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Climatology Part I

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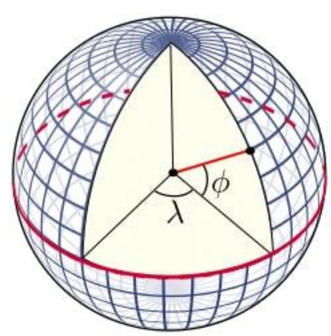
1. Latitudes and Longitudes

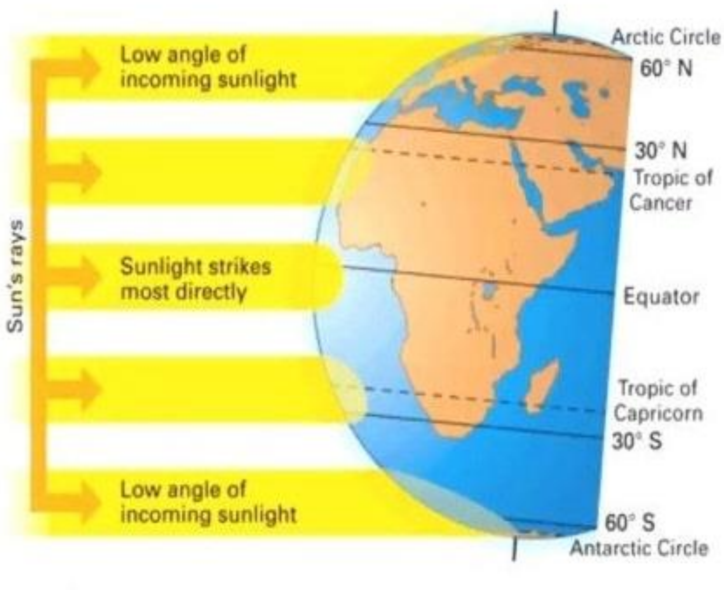
- Latitudes and Longitudes (coordinate system) are imaginary lines used to determine the location of a place on earth.
- Example: The location of New Delhi is 28° N Latitude, 77° E Longitude.



Latitude (ϕ) and longitude (λ) are defined on a perspective spherical modal (Wikipedia)

1.1 Latitude or Parallel

- Latitude is the angular distance of a place north or south of the equator measured in degrees from the centre of the earth.
- As the earth is **slightly flattened at the poles**, the **linear distance of a degree of latitude at the pole is a little longer than that at the equator**.
- For example, at the equator linear distance of a degree of latitude is 110.57 km (68.7 miles), at 45° it is 111.13 km (69 miles), and at the poles, it is 111.7 km (69.4 miles). The average is taken as **111 km (69 miles)**.



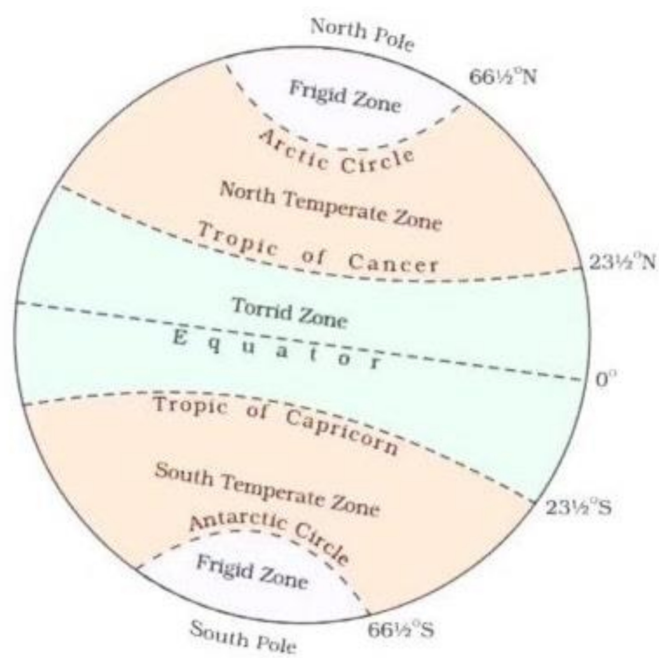
Latitudinal Heat zones of the earth

- The mid-day sun is exactly overhead at least once a year on all latitudes in between the Tropic of Cancer and the Tropic of Capricorn. This area, therefore, receives the maximum heat and is called the **torrid zone**.
- The mid-day sun never shines overhead on any latitude beyond the Tropic of Cancer and the Tropic of Capricorn. The angle of the sun's rays goes on decreasing towards the poles.
- As such, the areas bounded by the Tropic of Cancer and the Arctic circle, and the Tropic of Capricorn and the Antarctic circle, have moderate temperatures. These are, therefore, called **temperate zones**.
- Areas lying beyond the Arctic circle and the Antarctic circle are very cold. Here the sun does not rise much above the horizon. Therefore, its rays are always slanting. These are, therefore, called **frigid zones**.

Important parallels of latitudes

- Besides the **equator (0°)**, the **north pole (90° N)** and the **south pole (90° S)**, there are four important parallels of latitudes:
  1. The **Tropic of Cancer (23½° N)** in the northern hemisphere.
  2. The **Tropic of Capricorn (23½° S)** in the southern hemisphere.
  3. The **Arctic circle (66½° N)** in the northern hemisphere.
  4. The **Antarctic circle is (66½° S)** in the southern hemisphere.

Latitudinal Heat zones of the earth



1.2 Longitude or Meridian

- Longitude is an angular distance of a place east or west of the **Prime (First) Meridian** measured in degrees from the centre of the earth.

- On the globe, longitude is shown as a series of semi-circles that run from pole to pole passing through the equator. Such lines are also called **meridians**.
- It was decided in 1884 to choose the meridian which passes through the Royal Astronomical Observatory at **Greenwich, near London**, as the **zero meridian or prime meridian**.
- All other meridians radiate eastwards and westwards of the prime meridian up to 180°.
- Unlike the parallels of latitude, the meridians of longitude are of **equal length**.
- The meridians of longitude have one very important function; they determine local time in relation to **Greenwich Mean Time (GMT)**, which is sometimes referred to as **World Time**.

Longitude and Time

- Since the earth makes one complete rotation of 360° in one day or 24 hours, it passes through **15° in one hour** or **1° in 4 minutes**.
- The earth rotates from west to east, so **every 15° we go eastwards, local time is advanced by 1 hour**.
- Conversely, **if we go westwards by 15°, local time is retarded by 1 hour**.
- Thus, the **places east of Greenwich gain time**, whereas **places west of Greenwich lose time**.
- A traveller going eastwards gains time from Greenwich until he reaches the meridian 180° E when he will be 12 hours ahead of GMT (GMT+12).
- Similarly, in going westwards, he loses 12 hours when he reaches 180° W. There is thus a total difference of 24 hours or a whole day between the two sides of the 180° meridian.

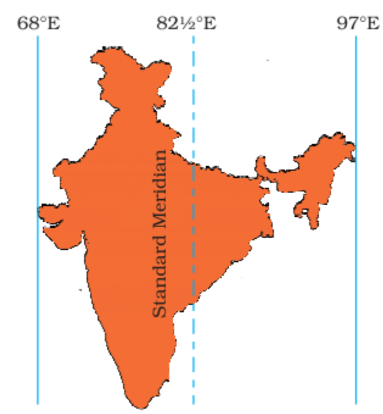
180° E and 180° W correspond to the same longitude. The difference is the direction of travel.

Standard Time and Time Zones

- Standard Time is the time corresponding to a certain longitude or longitudes as chosen by a country.
- Most countries adopt their standard time from the central meridian of their countries. E.g. **IST corresponds to the time at 82.5° E longitude**.
- In countries that have a very **large longitudinal extent** (**large east-west span**), such as Canada, USA, Russia, it would be inconvenient to have a single time zone. So, such countries have multiple time zones.
- For example, Russia has nine time zones, and Canada and USA have six time zones each.

Indian Standard Time

- Indian Standard Time (IST) is taken as the time at **82.5° E longitude** (passing close to the east of **Prayagraj or Allahabad**). Which means, **IST is 5 hours 30 mins ahead of GMT** (**IST = GMT+5:30**).



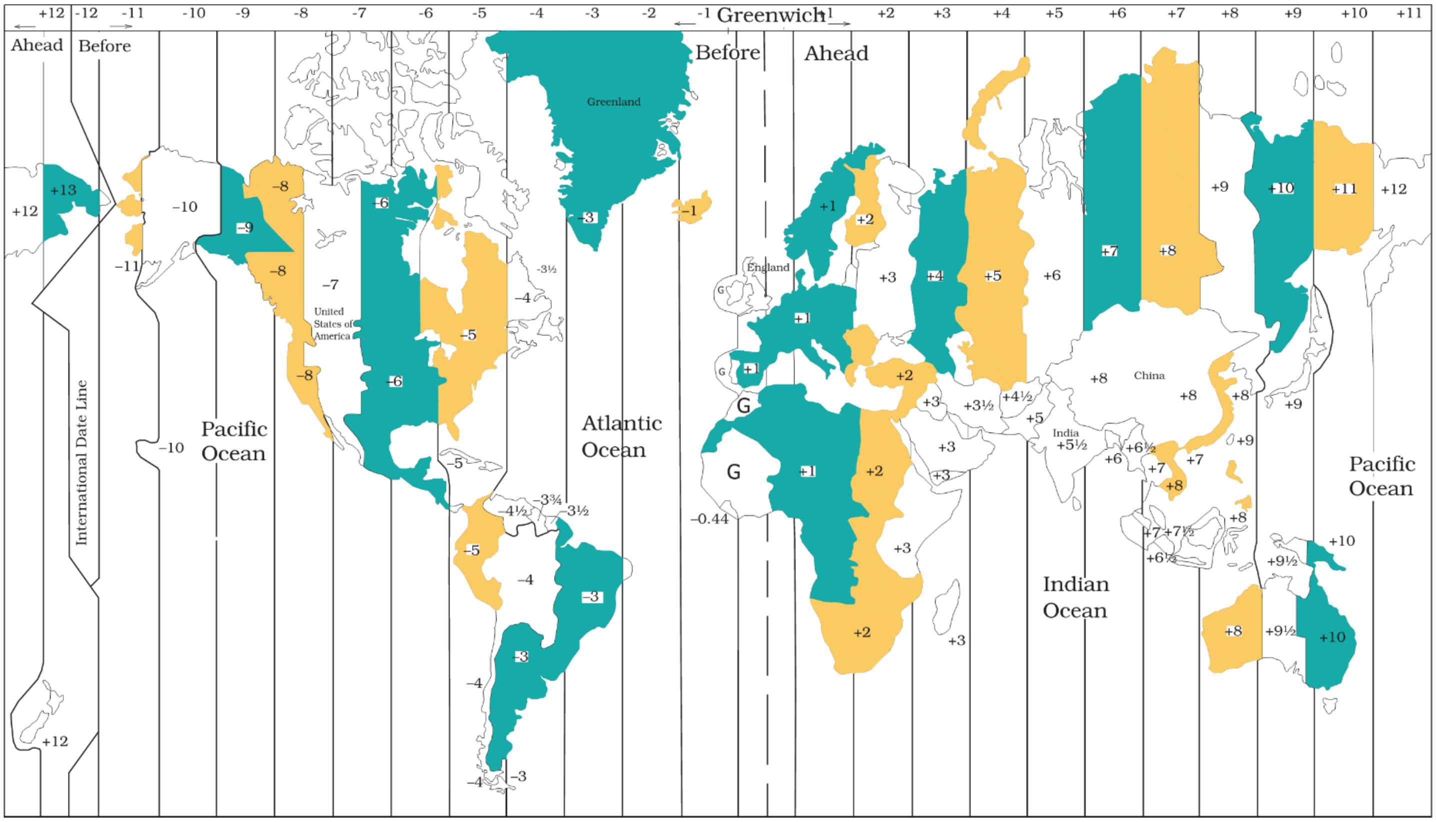
Longitudinal extent of India

Chaibagaan Time

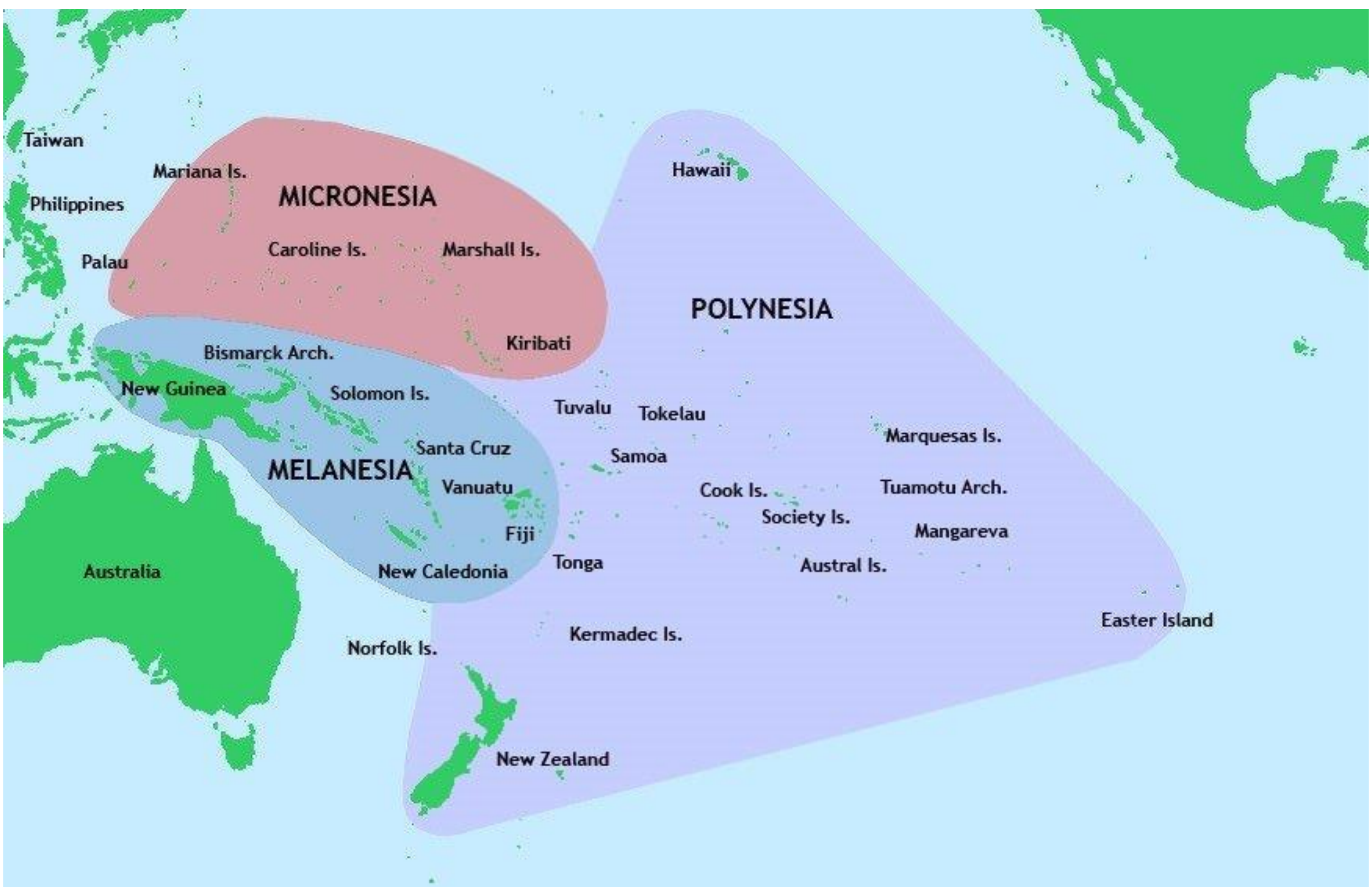
- One hundred fifty years ago, British colonialists introduced "Chaibagaan time" or "Bagaan time", a schedule observed by tea planters, which was **one hour ahead of IST**.
- This was done to improve productivity by optimising the usage of daytime.
- After Independence, Assam, along with the rest of India, has been following IST.
- The administration of the Indian state of Assam put forward a proposal to change its time zone back to Chaibagaan time to conserve energy and improve productivity.
- Indian government refused to accept such a proposal.

The International Date Line

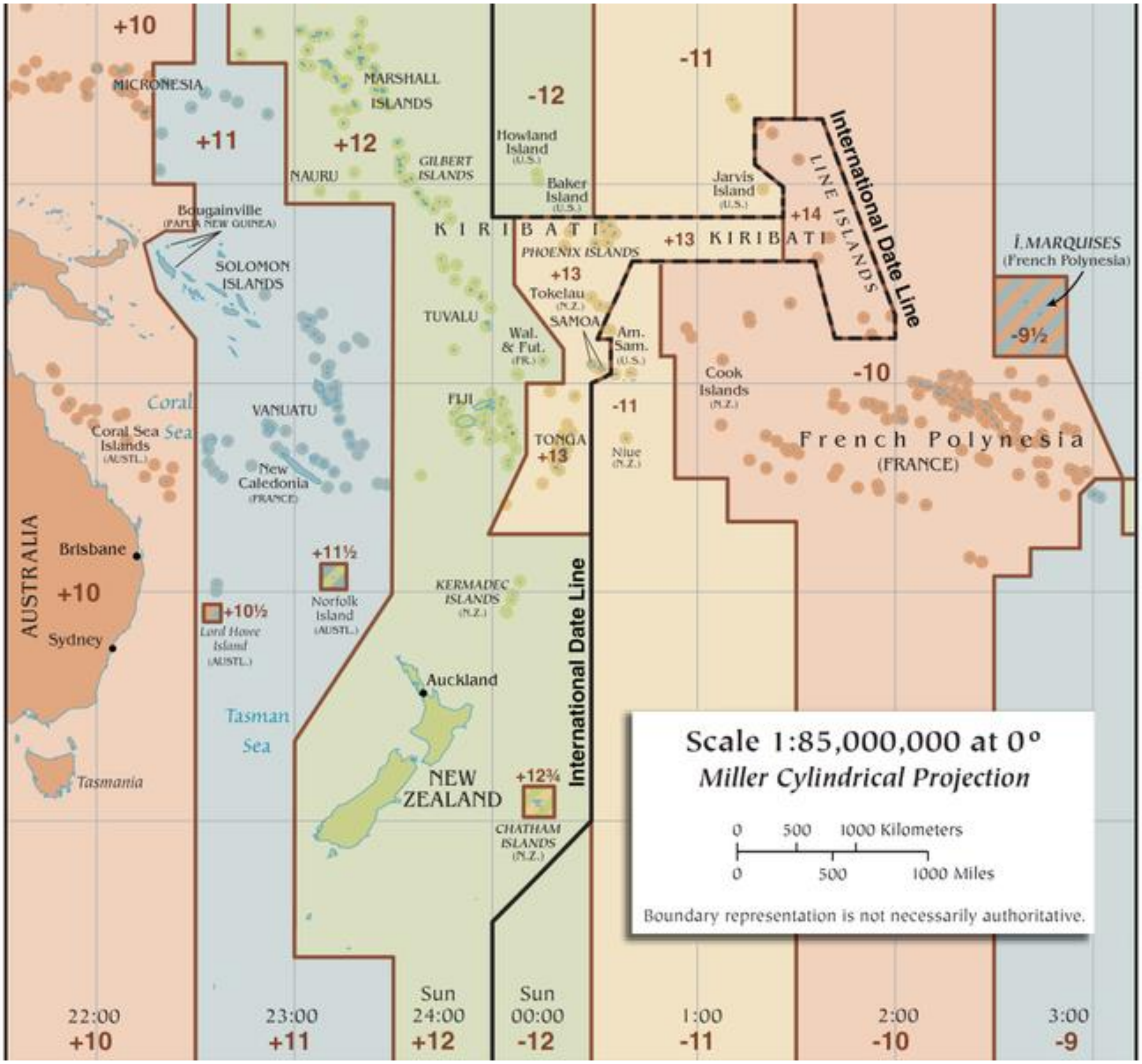
- The International Date Line (IDL) an imaginary line that passes through the Pacific Ocean.



Time Zones and International Date Line



The Island Groups of Australia, Polynesia, Melanesia and Micronesia



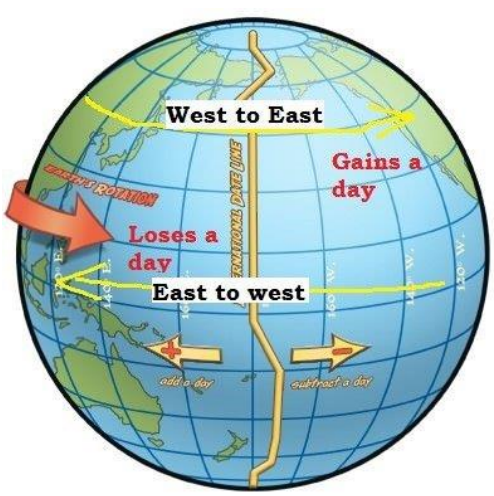
IDL cutting across Oceania (Australia, Melanesia, Micronesia and Polynesia) (Jailbird, via Wikimedia Commons)

Samoa, Christmas Island (Kiribati) and Tonga are the first places that welcome a New Year. Baker Island (USA) and Howland Island (USA) are the last to celebrate a new year.

- **Along the International Date Line, the date changes by exactly one day when it is crossed**.
- A traveller crossing the date line from east to west loses a day, and while crossing the dateline from west to east, he gains a day.

Explanation:

- 180° E is GMT+12 and 180° W is GMT-12, hence the difference between 180° E and 180° W is 24 hours.
- That is, time difference on either side of IDL is 24 hours. So, the date changes as soon as one crosses IDL.



International Date Line

Why is the international dateline drawn in a zig-zag manner?

- The International Date Line curves from the normal 180° meridian at the **Bering Strait**, and at the island groups of **Polynesia, Melanesia and Micronesia**.
- If the dateline was straight, then two regions of the same Island Country or Island group would fall under different date zones. Thus, to avoid any confusion of date, this line is drawn in a zig-zag manner.

Some of regions along the dateline keep Asiatic, or New Zealand standard time, others follow the American date and time.

1.3 Comparison: Latitude vs Longitude

Latitude	Longitude
• Angular distance of a point measured along the north or south of the equator	• Angular distance measured along the equator
• Latitudes are named south and north of Equator	• Longitudes are named east or west of Prime Meridian
• Also called as Parallels	• Also called as Meridian
• Equator = 0° Latitude	• Prime meridian = 0° Longitude
• Equator has the maximum length	• All longitudes are equal in length
• Equator, Tropic of Cancer 23.5° N, Tropic of Capricorn 23.5° S, Arctic circle 66.5° N, Antarctic circle 66.5° S, North Pole 90° N and South Pole 90° S are important latitudes	• Prime meridian 0° and International Date Line 180° E or 180° W are important longitudes
Both are used to determine the location of a point on earth. The location is identified with Co-ordinates	

Prelims Mock: Statements

1) A person travelling from Japan to Alaska across International Date Line will gain a day.
2) A person travelling from Hawaii to New Zealand across International Date Line will lose a day.
3) It is inconvenient for a country of greater latitudinal extent but smaller longitudinal extent (Chile for example) to have multiple time zones.
4) On a 24-hour clock, the time is 00:00 in London. Then the time in Mumbai on a 12-hour clock will be 05:30 AM.

Which of the above statements are false?

a) None
b) 1 and 2 only
c) 1, 2 and 3 only
d) 3 only

Explanation:

- If the time and date in Japan is 12:00 AM 01/01/2019, then the date in Alaska (USA) will be 31/12/2018. Thus, a person travelling from Japan to Alaska across the International Date Line will gain a day (Japan is more than 18 hours ahead of Alaska).
- IST is GMT+5:30. So, if it is 00:00 in London, then the time in India is 05:30 AM. If it is 23:00 GMT, 31/12/2018, then the time and date in India is 4:30 AM 01/01/2019.
- On a 24-hour clock, the time is 00:00 in London. Then the time in Mumbai on a 12-hour clock will be 05:30 AM.

Answer: a) None

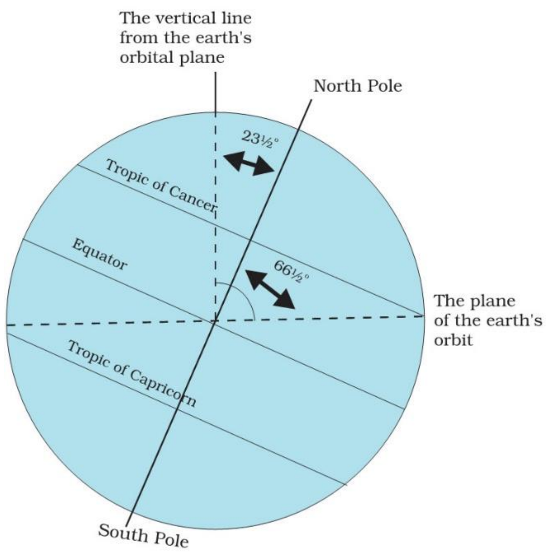
2. Motions of the earth

- Rotation and revolution are the most important motions of the earth.

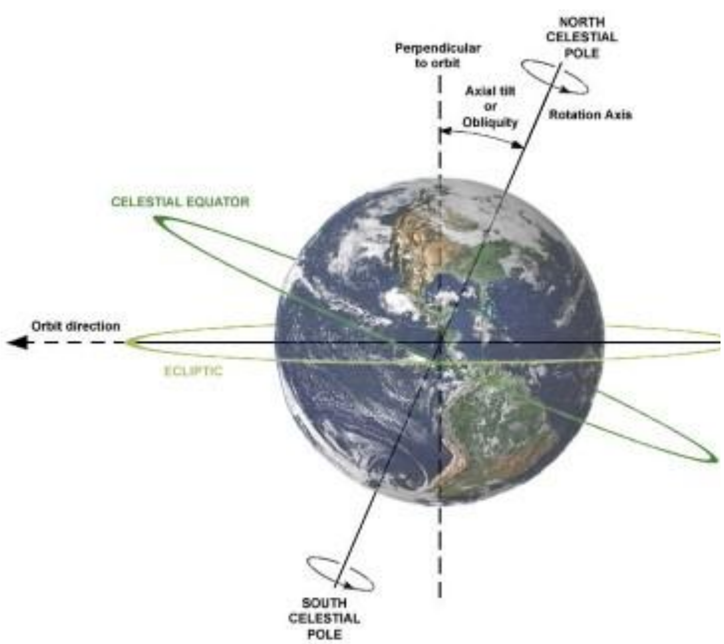
2.1 Rotation of Earth

- The spinning movement of the earth is called rotation.
- The Earth rotates around its axis in **west to east** direction.
- Earth's axis is the imaginary line that passes through the North Pole, earth's centre and the South Pole.

- Earth's axis is **antipodal** — meaning it passes through the centre of the earth connecting two exactly opposite ends.
- It takes approximately 24 hrs (**23 hours, 56 minutes, and 4 seconds**) to complete one rotation.
- **Days and nights occur due to rotation of the earth**.
- The circle that divides the day from night on the globe is called the **circle of illumination**.
- Earth rotates on a **tilted axis**. Earth's rotational axis makes an angle of **23.5°** with the normal, i.e. it makes an angle of **66.5° with the orbital plane of the earth (ecliptic plane)**.



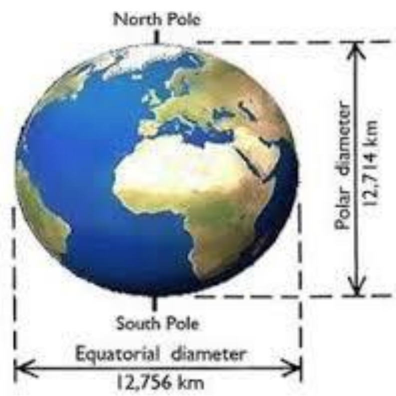
Inclination of the Earth's Axis



Inclination of the Earth's Axis

Shape of the earth

- The shape of the earth is **Geoid** (some sources mention is as **oblate spheroid**). That is, the earth is **slightly flattened at the poles and bulged at the equatorial region**.
- The radius at the equator is larger than at the poles due to the long-term effects of the **earth's rotation** (the **speed of rotation**, and hence the **centrifugal force**, is greater at the equator than at the poles).



