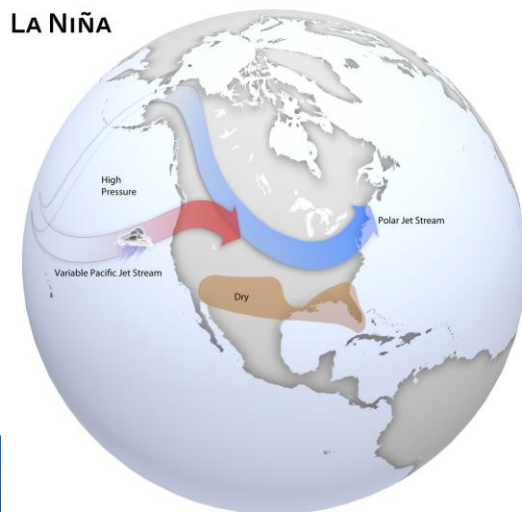


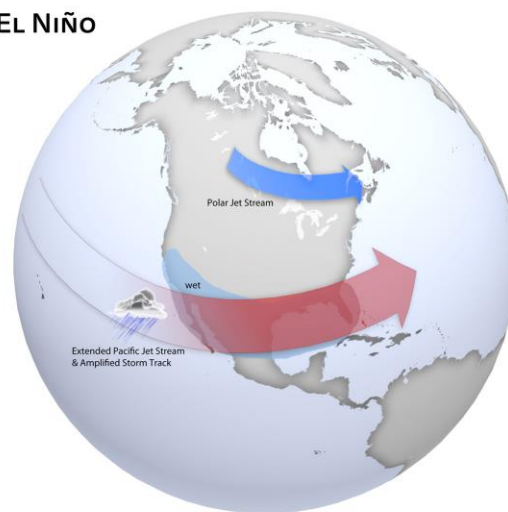
CHAPTER FOUR

4. AIR PRESSURE AND ATMOSPHERIC CIRCULATIONS

LA NIÑA



EL NIÑO



4.1. The concept of air pressure

- **Air pressure** is simply the *mass of air above* a given level.
- In most circumstances atmospheric pressure is closely approximated by the *hydrostatic pressure* caused by the *weight of air* above the measurement point.
- As we climb in altitude above Earth's surface, there are *fewer air molecules* above us; hence, *atmospheric pressure always decreases with increasing height*.
- Another concept is that our atmosphere is *highly compressible*. This means that the *weight of higher layers compresses the atmosphere beneath*, and so most of the molecules in our atmosphere are crowded close to Earth's surface.
- Hence, *air pressure decreases* with *height*, rapidly at *first*, then more slowly at *higher altitudes*.

✓ *turbulence*

4.2. Air pressure

4.2.1. Vertical and Horizontal Variation of Air Pressure

Vertical variation

- One way to change air pressure is to simply move up or down in the atmosphere.
- The pressure depends on the *density or mass of the* air. The *density of air depends on its temperature*, its *composition* and *force of gravity*.
- It is observed that the *density of air decreases* with *increase in height* so the *pressure* also *decreases with increase in height*.
- The *pressure at sea level is 1013.25* mb, at *50 km height* it becomes 0.93 mb and 80 km it is only 0.03 mb.
- This indicates how rapidly the *atmospheric gas becomes thinner* to *decrease density* and so the pressure. The pressure decreases on an *average at the rate* of about *34* mb *every per 300 meters height*.

But what causes the air pressure to change in the horizontal?

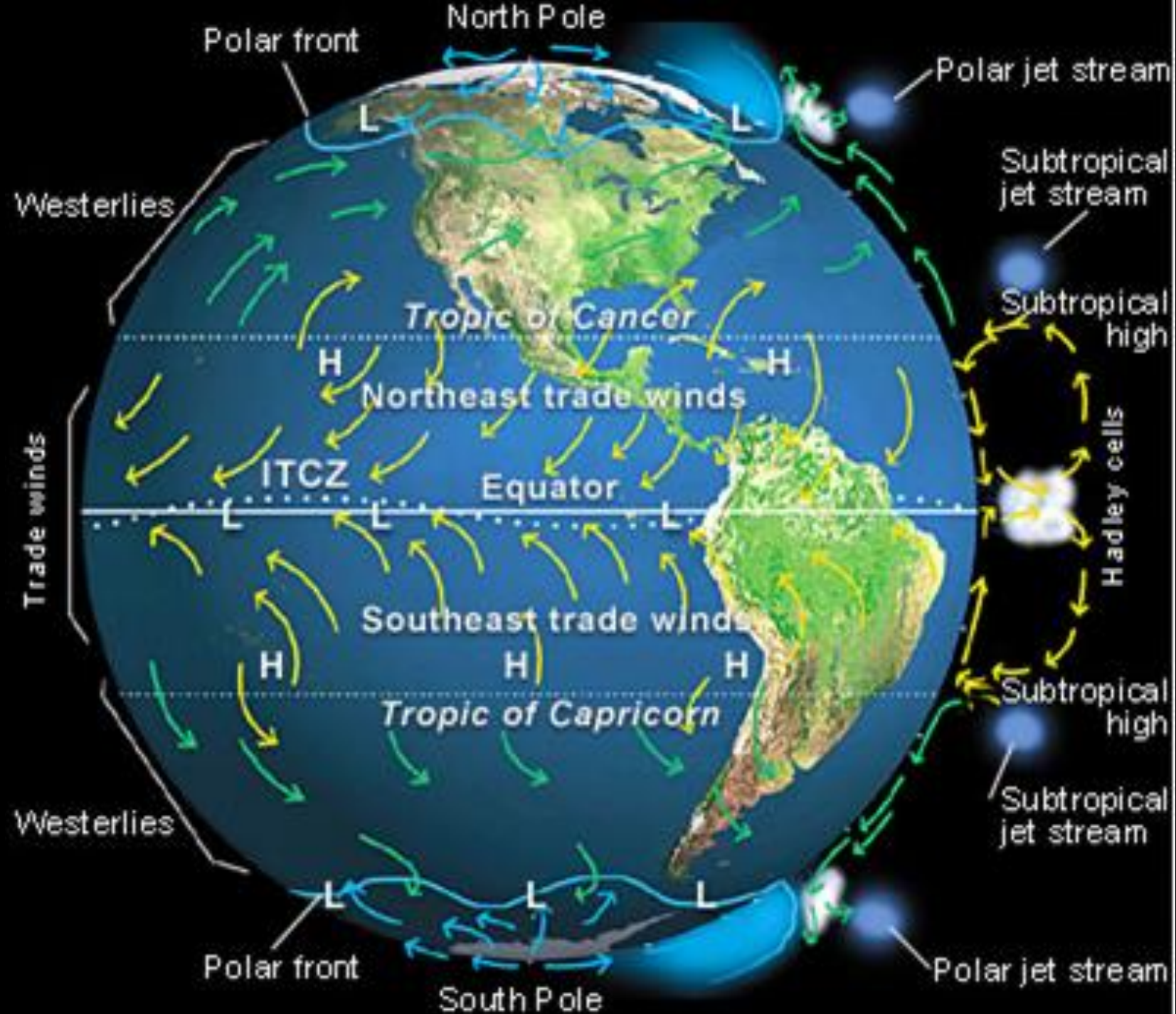
- The horizontal variation of atmospheric pressure depends on *temperature*, the *extent of water vapor*, **latitude**, and *land and water relationship*.
- The *horizontal difference in temperature* creates a *horizontal difference in pressure*.
- The **pressure difference** establishes a force (called the *pressure-gradient force*) that causes the air to move from *higher pressure* toward *lower pressure*.

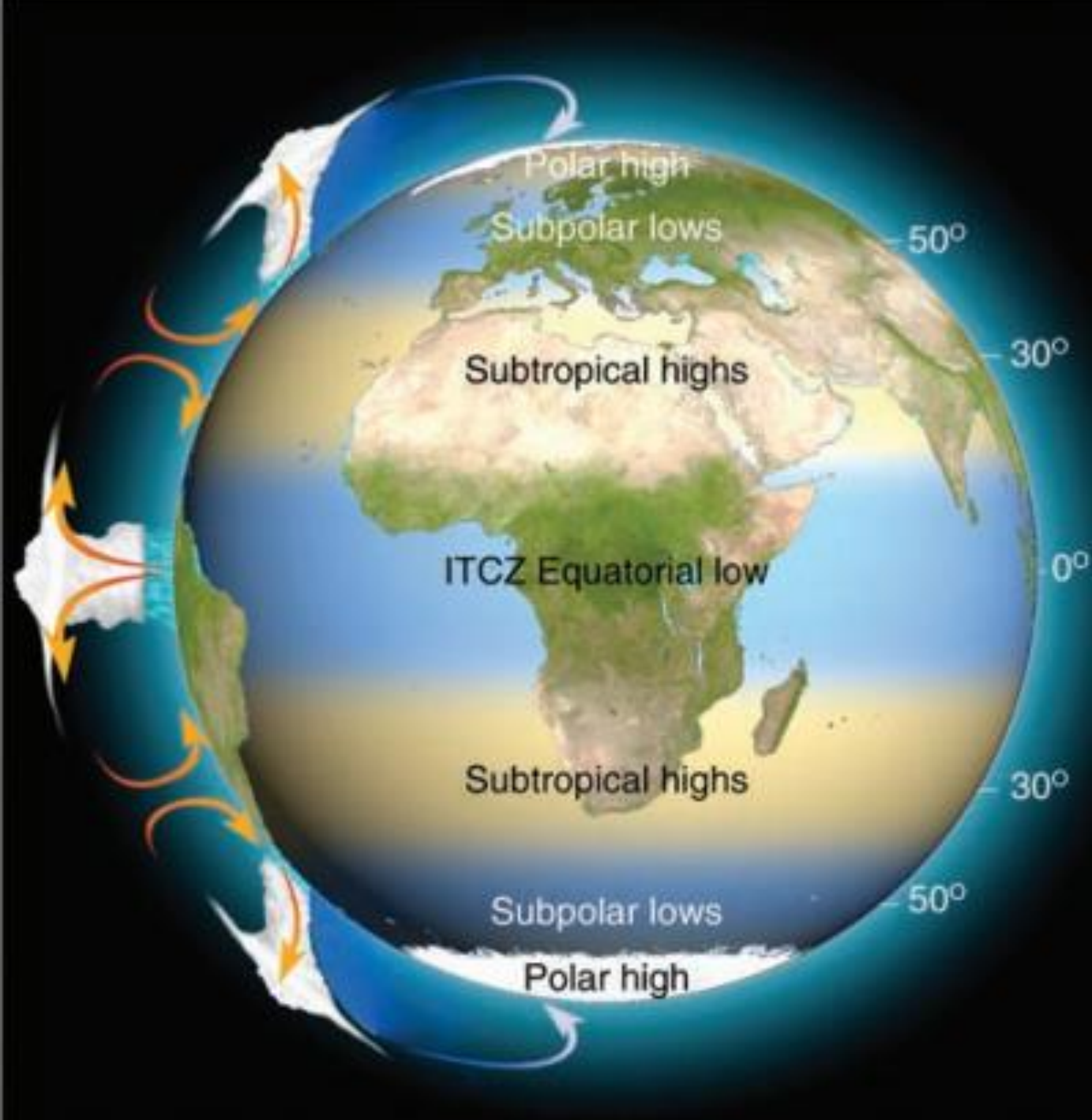
4.2.2. Global Pressure Belts



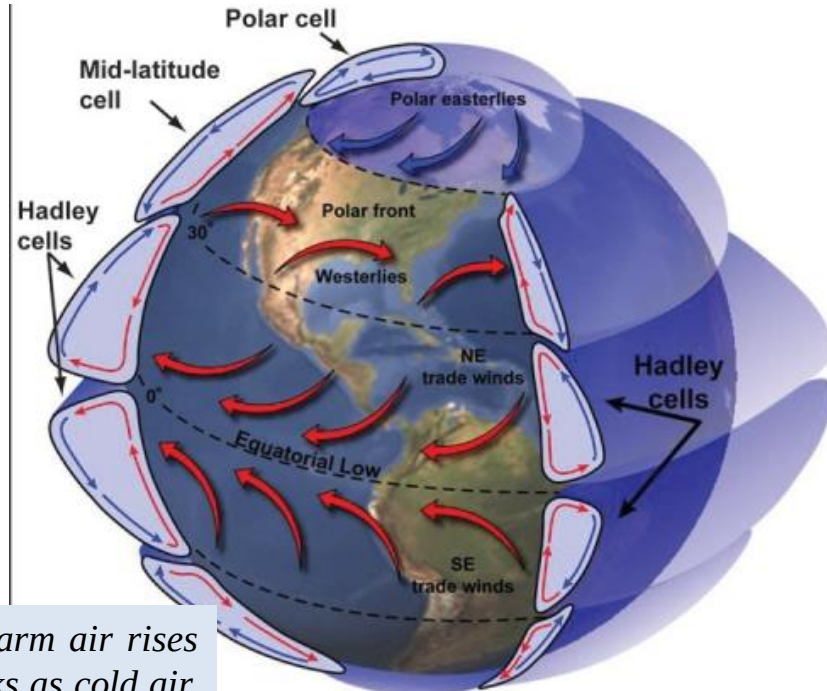
The connections between *atmospheric circulation*, *ocean currents* and *Earth's climate* are both **simple** and **wonderfully** complex.

- The figure below shows large-scale atmospheric circulation on Earth (three-dimensionality of the circulation).
- On the *right-hand side of the image* the arrows show *vertical and horizontal airflow as part of six convection cells*, **three** in each of the Northern and Southern hemispheres.
- ❑ The *central part of the image* shows *surface winds blowing from the east* (the *Trade winds*)
- ❑ The *west* (the *Westerlies*)
- ❑ The *Polar Easterlies* [are *not easily* seen in this image]





- **Hadley circulation** one of the most important concepts to understand.
- Pressure is driven by *unequal solar heating* as a *function of latitude*.
- The energy from our Sun is concentrated in the equatorial region and spread *comparatively thinly over* the **Polar Regions**.
- This is true on an average annual basis; Earth receives more solar energy at the *equator* than at the *poles*.
- As a result, the land, water, and air, over the equator are *warm*, and *air rises* over the *equator*.



