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1. Tropical Discontinuities — ITCZ

Tropical Discontinuities / Convergence Zones: In the tropics, the temperature (or density) contrast between two air masses is not as discernible as in higher latitudes. Hence fronts cannot be marked. However, a line of discontinuity can be drawn in the wind field in upper air charts and by inspection of the cloud pattern — called **Tropical Discontinuities** or **Convergence Zones**.

Inter Tropical Convergence Zone (ITCZ): A narrow zone along which T_m or T_e air from the N meets the T_m or E_m air from the S. Air masses within the tropics converge — hence the name ITCZ. ITCZ usually lies along the Equatorial Trough (ET). In summers it migrates up to **20° N** and in winters up to **Australia**. ITCZ is active in certain portions, about **75–150 km** length, where heavy showers occur and CB clouds predominate. On rare occasions it may be pushed up to S Bay of Bengal in winters and may initiate formation of cyclonic storms during the rainy season — ITCZ/ET coincides with Monsoon Trough.

Equatorial Front: Alternative term for ITCZ.

2. Easterly Waves

Easterly Waves: Troughs in tropical easterly winds forming on the ITCZ with fairly high frequency. They originate at sea at the boundary of T_m and E_m air masses. A minor surge of E_m air may distort the ITCZ and start the Easterly Wave. It moves in a more or less east-west direction.

- Weak at surface; better developed at **500 hPa** level and above.
- Wavelength: about **1500 km**.
- Move from **W to E** with speed **20–25 kmh** along the ITCZ.
- Most weather occurs in **rear of the wave trough**.

Easterly Waves in India

In winters, first noticed in Andaman Sea as shallow lows with troughs in upper air. Move westwards across south peninsula and emerge into Arabian Sea at about **15 kt** over sea, about **10 kt** over peninsula. Further progression westwards beyond Arabian Sea cannot be easily traced, but also affect Africa. In winters ITCZ is south of equator — on rare occasions these waves move into extreme south Bay, possibly causing disturbed weather for 3–4 days over Bay Islands, Tamil Nadu, Kerala and Arabian Sea Islands. During pre-monsoon season, ITCZ advances further north — frequency of easterly waves over India increases, helping formation of premonsoon cyclonic storms over Indian seas. During monsoon, easterly waves from Pacific Ocean move across SE Asia and reach head of Bay of Bengal. Some move further WNW; others develop into depressions, move NW and weaken gradually. Very infrequently, an easterly wave may develop into a depression over north Arabian Sea.

3. Peninsular Discontinuity (PD) / Dry Line

Peninsular Discontinuity (PD): A discontinuity forming over peninsular India (south of Lat. **23° N**) in April and May. Also called **Dry Line**. It separates hot and dry Tc air from the northern India from the comparatively cooler and moist air from the Bay of Bengal. This discontinuity gives rise to afternoon thunderstorms, at times with hail, strong northwesterly squalls and heavy showers. It remains more or less stationary for **3–4 days** before dissipating.

4. Surge

Surge / Pulse: Sudden strengthening of an air current in the same air mass. At a surge the air arrives faster than it is removed → accumulation of air at the surge line → **velocity convergence**. This is a common and strong disturbance in the monsoon season over the Arabian Sea.

- To the **west** of the surge line, wind may be about **40 kt** ahead of it; to the **east**, only about **10–15 kt**.
- Vertical ascent at a surge line causes growth of CU clouds, showers and gusts or squalls.
- Surge line moves in the **direction of the wind**. It ultimately reaches over the head of the Bay of Bengal.
- When a surge arrives, sky becomes overcast with very frequent and sharp showers, and strong gusty or squally winds.
- The surge line **activates ITCZ** and favours formation of depressions or cyclones on the ITCZ.

