Weather Theory

Objective

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

Motivation

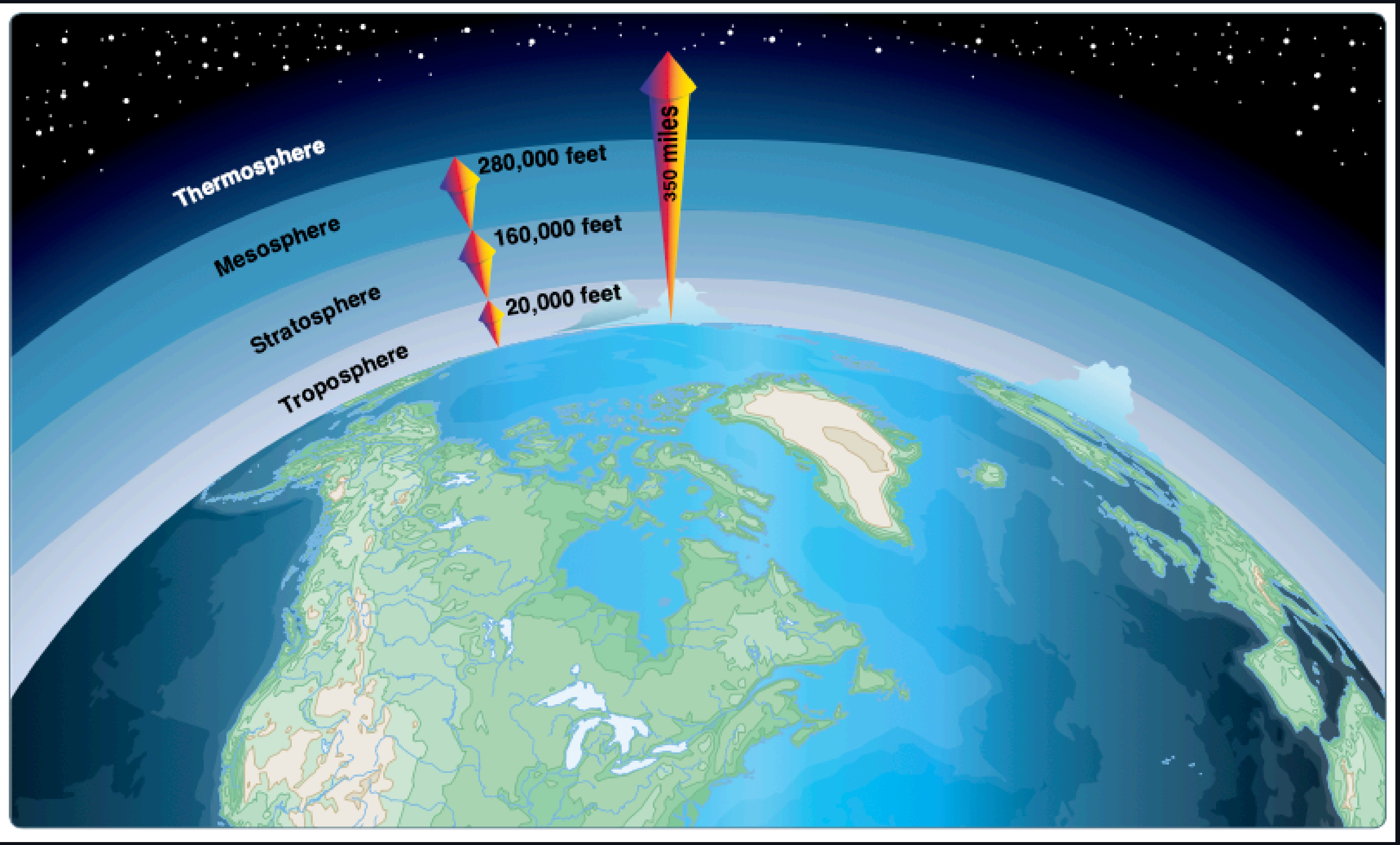
- We need to understand how weather affects airplane performance
- We want to effectively interpret weather data

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

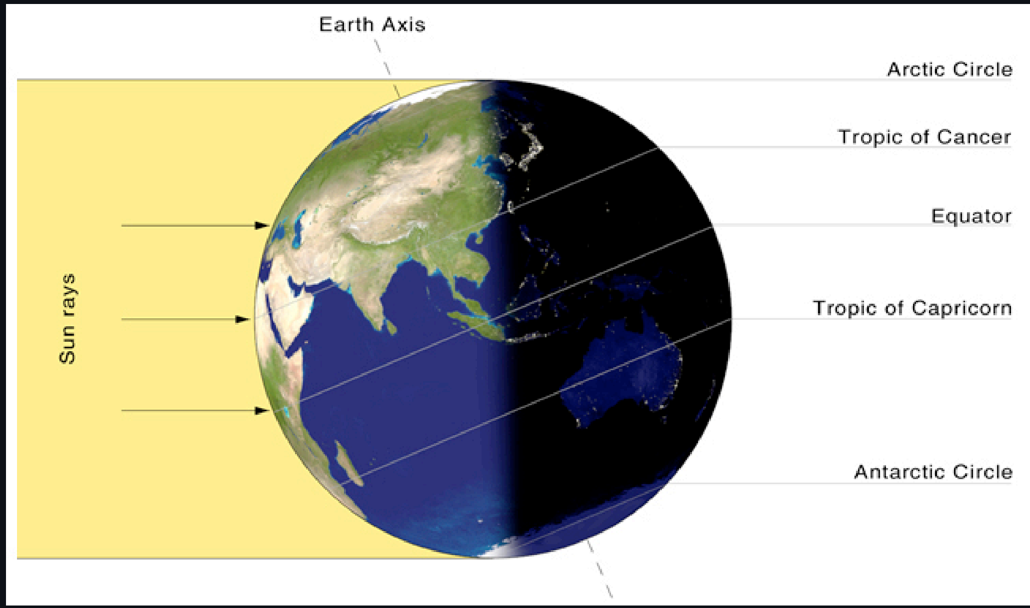
- The real atmosphere is always changing
- We use the **International Standard Atmosphere** as a fixed reference
  - 29.92 inches Hg at sea level
  - 15° C (59° F) at sea level
  - Temperature drops 2° per 1000 feet
  - Pressure drops 1" per 1000 feet

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

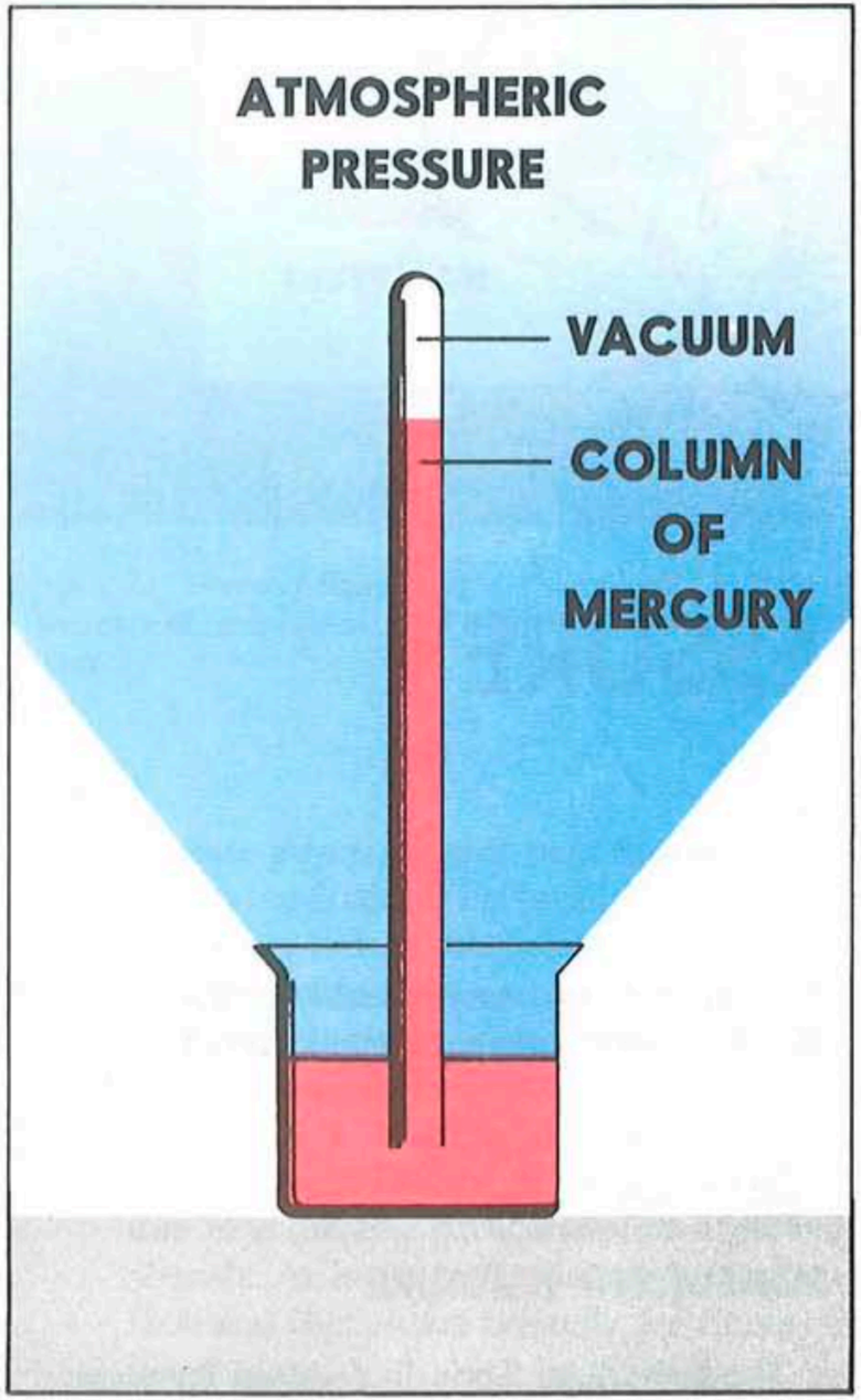
Temperature Variation

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



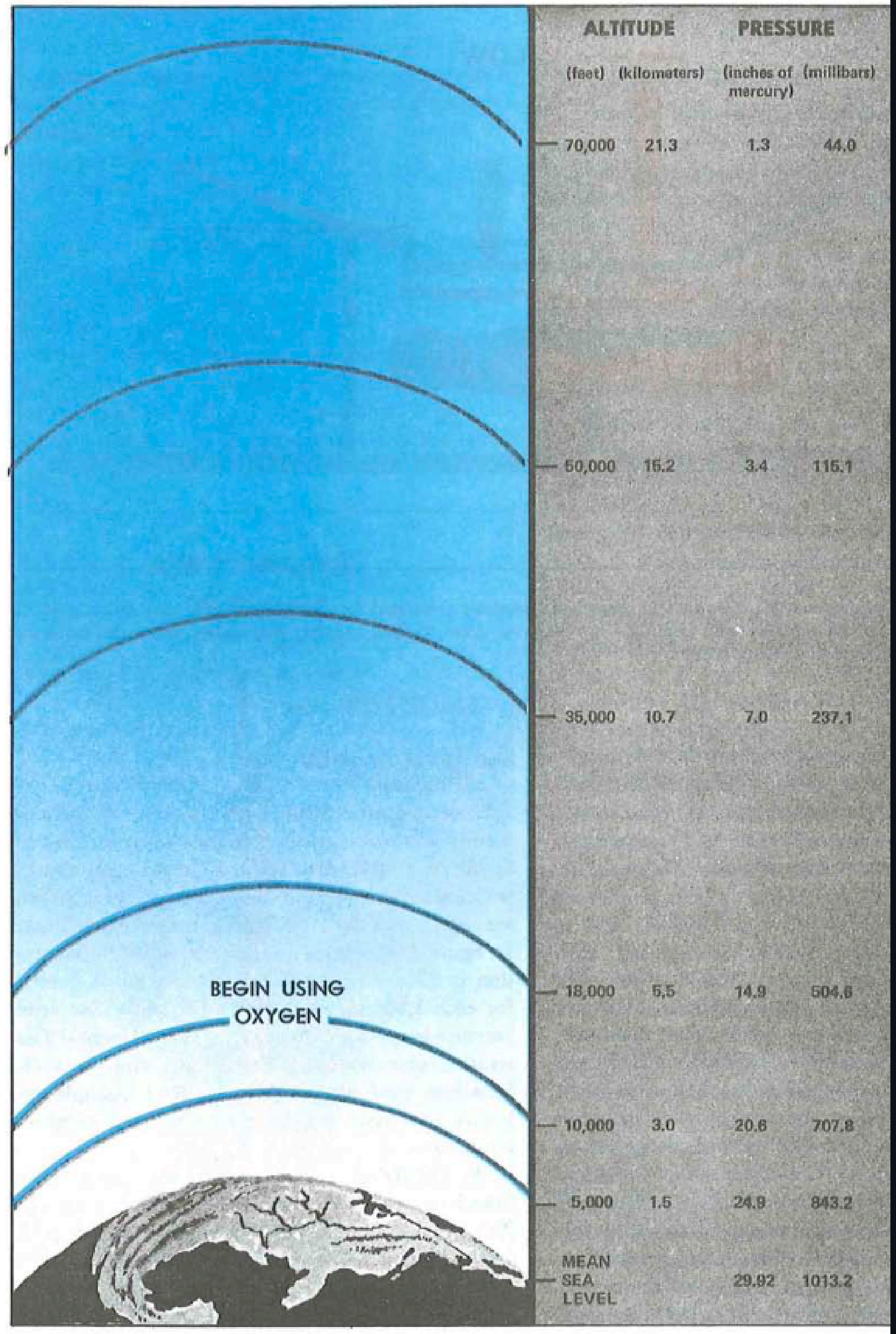
Temperature Variation (cont.)

- 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



Pressure

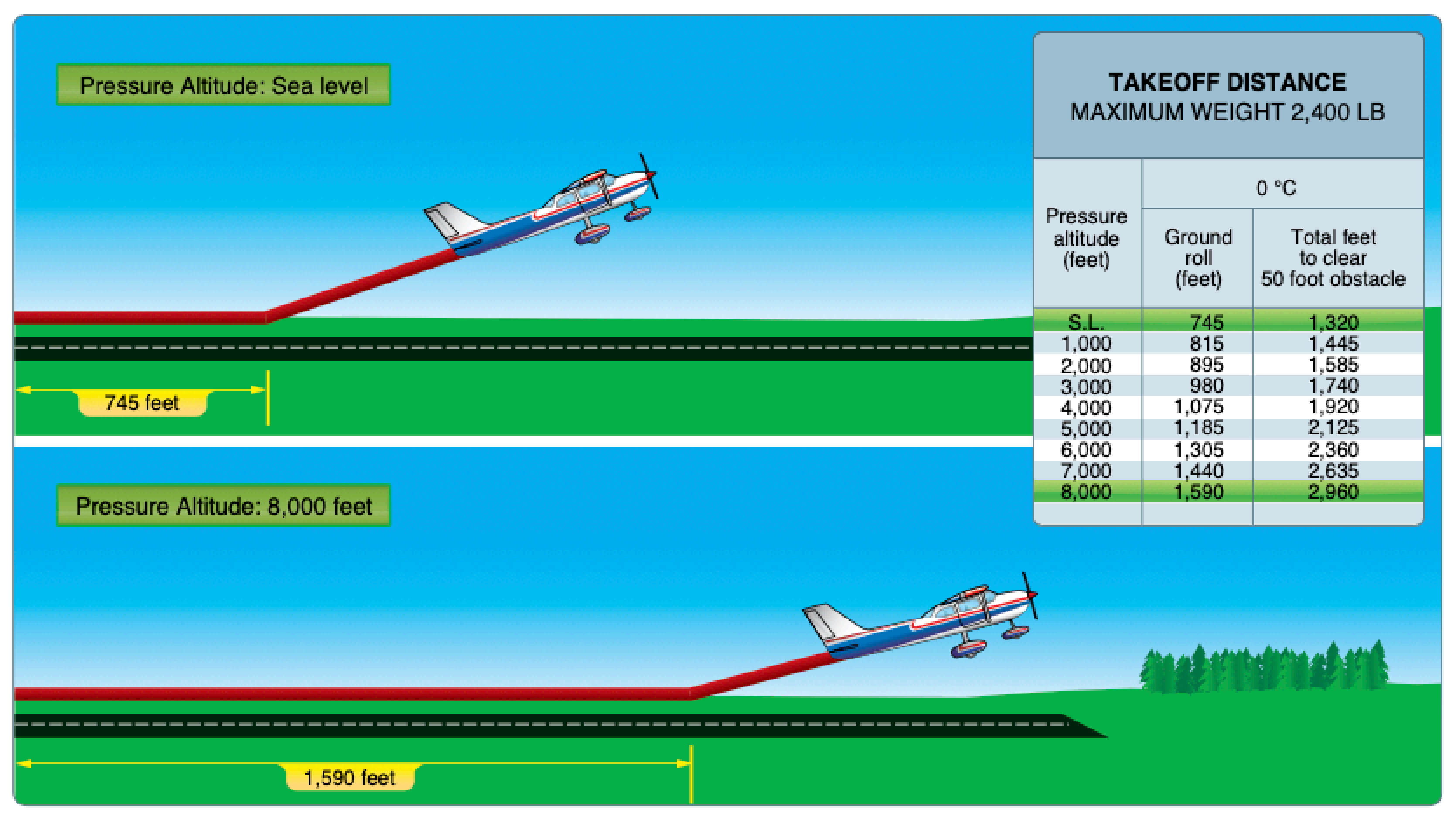
- Atmospheric pressure is the force per unit area exerted by the weight of the atmosphere
- Pressure units:
  - Pounds per square inch (PSI)
  - Millibars
  - Inches of mercury (e.g. 29.92" Hg)
- Ambient pressure at sea level:
  - ~14.7 (PSI)
  - 1013.2 millibars
  - 29.92" Hg



