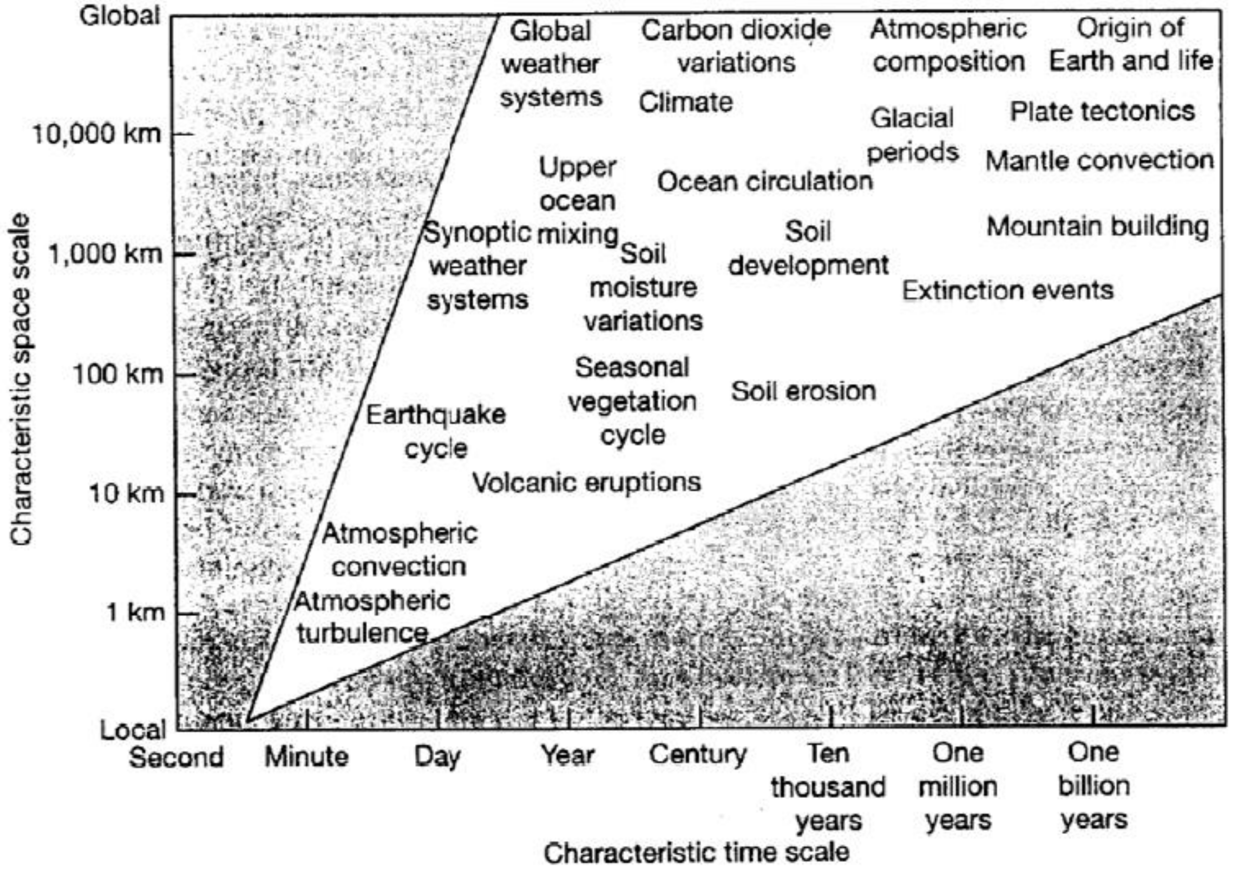
Atmospheric Forces and Motion

June 16th, 2021



Earth system processes grouped according to their space and time scales. The space scale is logarithmic, and the time scale is relative. (After Graedel and Crutzen, 1993.)

Weather and Climate

Weather – short-term atmospheric conditions for a specific area

Meteorology

Climate – aggregate long-term weather conditions

Climatology

Weather versus climate

TABLE 3-1 The Elements and Controls of Weather and Climate

Elements of Weather and Climate	Controls of Weather and Climate
Temperature	Latitude
Pressure	Distribution of land and water
Wind	General circulation of the atmosphere
Moisture content	General circulation of the oceans
	Altitude
	Topographic barriers
	Storms

Land and Water Contrasts

- Different kinds of surfaces react differently to solar energy, and surface characteristics plays a major role in how Earth's surface affects the heating of the air above it.
  - There are almost limitless kinds of surfaces on Earth, both natural and human made.
  - Each varies in its receptivity to insolation, which in turn affects the temperature of overlying air.
- Most significant contrasts occur between land and water surfaces.

Land and Water Contrasts

Heating

Generally, in comparison to water, land heats and cools faster and to a greater degree.

There are four main reasons why water and land are different:

- Specific heat—the amount of energy it takes to raise the temperature of 1 gram of a substance by 1°C. Water's specific heat is about five times as great as that of land, so it takes about five times more energy to raise its temperature.
- Transmission—water is a better transmitter than land (because it's transparent, while land is opaque). Heat diffuses over a much greater volume (and deeper) in water and reaches considerably lower maximum temperatures than on land.
- Mobility—water's mobility disperses heat both broadly and deeply; on land, heat can be dispersed only by conduction, and land is a very poor conductor.
- Evaporative cooling—water has more moisture, so more potential for evaporation and losing heat; cooling effect of evaporation slows down any heat buildup on water surface.

Land and Water Contrasts

Cooling—water surface cools more slowly and to a higher temperature as compared to land for one main reason:

Heat in water is stored deeply and brought only slowly to the surface.

Circular pattern is created so that entire body of water must be cooled before the surface temperature decreases significantly.

Implications for Differences

Oceans create more moderate climates for maritime areas, so that interiors of continents hold the hottest and coldest places on Earth.

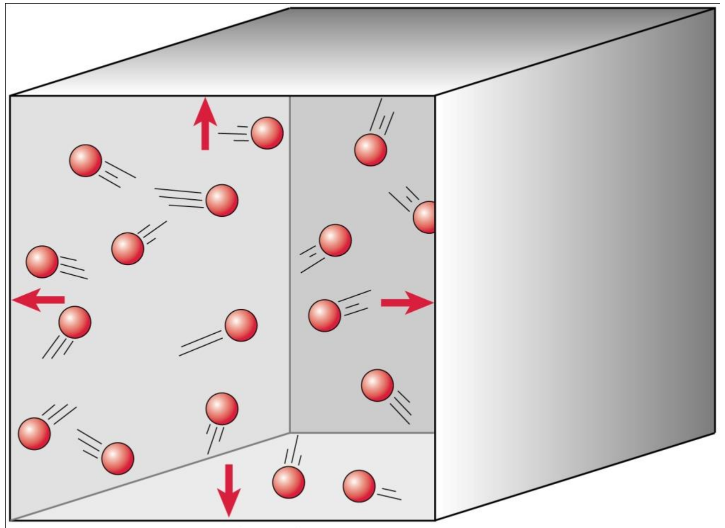
- Distinction between continental and maritime climates is the most important geographic relationship in the study of atmosphere.
- Oceans provide a sort of global thermostatically controlled heat source, moderating temperature extremes.
  - Northern Hemisphere has greater extremes in average annual temperature range because it is the land hemisphere—39 percent of its area is land surface.
  - Southern Hemisphere is water hemisphere—only 19 percent of its area is land.

Pressure

The Nature of Atmospheric Pressure

Definition: Atmospheric pressure—the force exerted by gas molecules on some area of Earth's surface or on any other body – including yours!!

- Omnidirectional force—exerted equally in all directions.
- Force drops with increasing altitude because actual number of gas molecules also drops.



Measuring Pressure

1. **Barometer**—instrument for measuring atmospheric pressure.
2. **Millibar**—an "absolute" measure of pressure, consisting of one-thousandth part of a bar, or 1000 dynes per square centimeter; equals 0.0147 pound per square inch.

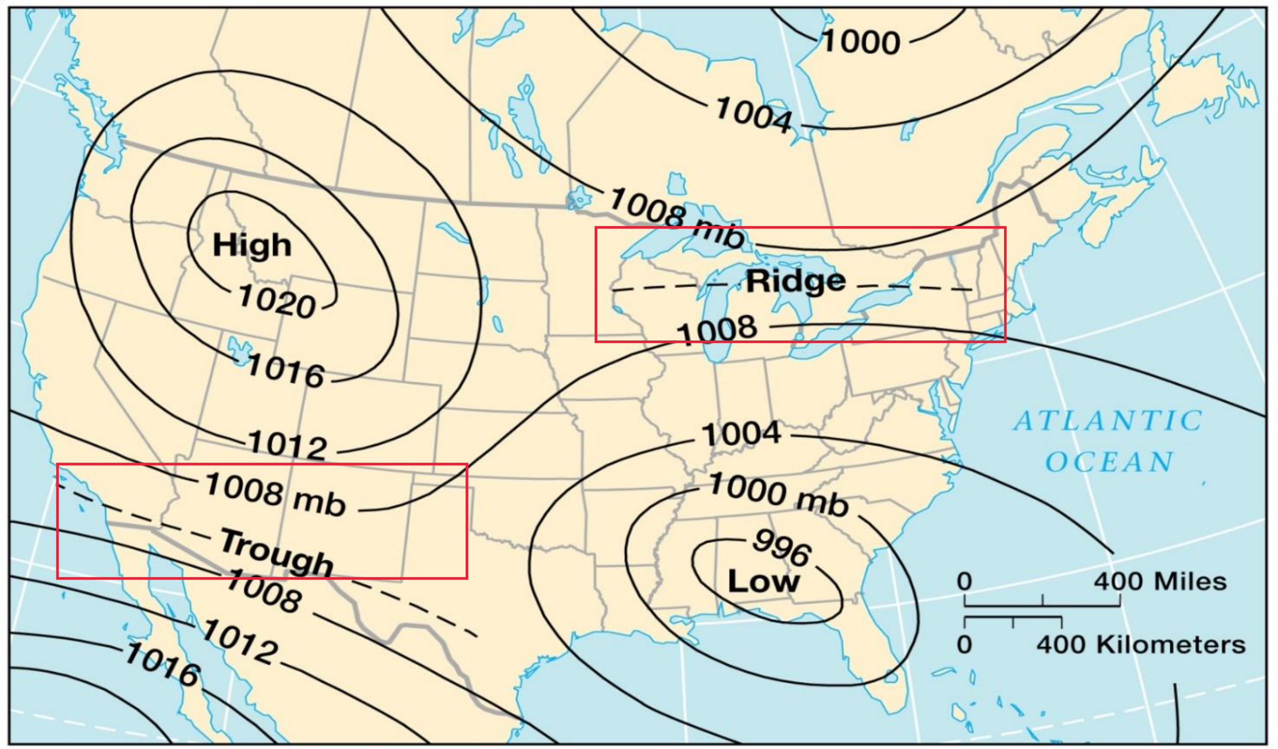
Average sea-level pressure is 1013.25 millibars.

