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Climatology Part II

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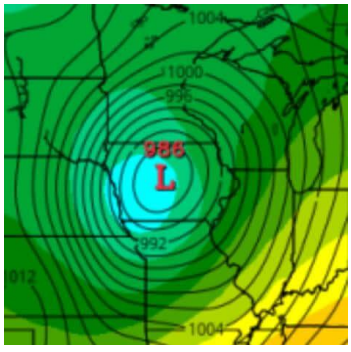
1. Tropical Cyclones

- Tropical cyclones originate over oceans in **tropical areas in late summers**.
- They are rapidly rotating violent storms characterised by
  - ✓ a **closed low-pressure centre with steep pressure gradients** (category 1 cyclones have a barometric pressure of greater than 980 millibars; category 5 cyclones can have central barometric pressure of **less than 920 millibars**),



Closed Isobars in a Tropical Cyclone

  - ✓ a **closed low-level atmospheric circulation** (winds converging from all directions — cyclonic circulation),
  - ✓ **strong winds** (squalls — a sudden violent gust of wind), and
  - ✓ a **spiral arrangement of thunderstorms** that produce very heavy rain **(torrential rainfall**).
- The low-pressure at the centre is responsible for the wind speeds.
- The closed air circulation (cyclonic circulation) is a result of **rapid upward movement of hot moist air** which is subjected to **Coriolis force**.

1.1 Conditions necessary for the Formation of a Tropical Cyclone

- **Large sea surface with temperature higher than 27° C.**
- **Presence of the Coriolis force enough to create a cyclonic vortex.**
- **A pre-existing weak low-pressure area or low-level-cyclonic circulation.**
- **Low wind shear.**
- **Upper-level divergence.**

Good Source of Latent Heat

- Ocean waters having temperatures of **27° C** and depth of warm water extending for **60-70 m** deep supply enough moisture, and hence **latent heat of condensation**, to generate and drive a tropical storm.
- Thick layer of warm water ensures that the deep convection currents within the water do not churn and mix the cooler water below with the warmer water near the surface.

Why tropical cyclones form mostly on the western margins of the oceans?

- Because of **warm ocean currents** (easterly trade winds drag ocean waters towards west) that flow from east towards west forming a thick layer of warm water with temperatures greater than 27°C.

Why are tropical cyclones very rare on the eastern margins of the oceans?

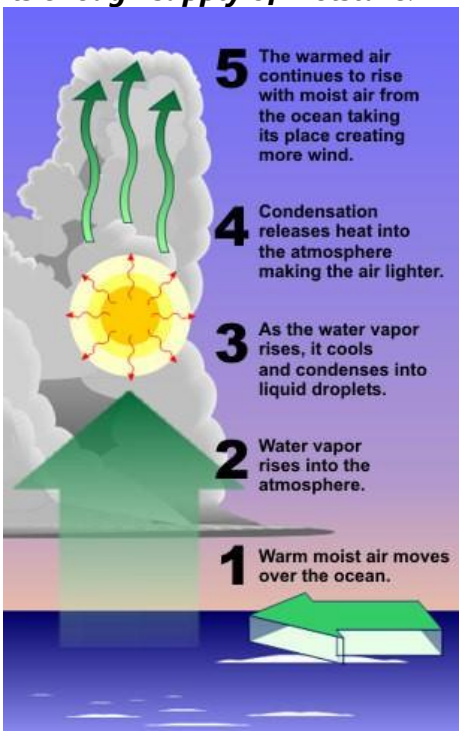
- The **cold currents** lower the surface temperatures of the eastern parts of the tropical oceans making them unfit for the breeding of cyclonic storms.

*Exceptional case: During **strong El Nino years**, strong hurricanes occur in the eastern Pacific. This is due to the accumulation of warm waters in the eastern Pacific due to **weak Walker Cell**.*

Why do tropical cyclones weaken on landfall?

- On landfall, the storm is cut-off from adequate moisture supply and hence it is deprived of latent heat of condensation. Thus, the storm dissipates (weakens or dies off) on landfall.

*Rising of humid air parcel ➔ ambient pressure on the air parcel decreases with altitude ➔ adiabatic lapse rate (fall in temperature of air parcel) ➔ condensation of moisture in air parcel due to low temperature ➔ **latent heat of condensation** is released in the process ➔ air parcel is heated further due to the release of latent heat of condensation and becomes less denser ➔ air parcel is further uplifted ➔ more air comes in to fill the gap ➔ new moisture is available for condensation ➔ latent heat of condensation is released. **The cycle repeats as long as there is enough supply of moisture**.*



Coriolis Force

- The **Coriolis force is zero at the equator,** but it increases with latitude.
- Coriolis force at 5° latitude is significant enough to create a storm (cyclonic vortex).
- About 65 per cent of cyclonic activity occurs between **10° and 20° latitude**.
- The cyclonic circulation is **anti-clockwise (counterclockwise) in the northern hemisphere** and **clockwise in the southern hemisphere**.

Why cyclones occur mostly in late summers?

1. Due to high specific heat of water, and mixing, the **ocean waters in northern hemisphere attain maximum temperatures in August** (in contract continents attain maximum temperatures in June-July).
2. Whirling motion (cyclonic vortex) is enhanced when the **doldrums** (region within ITCZ) over oceans are farthest from the equator (**Coriolis force increases with distance from the equator**).

Why do 'tropical cyclones' winds rotate counter-clockwise in the Northern Hemisphere?

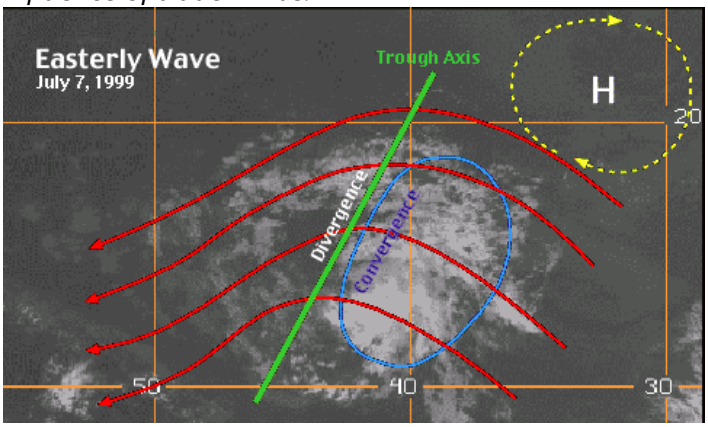
- As the earth's rotation sets up an apparent force (called the Coriolis force) that pulls the winds to the **right** in the Northern Hemisphere (and to the left in the Southern Hemisphere).
- So, when a low-pressure starts to form over north of the equator, the surface winds will flow inward trying to fill in the low and will be deflected to the right, and a **counter-clockwise rotation** will be initiated.
- The opposite (a deflection to the left and a clockwise rotation) will occur south of the equator.

Coriolis force is too tiny to effect rotation in water that is going down the drains of sinks and toilets. The rotation in those will be determined by the geometry of the container and the original motion of the water.

Low-level Disturbances

- Low-level disturbance is a **low-pressure trough (an extended region of low-pressure)** that moves from east to west in the form of **easterly wave disturbances** in the Inter-Tropical Convergence Zone (ITCZ).

A disturbance is a persistent group of thunderstorms with heavy rains and strong wind gusts.
Easterly wave disturbances: *it is a convective trough (thermal origin) — a persistent group of thunderstorms travelling together in east to west direction (westward traveling disturbances) under the influence of trade winds.*



Easterly wave disturbances

- Easterly wave disturbances act as **seedling circulations (birthplace)** for a large number of tropical cyclones. However, not all disturbances develop into cyclones.

Temperature Contrast Between Air Masses

- The convergence of air masses of different temperatures results in instability causing low-level disturbances which are a prerequisite for the origin and growth of violent tropical storms.
- Trade winds from both the hemispheres meet along the inter-tropical front (ITCZ). Temperature contrasts between these air masses must exist when the ITCZ is farthest from the equator so that the low-level disturbances can intensify into a depression (intensifying low-pressure cell).

Wind Shear

- Wind Shear is the difference between wind speeds at different altitudes.
- Tropical cyclones develop when the wind is uniform.

Why is convective cyclogenesis (tropical cyclogenesis) confined to tropics?

- **Because of weak vertical wind shear, cyclone formation processes are limited to latitude equatorward of the subtropical jet stream.**
- In the temperate regions, wind shear is high due to westerlies, and this inhibits convective cyclogenesis.

Why there are very few Tropical Cyclones during southwest monsoon season?

Large vertical wind shear

- The southwest monsoon is characterized by the presence of strong westerly winds (south-west monsoon winds) in the lower troposphere (below 3 km) and strong easterly winds in the upper troposphere (above 9 km). This results **in large vertical wind shear**. **Strong vertical wind shear inhibits cyclone development**.

Less time for development

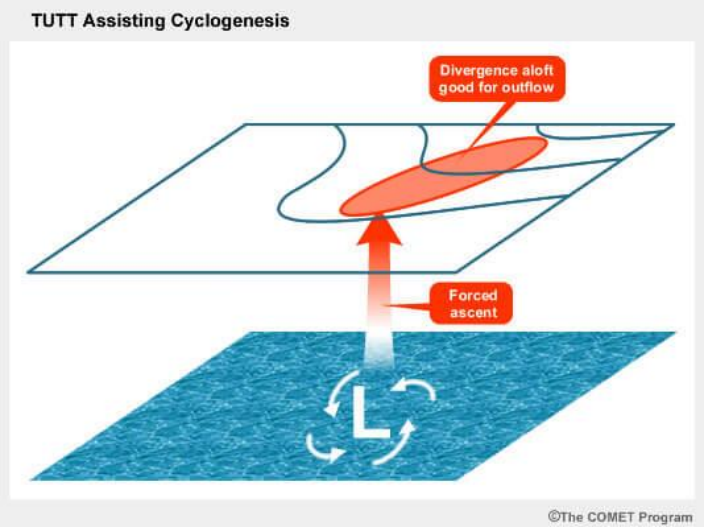
- The potential zone for the development of cyclones shifts to North Bay of Bengal during southwest monsoon season.
- Low-pressure system up to the intensity of depressions form along the monsoon trough (along ITCZ), which extends from northwest India to the north Bay of Bengal.
- The Depression forming over this area crosses Orissa-West Bengal coast in just a day or two as the bay is narrower to the north.
- These systems thus have shorter oceanic stay (they make landfall very quickly) and hence cannot intensify beyond the depression stage.

Upper Air Disturbance

- An **upper tropospheric cyclone** usually moves slowly from east to west and is prevalent in summer.
- Its circulations generally do not extend below 6000 m in altitude.
- The remains of this cyclone (**upper tropospheric westerly trough or tropical upper tropospheric trough**) from the westerlies move deep into the tropical latitude regions.

Troughs may be at the surface, or aloft. They may be convective (thermal origin — tropics), or frontal (dynamic origin — temperate regions).

- These troughs can assist tropical cyclogenesis and intensification by providing additional forced ascent.



Upper tropospheric westerly trough assisting convective cyclogenesis

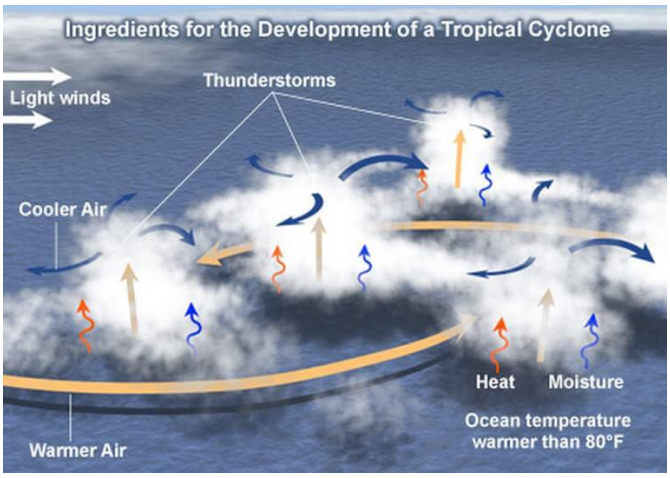
- As divergence prevails (upper tropospheric divergence) on the eastern side of the **troughs**, a rising motion occurs at the surface; this leads to the development of thunderstorms or intensification of existing storms.
- Further, these **abandoned troughs (remnants of temperate cyclones)** usually have cold cores, suggesting that the environmental lapse rate is steeper. Such instability encourages thunderstorms.
- An upper tropospheric westerly trough is important for **tropical cyclone forecasting**. This is because,
  1. Fast moving upper tropospheric westerly troughs can create **large vertical wind shear** over tropical disturbances and tropical cyclones which may inhibit their strengthening.
  2. Slow moving upper tropospheric westerly troughs can drive the tropical cyclones eastward or north-eastward.

Upper tropospheric trough can influence the Direction of a tropical cyclone

1.2 Convective Cyclogenesis (Development of Tropical Cyclones)

- **Cyclogenesis** is the development or strengthening of cyclonic circulation in the atmosphere.
- Cyclogenesis involves any of these three processes:
  1. **Convective cyclogenesis or tropical cyclone formation**.
  2. **Frontal cyclogenesis of extratropical cyclone formation**.
  3. **Mesocyclones forming as warm core cyclones giving rise to tornadoes and waterspouts**.

- The tropical cyclones have a **thermal origin**, and they develop over tropical seas during **late summers (August to mid-November)**.
- At these locations, under favourable conditions, **multiple thunderstorms** (strong local convectional currents) merge and create an intense **low-pressure system (low-level disturbance)**.



Multiple thunderstorms

Tropical depression (maximum sustained wind speed < 63 kmph)

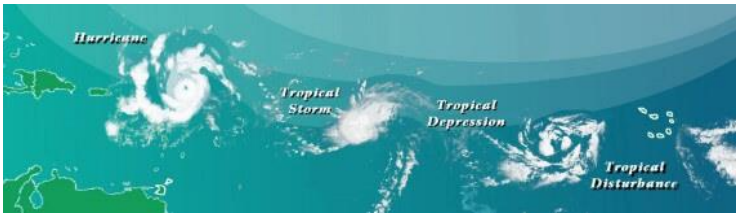
- The intense low-pressure system might acquire a whirling motion because of the **Coriolis force** giving rise to a tropical depression.
- A tropical depression has sustained winds below 63 kmph.

Tropical storm (63 kmph < maximum sustained wind speed < 119 kmph)

- Tropical depression develops into a tropical storm when the cyclonic circulation becomes more organised with maximum sustained winds at or above 63 kmph but below 119 kmph.
- At this point, the distinctive cyclonic shape starts to develop, although an **eye is not usually present**.

Tropical cyclone (maximum sustained wind speed > 119 kmph)

- As the tropical storm intensifies and acquires a maximum sustained wind speed of 119 kmph it develops into a tropical cyclone.
- A cyclone of this intensity (119 kmph) **tends to develop an eye, an area of relative calm (lowest surface atmospheric pressure in a tropical cyclone) at the centre of circulation**.



Stages of Cyclone Formation (Credits)

Maximum sustained wind speed

- India Meteorological Department (IMD) uses a 3 minutes averaging for the sustained wind.
- Maximum sustained wind is the **highest 3 minutes surface wind** occurring within the circulation of the system.

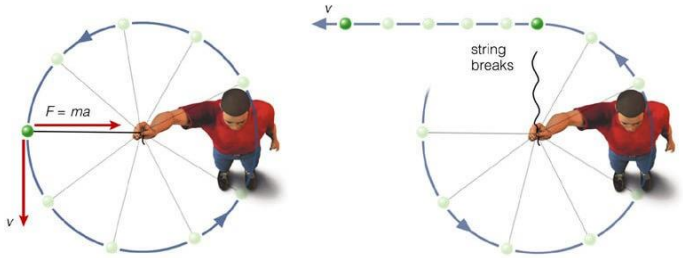
Mechanism – Early stage

- In the thunderstorm, air is uplifted as it is **warm and light**. At certain height, due to **lapse rate and adiabatic lapse rate**, the temperature of air falls, and moisture in the air undergoes **condensation**.
- Condensation releases **latent heat of condensation** making the air warmer. It becomes much lighter and is further uplifted.
- 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**.
- Due to excess moisture over oceans, the thunderstorm intensifies and sucks in air at much faster rate.
- The air from surroundings rushes in and undergoes deflection due to **Coriolis force** creating a **cyclonic vortex (spiralling air column).**
- Due to **centripetal acceleration**, the air in the vortex is forced to form a region of calmness called an **eye** at the centre of the cyclone.

Centripetal force pulling towards the centre is countered by an opposing force called centrifugal force.

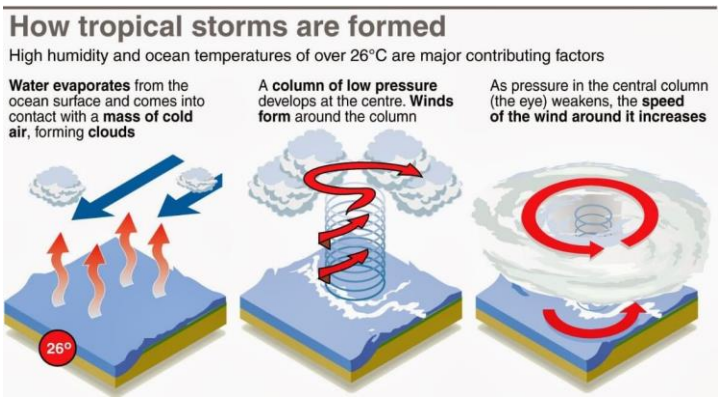
- The eye is created due to the tangential force acting on the high-speed wind that is flowing in a curvy path (intense low-pressure ➔ greater wind speeds ➔ greater Coriolis force ➔ greater deflection).

- The diameter of the eye depends on the wind speed. **Greater the wind speed, larger the eye region**.



In a cyclonic vortex, the intense low-pressure acts as the string that holds the vortex in place

- All the wind that is carried upwards loses its moisture and becomes cold and dense.
- It descends to the surface through the cylindrical eye region and at the edges of the cyclone.
- If the storm doesn't make landfall and if the ocean can supply more moisture, the storm will reach a mature stage.



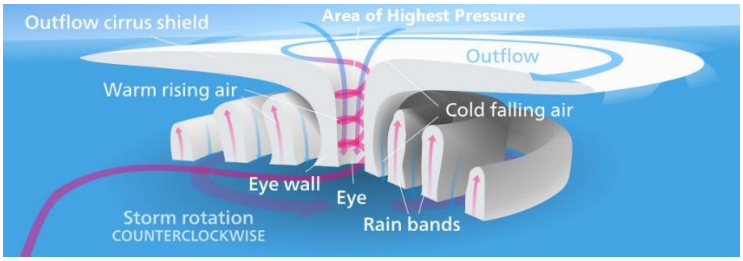
Characteristics of the eye

- The eye is a roughly circular area of comparatively **light winds and fair weather**.
- There is little or **no precipitation,** and sometimes blue sky or stars can be seen.
- Along the eye, the air is **slowly sinking** and is heated due to **compressional warming** (adiabatic).
- The eye temperature may be 10°C warmer or more at an altitude of 12 km than the surrounding environment, but only 0-2°C warmer at the surface in the tropical cyclone.
- Eyes range in size from 8 km to over 200 km across, but most are approximately 30-60 km in diameter.

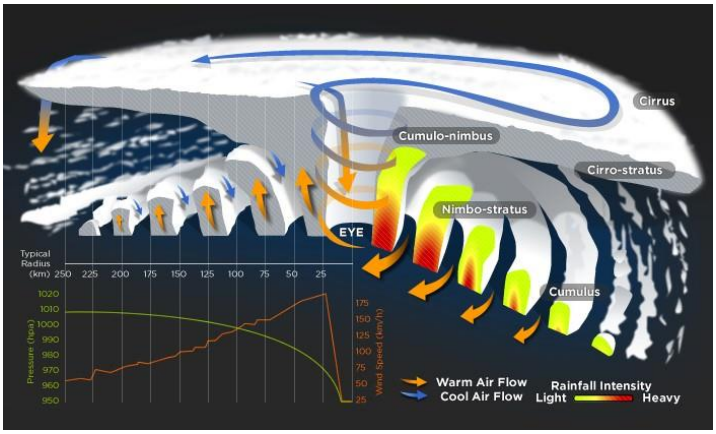
Characteristics of eyewall

- The eye is surrounded by an eyewall, the **most violent region** of the cyclone.
- It is a roughly circular ring of **deep convection (heaviest rainfall in a cyclone)**.
- Eyewall region experiences the **maximum sustained winds,** i.e. **fastest winds in a cyclone**.

Mechanism – Mature stage



A tropical cyclone in the northern hemisphere (anti-clockwise circulation) (Kelvinsong, Wikipedia)
Tropical cyclones have symmetrical elliptical shapes. They have a compact size can span in the range of 300 km to 1500 km.



A tropical cyclone in the southern hemisphere (clockwise circulation)

- At this stage, the spiralling winds create **multiple convective cells** called **rain bands** with **successive calm and violent regions**.
- Cloud formation is dense at the centre. The cloud size decreases from centre to periphery.

Central Dense Overcast (CDO)

- CDO is the **cirrus cloud shield** (mostly made up of hexagonal ice crystals) that results from the thunderstorms in the eyewall of a tropical cyclone and its rainbands.

- Before the tropical cyclone reaches very severe cyclonic storm (119 kmph), typically the CDO is uniformly showing the cold cloud tops of the cirrus with **no eye apparent**.
- The dry air flowing along the central dense overcast descends at the periphery and the eye region.

Rain bands (Spiral bands)

- Convection in tropical cyclones is organized into long, narrow rain bands which are oriented in the same direction as the horizontal wind.
- A direct circulation develops in which warm, moist air converges at the surface, ascends through these bands, diverges aloft, and descends on both sides of the bands.
- Because these bands **seem to spiral into the centre** of a tropical cyclone, they are called spiral bands.
- Rain bands are mostly made up of **cumulonimbus clouds (highest rainfall)**.
- The ones at the periphery are made up of **nimbostratus (prolonged rainfall)** and **cumulus clouds (least)**.

Vertical Structure of a Tropical Cyclone

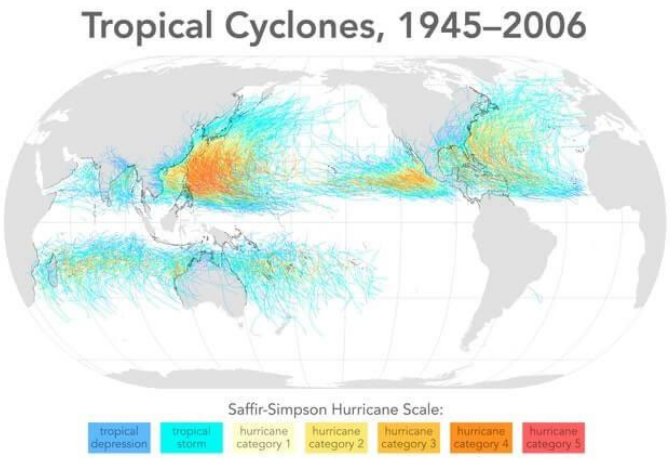
There are three divisions in the vertical structure of tropical cyclones.

- The lowest layer, extending up to 3 km and known as the inflow layer, is responsible for **driving the storm**.
- The middle layer, extending from 3 km to 7 km, is where the **main cyclonic storm** takes place.
- The outflow layer lies above 7 km. The maximum outflow is found at 12 km and above. The movement of air is **anticyclonic** in nature.

1.3 Breeding Grounds for Tropical Cyclones

The breeding grounds for tropical cyclones coincide with tropical regions with warm ocean currents.

- **Western Pacific (highest number of tropical cyclones)**: Philippines islands, eastern China and Japan where they are called typhoons.
- Western Atlantic (South-east Caribbean region) and Eastern Pacific where they are called hurricanes.
- Bay of Bengal and Arabian Sea where they are called cyclones.
- Around south-east African coast and Madagascar-Mauritius islands.
- North-west Australia.



Breeding Grounds for Tropical Cyclones

Regional names for Tropical Cyclones

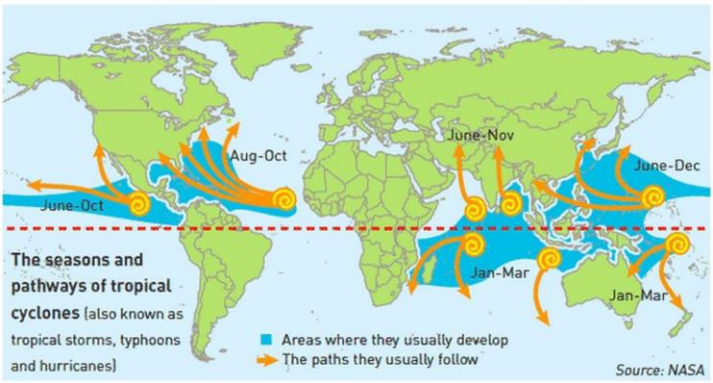
Regions	What they are called
Indian Ocean	Cyclones
Atlantic	Hurricanes
Western Pacific and South China Sea	Typhoons
Western Australia	**Willy-willies**

Regional names for various categories

Category	Australian name	US	NW Pacific	Arabian Sea /Bay of Bengal
—	Tropical low	Tropical depression	Tropical depression	Depression or severe depression
1	Tropical cyclone	Tropical storm	Tropical storm	Cyclonic storm
2	Tropical cyclone	Tropical storm	Severe tropical storm	Severe cyclonic storm
3	Severe tropical cyclone	Hurricane	Typhoon	Very severe cyclonic storm
4	Severe tropical cyclone	Hurricane	Typhoon	Very severe cyclonic storm
5	Severe tropical cyclone	Hurricane	Typhoon	Super cyclonic storm

1.4 Path of Tropical Cyclones

- Tropical cyclones generally follow a **parabolic path** with the parabolic axis being parallel to the isobars.
- Coriolis force, easterly and westerly winds, and upper tropospheric westerly trough influence the path of tropical cyclones.
- In the northern hemisphere**,** tropical cyclones **start with a westward movement** as the zone of formation is under the influence of easterlies (**trade winds**). The average speed is 15-20 kmph (360-480 km per day).
- They then turn northwards around 20° latitude because of the **Coriolis force** that deflects the path of the storm to its right. Their speed decreases to 10 kmph or even less.
- They turn further north-eastwards at around 25° latitude (Coriolis force deflects it further).
- They then turn **eastwards** around **30° latitude** (because of **westerly winds**).
- The **westward movement is the fastest** and they attain speeds of 25 kmph or more.
- They then lose energy and subside beyond 30° latitude because of **cool ocean waters** and **increasing wind shear due to westerlies**.
- In some instances, a tropical cyclone may avoid the general path and continue with its westward movement.
- Sometimes tropical cyclones are stalled near the coastline, dropping unprecedented amounts of rainfall.
- This could happen due to weak prevailing winds linked to a greatly expanded subtropical high-pressure system and northward migration of westerlies.



Which sector of the cyclone experiences strongest winds?

- Wind velocity, in a tropical cyclone, is more in right side of the storm (in most of the cases it is the poleward margin of the storm) than at centre and is moreover oceans than over landmasses.
- The "right side of the storm" is defined with respect to the storm's motion: if the cyclone is moving to the west, the right side would be to the north of the storm; if the cyclone is moving to the north, the right side would be to the east of the storm, etc.
- The strongest wind on the right side of the storm is mainly due to the fact that the **motion of the cyclone also contributes to its swirling winds**.
- A cyclone with a 145 kmph winds while stationary would have winds up to 160 kmph on the right side and only 130 kmph on the left side if it began moving (any direction) at 16 kmph.

1.5 Why only a fewer cyclones form over the Arabian Sea as compared to the Bay of Bengal?

- The average annual frequency of tropical cyclones in the north Indian Ocean (Bay of Bengal and Arabian Sea) is about **5 (about 5-6 % of the global annual average),** and about 80 cyclones form around the globe in a year. (**Most of them occur in Western Pacific and Western Atlantic**)
- The frequency is more in the Bay of Bengal than in the Arabian Sea, the ratio being **4:1.**

More low-level disturbances in Bay of Bengal

- Cyclones that form over the Bay of Bengal are either those that develop in-situ over southeast Bay of Bengal or remnants of typhoons over Northwest Pacific that move across south China sea to Indian Seas.
- As the frequency of typhoons over Northwest Pacific is quite high (about **35%** of the global

annual average), the Bay of Bengal also gets its increased quota.

- The cyclones over the Arabian Sea either originate in-situ over southeast Arabian Sea or remnants of cyclones from the Bay of Bengal that move across south peninsula.
- As the majority of Cyclones over the Bay of Bengal weaken over land after landfall, the frequency of migration into Arabian Sea is low.

The surface temperature of Bay of Bengal is higher

- Surface temperature in the Bay of Bengal is usually between 22 °C and 31 °C. It is cooler by 1-2 °C in the Arabian Sea because of the monsoon winds.

Arabian Sea surface has higher salinity

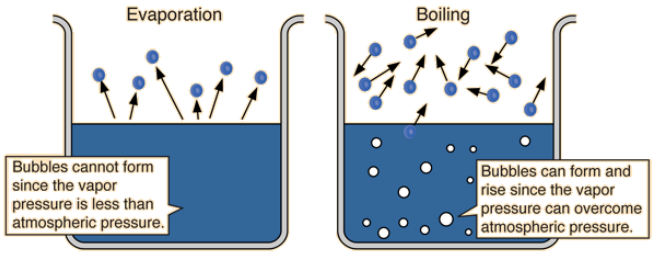
- Salinity near the surface in the northern Bay of Bengal can be as low as 31 ppt because the bay **receives lots of freshwater** from the Ganga, Brahmaputra, Irrawaddy, Godavari, and others.
- Salinity near the surface in the Arabian Sea is much higher than in the Bay of Bengal because evapouration over the Arabian Sea is much greater than precipitation and river runoff (**it loses more freshwater than it receives**).

Vapour pressure of water and rate of evapouration

- The rate of evapouration is controlled by vapour pressure of water.
- Just like air molecules exert pressure on water, water molecules exert a counter-pressure on the air molecules. This counter pressure is called as **vapour pressure of water**.
- **Higher the vapour pressure of water, higher is the rate of evapouration** and vice versa.
- The vapour pressure of water can be modified by:
  1. **Changing the air pressure:** higher wind speeds decreases air pressure and hence increase evapouration.

Bernoulli's principle: *Within a horizontal flow of fluid, points of higher fluid speed will have less pressure than points of slower fluid speed. Practical examples: Swinging Cricket Ball; Lift achieved by aeroplane wings.*

  2. **Changing the temperature of water:** when temperature of water is increased, the water molecules attain higher kinetic energy and hence the vapour pressure of water increases. This increases evapouration.
  3. **Changing salinity:** Increased salinity reduces the kinetic energy of the water molecules. This decreases evapouration.



