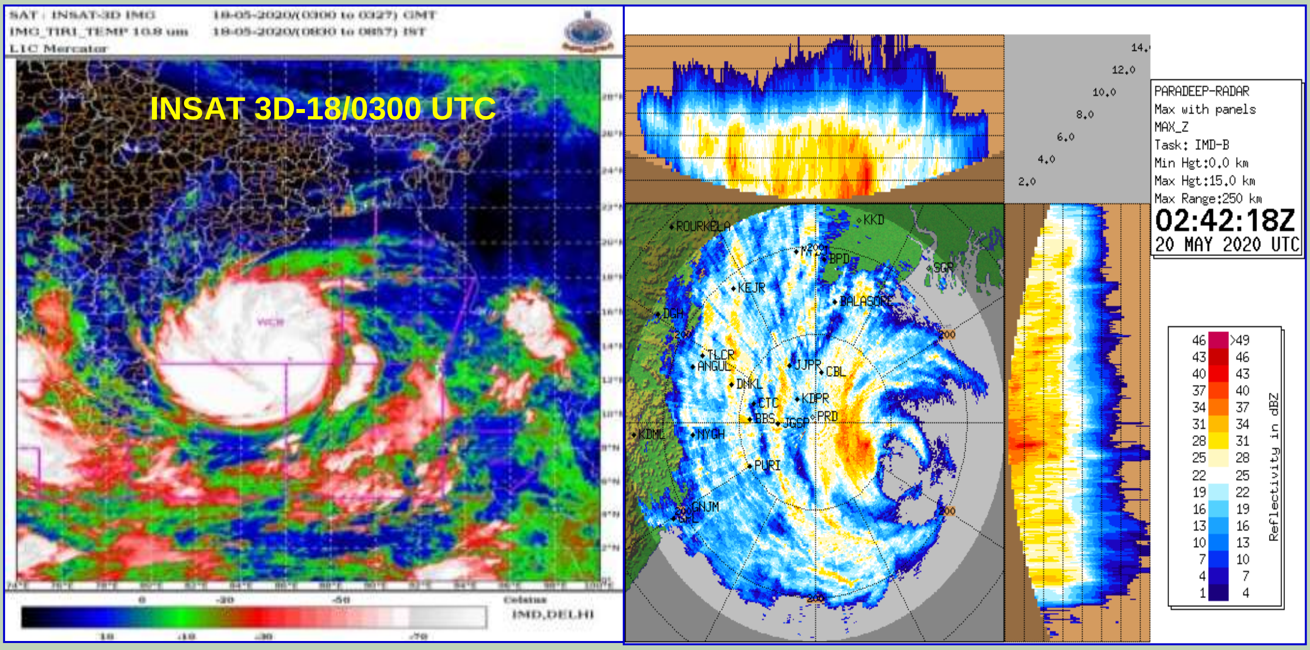
India Meteorological Department
Ministry of Earth Sciences

Ministry of Earth Sciences
Government of India

CYCLONE WARNING IN INDIA
STANDARD OPERATION PROCEDURE



INDIA METEOROLOGICAL DEPARTMENT
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MARCH, 2021

PREFACE

A tropical cyclone (TC) is a multihazard weather phenomenon, as it leads to heavy rainfall, gale wind and storm surge during the landfall. It also effects severely the marine activities during its life over the Sea. Though fewer tropical cyclones (about 7 % of global frequency) occur over the north Indian Ocean (NIO), it causes heavy loss of life and property over the region.

Various components of early warning system for TCs include (i) hazard analysis, (ii) monitoring (iii) modeling, (iv) forecasting, (v) impact & risk assessment, (vi) warning generation, presentation & dissemination, (vii) co-ordination with disaster management agencies, (viii) public education & reaching out and (ix) post-event review. Over the years, the India Meteorological Department (IMD) has built up a credible Cyclone Warning System for the country which utilises augmented observational network, satellites, radars, array of various global & regional numerical weather prediction (NWP) models and modern information and communication technology for analysis, forecasting and warning generation & dissemination. In the event of an approaching TC, IMD issues impact based warnings to all concerned including the government, the local population, media and stakeholders through a variety of communication channels. As a result, during recent years the loss of life due to TCs has been reduced significantly to less than 100 in any cyclone. However, the huge loss of property due to TCs is still a challenge to be addressed.

All the aspects of the early warning system of TCs have been standardized in the document “Standard Operational Procedure (SOP) for Cyclone Warning in India” to improve the efficiency of cyclone warning system. As there have been significant improvements in all the components of cyclone warning system during recent years including observations, modeling and communication, the Cyclone Warning Division of IMD has updated this document incorporating all the latest developments in the field. This SOP document will be useful to forecasters, early warning service providers and disaster management agencies in effectively mitigating disaster due to TCs.

Mrutyunjay Mohapatra

March 2021

Director General of Meteorology

Acknowledgements

I am thankful to all the Officers and Staff members of Cyclone Warning Division for their coordinated efforts that went into the formulation of the Manual entitled "Cyclone Warning in India-Standard Operation Procedure".

I hereby place on record my deep appreciation for the valuable contributions made by Mrs. Sunitha Devi, Scientist-F & Head Cyclone Warning Division and Mrs. Monica Sharma, Scientist-D, Cyclone Warning Division towards preparation, compilation, edition, review and publication of this manual. I express my sincere thanks and appreciation to Mr. Mukesh Kumar, SA, Mr. Santosh Singh, SA Mr. Gaurav Kumar Srivastav, SA, Mr. Aditya Chaudhary, SA, Ms. Shilpa Singh, SA and Mr. V. Vijay Kumar, Meteorologist B for their technical support in publication of this document.

Mrutyunjay Mohapatra

March 2021 **Director General of Meteorology**

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List of Acronyms

ACWC	Area Cyclone Warning Centre
ADT	Advanced Dvorak Technique
AIR	All India Radio
AMSS	Automatic Message Switching System
AMSU	Advanced Microwave Sounder Unit
ARB	Arabian Sea
ARG's	Automatic Rain Gauge Stations
AWS	Automatic Weather Station
BoB	Bay of Bengal
BoM	Bureau of Meteorology
C.I. No.	Current Intensity Number
CAPE	Convective Available Potential Energy
CCD	Charge Coupled Device
CDMC	Cyclone Distress Mitigation Committee
CDO	Central Dense Overcast
CDR	Cyclone Detection RADAR
CDs	Cyclonic Disturbances
CIMSS	Cooperative Institute for Meteorological Satellite Studies
CINE	Convective Inhibition Energy
CIPS	Cooperative Institute for Precipitation Systems
CLIPER Model	Climatology and Persistence Model
CMV	Cloud Motion Vectors
COU	Cone of Uncertainty
CPC	Climate Prediction Centre
CRC	Cyclone Review Committee
CTT	Cloud Top Temperature
CWC	Cyclone Warning Centre
CWD	Cyclone Warning Division
CWRC	Cyclone Warning Research Centre
DMDD	Digital Meteorological Data Dissemination
DMSP	Defence Met. Satellite Programme of U.S.A.
DPE	Direct Position Error
DRMS	District-wise Rainfall Monitoring Scheme

DWR	Doppler Weather RADAR
ECMWF	European Centre for Medium-Range Weather Forecasts
EEC Radars	Enterprise Electronics Corporation Radars
EIR	Enhanced Infrared
EPS	Ensemble Prediction System
FNMOC	Fleet Numerical Meteorology and Oceanography Centre
GEFS	Global Ensemble Forecast System
GFS	Global Forecast System
GMDSS	Global Maritime Distress Safety System
GPP	Genesis Potential Parameter
GTS	Global Telecommunication System
HFRT	High Frequency Radio Transmission
HSDT	High Speed Data Terminals
HWRF	Hurricane Weather Research and Forecasting
IADP	Intensive Agricultural Development Programme
IAF	Indian Air Force
ICAO	International Civil Aviation Organisation
IITD	Indian Institute of Technology Delhi
IMD	India Meteorological Department
IMDPS	Indian Meteorological Data Processing System
INCOIS	Indian National Centre for Ocean Information Services
INOSHAC	Indian Ocean & South Hemispheric Centre
INSAT	Indian National Satellite System
IOP	Intense Observation Period
IR	Infrared Red
IST	India Standard Time
ITCZ	Inter-Tropical Convergence Zone
IVRS	Interactive Voice Response System
JMA	Japan Meteorological Agency
JTWC	Joint Typhoon Warning Center
LES	Local Earth Station
LLCCs	Low level circulation centres
Max (Z)	Maximum reflectivity
MFI	Meteo France International

MHA	Ministry of Home Affairs
MJO	Madden-Julian oscillation
MM5	Fifth-Generation Penn State/NCAR Mesoscale Model
MME	Multi Model Ensemble
MSLP	Mean Sea Level Pressure
MSW	Maximum Sustained Wind
MW	Microwave
NASA GHCC	National Aeronautics and Space Administration- Global Hydrology and Climate Center.
NBDP	Narrow Band Direct Printing
NCMRWF	National Centre for Medium Range Weather Forecast
NDBP	National Data Buoy Programme
NDM	National Disaster Management
NDMA	National Disaster Management Authority
NDRF	National Disaster Response Force
NIDM	National Institute of Disaster Management
NIO	North Indian Ocean
NIOT	National Institute of Ocean Technology
NOAA	National Oceanic and Atmospheric Administration
NRL	Naval Research Laboratory
NSDC	National Satellite Data Centre
NWFC	National Weather Forecasting Centre
NWP	Numerical Weather Prediction
OLR	Outgoing Longwave Radiation
PBO	Pilot Balloon Observatories
PMSS	Probable Maximum Storm Surge
PPI(Z)	Plan Position Indicator
PRBS	Pseudo-Random Burst Technique
QPE	Quantitative Precipitation Estimation
RMC	Regional Meteorological Centre
RMR	Radius of Maximum Reflectivity
RMW	Radius of Maximum Wind
RS/RW	Radio sonde/ Radio wind
RSMC	Regional Specialized Meteorological Centre

RSS	Remote Sensing Systems
RTH	Regional Telecommunication Hub
SAARC	South Asian Association for Regional Cooperation
SCIP	Statistical-Dynamical Model for Cyclone Intensity Prediction
SDMC	SAARC Disaster Management Centre
SLP	Sea Level Pressure
SRI	Surface Rainfall Intensity
SST	Sea Surface Temperature
STDS	Satellite Tropical Disturbance Summary
TB	Brightness Temperature
TC	Tropical Cyclones
TCAC	Tropical Cyclone Advisory Centre
THORPEX	The Observing System Research and Predictability Experiment
TIGGE	THORPEX Interactive Grand Global Ensemble
TMI	TRMM Microwave Imager
TPC	Tropical Prediction Centre
TPW	Total Precipitable Water
TRMM	Tropical Rainfall Measuring Mission
UKMO	UK Meteorological Office
UTC	Coordinated Universal Time
UWT	Uniform Wind Technique
VHRR	Very High Resolution Radiometer
VIS	Visible
VOF	Voluntary Observing Fleet
VVP(Z)	Volume Velocity Processing
WMO	World Meteorological Organisation
WRF	Weather Research and Forecasting Model
WV	Water Vapour
WVWs	Water Vapour Winds

Chapter I
Introduction

A "Cyclonic Storm' or a "Cyclone" is an intense vortex or a whirl in the atmosphere with very strong winds circulating around it in anti-clockwise direction in the Northern Hemisphere and in clockwise direction in the Southern Hemisphere. The word "Cyclone" is derived from the Greek word 'Cyclos" meaning the coil of a snake. To Henri Piddington, the tropical storms in the Bay of Bengal and in the Arabian Sea appeared like the coiled serpents of the Sea and he named these storms as "Cyclones". Tropical cyclones are also referred to as 'Hurricanes' over Atlantic Ocean, 'Typhoons' over Pacific Ocean, 'Willy-Willies' over Australian Seas and simply as 'Cyclones' over north Indian Ocean (NIO).

1.1. Classification of cyclonic disturbances

Cyclones are intense low pressure areas - from the center of which pressure increases outwards. The amount of the pressure drop in the center and the rate at which it increases outwards gives the intensity of the cyclones and the strength of winds. The criteria followed by the India Meteorological Department (IMD) 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 given in Table 1.1.

Table 1.1. Criteria for classification of cyclonic disturbances over the North Indian Ocean

	Type of disturbance	Associated maximum sustained wind
1.	Low Pressure Area	Not exceeding 17 knots (<31 kmph)
2.	Depression	17 to 27 knots (31-49 kmph)
3.	Deep Depression	28 to 33 Knots (50-61 kmph)
4.	Cyclonic Storm	34 to 47 Knots (62-88 kmph)
5.	Severe Cyclonic Storm	48 to 63 Knots (89-117 kmph)
6.	Very Severe Cyclonic Storm	64 to 90 Knots (118-167 kmph)
7.	Extremely Severe Cyclonic Storm	91 to119 Knots (168-221 kmph)
8.	Super Cyclonic Storm	120 Knots and above (≥222 kmph)

1.2. Structure of Tropical Cyclone

Tropical Cyclones (TCs) are warm core low pressure systems having a large vortex in the atmosphere, which is maintained by the release of latent heat by convective clouds that form over warm oceans. In the northern hemisphere, the winds in a cyclone blow anticlockwise in the lower troposphere and clockwise in the upper troposphere. However, in the southern hemisphere, the winds of the cyclone blow in the opposite direction i.e. clockwise in the lower levels and anticlockwise in the upper levels.

A full-grown cyclone is a violent whirl in the atmosphere with 150 to 1000 km diameter and 10 to 15 km height. Gale winds of 150 to 250 kmph or more spiral around the center of the low pressure system with 30 to 100 hPa below the normal sea level pressure. In a fully developed cyclonic storm, there are four major components of horizontal structure viz. Eye, Wall cloud region, Rain/Spiral bands and Outer storm area. A schematic diagram is given in Fig.1.1.

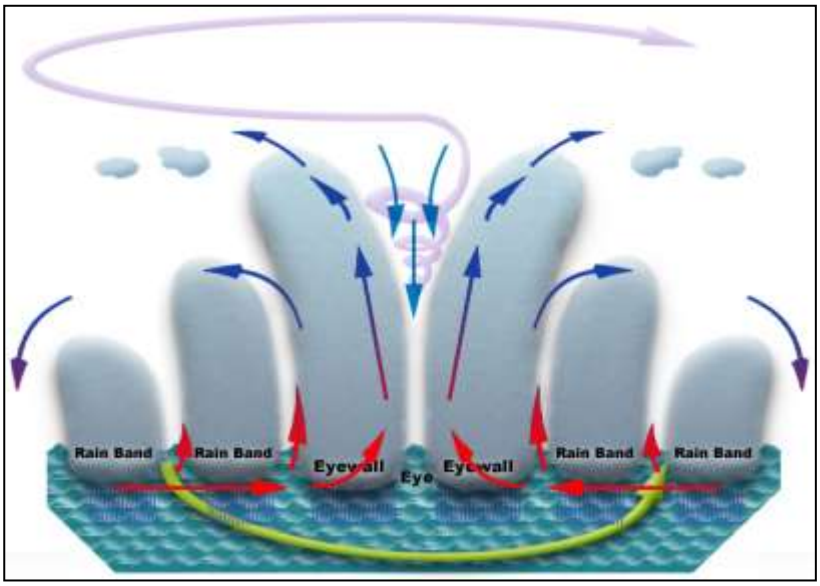


Fig.1.1 Schematic diagram of a cyclone

1.2.1. Eye

A typical imagery of cyclone showing eye is given in Fig.1.2. The most spectacular part of a matured cyclonic storm is its 'eye', which forms at the centre of the storm inside a Central Dense Overcast (CDO) region. The eye has a diameter of about 10 to 50 km, which is generally cloud free and is surrounded by thick wall clouds around it. It resembles an 'eye' when viewed in a satellite picture. It is a calm region with practically no rain. It is warmer than the surrounding region. The lowest estimated central pressure of 911 hPa was observed in case of Andhra cyclone of November 1977 followed by 919 hPa in the False Point cyclone (Odisha) in September 1885. The eye is generally seen when the storm is severe and the surface pressure falls below 980 hPa in the Indian Ocean areas. Sometimes, a double eye wall structure can also be seen when the storm becomes very intense.

1.2.2. Wall cloud region or eye wall

The eye is surrounded by a 10-15 km thick wall of convective clouds where the maximum winds occur. This is the most dangerous part of a cyclonic storm. The height of the wall goes up to 10 to 15 km. The intense convection in this wall cloud region produces torrential rain, sometimes of the order of 50 cm in 24 hrs. The 'Storm surge' associated with a cyclonic storm, responsible for 80% loss of human lives, occurs in the eye wall region. The exact position of this eye wall is identifiable with the Cyclone Detection Radars (CDR), as the Radius of Maximum Reflectivity (RMR) of radar beam coincides with the Radius of Maximum Wind (RMW) in a cyclonic storm.

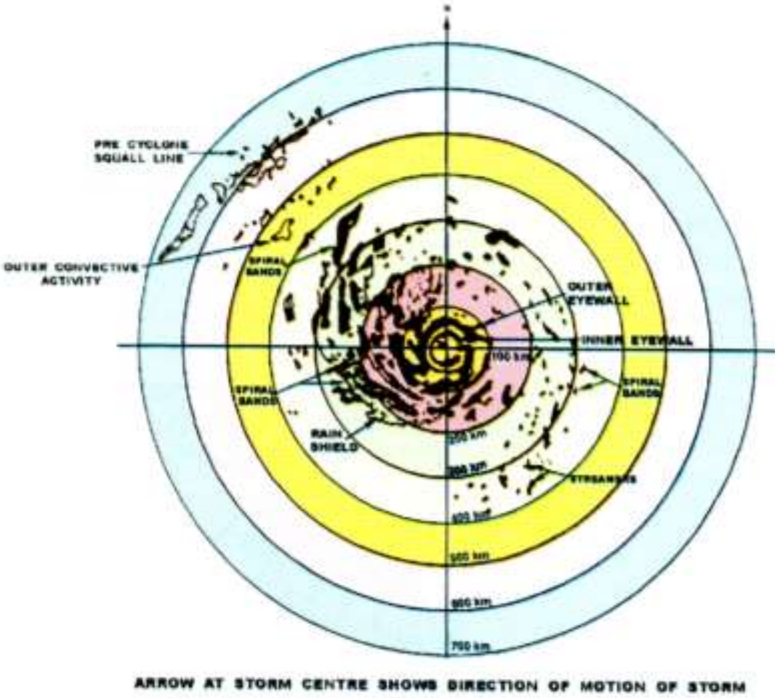


Fig.1.2. Composite structure of cyclone as seen in Radar imagery

1.2.3. Rain /spiral bands

Beyond the eye wall region, the major convective clouds in a cyclonic storm, responsible for heavy rains, have a spirally banded structure. These spiral bands are sometimes hundreds of kilometres long and a few kilometres wide. The spiral bands are easily identifiable in radar and satellite pictures (Fig.1.2 and 1.3), as a number of thunderstorm cells (Cumulonimbus clouds) are embedded in them that produce heavy rainfall (typical rate 3 cm/hr, which in extreme cases may reach upto 10 cm/hr).

These spirals also continuously change places and orientation with respect to the centre and rotate around it. The winds in this region continue to spiral around the centre with decreasing wind speed away from the centre. A dense cirrus shield of 400 to 500 km in diameter generally covers the central region along with the inner portion of the spiral bands.

1.2.4. Outer storm area:

This region is beyond 250 Km from the center, where the wind is cyclonic but wind speed decreases slowly outside. The typical 10 meter horizontal wind distribution with a cyclone is shown in Fig 1.4. The weather conditions in the outer storm area are better with scattered cumulus growth interspersed with spiral bands.

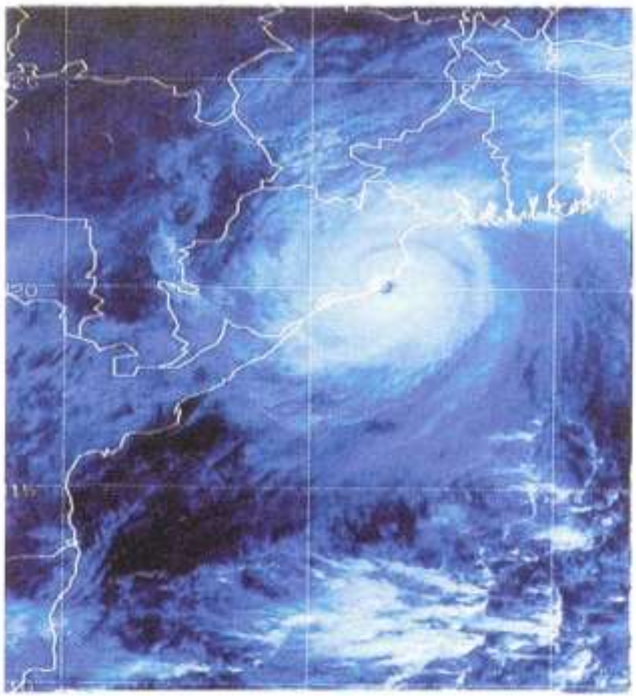


Fig.1.3. INSAT imagery of Odisha Super cyclone (25-31 Oct, 2009) showing eye of the cyclone

1.2.5. Vertical Structure:

The vertical structure of a cyclonic storm (Fig.1.4) can be divided into three layers viz. Inflow layer, middle layer and outflow layer.

i) The lowest layer from the surface to about 3 km is called the 'Inflow layer' where wind flow is towards the centre and contains a pronounced component of radial wind ($-V_r$). Most of this inflow layer occurs in the planetary boundary layer where friction plays a great role.

ii) The layer between 3 to 7.6 km is called the 'Middle layer' where the flow is mostly tangential with little or no radial component (inflow).

iii) The layer above 7.6 km upto the top of the storm is called the 'Outflow layer' where wind is anticyclonic (clockwise). Outflow is most pronounced around 12 Km level. Maximum warming occurs in the upper troposphere around 10 Km where temperature at times may be 15^0 C warmer than the environment.

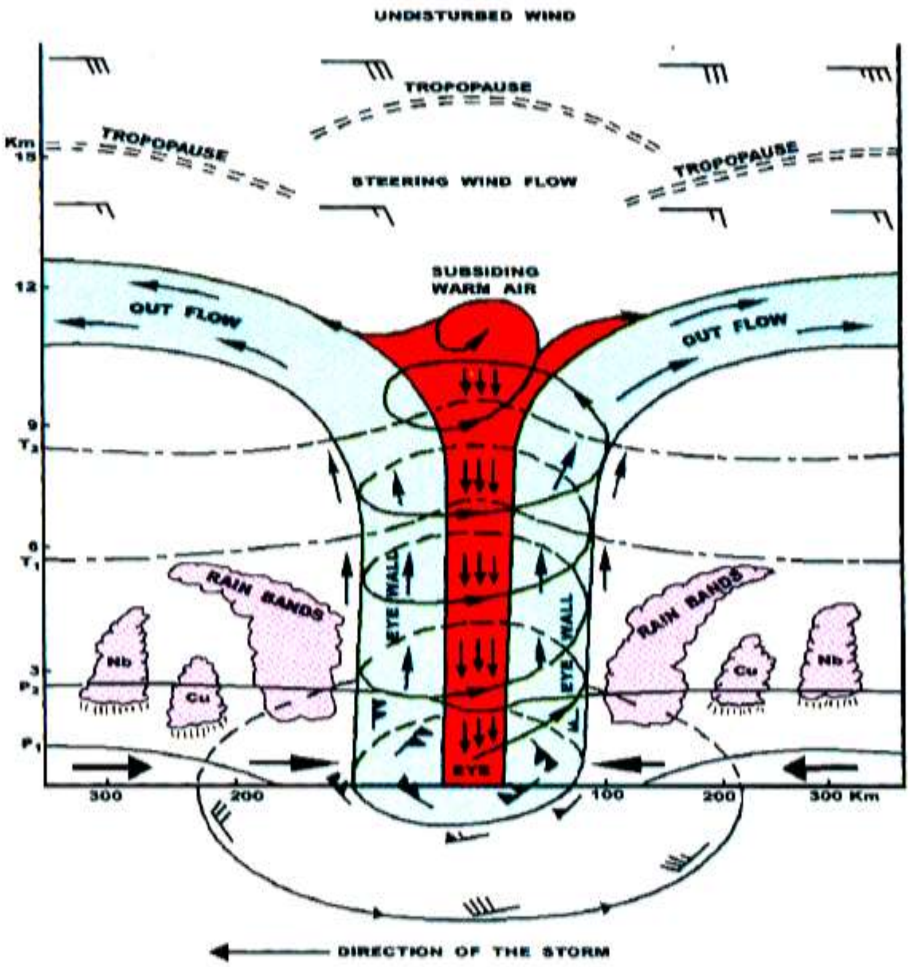


Fig.1.4. Vertical structure of a cyclone

1.2.6. Size of a cyclone:

The wind distribution around the centre of cyclone is not symmetric. Therefore, the wind distribution around a cyclone is described in in terms of radial extent of particular maximum sustained wind speed (MSW), viz., 34(17), 50(26) and 64(33) knot (ms^{-1}) from the circulation centre (referred as R34, R50 and R64) in each of four quadrants, viz., northeast (NE), southeast (SE), northwest (NW) and southwest (SW). The average size of a TC is the average radial extension of MSW of 34(17) knot (ms^{-1}). The average radial extension of

50(26) and 64(33) knot (ms^{-1}) constitute the size of inner core winds depending upon the intensity of the system.

The average size of TC (radius of 34(17) knot (ms−1) wind) over the AS is about 43(80), 72(133), 120(222) nm (km) respectively in case of CS, SCS, VSCS during pre-monsoon season and 70(130) nm (km) in case of both CS and SCS during postmonsoon season. Similarly, the average size of TC over BoB is about 73(135), 64(118) and 107(198) nm (km) in case of CS, SCS and VSCS respectively during pre-monsoon and 57(105), 64(118) and 102(189) nm (km) during post-monsoon season. The size of the SuCS, which occurred during pre-monsoon season over the AS and post-monsoon season over the BOB is about 120(222) and 130(241) nm (km) respectively.

The size of outer core (34(17) knot (ms−1) wind radial extension) as well as inner core winds (50(26) and 64(33) knot (ms−1) wind radial extension) increases significantly with increase in intensification of TC over BOB during both pre- and post-monsoon seasons. Over the AS, the size of outer core of the TC increases with increase in intensity during pre-monsoon season and no significant change during post-monsoon season.

The average sizes of outer core wind of the TCs over the BOB and AS as well as during pre and post-monsoon seasons differ from each other only in case of CS stage. The average size of CS is higher in pre-monsoon than in post-monsoon season over the AS and opposite is the case over the BOB. The average size of the CS over BOB is higher than that over the AS during pre-monsoon season and there is no significant difference during post-monsoon season. Though overall size (radius of 34(17) knot (ms−1) wind) of the TC during pre-monsoon season is larger over BOB, as compared to that over the AS, the inner core is smaller. In case of 64(33) knot (ms−1) wind, the radius in case of TC over the BOB is almost half of that over the AS.

The outer core of winds in TCs over the BOB is asymmetric in both pre- and post-monsoon seasons and for all categories of intensity of TCs. The region of higher radial extent shifts from southern sector in CS stage to northern sector in SCS/VSCS stage of TCs over the BOB during post-monsoon season. On the other hand, the asymmetry in inner core winds is significantly less during both the seasons and all categories of intensity. There is also no asymmetry in radial wind extension over the AS during both the seasons, except in case of outer core wind radial extension of VSCS during pre-monsoon season.

The low level environment like enhanced cross equatorial flow, lower and middle level RH, vertical wind shear and proximity of TC to the land surface are the determining factors for the size and asymmetry of TCs over the NIO.

The cross equatorial flow enhances the outer core wind (34(17) knot (ms−1) wind radii) in SW and SE quadrants of CS only and there is minimum role of northeast monsoon circulation in the surface wind distribution for the post-monsoon TCs over the AS. However, with the intensification of TC over the AS, the northeast monsoon circulation as well as cross equatorial flow positively influence the size of core wind (50(26) knot (ms−1) wind radii) of the TC over the AS in NW and SW quadrants.

The northeast monsoon circulation enhances only the outer core wind radii (34(17) knot (ms−1) wind radii) of SCS and VSCS in NW quadrant, whereas the cross equatorial flow in association with summer monsoon enhances both outer core (34(17) knot (ms−1)) and inner core (50(26) knot (ms−1)) wind radii in SW and SE quadrants of TC over BOB during pre-monsoon season.

The asymmetry is generally higher in the sector associated with higher RH in lower and/or middle levels. However, there is variation in relationship between the asymmetry in surface wind and the vertical distribution of RH in different quadrants within the lifecycle of a TC as well as from one TC to the other. Out of 12 cases considered for analyzing the relation between wind radii and RH, 10 cases show definite relationship as mentioned above and other two cases (growing phase of TC, Phailin) do not show any relationship.

The quadrant with maximum outer core (34(17) knot (ms−1) wind radii coincides with the quadrant with minimum vertical wind shear, when the TC is over the sea and not interacting with land surface. However, when the TC is over land surface and is under relatively strong shear condition, outer core wind radii are also higher in the quadrant associated with higher wind shear.

1.3. Life cycle of Tropical cyclone

The average life span of a cyclonic storm over the NIO is about 4 to 5 days which can be divided into four stages:

a) Formative Stage
b) Immature Stage
c) Mature Stage
d) Decaying Stage

The track of longest ever recorded cyclone over the NIO is shown in Fig.1.5. It originated over the South China Sea, moved west-northwestwards across Vietnam, Bay of Bengal, South India and Arabian Sea to Oman during Oct. 1924.

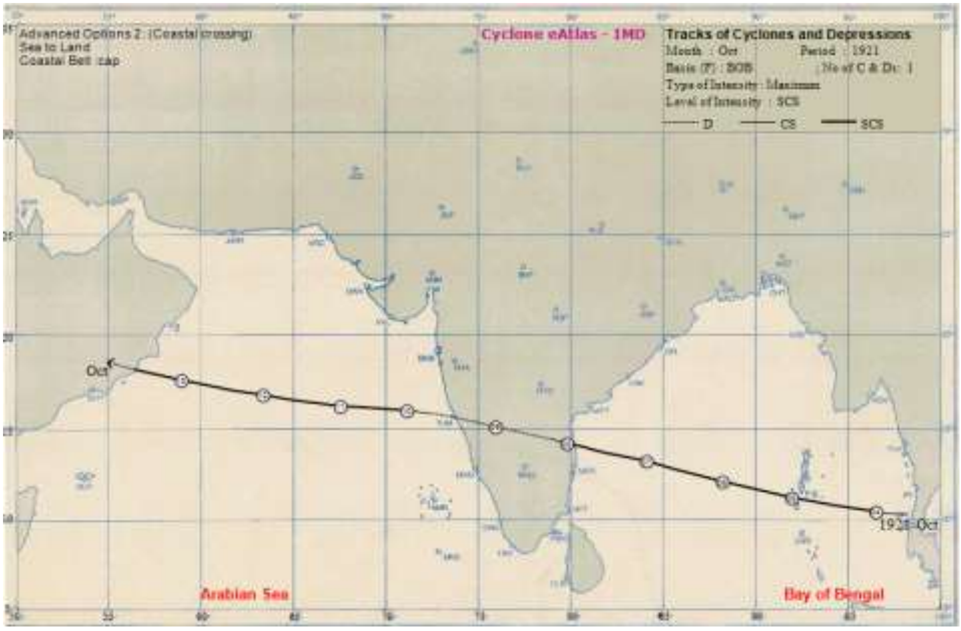


Fig.1.5. Longest life period cyclone over the NIO

1.3.1 Formative stage

The Formative Stage covers the period from the genesis of a cyclonic circulation to the cyclonic storm stage through low pressure, depression and deep depression stages. Following factors are considered favourable for cyclogenesis. These are:

i. Coriolis Parameter

ii. Low level positive vorticity

iii. Weak vertical wind shear of horizontal winds

iv. Warm Sea surface temperature (> 26.5° Celsius)

v. Large convective instability

vi. Large relative humidity at lower and middle troposphere

In general, cyclogenesis occurs over the warm oceanic regions away from the equator, where the moist air converges and weak vertical wind shear prevails. The cyclonic storm does not form near the equator, where the Coriolis force is zero. A little Coriolis force which is directly proportional to the sine of latitude angle (º) is required for turning of winds and hence formation of cyclonic storm. Pressure falls gradually during formative stage. Unusual pressure fall near the easterly wave, asymmetric strengthening of wind, elliptic or circular wind circulation over Inter-Tropical Convergence Zone (ITCZ - a region near equator where surface winds from both the hemispheres converge), isolated solid cloud mass in the satellite pictures are some of the indications of the cyclogenesis.

1.3.2. Immature Stage

In the Immature Stage, the central pressure of the system continues to fall till the lowest pressure is attained. The wind speed increases and usually at a distance of about 30-50 Km from the centre a well developed eye wall is seen. Duration of this stage can be as long as 3 days. At times, it may be an explosive occurrence in which pressure fall of 40 to 50 hPa in a day may occur. The cloud and rain pattern changes from disorganised squalls to narrow organised bands spiraling inward.

1.3.3. Mature Stage

During the Mature Stage, no further fall of pressure and increase of wind speed occur. In some cases, winds of very severe cyclonic storm can extend upto several hundreds of kilometres from the storm centre to the right of the direction of motion of the storm in the northern hemisphere.

1.3.4. Decaying Stage

In the Decaying Stage, the tropical storms begin to lose their intensity when they move over to land, over colder water or lie under an unfavourable large-scale flow aloft. In some cases, they come under the influence of an upper air trough and re-curve towards northeast. The storms weaken over land because of sharp reduction of moisture supply and increase in surface friction.

1.3.5. Life Period of a cyclone:

The average life period of cyclonic disturbances (CDs) over the NIO is about 2 days, 3 days, 3.5 days, 4 days, 5 days and 5.75 days respectively for D, DD, CS, SCS, VSCS and SuCS. VSCS have higher mean life period over both the ARB and the BOB in pre-monsoon, post-monsoon and year as a whole. While the VSCS stage has significantly higher duration over the ARB than over the BOB in pre-monsoon and the year as a whole, it is significantly higher over the BOB than over the ARB during post-monsoon season. During the monsoon season, the duration D, DD and CS stages are significantly higher over BOB than they are over the ARB.

1.4. Hazard due to cyclone

Disturbed weather occurs generally in association with low pressure systems that are seen over different parts of the globe. Areas of high pressure are characterized by fair weather. The severity of weather increases with the intensity of the low pressure. Observations show that intense low pressure systems like depressions and cyclones originate in the equatorial trough zone over warm ocean surface under certain favourable atmospheric conditions. The cyclonic storms cause heavy rains, strong winds and also high seas and devastate coastal areas at the time of landfall, leading to loss of life and property.

The expected damage associated with the cyclonic disturbances of different intensities along with action suggested to disaster managers is given in Table 1.2. Types of damages associated with a tropical cyclone are also shown in Fig.1.6. Detailed impacts of wind, rainfall and storm surge as well as marine impact are discussed in Section 1.4.1-1.4.4.

Table 1.2. Storm Intensity, Expected Damage and Suggested Actions

Intensity	Damage expected	Action Suggested
Deep Depression (DD) 50 – 61 kmph (28-33 knots)	Minor damage to loose and unsecured structures	Fishermen advised not to venture into the open seas.
Cyclonic Storm (CS) 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 (SCS) 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.
Very Severe Cyclonic Storm (VSCS) 118-167 kmph (64-90 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 (ESCS) 168-221 kmph (91-119 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 Cyclone (SuCS) 222 kmph and more (120 knots and more)	Extensive structural damage to residential and industrial buildings. Total disruption of communication and power supply. Extensive damage to bridges causing large-scale disruption of rail and road traffic. Large-scale flooding and inundation of sea water. Air full of 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.

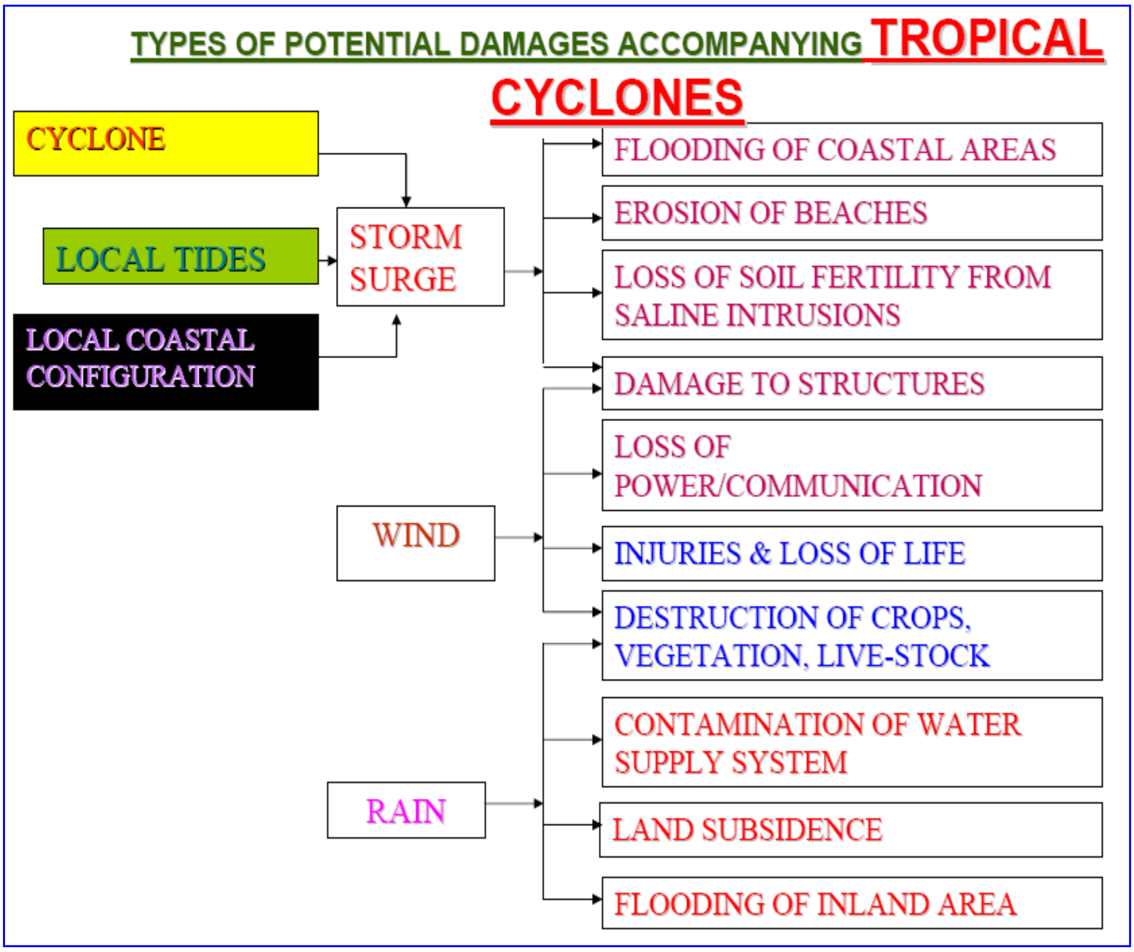


Fig.1.6.Types of Potential Damages accompanying Tropical Cyclones

1.4.1. Winds

The maximum sustained wind recorded in different coastal districts along the east and west coasts of India during 1891-2008 is shown in Fig. 1.7 The damages produced by winds are extensive and cover areas occasionally greater than the areas of heavy rains and storm surges which are in general localized in nature. The impact of the passage of the cyclone eye, directly over a place is quite different from that of a cyclone that does not hit the place directly. The latter affects the location with relatively unidirectional winds i.e. winds blowing from only one side, and the lee side is somewhat protected. An eye passage brings with it rapid changes in wind direction, which imposes torques and can twist the vegetation or even structures. Parts of structures that were loosened or weakened by the winds from one direction are subsequently severely damaged or blown down when hit upon by the strong winds from the opposite direction. A partial eye passage can also do considerable damage, but it is less than a total eye passage.

As tropical cyclones have a circular shape, an eye passage over a location exposes it to the maximum possible duration of destructive winds. The higher wind is also associated with convectively active eye-wall region and has higher wind gusts than outside it. The gustiness effect is amplified over land where friction reduces sustainable wind but not the peak gust. This widens the gap between the peak and the lull of the gusts even more, creating strong negative pressure forces on lee-side of buildings especially damaging metal sheet and wooden structures. Strong wind also exposes roofs to strong lifting forces. The typical damage to buildings is due to failure of roofing systems. Loss of roof irrespective of the material used, leads to water damage of the walls. When the roofs get blown off, the exterior walls lose the support provided by the roofing systems and collapse even in lesser wind intensity. Typical damage photograph due to cyclone Nargis is shown in Fig. 1.8.

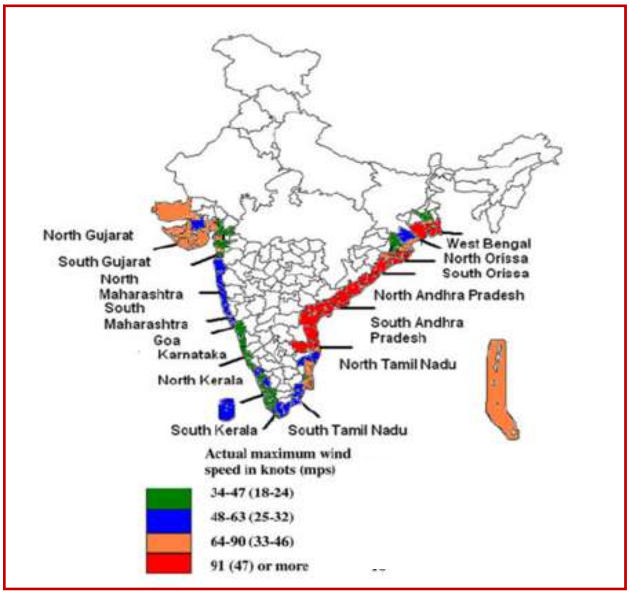


Fig.1.7: Maximum / Estimated MSW (in mps) that affected coastal districts of India during 1891-2008

Fig.1.8.Damage caused by Super cyclonic storm 'Amphan'

Winds are stronger in the right semi-circle with reference to the direction of motion of the cyclonic storm in the Northern Hemisphere. Occasionally, very strong winds are also encountered to the left side of the storm with respect to its motion. The total damage is significantly greater than that from the relatively unidirectional winds of a near miss with comparable intensity.

Under the action of wind flow, structures experience aerodynamic forces that include the drag force acting in the direction of the mean wind, and the lift force acting perpendicular to that direction. The structural response induced by the wind drag is commonly referred to as the 'along wind' response. It has been recognized that in the case of modern tall buildings which are more flexible, lower in damping, and lighter in weight than older structures, the natural frequency of vibration may be in the same range as the average frequency of occurrence of powerful gusts and therefore large resonant motions induced by the wind may occur. This must be taken into consideration in design of cyclone resistant buildings.

Many of the overhead communication networks are susceptible to damage when the winds reach 85 kts (158 kmph), This is especially the case for secondary telephone lines. Microwave towers are susceptible to misalignment when winds reach 85 kts (158 kmph). This affects local telephone, cellular service and long distance service. Microwave and radio towers are susceptible to destruction when winds reach 100 kts (186 kmph). At higher wind speed even larger antennas are also vulnerable and are blown off. Even large satellite communication dishes can be damaged in cyclones with sustained wind speeds of 135 kts (251 kmph). Coastal roads/locations are vulnerable to damage from inundation/waves run-up. The most detrimental hazards to roadways are uprooted trees, power poles and lines, and debris falling on roads and blocking them. This becomes a serious problem when winds reach 80 kts (149 kmph) or more.

1.4.2. Marine impact

The wind speed, condition of Sea and wave height associated with 'T' numbers of various categories of cyclonic disturbances, are given in Table 1.3

Table 1.3. Marine impact of cyclonic disturbances

S. N.	Intensity	Strength of wind(kmph/knots)	Satellite 'T' No.	Condition of Sea	Wave height (m)	Action suggested
1.	Depression	(i)(31- 40)/(17-21) (ii)(41- 49)/(22-27)	1.5	Moderate Rough	1.25-2.5 2.5-4.0	
2.	Deep Depression	(50–61)/(28-33)	2.0	Very Rough	4.0-6.0	Fishermen advised not to venture into the open seas.
3.	Cyclonic Storm	(62–87)/(34-47)	2.5-3.0	High	6.0-9.0	Total suspension of fishing operations
4.	Severe Cyclonic Storm	(88-117)/(48-63)	3.5	Very High	9.0-14.0	Total suspension of fishing operations.
5.	Very Severe Cyclonic Storm	(i)(118-167)/(64-90)	4.0-4.5	Phenomenal	Over 14.0	Total suspension of fishing operations.
6.	Extremely Severe Cyclonic Storm	(168-221)/(91-119)	5.0–6.0	Phenomenal	Over 14.0	Total suspension of fishing operations.
6.	Super Cyclonic Storm	222/120 and more)	>6.5	Phenomenal	Over 14.0	Total suspension of fishing operations.

1.4.3. Rainfall

Rainfall is generally very heavy and spread over a large area thus leading to excessive amount of water. Rains (sometimes even more than 30 cm per 24 hrs.) occur in association with cyclones. The daily probable maximum precipitation that affected the coastal districts of India due to TCs during 1891-2008 is shown in Fig. 1.9. Typical example of flood caused by Odisha Super Cyclone is presented in Fig. 1.10. Unabated rains give rise to unprecedented floods. Rainwater on the top of storm surge may add to the fury of the storm. Rain is an annoying problem for the people who become shelter less due to a cyclone. It creates problems in post cyclone relief operations also.

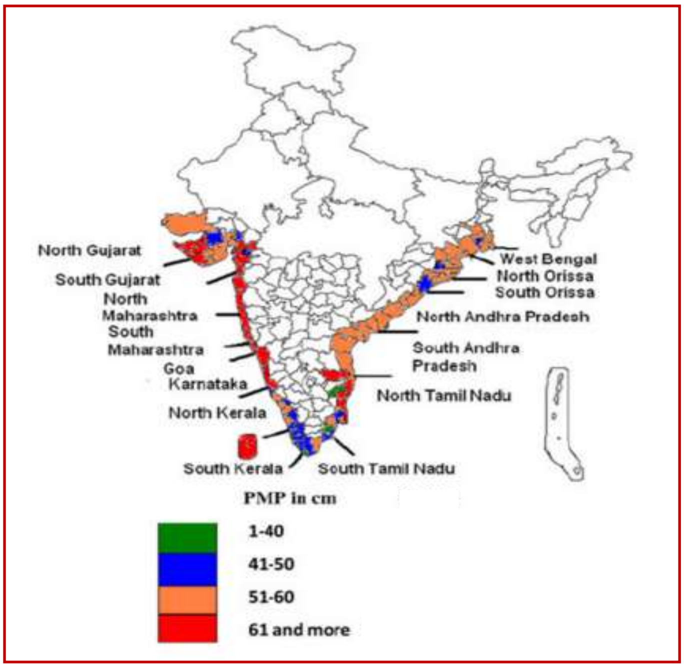


Fig.1.9: Daily Probable Maximum Precipitation (in cm) that affected coastal districts of India during 1891-2008

On the infrastructure front, the most critical problem after passage of any cyclone is the restoration of water distribution system. Strong winds along with heavy rains accompanied with floods/storm surge associated with the cyclone, devastate the critical parts of the power generation and distribution systems.

Fig.1.10. Flood caused by Odisha super cyclone, 25-31 October 1999

Even the strongest port and airport facilities, fuel and water storage tanks, high voltage transmission tower, etc., are vulnerable to damage. Soil erosion also occurs on a large scale. Heavy rains log the ground and cause softening of the ground due to soaking. This contributes to weakening of the embankments, the leaning over of utility poles or collapse of pole type structures.

1.4.4. Storm Surge

Storm surge is the major cause of devastation from tropical storms. Though, the deaths and destruction are caused directly by the winds in a tropical cyclone as mentioned above, these winds also lead to massive piling of Sea water in the form of what is known as storm surge that lead to sudden inundation and flooding of coastal regions.

The surge is generated due to interaction of air, sea and land. When the cyclone approaches near the coast, it provides the additional force in the form of very high horizontal atmospheric pressure gradient which leads to strong surface winds. As a result, sea level rises. It continues to rise, as the cyclone moves over shallower waters and reaches a maximum on the coast near the point of landfall. Storm surge is inversely proportional to the depth of Sea water. The depth varies from about 500 m at about 20^0 N in the north central Bay to about 5 m along the West Bengal-north Odisha coast. Because of the vast shallow continental shelf, the storm surges get amplified significantly in these areas. The northward converging shape of the Bay of Bengal provides another reason for the enhanced storm surge in these areas. There is another cause of sea level rise, viz., astronomical tide, which is well known. The rise due to high tide may be as high as 4.5 m above the mean sea level at some parts of Indian coast. The worst devastation is caused when the peak surge occurs at the time of high tide. As the leading edge of the storm surge crashes against the coastline, the speed of the surge puts great stress on the walls.

The debris like uprooted trees, fences and parts of broken houses, act as battering rams and cause further damage. The sand and gravel carried by the moving currents at the bottom of the surge can cause sand papering action of the foundations. The huge volume of water can cause such pressure difference that the house "floats" and once the house is lifted from the foundations, water enters the structure that eventually collapses. The probable maximum storm surge above tide levels in metre that affected the coastal districts of east & west coast of India during 1891-2008 is shown in Fig.1.11. Typical photograph of storm surge due to cyclone Nargis is shown in Fig.1.12.

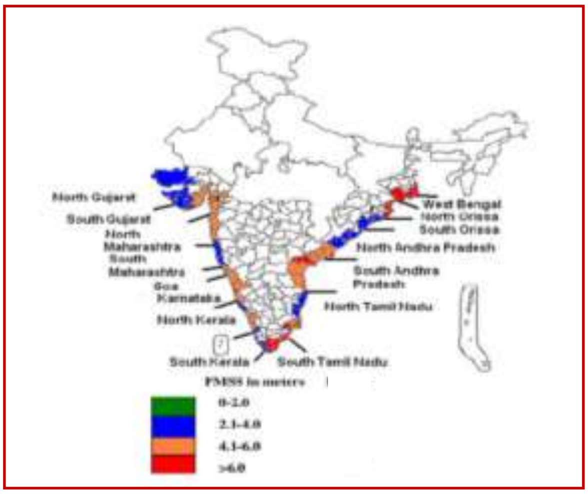


Fig.1.11. Probable maximum storm surge (PMSS) above tide levels (in metre) that affected coastal districts of east and west coasts of India

Fig.1.12. Storm surge caused by Very severe cyclonic storm 'Nargis'

1.4.5. Frequency of cyclones and severe cyclones affecting coastal districts of India:

The frequency of cyclones (MSW 34 knot or more) and severe cyclones (MSW 48 knot or more) affecting the coastal districts of India during 1891-2008 is shown in Fig.1.13 and 1.14 respectively.

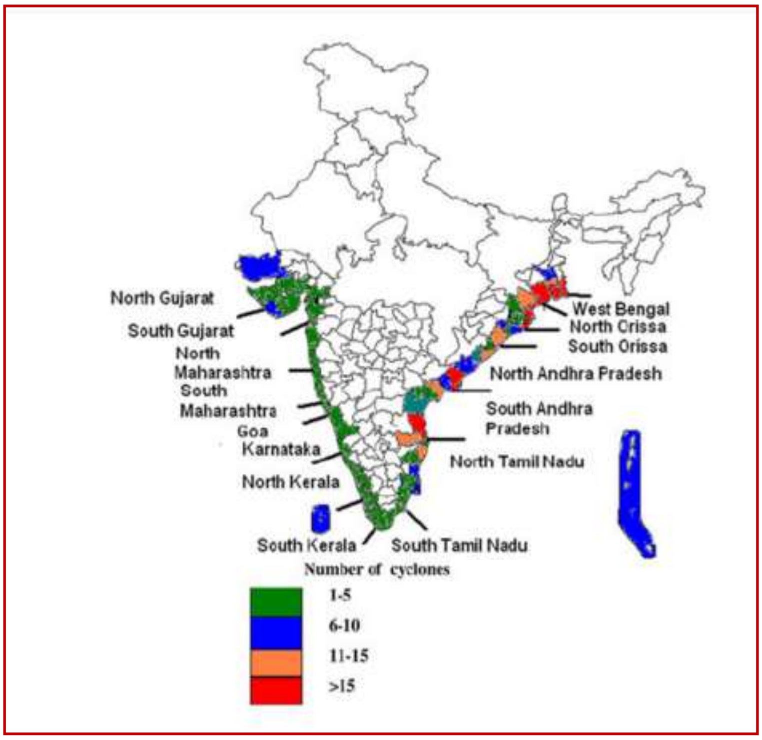


Fig. 1.13: Number of Cyclones (MSW of 34 knots or more) that affected coastal districts of India during 1891-2008

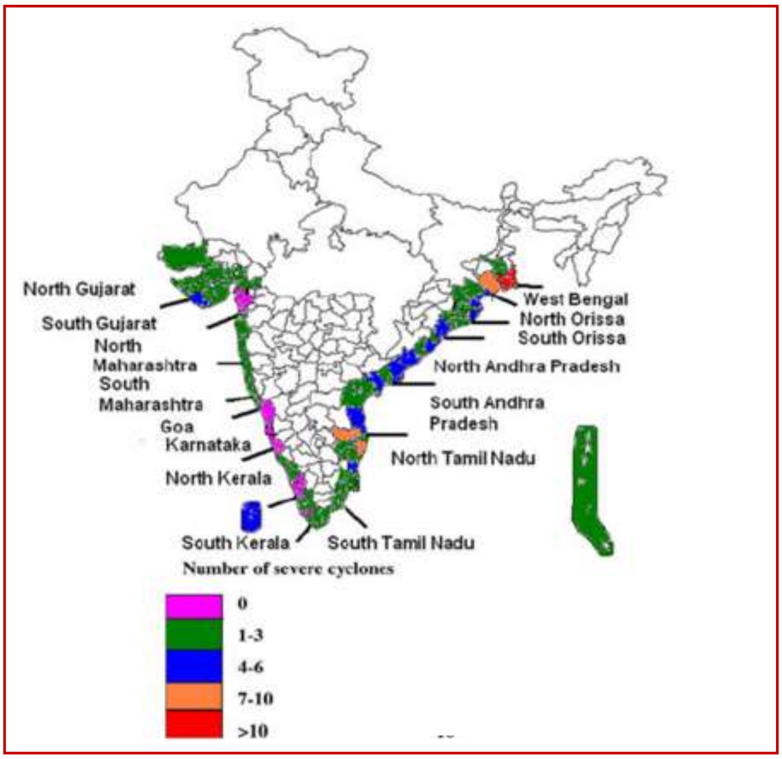


Fig. 1.14: Number of Severe Cyclones (maximum sustained wind speed (MSW) of 48 knots or more) that affected coastal districts of India during 1891-2008

1.4.6. Cyclone hazard prone districts of India:

Cyclone hazard proneness of districts of India based on frequency of total cyclones, total severe cyclones, actual/estimated maximum wind strength, Probable Maximum Storm Surge (PMSS) associated with the cyclones and Probable Maximum Precipitation (PMP) for all districts is presented in Fig. 1.15. The hazard maps prepared by committee constituted by NDMA in 2012 indicating total number of severe cyclones (maximum sustained wind speed (MSW) of 48 knots or more), total number of cyclones (MSW of 34 knots or more), actual/estimated MSW, probable maximum storm surge, daily probable maximum precipitation over coast are presented in Fig 1.16 (a-e). The cyclone parameters for various districts are presented in Table 3-5.

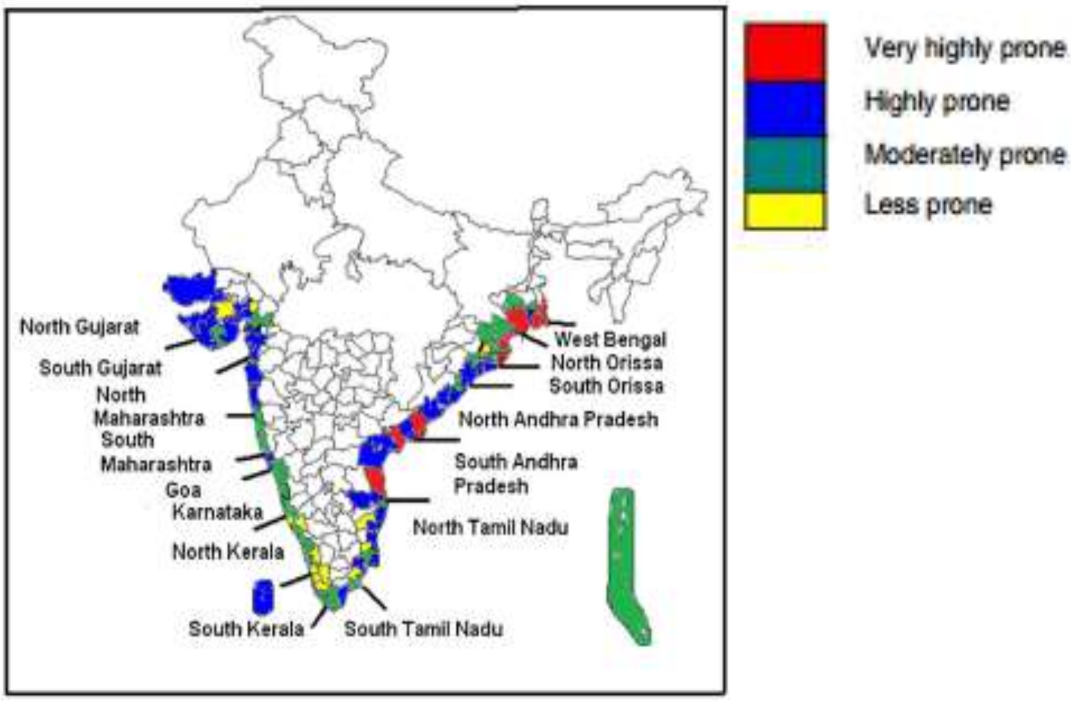


Fig.1.15: Cyclone hazard prone districts of India based on frequency of total cyclones, total severe cyclones, actual/estimated maximum wind strength, PMSS associated with the cyclones and PMP for all districts

Ninety-six districts including 72 districts touching the coast and 24 districts not touching the coast, but lying within 100 km from the coast have been classified based on their proneness. Out of 96 districts, 12 are very highly prone, 41 are highly prone, 30 are moderately prone, and the remaining 13 are less prone. Twelve very highly prone districts include South and North 24 Parganas, Medinipur, and Kolkata of West Bengal, Balasore, Bhadrak, Kendrapara, and Jagatsinghpur districts of

Odisha, Nellore, Krishna, and east Godavari districts of Andhra Pradesh and Yanam of Puducherry. The remaining districts of Odisha and Andhra Pradesh, which touch the coast are highly prone districts. The north Tamil Nadu coastal districts are more prone than the south Tamil Nadu districts (south of about 10◦N latitude). Most of the coastal districts of Gujarat and north Konkan are also highly prone districts. The remaining districts in the west coast and south Tamil Nadu are either moderately prone or less prone districts.

Table 1.4: Cyclone hazard prone districts of India touching coast (72) based on frequency of total cyclones, severe cyclones; strength of actual/estimated wind, PMSS and PMP

State	Districts	Degree of Proneness
Andhra Pradesh (AP)	Nellore	P1
	East Godavari	P1
	Krishna	P1
Odisha	Balasore	P1
	Kendrapara	P1
	Jagatsinghpur	P1
	Bhadrak	P1
Puducherry	Yanam	P1
West Bengal	South 24-Pragana	P1
	Medinipur	P1
AP	Srikakulam	P2
	Guntur	P2
	Visakhapatnam	P2
	West Godavari	P2
	Prakasam	P2
	Vizianagaram	P2
Daman & Diu	Diu	P2
Gujarat	Junagadh	P2
	Kutch	P2
Lakshadweep	Lakshadweep	P2
Odisha	Ganjam	P2
	Puri	P2
	Khordha	P2

State	Districts	Degree of Proneness
Puducherry	Karaikal	P2
Tamil Nadu	Pudukkottai	P2
	Cuddalore	P2
	Kanchipuram	P2
	Tiruvarur	P2
	Nagapattinam	P2
	Chennai	P2
	Ramanathapuram	P2
	Toothukudi	P2
	Tirunelveli	P2
Andaman & Nicobar Islands	A & N Islands	P3
Daman & Diu	Daman	P3
Goa	North Goa	P3
	South Goa	P3
Gujarat	Ahmedabad	P3
	Bhavnagar	P3
	Amreli	P3
	Jamnagar	P3
	Anand	P3
	Navsari	P3
	Surat	P3
	Valsad	P3
	Bharuch	P3
	Porbandar	P3
	Rajkot	P3
	Vadodara	P3
Karnataka	Udupi	P3
	Uttar Kannada	P3
	Dakshin Kannada	P3
Kerala	Kozhikode	P3
	Malappuram	P3
	Thrissur	P3
	Kannur	P3
	Kollam	P3
	Alappuzha	P3
	Thiruvananthapuram	P3
Maharastra	Thane	P3
	Mumbai suburban	P3
	Ratnagiri	P3
	Raigarh	P3
	Sindhudurg	P3
Puducherry	Puducherry	P3
	Mahe	P3
Tamil Nadu	Viluppuram	P3

	Thanjavur	P3
	Tiruvallur	P3
	Kanyakumari	P3
Kerala	Kasargod	P4
	Ernakulam	P4
Total districts		72

Degree of Proneness	Meaning
P1	Very Highly Prone
P2	Highly Prone
P3	Moderately Prone
P4	Less Prone

Table 1.5: Cyclone hazard prone districts of India not touching (24) the coast based on frequency of total cyclones, severe cyclones; strength of actual/estimated wind, PMSS and PMP

State	Districts	Degree of Proneness
West Bengal	North 24 Pragana	P1
	Kolkata	P1
AP	Chittor	P2
West Bengal	Howrah	P2
Dadra & Nagar Haveli	Dadra & Nagar Haveli	P3
Odisha	Mayurbhanj	P3
	Cuttack	P3
	Nayagarh	P3
	Gajapati	P3
	Jajpur	P3
	Keonjhar	P3
West Bengal	Hoogly	P3
	Bardhaman	P3
Gujarat	Surendra Nagar	P4
	Kheda	P4
Kerala	Wayand	P4
	Palakkad	P4
	Kottayam	P4
	Idukki	P4
	Pathanamthita	P4
Odisha	Dhenkanal	P4
Tamil Nadu	Ariyalur	P4
	Tiruvannamalai	P4
	Sivaganga	P4
Total Districts		24

Table 1.6: Cyclone parameters for districts (touching coast) along east coast and Andaman and Nicobar (A and N) Islands

State	Districts	No. of severe Cyclones	Total No. of Cyclones	Wind Speed in knots	PMSS in metres	PMP in cm
West Bengal	South 24-Parganas	16	29	115	12	52
	Medinipur	10	22	115	13	56
Orissa	Balasore	5	28	75	11	60
	Kendrapara	6	17	140	8.5	60
	Bhadrak	4	17	65	9.5	60
	Jagatsinghpur	4	17	140	6.5	60
	Ganjam	5	11	100	4	48
	Puri	1	6	140	4	60
	Khordha	0	4	100	4	52
Andhra Pradesh	Nellore	8	18	110	4.5	60
	East Godavari	4	17	125	4.5	52
	Srikakulam	5	12	100	4	56
	Guntur	0	0	127	7.5	56
	Visakhapatnam	4	8	125	4	52
	Krishna	5	12	127	5.5	56
	West Godavari	3	6	127	5	52
	Prakasam	3	5	115	6	52
	Vizianagaram	1	3	94	4	52
Tamil Nadu	Pudukkottai	1	1	55	7	52
	Kanchipuram	8	13	55	3.5	68
	Cuddalore	4	6	90	3.5	68
	Tiruvarur	3	6	90	5.5	60
	Nagappattinam	3	10	90	4.5	68
	Chennai	0	0	95	3.5	52
	Viluppuram	3	3	77	3.5	68
	Ramanathapuram	1	2	55	12	48
	Thoothukudi	1	1	55	7	52
	Tirunelveli	3	3	55	7	48
	Thanjavur	1	2	90	5.5	48
	Tiruvallur	0	5	95	4	56
	Kanyakumari	0	0	45	3	40
Puducherry	Puducherry	3	3	77	3.5	68
	Karaikal	3	10	90	4.5	52
	Yanam	4	17	125	4.5	52
Andaman & Nicobar Islands	Andaman & Nicobar Islands	1	8	90	–	N/A
Total	35					

Table 1.7: Cyclone parameters for districts (touching coast) along west coast and Lakshadweep Islands

State	Districts	No. of severe Cyclones	Total No. of Cyclones	Wind Speed in knots	PMSS in metres	PMP in cm
Gujarat	Junagadh	4	9	90	3.5	84
	Kutch	3	7	90	3.5	60
	Bhavnagar	3	5	90	4.5	56
	Jamnagar	1	2	90	3.5	72
	Porbandar	3	3	90	3.5	84
	Amreli	2	3	90	4	56
	Ahmedabad	1	1	90	4.5	60
	Anand	1	2	70	4.5	52
	Surat	0	0	45	4.5	88
	Navsari	0	1	70	4.5	88
	Valsad	0	0	45	5	104
	Bharuch	0	3	70	4.5	72
	Rajkot	2	4	90	3.5	72
	Vadodara	0	1	45	4.5	64
Daman & Diu	Daman	1	1	55	5	80
	Diu	4	9	90	3.5	80
Maharashtra	Thane	2	2	55	5	72
	Mumbai Suburban	1	1	55	5	95
	Ratnagiri	1	1	55	4	64
	Raigarh	0	1	55	5	72
	Sindhudurg	1	1	55	4	72
Goa	North Goa	0	0	55	4.5	64
	South Goa	0	0	55	4.5	64
Karnataka	Uttar Kannada	0	0	45	4.5	68
	Udupi	0	0	45	4.5	68
	Dakshin Kannada	0	0	45	4.5	92
Kerala	Kozhikode	1	1	45	4.5	60
	Malappuram	0	1	45	4.5	60
	Thrissur	0	1	45	4.5	52
	Kasargod	0	0	45	4	48
	Kannur	0	0	45	4	60
	Ernakulam	0	0	45	4	44
	Alappuzha	1	1	45	4	40
	Kollam	0	0	45	3.5	44
	Thiruvananthapuram	1	1	45	3	48
Lakshadweep	Lakshadweep	5	9	90	–	N/A
Puducherry	Mahe	1	1	55	4.5	60
Total	37					

Table 1.8: Cyclone parameters for districts of India not touching the coast, but within 100 km from the coast

State	Districts	No. of severe Cyclones	Total No. of Cyclones	Wind Speed in knots	PMSS in metres	PMP in cm
Dadra and Nagar Haveli	Dadra and Nagar Haveli	2	2	55	–	80
Gujarat	Surendra Nagar	2	2	55	0	56
	Kheda	0	0	45	0	52
Kerala	Wayanad	0	0	55	0	52
	Palakkad	0	1	55	0	52
	Kottayam	0	0	45	0	48
	Idukki	0	0	45	0	52
	Pathanamthitta	1	1	45	0	48
Tamil Nadu	Tiruvannamalai	0	2	55	0	40
	Ariyalur	0	4	45	0	52
	Sivaganga	0	3	55	0	40
AP	Chittoor	8	15	95	0	60
Orissa	Mayurbhanj	1	10	55	0	56
	Jajpur	0	2	65	0	60
	Keonjhar	0	5	45	0	52
	Dhenkanal	0	3	45	0	44
	Cuttack	1	4	140	0	52
	Nayagarh	1	7	65	0	52
	Gajapati	0	1	100	0	52
West Bengal	Hoogly	3	11	65	0	52
	Bardhaman	0	10	45	0	56
	Kolkata	12	23	115	0	52
	North 24 Parganas	11	23	115	0	52
	Howrah	12	23	115	0	50
Total	24					

1.5 Historical Cyclones and their impact:

The Indian Seas have historically been the deadlist basin with several cyclones responsible for more than 1 lakh of casualities. The 1970 Bhola cyclone killed about 3 lakhs people, perhaps, the maximum number as per the recorded history. Recently, cyclone, Nargis caused loss of 1,40,000 human lives in Myanmar in May 2008. After the availability of satellites for monitoring of cyclones, Odisha super cyclone of 1999 over the Bay of Bengal could be rated as the most intense tropical cyclone (TC) crossing Indian coast. Tables 1.4 (a) & 1.4(b) list some of the most intense TCs that had affected Indian coasts.

Table 1.9(a): Historical records of 12 most devastating cyclonic storms, which formed in the Bay of Bengal and made landfall on the East coast of India

S. N.	Date/Year	Category of Cyclone	Landfall and Relevant information
1	7–12 October, 1737	Super Cyclonic Storm	Crossed West Bengal coast over Sunderbans Surge height : 12 M Loss of life : 300,000
2	31 October, 1831	Very Severe Cyclonic Storm	Crossed Odisha coast near Balasore Surge height : 2 – 5 m Loss and damage: People killed - 22,000 Cattle heads lost - 50,000
3.	2–5 October, 1864	Very Severe Cyclonic Storm	Crossed West Bengal coast near Contai Surge height: The maximum height of the waves reached 12 m. Loss and damage, People killed - 50,000 (mostly due to drowning), and 30,000 (due to diseases as a result of inundation)
4.	1–2 November, 1864	Severe Cyclonic Storm	Crossed Andhra Pradesh coast near Machilipatnam Surge height: 4 m. Loss and damage : People killed - 30,000
5.	22 September, 1885	Super Cyclonic Storm	Crossed Odisha coast near False Point, Central pressure : 919 hPa, Surge height: 7 m. Loss of life : 5000
6.	14–16 October, 1942	Severe Cyclonic Storm	Crossed West Bengal coast near Contai Surge height : 3 – 5 m Loss and damage : People killed – 19,000 Cattle heads killed - 60,000

7.	8–11 October, 1967	Severe Cyclonic Storm	Crossed Odisha coast between Puri and Paradip on the morning of 9 October and then crossed Bangladesh coast during the night of 10 – 11 October. Intensity at the time of landfall: 85 knots (157 kmph) Loss and damage: People killed - 1,000, Cattle heads lost 50,000.
8.	26–30 October, 1971	Extremely Severe Cyclonic Storm	Crossed Odisha coast near Paradip early morning of 30 October Maximum wind: 150-170 kmph (81-92 kts.) Intensity at the time of landfall: 90 knot (167 kmph) Surge height : 4 – 5 m, north of Chandbali Loss and damage: People killed – 10,000; Cattleheads lost – 50,000; Houses damaged – 8,00,000
9.	14-20 November, 1977	Super Cyclonic Storm	Crossed Andhra Pradesh coast Nizampatnam at 1730 IST on 19 November. Maximum wind: Ongole: 102 kmph (55 kts.) Machilipatnam: 120 kmph (65 kts); Gannavaram: 139 kmph (75 kts.) Surge height : 5 m Intensity : T 6.5 Maximum estimated wind speed: 260 kmph (140 kts). Intensity at the time of landfall: 125 knot (230 kmph) Loss and damage: People killed - 10,000; Cattleheads – 27,000; Damage to crops and other property were estimated to be around Rs. 350 crores.

10.	4 – 11 May, 1990	Super Cyclonic Storm *	Crossed Andhra Pradesh coast at about 40 km south west of Machilipatnam around 1900 IST of 9 May Maximum wind: Machilipatnam: 102 kmph (55 kts); Gannavaram: 93 kmph (50 kts) Maximum estimated wind speed : 235 kmph (126 kts) Surge height : 4 – 5 m Intensity at the time of landfall: 100 knot (185 kmph) Intensity : T 6.5 Loss and damage : People killed – 967; the estimated cost of the damages to crops and properties - Rs. 2,248 crores.
11.	5 – 6 November, 1996	Very Severe Cyclonic Storm	Crossed Andhra Pradesh coast near Kakinada at midnight of 6 November Maximum wind:200 kmph (108 kts) Intensity at the time of landfall: 55 knot (102 kmph) Surge height : 3 – 4 m Loss and damage : People killed – 2000; People missing - 900; crops destroyed in 3,20,000 hectares of land; house destroyed – 10,000 Estimate of the loss for crops - Rs. 150 crores

12.	25 – 31 October, 1999	Super Cyclonic Storm	Crossed Odisha coast near Paradip at noon of 29 October. Maximum wind : 260 kmph (140 kts); Intensity at the time of landfall: 140 knot (260 kmph) Bhubaneshwar: 148 kmph (80 kts) Surge height : 6 – 7 m Intensity : T 7.0 Loss and damage : People killed = 9,885; People injured - 2,142; cattleheads perished - 3,70,297, Paddy crops in 16,17,000 hectares and other crop in 33,000 hectares damaged.

