Synoptic Aspects: Monitoring & Prediction of Cyclonic Storms

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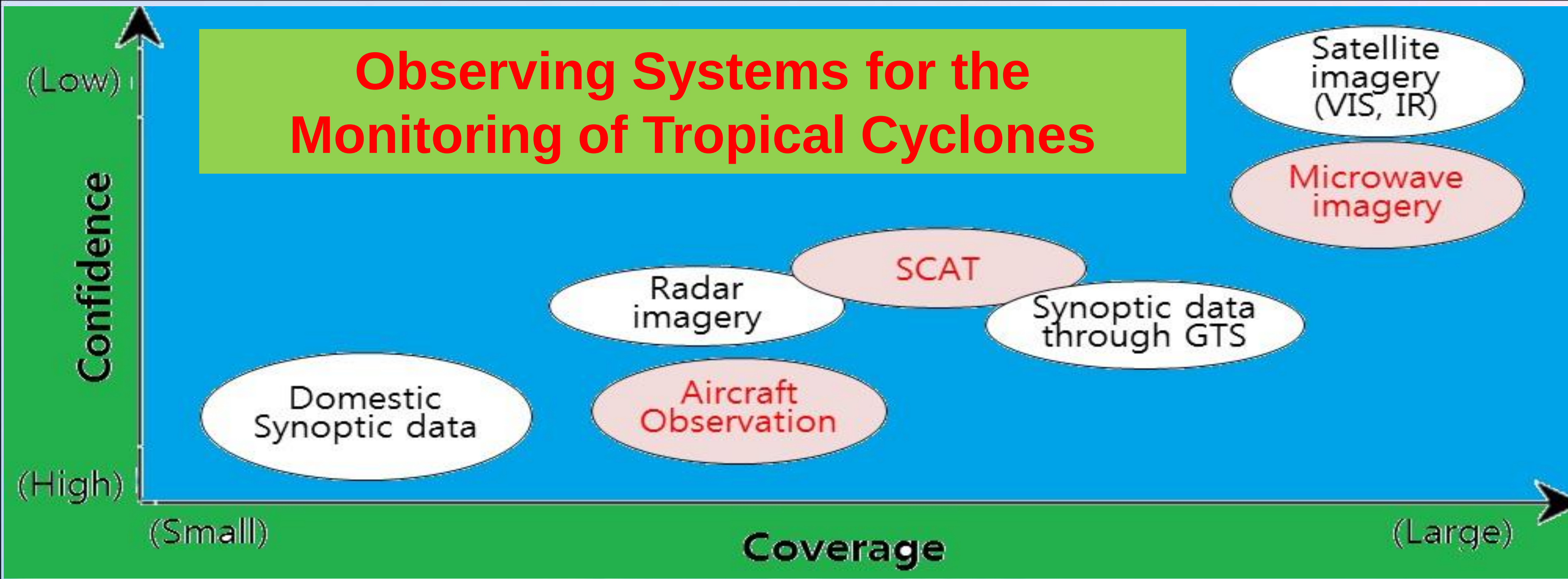
Organization

- Introduction
- What is the need of synoptic aspects of TCs?
- Assembly of relevant observations/information
  - ✓ Classification of Cyclonic Disturbances
  - ✓ Monitoring: Locating the centre & Estimation of intensity
  - ✓ Different stages of cyclones
  - ✓ Structure of Tropical Cyclone
- Prediction of Tropical Cyclone
  - ✓ Genesis /Formation
  - ✓ Movement
  - ✓ Intensification/Weakening
  - ✓ Hazard elements other than strong winds
- A few points about TCs
- *Concluding Remarks*

Observing Systems for the Monitoring of Tropical Cyclones

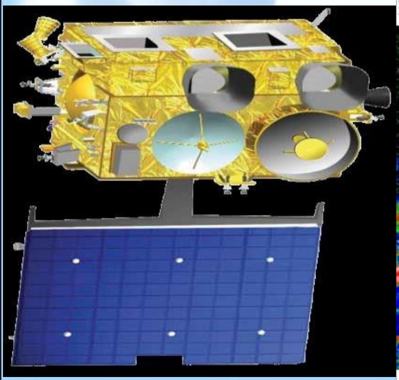


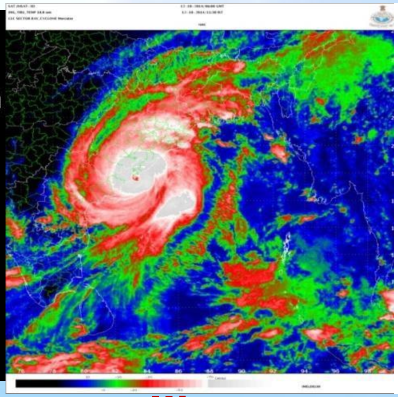
Cloud Images, BT, CTT, SST, RGB products, CTP, OLR, AMVs, shear, TPWC, PEs, Profiles and animation

Synoptic surface & Upper-air Observations: pressure, temperature, humidity, wind, change/tendency, rain & weather

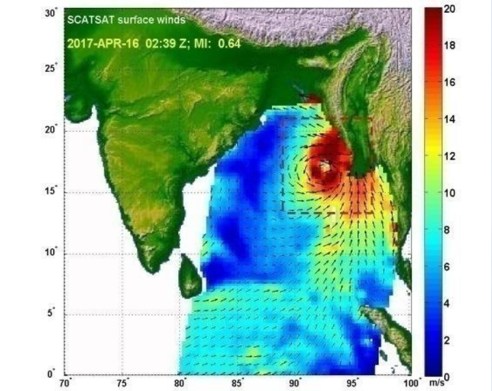
Surface wind structure

3-D echo (dBz) & wind structure

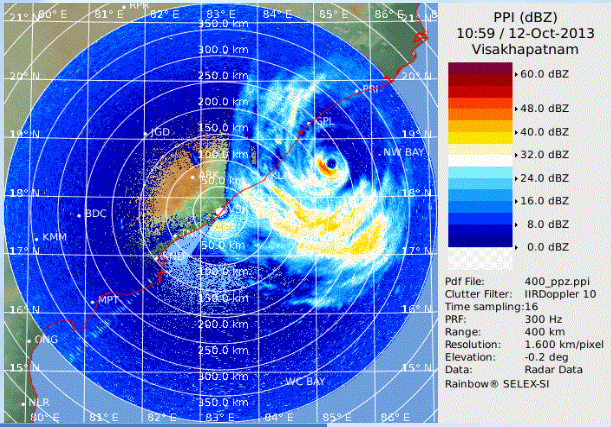




INSAT-3D & 3DR satellites



Scatterometer



Radar(33)

Classification of Cyclonic Disturbances

The criteria followed by the Meteorological Department of India to classify the low pressure systems in the Bay of Bengal and in the Arabian Sea as adopted by the World Meteorological Organisation (W.M.O.) are:

Types of Disturbances	**Associated wind speed in the Circulation**
1. Low Pressure Area	Less than 17 knots (< 31 kmph)
2. Depression	17 to 27 knots (31 to 49 kmph)
3. Deep Depression	28 to 33 knots (50 to 61 kmph)
4. Cyclonic Storm	34 to 47 knots (62 to 88 kmph)
5. Severe Cyclonic Storm	48 to 63 knots (89 to 118 kmph)
6. Very Severe Cyclonic Storm	64 to 89 knots (119 to 165 kmph)
7. Extremely Severe Cyclonic Storm	90 to 119 knots (166 to 221 kmph)
7. Super Cyclonic Storm	120 knots and above (222 kmph and above)

1 knot - 1.85 km per hour

MONITORING OF TROPICAL CYCLONIC DISTURBANCES

Location and Intensity estimation of cyclones

(a) Satellite:

(1) INSAT-3D, 3DR, ScatSat

(2) Other international satellites

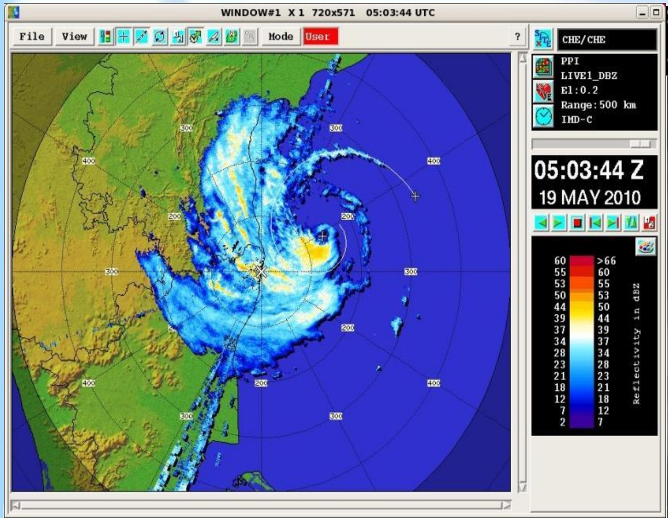
(b) Radar

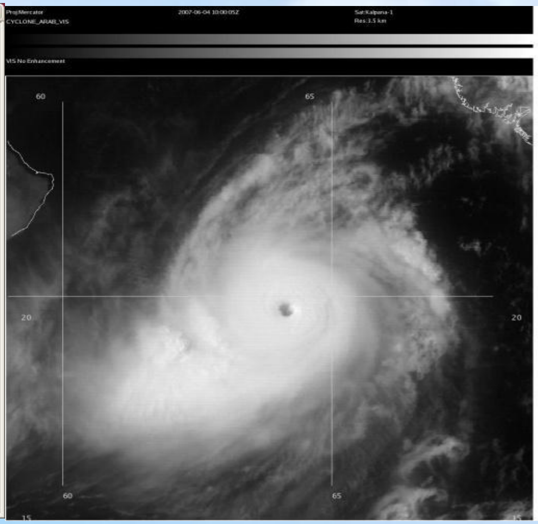
(c) Synoptic analysis

(d) Finally agreed official location and intensity

Also satellite observations help in deriving winds & humidity profiles

C.I. Number	*Max. Wind Speed (knots)*	*Pressure depth (in hPa)*
1	25	3.1
1.5	25	3.1
2	30	4.5
2.5	35	6.1
3	45	10.0
3.5	55	15.0
4	65	20.9
4.5	77	29.4
5	90	40.2
5.5	102	51.6
6	115	65.6
6.5	127	80.0
7	140	97.2
7.5	155	119.1
8	170	143.3





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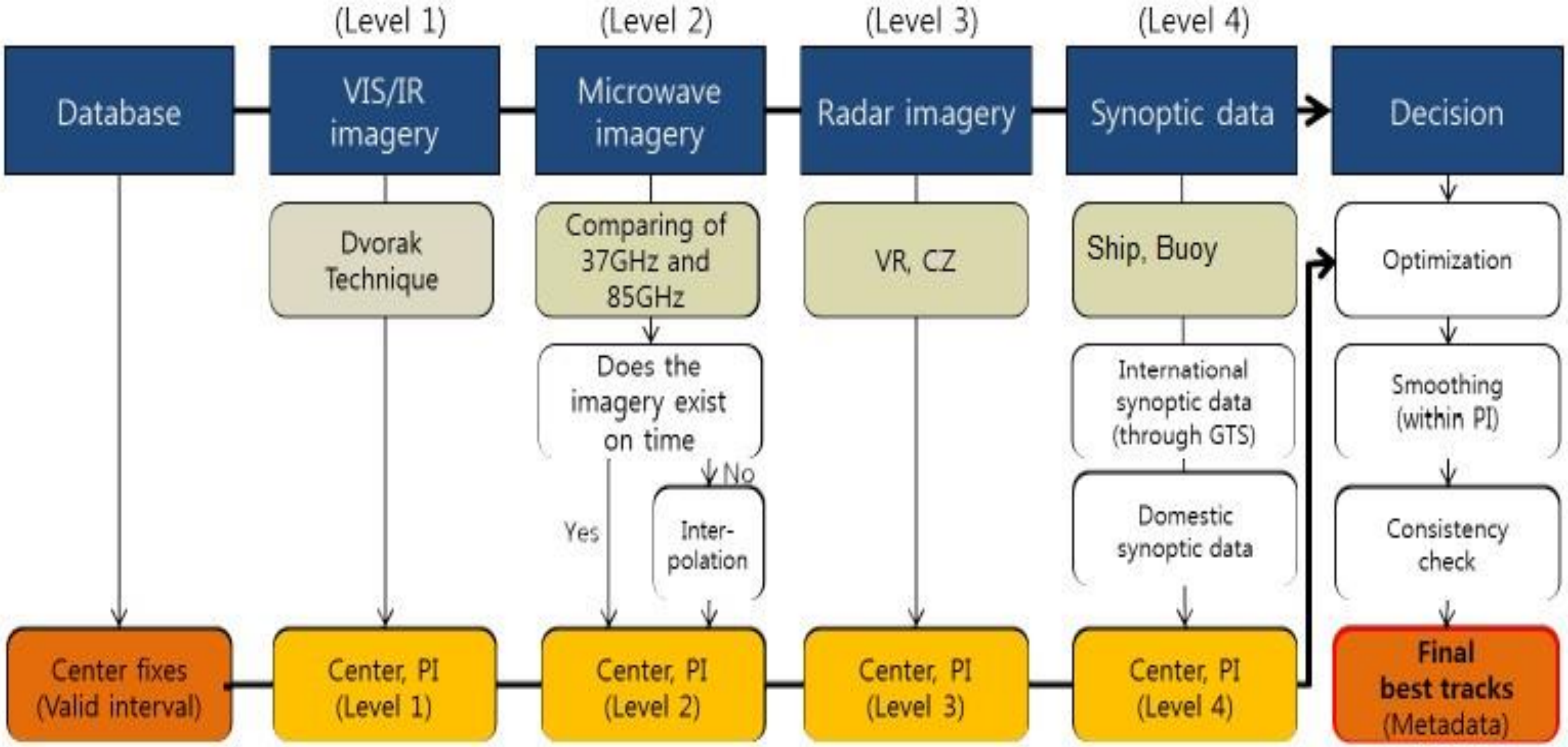
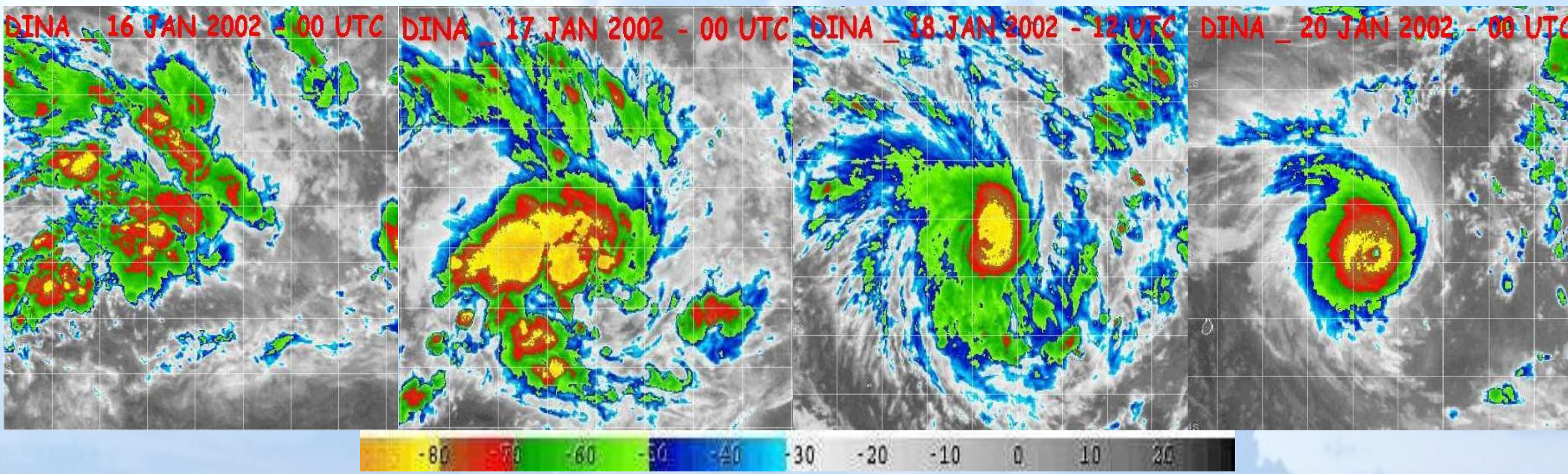
Centre and intensity fixing of cyclones



