Tropical Cyclone Monitoring : Location and Intensity

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INDIA METEOROLOGICAL DEPARTMENT

Presentation layout

- Introduction
- Cyclone Monitoring
  - Genesis
  - Location
  - Intensity
- Conclusions

Evolution of Cyclonic disturbances Over the Indian Seas

Low pressure system	Maximum sustained winds	
Low	< 17 knots	< 31 kmph
Depression	17 – 27 kts	31 – 51 kmph
Deep Depression	28 – 33 kts	52 – 62 kmph
Cyclone	34 – 47 kts	63 – 87 kmph
Severe Cyclone	48 – 63 kts	88 – 117 kmph
Very Severe Cyclone	64 – 119 kts	118 – 221 kmph
Super Cyclone	120 kts & above	222 kmph & above

System	Pressure deficit (hPa) at the centre
Low	1.0
Depression	1.0 – 3.0
Deep Depression	3.0 – 4.5
Cyclone	4.5-8.5
Severe Cyclone	8.5-15.5
Very Severe Cyclone	15.5-65.6
Super Cyclone	>65.6

Location of Centre:

(a) Synoptic position

(b) Satellite:

(c) Radar position :

(d) Centre determined by other warning centres

(e) Finally agreed official position

(f) Confidence

Location of Centre:

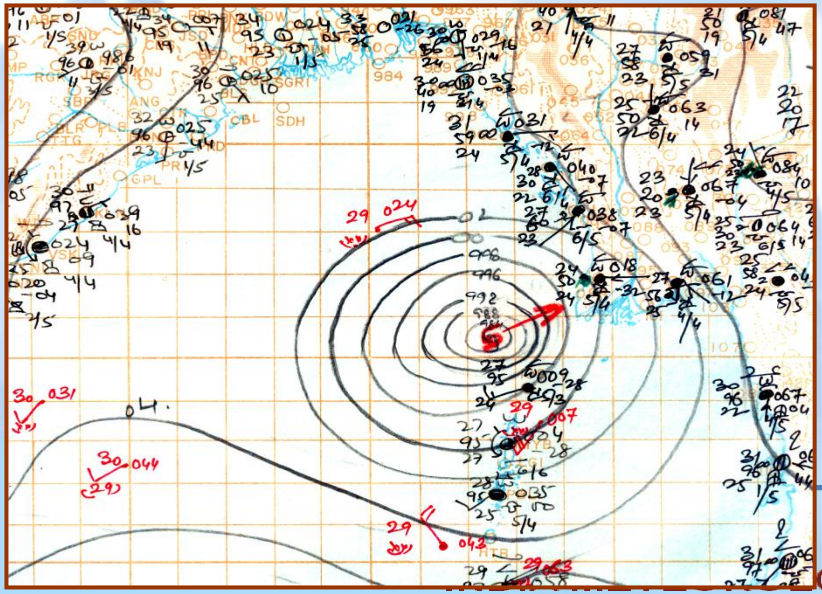
- When the system is far away from the coast and not within the radar range, satellite position gets more weight, though position is modified some times with availability of ship and buoy observations.
- When the system comes closer to the coast, radar position gets maximum preference followed by the satellite position.
- When the system is very close to coast or over the land surface, the coastal observations get the highest preference followed by radar and satellite observations.
- The average confidence level of locating the centre of the system over the NIO is about 50km.
- The landfall point and time of the TC is determined based on the available hourly coastal observationa and AWS.
- In their absence, the radar observations followed by satellite observation is used for this purpose.

Location of Centre:

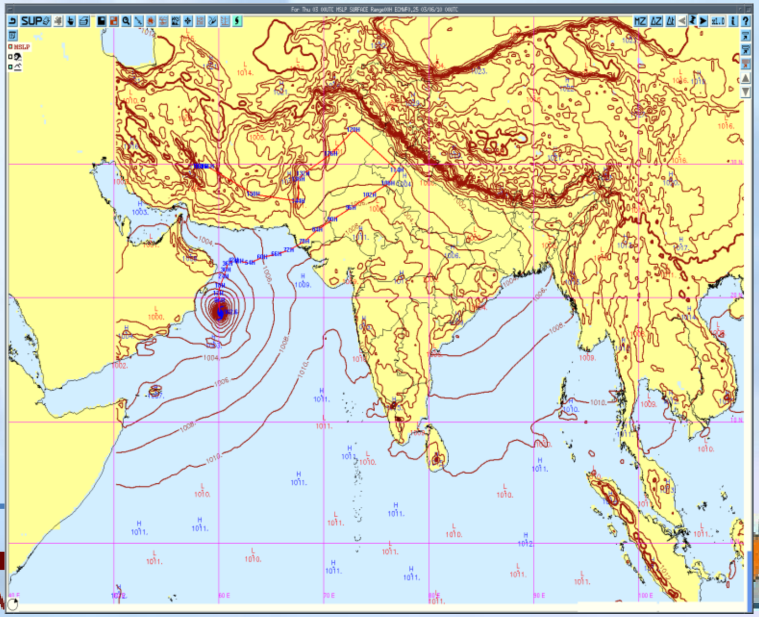
(a) Synoptic position

(Centre of the system is determined by considering the centroid of the wind distribution at the surface level. In the pressure field, the location of lowest mean sea level pressure is considered as the centre of the system.

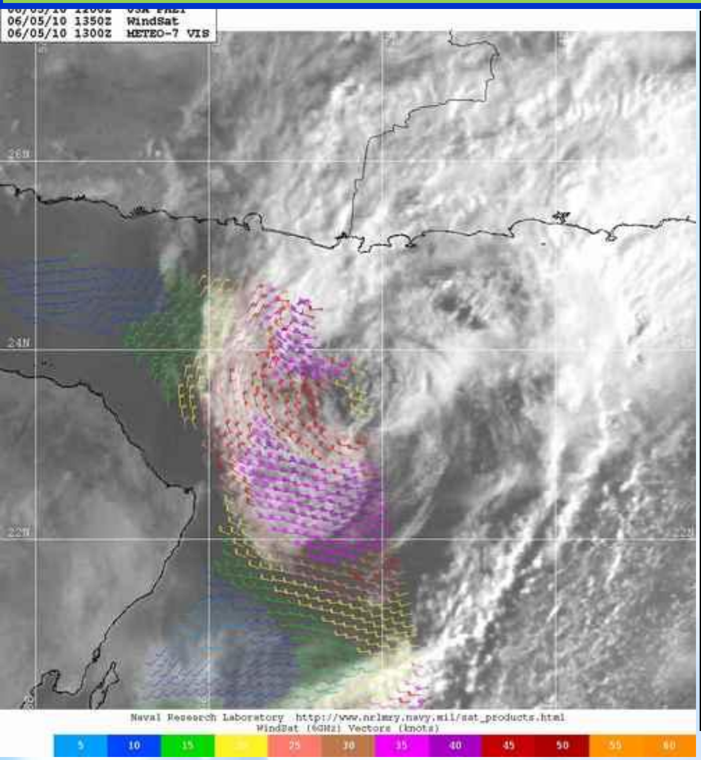
Isobaric analysis at mean sea level at 12UTC of 28 April 2006

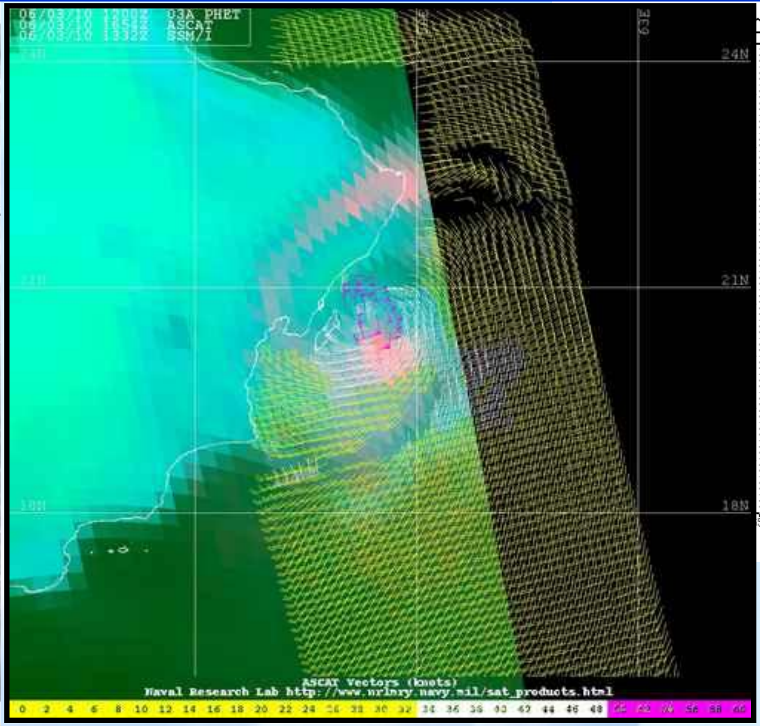


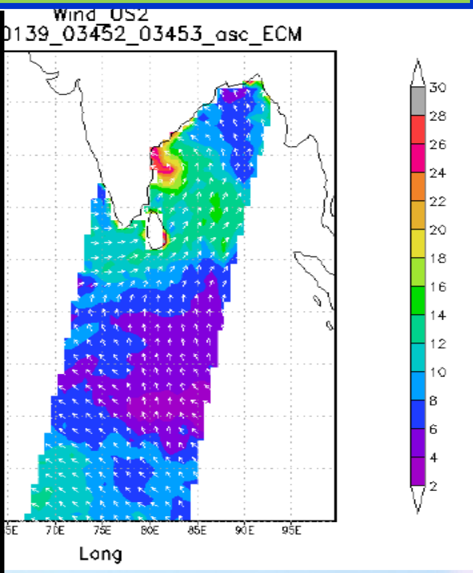
Isobaric analysis at mean sea level during cyclone, Phet at 00 UTC of 03 June 2010



Centre based on surface wind







Scatterometry products

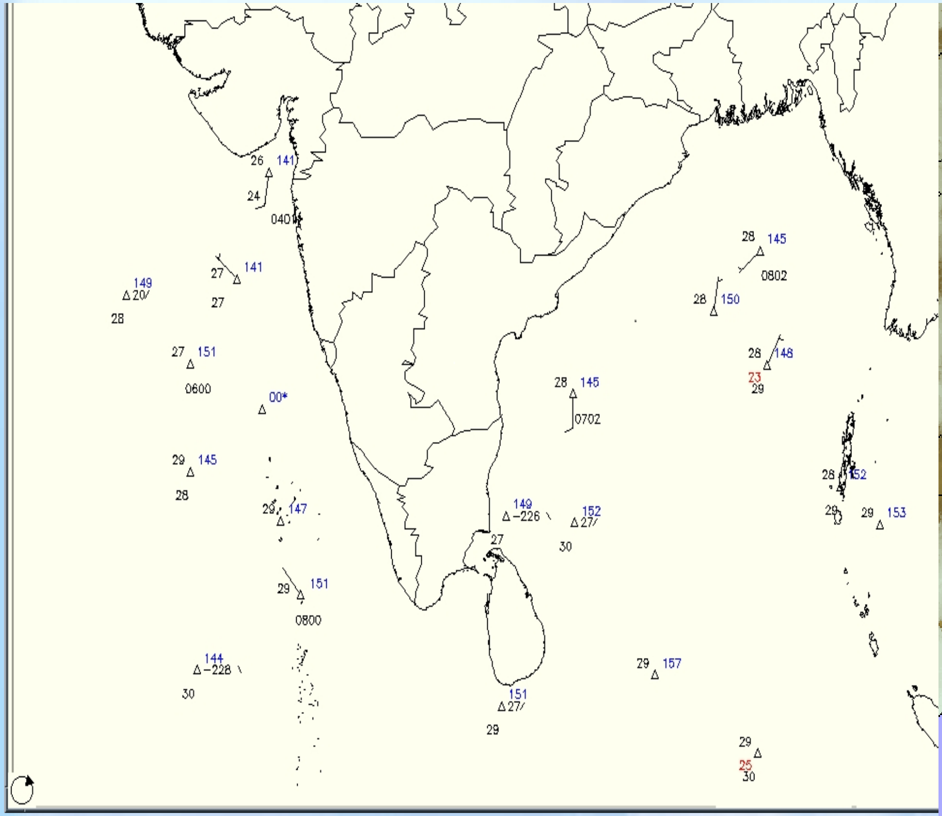
(only once/twice daily, rain contamination and unability to measure more than 50 knots, Less swath)