Table 1.9(b): Historical records of 11 most devastating cyclonic storms, which formed in the Arabian Sea and made landfall on the West coast of India

S. No.	Date/Year	Category of Cyclone	Landfall and Relevant information
1.	16 May 1618	Severe Cyclonic Storm	Crossed near Bombay (Mumbai) coast Loss and damage : People killed - 2,000
2.	30 October – 2 November, 1854	Severe Cyclonic Storm	Crossed near Bombay (Mumbai) coast on 1 November Loss and damage : People killed - 1,000 Property worth crores of rupees perished within four hours.

3.	18 – 23 November, 1948	Severe Cyclonic Storm	Crossed Maharashtra coast near Virar, 72 km north of Bombay (Mumbai) at about 0830 hrs. IST on 22 November. Maximum wind : Colaba: 120 kmph (65 kts) and Juhu: 151 kmph (81 kts.) Loss and damage : Great havoc and heavy loss of life and property and all means of traffic and communication were completely paralysed for two days. A number of small vessels and crafts capsized in the water of Bombay (Mumbai) harbour. Thousands of big trees uprooted and hundreds of buildings and hutments were rendered uninhabitable.
4.	23 – 25 May, 1961	Severe Cyclonic Storm	Crossed Maharashtra coast near Devgad on the night of 24 to 25 May. Loss and damage: 5 Lakhs fruit trees were reported to have been razed to the ground. 1,700 houses completely and 25,000 houses partially damaged.
5.	9 – 13 June, 1964	Severe Cyclonic Storm	Crossed Gujarat coast just west of Naliya during the late forenoon on 12 June. Maximum wind : Naliya: 135 kmph (73 kts); Dwarka: 105 kmph (57 kts); Porbandar: 74 kmph (40 kts) and Veraval: 83 kmph (45 kts.) Surge height : 2 m at Kandla Loss and damage: People killed – 27

6.	19 – 24 October, 1975	Very Severe Cyclonic Storm	Cossed Saurashtra coast about 15 km to the northwest of Porbandar at 1500 hours IST of 22 October Maximum wind: Jamnagar: 160 – 180 kmph (86-97 kts) Porbandar: 110 kmph (59 kts) Surge height: 4 – 6 m at Porbandar and Okha Intensity : T 6.0 Intensity at the time of landfall: 90 knot (167 kmph) Loss and damage: People killed – 85; Several thousands of houses were damaged, Many trees/ electric/telephone poles/roof tops blew; A train was also blown off its rails; loss of property was estimated to be Rs. 75 crores.
7.	31 May – 5 June, 1976	Severe Cyclonic Storm	Crossed Saurashtra coast near Bhavnagar on 3 June. Maximum wind : 90 knot (130 kmph) Intensity at the time of landfall: 70 knot Ship HAKKON MAGNUS: 167 kmph (90 kts) Loss and damage : People killed - 70 Cattleheads lost – 4500; Houses damaged - 25000 ; Damage estimated to be Rs. 3 crores.
8	14–20 November, 1977	Very Severe Cyclonic Storm *	Crossed Karnataka between Mangalore and Honavar in the early morning on 22 November. Intensity: T 5.5 Intensity at the time of landfall: 55 knot (102 kmph) Loss and damages : People killed - 72; 8,400 houses totally and 19,000 houses partially damaged; Loss estimated to be Rs. 10 Crores.
9.	4–9 November, 1982	Very Severe cyclonic Storm	Crossed Saurashtra coast, about 45 km east of Veraval on 8 November Intensity at the time of landfall: 65 knot (120 kmph) Loss and damage: People killed - 507 Livestock perished – 1.5 Lakh; Thousands of houses collapsed

10.	17-20 June, 1996	Severe Cyclonic Storm	Crossed south Gujarat coast between Veraval and Diu in the early morning of 19 June Intensity : T 3.5 Intensity at the time of landfall: 55 knot (102 kmph) Maximum wind : Veraval recorded 86 kmph (46 kts) at 0430 hrs IST of 19 June Storm surge : 5-6 m near Bharuch Loss and damage: People killed – 46 Cattle heads perished- 2113; No. of houses damaged – 29,595, loss of property - Rs. 18.05 Crore
11	4 – 10 June 1998	Very Severe Cyclonic Storm	Crossed Gujarat coast near Porbandar between 0630 and 0730 hrs IST of 9 June Intensity : T5.0 Maximum wind: 90 knot Intensity at the time of landfall: 90 knot (167 kmph) Jamnagar : 183 kmph (98 kts) at 0730 hrs IST of 9 June Surge height : 2 – 3 m above the astronomical tide of 3.2 m; Loss and damage: People killed – 1173; People missing – 1774 Loss of property worth to be Rs. 18.65. Crore

1.6. Climatology of Tropical Cyclones

1.6.1. Frequency of disturbances

It is now a well known fact of climatology that nearly 7 % of the global TCs form in the NIO. About 5 to 6 TCs occur in the NIO annually. However, they prominently occur during the pre-monsoon Season (March-April-May) and the post-monsoon Season (October-November-December). The month wise distribution of cyclonic disturbances over the NIO, Bay of Bengal and Arabian Sea are shown in Fig.1.16. The TCs develop in the ratio of 4:1 over the Bay of Bengal and the Arabian Sea.

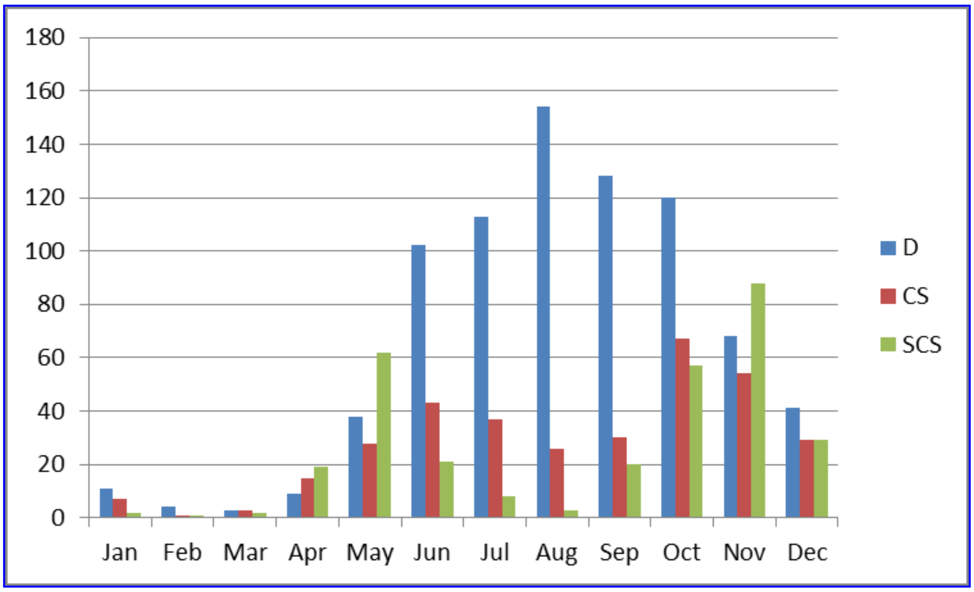


Fig.1.16(a): Monthly frequency of cyclonic disturbances over NIO during 1891-2019

D: Depression (Maximum sustained wind speed (MSW) 17-33 knot), CS: Cyclonic storm (MSW: 34-47 knot), SCS: Severe cyclonic storm (≥48 knot)

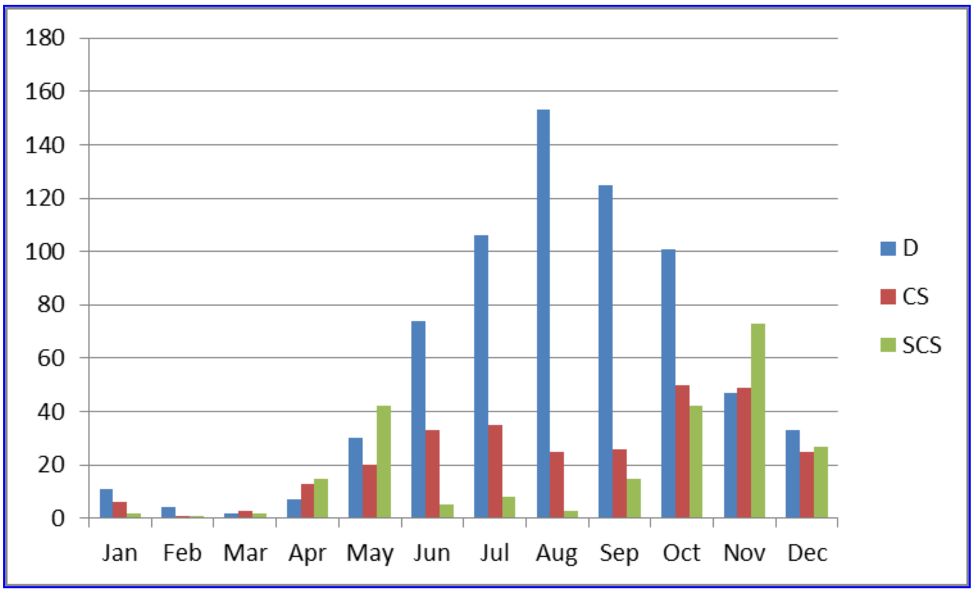


Fig.1.16(b). Monthly frequency of cyclonic disturbances over the BOB during 1891-2019

D: Depression (Maximum sustained wind speed (MSW) 17-33 knot), CS: Cyclonic storm (MSW: 34-47 knot), SCS: Severe cyclonic storm (≥48 knot)

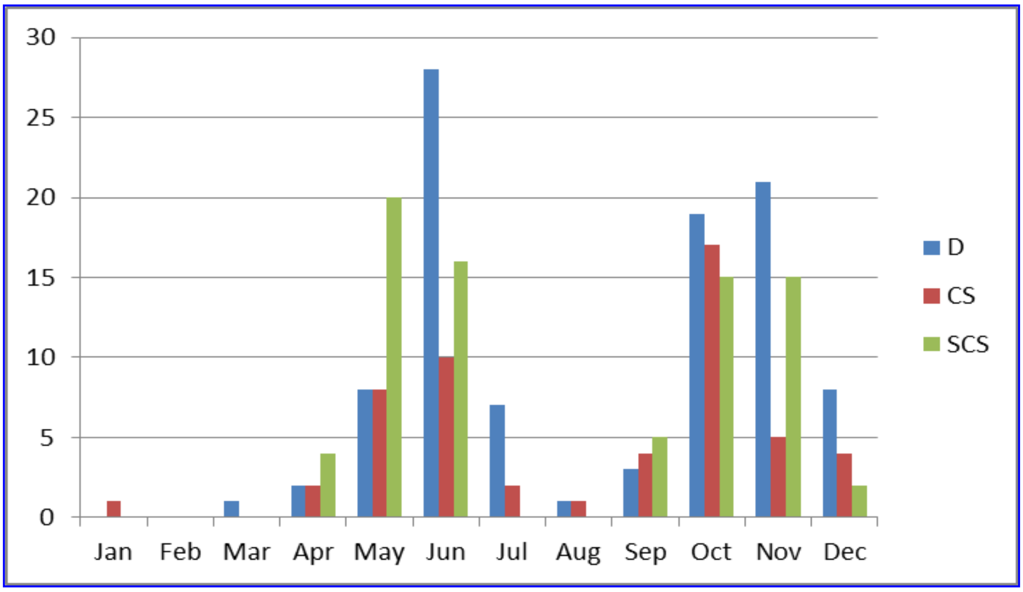


Fig.1.16 (c). Monthly frequency of cyclonic disturbances over Arabian Sea during 1891-2019

D: Depression (Maximum sustained wind speed (MSW) 17-33 knot), CS: Cyclonic storm (MSW: 34-47 knot), SCS: Severe cyclonic storm (≥48 knot)

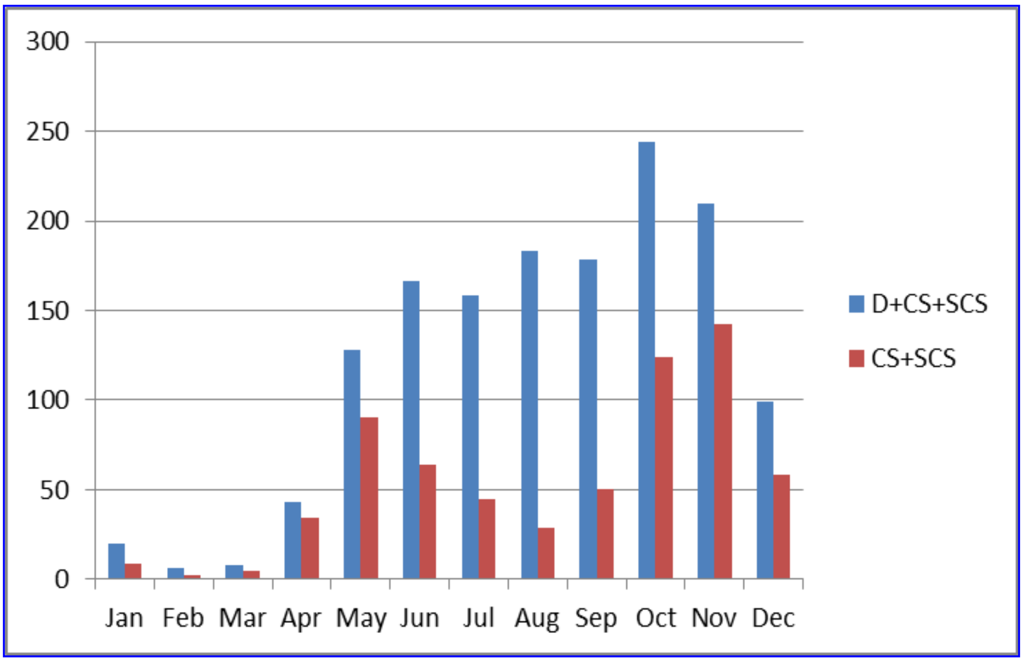


Fig.1.16 (d). Monthly frequency of total cyclonic disturbances (depression and above (MSW≥17 knot)) and total cyclones (Cyclonic storms and above (MSW≥34 knot)) during 1891-2019 over NIO

It is seen that the annual number of disturbances has ranged from 8 to 23. The number of cyclonic storms has varied from a minimum of 1 in 1949 to a maximum of 10 each in the years 1893, 1926 and 1930. The average number of cyclonic disturbances and cyclonic storms per year during 1891-2019 is about 12.4 and 5.2 respectively. More than 80% of all cyclonic disturbances occur during the months of May to November with a maximum in August. The monthly frequency of cyclonic storms shows two maxima, i.e. in May and November.

Considering the data during 1965-2020, about 10 CDs and 5 TCs develop over the NIO during a year including about 6.5 D, 1.8 CS, 0.9 SCS, 1.1 VSCS, 0.8 ESCS and 0.1 SuCS. The average frequency of D, CS, SCS, VSCS and ESCS over the BoB(AS) are 4.3(2.2), 1.4(0.4), 0.6(0.3), 0.8(0.2) and 0.6(0.2) respectively. The average frequency of CD, CS & above, SCS & above, VSCS & above and ESCS & above over the BoB(AS) is 7.8(2.3), 3.5(1.2), 2.2(0.8), 1.5(0.5) and 0.7(0.3) respectively. The frequencies of genesis and landfall of all categories of TCs are higher (by about 3 to 4 times) during post-monsoon than in pre-monsoon season over the BoB. While the genesis frequency is slightly higher in SCS, VSCS and ESCS category, the landfall frequency is almost same in both the seasons over the AS. The details are available in the publication Mrutyunjay Mohapatra, Monica Sharma, Sunitha S. Devi, S. V. J. Kumar and Bharati S. Sabade, 2021, **Frequency of genesis and landfall of different categories of tropical cyclones over the North Indian Ocean,** Mausam, 72(1).

The Bay of Bengal (BoB) is more prone for intense systems. Higher cyclonic disturbances (depressions and above) over the BoB is mainly due to the depressions/deep depressions during the monsoon Season developed over this region and the remnants of the systems formed over the south China Sea and emerging into BOB after moving west-northwestwards across southeast Asia.

1.6.2. Location of genesis

The frequency is very less over the west Arabian Sea mainly due to colder Sea surface temperature (SST). The genesis of cyclonic disturbances varies with respect to season. While genesis mostly takes place in lower latitudes in association with inter-tropical convergence zone (ITCZ) during pre-monsoon (March-May) and post-monsoon (October-December) seasons, it occurs over northerly latitude during monsoon season (June-September). This fact is illustrated in Fig.1.17.

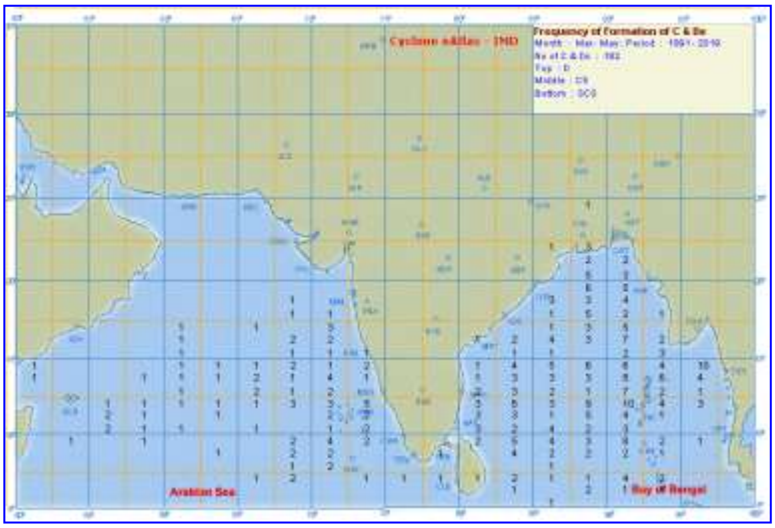
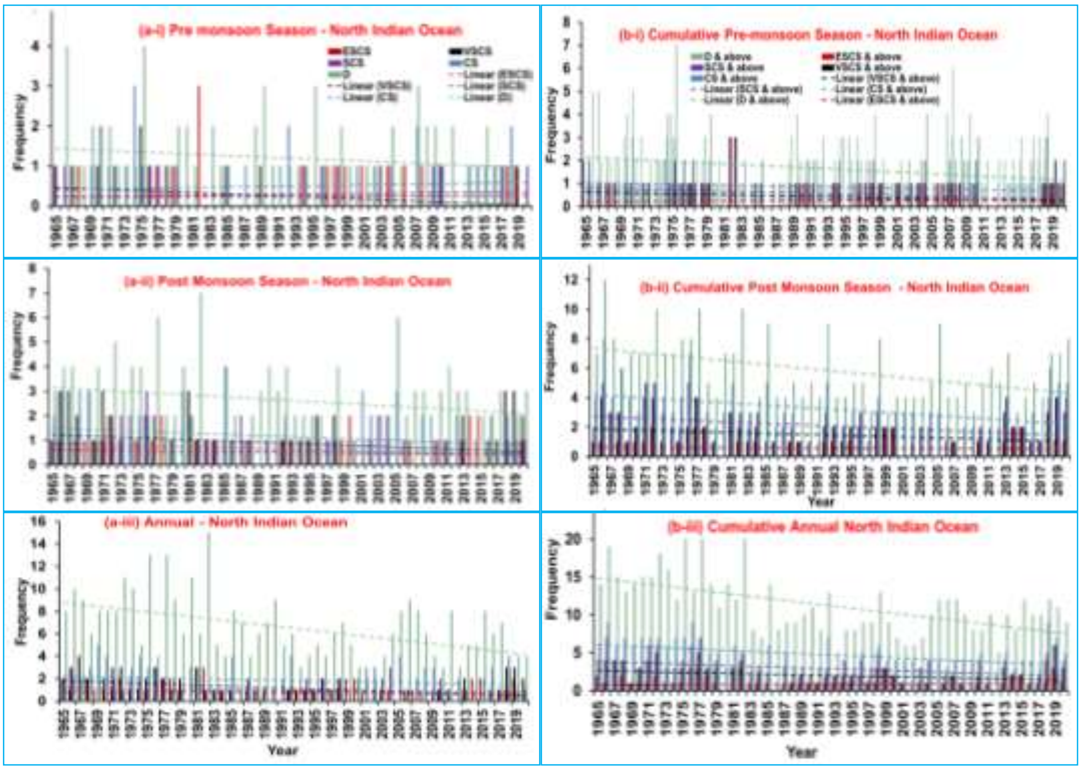


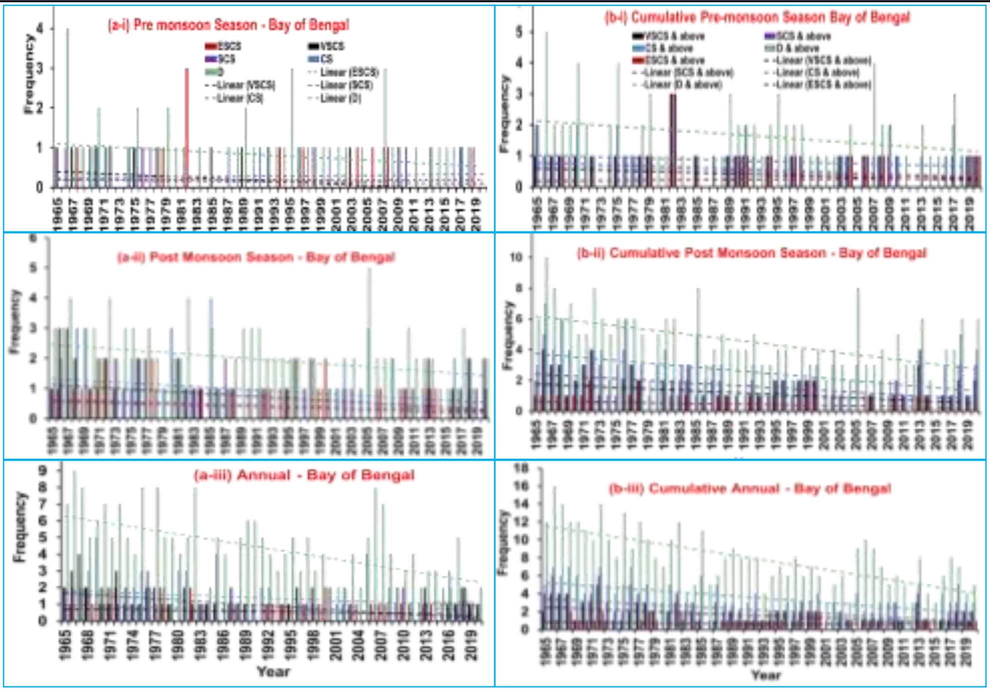
Fig.1.17 (a) Frequency of genesis of cyclonic disturbances over the NIO during pre-monsoon season

Fig.1.17 (b-c) Frequency of genesis of cyclonic disturbances over the NIO during (b) monsoon season and (c) post-monsoon season

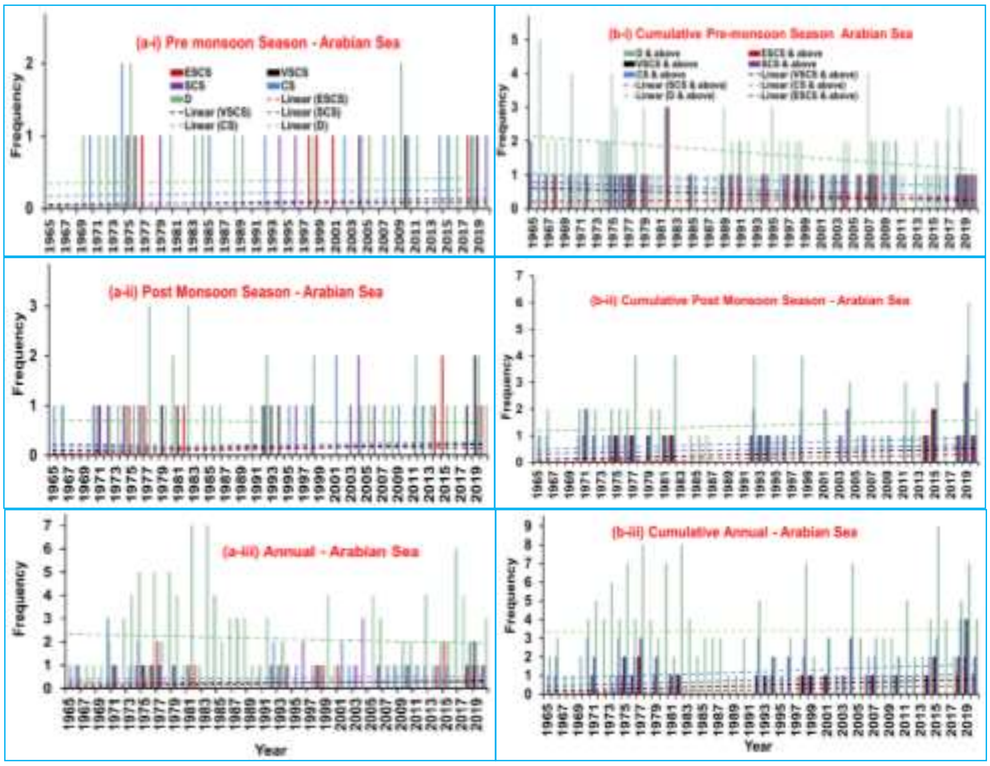
The time series of individual and cumulative frequency of formation of various categories of CDs during 1965-2020 over north Indian Ocean, Bay of Bengal and Arabian Sea during pre-monsoon & post monsoon seasons and the year as a whole is presented in Fig. 1.18(a-b). Considering the trend, it is seen that there is significantly decreasing trend in frequency of all categories of CDs including D/DD, CS, SCS, VSCS, ESCS over the BOB; and all except ESCS over the NIO during the year as a whole (Figs.1.19(a,b))). There is also decreasing trend in frequency of D & above, CS & above, SCS & above, VSCS & above and ESCS & above over the BOB and all the above except ESCS & aboveover the NIO during the year as a whole [Figs. .1.18(a,b)). However, there is no significant trend in frequency of any such category of storms over the AS during the period [Figs.1.20{a&b(i-iii)}] except that there is increasing trend in the frequency of ESCS. There is an increasing trend in the frequency of CS & above, SCS & above, VSCS & above and ESCS & above over **the AS during the year as a whole.**



Figs.1.18[a&b(i-iii)]: Individual and (b) cumulative frequency of various categories of TCs during (i) pre-monsoon, (ii) post-monsoon and (iii) year as a whole over the North Indian Ocean during the period 1965-2020



Figs.1.19 [a&b(i-iii)]. Same AS Fig.1.18, but over the Bay of Bengal (BoB)



Figs.1. 20[a&b(i-iii)]. Same as Fig.1.18, but over the Arabian Sea (AS)

[D: Depression & deep depression, CS: Cyclonic storm, SCS: Severe cyclonic storm, VSCS: Very severe cyclonic storm, ESCS: Extremely severe cyclonic storm, Linear: Linear trend line]

For details about the data, methodology and results the following publication may be referred in the following publication: Mrutyunjay Mohapatra, Monica Sharma, Sunitha S. Devi, S. V. J.

Kumar and Bharati S. Sabade, 2021, Frequency of genesis and landfall of different categories of tropical cyclones over the North Indian Ocean, Mausam, 72(1)

1.6.3. Intensification

The probabilities of intensification of a depression into a cyclonic storm and severe cyclonic storm and cyclonic storm into a severe cyclonic storm in different months are shown in Fig.1.21. The probability is maximum in the month of April followed by March, May and November in case of depression to cyclone and in the month of May followed by April and November in case of depressions to severe cyclonic storm.

More than 50% of the cyclonic disturbances (CDs) that form in the months of March, April, May, November and December intensify into storms. A third of the Bay CDs and half the number of the Arabian Sea CDs intensify into cyclones.

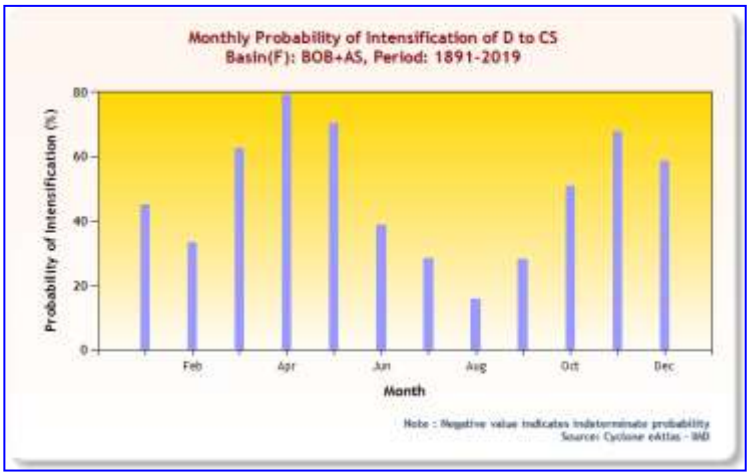


Fig.1.21(a).Monthly Probability of intensification of depression into a cyclone during 1891-2019

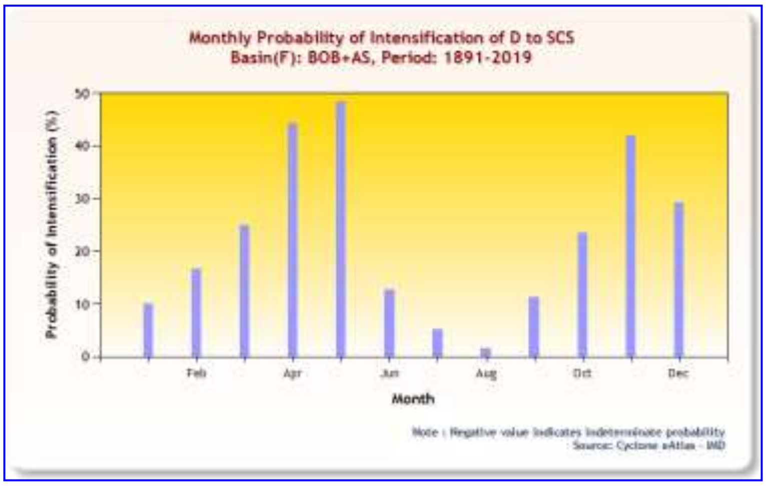


Fig.1.21(b). Monthly Probability of intensification of depression into a severe cyclonic storm during 1891-2019

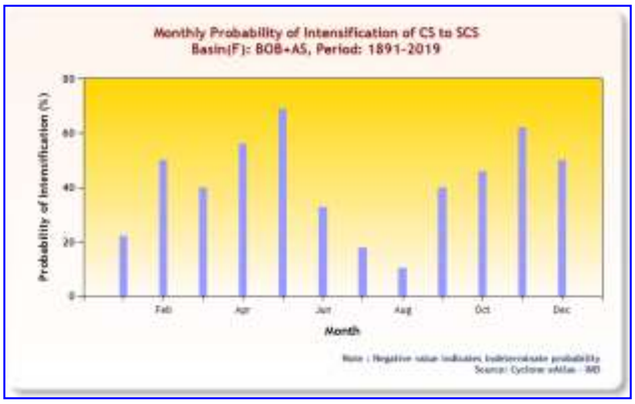


Fig.1.21 (c). Monthly Probability of intensification of cyclonic storm into a severe cyclonic storm during 1891-2019

About 10 CDs and 5 TCs develop over the NIO in a year (based on data during 1965-2020). Probability of intensification of D and TC into different individual categories of intensity of storm and cumulative categories of intensity of storm during pre-monsoon season, post-monsoon season and year as a whole over BOB, AS and NIO during 1965-2020 is presented in Fig. 1.22. Out of these CDs, about 47%, 29%, 20% and 9% of CDs intensify into CS, SCS, VSCS and ESCS respectively over the NIO. Similarly about 62%, 42% and 20% of total TCs intensify into SCS, VSCS and ESCS respectively over the NIO. There is 69% and 32% probability for an SCS to intensify into a VSCS and ESCS respectively and 47% probability for a VSCS to intensify into an ESCS. The probability of a CS to intensify into SCS, VSCS and ESCS is almost same for both BOB and AS and the probability of a CD becoming a TC is less over the BOB as compared to AS by about 07% during the year as a whole.

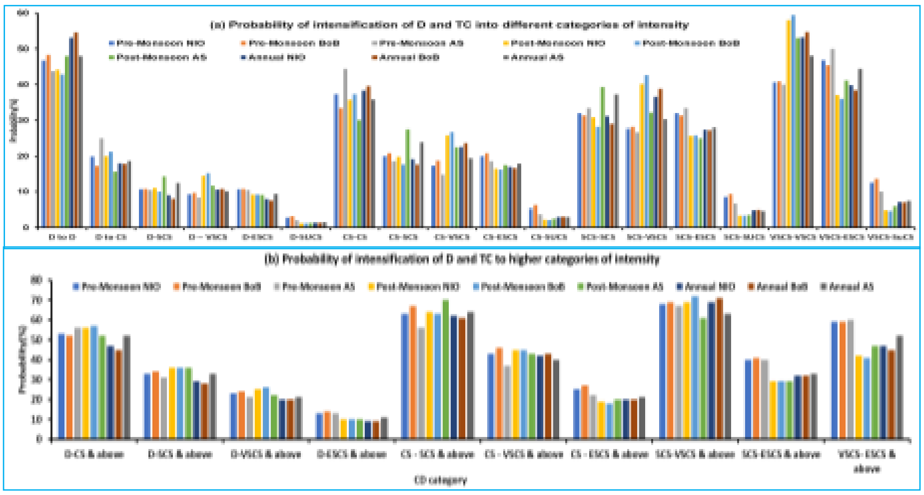


Fig. 1.22 (a&b). Probability of intensification of D and TC into different (a) individual categories of intensity of storm and (b) cumulative categories of intensity of storm during pre-monsoon season, post-monsoon season and year as a whole over BOB, AS and NIO during 1965-2020

1.6.4. Movement

The tracks of cyclones over the NIO during 1891-2019 are shown below. An electronic atlas has been published for tracks of CDs over the Bay of Bengal and Arabian Sea. Analysis of storm tracks with reference to their genesis, re-curvature and landfall points on 1°x1° scale along the Indian coasts have also been produced. Mostly the system developing over the NIO move in a northwesterly direction (Fig 1.23(a)). However, there are cases of recurvature towards the northeast or east to the southwest. The frequency of recurvature is higher towards the northeast compared to southwest or east. It is found that the probability of recurvature is higher over the Arabian Sea when the system moves to the north of 15^0N leading to more landfalls over Gujarat coast. Over the Bay of Bengal, there is no such preferred latitude/longitude for the re-curvature of the system. However the probability of recurvature towards the northeast is higher during the pre-monsoon Season.

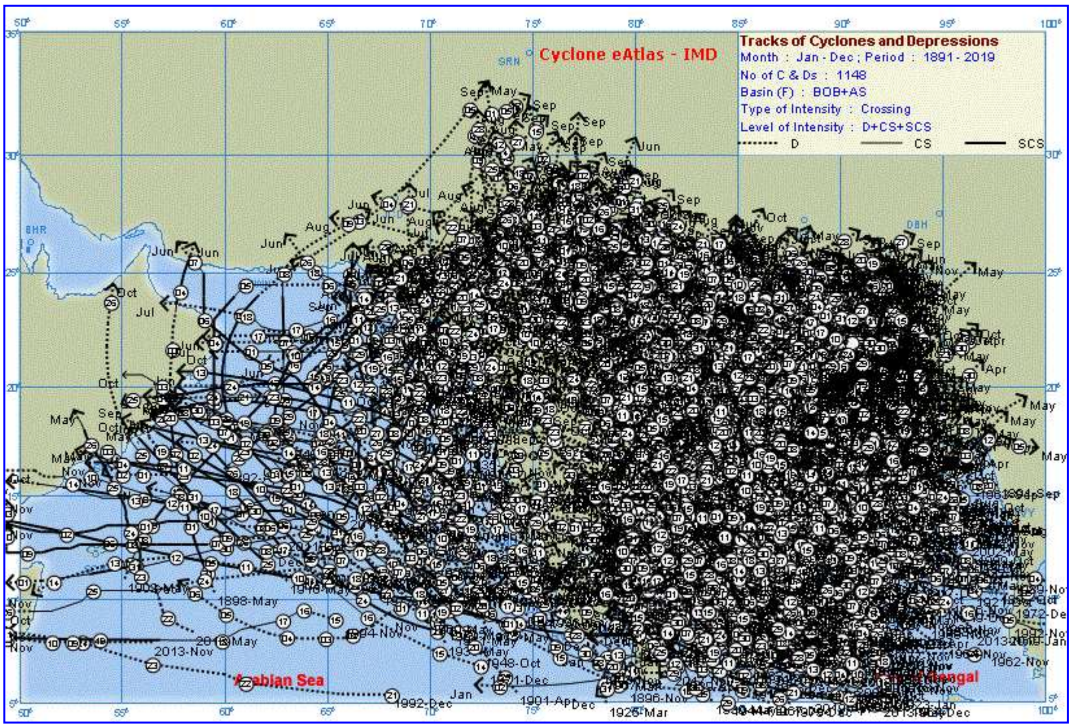


Fig.1.23 (a): Tracks of cyclones over the NIO during 1891-2019

The probability of direction of movement of cyclonic disturbances over the north Indian Ocean based on cyclone e-Atlas is shown in Fig.1.23 (b). Probability of direction of motion, vector speed and scalar speed of CDs during 1891-2019 is shown in Fig. 1.23 (c). Frequency of recurvature of C & Ds during 1891-2019 is shown in Fig. 1.23 (d). It is seen that the CDs over central parts of BoB and westcentral BoB exhibit highest probability of recurvature in northeast direction. Similarly over the AS, the CDs over the eastcentral and northeast AS exhibit highest tendency for recurvature in northeastwards direction.

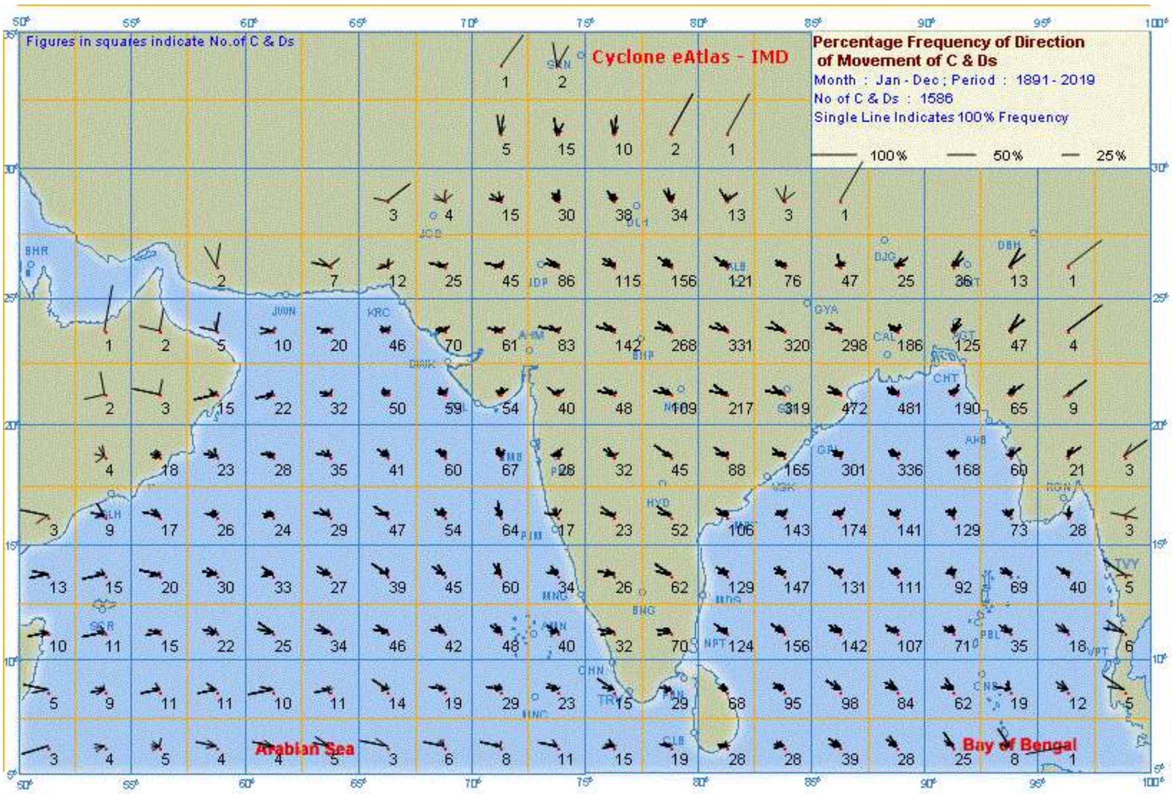


Fig.1.23(b) Probability of direction of movement of cyclonic disturbances over the NIO

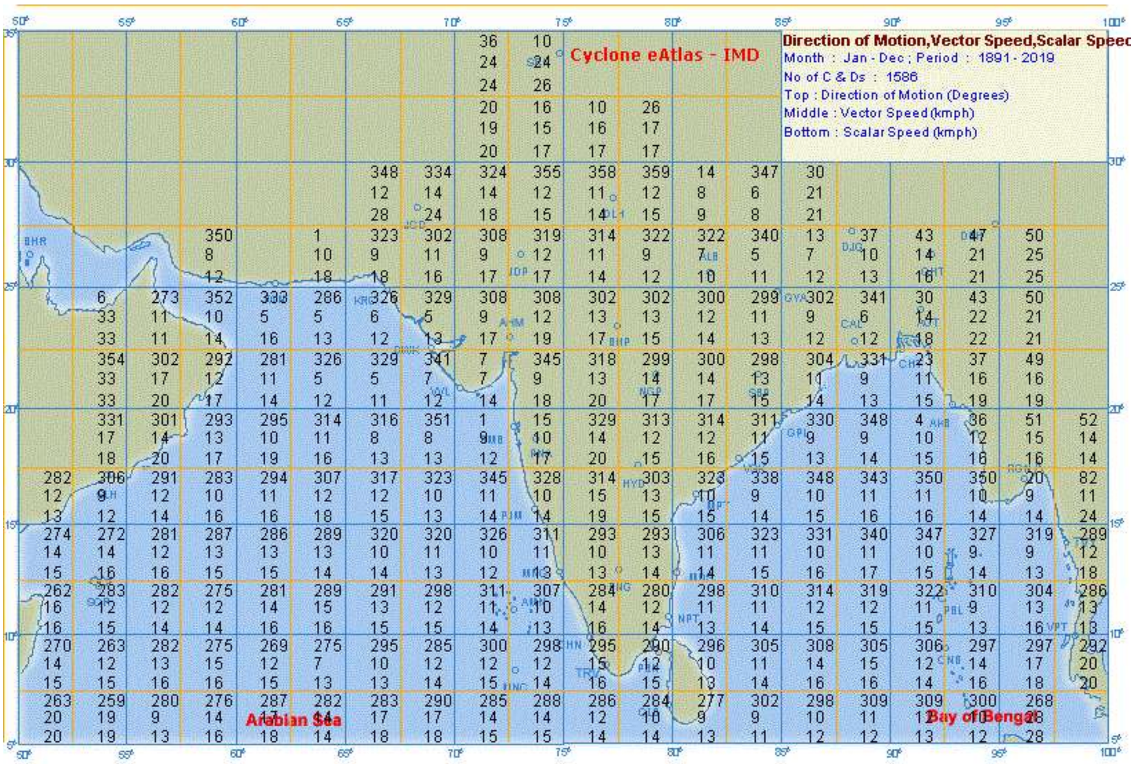


Fig.1.23 (c) Probability of direction of motion, vector speed and scalar speed of CDs during 1891-2019

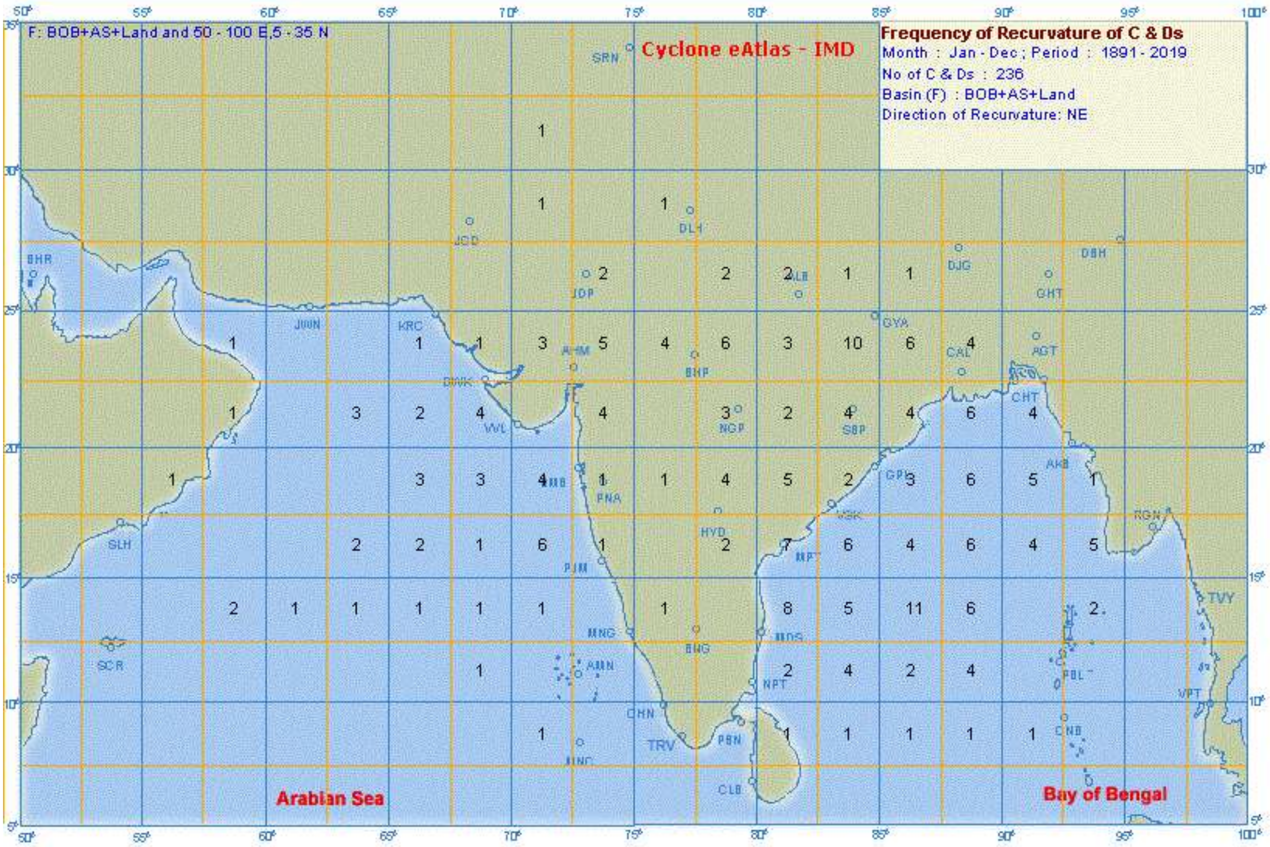


Fig. 1.23 (d) Frequency of recurvature of C & Ds during 1891-2019

1.6.5. Landfall

The Bay of Bengal TCs more often strike Odisha-West Bengal coast in October, Andhra coast in November and the Tamilnadu coast in December. Over 61 percent of the TCs in the Bay of Bengal strike different parts of the east coast of India, 23 percent strike coasts of Bangladesh and Myanmar and about 16 percent dissipate over the Sea itself. The cyclones crossing different coastal states are shown in Fig.1.24. Considering Arabian Sea, a significant number of cyclones dissipate over the sea itself before making any landfall (about 46%). Gujarat coast is the most prone for the cyclones developing over the Arabian Sea, with about 34% of total cyclones developing over Arabian Sea cross Gujarat coast followed by 17% crossing Oman and 3% crossing Pakistan coasts.

The time series of TCs landfalling over the Indian coasts and countries bordering BoB and AS during 1965 to 2019 is shown in Fig.1.25. There is a decreasing trend in landfalling CS, SCS, VSCS, CS & above, SCS & above, VSCS & above over the BoB. There is increasing trend in the frequency of ESCS, CS & above, SCS & above, VSCS & above and ESCS & above during the year as a whole over the AS.

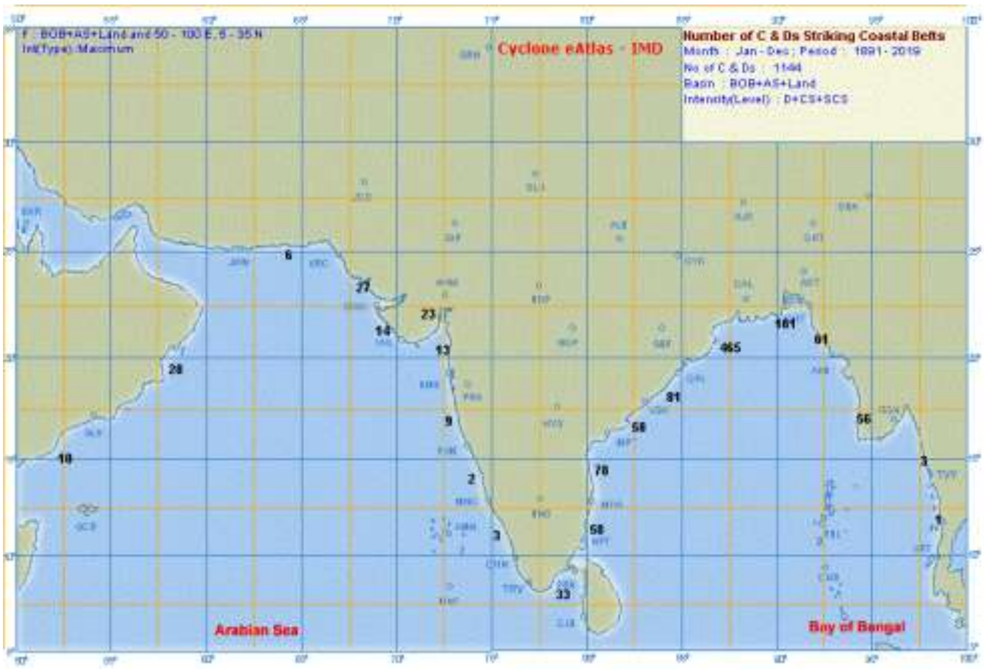
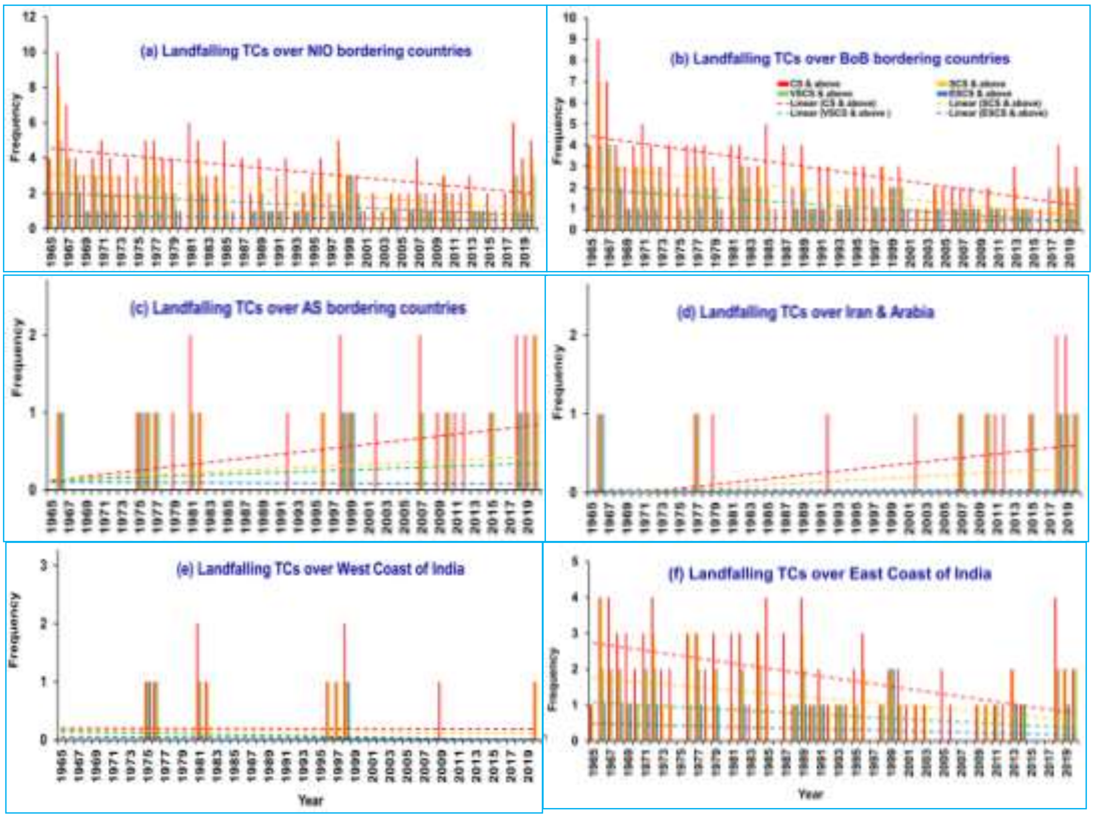
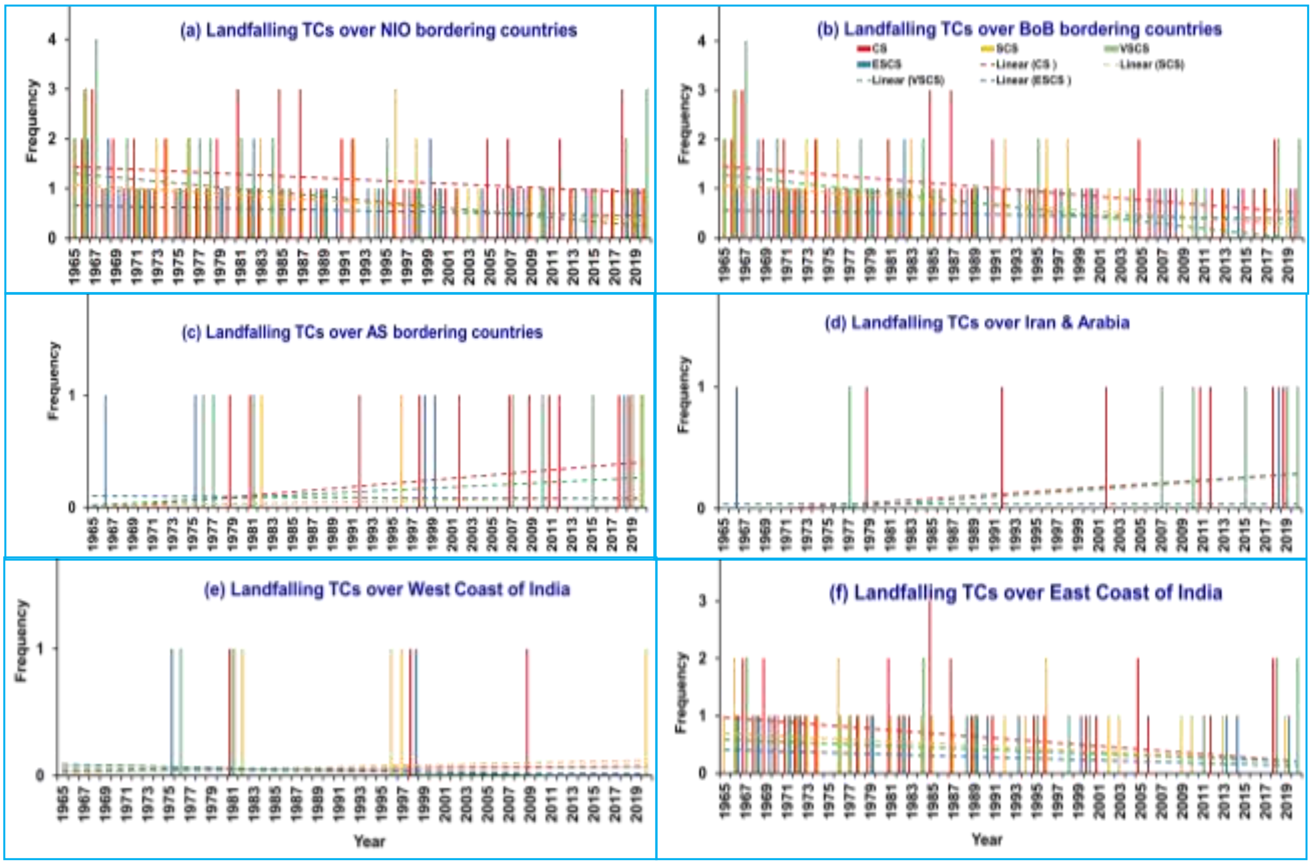


Fig. 1.24: CDs crossing different coastal belts in the BoB and AS during 1891-2019



Figs.1.25: Cumulative frequency of landfalling TCs over (a) NIO, (b) BoB & (c) AS and frequency of TCs landfalling over (d) Iran, Arabia & Africa (e) West coast of India & (f) East coast of India during 1965-2020

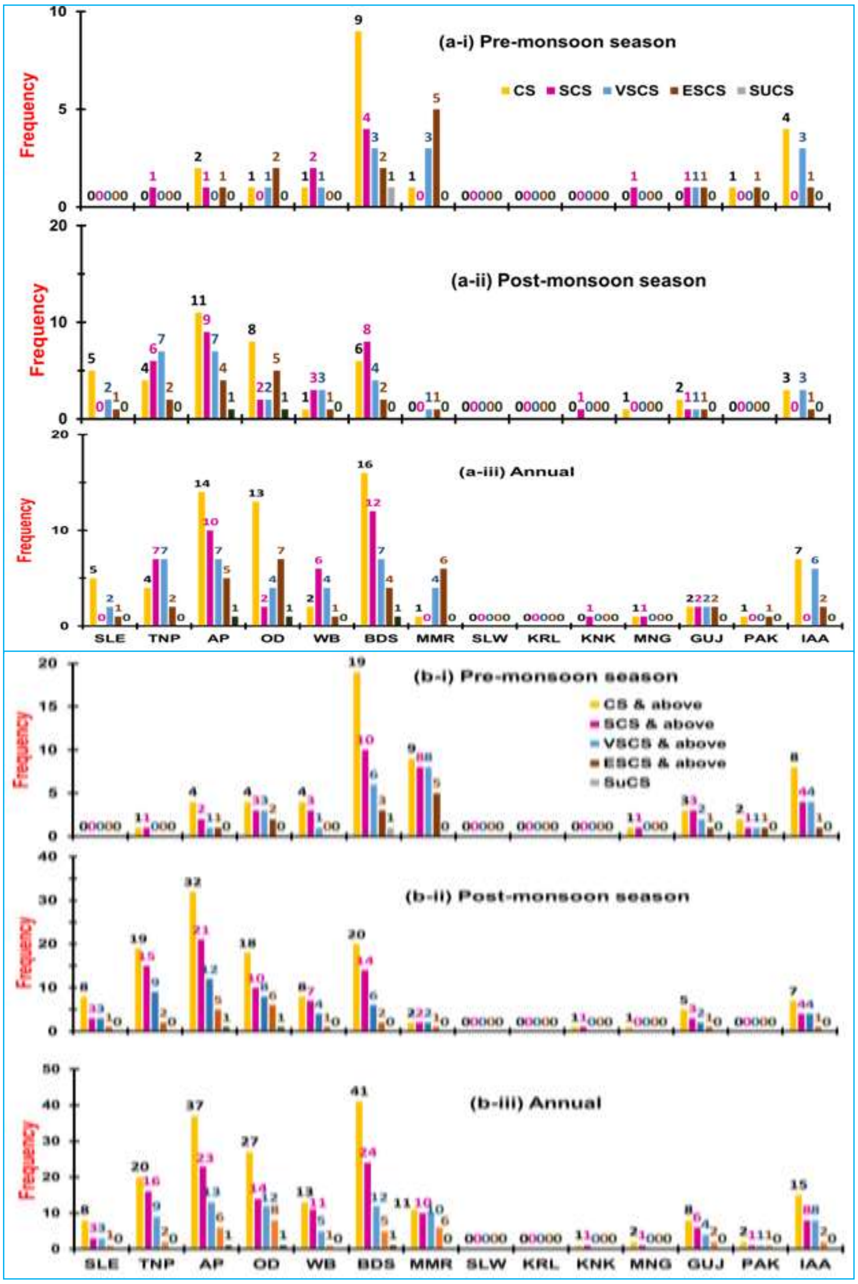


Figs.1.25 (ii): Individual frequency of landfalling TCs over (a) NIO, (b) BoB & (c) AS and frequency of TCs landfalling over (d) Iran, Arabia & Africa (e) West coast of India & (f) East coast of India during 1965-2020

TC: Tropical cyclone, BoB: Bay of Bengal, AS: Arabian Sea, NIO: North Indian Ocean, CS: Cyclonic storm, SCS: Severe cyclonic storm, VSCS: Very severe cyclonic storm and ESCS: Extremely severe cyclonic storm, Linear: Linear Trend Line

The individual and cumulative frequency of TCs crossing various coastal states and countries in the BoB and AS during 1965-2019 is shown in Fig. 1.26 (a & b) respectively. The most intense TCs (ESCS & above) cross the coast maximum over Orissa (ODS) followed by Andhra Pradesh (AP)/Myanmar (MMR) & Bangladesh (BDS) and low intensity TCs (CS/SCS) cross maximum over BDS followed by AP, ODS & Tamilnadu & Puducherry (TNP) and medium intensity TCs(VSCS) cross maximum over TN/AP/BDS followed by ODS/West Bengal (WB)/ Myanmar (MMR) during year as a whole. While maximum CS/SCS cross BDS, maximum VSCS cross BDS/MMR and maximum ESCS cross MMR coast during pre-monsoon season. While maximum CS/SCS/VSCS cross AP coast, maximum ESCS cross ODS coast during post-monsoon season. Over the AS, the landfall frequency of CS &

above and SCS & above and VSCS & above are maximum over Iran, Arabia & Africa (IAA) followed by Saurashtra & Kutch during both the seasons and year as a whole.



Figs.1.26 [a & b (i-iii)]. (a) Individual frequency and (b) cumulative frequency of various categories of landfalling TCs during (i) pre-monsoon, (ii) post-monsoon and (iii) year as a whole over the period 1965-2020

(TC: Tropical cyclone, CS: Cyclonic storm, SCS: Severe cyclonic storm, VSCS: Very severe cyclonic storm, ESCS: Extremely severe cyclonic storm and SuCS: Super Cyclonic Storm

SLE: Sri Lanka East, TNP: Tamilnadu and Puducherry, AP: Andhra Pradesh, OD: Odisha, WB: West Bengal, BDS: Bangladesh, MMR: Myanmar, SLW: Sri Lanka West, KRL: Kerala, KNK: Karnataka, MNG: Maharashtra and Goa, GUJ: Gujarat, PAK: Pakistan, IAA: Iran, Arabia and Africa)

The CDs mostly dissipate when they move over the land. Also, when a CD over the Sea comes across the unfavourable conditions like colder SST and high vertical wind shear, it dissipates over the sea itself. The frequency of dissipation is significantly higher over the West Arabian Sea, mainly due to colder SST. There are also significant numbers of cases of dissipation along the east cost of India, Bangladesh and Myanmar coasts.

The climatology of cyclonic disturbances presented here is based on data available in e-Atlas published by IMD. The limitation and scope of this Atlas have been discussed also by IMD (2008). One of the important limitations is that it does not include the short lived disturbances (life period < 12 hours).

Further, the climatology depends on the monitoring capability to detect the disturbances. The monitoring system over the region has undergone several changes with augmentation of surface observatories, introduction of RS/RW observations during 1930's, use of satellite since 1960s and implementation of meteorological buoys since 1997. Hence all these facts should be taken into consideration while analyzing the climatological characteristics of cyclonic disturbances over the NIO.

1.6.6. Translational Speed

The climatological characteristics of the average translational speed over the BoB, AS and NIO during the pre-monsoon & post monsoon seasons and the year as a whole based on the data during 1990-2013 are discussd below:

- The 06, 12 and 24 hourly average translational speeds of CDs over the NIO are about 13.9, 13.6 and 13.0 kmph respectively. The average speed is higher over the BOB than over the ARB, as 06, 12 and 24 hrly average speed is about 14.3, 13.9 and 13.4 kmph over the BOB against 13.1, 12.8 and 12.5 kmph over the ARB respectively.
- There is significant difference in average translational speeds of CDs with increase in intensity over BOB and ARB. The translational speed is higher in the stage of VSCS and SUCS stage in both the basins and in different seasons. Comparing the translational speeds in different seasons, it is minimum during winter seasons over all types of disturbances in both the Ocean basins.
- Comparing the translational speeds in different seasons over the ARB, the speed is higher in monsoon followed by pre-monsoon season in case of D, higher in post-monsoon followed by monsoon season in case of CS or higher intensity of the disturbance. In case of DD, it is higher in post-monsoon followed by pre-monsoon season.

- Considering BOB, the translational speed is maximum in monsoon followed by pre-monsoon season in case of D, DD, CS and followed by post-monsoon in case of SCS. There is no significant difference in translational speeds in case of VSCS and SuCS during pre-monsoon and post-monsoon seasons.

The details of data, methodology and results are available in the publication:

P. S. Chinchole and M. Mohapatra, 2016, Some Characteristics of translational speed of Cyclonic Disturbances over the North Indian Ocean during recent years, In Tropical cyclone activity over North Indian Ocean, Co-published by Springer and Capital Publishing Company, New Delhi, pp.153-168

The 06, 12 and 24 hourly average translational speed over the BOB, ARB and NIO during 1990-2020 season-wise and the year as a whole are available at www.rsmcnewdelhi.imd.gov.in

1.6.7. Life Period

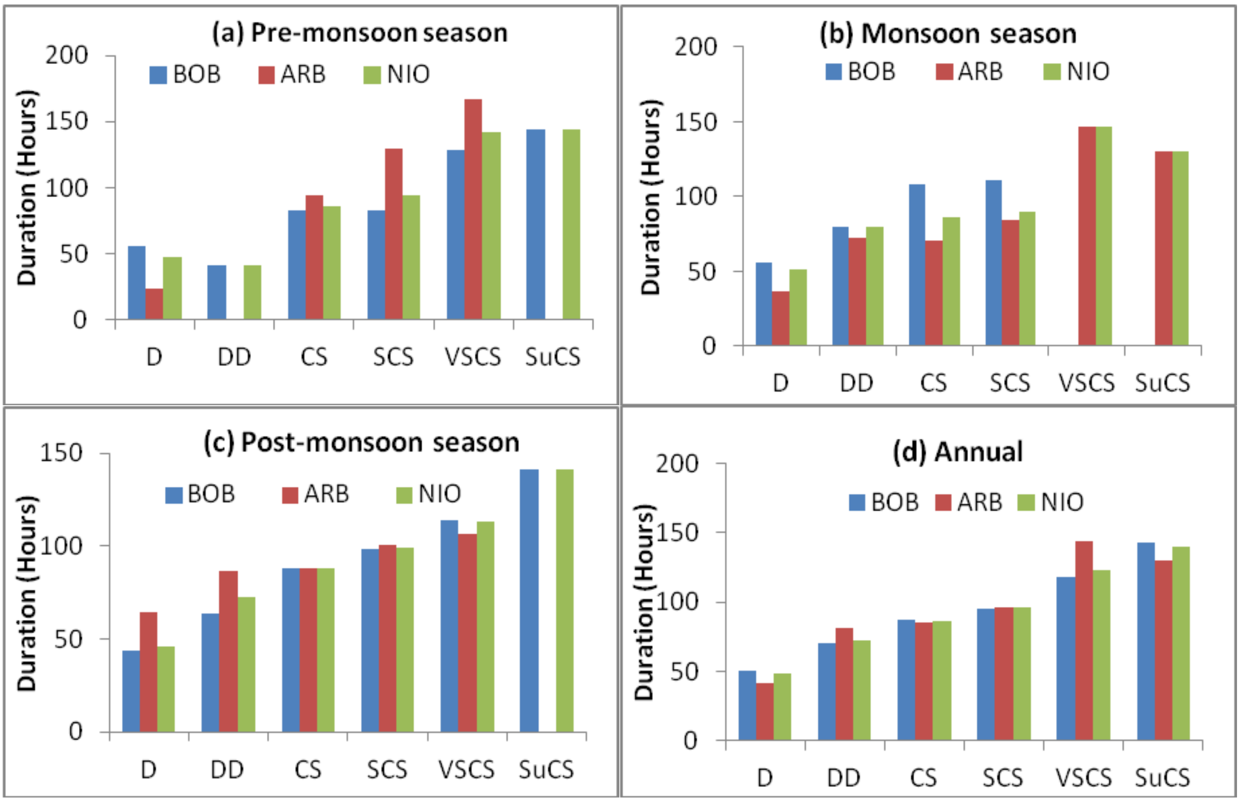


Fig.1.27: Mean duration in the life cycle of CDs over the BOB, the ARB and the NIO during (a) pre-monsoon season (b) monsoon season (c) post-monsoon season and (d) year as a whole based on the data of 1990-2013.

The climatological characteristics of the average life period of cyclonic disturbances (CD) over the BoB, AS and NIO season wise and category wise based on the data during 1990-2013 are discussed below:

- The average life period of CDs over the NIO is about 2 days, 3 days, 3.5 days, 4 days, 5 days and 5.75 days respectively for D, DD, CS, SCS, VSCS and SuCS.
- VSCS have higher mean life period over both the AS and the BOB in pre-monsoon, post-monsoon and year as a whole. While the VSCS stage has significantly higher duration over the ARB than over the BOB in pre-monsoon and the year as a whole, it is significantly higher over the BOB than over the ARB during post-monsoon season. During the monsoon season, the duration D, DD and CS stages are significantly higher over BOB than they are over the ARB.
- In respect of cumulative duration of stages, D and above to SCS and above during pre-monsoon, D and above during monsoon season D and above to VSCS and above during post-monsoon as well as the year as a whole are higher over the BOB than over the AS while the cumulative duration of stages of CS and above, SCS and above & VSCS and above are higher over the AS than over the BOB during monsoon season.

The details of data, methodology and results are available in the publication:

S.V.J. Kumar, V.Vijay Kumar, S.S. Ashthikar and M. Mohapatra, 2016, Life Period of Cyclonic Disturbances over the North Indian Ocean during recent years in Tropical Cyclone Activity over the North Indian Ocean, Co-published by Springer and Capital Publishers Pvt Ltd, New Delhi, pp.169-184

The duration of CDs over the BOB, AS and NIO during 1990-2020 season-wise and the year as a whole are available at www.rsmcnewdelhi.imd.gov.in

1.6.8 Velocity flux, accumulated cyclone energy and power dissipation index

The velocity flux (VF) is directly proportional to the maximum sustained surface wind speed (MSW) during the life period of TC. The accumulated cyclone energy (ACE) and power dissipation index (PDI) which are proportional to square and cube of the maximum wind speed respectively are calculated as sum of the six hourly square and cube of the maximum sustained wind speed during the life period of TC. While cyclone ACE is a measure of cyclone destruction potential, PDI is a measure of loss due to TCs. Basinwise and seasonwise comparison of mean velocity flux (VF), accumulated cyclone energy (ACE) and power dissipation index (PDI) during 1990-2020 for various categories of TCs is given in Table 1.10 & 1.11 respectively.

