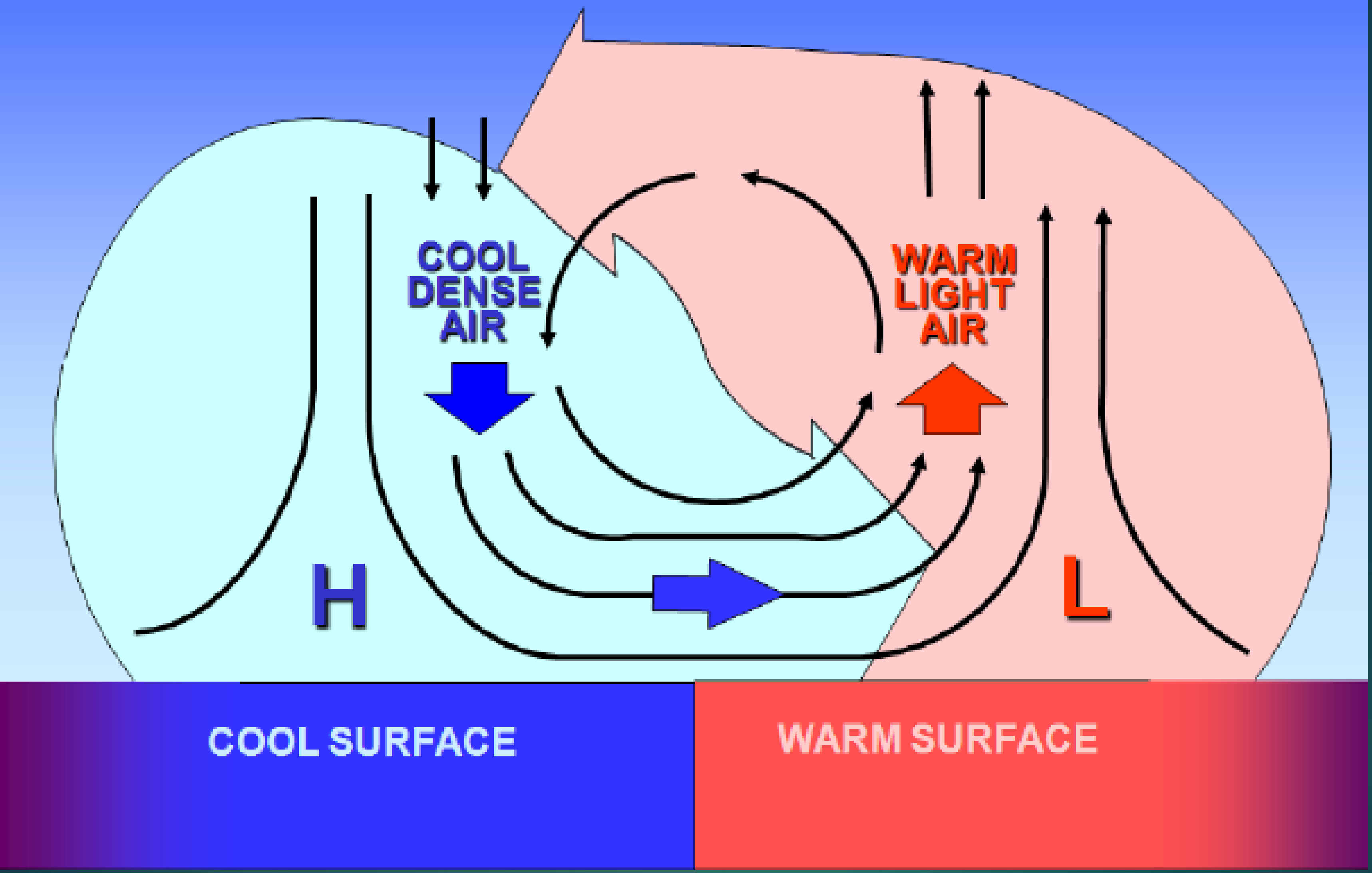


The result is that at the surface, wind spirals clockwise and outward from high pressure, and counter-clockwise and inward to low pressure. In very rugged terrain the winds may have little relation to pressure gradient because the friction force outweighs the other two forces.

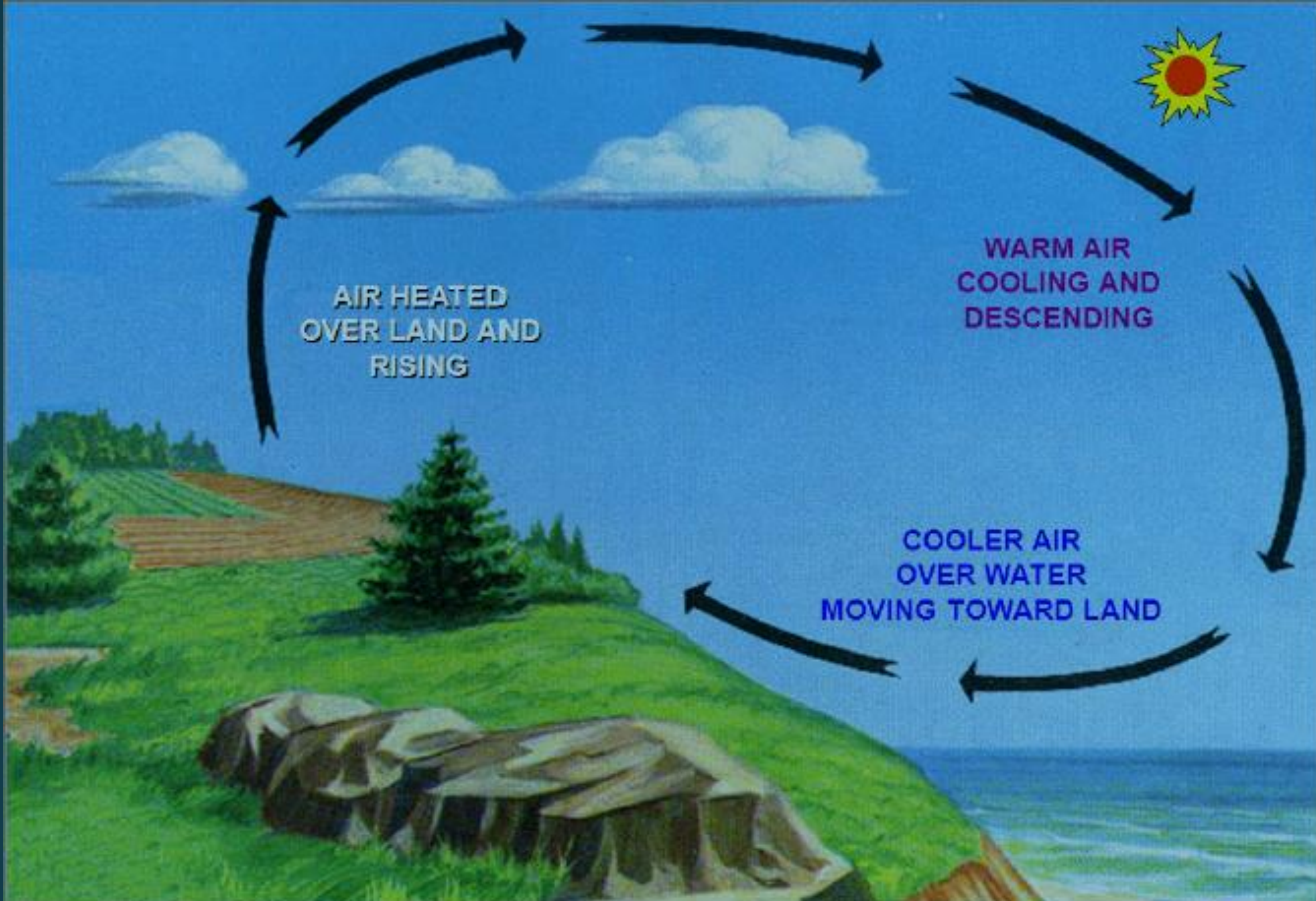

Search location...
Windy.com
Login
Radar & Satellite
Wind
Wind gusts
Rain, thunder
Temperature
Clouds
Waves
Air quality
More layers...
L
28.99
H
30.3
700hPa
3000m FL100
particles animation
pressure
More layers...
ECMWF
GFS
kt 0 5 10 20 30 40 60
Monday 22 - 5 PM
Monday 22
Tuesday 23
Wednesday 24
Thursday 25
Friday 26
Saturday 27
Sunday 28
Monday 29
Tuesday 30
Wednesday 1
© OpenStreetMap contributors


Search location...
Windy.com
Login
Radar & Satellite
Wind
Wind gusts
Rain, thunder
Temperature
Clouds
Waves
Air quality
More layers...
L
28.99
H
30.3
Surface
particles animation
pressure
More layers...
ECMWF
GFS
Monday 22 - 5 PM

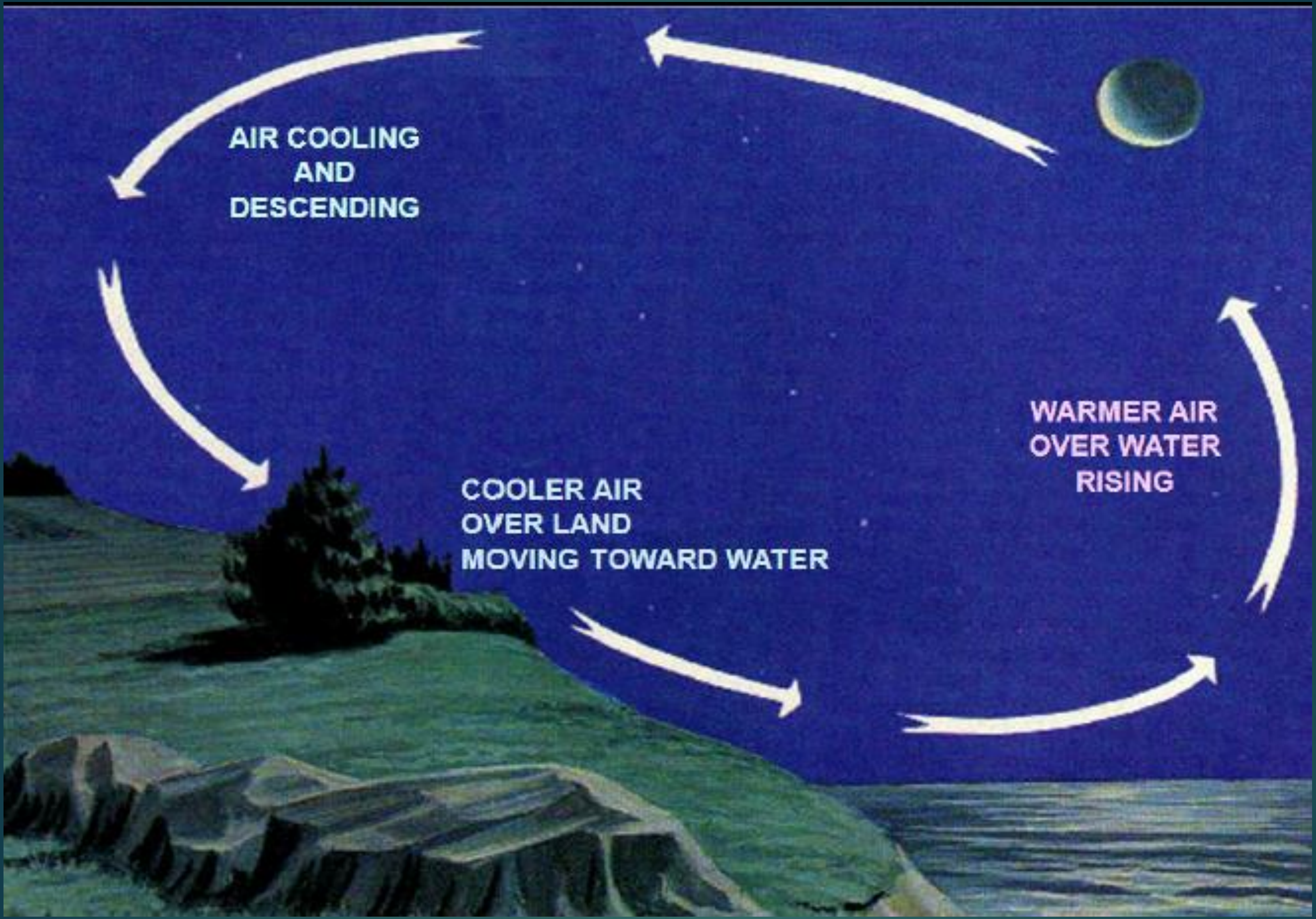
- Local winds are mainly driven by pressure gradient force
- They are over a smaller area, and have a shorter life span, so Coriolis force does not have as much time to act.
- PGF is set in motion by local warming and cooling of surfaces.



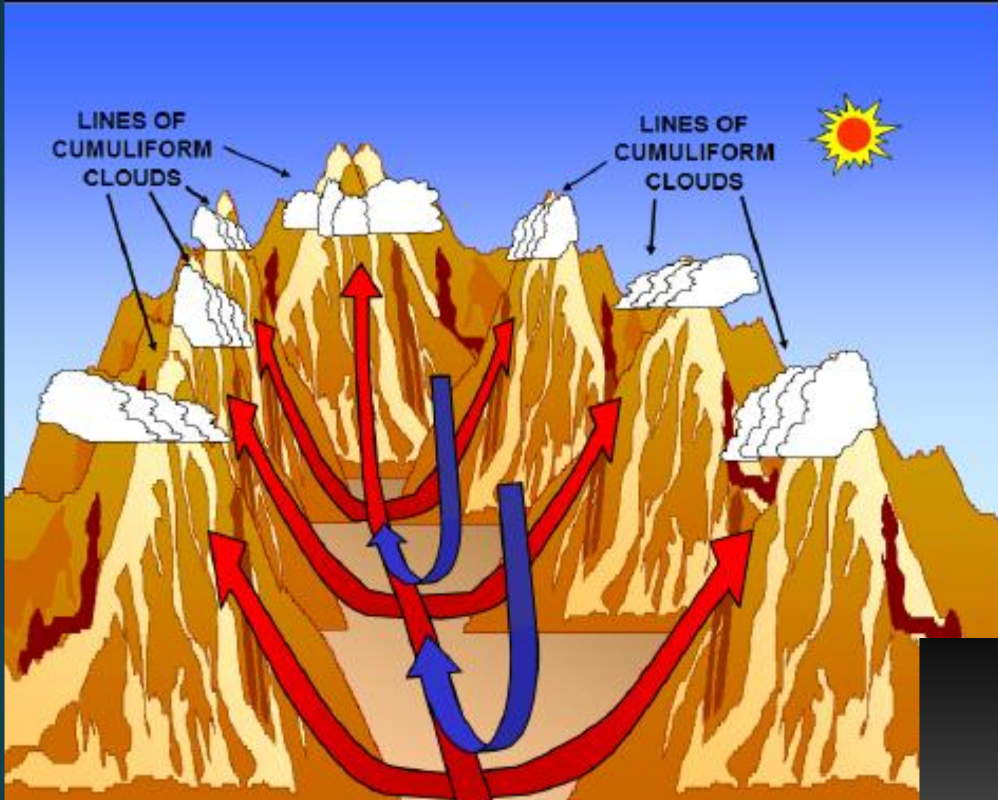
Wind blows from a high-pressure cool surface to a low-pressure warm surface. This is easiest to see when larger-scale wind patterns are weak.

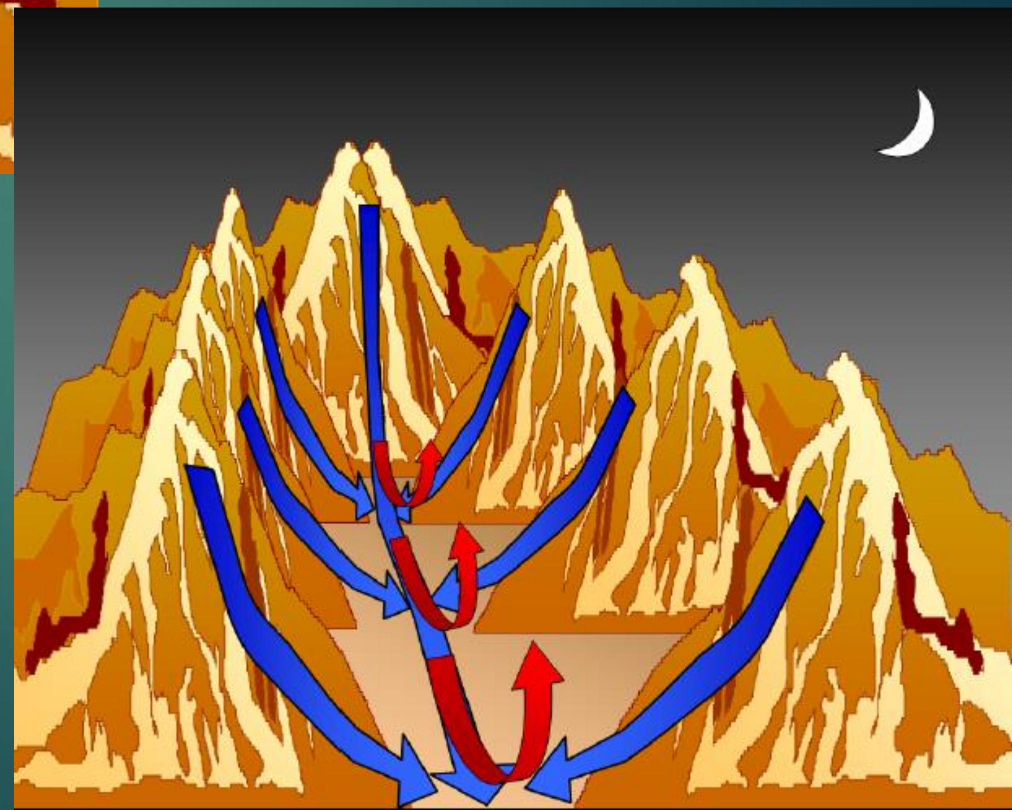


This is an example of a local wind called “sea breeze.” Air over land warms faster than air over water.



