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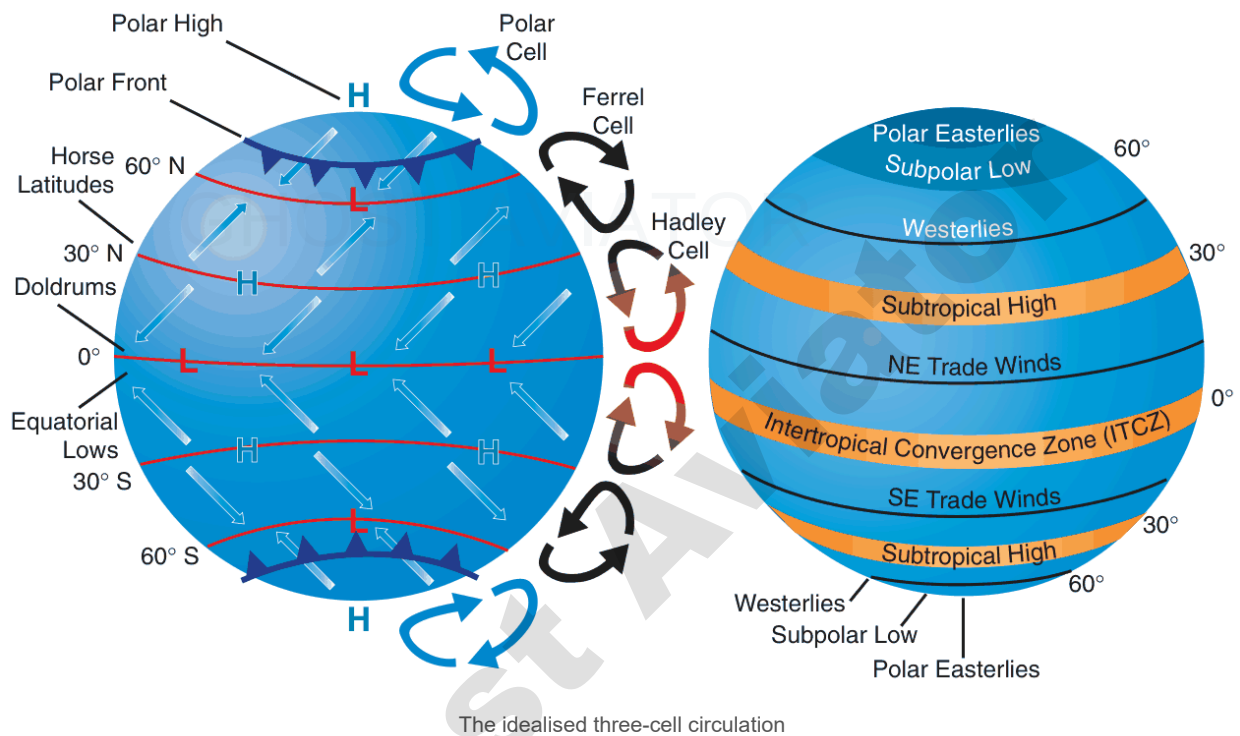
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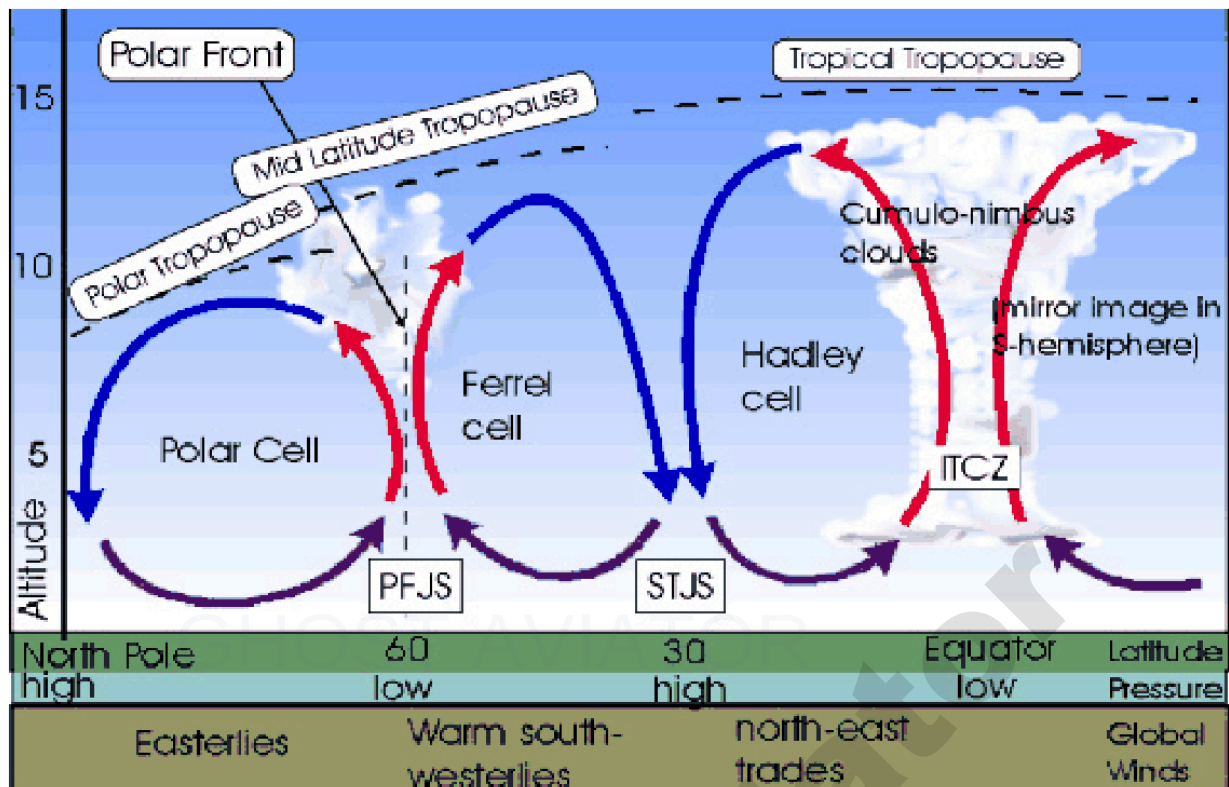
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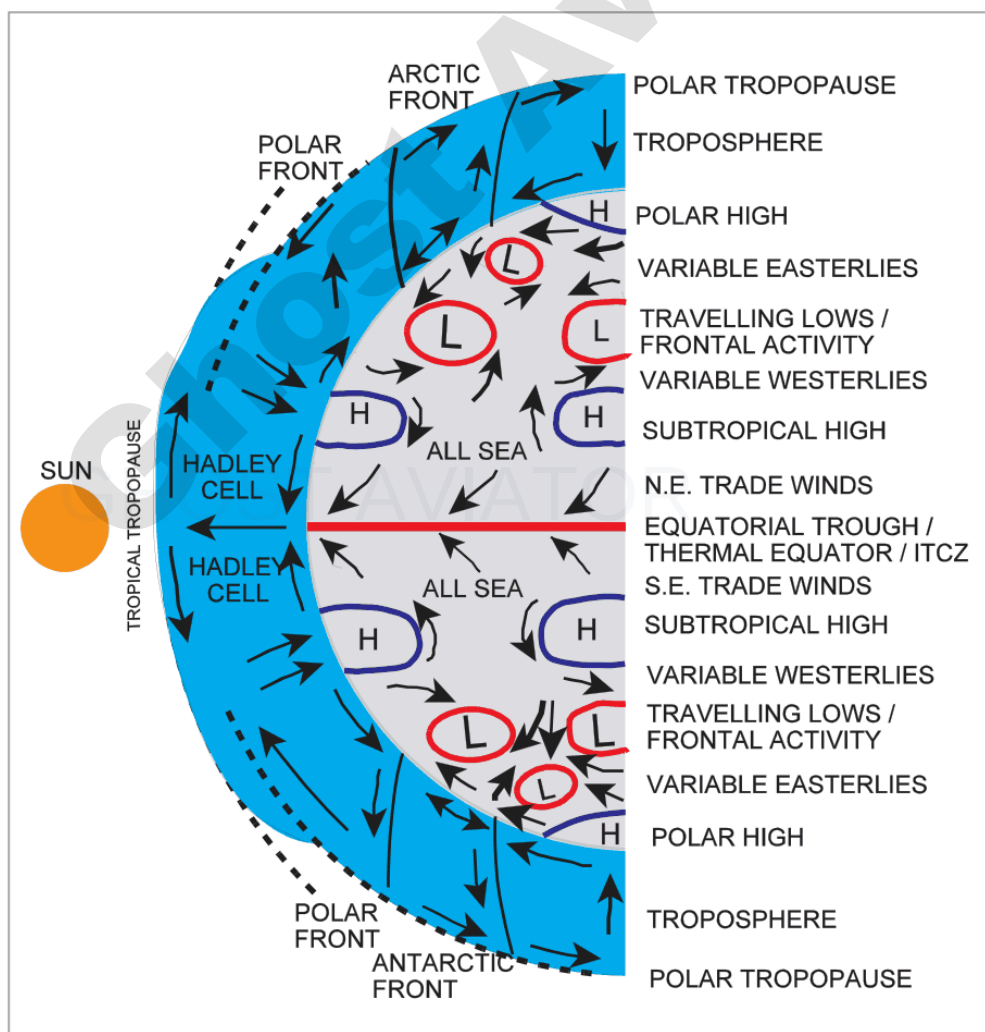
1. Three Cell Model of General Circulation