Table1.10: Basinwise comparison of mean velocity flux (VF), accumulated cyclone energy (ACE) and power dissipation index (PDI) during 1990-2020

Category	Season	VF X 10^2		ACE X 10^4		PDI X 10^6	
		BoB	AS	BoB	AS	BoB	AS
Super cyclonic storm	Pre-M	15.99	15.01	**15.14**	**12.60**	**15.65**	**11.59**
	Post-M	**13.05**	**23.55**	**11.82**	**23.45**	12.72	25.43
	Annual	**15.26**	**19.28**	**14.31**	**18.02**	15.65	18.51
Extremely severe cyclonic storm	Pre-M	12.51	13.87	9.23	9.24	7.50	7.91
	Post-M	**9.14**	**15.73**	**7.28**	**12.13**	*6.28*	*10.22*
	Annual	**10.26**	**14.80**	7.93	10.68	7.50	9.07
Very severe cyclonic storm	Pre-M	8.14	13.40	4.30	8.84	2.41	6.08
	Post-M	7.92	6.36	4.73	3.42	2.91	1.96
	Annual	7.95	8.76	4.67	5.12	2.41	3.18
Severe cyclonic storm	Pre-M	4.12	2.78	1.96	1.27	0.96	0.60
	Post-M	3.88	3.93	1.83	1.88	0.90	0.93
	Annual	3.94	3.55	1.86	1.68	0.96	0.82
Cyclonic storm	Pre-M	3.14	2.76	1.26	1.10	0.51	0.46
	Post-M	2.56	2.05	1.00	0.75	0.40	0.28
	Annual	2.65	2.36	1.04	0.90	0.51	0.36

Table 1.11: Season wise comparison of mean velocity flux (VF), accumulated cyclone energy (ACE) and power dissipation index (PDI) during 1990-2020

Category	Season	VF X 10^2		ACE X 10^4		PDI X 10^6	
		Pre-M	Post-M	Pre-M	Post-M	Pre-M	Post-M
Super cyclonic storm	NIO	15.75	18.30	14.50	17.64	14.63	19.07
	BoB	*15.99*	13.05	*15.14*	11.82	*15.65*	12.72
	AS	**15.01**	23.55	12.60	23.45	11.59	25.43
Extremely severe cyclonic storm	NIO	13.11	11.02	9.23	8.67	7.68	7.41
	BoB	12.51	9.14	9.23	7.28	7.50	6.28
	AS	13.87	15.73	9.24	12.13	7.91	10.22
Very severe cyclonic storm	NIO	*10.77*	7.40	6.57	4.29	4.25	2.59
	BoB	8.14	7.92	4.30	4.73	2.41	2.91
	AS	**13.40**	6.36	**8.84**	3.42	**6.08**	1.96
Severe cyclonic storm	NIO	3.45	3.90	1.61	1.85	0.78	0.91
	BoB	4.12	3.88	1.96	1.83	0.96	0.90
	AS	2.78	**3.93**	1.27	**1.88**	0.60	*0.93*
Cyclonic storm	NIO	2.97	2.42	1.19	0.93	0.49	0.37
	BoB	3.14	2.56	1.26	1.00	0.51	0.40
	AS	2.76	2.05	1.10	0.75	*0.46*	0.28

BoB: Bay of Bengal and AS: Arabian Sea, Bold: Values significant at 95% level, Italics: Values significant at 90% level

1.7. Naming of cyclones

The WMO/ESCAP Panel on Tropical Cyclones at its twenty-seventh Session held in 2000 in Muscat, Sultanate of Oman agreed in principle to assign names to the tropical cyclones in the Bay of Bengal and Arabian Sea. After long deliberations among the member countries, the naming of the tropical cyclones over NIO commenced from September 2004. RSMC, New Delhi is continuing the naming of Tropical Cyclones formed over NIO since October 2004. The first name was ‘ONIL’ which developed over the Arabian Sea (30 September to 03 October, 2004). According to approved principle, a list of 64 names in eight columns has been prepared. The name has been contributed by Panel members. The RSMC-tropical cyclones, New Delhi gives a tropical cyclone an identification name from the above name list. The Panel member’s name is listed alphabetically country-wise in each column. The names are used sequentially column-wise. The first name starts from the first row of column one and continues sequentially to the last row in column eight. The identification system covers both the Arabian Sea and the Bay of Bengal. These lists are used sequentially, and they are not rotated every few years unlike the Atlantic and Eastern Pacific lists. Since all the 64 names listed initially (Table- 1.12) got exhausted, a new list comprising 169 names contributed by the 13 Member countries of WMO/ESCAP Panel has been prepared and put in place since the pre-monsoon season of 2020. These are en-listed in Table – 1.13). A system will be named as per the Table once it intensifies into a cyclonic storm. During the stage of depression and deep depression, it will be named as per the serial number of the system for a given Ocean basin (e.g. Bay of Bengal and Arabian Sea). Hence the first system forming over the Bay of Bengal (BOB) and Arabian Sea (ARB) will be named as BOB/01 and ARB/01 respectively.

Table.1.12: Table for naming tropical cyclones for the north Indian Ocean region (including Bay of Bengal and Arabian Sea) effective from September, 2004 (All names in this list have been used). The last name Amphan was used in May, 2020.

Panel Member	Column one		Column two		Column three		Column four	
	Names	Pron’	Names	Pron’	Names	Pron’	Names	Pron’
B’desh	Onil	Onil	Ogni	Og-ni	Nisha	Ni-sha	Giri	Gi-ri
India	Agni	Ag’ni	Akash	Aakaa’sh	Bijli	Bij’li	Jal	Jal
Maldives	Hibaru	--	Gonu	--	Aila	--	Keila	--
Myanmar	Pyarr	Pyarr	Yemyin	Ye-myin	Phyan	Phyan	Thane	Thane
Oman	Baaz	Ba-az	Sidr	Sidr’	Ward	War’d	Murjan	Mur’jaan
Pakistan	Fanoos	Fanoos	Nargis	Nar gis	Laila	Lai la	Nilam	Ni lam
Sri Lanka	Mala	--	Rashmi	Rash’mi	Bandu	--	Viyaru	Viyaru
Thailand	Mukda	Muuk-dar	Khai Muk	Ki-muuk	Phet	Pet	Phailin	Pi-lin

Panel Member	Column five		Column six		Column seven		Column eight	
	Names	Pron’	Names	Pron’	Names	Pron’	Names	Pron’
B’desh	Helen	Helen	Chapala	Cho-po-la	Ockhi	Ok-khi	Fani	Foni
India	Lehar	Le’har	Megh	Me’gh	Sagar	Saa’gar	Vayu	Vaa’yu
Maldives	Madi	--	Roanu	--	Mekunu	--	Hikaa	--

Myanmar	**Nanauk**	**Na-nauk**	**Kyant**	**Kyant**	**Daye**	**Da-ye**	**Kyarr**	**Kyarr**
Oman	**Hudhud**	**Hud'hud**	**Nada**	**N'nada**	**Luban**	**L'luban**	**Maha**	**M'maha**
Pakistan	**Nilofar**	**Ni lofar**	**Vardah**	**Var dah**	**Titli**	**Titli**	**Bulbul**	**Bul bul**
Sri Lanka	**Ashobaa**	**Ashobaa**	**Maarutha**	**Maarutha**	**Gaja**	**Gaja**	**Pawan**	**Pavan**
Thailand	**Komen**	**Goh-men**	**Mora**	**Moh-rar**	**Phethai**	**Pay-ti**	**Amphan****	**Um-pun**

Table 1.13: New list of tropical cyclone names adopted by WMO/ESCAP Panel Member Countries in April 2020 for naming of tropical cyclones over North Indian Ocean including Bay of Bengal and Arabian Sea (First name was used in June, 2020)

WMO/ESCAP Panel Member countries	Column 1		Column 2		Column 3		Column 4	
	Name	Pron'	Name	Pron'	Name	Pron'	Name	Pron'
Bangladesh	Nisarga	Nisarga	Biparjoy	Biporjoy	Arnab	Ornab	Upakul	Upokul
India	Gati	Gati	Tej	Tej	Murasu	Murasu	Aag	Aag
Iran	Nivar	Nivar	Hamoon	Hamoon	Akvan	Akvan	Sepand	Sepand
Maldives	Burevi	Burevi	Midhili	Midhili	Kaani	Kaani	Odi	Odi
Myanmar	Tauktae	Tau'Te	Michaung	Migjaum	Ngamann	Ngaman	Kyarthit	Kjathi
Oman	Yaas	Yass	Remal	Re-Mal	Sail	Sail	Naseem	Naseem
Pakistan	Gulab	Gul-Aab	Asna	As-Na	Sahab	Sa-Hab	Afshan	Af-Shan
Qatar	Shaheen	Shaheen	Dana	Dana	Lulu	Lulu	Mouj	Mouj
Saudi Arabia	Jawad	Jowad	Fengal	Feinjal	Ghazeer	Razeer	Asif	Aasif
Sri Lanka	Asani	Asani	Shakhti	Shakhti	Gigum	Gigum	Gagana	Gagana
Thailand	Sitrang	Si-Trang	Montha	Mon-Tha	Thianyot	Thian-Yot	Bulan	Bu-Lan
United Arab Emirates	Mandous	Man-Dous	Senyar	Sen-Yaar	Afoor	Aa-Foor	Nahhaam	Nah-Haam
Yemen	Mocha	Mokha	Ditwah	Ditwah	Diksam	Diksam	Sira	Sira

WMO/ESCAP Panel Member countries	Column 5		Column 6		Column 7		Column 8	
	Name	Pron’	Name	Pron’	Name	Pron’	Name	Pron’
Bangladesh	Barshon	Borshon	Rajani	Rojoni	Nishith	Nishith	Urmi	Urmi
India	Vyom	Vyom	Jhar	Jhor	Probah o	Probaho	Neer	Neer
Iran	Booran	Booran	Anahita	Anahita	Azar	Azar	Pooyan	Pooyan
Maldives	Kenau	Kenau	Endheri	Endheri	Riyau	Riyau	Guruva	Guruva
Myanmar	Sapakyee	Zabagji	Wetwun	We’wum	Mwaihout	Mwei’hau	Kywe	Kjwe
Oman	Muzn	Muzn	Sadeem	Sadeem	Dima	Dima	Manjour	Manjour
Pakistan	Manahil	Ma-Na-Hil	Shujana	Shu-Ja-Na	Parwaz	Par-Waaz	Zannata	Zan Naa Ta
Qatar	Suhail	Es’hail	Sadaf	Sadaf	Reem	Reem	Rayhan	Rayhan
Saudi Arabia	Sidrah	Sadrah	Hareed	Haareed	Faid	Faid	Kaseer	Kusaer
Sri Lanka	Verambha	Ve-Ram-Bha	Garjana	Garjana	Neeba	Neeba	Ninnada	Nin-Na-Da
Thailand	Phutala	Phu-Ta-La	Aiyara	Ai-Ya-Ra	Saming	Sa-Ming	Kraison	Krai-Son
United Arab Emirates	Quffal	Quf-Faal	Daaman	Daa-Man	Deem	Deem	Gargoor	Gar-Goor
Yemen	Bakhur	Bakhoor	Ghwyzi	Ghwayzi	Hawf	Hawf	Balhaf	Balhaf

WMO/ ESCAP Panel Member countries	Column 9		Column 10		Column 11		Column 12		Column 13	
	Name	Pron'	Name	Pron'	Name	Pron'	Name	Pron'	Name	Pron'
Bangladesh	Meghala	Meghla	Samiron	Somiron	Pratikul	Protikul	Sarobor	Sorobor	Mahanisha	Mohanisha
India	Prabhanjan	Prabhanjan	Ghurni	Ghurni	Ambud	Ambud	Jaladhi	Jaladhi	Vega	Vega
Iran	Arsham	Arsham	Hengame	Hengame	Savas	Savas	Tahamtan	Tahamtan	Toofan	Toofan
Maldives	Kurangi	Kurangi	Kuredhi	Kuredhi	Horangu	Horangu	Thundi	Thundi	Faana	Faana
Myanmar	Pinku	Pinnku	Yinkaung	Jin Gaun	Linyone	Lin Joun	Kyeekan	Kji Gan	Bautphat	Bau'hpa
Oman	Rukam	Roukaam	Watad	Wa Tad	Al-jarz	Al-Jarouz	Rabab	Ra Bab	Raad	Raad
Pakistan	Sarsar	Sar-Sar	Badban	Baad-Baan	Sarrab	Sarrab	Gulnar	Gul-Nar	Waseq	Waa-Seq
Qatar	Anbar	Anbar	Oud	Oud	Bahar	Bahar	Seef	Seef	Fanar	Fanaar
Saudi Arabia	Nakheel	Nakheel	Haboob	Haboob	Bareq	Bariq	Alreem	Areem	Wabil	Wobil
Sri Lanka	Viduli	Viduli	Ogha	Ogha	Salitha	Salitha	Rivi	Rivi	Rudu	Rudu
Thailand	Matcha	Mat-Cha	Mahingsa	Ma-Hing-Sa	Phraewa	Phrae-Wa	Asuri	A-Su-Ri	Thara	Tha-Ra
United Arab Emirates	Khubb	Khubb	Degl	Degl	Athmad	Ath-Md	Boom	Boom	Saffar	Saf-Faar
Yemen	Brom	Brom	Shuqra	Shuqrah	Fartak	Fartak	Darsah	Darsah	Samhah	Samhah

If public wants to suggest the name of a cyclone to be included in the list, the proposed name must meet some fundamental criteria. The name should be short and readily understood when broadcast. Further the names must not be culturally sensitive and not convey some unintended and potentially inflammatory meaning. The suggested name pertaining to India may be communicated to Director General of Meteorology, India Meteorological Department, Mausam Bhawan, Lodi Road, New Delhi-110003 for consideration.

1.8. Early Warning System

As tropical cyclone cannot be tamed to reduce their adverse effects, one has to learn to live with them. Effective Cyclone Disaster Prevention and Mitigation Plan require:

- Hazard analysis
- Vulnerability analysis.
- Early Warning and Mitigation
- Community preparedness and planning at all levels to meet the exigencies.

Out of these early warning is a major component as evident from a survey conducted for the south Asian region. Considering all the above, it is important to observe and understand the development of tropical disturbances for forecasting and warning the various user agencies and general public. India Meteorological Department (IMD) monitors and predicts CDs over NIO and provides early warning services for management of the cyclone. Various components of early warning system for a cyclone include (i) monitoring and prediction, (ii) warning organization, (iii) warning generation, presentation & dissemination, (iv) coordination with disaster management agencies,(vii) public education & reaching out and (viii) post-event review. The entire early warning system of cyclone is depicted in Fig.1.28. All the above aspects of early warning system are discussed in the following Chapters.

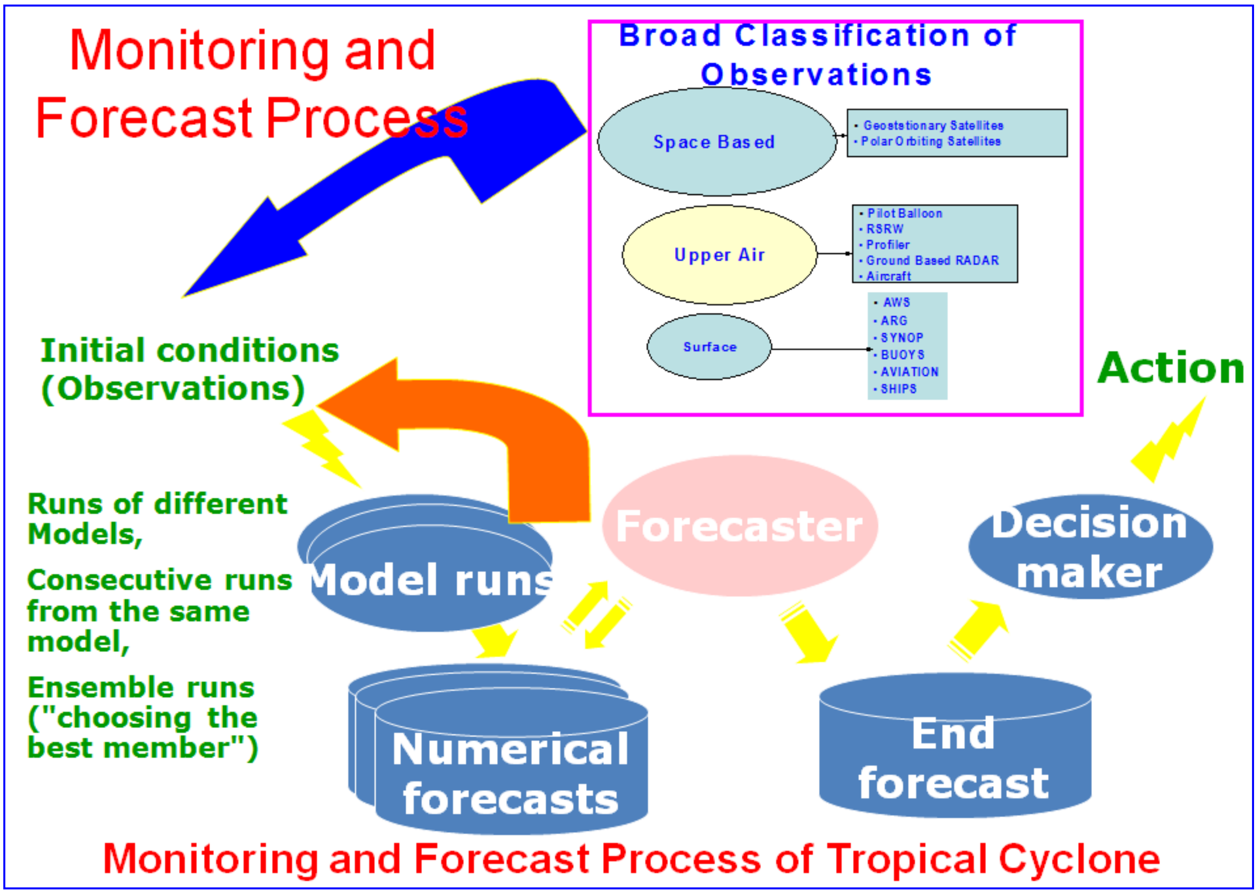


Fig.1.28 Monitoring and Forecasting Process of Tropical Cyclones over NIO

Chapter – II
Cyclone Warning Organisation

Cyclone warning is one of the most important functions of the India Meteorological Department and it was the first service undertaken by the Department as early as in 1865 and thus the service started before the establishment of the department in 1875.

2.1 Milestones

1864: Two severe cyclonic storms in quick succession hit the east coast of India, causing enormous loss of human lives and property – the first one struck Kolkata in October and the second one struck Machilipatnam in November.

1865: Concerned with these disasters, the Government appointed a committee in 1865 to formulate a scheme to develop a system of cyclone warnings. On the recommendations of the committee, Kolkata became the first port where a storm warning system was organised in the same year.

1875: Establishment of India Meteorological Department

1880: The storm warning scheme for west coast ports (Mumbai, Karachi, Ratnagiri, Vengurla, Karwar and Kumta) came into force.

1882: The ports at Sagar Islands, Mud Port and Diamond Harbour were also included in the list of ports getting storm warning messages.

1886: System of early warnings against cyclones was extended to cover all Indian ports.

1891: Publication of India Weather Review containing details of depressions and storms.

1898: Two different systems of storm warning signals (one for the east coast ports and another for west coast ports) were in use. A uniform system of storm warning signals was introduced at all the Indian ports.

Kolkata office was responsible for issuing storm warning to all the ports (including those of Burma) around the Bay of Bengal, while the west coast ports were served by the Bombay Meteorological Reporter initially and later from Simla which was then the headquarters of the Department.

1908: Meteorological Atlas of the Indian Seas and the North Indian Ocean published

1915: First PB observatory at Pune

1919: Second PB observatory at Kolkata

1925: Atlas of “Storm Tracks in the Bay of Bengal published. Classification of cyclones into cyclonic storms and severe cyclonic storms

1928: After the shift of the HQ of the Department from Simla to Pune in 1928, the storm warning work for west coast was done from Pune.

1945: With the formation of Regional Meteorological Centres, the storm warning work for the Bay ports on the east coast from Kalingapatnam southwards was transferred to Chennai (Meenambakkam).

1947: Responsibility for the Arabian Sea ports was taken over by the Meteorological Office at Santacruz (Mumbai).

1952: First Surface Observatory over Bay Islands.

1956: As the combination of the meteorological activities for aviation and marine interests in the same office had some drawbacks, these two activities were bifurcated to achieve a more efficient functioning of the storm warning service. Separate storm warning centres came to be established at Colaba (Mumbai)

1960: First Surface Observatory in Lakshadweep and Kerala

1963: Automatic picture transmission (APT) system donated by USA for receiving the satellite imagery from GOES satellites was established at Bombay.

1964: Revised Storm Atlas published for 1877-1890 and 1891-1960

1969: (i) Separate storm warning centres came to be established at Nungambakkam (Chennai).
(ii)The responsibility for the ports on the west coast from Karwar to south was also transferred from Mumbai to Chennai.
(iii)Government of India appointed a committee called the Cyclone Distress Mitigation Committee (CDMC) for Andhra Pradesh to examine various measures to mitigate human suffering and reduce loss of life and property due to cyclonic storms. Subsequently similar committees were set up for Odisha and West Bengal.

1970: First cyclone detection radar was set up at Visakhapatnam in 1970

1971: CDMC for Andhra Pradesh recommended IMD to establish Storm Warning Centre at Visakhapatnam for issuing cyclone warnings to coastal Andhra Pradesh.

1972: (i)CDMC for Odisha recommended IMD to establish storm warning centre at Bhubaneshwar for issuing cyclone warnings to coastal Odisha.
(ii) Establishment of Cyclone Warning Research Centre at Regional Meteorological Centre, Chennai to carry out research as per operational requirement

1973: (i) Storm warning centre was set up at Bhubaneshwar for catering to the needs of Odisha.
(ii)Regional Meteorological Centre (RMC) for Tropical Cyclones, New Delhi came into existence with the formation of WMO/ESCAP Panel.

1974: Storm warning centre was set up at Visakhapatnam for catering to the needs of Andhra Pradesh.
Classification of cyclones into cyclonic storms, severe cyclonic storms and severe cyclonic storms with core of hurricane winds

1979: Storm Atlas for 1891-1970 was published.

1971-80: Augmentation of PB and RS/RW Observatory

1983: Cyclone monitoring by Indian satellite, INSAT.

1988: (i)In pursuance of the recommendation of Cyclone Review Committee, Storm Warning Centre was established at Ahmedabad for catering the needs of Gujarat, Union Territory of Diu, Daman, Dadra and Nagar Haveli.
(ii)Regional Meteorological Centre (RMC) New Delhi was redesignated as Regional Specialized Meteorological Centre (RSMC) Tropical Cyclones, New Delhi and assigned the responsibility of issuing Tropical Weather Outlooks and Tropical Cyclone Advisories for the benefit of the countries in the WMO/ESCAP Panel region bordering the Bay of Bengal and the Arabian Sea, namely, Bangladesh, Maldives, Myanmar, Oman, Pakistan, Sri Lanka and Thailand.

1990: As per one of the recommendations of the Cyclone Review Committee (CRC), a Cyclone Warning Directorate was established in the Office of the Director General of Meteorology, New Delhi to co-ordinate the cyclone warning work in the country in totality and act as RSMC-Tropical Cyclones, New Delhi.

1991: First Annual RSMC Report on cyclonic disturbances over north Indian Ocean was published for the year, 1990.

1996: Addendum to Storm Atlas for the period of 1971-1990 was published.

1997: Deployment of 12 Meteorological Buoys by NIOT over the NIO

1999: Introduction of super cyclonic storm category and change of nomenclature from severe cyclonic storm with core of hurricane wind to very severe cyclonic storm
Use of surface wind derived from Quikscat.

2002: First Doppler Weather Radar established at Chennai.

2003 :Cyclone Warning Division acted as Tropical Cyclone Advisory Centre (TCAC), New Delhi as per requirement of International Civil Aviation Organisation (ICAO)

2004: Namiing of cyclones over north Indian Ocean was introduced

2005: Introduction of bi-weekly training for cyclone forecasters from WMO/ESCAP member Countries.
RSMC New Delhi Organised first traning for Tropical Cyclones Forecasters of WMO/ESCAP Panel member countries.
The area of responsibility of RSMC New Delhi Changed to cover entire North Indian Ocean from 2005.

2008: Publication of Electronic Atlas for the period of 1891 onward .
Issue of 72 hr forecast with forecast of Cone of Uncertainty from cyclone 'WARD'
Verification of Operational forecast
Inclusion of Prognosis & Diagnosis in RSMC Bulletin from cyclone 'NARGIS'
Introduction of Media Briefing on cyclone updates and Press Release from cyclone 'NARGIS'
Forecast Demonstration Project started for the period 15-October to 30 November and continuing since then.

2009:Operationalisation of IIT- D Storm Surge Model & issue of storm surge guidance for WMO/ESCAP member countries from cyclone 'BIJLI'. Warning system was modernised with introduction of Decision Support System (Synergie)
Introduction of Multi Model Ensemble Model for track prediction
Introduction of Dynamical Statistical Model for Intensity Prediction

2010:Forecast of Quadrant Wind Radii from cyclone 'GIRI'
Introduction of Quadrant Wind Bulletin from cyclone 'GIRI'

2011:Introduction of Ensemble Prediction System Model for Track Prediction. Web enabled E-Atlas developed

2012:Verification of Track, Intensity & Landfall forecast errors from 2003 onwards
Introduction of SMS to Disaster Managers
Introduction of HWRF Model for north Indian Ocean region from cyclone 'MURJAN'
Introduction of MME

2013:Extension of forecast upto a lead period of 120 hours from cyclone 'VIYARU'
Introduction of experimental coastal inundation forecast with experimental run of Advanced Circulation(AdCirc) model by INCOIS from cyclone 'PHAILIN'
Introduction of coded TC Vital from cyclone 'VIYARU'
Introduction of ADRR text bulletin for civil aviation
Introduction of Ensemble Prediction System (EPS) collaboration with Japan Meteorological Agency (JMA).
Introduction of SMS to fishermen through NCOIS network from cyclone 'PHAILIN'
IMD got appreciation worldwide for accurate prediction of cyclone PHAILIN
IMD got national award International Conference for Humanitarian Logistics (ICHL) Award

2014:Launching of a dedicated website for RSMC, New Delhi (www.rsmcnewdelhi.imd.gov.in)
SMS to farmers through farmers portal from cyclone 'HUDHUD'
Hourly updates around the time of landfall from cyclone 'HUDHUD
Digitisation of Annual RSMC Report on Cyclonic Disturbances
Modified Redii of cone of Uncertainty in Track forecast due to improvement in track forecast from cyclone Hudhud.
Probablistic forecast for cyclogenesis for next 3 days from 1st June 2014.

2015: Introduction of Public SMS under digital India Program.

2016: Severe Weather Forecast Demonstration Project -Bay of Bengal(SWFDP-BoB) started since May 2016.
Dissemination of cyclone warnings through Social Media Site.

2017: Introduction of Coupled HWRF Model, Princeton Ocean Model (POM) from cyclone 'Ockhi'

2018: Entire coast is covered with Doppler Weather Radar (DWR). Introduction of Extended Range forecast of cyclogenesis for next 2 weeks. Probabilistic forecast extended to 72 to 120 hrs. Started Track forecast from Depression stage instead of Deep Depression stage. Establishment of cyclone warning centre at MC Thiruvananthapuram.

2020: Introduction of cyclone track on interactive GIS platform
Also started the new list of names for cyclonic storms from June, 2020 with "Nisarga" (Bangladesh)

2.2. Organizational structure

At present, the cyclone warning organization of the India Meteorological Department (IMD) has three-tier system to cater to the needs of the maritime states. There are Area

Cyclone Warning Centres (ACWCs) at Chennai, Mumbai and Kolkata and Cyclone Warning Centre (CWCs) at Visakhapatnam, Ahmedabad and Bhubaneswar. The co-ordination of cyclone warning operations at the international & national level as well as liaison with the Central Government organizations & other agencies are done by Cyclone Warning Division (CWD) at IMD New Delhi. C.W.D., New Delhi is also functioning as Regional Specialised Meteorological Centre - Tropical Cyclones (RSMC - Tropical Cyclones), New Delhi.

2.2.1. Regional Specialized Meteorological Centre (RSMC)-Tropical Cyclones, New Delhi

There are five tropical cyclones regional bodies, i.e. ESCAP/WMO Typhoon Committee, WMO/ESCAP Panel on Tropical Cyclones, RA I Tropical Cyclone Committee, RA IV Hurricane Committee, and RA V Tropical Cyclone Committee. Under these regional bodies, there are six RSMCs as shown in Fig.2.1. The areas of responsibility of different RSMCs are shown in Fig. 2.1. The RSMC is responsible for monitoring and prediction of tropical cyclones over their respective regions.

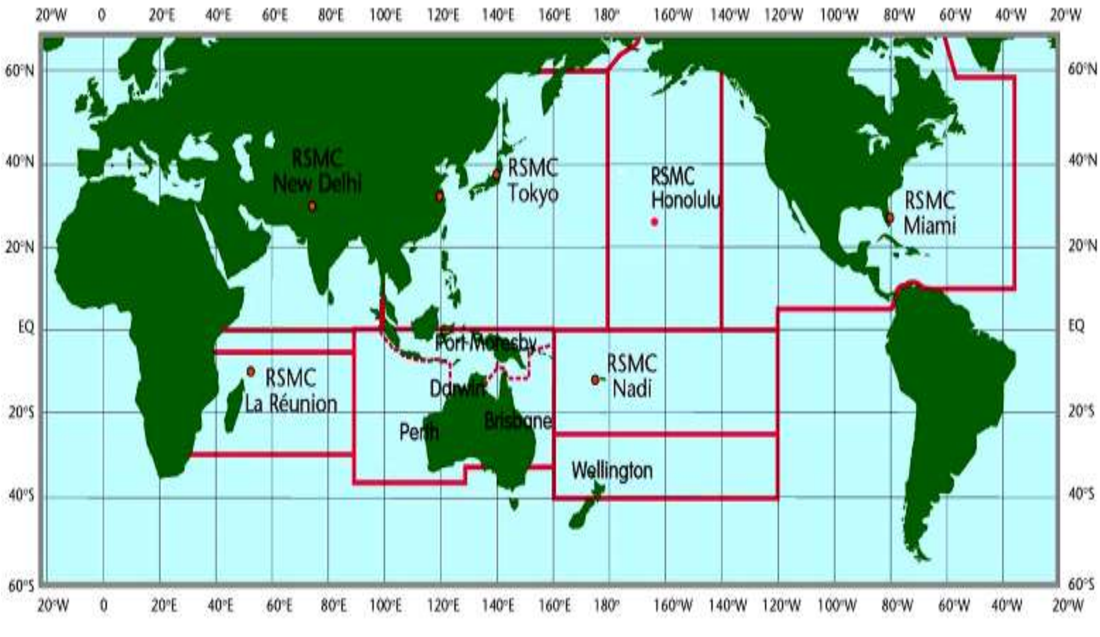


Fig.2.1 Area of responsibility of different RSMCs and TCWCs

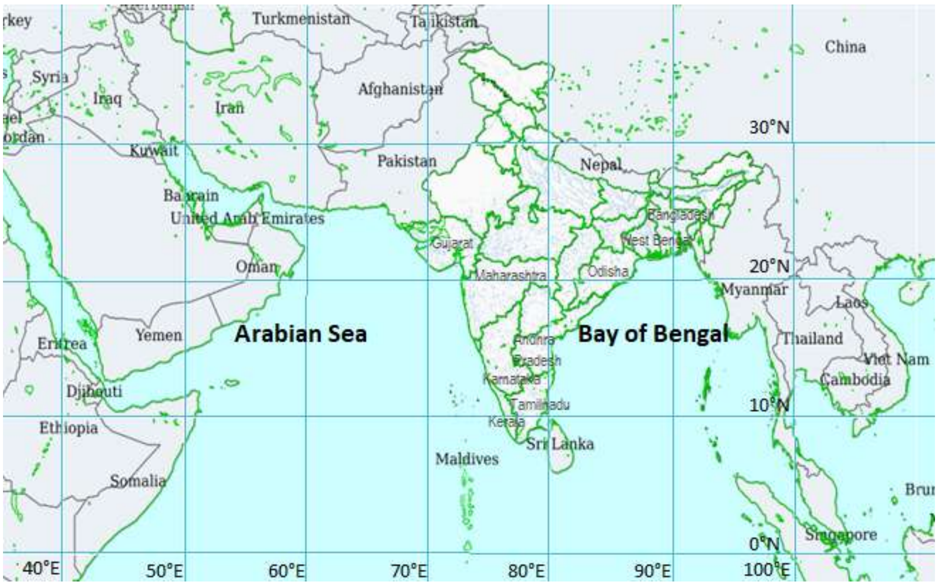


Fig 2.2 Area of responsibility of RSMC- Tropical Cyclones, New Delhi

The area of responsibility of RSMC- New Delhi covers Sea areas of north Indian Ocean north of equator between 45^0 E and 100^0 E and includes the member countries of WMO/ESCAP Panel on Tropical Cyclones viz, **Bangladesh, Maldives, Myanmar, Pakistan, Sri Lanka, Oman, Yemen, Thailand, Iran, Saudi Arabia, Qatar and UAE** as shown in Fig.2.2

2.2.2. Cyclone Warning Division

As per one of the recommendations of the Cyclone Review Committee (CRC), a Cyclone Warning Directorate co-located with RSMC Tropical Cyclones New Delhi was established in 1990 in the Office of the Director General of Meteorology, New Delhi to co-ordinate the cyclone warning work in the country in totality.

2.2.3. ACWCs/CWCs

With the establishment of the additional Centres at Bhubaneshwar and Visakhapatnam, the Storm Warning Centres at Kolkata, Chennai and Mumbai were named as *Area Cyclone Warning Centres* (ACWC) and the Storm Warning Centres at Visakhapatnam, Bhubaneshwar, Ahmedabad and Thiruvanathapuram as *Cyclone Warning Centres* (CWC). CWCs Thiruvanthapuram, Visakhapatnam, Bhubaneshwar and Ahmedabad function under the control of the ACWCs-Chennai, Kolkata and Mumbai respectively (Fig.2.3 & Table 2.1). M.C. Hyderabad liaises between CWC Visakhapatnam and Andhra Pradesh Government officials; warnings issued by CWC Visakhapatnam are sent to M. C. Hyderabad also for briefing the Andhra Pradesh Government officials at the State Capital.

The present organisational structure for cyclone warnings is a three-tier one, with the ACWCs/CWCs actually performing the operational work of issuing the bulletins and warnings to the various user interests, while the cyclone warnings (Directorate) New Delhi coordinates and guides the work of the ACWCs/CWCs, exercises supervision over their work and takes necessary measures for continued improvement and efficiency of the storm warnings system of the country as a whole. The ultimate responsibility for operational storm warning work for the respective areas however, rests with the ACWCs and CWCs.

Fig.2.3 Cyclone Warning Organisational Structure of IMD

Table 2.1 Area of Responsibility of ACWC/CWC

	Area of Responsibility		
Centre	***Sea area***	***# Coastal area***	***Maritime State***
ACWC Kolkata	Bay of Bengal	West Bengal, Andaman & Nicobar Islands.	West Bengal & Andaman & Nicobar Islands.
ACWC Chennai		Tamil Nadu & Pondicherry	Tamil Nadu , Puducherry & Karaikal.
CWC Thiruvananthapuram		Kerala & Karnataka	Kerala & Mahe Karnataka & Lakshadweep.
ACWC Mumbai	Arabian Sea	Maharashtra, Goa	Maharashtra, Goa.
CWC Bhubaneshwar	-	Odisha	Odisha
CWC Visakhapatnam	-	Andhra Pradesh	Andhra Pradesh , Yanam
CWC Ahmedabad	-	Gujarat, Diu, Daman, Dadra & Nagar Haveli	Gujarat, Diu, Daman, Dadra & Nagar Haveli

Coastal strip of responsibility extends upto 75 km. from the coast line.

2.2.4. Other offices

The co-ordination of the cyclone warning work is done through video conferencing exchange of bulletins and personal discussions, internet, mobile and STD calls and fax messages between Cyclone Warning Division, New Delhi and concerned ACWCs/CWCs on days of disturbed weather over the Sea areas. In addition, on occasions of cyclonic storms affecting the coastal areas, the weather bulletins issued by the ACWCs/CWCs for inclusion in the All India Radio (A.I.R) news cycles are consolidated and edited by CWD, before they are passed on to AIR New Delhi.

The storm warning work at the ACWCs/CWCs is supervised by Cyclone Warning Divison ant Headquarter.To improve the service and to bring about uniformity of practices, forecasting circulars and technical instructions are issued from time to time by CWD, New Delhi, NWFC, New Delhi arranges Annual Cyclone Review meetings for an appraisal of the action taken during the cyclones of the previous years as postmortem examination of this nature is of considerable benefit to operational forecasters. This enables them to correct past mistakes, if any, and to improve the performance in future.

Head (Satellite Application) prepares satellite account on cyclones within fifteen days and sends to CWD, New Delhi. The preliminary report for each & every cyclonic disturbance is prepared within 7 days after the dissipation of the weather system and detailed report is given within 1 month of dissipation of system. The Annual storm accounts and other reports regarding cyclones for supply to national and international agencies are prepared at CWD, New Delhi and CRS, Pune. The Cyclone Warning Division at Headquarter and Cyclone Warning Research Centre (CWRC) at Chennai has the responsibility to carry out the research required for improvement of cyclone warning servivces in the region.

Chapter - III
Needs for monitoring and prediction

3.1. Data and Products

The following inputs are needed for monitoring and prediction of cyclonic disturbances over the north Indian Ocean

❖ **Surface observational data and synoptic analysis products**

- Real time AWS/ARG data, Conventional Synoptic Observations, Coastal hourly observations, High wind speed Recorders (HWSR), ship and buoy data.
- Three hourly synoptic analysis charts

❖ **Upper air observational data and analysis products**

- Real time observation from pilot balloon and RS/RW or GPS sonde
- Upper air analysis charts
- Tephi-grams

❖ **Satellite products from IMD and international centres**

Visible imagery

- Tracking (locating the centre)
- Intensity analysis by Dvorak Technique

Infra-Red imagery

- Tracking (locating the centre)
- Structure analysis
- Intensity analysis by Dvorak technique

Water Vapour imagery

- Synoptic assessment of the storm environment)

Micro-wave imagery imagery

- Microwave (MW) Radiometer estimates of the following Parameters from Brightness Temperature (TB)
- Rain rate, total precipitable water (TPW), surface wind speed, sea surface temperature (SST), Salinity etc
- Estimates of Sea Surface Wind through backscattering based on MW Scatterometer
- Estimates of rain rate from backscattering of raindrops based on MW Rain Radar
- Estimates of Temperature/Moisture Profile based on MW Sounder

(Source: http://www.nrlmry.navy.mil/tc_pages/tc_home.html)

Bulletins

- Satellite fix (IMD and other centres)
- Cloud top temperature
- Special cyclone bulletin

❖ **Radar data and products**

i. Maximum reflectivity (Max (Z))
ii. Plan position indicator (PPI(Z))
iii. Volume velocity processing (VVP(Z))
iv. PPI (V)
v. Surface rainfall intensity (SRI)
vi. 24 hours Precipitation accumulation at 0300 UTC
vii. Track prediction products
viii. Uniform wind technique (UWT)
ix. Full resolution imagery of PPI(Z)/Max(Z)
x. Hourly radar bulletin

❖ **Dynamical and statistical Model products from various national and international centres**

NWP division makes the arrangement to provide all NWP model products and derived products. Additionally the NWP model products are also obtained from NCMRWF, IIT Delhi, Indian Air Force (IAF) etc.

❖ **Useful web sites for TC forecasting**

a. Tropical cyclone (TC) SITES

- MONTEREY Tropical Cyclones
- CIMSS Tropical Cyclones
- Winds from satellites (CIMSS)
- MIMIC-Total Precipitable Water vapour(CIMSS)
- Currently Active Tropical Cyclones
- Tropical Cyclone Intensity and Track Forecasts
- ECMWF-Latest Tropical Cycones
- Tropical prediction center links

b. TROPICAL WAVES

- OLR map from BoM
- CPC - Climate Weather Linkage: Madden - Julian Oscillation
- OLR animations NOAA
- Modes of variability seen in OLR-BoM

- CDC Map Room Climate Products
- Probability of a Tropical Cyclone
- Animation using Javascript Animation Player

c. SATELLITE DATA

- Satellite INSAT
- List of images from NRL Monterey
- CIMSS Tropical Cyclones
- TPC POLAR ORBITING SATELLITE DATA LINKS
- GPM
- RSS / Tropical Cyclone Microwave Data Archive
- NOAA AOML: Recent TMI SST Data

d. AMSU

- AMSU-A _ NASA
- AMSU _ UW-CIMSS

e. Satellite derived winds based on scatterometry (SCAT)

- OSCAT
- WindSat
- ASCAT
- EARS ERS-2 product viewer

f. SST AND HEAT POTENTIAL

- Tropical Cyclone Heat Potential
- Maximum Potential Hurricane Intensity
- Anomalies of SST (Nesdis_Noaa)
- Anomalies of SST (FNMOC)

g. NUMERICAL MODELS

- American models NOGAPS (FNMOC)
- Cyclone phase evolution: Analyses & Forecasts
- ECMWF-MSLP, wind speed at 850 hPa and geopotential 500 hPa

h. TC FORECAST BULLETINS

- Bulletins from SAB (Tropical Bulletins)
- Met Office: Tropical cyclones warnings and guidance
- Bulletins from JTWC
- Archived_bulletins from_JTWC
- La Reunion / Tropical Cyclone Centre / RSMC for SWIO

- Mauritius Meteorological Services
- TCWC-Jakarta
- RSMC, Tokyo

The check list for required products are given below

Table 3.1 Check list of Required Products

SN	Time	Product	Source
Observation			
1		MSLP Chart	synergie work station
2		Change chart	synergie work station
3		Departure Chart	synergie work station
4		10 m wind chart	synergie work station
5		Scatometry wind (Windsat, ASCAT & OSCAT)	http://manati.orbit.nesdis.noaa.gov/datasets/WindSATData.php/ http://www.knmi.nl/scatterometer/ascat_osi_25_prod/ascat_app.cgi http://www.knmi.nl/scatterometer/ascat_osi_12_prod/ascat_app.cgi http://manati.orbit.nesdis.noaa.gov/datasets/OSCATData.php/ http://www.knmi.nl/scatterometer/oscat_50_prod/ http://218.248.0.134:8080/OCMWebSCAT/html/controller.jsp
6		Hourly observation chart (mannually plotted)	Data from ACWC/CWC
7		Hourly chart (AWS & metar) from synergie When required	synergie work station
8		850 , 500, 200 hpa wind Chart	synergie work station
9		Quadrant Wind Chart (threshold of 28,34, 50 & 64 kts) winds	Synergie, NWP Division
10		Rainfall chart	synerie work station
11		INSAT imagery (VIS, IR, water vapour, QPE, OLR, lower level wind & upper level wind)	synerie work station, www.imd.gov.in
12		Meteosat imageries (Vorticity, lower level convergence, upper level divergence, vertical wind shear, wind shear tendency, low level wind & upper level wind)	http://tropic.ssec.wisc.edu/

13		Micowave imagery	(ii)(NOAA) http://www.nrlmry.navy.mil/tc_pages/tc_home.html
14		SST and Ocean thermal energy	http://www.aoml.noaa.gov/phod/cyclone/data/ni.html
15		Radar Products (Max (Z),PPI(Z),VVP(Z), PPI (V), Surface rainfall intensity, 24 hours Precipitation accumulation at 0300 UTC, *Track prediction products,*Uniform wind technique, *Full resolution imagery of PPI(Z)/Max(Z))	imd.gov.in, cwdhq2008@gmail.com
Bulletins/ Products			
16		JTWC bulletin (Text bulletin,warning graphic, ship avoidance & JTWC SAT fix bulletin)	http://www.usno.navy.mil/JTWC/
17		NOAA bulletins (position & intensity, mocrowave position & intensity)	http://www.ssd.noaa.gov/PS/TROP/tdpositions.html
18		IMD Sat bulletin	Sat Met/ Cwdhq2008@gov.in
19		MJO forecast	http://www.cawcr.gov.au/staff/mwheeler/maproom/RMM/
20		IMD Radar Bulletin	Concerned DWR Station
Forecast Models			
21		NWP models	Source
		a. GPP for genesis	cwdhq2008@gmail.com
		b.Rate of intensification index	cwdhq2008@gmail.com
		c. CIPS model for intensity	cwdhq2008@gmail.com
		d. WRF (IMD) NMM	cwdhq2008@gmail.com
		e. WRF (IMD) ARW	Synergie
		f. WRF (IITD)	cwdhq2008@gmail.com
		g. WRF (IAF)	cwdhq2008@gmail.com
		h. WRF (NCMRWF)	cwdhq2008@gmail.com
		i. MM5 (IAF)	cwdhq2008@gmail.com
		j. IMD GFS (574)	Synergie
		k. UKMO	Synergie/NCMRWF
		l. JMA	Synergie

		m. ECMWF	Synergie, http://www.ecmwf.int/products/
		n. Arpege Meteo-France	Synergie
		o.HWRF	IMD, NWP Division
		p.IMD model products	ftp://125.21.185.11/
		q. MME	NWP
		r.Ensemble Prediction System (EPS)	imd.gov.in, NWP Division, NCMRWF, TIGGE(JMA)
		s.NCMRWF GEFS	cwdhq2008@gmail.com
		t.CLIPER	CWD
		u.MOG	CWD
		v.Storm Surge model (Ghosh Nomogram)	CWD
		w.Storm Surge model (IITD)	CWD, IIT Delhi

3.2. Intensive Observational Phases (IOP)

→ IOP should be declared from the stage of depression if it has potential to intensify into a cyclone. CWD will take the decision and necessary action will be taken by concerned ACWC/CWC.

→ During IOP, concerned RMC/MC should make the arrangement to send the persons at every 50 km along with full equipment in the disturbed area to take the observations and transmit them.

→ All the RMC/MC will assure that there should be AWS at every 50 km in the coastal areas under their territory.

→ Hourly observations should be started immediately during IOP in the respective areas of RMC/MC and should reach at CWD by email otherwise by fax or telephone in addition to GTS communication.

→ **AWS:** DDGM (SI), Pune will ensure the real time transmission of data from AWS stations to DGM(ISSD) Delhi in GTS mobile synop format.

→ **Synoptic observations:** Synoptic observatories of IMD network of costal stations shall report data on hourly basis, during IOP. During normal period 3 hrly SYNOP will be collected. RSMC, New Delhi will write to concerned WMO/ESCAP Panel member countries to ensure the availability of synoptic data from respective region for the IOP period.

→ **Buoys:** Real-time collection of hourly data from deep Ocean and met-ocean buoy network over the Bay of Bengal from INCOIS Server will be made by Telecom Division.

→ **Upper air:**

- Upper air RS/RW data from IMD stations in coastal areas will be collected 12 hourly for normal days. However, during the IOP phase, if possible, 6 hourly data shall be collected. The flight terminating below 200 hPa are to be repeated.
- Due arrangements to receive all available Pilot Balloon data sets (twice daily) from the IAF will be made by ISSD
- Wind profiler support from the existing Gadanki and SHAR is to be activated so as to receive hourly profiles in the lower troposphere. CWD will request Director NARL Gadanki and Met I/C SHAR with copy to Principal Scientist, ISRO for organizing necessary observational support during IOP.

→ **DWR :** DWR support from coastal radarswith uniform storm scanning strategy will be ensured prior to the cyclone season.

→ **NWP:** It shall make all necessary arrangements for the generation of global and regional analyses fields data at 4 analysis times (00, 06,12,18 UTC) during IOP. Efforts will be made to bring out the Model forecast within three hours of the observation time.

→ **Coordination with international agencies**

Head RSMC, New Delhi shall request the WMO/ESCAP Panel countries about the IOP and solicit their cooperation in the real time exchange of data (surface, upper air and special observations) for their utilization in the generation of most representative meso-scale analysis fields for generating improved quality of track, intensity and landfall of tropical cyclones.

Chapter - IV

Observational aspects of cyclone warning system

4.1. Introduction

Observational network for cyclone forecasting require continuous monitoring of the horizontal and vertical structure of the atmosphere. Surface and upper air observations from various oceanic and land platforms are the basic data required by a cyclone forecaster. The latest technological advances like Satellites, Radar and computers provide invaluable support to the cyclone warning system, complementing the conventional observing system. The observational aspects of cyclone warning system include different types of observations (Fig.4.1a-b).

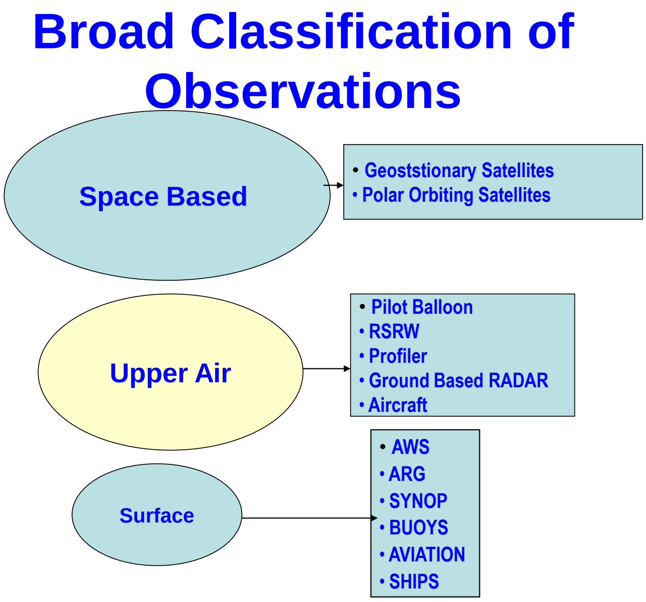


Fig.4.1(a). Classification of observations

The types of observations relevant to storm warning work are:

A. Surface observations from:

i) Land synoptic stations
ii) Ships
iii) Buoys
iv) Tide gauges
v) Aviation meteorological offices
vi) Automatic Weather Stations (AWSs)

B. Upper air observations from:

(i) Pilot balloon stations

(ii) GPS Sonde/ Radiosonde /Radiowind stations

(iii) Wind profiler stations

C. Radar Observations

D. Satellite observations

E. Aircraft observations

F. Microseism observations.

Each of the above observational systems is discussed in detail in the following sections.

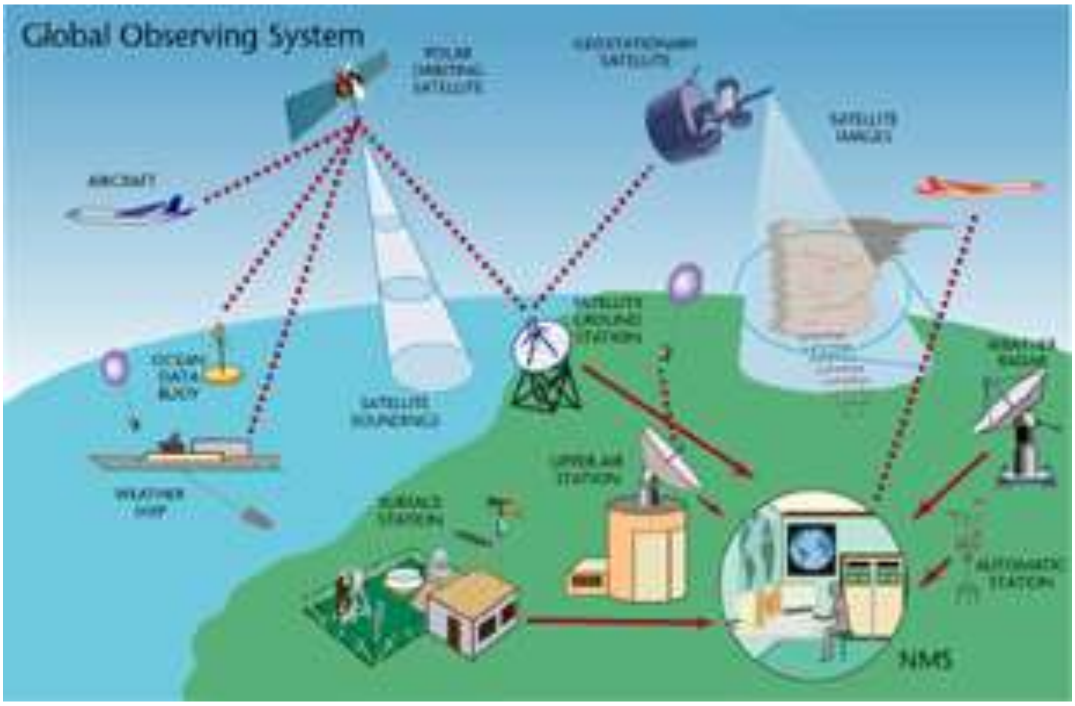


Fig.4.1(b). Observational network for cyclone monitoring

4.2. Surface (land, ocean) based observations

Surface data is the foundation over which the edifice of synoptic meteorology is built. Their horizontal coverage is generally good over populated land, and marginal to poor over oceanic or desert areas, although oceanic buoys and AWSs are being deployed and installed in large numbers and the situation has improved to a great extent in recent period.

Over land surface, data from an increasing number of AWSs contain information on wind, temperature, moisture and mean sea level pressure, with weather elements such as cloud cover or visibility mostly available from manned and aeronautical stations. Regional efforts are underway to collect, standardise and have quality control of data from observing networks from non-departmental government and non-government agencies.

Over the oceans, winds, SST and MSLP, measured on ships, buoys, and island stations, are important parameters used in cyclone forecasting. Even very isolated stations may play an important role in cyclone forecasting, especially when their input is used for NWP model output.

Apart from the surface observations of Voluntary Observing Fleet (VOF) ships, Array of buoys and tide gauge network form an integral part of ocean observing system. According to recent WMO report, 1250 surface drifting buoys are deployed. 6700 ships have been registered world wide, yet less than 2300 ships report regularly. Observations from buoys and ships are vital indeed in estimation of position, intensity and track of cyclones and all efforts should be made to maximise the reception of ships' data.

4.2.1. Land based conventional surface observatories

There are at present 559 surface observatories in India for recording meteorological parameters such as surface air pressure, temperature, humidity, wind, clouds, visibility and rainfall etc. Appendix-4.I & 4.2 give the list of all the coastal and island observatories of India and in neighbouring countries. IMD has classified the observatories as class I to Class VI, depending upon the Observatory setup and its purpose. The coastal observatories mentioned in the table are mostly Class I and Class II observatories. The corresponding WMO classification for Class I observatories are Principal Climate Observatories with 3 to 8 observations per day. It should have three autographic charts and should take observations for pressure, temperature, wind and rainfall. Class II observatories should take and communicate 2 sets of observations per day. Class V stations measure precipitation only and WMO has classified them as Precipitation stations.

In addition, the acquisition of surface data from the departmental and part time observatories, rainfall data from stations under District wise rainfall monitoring scheme (DRMS), Intensive Agricultural Development Programme (IADP) and All India General Scheme (AIGS) form an integral part of the cyclone warning observational network. As most of the stations in DRMS, IADP and AIGS function under the respective state governments, effective interaction with the concerned agencies is essential for maximising reception of real time data from these stations. During 2007 Tamil Nadu government and IMD signed an MOU for exchange of rainfall data in real time. Similar arrangements in other coastal states are desirable.

Proposed installation of AWS by various agencies of the Central and State governments along the coast is expected to give the required density to locate sub synoptic scale systems.

4.2.2 Cooperative Cyclone Reporting network of stations

As the regular coastal network is not dense enough to discern cyclonic storms of smaller dimensions, Co-operative Cyclone Reporting network of stations have been started along the coast on the recommendations of Cyclone Distress Mitigation committees (CDMCs). In Andhra Pradesh, there are 13 Cooperative Cyclone Reporting stations while Odisha state has 16 CDMC stations. The list of such CDMC stations is given in Appendix-4.3. These are all police stations and they collect rainfall and wind data and the information is passed on to IMD office through police wireless network and telephone. In most of these centres, it has been proposed to set up either AWS or telemetric rain gauge. The Cooperative network of observatories in the state of Andhra Pradesh will send the information to Cyclone Warning Centre at Vishakapatnam through Phone/e-mail/Police Wireless. These stations record only 03 and 12UTC observations during cyclone season and only 03UTC during non-cyclone season. Hourly observations can be obtained from these stations during cyclone situations. The reports are in plain language. There is a proposal by the concerned CDMC authorities to convert the 16 CDMC stations in Odisha into AWS stations.

In Maharashtra State, a special wireless network between IMD, Revenue Secretary, Mantralaya, Director of fisheries, police control room and collector’s office is functioning during monsoon season. This network should be activated during cyclone situations by appropriate liaison with the Chief Secretary’s Office. Similarly, there is wireless connectivity between CWC Bhubaneswar and Odisha State Control Room.

4.2.3. Time of Observations

The standard time for all observations is UTC. WMO recommendations state that the observation should be made in as short a time as possible just prior to the nominal time of observation. These observations are typically started by (HH-10) and pressure reading is taken last at the exact hour. The observation is to be transmitted before the hour is complete. As per national practice, 03 and 12UTC observations report Minimum and Maximum temperatures recorded on that day and 03UTC report also includes 24 hours total rainfall. Synoptic observation is the coded synoptic summary of the current weather at each of the large number of synoptic stations. These observations when plotted on a chart give the complete picture of the atmosphere as though from a bird’s eye view and hence the word ‘synoptic’ is used to describe these simultaneous observations. The observations taken at 00, 06, 12 and 18 UTC are called main synoptic observations and those taken at 03, 09, 15 and 21 are called auxiliary synoptic observation.

4.3. Ship Observations

International Meteorological Organisation, the predecessor of World Meteorological Organisation was primarily started to serve the Marine community. Before the advent of satellite, ships observations were the major source for locating cyclones. Observations from ships provide vital data about disturbances over sea areas. Though land stations along the coast supply much valuable information as the storm approaches the coast, ships reports from the cyclone field form the main source of conventional observations while the storm is still out at sea. Even with the advent of radars and satellites, ships observations are still very vital in cyclone forecasting.

4.3.1 Voluntary Observing Fleet (VOF)

The number of ships under Voluntary Observing Fleet is 203. It has merchant's ships of Indian as well as foreign ships and ships belonging to Indian navy. These ships are equipped with instruments to record meteorological parameters and some of the crew on board are trained in taking and recording the observations. These ships are categorised as selected ships, supplementary ships and auxiliary ships. Selected ships are equipped with sufficient certified meteorological instruments for making observations and report in the full SHIP code form (WMO FM 21V). In addition, these observations are recorded in the meteorological logbooks. The supplementary ships are equipped with limited number of certified meteorological instruments for making observations and they transmit reports in abbreviated code form (WMO SHIP Code Fm.22V). The observations are recorded in the meteorological logbooks. The auxiliary ships are normally without certified meteorological instruments and they transmit reports in reduced code form (WMO SHARED FM.23V) or in plain language during disturbed condition. The WMO publication International List of Selected, Supplementary and Auxiliary ships (WMO No.47 T.P 18) which gives information about all voluntary observing ships including the equipments on board and the call sign (Alpha numeric characters for ships identification) should be kept in all forecasting offices.

4.3.2. Recording and reporting of ship observations

Observations are taken both at main standard times (00, 06, 12 and 18 UTC) and supplementary observations (03, 09, 15 and 21 UTC) subject to non-interference in their navigational duties. Additional observations should be taken during sudden and dangerous weather developments and transmitted immediately, regardless of standard time.

4.4. Data Buoy Network

Department of Ocean Development, Government of India has established the National Data Buoy Programme (NDBP) in 1997 at National Institute of Ocean Technology (NIOT) Chennai. A network of fourteen data buoys (Table 4.1.) has been established both in

Arabian Sea and Bay of Bengal during the implementation period of 1997-2002, which has subsequently been increased to twenty-five and poised for further growth.

The moored data buoys are floating platforms, which carry sensors to measure Wind Speed & Direction, Atmospheric Pressure, Air Temperature, Humidity, Conductivity, Sea Surface Temperature, Current Speed & Direction and Wave Parameters. The wave parameters that are measured include significant wave height, average wave period, average wave direction, Swell wave height and Swell wave period. Maximum wave height and Period of the highest Wave are also measured. The buoys are equipped with global positioning system, beacon light & satellite transceiver. They have solar panels to charge the battery pack during daytime. The recorded observations are collected by Indian National Centre for Ocean Information Services (INCOIS), Hyderabad and sent as email to the forecasting offices apart from GTS transmission through IMD.

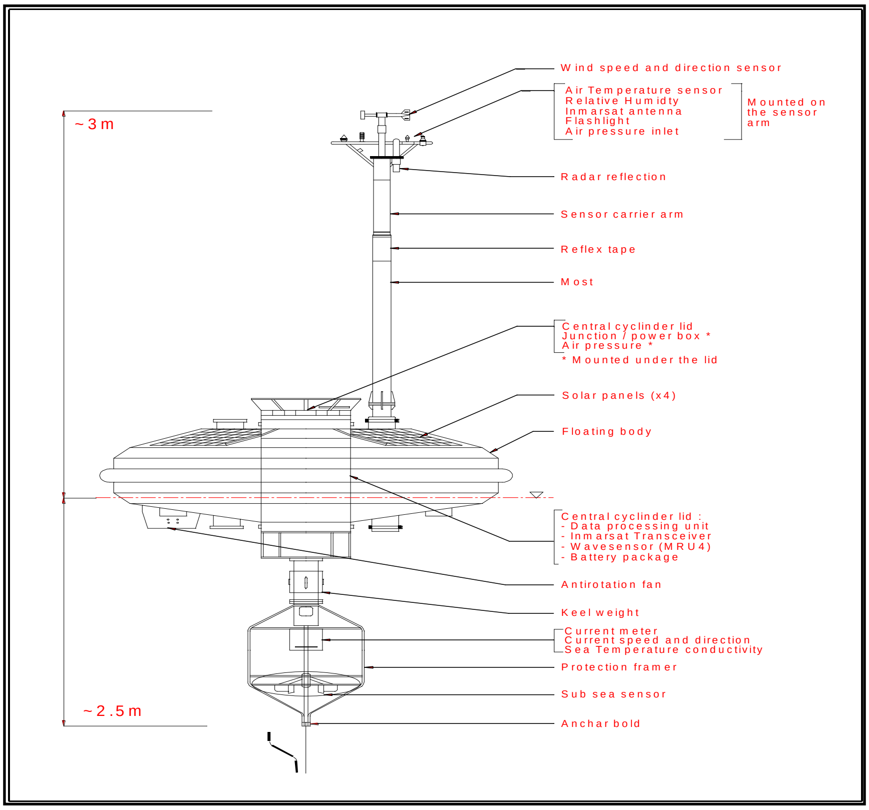


Fig.4.2.Picture of a Data Buoy deployed at Sea

Table 4.1 List of active buoys

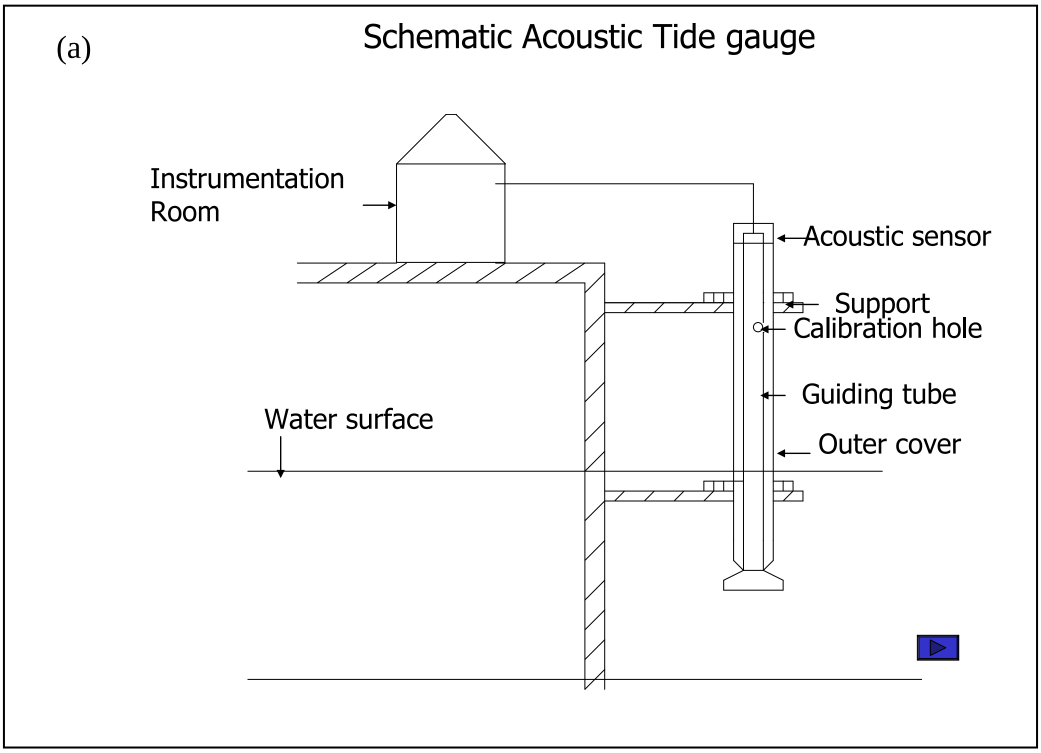
Basin	Buoy ID	Latitude	Longitude
Arabian sea	AD02	15.0	69.0
	AD03	12.0	69.0
	AD04	8.5	73.0

	AD05	10.5	72.3
	SW02	17.4	70.7
Bay of Bengal	BD02	18.0	90.0
	BD07	6.2	85.9
	BD08	18.2	89.7
	BD10	16.5	88.0
	BD11	14.2	82.9
	BD12	14.5	94.0
	BD13	11.0	86.5
Andaman	CB01	11.6	92.6
Lakshadweep	CB02	10.9	72.2

CB: Coastal buoy, SW: Shallow water buoy, AD: Arabian sea data buoy, BD: Bay of Bengal data buoy

4.5. Tide gauges

Tide gauges (Fig.4.3) have been installed at Chennai, Cochin, Tuticorin, Mangalore and Port Blair along the Indian Coasts. Under the Tsunami Observation Network Programme, the network is expanded further at Vizhinjam, Kavaratti, Nagapattinam, Haldia and Kakinada. All the tide gauges are linked with satellite and online data reception at NIOT is established with password protection. These tide gauges would give vital information about the tidal and swell waves.



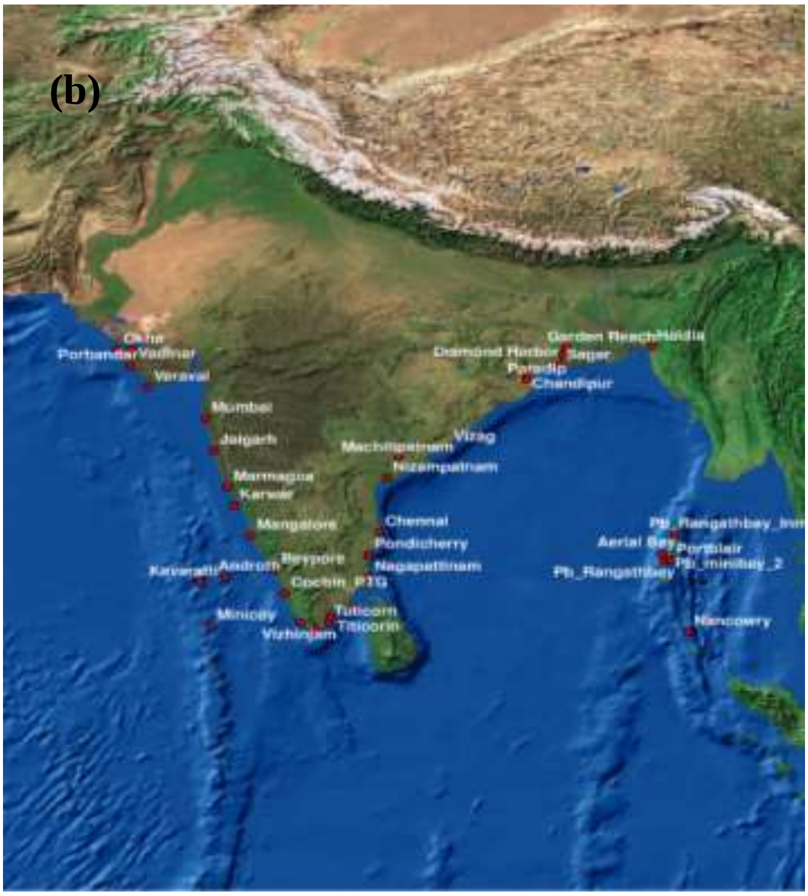


Fig.4.3 (a-b). Schematic acoustic tide gauge and Tide Gauge Network in India

4.6. Reports from Airport Meteorological Offices

Airport Meteorological Offices record half hourly/hourly meteorological reports and they are known by their acronym METAR. Those airports having round the clock air traffic control watch prepare reports at half hourly interval. In other airports they prepare half hourly reports during watch hours and hourly reports during other periods. In the event of occurrence of significant changes in wind, visibility, cloud and weather, special reports are prepared and are known as SPECI. These Meteorological reports would supplement the data already obtained from other sources. Aircrafts during flight, report wind and temperature at the cruising level at certain places designated as meteorological reporting points. These observations known as AIREPS/PIREPS are transmitted to communication unit of Airport Authority for onward transmission to airport meteorological office. Sometimes, landing pilots debrief the airport meteorological office. In vast data sparse ocean areas, these observations are invaluable. These data are plotted in the appropriate upper level chart (depending upon the cruise level).

4.7. Special observations from coastal stations

4.7.1. Need for special observations

Except for 03 and 12 UTC charts, the network of coastal observations at the other hours is not sufficient for cyclone warning work. During periods of disturbed weather out at Sea, observations from all the coastal and island observatories may be required at synoptic hours other than 03 and 12 UTC also. Therefore, it will be necessary to call for special observations on such occasions from observatories at some of the synoptic hours at which they may not take routine observations. Requisitions for special observations can be sent both by ACWCs & CWCs. Sometimes hourly observations are also required.

4.7.2. General instructions

The following are the general instructions for calling special observations from surface observatories:

Special observations are to be called from coastal and island stations for the preparation of 3 hourly synoptic charts (00, 03, 06, 09, 12, 15 and 21 UTC) from the depression stage onwards or even when a depression is expected to form for the preparation of special charts for the issue of three hourly bulletins.

When landfall is expected within 48 hrs

However, if a cyclonic storm is within striking distance from the coast and the landfall is expected within the next 48 hrs, hourly special observations may be called from a restricted coastal area towards which the storm is heading, for determining the position of the storm, its intensity as well the place and time of landfall etc., from the sequence of hourly changes at these coastal stations. The usefulness of these observations is given with an illustration in the next section. These messages are cryptic coded messages giving date, time, cloud cover, wind speed & direction and mean sea level pressure. They also include rainfall and pressure change during past 24 hours if available. The message does have the provision of indicating the wind speed in plain text if it exceeds 20 Knots. These messages are obtained at present E-mail, Automatic message switching systems and through telephone.

4.7.3. Discretion of Storm Warning Officer

It is left to the discretion of the Storm Warning Officer to decide how frequently the special observations are to be called in consultation with ACWC/CWC and CWD. He should consider each case on its merits.

4.7.4. Role of special observations in determining the period of Landfall

Special observations (Fig.4.4) are coastal observations from Indian stations reported at one-hour interval. The code used for the observations is YYGG Nddff pppWW 4RRP$_{24}$ P$_{24}$. The symbols have the usual meaning. In order to show the importance of these observations the special observations of three stations viz., Kakinada, Machilipatnam and Bapatla are plotted for the period 12UTC to 21UTC of 16th December 2003. The time of landfall could be discerned to be around 18UTC near Machlipatnam. The veering of wind at Machlipatnam and backing of winds at Bapatla reveals movement of the system between these two stations. The southeasterly winds at 19UTC indicate that system has entered the land. The highest value of 24 hours Pressure change also occurred in this period and clearly shows that landfall has occurred around this period.

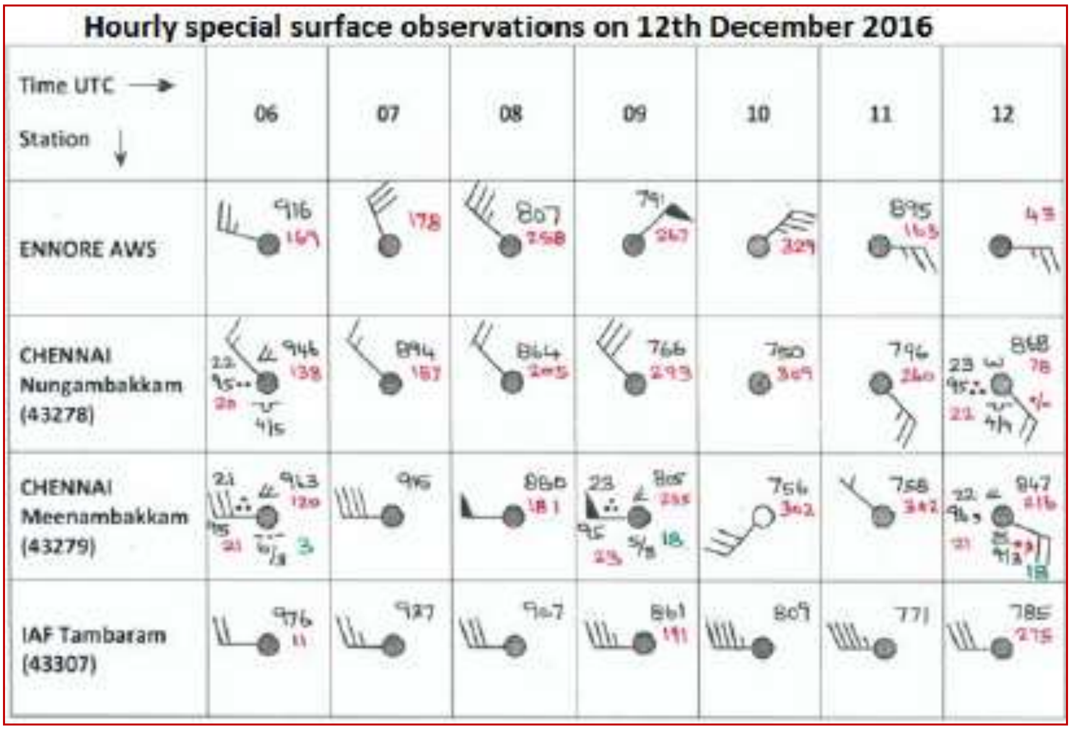


Fig.4.4. Typical coastal observations taken during cyclone Vardah monitoring

4.7.5 Importance of P$_{24}$P$_{24}$

In the previous section the importance of P$_{24}$P$_{24}$ observation is amply illustrated in determining the land fall period. In this section the importance of Isallobars is given. Lines passing through areas of equal pressure changes are known as Isallobars. An Isallobaric low is as good as a pressure low. The area of highest pressure fall (Isallobaric low) indicates the direction in which the system is heading. So Isallobars play a major role in prognosis of cyclone movement.