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

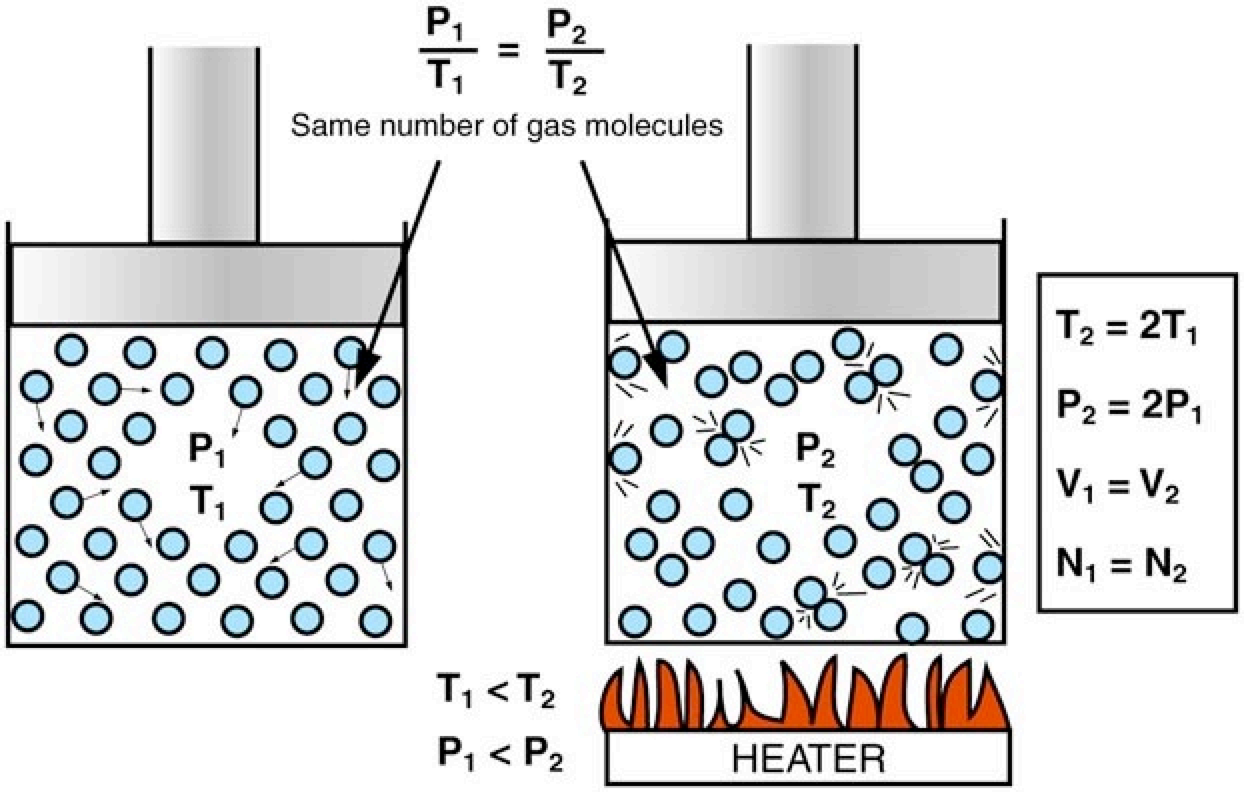
Less Pressure = Less Performance



Pressure altitude (feet)	0 °C	
	Ground roll (feet)	Total feet to clear 50 foot obstacle
S.L.	745	1,320
1,000	815	1,445
2,000	895	1,585
3,000	980	1,740
4,000	1,075	1,920
5,000	1,185	2,125
6,000	1,305	2,360
7,000	1,440	2,635
8,000	1,590	2,960

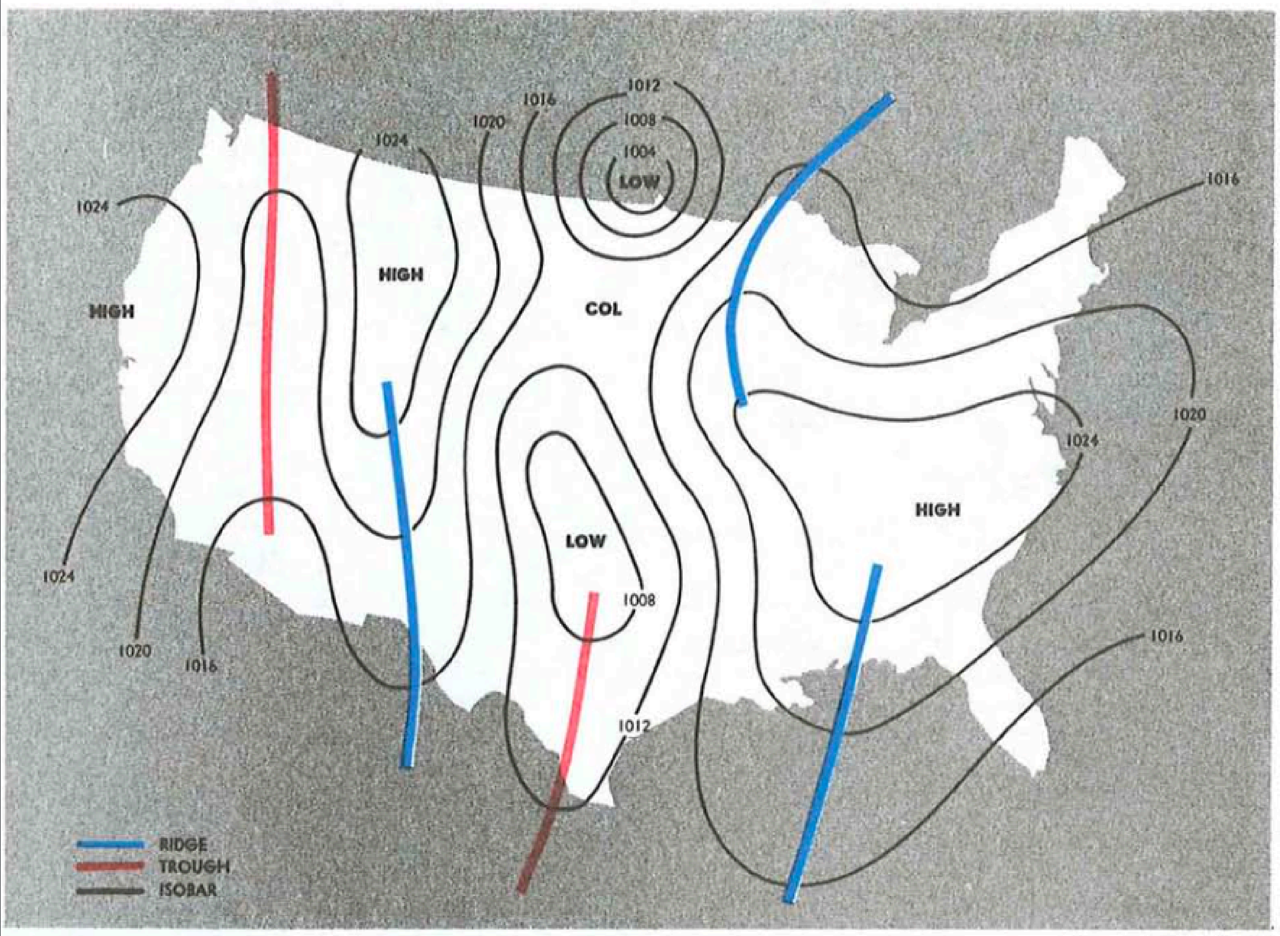
How does pressure change with temperature?

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

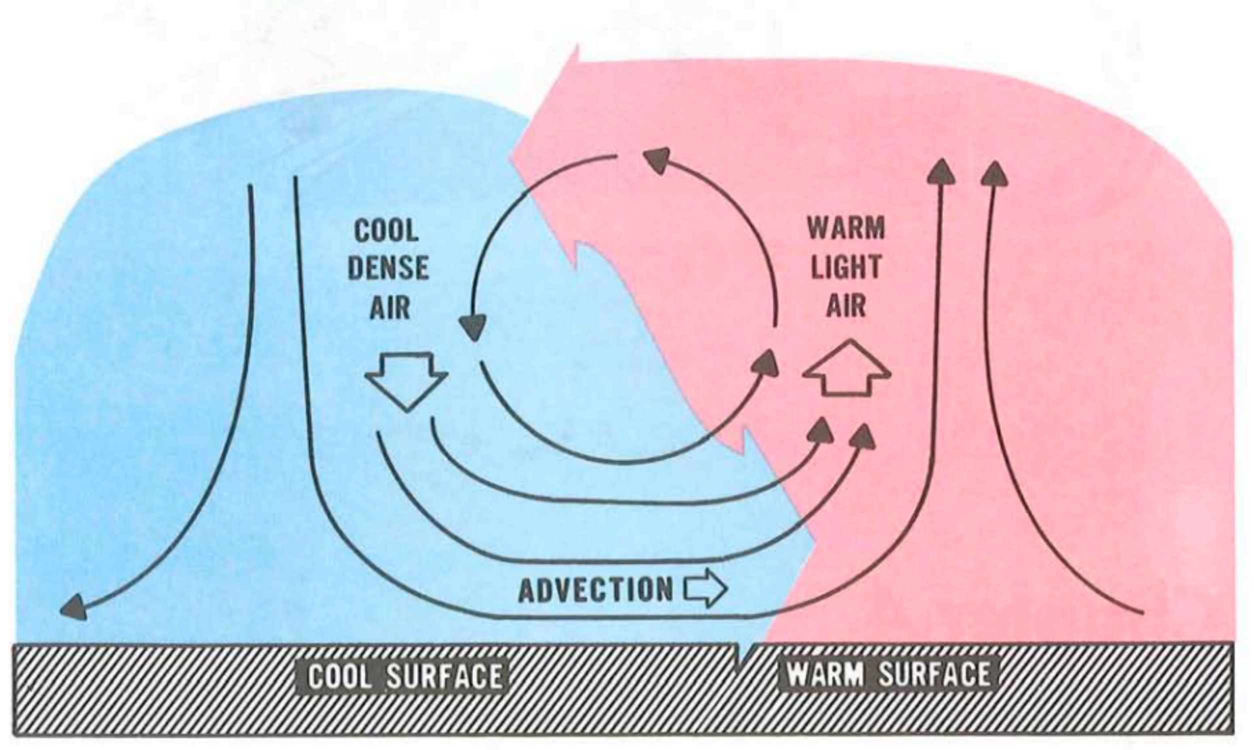


Mapping Pressure

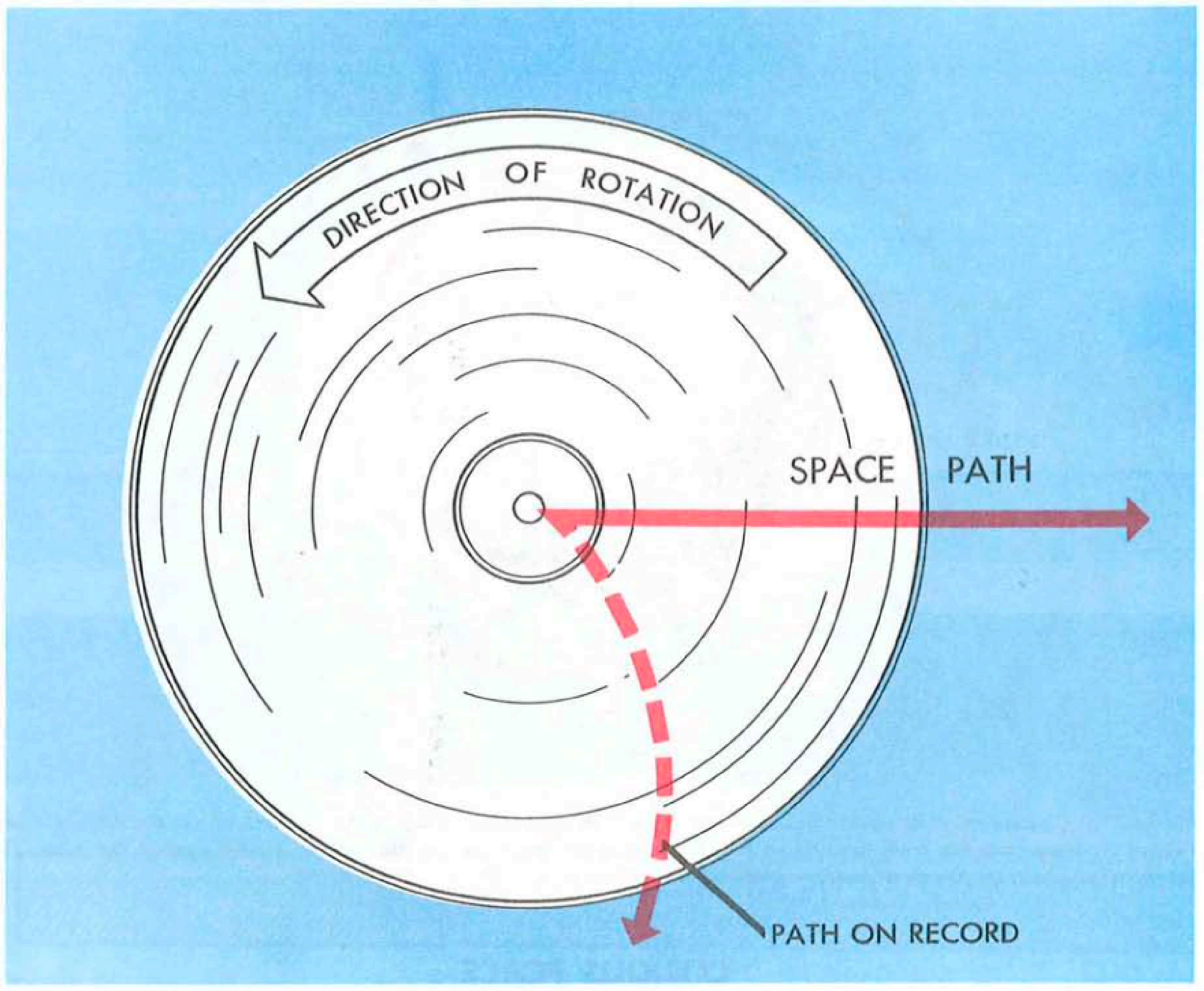
- What if we plot ambient pressure on a map?
- Black lines are called **isobars**: Lines of equal pressure
  - Like contours on a topographical map
  - Tightly spaced = big change in pressure over a small distance



Wind and Advection

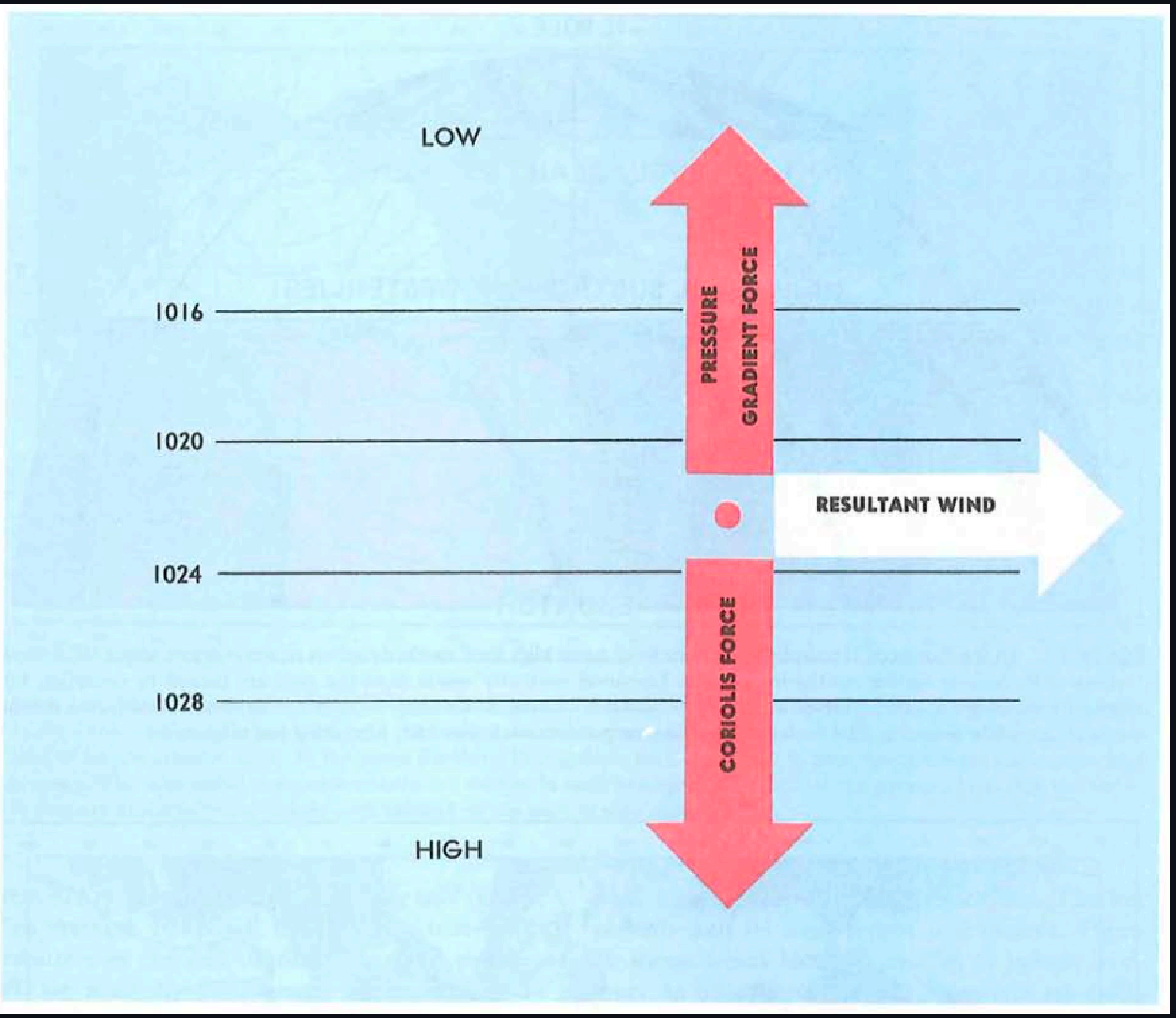


- Differences in temperature create differences in pressure
- Areas of high pressure want to equalize (move towards) areas of lower pressure
- This results in a **pressure gradient force**, which results in wind

