



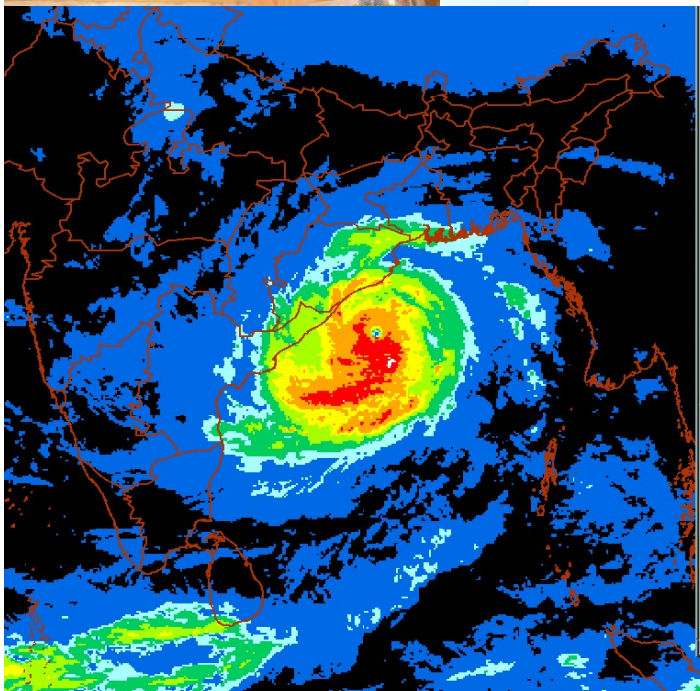
Chasing the Cyclone

MRUTYUNJAY MOHAPATRA
DIRECTOR GENERAL OF METEOROLOGY

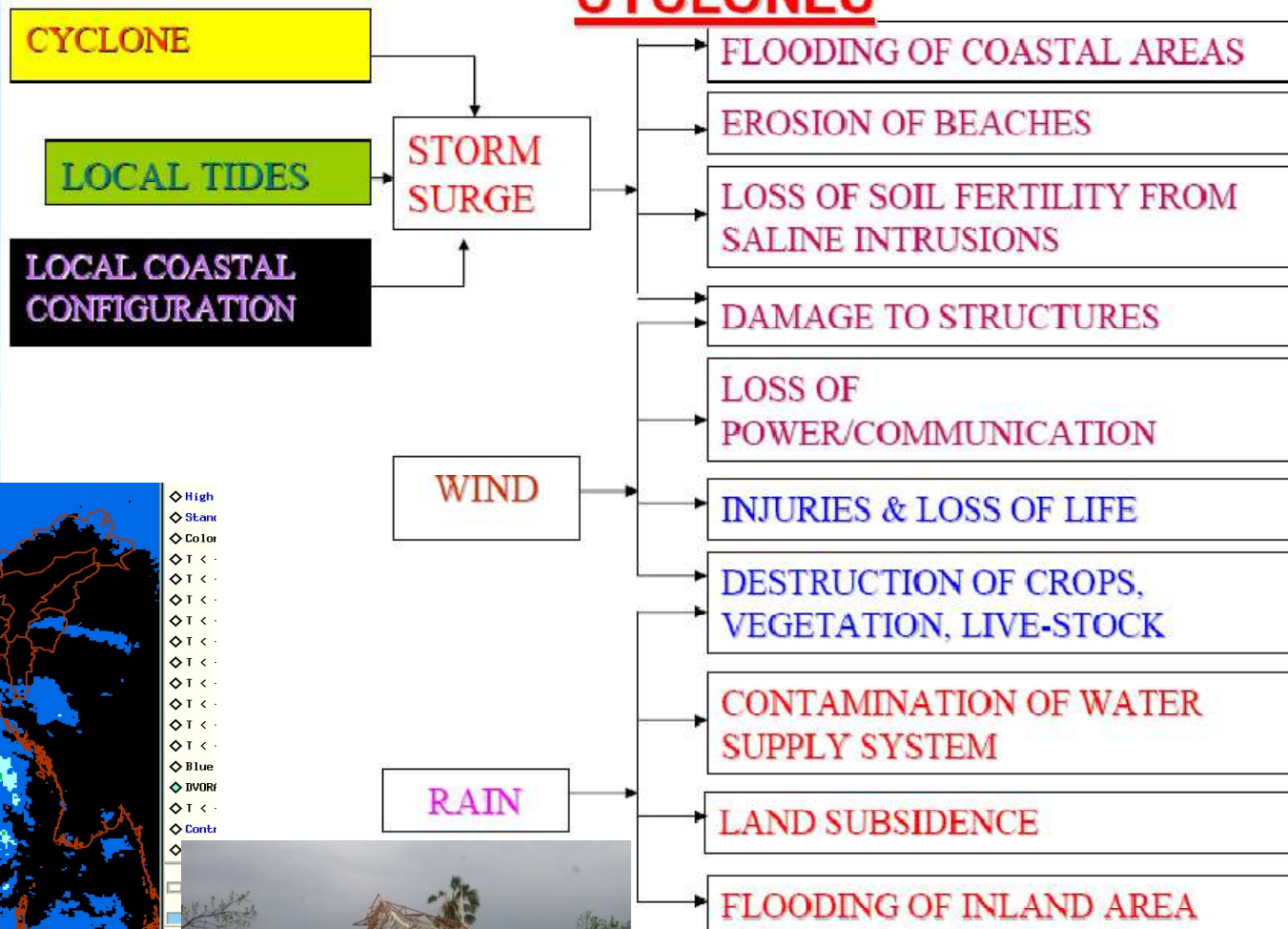
INDIA METEOROLOGICAL DEPARTMENT
NEW DELHI-110003

m.mohapatraimd@imd.gov.in

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INDIA METEOROLOGICAL DEPARTMENT



TYPES OF POTENTIAL DAMAGES ACCOMPANYING **TROPICAL CYCLONES**



A Few Facts about Tropical Cyclones(TCs)

- ❖ During 1970-2019, 33% of hydromet. disasters are caused by TCs.
- ❖ One out of three events that killed most people globally is TC.
- ❖ Seven out of ten disasters that caused biggest economic losses in the world from 1970-2019 are TCs.
- ❖ It is the key interest of 85 WMO Members prone to TCs
- ❖ Casualties of 300,000 in Bangladesh in 1970 is still ranked as the biggest casualties for the last five decades due to TC;
- ❖ Cyclone Monitoring, forecasting and warning services deals with application of all available modern technologies into operational services.

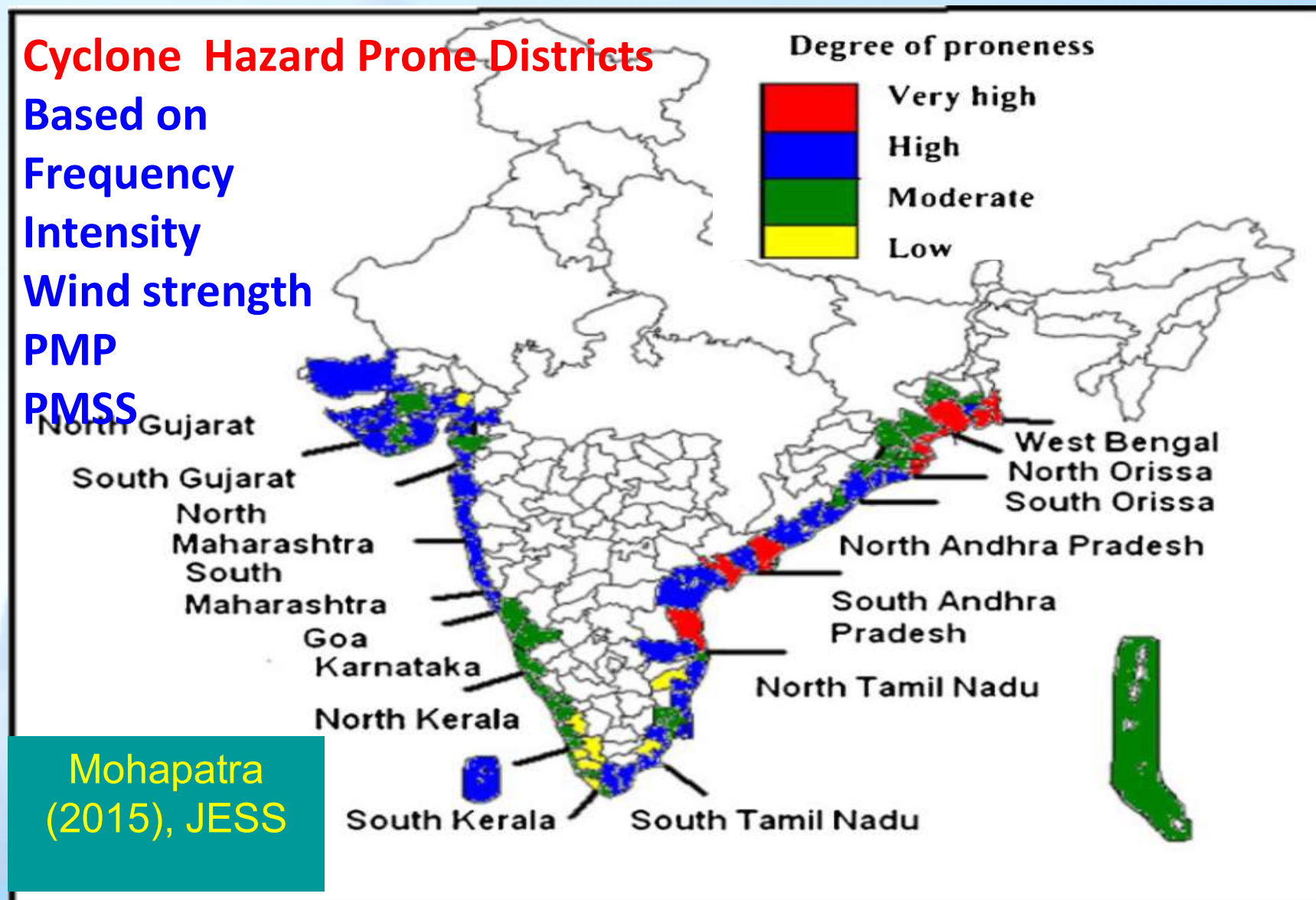
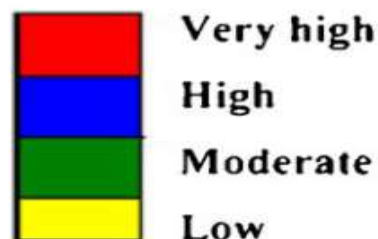


Cyclone Hazard Analysis

Cyclone Hazard Prone Districts

Based on
Frequency
Intensity
Wind strength
PMP
PMSS

Degree of proneness



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Cyclone

- ❖ A low pressure system, where the wind rotates in anticlockwise (clockwise) direction in northern (southern) hemisphere with a minimum sustained wind speed of 34 knots (62 kmph)
- ❖ **World Meteorological Organization's official definition :**
 - A tropical cyclone (hurricane, typhoon) is a synoptic scale (≥ 100 km) ,
 - non-frontal (no sharp gradient of temperature) **disturbance**,
 - **over** tropical or subtropical **waters** ,
 - **with** organized convection, **and definite** cyclonic surface wind circulation.

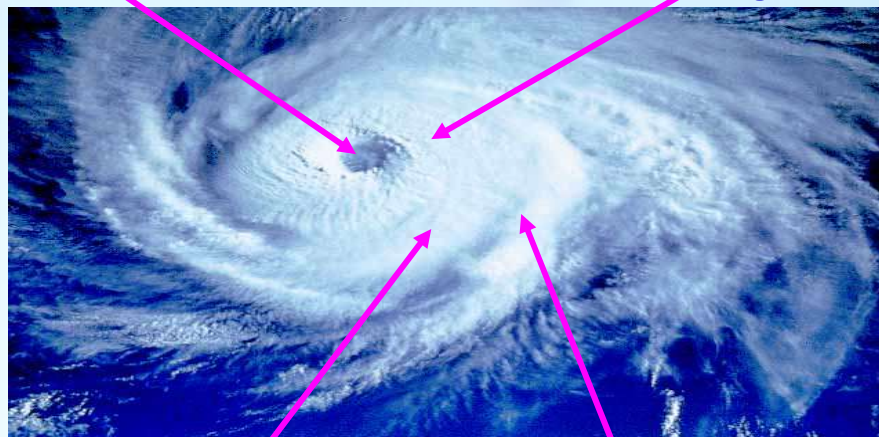
WESTERN PACIFIC	TYPHOONS	
AUSTRALIA	WILLY-WILLIES	
MEXICO	CORDONAZO	
PHILIPPINES	BAGIOUS	Named after a city 'BAGUIO' which experienced a rain fall of 116.8 cm in 24 hrs in July, 1911
INDIAN SEAS	CYCLONES	Derived from Greek word 'CYCLOS' – Coil of a Snake
ATLANTIC & EASTERN PACIFIC	HURRICANES	Derived from 'HURACON' - God of Evil (central American ancient aborigines call God of Evil as HURACON)



Tropical cyclone

Eye

Eye-wall



- ❖ Horizontal : 100-1000km
- ❖ Vertical : 10-15 km
- ❖ Wind speed : UP to 300 km / hr
- ❖ Average storm speed : About 300 km / day

Spiral cloud bands Convective cells

Eye Wall/ Wall Cloud : Ring of convective clouds around eye.

- ❖ Intense rainbands spiralling inwards. Most dangerous part of the TC.
 - ❖ Width of wall cloud is about 20-100 Km.
 - ❖ Region maximum pressure gradient, maximum temperature gradient, heaviest precipitation and strongest wind
- ❖ **EYE**: Central part, is known as eye. Diameter of eye: 10 to 100 Km
 - ❖ Formed by air sinking from upper levels to lower levels and is characterized by calm winds, clear sky and lowest pressure
 - ❖ Abrupt cessation of precipitation when eye passes over an area.
 - ❖ Shape : Circular or elliptical, Regular/diffused eye, Single/Double eye
 - ❖ Eye is warmer than the surrounding.



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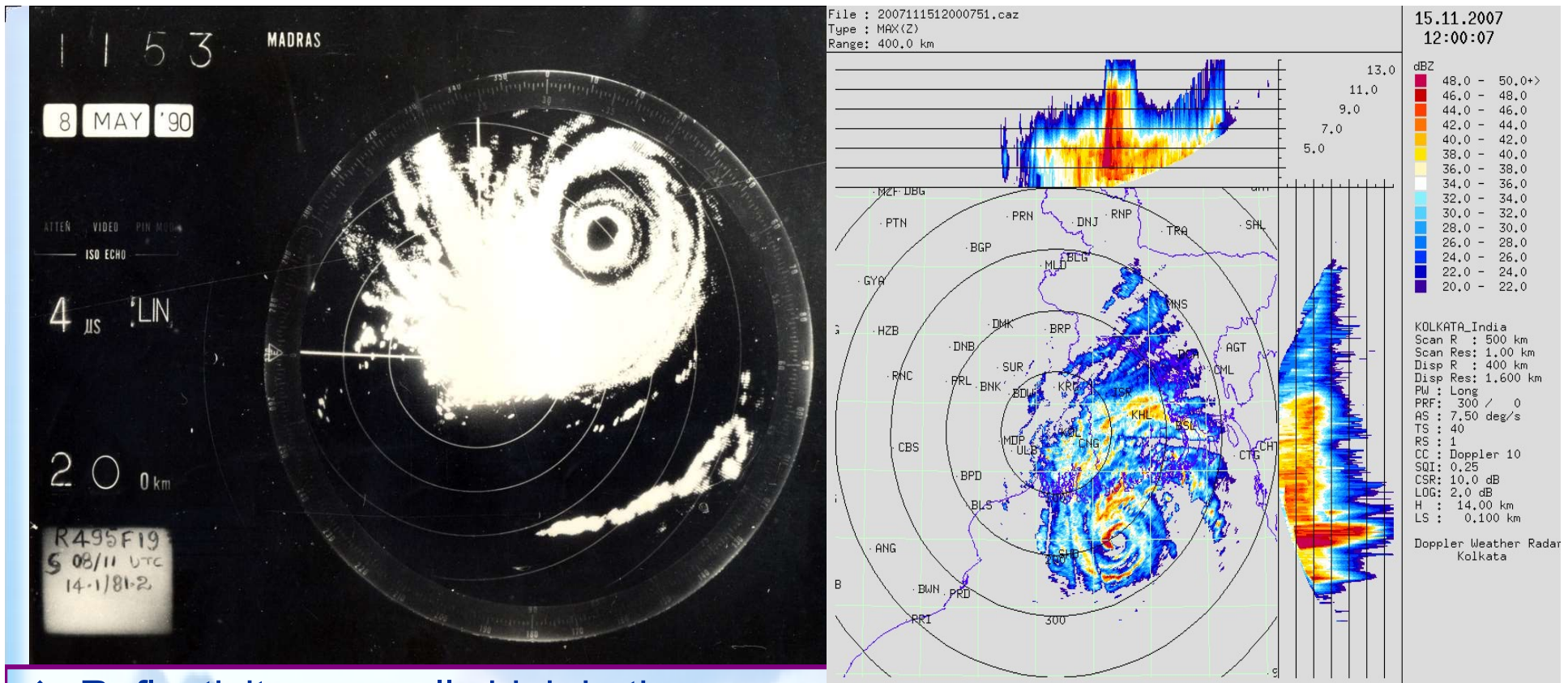


Classification of cyclones

Introduction Of Extremely Severe Cyclonic Storm Category Since 2015

Low pressure system	T Number	Maximum sustained surface wind speed		
		knots	mps	kmph
Low (L)/ Well marked Low	LLC/T 1.0	< 17	< 9	< 31
Depression (D)	T 1.5	17-27	9-14	31-49
Deep depression	T 2.0	28-33	15-17	50-61
Cyclonic storm	T 2.5-3.0	34-47	18-24	62-88
Severe cyclonic storm	T 3.5	48-63	25-32	89-117
Very Severe cyclonic storm	T 4.0-4.5	64-89	33-46	118-166
Extremely Severe Cyclonic Storm	T 5.0-6.0	90-119	47-61	167-221
Super Cyclonic Storm	T 6.5 -8.0	120 and above	62 and above	222 and above





- ❖ Reflectivity generally high in the eye-wall
- ❖ Rainbands :
 - composed of weaker echoes, but with cells of high reflectivity
 - spiraling outward from the centre
 - can be embedded in a large shield of stratiform rains
- ❖ Convective ring: the radial flow feeds the updraft from the convex side
- ❖ Spiral band: the swirling winds feed the updraft from the concave side



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Evolution of tropical cyclones

Tropical Disturbance (Low): DINA _ 16 JAN 2002 - 00 UTC

region of intense convective activity with surface winds of moderate intensity, and some indication of cyclonic motion.

