Tropical Cyclone Prediction: Track and Intensity

M Mohapatra

INDIA METEOROLOGICAL DEPARTMENT
MAUSAM BHAVAN, LODI ROAD , NEW DELHI-110003
mohapatraimd@gmail.com

भारत मौसम विज्ञान विभाग
INDIA METEOROLOGICAL DEPARTMENT

Presentation layout

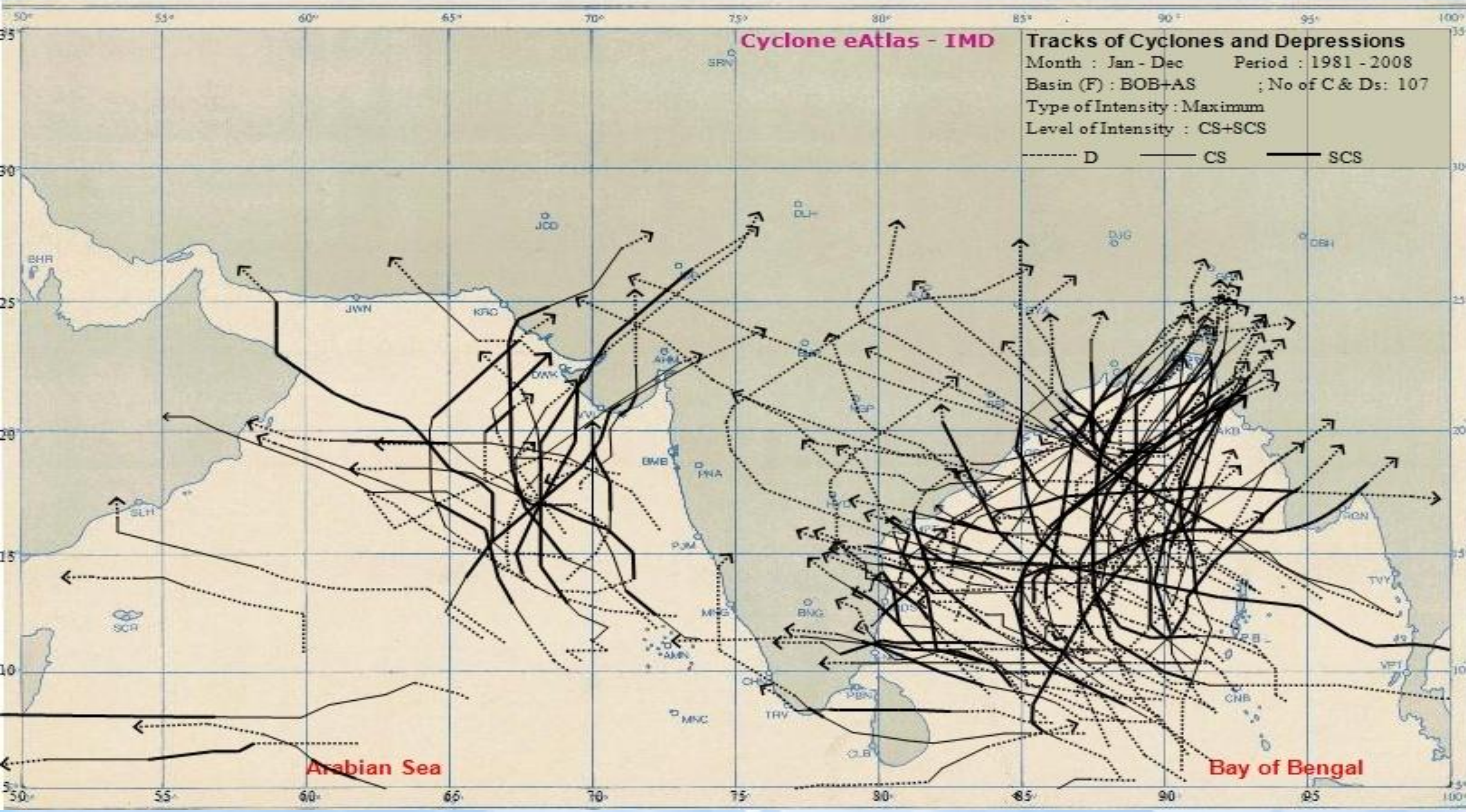
- ❖ Introduction
- ❖ Cyclone Prediction
  - ❖ Location/Track
  - ❖ Intensity
  - ❖ Adverse weather (Heavy rain, Gale wind, storm Surge)
- ❖ Problem areas and possible collaboration
- ❖ Conclusions

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

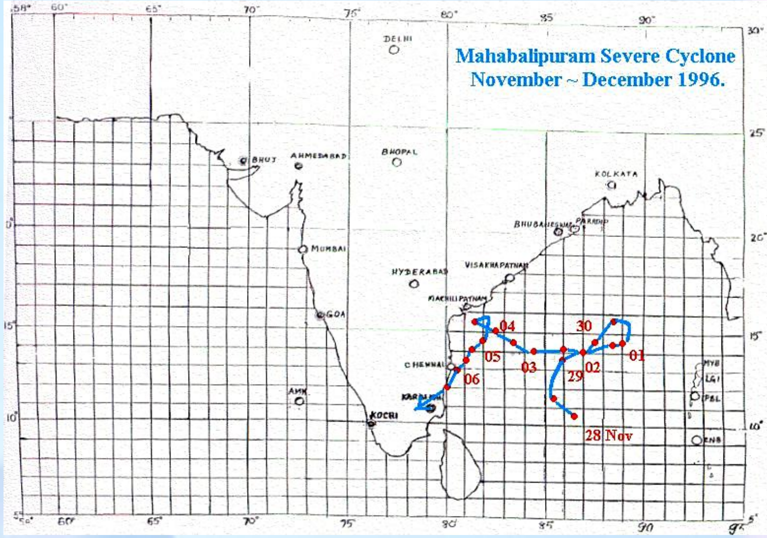
Movement of TCs

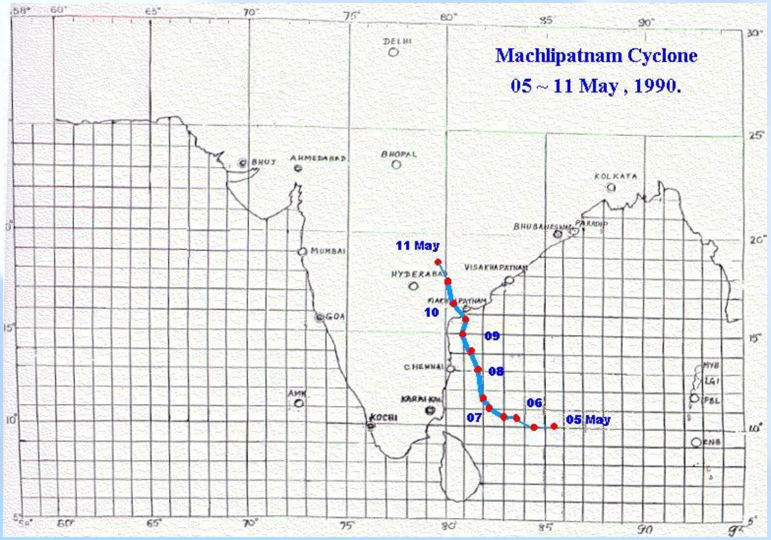


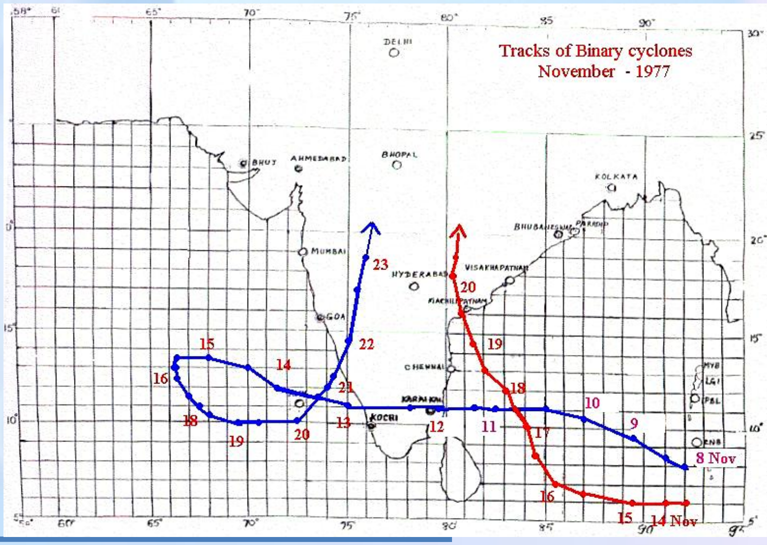
Tracks of cyclones over the north Indian Ocean during 1981-2008

At times cyclones display odd behaviour

- Display changing trends in motion
- Rapid intensification close to a populated coastline.
- Remaining quasi-stationary for long duration
- Displaying erratic tracks such as looping, sudden acceleration or deceleration
- Interaction with other weather systems







Cyclone track forecasting methods

i) Statistical Techniques
   i) Analogue
   ii) Persistence
   iii) Climatology
   iv) CLIPER,
   v) Chaos theory and Generic Algorithm method)

ii) Synoptic Techniques – Empirical Techniques

iii) Satellite Techniques Techniques

iv) Radar Techniques

v) NWP Models
   - Individual models (Global and regional)
   - IMDGFS (382, 574), NCMRWF (254), ARP (MeteoFrance, ECMWF, JMA, UKMO, NCEP, WRF (IMD, IITD, IAF), HWRF (IMD), QLM
   - MME (IMD) and MME based on Tropical Cyclone Module (TCM)
   - EPS (Strike probability, Location specific probability

vi) Operational (Consensus) forecast

PREDICTION OF MOVEMENT

- CLIMATOLOGY INDICATES PREDOMINANTLY 3 TYPES OF MOVEMENT

_ WESTERLY

_ NORTHWESTERLY

_ RECURVING FROM INITIALLY NORTHERLY TO NORTHEASTERLY DIRECTION

DUE TO NORMAL UPPER AIR FLOW PATTERN OVER SYSYTEM AREA

- THERE IS TENDENCY OF STORM TO MOVE POLE WARD DUE TO DIFFERENCE IN CORIOLIS PARAMETER IN NORTHERN AND SOUTHERN SECTOR OF THE STORM
- GREATER THE DIFFERENCE, FASTER WILL BE THE MOVEMENT
- MANY FORCES ACT ON THE STORM, HENCE TRACK NEVER SMOOTH
- THERE IS ALSO INTERACTION BETWEEN STORM AND EMBEDDED BASIC CURRENT. THIS MANIFESTS AS A TROCHOIDAL MOTION, CLEARLY SEEN IN RADAR FIXES

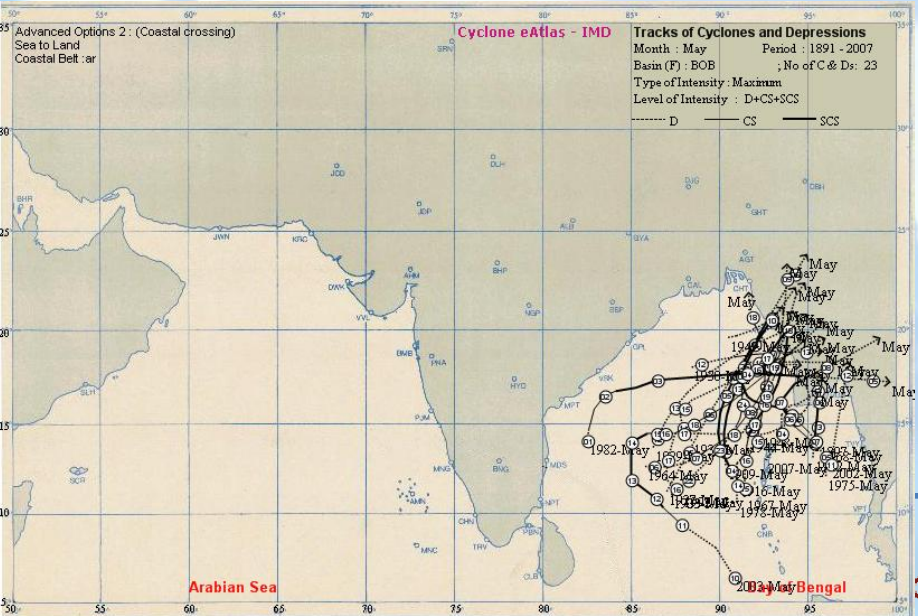
Analog method

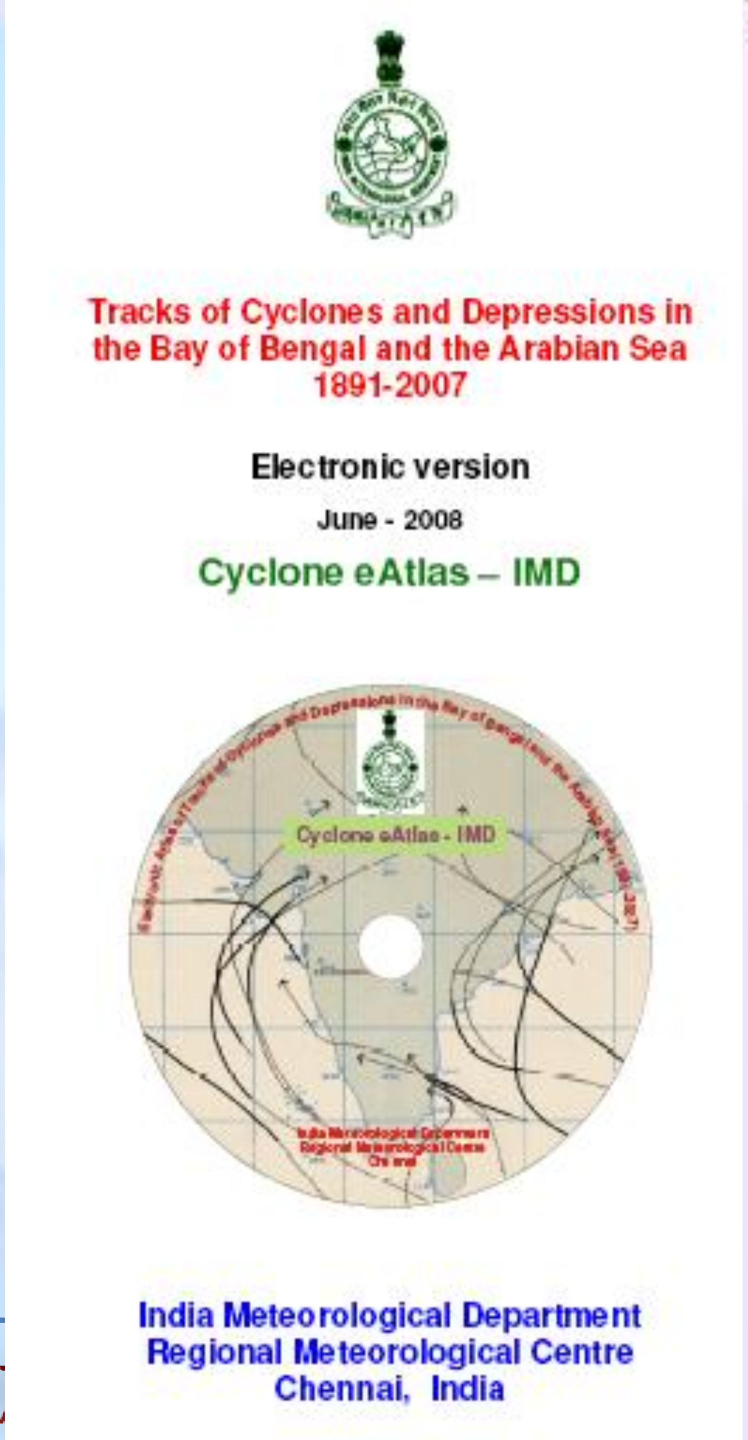
1. Six hourly best track data of cyclones over north Indian Ocean since 1990 in digital form

2. 12 hourly data in cyclone Atlas during 1891-2009

   Data from 1877-1890 are also available in hard copies in 1979 edition of cyclone Atlas

3. Adverse weather and damage reports

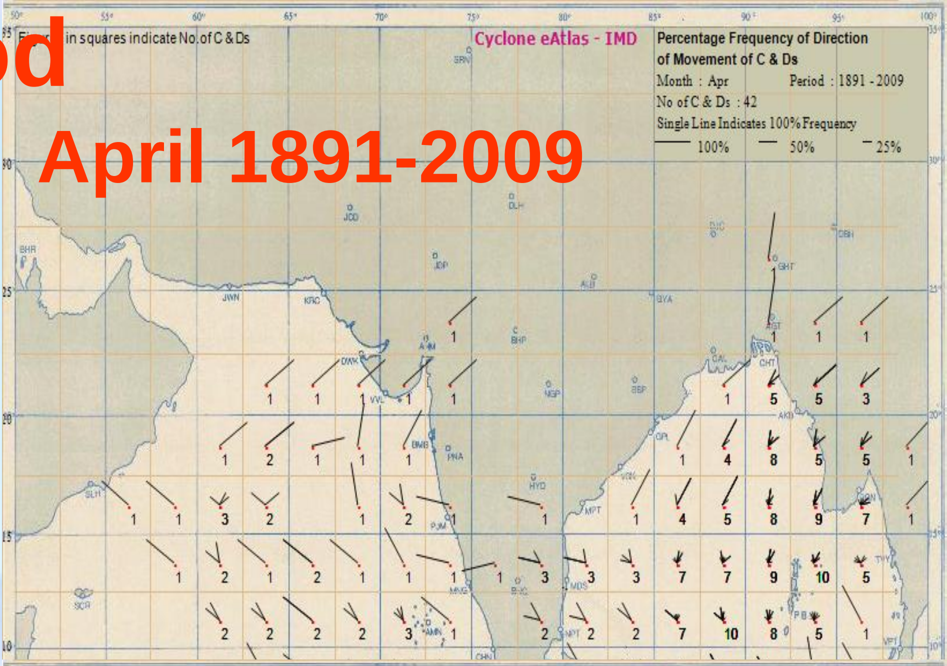




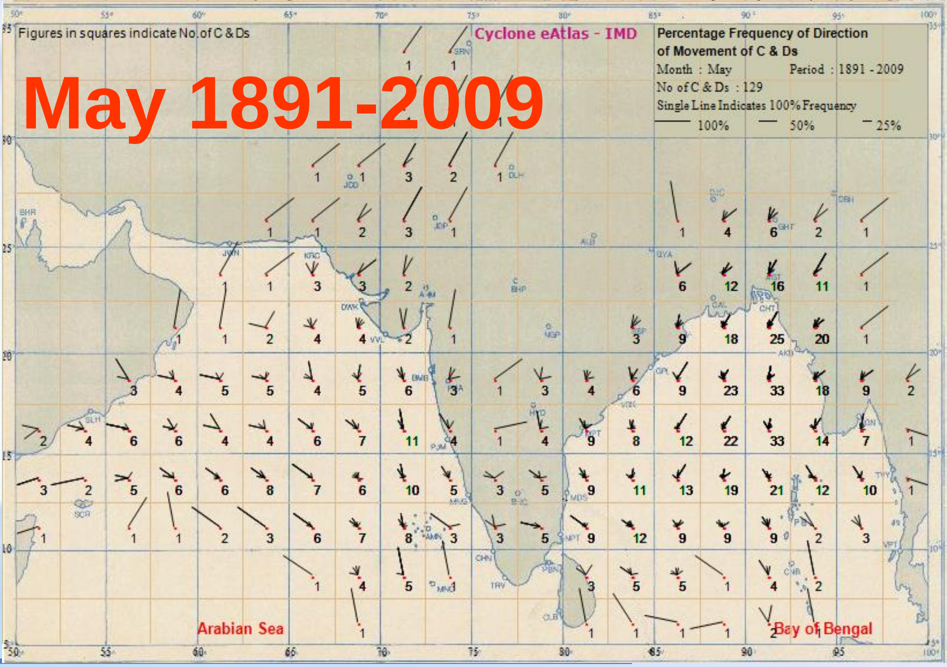
Climatological Method

- **Most of the cyclonic disturbances above 15^{o}N move in a north-northeasterly or northeasterly direction**
- **Below 15^{o}N and left of 90^{o} E they generally move in north-northwesterly or northwesterly direction over the Bay of Bengal.**
- **In Arabian Sea below 15^{o}N they move in a north-northwesterly and above it they move northeasterly direction.**

April 1891-2009

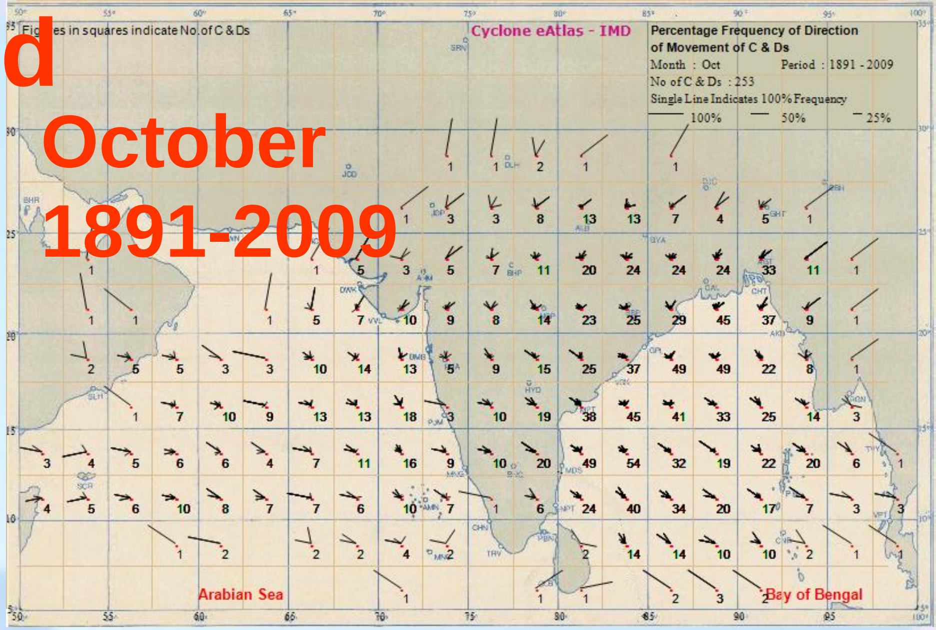


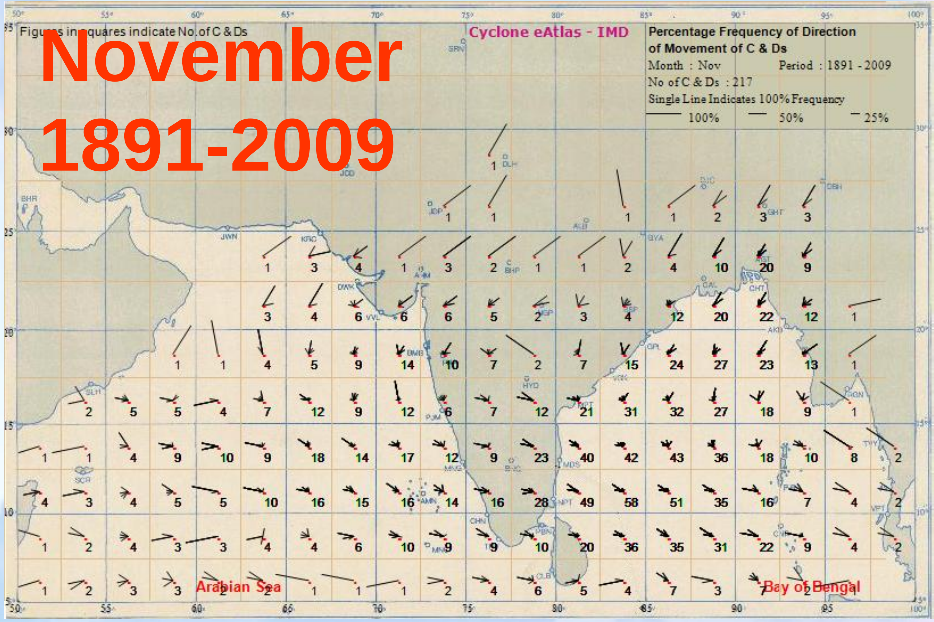
May 1891-2009



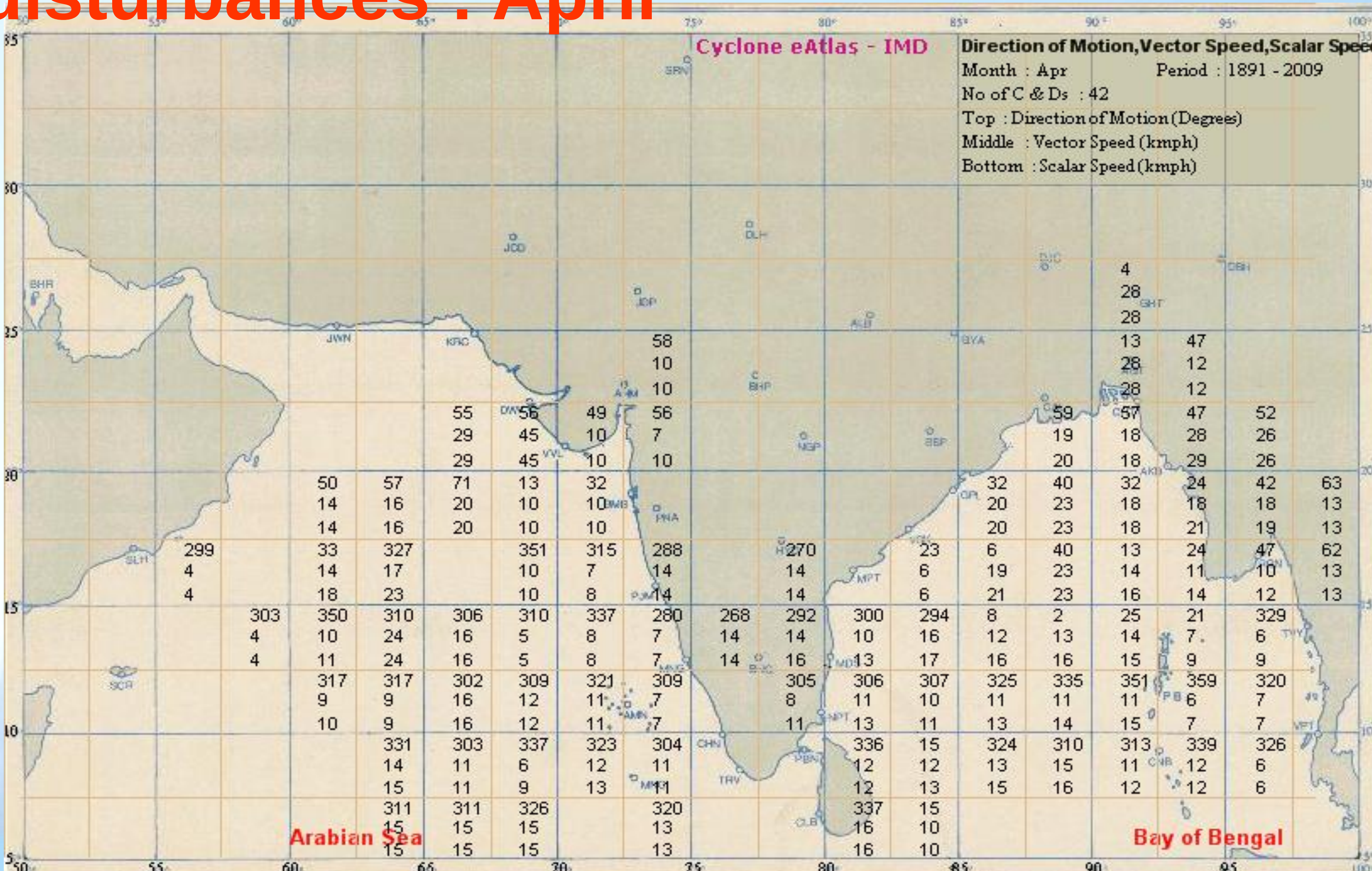
Climatological Method

- During October-November most of the cyclonic disturbances above 20^{o}N move in a north-northeasterly or northeasterly direction whereas below 15^{o}N they generally move in northwesterly direction over the Bay of Bengal.
- In Arabian Sea below 20^{o}N they move in a north-northeasterly and above it they move northeasterly direction.