Geoid

- The gravitation force is not the same at different latitudes on the surface. It is **greater near the poles and less at the equator**.
- This is because of
  a) The poles are closer to the centre due to the equatorial bulge and thus have a stronger gravitational field.
  b) The speed of rotation of the earth is greater at the equator than at the poles. Thus, the centrifugal force is greater at the equator. As the centrifugal force and the gravitational force are counteracting forces (acting in the opposite direction), the latter is slightly less at the equator compared to the poles.

Que: Shouldn't the gravity at the equator be greater as there is more mass at the equator?
Ans: The density of earth along the poles is greater than along the equator (because of the difference is speed of rotation). As a denser object of a given mass is smaller, you get closer to its centre of mass and experience a stronger gravitational force.

Temperature falls as we move from equator towards poles

- Temperature falls at the surface of the earth as one moves away from the equator towards poles.
- This is because of the **spherical (geoid)** shape of the earth and the position of the sun relative to earth.
- The **energy received per unit area decreases from equator to poles** as the equator receives direct sunlight and the sun's rays becomes **slant or oblique** as we move poleward.

Prelims mock: Statements

1. The shape of the Earth is Geoid.
2. The region that lies between Tropic of Cancer and Tropic of Capricorn is called Torrid Zone.
3. The temperature decreases from equator to poles because of the shape of the earth.
4. The North Pole is a latitude.

Which of the above statements are true?

a) 1 and 2 only
b) 1, 3 and 4 only
c) 1, 2 and 3 only
d) All

Answer: None are false, d) all

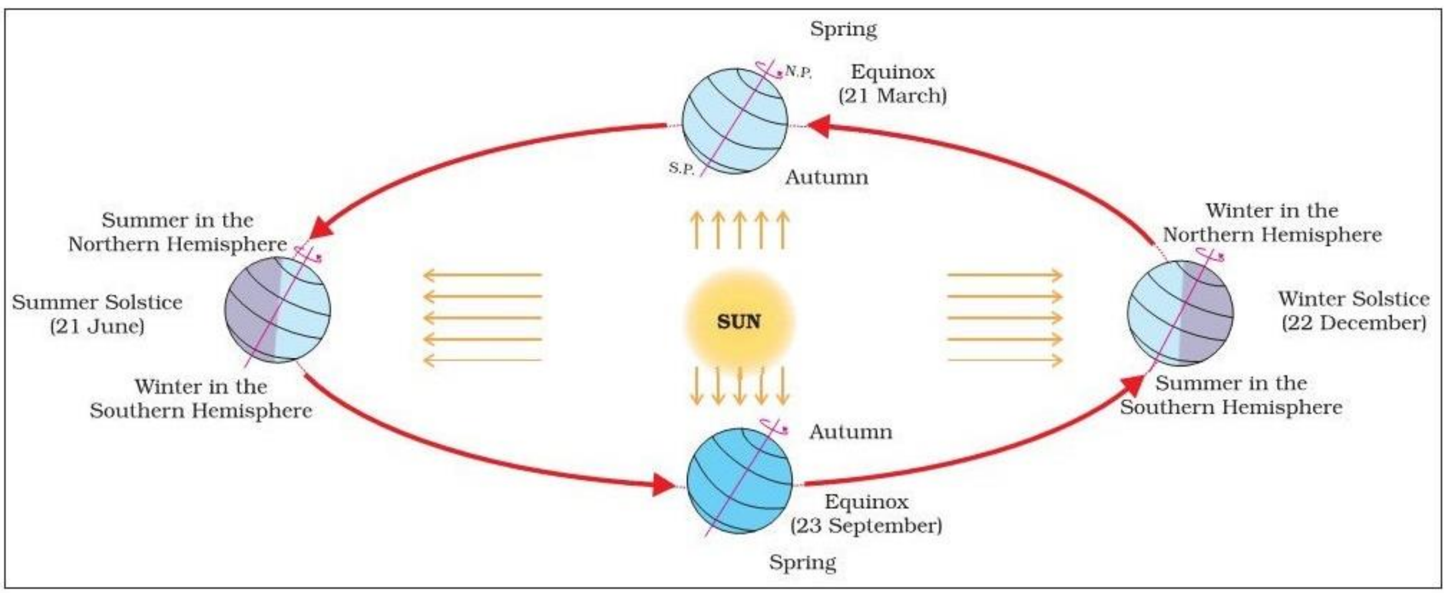
2.2 Revolution

- At the same time that the Earth spins on its axis, it also orbits or revolves around the Sun. This movement is called revolution.
- The plane in which the earth revolves around the sun is called as **orbital plane** or the **ecliptic**.

*Most large objects in orbit around the Sun lie **near the plane of Earth's orbit, known as the ecliptic**. The planets are very close to the ecliptic, whereas comets and Kuiper belt objects are at significantly greater angles to it.*

- It takes **365¼ days** (one year) for the earth to complete one revolution around the sun.
- Six surplus hours saved every year are added to make one day over a span of four years.
- This surplus day is added to the month of February. Thus, every fourth year, February is of 29 days instead of 28 days. Such a year with 366 days is called a **leap year**.

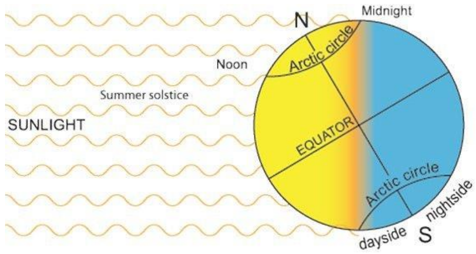
Solstice



Summer solstice

- On **21st June**, the northern hemisphere is tilted towards the sun, and the rays of the sun fall directly on the **Tropic of Cancer**. As a result, these areas receive more heat.
- Since a large portion of the northern hemisphere is getting light from the sun, it is **summer** in the regions north of the equator.
- The **longest day and the shortest night** all across the northern hemisphere occur on **21st June**.

- At this time in the southern hemisphere, all these conditions are reversed. It is winter season there. The nights are longer than the days.
- This position of the earth is called the **summer solstice**. *(For southern hemisphere 21st June is winter solstice)*
- During summer solstice the whole of Arctic region falls within the 'zone of illumination' all day long.



Winter solstice

- On **22nd December**, the **Tropic of Capricorn** receives direct rays of the sun.
- The **longest night and the shortest day** all across the northern hemisphere occur on **22nd December**.
- It is summer in the southern hemisphere with longer days and shorter nights. The reverse happens in the northern hemisphere.
- This position of the earth is called the **winter solstice**. *(For southern hemisphere 22nd December is summer solstice)*

Midnight sun

- Because of the axial tilt of the Earth, the Sun does not set at high latitudes in local summer.
- The number of days per year with potential midnight sun increases as one goes closer towards the poles.
- The Sun remains continuously visible for one day during the summer solstice (21st June in the Northern Hemisphere and 22nd December in the Southern Hemisphere) at the polar circle, for several weeks only 100 km closer to the pole, and for **six months at the pole**.
- At extreme latitudes, the midnight sun is usually referred to as **polar day**.
- At the poles themselves, the Sun rises and sets only once each year on the equinox.
- The opposite phenomenon, polar night, occurs in winter when the Sun stays below the horizon throughout the day.

The Sun sets and rises very close to the horizon at the higher latitudes

Daylight saving in temperate regions

- Daylight saving time (DST) or summer time is the practice of advancing clocks during summer months by one hour or more.
- In DST, evening time is increased by sacrificing the morning hours.

Normal days = Start office at 10 AM and close at 5 PM.
DST = Start office at 9 AM and Close at 4 PM

- Typically, users in regions with summer time (countries in extreme north and south) adjust clocks forward one hour close to the start of spring and adjust them backwards in the autumn to standard time.
- Advantages: benefits retailing, sports, and other activities that exploit sunlight after working hours. Reduces evening use of incandescent lighting, which was formerly a primary use of electricity.
- Disadvantages: DST clock shifts sometimes complicate timekeeping and can disrupt travel and sleep patterns.

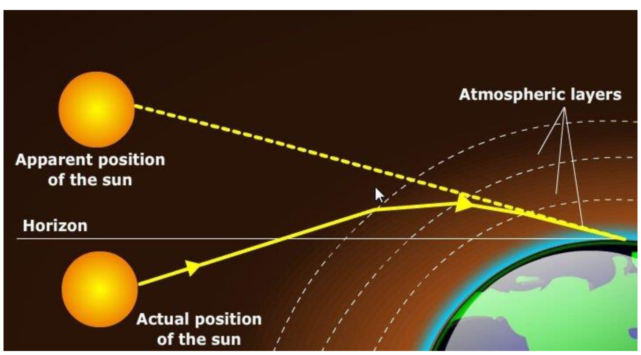
Equinox

- On **21st March** and **September 23rd**, direct rays of the sun fall on the equator.
- At this position, neither of the poles are tilted towards the sun; so, the whole earth experiences **equal days and equal nights**. This is called an equinox.

- On 23rd September, it is **autumn season** (season after summer and before the beginning of winter) in the northern hemisphere and **spring season** (season after winter and before the beginning of summer) in the southern hemisphere.
- The opposite is the case on 21st March when it is spring in the northern hemisphere and autumn in the southern hemisphere.

Days are always longer than nights at the equator

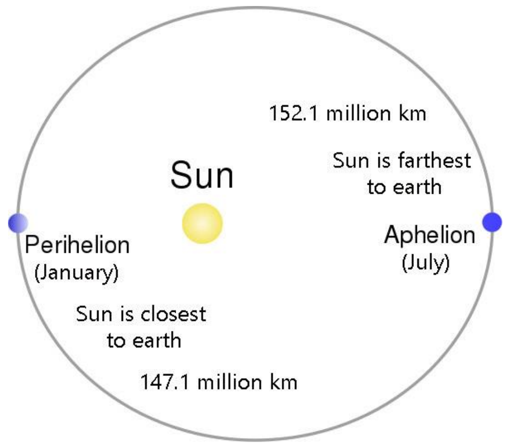
- If there was no atmosphere, there would be no refraction, and the daytime and night-time would be near equal at the equator, at least during equinoxes.
- But due to atmosphere, the sun's rays get refracted (bending of light due to change in density of the medium).
- Refraction is particularly stronger during the morning and the evening time when the sun's rays are slant.
- Even though the actual sun is below the horizon, its **apparent image** would appear above the horizon due to **refraction**. This makes the days longer than nights at the equator.



Apparent position of the Sun due to Refraction of Light

Perihelion and Aphelion

- The earth revolves around the sun in an **elliptical orbit** with the sun at one of the foci.
- Approximately every 100,000 years, Earth's orbital path changes from being nearly circular to elliptical due to gravitational influences of other planetary objects, particularly the Moon.
- The Earth is closest to the Sun at its **perihelion** which occurs about **two weeks after the December Solstice**.
- At perihelion position, the earth is about **147.1 million km away** from the sun.
- It is farthest from the Sun at its **aphelion** which occurs about **two weeks after the June Solstice**.
- At aphelion position, the earth is about **152.1 million km** away from the sun.
- The dates when Earth reaches the extreme points on its orbit are not fixed.



Perihelion and Aphelion

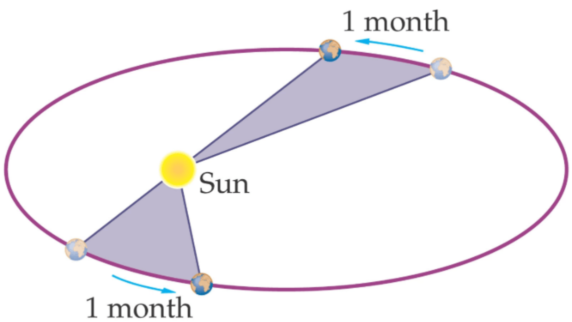
How much does the elliptical orbit affect the weather on earth?

Amount of energy received from the sun

- The difference in the amount of the sun's energy that the earth receives (called the solar constant) doesn't vary considerably between perihelion and aphelion.
- Throughout the year, the solar constant varies by very little due to the very small eccentricity of the earth's orbit (eccentricity of an ellipse varies between 0 and 1. A circle is an ellipse with eccentricity 0).
- After all, the distance difference between perihelion and aphelion is only a small fraction of Earth's average distance to the sun.
- In the southern hemisphere, the meagre solar constant increase is offset by the higher water to land ratio.

Duration of seasons

- The elliptical orbit does affect our weather by affecting the duration of the seasons, although this effect is not significant.
- Earth is farther away from the Sun in summer. Therefore, its orbital velocity is at its lowest, and it requires more time to travel from the summer solstice point to the autumnal equinox (September 23rd) than it needs to move between the winter solstice and vernal equinox (21st March).



The varying orbital speed of the earth (in the figure, the orbit of the earth is exaggerated)

- Thus, the winter is about 89 days, and the summer is approximately 92 days long.
- That is, **in the northern hemisphere the summer is slightly longer than the winter**.

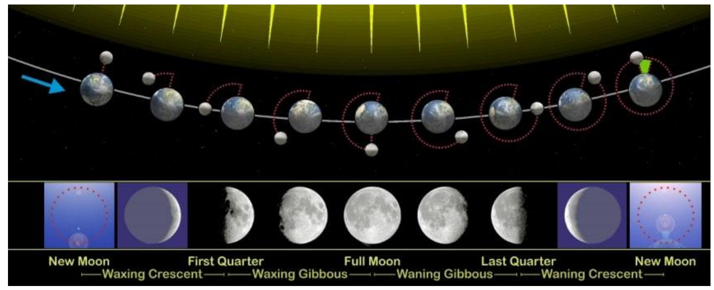
Kepler's second law of planetary motion *states that a line between the sun and the planet sweeps equal areas in equal times. Thus, the speed of the planet increases as it nears the sun and decreases as it recedes from the sun.*
The earth achieves its fastest orbital speed at the perigee and slowest orbital speed at the apogee*.*

Eclipse

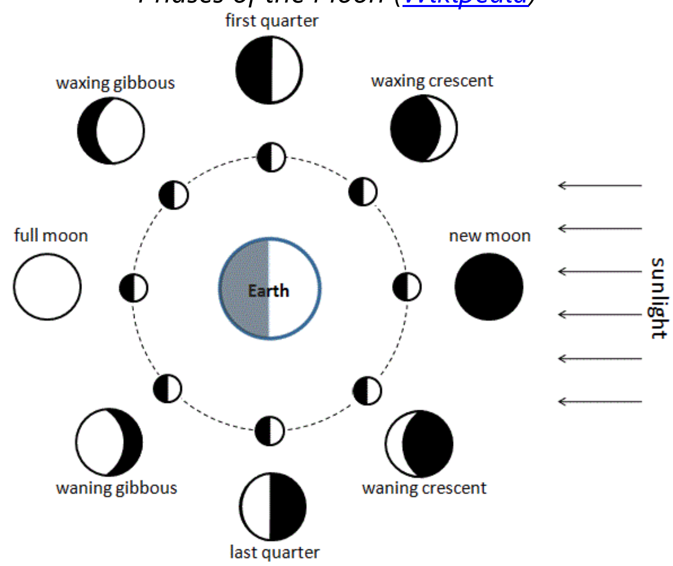
- An eclipse happens when a planet or a moon gets in the way of the sun's light.
- On earth, we experience two kinds of eclipses: 1) **solar eclipses that occur only on a new moon day** and **lunar eclipses that occur only on a full moon day**.
- Revolution of the moon around the earth close to the earth's ecliptic plane, proximity between the moon and the earth, and the relative apparent size of the sun and the moon, are all together responsible for the occurrence of solar and lunar eclipses.

The Sun's distance from Earth is about 400 times the Moon's distance, and the Sun's diameter is about 400 times the Moon's diameter. Because these ratios are approximately the same, the Sun and the Moon as seen from Earth appear to be approximately the same size.

Phases of the moon



Phases of the Moon (Wikipedia)



Phases of the Moon (Wikipedia)

- The lunar phase or phase of the Moon is the shape of the sunlit portion of the Moon as viewed from Earth.
- The Moon's rotation is **tidally locked** by Earth's gravity; therefore, most of the same lunar side always faces Earth. This near side is variously sunlit, depending on the position of the Moon in its orbit.

Tidal locking *is the situation when an object's orbital period matches its rotational period. E.g. the Moon's rotation time is* ***27.3 days****, just the same as its orbital time,* ***27.3 days****.*

- During the New moon phase, the Sun and the Moon are aligned on the same side of the Earth, and the side of the Moon facing Earth is under darkness.

- As the Moon waxes (the amount of illuminated surface as seen from Earth is increasing), the lunar phases progress through **new moon, crescent moon, first-quarter moon, gibbous moon, and full moon**.
- The Moon is then said to wane as it passes through the **gibbous moon, third-quarter moon, crescent moon, and back to new moon**.
- The lunar phases gradually and cyclically change over the period of a **synodic month** (about **29.53 days**), as the **orbital positions** of the Moon around Earth and Earth around the Sun **shift**.

Perigee and Apogee

- Like the Earth's orbit around the Sun, the Moon's path around the Earth is elliptical.
- The point in the Moon's orbit that is closest to the Earth is called the **perigee** and the point farthest from the Earth is known as the **apogee**.
- The terms are also sometimes used interchangeably with the Earth's Perihelion and Aphelion.
- In January 2019 perigee was ~3,57,000 km and apogee was ~4,06,000 km.
- The distance of perigee and apogee positions change from time to time.
- On average, the distance is taken as **382,900 kilometres** from the Moon's centre to the centre of Earth.

Sidereal period

- The orbit of a planet around the Sun measured with respect to the **fixed stars** is used to determine the sidereal period.
- The sidereal period of the Earth is **365.25 days** (Gregorian calendar month is about 30.44 days).
- The Moon's sidereal orbital period (the **sidereal month**) is **~27.3 days** — the time interval that the Moon takes to orbit 360° around the Earth relative to the **fixed stars**.

Synodic period

- Synodic period is the time required for a body within the solar system, such as a planet, the Moon, to return to the same position **relative to the Sun** as seen by an observer on the Earth.
- The Moon's synodic period is the time between successive recurrences of the same phase; e.g., between full moon and full moon.

The Moon completes one revolution

- ✓ ***relative to the fixed stars*** *in about* ***27.32 days*** *(a* ***sidereal month****) and*
- ✓ ***relative to the Sun*** *in about* ***29.53 days*** *(a* ***synodic month****).*

Thus, one Georgian year = 12 Georgian months = ~ 13.37 sidereal months =~ 12.37 synodic months

- The time difference in sidereal and synodic months is due to the **constantly shifting orbital positions of the Moon around Earth and of Earth around the Sun**.

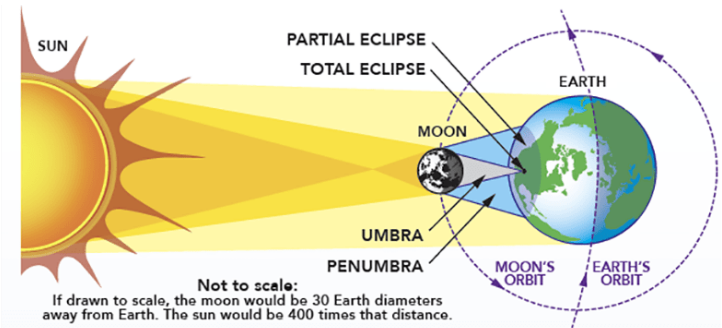
Supermoons & Micromoons

- The Moon's phase and the date of its approach to its perigee or apogee are not synced.
- When a Full Moon or New Moon occurs close to the **Moon's perigee**, it is known as a **Supermoon**.
- On the other hand, when a Full Moon or New Moon occurs close to the **Moon's apogee**, it is known as a **Micromoon**.

Supermoon and Micromoon

Solar Eclipse

- A solar eclipse happens when the moon gets in the way of the sun's light and casts its shadow on Earth.



Solar Eclipse ([NASA illustration])

- The type of solar eclipse that happens during each season (whether total, annular or partial) depends on **apparent sizes of the Sun and Moon**.

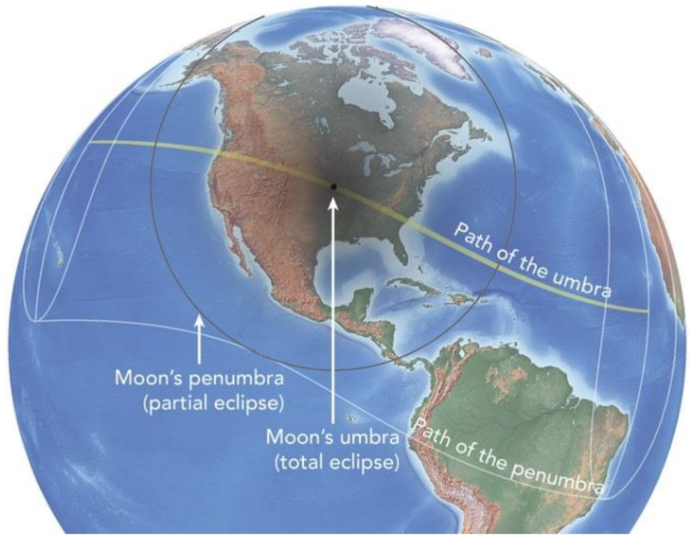
Total Solar Eclipse (Umbra)

- A total solar eclipse occurs when the sun and the moon are **exactly in line** with the Earth and the moon completely obscures the sun.
- During a total solar eclipse, the sun's **corona** is visible to the naked eye as a bright ring around the obscured sun.
- **A total solar eclipse happens about every year and a half somewhere on Earth**.
- The moon's shadow on Earth isn't very big, so only a small portion of places on Earth will see it.
- On average, the same spot on Earth only gets to see a solar eclipse for a few minutes about every 375 years!

Sun's Corona during a total solar eclipse

Umbra

- Umbra is the region of the shadow of the moon in which all light from the sun is completely excluded.
- Thus, in an eclipse of the Sun, the **regions within the umbra experience a total solar eclipse**.
- During any one eclipse, totality (total solar eclipse or umbra) occurs at best only in a narrow track on the surface of Earth. This narrow track is called the **path of totality**.



Path of totality (umbra) ([Credits])

Annular Solar Eclipse

- An annular eclipse occurs when the Sun and Moon are exactly in line with the Earth, but the **apparent size of the Moon is smaller (when the moon is at its apogee) than that of the Sun**.
- Hence the Sun appears as a very **bright ring** surrounding the dark disk of the Moon.

Annular Solar Eclipse

Partial Solar Eclipse (Penumbra)

- A partial eclipse occurs when the sun and the moon are **not exactly in line** with the earth and the moon only partially obscures the sun.
- This phenomenon can usually be seen from a large part of the Earth outside of the track of an annular or total eclipse.

- However, some eclipses can only be seen as a partial eclipse, because the umbra passes above the Earth's polar regions and never intersects the Earth's surface.
- Partial eclipses are virtually unnoticeable in terms of the sun's brightness as it takes well over 90% coverage to notice any darkening at all.
- A partial solar eclipse happens **at least twice a year** somewhere on Earth.

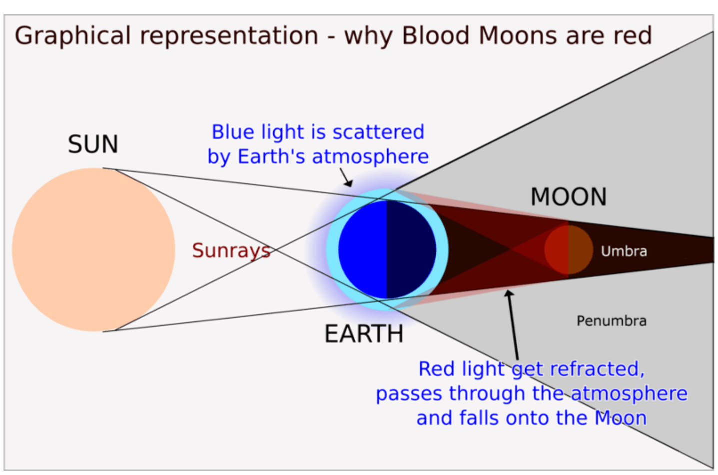
Penumbra

- Penumbra is the region of the shadow of the moon outside the umbra where the light from the Sun is partially blocked.
- Thus, in an eclipse of the Sun, the **regions within the penumbra experience partial solar eclipse**.

Lunar Eclipse

- During a lunar eclipse, Earth gets in the way of the sun's light hitting the moon. That means that during the night, a full moon fades away as Earth's shadow covers it up.
- If the moon passes through the lighter part of Earth's shadow, a **penumbral eclipse (partial eclipse)** occurs.
- If the moon passes through the darker part of Earth's shadow, an **umbral eclipse (total eclipse)** occurs.

Blood moon



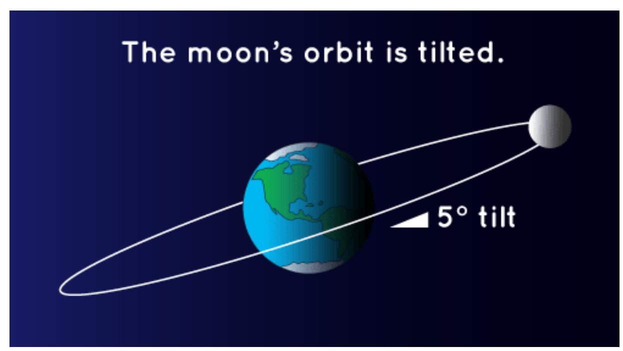
Lunar Eclipse and Blood Moon (Eggishorn, from [Wikimedia Commons](#))

- During a total lunar eclipse, a little bit of light from Earth's sunrises and sunsets (on the disk of the planet) falls on the surface of the moon.
- The moon can look reddish because of the Earth's atmosphere that absorbs the other colours while it bends (**refraction**) some sun-light toward the moon
- How red the moon appears can depend on how much pollution, cloud cover or debris there is in the atmosphere.

Why don't we have a lunar eclipse or a solar eclipse every month?

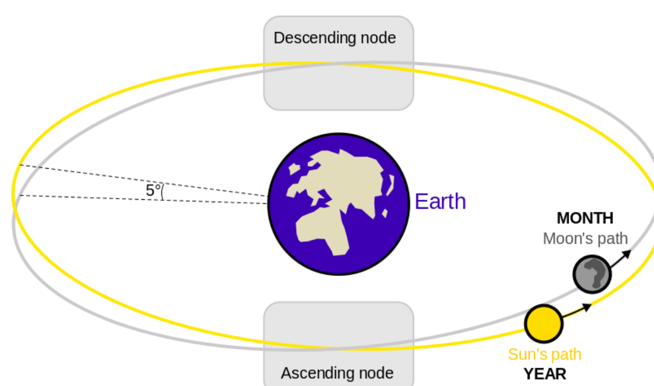
Why not every full moon day a lunar eclipse? Why not every new moon day a solar eclipse?

- Not every new moon causes a solar eclipse and not every full moon sees a lunar eclipse.
- This is because of the of **moon's tilted orbit around Earth** with respect to the earth's orbital plane (ecliptic).



Moons orbital plane is tilted to the earth's ecliptic (Earth's orbital plane) by about 5.1° ([NASA](#))

- Solar and lunar eclipses happen only during an eclipse season **when the plane of the Earth's orbit around the Sun crosses with the plane of the Moon's orbit around the Earth**.



Eclipse season occurs at the descending and the ascending nodes (SuperManu, Wikipedia)

- It is because of the non-planar and non-circular differences that eclipses are not a common event.
- If the orbit of the Earth around the Sun and the Moon's orbit around the Earth were both in the same plane, then **there would be a lunar eclipse at every full moon, and a solar eclipse at every new moon**.
- And if both orbits were perfectly circular, then each solar eclipse would be the **same type** every month.

