

# Weather Theory

## Objective

To understand basic meteorology concepts and how they relate to aviation, especially those that affect the safety of flight.

## Motivation

- We need to understand how weather affects airplane performance
- We want to effectively interpret weather data



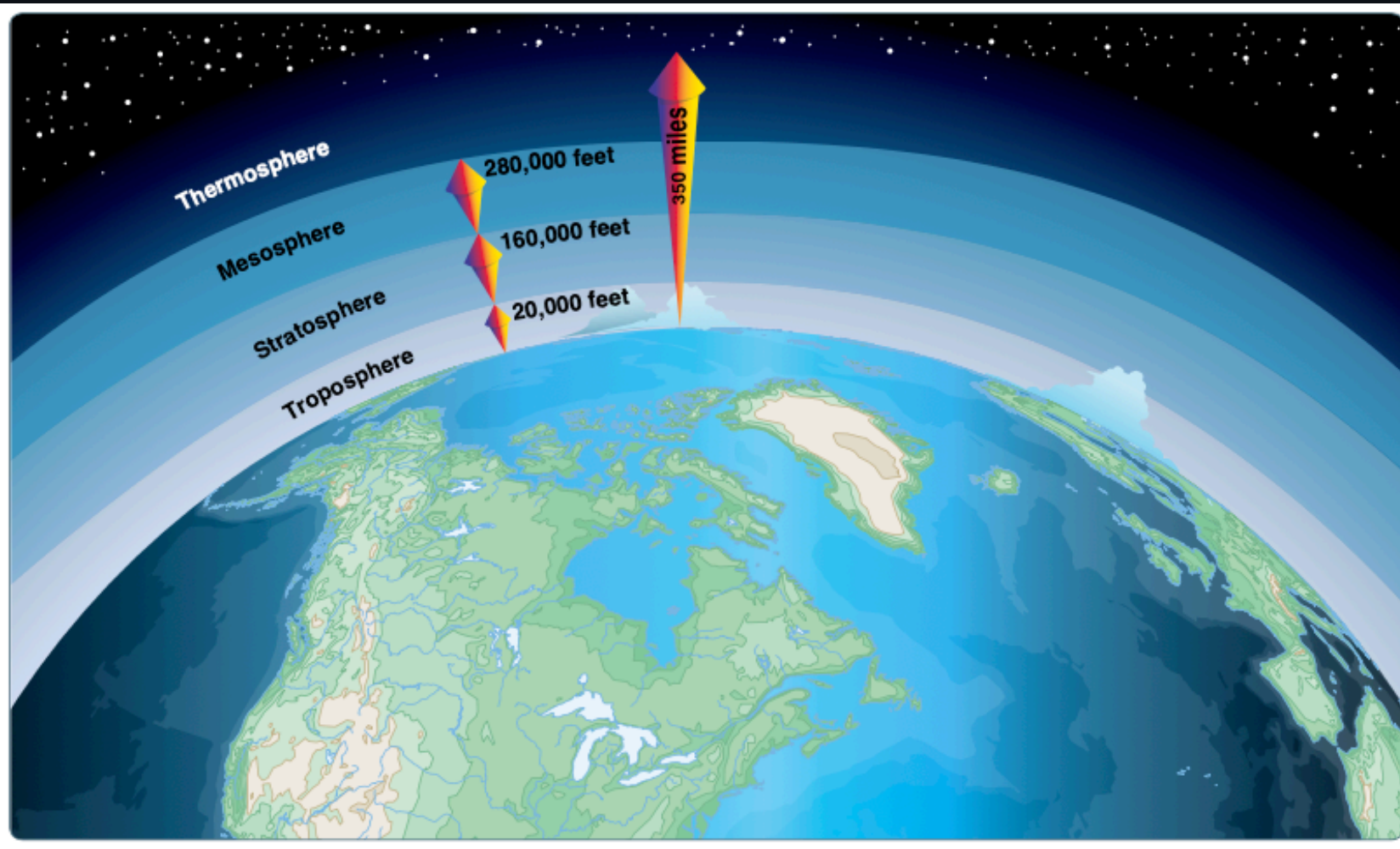
# What are the most important weather decisions we will make?



- Go/no go decisions
- Route planning
- Decisions to divert

# Overview

- The atmosphere
- Temperature
- Pressure
- Wind
- Turbulence
- Stability
- Moisture, fog, and clouds
- Air masses and fronts
- Thunderstorms



# Atmosphere

Air is around 78% nitrogen, 21% oxygen.

Remains a constant proportion as you ascend.

# The Standard Atmosphere

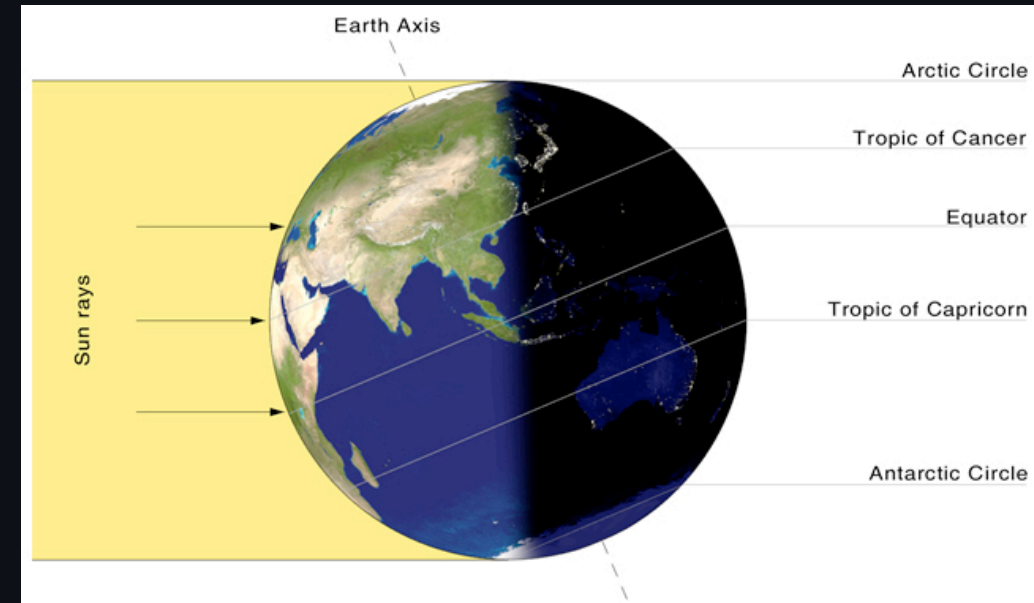
- The real atmosphere is always changing
- We use the **International Standard Atmosphere** as a fixed reference
  - 29.92 inches Hg at sea level
  - 15° C (59° F) at sea level
  - Temperature drops 2° per 1000 feet
  - Pressure drops 1" per 1000 feet

# Temperature

- Temperature describes the heat energy contained in a substance
- Substances absorb and retain heat differently
  - Land will become hot quickly and radiate lots of heat
  - Water will absorb and emit little heat energy

# Temperature Variation

- Diurnal variation: Changes in temperature from day to night
- Seasonal variation: Summer vs winter temperatures
- Latitude variation: Equatorial regions are hotter than polar regions



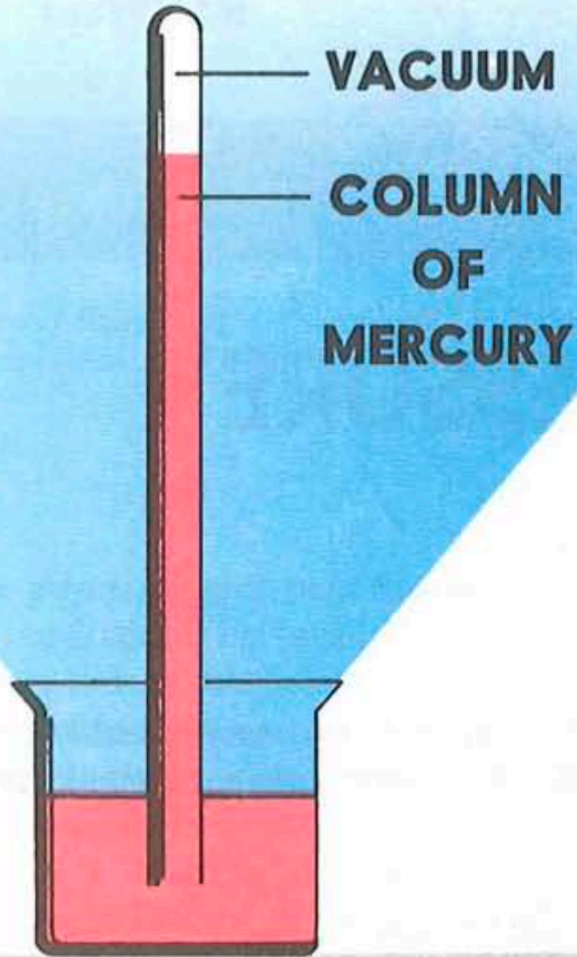


## Temperature Variation (cont.)

- Topography variation
  - Dry, barren surfaces emit heat more than wet or vegetated regions
- Altitude variation: Temperature decreases with altitude
  - Rate is given by the **lapse rate**
  - Average lapse rate is **2°** per 1000 feet



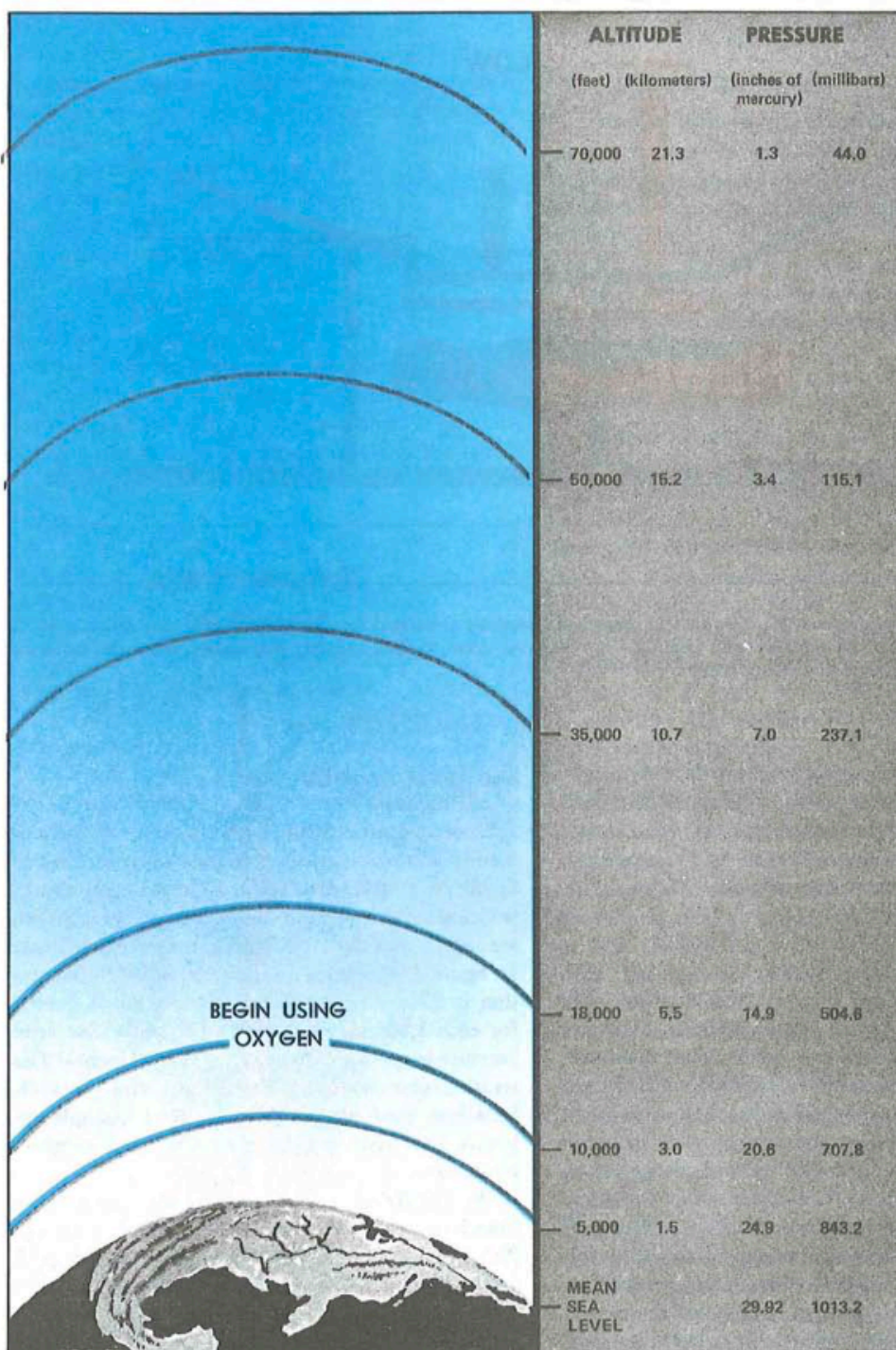
## ATMOSPHERIC PRESSURE



## Pressure

- Atmospheric pressure is the force per unit area exerted by the weight of the atmosphere
- Pressure units:
  - Pounds per square inch (PSI)
  - Millibars
  - Inches of mercury (e.g. 29.92" Hg)
- Ambient pressure at sea level:
  - ~14.7 (PSI)
  - 1013.2 millibars
  - 29.92" Hg

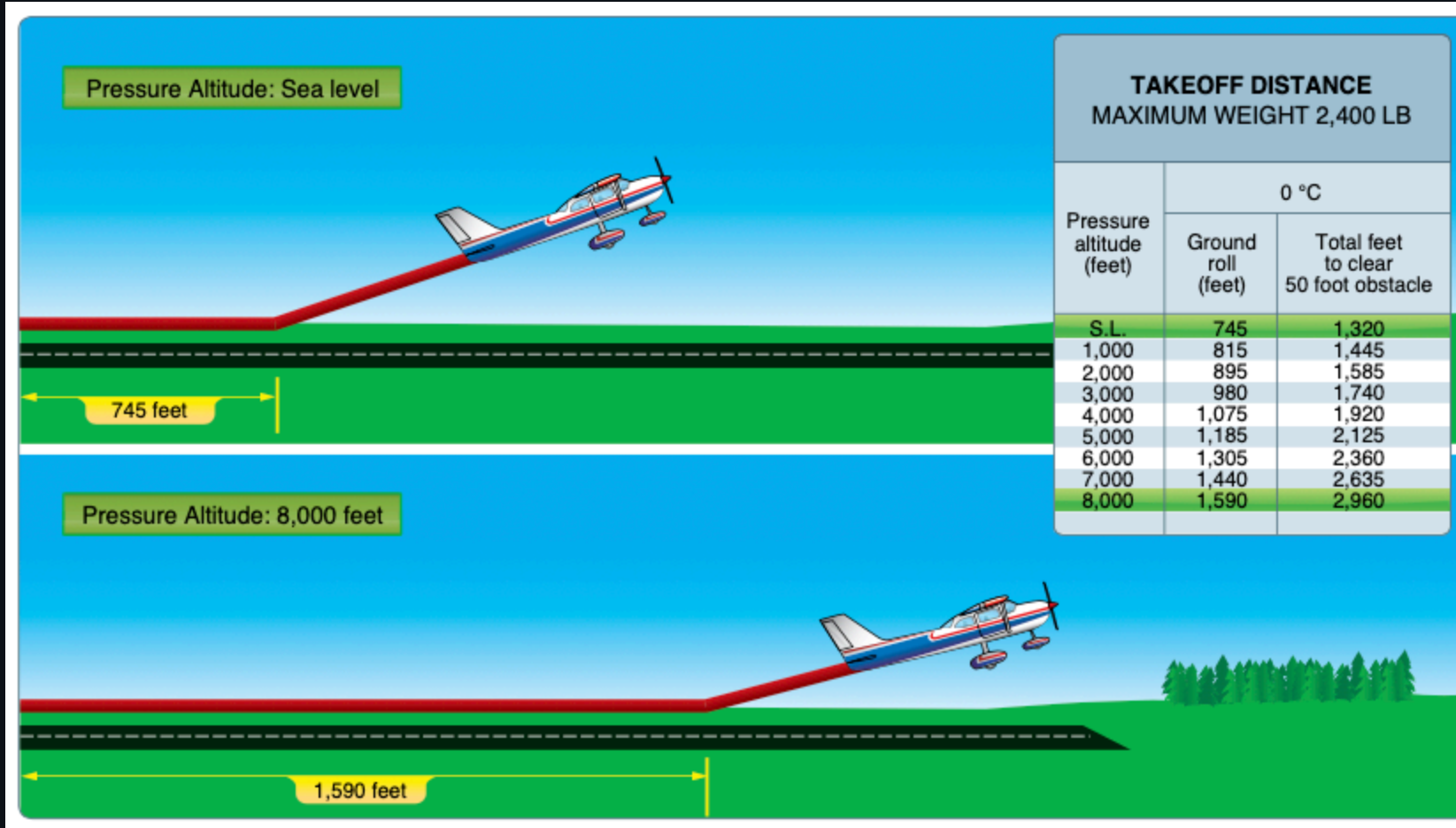




## How does pressure change with altitude?

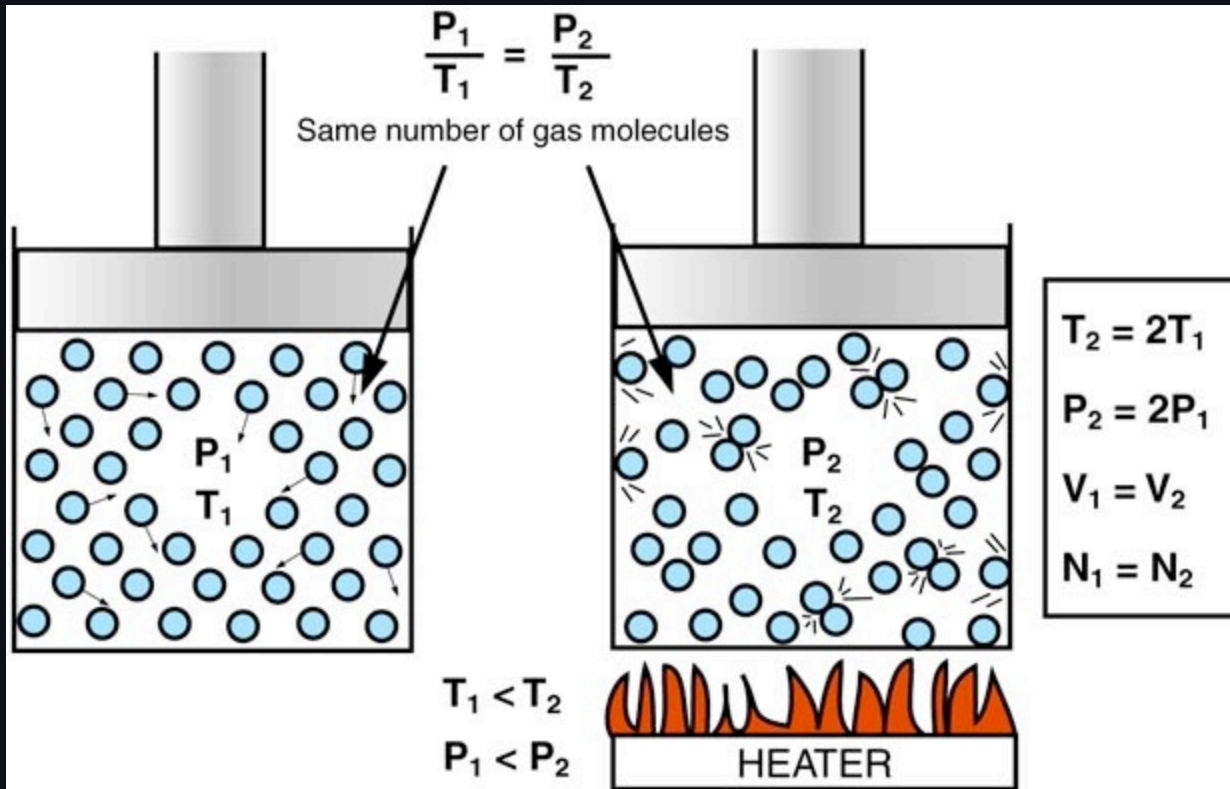
- Pressure decreases as you ascend in the atmosphere
- Barometric pressure is about 50% dense at 18,000 ft
- Standard atmosphere
  - 29.92" Hg at sea level
  - Pressure drops 1" Hg per 1000 feet