* **Hadley Cells** are patterns of atmospheric circulation in which warm air rises near the equator, cools as it travels poleward at high altitude, sinks as cold air, and warms as it travels equatorward

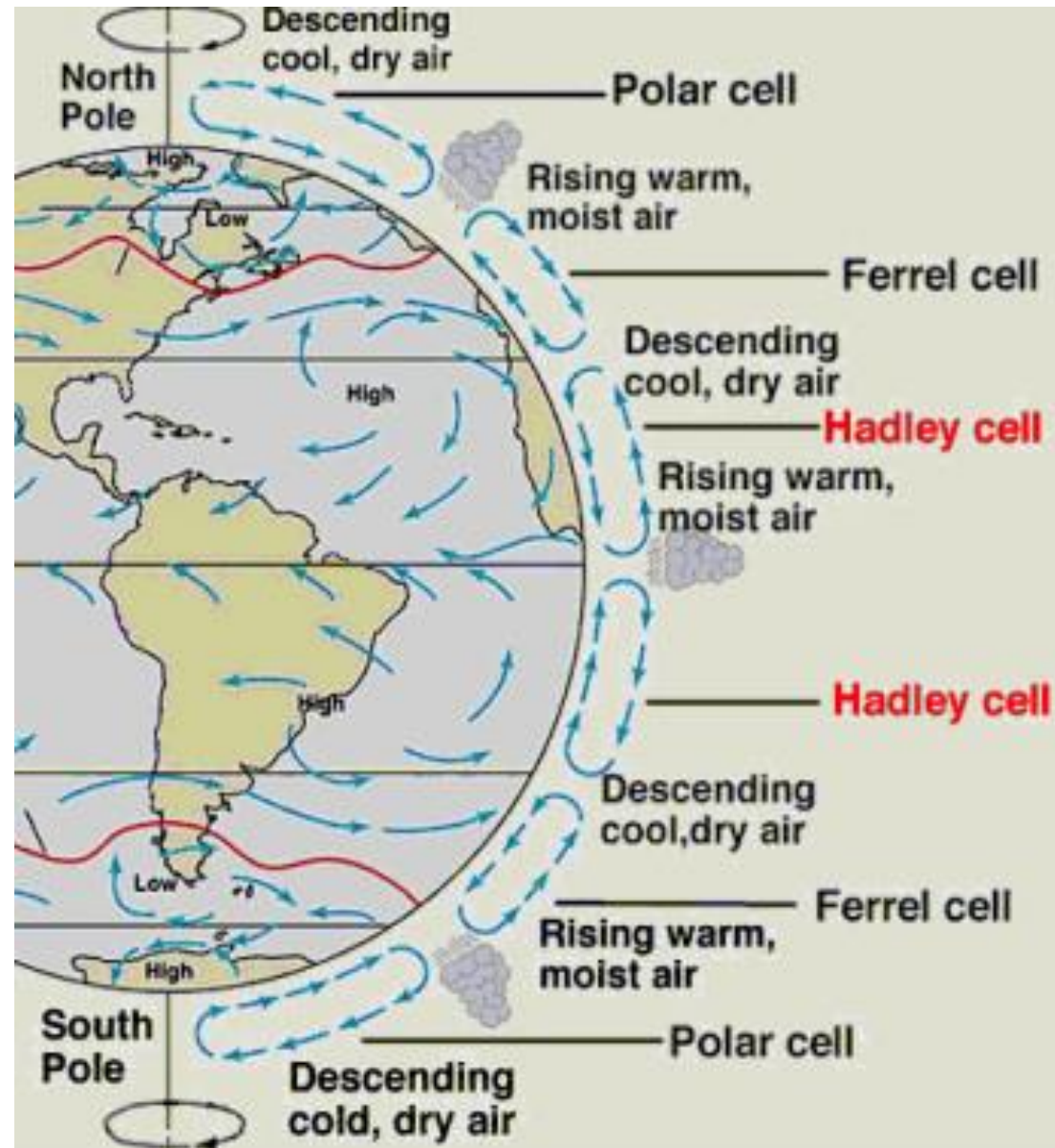
- This warm air rises through the atmosphere and flows poleward as an upper atmosphere winds that is, essentially, an ***air-mail package*** of ***heat*** known as a ***Hadley Cell***.
- The image above has arrows showing circulation in a vertical plane along one line of longitude but, of course, this circulation takes place everywhere on Earth.
- Hadley circulation is ***heat moves poleward*** in upper atmosphere winds and there is a ***return flow*** from ***north to south*** (in the Northern hemisphere) that sets up the ***Northeasterly Trade winds*** (with the help of the ***Coriolis effect***)

- 🌍 The Hadley Cell is set up by rising air over the equator.
- 🌍 The warm rising air causes low pressure at Earth's surface in the equatorial region.
- 🌍 By the same token, high pressure is set up at roughly 30° north and 30° south.
- 🌍 These belts of high pressure are caused by the descending limbs of the Hadley Cell at those latitudes.
- 🌍 In approximate terms, you can think of 30 deg. as the point at which upper atmosphere winds of the Hadley Cell have lost their heat.
- 🌍 The *cold air becomes dense and falls back to Earth's surface*, creating a belt of *high pressure*.
- 🌍 Similar there exist a wind circulation in mid-latitude ((*Ferrel Cell*) and high-latitude (*Polar Cell*).

➤ The *Hadley cell* is the circulation cell nearest the equator and has air rising at the equator and sinking near 30 degrees.

➤ The *Ferrel cell* is the circulation cell in the mid-latitudes where the air rises near 60 degrees and sinks near 30 degrees.

➤ The *Polar cell* is the circulation cell in the polar regions.



- Based on the horizontal variation of pressure, the following are important ***pressure belts***.

1. Equatorial Low Pressure Belts

- The ***Equatorial Low Pressure Trough***: This area is in the Earth's equatorial region (0°-10° North and South) and is ***composed*** of ***warm, light, ascending and converging air***.
- Because the converging air is ***wet*** and ***full of excess energy*** it ***expands*** and ***cools*** as it rises, creating the ***clouds*** and ***heavy rainfall*** that are *prominent throughout the area*.
- This ***low pressure zone*** trough also forms the ***ITCZ*** and ***trade winds***

🌐 Within a **few degrees** of equator is a belt of pressure, somewhat **lower than** the normal pressure (1013 mb), between 1011 mb and 1008 mb, which is known as the *Equatorial Trough* or *Low Pressure Belt*.

🌐 This is an area of *high temperature* and *high humidity*, commonly known as the *Doldrums*, where the *air* near sea level is *stagnant/motionless* or *sluggish*.

🌐 The *low pressure* is **due to heating**; as the *pressure* of a volume of air *decreases* when its *temperature increases*.

➤ It lays entirely *north of the equator* during *July*, because this is the summer hemisphere (*Northern Hemisphere*).

➤ The *trough* is by *no* means *uniform* in width, depth or position.

2. *Sub-Tropical High-Pressure Belts*



The *subtropical high-pressure belt* (STHP) laying at about latitude 30° N and S occur the sub-tropical high-pressure belts, sometimes known as the “*Horse Latitudes*”, zones of *calm* and *descending air* currents.

- It is a [high-pressure area](#) at the divergence of [trade winds](#) and the [westerlies](#).



STHP is a region in the subtropics of consistently **dry**, **warm**, and **sunny** weather.



The **high-pressure systems** over the subtropical oceans are known as *subtropical highs*.



In the Northern Hemisphere in summer, the *high-pressure belt* is dominated by two oceanic cells, one over the *eastern Pacific* and the other over the *eastern north Atlantic*.



Average pressure exceeds 1026 mb in the centers of the cells. The *sub-tropical highs* are largely developed by *dynamic*, rather than *thermal* causes.



Subsiding air from high levels is largely responsible for *their great pressure*.



Variations in their strength and form are among the most important features of the global energy balance since the air that diverges from them comprises a *large part of the entire air circulation* system on the surface.

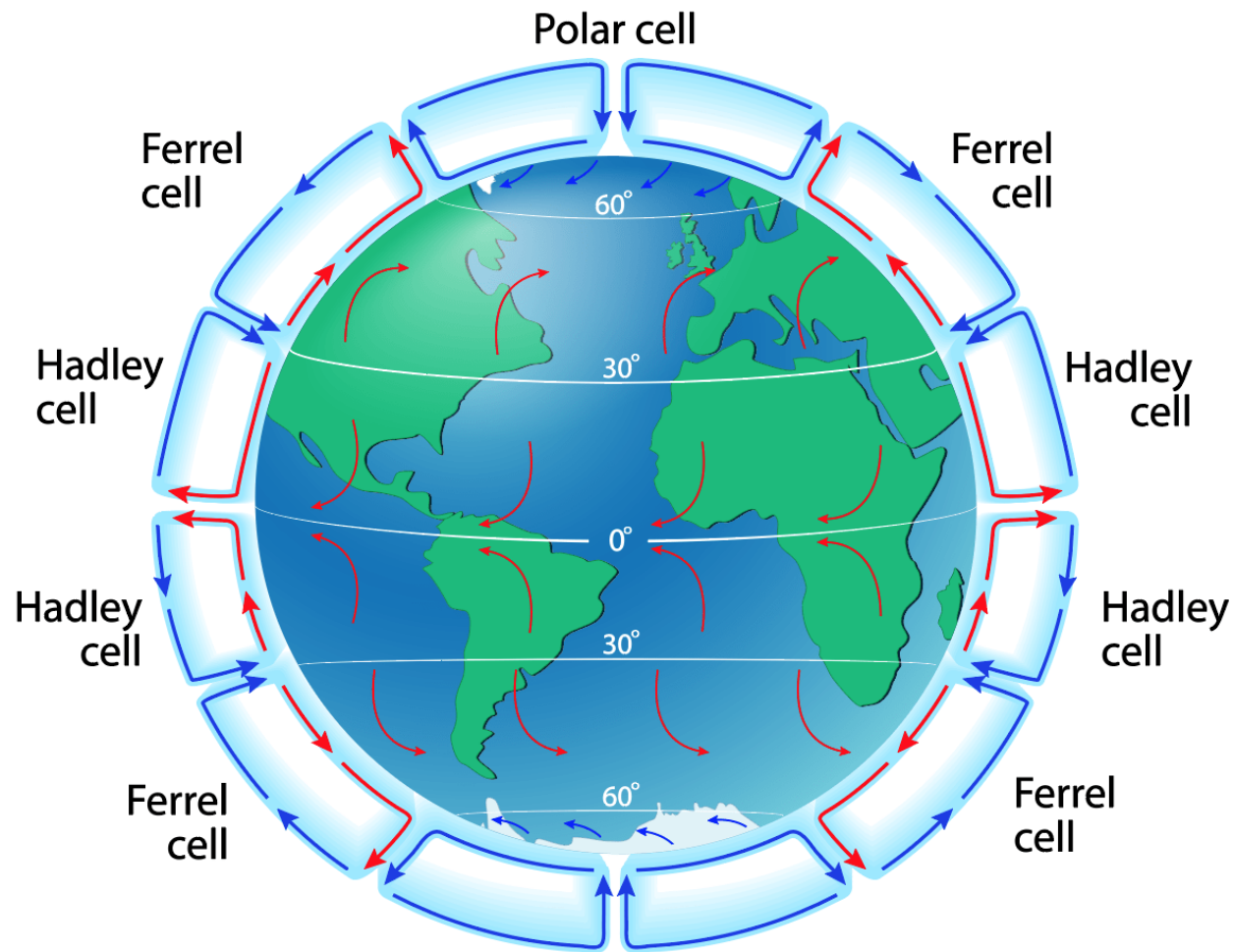
3. Sub-polar Low-Pressure Belts

- ✚ Nearer the poles occur the sub-polar low-pressure belts.
- ✚ It is obvious that the *low pressure is not caused by the temperature as there is low temperature throughout the year* (Which should have caused high pressure).
- ✚ This shows that the *low-pressure* belt is *dynamically* produced.
- ✚ One reason for this pressure distribution is that the rotation of the earth causes a *polar whirl* and therefore a tendency toward low pressure at the poles.
- ✚ But the intense cold around the poles causes the thermal effect to overcome the dynamic one, with the result that the low-pressure belts tend to be around just *outside the polar circles*.
- ✚ Since the frontal activity between cold and warm air in these latitudes is weak during the summer season, *strong sub-polar lows do not develop*.

4. *Polar High-Pressure Belts*

- PHPBs are located at 90° north and south and are *extremely cold* and *dry*.
- With these systems, *winds move away from the poles* in an **anticyclone** that *descends and diverges* to form the *polar easterlies*.
- However, they are *weak* because there is *little energy available in the poles* to make the systems strong.

➤ By studying these highs and lows, scientists are better able to understand the Earth's circulation patterns and predict the weather for use in **daily life, navigation, shipping**, and other important activities, making air pressure an important component of meteorology and other atmospheric science.



4.2.3. Factors for Variation of air Pressure

A. Air temperature

- Temperature makes changes in air pressure.
- In **cold** air, the **molecules are more closely packed together** than in warm air, so **cold air is denser** than warm air.

B. Altitude

- Pressure varies smoothly from the earth's surface to the **top of the atmosphere**.
- As *altitude increase, air pressure decrease*.
- Moreover, as low altitudes above the sea level, the pressure decreases by about *1.2kPa for every 100 meter*.

C. Rising and Sinking Air

- Since *warm air* is *less dense* and *creates less air pressure*, it *will rise*; *cold air* is *denser* and creates *greater air pressure*, and so it *will sink*.
- When *warm air rises*, *cooler air* will often *move* in to *replace* it, so wind often moves from areas where it's *colder* to areas where it's *warmer*.
- The greater the difference between the high and low pressure or the shorter the distance between the high and low-pressure areas, the *faster the wind will blow*.
- *Wind* also *blows faster* if there's nothing in its way, so winds are usually stronger over oceans or flat ground.
- Meteorologists can forecast the speed and direction of the wind by measuring *air pressure* with a barometer.

D. Wind Direction

- Although wind blows from areas of high pressure to areas of low pressure, it doesn't blow in a straight line. That's because the *earth is rotating*.
- In the *northern hemisphere*, the spin of the earth causes winds to curve *to the right* (to the *left* in the *southern hemisphere*).

□ This is called the *coriolis effect*

- So in the *northern hemisphere*, winds blow *clockwise* around an area of *high pressure* and *counter-clockwise* around *low pressure*.

4.2.4. Measures of Air Pressure

- Air pressure is measured using a ***BAROMETER***.
- Several different barometers exist; *two of the most common* are the ***mercury barometer*** and the ***aneroid barometer***.

I. Mercury Barometer

II. Aneroid Barometer

III. Cylindrical resonator barometer

IV. Electrostatic capacity barometer

4.3. Wind

- Wind is *air in motion*.
- It is produced by the *uneven heating* of the *earth's surface* by the *sun*.
- Since the earth's surface is made of *various land and water formations*, it *absorbs* the *sun's radiation unevenly*.