Prelims Question: Variations in the length of daytime and nighttime from season to season are due to

In simple words, seasons are caused due to?

a) the earth's rotation on its axis [causes day and night]
b) the earth's revolution around the sun in an elliptical manner
c) latitudinal position of the place
d) revolution of the earth on a tilted axis

- The earth's rotation on its axis causes day and night.
- The earth's revolution around the sun in an elliptical manner causes **perihelion** (closest position of earth to sun) and **aphelion** (farthest position of earth to sun).
- Latitudinal position of the place determines the amount of sunlight received.
- Revolution of the earth on a tilted axis **causes seasons** or variations in the length of daytime and nighttime from season to season.

Answer: d) revolution of the earth on a tilted axis

Rotation of earth ➔ Days and Nights

Revolution of earth on a tilted axis ➔ Seasons (Variations in the length of daytime and nighttime from season to season)

Revolution of the earth around the sun in an elliptical manner ➔ Perihelion and Aphelion

Revolution of the moon around the earth ➔ Phases of the Moon (New Moon, Full Moon)

Revolution of the moon around the earth in an elliptical manner ➔ Perigee and Apogee

Revolution of the moon on a tilted orbital plane around the earth ➔ Solar Eclipse and Lunar Eclipse

Revolution of the moon on a tilted orbital plane around the earth in an elliptical manner ➔ Moons apparent size is different for various Solar Eclipses (not all solar eclipses are similar)

3. Atmosphere

- Our planet earth is enveloped by a deep blanket of gases extending several thousands of kilometres above its surface. This gaseous cover of the earth is known as the atmosphere.
- Like land (lithosphere) and water (hydrosphere), the atmosphere is also an integral part of the earth and it is held in place by the gravitational influence of earth.

3.1 Evolution of Earth's atmosphere

- The first atmosphere consisted of gases in the solar nebula, primarily hydrogen.

Hadean eon (4,540 – 4,000 mya): The primordial atmosphere

- **Volcanic outgassing** created the primordial atmosphere.
- Outgassing from volcanism, supplemented by gases produced during the late heavy bombardment of Earth, produced the next atmosphere.

*During the **Late Heavy Bombardment** (4 billion years ago), a disproportionately large number of asteroids have collided with the early terrestrial planets including earth.*

- Over time, the Earth's surface solidified leaving behind hot volatiles which resulted in a **heavy CO_2 atmosphere** with hydrogen, nitrogen, inert gases and water vapour.
- After the formation of oceans, **dissolving in ocean water removed most CO_2 from the atmosphere**.
- Some CO_2 reacted with metals to form carbonates that were deposited as sediments.

- The early atmosphere contained almost **no oxygen**.
- Most of the lighter gases like the hydrogen and helium escaped into space and are continually escaping even to the present day due to **atmospheric escape** (outer layers stripped by solar wind).

Archean eon (4000 mya – 2500 mya)

- The atmosphere was **without oxygen,** and the atmospheric pressure was around **10 to 100 atmospheres**.
- Nitrogen formed the major part of the then stable "second atmosphere".
- Most of the nitrogen in the air was carried out from deep inside the earth by volcanoes.
- In the late Archean Eon, an oxygen-containing atmosphere began to develop, apparently produced by photosynthesising cyanobacteria.
- The constant re-arrangement of continents influenced the long-term evolution of the atmosphere by transferring carbon dioxide to and from large continental carbonate stores.

Proterozoic Eon (2500 mya – 541 mya): Oxygen in atmosphere

- Free oxygen did not exist in the atmosphere until about 2.4 billion years ago.
- O_2 showed major variations until reaching a steady state of more than 15% by the end of the Proterozoic.

Phanerozoic Eon (541 mya to present): The present atmosphere

- The amount of oxygen reached a peak of about 30% around 280 million years ago.
- Two main processes govern changes in the oxygen levels in the atmosphere:
  1. Plants use carbon dioxide from the atmosphere, releasing oxygen.
  2. Breakdown of **pyrite (iron sulphide)** and **volcanic eruptions** release **sulphur** into the atmosphere, which oxidises and hence **reduces the amount of oxygen in the atmosphere**. However, volcanic eruptions also release carbon dioxide, which plants can convert to oxygen.
- Periods with much oxygen in the atmosphere are associated with rapid development of animals.
- Today's atmosphere contains 21% oxygen, which is great enough for this rapid development of animals.

3.2 Composition of Atmosphere

- The composition of Earth's atmosphere is largely governed by the by-products of the life that it sustains.
- Dry air from Earth's atmosphere contains **78.08% nitrogen, 20.95% oxygen, 0.93% argon, 0.04% carbon dioxide**, and traces of hydrogen, helium, and other noble gases.
- The remaining gases are often referred to as trace gases, among which are the greenhouse gases, principally **carbon dioxide, methane, nitrous oxide**, and **ozone**.
- Various industrial pollutants also may be present as gases or **aerosols**, such as chlorine, fluorine compounds and elemental mercury vapor.
- Sulphur compounds such as hydrogen sulphide and sulphur dioxide (SO_2) may be derived from natural sources or industrial air pollution.

Permanent Gases of the Atmosphere

Name	Percentage by Volume
Nitrogen (N_2)	**78.08**
Oxygen (O_2)	**20.95**
Argon (Ar)	**0.93**
Carbon dioxide (CO_2)	**0.036**
Neon (Ne)	0.002
Helium (He)	0.0005
Krypto (Kr)	0.001
Methane (CH_4)	**0.000179**
Xenon (Xe)	0.00009
Hydrogen (H_2)	0.00005

NO AC NH KM

- Permanent atmospheric gases remain in fixed proportion to the total gas volume.
- Other constituents vary in quantity from place to place and from time to time.
- Heavier gases like nitrogen and oxygen tend to stick at the bottom of the atmosphere.

- The proportion of gases changes in the higher layers of the atmosphere in such a way that oxygen will be almost in negligible quantity at the height of 120 km.
- Similarly, carbon dioxide and water vapour are found only up to 90 km from the surface of the earth.

Important constituents of the atmosphere

Oxygen

- All living organisms inhale oxygen.
- Besides, oxygen can combine with other elements to form important compounds, such as, oxides.
- Also, **normal combustion is not possible without oxygen**.

Nitrogen

- It is a relatively inert gas and is an important constituent of all organic compounds.
- The main function of nitrogen is to control combustion by diluting oxygen, i.e., it prevents spontaneous combustion of oxygen in the atmosphere.
- It also indirectly helps in oxidation of different kinds.

Carbon Dioxide

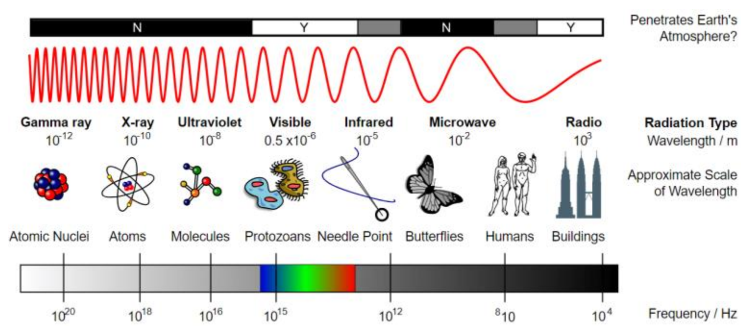
- Green plants, through photosynthesis, absorb carbon dioxide from the atmosphere.
- Being an **efficient absorber of heat**, carbon dioxide is a very important factor in the **heat energy budget**.
- With increased burning of fossil fuels – oil, coal and natural gas – the carbon dioxide percentage in the atmosphere has been increasing at an alarming rate.
- More carbon dioxide in the atmosphere means more heat absorption. This could significantly raise the temperature at lower levels of the atmosphere thus inducing drastic climatic changes.

Ozone (O_3)

- Ozone (O_3) is a type of oxygen molecule consisting of three oxygen atoms.
- It forms less than 0.00005% by volume of the atmosphere and is **unevenly distributed**.
- It is between 20 km and 30 km altitude (**stratosphere**) that the greatest concentrations of ozone are found.
- It is **formed at higher altitudes (due to interaction between O_2 and UV light)** and transported downwards.
- Ozone plays a crucial role in **blocking the harmful ultraviolet radiation** from the sun.

Water Vapour

- Water Vapour is one of the most variable gaseous substances present in atmosphere – constituting between **0.02% and 4%** of the total volume (in cold dry and humid tropical climates respectively).
- 90% of moisture content in the atmosphere exists within 6 km of the surface of the earth.
- Like carbon dioxide, water vapour plays a significant role in the insulating action, of the atmosphere.
- It absorbs not only the **long-wave terrestrial radiation** (**infrared or heat emitted by earth** during nights), but also a part of the **incoming short-wave solar radiation (visible and UV radiation)**.



Electromagnetic Spectrum (Inductiveload, via Wikimedia Commons)

- Water vapour is the source of precipitation and clouds.
- On condensation, it releases **latent heat of condensation** — the ultimate driving force behind all storms.

Solid Particles

- The Solid Particles present in the atmosphere consist of sand particles (from weathered rocks and also derived from volcanic ash), pollen grains, small organisms, soot, ocean salts; the upper layers of the atmosphere may even have fragments of meteors which got burnt up in the atmosphere.
- These solid particles perform the function of **absorbing, reflecting and scattering the radiation**.
- The solid particles are, consequently, responsible for the **orange and red colours at sunset and sunrise** and for the **length of dawn** (the first appearance of light in the sky before sunrise) and **Twilight** (the soft glowing light from the sky when the sun is below the horizon, caused by the **refraction** of the sun's rays by the atmosphere. Dusk: the darker stage of twilight.).
- The blue colour of the sky is also due to **selective scattering by dust particles**.
- Some of the dust particles are **hygroscopic** (i.e. readily absorbing moisture from air) in character, and as such, act as **nuclei of condensation**.
- Thus, dust particles are an **important contributory factor in the formation of clouds and different forms of precipitation, fog and hailstones**, etc.

Mains 2015: How far do you agree that the behaviour of the Indian monsoon has been changing due to humanising landscapes? Discuss.

- Humanising landscapes refers to the large-scale interaction of humans with the natural environment and the consequent changes brought upon due to such interactions.
- Examples of such interactions include urbanisation, industrialisation, deforestation and desertification, depletion of water resources, etc.
- Consequences of such interactions include rapid increase in concentration of greenhouse gases and aerosols in the atmosphere, global climate change, changes in sea surface temperature, alarming rate of depletion of natural resource, imbalances in the ecosystems, etc.

Impact on Monsoons

- The increasing incidence of El Nino, La Nina, El Nino Modoki, IOD, due to climate change post-industrial revolution has an overarching effect on the overall mechanism of the Indian Monsoons.
- Localised pollution (condensation nuclei), deforestation, on the other hand, cause a change in regional monsoon patterns.
- The impact of El Nino, La Nina, El Nino Modoki, etc. will be discussed in the chapter on 'Indian Monsoons'.
- Here let us focus on the impact of condensation nuclei on the behaviour of the Indian monsoons.

High concentration of condensation nuclei disrupts regional patterns of Indian monsoons

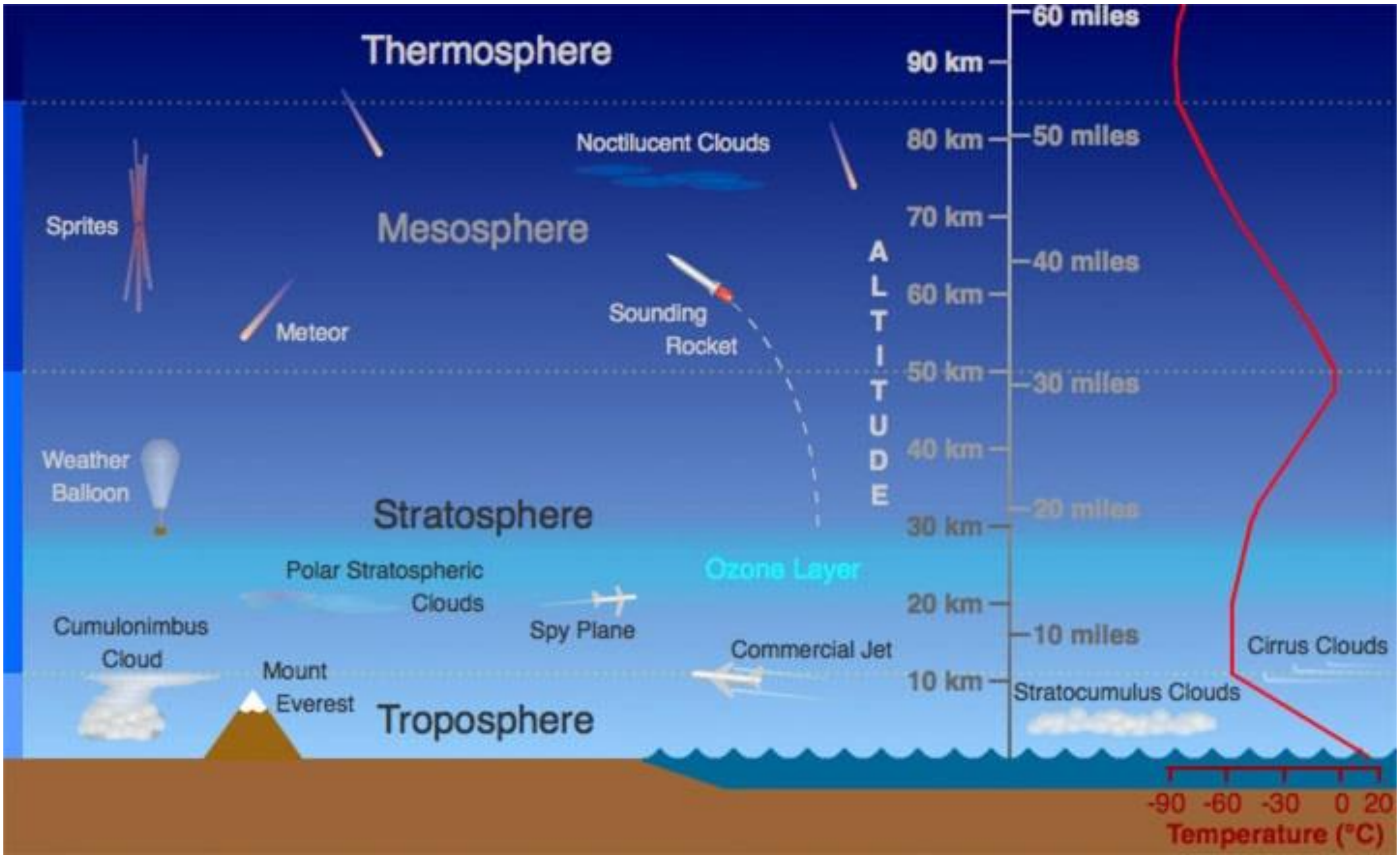
- Increase in the number of condensation nuclei due to increased availability of pollutants and dust particles will increase condensation of water vapour.
- As the urban atmosphere tends to have greater concentration of condensation nuclei due to vehicular pollution and construction activity, the monsoonal rainfall is disproportionately high in the urban areas.
- As a consequence, the agriculture-dependent rural areas tend to receive disproportionately low rainfall.

3.3 Structure of Atmosphere

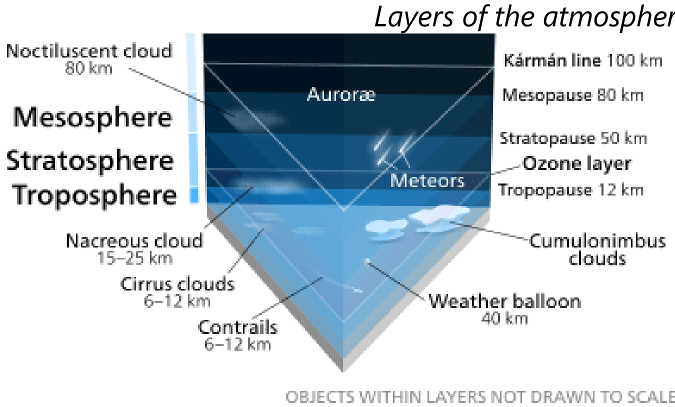
- The atmosphere can be studied as a layered entity – each layer having its peculiar characteristics. These layers are systematically discussed below.
  1. **Troposphere: 0 to 12 km**
  2. **Stratosphere: 12 to 50 km**
  3. **Mesosphere: 50 to 80 km**
  4. **Thermosphere: 80 to 700 km**
  5. **Exosphere: 700 to 10,000 km**

Troposphere

- Its altitude is 8 km at the poles and 18 km at the equator.



Layers of the atmosphere (*[Wikimedia Commons](#)*)



Layers of the atmosphere (Kelvinsong, [Wikimedia Commons](#))

- The **thickness is greater at the equator because of the heated air that rises to greater heights**.
- The troposphere ends with the Tropopause.
- The temperature in this layer, as one goes upwards, **falls** (positive lapse rate) at the rate of **6.5 °C per kilometre**.
- It is -45 °C at the poles and -80 °C over the equator at Tropopause (**greater fall in temperature above equator is because of the greater thickness of troposphere – 18 km**).
- The troposphere is marked by temperature inversion, turbulence and eddies.
- It is also meteorologically the most significant zone in the entire atmosphere (all weather phenomena like cyclones, rainfall, fog and hailstorm etc. are confined to this layer).
- It is also called the convective region since **all convection stops at Tropopause**.

Tropopause

- Topmost layer of troposphere.
- It acts as a boundary between troposphere and stratosphere.
- This layer is marked by constant temperatures.

Stratosphere

- It lies beyond tropopause, up to an altitude of 50 km from the earth's surface.
- The temperature in this layer remains constant for some distance but then rises (negative lapse rate) to reach a level of 0 °C at 50 km altitude.
- **This rise is due to the presence of ozone** (harmful ultraviolet radiation is absorbed by ozone).

- This layer is **almost free from clouds** and associated weather phenomenon, making conditions **most ideal for flying aeroplanes**.
- So, the aeroplanes fly in lower stratosphere, sometimes in upper troposphere where weather is calm.
- Sometimes, **cirrus clouds** are present at lower levels in this layer.

Ozonosphere

- It lies at an altitude between 20 km and 55 km from the earth's surface and spans the stratosphere and lower mesosphere. But the **highest concentration occurs between 20 km and 30 km**.
- Because of the presence of ozone molecules, **this layer absorbs and reflects the harmful ultraviolet radiation**.
- The **temperature rises** (negative lapse rate) at a rate of 5° C per kilometre through the ozonosphere.
- The ozonosphere is also called **chemosphere** because of a lot of chemical activity taking place.
- Ultraviolet light splits O_2 into individual oxygen atoms (atomic oxygen); the atomic oxygen then combines with unbroken O_2 to create ozone, O_3.
- The ozone molecule is unstable (although, in the stratosphere, long-lived) and when ultraviolet light hits ozone it splits into a molecule of O_2 and an individual atom of oxygen (**ozone-oxygen cycle**).
- Stratospheric ozone depletion is caused by chlorofluorocarbons, bromofluorocarbons and other ozone-depleting substances that increase the concentrations of **chlorine** and **bromine radicals**.
- Each of these radicals initiate and catalyse a chain reaction capable of breaking down over 100,000 ozone molecules.

Mesosphere

- Most of the **meteors burn up in this layer** on entering from the space.
- Temperatures drop with increasing altitude to the mesopause.
- **Mesopause is the coldest place on Earth** and has an average temperature around −85 °C.
- Just below the mesopause, the air is so cold that even the very scarce water vapour at this altitude can be sublimated into **polar-mesospheric noctilucent clouds**.
- These are the highest clouds and may be visible to the naked eye during sunset and sunrise.

Thermosphere

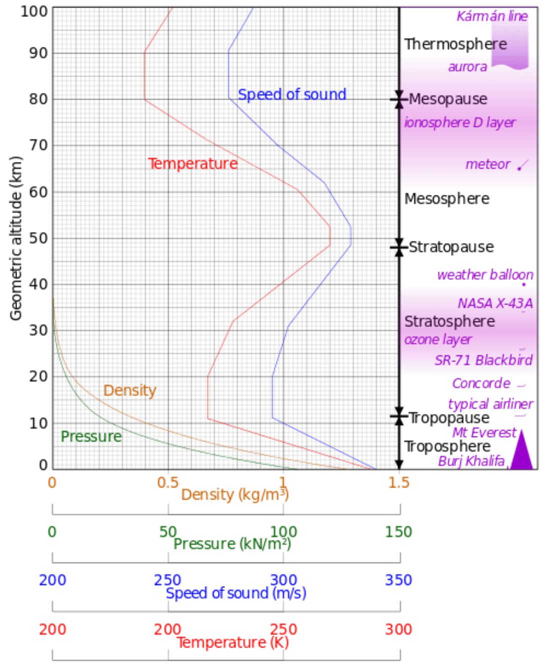
- In thermosphere temperature rises (negative lapse rate) very rapidly with increasing height **because of radiation from the sun**.
- **Ionosphere** is a part of this layer. It extends between 80-400 km.
- Though temperature is high, the atmosphere is **extremely rarefied** – gas molecules are spaced hundreds of kilometres apart. Hence a person or an object in this layer doesn't feel the heat.
- **The International Space Station and satellites orbit in this layer**.
- **Aurora's** are observed in lower parts of this layer.
- The **Kármán line**, located within the thermosphere at an altitude of 100 km, is commonly used to define the boundary between Earth's atmosphere and outer space.
- By international convention, this marks the beginning of space where human travellers are considered astronauts.

The mass of Earth's atmosphere is distributed approximately as follows:

- ✓ ***50% is below 5.6 km.***
- ✓ ***90% is below 16 km.***
- ✓ ***99.99997% is below 100 km, the Kármán line.***

Speed of sound follows temperature profile

- *This is because speed of sound is directly proportional to temperature as we move away from earth.*
- *Because in an ideal gas of constant composition the speed of sound depends only on temperature and not on the gas pressure or density.*



Speed of sound follows temperature profile

Exosphere

- This is the uppermost layer of the atmosphere extending beyond the ionosphere above a height of about 400 km.
- The air is extremely rarefied, and the temperature gradually increases through the layer.
- Light gases like helium and hydrogen float into the space from here.
- Temperature gradually increases through the layer (as it is exposed to direct sunlight).
- This layer coincides with space.

Atmospheric escape

- Certain light gases like hydrogen are constantly lost into space from exosphere due to atmospheric escape.
- Atmospheric escape of gases (**atmospheric stripping**) happens when gas molecules achieve escape velocity due to **low gravity** or due to energy received from the sun (heat, solar wind).
- Jovian planets retain gases with low molecular masses because of low temperatures and higher gravity.
- Titan, a moon of Saturn, and Triton, a moon of Neptune, possess significant nitrogen-rich atmospheres.
- **Earth's magnetic field** reduces atmospheric escape by protecting the atmosphere from solar wind that would otherwise greatly enhance the escape of hydrogen.

3.4 Importance of Earth's Atmosphere

- Earth is unique among plants as it has life and life on earth would not have been possible if not for the present state of atmosphere.

Life-giving gases

- Plants require carbon dioxide to survive while animals and many other organisms need oxygen for their survival.
- Nitrogen is fixed by bacteria and lightning to produce ammonia used in the construction of nucleotides and amino acids.

Regulates the entry of solar radiation

- All life forms need a particular range of temperature and a specific range of frequencies of solar radiation to carry out their biophysical processes.
- The atmosphere absorbs certain frequencies and lets through some other frequencies of solar radiation. In other words, the atmosphere regulates the entry of solar radiation.

Temperature balance

- The atmosphere also keeps the temperature over the earth's surface within certain limits.
- In the absence of the atmosphere extremes of temperature would exist between day and night.

Blocks harmful radiation

- The atmosphere helps to protect living organisms from genetic damage by solar ultraviolet radiation, solar wind and cosmic rays.

Shields the earth from impact objects

- The atmosphere also takes care of extra-terrestrial objects like meteors which get burnt up while passing through the atmosphere (**mesosphere** to be precise) due to friction.

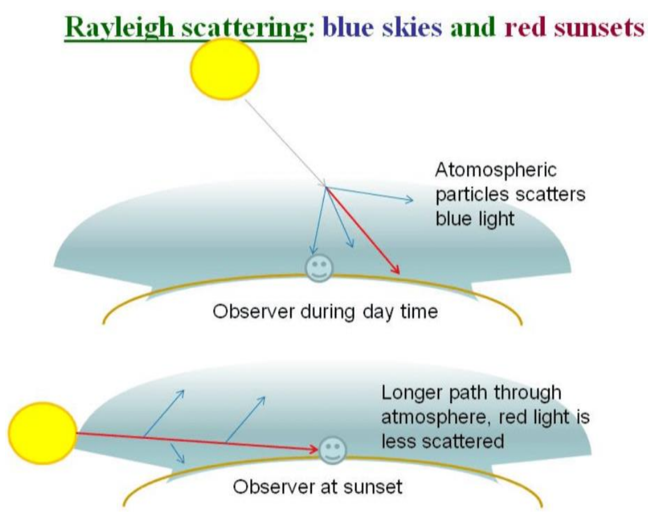
Weather and climate

- Weather is another important phenomenon which dictates the direction of many natural and human-made processes like plant growth, agriculture, soil-formation (weathering and erosion), human settlements, etc. Various climatic factors join together to create weather.

Water on earth exists in liquid state due to Atmosphere

- Since **liquids cannot exist without pressure**, an atmosphere allows liquid to be present at the surface, resulting in lakes, rivers and oceans.
- Earth and **Titan** are known to have liquids at their surface and terrain on the planet suggests that Mars had liquid on its surface in the past.

Scattering of light



Scattering by atmosphere (Credits)

- When light passes through Earth's atmosphere, photons interact with it through scattering.
- On an overcast, there is no direct radiation as it has all been scattered by the clouds.
- Due to a phenomenon called **Rayleigh scattering, shorter (blue) wavelengths scatter more easily than longer (red) wavelengths**. This is why the sky looks blue; you are seeing scattered blue light.
- This is also why sunsets are red. Because the Sun is close to the horizon, the Sun's rays pass through more atmosphere than normal to reach your eye. Much of the blue light has been scattered out, leaving the red light in a sunset.

4. Temperature Distribution on Earth

- The **differential amount of sun's energy received** by various latitudinal zones on earth is the primary reason behind the occurrence of seasonal patterns of weather and climate.
- Thus, understanding the patterns of distribution of temperature in different seasons is important for understanding various climatic features like wind systems, pressure systems, precipitation etc.

4.1 Ways of Transfer of Heat Energy

Radiation

- Radiation **doesn't** require a medium for heat transfer.
- Heat is transferred from one body to another **without actual contact or movement in the medium**.
- E.g. Heat transfer from sun to earth through space.

Insolation

- **Insolation** is the amount of sun's energy received in the form of radiation by the earth.
- It is measured as the amount of solar energy received per square centimetre per minute.
- Earth intercepts less than a billionth of solar radiation.
- Earth receives sun's radiation in the form of **short waves (visible light or wavelengths below visible light – most of it is ultraviolet radiation)** which are electromagnetic.
- The earth absorbs short wave radiation during daytime and reflects the **heat** received into space as **long-wave radiation (mostly infrared radiation which is nothing but heat)** during night.

Conduction

- The heat transfer through conduction happens due to **molecular activity** in a conducting medium. There is no actual movement of the medium itself.
- Generally, denser materials like iron, water are good conductors, and lighter medium like air are bad conductors of heat.

Convection

- Convection is the transfer of heat energy by **actual transfer of matter** or substance from one place to another. E.g. heat transfer by convection cells in a boiling pot of water, atmosphere or oceans.

Heat from the interior

- Some heat from within the earth's interior is transferred to the surface through volcanoes, springs and geysers. But this heat received at the surface is negligible compared to that received from sun.
- However, the heat received from the interior at the ocean bottom is key to the survival of deep ocean lifeforms that depend on bacteria that grow near the volcanic vents.
- At ocean depths, as sunlight is non-existent, photosynthesis is impossible. The bacteria rely on **chemosynthesis**, a process in which microbes use **chemicals** in the vent fluid to produce energy.