Mapping Pressure

Isobars: these are **isolines** that join areas of equal pressure - that is;

Isobars are lines joining points of equal atmospheric pressure.

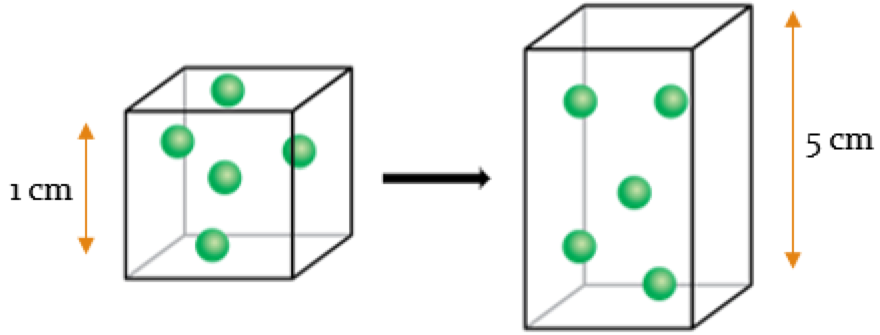
- **High and low** pressures are relative conditions, with the distinction depending on the pressure of the adjoining areas.
- **Ridge**—an elongated area of relatively high pressure.
- **Trough**—an elongated area of relatively low pressure.
- Pressure Gradient – Relative closeness of isobars



Factors Influencing Atmospheric Pressure

1. The pressure of a gas is proportional to its density and temperature.
2. Variations in any one—pressure, density, and temperature of the atmosphere—affect the other two.
   - **The ideal gas law**
   - Relationship is very complex, so difficult to make exact predictions of how change in one changes the others.

Density and Pressure



Density is the mass of matter in a unit of volume.

- The density of gases behaves differently from that of solids and liquids.
- Gases expand as far as the environmental pressure will allow.

For example: if you have a 10kg of gas in a container that has a volume of 1 cubic meter, the gas density is 10 kg/m^3.

If you transfer all the gas to a container with a volume of 5 cubic meters, the gas will expand to fill the larger volume.

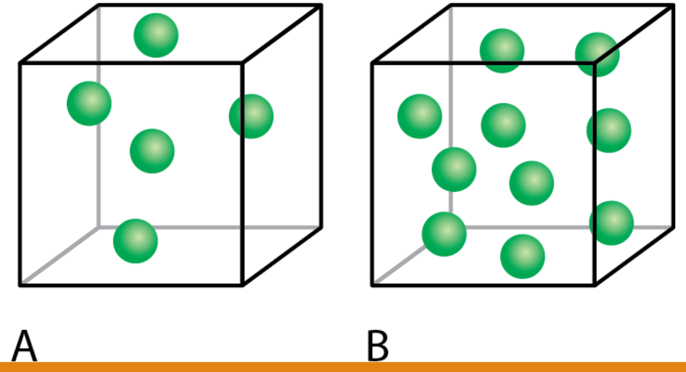
Therefore, the gas density in the larger container is only 2kg/m^3 (10 kg divided by 5 cubic meters).

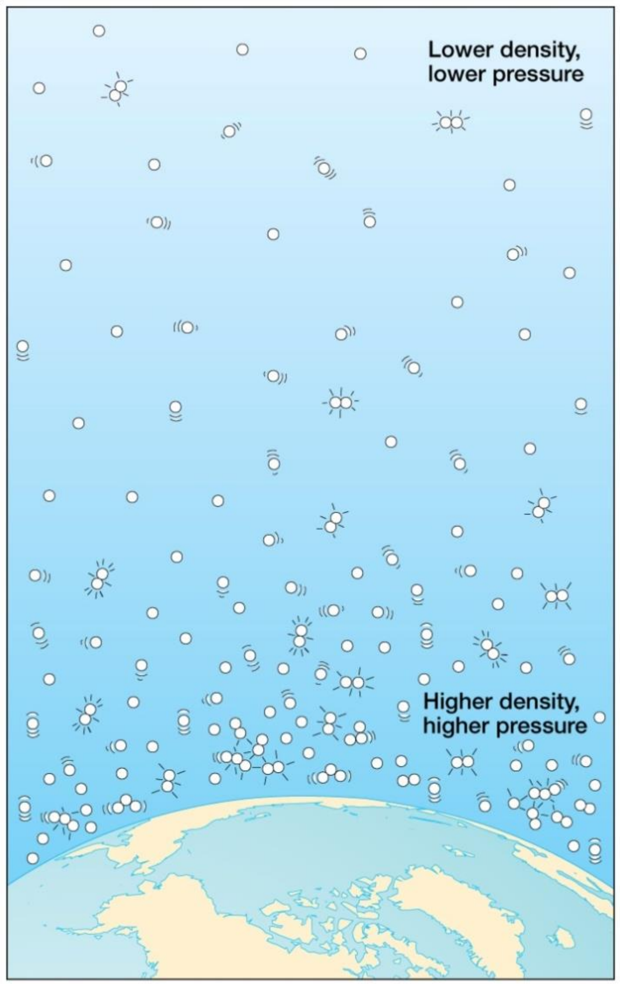
Density and Pressure

The denser the gas, the greater the pressure it exerts and *vice versa*.

At the lower altitudes, the gas molecules are packed more densely together; at higher altitudes, the air is less dense and there is a corresponding decrease in pressure.

At any level in the atmosphere, the pressure is directly proportional to the air density at that altitude.





Temperature and Pressure

If air is heated, the molecules become more agitated and they exert greater pressure.

Therefore, an increase in temperature equals an increase in pressure and a decrease in temperature equals a decrease in pressure.

But all conditions **MUST** remain the same (in particular, if volume is held constant), an increase in temperature of a gas produces an increase in pressure, and a decrease in temperature produces a decrease in pressure.

This might lead you to conclude that the air pressure will be high on warm days and low on cold days.

Temperature and Pressure

But the opposite tends to be true: warm air is generally associated with low atmospheric pressure and cool air with high atmospheric pressure.

When air is heated and no control is kept on its volume, it expands, which decreases its density.

Thus, if a mass of air is not confined, it will expand when heated and lead to a decrease in pressure as temperature increases.

Dynamic Influences on Air Pressure

Surface air pressure may also be influenced by dynamic factors such as the movement of air.

Generalizations regarding high and low pressure at the surface:

1. Strongly descending air is associated with high pressure at the surface—**a dynamic high**.
2. Very cold surface conditions are often associated with high pressure at the surface—**a thermal high**.
3. Strong rising air is often associated with low pressure at the surface—**a dynamic low**.
4. Very warm surface conditions are often associated with relatively low pressure at the surface—**a thermal low**.

The Nature of Wind

Wind

Horizontal movements of air; involve more area than do vertical motions.

Insolation is the ultimate cause of wind because all winds originate from the same basic sequence of events: **unequal heating of different parts of Earth's surface brings about temperature gradients that generate pressure gradients, and these pressure gradients set air into motion**.

Winds represent nature's attempt to even out the uneven distribution of air pressure across Earth's surface.

Direction of Movement

Depends on the interaction of three factors:

a) Pressure gradient force causes winds to move from areas of high pressure to areas of low pressure.

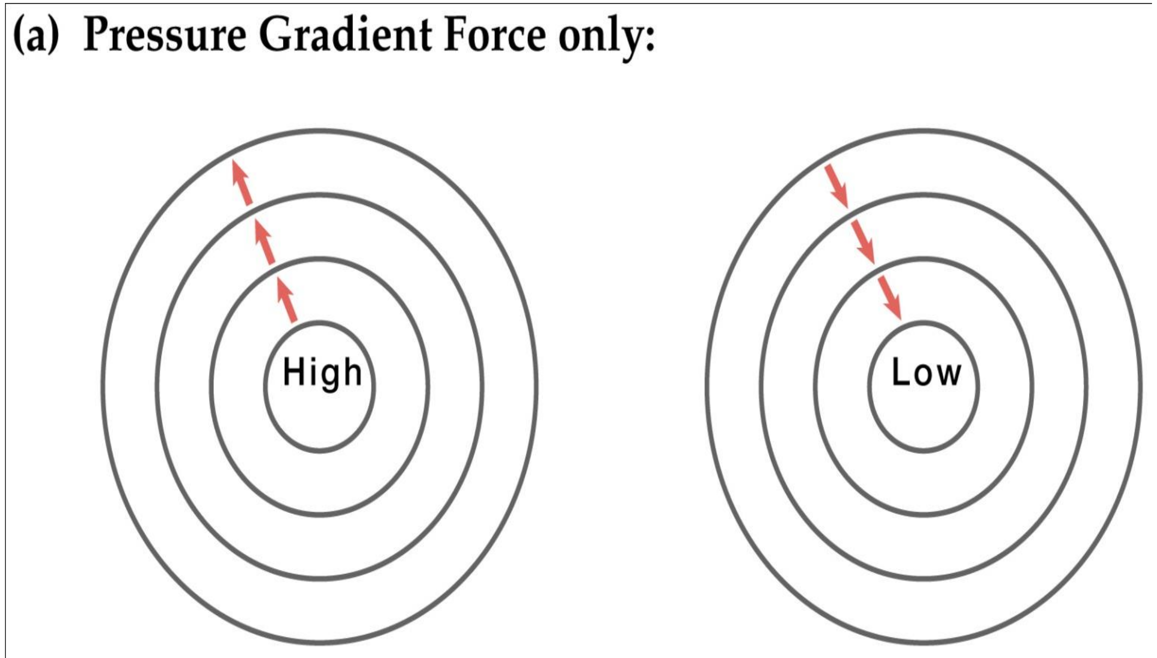
b) The Coriolis effect (Earth's rotation)

c) Friction or frictional force of Earth's surface slows wind movement and reduces the influence of the Coriolis effect.