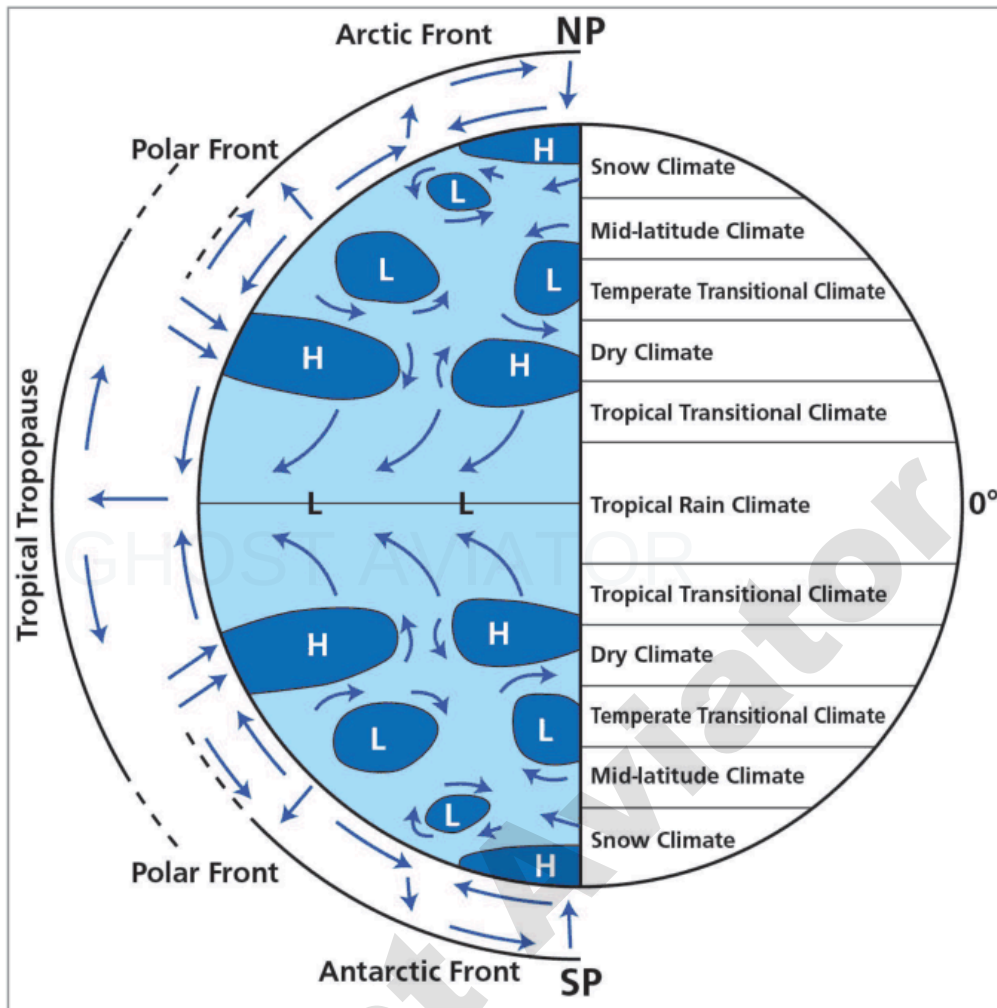
Definition: The Three Cell Model describes the average circulation of the atmosphere and the atmospheric energy transport. The energy balance over the globe is described in terms of three cells: **Hadley Cell**, **Ferrel Cell**, and **Polar Cell**.