At night this process reverses, as land also cools down faster than water when the sun sets. This is called a “land breeze.”





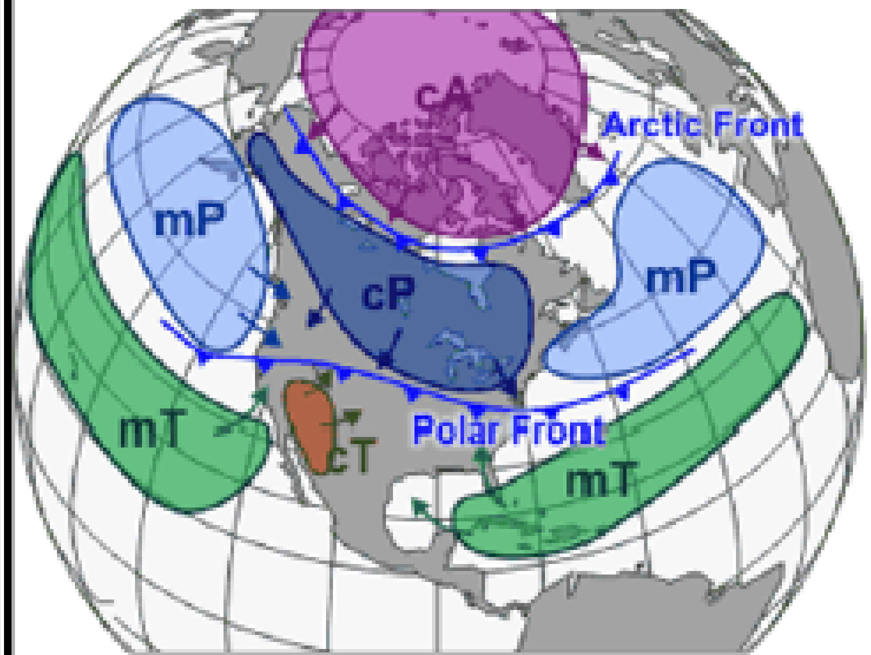
A similar phenomenon occurs in mountains, where the sloping terrain both heats and cools faster than the valleys, producing “valley breeze” and “mountain breeze.”

Air Masses and Fronts

Air Mass

An air mass is a large body of air with generally uniform temperature and humidity.

The longer the air mass stays over its source region, the more likely it will acquire the properties of the surface below.

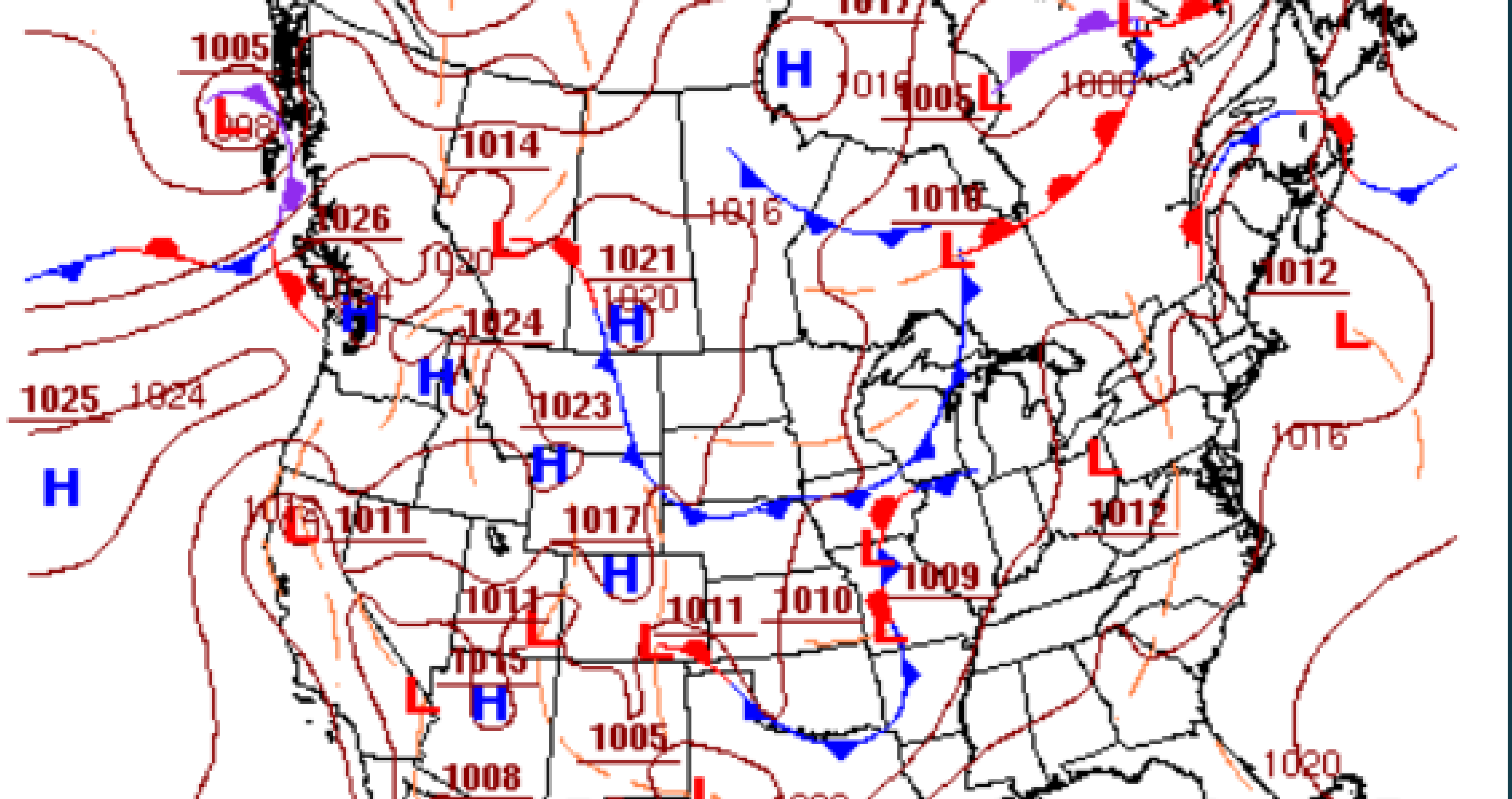


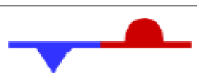
SOURCE REGION	Continental (c)	Maritime (m)
Arctic (A)	Continental Arctic (cA) *(Cold, dry)*	*Not Applicable*
Polar (P)	Continental Polar (cP) *(Cold, dry)*	Maritime Polar (mP) *(Cool, moist)*
Tropical (T)	Continental Tropical (cT) *(Hot, dry)*	Maritime Tropical (mT) *(Warm, moist)*

North America will typically have more than one type of air mass present at any given time.

Fronts

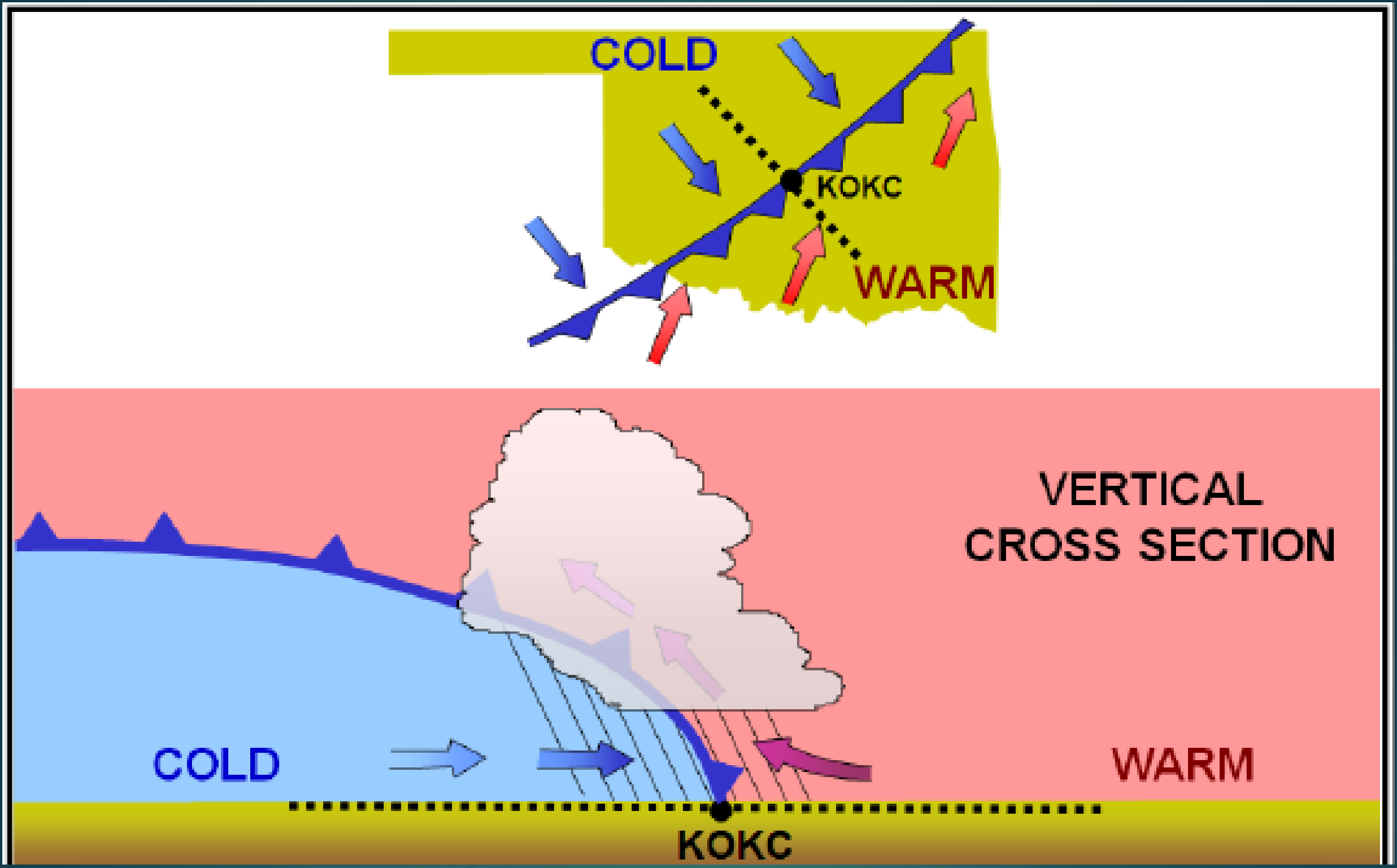
- Air masses can control the weather for relatively long time periods ranging from days to months.
- A front is a boundary or transition zone between two air masses.
- Most weather occurs along fronts.



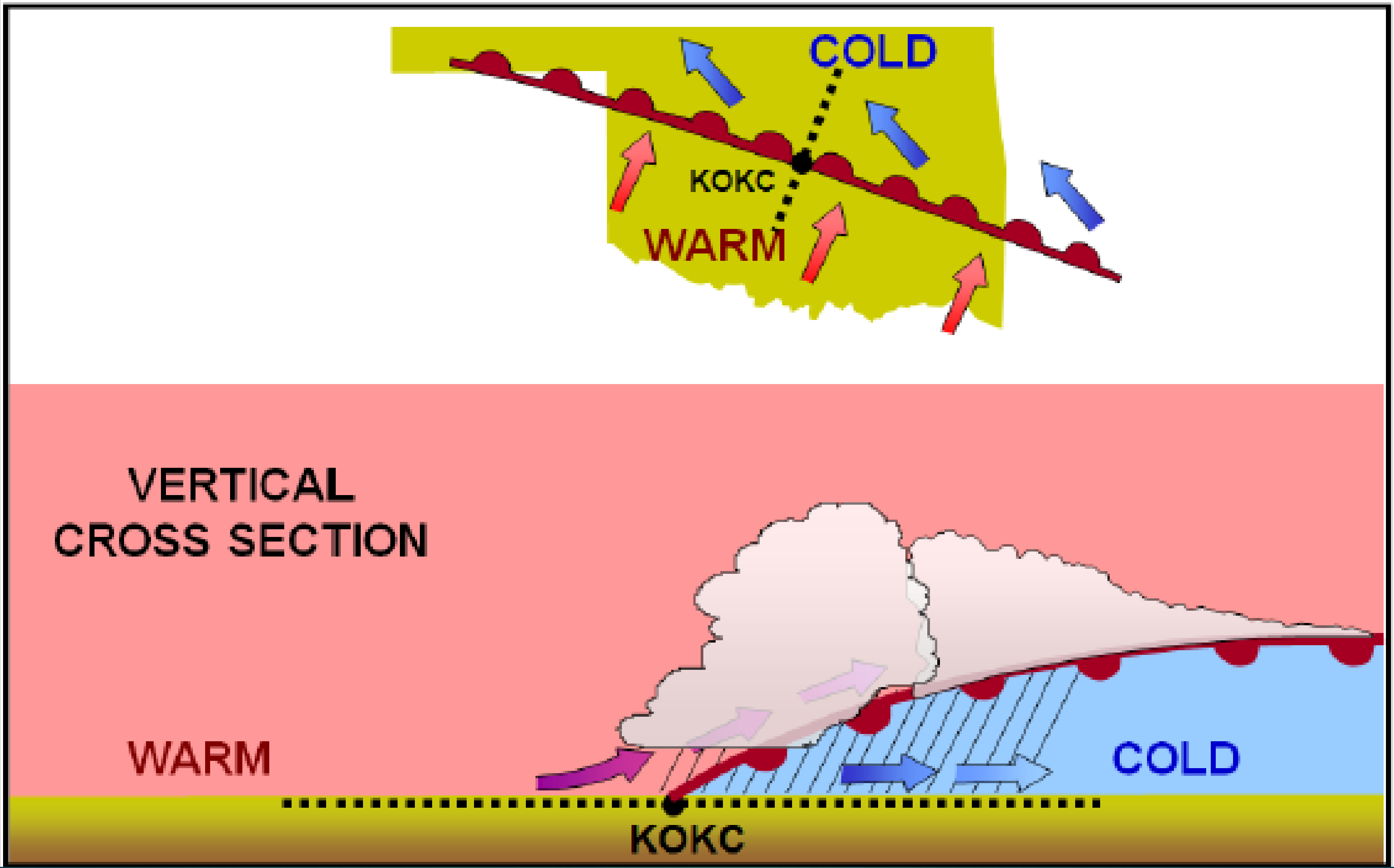
FRONT	CHART SYMBOL	DEFINITION
Cold Front		A front that moves in such a way that colder air replaces warmer air.
Warm Front		A front that moves in such a way that warmer air replaces colder air.
Stationary Front		A front which is stationary or nearly so.
Occluded Front		A composite of two fronts as a cold front overtakes a warm front or stationary front.

Note: Frontal symbols point in the direction of frontal movement.

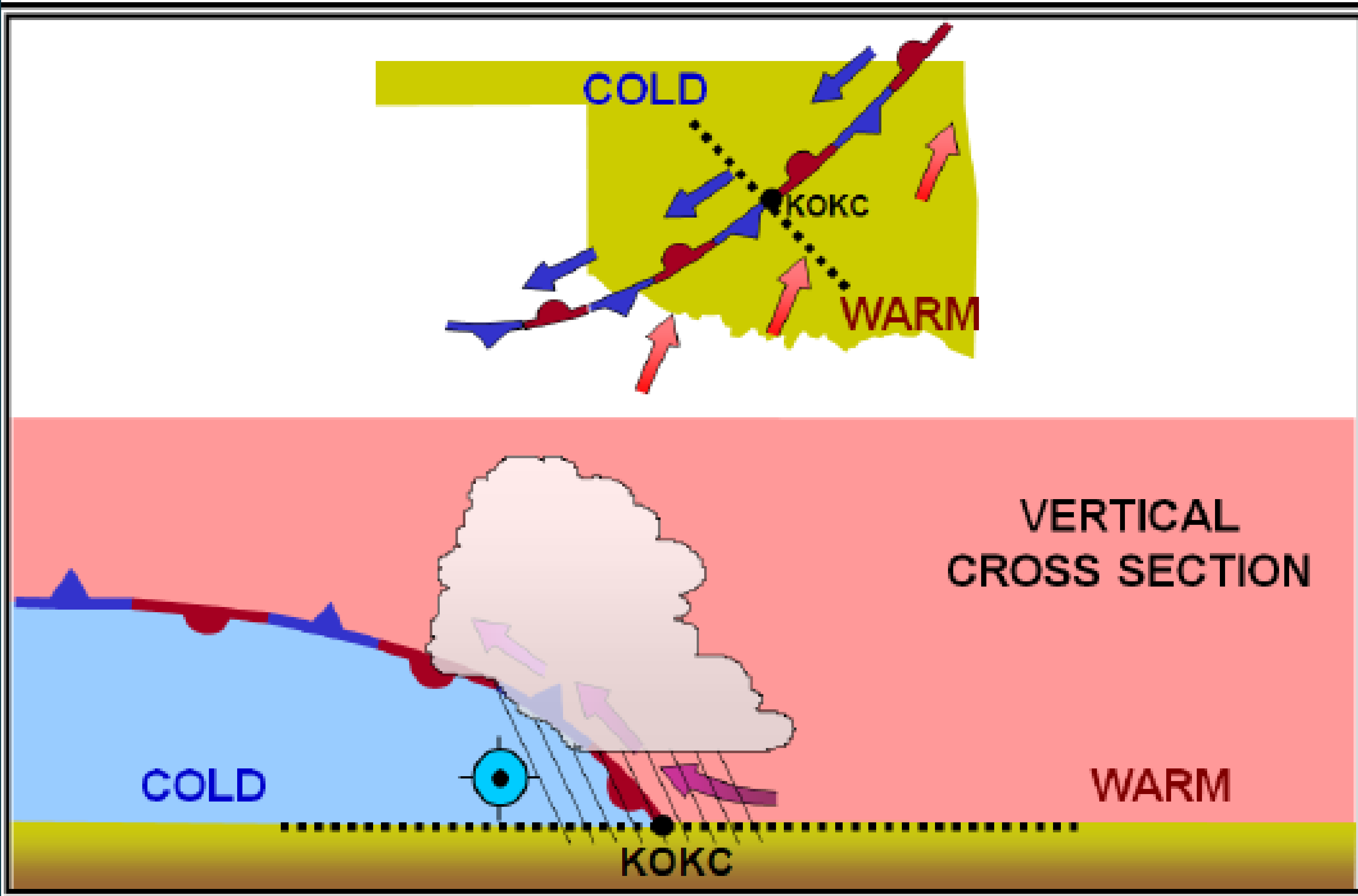
Fronts are depicted on weather charts with these symbols.