4.2 Factors Affecting Temperature Distribution

- The Angle of Incidence or the Inclination of the Sun's Rays
- Duration of Sunshine
- Transparency of Atmosphere
- **Albedo**
- Land-Sea Differential
- Prevailing Winds
- Ocean Currents
- Altitude
- Aspects of Slope
- Earth's Distance from Sun

The Angle of Incidence or the Inclination of the Sun's Rays

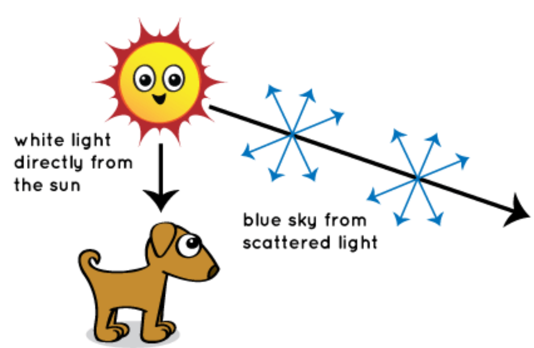
- The area lying close to the equator receive the maximum heat due to near vertical rays of the sun.
- The sun's rays get progressively slanting as one moves away from the equator towards poles.
- As a result, the heat received from the sun decrease as the distance increases from the equator.
- Areas lying close to the poles receive the least of sun's energy as the sun's rays are near horizontal.

Duration of Sunshine

- Heat received depends on day or night; clear sky or overcast, summer or winter etc.
- Earth's atmosphere plays an important role in moderating the temperatures between seasons and between days and nights.

Transparency of Atmosphere

- Aerosols (smoke, sooth, pollen), dust, water vapour, clouds etc. effect transparency.
- **If the wavelength of the radiation is more than the radius of the obstructing particle (such as a gas)**, then **scattering** of radiation takes place.



Scattering of Sun's light (NASA)

- If the wavelength is less than the obstructing particle (such as a dust particle), then **reflection** takes place.

- **Absorption** of solar radiation takes place if the obstructing particles happen to be **water vapour, ozone molecules, carbon dioxide molecules or clouds** (**Greenhouse effect**).
- Most of the light received by earth is **scattered light**.

Albedo

- **Albedo** of a surface is the proportion of sunlight that the surface can reflect back into space.
- Albedo of land is much greater than albedo of oceans and water bodies.
- Snow-covered areas reflect up to 70-90% of insolation.

Land-Sea Differential

- The **specific heat of water is 2.5 times higher than landmass**; therefore water takes longer to get heated up and to cool down.
- Average penetration of sunlight is more in water – up to 20 metres than in land – where it is up to 1 metre or less. Therefore, land cools or becomes hot more rapidly compared to oceans.
- In oceans, continuous convection cycle helps in heat exchange between layers **keeping diurnal and annual temperature ranges low**.

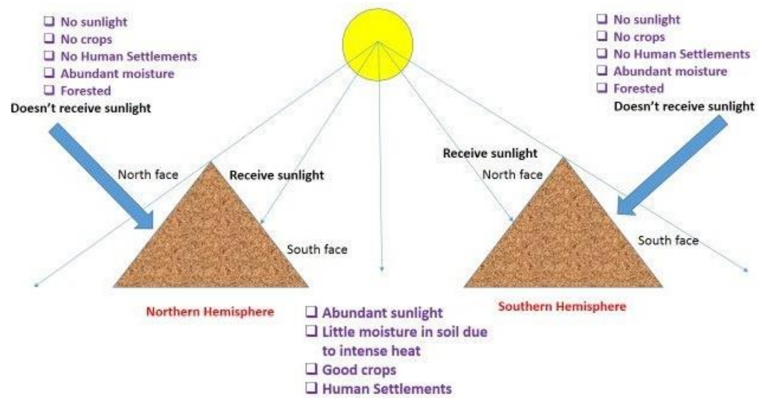
Temperature Anomaly

- The difference between the mean temperature of a place and the mean temperature of its parallel (latitude) is called the **temperature anomaly or thermal anomaly**.
- The **largest anomalies occur in the northern hemisphere and the smallest in the southern hemisphere.**

Prevailing Winds

- Winds transfer heat from one latitude to another. E.g. Poles would have been much colder if it is not for the moderating effect by the atmospheric circulation.
- Winds also help in exchange of heat between land and water bodies. E.g. **Land breeze and sea breeze**.

Aspects of Slope



Insolation along a sloping surface

- The direction and the steepness of the slope control the amount of solar radiation received locally.
- Slopes more exposed to the sun receive more solar radiation than those away from the sun's direct rays.
- Slopes that receive direct Sun's rays are dry due to **loss of moisture** through excess evaporation. These slopes remain barren if irrigational facilities are absent.
- But slopes with good irrigational facilities are good for agriculture due to abundant sunlight available. They are occupied by **dense human settlements**.
- Slopes that are devoid of direct sunlight are usually well forested.

Ocean Currents

- Ocean currents influence the temperature of adjacent land areas considerably.
- For example, U.K., considering its latitudinal location, has a relatively moderate climate due to the **warm North Atlantic Drift**.

Altitude

- With increase in height, pressure falls, the effect of greenhouse gases decreases and hence temperature decreases (applicable only to troposphere).
- The normal **lapse rate is roughly 1 °C for every 150-155 metres** of ascent (in troposphere).

Earth's Distance form Sun

- During its revolution around the sun, the earth is farthest from the sun **(~152 million km)** near **4th July**. This position of the earth is called **aphelion.**
- Near **3rd January**, the earth is the nearest to the sun **(~147 million km).** This position is called **perihelion.**
- Therefore, the annual insolation received by the earth on 3rd January is slightly more than the amount received on 4th July.
- However, the effect of this variation in the solar output is masked by other factors like the **distribution of land and sea and the atmospheric circulation**.
- Hence, this variation in the solar output does not have great effect on daily weather changes on the surface of the earth.

4.3 The Mean Annual Temperature Distribution

- The horizontal or latitudinal distribution of temperature is shown with the help of a map with isotherms.
- The Isotherms are imaginary lines joining places having equal temperature.
- Effects of altitude is not considered while drawing an isotherm (temperatures are reduced to sea levels).

General characteristics of isotherms

Generally, follow the parallels

- Isotherms have close correspondence with the latitude parallels mainly because the same amount of insolation received by all the points located on the same latitude.
- The isotherms are irregular over the northern hemisphere due to an **enhanced land-sea contrast**.
- The thermal equator (ITCZ) generally lies to the north of geographical equator.

Sudden bends at ocean-continent boundaries

- Due to differential heating of land and water and due to ocean currents, temperatures above the oceans and landmasses vary even on the same latitude.

Spacing between isotherms

- Narrow spacing between isotherms indicate high thermal gradient (rapid change in temperature).
- Wide spacing between isotherms indicate low thermal gradient (small or slow change in temperatures).

General Temperature Distribution

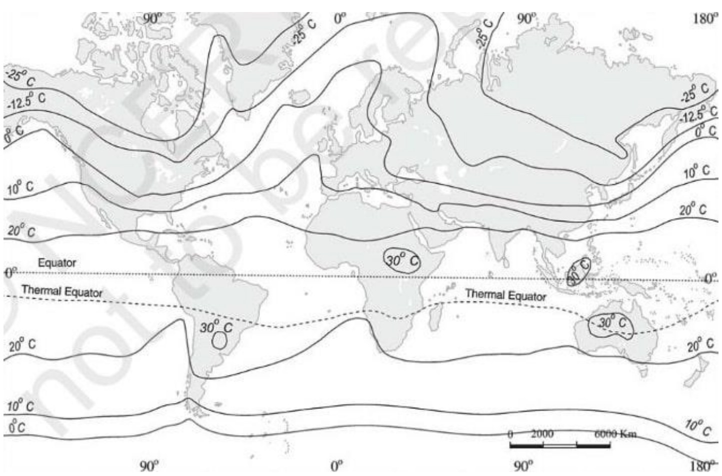
- The highest temperatures occur over tropics and subtropics.
- The lowest temperatures occur in polar and sub-polar regions and the interiors of large continental subpolar regions due to the effect of **continentality** (far from the moderating effect of the seas).
- Diurnal (daily) and annual range of temperatures are highest in the interiors of continents due to **continentality**.
- Diurnal and annual range of temperatures are least in oceans because of **high specific heat and mixing**.
- The **northern hemisphere is warmer** because of the **predominance of land over water** in the north.
- Low-temperature gradients are observed over tropics (sun is almost overhead the entire year).
- High-temperature gradients are observed over middle and higher latitudes (sun's apparent path varies significantly from season to season).
- Temperature gradients are usually low over the eastern margins of continents because of **warm ocean currents**.
- While passing through an area with warm ocean currents, the isotherms show a **poleward shift**.
- E.g. North Atlantic Drift and Gulf Stream in Northern Atlantic; Kurishino Current and North Pacific current combined in Northern Pacific.
- Temperature gradients are usually high over the western margins of continents because of **cold ocean currents**.

- Mountains also affect the horizontal distribution of temperature. For example, the Himalayas insulate India from the cold winds of Siberia, the Rockies and the Andes block the oceanic influence from going inwards into North and South America.

Seasonal Temperature Distribution

- In general, the effect of the latitude on temperature is well pronounced on the map, as the isotherms are generally parallel to the latitude.
- The deviation from this general trend is more pronounced in January than in July, especially in the northern hemisphere **because of the land surface area** which is much larger than in the southern hemisphere.

Seasonal Temperature Distribution – January



Isotherm map for the month of January

- During January, it is winter in the northern hemisphere and summer in the southern hemisphere.

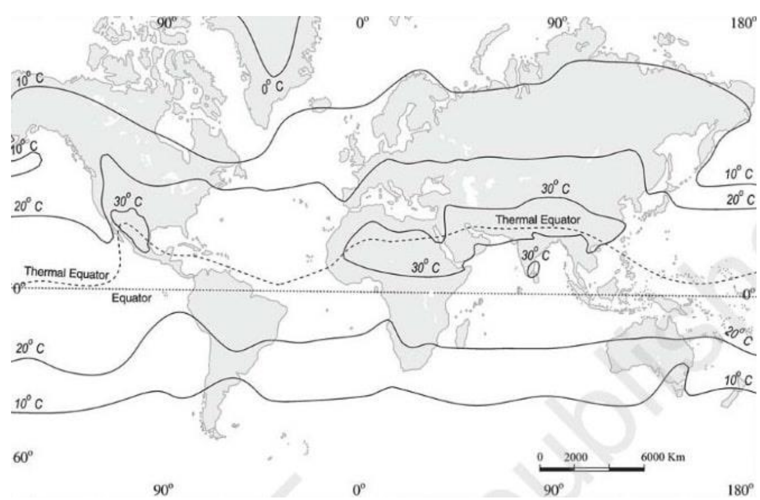
Northern Hemisphere

- The western margins of continents are warmer than their eastern counterparts since the **Westerlies** are able to carry high temperature (from the oceans) into the landmasses.
- The isotherms are closer on the eastern margins as temperature gradient is high because of the **less moderating effect of the oceans** (westerlies flow from west to east).
- The isotherms deviate to the north over the ocean.
- For example, the presence of **warm Gulf Stream and North Atlantic drift** make the Northern Atlantic warmer and the isotherms show a poleward shift indicating that the currents are able to carry high temperatures poleward.
- The isotherms deviate to the south over the continents (**due to continentality**) as the cold polar winds are able to penetrate southwards into the interiors.
- Lowest temperatures are recorded over northern Siberia and Greenland.

Southern Hemisphere

- The effect of the ocean is well pronounced in, and the isotherms exhibit a more regular behaviour.
- The isotherms are more or less parallel to the latitudes, and the variation in temperature is gradual.
- The high-temperature belt runs in the southern hemisphere, somewhere along 30° S latitude (**subtropics are devoid of cloud cover due to anticyclonic circulation at the surface**).
- The thermal equator lies to the south of geographical equator (because the Intertropical Convergence Zone or ITCZ has shifted southwards with the apparent southward movement of the sun).

Seasonal Temperature Distribution – July



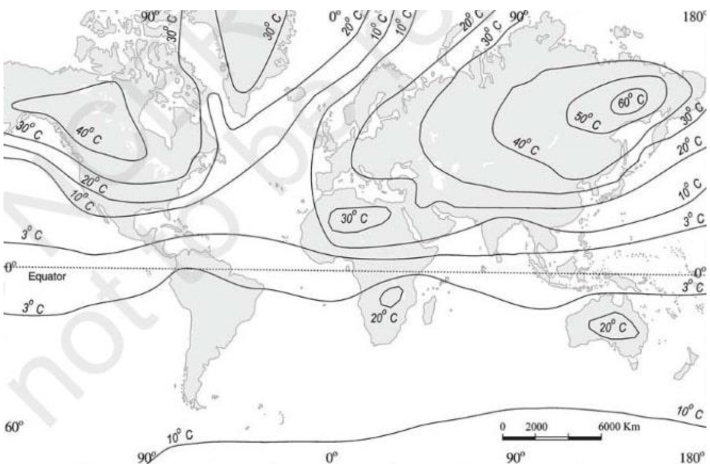
Isotherm map for the month of July

- During July, it is summer in the northern hemisphere and winter in the southern hemisphere.

- The isotherms generally run parallel to the latitudes.
- Thermal equator lies to the north of the geographical equator.
- The equatorial oceans record warmer temperature, more than 27 °C.
- Over the land more than 30 °C is noticed in the subtropical continental region of Asia, along the 30° N latitude.

Northern Hemisphere

- The highest annual range of temperature is more than 60° C over the Siberian region (**continentality**).
- The least range of temperature, 3° C, is found between 20° S and 15° N.



The range of temperature between January and July. It is highest in the Siberian region

- Over the northern continents, a poleward bend of the isotherms indicates that the landmasses are overheated, and the hot tropical winds are able to go far into the northern interiors.
- The isotherms over the northern oceans show an equatorward shift indicating that the **oceans are cooler** and are able to **carry the moderating effect into tropical interiors**.
- The lowest temperatures are experienced over Greenland.
- The highest temperature belt runs through northern Africa, West Asia, north-west India arid south-eastern USA.
- The temperature gradient is irregular and follows a zig-zag path over the northern hemisphere.

Prelims Practise: The main reason that the earth experiences highest temperatures in the subtropics in the northern hemisphere rather than at the equator is:

a) Subtropical areas tend to have less cloud cover than equatorial areas.
b) Subtropical areas have longer day hours in the summer than the equatorial.
c) Subtropical areas have an enhanced "greenhouse effect" compared to equatorial areas.
d) Subtropical areas are nearer to the oceanic areas than the equatorial locations.

Explanation:

- There is no cloud cover in the subtropics because of the subsiding air and the consequent divergence (anticyclonic circulation) at the surface.
- Subtropical areas have longer day hours in the summer than the equatorial, but the difference is not substantial.
- Moreover, the weather in the equatorial region is turbulent with dense overcast skies and most of the heat is lost in the form of **latent heat of vaporisation**.

Answer: a) Subtropical areas tend to have less cloud cover than equatorial areas.

Southern Hemisphere

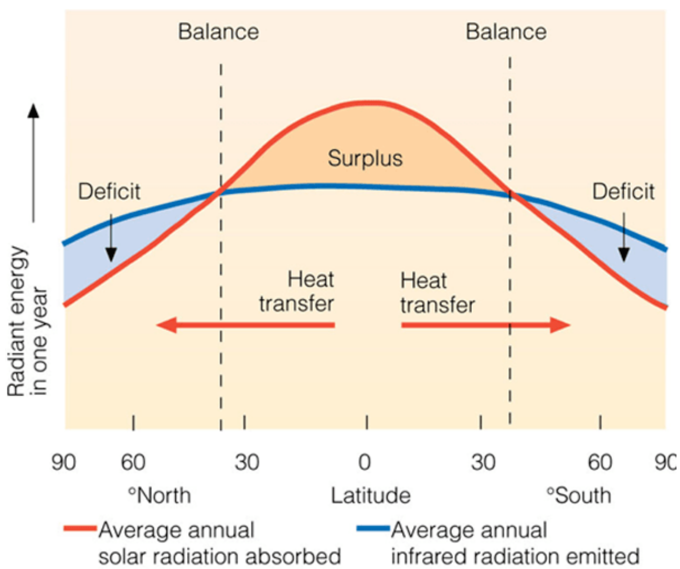
- The gradient becomes regular over the southern hemisphere but shows a slight bend towards the equator at the edges of continents.

4.4 Latitudinal Heat Balance

- Regions within the equator and 40° N and S latitudes receive abundant sunlight and hence more heat will be gained than lost. Hence, they are **energy surplus regions.**
- Regions beyond 40° N and S latitudes lose more heat than that gained from sunlight. Hence, they are **energy deficit regions** (because of **slant sunlight and high albedo of polar regions**).
- Going by this logic, the tropics should have been getting progressively hotter and the poles

progressively cooler. And the planet would have been inhospitable except for few regions near mid-latitudes.

- But this is not the case as the atmosphere and the oceans transfer excess heat from the tropics (energy surplus region) towards the poles (energy deficit regions) making up for heat loss at higher latitudes.
- And **most of the heat transfer takes place across the mid-latitudes (30° to 50)**, and hence much of the **stormy weather (jet stream and temperate cyclones)** is associated with this region.
- Thus, the transfer of surplus energy from the lower latitudes to the deficit energy zone of the higher latitudes maintains an overall balance over the earth's surface.



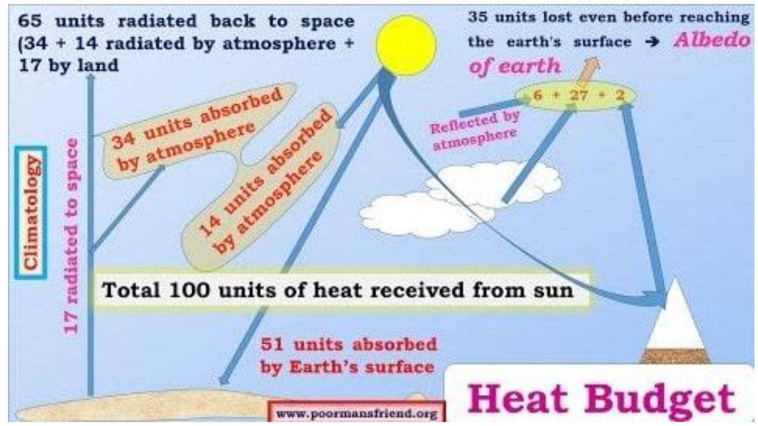
Latitudinal Heat Balance (Credit: NASA)

4.5 Heat Budget

- The earth receives a certain amount of Insolation **(short waves – UV and visible part of the electromagnetic spectrum)** and gives back **heat** into space by terrestrial radiation **(longwave or infrared radiation).**
- Through this give and take, or the heat budget, the earth maintains a constant temperature.

Prelims Practise: The atmosphere is mainly heated by the:

a) Short wave solar radiation
b) Long wave terrestrial radiation
c) Reflected solar radiation
d) Scattered solar radiation



Explanation:

- 51 units of the incoming shortwave (daytime) radiation is directly absorbed by the earth's surface.
- **35 units are lost even before reaching the surface** due to albedo (2 units), reflection by atmosphere (6 units) and reflection by the clouds (27 units).
- The remaining 14 units of the incoming shortwave (daytime) radiation is absorbed by the atmosphere.
- Hence, the incoming shortwave radiation is responsible for only 14 units out of the **total 48 units absorbed by the atmosphere**.
- The remaining **34 units are received from the outgoing longwave (infrared) terrestrial radiation**.

Answer: d) Long wave terrestrial radiation

Answer in 30 words

1) How does the unequal distribution of heat over the planet earth in space and time cause variations in weather and climate?
2) What are the factors that control temperature distribution on the surface of the earth?
3) In India, why is the day temperature maximum in May and why not after the summer solstice? (Hint: **By June 21st Monsoons cover more than half of India**)
4) Why is the annual range of temperature high in the Siberian plains? (Hint: **Continentality**)

Answer in 150 words

1) How do the latitude and the tilt in the axis of rotation of the earth affect the amount of radiation received at the earth's surface?
2) Discuss the processes through which the earth-atmosphere system maintains heat balance.
3) Compare the global distribution of temperature in January over the northern and the southern hemisphere of the earth.

4.6 Vertical Distribution of Temperature

To understand the vertical distribution of temperature we need to know about latent heat, lapse rate and adiabatic lapse rate
The terms 'Adiabatic Lapse Rate' and 'Latent Heat of Condensation' frequently occur in climatology. Understanding these terms once for all will help immensely in understanding the subsequent topics of climatology.

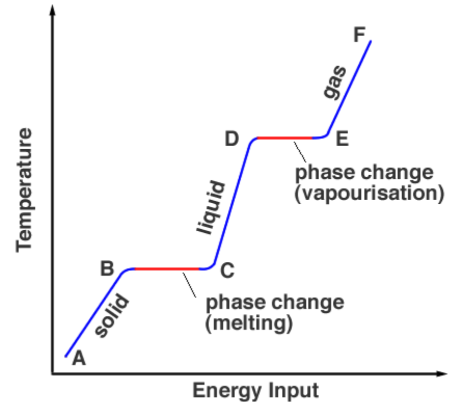
Latent Heat of Condensation

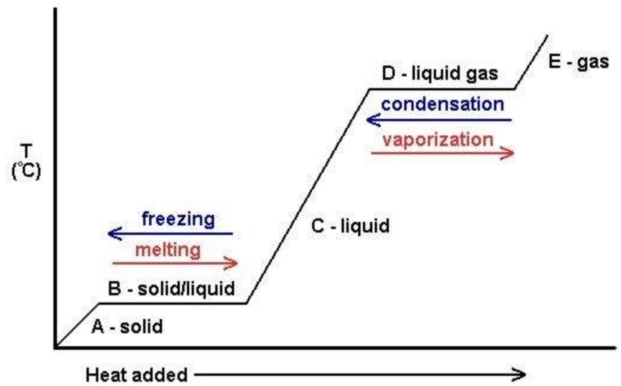
- Adiabatic lapse rate determines the **rate of condensation** in the atmosphere which in turn determines the amount of **latent heat of condensation** released.
- The heat released in the form of **latent heat of condensation** supplies the energy necessary for the formation of towering cumulonimbus thunderstorm cloud and the formation of tropical cyclones.

Latent Heat

- Latent heat is the amount of energy absorbed or released by a substance during a change in its physical state (phase change) that occurs **without changing its temperature**.
- For example, when a pot of water is kept boiling, the temperature remains at 100 °C until the last drop evaporates because all the heat being added to the liquid is absorbed as **latent heat of vaporisation** and carried away by the escaping vapour molecules.
- Similarly, while ice melts, it remains at 0 °C, and the liquid water that is formed with the **latent heat of fusion** is also at 0 °C.

Explanation





Graph: On X – axis: Heat supplied to the system; On Y – Axis: Temperature change in the system

- From the above graph, we can observe that there is no change in temperature in the system during change of state or phase change. Then where did the heat supplied go?
- Initially, the heat supplied is used to raise the temperature of the system (A-B and then C-D)
- During phase change, the heat supplied is consumed to turn solid into liquid (B-C: **latent heat of fusion – heat absorbed**) and then liquid into gas (D-E: **latent heat of vaporisation – heat absorbed**).
- Thus, the heat supplied in used in phase change. Hence temperature of the system remains constant during phase change process. (B-C & D-E)
- But when gas turns into liquid (**latent heat of condensation – heat released**) or liquid into solid (**latent heat of fusion – heat released**), heat is released (this heat is the heat that was used during the phase change process).
- **Thus, latent heat of condensation is the heat released when gases turn into liquid**.

When water vapour in atmosphere condenses into raindrops latent heat of condensation is released. Water evaporates from the ocean surface by absorbing latent heat of vaporisation.

Lapse Rate

- Lapse rate (**Temperature Lapse** or **Temperature Lapse Rate**) is the rate of change in temperature of the atmosphere with altitude (elevation).
- The lapse rate is considered **positive** when the temperature decreases with elevation, **zero** when the temperature is constant with elevation, and **negative** when the temperature increases with elevation **(temperature inversion)**.
- Hence, the lapse rate of troposphere below tropopause is positive, the lapse rate of tropopause is zero, and the lapse rate of stratosphere is negative.
- The fall in temperature with altitude is primarily due to the following reason:
  - ✓ Atmosphere is mostly transparent to in the incoming shortwave radiation but actively absorbs the outgoing terrestrial (longwave) radiation.
  - ✓ Greenhouse house gases like CO_2, water vapor, are the primary absorbers of the terrestrial radiation and their concentration is highest at the earth's surface and goes on decreasing with altitude. Hence, temperature falls with altitude.
- The lapse rate of **non-rising air (environmental lapse rate)** is highly variable, being affected by **radiation, convection, condensation and concentration of greenhouse gases**.
- It averages about **6-6.5 °C per kilometre (1 °C for every 153-165 metres)** in the lower atmosphere (troposphere).

Adiabatic Lapse Rate (ALR)

- Lapse rate is the rate of fall in temperature of atmosphere with elevation.
- Adiabatic Lapse Rate is the rate of fall in temperature of a **rising or a falling** air parcel adiabatically.
- Adiabatic change refers to the **change in temperature with pressure**.
- Adiabatic Lapse rate is governed by **Gas law.**

Adiabatic or adiabatically: *Heat* ***doesn't*** *enter or leave the system. All temperature changes are internal.*
Gas law*: According to gas law Pressure 'P' is directly proportional to Temperature 'T' when Volume 'V' is a constant.*

Relation between pressure, temperature and volume

Example 1: A balloon

- When we blow air into a balloon, pressure increases but temperature doesn't increase due to proportionate increase in volume (here V is not constant).
- When excess air is blown, balloon bursts as it cannot withstand the pressure.

Example 2: Vehicle tube

- In a vehicle tube, volume remains constant. When air is blown, pressure increases and hence the temperature.
- We are usually advised not to have full-blown tubes because when vehicle travels on a road, the friction between the tire and the road increases the temperature of the air in the tube.
- As temperature is directly proportional to pressure, increase in temperature leads to increase in pressure and at certain pressure threshold, the tire bursts.

The above examples explain the relation between Pressure, Temperature and Volume.
But the processes are **non-adiabatic** as there is (will be) heat exchange between the system and the external environment.

Adiabatic Process: Temperature changes in a parcel of rising or falling air

- An air bubble rises in water whereas stone sinks. This is obvious. The stone is denser (heavier than water), and it sinks whereas the air bubble is less dense (lighter than water) and it rises.

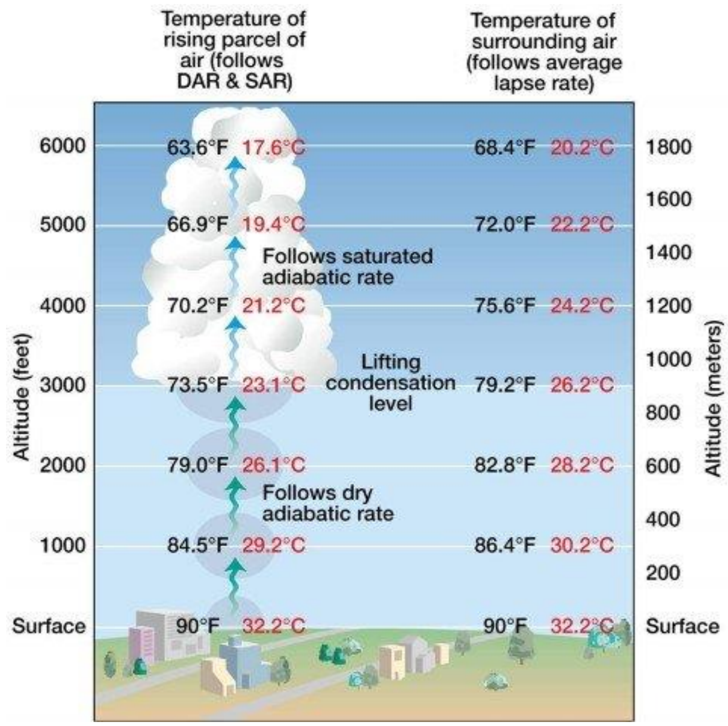
- Similarly, a parcel of air rises when it is less dense than the surrounding environment, and it falls when its density becomes greater than the surrounding environment.
- When an air parcel is subjected to differential heating compared to the surrounding air, it becomes lighter (less dense) or heavier (denser) depending on whether the air parcel is heated or cooled.