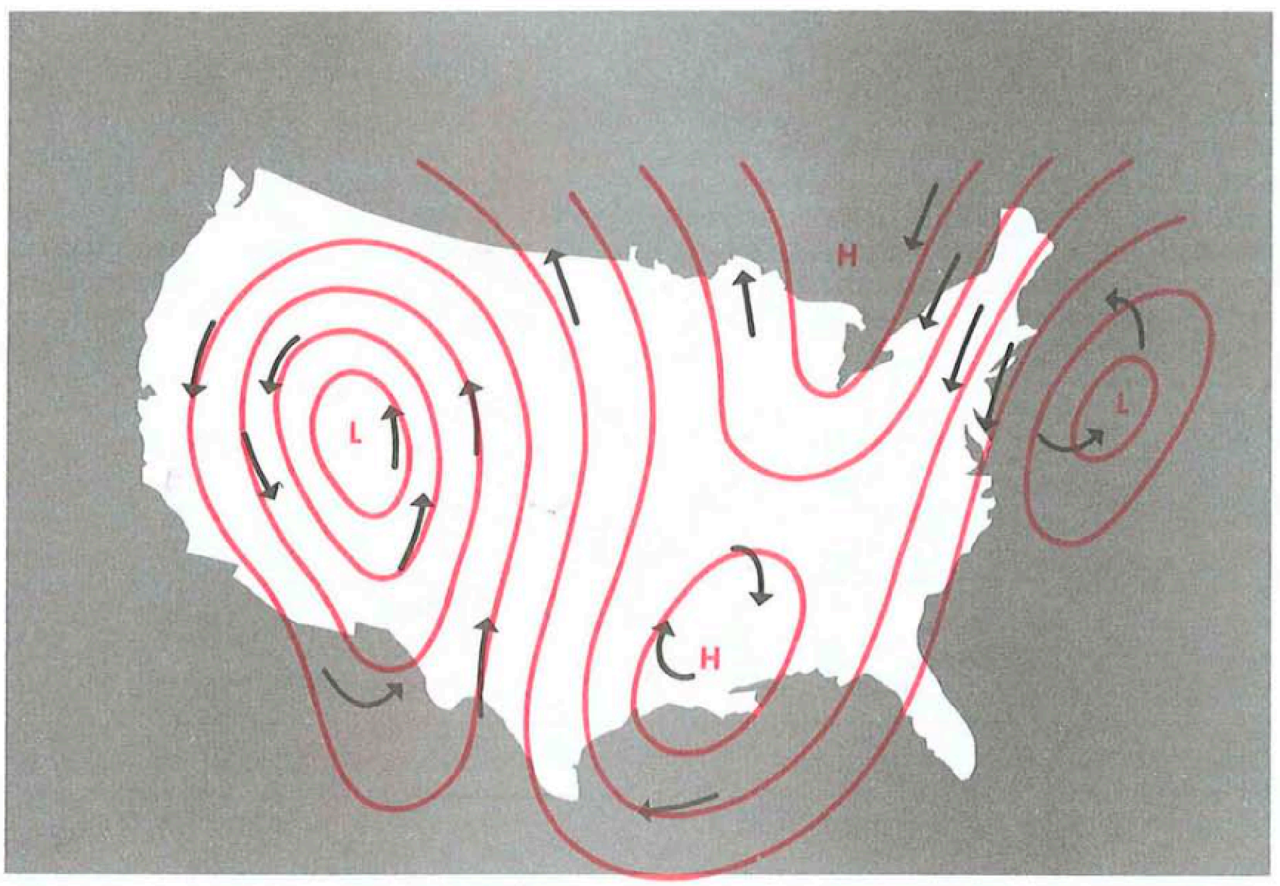


Coriolis Force

- 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



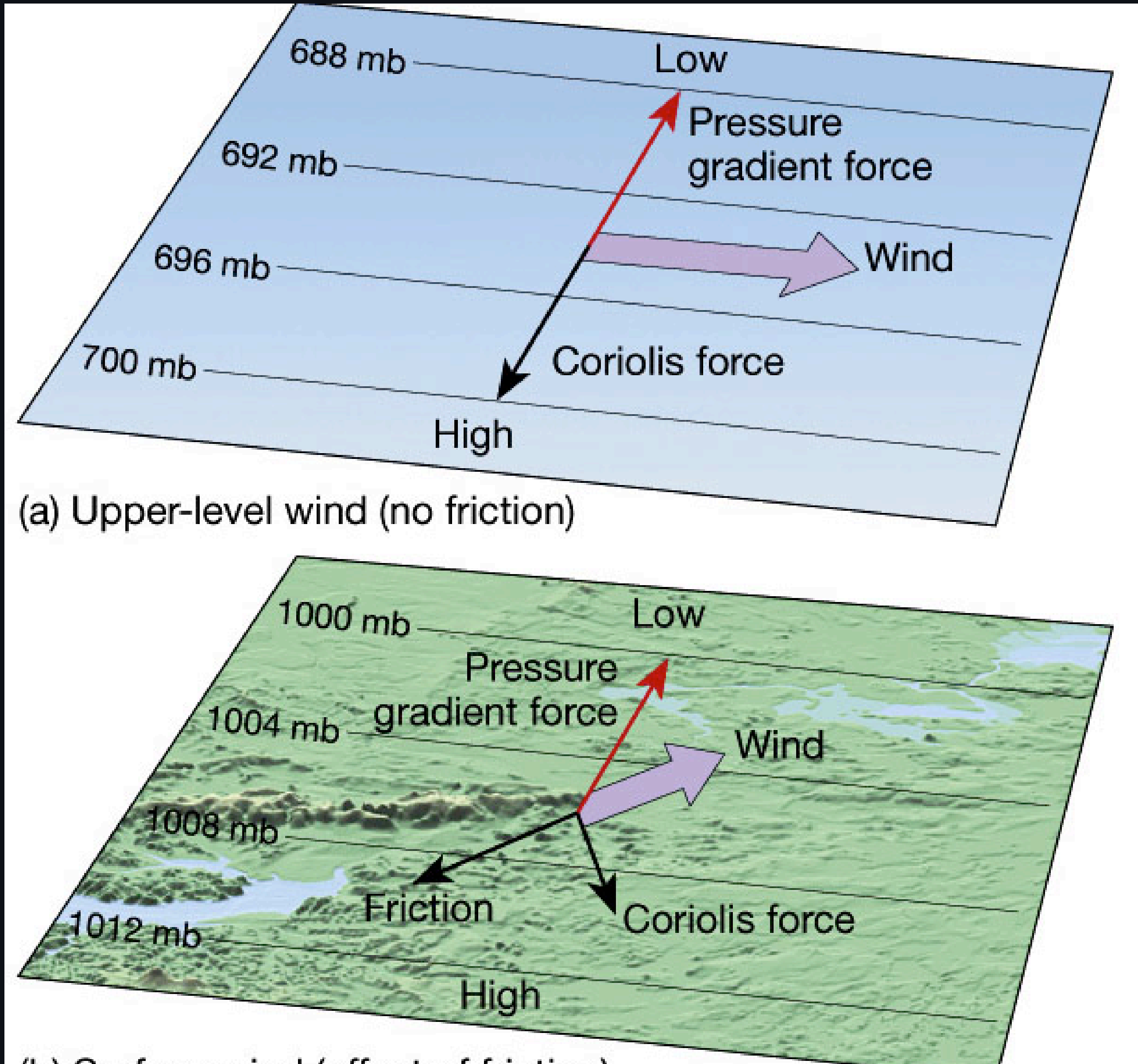
Wind and Isobars

In the northern hemisphere:

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

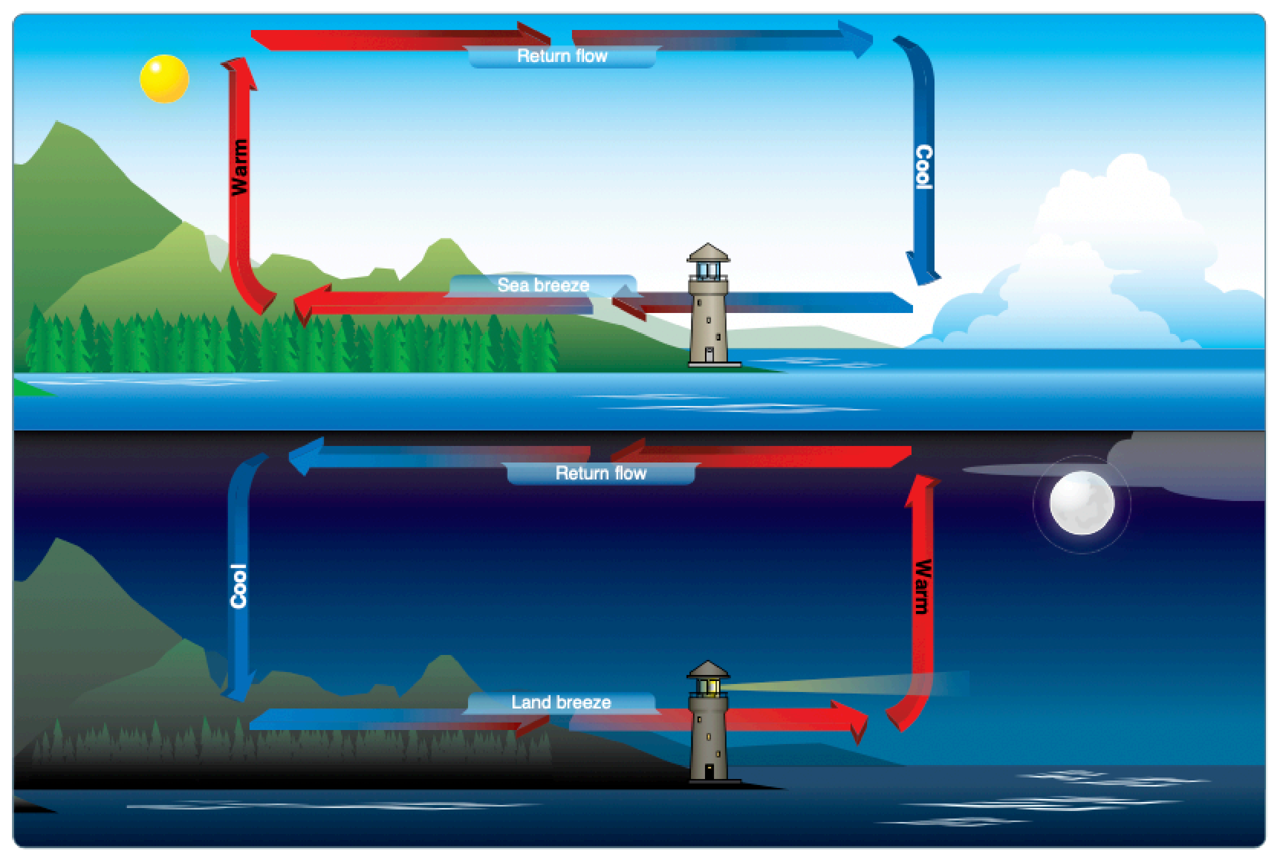
Surface Friction

- 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)

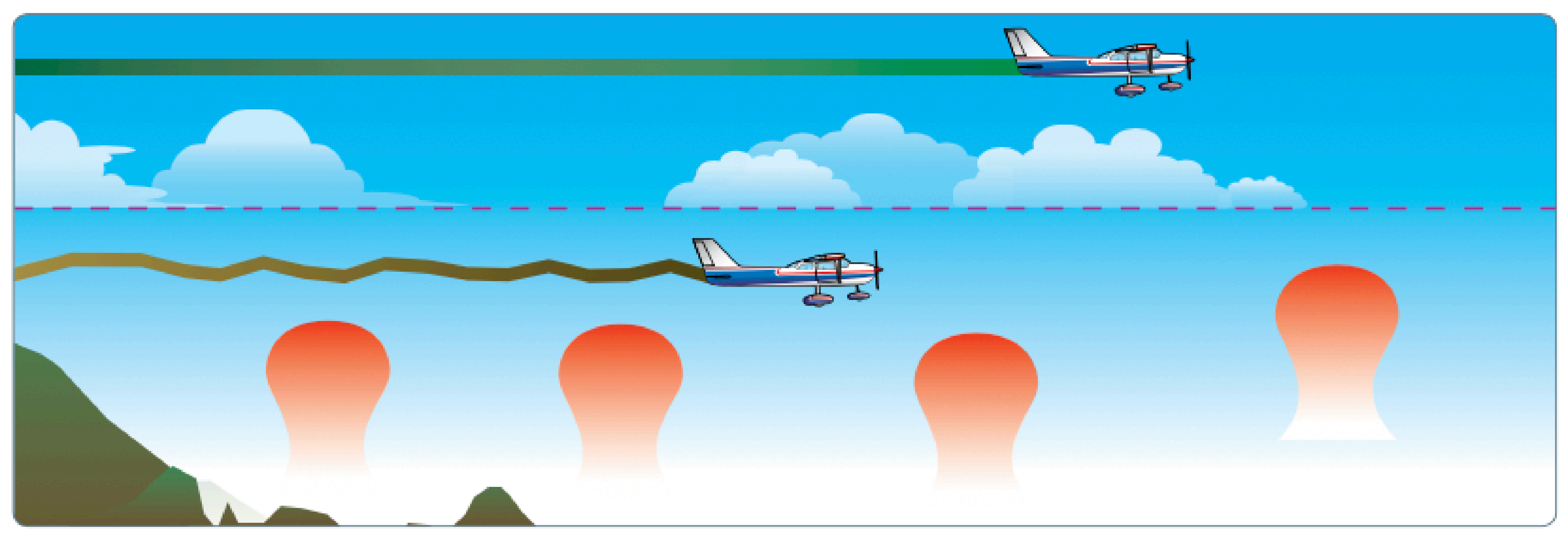


Sea breeze and land breeze

- 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)