# Less Pressure = Less Performance



# How does pressure change with temperature?

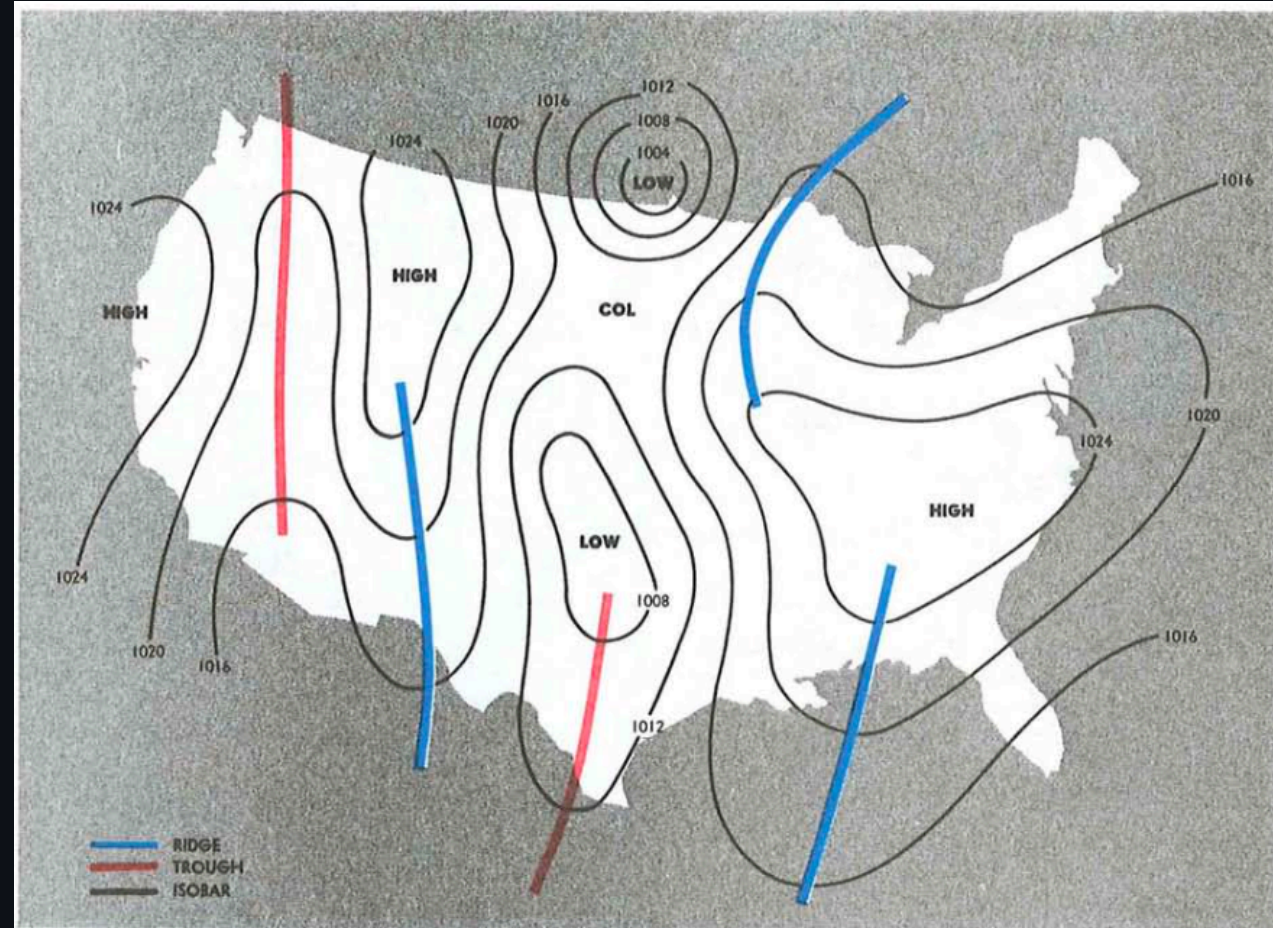
- How does air change with temperature?
- Higher temperature = higher pressure
- Air expands as it gets warmer



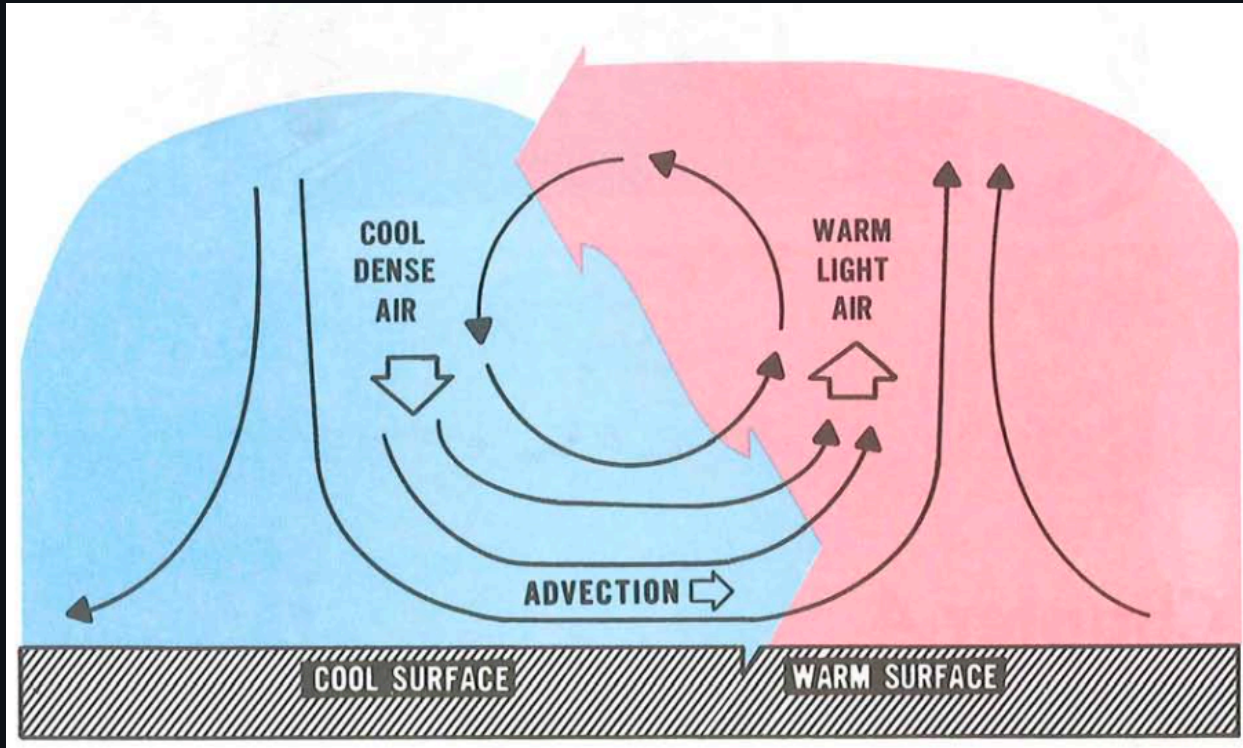


# Mapping Pressure

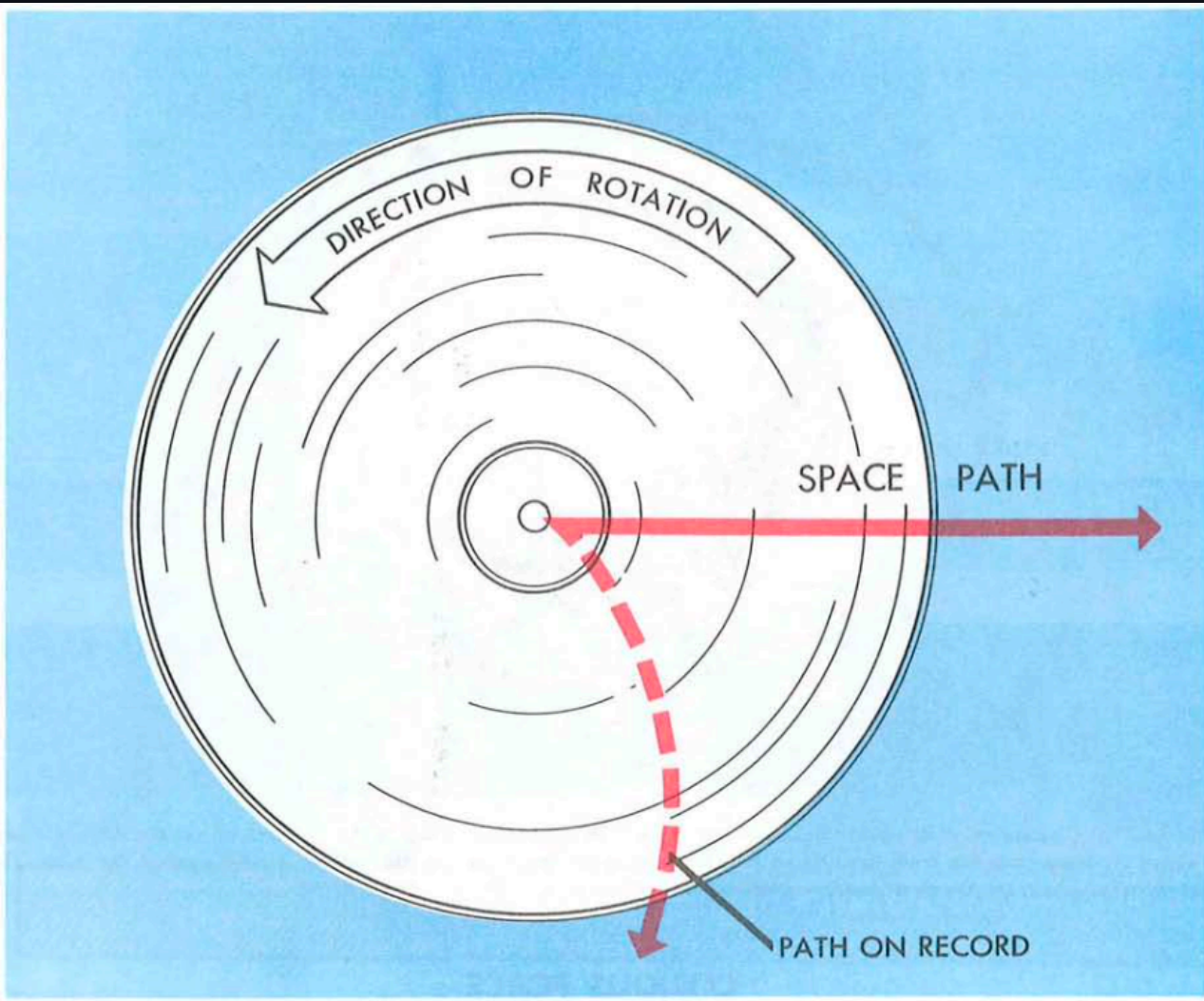
- What if we plot ambient pressure on a map?
- Black lines are called **isobars**:  
Lines of equal pressure
  - Like contours on a topographical map
  - Tightly spaced = big change in pressure over a small distance



# Wind and Advection



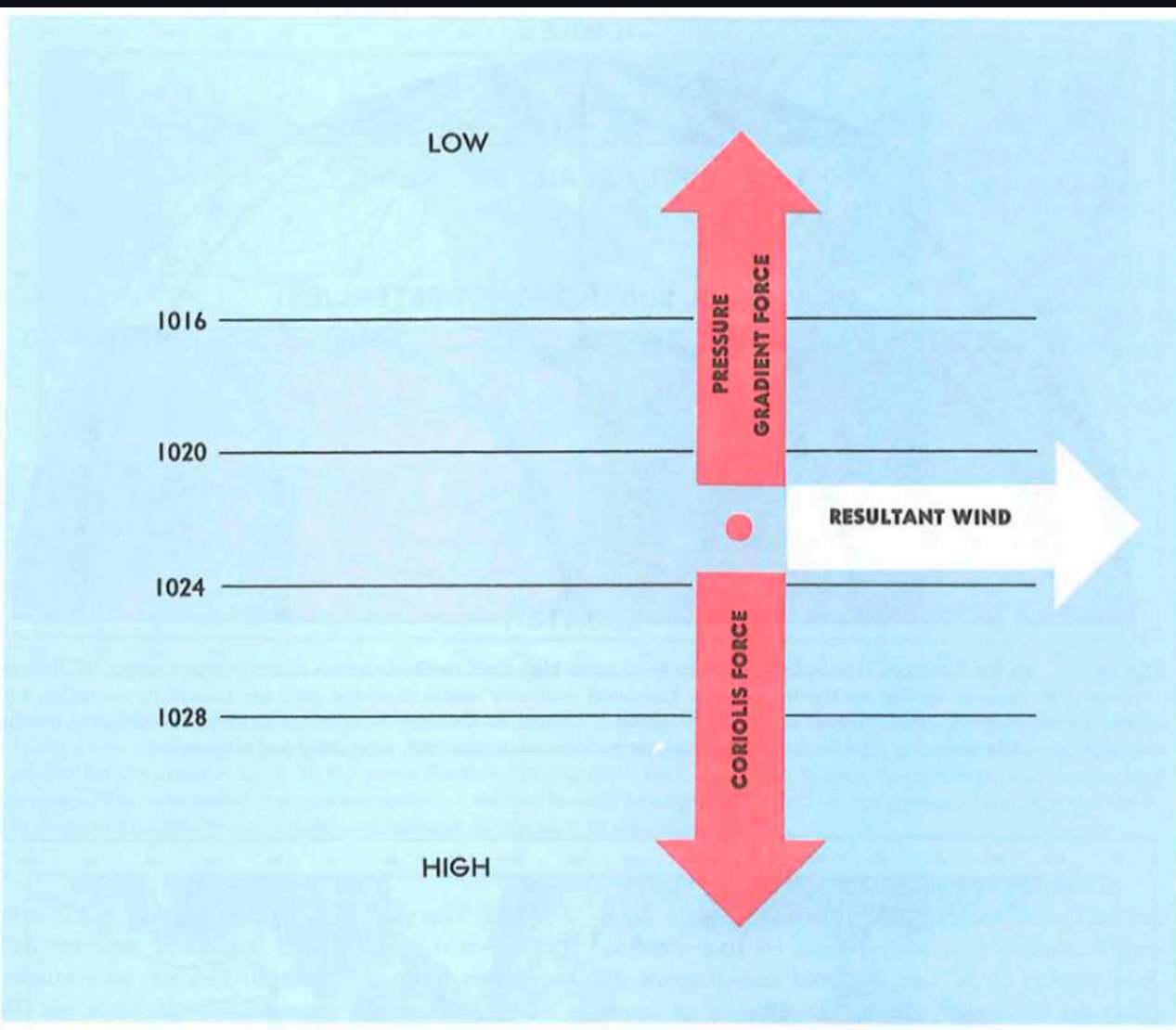
- Differences in temperature create differences in pressure
- Areas of high pressure want to equalize (move towards) areas of lower pressure
- This results in a **pressure gradient force**, which results in wind



## Coriolis Force

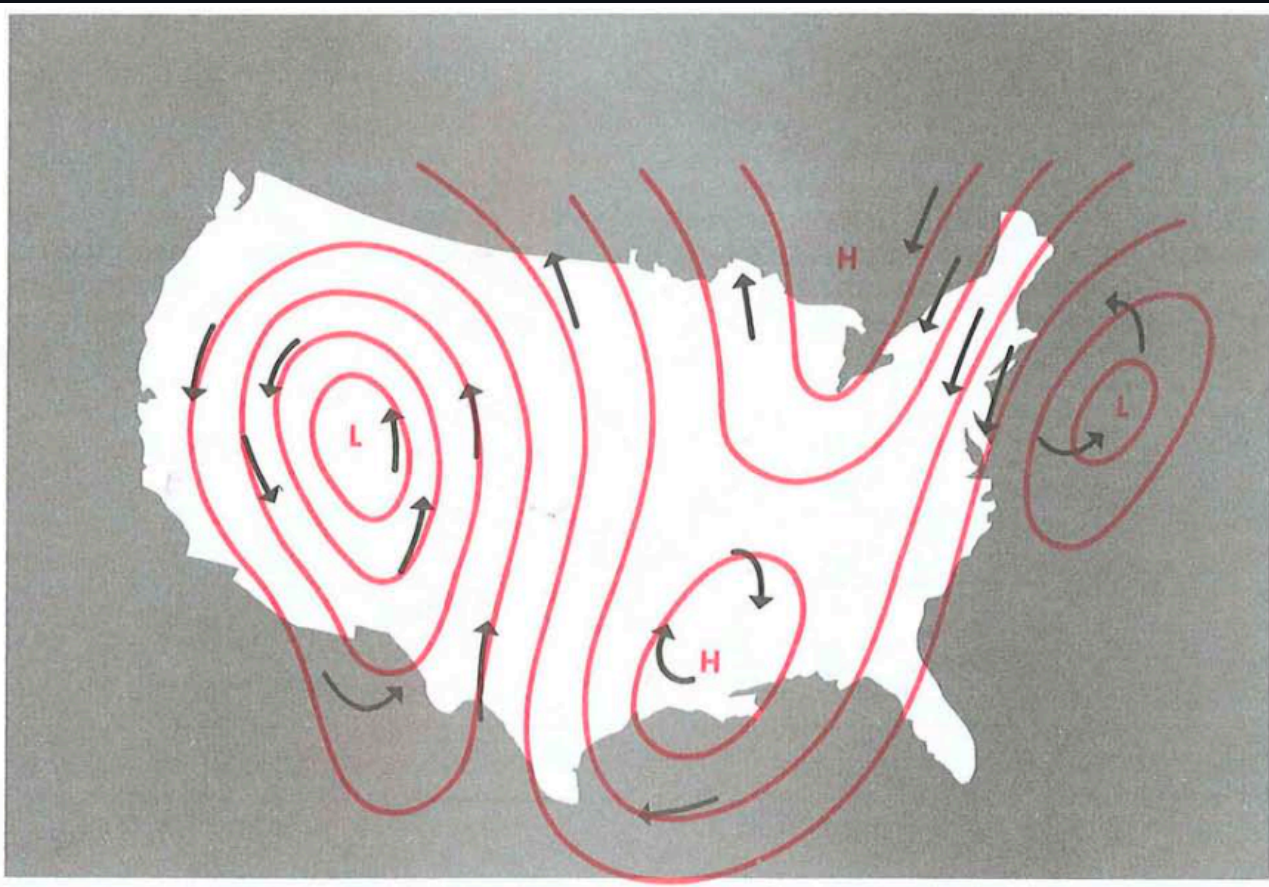
- The Earth is spinning, so objects that move in a straight line in space appear to be deflected to the right on the surface
- This "force" is zero at the equator and increases towards the poles