A parcel of rising or falling air

- When an air parcel receives more heat than the surrounding air, its temperature increases leading to an increase in volume (increase in volume implies the air parcel is getting less dense).
- The air parcel becomes lighter than the surrounding air, and it starts to rise. This process is **non-adiabatic** (there is heat exchange between the air parcel and the external environment).
- But when the air parcel starts to rise, the ambient pressure on it starts to fall (the atmospheric pressure decreases with height, so the pressure on the air parcel decreases with height).
- With the fall in ambient pressure, the volume of the air parcel increases and the hence the temperature of the air parcel falls (gas law).
- This is an **adiabatic** process as there is no heat exchange between the air parcel and the external environment. Temperature changes are only due to change in pressure or volume or both.
- This fall in temperature with the rising of the air parcel is called **adiabatic temperature lapse.**
- And the rate at which it happens is called **adiabatic lapse rate** (this is **positive** adiabatic lapse rate as the temperature is falling).
- The fall in temperature aids condensation of water vapour. Condensation of water vapour releases **latent heat of condensation** in the process.
- The latent heat of condensation is the **major driving force behind tropical cyclones, convectional rain.**
- Rising of a parcel of air (and associated positive adiabatic lapse rate) is the first step in the formation of thunderstorms, tornadoes and cyclones.

A parcel of falling air

- When an air parcel is in the upper levels, it gets cooled due to lower temperatures (because of lapse Rate).
- Its volume falls, and its density increases. When it becomes denser than the surroundings, it starts to fall.
- This also happens when an air parcel is in contact with cooler surfaces like mountain slopes.
- The beginning of fall is a non-adiabatic process as there is an exchange of heat between the air parcel and the surrounding environment.
- When an air parcel is falling, the atmospheric pressure acting on it will increase, and its internal temperature will increase adiabatically (this is negative adiabatic lapse rate as the temperature is rising).



Adiabatic Lapse Rate and Lapse Rate

- ***Lapse Rate*** ➔ *change in temperature with height.*
- ***Adiabatic Lapse Rate*** ➔ *change in temperature of a rising parcel of air without either losing heat to the external environment or gaining heat from the external environment.*
- ***Rising parcel of air*** ➔ *On ascent, the air expands as pressure decreases. This expansion reduces the temperature and aids condensation of water vapour. Condensation of water vapour releases the* ***latent heat of condensation*** *in the process.*

- ***Falling parcel of air*** ➔ *On descent through atmosphere, the lower layers are compressed under atmospheric pressure. As a result, the temperature increases.*
- ***Katabatic Wind*** ➔ *a hot dry wind that blows down a mountain slope. It is an example for a falling parcel of air in which the temperature changes happening adiabatically.*

Dry Adiabatic Lapse rate (DALR)

- The Dry Adiabatic Lapse Rate (DALR) is the rate of fall in temperature with altitude for a parcel of **dry or unsaturated air** (air with less moisture) rising under adiabatic conditions.
- Unsaturated air has less than 100% relative humidity.

Saturated air ➔ *The air cannot hold any more moisture. Its stomach is full.*
Unsaturated air ➔ *Its stomach is not full. It can accommodate some more moisture.*

- When a rising air parcel has little moisture (below normal), condensation during upliftment is low, the latent heat of condensation released is low (less additional heat from inside).
- As a result, the fall in temperature with height is greater compared to the adiabatic lapse rate of a normal parcel of air.
- The dry adiabatic lapse rate for the Earth's atmosphere is around **9.8 °C per kilometre**.
- Dry Adiabatic Lapse rate is mainly associated with **stable conditions (because it has less moisture).**

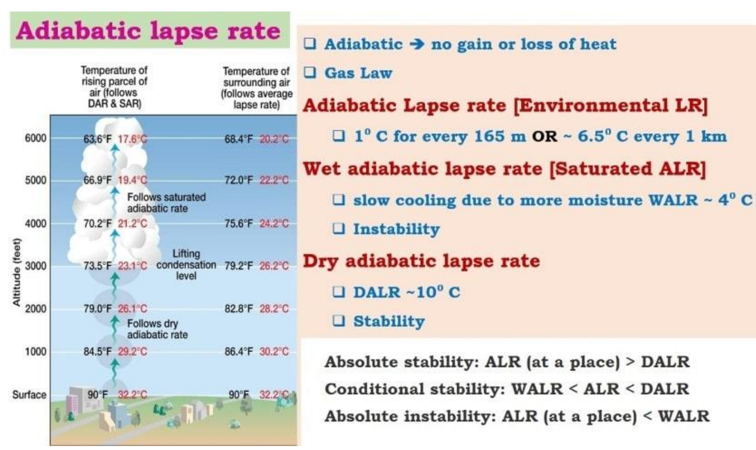
Wet Adiabatic Lapse Rate (WALR)

- When an air parcel that is saturated (stomach full) with water vapour rises, some of the vapour will condense and release latent heat (additional heat from inside).
- This process causes the parcel to cool more slowly than it would if it were not saturated.
- The moist adiabatic lapse rate varies considerably because the amount of water vapour in the air is highly variable.
- The greater the amount of vapour, the smaller the adiabatic lapse rate (because the condensation process keeps on adding more latent heat of condensation). On an average, it is taken as **4 °C per kilometre**.
- Wet Adiabatic Lapse rate is mainly associated with **unstable conditions (because it has more moisture).**
- As an air parcel rises and cools, it may eventually lose its moisture through condensation; its lapse rate then increases and approaches the dry adiabatic value.

Significance in meteorology (weather forecasting)

- The difference between the normal lapse rate in the atmosphere and the dry and moist adiabatic lapse rates determines the vertical stability of the atmosphere.
- For this reason, the lapse rate is of prime importance to meteorologists in forecasting certain types of cloud formations, the incidence of thunderstorms, and the intensity of atmospheric turbulence.

Weather conditions at different adiabatic lapse rates



Weather conditions at different adiabatic lapse rates

- **LR = 6 °C/km**
- **DALR ➔ ALR > 6 °C/km**
- **WALR ➔ ALR < 6 °C/km**

- ***Absolute stability: ALR (at a place) > DALR ➔ Little moisture in the air parcel (it won't rain)***
- ***Conditional stability: WALR < ALR < DALR ➔ Normal moisture conditions (it may or may not rain)***
- ***Absolute instability: ALR (at a place) < WALR ➔ Excess moisture in the air parcel (it will rain)***

Absolute stability: ALR (at a place) > DALR

- The above condition means that there is little moisture in air.
- When there is little moisture, condensation of water vapour is low, so latent of condensation released will be low, and the rising parcel of air gets cold quickly, and it falls to the ground once it becomes denser.
- So, there will be no cloud formation, and hence there will be no rain (thunderstorms).
- This simply means that the condition is stable.

Conditional stability: WALR < ALR < DALR

- The above condition means that there is enough moisture in air and there are chances of thunderstorms.
- When there is considerable moisture in the air parcel, condensation of water vapour will be reasonably high, so latent of condensation released will be adequate to drive a thunderstorm.
- The occurrence of thunderstorm depends on external factors.
- So, the weather will be associated with conditional stability (it may rain, or it may not rain)

Absolute instability: ALR (at a place) < WALR

- The above condition means that there is more moisture in air and there will be thunderstorms.
- When there is unusually high moisture in the air parcel, condensation of water vapour will be very high, so latent of condensation released will be great enough to drive a violent thunderstorm.
- So, the weather will be associated with absolute instability.

Temperature Inversion

UPSC mains 2013: What do you understand by phenomenon of "temperature inversion" in meteorology? How does it affect weather and habitants of the place?

- **Under normal conditions, temperature usually decreases with altitude (positive lapse rate)**.
- Temperature inversion is a reversal of the normal behaviour of temperature in the troposphere, in which a layer of cool air at the surface is overlain by a layer of warmer air (temperature increases with altitude — negative lapse rate).
- In other words, the vertical temperature gets inverted during temperature inversion.

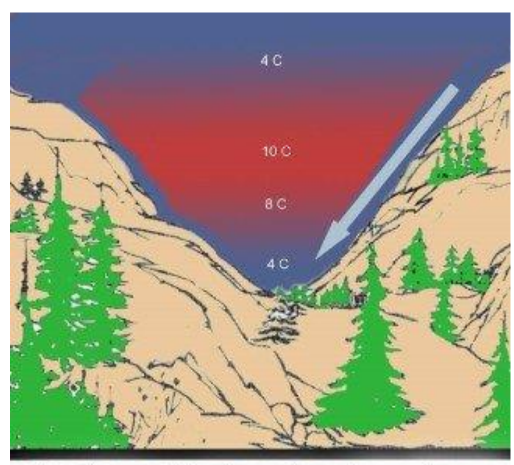
Temperature Inversion

Ideal Conditions for Temperature Inversion

1. **Long nights**, so that the outgoing radiation is greater than the incoming radiation.
2. **Clear skies**, which allow unobstructed escape of radiation.
3. **Calm and stable air**, so that there is no vertical mixing at lower levels.

Types of Temperature Inversion

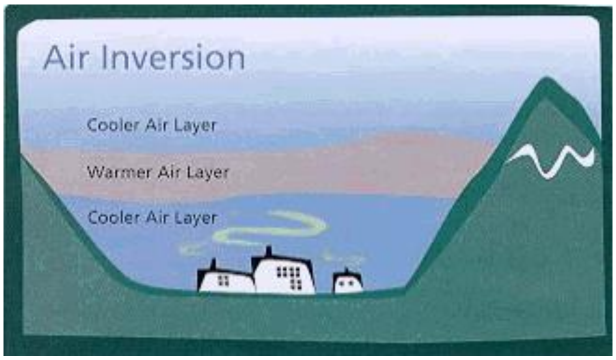
Temperature Inversion in Intermontane Valley (Air Drainage Type of Inversion)



Zone of warm nighttime temperatures above a valley temperature inversion. (From Schroeder and Buck, 1970)

- Sometimes, the temperature **along a sloping surface** increases instead of decreasing with elevation.

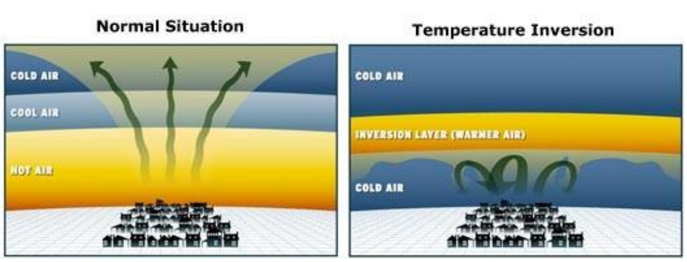
- Here, the top part of the sloping surface radiates heat back to space rapidly and cools the surrounding air making it denser.
- The cold air sinks towards the bottom along the slope and settles as a zone of low temperature at the bottom while the upper layers are relatively warmer.
- This kind of temperature inversion is very strong in the middle and higher latitudes and regions with high mountains or deep valleys.



Temperature Inversion in Intermontane Valley (Air Drainage Type of Inversion)

Ground Inversion (Surface Temperature Inversion)

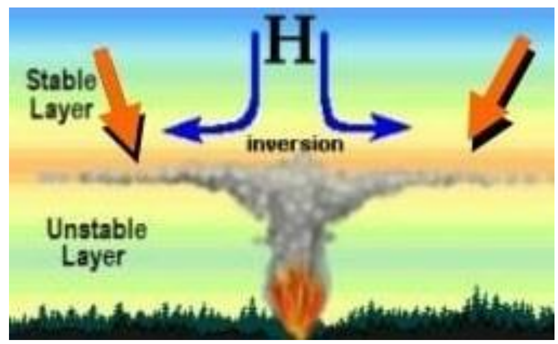
- This type of inversion occurs when air in contact with a colder surface becomes cooler than the overlying atmosphere.
- This occurs most often on clear nights when the ground cools off rapidly by radiation.
- If the temperature of surface air drops below its dew point, **fog** may result.
- This kind of temperature inversion is very common in the **higher latitudes**.
- In the lower and middle latitudes, this kind of inversion gets destroyed easily during daytime.



Ground Inversion (Surface Temperature Inversion)

Subsidence Inversion (Upper Surface Temperature Inversion)

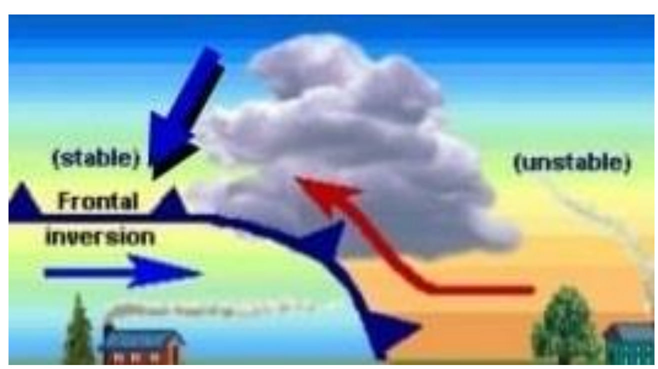
- A subsidence inversion develops when a widespread layer of air descends.
- As it descends, the ambient atmospheric pressure increases and the layer is compressed and heated.
- If the air mass sinks low enough, it forms a warm intermediate layer which is at a higher temperature compare to the layers below, producing a temperature inversion.
- Subsidence inversions are common over areas located under large **high-pressure centres**.
- Such conditions occur in the northern continents in winter and over the subtropical oceans.
- This temperature inversion is also called upper surface temperature inversion because it takes place in the upper parts of the atmosphere.



Subsidence Inversion (Upper Surface Temperature Inversion)

Frontal Inversion (Advectional type of Temperature Inversion)

- A frontal inversion occurs when a cold air mass undercuts a warm air mass and lifts it aloft.
- This kind of inversion has considerable slope, whereas other inversions are nearly horizontal.
- Also, humidity may be high, and clouds may be present immediately above it.
- This type of inversion is **unstable** and is **destroyed as the weather changes**.



Frontal Inversion (Advectional type of Temperature Inversion)

Effects of Temperature Inversion

- **Convection is inhibited**: An inversion acts as a cap on the upward movement of air from the layers below.
- Convection is limited to levels below the inversion, and the rainfall is below normal.
- In regions where a pronounced low-level inversion is present, **convective clouds cannot grow high enough** to produce rain.
- **Pollution is exacerbated**: diffusion of dust, smoke, and other pollutants is limited due to stable conditions.
- Visibility may be greatly reduced below the inversion due to the accumulation of dust and smoke particles.
- Because air near the base of an inversion tends to be cool, **fog** is frequently present there. Fog lowers visibility affecting vegetation and human settlements.
- Inversions also affect diurnal variations in temperature. Diurnal variations tend to be very **small**.

Effect on intermontane valley regions

- The temperature of the air at the valley bottom can go below freezing whereas the air at higher altitude remains comparatively warm.
- The trees along the lower slopes are bitten by frost, whereas those at higher levels are free from it.
- Houses and farms in intermontane valleys are usually situated along the upper slopes, avoiding the cold and foggy valley bottoms.
- For instance, **coffee growers of Brazil and apple growers and hoteliers of mountain states of Himalayas** in India avoid lower slopes.
- Air pollutants such as dust particles and smoke do not disperse in the valley bottoms.

5. Pressure Systems and Wind Systems

5.1 Atmospheric pressure

- The weight of a column of air contained in a unit area from the mean sea level to the top of the atmosphere is called the atmospheric pressure.
- The atmospheric pressure at sea level is **1034 gm per square centimetre**.
- Atmosphere (atm) is an internationally recognised unit for measuring atmospheric pressure at a place.
- The units used by meteorologists are **millibars (mb)** and **Pascal (Pa)**.
- One millibar is equal to the force of one gram on a square centimetre.
- A pressure of 1000 millibars is equal to the weight of 1.053 kilograms per square centimetre.
- The normal pressure at sea level is taken to be about **1013.25 millibars** (equal to the weight of a column of mercury 75 cm high).

1 atm = 1013.25 millibars (mb) = 101325 pascals (Pa) = 101.325 kilopascals (kPa)

- Atmospheric pressure varies from place to place due to differences in topography, sun's insolation and related weather and climatic factors.

5.2 Atmospheric pressure cells

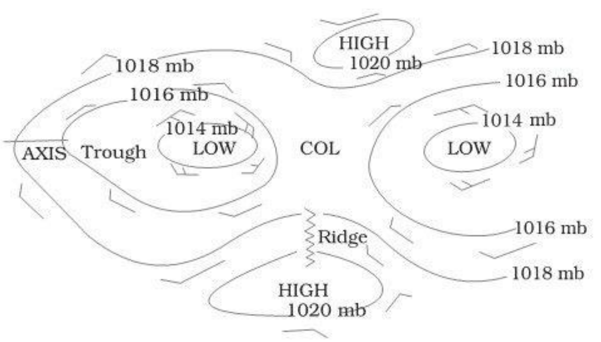
- When heated, the volume of a parcel of air increases (air expands) and hence the pressure within the air parcel falls creating a **low-pressure cell** (low-pressure centre).
- When cooled, the volume of the air parcel decreases (air is compressed) and hence the pressure within the air parcel increases creating a **high-pressure cell** (high-pressure centre).
- A combination of atmospheric pressure cells give rise to distinct pressure systems within the atmosphere.
- Distribution of continents and oceans have a marked influence over the distribution of pressure.
- In **winter, the continents are cooler than the oceans and tend to develop high-pressure centres, whereas, in summer, they are relatively warmer and develop low pressure**. It is just the reverse with the oceans.

5.3 Isobars

- **Isobars** are lines connecting places having equal pressure.
- The spacing of isobars expresses the rate of pressure changes and is referred to as **pressure gradient.**
- Close spacing of isobars indicates a steep or strong pressure gradient, while wide spacing suggests weak gradient.
- The pressure gradient may thus be defined as the decrease in pressure per unit distance in the direction in which the pressure decreases most rapidly.

Closed Isobars or Closed Pressure centres

- Low-pressure system (low-pressure cell) is enclosed by one or more isobars with the lowest pressure in the centre.
- High-pressure system (high-pressure cell) is also enclosed by one or more isobars with the highest pressure in the centre.



Closed Isobars

5.4 Vertical Variation of Pressure

- In the lower atmosphere, the pressure decreases rapidly with height.
- The decrease in pressure with altitude, however, is not constant because of the factors that control air density (temperature and amount of water vapour) are highly variable.
- Since air pressure is proportional to **density as well as temperature**, it follows that a change in either temperature or density will cause a corresponding change in the pressure.
- In general, the atmospheric pressure decreases on an average at the rate of about 34 millibars every 300 metres of height.
- The vertical pressure gradient force is much larger than that of the horizontal pressure gradient. However, it is generally balanced by a nearly equal but opposite **gravitational force**. Hence, we do not experience strong upward winds.

Standard Pressure and Temperature

Level	**Pressure in mb**	**Temperature °C**
Sea Level	1,013.25	15.2
1 km	898.76	8.7
5 km	540.48	-17. 3
10 km	265.00	-49.7

- At the height of Mt. Everest, the air pressure is about two-thirds less than what it is at the sea level.

5.5 Factors affecting Wind Movement

Wind: horizontal movement of air
Currents: vertical movement of air.

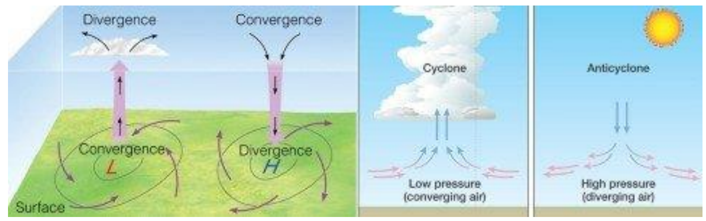
- The factors that affect wind movement are **pressure gradient force, buoyant force, friction, Coriolis force, gravitational force and centripetal acceleration**.

Pressure Gradient Force

- The pressure gradient (difference in pressure) between atmospheric pressure cells and the surroundings causes the movement of air from relatively high-pressure centres to relatively low-pressure centres.
- This movement (motion) of air is called as wind. Greater the pressure difference, greater is the wind speed.
- Small differences in pressure are highly significant in terms of the wind direction and velocity.
- The pressure gradient is strong where the isobars are close to each other and is weak where the isobars are apart.
- The wind direction follows the direction of pressure gradient, i.e. **perpendicular to the isobars.**

Buoyant force

- The atmospheric pressure cells also determine whether the air sinks or rises at a place.
- The surrounding atmosphere exerts buoyant force on low-pressure cells and hence the air within a low-pressure cell rises.
- On the other hand, the air within a high-pressure cell sinks as it is denser than the surrounding atmosphere.
- Rising air is associated with convergence and unstable weather (cyclonic conditions) whereas the sinking (subsiding) air is associated with divergence and stable conditions (anticyclonic conditions).
- A rising pressure indicates increasing stability, while a falling pressure indicates the weather becoming more unstable.
- The converging wind movement around a low is called **cyclonic circulation**.
- Around a high, the wind diverges, and the movement is called **anti-cyclonic circulation**.
- The wind circulation at the earth's surface is associated with an exactly opposite wind circulation above in the upper troposphere.
- Apart from convergence, convection currents, orographic uplift and uplift along fronts cause the rising of air, which is essential for the formation of clouds and precipitation.



Divergence and Convergence. Cyclonic and Anticyclonic conditions

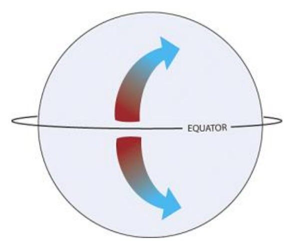
Pressure System	Pressure Condition	Pattern of Wind Direction	
		Northern Hemisphere	**Southern Hemisphere**
Cyclone	Low	Anticlockwise	Clockwise
Anticyclone	High	Clockwise	Anticlockwise

Frictional Force

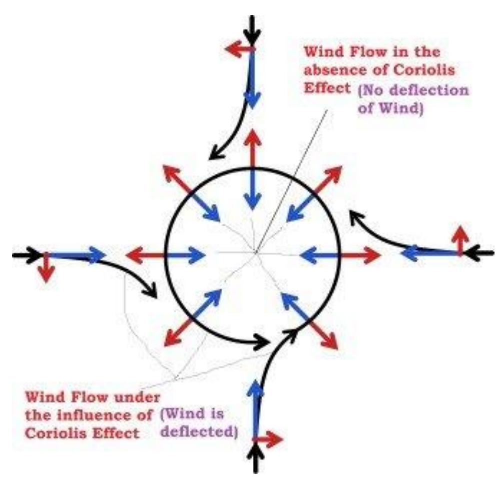
- The irregularities of the earth's surface resist the wind movement in the form of friction.
- The influence of friction generally extends up to an elevation of 1-3 km.
- Over the sea surface, the friction is minimal.
- At the surface, due to high friction, the wind direction makes high angles with isobars.

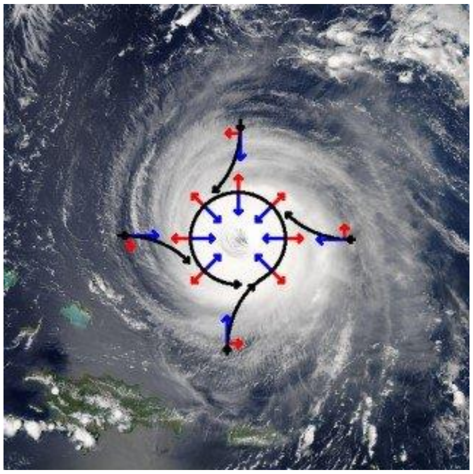
Coriolis force

- Due to the earth's rotation, winds do not cross the isobars at right angles as the pressure gradient force directs but get deflected from their original path.
- This deviation is the result of the earth's rotation and is called the Coriolis effect.
- Due to this effect, **winds in the northern hemisphere get deflected to the right** of their path and those in the **southern hemisphere to their left (Farrell's Law)**.
- This deflection force does not seem to exist until the air is set in motion and increases with **wind velocity** and an **increase in latitude**.



Farrell's Law: winds in the northern hemisphere get deflected to the right





Cyclones in the northern hemisphere rotate anti-clockwise due to Coriolis force

Coriolis effect

- The Coriolis effect is the **apparent deflection of objects** (such as aeroplanes, wind, missiles, sniper bullets and ocean currents) moving in a straight path **relative** to the earth's surface.

Causes of the Coriolis Effect

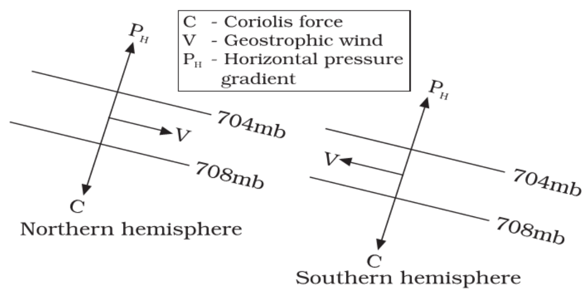
- As the earth spins in a counter-clockwise direction on its axis any object flying over a long distance appears to be deflected.
- This occurs because as something moves freely above the earth's surface, the earth is moving east under the object at a faster speed.
- As the object moves away for the equator the speed of the earth's rotation decreases and Coriolis effect (deflection) increases.
- A plane flying along the equator itself would be able to continue flying on the equator without any apparent deflection. A little to the north or south of the equator, the plane would be deflected.

Myth about Coriolis Effect: One of the biggest misconceptions associated with the Coriolis effect is that it causes the rotation of water down the drain of a sink or toilet. But such rotation is result of shape and orientation of the container. Coriolis effect is negligible to cause any deflection at such minor distances.

- The Coriolis effect is related to the motion of the object, the motion of the Earth, and the latitude.
- For this reason, the magnitude (Coriolis force) of the effect is given by $2v\omega \sin \phi$, in which v is the velocity of the object, ω is the angular velocity of the Earth, and ϕ is the latitude.
- At the equator, $\phi = 0°$ and at the poles, $\phi = 90°$. Thus, the **Coriolis force is zero at the equator but increases with latitude, reaching a maximum at the poles**.

Geostrophic Wind

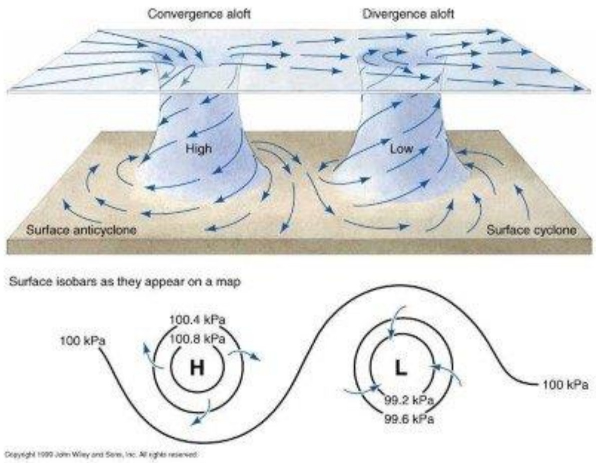
- The Coriolis force acting on a body increases with increase in its velocity.
- The winds in the upper atmosphere, 2-3 km above the surface, are free from frictional effect of the surface and are controlled by the pressure gradient and the Coriolis force.
- When isobars are straight, and when there is no friction, the **pressure gradient force is balanced by the Coriolis force, and the resultant wind blows parallel to the isobar** (deflection of the wind is maximum).
- This wind is known as the **geostrophic wind.**



Geostrophic wind vector parallel to the isobars

Centripetal Acceleration

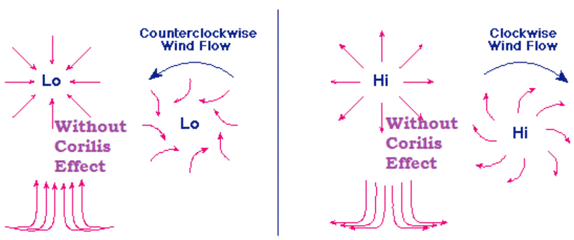
- It acts only on air that is flowing around centres of circulation.
- Centripetal acceleration creates a force directed at right angles to the wind movement and inwards towards the centres of rotation.
- This force produces a circular pattern of flow (vortex) around centres of high and low pressure.