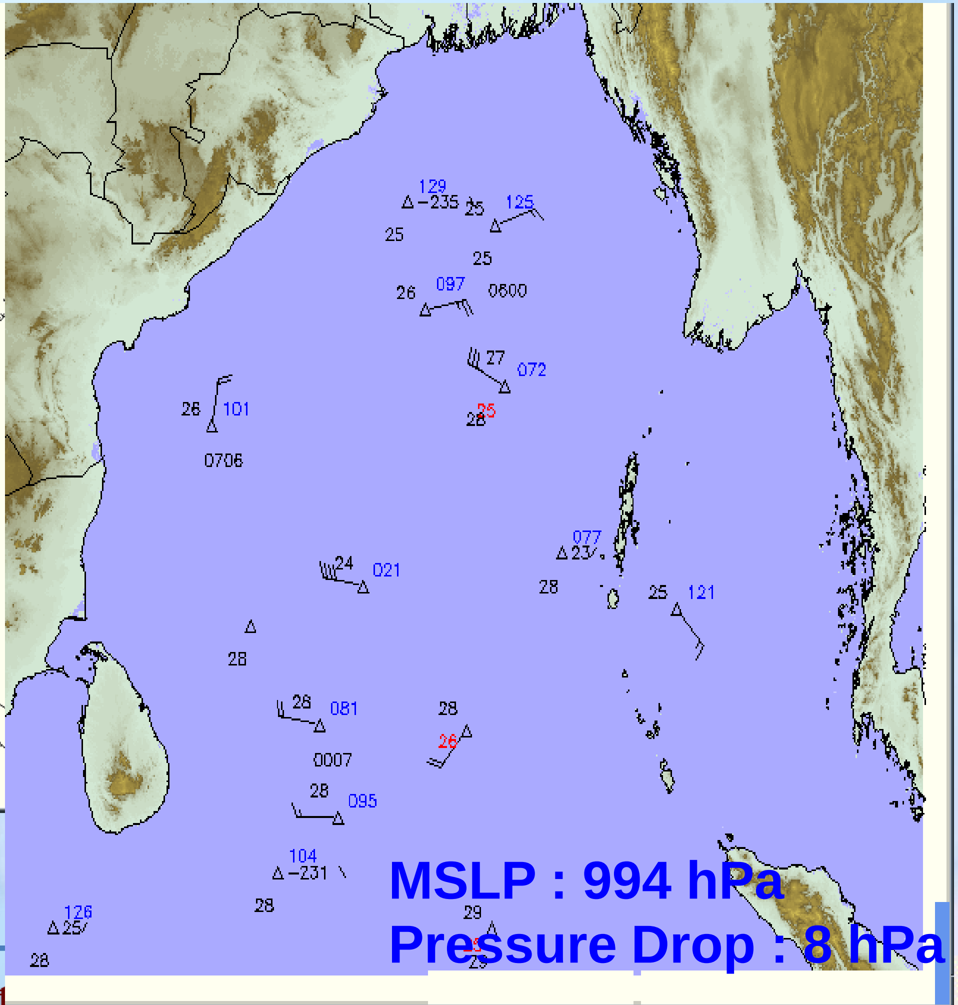
Ships

Buoys

Buoy and ships observations for MSLP and wind centre

27 Dec 2011: 03UTC
CS: 12.0N/87.0E, 40Knots

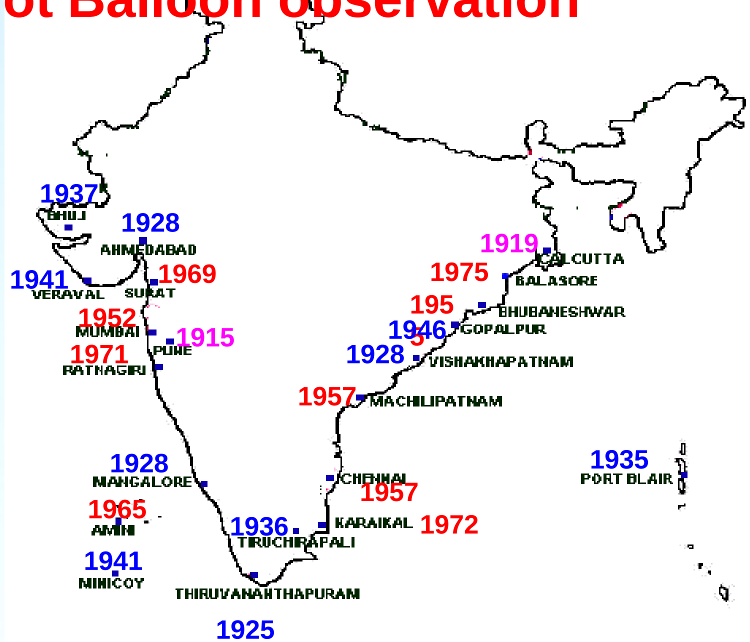


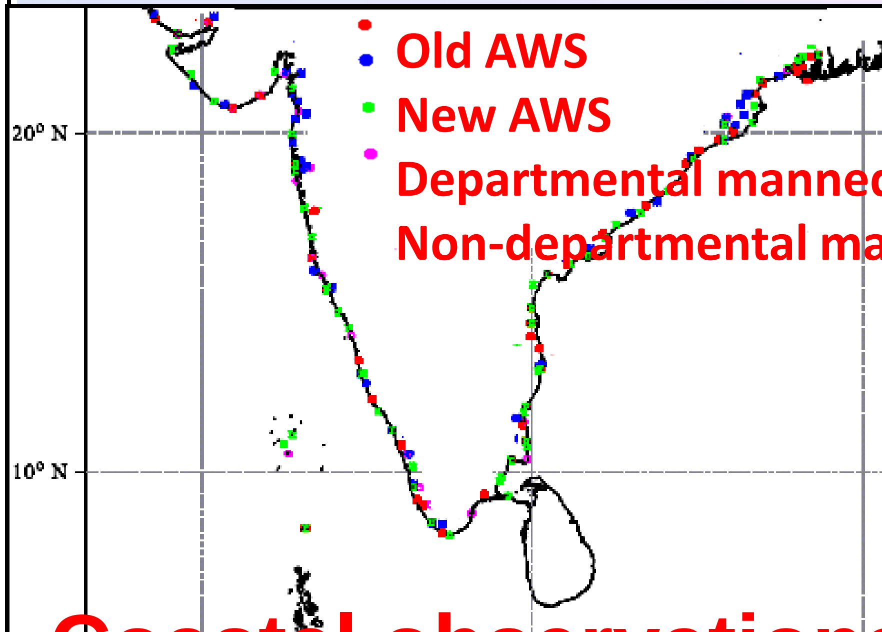


MSLP : 994 hPa
Pressure Drop : 8 hPa

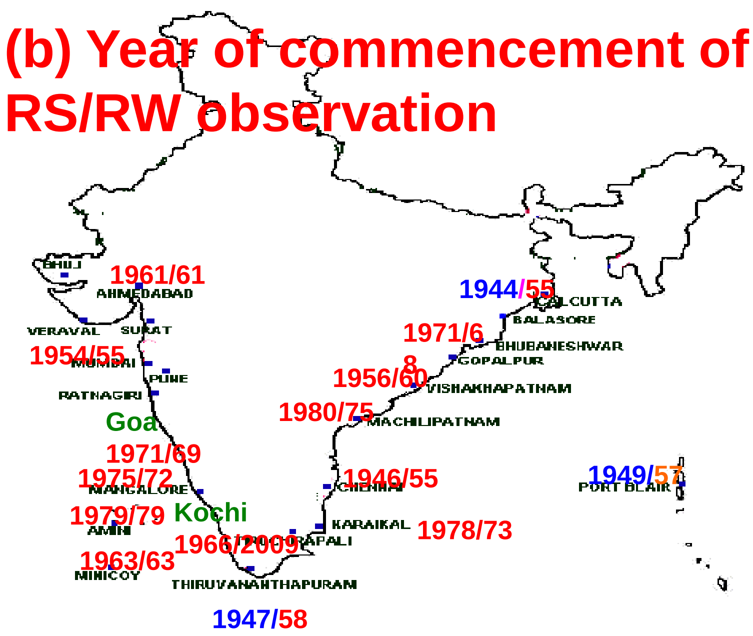
Coastal observations for MSLP and wind centre

(a) Year of commencement of Pilot Balloon observation

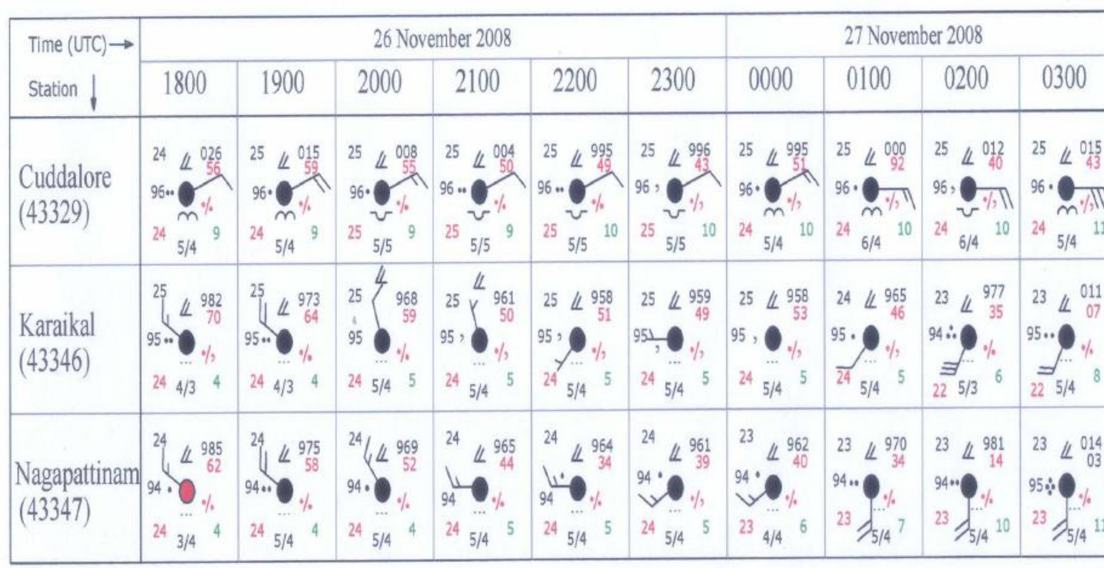




(b) Year of commencement of RS/RW observation



Hourly Observations of NISHA cyclonic storm during 25-27 November 2008



Utility of Coastal Hourly Observations for landfall point and time

Hourly Observations of KHAIMUK cyclonic storm during 13-16 November 2008

Time (UTC) → / Station ↓	15 November 2008 → 1500	1600	1700	1800	1900	2000	2100	2200
Ongole (43221)	22 031 32 96 21 2	22 029 36 95 21 2	23 005 59 95 23 4/4 2	23 015 48 96 22 3/4 2	24 010 47 96 23 3/5 2	24 995 57 96 23 3/5 2	25 983 65 96 23 3/5 2	25 984 61 96 23 3/5 2
Kavali (43245)	22 008 56 96 19 —	23 007 63 96 21 5/4 1	23 010 59 96 21 4/4 1	23 005 63 96 22 4/4 1	23 982 83 96 22 4/4 1	23 956 98 96 22 4/4 1	25 956 94 96 25 4/4 2	25 952 97 96 24 4/4 2
Nellore (43240)	23 010 54 96 22 4/4 —	22 014 54 96 22 4/4 1	23 012 57 95 22 3/4 1	23 996 68 95 22 4/4 2	22 995 67 95 22 5/4 3	23 983 69 96 22 4/5 3	23 986 58 96 22 4/5 3	23 997 46 96 22 4/5 3

Location of Centre:

(b) Satellite

- In the initial stage, the centre is determined, from the centre of the low cloud lines (IMD, 2003).
- Similar is the case in shear pattern, when the convection lies away from the centre.
- As the system intensifies and acquires the banding pattern, the centre is determined from the banding feature.
- In the CDO pattern, the centre of CDO is the centre of the system.
- In the eye pattern, the centre determination is easier and accurate as it is same as the centre of the eye of the cyclone.

Tropical Cyclone Module and

- Microwave imageries being used
- Tropical cyclone module
- Has been installed and will be utilised along with Navy NRL website to analyse microwave imageries.

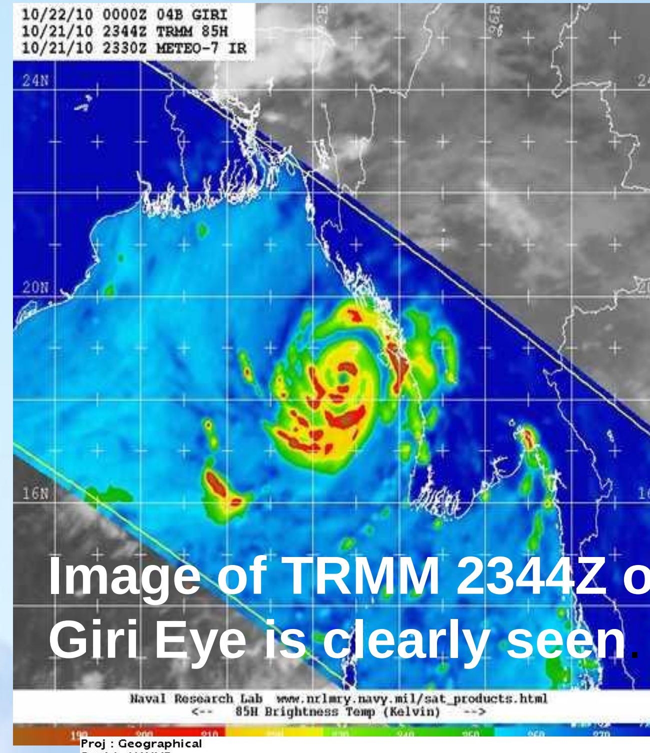
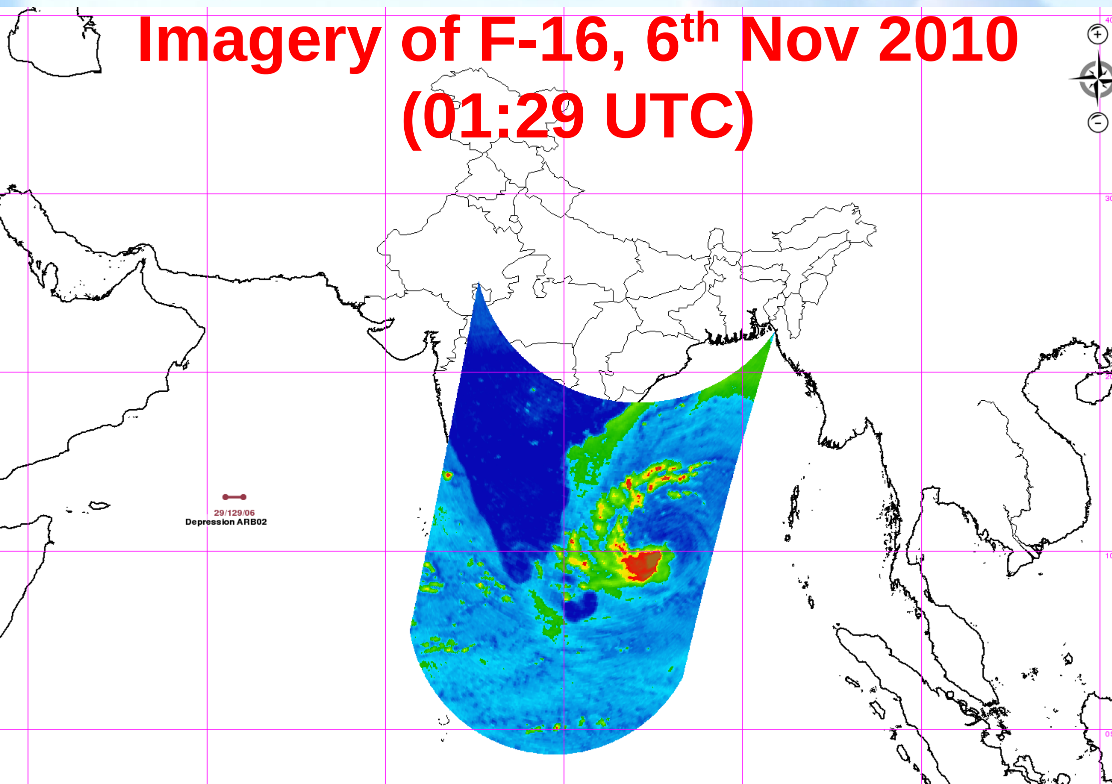
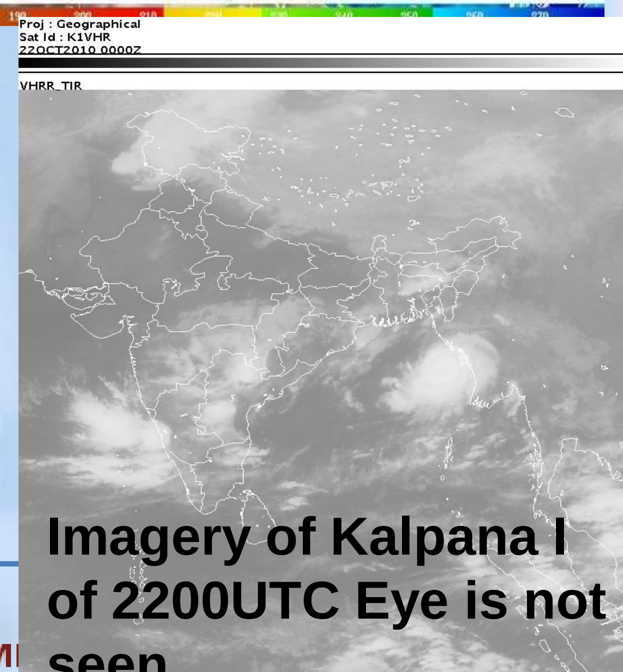