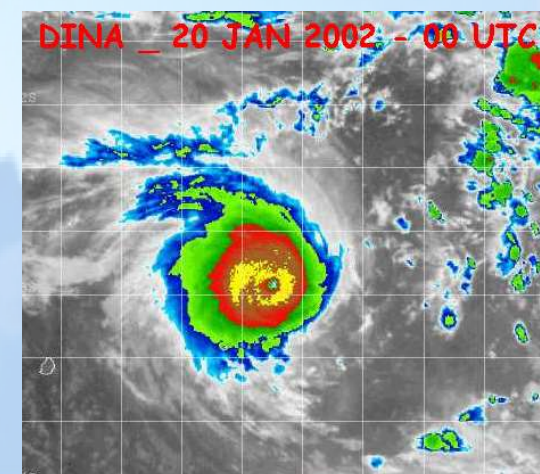
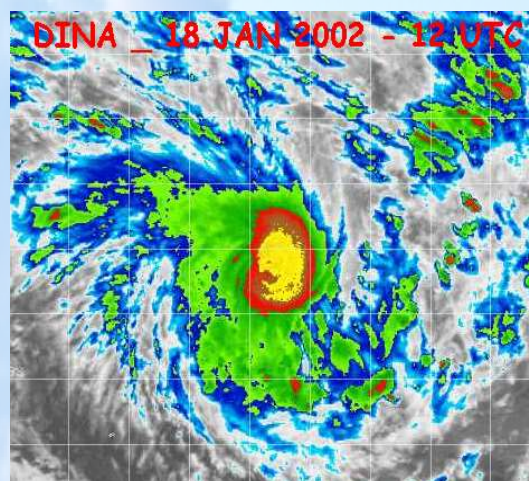
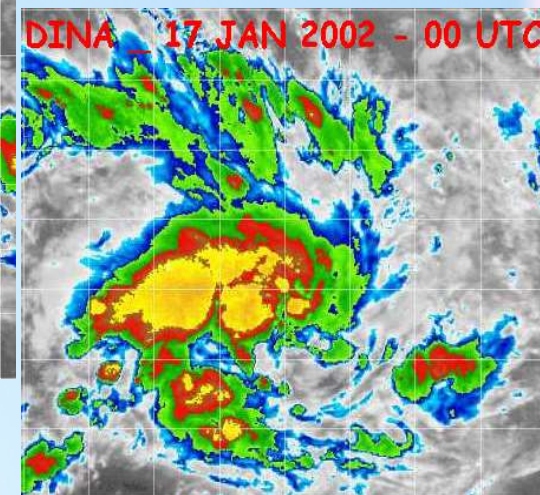
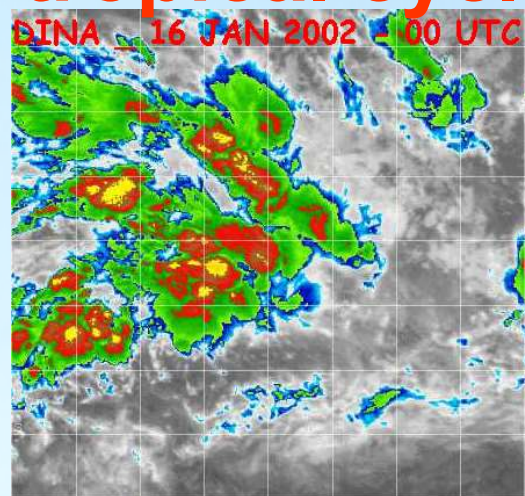
Depression/deep depression

: close circulation with wind speed (averaged over 1 to 10 min) less than 34 kt (63 km/h)

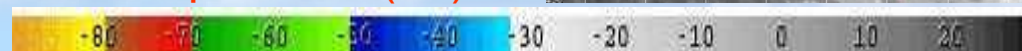
Cyclonic storm/ severe

cyclonic storm: winds between 34 and 63 kt (63-117 km/h)

Very severe cyclonic storm (Hurricane , Typhoon) : winds reaching or stronger than 64 kt (118 km/h)



Cloud Top
Temperature (°C)



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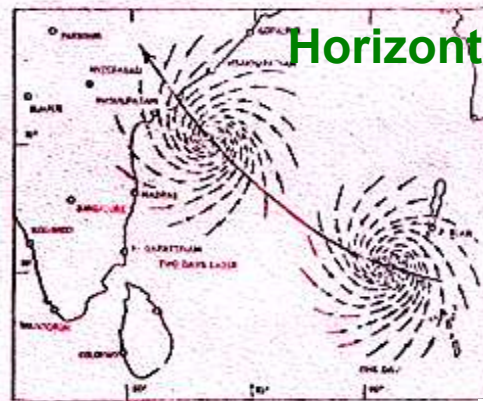
LIFE CYCLE

Life cycle can be divided into the following 4 stages:

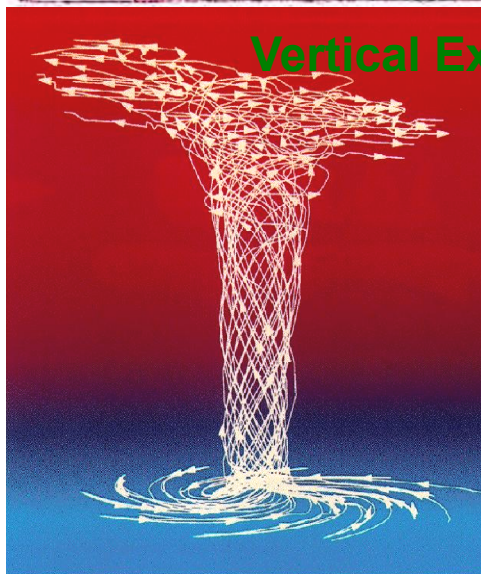
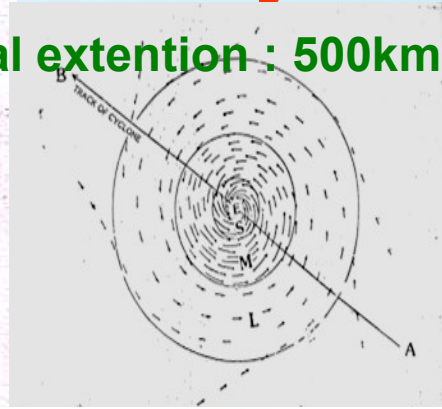
- (i) Formative stage (a few days)
 - (ii) Immature stage (1/2 day to 2-3 days)
 - (iii) Mature stage (1/2 day to 2-3 days)
 - (iv) Decaying stage (2-3 days)
- Cyclogenesis is said to have occurred with formation of a depression.
 - Central pressure falls gradually along with increase in surface wind speed during formative and immature stage. Size also increases
 - During mature stage, intensity remains same (central pressure and wind). But size may increase
 - During Decaying stage, intensity decrease (central pressure increases and wind decreases). Decay occurs due to landfall, colder sea, unfavourable atmospheric condition, interaction with other TC.
 - The average life period of a cyclone over the north Indian Ocean is about 5 days.



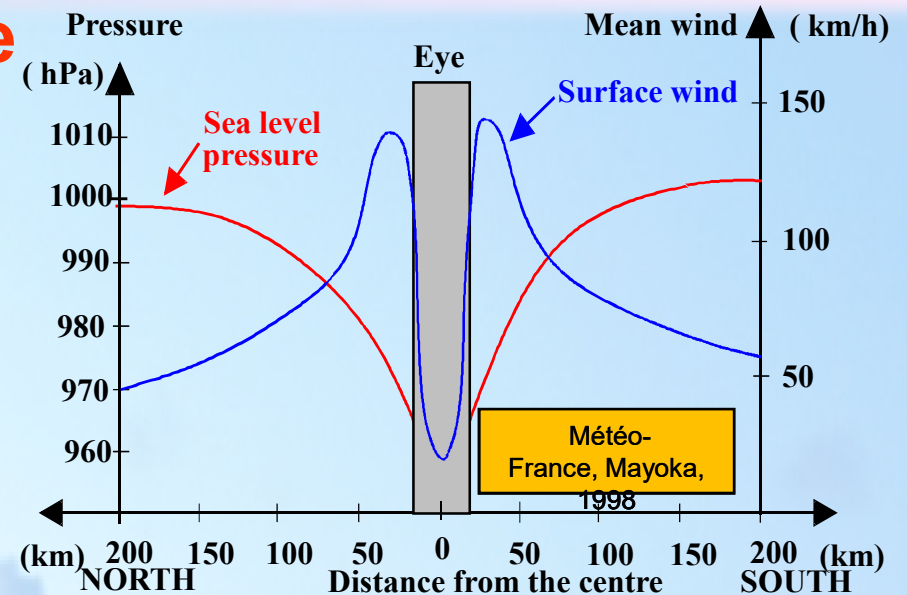
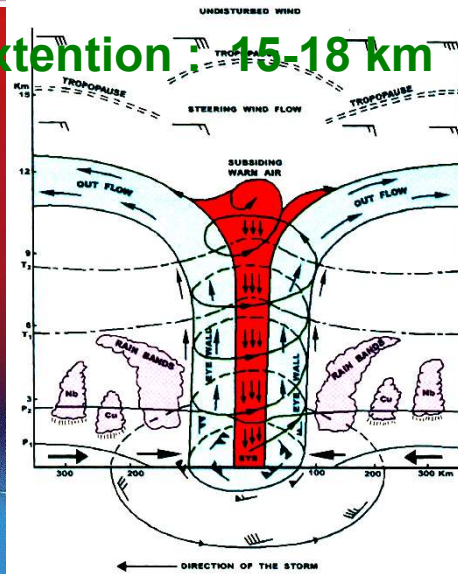
Structure of a Cyclone



Horizontal extension : 500km



Vertical Extension : 15-18 km



➤ Vertically : three distinct layers

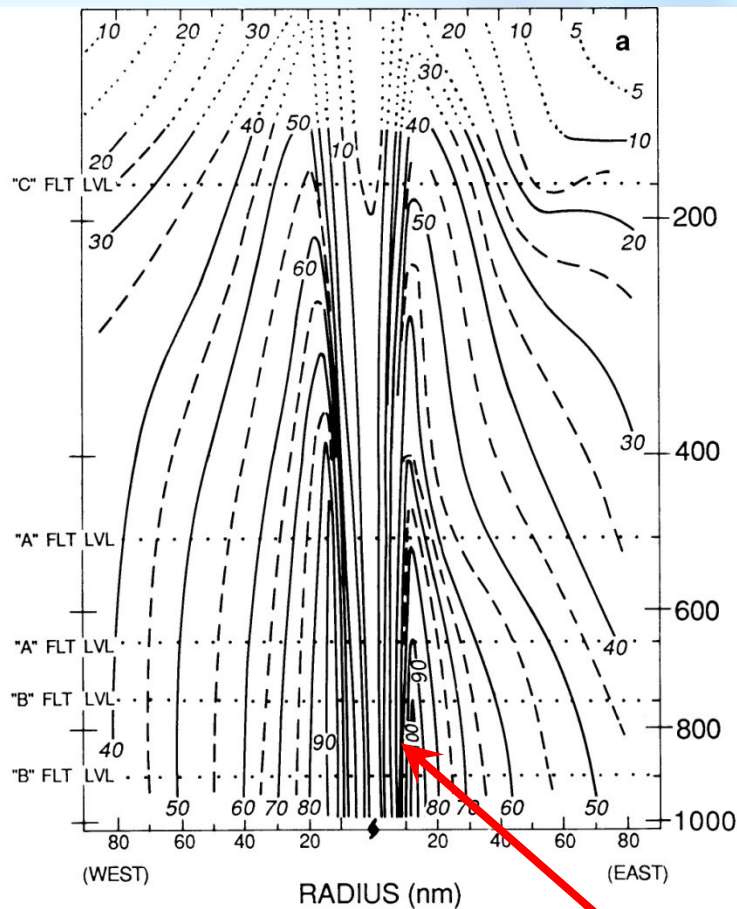
(i) *Inflow layer:*

- Predominant cyclonic flow towards centre from surface upto about 3 Kms.
- Diameter of TC remains same in inflow layer and Symmetric near core & asymmetric outwards.
- Strongest inflow : surface to 1Km.

- *Middle layer:* weak inflow, extends from 3 Km to 7.6 km. diameter decreases with height.
- *Outflow layer:* Above 7.6 km. Maximum outflow at 12 km height.
- Flow is cyclonic near core but anti-cyclonic further outwards.
- diameter is small and is about 1° Lat/ Long at 12 km height.

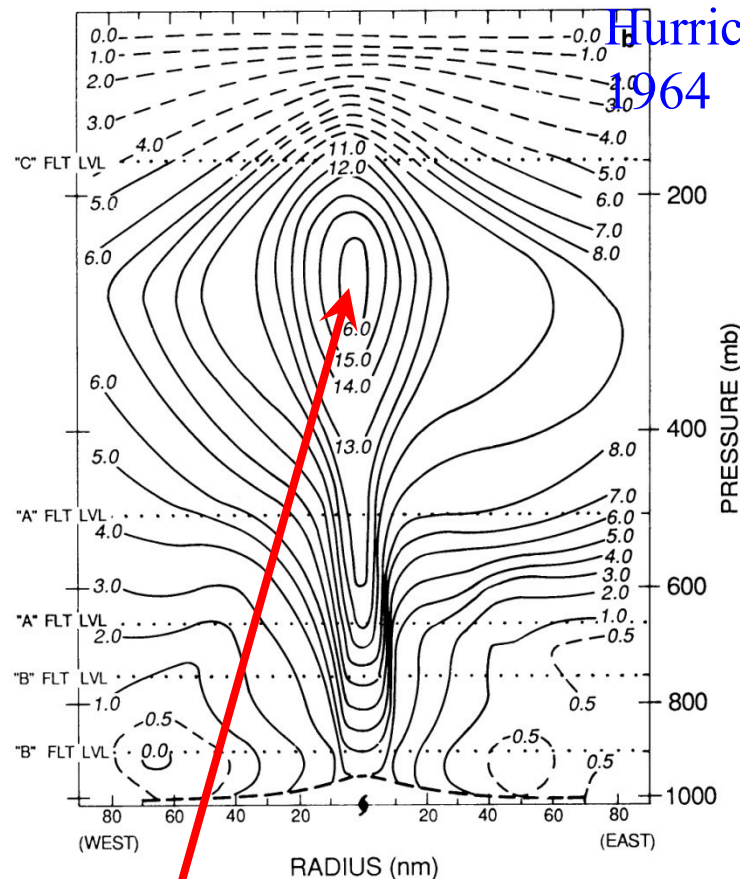
Wind and Temperature cross-section

Wind Speed



Max winds near the centre and near the surface

Temperature Anomaly



Warm core, strongest ~300 hPa(10 km)

Hurricane Hilda, 1964

Hawkins & Rubsam, 1968



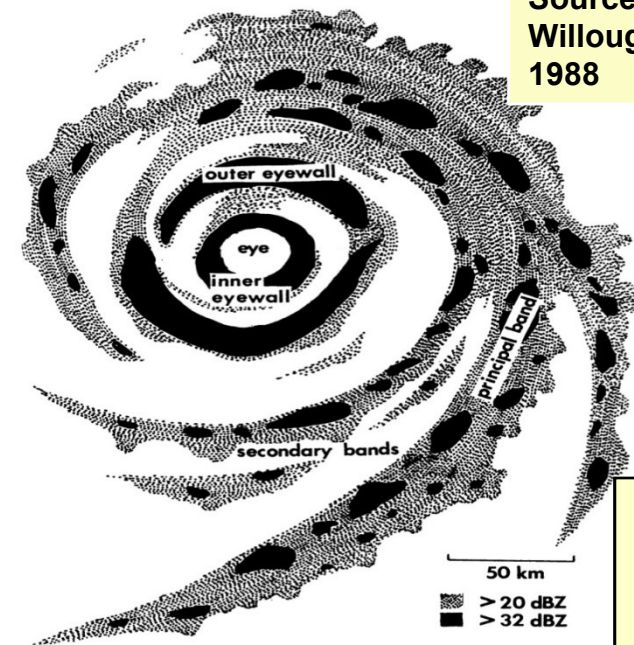
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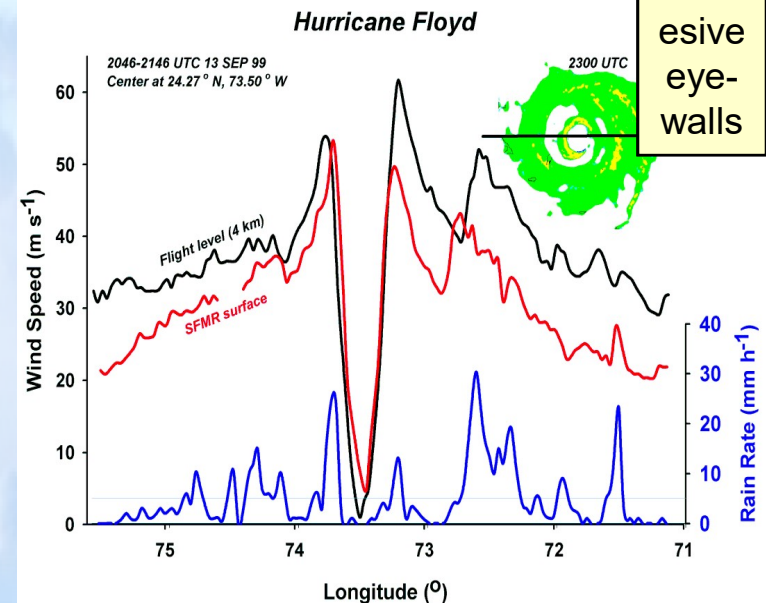
Double Eyewall

- ❖ Sometimes after the formation of eye and eye wall, another eye-wall forms.
- ❖ There will be inner eye and outer eye, inner eye wall and outer eyewall
- ❖ If existing inner wall cloud weakens and outer wall cloud forms or double wall cloud is noticed, the system is undergoing changes in intensity.
- ❖ Normally in this case intensity reduces.
- ❖ Intensity again increases as two eye-walls merge leading to one eye wall.
- ❖ At this stage, cyclone will have a larger eye
- ❖ Process of formation of the second eye-wall, weakening of inner eye-wall and its replacement by outer eyewall is termed as eye-wall replacement cycle (ERC).

Source :
Willoughb,
1988

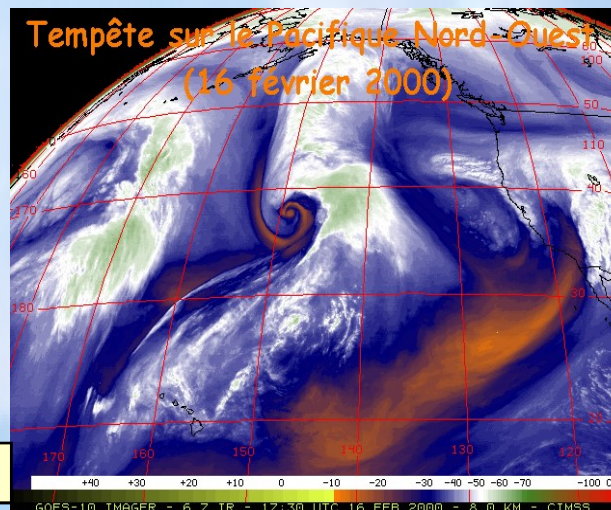


Exa
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of
succ
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eye-
walls

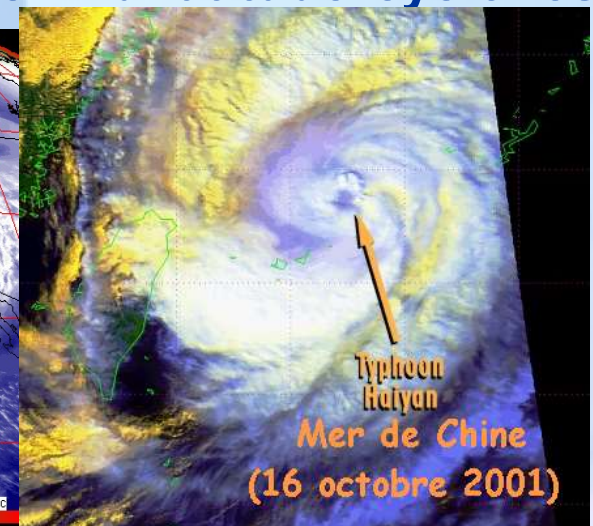


Tropical cyclones and extra-tropical cyclones

- **Tropical cyclones** are atmospheric disturbances resulting from release of latent heat in upper layers of tropical oceans. **Mid-latitude cyclones** extract their energy from horizontal gradients of temperature in atmosphere.
- **Tropical cyclones** result from barotropic process (little horizontal temperature gradient) and **mid-latitude cyclones** from baroclinic process (large temperature gradient)
- In **tropical cyclones**, strongest winds occur near surface, In **mid-latitude cyclones**, it occurs in upper troposphere (at 8-12 km).
- Tropical Cyclones are warm core system, while mid-latitude cyclones are cold core systems



F. Roux, 2006



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Tropical Cyclone and Tornado

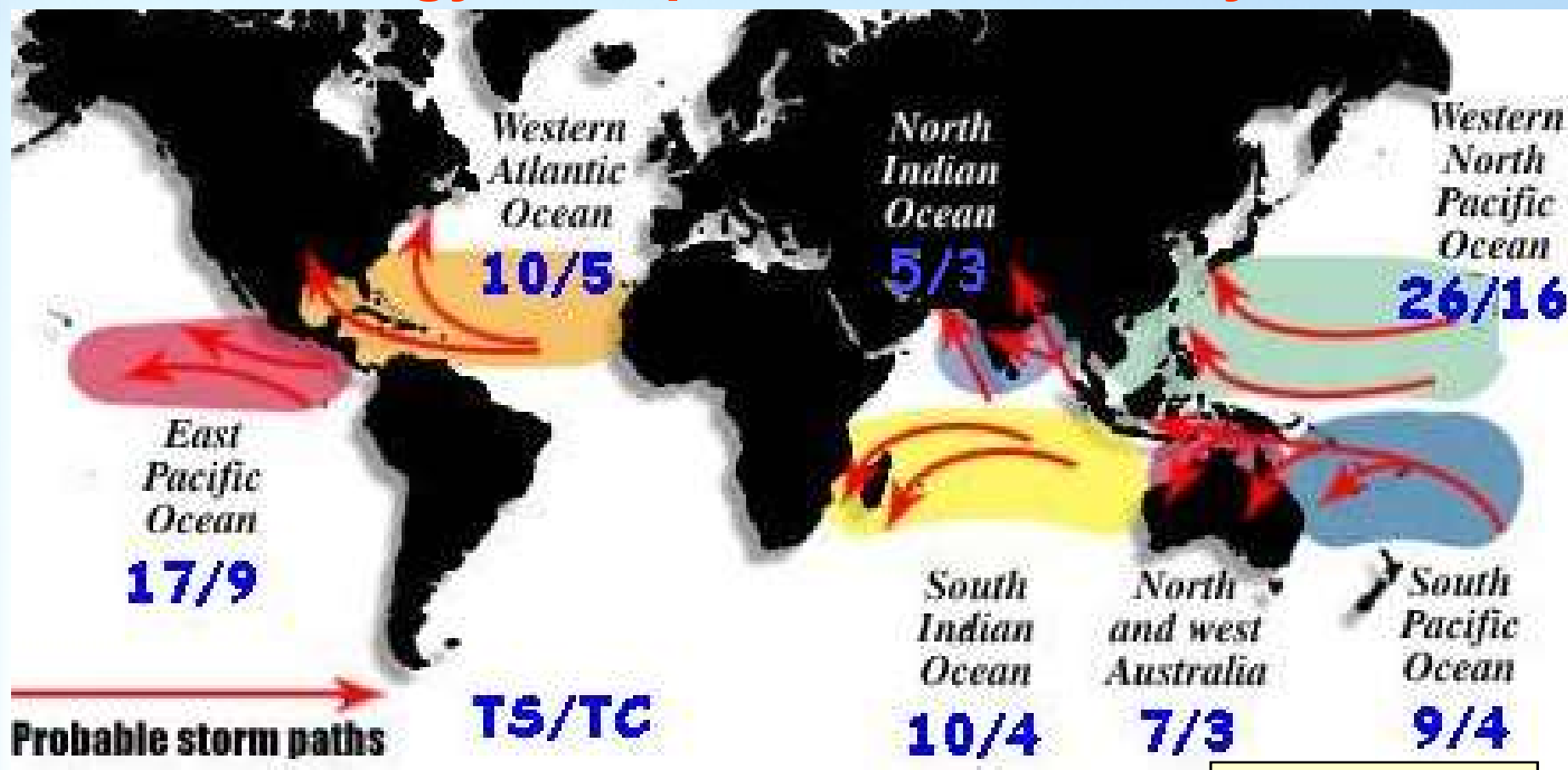
- Both are very intense atmospheric swirls, but have little in common
- **Tornadoes** have diameters of a few tens to a few hundreds meters and they are produced by severe thunderstorms in presence of strong convective instability and variation of wind with altitude.
- **Tropical cyclones** have diameters of hundreds of kilometers and they occur in conditions of weak or neutral convective instability and light wind in the environment.