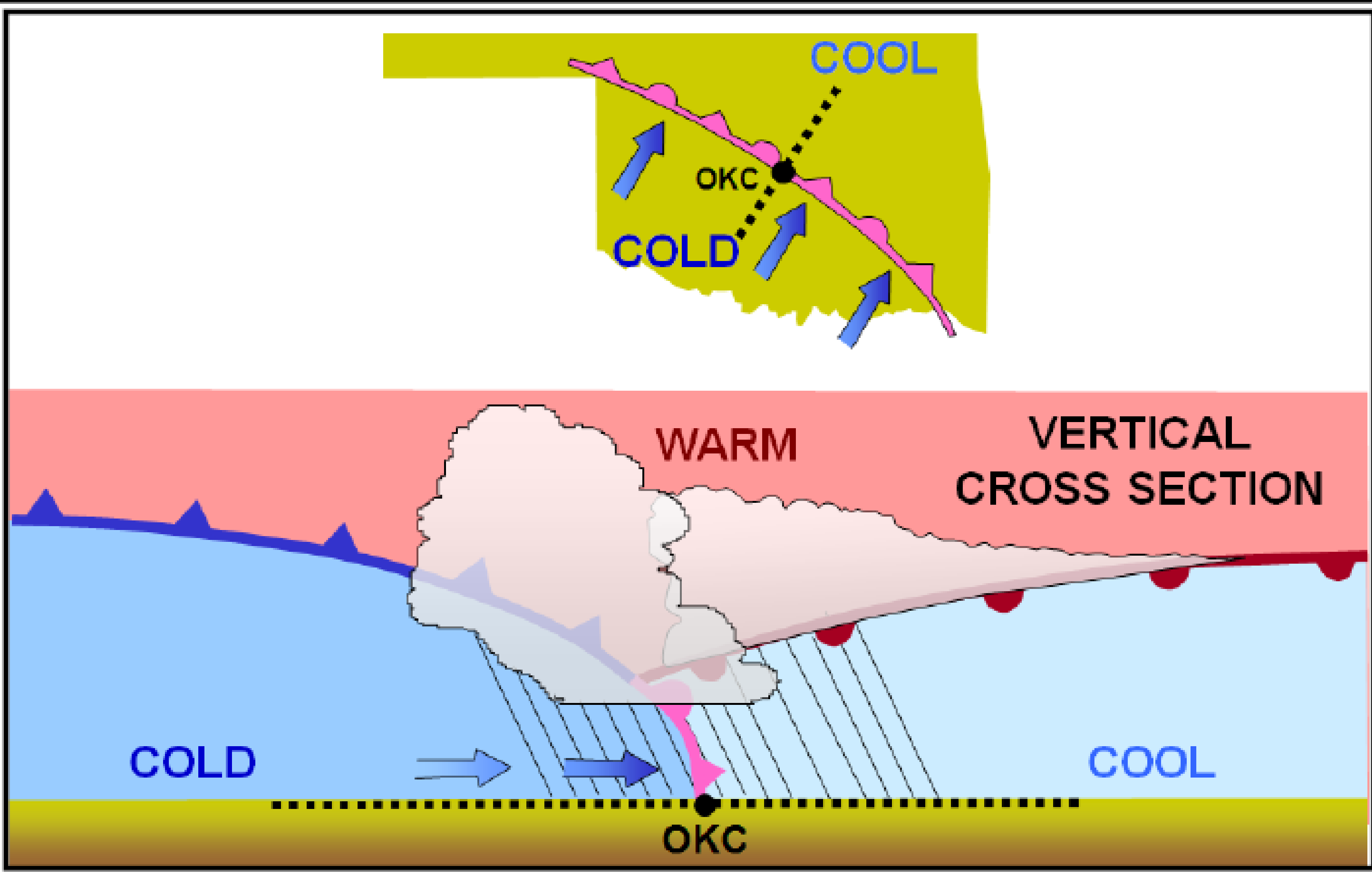
Fronts also have a vertical structure. Cold fronts have steep slopes, and the warm air is forced up abruptly. This often leads to a narrow band of showers and thunderstorms at or just ahead of the front.



Warm fronts typically have a more gentle slope, so the warm air rises gradually. This favors the development of widespread cloudiness and precipitation along the front.



Stationary frontal slope can vary, but clouds and precipitation will still form in the warm rising air along the front.



Cold fronts typically move faster than warm fronts, so in time they catch up to them. Where the two fronts merge, an occluded front forms and the rising warm air is lifted even farther.

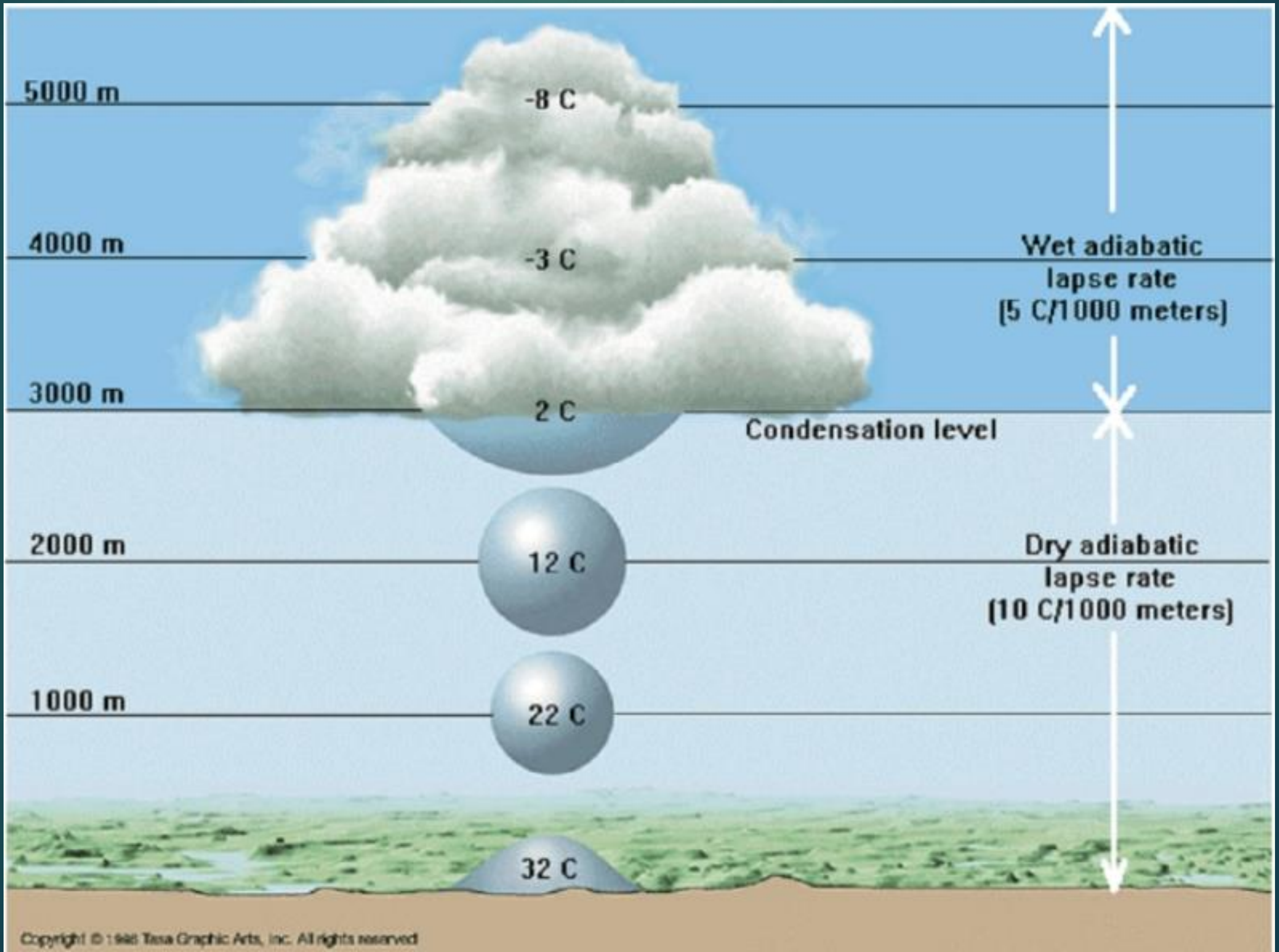
Vertical Motion of the Atmosphere

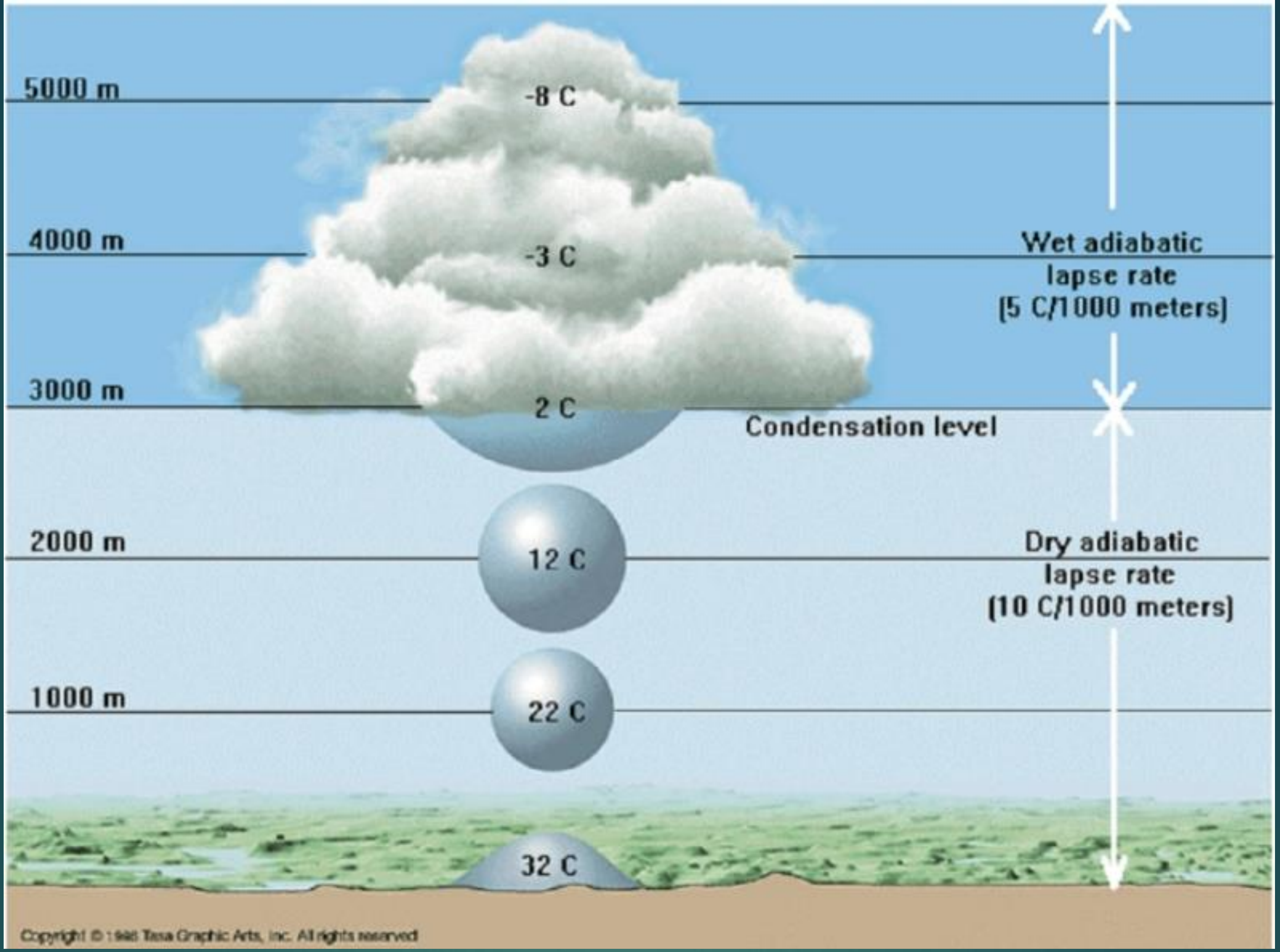
Atmospheric Stability

- The stability of the atmosphere depends on its ability to resist vertical motion.
- A stable atmosphere makes vertical movement difficult, and small vertical disturbances dampen and disappear.
- In an unstable atmosphere, small vertical air movements tend to become larger, resulting in turbulence, convective activity, extensive clouds, and severe weather.

Adiabatic Process 1.0 -- Hot Air Rises

Rising air expands and cools due to the decrease in air pressure as altitude increases.





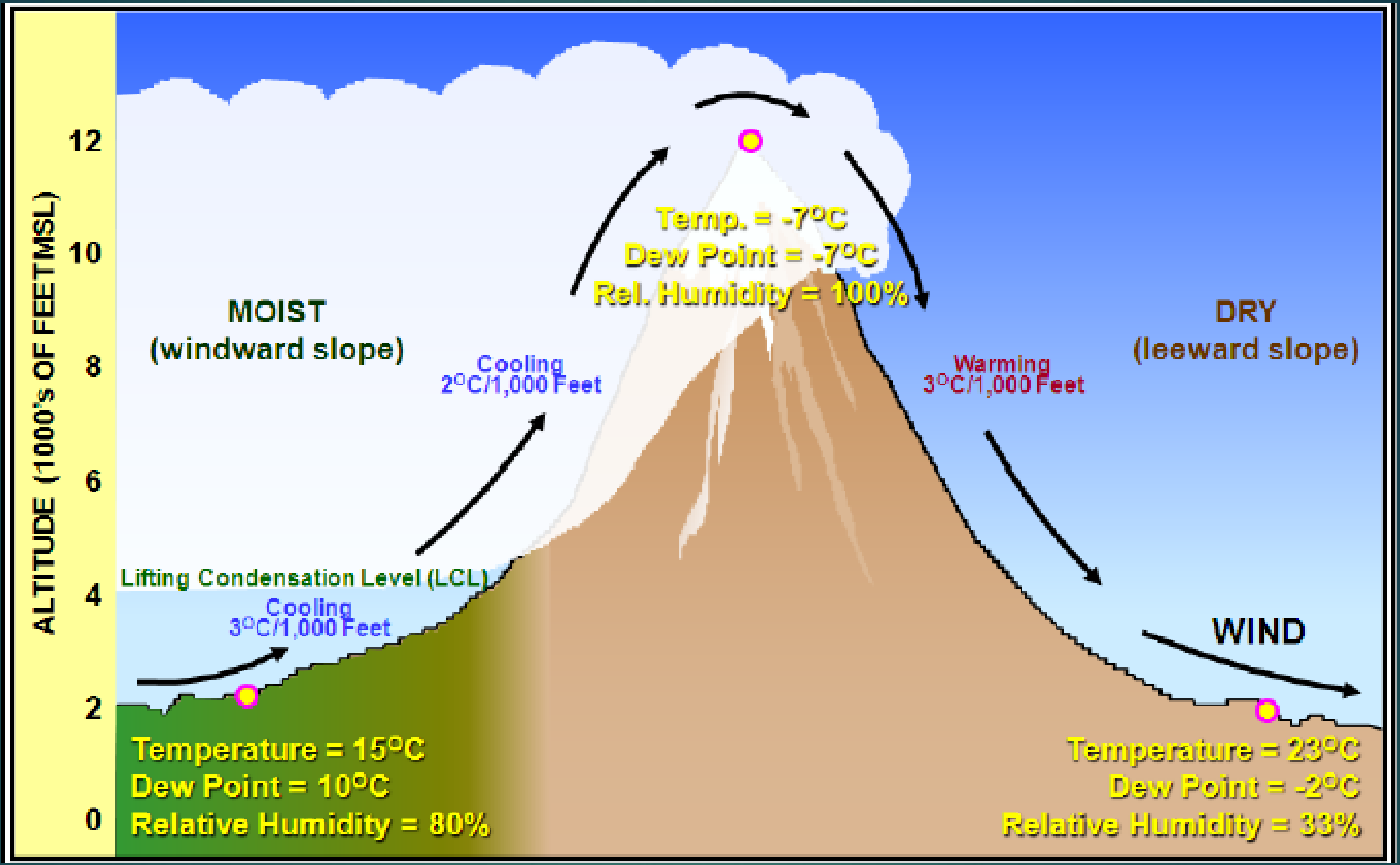
Moist air is lighter and cools more slowly than dry air. So It rises faster and must rise higher before its temperature cools to that of the surrounding air. This makes moist air inherently unstable.