Vapour Pressure and Rate of Evapouration (Credits)

Higher stratification in Bay of Bengal

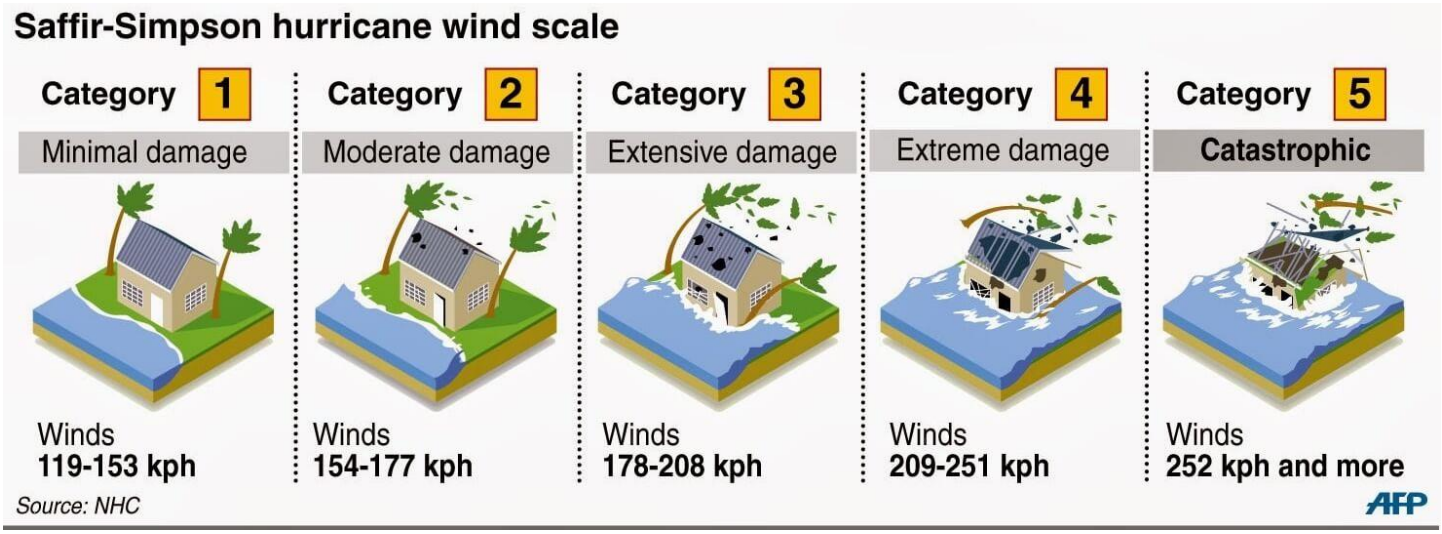
- If all the freshwater that the bay receives during a year is accumulated and spread uniformly over its entire surface, it would form a layer over a metre thick.
- Freshwater is less dense compared to saline water. Hence **vertical mixing is inhibited in Bay of Bengal**.
- On the other hand, high evapouration and low inflow of fresh water increases salinity (water becomes denser) at the surface in the Arabian Sea, and this increases vertical mixing.

Monsoon winds drive away moisture

- Though the monsoon winds increase evapouration in the Arabian Sea, the moisture is constantly driven away by the winds towards India.

1.6 Tropical Cyclone Scale

Cyclone Category	Wind Speed in Kmph	Damage Capacity
01	120-150	Minimal
02	150-180	Moderate
03	180-210	Extensive
04	210-250	Extreme
05	250+	Catastrophic
Values rebounded off to make it easy to remember		



Saffir-Simpson hurricane wind scale

Tropical Cyclone Scale by Indian Meteorological Department

S. No.	Intensity	Strength of wind	Wave height (m)
1.	Depression (L)	31- 49 kmph (17-27 knots)	1-4
2.	Deep Depression (DD)	50 - 61 kmph (28-33 knots)	4-6
3.	Cyclonic Storm (CS)	62 - 87 kmph (34-47 knots)	6-9
4.	Severe Cyclonic Storm (SCS)	88-117 kmph (48-63 knots)	9-14
5.	**Very Severe Cyclonic Storm (VSCS)**	**118-166 kmph (64-89 knots)**	**14+**
6.	**Extremely Severe Cyclonic Storm (ESCS)**	**167-221 kmph (90-119 knots)**	**14+**
7.	**Super Cyclonic Storm (SuCS)**	**222+ kmph (120+ knots)**	**14+**

Source

- The knot is a unit of speed equal to one nautical mile (1.852 km) per hour.
- A vessel travelling at 1 knot along a meridian travels approximately one minute of geographic latitude in one hour.

1 international knot = 1 nautical mile per hour = 1.852 kilometres per hour = 0.514 metres per second

1.7 Damage associated with Tropical Cyclones

- The dangers associated with cyclonic storms are generally three fold.

1. **Floods**
2. **Winds**
3. **Storm Surge**

Intensity	Damage expected	Measures to be taken
Depression	• Minor damage to unsecured structures	• Fishermen advised not to venture into the open seas.
Deep Depression		
Cyclone	• Damage to thatched huts. • Breaking of tree branches. • Minor damage to power and communication lines.	• Total suspension of fishing operations
Severe Cyclone	• Extensive damage to thatched huts. • Flooding of escape routes.	• Coastal hutment dwellers to be moved to safer places.
Very Severe Cyclone	• Extensive damage to kutcha houses. • Minor disruption of rail and road traffic. • Potential threat from flying debris.	• Mobilise evacuation from coastal areas.

Extremely Severe Cyclone	• Extensive damage to kutcha houses. • Large-scale disruption of power and communication lines. • Disruption of rail and road traffic due to extensive flooding.	• Extensive evacuation from coastal areas. • Diversion or suspension of rail and road traffic.
Super Cyclone	• Extensive structural damage to residential and industrial buildings. • Total disruption of communication and power supply. • Extensive damage to bridges causing large-scale disruption of rail and road traffic. • Large- scale flooding and inundation of sea water.	• Large-scale evacuation of coastal population. • Total suspension of rail and road traffic.

Floods

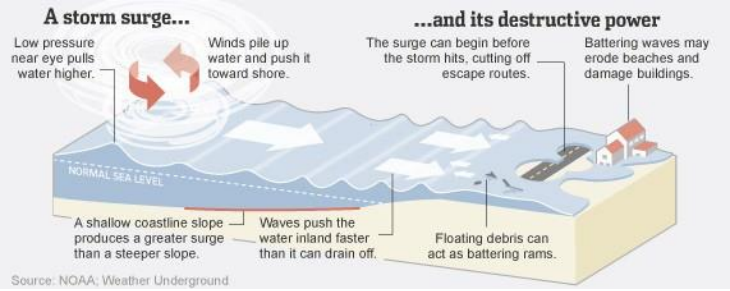
- Precipitation of about 50 cm/day is quite common within a cyclonic storm.
- Record rainfall in a cyclonic storm has been as low as trace to **as high as 250 cms**.
- The intensity of rainfall is about 85 cms/day within a radius of 50 km and about 35 cms/day between 50 to 100 km from the centre of the storm.

Wind

- The strong wind speed associated with a cyclonic storm (60-90 kmph) can result into some damage to kutcha houses and tree branches likely to break off.
- Winds of a severe Cyclonic storm (90-120 kmph) can cause uprooting of trees, damage to pucca houses and disruption of communications.
- The wind associated with a very severe Cyclonic storm and super cyclonic storm can uproot big trees, cause widespread damages to house and installations and total disruption of communications.
- The maximum wind speed associated with a very severe Cyclonic storm that hit Indian coast in the past 100 years was **260 kmph** in Oct 1999 (**Paradeep Super cyclone**).

Storm surge

- Storm Surge (tidal wave — long wavelength) is an abnormal rise of sea level as the cyclone makes landfall.
- The rise of sea level occurs due to the convergence of winds at great speeds that drag water and cause accumulation of high water column just below the centre of the cyclone.



Storm surge

- The destructive power of the storm surge depends on intensity of the cyclone and coastal bathymetry (shallower coastlines face surges of greater heights).
- Seawater inundates the coastal strip causing loss of life, large scale destruction to property & crop.
- Increased salinity in the soil makes the land unfit for agricultural use for two or three seasons.

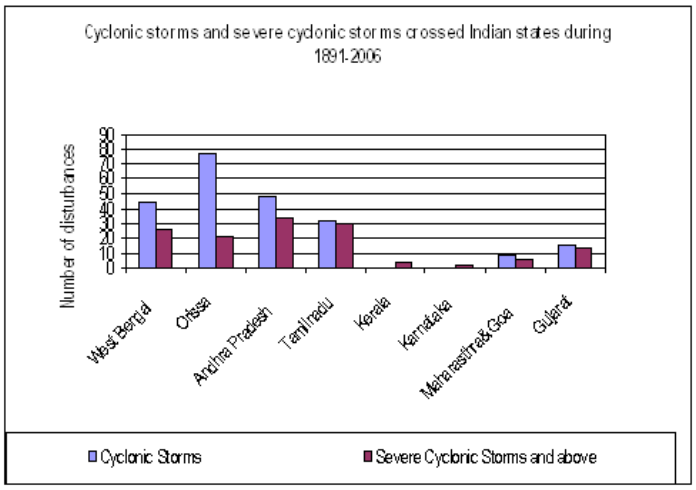
What is storm tide?

- The storm tide is the combination of **storm surge and the astronomical tide**.
- Storm surge is accentuated if the landfall time **coincides with that of high tides**.

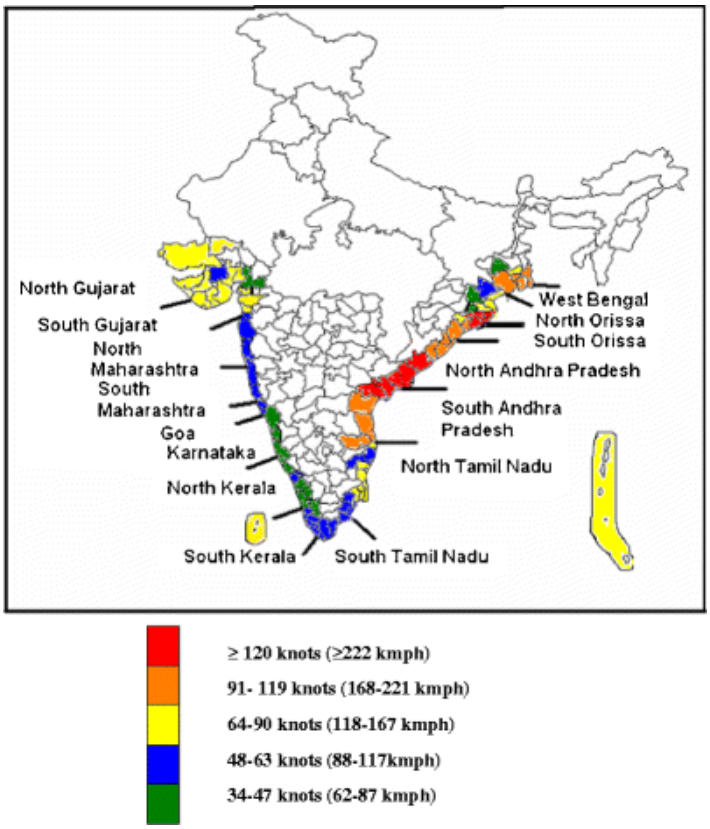
Cyclone	Strength	Region affected	Damage
1970 Bhola cyclone	Extremely Severe Cyclone	West Bengal and Bangladesh	• Deadliest tropical cyclone • 5,00,000+ fatalities
1999 Odisha Cyclone	Super Cyclone	Odisha	• Strongest recorded tropical cy-

(Paradeep Super cyclone)	**Maximum sustained wind speed of 260 kmph**		clone in the North Indian Ocean • 30,000+ fatalities
2008 Nargis Cyclone	Extremely Severe Cyclone	Irrawaddy delta (Myanmar)	• 1,00,000+ fatalities • Costliest cyclone in the region
High number of fatalities in all these cyclones was due to **storm surge**. The delta regions are always at higher risk because of low gradient.			

States Vulnerable to Cyclones



Most number of severe cyclonic storms strike Andhra Pradesh.



Andhra Pradesh and Odisha are at greater risk of receiving strong cyclones

1.8 Positive effects of Tropical Cyclones

Tropical cyclones bring rainfall to rain shadow and other parched regions

- Rainshadow regions of Western Ghats ad semi-arid regions in south India (Telangana, Rayalaseema, Hyderabad-Karnataka, Vidarbha) sometimes receive copious rain during the cyclone season.

Break up Red Tide

- Red tide is a phenomenon which involves **discolouration of coastal waters caused by algal blooms**.
- The algal bloom **deplete oxygen** in the waters and release harmful toxins.
- As tropical cyclones move across the ocean, winds and waves mix and break up patches of bacteria and can bring an earlier end to the red tide.

Replenish Barrier Islands

- Tropical cyclones have the power to pick up substantial amounts of sand, nutrients and sediment on the ocean's bottom and bring it towards barrier islands.
- Storm surge, wind and waves will often move these islands closer to the mainland as sand is pushed or pulled in that direction.

Speed dispersal to faraway locations

- Tropical cyclone wind blow spores and seeds further inland from where they would normally fall; this effect can be seen a thousand miles inland as storms move away from the shoreline.
- These seeds can replenish lost growth after fires and urbanisation.

1.9 Naming of Cyclones

Mains 2013: The recent cyclone on east coast of India was called 'Phailin'. How are the tropical cyclones named across the world? Elaborate.

- WMO (World meteorological organisation) divided the world Oceans into Basins and assigned the responsibility of naming the Cyclones to the respective regional bodies.
- Each regional body has its own rules in naming cyclones.
- In most regions, pre-determined alphabetic lists of alternating male and female names are used.

Why name them?

- Since the storms can often last a week or even longer and more than one cyclone can be occurring in the same region at the same time, names can reduce the confusion about what storm is being described.
- Naming them after a person/flower/animal etc. makes it easier for quick information exchange.

Northern Indian Ocean Region

- The names of cyclones in Indian Seas are not allocated in alphabetical order but are arranged by the name of the country which contributed the name.
- It is usual practice for a storm to be named when it reaches tropical storm strength (**63 kmph**).
- The Indian Meteorological Department (IMD) which issues cyclone advisories to eight countries has a list of names contributed by each of them.
- Every time a cyclone occurs, a name is picked in the order of the names that are already submitted.
- Each country gets a chance to name a cyclone. After all the countries get their turn, the next list of names is followed.

Contributed by	Name			
Bangladesh	Helen	Chapala	Ockhi	Fani
India	**Lehar(2013)**	**Megh**	**Sagar**	**Vayu**
Maldives	Madi	Roanu	Mekunu	Hikaa
Myanmar	Na-nauk	Kyant	Daye	Kyarr
Oman	**Hudhud**	Nada	Luban	Maha
Pakistan	**Nilofar**	Vardah	Titli	Bulbul
Sri Lanka	Priya	Asiri	Gigum	Soba
Thailand	Komen	Mora	Phethai	Amphan

Names contributed by countries in the Northern Indian Ocean Region

1.10 Warning of Tropical Cyclones

- Detection of any unusual phenomena in the weather leading to cyclones has three main parameters: **fall in pressure, increase in wind velocity, and the direction and movement (track) of storm.**
- Monitoring is also done by aircraft which carry a number of instruments including a weather radar.
- Cyclone monitoring by satellites is done through very high-resolution radiometers to obtain an image of the cloud cover and its structure.
- Today, it is possible to detect a cyclone right from its genesis in the high seas and follow its course, giving a warning at least 48 hours before a cyclone strike.
- However, the predictions of a storm course made only 12 hours in advance do not have a very high rate of precision.

4-stage IMD warning system for tropical cyclones

IMD and Cyclone Disaster Management

- 1999, IMD introduced a 4-Stage warning system to issue cyclone warnings to the disaster managers.

Pre-Cyclone Watch

- Issued when a depression forms over the Bay of Bengal irrespective of its distance from the coast.
- The pre-cyclone watch is issued at least 72 hours in advance of the commencement of adverse weather.
- It is issued at least once a day.

Cyclone Alert (Colour code Yellow)

- Issued at least 48 hours before the commencement of the bad weather when the cyclone is located beyond 500 Km from the coast.

- It is issued every three hours.

Cyclone Warning (Colour code Orange)

- Issued at least 24 hours before the commencement of the bad weather when the cyclone is located within 500 Km from the coast.
- Information about time/place of landfall are indicated in the bulletin.
- Accuracy in estimation increases as the cyclone comes closer to the coast

Post-landfall outlook (Colour code Red)

- It is issued 12 hours before the cyclone landfall when the cyclone is located within 200 km from the coast.
- More accurate information about time/place of landfall and associated bad weather are indicated in the bulletin.

2. Jet streams

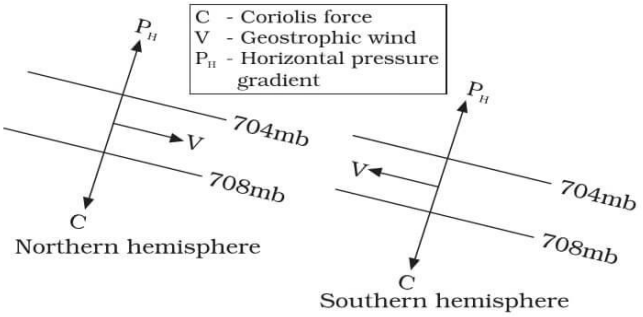
Jet streams are

- ✓ **Circumpolar** (circle around the earth with poles as their centres),
- ✓ **narrow, concentrated bands of** (the air in the stream is directed towards the axis of the stream making it very narrow — 50-150 km across)
- ✓ **upper tropospheric,**
- ✓ **westerly,**
- ✓ **geostrophic streams,**
- ✓ **flowing at high velocity,**
- ✓ **with a degree of meandering.**

2.1 Explanation of Jet Streams

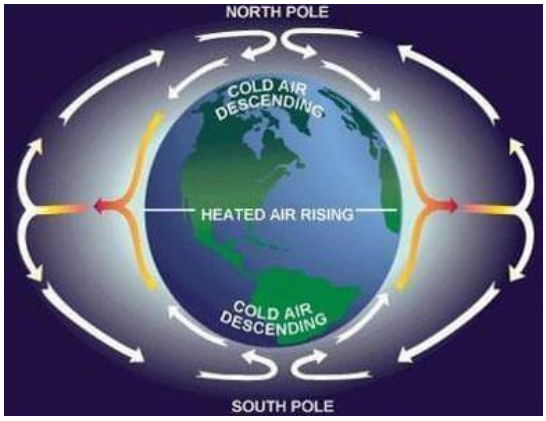
Geostrophic Wind

- 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. Jet Stream is a geostrophic wind.**



Geostrophic wind vector parallel to the isobars

Why don't winds flow from tropical high-pressure (in upper troposphere) to polar low (in upper troposphere) directly as shown in figure below?



General air circulation when the effect of Coriolis force is ignored

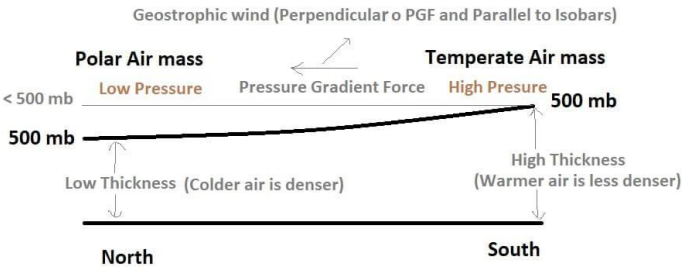
- Because these winds are **geostrophic**, i.e., they flow at **great speeds** due to **low friction** and are subjected to **greater Coriolis force**.
- Thus, they are deflected greatly giving rise to three distinct cells called **Hadley cell, Ferrel Cell** and **Polar cell**.
- That is, instead of one big cell we have three small cells that combinedly produces the same effect.
- *Hadley Cell and Polar Cell are thermal in origin (convection). Ferrel Cell is dynamic in origin*

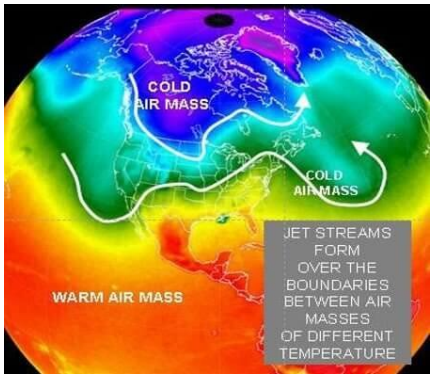
(Coriolis Force and blocking effect of converging winds). These cells are part of general circulation.

- *Jet Streams are formed due to pressure difference between air masses and Coriolis Force.*

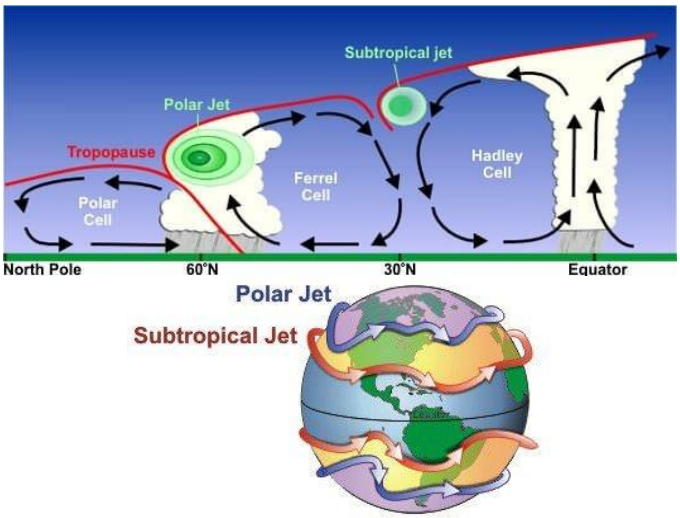
Upper tropospheric westerlies

- Jet streams are produced due to winds flowing from tropics towards poles in the upper troposphere (just below the tropopause).
- Jet stream produced between polar and temperate air masses is called as **polar jet stream or polar jet**.
- Jet stream produced between temperate and tropical air masses is called as **subtropical jet stream**.
- In **polar jet streams** wind flows from **temperate region towards polar region**, and in **subtropical jet streams,** winds flow from **subtropics towards temperate region**.
- *In the upper troposphere, the wind flows from less denser air mass towards the poles due to **thermal effect** (poles receive less heat and equator receives more heat. So, at the surface the winds flow from pole towards the equator whereas at an altitude the winds flow from equator towards poles).*
- *The high-pressure gradient force is directed from south to north.*





Polar Jet Stream is formed between temperate and polar air masses



Polar jet is stronger; Subtropical jet is higher

- Anything moving from tropics towards poles deflects towards their right in the northern hemisphere and towards their left in the southern hemisphere due to **Coriolis effect**.
- Thus, jet streams flow from **west to east** in both the hemispheres and hence they are called westerlies or upper-level westerlies.
- Both the Northern and Southern hemispheres have jet streams, although the jet streams in the north are more forceful due to greater temperature gradients.

Why does polar jet and subtropical jet flow at different altitudes?

- Polar jet streams flow **6 – 9 km** above the ground and Sub-tropical jet streams flows **10 – 16 km** above the grounds.
- This is because the troposphere is thicker at equator (17 to 18 km) than at poles (8 to 9 km).

High velocity

- The friction in the upper troposphere is also quite low due to less dense air.
- Temperature also influences the velocity of the jet stream.
- The greater the difference in air temperature, the faster the jet stream.
- Jet stream can reach speeds of up to 400 kmph or greater.
- The jet streams have an average velocity of 120 kmph in winter and 50 kmph in summer.

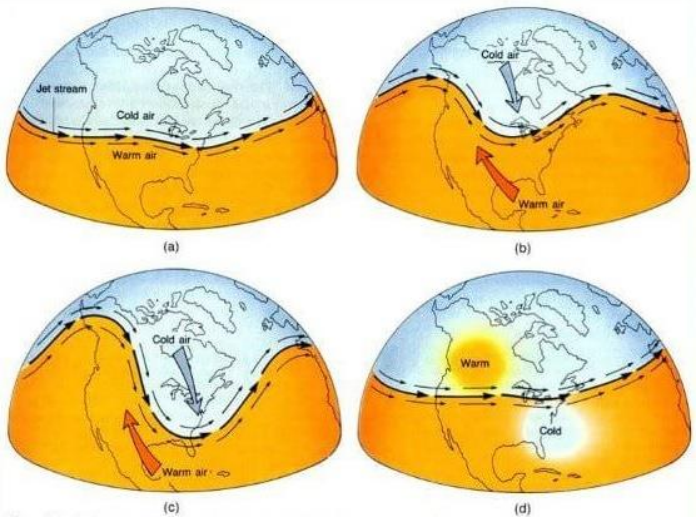
- These jet streams also have cores where the speed is much greater.

Winds are highest in the core

Meandering

- When the temperature contrast is maximum, jet stream flows in near straight path.
- But when temperature contrast reduces (jet stream is weak), the jet stream starts to follow a meandering path (wavy, irregular manner with a poleward or equatorward component).
- Thus, meandering depends on **temperature contrast (temperature gradient).**
- *High temperature gradient ➔high-pressure gradient ➔ greater wind speed ➔ greater Coriolis force ➔ geostrophic stream ➔ wind direction is parallel to isobars (perfect west-east flow).*
- *Low temperature gradient ➔ low variable Coriolis force ➔ winds start to meander*

Rossby Waves

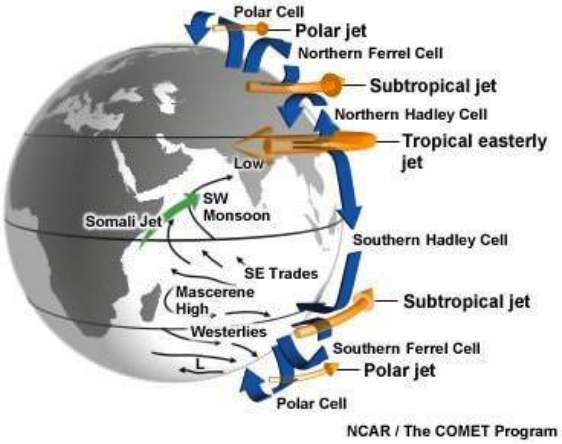


Meandering Jet Streams or Rossby Waves

- The meandering jet streams are called **Rossby Waves.**
- Rossby waves are natural phenomenon in the atmosphere and oceans due to rotation of earth.
- In Rossby waves are polar air moves toward the equator while tropical air moves poleward.
- A meander is called **peak or ridge** if it is towards poles and **trough** if it is towards equator.
- The existence of these waves explains the low-pressure cells **(cyclones)** and high-pressure cells **(anticyclones)**.

2.2 Permanent jet streams

- Polar jet and subtropical jet are **permanent jet streams** that breeze through the upper troposphere for most part of the year.



Permanent and Temporary Jet Streams

Subtropical jet stream (STJ)

- During winter, the STJ is nearly continuous in both hemispheres.
- The STJ exists all year in the southern hemisphere. However, it is intermittent in the northern hemisphere during summer when it migrates north.
- The STJ can be temporarily displaced when strong mid-latitude troughs (remnants of temperate cyclones) extend into subtropical latitudes.
- When these displacements occur, the subtropical jet can merge with the polar front jet (related to cloudbursts. We will study this in Indian Monsoons).
- STJ is closely connected to the Indian and African summer monsoons (we will study this in Indian Monsoons).

Polar front jet (PFJ)

- The strongest jet streams are the polar jets, and subtropical jets are somewhat weaker.
- The northern Polar jet stream follows the sun, i.e., it slowly migrates northward in summer, and southward in winter.
- The polar front jet is closely related to the polar front (frontogenesis process in mid-latitudes).
- It has a more variable position than the sub-tropical jet.
- In summer, its position shifts towards the poles and in winter towards the equator.
- The jet is strong and continuous in winter.
- It greatly influences climates of regions lying close to 60° latitude.
- It determines the path and speed and intensity of temperate cyclones.

2.3 Temporary jet streams

- Other than polar jet and subtropical jet, there are **temporary jet streams** which appear only in a particular season.
- They are few. Important ones are Somali Jet and The African Easterly Jet.
- They are major high-velocity winds in the lower troposphere, and hence they are called low-level jets (LLJs).

The Somali Jet

- The Somali Jet is a south-westerly jet.
- The Somali jet occurs during the summer over northern Madagascar and off the coast of Somalia.
- The jet is most intense from June to August.
- The jet remains relatively steady from June to September before moving southward to the southern Indian Ocean during the winter.

(More details about Somali Jet is given under Indian Monsoons)

The Tropical Easterly Jet or African Easterly Jet

- The TEJ is a unique and dominant feature of the northern hemispheric summer over southern Asia and northern Africa. The TEJ is found near between 5° and 20°N.
- It is fairly persistent in its position, direction, and intensity from June through the beginning of October.
- During the South Asian summer monsoon, the TEJ induces secondary circulations that enhance convection over South India and nearby ocean.
- The establishment and maintenance of the TEJ is not fully understood, but it is believed that the jet may be caused by the uniquely high temperatures and heights over the Tibetan Plateau during summer (dry air encounters more humid air at high altitudes).
- The TEJ is the upper-level venting system for the strong southwest monsoon.
- In recent years due to the decrease in the temperature contrast between the land and sea over the Indian subcontinent, the TEJ has shown a decreasing trend (not good).

2.4 Influence of Jet Streams on Weather

- Jet streams help in maintenance of latitudinal heat balance by mass exchange of air.
- Sub-tropical jet stream and some temporary jet streams together influence Indian Monsoon patterns. (more about this while studying India Monsoons in Indian geography)
- Jet streams also exercise an influence on movement of air masses which may cause prolonged drought or flood conditions.

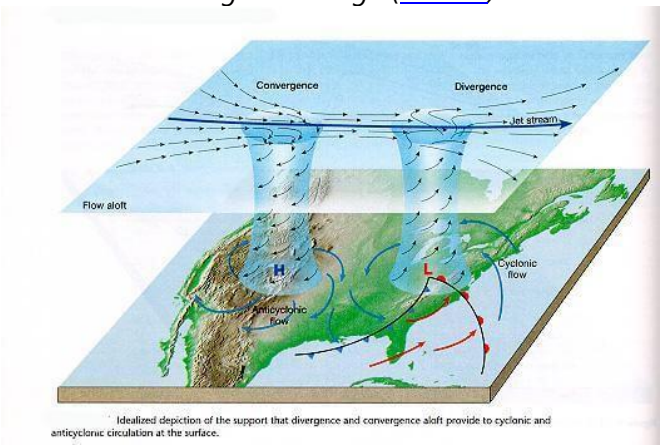
Jet Streams and Weather in Temperate Regions

- PFJ play a key role in determining the weather because they usually separate colder air and warmer air.
- Jet streams generally push air masses around, moving weather systems to new areas and even causing them to stall if they have moved too far away.
- PFJ play a major role in determining the **path and intensity of frontal precipitation and frontal cyclones**.
- Weak PFJ also results in **slipping of polar vortex** into temperate regions.