Pressure Gradient Force

The pressure-gradient force acts at right angles to the isobar in the direction of the lower pressure.

If there were no other factors to consider, that is the way the air would move, crossing the isobar at 90 degrees, however such a flow rarely occurs in the atmosphere.

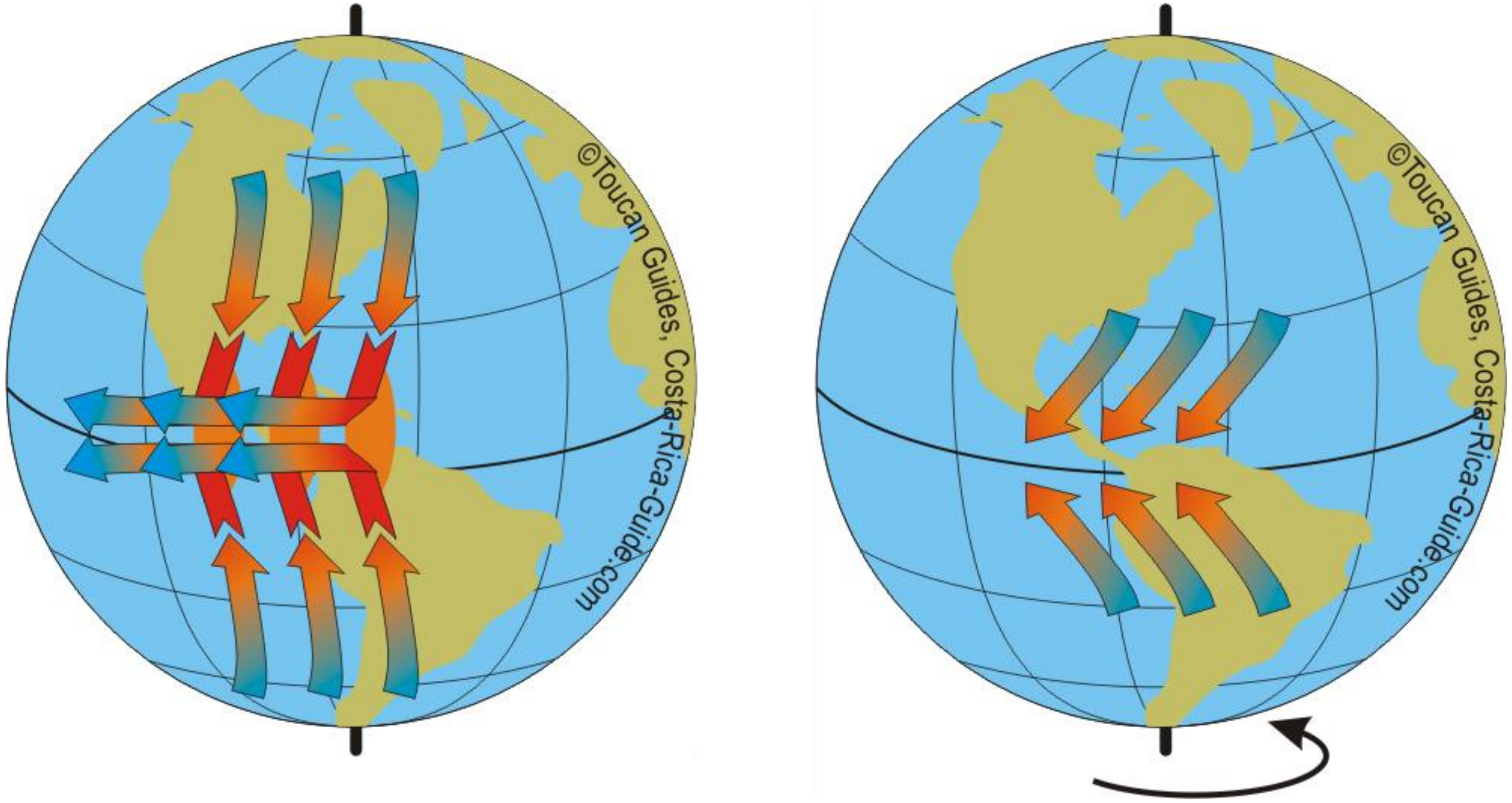


Coriolis Effect – Earth's Rotation

Horizontal influence on earthy motions - all things that move over the surface of the Earth or in Earth's atmosphere appear to drift sideways

Mathematically described by Gaspard G. Coriolis (1792-1843) =-**Coriolis effect or Coriolis Force**

Objects are deflected to the right of their paths in the Northern Hemisphere and to the left of their paths in the Southern Hemisphere.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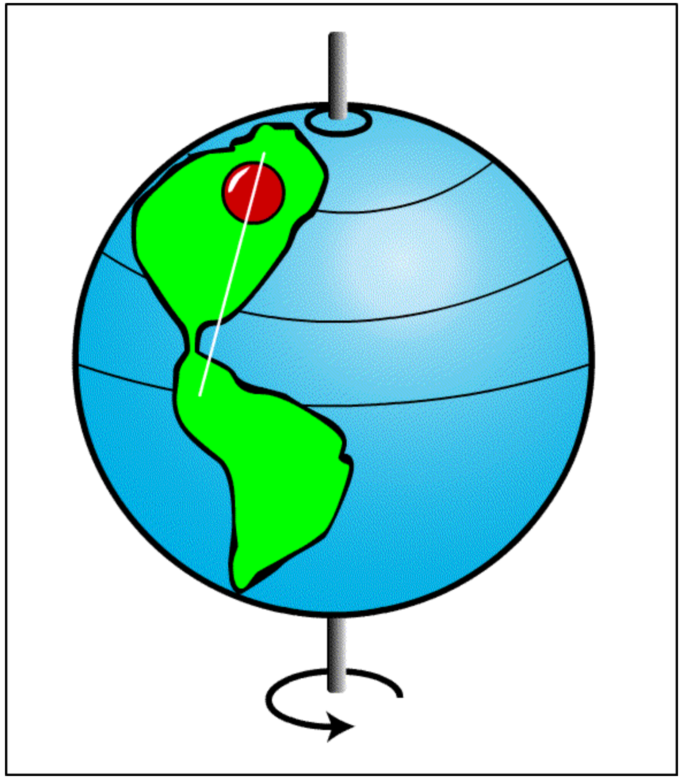
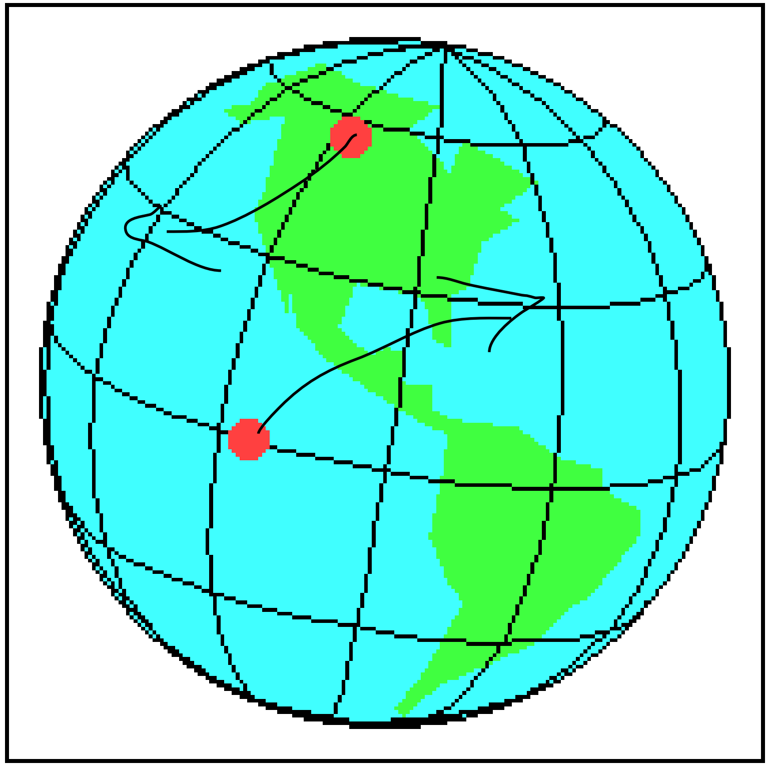
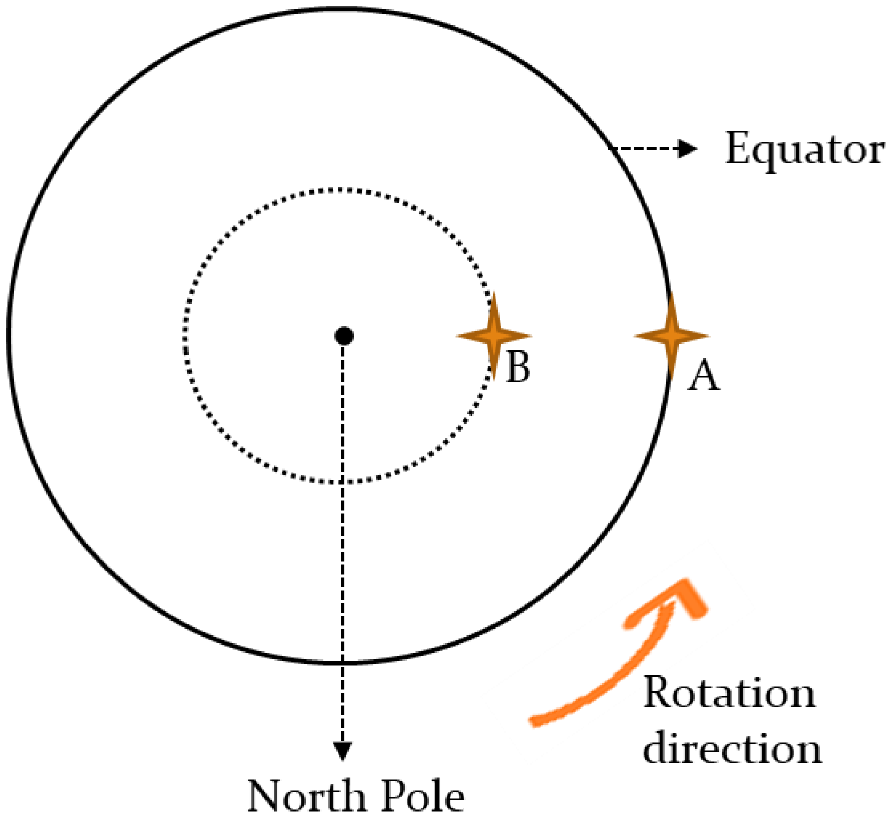
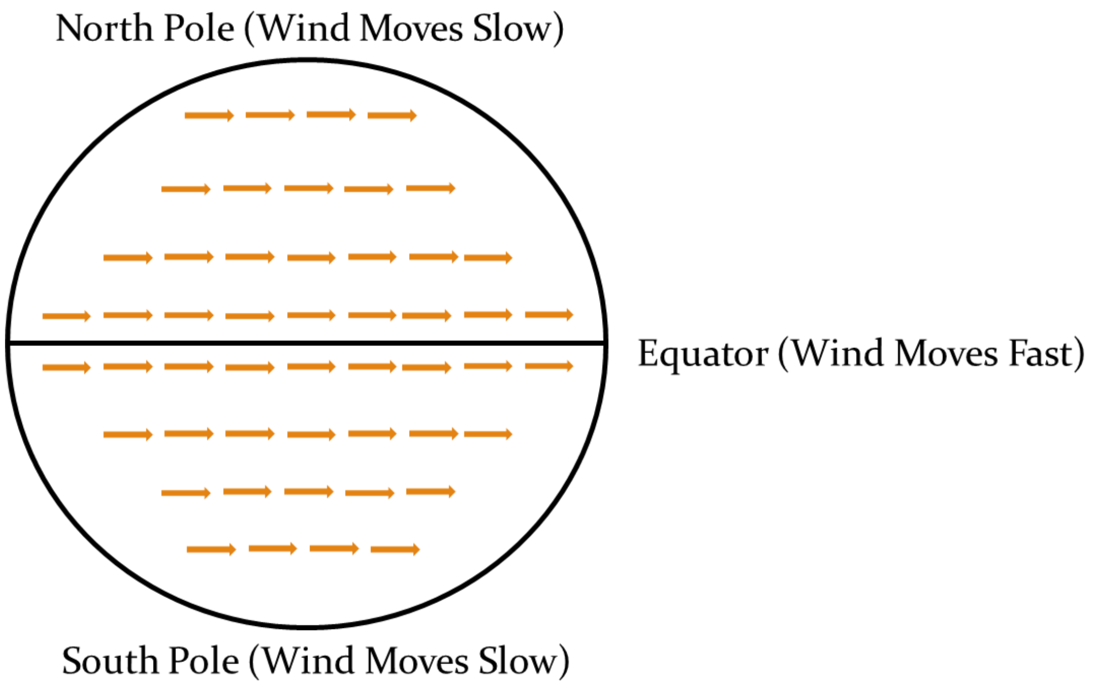