Adiabatic Process 2.0 – Moist Air Rises Faster

Sources of Vertical Motion of Air

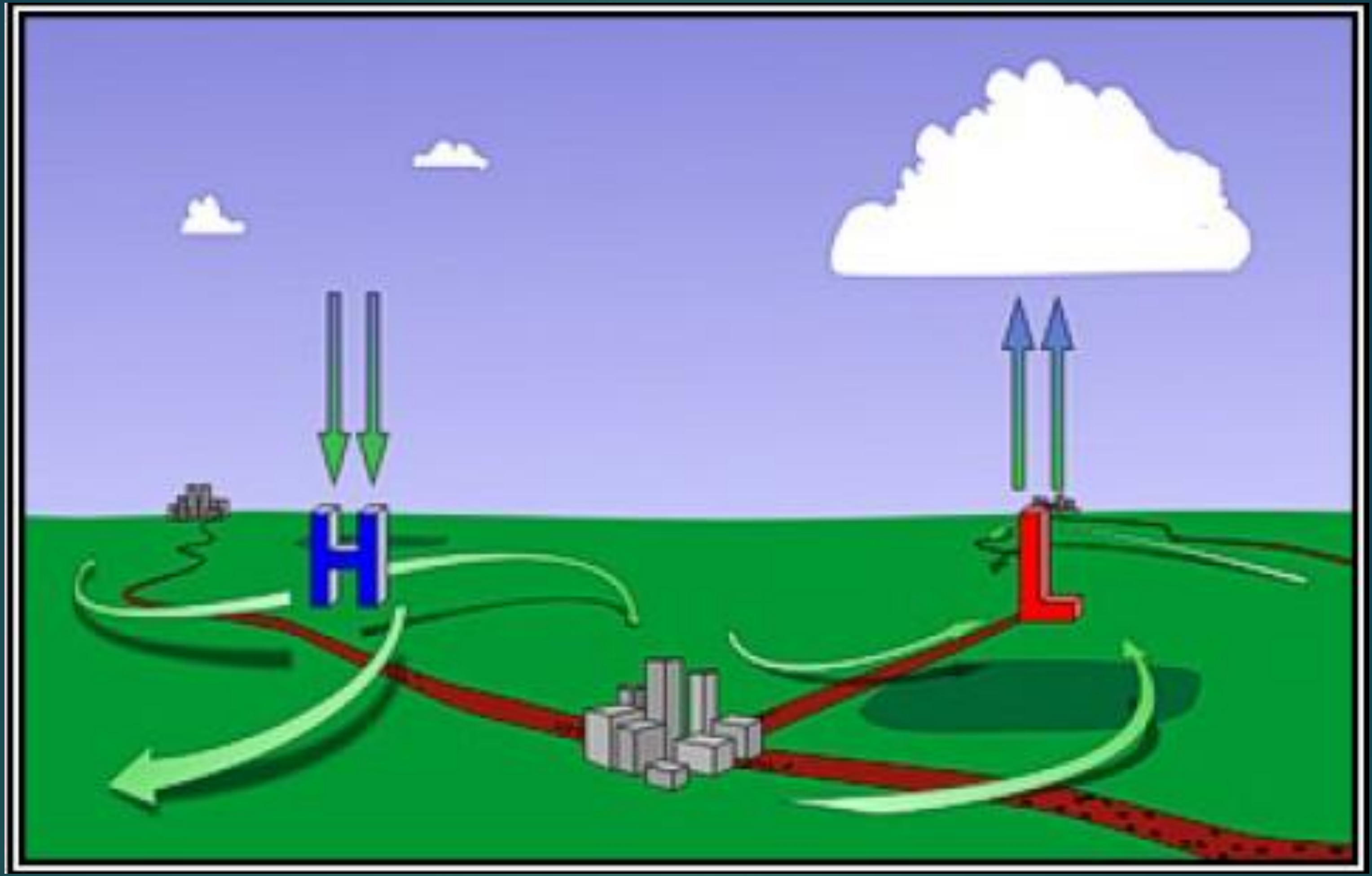
- Orographic
- Frictional
- Frontal Lift
- Buoyancy

Orographic Lifting



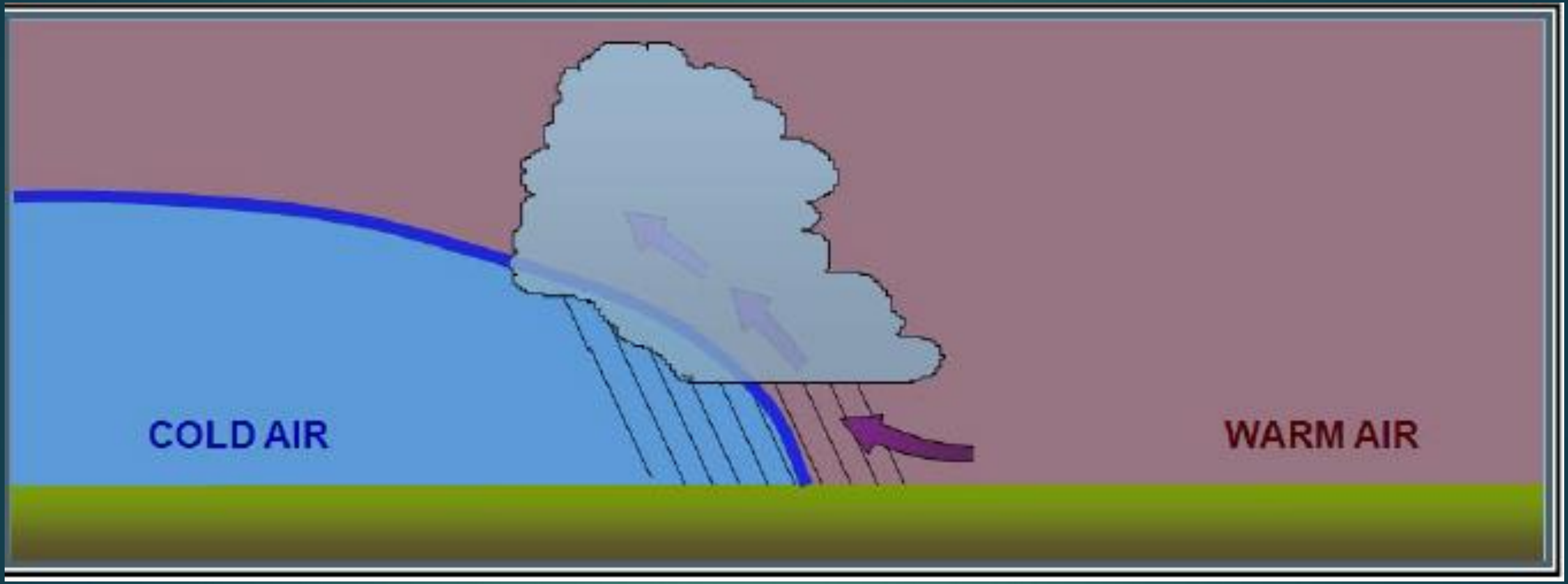
Winds blowing across mountains and valleys cause the moving air to alternately ascend and descend. The resulting expansional cooling and compressional warming of air creates clouds and precipitation.

Frictional Effects



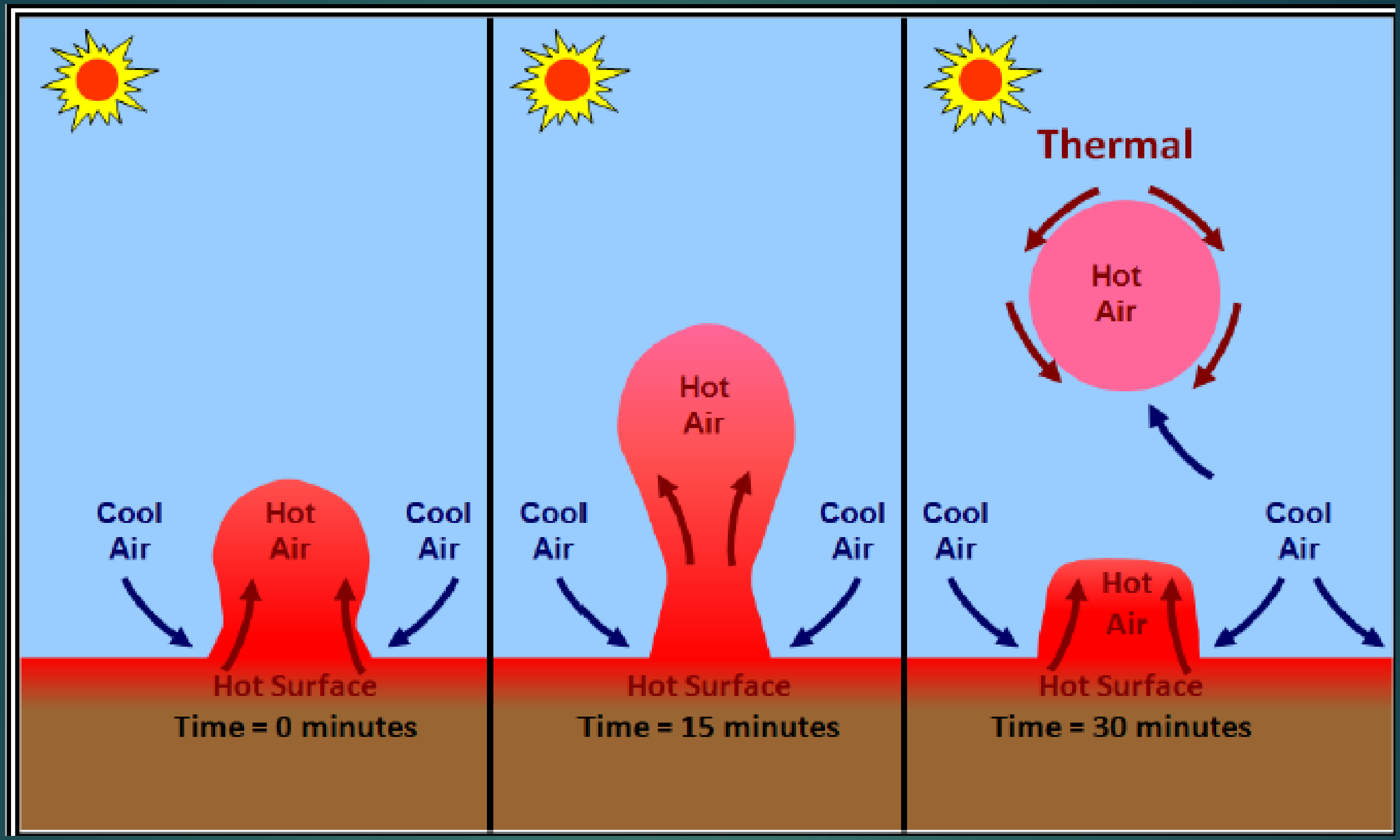
Wind spirals clockwise/outward from high pressure; counterclockwise/ inward towards low pressure. Over surface highs, the air sinks, compresses, and warms, causing clouds to dissipate. Over surface lows the air rises, expands, and cools, favoring the formation of clouds and precipitation.

Frontal Lift



Frontal lift occurs when the denser air of a cold front wedges under the warm, less dense air of the warm front it is overrunning. Clouds and precipitation form.

Buoyancy



Air near the ground warms at different rates depending on the insular and reflective properties of the ground with which it is in contact. The warm air rises faster than the cool air, creating "bubbles of turbulence.

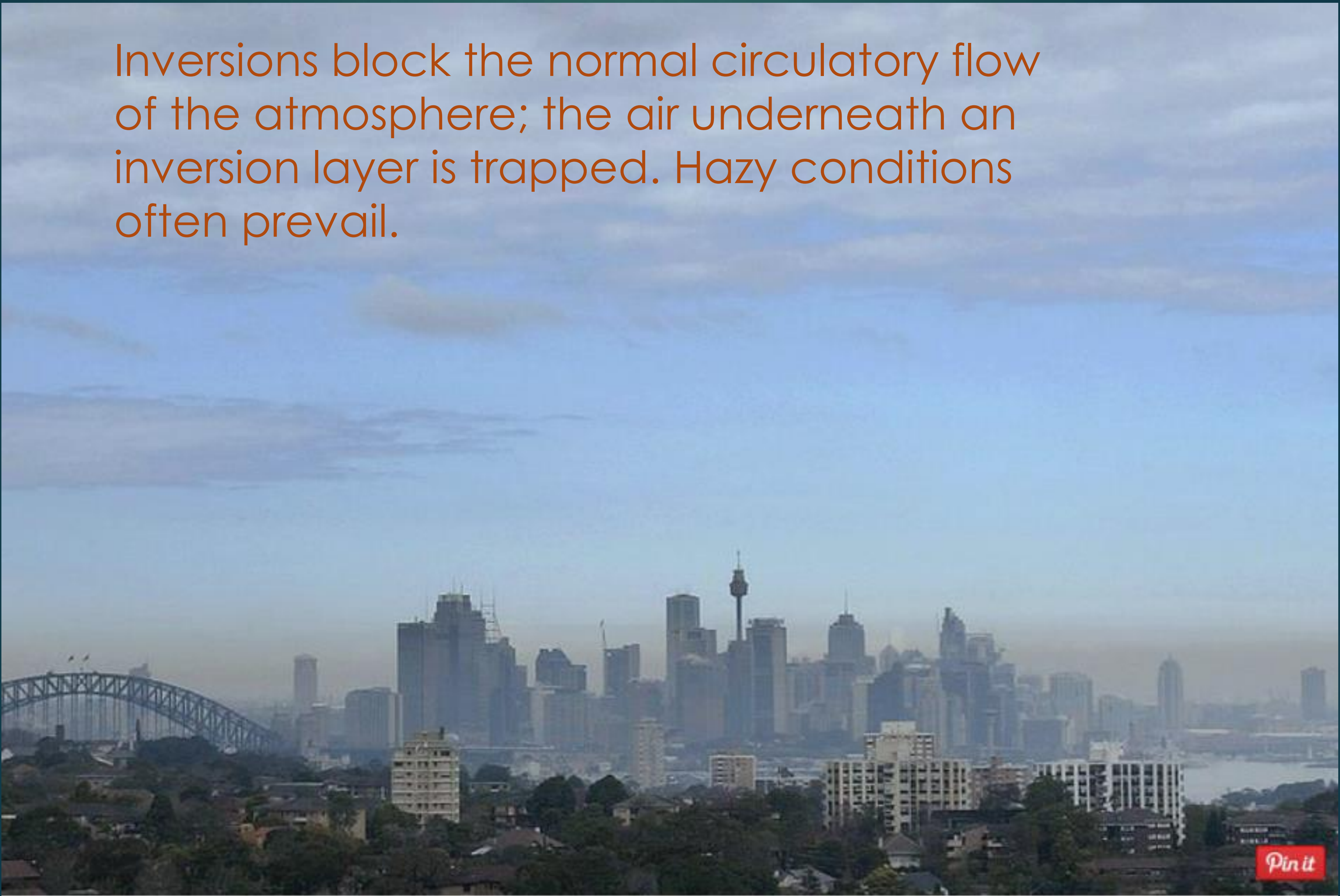
Temperature inversions

Areas where the normal decrease in air temperature with increasing altitude is reversed and air above the ground is warmer than the air below it.

- A warm, less dense air mass moves over a dense, cold air mass (Great Lakes in early summer)
- Radiational inversion: surface cooling by longwave radiation emission into space. Pronounced on clear, dry nights. The air closer to the surface cools faster than the air above. Usually dissipates when the surface is warmed by the sun rising.

Temperature inversions

Inversions block the normal circulatory flow of the atmosphere; the air underneath an inversion layer is trapped. Hazy conditions often prevail.



