Achievements and Challenges in Tropical Cyclone Forecasting over North Indian Ocean

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TROPICAL CYCLONE FORECASTING IN INDIA:
A PARADIGM SHIFT

- **FRONT LINE MAGAZINE (NOV 1999): SCIENTIFIC FAILURES.**
  The scientific systems whose responsibility it was to predict the contours of the cyclone did a far from perfect job. To be able to do a better job next time around, an integrated approach to cyclone studies is needed.

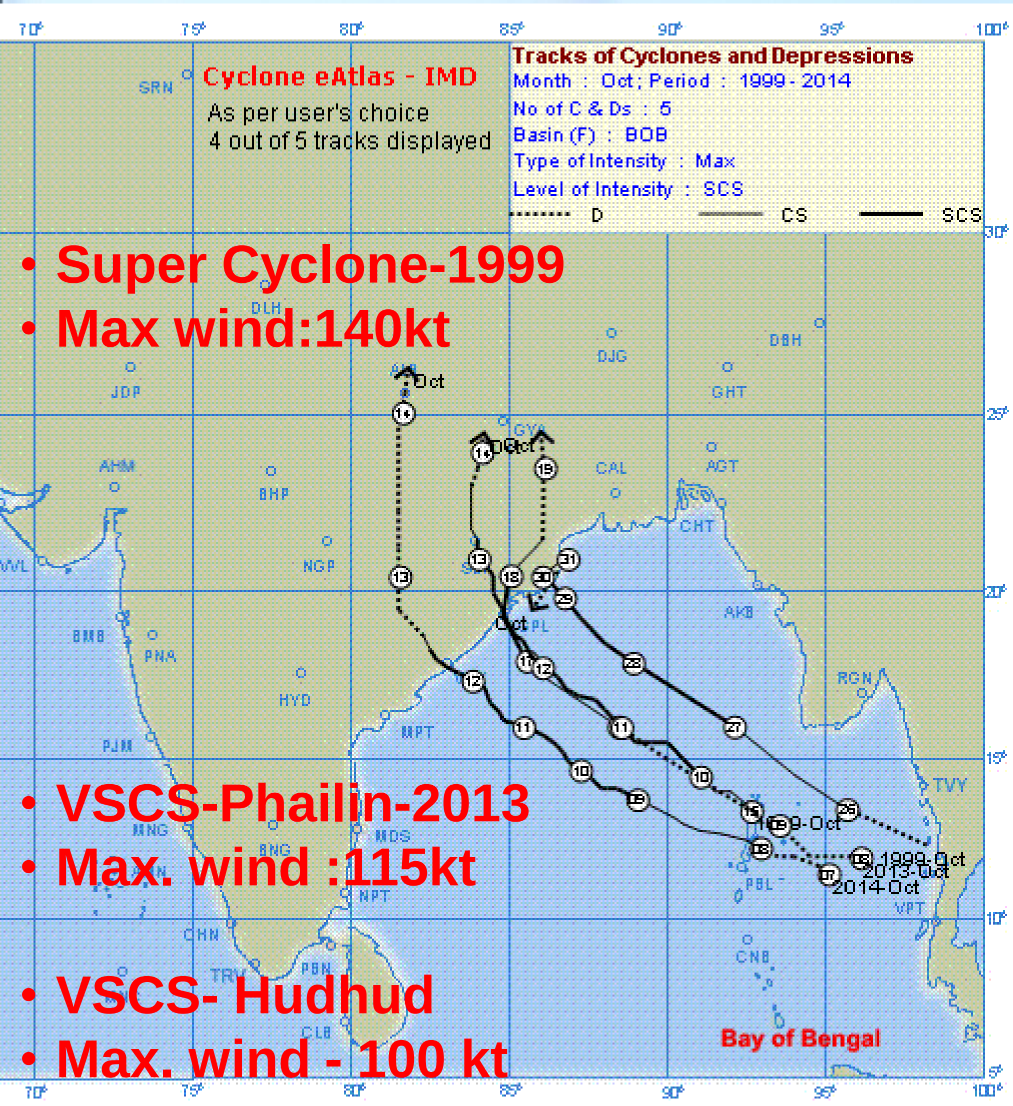
- **FRONT LINE MAGAZINE (NOV 2013): ACING THE STORM.**
  The India Meteorological Department, with improved models and observation systems and greater forecast skills, predicts accurately not only the intensity of cyclone Phailin but also its landfall.

Worldwide Appreciation of Cyclone Warning in India :

Text of PM Shri Narendra Modi's address

"I must congratulate …. their accurate prediction of Cyclone Hudhud saved thousands of lives ……..." on 14 Oct 2014 during visit to Vizag.