4.7.6. Discontinuance of special observations

After the system has crossed coast and special observations are no longer needed, the observatories concerned should be informed immediately to discontinue the special observations in consultation with CWC/ACWC and CWD. Special care should be taken to see that the observations are not received after instructions to discontinue them have been issued. Further messages to stop the observations have to be issued to such observatories which still continue to send the special observations.

4.8. Automatic Weather Stations

Presently, about 711 Automatic Weather Stations (AWS) are located all over India. Data are being received at the Central Earth Receiving station located at Pune. In addition, 1350 Automatic Rain gauge stations (ARG's) are located countrywide. In addition 20 nos of High Wind speed recorders are installed for continuous monitoring of High wind speeds along east & west coast of India.

Fig.4.5. Schematic diagram of an AWS

Automatic Weather Stations (Fig.4.5) use state-of-art data logger and transmitter with sensors interfaced for data sampling and recording. Meteorological sensors for Air Temperature, Relative Humidity, Atmospheric Pressure, Rainfall, Wind Speed and Wind Direction are interfaced with both Sutron and Astra make AWS. Apart from these parameters, at few selected Sutron-make AWSs have additional sensors for Global Solar Radiation, Soil Temperature and Soil Moisture.

AWS transmit data in UHF frequency 402.75 MHz, every hour in their allocated time slots which are received by the Data Relay Transponder of the geostationary satellite

Kalpana-1 and are retransmitted by the satellite at a downlink frequency of 4506.05 MHz to the Central Receiving Earth Station located at Pashan, Pune. The technique utilized for transmission is called Pseudo-Random Burst Technique (PRBS) where a defined number of AWS transmit three times in a 10-minute window allocated to them.

The raw data received from all AWS is processed at the Earth Station and the synoptic data in WMO Synop Mobile FM-14 Ext format is transmitted to AMSS Mumbai via ftp through 64 kbps leased line which is then put to the Global Telecommunication System (GTS) by AMSS Mumbai every hour. The processed data is archived at Earth Station, Pune. Synoptic charts plotted in synergie system using data from AWS are available for forecasters

Fig.4.6. The surface Observatory Network of IMD

4.9. Upper air observations

Wind and temperature data of the upper atmosphere is collected by using Pilot balloons and Radiosonde/Radiowind.

4.9.1. Pilot Balloon Observatories

Meteorological conditions in the upper air have an important bearing on the expected weather. Observations for measurement of wind speed and direction alone are made 2 to 4 times a day at Pilot Balloon Observatories (PBO), which use optical theodolites. Upper wind measurements made at PBO are limited to a few km heights.

These observations are vital in determining whether the system would dissipate due to entrainment of dry land air, in locating the ridge and to know about the steering currents for determining Cyclone movement. But in overcast Sky conditions with low clouds, it may not be possible to take the observation as the balloon may disappear in the cloud. In that situation Radiosonde/ Radiowind provide the upper air data. There are 62 pilot balloon observatories spread all over the country (Fig.4.6). WMO has established standard times for conducting upper air observations and the four synoptic hours of 00, 06, 12 and 18 UTC are the designated hours. Most balloons are released actually 30 to 45 minutes before these times and the scheduled observation period coincides with the middle of the observation. If only two observations are taken, it is taken at 00 and 12UTC. Under international practice, if only one observation is taken, it is taken at 00 or 12 UTC, whichever is closest to the local sunrise time.

4.9.2. Radiosonde/Radiowind Observations

Radiosondes serve as main observing system for determination of detailed vertical structure of the atmosphere. This is due to their excellent vertical resolution (provided full resolution data are being transmitted instead of standard/significant level data only). Vertical stability analyses which require data in great details are not necessarily captured by NWP models; but can be obtained from, radiosonde data. Moreover, radiosonde data are very essential in NWP analyses and model assessment. Radiosondes are of primary importance in synoptic forecasting also for identifying the position of the ridge, steering current and thermal advection

There are at present 62 Pilot Balloon Observatories, 56 Radiosonde/ Radio wind observatories. All the 56 stations are latest of the art- GPS based observatories. Out of 56, six RS/RW stations at Regional Meteorological Centre‘s (New Delhi, Mumbai, Kolkata, Chennai, Guwahati and Nagpur) are of WMO-GUAN (Global Climatological Observations System Upper Air Network) standards. Formal request for inclusion of these stations into GUAN network has been made with GCOS secretariat through Secretary General WMO. (Fig.4.7). The computation is fully automated with a data resolution of two seconds. Usually 00 and 12 UTC observations are taken. For 06 and 18 UTC observations, Pilot balloons are used. When a cyclonic storm is coming closer, taking Pilot balloon observations may be difficult. In that event special Radio sonde/Radar wind observations are taken.

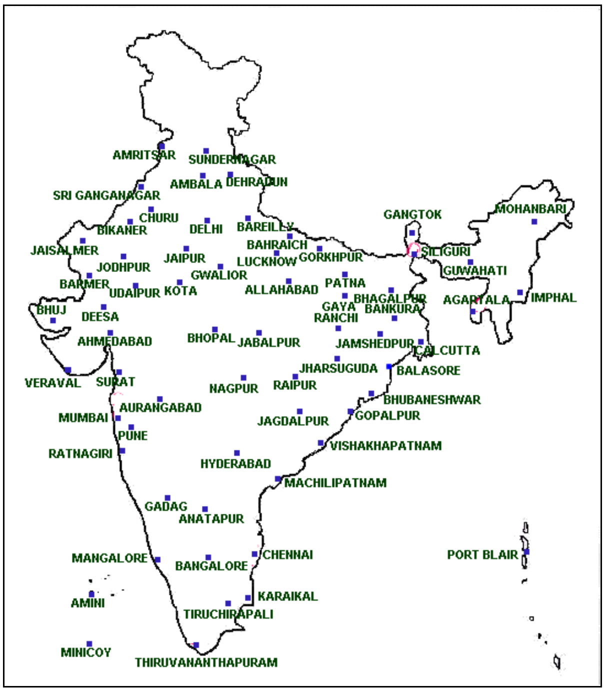


Fig.4.6. Pilot balloon observatory network of India

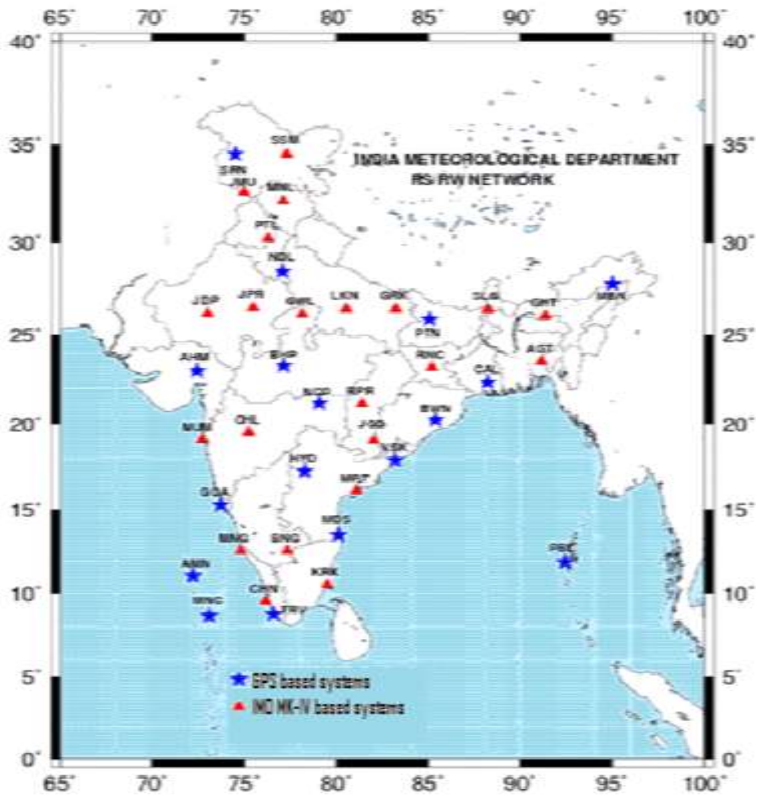


Fig.4.7. RS/RW network of India

4.9.3. Wind Profilers

Under modernization plan (Phase-I) of IMD , four nos. of wind profilers are likely to be installed in IMD's upper air network. A profiler is an all-weather, unattended, vertically pointing clear-air Doppler radar. It comprises of a ground system for measuring the atmospheric wind parameters. Wind profiler system is capable of continuously measuring vertical profiles of wind speed and wind direction. IMD is planning to install systems, which will operate at a fixed frequency in 420-435 MHz (tropospheric type with height coverage of around 10 kms) and 1200 to 1375 MHz band (boundary layer type with height coverage up to around 3 kms). The system includes all items necessary to measure, process, output, archive and display the atmospheric wind data. The data received from profilers can be used objectively by the assimilation of profiler observations into routine NWP model runs. At present there are two wind profilers operating from Pune and Gadanki. A typical wind profiler is shown in Fig.4.8

Fig.4.8 A schematic representation of a Wind Profiler

4.10. Microseism Observations

The seismological observatories are equipped with micro seismographs to record microseisms due to disturbed weather at sea. The seismographs at the coastal and island stations could be utilised during storm period. Microseism observations could be differentiated as monsoon type, storm type etc. As far as operational use is concerned, it is restricted to detection of the presence of cyclonic storm. Large Microseism amplitudes are recorded, when the cyclonic storm is within 320 Km from the coast. The forecasters seldom use microseism observations due to rapid strides made in Satellite and Radar meteorology.

4.11. Quality control of observations

In the forecasting offices, after the reception of data from the field stations, discrepancies could be detected during the plotting of chart. The concerned observatory is asked to check and repeat the observation. The automatic message switching system installed at the regional telecommunication hub and at most of the regional meteorological centres has also a validation menu. Validation is done to check the format, header and text. Format validation checks the sequence number of message, whether "="sign comes at end of the message etc. Header validation checks whether proper header is given for the message. Origin of the observation is also validated. A particular observation is expected only from its regional correction centre and if it comes from another centre, validation of the same is required.

Then the message is validated for text. Whether each group contains five digit numbers is checked and whether mandatory groups are included in the message. Then each group is validated. For example, if I_R were indicated as 2, system would check whether rainfall group is included. The system itself contains the extreme value limit for different weather elements for each station. Checking is done for each element. In some cases, provision for auto-correction is there. While running the Numerical weather prediction models, all the synoptic and upper air observations are used. These observations are once again checked before interpolation for generating the grid point values.

4.12. Radar Observations

Currently, 10 Doppler Weather Radars (DWR) are in operation along the east coast of India including DWR at Agartala, Kolkata, Chandipur, Paradip, Gopalpur, Visakhapatnam, Machhilipatnam, Sriharikota, Chennai and Karaikal and 5 along the west coast including DWR at Thiruvananthapuram, Kochi, Goa, Mumbai and Bhuj.

4.12.1. Tracking by S-band Doppler radars

The S-band radars operate at 10 cm wave length and give a good coverage for tracking the cyclones over the Sea. Although the maximum range for cyclone detection radar *is* 500 km., the effective range is limited to 400 km mainly due to earth's curvature at long ranges. When a disturbance is approaching the coastal radar station directly, with the normal speed of about 10 – 15 km. per hour, this range provides roughly a 24 hour tracking time between the first detection of the eye and the final landfall. A further period of a few hours may also be gained if well developed spiral band ahead of the centre of the cyclone appears first on the radar scope enabling determination of the centre with the help of spiral overlay technique.

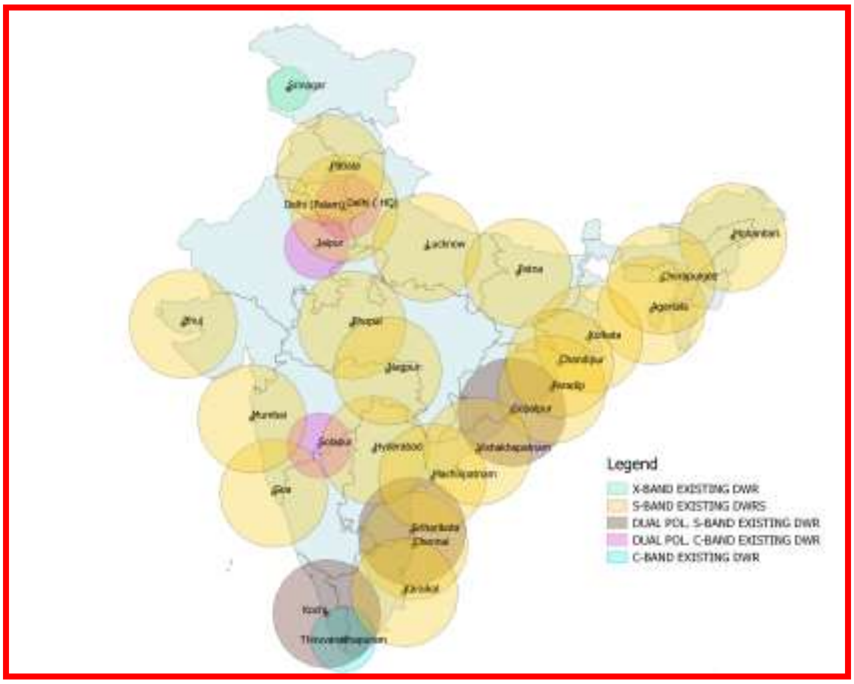


Fig.4.9. Radar Network

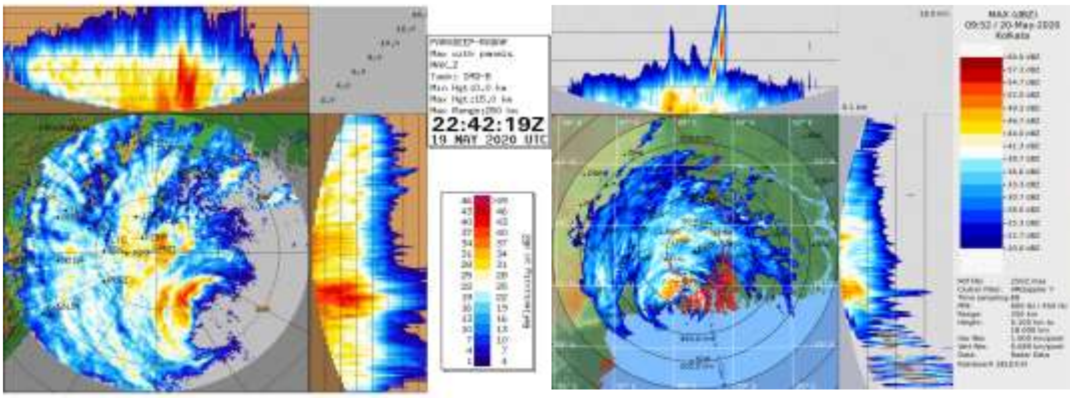


Fig.4.10. Typical DWR products used for cyclone monitoring during SuCS Amphan

Doppler Weather Radars provide vital information on radial velocity and spectral width, in addition to reflectivity which is also available from conventional (analog type) of radars. However, the radial velocity information is restricted to 250 km only. Also the surface rainfall intensity estimation is possible and is restricted to a maximum of 150 km range due to the Earth curvature. Typical products are shown in Fig.4.10. Reflectivity estimates obtained from these radars are more accurate in comparison to those from conventional radars as the Doppler Weather Radars have capability for correcting the values for clutters, partial beam filling, beam blockage and bright band. The Doppler Weather Radars generate various derived products in addition to primary PPI and RHI displays. Surface Rainfall Intensity (second level product derived from reflectivity) and other hydrological products like Precipitation Accumulation (PAC), Vertical Integrated Liquid (VIL) are very important for issuing warnings for heavy rain, fresh flood and hail. The algorithms for generation of these products employ some adaptable parameters which depend on drop size distribution (DSD) present in the precipitation The DSD is different for different seasons, geographical location and type of precipitation. There are following three base data products, which are generated directly by the Doppler Weather Radar.

- Reflectivity (Z)
- Radial Velocity (V)
- Spectrum Width (W)

These base data products are displayed in website in the following format.

(a) Basic image products

- MAX(Z) Product
- Plan Position Indicator(Z)
- Plan Position Indicator, PPI(Z)-Close Range
- Volume Velocity Processing(2)
- Plan Position Indicator(V)
- Surface Rainfall Intensity
- Precipitation Accumulation (PAC) 24 hrs at 0300 UTC
- PCAPPI-1km
- Wind-1km

(b) RADAR animation

- MAX(Z) Product
- Plan Position Indicator(Z)
- Plan Position Indicator(V)
- Surface Rainfall Intensity
- Pseudo constant altitude PPI (PCAPPI)

(c) RADAR mosaic products

- Still image
- Animation 3 Hrs.

(d) Radar products in GIS

- Pseudo constant altitude PPI (PCAPPI)-1km
- Plan Position Indicator(Z)
- MaX(Z) Product
- Plan Position Indicator(Z)
- Volume Velocity Processing
- Wind-1km

PRIMARY PRODUCTS :

The products not available in website, but generated by the DWR include the following:

(a) Standard Met. Products:

- CAPPI -Constant Altitude PPI,
- VCUT -Vertical Cut,
- ETOP -Echo Top,
- EBAS -Echo Base

(b) Extended Met. Products

- VAD -Velocity Azimuth Display,
- UWT -Uniform Wind Technique

(c) Hydrological Products

- VIL -Vertical Integrated Liquid

(d) Shear Products

- RDS -Radial Shear
- AZS -Azimuthal Shear
- ELS -Elevation Shear
- RAS -Radial Azimuthal Shear
- RES -Radial Elevation Shear
- 3DS -3 D Shear
- HZS -Horizontal Shear
- VCS -Vertical Shear
- LTB -Layer Turbulence

(e) Warning & Forecasting Products

- HHW -Hail Warning
- TRK -Storm Tracking

4.12.2. Radars in neighbouring countries

Available information about cyclone warning radars in the neighbouring countries is given in Table 4.2 as a matter of interest. Occasionally, radar reports may be received from these radar centres. Also the radar products available from their concerned National Meteorological Services may be referred.

Table. 4.2 Cyclone Warning Radars in the neighbouring countries

S. No.	***Station Coast***		***Wave length***	***Remarks***
1.	Kyaukpyu	Myanmar	10 cm	Operational since 1979
2.	Molvi Bazar	Bangladesh	10 cm	Operational since 2009
3.	Cox'z Bazar	-do-	10 cm	Operational since 1990
4.	Dhaka	- do -	10 cm	- do -
5.	Khepupara(21.59ºN/90.14ºE)	-do-	10 cm	Operational since 1982
6.	Rangpur	- do -	10 cm	Operational since 1999
7.	Trincomalee	SriLanka	10 cm	Operational since 1982
8.	Karachi	Pakistan	5.6 cm	Functioning since 1991.
9.	Bangkok	Thailand	10 cm	Operational since 1992
10.	Mahe	Maldivs	10cm	Operational since 2008

4.12.3. X-Band Radars:

X-band radars along Coastal Belt

The details of X-Band 3- cm radars that are functioning along the coast line of India are given in Table 4.3. X-Band EEC radars are Computer controlled state of art radars which provide product through software and pictures of cloud are presented in different colours according to the intensity of the cloud. X-band EEC radars generate algorithm based derived products similar to reflectivity based products of Doppler weather Radar. EEC Wind finding radars have capability of being used as storm detection radars also.

Table 4.3: X-Band 3- cm radars along the coast line of India

S.No.	**Station name**	**Coast Remarks**
1.	Kolkata West Bengal	EEC X-Band ,Weather Radar
2.	Bhubaneshwar Odisha	EEC X-Band ,Wind Finding Radar
3.	Visakhapatnam Andhra Pradesh	EEC X-Band, Wind Finding Radar
4.	Chennai Tamil Nadu	EEC X-Band ,Weather Radar
5.	Thiruvananthapuram Kerala	BEL X-Band, Wind Finding cum, Weather Radar

6.	Mangalore Karnataka	EEC X- Band, Wind Finding Radar
7.	Panaji, Goa	EEC X-Band ,Wind Finding Radar
8.	Mumbai Maharashtra	BEL X-Band ,Weather Radar
9.	Karaikal Tamil Nadu	BEL X-Band ,Weather Radar
10.	Machilipatnam Andhra Pradesh	BEL X-Band, Weather Radar

The coastal X-band radars at Mangalore and Thiruvananthapuram may be used in storm situations affecting Karnataka and Kerala coasts; those at Mumbai, Goa, Chennai, Visakhapatnam and Kolkata will also be useful as a standby if the cyclone detection radars at these places become temporarily unserviceable. In case of unserviceability of the cyclone detection radar at Paradip, X-band radar at Bhubaneswar can serve as a standby.

4.12.4. Operation of radar and availability of radar observations

In undisturbed weather:

The cyclone detection radar will be operated as a routine at 0600 UTC every day for checking the overall performance of the radar. This will be the daily routine during undisturbed weather. There is no need to operate the radar beyond its routine operation when any system is more than 800 km. away from the radar station. The Doppler Weather Radar will be in continuous operation in all seasons.

When disturbances are developing:

Whenever a depression or cyclonic storm lies between 400 and 800 km from the station and this information is conveyed to the radar station by ACWC/CWC or when precipitation echoes suggestive of development of a storm are observed on the radar-scope, the radar will be operated once every 3 hours (at full hours UTC).

Deep depressions and depressions

Hourly observations are adequate in the case of deep depressions and three hourly in the case of depressions within the range of the radar.

When storm is within the radar range

The radar is operated every hour or more frequently depending on the requirements concerned when the storm is within the radar range. The radar station will revert to routine only when the above conditions have ceased to be valid.

When eye is located

When the ***eye*** is located between 200 and 400 km. from the station, the radar is operated hourly, but more frequent observations (half hourly, or every 10 minutes) are made as required by the situation.

Continuous operation

The radar will be operated continuously, if necessary, when the cyclone center is at a distance of 200 km. or less from the radar station over the sea and until such time as the disturbance continues as a cyclone over land even after crossing coast.

The above paragraph refers to emergency measures and will apply only in the case of cyclonic storms. "Frequency of radar reports (RAREPs) is be hourly and close co-ordination between officers of the Radar station and the associated Cyclone Warning Centre(s) is maintained for getting more frequent observations, if found necessary".

4.12.5. Radar Bulletin

Three hourly/hourly bulletins are prepared by Radar Centres and transmitted to concerned ACWCs/CWCs and CWD for use in Cyclone Warning. An example of such a bulletin in standard format is given in Table 4.4. The Radar stations can provide the location of cyclone to All India Radio (AIR) Stations when cyclone is tracked with confidence.

Table 4.4: Example of Radar based Cyclone Bulletin

Radar based Cyclone Bulletin	
Name of reporting Radar	Doppler Weather Radar, Chennai
Date and Time (UTC) of observation	20161212_0500 UTC
Geo-coordinates of Radar	13.0728 N; 80.2883 E
Name of Cyclone	Vardah
Information about eye of cyclone	**Yes**
Is the eye Visible (Yes/No)	Yes
Shape of the eye	Irregular
Diameter of eye (km)	34.44 km
Estimation of centre for cyclone based on Eye/Spiral band observation	12.18525N 80.834E
Echo top (height 20 dBz) of rain bearing clouds around the cyclone within 100 km radius	10.28 km
Maximum radar reflectivity (dBz) of rain bearing clouds 101 deg-Az around the cyclone within 100km radius	63.0 dBz, 36.2 km range, 101 deg-Az, 5.02 km height
Maximum reflectivity at any other area Spiral/streamers etc	
Maximum radial velocity in eyewall/spiral band region (mps) Its height (km) and its position (Azimuth and distance from Radar)	51 m/s at 0.493 km height
Maximum velocity in any other area (spiral/streamers/rain shields etc.)	
Tendency of cyclone	
Intensity (Increasing/Decreasing)	
Duration for which the information on movement of the system pertains to	1 hours
Direction of movement	WSW
Estimated speed of movement	23.6 km/hr
Any other feature (s)	Leading for landfall closer in next

	few hours

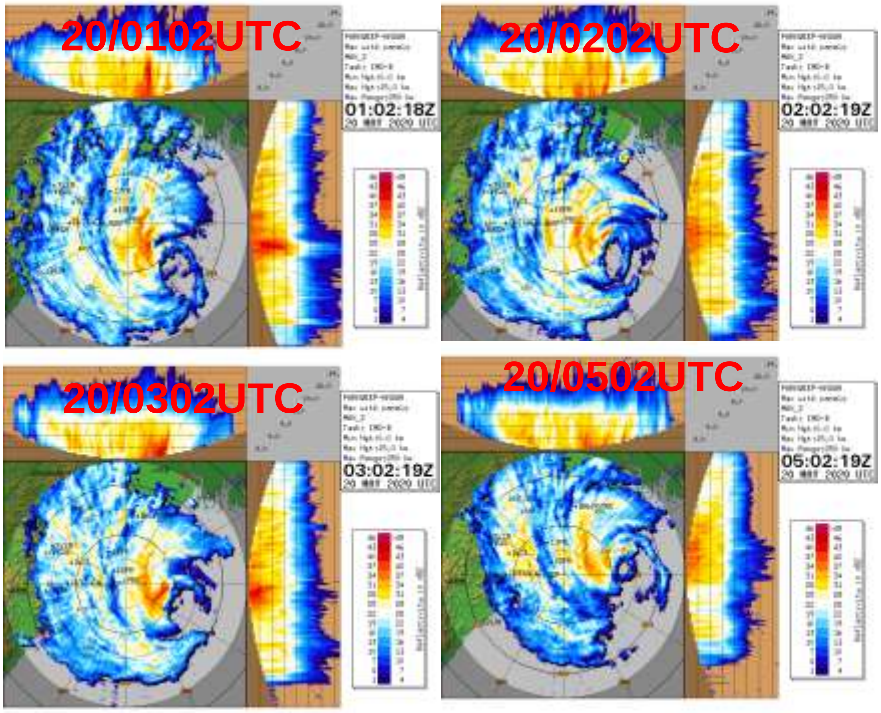


Fig.4.11: Realtime MAXZ images of SuCS AMPHAN

4.13. Satellite Cloud Imagery Data and Derived products useful in cyclone warning

4.13.1. Cloud Imagery Data

At present IMD is receiving and processing meteorological data from two Indian satellites namely Kalpana-1 and INSAT-3A. Kalpana-1 was launched on 12th September, 2002 and is located at 74^0 E. INSAT-3A was launched on 10 April, 2003 and is located at 93.5^0 E. Kalpana-1 and INSAT-3A both have three channel Very High Resolution Radiometer (VHRR) for imaging the Earth in Visible (0.55-0.75 um), Infra-Red (10.5-12.5um) and Water vapour (5.7-7.1um) channels having resolution of 2X2 km. in visible and 8X8 km. in Water vapour (WV) and Infra red (IR) channels. In addition, the INSAT-3A has a three channel Charge Coupled Device (CCD) payload for imaging the earth in Visible (0.62-0.69um), Near IR (0.77-0.86um) and Short Wave IR (1.55-1.77um) bands of Spectrum. The Resolution of CCD payload in all the three channels is 1kmx 1 km. At present about 48 nos. of satellite images are taken daily from Kalpana-1 which is the main operational satellite and 9 images are taken from INSAT-3A. Imaging from CCD is done 5 times during daytime only. All received data from the satellite are processed and archived in National Satellite Data Centre (NSDC), New Delhi.

Indian Meteorological Data Processing System (IMDPS) is processing meteorological data from INSAT VHRR and CCD data and supports all operational activities of the Satellite Meteorology Division on round the clock basis. Cloud Imagery Data are processed and transmitted to forecasting offices of the IMD as well as to the other users in India and foreign countries.

To supplement these observations, cloud imagery data from METEOSAT-5 satellite, which is also located to observe Indian region, from 63 deg E long, are also being received in VIS (0.4-1.1mm), IR (10.5-12.5mm) and Water Vapour channels(5.7-7.1mm). Since all these satellites are geostationary satellites, cloud imagery data from these satellites are frequently ingested. It is 3 hourly in case of INSAT and half hourly in case of Kalpana-1 and ranges from half to one and half-hourly in case of METEOSAT-5 satellite. In addition to above mentioned geostationary satellites, cloud imagery data from the NOAA and METOP satellite are being received at HRPT stations at New Delhi, Chennai and at Guwahati whenever these satellites pass over Indian region. NOAA satellites pass over near local noon and near mid night at pre-assigned hours and normally imagery data in five/four channels are being received twice from each satellite during day/night pass. Apart from these six channel imagery data from NOAA AVHRR payload, TOVS data are also received from NOAA satellite for deriving temperature and moisture profiles. The cloud imagery radiance data from Kalpana geostationary satellite are used for making cloud Imageries and for deriving various Satellite Derived Products i.e., OLR, CMV, QPE & SST. Cloud imageries are very useful for locating the tropical Cyclone position, its intensity by Dvorak Technique and speed and direction of movement and track of cyclone from sequence of imageries and the amount of convection associated with the tropical cyclone. The derived products help further in knowing these aspects of a cyclone. Both cloud imagery and the Derived Products help in diagnosing and forecasting the tropical cyclone intensity and position.

4.13.2. Derived Products used for diagnosing a Tropical Cyclone

Several products, which can be used in meteorology in general, are derived from satellite cloud imagery radiance data. Following products are available with Kalpana cloud imagery data. Apart from generating half hourly cloud imagery, IMDPS produces Satellite Data derived products from the processed data as follows:

- Cloud Motion Vectors (CMV) are derived with 2.5^0 resolution using three consecutive half hourly images from the operational Kalpana-I Satellite. CMVs are generated at 00, 03, 06, 09, 12, 15, 18 and 21 UTC using IR imagery daily.

- Water Vapour Winds (WVWs) are derived with 12.5^0 resolution using three consecutive half hourly images from the operational Kalpana-I Satellite. WVWs are generated at 00, 03, 06, 09, 12, 15, 18 and 21 UTC using water vapour imageries data.

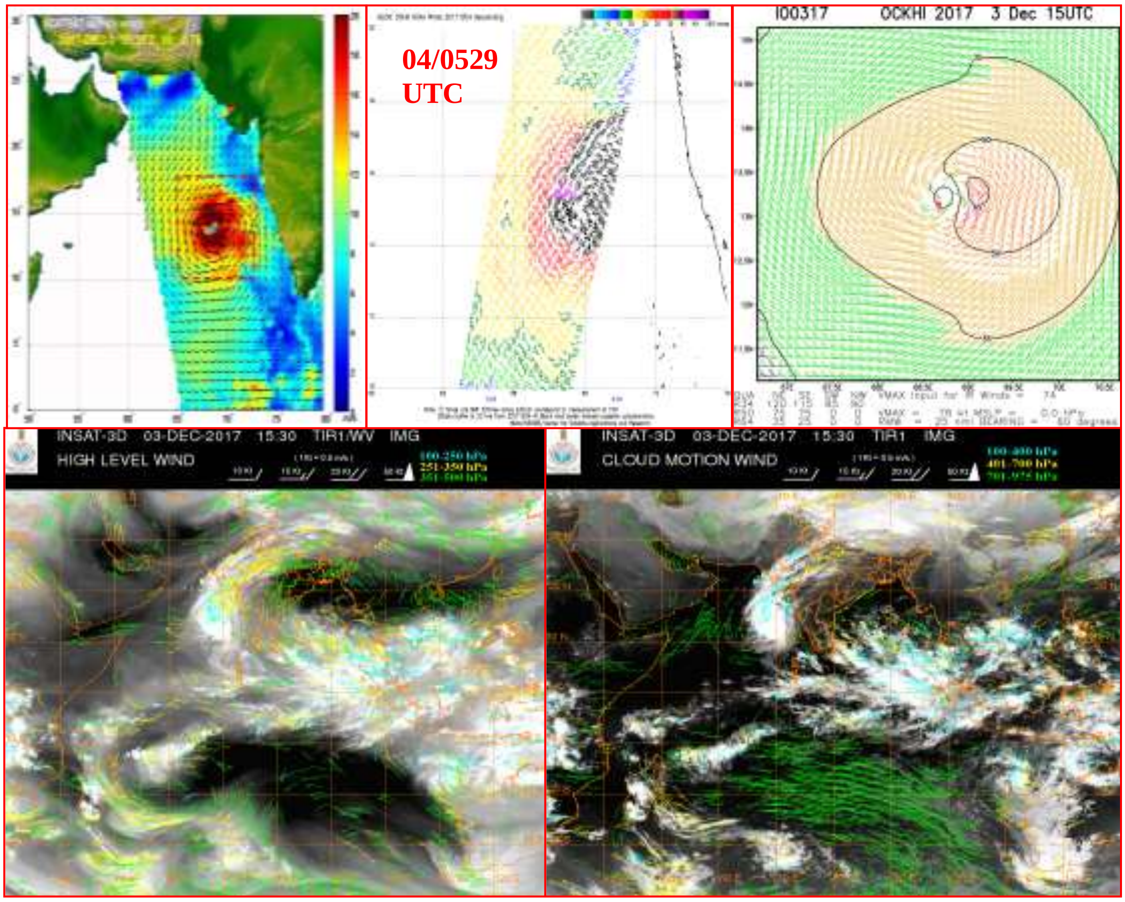


Fig.4.12. Wind data available through satellites

These CMV's/WVWs are being transmitted on MDD for utilization by other forecasting stations. These wind data are useful in monitoring tropical cyclones location and intensity (Fig.4.12).

- Sea Surface Temperatures (SST) are computed at 1^0 x 1^0 grid intervals from all Kalpana-I data on half hourly /daily /weekly/monthly basis. These SST are available on nearly cloud free regions. Unfortunately, where there is a tropical cyclone, SSTs are not available due to heavy cloudiness. Yet SST before the TC formation are helpful in deciding the probable region for generation of a TC.
- Outgoing Longwave Radiation (OLR) are computed at 0.25^0 x 0.25^0 grid intervals from all Kalpana-I data on half hourly /daily /weekly/monthly basis. OLR pattern are being derived

from IR cloud imagery Radiance data and the same are also transmitted for use at other forecasting centres. These OLR patterns although useful for forecasting T.C. intensity and also find application in numerical models and for rough estimation of direction of movement and intensity of convection present. OLR are averaged daily, weekly and monthly.

- Quantitative Precipitation Estimation (QPE) is generated at 1^0 x 1^0 Grid from Kalpana-1 imagery on half hourly/daily/weekly/monthly basis. These are also transmitted on MDD. The QPE are useable in finding the precipitation potential of a T.C.
- At present Dvorak technique is widely used but manually applied. Recently efforts have been made for automation of this technique. Automated Dvorak technique is running in experimental mode at Satellite Meteorology Division of IMD.

4.13.3. Tropical Cyclone bulletins based on Satellite Cloud Imagery Data and Derived Products:

During normal weather 3-hourly Bulletins called Satellite Bulletins based on Satellite Cloud Imagery Data and derived products are made at Satellite Meteorology Division of IMD, New Delhi. These 3-hourly bulletins are transmitted through MDD for utilization by forecasting offices. But when there is a tropical cyclone over the Bay of Bengal or the Arabian Sea, these Satellite Bulletins are prepared each hour and transmitted through MDD. In these bulletins, the centre and intensity of cyclone as estimated by Dvorak Technique, its past motion and amount of convection associated with tropical cyclones and other characteristic features are described.

Based on different satellite cloud imagery data and their derived products, the US Weather Bureau, Washington, issues daily bulletins called "Satellite Tropical Disturbance Summary"(STDS) for the different oceanic areas, describing the major cloud system and disturbed weather area. The information contained in the STDS includes location and intensity of the tropical systems, if any, in the area, their past movement, associated cloud bands etc . The intensity and related details are given in Dvorak's T-code form. The summary for the Indian Ocean covers Arabian Sea and Bay of Bengal also. These bulletins are received at New Delhi on the GTS and retransmitted to the ACWCs/CWCs, Weather Central Pune and other Forecasting Offices in India. As these are received only after a lapse of some hours after the picture time, they may not be useful for immediate operational purposes. However, they are utilized for comparing our assessment of the centre and intensity of the system with that of the U.S. Weather Bureau.

Satellite information about disturbances over the Indian seas is also available in the storm warning bulletins issued from U.S. Fleet Weather Central (Joint Typhoon Warning Centre-JTWC). This is based on the pictures received through the satellites of the Defence

Met. Satellite Programme (DMSP) of U.S.A. These bulletins are also received at New Delhi on the GTS and distributed to the concerned offices

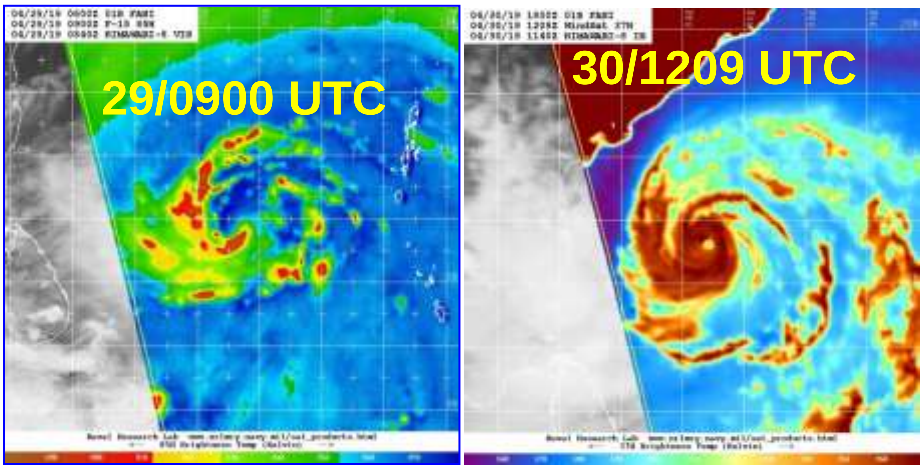


Fig.4.13. Microwave imageries of ESCS FANI

Appendix 4.1 List of Coastal stations in India

Station Index	Station	Latitude	Longitude	Class	00Z	03Z	06Z	09Z	12Z	15Z	18Z	21Z
42903	Sagar Islands	21 45N	88 03E	IIb	0	X	0	0	X	0	0	0
42807	Kolkota(Alipore)	22 32N	88 20E	I	X	X	X	X	X	X	X	X
42809	Kolkota(DumDum)	22 39N	88 20E	I	X	X	X	X	X	X	X	X
42812	Canning	22 15N	88 40E		0	X	0	0	X	0	0	0
42811	Diamond harbour	22 11N	88 12E		X	X	X	X	X	X	X*	X*
42803	Midnapore	22 25N	87 19E	IIb	0	X	0	0	X	0	0	0
42901	Digha	21 50N	87 47E		X	X	X	X	X	X	X*	X*
42810	Basirhat	22 39N	87 52E									
42900	Contai	21 47N	87 45E	IIb	0	X	0	0	X	0	0	0
42895	Balasore	21 31N	86 56E	I	0	X	X	X	X	X	0	0
42973	Chandbali	20 47N	86 44E	I	0	X	X	X	X	X	X	X
42971	Cuttack	20 28N	85 56E	IIb	0	X	0	0	X	0	0	0
42976	Paradip	20 18N	86 41E	IIa	0	X	0	0	X	0	0	0
42971	Bubaneshwar	20 15N	85 50E	I	X	X	X	X	X	X	X	X
43053	Puri	19 48N	85 49E	I	X	X	X	X	X	X	X	X
43049	Gopalpur	19 16N	84 53E	I	X	X	X	X	X	X	X	X
43105	Kalingapatnam	18 20N	84 08E	I	X	X	X	X	X	X	X	X
43149/150	Vishakapatnam	17 43N	83 14E	I	X	X	X	X	X	X	X	X
43189	Kakinada	16 57N	82 14E	I	X	X	X	X	X	X	X	X
43147	Tuni	17 21N	82 33E	I	X	X	X	X	X	X	X	X
43243	Kavali	14 54N	79 59E	I	X	X	X	X	X	X	X	X
43184	Nidadavole	16 50N	81 35E	IIb	0	X	0	X	X	0	0	0
43187	Narsapur	16 26N	81 42E	I	X	X	X	X	X	X	X	X

43181	Gannavaram	16 42N	80 48E	I	X	X	X	X	X	X	X	X
43180	Vijayawada	16 31N	80 37E	IIb	0	X	0	0	X	0	0	0
43185	Machlipatnam	16 12N	81 09E	I	X	X	X	X	X	X	X	X
43220	Bapatla	15 54N	80 28E	I	0	X	X	X	X	0	0	0
	Vadaveru	15 48N	80 25E	IIb0	0	X	0	0	X	0	0	0
43221	Ongole	15 30N	80 05E	I	X	X	X	X	X	X	X	X
43245	Nellore	14 27N	79 59E	I	X	X	X	X	X	X	X	X
43279	Minambakkam	13 00N	80 12E	I	X	X	X	X	X	X	X	X
43278	Nungambakkam	13 04N	80 11E	I	0	X	X	X	X	0	0	0
43328	Pondicherry	11 58N	79 49E	I	X	X	X	X	X	X	X	X
43329	Cuddalore	11 46N	79 46E	I	X	X	X	X	X	X	X	X
43207	Parangipettai	11 30N	79 46E	IIb	0	X	0	0	X	0	0	0
43346	Karaikal	10 55N	79 50E	I	X	X	X	X	X	X	X	X
43347	Nagapattinam	10 46N	79 51E	I	X	X	X	X	X	X	X	X
43249	Vedaranyam	10 22N	79 51E	IIb	0	X	0	0	X	0	0	0
43348	Adiramapattinam	10 20N	79 23E	I	X	X	X	X	X	X	X	X
43361	Tondi	09 44N	79 02E	I	X	X	X	X	X	X	X	X
43363	Pamban	09 16N	78 18E	I	X	X	X	X	X	X	X	X
	Valinokam	09 10N	78 39E	IIb0	0	X	0	0	X	0	0	0
43379	Tuticorin	08 45N	78 11E	I0	0	X	X	X	X	0	0	0
43376	Palayamkottai	08 44N	77 45E	IIb	0	X	0	0	X	0	0	0
	Manalmelkudi	10 03N	79 14E	IIb	0	X	0	0	X	0	0	0
43377	Kanniyakumari	08 05N	77 30E	IIa	0	X	X	0	X	0	0	0
43371	Thiruvanathapuram	08 29N	76 57E	I	X	X	X	X	X	X	X	X
43354	Punalur	09 00N	76 55E	IIb	0	X	0	0	X	0	0	0
43352	Alappuzha	09 33N	76 25E	IIa	0	X	0	0	X	0	0	0
43355	Kottayam	09 32N	76 36E	IIb	0	X	0	0	X	0	0	0
43314	Kozhikode	11 15N	75 47E	I	X	X	X	X	X	X	X	X
43315	Cannur	11 50N	75 20E	IIa	0	X	0	0	X	0	0	0
43285	Mangalore	12 57N	74 53E	IIa	0	X	0	0	X	0	0	0
43284	Bajpe	12 55N	74 53E	I	X	X	X	X	X	X	X	X
43226	Honavar	14 17N	74 27E	I	X	X	X	X	X	X	X	X
43225	Karwar	14 47N	74 08E	I	0	X	X	X	X	0	0	0
43196	Mormugoa	15 25N	73 47E	I	0	X	X	X	X	0	0	0
43192	Panjim	15 29N	73 49E	I	X	X	X	X	X	X	X	X
43193	Vengurla	15 52N	73 38E	IIc	0	X	0	0	X	0	0	0
43153	Devgarh	16 23N	73 21E	IIb	0	X	0	0	X	0	0	0
43110	Ratnagiri	16 59N	73 20E	I	X	X	X	X	X	X	X	X
43109	Harnai	17 49N	73 06E	IIa	0	X	X	X	X	0	0	0
43058	Alibagh	18 38N	72 52E	IIa	0	X	0	0	X	0	0	0
43057	Mumbai(coloba)	18 54N	72 49E	I	0	X	X	0	X	0	0	0
43003	Mumbai(Santacruz)	19 07N	72 51E	I	X	X	X	X	X	X	X	X
42001	Dahanu	19 58N	72 43E	I	X	X	X	0	X	0	X	0
42840	Surat	21 12N	72 50E	IIb	X	X	X	X	X	X	X	X
-	Bharuch	21 44N	73 00E	IIb	0	X	0	0	X	0	0	0
42838	Bhavnagar	21 45N	72 12E	I	0	X	X	0	X	0	0	0
42909	Veraval	20 54N	70 22E	I	X	X	X	X	X	X	X	X
42830	Porbander	21 39N	69 40E	I	X	X	X	X	X	X	X	X
42832	Keshod	21 19N	70 19E	IIa	X	X	X	X	X	X	X	X
42730	Okha	22 29N	69 05E	I	X	X	X	X	X	X	X	X
42731	Dwarka	22 22N	69 05E	I	X	X	X	X	X	X	X	X
42639	New kandla	23 00N	70 13E	IIb0	0	X	0	0	X	0	0	0

42631	Naliya	23 15N	68 51E	I	X	X	X	X	X	X	X	X
42634	Bhuj	23 15N	69 40E	I	X	X	X	X	X	X	X	X
43226	Agathi	10 51N	72 28E	IIb	0	X	0	0	X	0	0	0
43311	Amini	11 07 N	92 56E	I	X	X	X	X	X	X	X	X
43334	Androth	10 48N	73 59E	Iib	0	X	0	0	X	0	0	0
43369	Minicoy	08 18N	73 09E	I	X	X	X	X	X	X	X	X
43385	Kondul	07 13N	93 44E	IIb	0	X	0	0	X	0	0	0
43382	Nancowri	07 59N	93 32E	IIb	0	X	0	0	X	0	0	0
43367	Carnicobar	09 09N	92 49E	IIb	X	X	X	X	X	X	X	X
43364	Hut bay	10 35N	92 33E	IIb0	0	X	0	0	X	0	0	0
43333	Portblair	11 40N	92 43E	I	X	X	X	X	X	X	X	X
43310	Longisland	12 25N	92 56E	IIb	0	X	0	0	X	0	0	0
43309	Mayabandar	12 55N	92 55E	IIb	0	X	0	0	X	0	0	0

Appendix 4.2. List of Foreign Coastal stations

Station Index	Station	Latitude	Longitude	00Z	03Z	06Z	09Z	12Z	15Z	18Z	21Z
41756	Jiwani	25 04N	61 48E	X	X	X	X	X	X	X	X
41759	Pasni	25 16N	63 29E	X	X	0	0	X	0	0	0
41782	Karachi	24 48N	66 59E	X	X	X	X	X	X	X	X
43413	Mannar	08 59N	79 55E	X	X	X	X	X	X	X	X
43424	Puttalam	08 02N	79 50E	X	X	X	X	X	X	X	X
43495	Galle	06 02N	80 13E	X	X	X	X	X	0	X	0
43466	Colombo	06 54N	79 52E	X	X	X	X	X	X	X	X
43497	Hambantota	06 07N	81 08E	X	X	X	X	X	X	X	X
43436	Batticloa	07 43N	81 42E	X	X	X	X	X	X	X	X
43418	Trincomalee	08 35N	81 15E	X	X	X	X	X	X	X	X
43404	Jaffna	09 39N	88 01E	X	X	X	X	X	0	X	0
43400	Kankasanturai	09 48N	80 04E	X	X	X	X	X	X	X	X
41941	Chandpur	20 16N	90 42E	X	X	X	X	X	X	X	X
41950	Barisal	22 45N	90 22E	X	X	X	X	X	X	X	X
41953	Majidcourt	22 52N	91 06E	X	X	X	X	X	X	X	X
41960	Patuakhali	22 20N	90 20E	X	X	X	X	X	X	X	X
41963	Hatia	22 26N	91 06E	X	X	X	X	X	X	X	X
41964	Sandwip	22 29N	91 26E	X	X	X	X	X	X	X	X
41984	Khepura	21 59N	90 14E	X	X	X	X	X	X	X	X
41977	Chittagong	22 21N	91 49E	X	X	X	X	X	X	X	X
41992	Cox'sBazzar	21 26N	91 56E	X	X	X	X	X	X	X	X
41989	Kutubdia	21 49N	91 51E	X	X	X	X	X	X	X	X
41998	Teknaf	20 52N	92 18E	X	X	X	X	X	X	X	X
48062	Sittwe	20 08N	92 53E	X	X	X	X	X	0	X	0
48071	Kyaukpyu	19 25N	93 33E	X	X	X	X	X	0	X	0
48080	Sandoway	18 28N	94 21E	X	X	X	X	X	0	X	0
48094	Pathein	16 46N	94 46E	X	X	X	X	X	0	X	0
48097	Yangon	16 46N	96 10E	X	X	X	X	X	X	X	X
48103	Moulmein	16 30N	97 37E	X	X	X	X	X	0	X	0
48107	Ye	15 15N	97 52E	X	X	X	X	X	0	X	0
48108	Dawei	14 06N	98 13E	X	X	X	X	X	0	X	0
48109	Coco Island	14 07N	93 22E	X	X	X	X	X	0	X	0
48110	Mergui	12 26N	98 36E	X	X	X	X	X	0	X	0
48112	Victoria Ponit	09 58N	98 35E								

48565	Phuket Airport	08 07N	98 19E								
	Kawthaung	09 58N	98 35E	X	X	X	X	X	0	X	0
41240	Khasab	26 20N	56 23E	0	X	X	X	X	X	X	0
41246	Sohar majis	24 28N	56 38E	X	X	X	X	X	X	X	X
41256	Seeb	23 35N	58 17E	X	X	X	X	X	X	X	X
41268	Sur	22 32N	59 28E	X	X	X	X	X	X	X	X
41288	Masirah	20 40N	58 54E	X	X	X	X	X	X	X	X
41316	Salalah	17 02N	54 05E	X	X	X	X	X	X	X	X

Appendix 4.3. List of Co-operative Cyclone Reporting Network of Stations (Andhra Pradesh & Orissa)

S. No	Station	District	Nearest Telegraphic Office	Distance From Station
Andhra Pradesh				
1	Palasa	Srikakulam	Palasa	2 km
2	Sompeta	Srikakulam	Sompeta	100 meters
3	Anakapalli	Vishakapatnam	Anakapalli	1.5 km
4	Rajamundry	East Godavari	Rajamundry	2.5 km
5	Yanam	East Godavari	Yanam	1.0 km
6	Razaole	East Godavari	Razaole	200 meters
7	Eluru	West Godavari	Eluru	1.0 km
8	Challapalli	Krishna	Challapalli	0.5 km
9	Avani Gadda	Krishna	Avani Gadda	200 meters
10	Nagayalanka	Krishna	Nagayalanka	1.0 km
11	Bantimalli	Krishna	Bantimalli	1.0 km
12	Kothapatnam	Prakasam	Kothapatnam	200 meters
13	Narasapuram	Nellore	Narasapuram	0.5 km
Odisha				
1	Bhograi	Balasore	Bhogral	2Km
2	Basta	Balasore	Basta	1 Km
3	Bhadrak	Balasore	Bhadrak	2 Km
4	Bansara	Balasore	Bansara	2 Km
5	Rajkanika	Cuttack	Rajkanika	2 Km
6	Aul	Cuttack	Aul	2 Km
7	Rajnagar	Cuttack	Rajnagar	1 Km
8	Kendrapara	Cuttack	Kendrapara	2 Km
9	Mahakalpara	Cuttack	Mahakalpara	2 Km
10	Jagatsingpur	Cuttack	Jagatsingpur	1 Km
11	Ersama	Cuttack	Ersama	2 Km
12	Nimapara	Puri	Nimapara	0.5 Km
13	Brahmagiri	Puri	Brahmagiri	1 Km
14	Krishnaprasad	Puri	Krishnaprasad	0.5 Km
15	Chatrapur	Ganjam	Chatrapur	0.5 Km
16	Berhampur	Ganjam	Berhampur	3 Km

Chapter V
Monitoring and Prediction technique

5.1. Monitoring and prediction of cyclogenesis

Following steps are followed for monitoring and prediction of cyclogenesis (formation of depression) over the north Indian Ocean.

5.1.1. Road Map

Step I

- Location of deep convection areas on geostationnary satellite imagery (on Synergie)
- Presence of a pre-existing disturbance in the lower atmosphere : analysis of pre-extisting lows in the ITCZ (their location, organization, intensity)
- Animated visible and IR geostationnary imagery on Synergie : estimation of the areas of organizing deep convection, their evolution during the last 24 hours; first estimation of associated LLCCs (low level circulation centers); analysis of exposed LLCCs (when out of deep convection).
- Micro-Wave imagery over suspected convective areas (Monterey website, or Synergie Cyclone), to see the low or mid-level improving cyclonic organization, under Cirrus clouds.

(http://www.nrlmry.navy.mil/tc_pages/tc_home.html)

Step II

- Ocean surface winds derived from satellite :

-OSCAT : http://manati.orbit.nesdis.noaa.gov/oscat/ Ocean Surface Winds derived from the SeaWinds Scatterometer aboard the QuikSCAT satellite

-ASCAT : http://manati.orbit.nesdis.noaa.gov/ascat/ Ocean Surface Vector Winds derived from the Advanced Scatterometer (ASCAT - 50km) aboard the EUMETSAT METOP satellite

-WINDSAT : http://manati.orbit.nesdis.noaa.gov/windsat/ Ocean Surface Winds derived from WindSat/Coriolis Measurements

Step III :

SST exceeding 26°C and a deep thermocline (50 m)

- Analysis of SST in models available in Synergie
- http://www.aoml.noaa.gov/phod/cyclone/data/ni.html
- IMD (Satellite)

- Depth of the 26°C isotherm. SST field provided on a daily basis from TMI measurements (Tropical Rainfall Measuring Mission's Microwave Imager).
- SST f rom TMI (Fig.5.1 as an example)
- Estimation derived from See Height Anomaly on altimeter satellite observation.
- Ocean Thermal Energy

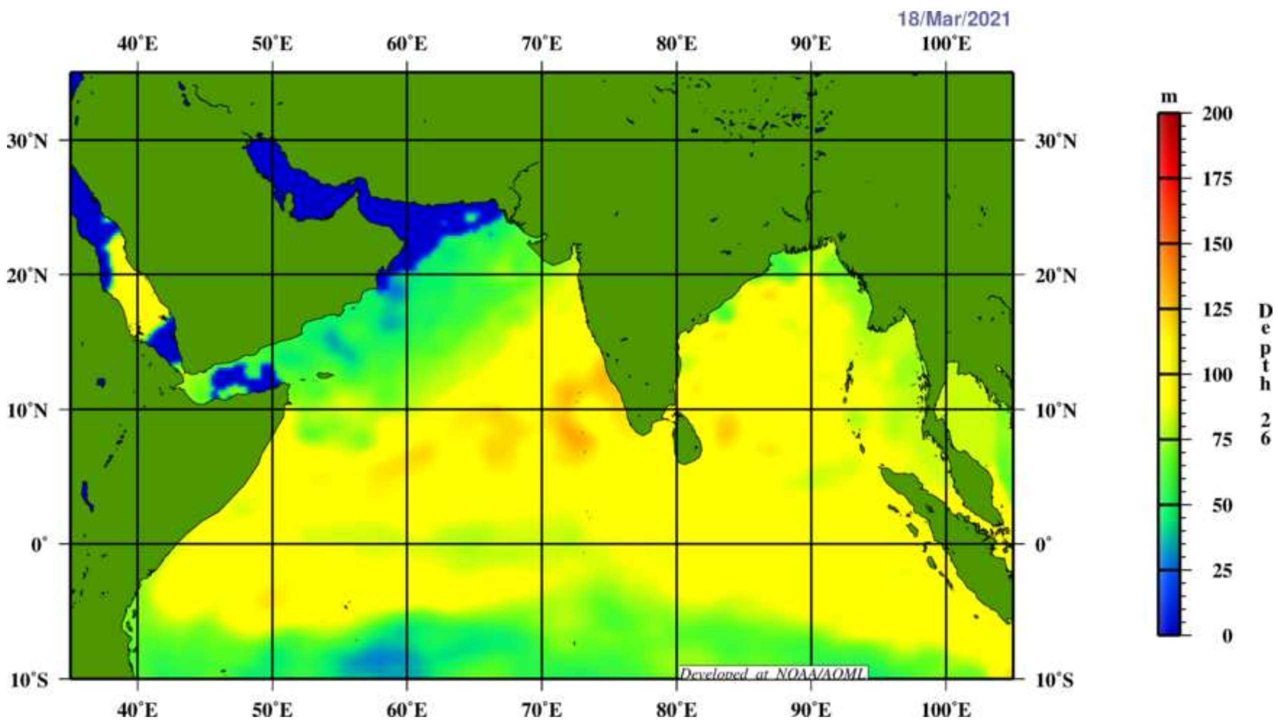


Fig.5.1 SST as on 18th March, 2021

Step IV

- Conditional instability through a deep atmospheric layer
- Area of deep convection on satellite imagery
- Favorable synoptic scale conditions for development of deep convection (Madden Jullian Oscillation (MJO)/Outgoing Longwave Radiation (OLR)) : http://www.bom.gov.au/bmrc/clfor/cfstaff/matw/maproom/OLR_modes/
- Maps of the MJO real-time filtered OLR anomalies, each averaged for a period of 7 days. The first map is for the most recent 7 days of observed data (Fig.5.2). 3 subsequent maps are the forecasts of the MJO OLR anomalies. Blue shading is an indication of enhanced convection and rainfall.Orange shading is an indication of suppressed conditions Tropical lows mainly develop during enhanced or neutral convection phase.
- Forecast of (Poor or No) risk of development up to 7 days possible when dry phase is forecasted

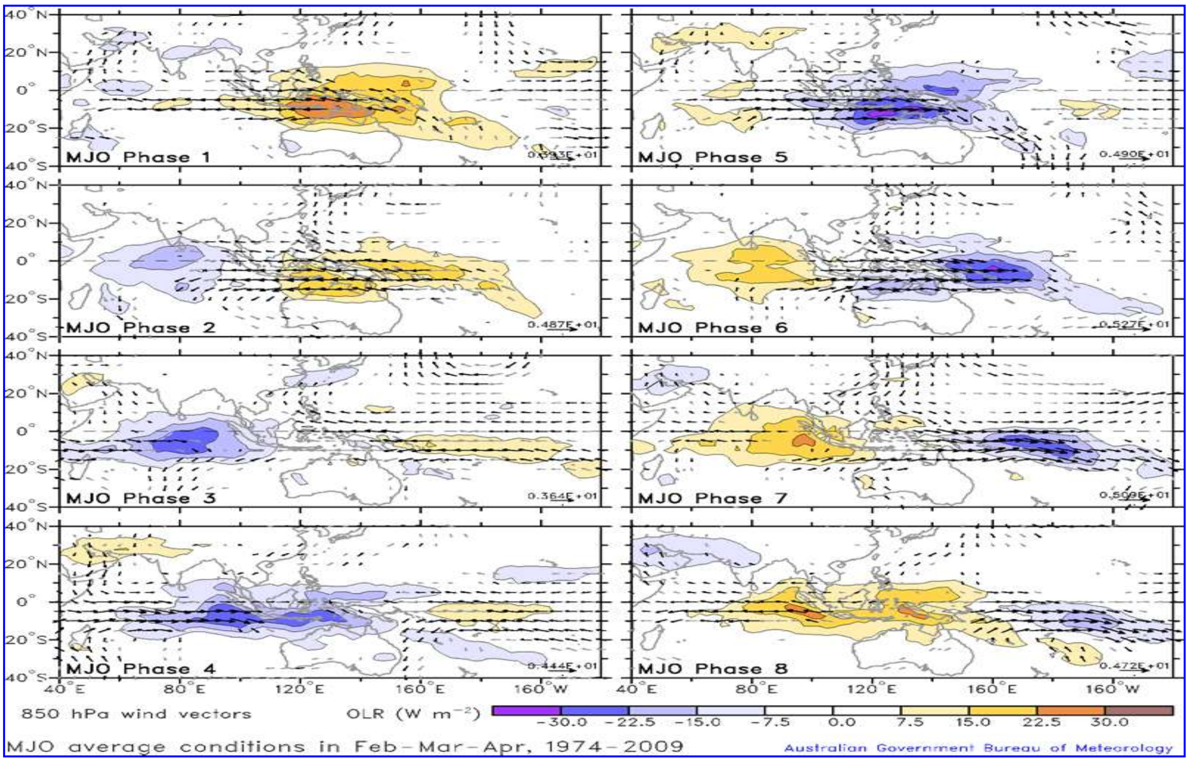


Fig.5.2 Real-time MJO-OLR forecast

Step V

• Large values of relative humidity in the lower and middle troposphere.

Step VI

❖ Significant value of planetary vorticity (Coriolis force) ~5 degrees distance from Equator.

Tropical storm can been observed ~ 2.5° sometimes also

❖ Weak vertical shear of the horizontal winds

- Upper level winds at 200/300 hPa

  http://cimss.ssec.wisc.edu/tropic2/

  Wind Shear based on satellite observation is defined as follows:

  Wind Shear =(150-300) mb layer mean minus (700-925)mb layer mean

  Wind shear is classified as follows:

  5-10 kt : weak (favorable for development)

  10-20 kt : moderate (unfavorable for weak system, or neutral for mature cyclone)

  >20kt : strong (unfavorable)

❖ Good upper level outflow

- Models analysis

❖ Good low level inflow

- Models analysis
- Low level winds data (Ocean Sat-II)

5.1.2. Tools to use for tropical activity daily watch

❖ VIS and IR geostationnary animation over the last 24 hours
  - Superimposed with EIR in Dvorak colors
  - Observations data

❖ Synergie Macro for each avalaible numerical models
  - SLP (sea level pressure)
  - Absolute Vorticity at 850 hPa (only negative values) : measures the rotation of air over itself. A minimum of Ta850 shows deep convection organizing with circulation.
  - Low level winds (Favorable low level surges, or inflows, with trade wind or monsoon wind)
  - Upper level winds (200 hPa), threshold at 20 kt : upper level outflows, high or ridges favorable for good divergence, vertical wind sheared areas rtc.

❖ Internet data :
  - Scatterometry winds
  - Micro-wave imagery for developing lows
  - CIMSS maps (vertical wind shear, upper level divergence)
  - MJO/OLR dry or enhanced convection phases.

5.1.3. Methodology for tropical activity daily watch

(i). First step is rapid analysis of the tropical convective activity

- Is it poor, moderate or strong?
- What is its evolution during the last 24 hours?
- The deep convection has intensified or not (in geographical extension, in intensity, coldness of Cb's top and in cyclonic organization)?
- Comparison must be done with the days before at the same hours, to avoid to be influenced by the diurnal effect over ocean. Deep convection naturally intensifies (deepness and extension) during the night, between 15 UTC and 02 UTC (maximum of deep convective activity at the end of the night, near 23 UTC-01UTC).

(ii). Whether existence of deep convection clusters since more than 24 hours.

(iii). Is there one (or several) associated low level circulation center(s) (LLCCs)? Estimation of their location, motion and intensity (MSLP and associated max mean winds) by

- Satellite imagery (classical and Micro-wave), Quikscat data, surface observations.
- Estimation of their potential for intensification :
- Numerical models forecasts
- Analysis of the environment : SST, OLR, Wind shear, low level inflows, upper level outflows, Potential vorticity, Potential temperature

(iv). Estimation of the risk for development of a depression

- No risk, risk poor, moderate, or high?
- At least for the next 24 hours
- Beyond, if possible :
- If all the NWP models develop a significant low in the same area and at the same range and show the formation of depression in 36-48 hrs : "for the next 24 hours, the risk for development of a Depression is poor, but it becomes moderate near…. for the next 36 to 48 hours"
- If all the NWP models do not develop anything, in a dry phase of MJO : "there is no risk for development of a Depression during the next 3 days"

5.2. Monitoring of cyclonic disturbances (depression and above)

The cyclone monitoring and forecasting aims at monitoring and providing information to the public and disaster management agencies on the following aspects:

a. The current location and intensity of the cyclone

b. Associated sustained maximum wind, estimated central pressure, pressure drop at the centre, shape and size of cyclone.

c. Past movement, speed and direction

d. Forecasting the intensity and track, wind distribution, radii of quadrant wind for different thresholds like 28, 34, 50 and 64 knots

e. Time and location of landfall

f. Coastal areas likely to be affected by gale force wind and their time of occurrence

g. Estimated height of tidal waves/ Storm surge/ the part of the coast likely to be affected by tidal waves /storm surge and the time of occurrence

h. Area to be affected by heavy/ very heavy/extremely rainfall and the time of occurrence.

i. State of sea and wave height

The monitoring and prediction of location and intensity of the system is mainly based on (a) Synoptic, (b) satellite and (c) radar observations. When system is far out at sea, satellite observation is given more weightage. When it comes within radar range, radar is given highr weightage followed by satellite and synoptic observations. When the system is close to coast, the synoptic observation gets maximum weightage followed by Radar and satellite.

The average confidence level of locating the centre of the system over the NIO is about 50km. It should , however, be borne in mind that in the case of relatively weaker system, the available radar and satellite pictures are much less decisive and it is more difficult to locate and estimate the intensity of the system.

There can be small differences in the location of the centres by the different methods, such as, radar, satellite, synoptic observations etc. However, if the system is intense and well defined eye is reported by radar, then the radar center should be taken in view of its greater accuracy. Even here, several workers have reported systematic differences upto about 50 Km between the eye seen in the radar and that reported by aircraft reconnaissance flight.

5.2.1. Synoptic analysis

The analysis of synoptic observations is performed four times daily at 00, 06, 12, and 18 UTC. During cyclonic disturbances (depression and above intensity), synoptic charts are prepared and analysed every three hour to monitor the tropical cyclones over the north Indian Ocean. The centre of the cyclonic disturbance is synoptically defined as the point of lowest pressure in the pressure field and the centroid of the cyclonic wind field. In the 10 meter wind field, a perpendicular is drawn from the direction of the wind. The meeting point of these perpendiculars determines the centre of the disturbance. In case there are two or more meeting points, the centroid determines the centre of disturbance.

When the system comes closer to the coastline, the system location and intensity are determined based on hourly observations from CDR and DWR stations as well as coastal observatories. The AWS stations along coast are also very useful as they provide hourly observations on real time basis. The WVWV and CMV in addition to the conventional wind vectors observed by Radio Wind (RW) instruments are very useful for monitoring and prediction of cyclonic disturbance, especially over the Sea region.

A new weather analysis and forecasting system has been installed at IMD, New Delhi, which has the capability to plot and analyse different weather parameters, INSAT & radar imagery and NWP products using PC software known as SYNERGIE procured from

Meteo France International (MFI). It has a tropical cyclone module, to deal with various aspects of cyclonic disturbance.

The direction and speed of the movement of a tropical cyclone are determined primarily from the three hourly displacement vectors of the centre of the system and by analyzing satellite imageries.

5.2.2. Satellite analysis

Dvorak technique with its international algorithm has been the mainstay of analysis, particularly of intensity of TCs. Cloud imageries from Geostationary Meteorological Satellites INSAT-3A and METSAT (KALPANA-1) are the main sources of information for the analysis of tropical cyclones over the data-sparse region of north Indian Ocean. Data from Ocean buoys also provide vital information. Ship observations are also used critically during the cyclonic disturbance period.

5.2.2.1.Position and Intensity of a tropical cyclone by Dvorak Technique

Dvorak Technique is basically a pattern recognition technique. The technique relies on four distinct geographical properties that relate organized cloud pattern to cyclone intensity. Two are kinematic namely vorticity and vertical wind shear and the other two are thermodynamical viz. convection and core temperature. The strength and distribution of circular winds (by implication vorticity) in a cyclone organizes the cloud into the patterns that Dvorak relates to maximum sustained surface wind (MSW). External/environmental shear is a kinematic force that works to distort the vorticity and hence the cloud pattern. Dvorak found that degree of distortion was also related to maximum sustained wind.

Both visible and IR imageries are used Dvorak pattern recognition technique. Detailed methodology for determining the intensity is shown in fig. 5.5 (a-b)

Dvorak Technique uses a skill from T1 to T8 in the interval of 0.5. The relation between T.No., MSW and Pressure drop is shown in table 5.1.

This classification of intensity is based on two parameters arrived at on an analysis of the cloud features as seen in the satellite pictures of the disturbance. These are 1) the central features which define the cloud system centre and its relation to dense overcast clouds (CF) and 2) the outer banding features (BF). The intensity of the tropical system is indicated by a code figure called T Number which is the sum of the central feature (CF) and banding features (BF).

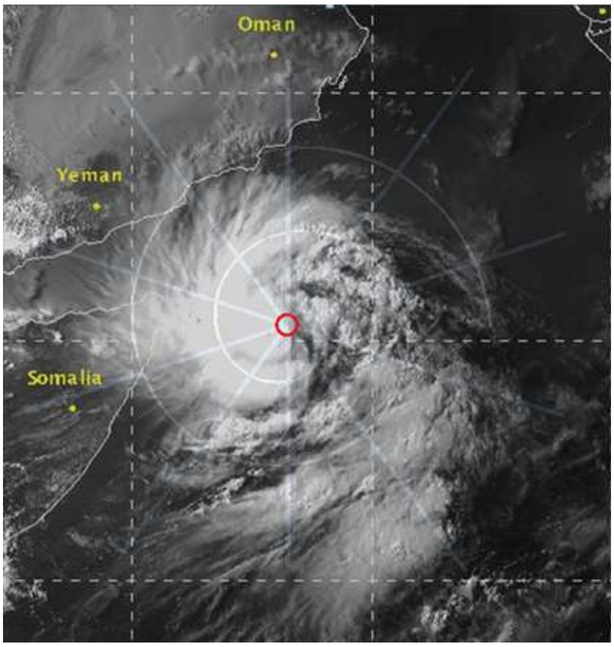


Fig. 5.3. Position and Intensity of a tropical cyclone by Dvorak Technique

Table 5.1. Dvorak's classification of cyclonic disturbances

C.I.Number	***Max.Wind Speed(MSW)(knots)***	***Pressure drop(hPa)***
1.0	25	3.1
1.5	25	3.1
2 0	30	4.5
2.5	35	6.1
3.0	45	10.0
3.5	55	15.0
4.0	65	20.9
4.5	77	29.4
5.0	90	40.2
5.5	102	51.6
6.0	115	65.6
6.5	127	80.0
7.0	140	97.2
7.5	155	119.1
8.0	170	143.3

In curved band pattern convection in the bands of outer core of the cyclone is used in pattern recognition by Dvorak technique using satellite measured IR cloud temperature in the cyclone inner core. Dvorak technique relates convective vigour to the intensity of the system.

In central dense overcast (CDO) pattern, size and temperature of the CDO determines the intensity. In shear pattern, the distance between the LLCC and the sharp boundary of the convective cloud determines the intensity of the system.

In case of cyclones with eyes the technique determines the temperature of the eye and the surrounding eye wall clouds using IR data and relates to the intensity with warmer/cooler eye/wall cloud temperatures respectively indicating greater intensity.

Another feature of the technique is the Current Intensity number (C.I.) which relates directly to the intensity (in term of wind speed) of the cyclone. The C.I. number may differ from the T number on some occasions to account for certain factors which are not directly related to cloud features. The empirical relationship between C.I .number and the maximum wind speeds (according to Dvorak) are given in Table 5.1. Col. 3 of the Table 5.1 gives the pressure depths (peripheral pressure minus central pressure in hPa) as applicable for Indian Sea area using the relation Vmax = 14.2 X SQRT (Pn-Po) .