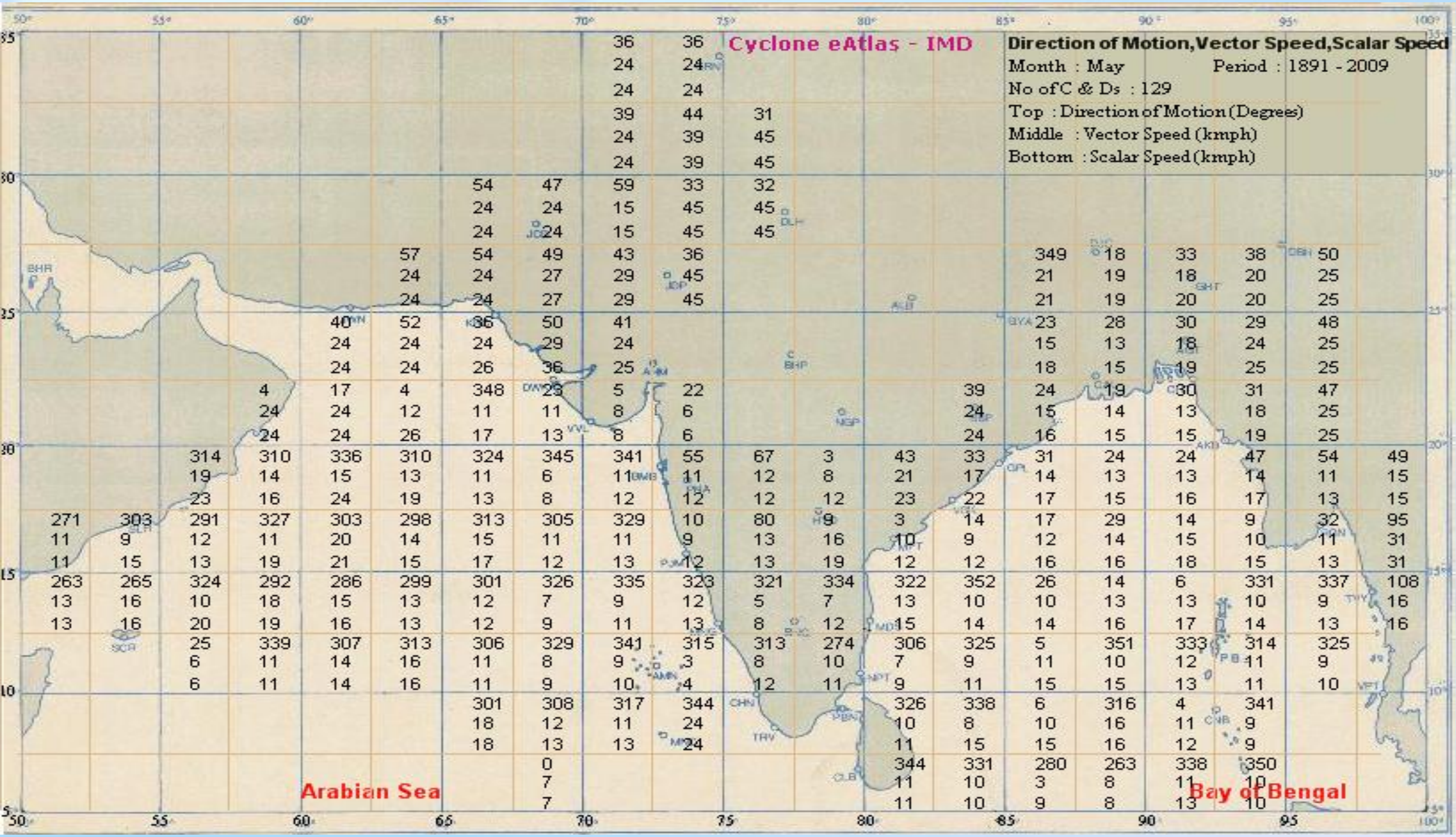


Climatology of Speed of cyclonic disturbances : April

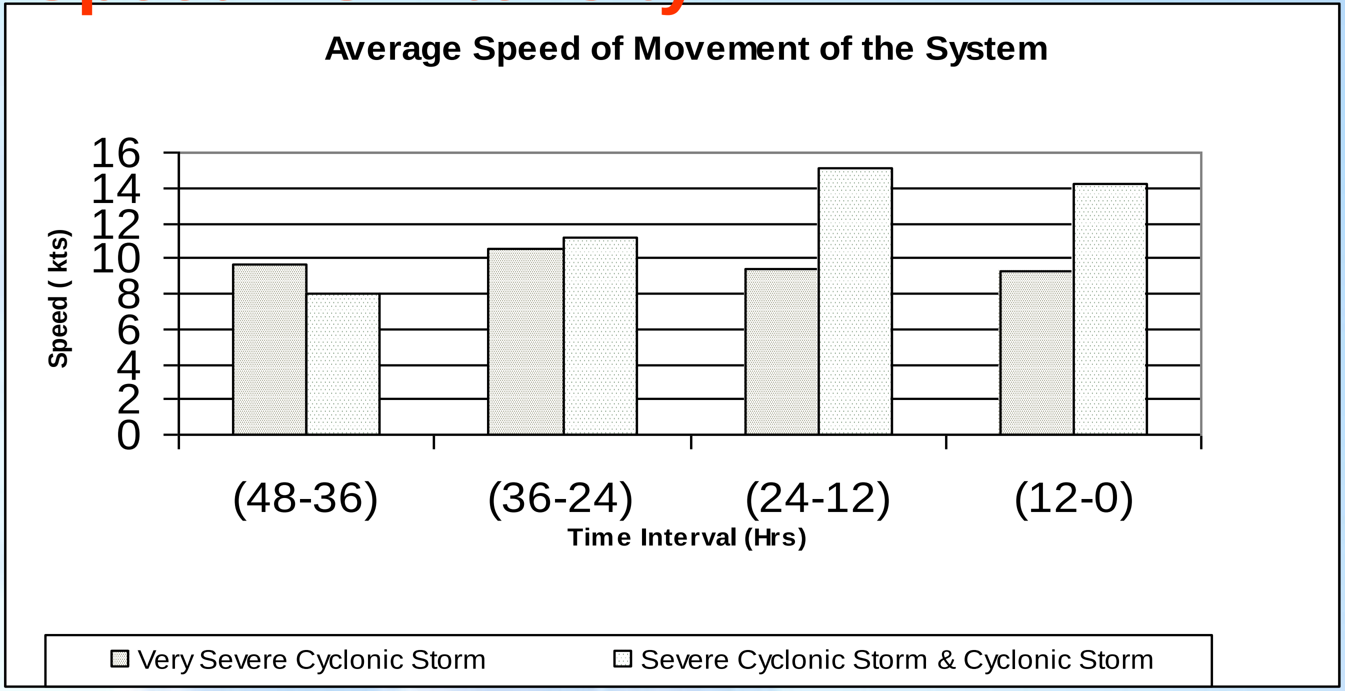


भारत मौसम विज्ञान विभाग
INDIA METEOROLOGICAL DEPARTMENT

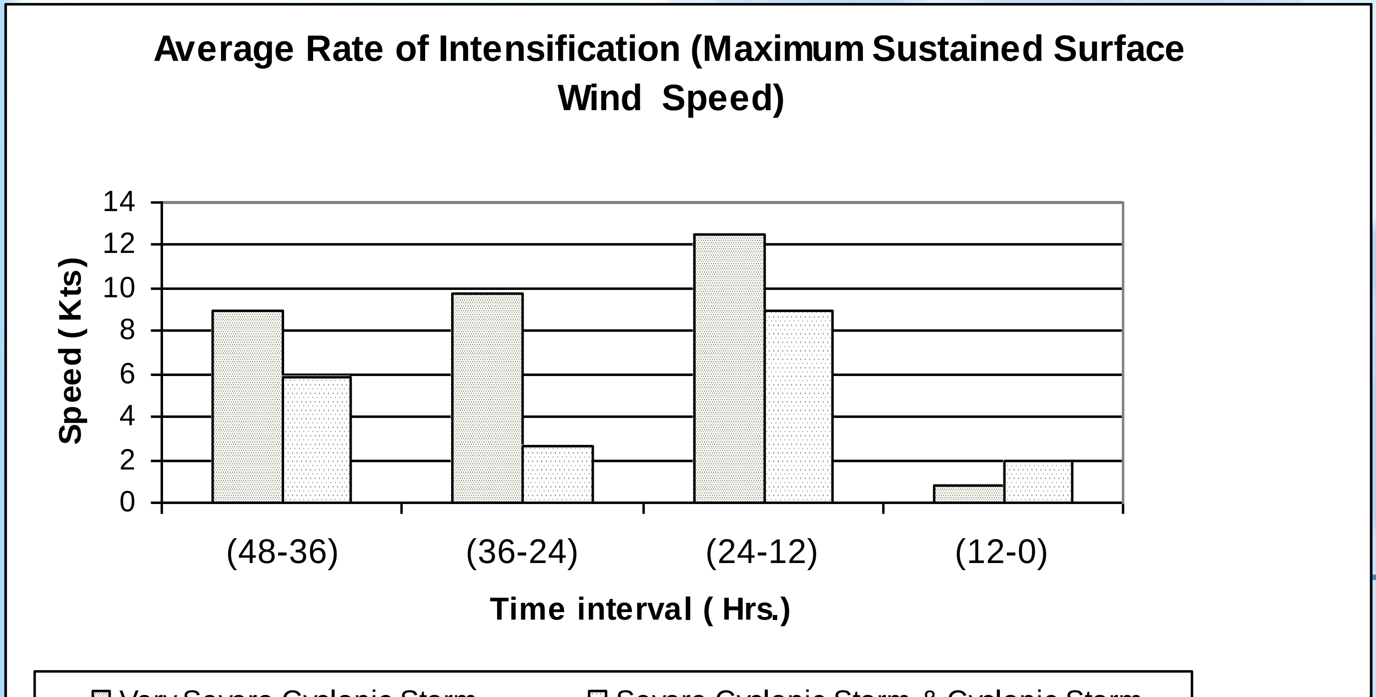
Climatology of Speed of cyclonic disturbances : May



Climatology of Speed VS Intensity



Max. Speed of Movement of SCS (24-12)hrs & in Case VSCS (36-24)Hrs



Max. Rate of Intensification CS & SCS (24-12)hrs and in Case VSCS is also (24-12)Hrs

CLIPER Model

- Its working principle is very simple, it takes monthly climatology of movement and speed of cyclonic disturbances from input files.

- It calculates the persistency of direction of movement and speed of the cyclonic disturbances for 09,12 and 24 hours as per our choose and forecast for the persistency for next 108 hours.

- It calculates the weighted mean of monthly climatology of direction of movement & direction of speed and persistency of movement & direction of speed which is the resultant direction of motion and speed of the cyclonic disturbance.

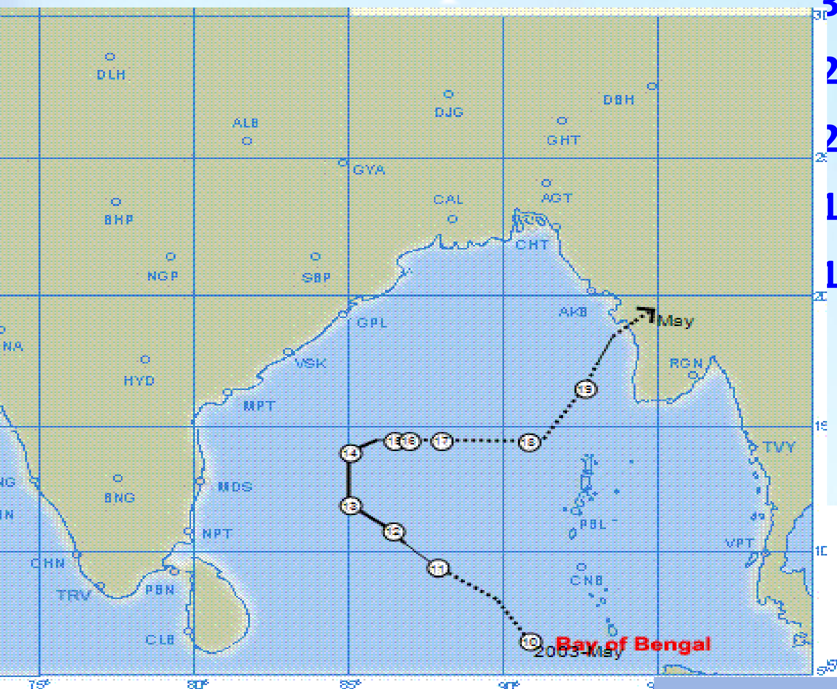
Example

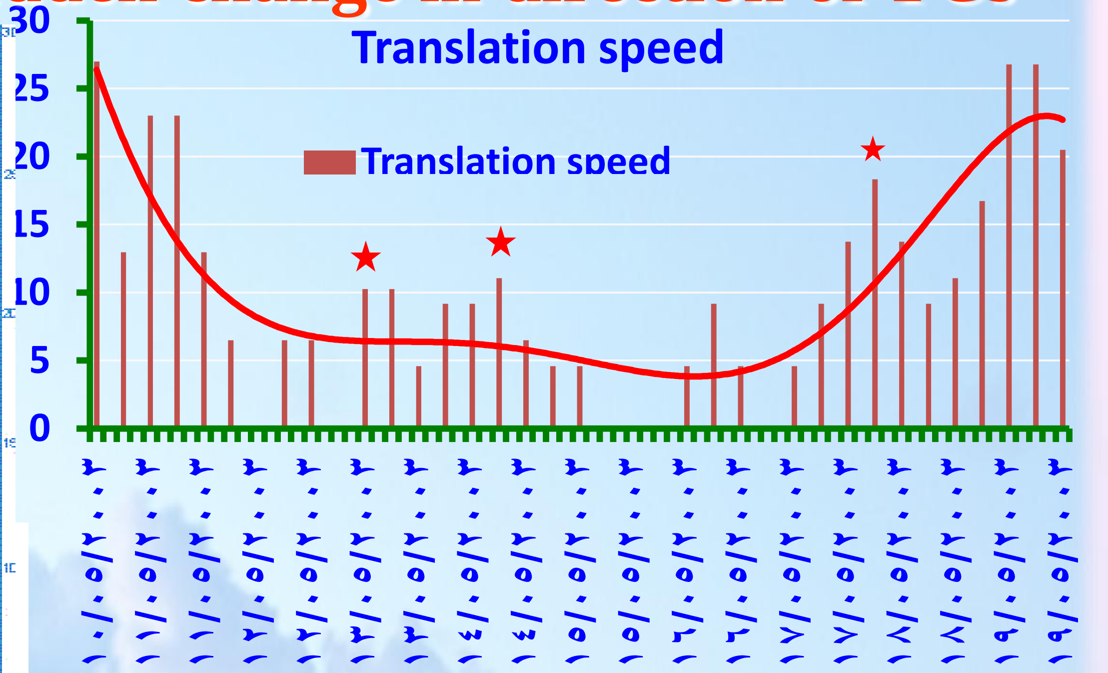
- DATE=28 MONTH=5
- PRESENT LAT/PRESENT LONG= 14.500000 90.5
- PAST LAT/PAST LONG= 13.5 88.0
- **
- **** CLIMATOLOGY OF STORMS *****
- **
- FORECAST POSITIONS BASED ON PERSISTENCE:
- 0HOUR 14.5N 90.5E
- 12HOUR 15.5N 93.0E
- 24HOUR 16.5N 95.5E
- 36HOUR 17.5N 98.0E
- 48HOUR 18.5N 100.5E
- 60HOUR 19.5N 103.0E
- 72HOUR 20.5N 105.5E
- 84HOUR 21.5N 108.0E
- 96HOUR 22.5N 110.5E
- 108HOUR 23.5N 113.0E
- **
- FORECAST BASED ON SEASONAL CLIMATOLOGY
- 0HOUR : 14.5N 90.5E
- 12HOUR : 15.9N 90.3E
- 24HOUR : 17.1N 90.4E
- 36HOUR : 18.3N 90.6E
- 48HOUR : 19.6N 90.8E
- 60HOUR : 21.0N 91.1E
- 72HOUR : 22.1N 91.5E
- 84HOUR : 23.3N 91.9E
- **** CLIMATOLOGY NOT AVAILABLE ***
- AVERAGE OF PERSISTENCE AND CLIMATOLOGY:
- 0HOUR LAT 14.5N 90.5E
- 12HOUR LAT 15.7N 91.7E
- 24HOUR LAT 16.8N 93.0E
- 36HOUR LAT 17.9N 94.3E
- 48HOUR LAT 19.1N 95.7E
- 60HOUR LAT 20.3N 97.1E
- 72HOUR LAT 21.3N 98.5E
- 84HOUR LAT 22.4N 100.0E
- **

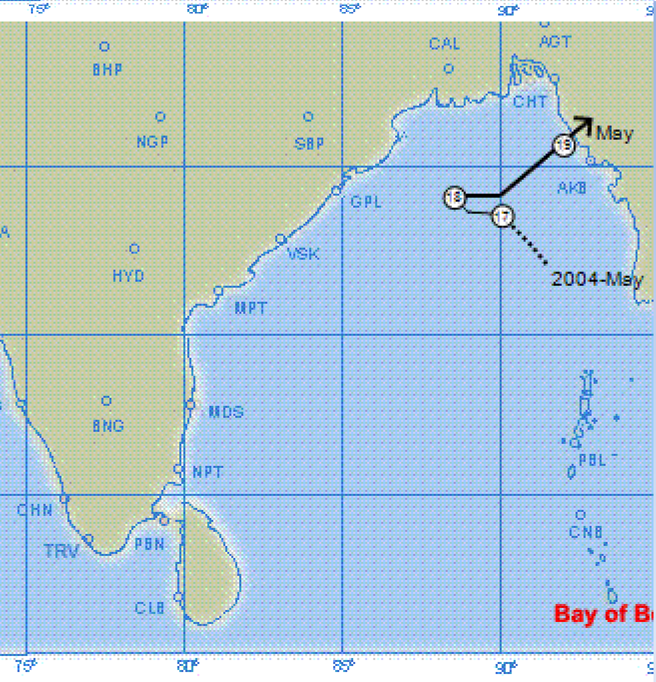
Performance of CLIPER Model: GONU

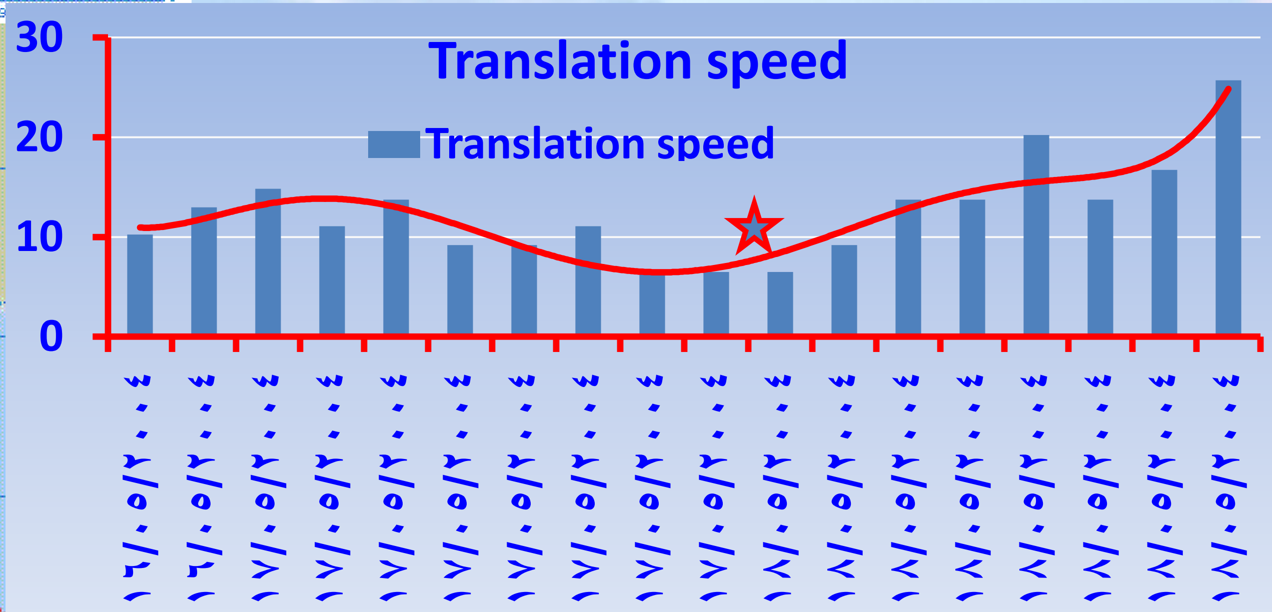
Based Time	12 Hours Error		24 hours error	
	operational	Cliper	Operational	Cliper
021200	53	77	231	320
021800	77	113	246	336
030000	229	175	222	228
030600	167	111	228	153
031200	105	193	76	309
031800	119	153	152	228
040000	56	76	00	104
040600	111`	76	123	55
041200	00	111	00	196
041800	165	117	154	196
05000	117	117	76	190
050600	00	117	-	-
051200	55	51	-	-
Total	1254	1545	1508	2315
No. of observation	13	13	11	11
Average Error	96	118	137	210