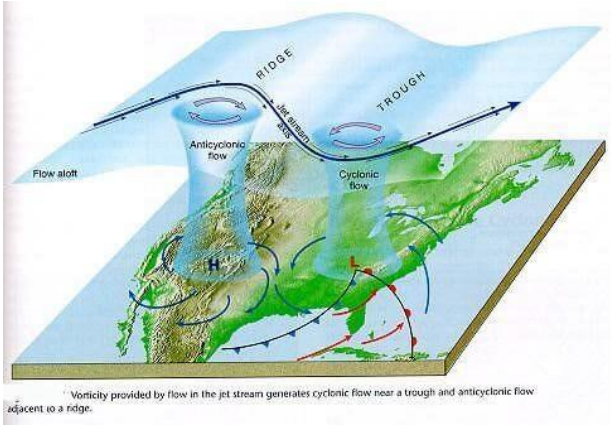
Explanation

- The jet stream drives temperate weather through phenomena called troughing, ridging, and jet streaks.
- Ridges occur where the warm air (at high-pressure) pushes against the cold air.
- Troughs occur where cold air (at lower pressure) drops into warm air.
- This condition occurs due to weak jet stream (lesser temperature contrast between air mass-es).

Trough and ridge (Credits)



Idealized depiction of the support that divergence and convergence aloft provide to cyclonic and anticyclonic circulation at the surface.



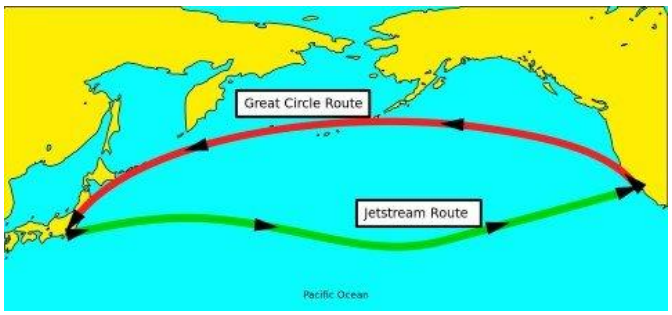
Vorticity provided by flow in the jet stream generates cyclonic flow near a trough and anticyclonic flow adjacent to a ridge.

Jet Streak; Ridge and Trough

- Troughs and ridges are analogous to low-pressure (troughs) and high-pressure (ridges).
- Active weather occurs ahead of a trough and quiet weather beneath a ridge.
- The ridges and troughs give rise to jet streaks.
- They form in response to localised but major temperature-gradients.
- The process of winds exiting a trough or a jet streak, known as divergence, creates a void in the upper atmosphere. Air will rush up from lower altitudes to fill the void.
- This upward rush of air from the surface creates a low-pressure system.
- The Coriolis effect creates the cyclonic rotation that is associated with depressions.
- The winds entering the jet streak are rapidly converging, creating a high-pressure at the upper level in the atmosphere. This leads to divergence (high-pressure) at the surface (anticyclonic condition).
- The Coriolis effect creates the anticyclonic rotation that is associated with clear weather.

2.5 Jet Streams and Aviation

- Jet streams are used by aviators if they have to fly in the direction of the flow of the jet streams and avoid them when flying in opposite direction.



- Jet streams can also cause a bumpy flight because the jet stream is sometimes unpredictable and can cause sudden movement, even when the weather looks calm and clear.
- During volcanic eruptions plumes of volcanic ash tend to get sucked into the same jet stream that aeroplanes use for travel.

3. Temperate Cyclones

- Cyclonic systems developing in the mid and high latitude **(35° latitude and 65° latitude in both hemispheres)**, beyond the tropics are called temperate cyclones.
- They are known as **mid-latitude cyclones, extratropical cyclones, frontal cyclones or wave cyclones**.
- Unlike the **tropical cyclones (convective cyclogenesis)** which have a **thermal origin**, the **temperate cyclones (frontal cyclogenesis)** have a **dynamic origin** (complex interaction of air masses under the influence of Coriolis force).
- To understand the mechanism of frontal cyclogenesis (origin and development of temperate cyclones) it is important for us to understand the concepts of **air masses** and **fronts**.

3.1 Air Masses

- An air mass is a large body of air having **little horizontal variation** in **temperature** and **moisture**.
- Air masses are an integral part of the planetary wind system and are associated with one or other wind belt.
- They extend from **surface to lower stratosphere** and are across thousands of kilometres.

Source regions

- When a large parcel of the air remains over a homogenous area for a sufficiently longer time, it acquires the characteristics of the area.
- The homogenous regions can be the vast ocean surface or vast plains and plateaus.
- The homogenous surfaces, over which air masses form, are called the **source regions.**
- The main source regions are the **high-pressure belts** in the **subtropics (giving rise to tropical air masses)** and around the **poles (the source for polar air masses).**
- Source region establishes **heat and moisture equilibrium** with the overlying air mass.
- When an air mass moves away from a source region, the upper level maintains the physical characteristics for a longer period.
- This is possible because air masses are stable with stagnant air which **do not facilitate convection**.
- Conduction and radiation in such stagnant air is not effective.

Conditions for the formation of Air Masses

- Source region should be extensive with **gentle, divergent air circulation** (gentle anticyclonic circulation).
- Areas with **high-pressure but little pressure difference** or pressure gradient are ideal source regions.
- There are **no** major source regions in the mid-latitudes as these regions are dominated by frontal cyclones and other disturbances.

Air masses based on Source Regions

There are five major source regions. These are:

1. Warm tropical and subtropical oceans;
2. The subtropical hot deserts;
3. The relatively cold high latitude oceans;
4. The very cold snow covered continents in high latitudes;
5. Permanently ice-covered continents in the Arctic and Antarctica.

Accordingly, following types of airmasses are recognised:

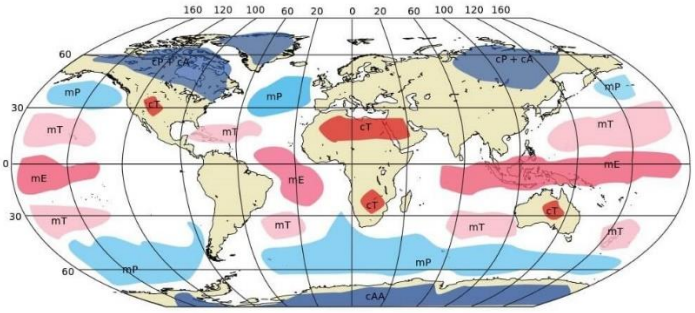
1. Maritime tropical (mT);
2. Continental tropical (cT);
3. Maritime polar (mP);
4. Continental polar (cP);
5. Continental arctic (cA).

The first letter describes moisture properties of the air mass.

- c: continental air masses (dry)
- m: maritime air masses (moist)

The second letter describes source region of the air mass.

- T: Tropical
- P: Polar
- A: Arctic or Antarctic



Air masses (Wikipedia)

- Tropical air masses are warm, and polar air masses are cold.
- The heat transfer processes that warms or cools the air takes place slowly.

Cold Air Mass

- A cold air mass is one which is colder than the underlying surface.

Cold source regions (polar air masses)

- Arctic Ocean – cold and moist
- Siberia – cold and dry
- Northern Canada – cold and dry
- Southern Ocean – cold and moist

Warm Air Mass

- A warm air mass is one which is warmer than the underlying surface.

Warm source regions (tropical air masses)

- Sahara Desert - warm and dry
- Tropical Oceans - warm and moist

Continental Polar Air Masses (cP)

- Source regions of these air masses are the Arctic basin, northern North America, Eurasia and Antarctica.
- Dry, cold and stable conditions characterize these air masses.
- The weather during winter is frigid, clear and stable. During summer, the weather is less stable with lesser prevalence of anticyclonic winds, warmer landmasses and lesser snow.

Maritime Polar Air Masses (mP)

- The source region of these air masses are the oceans between **40° and 60° latitudes**.
- These are those continental polar air masses which have moved over the warmer oceans, got heated up and have collected moisture.
- The conditions over the source regions are **cool, moist and unstable**.
- The weather during winters is characterized by high humidity, overcast skies and occasional fog and precipitation. During summer, the weather is clear, fair and stable.

Continental Tropical Air Masses (cT)

- The source regions of the air masses include tropical and sub-tropical deserts of Sahara in Africa, and of West Asia and Australia.
- These air masses are **dry, hot and stable** and do not extend beyond the source.
- They are dry throughout the year.

Maritime Tropical Air Masses (mT)

- The source regions of these air masses include the oceans in tropics and sub-tropics such as Mexican Gulf, the Pacific and the Atlantic oceans.
- These air masses are **warm, humid and unstable.**
- The weather during winter has mild temperatures, overcast skies with fog.
- During summer, the weather is characterized by high temperatures, high humidity, cumulous clouds and convectional rainfall.

Influence of Air Masses on World Weather

- The properties of an air mass which influence the accompanying weather are **vertical temperature distribution** (indicating its stability and coldness or warmness) and the **moisture content.**

- The air masses carry atmospheric moisture from oceans to continents.
- They transport **latent heat**, thus contributing to latitudinal heat balance.
- Most of the migratory atmospheric disturbances such as cyclones and storms originate at the **contact zone** between different air masses called as fronts.
- Characteristics of the air masses involved determine the weather associated with the disturbances.

3.2 Fronts

- Understanding front formation and types of fronts is important to understand the formation of **mid-latitude cyclones and the dominant weather patterns of mid-latitudes.**
- Fronts are the typical features of **mid-latitudes weather (temperate region – 30° - 65° N and S).** They are uncommon (unusual) in tropical and polar regions.
- Front is a three-dimensional **boundary zone formed between two converging air masses** with **different physical properties** (temperature, humidity, density).
- The two air masses **don't merge readily** due to the effect of the converging atmospheric circulation, different physical properties, relatively low diffusion coefficient and a low thermal conductivity.

Front Formation

- The process of formation of a front is known as **frontogenesis (war between two air masses)**, and dissipation of a front is known as **frontolysis (one of the air masses win against the other).**
- Frontogenesis involves **convergence** of two distinct air masses.
- Frontolysis involves overriding of one of the air masses by another.
- In northern hemisphere **frontogenesis** (convergence of air masses) happens in **anti-clockwise direction** and southern hemisphere, **clockwise direction**. This is due to **Coriolis force**.
- **Mid-latitude cyclones (temperate cyclones or extra-tropical cyclones) occur due to frontogenesis.**

General Characteristics

- The temperature contrast influences the thickness of frontal zone in an **inversely proportional manner**.
- That is, two air masses with higher temperature difference do not merge readily.
- Thus, the front is less thick when it is formed between two air masses with higher temperature difference.
- With a sudden change in temperature through a front, there is a change in pressure also.
- The frontal activity is invariably associated with **cloudiness and precipitation** because of ascent of warm air which cools down **adiabatically**, condenses and causes rainfall.
- The intensity of precipitation depends on the **slope of ascent and amount of water vapour present in ascending air.**
- Front experiences wind shift since the wind motion is a function of pressure gradient and Coriolis force.

***Wind Shift**: A change in wind direction of 45 degrees or more in less than 15 minutes with sustained wind speeds of 10 knots or more throughout the wind shift.*
1 knot = 1.852 kmph
1 Nautical Mile = 1.852 km

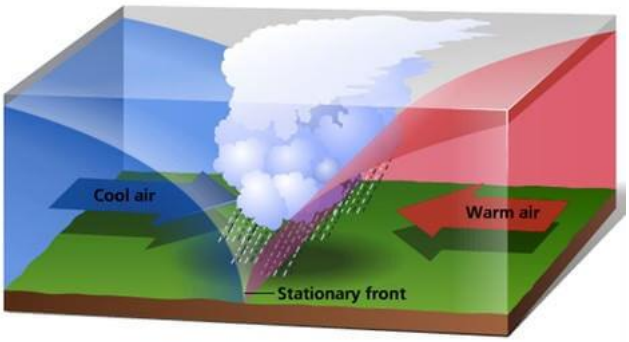
Classification of Fronts

- Based on the mechanism of frontogenesis and the associated weather, the fronts can be studied under the following types.

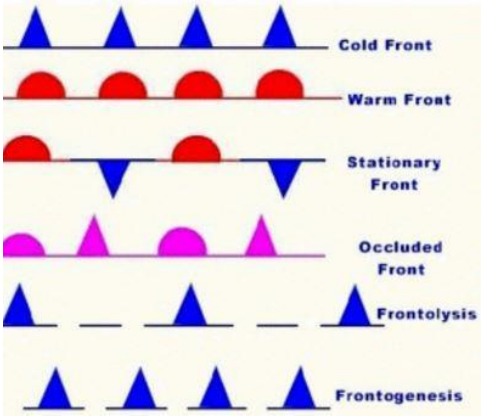
Stationary Front

- When the surface position of a front does not change (when two air masses are unable to push against each other; a draw), a stationary front is formed.
- The wind motion on both sides of the front is **parallel to the front**.
- Warm or cold front stops moving, so the name stationary front.

- Once this boundary resumes its forward motion, it becomes a warm front or cold front.



Stationary Front



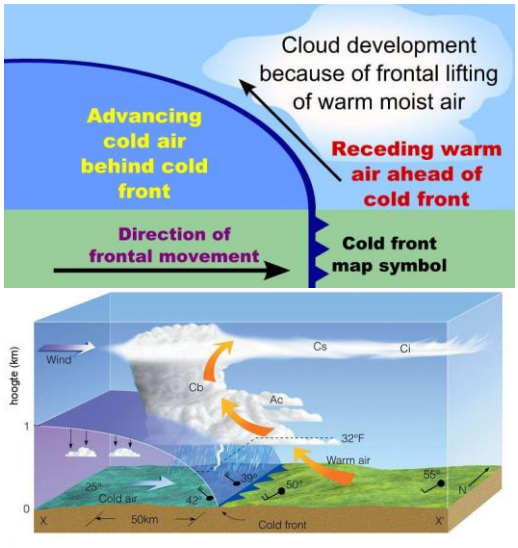
Symbols to indicate various fronts, frontogenesis and frontolysis.

Weather along a stationary front

- **Cumulonimbus clouds** are formed.
- Overrunning (uplifted air) of warm air along such a front causes **frontal precipitation**.
- Frontal cyclones migrating along a stationary front can dump **heavy amounts of precipitation**, resulting in **significant flooding** along the front.

Cold Front

- Such a front is formed when a cold air mass replaces a warm air mass by advancing into it or that the warm air mass retreats and cold air mass advances (cold air mass is the clear winner).
- In such a situation, the transition zone between the two is a **steep sloped** cold front.
- **Cold front moves up to twice as quickly as warm fronts**.
- Frontolysis begins when the warm air mass is completely uplifted by the cold air mass.

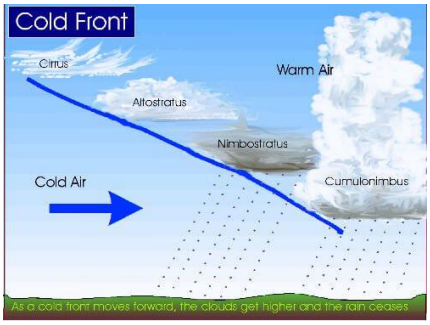


Cold Front

Weather along a cold front

- The weather depends on a narrow band of cloudiness and precipitation (because the slope is steep).
- Severe storms can occur. During the summer months, **thunderstorms** are common in **warm sector.**
- In some regions, **tornadoes** occur in warm sector.
- Cold fronts produce **sharper changes in weather (because upliftment of air is quite rapid)**.
- Temperatures can drop more than 15 degrees within the first hour.

Cloud formation along a cold front



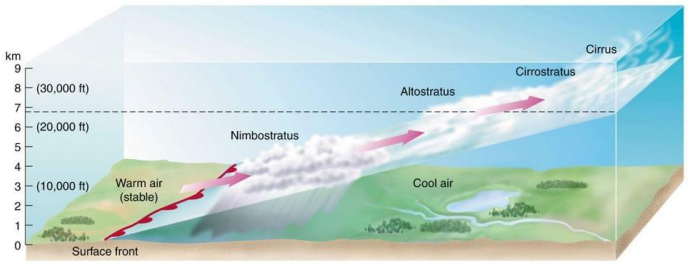
Cloud formation along a cold front

- The approach of a cold front is marked by increased wind activity in warm sector and the appearance of **cirrus clouds**, followed by lower, **denser altocumulus** and **altostratus.**
- At actual front, dark **nimbus and cumulonimbus clouds** cause heavy showers.

- A cold front passes off rapidly, but the **weather along it is violent**.

Warm Front

- It is a **sloping frontal surface** along which active movement of warm air over cold air takes place (warm air mass is too weak to beat the cold air mass).
- Frontolysis (front dissipation) begins when the warm air mass makes way for cold air mass on the ground, i.e. when the warm air mass completely sits over the cold air mass.



*Warm front; There is **no cumulonimbus cloud formation** along a warm front*

Weather along a warm front

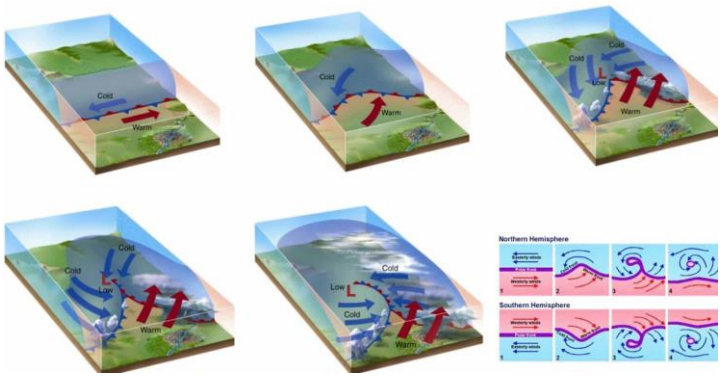
- As the warm air moves up the slope, it condenses and causes precipitation but, unlike a cold front, the temperature and wind direction changes are **gradual.**
- Such fronts cause **moderate to gentle precipitation** over a large area, over several hours.
- The passage of warm front is marked by **rise in temperature and pressure**.

Clouds along a warm front

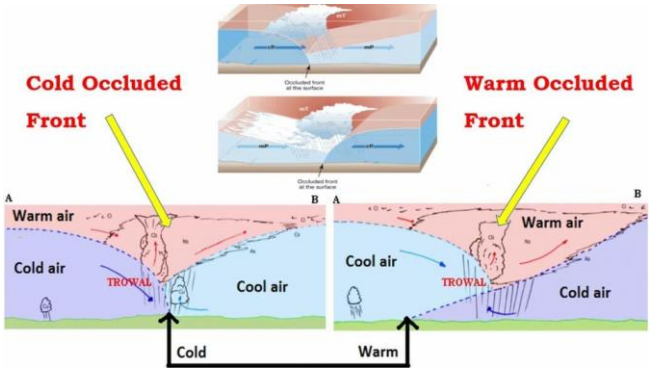
- With the approach, the hierarchy of clouds is—-cirrus, stratus and nimbus (**no cumulonimbus clouds** as the gradient is gentle).
- **Cirrostratus clouds** ahead of the warm front create a halo around sun and moon.

Occluded Front

- **Occlusion:** a process by which the cold front of a rotating low-pressure system catches up the warm front so that the **warm air between them is forced upwards.**
- Such a front is formed when a **cold air mass overtakes a warm air mass** and goes underneath it.



- Frontolysis begin when warm sector diminishes, and the cold air mass completely undertakes the warm sector on ground.
- Thus, a long and backward swinging occluded front is formed which could be a **warm front type or cold front type occlusion**.

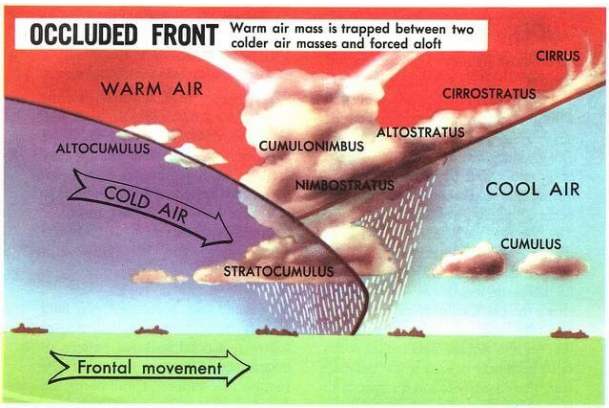


Weather along an occluded front

- Weather along an occluded front is complex — a **mixture of cold front type and warm front type weather**. Such fronts are common in western Europe.
- **The formation mid-latitude cyclones involve the formation of occluded front**.

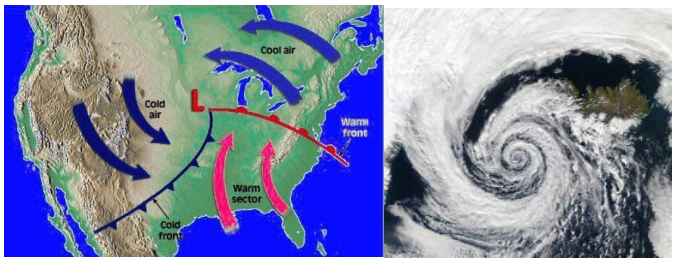
Clouds along an occluded front

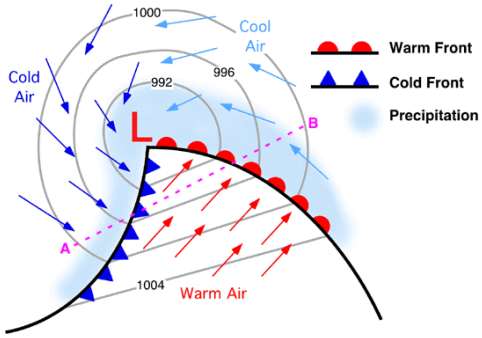
- A combination of clouds formed at cold front and warm front.
- Warm front clouds and cold front clouds are on opposite side of the occlusion.



Stationary Front	• **Tie – No clear Winner**
Cold Front	• **Cold Air mass is the clear winner.**
Warm Front	• **The warm air mass picks up a fight but fails to beat the cold air mass.** • **Cold Air mass is the winner.**
Occluded Front	• **Cold Front + Warm Front** • **Double win for cold air mass**
Cold Front, Warm Front and Occluded front are examples of Temperature Inversion.	

3.3 Origin and Development of Temperate Cyclones





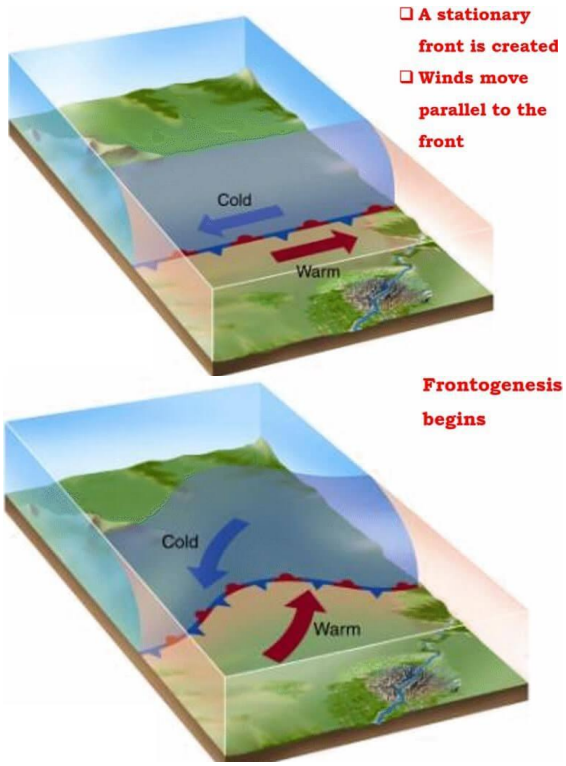
The isobars are not closed in a temperate Cyclones

Polar Front Theory

- According to this theory, the warm-humid air masses from the tropics meet the dry-cold air masses from the poles and thus a polar front is formed as a surface of discontinuity.
- Such conditions occur over **sub-tropical high, sub-polar low-pressure belts** and along the **tropopause**.

Explanation

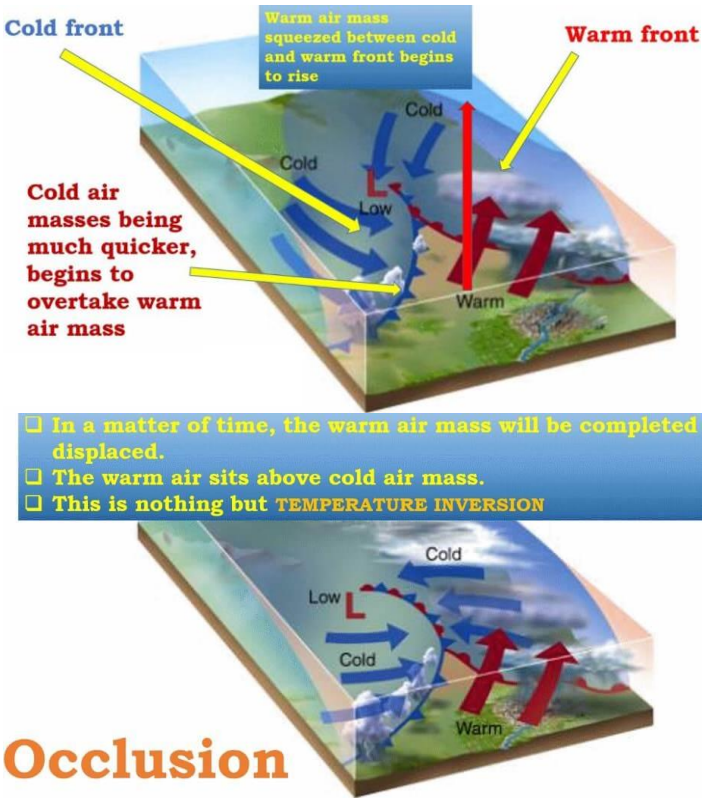
- In the northern hemisphere, warm air blows from the south and cold air from the north of the front.
- When the pressure drops along the front, the warm air moves northwards, and the cold air move towards south setting in motion an **anti-clockwise cyclonic circulation (Coriolis Force; northern hemisphere).**



Convergence of air masses

- The warm air glides over the cold air and a sequence of clouds appear over the sky ahead of the warm front and cause precipitation.
- The cold front approaches the warm air from behind and pushes the warm air up. As a result, cumulus clouds develop along the cold front.
- This leads to a **well-developed extratropical cyclone**, **with a warm front and a cold front**.
- There are pockets of warm air or warm sector wedged between the warm front and the cold front.

- The **cold front moves faster** than the warm front ultimately overtaking the warm front.
- The wedged warm air is completely uplifted (frontolysis), and the front is **occluded (occluded front),** and the cyclone dissipates.
- **Thus, temperate cyclone is intense frontogenesis involving mainly occlusion type fronts**.



Cold front moves faster

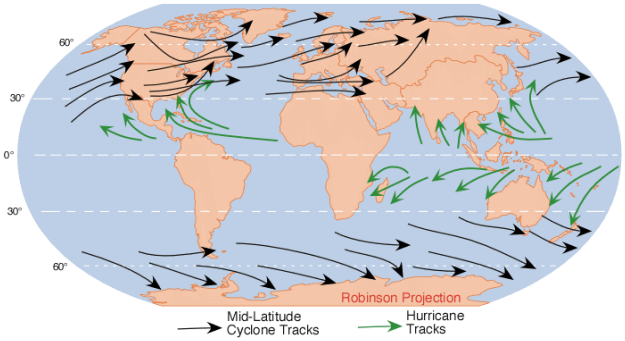
- Normally, individual frontal cyclones exist for about 3 to 10 days moving in a generally **west to east direction**.
- Precise movement of this weather system is controlled by the orientation of the **polar jet stream** in the upper troposphere.

Seasonal Occurrence of Temperate Cyclones

- The temperate cyclones occur mostly in **winter, late autumn and spring**.
- They are generally associated with rainstorms and cloudy weather.
- During summer, all the paths of temperate cyclones shift northwards, and there are only few temperate cyclones over sub-tropics and the warm temperate zone, although a high concentration of storms occurs over Bering Strait, USA and Russian Arctic and sub-Arctic zone.

Distribution of Temperate Cyclones

1. USA and Canada – extend over Sierra Nevada, Colorado, Eastern Canadian Rockies and the Great Lakes region,
2. the belt extending from Iceland to Barents Sea and continuing over Russia and Siberia,
3. winter storms over Baltic Sea,
4. Mediterranean basin extending up to Russia and even up to India in winters (called **western disturbances**) and the Antarctic frontal zone.



Distribution of Temperate Cyclones and Tropical Cyclones

Characteristics of Temperate Cyclones

Size and Shape

- The temperate cyclones are asymmetrical and shaped like an inverted 'V'.
- They stretch over 500 to 600 km.
- They may spread over 2500 km over North America.
- They have a height of 8 to 11 km.

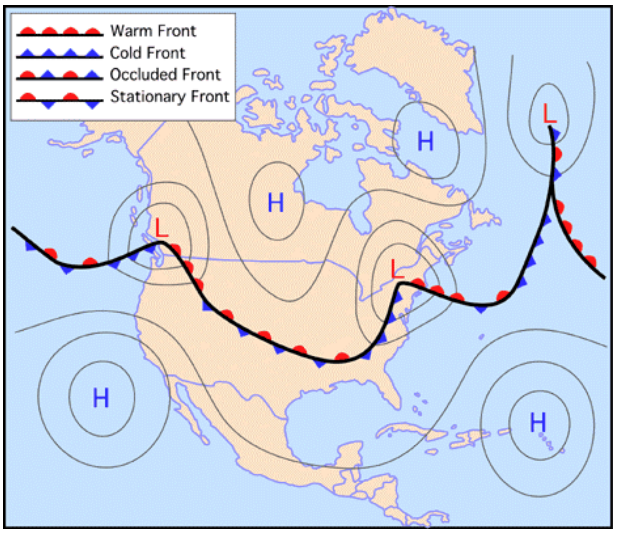
Shape of a Temperate Cyclone

Wind Velocity and Strength

- The wind strength is more in eastern and southern portions, moreover North America compared to Europe.
- The wind velocity increases with the approach but decreases after the cyclone has passed.

Orientation and Movement

- Polar jet stream plays a major role in the formation and hence influences the path of temperate cyclones.



