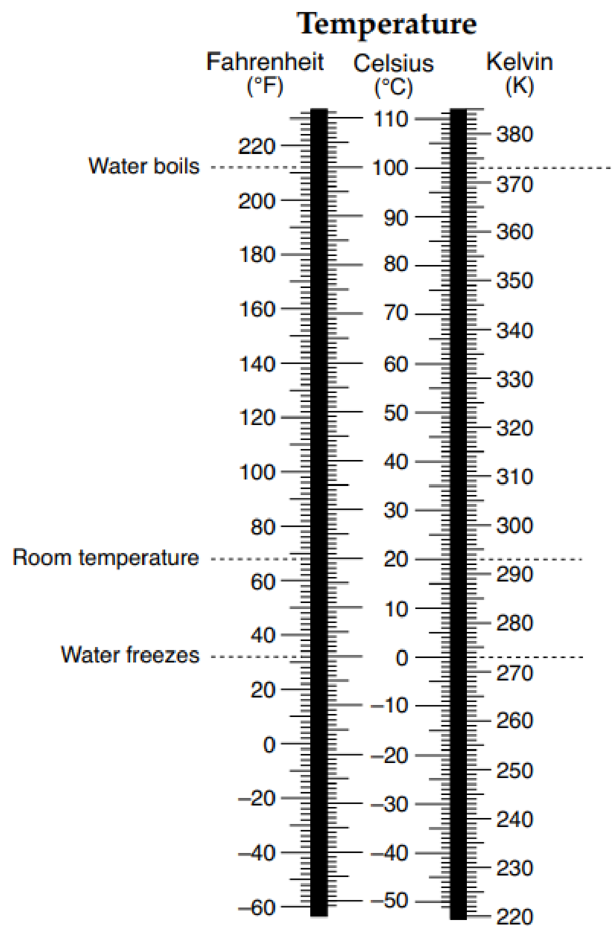
# Topic 7:  Weather

## Topic 7 Section 1

Overview:  weather affects what you buy, your health, crops, heating and cooling costs, and what type of clothes you wear.  Weather is the state of variables in the atmosphere at a given location for a short period of time.

Most weather variables occur in the troposphere and include:

- temperature
- air pressure
- wind
- moisture
- cloud cover
- precipitation
- storms

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Atmospheric temperature

Most of the world uses the Celsius temperature scale, the US uses the Fahrenheit scale, and most scientists use either the Celsius or the Kelvin temperature scale

You can easily convert these scales using the temperature section on page 12 of the PS/ESRT

Air temperature is usually measured using a thermometer

Air temperature maps use isolines called isotherms

Heating of the atmosphere

The Sun is the origin of most of the heat in our atmosphere

Generally, the atmosphere gets most of its heat from the surface of the Earth – more insolation results in more surface heating and higher atmospheric temperatures

Methods which heat the atmosphere include:

- conduction – air that touches the surface of the Earth
- direct absorption of insolation
- absorption of long wave infrared emitted by the surface of the Earth
- condensation – 2260 J/g for water vapor forming liquid
- Coriolis effect – causes winds which generate heat from friction on Earth’s surface

Transfer of heat by convection currents

Most of the transfer of heat within the atmosphere occurs by convection within the troposphere (since convection operates based on density differences in a gravity field, as the density of the atmosphere changes with elevation, eventually warmer air does not rise higher than the limit of the troposphere)

# Topic 7: Weather

Heating and cooling of air caused by compression and expansion

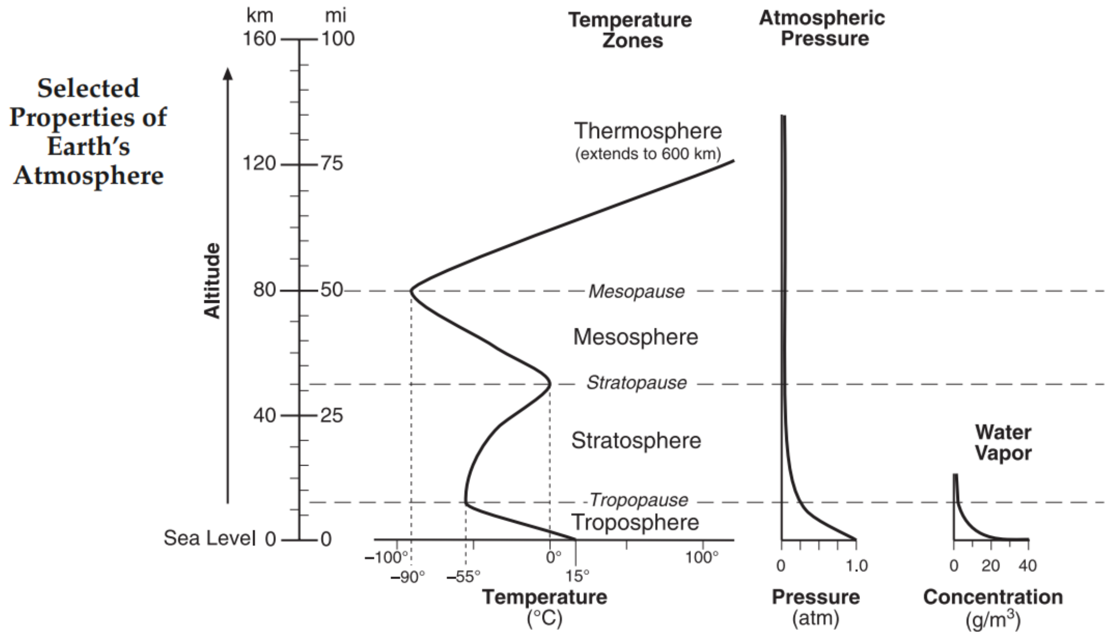
Expanding air will cool

As air rises, it will have less air (less weight) above it and it will expand and cool