Comparison of Odisha Super cyclone (1999) and Very Severe Cyclonic Storm (VSCS) Phailin (2013) and Hudhud (2014)

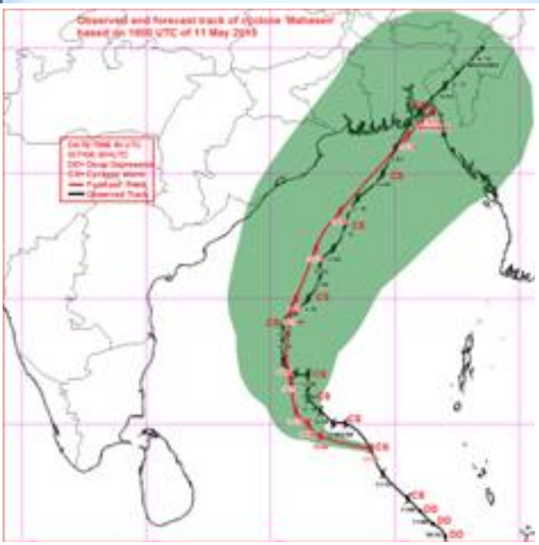


- **Super Cyclone-1999**
- **No objective forecast**
- **Lead period was less (24 hrs)**
- **Accuracy was moderate**
- **Poor Warning communication and triggering mechanism**
- **Poor response and evacuation (44, 000 people)**
- **9887 people died**

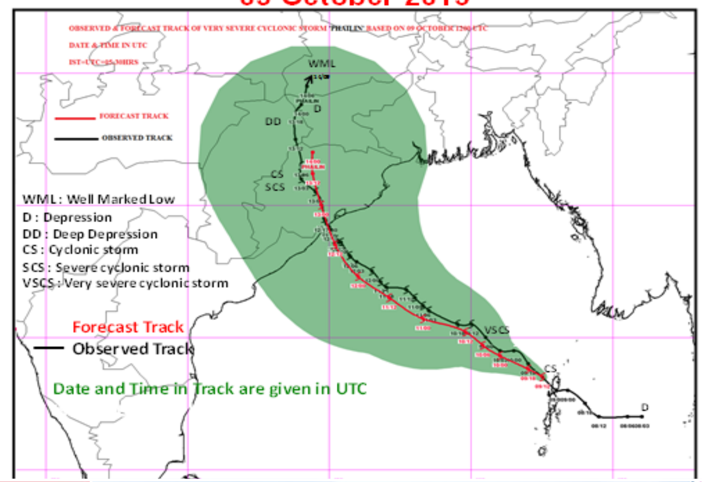
- **VSCS-Phailin and Hudhud**
- **Objective track, intensity and landfall forecast-5 day lead**
- **Accurate impact based warning (Rain, storm surge)**
- **Effective communication and triggering mechanism**
- **Effective response and evacuation (1 Million people)**
- **21 and 46 people died**

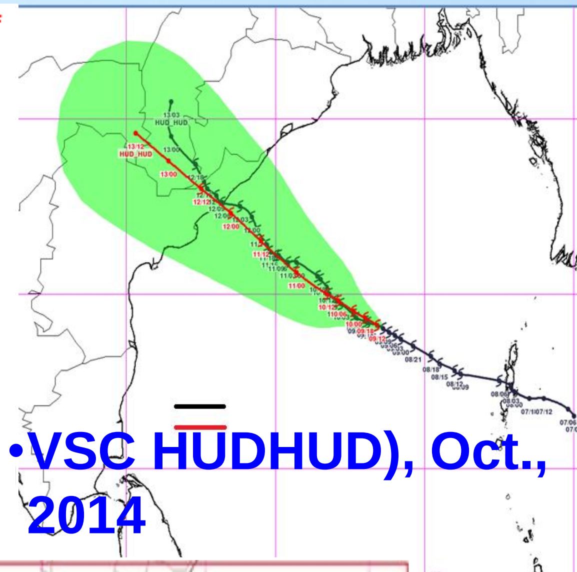
Phailin and Hudhud are not an isolated case of success

- Due to several initiatives taken by IMD, Ministry of Earth sciences (MoES), Govt of India, the cyclone forecast has improved in recent years significantly