http://studysoaring.stlsoar.org/weather.htm



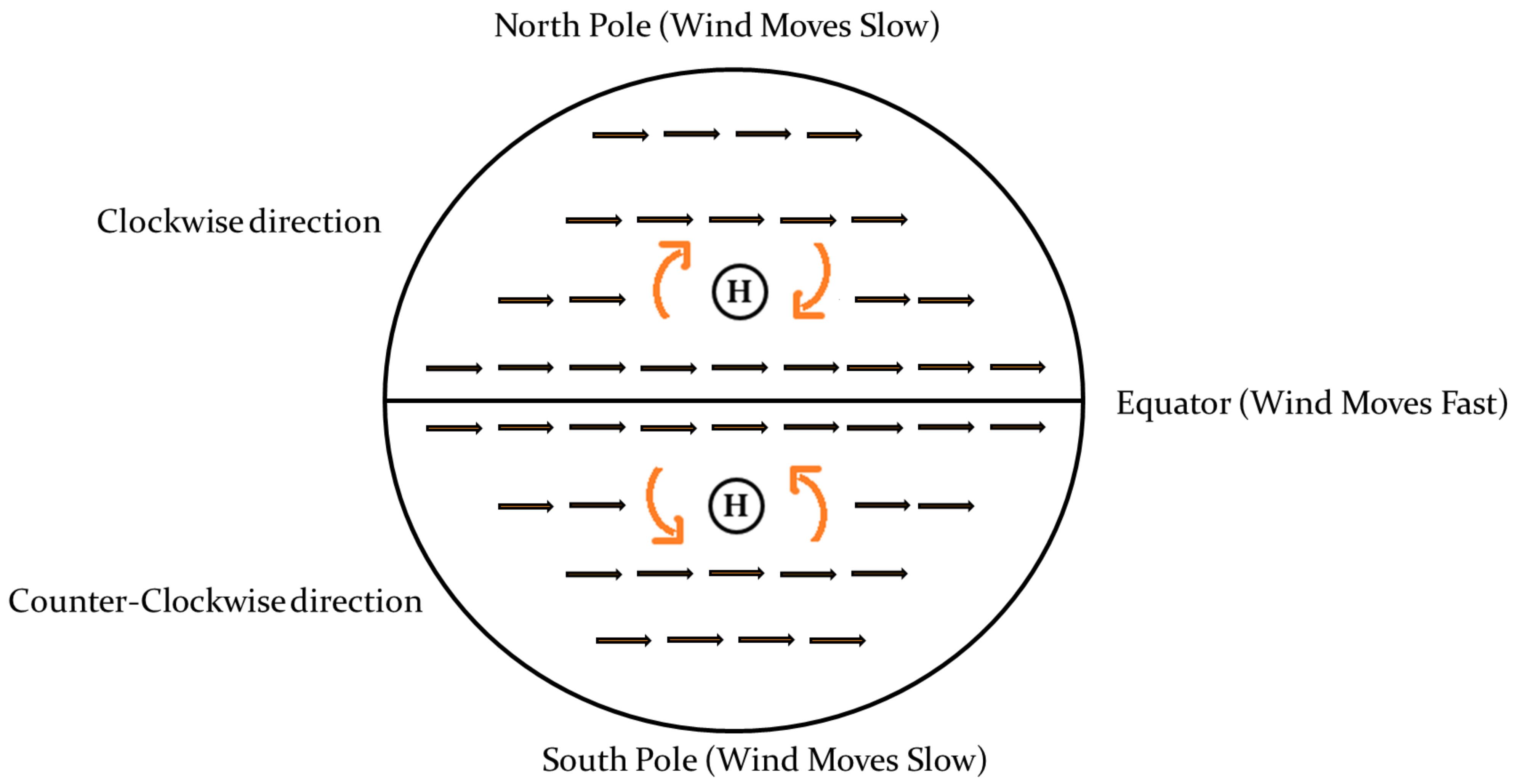


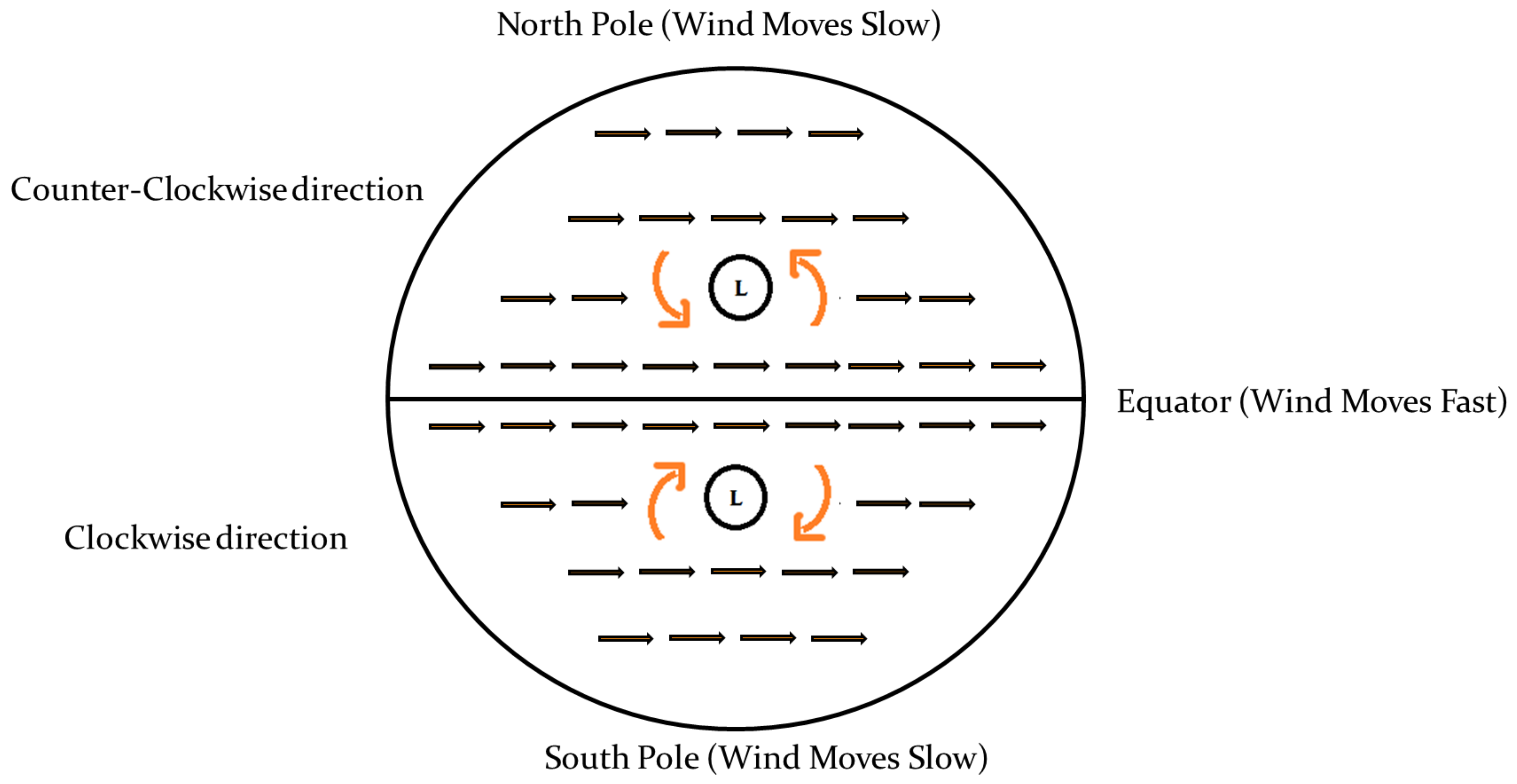
- A is point on the equator and B is point near to the poles.
- Point A moves faster compared to Point B in order to complete one rotation.
- The wind moves fast near the equator when compared to that of the poles.
- So, deflection is greater at the poles than at the equator.