4.3.1 Causes of Wind (air movement)[laws of horizontal movement]

- Winds are caused by uneven heating of the earth's surface by the sun, the uneven heating of the atmosphere, the irregularities of the earth's surface, and rotation of the earth.
- Wind flow patterns are modified by the *earth's terrain, bodies of water*, and *vegetative cover*.

- As the *sun warms the Earth's surface*, the *atmosphere warms too*.
- *Some parts* of the Earth receive *direct rays* from the sun all year and are *always warm*.
- Other places receive *indirect rays*, so the climate is colder.
- *Warm air*, which weighs less than cold air, rises. Then cool air moves in and **replaces** the rising warm air.
- This movement of air is what makes the *wind blow*.
- Wind is *moving air* and is caused by differences in **air pressure** within our atmosphere.
- Air moves from *high-pressure* areas toward areas of *low pressure*.
- The *greater the difference in pressure*, the *faster the air flows*.

4.3.2. Forces Affecting Winds

- Air is constantly moving to seek equilibrium between areas of more air molecules (**higher pressure**) and those with less (**lower pressure**).
- You have probably experienced this by opening a container that has been vacuum-packed. Because the container is vacuum packed, there is **less air inside** (lower pressure) than **outside** (higher pressure).
- When you open the container you hear a "whoosh" as air *rushes into it*.
- The *air rushing from outside the container into it* is **wind**, albeit at the microscale.
- The direction and speed of the wind represent the balance between three basic forces acting on it:
 - the *pressure gradient*,
 - the *Coriolis force*,
 - *surface friction* and *gravity*.

1. Pressure Gradient

- In fluid mechanics, the pressure-gradient force is the force that results when there is a difference in pressure across a surface.
- The spacing of isobars indicates the change in pressure over distance otherwise known as a *Pressure Gradient*.
- *Change in pressure* over *distance* happened by the *unequal heating* of the *Earth's surface*.
- This happened when *one location receives more incoming energy* than another, possibly because one place has a higher sun angle than another.
- *Pressure gradient* initially causes the air to flow from *higher toward lower pressure* creating a wind.
- So in terms of a *cause-and-effect relationship*:

Energy gradient -> *temperature gradient* -> *pressure gradient* -> *wind*

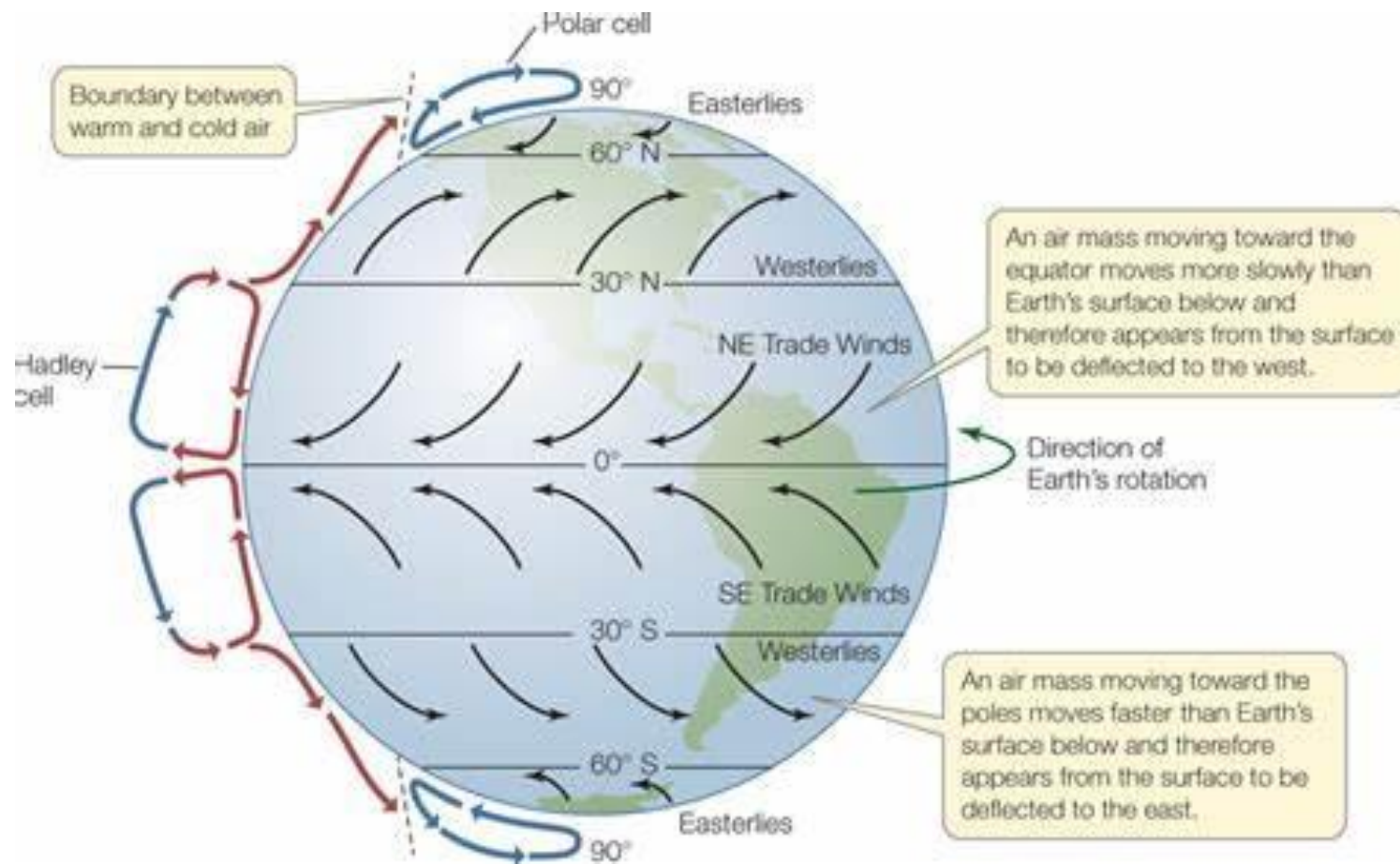
- The *orientation* or *direction* of a *pressure gradient* is always described as being from *higher toward lower pressure*.
- The *speed of the wind* is controlled by the strength of the *pressure gradient*, the *stronger* the *pressure gradient* the *higher* the *wind speed*.
- The *strength* of the pressure gradient can be discerned/distinguished from the *spacing of isobars* on a weather map

$$\text{Pressure gradient} = \frac{\text{difference in pressure}}{\text{distance}}$$

- If place A has a pressure of 15 Mb while Place B has a pressure of 25 Mb. On the other hand, Place C and Place D have pressures of 32 and 41 Mb respectively.
- If the distance between places A&B is 2 kilometers while the distance between Places C &D is 3 kilometers.
- In which of the two areas (in between A&B or C&D) does higher speed wind will be available?

2. Coriolis Force

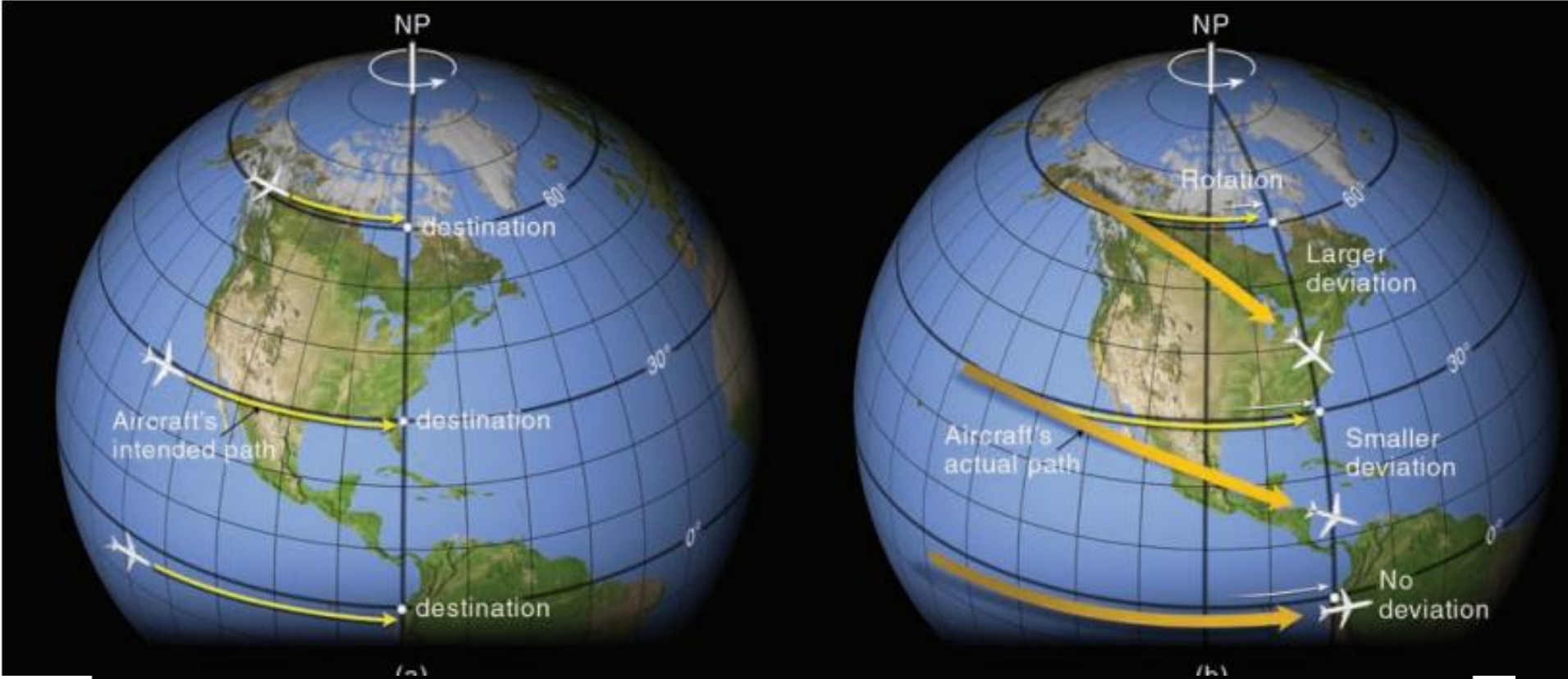
- The **Coriolis force** describes an apparent force that is **due to the rotation of the Earth**.
- All free-moving objects, such as *ocean currents, aircraft, artillery projectiles*, and even *air molecules* seem to *deflect from a straight-line path* because *Earth rotates under them*.
- The Coriolis force appears to deflect the wind to the right of its intended path in the ***Northern Hemisphere*** and to the left of its intended path in the ***Southern Hemisphere***.



The magnitude of the Coriolis force varies with the speed of the moving object and the latitude.

In each case, as the wind speed increases, the Coriolis force increases; hence, the stronger the wind speed, the greater the deflection.

Moreover, the Coriolis force increases for all wind speeds from a value of zero at the equator to a maximum at the poles.



● **FIGURE 8.23** Except at the equator, a free-moving object heading either east or west (or any other direction) will appear from Earth to deviate from its path as Earth rotates beneath it. The deviation (**Coriolis force**) is greatest at the poles and decreases to zero at the equator. Notice that the aircraft's deviation from its intended destination is greatest at high latitudes and nonexistent at the equator.

Activ.

- Imagine in Fig. 8.23 that there are three aircraft, each at a different latitude and each flying along a straight-line path, with no external forces acting on them. The destination of each aircraft is due east and is marked on the diagram (see Fig. 8.23a).
- Each plane travels in a straight path relative to an observer positioned at a fixed spot in space.
- Earth rotates beneath the moving planes, causing the destination points at latitudes 30deg and 60deg to change direction slightly when seen by an observer in space (see Fig. 8.23b). To an observer standing on Earth, however, it is the plane that appears to deviate. The amount of deviation is greatest toward the pole and non-existent at the equator. Therefore, the Coriolis force has a far greater effect on the plane at high latitudes (large deviation) than on the plane at low latitudes (small deviation). On the equator, it has no effect at all. The same, of course, is true of its effect on winds.

- The amount of deflection depends upon:
 1. the rotation of Earth
 2. the latitude
 3. the object's speed*

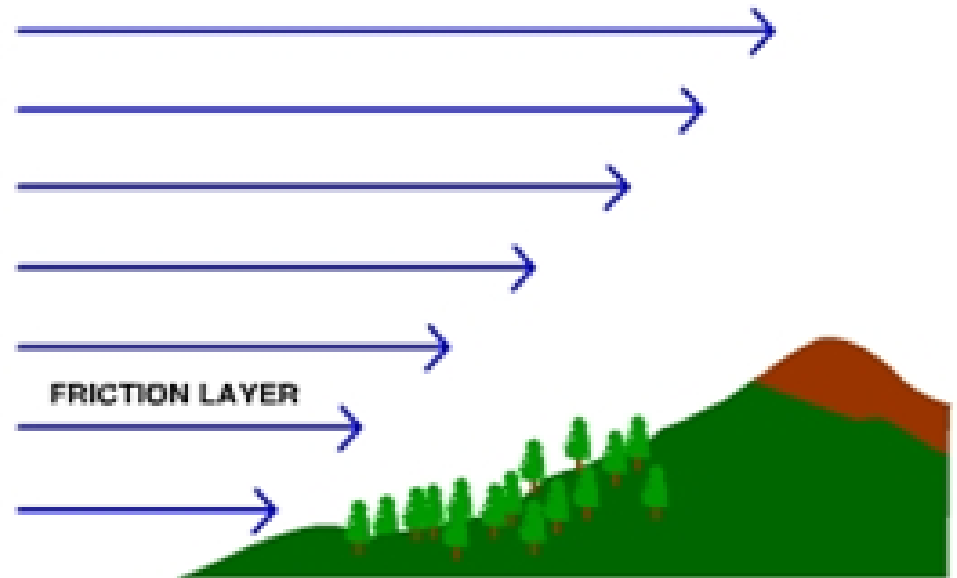
These three factors are grouped together and shown in the expression

- ***Coriolis force*** = $2mV\Omega \sin\phi$, where m is the object's mass, Ω is Earth's angular rate of spin (a ***constant***), V is the speed of the object, and ϕ is the latitude.
- In addition, the Coriolis force acts at right angles to the wind, only ***influencing wind direction*** and never wind speed.

3. Friction

- Generally speaking *wind speed increases* with height above the surface as the *frictional force of surface diminishes with height*.
- The *friction imposed on air mechanically slows* the *wind* and *diverts* its *direction*.
- The *Friction Layer* is the layer of air that is influenced by friction caused by the surface.
- The friction layer varies in height across the Earth, but for the most part, lays within about a **kilometer** of the surface.