- The Coriolis force acts proportionally to wind speed and opposite the pressure gradient force
- This results in wind flowing *parallel* to the isobars





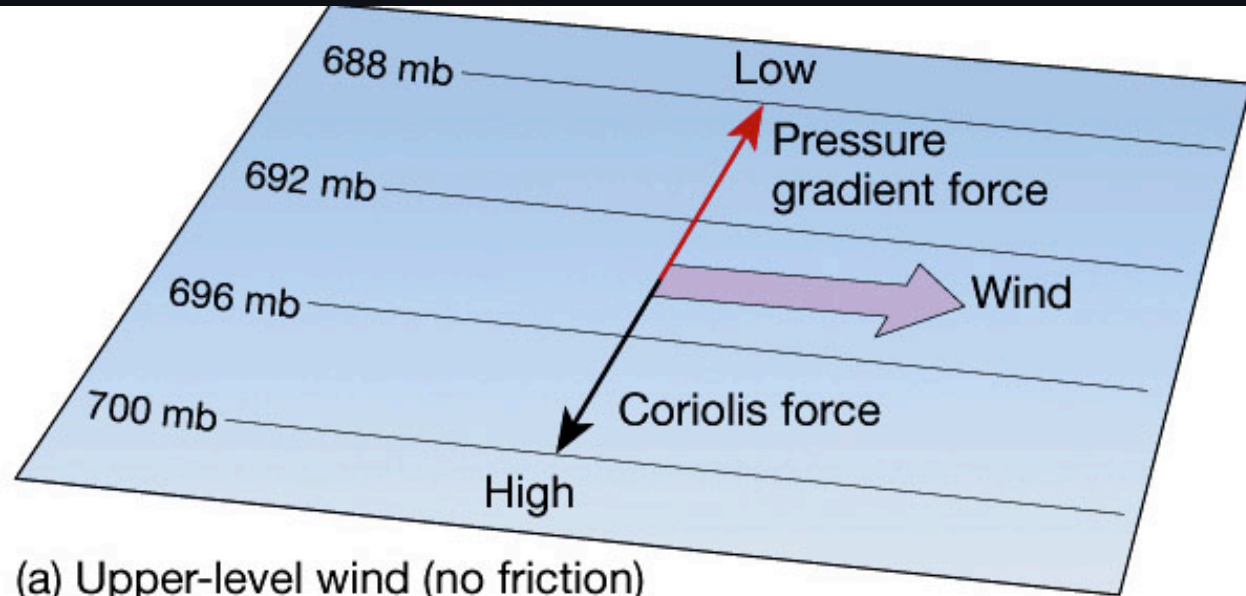
## Wind and Isobars

In the northern hemisphere:

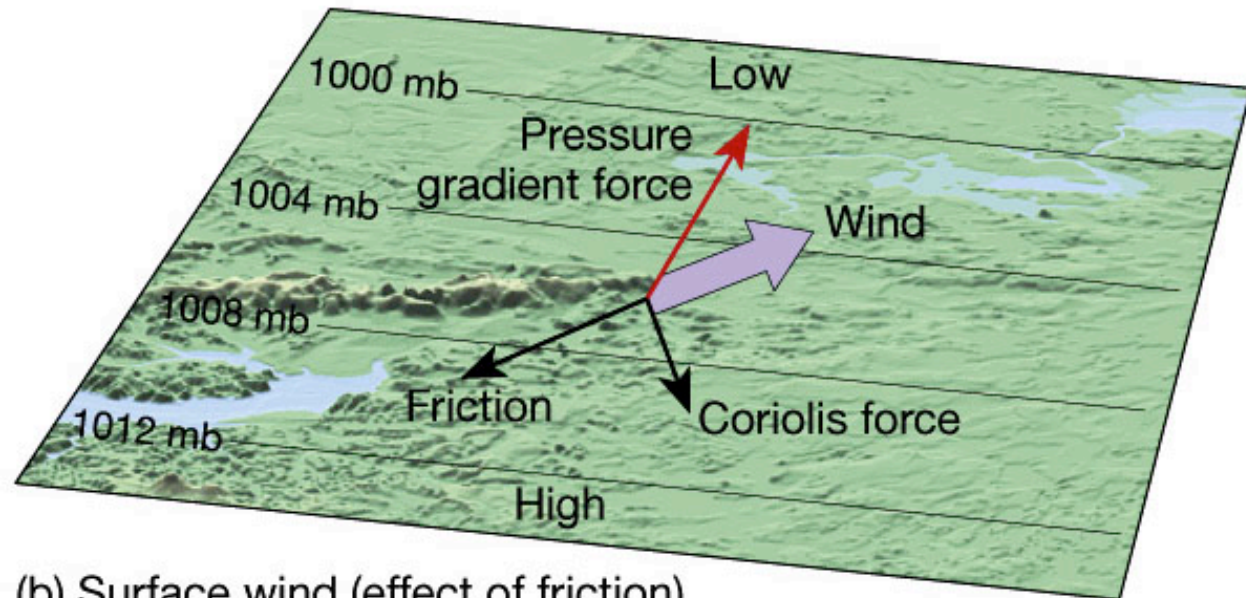
- Low pressure, inward and clockwise: anticyclonic
- High pressure, outward and counterclockwise: cyclonic

# Surface Friction

- When wind is close to the ground additional friction influences the wind direction
- Wind will flow at an angle across the isobars

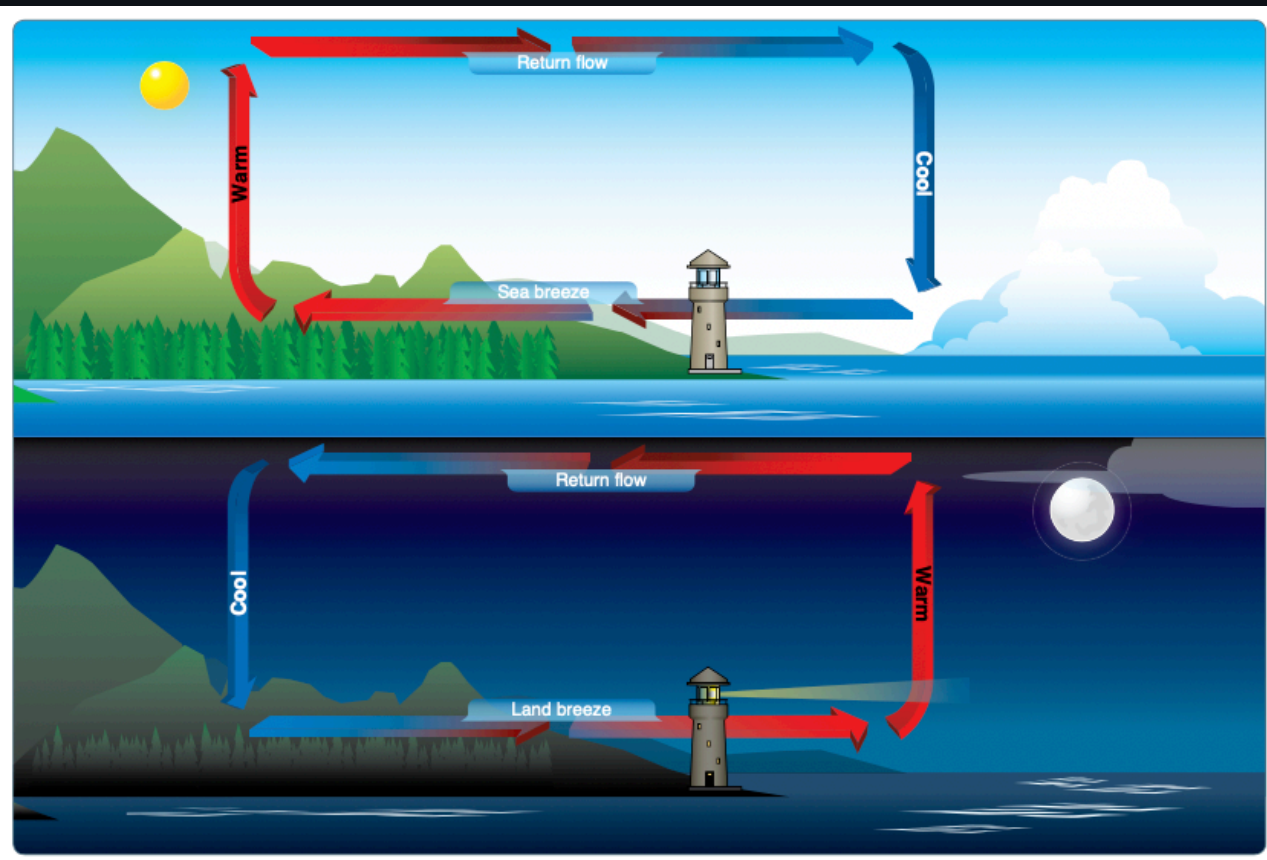


(a) Upper-level wind (no friction)



(b) Surface wind (effect of friction)

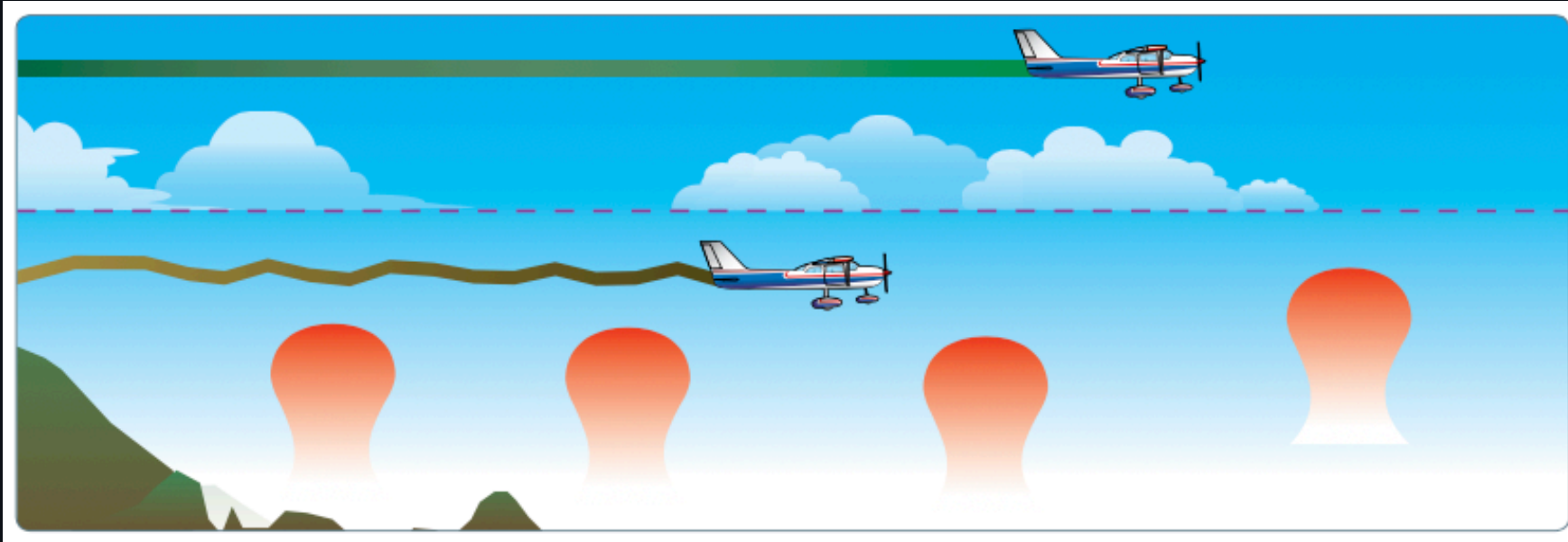
# Sea breeze and land breeze



- Sea breeze:
  - Land heats quickly, hot air rises
  - Low pressure which draws cool air from the sea onshore (on-shore wind)
- Land breeze:
  - Land cools faster, so warm air over water rises
  - Draws air towards the sea (off-shore wind)

**Turbulence**

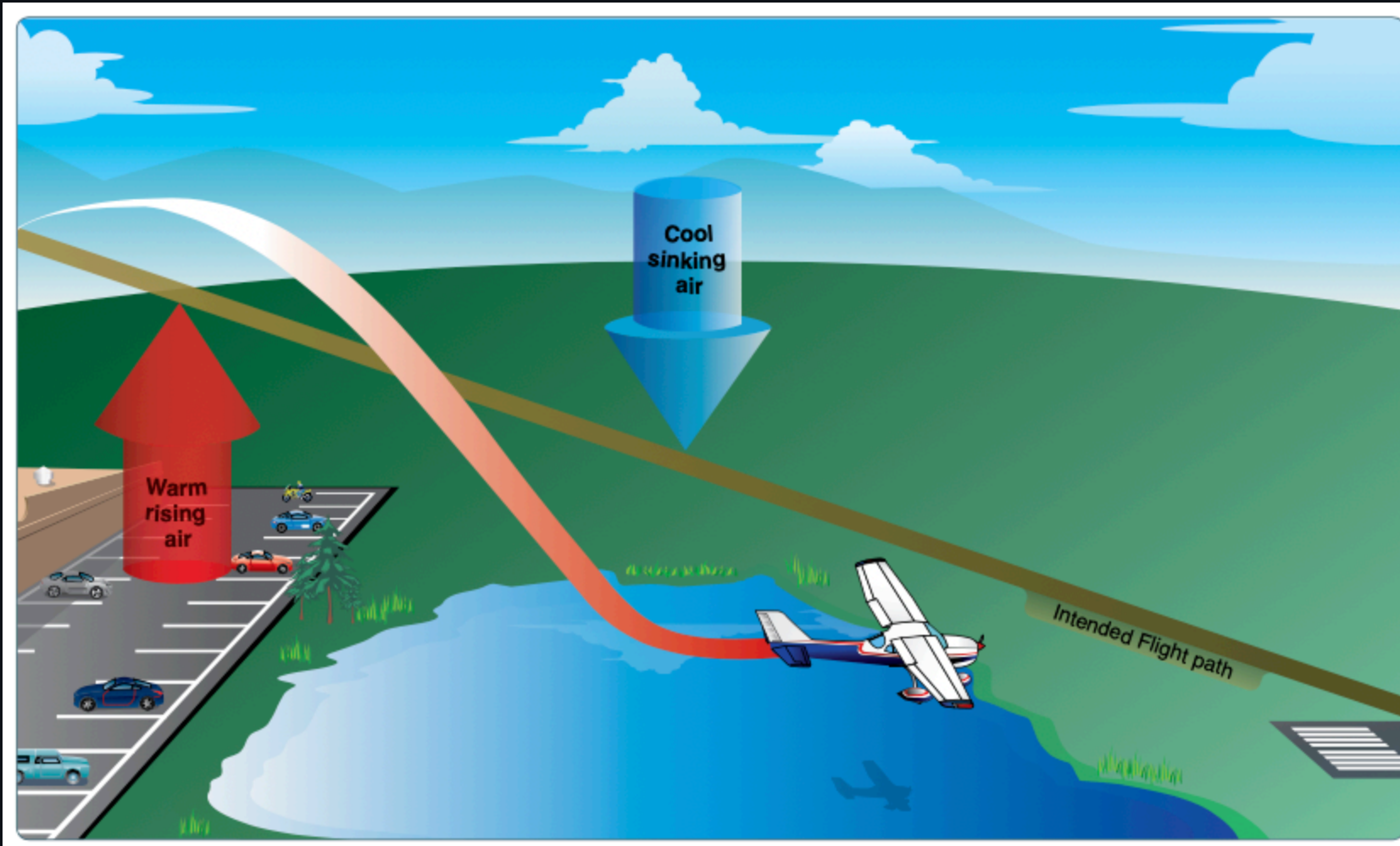
# Convective Heating

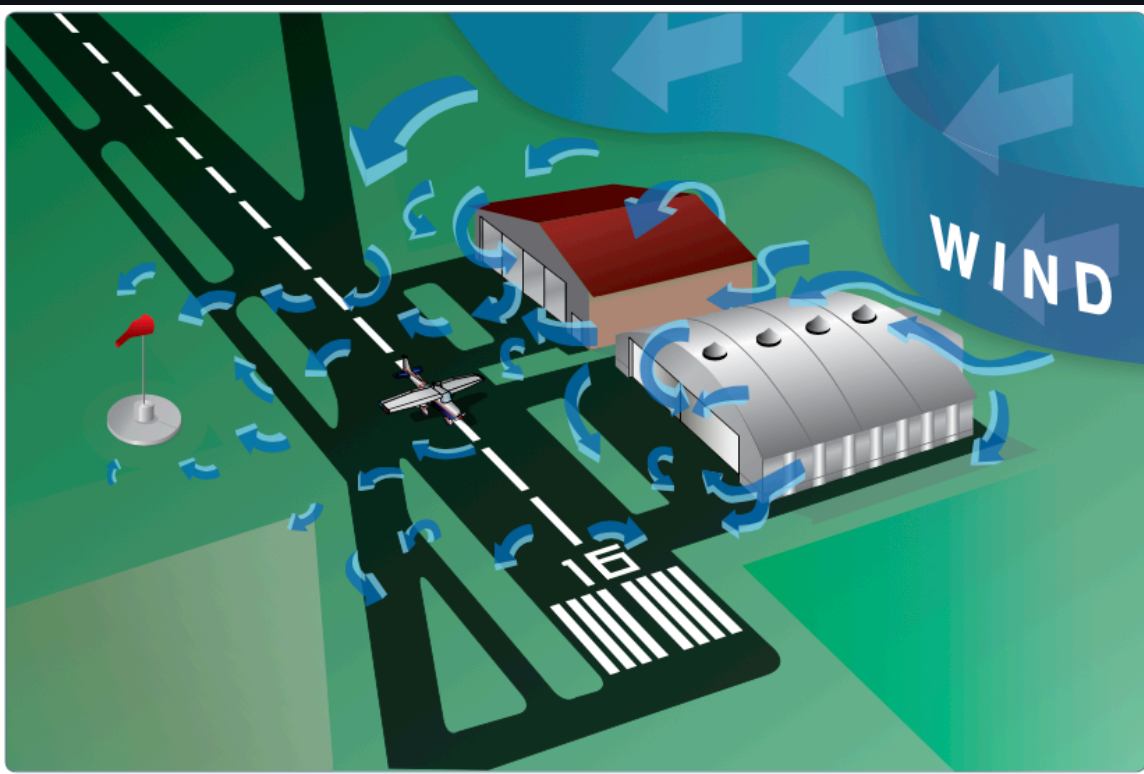


- Paved areas, plowed fields, dirt absorb and give off more heat quickly
- Trees, water, vegetation give off heat more slowly
- This uneven heating makes more warm pockets of air that cause turbulence