F. Roux, 2006



Climatology of tropical storms and cyclones



F. Roux, 2006

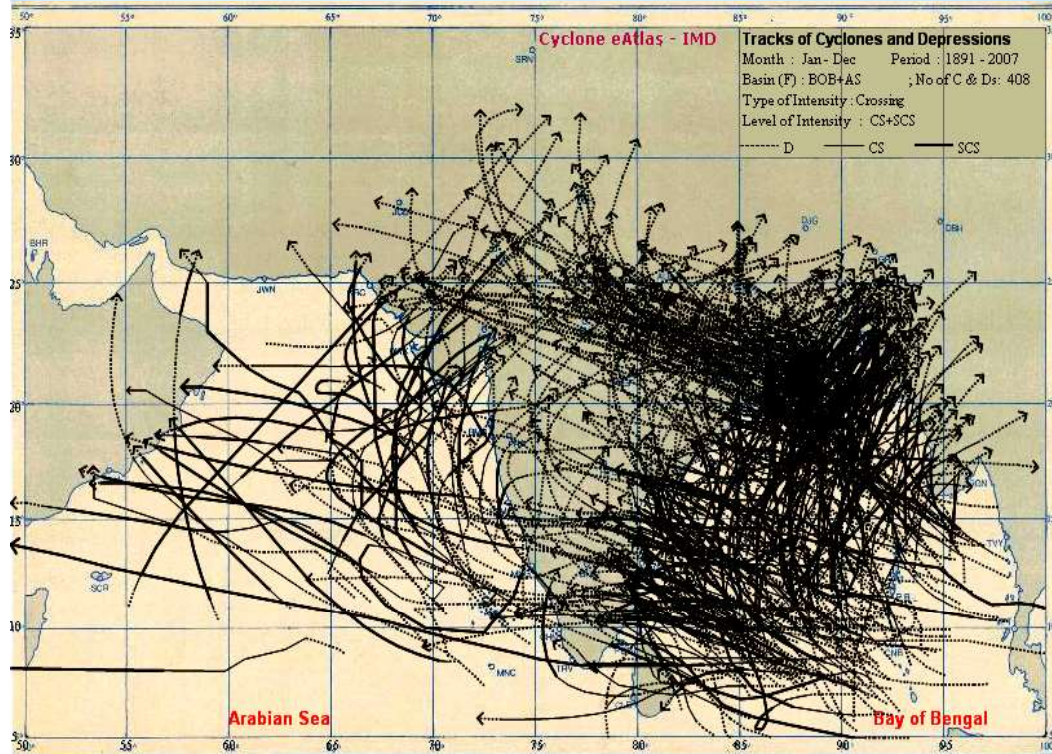
Average annual number (1970-2000) of tropical storms/cyclones over each ocean basin (average around the globe : 84 TS / 44 TC) and average track of the disturbances



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Cyclones over NIO



- ❖ Out of 80 forming over the globe, five form over north Indian Ocean
- ❖ Ratio of TCs between Bay of Bengal and Arabian Sea – 4:1
- ❖ Year to year variation - Quite large. Minimum No. of cyclones in a year - One (1949),
- ❖ Maximum No. of cyclones in a year – Ten (1893, 1926, 1930, 1976)

- ❖ Bay of Bengal is a vast warm pool adjoining the warm pool of the western North Pacific.
- ❖ The ocean currents in the Bay of Bengal are quite complex.
- ❖ The bathymetry of this coast is also very complex due to a number of rivers, deltaic regions and orography



Chasing the cyclone for Mitigation

- ❖ Reduction of cyclone disasters depends on several factors including
 - hazard analysis,
 - vulnerability analysis,
 - preparedness & planning,
 - early warning and mitigation.
- ❖ The early warning is a major component as evident from a survey conducted for the south Asian region.
- ❖ The early warning component includes
 - skill in monitoring and prediction of cyclone,
 - effective warning products generation and dissemination,
 - coordination with emergency response units and
 - the public perception about the credibility of the official predictions and warnings.



Chasing the cyclone through Early Warning System

Broad Classification of Observations

Space Based

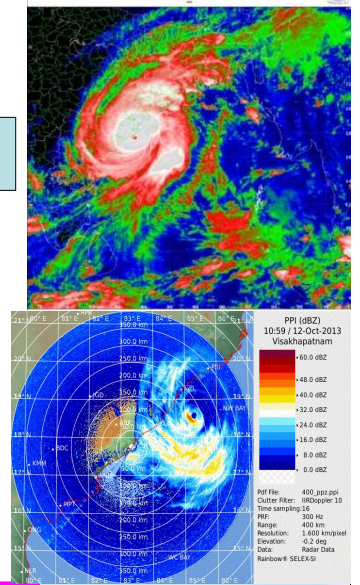
- Geostationary Satellites
- Polar Orbiting Satellites

Upper Air

- Pilot Balloon
- RSRW
- Profiler
- Ground Based RADAR
- Aircraft

Surface

- AWS
- ARG
- SYNOP
- BUOYS
- AVIATION
- SHIPS



Initial conditions
(Observations)

Runs of different
Models,

Consecutive runs
from the same
model,

Ensemble runs
("choosing the
best member")

Model

Forecaster

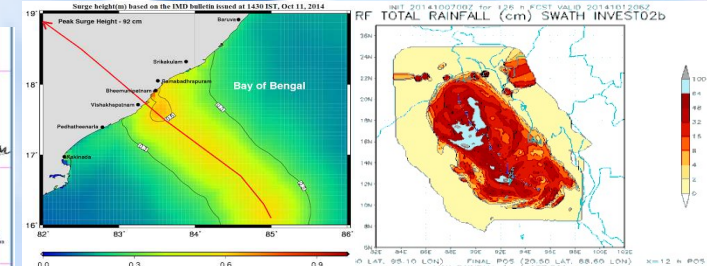
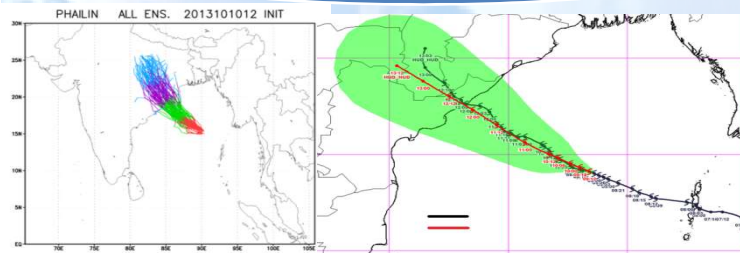
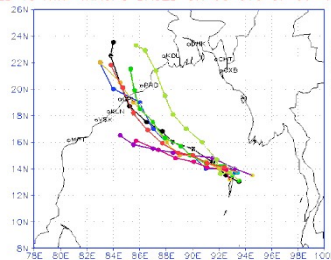
Action

Decision
maker

Numerical
forecasts

End
forecast

TROPICAL CYCLONE "PHAILIN"
OBSERVED vs NWP TRACKS BASED ON 00 UTC OF 09-10-2013



Chasing down Tropical Cyclone for disaster management

Step-1: Pre cyclone exercise



Preparations commenced in the beginning of April.

- Countdown for TC commences with organization of pre-cyclone exercise on onset of cyclone season (April & Oct.).
- IMD takes stock of their preparedness w.r.t. inventories, instruments, computers, radars and contact details.
- Meeting is organised to develop direct interaction with the disaster managers for ensuing season cyclone management.
- Letters are issued to all stakeholders like AIR, TV, Ports, Fisheries, Telecom, Railways, Surface Transport, NDMA, NDRF, MHA, PIB, and Chief Secretaries.
- Mock cyclone exercise conducted with participation of IMD.

- Daily diagnosis and prognosis commenced from **25th April** as per SOP.
- The **first alert** about possible development of cyclone, AMPHAN was sounded on **7th May**.



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Chasing down Tropical Cyclone for disaster management

Step-2: Extended range outlook

- Issue of extended range forecast (15 days forecast) for possible cyclogenesis every Thursday giving probability of cyclogenesis (formation of depression) as:
low(1-33%), moderate(34-67%), high(68-100%): next 2 weeks.
- Bulletin uploaded in website & sent to all concerned by email.

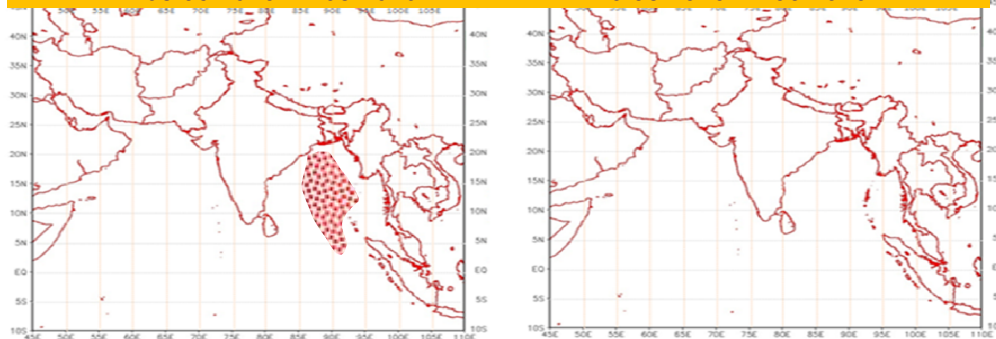
Countdown stage 8 (7th May 2020, 1330 hrs IST)

- Extended range outlook issued on 7th May indicating cyclogenesis (formation of depression) over south BoB with movement towards north BoB. (6 days prior to formation of Low pressure area on 13th May, 9 days prior to formation of depression and 13 days prior to landfall on 20th May)
- Continuous monitoring commenced and four bulletins issued per day during 7th to 12th May in association with the cyclonic circulation

NORTH INDIAN OCEAN EXTENDED RANGE OUTLOOK FOR CYCLOGENESIS

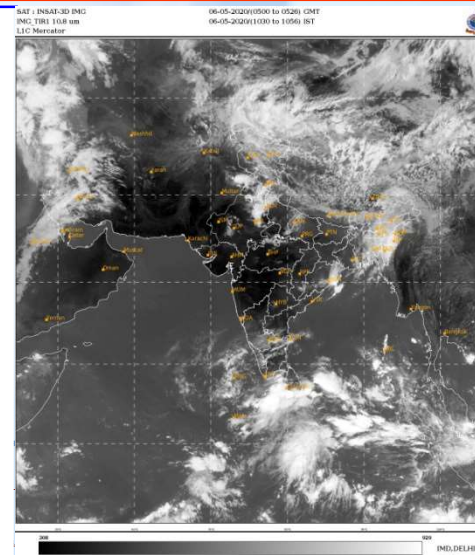
WEEK 1: 08.05.2020-14.05.2020

WEEK 2: 15.05.2020-21.05.2020



**PROBABILITY OF CYCLOGENESIS
(FORMATION OF DEPRESSION OR HIGHER INTENSITY)**
LOW (1-33% PROBABILITY)
MODERATE (34-67% PROBABILITY)
HIGH (68-100% PROBABILITY)

CONFIDENCE



Chasing down Tropical Cyclone for disaster management

Step-3: Medium range forecast

Count down stage 7

- Round the clock watch is maintained for 365 days.
- A “Tropical Weather Outlook” is issued everyday indicating probability of cyclogenesis during next 5 days as
 - nil (0%), low (1-25%), moderate (26-50%), fair (51-75%) and high (76-100%).
- Daily bulletin is issued discussing model guidance, prognostic & diagnostic features, expected formation of Low pressure area (place and date) its and probability of cyclogenesis

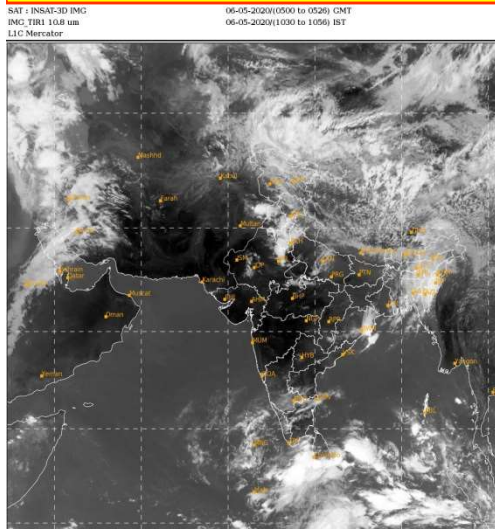
Step-4: Formatio n of low pressure area

- Six hourly bulletins commences indicating possible intensification low into depression (cyclogenesis) and further into cyclone and its movement.
- A special message is issued to disaster managers
- Press release is issued indicating the possible intensification, movement and expected adverse weather along the coast.



CHASING DOWN SUCS “AMPHAN” FOR DISASTER MANAGEMENT

Step-5: Formation of low pressure area



India Meteorological Department
Earth System Science Organisation
(Ministry of Earth Sciences)

INFORMATORY MESSAGE: 01 (BOB 01/2020)

TIME OF ISSUE: 1330 HOURS IST DATED: 13.05.2020

FROM: INDIA METEOROLOGICAL DEPARTMENT (FAX NO. 24643965/24699216/24623220)

TO: CONTROL ROOM, NDM, MINISTRY OF HOME AFFAIRS (FAX NO. 23093750)

CONTROL ROOM NDMA (FAX NO. 26701729)

CABINET SECRETARIAT (FAX NO. 23012254, 23018630)

PS TO HON'BLE MINISTER FOR S & T AND EARTH SCIENCES (FAX NO. 23316745)

SECRETARY, MOES (FAX NO. 24629777)

N.O. (INTEGRATED DEFENCE STAFF AND CDS) (FAX NO. 23005137/23005147)

DIRECTOR GENERAL, DOORDARSHAN (23386843)

DIRECTOR GENERAL, AIR (23421105, 23421219)

PIB MOES (FAX NO. 23386842)

UNI (FAX NO. 23366841)

D.O. NATIONAL DISASTER RESPONSE FORCE (NDRF) (FAX NO. 26105912, 2436 3260)

DIRECTOR, PUNCTUALITY, INDIAN RAILWAYS (FAX NO. 23386503)

CHIEF SECRETARY, ANDAMAN & NICOBAR ISLANDS (FAX NO. 03192- 232856)

CHIEF SECRETARY, WEST BENGAL (FAX NO. 033-2214520)

CHIEF SECRETARY, GOVT. OF ODISHA (FAX NO. 0674- 2536680)

CHIEF SECRETARY, ANDHRA PRADESH (FAX NO. 0863-2444029, 08645-246680)

CHIEF SECRETARY, TAMIL NADU (FAX NO. 044-25672304)

CHIEF SECRETARY, PUDUCHERRY (FAX NO. 0413-2337575, 2334145)

CHIEF SECRETARY, KERALA (FAX NO. 0413-2337575, 2327176, 2327395)

CHIEF SECRETARY, LAKSHADWEEP ISLANDS (FAX NO. 0413-262194)

Sub: Formation of a Low Pressure area over southeast Bay of Bengal and adjoining south Andaman Sea and its likely intensification into a Cyclonic Storm by 16th May, evening.

A Low Pressure Area has formed over southeast Bay of Bengal and adjoining south Andaman Sea, in the morning of today, the 13th May 2020.

It is very likely to concentrate into a Depression over central parts of south Bay of Bengal on 15th and further intensify into a Cyclonic Storm over southwest and adjoining west-central Bay of Bengal by 16th evening. It is very likely to move northwestwards initially till 17th May and then re-curve north-northeastwards.

In association with the above system, the conditions will become favourable for advance of southwest monsoon over south Bay of Bengal, Andaman Sea and Andaman & Nicobar Islands around 16th May 2020.

Under its influence, the following adverse weather is likely over south & central Bay of Bengal and adjoining Andaman Sea from 15th May onwards.

Countdown stage 6 (13th May 2020, 1330 hrs IST)

- It began on 13th May, with formation of LPA over south Andaman Sea (3 days prior to formation of depression on 16th and 7 days prior to landfall).
- Special Informatory Message issued to central and state level disaster managers of east coast states and Andaman Nicobar Islands at 1330 hrs IST indicating the likely development of a cyclonic storm over BoB.
- Press Release issued for media & general public in this regard.
- Fishermen were advised not to venture into identified sea region which was expected to experience adverse weather.
- Daily four bulletins till 16th May were issued from NWFC in association with this low pressure area.



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Seasonal cyclogenesis parameter

**THERMAL
POTENTIAL**

**DYNAMIC
POTENTIAL**

Ocean thermal energy

Humidity

Instability

The Coriolis parameter

Low level relative vorticity

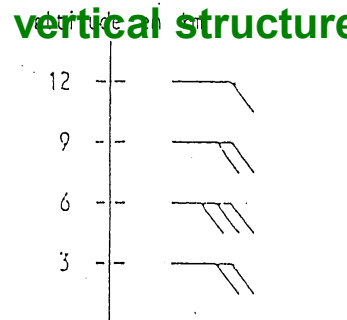
Inverse of tropospheric
vertical wind shear

Vertical Wind Shear

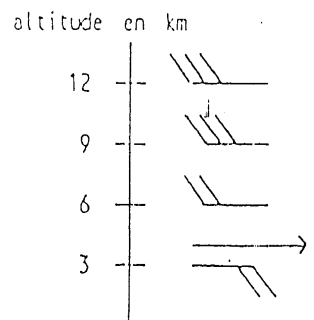
Unfavorable
vertical structure

Relative vorticity

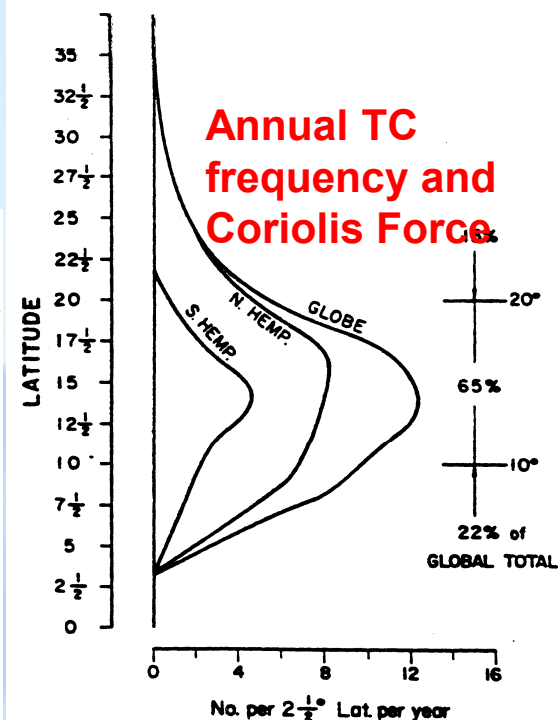
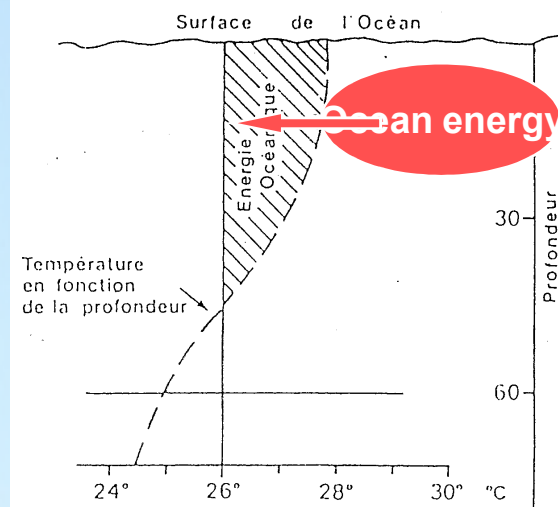
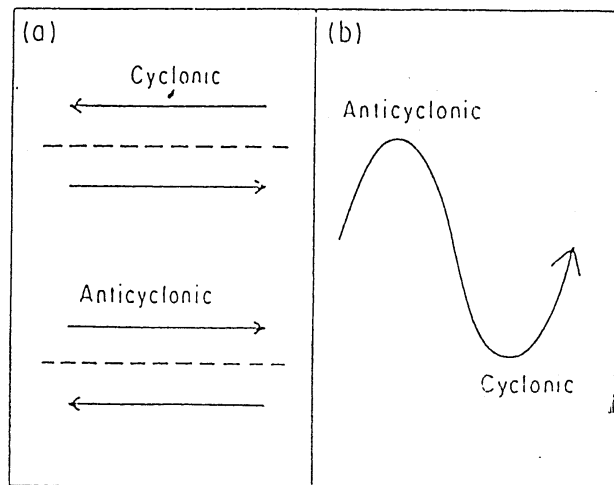
**Favorable
vertical structure**



structure verticale
favorable



structure verticale
défavorable

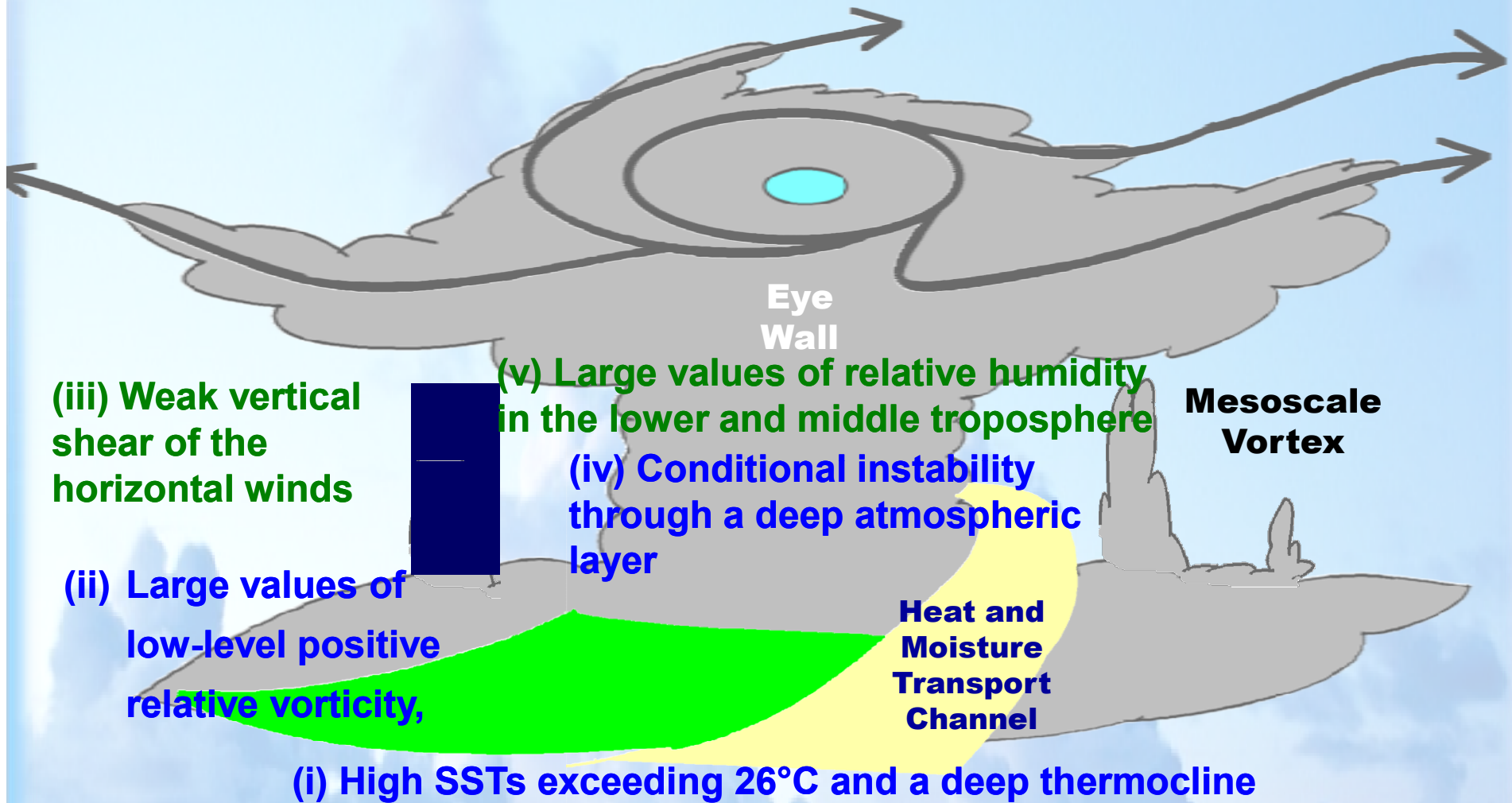


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Factors Affecting Genesis and intensification of Cyclone