- Friction slows winds within about **1 km** of the Earth's surface by breaking into turbulent eddies.
- The *atmospheric zone subjected to friction* is named as *atmospheric boundary layer*.



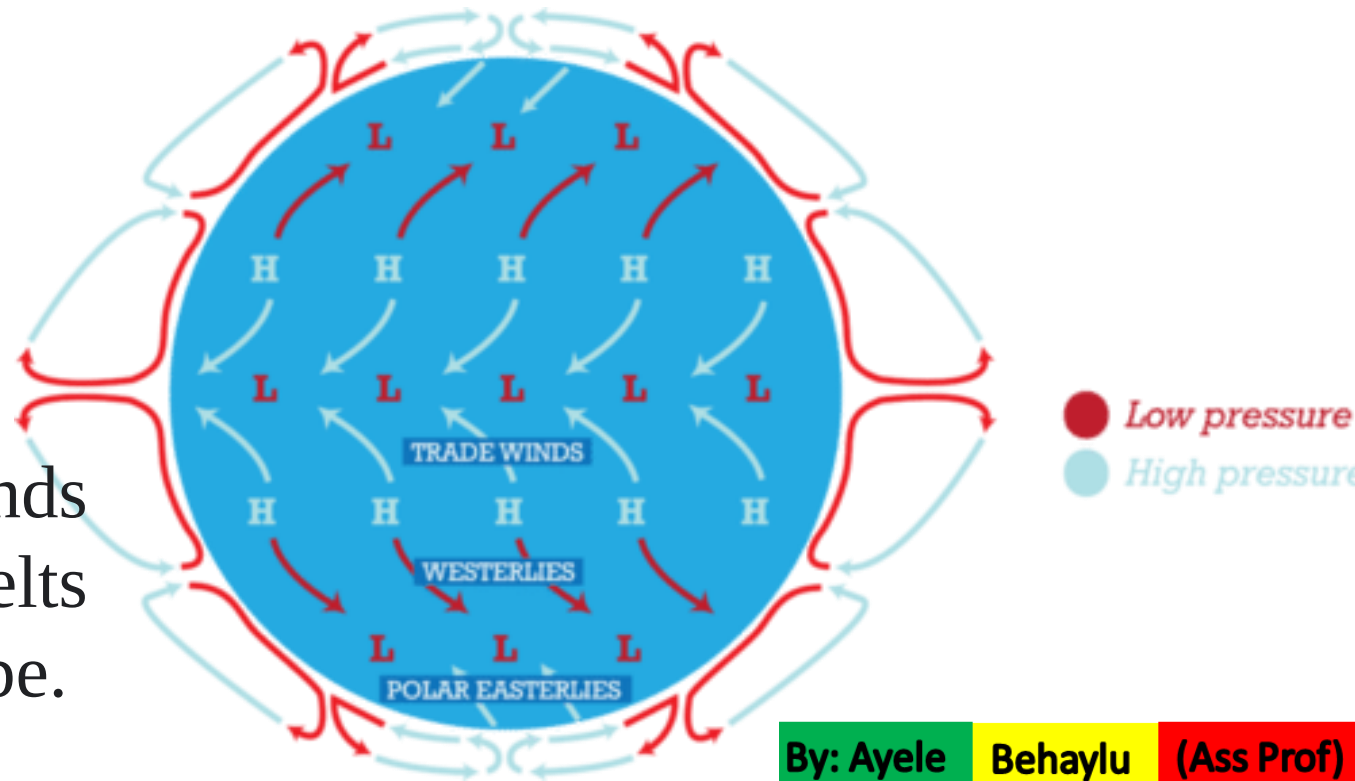
4. Gravity

- Gravity is the force that holds an object (e.g. air parcel) on the Earth's surface.
- It accelerates a unit mass of any object at a rate 9.8 m/sec each second as the combination of gravitational and much weaker centripetal force.
- The *gravity force always acts **downward** and **perpendicular** to the **Earth's surface**.*
 - Therefore, it does not modify horizontal winds.

4.3.3. Types of winds: global/planetary, regional, and local

Global/planetary winds

- Global winds are winds that occur in belts that go all around the planet.
- Like local winds, global winds are caused by **unequal heating** of the atmosphere.



- Global winds occur in belts around the globe.

1. Trade Winds



<https://youtu.be/NQ3Tj-tdQIk>

- The *trade winds* are just air movements toward the *equator*.
- They are *warm, steady breezes* that *blow* almost *continuously*.
- The Coriolis Effect makes the trade winds appear to be curving to the west, whether they are traveling to the equator from the south or north.
- The *doldrums* is an area of *calm weather*.
- The trade winds coming from the south and the north *meet near the equator*.
- These converging trade winds produce general upward winds as they are heated, so there are *no steady surface winds*.

2. Prevailing Westerlies

- Between 30 and 60 degrees latitude, the winds that move toward the poles appear to ***curve to the east.***
- Because winds are named from the direction in which they originate, these winds are called ***prevailing westerlies.***

3.Polar Easterlies

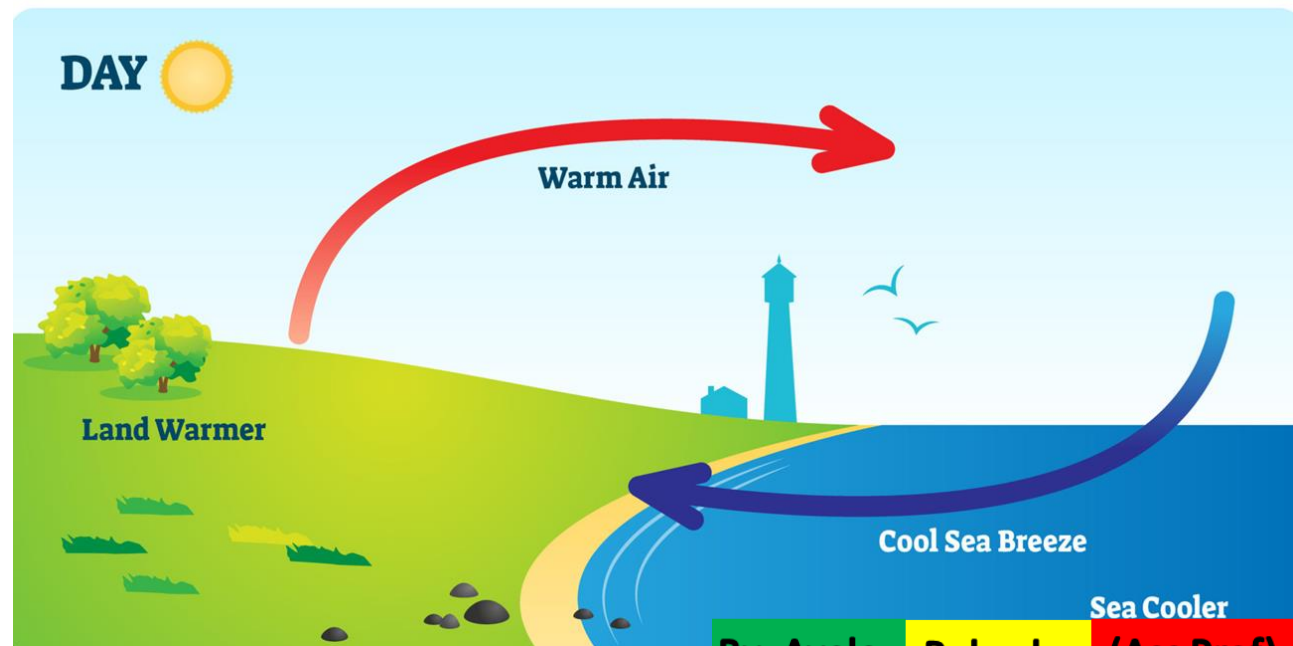
- At about ***60 degrees*** latitude in both hemispheres, the prevailing westerlies join with the polar easterlies to reduce upward motion.
- The ***polar easterlies*** form when the atmosphere over the poles cools. This ***cool air then sinks and spreads over the surface.***
- As the air flows away from the poles, it is turned to the west by the Coriolis effect.
- Again, because these winds begin in the east, they are called ***easterlies.***

Local Winds

Land and Sea Breezes

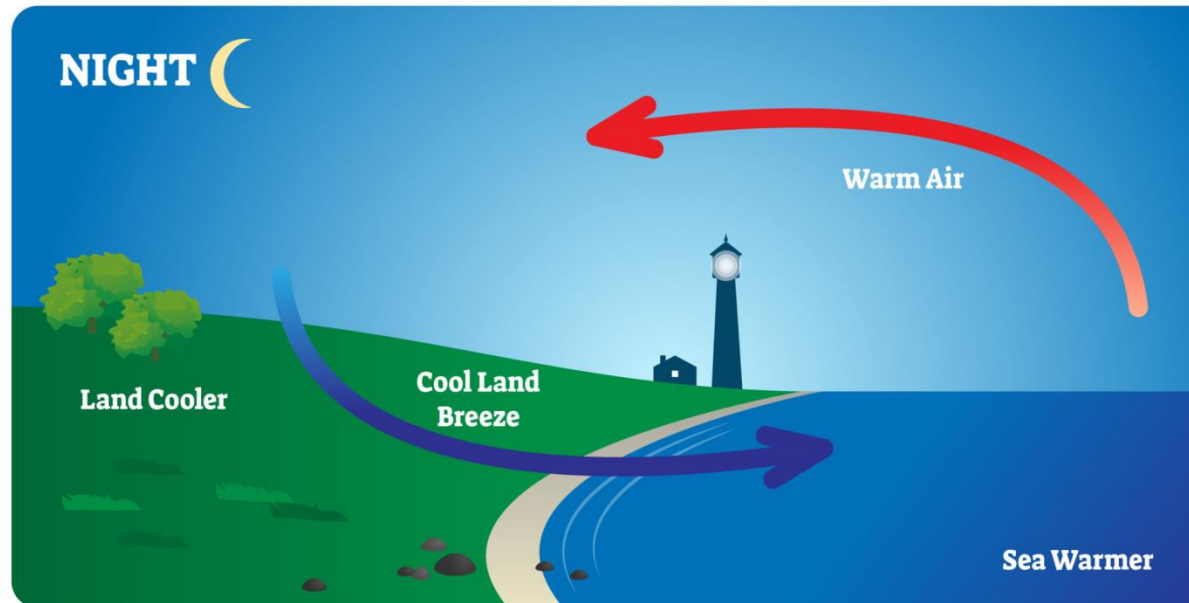
- There is a diurnal (daily) contrast in the heating of local water and land areas similar to the seasonal variation of the monsoon.
- During the day, the *land is warmer than the water area*; at night, the land area is cooler than the water area.

- A slight variation in pressure is caused by this temperature contrast.



- During the **day**, the wind blows from **water areas to land areas** and is called a **sea breeze**.
- This temperature difference creates an area of slightly lower surface pressures over land compared to the now cooler waters.
- The result is a **wind flow** from **water to land**.
- The sea breeze usually begins during midmorning (09:00-11:00) when the land areas become warmer than adjacent ocean waters.

- At **night** the wind blows from **land to sea** and is called a **land breeze**.



- By mid afternoon (maximum heating) the sea breeze will reach its maximum speed and may be strong enough to be influenced by the Coriolis force, which causes it to flow at an angle to the shore.
- The sea breeze is most pronounced in late spring, summer, and early fall when maximum temperature differences occur between land and water surfaces.
- A decrease in temperature and an increase in humidity and wind speed mark the start of a sea breeze.

- The sea breeze continues until the land area cools sufficiently to dissipate the weak low pressure. After sunset, the land cools at a faster rate than the adjacent waters and eventually produces a complete reversal of the winds. As the land continues to cool through the evening hours, a weak area of high pressure forms over the land.
- The water area, with its warmer temperatures, has slightly lower pressure and again a flow is established; however, the flow is now from land to water (offshore).

The Mountain and Valley Breezes

- Another combination of local winds that undergoes a daily reversal consists of the mountain and valley breezes.
- On a *warm sunny* day the *mountain slopes* are heated **more** than the *valley floor*.
- Hence, the pressure is low over the slopes while it is comparatively high in the valleys below.
- As a result gentle wind begins to blow from valley towards the slopes and is a *valley breeze*.

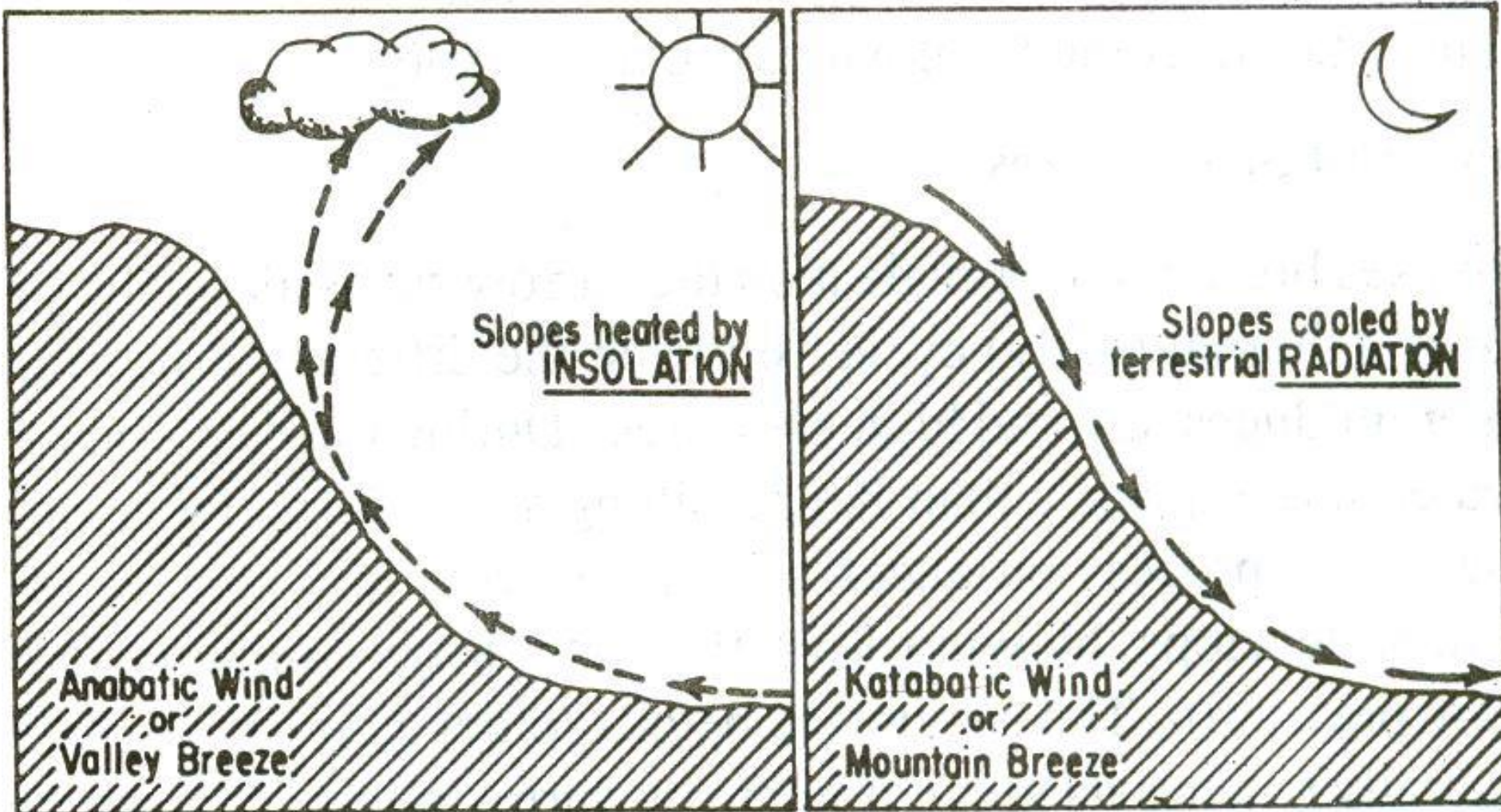


- *After sunset*, the *rapid radiation* takes place on the *mountain slopes*.
- Here, *high pressure* develops more rapidly than on the valley floor.
- *Cold arid heavy air of mountain slopes* starts *moving down* towards the valley floor.