Vertical section of the cells and jet streams





World climatic zones

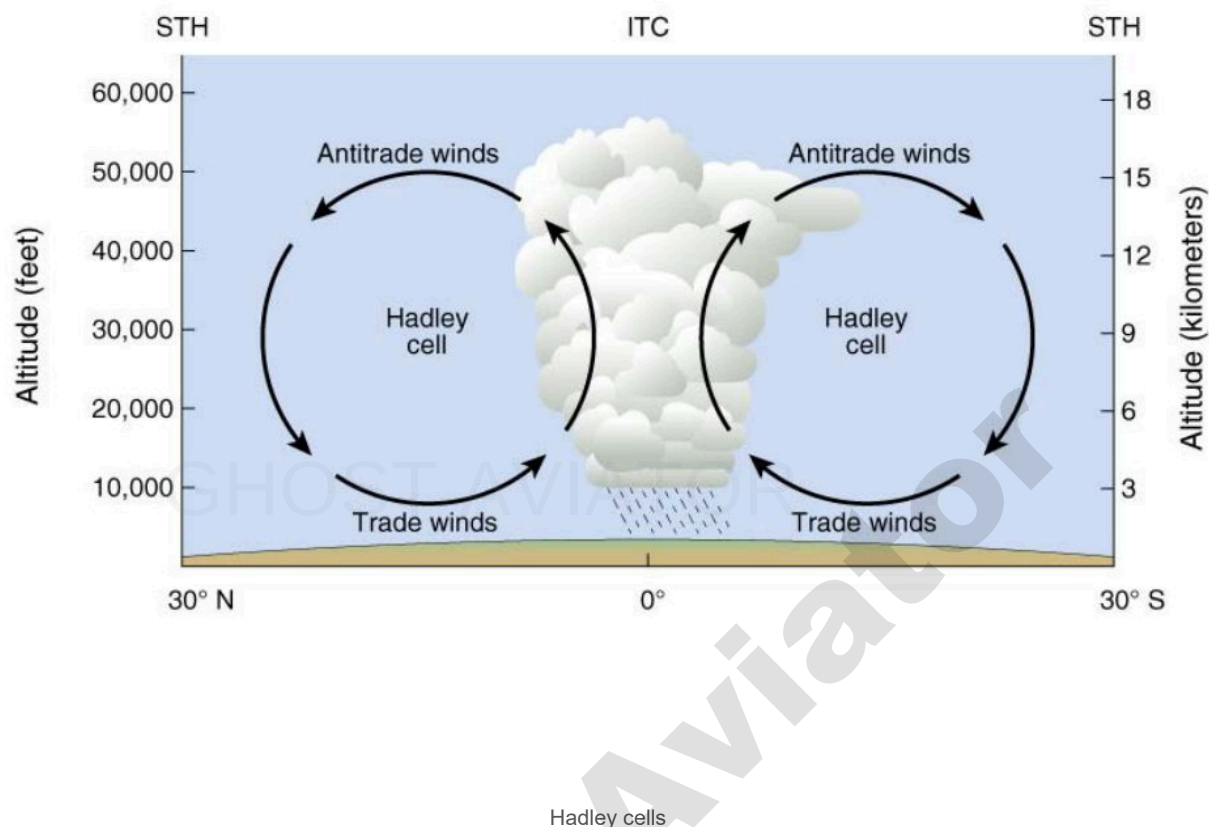
flowchart LR

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A["Equatorial Heating\n(ITCZ)"] --> B["Air rises at Equator\n(Hadley Cell)"]
B --> C["Moves poleward\nat upper levels"]
C --> D["Sinks at 30°N/S\nSubtropical High"]
D --> E["Trade Winds\n(surface flow back to equator)"]
E --> A
D --> F["Poleward flow\nat surface (Ferrel Cell)"]
F --> G["Meets Polar Air at 60°N/S\nPolar Front"]
G --> H["Air rises\nat Polar Front"]
H --> I["Polar Cell:\nAir sinks at poles\nPolar Easterlies"]
    
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2. Hadley Cell

Hadley Cell operates between the equator and approximately **30°N/S**.



- Intense solar radiation at the equatorial region heats the surface and causes air to rise.
- Rising air forms convective clouds and heavy precipitation — this region is known as the **Inter-Tropical Convergence Zone (ITCZ)**.
- In this zone, NE Trades from the N hemisphere and SE Trades from the S hemisphere converge, hence the name ITCZ.
- ITCZ moves north and south following the sun during the year.
- Due to solar heating, rising air reaches about **30°N** and becomes a westerly wind due to the Coriolis force — these are **Zonal Westerlies**.
- The westerly winds keep strengthening with height and establish a **Subtropical Jet** just below the tropopause.
- Poleward-moving air piles up in the subtropical regions and forms a high pressure belt at the surface — **Subtropical High**.
- Subsidence inhibits cloud formation — this is why large deserts occur near **30°N** and **30°S**.

Mnemonic: "Heat Rises At ITCZ, Trades Return" — Hadley Cell: equatorial heating → ITCZ rise → subtropical sink → Trade Winds return.

3. Ferrel Cell

Ferrel Cell operates between approximately **30°N/S** and **60°N/S**.

- Some of the diverging air at the surface near **30°N** moves polewards and is deflected to the right by the Coriolis force.
- At about **60°N** the Coriolis-deflected air rises, cools, and condenses — forms clouds.
- This rising air returns equatorwards at upper levels.
- This is the general region of the **polar front**.

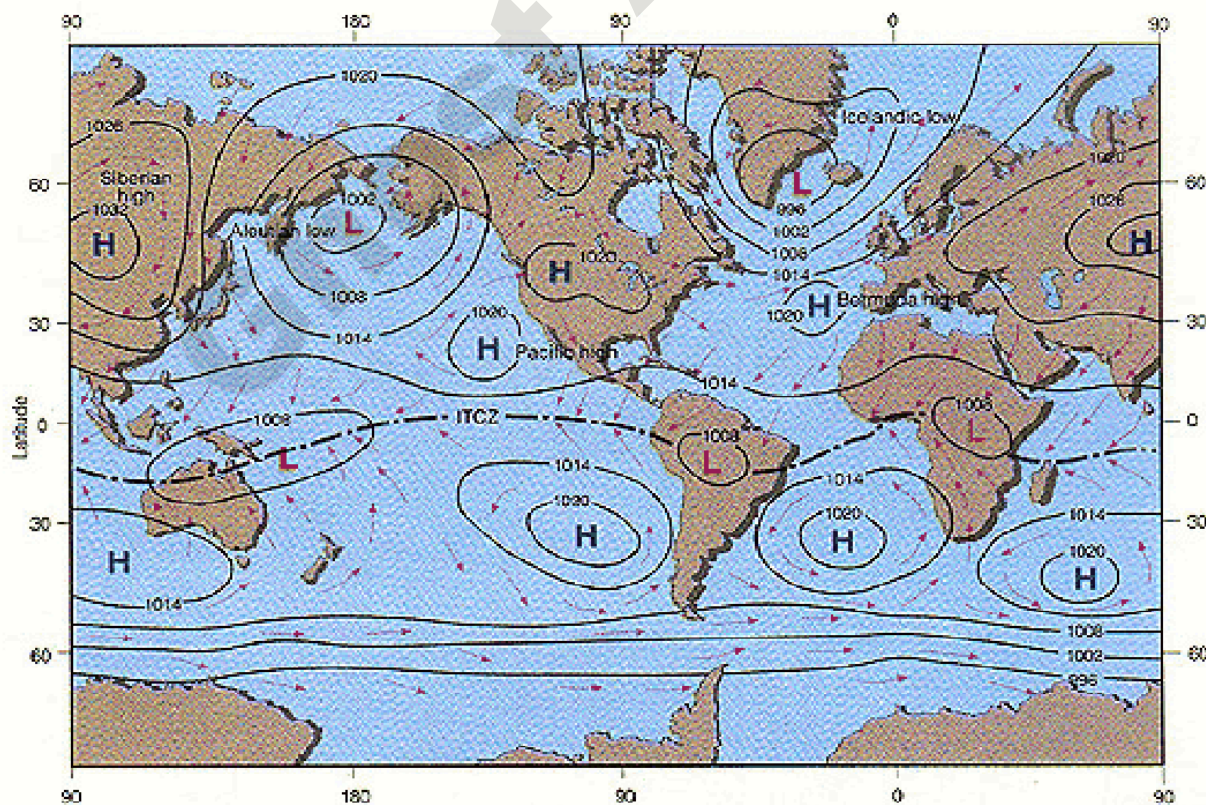
4. Polar Cell

Polar Cell operates between **60°N/S** and the poles (**90°N/S**).