Image of TRMM 2344Z of Giri Eye is clearly seen.



Imagery of F-16, 6th Nov 2010 (01:29 UTC)

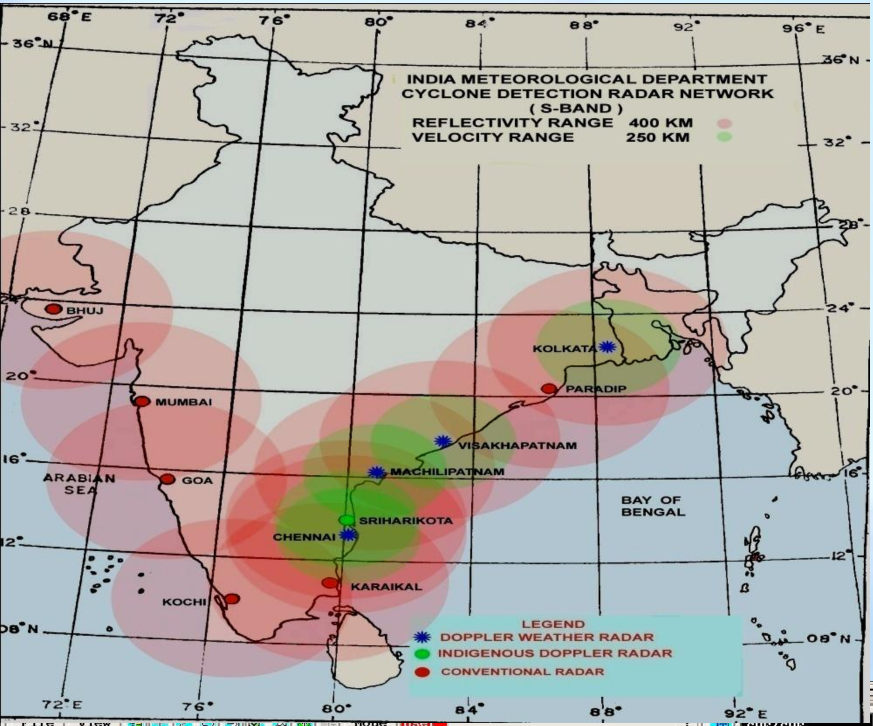


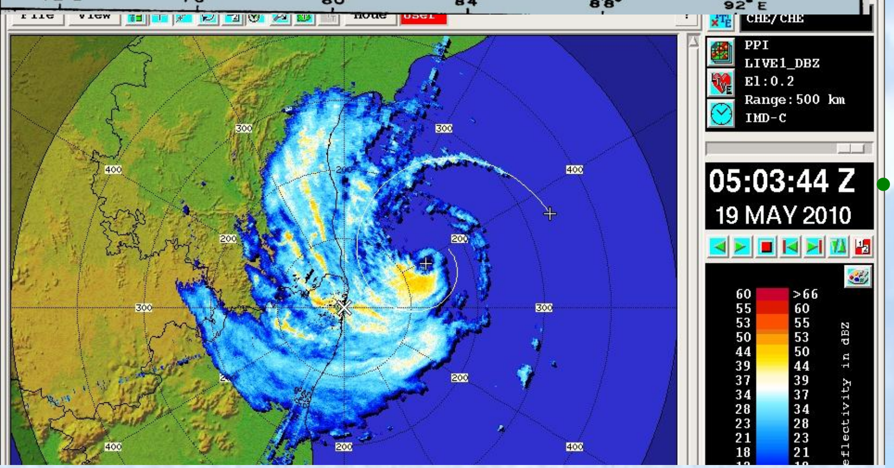
Imagery of Kalpana I of 2200UTC Eye is not seen.

Cyclone centre fixing using Doppler Weather Radar

1. Initial Centre fixing is essential for accurate model predictions.
2. Required for accurate short range forecasts
3. Multiple circulations within the centre can be detected
4. Cloud centre is generally located accurately but may not be the cyclone centre
5. Satellite centre is different from Radar centre in some cases
6. Vortex tilt can be seen in radar data

Center fixing by Radar

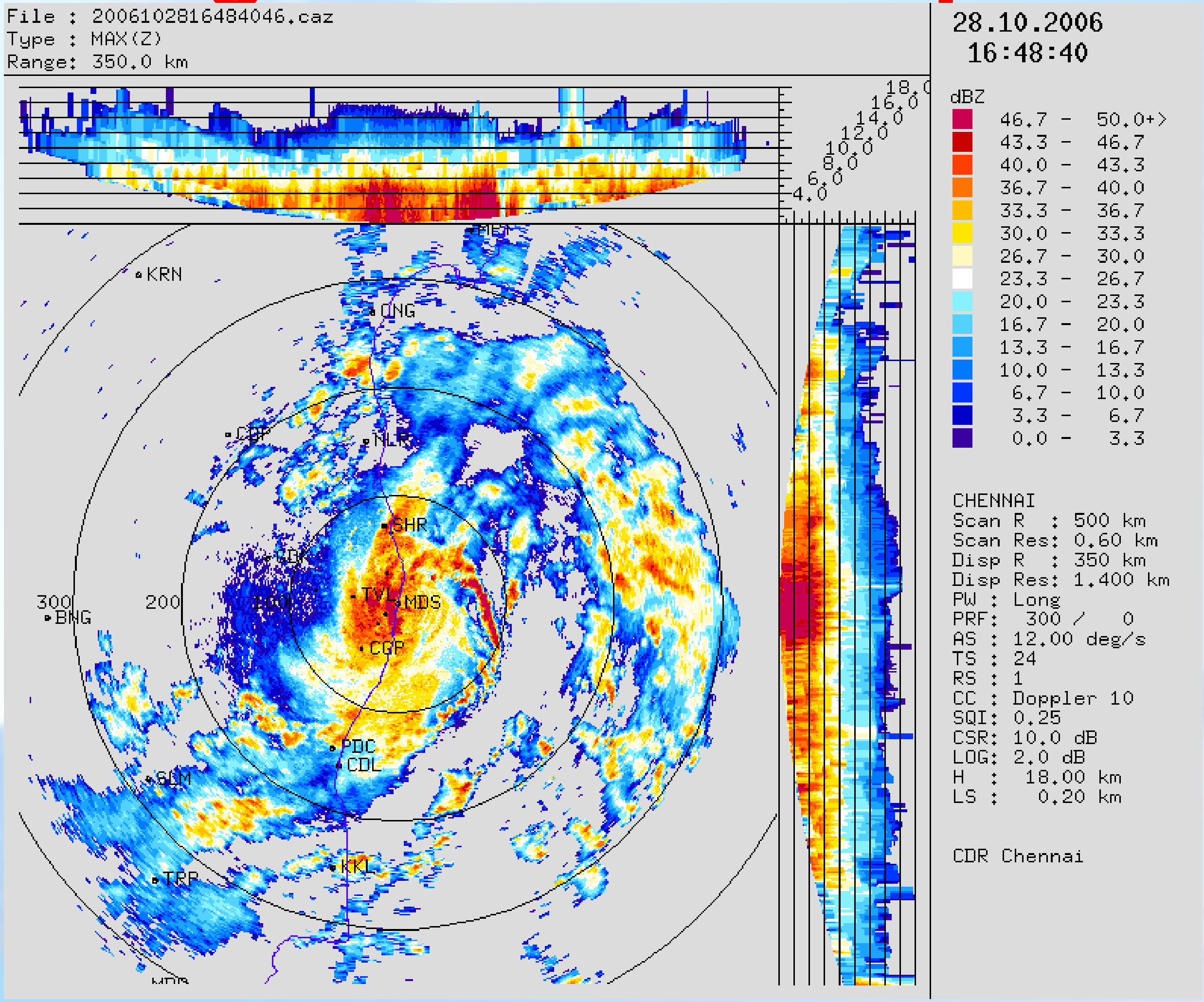




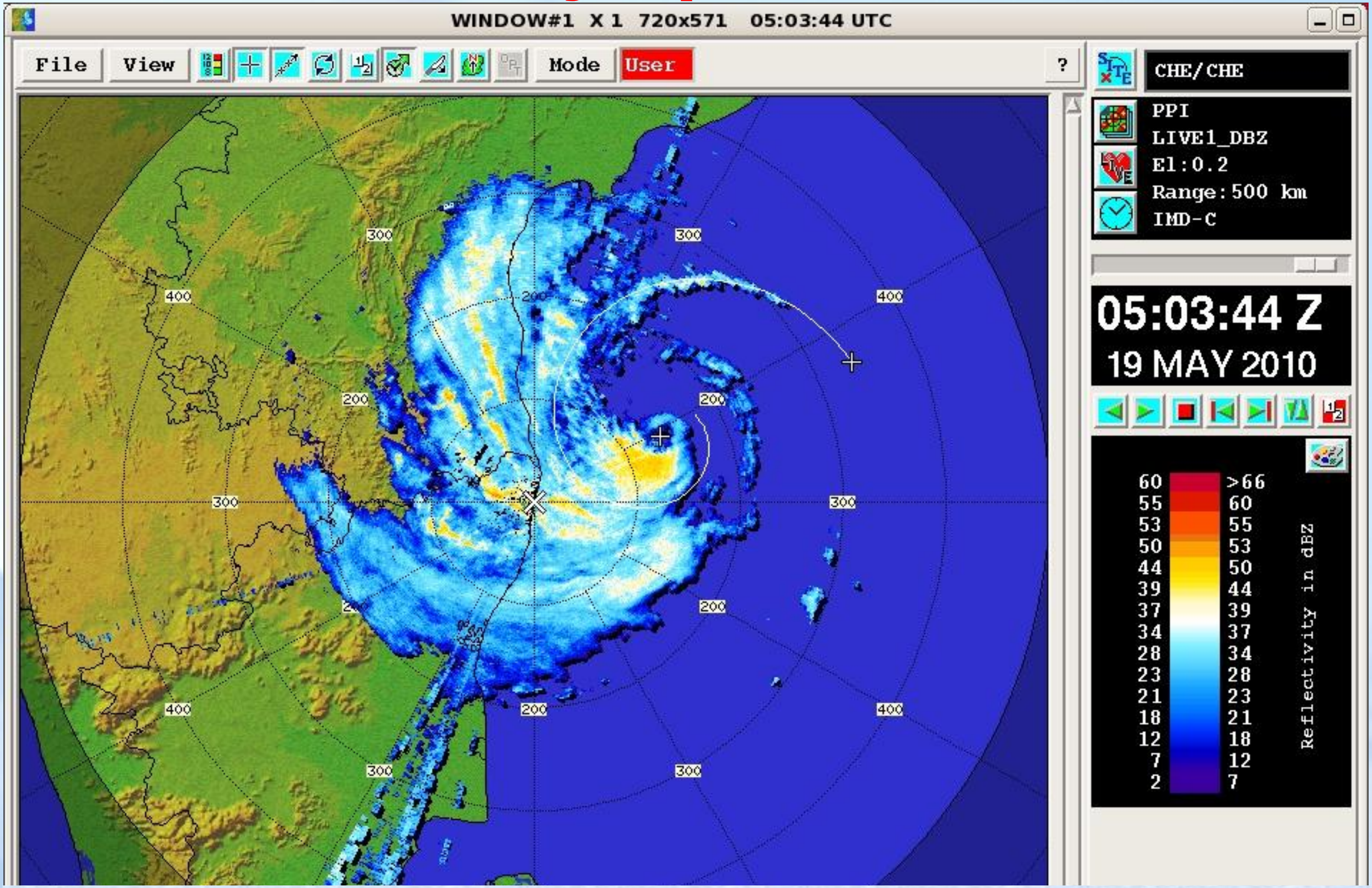
Radar Cyclone center: 13.6325°N 81.4065°E

- Eye or the centre is derived from a continuous and logical sequence of observations.
- Geometric centre of the echo-free area -centre.
- If the wall cloud not completely closed, centre is found by sketching the smallest circle or oval superimposed on inner edge of existing portion of wall cloud.
- When wall cloud is not developed fully but centre of circulation is identifiable its reported similar to eye.