Clouds and Precipitation

To review:

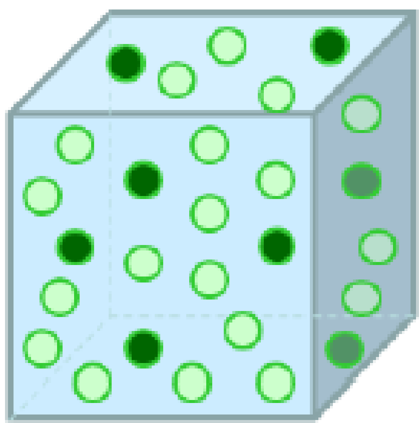
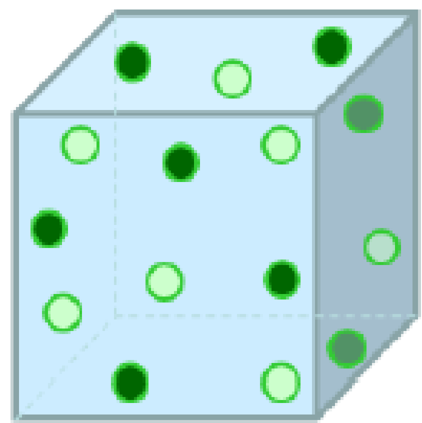
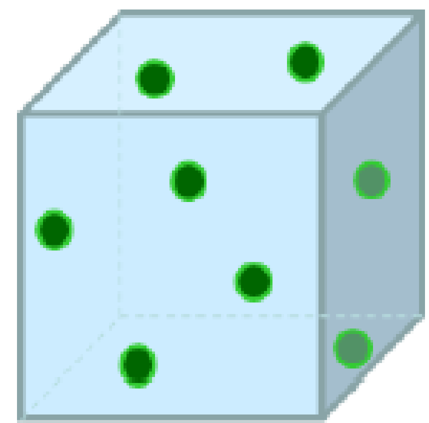
- ➢ Warm air holds more moisture than cold air
- ➢ Warm air rises
- ➢ Air cools as it rises

The moisture content of the air is described by two related concepts:

- Relative humidity
- Dewpoint

Relative humidity

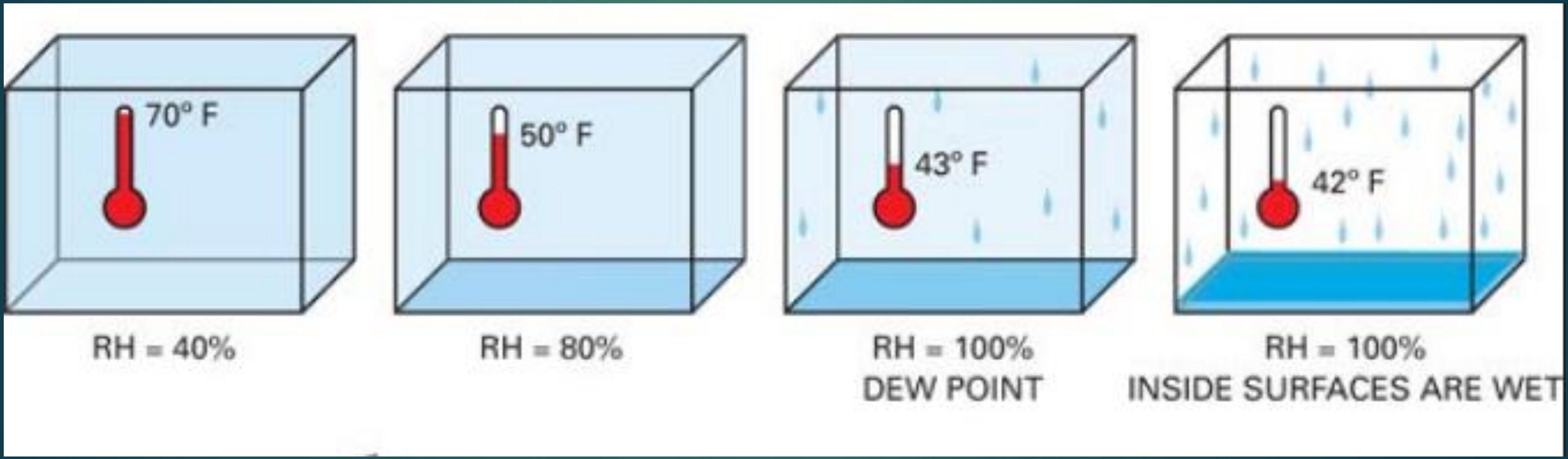
Humidity is the amount of water vapor present in the atmosphere at a given time. Relative humidity is the actual amount of moisture in the air compared to the total amount of moisture the air could hold at that temperature.

Temperature (at sea level)	30°C	20°C	10°C
● Actual gram of water vapor ○ Potential gram of water vapor			
Relative Humidity	8/27 = 30% (unsaturated)	8/15 = 53% (unsaturated)	8/8 = 100% (saturated)

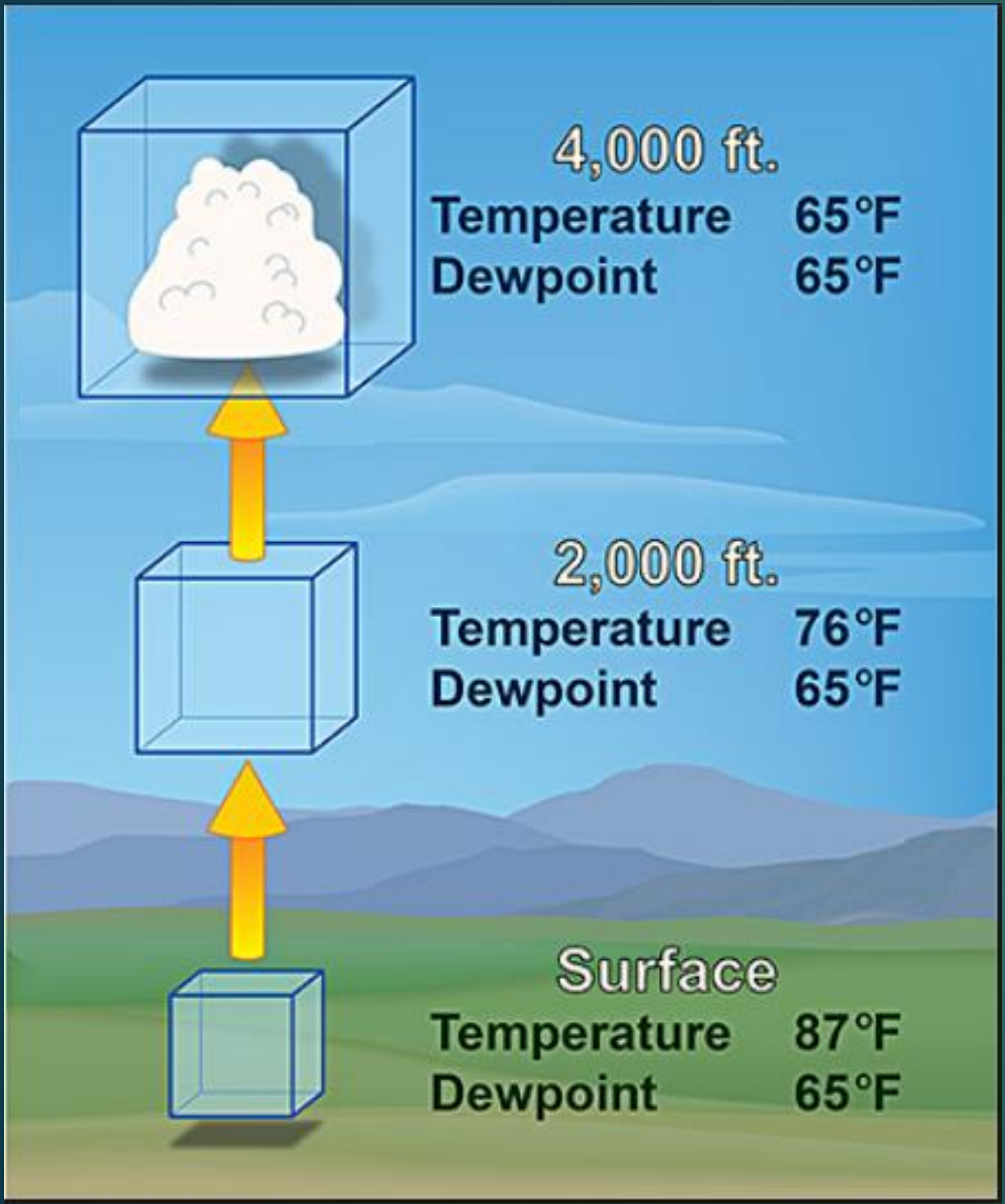
Dewpoint

Dewpoint is the temperature below which an air parcel cannot hold any more water.

When temperature = dewpoint, water condenses out of the air in the form of dew, fog, frost, clouds, rain, or snow.



Air cools as it rises



When the air rises, and its temperature falls, to the point where

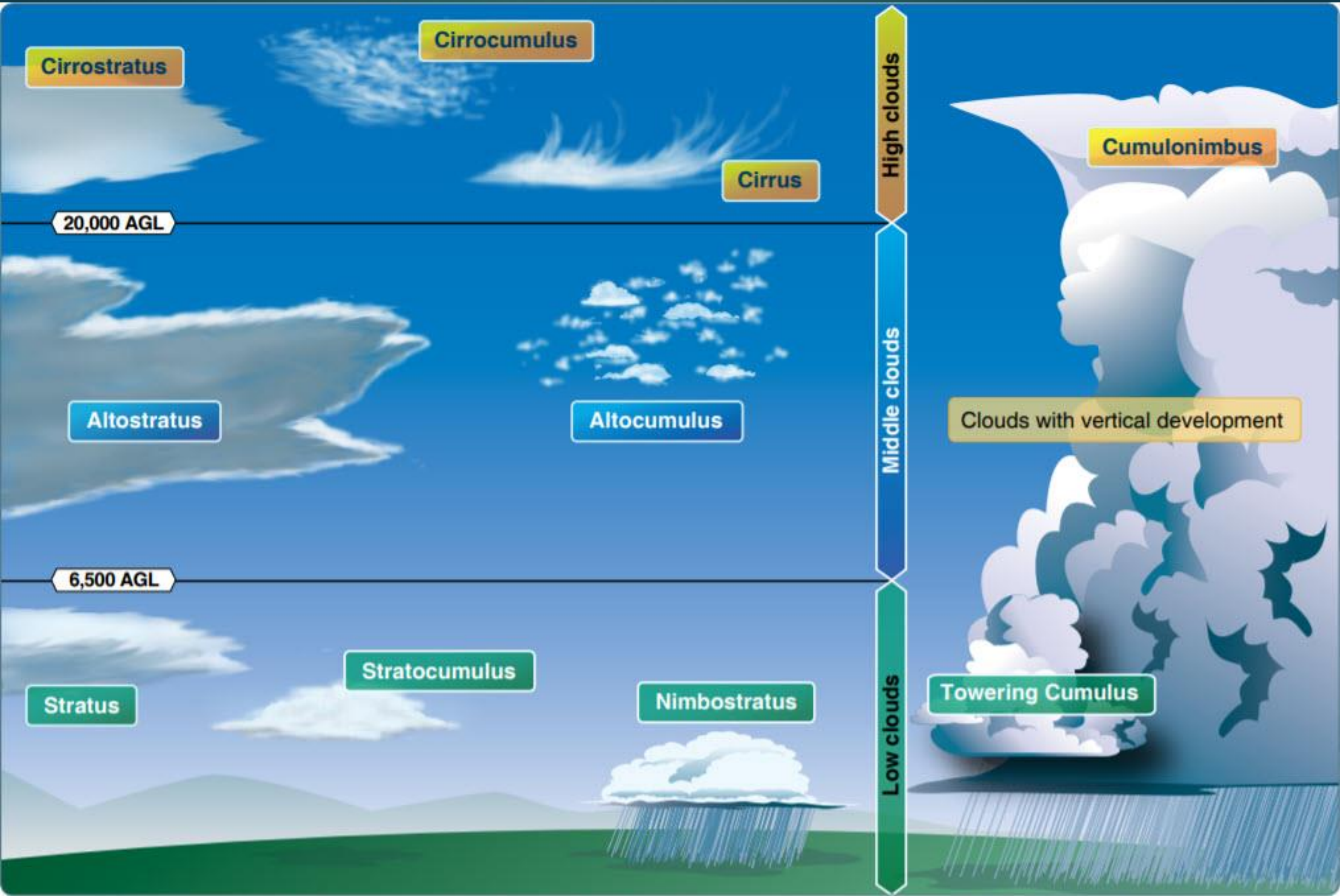
temperature = dewpoint

a cloud forms.

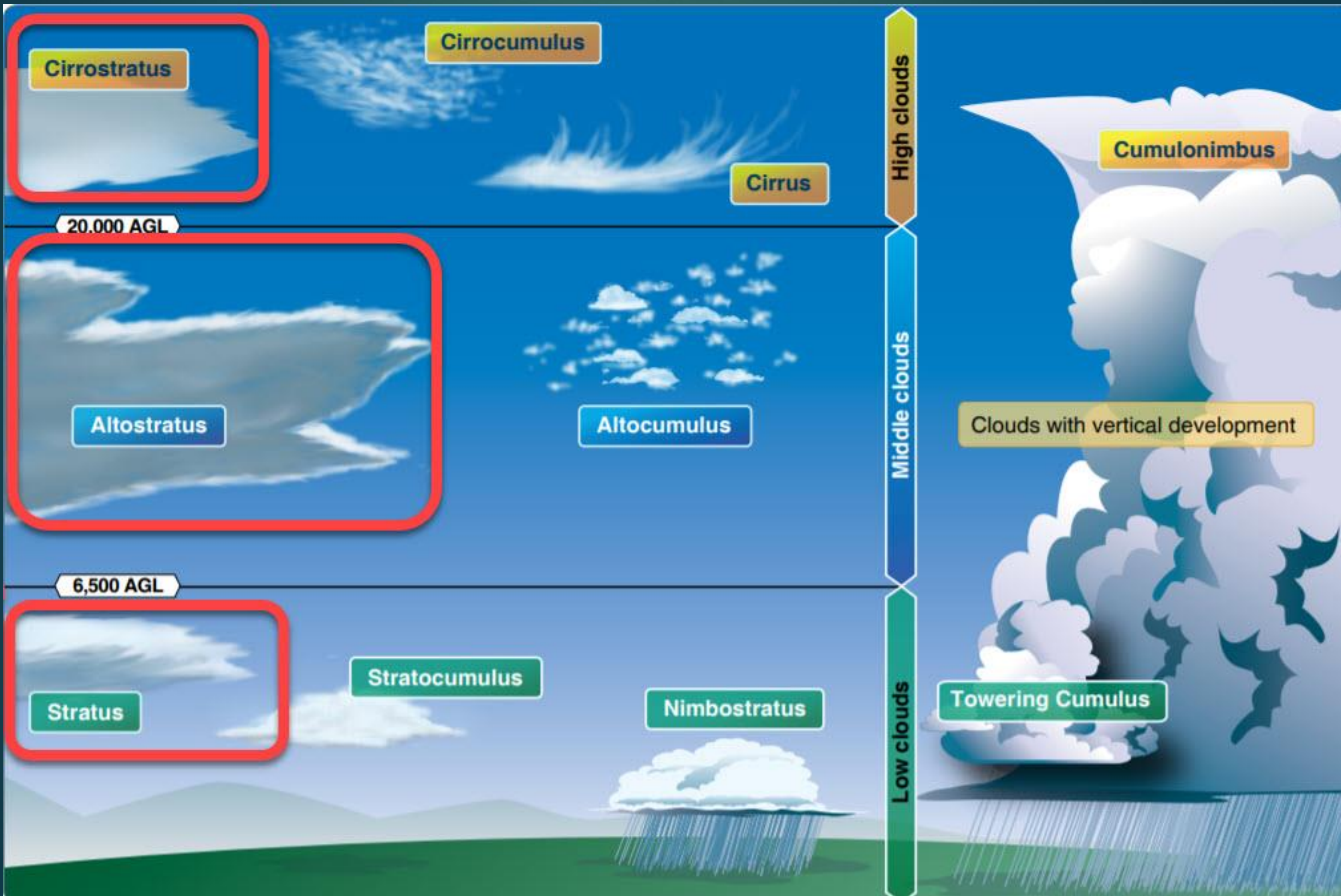
Clouds

- A cloud is a visible aggregate of minute water droplets and/or ice particles in the atmosphere above the Earth's surface.
- Fog differs from cloud only in that the base of fog is at the Earth's surface while clouds are above the surface.
- Clouds form in the atmosphere as a result of condensation of water vapor in rising currents of air, or by the evaporation of the lowest layer of fog.
- Rising currents of air are necessary for the formation of vertically deep clouds capable of producing precipitation heavier than light intensity.