Westerly Path of a Frontal Cyclone System

- Since these cyclones move with the **westerlies**, they are oriented **east-west**.
- If the storm front is east-west, the centre moves swiftly eastwards.
- If the storm front is directed northwards, the centre moves towards the north, but after two or three days, the pressure difference declines and the cyclone dissipate.
- In case the storm front is directed southwards, the centre moves quite deep southwards-even up to the Mediterranean region (sometimes causing the Mediterranean cyclones or **Western Disturbances** — they are very important as they bring rains to North-West India – Punjab, Haryana).

Structure

- The north-western sector is the cold sector and the north-eastern sector is the warm sector (Because cold air masses in north and warm air masses in south push against each other and rotate anti-clockwise in northern hemisphere).

Associated Weather

- The approach of a temperate cyclone is marked by fall in temperature, fall in the mercury level, wind shifts and a **halo around the sun and the moon**, and a thin veil of **cirrus clouds**.
- A light drizzle follows which turns into a heavy downpour. These conditions change with the arrival of the warm front which halts the fall in mercury level and the rising temperature.
- Rainfall stops and clear weather prevails until the cold front of an anticyclonic character arrives which causes a fall in temperature, brings cloudiness and rainfall with thunder. After this, once again clear weather is established.
- The temperate cyclones experience more rainfall when there is slow movement and a marked difference in rainfall and temperature between the front and rear of the cyclone. Anticyclones generally accompany these cyclones.

4. Tropical Cyclones and Temperate Cyclones — Comparison

	Tropical Cyclone	Temperate Cyclone
Origin	• **Thermal Origin.**	• **Dynamic Origin:** Coriolis Force, Movement of air masses.
Latitude	• Confined to 10-30° N and S of equator.	• Confined to 35-65° N and S of equator. • More pronounced in Northern hemisphere due to **greater temperature contrast**.
Frontal system	• Absent.	• The very cyclone formation is due to frontogenesis. (Occluded Front).
Formation	• They form only on seas with temperature more than 26-27^0 C.	• Can form **both** on land as well as seas.

	• They dissipate on reaching the land.	
Season	• Seasonal: Late summers (Aug-Nov).	• Irregular. But few in summers and **more in winters**.
Size	• Limited to small area. • Typical size: 100 – 500 kms in diameter. • Varies with the strength of the cyclone.	• They cover a larger area. • Typical size: 300 – 2000 kms in diameter. Varies from region to region.
Shape	• Elliptical	• Inverted 'V'
Rainfall	• Heavy but does not last beyond a few hours. • If the cyclone stays at a place, the rainfall may continue for a few days.	• In a temperate cyclone, rainfall is slow and continues for many days, sometimes even weeks.
Wind Velocity and destruction	• Much greater. • 100 – 250 kmph • 200 – 1200 kmph in upper troposphere) • Greater destruction due to **winds, storm surges and torrential rains.**	• Comparatively low. • Typical range: 30-150 kmph. • Less destruction due to winds but more destruction due to **flooding.**
Isobars	• Complete circles and the **pressure gradient is steep**	• Isobars are usually 'V' shaped and the pressure gradient is low.
Lifetime	• Doesn't last for more than a week	• Lasts for 2-3 weeks.
Path	• East – West. Turn North at 20^0 latitude and west at 30^0 latitude. • Move away from equator. • The movement of Cyclones in Arabian Sea and Bay of Bengal is a little different. • Here, these storms are superimposed upon the **monsoon circulation** of the summer months, and they move in northerly direction along with the monsoon currents.	• West – East (Westerlies; Jet Streams). • Move away from equator.
Temperature distribution	• The temperature at the centre is almost equally distributed.	• All the sectors of the cyclone have different temperatures
Calm region	• The centre of a tropical cyclone is known as the eye. The wind is calm at the centre with no rainfall.	• In a temperate cyclone, there is not a single place where winds and rains are inactive.
Driving force	• The tropical cyclone derives its energy from the **latent heat of condensation**, and the difference in densities of the air masses does not contribute to the energy of the cyclone.	• The energy of a temperate cyclone depends on the temperature, humidity and **density differences of air masses**.
Influence of Jet streams	• The relationship between tropical cyclones and the upper level air-flow is not very clear.	• The temperate cyclones, in contrast, have a distinct relationship with upper level air flow (jet streams, Rossby waves etc.)
Clouds	• The tropical cyclones exhibit fewer varieties of clouds – cumulonimbus, nimbostratus, etc.	• The temperate cyclones show a variety of cloud development at various elevations.
Surface anticyclones	• The tropical cyclones are not associated with surface anticyclones and they have a greater destructive capacity.	• The temperate cyclones are associated with anticyclones which precede and succeed a cyclone. • These cyclones are not very destructive.
Influence on India	• Both coasts affected. But east coast is the hot spot.	• Bring rains to North-West India. • The associated instability is called '**Western Disturbances**'.
Weather Prediction	• Tough as the movement can be erratic due to a lot of factors.	• Easy because of the general westerly path of the cyclone, less variable jet stream path and simple frontal system.

- Titbit: In certain instances, two cyclones move toward each other and revolve around one another, with the smaller and less intense one moving more quickly. This phenomenon is called the **Fujiwhara effect**.

5. Polar Vortex

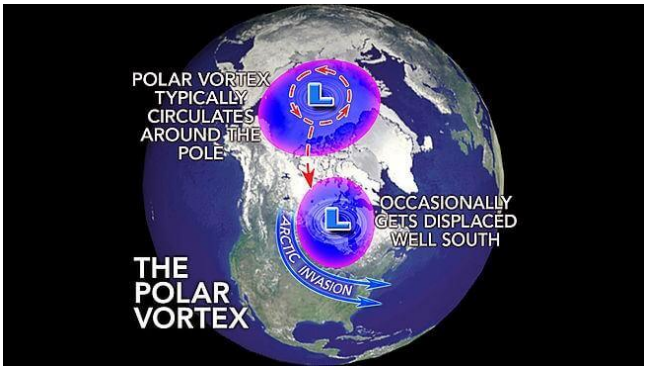
- Polar vortex (circumpolar vortex) is a **polar cyclone.**
- Arctic or polar cyclones occur in polar regions and can reach up to 2,000 km wide.
- Polar cyclones differ with others because they are not seasonal. They can occur at any time of the year.
- Polar cyclones **can also form quickly (sometimes less than 24 hours)**, and their direction or movement **cannot be predicted**.
- They can last from a **day up to several weeks**.
- Most frequently, polar cyclones develop above northern Russia and Siberia.
- A polar vortex is a large pocket of very cold air, typically the coldest air in the Northern Hemisphere, which sits over the polar region during the winter season.
- Polar Vortex is a
  - ✓ Cold;
  - ✓ Circumpolar;
  - ✓ Upper tropospheric low-pressure: sometimes extending till the lower levels of **stratosphere** (at poles, the troposphere extends only up to 8-9 km);
  - ✓ Large cyclonic parcel of air (about 1000 km across) (counter-clockwise in the Northern Hemisphere)
- Polar vortex is closely associated with **jet streams (Rossby waves).**
- It is formed mainly in winter and gets **weaker in summer**.
- It surrounds **polar highs** and lie within the polar front (boundary separating the temperate and polar air masses).

5.1 Polar Vortex Cold Wave

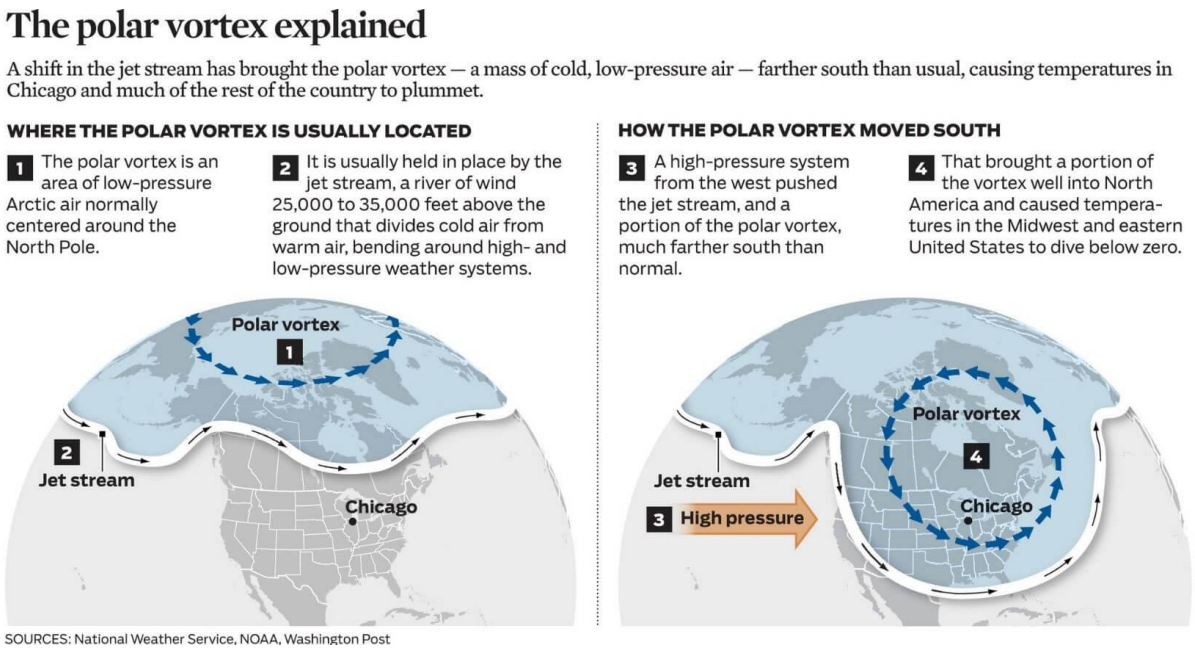
Polar Vortex slipping into Mid-latitudes,
Breakdown of the polar vortex,
Sudden stratospheric warming,
Polar vortex event.
All the above terms mean the same — Polar Vortex Cold Wave.

- The polar vortex will remain in its place when the westerlies along with the polar jet are strong (strong polar vortex means that there is **huge temperature contrast** between the temperate and polar regions).
- **When the polar vortex is weak**, it intrudes into the mid-latitude regions by buckling the general wind flow pattern. This leads to **significant cold outbreaks** in the mid-latitude regions.
- The vortex is capable of delivering sub-zero temperatures to the United States and Canada where is occurs the most.

How it slips



- The Polar jet traverses somewhere over 65° N and S latitudes. When the temperature contrast between polar and temperate regions is maximum, the jet is very strong, and the meandering is negligible.
- But when the temperature contrast is low, the jet starts to meander (Rossby waves).
- Meandering jet creates alternating low and high-pressure cells.
- High-pressure cells are created below the ridges and the low-pressure cells below the troughs (this is because of the upper air circulations created by the jet).
- With severe meandering, the high-pressure cells push over to north and displace the polar cyclone from its normal position i.e. the cyclone moves away from the pole and slips into the temperate regions.
- With the strengthening of the jet, the high-pressure cells become weak and retreat to their normal latitudinal positions.



Polar Vortex slipping into temperate regions

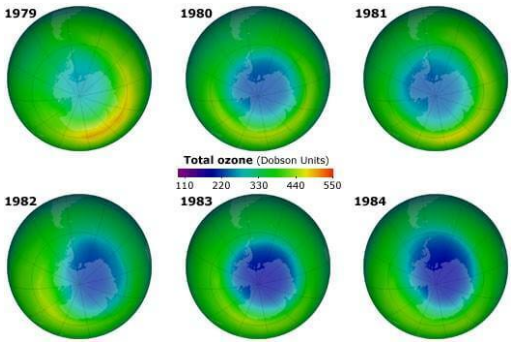
- With the retreat of the high-pressure cells, the polar cyclone moves back to its normal position.

5.2 Polar Vortex and Ozone Depletion at South Pole

- Polar vortex and ozone depletion are two distinct but related phenomena.

Ozone depletion

- There is a steady decline of about 4% in the total volume of ozone in Earth's stratosphere.
- Much larger decrease in stratospheric ozone is observed around **Earth's polar regions**.
- Depletion of ozone is due to increase in **halocarbons** in the atmosphere.

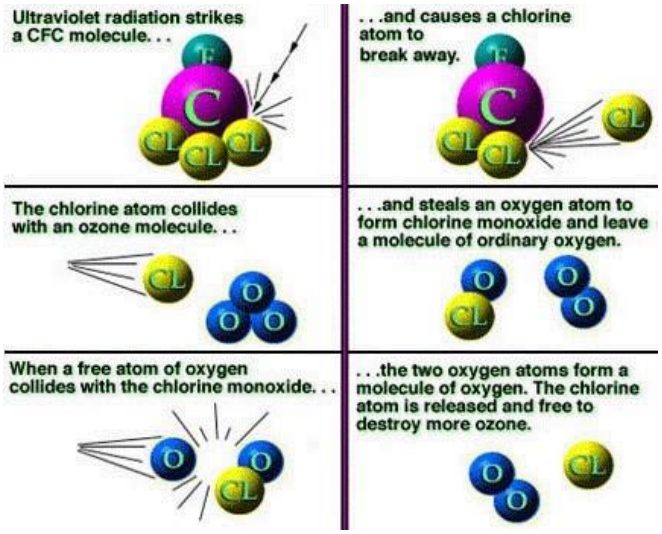


Ozone Hole at the South Pole

Halocarbon: a compound in which the hydrogen of a hydrocarbon is replaced by halogens like chlorine, bromine, iodine etc.
Halogen: group of reactive non-metallic elements like fluorine, chlorine, bromine, iodine, etc.

Halogen atoms like chlorine destroy ozone

- **Photodissociation** (under the influence of sunlight) of **ozone-depleting substances** (ODS) like **halocarbon refrigerants, solvents, propellants, and foam-blowing agents (CFCs, HCFCs, carbon tetrachloride and trichloroethane, freons, halons)** creates **free chlorine atoms** that destroy ozone.

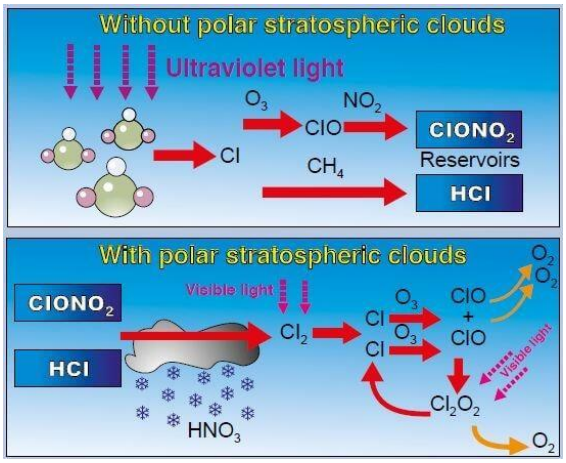


Photodissociation of ozone-depleting substances break O_3 into O_2

But how does a chlorine atom reach to such high levels of atmosphere?

Polar Stratospheric Clouds (PSCs)

- They are nacreous clouds that extend from 12-22 km above the surface.
- Nacreous clouds are rare clouds in frigid regions of the **lower stratosphere**.
- They are mostly visible within two hours after sunset or before dawn.
- They are bright even after sunset and before dawn because at those heights there is still sunlight.
- They are seen mostly during winter at high latitudes.
- PSCs or nacreous clouds contain water, **nitric acid and/or sulfuric acid**.
- They are **formed mainly during the event of polar vortex in winter**; **more intense at south pole**.
- The **Cl-catalysed ozone depletion is enhanced in the presence of polar stratospheric clouds.**
- PSCs convert **reservoir compounds** into reactive **free radicals (Cl and ClO)** thereby significantly **increasing the reactive halogen radicals**. These **free radicals accelerate depletion of ozone**.
- Thus, **polar vortex, in the form of PSCs, accelerate ozone depletion**.



Ozone Depletion is Enhanced by PSCs

Prelims question: The formation of ozone hole in the Antarctic region has been a cause of concern. What could be the reason for ozone depletion at poles?

a) Presence of prominent tropospheric turbulence; and inflow of chlorofluorocarbons
b) Presence of prominent polar front and stratospheric Clouds and inflow of chlorofluorocarbons
c) Absence of polar front and stratospheric clouds; and inflow of methane and chlorofluorocarbons
d) Increased temperature at polar region due to global warming

Explanation:

- Ozonosphere 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.
- **To destroy ozone, ozone-depleting substances** (ODS) like **CFCs, HCFCs, etc. needs to be carried up to the lower levels of stratosphere**.
- **And the only weather phenomenon that can reach to this level are Polar Vortex and** towering tropical cumulus clouds.
- But **towering cumulus clouds do not occur at the poles**.

Question: The formation of ozone hole in the Antarctic region has been a cause of concern. What could be the reason for ozone depletion at poles?

- Presence of prominent tropospheric turbulence: they don't reach the stratosphere.
- Presence of prominent polar front: essential to keep polar vortex in its place. Polar vortex gives rise to stratospheric Clouds.
- Presence of stratospheric Clouds: they have the necessary ingredients (**nitric acid and/or sulfuric acid**) to amplify ozone depletion.
- Absence of polar front and stratospheric clouds: polar vortex slips into the temperate region.
- Inflow of methane: **methane (CH_4) is not in the list of ozone-depleting substances**.
- It doesn't contain a halogen like chlorine, bromine, fluorine, etc. But it reacts with halogens to create **reservoir compounds**.

- Increased temperature at polar region due to global warming: this doesn't have any direct impact on ozone depletion at the poles.

6. El Nino

- Warming and cooling of the Pacific Ocean is most important in terms of general atmospheric circulation.

6.1 Normal Conditions

- In a normal year, a surface **low-pressure** develops in the region of **northern Australia and Indonesia** and a **high-pressure** system over the **coast of Peru**.
- As a result, the **trade winds** over the Pacific Ocean move strongly from **east to west.**
- The easterly flow of the trade winds carries warm surface waters **westward**, bringing **convective storms (thunderstorms)** to Indonesia and coastal Australia.
- Along the coast of Peru, cold bottom **cold nutrient-rich water wells up** to the surface to replace the warm water that is pulled to the west.

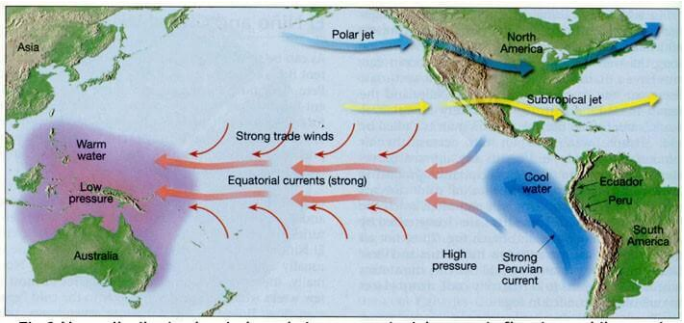
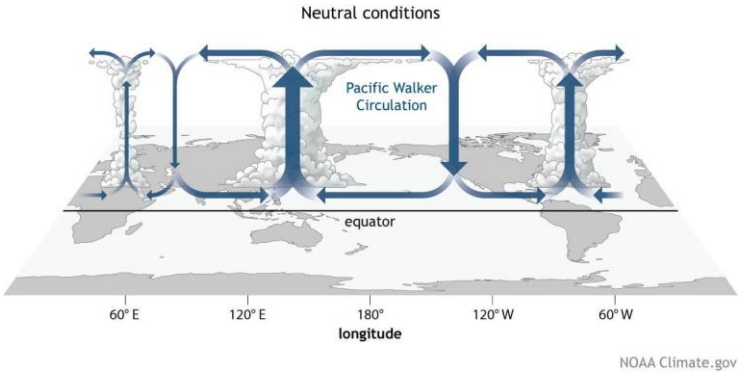


Fig.6 Normally, the trade winds and strong equatorial currents flow toward the west. At the same time, an intense Peruvian current causes upwelling of cold water along the west coast of South America.

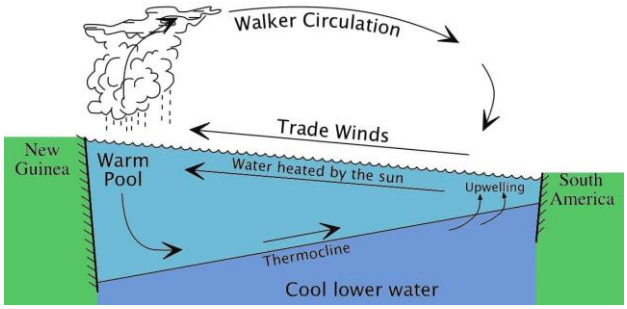
Normal Conditions: Warm water accumulation in Western Pacific and cold water upwelling in Eastern Pacific

Walker circulation (Normal Years)

- The Walker circulation (Walker cell) is caused by the pressure gradient force that results from a **high-pressure system over the eastern Pacific Ocean**, and a **low-pressure system over Indonesia.**
- The Walker cell is indirectly related to upwelling off the coasts of Peru and Ecuador. This brings **nutrient-rich cold water to the surface**, increasing **fishing stocks.**



Normal Conditions: Thunderstorms in equatorial western Pacific and calm conditions in equatorial eastern Pacific



Atmospheric circulation typically found at the equatorial Pacific. (Photo: W.S. Kessler, NOAA/PMEL)

***Thermocline**: a temperature gradient in a body of water, separating layers at different temperatures.*

6.2 During El Nino year

- El Niño is the name given to the occasional development of **warm ocean surface waters along the coast of Ecuador and Peru**.
- In an El Niño year, air pressure drops over large areas of the central Pacific and along the coast of South America.
- The normal low-pressure system is replaced by a weak high in the western Pacific (the **southern oscillation**).
- This change in pressure pattern causes the **trade winds to be reduced — Weak Walker Cell.** Sometimes Walker Cell might even get reversed.
- This reduction allows the **equatorial counter current (west to east current along calm doldrums)** to accumulate warm ocean water along

the coastlines of Peru and Ecuador replacing the cool Peruvian current.

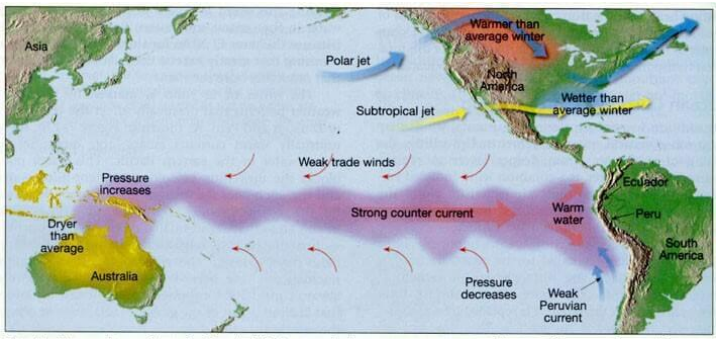
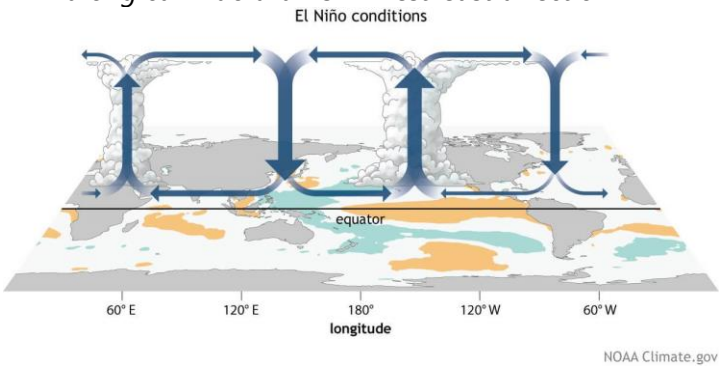


Fig.14 Upon the advent of an ENSO event, the pressure over the eastern and western Pacific flip-flops. This causes the trade winds to diminish, leading to an eastward movement of warm water along the equator. As a result, the surface waters of the central and eastern Pacific warm, with far-reaching consequences to weather patterns.

El Nino conditions: Equatorial counter current flows along calm doldrums in west-east direction



El Nino conditions: Drought in Northern Australia and floods in Central America

- The accumulation of warm water causes the thermocline to drop in the eastern part of Pacific Ocean which **cuts off the upwelling of cold deep ocean water** along the coast of Peru.
- Climatically, the development of an El Niño brings **drought to the western Pacific**, **rains to the equatorial coast of South America**, and **convective storms and hurricanes to the central Pacific.**
- El Niño normally occurs around **Christmas** and usually lasts for a few weeks to a few months.
- Sometimes an extremely warm event can develop that lasts for much longer periods.
- In the 1990s, strong El Niños developed in 1991 and lasted until 1995.

El Nino Southern Oscillation (ENSO)

- This phenomenon is closely monitored and is used for long-range forecasting in major parts of the world.
- The formation of an **El Niño (circulation of surface ocean current)** is linked with Pacific Ocean circulation pattern known as the **southern oscillation (circulation of atmospheric pressure).**
- Southern Oscillation, in oceanography and climatology, is a coherent inter-annual **fluctuation of atmospheric pressure** over the tropical Indo-Pacific region.
- El Nino and Southern Oscillation coincide most of the times hence their combination is called **ENSO – El Nino Southern Oscillation.**
- In the years when the ENSO is strong, large-scale variations in weather occur over the world.
- The arid west coast of South America receives heavy rainfall, drought occurs in Australia and sometimes in India and floods in China.

Only El Nino == Warm water in Eastern Pacific + Cold water in Western Pacific.
Only SO == Low-pressure over Eastern Pacific + High-pressure over Western Pacific
ENSO = (Warm water in Eastern Pacific + Low-pressure over Eastern Pacific) + (Cold water in Western Pacific + High-pressure over Western Pacific).

Effects of El Nino

- The warmer waters had a **devastating effect on marine life** existing off the coast of Peru and Ecuador.
- Fish catches off the coast of South America were lower than in the normal year.
- **Severe droughts occur in Australia, Indonesia, India and southern Africa.**
- Heavy rains in California, Ecuador, and the Gulf of Mexico.

Normal Conditions

- ***Eastern Pacific == Coast of Peru and Ecuador == Cold Ocean Water == Good for Fishing.***
- ***Western Pacific == Indonesia and Australia == Warm Ocean Water == Plenty of rains.***

El Nino

- ***Eastern Pacific == Coast of Peru and Ecuador == Warm Ocean Water == Fishing industry takes a hit.***
- ***Western Pacific == Indonesia and Australia == Cold Ocean Water == Drought.***

El Nino impact on Indian Monsoons

- El Nino and Indian monsoon are **inversely related**.
- The location of low-pressure and hence the rising limb over Western Pacific is considered to be conducive to good monsoon rainfall in India.
- **Its shifting eastward** from its normal position, such as in El Nino years, **reduces** monsoon rainfall in India.
- The most prominent droughts in India have been El Nino droughts, including the recent ones (2014-16).
- However, not all El Nino years led to a drought in India. For instance, 1997/98 was a strong El Nino year, but there was no drought (this is because of **Indian Ocean Dipole – IOD**).
- On the other hand, a moderate El Nino in 2002 resulted in one of the worst droughts.
- El Nino directly impacts India's agrarian economy as it tends to lower the production of summer crops such as rice, sugarcane, cotton and oilseeds.
- The ultimate impact is seen in the form of high inflation, and low gross domestic product growth as agriculture contributes around 14 per cent to the Indian economy.

Southern Oscillation Index and Indian Monsoons

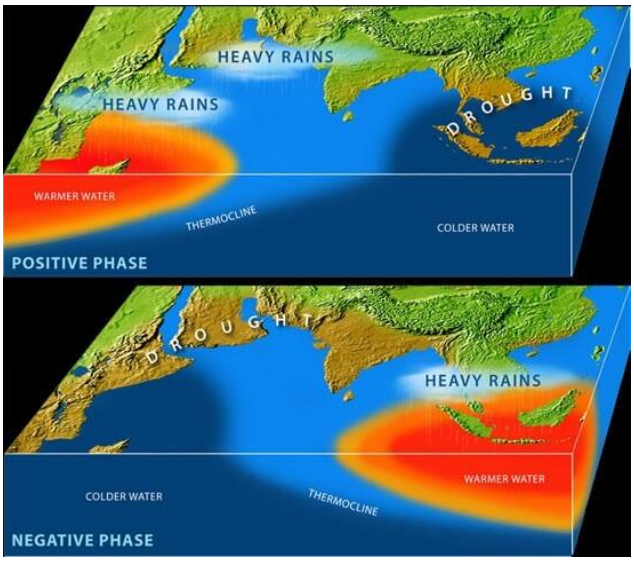
- Southern Oscillation Index (SOI) is used to measure the intensity of the Southern Oscillation.
- This is the difference in pressure between **Tahiti in French Polynesia** (Central Pacific), representing the Central Pacific Ocean and **Port Darwin**, in northern Australia representing the Eastern Pacific Ocean.
- The positive and negative values of the SOI, i.e. Tahiti minus the Port Darwin pressure are pointers towards good or bad rainfall in India.

Positive SOI	Negative SOI
Tahiti (eastern Pacific) pressure greater than that of Port Darwin (western Pacific)	**Reverse**
Drought conditions in Eastern Pacific and good rainfall in Western Pacific	**Reverse**
Good for Indian Monsoons	**Bad for Indian Monsoons**

Indian Ocean Dipole effect (Not every El Nino year is same in India)

- In the recent decades, the ENSO-Monsoon relationship seemed to weaken in the Indian subcontinent. For e.g. the 1997, strong ENSO failed to cause drought in India.
- It was discovered that just like ENSO was an event in the Pacific Ocean, a similar seesaw ocean-atmosphere system in the Indian Ocean was also at play.
- It was discovered in 1999 and named the **Indian Ocean Dipole (IOD).**
- The Indian Ocean Dipole (IOD) is defined by the **difference in sea surface temperature between two areas** (or poles, hence a dipole) — a western pole in the **Arabian Sea** (western Indian Ocean) and an eastern pole in the **eastern Indian Ocean** south of Indonesia.
- IOD starts to develop in the equatorial region of Indian Ocean in April and is best devolved in October.
- With a **positive IOD** winds over the Indian Ocean blow from east to west (**from Bay of Bengal towards Arabian Sea**).
- This results in the Arabian Sea (western Indian Ocean near African Coast) being much warmer and eastern Indian Ocean around Indonesia becoming colder and dry.

- In the negative dipole year (**negative IOD**), reverse happens making Indonesia much warmer and rainier.