Cyclonic Spiral bands
Fitting centre with spirals

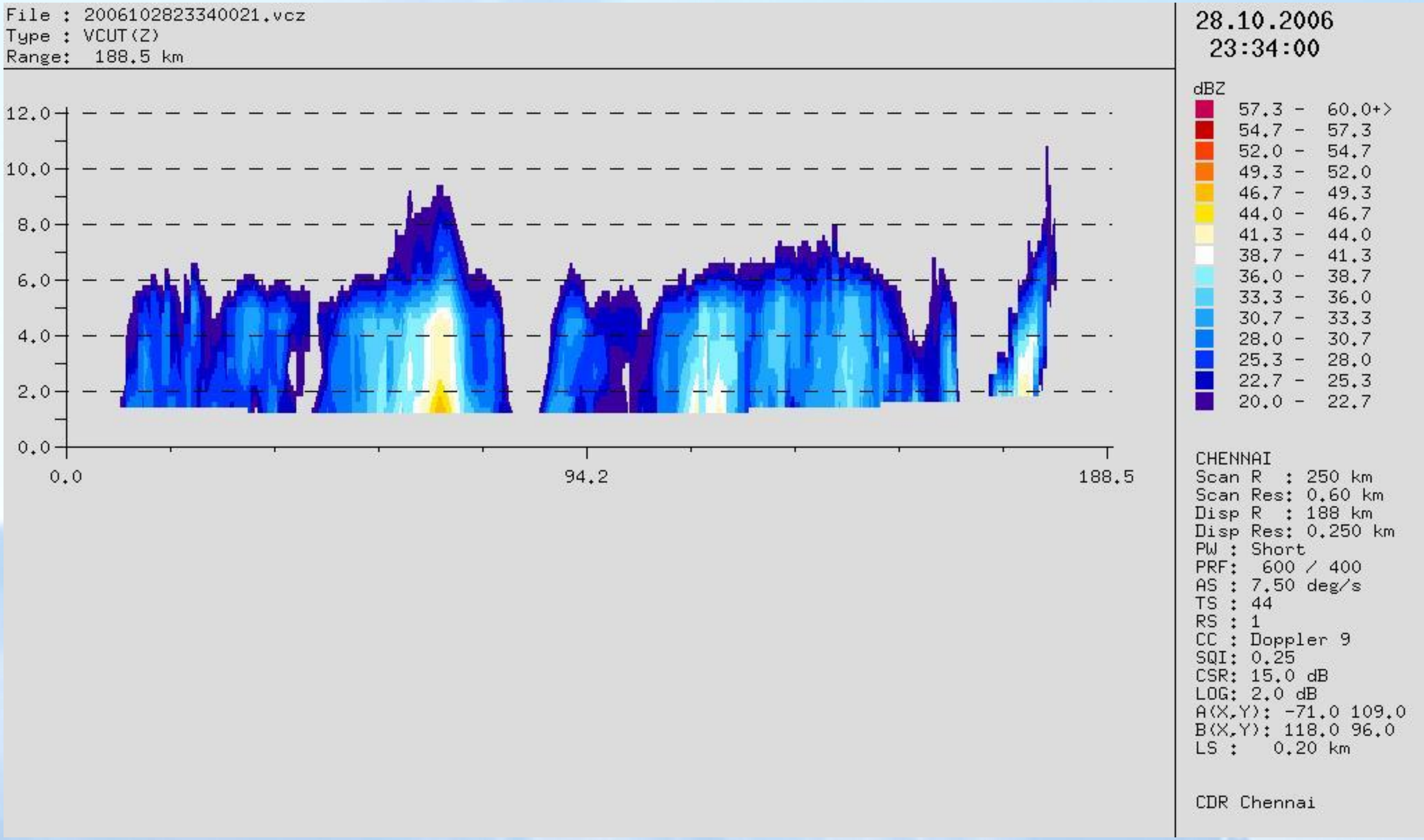


Movement Prediction and center fixing in eye pattern

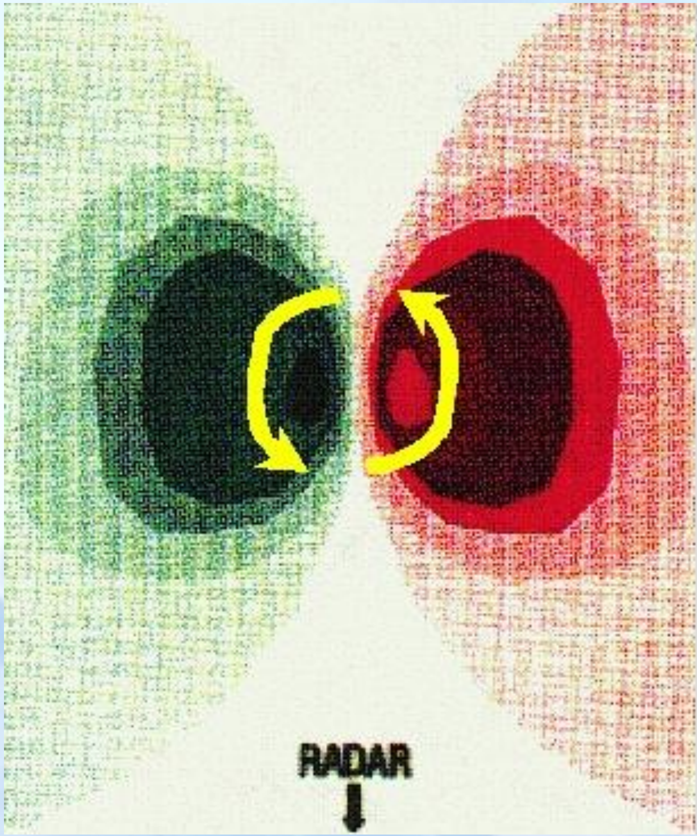


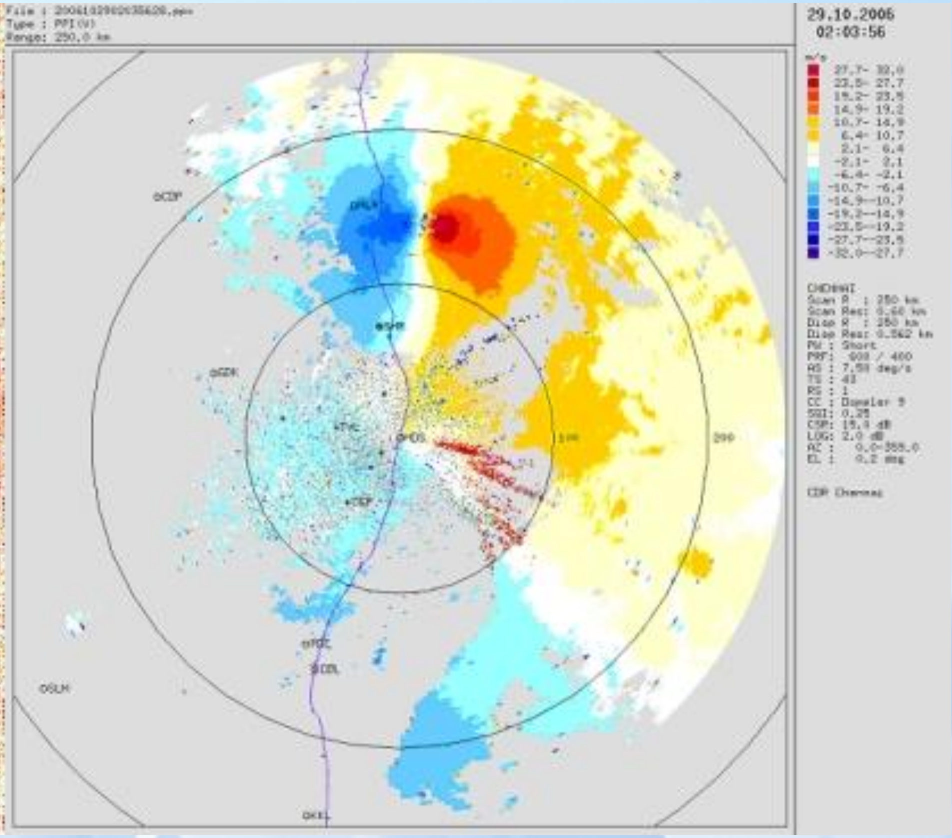
Radar Cyclone center: 13.6325ºN 81.4065ºE

Cyclone centre using V-Cut



Radial Velocity Couplet





Location estimation error

- It is about is about 55 km over the sea areas (standard error of satellite estimation).
- Location error of a depression is more than a TC.
- According to Elsberry (2003), the errors in determining the TC centre over the northwest Pacific Ocean can be upto 50 km by satellite fixes, 20-50 km by radar observations and by about 20 km by aircraft reconnaissance.
- Landfall point estimation error is 140 km or more prior to 1891 for west coast and more than 105 km for east coast. It reduced to about 100 km by the end of 1940 for both the coasts and to 55 km by the end of 1960. It further reduced to about 25 km by 2010 mainly due to installation of coastal AWS during late 2000s.
- Landfall time estimation error may be about half an hour since 1974 with introduction of coastal hourly observations and CDRs. During 1960-1974, it may be at least one and a half hour with the three hourly observations.

Methods for Estimating Intensity

- Beaufort Scale (0-12: Calm to hurricane)
- Anemometers – Biases in Early Instruments
- Pressure-Wind Relationships
- Utilizing Size (Radius of Maximum Wind) Information
- Storm Surge
- Wind-caused Structural Damage
- Inland Wind/Pressure Decay Models
- Satellite (polar – 1960, DvoraK technique 1974, INSAT 1982)
- Buoys
- Aircraft Reconnaissance (?)

Intensity estimation:

(a) Satellite:

(1) INSAT/METSAT

(2) Intensity from NOAA SSD:

(b) Radar

(c) Synoptic analysis

(d) Model analysis

(e) Intensity determined by other warning centres

(e) Finally agreed official intensity

(f) Confidence

In synoptic method, the available surface observations are taken into consideration to find out maximum sustained wind and number of closed isobars at the interval of 2 hPa within a specified region around the system centre (5 deg. Lat/long. Box)

Intensity estimation: Dvorak's Technique

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

The technique relies on four distinct geophysical properties that relate organised cloud patterns to TC intensity.

1. Vorticity, 2.Vertical wind shear,

3. Convection, and 4. Core temperature.

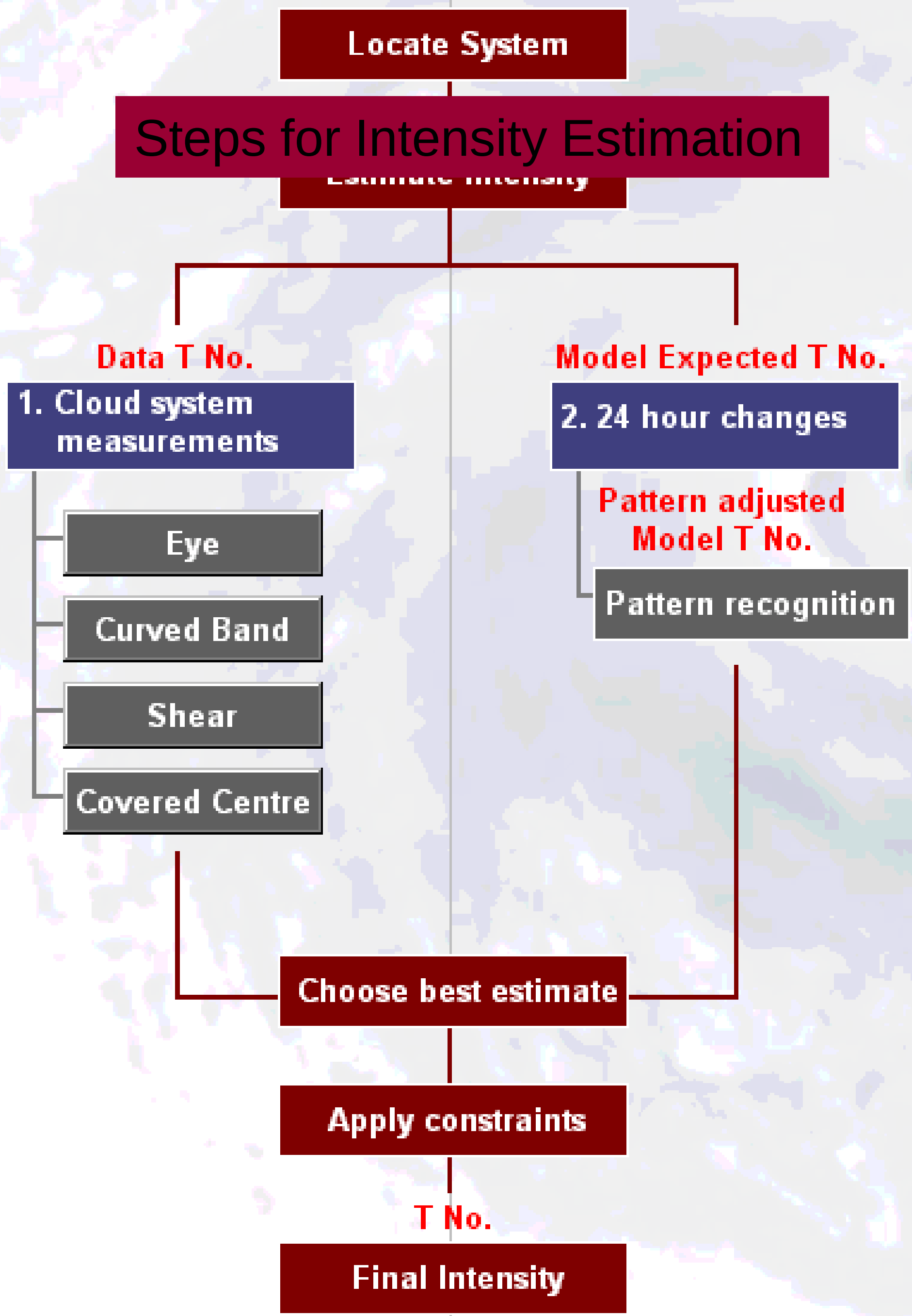
Recent developments

1. ADT
2. AODT
3. Application of DT to microwave imageries
4. Application of DT over land

Limitations

Not verified over NIO, Averaging problem, Pressure wind relationship also not verified