Monitoring the Evolution of tropical cyclones

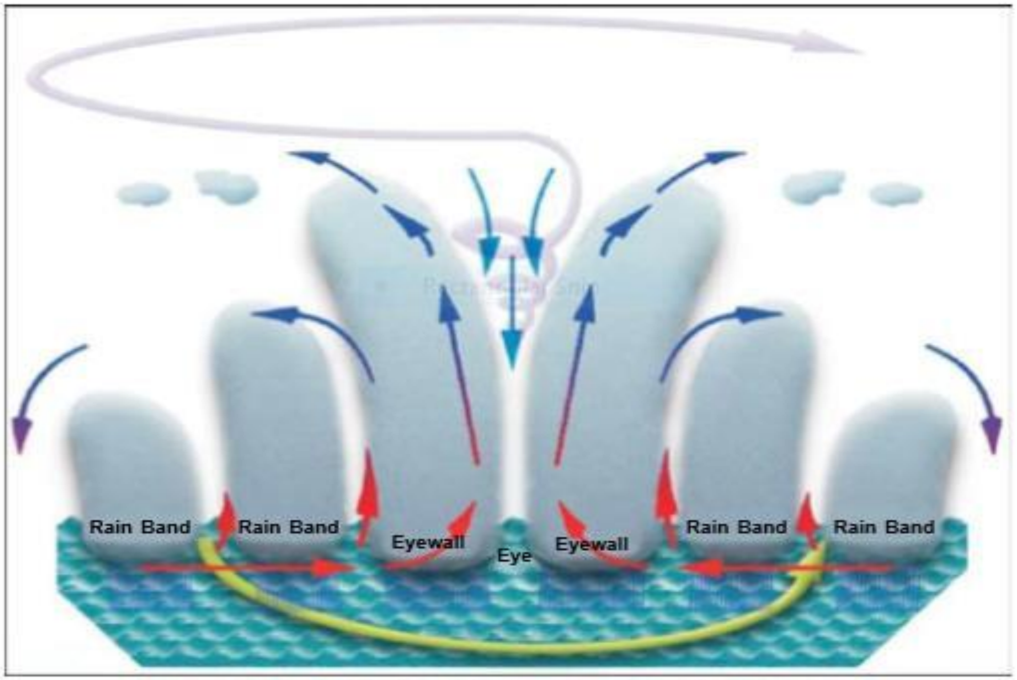
- **Tropical Disturbance (Low):** Region of intense convective activity with surface winds of moderate intensity, and some indication of cyclonic motion.
- **Depression/deep depression:** Close circulation with wind speed (averaged over 1 to 10 min) less than 34 kt (63 km/h)
- **Cyclone / Severe Cyclone:** Winds between 34 and 63 kt (63-117 km/h)
- **Very Severe Cyclone:** Winds reaching or stronger than 64 kt (118 km/h)



Cloud Top Temperature (° C)

Life Cycle of a Tropical Cyclone

- **Formative Stage : Outer circulation contracts a little and the core intensifies**
- **Immature Stage : Intensity increases to a maximum as the size remains almost the same**
- **Mature Stage : TC grows in area but no further intensification takes place- inner core winds persist**
- **Decaying Stage : Inner core winds decrease rapidly as it enters land, moves over cold areas or to the belt of strong westerlies. All these cause the system to weaken**



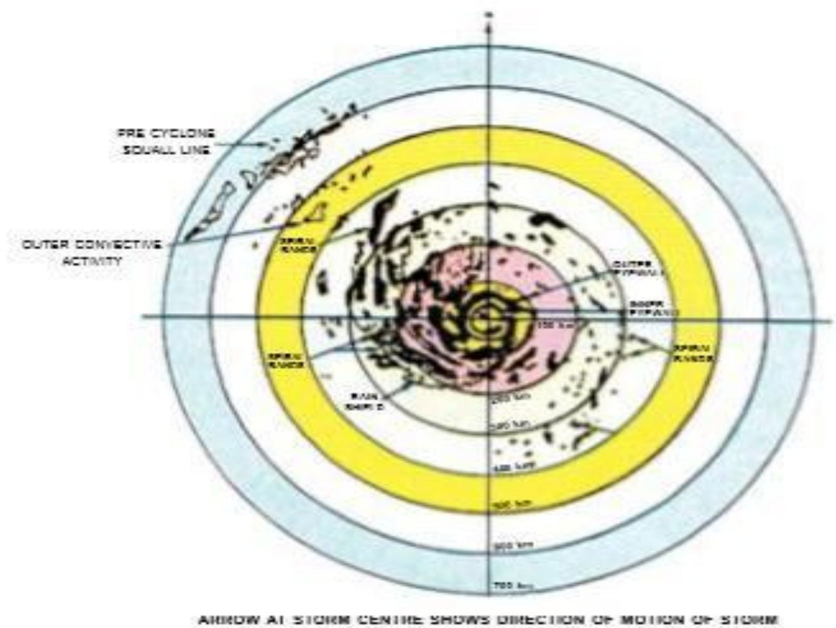


Fig.1.2. Composite structure of cyclone as seen in Radar imagery

Important attributes of a cyclone are:

- Eye/Eye Diameter
- Size
- Strength/Intensity (central pressure)
- Radius of maximum winds
- Size of the storm
- Pressure of the outer most closed isobar

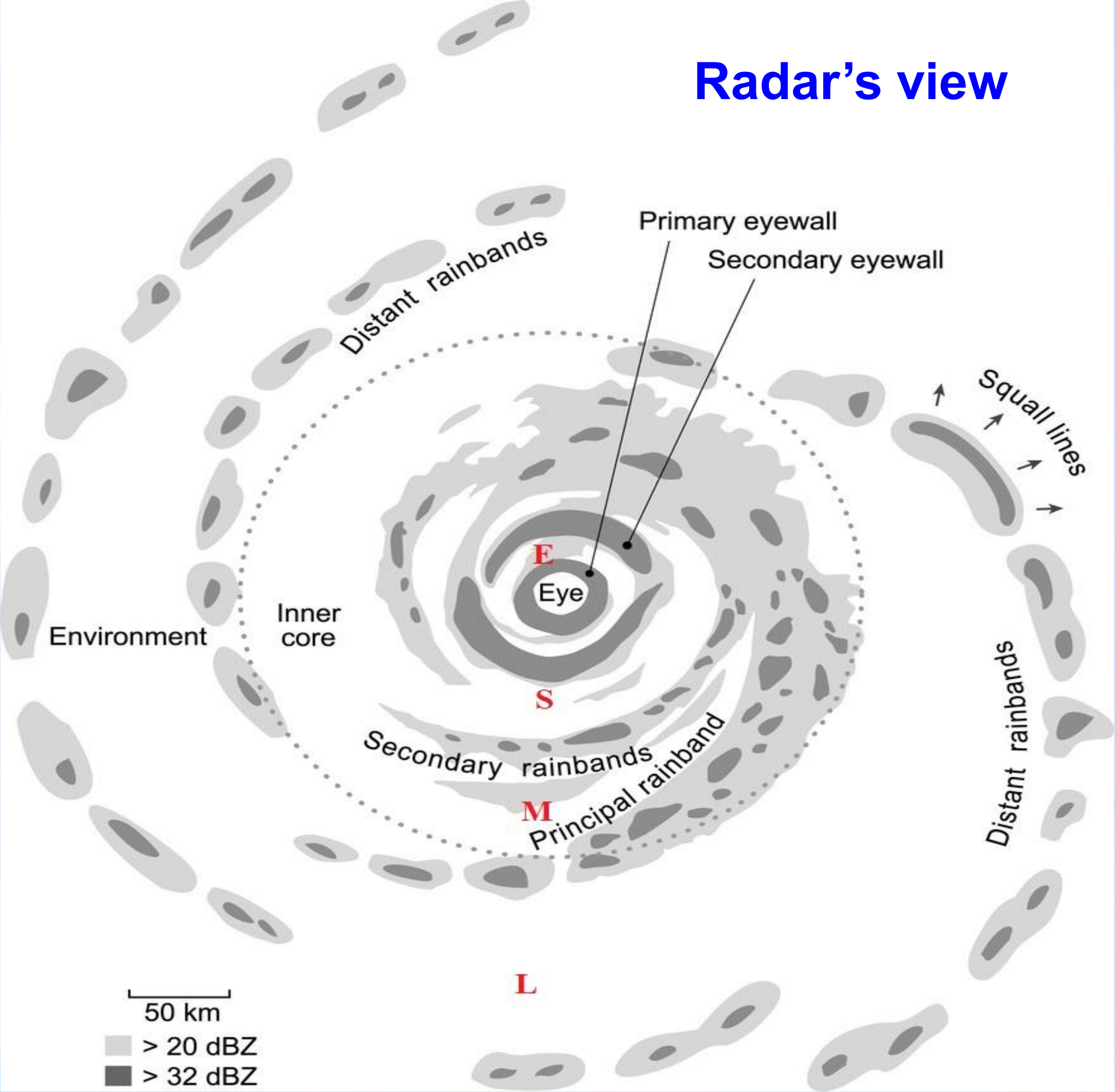
Above parameters and their changes with time enable us to predict the position and maximum height of storm surge, maximum sustained wind and wind swath