Translation speed and sudden change in direction of TCs

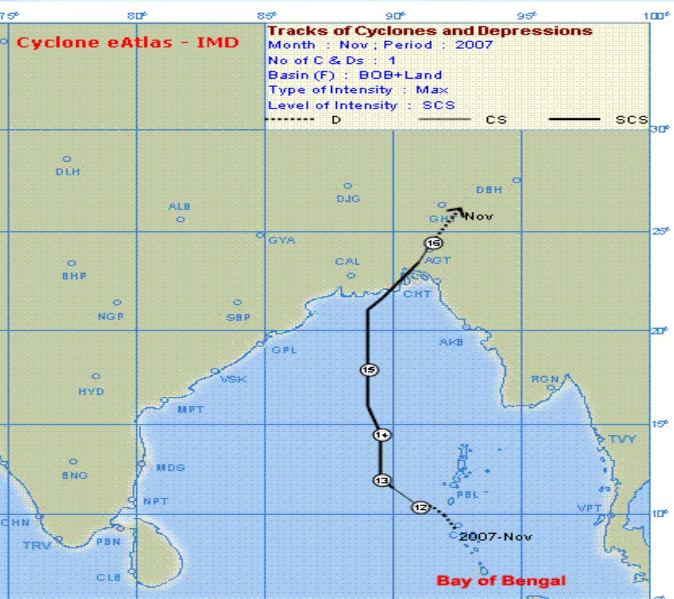


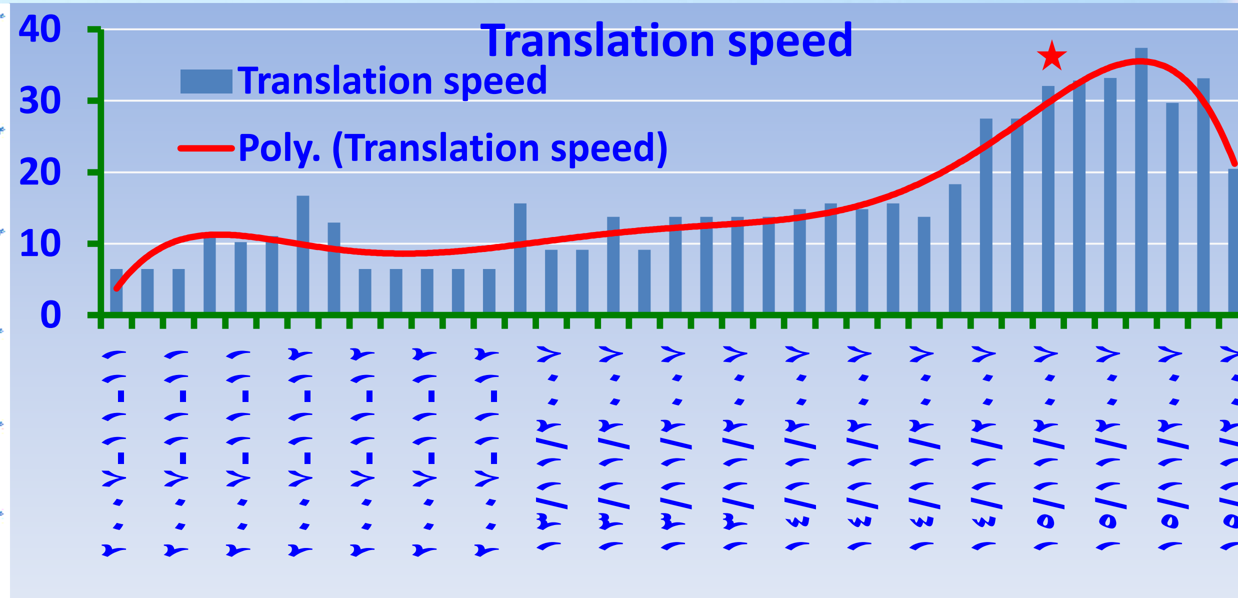


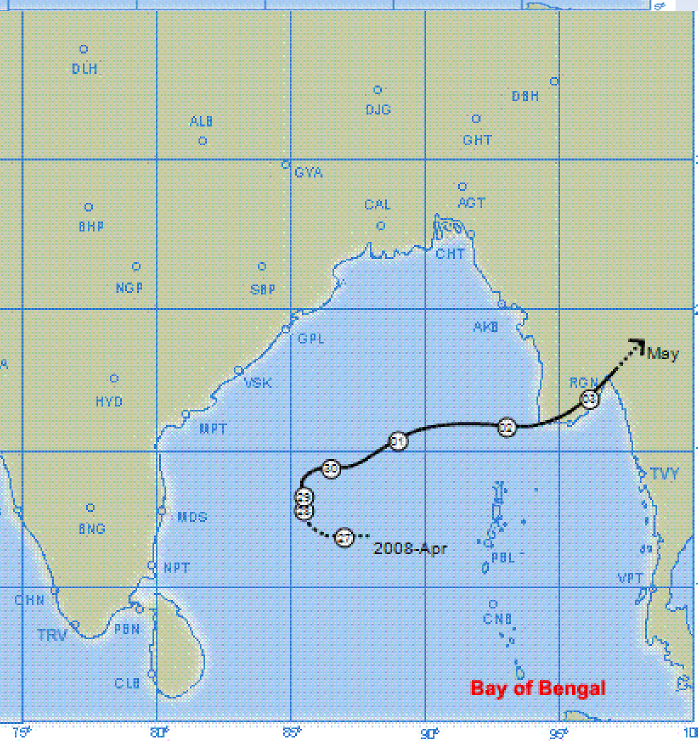


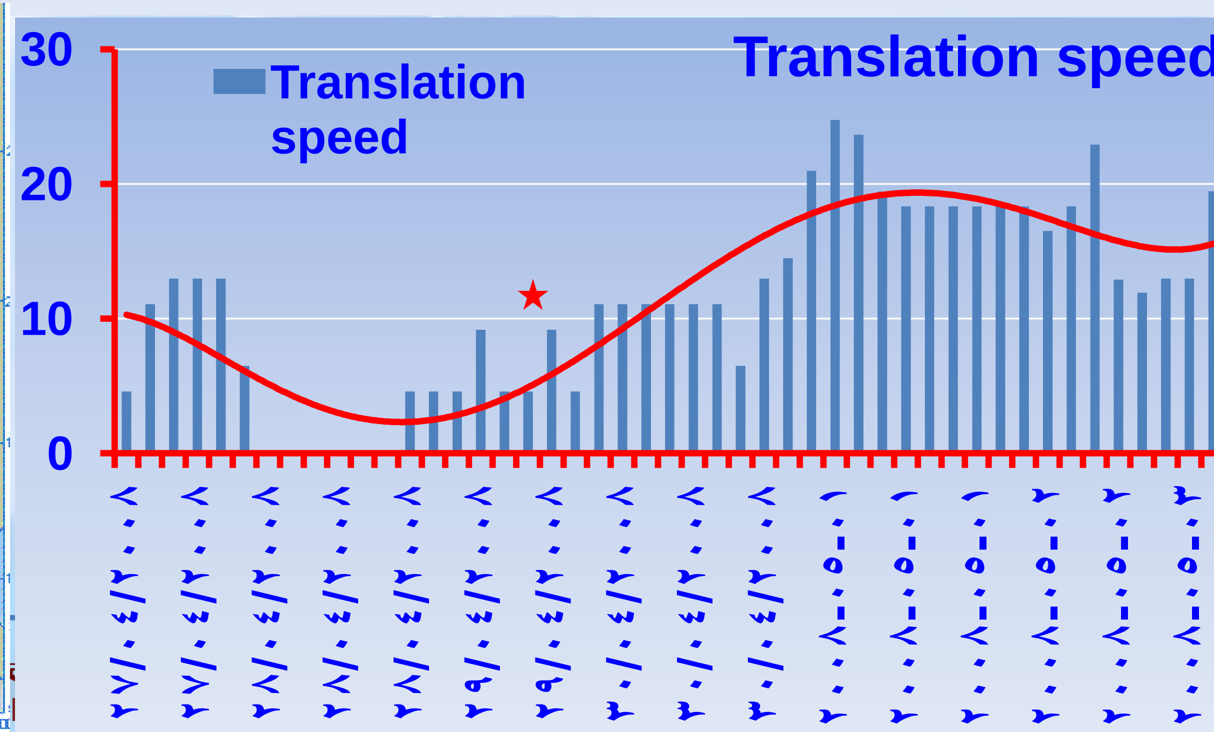


Translation speed and sudden change in direction of TCs

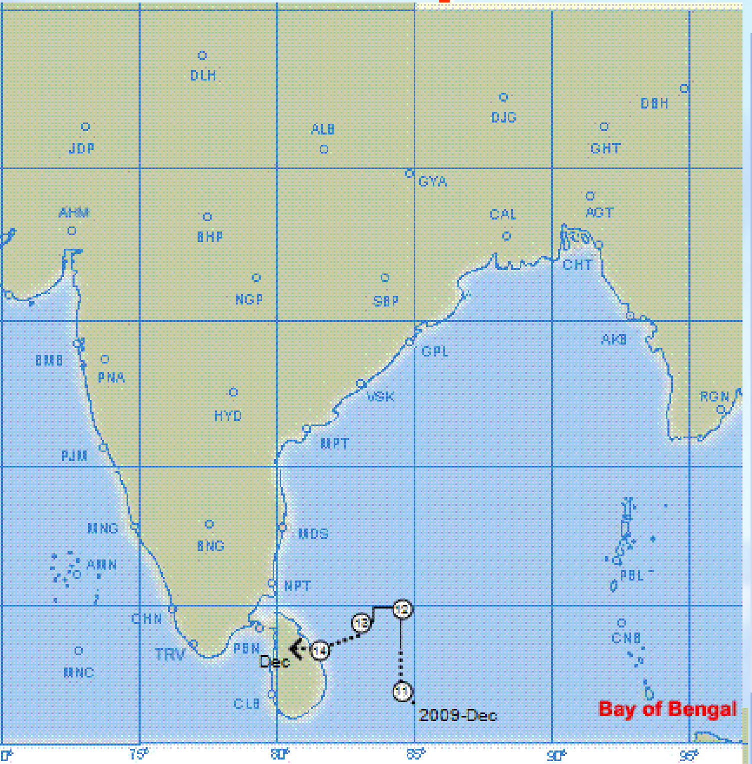


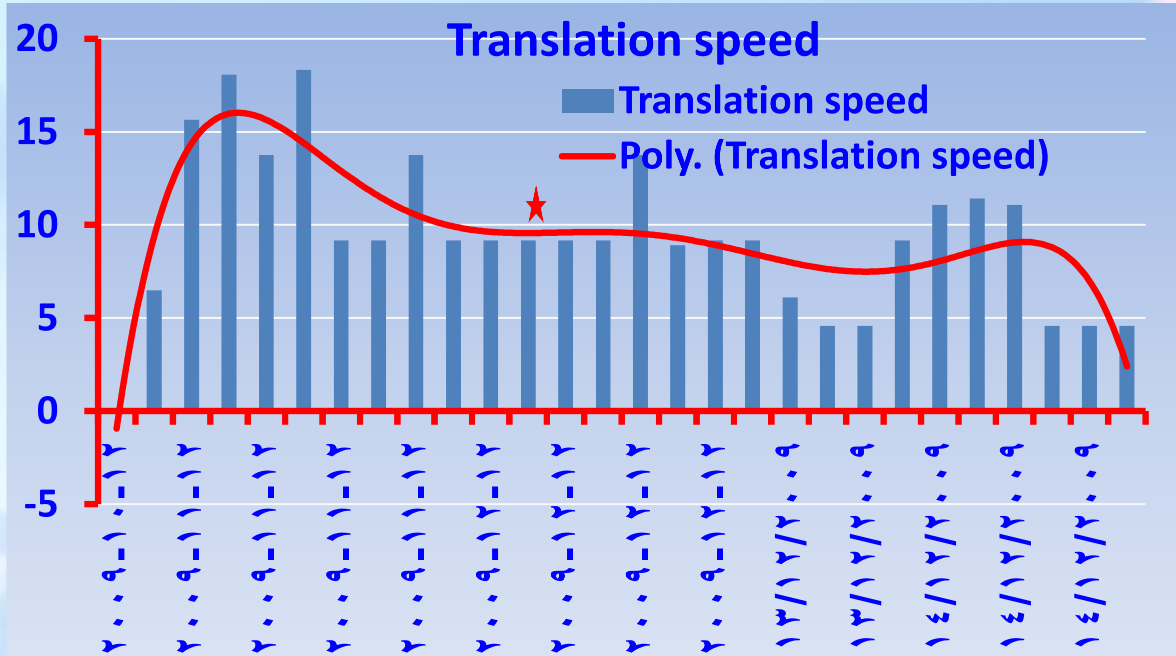


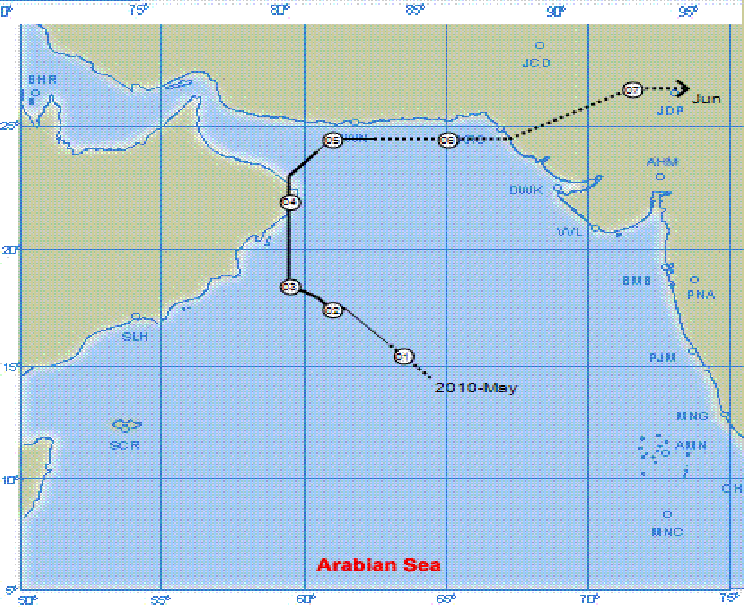


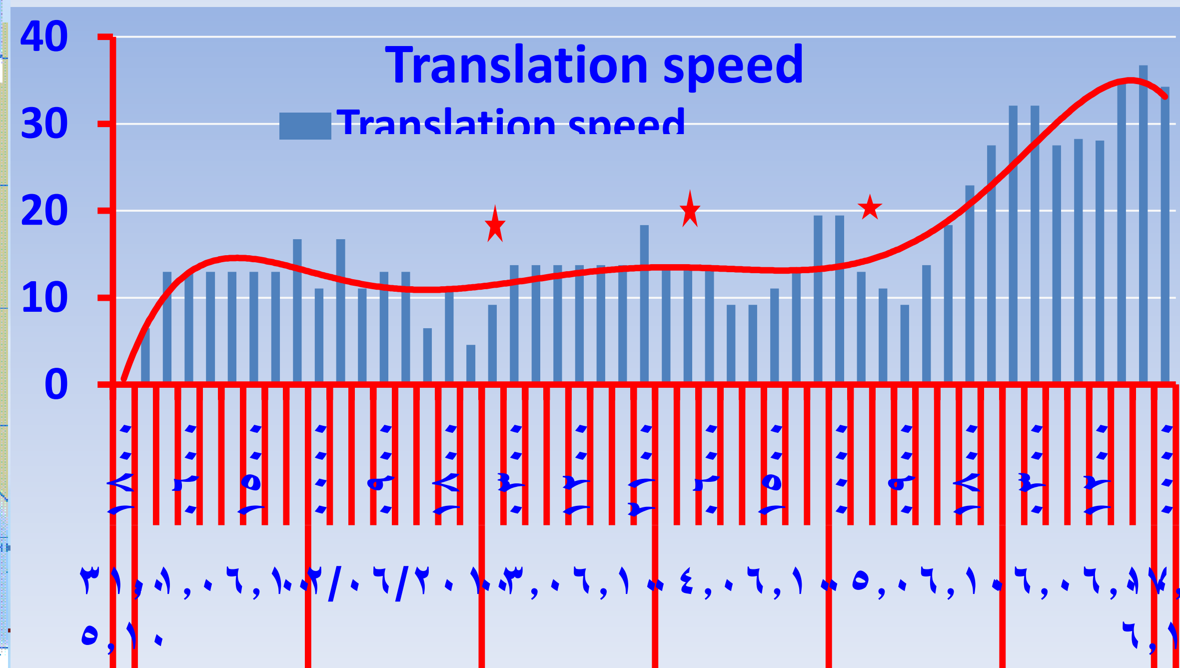


Translation speed and sudden change in direction of TCs

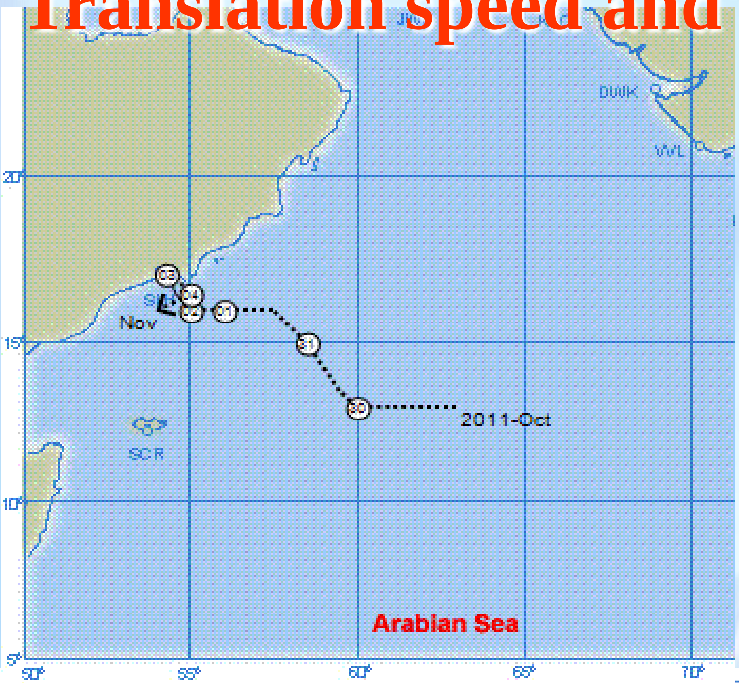


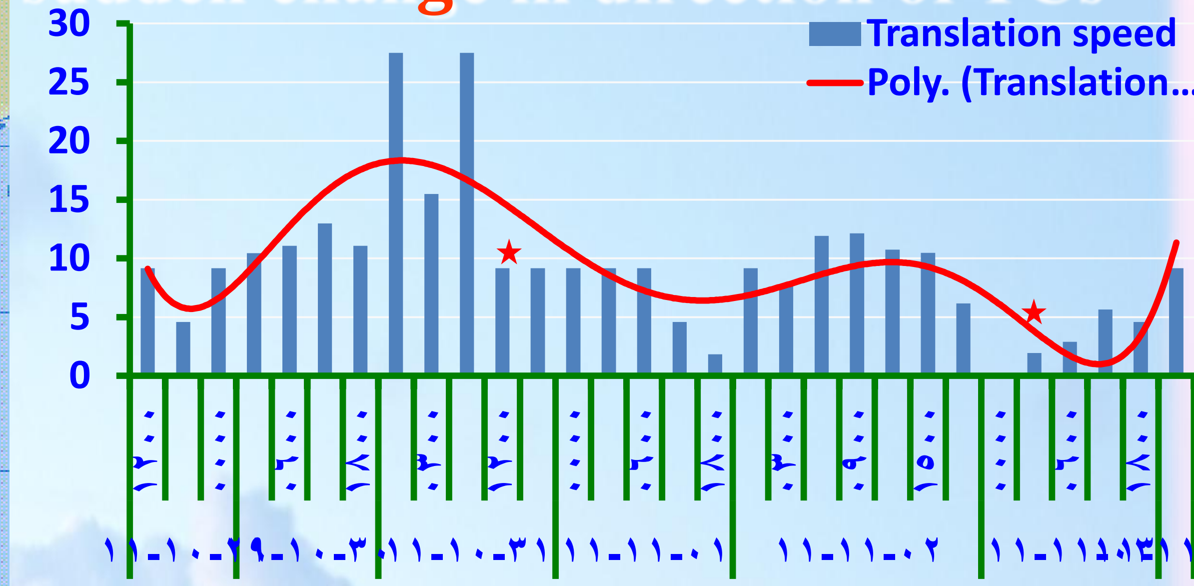


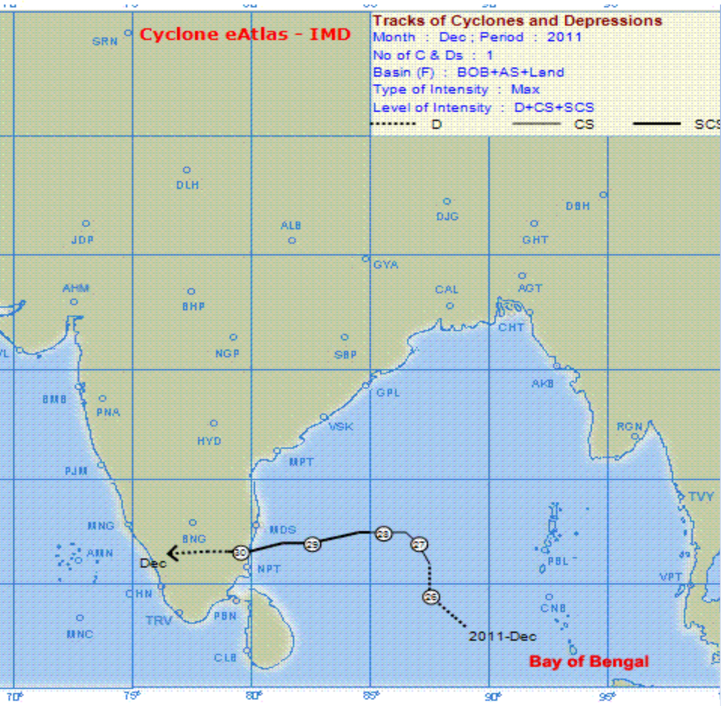


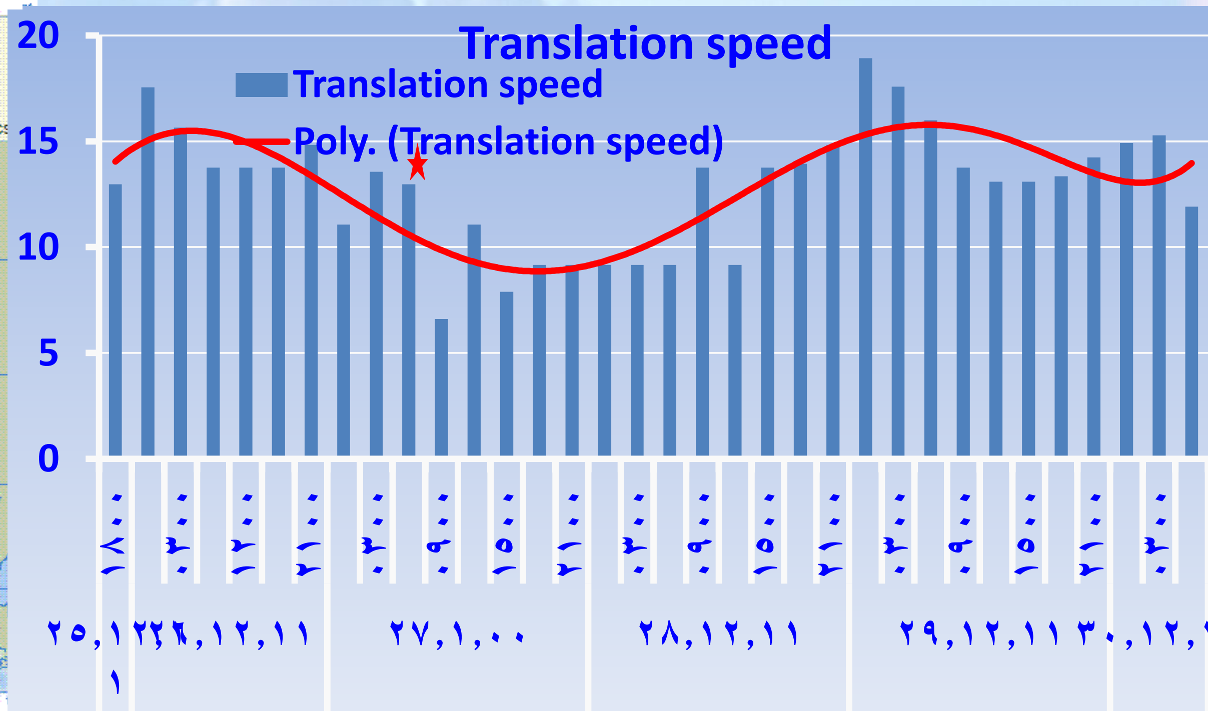


Translation speed and sudden change in direction of TCs

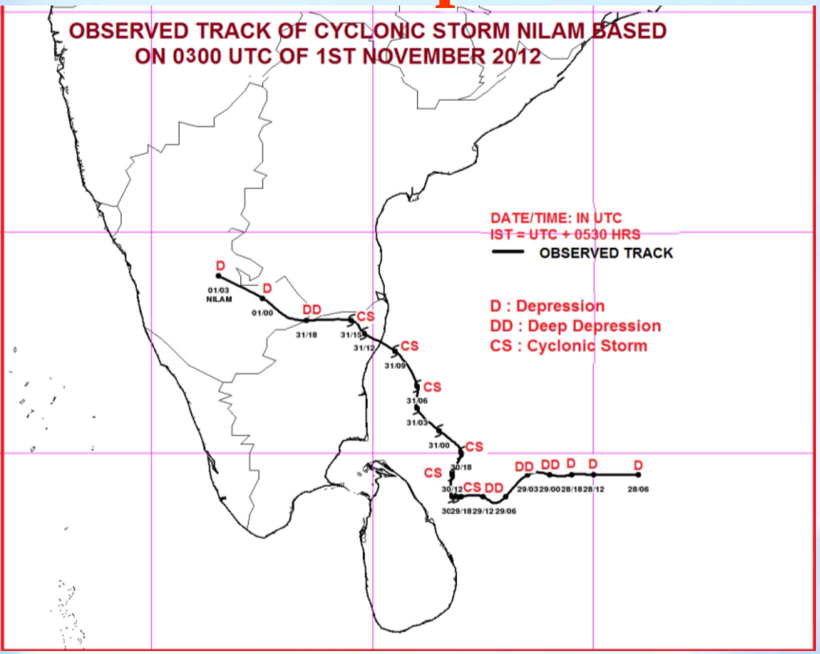




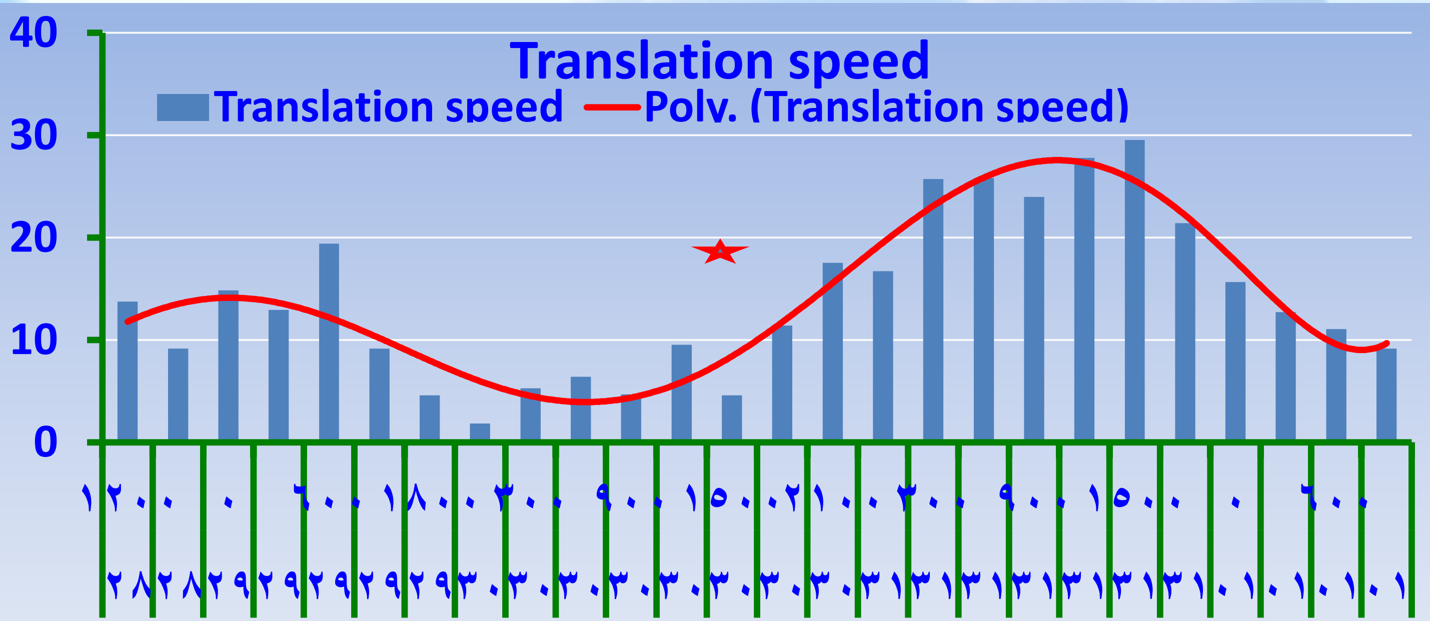




Translation speed and sudden change in direction of TCs



- To summarise, the translation speed gradually decreases for about 24 hrs period pror to change in direction of movement.
- Minimum translation speed becomes about 10 kmph in most of the cases
- This is true for both cases of increase in northerly and southerly components during the change



Track forecasting by synoptic method

TC Motion: The Beta Effect

- The "beta effect" accounts for 10-20% (up to 2 m/s) of TC motion

$$\frac{\partial \zeta}{\partial t} = -\left(u\frac{\partial \zeta}{\partial x} + v\frac{\partial \zeta}{\partial y}\right) - v\beta$$

Local Vorticity Change | Advection of Vorticity | Beta

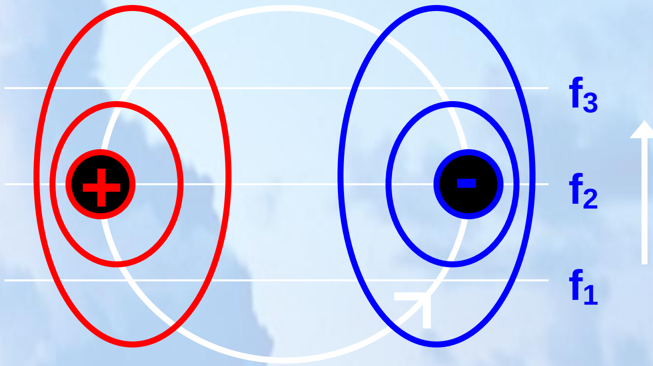
- Results from quasi-symmetric cyclonic flow superimposed on the north-south gradient of the Coriolis force (β = d**f** / dy)

- "Simple" explanation from the Cartesian non-divergent barotropic vorticity equation

- **Beta Contribution:** An air parcel displaced southward (northward) will acquire positive (negative) relative vorticity

- Results in an east-west dipole of maximum negative-positive vorticity generation across the cyclone

Vorticity Generation via Beta



Initially Symmetric Cyclonic Vortex

Source:Dr Matthew D. Eastin

TC Motion: The Beta Effect

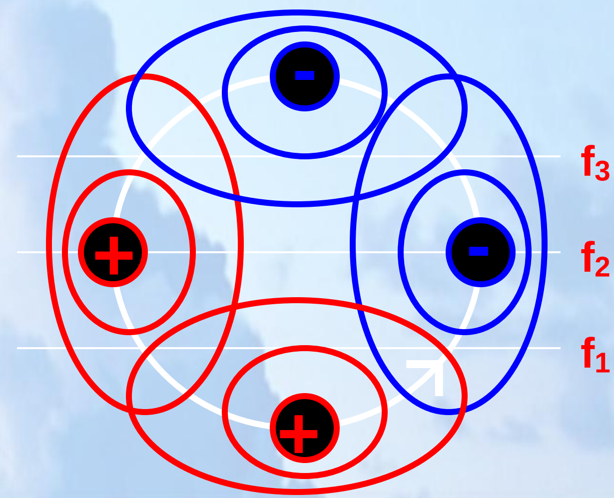
- **Advection Contribution:** The resulting cyclonic advection of the Beta-generated vorticity produces a north-south dipole of local vorticity change

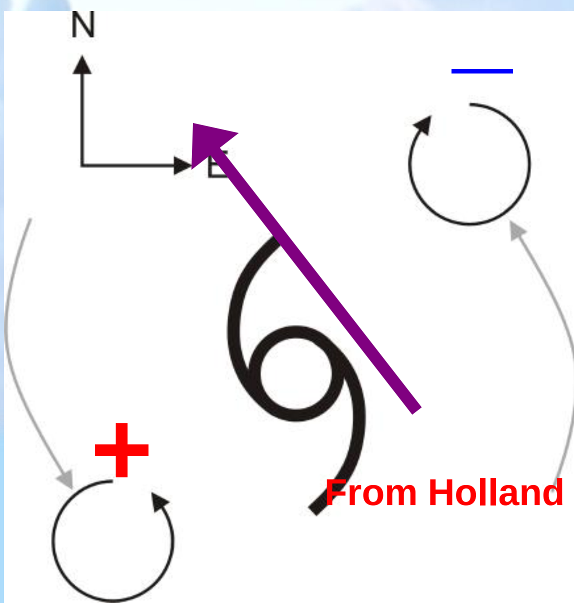
- Their combination **locally** produces two vorticity maxima, called "**beta gyres**", that induce a **northwesterly** component to TC motion (in the northern hemisphere)

$$\frac{\partial \zeta}{\partial t} = -\left(u\frac{\partial \zeta}{\partial x} + v\frac{\partial \zeta}{\partial y}\right) - v\beta$$

Local Vorticity Change | **Advection of Vorticity** | **Beta**

Vorticity Generation via Beta and Vorticity Advection



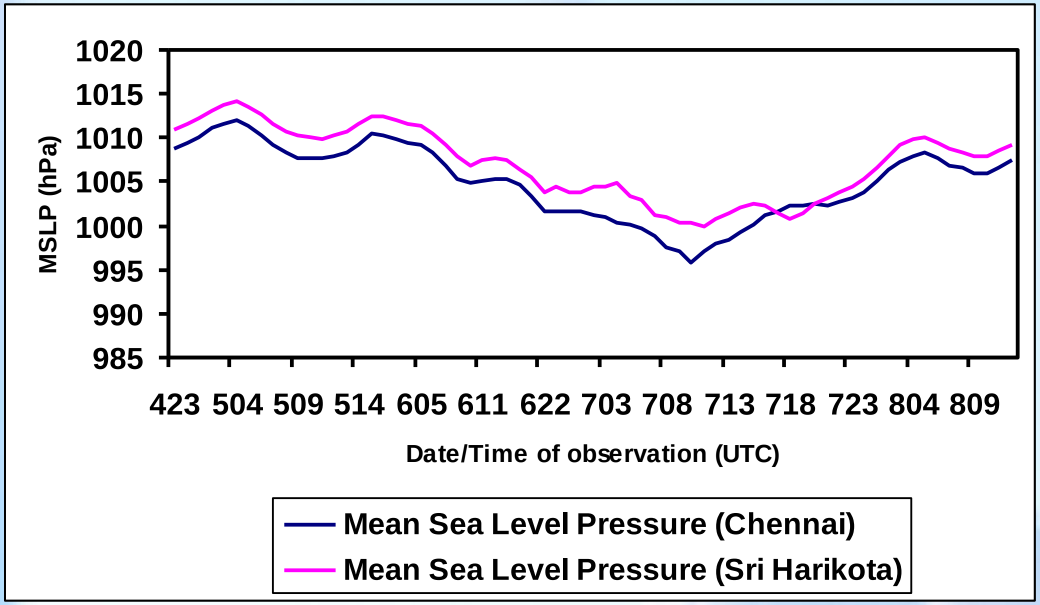


From Holland (1983)

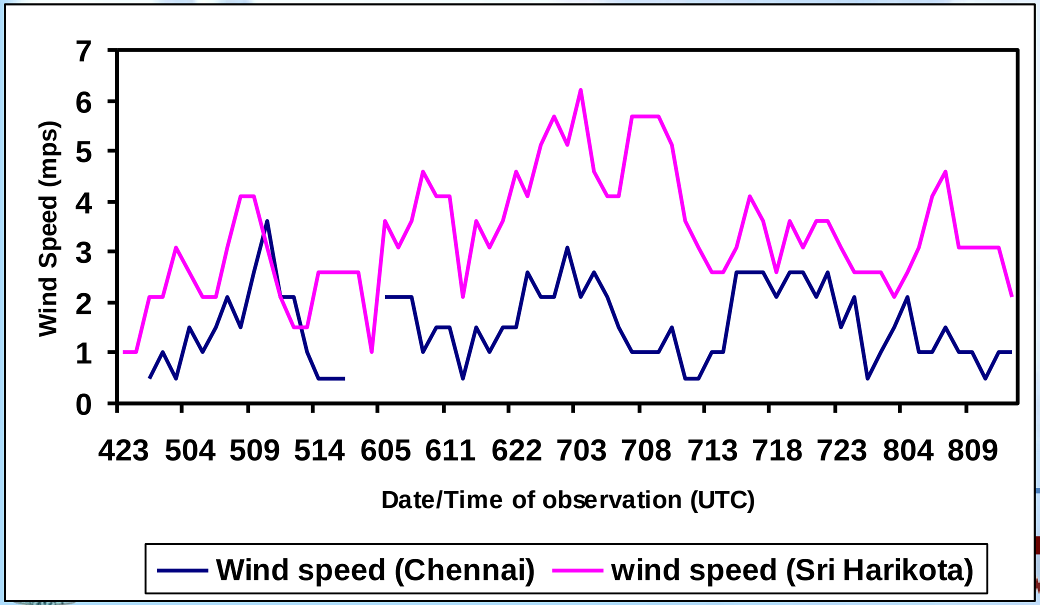
TC Motion (Synoptic) : Importance of P२४P२४

- The importance of P२४P२४ observation is amply illustrated in determining the track and land fall point.
- The importance of Isallobars
  - 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 cyclonic storms movement.