- This is known as the *mountain breeze*.

- ❑ The *valley* and *mountain* breezes are also named *anabatic* and *katabatic* breezes respectively.



Hot Winds

- Loo, Foehn and Chinook are important hot winds of local category.

(A) Loo

- Loo are hot and dry winds, which blow very strongly over the northern plains of India and Pakistan in the months of May and June. Their direction is from west to east and they are usually experienced in the afternoons. Their temperature varies between 45°C to 50°C .

(B) Foehn

- Foehn is strong, dusty, dry and warm local wind which develops on the leeward side of the Alps mountain ranges. Regional pressure gradient forces the air to ascend and cross the barrier. Ascending air sometimes causes precipitation on the windward side of the mountains. After crossing the mountain crest, the Foehn winds starts descending on the leeward side or northern slopes of the mountain as warm and dry wind. The temperature of the winds vary from 15°C to 20°C which help in melting snow. Thus making pasture land ready for animal grazing and help the grapes to ripe early.

(C) Chinook

- Chinook is the name of hot and dry local wind which moves down the eastern slopes of the Rockies in U.S.A. and Canada. The literal meaning of chinook is 'snow eater' as they help in melting the snow earlier. They keep the grasslands clear of snow. Hence they are very helpful to ranchers.

Cold Winds

- The local cold winds originate in the *snow-capped mountains* during winter and move down the *slopes towards the valleys*. They are known by different names in different areas.

(A) Mistral

- Mistrals are most common local cold winds. They originate on the Alps and move over France towards the Mediterranean Sea through the Rhone valley. They are very cold, dry and high velocity winds. They bring down temperature below freezing point in areas of their influence. People in these areas protect their orchards and gardens by growing thick hedges and build their houses facing the Mediterranean Sea.

Regional (Seasonal Wind)

1. Monsoon Winds

- The term *monsoon* is of Arabic origin and means *season*.
- The monsoon wind is a *seasonal wind* that blows from *continental interiors* (or *large land areas*) to the *ocean in the winter*; they blow in the opposite direction during the *summer*.
- The *monsoon wind* is most pronounced over India, although there are other regions with noticeable monsoon winds.
- Monsoon winds are a result of *unequal heating* and *cooling* of *land* and *water* surfaces.

- During winter a massive area of cold high pressure develops over the extensive Asiatic continent.
- This high pressure is due primarily to cold arctic air and long-term radiation cooling. To the south, the warm equatorial waters exist and, in contrast, the area has relatively lower surface pressures.
- The combination of high pressure over Asia and low pressure over the Equatorial Belt sets up a pressure gradient directed from north to south.
- Because of the flow around the massive Siberian high, northeast winds begin to dominate the regions from India to the Philippines.

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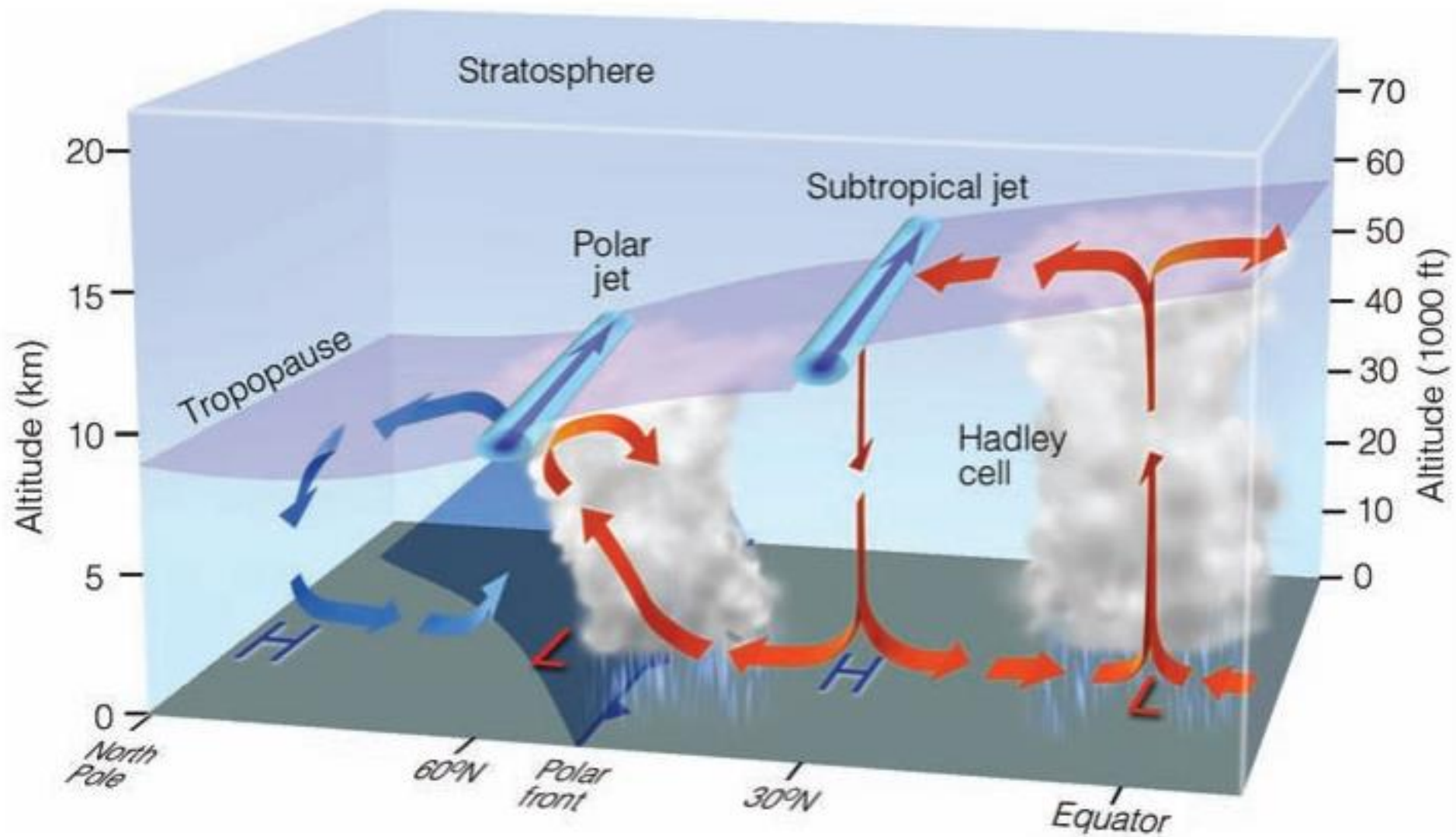
4.3.4. Upper air circulation – jet stream (concept, origin, and effects)

Jet Streams

- Atmospheric **jet streams** are *swiftly flowing* air currents thousands of *kilometers* long, a few hundred kilometers wide, and only a few kilometers thick.
- Wind speeds in the central core of a jet stream often exceed 100 knots and occasionally exceed 200 knots.
- Jet streams are usually found at the tropopause at elevations between 10 and 15 km, although they may occur at both higher and lower altitudes.
- **Jet streams** were first encountered by high-flying military aircraft during World War II, but their existence was suspected before 1940.
- Ground-based observations of fast-moving *cirrus clouds* had revealed that westerly winds aloft must be moving rapidly.

- **Jet streams** are strong, upper tropospheric flows that are quasi-horizontal in nature.
- They originate due to differential heating of the earth's surface and form at the boundaries of adjacent air masses with significant temperature differences.
- The factors that influence the flow of the jet stream are the landmasses and the Coriolis effect.

- Figure below illustrates the average position of two jet streams, the tropopause, and the general circulation of air for the Northern Hemisphere in winter.
- Both jet streams are located at tropopause gaps, where mixing between tropospheric and stratospheric air takes place.
- The jet stream situated near 30deg latitude at about 13 km above the subtropical high is the subtropical jet stream.
- To the north, the jet stream situated at a lower altitude of about 10 km, near the polar front, is known as the **polar front jet stream** or, simply, the polar jet stream. Since both are found at the tropopause, they are referred to as tropopause jets.



4.3.5. Wind measurement

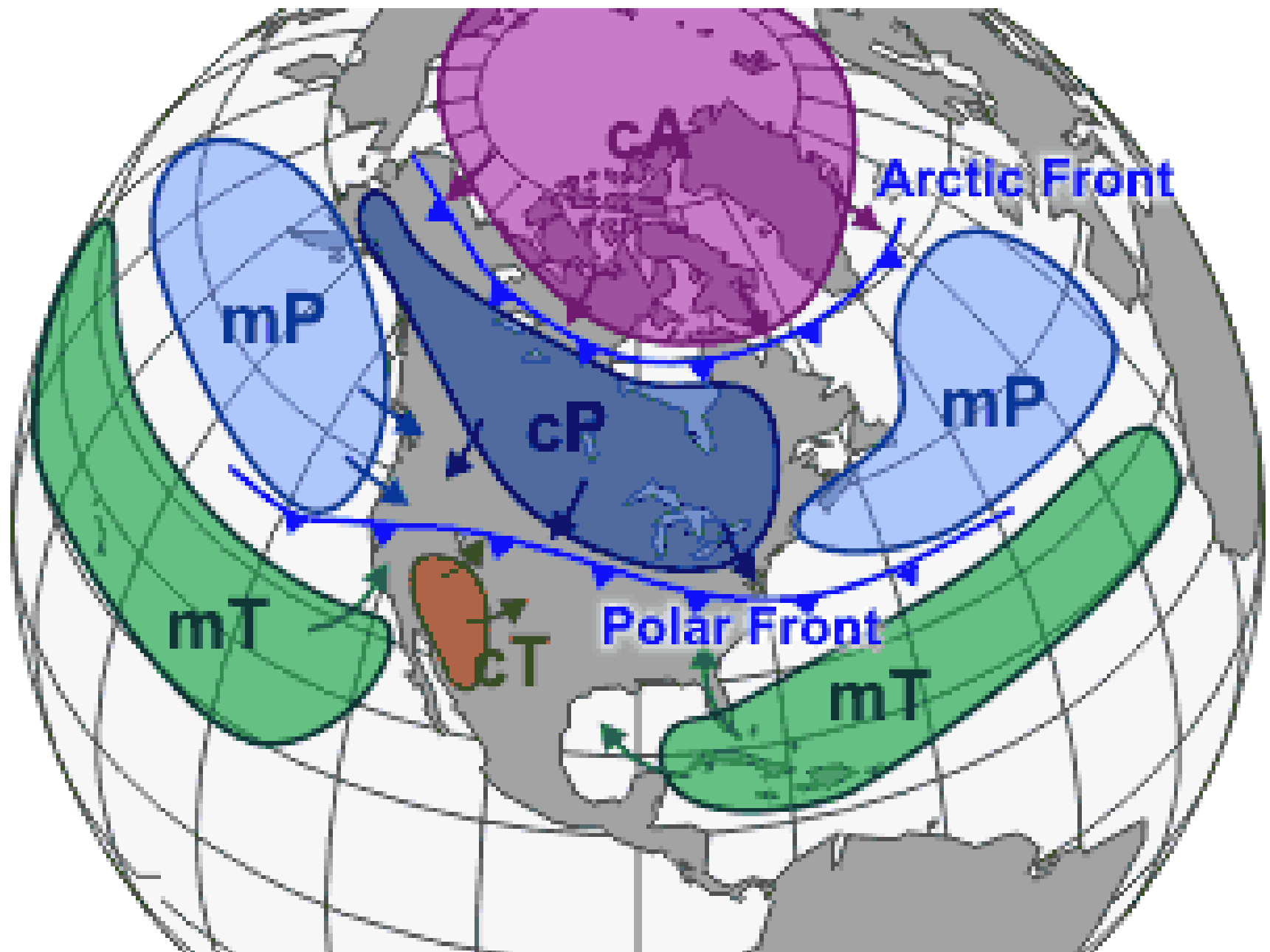
Students please have a look on what we discussed in chapter one under the subtopic: “measurements of weather and climate elements”

4.4. Climate and Weather Phenomena

4.4.1. Air Mass and fronts: Typology, origin, characteristics

Air Masses

- An air mass is a *large body of air that has relatively uniform temperature* and *humidity* characteristics.
- The regions where **air masses** form are referred to as *air mass source regions*.
- If air remains over a source region long enough, it will *acquire the properties of the surface below*.
- *Ideal source regions* are regions that are generally flat and of uniform composition.
- Examples include central Canada, Siberia, the northern and southern oceans, and large deserts.