Indian Ocean Dipole

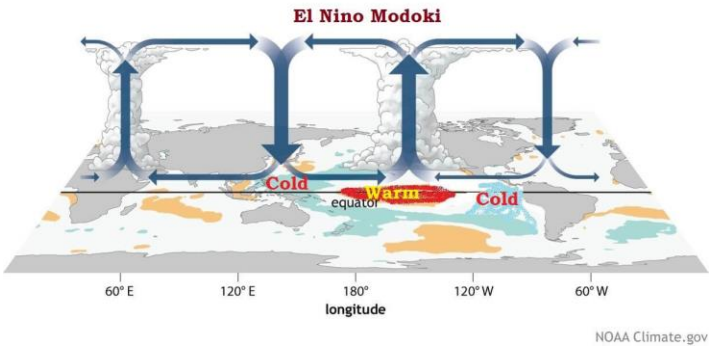
- It was demonstrated that a positive IOD index often negated the effect of ENSO, resulting in increased Monsoon rains in several ENSO years like the 1983, 1994 and 1997.
- Similar to ENSO, the atmospheric component of the IOD was later discovered and named as **Equatorial Indian Ocean Oscillation (EQUINOO: oscillation of warm water and atmospheric pressure between Bay of Bengal and Arabian Sea).**

Impact of IOD on Cyclogenesis in Northern Indian Ocean

- Positive IOD (Arabian Sea warmer than Bay of Bengal) results in more cyclones than usual in Arabian Sea.
- Negative IOD results in stronger than usual cyclogenesis in Bay of Bengal. Cyclogenesis in Arabian Sea is suppressed.

6.3 El Niño Modoki

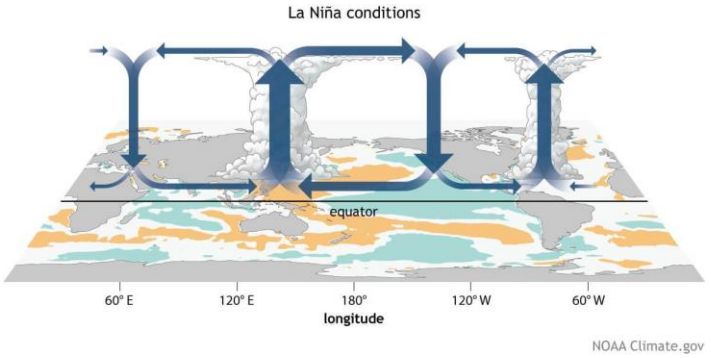
- El Niño Modoki is a coupled ocean-atmosphere phenomenon that is slightly different from El Niño.
- Conventional El Niño is characterised by **strong anomalous warming in the eastern equatorial Pacific**.
- Whereas, El Niño Modoki is associated with **strong anomalous warming in the central tropical Pacific and cooling in the eastern and western tropical Pacific**.
- Such zonal gradients result in anomalous **two-cell Walker Circulation** over the tropical Pacific, with a wet region in the central Pacific and dry region in the western and eastern Pacific.



El Niño Modoki: Droughts in Western and Eastern Pacific; copious rainfall in the Central Pacific

6.4 La Nina

- After an El Niño event weather conditions usually return to normal.
- However, in some years the trade winds can become **extremely strong,** and an abnormal accumulation of cold water can occur in the central and eastern Pacific. This event is called a La Niña.



La Nina: Abnormally heavy monsoons in India and Southeast Asia

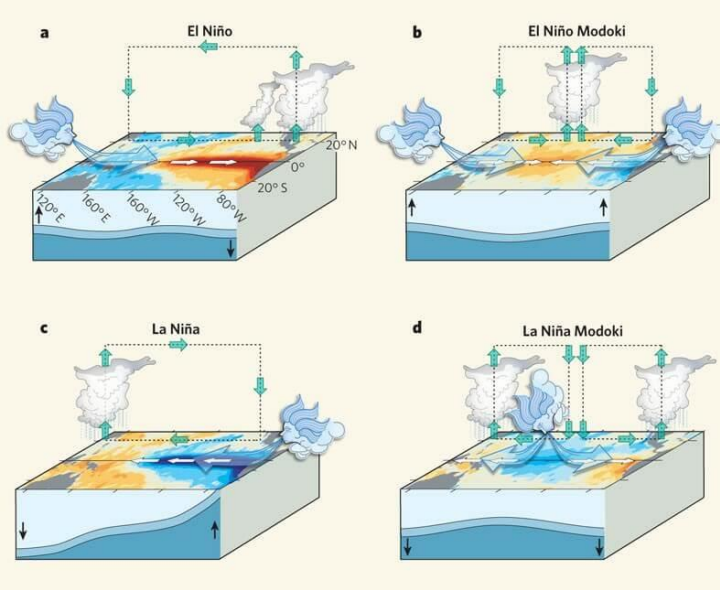
Effects of La Nina

- A strong La Niña occurred in 1988 and scientists believe that it may have been responsible for the summer drought over central North America.

- During this period, the Atlantic Ocean has seen very active hurricane seasons in 1998 and 1999.
- One of the hurricanes that developed, named **Mitch**, was the strongest October hurricane ever to develop in about 100 years of record keeping.

Some of the other weather effects of La Niña include

- **Abnormally heavy monsoons in India and Southeast Asia**,
- Cool and wet winter weather in south-eastern Africa, wet weather in eastern Australia,
- Cold winter in western Canada and north-western United States,
- Winter drought in the southern United States.



7. Koppen's Scheme of Classification of Climate

- The most widely used classification of climate is the empirical climate classification scheme developed by V. Koppen.
- **Empirical**: verifiable by observation or experience rather than theory or pure logic. E.g. when dropped stone falls to the ground – logic. Drop a stone to confirm that it falls to the ground – empirical.
- Koppen identified a close relationship between the **distribution of vegetation** and **climate.**
- He selected certain values of **temperature** and **precipitation** and related them to the **distribution of vegetation** and used these values for classifying the climates.
- Koppen recognized five major climatic groups; four of them are based on temperature and one on precipitation.
- The capital letters: **A, C, D and E delineate humid climates** and **B dry climates**.
- The climatic groups are subdivided into types, designated by small letters, based on seasonality of precipitation and temperature characteristics.
- The seasons of dryness are indicated by the small letters: f, m, w and s.

f	**no dry season**
m	**monsoon climate**
w	**winter dry season**
s	**summer dry season**

- The small letters a, b, c and d refer to the degree of severity of temperature.
- The small letters h and k refer to tropical and mid-latitude regions respectively.
- The B - Dry Climates are subdivided using the capital letters **S for steppe or semi-arid** and **W for deserts**.

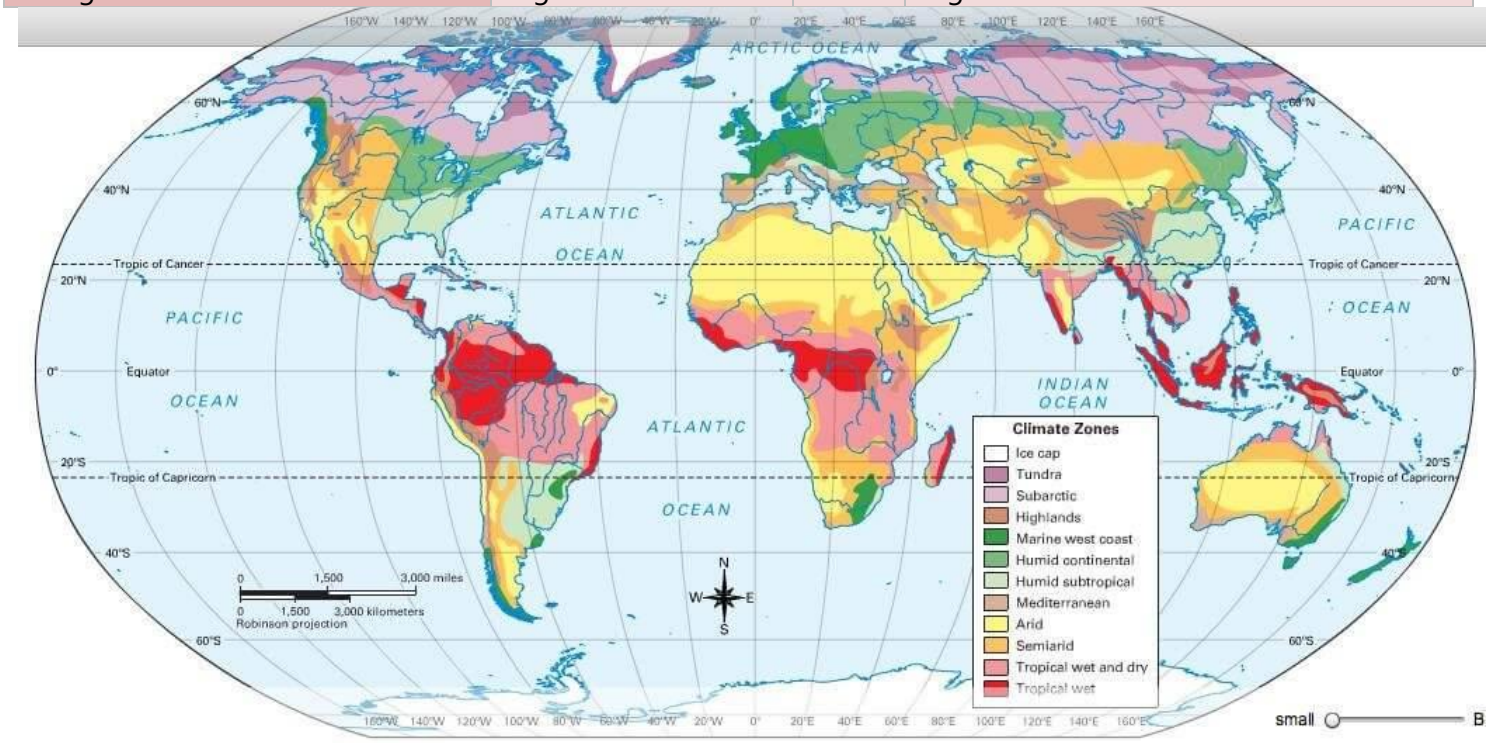
S	Steppe
W	Desert

Climatic Groups According to Koppen

Climatic Group	Characteristics
A – Tropical	Average temperature of the coldest month is 18 °C or higher
B – Dry Climates	Potential evapouration exceeds precipitation
C – Warm Temperate	The average temperature of the coldest month of the (Mid-latitude) climates years is higher than minus 3 °C but below 18 °C (-3 °C to 18 °C)
D – Cold Snow Forest Climates	The average temperature of the coldest month is minus 3 °C or below
E – Cold Climates	Average temperature for all months is below 10 °C
H – High Land	Cold due to elevation

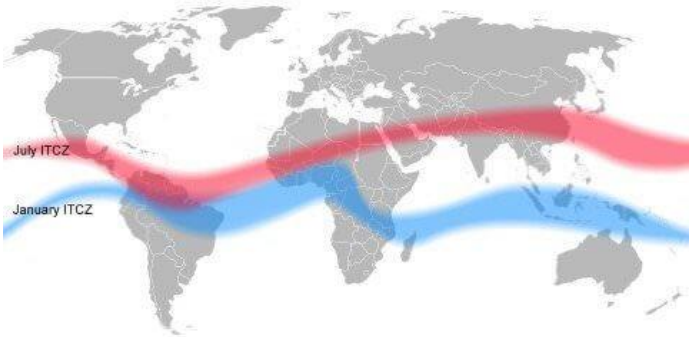
Climatic Types According to Koppen

Climatic Group	Type	Code	Characteristics
A-Tropical Humid Climate	Tropical wet	Af	No dry season
	Tropical monsoon	Am	Monsoonal. Short dry season
	Tropical wet and dry	Aw	Winter dry season
B-Dry Climate	Subtropical steppe	BSh	Low-latitude semi-arid or dry
	Subtropical desert	BWh	Low-latitude arid or dry
	Mid-latitude steppe	BSk	Mid-latitude semi-arid or dry
	Mid-latitude desert	BWk	Mid-latitude arid or dry
C-Warm temperate (Mid-latitude) Climates	Humid subtropical	Cfa	No dry season, warm summer
	Mediterranean	Cs	Dry hot summer
	Marine west coast	Cf	No dry season, warm and cool summer
D-Cold Snow-forest Climates	Humid continental	Df	No dry season, severe winter
	Subarctic	Dw	Winter dry and very severe
E-Cold Climates	Tundra	ET	No true summer
	Polar ice cap	EF	Perennial ice
H-Highland	Highland	H	Highland with snow cover



7.2 A – Tropical Humid Climates

- Tropical humid climates exist between Tropic of Cancer and Tropic of Capricorn.
- The sun being overhead throughout the year and the presence of **Inter Tropical Convergence Zone (ITCZ)** make the climate hot and humid.
- **Annual range of temperature is very low,** and **annual rainfall is high**.



ITCZ in summer and winter

- The tropical group is divided into three types, namely
  1) **Af – Tropical wet climate;**
  2) **Am – Tropical monsoon climate;**
  3) **Aw – Tropical wet and dry climate.**

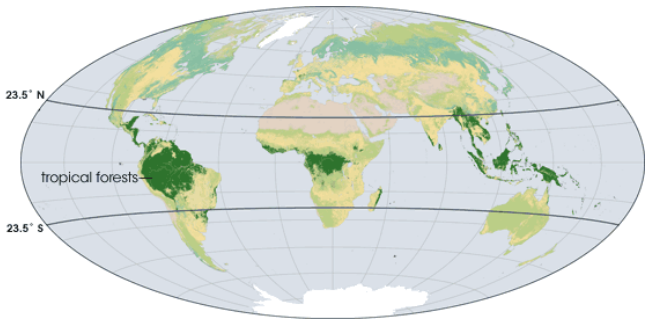
Tropical Wet Climate (Af: A – Tropical, f – no dry season)

- Also known as **The Hot, Wet Equatorial Climate**, **Equatorial Rainforest Climate**.
- The regions are generally referred as **Equatorial Rainforests, Equatorial Evergreen Forests, Tropical Moist Broadleaf Forest, Lowland Equatorial Evergreen Rainforest**.

Evergreen forest

Distribution

- Mostly between **5° N and S of Equator**. (little or no Coriolis Force == **no tropical cyclones**)
- Its greatest extent is found in the **lowlands of the Amazon, the Congo, Malaysia and the East Indies.**



Distribution of tropical wet climate

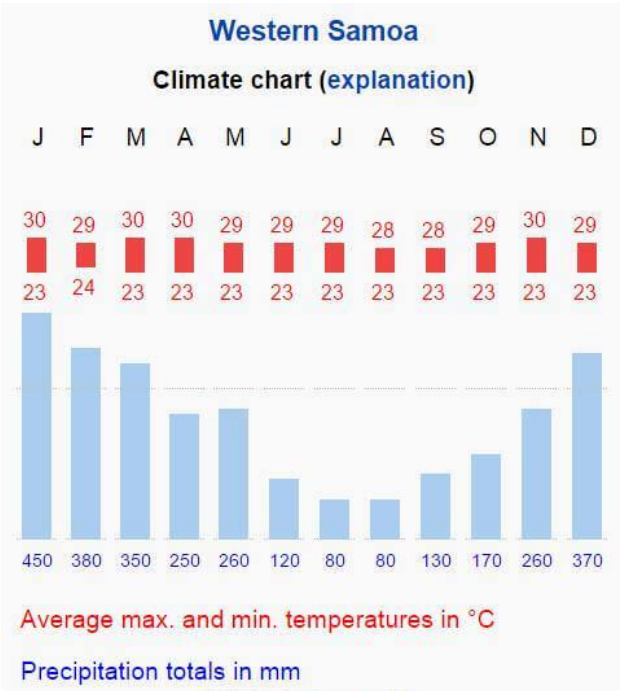
Equatorial Climate

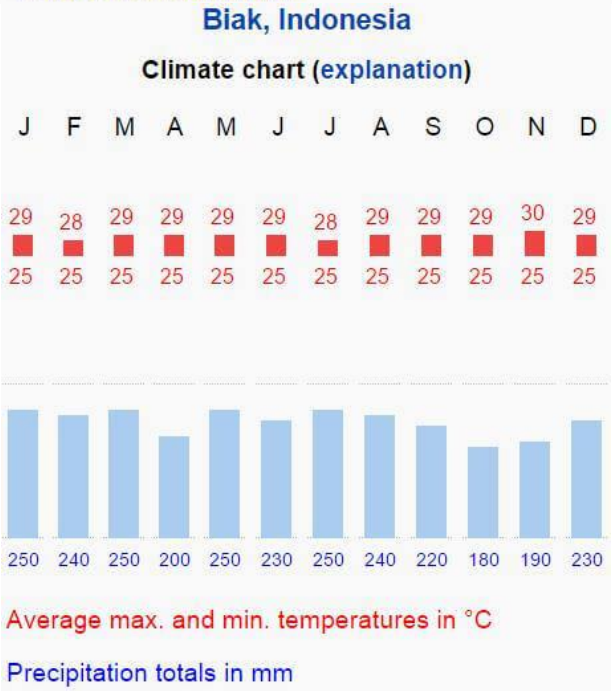
- The climate is dominated by **maritime tropical air masses (high humidity)**.

Temperature

- Temperature is **uniform** throughout the year.
- The mean monthly temperatures are always around **27°C** with very little variation.
- **There is no winter** (typical to equatorial rainforest climate).
- Cloudiness and **heavy precipitation** moderate the daily temperature.
- Regular land and sea breezes assist in maintaining a truly equable climate.
- The diurnal range of temperature is **small**, and so is the annual range.

Climate Graphs





Climate Graphs for regions with tropical wet climate

Precipitation

- **Heavy thunderstorms occur almost every day in the afternoons**.
- Precipitation is heavy and **well distributed throughout the year**.
- Annual average is always above **150 cm**.
- In some regions, the annual average may be as high as 250-300 cm.
- There is **no month without rain (distinct dry season is absent)**.
- The monthly average is above **6 cm** most of the times.
- There are two periods of maximum rainfall, **April** and **October** (shortly after the equinox).
- Least rainfall occurs in June and December (solstice: sun is farthest from the equator).
- The **double rainfall peaks coinciding with the equinoxes is typical to equatorial climates** (not found in any other type of climate).

Equatorial Vegetation

- High temperature and abundant rainfall support a luxuriant **tropical rain forest**.
- In the Amazon lowlands, the forest is so dense that it is called **selvas**.

Selvas: *A dense tropical rainforest usually having a cloud cover (dense canopy).*

- The **growing season here is all the year round** — seeding, flowering, and decaying do not take place in a seasonal pattern.
- The equatorial vegetation comprises a multitude of evergreen trees that yield tropical hardwood, e.g. **mahogany, ebony, dyewoods** etc.
- Many parts of the tropical rain forests have been cleared either for lumbering or shifting cultivation.
- In the coastal areas and brackish swamps, **mangrove forests** thrive.

Canopy

- From the air, the tropical rain forest appears like a thick canopy of foliage, broken only where it is crossed by large rivers or cleared for cultivation.

Canopy

- All plants struggle upwards (most **epiphytes**) for sunlight resulting in a peculiar layer arrangement.

Epiphytes

Epiphyte: *An epiphyte is a plant that grows **harmlessly** upon another plant (such as a tree) and derives its moisture and nutrients from the air, rain, and sometimes from debris accumulating around it.*

- The tallest trees attain a height close to **50 m**.
- The smaller trees beneath form the next layer.
- The ground is rooted with ferns and herbaceous plants which can tolerate shade.
- Because the trees cut out most of the sunlight, the **undergrowth is not dense**.

Multiple species

In spite of dense forests, countries in equatorial regions are net importers of timber. Comment.

- Though the tropics have great potential in timber resources, commercial extraction is **difficult.**
- **Multiple species** of trees occur in a particular area (trees **do not occur in homogenous stands or pure stands**) making commercial exploitation a difficult task.

- Many of the tropical hardwoods (very heavy) **do not float** readily on water, and this makes transportation an expensive matter.
- It is therefore not surprising that many tropical countries are **net timber importers**.

Life and Economy

Agriculture

- The forests are sparsely populated.
- In the forests, most primitive people live as **hunter-gatherers**.
- The more advanced ones practice **shifting cultivation.**
- Food is abundantly available. People generally don't stock food for the next day.

Commercial

- In the **Amazon Basin,** the **Indian tribes** collect wild **rubber**.
- In the Congo Basin, the **Pygmies** gather nuts.
- In the jungles of Malaysia, the **Orang Asli** make all sorts of cane products.

The names of the tribes come under Social Geography – Prelims

Shifting Cultivation or Slash and Burn Cultivation.

- This type of cultivation is followed in many parts of the world where dense forests are common (In India, North-East is known for this type of cultivation).
- Tribes cut the trees in a plot, burn them and cultivate the plot till the fertility is exhausted.
- Once the fertility is exhausted, the clearing is abandoned, and they move on to a new plot.
- In the clearings for shifting cultivation, crops like, maize, bananas and groundnuts are grown.

Plantation Boom

- With the coming of the Europeans, many large plantations have been established, especially in **Java, Sumatra, Malaysia, West Africa and Central America**.
- The climate is very Favourable for the cultivation of certain crops that are highly valued in the industrial West. The most important is **natural rubber.**
- **Malaysia and Indonesia** are the leading producers. The home country, **Brazil** exports practically no natural rubber.
- **Cocoa** is another important crop which is cultivated in **West Africa**, bordering the **Gulf of Guinea**. The two most important producers are **Ghana and Nigeria**. All the cocoa here goes into American and European **chocolate industry**.
- From the same area another crop, **oil palm**, has done equally well and many countries like Indonesia have now taken to its cultivation.

Palm plantations in Indonesia

- Other important crops include coconuts, sugar, coffee (Brazil), tea, tobacco, spices, etc.
- The plantations destroyed nearly half of equatorial forests.

Plantations	Region(s)
Palm	Malaysia, Indonesia
Sugarcane	Brazil
Coffee	Brazil
Rubber	Malaysia, Indonesia
Cocoa	Ghana, Nigeria

Factors Affecting the Development of Equatorial Regions

Equatorial climate and health

- Excessive heat (sun-stroke) and high humidity creates serious physical and mental handicaps.
- High humidity feeds many tropical diseases such as malaria and yellow fever.
- Communicable diseases are rampant as germs and bacteria are transmitted through moist air.

- Insects and pests not only spread diseases but are injurious to crops.

Jungle hinders development

- The construction of roads and railways is a risky business as workers are exposed to wild animals, poisonous snakes, insects and most importantly tropical diseases.
- Once completed, they have to be maintained at a high cost.

Rapid deterioration of tropical soil

Why does restoration of lost forests take decades in equatorial regions?

- The fertility of topsoil in rainforest regions is very poor.
- Torrential downpours leach out most of the topsoil nutrients.

Leaching: *percolation and draining way of nutrients due to rainwater action*.

- The soil deteriorates rapidly with subsequent soil erosion and soil impoverishment.
- It takes **decades** to replenish the soil of lost nutrients.
- Thus, a seed doesn't usually germinate, and even if it does, its development is hindered due to little availability of sunlight.
- **Lalang (tall grass)** and thick undergrowth spring up as soon as the trees are cut. They choke the restoration of forests.
- Indonesian island of Java is an exception because of its rich volcanic ashes.

Difficulties in livestock farming

- Livestock farming is greatly handicapped by an **absence of meadow grass**.
- The grass is so **tall and coarse** that it is not nutritious.
- The few animals like buffaloes are kept mainly for domestic use. Their yield in milk or beef is well below those of the cattle in the temperate grasslands.
- In Africa, domesticated animals are attacked by **tsetse flies** that cause ngana, a deadly disease.

Mineral resources

- Gold, copper, diamonds, and other precious metals and gemstones are important resources that are found in rainforests around the world.
- Extracting these natural resources is a destructive activity that damages the rainforest ecosystem.
- Examples are **gold mining in the Brazilian and Peruvian Amazon**, **rare earth mining in the Congo**, and **gold and copper mining in Indonesia and Papua New Guinea.**
- Some of the world's most promising oil and gas deposits lie deep in tropical rainforests.
- **Oil and gas development** often take a heavy toll on the environment and local people (this happened in Ecuador — **resource curse**).
- More than 70 per cent of the Peruvian Amazon is now under concession for oil and gas.

Tropical Monsoon Climate (Am: A – Tropical, m – monsoon)

- Monsoons are **land and sea breezes** on a much larger scale.
- Unlike equatorial wet climate, monsoon climate is characterized by **distinct wet and dry seasons** associated with **seasonal reversal of winds**.
- **Floods** in wet season and **droughts** in dry season are common.

Tropical Monsoon Climate: Floods in wet season and droughts in dry season

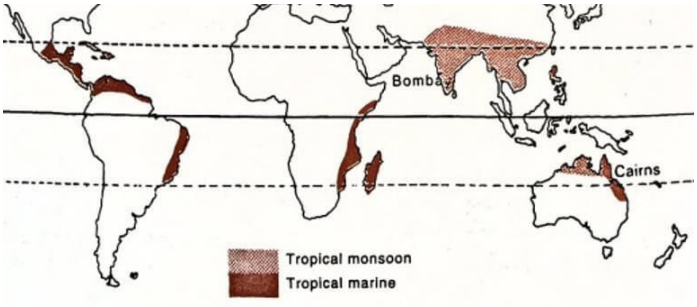
- Usually, there are three seasons namely **summer, winter and rainy** season.

Distribution

- Occur within **5° to 30°** N and S of the equator.
- **On-shore** (winds flowing from sea to land) tropical monsoons occur in the summer and

off-shore (winds flowing from land to sea) dry monsoons in the winter.

- They are best developed in the **Indian sub-continent, Burma, Thailand, Laos, Cambodia, parts of Vietnam and south China and northern Australia**.



Tropical Monsoon Climate Distribution

Climate

- The basic cause of monsoon climates is the difference in the **rate of heating** and cooling of land and sea (This is old theory. New theory explained in Indian Climate).

Temperature

- Monthly mean temperatures **above 18 °C.**
- Temperatures range from 30-45 °C in summer. Mean summer temperature is about 30 °C.
- In winters, temperature range is 15-30 °C with mean temperature around 20-25 °C.

Precipitation

- Annual mean rainfall ranges from **200-250 cm**. In some regions, it is around 350 cm.
- Places like **Cherrapunji and Mawsynram** receive an annual rainfall of about **1000 cm.**

Cherrapunji and Mawsynram *(wettest places on earth by annual rainfall — a little over 1150 cm per year) lie on the windward side of the Meghalaya hills, so the resulting* ***orographic lift (orographic rainfall)*** *enhances precipitation. Also, they are located between mountains which enhances cloud concentration due to* ***funnelling effect.***

Seasons

- Seasons are chief characteristics of monsoon climate.

The cool, dry season (October to February)

- Out blowing dry winds, the North-East Monsoon, bring little or no rain to the Indian sub-continent.
- However, a small amount of rain falls in Punjab from cyclonic sources (**Western Disturbances**: Frontal precipitation brought by jet streams), and this is vital for the survival of winter cereals.
- North-East Monsoons blowing over the Bay of Bengal acquires moisture and bring rains to the south-eastern tip of the peninsula at this time of the year (Nov-Dec).

The hot dry season (March to mid-June)

- The temperature rises sharply with the sun's northward shift to the Tropic of Cancer.
- Day temperatures of 35 °C are usual in central India and the mean temperature in Sind, and south India may be as high as 44 °C.
- Coastal districts are a little relieved by sea breezes.
- There is practically little rain. **Hailstorms** occurs here and there in April, May.

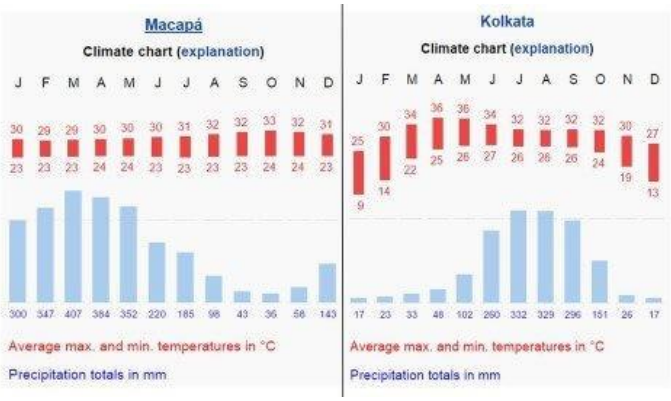
The rainy season (mid-June to September)

- With the 'burst' of the South-West Monsoon in mid-June, torrential downpours sweep across the country. Almost all the rain for the year falls within this rainy season.
- This pattern of **concentrated heavy rainfall** in summer is a characteristic feature of the tropical monsoon climate.

The Retreating Monsoon

- The amount and frequency of rain decreases towards the end of the rainy season.
- It retreats gradually southwards after mid-September until it leaves the continent altogether.
- The skies are clear again and the cool, dry season returns in October, with the out blowing North-East Monsoon.

Climate Graph



Climate Graphs of regions with Tropical Monsoon Climate

Tropical Marine Climate

- Outside the monsoon zone, the climate is **modified by the influence of the on-shore trade winds all the year round**. This type of climate is called Tropical Marine Climate.
- Such a climate has a more **evenly distributed rainfall**.
- Such a climate is experienced in Central America, West Indies, north-eastern Australia, the Philippines, parts of East Africa, Madagascar, the Guinea Coast and eastern Brazil.
- The rainfall is both **orographic** where the moist trades meet upland masses as in eastern Brazil, and **convectional** due to intense heating during the day and in summer.
- Its tendency is towards a **summer maximum without any distinct dry period**.
- Due to the steady influence of the trades, the Tropical Marine Climate is **more favourable for habitation**, but it is **prone to severe tropical cyclones, hurricanes or typhoons.**

Tropical Monsoon Forests

- **Also known as drought-deciduous forest; dry forest; dry-deciduous forest; tropical deciduous forest.**
- **Broad-leaved hardwood trees are found here**. They are well developed in **southeast Asia.**
- Trees are normally deciduous, because of the marked dry period, during which they shed their leaves to withstand the drought (they shed their leaves to prevent loss of water through **transpiration**).
- The forests are more open and **less luxuriant** than the equatorial jungle, and there are far **fewer species.**
- Where the rainfall is heavy, e.g. in southern Burma, peninsular India, northern Australia and coastal regions with a tropical marine climate, the resultant vegetation is luxuriant.
- With a decrease in rainfall in summer, the forests thin out into **thorny scrubland or savanna** with scattered trees and tall grass.
- In parts of the Indian sub-continent (rain shadow regions — regions east of Western Ghats like north Karnataka, Telangana, Vidarbha), rainfall is so deficient that semi-desert conditions are found in summer.
- Monsoonal vegetation is thus most varied, ranging from forests to thickets, and from savanna to scrubland.

Population and Economy in Monsoon Climate

- Monsoon climatic regions support **high population density**.
- Income levels are low as most of these regions are still developing.
- **Subsistence farming** is the main occupation.

Subsistence farming: crops grown with an intention to secure food for the season. The crops are not sold as the production is very low.

- Intensive cultivation is common in regions with irrigational facilities.
- **Shifting cultivation** is followed in North-East India and South-East countries.
- Major crops include **rice, sugar, cotton, jute, spices**, etc.
- Cattle and sheep rearing are carried out for domestic and commercial purposes.
- **Livestock industry is not as profitable as in temperate regions**.