TC Motion : Utilityof AWS



MSLP and wind speed measured by AWS from 2300 UTC of 04 November to 1200 UTC of 08 November 2010 during severe cyclonic storm, JAL



- **The AWS data including wind and pressure could very well help in monitoring the genesis, intensity, structure and movement of the landfalling cyclonic disturbances.**

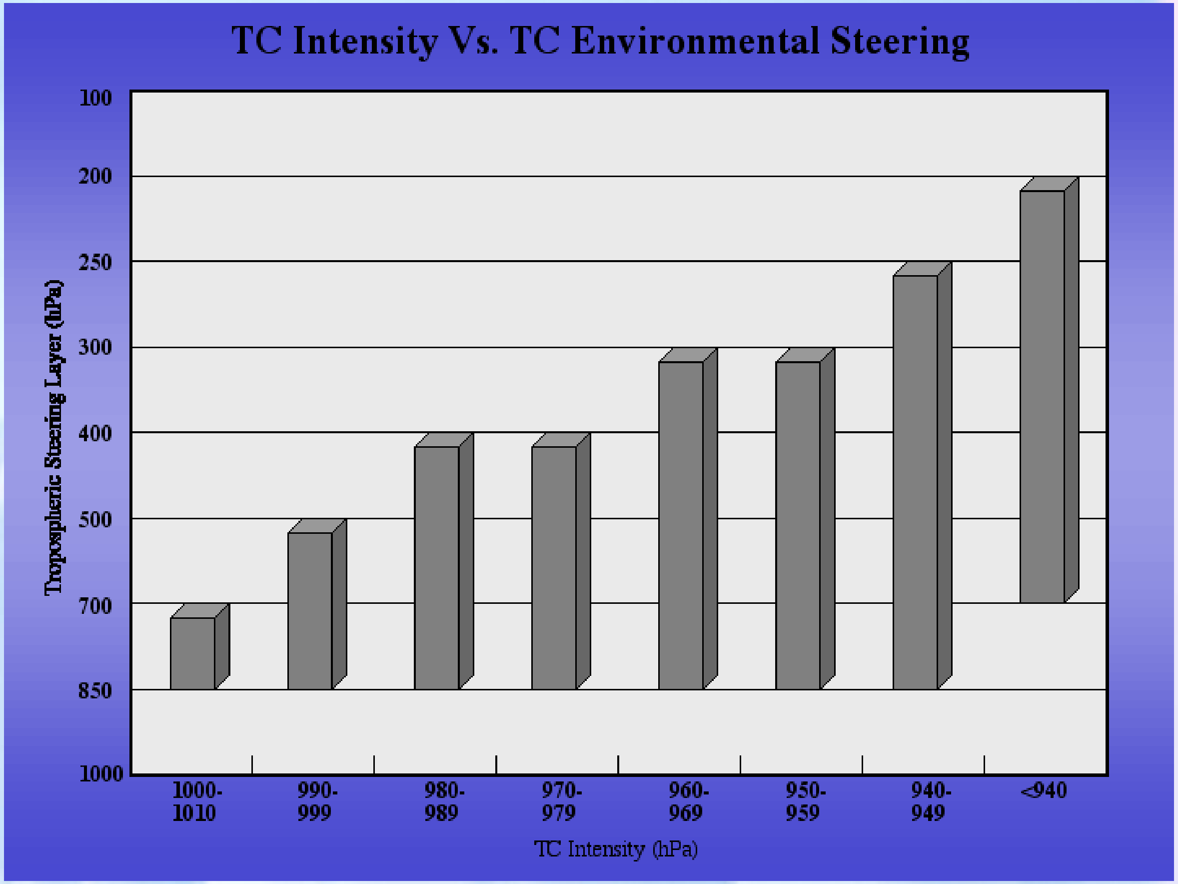
TC Motion (Synoptic): Steering Flow

Motion of Individual TCs:

- The deep layer environmental flow accounts for a large fraction (up to 80%) of TC motion
- Assumes the TC acts as a passive vortex moving with the speed and direction of the mass-weighted deep layer flow
- When a deep layer estimate is unavailable use the following:

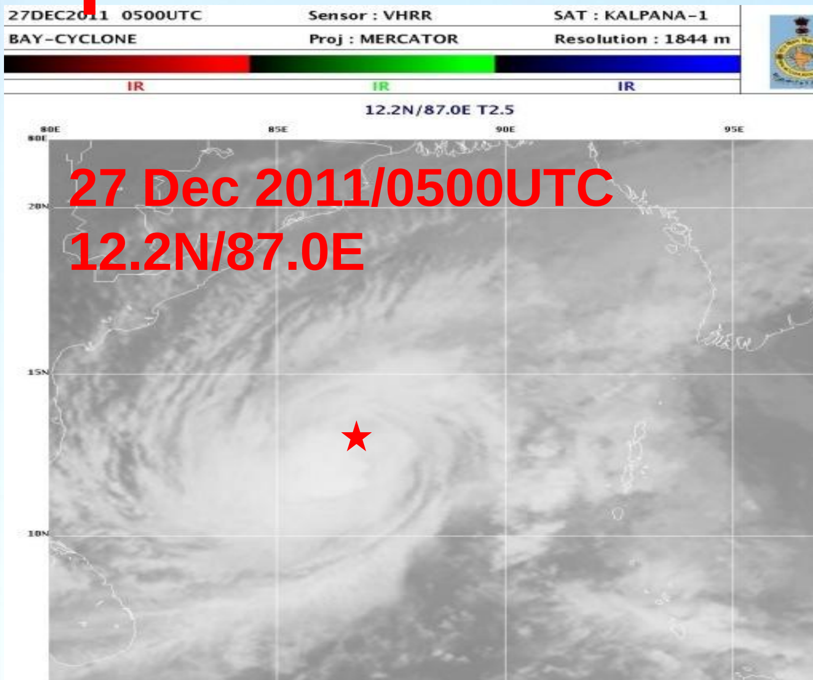
  TD and TS: 700 mb flow

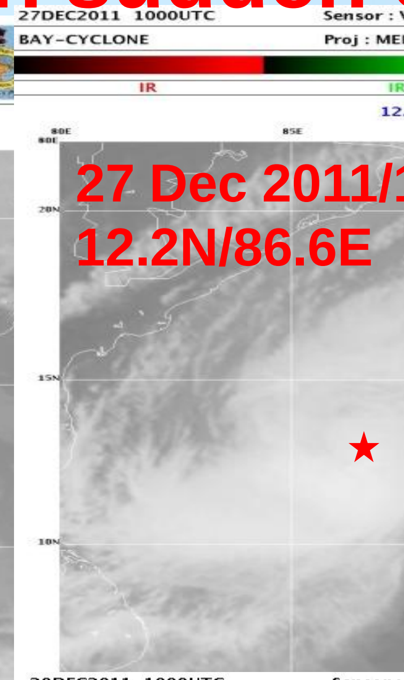
  Hurricane: 500 mb flow



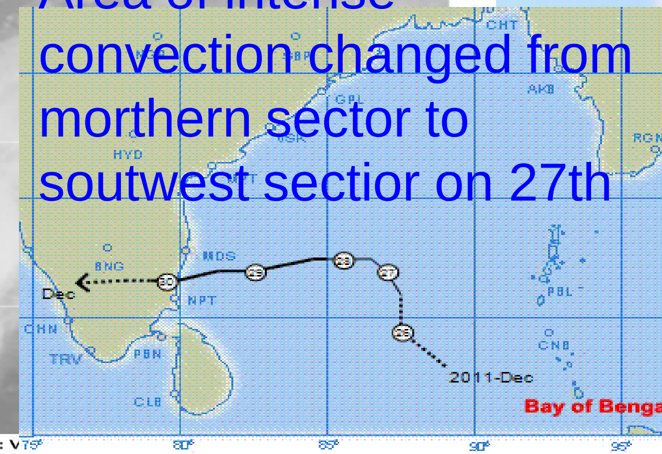
From Velden and Leslie (1991)

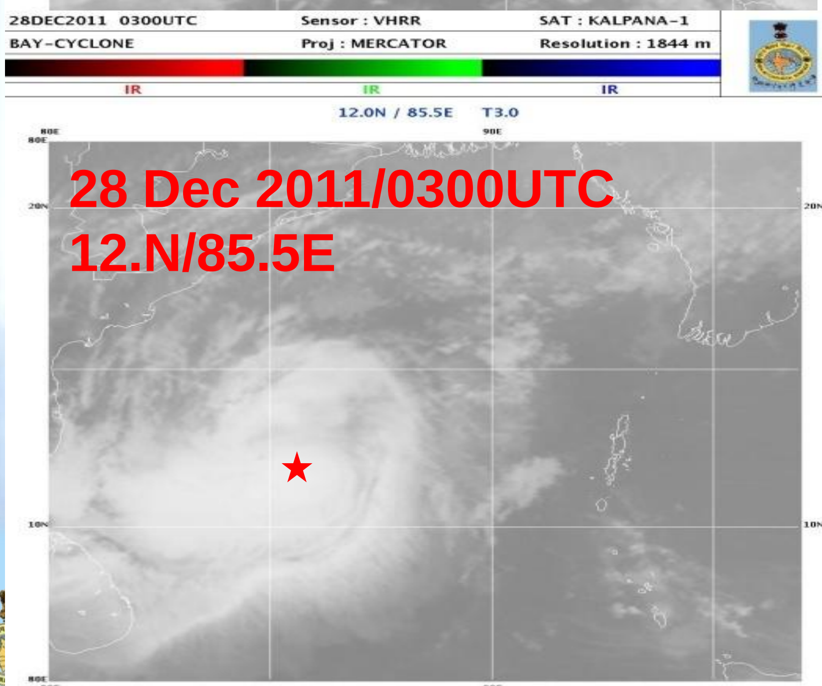
Impact of Convection sudden change in track :

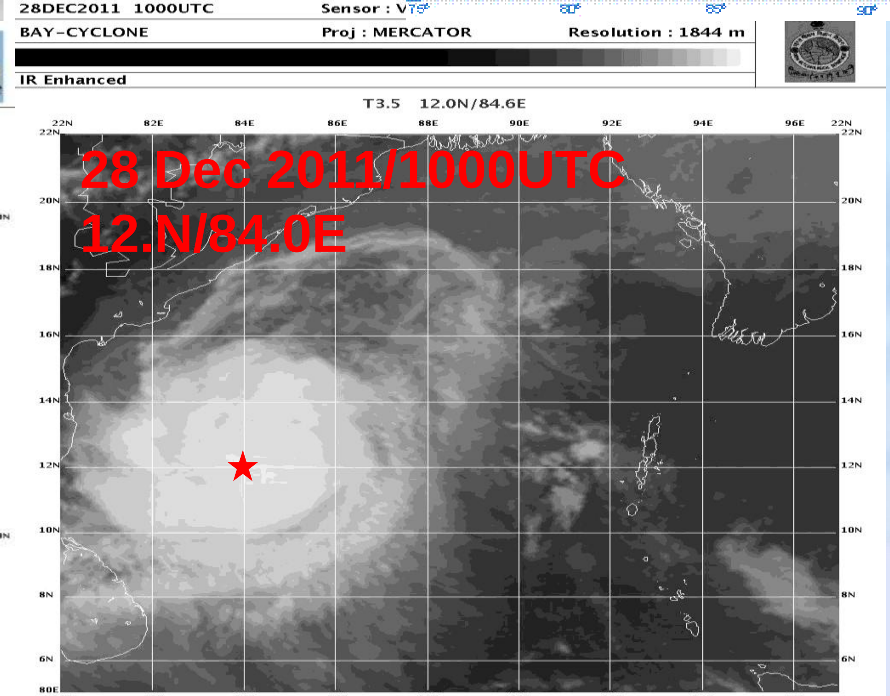




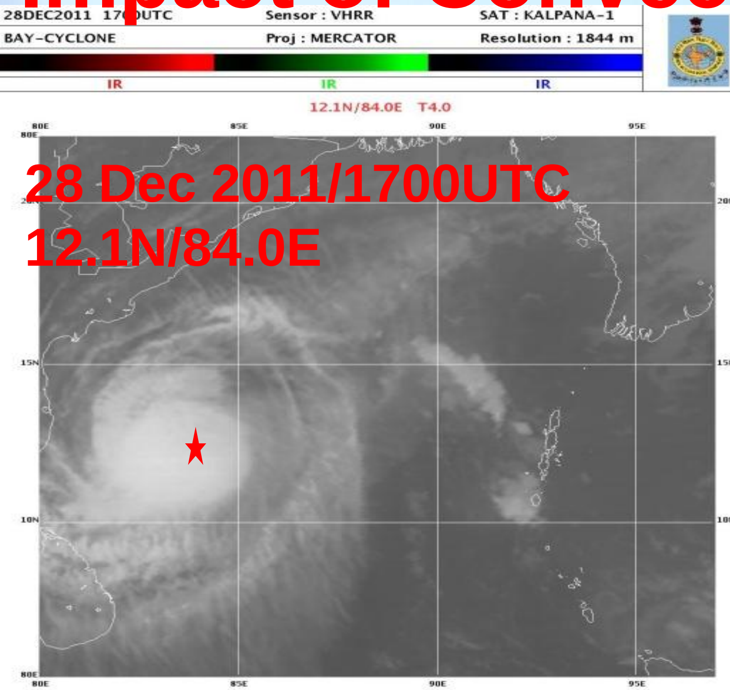
Area of intense convection changed from morthern sector to soutwest sector on 27th

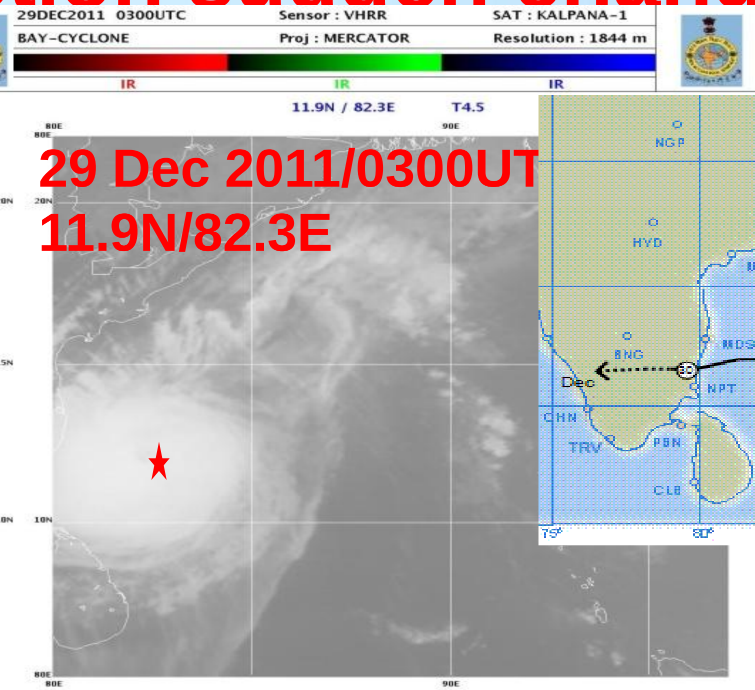


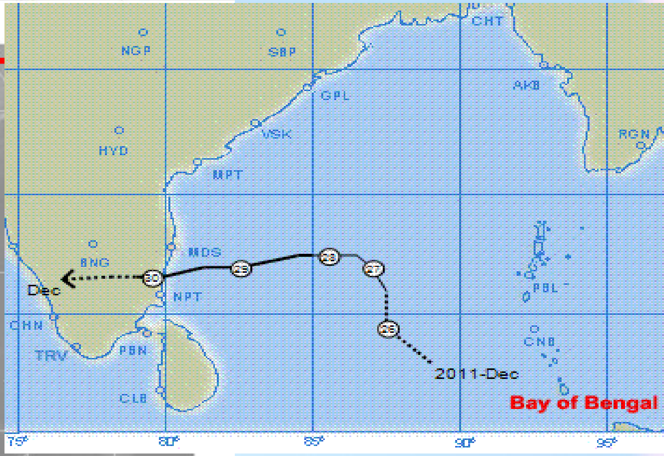


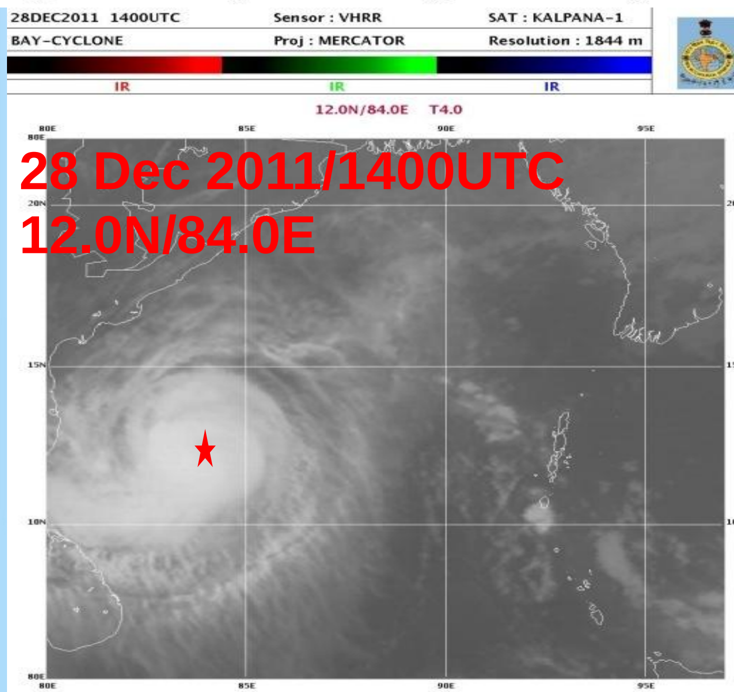


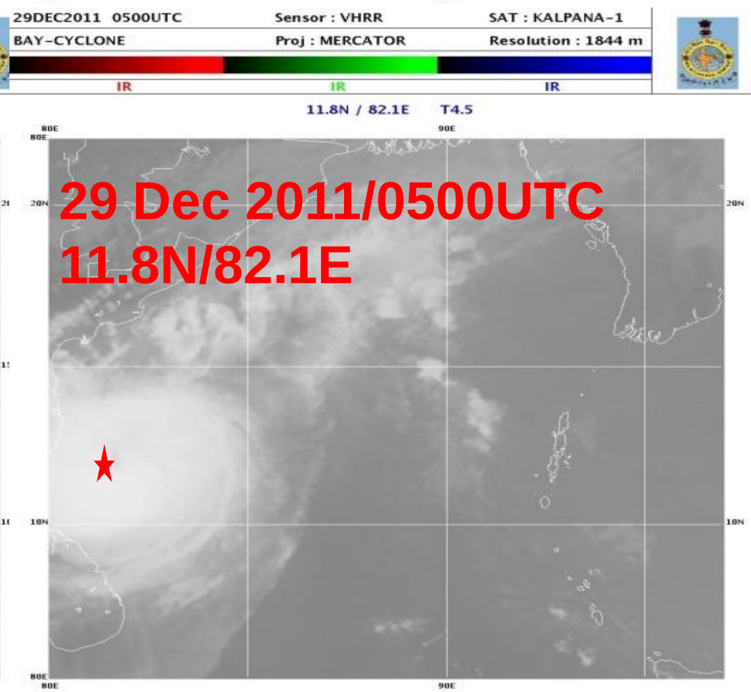
Impact of Convection sudden change in track







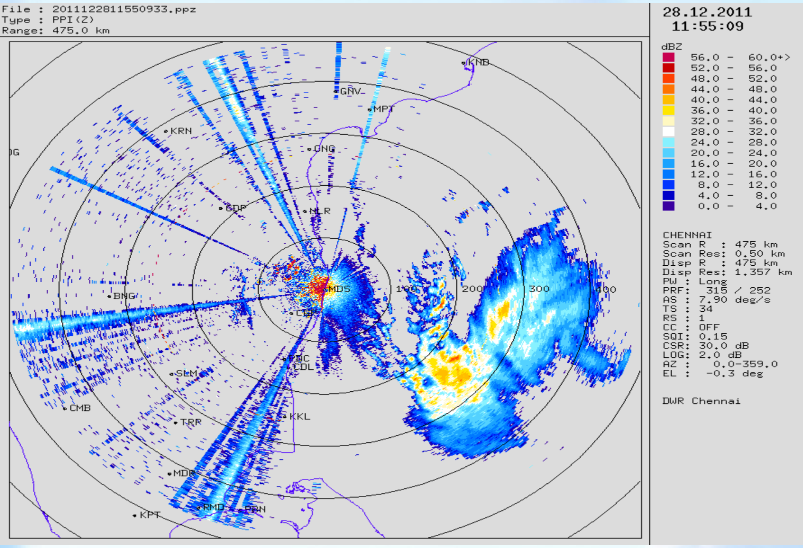


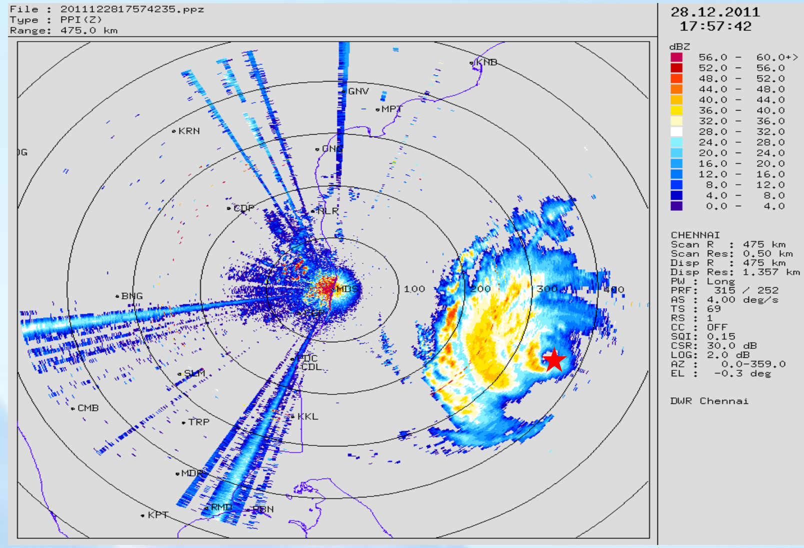


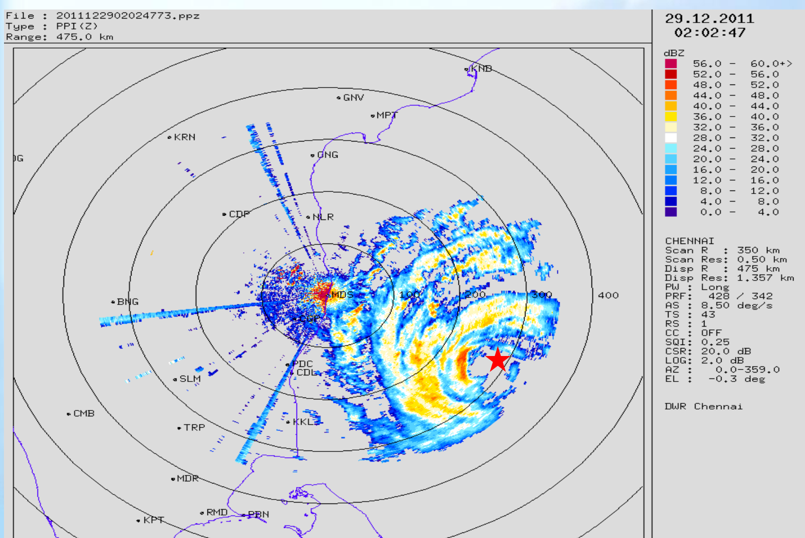
Area of intense convection consolidated around system centre gradually on 29th

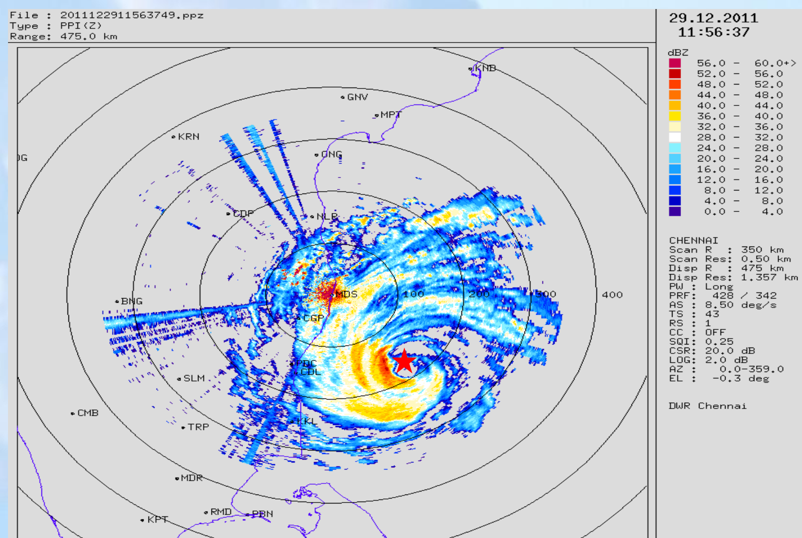
Impact of convection on sudden change in track

Southward shifting of area of intense convection is also seen in DWR imageries

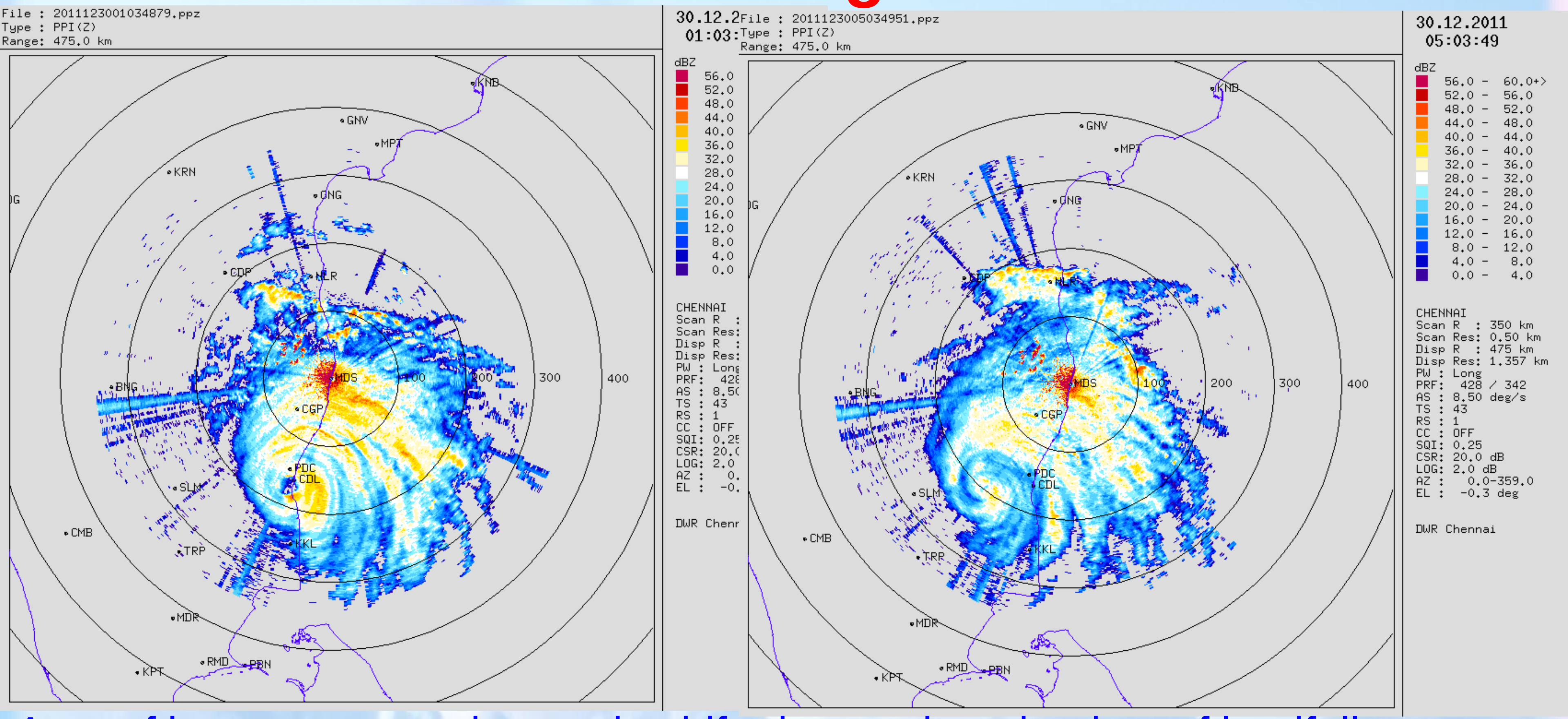








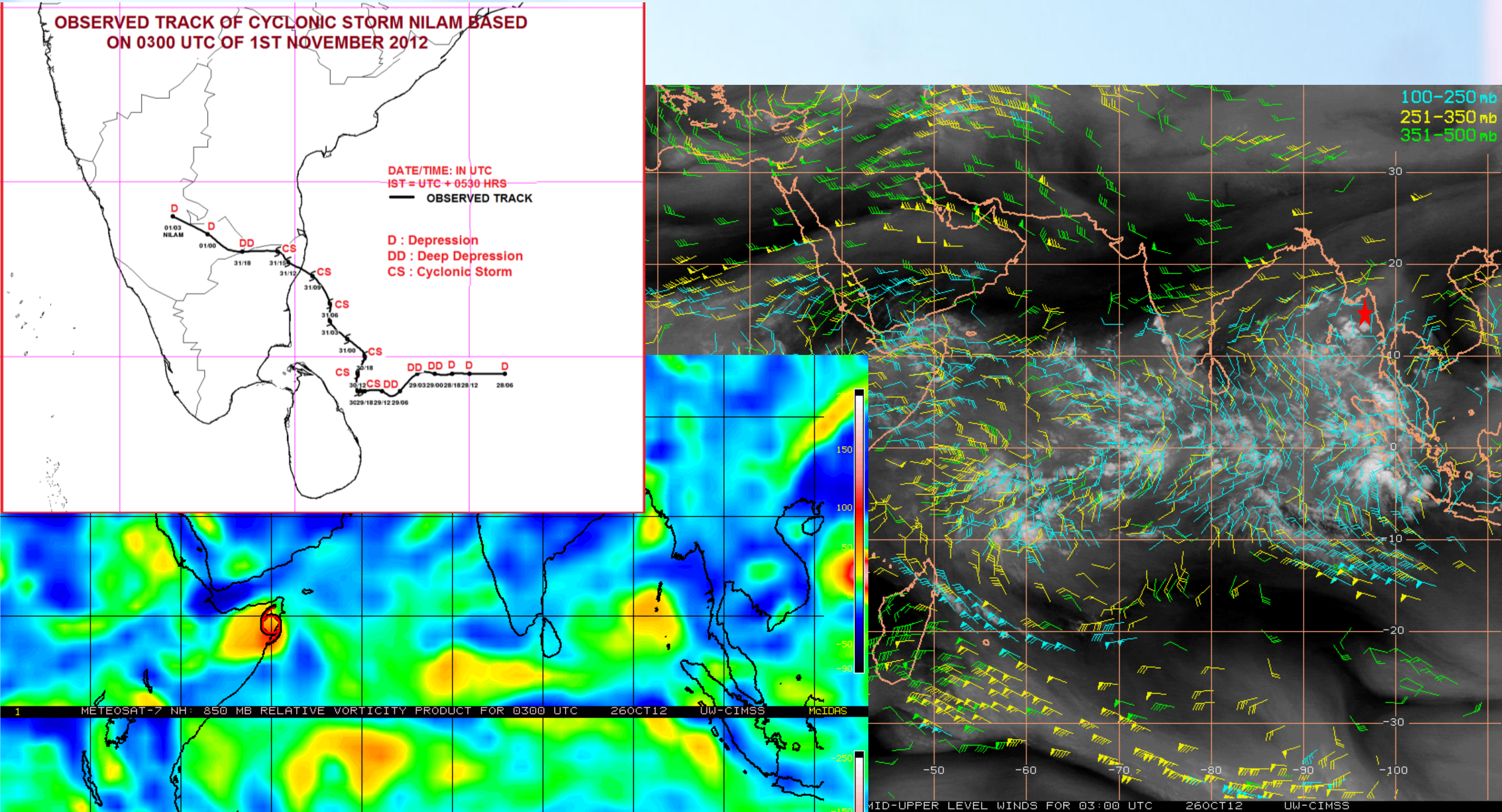
Impact of convection on sudden change in track :



Area of intense convection again shifted to north at the time of landfall

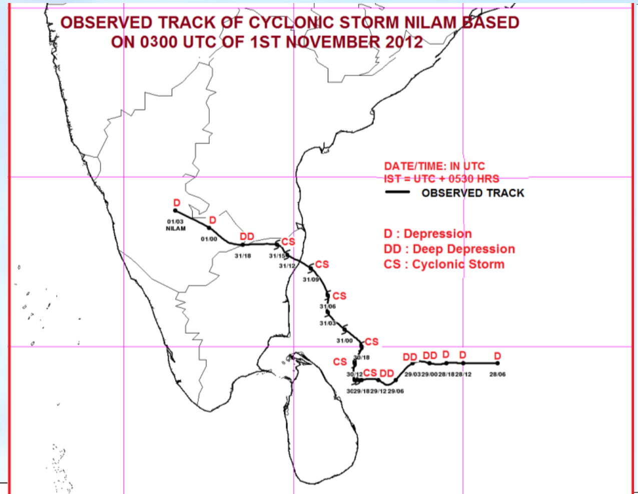
Impact of steering ridge, vorticity and large scale circulation on sudden change in track

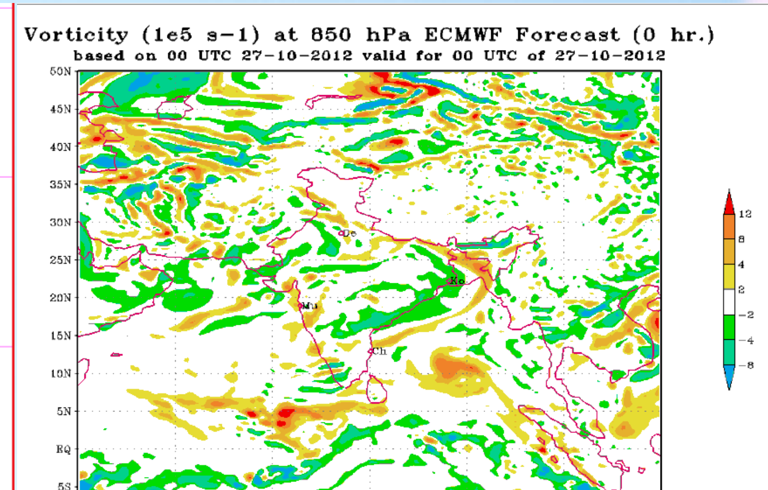
- Example : Cyclonic storm NILAM (28 Oct-01 Nov, 2012)
- Anti-cyclone located to northeast of system
- Ridge extended southward on 26th