Air Mass Classification

- Air masses are classified according to their *temperature* and *moisture* characteristics.
- They are grouped into four categories based on their *source region*.
- Air masses that originate in the **cold, polar regions** are designated with a capital "**P**" for polar.
- Air masses that originate in the **warm, tropical regions** are designated with a capital "**T**" for tropical.
- Air masses that originate over **land** will be **dry** and are designated with a lowercase "**c**" for *continental*.
- Air masses that originate over **water** will be **moist** and are designated with a *lowercase* "**m**" for maritime.
- These letters are combined to indicate the *type of air mass*:

cP: cold, dry air mass

mP: cold, moist air mass

cT: warm, dry air mass

mT: warm, moist air mass

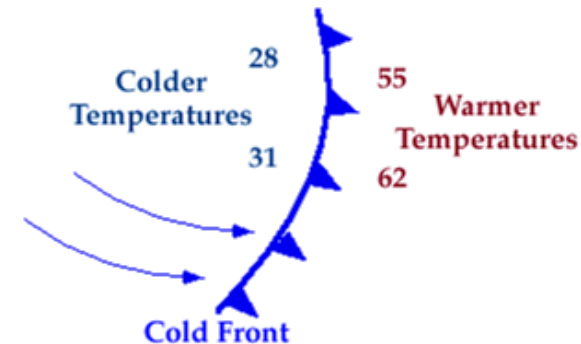
- In winter, one more type of air mass may form, an extremely **cold, dry air mass** referred to as **cA**, *continental arctic*.
- Once formed, air masses can move out of their source regions bringing cold, warm, wet, or dry conditions to other parts of the world.

Fronts

- A front is simply the **boundary** between *two air masses*.
- Fronts are classified by: which type of air mass (cold or warm) is *replacing the other*.

Cold Fronts

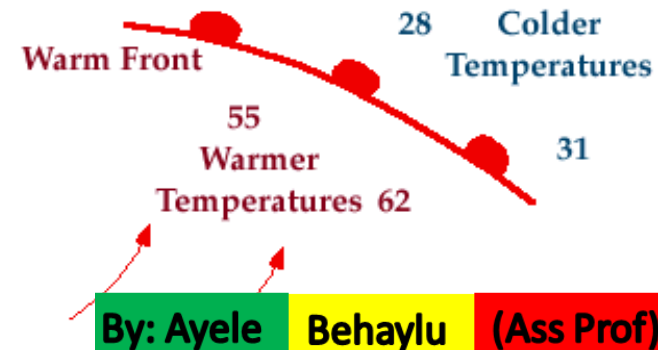
- A *front* is called a **cold front** if the **cold air mass** is **replacing** the **warm air mass**.
- The air behind a cold front is colder and typically drier than the air ahead of it, which is generally warm and moist.
- There is typically a shift in wind direction as the front passes; along with a change in pressure tendency (pressure falls prior to the front arriving and rises after it passes).
- **Cold fronts** have a **steep slope**, which causes air to be forced upward along its leading edge.
- This is why there is sometimes a **band of showers** and/or **thunderstorms** that line up along the leading edge of the cold front.
- **Cold fronts** are represented on a weather map by a **solid blue line** with **triangles** pointing in the direction of its movement.



Warm Fronts

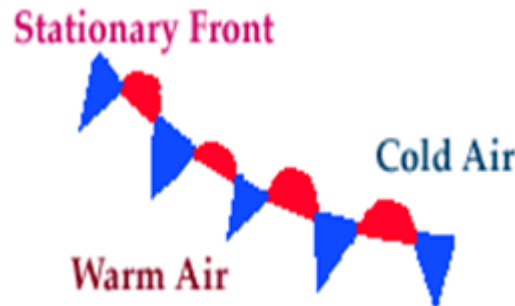
➡ <https://youtu.be/uLvU9O17lw0>

- A **warm front** occurs when a **cold air mass** is receding (i.e. a **warm air mass** is replacing a cold air mass).
- The air behind a warm front is warm and moist, while the air ahead of a warm front is cooler and less moist.
- Similar to the cold front, there will a *shift in wind direction* as the front passes and a change in pressure tendency.
- **Warm fronts** have a **gentler slope** than cold fronts, which often leads to a gradual rise of air.
- This gradual rise of air favors the development of widespread, continuous precipitation, which often occurs along and ahead of the front.
- Warm fronts are represented on a weather map by a **solid red line** with **semi-circles** pointing in the direction of its movement.



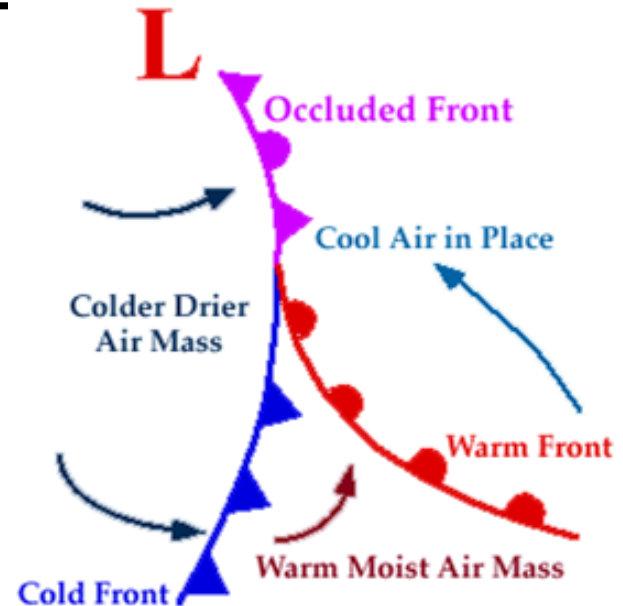
Stationary Fronts

- A stationary front is a front that is *not moving*.
- Although the *frontal boundary does not move*, the air masses may move parallel to the boundary.
- Stationary fronts can also produce significant weather and are often tied to flooding events.
- Stationary fronts are represented on a weather map by alternating **red** and **blue** lines, with blue *triangles* and *red semi-circles* facing opposite directions.



Occluded Fronts

- Generally, *cold fronts* move *faster* than *warm fronts*.
- Sometimes in a storm system the cold front will "catch up" to the warm front.
- An occluded front forms as the cold air behind the cold front meets the cold air ahead of the warm front. Whichever air mass is the coldest undercuts the other.
- The boundary between the two cold air masses is called an *occluded front*.
- Occluded fronts are represented on weather maps by a *solid purple line* with alternating *triangles* and *semi-circles*, pointing in the direction of its movement.



4.4.2. Cyclones and Anti-cyclones

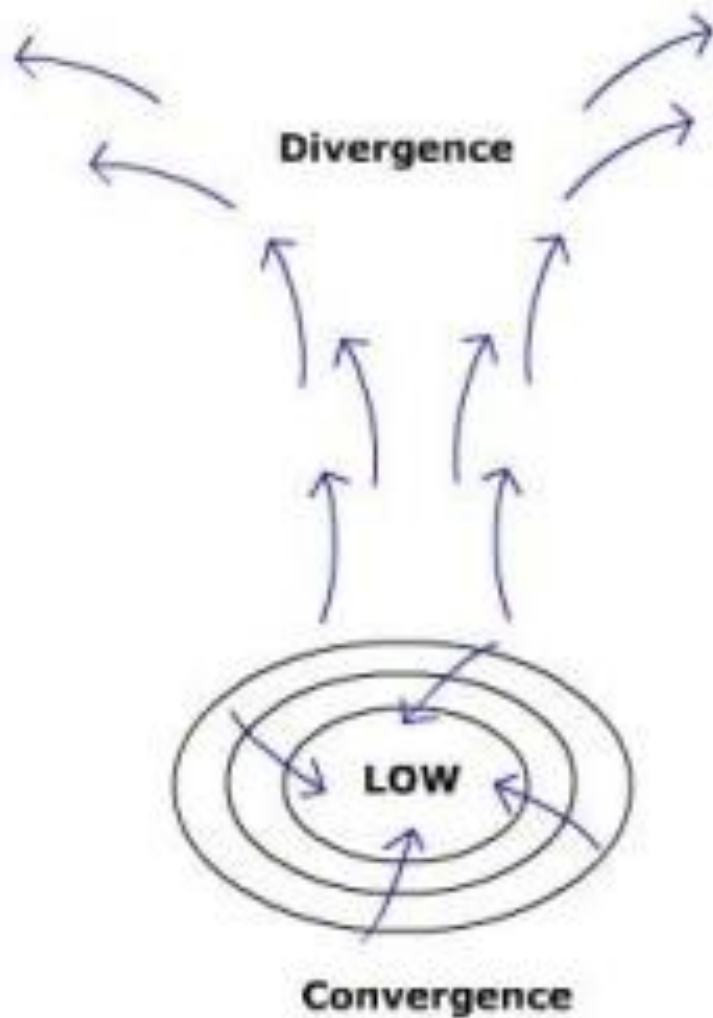
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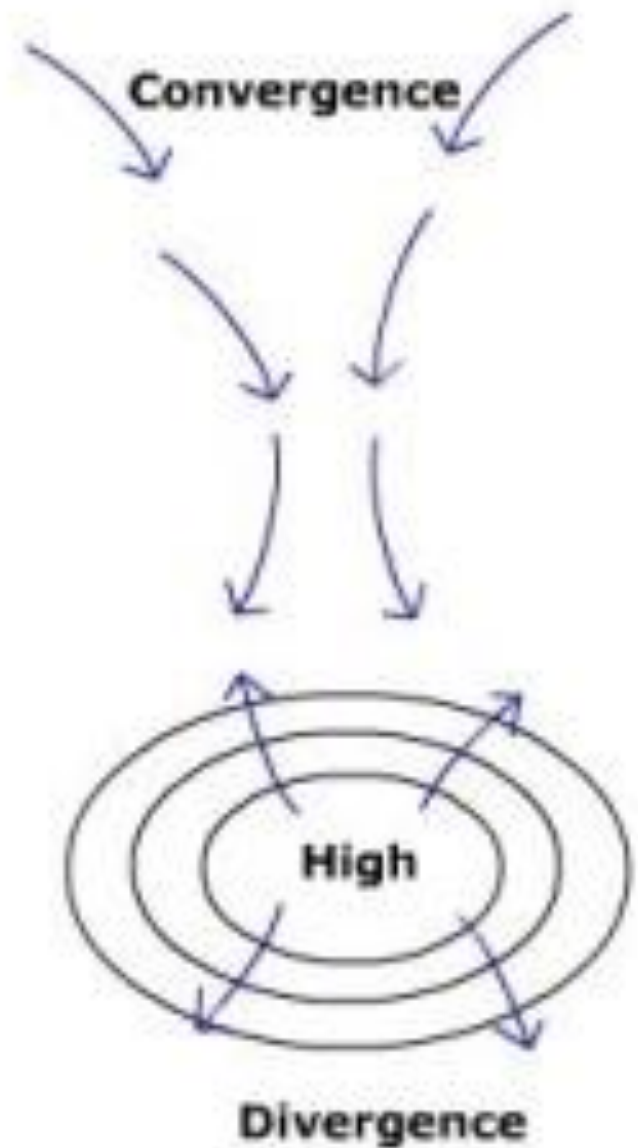
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- **Cyclones** are areas of low pressure.
- Cyclones usually exhibit nearly circular isobars.
- If isobars are oblong or elongated with the lowest pressure near the center we call them ***TROUGHS***.
- As air enters an area of low pressure from all directions, the Coriolis effect bends the direction of the wind to the right of its path.
- This creates a counterclockwise rotation around the low and **convergence** near the center of the system.
- As the air collides near the center it is forced aloft where **DIVERGENCE** takes air away from the center of the system.
- The upper-level divergence is necessary for the system to be maintained as an area of low pressure.
- Without the divergence, the system would fill with air and the horizontal pressure differences would be equalized causing the system to dissipate.

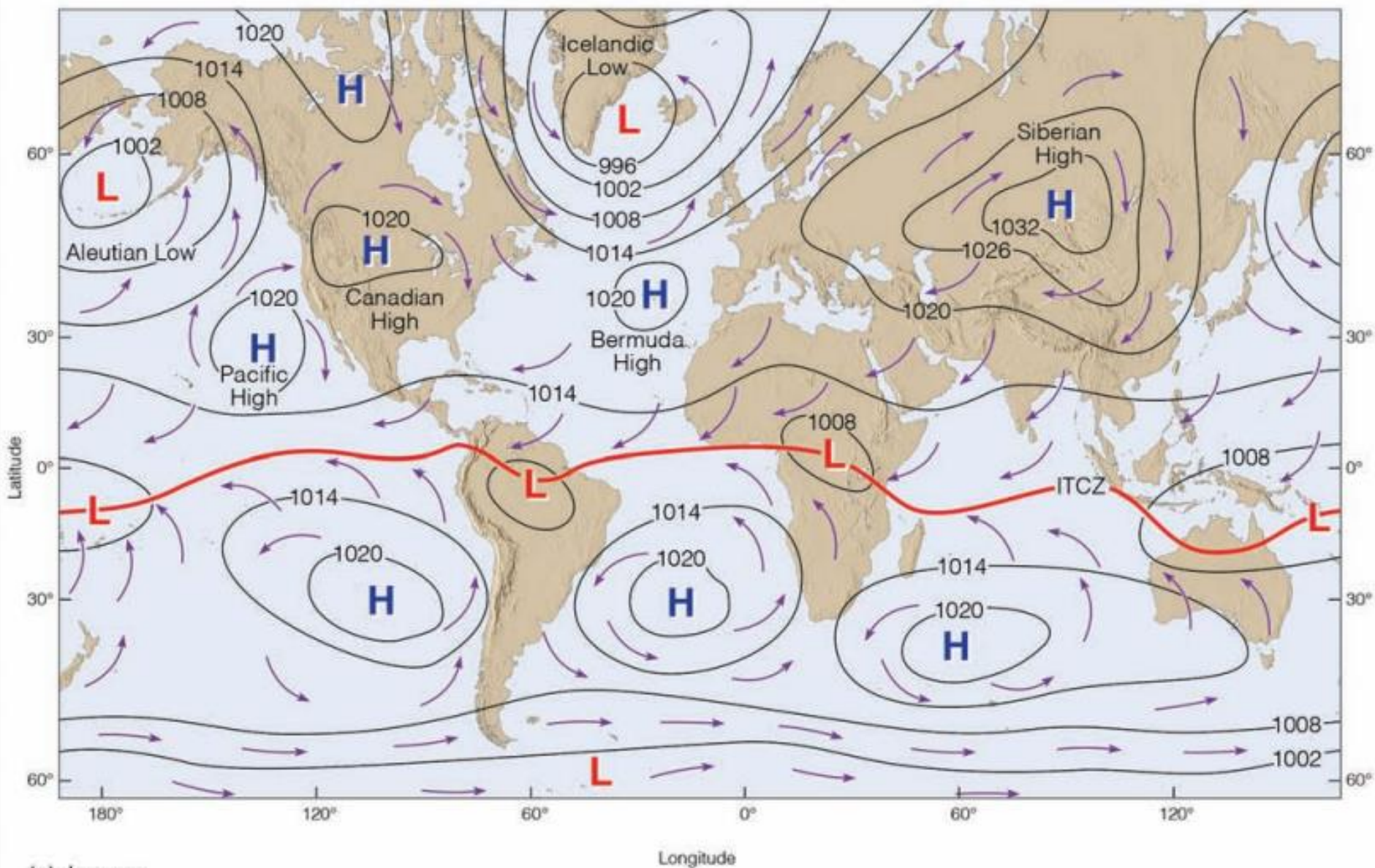
- **Anticyclones** are areas of **high pressure** that exhibit nearly circular isobars.
- If isobars are oblong or elongate with the highest pressure near the center we call them ***RIDGES***.
- For high pressure areas, air descends toward the surface due to convergence aloft.
- As the ***air nears the surface*** it is forced outward (divergence) from the center.
- The Coriolis effect bends the air to the right of its path creating a clockwise rotation around the high.