Lumbering

- Most of the forests yield valuable timber and are prized for their **durable hardwood.**
- Lumbering is undertaken in the more accessible areas. This is particularly important in continental South-East Asia.

- Of the tropical deciduous trees, **teak,** of which **Burma** is the leading producer (three – quarters of the world's production), is the most sought after.
- It is valuable on account of its **durability, strength, immunity to shrinkage, fungus attack and insects.**
- Teak logs are so heavy that they will not float readily on water. It is therefore necessary to 'poison' the tree several years before actual felling so that it is dry and light enough to be floated down the **Chindwin** and the **Irrawaddy** to reach the sawmills at **Rangoon.**
- Other kinds of timber include **Neem, Banyan, Mango, Teak, Sal, Acacia, Eucalyptus.**
- Together with the forests are bamboo thickets, which often grow to great heights.

Agricultural Development in the Monsoon Lands

- Much of the monsoon forest has been cleared for agriculture to support the very dense population.
- Farms are small, and the people are forever **land hungry.** Industrialisation makes things worse.
- Farming is the dominant occupation of the Indian sub-continent, China, South- East Asia, eastern Brazil and the West Indies. The following types of agriculture are recognisable.

Crops

- **Rice** is the most important staple crop.
- Irrigation water from rivers, canals, dams or wells is extensively used in the major rice producing countries.
- Other food crops like **maize, millet, sorghum, wheat, gram and beans** are of subsidiary importance. They are cultivated in the drier or cooler areas where rice cannot be grown.

Lowland cash crops

- The most important crop in this category is **cane sugar**.
- As much as two-thirds of world's sugar production comes from tropical countries.
- Some of the major producers include **India, Java, Formosa, Cuba, Jamaica, Trinidad and Barbados.**
- **Jute** is confined almost entirely to the **Ganges - Brahmaputra delta**, in India and Bangladesh.
- Other crops include cotton, a major commercial crop of the Indian sub-continent.

Highland plantation crops

- The colonisation of tropical lands by Europeans gave rise to a new form of cultivated landscape in the cooler monsoonal highlands.
- Thousands of acres of tropical upland forests were cleared to make way for plantation agriculture in which tea and coffee are the most important crops.

Coffee

- Coffee originated in **Ethiopia** and **Arabia**.
- But **Brazil** accounts for almost half the world's production of coffee.
- It is mainly grown on the **eastern slopes of the Brazilian plateau**.
- The crop is also cultivated on the highland slopes in the Central American states, India and eastern Java.

Tea

- Tea originated in **China** and is still an important crop there.
- It requires **moderate temperatures** (about 15°C), **heavy rainfall** (over 150 cm) and **well-drained highland slopes.**
- It thrives well in the tropical monsoon zone (highlands).
- The best regions are thus the **Himalayan foothills of India and Bangladesh**, the **central highlands of Sri Lanka** and **western Java**, from all of which it is exported.
- In China, tea is grown mostly for local consumption.

Shifting Cultivation

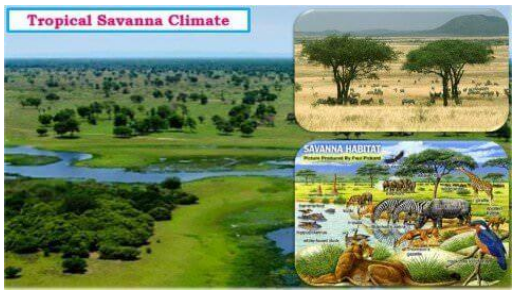
- This most primitive form of farming is widely practised.

- Instead of rotating the crops in the same field to preserve fertility, the tribesmen move to a new clearing when their first field is exhausted.
- Farming is entirely for **subsistence**.
- As tropical soils are **rapidly leached and easily exhausted, the first crop may be bountiful, but the subsequent harvests deteriorate.**

Region	Name of Shifting Cultivation
Malaysia	Lacking
Burma	Taungya
Thailand	Tamrai
Philippines	Caingin
Java	Humah
Sri Lanka	Chena
Africa and Central America	Milpa
North-east India	**Jhum**

Savanna or Tropical Wet and Dry Climate (Aw: A – Tropical, w – dry winter)

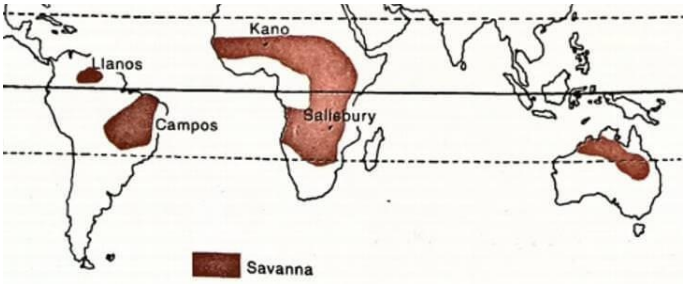
- Savanna climate has **alternate wet and dry seasons**
- There is **no distinct rainy season** like in monsoon climate.
- **Rains occur in warm summer** months.
- Floods and droughts are common.
- Vegetation, wildlife and human life are quite different from monsoon climate regions.



Typical savanna climate conditions

Distribution of Savanna Climate

- It is confined within the tropics and is best developed in **Sudan**, hence its name the **Sudan Climate**.
- It is a **transitional type** of climate found between the **equatorial rainforests** and **hot deserts.**



Savanna climate distribution: transitional zones between the equatorial rainforests and hot deserts

African Savanna

- The belt includes **West African Sudan** and then curves southwards into East Africa and southern Africa north of the Tropic of Capricorn.

South American Savanna

- There are two distinct regions namely the **Llanos** of the **Orinoco** basin (north of the equator) and the **Compos** of the Brazilian Highlands (south of the equator).

Australian savanna

- The Australian savanna is located south of the monsoon strip (northern Australia) running from west to east north of the Tropic of Capricorn.

Indian Savanna

- Certain parts across Northern Karnataka, Southern Maharashtra and Telangana exhibit characteristics of both semi-arid and savanna climate.
- Irrigational projects that came up after independence have drastically modified the savanna characteristic of the region.

Savanna Climate

Rainfall

- Savanna climate receives **considerably less annual rainfall**.
- Mean annual rainfall ranges from **80 – 160 cm**.
- Rainfall **decreases with distance from equator**.
- In the northern hemisphere, the rainy season begins in May and lasts till September.

- In the southern hemisphere, the rainy season is from October to March.

Temperature

- Mean annual temperature is **greater than 18°C.**
- The monthly temperature hovers between 20 °C and 32 °C for lowland stations.
- **Highest temperatures do not coincide with the period of the highest sun** (e.g. June in the northern hemisphere) but occur just before the onset of the rainy season, i.e. April in Northern Hemisphere and October in Southern Hemisphere.
- **Days are hot and nights are cold**. This **extreme diurnal range** of temperature is another characteristic feature of the Sudan type of climate.

Winds

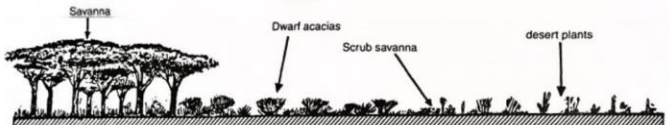
- The prevailing winds of the region are the **trade winds**, which bring rain to the coastal areas.
- They are strongest in the summer (favourable position of ITCZ) but are relatively dry by the time they reach the continental interiors or the western coasts (trade winds are easterlies – flow from east to west. Hence, **rainfall decreases from east to west**).
- In West Africa, the North-East Trades blow offshore (continent to sea) from the Sahara Desert and reach the Guinea coast as a dry, dust-laden winds.

What is the reason for alternating wet and dry seasons in Savanna type climate?

- On-shore winds is summer bring rains.
- Off-shore winds in winter keep the climate dry.

Natural Vegetation of Savanna Climate

- The savanna landscape is typified by **tall and coarse grass** (6 to 12 feet high) **and short trees**.
- The **elephant grass** may attain a height of even 15 feet.
- The grasslands are also called as **bush-veld.**
- Grasses appear greenish and well-nourished in the rainy season.
- Grasses die down in the dry season increasing the risk of forest fires.
- The trees are **deciduous**, shedding their leaves in the cool, dry season to prevent transpiration, e.g. acacias.
- Trees usually have **broad trunks**, with water-storing devices to survive through the prolonged drought.
- Many trees are umbrella shaped, exposing only a narrow edge to the strong winds.
- As the rainfall diminishes towards the deserts, the savanna merges into thorny scrub (semi-arid).



Vegetation in the savanna regions

Animal Life of the Savanna

- Rich animal diversity is the characteristic of savanna climate.
- Most of the National Geographic and Animal Planet documentaries on wild animals are shot in savanna regions.
- The herbivorous include the zebra, antelope, deer, elephant etc. and carnivorous animals include the lion, tiger, leopard, hyena, panther, jaguar, jackal etc.
- Species of reptiles and mammals including crocodiles, alligators, giant lizards live together with the larger rhinoceros and hippopotamus in rivers and marshy lakes.
- Seasonal migration of animals in search of food is typical characteristic of savanna animal life.
- The savanna is known as the **big game country** as animals are hunted down both legally and illegally.

Life and Economy in the Savanna

- Many tribes live in savanna region.
- Tribes like the **Masai** tribes of the East African plateau are pastoralists whereas **Hausa** of northern Nigeria are settled cultivators.
- The old grazing grounds of Masai tribes in the **Kenyan Highlands** were taken over by the

white immigrant settlers for plantation agriculture (coffee, tea, cotton) and dairy farming.
- The cattle kept by the Masai are kept entirely for the supply of milk. They don't slaughter cattle for meat. **Agriculture is barely practised**.
- The Hausa are a tribe of settled cultivators who inhabit the savanna lands of the Nigeria. They are more advanced in their civilisation.
- They do not practice shifting cultivation. Instead, they clear a piece of land and use it for several years.

Farming

- Droughts are long due to unreliable rainfall.
- Political instability hinders the development of agricultural infrastructure.
- The Sudan Climate, with **distinct wet-and-dry periods,** is also responsible for the **rapid deterioration of soil fertility**.
- During the rainy season, torrential downpours of heavy rain cause leaching of nitrates, phosphates and potash.
- During the dry season, intense heating and evapouration dry up most of the water.
- Many savanna areas, therefore, have **poor lateritic soils** which are incapable of supporting good crops.

Crops in Savanna

- Settlements in central Africa, northern Australia and eastern Brazil have shown that the savannas have immense agricultural potential for **plantation agriculture** of cotton, cane sugar, coffee, oil palm, groundnuts and even tropical fruits.
- Tropical Queensland, despite its scarcity of labour force, has been very successful in developing its huge empty land.
- Kenya, Uganda, Tanzania and Malawi have already taken to large-scale production of cotton.
- In West Africa, the commercial cultivation of groundnuts, oil palm and cocoa have been gradually extended into the savanna lands.
- In the cooler highlands, temperate crops have been successfully raised.

Cattle rearing

- The savanna is said to be the **natural cattle country,** and many of the native people are pastoralists.
- But the **quality of grass doesn't support large scale ranching (typical to all tropical climates)**.
- Grasses here are no match to nutritious and soft grasses of temperate grasslands.
- The cattle varieties are also poor and yield little meat or milk.
- The export of either beef or milk from the tropical grasslands is so far not important.
- Few regions progressed with the adaptation of science and technology.
- **Queensland** has become Australia's largest cattle producing state. Both meat and milk are exported.

7.3 B – Dry Climate

- Grasslands and deserts are classified under B – dry climate.
- Grasslands include **subtropical savanna grasslands (BSh)** and **temperate steppe grasslands (BSk)**.
- Deserts are regions where **evapouration exceeds precipitation.**
- There are mainly two types:
  1. hot like the **hot deserts** of the Saharan type (BWh) and
  2. **temperate or mid-latitude deserts** like the **Gobi Desert** (BWk).

Hot Desert Climate (BWh: B – Dry, W – Desert, h – low latitude)

- The aridity of the hot deserts is mainly due to the effects of **off-shore trade winds**; hence they are also called **trade wind deserts.**
- The major hot deserts of the world are located on the **western coasts of continents** between latitudes **15° and 30°N and S**.
- They include the biggest **Sahara Desert** (3.5 million square miles), **Great Australian Desert, Arabian Desert, Iranian Desert, Thar Desert, Kalahari** and **Namib Deserts**.
- In North America, the desert extends from Mexico into U.S.A. and is called by different names

at different places, e.g. the **Mohave, Sonoran, Californian** and **Mexican Deserts.**

- In South America, the **Atacama or Peruvian Desert is the driest of all deserts** (driest place on earth — **rain shadow effect of the Andes**, **off-shore trade winds, westerlies blow to the south of Tropic of Capricorn, cold ocean currents: upwelling of cold water due to Walker Circulation**) with less than 2 cm of rainfall annually.

Atacama Desert is the driest place on earth with less than 2 cm annual rainfall.

Mid-Latitude Desert Climate (BWk: B – Dry, W – Desert, k – high latitude)

- The temperate deserts are rainless because of either **continentality** **(e.g. Gobi Desert) or rain-shadow effect** (**e.g. Patagonian Desert** due to **rain-shadow effect of Andes**).
- Amongst the mid-latitude deserts, many are found on plateau and are at a considerable distance from the sea.
- These are **Ladakh, The Kyzyl Kum, Turkestan, Taklimakan and Gobi deserts of Central Asia, drier portions of the Great Basin Desert of the western United States** and **Patagonian Deserts of Argentina etc.**
- The Patagonian Desert is more due to its rain-shadow position on the leeward side of the lofty Andes than due to continentality.

Desert Climate

Rainfall (Both Hot and Cold deserts)

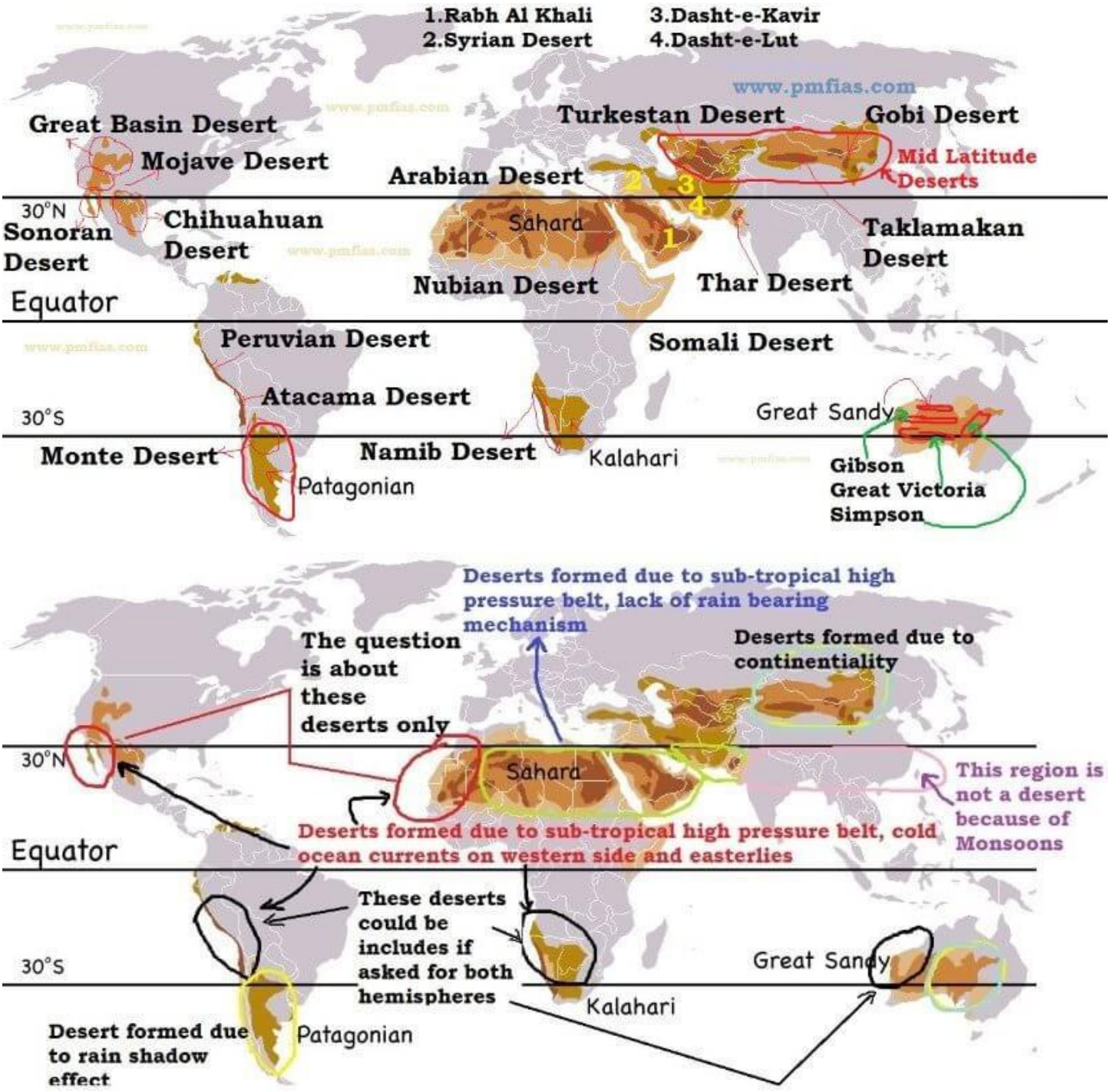
- Deserts, whether hot or mid-latitude have an annual precipitation of **less than 25 cm.**
- **Atacama (driest place on earth)** has practically no rain at all.
- Rain normally occurs as violent thunderstorms of the convectional type occasionally causing flash floods.

Temperature of Hot deserts

- There is **no cold season** in the hot deserts and the average summer temperature is high around 30°C.
- The highest temperature recorded is **57.77 °C in 1922 at Al Azizia, Libya**.
- The reasons for the high temperatures are obvious — a clear, cloudless sky, intense insolation, dry air and a rapid rate of evapouration.
- Coastal deserts by virtue of their maritime influence and the cooling effect of the cold currents have much lower temperatures.
- The desert interiors, however, experience much higher summer temperatures and the winter months are rather cold.
- The **diurnal range of temperature in the deserts is very great**. Intense insolation by day in a region of dry air and no clouds causes the temperature to rise with the sun.
- But as soon as the sun sets, the land loses heat very quickly by radiation and the mercury levels drop.
- **High diurnal temperature range** is a typical feature of hot deserts. Average diurnal range (difference between maximum and minimum temperature that occur within a day) varies from 14 to 25 °C.
- Frosts may occur at night in winter.

Climatic Conditions in the Mid-latitude deserts

- These inland basins lie hundreds of miles from the sea and are sheltered by the high mountains all around them. As a result, they are **cut off from the rain-bearing winds**.



Major Deserts of the World

- Occasionally depressions may penetrate the Asiatic continental mass and bring light rainfall in winter. Due to their coldness and elevation, snow falls in winter.
- The **annual range of temperature is much greater than that of the hot deserts**.
- **Continentality** accounts for these extremes in temperature.
- Winters are often severe, freezing lakes and rivers, and strong cold winds blow all the time. When the ice thaws in early summer, floods occur in many places.

Desert Vegetation

- The predominant vegetation of both hot and mid-latitude deserts is **xerophytic** or drought-resistant.
- This includes the cacti, thorny bushes, long-rooted wiry grasses and scattered dwarf acacias.
- Trees are rare except where there is abundant groundwater to support clusters of **date palms.**

- Along the western coastal deserts washed by cold currents as in the Atacama Desert, support a thin cover of vegetation.
- Intense evapouration increases the salinity of the soil so that the dissolved salts tend to accumulate on the surface forming hard pans (Bajada, Palaya).
- Absence of moisture retards the rate of decomposition and desert soils are very deficient in humus.
- Most desert shrubs have long roots (in search of groundwater) and are well spaced out to gather moisture.
- Plants have **few or no leaves,** and the foliage is either **way, leathery, hairy or needle-shaped** to reduce the loss of water through transpiration.
- The seeds of grasses and herbs have **thick, tough skins** to protect them while they lie dormant for years.

Desert vegetation

Life in the Deserts

- Despite its inhospitality, the desert has always been peopled by different groups of inhabitants.

Tribe	Desert	Occupation
Bedouin Arabs	Arabia	nomadic herdsmen
Tuaregs	Sahara	nomadic herdsmen
Gobi Mongols	Gobi	nomadic herdsmen
Bushmen	Kalahari	primitive hunters and collectors.
Bindibu	Australia	primitive hunters and collectors.

The settled cultivators

- Modem concrete dams constructed across the Nile, e.g. **Aswan and Sennar Dams** improved agriculture.
- In the same way, desert cultivators rely on the **Indus in Pakistan**, the **Tigris-Euphrates in Iraq**, and the **Colorado in the Imperial Valley of California**.
- In the deserts, wherever there are oases (depressions where underground water reaches the surface), some form of settled life is bound to follow.
- Some of them are abnormally large like the **Tafilalet Oasis in Morocco** which measures 5,000 square miles.
- A wall is usually constructed around the oasis to keep out the violent dust storms called **simooms.**
- The most important tree is the date palm. The fruit is consumed locally and also exported.
- Other crops cultivated include maize, barley, wheat, cotton, cane sugar, fruits and vegetables.

The mining settlers

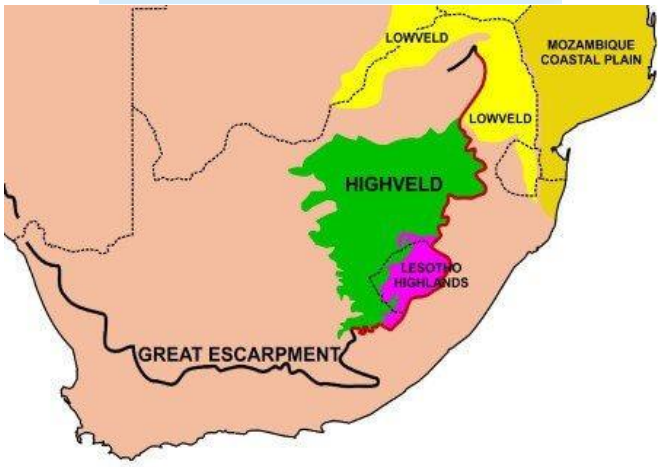
- **Gold** is mined in Great Australian Desert. **Kalgoorlie and Coolgardie** have become large towns.
- In the Kalahari Desert (thirstland), the discovery of **diamonds** and **copper** has brought many white men.
- In Atacama, in northern Chile, large mining camps have been established for the mining of **caliche (cemented gravels)** from which **sodium nitrate**, a valuable fertiliser, is extracted.
- Besides nitrates, **copper** is also mined. **Chuquicamata** is the world's largest copper town.
- In the deserts of North America, **silver is mined in Mexico**, **uranium in Utah a**nd **copper in Nevada**.
- Discovery of oil, in many parts of the Saharan and Arabian Deserts, has transformed the region.

Steppe or Temperate Grassland Climate (BSk: B – Dry, S – Steppe, k – high latitude)

- Steppe climate is also known as Temperate Continental Climate.

Distribution of temperate and tropical grasslands

Steppe grasslands in the Mongolian region



Distribution

- Most of the temperate grasslands lie in the **interiors of the continents** in the **westerly wind belt**.
- Some of the grasslands are formed due to rain shadow effect of the mountains (good rains on the windward side; on the leeward side deserts or grasslands are formed).

- Grasslands are **practically treeless** due to continentality (deep within the interiors of the continents where rain-bearing winds don't reach) and/or rain shadow effect.
- In Eurasia, they are called the **steppes** and stretch eastwards from the shores of the Black Sea to the foothills of the Altai Mountains.

Temperate Grassland	Region
Pustaz	**Hungary and surrounding regions**
Prairies	**North America (between the foothills of the Rockies and the Great Lakes)**
Pampas	**Argentina and Uruguay (Rain-shadow effect)**
Bush-veld (more tropical)	**Northern South Africa**
High Veld (more temperate)	**Southern South Africa**
Downs	**Australia: Murray-Darling basin of southern Australia**
Canterbury	**New Zealand (rain shadow effect of Southern Alps)**

Climate

Temperature

- Climate is continental with **extremes of temperature**.
- The summers are hot, and the winters are cold.
- Summers are very warm and over 18-20 °C.
- In the southern hemisphere, the summers are never severe due to very narrow landmasses.

Precipitation

- The average rainfall may be taken as about **45 cm**.
- But precipitation varies according to location from **25 cm to 75 cm (below 25 cm it is desert climate)**.
- The heaviest rain comes in June and July (late spring and early summer).
- Most of the winter months have about 2.5 cm of precipitation, brought by the occasional depressions of the Westerlies and coming in the form of snow.
- The maritime influence in the southern hemisphere causes more rainfall.

Chinook (Snow eaters)

- Chinook is a **hot local katabatic wind** that blows down the eastern slopes of the Rockies.
- It is similar to the Fohn in Switzerland and comes in a south-westerly direction to the **Prairies**.
- It comes with the depressions in winter from the Pacific coast ascending the Rockies and then descending to the Prairies (katabatic wind).
- It is a hot wind and may raise the temperature by 5 °C within a matter of 20 minutes.
- It melts the snow-covered pastures and benefits agriculture and animal ranching.

Natural Vegetation of Steppe Climate

Grasses

- Greatest difference from the tropical savanna is that steppes are practically **treeless,** and the **grasses are much shorter**.
- Grasses are tall, fresh and **nutritious**. This is typical of the grass of the wheat-lands in North America, the **rich black earth or chernozem areas of Ukraine** and the better-watered areas of the Asiatic Steppes.
- Where the rainfall is light or unreliable, or the soil is poor, as in the continental interiors of Asia the short steppe type of grass prevails.
- The grasses are not only shorter but also **wiry** (lean, tough) and **sparse** (thinly dispersed or scattered).
- These areas are **less suitable for arable farming** and are used for some form of **ranching** as in the High Plains of U.S.A.
- The growth of grasses is not abruptly checked by summer droughts or winter cold.

Trees

- Poleward, an increase in precipitation gives rise to a transitional zone of wooded steppes where some **conifers** gradually appear.
- In the cultivated regions, such as the wheat farms of the Prairies, double rows of trees are planted around the house to shield the occupants from the strong wind.

Animals

- Temperate grasslands do not have much animal diversity (Savanna: high animal diversity).
- **Horses** are common in Asian Steppes.

Economic Development of Steppes

Wheat and Maize Cultivation

- Cultivation was unknown just before a century, and the region was one of the most sparsely populated parts of the world.
- In recent years, the grasslands have been ploughed up for extensive, mechanised wheat cultivation and are now the **'granaries of the world' (Prairies).**
- Besides wheat, maize is increasingly cultivated in the warmer and wetter areas.

Ranching

- The tufted grasses have been replaced by the more **nutritious Lucerne or alfalfa grass** for cattle and sheep rearing.
- These temperate grasslands are now the **leading ranching regions** of the globe (e.g. **Pampas of Argentina**).

Nomadic herding in Asian Steppes

- This type of migratory animal grazing has almost disappeared from the major grasslands.
- The herders were wandering tribes, e.g. the **Kirghiz**, and the **Kazakhs.**
- Now under the Communist regime, they are being forced to settle down.
- The steppes have been made into huge **collective farms** and state farms for ranching or producing cereals.

Extensive mechanised wheat cultivation

- The **temperate grasslands** are ideal for **extensive wheat cultivation**.
- The **levelness** of the Steppes and other temperate grasslands all over the world makes ploughing and harvesting a comparatively easy job.
- In the **Prairies, the Argentinian Pampas, the Ukrainian Steppes** and the **Downs of Australia**, agriculture is completely mechanised.

Pastoral farming

- The natural conditions suit animal farming.
- With the development of refrigerated ships in the late nineteenth century, the temperate grasslands became major pastoral regions, exporting large quantities of beef, mutton, wool, hides.
- Milk, butter, cheese and other dairy products are also important in some parts of the North American grasslands.

Grassland	Major Economic Activity
Prairies	• **Wheat Granaries** • **Extensive Ranching**
Pustaz	• **Rich black soil** • **Abundant wheat production** • **Sugar from Sugar beet (Beta vulgaris, is a plant whose root contains a high concentration of sucrose)** • **Countries like Hungary, Ukraine, Romania etc.**
Pampas	• **Alfalfa: nutrient-rich grass** • **Ranching, cattle rearing; Dairy products** • **Extensive wheat producing region** • **Economy depends on wheat and beef export**

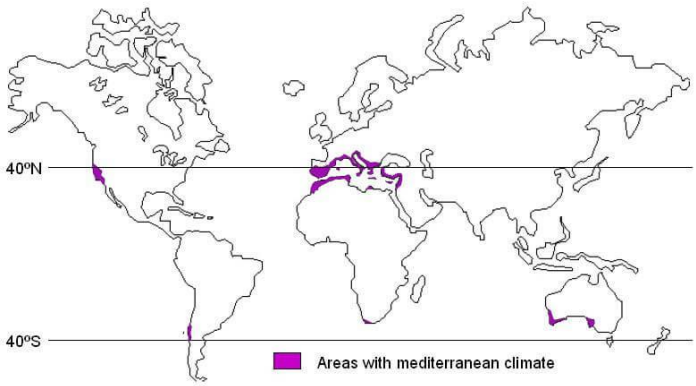
Downs and Canterbury	• **Sheep and Cattle rearing,** • **Merino sheep: wool production**
Veldts	• **Maize farms** • **Sheep and Cattle rearing**

7.4 C – Warm Temperate (Mid-latitude) Climates

C-Warm temperate (Mid-latitude) Climates	Humid subtropical	Cfa	No dry season, warm summer
	Mediterranean	Cs	Dry hot summer
	Marine west coast	Cf	No dry season, warm and cool summer

Mediterranean Climate (Cs: C – Warm Temperate, s – Dry summer)

- Mediterranean Climate is also known as **Warm Temperate Western Margin Climate** or **Warm Temperate West Coast Climate**.



Distribution of Mediterranean Climate

Distribution

- They are confined to the western portion of continents, between **30° and 45°** N and S of the equator.
- The basic cause of this type of climate is the **shifting of the wind belts (westerly wind belt)**.
- Mediterranean Sea has the greatest extent of this type of **winter rain climate (winter maxima)**.
- The best-developed form of this climatic type is found in **central Chile.**

Other Mediterranean regions include:

- **California (around San Francisco),**
- **The south-western tip of Africa (around Cape Town),**
- **Southern Australia, and south-west Australia (Swanland).**

Climate

- Climate is characterised by clear **skies and high temperatures.**
- **The summers are hot and dry, and the winters are cool and wet**.
- Mean annual precipitation ranges from **35-90 cm.**
- Temperature of warmest month is greater than or equal to 10° C.
- Temperature of coldest month is less than 18° C but greater than –3° C.
- Climate is **not extreme** because of cooling from water bodies.