Structure of a Tropical Cyclone (View from the top)

Wind zones:-

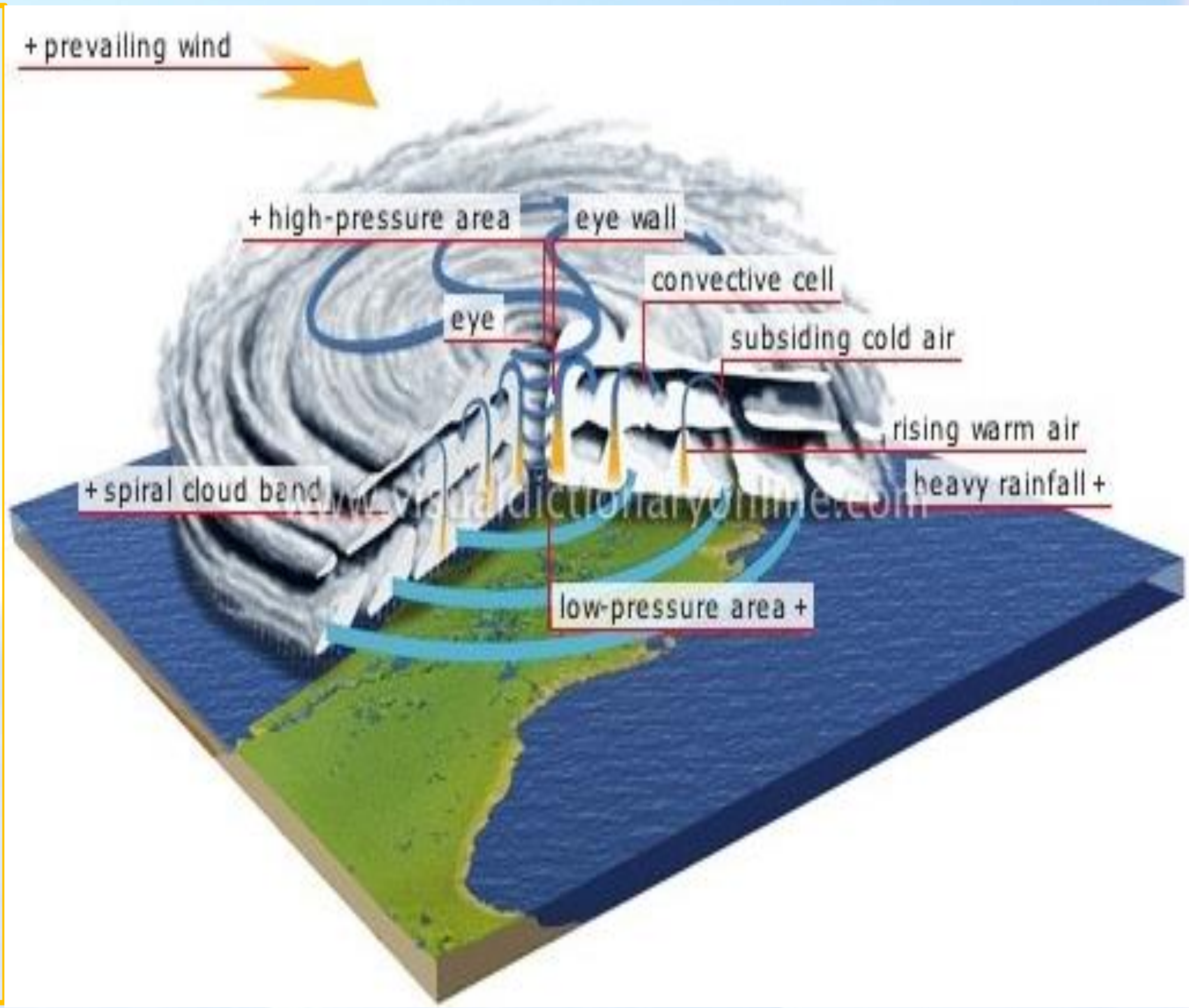
- **E :- Eye, Calm central area 10-30 km in diameter**
- **S :- Inner ring of hurricane winds 100 kmph or more, 50-150 km wide**
- **M :- Outer storm area of moderate winds 20-50 kmph with overcast skies & occasional squalls**
- **L :- Outer most area of light winds**

Radar's view



Vertical Structure of Tropical Cyclone

- **Inflow Layer** – Pronounced inward radial component extending most of lower tropospheric layer, most pronounced inflow above frictional layer
- **Mid-tropospheric Layer** - where there is very little radial motion
- **Outflow Layer** - in upper troposphere extending to the top of TC.
- **Maximum outflow is near 200 hpa**



- **In a tropical cyclone the central part consisting of the eye and wall cloud (inside a 50 km radial distance from the centre) is on the meso-scale while the rest of the cyclone is on the synoptic scale → Complex Scales of Motion**

Size Characteristics of Tropical Cyclones over NIO

i) Horizontal Extension : 150 – 1000 kms

ii) Vertical Extension : About 15 Km

iii) Small Size : Diameter up to 300 Km

iv) Medium Size : Diameter 300 – 700 Km

v) Large Size : Diameter more than 700 Km

PREDICTION OF TROPICAL CYCLONIC DISTURBANCES

Tropical Cyclone Prediction

- **Forecast of Tropical Cyclone Formation**
- **Forecasts of**
  - ✓ **TC Movement**
  - ✓ **TC Intensification**
  - ✓ **Associated Severe weather elements – Rainfall, Gales and Storm Surge**
  - ✓ **Landfall**
  - ✓ **Weakening**

PREDICTION OF TROPICAL CYCLONE FORMATION

Tropical Cyclone Formation or Genesis

---------- Herbert Riehl (1954)

"We observe universally that tropical storms form only within pre-existing disturbances…. An initial disturbance therefore forms part of starting mechanism. A weak circulation, low pressure and deep moist layer are present at the beginning. The forecaster need not look into areas which contain no such circulation"

Synoptic – scale aspects for TC formation

- TCs form from pre-existing disturbances with abundant deep convection
- Pre-existing disturbance must acquire warm core thermal structure throughout troposphere
- Increase in lower tropospheric relative vorticity over horizontal scale of 500-800 kms
- Large scale environment with low vertical wind shear
- Appearance of curved banding features in satellite imageries
- Large scale outflow over the area in Upper Troposphere

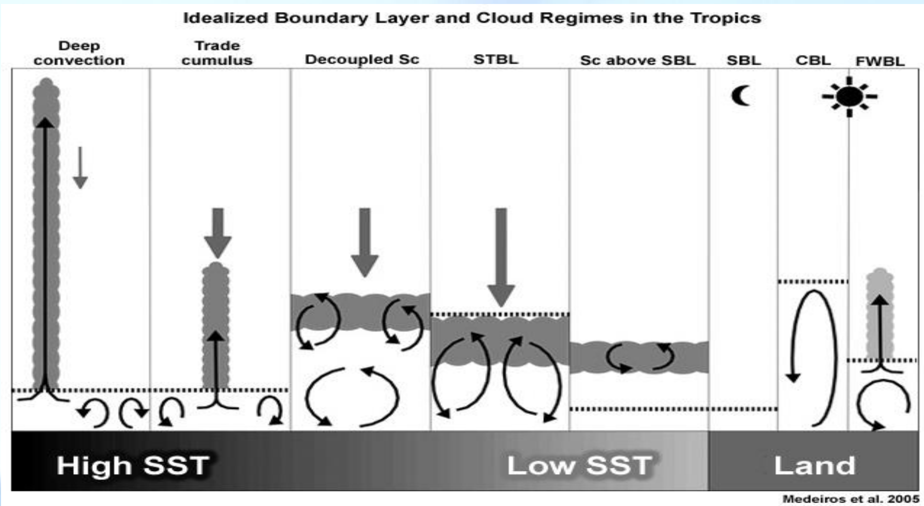
Synoptic – scale aspects for TC formation