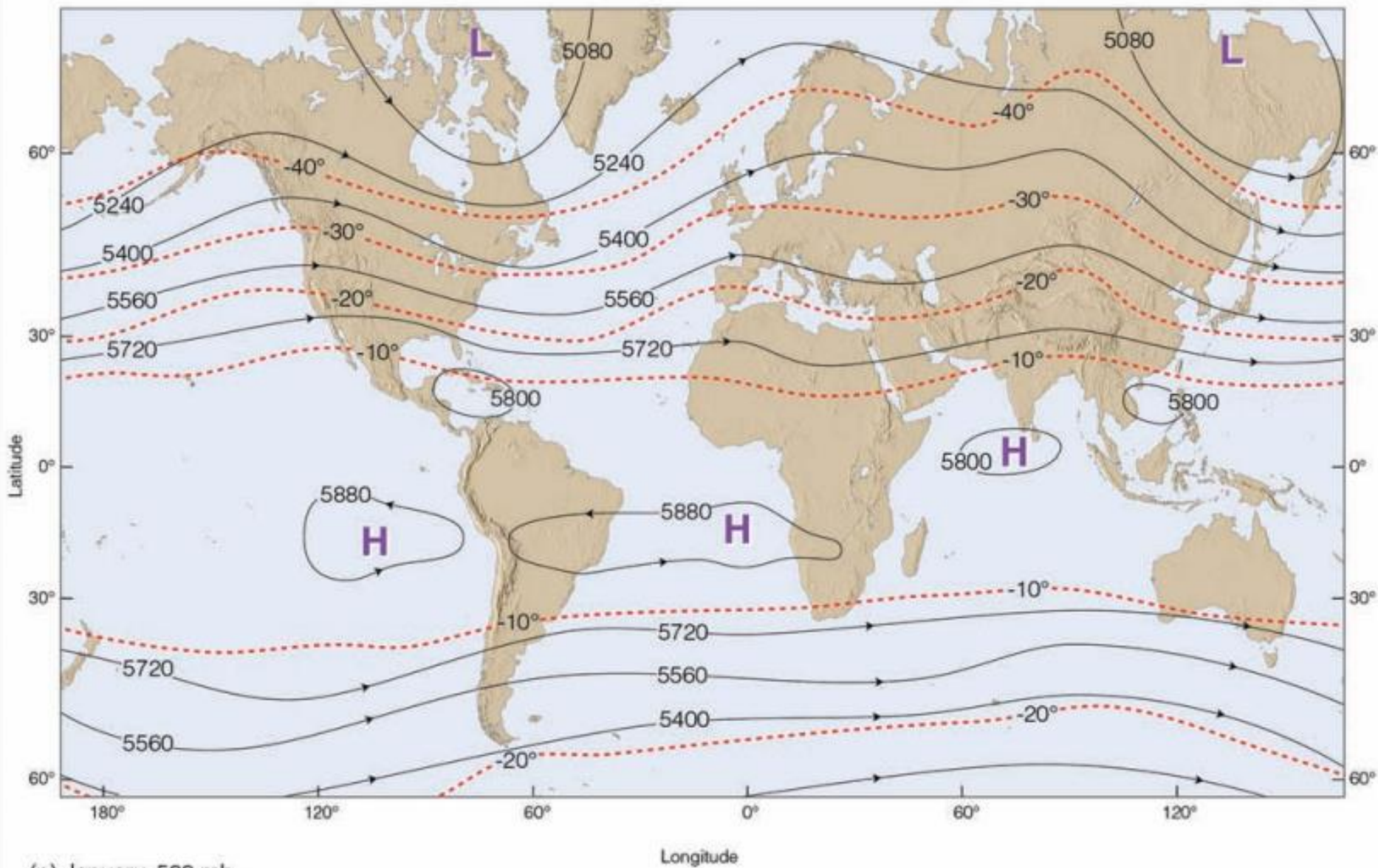
Circulation within a low pressure system in the Northern Hemisphere



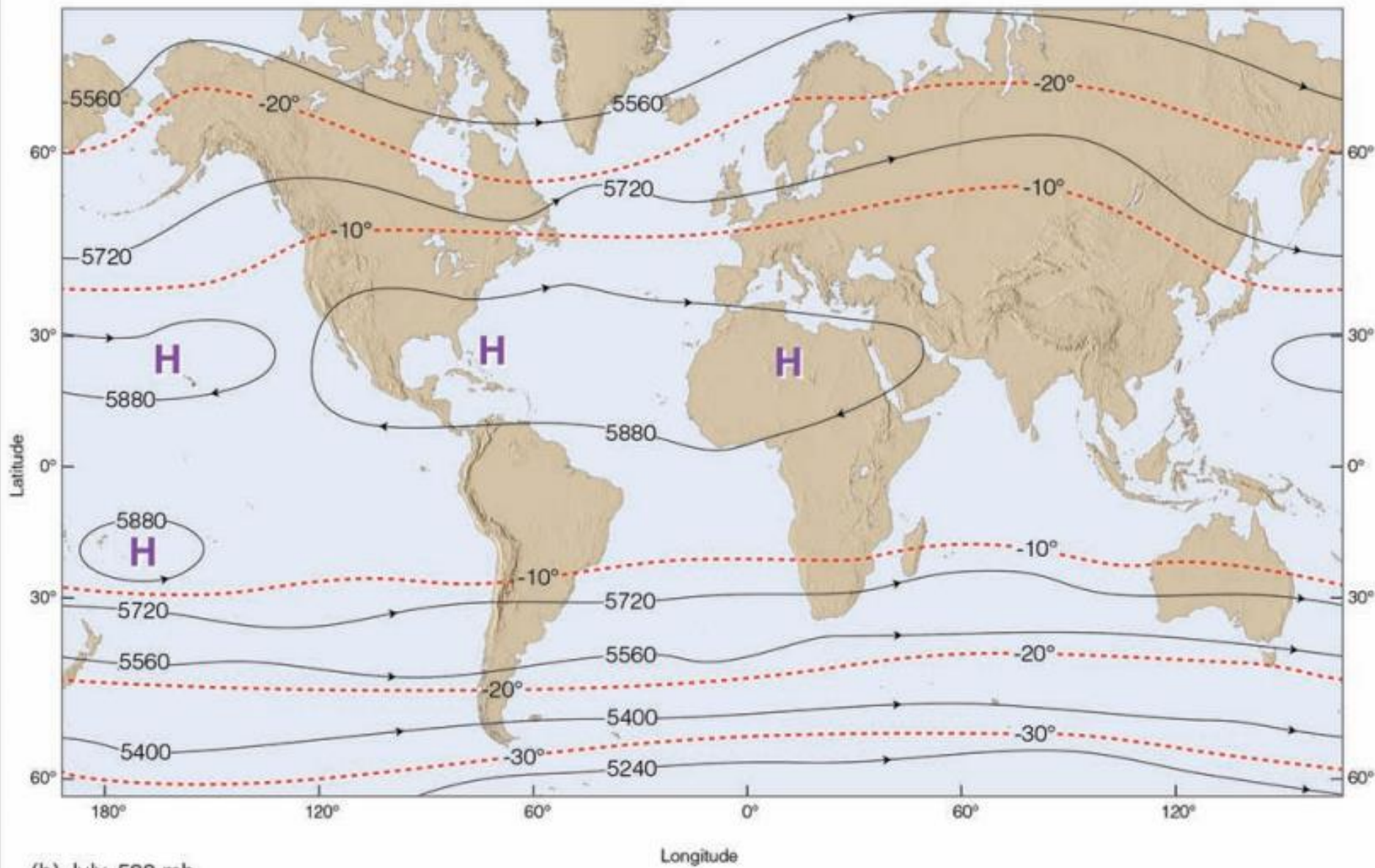
Circulation within a high pressure system in the Northern Hemisphere



(a) January



(a) January, 500 mb



4.4.3. Hurricanes, Thunderstorms and Tornadoes

Hurricanes



<https://youtu.be/hQRbL3MBTXA>

A **hurricane** is an *intense storm of tropical origin*, with sustained winds of at least 64 knots (74 mi/hr) and with considerably higher gusts, that forms over the warm northern Atlantic and eastern North Pacific Oceans.

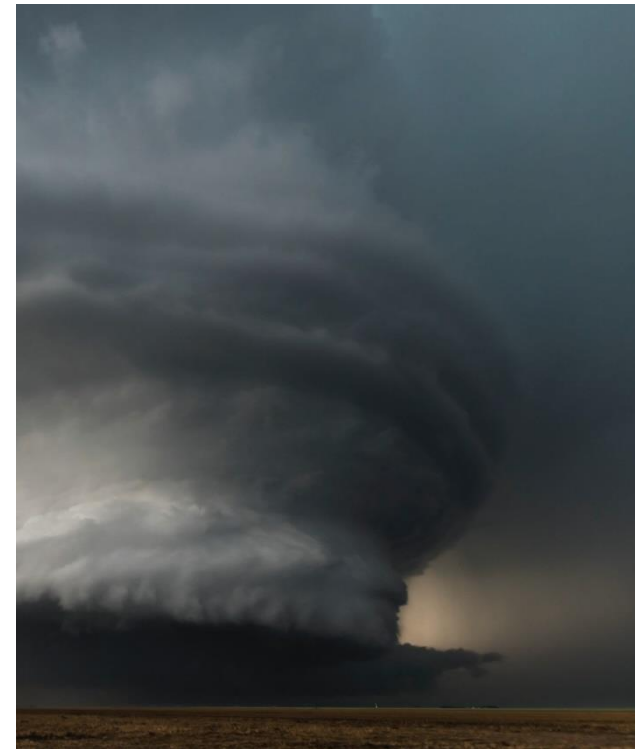
- **Hurricanes** are composed of *intense convective clouds* (thunderstorms) that sometimes grow to over 15 km (50,000 ft) in height.
- This same type of storm is given different names in different regions of the world.
- In the *western North Pacific*, it is called a *typhoon*, in *India* a *cyclone*, and in *Australia* a *tropical cyclone*.
- By international agreement, *tropical cyclone* is the general term for all hurricane-type storms that originate over tropical waters.
- For simplicity, we will refer to all of these storms as **hurricanes**



Thunderstorms

A thunderstorm, also known as an electrical storm or a lightning storm, is a storm characterized by the presence of lightning and its acoustic effect on the Earth's atmosphere, known as **thunder**.

- Thunderstorms are *convective storms* that form with *rising air*.
- So the birth of a thunderstorm typically involves **warm, moist air** rising in a conditionally unstable environment.
- The rising air may be a parcel of air ranging in size from a large balloon to a city block. Or an entire layer, or slab of air, may be lifted. As long as the rising air is warmer (less dense) than the air surrounding it, there is an upward-directed *buoyant force* acting on it. The warmer the parcel is compared to its surroundings, the greater the buoyant force and the stronger the convection.



Tornadoes

- A **tornado** is a *rapidly rotating column* of air, extending down from a *cumuliform cloud*, that blows around a small area of intense low pressure with a circulation that reaches the ground.
- A tornado's circulation is present on the ground either as a funnel-shaped cloud or as a swirling cloud of dust and debris.
- Sometimes called *twisters* or *cyclones*, tornadoes can assume a variety of shapes and forms that range from twisting ropelike funnels, to cylinder-shaped funnels, to massive black wedge-shaped funnels, to funnels that resemble an elephant's trunk hanging from a large cumulonimbus cloud.



4.4.4. El Niño-Southern Oscillation (ENSO) or El Niño and La Niña

- **El Niño** (Spanish for “the Child” in reference to baby Jesus) = warm surface current in the *equatorial eastern Pacific* that occurs periodically around *Christmastime*.
- The *sudden warming* of a vast area of the *equatorial Pacific ocean surface*.
- Typically starts off *Peru* and works up the coast to western *Mexico* and *California*.

- **La Niña** (female child) refers to the *periodic cooling of ocean surface temperatures* in the central and east-central equatorial Pacific.
- **La Niña** originally referred to an *annual cooling of ocean waters* off the *west coast of Peru and Ecuador*.
- Scientists call these phenomena the El Niño-Southern Oscillation (ENSO) cycle.
- **Southern Oscillation** = change in atmospheric pressure over the *Pacific Ocean* accompanying *El Niño*
- **ENSO** describes a combined oceanic-atmospheric disturbance

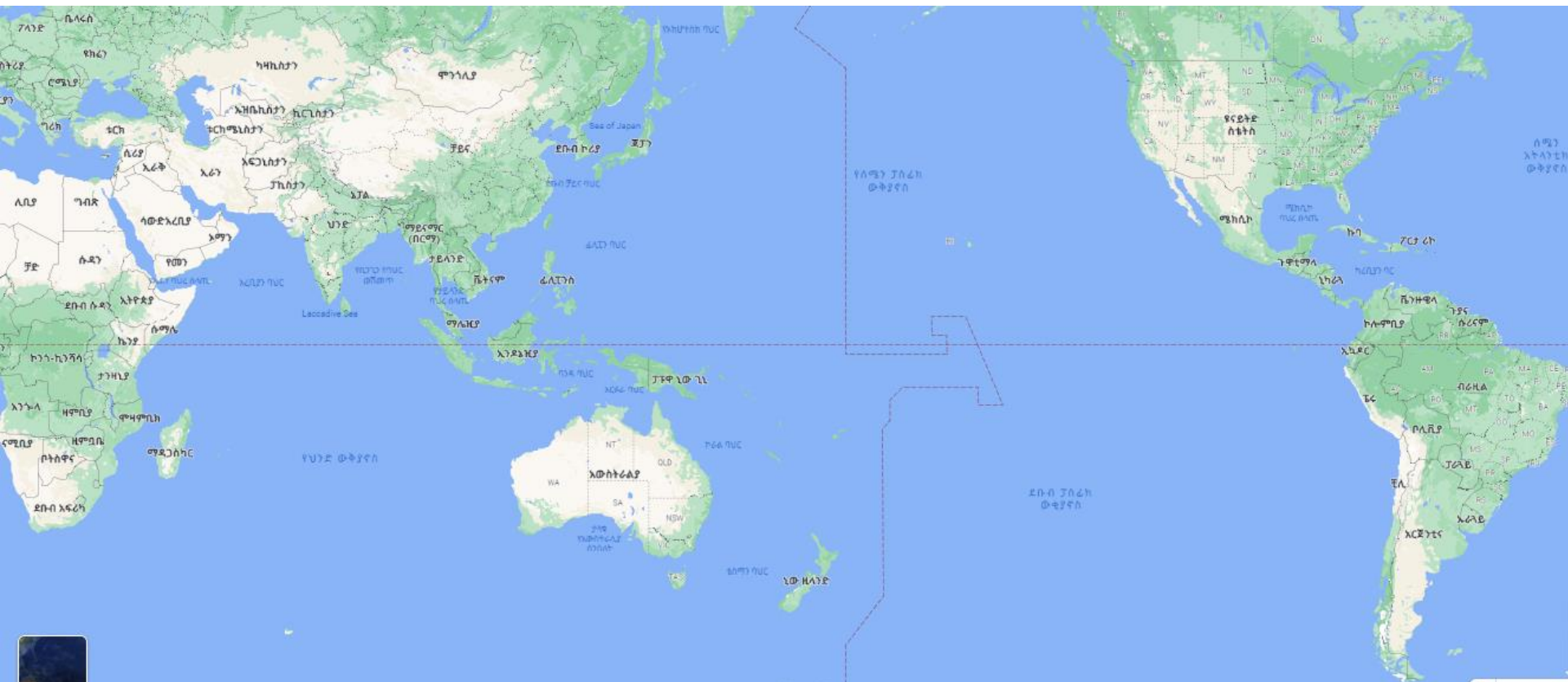
Why El Niño occurs?