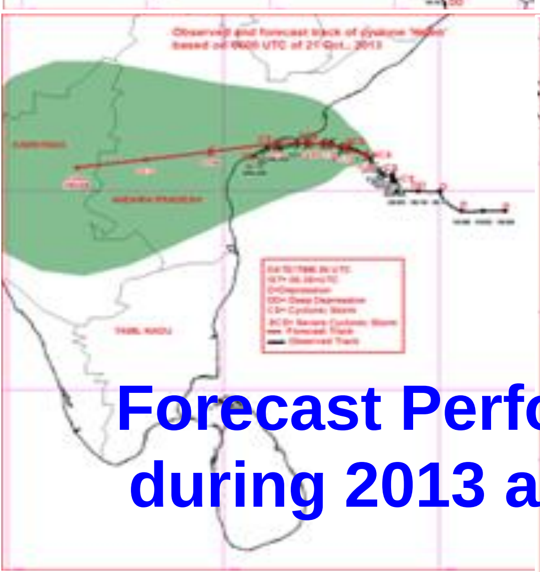


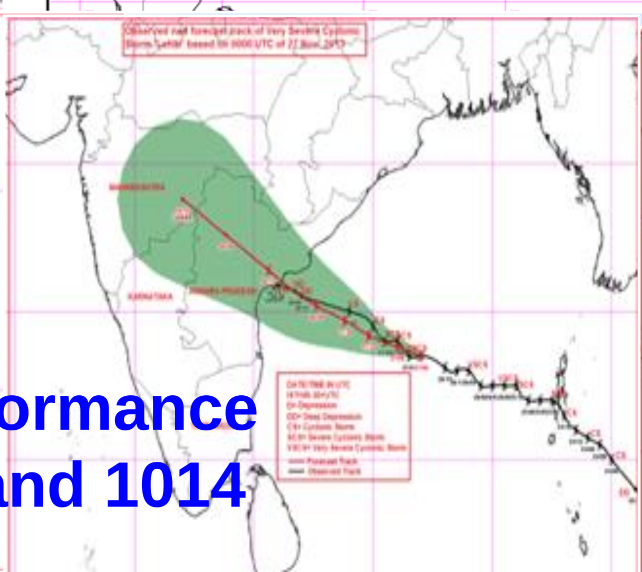
Observed and Forecast Track based on 1200 UTC of 09 October 2013