Compressing air causes heating

As air sinks, it will have more air (more weight) above it to compress and warm it

Observe how air temperature changes as elevation in the troposphere increases:

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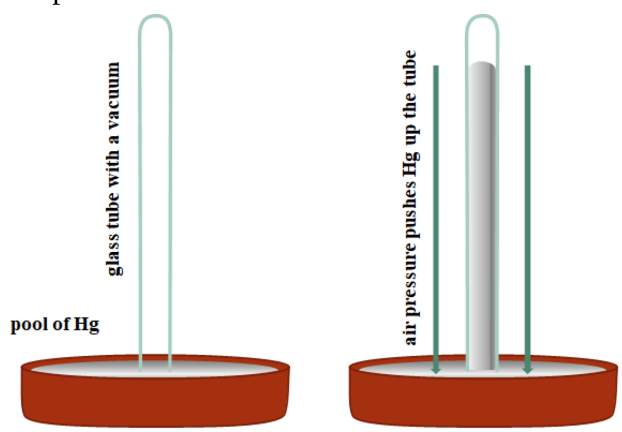
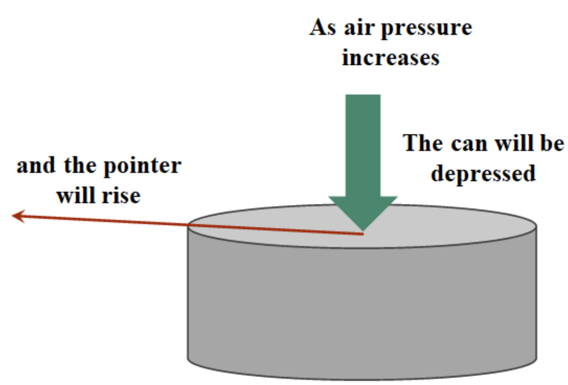
## Topic 7 Section 2

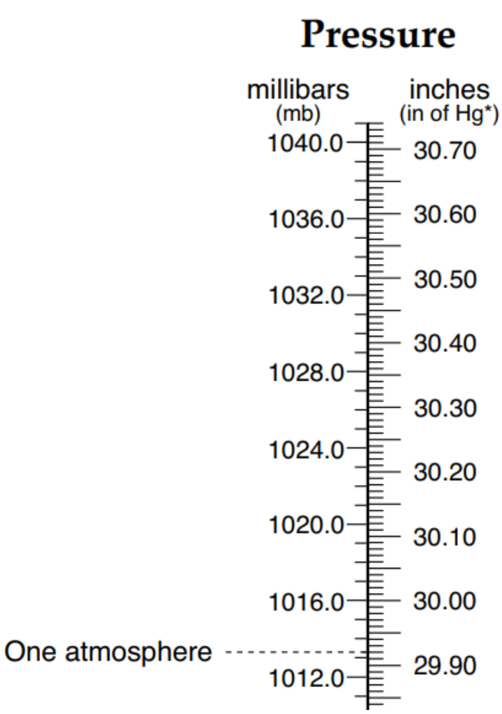
- Atmospheric pressure and density
  - Air pressure and density are directly related
    - As density increases, the weight of a given volume of air also increases
    - Air pressure (atmospheric pressure or barometric pressure) is the weight of air divided by the surface area
- Measurement of and changes in air pressure
  - Barometer – an instrument used to measure air pressure
    - Mercury barometer
      - A vacuum is generated in a tall glass tube
      - The open end of the tube is submerged in a pool of Hg
      - Air pressure will push Hg up the tube until the pressure from the Hg equals the pressure of the air outside the tube
      - Problems with Hg barometers
        - difficult to transport
        - Hg is toxic




    - Aneroid barometer
      - A sealed can has a pointer attached the top of the can
      - As air pressure changes, the top of the can will rise or fall




    - Aneroid barometer

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- Standard pressure
  - 29.92 inches of mercury (Hg)
  - 14.7 pounds per square inch
  - 1013.2 millibars
- Air pressure is often shown on weather maps using isolines called *isobars*

# Topic 7: Weather

Effect of temperature on air pressure

Air expands as temperature increases causing density and air pressure to decrease

Effect of water vapor on air pressure

Nitrogen, $N_2$, has a mass of 28 g/mole

Oxygen, $O_2$, has a mass of 32 g/mole

Water, $H_2O$, has a mass of 18 g/mole

As water replaces volumes of $N_2$ and $O_2$, the density and air pressure will decrease

Effect of altitude on air pressure

Remember that air pressure is the result of the weight of the air above a given position

Increasing the elevation or altitude as you climb a hill means there is less air above you

Increasing altitude results in less weight of air above you and decreases air pressure

Summary: increasing temperature, moisture content, or altitude will decrease air pressure

Topic 7 Section 3

Wind – horizontal movement of air parallel to the surface of the Earth

Wind is a vector – it needs a magnitude and direction to describe

- use a wind vane to determine wind direction (see right)
- use an anemometer to determine wind speed (see below right)