Steps for Intensity Estimation



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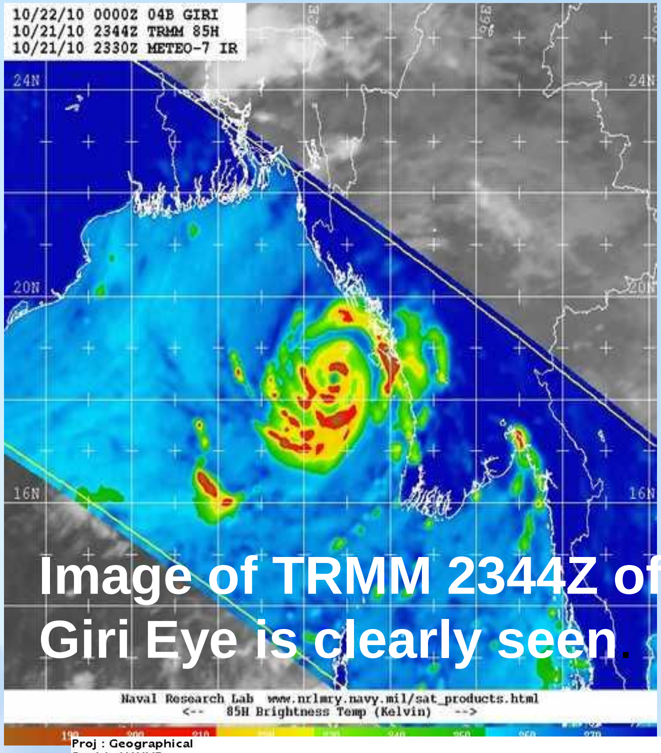

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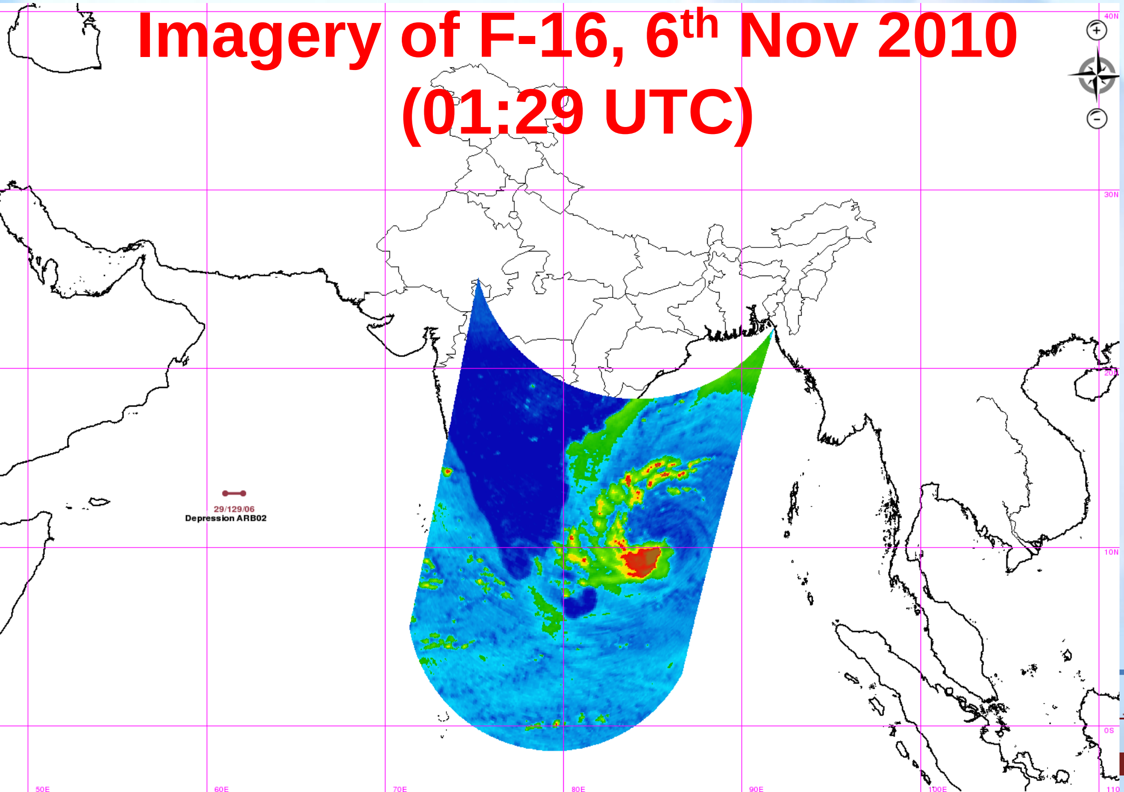
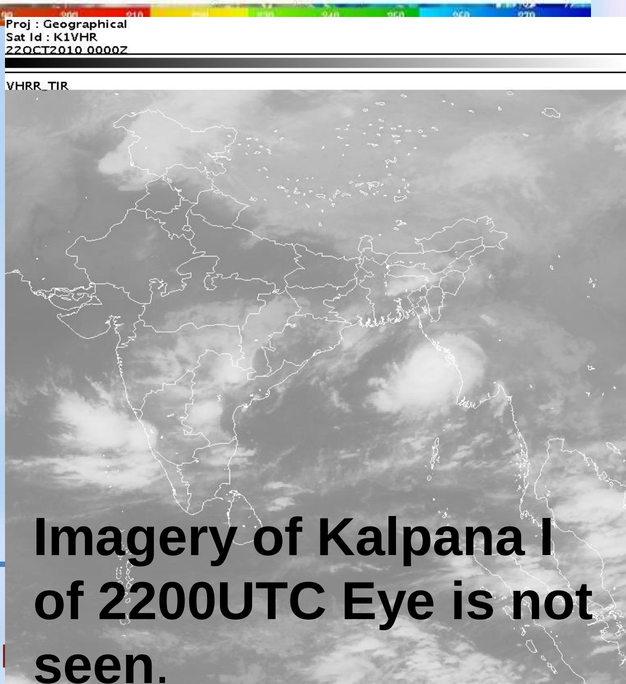


Imagery of F-16, 6th Nov 2010 (01:29 UTC)



Imagery of Kalpana I of 2200UTC Eye is not seen.

Date	Time (UTC)	Lat (E)	Long (E)	T. No.	C.T.T (C)
25.10.12	1200			LLC	
26.10.12	1500	12.0	91.5	1.0	-75
	1700	12.0	91.5	1.0	-71
	2100	12.2	91.5	1.0	-81
27.10.12	0000	12.2	91.5	1.0	-80
	0300	12.0	91.0	1.0	
	0600	12.0	91.0	1.0	-79
	0900	12.0	90.5	1.0	-76
	1200	12.0	90.0	1.0	-79
	1500	12.0	90.0	1.0	-85
	1700	12.0	89.5	1.0	-87
	2100	11.5	88.5	1.0	-88
28.10.12	0000	11.0	87.5	1.0	-91
	0300	10.0	87.5	1.0	-87
	0600	9.5	87.0	1.5	-84
	0900	9.5	86.0	1.5	-83
	1200	9.5	85.0	1.5	-86
	1500	9.5	84.5	1.5	-83
	1700	9.5	84.5	1.5	-91
	2100	9.5	84.5	1.5	-91

Date	Time (UTC)	Lat (E)	Long (E)	T. No.	C.T.T (C)
29.10.12	0000	9.5	84.0	2.0	-86
	0100	9.4	83.8	2.0	
	0200	9.4	83.8	2.0	
	0300	9.3	83.3	2.0	-80
	0400	9.2	83.3	2.0	
	0500	9.0	83.0	2.0	
	0600	8.9	82.8	2.0	-81
	0700	8.7	82.7	2.0	
	0800	8.7	82.6	2.0	
	0900	8.7	82.5	2.0	-85
	1000	8.7	82.5	2.0	
	1100	8.7	82.5	2.0	
	1200	8.7	82.5	2.0	-84
	1300	8.7	82.5	2.0	
	1400	8.7	82.5	2.0	
	1500	8.7	82.3	2.0	-79
	1600	8.7	82.3	2.0	
	1700	8.7	82.2	2.0	-83
	2100	8.7	82.0	2.0	
	2200	8.7	82.0	2.0	
	2300	8.7	82.0	2.0	-84

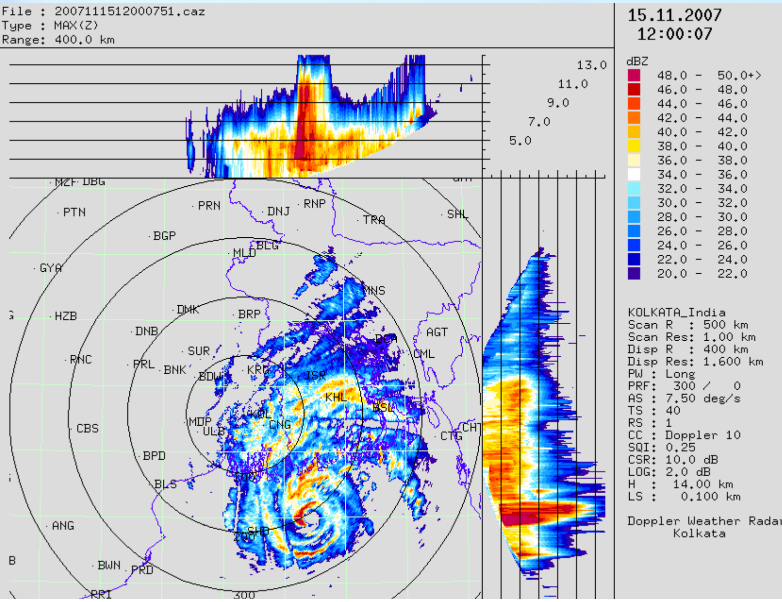
Date	Time (UTC)	Lat (E)	Long (E)	T. No.	C.T.T (C)
30.10.12	0000	8.7	82.0	2.0	-83
	0100	8.7	82.0	2.0	
	0200	9.0	82.0	2.0	
	0300	9.0	82.0	2.5	-85
	0400	9.0	82.0	2.5	
	0500	9.0	82.0	2.5	
	0600	9.2	82.0	2.5	-82
	0700	9.3	82.0	2.5	
	0800	9.3	82.0	2.5	
	0900	9.3	82.0	2.5	-85
	1000	9.4	81.9	2.5	
	1100	9.5	81.9	2.5	
	1200	9.5	81.9	2.5	-88
	1300	9.5	81.9	2.5	
	1400	9.5	81.9	2.5	
	1500	9.5	81.9	2.5	-89
	1600	9.5	81.9	2.5	
	1700	9.6	81.8	2.5	-93
	2100	10.2	81.8	2.5	-94
	2200	10.2	81.8	2.5	
	2300	10.3	81.8	2.5	

Date	Time (UTC)	Lat (E)	Long (E)	T. No.	C.T.T (C)
31.10.12	0000	10.4	81.7	3.0	-96
	0100	10.4	81.7	3.0	-92
	0200	10.4	81.2	3.0	-88
	0300	10.5	81.1	3.0	-85
	0400	10.5	81.0	3.0	
	0500	10.8	81.0	3.0	
	0600	11.0	80.9	3.0	-84
	0700	11.2	80.7	3.0	
	0800	11.4	80.5	3.0	
	0900	11.7	80.3	3.0	-86
	1000	11.9	80.3	3.0	
	1100	12.2	80.3	3.0	
	1200	12.5	80.0	Overland	-85

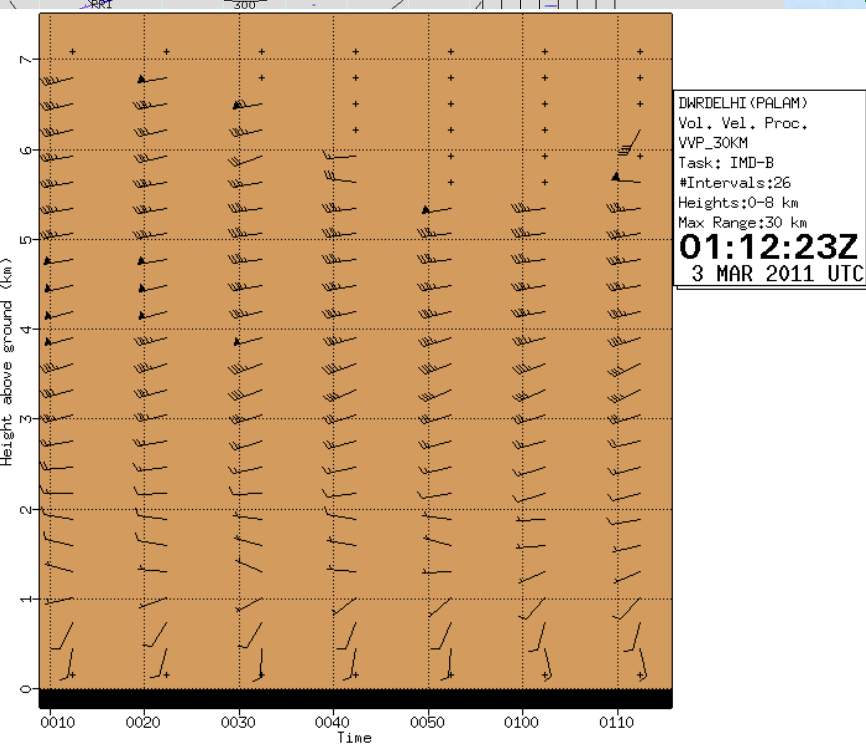
Position and Intensity Table

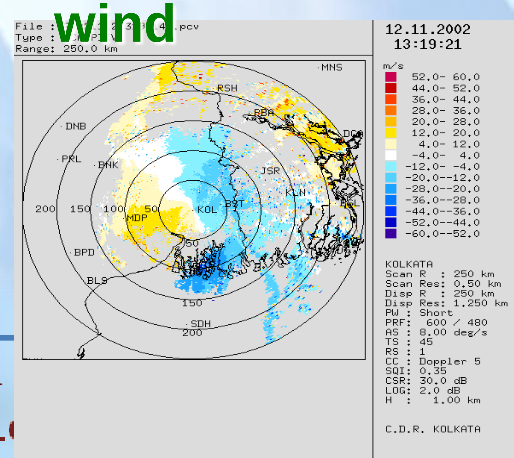
Date/ Time (UTC)	SAT MET POS			NOAA POS			JTWC POS			SYNOP POS		
	Lat.	Long.	T.No.	Lat.	Long.	T.No.	Lat.	Long.	T.No.	Lat.	Long.	T.No.
28 /00	11.0	87.5	1.0	9.8	85.2	1.5	-	-	-	9.5	86.0	1.5
28/06	9.5	87.0	1.5	9.7	84.6	1.5	9.4	84.0	1.5	9.5	86.0	1.5
28/12	9.5	85.0	1.5	9.6	85.1	2.5	9.9	85.0	1.5	9.5	85.0	1.5
29/00	9.5	84.0	2.0	8.7	83.0	2.5	9.6	83.7	2.0	9.5	84.0	2.0
30/00	8.7	82.0	2.0	8.6	81.8	3.0	8.8	83.4	2.5	9.0	82.0	2.0
30/03	9.0	82.0	2.5	8.2	82.0	3.5	8.8	83.4	2.5	9.0	82.0	2.5
31/00 **	10.4	81.7	3.0	10.3	82.1	3.5	10.3	81.8	3.0	10.5	81.5	3.0
**	DWR CHN POS											
	10.3	81.7	Fair									