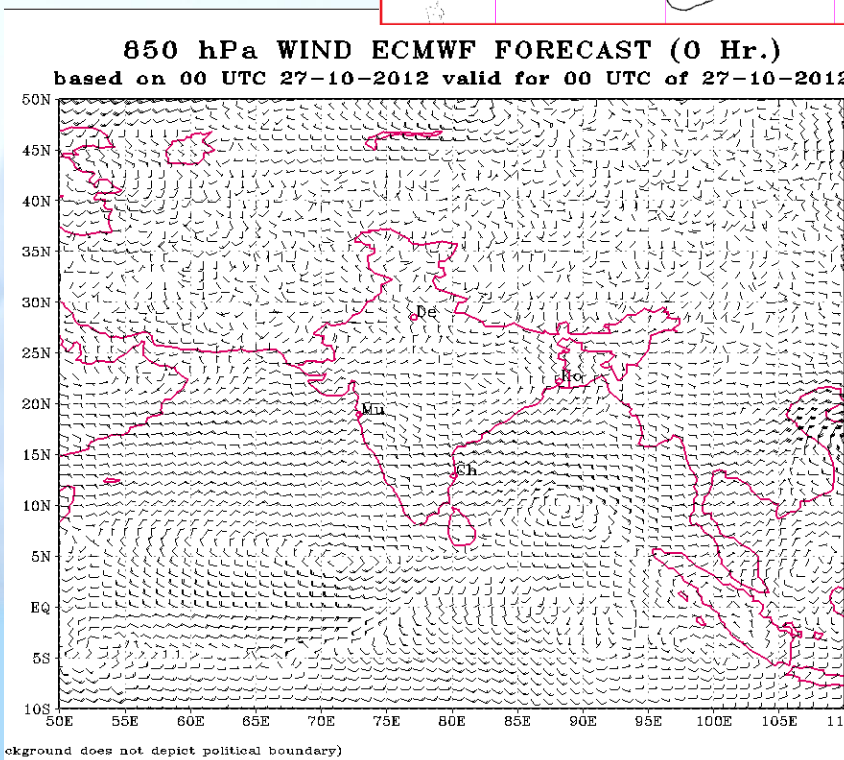


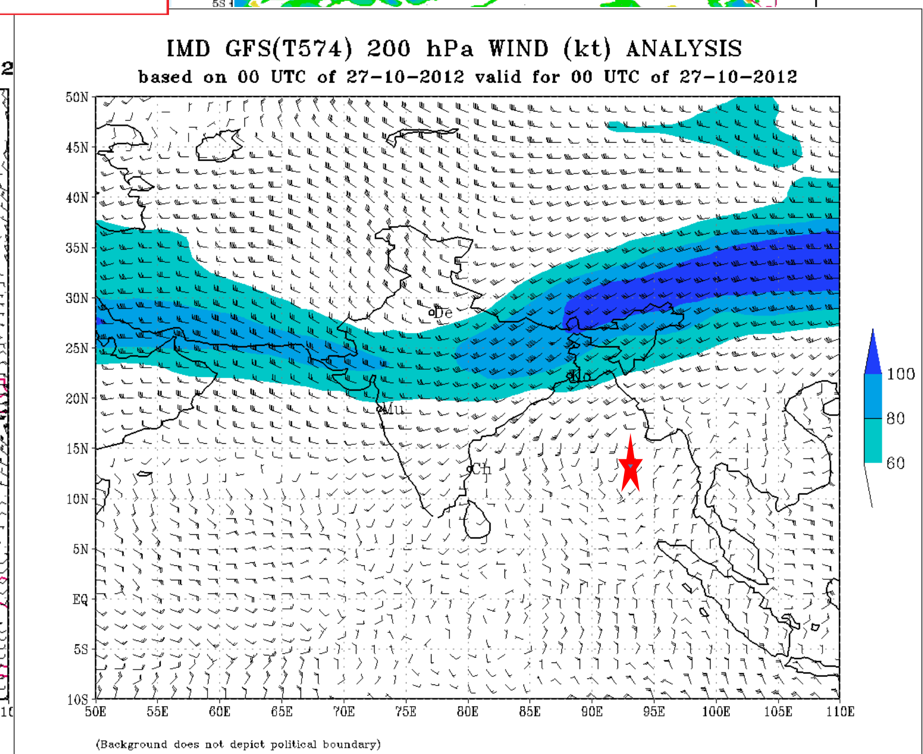
Impact of steering ridge, vorticity and large scale circulation on sudden change in track

- Anti-cyclone located to northeast of system
- Ridge extended southward on 27th



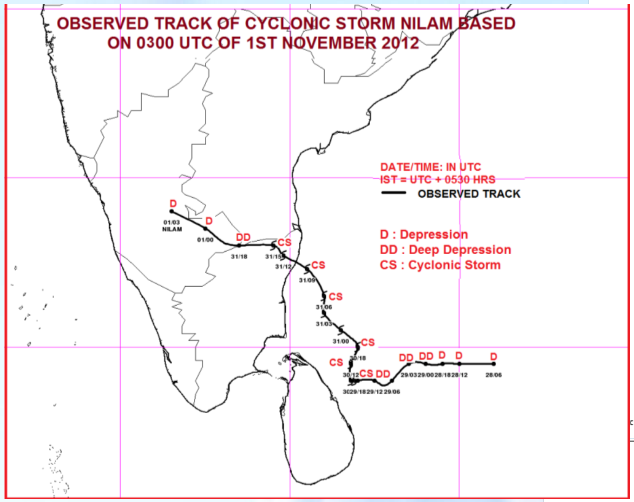


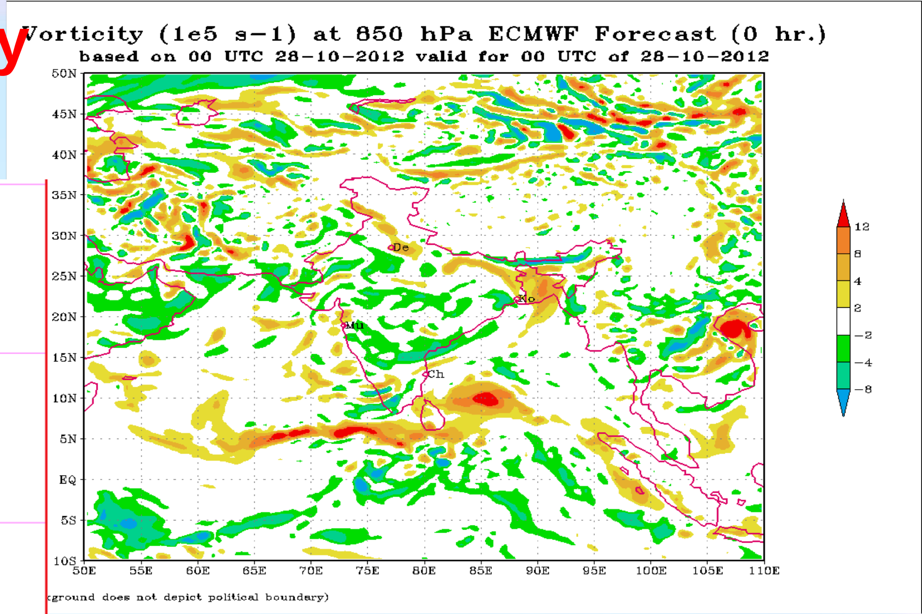


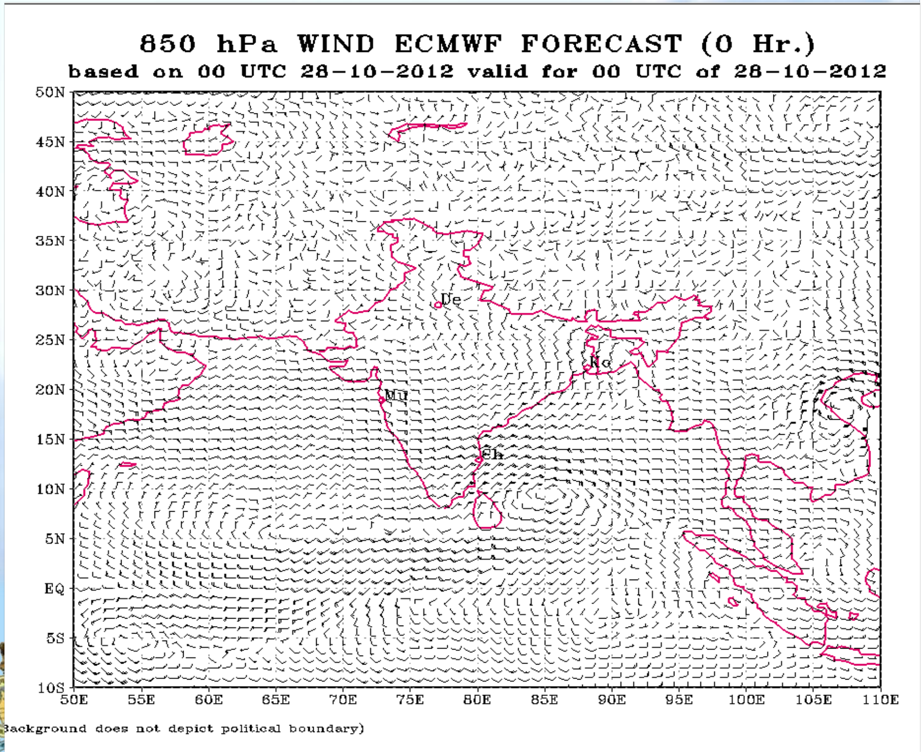


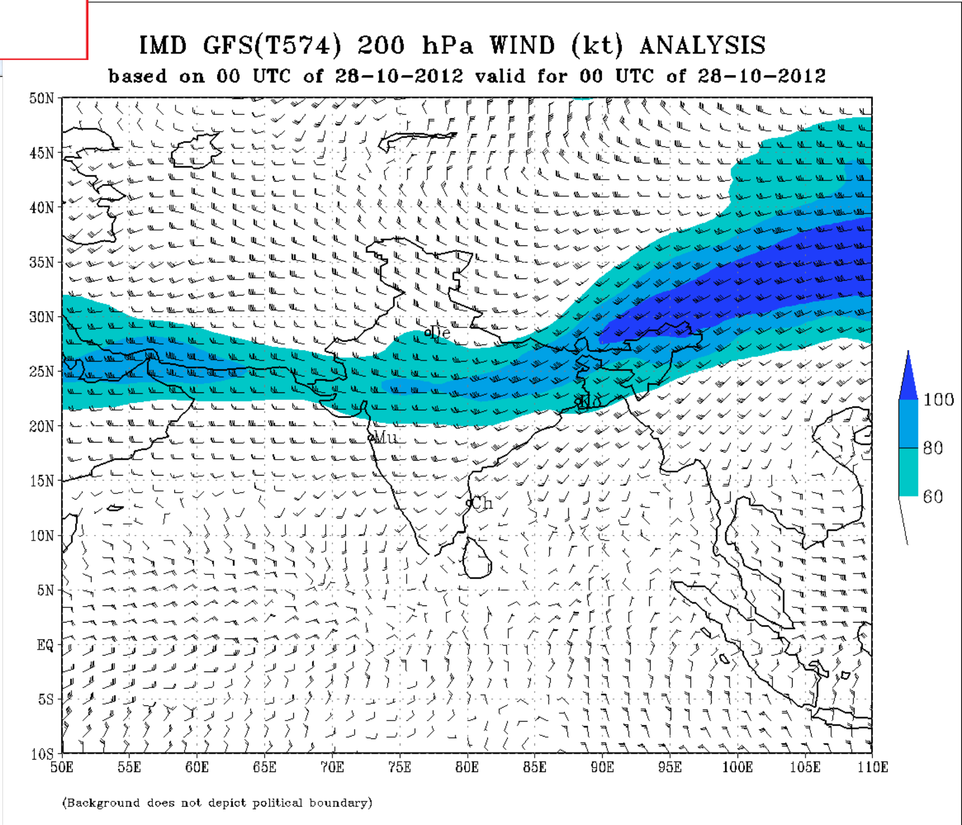
Impact of steering ridge, vorticity and large scale circulation

- Anti-cyclone is less marked
- Extension of ridge to south reduced

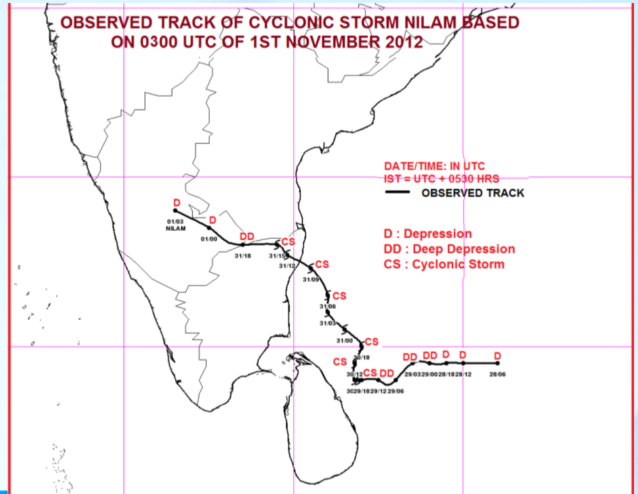


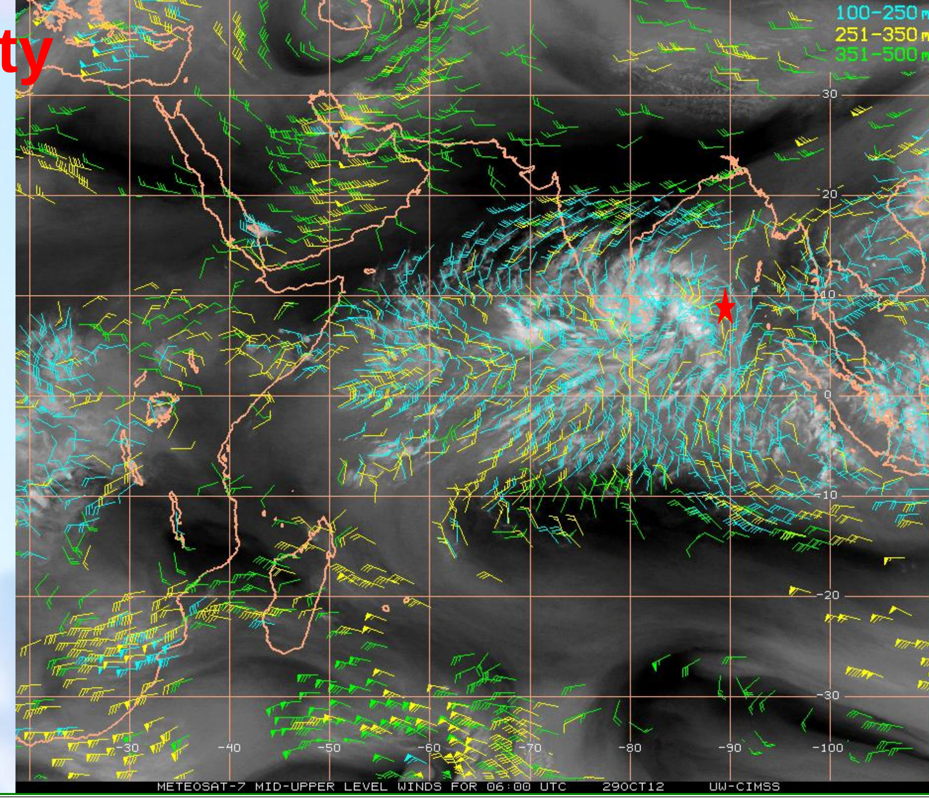


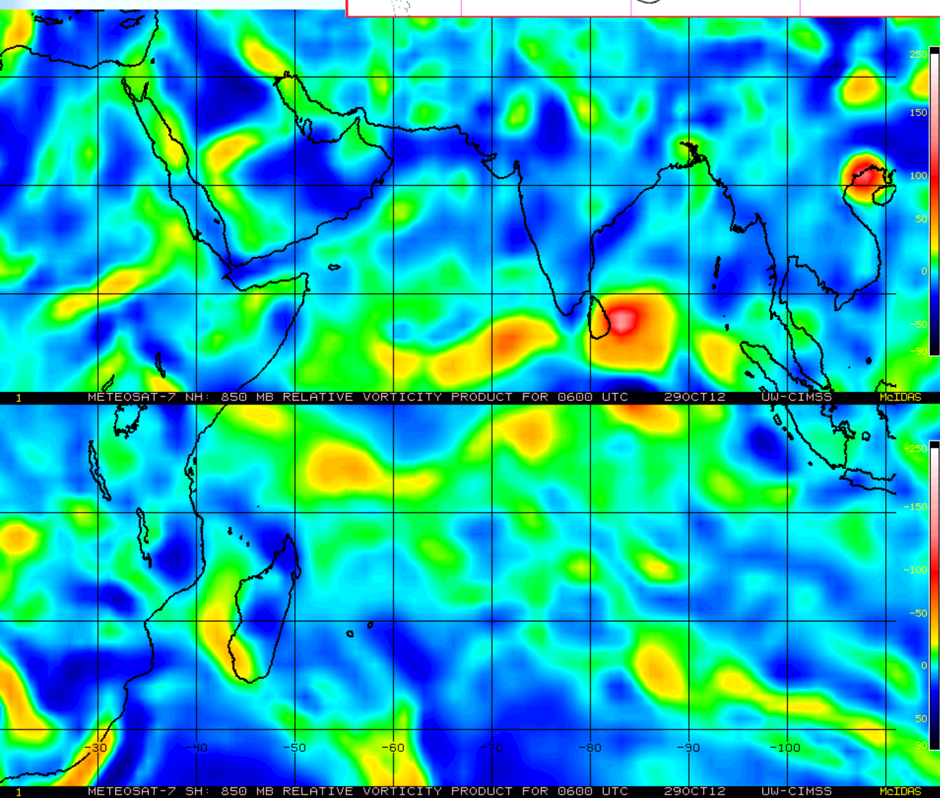


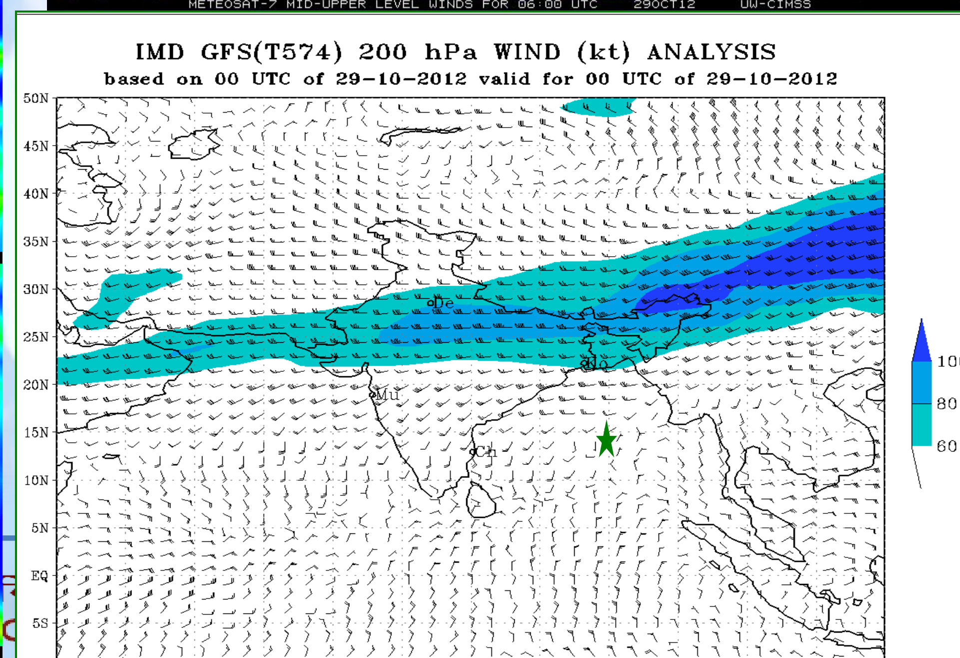


Impact of steering ridge, vorticity and large scale circulation









TC Motion (Synoptic): Trochoidal Motions

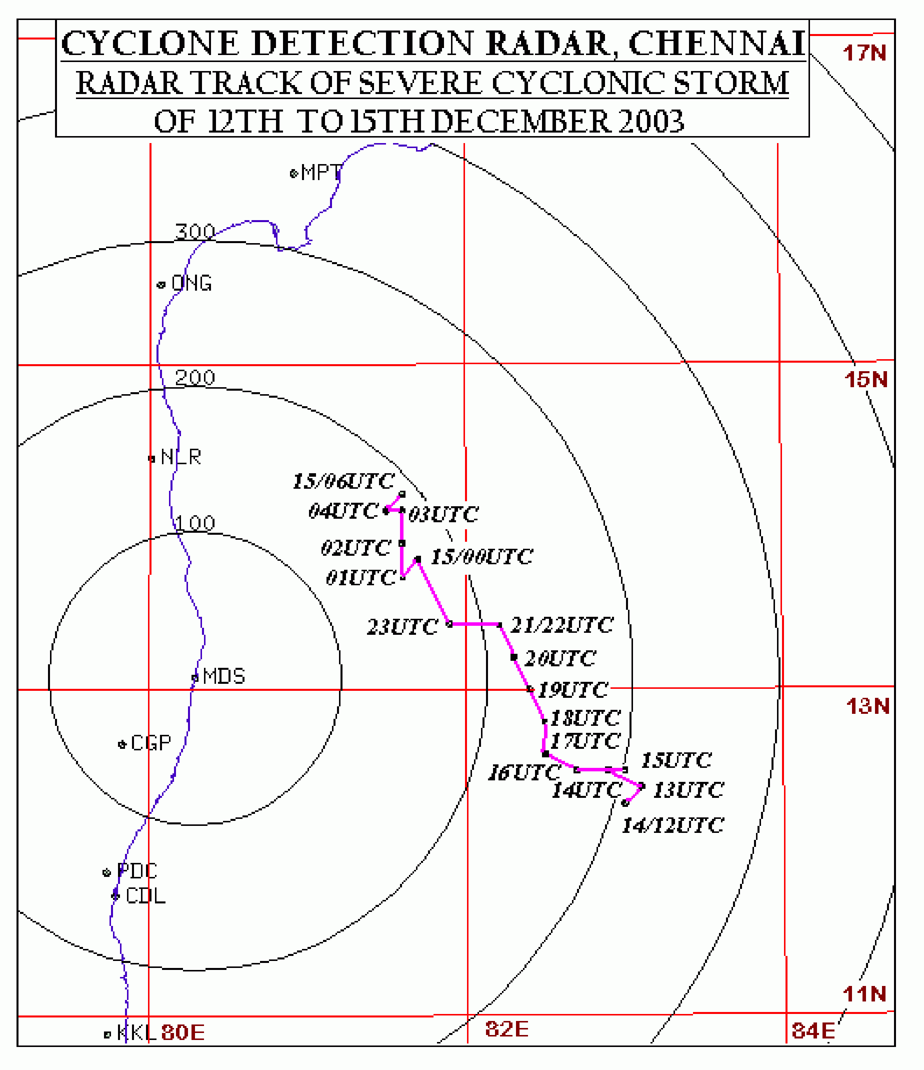
Motion of Individual TCs:

•Many cyclones experience “wobbles”, or oscillations, with respect to their time averaged motion vector (usually less than the eye diameter)

• This trochoidal motion is believed to result from the co-rotation of the TC’s circulation center with a smaller mesovortex (perhaps generated by a deep convective burst)

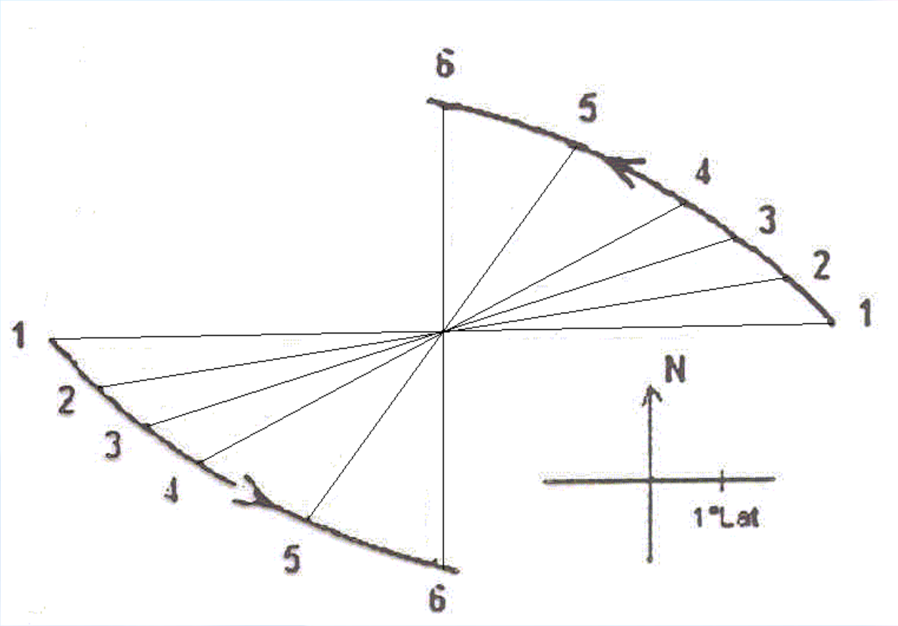
• Trochoidal motions are often removed from the official ”best” track

• Trochoidal motions are often misinterpreted as “turns” if TC is tracked from center fix to center fix….forecasters beware



TC Motion (Synoptic) Fujiwhara effect

- Attraction between 2 tropical cyclones close enough each other (named by Dr S. Fujiwhara who first studied the phenomenon)
- The Fujiwhara effect depends on the compared size and intensity of both systems
- It is possible to separate the motion of both vortex as a rotation around their centroid



Empirical rule for the Fujiwhara effect :

Dominates when distance between vortex < 6 degrees of latitude

Becomes progressively less important than the average basic current for a separation distance of 7 to 15 degrees

Is too weak for more than 15 degrees.

Motion of Individual TCs:

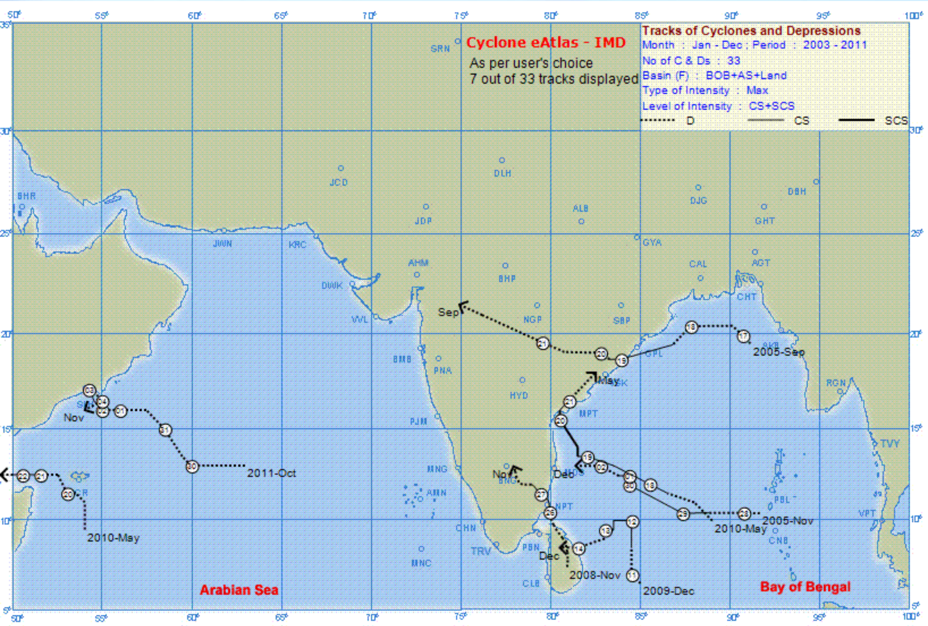
- Some storms tend to drift toward their latent heating centroid (which may be offset from the circulation center due to vertical shear)

- Some storms drift toward synoptic- scale troughs (particularly if the trough is deepening)

- Many storms will move toward a weakness in a ridge (a relative low pressure in a high pressure system)

- Common theme: TCs tend to drift toward other areas of low pressure

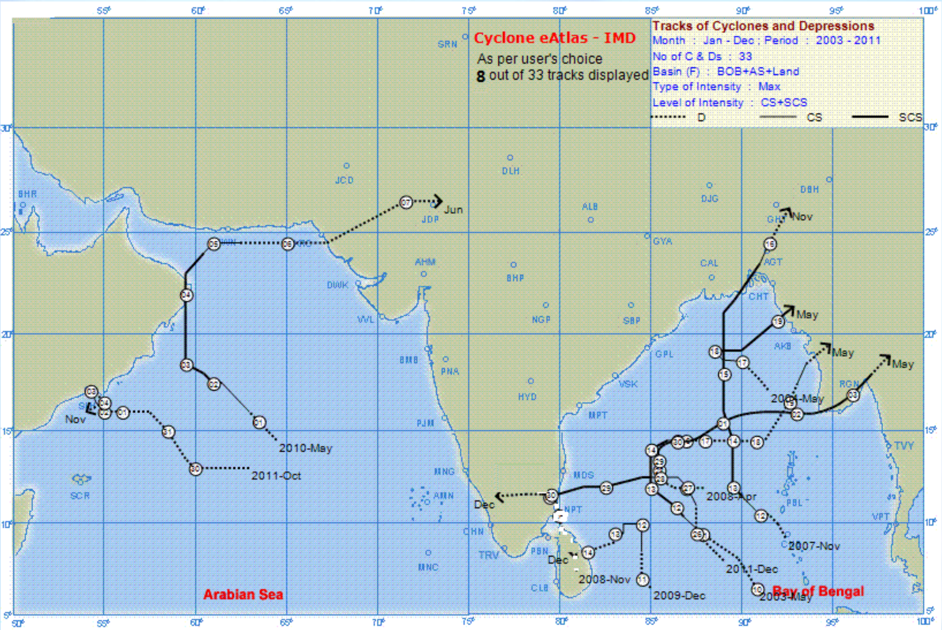
Slow movement near coast



- There were seven out of 33 TCs during 2003-2011 which showed slow movement near the coast.
- It includes 2 over AS and 5 over the BOB.
- It consisted of one looping TC over the AS and three recurving TCs over the BOB.