A dry, warm summer with off-shore trades

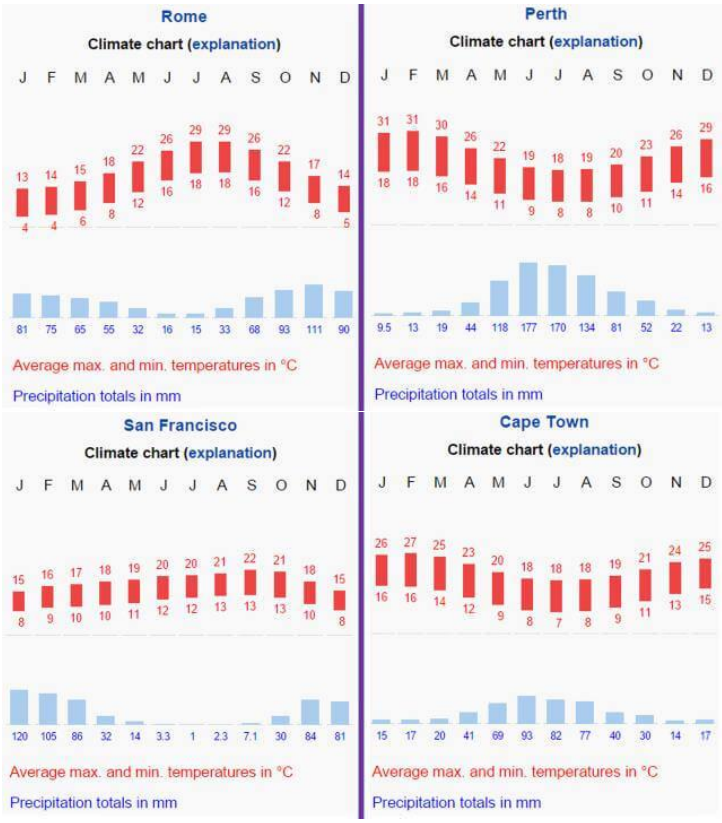
- In summer, the belt of influence of the **Westerlies is shifted a little poleward**.
- Rain-bearing winds are therefore not likely to reach the Mediterranean lands.
- The **prevailing trade winds (tropical easterlies) are off-shore,** and there is practically no rain.
- Strong winds from inland desert regions pose the risk of wildfires.

Rainfall in winter with on-shore Westerlies

- The Mediterranean lands receive most of the precipitation in **winter** when the westerlies shift equatorward.
- In the northern hemisphere, the prevailing **on-shore westerlies** bring much cyclonic rain from the Atlantic (winter rain is a characteristic feature of Mediterranean Climate).

- The **rain comes in heavy showers and only on a few days with bright sunny periods between them**. This is another characteristic feature of the Mediterranean winter rain.
- Though the downpours are infrequent, they are often very torrential, and in mountainous districts, **destructive floods** occur.

Climate Graphs



Climate graphs of cities with Mediterranean climate

Local winds of the Mediterranean Climate

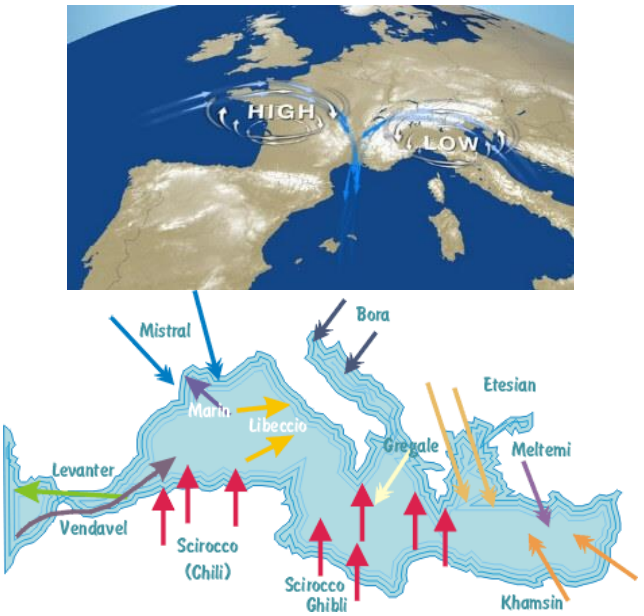
- Many local winds, some hot, others cold are common around the Mediterranean Sea.

Sirocco

- This is a hot, dry dusty wind which originates in the **Sahara Desert**.
- After crossing the Mediterranean Sea, the Sirocco is slightly cooled by the absorption of the water vapour.
- Its scorching heat withers (dry up or shrivel from loss of moisture) vegetation and crops.
- This may be **blood rain** because the wind is carrying the red dust of the Sahara Desert.

Mistral

- Mistral is a **cold wind** from the north, rushing down the **Rhone valley** in violent gusts.
- The velocity of the Mistral is intensified by the **funnelling effect** in the valley between the **Alps** and the **Central Massif (Plateau in France)**.



Local winds in the Mediterranean

- A similar type of cold north-easterly wind experienced along the **Adriatic coast** is called the **Bora.**
- **Tramontane** and **Gregale** are similar **cold winds** of the Mediterranean Sea.

Natural Vegetation in the Mediterranean Climate

Mediterranean Climate

- Trees with **small broad leaves** are widely spaced and **never very tall**.

- The **absence of shade** is a distinct feature of Mediterranean lands.
- Plants are in a continuous struggle against heat, dry air, excessive evapouration and prolonged droughts.
- They are, in short **xerophytic (drought tolerant)**.

Mediterranean evergreen forests

- These are open woodlands with **evergreen oaks** found only in the climatically most favoured regions.
- The trees are stunted, with massive trunks, small leathery leaves and a wide-spreading root system.
- The **cork oaks** are valued for their thick barks, used for making **wine-bottle corks**.
- In Australia, the **eucalyptus** forests replace the evergreen oak.
- The giant **redwood** is typical of the **Californian** trees.

Evergreen coniferous trees

- These include the various kinds of **pines, firs, cedars** and **cypresses** which have evergreen, needle-shaped leaves and tall, straight trunks.

Mediterranean bushes and shrubs

- This is perhaps the most predominant type of Mediterranean vegetation.

Grass

- Conditions in the Mediterranean **do not suit grass**, because most of the rain comes in the cool season when growth is slow.
- Even if grasses do survive, they are so wiry (lean, tough) and bunchy that they are **not suitable for animal farming.** Cattle rearing is thus unimportant in the Mediterranean.

Agriculture in the Mediterranean Climate

Orchard farming

- The Mediterranean lands are also known as the **world's orchard lands.**
- The Mediterranean lands account for 70 per cent of the world's exports of citrus fruits.
- The **olive tree** is probably the most typical of all Mediterranean cultivated vegetation.
- A wide range of citrus fruits such as oranges, lemons, limes, citrons and grapefruit are grown.
- Besides citrus fruits, many nut trees like chestnuts, walnuts, and almonds are grown.
- The fruit trees have long roots to draw water from considerable depths during the long summer drought.
- The thick, leathery skin of the citrus fruits prevents excessive transpiration.
- The long, sunny summer enables the fruits to be ripened and harvested.

Crop cultivation and sheep rearing

- **Wheat** is the leading food crop. **Barley** is the next most popular cereal.
- The mountain pastures, with their cooler climate, support a few sheep, goats and sometimes cattle.
- **Transhumance** is widely practised (seasonal movement up and down the hills in search of pastures).

Wine production

- **Viticulture** is by tradition a Mediterranean occupation.
- The Mediterranean regions account for three-quarters of the world's production of wine.
- Some 85 per cent of grapes produced, go into wine.

Economy

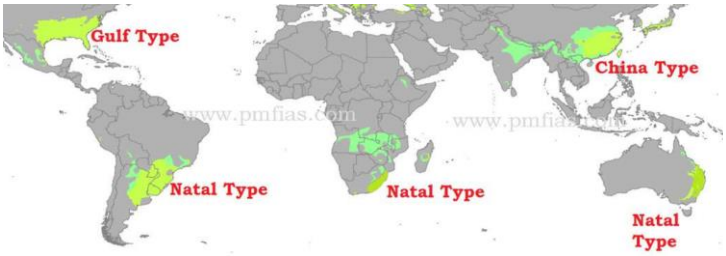
- **The regions are a net exporter of citric fruits and net importer of dairy products.**
- Clear skies in summer and good landscapes **encourage tourism (a lot of Indian Songs are shot here).**
- European Mediterranean has many ancient cities and are famous for their health and pleasure resorts.

Warm Temperate Eastern Margin Climate (Cfa)

- Cfa: C – warm temperate, f – no dry season, a – hot summer.
- It is also known as Humid subtropical climate.
- This type of climate is found between **20° and 35° N and S latitude** (warm temperate latitudes or subtropics; hence it is also known as Humid subtropical climate); on the **east coast** in both hemispheres.

Different variants of Warm Temperate Eastern Margin Climate include the

a) **Temperate monsoon Climate or China Type Climate,**
b) **Gulf Type Climate and**
c) **Natal Type Climate.**



China Type

- Temperate Monsoon or China Type climate is observed in most parts of China.
- The climate is also observed in **southern parts of Japan**.

Summer

- Intense heating within interiors (Tibet, desert region) sets up a region of low-pressure in summer attracting tropical Pacific air stream (South-East Monsoon).
- Monsoon does not 'burst' as suddenly, nor 'pour' as heavily as in India.
- Typhoons form mostly in late summer, from July to September.

Winter

- In winter, there is **intense pressure over Siberia,** and the continental polar air stream flows outwards as the North-West Monsoon, bitterly cold and very dry.
- There is little rain but considerable snow on the windward slopes.

Gulf Type

- Found in **south-eastern U.S.A**., bordering the Gulf of Mexico where continental heating in summer induces an inflow of air from the cooler Atlantic Ocean.
- Monsoonal characteristics are **less intense** compared to China type.
- There is **no complete seasonal wind reversal**.
- Hurricanes occur in September and October.

Natal Type

- Found in in **New South Wales (Australia), Natal (South Africa), Parana-Paraguay-Uruguay basin (South America).**
- Natal type is different from temperate monsoon or China type as it **receives rainfall from onshore Trade Winds all the year round**.
- The narrowness of the continents and the dominance of maritime influence **eliminate the monsoonal elements.**
- The South-East Trade Winds bring about a more even distribution of rainfall throughout the year

Climate type	Feature
China type	Temperate monsoonal
Gulf type	Slight-monsoonal
Natal type	Non-monsoonal

Climate

- Characterised by a **warm moist summer** and a **cool, dry winter** (winters are also moist in Natal Type).

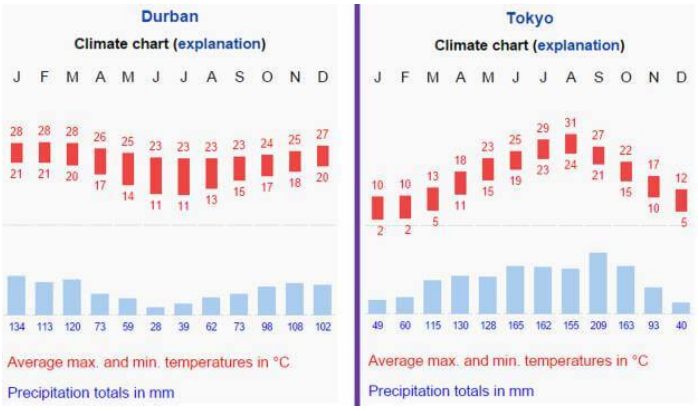
Temperature

- The mean monthly temperature varies between 4 °C and 25 °C and is strongly modified by **maritime influence.**
- Occasionally, the penetration of **cold air (Polar Vortex)** from the continental interiors may bring down the temperature to freezing point.
- Though frosts are rare, they occasionally occur in the colder interiors.

Precipitation

- Rainfall is more than moderate, anything from **60 cm to 150 cm**.
- This is adequate for all agricultural purposes and hence supports a wide range of crops.
- Areas which experience this climate are **very densely populated**.
- There is a **fairly uniform distribution of rainfall throughout the year**.
- Rain comes either from convectional sources or as orographic rain in summer, or from depressions in prolonged showers in winter.
- **In summer, the regions are under the influence of moist, maritime airflow from the subtropical anticyclonic cells.**
- Local storms, e.g. **typhoons**, and **hurricanes**, also occur.

Climate Graphs



Climate graphs of places with Humid subtropical climate

Natural Vegetation

- Supports a luxuriant vegetation.
- The lowlands carry **both evergreen broad-leaved forests and deciduous trees** (**hardwood**).
- On the highlands, are various species of conifers such as pines and cypresses which are important **softwoods.**
- Perennial plant growth is not checked by either a dry season or a cold season.

Timber

- The forests of China and southern Japan also have considerable economic value and include oak, camphor, etc.
- South-eastern Brazil, eastern Paraguay, north-eastern Argentina have Parana pine, and the **quebracho** (axe-breaker, an extremely hard wood used for tanning).
- Eastern Australia have Eucalyptus forests.
- In Natal, palm trees thrive.
- The Gulf states of U.S.A. have lowland deciduous forests.

Economic Development

Region	Major Cropping Patterns
South-Eastern China	• Rice, tea and mulberries (sericulture) • Sericulture is declining
South-Eastern USA	• Widespread cultivation of maize and cotton in the Corn and Cotton Belts of U.S.A • Fruit and tobacco are also grown
Natal, South Africa	• Sugarcane
South America	• Coffee and maize and dairying

Farming in monsoon China

- A third of the world's rice is grown in China, though the huge population leaves very little for export.
- Monsoon China has all the ideal conditions for padi cultivation; a warm climate, moderately wet throughout the year, and extensive lowlands with fertile moisture-retentive alluvial soil, which if necessary, can be easily irrigated.
- As the flat lands are insufficient for rice cultivation, farmers move up the hill-slopes and grow padi on terraced uplands.

Agriculture in the Gulf states

- Lack of population pressure and the urge to export gave rise to **corn, cotton and tobacco.**

Corn

- The humid air, the sunny summer and the heavy showers suit the crop well.
- It is grown right from the Gulf coast to the Mid-west south of the Great Lakes, with the greatest concentration in the Corn Belt of Nebraska, Iowa, Indiana and Ohio.
- The region accounts for more than half the world's production of corn, but only 3 per cent of the world's export.
- This is because most of the corn is used for **fattening animals**, mostly **cattle and pigs (thriving beef and pork industry).**
- The fattened animals are then sold to the meat plants in Chicago and Cincinnati to be processed into **'corned beef' (**from here the beef is exported through **Great Lakes** and **St Lawrence waterway**).
- Apart from its ease of cultivation, corn's most outstanding feature is its prolific yield.
- It gives almost twice as much food (mainly starch) per acre as wheat or other cereals.
- This explains why it is so widely cultivated in both the warm temperate and the tropical latitudes.

Cotton

- Of the cash crops grown in the Gulf states, none is comparable with cotton.
- The Gulf type of climate is undoubtedly the **best for cotton growing**.
- Its long, hot growing season with 200 days frost free and a moderately high temperature permits the crop to grow slowly and mature within six months.
- In the very south, in the Gulf-lands, the heavy rainfall damages the lint. This area is, therefore, less suitable for cotton and is devoted to **citrus fruits**, **cane sugar** and **market gardening**, as in Florida.
- The commercial cultivation of cotton is now concentrated only in the most favourable areas which are the **Mississippi flood plains** and **Atlantic coastlands**.
- The most dreaded enemy of the Cotton Belt is the **boll-weevil**. The pest multiplies rapidly. The pest is responsible for the **westward migration of the Cotton Belt**.

Tobacco

- It is a native crop of America.
- Virginia tobacco is famous.
- The humid atmosphere, the warmth and the well-drained soils of the Gulf states, enable tobacco to be successfully cultivated in many of the eastern states of U.S.A.
- No less than half the tobacco that enters international trade comes from these states.

Crops in Southern Hemisphere

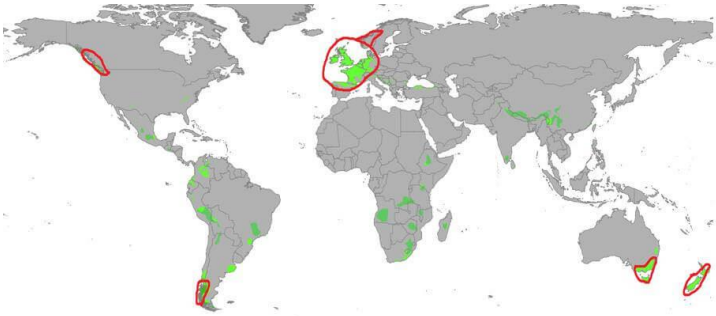
- In the coastlands of Natal, **cane sugar** is the dominant crop, followed by **cotton** and **tobacco** in the interior.
- Maize is extensively cultivated for use both as food and animal fodder for cattle rearing.
- In South America where rainfall is less than 120 cm, there is much grassland on which many cattle and sheep are kept for meat, wool and hides.
- The extensive natural pastures provide valuable forage for both cattle and sheep.
- Further north in southern Brazil, the rainfall increases to more than 120 cm, and forest gradually replaces grass.
- Here the important occupations are the cultivation of yerba mate (Paraguay tea) and the lumbering of araucaria or Parana pine. Cattle and sheep are reared, and maize and cane sugar are grown.
- In eastern Australia, Giant eucalyptus trees rise one above the other right up the Eastern Highlands.
- But with the influx of European immigrants, much of the forest has been cleared for settlement and dairying.
- The eastern margin of New South Wales is now the chief source of Australia's milk, butter and cheese, besides cotton, cane sugar and maize which are increasingly grown in the north.

British Type Climate or Cool Temperate Western Margin Climate (Cf)

- Cf: C – Warm temperate, f – no dry season
- It is also known as North-West European Maritime Climate.

- The cool temperate western margins are **under the influence of the Westerlies all-round the year.**
- They are the regions of **frontal cyclonic activity (temperate cyclones)**.
- This type of climate is typical to Britain, hence the name 'British Type'.
- Also called as North-West European Maritime Climate due to **greater oceanic influence.**

Distribution of British Type Climate



Distribution of British Type Climate

Europe

- Most pronounced in and around Britain.
- In Europe, the climate extends far inland into the lowlands of North-West Europe (northern and western France, Belgium, the Netherlands, Denmark, western Norway and also north-western Iberia).

North America

- High Rockies prevent the on-shore westerlies from penetrating far inland.
- Hence, it is confined mainly to the coastlands of British Columbia.

Southern Hemisphere

- The climate is experienced in southern **Chile, Southern Australia, Tasmania** and most parts of **New Zealand (regions east of Southern Alps).**

Climate .

- The climate is very favourable for maximum human output.

Temperature

- The mean annual temperatures are usually between 5 °C and 15 °C.
- Summers are moderately warm.
- Winters are **abnormally mild** because of the warming effect brought by **warm North Atlantic Drift.**
- Sometimes, unusual cold spells are caused by the invasion of **cold polar continental air** from the interiors.
- Ports are never frozen, but frosts do occur on cold nights.

Precipitation

- **Rainfall occurs throughout the year with winter maxima (due to frontal cyclones).**
- Western margins have the heaviest rainfall due to westerlies.
- In New Zealand, the western margins are subjected to heavy orographic rainfall whereas the eastern **Canterbury plains** receive comparatively less rainfall due to **rain-shadow effect.**

Canterbury Plains are to the east of Southern Alps

The seasons

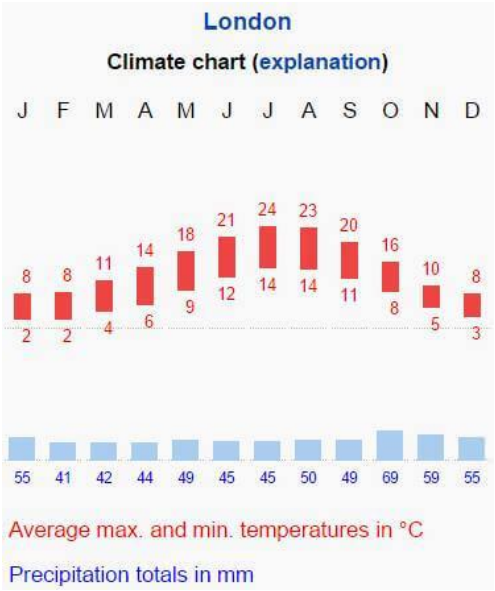
- As in other temperate regions, there are **four distinct seasons** (something that is conspicuously absent in the tropics).

Rainforest: Only Rainy season; Tropical Monsoon: Summer, Winter and Rainy: Tropical Savanna: Summer (rains) and Winter.

- Winter is the season of cloudy skies, foggy mornings, and many rainy days from the passing depressions.

- Spring is the driest and the most refreshing season when people emerge from the depressing winter.
- This is followed by the long, sunny summer.
- Next is the autumn with the roar of gusty winds; and the cycle repeats itself.

Climate Graph British Type Climate



Climate graph of London

Natural Vegetation in British Type Climate

- The natural vegetation of this climatic type is **deciduous forest** (trees shed their leaves in the **cold season**).
- This is an adaptation for protecting themselves against the winter snow and frost.
- Shedding begins in **autumn, the fall season**.
- Some of the common species include oak, elm, ash, birch, beech, and poplar.
- In the wetter areas grow willows (lightweight cricket bats are made from willows. In India willows are found in Kashmir).
- Higher up the mountains, deciduous trees are generally replaced by the **conifers** which can survive a higher altitude, a lower temperature and poorer soils.

Economy in British Type Climate

Lumbering is quite profitable

- Unlike the equatorial forests, the **deciduous trees** occur in **pure stands** and have greater lumbering value.
- The open forests with **sparse undergrowth** mean that logging, transportation are easy and economical.
- The **deciduous hardwoods** are excellent for both fuel and industrial purposes.
- In Tasmania, the **temperate eucalypts** are also extensively felled for the lumbering industry.
- Higher up the mountains, **conifers (softwood)** are felled and transported to **paper and pulp industry**.
- They are extensively used in cardboard making.

Industrialisation

- The regions are **highly industrialized** with high standard of living.
- Britain, France and Germany have significant mineral resources and are heavily industrialised.
- The countries are concerned in the production of machinery, chemicals, textiles rather than agriculture, fishing or lumbering, though these activities are well represented in some of the countries.
- **Ruhr region in Germany, Yorkshire, Manchester and Liverpool** regions in Britain are significant for wide-ranging manufacturing industries.
- Automobile industry is the most significant (BMW, Volkswagen, Audi, Mercedes-Benz and many other world leading car manufacturers have their headquarters in Germany).
- Industries based on dairy products thrive in **Denmark, Netherlands and New Zealand.**
- Tasmania is important for **merino wool production**. Wool produced here is exported to textile factories in England, Japan, China etc.
- Fishing is particularly important in Britain, Norway and British Columbia.

Agriculture

- A large range of cereals, fruits and root crops are raised, mainly for home consumption.
- North-West Europe, which includes some of the most crowded parts of the globe, has little sur-

plus for export. It is, in fact, a **net importer of food crops, especially wheat**.

Market gardening

- All the north-western European countries are highly industrialised and have high population densities.
- There will normally be great demand for fresh vegetables, eggs, meat, milk and fruits.
- As the crops are perishable, a good network of transport is indispensable.
- The produce is shipped by high-speed trucks (truck farming, which is commonly used in the United States)
- In Australia, high-speed boats ply across the Bass Strait daily from Tasmania (**garden state**) to rush vegetables and fruits to most of the large cities in mainland Australia.

Mixed farming

- Arable farms are devoured by factories and **wheat is now a net import item in Europe**.
- Throughout north-western Europe, farmers practice both arable farming (cultivation of crops on ploughed land) and pastoral farming (keeping animals on grass meadows).
- Amongst the cereals, wheat is the most extensively grown, almost entirely for home consumption.
- The next most important cereal raised in the mixed farm is **barley**.
- The better quality barley is sold to the breweries for **beer-making or whisky distilling**.
- The most important animals kept in the mixed farm are cattle.
- The countries bordering the North Sea (Britain, Denmark, the Netherlands) are some of the most advanced dairying countries where cattle are kept on a **scientific and intensive basis.**

Dairying

- The temperate western margin type of climate is almost ideal for **intensive dairying.**
- Cheese is a specialized product of the Netherlands.
- From Denmark and New Zealand comes high-quality butter.
- Milk is converted to cream (**less perishable** than fresh milk) and is exported to all regions across the globe.
- Fresh milk is converted into various forms of **condensed or evapourated milk**, and exported around the world for baby-feeding, confectionery, ice-cream and chocolate making.

Beef cattle

- Besides dairying, some cattle are kept as beef cattle.
- In Argentina or Australia, meat production is the primary concern.
- The high rate of beef consumption in Europe necessitates large imports of **frozen and chilled beef.**
- The **pigs and poultry** act as **scavengers** that feed on the left-overs from root-crops and dairy processes.
- In this way, Denmark is able to export large quantities of bacon (cured meat from the back or sides of a pig) from pigs that are fed on the **skimmed milk, a by-product of butter-making.**

Sheep rearing

- Sheep are kept both for wool and mutton.
- Britain is the home of some of the best-known sheep breeds.
- With the greater pressure exerted on land by increased urbanisation, industrialisation and agriculture, sheep rearing is being pushed further and further into the less-favoured areas.
- Britain was once an exporter of wool (but now it imports from Australia).
- Today it exports only British pedigree animals to the **newer sheep lands of the world (Australia).**
- In the southern hemisphere, sheep rearing is the **chief occupation of New Zealand**, with its greatest concentration in the **Canterbury Plain (the rain shadow region)**.
- Favourable conditions include extensive meadows, a mild temperate climate, well-drained level ground, scientific animal breeding, refrigera-

tion (enables the export of chilled Canterbury lamb and Corriedale mutton to every corner of the globe).

Other agricultural activities

Potatoes

- **Potatoes** feature prominently in the domestic economy of the cool temperate regions.
- It is the staple food in supplementing wheat or bread for millions of people.
- Potato yields far more starch than any cereals and can be cultivated over a range of climatic and soil types.

Beet Sugar

- Found almost exclusively in north-western Europe (including European Russia) and parts of U.S.A.
- The beet is crushed for sugar, and the green tops are used as animal fodder. Producing sugar from beet sugar started during the Napoleonic Wars when military blockades caused a scarcity of sugar.

7.5 D – Cold Snow-forest Climates

Taiga Climate or Boreal Climate (Dfc: f – no dry season, c – cold summer)

- It is also known as Siberian Climate OR Cool Temperate Continental Climate OR Continental Sub-Polar Climate (**just below Arctic circle — 50° to 70° N**).
- Taiga Climate is found **only** in the northern hemisphere due to great east-west extent.
- It is absent in the southern hemisphere because of the narrowness of landmasses and **strong oceanic influence** in the high latitudes.
- On its poleward side, it merges into the **Arctic tundra**; equatorward it fades into **steppe climate.**

Distribution

- It stretches along a continuous belt across **central Canada**, some parts of **Scandinavian Europe** and most of **central and southern Russian**.

Taiga Climate or Boreal Climate

Taiga Climate

Taiga Vegetation

Temperature

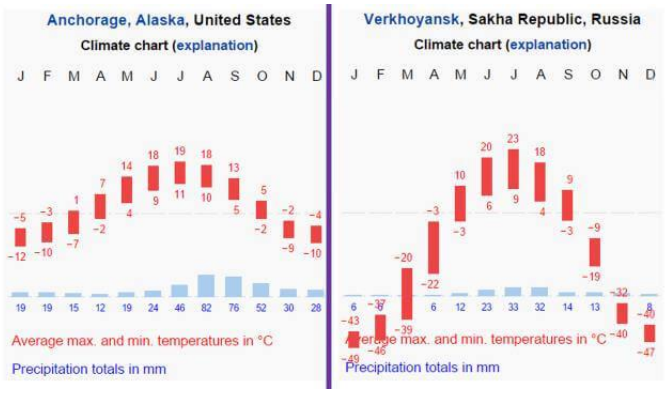
- Summers are brief and warm (20-25 °C) whereas winters are long and cold (30-40 °C below freezing).
- Some of the lowest temperatures in the world are recorded in **Verkhoyansk** (68° N) where -67 °C was once recorded.
- Annual temperature range of is the greatest due to continentality (almost 50-60 °C in Siberia).
- In North America, the extremes are less severe, because of the continent's lesser east-west stretch.
- All over Russia, nearly all the rivers are **frozen**. In normal years, the Volga is ice-covered for about 150 days.
- Occasionally cold, polar local winds such as the **blizzards of Canada** and **buran of Eurasia** blow violently.
- Permafrost (subsurface layer of soil that remains below freezing throughout the year) are generally absent as **snow is a poor conductor of heat** and protects the ground from the severe cold above.

Precipitation

- Maritime influence in the interiors is absent.

- Frontal disturbances might occur in winter.
- Typical annual precipitation ranges from 38 cm to 63 cm.
- It is quite **well distributed throughout the year**, with a **summer maximum** (convectional rains).
- In winter the precipitation is in the form of snow.

Climate Graph



Climate graphs of places with Taiga Climate

Natural Vegetation

- The predominant vegetation is **evergreen coniferous forest** as they require little moisture.
- Pine, fir (e.g. douglas fir and balsam fir), spruce and larch are the four major species of conifers.
- The greatest single band of the coniferous forest is the **taiga** (Russian word for coniferous forest) in Siberia.
- In Europe, the countries that have a similar type of climate and forests are **Sweden** and **Finland**.
- There are small amounts of natural coniferous forest in Germany, Poland, Switzerland, and other parts.
- In North America, the belt stretches from **Alaska** across **Canada** into **Labrador**.
- In the southern hemisphere, coniferous forests are found only on the mountainous uplands of southern Chile, New Zealand, Tasmania and south-east Australia.

Characteristics of Coniferous forests

- Coniferous forests are of **moderate density** and are more uniform.
- The trees in coniferous forests grow straight and tall.
- Almost all conifers are **evergreen**. There is no annual replacement of new leaves as in deciduous trees.
- The same leaf remains on the tree for as long as five years.
- Food is stored in the trunks, and the bark is thick to protect the trunk from excessive cold.
- Conifers are conical in shape with sloping branches that prevent snow accumulation.
- Their shape also offers little grip to the violent winds.
- Transpiration can be quite rapid in the warm summer. So, leaves are small, thick, **leathery** and needle-shaped **to check excessive transpiration.**
- The soils of the coniferous forests are **poor.** They are excessively **leached** and very **acidic**.
- Humus content is also low as the evergreen leaves barely fall and the rate of decomposition is slow.
- Under-growth is negligible because of the poor soil conditions.
- Absence of direct sunlight and the short duration of summer are other contributory factors.
- Coniferous forests are also found in regions with high elevation (Example: the forests just below the snowline in Himalayas).
- But on very steep slopes where soils are immature or non-existent, even the conifer cannot survive (Example: Southern slopes of Greater Himalayas).