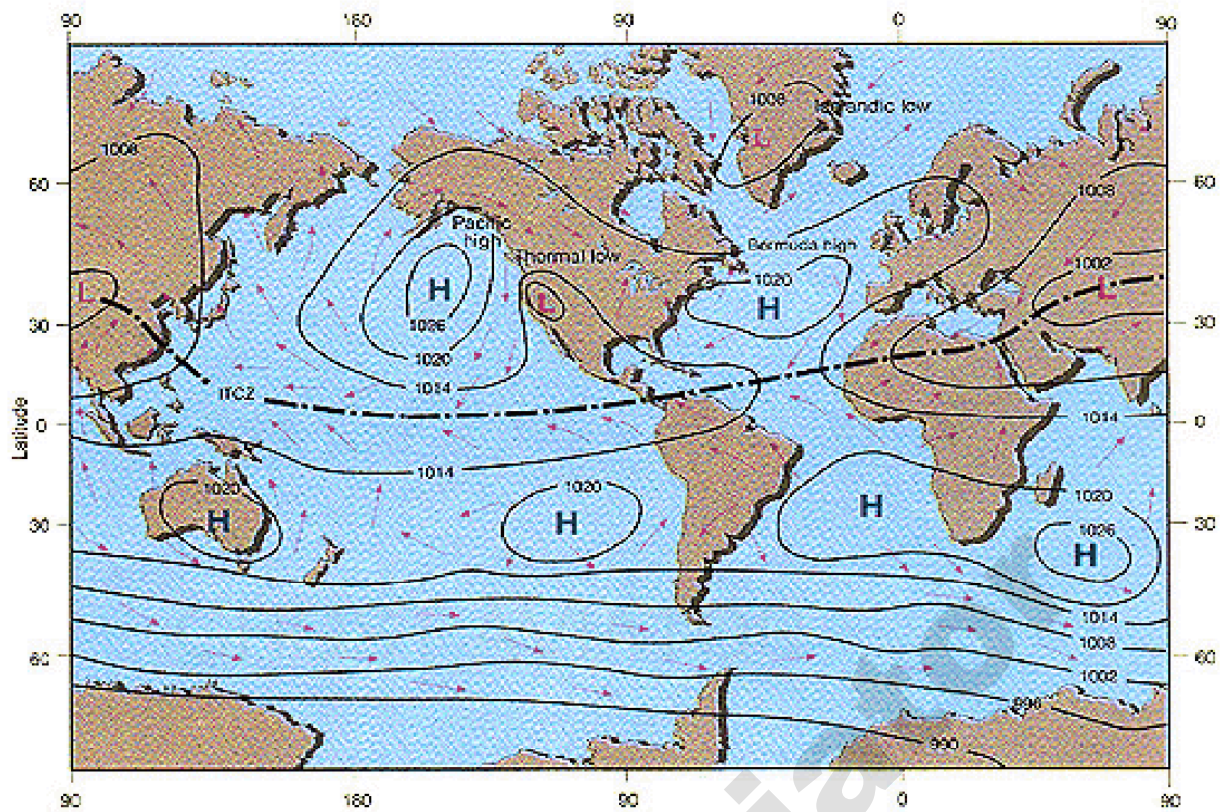
- Sinking air at the poles warms and results in high pressure over the poles.
- At the surface, poleward-moving air gets pulled to the right by the Coriolis force (in the northern hemisphere), forming the **polar easterly winds**.
- The warm subtropical air meets the cold polar air and forms the boundary known as the **polar front**.
- The large temperature contrast at the polar front causes the **polar front jet stream** to occur in the vicinity of the polar cell.

5. Surface Characteristics — Three Cell Model

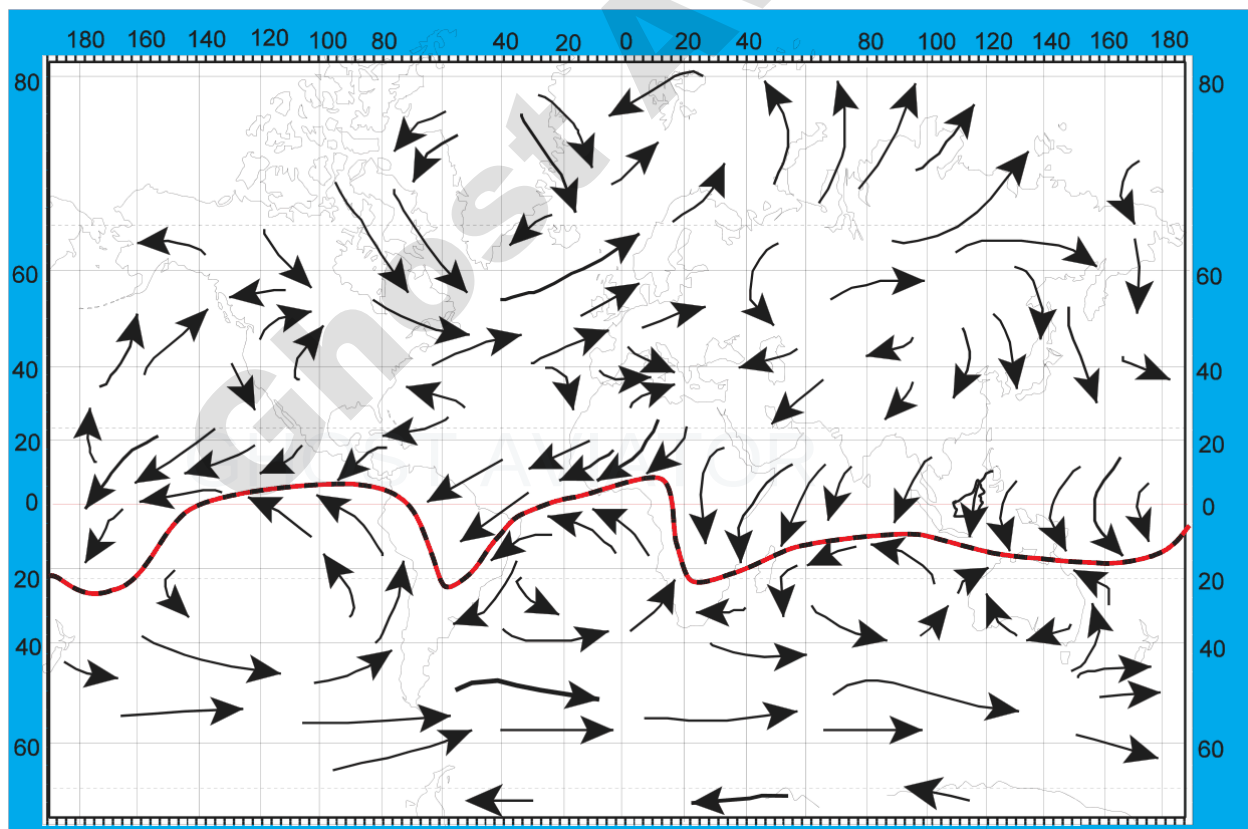
Feature	Description	Location
Equatorial Doldrums	Rising air creates calms or doldrums	Equatorial region
ITCZ	Along the equator — rising air zone of convection	Near equator (moves N/S seasonally)
Trade Winds	Steady NE winds in N hemisphere; SE winds in S hemisphere	0°–30° N/S
Horse Latitudes	Descending branch of Hadley cell — calm winds, high pressure	Lat 30–40°
Roaring Forties	Westerlies blow between 35° and 60° lat	Both hemispheres
Furious Fifties	Very strong Westerlies — mid latitude flow	Around 50° lat
Crying Sixties	Very noisy Westerlies (35° to 60°)	Around 60° lat
Polar Front	Boundary between cold polar air moving equatorwards and warm subtropical air moving polewards	Near 60° lat
Polar Easterly Winds	Cold polar air moving southwest meets prevailing westerlies to form polar front	Polar regions



Surface pressure in January



Surface pressure in July



Prevailing surface winds in January

Important: In the **equatorial regions**, the upper tropospheric winds are **Easterlies**. In a narrow belt near the equator, the winds in the upper troposphere are westerly, known as **Zonal Westerlies**.