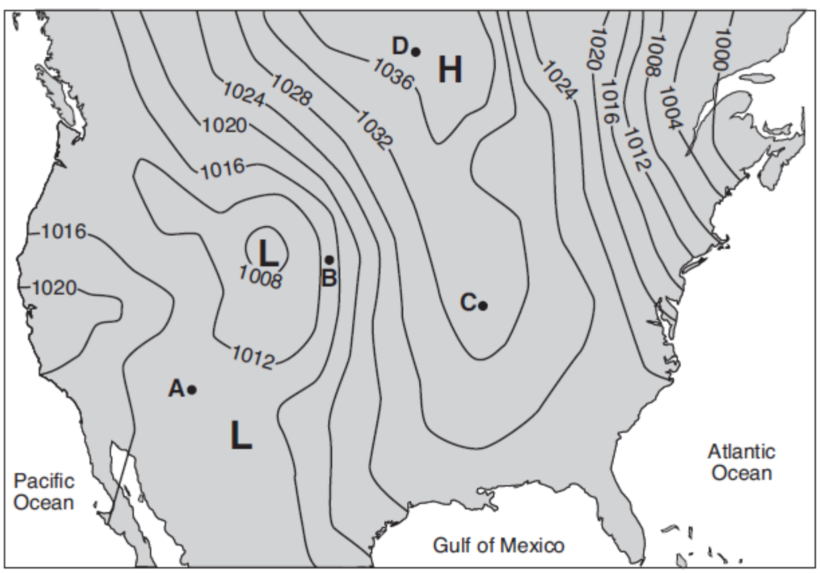
Wind Vane

Anemometer

Wind speed

Winds are caused by differences in air pressure which are often the result of changing temperature and water vapor content

- air moves from high pressure to low pressure
- the difference in air pressure over a distance is the *air pressure gradient*
- the closer isobars are to each other on a weather map, the greater the air pressure gradient and the faster wind speeds will be
- winds are measured by an anemometer (see right)
- wind speed is measured in miles per hour or knots (nautical miles per hour – one knot = 1.15 miles per hour)
- winds are affected by Coriolis effect




Wind speed is greatest at point B because the air pressure gradient is greater at point B (the isobars are closer together at B).

Wind direction

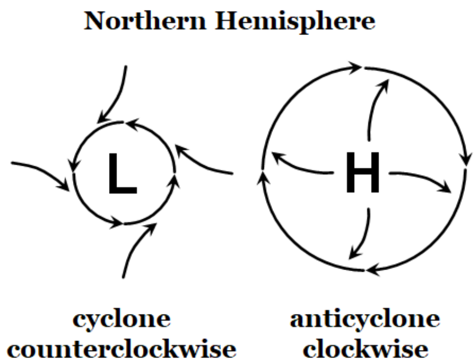
Wind moves from areas of high pressure to areas of low pressure

Which direction will the wind move from Point B (see above)?

Toward the west (toward the low pressure nearby).

The Coriolis effect will modify wind direction except at the equator

- wind is deflected to the right in the Northern Hemisphere
- wind is deflected to the left in the Southern Hemisphere




Winds are named for the direction from which they come

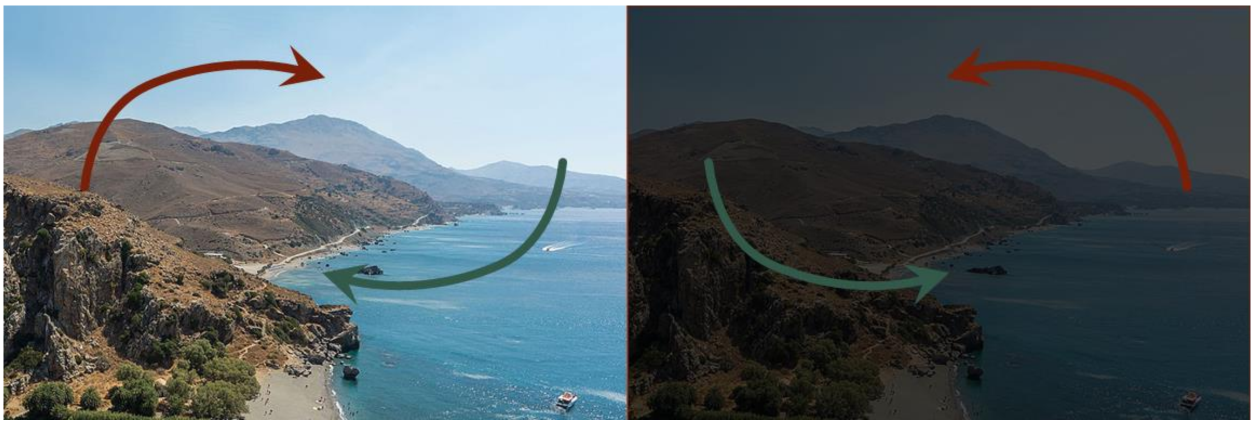
What is the name of a wind that originates from Point B (see above)?

The wind at Point B is an east wind (it travels *from the east* to the west).

The arrowhead on a wind vane (see top right on page 3) points into the wind

Name the wind shown by the wind vane. The wind vane indicates a west wind.

Land and Sea Breezes



Explain why there is a sea breeze in the daylight picture above (left side).

Land has a lower specific heat and warms faster during daylight hours causing air over the land to rise which forms a convection current drawing cooler air from the sea (a sea breeze).

Explain why there is a land breeze in the nighttime picture above (right side).

Land has a lower specific heat and cools faster during nighttime hours causing air over the sea to rise which forms a convection current drawing cooler air from the land (a land breeze).

Formation of waves on surface water

Friction from wind moving over surface water causes energy to be transferred to the water in the form of waves

- stronger winds create larger waves
- waves that reach the shore results in erosion at the shoreline

## Topic 7 Section 4

General circulation of air in the troposphere

Unequal insolation due to change in latitude causes unequal heating of the troposphere

Due to gravity and density differences:

- warm air will rise and cool air will be pulled to Earth's surface
- humid air will rise and dry air will be more dense and pulled to Earth's surface