5. Shear Lines

Shear Lines: Created when in the same air mass the wind speed decreases markedly from south to north or vice versa. Common over Arabian Sea during monsoon season. At a shear line, friction between air moving at different velocities causes a small-scale ascent. If shear extends vertically, ascent reaches to higher levels — stratiform layer clouds (ST, AS, NS) form, extending to about **500 km** across. When a fresh surge arrives, large CU and CB clouds get embedded at the leading edge, which are at right angles to the shear line. **Surge and Shear Lines are a characteristic feature of vigorous monsoon.**

6. Low Pressure Systems Classification

Classification of Low Pressure Systems (based on wind speed over sea at 900 m; over land at 900 m — considered same):

System	Wind Speed Over Sea
Low Pressure	< 17 kt
Depression	17–27 kt
Deep Depression	28–33 kt
Cyclonic Storm	34–47 kt
Severe Cyclonic Storm	48–63 kt
Very Severe Cyclonic Storm	64–<120 kt
Super Cyclone	120 kt or more

Memory Aid: 17 / 27 / 33 / 47 / 63 / 120 kt — progression of thresholds. The DGCA exam frequently tests the 34–47 kt range for Cyclonic Storm and 48–63 kt for Severe Cyclonic Storm.

7. Monsoon Depressions

Monsoon Depression: A low-pressure area with two or more closed isobars at 2 hPa interval. In India they form over NE India during monsoon and are termed **Monsoon Depressions**. Surface winds are **17–33 kt**. Also form over Arabian Sea and land too. Land depressions mostly form over NE India. In June, July and August depressions form over head Bay of Bengal (N of 18 N). In September they form around 14 N. In Arabian Sea they originate **5° off coast**, N of 12 N and move N/NW.

Average life of a monsoon depression: **3–5 days**

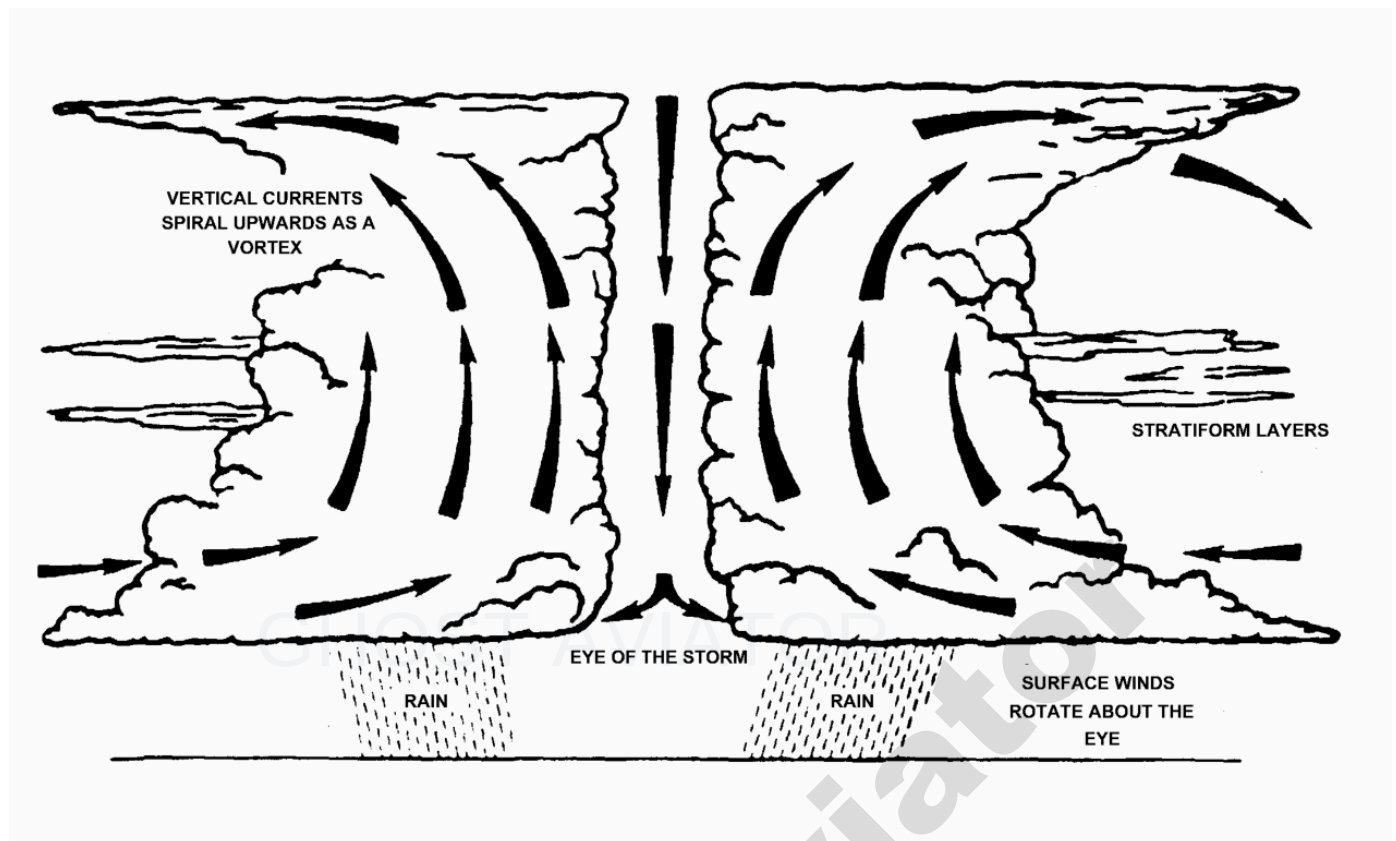
Weather in Monsoon Depression:

- Worst weather occurs in the **SW sector** — rainfall is steady and heavy in a belt of about **400 km** width. Elsewhere it is scanty.
- At time of re-curvature, rain belt shifts to **N–NE sector**. Showery precipitation occurs in rear of depression when winds are strong S–SWly.
- Associated upper air cyclonic circulation extends up to about **300 hPa**.
- Monsoon depression slope SWwards with height. E.g., if surface system is over Kolkata, it would be over Visakhapatnam at 300 hPa (9 km).
- **Fair weather over Assam during monsoon indicates intensification or formation of a depression over head Bay or vice versa.**

8. Tropical Cyclones (TRS)

Tropical Cyclone (TC) / Tropical Revolving Storm (TRS): Non-frontal low-pressure system with numerous TS, strong winds and heavy rain. Form over warm tropical waters (temperature **>26°C**), between Lat **5–25°**. Below **5°** there is no Coriolis force → TC cannot form. Above **25°** it is cold.

Maximum sustained wind in a TC is **34 kt or more**. As per IMD it is the **highest 3 min (some countries 1 and 10 min) averaged surface wind** within the circulation at **10 m height**.



Cross-section of a tropical revolving storm

Names by Region: Depending on location and strength — Hurricane (Atlantic), Typhoon (NW Pacific), Tropical Storm, Cyclonic Storm, Tropical Revolving Storm, simply Cyclone.

Necessary Conditions for TC Formation

1. **Warm sea** ($>26^{\circ}\text{C}$) to a depth of **60 m** to provide abundant evaporation.
2. **High RH** above 7000 m to facilitate condensation of water vapours into drops and release latent heat.
3. **Instability** for vertical development, and **Coriolis Force** to spiral wind inward.
4. **Very little Wind Shear**. WS preferably below **20 kt** from 850 to 200 hPa. WS will distribute latent heat and intensification will suffer.

Characteristics — Mature Phase (4 Parts)

Zone	Size	Description
Eye	Mostly 30–65 km diameter	Light winds, often clear skies; warmest (warmer by 0–2°C at surface, up to 10°C at 12 km). Inversion from 1 to 3 km. Surrounded by eyewall — ring of towering CB clouds.
Inner Storm Area (Hurricane Core)	50–150 km	Winds >64 kt, violent squalls, torrential rains; thick dark CB clouds called Eye Wall / Wall Clouds . Most hazardous part. Pressure gradient very steep. TC exhibit concentric eye walls.
Outer Storm Area	About 400 km	Gale force winds (34 kt+) and occasional squalls. Winds decrease outwards. Spiral bands of clouds.
Edge of Storm	Beyond outer area	Winds are weak and clouding diminishes.