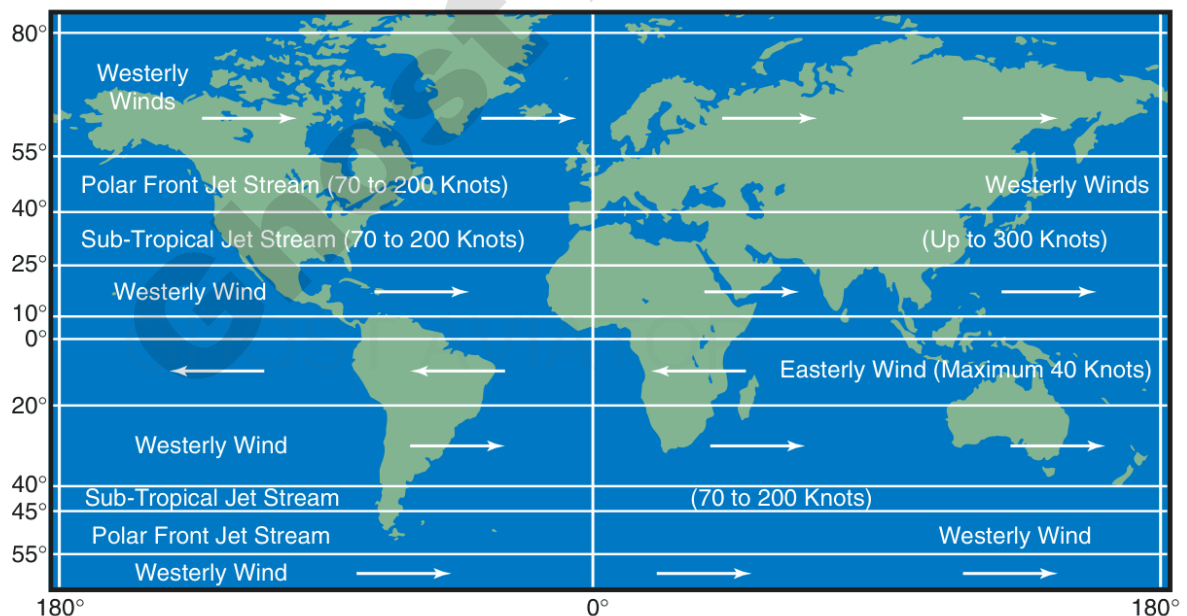
Upper Tropospheric Winds:

- The zonal flows in the upper troposphere govern the movement of disturbances in the pressure and wind patterns.
- Disturbances of **middle latitudes move from west to east** in the westerly current.
- Tropical disturbances form in the equatorial low pressure belt and move in a **westerly direction**, steered by the high level easterly flow.
- Tropical disturbances reaching the zone of transition in the upper level flow change course (or recurve) and begin to move in an opposite direction.

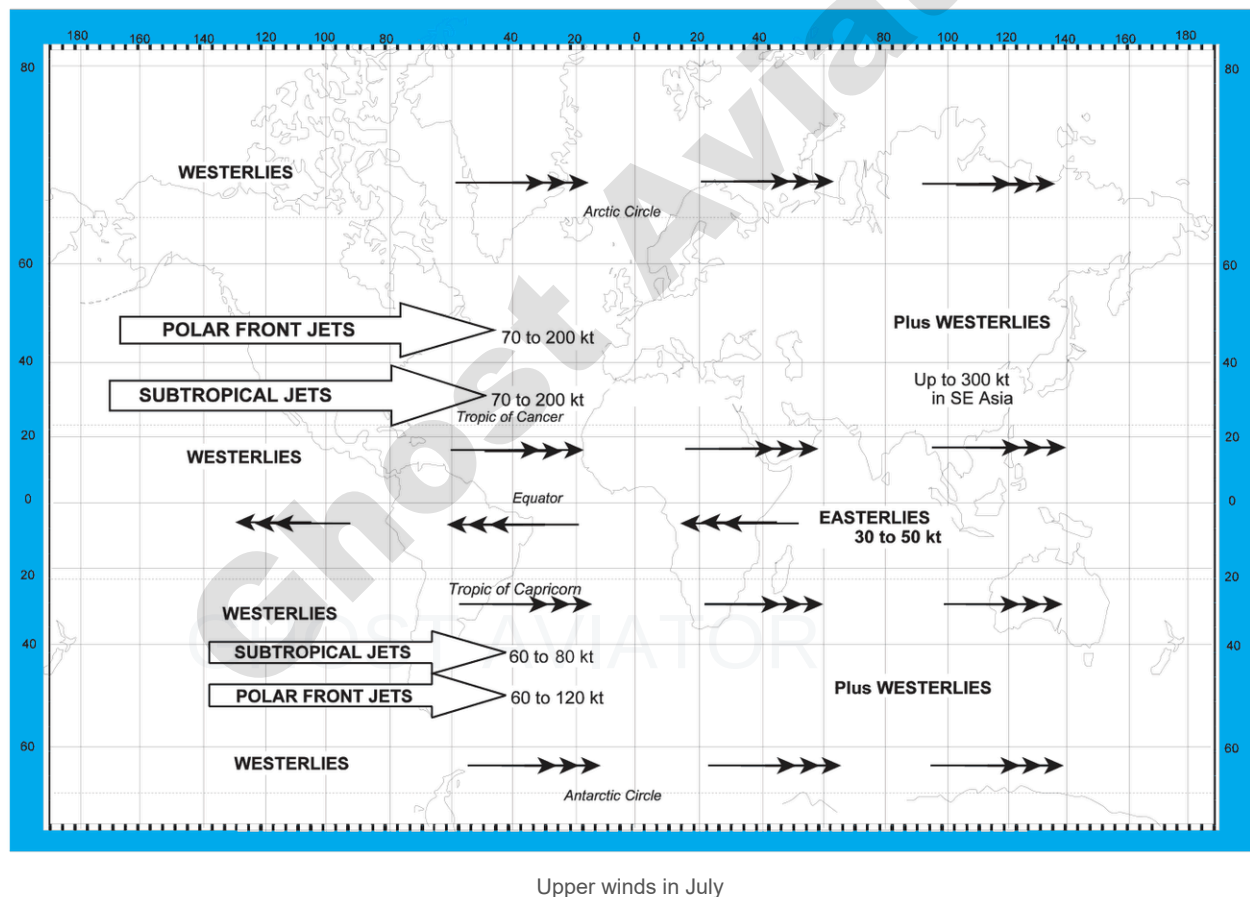
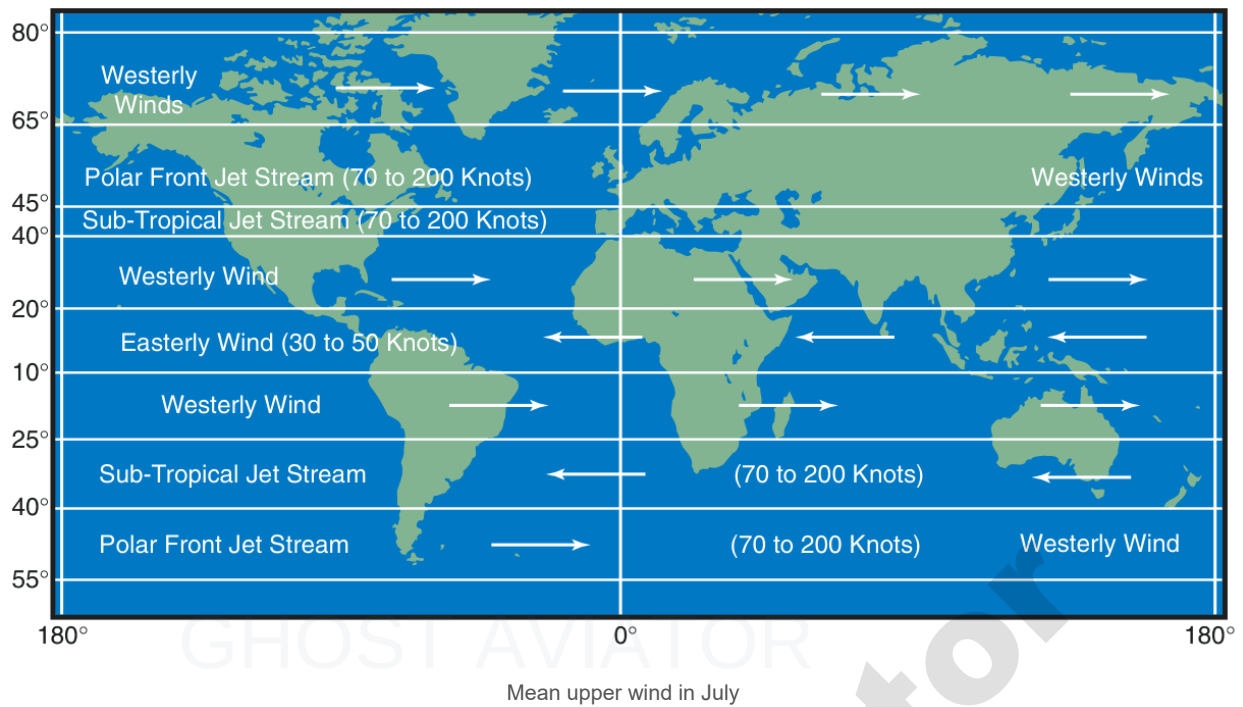
6. Standing Waves (Stationary Waves / Standing Eddies)