# Uneven Surface Heating

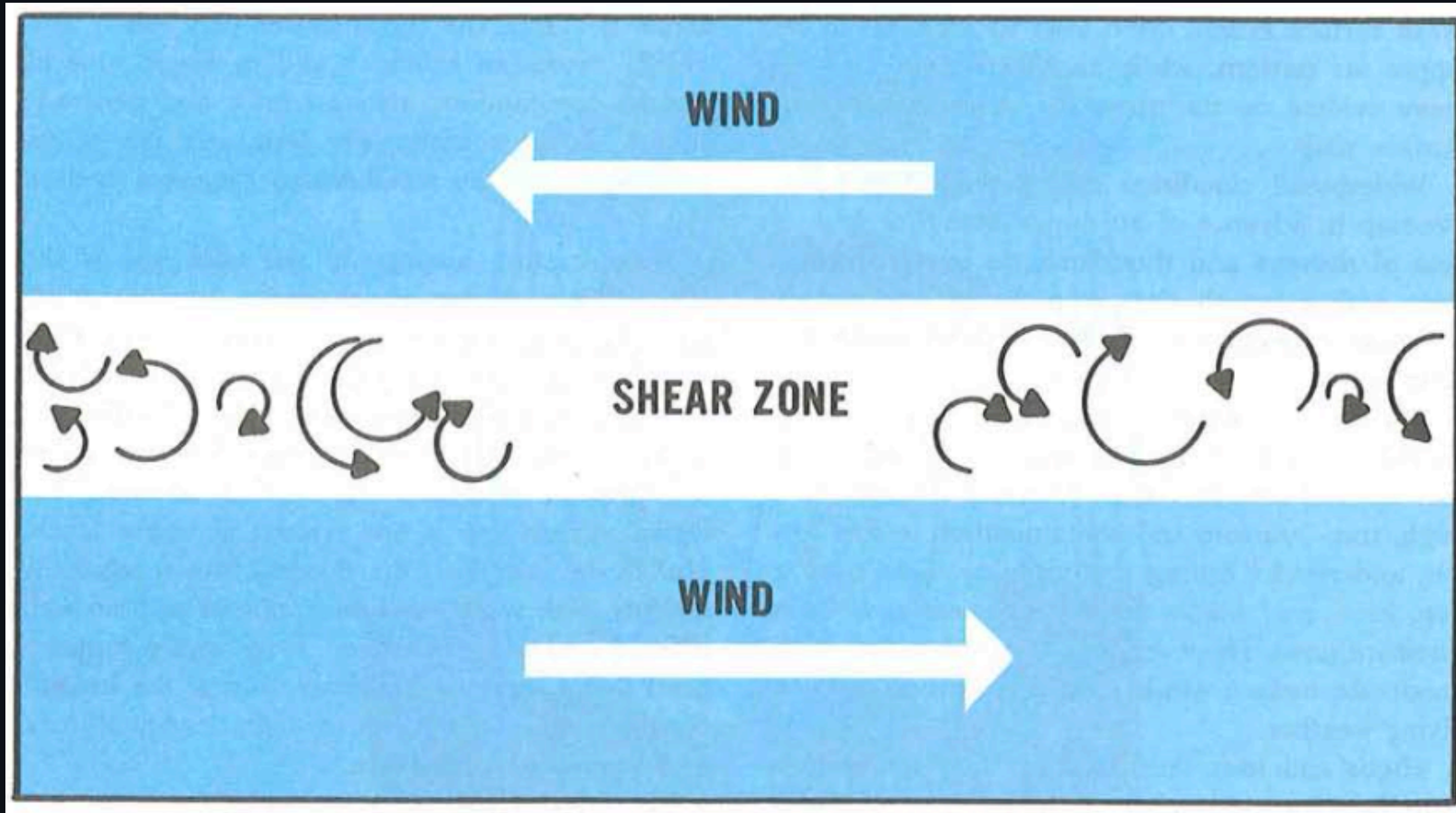




## Turbulent flows from obstructions

- Near the ground: hangars, buildings
- Mountains, ridges, bluffs

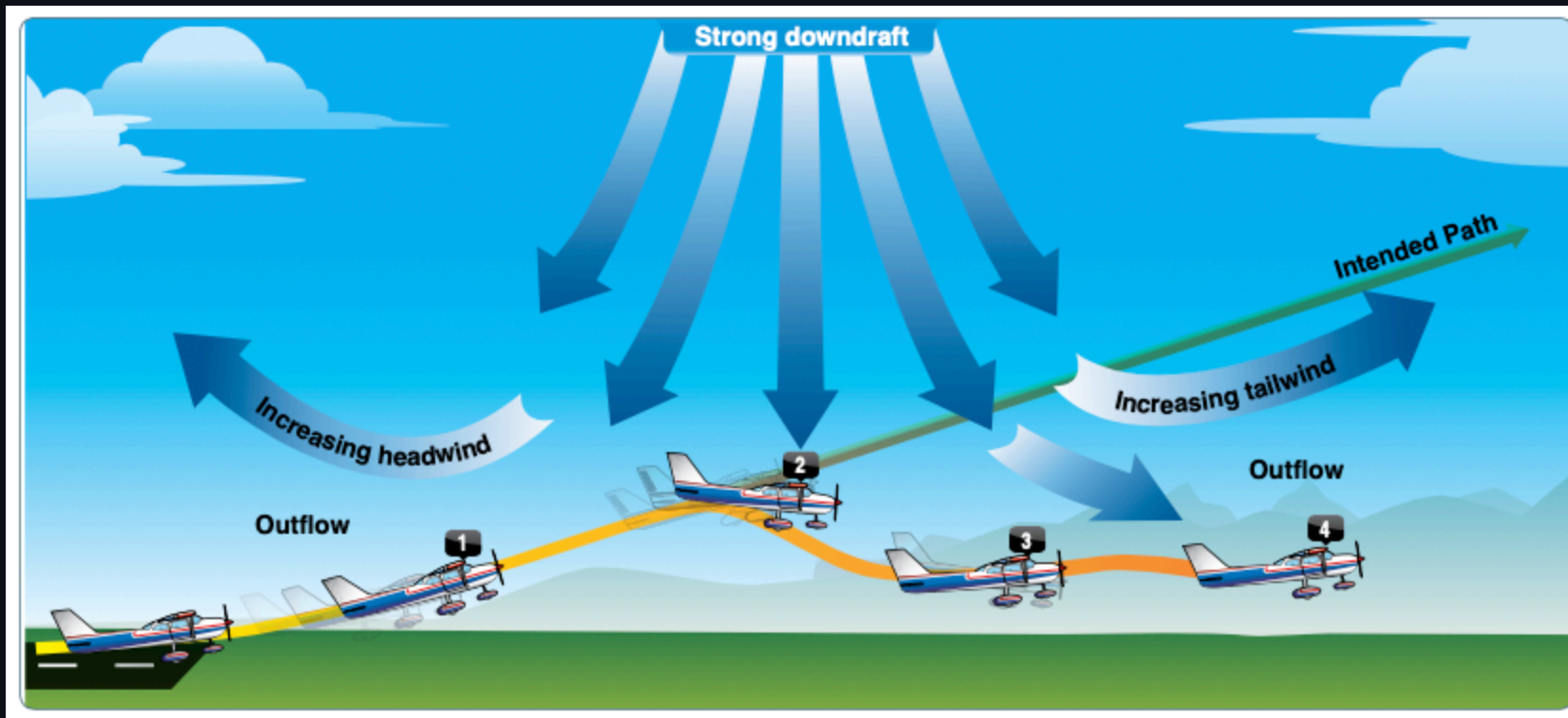
# Wind shear



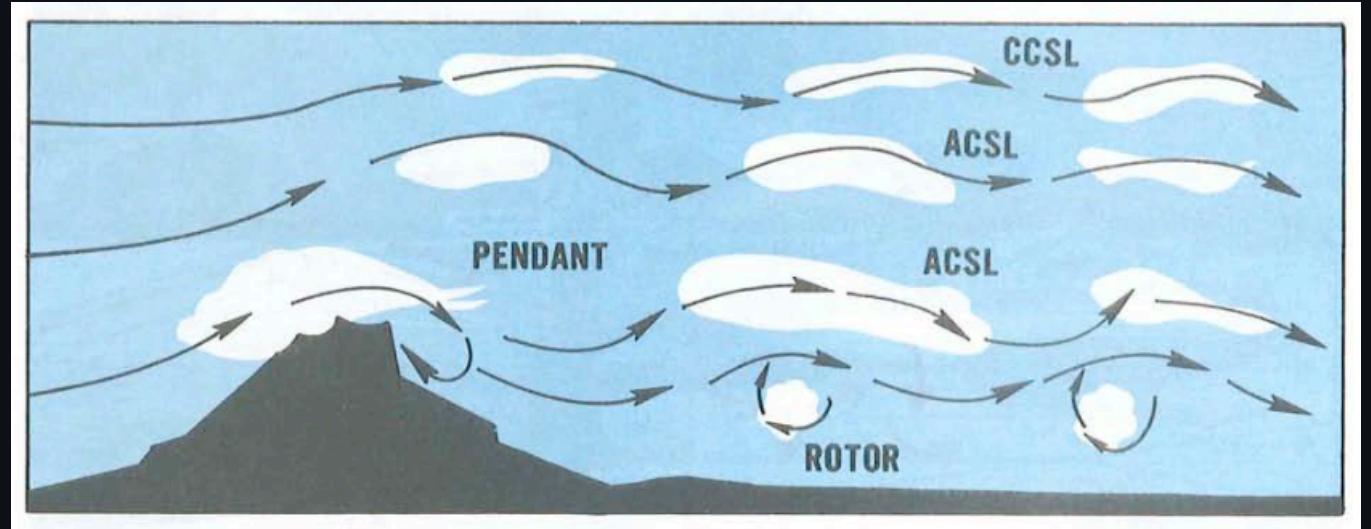
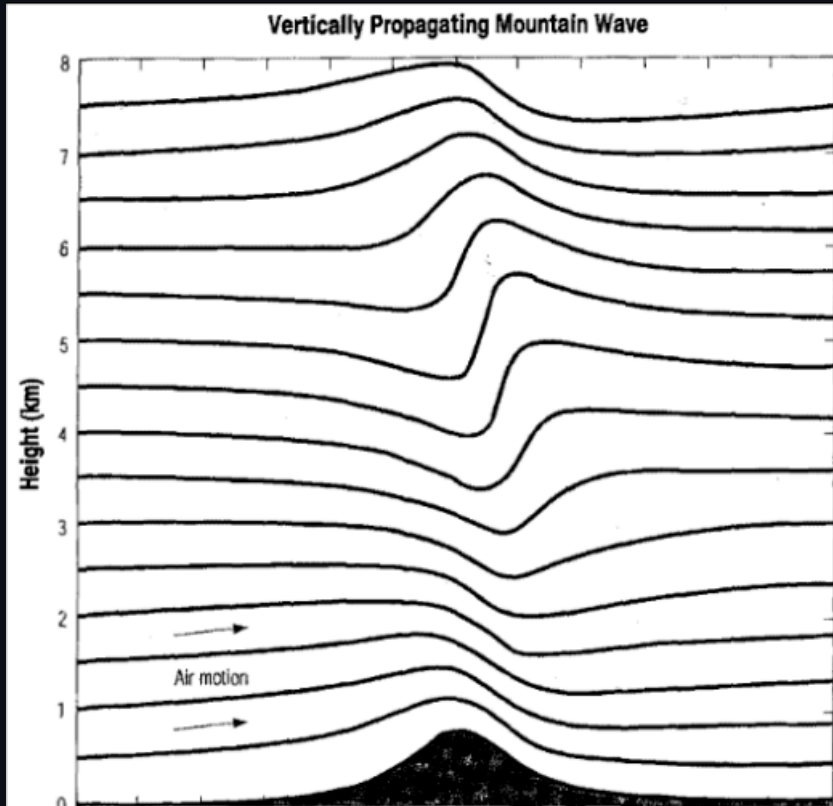
- Turbulent area with mixing between two air different air masses

# Low-level wind shear

- Microbursts, often the vicinity of thunderstorms
- Especially dangerous near the ground



# Mountain Wave



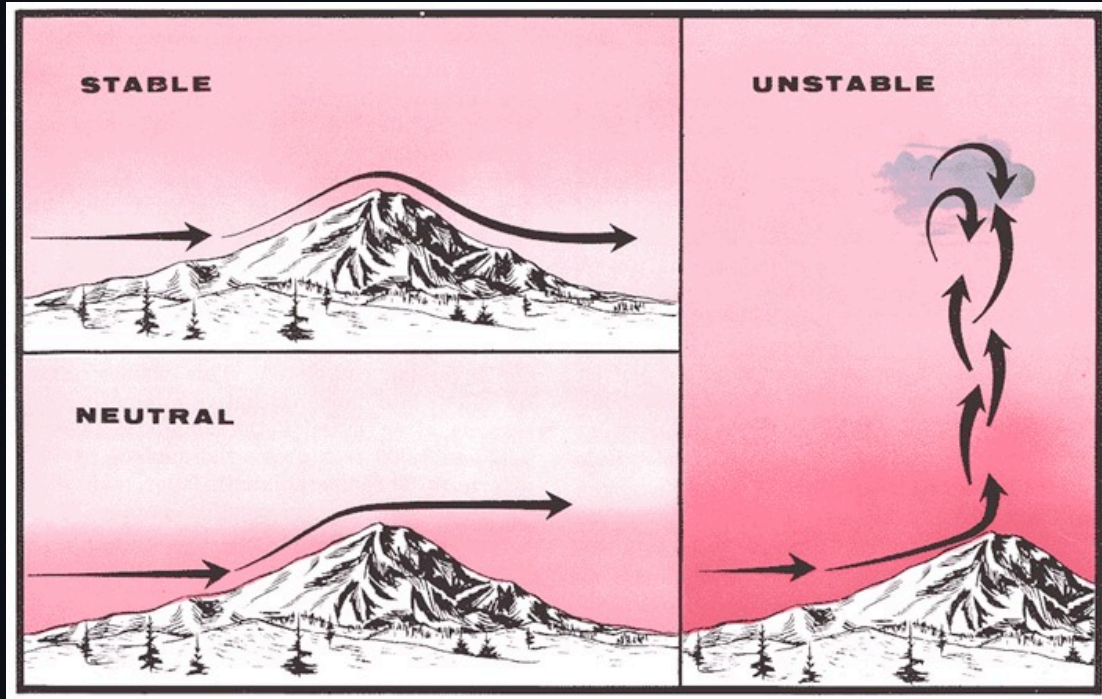
- Large updrafts on the upwind side of the ridge
- Large downdrafts on the leeward side
- Turbulence can be violent in the rotor
- Can extend for 100 miles downwind



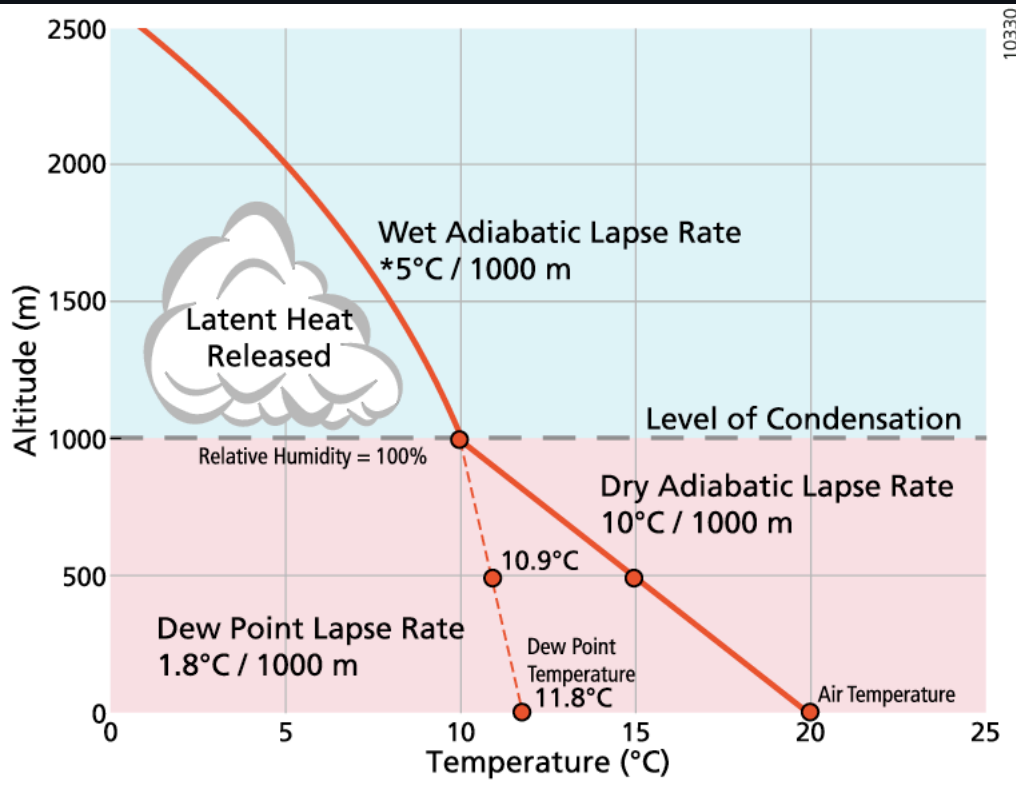
**Lenticular clouds often indicate mountain wave**