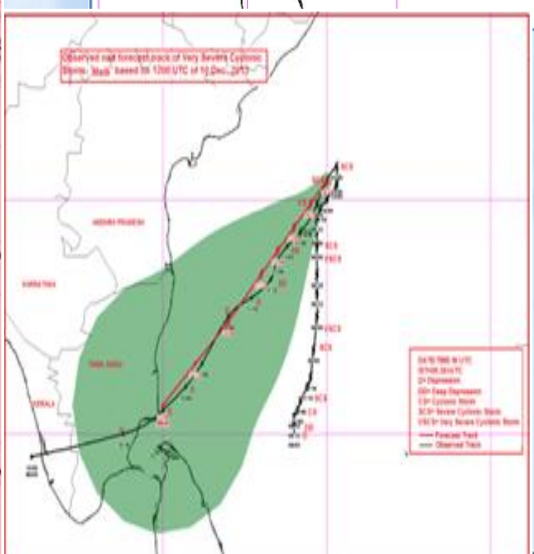




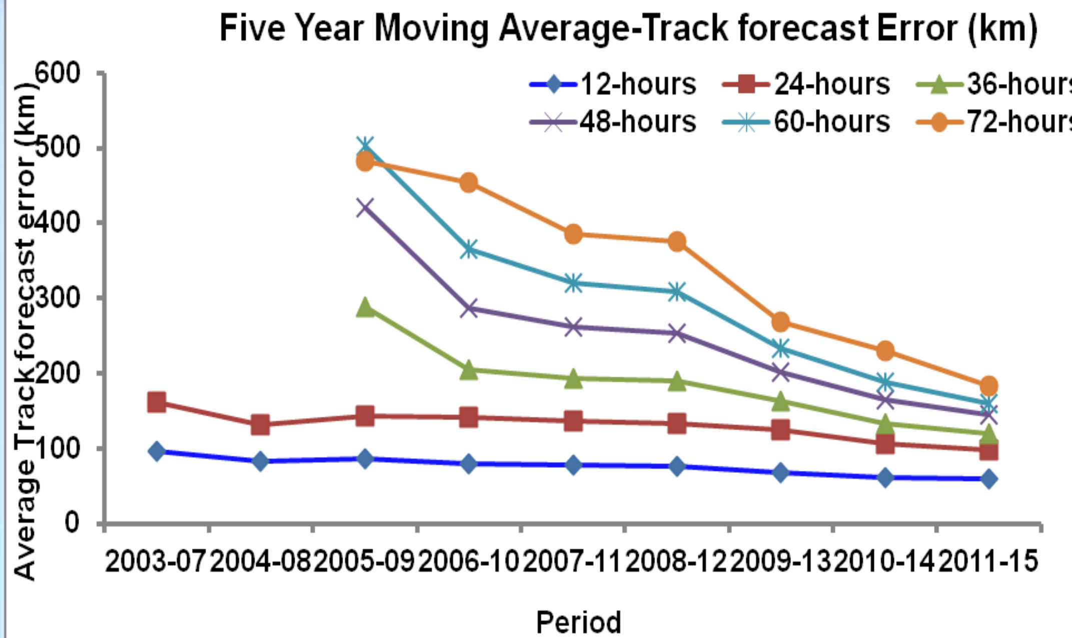
- VSC HUDHUD), Oct., 2014

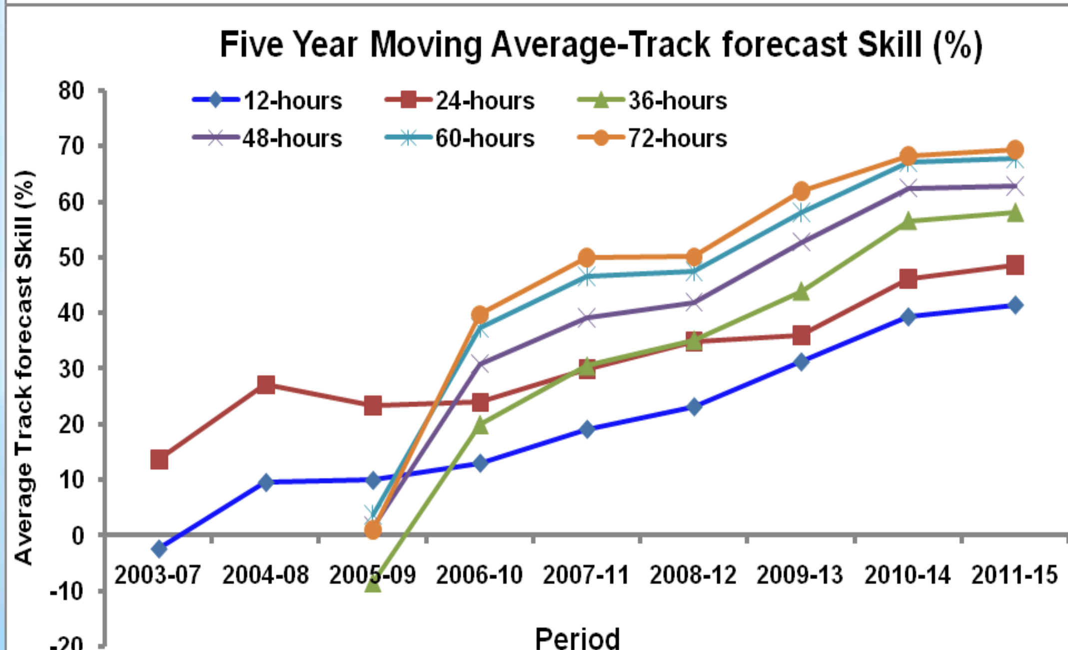






Forecast Performance during 2013 and 1014





Average error in km (2011-15)

Lead	Error	Lead	Error
12 hr – 59.1		48 hr-	145.5 km
24 hr – 97.5		60 hr-	160.4 km
36 hr – 120.0		72 hr-	183.2 km

Reduction in error from 2006-10 to 2011-15 :

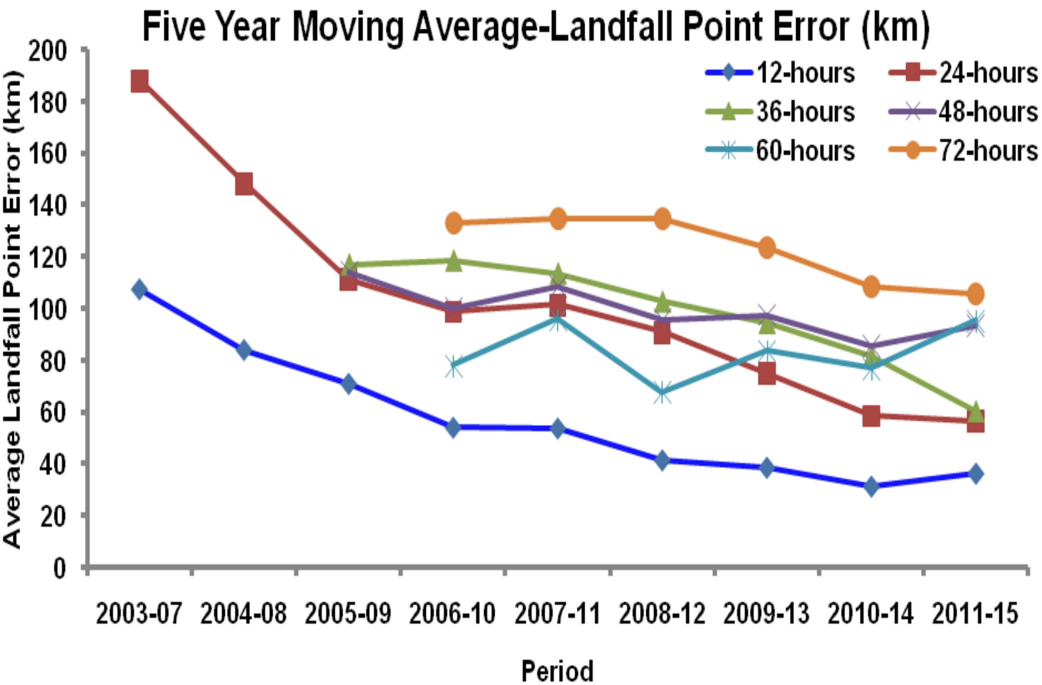
12 hr : 26%, 24 hr : 31%
36 hr : 41%, 48 hr : 49%
60 hr : 56%, 72 hr : 60%