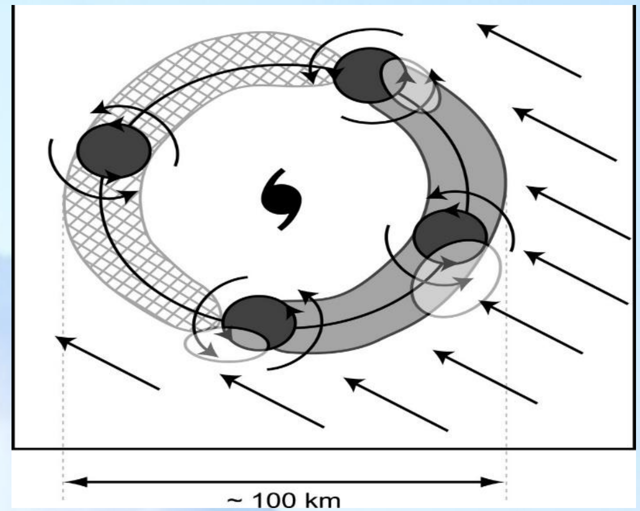
- There are two primary influences on tropical cyclone formation: i) internal & ii) environmental
  - Both are equal in importance during the initial formative stages of a tropical disturbance.
  - Environmental influence :Enhancement of low-level convergence and increase in organization associated with a developing tropical disturbance or convective cloud cluster
  - As the disturbance becomes more organized and self-sufficient, the importance of the environment in maintaining the structure of the disturbance reduces
  - TCs have been observed to develop from the inner core outward and also decay from the inner core outward due to internal influence

Background Requirements: Possible Tropical Cyclone Formation

- Climatology is right (i.e., region, season, SST, etc.)

- Synoptic Flow pattern is right (monsoon trough , high vorticity , small vertical wind shear, etc.)





- Active Mesoscale Convection System (MCS) is present within a cloud cluster system

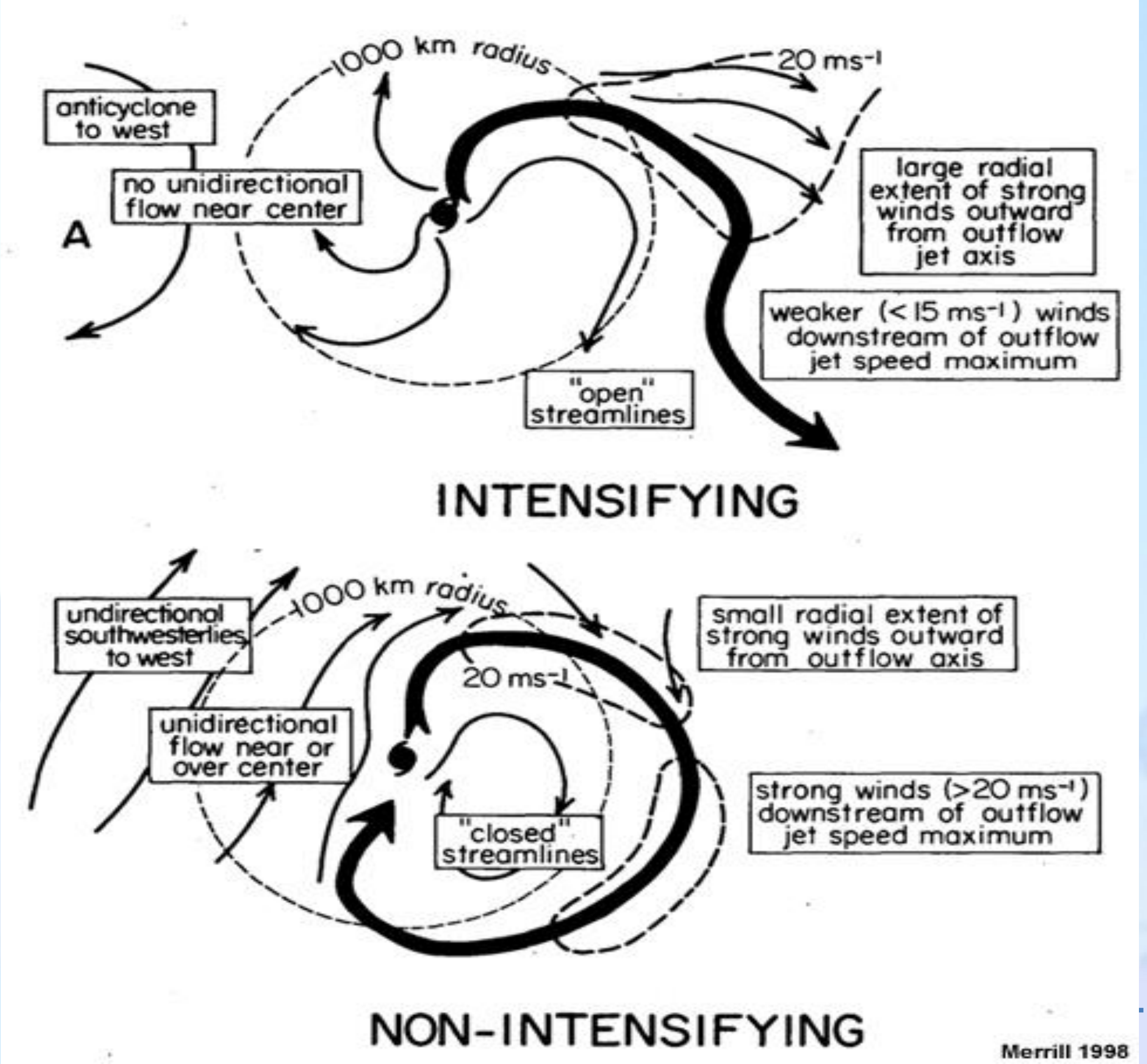
➢ <u>Large values of Relative Vorticity and small vertical wind shear do not guarantee development of TC</u>

➢ <u>They only indicate that probability of TC formation is high</u>

Tropical Cyclone Formation – Role of upper winds

- Upper-troposphere anticyclone over a pre-storm disturbance with a small vertical shear combine to create a favourable environment for TC formation.
- Many times, upper-level anticyclonic flow is accompanied by large vertical shear which inhibits tropical cyclone formation.
- In situations where vertical shear is weak, upper-level flow can ventilate the pre-storm disturbance.
  - ✓ If the latent heat released in the upper troposphere is carried away faster than it can be replenished by the low-level convergence and resulting convection, the disturbance will not develop.
  - ✓ If an upper-level outflow pattern does not develop even after the formation of initial disturbance , the system will retain too much mass in the upper-levels which discourage continued low-level convergence

Upper Tropospheric Factors affecting Tropical Cyclone Intensity



Tropical Cyclone triggers

- Trigger is anything that creates synoptic scale horizontal convergence in atmospheric boundary layer.
- It forces upward motion which initiates and support organised cluster of thunderstorm cells (incipient tropical disturbance)

- Some of the triggers noticed are
  - ITCZ
  - Easterly waves, Monsoon troughs
  - Mid-latitude fronts that reach tropics
  - Tropical Upper-Tropospheric Troghs (TUTT)