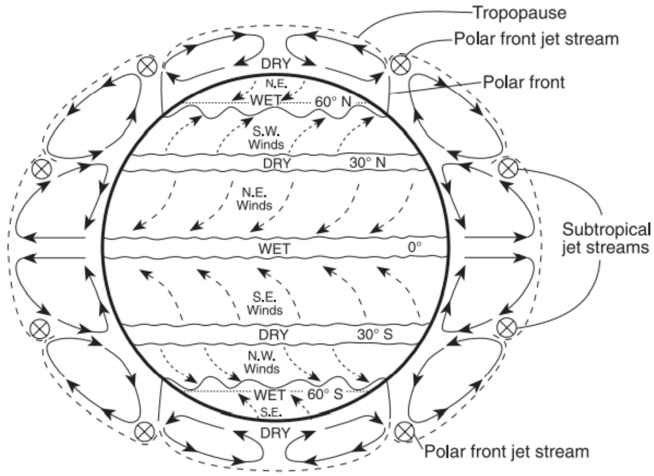
Convection cells

Differences in air density cause differences in air pressure and cause convection cells on a *global* scale

**Planetary Wind and Moisture Belts in the Troposphere**

The drawing on the right shows the locations of the belts near the time of an equinox. The locations shift somewhat with the changing latitude of the Sun's vertical ray. In the Northern Hemisphere, the belts shift northward in the summer and southward in the winter.

(Not drawn to scale)

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0° and 60° are regions of convergence (convection cells push air together)

Is air moist or dry and is it rising or falling at regions of convergence? Explain.

Moist air is rising in regions of convergence because it has picked up heat and moisture from Earth's surface and both factors reduce the air density

30° and 90° are regions of divergence (convection cells cause air to move apart)

Is air moist or dry and is it rising or falling at regions of divergence? Explain.

Dry air is falling in regions of divergence because the air cools as it rises in the troposphere causing moisture to condense out of the air making it dry; both these factors increase air density causing gravity to pull the air down

Notice there are two polar and two subtropical jet streams in the upper troposphere

- winds in the jet stream travel at about 200 miles per hour or more
- planes traveling west to east can save an hour or more by flying in the jet stream
- the jet stream steers air masses and have important effects on the weather in the continental United States

Planetary wind and pressure belts

Winds will blow away from regions of divergence (high air pressure and low moisture) and toward regions of convergence (low air pressure and high moisture)

Due to Coriolis effect, the resulting planetary winds will be deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere

Does air near the North Pole tend to move north or south? Explain.

Air from the North Pole tries to move south because there is high pressure at the North Pole (cold, dry air from convergence); the Coriolis effect deflects the wind westward (there are northeast winds near the North Pole)

- Because winds in planetary belts tend to travel in the same direction most of the time, we call the winds formed by these belts *prevailing winds*

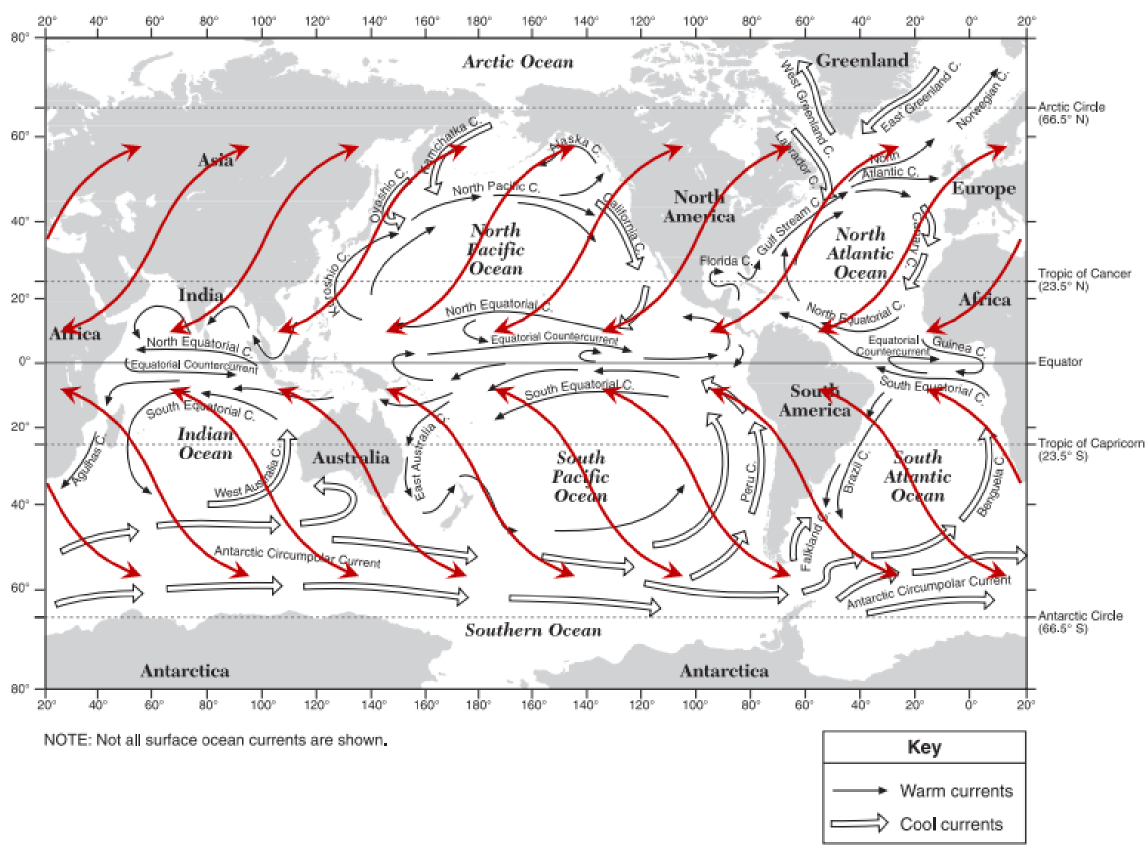
Seasonal shifting of the wind and pressure belts