Average during last five years (2011-15)

12 hr : 41.4% 24 hr- 48.5%,
36 hr : 58.1% 48 hr- 62.7%
60 hr : 67.8% 72 hr- 69.3%

Improvement in skill from 2006-10 to 2011-15

12 hr : 220% 24 hr: 103%,
36 hr : 190% 48 hr: 104%,
60 hr : 82% 72 hr: 75%

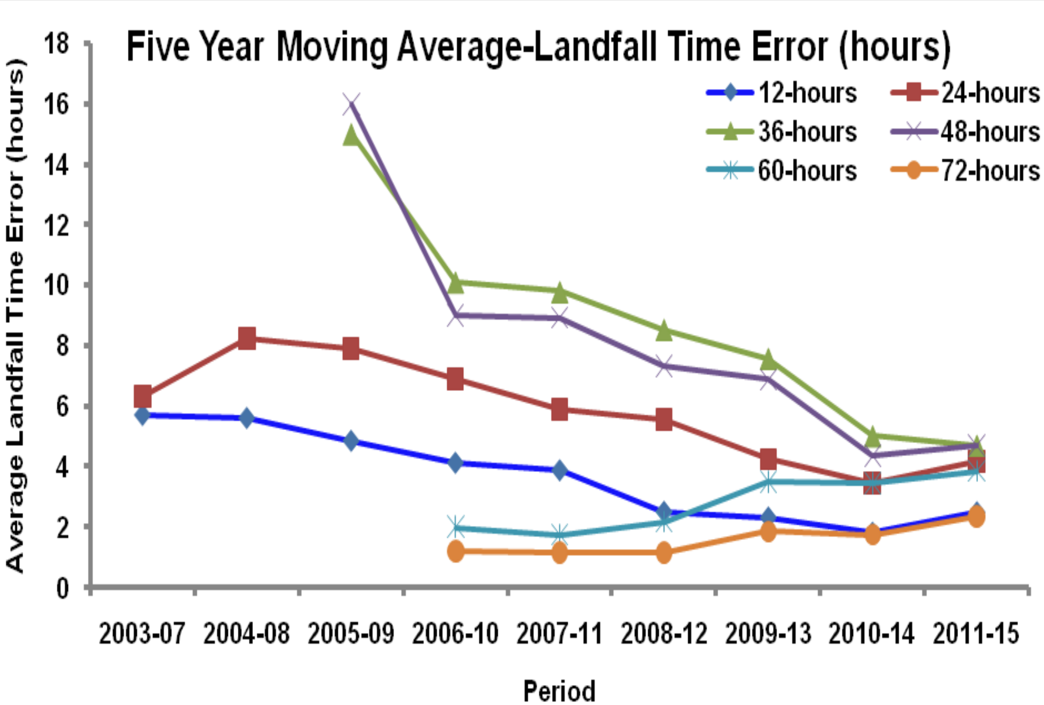


Average error in km (2011-15)

Lead	Error	Lead	Error
12 hr – 36.5		24 hr-	56.3 km,
36 hr – 60.6		48 hr-	93.5 km
60 hr – 95.2		72 hr-	105.7 km

Reduction in Landfall point error from 2006-10 to 2011-15:

12 hr : 33%, 24 hr : 43%
36 hr : 49%, 48 hr : 67%
68 hr : -22%, 72 hr : 21%

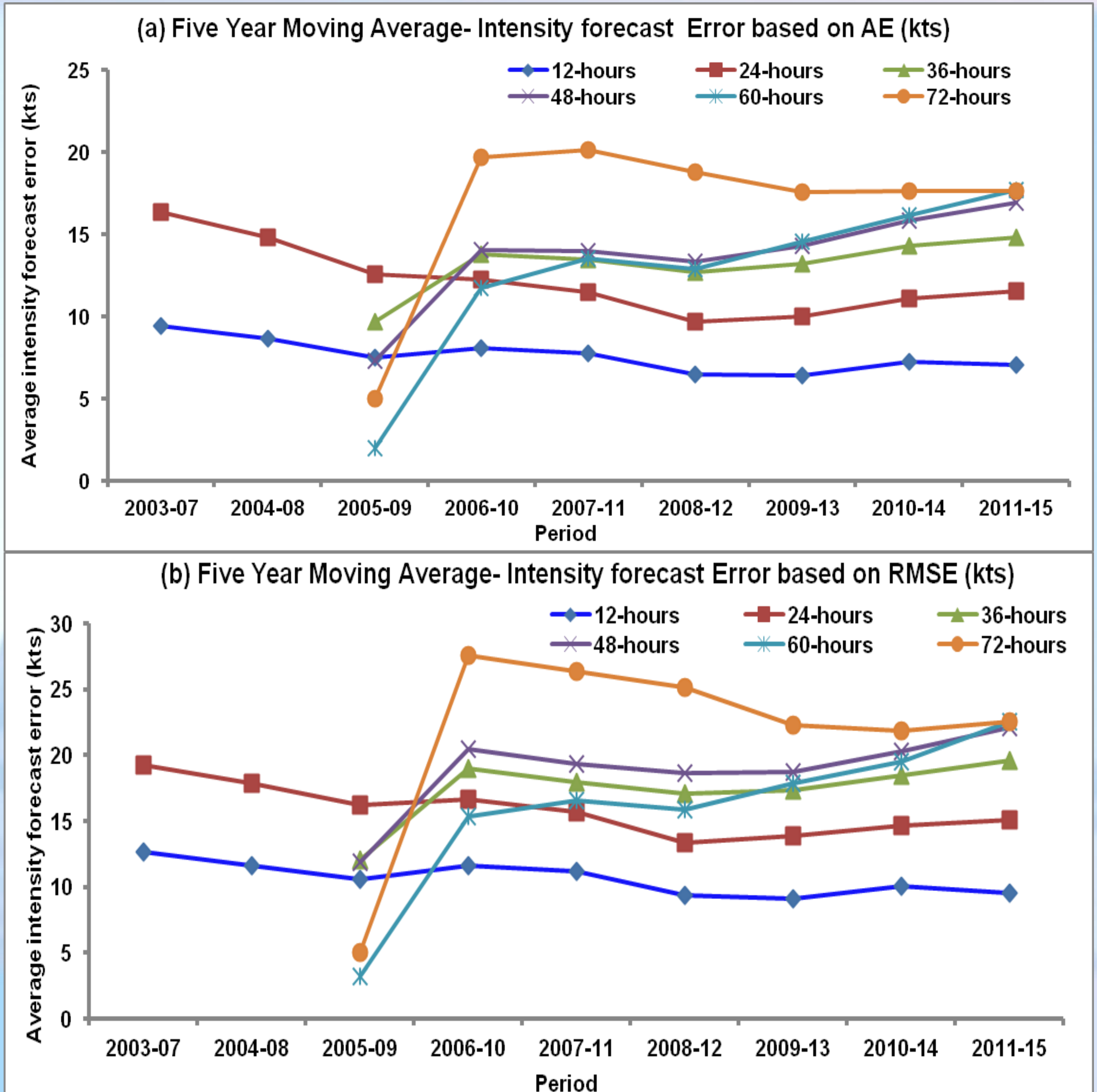


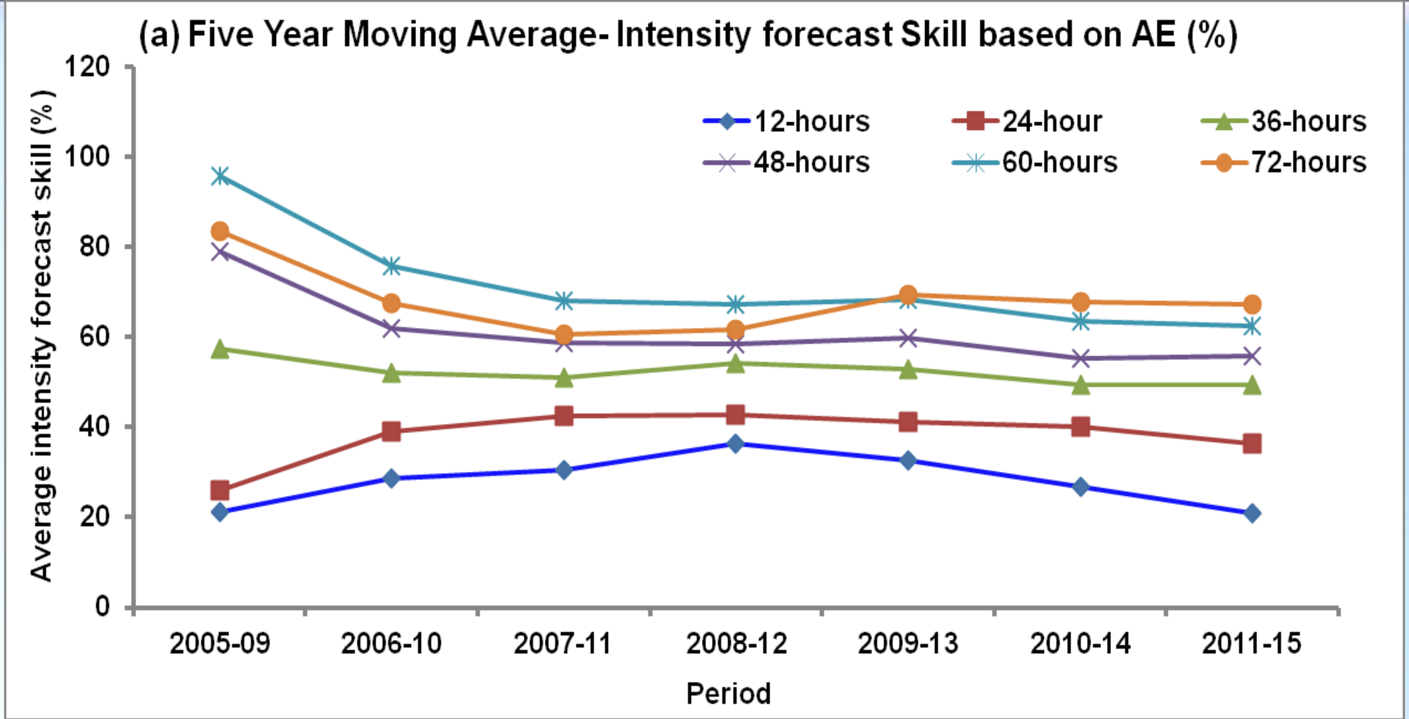
Average error in hr (2011-15)