The centre of the low level cyclonic circulation as evident from the low cloud lines is considered as the centre of the system. As during night the visible imagery is not available, the low cloud lines cannot be detected. As a result, the location of the centre during night time cannot be determined correctly. It is more so when it is a low intensity system like depression/cyclonic storm. When the system intensifies into a severe cyclone with appearance of eye feature, the location of the centre becomes most accurate and it is the centre of the eye. The eye can be detected in both visible and IR imageries. Further in case of curved band pattern or CDO pattern centre can be more accurately determined compared to shear pattern. The centre determined by logarithmic spirals fitted to the curved band pattern determines the centre of the system. The centre of the CDO pattern similarly is taken as the centre of cyclone. The centre of low cloud lines is the only solution to determine the centre of cyclone in case of shear pattern and hence, the error in determining the location of the centre at night is maximum in case of shear pattern.

To overcome the above problems, the microwave imageries can be utilized. Microwave imageries at night can detect the cloud features and hence the centre of cyclone as the centre of the cyclone as the microwave radiation can penetrate through the clouds associated with the cyclone. Examples of determination of centre and intensity of the cyclone by satellites are shown in Fig.5.3

Model of tropical cyclone development used in intensity analysis (curved band pattern type).

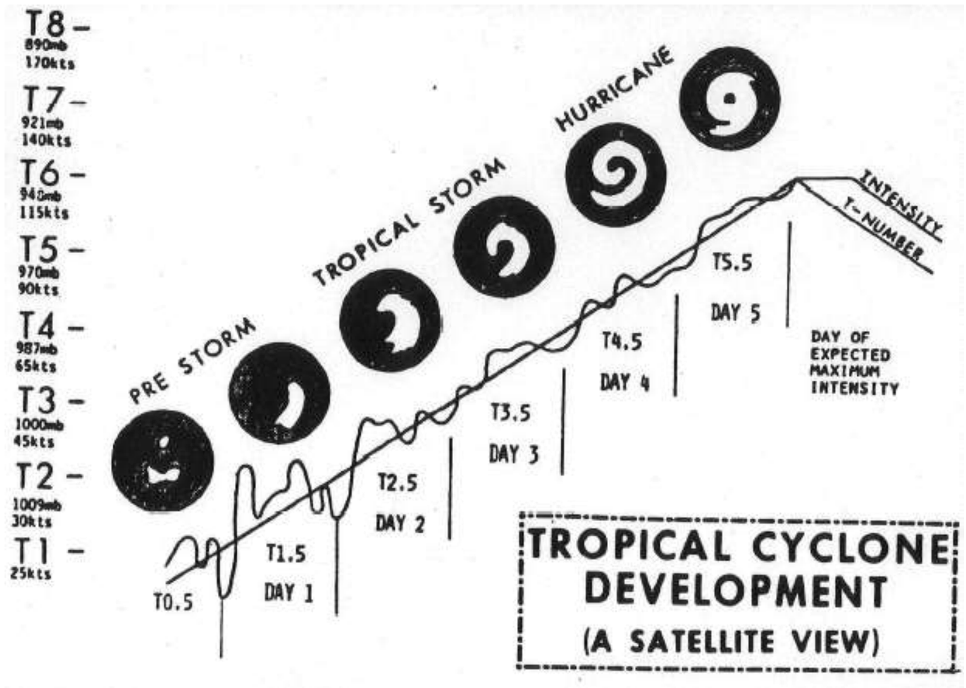


Fig.5.4. Model of tropical cyclone development used in Intensity analysis

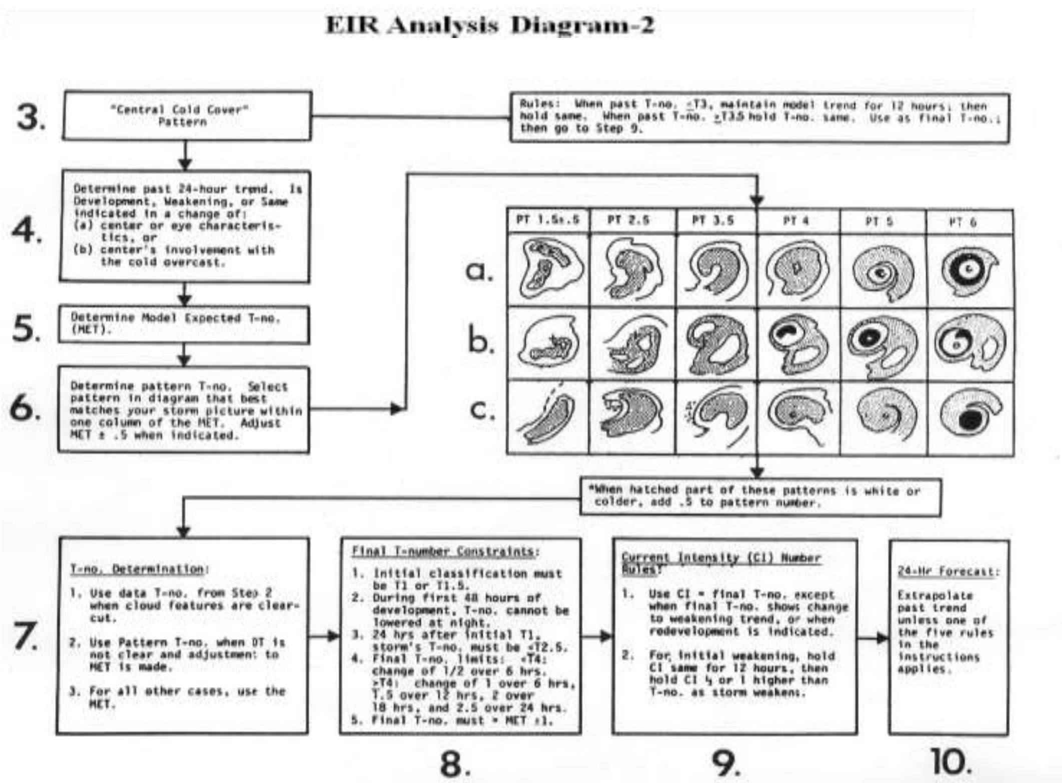


Fig.5.5 (a) EIR analysis diagram for determining the Intensity

VIS Analysis Diagram-2

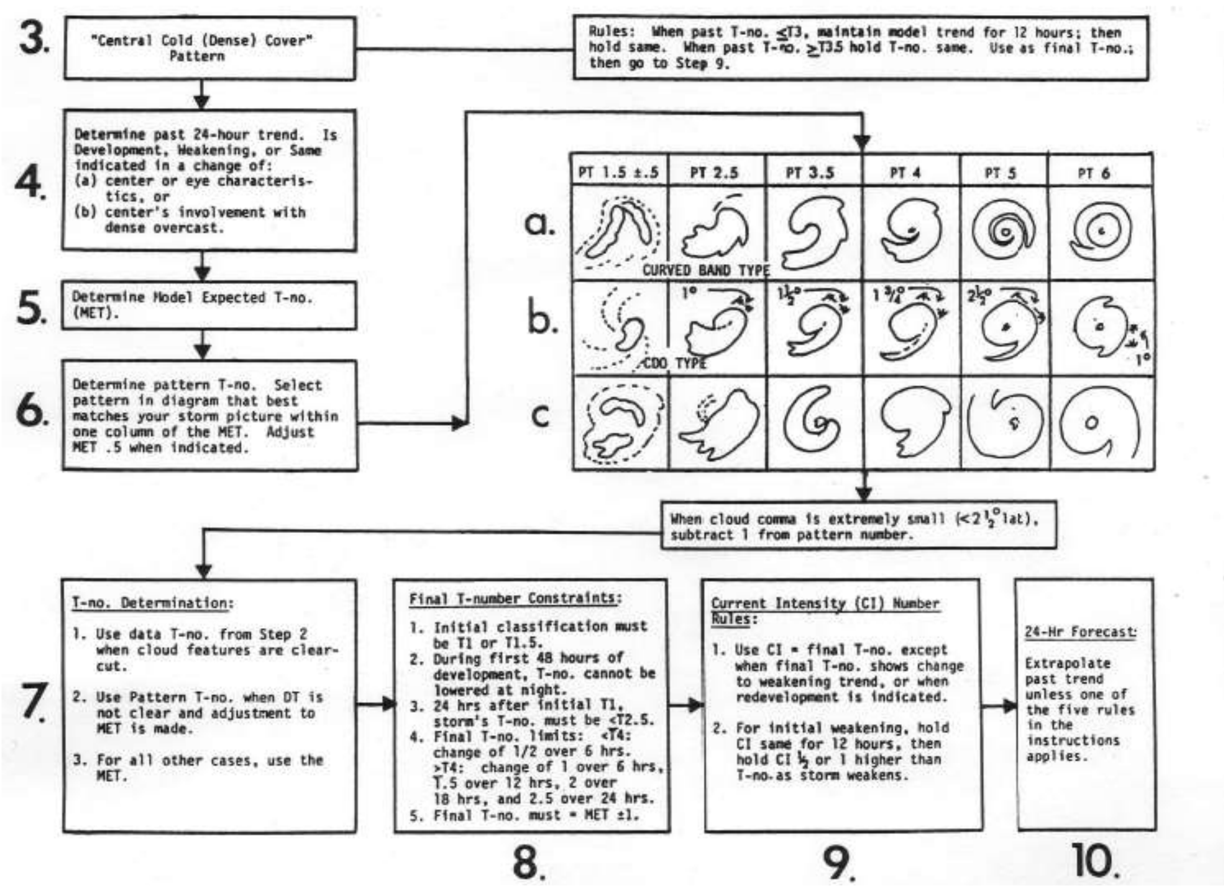


Fig.5.5 (b) Vis analysis diagram for determining the Intensity

5.2.3. Radar Techniques for fixing centre and intensity of cyclone Centre of cyclone

The techniques for fixing the centre is given briefly below to serve as a background material to the forecaster in interpreting the radar pictures, or sketches or RAREP messages received at the forecasting centers. The *eye* or the centre of the cyclone can be derived from a continuous and logical sequence of observations. The geometric centre of the echo-free area will be reported as the *eye location*. If the wall cloud is not completely closed, it is still usually possible to derive an eye location with a high degree of confidence by sketching the smallest circle or oval that can be superimposed on the inner edge of the existing portion of the wall cloud. When the wall cloud is not developed fully but a centre of circulation is identifiable, then this feature should be observed and reported similar to the eye. When the eye or centre is indistinct or outside the range or the radar beam overshoots the inner eyewall when it does not extend very high, spiral band overlays are used to estimate the location of the centre. Use of logarithmic spirals has been described in detail in the Appendix II of Chapter 5 of instructions for Cyclone Detection Radar stations in I. Met. D. *Weather*

Radar Observations Manual – 1976. At times, instead of fully *closed eye*, only an arc of an eye wall may be seen which is reported as *open eye*.

Information on various characteristics of the eye wall cloud and changes thereof, is often useful to the meteorologist in assessing the intensity of the cyclone. Thus the decrease in size of a closed eye with time is usually an indication of intensification. Changes in the definition of the eye wall, improvement in its symmetry, the angle of arc visible, the radar echo intensity and the heights of echo tops in the eye wall are usually associated with changes in intensity of the storm.

Hence when an eye is seen on radar, the radar meteorologist should try to give as much information as possible on the above parameters. When the wall cloud is within a range of 200 km from the radar, the echo intensity and the echo top heights at various points should also be objectively evaluated using the isoecho/attenuator facilities and the RHI scope and applying necessary corrections. The information may be included in the appropriate code in the radar reports. Wherever necessary, additional information in plain language can be given. The polar diagrams may also be annotated to give this information.

This information should however be used with caution by the forecaster. There can be appreciable measurement errors in echo heights and intensities. The changes in anyone parameter may be only poorly correlated with storm intensity. There can also be considerable time-lag between the observed changes in eye characteristics and the changes in the winds and pressure associated with the system.

5.3. Characteristics of cyclonic disturbance

5.3.1. Location:

The location of the centre of the TC is determined based on (a) synoptic, (b) satellite (geostationary & polar orbiting satellites) and (c) Radar observations. When the TC is far away from the coast and not within the radar range, the satellite estimates get more weightage and necessary corrections are carried out based on available ships, buoys and island observations. When the TC is within the Radar range, radar estimates get maximum preference followed by satellite and coastal observations. When TC is very close to coast or over the land surface, coastal observations get the highest preference followed by radar and satellite observations. When the TC is over land, only surface observations will be the determining factor (IMD, 2013). In the pressure field, the location of lowest pressure is considered as centre and in the wind field, the centre determined by the streamline analysis of 10m wind is considered as the centre of TC. In the radar imagery, the centre is determined with the help of a logarithmic spiral, in case of spiral band structure and the centre of the eye in the radar imagery is considered as the centre of the TC with the development of eye (IMD, 1976). In satellite method, the centre of eye and the centre of central dense overcast (CDO) are considered as the centre of TC in case of eye and CDO pattern respectively. The centre estimated with a logarithmic spiral is the centre of TC in case of curved band/ spiral pattern. In case of shear pattern, the centre of low level circulation as observed in visible imagery is considered as centre of TC. As during night the visible imagery is not available, the low cloud lines cannot be detected. As a result, the location of the centre during night time cannot be determined correctly. It is more so when it is a low intensity system like depression/cyclonic storm. When the system intensifies into a severe cyclone with appearance of CDO/eye feature, the location of the centre becomes most accurate and it is the centre of the CDO/eye. The eye can be detected in both visible and IR imageries. Hence, in case of curved band pattern or CDO pattern, centre can be more accurately determined compared to shear pattern. Thus the error in determining the location of the centre at night is maximum in case of shear pattern. To overcome the above problems, the microwave imageries can be utilized. Microwave imageries at night can detect the cloud features and hence the centre of cyclone as the centre of the TC. As regards availability, the products from geostationary satellites provide half hourly images and capture radiations in visible and IR bands. These radiations are reflected from the top of cloud and hence IR and visible provide centre at the top of cloud and not from the surface level. The resolution for IR is 4/8 km and that for visible imagery is 1 km. The polar orbiting satellites provide microwave imageries which can capture radiations in oxygen band and thus provide the centre from the lower level. However, microwave imageries are not available all the time. So, we take the imagery of nearest available time and interpolate the centre for current time. Detailed procedure is available in Dvorak (1984). The entire process of determining the centre of the TC is shown in fig.1. The accuracy of estimation of location and the availability of data over the region are shown in fig.2.

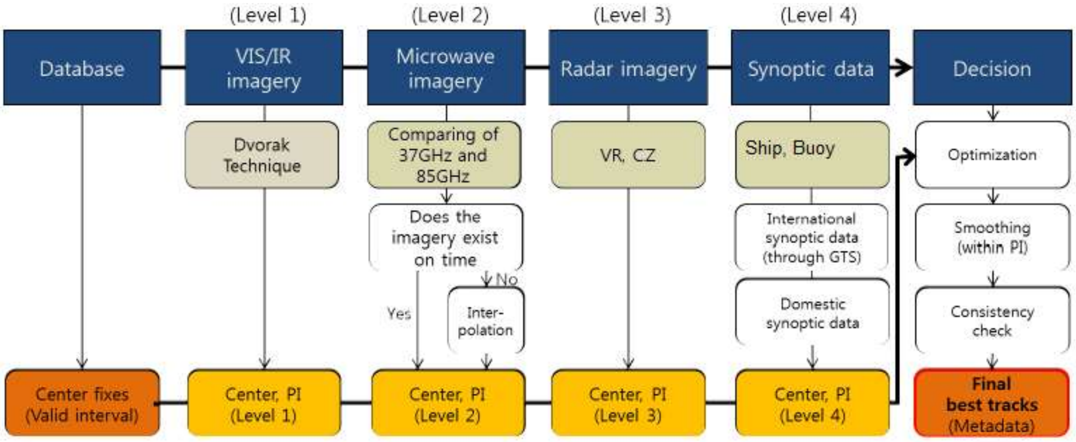


Fig.5.6 Steps involved in determination of location of centre of TC

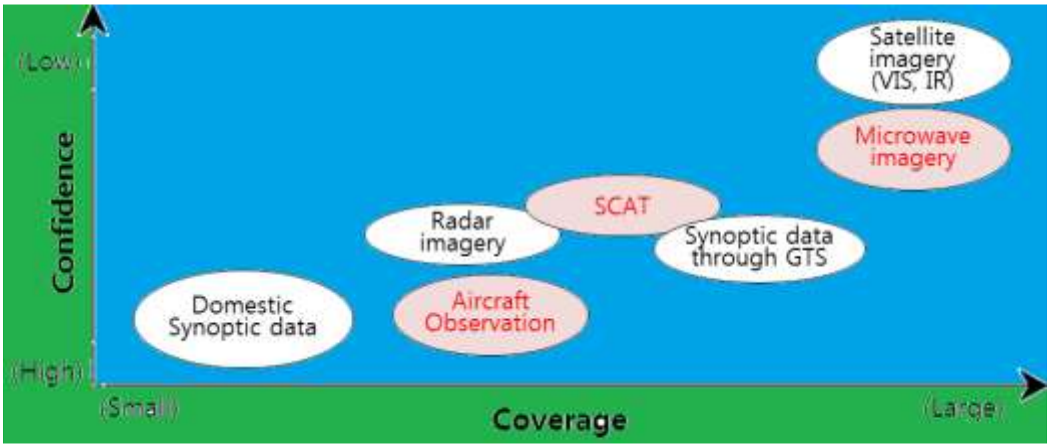


Fig.5.7 Relative availability and confidence of forecaster

5.3.2. **Intensity:**

The intensity of the system is measured in terms of 3-min average MSW at surface level (10m above ground level) (IMD, 2003, 2013). Maximum wind is determined basically from Dvoark's technique. However the following technique is followed for better accuracy:

1. Wind reported by ships and buoys.
2. Wind observed by scatteometry i.e. OCEANSAT & ASCAT.
3. Radar
4. CMV/ AMV reduced to 10 meter wind

Various steps involved in determination of intensity are shown in fig.3.

When TC is over deep sea, Dvorak's technique (Dvorak, 1984) is used for estimation of intensity. For this purpose, the intensity of the tropical system is indicated by a code figure called T Number based on pattern recognition technique by Dvorak (1984). This technique relies on four distinct geophysical properties that relate organized cloud pattern to TC intensity. Two are kinematic namely vorticity and vertical wind shear and the other two are thermodynamical viz. convection and core temperature. The strength and distribution of circular winds (by implication vorticity) in a TC organizes the cloud into the patterns that Dvorak relates to MSW. External/environmental shear is a kinematic force that works to distort the vorticity and hence the cloud pattern. Dvorak found that degree of distortion was also related to MSW. Dvorak Technique uses a scalefrom T1 to T8 in the interval of 0.5. The relation between T.No., MSW and Pressure drop is shown in table 1.

This classification of intensity is based on two parameters arrived on an analysis of the cloud features as seen in the satellite pictures of the disturbance. These are 1) the central features (CF) which define the cloud system centre and its relation to dense overcast clouds and 2) the outer banding features (BF). The intensity of the tropical system is indicated by a code figure called T Number which is the sum of the CF and BF.

In central dense overcast pattern, size and temperature of the CDO determines the intensity. In shear pattern, the distance between the LLCC and the sharp boundary of the convective cloud determines the intensity of the system. In the curved band/spiral band pattern, the logarithmic spiral is used to estimate number of parts of the logarithmic spiral covered with convective clouds and accordingly T number is determined.

In case of TCs with eyes the technique determines the temperature of the eye and the surrounding eye wall clouds using IR data and relates to the intensity with warmer/cooler eye/wall cloud temperatures respectively indicating greater intensity.

Another feature of the technique is the Current Intensity number (C.I.) which relates directly to the intensity (in term of MSW) of the TC. The C.I. number may differ from the T number on some occasions to account for certain factors which are not directly related to cloud features. The empirical relationship between C.I .number and the maximum wind speeds (according to Dvorak) are given in Table 1. Col. 3 of the Table 1 gives the pressure drop as applicable for Indian Sea area using the relation Vmax = 14.2 X SQRT (ΔP).

When the system is in the Radar range, we consider the radial velocity observed by Radar for intensity estimation (IMD, 1976). The radial velocity observed from Radar is converted to 10m wind using appropriate conversion factor (Raghavan, 1997). When the system is over the coast, the observations from High Wind Speed Recorders (HWSRs) and conventional anemometers are considered for intensity estimation.

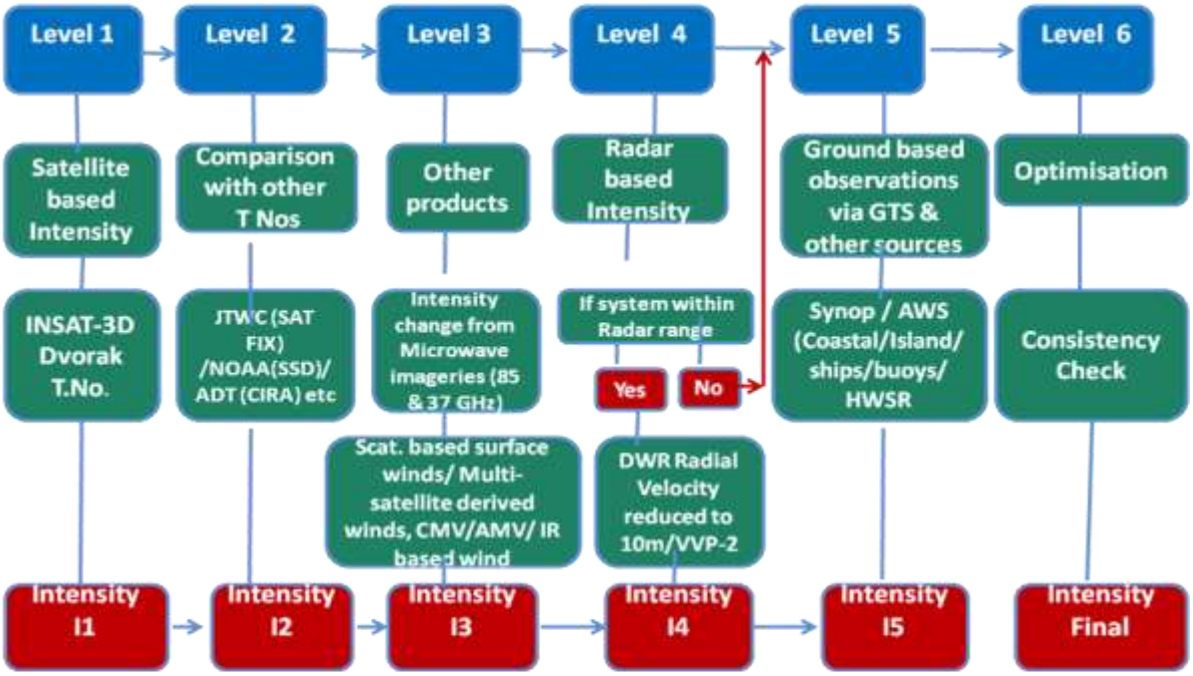


Fig.5.8 Steps involved in determination of Intensity of a TC

5.3.3. Estimated Central Pressure (ECP), Pressure drop, and pressure of outer most closed isobar(OCI)

Estimated Central Pressure is derived basically by Dvorak's technique given in Table 5.1. Also the pressure reported by ship, buoy, coastal/island observation is taken into consideration. The pressure drop (ΔP) at the centre is defined as the difference between P_o and P_c, where P_o is the pressure of outermost closed isobar (OCI) and P_c is the pressure at the centre of TC. It is is obtained using the relation Vmax = 14.2 X SQRT (ΔP) (Mishra and Gupta, 1976). The outermost closed isobar (OCI) is defined as the isobar surrounding the centre of the system which is circular or elliptical in nature and beyond which the isobars are either not closed or deformed. As the BoB and AS are small Ocean basins and there are observations from coast, island, ships and buoys, it is possible on most of the occassions to find out the OCI. Using P_o and ΔP, P_c can be determined. However, further corrections are applied based on available MSLP values from nearby ships, buoys and island observations.

5.3.4. Radius of outermost closed isobar (ROCI):

The ROCI is defined as the radius of OCI, if it happens to be circular. If OCI is elliptical, the average of semi-major and semi-minor axes of the ellipse will be the ROCI.

5.3.5. Radius of 28, 34, 50 and 64 knots wind:

The structure of TC is described in terms of maximum radial extent of the winds in four geographical quadrants, viz., NW, NE, SW and SE for thresholds of 28, 34, 50 and 64 knots, referred to as R28, R34, R50 & R64. The primary methods for TC wind field estimation by IMD involves satellite based scatterometer estimates, cloud motion vectors, water vapour based wind vectors, wind estimates from brightness temperatures, multiplatform satellite based wind developed by CIRA, estimates from RADAR products and NWP model analyses products (IMD, 2013, Mohapatra and Sharma, 2015). Consensus analysis that gathers all the available observation and uses synoptic and climatological guidance are utilised to issue best estimates of surface wind radii in four geographical quadrants. Various steps involved in determination of intensity are shown in fig.4.

The climatological guidance is based on the study carried out by Mohapatra and Sharma (2015). Climatologically, it is seen that during cyclonic storm (CS) stage, for an increase in MSW by 5 knots there is an increase in R34 by 15 km. When the system intensifies to a severe cyclonic storm (SCS), for an increase of 5 knots in intensity, the wind radii increases by 25 km and upon intensification into VSCS, there is an increase of 5 km when MSW increases by 5 knots. The detailed classification of TCs over the NIO into CS, SCS & VSCS etc. are given in IMD (2013).

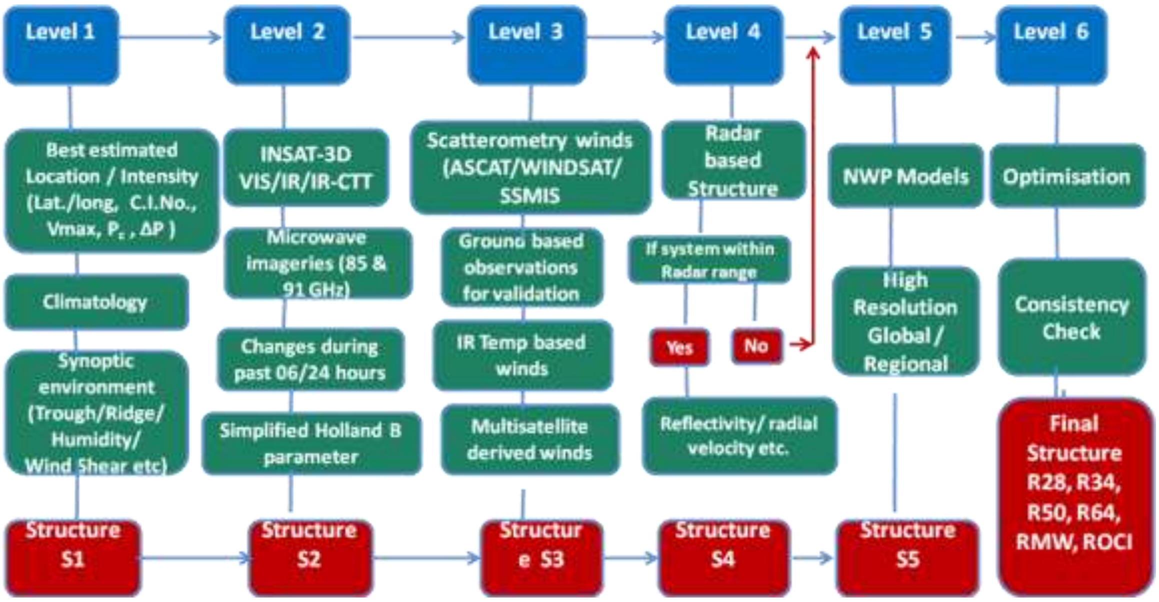


Fig.5.9 Steps involved in determination of structure of a TC

5.3.6. Radius of Maximum Wind (RMW):

There is no direct observation of Radius of Maximum Wind (RMW). It is the distance of location of maximum wind from the centre of the cyclone. It is estimated from maximum wind and place of occurrence as discussed above. In addition radius of maximum wind can be calculated from satellite and radar. In radar the radius of maximum reflectivity is considered as RMW. In satellite the radius of maximum reflectivity in visible imagery and the radius of lowest cloud temperature in IR imagery is considered as radius RMW. In the absence reliable observations climatology may be referred.

RMW is defined as the average distance from the centre of the TC to the location of occurrence of maximum wind in the wall cloud region. RMW can be estimated by the satellite and Radar observations as well as the derived winds from the satellites. Based on the satellite IR imagery with cloud top temperature (CTT) distributions, the zone of maximum reflectivity in the wall cloud region can be determined (Kalsi, 2002). The distance from the centre to the location of coldest temperature surrounding the centre determines the radius of maximum reflectivity (RMR). In this process, we assume that the RMW is same as the RMR. As the IR imageries have resolution of 4/8 km, there can be an error of 4/8 km in this process. Further, there can be error in estimation of location leading to error in RMW. As the centre determination is most accurate for the eye pattern followed by CDO, curved band and shear pattern, the accuracy in determination of RMW will also be maximium in eye pattern and minimum in shear pattern of the TC. With respect to the intensity of TC, the confidence in RMW estimate will be lower in case of low intensity storms and will be higher in case of high intensity storms llike VSCS Phailin and Hudhud. RMW can be better estimated from Radar, when the system is in the Radar range. In Radar, RMW is defined as RMR (Raghavan, 1997, 2013). RMW is also available from the winds derived from multiplatform satellite observations developed by CIRA. Detailed study of CIRA data is given by Knaff et al (2011). However, there is limitation in estimation of RMW through derived winds as the number of observations in the core region may be less and standard deviation in estimation of RMW is high. As a thumb rule, the RMW is assumed as half of the average radial extension of the core wind around the centre of TC e.g. if a TC is a VSCS (MSW>64 knots), the average radial extent of 64 knots winds will be considered for calculating the RMW. If it is a severe cyclonic storm (SCS), (MSW>47 knots) or a cyclonic storm (MSW>34 knots), the average radial extent of 50 knots or 34 knots winds respectively will be considered for calculating the RMW.

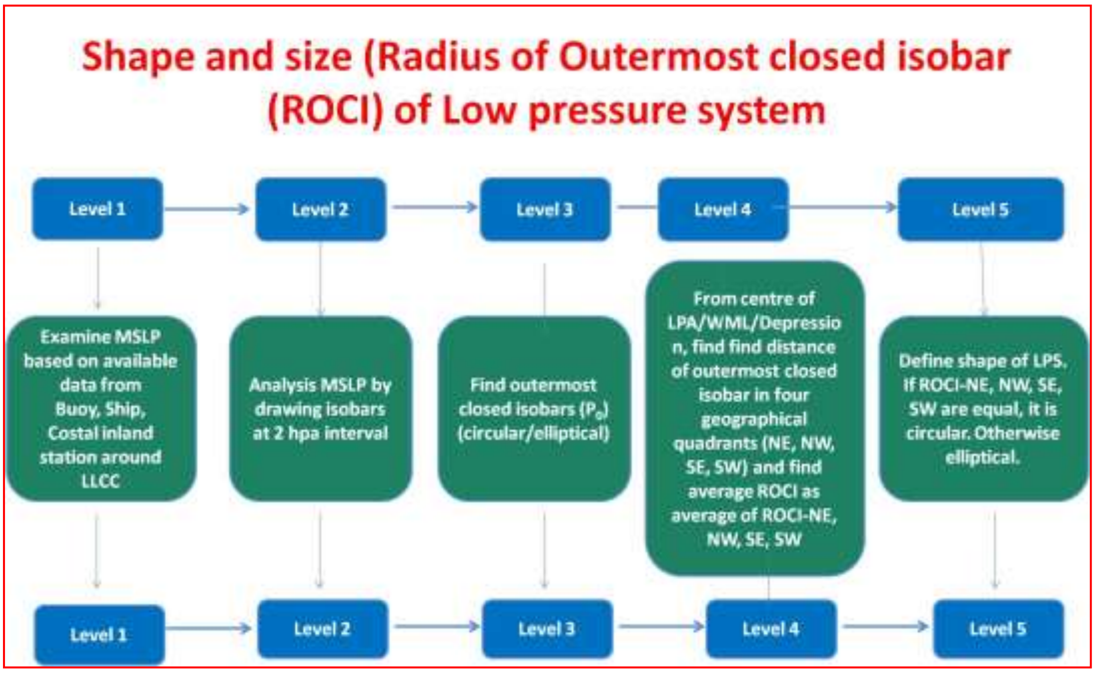


Fig.5.10 Steps involved in determination of shape and size of ROCI

5.3.7. Depth of convection:

The vertical depth of the system is considered in 3 categories viz. shallow, medium and deep for the NIO. It is considered as shallow if it is a depression (MSW 17-27 knots), medium if it is a deep depression (MSW 28-33 knots) and deep for TCs (MSW ≥ 34 knots).

5.3.8. Heavy Rain:

Realised heavy rain can be analised from (1) Actual observations. (2) Quantitative precipitation (QPE) from satellite (3) QPE from radar and Surface Rainfall Intensity (SRI). from Radar (4) Tropical Rainfall Measurement Mission (TRMM). The distribution and intensity of rainfall is described as given in Table 5.2 and 5.3 respectively.

Table 5.2. Distribution of rainfall

Distribution	No. Of places	Description
Isolated	One or two places	<25% of area gets rainfall
Scattered	A few places	(26 –50)% of area gets rainfall
Fairly Widespread	A many places	(51 – 75)% of area gets rainfall
Wide Spread	Most place	(76 – 100)% of area gets rainfall

Table 5.3. Intensity of rainfall

Descriptive term used	Rainfall amount in mm
No rain	0.0
Very light rain	0.1- 2.4
Light rain	2.5 – 15.5
Moderate rain	15.6 – 64.4
Heavy rain	64.5 – 115.5
Very heavy rain	115.6 – 204.4
Extremely heavy rain	204.5 or more
Exceptionally heavy rain	When the amount is a value near about highest recorded rainfall at or near the station for the month or season. However, this term will be used only when the actual rainfall amount exceeds 12 cm.

5.3.9. State of Sea:

State of sea is described in bulletin in qualitative terms as given in Table 5.4. The sea condition is described based on the prevailing wind condition. Though it is qualitative it corresponds to the height of the wave as mentioned in the table. Further the sea condition analised based on NWP models. The following websites should be followed for this purpose.

1. INCOIS: http://www.incois.gov.in
2. NCMRWF: http://www.ncmrwf.gov.in/
3. ECMWF: http://www.ecmwf.int

Table 5.4. Sea Condition

Descriptive Term	Height in metres	Wind Speed in Knots (Kmph)	Beaufort Scale
Calm (glassy)	0	0	0
Calm (rippled)	0 - 0.1	1 - 3 (2 - 6)	1
Smooth (waveless)	0.1 - 0.5	4 - 10 (7 - 19)	2 - 3
Slight	0.5 - 1.25	11 - 16 (20 - 30)	4
Moderate	1.25 - 2.5	17 - 21 (31 - 39)	5
Rough	2.5 - 4.0	22 - 27 (41 - 50)	6
Very rough	4.0 - 6.0	28 - 33 (52 - 61)	7
High	6.0 - 9.0	34 - 40 (63 - 74)	8
Very high	9.0 - 14.0	41 - 63 (76 - 117)	9 - 11
Phenomenal	Over 14	64 or above (119 or above)	12

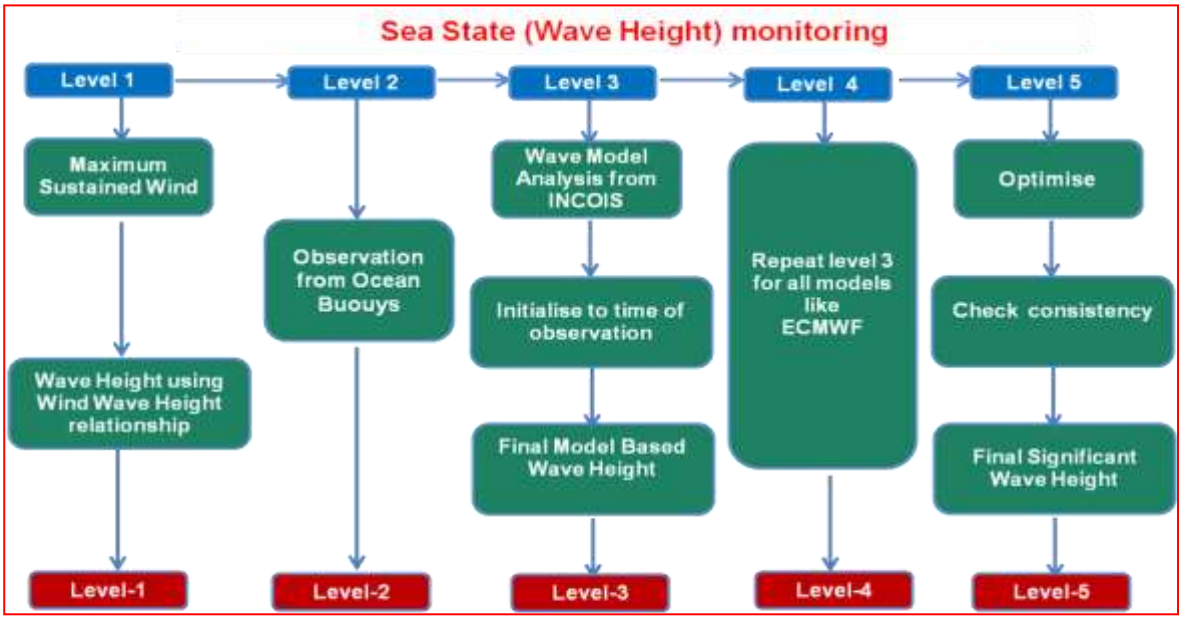


Fig.5.11 Steps involved in Sea State Monitoring

5.4. Prediction of Characteristics of Cyclonic Disturbances

Following elements are predicted.

(i) Track

(ii) Intensity (Maximum wind)

(iii) Radius of maxixmum wind

(iv) Radii of 28, 34, 50 and 64 knots wind in four quadrants

(v) Heavy rainfall (Time of occurrence, area of occurrence, intensity)

(vi) Squally/Gale wind at the time of landfall (Time of occurrence, area of occurrence, intensity)

(vii) Storm surge (Time of occurrence, area of occurrence, height and area to be inundated)

5.4.1. TC Analysis Tools and Techniques

Various kinds of analytical procedure are described in Cyclone Manual (IMD, 2003). A systematic check list is prepared for identification of location and intensity of TC and also for the prediction of track and intensity. The procedure necessarily deals with determination of location and intensity along with other characteristics of the TC like associated sustained maximum wind, estimated central pressure and pressure drop at the centre, shape and size, radius of outermost closed isobar, point and time of landfall, if any or area of dissipation etc. with the available observations in the storm region.

To ensure the availability of the data and forecast products from various national and international sources at Cyclone Warning Division, IMD, New Delhi, an institutional mechanism has been developed in consultation with all the stake holders.

The TC analysis, prediction and decision-making process is made by blending scientifically based conceptual models, dynamical & statistical models, meteorological datasets, technology and expertise. Data from conventional observational network, automatic weather stations (AWS), buoy & ship observations, cyclone detection radars and satellites are used for this purpose. A weather analysis and forecasting system in a digital environment is used to plot and analyse different weather parameters, satellite, Radar and numerical weather prediction (NWP) model products. The manual synoptic weather forecasting has been replaced by hybrid systems in which synoptic method could be overlaid on NWP models supported by modern graphical and GIS applications to produce high quality analyses and forecast products. The automation of the process has increased the efficiency of system, visibility of IMD and utility of warning products. The TC Module installed in this forecasting system has the following facilities.

- Analysis of all synoptic, satellite and NWP model products for genesis, intensity and track monitoring and prediction
- Preparation of past and forecast tracks upto 120 hrs
- Depiction of uncertainty in track forecast
- Structure forecasting (Forecast of wind in different sectors of cyclone)

A few examples on the products of TC module are shown in Figure 5.6. However all the data are not still available in TCM through synergie system. For better monitoring and prediction, additional help is taken of ftp and websites to collect and analyse:

- Radar data and products from IMD's radar network and neighbouring countries
- Satellite imageries and products from IMD and international centres
- Data, analysis and forecast products from various national and international centres

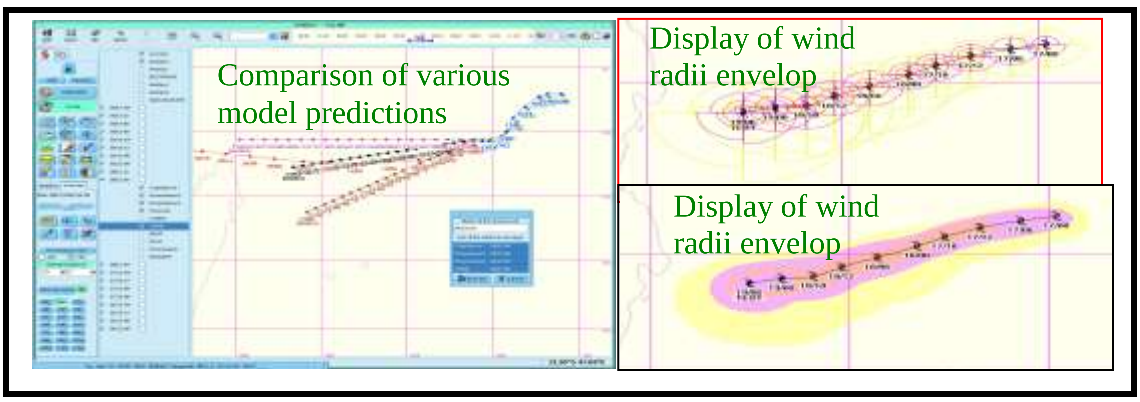


Fig.5.12. Utility of modernised cyclone analysis and forecasting system

The synoptic charts are prepared and analysed every three hour to monitor the TCs over the NIO. Cloud imageries from Geostationary Meteorological Satellites INSAT-3D and 3DR are the main sources of information for the analysis of TCs over the data-sparse region of NIO. Considering the intensification of cyclonic storms into severe cyclonic storms over 2.5 x 2.5 degree blocks of the Bay of Bengal and Arabian Sea, the frequency of such cases increased over the deep Oceanic areas like the case of genesis of depression and its intensification into cyclonic storms during satellite era (Mohapatra et al, 2012). There has been also increase along the entire east coast as well as Gujarat coast. Unlike the case of genesis of depression and its intensification into cyclones, the frequency of intensification of cyclone into the severe cyclone also increased over the head Bay of Bengal since 1961 due to better detection. Dvorak technique (Dvorak, 1984) is used to estimate the location and intensity of the system since its inception in 1960s. Data from ocean buoys also provide vital information. Ship observations are also used critically during the cyclonic disturbance period. A standard operation procedure is followed for monitoring and prediction, details of which are given in the following section.

5.4.2. cyclone Track Forecasting

Currently following methods are used by IMD for track forecasting.

i) Statistical Techniques
- Analogue
- Persistence
- Climatology
- Climatologi and persistence (CLIPER) developed
- Chaos theory and Generic Algorithm method) developed by Indian Space Research Organisation (ISRO)

ii) Synoptic Techniques – Empirical techniques

iii) Satellite Techniques- Empirical technique

iv) Radar Techniques- Empirical technique

v) NWP Models
- Individual models (Global and regional)
- IMDGFS (1534), ARP (Meteo-France), ECMWF, JMA, UKMO, NCEP, WRF, HWRF (IMD), NCMRWF-UM (NCUM), UM regional model (UMRM)
- MME (IMD) and MME based on TC Module (TCM)
- Ensemble prediction system (EPS) (Strike probability, Location specific probability) based on GFS, UKMO, ECMWF models NCUM etc.

- TIGGE EPS products

Following NWP products from deterministic models are considered useful for cyclone warning apart from track and intensity forecast.

❖ Analysed and forecast grid point fields of basic flow variables at different pressure levels:

❖ Sea level pressure

❖ Geopotential

❖ Wind

❖ Temperature

❖ Humidity

❖ Forecast rainfall

❖ Derived fields :

- Vorticity
- Divergence
- Vertical motion
- Integrated moisture flux divergence
- Precipitable water
- Vertical wind shear
- Equivalent potential temperature and its lapse rate.
- Convective Available Potential Energy (CAPE) and Convective Inhibition Energy (CINE)

Apart from the above models, the model product from INCOIS/NCMRWF and storm surge models of IIT, Delhi are considered for wave forecasting and storm surge prediction. Examples of track prediction by individual models in case of TC, Phailin and EPS product in case of TC, Vardah are ashown in Fig.5.7(a) and Fig.5.7(b) respectively.

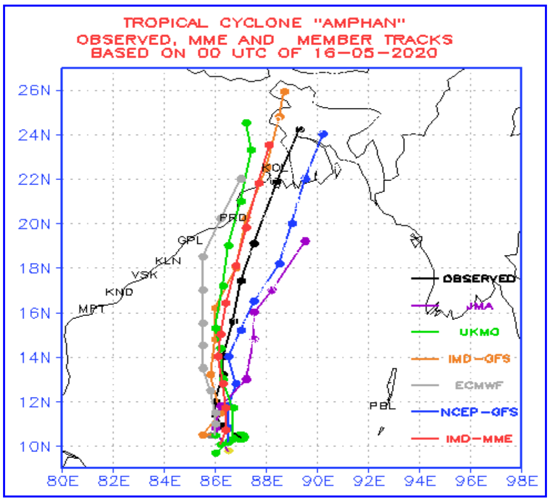


Fig.5.13 (a). Track prediction of TC, VARDAH by NWP models

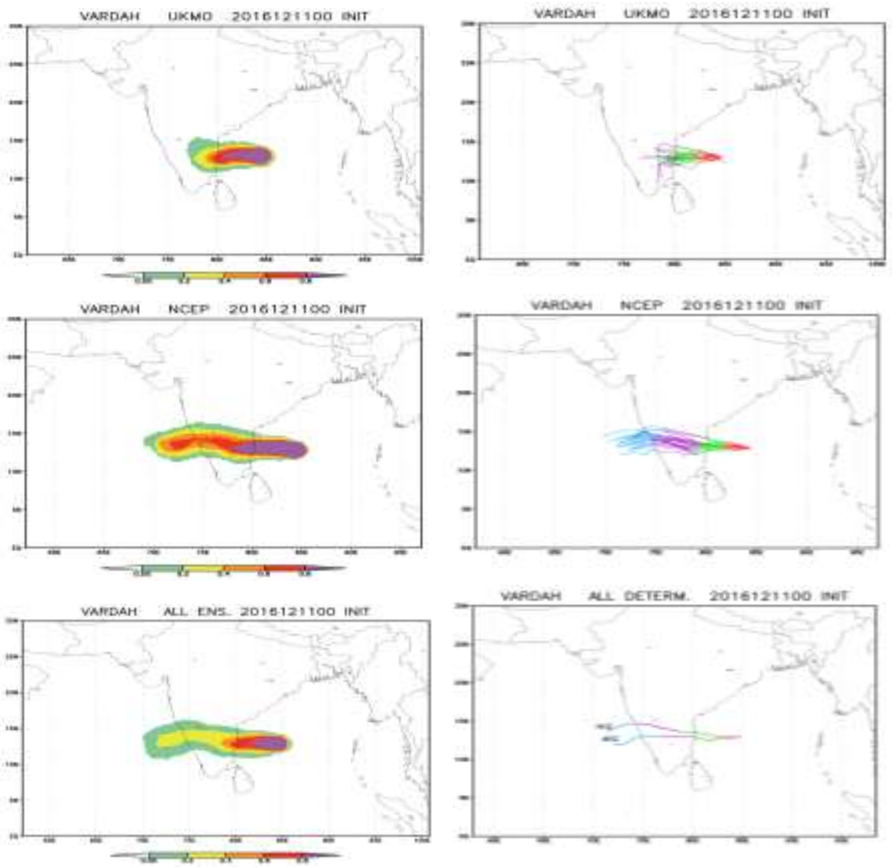


Fig.5.13 (b). Track prediction of TC, Vardah by EPS

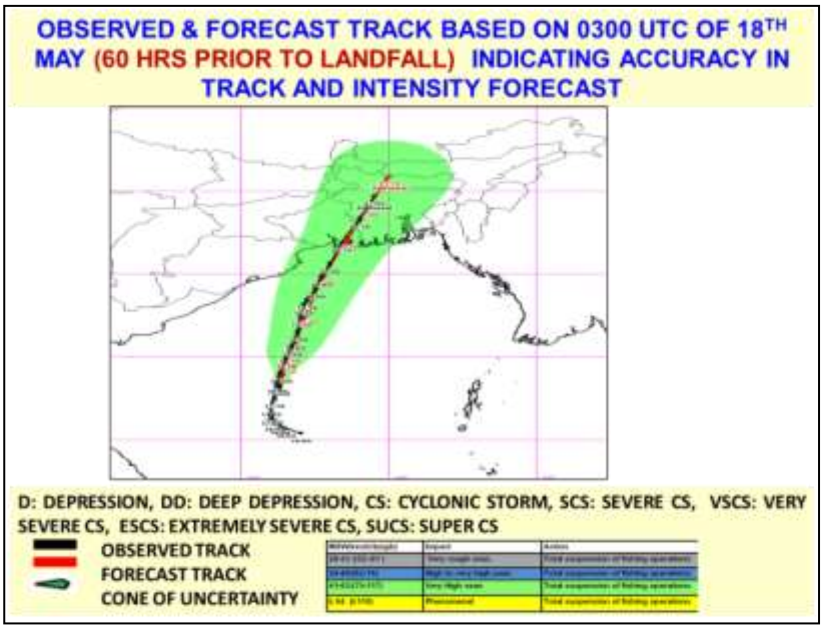


Fig.5.14. A typical example of observed and forecast track of SuCS Amphan

Unlike National Hurricane Centre (NHC), USA, IMD does not use the interpolated track forecasts from the late models. All the NWP models as mentioned above are late models as the model output is available to forecasters as late as six to twelve hrs. Similarly all the NWP models as mentioned above do not use synthetic vortex and vortex relocation. HWRF etc. use synthetic vortex, global model like ECMWF does not use these processes.

In the synoptic method, prevailing environmental conditions like wind shear, low to upper level wind and other characteristics as mentioned in cyclone manaual and check list (IMD, 2003) are considered. All these fields in the NWP model analyses and forecasts are also considered. The development of characteristic features in satellite and radar observations is also taken into consideration for predicting the intensity. While, the synoptic, statistical and satellite/radar guidances help in short range track forecast (upto 12 hrs), the NWP guidance is mainly used for 24-120 hr forecasts. Hence, the RSMC forecast tracks result from a manually analyzed forecasting process, which relies on output from several NWP models (RSMC, 2010) as discussed above. Consensus forecasts that gather all or part of the numerical forecast tracks and uses synoptic and statistical guidance are utilised to issue official forecast.

IMD introduced the objective TC track forecast valid for next 24 hrs over the NIO (NIO) in 2003. It further extended the validity period upto 72 hrs in 2009 and upto 120 hrs in 2013. The track forecast has been issued by RSMC, New Delhi from deep depression stage onwards since 2009 for 12, 24, 36, 48, 60 and 72 hr forecast periods. The TC forecast is issued 6 times a day at the interval of three hours, i.e. based on 00, 03, 06, 09, 12, 15, 18 and 21 UTC observations. The forecasts are issued about three hours after the above mentioned observation time. An example of the product during cyclone Vardah is shown in Figure 5.8. It may be mentioned that the RSMC, Tokyo introduced 24 hr objective forecast in 1982, 48 hr forecast in 1988, 72 hr forecast in 1997 and 96 & 120 hr forecast in 2009 for northwest Pacific Ocean. Similarly, National Hurricane Centre and RSMC, Miami, USA introduced 24 hr objective forecast in 1954, 48 hr forecast in 1961, 72 hr forecast in 1972 and 96 & 120 hr forecast in 2001 for Atlantic Ocean. Prior to 2003, the TC forecasts issued by IMD for the NIO were subjective and textual in form without mentioning expected location of the TC in 12 and 24 hr forecast period.

5.4.3. Cone of uncertainty in Track forecast

The "cone of uncertainty"-also known colloquially as the "cone of death," "cone of probability," and "cone of error"-represents the forecast track of the centre of a TC and the likely error in the forecast track based on predictive skill of past years. Most World meteorological Organisation (WMO) designated Regional Specialised Meteorological Centre (RSMCs) for TCs including Miami, Florida; Tokyo, Japan; and Hawaii, USA and TC Warning Centers (TCWCs) currently display COU around their official track forecasts, using a climatological method based on their area of responsibility. For each forecast lead time, an uncertainty circle is built whose radius is taken as a fixed quantile (e.g., 67% for Miami, 70%

for Tokyo) of the distribution of direct position error (DPE) computed over several previous seasons. The Joint Typhoon Warning Centre (JTWC) in Hawaii produces COU for TCs over Pacific Ocean and Indian Ocean, whose radii are the sum of the climatological average DPE and the predicted 34-knot wind radius.

The cone of uncertainty in the forecast has been introduced with effect from the cyclone, 'WARD' during December, 2009. It is helpful to the decision makers as it indicates the standard forecast errors in the forecast for different periods like 12, 24, 36, 48, 60 and 72 hrs since 2009 and upto 120 hrs since 2013. The radii of circles used to construct the COU are 75, 150, 200, 250, 300 and 350 km respectively for 12, 24, 36, 48, 60 and 72 hrs forecasts based on past average errors of official forecasts upto 72 hrs and extraploted errors for 84,96,108 and 120 hrs forecast. It is found that the observed track lies within the forecast COU in about 60% of the cases. It is in agreement with those over other Ocean basins. The entire track of the TC remains within the COU roughly 60-70% of the time over the northern Atlantic Ocean and Pacific Oceans.

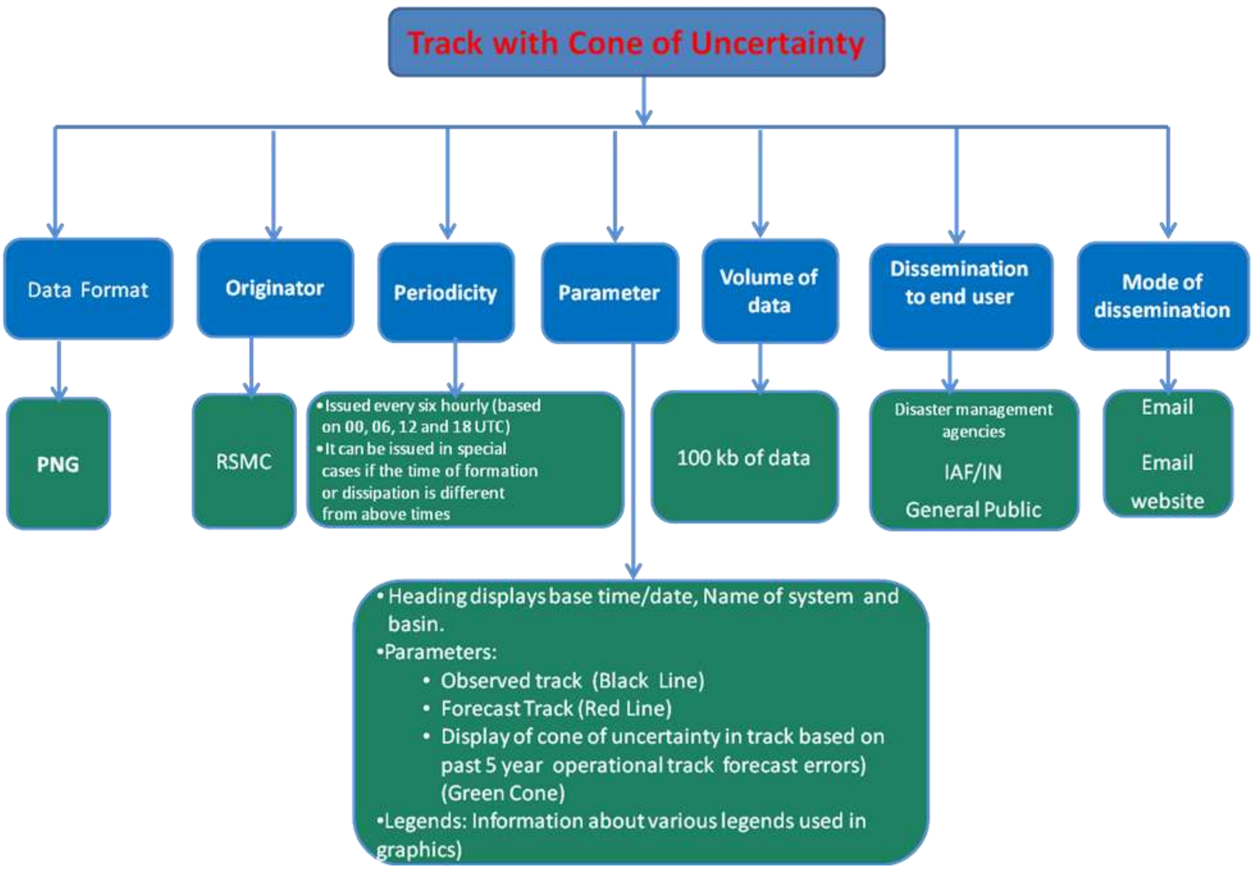


Fig.5.15 Steps involved in forecasting track with cone of uncertainty

5.4.4. Intensity forecasting

The intensity forecast has been issued by RSMC, New Delhi from deep depression stage onwards since 2009 for 12, 24, 36, 48, 60 and 72 hr forecast periods. It has been issued during CS stage onwards during 2003-2008 and for 12 and 24 hrs forecast periods only. The TC intensity forecast is issued 4 times a day at the interval of six hours, i.e. based on 00, 06, 12 and 18 UTC observations valid upto 24 hrs during 2003-2008 and upto 72 hrs since 2009 in every three hourly intervals. The forecasts are issued about three hours after the above mentioned observation time. Following methods are used by IMD for intensity forecasting of TCs over the NIO.

i) Statistical Techniques
   a. Analogue
   b. Persistence
   c. Climatology
ii) Synoptic Technique – Empirical Techniques
iii) Satellite Technique- Empirical technique
iv) Radar Technique- Empirical technique
v) NWP Models
   • Individual models (Global and regional)
      • IMDGFS (382, 574), ARP (Meteo-France), ECMWF, JMA, UKMO, NCEP
      • WRF (IMD, IITD, IAF), HWRF (IMD)
vi) Dynamical Statistical Model (Statistical Cyclone Intensity Prediction-SCIP)

5.4.4.1. Statistical Dynamical model for Cyclone Intensity Prediction

A statistical-dynamical model for cyclone intensity prediction (SCIP) has been implemented for real time forecasting of 12 hourly intensity up to 120 hours. The model parameters are derived based on model analysis fields of past cyclones. The parameters selected as predictors are: Initial storm intensity, Intensity changes during past 12 hours, Storm motion speed, Initial storm latitude position, Vertical wind shear averaged along the storm track, Vorticity at 850 hPa, Divergence at 200 hPa and Sea Surface Temperature (SST). For the real-time forecasting, model parameters are derived based on the forecast fields of ECMWF model. The method is found to be promising for the operational use.

There is no CLIPER model for intensity prediction unlike the Atlantic and Pacific basins. In the synoptic method, prevailing environmental conditions like wind shear, sea surface temperature, Ocean thermal energy, low level inflow, upper level outflow etc as mentioned in the section 5.1.1 for genesis are considered for intensification also. All these fields in the NWP model analyses and forecasts are also considered. The development of characteristic features in satellite and radar observations is also taken into consideration for predicting the intensity. While, the synoptic, statistical and satellite/radar guidances help in short range intensity forecast (upto 12/24 hrs), the NWP guidance is mainly used for 24-120 hr forecasts. Hence, the RSMC, New Delhi official forecast intensity results from a manually analyzed forecasting process, which relies on output from several NWP models (RSMC, 2010) as mentioned above. Consensus forecasts that gather all or part of the numerical forecast intensities and uses synoptic and statistical guidance are utilised to issue official forecast.

5.4.5. Quadrant wind forecasting

The TC wind radii forecasts are generated in terms of the radii of 34kts, 50kts and 64kts (1kt = 0.52 ms^{-1} or 1.85 kmph) winds in four geographical quadrants around the TC (thereafter referred to individually as R34, R50 and R64 for 34kts, 50kts and 64kts wind thresholds respectively or collectively as wind radii in units of nautical miles (1nm=1.85km)). These wind radii represent the maximum radial extent of winds reaching 34kts, 50kts and 64kts in each quadrant. The initial estimation and forecast of the wind radii of TC is rather subjective and strongly dependent on the data availability, climatology and analysis methods. The subjectivity and reliance on climatology is amplified in NIO in the absence of aircraft observations. However, recently with the advent of easily accessible remote sensing derived surface and near surface winds (e.g. Ocean Sat., Special Sensor Microwave Imager (SSMI), low level atmospheric motion vectors and Advanced Microwave Sounder Unit (AMSU) retrival methods) and advances in real time data analysis capabilities, IMD introduced TC wind radii monitoring and prediction upto 72 hrs product in Oct.,2010 it was extended to 120 hrs since 2014. The inputs for monitoring are obtained from following observations

- Ship
- Buoy
- ScatSat.
- Lower level Atmospheric Motion Vectors
- Cloud Motion Vectors
- Water vapour based wind vectors
- Special Sensor Microwave Imager (SSMI) data
- Advanced Microwave Sounder Unit (AMSU)
- Latest advances in real time data analysis capabilities
- DWR(when system is within the radar range)
- Coastal wind observations

The initial wind radii estimates have become less subjective due to the tools and products mentioned above. While better initial estimates of R34, R50 and R64 are becoming available, forecasting these wind radii remains a difficult task. It is mainly because of the fact that we do not have any objective wind radii forecast methods and current NWP models fail to produce forecasts that are better than climatology.

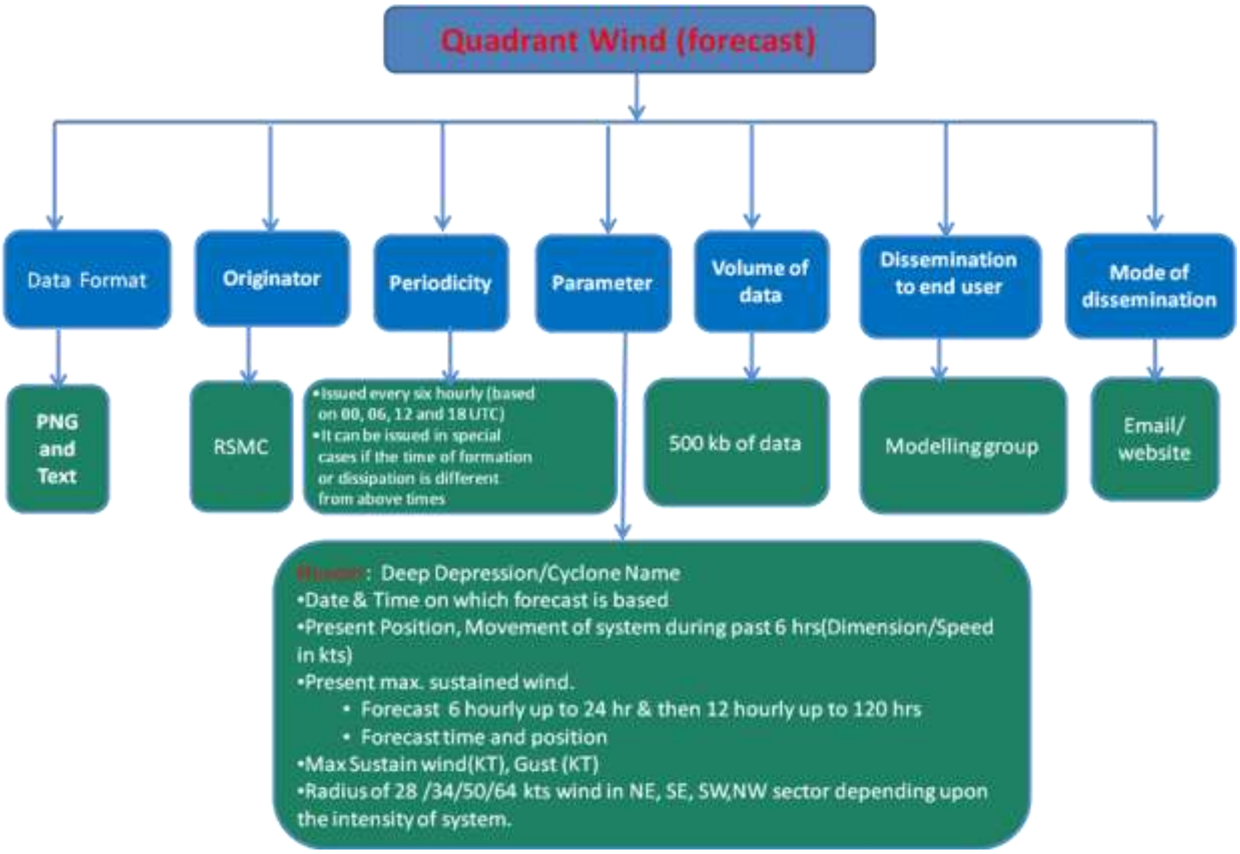


Fig.5.16 Flow Chart for Quadrant Wind forecasting

The road map for monitoring and prediction of quadrant wind radii is given below.

(a) Date and time of initial condition
(b) Official location and Intensity (T/ C.I. No., maximum wind and centre position)
(c) Initial TC wind radii estimation

- Wind radii based on Scatsat/ASCAT/Windsat wind
- SSMI based wind radii
- Wind radii based on lower level atmospheric motion vectors
- Wind radii by AMSU retrieval method
- Wind radii based on global and regional NWP model analyses
- Wind radii based on DWR wind retrieval
- Value addition based on coastal, ship and buoy observations

- Climatological consideration

(d) Official forecast of TC intensity and track upto 120 hrs.

(e) Persistence forecast based on initial wind radii and past 12 hrs trend.

(f) Climatological forecast of TC wind radii

(g) NWP Model forecasts of 10 metre wind radii

  - Select the model most appropriate to initial condition
  - Compare the wind field distribution to the actual wind
  - Calculate the wind radii in four quadrants for the threshold of 34kts, 50kts and 64kts surface wind
  - Make corrections based on actual wind, climatology, intensity of the system and radius of maximum wind

(h) Official TC wind radii forecast in four quadrants for the threshold of 34kts, 50kts and 64kts based on S.N. (b-g)

A typical example of the quadrant wind radii product is shown in Fig.5.9.

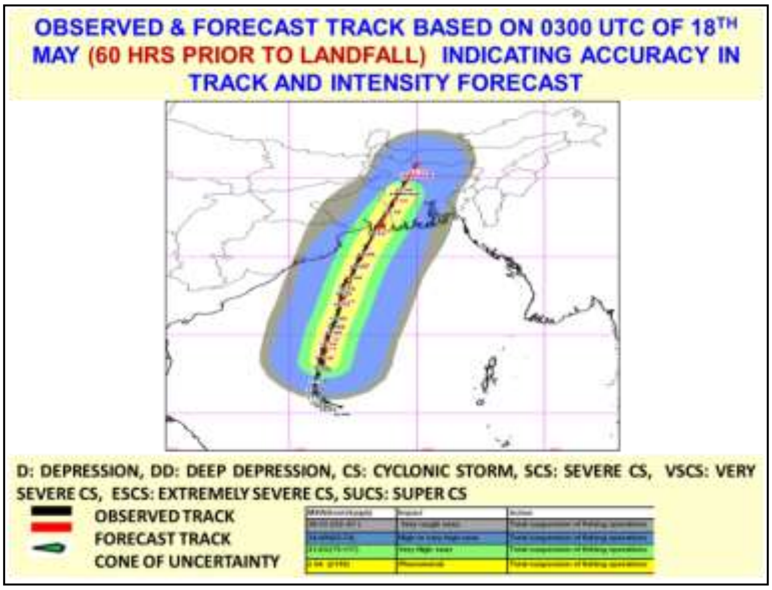


Fig.5.17. A typical graphical presentation of quadrant wind forecast during SuCS AMPHAN

5.4.6. Prediction of heavy rainfall

The following are the parameters for prediction of rainfall

- Time of commencement
- Duration
- Area
- Intensity

The followings are the methods for prediction of heavy rainfall

- Synoptic method
- Climatology method
- Satellite method
- Radar technique
- NWP technique

Typical rainfall prediction by NWP model in association with cyclone Phyan is shown in Fig. 5.10. While NWP technique provides prediction for different lead period, Satellite and radar provides quantitative precipitation estimates during past 3/12/24 hrs. The intensity and spatial distribution of rainfall estimated by satellite and radar are extrapolated to issue forecast. In synoptic and climatology method, synoptic climatology of rainfall, intensity and spatial distribution are used. In this method the forecast depends on the expertise of the forecaster. The final forecast is the consensus arrived from various methods as mentioned above.

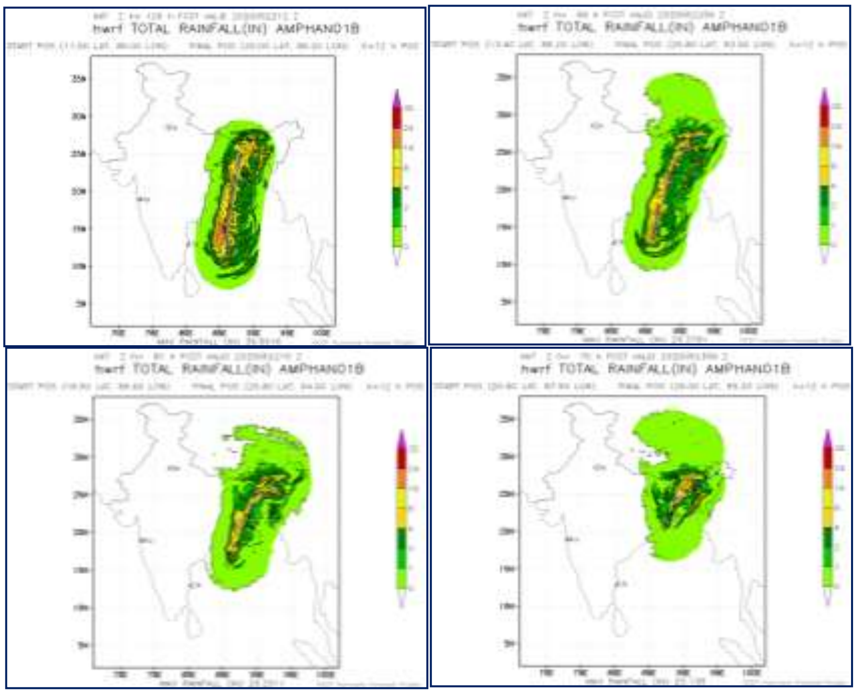


Fig.5.18. Typical rainfall prediction by HWRF model

5.4.7. Gale wind prediction

The following are the parameters for prediction of gale wind

- Time of commencement
- Duration
- Area
- Intensity

The following methods are utilised for prediction of gale wind

- Synoptic method
- Climatological method
- Satellite method (region of maximum reflectivity and mesoscale vortices)
- Radar technique (Uniform wind technique, PPV2 and Radial Velocity)
- NWP technique (10 meter wind forecast)
- Dynamical statistical model

In the satellite method region of maximum reflectivity and mesoscale vortices are assumed to be associated with higher wind. In radar technique, the direct wind observation are available though uniform IMD technique, PPV2 product and radii velocity measurements. The wind estimates from satellite and radar and other observations are extrapolated to forecast the wind. Maximum sustained wind are also available from other sources like Scatteometry wind Oceansat, Wind sat, ASCAT, Buoy, Ships apart from estimated by Dvork technique.

Though the wind forecasts by the models are underestimated the initial condition of wind from the model can be corrected based on actual observations and accordingly model forecast wind can be derived. The forecast based on dynamical statistical model also can be utilised in the similar manner.

5.4.8. Storm surge

The followings are the parameters for prediction of storm surge.

- Time of commencement
- Duration
- Area I
- Intensity

The followings are the methods used for prediction of storm surge

- IMD Nomogram (Ghosh model)
- IIT Delhi Model
- Probable maximum storm surge

Nomogram and IIT Delhi model are used to calculate the storm surge. The probable maximum storm surge should be referred while issuing storm surge forecast for comparison.