Out flow channel



(Heavily dependent on Ocean observations)



Short to Medium Range Genesis Forecast

Tropical Weather Outlook dated 11th May
(5 days prior to formation of depression on 16th May)



REGIONAL SPECIALISED METEOROLOGICAL CENTRE-TROPICAL CYCLONES, NEW DELHI
TROPICAL WEATHER OUTLOOK



REGIONAL SPECIALISED METEOROLOGICAL CENTRE-TROPICAL CYCLONES, NEW DELHI
TROPICAL WEATHER OUTLOOK



DEMS-RSMC TROPICAL CYCLONES NEW DELHI DATED 11.05.2020

TROPICAL WEATHER OUTLOOK FOR NORTH INDIAN OCEAN (THE BAY OF BENGAL AND ARABIAN SEA) VALID FOR NEXT 120 HOURS ISSUED AT 0600 UTC OF 11.05.2020 BASED ON 0300 UTC OF 11.05.2020.

BAY OF BENGAL:

YESTERDAY'S CYCLONIC CIRCULATION OVER SOUTH ANDAMAN SEA & ADJOINING SUMATRA COAST EXTENDING UPTO MID-TROPOSPHERIC LEVELS PERSISTS OVER THE SAME REGION AT 0200 UTC OF TODAY THE 11TH MAY 2020.

UNDER ITS INFLUENCE A LOW PRESSURE AREA IS VERY LIKELY TO FORM OVER SOUTHEAST BAY OF BENGAL (BOB) AND ADJOINING ANDAMAN SEA AROUND 13TH MAY. IT IS LIKELY TO BECOME MORE MARKED OVER SOUTH BOB DURING SUBSEQUENT 72 HOURS.

DEMS-RSMC TROPICAL CYCLONES NEW DELHI DATED 13.05.2020

TROPICAL WEATHER OUTLOOK FOR NORTH INDIAN OCEAN (THE BAY OF BENGAL AND ARABIAN SEA) VALID FOR NEXT 120 HOURS ISSUED AT 0600 UTC OF 13.05.2020 BASED ON 0300 UTC OF 13.05.2020.

BAY OF BENGAL:

A LOW PRESSURE AREA HAS FORMED OVER SOUTHEAST BAY OF BENGAL (BOB) AND ADJOINING SOUTH ANDAMAN SEA WITH ASSOCIATED CYCLONIC CIRCULATION EXTENDING UPTO MID-TROPOSPHERIC LEVELS.

IT IS VERY LIKELY TO CONCENTRATE INTO A DEPRESSION OVER CENTRAL PARTS OF SOUTH BAY OF BENGAL ON 15TH MAY AND FURTHER INTENSIFY INTO A CYCLONIC STORM OVER SOUTHWEST AND ADJOINING WESTCENTRAL BAY OF BENGAL BY 16TH EVENING. IT IS VERY LIKELY TO MOVE NORTHWESTWARDS INITIALLY TILL 17TH AND THEN RECURVE NORTH-NORTHEASTWARDS.

PROBABILITY OF CYCLOGENESIS DURING NEXT 120 HRS:

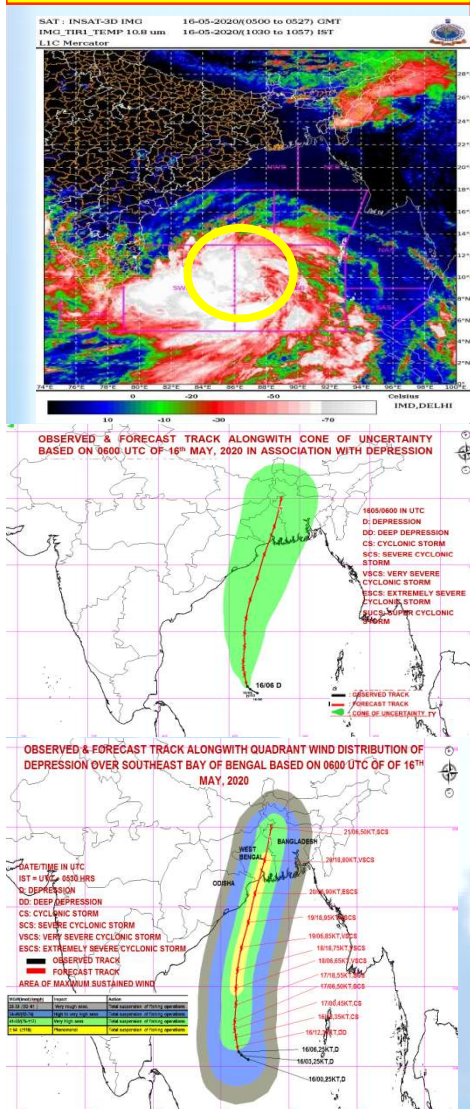
0-24 HRS	24-48 HRS	48-72 HRS	72-96 HRS	96-120 HRS
NIL	NIL	NIL	NIL	LOW

PROBABILITY OF CYCLOGENESIS DURING NEXT 120 HRS:

0-24 HRS	24-48 HRS	48-72 HRS	72-96 HRS	96-120 HRS
NIL	NIL	MOD	HIGH	HIGH

Chasing down to the arrival of TC with disaster management

Step-5: Count down 5: Formation of depression: Pre-Cyclone Watch



- **Pre Cyclone Watch: At least 72 hrs prior to beginning of adverse weather along coast**
- **National Bulletin (5 times/day) to disaster managers at centre & state**
- **Information of current status, forecast track, intensity for 72 hrs, adverse weather, state of sea, fishermen warning**
- **Special Tropical Weather Outlook for National/International users (5 times/day)**

- Depression–16th (0530 IST), Deep depression- 16th (1430 IST)
- Cyclonic Storm – 16th (1730 IST), Severe Cyclonic Storm –17th (0830 IST)
- Very Severe Cyclonic Storm– 17th (1430 IST):
- Extremely Severe Cyclonic Storm –18th (0230 IST):
- **Super cyclonic storm : 18th 1130 IST**
- Crossed West Bengal – Bangladesh coasts with sustained maximum wind speed of **155-165 kmph gusting to 185 kmph** across Sundarbans during 1530 – 1730 IST of 20th May.
- Weakened gradually and became insignificant over NE states on 22nd May 2020

D: DEPRESSION, DD: DEEP DEPRESSION, CS: CYCLONIC STORM, SCS: SEVERE CS, VSCS: VERY SEVERE CS, ESCS: EXTREMELY SEVERE CS, SUCS: SUPER CS

- **OBSERVED TRACK**
- **FORECAST TRACK**
- **CONE OF UNCERTAINTY**



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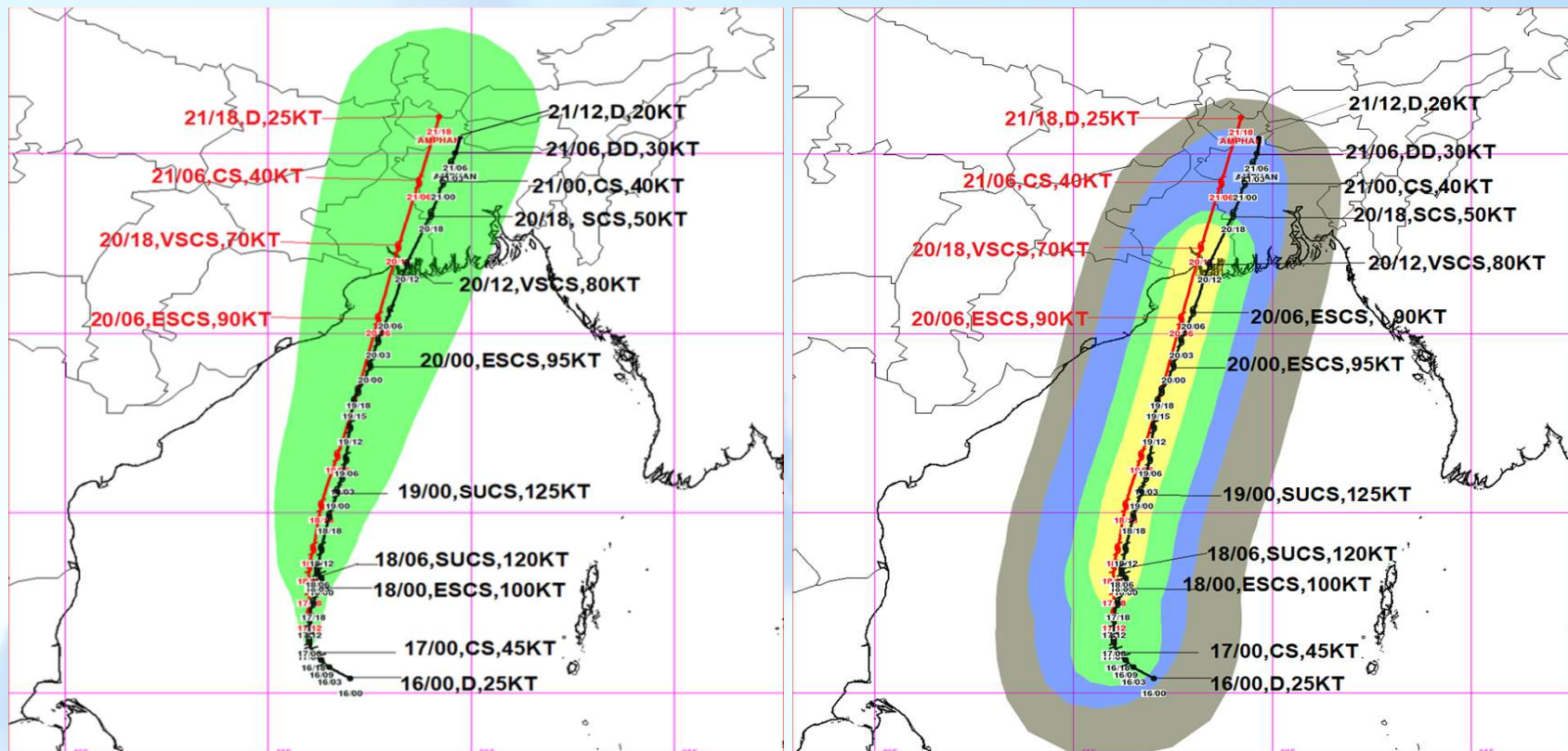
COUNTDOWN FOR SUCS “AMPHAN” WITH DISASTER MANAGEMENT

Countdown stage 5 (16th May 2020, 0845 hrs IST)-Pre Cyclone Watch:

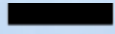
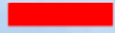
- Depression formed over southeast BoB on 16th May morning.
- Structured bulletins (5 times/day) giving quantitative track and intensity forecast as well as adverse weather warning commenced.
- In first bulletin in at 0845 hrs IST of 16th May (104 hrs prior to landfall), Pre-cyclone Watch for West Bengal-north Odisha coasts was issued.
- It stated the system to intensify into cyclone and cross West Bengal coast with maximum sustained wind speed of 155-165 gusting to 180 kmph on 20th A/N.
- Predicted heavy to very heavy rainfalls at few places with extremely heavy falls at isolated places over Gangetic West Bengal on 20th May. For coastal Odisha, hvy rainfall at isolated places from 18th May evening, hvy to very hvy falls at few places on 19th and isolated hvy rainfall over northeast Odisha on 20th.
- First NCMC meeting held under chairmanship of Cabinet Secretary on 16th May for preparedness & similar meetings conducted at state level in Odisha and West Bengal with participation by stakeholders.
- DGM, IMD presented current status and forecast about cyclone, expected adverse weather, area to be affected, damage expected and suggested actions.
- Accordingly the actions were planned as per the instruction of NCMC.



OBSERVED TRACK & FORECAST TRACK BASED ON 0600 UTC OF 17TH MAY (84 HRS PRIOR TO LANDFALL) INDICATING ACCURACY IN TRACK AND INTENSITY FORECAST



D: DEPRESSION, DD: DEEP DEPRESSION, CS: CYCLONIC STORM, SCS: SEVERE CS, VSCS: VERY SEVERE CS, ESCS: EXTREMELY SEVERE CS, SUCS: SUPER CS

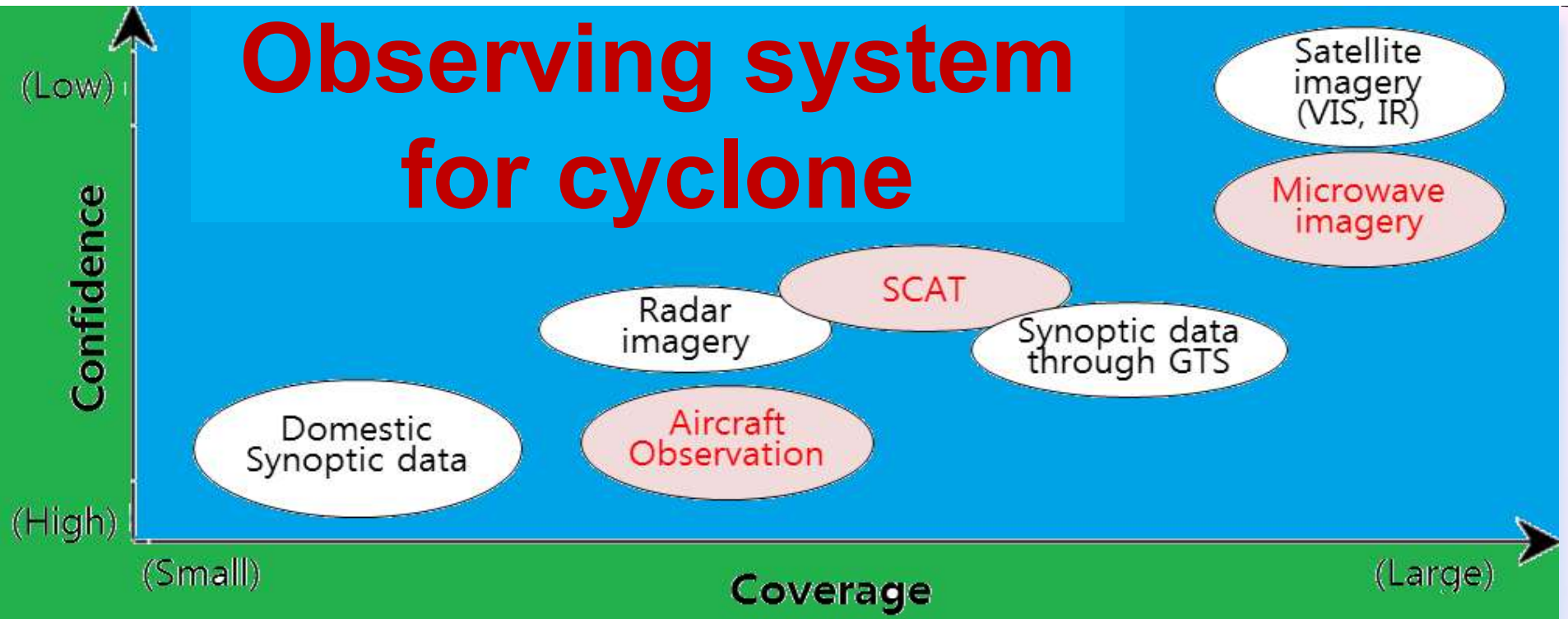
 OBSERVED TRACK
 FORECAST TRACK
 CONE OF UNCERTAINTY



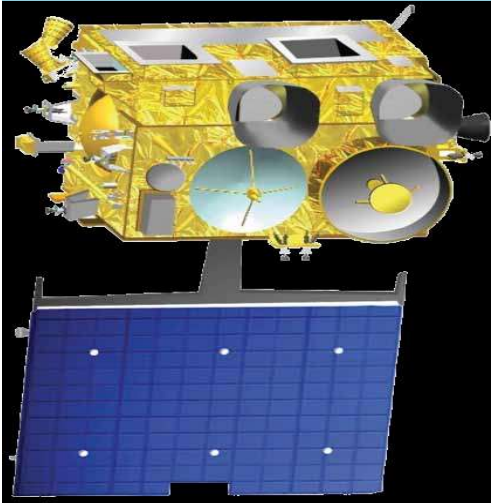
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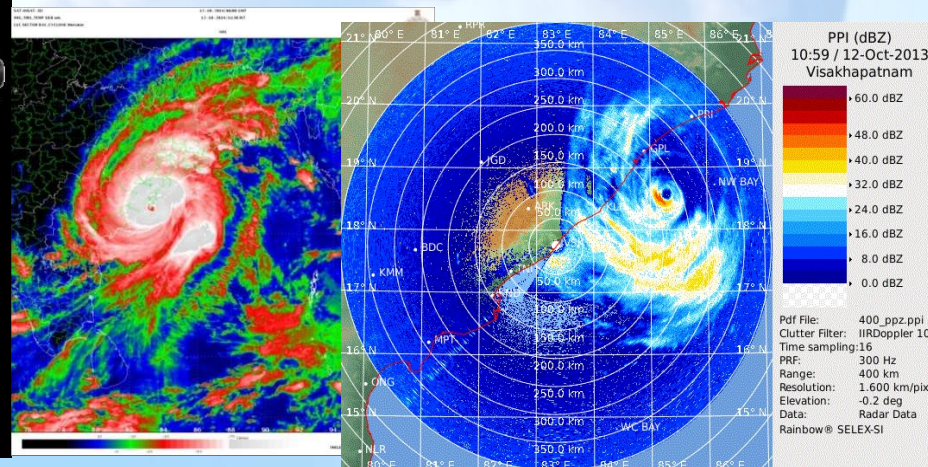
Observing system for cyclone



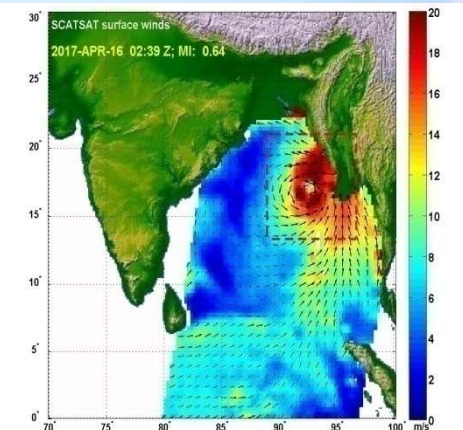
INSAT-3D & 3DR



Satellite Radar(24)



Scatterometer based wind



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Location and Intensity estimation of cyclones

(a) Satellite:

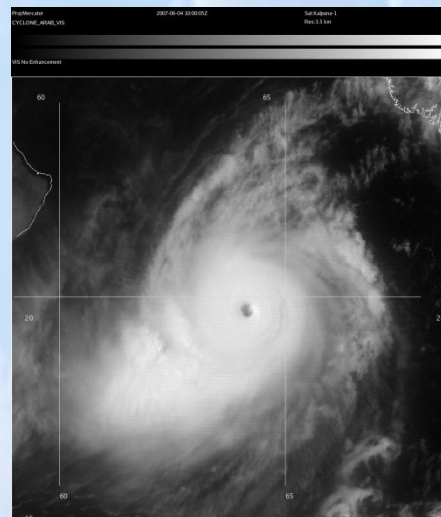
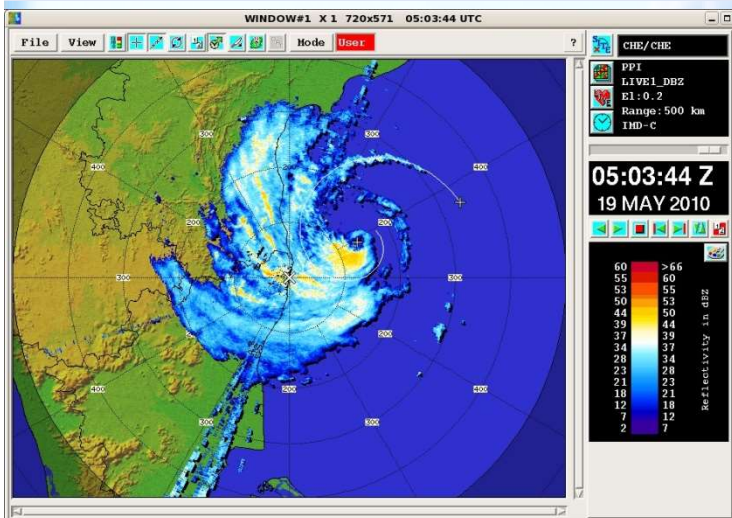
(1) INSAT-3D, 3DR, ScatSat

(2) Other international satellites

(b) Radar

(c) Synoptic analysis

(d) (e) Finally agreed official location and intensity



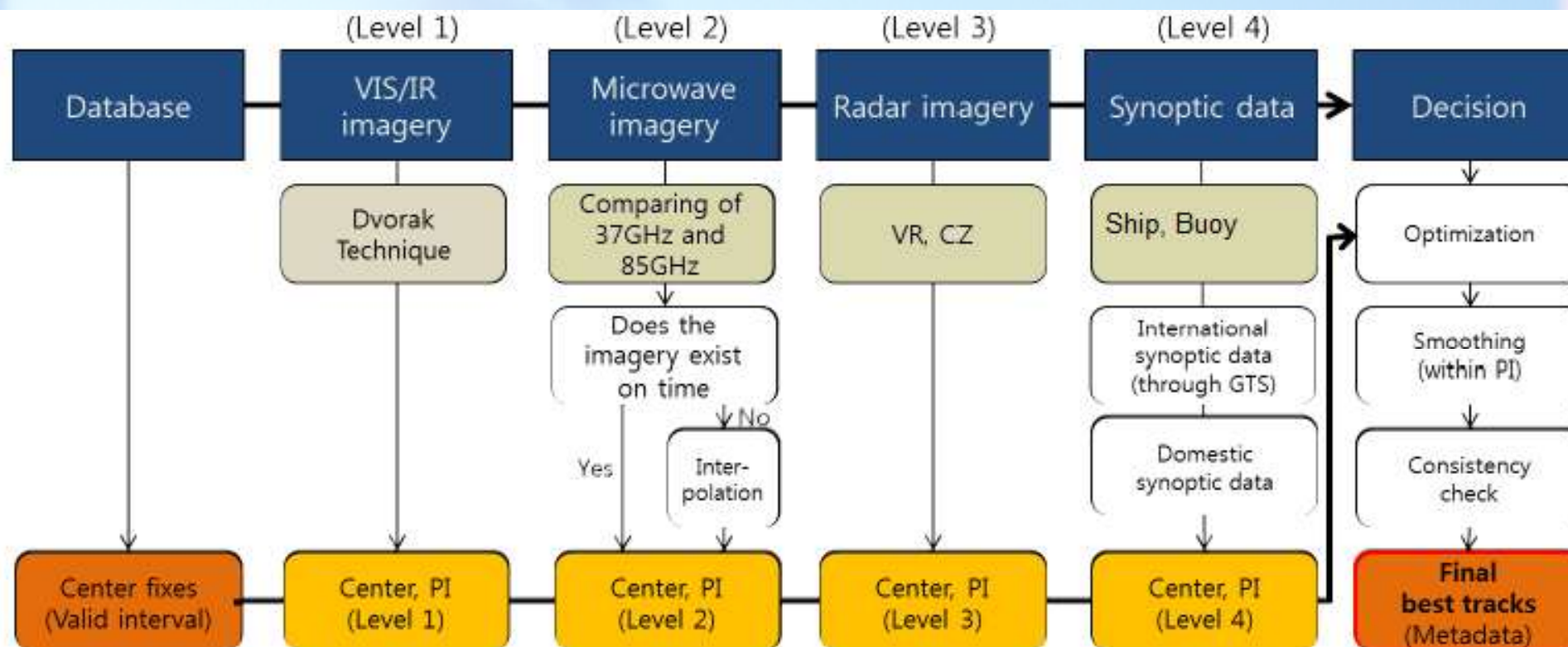
<i>C.I. Number</i>	<i>Max. Wind Speed (knots)</i>	<i>Pressure depth (in mb)</i>
1	25	3.1
1.5	25	3.1
2	30	4.5
2.5	35	6.1
3	45	10.0
3.5	55	15.0
4	65	20.9
4.5	77	29.4
5	90	40.2
5.5	102	51.6
6	115	65.6
6.5	127	80.0
7	140	97.2
7.5	155	119.1
8	170	143.3



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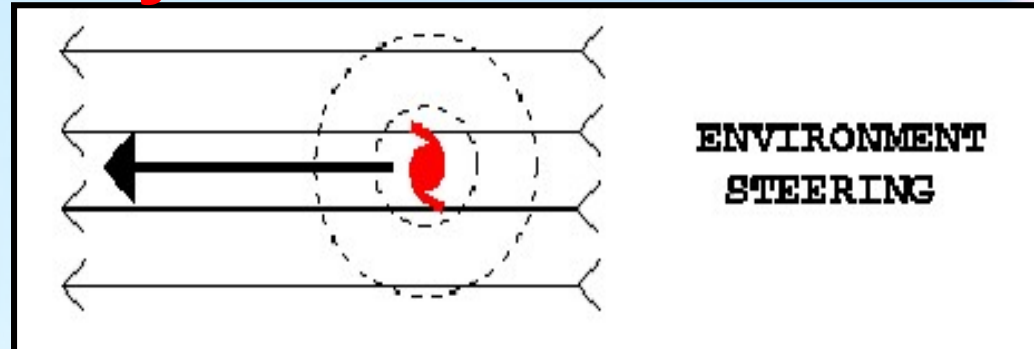
Centre and intensity fixing of cyclones



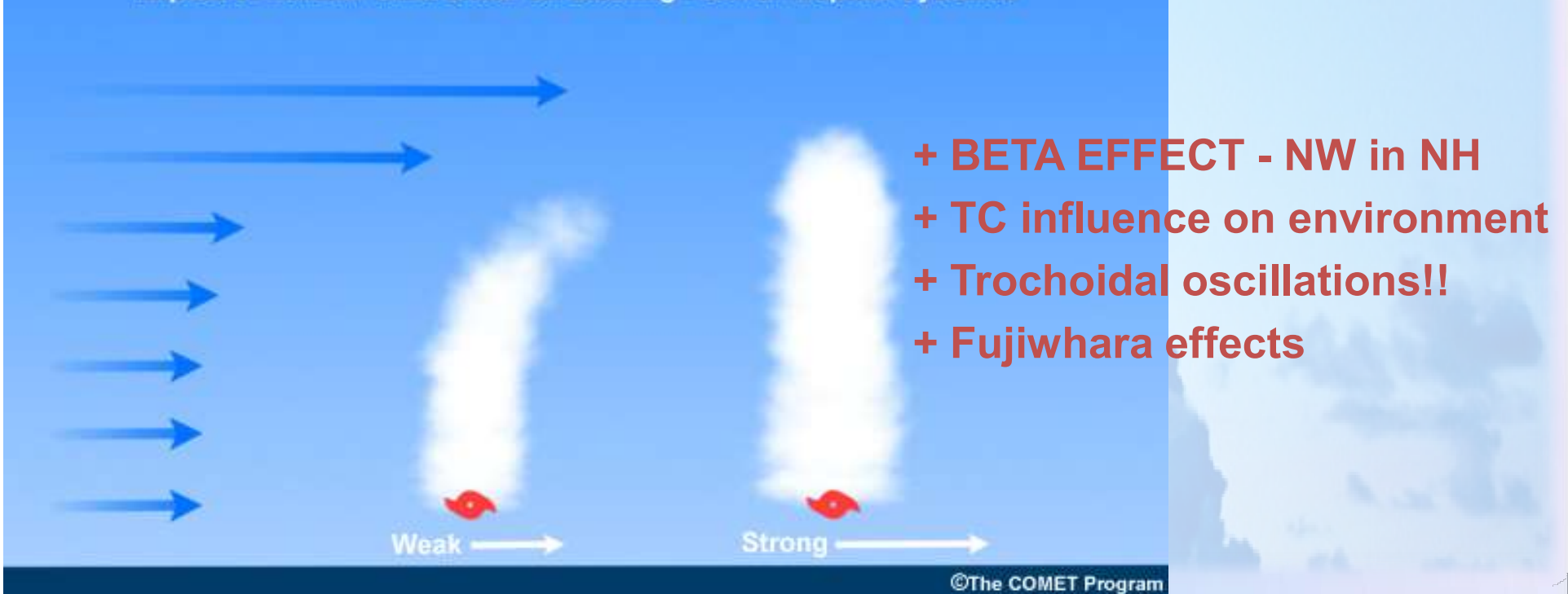
Movement of a Cyclone

“Cork-in-a-stream”

- Depth?
- Define environment?
- 50-80% of variance over 12-24 h

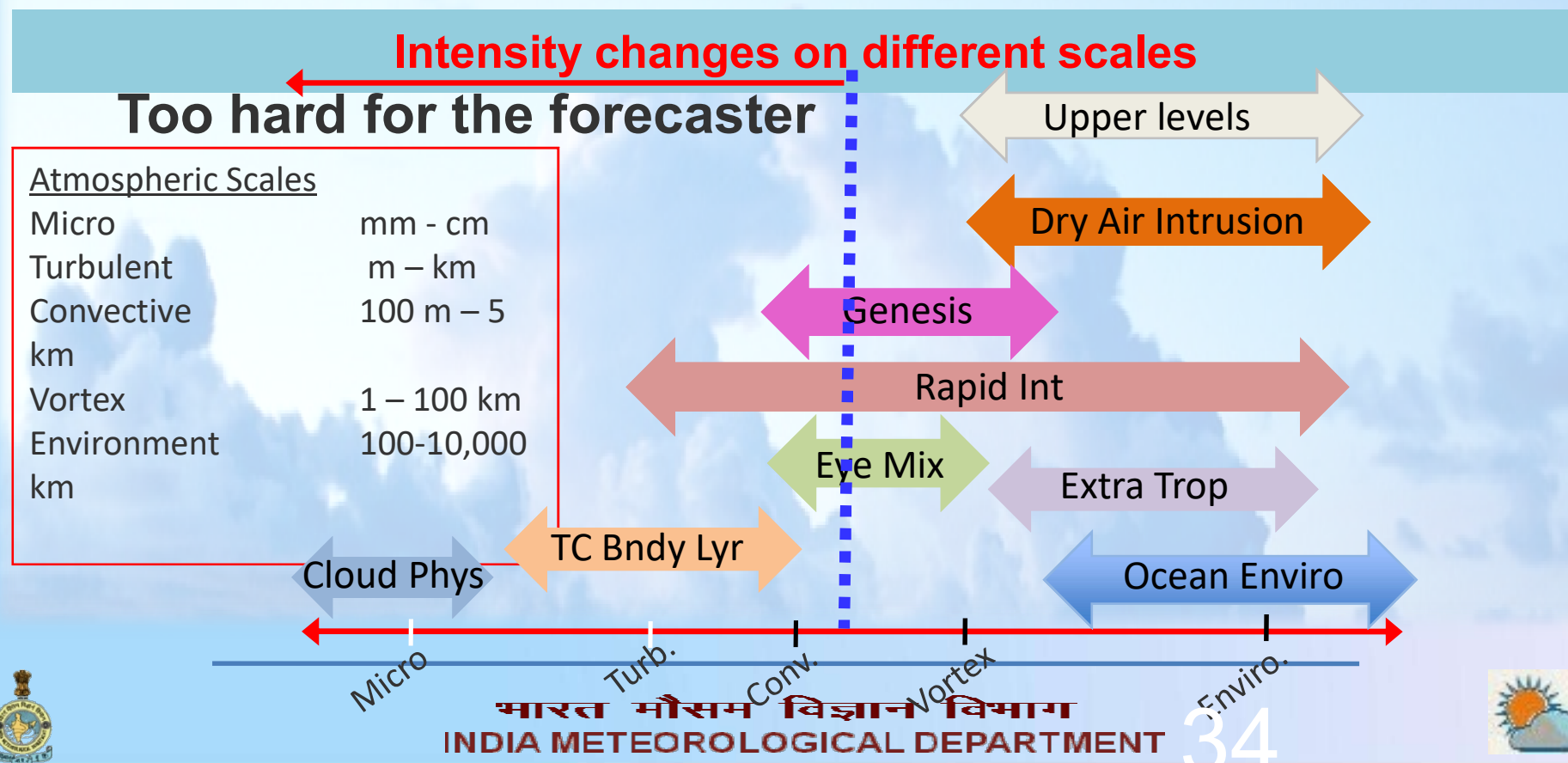


Impact of Vertical Wind Shear on Steering Flow of Tropical Cyclones



TC Intensity

- ❖ Difficulty with initial conditions:
- ❖ Need to represent complex process interactions across spatial scales (e.g., eyewall replacements; resolution)
- ❖ Difficulty in representing physical TC processes (e.g., convection and swirling PBL over complex surface)
- ❖ Incomplete understanding of physical processes



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 kn)

Critical elements

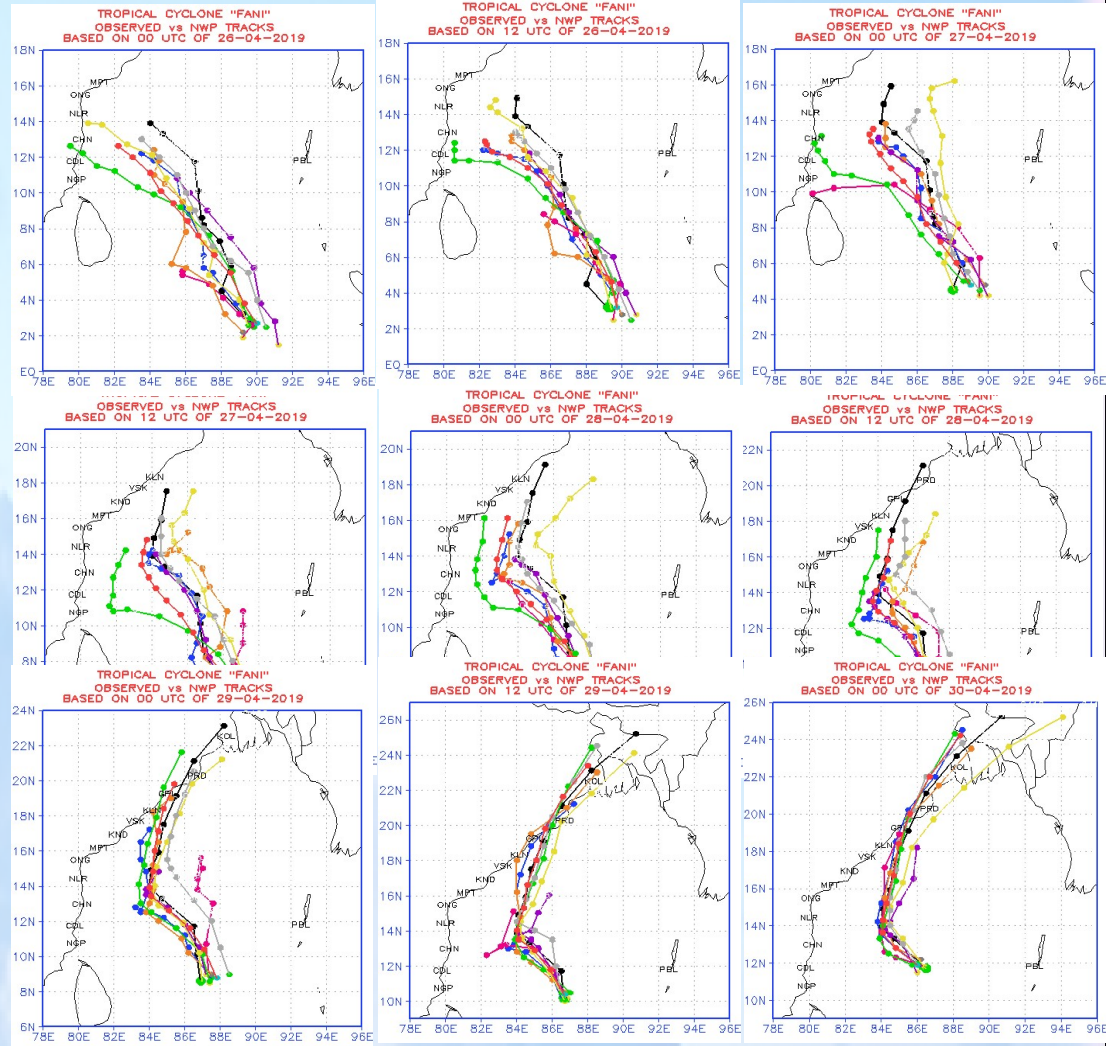
1. Good Analysis and environment assessment
 2. Persistence (esp. for first 12h)
 3. Changes in the environment (NWP) Conceptual Models
 4. Objective outputs:
statistical, NWP trends & consensus; STIPS
 5. Existing policy
- ⇒ Combining Subjective Vs Objective
- ⇒ Picking Rapid Intensification/weakening



TOOLS & TECHNOLOGY FOR TC TRACK FORECASTING

- i) Statistical Techniques
Analogue, Persistence,
Climatology, **CLIPER**
- i) Synoptic Techniques –
Empirical Techniques
- ii) Satellite Techniques
Techniques
- iii) Radar Techniques
- v) NWP Models

- Individual models
- IMDGFS (1534), NCUM, ECMWF
Meteo-France(ARP), JMA, UKMO,
NCEP, WRF (IMD), HWRF (IMD)-
coupled with POM & HYCOM,
- UM-R
- MME (IMD) and MME based on Tropical Cyclone Module (TCM)
- EPS (Strike probability, Location specific probability :



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TOOLS & TECHNOLOGY FOR TC INTENSITY FORECASTING

i) Statistical Techniques

Analogue, Persistence, Climatology
(CLIPER)

i) Synoptic Techniques

ii) Satellite Techniques

iii) Radar Techniques

v) NWP Models

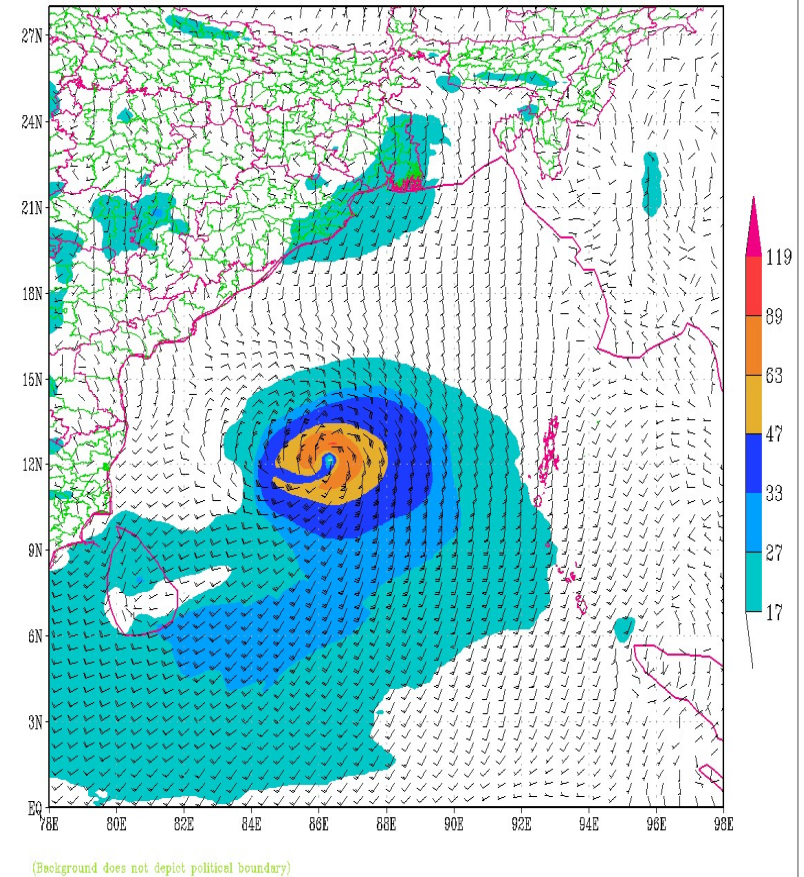
vi) Dynamical Statistical Model (SCIP) :

SCIP is being run from T1.5 stage
since 2018

vii) RI technique

Operational Forecast

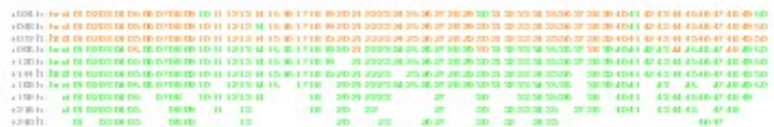
IMD: GFS(12Km) 10m WIND (barb)& GUST (shaded:kt) FORECAST (00 HR)
based on 00 UTC of 30-04-2019 valid for 00 UTC of 30-04-2019