Lead	Error	Lead	Error
12 hr – 2.5		24 hr-	4.2 hr,
36 hr – 4.7		48 hr-	4.7 hr,
60 hr – 3.9		72 hr-	2.4 hr

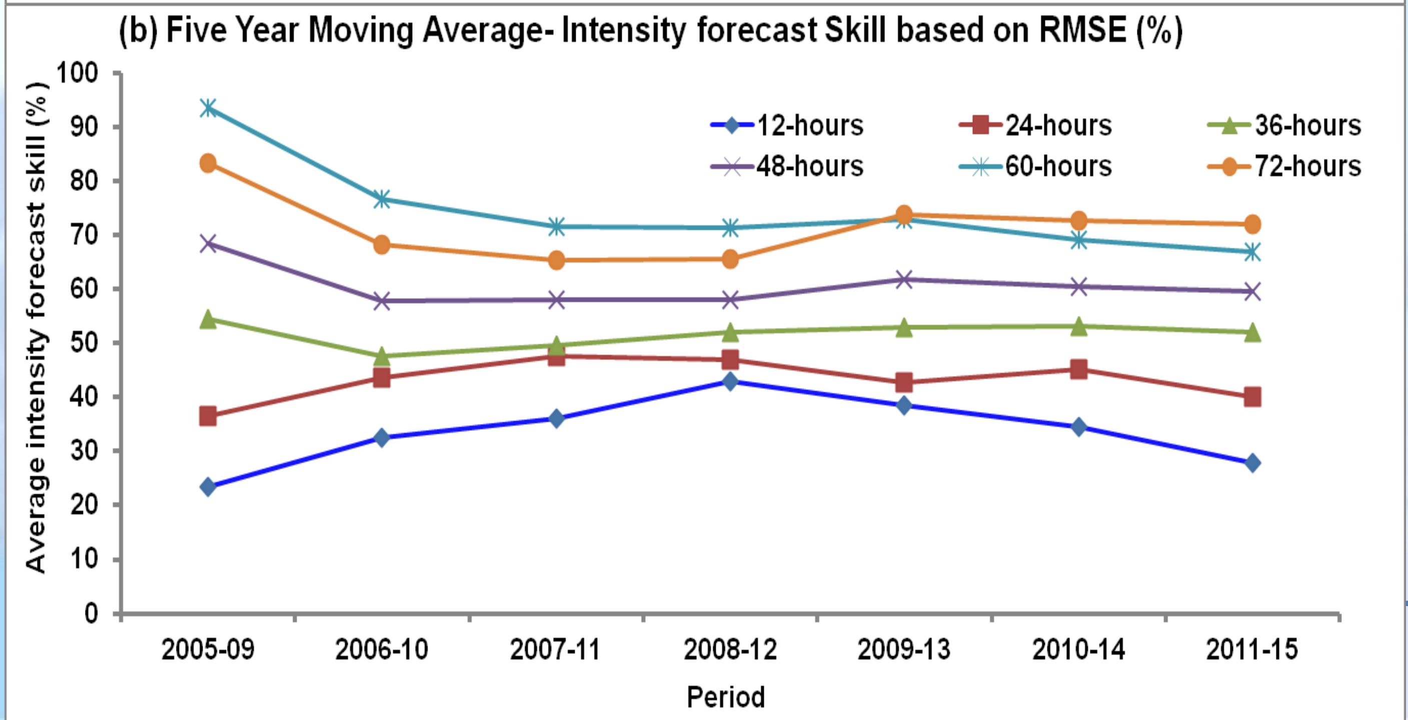
Reduction in Landfall time error from 2006-10 to 2011-15:

12 hr : 40%, 24 hr : 40%
36 hr : 54%, 48 hr : 48%
68 hr : -93%, 72 hr : -96%


(a) Five Year Moving Average- Intensity forecast Error based on AE (kts)
12-hours
24-hours
36-hours
48-hours
60-hours
72-hours
Average intensity forecast error (kts)
0
5
10
15
20
25
2003-07
2004-08
2005-09
2006-10
2007-11
2008-12
2009-13
2010-14
2011-15
Period
(b) Five Year Moving Average- Intensity forecast Error based on RMSE (kts)
12-hours
24-hours
36-hours
48-hours
60-hours
72-hours
Average intensity forecast error (kts)
0
5
10
15
20
25
30
2003-07
2004-08
2005-09
2006-10
2007-11
2008-12
2009-13
2010-14
2011-15
Period