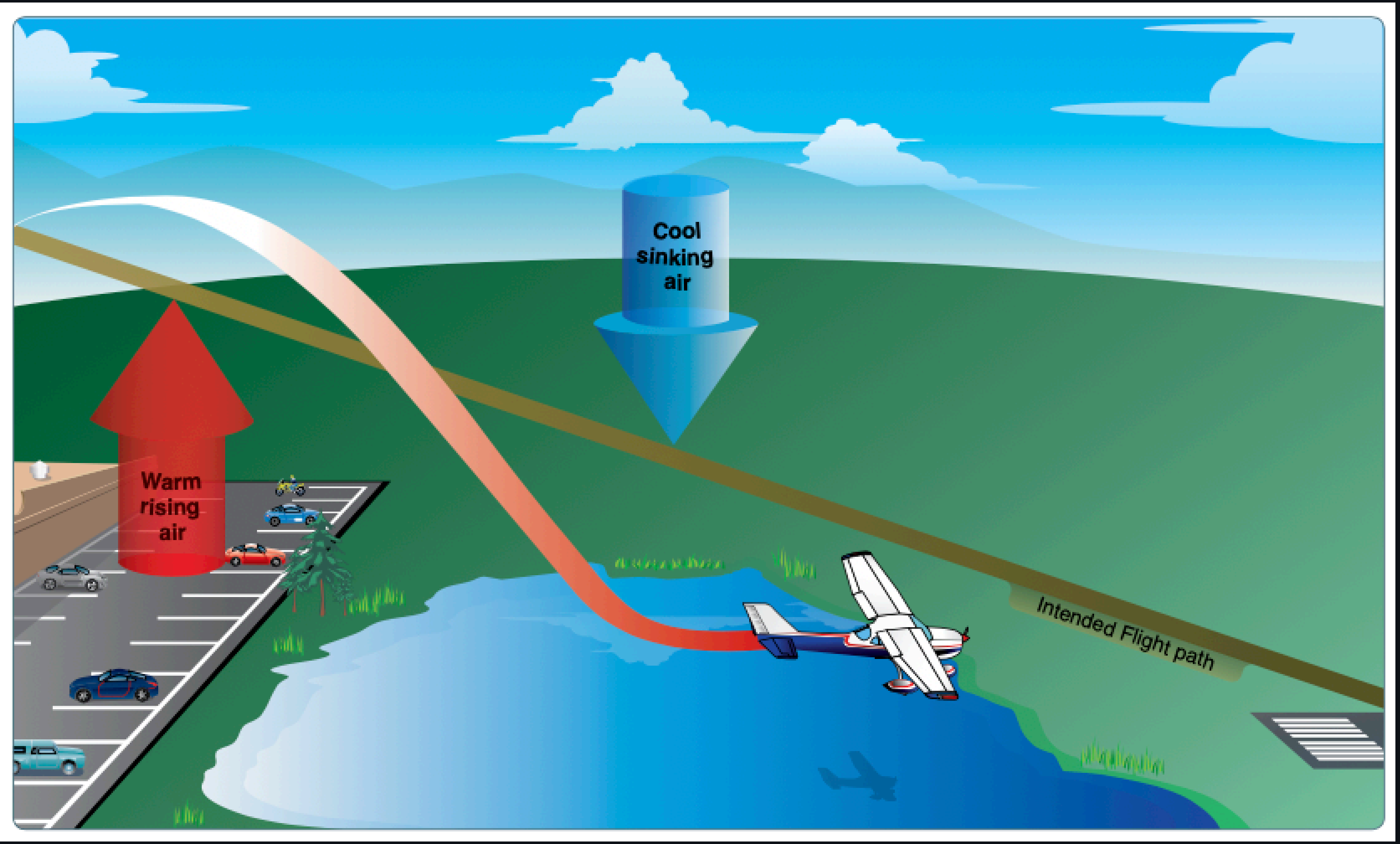
Turbulence

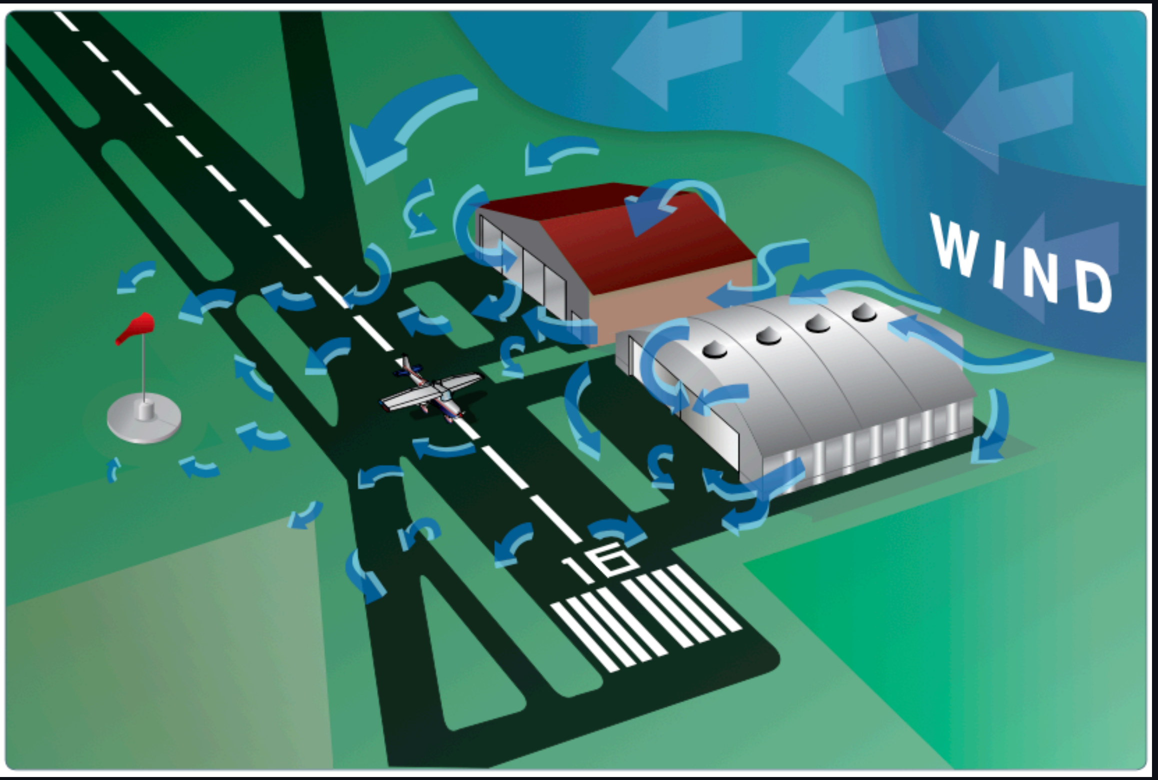
Convective Heating



- 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

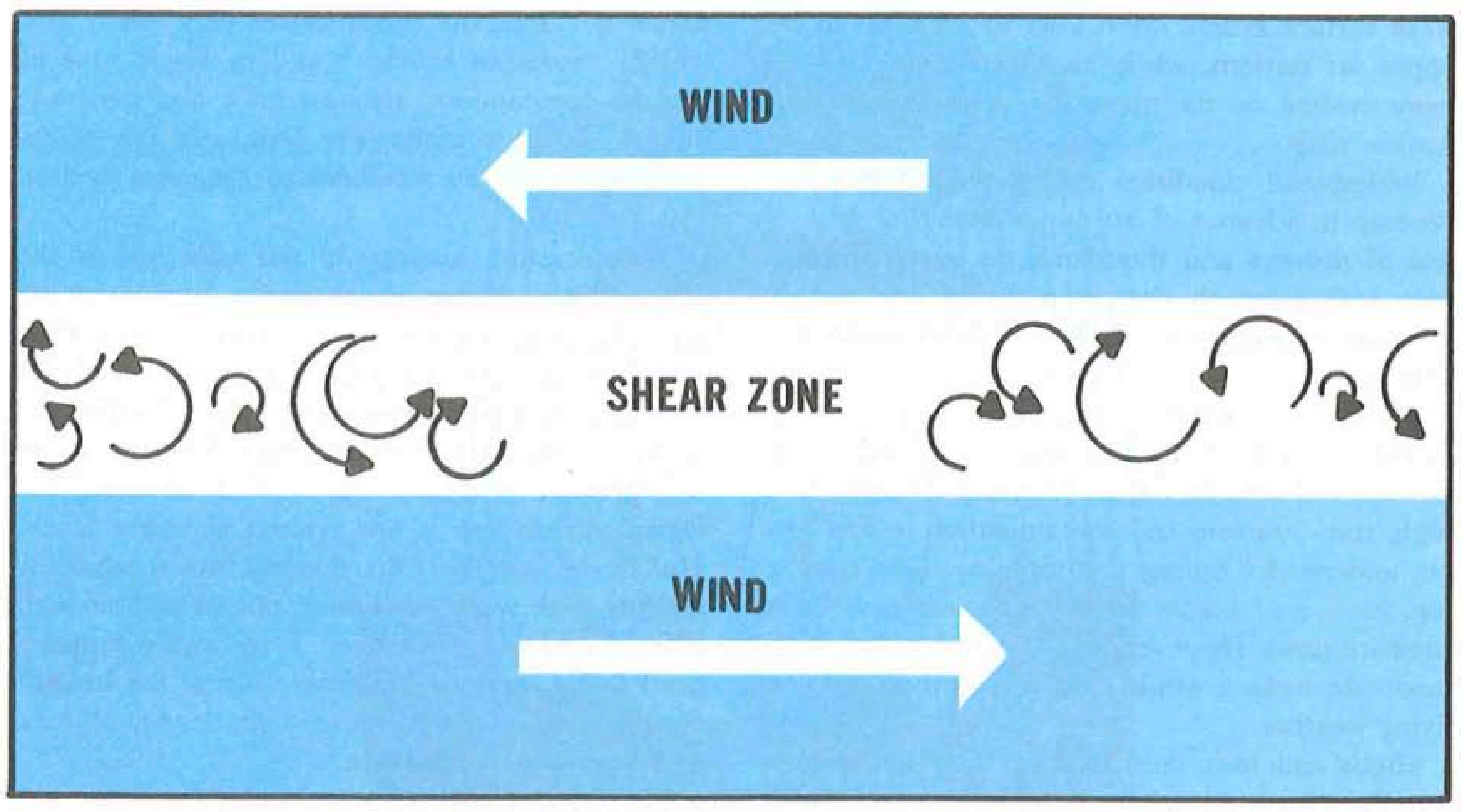




Turbulent flows from obstructions

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

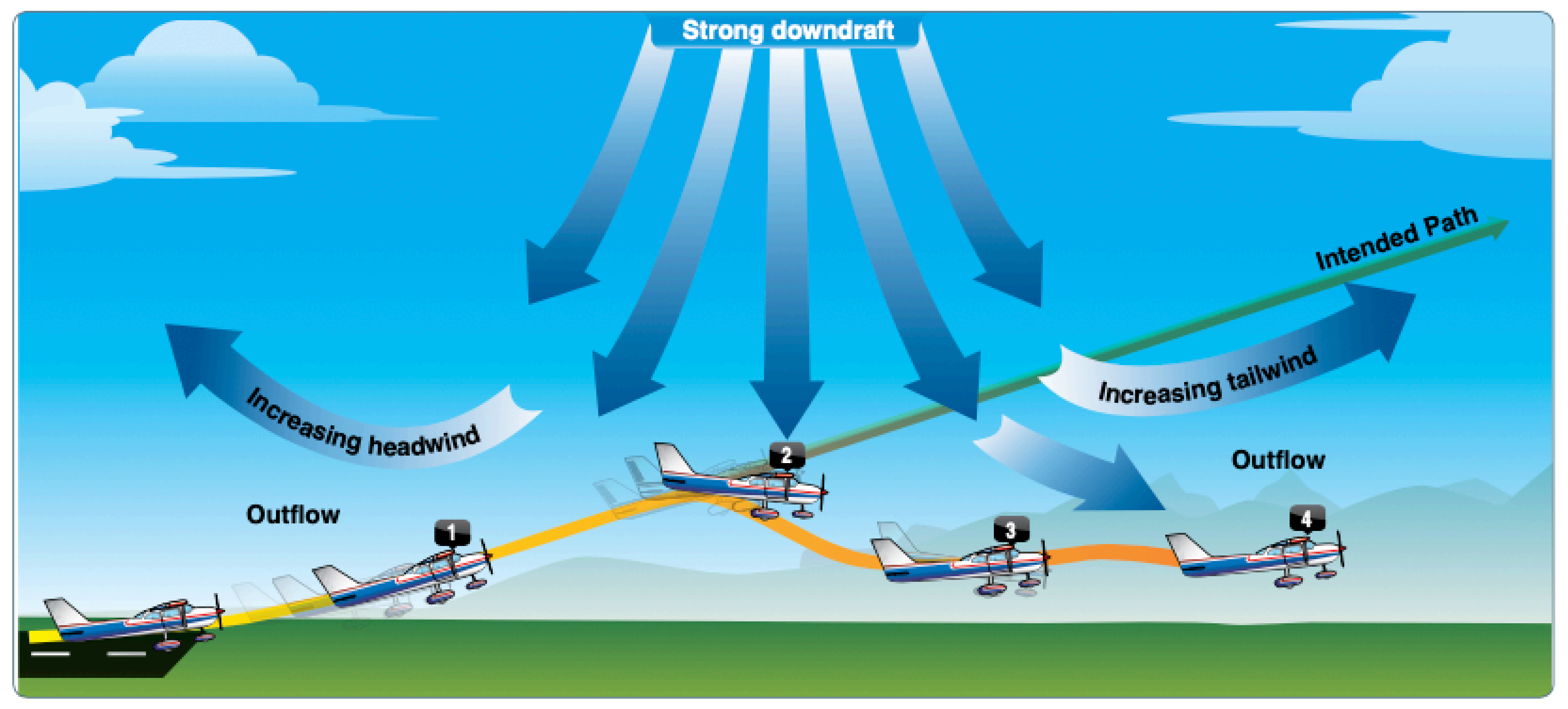
Wind shear



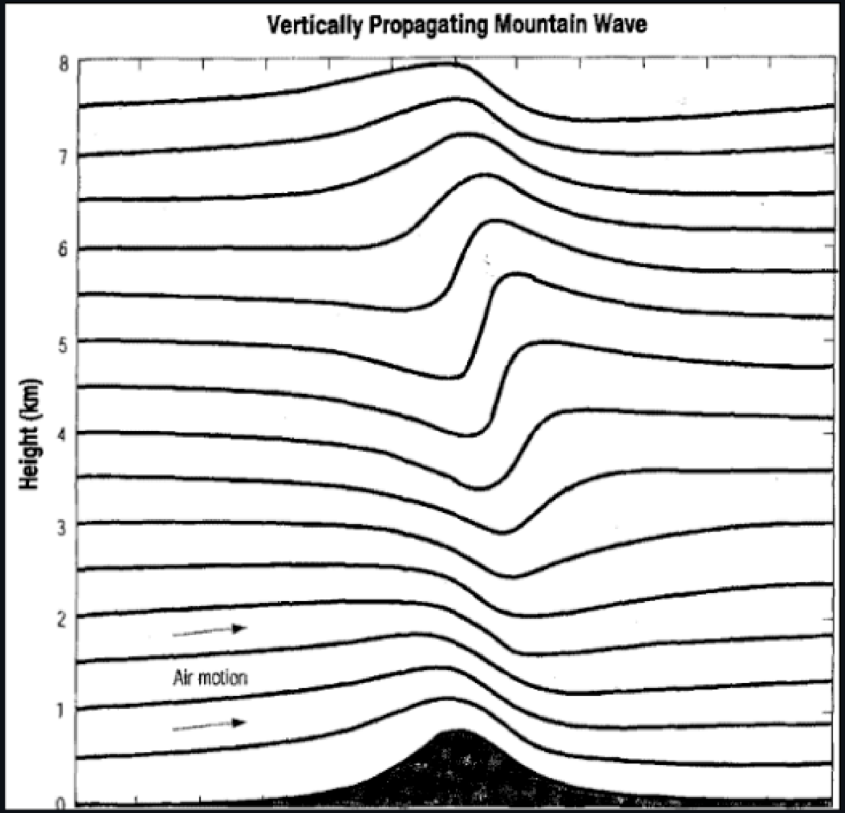
- Turbulent area with mixing between two air different air masses

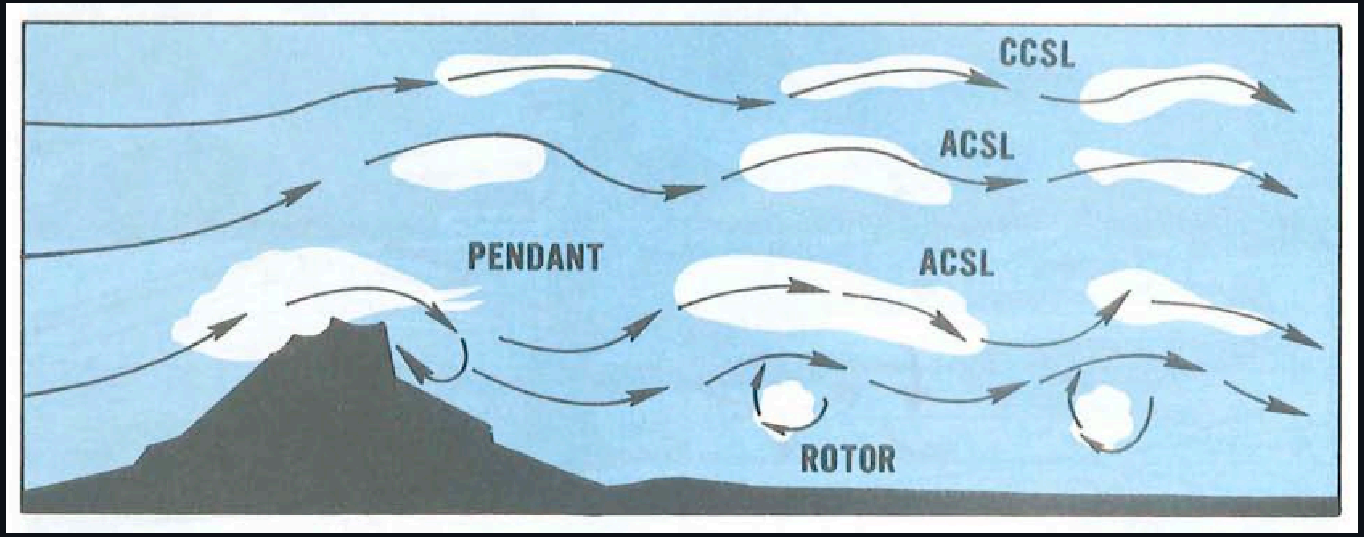
Low-level wind shear

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



Mountain Wave

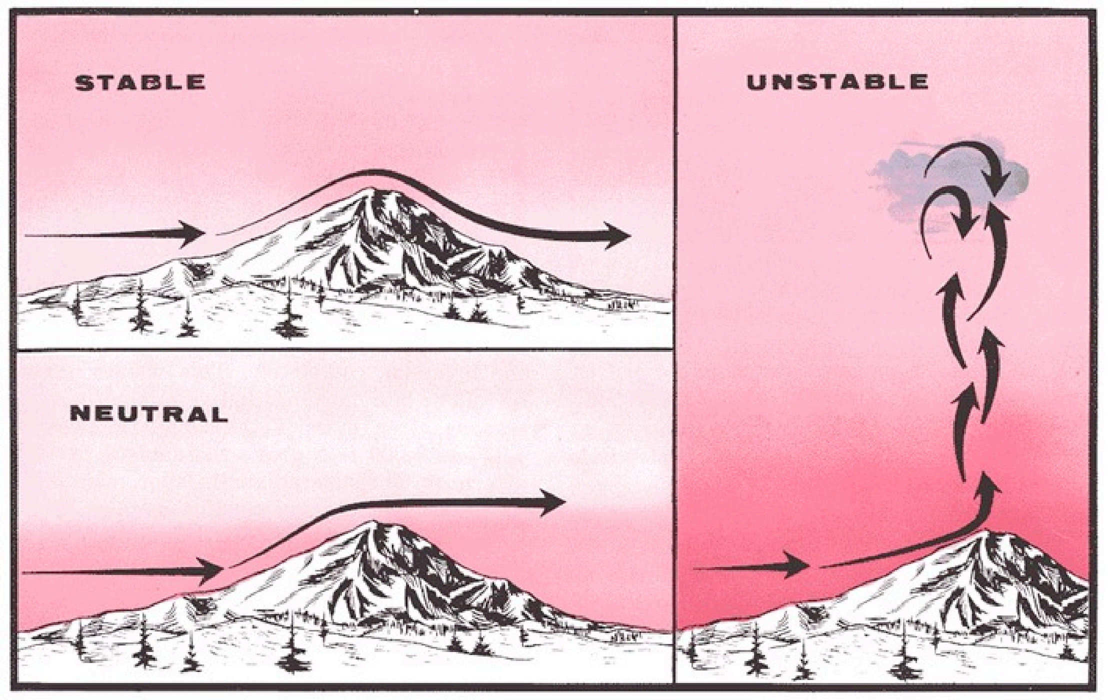




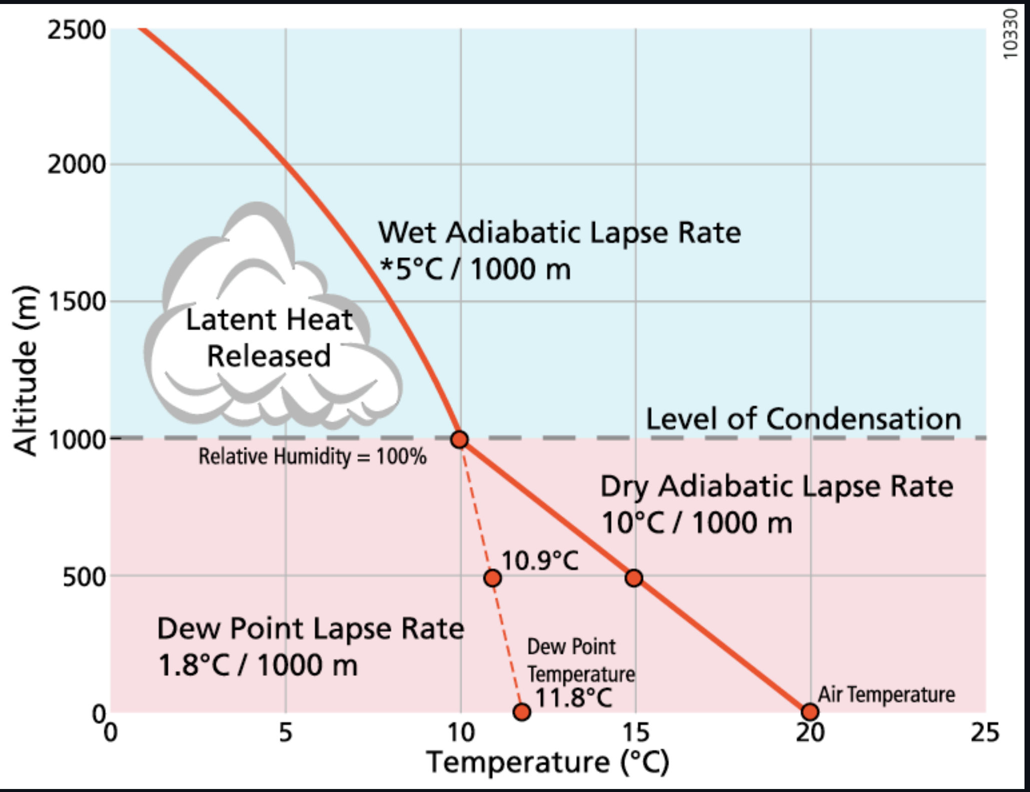
- Large updrafts on the upwind side of the ridge
- Large downdrafts on the leeward side
- Turbulence can be violent in the rotor
- Can extend for 100 miles downwind