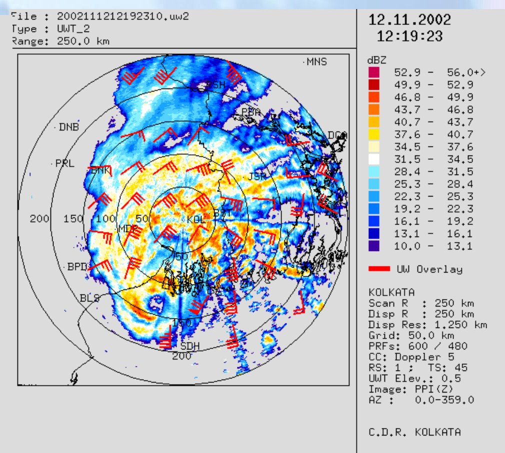
Intensity estimation by Radar



- (a) Radius of maximum reflectivity mostly corresponds to radius of maximum wind
- (b) Radial wind
- (c) Wind distribution by uniform wind technique
- (d) Vertical profile over the station
- (e) Mosaic products
- (f) Use of conversion technique for obtaining 10m wind from radial wind

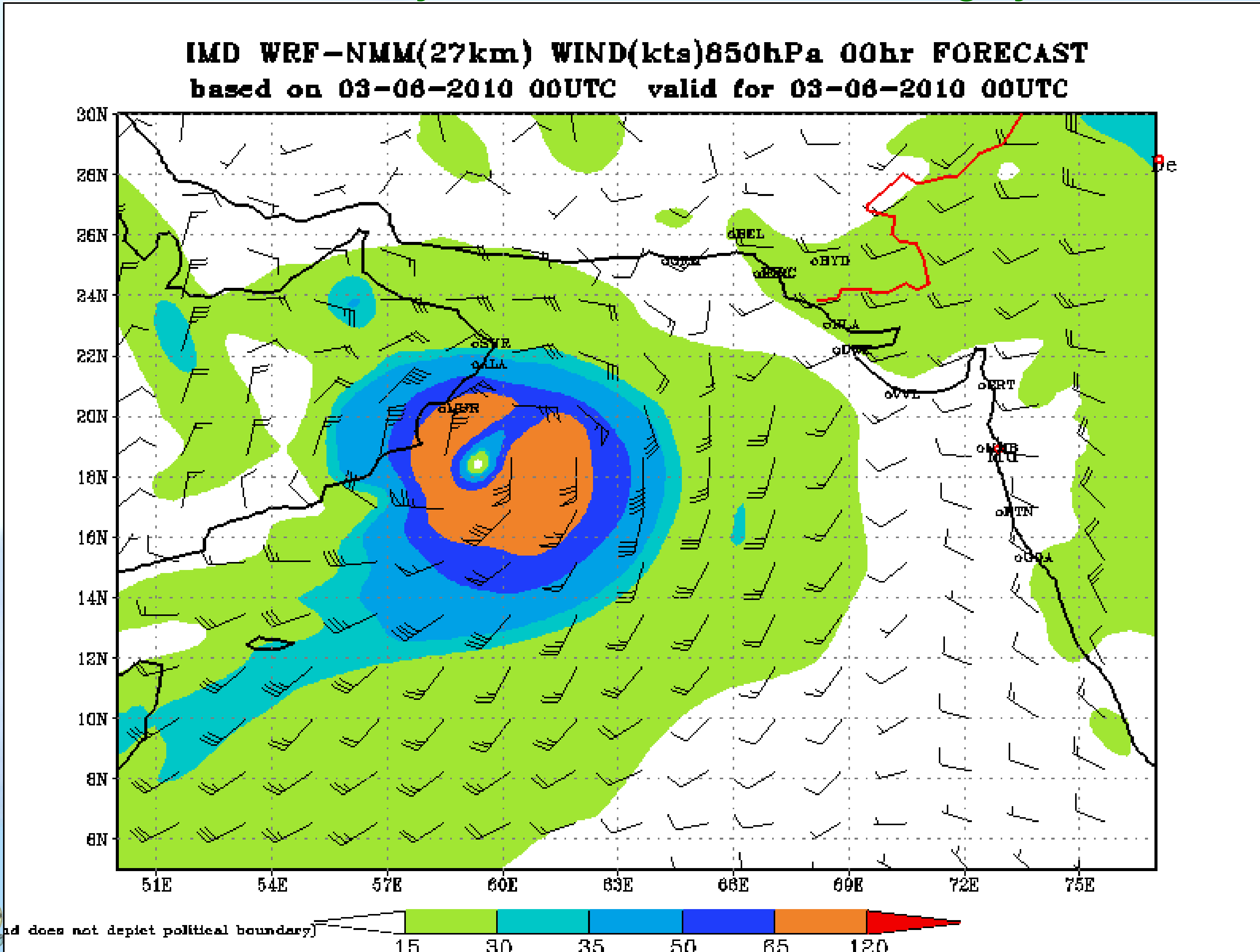


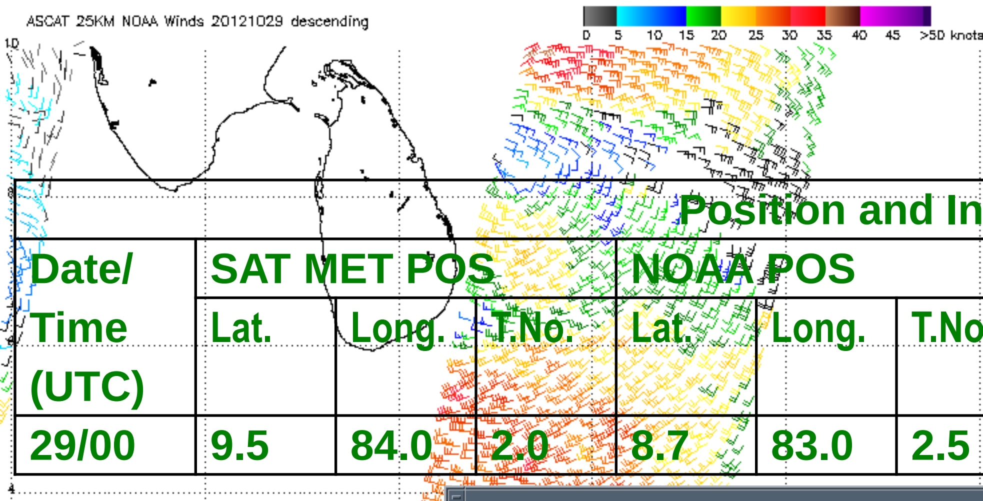




Intensity estimation from NWP Model analysis

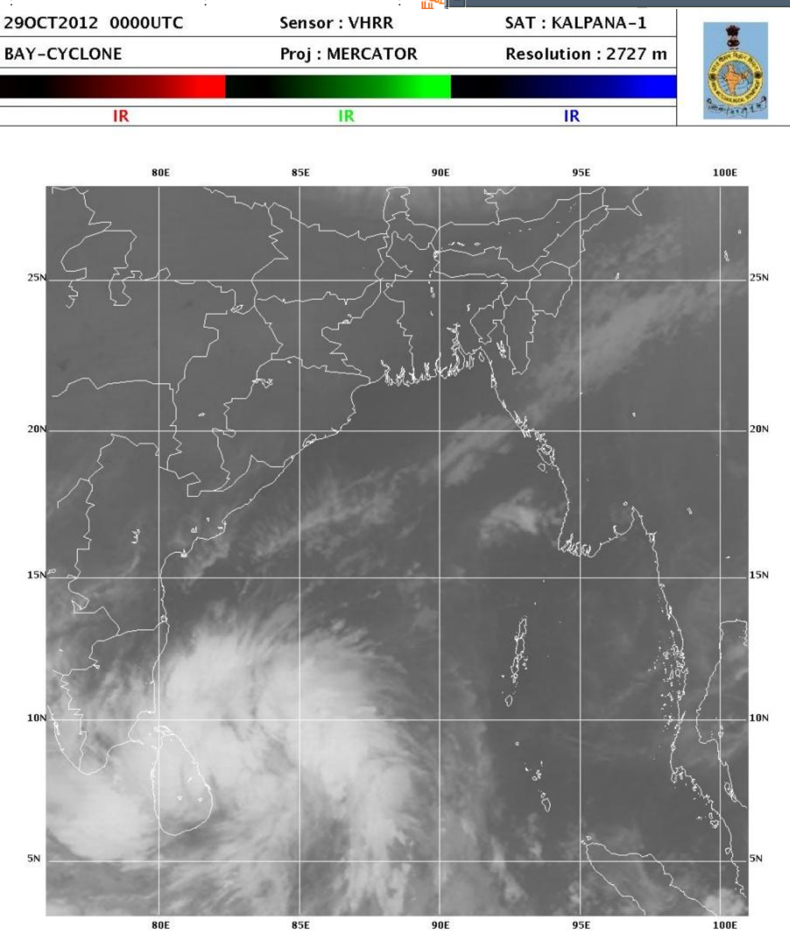
Wind analysed from WRF model during cyclone, Phet

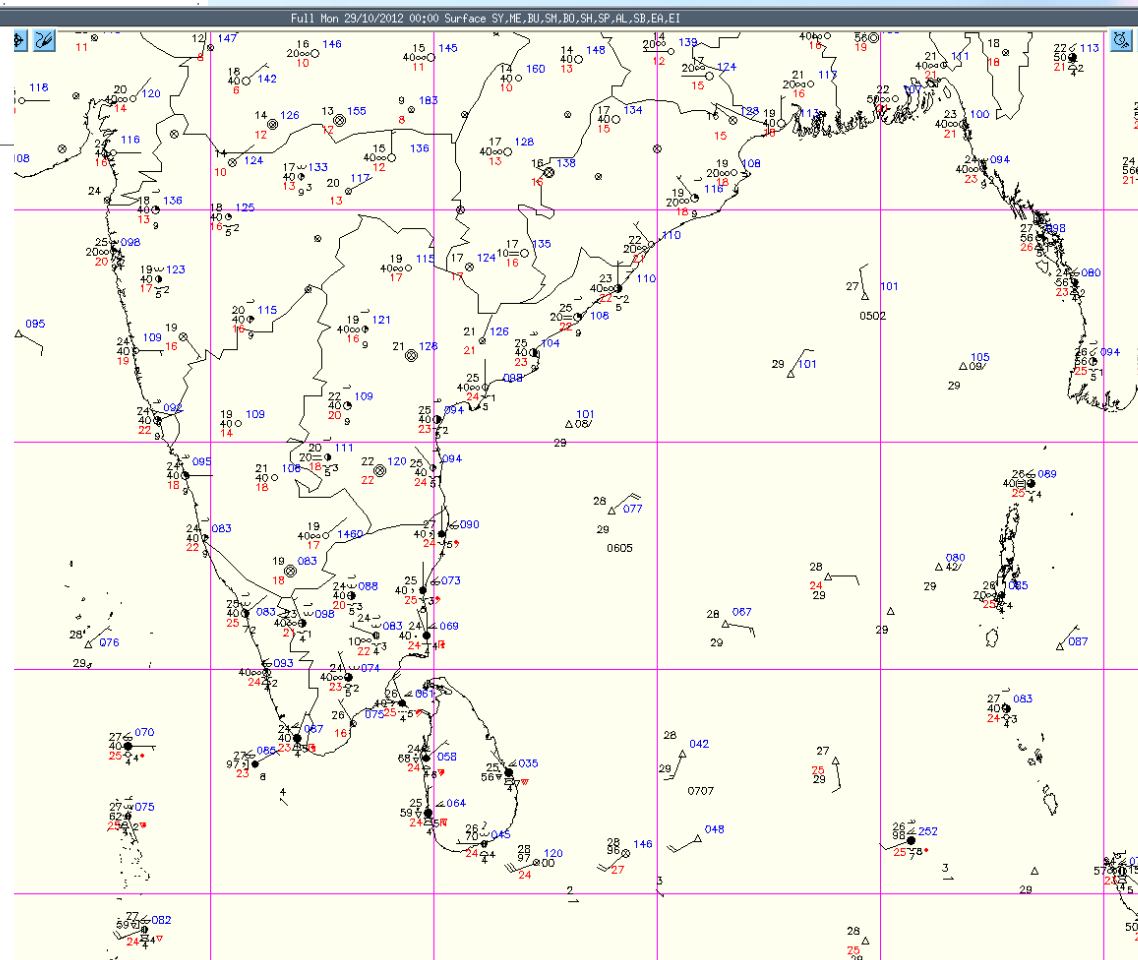




Position and Intensity Table

Date/ Time (UTC)	SAT MET POS			NOAA POS			JTWC POS			SYNOP POS		
	Lat.	Long.	T.No.	Lat.	Long.	T.No.	Lat.	Long.	T.No.	Lat.	Long.	T.No.
29/00	9.5	84.0	2.0	8.7	83.0	2.5	9.6	83.7	2.0	9.5	84.0	2.0