Extent and Movement

- TC is a vast violent whirl of **150 to 800 km**, spiraling around a centre.
- Moves over sea at **300 to 500 km/day** at **15–20 kmh**. Generally TC move westwards up to **25° N/S** then recurve and move E.

Pressure

- Central pressure in TC: between **1000–900 hPa**. On average the central pressure is **5–6 hPa** below surface. In extreme cases may be about **70 hPa** less.
- Pressure gradient very steep up to a radius of **100 km**.

Worst Weather Sector:

- In the **N hemisphere** → worst weather in the **right forward sector**.
- In the **S hemisphere** → worst weather in the **left forward sector**.

Upper Air Circulation

Cyclonic circulation in a TC may extend to **40,000 ft**. Axis of circulation is almost vertical. In the inner storm area, winds of hurricane force persist up to about **7000 ft**. Thereafter, winds weaken. Wind speeds at surface and upper air are stronger in the **right half** in N hemisphere.

Tropical Storms Over India

- Size varies from **50–2000 km radius**, average **300–600 km**.
- Form over Bay of Bengal and Arabian Sea → move inland.
- Damage mainly due to very strong winds, torrential rain and inundation — **storm wave and high tides**.
- Indian cyclones have very small life span (**3–5 days**, max 6–7 days, even for recurring ones).
- Average life of Indian cyclones: **3–5 days**.
- Notable recent storms: VSCS **Phailin** (2013, Odisha, max wind 220 kmh), **Hudhud** (2014, AP, max wind 205 kmh, CP 960 hPa), **Vardā** (2016, Andaman/Chennai, 155 kmh), **Nilofar** (2014, Arabian Sea, max wind 215 kmh), **Biparjoy** (Jun 2023, Arabian Sea, extremely severe cyclonic storm — peaked 15 June, made landfall 16 June near Naliya, Gujarat).