Standing Wave (also called Stationary Wave and Standing Eddies): A combination of two waves moving in opposite directions, each having the same amplitude and frequency. Due to interference, the waves are superimposed and their energies are either added or cancelled.

MEAN UPPER WIND — JANUARY



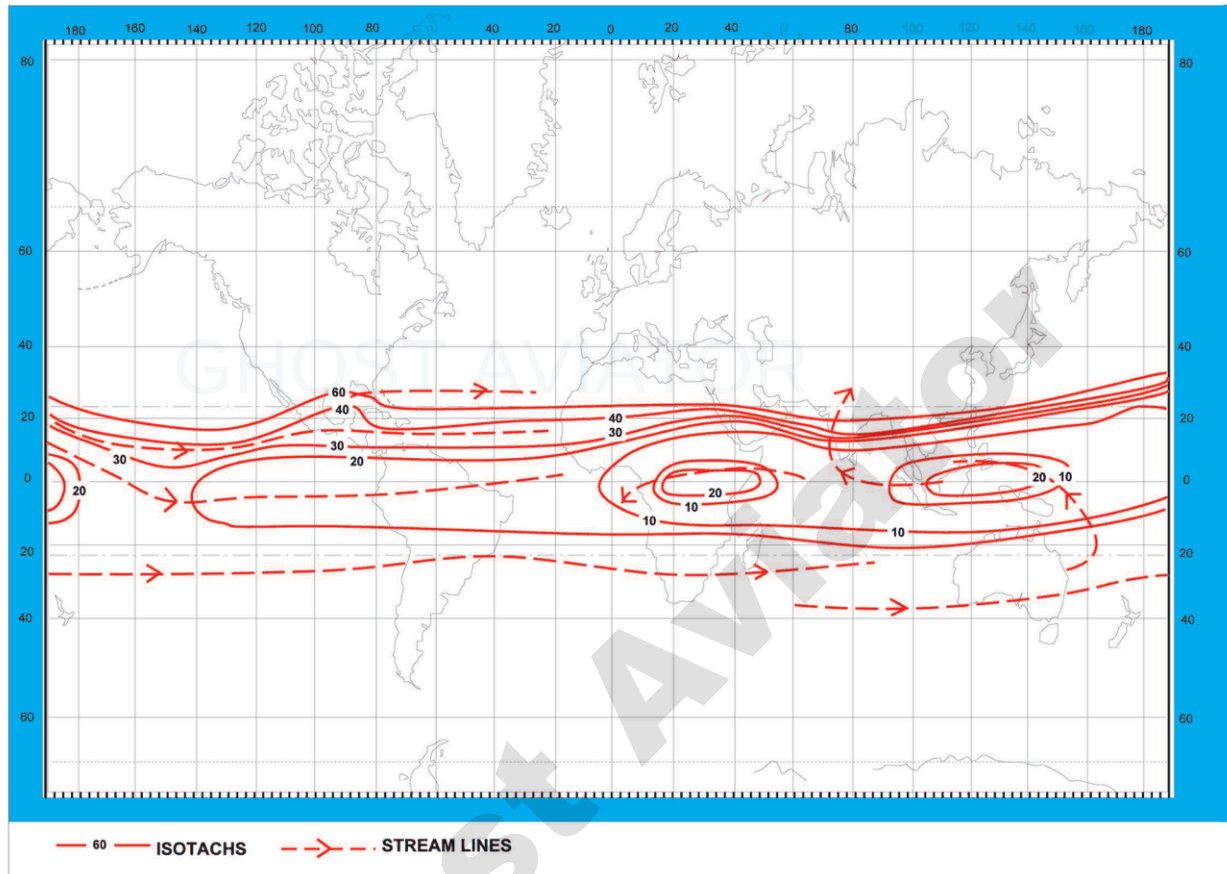
Mean upper wind in January



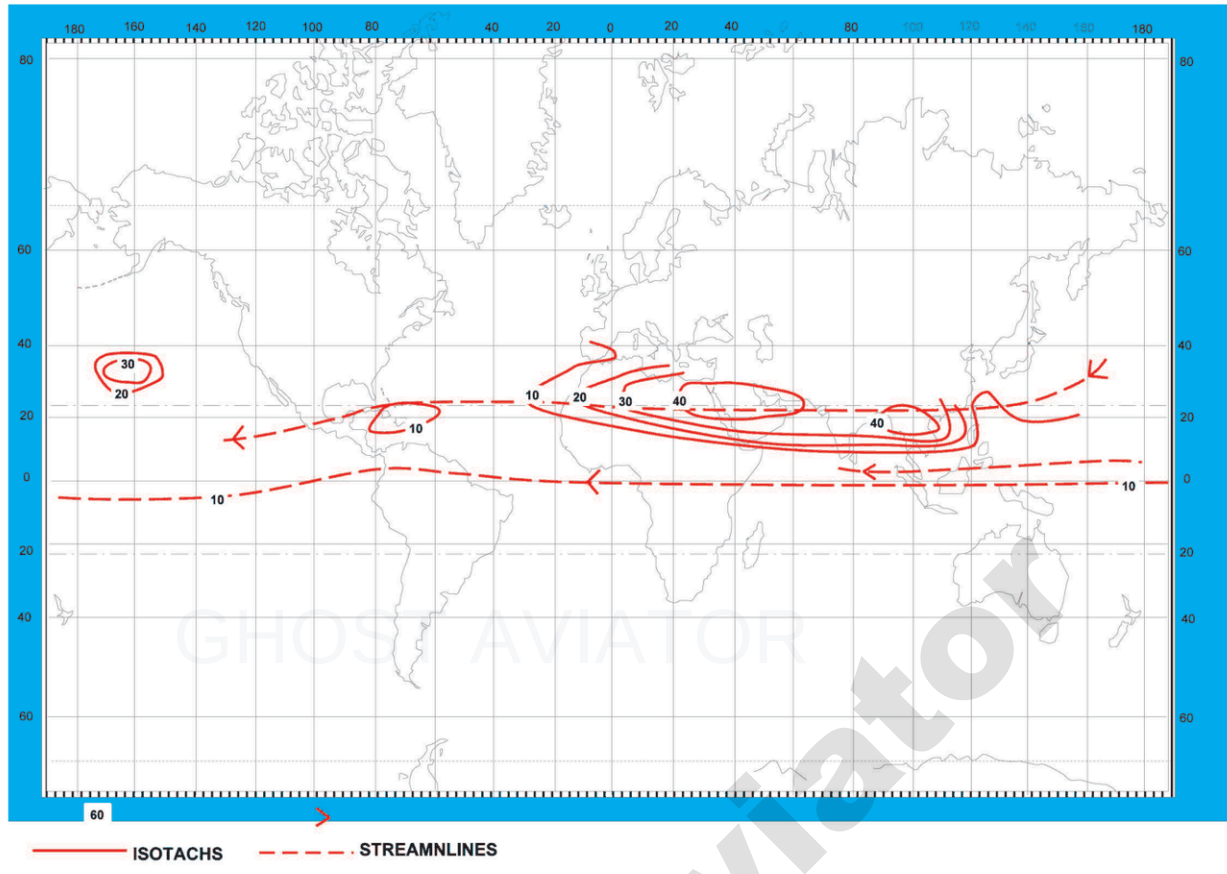
- Atmospheric Standing Waves are **Zonally time averaged General Circulation**.
- Time period for averaging is over a month to a season.
- These waves arise due to mountains, continents, oceans, and different sea surface temperatures.
- N/S winds due to these waves transport cold and warm air which affect the overall climate.
- They advect moisture over the continents.
- **Stationary waves are capable of altering the storm tracks.**

7. Rossby Waves (Planetary Waves)

Rossby Waves (also known as Planetary Waves): A type of inertial waves that naturally occur in rotating atmosphere and oceans. They are giant longitudinal curves (troughs and ridges) in high-altitude winds.



Equatorial upper winds in January



Equatorial upper winds in July

- Associated with pressure systems and jet streams, and have a major influence on weather.
- The meandering jet streams are Rossby waves.
- Oceanic Rossby waves move along the boundary between the warm upper layer and the cold part of the ocean.
- The Atmospheric Rossby waves are big, having wavelengths ranging from **m and km (gravity waves)** to thousands of km (planetary waves).
- Named after the discoverer **Carl Rossby in 1930s**.

Exam Tip: Rossby waves = Planetary waves. The jet streams meander as Rossby waves. These influence storm tracks and weather systems in the mid-latitudes.

8. General Circulation of the Tropical Lower Stratosphere

The circulation in the lower stratosphere comprises large-scale vertical waves forced by the westward propagating Rossby waves — a phenomenon called **Rossby-wave pumping**.

- These waves have a period of a few weeks to a few months.
- The circulation affects surface climate through **radiative changes**.
- Circulation remains confined to the lower stratosphere only.

Quick Revision Summary

- Three cells: **Hadley** (equator–30°), **Ferrel** (30°–60°), **Polar** (60°–poles)
- ITCZ = convergence of NE and SE Trade Winds near equator; moves seasonally