# Atmospheric Stability

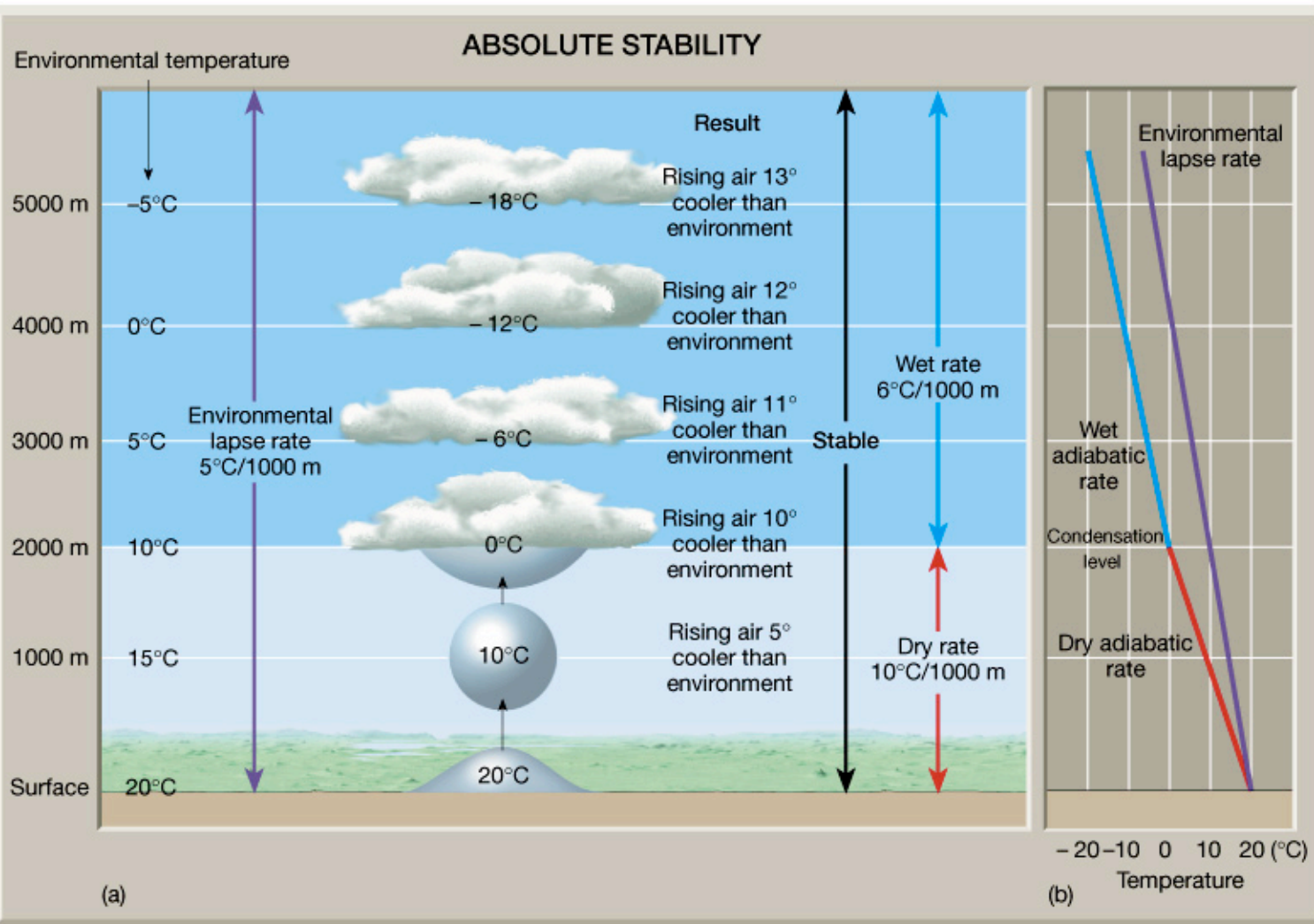


The tendency of atmosphere to resist or encourage vertical motion



## Adiabatic Cooling

- Adiabatic cooling: Air loses temperature as it rises, since the ambient pressure decreases
- A parcel of air lifted from the surface will cool at the **dry adiabatic lapse rate**
  - 3 °C (5.4 °F) per 1,000 feet
  - This is independent of the lapse rate of the air mass surrounding it

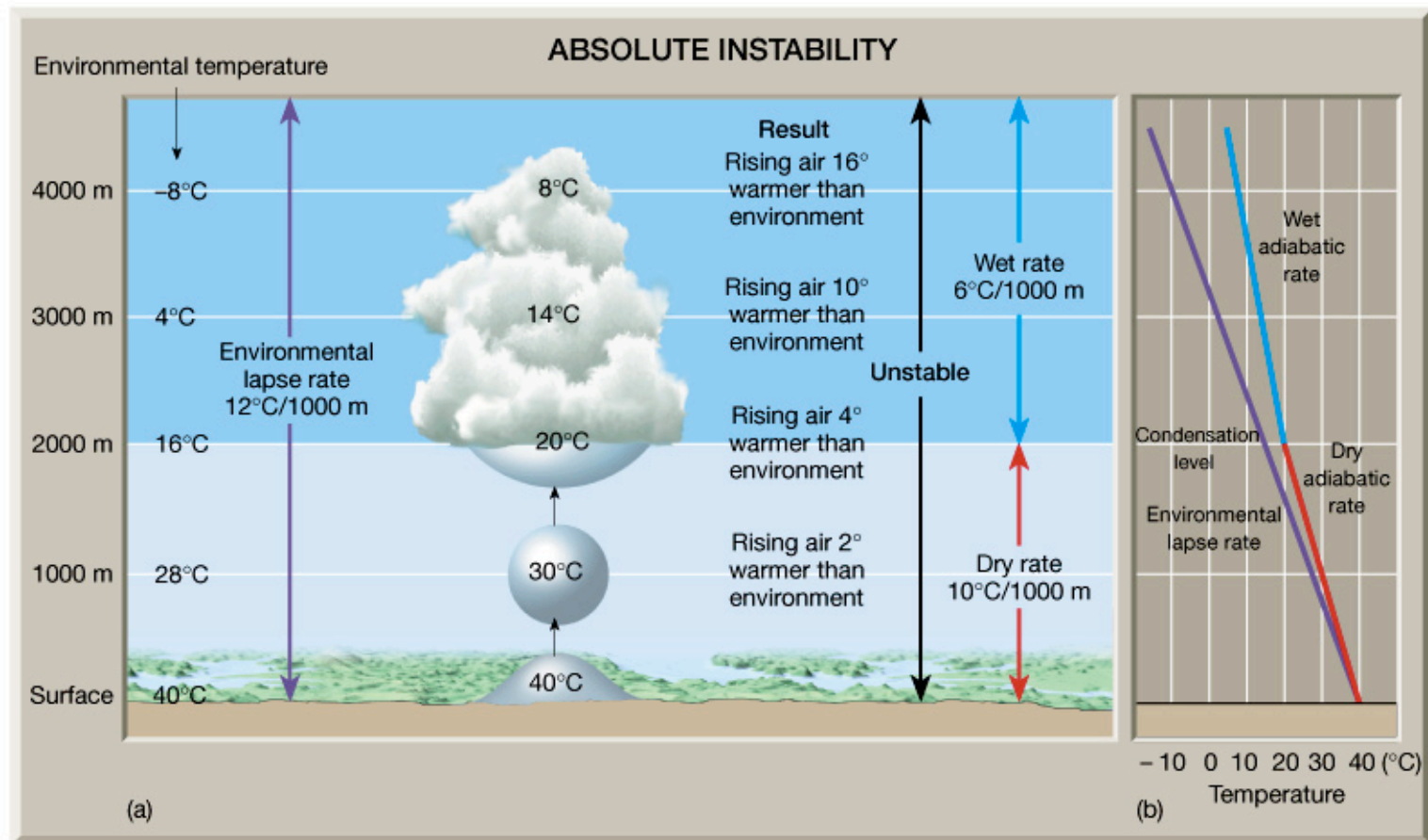


If the parcel cools faster than the surrounding air, it will want to descend:  
**stability**

Example:

- Parcel lapse rate: 3° per 1000'
- Atmospheric lapse rate: 2.5° per 1000'



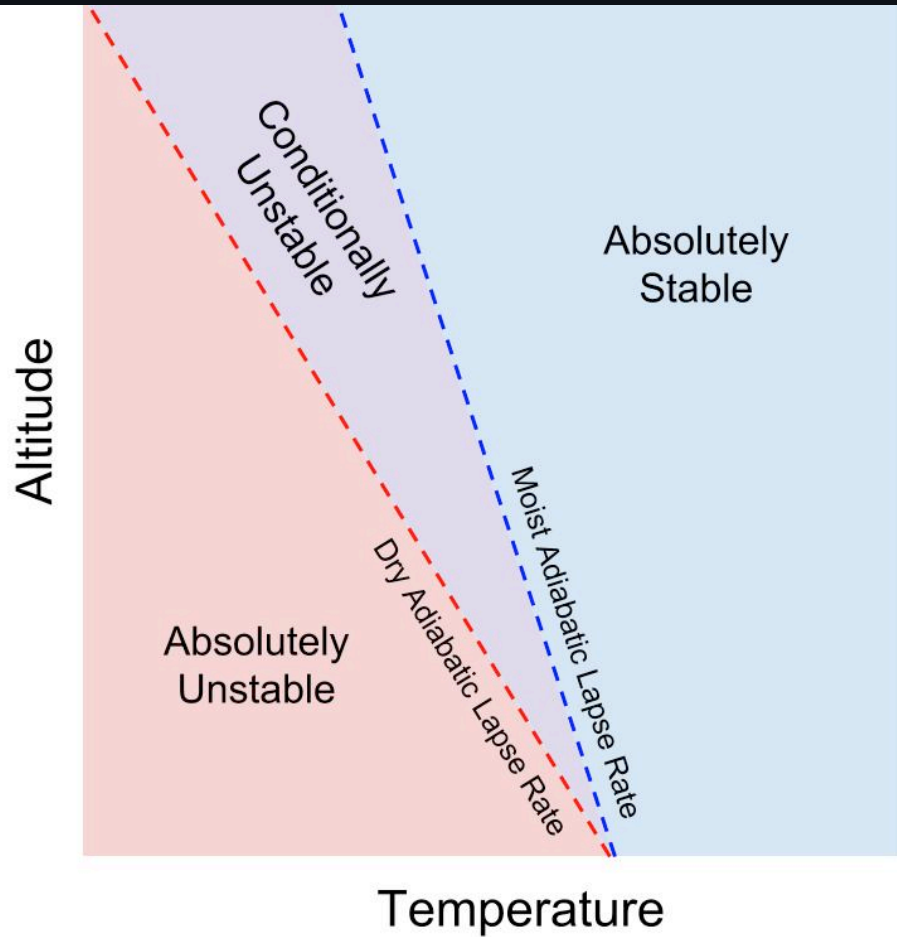


If the parcel cools slower than the surrounding air, it will want to ascend:  
**instability**

Example:

- Parcel lapse rate: 3° per 1000'
- Atmospheric lapse rate: 3.5° per 1000'





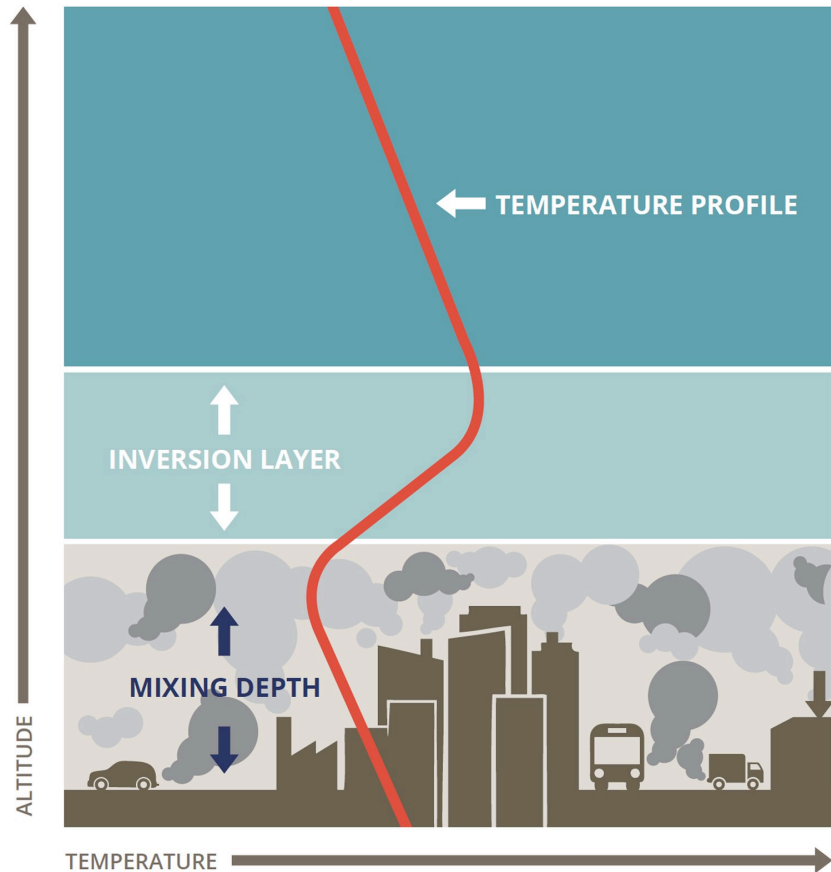
## Moisture and Stability

- Moisture decreases air density
- Moist air cools at a slower rate than dry air
- **Conditionally unstable** means air is unstable until it saturates, then it becomes stable

# Stability Summary

- Cool, dry air is stable and resists vertical movement
- Warm, moist air produces the most instability
  - A fast lapse rate indicates an unstable atmosphere

| Info                                          | Weather       | Runway          | Procedure | NOTAM |
|-----------------------------------------------|---------------|-----------------|-----------|-------|
| METAR                                         | TAF           | MOS             | Daily     | Winds |
| 6h 58m ago                                    |               |                 |           |       |
| 17:30 PDT                                     |               |                 |           |       |
| 3,000'                                        | 23°C (ISA+14) | 223° at 43 kts  |           |       |
| 6,000'                                        | 15°C (ISA+12) | 235° at 44 kts  |           |       |
| Rapid temperature drop: possible unstable air |               |                 |           |       |
| 9,000'                                        | 6°C (ISA+9)   | 245° at 38 kts  |           |       |
| 12,000'                                       | -1°C (ISA+8)  | 241° at 39 kts  |           |       |
| 15,000'                                       | -8°C (ISA+7)  | 234° at 46 kts  |           |       |
| 18,000'                                       | -15°C (ISA+6) | 232° at 54 kts  |           |       |
| 21,000'                                       | -21°C (ISA+6) | 232° at 70 kts  |           |       |
| 24,000'                                       | -28°C (ISA+5) | 231° at 78 kts  |           |       |
| 27,000'                                       | -34°C (ISA+4) | 233° at 88 kts  |           |       |
| 30,000'                                       | -41°C (ISA+3) | 234° at 98 kts  |           |       |
| 33,000'                                       | -47°C (ISA+3) | 233° at 101 kts |           |       |
| 36,000'                                       | -52°C (ISA+4) | 233° at 90 kts  |           |       |

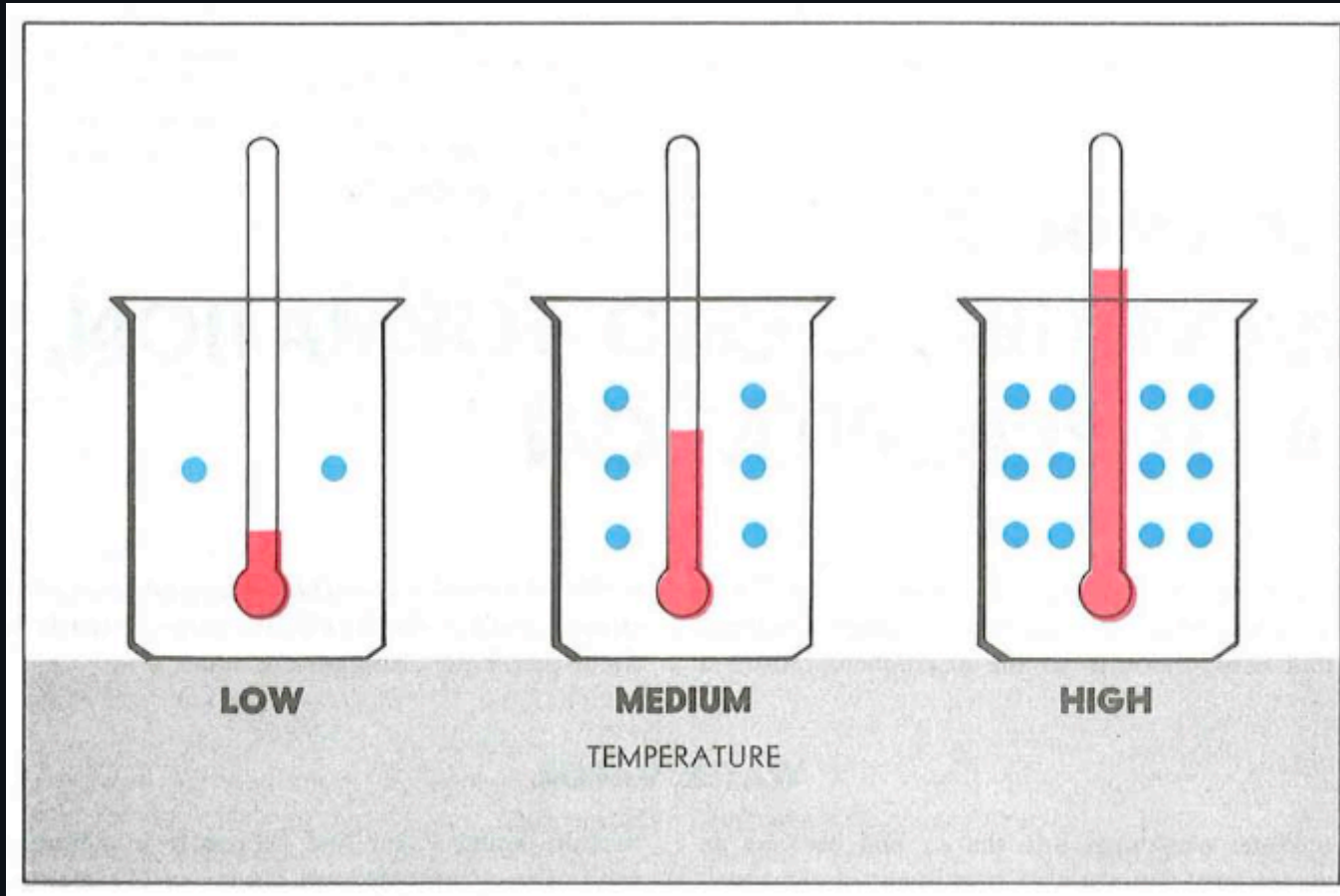


## Temperature Inversions

- Layers where temperature *increases* with altitude
- Often occurs on clear, cool nights, when the ground cools the air above it
- Can trap pollutants below the layer
- Smooth air can often be found above the inversion