Lenticular clouds often indicate mountain wave

Atmospheric Stability

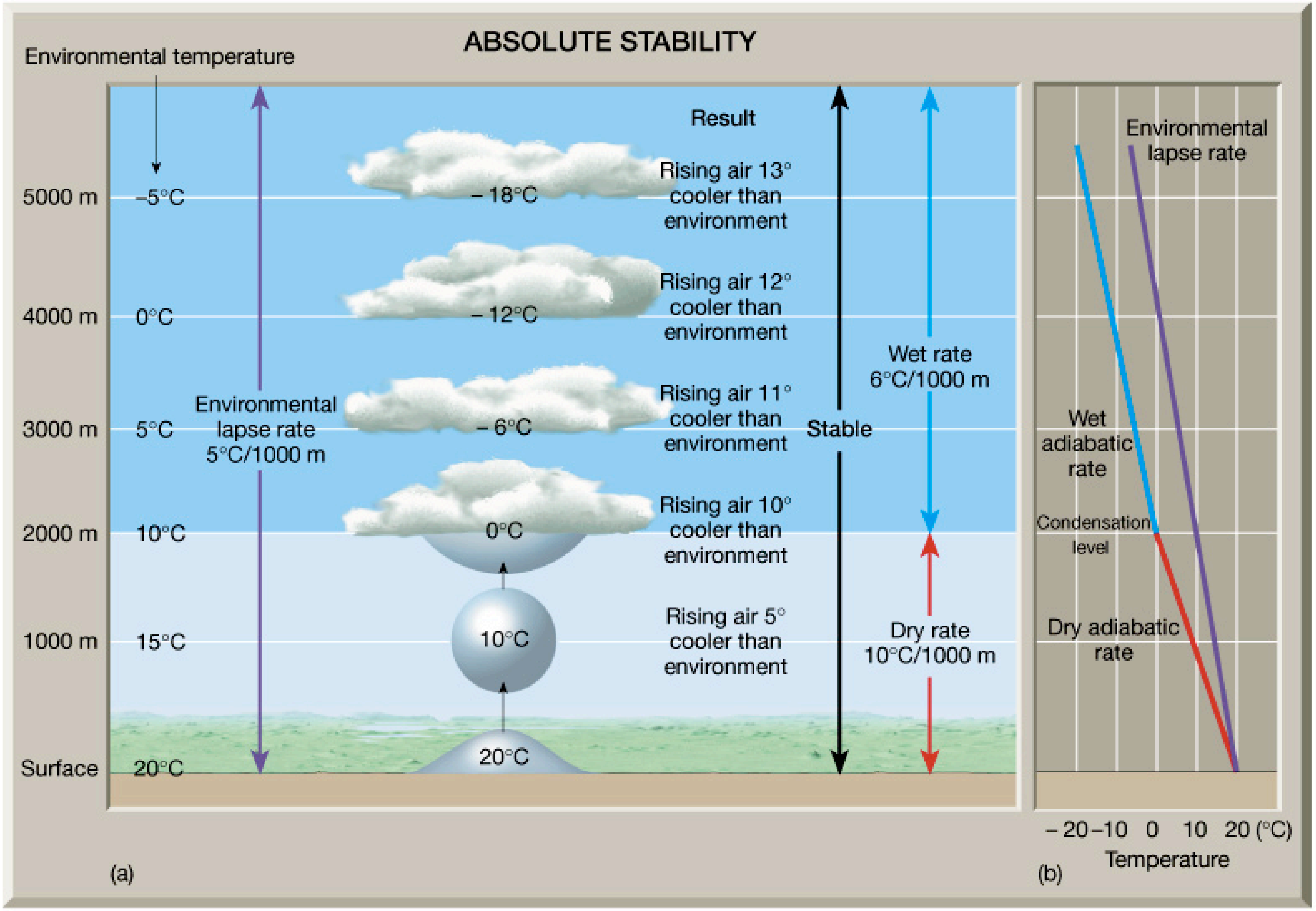


The tendency of atmosphere to resist or encourage vertical motion



Adiabatic Cooling

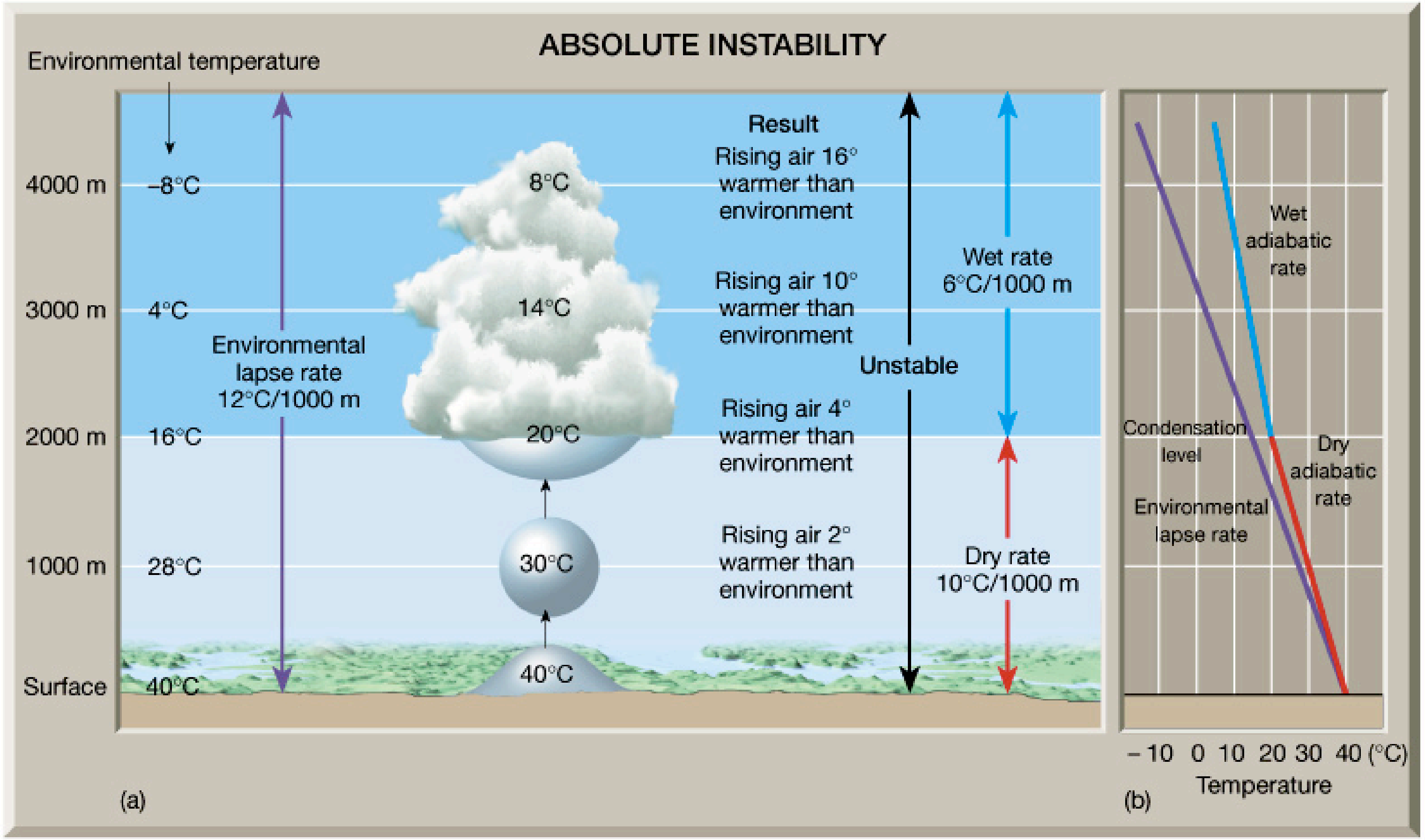
- Adiabatic cooling: Air loses temperature as it rises, since the ambient pressure decreases
- A parcel of air lifted from the surface will cool at the **dry adiabatic lapse rate**
  - 3 °C (5.4 °F) per 1,000 feet
  - This is independent of the lapse rate of the air mass surrounding it



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

Example:

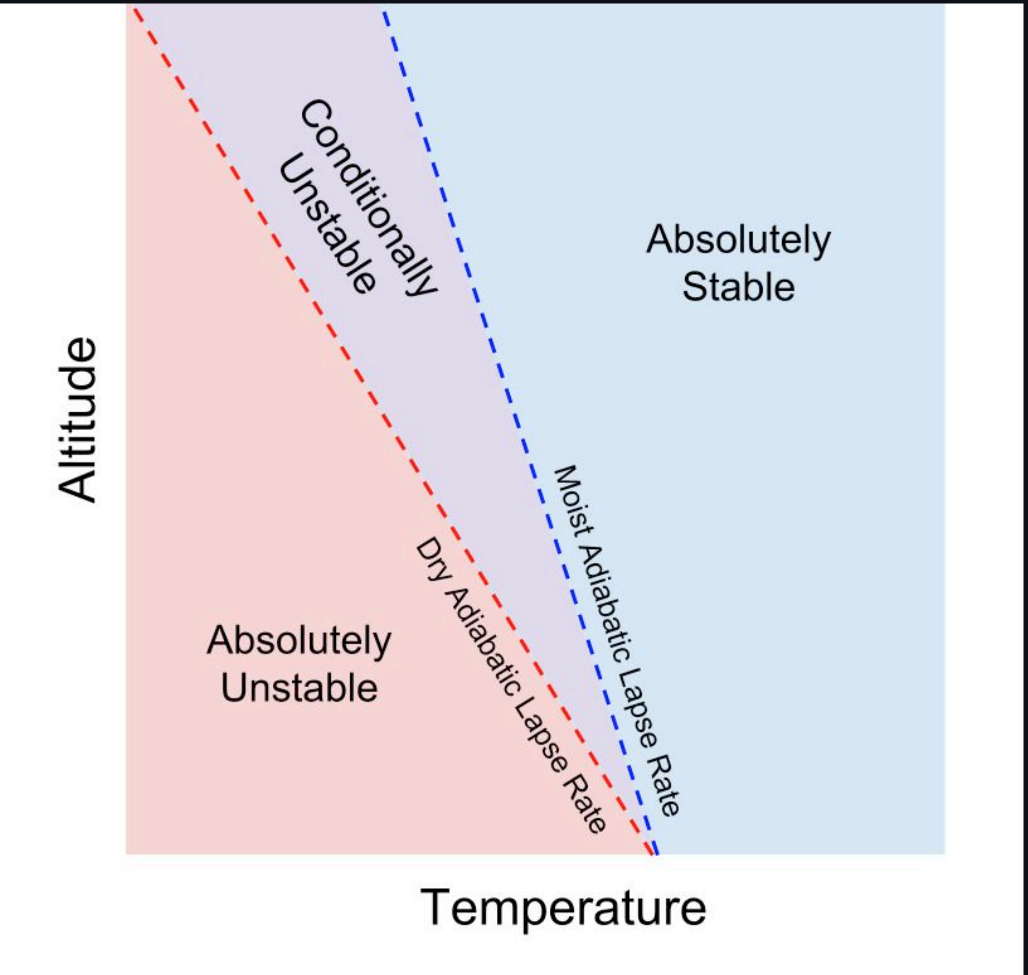
- Parcel lapse rate: 3° per 1000'
- Atmospheric lapse rate: 2.5° per 1000'



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

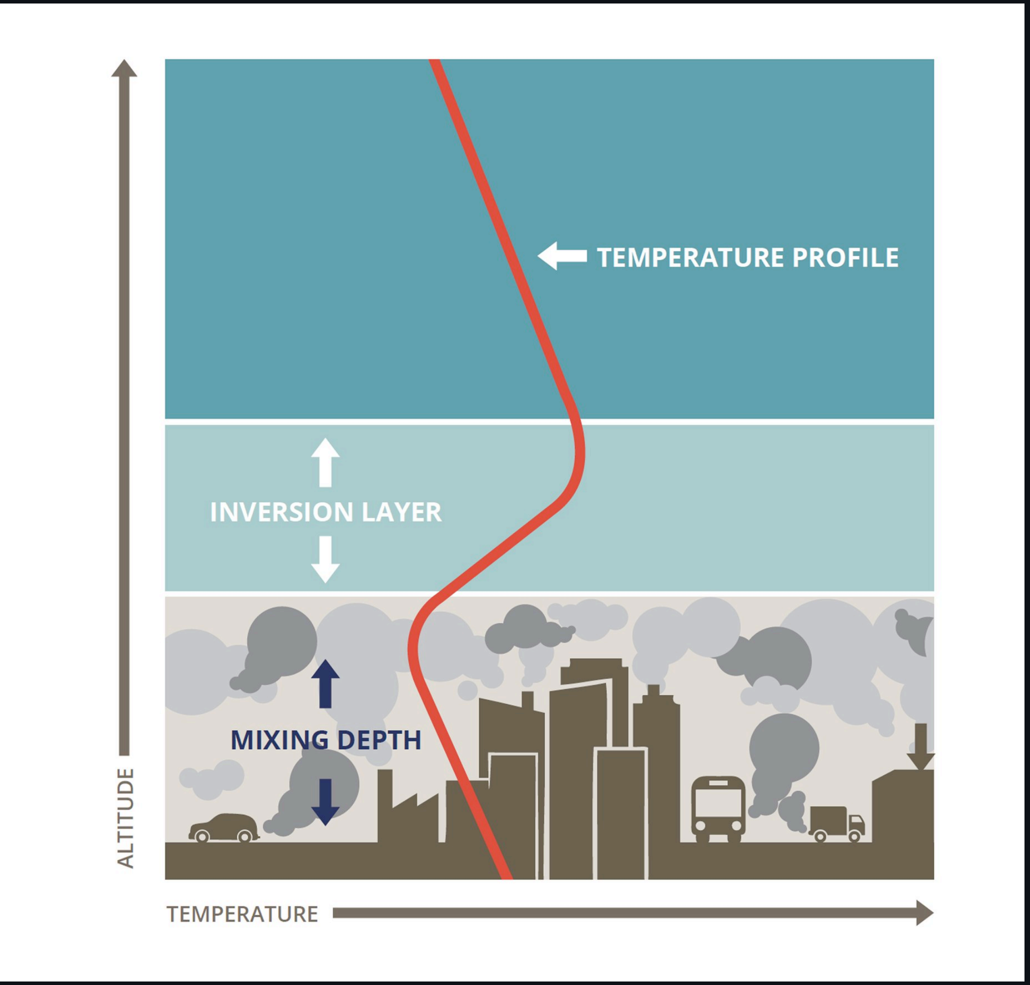
Info | Weather | Runway | Procedure | NOTAM

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

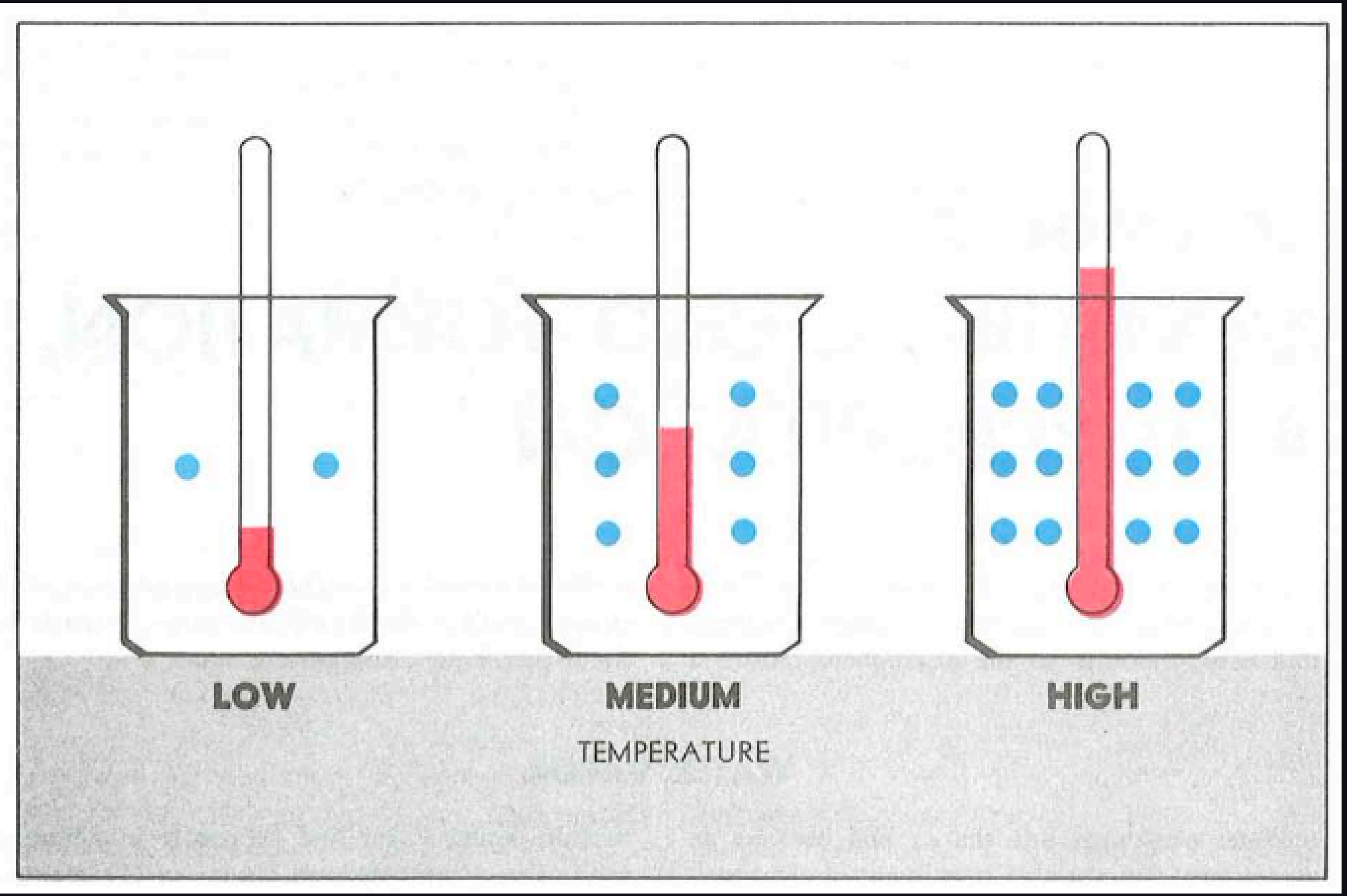


Temperature Inversions

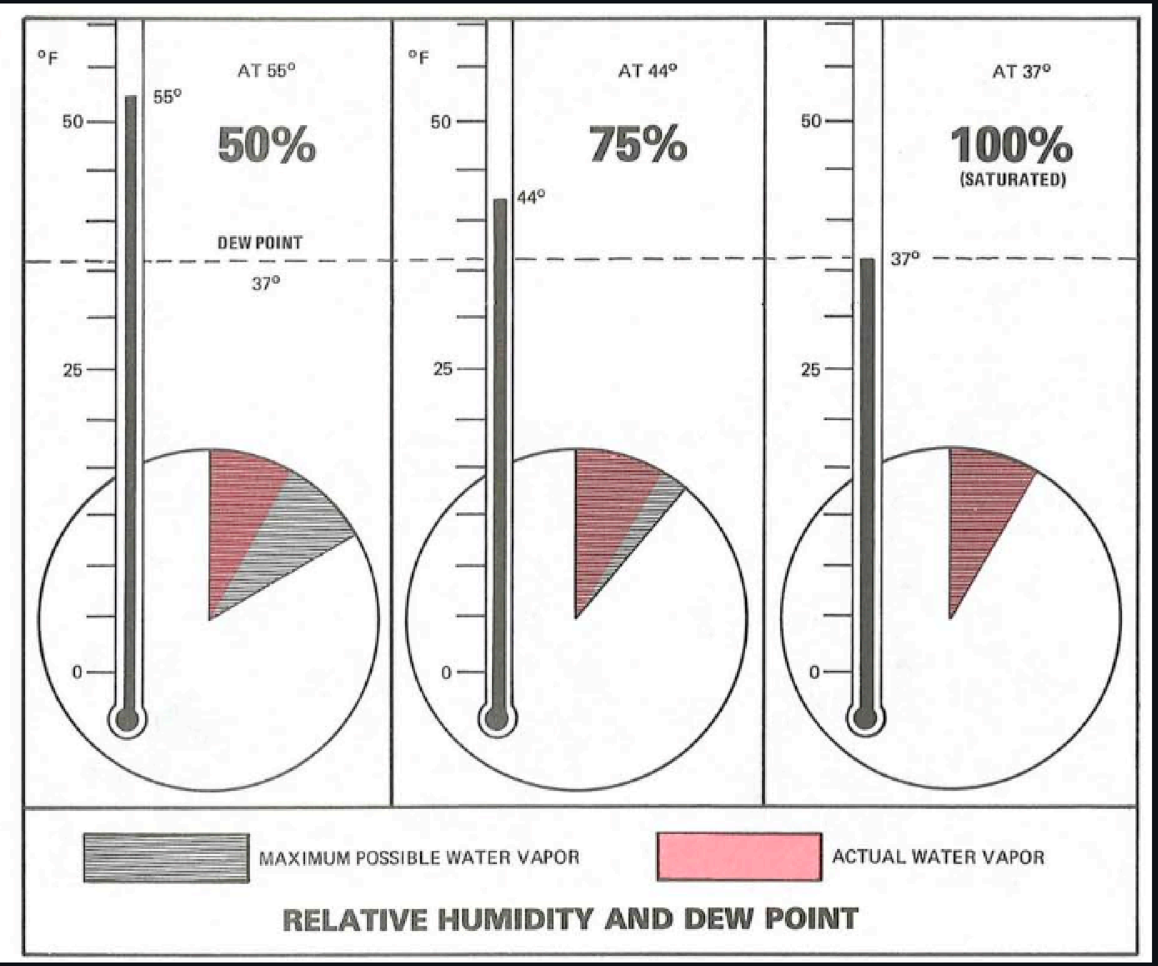
- Layers where temperature *increases* with altitude
- Often occurs on clear, cool nights, when the ground cools the air above it
- Can trap pollutants below the layer
- Smooth air can often be found above the inversion