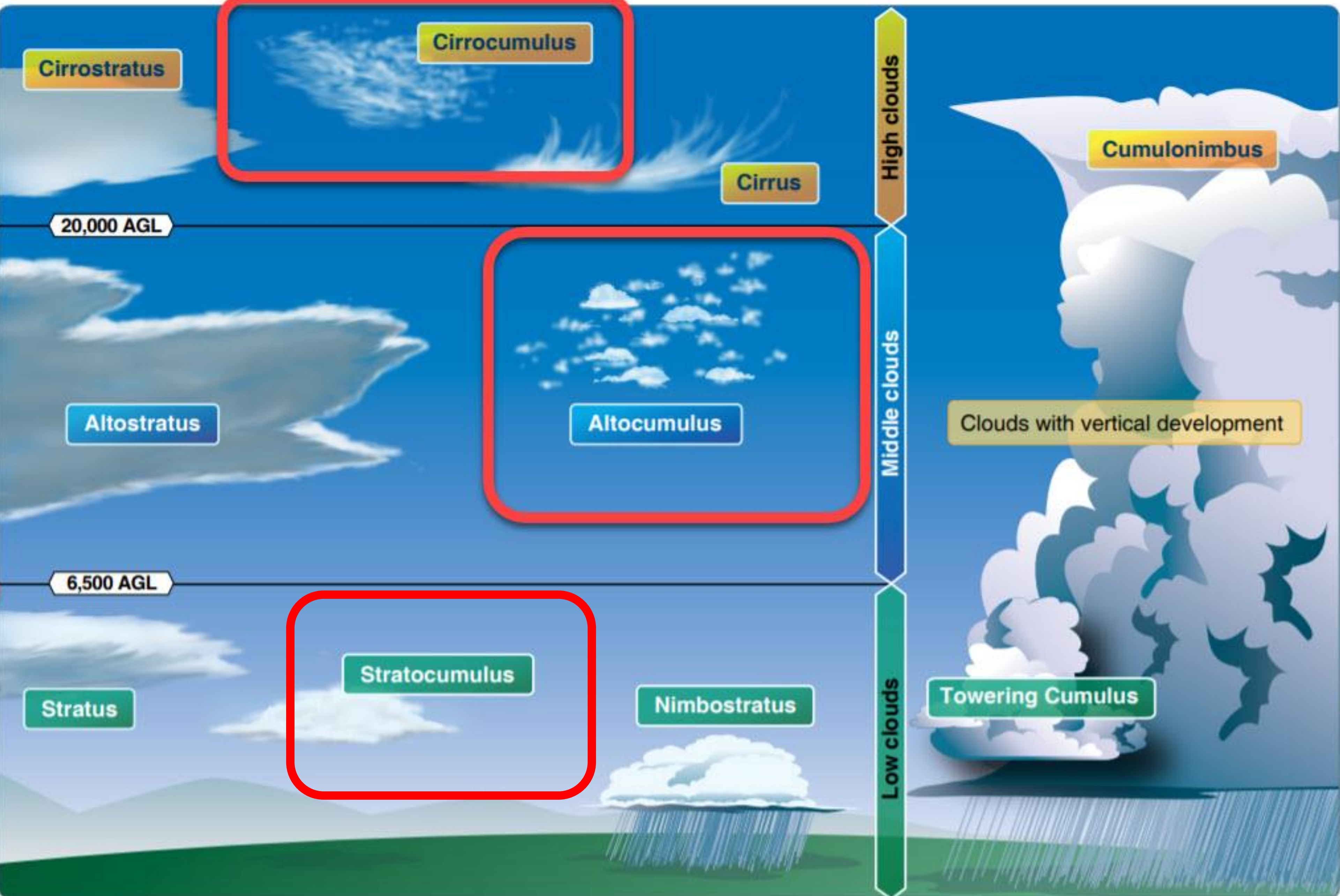
Clouds – cloud types defined by height and shape



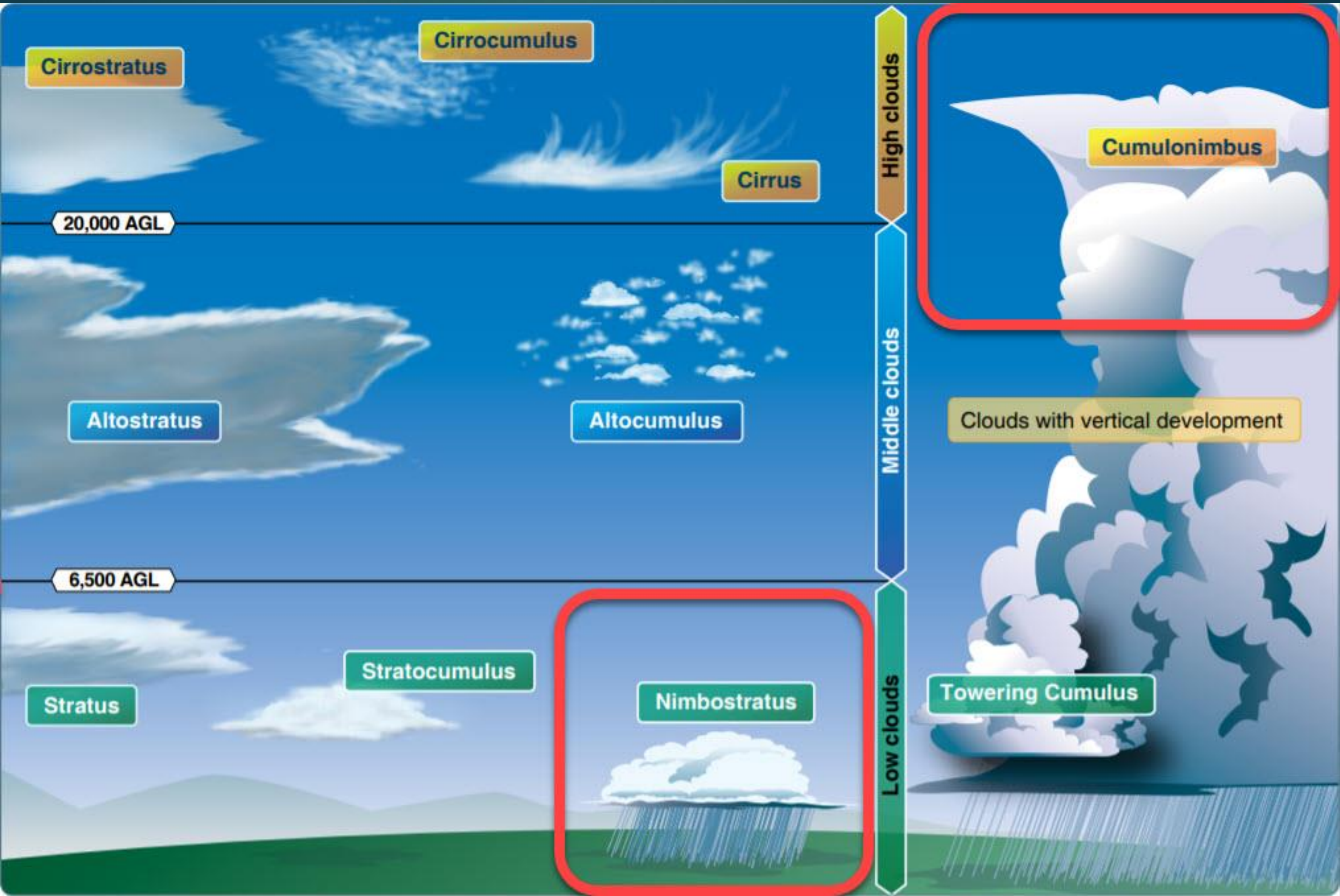
Stratus (strata = flat layers)



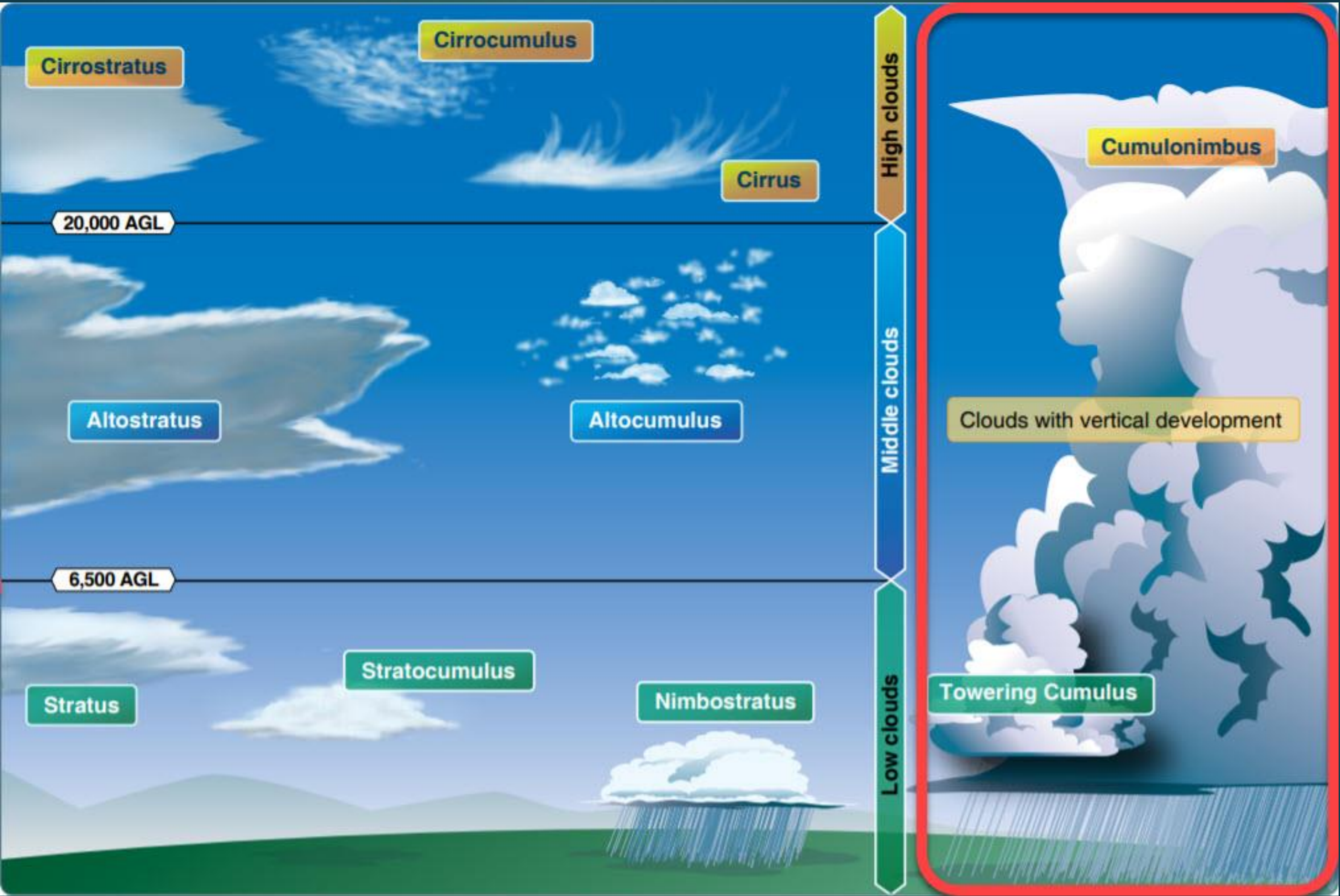
Cumulus = “heap or pile”



Nimbus = “rain”


Cirrocumulus
Cirrostratus
Cirrus
High clouds
Cumulonimbus
20,000 AGL
Altostratus
Altocumulus
Middle clouds
Clouds with vertical development
6,500 AGL
Stratocumulus
Stratus
Nimbostratus
Low clouds
Towering Cumulus

Clouds – cloud types



Precipitation

Precipitation is any of the forms of water particles, whether liquid or solid, that fall from the atmosphere and reach the ground.

- Precipitation formation requires three ingredients:

- water vapor
- sufficient lift to condense the water vapor into clouds
- a growth process that allows cloud droplets to grow large and heavy enough to fall as precipitation.

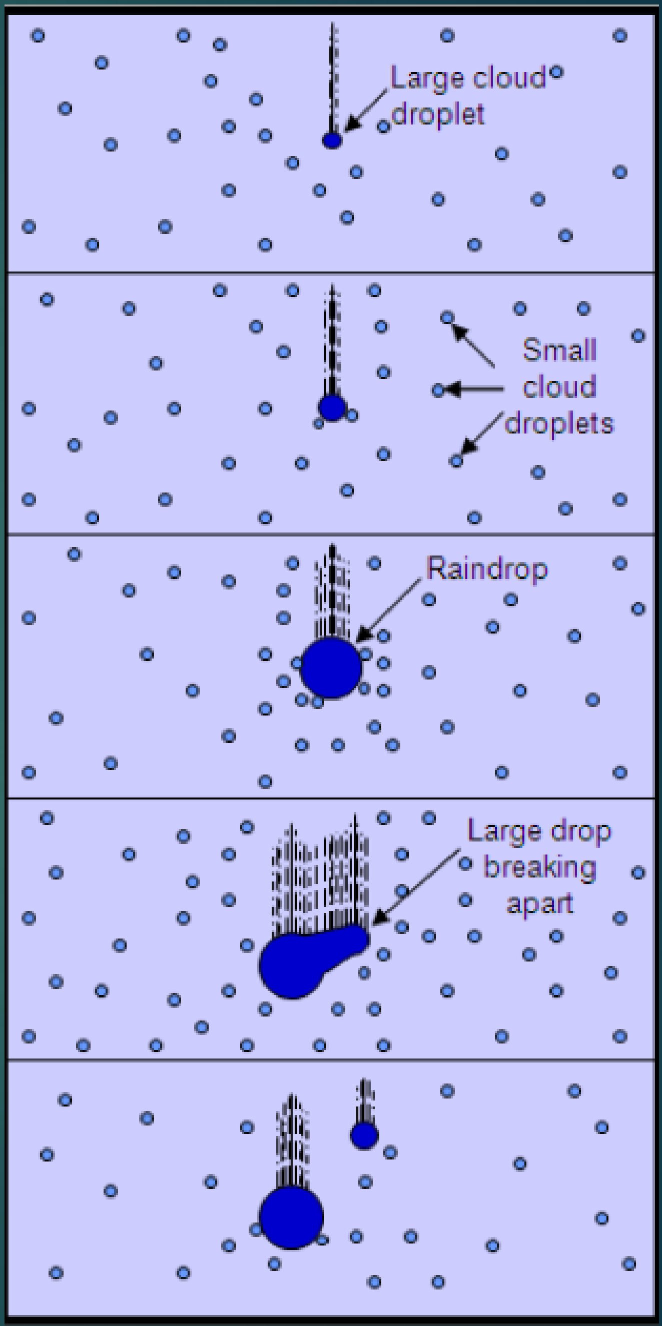
- drizzle
- rain
- snow
- snow grains
- ice crystals
- ice pellets
- hail
- small hail/snow pellets

Formation of Precipitation

Cloud droplets and/or ice crystals are too small and light to fall to the ground as precipitation.

Collisions occur between cloud droplets of varying size and different fall speeds, sticking together or coalescing to form larger drops.

The drops become too large to be suspended in the air, and they fall to the ground as rain.