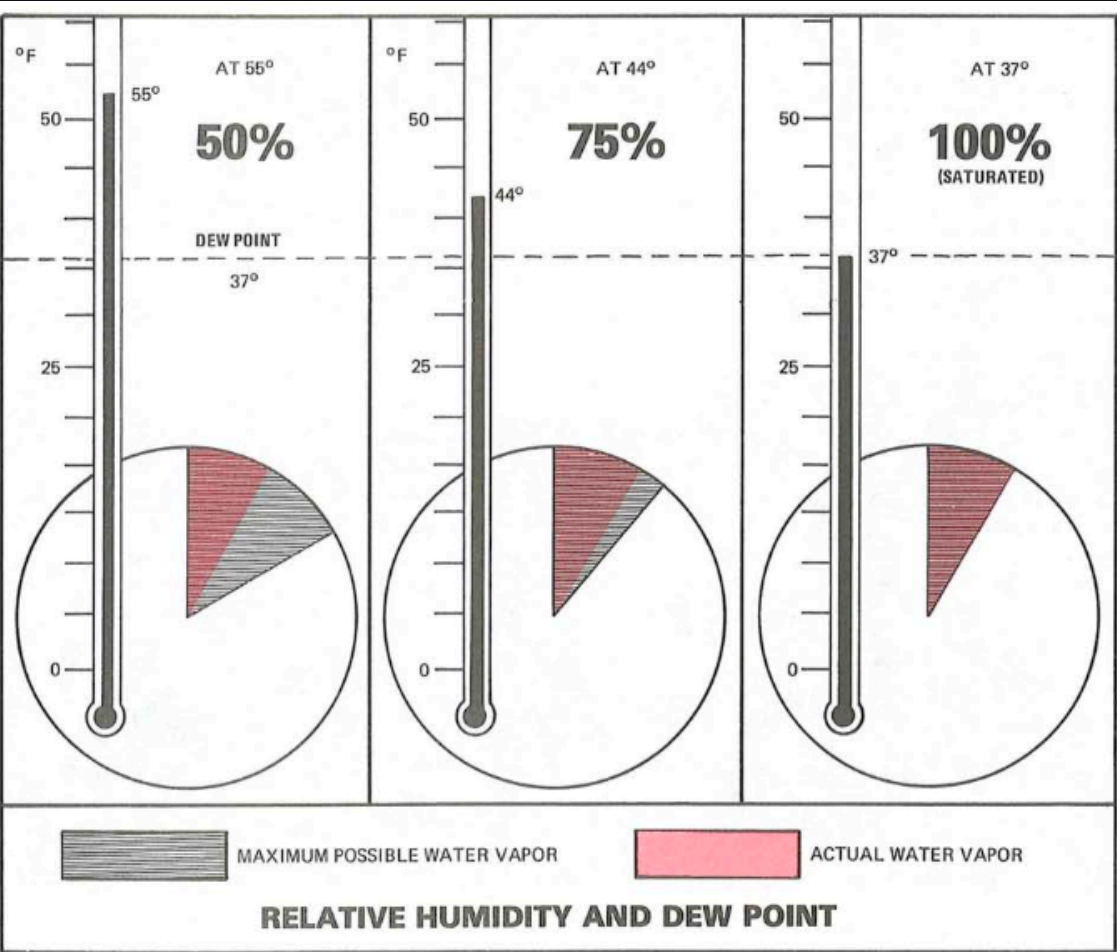
# Moisture and Clouds

# Moisture and Temperature



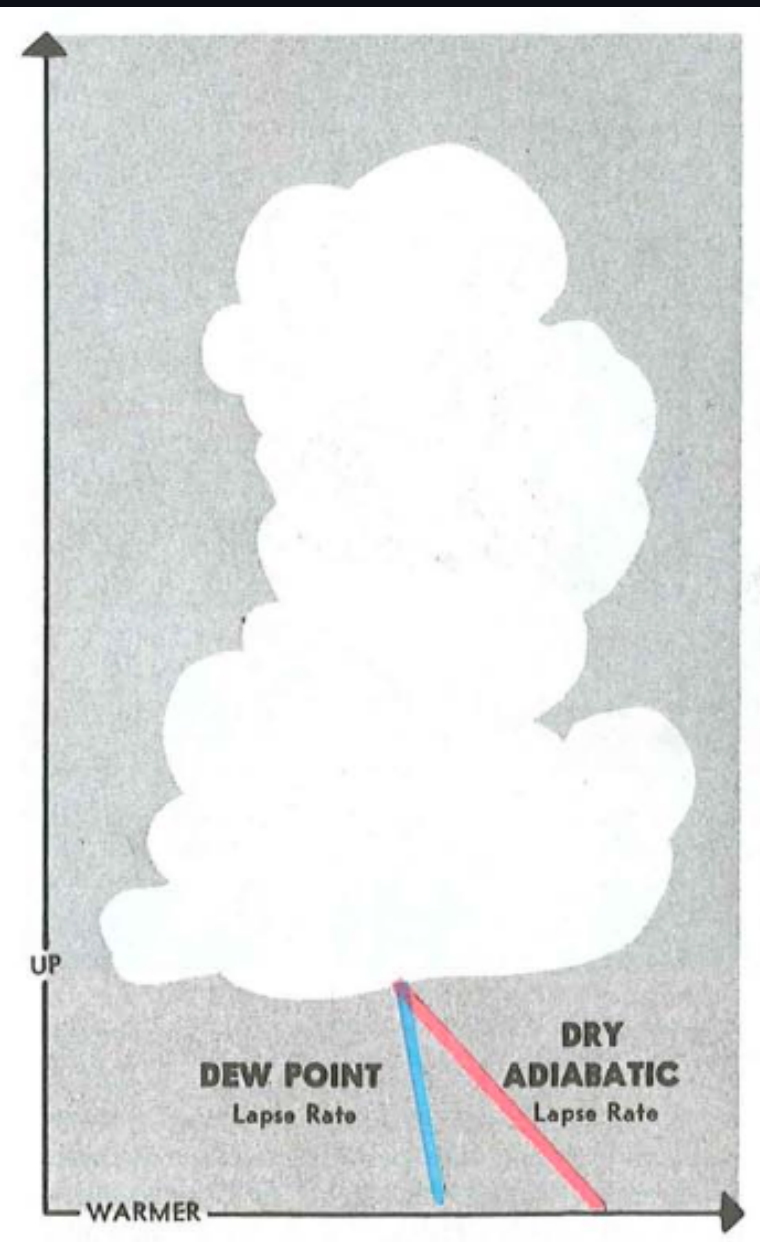
Every 20°F increase in temperature doubles the capacity of water the air can hold





## Dewpoint and Relative Humidity

- **Relative humidity** is the percentage of water in the air vs. how much water the air could hold at that temperature
- **Dewpoint** is the point at which the air would be completely saturated by the current amount of water



## Saturated Air

Saturated air bring clouds, fog, and precipitation

- Clouds often form when unstable air rises and cools to the dewpoint
- Dew and frost: form when surfaces cool beyond the dewpoint and water condenses on the side

## Fog - Ground Clouds

Fog forms when the ground cools the air above it to its dewpoint, then the water vapor condenses and forms a cloud.





## Radiation fog

- Clear, windless nights with sufficient humidity
- Ground cools the air above it
- Dissipates quickly with a rise in temperature or light winds





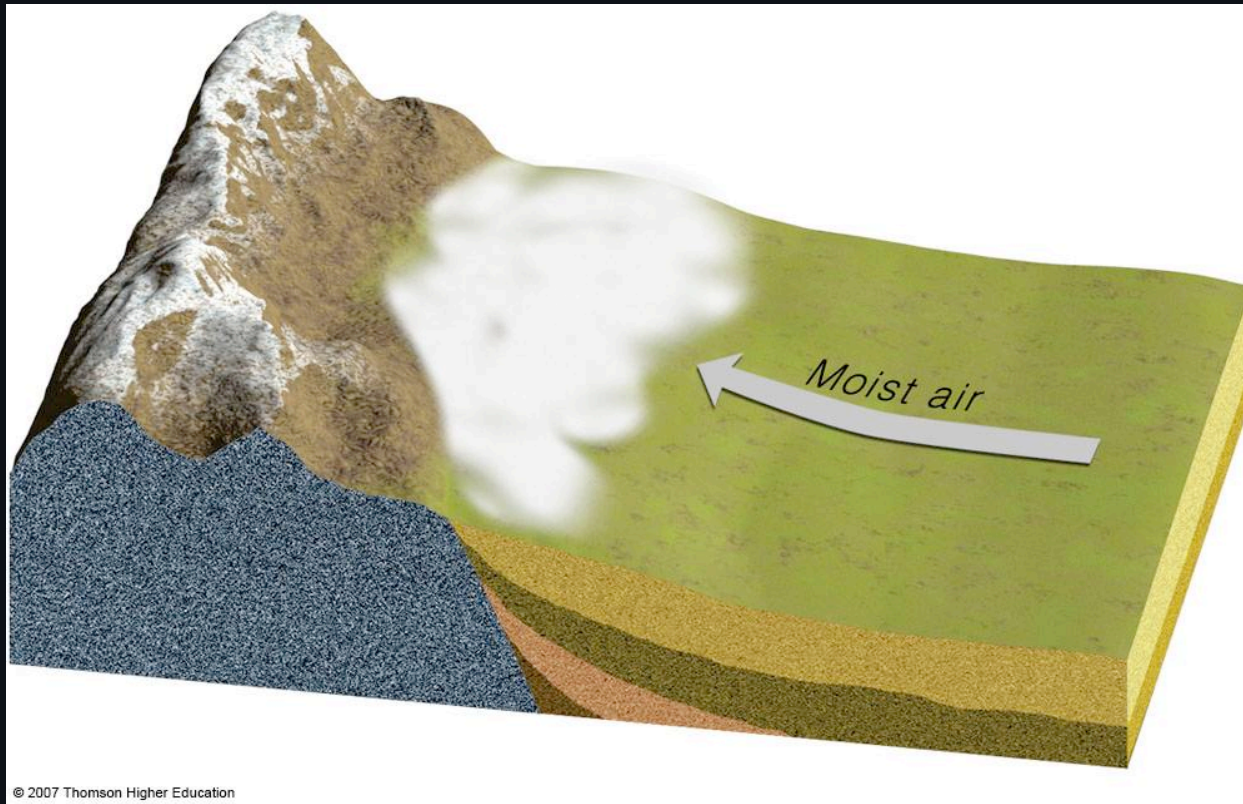
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## Advection fog

- Warm, moist air moves over a colder surface
- Requires wind, up to 15 knots
- Coastal regions are particularly effected (U.S. west coast)



# Upslope fog



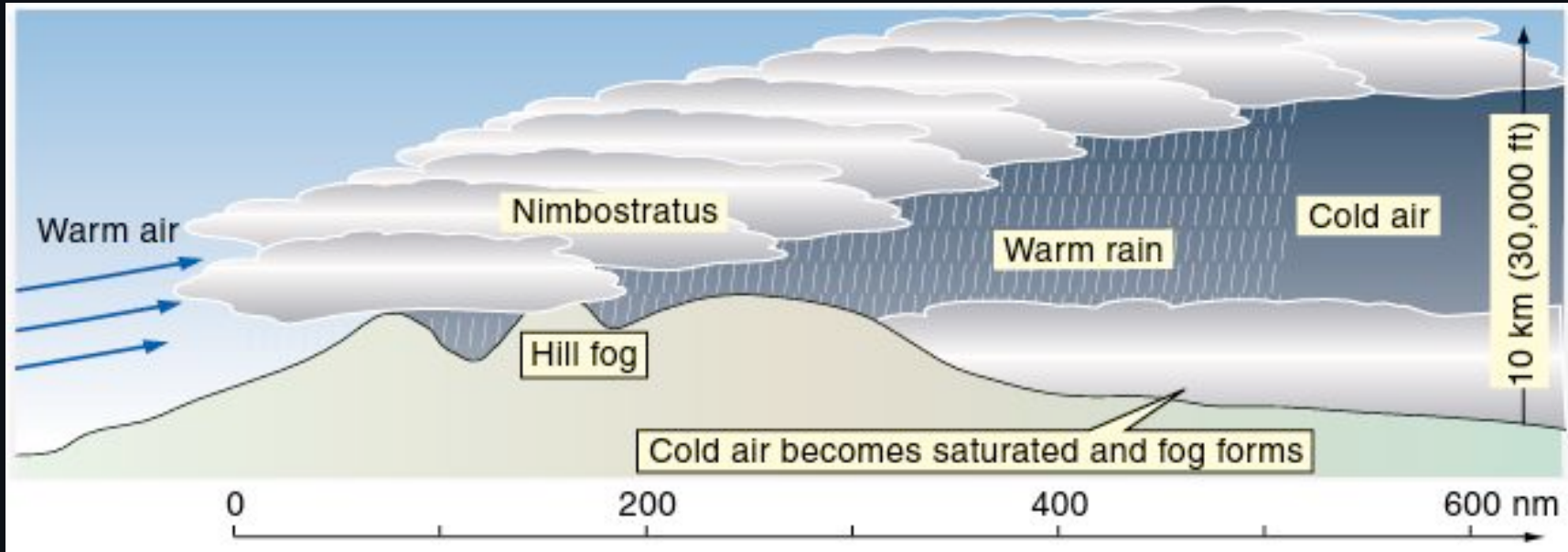
- Moist air is forced up a slope
- Air then adiabatically cools to dewpoint and fog forms

## Steam fog



Cold, dry air moves over water, causing evaporation from the water

# Front / Precipitation Fog



- Often associated with a warm front
- Rain falls into air mass below it, raising it's humidity

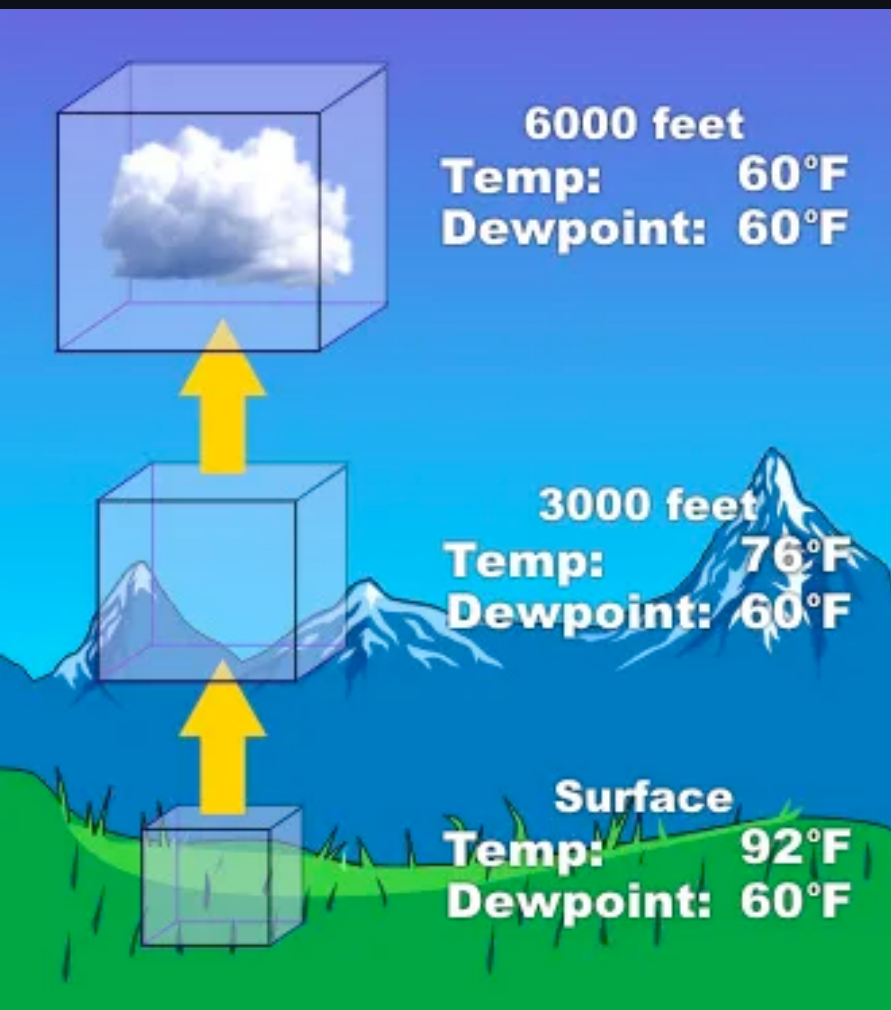
# Virga



- Precipitation that evaporates or sublimates before reaching the ground
- Can be associated with thunderstorms (sometimes called a "dry thunderstorm")
- Is visible on radar return (NEXRAD), even though no rain is falling at the surface