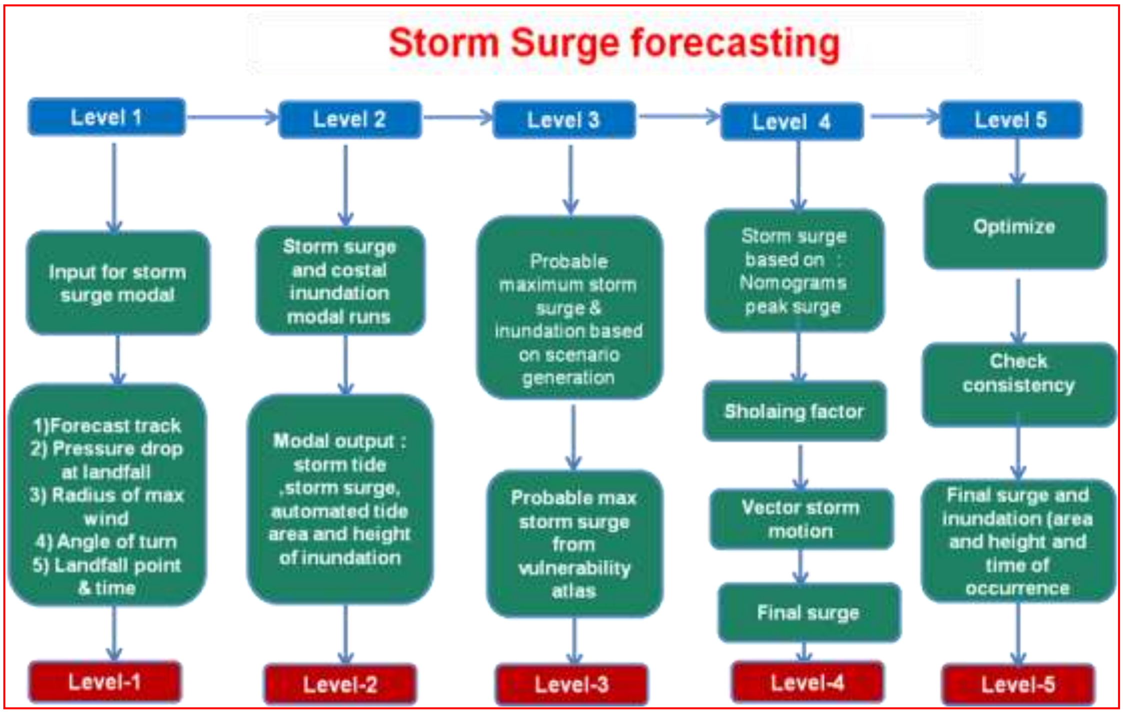


Fig.5.19 Steps involved in storm surge forecasting

5.4.8.1. Nomograms

Ghosh model nomograms are based on the numerical solution to the hydrodynamical equations governing motion of the Sea. The nomograms are prepared relating peak surge with various parameters such as pressure drop, radius of maximum wind, vector motion of the cyclone and offshore bathymetry.

5.4.8.2. IIT Delhi Storm Surge Model and INCOIS coastal inundation model

The dynamical model of IIT Delhi is fully non-linear and is forced by wind stress and quadratic bottom friction following the method of numerical solution to the vertically integrated mass continuity and momentum equations. The updated version of the model currently in operational use covers an analysis area lying between lat. 2.0^0 N and 22.25^0 N and long. 65.0^0 E & 100.0^0 E. The meteorological, hydro-dynamical and bathymetry parameters are the inputs for this model.

The method uses a conditionally Table semi-implicit finite difference stair step scheme with staggered grid for numerical solution of the model equation. The bottom stress is computed from the depth-integrated current using conventional quadratic equation. The bathymetry of the model is derived from Naval Hydrographic charts applying cubic spline technique. The storm surge models developed by IIT, Delhi (IITD) for different Panel member countries have been installed at RSMC, New Delhi. It is providing storm surge guidance to member countries in tropical cyclone advisory bulletin since April, 2009. Similarly, the ADCIRC coastal inundation model is run at INCOIS based on inputs provided by IMD to provide coastal inundation forecast. The examples of strom Surge and coastal inundation Predicted by IITD model and ADCIRC model run at INCOIS, Hyderabad are shown in Fig. 5.11. The strom surge prediction is largely dependent on the predicted characteristics of the cyclones like, track, intensity and point of landfall.

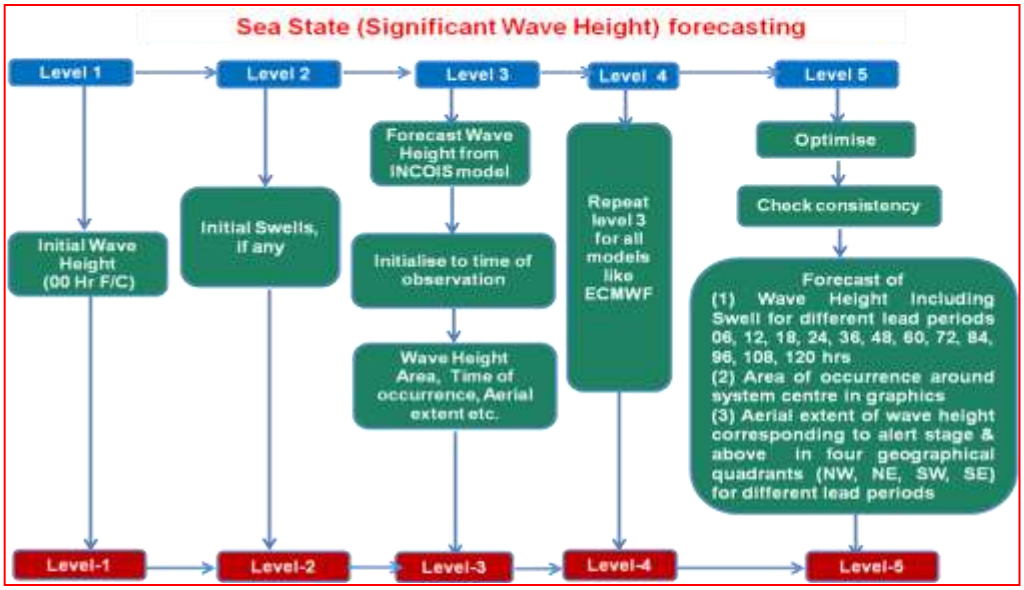


Fig.5.20 Steps involved in Sea State forecasting

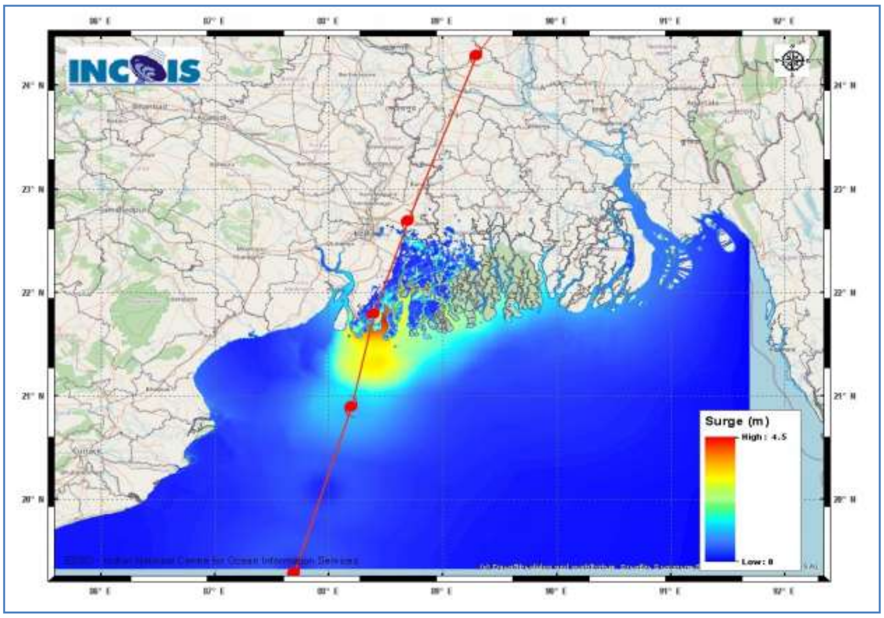


Fig.5.21. Typical Storm surge prediction guidance based on INCOIS (19th May 2020/1800 IST) in case of SuCS 'Amphan'

5.5. Check list for decision making

The very process of the detection and forecasting of the cyclonic storm should be made logical, all technical features should be identified and given due place in reaching conclusions so that no snap decisions based on preconceived notions are taken. The conclusions should be arrived at step by step. It is essential therefore that a check list for decision making should be devised and the forecaster meticulously fills in all the technical details available and skillfully draws conclusions.

The check list should be prepared for all steps of cyclone monitoring and prediction as mentioned below.

- ❖ Genesis
- ❖ Monitoring of location shape, size, intensity and wind distribution
- ❖ Forecast location, intensity, movement, wind distribution and sea conditions.
- ❖ Landfall processes
    - Heavy rain
    - Gale wind
    - Storm surge

The detailed check list for this purpose is given below. For further details about the physical features, the Forecasting Manual/Cyclone Manual can be referred to.

Check list for monitoring and prediction of CDs over the North Indian Ocean

Dated……………… Time……………..

1. Satellite features :

Convection

a. Region and intensity of convection

b. Cloud Top Temperature

c. Current organisation of convection (Convective cloud cluster/ Low Level Circulation/ Vortex)

d. If it is a vortex, location and intensity of vortex

e. Tendency of organization :

f. Number of days the convection is persisting as

i. Cloud cluster

ii. Low level circulation

iii. Vortex (T1.0, T1.5)

2. Mean sea level pressure (MSLP)

Central pressure:,……………. Outer most closed isobar Pressure:…………

Radius of outermost closed isobar………………..Pressure deficit …………..

No. of closed isobar (within 6 deg):

Shape of isobar (circular/elliptical)…………….., Size of the system (lat./long.)…………

3. Number of days the low pressure area is persisting :………………

4. Region of occurrence of low pressure area :…………………..

5. 24 hrs pressure change **………………**

a. General description :……………..

b. Maximum fall and station/buoy **:……………..**

6. Pressure departure from normal

a. General description :…………………..

b. Maximum negative departure and station…………………..

7. Circulation:…………………

a. Vertical extension :………………..

b. Tilting…………….

c. Wind speed (sector):west/ east/ north/ south ………………….

Surface …………………., 0.9 km amsl…………………,1.5 km amsl……….

d. Maximum wind

Surface……………., 0.9 km amsl ………………

e. Region of occurrence of maximum wind

Surface……………………….,0.9 km amsl ………………….

f. Distance of maximum wind from centre of circulation at

Surface…………………………………..

Lower level……………………………:

8. Upper Tropospheric Ridge (200 hPa level) position :………………..

9. Location of upper tropospheric anti-cyclonic circulation :…………………

10. Location of upper Tropospheric Westerly Trough (Latitude and Longitude)………..

11.(a)- SST (based on satellie, buoy and ship observation) :……………

(b)- Ocean thermal Energy :-………………

12. Rainfall/QPE

a. Rainfall during past 12 hrs (Maximum value and region of occurrence) …………

b. Rainfall during past 24 hrs (Maximum value and region of occurrence) …………..

c. Tendency (Increasing/decreasing) :………………..

13. OLR :

a. Daily mean (Maximum value and region of occurrence) :…………………

b. 3 hourly mean (Maximum value and region of occurrence) :………………

c. Tendency (Increasing/decreasing) **: …………….**

14. Cloud :………………

15. Significant weather (Thunderstorm/squall report) :…………………

16. Any other low pressure system in neighbourhood including systems in Nothwest Pacific Ocean and south Indian Ocean

a. Location ………………

b. Intensity………………

c. Tendency of intensification (Intensifying/weakening) ………………

d. Movement : …………….

17. Lower level convergence :

a. Maximum value and region of occurrence :……………

b. Convergence in forward sector ……………………..

c. Tendency during past 06/12/24 hrs ……………………

18. Upper level divergence :

a. Maximum value and region of occurrence :……………

b. Divergence in forward sector ……………………..

c. Tendency during past 06/12/24 hrs …………………..

19. Lower level vorticity

a. Maximum value and region of occurrence) :……………..

b. Vorticity in forward sector ………………

c. Tendency during past 06/12/24 hrs ………………….

20. Vertical wind shear

a. Minimum value and region of occurrence) :…………………..

b. Wind shear in forward sector ………………………

21. Wind shear tendency

a. Minimum value and region of occurrence :……………………

b. Wind shear tendency in forward sector :……………………..

22. Any other features : (1):

(2)

23. Location and intensity from other sources

a. NOAA SSD

b. JTWC etc

24. MJO Product (a) Statistical

(b) Dynamical

25.Location and intensity

Source		Time	Location	intensity
Synoptic				
Sat Met (VIS/IR)				
Sat Met (Microwave)				
Sat Met (ADT)				
NOAA (VIS/IR)				
NOAA (Microwave)				
NOAA (ADT)				
JTWC (Sat Met)				
JTWC (Bulletin)				
ADT				
SATCON				
MainSat Wind				
Radar	1.			
	2.			
	3.			
Official				

Past movement

Hours	Direction	Speed
06 hrs		
12 hrs		
24 hrs		

26. Forecast based on Statistical and NWP models

Model	00	06	12	18	24	36	48	60	72	84	96	108	120
a. GPP													
b. ARPEG (FRANCE)													
c. HWRF (IMD)													
d. WRF (IMD)													
e. WRF (IITB)													
f. UMRM (NCMRWF)													
g. IMD GFS(1534)													
h. UKMO													
i. NCUM													
j. JMA													
k. NCEP GFS													

l. ECMWF														
m. MME														
n. Dynamical Staistical Model (IMD)														
o. EPS	GFS													
	UMEPS													
	ECMWFEPS													
	UKMOEPS													
	NCEP EPS													
p. CLIPER														
q. Storm Surge model (Ghosh Nomogram)														
r.Storm Surge model (IITD)														
s. INCOIS Model														

27. Observed and Forecast radii of Quadrant Winds (10 m wind) based on NWP models

Model		00 NE/NW/SE/SW	06 NE/NW/SE/SW	12 NE/NW/SE/SW	24 NE/NW/SE/SW	36 NE/NW/SE/SW	48 NE/NW/SE/SW	60 NE/NW/SE/SW	72 NE/NW/SE/SW	84 NE/NW/SE/SW	96 NE/NW/SE/SW	108 NE/NW/SE/SW	120 NE/NW/SE/SW
ECMWF	R-64 kt												
	R-50 kt												
	R-34 kt												
	R-28 kt												
HWRF	R-64 kt												
	R-50 kt												
	R-34 kt												
	R-28 kt												
IMD GFS	R-64 kt												
	R-50 kt												
	R-34 kt												
	R-28 kt												
Climatology	R-64 kt												
	R-50 kt												
	R-34 kt												
	R-28 kt												

28. Heavy rainfall prediction of models

Observations						
Heavy Raifall during past 24 hrs (Amount, Area)						
Surface						
Satellite						
Radar						
		Forecast				
Model		**24**	**48**	**72**	**96**	**120**
GPP						
ARPEG (FRANCE)						
HWRF (IMD)						
WRF (IMD)						
WRF (IITB)						
UMRM (NCMRWF)						
IMD GFS(1534)						
UKMO						
NCUM						
JMA						
NCEP GFS						
ECMWF						
MME						
Dynamical Staistical Model (IMD)						
EPS	GFS					
	UMEPS					
	ECMWFEPS					
	UKMOEPS					
	NCEP EPS					
CLIPER						
Storm Surge model (Ghosh Nomogram)						
Storm Surge model (IITD)						
INCOIS Model						

29. Official Forecast

Forecast	00	06	12	18	24	36	48	60	72	84	96	108	120
Intensity (kt)													
Location (deg)													
R-64 kt Wind NE/NW/SE/SW													
R-50 kt Wind NE/NW/SE/SW													
R-34 kt Wind NE/NW/SE/SW													
R-28 kt Wind NE/NW/SE/SW													
Storm surge(m)	IMD Nomogram :					IITD Model:							
Gale wind (kt)													
Heavy rain (cm)													
Wave													

Chapter- VI
Bulletins and Warning

6.1 Introduction

The design of a TC warning system in IMD takes into consideration of the prevailing state of the meteorological science, the available technological means of communication, the built-up environment such as dwellings, socio-economic conditions, appropriateness of protective actions as well as the expectations of the society. To maximise relevance and effectiveness of the TC warning, strategies are formulated in respect of the design of the forecast, triggering mechanisms, coordination with disaster management agencies, warning products generation, presentation & dissemination. Scientific and technological advances in TC forecasting are translated into effectiveness of TC warning. The forecast and warning operations and decision-making process is made by blending scientifically based conceptual models, meteorological datasets, technology and expertise. Various bulletins issued by IMD are as follows.

1. Bulletins issued by RSMC, New Delhi
    - Tropical Weather Outlook
    - Tropical Cyclone Advisories
    - Tropical Cyclone Advisories for Civil Aviation
2. Bulletins issued by INOSHAC, Pune
    - Global Maritime Distress Safety System (GMDSS)
3. Bulletins issued by Cyclone Warning Division
    - Bulletin for India coasts
4. Bulletins issued by ACWCs/ CWCs
    - Four Stage Warning Bulletin
    - Sea Area Bulletin-
    - Coastal Weather Bulletins
    - *Warnings to Ports*
    - Warnings for Fisheries
    - Bulletins for All India Radio (AIR)
    - Coastal Bulletins for AIR news cycle
    - Registered/designated warnees
    - Press Bulletins

- Aviation Warnings
- Bulletins for Indian Navy

6.2. Bulletins issued by RSMC, New Delhi

The tropical weather outlook is issued once daily by RSMC, New Delhi throughout the year under normal weather conditions based on 0300 UTC observations. An additional Special Tropical Weather outlook is issued again based on 1200 UTC observations when a depression is located over the north Indian Ocean region. When a system reaches the cyclonic storm stage, Cyclonic Storm Advisories will be issued at 00, 03, 06, 09, 12, 15, 18 and 21 UTC. Supplementary advisories may also be issued as necessitated by circumstances e.g., change in intensity or movement. The bulletins issued by RSMC, New Delhi are briefly described below:

6.2.1. Tropical Weather Outlook

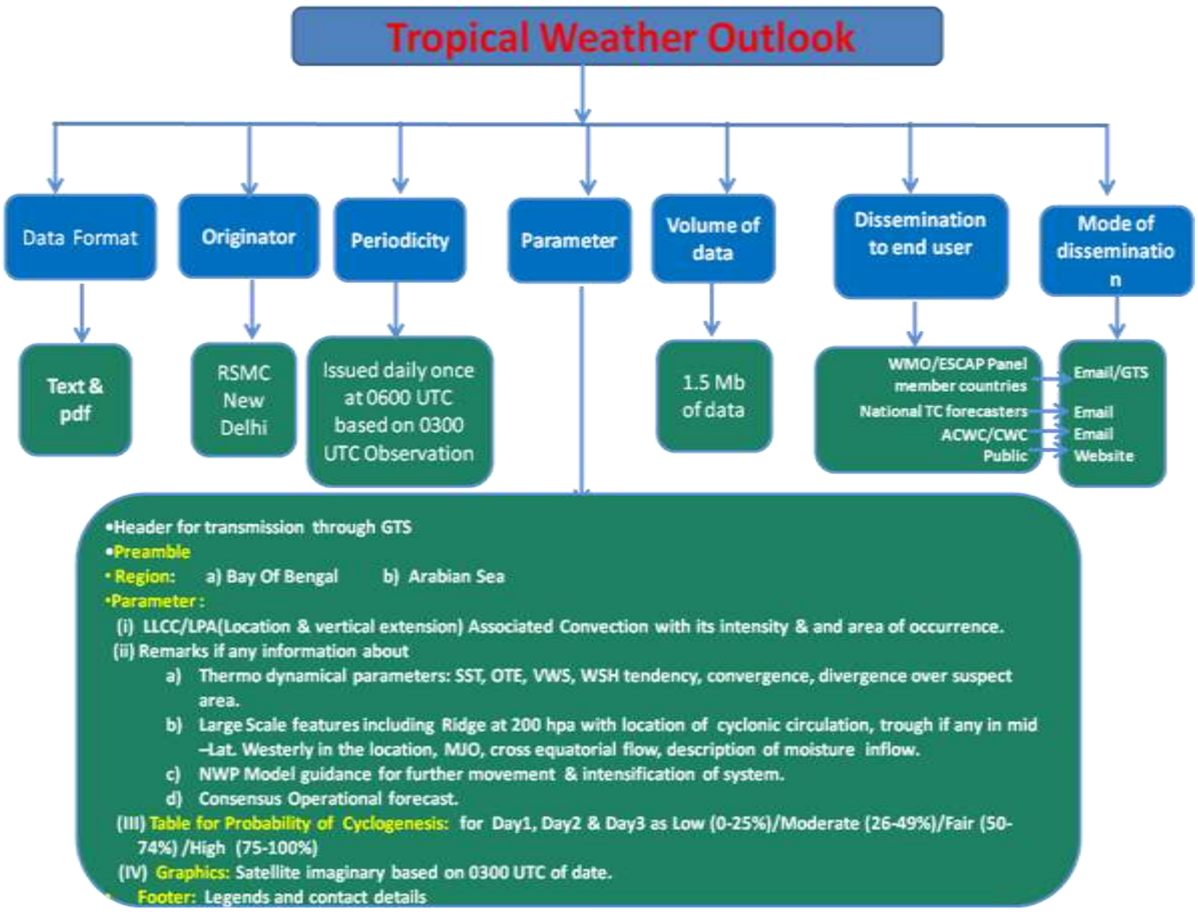
Tropical Weather Outlook is issued daily at 0600 UTC based one 0300 UTC observations in normal weather for use of the member countries of WMO/ESCAP Panel. Description of Tropical Weather Outlook Bulletin contains the following

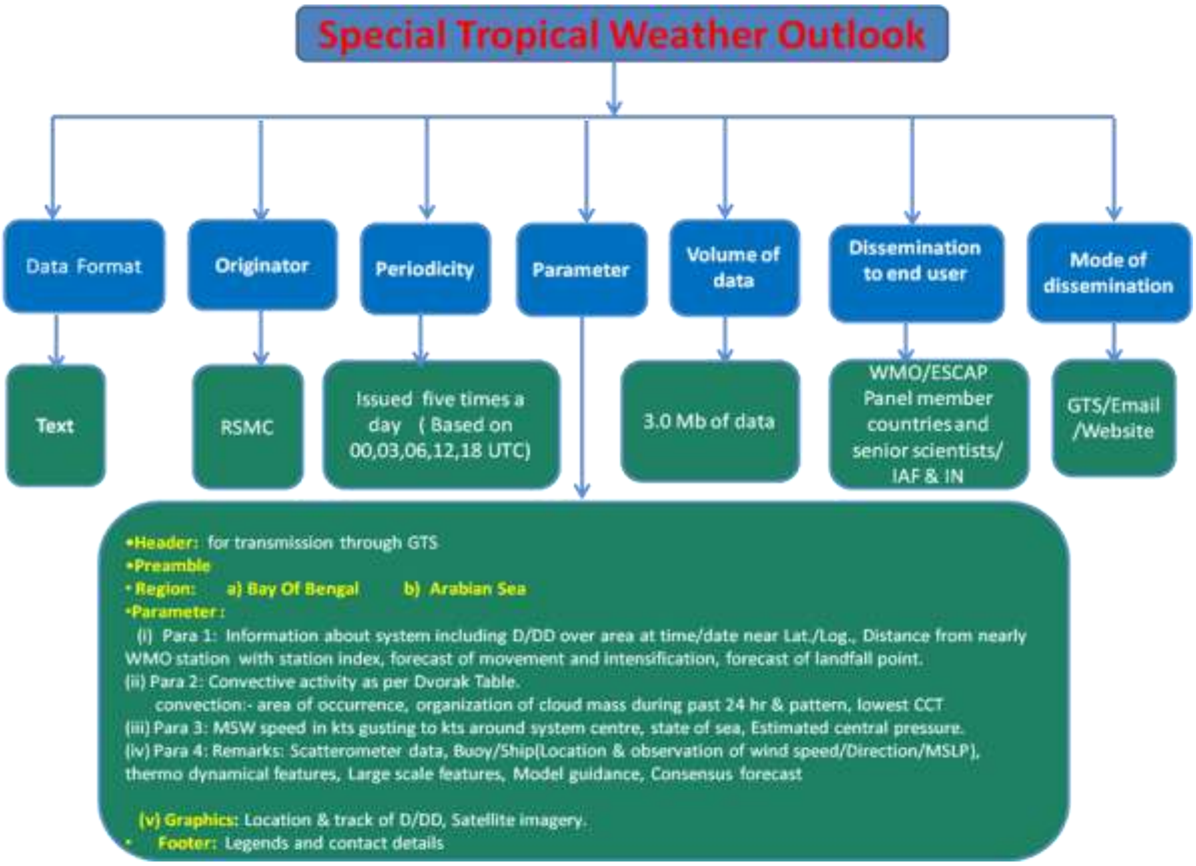
- convective activity ;
- meteorological situation over the basin ;
- observed lows ;
- their potential of intensification at short range (risk for development of a depression (T 1.5) within the next 72 hours(00-24, 24-48, 48-72 hrs))Since June 2014 and upto 120 hrs (00-24, 24-48, 48-72, 72-96,96-120 hrs) Since April 2018.

A special weather outlook is issued at 1500 UTC based on 1200 UTC observations when a tropical depression lies over north Indian Ocean. The special tropical outlook indicates discussion on various diagnostic and prognostic parameters apart from the 72 hours track and intensity forecast from the stage of deep depression. The track and intensity forecast are issued for +06, +12, +18, +24, +36, +48, +60, +72, +96 and +120 hours or till the system is likely to weaken into a low pressure area. It also includes the description of current location & intensity and past movement description of satellite imageries. The time of issue of this bulletin is HH+ 3 hours.

The Special Tropical Weather Outlook Bulletin, to be issued five times a day (based on 00, 03, 06, 12, 18 UTC) contains the following.

- Current location and intensity
- Past movement
- Convective activity ;
- T number, estimated central pressure and Maximum sustained surface wind (MSW)
- Sea condition
- 120 hrs (00, 06, 12, 18, 24, 36, 48, 60, 72, 84, 96, 108 and 120 hrs) or less forecast track, intensity and quadrant winds for thresholds of ≥ 28, 34, 50 and 64 kts (Text and graph) from deep depression stage onwards till the weakening of the system.
- Storm surge guidance (if any)
- Meteorological situation over the basin (Diagnosis and prognosis)





6.2.2. Tropical Cyclone Advisories

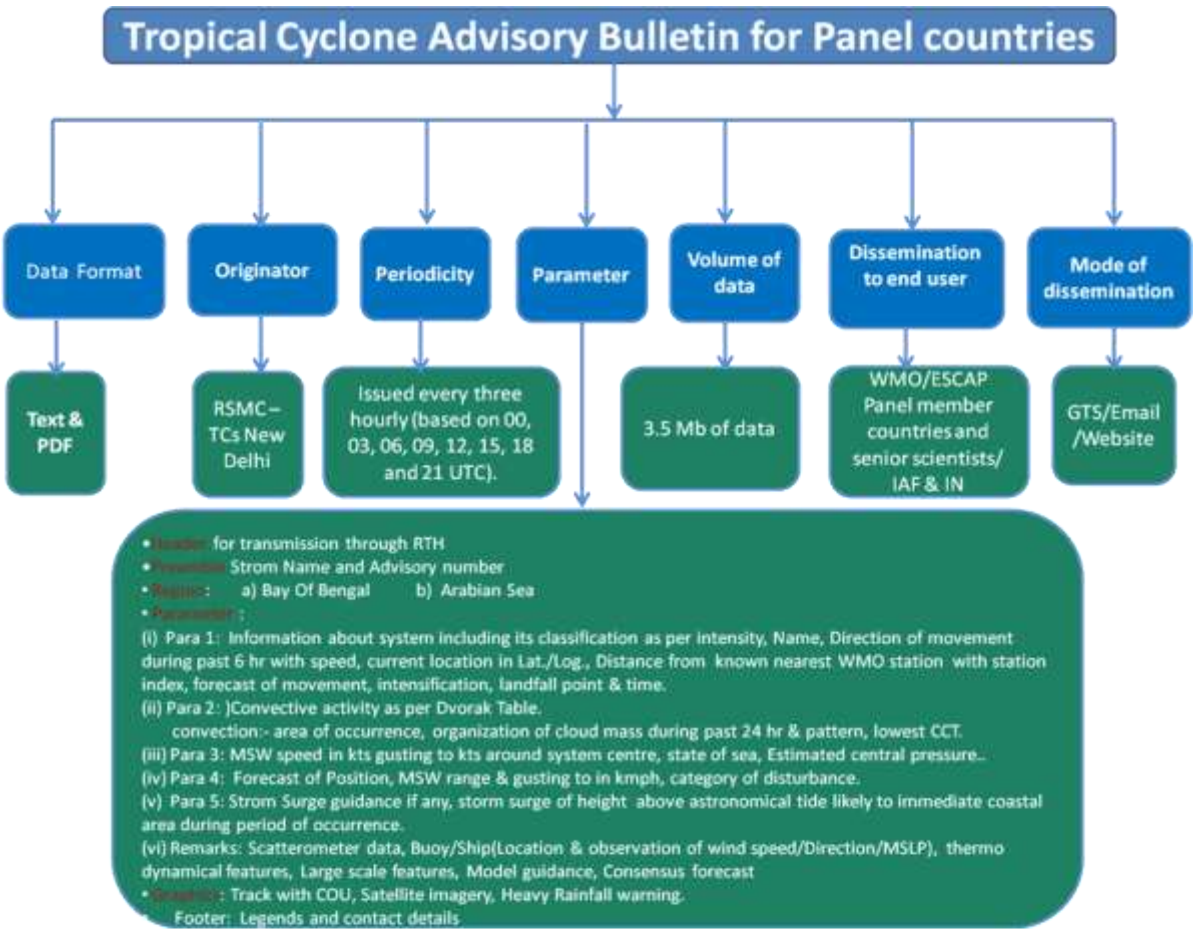
Tropical cyclone advisories are issued at 3 hourly intervals based on 00, 03, 06, 09, 12, 15, 18 and 21 UTC observations. The time of issue is HH+03 hrs. Tropical cyclone advisories are transmitted to panel member Countries through global telecommunication system (GTS) and are also made available on real time basis through internet at IMD's website: http://www.imd.gov.in. and e-mail. RSMC, New Delhi can also be contacted through e-mail cwdhq2008@gmail.com) for any real time information on cyclonic disturbances over north India Ocean.

Tropical Cyclone Advisory Bulletin for Panel countries (RSMC Bulletin), contains the following.

- Current Location and Intensity
- Past movement
- Convective activity ;
- T number, estimated central pressure and Maximum sustained surface wind (MSW)
- Sea condition

- 120 hrs (00, 06, 12, 18, 24, 36, 48, 60, 72, 84, 96, 108 and 120 hrs) or less forecast track, intensity and quadrant winds for thresholds of ≥ 28, 34, 50 and 64 kts (Text and graph)
- Storm surge guidance (if any)
- Meteorological situation over the basin (Diagnosis and prognosis) under remark column.

Format of Tropical Cyclone Advisory bulletin issued by RSMC is discussed under remarks column.



Format of Bulletins:

Format of Tropical Cyclone Advisory Bulletin issued by RSMC, New Delhi

भारत मौसम विज्ञान विभाग
INDIA METEOROLOGICAL DEPARTMENT

FROM: RSMC – TROPICAL CYCLONES, NEW DELHI
TO: ALL WMO/ESCAP PANEL MEMBER COUNTRIES
TROPICAL CYCLONE ADVISORY

SYSTEM NAME…………… ADVISORY NO …….. ISSUED AT ……UTC OF ………..(DATE) BASED ON ….. UTC ………..(DATE).

THE CYCLONIC STORM **………..** OVER …………….. (LOCATION AND MOVEMENT) AND DISTANCE FROM TWO/THREE COASTAL STATIONS (INDEX NUMBER). …….LIKELY MOVEMENT AND INTENSITY

INTERPRETATION OF SATELLITE IMAGERY (T. No., CLOUD TOP TEMPERATURE (CTT) AND ASSOCIATED CONVECTION ETC.).

SUSTAINED MAXIMUM SURFACE WIND SPEED IN KNOTS AROUND SYSTEM CENTRE, THE STATE OF THE SEA .AROUND THE SYSTEM CENTRE AND THE ESTIMATED CENTRAL PRESSURE IN…..hPa ETC.

72 HOURS FORECAST OF POSITION AND INTENSITY BASED ON LATEST ANALYSIS WITH NWP MODELS AND OTHER CONVENTIONAL TECHNIQUES IN TABULAR FORM,

DATE/TIME(UTC)	POSITION (LAT. ^{0}N/ LONG. ^{0}E)	SUSTAINED MAXIMUM SURFACE WIND SPEED (KMPH)	CATEGORY
DD-MM-YYYY/TTTT	……/……	…….. gusting to ……..	DEPRESSION/DEEP DEPRESSION/CYCLONIC STORM ETC

REMARKS:

- Synoptic guidance to explain movement and intensification / weakening of the system.
- Dynamical-statistical model guidance with respect to track/intensity
- Conclusion based on synoptic and nwp model guidance.
- Supporting observations
- Consensus decision

Time of Origin …………..HRS IST

GRAPHICS ON CURRENT & FORECAST TRACK ALONGWITH CONE OF UNCERTAINTY AND QUADRANT WIND DISTRIBUTION ARE GIVEN AS APPENDIX

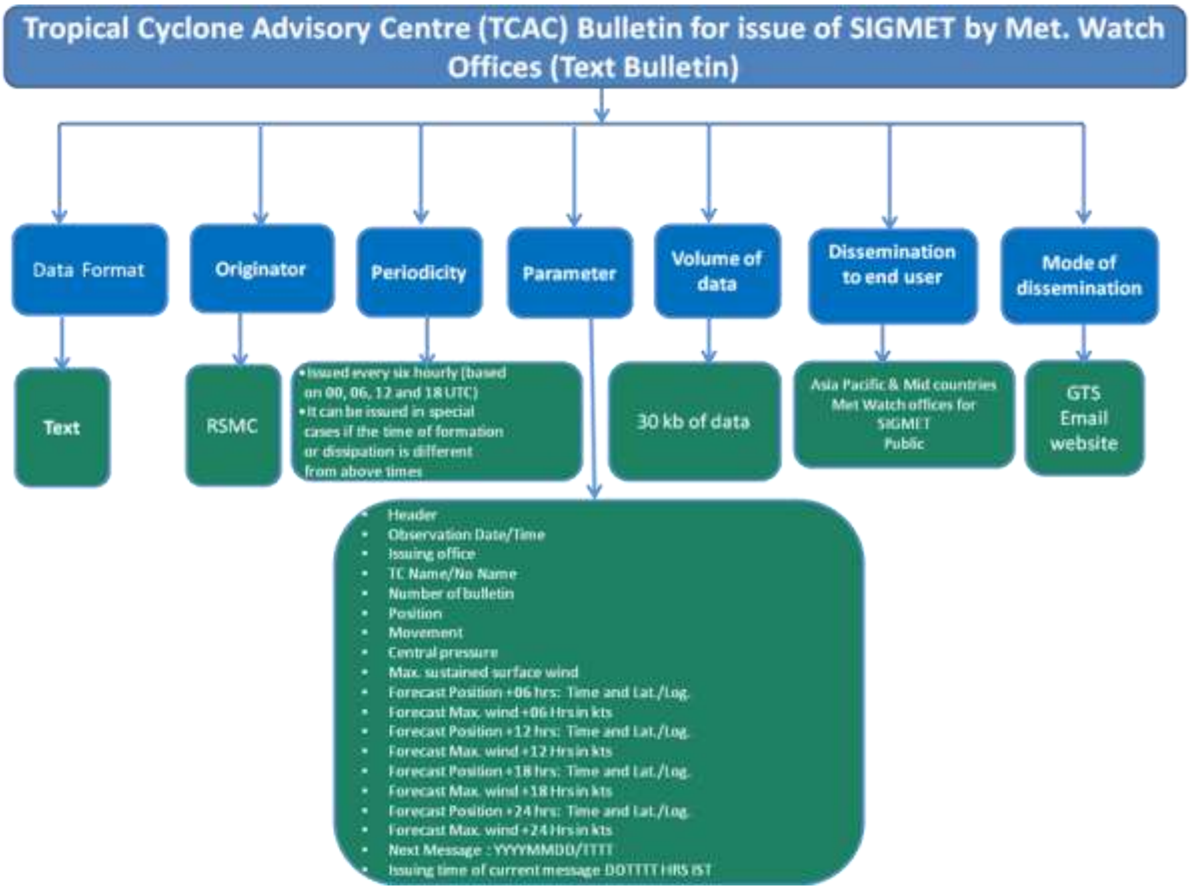
6.2.3. Tropical Cyclone Advisories for Civil Aviation

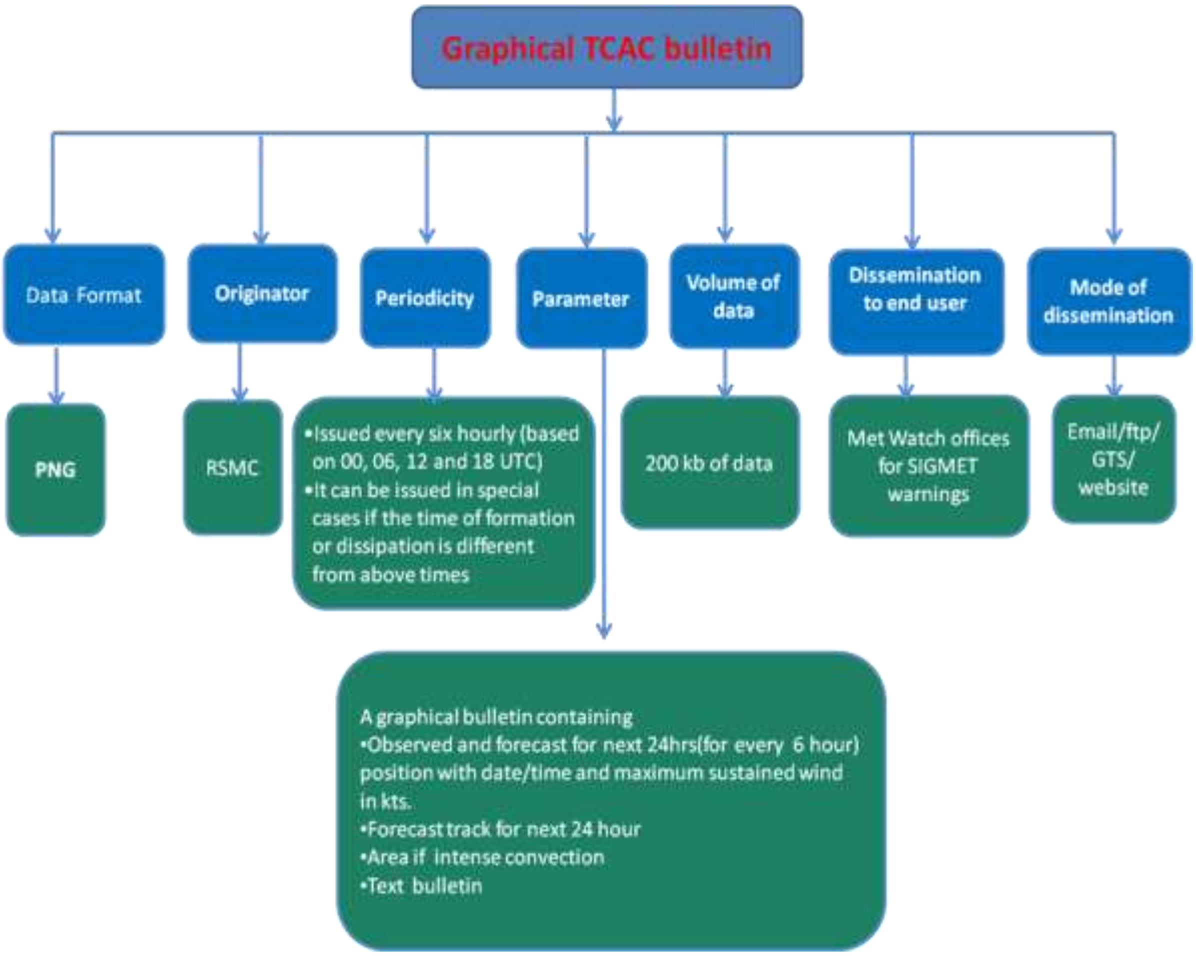
Tropical Cyclone Advisories for civil aviation are issued for international aviation as soon as any disturbance over the north Indian Ocean attains or likely to attain the intensity of cyclonic storm (sustained surface wind speed ≥ 34 knots) within next six hours. These bulletins are issued at six hourly intervals based on 00, 06, 12 and 18 UTC synoptic charts and the time of issue is HH+03 hrs. These bulletins contains present location of cyclone in lat./long., max sustained surface wind (in knots), direction of past movement and estimated central pressure, forecast position in Lat./Long and forecast winds in knots valid at HH+6, HH+12, HH+18 and HH+24 hrs in coded form. The tropical cyclone advisories are transmitted on real time basis through GTS and AFTN channels to designated International Airports of the region prescribed by ICAO.

The Tropical cyclone advisory centre (TCAC) bulletin has following characteristics.

- It is a text cum graphical bulletin.
- Issued from cyclone stage till it weakens into a deep depression
- The format of bulletin is given below.

FORMAT OF TCAC BULETIN





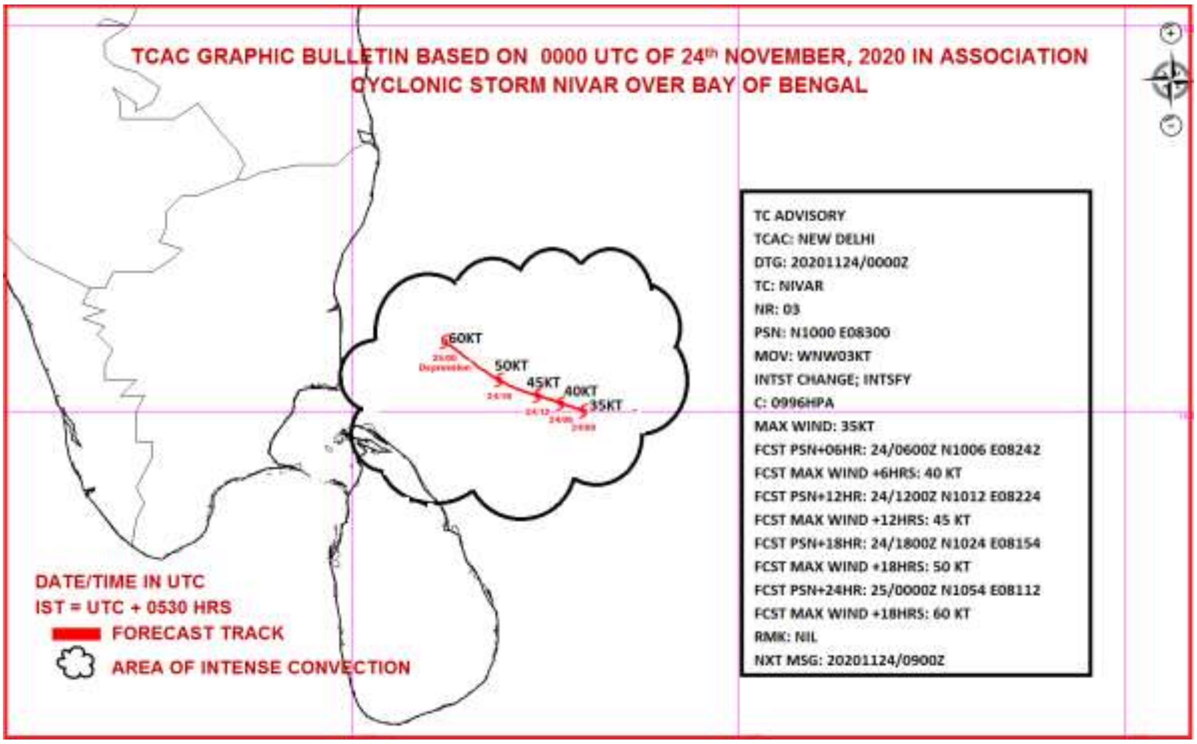
Examples:

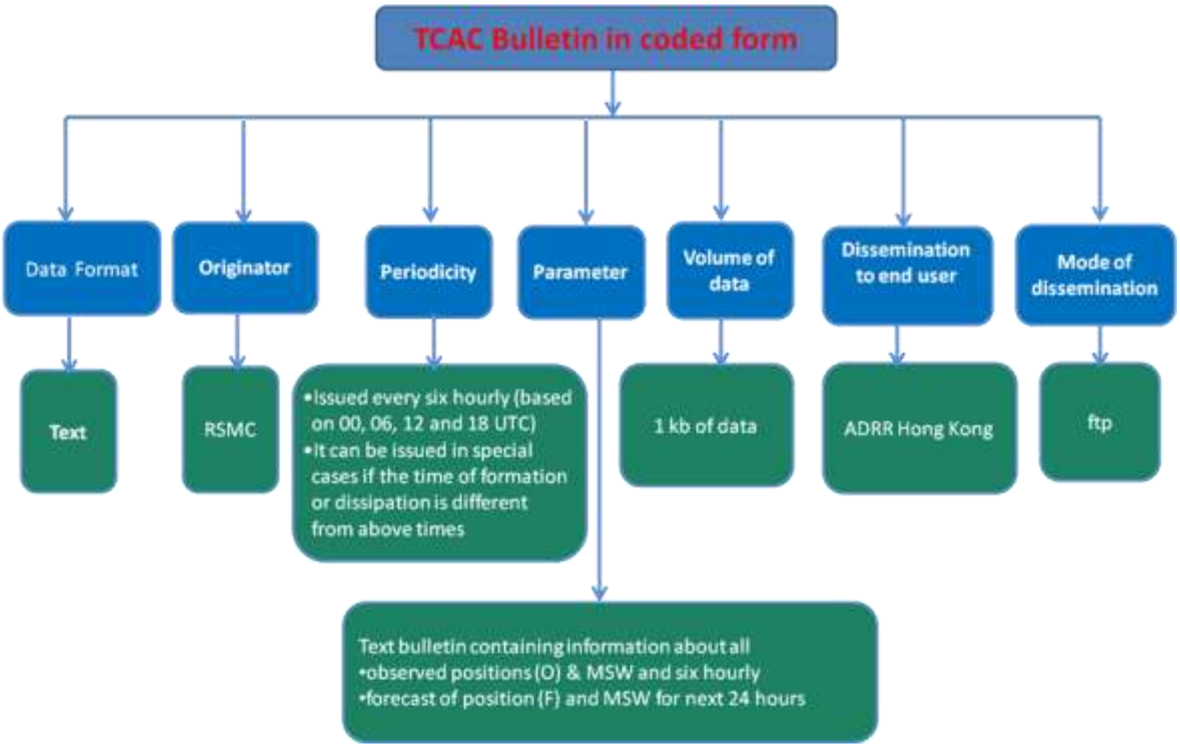
TCAC Text Bulletin

TCAC Bulletin in Textual form

TC ADVISORY
TCAC: NEW DELHI
DTG: 20201124/0000Z
TC: NIVAR
NR: 03
PSN: N1000 E08300
MOV: WNW03KT
INTST CHANGE; INTSFY
C: 0996HPA
MAX WIND: 35KT
FCST PSN+06HR: 24/0600Z N1006 E08242
FCST MAX WIND +6HRS: 40 KT
FCST PSN+12HR: 24/1200Z N1012 E08224
FCST MAX WIND +12HRS: 45 KT
FCST PSN+18HR: 24/1800Z N1024 E08154
FCST MAX WIND +18HRS: 50 KT
FCST PSN+24HR: 25/0000Z N1054 E08112
FCST MAX WIND +18HRS: 60 KT
RMK: NIL
NXT MSG: 20201124/0900Z

TCAC Graphics Bulletin:





ADRR:

```
0001
AMPHAN
2020051600 10.4 87.0 025 O
2020051606 10.7 86.9 030 O
2020051612 10.9 86.3 035 O
2020051618 11.1 86.1 035 O
2020051700 11.4 86.0 045 O
2020051706 11.5 86.0 055 O
2020051712 12.0 86.0 065 O
2020051718 12.5 86.4 080 O
2020051800 13.2 86.3 100 O
2020051806 13.4 86.2 120 O
2020051812 14.0 86.3 125 O
2020051818 14.9 86.5 125 O
2020051900 15.6 86.7 120 O
2020051906 16.5 86.9 115 O
2020051912 17.4 87.0 105 O
2020051918 18.4 87.2 100 F
2020052000 19.4 87.4 95 F
2020052006 20.6 87.8 90 F
2020052012 21.8 88.3 85 F
```

6.3. Global Maritime Distress Safety System (GMDSS)

Under Global Maritime Distress Safety System (GMDSS) scheme, India has been designated as one of the 16 services in the world for issuing Sea area bulletins for broadcast through GMDSS for MET AREA VIII (N), which covers a large portion of north Indian Ocean. As a routine, two GMDSS bulletins are issued at 0900 and 1800 UTC. During cyclone situations, additional bulletins (up to 4) are issued for GMDSS broadcast. The area of responsibility and designated National Meterological Services for issue of weather and sea area bulletins is shown in Fig.6.1. List of **s**tations issuing cyclone warnings for ships on the high seas is given in table 6.1.

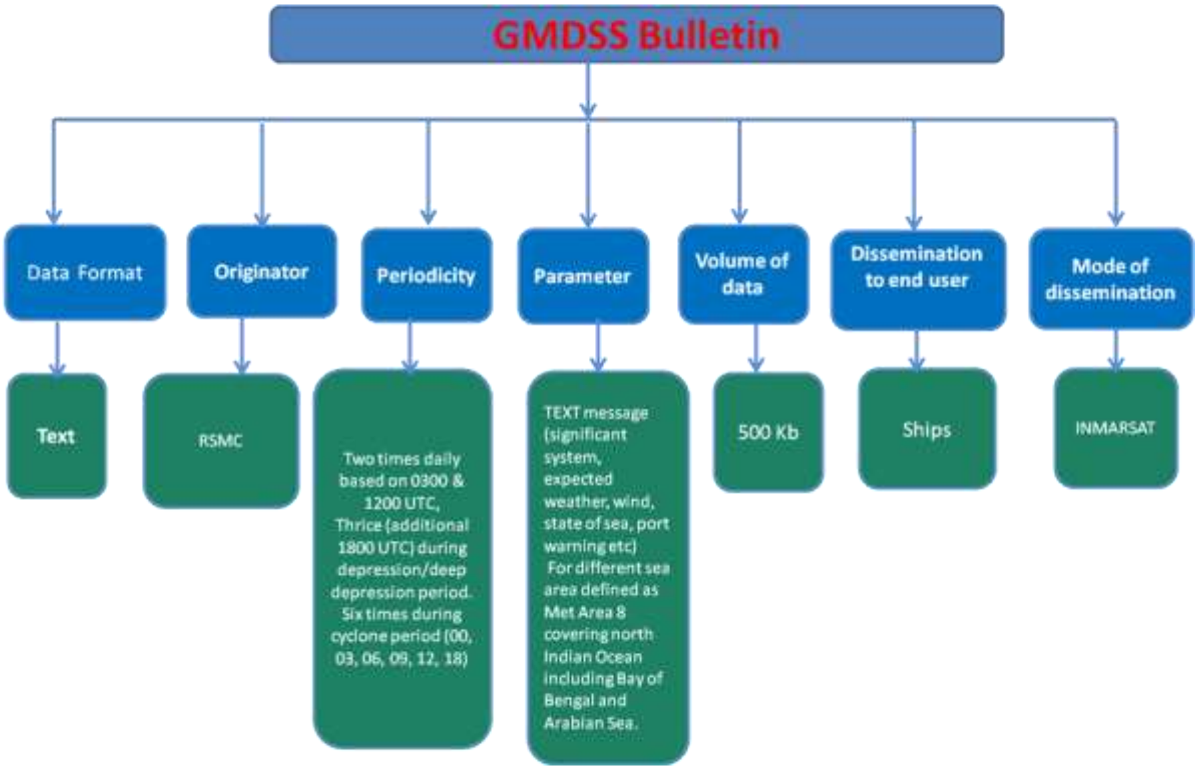
Fig.6.1. AREA OF RESPONSIBILITY AND DESIGNATED NATIONAL METEOROLOGICAL SERVICES FOR THE ISSUE OF WARNINGS AND WEATHER AND SEA BULLETINS FOR THE GMDSS

Table 6.1 : Stations issuing cyclone warnings for ships on the high seas

Station	**Call sign of Coastal Area covered Radio Station**	**Area covered**
Bangladesh, Chittagong	ASC	Bay of Bengal north of 18°N Lat.
India, Mumbai		Arabian Sea north of Lat. 5°N and east of Long. 60°E excluding the area north of Lat. 20°N and west of Long. 68°E. The eastern boundary of the Arabian Sea for which these bulletins are issued by Mumbai is Long. 80°E meridian excluding the Gulf of Mannar.
India, Kolkata		Bay of Bengal north of Lat. 5°N except the area between the coastline on the east and the line drawn through the points 18°N 94.5°E, 18°N 92°E, 13.5°N 92°E, 13.5°N 94°E, 10°N 94°E, 10°N 95°E and 5°N 95°E. The western boundary of the sea area for which bulletins are issued by Kolkata is up to and inclusive of the Gulf of Mannar (i.e., 77.5°E meridian).
***India,** Chennai		Bay of Bengal bulletins issued by ACWC Kolkata are being broadcast through Navtex, Chennai by Narrow Band Direct Printing (NBDP)
Myanmar, Yangon	XYR	Bay of Bengal except area west of Long. 92°E and South of 10°N Lat.
Oman (Sultanate of)	A4M	Muscat Coastal Radio Station
****Pakistan,** Karachi	ASK	Arabian Sea north of 20°N, Gulf of Oman and Persian Gulf.
Sri Lanka, Colombo	4PB	Indian Ocean, Arabian Sea and Bay of Bengal from the equator to 100N between 600E and 950E. The area 50N to 100N between 600E and 950E is an overlap with India.
Thailand, Bangkok	HSA HSS	Gulf of Thailand, west of southern Thailand. Strait of Malacca and South China Sea.

***** Under the new Marine Meteorological Broadcast system, GMDSS (Global Marine Distress Safety System) of IMO/WMO, India issues two bulletins at 0900 and 1800 UTC everyday for broadcast through INMARSAT SAFETY SYSTEM. Additional bulletins are broadcast during Cyclone period.

****** To comply IMO/WMO GMDSS and marine Meteorological Broadcast System Pakistan issues the high seas forecast / Marine bulletins for met area-IX daily at 0700 UTC for broadcast through INMARSAT SAFEYNET SYSTEM. These bulletins are issued at 1900 UTC if so required.



6.3.1. Transmission of GMDSS bulletin:

India is one of the issuing services of Met area VIII (N) among the 16 issuing services of WMO Marine broadcast system under the GMDSS. In India, the weather forecast and warning bulletin is prepared by ACWC (Area Cyclone Warning Centre) Mumbai for the Arabian sea, by ACWC, Calcutta for the Bay of Bengal and INOSHAC (Indian Ocean & South Hemispheric Centre), Pune for Indian Ocean, North of equator upto 5°N, for their areas of responsibility. The bulletins are compiled by INOSHAC, Pune and transmitted to RSMC, New Delhi. RSMC, New Delhi edits the final bulletin if required and transmits to Tele-communication Division (Regional Telecommunication Hub (RTH), New Delhi) for further transmission through local earth station (LES), Arvi as shown in Fig.6.2.

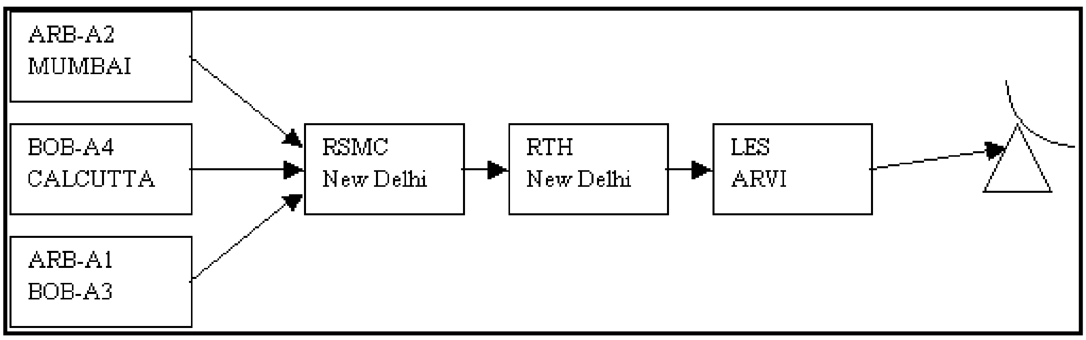


Fig.6.2.Transmission of GMDSS Bulletin

6.3.2. Frequency of Broadcasts

To start with as a routine only, one GMDSS bulletin for METAREA VIII (N) was broadcast at 0900 UTC. From October 1998, a second bulletin is also broadcast at 1800 UTC. During Cyclone situations, additional bulletins (up to 4) are also being issued for GMDSS broadcast depending on the requirement.

In addition, India is also issuing weather and warning bulletins to the NAVTEX transmitting stations located at Mumbai and Chennai.

6.3.3. Modality of transfer of GMDSS bulletin to CES ARVI

GMDSS BULLETIN is transferred to CES ARVI in manual mode using a dedicated telex terminal connected to the “store and forward switching computer” of the CES ARVI. The procedure involves dialing, login, entering C codes, Start of the message (BT), text and end of the message characters. On an average, it takes 5 minutes to transmit the message to CES ARVI at the normal telex speed of 50 baud. It takes another 2-3 minutes for the message to be received at the monitoring terminal to check its correctness and clarity.

The operational GMDSS broadcast is currently operating smoothly without any noticeable problems. The feedback response received from a few shipping companies are very encouraging.

6.3.4. Sample of GMDSS bulletin

SHIPPING BULLETIN FOR MET AREA VII NORTH OF EQUATOR VALID FOR 24 HOURS FROM 2002 07 18 0900 UTC: 18 JULY 2002

PART I:

NO STORM WARNING

PART II:

YESTERDAYS LOW PRESSURE AREA NOW LIES OVER NW BAY AND ADJOINING ORISSA (.)

THE OFF-SHORE TROUGH OVER THE ARABIAN SEA NOW RUNS FROM SAURASHTRA COAST TO KERALA COAST (.)

WEATHER SEASONAL OVER REST METAREA VIII (N)

ARB A1 ARABIAN SEA: EQUATOR TO 10 DEG. N AND W OF 80 DEG.E (.)

A1-FORECAST FOR 24 HOURS

I)WIND SPEED AND DIRECTION:-1)W OF 60 DEG E SSE-LY 10/20 KTS

BEC SSW-LY 10/25 KTS TO THE N OF 4 DEG N(.)

2)E OF 60 DEG E ANTICYCLONIC 05/20 KTS (.)

II)WEATHER:-1)W OF 65 DEG E :SCATTERED RA/TS(.)

2)E OF 65 DEG E:FAIRLY WIDESPREAD RA/TS (.)

III)VISIBILITY:-1)W OF 65 DEG E :N:6-4 NM(.)

2))E OF 65 DEG E:4-3 NM (.)

IV)WAVE HEIGHT:-1)W OF 60 DEG E 1-4 MTR (.)

2)E OF 60 DEG E 0.5-3 MTR (.)

A1-FORECAST FOR 48 HOURS

I)WIND SPEED AND DIRECTION:-1)W OF 60 DEG E SSW-LY 10/20 KTS BEC 10/25 KTS TO THE N OF 5 DEG N(.)

2)E OF 60 DEG E ANTICYCLONIC 10/20 KTS (.)

II)WEATHER:-1)W OF 65 DEG E AND S OF 5 DEG N :WIDESPREAD RA/TS(.)

2)E OF 60 DEG E AND N OF 5 DEG N:WIDESPREAD RA/TS (.)

3)REST AREA:ISOLATED RA/TS(.)

III)VISIBILITY:-1)W OF 65 DEG E AND S OF 5 DEG N :3-2 NM(.)

2)E OF 60 DEG E AND N OF 5 DEG N:3-2 NM(.)

3)REST AREA:8-6 NM(.)

IV)WAVE HEIGHT:-1)W OF 60 DEG E 1-4 MTR (.)

2)E OF 60 DEG E 1-3 MTR (.)

A2-FORECAST FOR 24 HOURS

I)WINDSPEED AND DIRECTION:-S/SW-LY 10/25 KTS BEC W/NW-LY 05/20 KTS TO THE E OF 65 DEG E (.)

II)WEATHER:1)E OF 65 DEG E AND S OF 23 DEG N:WIDESPREAD RA/TS(.)

2)E OF 62 DEG E TO 65 DEG E AND N OF 23 DEG N: ISOLATED RA/TS(.)

3)REST AREA FAIR (.) III)VISIBILITY:1)E OF 65 DEG E AND S OF 23 DEG N:4-3 NM(.)

2)E OF 62 DEG E TO 65 DEG E AND N OF 23 DEG N: 8-6 NM(.)

3)REST AREA :10-8 NM(.)

IV)WAVE HEIGHT:1)W OF 65 DEG E 1-4 MTR (.)

2)E OF 65 DEG E 0.5-3 MTR (.)

A2-FORECAST FOR 48 HOURS I)WINDSPEED AND DIRECTION:-S/SW-LY 10/25 KTS BEC W-LY 05/20 KTS TO THE E OF 65 DEG E (.)

II)WEATHER:1)E OF 62 DEG E AND S OF 20 DEG N:WIDESPREAD RA/TS(.)

2)E OF 64 DEG E AND N OF 20 DEG N: ISOLATED RA/TS(.)

3)REST AREA FAIR (.) III)VISIBILITY:1)E OF 62 DEG E AND S OF 20 DEG N:3-2 NM(.)

2)E OF 64 DEG E AND N OF 20 DEG N: 8-6 NM(.)

3)REST AREA :10-8 NM(.)

IV)WAVE HEIGHT:1)W OF 65 DEG E 1-4 MTR (.)

2)E OF 65 DEG E 0.5-3 MTR (.)

BOB A3-BAY OF BENGAL:EQUATOR TO 10 DEG N BETWEEN E OF 80 DEG E AND WEST OF 10 DEG N/98 DEG 30 MIN E TO 6 DEG N/95 DEG E AND THENCE S-WARDS TO EQUATOR(.)

A3-FORECAST FOR 24 HOURS I)WINDSPEED AND DIRECTION:1)E OF 90 DEG E AND S OF 5 DEG N: ANTI-CYCLONIC 05/10 KTS (.)

2)REST AREA: SSE-LY 05/20 KTS BEC SSW-LY 10/25 KTS TO THE N OF 3 DEG N(.)

II)WEATHER:-FAIRLY WIDESPREAD RA/TS (.)

III)VISIBILITY:-4-3 NM (.) IV)WAVE HEIGHT:-0.5-4 MTR (.)

A3-FORECAST FOR 48 HOURS

I)WINDSPEED AND DIRECTION: 1)W OF 85 DEG E:SE-LY 05/10 KTS BEC S/SW-LY 10/25 KTS TO THE N OF 1 DEG N(.)

2)E OF 85 DEG E:ANTICYCLONIC 05/20 KTS(.)

II)WEATHER:-FAIRLY WIDESPREAD RA/TS (.)

III)VISIBILITY:-4-3 NM (.)

IV)WAVE HEIGHT:-0.5-4 MTR (.)

BOB: A4: BAY OF BENGAL N OF 10 DEG N AND E OF 80 DEG E (.)

A4-FORECAST FOR 24 HOURS

I)WINDSPEED AND DIRECTION:SSW-LY:10/25 KTS BEC CYCLONIC 05/15 KTS TO THE N OF 17 DEG N(.)

II)WEATHER:-WIDESPREAD RA/TS (.)

III)VISIBILITY:-3-2 NM (.)

IV)WAVE HEIGHT:-0.5-4 MTR (.)

A4-FORECAST FOR 48 HOURS

I)WINDSPEED AND DIRECTION: WSW/SW-LY:10/25 KTS BEC CYCLONIC 05/10 KTS TO THE N OF 20 DEG N(.)

II)WEATHER:-WIDESPREAD RA/TS (.)

III)VISIBILITY:-3-2 NM (.)

IV)WAVE HEIGHT:-0.5-4 MTR (.)

TOO:-18/1330 EF

ISSUED BY INDIA METEOROLOGICAL DEPARTMENT

MOD : Moderate, RGH : Rough, WDS : Widespread, FWDS : Fairly widespread, SCT : Scattered, RA : Rain, TS : Thundershower, KT : Knot, DEG N : Degree North, BEC: Becoming, W/SW : West/southwest,

6.4. Bulletin for India coasts

6.4.1. Four Stage Warning Bulletin issued by Cyclone Warning Division:

Bulletin for India coast is issued in different stages as mentioned below.

- Pre-cyclone watch,
- Cyclone alert,
- Cyclone warning,
- Post landfall outlook
- De-warning

These bulletins are issued from the stage of depression onwards. During the stage of depression/deep depression; it is issued based on 00, 03, 06, 12, and 18 UTC observations. When the system intensifies into a cyclonic storm over north Indian Ocean, these bulletins are issued at 00, 03, 06, 09, 12, 15, 18 and 21 UTC (every three hourly interval) based on previous observations. This bulletin contains present status of the system i.e. location, intensity; past movement and forecast intensity & movement for next 120 hours or till the system weaken into a low pressure area, likely landfall point & time and likely adverse weather including heavy rain, gale wind & storm surge. Expected damage and action suggested are also included in the bulletins. This bulletin is completely meant for national users.

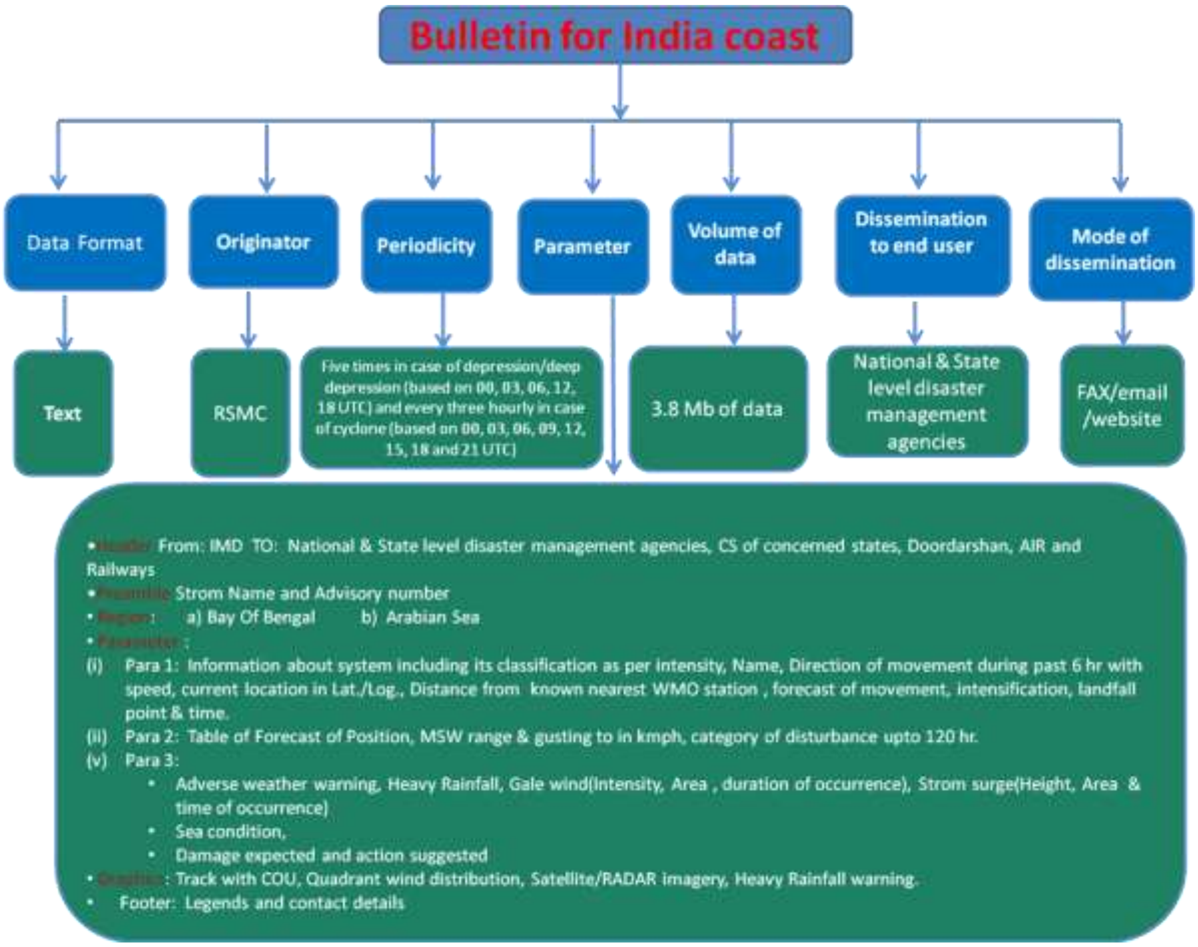
At national level, cyclone warning is furnished on a real time basis to the Control Room in the Ministry of Home Affairs, Government of India, besides other Ministries & Departments of the Central Government. This Division provides cyclone warning bulletins to Doordarshan and All India Radio (AIR) at New Delhi for inclusion in the National broadcast/telecast. Bulletins are also provided to other electronic and print media and concerned state Governments.

Different colour codes are being used since post monsoon season of 2006 at different stages of the cyclone warning bulletins (cyclone alert-yellow, cyclone warning-orange and post landfall outlook-red), as desired by the National Disaster Management.

Description of this bulletin contains the following:

- Date and time of issue
- Current Location and Intensity
- Past movement
- Maximum sustained surface wind (MSW)
- 72 hrs (00, 06, 12, 18, 24, 36, 48, 60, 72, 84, 96, 108 and 120 hrs) or less forecast track and intensity (Text and graph) from deep depression stage onwards till the weakening of the system.
- Forecast track and intensity as mentioned above.
- Adverse weather (Text and graph)
- Advisory and action suggested
- Time of issue of next bulletin

In case of depression, only plain language forecast will be given without the quantitative 72 hr forecast track and intensity as mentioned above.



Format of Bulletin for India Coast issued by Cyclone Warning Division, New Delhi

FROM: INDIA METEOROLOGICAL DEPARTMENT

TO: NATIONAL DISASTER MANAGEMENT/SENIOR GOVERNMENT FUNCTIONARIES / STATE RELIEF COMMISSIONERS OF MARITIME STATES/ALL INDIA RADIO/ DOOR DARSHAN

Bulletin No…….

Dated: Time of issue: hours IST

SUB: CYCLONIC STORM `X' OVER ………..: CYCLONE ALERT/WARNING FOR ……… COAST - YELLOW/ORANGE / RED MESSAGE

The cyclonic storm **………..** over …………….. (location and movement) and distance from two/three coastal stations (name). …….likely movement and intensity

Based on latest analysis with numerical weather prediction (NWP) models and other conventional techniques, estimated track and intensity of the system are given in the table below:

DATE/TIME(UTC)	POSITION (LAT. ^{0}N/ LONG. ^{0}E)	SUSTAINED MAXIMUM SURFACE WIND SPEED (KMPH)	CATEGORY
DD-MM-YYYY/TTTT	……/……	…….. gusting to ……..	DEPRESSION/DEEP DEPRESSION/CYCLONIC STORM ETC

Adverse weather due to heavy rain, Gale Wind and Storm Surge:

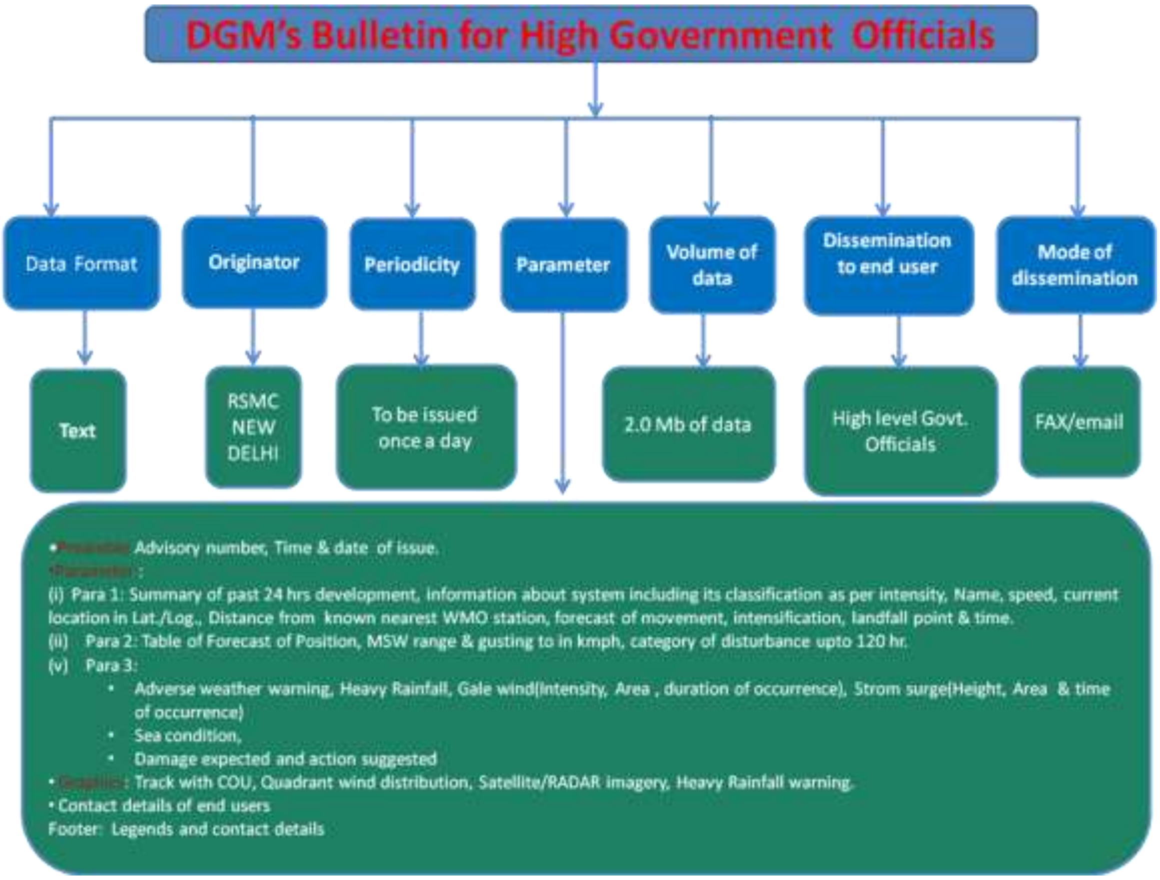
State of sea:

Damage expected:

Advice and action suggested:

Time of issue of next bulletin: hrs. IST

GRAPHICS ON CONE OF UNCERTAINTY, CURRENT & FORECAST TRACK AND QUADRANT WIND DISTRIBUTION ARE GIVEN AS APPENDIX



6.4.2. DGM's Bulletin for high Govt. officials

DGM's Bulletin for high Govt officials is issued as follows.