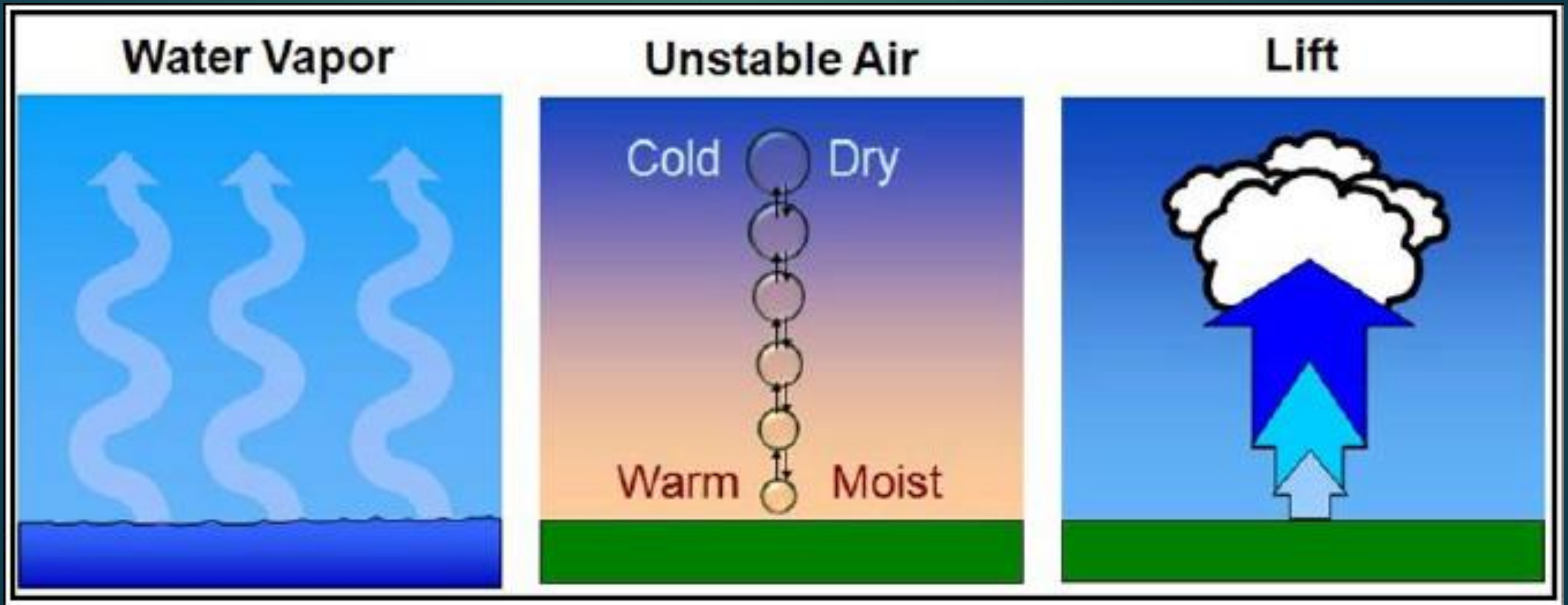
Thunderstorms and Turbulence

Thunderstorms

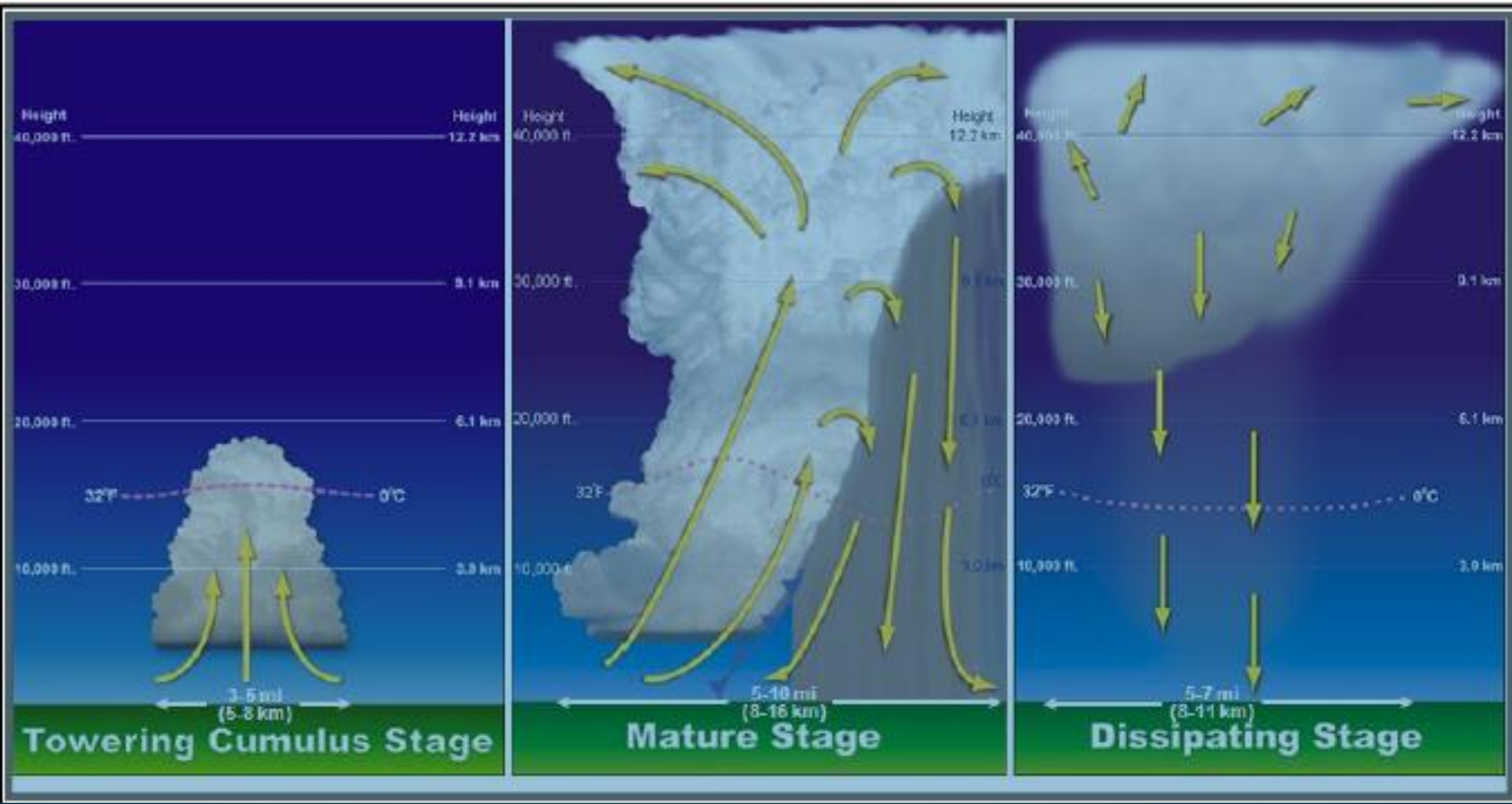
- Extensive vertical development
- Unstable and turbulent
- Contain large amounts of moisture
- Produce a number of hazards to aviation

Requirements for thunderstorm formation:

- Water vapor
- Unstable air
- Lift

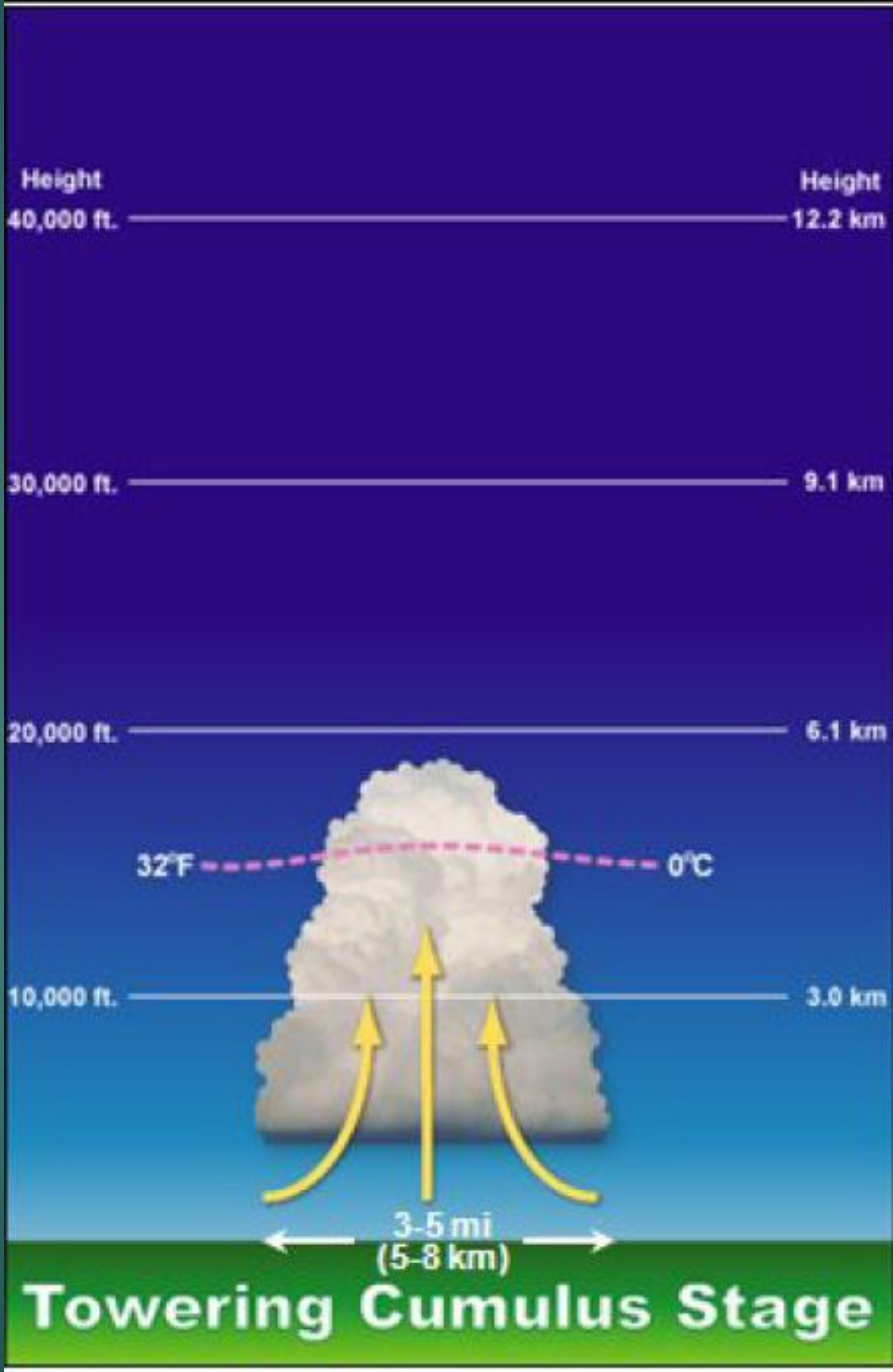


Thunderstorms have a predictable life cycle



Towering cumulus

The distinguishing feature of the towering cumulus stage is a strong convective updraft. The updraft is a bubble of warm, rising air concentrated near the top of the cloud which leaves a cloudy trail in its wake. Updraft speeds can exceed 3,000 feet per minute.

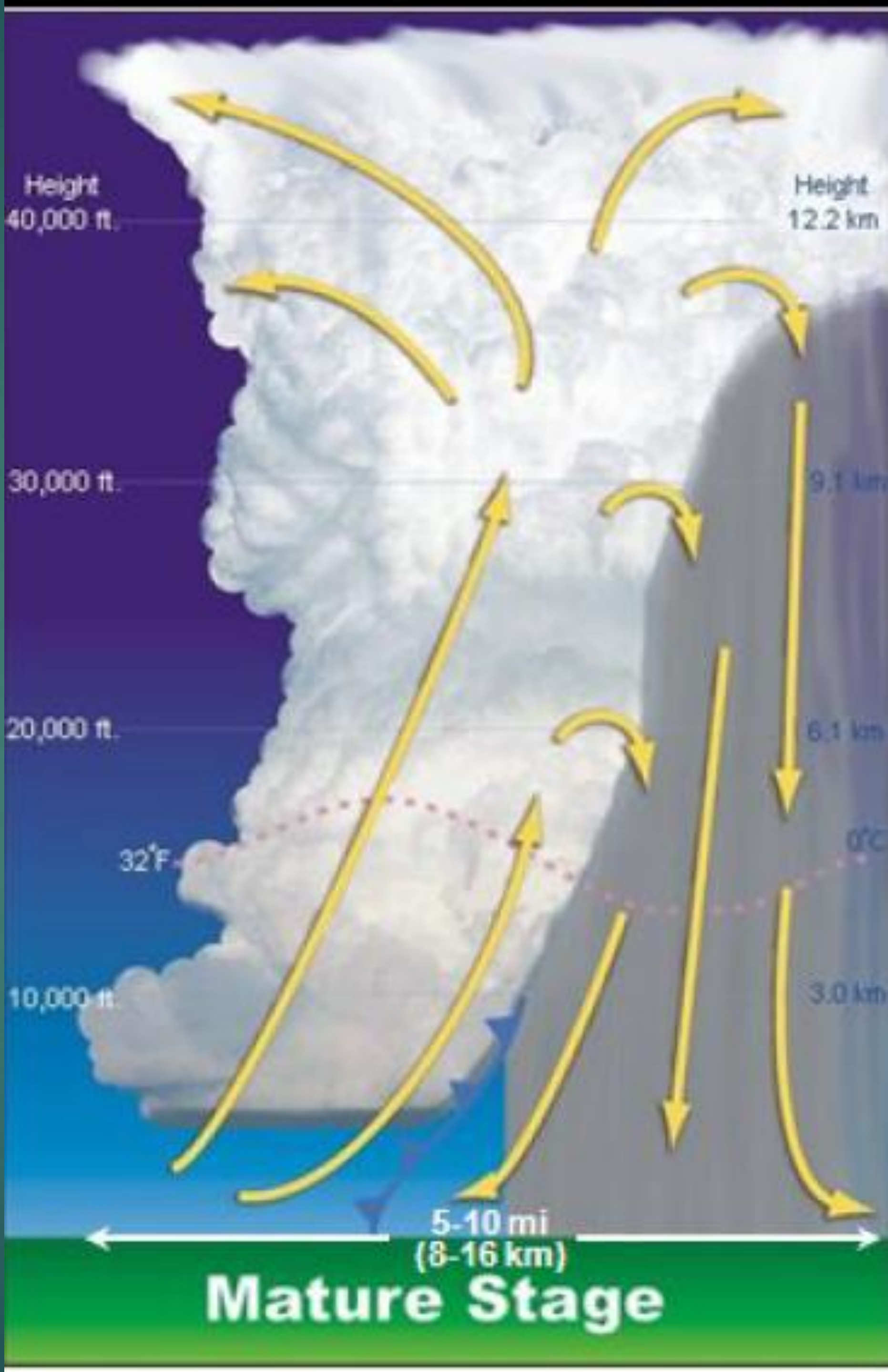


Mature

The cell transitions to the mature stage when precipitation reaches the surface.

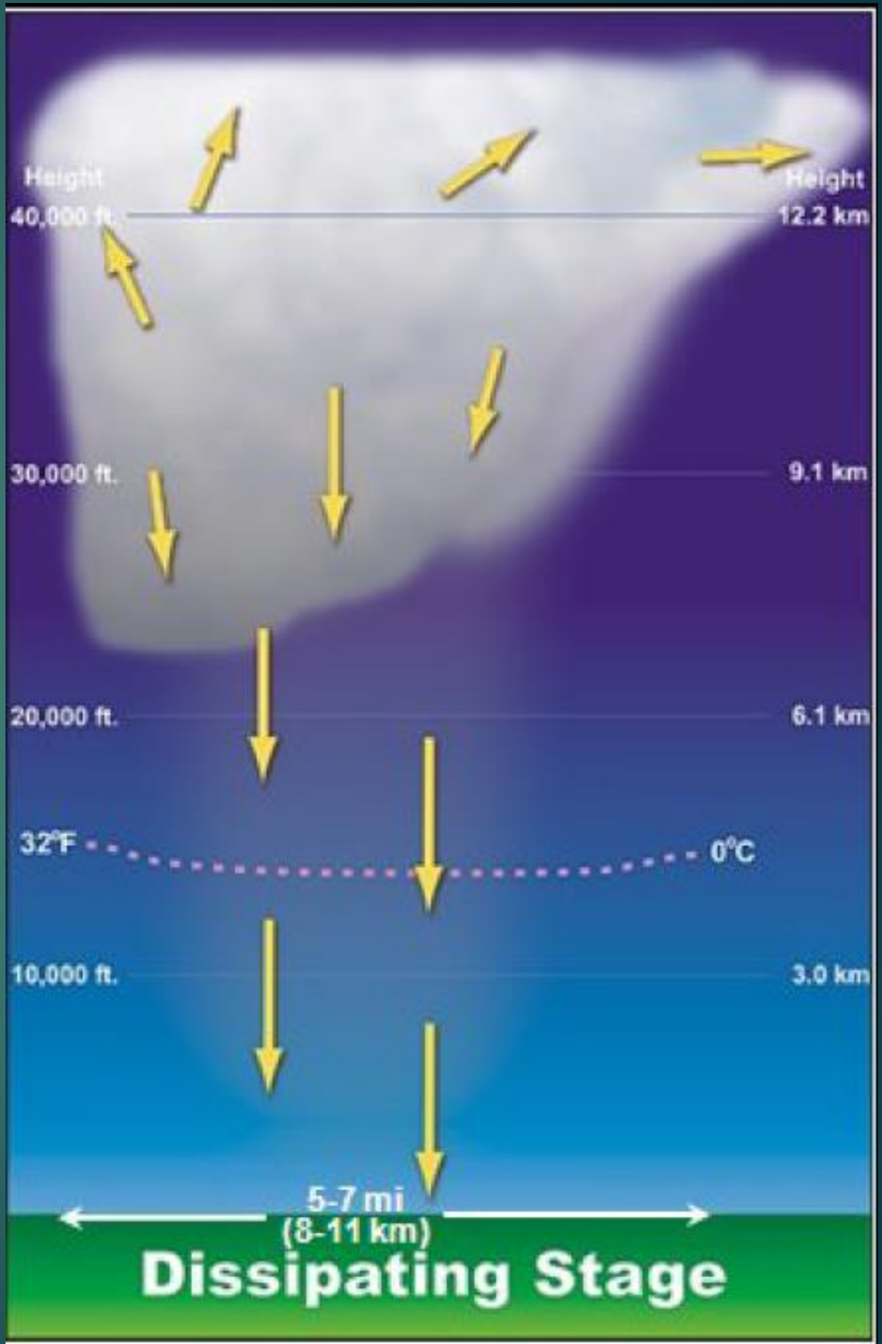
Precipitation descends through the cloud and drags the adjacent air downward, creating a strong downdraft alongside the updraft.

Weather hazards reach peak intensity toward the end of the mature stage.



Dissipating

The dissipating stage is marked by a strong downdraft embedded within the area of precipitation. Subsiding air replaces the updraft throughout the cloud, effectively cutting off the supply of moisture provided by the updraft. Precipitation tapers off and ends. Compression warms the subsiding air and the relative humidity drops.

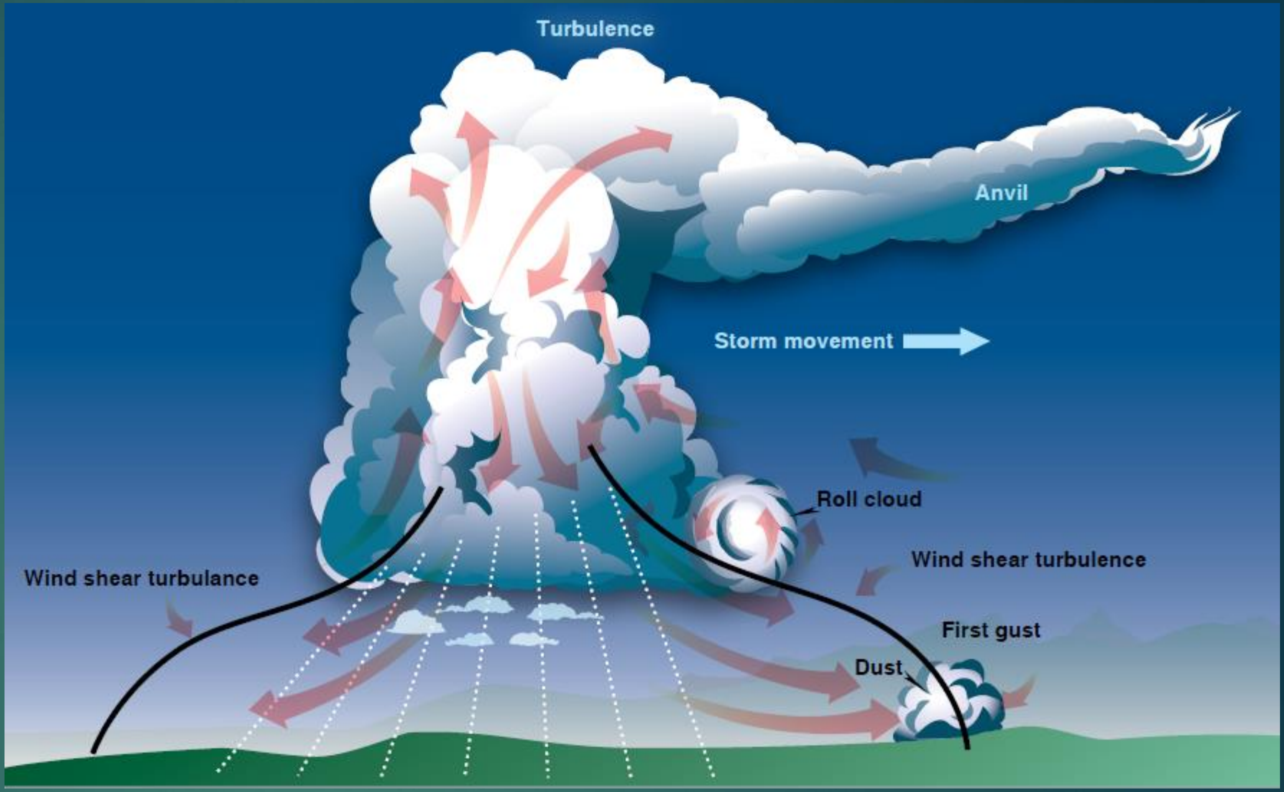


Thunderstorm Hazards

- Lightning
- Icing
- Hail
- Rapid Altimeter Changes
- Static Electricity
- Tornados
- Turbulence
- Adverse Wind
- Downbursts

Turbulence

Turbulence is present in all thunderstorms. Severe or extreme turbulence is common.