Coriolis Effect

There are four basic points to remember regarding the Coriolis effect:

1. Free-moving objects appear to deflect to right in Northern Hemisphere and to left in Southern Hemisphere;
2. The apparent deflection is strongest at the poles, decreasing progressively toward equator, where there is zero deflection;
3. Fast-moving objects seem to be deflected more than slower ones because Coriolis effect is proportional to speed of object;
4. Coriolis effect influences the direction only, not the speed.


North Pole (Wind Moves Slow)
Clockwise direction
H
Equator (Wind Moves Fast)
H
Counter-Clockwise direction
South Pole (Wind Moves Slow)

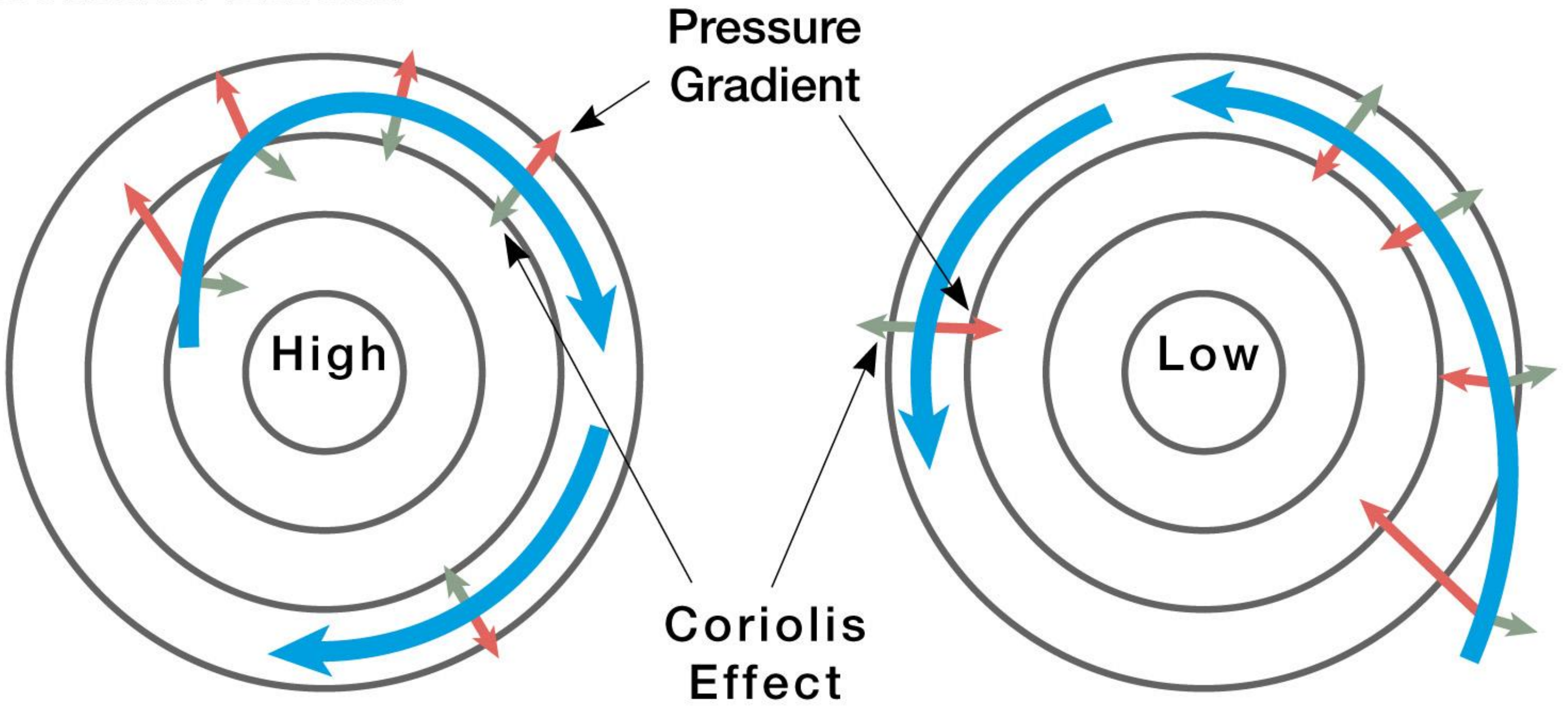

North Pole (Wind Moves Slow)
Counter-Clockwise direction
L
Equator (Wind Moves Fast)
L
Clockwise direction
South Pole (Wind Moves Slow)

Coriolis Effect – Earth's Rotation

There is an eternal battle between **the pressure gradient force** moving air from **high toward low pressure** and the deflection of the **Coriolis effect 90 degrees** from its pressure- gradient path:

- **the Coriolis effect keeps the wind from flowing directly down a pressure gradient, while the pressure gradient prevents the Coriolis effect from turning the wind back up the pressure slope.**
- **Where these two factors are in balance – as is usually the case in the upper atmosphere – wind moves parallel to the isobars and is called *Geostrophic wind.***

(b) Upper Atmosphere—Pressure Gradient Force and Coriolis Effect:



NOTE: In the upper Atmosphere an approximate balance develops between the pressure gradient force and the Coriolis effect deflection, resulting in geostrophic wind blowing parallel to the isobars; wind circulates clockwise around a high and counterclockwise around a low pressure in the Northern Hemisphere.

Friction

Near the ground (**below 1000m or so**) FRICTION complicates the movement of wind

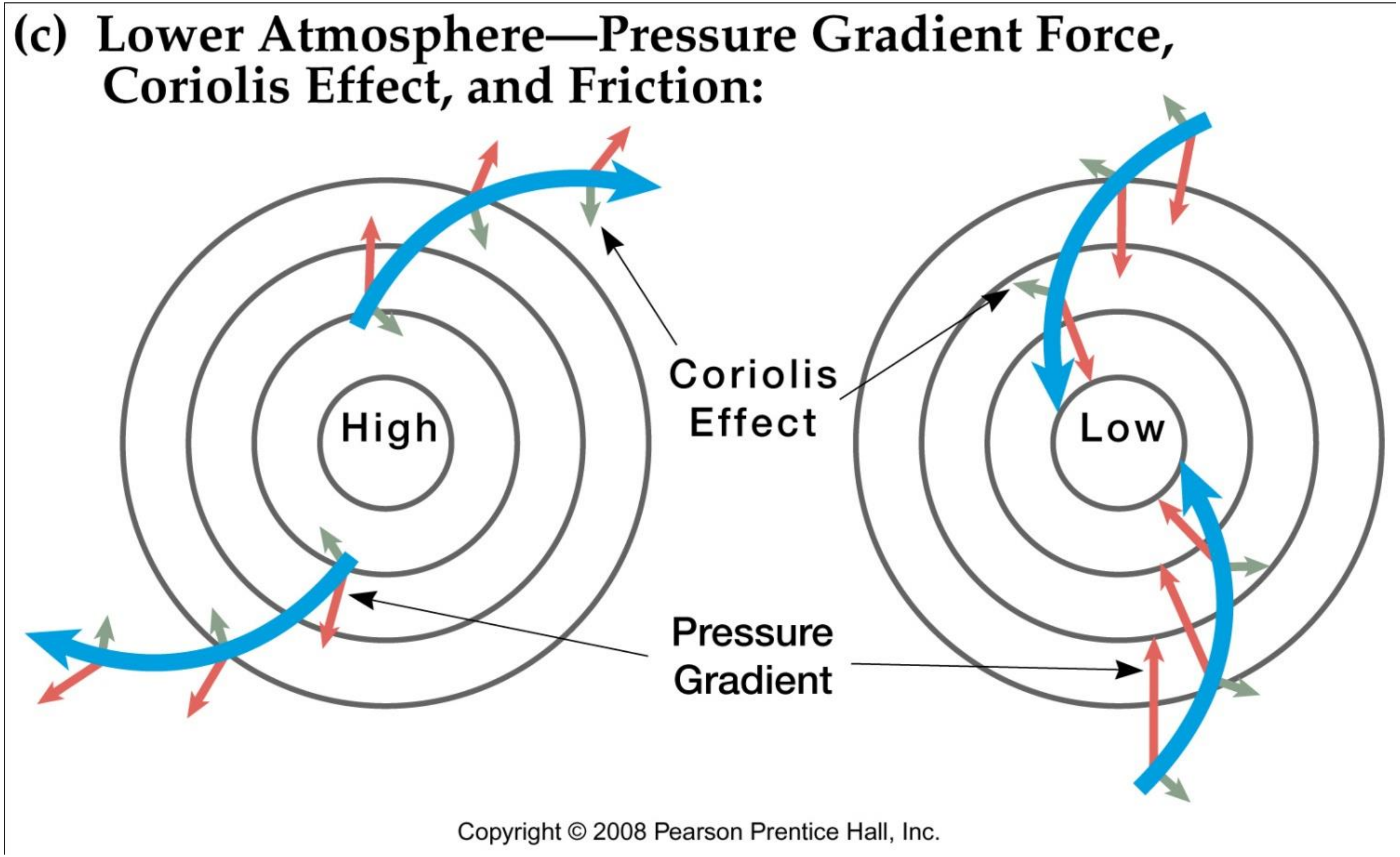
Mountains, hills, vegetation, the built environment…

The frictional drag of Earth's surface slows wind movement and so the influence of the Coriolis effect is reduced (you will recall that rapidly moving objects are deflected more by the Coriolis effect that are slowly moving objects).