Moisture and Clouds

Moisture and Temperature

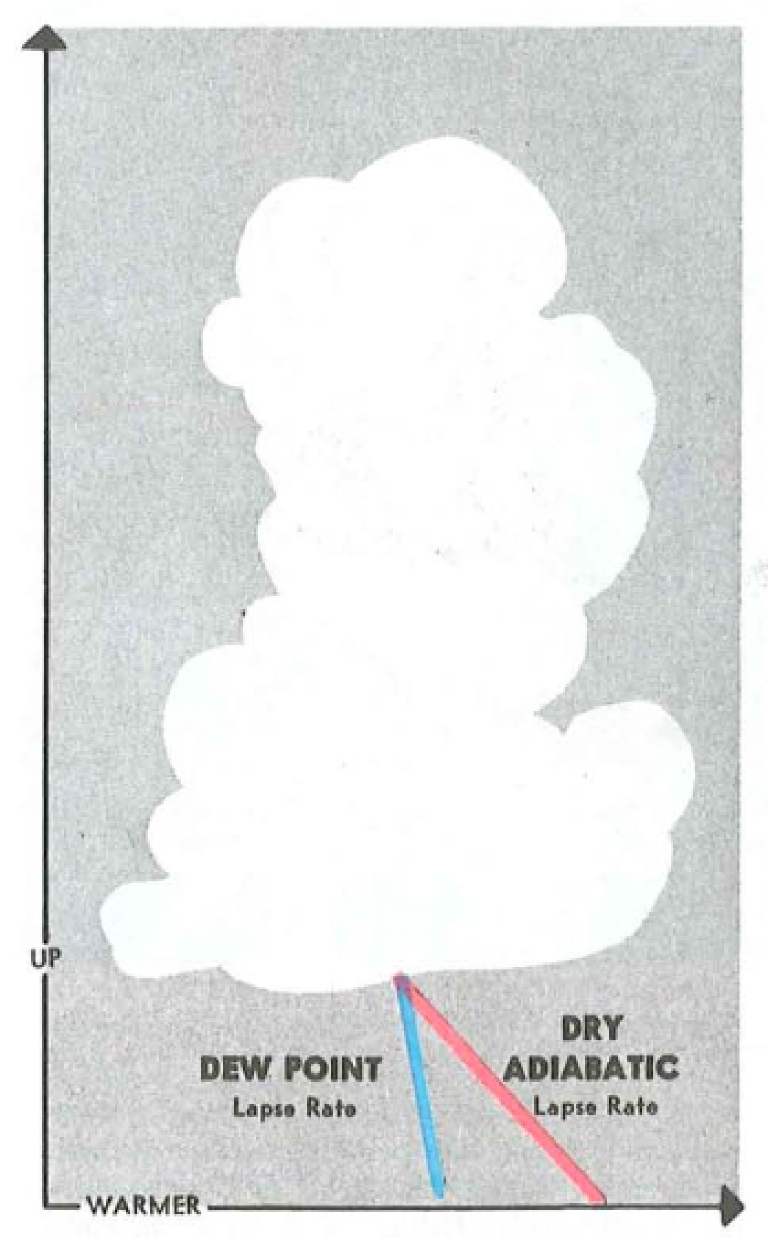


Every 20°F increase in temperature doubles the capacity of water the air can hold



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.

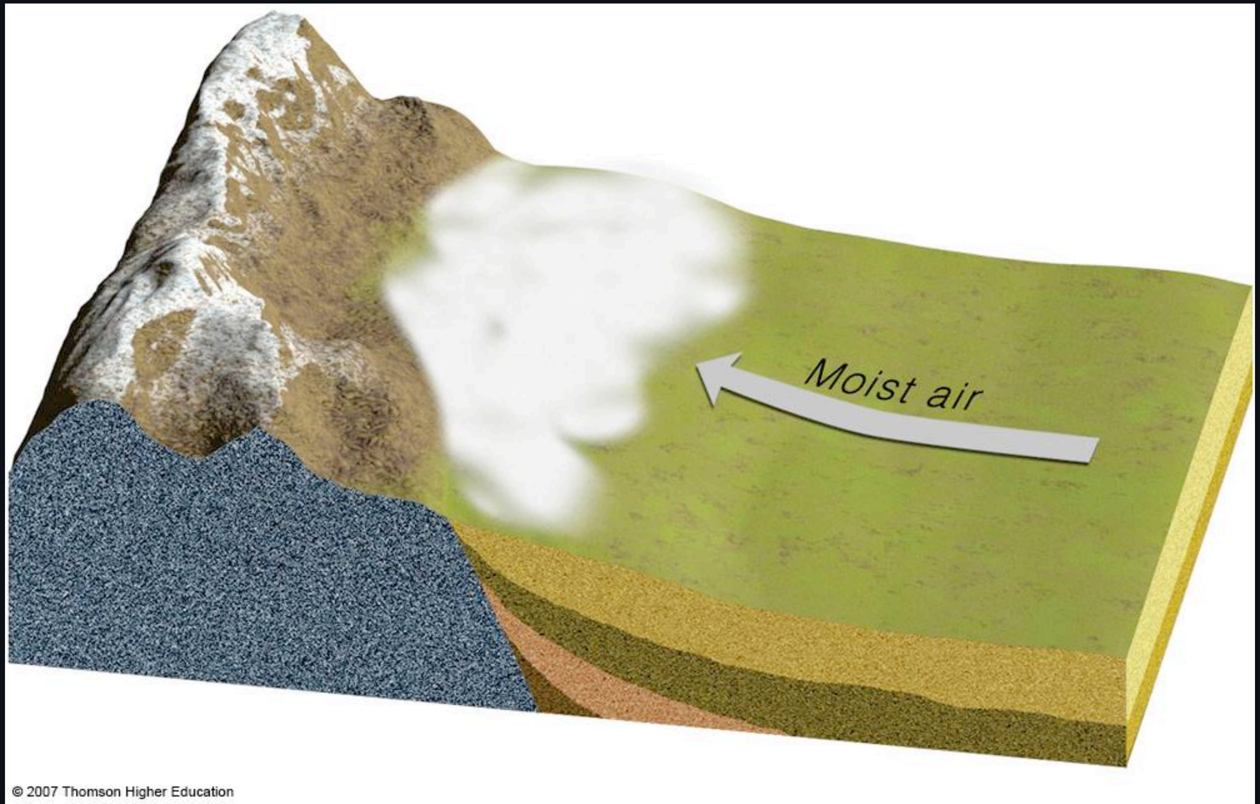
Radiation fog

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

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

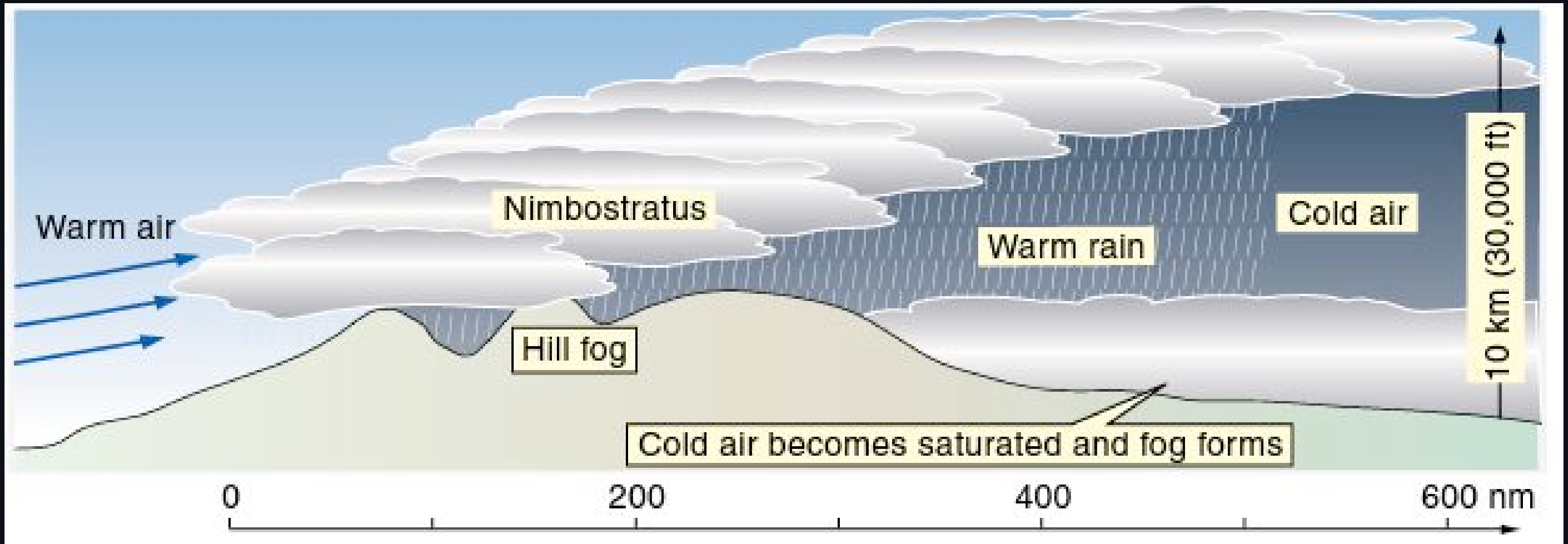


- Moist air is forced up a slope
- Air then adiabatically cools to dewpoint and fog forms

Steam fog

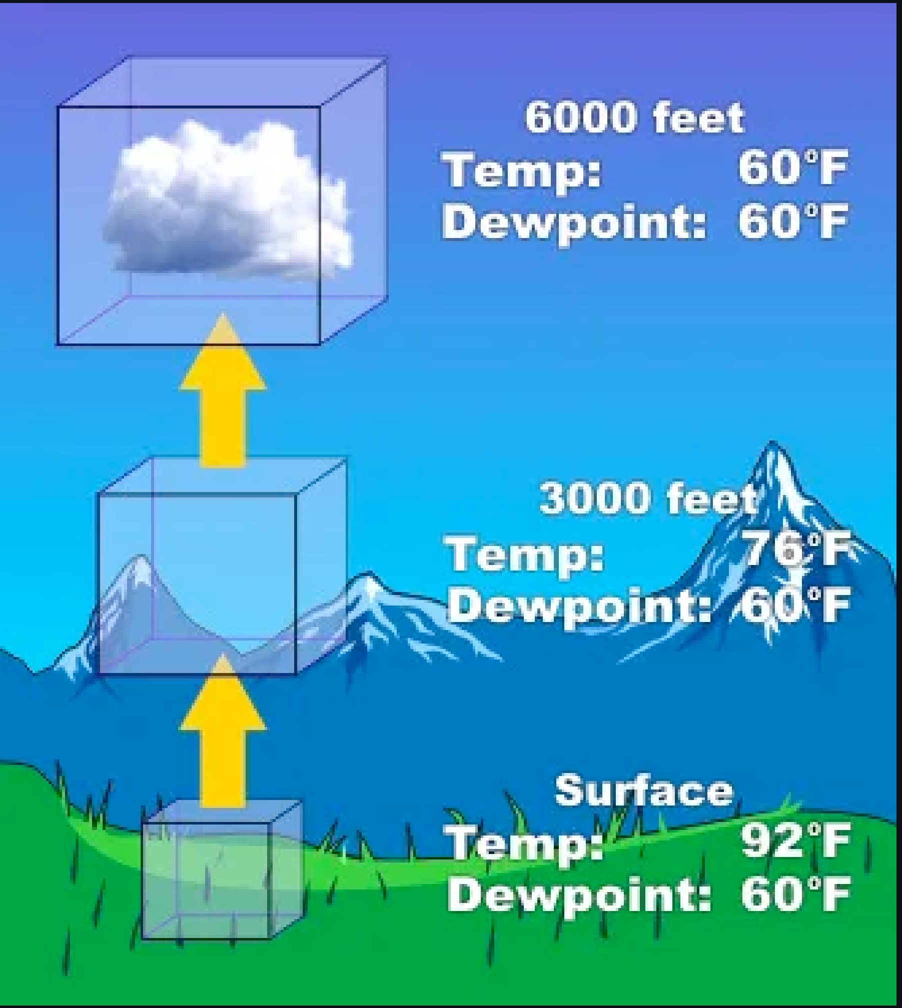
Cold, dry air moves over water, causing evaporation from the water

Front / Precipitation Fog



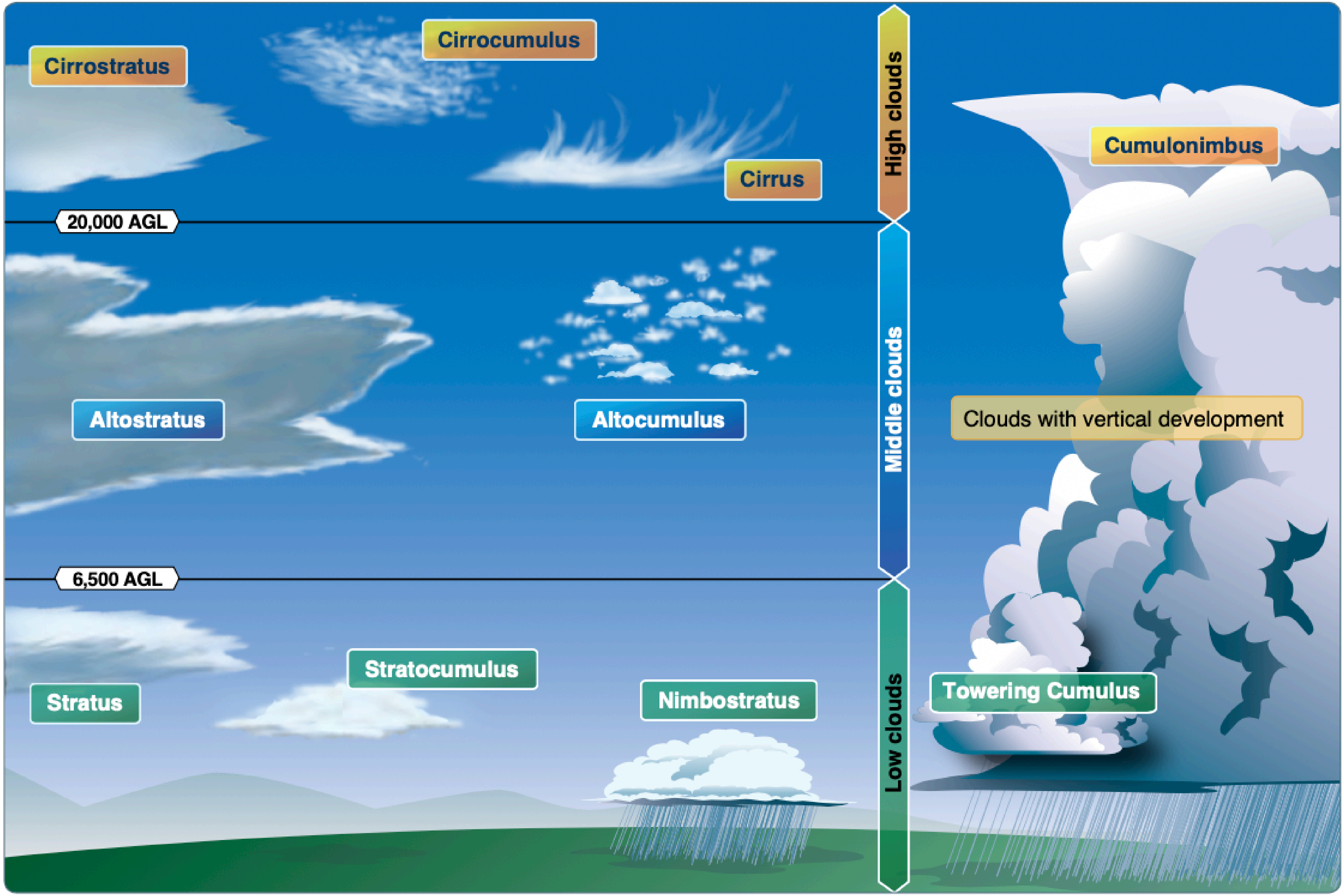
- Often associated with a warm front
- Rain falls into air mass below it, raising it's humidity