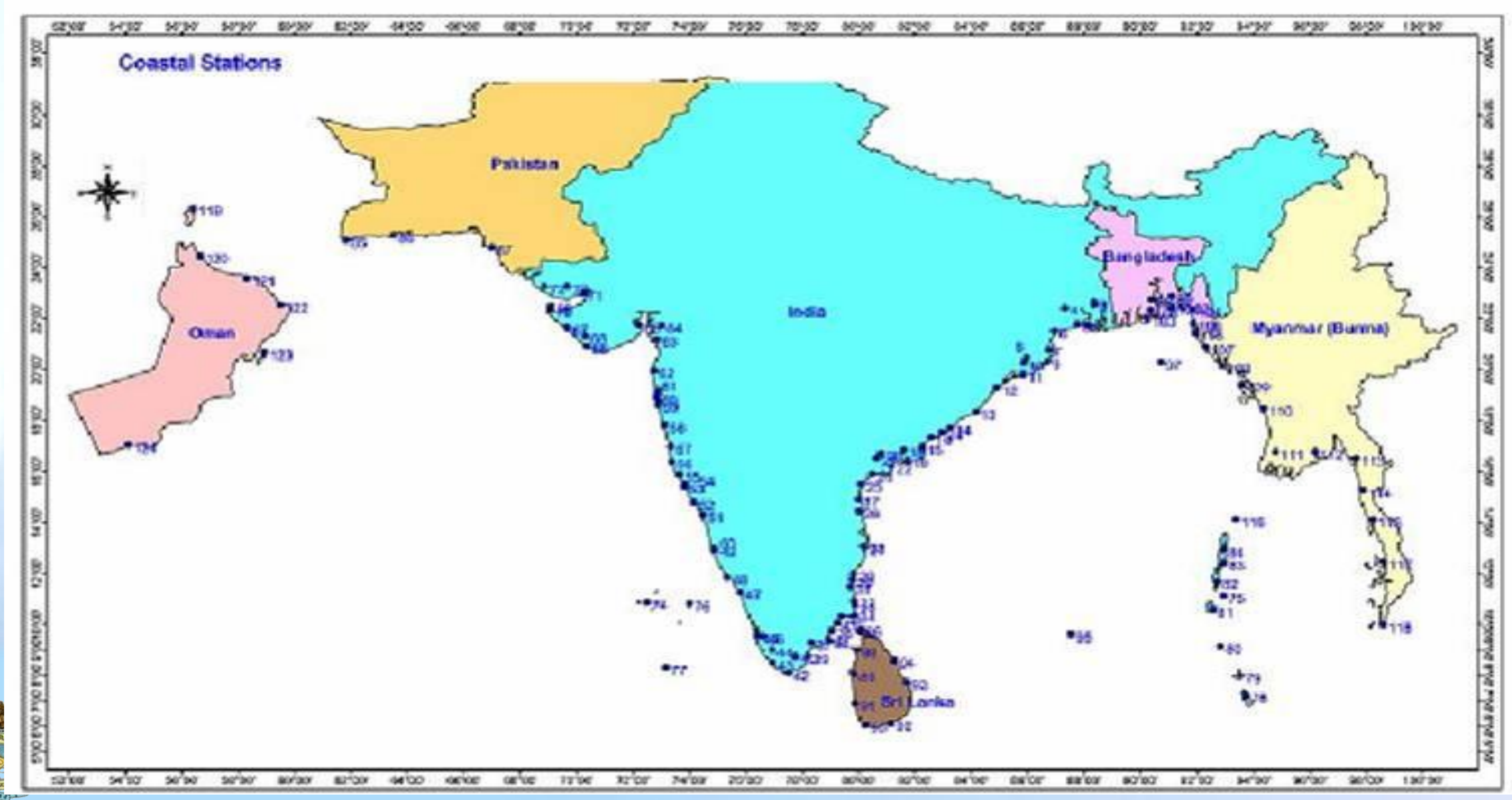


Intensity estimation error

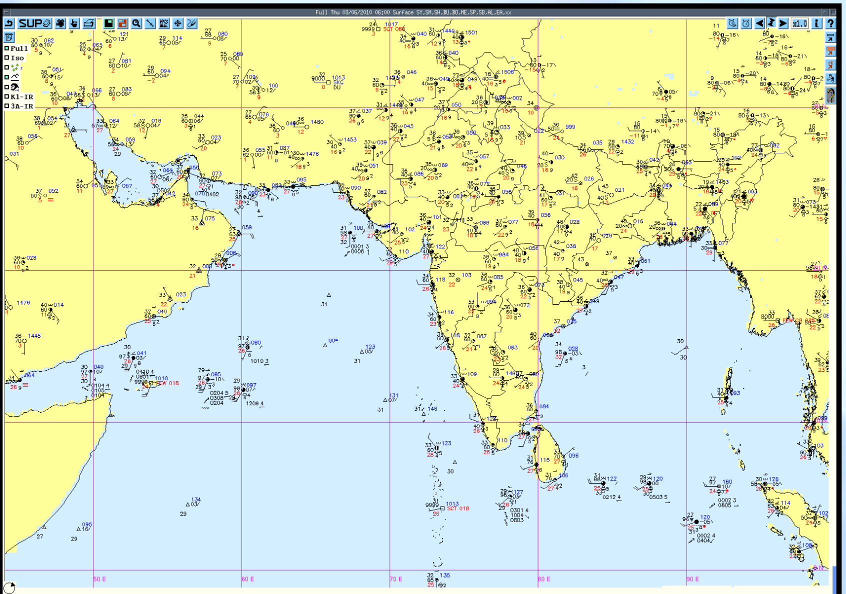
- Average error in MSW estimation has reduced over the years.
- During the pre-satellite era (till 1960), the average error in intensity estimation may be at least one stage in Beaufort scale (5-15 knots or 3-8 mps upto severe cyclonic storm stage).
- There is no classification of intensity between very severe cyclonic storm and above intensity in Beaufort scale.
- The error could have reduced gradually during polar satellite era.
- It could have been T0.5 (05-20 knots or 3-10 mps) with the introduction of Dvorak's classification of intensity since 1974 (Goyal et al, 2012)

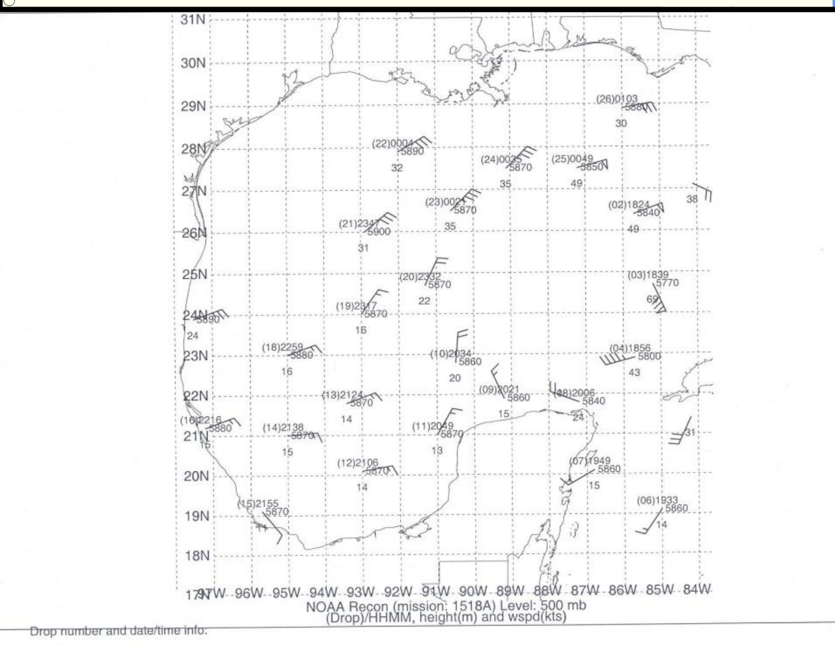
(Synoptic Surface)-Panel Member countries

- Data reception from Member countries real time basis has to be improved and ensured for real time reception
- Hourly observations from these states has been requested
- However, half an hourly METER/SPECI observations are available in Synergie from all the stations



Limitations in location and intensity estimation





Example of Cyclone PHET

over North Indian Ocean

Limited observational data

No aircraft reconnaissance

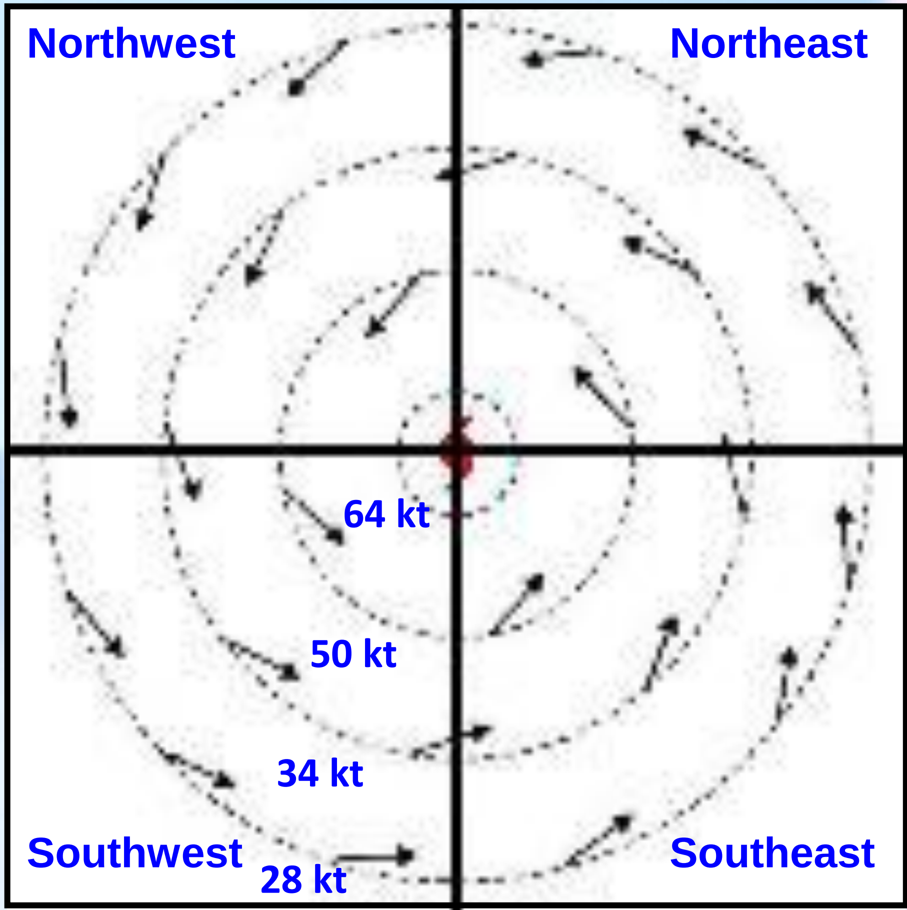
TC, RITA

over North Atlantic Ocean

based on Dropsonde wind and SFMR data

Characteristic features of wind radii

- Wind radii represents the maximum radial extent of winds reaching a threshold value in each quadrant.
- It is represented in nautical miles (1nm=1.85 km).
- The wind radii forecasts are issued over the sea area only as per the requirement of the users.
- The TC wind radii forecasts are generated in terms of the radii of winds reaching 34kts, 50kts and 64kts value in four geographical quadrants around the tropical cyclone. In addition, radii of 28 kts is also added.



Radii of surface wind thresholds used by IMD for TC forecasting

- These are referred as R28, R34, R50 and R64 respectively.

Threshold Criteria

- The thresholds of 34kts, 50kts and 64kts are chosen according to users requirement.

➢ the wind of 34kts corresponds to gale wind threshold

➢ the wind of 50kts is the requirement of mariners

➢ the wind of 64kts is the wind with hurricane force.