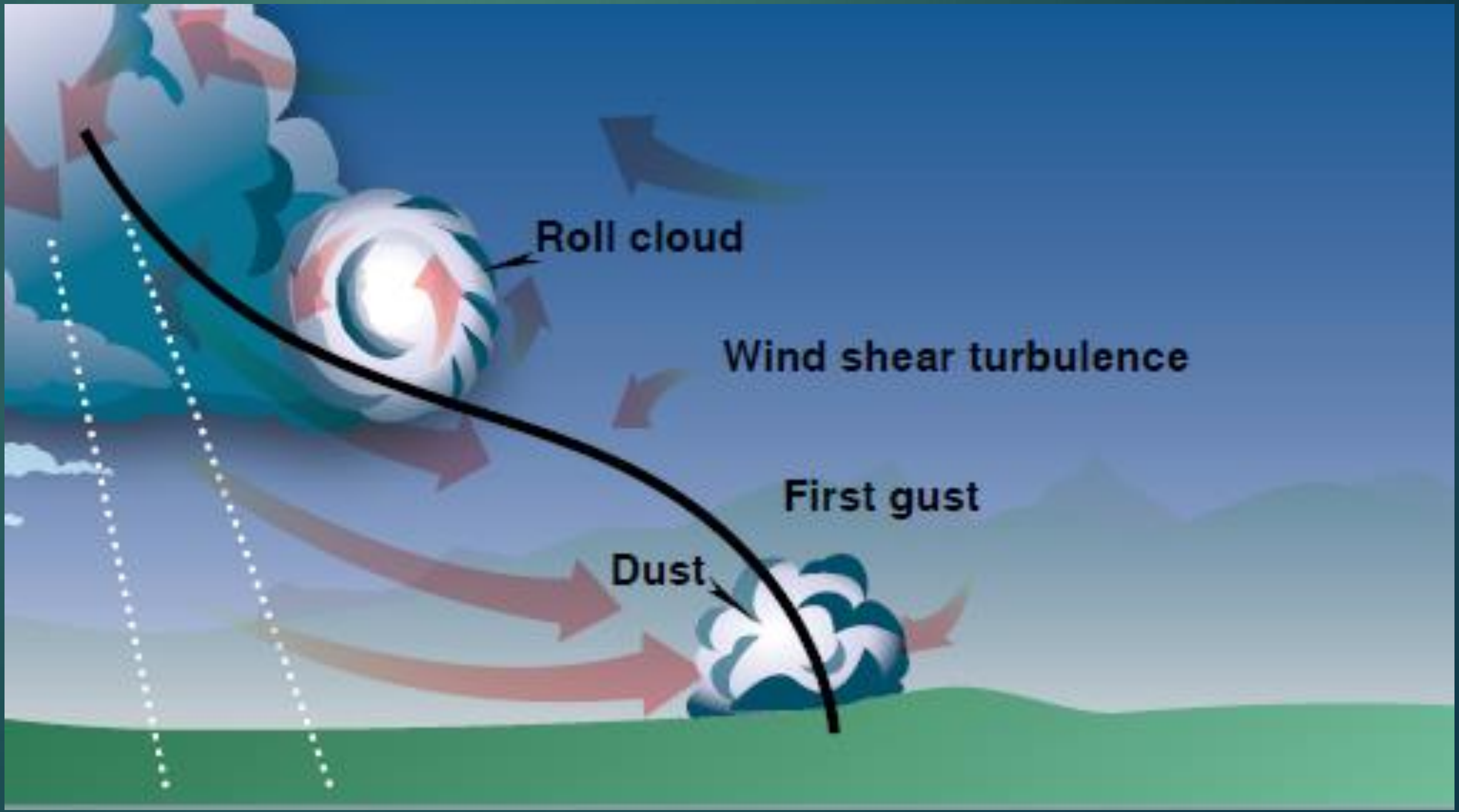
Gust loads can be severe enough to stall an aircraft at maneuvering speed or to cause structural damage at cruising speed. The strongest turbulence occurs with shear between updrafts and downdrafts. Outside the cumulonimbus cloud, turbulence has been encountered several thousand feet above, and 20 miles laterally from, a severe storm.

Turbulence

The wind-shear zone between the gust front and surrounding air is very turbulent airspace. The surface position of the gust front can be identified by a line of dust or debris along the ground, a line of spray along bodies of water, or a shelf cloud as seen here.

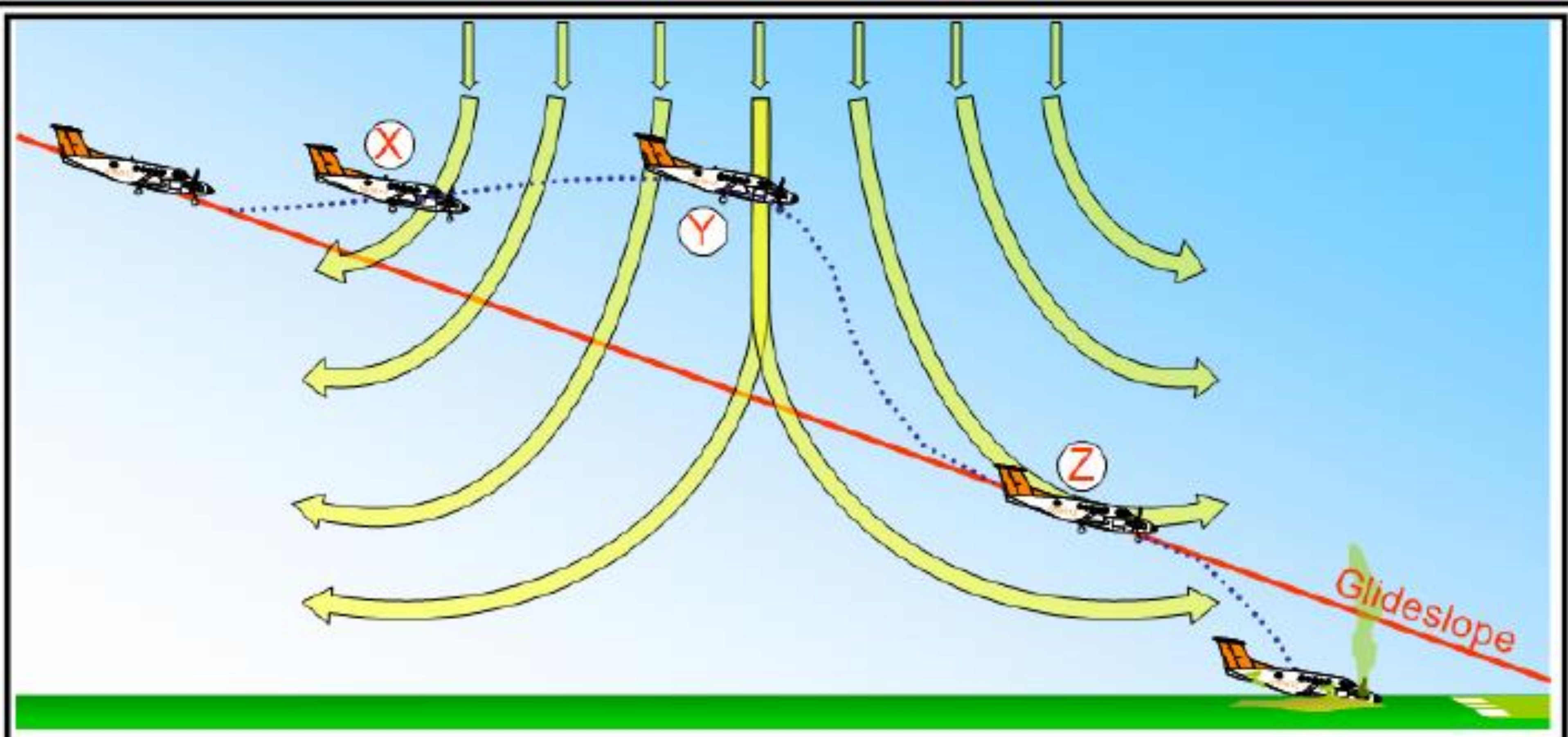
Adverse winds

Adverse winds are always found within thunderstorms and often many miles away from the precipitation area. The area along and immediately behind the gust front is particularly dangerous because this is where rapid and sometimes drastic changes in surface winds occur.



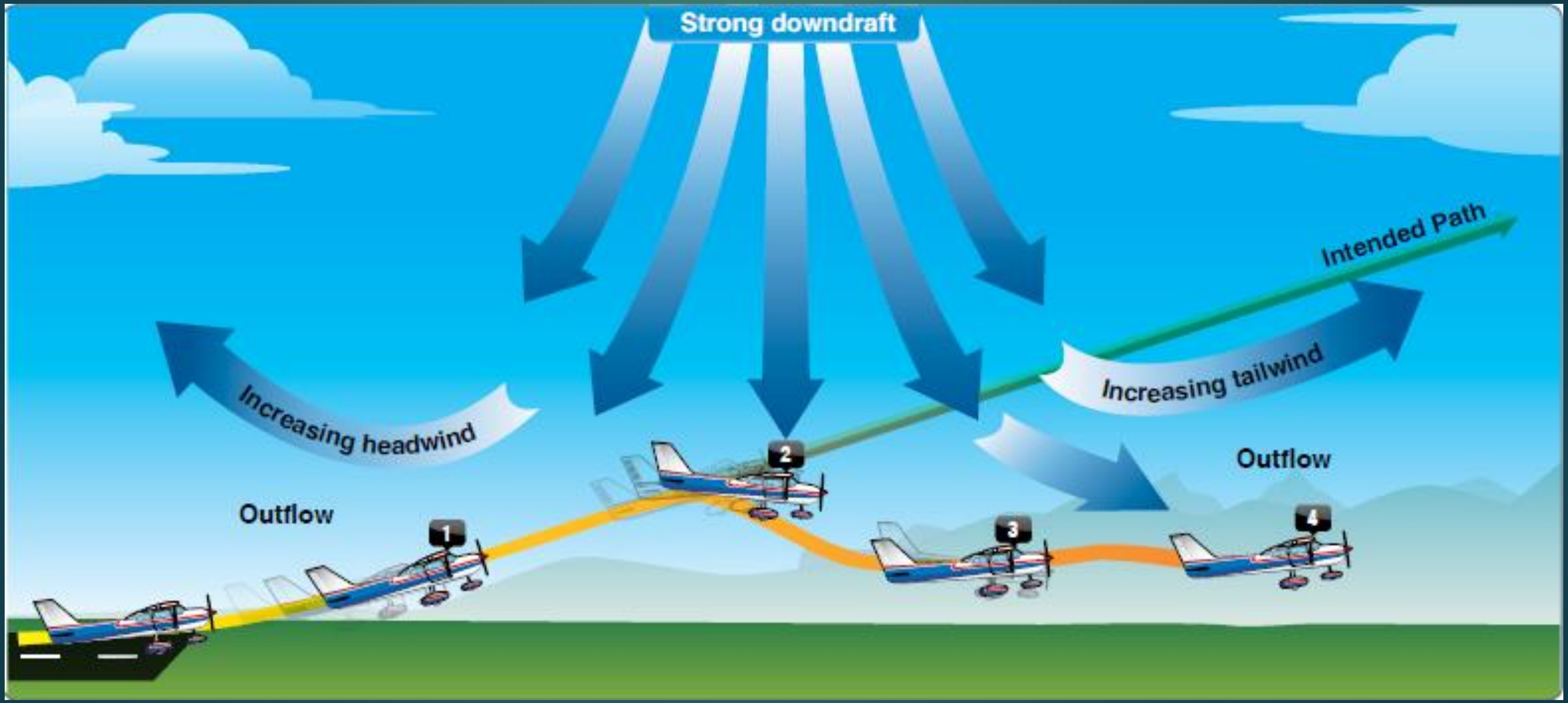
Adverse winds

Crosswinds, gusts, sudden wind shifts, and downbursts can lead to a crash during takeoffs, approaches, and landings.



Low level wind shear

While microbursts are often associated with thunderstorms, they can occur far away from visible precipitation.



Other Causes of Turbulence

- Convection
- Mechanical Turbulence
  - Mountain Waves
  - Wind Shear
  - Temperature Inversion
  - Clear Air Turbulence

Obstructions to Visibility

- Fog
- Mist
- Haze
- Smoke
- Precipitation
- Blowing Snow
- Dust Storms
- Sandstorms
- Volcanic Ash

Fog

Fog forms when the temperature of the air and the dewpoint are the same. This may occur through cooling of air or by adding moisture. Fog seldom forms when there is a more than 2°C (4°F) difference between the air temperature and the dewpoint.

Fogs caused by cooling of air	Fogs caused by adding moisture
Radiation fog	Frontal fog
Advection fog	Steam fog
Upslope fog	

Fogs caused by cooling of air

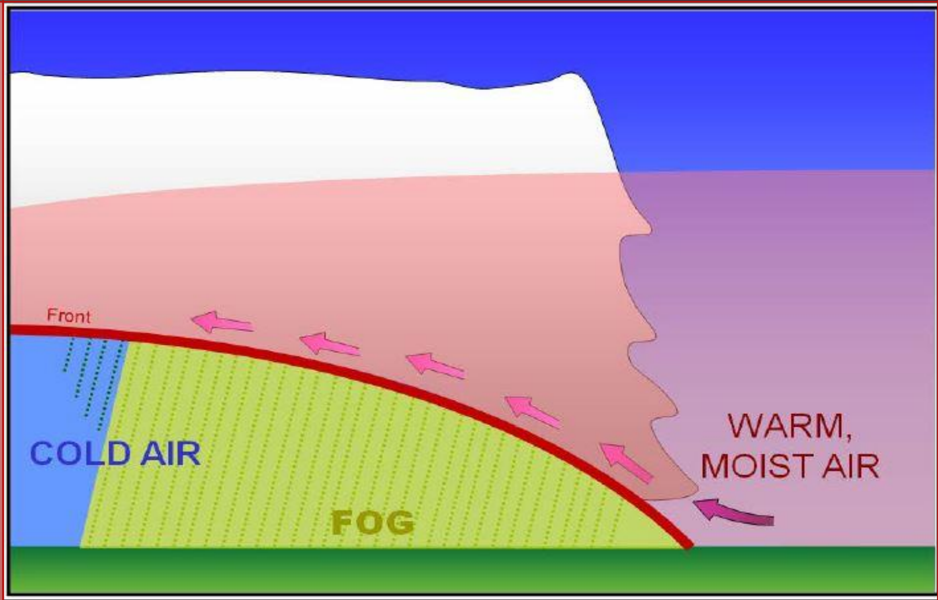
Radiation fog is produced over a land area when radiational cooling reduces the air temperature to or below its dewpoint.

Advection fog forms when moist air moves over a colder surface and cools below its dewpoint.

Upslope fog forms as a result of moist, stable air being adiabatically cooled to or below its dewpoint as it moves up sloping terrain.

Fogs caused by adding moisture

Frontal fog is formed when warm, moist air is lifted over a front. If the cold air below is near its dewpoint, evaporation from the precipitation may saturate the cold air and form fog. It is most commonly associated with warm fronts, but can occur with other fronts as well.



Steam fog is formed when very cold air moves across relatively warm water. It is commonly observed over lakes and streams on cold autumn mornings, and over the ocean during the winter when cold air masses move off the continents and ice shelves.

Icing: Two Types (only one is weather)

- Structural Icing
- Engine icing
  - Carburetor icing (aspirated engines)
  - High ice/water content (turbine engines)

Icing Factors

- Structural airframe icing occurs when supercooled water comes into contact with aircraft surfaces
- Clear ice can occur at any altitude above the freezing level
- High altitude precipitation may be clear, rime, or mixed
- Icing can occur anytime the temperature approaches 0 °C and visible moisture is present.
- The heaviest icing hazards occur in clouds below 6,500 ft
- Altostratus clouds (~6,500 – 20,000 ft) also contain moderate icing hazards
- Clouds are infrequent above 20,000 ft, making high altitudes less of an icing hazard