- Subtropical High formed by subsidence at **30°** — causes deserts
- Polar front jet near **60°** lat; Subtropical jet near **30°** lat
- Horse Latitudes at **30–40°**; Roaring Forties/Furious Fifties/Crying Sixties between **35°–60°**
- Middle latitude disturbances move W→E; Tropical disturbances move E→W (recurve later)
- Rossby/Planetary waves: meander of jet stream; named Carl Rossby, **1930s**
- Upper equatorial troposphere = Easterlies; narrow belt near equator = Zonal Westerlies

GHOST AVIATOR

Ghost Aviator

GHOST AVIATOR

Practice Q&A

Q1. The polewards moving air piles up in the subtropical regions and forms high pressure belt at the surface, it is called:

(a) Subtropical high (b) Polar High (c) Equatorial high

✅ **Correct Answer: (a) Subtropical high**

At ~30°N/S, the poleward-moving Hadley cell air sinks, forming the Subtropical High pressure belt at the surface.

❌ (b) Polar High: This forms at the poles due to cold sinking air — not at 30°. ❌ (c) Equatorial high: The equator is a region of low pressure and rising air (ITCZ) — not high pressure.

🏠 **Instructor's Note:** Subtropical High = 30°N/S sinking air. Remember: "Sink at 30° = Subtropical High = Deserts = Horse Latitudes."

Q2. _____ occurs over subtropical high.

(a) advection (b) convection (c) subsidence

✅ **Correct Answer: (c) subsidence**

Subtropical Highs are characterised by descending/sinking air (subsidence), which inhibits cloud formation and causes clear skies and deserts below.

❌ (a) Advection: Horizontal movement of air — not the defining characteristic here. ❌ (b) Convection: Rising air — this happens at the ITCZ/equator, opposite of what happens at subtropical highs.

🏠 **Instructor's Note:** Subsidence = sinking = subtropical high = desert belt. Convection = rising = ITCZ = clouds/rain.

Q3. The occurrence of large deserts near 30N and 30S are due to large scale:

(a) advection (b) convection (c) subsidence

✅ **Correct Answer: (c) subsidence**

Large-scale subsidence at the subtropical highs (~30°N/S) suppresses cloud formation and precipitation, creating desert regions (Sahara, Arabian Desert, etc.).

✗ (a)(b): Same reasoning as Q2 — only subsidence inhibits cloud formation.

🏠 **Instructor's Note:** Deserts at 30°N/S = Subtropical high = Subsidence. Classic DGCA link between synoptic-scale subsidence and desert climatology.