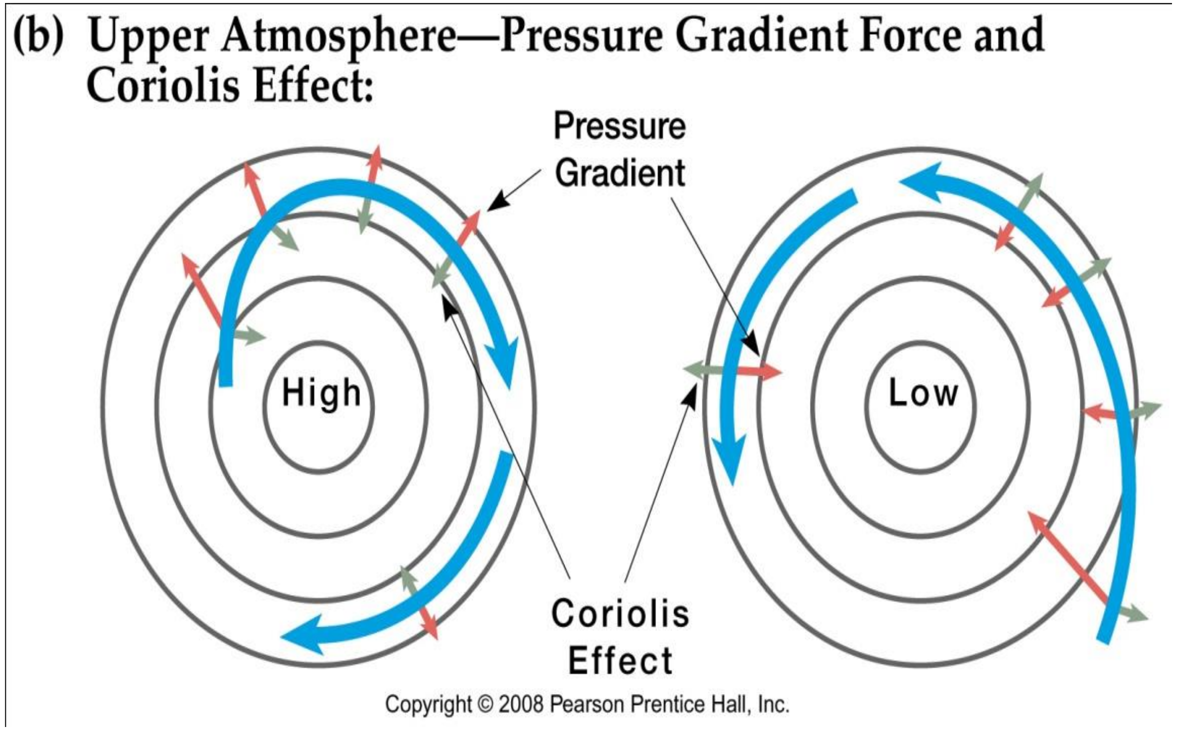
Instead of flowing perpendicular to the isobars (in response to the pressure gradient) or parallel to them (where pressure gradient force and the Coriolis effect are in balance), the wind takes an intermediate course between the two and crosses the isobars at angles between **0 degrees and 90 degrees**.

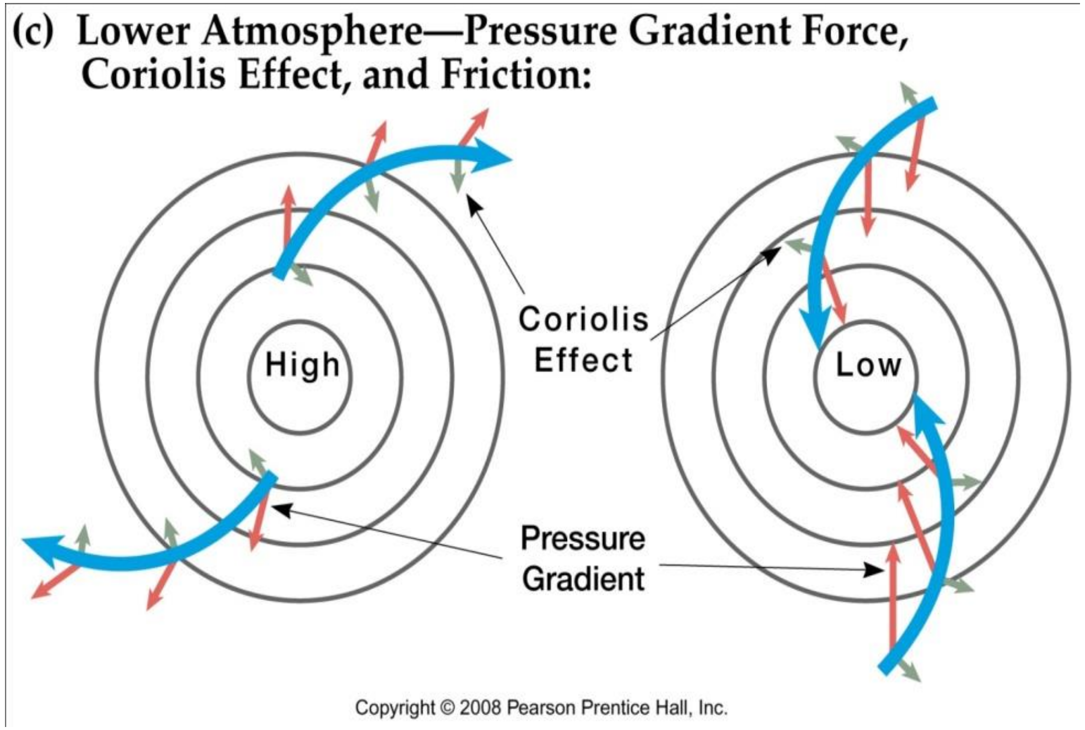
In essence, friction reduces wind speed, which in turn reduces the Coriolis effect deflection – thus, although the Coriolis effect does introduce a deflection to the right (in the Northern Hemisphere) **the pressure gradient** "**wins the battle**" and air flows into an area of low pressure and away from an area of high pressure

REPEAT: As a general rule, the frictional influence is greatest near Earth's surface and diminishes progressively upward.



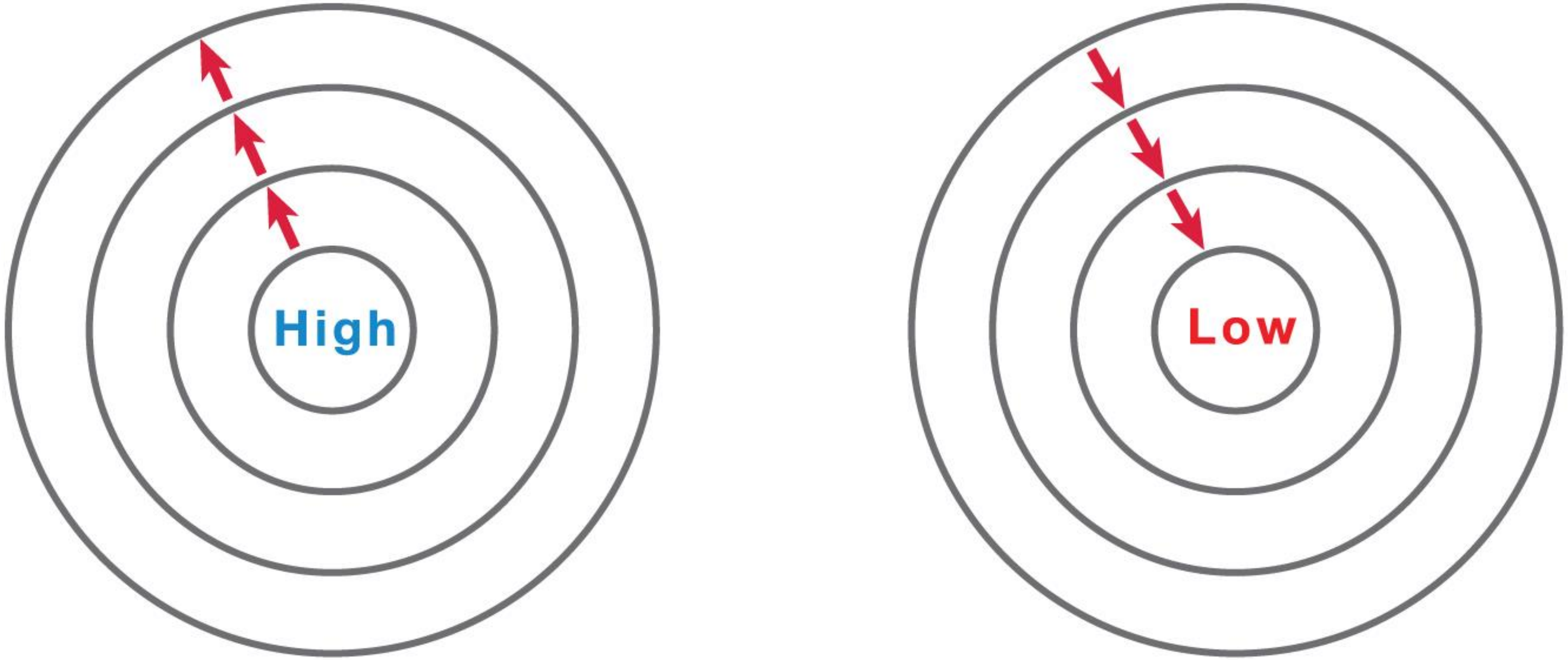
Note: in the lower atmosphere, friction slows the wind (which results in less Coriolis effect deflection) and so wind diverges clockwise out of a high and converges counterclockwise into a low in the Northern Hemisphere.