Centripetal acceleration produces a circular flow

Why are there no tropical cyclones at the equator?

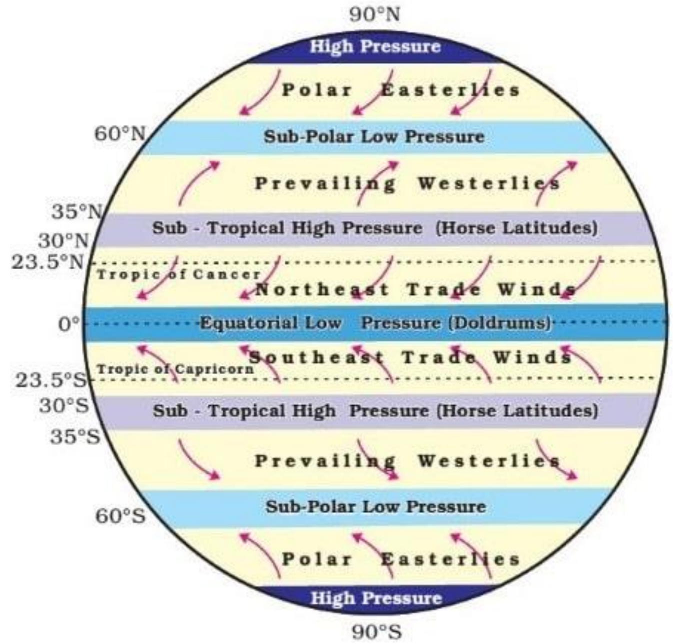
- The low pressure close to the equator gets filled instead of getting intensified, i.e., there is **no spiralling of air due to zero Coriolis effect**. The winds directly get uplifted vertically to form thunderstorms.



Vertical movement of air with and without Coriolis effect

5.6 Horizontal Distribution of Pressure

- Horizontal distribution of pressure is studied by drawing isobars at constant levels by eliminating the effect of altitude on pressure.
- There are seven distinctly identifiable zones of horizontal pressure systems or **pressure belts**.
  1. ***equatorial low,***
  2. ***the sub-tropical highs*** (along 30° N and 30° S),
  3. ***the sub-polar lows*** (along 60° N and 60° S), and
  4. ***the polar highs.***
- Except the equatorial low, all others form matching pairs in the northern and southern hemispheres.



Major Pressure Belts and Wind Systems

- The pressure belts are **not permanent** in nature. They oscillate with the apparent movement of the sun. In the northern hemisphere in winter they move southwards and in the summer northwards.

Equatorial Low-Pressure Belt or 'Doldrums'

- Th equatorial low-pressure belt lies between **10°N and 10°S latitudes**.
- The position of the belt varies with the apparent movement of the Sun.
- Its width may vary seasonally between 5°N and 5°S and 20°N and 20°S.
- This belt happens to be the **zone of convergence of trade winds (Intertropical Convergence Zone or ITCZ)** from two hemispheres from sub-tropical high-pressure belts.
- This belt is also called the **doldrums**, because of the **extremely calm air movements**.

Zone of convergence of trade winds - ITCZ

Formation

- As this region lies along the equator, it receives highest amount of insolation.
- Due to intense heating, the air gets heated up creating a low-pressure region (**thermally formed**).

Climate

- The air at the margins of the low-pressure region rises (convection) giving rise to clouds and turbulent weather along the margins.
- **Only vertical currents are found,** and the **surface winds** are almost absent since winds rise near the margin itself.
- Hence the region within the belt is characterised by **extremely low pressure** yet **calm weather conditions**.
- As the larger part of the low-pressure belt passes along the oceans, the winds obtain huge amount of moisture.
- Vertical winds carrying moisture from **cumulonimbus thunderstorm clouds** (convectional rainfall).
- The rising air loses all its moisture by the time it reaches the upper parts of the troposphere.
- In spite of high temperatures and moisture, **cyclones are not formed 5°N and 5°S of the equator because of negligible Coriolis force**.

Sub-Tropical High-Pressure Belt or Horse Latitudes

- The sub-tropical highs extend from near the tropics to about **35°N and S.**

Formation

- After complete loss of moisture, the air moving away from the equatorial low-pressure belt and the subtropical low-pressure belt in the upper troposphere is dry and cold.
- The **blocking effect of air at upper levels** because of the **Coriolis force forces the cold, dry air to** subside at 30°N and S.
- So, the high pressure (**dynamically formed**) along this belt is due to **subsidence of air coming from the equatorial region and the subpolar region**.

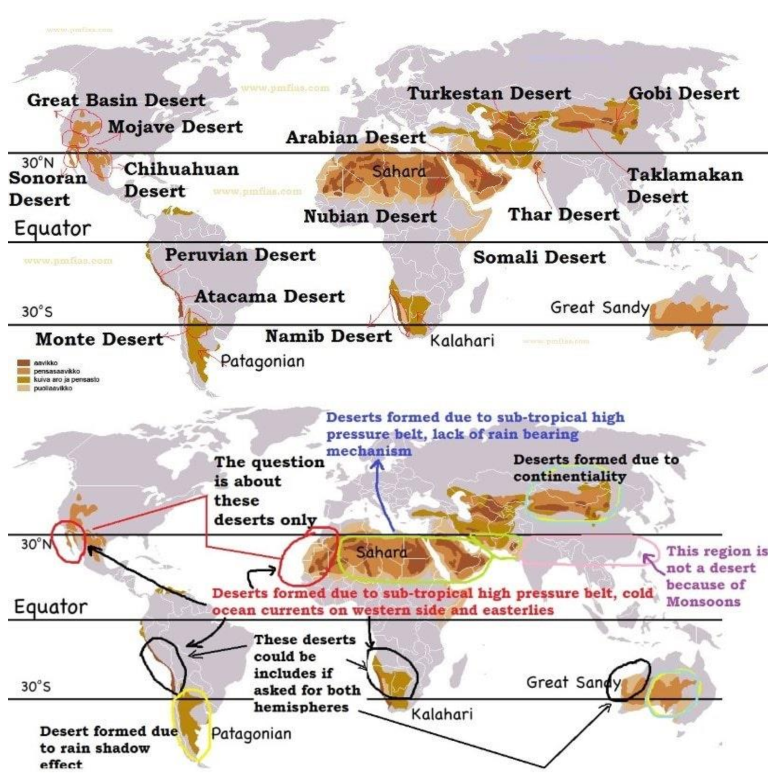
Climate

- The **subsiding air is warm (heated due to increases in ambient pressure) and dry, therefore, most of the deserts are present along this belt, in both hemispheres**.
- A calm condition **(anticyclonic)** with feeble winds is created in this high-pressure belt.
- The descending air currents feed the winds blowing towards adjoining low-pressure belts.
- This belt is **frequently invaded by tropical and extra-tropical disturbances**.

Horse Latitudes

- The corresponding latitudes of sub-tropical high-pressure belt are called **horse latitudes.**
- In early days, the sailing vessels with cargo of horses found it difficult to sail under calm conditions of this high-pressure belt.
- They used to throw horses into the sea when fodder ran out. Hence the name horse latitudes.

Mains 2013: Major hot deserts in northern hemisphere are located between 20-30 degree north and on the western side of the continents. Why?



Major Deserts of the World

Why between 20 – 30 degree?

- The subsiding air is warm and dry; therefore, most of the deserts are present along this belt, in both hemispheres.

Why on western side of the continents?

- We will get answer for this while studying ocean currents.

Sub-Polar Low-Pressure Belt

- The subpolar low-pressure belts are located between **45°N** and the **Arctic circle (66.5° N) and 45°S and the Antarctic circles (66.5° S) respectively.**
- Owning to low temperatures the subpolar low-pressure belts are not very well pronounced year long.

Formation

- These are **dynamically produced** due to
  1. **Coriolis Force** (produced by **rotation of the earth on its axis) and**.
  2. **Ascent of air as a result of convergence of westerlies (coming from the subtropical high-pressure regions) and polar easterlies (coming from the polar regions)**.
- Subpolar low-pressure belts are mainly encountered above **oceans.**

Seasonal behaviour

- During winter, because of a high contrast between land and sea, this belt is broken into two distinct low centres – one in the vicinity of the Aleutian Islands and the other between Iceland and Greenland.
- During summer, a lesser contrast results in a more developed and regular belt.
- The belt in the southern hemisphere is not as well differentiated.

Climate

- The area of contrast between cold and warm air masses produces **polar jet streams** which encircles the earth at 60 degrees latitudes and is focused in these low-pressure areas.

Polar High-Pressure Belt

- The polar highs are small in area and extend around the poles.
- They lie around poles between 80 – 90° N and S latitudes.

Formation

- The air from sub-polar low-pressure belts after saturation becomes dry. This dry air becomes cold while moving towards poles through upper troposphere.
- The cold air (heavy) on reaching poles subsides creating a high-pressure belt at the surface of earth.

Factors Controlling Pressure Systems

Thermal Factors

- When air is heated, it leads to low pressure, and when it is cooled, it leads to high pressure.
- Formation of **equatorial low and polar highs** are examples of thermal lows and thermal highs.

Dynamic Factors

- Apart from variations of temperature, the formation of pressure belts may be explained by dynamic factors arising out of **pressure gradient forces, apparent movement of sun and rotation of the earth (Coriolis force).**

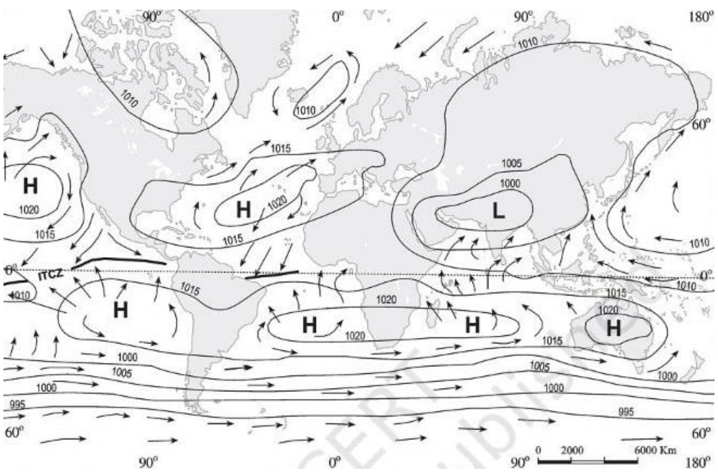
Example

- The **rate of deflection of wind increases with distance from the equator (Coriolis force).**
- The defection is higher in the upper troposphere due to less friction.
- As a result, by the time the poleward directed winds in the upper troposphere reach 25° latitude, they are deflected into a nearly west-to-east flow.

- Similarly, equatorward directed winds in the upper troposphere are deflected into a nearly east-to-west flow.
- This produces a **blocking effect** and the air piles up. This causes a general subsidence in the areas between the tropics and 35°N and S, and they develop into high-pressure belts.

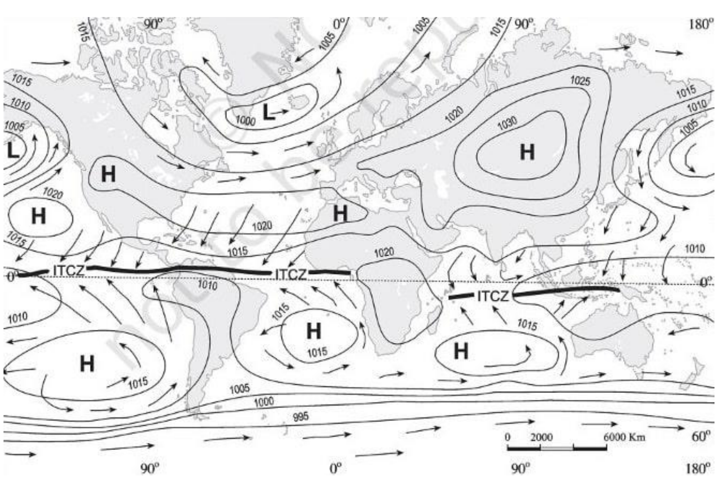
Pressure belts in July

- In the northern hemisphere, during summer, with the apparent northward shift of the sun, the thermal equator (belt of highest temperature) is located north of the geographical equator.
- The pressure belts shift slightly north of their annual average locations.



Pressure belts in July

Pressure belts in January

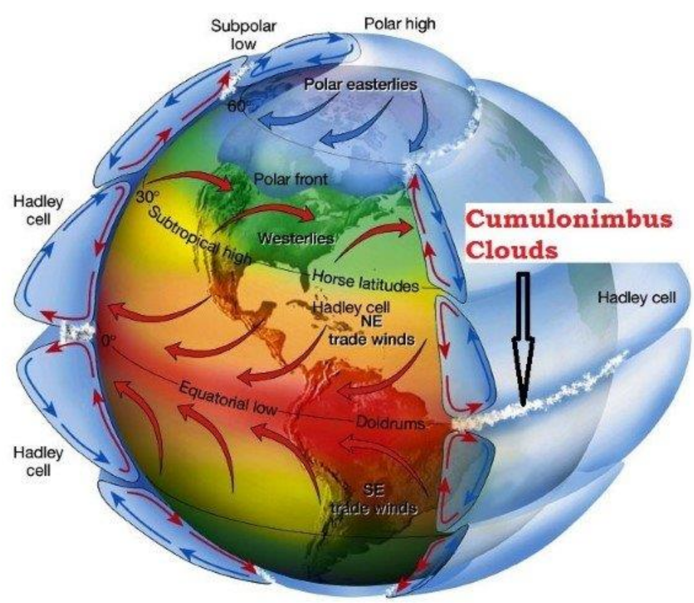


Pressure belts in January

- During winter, the conditions are reversed, and the pressure belts shift south of their mean locations.
- Opposite conditions prevail in the southern hemisphere. The amount of shift is, however, less in the southern hemisphere due to predominance of water.

5.7 Pressure systems and General Circulation

- The pattern of planetary winds depends on:
  - ✓ latitudinal variation of atmospheric heating;
  - ✓ emergence of pressure belts;
  - ✓ the migration of belts following apparent path of the sun;
  - ✓ the distribution of continents and oceans;
  - ✓ the rotation of earth.
- The pattern of the movement of the planetary winds (permanent winds) is called the **general circulation** of the atmosphere.
- The general circulation of the atmosphere also sets in motion the **ocean water circulation** which influences the earth's climate.



General Circulation

Hadley Cell

- The air at the equatorial low-pressure belt rises because of the convection currents.
- The air reaches the top of the troposphere up to an altitude of 14 km and moves towards the poles.

- This causes accumulation of air at about 30° N and S.
- Part of the accumulated air sinks to the ground and forms a subtropical high.
- At the surface a component of the diverging wind from the subtropical high flows towards the equator as the **easterlies (northeast to southwest)**.
- The easterlies from either side of the equator converge at the equatorial low pressure and the cycle repeats.
- Such circulations of wind is called a cell. Such a cell in the tropics is called **Hadley Cell.**

Ferrel Cell

- In the middle latitudes, the circulation is that of sinking cold air that comes from the poles and the rising warm air that blows from the subtropical high.
- At the surface, these winds are called westerlies, and the cell is known as the **Ferrel cell.**

Polar Cell

- At polar latitudes, the cold dense air subsides near the poles and blows towards middle latitudes as the polar easterlies. This cell is called the **polar cell.**

These three cells set the pattern for the general circulation of the atmosphere. The transfer of heat energy from lower latitudes to higher latitudes maintains the general circulation.

5.8 Classification of Winds

Permanent winds or Primary winds or Prevailing winds or Planetary Winds

- ❑ The **trade winds, westerlies and polar easterlies.**

Secondary or Periodic Winds

- ❑ Seasonal winds: These winds change their direction in different seasons. E.g. Monsoons in South Asia.
- ❑ Periodic winds: **Land and sea breeze, mountain and valley breeze** etc.

Local winds

- ❑ These blow only during a particular period of the day or year in a small area.
- ❑ Winds like **Loo, Mistral, Foehn, Bora** etc.

Primary winds or Prevailing Winds or Planetary Winds

- The winds blowing almost in the same direction throughout the year are called prevailing or permanent winds.
- These are also called as invariable or planetary winds because they involve larger areas of the globe.
- The two most significant winds for climate and human activities are **trade winds** and **westerly winds**.

The Trade Winds

- The trade winds are those blowing from the **sub-tropical high-pressure** areas towards the **equatorial low-pressure belt**.
- Therefore, these are confined to a region between **30°N and 30°S** throughout the earth's surface.
- They flow as the **north-eastern trades** in the northern hemisphere and the **south-eastern trades** in the southern hemisphere.
- Trade winds are **descending** and stable in areas of their origin (sub-tropical high-pressure belt), and as they reach the equator, they become **humid and warmer** after picking up moisture on their way.
- The trade winds from two hemispheres meet near the equator, and **due to convergence, they rise and cause heavy rainfall.**
- The eastern parts of the trade winds associated with the cool ocean currents are drier and more stable than the western parts of the ocean.

The Westerlies

- The westerlies are the winds blowing from the **sub-tropical high-pressure belts** towards the **sub-polar low-pressure belts**.
- They blow from **southwest to northeast** in the northern hemisphere and **northwest to southeast** in the southern hemisphere.

- The westerlies of the southern hemisphere are **stronger** and persistent due to the vast expanse of water, while those of the northern hemisphere are **irregular** because of uneven relief of vast land-masses.
- The westerlies are best developed between **40° and 65°S latitudes**. These latitudes are often called **Roaring Forties, Furious Fifties, and Shrieking Sixties** – dreaded terms for sailors.
- The poleward boundary of the westerlies is highly fluctuating.
- These winds produce **wet spells** and variability in weather.

The Polar easterlies

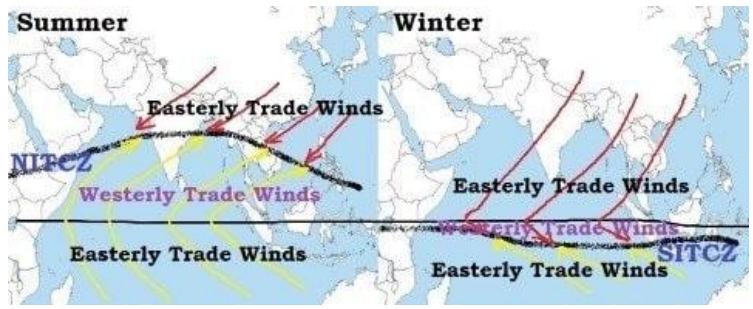
- The Polar easterlies are dry, cold prevailing winds blowing from **north-east to south-west direction** in Northern Hemisphere and **south-east to north-west** in Southern Hemisphere.
- They blow from the **high-pressure polar** areas of the **sub-polar lows**.

Secondary or Periodic Winds

- These winds **change their direction with change in season**.
- **Monsoons** are the best example of large-scale modification of the planetary wind system.
- Other examples of periodic winds include **land and sea breeze, mountain and valley breeze, cyclones and anticyclones,** and **air masses.**

Monsoons

- Monsoons were traditionally explained as **land and sea breezes on a large scale.**
- They were earlier considered as a **convectional circulation on a giant scale.**
- The monsoons are characterized by **seasonal reversal** of wind direction.
- During summer, the trade winds of southern hemisphere are pulled northwards by an apparent northward movement of the sun and by an intense low-pressure core in the north-west of the Indian subcontinent.
- While crossing the equator, these winds get deflected to their right under the effect of **Coriolis force.**
- These winds now approach the Asian landmass as south-west monsoons.
- During winter, these conditions are reversed, and a high-pressure core is created to the north of the Indian subcontinent.
- **Divergent winds** are produced by this **anticyclonic movement** which travels southwards towards the equator. This movement is enhanced by the apparent southward movement of the sun.
- These are north-east or winter monsoons which are responsible for some precipitation along the east coast of India.

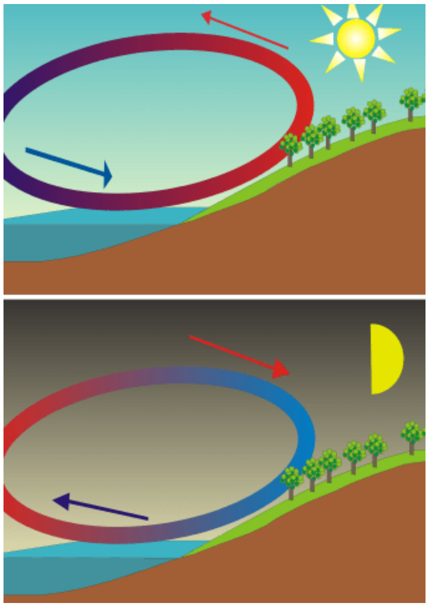


Indian Monsoon seasonal wind direction

- The monsoon winds flow over India, Pakistan, Bangladesh, Myanmar (Burma), Sri Lanka, the Arabian Sea, Bay of Bengal, south-eastern Asia, **northern Australia, China** and **Japan.**
- Outside India, in the eastern Asiatic countries, such as China and Japan, the **winter monsoon is stronger** than the summer monsoon.

Land Breeze and Sea Breeze

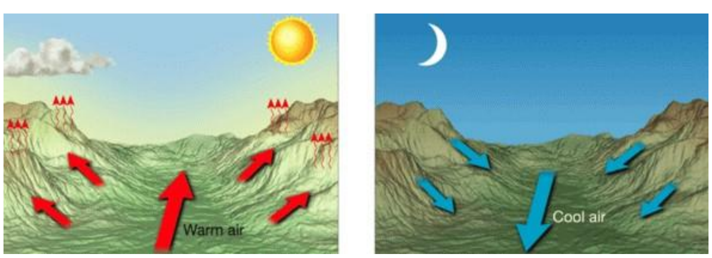
- During the day the land heats up faster and becomes warmer than the sea.
- Therefore, over the land, the air rises giving rise to a low-pressure area, whereas the sea is relatively cool and the pressure over sea is relatively high.
- Thus, pressure gradient from sea to land is created, and the wind blows from the sea to the land as the sea breeze.
- In the night the reversal of condition takes place. The land loses heat faster and is cooler than the sea.
- The pressure gradient is from the land to the sea and hence land breeze results.



Land Breeze and Sea Breeze (Ingwik, via [Wikimedia Commons](#))

Valley Breeze and Mountain Breeze

- In mountainous regions, during the day the slopes get heated up, and air moves upslope.
- The air from the valley blows up the valley to fill the resulting gap. This wind is known as the valley breeze.
- During the night the slopes get cooled, and the dense air descends into the valley as the mountain wind.
- The cool air, of the high plateaus and ice fields draining into the valley, is called **katabatic wind (high-density air flowing down the slope).**



Valley Breeze and Mountain Breeze ([Credits](#))

Tertiary or Local Winds

- Local differences of temperature and pressure produce local winds.
- Such winds are local in extent and are confined to the lowest levels of the troposphere. Some examples of local winds are discussed below.

Loo

- In the plains of northern India and Pakistan, sometimes a very hot and dry wind blows from the west in **May and June**, usually in the afternoons. It is known as **loo.**
- Its temperature invariably ranges between **45 °C and 50 °C**. It may cause **sunstroke** to people.

Foehn or Fohn

- Foehn is a **hot wind** of local importance in the **Alps**.
- It is a strong, gusty, dry and warm wind which develops on the leeward side of a mountain range.
- As the windward side takes away whatever moisture there is in the incoming wind in the form of orographic precipitation, the air that descends on the leeward side is dry and warm **(katabatic wind).**
- The temperature of the wind varies between 15°C and 20°C.
- The wind **helps animal grazing** by melting snow and **aids the ripening of grapes**.

Chinook

- Chinooks are foehn like winds in **USA and Canada** move down the west slopes of the **Rockies.**
- It is **beneficial to ranchers** east of the Rockies as it keeps the grasslands clear of snow during much of the winter.

Mistral

- Mistral is one of the local names given to such winds that blow from the Alps over France towards the Mediterranean Sea.
- It is channelled through the Rhone valley. It is **very cold and dry with a high speed**.
- It brings blizzards into southern France.

Sirocco

- Sirocco is a **Mediterranean wind** that comes from the **Sahara** and reaches hurricane speeds in North Africa and Southern Europe.
- It arises from a warm, dry, tropical air mass that is pulled northward by low-pressure cells mov-

ing eastward across the Mediterranean Sea, with the wind originating in the **Arabian or Sahara deserts.**

- The hotter, drier continental air mixes with the cooler, wetter air of the maritime cyclone, and the counter-clockwise circulation of the low propels the mixed air across the southern coasts of Europe.
- The Sirocco causes dusty dry conditions along the northern coast of Africa, storms in the Mediterranean Sea, and cool, wet weather in Europe.

Major Local Winds across the world

Cold Wind	Warm Wind
Pampero	***Foehn***
Gregale	***Chinook***
Bora	***Zonda***
Tramontane	***Loo***
Mistral	***Sirocco***

Loo	Hot	Harmful	Plains of northern India and Pakistan
Mistral	Cold	Harmful	Rhine valley – Southern France
Sirocco	Hot	Harmful	Mediterranean wind that comes from the Sahara
Fohn	Hot	Beneficial	Leeward side of Alps
Chinook	Hot	Beneficial	Leeward side of Rockies

Prelims Practise

1. If the surface air pressure is 1,000 mb, the air pressure at 1 km above the surface will be: (a) 700 mb (c) 900 mb (b) 1,100 mb (d) 1,300 mb
2. The Inter Tropical Convergence Zone normally occurs: (a) near the Equator (b) near the Tropic of Cancer (c) near the Tropic of Capricorn (d) near the Arctic Circle
3. The direction of wind around a low pressure in northern hemisphere is: (a) clockwise (c) anti-clockwise (b) perpendicular to isobars (d) parallel to isobars

Answers: 1) c. 900 mb; 2) a. Equator 3) c. anti-clockwise

30 words

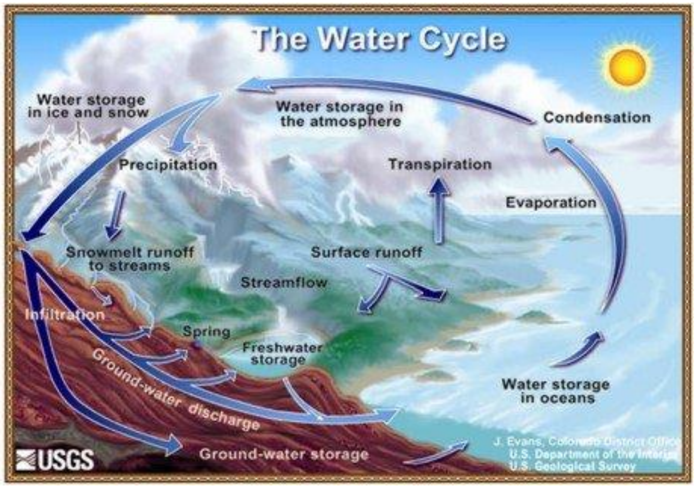
1. While the pressure gradient force is from north to south, i.e. from the subtropical high pressure to the equator in the northern hemisphere, why are the winds north easterlies in the tropics? (Hint: Coriolis force)
2. What are the geostrophic winds?
3. Explain the land and sea breezes.

150 words

- Discuss the factors affecting the speed and direction of wind.
- Draw a simplified diagram to show the general circulation of the atmosphere over the globe. What are the possible reasons for the formation of subtropical high pressure over 30° N and S latitudes?