Clouds



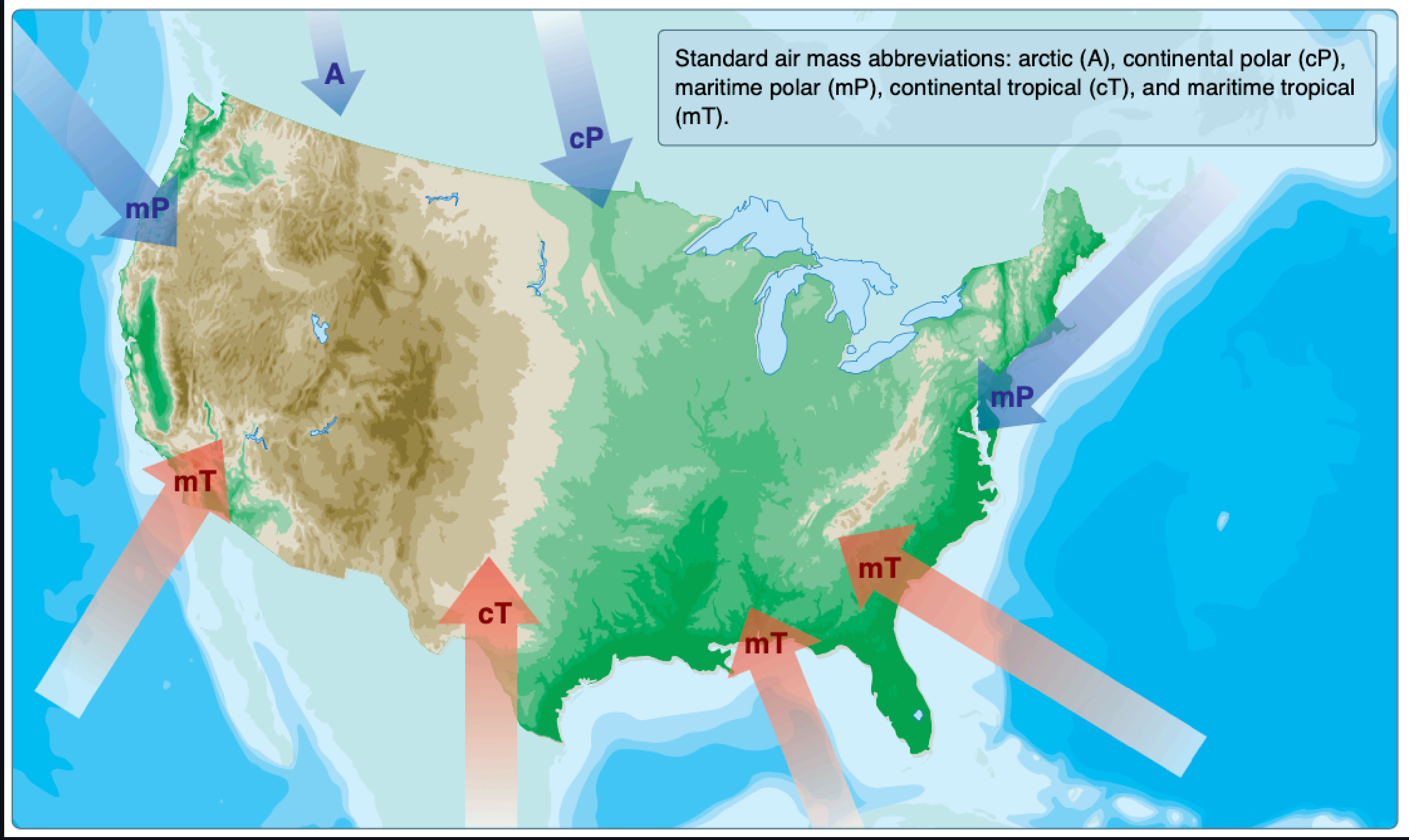
Cloud Formation

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


Cirrostratus
Cirrocumulus
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

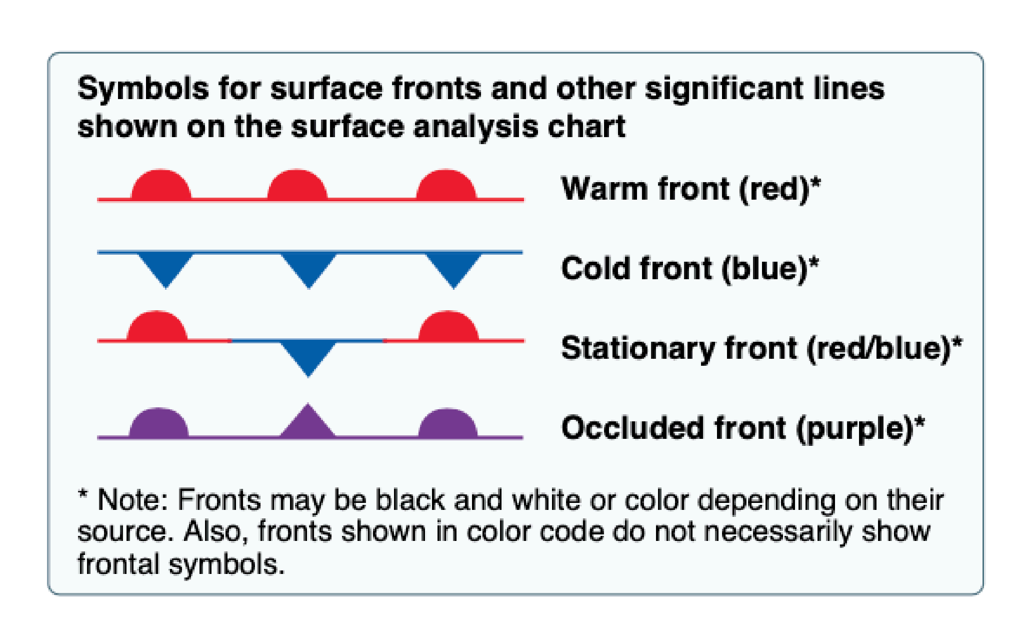
Air Masses

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

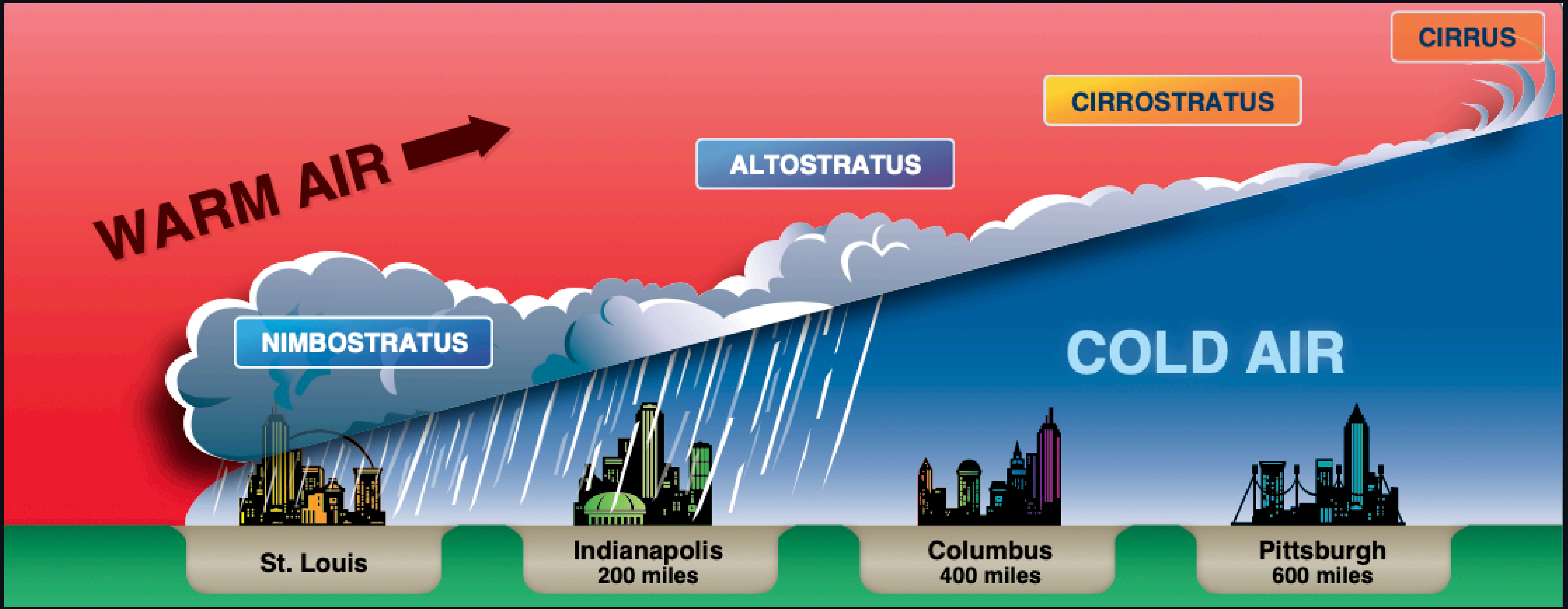


Fronts

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

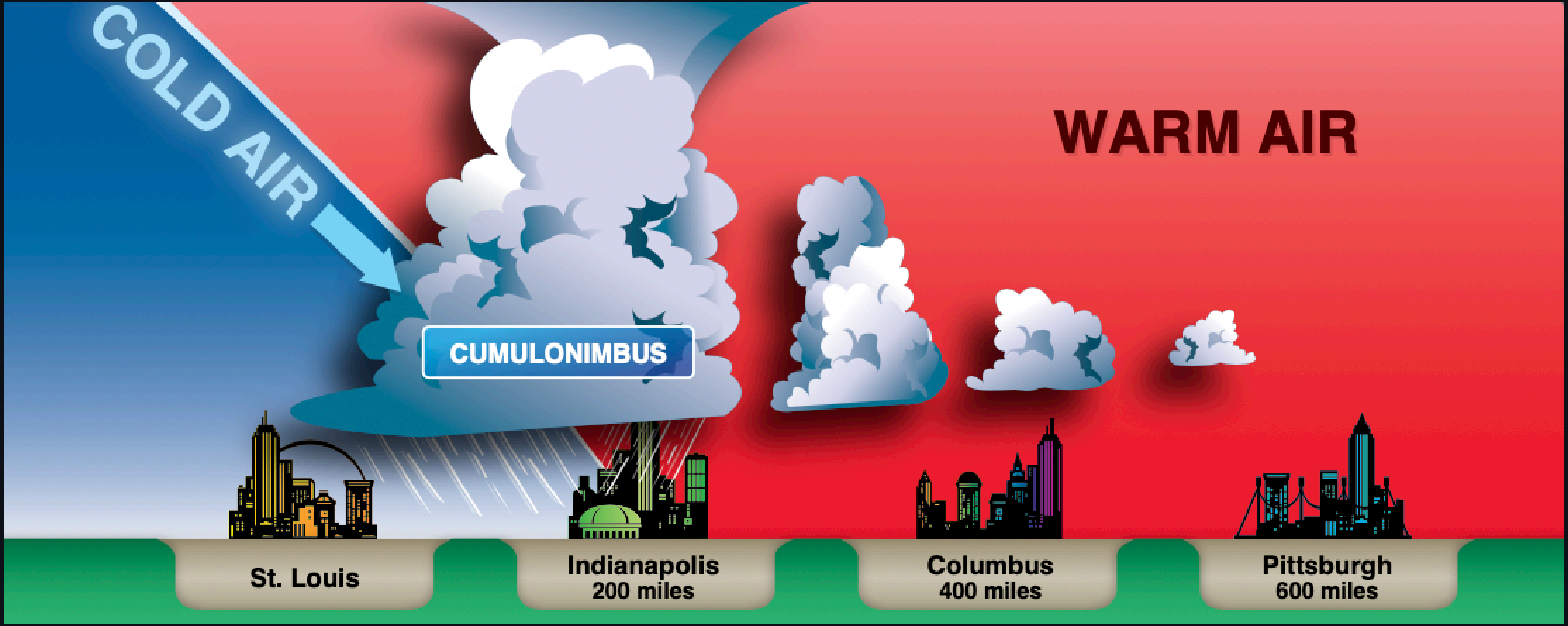


Warm Fronts - Shallow frontal slope

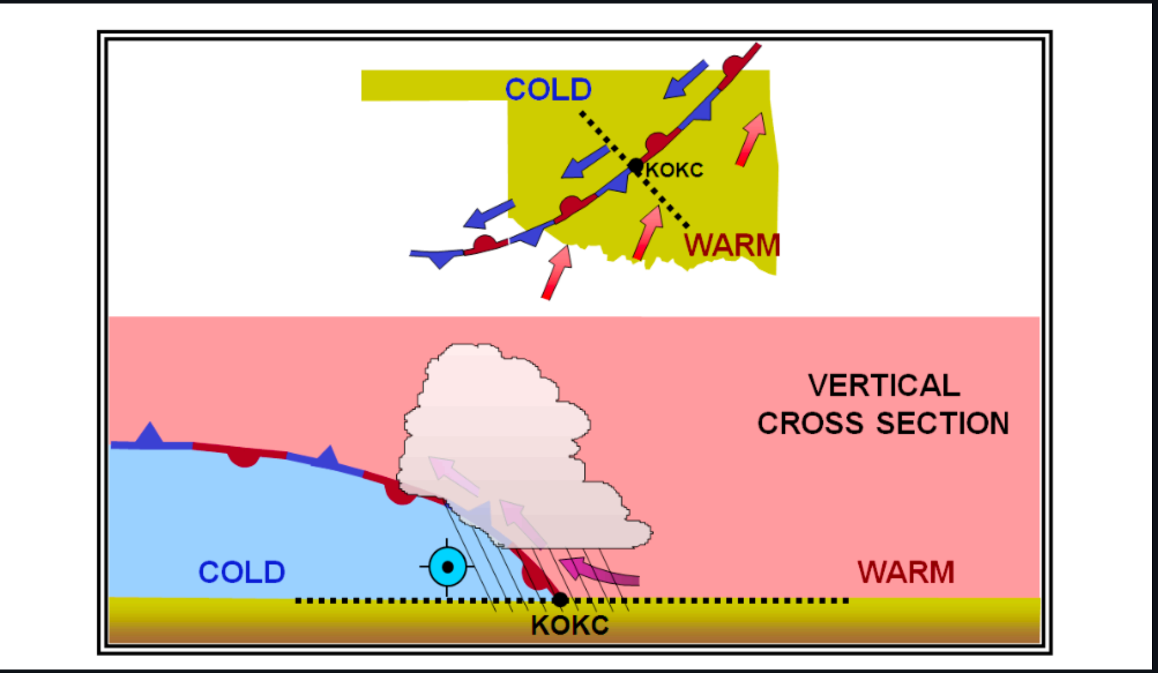


- Warm, often moist air that slides slowly over a colder air mass (shallow frontal slope)
- Ahead of the front, cribriform or stratiform clouds and light precipitation
- Poor visibility, haze as the front passes

Cold Fronts - Steep frontal slope

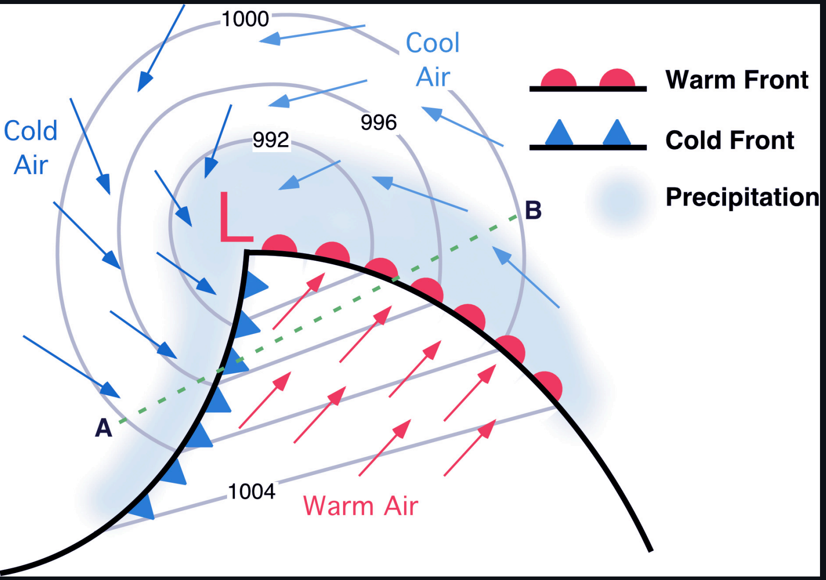


- Cold, dense, stable air quickly slides under and replaces a warmer air mass
- May produce a concentrated band of precipitation and thunderstorms
- Squall lines may form ahead of a fast-moving cold front



Stationary Front - Equal air masses

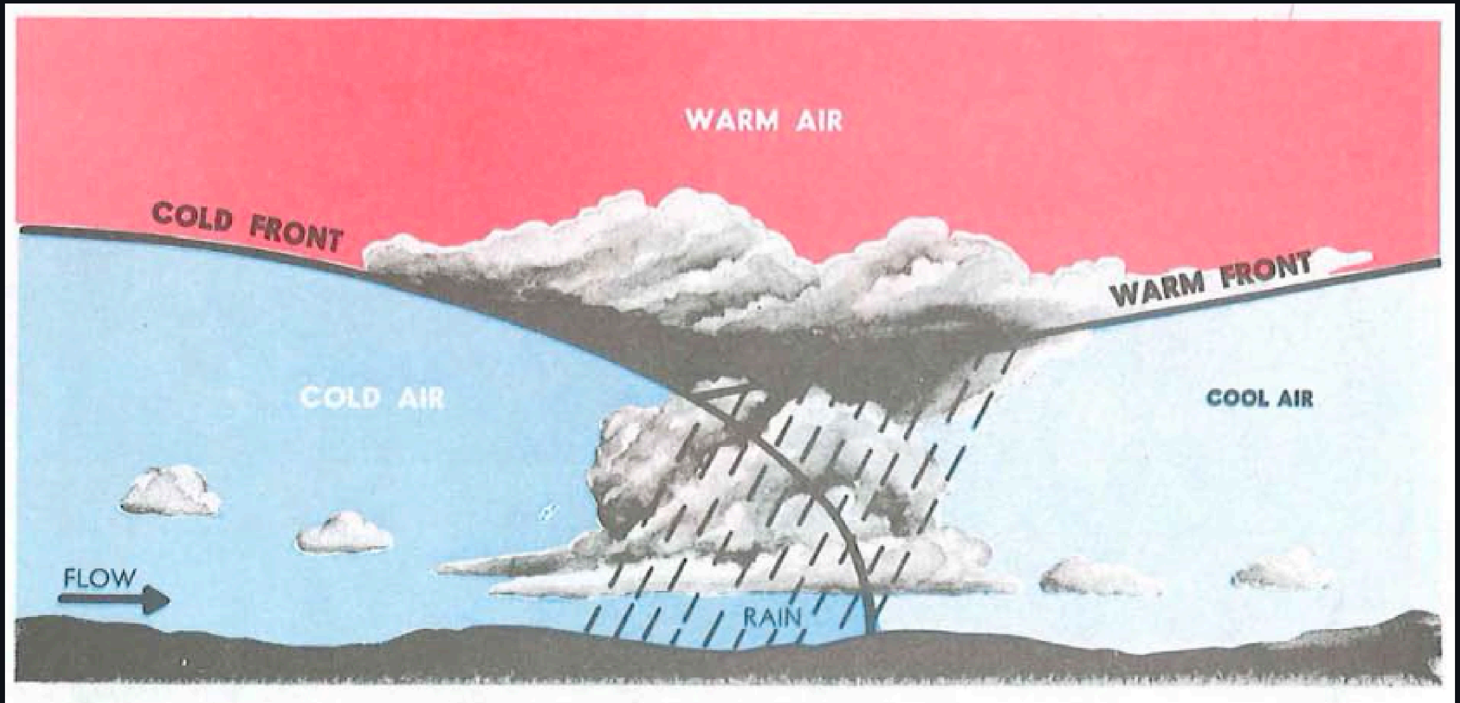
- Air masses with relatively equal forces can remain stationary for several days
- Weather is a mixture of cold front/warm front conditions
- Precipitation is common