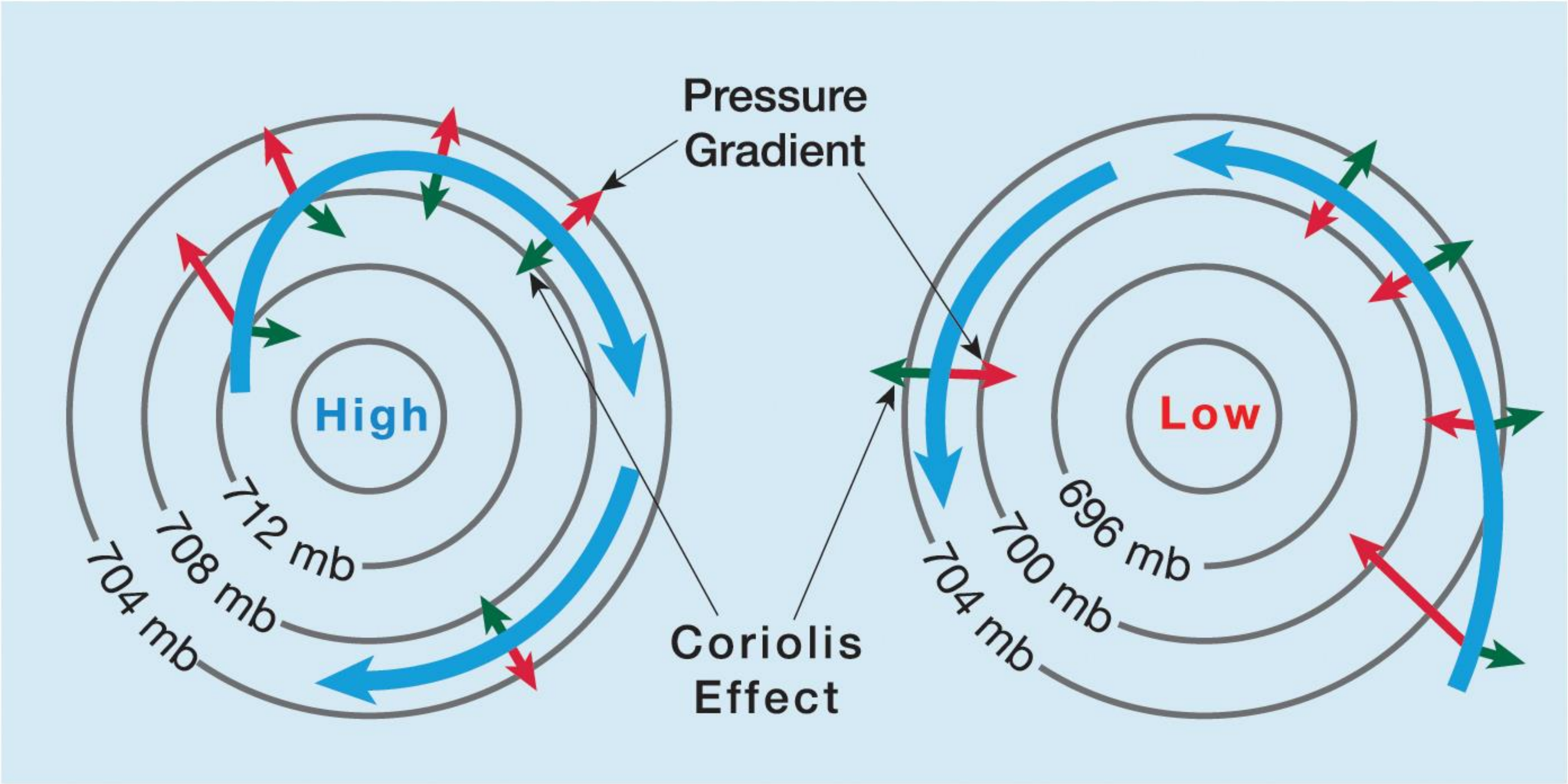
Coriolis Effect and Friction

Wind movement summarized…

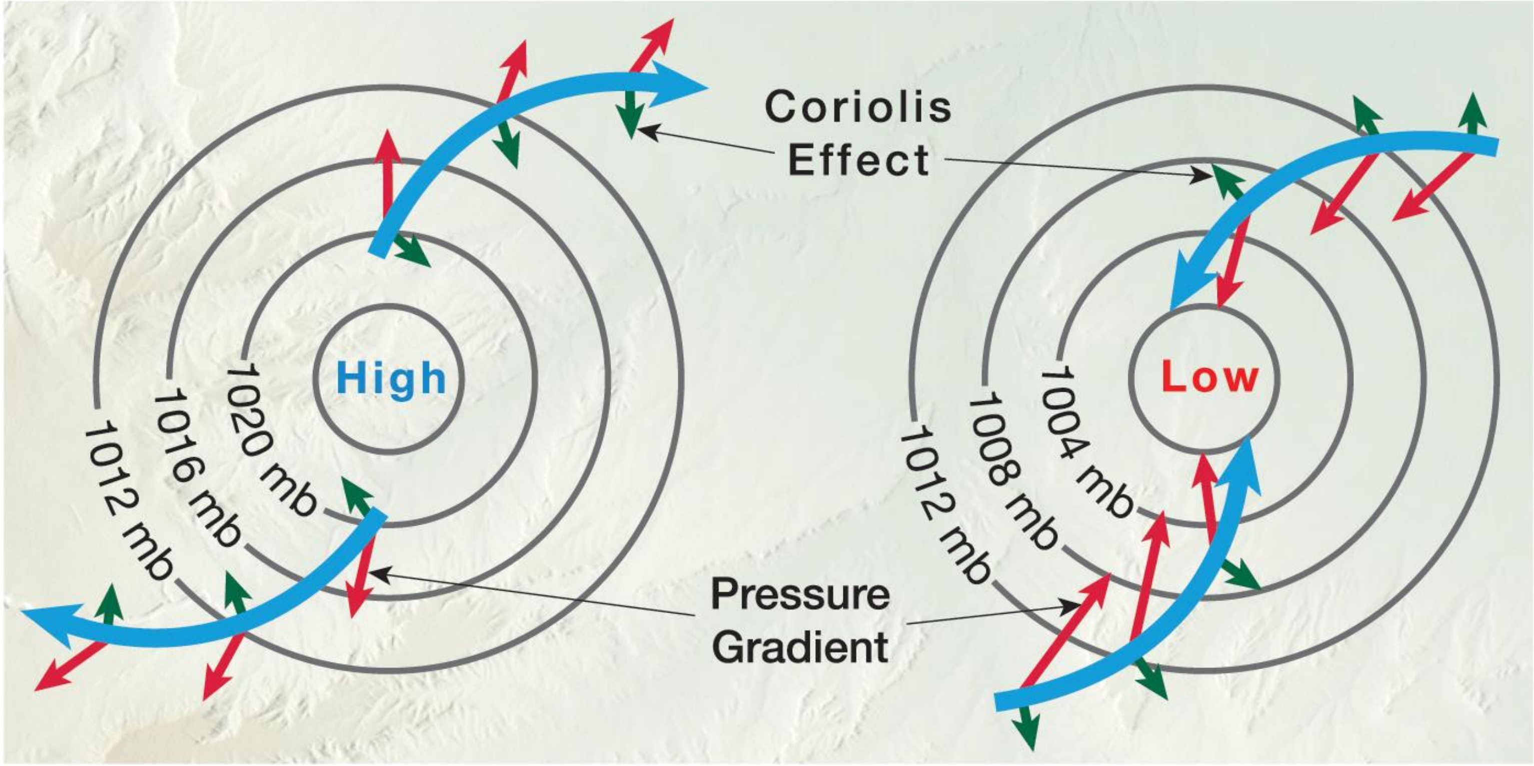


(a) If pressure gradient force were the only factor, wind would blow “down” the pressure gradient away from high pressure and toward low pressure, crossing the isobars at an angle of 90°.

In the upper atmosphere (above about 1000m/3300 ft.)



(b) In the upper atmosphere the balance between the pressure gradient force and the Coriolis effect results in geostrophic wind blowing parallel to the isobars.



(c) In the lower atmosphere, friction slows the wind (which results in less Coriolis effect deflection) and so wind diverges clockwise out of a high and converges counterclockwise into a low in the Northern Hemisphere.

Circulation Patterns

Distinct and predictable wind-flow patterns develop around all high-pressure and low- pressure centers – patterns **determined by the pressure gradient, Coriolis effect and friction**.

Eight circulation patterns are possible because of the interaction of the pressure gradient, Coriolis effect, and friction. **Four in the Northern Hemisphere and four in the Southern Hemisphere**.

- Four involve anticyclones.
- Four involve cyclones.

Cyclone—low-pressure cell.

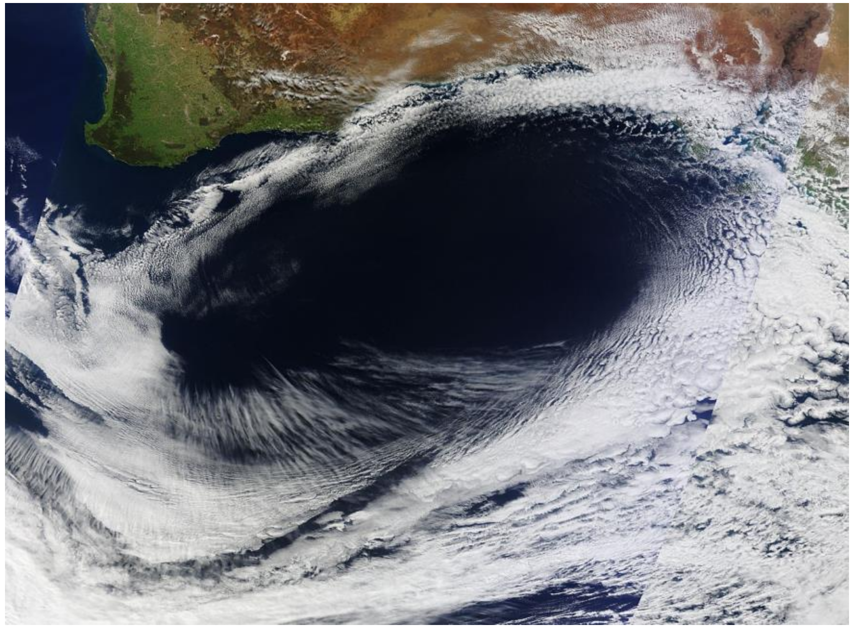
***Anticyclone**—high-pressure cell.*

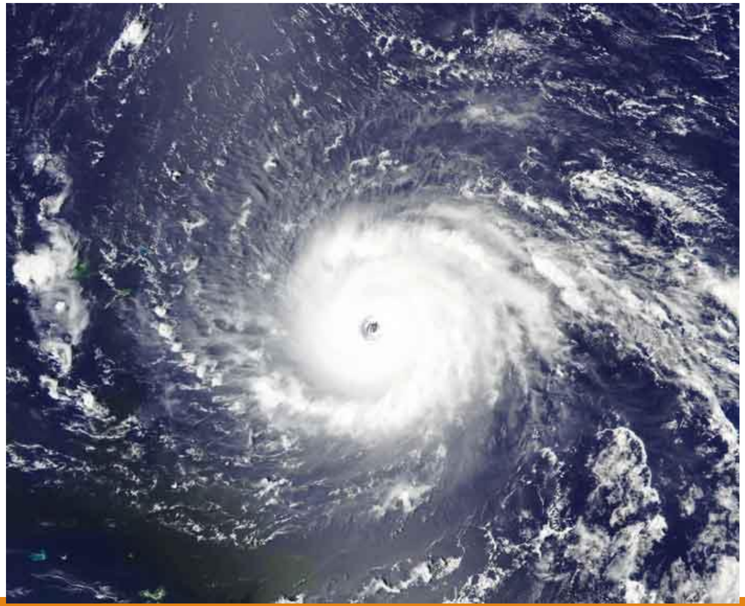
Cyclone and Anticyclones

Each is dependent on the cell's location (hemisphere and altitude [whether surface-layer or upper atmosphere]).