- El Niño occurs due to changes in the normal patterns of *trade wind circulation*.
- Normally, these winds (TWs) move *westward*, carrying *warm surface water* to Indonesia and Australia and *allowing cooler water to upwell along the South American coast*.
- For *reasons not yet fully understood*, these trade winds can sometimes be *reduced*, or even *reversed*.

Why La-Niña Occurs?

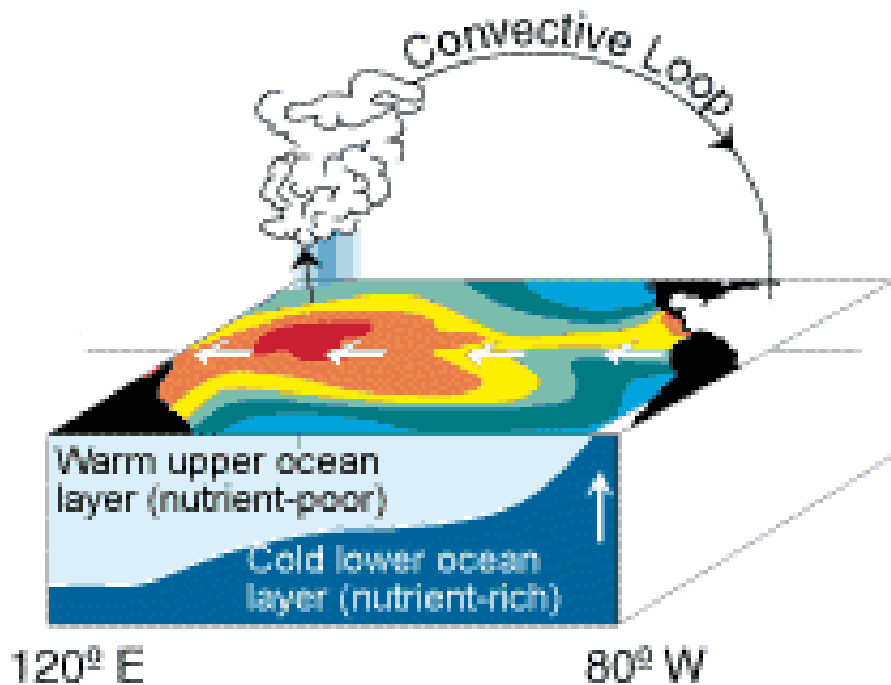
- *La Niña* is thought to occur **due to increases in the strength of the normal patterns of trade wind circulation.**
- Under normal conditions, these winds move westward, carrying warm surface water to Indonesia and Australia and allowing cooler water to up well along the South American coast.
- For reasons not yet fully understood, periodically these trade winds are strengthened, increasing the amount of cooler water toward the coast of South America and reducing water temperatures.

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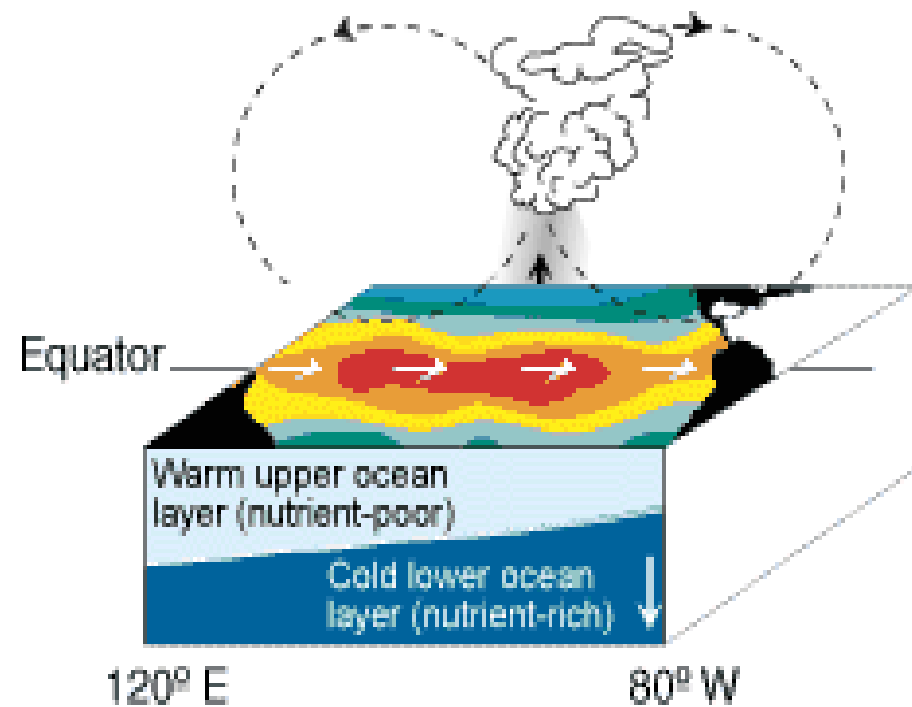


Comparison of Normal and El Niño Conditions

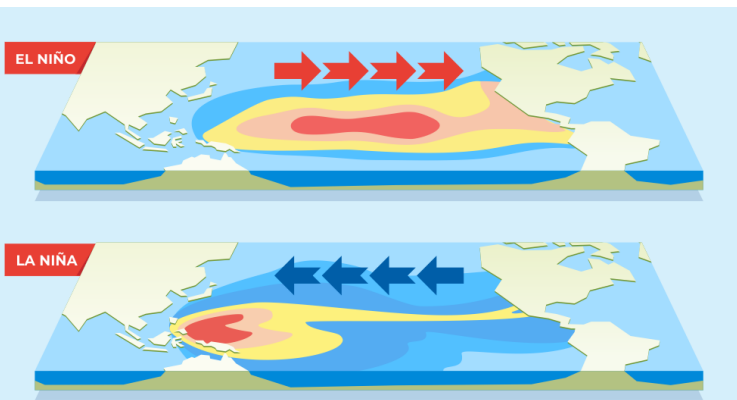
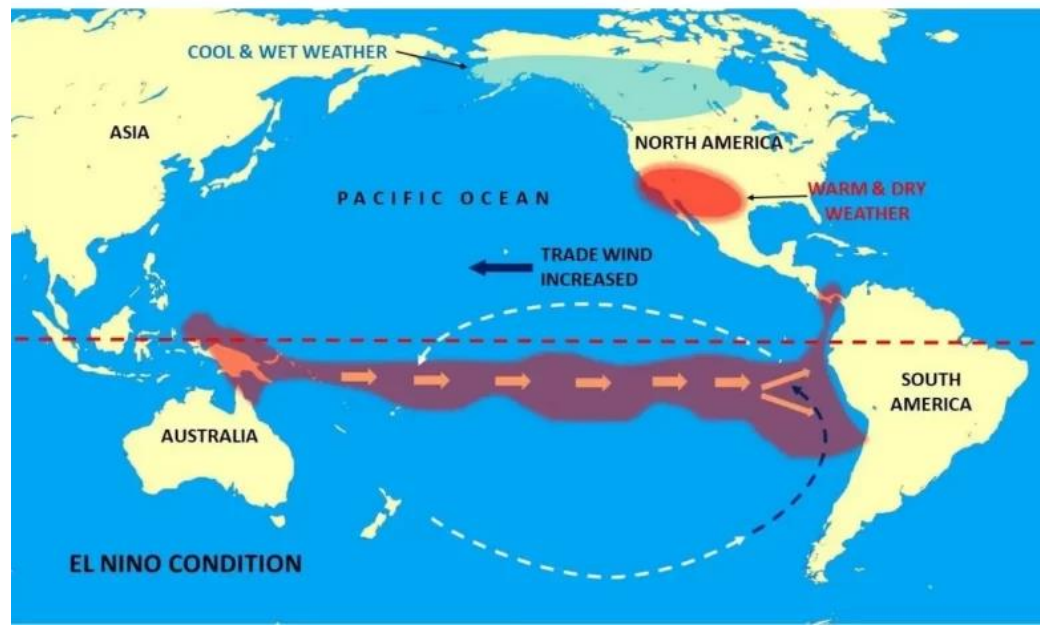
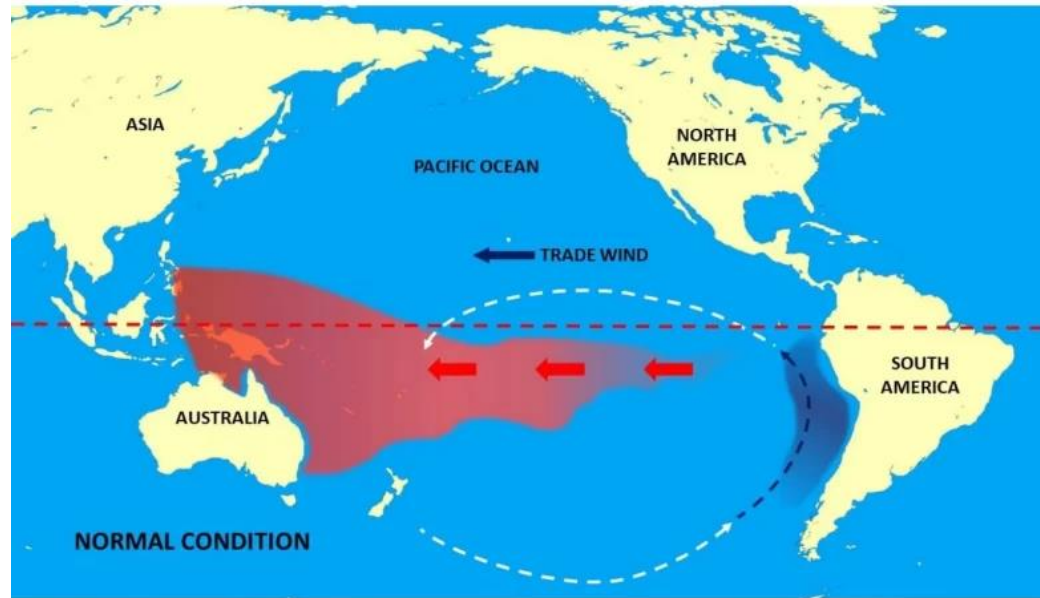
Normal conditions



El Niño conditions

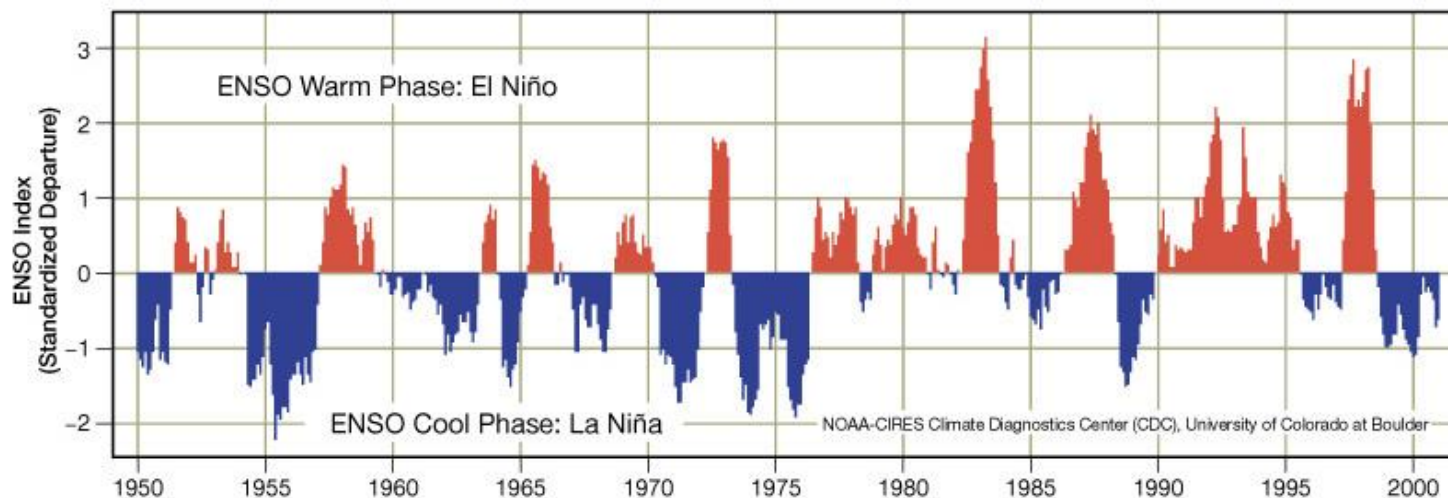


The EL Nino Phenomenon



El Niño recurrence interval

- Typical recurrence interval for El Niños is 2 to 12 years
- Pacific has alternated between El Niño and La Niña events since 1950



- An El Niño event may last for many months, having significant economic and atmospheric consequences worldwide (18 months).
- During the past forty years, ten of these major El Niño events have been recorded, the worst of which occurred in 1997-1998.
- Previous to this, the El Niño event in 1982-1983 was the strongest.
- Some of the El Niño events have persisted for more than one year.