Q4. A part of the sinking air over the subtropical highs flows towards the equator, turning west (in the northern hemisphere) due to the Coriolis force. This surface air is called:

(a) Trade winds (b) Westerlies (c) Doldrums

✅ **Correct Answer: (a) Trade winds**

The surface return flow from subtropical highs towards the ITCZ is deflected westward by the Coriolis force, creating the NE Trade Winds (NH) and SE Trade Winds (SH).

✗ (b) Westerlies: These blow in the mid-latitudes poleward of 30°. ✗ (c) Doldrums: These are the calm areas at the ITCZ, not a wind system from the subtropical high.

🏠 **Instructor's Note:** Trade Winds blow from subtropical high TOWARD equator — NE in NH, SE in SH. They are the surface branch of the Hadley Cell.

Q5. The huge vertical circulations, one between the equator and 30N and another between equator and 30S, are called:

(a) Hadley Cells (b) Ferrel Cells (c) Polar cells

✅ **Correct Answer: (a) Hadley Cells**

Hadley Cells are the large convective cells between the equator and ~30°N/S, driven by solar heating at the ITCZ and sinking at the subtropical highs.

✗ (b) Ferrel Cells: These are in the mid-latitudes (30°–60°). ✗ (c) Polar Cells: These are between 60° and the poles.

🏠 **Instructor's Note:** Hadley=equator-30°, Ferrel=30°-60°, Polar=60°-90°. Use "HFP" — Hat, Ferrel, Pole!

Q6. Descending branch of the Hadley cell marked by calm winds and high pressure at the surface are called:

(a) Tropical Latitudes (b) Middle latitudes (c) Horse Latitudes

✅ **Correct Answer: (c) Horse Latitudes**

Horse Latitudes (approximately 30–40°) are characterised by calm winds, subsidence, and high pressure — the descending branch of the Hadley cell.

❌ (a) Tropical Latitudes: These are near the equator/ITCZ region, not at 30–40°. ❌ (b) Middle latitudes: These span 30°–60° and include the Ferrel cell — broader term, not specifically calm.

🏠 **Instructor's Note:** "Horse Latitudes" — historically ships got stuck in calms here and threw horses overboard to save water. Located at ~30–40°N/S.

Q7. The winds in the upper troposphere in the equatorial regions are:

(a) Westerlies (b) Easterlies (c) Zonal Westerlies

✅ **Correct Answer: (b) Easterlies**

In the equatorial regions, the upper tropospheric winds are Easterlies. (Note: a narrow belt near the equator has Zonal Westerlies, but the general equatorial upper troposphere is dominated by Easterlies.)

❌ (a) Westerlies: These occur in mid-latitudes in the upper troposphere. ❌ (c) Zonal Westerlies: Only in a narrow belt near the equator.

🏠 **Instructor's Note:** DGCA exam: Upper equatorial troposphere = Easterlies. This steers tropical disturbances from east to west.

Q8. The disturbances of middle latitudes move from:

(a) Easterly direction (b) Westerly direction (c) Southerly direction

✅ **Correct Answer: (b) Westerly direction**

Middle latitude disturbances move from west to east in the westerly current (the Ferrel Cell/Roaring Forties region). This is steered by the upper westerlies.

❌ (a) Easterly: Tropical disturbances move in an easterly (westward) direction. ❌ (c) Southerly: Not a primary direction for mid-latitude systems.

🏠 **Instructor's Note:** Mid-lat disturbances = W to E. Tropical disturbances = E to W (recurve later). Key for tropical meteorology questions!

Q9. The tropical disturbance which form in the equatorial low pressure belt move in a:
(a) Easterly direction (b) Westerly direction (c) Northerly direction

✅ **Correct Answer: (b) Westerly direction**

Tropical disturbances form in the equatorial low pressure belt and move westward, steered by the high-level easterly flow.

❌ (a) Easterly direction: This refers to the wind direction from east — but the movement is towards the west (westerly direction of movement). ❌ (c) Northerly: Not applicable for initial movement.

👉 **Instructor's Note:** "Westerly direction" = moving westward. Tropical disturbances are steered westward by upper-level easterlies until they recurve poleward when they reach mid-latitudes.

Q10. Latitudinally, on the average there is radiation in the tropics than in the polar regions.
(a) surplus (b) deficit (c) balance

✅ **Correct Answer: (a) surplus**

The tropics receive more solar radiation than they emit (radiation surplus). The poles emit more than they receive (radiation deficit). This imbalance drives the general circulation.

❌ (b) Deficit: This applies to polar regions. ❌ (c) Balance: There is no balance latitudinally — this imbalance is the DRIVER of general circulation.

👉 **Instructor's Note:** Tropics = radiation SURPLUS → drives Hadley cell. Poles = radiation DEFICIT. The general circulation transfers energy from surplus to deficit regions.

Q11. The systems like highs, lows, cyclonic and anticyclonic circulations etc. are associated with distinct types of weather. A study of the behaviour of these systems, known as:
(a) Synoptic Meteorology (b) Climatology (c) Physical Meteorology

✅ **Correct Answer: (a) Synoptic Meteorology**

Synoptic Meteorology is the study of weather systems (highs, lows, fronts, cyclones) and their associated weather, using synoptic-scale charts and observations.

❌ (b) Climatology: The study of long-term average weather patterns over a region. ❌ (c) Physical Meteorology: Deals with physical properties of the atmosphere — radiation, optics, thermodynamics.

 **Instructor's Note:** Synoptic = weather maps and systems. Physical = properties of atmosphere. Climatology = long-term averages. Know all three branches for DGCA.

Q13. Steady NE winds in the N hemisphere and SE winds in the S hemisphere are called: (a) Easterly winds (b) Trade Winds (c) Tropical Winds

 Answer: (b) Trade Winds

 (a) 'Easterly winds' is a general term. (c) 'Tropical Winds' is not a technical name.

 NE Trades in the north, SE Trades in the south.

Master Reference Tables

Numerical Values & Key Latitudes

Feature	Latitude	Notes
ITCZ / Doldrums	~0° (equator)	Moves N/S seasonally with sun
Subtropical High / Horse Latitudes	30–40°	Descending Hadley branch; deserts below
Subtropical Jet Stream	~30°	Just below tropopause
Roaring Forties / Ferrel Cell	35°–60°	Furious Fifties, Crying Sixties in SH
Polar Front / Polar Front Jet	~60°	Boundary between Ferrel and Polar cells
Polar Easterlies	60°–90°	Cold air from poles
Rossby waves named	—	Carl Rossby, 1930s

Cell Characteristics Summary

Cell	Latitude Band	Surface Wind	Jet Stream
Hadley	0°–30°	Trade Winds (NE/SE)	Subtropical Jet
Ferrel	30°–60°	Westerlies	Polar Front Jet
Polar	60°–90°	Polar Easterlies	Polar Jet

Mnemonics

Mnemonic	Meaning
HFP	Hadley-Ferrel-Polar (equator to pole)
"Sink at 30 = Desert"	Subtropical subsidence → Horse Latitudes → Deserts
"Tropics = Surplus"	Radiation surplus drives Hadley cell
"Mid-lat W→E, Tropical E→W"	Direction of disturbance movement
"Rossby = Planetary = Jet meanders"	Carl Rossby 1930s; wavelengths m to 1000s km