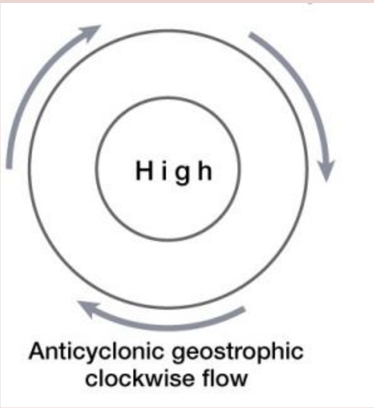
High-Pressure Circulation Patterns – **anticyclones**

Low-Pressure Circulation Patterns – **cyclones**

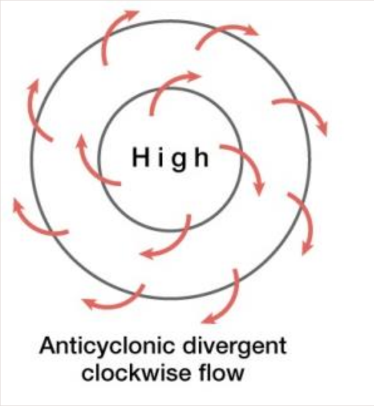




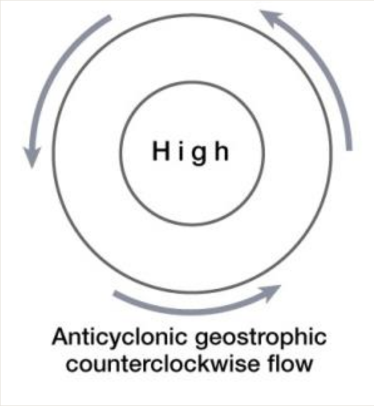
Anticyclones



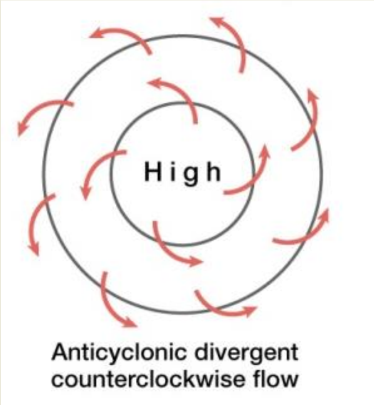
1. In the upper atmosphere of the Northern Hemisphere wind move clockwise in a geostrophic manner (parallel to the isobars).



2. In the friction layer (lower altitudes) of the Northern Hemisphere, there is a divergent clockwise flow with air spiraling away from the high-pressure center.

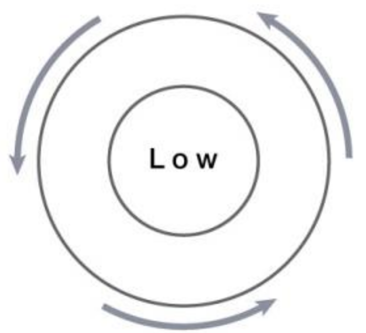


3. In the upper atmosphere of the Southern Hemisphere wind move counterclockwise in a geostrophic manner.



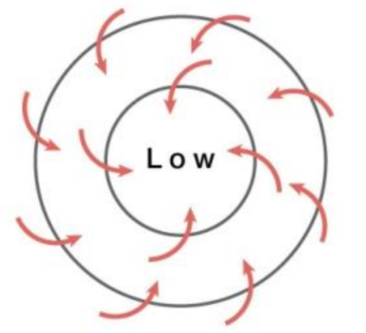
4. In the friction layer (lower altitudes) of the Southern Hemisphere, there is a mirror image of the Northern Hemisphere. The air diverges in a counterclockwise pattern.

Cyclones



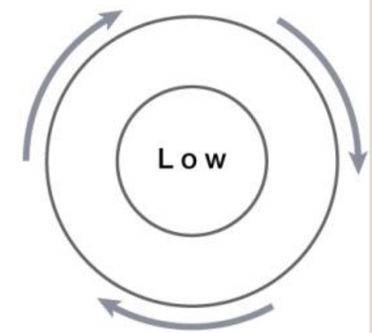
Cyclonic geostrophic counterclockwise flow

5. In the upper atmosphere of the Northern Hemisphere wind move counterclockwise in a geostrophic manner (parallel to the isobars)



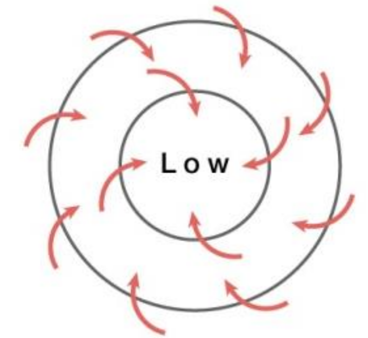
Cyclonic convergent counterclockwise flow

6. In the friction layer (lower altitudes) of the Northern Hemisphere, there is a convergent counterclockwise flow with air moving into the low-pressure center



Cyclonic geostrophic clockwise flow

7. In the upper atmosphere of the Southern Hemisphere winds move clockwise in a geostrophic manner



Cyclonic convergent clockwise flow

8. In the friction layer (lower altitudes) of the Southern Hemisphere, there is a mirror image of the Northern Hemisphere

Hurricane Formation

Hurricanes need:

Low pressure cell

Warm temperatures

Moist ocean air

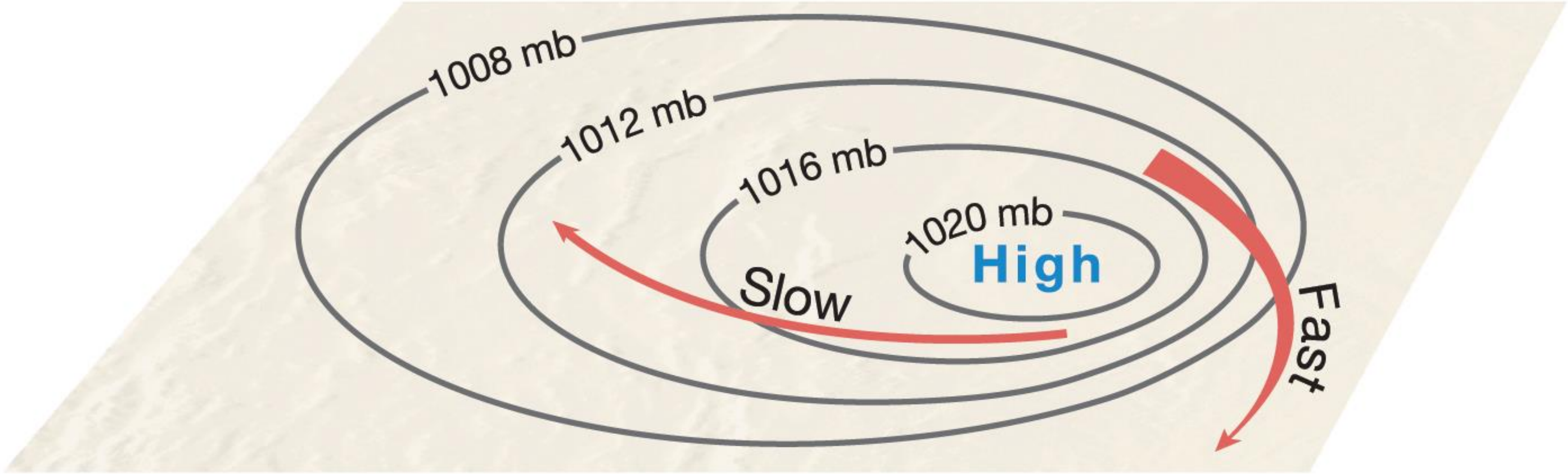
Winds near the tropics (Tropical winds, near the equator)

Tropical wave → Tropical Disturbance → Tropical Depression → Tropical Storm→ Hurricane.

Wind Speed

Is determined by pressure gradient.

- The steeper its slope, the faster the wind.
- Closer spacing of isobars, steeper the pressure gradient, faster the wind blows
- We measure wind speed in nautical miles.



Vertical Variations in Pressure and Wind

Atmospheric pressure usually decreases rapidly with height.

Wind speed usually increases with height; winds tend to move faster above friction layer.

TABLE 5-1 How Atmospheric Pressure Varies with Altitude

Altitude		
Kilometers	Miles	Pressure (millibars)
18	11	75.6
16	10	104
14	8.7	142
12	7.4	194
10	6.2	265
9.0	5.6	308
8.0	5.0	356
7.0	4.3	411
6.0	3.7	472
5.0	3.1	540
4.0	2.5	617
3.5	2.2	658
3.0	1.9	701
2.5	1.6	747
2.0	1.2	795
1.5	0.9	846
1.0	0.6	899
0.5	0.3	955
0	0	1013