6. Hydrological Cycle (Water Cycle)

- There is a continuous exchange of water between the atmosphere, the oceans and the continents through the processes of **evaporation, transpiration, condensation and precipitation.**
- The moisture in the atmosphere is derived from water bodies through **evaporation** and from plants through **transpiration (evapotranspiration)**.
- Evaporated water undergoes **condensation** and forms clouds.
- When saturation is reached, clouds give away water in the form of **precipitation.**
- Since the total amount of moisture in the entire system remains constant, a balance is required between evapotranspiration and precipitation. The hydrological cycle maintains this balance.



Water Cycle

6.1 Water Vapour in Atmosphere

- Water vapour in air varies from **zero to four per cent** by volume of the atmosphere (averaging around **2%** in the atmosphere).
- Amount of water vapour in atmosphere (humidity) is measured by, an instrument called **hygrometer.**

Significance of Atmospheric Moisture

- Water vapour absorbs **both incoming and outgoing** radiation and hence plays a crucial role in the **earth's heat budget**.
- The amount of water vapour present decides the **quantity of latent energy stored** up in the atmosphere for development of storms and cyclones.
- The atmospheric moisture affects the human body's rate of cooling by influencing the sensible temperature.

Humidity

- Water vapour present in the air is known as **humidity.**

Absolute Humidity

- The **actual** amount of the water vapour present in the atmosphere is known as the **absolute humidity.**
- It is the **weight** of water vapour per unit volume of air and is expressed in terms of grams per cubic metre.
- The absolute humidity **differs** from place to place on the surface of the earth.
- The ability of the air to hold water vapour depends entirely on its **temperature.**
- **Warm air can hold more moisture than cold air**.
- Absolute humidity is greater over oceans because of greater availability of water for evaporation.

Relative Humidity

- The percentage of moisture present in the atmosphere as compared to its full capacity at a given temperature is known as the **relative humidity**.

Relative Humidity = [Actual amount of water vapour in air (absolute humidity)/humidity at saturation point (the maximum water vapour air can hold at a given temperature)] X 100

- With the change of air temperature, the capacity to retain moisture increases or decreases and the relative humidity is also affected.
- The relative humidity determines the amount and rate of evaporation, and hence it is an important climatic factor.
- Air containing moisture to its full capacity at a given temperature is said to be **saturated**.
- At this temperature, the air cannot hold any additional amount of moisture. Thus, **relative humidity of the saturated air is 100%**.
- If the air has half the amount of moisture that it can carry, then it is unsaturated, and its relative humidity is only 50%.
- **Relative humidity is greater over the oceans and least over the continents** (absolute humidity is greater over oceans because of greater availability of water for evaporation).

Change in Relative humidity

Relative humidity can be changed in either of the two ways:

1. **By adding moisture through evaporation** (by increasing absolute humidity): **if moisture is added by evaporation, the relative humidity will increase** and vice versa.

2. **By changing temperature of air** (by changing the saturation point): **a decrease in temperature (hence, decrease in moisture-holding capacity/decrease in saturation point) will cause an increase in relative humidity** and vice versa.

- Consider 1 m^3 of air at a temperature 'T'.
- Let us assume that saturation occurs when 0.5 kg of water vapour is present in 1 m^3 of air.
- That is, relative humidity will be 100% if 1 m^3 of air contains 0.5 kg of water vapour at temperature T (saturation temperature or saturation point).
- Assume that 1 m^3 of air at a given time consists of 0.2 kg of water vapour at a temperature 'T'.

Here,
Absolute Humidity = 0.2 kg/m3 and
Relative Humidity = 40% (0.2/0.5 X 100)
Relative humidity is expressed as % whereas absolute humidity is expressed in absolute terms.

- Now to make the air saturated (100% relative humidity),
  1. we can add that additional 0.3 kg of water vapour by evaporation. OR
  2. we can decrease the temperature.
- If we decrease the temperature, the saturation point will come down.

Explanation:

- Let us assume that the temperature of 1 m^3 of air is decreased by 2 °C.
- The water holding capacity will fall due to decrease in temperature.
- Let us assume that the water holding capacity decreases by 0.1 kg/m^3 for 1 °C fall in temperature.
- So, for 2 °C fall in temperature, the fall in water holding capacity is 0.2 kg/m^3.
- Hence the new saturation point occurs at 0.3 kg/m^3 of air [0.5 kg/m^3 – 0.2 kg/m^3].
- So now we can saturate 1 m^3 of air by adding just 0.1 kg instead of 0.3 kg as in the earlier case.

[because, initially, we assumed that 1 m3 of air at a given time consists of 0.2 kg of water vapour at a temperature 'T'.]

Dew point

- The air containing moisture to its full capacity at a given temperature is said to be **saturated.**
- It means that the air at the given temperature is incapable of holding any additional amount of moisture.
- The temperature at which saturation occurs in a given sample of air is known as **dew point.**
- **Dew point occurs when Relative Humidity = 100%.**

Specific Humidity

- It is expressed as the **weight of water vapour per unit weight of air** (grams of water vapour per kilogram of air).
- Specific humidity is **not** affected (does not vary) by changes in pressure or temperature (because weight of water vapour in atmosphere is not significantly influenced by temperature).
- The only way of changing specific humidity is by adding (evaporation) or removing (precipitation) of moisture.

6.2 Evaporation

- Evaporation is a process by which water is transformed from **liquid to gaseous state**.
- The oceans contribute **84%** of the annual total and the continents **16%.**
- The highest annual evaporation occurs in the **sub-tropics of the western North Atlantic** and **North Pacific** because of the influence of the **Gulf Stream** and the **Kurishino Current**, and in the **trade wind zone of the southern oceans**.
- The land maximum occurs in equatorial region because of **high insolation** and luxuriant **vegetation.**

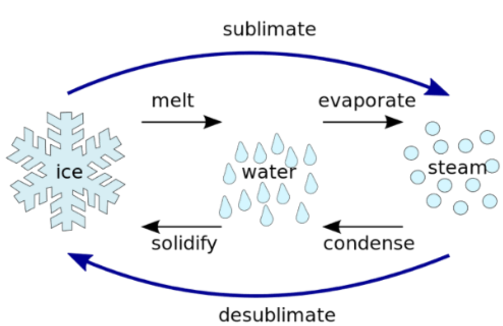
Factors Affecting Rate of Evaporation

- **Amount of water available.**
- **Area of evaporating surface.**
- **Temperature.**
- **Relative humidity:** air with low relative humidity has more space for moisture and hence evaporation increases.

- **Wind:** Movement of air replaces the saturated layer with the unsaturated layer. Hence, greater the wind speed, the greater is the evaporation.
- Whenever there is a combination of **high temperature**, very **low relative humidity** and **strong winds**, the rate of evaporation is exceptionally high. This leads to **dehydration of soil** to a depth of several inches.
- **Air Pressure:** Evaporation is also affected by the atmospheric pressure exerted on the evaporating surface. Lower pressure over open surface of the liquid results in a higher rate of evaporation.
- **Composition of water:** Evaporation is **inversely proportional to salinity of water.**
- Rate of evaporation is always greater over fresh water than over salt water. [Because of the reduction in the vapour pressure (ability of the water molecules to bounce off the surface) at the water surface due to salinity.]
- Under similar conditions, ocean water evaporates about 5% more slowly than fresh water.
- **More evaporation by plants:** Water from plants generally evaporates at a faster rate than from land.

6.3 Condensation

- The transformation of **water vapour into water** is called **condensation**.
- Condensation is caused by the **loss of heat** (**latent heat of condensation, opposite of latent heat of vaporisation).**
- When moist air is cooled, it may reach a level when its capacity to hold water vapour ceases (Saturation Point = 100% Relative Humidity = Dew Point reached).



Phase change

- Then, the excess water vapour condenses into liquid form. If it directly condenses into solid form, it is known as **sublimation**.
- In free air, condensation results from cooling around very small particles termed as **hygroscopic condensation nuclei**.
- Particles of **dust, smoke, pollen** and **salt** from the ocean are particularly good nuclei because they absorb water.
- Condensation also takes place when the moist air comes in contact with some colder object and it may also take place when the temperature is close to the **dew point.**
- Condensation, therefore, depends upon the **amount of cooling** and the **relative humidity** of the air.
- Condensation takes place:
    1. **when the temperature of the air is reduced to dew point** with its volume remaining constant (**adiabatically**),
    2. **when both the volume and the temperature are reduced** (brings down saturation temperature),
    3. **when moisture is added to the air through evaporation** (increase in relative humidity),
- After condensation, the water vapour or the moisture in the atmosphere takes one of the following forms — **dew, frost, fog and clouds**.
- Condensation takes place when the **dew point is lower than the freezing point as well as higher than the freezing point**.

Processes of Cooling for Producing Condensation

Adiabatic Temperature Changes

- When the air rises, it expands. Thus, heat available per unit volume is reduced and, therefore, the temperature is also reduced.
- Such a temperature change which does not involve any subtraction of heat, and cooling of air takes place only by ascent and expansion, is termed 'adiabatic change'.
- The vertical displacement of the air is the major cause of **adiabatic and katabatic** (cold, dense air flowing down a slope) temperature changes.

- Near the earth's surface, most processes of change are **non-adiabatic** because horizontal movements often produce mixing of air and modify its characteristics.

Non-Adiabatic Temperature Changes

- Non-adiabatic processes include cooling by **radiation, conduction or mixing** with colder air. The air may be cooled due to loss of heat by radiation.
- The non-adiabatic processes of cooling produce only dew, fog or frost. They are **incapable** of producing a substantial amount of precipitation.
- In case there is direct radiation from moist air, the cooling produces **fog or clouds**, subject to presence of hygroscopic nuclei in the air.
- Cooling by contact with a cold surface produces **dew, frost or fog** depending on other atmospheric conditions.

6.4 Forms of Condensation

- The forms of condensation can be classified on the basis of temperature at which the dew point is reached.
- Condensation can take place when the dew point is
  - ✓ **lower than the freezing point,**
  - ✓ **higher than the freezing point.**
- **White frost, snow, hailstones and some clouds (cirrus clouds)** are produced when the temperature is lower than the freezing point.
- **Dew, fog and clouds** result even when the temperature is higher than the freezing point.
- Forms of condensation may also be classified on the basis of their location, i.e. at or near the earth's surface and in free air.
- **Dew, white frost, fog and mist** come in the first category, whereas **clouds** are in the second category.

Dew

- When the moisture is deposited in the form of water droplets on cooler surfaces of solid objects (rather than nuclei in air above the surface) such as stones, grass blades and plant leaves, it is known as dew.
- The ideal conditions for its formation are **clear sky, calm air, high relative humidity**, and **cold and long nights**.

For the formation of dew, it is necessary that the **dew point is above the freezing point.**

Dew

White Frost

- Frost forms on cold surfaces when condensation takes place **below freezing point (0° C)**, i.e. the **dew point** is at or below the freezing point.
- The excess moisture is deposited in the form of **minute ice crystals** instead of water droplets.
- The ideal conditions for the formation of white frost are the same as those for the formation of dew, except that the **air temperature must be at or below the freezing point.**

White Frost

Fog

- When the temperature of an air mass containing a large quantity of water vapour falls all of a sudden (mostly due to temperature inversion), condensation takes place within itself on fine dust particles.
- So, the fog is a **cloud with its base at or very near to the ground**.

- Because of the **fog and mist**, the visibility becomes poor to zero.

Fog

- In urban and industrial centres smoke provides plenty of nuclei which help the formation of fog and mist. Such a condition when fog is mixed with smoke is described as **smog.**
- **Radiation fog** results from radiation, cooling of the ground and adjacent air. These fogs are **not very thick and** are usual in winters.
- Fogs formed by condensation of warm air when it moves horizontally over a cold surface, are known as **advectional fog**. These fogs are **thick and persistent**. Occurs over warm and cold water mixing zones in oceans.
- **Frontal or precipitation fog** is produced due to convergence of warm and cold air masses where warm air mass is pushed under by the heavier cold air mass.
- Precipitation in the warm air mass condenses to produce fog at the boundary of the two air masses. These are called **frontal or precipitation fog**.
- **In fog visibility is less than one kilometre**.

Mist

- The difference between the mist and fog is that mist contains more moisture than fog.
- In mist, each nucleus contains a thicker layer of moisture.
- Mists are frequent over mountains as the rising warm air up the slopes meet a cold surface.
- Water droplets also form mist, but with less merging or coalescing. This means mist is less dense and quicker to dissipate.
- Fogs are drier than mist, and they are prevalent where warm currents of air come in contact with cold currents.
- **In mist, visibility is more than one kilometre but less than two kilometres.**

Mist

Smog

- Smog = **smoke + fog (smoky fog)** caused by the burning of large amounts of **coal, vehicular emission** and **industrial fumes** (primary pollutants).
- Smog contains soot particulates like smoke, **sulphur dioxide, nitrogen dioxide** and other components.
- At least two distinct types of smog are recognised: **sulphurous smog** and **photochemical smog**.

Smog

Primary and secondary pollutants

- A primary pollutant is an air pollutant emitted directly from a source.
- A secondary pollutant is not directly emitted as such, but forms when other pollutants (primary pollutants) react in the atmosphere.
- Examples of a secondary pollutant include **ozone**, which is formed

- ✓ **when hydrocarbons (HC) and nitrogen oxides (NO_x) combine in the presence of sunlight;**
- ✓ **when NO combines with oxygen in the air; and**
- ✓ **due to acid rain (sulphur dioxide or nitrogen oxides react with rainwater to form acid rain).**

Sulphurous smog

Sulphurous smog

- Sulphurous smog is also called **London smog** (first formed in London due to industrial revolution).
- Sulphurous smog results from a high concentration of **sulphur oxides** in the air and is caused by the use of **sulphur-bearing fossil fuels, particularly coal** (coal was the mains source of power in London during nineteenth century. The effects of coal burning were observed in early twentieth century).
- This type of smog is aggravated by **dampness** and a **high concentration of suspended particulate matter** in the air.

Photochemical smog

- Photochemical smog is also known as **summer smog or Los Angeles smog.**
- Photochemical smog occurs most prominently in urban areas that have large numbers of automobiles (**nitrogen oxides** are the primary emissions).
- Photochemical smog forms when **nitrogen oxides** (primary pollutant) and **volatile organic compounds** (primary pollutants) react together in the presence of sunlight to form **ozone** (secondary pollutant).

NO + VOC (volatile organic compounds) $\longrightarrow$ ***NO_2 (Nitrogen Dioxide)***

NO2 + UV (sunlight) $\longrightarrow$ ***NO + O (Nitrogen Oxide + atomic oxygen)***

O + O_2 $\longrightarrow$ ***O_3 (Ozone)***

NO_2 + VOC $\longrightarrow$ ***PAN (peroxyacetyl nitrate), etc.***

Final result: ***NO + VOC + O_2 + UV*** $\longrightarrow$ ***O_3, PAN, and other oxidants***

Ozone in stratosphere it is beneficial, but near the earth's surface it results in global warming as it is a greenhouse gas

- The resulting smog causes a light brownish colouration of the atmosphere, reduced visibility, plant damage, irritation of the eyes, and respiratory distress.

Photochemical smog

Effects of Smog

- Smog is a combination of airborne particulate matter, like soot, and invisible toxic gases including **ozone (O3), carbon monoxide (CO), sulphur dioxide (SO2)**, which are **carcinogens (cancer-causing agents).**
- The **atmospheric pollution** levels of Los Angeles, Beijing, Delhi, Mexico City and other cities are increased by **inversion** that traps pollution close to the ground.
- It is usually highly toxic to humans and can cause severe sickness, shortened life or death.
- Temperature inversions are accentuated, and **precipitation is reduced**.
- Smog-related Haze lowers visibility.

Mains 2015: Mumbai, Delhi and Kolkata are the three megacities of the country, but the air pollution is much more serious problem in Delhi as compared to the other two. Why is this so? (200 words)

- In spite of similar urbanisation, air pollution is much more severe in Delhi compared to that in Mumbai and Kolkata. This is because of

Geography and Climate

- This the **most detrimental factor**. Delhi is a **continental city** while the other two are coastal. Land and See Breezes in Mumbai and Kolkata carry pollutants away from the city. There is no such advantage to Delhi as it is land locked.
- Also, the **duration of monsoon winds** is short in Delhi compared to the other two.
- Delhi faces severe cold wave in winter compared to the other two. Cold climate here creates temperature inversion which traps the pollutants, mainly smog, for a longer duration.

Polluting Industry in close vicinity in Delhi.

- Delhi and its immediate neighbourhood are the hotbed of polluting industries which are primarily coal-fuelled. Burning coal releases oxides of sulphur which forms sulphurous smog.
- This type of smog is more pronounced in Delhi than in the other two cities due to geography and climate.

Vehicular Emissions

- All the three cities contribute nearly equal vehicular emissions rich in CO_2 and NO_2. NO_2 results in photochemical smog. Here again, Delhi is worst hit due to its geography and climate.

Farm Straw Burning

- Delhi is at the heart of major agricultural region. Burning of farm straw in the surrounding regions also adds to Delhi's pollution levels.

226 words.

Haze

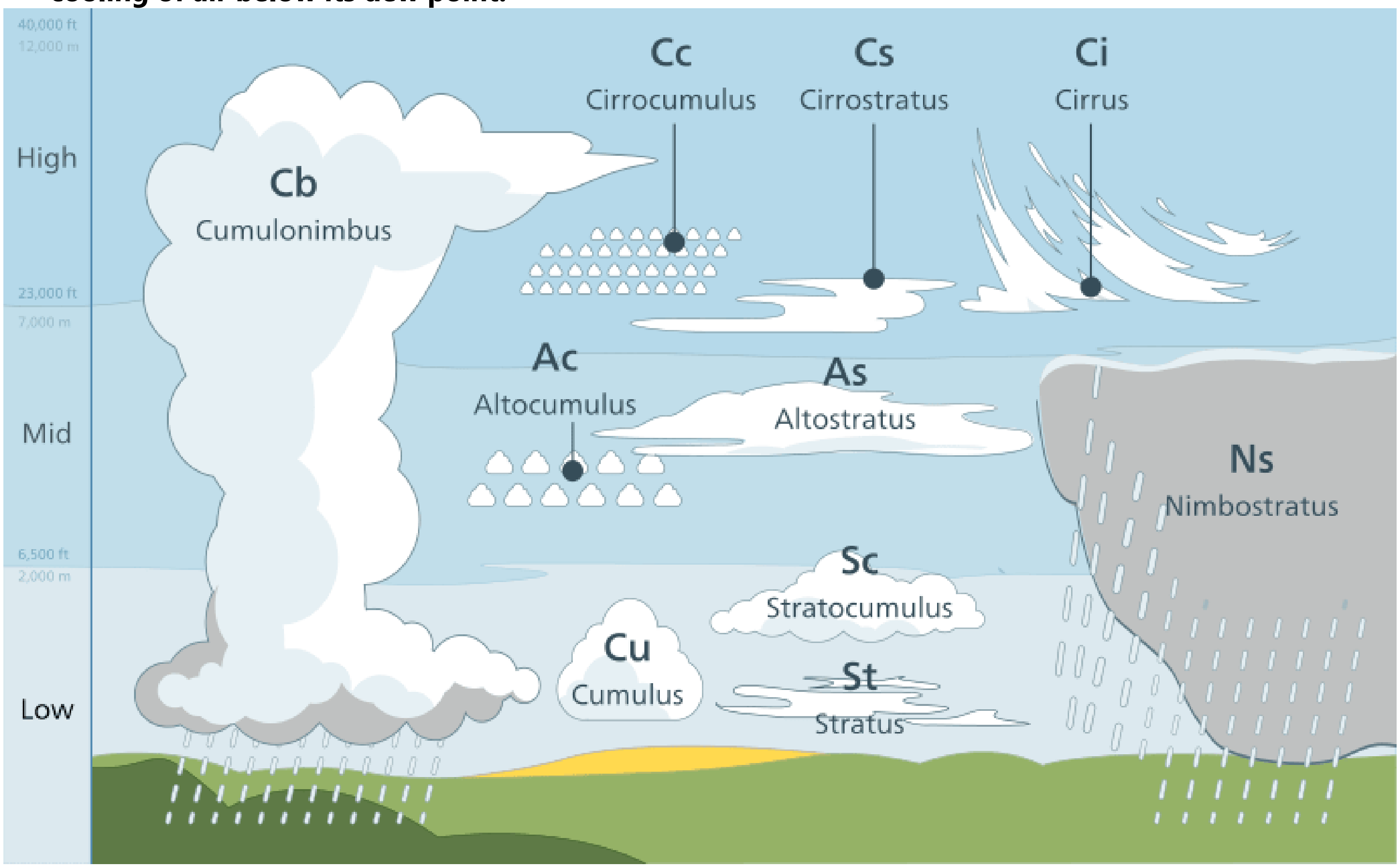
- In a haze dust, smoke and other dry particles obscure the clarity of the sky.
- There is no condensation in haze. Smog is similar to haze, but there is condensation in smog.
- Sources for haze particles include farming (ploughing in dry weather), traffic, industry, and wildfires.

Haze

Toxic Chemical	Sources	Environmental Effects
Nitrogen Oxides (NO and NO_2)	• combustion of oil, coal, gas • bacterial action in soil • forest fires, volcanic action • lightning	• decreased visibility due to yellowish colour of NO_2 • NO_2 can suppress plant growth
Volatile Organic Compounds (VOCs)	• evaporation of fuels • incomplete combustion of fossil fuels	• eye irritation • respiratory irritation • some are carcinogenic • decreased visibility due to blue-brown haze
Ozone (O_3)	• formed from photolysis of NO_2 • sometimes results from stratospheric ozone intrusions	• decreased crop yields • retards plant growth • **damages plastics** • breaks down rubber
Peroxyacetyl Nitrates (PAN)	• formed by the reaction of NO_2 with VOCs	• eye irritation • high toxicity to plants • **damaging to proteins**

Clouds

- Cloud is a mass of minute water droplets or tiny crystals of ice formed by the condensation of the water vapour in free air at considerable elevations.
- Clouds are caused mainly by the **adiabatic cooling of air below its dew point.**
- As the clouds are formed at some height over the surface of the earth, they take various shapes.
- According to their height, expanse, density and transparency or opaqueness clouds are grouped under four types: **(i) cirrus; (ii) cumulus; (iii) stratus; (iv) nimbus.**



Types of clouds (Valentin de Bruyn / Coton, from Wikimedia Commons)

Cirrus Clouds

- Cirrus clouds are formed at high altitudes (8,000-12,000m). They are made of ice crystals.
- They are thin and detached clouds having a feathery appearance. They are always white.

Cumulus Clouds

- Cumulus clouds look like cotton wool. They are generally formed at a height of 4,000-7,000 m.
- They exist in patches and can be seen scattered here and there. They have a flat base.

Stratus Clouds

- As their name implies, these are layered clouds covering large portions of the sky.
- These clouds are generally formed either due to loss of heat or the mixing of air masses with different temperatures.

Nimbus Clouds

- Nimbus clouds are black or dark grey. They form at middle levels or very near to the surface of the earth.
- These are extremely dense and opaque to the rays of the sun.
- Sometimes, the clouds are so low that they seem to touch the ground.
- Nimbus clouds are shapeless masses of thick vapour.

A combination of these four basic types can give rise to the following types of clouds:

- **High clouds – cirrus, cirrostratus, cirrocumulus;**
- **Middle clouds – altostratus and altocumulus;**
- **Low clouds – stratocumulus and nimbostratus (long duration rainfall cloud; rain bands in tropical cyclones) and**
- **Clouds with extensive vertical development – cumulus and cumulonimbus (thunderstorm cloud)**

Types of Clouds

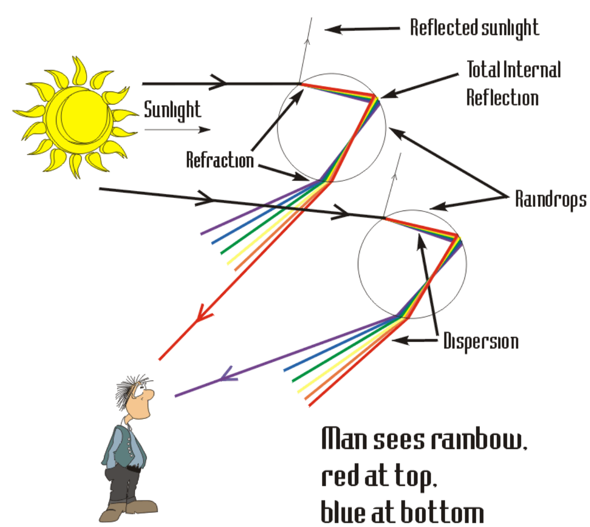
Sun's halo is produced by the refraction of light in: [2002]

a) water vapour in Stratus clouds
b) ice crystals in Cirro-Cumulus clouds
c) ice crystals in Cirrus clouds
d) dust particles in Stratus clouds

- Halos (22° halo) are caused by both **refraction and reflection of sunlight by ice crystals in cirrus clouds**.

Sun's halo

- Just like a rainbow (caused due to **reflection, refraction, dispersion and total internal reflection** of light by water droplets), halos around the sun (or moon — moon ring or winter halo) are personal.
- Everyone sees their particular halo, made by particular ice crystals, which are different from the ice crystals making the halo of the person standing next.



Formation of a rainbow ([Credits: Rebecca McDowell](#))

Answer: b) ice crystals in Cirrus clouds

6.5 Precipitation

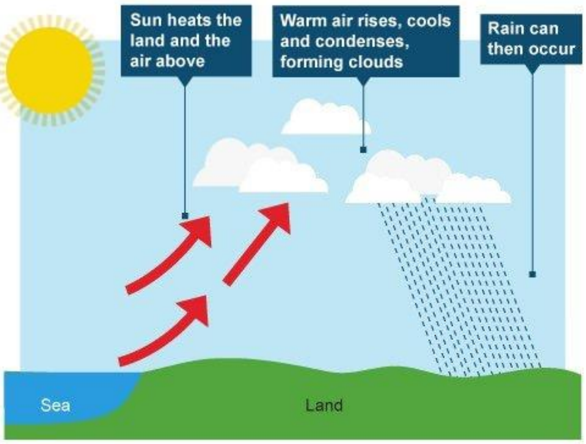
- Condensation of water vapour followed by release of moisture is known as precipitation.
- The process of continuous condensation in air helps the condensed particles to grow in size.
- When the resistance of the air fails to hold them against the force of gravity, they fall on to the earth's surface as different forms of precipitation. Precipitation may happen in liquid or solid form.
- Precipitation in the form of drops of water is called rainfall when the drop size is more than **0.5 mm**.
- It is called **Virage** when raindrops evaporate before reaching the earth while passing through dry air.
- **Drizzle** is light rainfall with drop size being less than 0.5 mm, and when evaporation occurs before reaching the ground, it is referred to as **mist.**
- When the temperature is lower than the 0° C, precipitation takes place in the form of fine flakes of snow and is called **snowfall**. Moisture is released in the form of hexagonal crystals.
- Besides rain and snow, other forms of precipitation are **sleet** and **hail**, though the latter are limited in occurrence and are sporadic in both time and space.
- **Sleet** is frozen raindrops and refrozen melted snow-water. When a layer of air with the temperature above freezing point overlies a subfreezing layer near the ground, precipitation takes place in the form of sleet.
- Raindrops, which leave the warmer air, encounter the colder air below. As a result, they solidify and reach the ground as small pellets of ice not bigger than the raindrops from which they are formed.
- Sometimes, drops of rain after being released by the clouds become solidified into small rounded solid pieces of ice and which reach the surface of the earth are called **hailstones**.
- These are formed by the rainwater passing through the colder layers. Hailstones have several **concentric** layers of ice one over the other.
- **Rainfall:** drop size more than 0.5 mm.
- **Virage:** raindrops evaporate before reaching the earth.
- **Drizzle:** light rainfall; drop size less than 0.5 mm.
- **Mist:** evaporation drizzle occurs before reaching the ground leading to foggy weather.
- **Snowfall:** fine flakes of snow fall when the temperature is less than 0° C.
- **Sleet:** frozen raindrops and refrozen melted snow; mixture of snow and rain or merely partially melted snow.
- **Hail:** precipitation in the form of hard rounded pellets (5 to 50 mm) is known as hail.