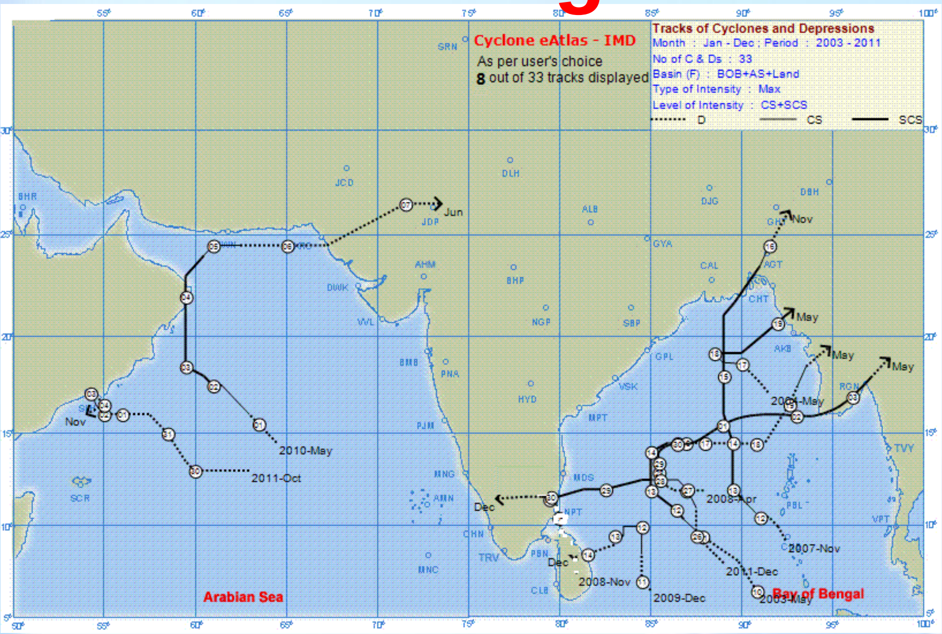
- The slow moving TCs mostly occurred to the south of 15^0N in both BOB and AS unlike the rapidly moving TCs and TC showing sudden change in direction.
- The role of land surface processes in accelerating and retarding the speed of TC approaching the coast needs investigation.

Sudden change in direction of movement



- Out of 33 TCs developed during 2003-2011, 8 TCs had sudden change in direction of movement
- It consists of two over the AS and six over the BOB.
- The analysis indicates that both the sudden changes in tracks over the AS occurred when the TC lay to the north of 15^0N.
- On the other hand, there are cases of such changes occurring in the BOB to the south of 13^0N (2 out of 6)
- While there has been a single case of looping track (over AS), most of the sudden changes in direction have occurred towards right of the previous direction of movement (6 out of 8, 75%).
- Considering the season of occurrence of such tracks, It has occurred more frequently during pre-monsoon (March-May) season (5) than in post-monsoon (October-December) season (3)

Sudden change in direction of movement

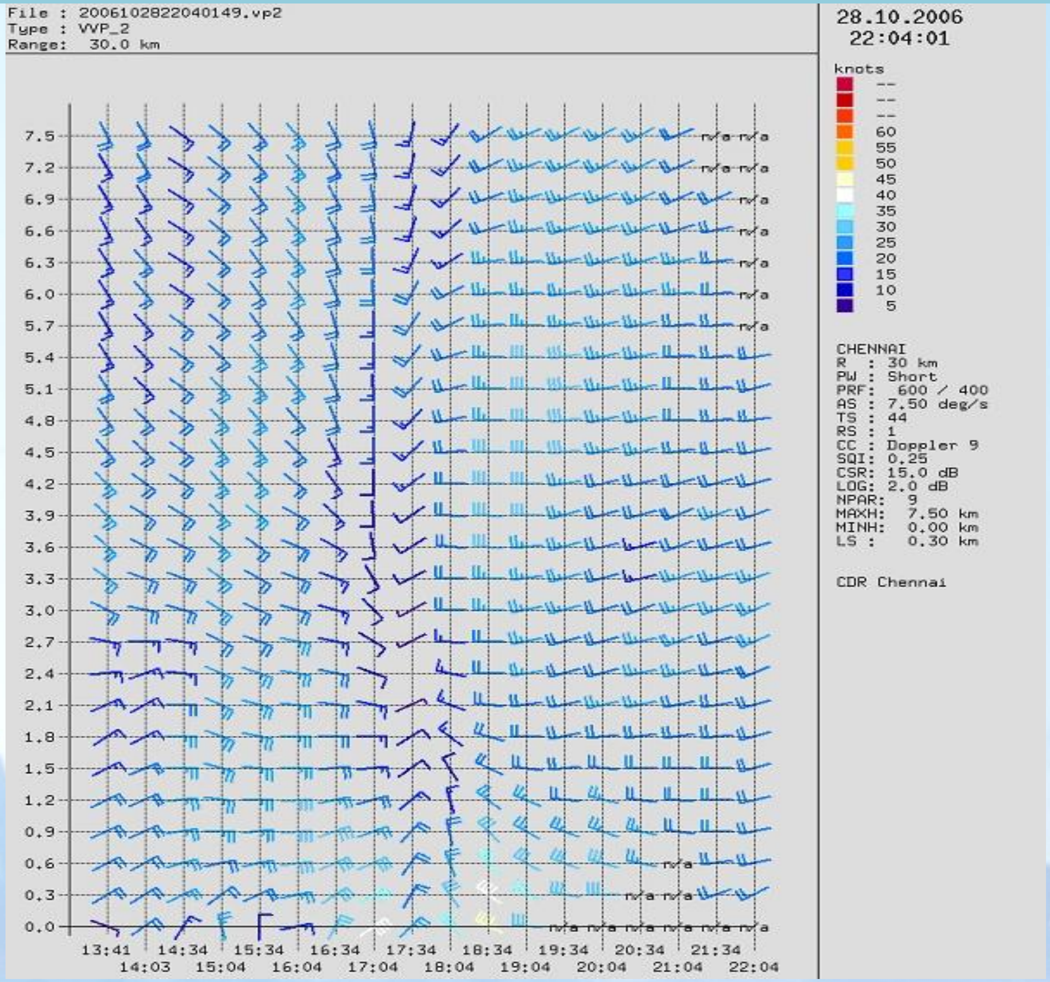


- Recurvature towards right may be attributed to the fact that the TCs over the NIO, while move towards more northerly latitude may recurve towards right under the influence of the deep trough in middle and upper tropospheric westerlies lying to the left of the TC centre.
- More cases in pre-monsoon season may be due to recurvature under influence of trough in westerlies which is predominant in pre-monsoon season.
- Another feature which contributed to the sudden change in direction of movement towards right is the middle/ upper tropospheric steering ridge/ anti-cyclonic circulation lying to the east of the TC centre

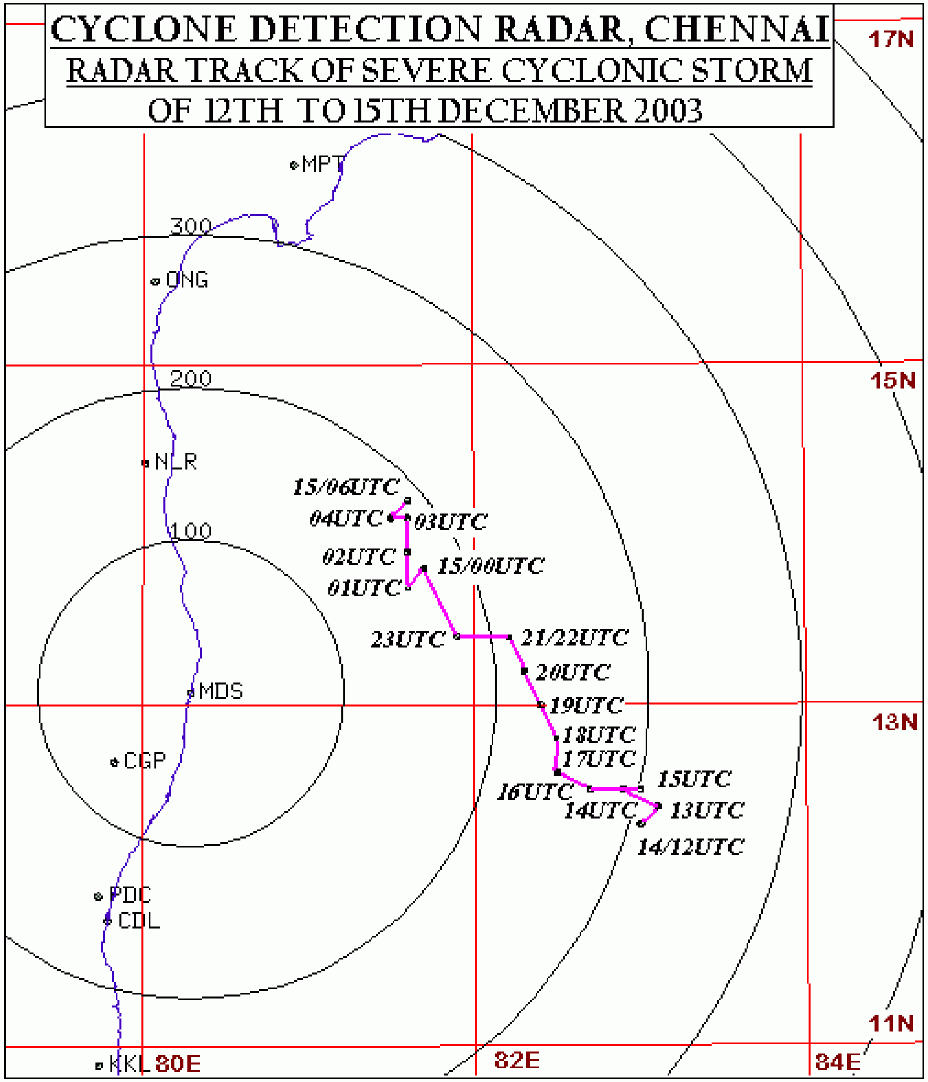
Track forecasting by radar and satellite

1. Pre-cyclone squall lines (Region of occurrence, time of occurrence
2. Precipitation characteristics (Place and time of occurrence of maximum precipitation)
3. OLR
4. Maximum reflectivity
5. Steering flow

Cyclone movement – Vertical time section-VVP2



Cyclone Track Prediction



Squall Lines & rain bands:

- Squall lines are a kind of linear organized meso-scale convective systems, cause thunderstorms and torrential rain. Generally it appear ahead of landfalling TCs.

- Squall lines tend to form in the transition area between the TCs and sub-tropical high in a moist environment & with a weaker cold pool than their mid latitude counterparts.

- As per yihong Duan et.al (2011)about 40% of landfalling TCs are associated with Pre-Tc squall lines.

- The squall lines as per Parker and Johns's (2000), the region of ≥ 40 dBz reflectivity extend longer than 100 kms for at least 2-3 hours and convection of this region is organized in linear or quasi linear shape with an apparent common leading edges.

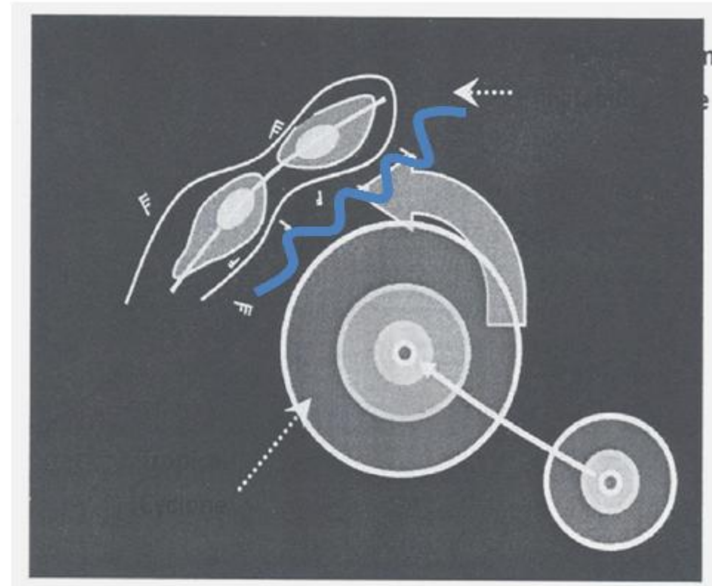


Fig.5 Schematic diagram of the genesis of pre-TC-squall line

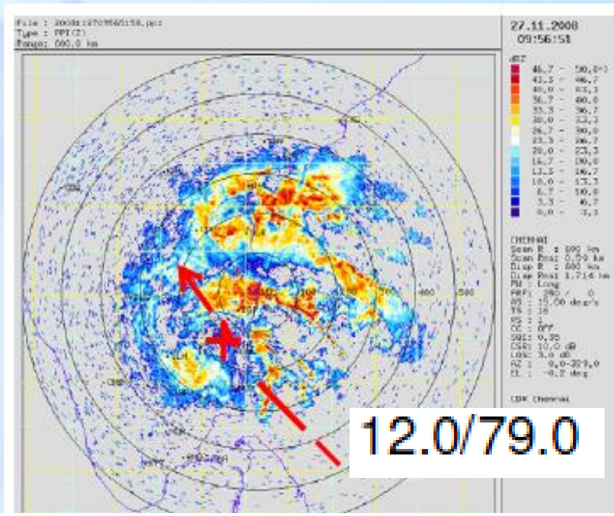


Fig. 3: Doppler weather Radar Chennai imagery in association with cyclonic storm NISHA

TC Motion : Operational NWP Models

- ## Medium Range Forecast

  > *GFS T-382 /574 L64 with GDAS (00 & 12 UTC)*

  >NWP products available from ECMWF, GFS (NCEP), JMA (Japan Meteorological Agency), UKMO also provided for medium range guidance and genesis prediction.

  >NWP division also provided six hourly intensity forecasts and genesis potential inputs during cyclone conditions.

- ## Short Range Forecast

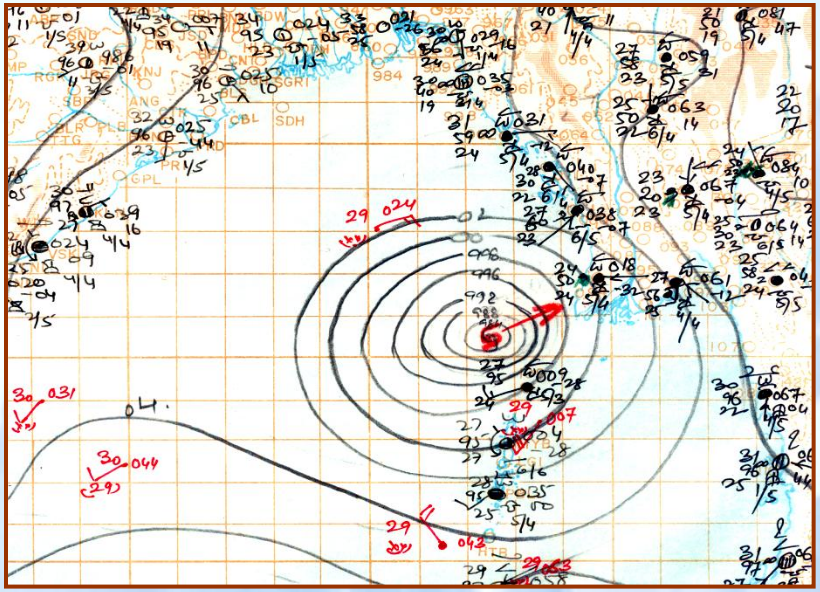
  > *WRF (ARW) VAR at 27 km and 9 km*
  > *WRF (NMM/HWRF) at 9 km for TC 4 times a day*
  > *QLM at 40 km (00 & 12 UTC)*
  > *MME Cyclone Forecast*

- ## Extended Range Forecasts

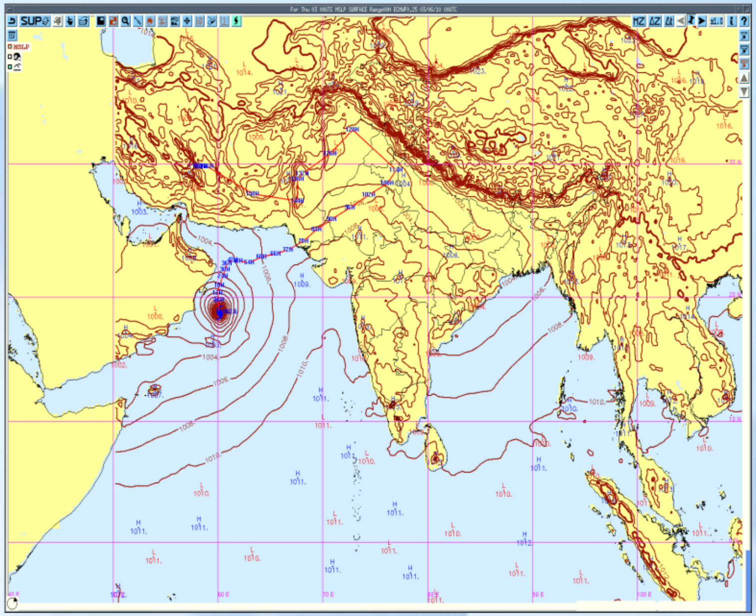
TC Motion (Models)

❖ The input would be **made more objective** by analysing various products through Synergie system.

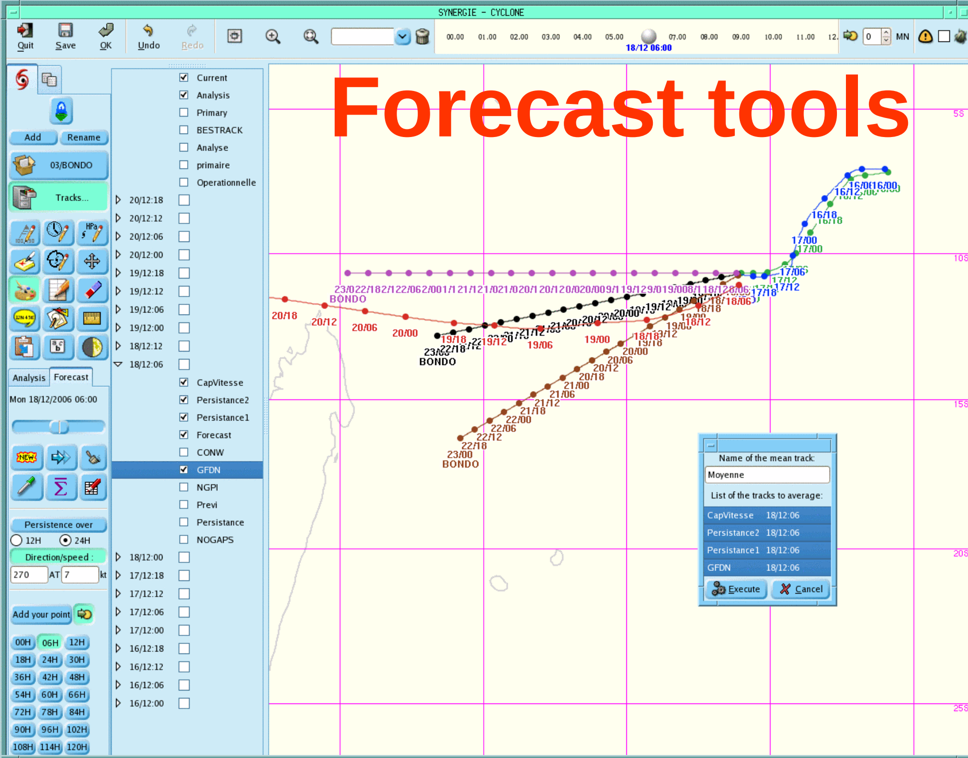
Isobaric analysis at mean sea level at 12UTC of 28 April 2006

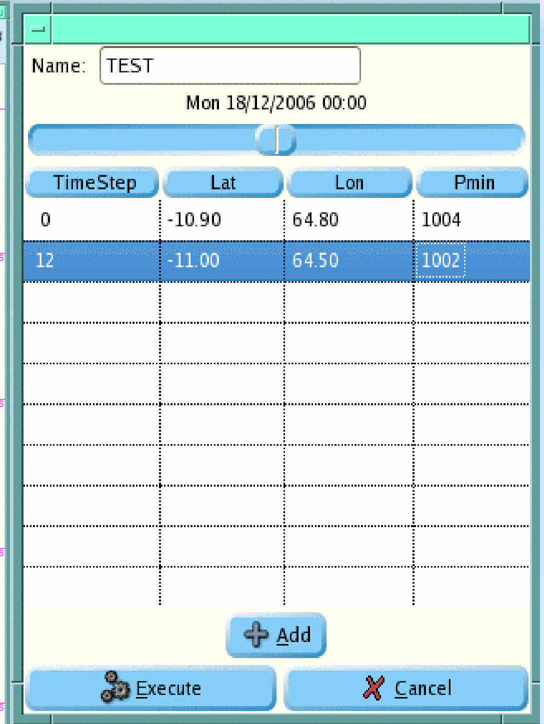


Isobaric analysis at mean sea level during cyclone, Phet at 00 UTC of 03 June 2010

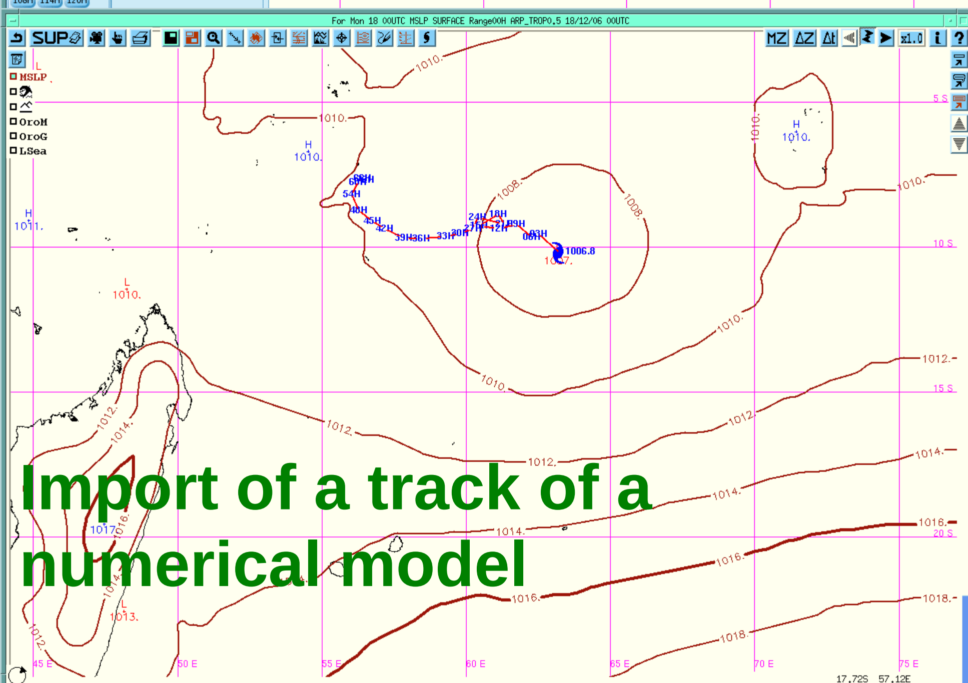


Forecast tools





Import of a track of a numerical model



TRACK PREDICTION BY NWP MODELS AND MME

- WRF
- QLM
- JMA
- ECMWF
- IMD GFS

MME

MME Cyclone Track Prediction

12-hourly forecast latitude (LAT^f) and longitude (LON^f) positions at time t is defined as:

$$LAT^f_t = a_o + a_1 ECMWF_t^{lat} + a_2 GFS_t^{lat} + a_3 JMA_t^{lat} + a_4 WRF_t^{lat} + a_5 QLM_t^{lat}$$

$$LON^f_t = a'_o + a'_1 ECMWF_t^{lon} + a'_2 GFS_t^{lon} + a'_3 JMA_t^{lon} + a'_4 WRF_t^{lon} + a'_5 QLM_t^{lon}$$

for t = forecast hour 12, 24, 36, 48, 60 and 72

Overview of the Operational HWRF

❖ **HWRF Atmosphere**

- **Movable, two-way nested vortex following grid**
- **9km inner domain and 27km outer domain, 42 vertical layers**
- **Advanced physics from GFDL/GFS**
- **Advanced vortex initialization with GSI/3DVAR**

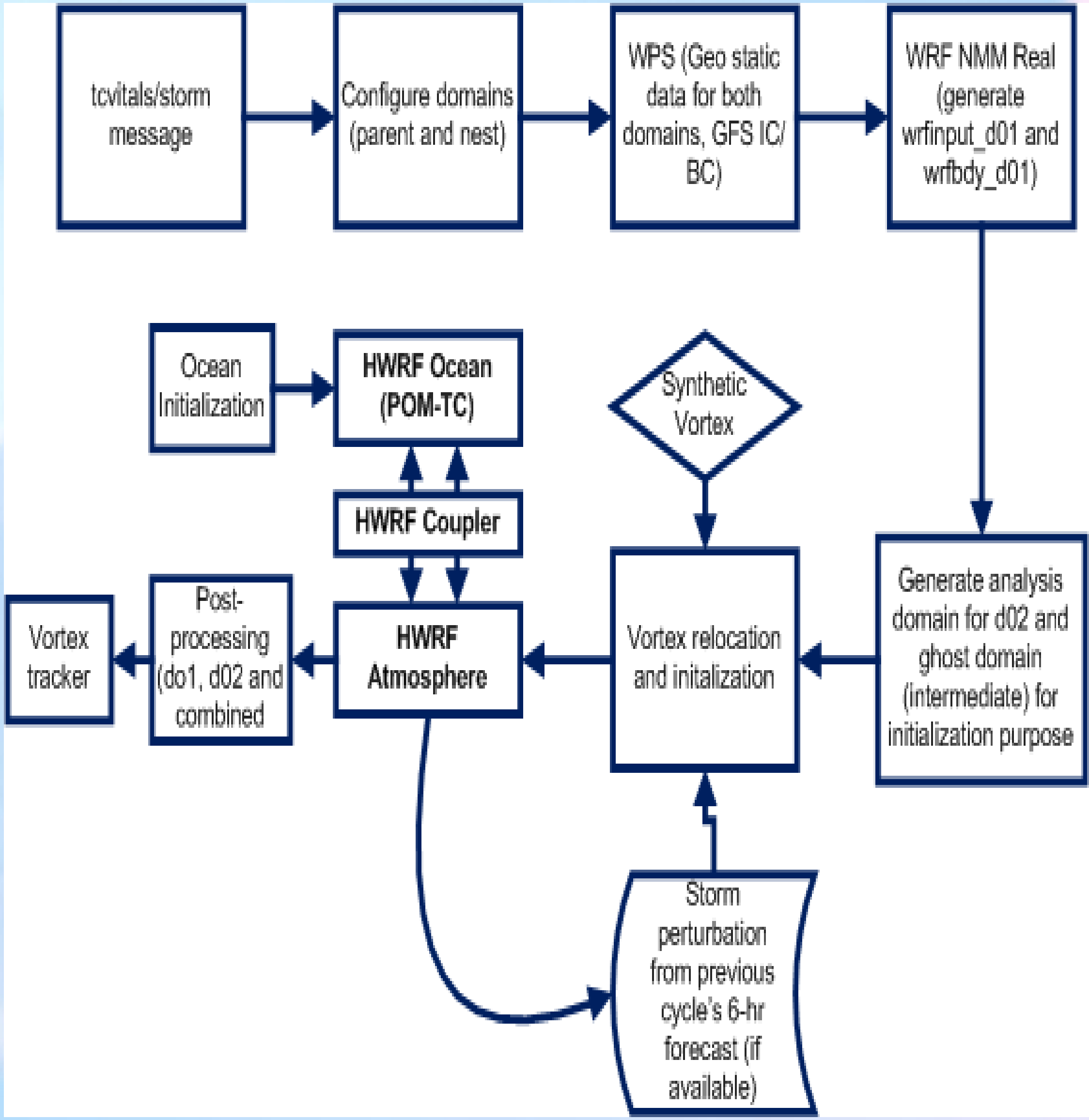
❖ **HWRF Ocean**

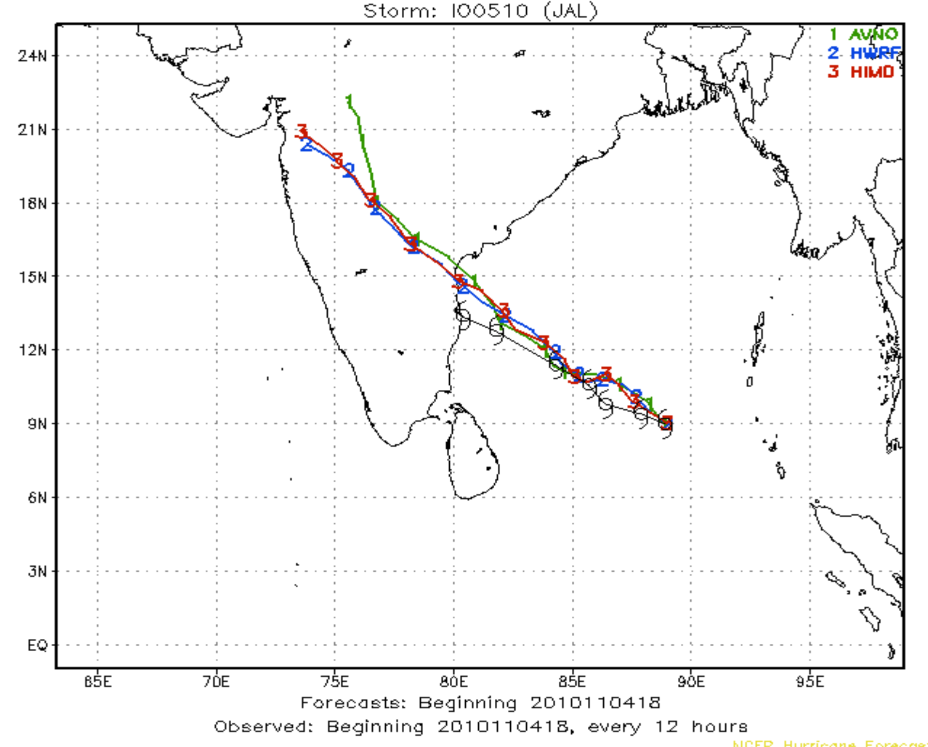
- **Coupled to Princeton Ocean Model (POM) in the Atlantic Basin**