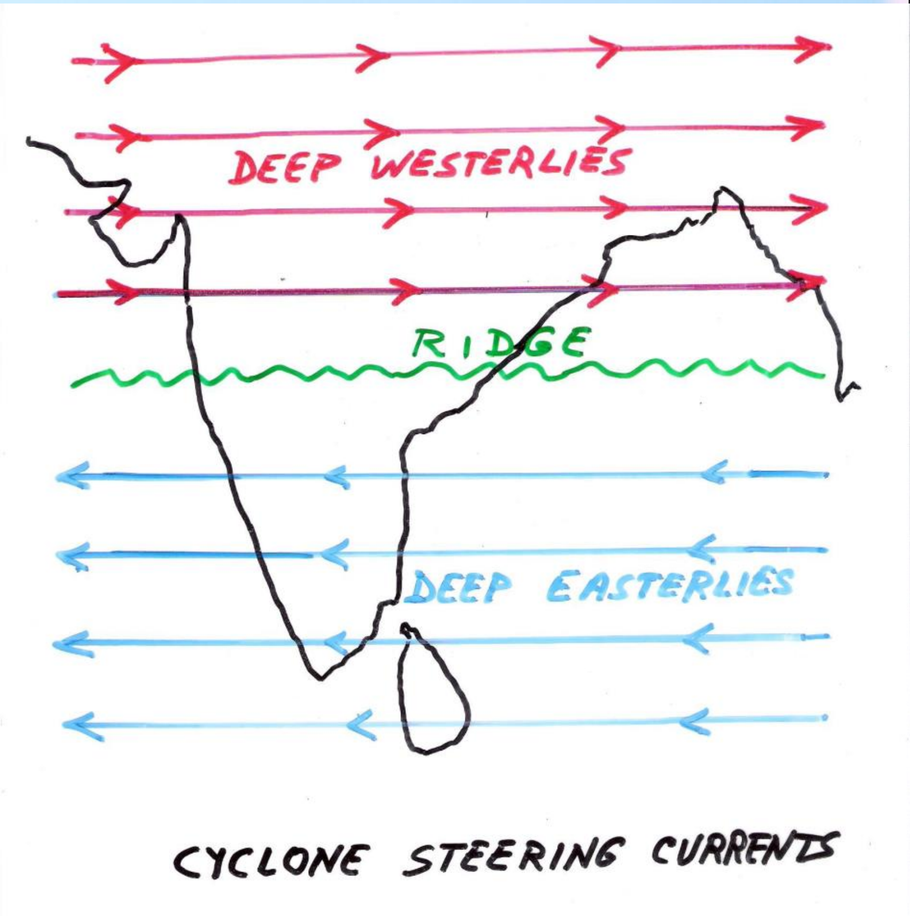
Prediction of Tropical Cyclone Movement

- **Surface observations**
  - **Pressure Change –**
    - 24 hour pressure change a reliable sign of an approaching Cyclone.
    - Pressure falls slowly in the initial stage and more rapidly as the system moves closer to the station
  - **Wind** - Shift of wind direction or sudden increase in speed of coastal stations give a clue where cyclone is moving

PREDICTION OF TROPICAL CYCLONE MOVEMENT

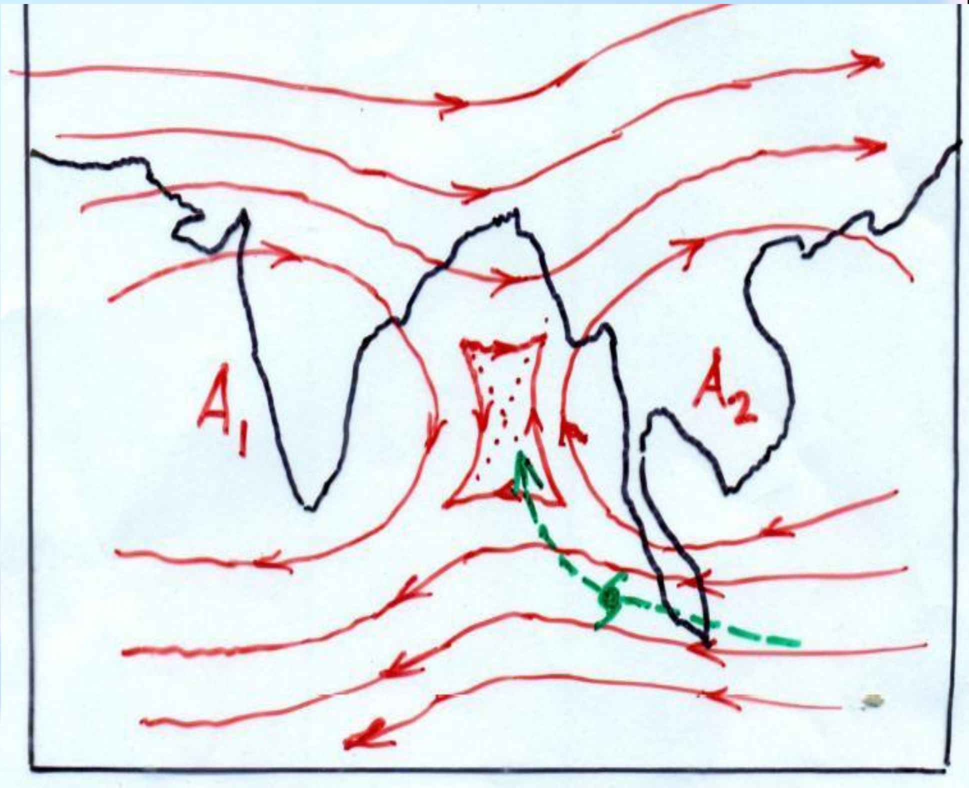
Prediction of Tropical Cyclone Movement

- **Upper air Observations**
- **Steering Concept:**
  - **TC is steered by the basic current in which is embedded**
  - **Broad ideas used were**
    - ✓ **High level Flow (200-150 hPa)**
    - ✓ **Average Flow in the layer 500 – 200 hPa**
    - ✓ **Pressure weighted mean winds of 500 , 300, 200 hPa levels with weights 3, 4 and 3 – determined empirically**



Prediction of Tropical Cyclone Movement

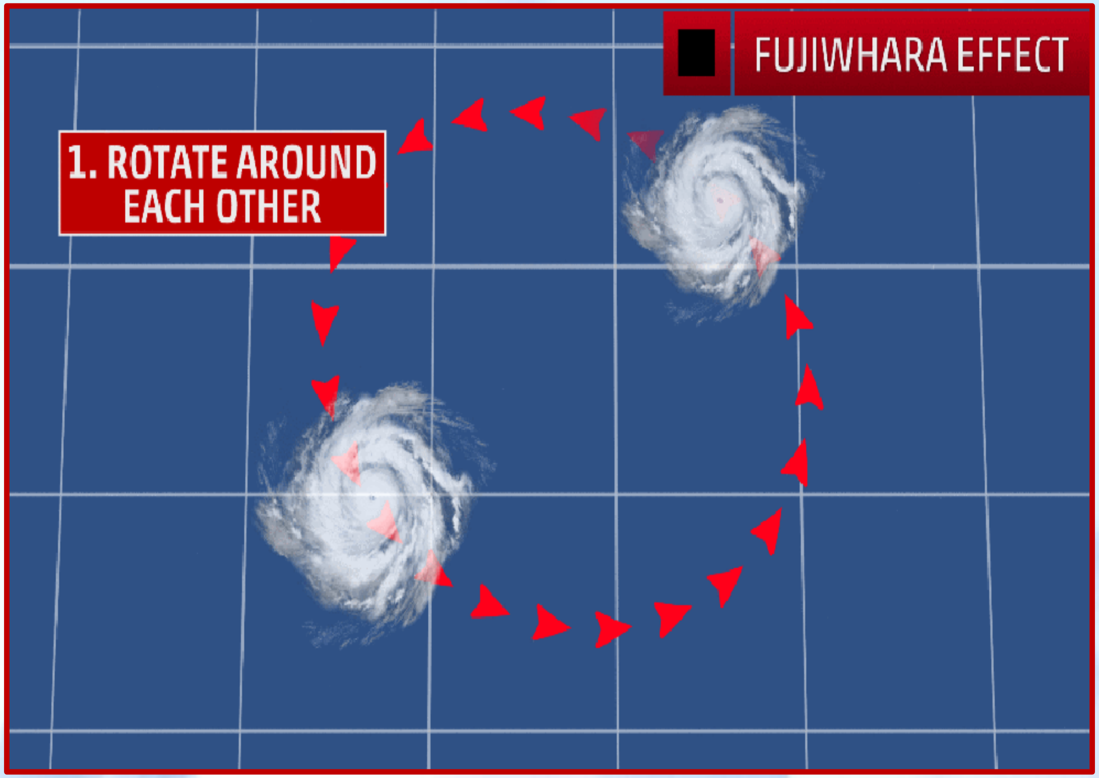
- ✓ Upper air Observations
- ✓ Recurvature
  - Large amplitude trough in the westerlies located a few km to the west of cyclone centre
  - “COL” region between two anticyclone cells above the system centre down below
  - When a tropical cyclone approaches a col region between two upper tropospheric anticyclones, the cyclone slows down and either recurve or create looping motion.
  - Location of centre with respect to the ridge line:

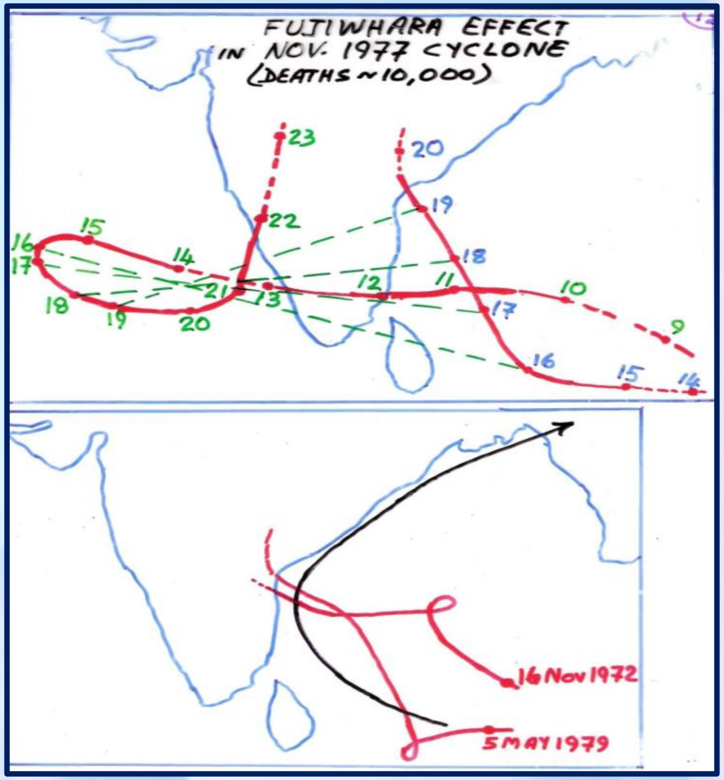


- Centre is 3 deg or more south of ridge line – movement in west or west-northwesterly direction
- Centre is within 3 deg south of ridge line – movement in northwesterly direction & Slow down in speed
- Centre north of ridge line – display recurvature and movement towards north and then northeast with increased speed

Prediction of Tropical Cyclone Movement

Interaction phenomenon between two tropical cyclones is called Fujiwhara effect





- Two storms that are relatively equal in their strength, can gravitate closer. Once this happens, they could “dance” around each other for a bit.
- If one hurricane is a lot stronger than the other, the smaller one will orbit and eventually get absorbed to to evolve into one larger storm.
- The third possibility would be pivoting away from each other, shooting them out in two different directions.

Movement Characteristics of Tropical Cyclones over NIO

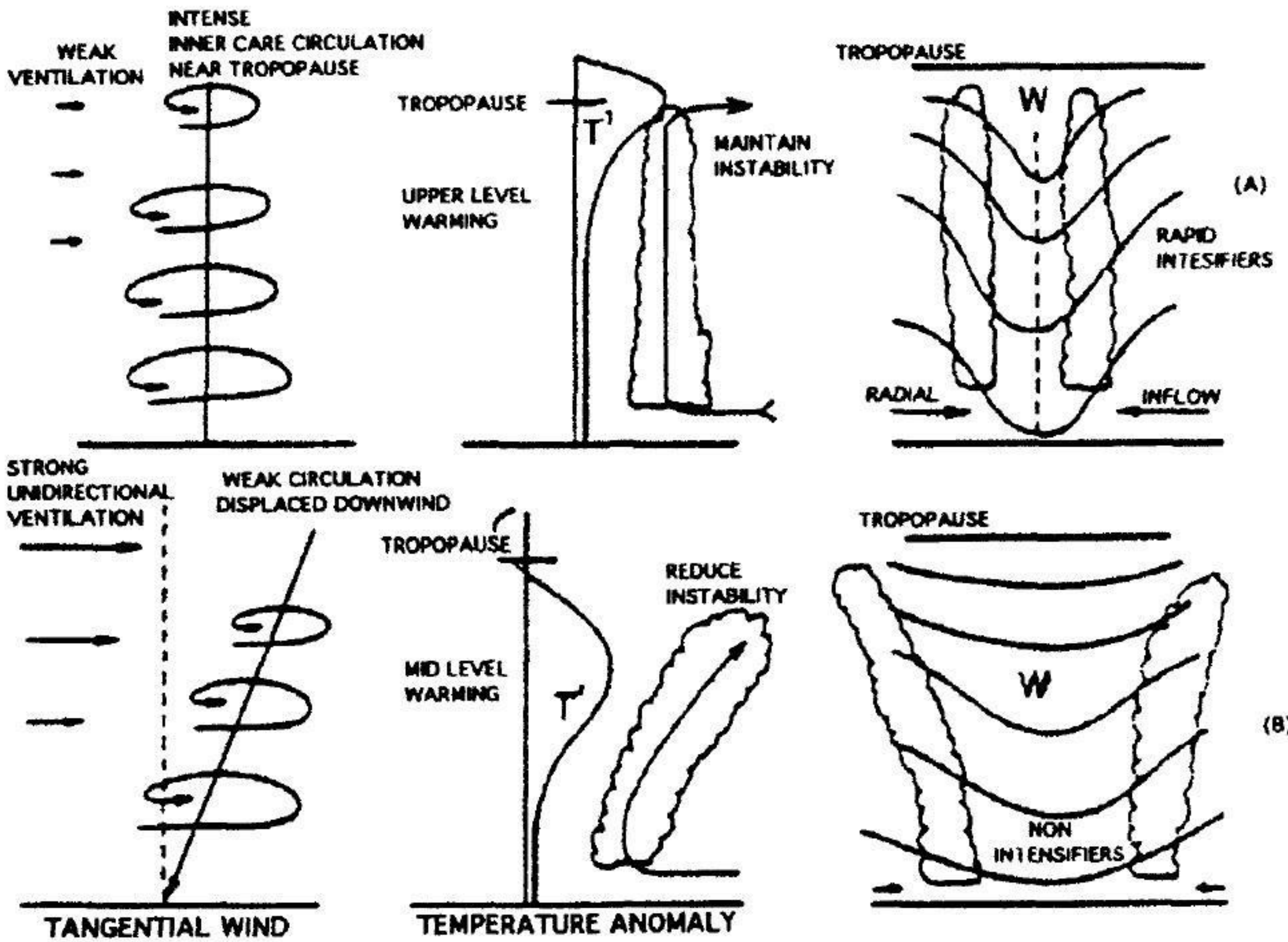
Speed of Cyclone movement

- Slow moving : Speed 10-14 kmph
- Normal : Speed 15-20 kmph
- Fast moving : Speed > 20 kmph

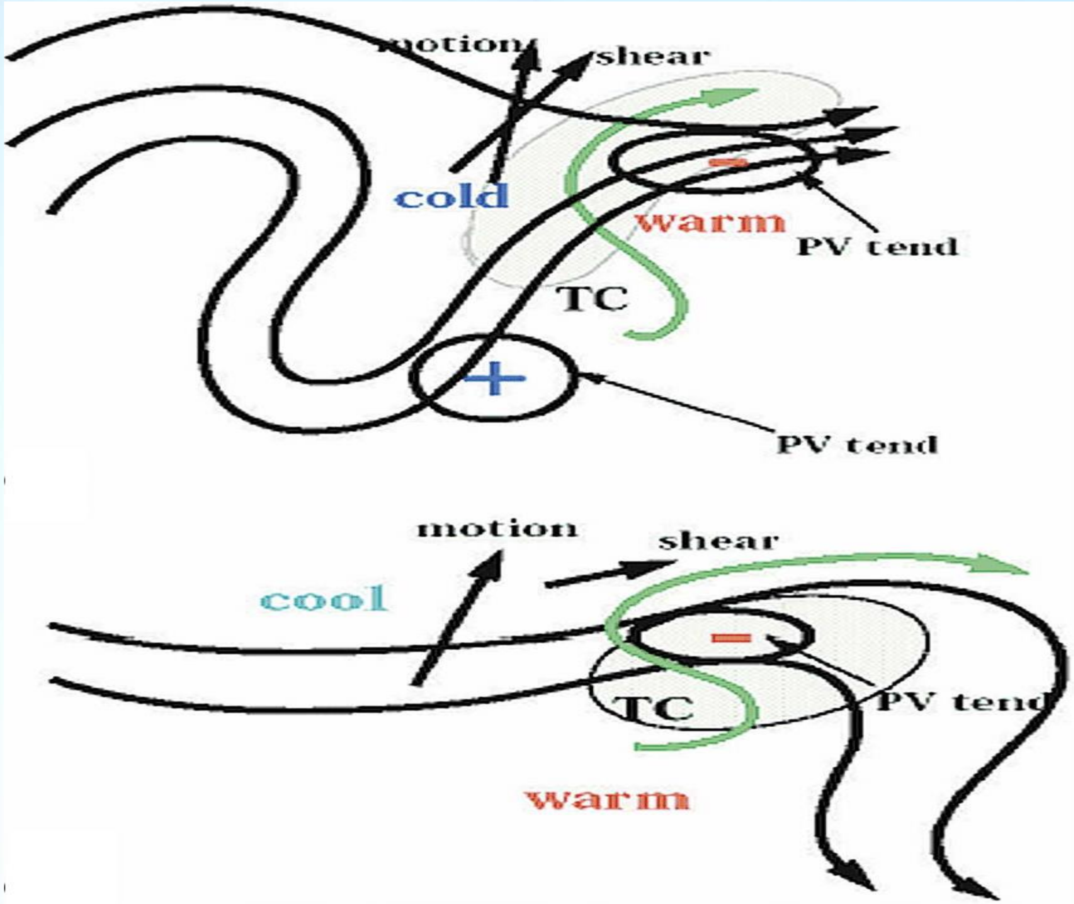
- Small size systems are generally fast moving
- Large size systems are slow moving in general