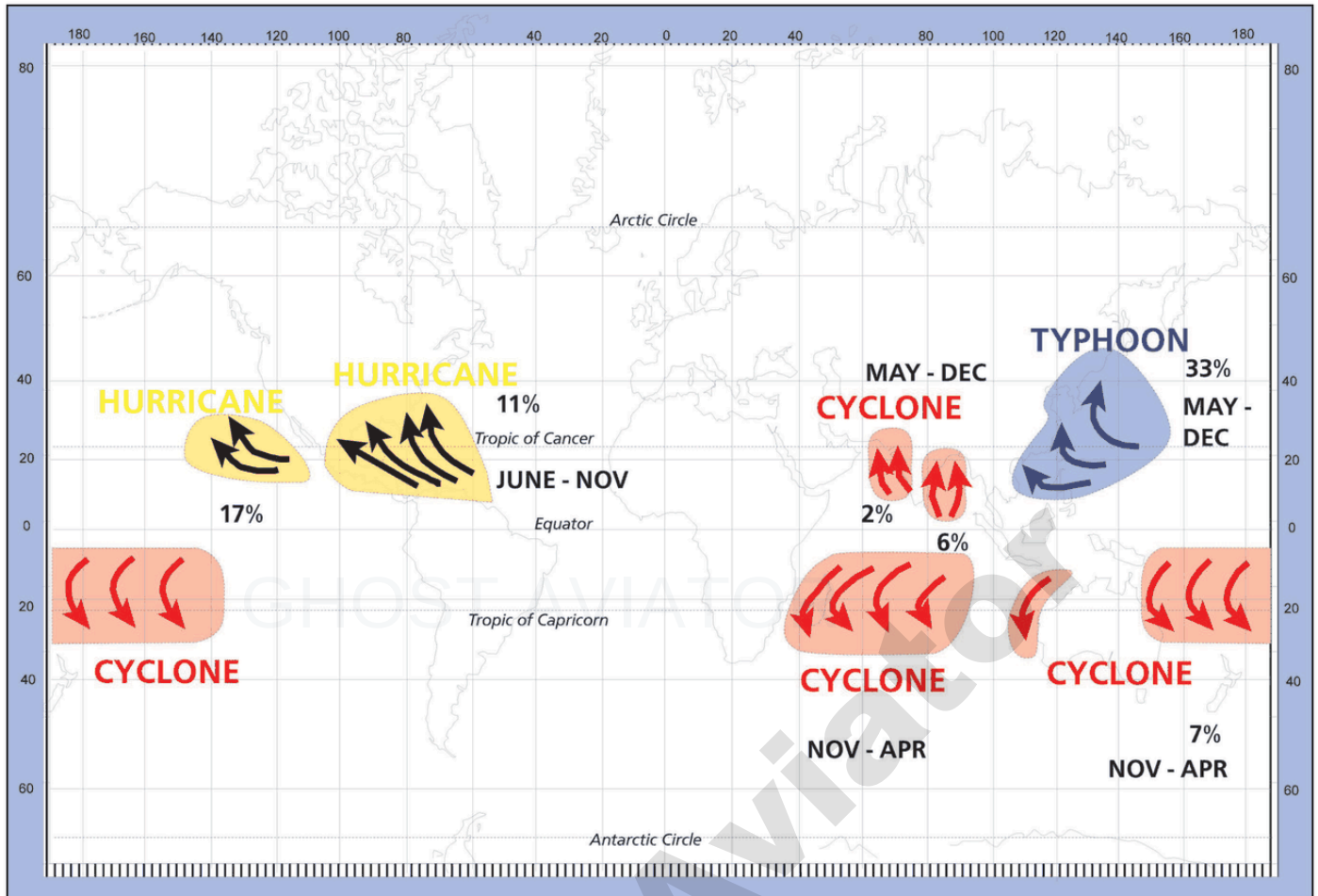
Flying Conditions in TC

Flying Conditions — Tropical Cyclone:

- Clouds in spiraling bands — unbroken cloud mass or reach **18–20 km**; severe turbulence in CB towers.
- Frictional turbulence in lowest layers due to strong winds.
- Strong up and downdraughts throughout storm.
- Rain in central area and lowest layers — torrential; winds very strong.

9. Frequency of Cyclones

- Frequency in Bay of Bengal and Arabian Sea is almost nil in **February and March**. Frequent in **May, June, October and November**. **Maximum frequency in October and November**.
- TC do **not** form in S Atlantic Ocean — ITCZ never moves S of 5° S in S Atlantic.
- In NW Pacific, TC occur throughout the year.
- Annual frequency of TC in Bay of Bengal is **4.5** and in Arabian Sea is **1.1**.



Tropical revolving storms of the world

Avoidance of Tropical Cyclone in Flight: On whatever compass course the cyclone is approached, **strong winds from the port indicate that the centre lies somewhere ahead.** To avoid the cyclone, alter the course until the wind is from starboard and is weakening.

10. Frontal Depressions

Formation of a Frontal Depression / Cyclone: A stationary or quasi-stationary polar front, in the N hemisphere, has warm tropical air to the south and colder polar air to the north. When warm air penetrates into a stationary polar front, a wave is generated. If this wave is stable, it moves eastwards along the front without intensification. If unstable, it intensifies. Pressure falls in the region where the bulge has occurred — cyclonic circulation develops into a depression. Ahead = cold air displaces warm air (**cold front**). These fronts are carried rear of the cyclonic centre cold air replaces warm air along with winds as the depression moves with the warm front preceding the cold front.