- It is issued once a day.
- It summarises past 24 hrs development in terms of track and intensity.
- It contains past 24 hrs weather
- Other contents are same as that of bulletin for India coast as discussed in Sec.6.3.1

The format of this bulletin is same as the format of 'Bulletin for India coast incorporating all the above features.

6.4.3. Bulletin through SMS

Since 2009, IMD has started SMS based weather and alert dissemination system through AMSS (Transmet) at RTH New Delhi. To further enhance this initiative, India Meteorological Department has taken the leverage of Digital India Programme to utilize "Mobile Seva" of Department of Electronics and Information Technology (DeitY), Ministry of Communication and Information Technology; Govt. of India for SMS based Warnings /Weather information dissemination for a wide range of users.

The SMS based cyclone alert to the registered users including public was inaugurated on 25th December 2014. The SMS-based alert/warnings are issued to registered farmers through Kisan portal of Govt. of India (Ministry of Agriculture) and to registered fishermen through Indian National Centre for Ocean Information Sciences (INCOIS), Hyderabad also.

6.4.4. Personal briefing

At the national level, the personal briefings are provided by Cyclone Warning Division to national disaster management agencies including cabinet secretariat, MHA, NDRF and NDMA and pressing and electronic media.

6.4.5. Press conference

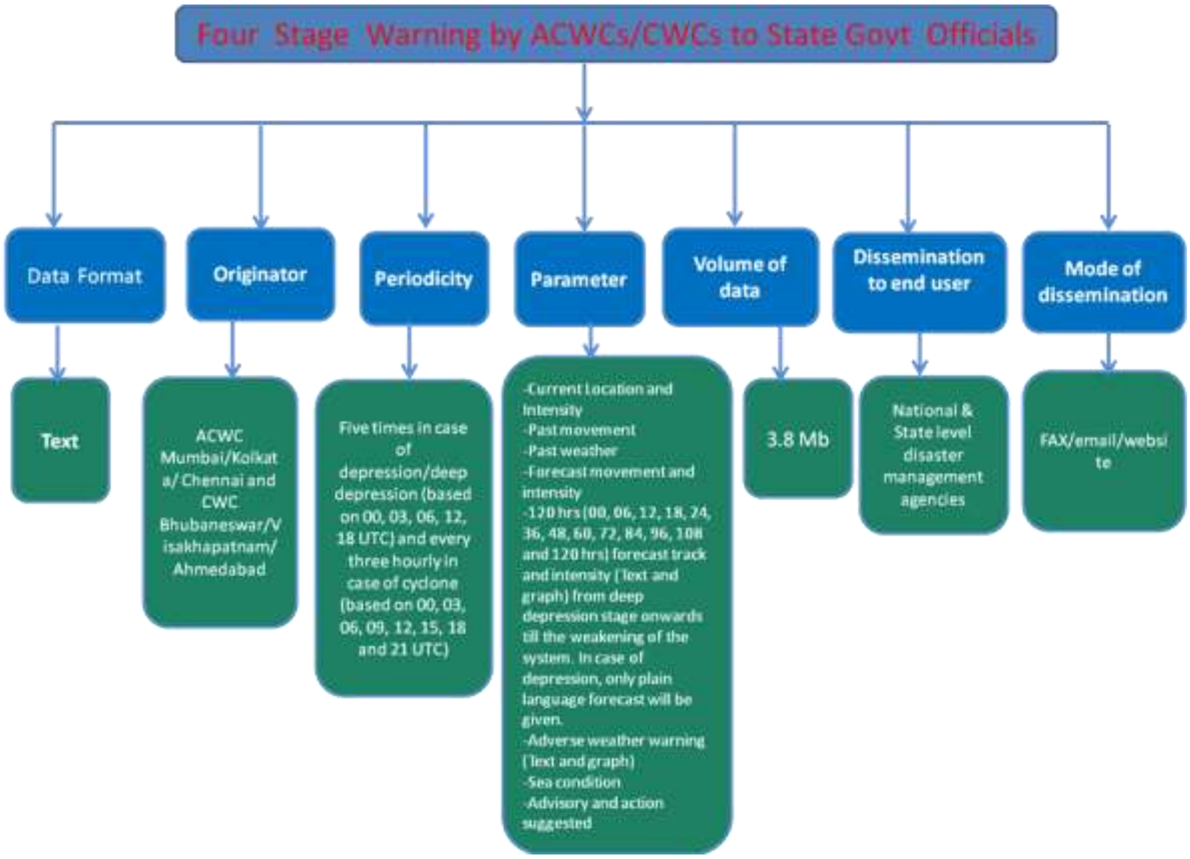
A press conference is held under the chairmanship of Director General of Meteorology, IMD at New Delhi well in advance for the press and electronic media. All the details about the cyclonic storm and associated adverse weather, likely impact and action suggested to public and disaster management agencies are provided in this conference

6.5. User specific bulletins issued by ACWCs/CWCs

The ACWCs/CWCs issue warnings to ships in the high seas, ships in coastal waters, ports, fishermen, government officials and the general public regarding adverse weather likely to be experienced in their respective areas. The bulletins and warnings issued by ACWCs/CWCs for their respective areas of responsibility include

- Four stage warning bulletin
- Sea area bulletins for ships plying in High Seas
- Coastal weather bulletins for ships plying in coastal waters
- Bulletins for Indian Navy
- Port Warnings
- Fisheries Warnings
- Four stage warnings for Central and State Govt. Officials
- Bulletins for broadcast through AIRs for general public
- Warning for registered users
- Bulletins for press
- Warnings for Aviation (issued by concerned Aviation Meteorological Offices)

6.5.1. Four Stage Warning Bulletin The most important warning for disaster management is the one issued to government officials under a four-stage warning system. The **First Stage** warning known as **"PRE CYCLONE WATCH"** issued 72 hours in advance of commencement of adverse weather contains early warning about the development of a cyclonic disturbance in the NIO, its likely intensification into a TC and the coastal belt likely to experience adverse weather. The **Second Stage** warning known as **"CYCLONE ALERT"** is issued at least 48 hrs in advance of the expected commencement of adverse weather over the coastal areas. It contains information on the location and intensity of the storm, likely direction of its movement, intensification, coastal districts likely to experience adverse weather and advice to fishermen, general public, media and disaster managers. The **Third Stage** warning known as **"CYCLONE WARNING"** is issued at least 24 hours in advance of the expected commencement of adverse weather over the coastal areas. These warnings give the latest position of cyclone and its intensity, likely point and time of landfall, associated heavy rainfall, strong wind and storm surge alongwith their impact and advice to general public, media, fishermen and disaster managers. The **Fourth Stage** of warning known as **"POST LANDFALL OUTLOOK"** is issued atleast 12 hours in advance of expected time of landfall. It gives likely direction of movement of the cyclone after its landfall and adverse weather likely to be experienced in the interior areas. However, this is applicable for the TCs developing over open sea like central Bay of Bengal or Arabian Sea. It is not applicable to the systems developing in land locked areas or near the coast and under rapidly intensifying scenario. In such situation a Cyclone Alert can be issued directly without issuing the Pre-Cyclone Watch and Cyclone Warning can be issued directly without issuing Cyclone Alert. The genesis, location, it’s distance from expected coast and expected number of days for landfall will decide the possibilities of providing all cycles of cyclone warning SOP. All the above warnings are issued by ACWCs/CWCs/and CWD. Format for Alert/Warning bulletin and Post Landfall Outlook are shown below:



Format for State/Central Govt. Officials/Vital installations / Registered Users Cyclone

Alert/ Cyclone Warning Bulletin

Cyclone Alert/ Cyclone Warning Bulletin No.:

Date and Time of Issue:

(i) <u>Information on cyclone</u> : The cyclonic storm lay over............ Bay of Bengal/Arabian Sea Center .... kms. .... (Direction) of .... place at _____ IST.

(ii)<u>Forecast</u>

Furtherintensification:

Direction of Movement:

Expected landfall area:

Expected time of landfall:

(iii) <u>Weather Warning</u>

(a) Rainfall .... in .... Districts (Names)

(b) Gales reaching .... in .... Districts (Names)

(c) Gale force winds reaching 35 knots in .... Districts

(d) Tidal waves .... in coastal areas of .... Districts (Names)

(e) Sea condition:

(f) Damage (As per IMD instruction) .... Districts (Names)

(g) Likely impacts as per IMD Monograph on “Damage Potential of Tropical [Depending on Intensity of Storm (T-No)]

(a) Fishermen not to venture into open sea.

(b) Evacuation of people from low lying areas to safer places/Cyclone Shelters.

(c) General public in the threat area advised to be indoors.

(d) Rail & road transport to be regulated.

FORMAT FOR POST LANDFALL OUTLOOK

(To be appended at the end of the Cyclone Bulletin issued 12 hrs before estimated landfall time)

POST LANDFALL OUTLOOK FOR MCs/RMCs ………………………..

Even after landfall, the system is likely to maintain its intensity for …………………. Hours and weaken gradually AAA under its influence, rains at most/many places with heavy to very heavy falls at ……………………………… likely to commence/continue in ………………………… (coastal districts) from …………… (time)……………………. (day) ……………………… (dates) causing inundation of low-lying areas AAA Gale winds/squally winds speed reaching ……………. Kmph likely commence/continue in …………………………………..(coastal districts) from ………(time)on……………………(day)…………… (date) causing damages to ……………………………. (property as indicated in IMD monograph on "DAMAGE POTENTIAL OF TROPICAL CYCLONE") and …………………… (vegetation) and general disruption of communication and power supply for ……………………………

2. As the cyclone moves inland …………………….. Interior districts may also experience heavy/very heavy rain accompanied with gale with speed reaching ……………. Kmph commencing from ……………… (time) on ………………. (day) …………………. (date) for ………….. hrs, causing flooding of low lying areas and damage to property as indicated in imd monograph on "DAMAGE POTENTIAL OF TROPICAL CYCLONE" (as per IMD instruction)

3. People are advised to remain indoors/in safe places and cooperate with state government officials and disaster management agencies.

6.5.2. Sea Area Bulletin

Sea area bulletins for Bay of Bengal are issued by ACWC Kolkata and are broadcast by the coastal radio stations at Kolkata (VWC) and Chennai (VWM) and those for Arabian Sea are issued by ACWC Mumbai and are broadcast by the coastal radio station at Mumbai (VWB). The area covered by these bulletins which is the area of responsibility assigned to India by the World Meteorological Organisation (WMO), is shown in Fig.6.3.

During undisturbed weather, only two bulletins are issued per day, known as Daily bulletins. In the event of disturbed weather, a third bulletin known as extra is broadcast, if considered necessary. However, when a depression has actually formed, the Extra bulletin must be issued. When a cyclonic storm has developed, every attempt should be made to broadcast three additional bulletins a day. The three additional bulletins are known as Storm bulletins which together with the three bulletins mentioned earlier, make up a total of six bulletins a day. Storm three i.e. GASBAG bulletin (1500 UTC) should be issued on routine basis during cyclone situation. These bulletins are broadcast at fixed hours according to a schedule. In addition, if any unexpected development of weather warrants urgent communication to ships, in between scheduled broadcasts, it is broadcast in the form of a special bulletin, called Hexagon which should be issued immediately after the development is noticed. A code word (which is not for broadcast) is prefixed to each of the bulletins as a preamble for easy identification by the coastal radio stations on receipt. These are given in the table 6.2:

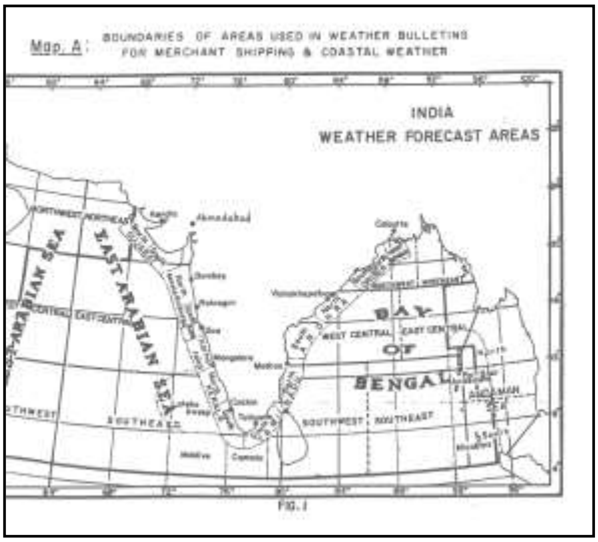


Fig. 6.3. Area of coverage for issue of coastal weather bulletin and sea area bulletin

Table 6.2 Prefix of Code Word to Sea Area Bulletin for coastal Radio Stations

Code word	Type of bulletin	Chart on which based (UTC)
ELECTRON	Storm-One	0000
AURORA	Daily-One	0300
FORMULA	Storm-Two	0900
BALLOON	Daily-Two	1200
GASBAG	Storm-Three	1500
DEW DROP	Extra	1800
HEXAGON	Special	

Format of 'daily' bulletin

The formats for the three messages are as follows:

i) Aurora/ Balloon OBS Date…………….. Part One etc……………… Part Two etc. …………..

ii) OBS Date…… Part Three Area Forecast etc. ………..Part Four Analysis etc. ……………

iii) OBS Date …Part Five Ships' Broadcast etc. …..Part Six 0300 Z synop etc. …

In case of 'extra', 'storm' and 'special' type, bulletin consists of only Part I

Format of Part – I

When a depression or a cyclonic storm has formed or is expected to form or when gales are expected, Part I of the bulletin will contain the following items in the order mentioned below:

(1) International Safety Call sign (TTT).

(2) Statement of type of warning (Warning, gale warning, cyclone warning etc.)

(3) Date and time of reference in UTC in the international six figure date-time group.

(4) Type of disturbance (low, when it is expected to intensify into a depression before broadcast of the next bulletin, depression, monsoon gale, cyclonic storm etc.) with central pressure in hPa in the case of disturbances of cyclonic storm intensity and above.

(5) Location of disturbance in terms of latitude and longitude.

(6) Direction and speed of movement of disturbance. (The direction may be given in 16 points of compass or in degrees to the nearest ten; the speed is given in knots.) The departmental practice is to give the direction in sixteen points of the compass.

(7) Extent of area affected.

(8) Speed and direction of wind in various sections of the affected area. (Wind speeds are given, if possible, for different distances from the centre, in different sectors of the storm area. Wind speeds are given in knots and distances in nautical miles.)

(9) Further indications, if any

Contents of Part-II: When there is no warning in the area, Part I in the Daily bulletin contains the words *No storm warning*. In Part II, Weather is characterized as *Seasonal* when there is no synoptic system in the area. However, during the monsoon season, the strength of the monsoon is described according to corresponding wind speed over the area.

Contents of Part III:

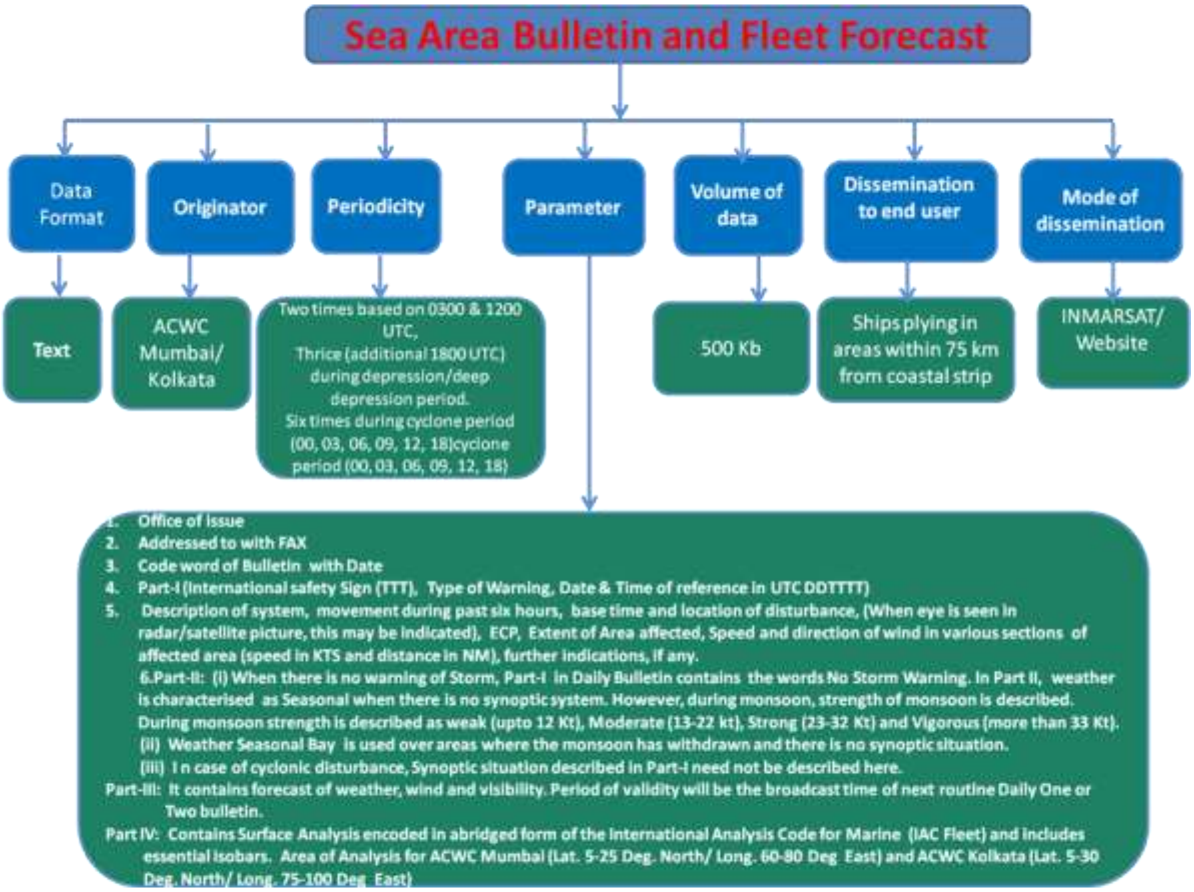
Part III contains a forecast of (i) weather, (ii) wind and (iii) visibility. The period of validity of the forecast should be till the broadcast time of the next routine *Daily* One or Two bulletins. The message should begin with a preamble on the period of validity of the forecast, which will be indicated by the phrase *Forecast valid till …… UTC of ………. (date)*. Forecast of weather (such as rain, rainsqualls, thunderstorms etc.) is given only for areas over which it is expected to occur. No forecast is included for areas where no weather is expected. Wind direction is given in eight points of the compass and the wind speed in knots.

Contents of Part IV

Part IV of the bulletin contains surface analysis encoded in the abridged form of the International Analysis Code for marine use (IAC FLEET) and includes essential isobars. ACWC Mumbai issues analysis for the area from Lat. $5^0 – 25\,^0$ N and Long $60\,^0 – 80^0$ E and ACWC Kolkata for the area from Lat. $5^0 – 30^0$ N and Long. $75^0 – 100^0$ E.

Part V : Data of observations from ships in WMO codes.

Part VI : Data of observations from selected land stations and upper air reports in WMO codes.



6.5.3. Coastal Weather Bulletins

These bulletins are meant for ships plying in coastal waters. These are for the benefit of ships sailing close to the coast and are issued by the ACWCs Kolkata, Chennai, Mumbai and CWCs Visakhapatnam, Bhubaneshwar, and Ahmedabad for the different coastal areas (Fig.6.3) under their responsibility. These bulletins are broadcast in Morse code as well as by NAVTEX stations in plain language from the 11 coastal DOT radio stations – 6 on the west coast, 4 on the east coast and 1 in Andaman and Nicobar Islands. From CWC Ahmedabad, coastal bulletins are issued twice daily to ACWC Mumbai and Mumbai Radio for both South Gujarat and North Gujarat coast. Similarly, CWC Bhubaneswar and Visakhapatnam send the bulletins to ACWC, Kolkata/ Kolkata Radio and ACWC, Chennai/ Chennai Radio respectively. The format of Coastal Weather Bulletin is given below. As in the case of sea area bulletins, the coastal weather bulletin is issued twice daily based on 03 & 12 UTC in normal weather, thrice a day based on 03, 12 & 18 UTC in case of depression/deep depression stage and 5/6 times a day at 00, 03, 06, 09, 12 & 21 UTC in cyclone stage. In undisturbed weather, the two bulletins issued are based on 0300 and 1200 UTC charts and they are called Daily One and Daily Two, corresponding to Aurora and Balloon sea area bulletins. However, during periods of disturbed weather, when Extra, Storm or Special sea area bulletins are issued, corresponding coastal bulletins are also to be issued for the particular coast which is likely to be affected, necessitating the hoisting of signals of LC-III and above at the ports. If local weather along a coast is not affected by the disturbance, additional coastal bulletins for the coast need not be issued. Each bulletin (*Daily*, *Extra*, *Storm* and *Special*) contains the following information in the order given below :

(1) Name of coastal Strip

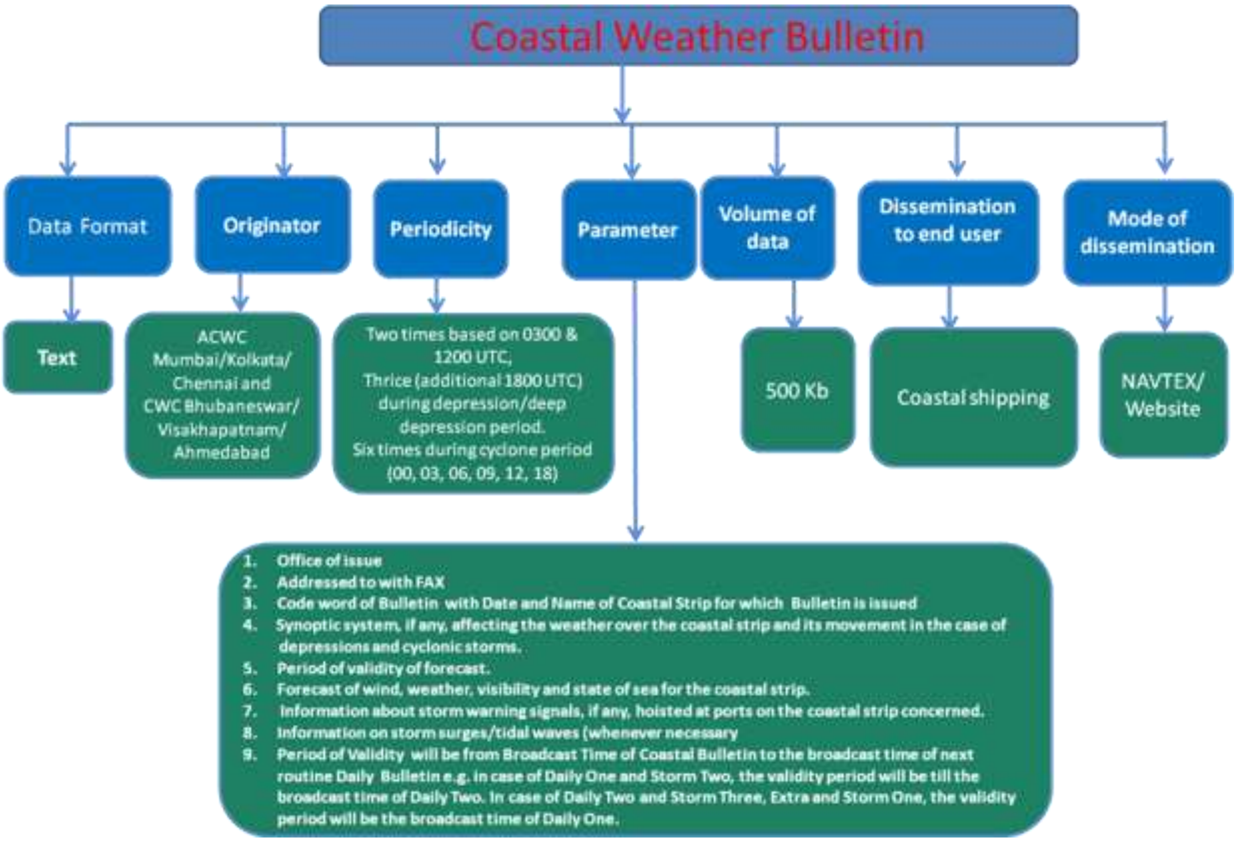
(2) Synoptic system, if any, affecting the weather over the coastal strip and its movement in the case of depressions and cyclonic storms.

(3) Period of validity of forecast.

(4) Forecast of wind, weather, visibility and state of sea for the coastal strip.

(5) Information about storm warning signals, if any, hoisted at ports on the coastal strip concerned.

(6) Information on storm surges/tidal waves (whenever necessary).



6.5.4. Fleet forecast for Indian Navy

Since Naval ships normally do not keep watch on commercial W/T wavelengths and
hence do not listen to the broadcasts from the coastal radio stations, separate weather
bulletins for broadcast to the ships of the Indian Navy are issued to the Naval W/T stations.

The bulletins that are issued exclusively for broadcast to Indian Naval ships are called the Fleet Forecasts. Fleet Forecasts are issued exclusively for broadcast to Indian Naval ships through Naval W/T stations. They are issued twice daily, corresponding to *Aurora* and *Balloon* sea area bulletins. The offices which issue the Fleet forecasts and their areas of responsibility are shown in Fig. 6.4 and Table 6.3.

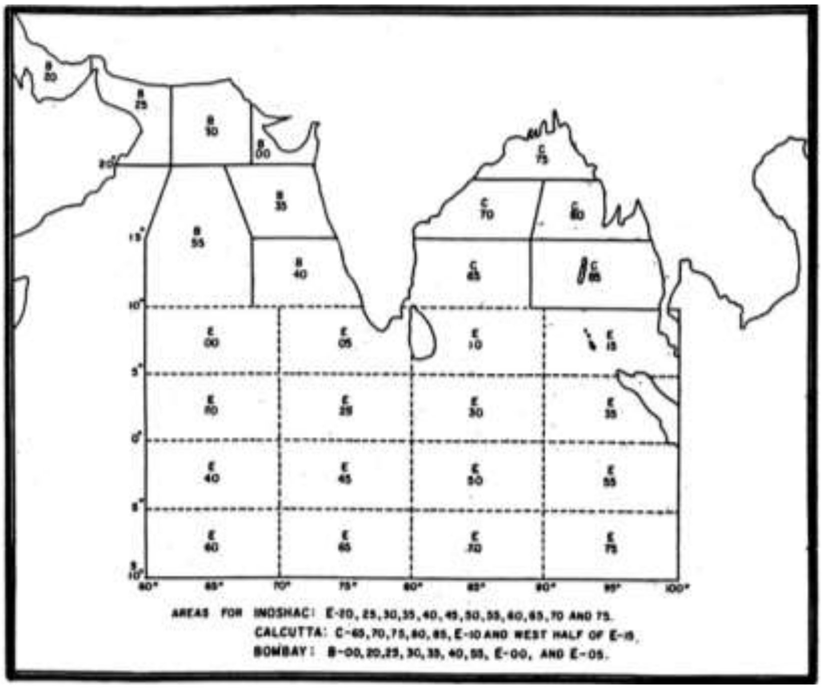


Fig.6.4.Map showing areas for fleet forecast issued by IMD

Table 6.3. Area of responsibility for fleet forecast

S. No.	***Office of issue***	***Area of responsibility***	***Sub-areas***
1.	ACWC Mumbai	Arabian Sea to the north of Lat. 5^{o}N and East of Long.60^{o}E, Gulf of Oman and Persian Gulf	B 00, 20, 25, 30, 35, 40, 55 & E 00, 05
2.	ACWC Kolkata	Bay of Bengal and Andaman Sea to the north of Lat. 5^{o}N	C 65, 70, 75, 80, 85 E10 and West half of E 15.
3.	INOSHAC, Pune	Indian Ocean between Lat.5^{o}N and 10^{o}S and Long.60^{o}E and 100^{o}E	E 20, 25, 30, 35, 40,45, 50, 55, 60, 65, 70,75.

6.5.4.1. Items in Fleet Forecast

The Fleet Forecast is in plain language and contains a brief general inference for the area including warnings. In the case of Bay of Bengal and Arabian Sea, the inference will conform to the *Aurora* and *Balloon* bulletins issued by ACWCs Mumbai and Kolkata. The forecast covers surface wind, visibility and state of sea and an *outlook* for the next 12 hours. Fixed times of origin are given to the Fleet Forecast messages – 0800 UTC in the case of day bulletin and 1700 UTC in the case of the night bulletin. These Fleet forecasts are broadcast by Naval W/T station, Mumbai, during weather broadcast periods commencing from 0930 UTC and 1830 UTC respectively. Fleet Forecast messages should be brief with the view that the requirements of ships at sea are principally wind (direction and speed) and visibility and hence the area forecasts must contain only these two elements and their variations. The central pressure is given from Storm stage upwards. The two daily forecasts are valid for 12 hours from 1000 UTC and 2200 UTC respectively. Outlook for next 12 hours in clear terms from the termination of the forecast period should be appended to both day and night bulletins as a routine. When weather conditions are reasonably stable, the evening forecast may be abbreviated with reference to the previous morning forecast.

6.5.4.2. Mode of Transmission of Fleet Forecast to Naval W/T Mumbai

ACWC Kolkata and INOSHAC Pune send their Fleet Forecasts to RCC Mumbai through Departmental telecommunication channels. These Fleet Forecasts together with the one issued by ACWC Mumbai are transmitted to Naval W/T Station, Mumbai, through the Naval Met.Office, Mumbai.

6.5.5. *Warnings to Ports*

6.5.5.1. Hoisting of signals

A uniform system of storm warning signals was introduced at all the ports in India from 1st April 1898 and it is still in vogue with very little changes. The salient features of the system are described below :

(i) General System

A General System with eleven signals (Table 6.4), the first two of which (signals No. I and II) indicate the existence of distant disturbed weather, the next eight (signals III to X) indicate that the port itself is threatened by bad weather and the last one (signal No. XI) indicates that the communication with the ACWC/CWC had broken down and that in the opinion of the local Port Officer, there is danger of bad weather. Signals No. I and II are called Distant Signals and the rest Local signals. The ports where this system of signals is in use are called General Ports.

(ii) Extended System

An Extended System which in addition to the eleven signals of the General System, has six Section signals (Details are given in Cyclone Manual) to indicate the location of the disturbance. These additional signals are hoisted along with Distant Signals. This system is a special case of the General System and is in use only at a few ports on the east coast (Bay of Bengal). These ports are: Sagar Island, Kakinada, Chennai, Cuddalore and Nagapattinam. These ports are called Extended Ports. There is no port under the Extended System on the west coast.

(iii) Brief System

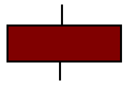
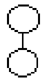
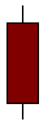
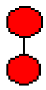
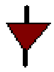
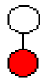
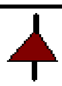
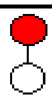
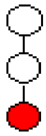
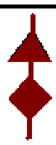
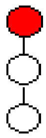
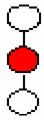
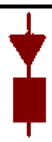
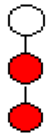
A Brief Systems consisting of only five of the signals of the General Systems (viz. Signal Nos. III, IV, VII, X and XI). These are hoisted in association with prospects of bad weather at the port itself caused by disturbances out at sea. This system of signals is in use in ports frequented mainly by smaller vessels engaged in local traffic and these ports are called Brief Ports.

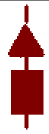
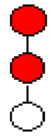
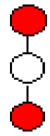
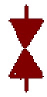
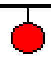
(iv) Ports without Signals

In addition, there are some minor ports where no signals are hoisted but which get a special type of warning message; they are called Ports without signals. For purposes of warning, these ports are treated as Brief ports and corresponding port warnings are issued when adverse weather threatens them although no signals are advised to be hoisted. These warning messages will contain information on the location, intensity and direction of movement of the disturbance and the expected weather over the port.

The India Meteorological Department (through the ACWCs/CWCs) maintains a port warning service by which the port officers are warned by telefax about disturbed weather likely to affect their ports. On receipt of the warning bulletin from the ACWC/CWC, the port officers hoist appropriate visual signals prominently on signal masts so that they are visible from a distance. Mariners and other sea-faring people, including fishermen who may not be literate, are generally aware of the meaning of these signals and the port authorities are always ready to explain them whenever necessary. At some ports, the meanings of the signals are displayed in English as well as in the local languages prominently on a notice board. While the India Meteorological Department is responsible for issuing the warnings, the port authorities arrange the display of signals. In addition to hoisting the signals, the port officers in most cases, make arrangements for disseminating the warnings received by them, to country craft and sailing vessels in the harbours. The port warning signals (general system) used in India are shown in Table 6.4

Table 6.4. Port Warning Signals (General System) used in India

Signal/Flag No.		NAME	Symbols		Description
			Day	Night	
1	DISTANT BAD WEATHER	DC1			Depression far at sea. Port NOT affected.
2		DW2			Cyclone far at sea. Warning for vessels leaving port.
3	LOCAL BAD WEATHER	LC3			Port Threatened by local bad weather like squally winds.
4		LW4			Cyclone at sea. Likely to affect the port later.
5		D5			Cyclone likely to cross coast keeping port to its left.
6.	DANGER	D6			Cyclone likely to cross coast keeping port to its right.
7.		D7			Cyclone likely to cross coast over/near to the port.
8.		GD8			Severe cyclone to cross coast keeping port to its left.

9.	**GREAT DANGER**	**GD9**			**Severe cyclone to cross coast keeping port to its right.**
10.		**GD10**			**Severe cyclone to cross coast over or very near to the port.**
11.		**XI**			**Communication failed with cyclone warning office.**

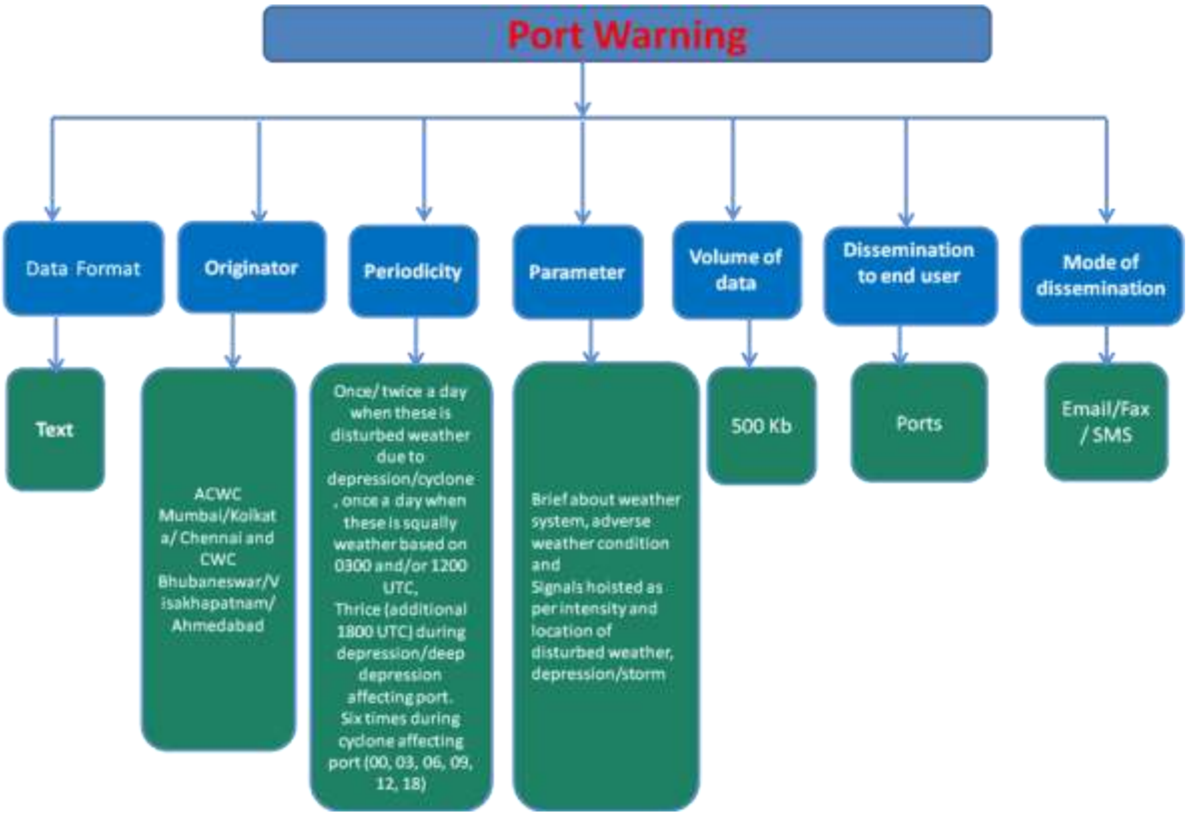
6.5.5.2. Frequency of Issue and contents of Port Warning Bulletin

Ports in the maritime States are warned 5 to 6 times a day during periods of cyclonic storm by telefax. The warnings contain information about the location, intensity and expected direction of movement of the storm or depression, the part of the coast where it is expected to strike and the type of signal which the port should hoist. As landline communication between the port and the CWC may break down during a cyclone, provision exists for using state and inter-state police W/T channels wherever available for passing on the warnings.

6.5.5.3. Format for Port Warning

Port Warning No.
Date and Time for Issue
(i) Information on cyclone: The cyclonic storm lay over Bay of Bengal/Arabian Sea near Lat.__/Long. _____ at a distance ________ km. from ___________ at _______ IST ______ Estimated Central Pressure ________ hPa.
(ii)<u>Forecast:</u>
Further intensification:
Direction of Movement:
Expected Landfall Area :
Expected Time of Landfall :
<u>Advice for hoisting Storm Warning Signals</u>:

Likely impacts and actions : Depending on intensity of the storm as per IMD Monograph on “Damage Potential of Tropical cyclones.



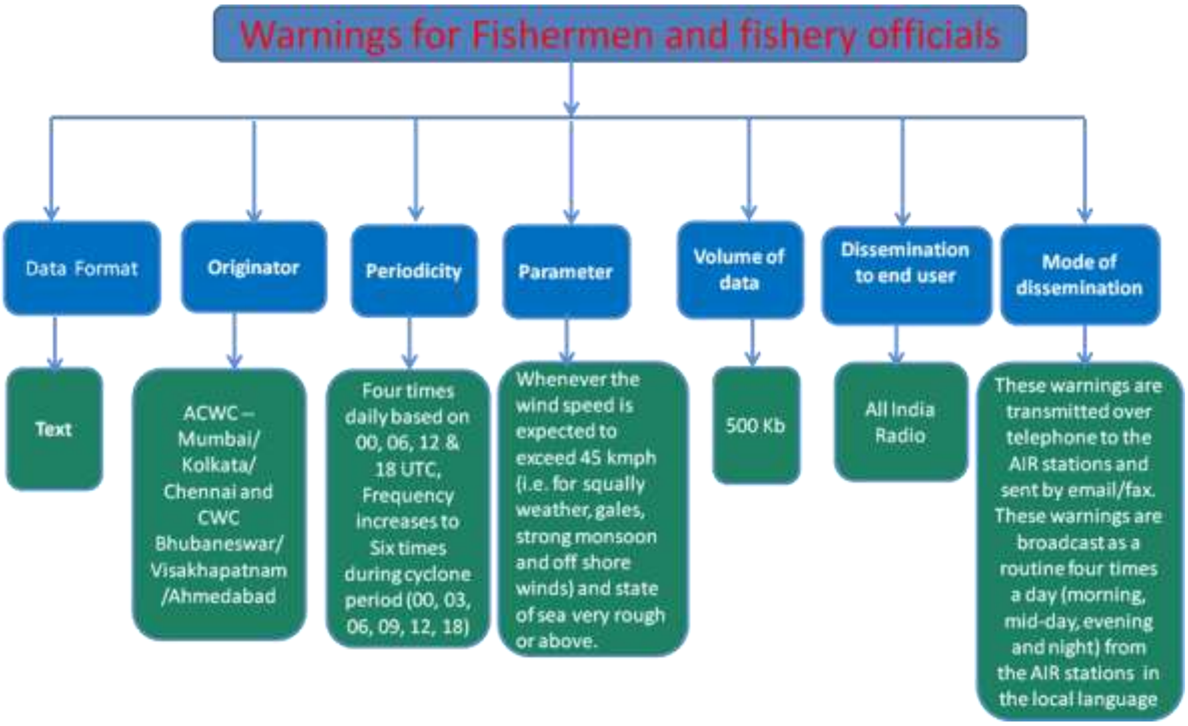
6.5.6. Warnings for Fisheries

6.5.6.1. Criteria for warnings

Warnings for fishing interests are issued by the ACWCs/CWCs whenever the wind speed is expected to exceed 45 kmph (i.e. for squally weather, gales, strong monsoon and off shore winds) and state of sea very rough or above. These warnings are transmitted by landline telegram or over telephone to the AIR stations (about 30 in number) in the maritime states. These warnings are broadcast as a routine four times a day (morning, mid-day, evening and night) from the AIR stations in the local language. During a cyclonic storm, such warnings are covered in the cyclone bulletins sent to the AIR stations at hourly or 3 hourly intervals for frequent broadcast. The fishermen can listen to these broadcasts through portable radio receiving sets.

6.5.6.2. Warnings through FAX

In addition to warnings broadcast by AIR stations, direct warning messages are also sent by telefax to a large number of officials belonging to the fisheries departments in maritime states.



6.5.6.3. Format for fisheries Warning

Fisheries warning No. _______________

Date and Time of Issue _____________

Information on Cyclone:

Cyclonic Storm lay over ________________ Bay of Bengal / Arabian Sea at a distance

_______________ kms. _______________ from _________ at ______________

IST on _________________ (date)

Forecast:

Further intensification

Direction of Movement

Expected landfall area

Expected time of landfall

Warnings : Wind, Sea Condition and Tidal Waves

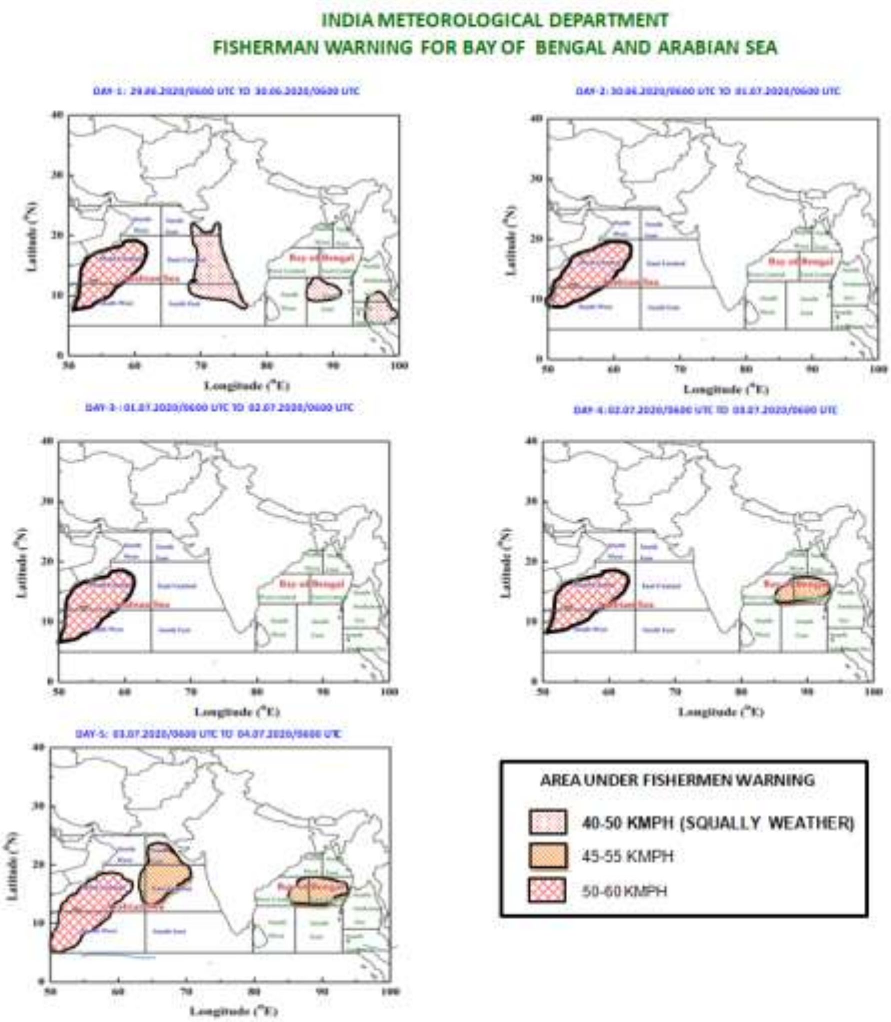
Storm Warning Signals at ports

Advice and Action: i) Fishermen not to venture into open seas

ii) Fishermen at Sea not to come to the ports (names)_____ in coast.

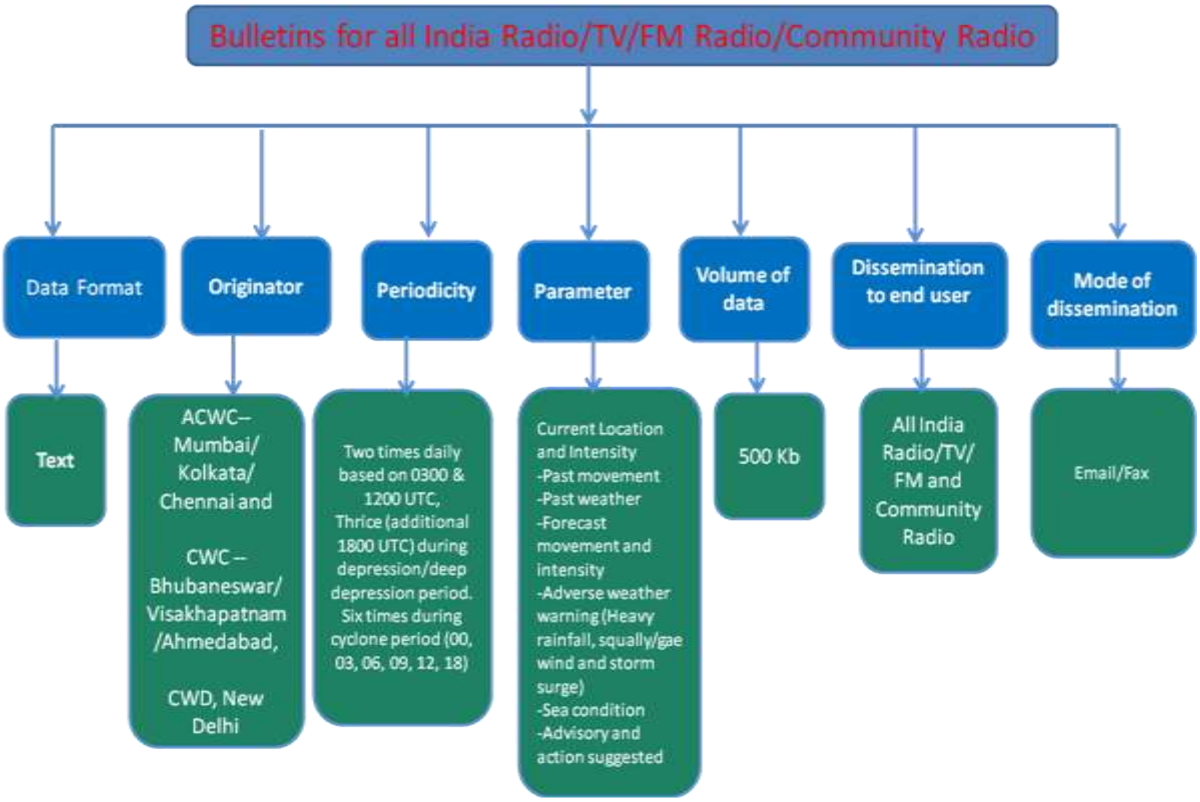
iii) Fishermen to be cautious while going out in the sea
iv) Fishermen are advised to return to coast

Fishermen warnings are also issued in graphical format since April, 2018. These bulletins are available at www.rsmcnewdelhi.imd.gov.in and www.mausam.imd.gov.in. Sample bulletin is given below:



6.5.7. Bulletins for All India Radio (AIR)

The cyclone warnings are also broadcast through AIR stations. After issuing the *Cyclone Alert* to the Chief Secretary and Collectors by FAX/mobile, the *Cyclone Warning* is also passed on to the concerned AIR stations for broadcast. In the *Cyclone Alert* message, the recipients are informed that the subsequent cyclone warnings will be broadcast from the concerned AIR station. When the cyclone is beyond the range of the coastal cyclone detection radar, that is, more than 400 km away from the coast, cyclone warnings are issued 6 times a day to the AIR stations and each warning is broadcast at frequent intervals interrupting the routine programme. When the cyclone comes within the radar range and is tracked by the radar hour to hour, cyclone warnings are issued every hour to AIR stations. During cyclone periods, the concerned AIR stations keep round the clock watch for broadcasting cyclone warnings.



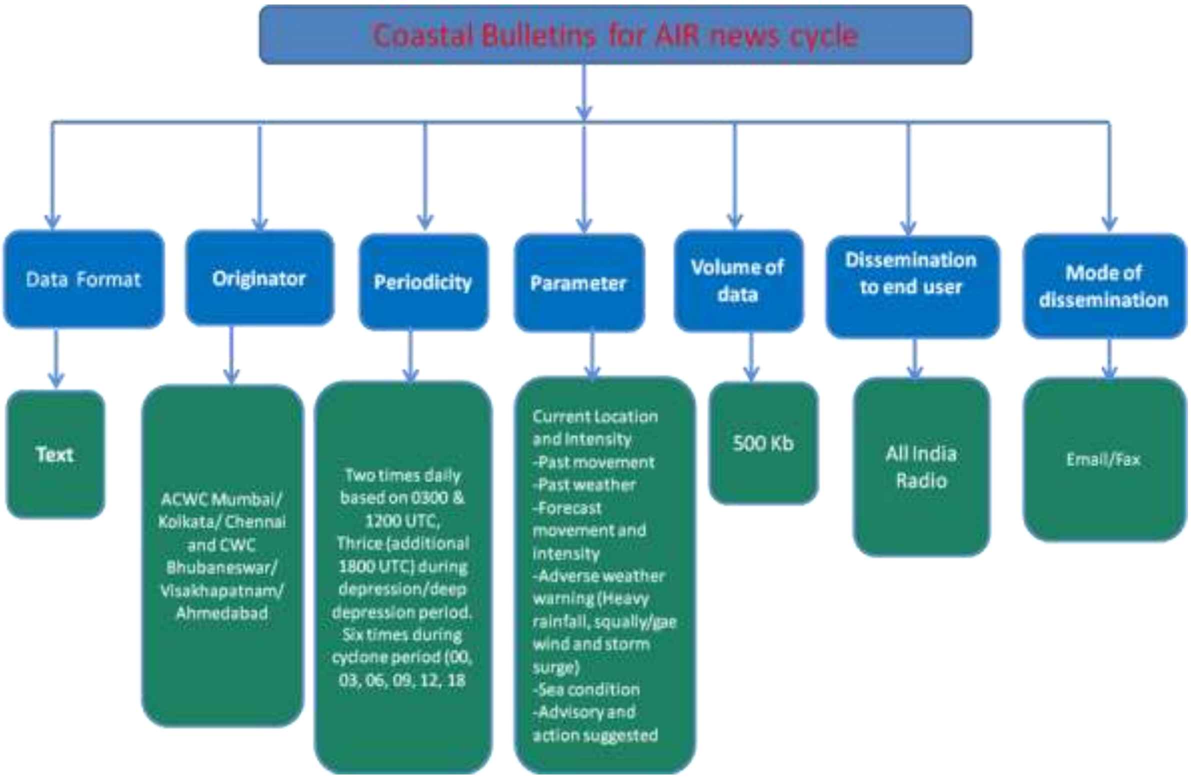
6.5.7.1. Format for Cyclone Alert/Warning Bulletin for AIR/Press / Public :

Cyclone Alert / Warning Bulletin No. ______ issued by _____ at _____ Hrs. IST on _________ (Date) for repeated broadcast at hourly / half hourly intervals. Cyclone Alert / Warning for _______ Districts. Cyclone centred at _____ hrs. IST of ________ (date) about ____________ kms. ________ of (direction) _______(Place). Expected to intensify further and move in a _________ direction and cross _______ coast near / between ____________ (Place)________ (day/time). Under its influence heavy to very heavy rain likely cause floods in _______ districts commencing from _________ (time/day). Gales speed reaching ______ kmph causing _______ damage ________in districts commencing from ____________ (Date/Time) Gale force winds reaching 70 kmph likely extend into _________ Districts,

causing damage ___________ in ________ districts. Tidal wave of ________ m Likely inundate low lying area of _______ Districts at the time of crossing coast.
Advice to Fishermen :
Public advised to cooperate with the State authorities in disaster management efforts.

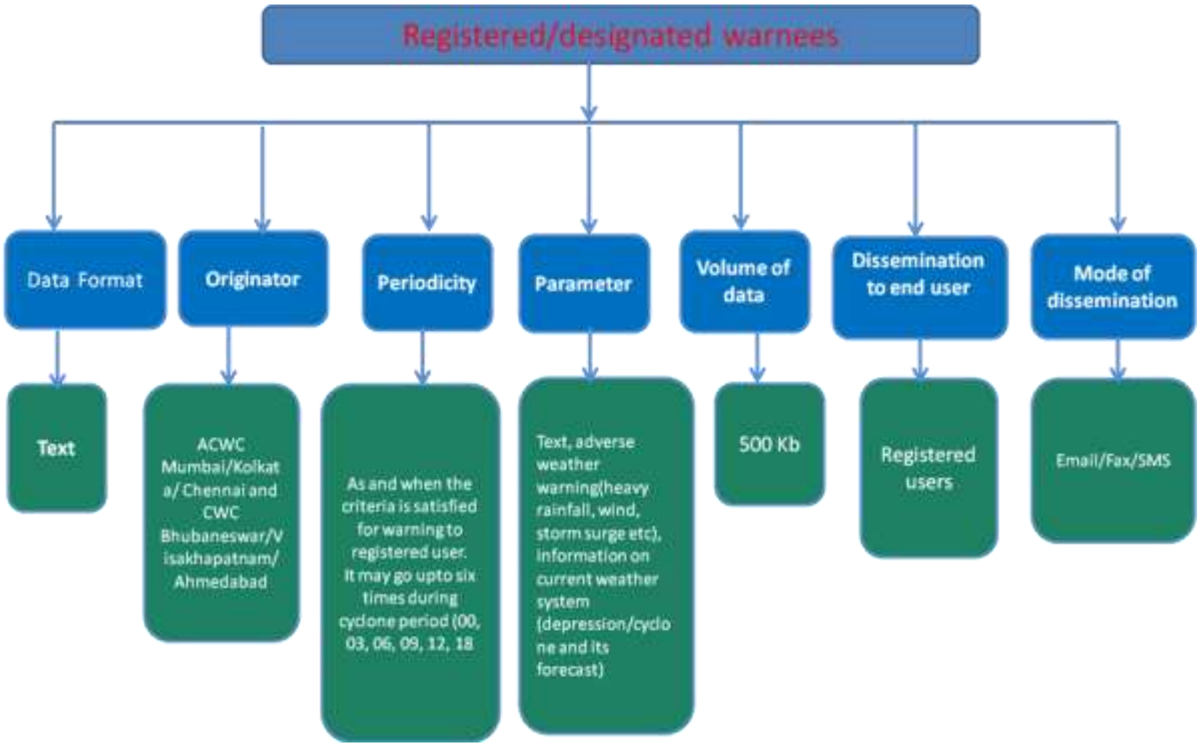
6.5.8. Coastal Bulletins for AIR news cycle

In addition, arrangement has also been made with AIR New Delhi for broadcast of coastal weather bulletins for the different coastal belts, in Hindi, English and the local languages in the AIR news cycles three times a day, viz., in the morning, mid-day and at night. These bulletins contain information on the location, intensity and expected direction of movement of the cyclone, state of sea off the coast and expected adverse weather (heavy rain, gales and tidal waves) in the coastal districts.



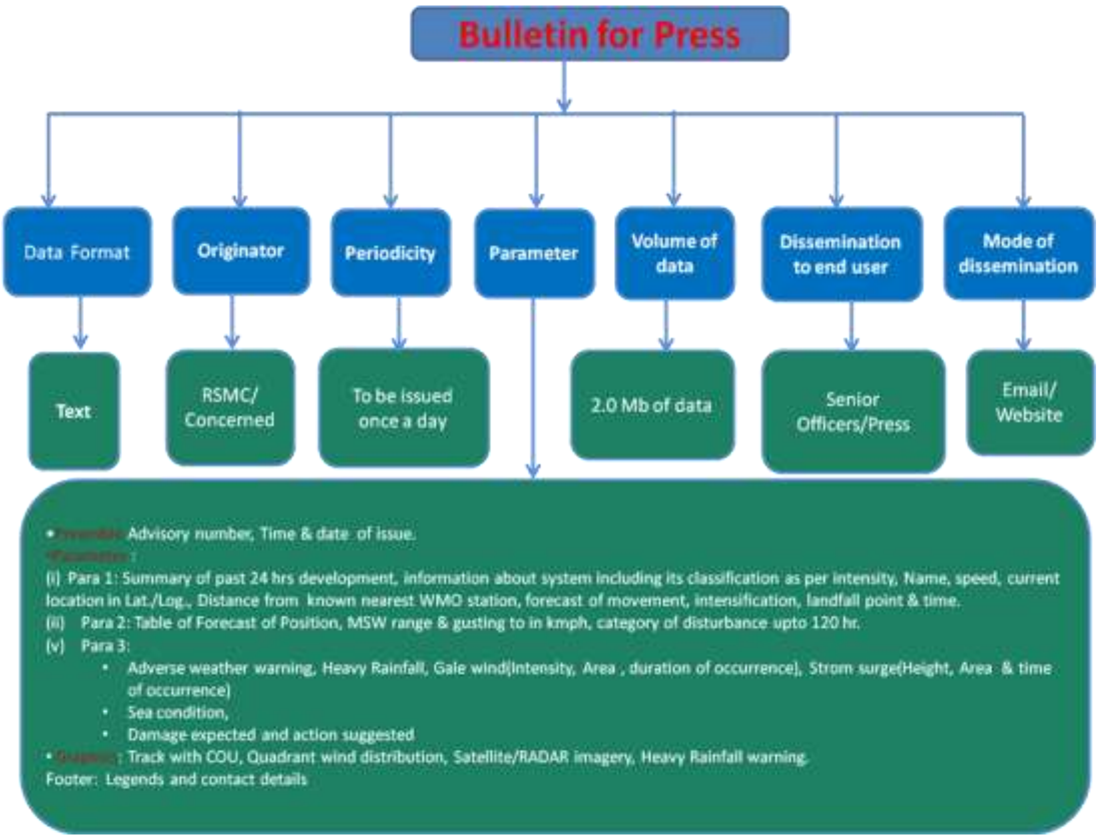
6.5.9. Registered/designated warnees

Warnings for heavy rain and gales are also issued by FAX/ e-mail/mobile to officers of the Revenue, P.W.D., Irrigation and Highways, DOT., Railways etc., who are on the warning list of the ACWCs/CWCs. For Andhra Pradesh, CWC Visakhapatnam gives these warnings from depression stage while MC Hyderabad issues during other periods. In addition, the warnings are kept in the Website for information.



6.5.10. Press Bulletins

Special press bulletins are issued during periods of cyclonic storms to local newspapers for giving publicity to the warnings.



6.5.11. Aviation Warnings

Warnings for airports and flight operations likely to be affected by tropical cyclones are issued by the concerned Aviation Meteorological Offices.

6.5.12.Bulletin through satellite based cyclone warning dissemination system(CWDS)

For quick dissemination of warning against impending disaster from approaching cyclones, IMD has installed specially designed receivers within the vulnerable coastal areas for transmission of warnings to the concerned officials and people using broadcast capacity of INSAT satellite. This is a direct broadcast service of cyclone warning in the regional languages meant for the areas affected or likely to be affected by the cyclone. There are 352 Cyclone Warning Dissemination System (CWDS) stations along the Indian coast; out of these 101 digital CWDS are located along Andhra coast. The IMD's Area Cyclone Warning Centres (ACWCs) at Chennai, Mumbai & Kolkata and Cyclone Warning Centre (CWCs) at Bhubaneswar, Visakhapatnam & Ahmedabad are responsible for originating and disseminating the cyclone warnings through CWDS. The bulletins are generated and transmitted every hour in three languages viz English, Hindi and regional language. The cyclone warning bulletin is up-linked to the INSAT in C band. For this service, the frequency of transmission from ground to satellite (uplink) is 5859.225 MHz and downlink is at 2559.225 MHz. The warning is selective and will be received only by the affected or likely to be affected stations. The service is unique in the world and helps the public in general and the administration, in particular, during the cyclone Season. It is a very useful system and has saved millions of lives and enormous amount of property from the fury of cyclones. The digital CWDS have shown good results and working satisfactorily.

6.5.13.Personal Briefing

In addition to the FAX message, the Chief Secretary of the concerned state is also kept informed over telephone/mobile/fax/internet by the ACWC/CWC about the location, movement and intensity of the storm and the areas expected to experience severe weather.

6.5.14. Bulletin through SMS

The bulletins are sent through various state disaster management agencies and the chief secretary, relief commissioner etc in case of a landfalling cyclone.

6.6. Other products generated by Cyclone Warning Division, New Delhi

Following graphical products are developed every six hours based on 00, 06,12 & 18 UTC by the CWD and sent to users. These products are also uploaded on the cyclone page of IMD website. The examples of these products are shown in Fig.6.3

(i) Past and 120 hrs (00, 06, 12, 18, 24, 36, 48, 60, 72, 84, 96, 108 and 120 hrs) forecast track and intensity with cone of uncertainty

(ii) Past and 120 hrs (00, 06, 12, 18, 24, 36, 48, 60, 72, 84, 96, 108 and 120 hrs) forecast track with quadrant winds

(iii) TCAC bulletin in graphical format

(iv) Storm surge guidance

(v) Adverse weather warning graphics

6.6.1.Track and Cone of Uncertainty

Cone of Uncertainty has been introduced since Dec 2009, with effect from cyclone, WARD. It is based on the standard errors of last five years of different forecast periods. The standard errors are given in table 6.5 and an example of the uncertainty forecast is shown in the Fig. 6.5.The standard error for a given forecast time is considered as radius of the circle (R) with forecast latitude & longitude point as the centre of the circle. The cone of uncertainty is the tangent line constructed from the circles drawn for all forecast points.

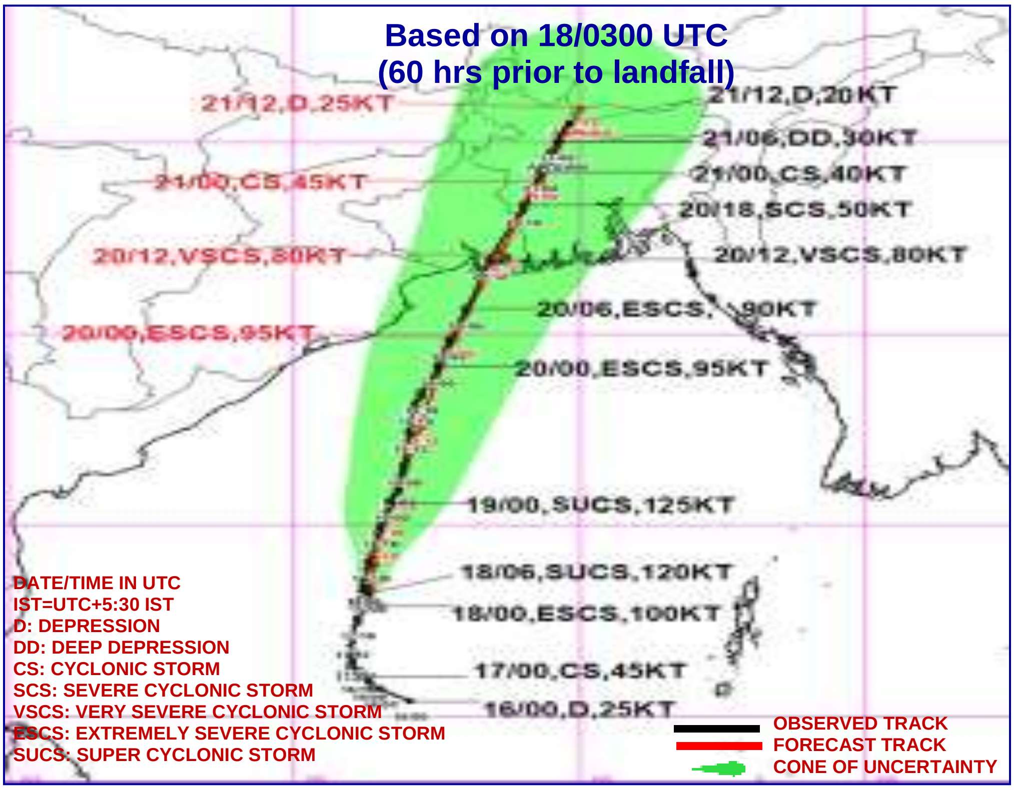
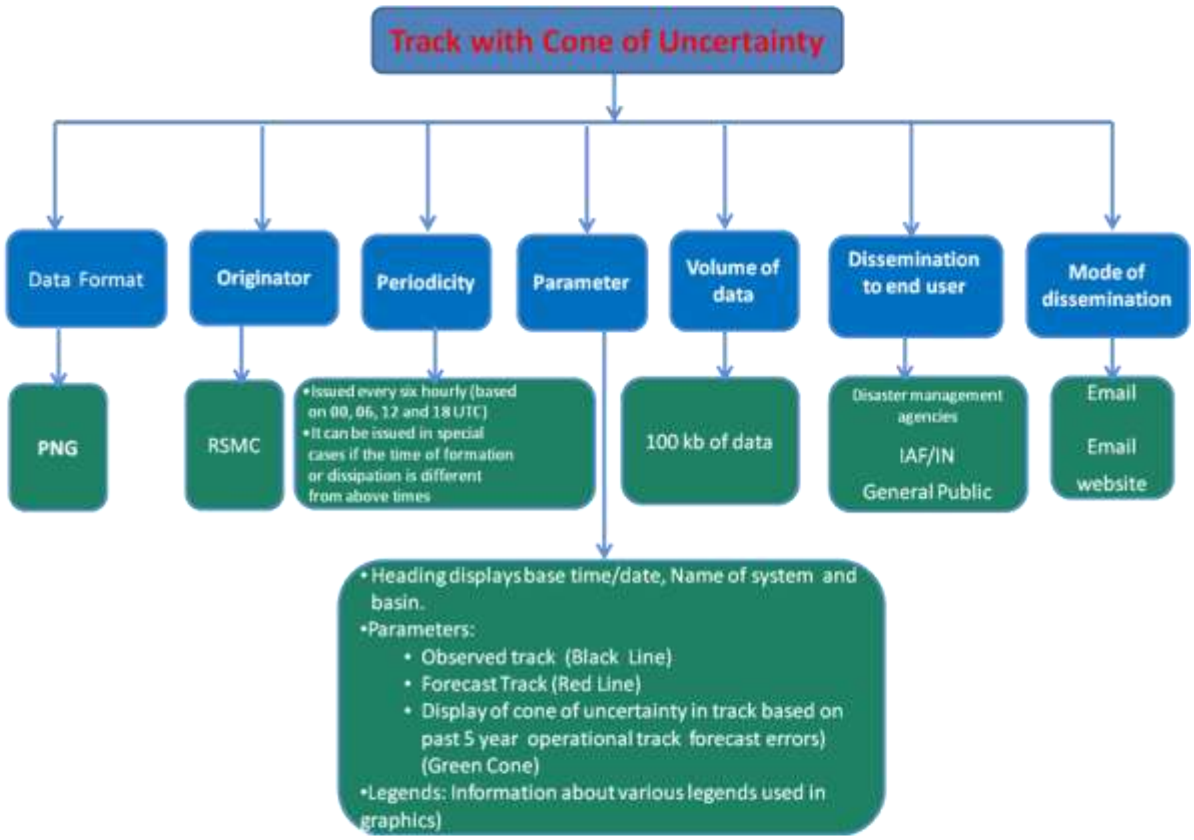


Fig.6.5. Typical example of track alongwith cone of uncertainty forecast issued by IMD

Table 6.5. Radius of circle to construct cone of uncertainty

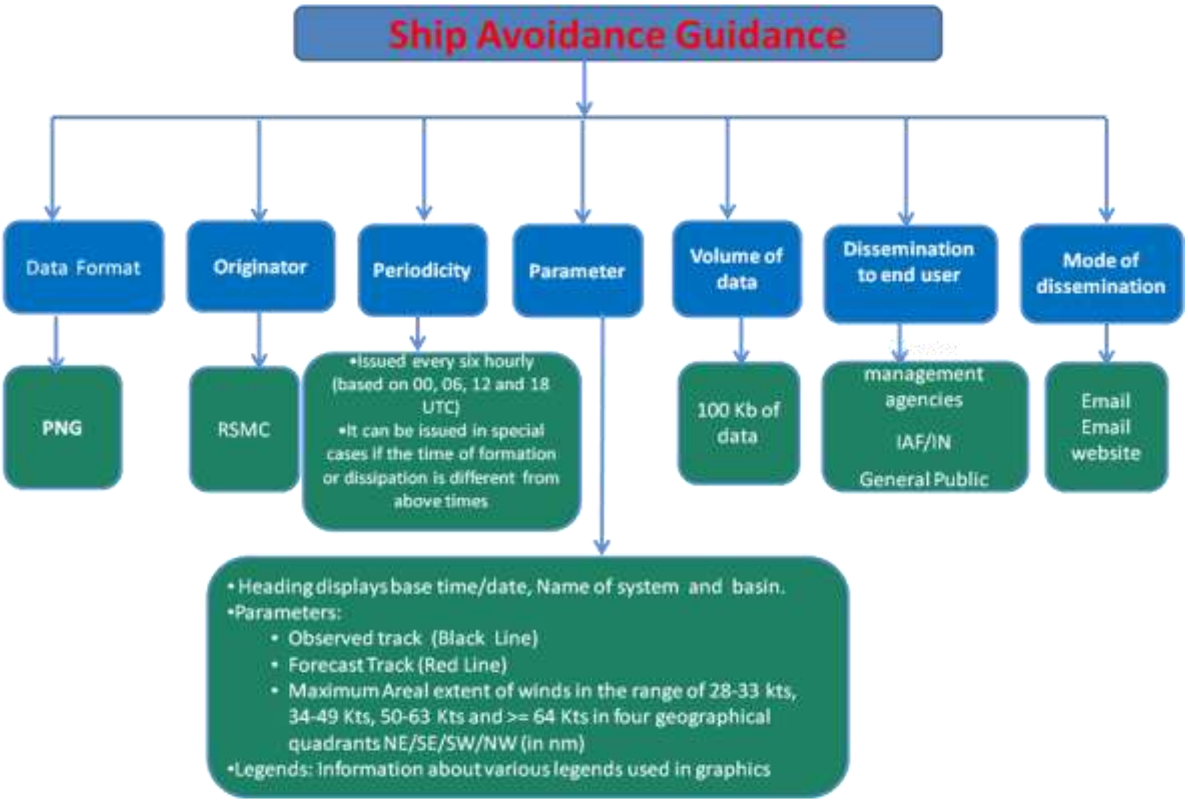
F/C Period	Radius of the circle to construct cone of uncertainty (km/nm) w.e.f.			
	*2009	$2013	@2014	#2019
12 hr	75/40	75/40	55/30	55/30
24 hr	150/80	150/80	110/60	85/45
36 hr	200/110	200/110	150/80	105/55
48 hr	250/135	250/135	185/100	130/70
60 hr	300/160	300/160	220/120	160/85
72 hr	350/190	350/190	250/135	175/95
96 hr	-	415/225	305/165	240/130
120 hr	-	490/265	360/195	295/160

Commenced wef cyclone *WARD (for lead period extending upto 72 hours based on track forecast errors during 2004-08), $VIYARU (lead period extended to 120 hours), @HUDHUD (reduction in COU values based on average track forecast errors during 2009-13) and #FANI (reduction in COU values based on average track forecast errors during 2009-13 (about 30% further reduction in COU values based on average track forecast errors during 2014-18).