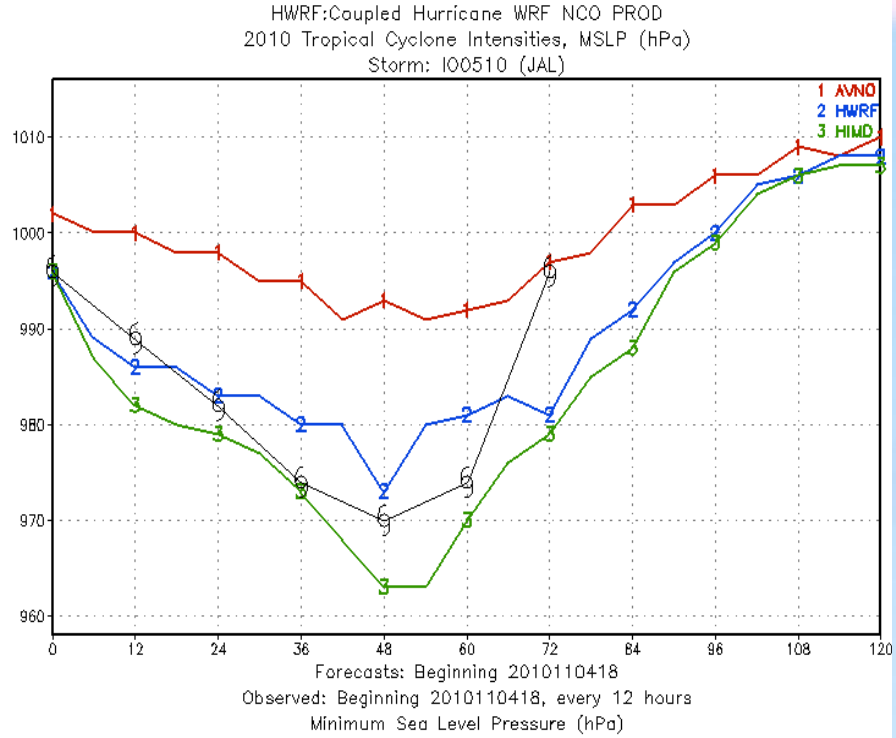
▪ **Operational HWRF products**

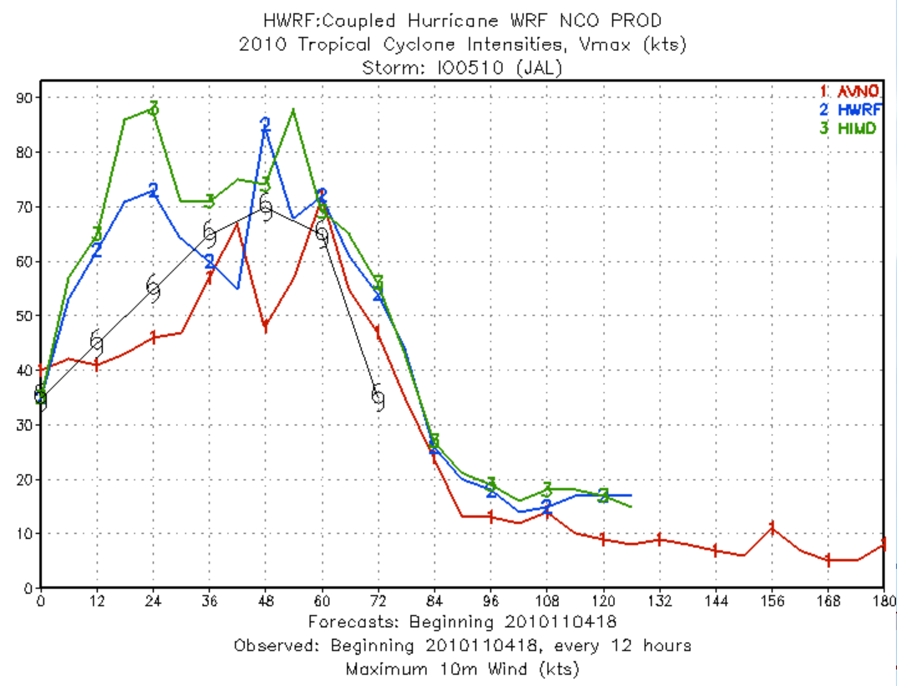
- **Numerical guidance on 6-hrly hurricane track and intensity for as many as five storms (both Atlantic and Eastern Pacific)**
- **High-resolution swaths (hourly, 10th of a degree) for wind and precipitation along the projected storm path**
- **Simulated GOES synthetic satellite imagery (IR, VIS and WV) and radar reflectivity**

▪ **Four years into operations, since 2007**



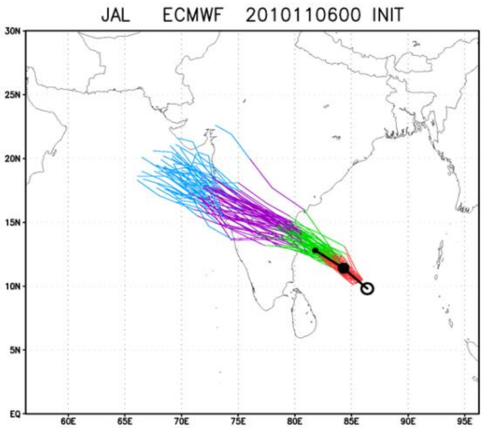


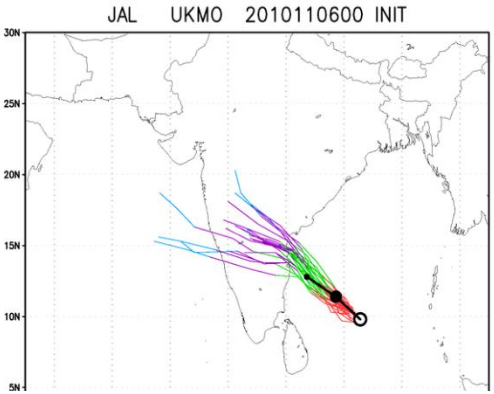


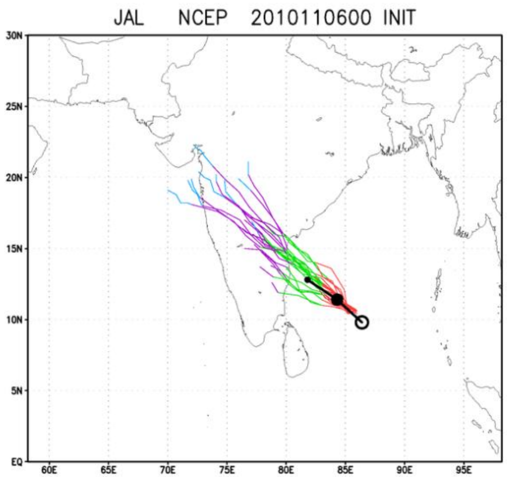


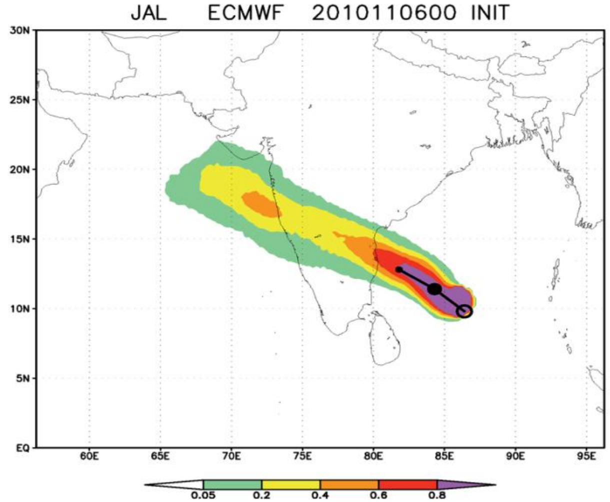
‘JAL’ , 4 to 7 November 2010, Bay of Bengal

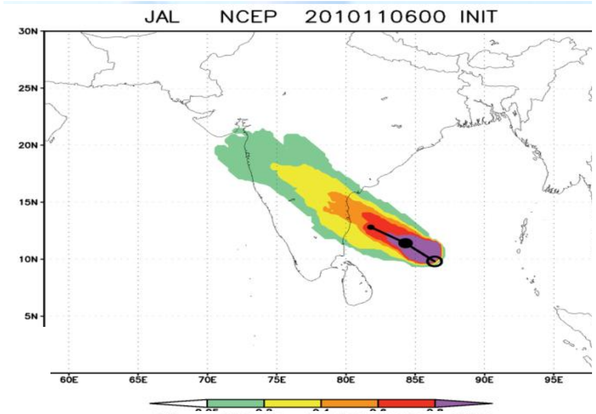
Ensemble track forecast of cyclone JAL

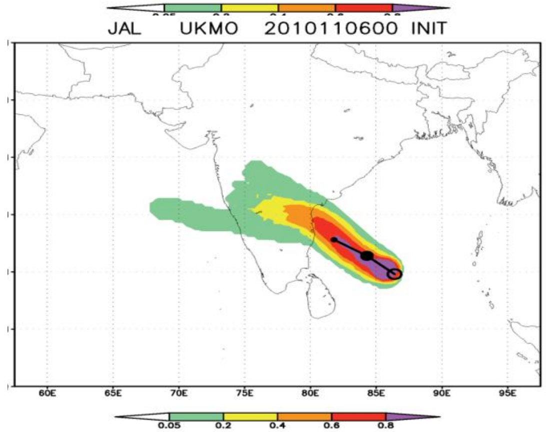


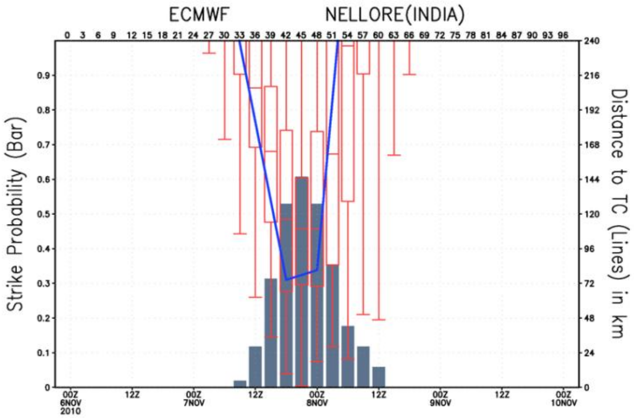


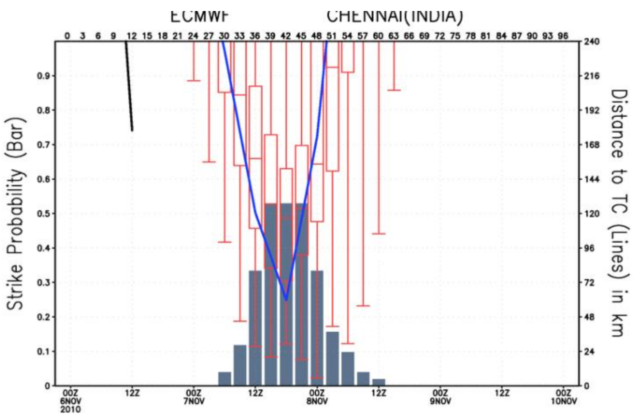


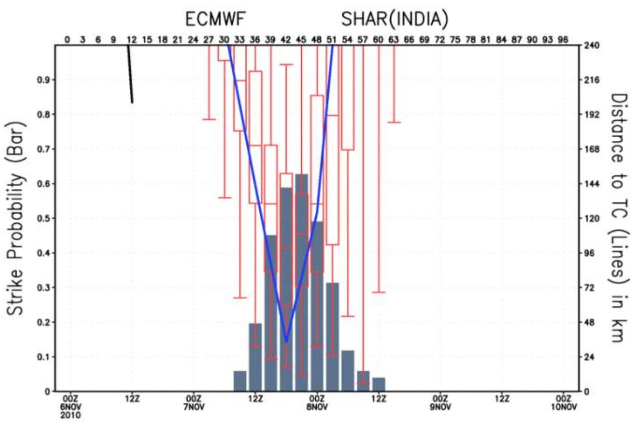


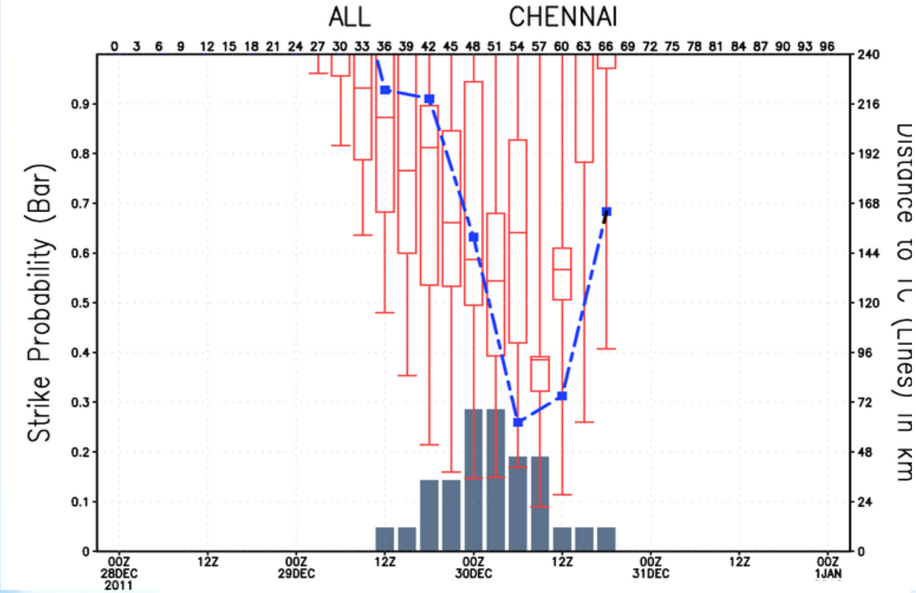


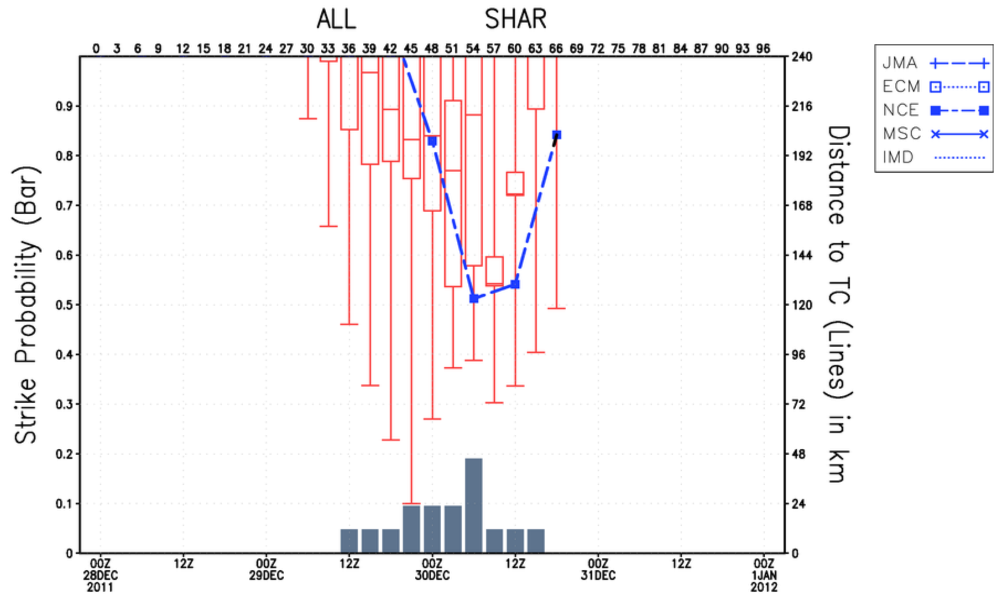


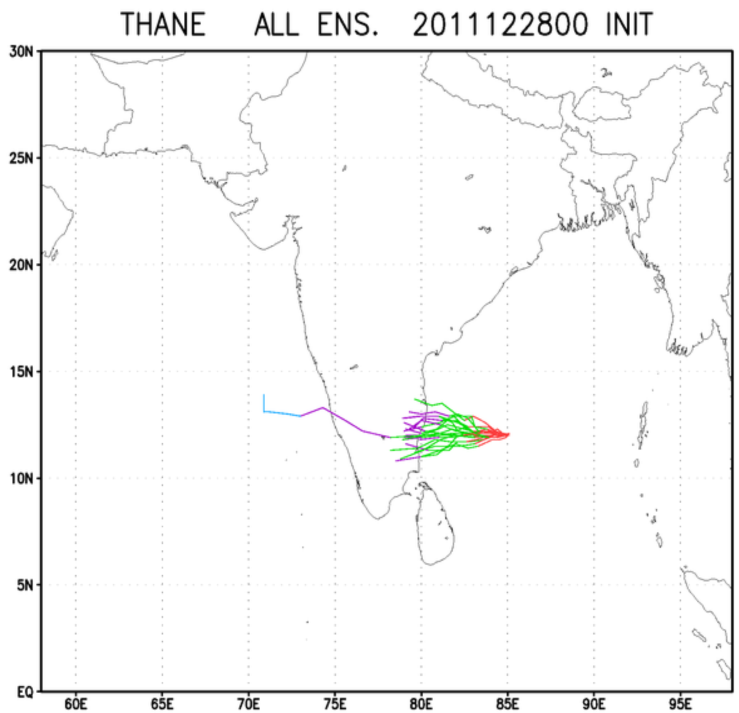












IMD - http://202.54.31.44/

NCEP - http://ruc.noaa.gov/tracks

ECMWF, NCEP Deterministic and Ensemble TC track forecasts, Strike Probability Maps .'THANE' , 26-30 December 2011

Check list for the north Indian Ocean

Model	06	12	18	24	36	48	60	72	More
a. GPP b. SCIP									
c. WRF (IMD)									
d. WRF (IITD)									
e. HWRF (IMD)									
f. WRF (NCMRWF)									
g. WRF (IAF)									
h.QLM									
i. CLIPER									
j. MOG									

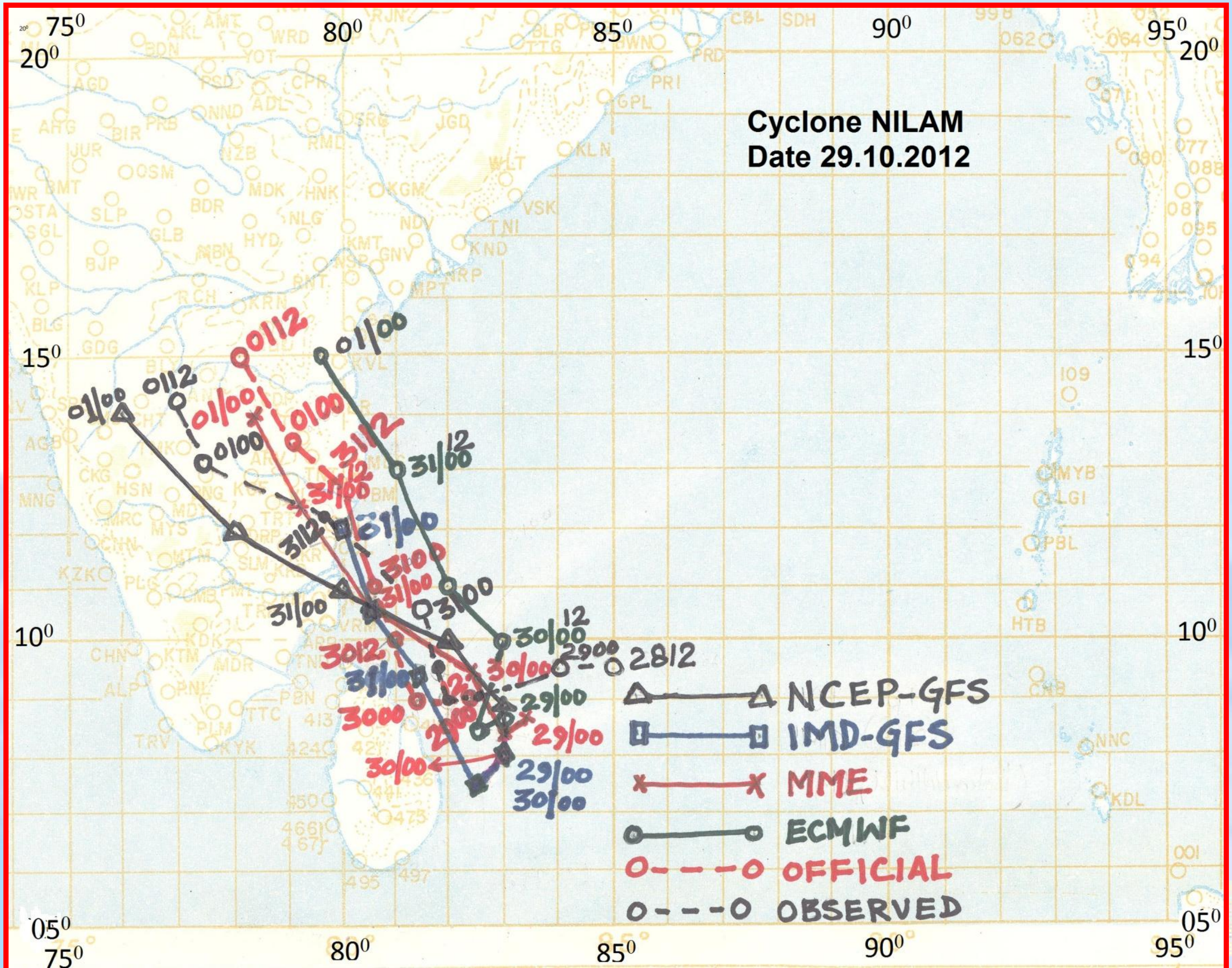
Check list for the north Indian Ocean

Model	06	12	18	24	36	48	60	72	More
i. T574/382/254									
j. UKMO									
j. JMA									
k. COLA									
l. ECMWF									
MME									
MME (TCM)									
EPS									

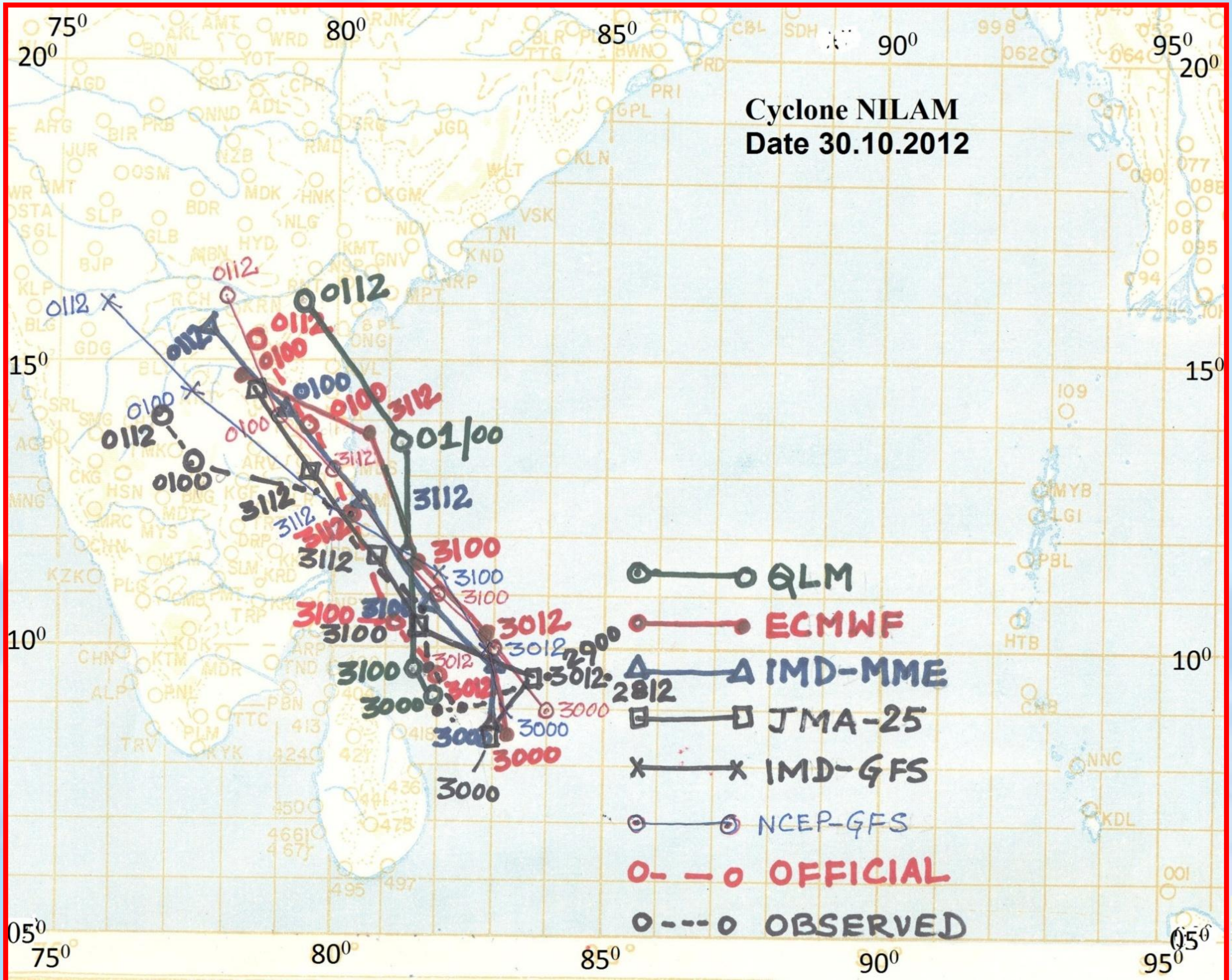
Check list for the north Indian Ocean

Forecast	00	06	12	18	24	36	48	60	72
Intensity									
Location									

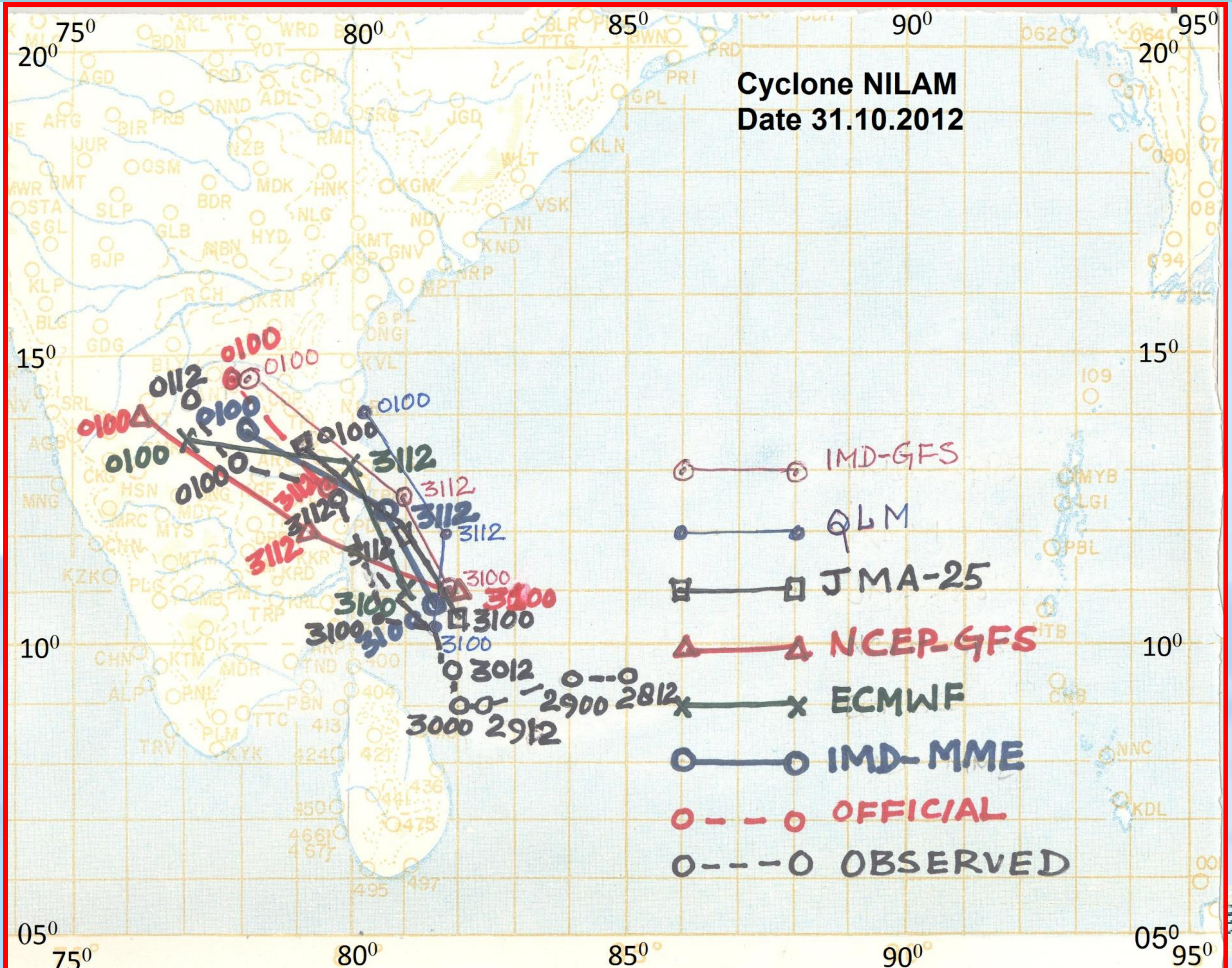
NWP Model Guidance



NWP Model Guidance



NWP Model Guidance



TC intensity forecasting methods

i) Statistical Techniques
   i) Analogue
   ii) Persistence
   iii) Climatology
   iv) CLIPER,

ii) Synoptic Techniques – Empirical Techniques (as discussed in case of genesis)

iii) Satellite Techniques Techniques

iv) Radar Techniques

v) NWP Models
   - Individual models (Global and regional)
   - IMDGFS (382, 574), NCMRWF (254), ARP (MeteoFrance, ECMWF, JMA, UKMO, NCEP, WRF (IMD, IITD, IAF), HWRF (IMD), QLM
   - Wind probability (To be developed) and risk
   - Threat graphics (To be developed)

vi) Dynamical Statistical Model (SCIP)

Operational (Consensus) forecast

Intensity forecasting by satellite method

- Continuous observation of cloud features in visible and IR imageries
- Use of microwave imageries
- Derived products
- (wind shear, vorticity, convergence/divergence
- Monitoring of brightness temperature/ cloud top temperature
- OLR
- QPE

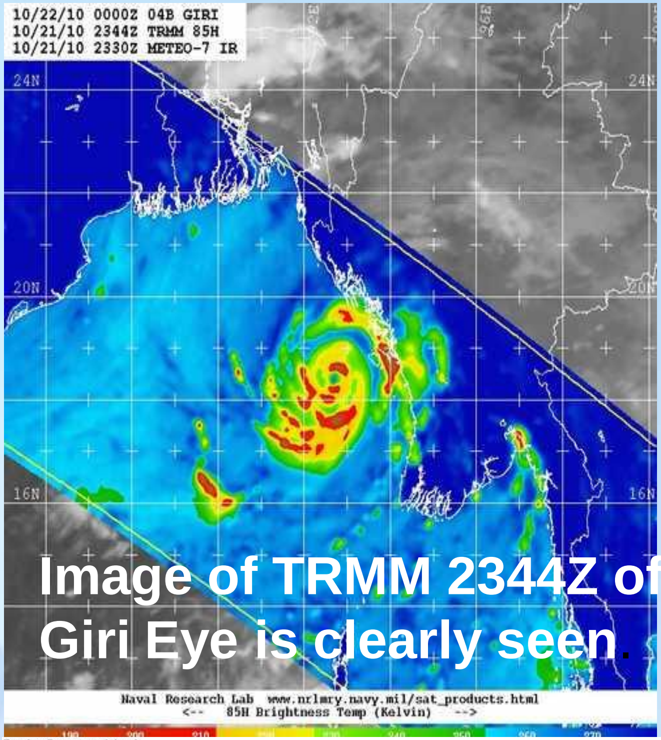
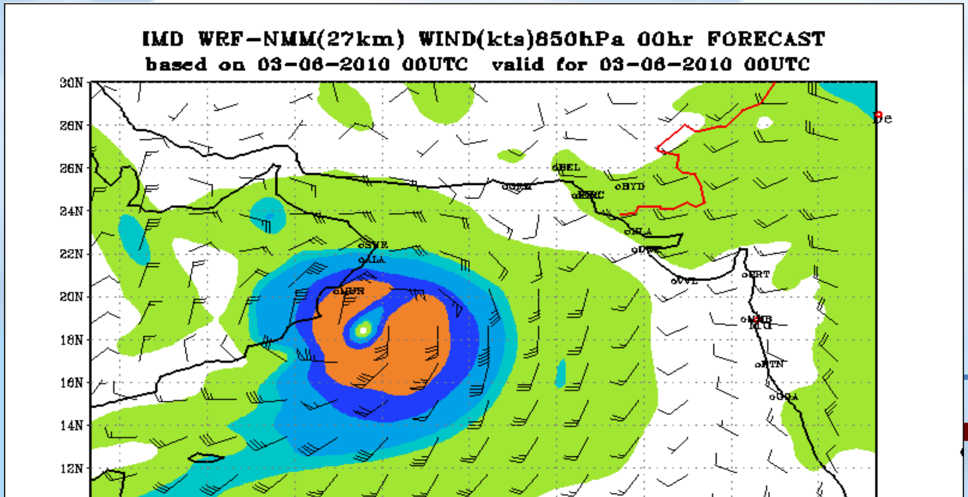
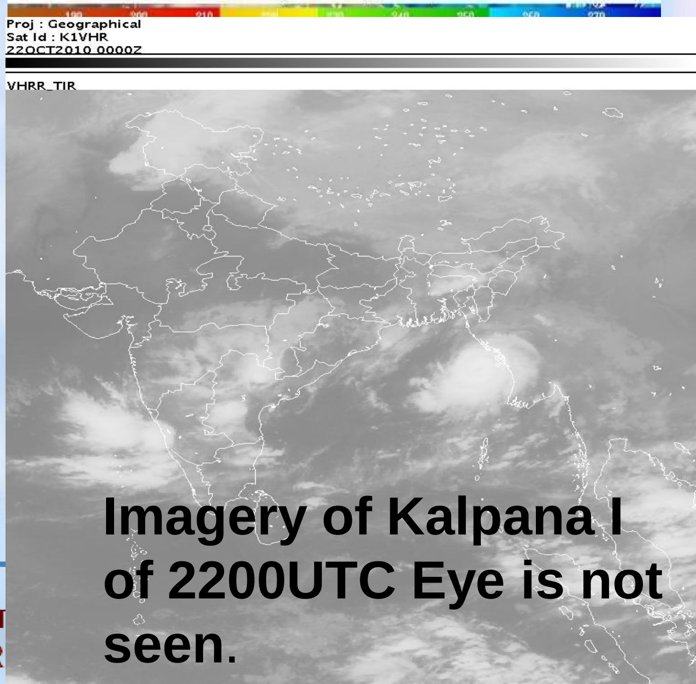


Image of TRMM 2344Z of Giri Eye is clearly seen.