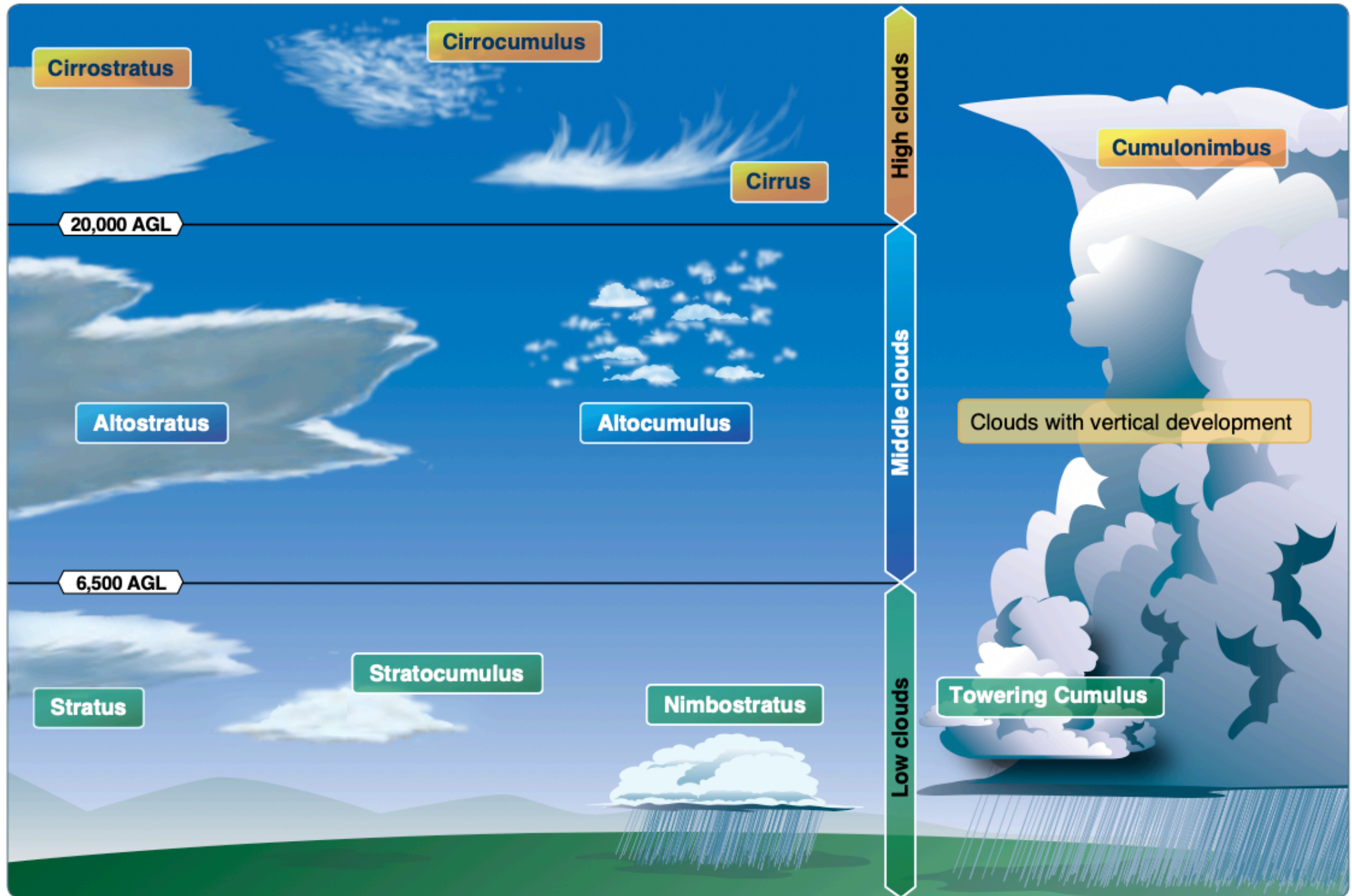
**Clouds**





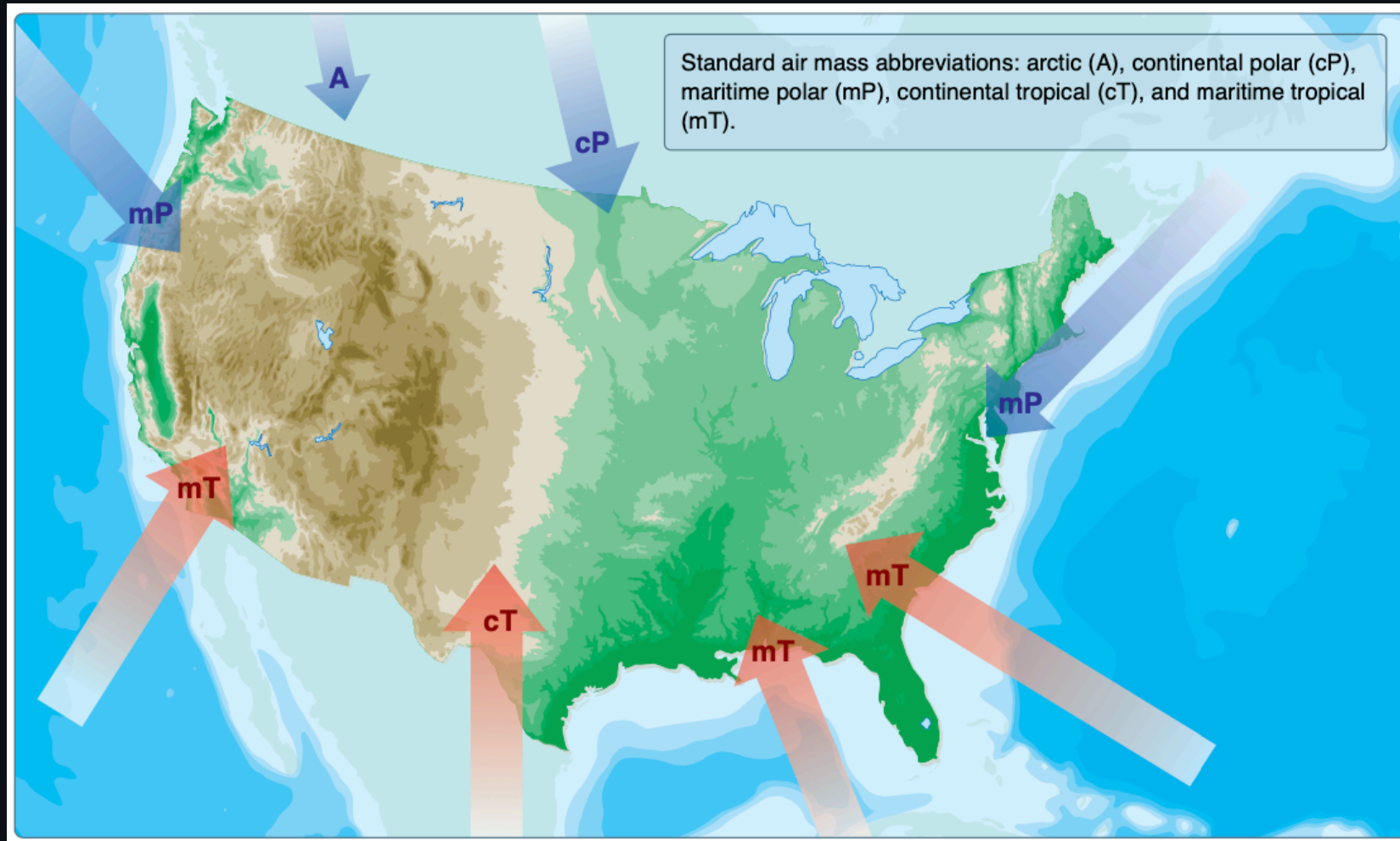
## Cloud Formation

- Three ingredients for clouds to form: Moisture, cooling, condensation nuclei
  - Moisture condenses onto minuscule particles of matter



# Air Masses

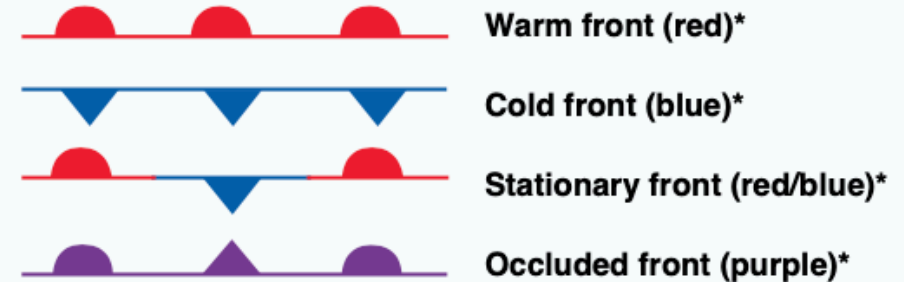
- Form from large source regions
- Deserts, oceans, large lakes, polar caps
- Source conditions may develop for days



# Fronts

- Fronts form as interactions between these air masses
- As front pass:
  - Pressure will change
  - The temperature will change
  - The wind direction will change

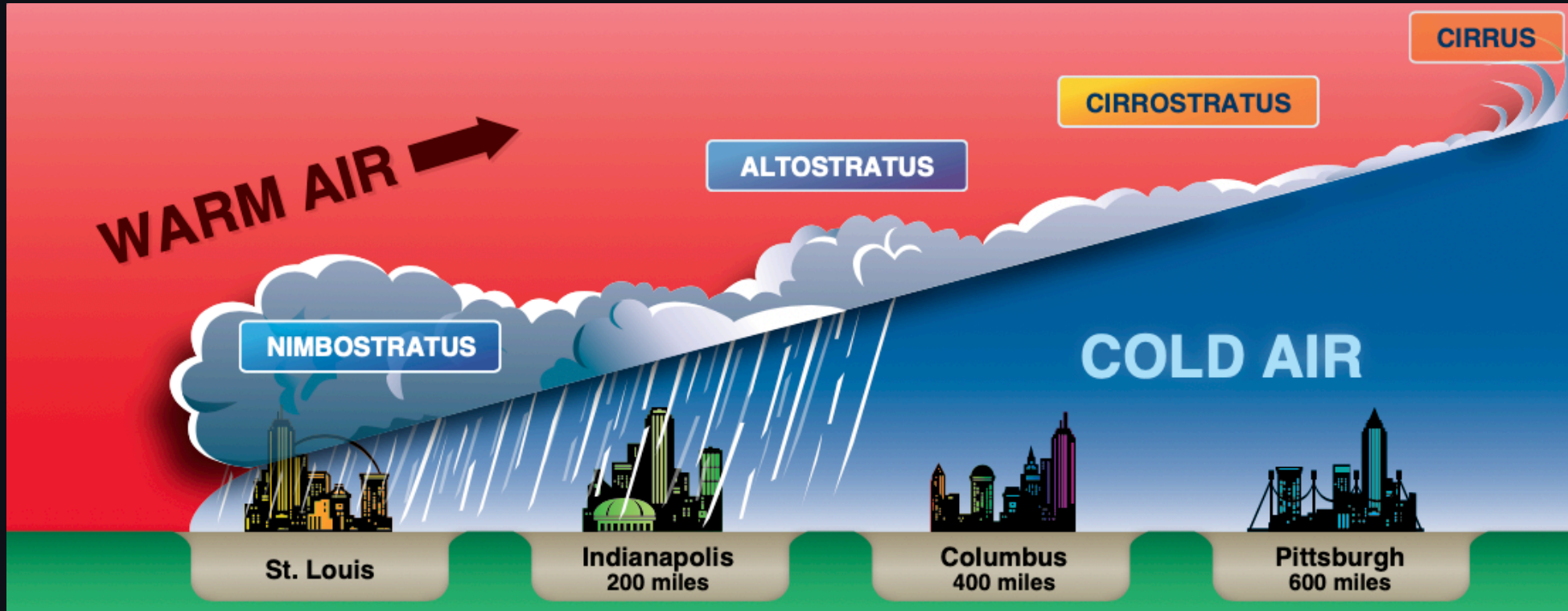
**Symbols for surface fronts and other significant lines shown on the surface analysis chart**



\* Note: Fronts may be black and white or color depending on their source. Also, fronts shown in color code do not necessarily show frontal symbols.



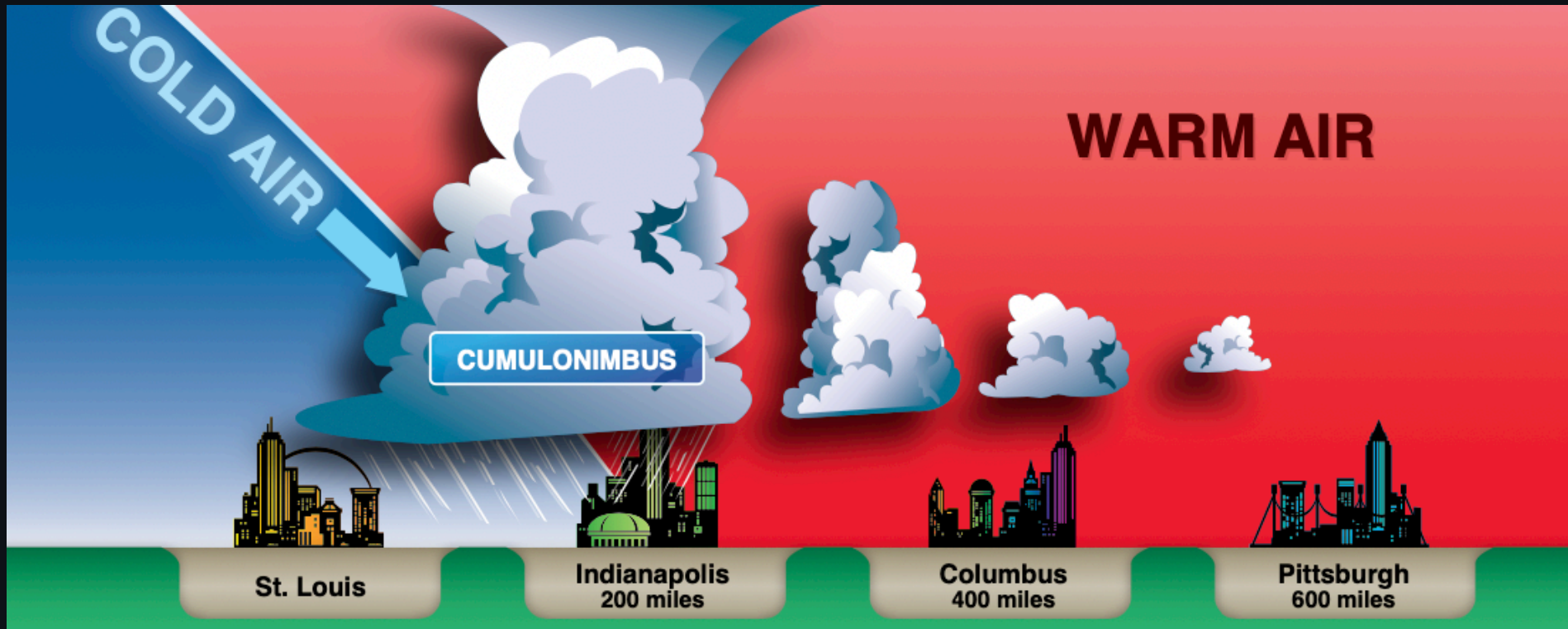
## Warm Fronts - Shallow frontal slope



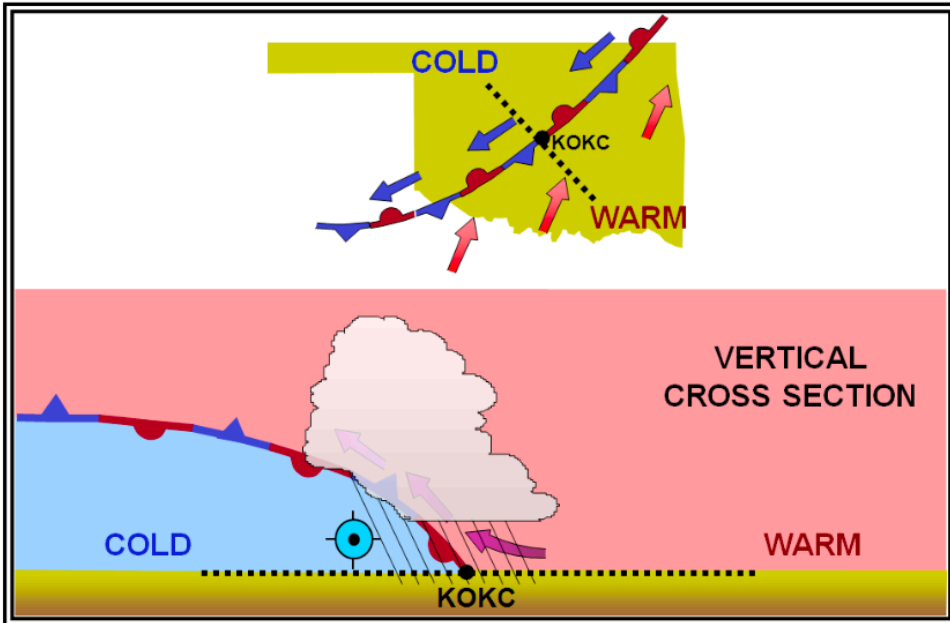
- Warm, often moist air that slides slowly over a colder air mass (shallow frontal slope)
- Ahead of the front, cirriform or stratiform clouds and light precipitation
- Poor visibility, haze as the front passes



# Cold Fronts - Steep frontal slope

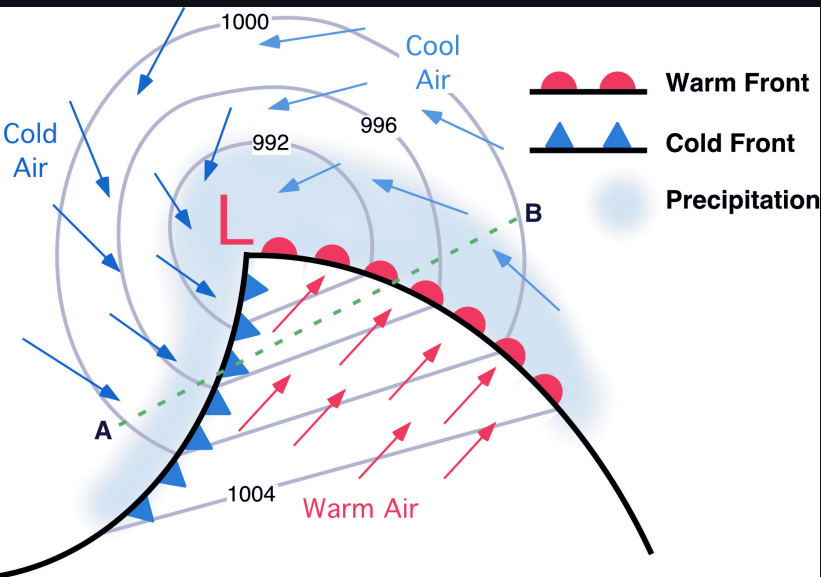


- Cold, dense, stable air quickly slides under and replaces a warmer air mass
- May produce a concentrated band of precipitation and thunderstorms
- Squall lines may form ahead of a fast-moving cold front



## Stationary Front - Equal air masses

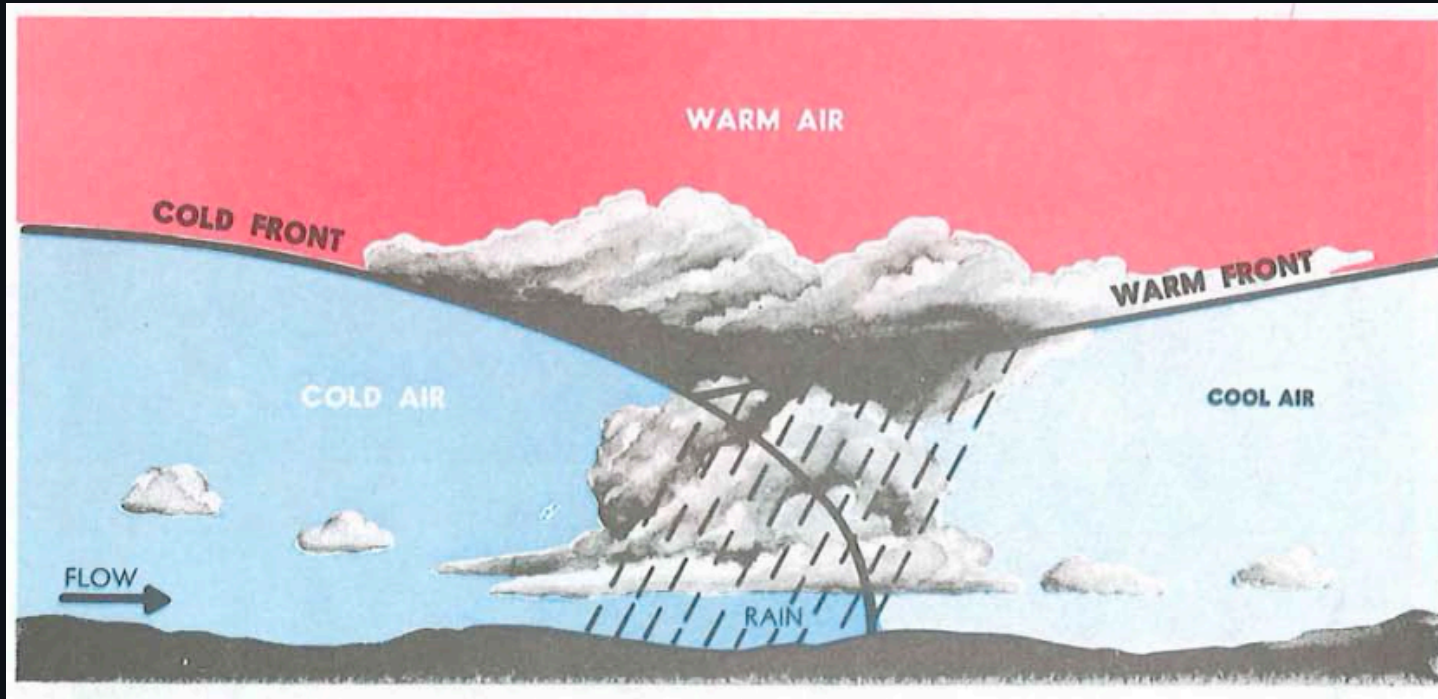
- Air masses with relatively equal forces can remain stationary for several days
- Weather is a mixture of cold front/warm front conditions
- Precipitation is common