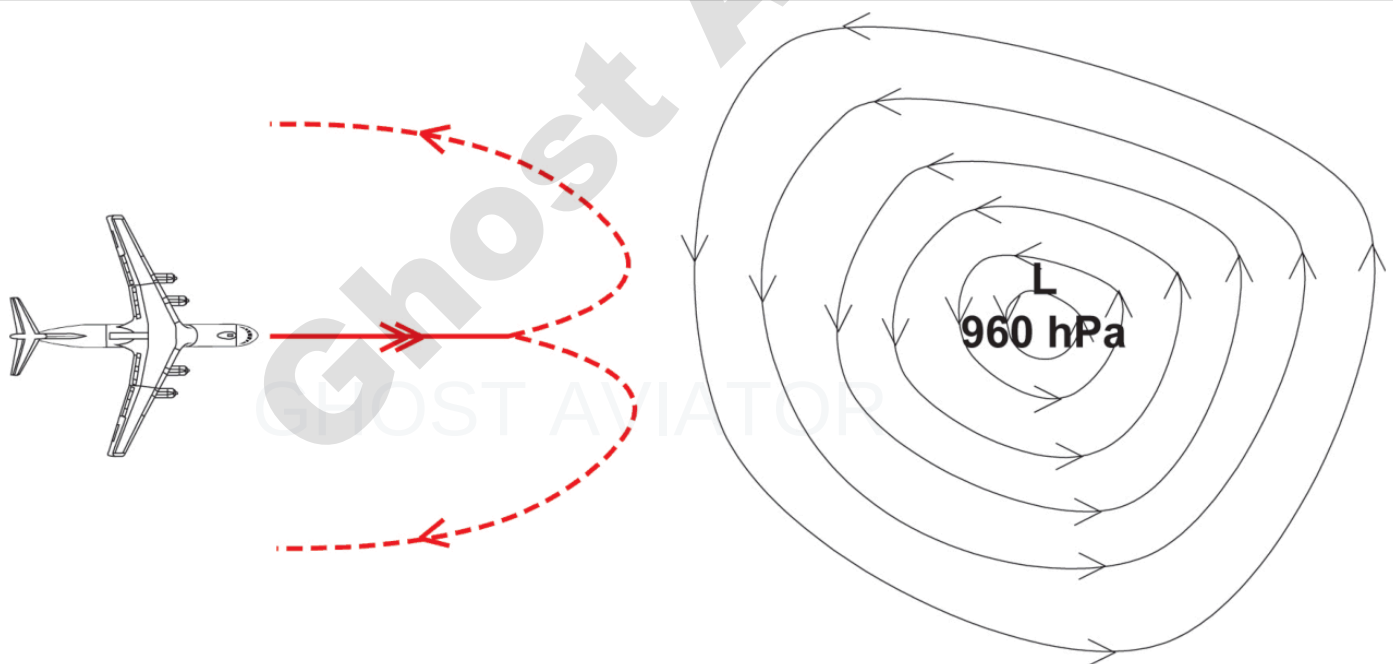
These depressions of middle latitudes are called **extra-tropical depressions**. Generally move towards E or ENE, being steered by the westerly currents in these latitudes. When a depression on the polar front occludes, the unoccluded portion trails at a lower latitude. Conditions then become favourable for secondary depressions — this may repeat at a still lower latitude → **family of 3 or 4 depressions** → **Cyclone Families**. They sometimes move eastwards together. **Saffir-Simpson Scale of CS and T Classification and for Cyclones is at Appendix B.**

11. Flying Hazards in Tropical Cyclones

flowchart TD

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A[Flying Hazards - Tropical Cyclone] --> B[Structural]
A --> C[Navigation]
A --> D[Weather]
B --> B1[Severe turbulence in CB\nViolent up/downdraughts\nng-load risk to airframe]
C --> C1[Altimeter unreliable\nrapid pressure changes]
C --> C2[Instrument disorientation]
D --> D1[Torrential rain\nZero visibility in wall clouds]
D --> D2[Severe icing\nin CB towers]
D --> D3[Lightning\nSt Elmo's Fire]
  
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Avoiding a tropical revolving storm

Never fly through the Eye Wall. The eye may appear calm but transitioning through the eye wall in either direction means traversing the most violent zone of the storm.