- Because of Earth's axial tilt and the resulting seasons, there is an apparent north/south shift of vertical rays of the Sun
  - The result is that many parts of the Earth will be influence by different wind and/or pressure belts during different seasons of the year
    - These shifts explain why NYS experiences cold polar NE winds in winter and warm SW winds in the summer
  - Some parts of the Earth experience regular and extreme shifts in weather due to these shifts called *monsoons*
    - India and much of SE Asia have dry winter monsoons and wet summer monsoons
  - The weather in most of the continental United States is driven by the southwesterly prevailing winds and therefore most weather patterns will track from the southwest toward the northeast

Formation of surface ocean currents

- Prevailing winds, the Coriolis effect, and blocking by landmasses combine to form circular ocean currents that tend to spin clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere
  - Some currents can be affected by seasonal shifts in winds
  - Notice the circumpolar current in the Southern Hemisphere due to lack of landmasses

**Surface Ocean Currents**




Physical Setting/Earth Science Reference Tables — 2011 Edition, page 4 with overlay of global winds

Topic 7 Section 5

Atmospheric Moisture

Water exists in three states:

- gas (vapor) in the atmosphere
- liquid in streams, lakes, and oceans
- solid in glaciers and other ice

Moisture (water vapor) enters the atmosphere by:

- evaporation (largest contributor since oceans cover 70% of Earth's surface)
- transpiration (released by plants)
- sublimation of ice to gas

Energy of evaporation and transpiration of water

2260 J / g of energy is required for evaporation and transpiration (*evapotranspiration*)

Most of this energy comes from sunlight

Since the molecules with the most energy are the ones that enter the vapor phase, the average kinetic energy (temperature!) of the remaining objects will be lower, ie., evapotranspiration is a cooling process

The kinetic energy that leaves is converted into potential energy (chemical bonds were broken)

Process of evaporation

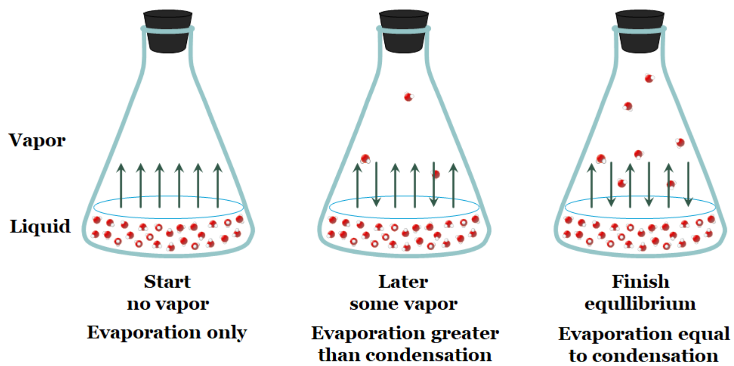
Start with a sealed bottle with liquid water and no gas or water vapor:

The only process possible is evaporation

Once a small amount of water vapor has formed:

More water will evaporate but some molecules may condense to form liquid

Eventually, equilibrium will occur




The rate of evaporation equals the rate of condensation

This is a *dynamic equilibrium* – the water molecules are always changing between vapor and liquid, but the number of liquid and vapor molecules trading places will be equal

Factors affecting evaporation rates of water

- amount of energy available – high energy means high temperature and faster evaporation
- surface area of the water – higher surface areas equate to faster evaporation
- saturation of the air – high moisture in air means slower evaporation
- wind speed – higher wind speeds will remove moist air and speed evaporation

# Topic 7: Weather

Humidity, temperature, and dew point

Humidity is a general term that refers to the amount of water vapor in the atmosphere

Absolute humidity – mass of water vapor in a given volume of air (usually grams/meter$^3$)

Moisture capacity – the maximum absolute humidity at a given temperature

Moisture capacity increases rapidly with increasing temperature

Relative humidity – percentage of saturation

$$\frac{absolute\ humidity}{moisture\ capacity} \times 100$$

Relative humidity and temperature

If the absolute humidity is constant, a temperature change causes the moisture capacity to change and therefore the relative humidity will change as temperature changes

Dew point – temperature at which the absolute humidity equals the moisture capacity

Dew point and temperature

If the absolute humidity is constant, temperature changes will ***not*** change the dew point

For this reason, most weather stations report dew point instead of relative humidity

Measuring relative humidity

Two instruments can be used to measure the relative humidity:

- sling psychrometer – uses a normal thermometer (dry-bulb thermometer) and a second thermometer with a damp wick or sock (wet bulb-thermometer)
  - Evaporation from the wick or sock will cool the wet-bulb thermometer
  - The evaporation rate depends on the absolute humidity
- hygrometer – comes in two types:
  - A wick hygrometer works the same way a sling psychrometer does except you don't have to whirl it over your head
  - A hair hygrometer works because the length of hair depends on the absolute humidity

Determine relative humidity:

Measure the temperatures of a dry- and a wet-bulb thermometer

Find the dry-bulb temperature on the left side of the relative humidity table (ESRT, pg 12)

Subtract the wet-bulb reading from the dry-bulb reading

Locate the difference between the wet- and dry-bulb readings on the top of the table

Find the position where the vertical column and horizontal row meet

This number is the relative humidity (in percent)

Example: if the dry-bulb temperature is 24°C and the wet-bulb temperature is 16°C, what is the relative humidity?

24°C – 16°C = 8°C

Reading 24°C on the left and 8°C on the top gives 42% relative humidity at the intersection

Determine dew point:

Follow the exact same procedure for the wet- and dry-bulb readings but use the dew point table on the ESRT, pg 12

Example: if the dry-bulb temperature is 24°C and the wet-bulb temperature is 16°C, what is the relative humidity?