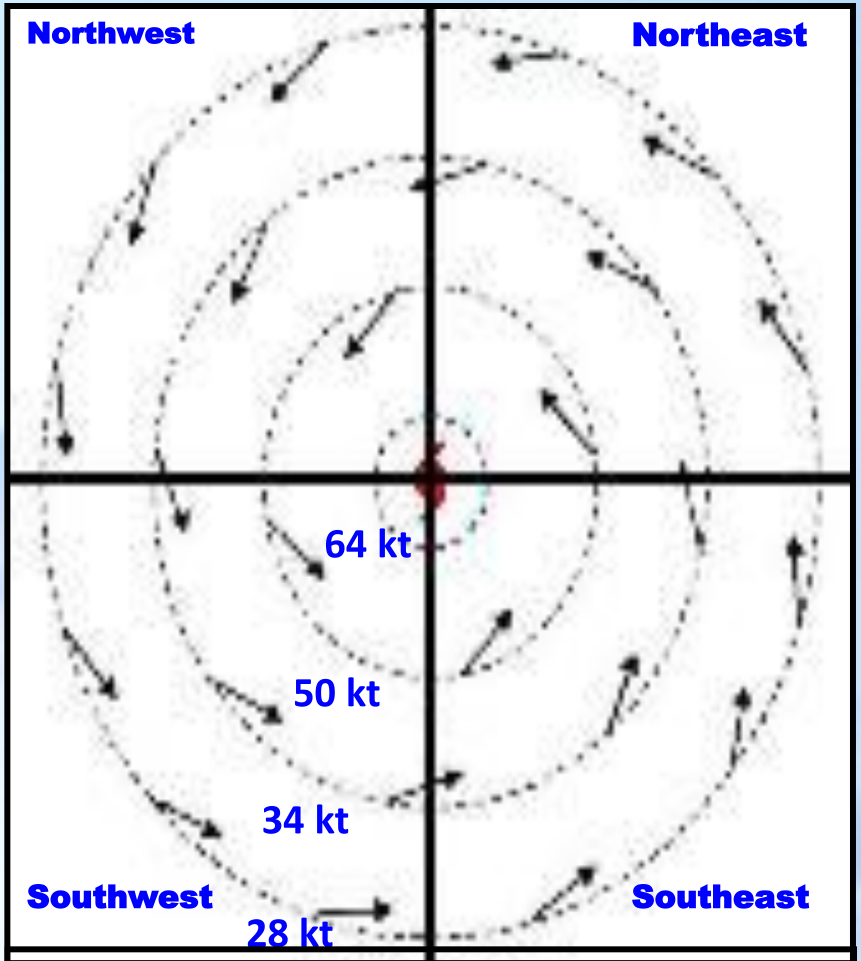
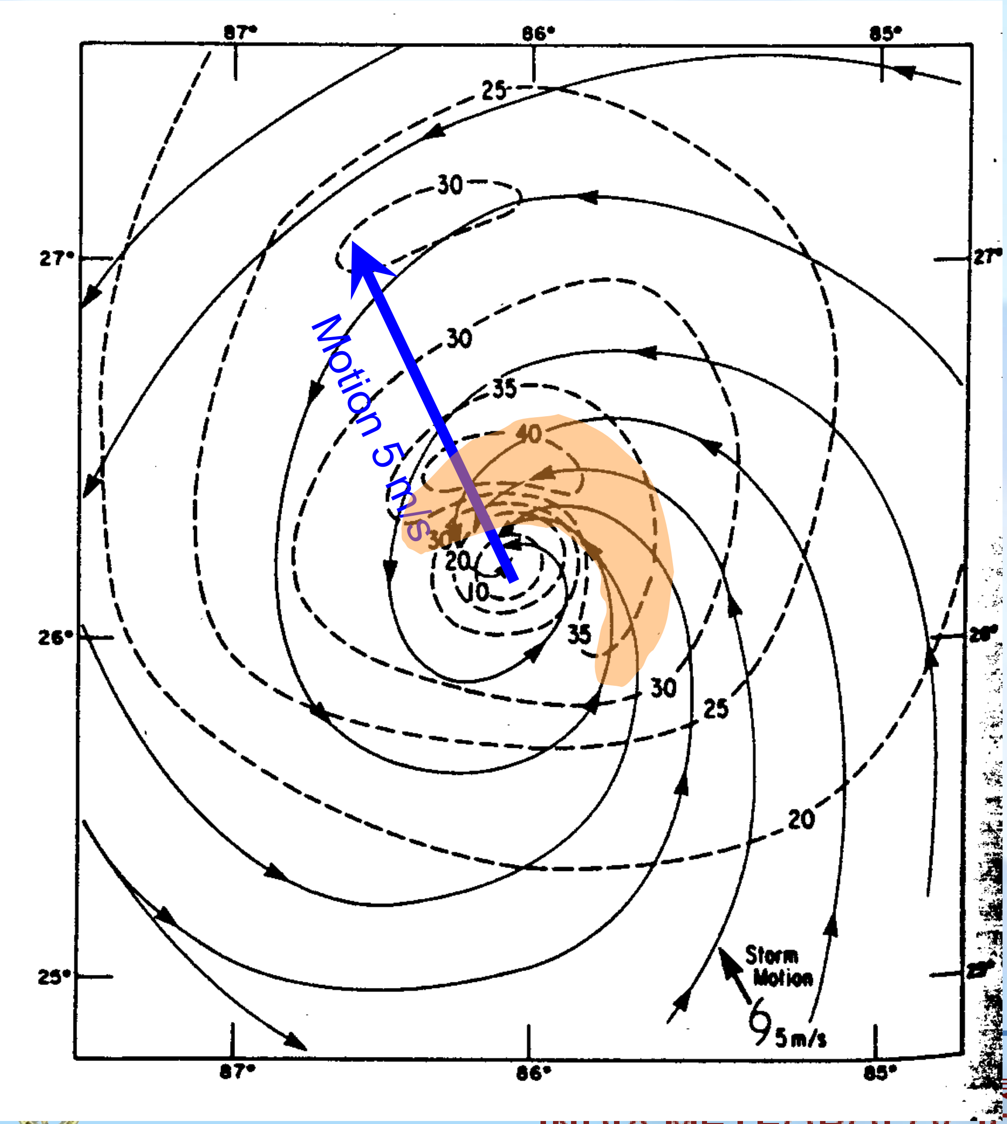


Fig.1. Radii of surface wind thresholds used by IMD for TC forecasting

Surface Winds



- Surface wind speed is between about 0.65 and 1 times the gradient wind speed.
- There is usually one maximum, in the right rear quadrant in NH (left forward quadrant in SH).
    - The maximum wind can be in other quadrants.
    - There can be a double maximum.
- The maximum usually rotates to the side of the storm, with height.

Hurricane Frederick, Powell (1982)

Methodology for TC wind radii monitoring

The inputs for monitoring are obtained from following observations

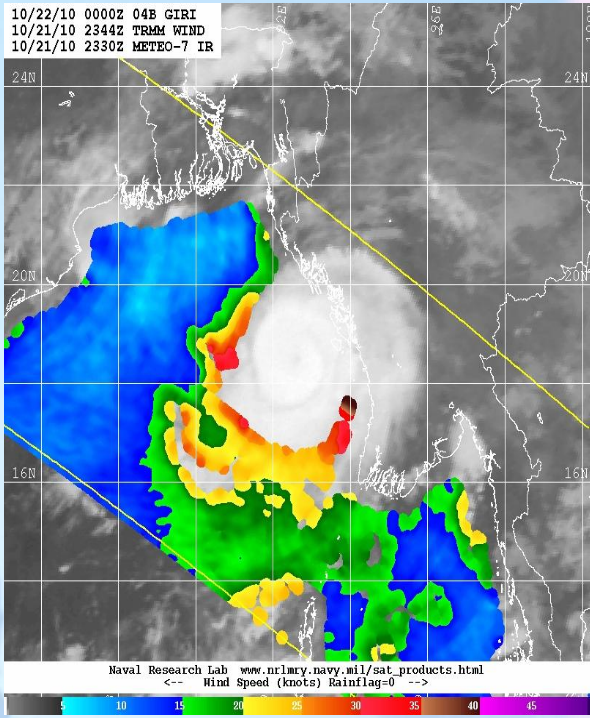
- Ship
- Buoy
- OceanSat.
- Lower level Atmospheric Motion Vectors
  - Cloud Motion Vectors
  - Water vapour based wind vectors
- Special Sensor Microwave Imager (SSMI) data
- Advanced Microwave Sounder Unit (AMSU)
- Latest advances in real time data analysis capabilities
- DWR(when system is within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

Tropical Cyclone Module and wind monitoring and forecasting over north Indian ocean

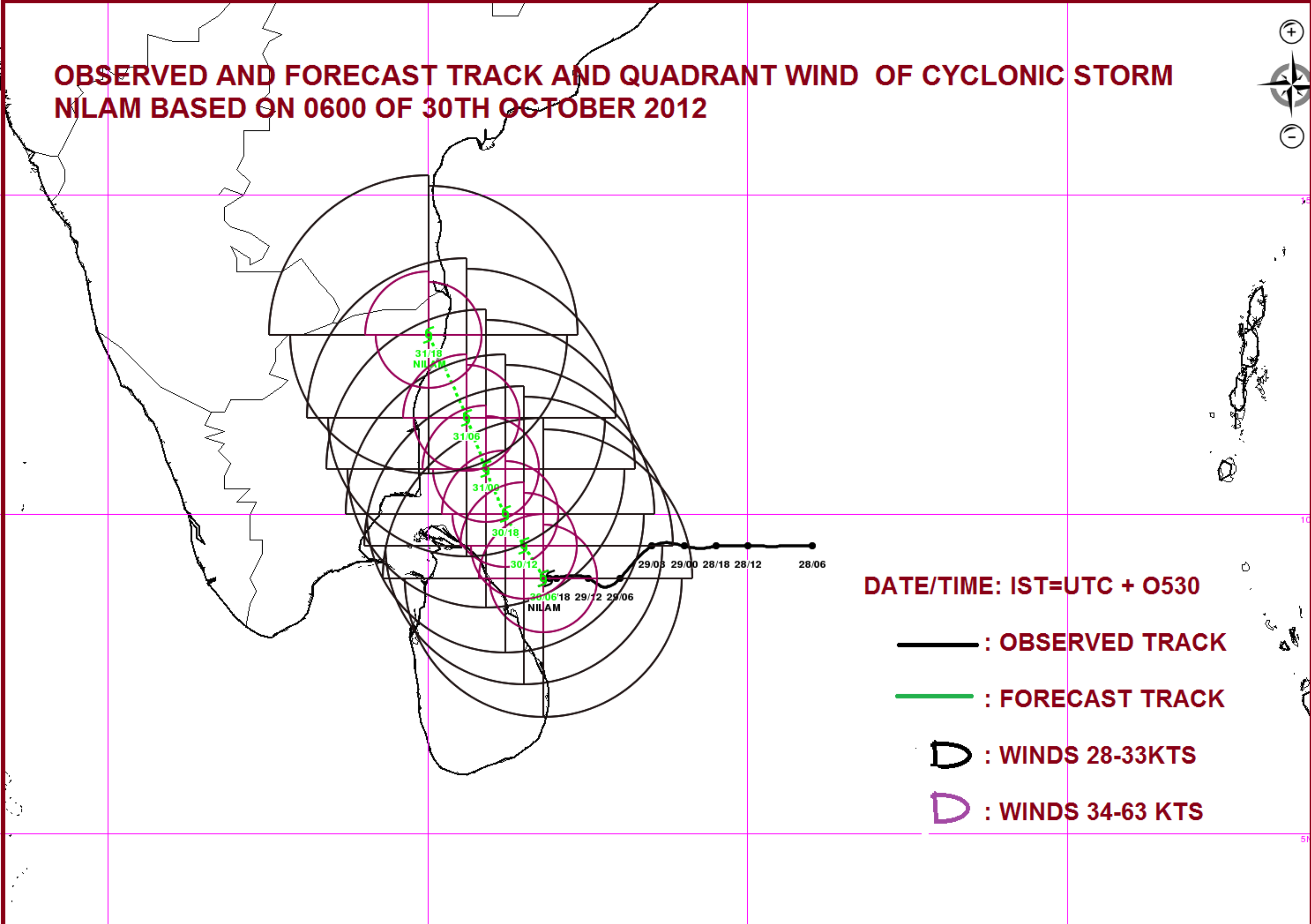
Date and time of initial condition

i.Official location and Intensity (T/ C.I. No., maximum wind and centre position

ii.Initial TC wind radii estimation



- a) Wind radii based on Oceansat/ASCAT/Windsat wind
- b) SSMI based wind radii
- c) Wind radii based on lower level atmospheric motion vectors
- d) Wind radii by AMSU retrieval method
- e. Wind radii based on global and regional NWP model analyses
- f. Wind radii based on DWR wind retrieval
- g. Value addition based on coastal, ship and buoy observations
- h. Climatological consideration
- i. Official TC wind radii based on S.N. (a-e).



भारत मौसम विज्ञान विभाग
INDIA METEOROLOGICAL DEPARTMENT

Preparation of check list for decision making

(A) Synoptic features

(B) Satellite features

(C) NWP features

(D) Radar features

Check list for the north Indian Ocean

Dated **Time**

1. 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.)

2. Number of days the low pressure area is persisting :

3. Region of occurrence of low pressure area :

Check list for the north Indian Ocean

4. 24 hrs pressure change

    a. General description :

    b. Maximum fall and station/buoy :

5. Pressure departure from normal

    a. General description :

b. Maximum negative departure and station :

6. Circulation:

    a. Vertical extension :

    b. Tilting

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

        Surface

        0.9 km

        1.5 km

    d. Maximum wind (Magnitude, Region of occurrence and Distance of maximum wind from centre of circulation at surface level

Check list for the north Indian Ocean

7. **Lower level convergence :**
   a. Maximum value and region of occurrence) :
   b. Convergence in forward sector
   c. Tendency during past 06/12/24 hrs
8. **Upper level divergence :**
   a. Maximum value and region of occurrence :
   b. Divergence in forward sector
   c. Tendency during past 06/12/24 hrs
9. **Lower level vorticity**
   a. Maximum value and region of occurrence) :
   b. Vorticity in forward sector
   c. Tendency during past 06/12/24 hrs
10. **Vertical wind shear**
    a. Minimum value and region of occurrence) :
    b. Wind shear in forward sector
11. **Wind shear tendency**
    a. Minimum value and region of occurrence :
    b. Wind shear tendency in forward sector :

Check list for the north Indian Ocean

12. QPE
    a. QPE during past 12 hrs (Maximum value and region of occurrence) :
    b. QPE 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. SST
    a. Maximum SST and region of occurrence
    b. SST in forward sector
    c. Tendency in SST
15. Location and intensity from other sources
    a. NOAA SSD
    b. JTWC

Check list for the north Indian Ocean

Radar features :

1. Pattern : Line curve/Spiral band/Eye
2. line Curve (Number and tendency, associated maximum reflectivity and its place of occurrence
3. Characteristics of spiral bands (Number and tendency, Maximum reflectivity and its place of occurrence)
4. Eye characteristics :
   - (i) Visible/Invisible width Tendency
   - (ii) Open/ closed, If open howmuch and tendency
   - (iii) Circular/elliptical
5. Characteristics of eye wall
   - (i) maximum reflectivity and its place of occurrence and tendency
   - (ii)Single eye wall/ double eye wall
   - (iii)Size of eye and eye wall (Diameter/radius)
6. Pre-cyclone squall lines (Region of occurrence, time of occurrence
7. Precipitation characteristics (Place and time of occurrence of maximum precipitation)
8. Radius of maximum reflectivity (in different quadrants)
9. Radius of maximum wind (in different quadrants)
10. Vertical extension of convective clouds
11. Radar estimaded location of centre with confidence (Multiple centres in case of multiple radars) and intensity with confidence

Thank you