Economic Development

- Lot of coniferous forests in the northern hemisphere are still untouched due to **remoteness.**
- Only a small fraction of coniferous forests in Canada, Russia etc. are exploited.
- Agriculture is most unlikely as few crops can survive in the sub-Arctic climates.

Trapping

- Many fur-bearing animals are trapped in northerly lands of Canada and Eurasia.
- Wherever the cold is severe, the quality and thickness of the fur increases.
- In Canada trappers and hunters, armed with automatic rifles, reside in log cabins in the midst

of the coniferous forests to track down these animals.
- Muskrat, ermine, mink, and silver fox are the most important fur-bearing animals.
- To ensure a more regular supply of furs, many fur farms have been established in Canada and Siberia.

Lumbering

- This is the **most important occupation** of the Siberian type of climate.
- The vast reserves of softwood coniferous forests provide the basis for the lumbering industry.
- The world's greatest softwood producers are Russia, U.S.A., Canada and the **Fennoscandian countries (Finland, Norway and Sweden).**
- Contract labourers called lumberjacks used to temporarily move to the forest regions to fell the trees. Now felling is done by machines.
- **Rivers for transportation:** The softwood logs easily float on rivers. Hence rivers are used to transport logs to the sawmills located down the stream.
- **Sawmilling:** Logs are processed in sawmills into timber, plywood, and other constructional woods.
- **Paper and pulp industry:** Timber is pulped by both chemical and mechanical means to make wood pulp. Wood pulp is the raw material for paper-making and newsprint. U.S.A. is the leader.
- But in the field of newsprint, **Canada** accounts for almost half of the world's total annual production.
- **As a fuel:** Very little softwood is burnt as fuel as its industrial uses are far more significant.
- **As an industrial raw material:** In Sweden, matches form a major export item.
- From the by-products of the timber, many chemically processed articles are derived such as rayon turpentine, varnishes, paints, dyes, liquid resins, wood-alcohols, disinfectants and cosmetics.

Factors that favour lumbering in Taiga climate

Softwood trees

- The coniferous forest belts of Eurasia and North America are the **richest sources of softwood.**

Demand

- Softwood is used in construction, furniture, matches, **paper and pulp, rayon** and chemical industry.

Limited species

- The conifers are **limited in species**. Pine, spruce and fir in the northern forests and larch in the warmer south are the most important.

Pure stands

- Unlike rainforests, they occur in **homogeneous groups (pure stands)**.
- This saves time, costs and enhances the commercial value of the felled timber.
- Lumbering is normally carried out in the winter when the sap ceases to flow (sap stays in the ground, and the wood is lighter).

Cheap means of transportation

- The snow-covered ground makes logging and haulage (commercial transport) a relatively easy job.
- The logs are dragged to the rivers and float to the saw-mills downstream when the rivers thaw in spring.
- It is quite easy in Canada, Norway and Sweden as the rivers are not frozen for a greater part of the year.
- But in Russian taiga, most of Siberian rivers drain poleward into the Arctic Ocean which is frozen for three-quarters of the year, and there are few saw-mills there.
- However, with the use of the Northern Sea Route, which links Murmansk and Vladivostok via the Arctic Ocean, development is increasing.

Cheap electricity

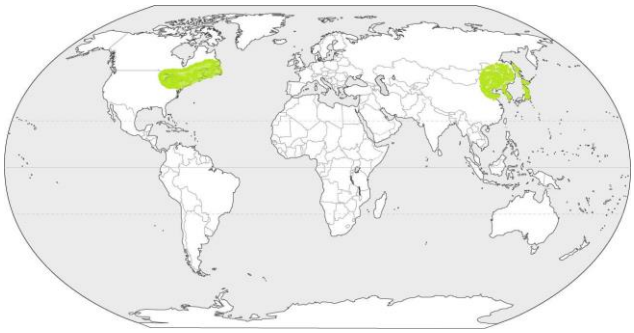
- Cheap hydro-electricity for driving the saw-mills is harnessed in the mountainous uplands of North America and Europe and has greatly assisted the lumbering industry.

Laurentian Climate or Cool Temperate Eastern Marine Climate (Dfc)

- Dfb: f – no dry season, b – warm summer.
- It is an intermediate type of climate between the **British Type Climate (moderate)** and the **Taiga Type Climate (extreme)**.
- It has features of **both** the maritime and the continental climates.

Distribution of Laurentian Climate

- Laurentian type of climate is found only in two regions and that too only in the northern hemisphere.
- North-eastern North America, including **eastern Canada, north-east U.S.A.**, and **Newfoundland**. This may be referred to as the North American region.
- Eastern coastlands of Asia, including eastern **Siberia, North China, Manchuria, Korea and northern Japan.**



Absent in Southern Hemisphere

- In the southern hemisphere only a small section of continents extends south of 40° S latitude.
- Some of these small sections come under the rain-shadow region of Andes (Patagonia).
- So, these regions are subjected to **aridity** rather than continentality.
- In other regions, the oceanic influence is so profound that neither the continental nor the eastern margin type of climate exists.

Climate

Temperature

- Characterized by **cold, dry winters and warm, wet summers**.
- Winter temperatures is below freezing-point and snow fall is quite natural.
- Summers are as warm as the tropics (~25 °C).

Precipitation

- Rainfall occurs throughout the year with **summer maxima** (easterly winds from the oceans bring rains).
- Annual rainfall ranges from 75 to 150 cm (two-thirds of rainfall occurs in the summer).
- Dry **westerlies** that blow from continental interiors dominate winters.

The North American region

- In summer, prolonged heat waves cause discomfort.
- In winter, the temperature drops below freezing and snowfall occurs.
- Precipitation occurs **all-round the year** due to the influence of **warm Gulf Stream** (increases the moisture of easterly winds in summer) and the **Great Lakes** (westerlies, temperate cyclones in winter).
- The **warm Gulf Stream** increases the moisture of easterly winds.
- Convergence of the warm Gulf Stream and the cold Labrador Current near Newfoundland produces dense mist and fog and gives rise to much precipitation.
- It is said that Newfoundland experiences more **drizzles** than any other part of the world.

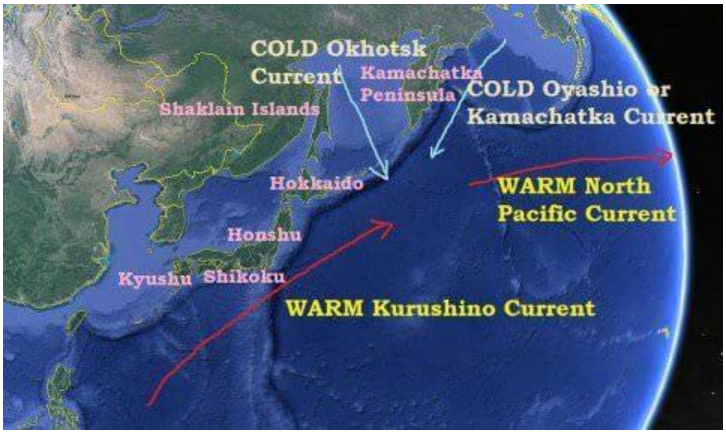
Cold and warm ocean current mixing zone off Newfoundland

The Asiatic region

- Rainfall distribution of the Asiatic region is **far less uniform** when compared to North American Region.
- Winters are cold and **very dry** while summers are very warm and **exceptionally wet**.
- The rainfall regime resembles the **tropical monsoon type** in India.
- Intense heating in interior of China in summer creates a region of low-pressure, and moisture-laden winds from the Pacific Ocean and the Sea of Japan blow in as the **South-East Monsoon**.
- Thus, the Laurentian type of climate in China is often described as the **Cool Temperate Monsoon Climate**.
- It has a very long, cold winter, and a large annual range of temperature.
- Much of the winter precipitation in northern China, Korea and Hokkaido, Japan, is in the form of **snow.**

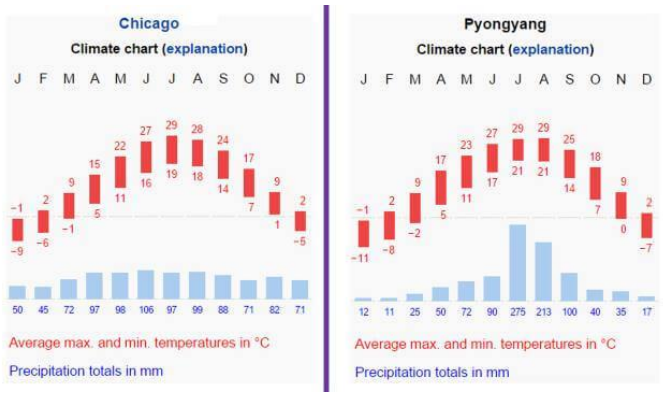
Japan

- The climate of Japan is modified by the **meeting of warm and cold ocean currents.**
- It receives adequate rainfall from both the South-East Monsoon in summer and the North-West Monsoon in winter (western coasts of Japan)
- The **warm Kuroshio** makes the climate of Japan less extreme.
- The meeting zone between **warm Kuroshio** from south and **cold Oyashio** from the north produce fog and mist, making north Japan a **second Newfoundland**.
- **Fishing** replaces agriculture as the main occupation in many of the **indented coastlands**.



Cold and warm ocean current mixing zone off Japan

Climate Graph



Climate graph of places with Laurentian climate

Natural Vegetation

- The predominant vegetation is **cool temperate forest**.
- The heavy rainfall, the warm summers and the damp air from fogs, all **favour** the growth of trees.
- Forest tend to be **coniferous** north of the 50° N latitude.
- In the Asiatic region (eastern Siberia and Korea), the coniferous forests are a continuation of the great coniferous belt of the taiga.

Lumbering

- From Laurentian Climate regions, both temperate hardwood and temperate softwood are obtained.
- Much of the coniferous forests of fir, spruce and larch are exploited to a great extent.
- Conifers are present in **pure stands** with only a handful of species.
- Eastern Canada is the heart of the Canadian timber and wood pulp industry (**St. Lawrence River helps in export**).
- South of latitude 50° N., the coniferous forests give way to *deciduous forests*. Oak, beech, maple and birch are most common.
- They have been extensively felled for the extraction of **temperate hardwood.**
- In Manchuria, Korea and Japan, the forests have made way for the **agriculture.**

Economic Development

- Lumbering, **timber, paper and pulp** industries are the most important economic undertakings.
- Agriculture is less important because of long and severe winters.
- In the North American region, farmers are engaged in **dairy farming.**
- The **Annapolis Valley in Nova Scotia** is the world's most renowned region for **apples.**
- Fishing is, however, the most outstanding economic activity.

Fishing off Newfoundland

- Regions around the **Grand Banks of Newfoundland** are the **world's largest fishing grounds.**
- Mixing of **warm Gulf Stream** and **cold Labrador currents** make the region the most productive fishing ground on earth.
- The gently sloping continental shelves stretch for over 200 miles south-east of Newfoundland, and off the coasts of the Maritime Provinces and New England. Hence microscopic plankton are abundant.

Fish feed on minute marine organisms called plankton. Plankton is abundantly available in shallow waters (continental shelves) where they have access to both sunlight as well as nutrients. Also, cold and warm water mixing creates upwelling of cold nutrient-rich water to the surface.

- Fish of all types and sizes feed and breed here and support a **thriving fishing industry.**
- In Newfoundland, fishing industry employs almost the entire population.
- Further inland, in lakes and rivers (St. Lawrence and the Great Lakes), freshwater fish like salmon are caught.
- All the fishing activities are carried out by highly mechanised trawlers which can store fish in refrigerated chambers for months.
- St. John's, chief port of Newfoundland is the headquarters of the Grand Banks fishing industries.
- All processing activities like cutting, cleaning, packing for disposal are done at the ports itself.
- Along with Canada and U.S.A., countries like Norway, France, Britain, Portugal, Denmark, Russia and Japan, also send fishing fleets to the Grand Banks.
- Over-fishing is a growing problem.

Fishing off Japan

- North-west Pacific surrounding the islands of Japan is another very important fishing grounds of the world.
- Majority of the people in the region depend on fishing for survival.
- **Hakodate** and **Kushiro** are large fishing ports with complete refrigeration facilities.
- Japan accounts for a sixth of the world's total annual fish caught.
- The Japanese fishing trawlers venture far and wide into the Arctic, Antarctic and the Atlantic waters.
- Large whaling fleets with processing plants venture into distant regions as far as Arctic and Antarctic (**Japan is criticized for its whaling operations**).
- The Japanese make use of fish wastes, fish meal and seaweeds as fertilizers in their farms.
- Japan is one of the few countries that has taken to seaweed cultivation (India is taking baby steps).
- Coastal farms that are submerged in water grow weeds for sale as fertilizers, chemical ingredient and food.
- Another aspect of Japanese fishing is pearl culture. Pearls are harvested from **pearl oysters**.
- As natural pearls are difficult to obtain, the Japanese have begun to harvest cultured pearls.

Why is fishing the dominant occupation of Japan?

- The mountainous nature of Japan and parts of mainland eastern Asia support little agricultural activity (80 per cent land in Japan is classified as 'non-agricultural'. Around 50% of the total land is covered by forests).
- Japan is not well endowed with natural resources. Hence fishing forms a dominant aspect of the economy.
- The scarcity of meat (there is little pasture in Japan for livestock farming of any kind) popularised fish as the principal item of diet

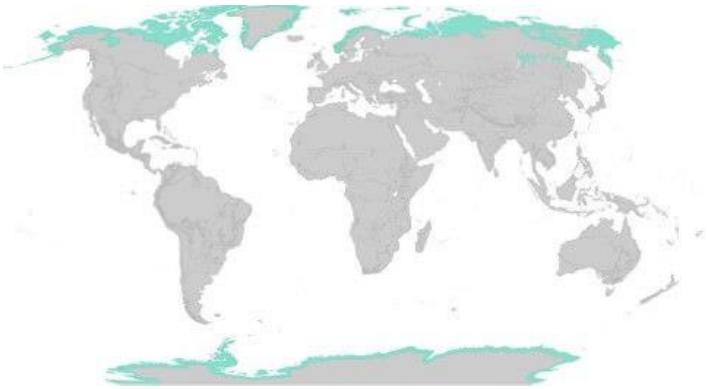
and the chief protein food of the Japanese and the Chinese as well.
- There exists a great demand for fish and fish products in the nearby countries where fishing industry is under-developed.
- Japan has huge stakes in international fishing enterprises and her advanced fishing techniques give her an edge over competitors.
- Advanced financial services, encouraging government policy, advanced technology at hand, skilled workforce with decades of experience in fishing and the only available natural resource to exploit, make Japan a leader in fishing industry.

Geographical advantage

- The continental shelves around the islands of Japan are rich in plankton, due to the meeting of the warm Kuroshio and the cold Oyashio currents and provide excellent breeding grounds for all kinds of fish.
- The **indented coastline of Japan** provides **sheltered fishing ports**, calm waters and safe landing places, ideal for the fishing industry.

7.6 E – Cold Climates

Tundra Climate or Polar Climate or Arctic Climate



Distribution of Tundra Climate

Distribution

- Found in regions **north of the Arctic Circle and south of Antarctic Circle**.
- The ice-caps are confined to highlands and high latitude regions of Greenland and Antarctica.
- In the southern hemisphere, Antarctica is the greatest single stretch of ice-cap (10,000 feet thick).
- The lowlands – coastal strip of Greenland, the barren grounds of northern Canada and Alaska and the Arctic seaboard of Eurasia, have tundra climate.

Climate

Temperature

- The tundra climate is characterized by a very **low mean annual temperature**.
- In mid-winter temperatures are as low as 40 – 50 °C below freezing. Summers are relatively warmer.
- Normally not more than four months have temperatures above freezing-point.
- Within the Arctic and Antarctic Circles, there are weeks of continuous darkness (earth's tilted axis and revolution around the sun).
- The ground remains solidly frozen and is inaccessible to plants.
- Frost occurs at any time and blizzards, reaching a velocity of 130 miles an hour is not infrequent.

Precipitation

- Precipitation is mainly in the form of snow and sleet.
- Convectional rainfall is generally absent.

Natural Vegetation

- There are **no trees** in the tundra.
- Lowest form of vegetation like mosses, lichens etc. are found here and there.
- Climatic conditions along the coastal lowlands are a little favourable.
- Coastal lowlands support hardy grasses and reindeer moss which provide the only pasturage for reindeers.
- In the brief summer, berry-bearing bushes and Arctic flowers bloom.
- In the summer, birds migrate north to prey on the numerous insects which emerge when the snow thaws.

- Mammals like the wolves, foxes, musk-ox, Arctic hare and lemmings also live in tundra regions.
- Penguins live only in Antarctic regions.

Human Activities

- Human activities of the tundra are largely confined to the coast.
- People live a semi-nomadic life.
- In Greenland, northern Canada and Alaska live the **Eskimos.**
- During winter they live in compact **igloos.**
- Their food is derived from fish, seals, walruses and polar bears.
- Nowadays rifles instead of traditional harpoons are used to track down animals.

Recent Development of the Arctic Region

- New settlements have sprung up because of the discovery of minerals.
- Gold is mined in Alaska, petroleum in the Kenai Peninsula, Alaska; and copper at the Rankin Inlet, Canada.
- With the declining reserves of iron ore around the Great Lakes, iron ore deposits in Labrador are gaining importance. New railway lines have been constructed to bring the ores to the St. Lawrence River.
- Rich deposits of iron ores at Kiruna and Gallivare helped Sweden enjoy a prosperous export trade in iron and steel and other metallurgical products.
- New ports on the Arctic seaboard of Eurasia has made it possible to ship timber and fur from Siberia. Modern ice-breakers makes the frozen seas navigable.

7.7 Questions

Previous prelims questions

Q1.

Assertion (A): Areas near the equator receive rainfall throughout the year.

Reason (R): High temperatures and high humidity cause convectional rain in most afternoons near the equator.

In the context of the above two statements, which one of the following is correct?

a) Both A and R are true, and R is the correct explanation of A
b) Both A and R true but R is not a correct explanation of A
c) A is true but R is false
d) A is false but R is true

Q2.

Assertion (A): Areas lying within five to eight degrees latitude on either side of the equator receive rainfall throughout the year.

Reason (R): High temperatures and high humidity cause convectional rain to fall mostly in the afternoons near the equator. [2003]

a) Both A and R are individually true, and R is the correct explanation of A
b) Both A and R are individually true, but R is not the correct explanation of A
c) A is true but R is false
d) A is false but R is true

Q3.

A geographic area with an altitude of 400 metres has following characteristics. [2010]

Month	J	F	M	A	M	J	J	A	S	O	N	D
Average maximum temp °C	31	31	31	31	30	30	29	28	29	29	30	31
Average minimum temp °C	21	21	21	21	21	21	20	20	20	20	20	20
Rainfall (mm)	51	85	188	158	139	121	134	168	185	221	198	86

If this geographic area were to have a natural forest, which one of the following would it most likely be?

a) Moist temperate coniferous forest
b) Montane subtropical forest
c) Temperate forest
d) Tropical rain forest

Q4.

Assertion (A): Unlike temperate forests, the tropical rain forests, if cleared, can yield productive farmland that can support intensive agriculture for several years even without chemical fertilizers.

Reason (R): The primary productivity of the tropical rain forest is very high when compared to that of temperate forests. [2003]

a) Both A and R are individually true, and R is the correct explanation of A.
b) Both A and R are individually true, but R is not the correct explanation of A
c) A is true, but R is false
d) A is false, but R is true

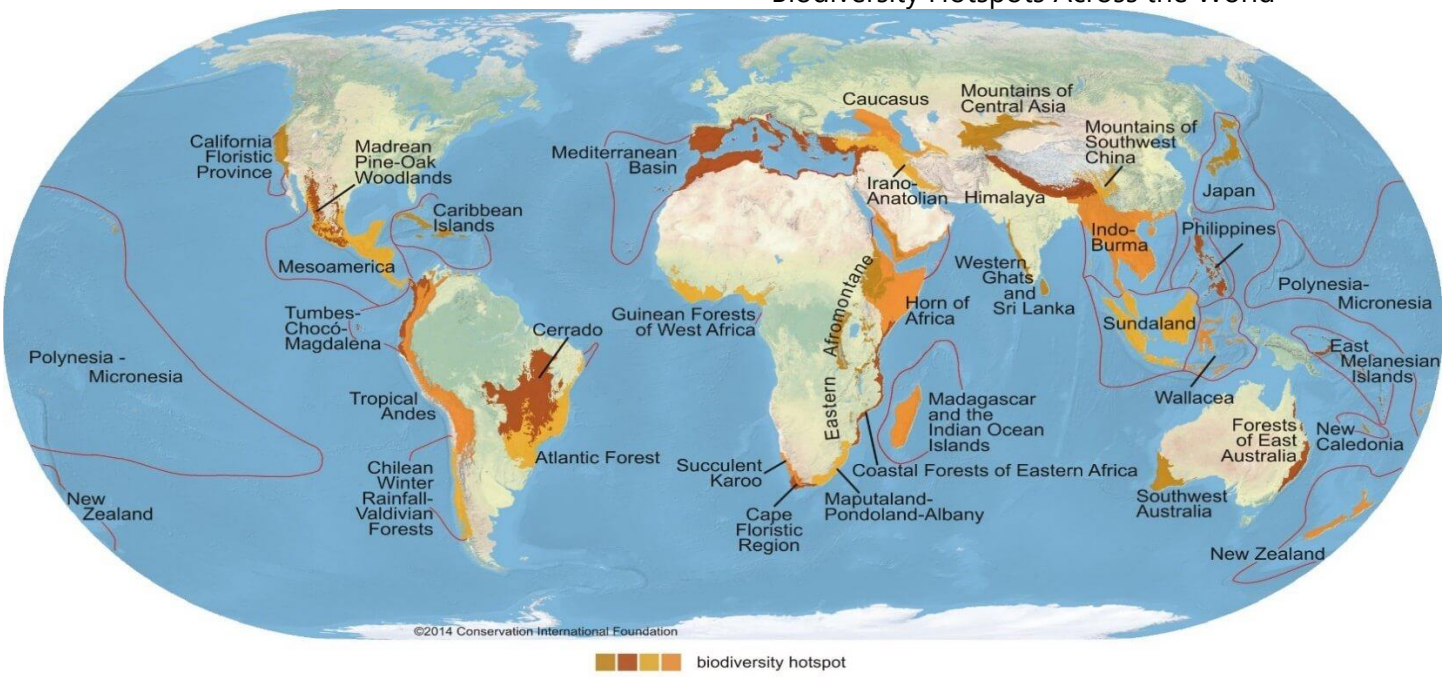
Q5.
Consider the following statements: [2010]

1) Biodiversity hotspots are located only in tropical regions.
2) India has four biodiversity hotspots, i.e., Eastern Himalayas, Western Himalayas, Western Ghats and Andaman and Nicobar Islands.

Which of the statements given above is/are correct?

a) 1 only
b) 2 only
c) Both 1 and 2
d) Neither I nor 2

Biodiversity Hotspots Across the World



Q6.
The seasonal reversal of winds is the typical characteristic of

a) Equatorial climate
b) Mediterranean climate
c) Monsoon climate
d) All of the above climates

Q7.
Which one of the following is the characteristic climate of the Tropical Savannah Region? [2012]

a) Rainfall throughout the year
b) Rainfall in winter only
c) An extremely short dry season
d) A definite dry and wet season

Q8.
A geographic region has the following distinct characteristics: [2010]

1. Warm and dry climate
2. Mild and wet winter
3. Evergreen Oak trees

The above features are distinct characteristics of which one of the following regions?

a) Mediterranean
b) Eastern China
c) Central Asia
d) Atlantic coast of North America

Q9.

Which one among the following covers the highest percentage of forest area in the world? [2003]

a) Temperate coniferous forests
b) Temperate deciduous forests
c) Tropical monsoon forests
d) Tropical rain forests

Answers:

Q1. a) Both A and R are true, and R is the correct explanation of A
Q2. a) Both A and R are true, and R is the correct explanation of A
Q3. d) Tropical rain forest
Q4. d) A is false but R is true

- The tropical rain forests, if cleared, can yield productive farmland: this statement is wrong. The tropical soils are heavily leached. Some fertility is added by burning down the felled trees. This little fertility is lost after 2-3 crops.
- Can support intensive agriculture for several years even without chemical fertilizers: this is also wrong. Intensive agriculture for several years is not possible without adding fertilizers.

Q5. d) Neither

- Biodiversity hotspots are located even outside tropics. E.g. Eastern Himalayas, Parts of Mediterranean, etc.
- India has three biodiversity hotspots i.e., Eastern Himalayas, Western Ghats and Andaman and Nicobar Islands.
- The is no biodiversity hotspot called Western Himalaya.

Q6. C) Monsoon
Q7. d) A definite dry and wet season

- Equatorial Rainforest: Rainfall throughout the year
- Mediterranean: Rainfall in winter only
- An extremely short dry season: I don't think there is any specific climate that fits this description
- Savanna: A definite dry winter and wet summer

Q8. Ans: a) Mediterranean (Evergreen oaks and winter maxima)

- Eastern China (China Type – it is not dry)
- Central Asia (Temperate Desert – it is dry but there are no oaks)
- Atlantic coast of North America (it is not dry)

Q9. Ans: a) Temperate coniferous forests

- In Indian **Tropical Moist Deciduous (37%)** cover the highest percentage followed by **Tropical Dry Deciduous (28%)**

Descriptive questions

1. Distinguish between hardwoods and softwoods. What are industrial uses made of them? Account for their large scale production for export in any one country.
2. What is meant by
   - ✓ the taiga
   - ✓ the veld
   - ✓ the selvas
3. Describe the role played by forest products in the economy of either Canada or Sweden.
4. Compare and contrast the climate of the following pairs of areas.
   - ✓ Laurentian Climate in the North American region and the Asiatic region.
   - ✓ Tropical monsoon Climate of India and the Warm Temperate Eastern Margin (China type) Climate in S. China.
   - ✓ The Steppe type of climate in Eurasia and the Siberian type (Taiga climate) of climate in northern Canada.
   - ✓ The Tundra Climate of Greenland and Trade Wind Desert Climate of central Australia.
5. Name the major fishing areas of the world. Explain the geographical factors which have contributed to its importance.
6. Write brief notes on
   - ✓ The economy of the forests of the Laurentian regions.
   - ✓ Fishing in Japan.
7. Why does tropical cyclone originate over the seas? In which part of the tropical cyclone do torrential rains and high-velocity winds blow and why?
8. What type of climate is characterized by two periods of maximum rainfall? Explain why this is so.

- Hint: Equatorial Rainforest. Sun is overhead during Equinoxes. So, the ITCZ passes twice over the region.

9. Write brief notes on any three of the following statements about the equatorial regions.
   - ✓ Large-scale livestock farming is least developed in wet equatorial areas.
   - ✓ The greatest single drawback to commercial lumbering in equatorial regions is inaccessibility.
   - ✓ The equatorial environment is best suited to plantation agriculture (Good rainfall, humid climate, cheap labour, good markets in Europe and North America).
10. Explain the following statements.
    - ✓ The east coasts of continents within the tropics have much heavier rainfall than the interiors or the west coasts [Hint: Easterly trade winds].
    - ✓ Near the equatorial latitudes, the period of maximum rainfall is closely related to the movements of the overhead sun [Hint: Inter-Tropical Convergence Zone shifts according to the apparent movement of the Sun].
    - ✓ There is a marked difference in temperature between the east and west coasts of countries in latitudes 20° to 35°N [Hint: Ocean currents].
11. Explain why
    - ✓ The savanna is the natural home of cattle.
    - ✓ Rainfall in the Sudan Climate is concentrated in the summer.
12. Give an explanatory account of any two of the following.
    - ✓ Sheep outnumber the population of New Zealand by 20:1.
    - ✓ No country produces and exports more wool than Australia.
    - ✓ Market-gardening is a product of urbanisation.
13. Write a geographical account of the following economic activities.
    - ✓ Mixed farming
    - ✓ Beet sugar cultivation
    - ✓ Cool temperate orchard farming
    - ✓ Sheep rearing
    - ✓ Woollen textile industry
14. Give a reasoned account of any two of the following.
    - ✓ Cotton cultivation in the United States of America.
    - ✓ Padi growing in monsoon China.
    - ✓ Dairying in eastern Australia.
    - ✓ Lumbering in Canada.
15. Give an explanatory account of any three of the following.
    - ✓ Local storms (e.g. typhoon, hurricane, pampero) are often associated with the Warm Temperate Eastern Margin Climate.
    - ✓ U.S.A. accounts for more than 50 per cent of world production of corn (i.e. maize) but only 3 per cent of world exports.
    - ✓ Farming in monsoon China is usually on a subsistence basis, and the peasants are permanently 'land-hungry'.
16. Explain how the aridity of the desert is related to
    - ✓ off-shore Trade Winds
    - ✓ the Sub-Tropical High-pressure Belts (the Horse Latitudes)
    - ✓ cold ocean currents
17. Bring out any distinct differences between the hot deserts and mid-latitude deserts in
    - ✓ climate
    - ✓ vegetation
    - ✓ way of life
18. Explain any three of the following.
    - ✓ The hot deserts of the world are located on the western coasts of continents.
    - ✓ Patagonia is a desert in the rain shadow of the Andes.
    - ✓ The annual range of temperature is much greater at Kashgar (Gobi) than at Iquique (Atacama).
19. Write brief notes on any three of these topics.
    - ✓ Date palm cultivation in an oasis.
    - ✓ The role of oil in the development of desert economy.
20. Compare and contrast tropical and temperate grasslands in respect of
    - ✓ their seasonal responses to climatic changes
    - ✓ their economic importance
21. Give a reasoned account
    - ✓ Asiatic Steppes: nomadic herding
    - ✓ Canadian Prairies: spring wheat cultivation
    - ✓ Argentine Pampas: beef cattle ranching
    - ✓ S. African Veld: maize growing
    - ✓ Australian Downs: sheep grazing

22. Explain why when Chinooks are more frequent in the Prairies, the winters are milder.
23. Give an explanatory account of the following statements about economic activities of the Mediterranean lands.
    - ✓ Orchard farming is the predominant occupation.
    - ✓ The chief cereal cultivated is hard, winter wheat.
    - ✓ Pastoral farming is of little importance.
24. Write geographical notes on any three of the following.
    - ✓ The Mediterranean Climate is typified by dry, sunny summers and wet, mild winters.
    - ✓ Hot, dusty Sirocco and cold stormy Mistral.
    - ✓ Mediterranean woodlands, shrubs and scrub.
    - ✓ Three-quarters of the world's wine comes from the Mediterranean regions of Europe.