12. Quick Revision Summary

Quick Revision — Chapter 18: Tropical Systems

- ITCZ = narrow zone where Tm/Te air from N meets Tm/Em from S; migrates to **20° N** (summer), Australia (winter)
- Easterly waves: wavelength **1500 km** ; speed **20–25 kmh** ; weather in rear of trough
- PD (Dry Line) = peninsular India (S of **23°N**); April–May; stationary **3–4 days**
- Surge = sudden wind strengthening in same air mass; activates ITCZ; west = **40 kt** , east = **10–15 kt**
- LPS classification: Low <17 kt → Depression 17–27 → Deep Dep 28–33 → CS 34–47 → SCS 48–63 → VSCS 64–120 → Super >120 kt
- Monsoon depression: **3–5 days** life; worst weather SW sector; upper circulation to **300 hPa**
- TC forms: SST **>26°C** , depth **60 m** , Lat **5–25°** , low shear (<20 kt), high instability
- TC eye: **30–65 km** ; Inner storm: **50–150 km** ; Outer storm: **~400 km**
- Worst sector: N hemisphere = **right forward**; S hemisphere = **left forward**
- TC India frequency: max **Oct–Nov**; BoB annual avg **4.5** , Arabian Sea **1.1**
- Avoidance: port winds → centre ahead → alter till starboard winds weakening
- Central pressure: **900–1000 hPa** ; steep gradient to **100 km** radius

13. Practice Q&A

Q1. Wind speed in a tropical severe cyclone is:

(a) 27–33 kt (b) 48–63 kt (c) 17–27 kt

✓ Correct Answer: (b) 48–63 kt — Severe Cyclonic Storm category

✗ Distractors: (a) 28–33 kt = Deep Depression. (c) 17–27 kt = Depression. Candidates often confuse categories — use the table.

💡 Mnemonic table: 17/27/33/47/63/120. Severe CS = 48–63 kt. "48 to 63 = Severe".

Q2. Fronts are characteristic of: (a) Tropical cyclone (b) Extra-tropical depressions (c) Monsoon depressions

✓ Answer: (b) Extra-tropical depressions — Fronts are a feature of extra-tropical (mid-latitude) depressions. Tropical cyclones and monsoon depressions form in a uniform warm, moist air mass and have no fronts.

✗ (a) and (c) are non-frontal.

💡 Tropical = no front.

Q3. In a mature tropical cyclone, the eye area is characterised by:

(a) Moderate weather (b) Stormy weather (c) Calm wind, little clouding and practically no rainfall

✓ Answer: (c) calm wind, little clouding and practically no rainfall — The eye of a mature tropical cyclone has calm or light winds, little cloud and almost no rain. The worst weather is in the eye wall surrounding it.

✗ (a) and (b) describe the eye wall and the rain bands, not the eye.

💡 Eye = calm. Eye wall = violent.

Q4. Cyclonic storms cross the Tamil Nadu coast during: (a) Oct–Nov (b) Jul–Aug (c) Feb–May

✓ Answer: (a) Oct–Nov — Tamil Nadu is hit by post-monsoon cyclones from the Bay of Bengal, mainly in October and November.

✗ (b) Jul–Aug is the monsoon, when depressions rather than cyclones form. (c) Feb–May is a quiet period for cyclones on this coast.

💡 Tamil Nadu cyclones: October–November (north-east monsoon).

**Q5. Cyclonic storms form over Indian seas during:
(a) SW monsoon (b) Winter Season (c) Pre-Monsoon & Post Monsoon**

✓ Correct Answer: (c) Pre-Monsoon (May–Jun) & Post Monsoon (Oct–Nov) — peak cyclone seasons

✗ Distractors: (a) During SW Monsoon, vertical wind shear is high → inhibits TC development. (b) Winter = near nil frequency (Feb–Mar).

💡 "Cyclones sandwich the monsoon" — they peak before (May–Jun) and after (Oct–Nov) the SW monsoon.

**Q6. TRS occurs over Indian seas in:
(a) Equatorial Region (b) 5–15° N (c) 0–5° N**

✓ Correct Answer: (b) 5–15° N — TC form between 5° and 25°; Indian seas primarily 5–15°N

✗ Distractors: (a) Equatorial region has insufficient Coriolis force. (c) 0–5° N has practically no Coriolis — TC cannot form below 5°.