## Occluded front - Cold front overtaking

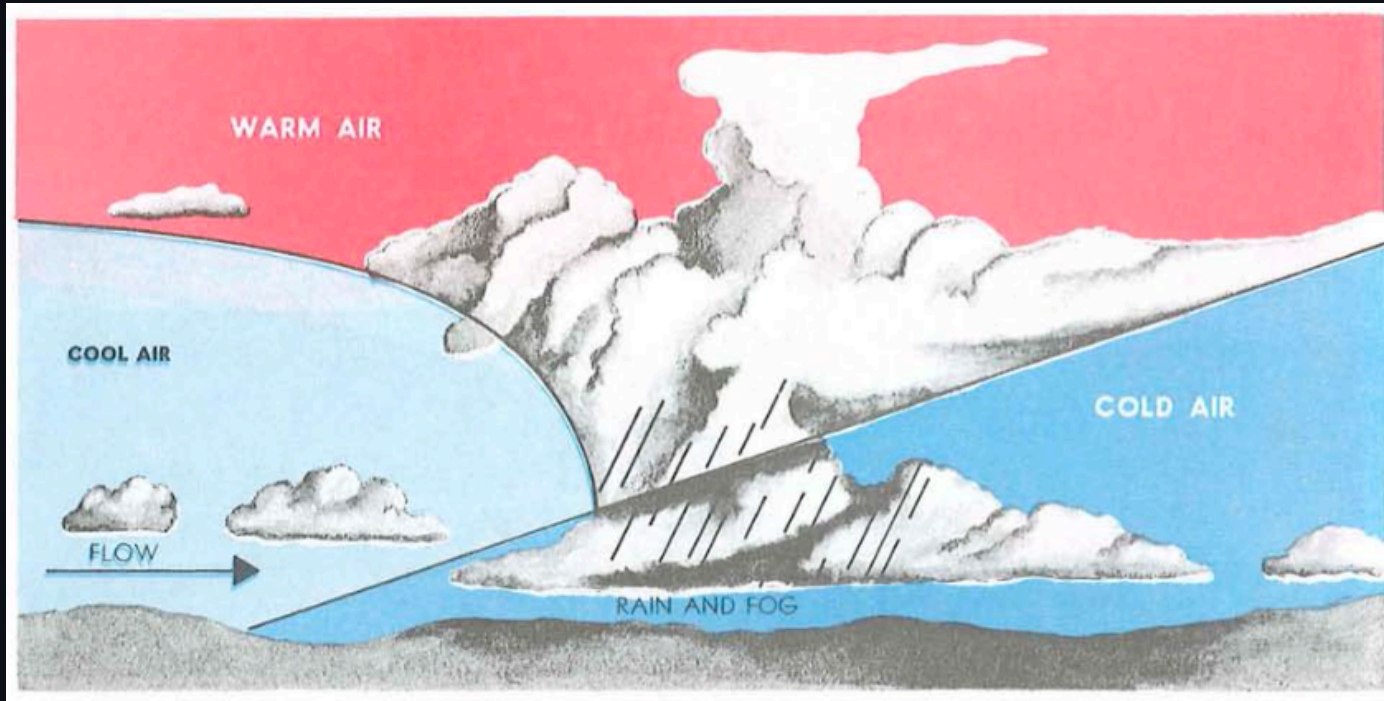
- Cold fronts typically move faster than warm fronts, so they catch up to warm fronts
- Two types:
  - Cold-front occlusion: A air is colder than B air
  - Warm-front occlusion: B air is colder than A air

# Cold-front Occlusion



- Cold front pushes warmer air aloft, stability
- Mixture of cold/warm front weather

# Warm-front Occlusion



- Cold front "rides up" over the warm front, cooling aloft, instability
- Can cause severe thunderstorms, rain, fog





# Thunderstorms

- Three ingredients:
  - Instability
  - Lifting action
  - Moisture
- Heavy rain, hail, strong winds

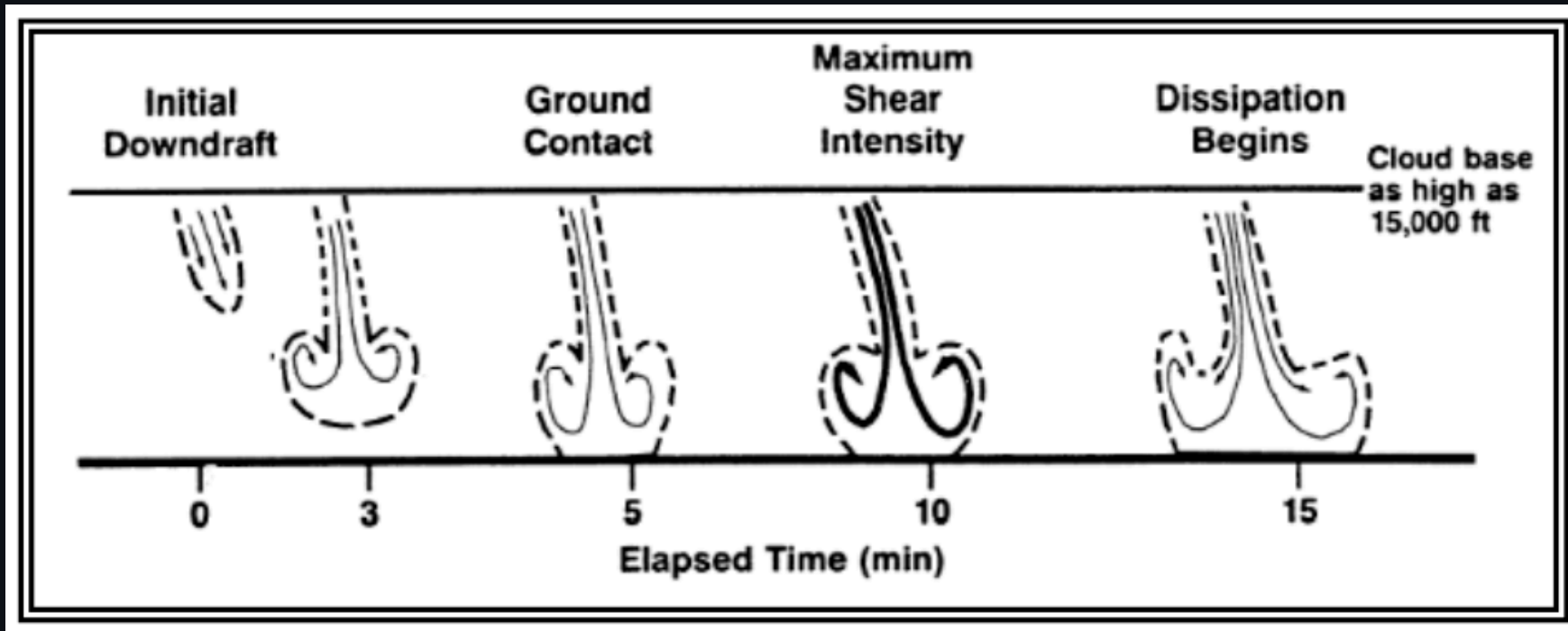
# Stages of a Thunderstorm

- Cumulus stage
  - Air rises, strong updrafts occur
- Mature stage
  - Moisture is too heavy for cloud to support, precipitation starts falling, this causes a downdraft
  - Vertical motion is stalled, and top of the cloud forms the anvil shape
- Dissipating stage
  - Downdrafts spread and replace updrafts

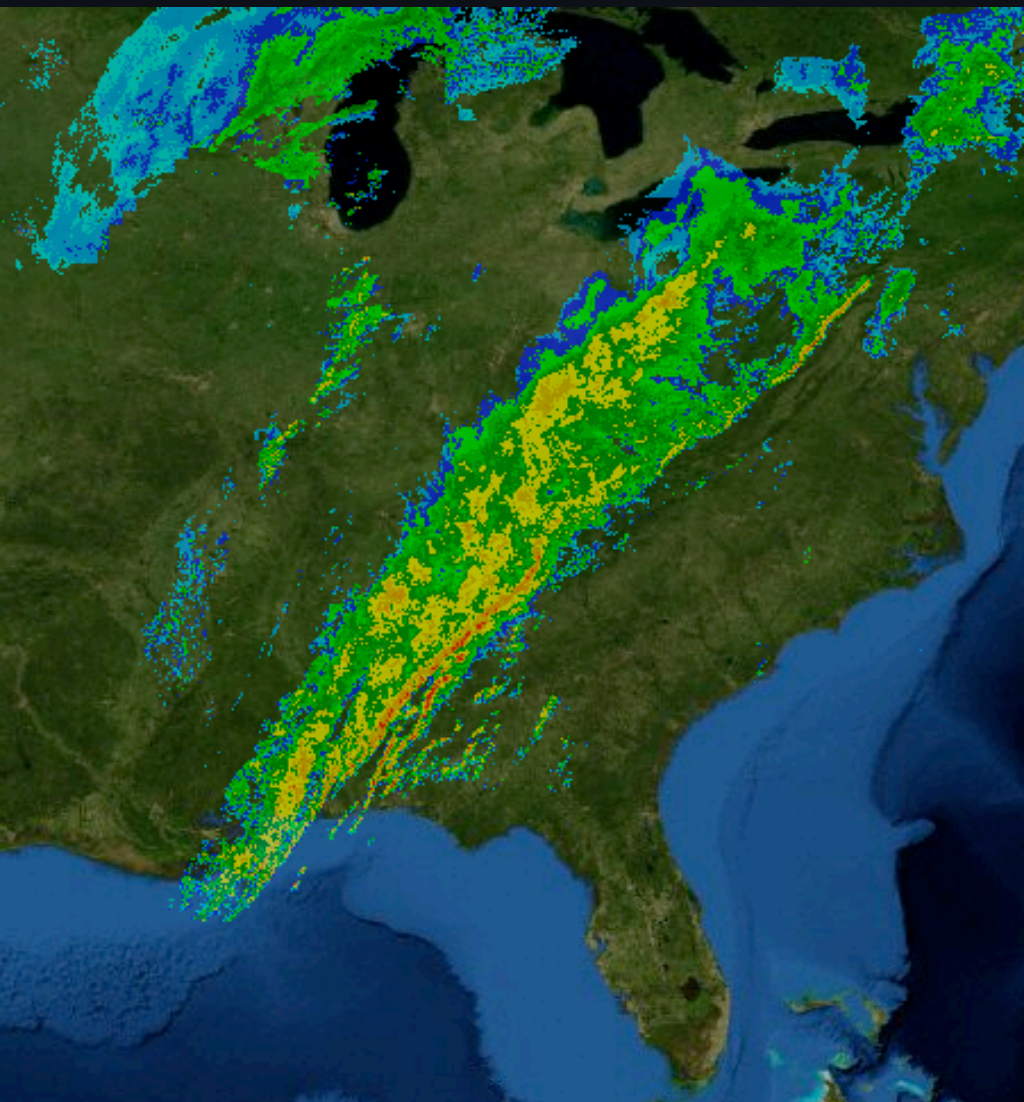
# Thunderstorm Hazards

- Heavy rain
- Engine water ingestion
- Hail which may be thrown miles from the storm
- Violent turbulence in the storm and in the vicinity
- Wind shear turbulence and microbursts near the surface
- Supercooled water droplets that can freeze on impact with an airplane
- Lightning: Temporarily blindness, radio interference, magnetic compass errors

# Microbursts



- Result of strong downdrafts that form out of a storm ( $> 6000$  fpm)
- Can cause severe windshear when they impact the ground
- Approximately 1-3 miles in diameter, last for 5-15 minutes



## Squall Lines

- Large line of steady-state thunderstorms
- Often associated with the passage of a fast-moving cold front



# Thunderstorm Avoidance

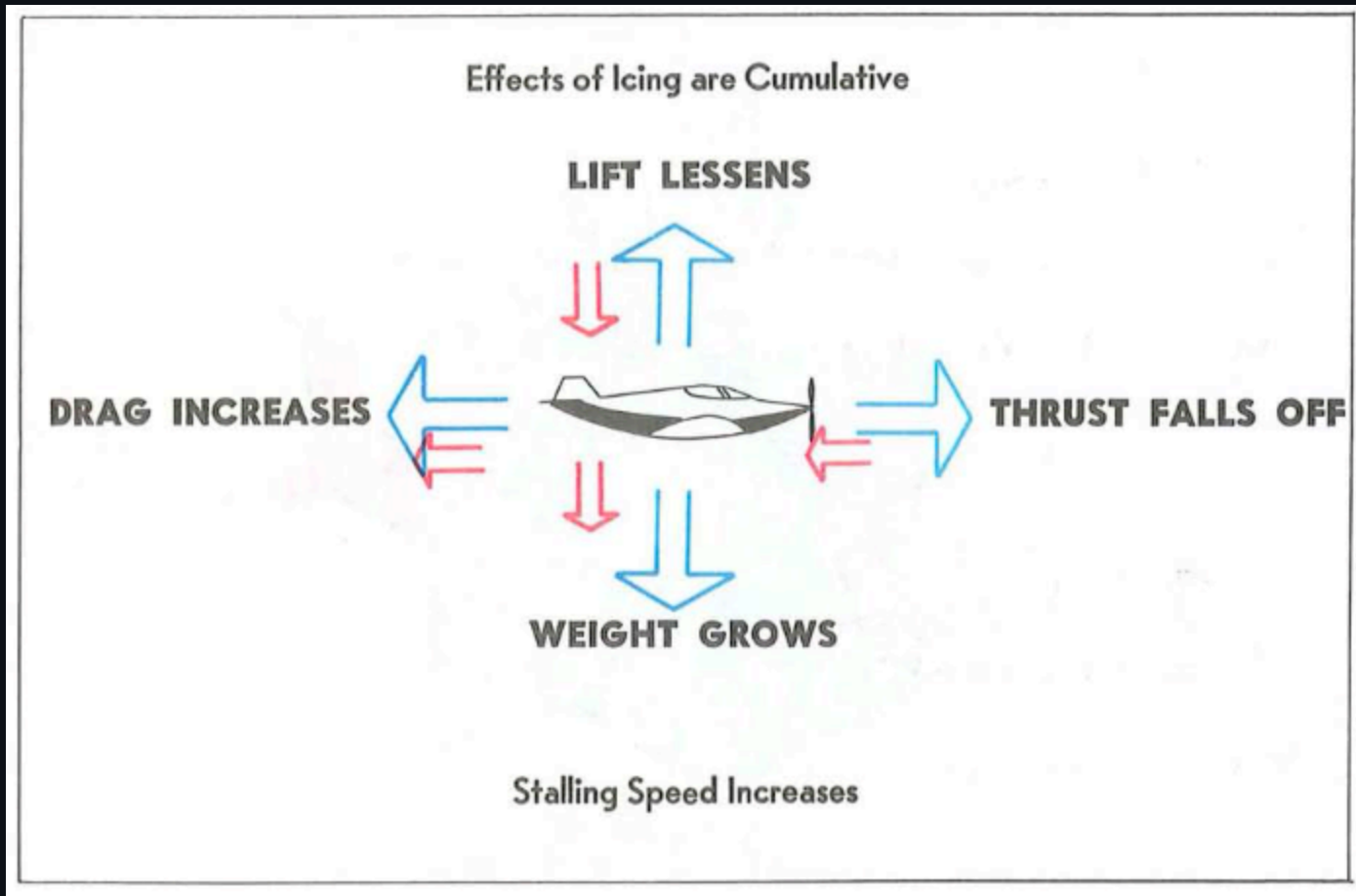


- It is impossible to fly over most thunderstorms, especially in a light aircraft
- Circumnavigate a severe or large-echo thunderstorm by at least 20nm
- Visual appearance to be a reliable indicator of turbulence
- Never use NEXRAD for navigating through thunderstorms
- More information in 00-24C

**Icing**

# Structural Icing

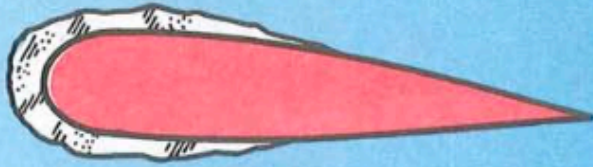
Buildup of ice on the airplane structure can be extremely hazardous



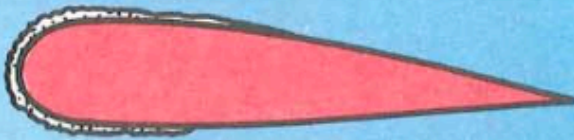
# Conditions for Icing

1. Aircraft is flying through visible moisture (clouds, vapor)
2. Temperature at the point where the moisture strikes must be  $0^{\circ}\text{C}$  or colder

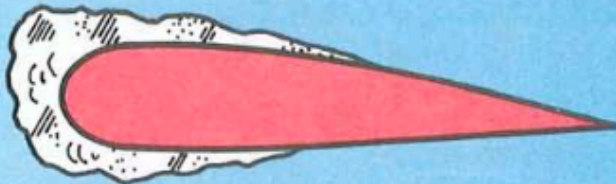




CLEAR – HARD AND GLOSSY



RIME – BRITTLE AND FROST-LIKE



MIXED – HARD ROUGH  
CONGLOMERATE

## Types of Icing

- Clear icing: Often forms when large drops of moisture freeze after contacting the fuselage
  - Common at lower altitude
- Rime icing: Small droplets freeze rapidly, leading to a rough surface
  - Common at higher altitudes



# Summary

- The Atmosphere: ISA, most weather is in the troposphere
- Temperature: Uneven heating
- Pressure: Temperature creates pressure differences
- Wind: High pressure to low pressure
- Turbulence: Unstable air, ground interference, mountain wave
- Stability: Fast lapse rate indicates instability
- Moisture, Fog, and Clouds: Clouds forms when air reaches its dewpoint
- Air masses: Air masses interact in frontal areas
- Thunderstorms: Hazardous weather for all aircraft

## **Knowledge Check**

What are the three ingredients needed for a thunderstorm to form?

## Knowledge Check

You're planning a flight and trying to determine a cruising altitude. According to the forecasts, the cloud bases are around 4,500' MSL. Which cruising altitude would most likely have a smoother ride, 3000' or 6000'?

## Knowledge Check

Coming into land at a new airport, the weather report states that the wind is blowing 12 knots, gusting to 19 knots. How would you change your approach and landing?