Occluded front - Cold front overtaking

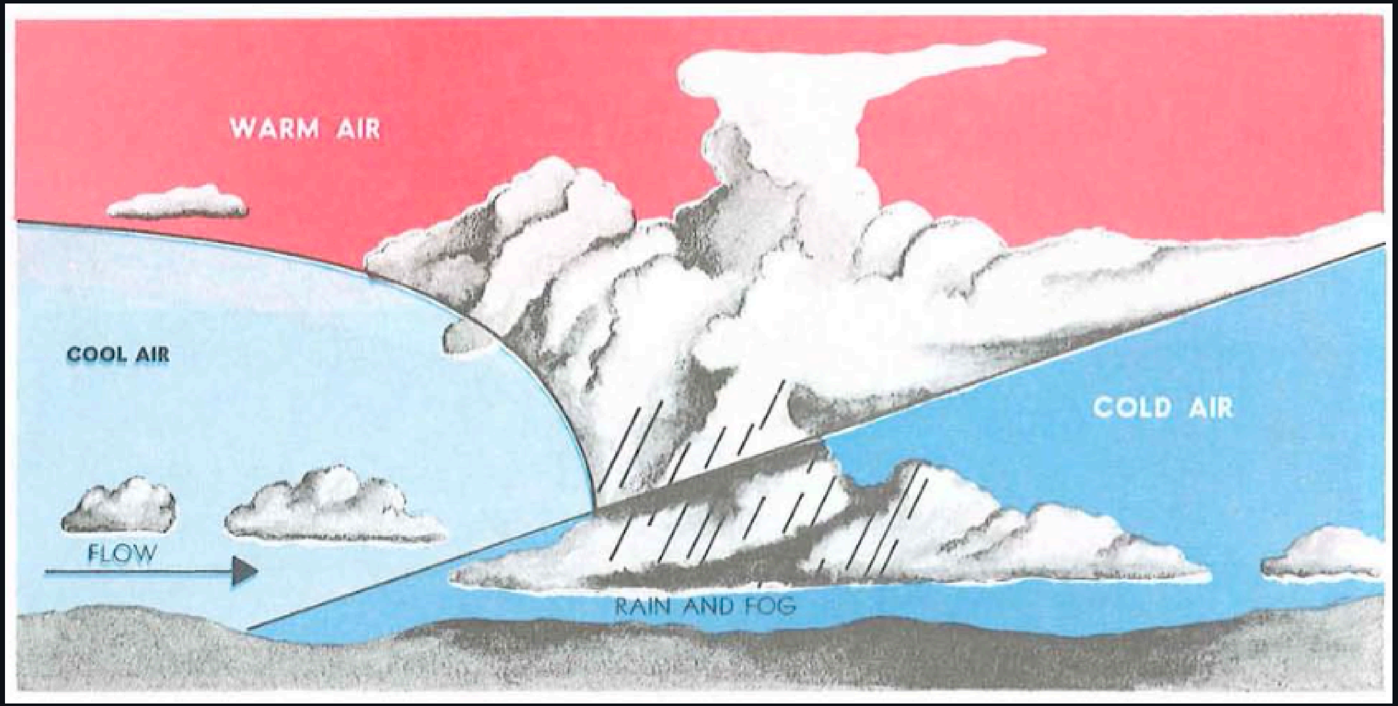
- Cold fronts typically move faster than warm fronts, so they catch up to warm fronts
- Two types:
  - Cold-front occlusion: A air is colder than B air
  - Warm-front occlusion: B air is colder than A air

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

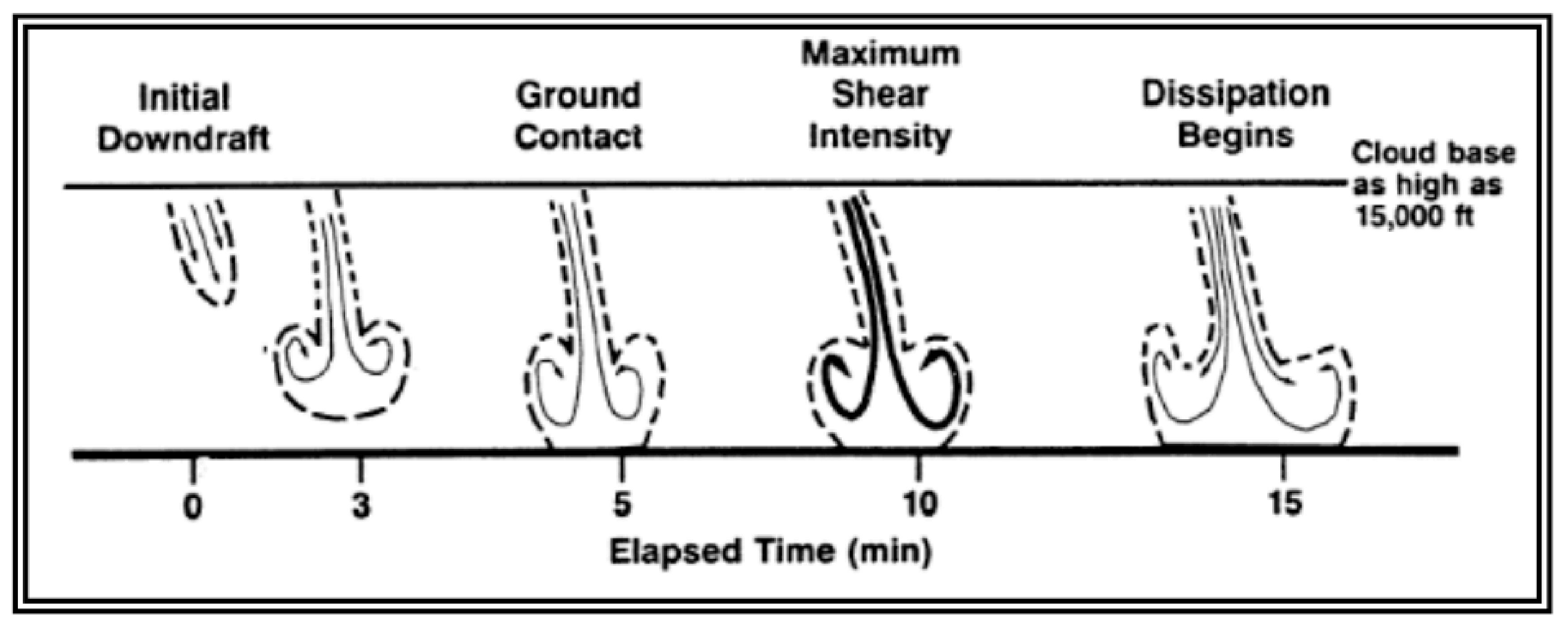
Stages of a Thunderstorm

- 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

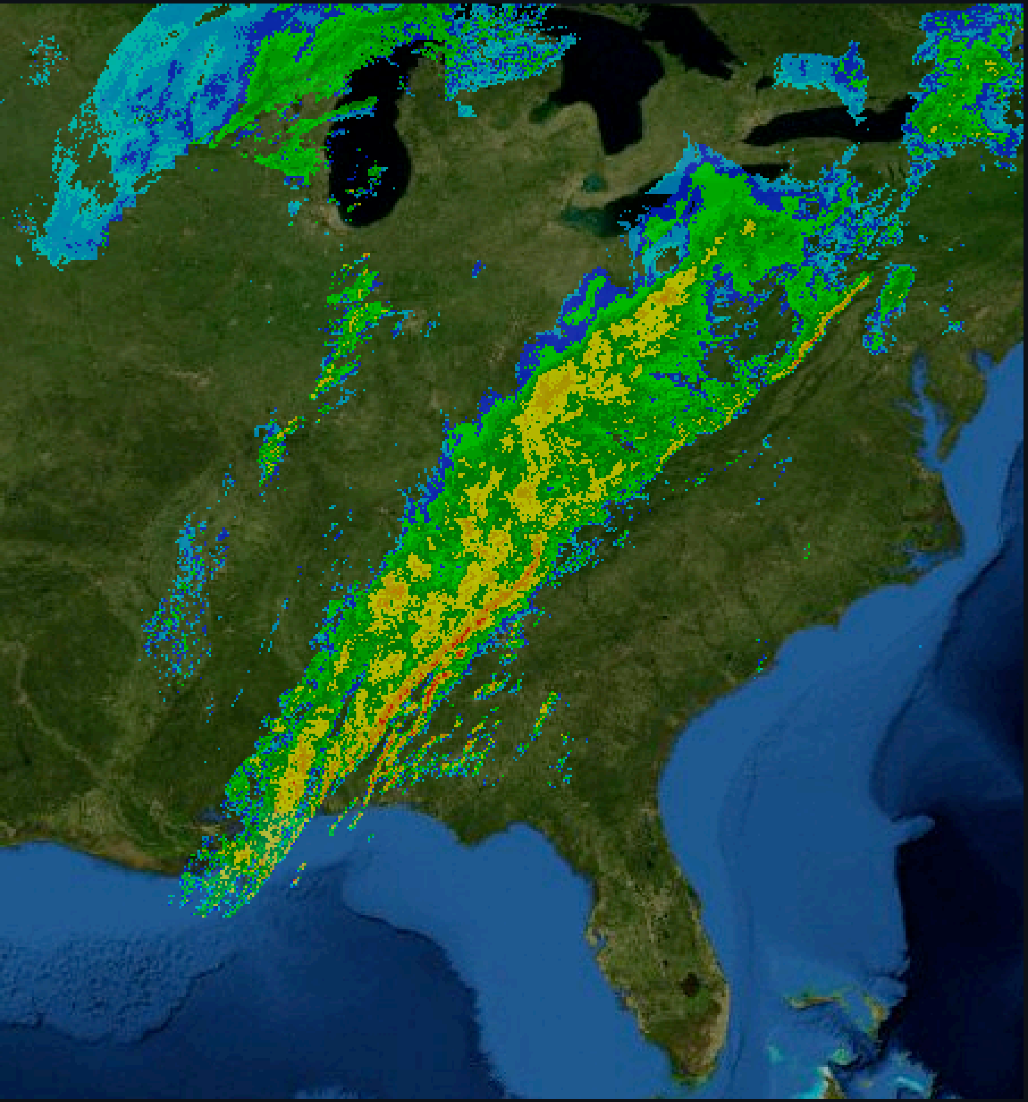
Thunderstorm Hazards

- 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

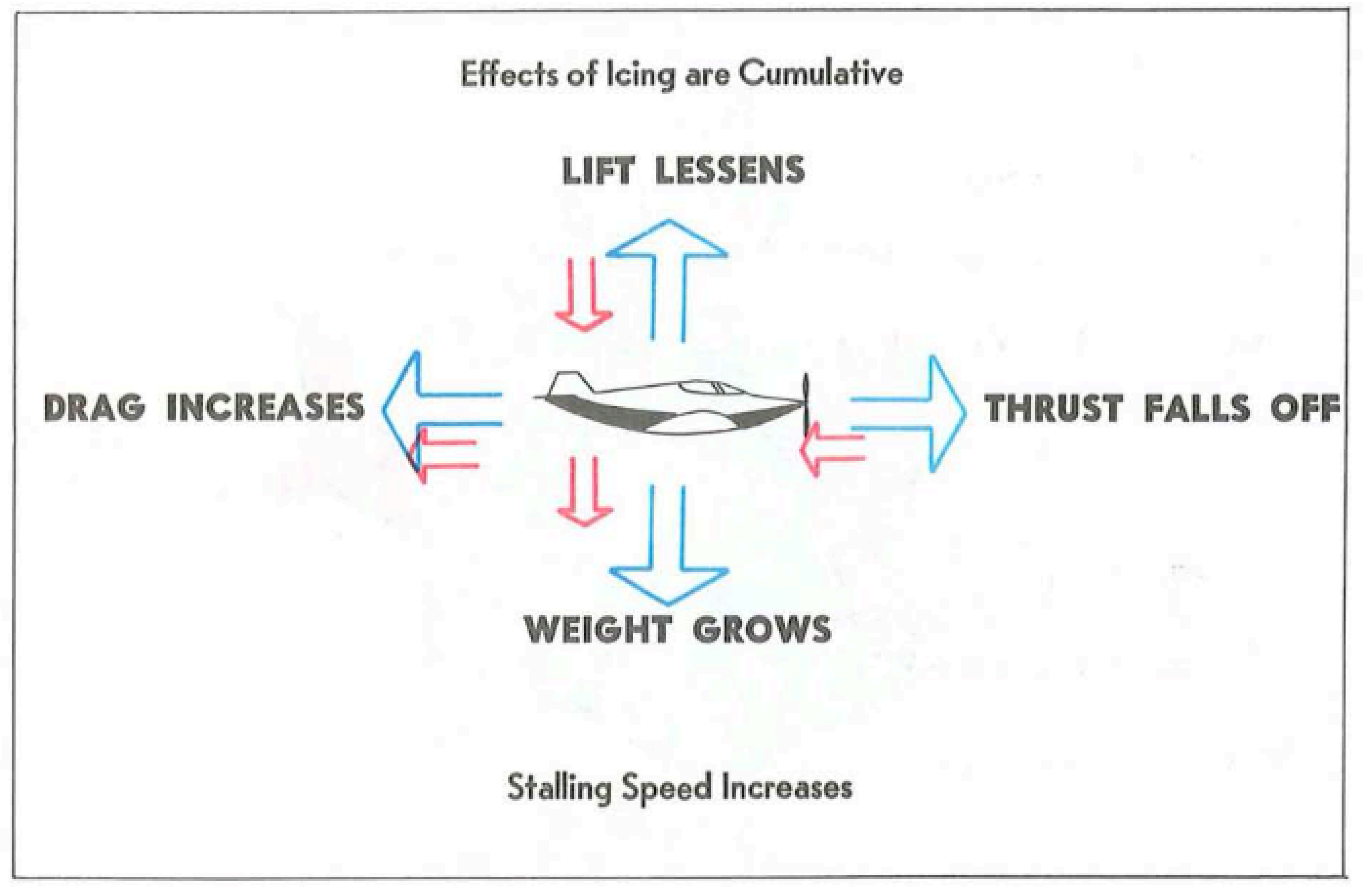
Thunderstorm Avoidance

- 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

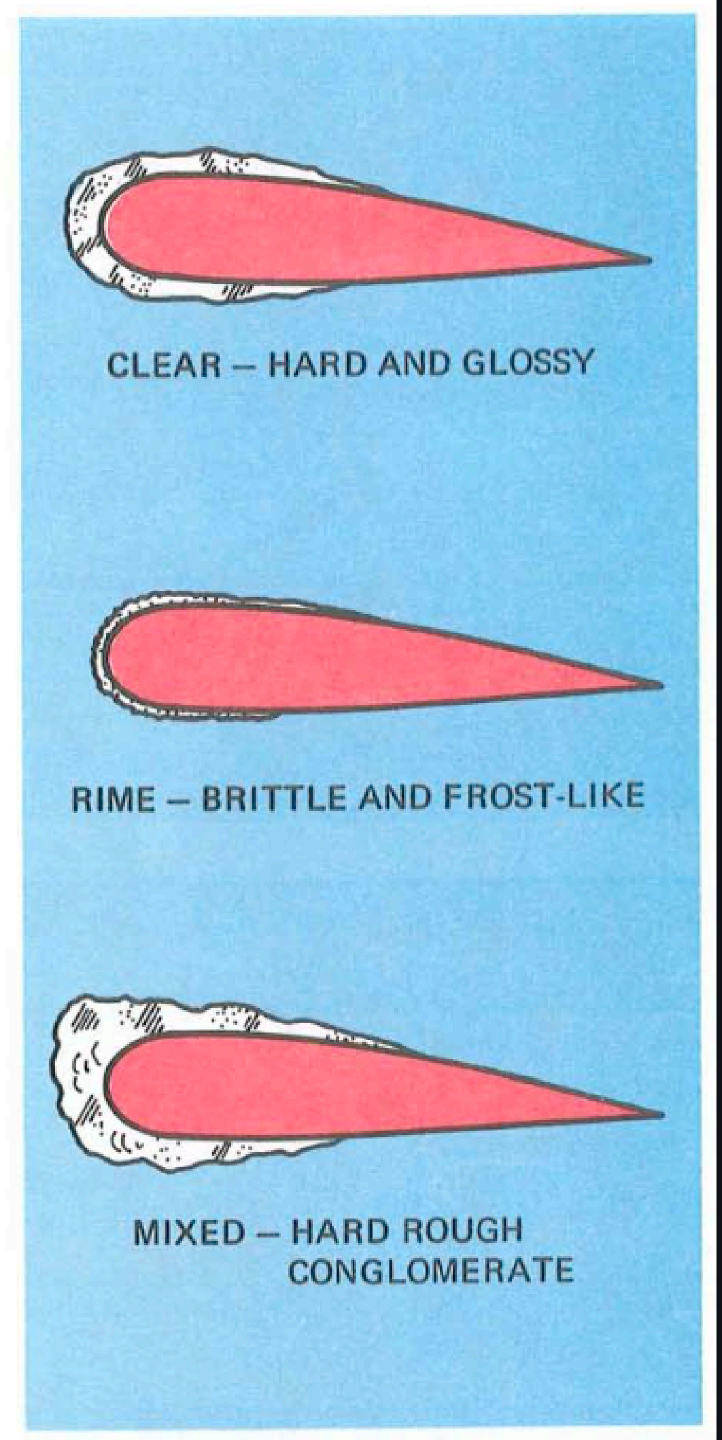
Structural Icing

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° C or colder



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 ingredient 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?