6.6.2.Ship avoidance guidance

Radius of circle to construct the area of ship avoidance guidance is given in Table 6.6. The radius of this circle is the combination of radius of cone of uncertainty and the



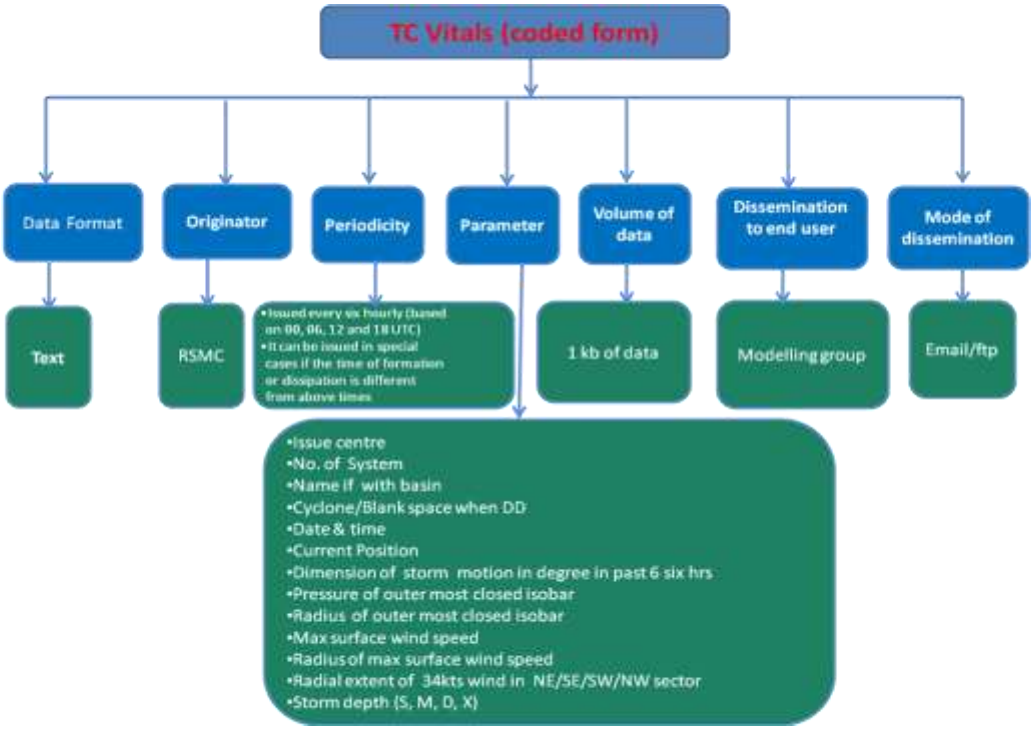
radius of gale wind (34 kts or more).

Table 6.6.Radius of circle to construct the cone of ship avoidance guidance

F/C Period	Radius (km/nm) of circle to construct cone of ship avoidance
12 hr	Radius of 34 kts wind + 55/30
24 hr	Radius of 34 kts wind + 110/60
36 hr	Radius of 34 kts wind + 150/80
48 hr	Radius of 34 kts wind + 185/100
60 hr	Radius of 34 kts wind + 220/120
72 hr	Radius of 34 kts wind + 250/135

6.6.3 Tropical Cyclone (TC) Vitals

The TC vital contains the vital components required to describe a TC. It contains the location, intensity, radius of maximum wind, radii of 28, 34, 50 and 60 knots wind threshold in four different quadrants of the system (northeast, northwest, southeast and southwest) at the initial state and forecast states upto 72 hrs. The quadrant wind forecast is issued from the deep depression stage only and when the system is over sea. Issued 4 times a day based on 00, 06, 12 and 18 UTC observation and analyses. It is issued within 3 hrs of time of observation.



6.6.3.1. Format of TC Vitals

QUADRANT WIND DISTRIBUTION IN ASSOCIATION WITH______________(Name of the system) over ___________(area and basin)

DATE AND TIME BASED UPON WHICH FORECAST IS PREPARED:

PRESENT DATE AND TIME: _______ UTC

PRESENT POSITION: _ _._ ^{0}N/ _ _ ._ ^{0} E

POSITION ACCURATE TO 50 KM

MOVEMENT (DDD/FF) DURING PAST SIX HOURS: _ _ _ /_ _KT

PRESENT WIND DISTRIBUTION:

MAX SUSTAINED WINDS: _ _ KT, GUSTS _ _ KT

RADIUS OF MAXIMUM WIND :

FORECASTS:

06 HRS, VALID AT:

DDHHMM Z(Time in UTC) _ _ . _ ^{0}N/_ _._ ^{0} E (F/C position in latitude/Longitude)

MAX SUSTAINED WINDS: _ _ KT, GUSTS _ _ KT (Maximum sustained wind and gust in knots)
RADIUS OF 064 KT WINDS:

_ _ NM NORTHEAST QUADRANT
_ _ NM SOUTHEAST QUADRANT
_ _ NM SOUTHWEST QUADRANT
_ _ NM NORTHWEST QUADRANT

RADIUS OF 050 KT WINDS:

_ _ NM NORTHEAST QUADRANT
_ _ NM SOUTHEAST QUADRANT
_ _ NM SOUTHWEST QUADRANT
_ _ NM NORTHWEST QUADRANT

RADIUS OF 034 KT WINDS:

_ _ NM NORTHEAST QUADRANT
_ _ NM SOUTHEAST QUADRANT
_ _ NM SOUTHWEST QUADRANT
_ _ NM NORTHWEST QUADRANT

RADIUS OF 028 KT WINDS:

_ _ NM NORTHEAST QUADRANT
_ _ NM SOUTHEAST QUADRANT
_ _ NM SOUTHWEST QUADRANT
_ _ NM NORTHWEST QUADRANT

Forecast is similarly prepared for 12, 18, 24, 36, 48, 60 and 72 hrs. A graphics version of this bulletin is also prepared and sent to users as well as put up in website. A typical example is shown in Fig.6.6.

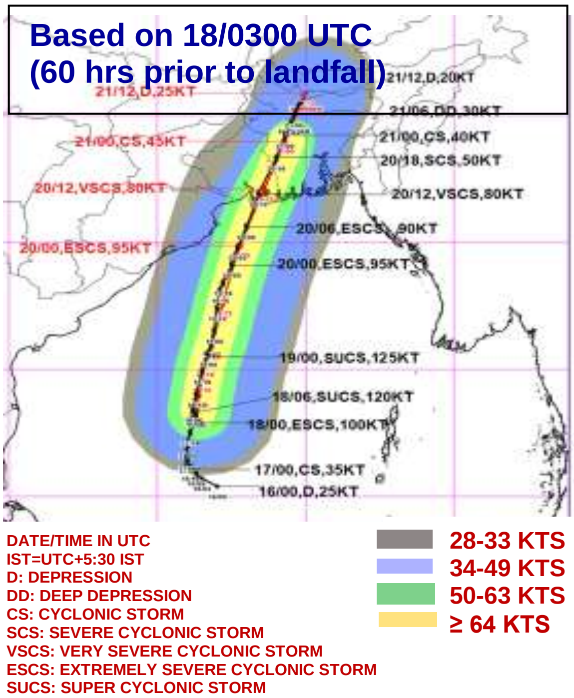
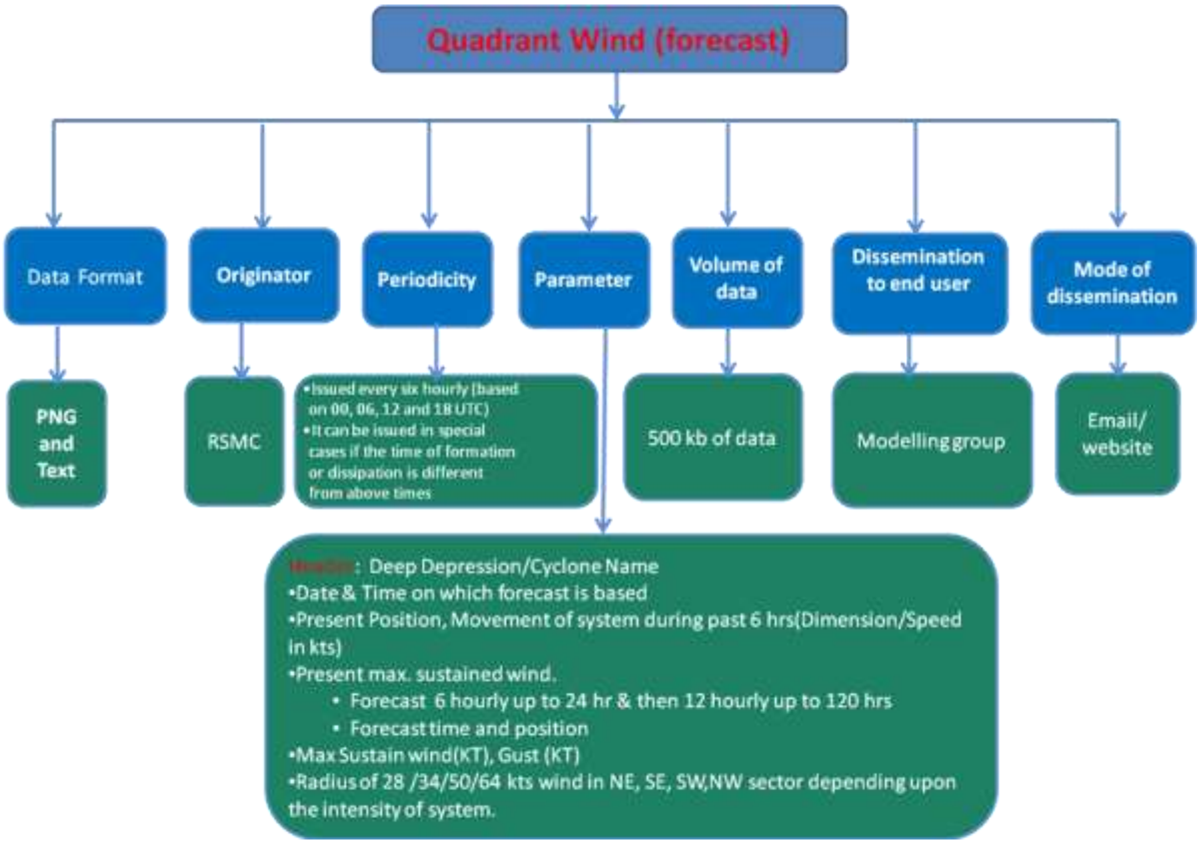


Fig.6.6. Typical example of radii of quadrant wind forecast issued by IMD



6.6.4. Storm surge warning

In the bulletin for India coast storm surge guidance is provided. It depicts the height of storm surge expected aboved the astronomical tide along the coast. Storm surge guidance for WMO/ESCAP Panel countries is being issued issued as and when necessary from April, 2009 onwards as per their requirement. It is added in the Tropical Cyclone Advisory Bulletin for WMO/ESCAP Panel Member countries. An example of storm surge guidance based on IIT, Delhi model is shown in Fig.6.7.

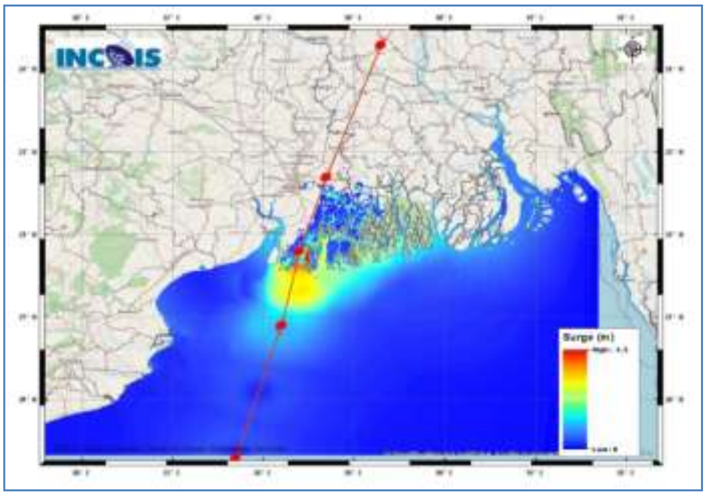


Fig.6.7. . Typical Storm surge prediction guidance based on INCOIS (19th May 2020/1800 IST) model in case of SuCS 'Amphan'

The storm surge guidance is provided in both text and graphic format. The guidance in text form is added in the bulletin for India coast. The storm surge warning in graphics is uploaded in website of IMD.

6.6.5. Heavy rainfall warning

In the bulletin for India coast heavy rainfall warning is provided. It describes the area of occurrence, time of occurrence and intensity of heavy rainfall. The heavy rainfall is provided in three categories, viz., heavy rainfall (7-12 cm), very heavy rainfall (13-24 cm) and extremely heavy rainfall (25 cm or more) expected in next 24 hrs. A graphical product is also given indicating the heavy rainfall warning. An example of heavy rainfall warning graphics is shown in Fig.6.8. This product is available in website of IMD.

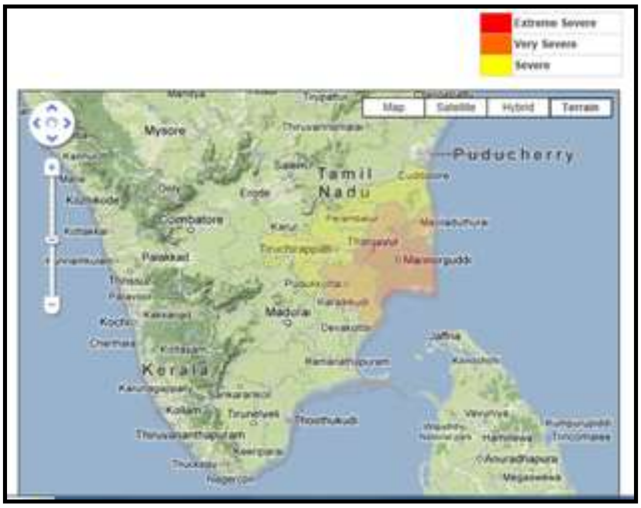


Fig.6.8. A typical example of heavy rainfall warning graphics issued by IMD

6.6.6. Gale waind warning

In the bulletin for India coast gale wind warning is provided. It describes the area of occurrence, time of occurrence and intensity of gale/squally wind along and off coastal districts. Depending upon the expected gale wind speed, the expected damage is indicated in the bulletin.

6.6.7. Crucial observations

Crucial observations leading to decision of location and intensity is also mentioned in the bulletin issued for WMO ESCAP Panel countries.

6.6.8. Satellite and Radar features

The characteristic features as observed in satellite and radar are included in the bulletin issued for WMO ESCAP Panel countries.

6.6.9. Prognosis and diagnosis

The prognostic and diagnostic features based on the prepared check list and decision making process is written at the end of the bulletin issued for WMO ESCAP Panel countries.

6.6.10. Significant past weather

Significant past weather is mentioned in the Bulletin for India coast. It is helpful for disaster management. It usually includes past 24 hr heavy rainfall recorded in different stations and also the gale wind observed in different places.

6.7. Damage potential and action suggested in the bulletin

The bulletin for India coast gives the expected damage and action suggested as given in Table 6.7.

Table 6.7. Damage potential and action suggested in Bulletin for India coast

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.
Very Severe Cyclonic Storm 118-167 kmph (64-90 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.
Very Severe Cyclonic Storm 168-221 kmph (91-119 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 Cyclone 222 kmph and more (120 knots and more)	Extensive structural damage to residential and industrial buildings. Total disruption of communication and power supply. Extensive damage to bridges causing large-scale disruption of rail and road traffic. Large-scale flooding and inundation of sea water. Air full of 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.

6.8. Time of issue of Bulletins

The time of issue of bulletin when the system is depression/cyclonic storm is given in Table 6.8 and 6.9.

In addition to the above mentioned table, the time of issue of Special Tropical Weather outlook may be issued at any time depending upon the formation/landfall of depression. For example, if the depression forms/crosses coast/dissipates over the sea at 0900 UTC, then the special tropical weather outlook can be issued based on 0900 UTC observation.

* In addition to the above mentioned table, the time of issue of TCAC Bulletin may be issued at any time depending upon the formation of cyclonic storm/landfall of cyclone. For example if cyclonic storm forms/crosses the coast at 0900 UTC then the bulletin may be issued based on 0900 UTC observations.

** DGM bulletin may be issued at any time on the change of intensity/landfall of the system.

*** TC vital is issued from Deep Depression stage onwards.

Table 6.8. Time of issue of bulletin when the system is depression/deep depression

Bulletin	Base Time	Issue Time	Base Time	Issue Time	Base Time	Issue Time	Base Time	Issue Time	Base Time	Issue Time	Base Time	Issue Time	Base Time	Issue Time	Base Time	Issue Time
Bulletin for Indian coast	0000	0300	0300	0600	0600	0900	0900	1200	1200	1500	1500	1800	1800	2100	2100	0000
Special Weather Outlook					0600	0900			1200	1500						
**DGM's			0300	0600												
***TC Vital	0000	0300			0600	0900			1200	1500			1800	2100		

Table 6.9. Time (UTC) of issue of bulletin when the system is cyclonic storm

Bulletin	Base Time	Issue Time	Base Time	Issue Time	Base Time	Issue Time	Base Time	Issue Time	Base Time	Issue Time	Base Time	Issue Time	Base Time	Issue Time	Base Time	Issue Time
Bulletin for Indian coast	0000	0300	0300	0600	0600	0900	0900	1200	1200	1500	1500	1800	1800	2100	2100	0000
RSMC	0000	0300	0300	0600	0600	0900	0900	1200	1200	1500	1500	1800	1800	2100	2100	0000
*TCAC	0000	0300			0600	0900			1200	1500			1800	2100		
TC Vital	0000	0300			0600	0900			1200	1500			1800	2100		
**DGM's			0300	0600												

6.9. Numbering of bulletins

The bulletins for India coast are numbered as follows. The first bulletin issued in connection with the second cyclonic disturbance over the Arabian Sea is given a number as ARB/2/1. The bulletin is further numbered from the issue of cyclone alert as cyclone alert No. 1, 2 etc., Cyclone warning No 1, 2, … etc.

6.10.Reference time

The reference time mentioned in the bulletin has the following meaning.

- EARLY HOURS 0000 - 0400 HRS. IST
- MORNING 0400 - 0800 HRS. IST
- FORENOON 0800 - 1200 HRS. IST
- AFTERNOON 1200 - 1600 HRS. IST
- EVENING 1600 - 2000 HRS. IST
- NIGHT 2000 - 2400 HRS. IST
- EARLY MORNING 0400 - 0600 HRS. IST
- AROUND NOON 1100 - 1300 HRS. IST

6.11. Terminologies in the bulletins

Some of the important terminology used in the bulletin pertain to description of sea condition, amount/ intensity of heavy rainfall, distribution of rainfall etc. These are presented in following Tables.

Table 6.10.: State of Sea

Descriptive Term	Height Metres	Wind Speed Knots (Kmph)	In Beaufort Scale
CALM (GLASSY)	0	0	0
CALM (RIPPLED)	0 - 0.1	1 - 3 (2 - 6)	1
SMOOTH (WAVELESS)	0.1 - 0.5	4 - 10 (7 - 19)	2 - 3
SLIGHT	0.5 - 1.25	11 - 16 (20 - 30)	4
MODERATE	1.25 - 2.5	17 - 21 (31 - 39)	5
ROUGH	2.5 - 4.0	22 - 27 (41 - 50)	6
VERY ROUGH	4.0 - 6.0	28 - 33 (52 - 61)	7
HIGH	6.0 - 9.0	34 - 40 (63 - 74)	8
VERY HIGH	9.0 - 14.0	41 - 63 (76 - 117)	9 - 11
PHENOMENAL	OVER 14	64 or above (119 or above)	12

Table 6.11. Distribution of Rainfall

Distribution	No. of Places	Description
Isolated	Isolated/One or two places	<25% of area gets rainfall
Scattered	A few places	(26 –50)% of area gets rainfall
Fairly Widespread	Many places	(51 – 75)% of area gets rainfall
Wide Spread	Most places	(76 – 100)% of area gets rainfall

Table 6.12. Intensity of Rainfall

Descriptive term used	Rainfall amount in mm
No rain	0.0
Very light rain	0.1- 2.4
Light rain	2.5 – 15.5
Moderate rain	15.6 – 64.4
Heavy rain	64.5 – 115.5
Very heavy rain	115.6 – 204.4
Extremely heavy rain	204.5 or more
Exceptionally heavy rain	When the amount is a value near about highest recorded rainfall at or near the station for the month or season. However, this term will be used only when the actual rainfall amount exceeds 12 cm.

6.12. Check list for procedures

Due to the very heavy work load at the time of cyclone situations, utmost care should be taken not to miss any aspect of storm warning work. It is therefore essential to have a check list so that warnings issued, etc., are systematically checked. Format given below is used as check list to ensure issue of appropriate warnings (Table 6.13).

Table 6.13(a) Check list of dissemination of bulletin by Cyclone Warning Division

Date Time (UTC)

S.N.	Name of the bulletin	Mode of dissemination	Time of issue	Time of dissemination	Remark	Initial
1	Bulletin for Indian coast	FAX				
2	RSMC bulletin	GTS				
3	TCAC text bulletin	GTS				
4	Bulletin for Indian coast	email				
5	RSMC bulletin	email				
6	SMS (IMD offials)	SMS				
7	SMS (Disaster management officers at Delhi)	SMS				
8	SMS (State disaster management officers and	SMS				

	ACWC/CWC officers) State:					
9	SMS (State disaster management officers and ACWC/CWC officers State:	SMS				
10	TCAC Bulletin (Honkong website)	ftp				
11	TCAC graphical bulletin (ftp)	ftp				

Table 6.13.(b) Cyclone Warning Check List for ACWCs/CWCs

S. No.	Item	**Bulletin based on 15UTC**	**Bulletin based on 18UTC**	**Bulletin based on 00UTC**	**Bulletin based on 03UTC**	**Bulletin based on 09UTC**	**Bulletin based on 12UTC**	**Special Bulletin, (if reqd. based on 2100 & 0600 UTC)**
1.	Inference							
2.	Coastal Bulletin							
3.	Port Warnings							
4.	4Stage Warnings							
5.	AIR Bulletins							
6.	Gale Warnings (designated/registered page)							
7.	HRW (Designated/ registred page)							
8.	Request for special observation or their discontinuance							
9.	Fisheries bulletin to AIR							
10.	Bulletin for AIR News cycle							
11.	CQ for OBS from ships							
12.	Tentative Aurora							
13.	Daily weather Report							
14.	Routine midday AIR Bulletin							
15.	Press Bulletin							
16.	Modification of local forecast							

Chapter-VII

Cyclone Warning Dissemination

7.1. Cyclone Warning Dissemination

Cyclone warnings are disseminated to various users through different means as mentioned below.

- Telephone
- Tele-fax
- VHF/HFRT
- Satellite based cyclone warning dissemination system (CWDS)
- Police Wireless
- AFTN (Aviation)
- Internet (e-mail)
- Websites
- Radio/TV network
- Mobile Phones
- Interactive Voice Response System (IVRS)

These warnings/advisories are put in the website, www.imd.gov.in of IMD. In IVRS (Fig.7.1), the requests for weather information and forecasts from general public are automatically answered. For this purpose, the person has to dial a toll free number "18001801717" from anywhere in the country. This system has been installed at 26 Meteorological Centres/ Regional Meteorological Centres. High Speed Data Terminals (HSDT) are installed at almost all MCs and RMCs. HSDTs are capable of sending short warning message as SMS and the whole warning message as email.

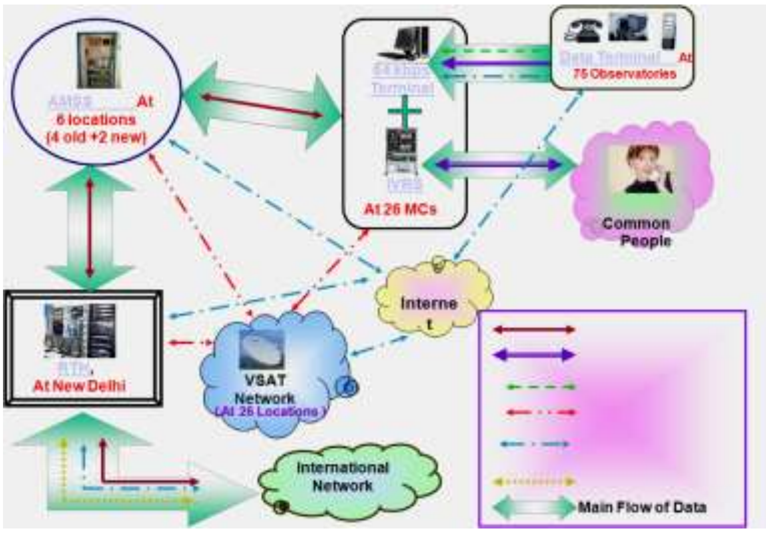
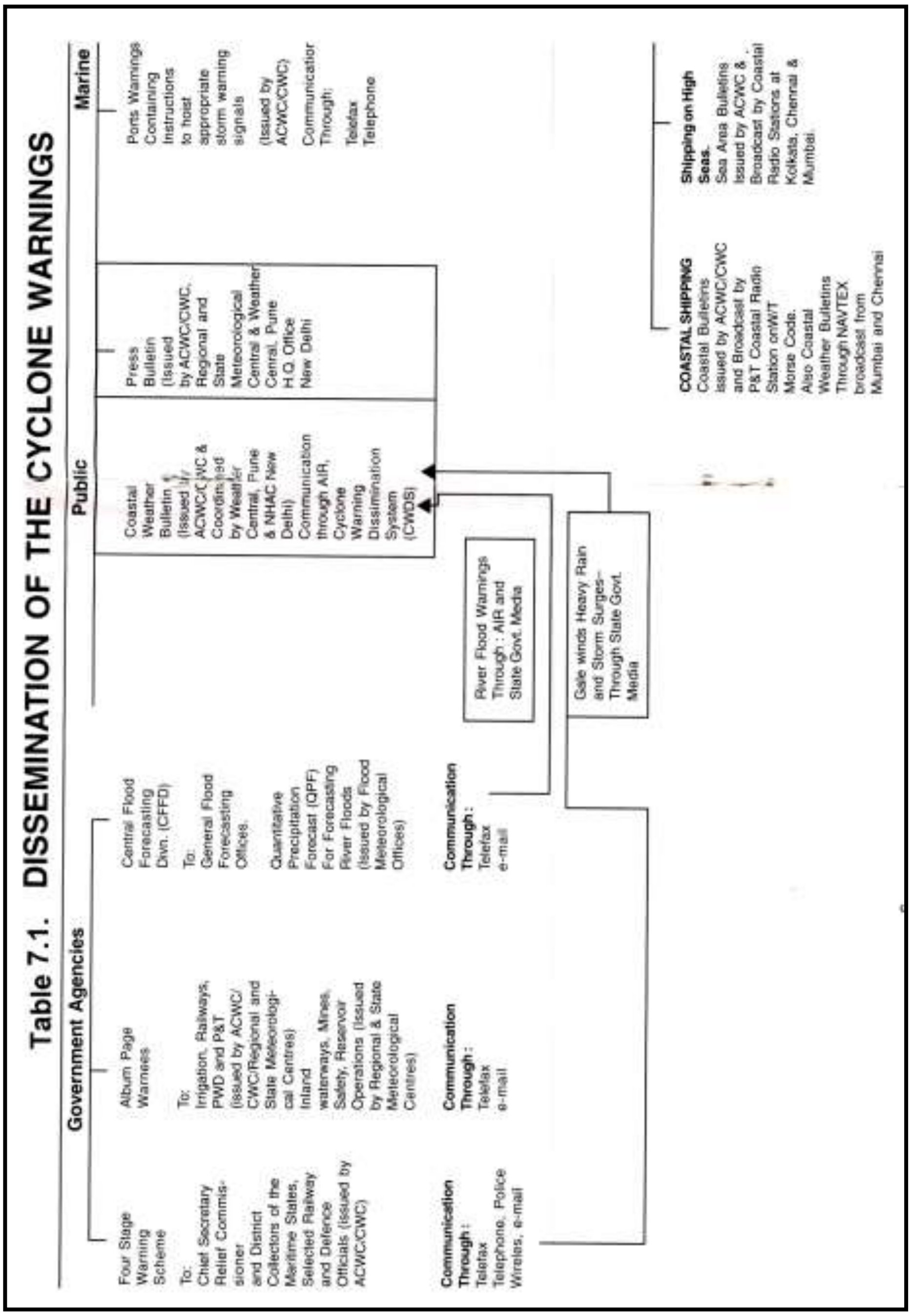


Fig.7.1 Interactive Voice Response system



As telephonic communication often breaks down during cyclones, the warnings meant for the Chief Secretary and Collectors of coastal districts are passed on to these officials through FAX or by telephone to ensure that the warnings reach these officials quickly to enable them to take precautionary measures promptly.

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Interactive Map

Chapter- VIII

Pre-cyclone Exercise

The following are the instructions for action to be taken in the months preceding the pre and post -monsoon cyclone seasons (i.e. by about April and September) of each year.

8.1. Telecommunications

(1) The Director in-charge at the ACWC/CWC will contact personally the General Manager-Telephones, General Manager-Maintenance and Senior officials in-charge of telefax/mobile/internet communication systems at their respective stations and ensure that :

a) the local communication links at the ACWC/CWC consisting of Telephone/Telefax/mobile/internet connections are maintained in good working condition, especially during the days of cyclonic storms.

b) the telecommunication circuits connecting the station to other Meteorological Offices are maintained at highest efficiency. They may also be requested to designate local officers to serve as liaison officers for this purpose so that they can be contacted at times of breakdown to ensure quick service.

(2) Telefax machines at the stations should be maintained in good working condition. Essential spare parts should be requisitioned well in time and kept in store so that no breakdown occurs in the crucial time for want of these; maintenance staff also should be available on the spot during days of disturbed weather for immediate rectification of faults.

(3) Police W/T: Any action required in connection with the issue of warnings through Police W/T should be completed. In particular, any shortcomings in this mode of communications noticed in the previous storm season should be discussed with the State Government authorities and remedial action should be taken.

8.2. Publicity and Broadcast of Warnings

Posters and films

The ACWCs/CWCs should write to the State Government officials concerned for giving publicity to the people in the coastal districts about cyclones through cyclone posters and exhibition of the film on cyclones.

Radio and TV Talks

Talks on radio and television should be arranged by the ACWCs and CWCs on the hazards of cyclones and precautionary measures to be taken before, during and after the storms. The system of warnings should be explained.

All India Radio

The station Directors of All India Radio station in the concerned State(s) should be alerted about the broadcast of cyclone warnings through AIR and to ensure that the stations keep extended watch for broadcast of additional weather bulletins whenever required. They should be requested to include storm warning bulletins in their Vividh Bharati broadcasts and FM Channel also at frequent intervals as these have popular appeal.

Newspapers

Proper liaison should be established with local newspapers for prompt publication of latest warnings.

8.3. Observational data and Organisation

Inspection of coastal observatories

All the coastal observatories and co-operative cyclone reporting network of stations (as well as Police W/T stations in Tamil Nadu) should be inspected once in a year during April or September to ensure that the instruments at these stations are in good condition and the observers are familiar with correct recording and reporting of observations. If any persistent error is noticed in the recording or reporting, the observer should be immediately instructed. Similarly, where the observatory sends its observations to the MC/RMC through W/T, telephone/FAX/e-mail, the communication aspects should also be checked up.

Radar and DMDD

Any deficiency in the operation of the cyclone detection radars, RS/RW and DMDD stations in the region should be immediately brought to the notice of DDGM (UI)/ DGM (Satellite Meteorology) by the MC/RC concerned for immediate rectification. Maintenance of SDUC equipment and satellite equipment should be done by DGM (Sat. Met.) New Delhi.

8.4. Reference publications and forms

Relevant reference publications, such as, Code of storm warning signals for use at Indian maritime ports, Weather services to shipping, fishing vessels and maritime interests , the tide tables for the year, storm track atlas, code books, cyclone manual and required nomograms and T-classification tables for interpreting and assessing storm intensity from satellite pictures, etc., should be made readily available for storm warning work. Sufficient stock of all special type of charts and forms required for cyclone work should be kept at the ACWCs/CWCs/CWD.

8.5. Cyclone Manual

As a part of the pre-storm season exercise, the officers and staff of ACWCs/CWCs/CWD engaged in storm warning work may go through the chapters of Cyclone Manual before each storm season and refresh themselves with the various procedures, so that procedural mistakes are totally avoided in operational work. A few informal classes should also be conducted for the benefit of persons newly posted to storm warning work. All the officers and members of staff should make themselves familiar with the list of various types of warnees to be warned and the formats in which these warnings are to be issued. The Action Books may be checked up to ensure that all the items listed there are updated. The formats of the various warnings should also be kept ready for reference.

8.6. Telephone Fax and e-mail address

The telephone, V-Sat, Fax, E-mail, mobile nos., addresses etc. of different ACWCs/CWCs/ Radar stations and other concerned offices such as local Doordarshan, AIR, Chief Secretary, Revenue Secretary, SRC, State Disaster Mitigation Authority, Port offices, Fisheries officials should be readily available. In addition to above, the CWD should also maintain above updated information in respect of national level disaster management agencies including NDM, NDMA etc.

8.7. Staff Matters

For relieving the heavy stress and strain on the forecasters in storm warning centres during storm period, CWD/ACWCs/CWCs should build up a reserve of personnel in the cadre of officers at these centres by training personnel working in the other units in storm warning work. For this purpose, all these persons may attend the forecasting work one day in a week by turn. Similar steps may be taken in CDRs to train reserve personnel wherever possible.

It is also essential that the staff posted at ACWCs/CWCs and coastal observatories are quite familiar with the various procedures connected with the cyclone warning work. The best available staff may be utilised in connection with storm warning work in view of its importance to the public. Sanctioning of leave to the staff engaged in operational forecasting work may be regulated to ensure availability of required number of trained and experienced persons for storm warning work.

8.8. Circular letter to warnees

Warnees to listen to AIR

A circular letter is issued every year by about March or April and September by the ACWC/CWC informing the warnees that whenever they receive the first warning for cyclone, they may commence listening to the regional All India Radio Stations for latest information about the storm and its further movement and intensification.

Action taken by warnees

The action taken by the warnees on receipt of our warning messages should also be obtained from them by asking them through a circular letter to send the monthly statements in the required proforma (OBS 213 forms). Such action as may be necessary on these statements has to be taken by the concerned ACWC/CWC. The warnees have to be supplied with the forms every year.

Circular letter to Chief Secretaries

A circular letter may be sent to the Chief Secretaries of maritime states for designating officers of these states for liaison with the storm warning centres on behalf of the State Government during cyclone periods.

Circular letter to the Port Officers

In the beginning of each cyclone season, the port officers are informed through a circular letter that they would be getting port warning messages from the ACWC/CWC whenever occasion demands. After the receipt of the first message at the port, the ports are expected to get at least one message in 24 hours in the case of distant signals or more frequently whenever local signals are hoisted, till the advice for lowering the signals is received. In case, a port officer fails to receive such messages in time after the receipt of the first message, he has to take the initiative in contacting the ACWC/CWC to find out the actual position.

8.9. Ports

Visit to ports

The ports are visited at least once in two years by officers who are well conversant with storm warning work. Usually, one of the officers of the ACWC/CWC proceeds on these tours as he will be in the best position to keep liaison with ports receiving storm warnings. He will also examine the arrangement for display of storm warning signals and also find out how effectively the storm warning system functioned particularly during periods of depressions or storms. The visiting officer will see that all the day and night signals are available and in proper condition, ready to be hoisted when warning telegrams to hoist them are received. After each visit, the officer submits a report about his visit incorporating his suggestions for the improvement of the warning system. The form of Hand-book of Ports is also filled up by the Officer and these reports are to be sent to the concerned ACWC for consolidation and submission to DDGM(WF) with suitable recommendations for further action.

Guidelines

The following guidelines in connection with the visits to ports may be followed:

i) Every port exhibiting signals should normally be visited once in two years.

ii) The visits to the ports without signals are to be undertaken primarily to ensure that (a) satisfactory arrangements exist at these ports for the reception of warnings and (b) their prompt communication to the people concerned. It may, therefore, be useful to visit these ports also, say at least once in four or five years.

(iii) Ports affected by a storm may also be specially visited as and when considered necessary in order to ascertain how the warning system functioned during the storm.

(iv) The visits to ports are to be treated more or less on a par with the inspection of observatories and may therefore be arranged for by the DDGM at their discretion.

(v) The programme of visit to ports may be forwarded to CWD and DDGM (WF)'s office before the tours are actually undertaken.

(vi) In case, DDGM (WF)'s office at any time considers that a particular port should be visited for a special reason, the R.M.C. concerned will be advised.

Early action

Action as suggested by the visiting officers in their inspection reports should be examined for early implementation as may be found necessary.

8.10 Meeting with the Chief Secretaries of the Maritime States

Participation in the Annual conference of Collectors

The Officer-in-charge of the ACWCs/CWCs/MCs connected with storm warning work will meet the Chief Secretaries of the concerned States every year to apprise them of our storm warning service. The Chief Secretaries of the maritime States may also be requested to invite the DDGM (RMCs) of Mumbai, Kolkata and Chennai for participating in the Annual conference of Collectors so that they can explain to the Collectors the functioning of the storm warning organisation and other details regarding the issue of warnings, etc., There can also be discussions between the Storm Warning Officers on the one hand and the State Government officials on the other for a better understanding and improvement of the storm warning system particularly regarding the dissemination of storm warning messages.

Meeting Chief Secretary

The officers-in-charge of ACWCs/CWCs/MCs connected with storm warning work should also meet the Chief Secretary whenever a new incumbent takes office.

8.11. Visit to coastal radio station

When an official proceeds on tour to observatories, they may visit the coastal radio stations (if it functions there) and impress on the staff, the need to receive as many ship's observations as possible and to pass them promptly to the Meteorological offices.

8.12. User's Workshop

The ACWC's and CWC's should organize the User's Workshop, preferably once in two years to apprise the User's about the cyclone warning activity of IMD and collect their comments and feedback for further improvement of cyclone warning services in the country.

Chapter- IX
Post Cyclone Action

The present procedures and instructions on the various items of post-cyclone action are described in this chapter.

9.1. Preliminary and final reports

Immediately after a storm crosses coast and weakens into a depression, a preliminary report is prepared and put up in the website within a week by CWD, New Delhi. The final report which will be prepared within a month will be arranged under the following heading:

(1) Brief history of the storm.

(2) Weather and damage caused.

(3) Warnings to State Government officials.

(4) Broadcasts of warnings over AIR (and T.V.).

(5) Port warnings.

(6) Fisheries warnings.

(7) Adequacy and timeliness of warnings.

(8) Performance of NWP and statistical models.

(9) Forecast and Warning verification results

The brief history will contain an account of the system from the depression stage onwards including its intensification into a storm/ severe storm, landfall and subsequent weakening. Crucial observations, if any, should be briefly referred to. A tentative track of the cyclone as well as the path as tracked by the Cyclone Detection Radar (if the cyclone was under radar surveillance) should also be included.

The important points under *Weather and damage caused* to be covered under this heading are:

i) Areas affected by severe weather associated with the storm-tidal waves, gales, heavy rainfall including floods. Districts, taluks, towns or villages worst affected may be specifically mentioned.

ii) Extent of damage caused to (a) agricultural and garden crops (b) buildings, (c) railway tracks and stations, (d)Telegraphic and electrical poles and installations (e) highways, avenue trees etc. (f) Dams and minor irrigation (g) estimated loss of life (human as well as cattle), loss of property and people rendered homeless. (h) Damage to ships at ports and port installations. This should be based on available reports in newspapers, from Touring Officer's report as well as from Government sources. However, the preliminary report should not be unduly delayed awaiting the Touring Officers' return to Head

Quarters. Under *Warning to State Government Officials,f*our Stage Warnings including pre-cyclone watch and post land fall outlook to State Government officials such as Chief Secretary, Collectors of Coastal Districts etc., should be given in this para briefly.

Specific mention should be made as to:

(i) When the information about the cyclonic storm (viz., Pre-cyclone watch and "Cyclone Alert") was first conveyed to the Chief Secretary (ies) of the concerned State Government(s) and the coastal District Collectors.

(ii) When the first numbered warning under the Four Stage Warning System was sent to the above officials

(iii) The elements for which the warnings were issued and the number of times warnings were sent to them during the storm period.

Under *Broadcasts of Warnings over A.I.R*., the information given here should cover:

i) Special AIR Bulletins under the Four Stage warning system and the times of issue of the first and subsequent crucial bulletins as well as the total number of bulletins issued.

ii) The number of hourly bulletins issued after the storm came within the range of cyclone detection radar and tracked with a high degree of confidence

iii) Whether the watch hours of the A.I.R. station were extended and if so the period of extension.

iv) The time of issue of the first coastal weather bulletin for broadcast in AIR news cycle from New Delhi and total number of such bulletins issued.

Under *Port Warnings,* the progression of signals hoisted at the various ports may be given. The first hoisting and subsequent lowering of Great Danger / Danger Signals should be mentioned.

Report on Fisheries Warnings should contain

i) Whether appropriate warnings commensurate with the intensity of the system were included in the four routine daily AIR bulletins for fishermen and in the warnings for fisheries officials in the designated / registered pages.

ii) Whether advice to fishermen not to venture into the sea was conveyed sufficiently early.

Under *Adequacy and timeliness of warnings,* it should include the verification report of forecasts issued by IMD. How far the warnings were timely and adequate should be mentioned. The effectiveness of the storm warning system has to be assessed from the user's point of view by having personal discussion with the recipients of the different warnings. For this purpose, the DDGM should meet the Chief Secretary of the concerned state. The DDGM can travel by air without making a reference to H.Q. to meet the Chief Secretary and the concerned port officials, fisheries officials, etc. immediately after a cyclonic storm has hit the coastal areas. The touring Officer's report if available by this time should also be utilised. Newspaper comments and/or extracts of appreciation expressed by public/officials who were recipients of the warnings should be included.

To facilitate the preparation of the preliminary report the particulars of all warnings issued are to be tabulated by the ACWC/CWC in the format given in Appendix A.

9.2. Press Bulletin

Immediately after the system has crossed the coast, a special press bulletin highlighting the timely warnings given by the Department should be issued. The press bulletin may be issued by the DDGM and a copy sent to DDGM(WF) and DDGM(S).

9.3. Final Report

The preliminary report will be followed by a detailed final report to be prepared by the ACWC and sent to DDGM(WF), Pune with a copy to DDGM(S), New Delhi. Whenever necessary, the CWC will send the relevant material in the required format to the parent ACWC for preparing the report. The final report will have 9 statements with the following contents;

1. History of the storm, its track, crucial observations that helped in assessing the intensity of the storm and details of damage caused.
2. Port warnings
3. Cyclone bulletins to local AIR stations and AIR New Delhi for News cycle.
4. Four Stage Warnings including pre-cyclone watch and post landfall outlook to State Govt. officials and warnings to fishermen.
5. Statement of special observations called for
6. Statement of air field warnings.
7. List of FAX messages.
8. In addition, a statement giving copies of log book entries indicating the action taken by the Meteorologist for alerting high ranking State Government officials responsible for taking precautions may also be sent as Statement VIII. Verification of forecast of rainfall and landfall (May be sent alongwith the brief report with Appendix B in case of cyclonic storm which do not cause any damage/serious damage.

9.4. Scrutiny of Action Taken by ACWC/CWC

It is also desirable that DDGM scrutinise the action taken by the ACWCs/ CWCs and bring to the notice of the persons concerned any major omissions or discrepancies either in the text of the warnings issued or the procedure followed. Such instances should also be brought to the notice of DDGM (WF) by the DDGM RMC while forwarding the reports together with their assessment on the timeliness and adequacy of the warnings issued by the ACWCs/CWCs. The final scrutiny will be carried out by DDGM (WF) Pune and the remarks will be sent to the ACWCs with a copy to DDGM(S) New Delhi. ACWC will send the relevant portions of DDGM (WF)'s remarks to the CWC whenever necessary. DDGM will also arrange to check up whether all the Designated / Registered warnees concerned have been warned in connection with the storm and point out omission, if any, in this regard to ACWC/CWC, as warnings issued to Designated / Registered warnees are not included in any of the statements in the final report sent to DDGM (WF).

9.5. Visit of Officer to Cyclone affected areas

9.5.1. Assessment of damage

Whenever a cyclonic storm/severe cyclonic storm, on striking coast, causes considerable damage to life and property, an officer from the concerned region should be sent on tour to visit the affected areas to assess the nature and extent of the damage caused, both from the economic and scientific points of view. DDGM (WF) Pune and DDGM (S) New Delhi should be informed by FAX about the tour. The touring officer should visit the crucial locations in the storm-affected area, contact various State and Central Government officers and interview people to examine how effectively the storm warning system worked. He will submit his report to the DDGM immediately after his return from tour.

9.5.2. Purpose of survey

The main purpose of a survey of the damage caused by the cyclones is to assess in greater detail than is possible with the available synoptic observations and press reports, the track, intensity and other characteristics of the storm and to evaluate the effectiveness of the warnings issued. The touring officer's report should, therefore, include the following:

(i) Track followed by the storm.
(ii) The 'eye' or calm centre and its characteristics
(iv) Duration of the lull period
(v) Areas affected by gales and relative strength of winds in the different quadrants.
(vi) Estimate of the maximum wind speed
(vii) Recession of the sea
(viii) Storm surges
(ix) Rainfall associated with the storm
(x) Comments from the recipients of the warnings about accuracy and timeliness of the warnings;
(xi) Suggestions and recommendations for the improvement of the storm warning

system/ observational network, etc.

Keeping the above in view, the touring officer should try to obtain and keep a record of such information which will enable him to estimate, as quantitatively and objectively as possible, the above features associated with the storm. In order to assist the Meteorological Officer who goes for such a survey, detailed guidelines are available in SOP for Post-event Survey (SOP No.1/2013). It is also advisable that the officers at CWC and ACWCs go through the reports of such past surveys made earlier, to familiarise themselves with the work. The offices should also keep these touring officer's reports bound as permanent records as they contain valuable scientific data on storms, collected with great effort, which may be required in the future.

9.5.3. Annual Cyclone Review Meeting

The primary aim of these meetings is to recommend steps for further improvements in the storm warning service on the basis of the actual working of the system during the storm season of the previous year. Towards this end, discussions should centre around the following points regarding the storms of the year under review:

1 Accuracy and timeliness of the warnings issued by the different ACWCs/ CWCs.
2 Notable successes and failures.
3 Comments on unsatisfactory warnings, if any, and where possible, the manner in which they could be improved.
4 Adequacy or otherwise of data in each case, including ships observations, radar and satellite observations and aircraft reports.
5 Adequacy or otherwise of telecommunication facilities, both for receipt of data and dissemination of warnings.
6 Deficiencies, if any, in any other aspects of the organisation which require improvement.
7 Major synoptic problems, from the standpoint of analysis and prognosis, experienced in the different cases. These may include steering, intensification and weakening of the systems, estimation of wind speed, storm surges, heavy rainfall etc.

9.5.4 Back-plotting and re-analysis

After the storm is over, all the working charts have to be completed by back plotting the late data, ships' log etc. and the charts re-analysed in all the Storm Warning Centres.

Based on the re-analysis after back-plotting of charts and utilising additional information available through touring officers' reports, radar and satellite pictures etc., the centres will be refixed and the tracks of the storms finalised at DDGM(WF)'s office and be presented in ACR meeting. It will be reviewed by a track finalization committee. The finalized track will be considered for official purposes and future records. The final storm accounts will be prepared by DDGM(WF)'s office and sent by March/April for publication in the July issue of 'Mausam" and the same will be considered by CWRC, Chennai for modifying the e-Atlas.

APPENDIX: A (Preliminary Report)

Action taken by ACWC/ CWC ________________________ on the __________________ cyclonic storm of __________ (date)

Date	Time of chart UTC.	System, its intensity location & expected movement	Port Warnings	Four stage warnings (including Pre-cyclone watch and post land fall outlook) to State Government officials	Serially numbered cyclone bulletins to local AIR stations and coastal weather bulletins for News Cycle	Warnings to fishermen.
1.	2	3	4	5	6	7
			This column will show the ports warned, the signals at these ports and the time of issue of the warnings.	This column will show the collectors and Chief Secretaries warned, the elements for which they are warned and the area covered by the warnings (in terms of districts.) Time of issue______ IST to____________ IST	This column will show the local AIR stations to whom the cyclone bulletins were sent, their serial number, the elements and area covered (The elements and area need not be repeated in this column if they are the same as in column 5). (Time of issue _____ IST to _________ IST) Also indicate whether coastal weather bulletins sent to AIR New Delhi for News Cycle and the times of issue.	This column will show the coastal areas warned (in terms of districts), the elements, AIR stations to which sent (Time of issue___ IST to _____ IST)

APPENDIX – B (FINAL REPORT)

STATEMENT – 1

A BRIEF ACCOUNT OF THE STORM WITH TRACK OF THE STORM

STATEMENT – II

STATEMENT OF PORT WARNING MESSAGES

Date	Time of issue of telegram IST	Chart on which based UTC.	Ports to which sent	Text of messages

STATEMENT – III

SPECIAL BULLETINS (INCLUDING COASTAL WEATHER) TO A.I.R. STATIONS

Date	Time of issue of telegram IST	Chart on which based UTC.	A.I.R. Station to which sent	Text of messages

STATEMENT – IV

FISHERIES AND FOUR STAGE WARNINGS

Date	Time of issue (IST)	Chart on which based UTC	Text of warning	To whom sent

STATEMENT - V

SPECIAL OBSERVATIONS CALLED FOR

Date and time of requisition IST	Station	Observations called for		Frequency of observations
		From	To	
Example:				
140640	Puri	150600Z	181500 Z	Hourly
160850	Cuddalore	171500Z	190000 Z	3 Hourly

STATEMENT – VI

AIR FIELD WARNINGS

Date	Time of issue UTC/IST	Text	Issued by (Forecasting Office)

STATEMENT – VII

LIST OF FAX/email MESSAGES

Date	To whom	Purpose	Remarks

STATEMENT – VIII

COPIES OF LOG BOOK ENTRIES FOR ALERTING HIGH RANKING STATE GOVERNMENT OFFICIALS

Date	Time	Official contacted	Text of Message	Mode of contact (telephone etc.)	By whom

<u>Statistics of bulletins issued by Cyclone Warning Division</u>

S.N	Bulletin type	No. of Bulletins	Issued to
1	Informatory Message		1. IMD website, RSMC New Delhi website and Mausam website 2. FAX and e-mail to Control Room Ministry of Home Affairs & National Disaster Management Authority, Cabinet Secretariat, Minister of Science & Technology, Headquarter Integrated Defence Staff, Director General Doordarshan, All India Radio, National Disaster Response Force, Press Information Bureau, Chief Secretary to Government of concerned states.
2	National Bulletin		1. IMD website, RSMC New Delhi website and Mausam website 2. FAX and e-mail to Control Room Ministry of Home Affairs & National Disaster Management Authority, Cabinet Secretariat, Minister of Science & Technology, Headquarter Integrated Defence Staff, Director General Doordarshan, All India Radio, National Disaster Response Force, Press Information Bureau, Chief Secretary to Government of Government of concerned states
3	RSMC Bulletin		1. IMD's website, RSMC website and Mausam website 2. WMO/ESCAP member countries through GTS and E-mail
4	GMDSS Bulletins		1. IMD website, RSMC New Delhi website 2. Transmitted through WMO Information System (WIS) to Joint WMO/IOC Technical Commission for Ocean and Marine Meteorology (JCOMM)
5	Tropical Cyclone Advisory Centre Bulletin		1. Met Watch offices in Asia Pacific regions and middle east through GTS to issue Significant Meteorological information for International Civil Aviation 2. WMO's Aviation Disaster Risk Reduction (ADRR), Hong Kong through ftp 3. RSMC website
6	Tropical Cyclone Vital Statistics		Modelling group of IMD, National Centre for Medium Range Weather Forecasting Centre (NCMRWF), Indian National Centre for Ocean Information Services (INCOIS), Indian Institute of Technology (IIT) Delhi, IIT Bhubaneswar etc.
7	Warnings through SMS		SMS to disaster managers at national level and concerned states (every time when there was change in track, intensity and landfall characteristics) to (i) General Public by IMD Headquarters to users registered at RSMC website www.rsmcnewdelhi.imd.gov.in (ii) senior level disaster managers at centre and affected states along the east coast by IMD Headquarters (iii) to registered users including fishermen by INCOIS (iv) Joint INCOIS-IMD joint bulletins (in short template) through NAVIC (for communication to fishermen in open

			sea) (v) Farmers in the affected regions of by Kisan Portal (vi) Notifications through Mobile App UMANG (vii) Google Alert notifications (viii) Alerts through Common Alerting Protocol
8	Warnings through Social Media		a)Whatsapp b) Facebook c) Tweeter d) Mobile Apps
9	Press conference		
10	Press Release		Disaster Managers, Media persons by email and through website
11	Press Briefings		
12	Hourly Updates		Hourly bulletins by email, website, social media

Statistics of bulletins issued by Regional Offices (including various ACWCs and CWCs)

S.No.	Type of Bulletin Number	No. of Bulletins issued
1.	Sea Area Bulletins	
2.	Coastal Weather Bulletins	
3.	Fishermen Warnings issued	
4.	Port Warnings	
5.	Heavy Rainfall Warning	
6.	Gale Wind Warning	
7.	Storm surge Warning	
8.	Information & Warning issued to State Government and other Agencies	
9.	SMS	
10.	No. of Press releases	
11.	No. of impact based warnings for a. District b. City	
12.	No. of whatsapp messages	
13.	No. of updates on facebook	
14.	No. of updates on tweeter	
15.	No. of warning videos released	

STATEMENT – IX

Verification of genesis, track, landfall, intensity forecasts and COU accuracy.

IMD introduced the objective TC track and intensity forecast over the NIO in 2003 from CS stage for next 24 hrs, in 2009 from DD stage for next 72 hrs, in 2013 from DD stage for next 120 hrs and in 2019 from D stage for next 120 hrs. The forecasts are verified as per the standard practises adopted by various national meteorological agencies and recommended by the World Meteorological Organisation (WMO) (WMO, 2013). The methodology followed by RSMC New Delhi for verification of various forecasts is presented below:

A) Track Forecast Error and Skill

The TC track verification is carried out for 6-hrly forecasts issued at 00, 06, 12 and 18 UTC from the stage of DD and is continued till the TC dissipates into D. RSMC New Delhi determines the absolute track error or direct position error (DPE) for verification of the track forecast. The DPE is the great circle distance between a TC's forecast position and the observed position at the forecast verification time. The average DPE for a given TC is the average of all DPEs calculated based on 00, 06, 12 and 18 UTC forecasts during the life period of the TC. For the purpose of forecast verification, IMD's operational best track data is considered as actual position of TC. The actual position from the stage of DD to the D stage while weakening is considered for forecast verification.

The skill of the TC track forecasts is evaluated based on the calculation of DPE with respect to the CLIPER (Climatology and Persistence) model forecast errors. The CLIPER model is based on combination of persistence and climatological forecast with equal weightage. The persistence forecast is based on the past 12 hr trend in motion of the current TC which is linearly extrapolated to find out forecast location (lat./long.) for +12, +24, ……,+120 hrs. The climatological forecast assumes that TC will move with average speed and direction of all past TCs near that location. In climatological method, the average direction & speed of TC based on past long period data set over a 2.5^0X2.5^0 latitude/longitude grid is utilised to find out the forecast position (lat./long.) for next 12 hrs for the given location of the TC in that latitude/longitude grid. Based on the forecast location of TC at +12 hrs in a 2.5°x2.5° latitude / longitude grid, climatological average speed & direction is utilised again to find the next forecast position of TC. This process continues to find the forecast position of +12, +24, …+120 hrs. The forecast positions thus obtained from climatology & persistence method are used to find the mean position through equal weightage to persistence & climatology forecasts. The data utilised for the CLIPER model is based on the period of 100 years (1891-1990). IMD uses the CLIPER model to calculate the

DPE of CLIPER model for the TCs over the NIO. The gain in skill in relation to CLIPER, is determined by:

$$Gain\ in\ skill = \frac{CLIPER\ \ DPE - DPE}{CLIPER\ \ DPE} \times 100\%$$

Track error and skill

Lead Period (hrs)	N	Average track forecast		LPA track forecast during preceding five years	
		Error (km)	Skill (%)	Error (km)	Skill (%)

B) Annual track forecast error and skill

Based on the error statistics for individual TCs, the average error statistics for the season is calculated by considering the sample weighted mean. If $x_1, x_2, \ldots x_n$ are the DPEs for the TCs 1, 2,...n with the number of forecasts verified as $i_1, i_2, \ldots, i_n$, then the average DPE for the season / year is given by

$$DPE_{ave} = \frac{i_1x_1 + i_2x_2 + i_3x_3 + i_4x_4 + i_5x_5 + \ldots\ldots i_nx_n}{i_1 + i_2 + i_3 + i_4 + i_5 + \ldots.i_n}$$

Annual Track error and skill

Lead Period (hrs)	TC1	TC2	TC3	Annual Average track forecast during the year		LPA track forecast during preceding five years	
				Error (km)	Skill (%)	Error (km)	Skill (%)

Interannual Track error and skill

Year	12hr	24hr	120 hr	Annual Average during the year	LPA errors during preceding five years

C) Climatology of track forecast variation

The climatological average of DPE during the last five years is considered to define the current status of forecast errors over an Oceanic basin. It is very useful for the Ocean basin like NIO, where the annual sample size is small as less number of TCs form in a year as compared to other basins. This climatological average over the NIO basin is determined as the sample weighted average of annual errors of e1, e2, e3, e4 and e5 during the five years. If n1, n2, n3, n4 and n5 number of forecasts are verified in these corresponding five years, the climatological DPE is given as:

$$DPE = \frac{n_1 e_1 + n_2 e_2 + n_3 e_3 + n_4 e_4 + n_5 e_5}{n_1 + n_2 + n_3 + n_4 + n_5}$$

Similarly, skill during five years is calculated by following weighted mean approach.

D) Intensity Forecast Error and Skill

IMD introduced the objective TC intensity (wind) forecast valid for next 24 hrs over the NIO in 2003 and extended up to 72 hr in 2009. The TC intensity forecast is issued 4 times a day at the interval of six hours, i.e. based on 00, 06, 12 and 18 UTC observations with every three hourly updates and validity period extended upto 120 hrs since 2013. The forecasts are issued about three hours after the observation time. Intensity forecast in terms of central pressure is not provided by RSMC New Delhi. : Intensity forecast error is calculated based on the forecast MSW and actual MSW. We calculate intensity forecast errors in terms of (a) absolute error (AE) and (ii) root mean square error (RMSE). The data base includes every six hourly forecasts of MSW with validity period of 120 hrs. Thus, we calculate intensity forecast errors for 12, 24, 36, 48, 60, 72, 84, 96, 108 and 120 hrs forecasts. The average AE is defined as the average of the magnitude of difference between the forecast and actual value of MSW. The MAE provides an indication of the average magnitude of the error. The RMSE is the square root of the mean squared error. The RMSE is a measure of dispersion in the errors and indirectly measures the error due to outliers. Higher the number of outliers, more is the RMSE.

Evaluation of TC intensity forecasts has been carried out from the year 2009 onwards by calculating the average AE (AAE) and the RMSE in the forecast of MSW for all 12-, 24-, 36-, 48-, 60-, 72-h, 84-h & 120-h intensity forecasts made for each TC. The seasonal / annual AAE & RSME have been determined as the sample weighted mean of all TCs that occurred during the season / year.

The skill of the forecast is evaluated against the persistence forecast. The persistence forecast calculates the past 12 hr trend in MSW of the current TC and assumes that TC will intensify/decay with the same trend in MSW during next 120 hrs. The past 12 hr. trend in intensity is defined as the difference in of intensity (MSW) at the initial time of forecast and intensity (MSW) 12 hr before the initial time. The forecast intensity by persistence method is determined for +12, +24,….+120 hrs or till the dissipation of the system into a low pressure area (MSW<17 kts). Since persistence method is based entirely on current and past 12 hr MSW, techniques that do not improve on this have no real skill. Persistence based errors also help in assessment of difficulty in intensity forecast for different TCs over various basins. However, persistence based method is not applicable in case of rapidly intensifying/weakening cases.

The gain in skill in relation to persistence method (PER) is quantified in percentage terms by the following:

Gain (loss) in skill (%) in terms of AAE= $\frac{(PER_{AAE} - AAE)}{PER_{AAE}} \times 100$

Similarly skill in terms of RMSE is calculated.

Intensity forecast error and skill

Lead Period (hrs)	N	Average Intensity Error (kts)		Skill (%) in intensity forecast		LPA during preceding 5 years Intensity forecast			
						Error (kts)		Skill (%)	
		AE	RMSE	AE	RMSE	AE	RMSE	AE	RMSE

E) Annual variation in intensity forecast error & skill

Annual average intensity forecast error based on AE is calculated by taking the mean intensity forecast errors of all the cyclones during a year and the No. of observations verified. If, i_1, i_2, .. are the No. of six hourly forecasts verified for cyclone 1, 2, ... & E1, E2, …..are the mean intensity forecast errors for cyclone 1, 2…based on AE. The annual average error in intensity forecast based on AE (AAE) and RMSE is calculated following the weighted mean approach as

$$AAE = \frac{i_1E_1 + i_2E_2 + i_3E_3 + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots i_n x_n}{i_1 + i_2 + i_3 + i_4 + i_5 + \ldots.i_n}$$

Annual Intensity forecast error and skill

Lead Period (hrs)	TC1	TC2	TC3	Average Intensity Error (kts)		Skill (%) in intensity forecast		LPA Intensity forecast during preceding 5 years			
								Error (kts)		Skill (%)	
				AE	RMSE	AE	RMSE	AE	RMSE	AE	RMSE

Interannual Intensity forecast Error

Year	12hr	24hr	120 hr	Annual Average intensity forecast error based on		LPA errors during preceding five years
				AE	RMSE	

Interannual Intensity forecast Skill

Year	12hr	24hr	120 hr	Annual Average intensity forecast skill based on		LPA skill during preceding five years
				AE	RMSE	

F) Climatology of intensity forecast errors

The climatological average error (AE) in TC intensity forecast for the NIO is determined as the sample weighted mean of errors in forecasts issued during the recent five years. If $AE_{1,}$ $AE_{2,}$ $AE_{3,}$ AE_4 and AE_5 are the annual average AE for the year 1,2,3,4 and 5 with number of observations verified as $n_{1,}$ $n_{2,}$ $n_{3,}$ n_4 and n_5 respectively, the climatological AE is given as

$$AE = \frac{n_1 AE_1 + n_2 AE_2 + n_3 AE_3 + n_4 AE_4 + n_5 AE_{5n}}{n_1 + n_2 + n_3 + n_4 + n_5}$$

G) TC Landfall Point and Time forecast verification

The TC landfall forecast errors are analysed by determining the absolute position error and time error. The landfall point forecast error (LPE) is measured by the distance between the RSMC forecast landfall point and the actual landfall point according to RSMC best-track estimates. Thus the landfall point error is the great circle distance between a TC's forecast landfall point and the observed landfall point irrespective of the time of landfall. Similarly, the landfall time forecast error (LTE) is measured by the difference in the RSMC forecast landfall time and the actual landfall time according to RSMC best-track estimates. As the forecast landfall point and time may not be the positions defined at 00, 06, 12 and 18 UTC in forecast track, the forecast landfall point and time have been determined by applying the linear interpolation technique to the forecast location before landfall and after landfall. The landfall forecast issued for 12, 24, 36, …..upto 120 hrs before the actual time of landfall of a given TC have been verified against the IMD's best track based actual point and time of landfall. The lead time of such forecast decreases if the life period of the TC is less or it dissipates rapidly.

Average Landfall Point and Time

Lead Period (hrs)	Base Time (UTC)	Landfall Point				Landfall Time (UTC)		Operational Error		LPA error during preceding five years	
		Forecast		Actual		Forecast	Actual	LPE (km)	LTE (hrs)	LPE (km)	LTE (hrs)
		Lat(^{0}N)	Long(^{0}N)	Lat(^{0}N)	Long(^{0}N)						

Annual Average Landfall Point and Time

Lead Period (hrs)	TC1	TC2	TC3	Annual Average landfall errors during during the year in		LPA errors during preceding five years
				Point (km)	Time (hrs)	
12						

Inter Annual Average Landfall Point and Time

Year	12hr	24hr	120 hr	Annual Average landfall forecast error		LPA errors during preceding five years	
				Point (km)	Time (hrs)	Point (km)	Time (hrs)

H) Cone of Uncertainty forecast

To determine the accuracy of COU forecast, number of observations within the COU and outside COU for each lead period of forecast is determined and percentage correct is found out. For getting the annual percentage correct, weighted mean approach is followed.

E) VERIFICATION OF FORECAST OF RAINFALL

A				
Date/time	Name of District	Forecast of heavy / very heavy rainfall/extremely heavy rainfall	Actual	Percentage of accuracy
				Total :

Note : For verification of rainfall forecast DRMS data may be utilised.

VERIFICATION OF FORECAST OF GALE WIND

B				
Date/time	Name of District	Forecast of gale wind (kts/kmph)	Actual wind (kts/kmph)	Error

VERIFICATION OF FORECAST OF STORM SURGE

C				
Date/time	Name of District	Forecast of Storm surge height(m)	Actual Storm surge height(m)	Error

Chapter X
Management of Cyclone and Common Man

Inundations caused by storm surge, uprooting of trees and damage caused by that, flooding of low lying areas due to heavy rain and damage to houses and communication due to very strong winds are the devastations due to cyclone, which can not be protected by a common man and has to be mentally prepared to accept the loss. However, a common man can take many important precautionary steps to save life and property. Some of these steps are mentioned below.

10.1. Steps to be taken before the cyclone

(i) Check houses, secure loose tiles by cementing wherever necessary, repair doors and windows.

(ii) Check the area around the house -remove dead or dying trees, anchor removable objects like lumber piles, loose bricks, garbage cans, sign-boards, loose zinc sheets etc.

(iii) Keep some wooden boards ready so that glass windows can be boarded.

(iv) Keep a hurricane Lantern filled with kerosene, flash light and enough dry cells.

(v) Promptly demolish condemned buildings.

(vi) Those who have radio sets should ensure that the radio is fully serviceable. In the case of transistors an extra set of batteries should be kept handy.

10.2. Steps to be taken during the cyclone

(i) Keep your radio on and listen to latest weather warnings and advisories from the nearest AIR station. Pass the information to others.

(ii) Avoid being misled by rumours. Pass only the official information you have got from the radio to others.

(iii) Get away from low lying beaches or other locations which may be swept by high tides or storm waves. Leave sufficiently early before your way to high ground gets flooded. Do not delay and run the risk of being marooned.

(iv) If your house is out of danger from high tides and flooding from the river, and it is well built, it is then probably the best place. However, please act promptly if asked to evacuate.

(v) Be alert for high water in areas where streams of rivers may flood due to heavy rains.

(vi) Board up glass windows or put storm shutters in place. Use good wooden planks Securely fastened. Make-shift boarding may do more damage than none at all. Provide strong suitable support for outside doors.

(vii) If you do not have wooden boards handy, paste paper strips on glasses to prevent splinters flying into the house.

(viii) Get extra food, especially things which can be eaten without cooking or with very little preparation. Store extra drinking water in suitably covered vessel.

(ix) If you are in one of the evacuation areas, move your valuable articles to upper floors to minimise flood damage.

(x) Have cyclone lantern, flash lights and/or other emergency light in working condition and keep them handy.

(xi) Check on everything that might blow away or be torn loose. Kerosene tins, cans, agricultural implements, garden tools, road signs and other objects become weapon of destruction in strong winds. Remove them and store them in a covered room.

(xii) Be sure that a window or door can be opened on the lee side of the house i.e. the side opposite the one facing the wind.

(xiii) Make provisions for children and adults requiring special diets.

(xiv) If the centre of' 'eye' of the storm passes directly over your place, there will be a lull in the wind and rain, lasting for half an hour or more. During this period stay in safe place. Make emergency repairs during the lull period if necessary, but remember that strong wind will return suddenly from the opposite direction, frequently with even greater violence.

(xv) Be calm. Your ability to meet emergency will inspire and help others.

10.3. Steps to be taken after Cyclone

(i) They should remain in shelters until informed by those in charge that they may return home.

(ii) Any loose and dangling wire from the lamp post should be strictly avoided.

(iii) People should keep away from disaster areas unless they are required to assist.

(iv) Anti-social elements should be prevented from doing mischief and reported to the police.

(v) Cars, buses lorries and carts should be driven carefully.

(vi) The houses and dwellings should be cleared of debris.

(vii) The losses should be reported to the appropriate authorities.

(viii) Relatives should be promptly informed about the safety of persons in the disaster area.

10.4. Linkage of IMD with Cyclone Disaster Management

IMD has established linkages/institutional arrangements with disaster management agencies both at the centre and in the states. During normal weather conditions four bulletins are transmitted to Control Room of National Disaster Management Division (NDM). In a case of depression developing over north Indian Ocean which has the potential to affect Indian coast, special bulletins at-least five times a day. When the system intensifies into a cyclonic storm, the cyclone warning bulletins are issued every three hourly. At present 4 stage warning procedure as discussed earlier is followed for issuing bulletins to NDM Control Room. When the system weakens or not going to affect Indian coast, a dewarning message is also issued to NDM Control Room. The cyclone warning bulletins are also passed on to State Government Authorities/District Collectors who are in constant touch with Cyclone Warning Centres. The centres and local committees consisting of various departments dealing with disaster management issues meet at the time of crisis and take necessary follow up actions with the input on warning from IMD.

The linkage between IMD and disaster management agencies exists in all stages, viz.,

(a) Pre-cyclone preparedness during season
(b) During occurrence of cyclone
(c) Post-cyclone action stage

Further linkage also exists in the following

(d) Capacity building through research and development, training and infrastructure development including construction of cyclone shelter etc and preparation of guideline for management of cyclone
(e) Hazard, vulnerability and risk analysis for cyclone disaster mitigation

Chapter - XI
Conclusions and future scope

The design of a TC warning system in IMD takes into consideration of the prevailing state of the meteorological science, the available technological means of communication, the built-up environment such as dwellings, socio-economic conditions, appropriateness of protective actions as well as the expectations of the society. To maximise relevance and effectiveness of the TC warning, strategies are formulated in respect of the design of the forecast, triggering mechanisms, coordination with disaster management agencies, warning products generation, presentation & dissemination. Scientific and technological advances in TC forecasting are translated into effectiveness of TC warning. The forecast and warning operations and decision-making process is made by blending scientifically based conceptual models, meteorological datasets, technology and expertise.

IMD continuously expands and strengthens its activities in relation to observing strategies, forecasting techniques, disseminating methods and research relating to different aspects of TC to ensure most critical meteorological support through observations, analysis, predictions and warnings to disaster managers and decision makers not only in the country but also to the NIO rim countries.

India Meteorological Department
Ministry of Earth Sciences
Government of India

DAMAGE DUE TO SUPER CYCLONIC STORM ‘AMPHAN’

Hanging electric pole
(The Hindu)

Damaged homes (Outlookindia.com)

Flooded Kolkata Airport (NDTV)

Flooded area of West Bengal (cnn.com)

A bus crashed after a tree fell on it in
Kolkata (The Hindu)

Uprooted trees (dnaindia.com)

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