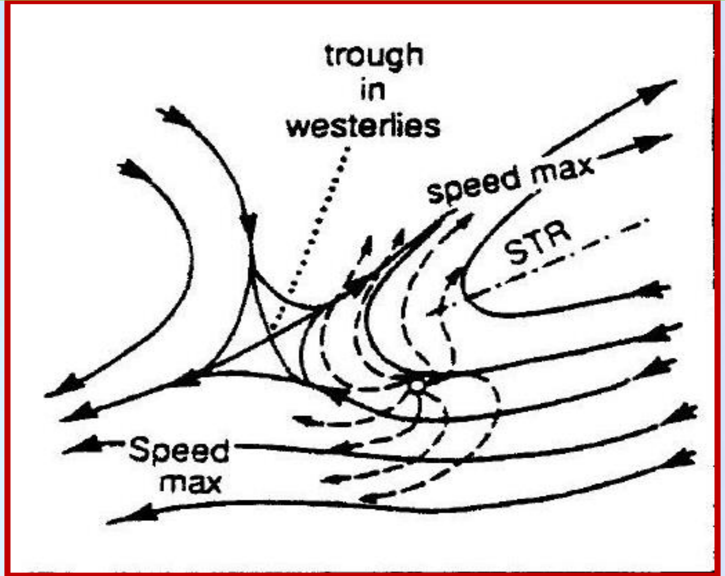
PREDICTION OF TROPICAL CYCLONE INTENSIFICATION

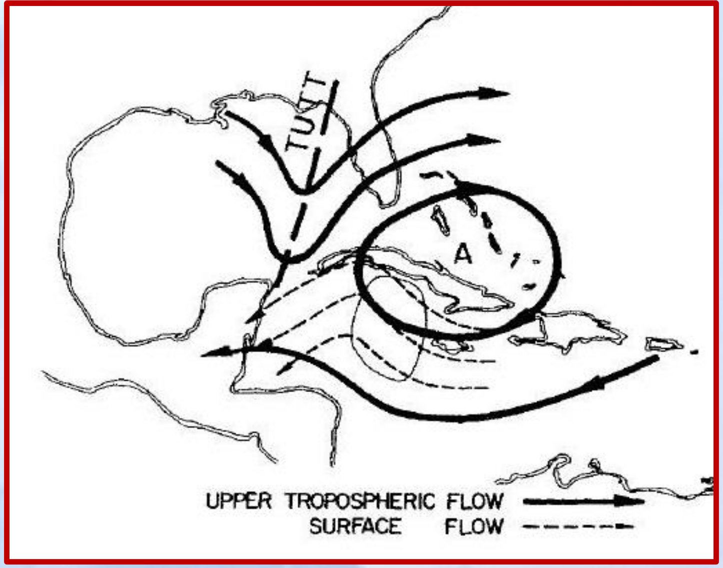
Conditions for TC development
(A) Favourable and (B) Unfavourable



Tropical Cyclone Intensification – role upper troposphere winds







TUTT would act as a process to diminish the inhibiting influences of vertical shear and upper level ventilation over the disturbance.

Tropical Upper Tropospheric Trough (TUTT)

Weakening of Tropical Cyclones

- TCs are known to maintain their internal energy for very long time, but they are liable to weaken
- They start weakening under following situations
  - Move over region of colder SST
  - Hostile upper winds : TC extend to great heights when light winds prevail aloft. Unusually strong winds at this level blow off high cloud tops and the system gets disorganised
  - Move over land : Moisture cut off, Frictional force acting against etc
  - Cold and dry air entrainment in mid tropospheric levels

Tropical Cyclone Hazard Characteristics

Rainfall

- Depends on the size, direction and speed of motion of the cyclone.
- Slow moving & large size cyclones produce more rain compared to fast moving small size systems.
- Rainfall intensity can be ~10-12 cm/hour in the core of the cyclone.
- Intensities of the order of 4-6 cm/hour also occur over smaller areas (~100 sq.km) and for shorter durations (~1 hour) outside the core.
- Very heavy rainfall of the order of 35 to 40 cm occur in respect of severe cyclones and of the order of 20 to 30 cm in case of cyclones.
- 90 % of the rainfall is limited within 200 km radius of the cyclone
- The extension of heavy rainfall belt along the coast at the time of TC landfall depends upon the orientation coast with the system movement.
- Rainfall is maximum in
    - Westward moving cyclone - left forward sector
    - Northward moving cyclone - forward sector
    - Northeasterly moving Cyclone - Right Forward sector

Storm Surge

- ✓ Abnormal rise of sea level as the cyclone crosses the coast
- ✓ Sea water inundates the coastal strip causing loss of life, large scale destruction to property & crop
- ✓ Increased salinity in the soil over affected area makes the land unfit for agricultural use for two or three seasons
  - ✓ Storm surge depends on :-
    - ➢ Cyclone intensity
    - ➢ Bathymetry of the coastline
    - ➢ Coastal configuration
    - ➢ Angle at which the cyclone strikes the coast
    - ➢ Time of landfall

Additional Characteristics of Tropical Cyclone Hazards

- **Very heavy rainfall generally commences about 9-12 hours before cyclone landfall**
- **Gale force winds commence about 6-9 hours in advance of cyclone landfall**
- **Maximum storm surge may appear at or near the landfall time to the right of cyclone track**

About prediction – General facts

* Since the extent of the cyclone core hardly exceeds 100 kilometers, disastrous impacts are highly localized. Initially a cyclone offers a macro scale threat and as it approaches the coast the probable area of risk shrinks.
* Thus it is important to distinguish between a "direct hit" and fringe experience.
* Actually less than 20% or so actually witness the core region while most others go through fringe conditions of the cyclones.
* This lulls to a false sense of complacency for the next time. The truth is the conditions a few km away could have been deadly.
* Hence the prediction of place and time of land fall is very critical when compared to other aspects of cyclone

What Intensifies TCs?

- ❖ Increased Low-Level Relative Vorticity
- ❖ Increased Upper-level Outflow
- ❖ Decrease in Wind Shear
- ❖ Warm Sea Surface Temperature
- ❖ Strong Radial Inflow (moisture, heat, angular momentum)
- ❖ Moistening of low-mid levels -heavy precipitation
- ❖ Evidenced in the patterns of the convection

What weakens TCs?

- Movement Over Land
- Strong Vertical Wind Shear
- Restricted Outflow
- Cool SSTs
- Slow moving TCs (cooler SST by mixing)
- Dry air intrusion
- Fast TC Motion (> 20 kt)

Critical elements

1. Good Analysis and environment assessment
2. Persistence (esp. for first 12h)
3. Changes in the environment (NWP) Conceptual Models
4. Objective outputs:
   statistical, NWP trends & consensus; SCIPS

5. Existing policy

⇒ Combining Subjective Vs Objective
⇒ Picking Rapid Intensification/weakening

Concluding Remarks

- **Numerical / dynamical models have improved tremendously in their capability in providing accurate guidance in terms of track as well as intensity prediction at least 4-5 days in advance.**
- **However, knowledge of 'synoptic Meteorology' is highly essential for the Forecasters to interpret the Numerical model Guidance effectively for the easy understanding of the large scale dynamics and to arrive at the final decision.**
- **This is especially so, in case of complex tracks involving, Looping, re-curvature, Binary / Fujiwhara type interactions and lack of consensus between different NWP model forecasts.**

THANK YOU