24°C – 16°C = 8°C

Reading 24°C on the left and 8°C on the top gives 10°C dew point at the intersection

# Topic 7: Weather

Cloud formation

- If the temperature of the air falls below the dew point, water vapor will condense to form liquid droplets above 0°C or undergo vapor deposition to form ice crystals
  - If the water droplets / ice crystals are dense enough to be visible they form clouds
    - If the water droplets / ice crystals are thin enough to see through, they are called haze
  - If the water droplets / ice crystals form on the surface of the Earth they are dew or frost
  - If water droplets form just above the Earth's surface, they are called fog
- Cloud cover is the fraction of the sky obscured by clouds and is reported on some weather maps (see symbols for weather station models on ESRT pg 13)
- Condensation and deposition require surfaces on which to form
  - At ground level, dew and frost form on leaves, grass, or objects
  - High in the sky, water droplets and ice crystals form on aerosols (dust, salt, or ash)

Precipitation

- Water droplets or ice crystals that become large enough for gravity to cause them to fall from the sky are called *precipitation*
  - Forms of precipitation:
    - rain – liquid droplets larger than 0.2 mm (may be snow that melted on the way down)
    - drizzle – liquid droplets from 0.05 to 0.2 mm
    - snow – falling ice crystals
    - sleet – liquid drops above 0°C freeze as they fall through air below 0°C
    - freezing rain – liquid drops in air above 0°C freezes on the surface below 0°C
    - hail – cloud bottoms above 0°C and tops below 0°C, water moving up and down due to high winds in the clouds can build up ice layers and fall as hail
- Showers (can be rain or snow)
  - Rapidly forming, rapidly ending, brief and heavy precipitation
- Rain gauge – a device that catches and measures liquid precipitation
- Condensation / precipitation usually forms when air rises
  - Air usually rises due to:
    - fronts
    - movement over mountains
    - air warmed by insolation on an area that absorbs a lot of insolation

Atmospheric transparency and precipitation

- Pollutants caused by people or other natural aerosols in the air lower its *transparency*
  - Low transparency lowers the amount of insolation that reaches the surface of the Earth
  - Aerosol content that is so high that distance objects appear blurred or cause a cloudless sky to appear some other color than blue is called *haze*
    - Haze that is highly polluted usually appears brown and is called *smog*
  - Condensation and/or deposition can form on aerosols and precipitation can further remove aerosols from the atmosphere and increase transparency
- Visibility – how far you can see along Earth's surface in miles
  - Precipitation and haze can lower visibility
  - Visibility is often reported on weather maps and station models

Topic 7 Section 6

Air masses and fronts

Weather is usually the result of different air masses as they interact at their boundaries

Air mass – a large body of air in the troposphere with similar characteristics of pressure, temperature, and moisture content

Characteristics of air masses

Air masses form when large bodies of air remain stationary over a part of Earth's surface for a long enough time to acquire some of the characteristics of that surface

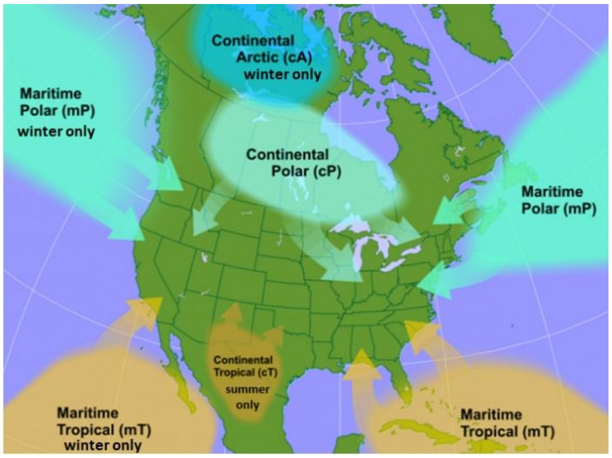
The geographic regions over which air masses form are called *source regions*

Source regions from high latitudes will form air masses with low temperatures

Source regions from low latitudes will form air masses with high temperatures

Source regions that are land masses form dry air masses

Source regions that are water form wet air masses




Arrows indicate tracks of air masses

Courtesy of Pennsylvania State University

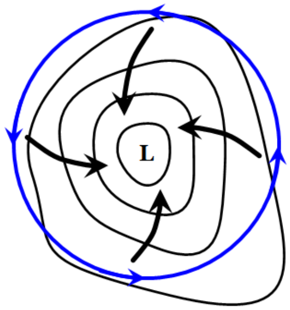
Lows and highs

Air masses in the troposphere are divided into two types by pressure and wind direction:

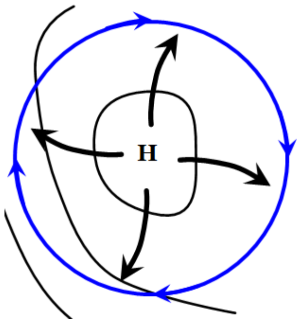
- Lows (L) – low pressure air masses are also called *cyclones*
  Winds circulate counterclockwise in cyclones in the Northern Hemisphere
  Lows are associated with stormy weather, thick cloud cover, high precipitation, and high winds
- Highs (H) – high pressure air masses are also called *anticyclones*
  Winds circulate clockwise in anticyclones in the Northern Hemisphere
  Highs are associated with cooler temperatures, clear skies, and little or no precipitation

Winds from highs and lows circulate in the opposite direction in the Southern Hemisphere

**Coriolis cyclone and wind direction**

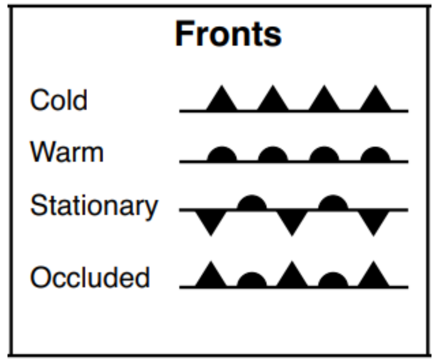



**Coriolis anticyclone and wind direction**



Fronts

The interface or boundary where two fronts with different characteristics meet is called a *front*