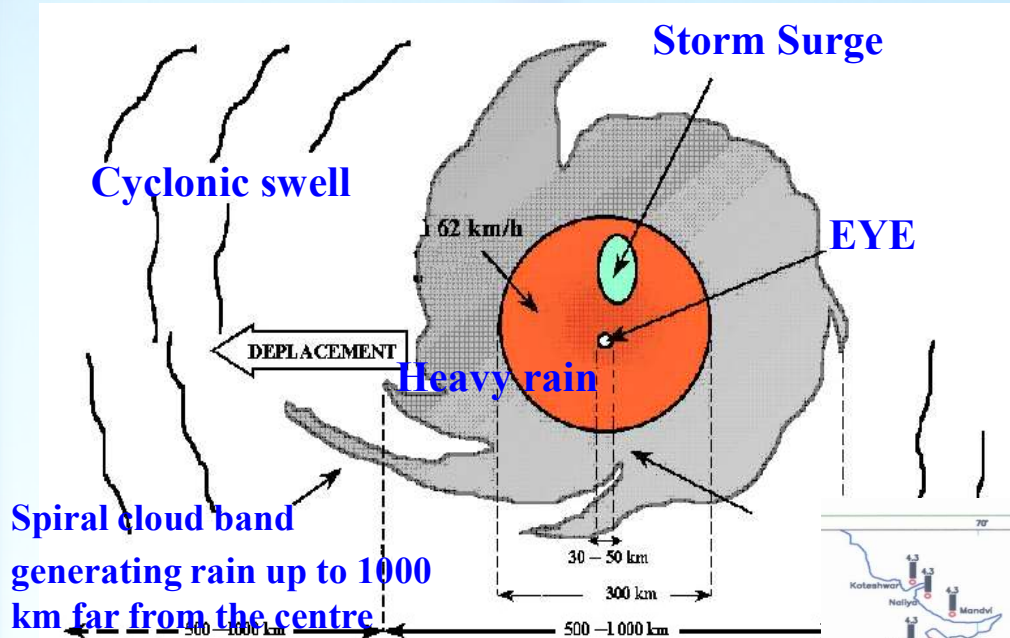
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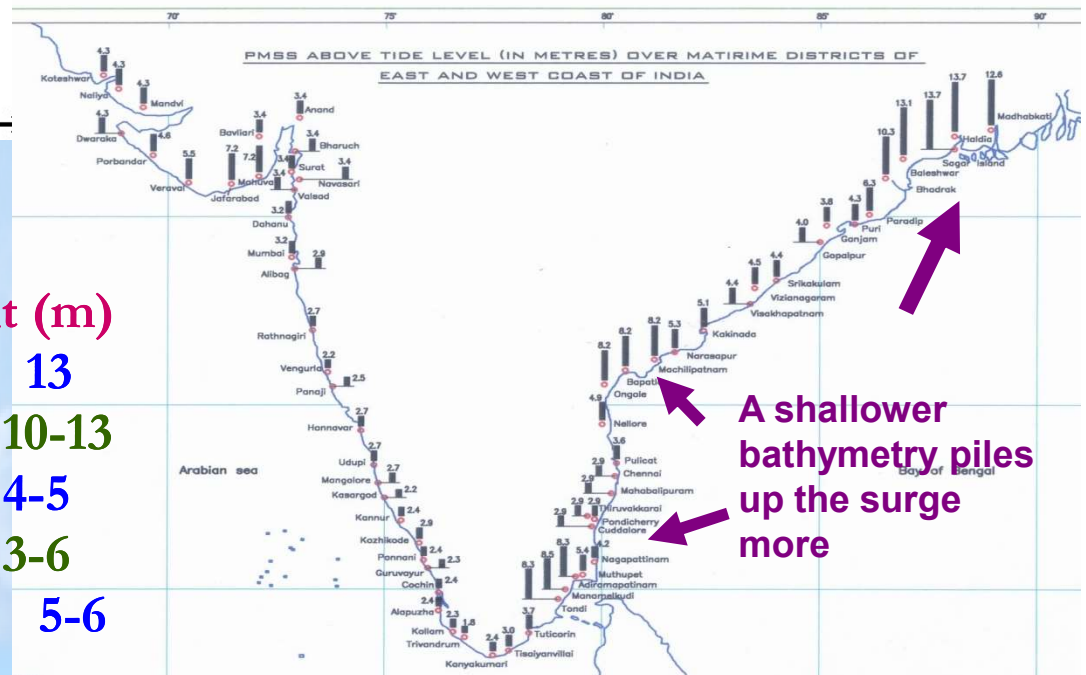
Is there a risk to southern Andhra Pradesh?
What information could help?



Dangers of a TC in the northern hemisphere



Heavy Rainfall
Gale Wind
Storm Surge



Cyclones

Hooghly river (WB), 7 October 1737: 13

Contai (WB),5 October 1864 : 10-13

Paradip, Orissa, October 1971 : 4-5

Balasore Orissa, May 1989 : 3-6

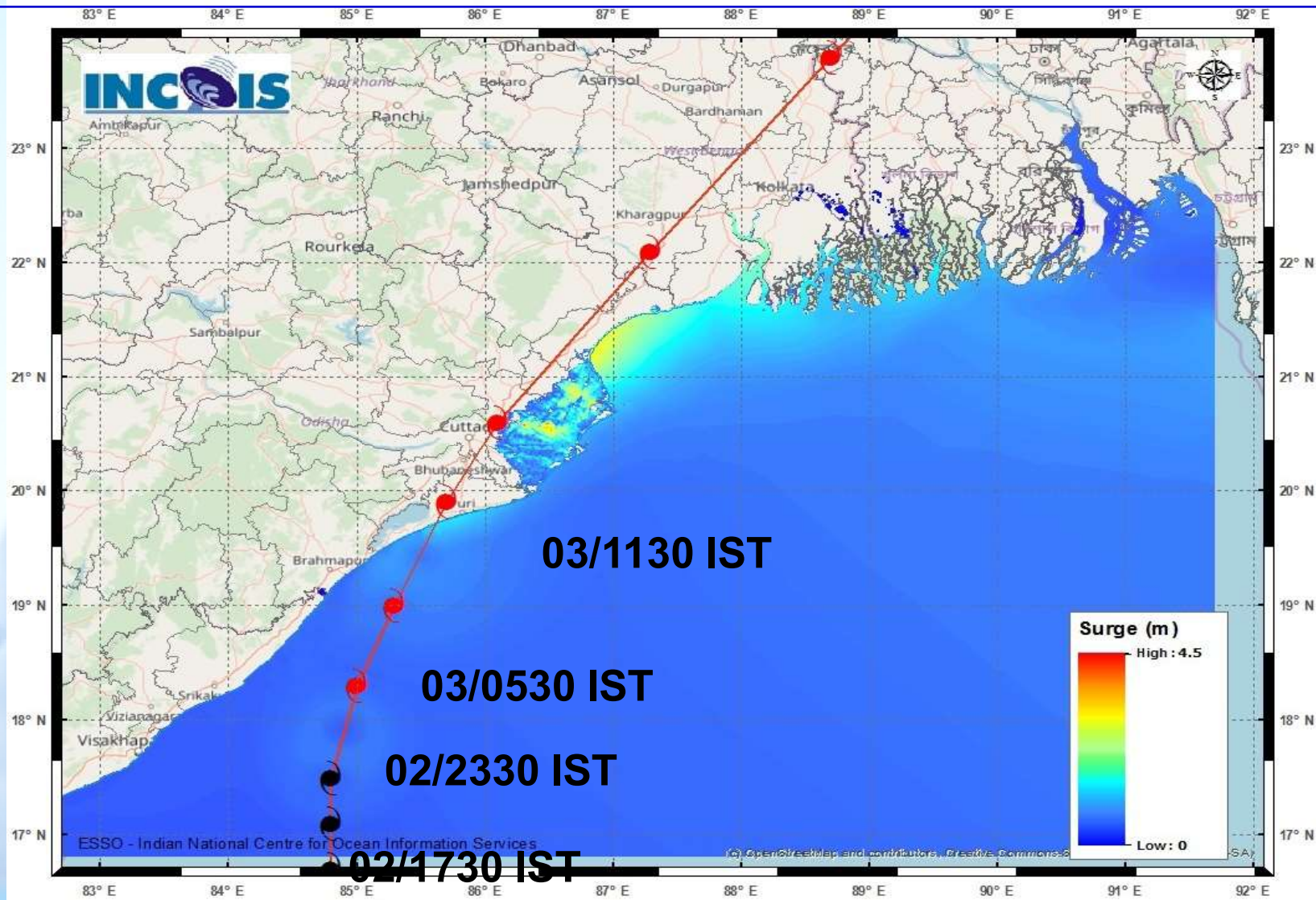
Orissa Super Cyclone, October 1999: 5-6



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STORM SURGE GUIDANCE ASSOCIATED WITH ESCS “FANI” (BASED on IC – 02 May 1730 hr IST)



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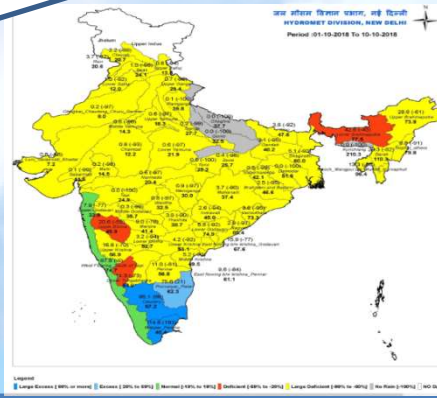
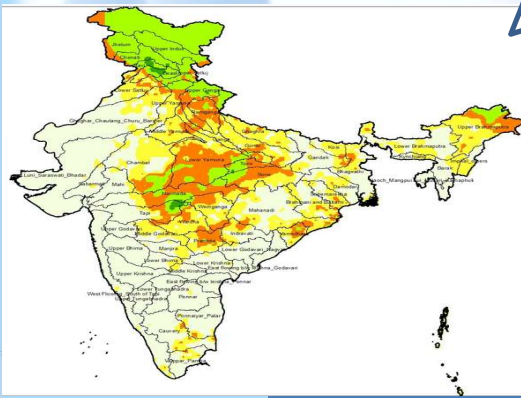
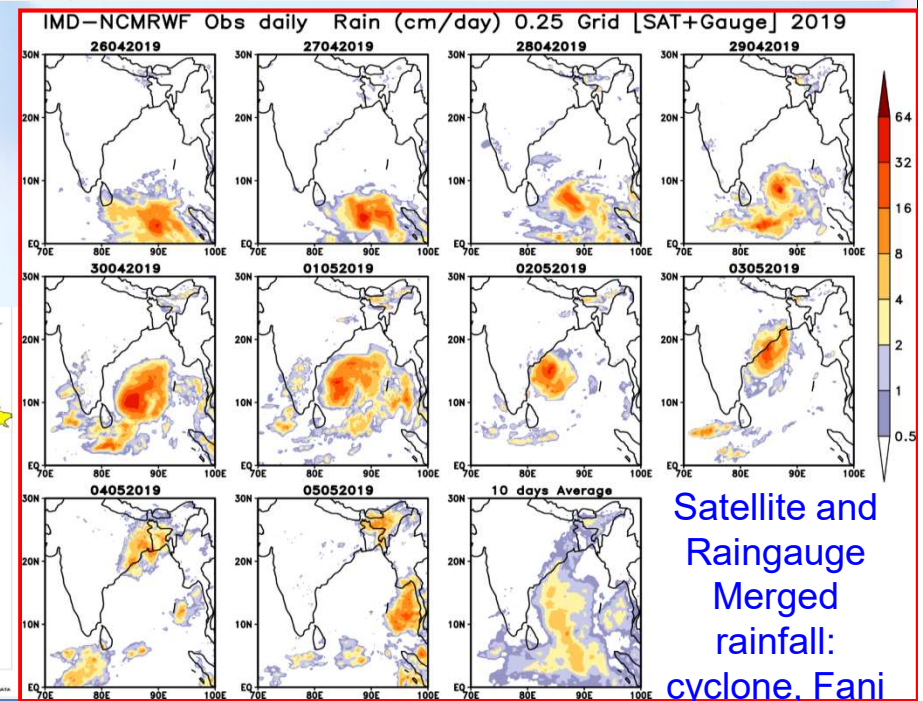
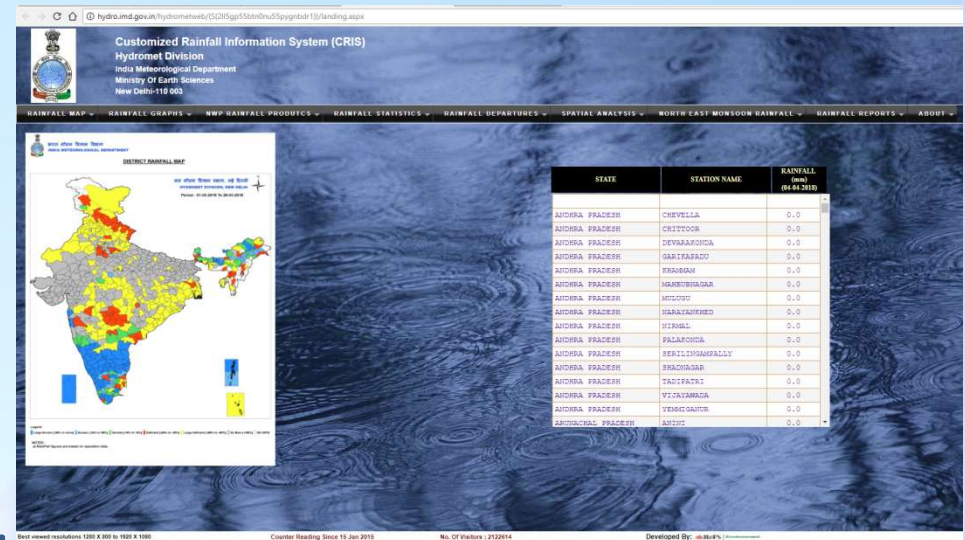


RAINFALL MONITORING DURING CYCLONE

❑ Customized Rainfall Information System using GIS platform includes;

- Preparation of operational real time rainfall maps, graphs and statistics (Daily ~130 rainfall products are generated on real time basis)

River basin-wise spatial analysis and statistics of observed rainfall is useful for flood forecasting and water resource management



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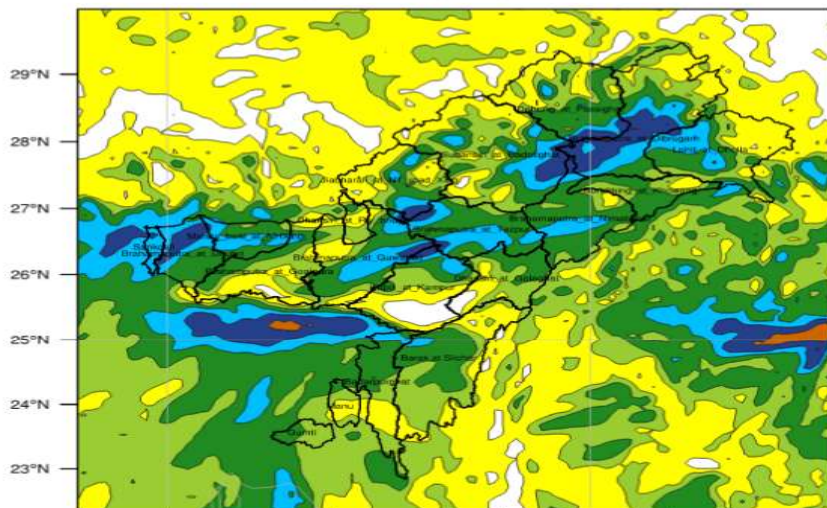
NWP Model support for Flood

Forecasting in Cyclone Sub basin wise Dynamical Model Rainfall

FLOOD MET OFFICE, GUWAHATI

Init: 2016-08-31_00:00:00
Valid: 2016-09-01_03:00:00

IMD WRF Rainfall (mm) Forecast (24hr)



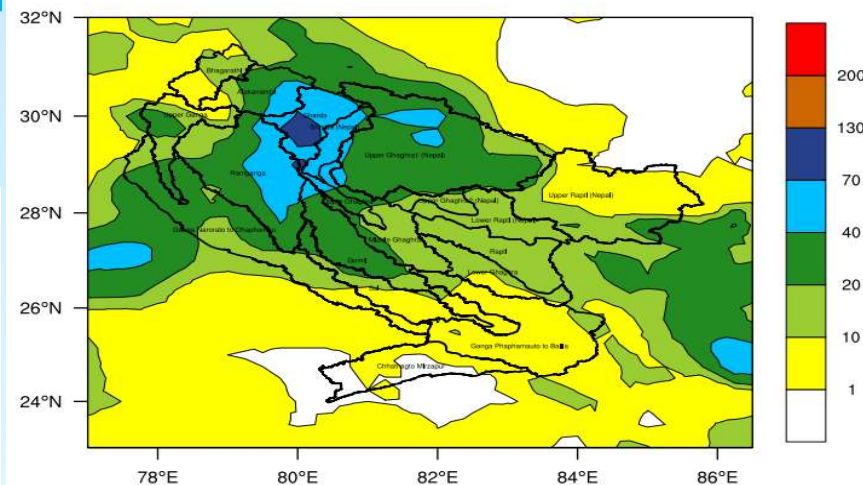
Sub basin wise Average Rainfall Estimation

Badarpurghat =	21 mm	Dhansiri_at_Golaghat =	25 mm
Barak_at_Silchar =	17 mm	Dhansiri_at_Riy_bridge =	16 mm
Brahmaputra_at_Dhubri =	47 mm	Gumti =	11 mm
Brahmaputra_at_Nimatihat =	31 mm	Jahhharali_at_NT_road_Xing =	21 mm

FLOOD MET OFFICE LUCKNOW

IMD MME Rainfall(mm) Forecast (24hr)

DAY2 FCST VALID FOR 26062015 TILL 08:30 IST



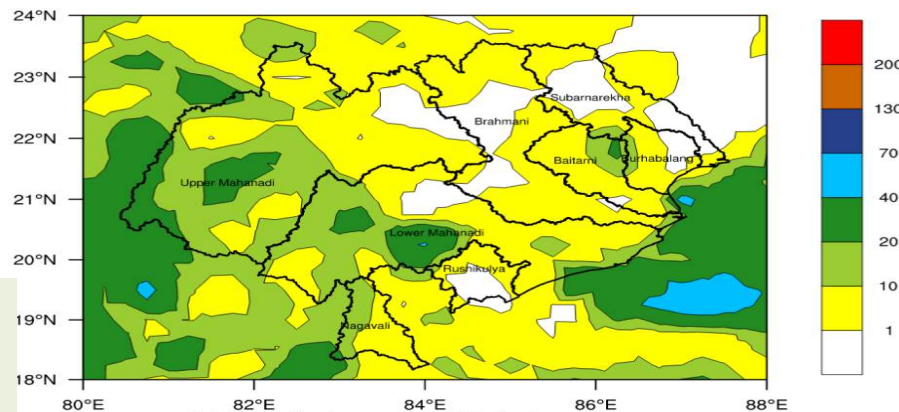
Sub basin wise Average Rainfall Estimation

Alamnaga =	6 mm	Rapti =	6 mm
Bhugathi =	6 mm	Sat =	5 mm
Chitrangula_Marasur =	5 mm	Sharda =	5 mm
Ganga_Nararata_Chapramasi =	18 mm	Sharda_Nararata =	13 mm
Ganga_Phadmanarata_Balla =	2 mm	Upper Ganga =	5 mm
Gomti =	5 mm	Upper Ghaghara =	5 mm
Lower Ghaghara =	5 mm	Upper Ghaghara_Nararata =	5 mm
Lower Rapti_Nararata =	5 mm	Upper Rapti_Nararata =	5 mm
Middle Ghaghara =	5 mm		
Ranganga =	21 mm		

FLOOD MET OFFICE BHUBANESWAR

IMD GFS Rainfall(mm) Forecast (24hr)

Day 1 FCST valid for: 01.09.2016 TILL 08:30 IST



Sub basin wise Average Rainfall Estimation

Baitarni =	7 mm
Brahmani =	2 mm
Burhabaling =	3 mm
Lower Mahanadi =	11 mm
Nagavali =	8 mm
Rushikulya =	2 mm
Subarnarekha =	2 mm
Upper Mahanadi =	10 mm
Vamsdhara =	7 mm

Derived products available at website:

- WRF(ARW) (9x9) (00UTC & 12 UTC) for 3 days
- Multi-Model Ensemble (27x 27) (00UTC) for 5 days
- GFS (12x12) (00UTC) for 7 days



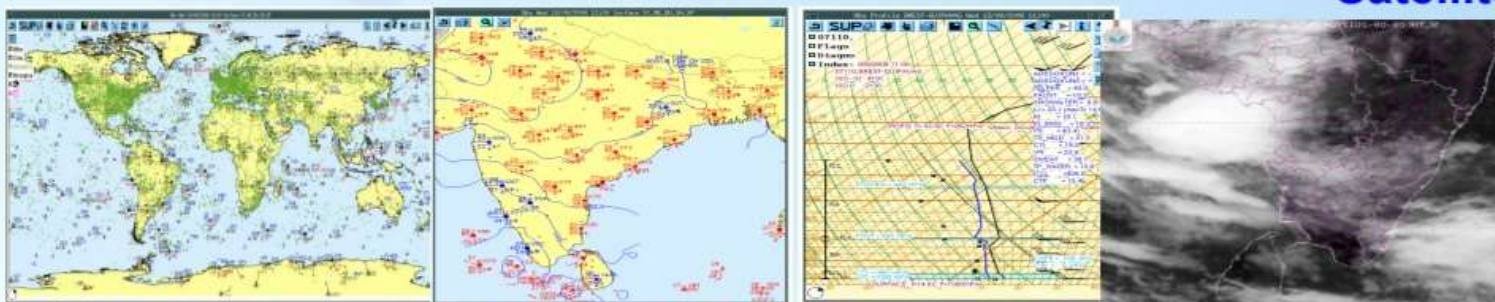
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Decision Support System for cyclone forecasting:

Geospatial Application in decision making

Satellite

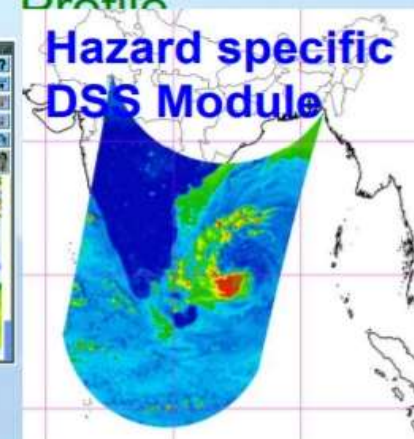


Global plotting Conditional plotting

But available at limited places



Profile Hazard specific DSS Module



Plane trajectories

Gau



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Chasing down to the arrival of TC with disaster management

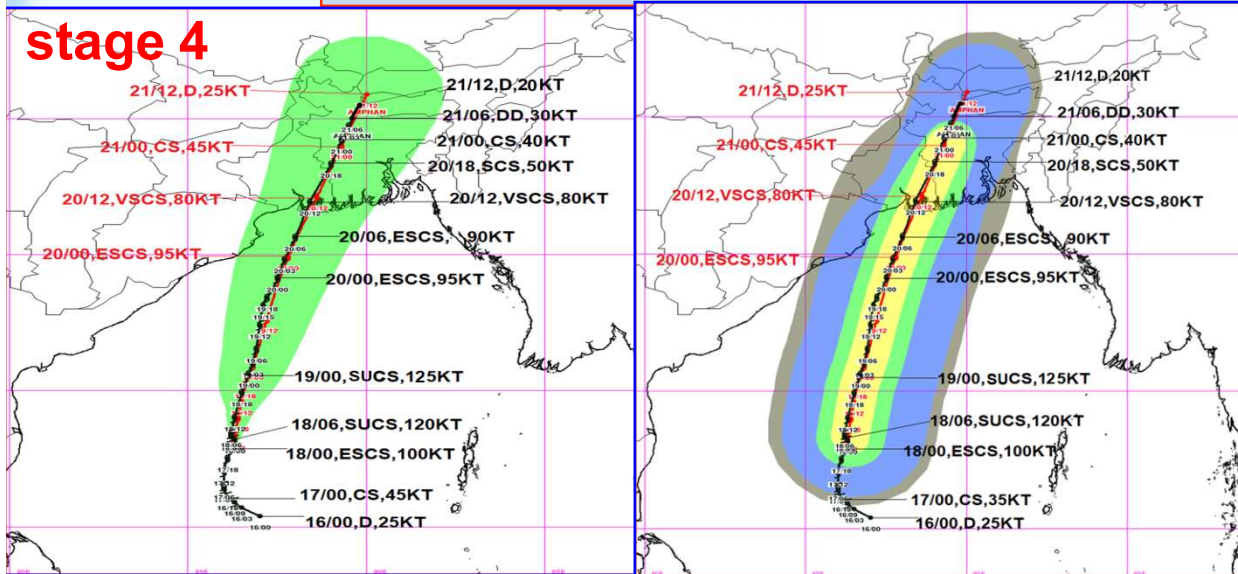
**Step-6:
Formation
of cyclonic
storm:
Cyclone
Alert**

- **Cyclone Alert: At least 48 hrs prior to beginning of adverse weather**
- **Information of current status, forecast track, intensity upto 120 hrs, adverse weather, state of sea, fishermen warning, damage expected & action suggested**

Count down

❖ **Tropical Cyclone Advisory (3 hourly) for international users**

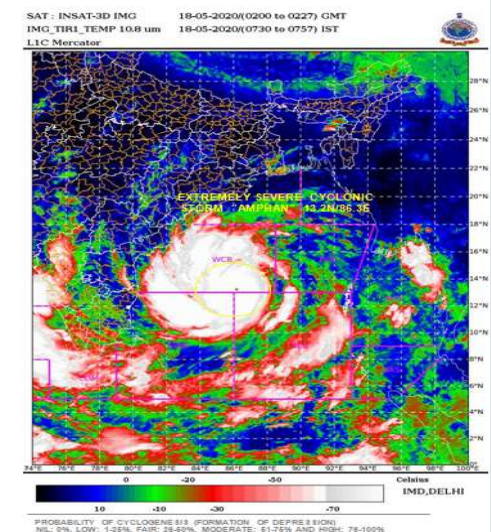
stage 4



D: DEPRESSION, DD: DEEP DEPRESSION, CS: CYCLONIC STORM, SCS: SEVERE CS, VSCS: VERY SEVERE CS, ESCS: EXTREMELY SEVERE CS, SUCS: SUPER CS

— OBSERVED TRACK
— FORECAST TRACK
— CONE OF UNCERTAINTY

OBSERVED TRACK & FORECAST TRACK BASED ON 0300 UTC OF 18TH MAY (60 HRS PRIOR TO LANDFALL) INDICATING ACCURACY IN TRACK AND INTENSITY FORECAST



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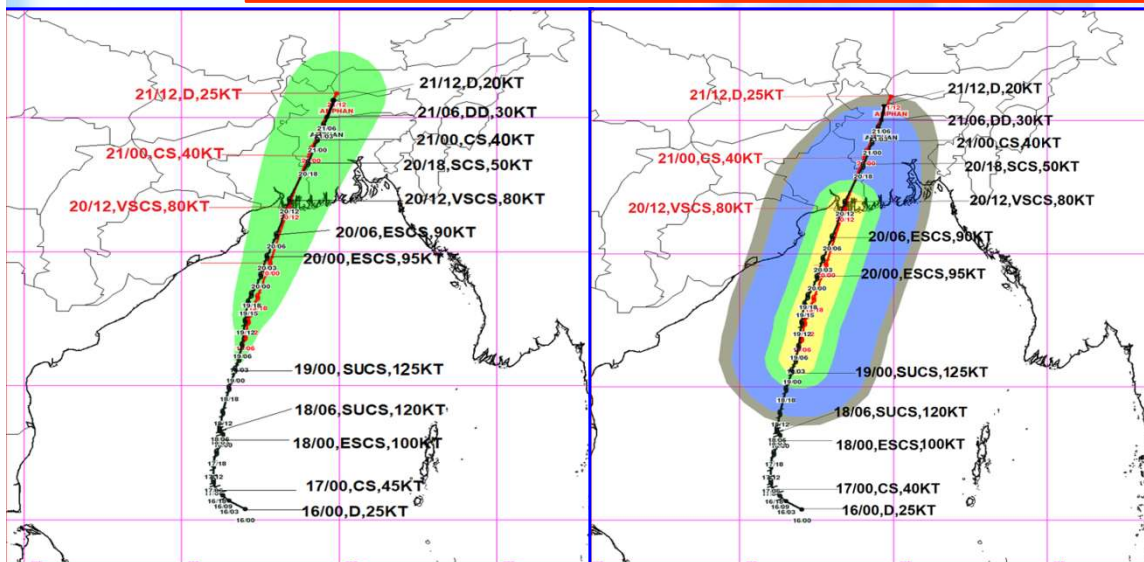


Chasing down Tropical Cyclone for disaster management

Step-7: Cyclone Warning

Count down stage 2

- **Cyclone Warning:** At least 24 hrs prior to beginning of adverse weather over a coastal state
- **Information of current status, forecast track, intensity upto 120 hrs, adverse weather (Heavy rain, wind, storm surge, state of sea, fishermen warning, damage expected & action suggested**
- ❖ **Tropical Cyclone Advisory (3 hourly) for international users**
- ❖ **Post landfall outlook:** At least 12 hrs prior to landfall with information about track, intensity, movement & adverse weather expected after landfall till its cyclone intensity.



OBSERVED TRACK & FORECAST TRACK BASED ON 0300 UTC OF 19TH MAY (36HRS PRIOR TO LANDFALL) INDICATING ACCURACY IN TRACK AND INTENSITY FORECAST

D: DEPRESSION, DD: DEEP DEPRESSION, CS: CYCLONIC STORM, SCS: SEVERE CS, VSCS: VERY SEVERE CS, ESCS: EXTREMELY SEVERE CS, SUCS: SUPER CS

 OBSERVED TRACK
 FORECAST TRACK
 CONE OF UNCERTAINTY



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INDIA METEOROLOGICAL DEPARTMENT



COUNTDOWN FOR SUCS “AMPHAN” WITH DISASTER MANAGEMENT

Count down stage 3 (18th May, 0845 hrs IST)-Cyclone Warning (Orange Message)

- Upgradation of cyclone alert to warning on 18th morning (56 hrs prior to landfall).
- Storm surge warning issued: 4-5 m above astronomical tide for south & north 24 Parganas and about 3-4 meters for east Medinipur districts.
- Joint press conferences by IMD & NDRF about impending disaster.
- 2nd NCMC meeting under chairmanship of cabinet secretary held on 18th May and similar meetings at state level in Odisha and West Bengal.
- Review meeting also conducted under chairmanship of Home Minister on 18th. Another review meeting under chairmanship of Prime Minister on 18th with high level disaster management authorities.
- DGM, IMD made presentations on all meetings.
- Follow-up actions on the ongoing preparedness and mitigation measures were sharpened.
- Joint Press Conferences organized by Press Information Bureau (PIB) were addressed by DGM IMD and DG NDRF on 18th, 19th, 20th and 21st May.
- DGM IMD appeared live on Facebook on 18th and facilitated frequent briefings to media persons from IMD HQ and CWC, Bhubaneswar and Kolkata.



Chasing down Tropical Cyclone for disaster management

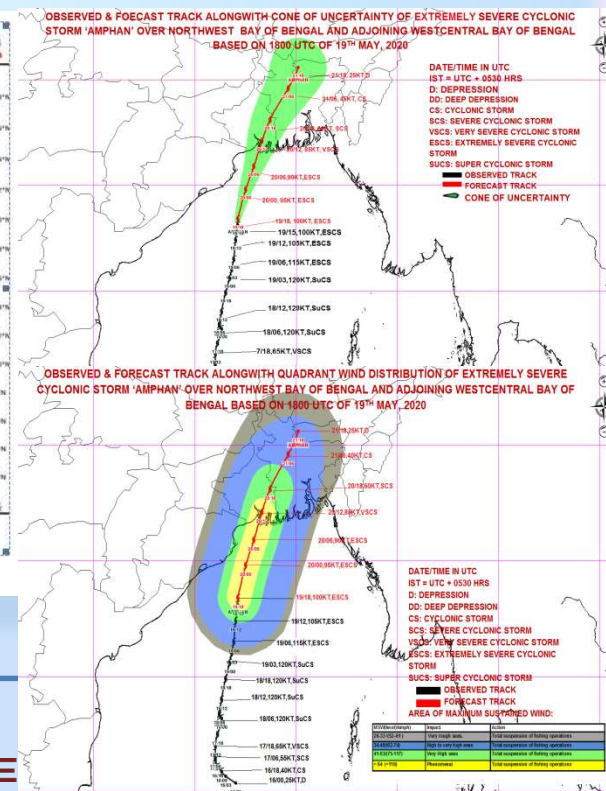
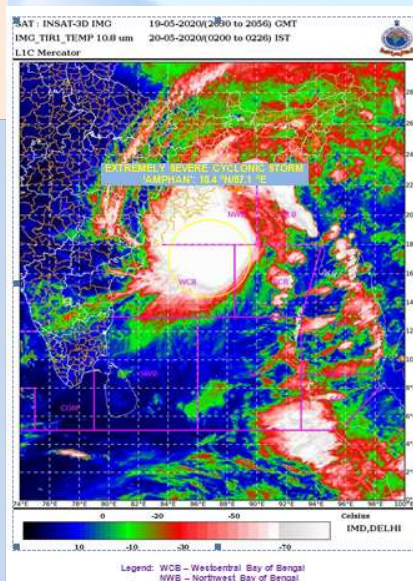
Step-8: Post Landfall Outlook

Count down stage 2

- **Post landfall outlook:** At least 12 hrs prior to landfall with information about track, intensity, movement & adverse weather associated with system after landfall till it maintains cyclone intensity.
- It is an appendix to already numbered cyclone warning
- Information of current status, forecast track, intensity upto 120 hrs, adverse weather (Heavy rain, wind, storm surge, state of sea, fishermen warning, damage expected & action suggested
- ❖ Tropical Cyclone Advisory (3 hourly) for international users

SuCS "Amphan" (19th May, 2330 hrs IST)-Post Landfall Outlook

It commenced in the midnight of 19th May (17 hrs prior to landfall) with the release of post landfall outlook (Red Message) for interior districts of Gangetic West Bengal, Assam and Meghalaya after landfall in addition to continued cyclone warning for coastal districts of north Odisha and West Bengal.



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Step-9: Hourly Update

- Hourly bulletins commence at least 12 hours prior to landfall
- Details about current status & forecast, expected landfall process, ongoing and expected heavy rain, wind & storm surge.

Countdown stage 1 (20th May 2020, 0630 hrs IST)-Hourly Updates

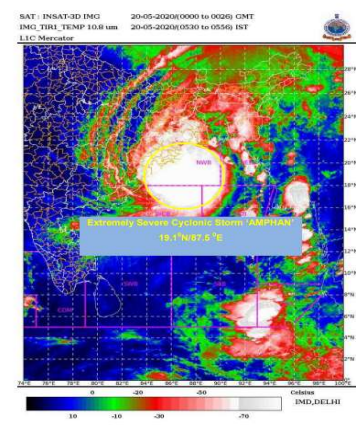
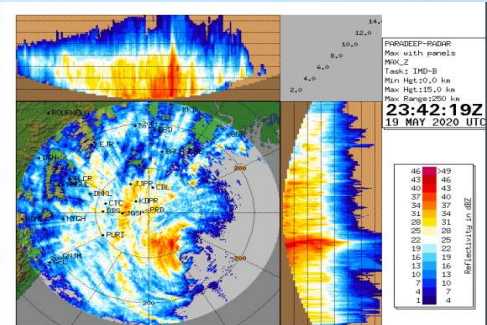
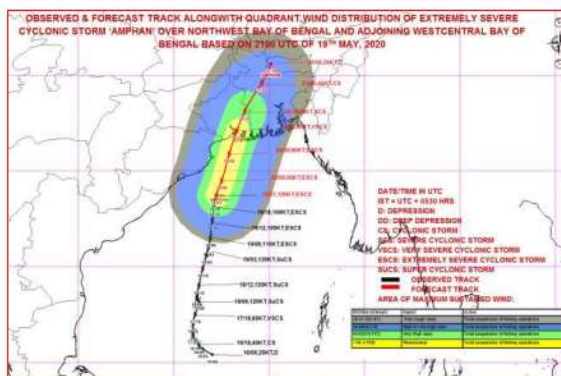
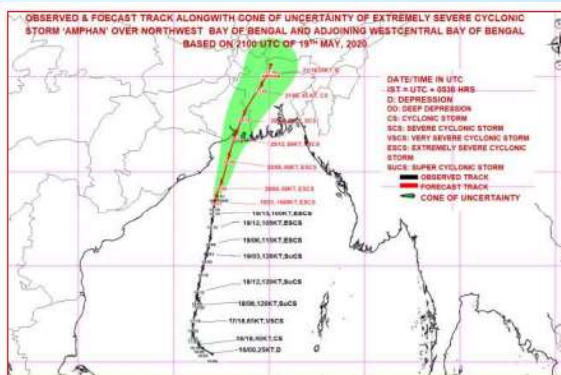
HOURLY UPDATE ON SUPER CYCLONIC STORM 'AMPHAN' OVER NORTH WEST BAY OF BENGAL & ADJOINING WEST CENTRAL BAY OF BENGAL.

BULLETIN NO. 1

DATE: 20-05-2020

TIME OF ISSUE: 0630 HRS IST

DATE/TIME (IST) OF OBSERVATION	0530 HRS IST OF 20-05-2020 / 0000 UTC OF 20.05.2020
CURRENT LOCATION LATITUDE/LONGITUDE	SUPER CYCLONE AMPHAN CENTRED AT 0530 HRS IST OF TODAY, THE 20TH MAY 2020, AS AN EXTREMELY SEVERE CYCLONIC STORM OVER NORTHWEST BAY OF BENGAL NEAR LAT. 19.1°N AND LONG. 87.5°E, ABOUT: • 155 KM NEARLY SOUTH OF PARADIP. • 280 KM SOUTH-SOUTHWEST OF DIGHA. • 425 KM SOUTH-SOUTHWEST OF KHEPUPARA (BANGLADESH)
CURRENT INTENSITY NEAR CENTER	170-180 KMPH GUSTING TO 200 KMPH.
OBSERVATIONS FROM THE COAST	WINDSPEED : PARADIP-96, CHANDBALI-65, BHUBANESHWAR-41, BALASORE-41, PURI-39 AND GOPALPUR-30 KMPH. RAINFALL: PARADIP-144, CHANDBALI-56, BHUBANESHWAR-35, BALASORE-39, PURI-58 AND GOPALPUR-08 MM SINCE 08:30 IST OF 19 MAY 2020.
PAST MOVEMENT	MOVED NORTH-NORTHEASTWARDS WITH A SPEED OF 14 KMPH DURING PAST 6 HOURS.
FORECAST MOVEMENT, INTENSITY AND LANDFALL	TO MOVE NORTH-NORTHEASTWARDS AND CROSS WEST-BENGAL-BANGLADESH COAST BETWEEN DIGHA AND HATIYA CLOSE TO SUNDEBANS DURING AFTERNOON TO EVENING OF TODAY WITH A WIND SPEED OF 155-165 KMPH GUSTING TO 185 KMPH.



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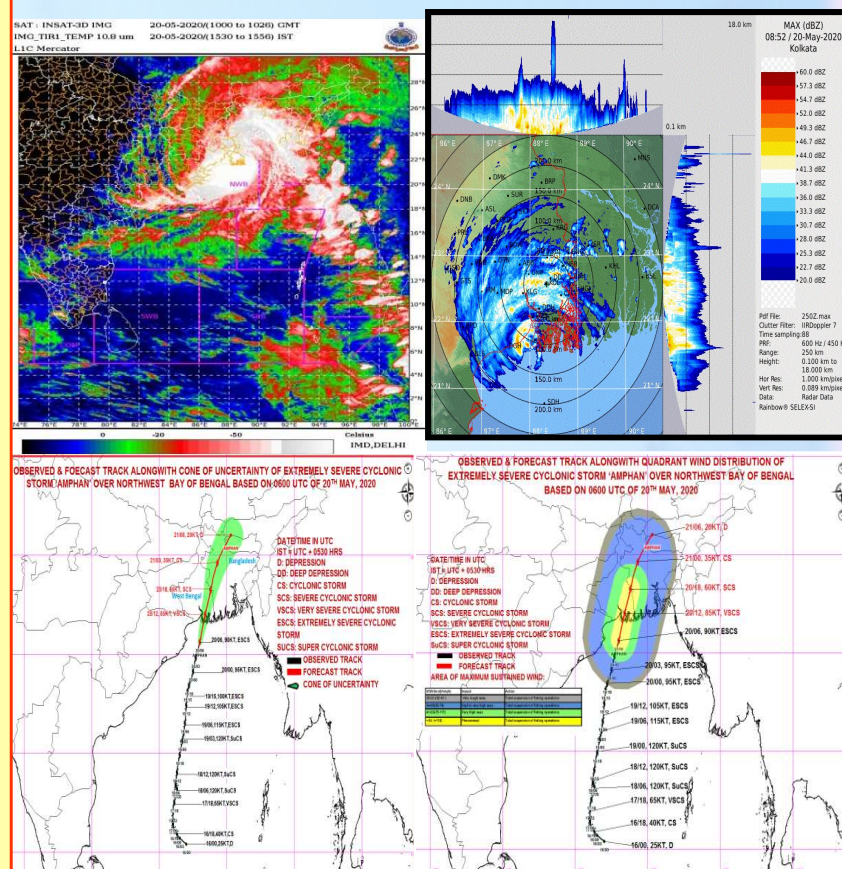
Chasing down Tropical Cyclone for disaster management

Step-10: Landfall process

- Hourly bulletins continue during landfall process which takes about 2 to 3 hrs
- Information on landfall point & time,
- Details of current status and forecast, ongoing and expected adverse weather like heavy rain, wind and storm surge.

Count down stage zero (20th May 2020, 1430 hrs IST): Commencement of landfall process

- continued for 2-3 hours till the system crossed West Bengal coast between Digha (West Bengal) and Hatiya Islands (Bangladesh) over Sundarbans between 1530 and 1730 hrs IST of 20th May with wind speed of 155-165 gusting to 185 kmph.
- Maximum storm surge of 4.6 meter above the astronomical tide was realised as predicted.
- extremely heavy rainfall occurred over north coastal Odisha and coastal West Bengal including Kolkata as predicted.



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Chasing down Tropical Cyclone for disaster management

Step-11 De- warning

Count UP stage 1

- After landfall, three hourly bulletins continue till it maintains cyclone intensity.
- Six hourly bulletins commence when it weakens into a deep depression and till it becomes insignificant.
- De-warning for a coast issued, when coast is free from impact .
- It is also issued in case cyclone weakens over sea under adverse environmental conditions.