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

विभा DEPAR

Intensity forecasting by radar

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. Vertical extension of convective clouds

CLIMATOLOGY : DISTRIBUTION OF WIND IN DEPRESSION AND STORM

- WINDS CLOSER TO CENTRE ARE WEAK IN A DEPRESSION OR LOW. HIGHER WIND OCCURS ABOUT 2-3 DEG AWAY FROM CENTRE
- WIND SPEED IS HIGHER NEAR THE CENTRE IN A CYCLONIC STORM
- ASYMMETRY IN WIND FIELD IS MORE IN DEPRESSION THAN IN CYCLONE
- HENCE THERE MAY BE DIFFICULT SITUATION IF ONLY WIND SPEED IS CONSIDERED. OTHER INPUTS LIKE SATELITTE AND RADAR INPUTS SHOUD BE TAKEN INTO CONSIDERATION.
- SIGNIFICANT DEPARTURE FROM NORMAL WIND IN TERMS OF DIRECTION OR SPEED OR UNUSUAL DIURNAL VARIATION SHOULD BE NOTED AS POTENTIAL INDICATOR.

Statistical Tropical Cyclone Intensity Prediction (SCIP) Model

Intensity change (dv_t) during the time interval t is defined as:

$$dv_t = a_o + a_1\,IC12 + a_2\,SMS + a_3\,VWS + a_4\,D200 + a_5\,V850 + a_6\,ISL + a_7\,SST + a_8\,ISI$$

for t= forecast hour 12, 24, 36, 48, 60 and 72

The predictors:

(a) Persistence:

(i) Initial storm intensity (ISI)

(ii) Previous 12 hours change in the intensity (IC12)

(b) Thermodynamical factors :

(i) Storm motion speed (SMS)

(ii) Sea surface temperature (SST)

(c) Dynamical factors :

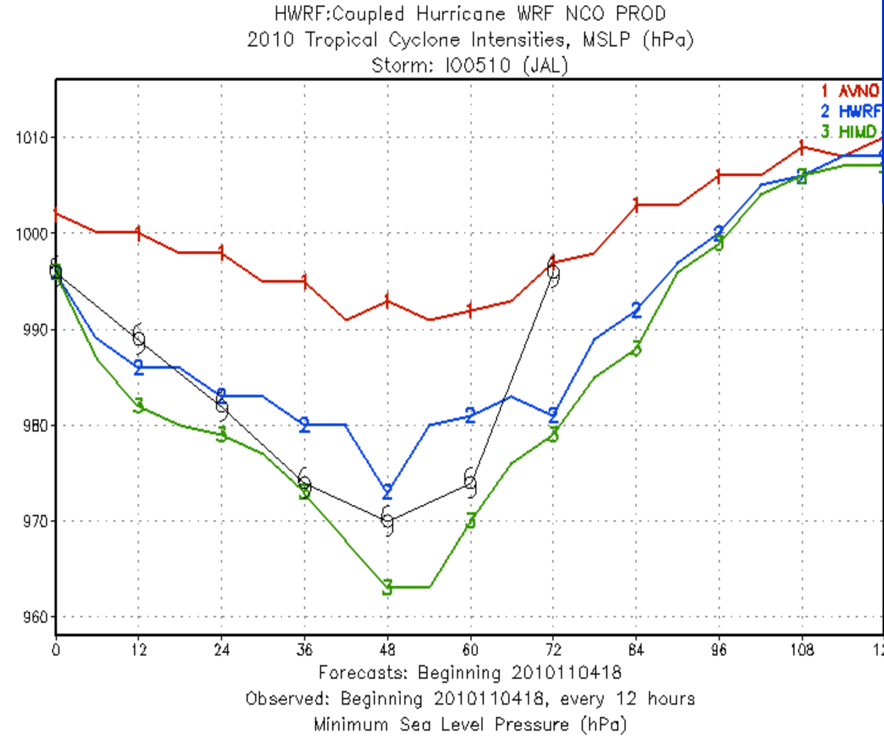
(i) Initial storm latitude position (ISL)

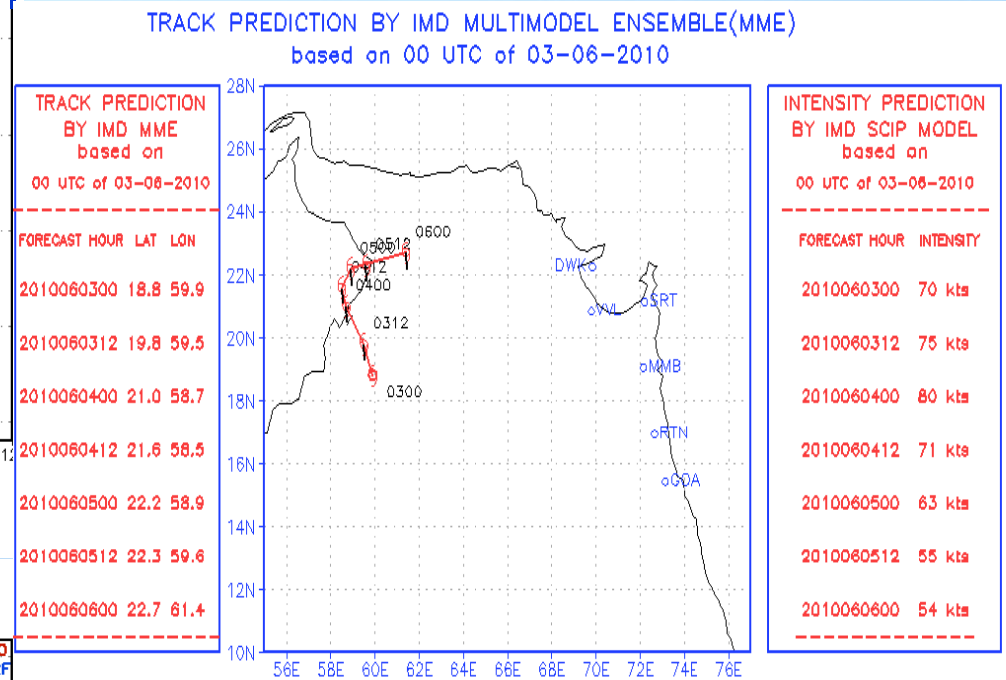
(ii) Vertical wind shear (850-200) hPa averaged along storm track (VWS)

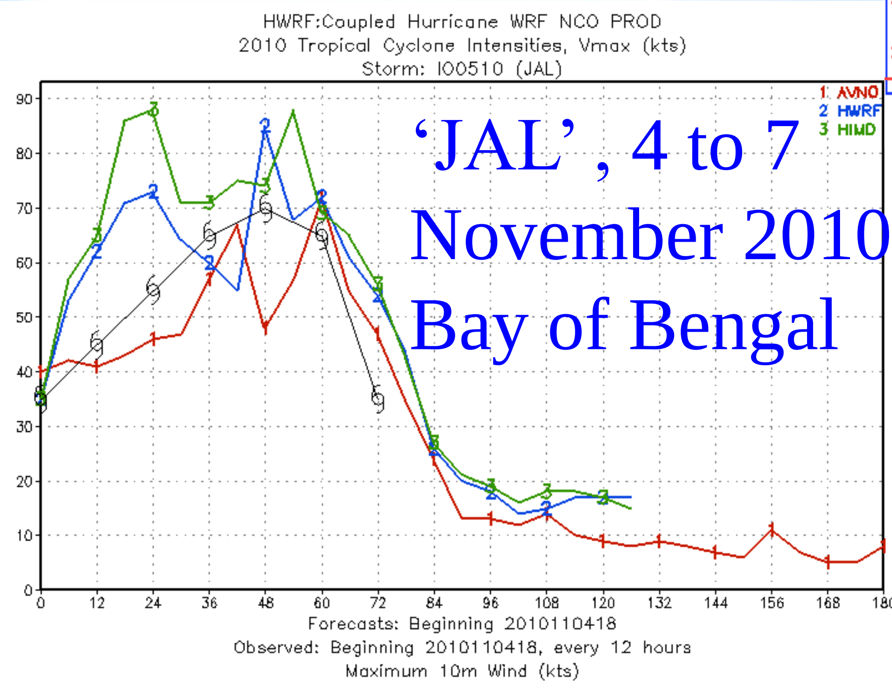
(iii) Vorticity at 850 hPa (V850)

(iv) Divergence at 200 hPa (D200)

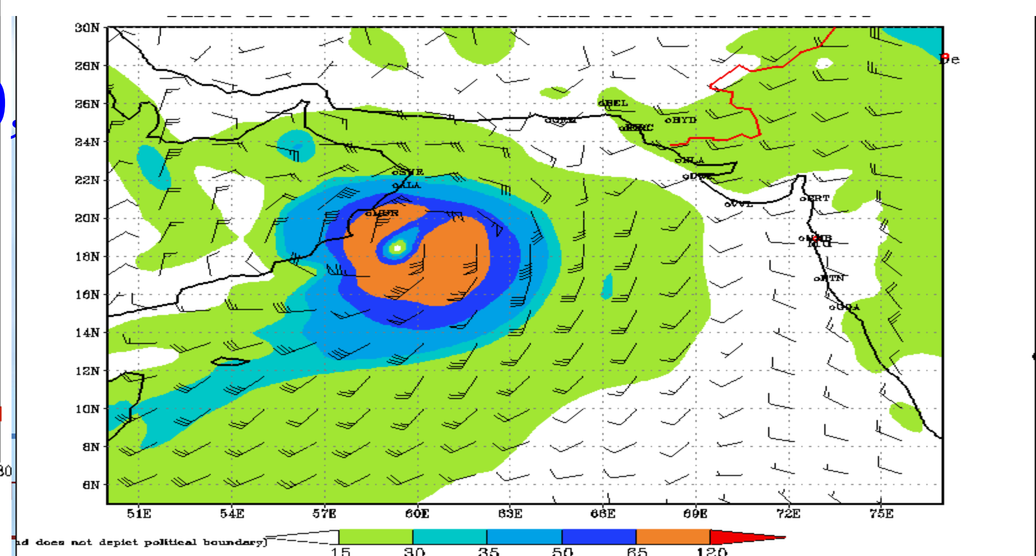
NWP guidance for TC intensity forecasting







‘JAL’ , 4 to 7 November 2010, Bay of Bengal



Forecast of TC wind radii

Road Map

a. Official forecast of TC intensity and track upto 72 hrs.

b. Persistence forecast based on initial wind radii and past 12 hrs trend.

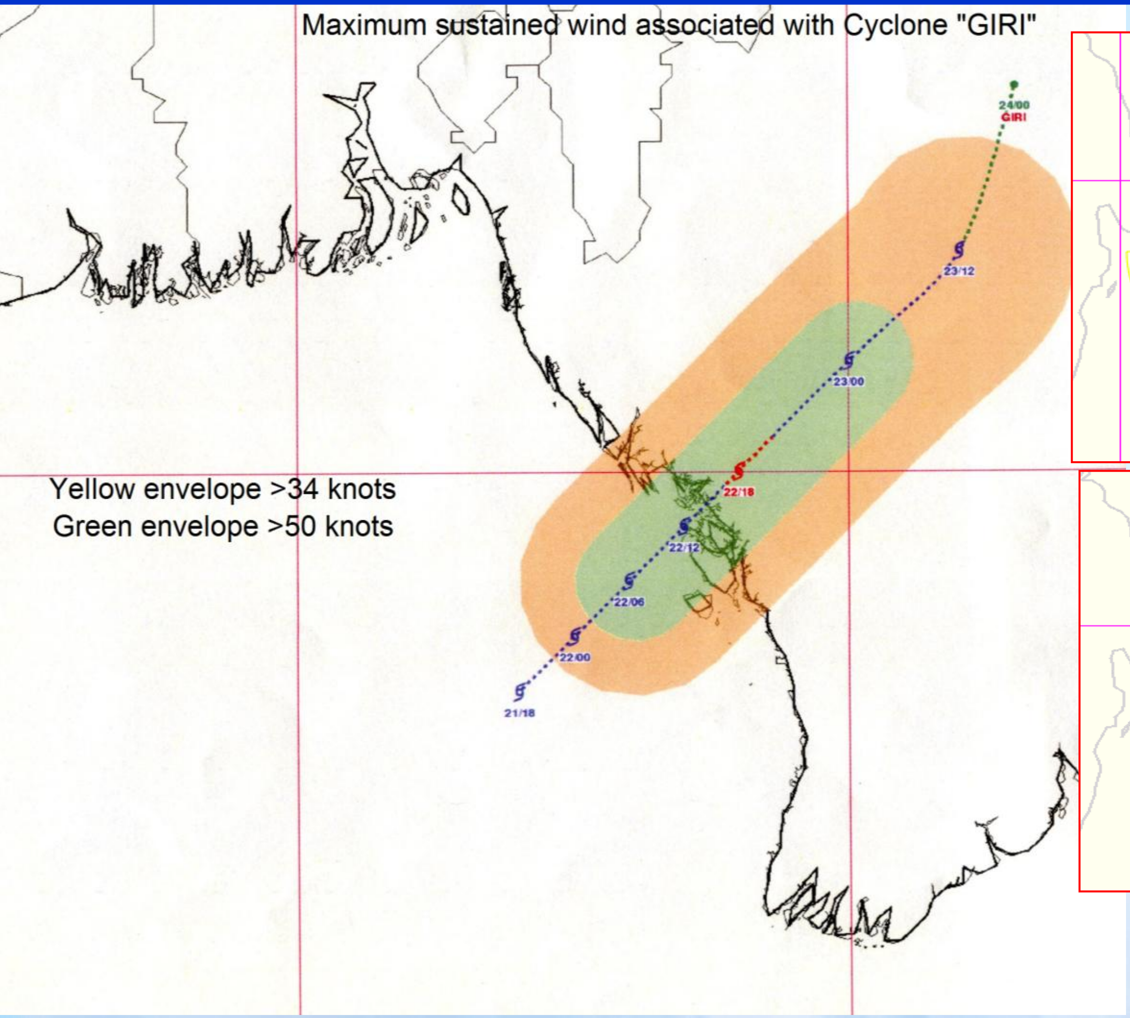
c. Climatological forecast of TC wind radii

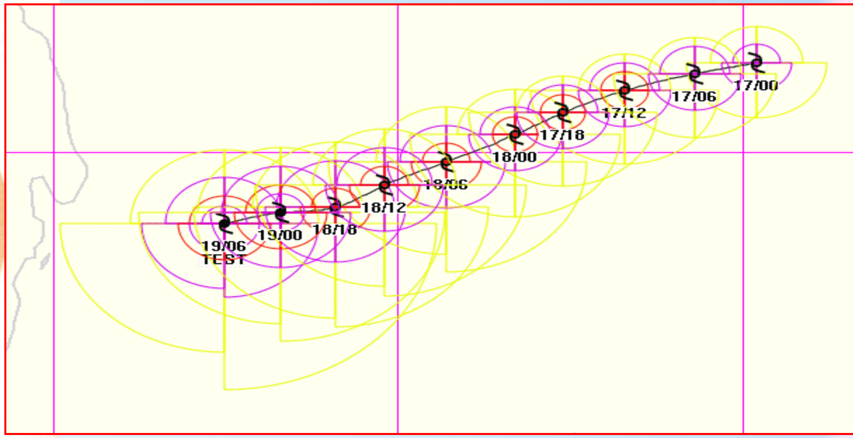
d. NWP Model forecasts of 10 metre wind radii

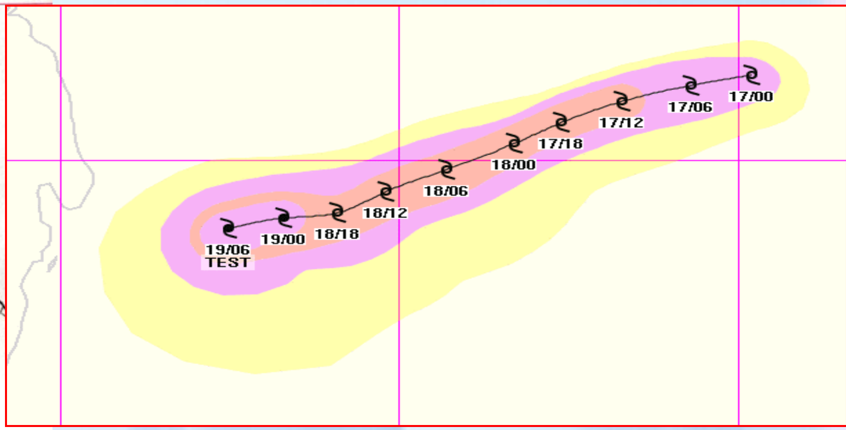
- Select the model most appropriate to initial condition
- Compose the wind field distribution to the actual wind
- Calculate the wind radii in four quadrants for the threshold of 34kts, 50kts and 64kts surface wind

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

A typical graphical presentation of cyclone wind forecast during cyclone, GIRI







Display of wind radii (quadrants)

Issues related to track forecasting

- Early models
- Late models
- Interpolation of model track forecast for real time use like use of GFSI in stead of GFS
- Error is still high
- Dispersion in tracks is very high in some cases

Average Track Prediction Errors over NIO during 2008-11 using Different Models

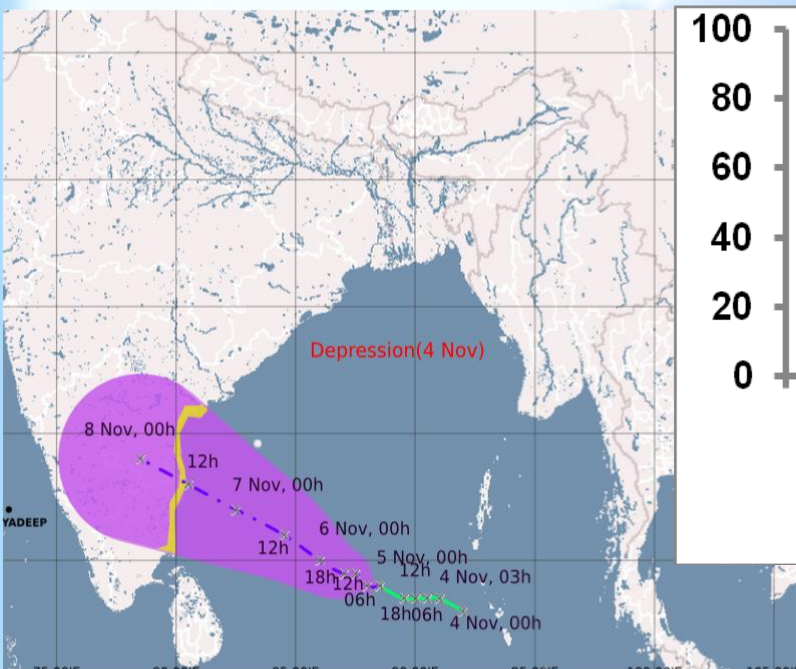
FCST Period	Forecast error (in km) using various models						
	ECMWF	NCEP / GFS	JMA	T382	MM5	WRF	CLIPER
0 hr	100	169	165	-	80	-	0
24 hr	103	173	170	125	216	146	180
48 hr	174	190	235	194	292	201	363
72 hr	246	334	268	290	356	265	540

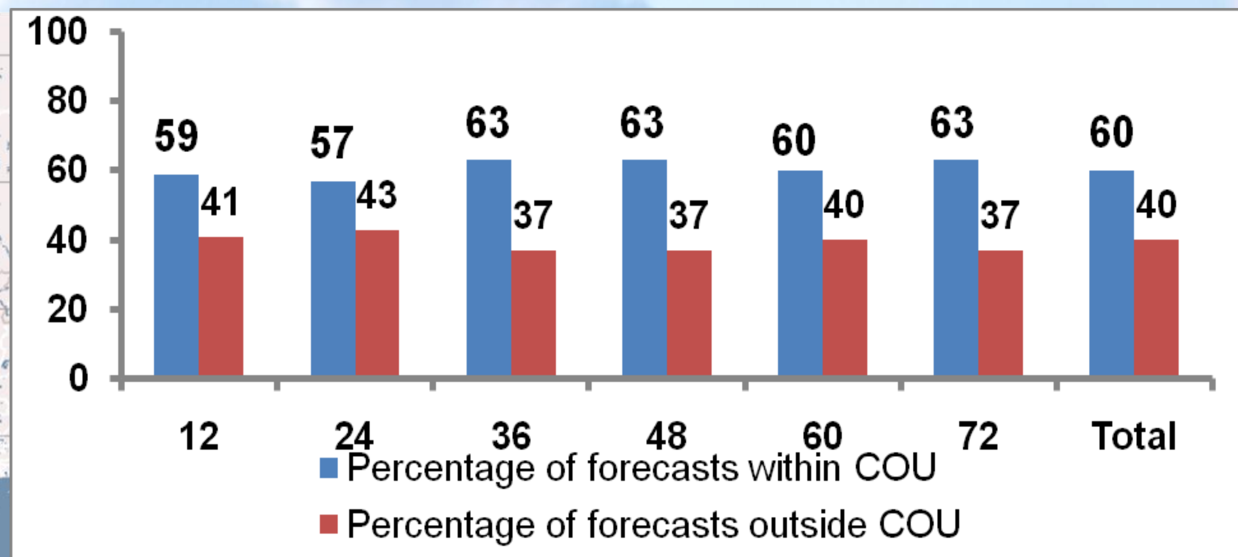
Cone of Uncertainty : Data and Methodology

Forecast period (hrs)	Standard error (nm)	Standard error (kms)
12	40	75
24	80	150
36	110	200
48	135	250
60	165	300
72	190	350

INDIA METEOROLOGICAL DEPARTMENT

Observed and Forecast Track





Factors Contributing Towards Track Forecast Improvement

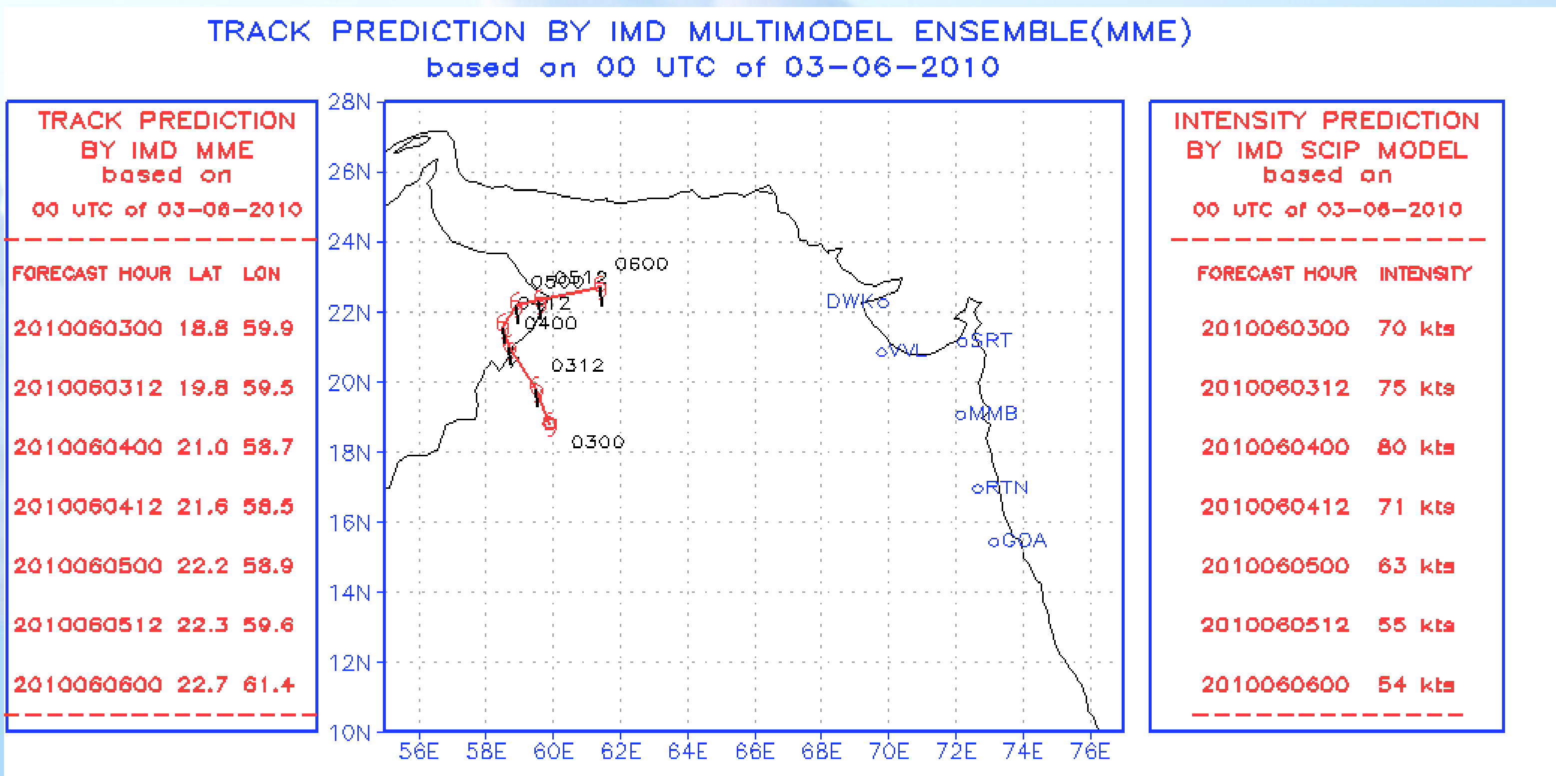
- **Greater use of Conventional and Non-Conventional data to correctly position the vortex, represent structure of storms and define large-scale environment (Improved Data Assimilation)**
- **Continuous model development including Physical Parameterization**
- **Higher Resolution of forecast models**
- **Use of Synthetic Vortex**
- **Implementation of HWRF**
- **EPS and super-EPS**

Study needed (Track and intensity prediction)

- Numerical Modeling should be taken up as per the requirement of cyclone warning
  - Effort to be made for NWP modeling for landfall processes
  - Attempt to be made to understand land interaction with the system leading to change in intensity, track and associated rain and wind
- Evaluation of NWP and statistical models by calculating skill score
- CLIPER
  - CLIPER model for track prediction being updated with new data
  - CLIPER model for intensity prediction to be developed

Difficulties and Limitations in wind radii forecasting

- Unavailability of objective wind radii forecast methods
- ❖ Numerical Weather Prediction (NWP) models fail to produce forecasts that are better than climatology
- ❖ Wind radii forecasts depend on track and intensity forecasts.
- ❖ It is very sensitive to vortex initialisation in NWP models and intensity forecasts.



Difficulties and Limitations

- Over the past several years, there have been large improvements in track skill (RSMC, New Delhi, 2011) and modest improvements in the intensity skill like other Ocean basins.
- Intensity and track errors at 24 hrs (say) are still of the order of 15kts and 130 km.
- These errors, particularly the intensity errors negatively affect wind radii forecasts.
- The poor intensity forecast is particularly pronounced when intensity forecast fail to or falsely forecast winds that exceed the 34kts, 50kts and 64kts thresholds.

Thank you