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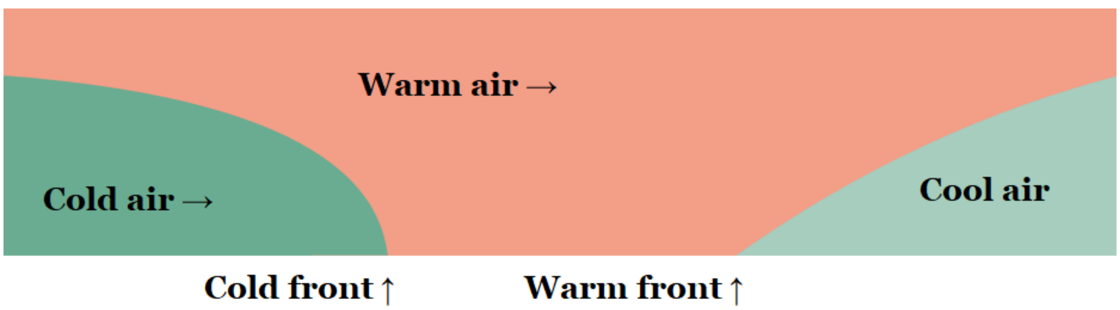
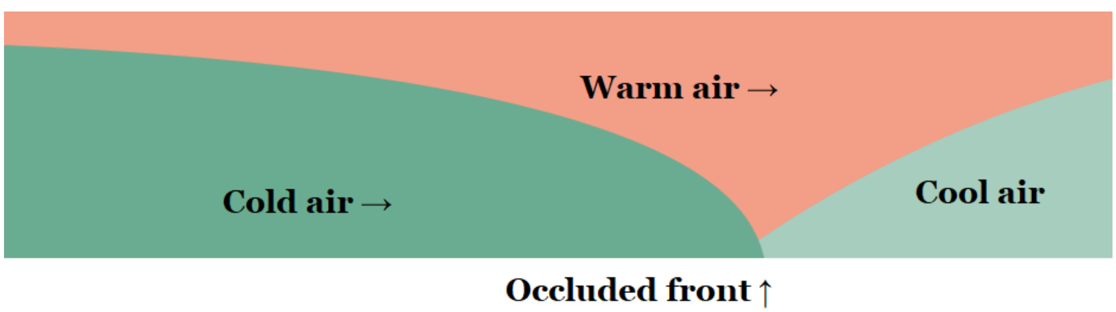
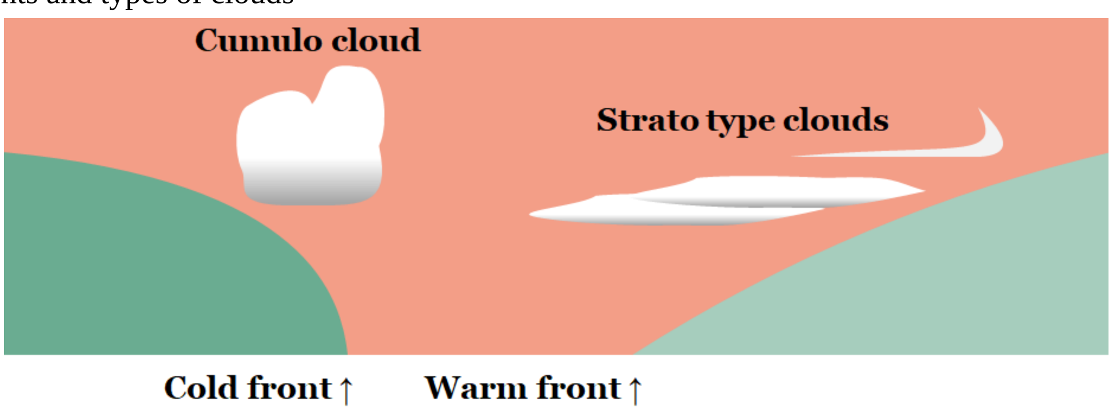
- Cold front – the boundary of an advancing cold air mass
- Warm front – the boundary of an advancing warm air mass
- Occluded front – occurs when a more dense cold air mass lifts a less dense warm air mass off the ground
- Stationary front – occurs when two air masses with differing characteristics remain in the same relative positions
- Polar front – the ever changing boundary in mid latitudes between cold air masses near the poles and warm air masses near the equator




Fronts and types of clouds



Topic 7 Section 7

Storms and severe weather

Storm – a violent or severe disturbance in the atmosphere that usually creates dangerous conditions on Earth's surface

Most storms are associated with high winds, heavy precipitation, and low air pressure in mid-latitude cyclonic conditions

Types of storms:

- mid-latitude cyclones
- hurricanes
- thunderstorms
- tornadoes
- hail
- blizzards

Mid-latitude or cyclonic storms

Air movement at polar fronts of mid-latitudes can result in occluded fronts that lift warm air masses to form cyclones

Rotation in cyclones is a result of the Coriolis effect (counterclockwise in the Northern Hemisphere)

Cyclonic storms are responsible for much of the precipitation in the contiguous US

Cyclonic storms are associated with thunderstorms, hail, and tornadoes

Hurricanes

In late summer and early fall, low pressure centers form over tropical waters

The energy of a hurricane comes from the condensation of millions of gallons of water vapor which acquired its energy from evaporation of ocean water

When wind speeds reach 74 miles per hour, these storms are called hurricanes

Similar storms in other parts of the world are called typhoons and cyclones

Hurricanes often have wind speeds in excess of 150 miles per hour

Hurricanes cause large ocean waves that are a danger to ships

The largest danger from hurricanes is when they strike land

- high winds damage buildings and cause flying debris
- high precipitation causes flooding
- storm surge – low pressure at the eye allows high sea levels