Amphan : Count up stage 1 (20th May 2020, 1830 hrs IST)-Post landfall follow up

- Hourly bulletins continued till it maintains cyclone intensity over Indian Region i.e. till 0230 hrs IST of 21st May.
- It passed over Kolkata around 2100 hrs IST of 20th May as a VSCS with wind speed of 120-130 kmph gusting to 145 kmph as per the prediction 3 days earlier.
- Regular 3 hourly bulletins continued till system maintained CS intensity (morning of 21st May).
- Six hourly bulletins in the weakening phase continued till midnight of 21st May
- Thereafter, IMD maintained watch over the system till it became insignificant on 22 May



Stages of Warning and Colour codes

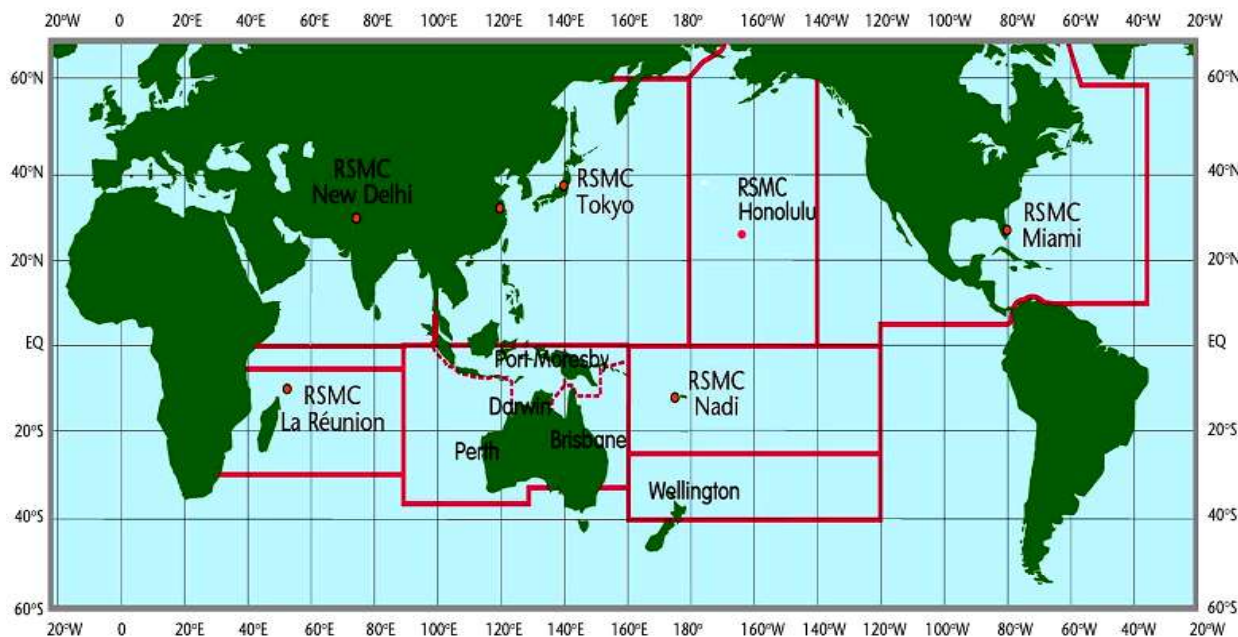
Different colour codes as mentioned below are being used since post monsoon season of 2006 for the different stages of the cyclone warning bulletins as desired by the National Disaster Management.

Stage of warning	Colour code
Cyclone Alert	Yellow
Cyclone Warning	Orange
Post landfall out look	Red



Cyclone Warning Organisation

Institutional Mechanism



- IMD is mandated to monitor and issue warnings regarding tropical cyclones over the north Indian ocean for the country.
- **International Responsibility:**
 - ❖ IMD also acts as RSMC to provide tropical cyclone advisories to **13** countries under WMO/ESCAP Panel (Bangladesh, India, Maldives, Myanmar, Oman, Pakistan, Sri Lanka, Thailand, Yemen, UAE, Saudi Arabia, Qatar, Iran).
 - ❖ Acts as a Tropical Cyclone Advisory Centre for international civil aviation
 - ❖ Provides Global maritime Distress Support System (GMDSS) over NIO.



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BULLETINS AND WARNINGS for NATIONAL PURPOSE

❖ Four stage cyclone warning

- i. Sea area bulletin
- ii. Coastal weather bulletin
- iii. Bulletins for Indian navy
- iv. Fisheries warnings
- v. Port warnings
- vi. Aviation warning
- vii. Bulletins for AIR/ Doordarshan/ press
- viii. CWDS bulletins
- ix. Warnings for registered/ designated users.
- x. **Impact based forecast and warning**



Damage Potential of Cyclones

Intensity	Damage expected	Action Suggested
Deep Depression 50 – 61 kmph (28-33 knots)	Minor damage to loose and unsecured structures.	Fishermen advised not to venture into the open seas.
Cyclonic Storm 62 – 87 kmph (34-47 knots)	Damage to thatched huts. Breaking of tree branches causing minor damage to power and communication lines	Total suspension of fishing operations
Severe Cyclonic Storm 88-117 kmph (48-63 knots)	Extensive damage to thatched roofs and huts. Minor damage to power and communication lines due to uprooting of large avenue trees. Flooding of escape routes.	Total suspension of fishing operations. Coastal hutment dwellers to be moved to safer places. People in affected areas to remain indoors.



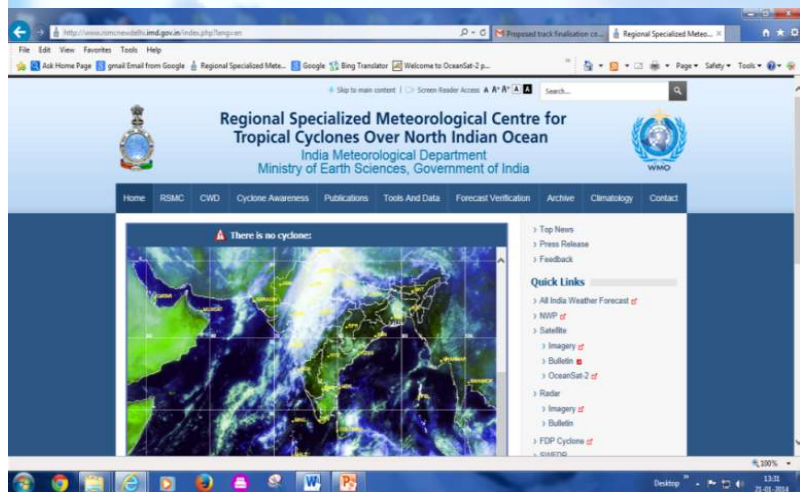
Damage Potential of Cyclones

Intensity	Damage expected	Action Suggested
Very Severe Cyclonic Storm 118-166 kmph (64-89 knots)	Extensive damage to kutcha houses. Partial disruption of power and communication line. Minor disruption of rail and road traffic. Potential threat from flying debris. Flooding of escape routes.	Total suspension of fishing operations. Mobilise evacuation from coastal areas. Judicious regulation of rail and road traffic. People in affected areas to remain indoors.
Extremely Severe Cyclonic Storm 167-221 kmph (90-119 knots)	Extensive damage to kutcha houses. Some damage to old buildings. Large-scale disruption of power and communication lines. Disruption of rail and road traffic due to extensive flooding. Potential threat from flying debris.	Total suspension of fishing operations. Extensive evacuation from coastal areas. Diversion or suspension of rail and road traffic. People in affected areas to remain indoors.
Super Cyclonic Storm 222 kmph and more (120 knots and more)	Extensive structural damage to residential & industrial buildings. Total disruption of communication and power supply. Extensive damage to bridges causing large-scale disruption of rail, road traffic. Large-scale flooding & inundation of sea water. Flying debris	Total suspension of fishing operations. Large-scale evacuation of coastal population. Total suspension of rail and road traffic in vulnerable areas. People in affected areas to remain indoors.

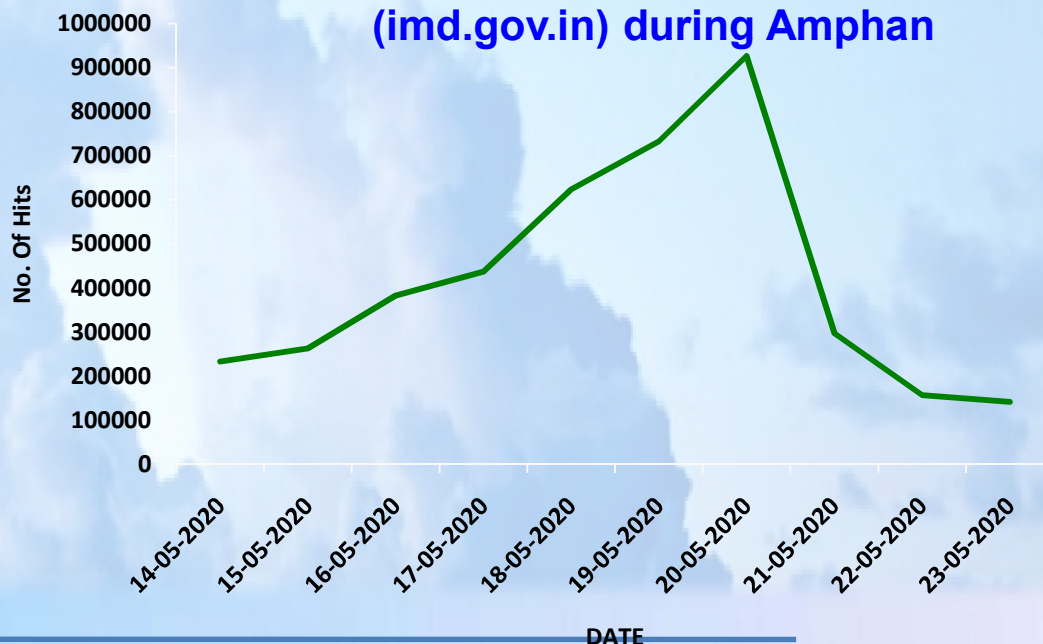


Advances in Warning Dissemination Mechanism

- ❖ Telephone, Tele-fax, Mobile Phones (SMS) through IMD severe weather network, Agromet Network, INCOIS network.
- ❖ VHF/HFRT/Police Wireless
- ❖ Satellite based cyclone warning dissemination System
- ❖ Aeronautical Fixed Terminal Network
- ❖ Global telecommunication system (GTS) :
- ❖ Websites, Dedicated website for cyclone (rsmcnewdelhi.imd.gov.in)
- ❖ Radio/TV, News Paper network (AM, FM, Community Radio, Private TV) : Prasar Bharati and private broadcasters
- ❖ NAVTEX , Internet (e-mail), ftp
- ❖ GAMES and NAVIK



Number of unique visitors on IMD website (imd.gov.in) during Amphan



Chasing down Tropical Cyclone for disaster management

Step-12 Documen tation

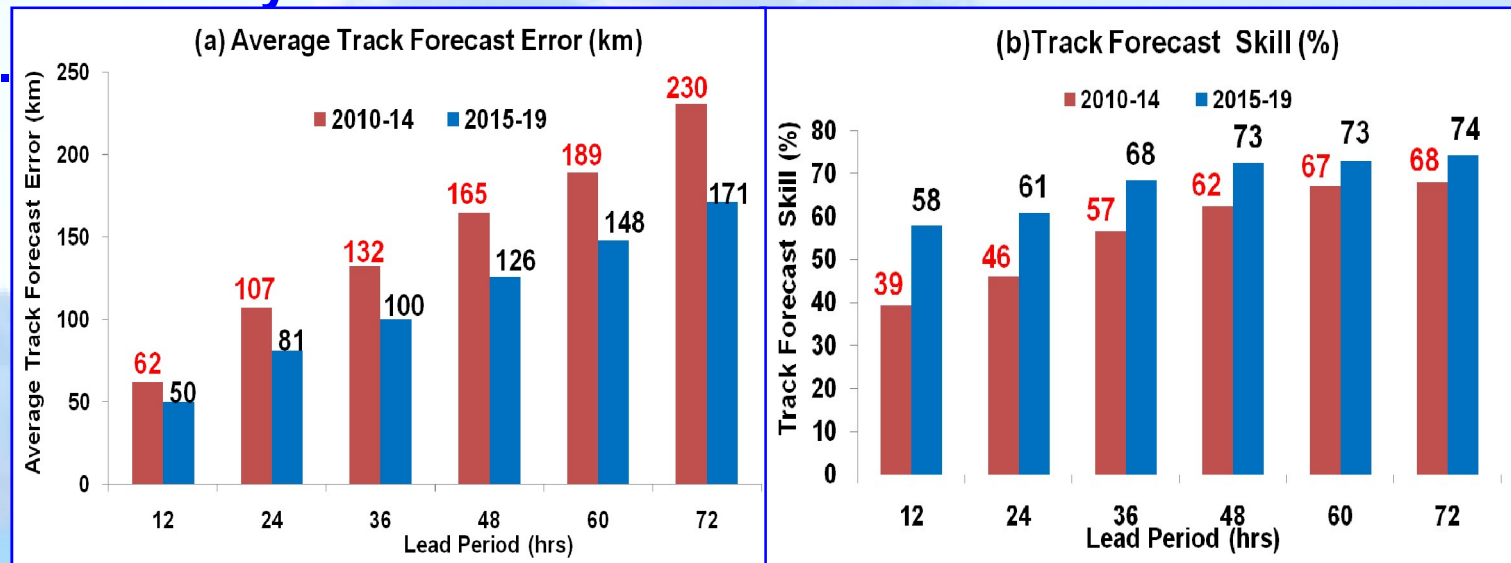
Count Up Stage 2

- Last press release after dissipation of cyclone provides life history, associated weather and warning performance
- Preliminary report prepared within seven days of dissipation of cyclone,
- Contains brief life history, performance of forecast and warning services, challenges and lessons learnt
- Communicated to disaster managers, press/electronic media.
- It is uploaded in IMD website (www.mausam.imd.gov.in, www.rsmcnewdelhi.imd.gov.in)
- Vital parameters of cyclone are archived in digital form in archive page of website for future reference as well as research and development (www.rsmcnewdelhi.imd.gov.in).



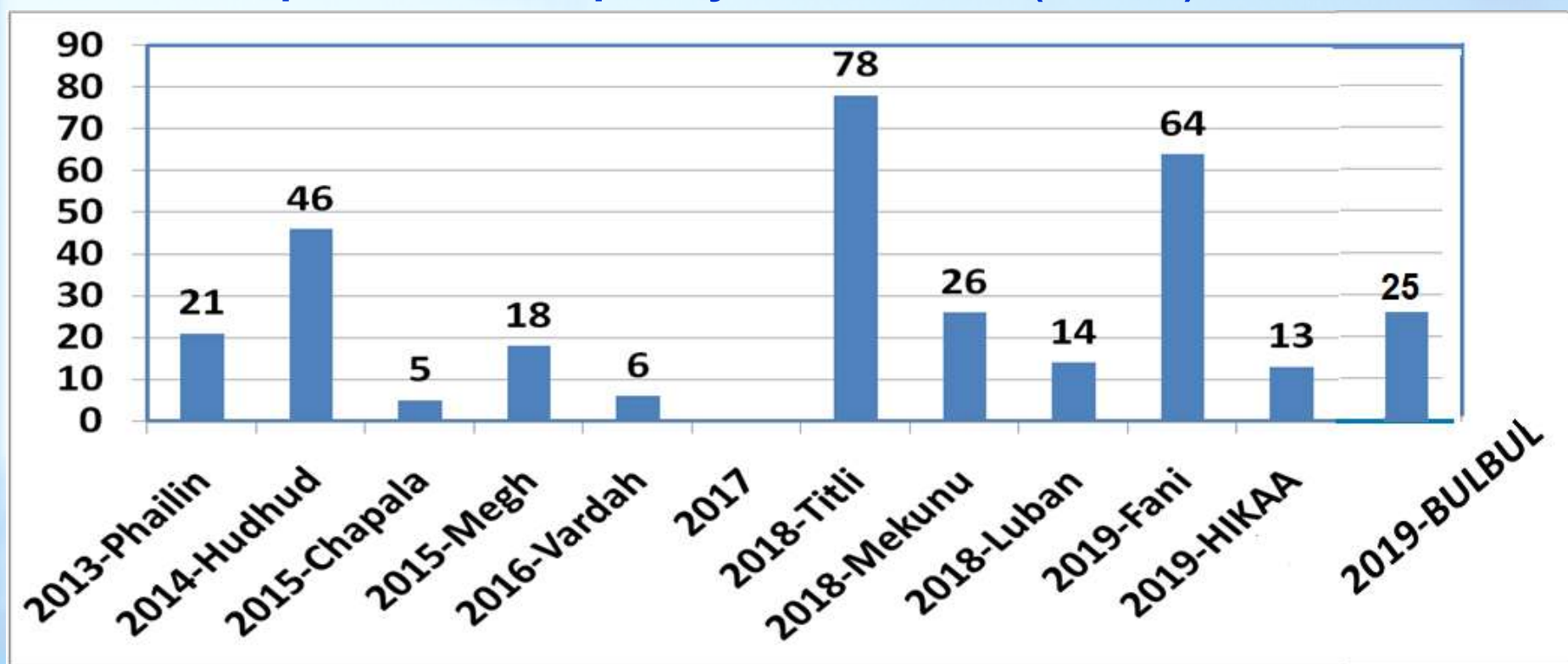
Cyclone Forecast Accuracy

- ❖ The forecast accuracy is at par with leading centres of the world.
- ❖ The cyclone track forecast errors of IMD has reduced from 124 km in 2009-13 to 86 km in 2015-19 for 24 hr forecast, from 202 to 132 km for 48 hrs forecast and from 268 to 177 km for 72 hrs forecast.
- ❖ The 24 hr cyclone landfall forecast error has reduced from 91 km to 42 km during the same period.
- ❖ The error in intensity forecast is about 10-15 knots for 24-72 hr forecasts.



OUTCOME: Loss Of Lives Due To Very Severe Cyclones crossing coast

- Significant reduction in human deaths due to cyclones
- Number of deaths less than 100 in recent years compared to thousands due to similar cyclones in past,
- For example. Odisha Super Cyclone in 1999 (10,000)



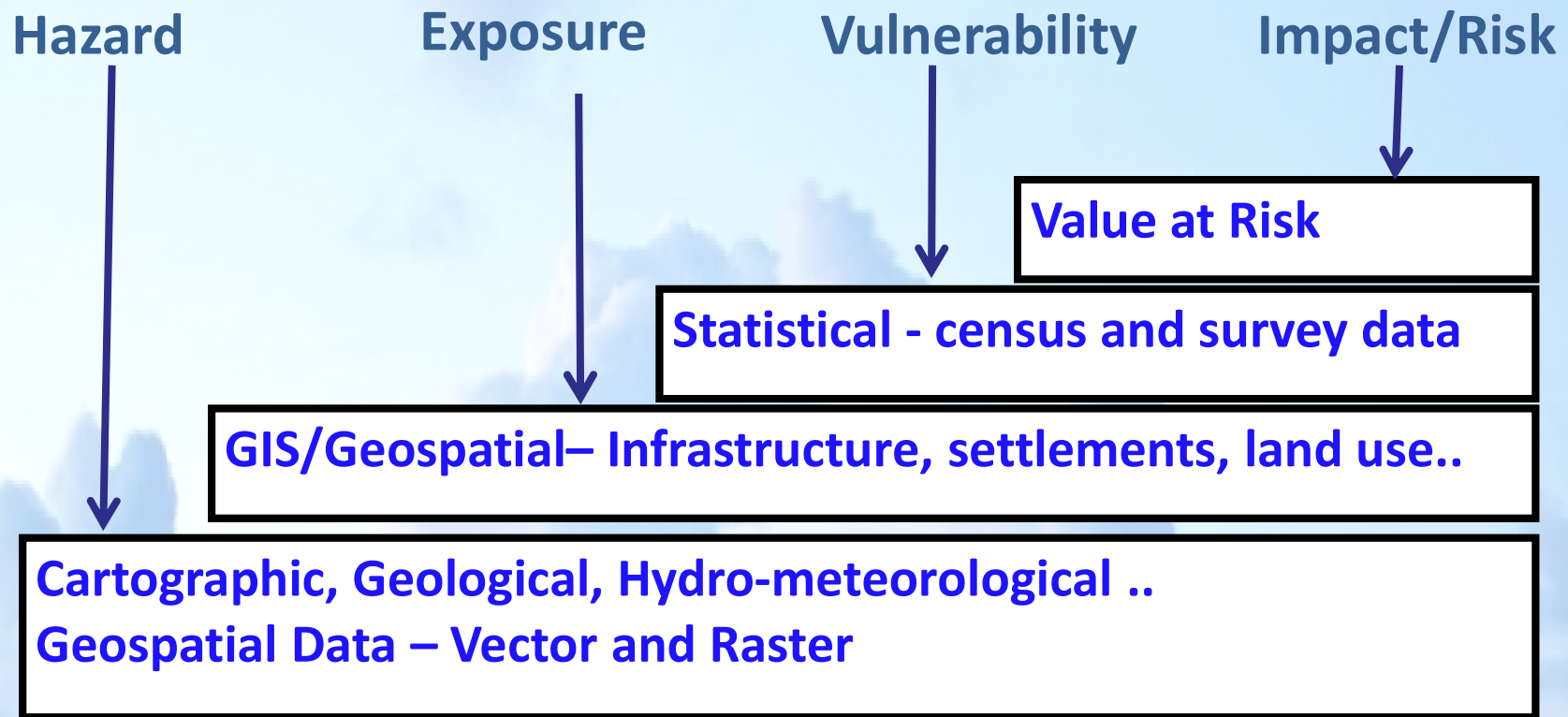
Way Ahead

- ❖ Still there are gaps in technology vis-a-vis capability.
- ❖ Gap in scientific understanding required for better forecasting that includes:
 - Detailed structure and dynamics of cyclones over the
 - Interaction between cyclone, Ocean, the surrounding environment
 - Internal physical and dynamical processes in clouds.
- ❖ Gap in observational and modeling systems for forecasting with high spatial resolution
- ❖ There is still scope for improvement in Forecast skill with the above
- ❖ Warning dissemination to be further improved for most vulnerable groups at last mile (Along the coast and in the sea).
- ❖ MoES is continuously upgrading its plan and strategy for all the above
- ❖ Lessions learnt from past cyclones will be used for future



Impact based Forecasting (from static to dynamic)

Translating hazard information into impact scenarios



Thank you



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