💡 TC: Below 5° = NO. Between 5–25° = YES. Above 25° = cold sea, weakens.

Q7. During the months of July, August, Monsoon Depression form over:

(a) Over Head Bay (b) Central Bay (c) South Bay

✓ Correct Answer: (a) Over Head Bay — N of 18°N during June, July, August

✗ Distractors: (b) Central Bay = later in season. (c) South Bay = different systems.

💡 "Jul–Aug = Head Bay depressions" — this is a direct factual question. Memorise: Head Bay = Jul–Aug.

Q8. In a monsoon depression maximum weather occurs in:

(a) SE sector (b) NW sector (c) SW sector

✓ Correct Answer: (c) SW sector — worst weather (steady heavy rainfall in ~400 km belt)

✗ Distractors: (a) SE sector = relatively fair. (b) NW sector = also relatively clear. SW sector = convergence zone with heaviest rainfall.

💡 Monsoon Depression SW sector = worst. At recurvature it shifts to N–NE. "South-Worst".

Q9. During re-curvature maximum weather in a monsoon depression occurs in:

(a) SE sector (b) NW sector (c) SW sector (d) NE sector

✓ Correct Answer: (d) NE sector — at time of re-curvature the rain belt shifts to N–NE sector

✗ Distractors: (c) SW sector = before re-curvature. At re-curvature the track changes and the rain belt migrates to N-NE.

💡 Straight track = SW worst. Re-curvature = NE worst. This is a two-part factual combination frequently tested.

Q10. On whatever compass course the cyclone is approached, strong winds from the port indicate that the centre lies somewhere:

(a) Ahead (b) Behind (c) Port (d) Starboard

✅ Correct Answer: (a) Ahead — port winds = centre ahead; alter course till wind from starboard and weakening

✗ Distractors: (b) Behind would mean you've passed it. (c) Port side = direction of wind, not centre. (d) Starboard = the direction to aim for to escape.

💡 Avoidance rule: "PORT wind = centre AHEAD → turn until STARBOARD wind is WEAKENING = escaping the cyclone."

14. Master Reference Tables

Low Pressure System Classification

System	Wind Speed (kt)
Low Pressure	< 17 kt
Depression	17–27 kt
Deep Depression	28–33 kt
Cyclonic Storm	34–47 kt
Severe Cyclonic Storm	48–63 kt
Very Severe Cyclonic Storm	64–<120 kt
Super Cyclone	≥ 120 kt

TC Structure Summary

Zone	Radius	Key Feature
Eye	30–65 km dia	Calm, clear, warm (+0–2°C surface, +10°C at 12 km)
Eye Wall / Hurricane Core	50–150 km	Winds >64 kt; worst turbulence; wall clouds
Outer Storm	~400 km	Gale force; spiral cloud bands
Edge of Storm	Beyond 400 km	Weak winds; clouding diminishes

All Numerical Values

Parameter	Value
ITCZ active portion length	75–150 km
ITCZ summer migration	Up to 20°N
Easterly wave wavelength	~1500 km
Easterly wave speed	20–25 kmh
Easterly wave altitude best development	500 hPa
Surge west of surge line	~40 kt
Surge east of surge line	10–15 kt
TC SST requirement	>26°C to depth of 60 m
TC latitude range	5–25°
TC max sustained wind (IMD)	34 kt or more (highest 3 min avg at 10 m)
TC size range	150–800 km
TC daily movement	300–500 km/day at 15–20 kmh
TC upper circulation	To 40,000 ft
Hurricane force winds persist to	~7000 ft
TC central pressure	900–1000 hPa
TC pressure gradient radius	100 km
BoB annual TC frequency	4.5
Arabian Sea annual TC frequency	1.1
Monsoon depression life	3–5 days
Monsoon dep upper circulation	To 300 hPa
Monsoon dep heavy rain belt width	~400 km