When hurricanes move over land they lose energy due to friction with Earth's surface

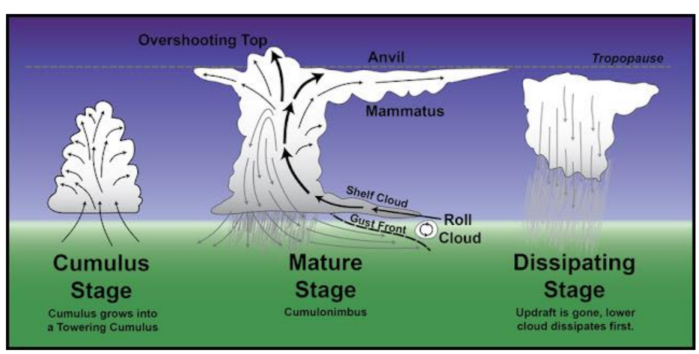
They are also no longer being pumped up with energy from water vapor from the ocean

Thunderstorms

Over 2000 thunderstorms occur on Earth at all times

Thunderstorms are heavy rainstorms accompanied by thunder, lightning, and often hail

Only thunderstorms have enough up and down movement within clouds to generate hail



# Topic 7: Weather

- Tornadoes
  - Tornadoes are the most violent of all storms
    - Most tornadoes are about 100 feet in diameter but they can exceed a half-mile
    - Most tornadoes only last a few minutes but they can last over an hour
    - Wind speeds can exceed 350 miles per hour
  - The greatest danger from tornadoes is flying debris
- Blizzards
  - Blizzards are storms with wind speeds of 35 miles per hour or greater accompanied by considerable amounts of blowing or falling snow
    - The danger from blizzards include disruption of communication, the shut down of transportation, and the danger from freezing
- Emergency preparedness for storms
  - It is important to know how to react to different types of storms to prevent injury, loss of property, and death
    - Proper planning and preparedness is the key to mitigating the dangers of storms
      - Proper planning includes plans at all levels:  individuals, families, communities, and governments
      - Preparedness includes emergency supplies such as food, water, lighting, heat, blankets, and backup power
  - Explain the proper emergency response to each of the following:
    - Hurricanes
    - Thunderstorms
    - Tornadoes
    - Blizzards

Topic 7 Section 8

Weather prediction and probability

Probability is the chance of the occurrence of an event

Computers use data collected over more than 100 years

Weather predictions compare current conditions to similar conditions on record

Predictions are based on the percentages of weather resulting from these similar conditions

Some simple relationships are

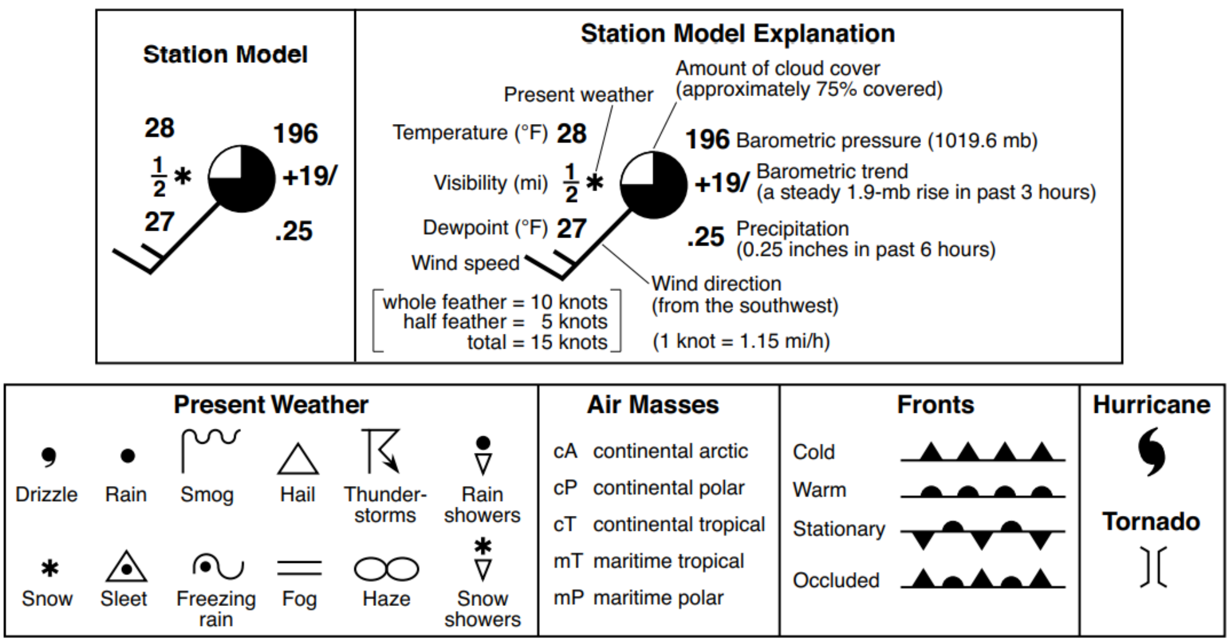
- air pressure and temperature – as temperature increases, air pressure decreases
- precipitation and dewpoint – when temperatures are near the dewpoint, the chance of precipitation increases
- air pressure gradient and wind speed – greater pressure gradients result in higher winds
- falling air pressure and precipitation – rapidly falling air pressure increases the chances of precipitation in the very near future

Weather maps and station models

Synoptic weather map – weather data collected and sent to a central location is used to generate a map showing a summary of weather variables for a short period of time

Circles on weather maps use symbols to save space and yet provide information

These circles are called *station models*

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Other aids in weather prediction

Weather cross sections (see the diagrams in the Fronts section on page 13)

Radar – RAdio Detection And Ranging, especially doppler radar

Satellites