6.6 Types of Rainfall

- On the basis of origin, rainfall may be classified into three main types – the **convectional, orographic or relief** and the **cyclonic or frontal.**

Convectional Rainfall

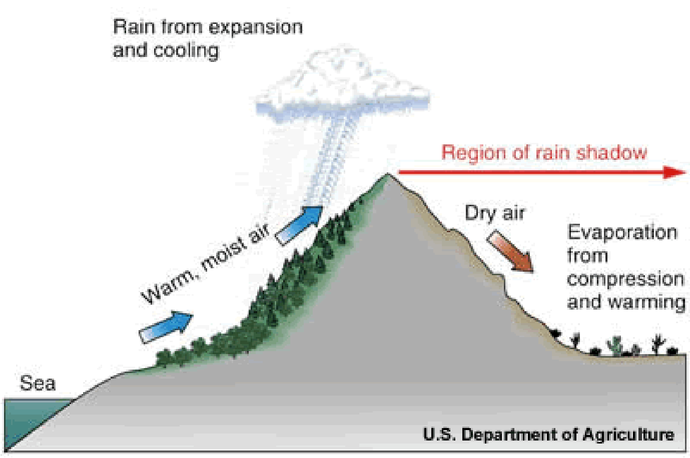
- The air on being heated, becomes light and rises in convection currents.
- As it rises, it expands and loses heat, and consequently, condensation takes place, and cumulous clouds are formed (when convection is rapid and intense cumulonimbus clouds are formed).
- This process releases **latent heat of condensation** which **further heats the air and forces the air to go further up**.
- Convectional precipitation is heavy but of **short duration**, **highly localised** and is associated with minimum amount of cloudiness.
- It occurs mainly during **summer** and is common over **equatorial doldrums** in the Congo basin, the Amazon basin and the islands of south-east Asia.



Convectional rainfall

Orographic Rainfall

- This type of precipitation occurs when warm, humid air strikes an orographic barrier (a mountain range).
- Because of the initial momentum, the air is forced to rise. As the moisture-laden air gains height, it expands (because of fall in ambient pressure) and the temperature falls (adiabatic).
- Condensation sets in, and soon saturation (dew point) is reached. The surplus moisture falls as orographic rainfall along the windward slopes.
- After giving rain on the windward side, the winds are relatively dry and cold. They reach the leeward slope and descend (katabatic wind), and their temperature rises due to increase in ambient pressure.

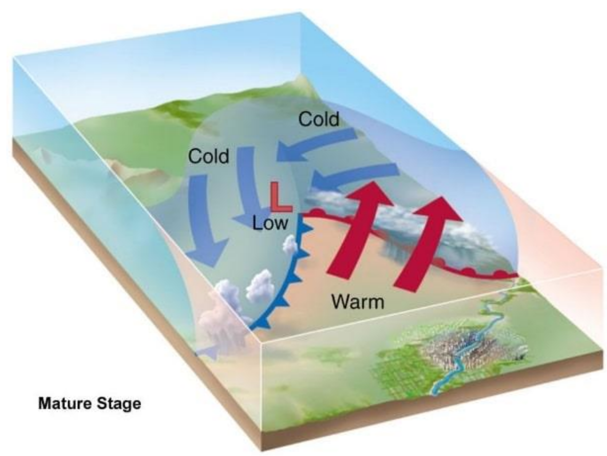


Orographic rainfall

- Their capacity to take in moisture increases (relative humidity decreases) and hence **the leeward slopes remain rainless and dry**.
- The area situated on the leeward side, which gets less rainfall is known as the **rain-shadow area** (some arid and semi-arid regions are a direct consequence of rain-shadow effect. Example: **Patagonian Desert in Argentina, Eastern slopes of Western Ghats, etc.**).
- The rainfall in rain shadow area is known as the **relief rain**. Example: Mahabaleshwar, situated on the windward side of Western Ghats, receives more than 600 cm of rainfall, whereas Pune, lying in the rain shadow area, receives only about 70 cm.

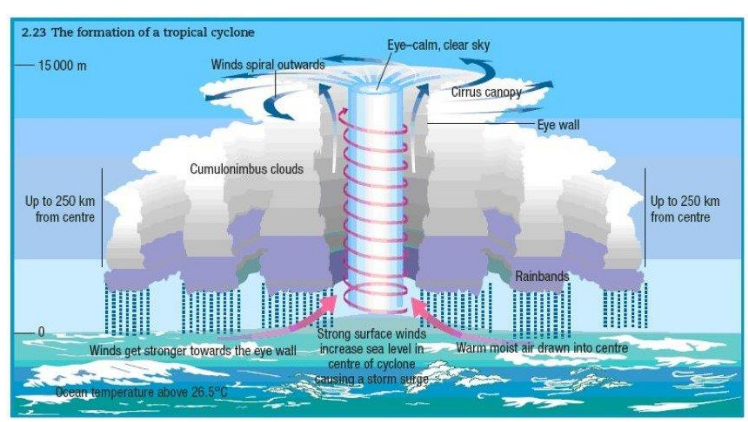
Frontal Rainfall

- When two air masses with different temperatures meet, turbulent conditions are produced.
- Along the front convection occurs and causes precipitation (we will study this in Fronts).
- For instance, in north-west Europe, cold continental air and warm oceanic air converge to produce **heavy rainfall** in adjacent areas.



Frontal Rainfall

Cyclonic Rain



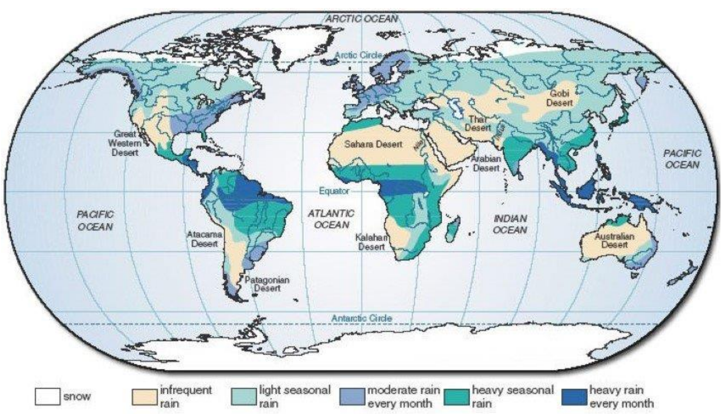
Cyclonic Rainfall in Tropical Cyclones

- Cyclonic Rainfall is **convectional rainfall on a large scale** (we will see this in detail later).
- The precipitation in a tropical cyclone is of convectional type while that in a temperate cyclone is because of frontal activity.

Monsoonal Rainfall

- This type of precipitation is characterized by **seasonal reversal of winds** which carry oceanic moisture (especially the south-west monsoon) with them and cause extensive rainfall in south and southeast Asia.

World Distribution of Rainfall



World Distribution of Rainfall

- Different places on the earth's surface receive different amounts of rainfall in a year and that too in different seasons. In general, as we proceed from the equator towards the poles, rainfall goes on decreasing steadily.
- The coastal areas of the world receive greater amounts of rainfall than the interior of the continents.
- The rainfall is more over the oceans than on the landmasses of the world because of being great sources of water.
- Between the latitudes 35° and 40° N and S of the equator, the rain is heavier on the eastern coasts (because of warm ocean currents) and goes on decreasing towards the west.
- But, between 45° and 65° N and S of equator, due to the **westerlies**, the rainfall is first received on the western margins of the continents, and it goes on decreasing towards the east.
- Wherever mountains run parallel to the coast, the rain is greater on the coastal plain, on the windward side and it decreases towards the leeward side. E.g. Rainfall along Western Ghats.
- On the basis of the total amount of annual precipitation, major precipitation regimes of the world are identified as follows.
- The equatorial belt, the windward slopes of the mountains along the western coasts in the cool temperate zone and the coastal areas of the monsoon land receive heavy rainfall of over 200 cm per annum.
- Interior continental areas receive moderate rainfall varying from 100-200 cm per annum.
- The coastal areas of the continents receive moderate amount of rainfall.
- The central parts of the tropical land and the eastern and interior parts of the temperate lands receive rainfall varying between 50-100 cm per annum.
- Areas lying in the **rain shadow zone** of the interior of the continents and high latitudes receive very low rainfall — less than 50 cm per annum.
- In some region's rainfall is distributed evenly throughout the year such as in the equatorial belt and in the western parts of cool temperate regions.
- In the other regions, the rainfall distribution is variable seasonally.

Prelims Practise

1. Which one of the following process is responsible for transforming liquid into vapour? (a) Condensation (b) Transpiration (c) Evaporation (d) Precipitation
2. The air that contains moisture to its full capacity: (a) Relative humidity (b) Specific humidity (c) Absolute humidity (d) Saturated air
3. Which one of the following is the highest cloud in the sky? (a) Cirrus (b) Stratus (c) Nimbus (d) Cumulus

Answers: 1. c) Evaporation; 2. d) Saturated air 3. c) Cirrus

30 words

- Name the three types of precipitation.
- Explain relative humidity.
- Why does the amount of water vapour decrease rapidly with altitude? (Hint: Lapse rate ➔ Condensation)
- Why is winter air dry compared to the summer air? (Hint: Low temperature aids condensation)
- How are clouds formed? Classify them

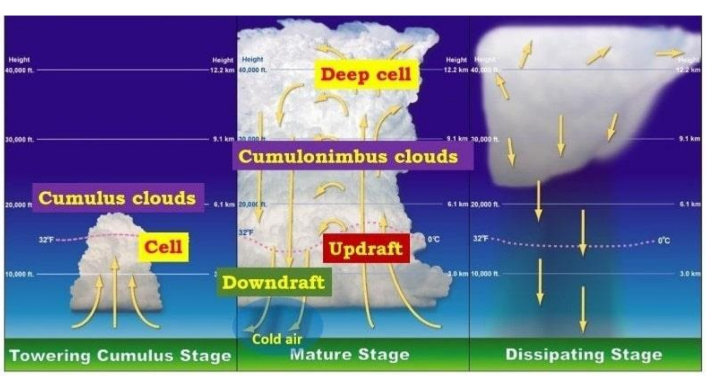
150 words

- Discuss the salient features of the world distribution of precipitation.
- What are forms of condensation? Describe the process of dew and frost formation.

7. Thunderstorm

- Thunderstorms and tornadoes are **severe local storms that involve rapid convection or upliftment of air**.
- They are of **short duration**, occurring over a **small area** but are **violent**.
- Thunderstorm is a storm with **thunder and lightning** and typically also **heavy rain or hail.**
- Thunderstorms **mostly occur on ground** where the temperature is high.
- Thunderstorms are less frequent on water bodies due to low temperature.
- Worldwide, there are an estimated 16 million thunderstorms each year, and at any given moment, there are roughly 2,000 thunderstorms in progress.

7.1 Formation of a thunderstorm



Formation of a Thunderstorm

Stage 1: Cumulus stage

- Ground is significantly heated due to solar insolation.
- A low pressure starts to establish due to intense upliftment of an air parcel (convention).
- Air from the surroundings start to rush in to fill the low pressure.
- Intense convection of moist hot air builds up a towering cumulonimbus cloud.

Stage 2: Mature stage

- Condensation releases **latent heat of condensation** making the air warmer.
- It becomes much lighter and is further uplifted.
- Intense updraft of rising warm air causes the cloud to grow bigger and rise to greater height.
- The space is filled by fresh moisture-laden air.
- Condensation occurs in this air, and the cycle is repeated **as long as the moisture is supplied**.
- Later, downdraft brings down to earth the cool air and rain.
- The incoming of thunderstorm is indicated by violent gust of wind. This wind is due to the intense downdraft.

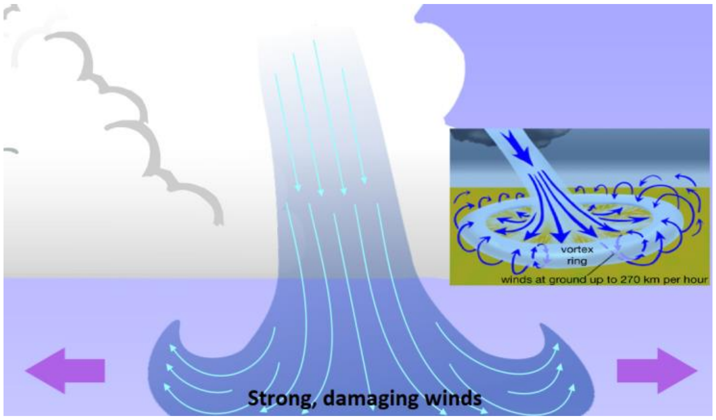
Motion of a thunderstorm

- Path of a thunderstorm is erratic. Motion is primarily due to **interactions of its updrafts and downdrafts.**
- The speed of isolated storms is typically about 20 km (12 miles) per hour, but some storms move much faster.
- In extreme circumstances, a supercell storm may move 65 to 80 km (about 40 to 50 miles) per hour.

Downbursts

- Downdrafts are referred to as macrobursts or microbursts.
- Macroburst is more than 4 km in diameter and can produce winds as high as 60 metres per second, or 215 km per hour.
- A microburst is smaller in dimension but produces winds as high as 75 metres per second, or 270 km per hour

- They are **seriously hazardous to aircraft**, especially during take-offs and landings.

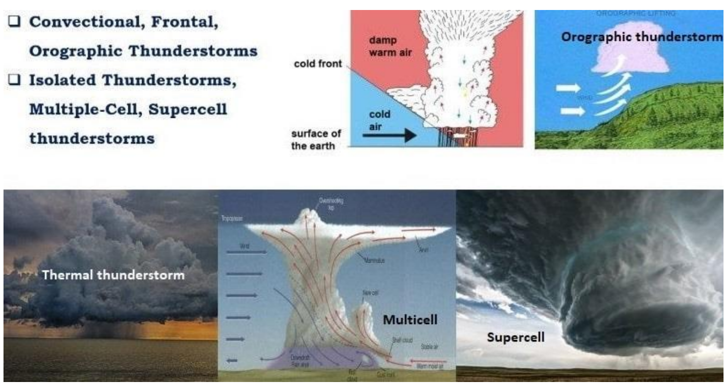


Downburst (Credits)

Stage 3: Dissipating stage

- When the clouds extend to heights where sub-zero temperature prevails, hails are formed, and they come down as hailstorm. Intense precipitation occurs.
- In a matter of few minutes, the storm dissipates, and clear weather starts to prevail.

7.2 Types of Thunderstorms



Types of Thunderstorms

- Convectional, Frontal, Orographic Thunderstorms.
- Isolated Thunderstorms, Multiple-Cell Thunderstorms, Supercell thunderstorms.

Thermal thunderstorm

- Caused due to intense heating of ground during summer (cumulonimbus cloud and convectional rain).

Orographic thunderstorm

- Forceful upliftment of warm moist air parcel when it passes over a mountain barrier creates cumulonimbus cloud causing heavy precipitation on the windward side.
- **Orographic cloudbursts are common in Jammu and Kashmir, Cherrapunji and Mawsynram.**

Frontal thunderstorm

- Thunderstorms occurring along cold fronts.

Single-cell thunderstorm (Isolated thunderstorm)

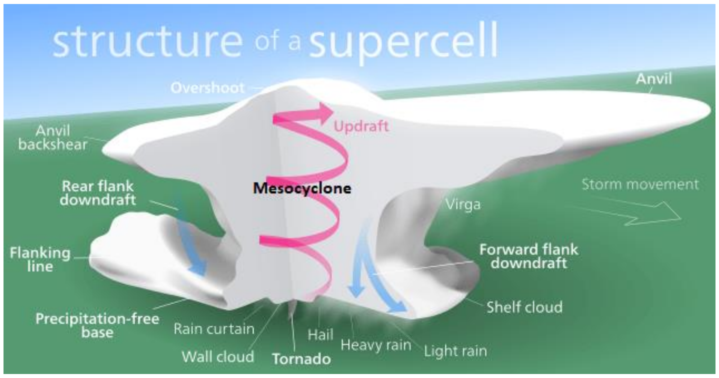
- Single-cell thunderstorms are small, brief, weak storms that grow and die within an hour or so. They are typically driven by heating on a summer afternoon.
- Single-cell storms may produce brief heavy rain and lightning.
- They are very common in India during summers, mostly April, May.
- In **Kerala,** they are called **Mango Showers** and in Karnataka **Blossom showers**.

A multi-cell thunderstorm

- A multi-cell storm is a thunderstorm in which new updrafts form along the leading edge of rain-cooled air (the gust front).
- Individual cells usually last 30 to 60 minutes, while the system as a whole may last for many hours.
- Multicell storms may produce hail, strong winds, brief tornadoes, and flooding.

A supercell thunderstorm

- A supercell is a long-lived (greater than 1 hour) and highly organised storm feeding off an updraft (a rising current of air) that is tilted and rotating.
- Most large and violent tornadoes come from supercells.



Supercell (Wikipedia)

Mesocyclone

- A mesocyclone is a rotating vortex of air within a supercell thunderstorm.
- Mesocyclones sometimes produce tornadoes.

7.3 Tornado

- Tornado is a small-diameter column of violently rotating air developed within a convective cloud and in contact with the ground.
- Tornados occur most often in association with thunderstorms during the spring and summer in the mid-latitudes of both the Northern and Southern Hemispheres.
- Tornadoes generally occur in **middle latitudes because of convergence of warm and cold air masses**.

Formation

- When warm, humid air meets a cold airmass, horizontally spinning winds are created.
- As the warm air rises, it begins rotating vertically forming a mesocyclone in the centre of the Cumulonimbus cloud. This is a supercell.
- The rotating warm air condenses into rain which in turn pulls the mesocyclone closer to the ground; then the tornado begins to form.

Composite of five shots of Tornadogenesis (Wiki)

- Heavy rains in front of the tornado cause downdrafts.
- These whirling atmospheric vortices can generate the strongest winds known on Earth: wind speeds in the range of 500 km (300 miles) per hour.
- They are often referred to as **twisters.**

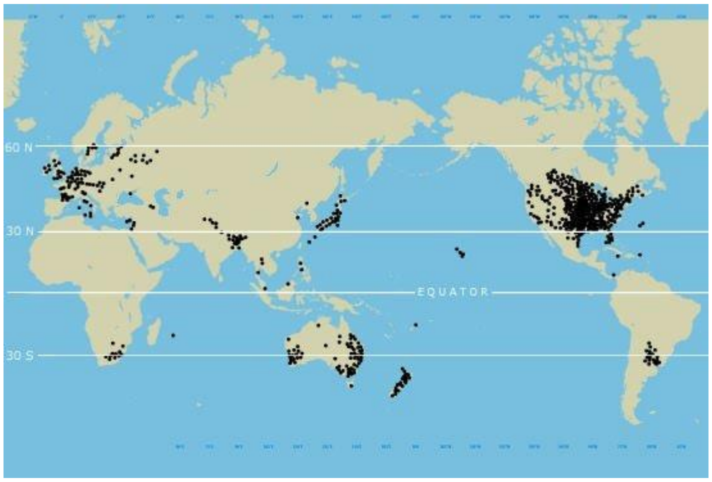
Waterspout

- Waterspout is an intense columnar vortex (usually appearing as a funnel-shaped cloud) that occurs over a body of water.

Waterspout

- They are connected to a towering cumulonimbus cloud.
- They are weaker than most of its land counterparts, i.e. tornadoes.
- Most waterspouts do not suck up water; they are small and weak rotating columns of air over water.

Distribution of tornadoes



Distribution of tornadoes

- The temperate and tropical regions are the most prone to thunderstorms and tornadoes.
- Tornadoes have been reported on all continents except Antarctica.
- United States has the most violent tornadoes.

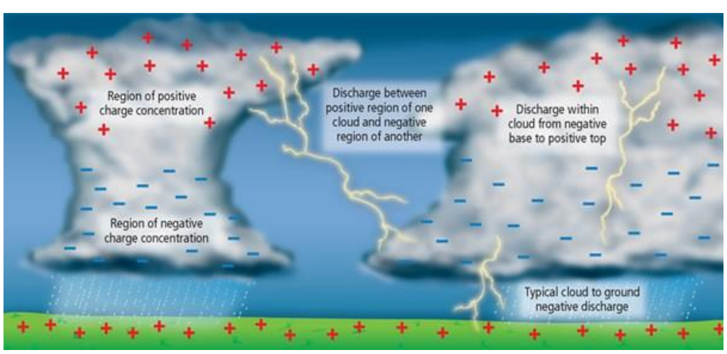
- Canada reports the second largest number of tornadoes.
- In the Indian sub-continent, **Bangladesh** is the most prone country to tornadoes.

7.4 Lightning and thunder

- Water vapour condenses into small ice crystals when it moves upward in the cumulonimbus cloud.
- The ice crystals continue to move up until they gather enough mass that can overcomes the buoyant force.
- This leads to a system where smaller ice crystals move up while bigger crystals come down.
- The resulting collisions trigger the **release of electrons**, in a process very similar to the generation of electric sparks (this is called as **ionisation**)

In ionisation, an electron in the outer shell is peeled out of the atom, and the atom become an ion.
There are two types of ions based on charge – cation and anion.
Cation: A cation is an atom or a molecule which is positively charged, i.e. it has a greater number of protons than electrons.
Anion: An anion is an atom or molecule which is negatively charged, i.e. it has a greater number of electrons than protons.

- The moving free electrons cause more collisions and more electrons are released and a chain reaction ensues.
- The process results in a situation in which the **top layer of the cloud gets positively charged (cations) while the middle and bottom layers are negatively (anions) charged**.



Lightning (Credits)

- The electrical potential difference between the top and the bottom layers is huge, of the order of 109 or 1010 volts.
- In little time, a huge current, of the order of 105 to 106 amperes, starts to flow between the layers.
- It produces heat, leading to the heating of the air column between the two layers of cloud.
- It is because of this heat that the air column looks red during lightning.
- The heated air column expands and produces shock waves that result in thunder.

Thunder

- Thunder is the sound caused by the discharge of atmospheric electrical charge (plasma — ionised gas medium — 30,000 °C) by lightning.
- The channel pressure of the electric charge greatly exceeds the ambient (surrounding) pressure, and the channel expands at a supersonic rate (speed of sound).
- The resultant shock wave decays rapidly with distance and is eventually heard as thunder once it slows to the speed of sound.
- Thunderbolt is a flash of lightning accompanied by a crash of thunder.

Lightning from cloud to Earth

- Earth is a good conductor of electricity but is electrically neutral.
- In comparison to the middle layer of the cloud, however, it becomes positively charged.
- As a result, a flow of current (about 20-15%) gets directed towards the Earth as well.
- It is this current flow that results in the damage to life and property.
- Once about 80-100 m from the surface, lightning tends to change course to hit the taller objects (guess why very tall buildings have a vertical pole above).
- This is because travelling through air, which is a bad conductor of electricity, electrons try to find a better conductor, and also the shortest route to the relatively positively charged Earth's surface.

Lightning strikes the metallic tower of the building

- The most lightning activity on Earth is seen on the shore of **Lake Maracaibo in Venezuela**.

Lightning deaths

- Several thousand thunderstorms occur over India every year.
- Incidents of lightning have been showing an increasing trend over the last 20 years, especially near the foothills of the Himalayas.
- People are rarely hit directly by lightning. But such strikes are almost always fatal.
- The most common way in which people are struck by lightning are by ground currents.
- The electrical energy, after hitting a tree or any other object, spreads laterally on the ground for some distance, and people in this area receive electrical shocks.
- It becomes more dangerous if the ground is wet, or there is conducting material like metal on it.

Precautions

- Moving under a tree or lying flat on the ground can increase risks.
- Even indoors, electrical fittings, wires, metal and water must be avoided.

(Source)

7.5 Hailstorm

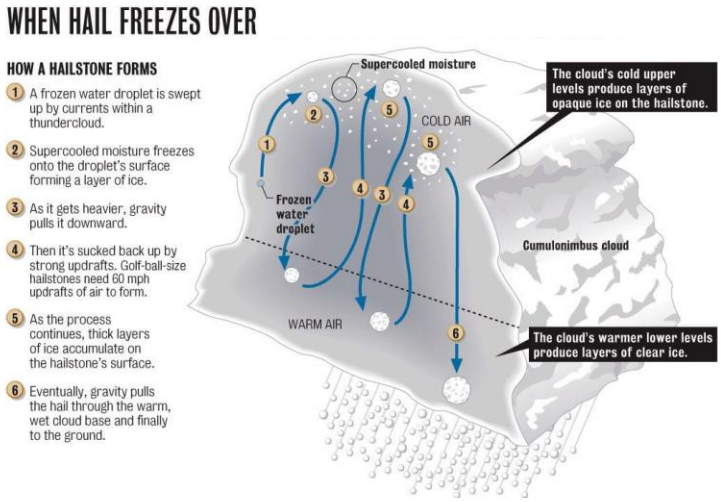
- Hail is a form of **solid precipitation** in which frozen pellets fall in showers from a **cumulonimbus cloud**.
- Any thunderstorm which produces hail that reaches the ground is known as a hailstorm.
- A hailstone is a layered irregular lump of ice. It is made of thick and translucent layers, alternating with layers that are thin, white and opaque.
- Hailstones are produced in almost all thunderstorms, but in most of the cases, they don't reach the surface.

Favourable conditions for hail formation

- Strong, upward motion of air (updraft) within the parent thunderstorm.
- High liquid water content.
- Great vertical extent of the cumulonimbus cloud.
- **Good portion of the cloud layer is below freezing 0 °C**.
- High surface temperatures. Hail growth is greatly inhibited during cold surface temperatures.

Formation of hail

- Hail begins as water droplets in a cumulonimbus cloud. As the droplets rise and the temperature goes below freezing, they freeze on contact with **condensation nuclei**.
- The storm's updraft with great wind speeds (180 kmph) blows the forming hailstones up the cloud.
- When the hailstone moves into an area with a high concentration of supercooled water droplets, it acquires new opaque layer.
- The hailstone will keep rising in the thunderstorm until its mass can no longer be supported by the updraft.
- It doesn't fall immediately to the surface because of melting, friction with air, wind, and interaction with rain and other hailstones that slow its descent. In the process, it acquires more layers.
- It then falls toward the ground while continuing to grow, based on the same processes, until it leaves the cloud.
- Finally, it may fall to the surface as hailstone if it can overcome the frictional force of the wind and ground temperature.



Hailstorm formation

- Hailstones can grow up to 15 centimetres and weigh more than 0.5 kg. Generally, the larger hailstones will form some distance from the stronger updraft where they can pass more time growing.
- Hail is less common in the tropics despite a much higher frequency of thunderstorms than in the mid-latitudes because the atmosphere over the tropics tends to be warmer over a much greater altitude.

Feb 2019: Severe hailstorm in Delhi-NCR

- Delhi and the surrounding regions experienced a very severe hailstorm in February 2019.
- A hailstorm is not unusual in the winter months. However, a hailstorm this severe was unprecedented.
- A number of factors contributed to making it severe.
    1. Western disturbance supplied enough moisture for the formation of thundercloud and hail formation.
    2. Confluence of winds from Bay of Bengal and Arabian Sea met over northern India (confluence of air masses with varying physical properties can cause severe thunderstorms).
    3. At the same time, jet streams were passing over the northern plains and helped in deep cloud formation at the lower level (upper-level divergence will cause convergence at the surface).

7.6 Hazards posed by thunderstorms and associated phenomenon

- Many hazardous weather events are associated with thunderstorms.
- Under the right conditions, rainfall from thunderstorms causes flash flooding (cloudburst).
- Lightning is responsible for many fires around the world each year and causes fatalities.
- Hail damages crops, vehicle windshields, windows, and kills livestock caught out in the open.
- Strong (120 mph) winds associated with thunderstorms knock down trees, power lines and mobile homes.
- Downbursts pose a huge risk to aircraft during take-off and landing (especially in the ITCZ zone).
- Tornadoes (with winds up to about 300 mph) can destroy all but the best-built human-made structures.