(a) Five Year Moving Average- Intensity forecast Skill based on AE (%)
Average intensity forecast skill (%)
Period
12-hours
24-hour
36-hours
48-hours
60-hours
72-hours
0
20
40
60
80
100
120
2005-09
2006-10
2007-11
2008-12
2009-13
2010-14
2011-15



(b) Five Year Moving Average- Intensity forecast Skill based on RMSE (%)
Average intensity forecast skill (%)
Period
12-hours
24-hours
36-hours
48-hours
60-hours
72-hours
0
10
20
30
40
50
60
70
80
90
100
2005-09
2006-10
2007-11
2008-12
2009-13
2010-14
2011-15

Outcome of IMD initiative

- Genesis forecast (3 days) in advance
- Track, intensity and landfall forecast : 5 days in advance

❖ Increase in confidence of disaster managers and general public

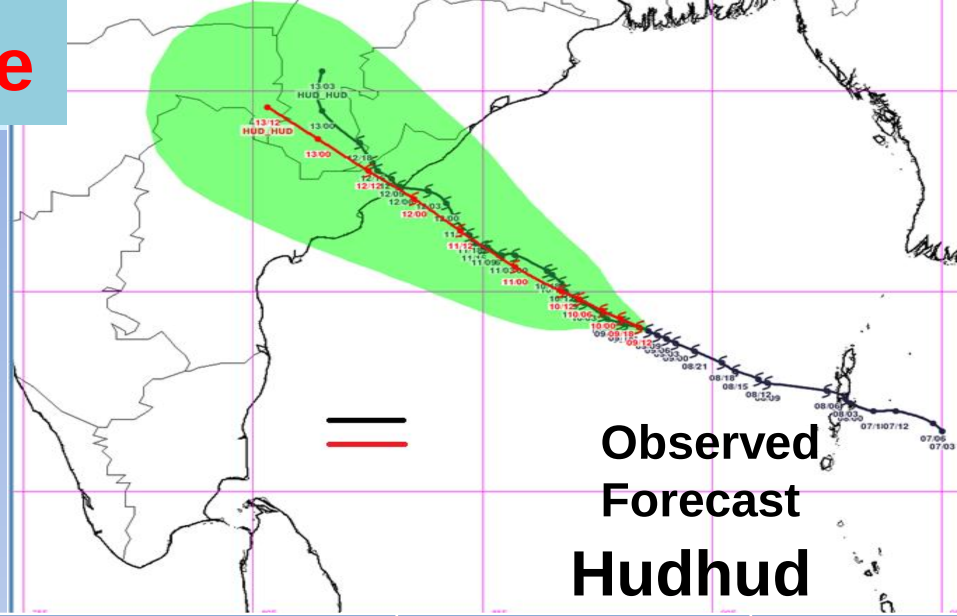
❖ Effective management of cyclone

❖ Minimum loss of lives
  - (22 in Phailin (2013) and 46 in Hudhud (2014) against 9885 in Odisha super cyclone (1999)

❖ Minimum loss of live stocks

❖ Minimum Govt expenditure towards evacuation

❖ Minimum Govt expenditure towards payment of exgratia for loss of lives



Parameter	Super Cyclone, 1999	Hudhud 2014
Loss of human life	9887	46
Ex-gratia paid by Govt. @ Rs 0.6 Million	Rs 5932.2 Million	Rs 27.6 Million
Area of evacuation	500 km	200 km
Cost of evacuation (10 Million/km)	5000 Million	2000 Million

Assumption: similar amounts would have been spent for evacuation and payment of ex-gratia in 1999 as in 2014

ACCURACY ACHIEVED MAINLY BECAUSE:

Science and Technological Upgradation

- **Improvement in observational network (Ocean, land and atmosphere) and quality of data (DWR, Ship, Buoys, AWS, High wind speed recorders etc.)**
- **Satellite images and derived products (Kalpana, INSAT 3A, Oceansat-II) other international satellites**
- **Fast communication and data Exchange system**
- **Superior computational capabilities, super computer facilities**
- **Improved Numerical modelling capabilities (GFS, WRF, HWRF)**
- **Skilled Human Resource Capabilities**
- **Improved tools and techniques of forecasting including DSS**
- **Excellent support and Inter- ministerial collaborations within different sister organisations of MoES and also with other R & D institutes like IIT, IISc and Universities etc**
- **International collaborations**
- **Research and Development**

Current Status of TC Monitoring vis-à-vis Global Scenario

(a) Geo-Satellite (INSAT/METEOSAT)

Visible and Infrared imagery (Dvorak Tachnique)

Surface wind : ASCAT, Windsat(only twice a day)

(b) Structure : Polar sat (microwave imagery)

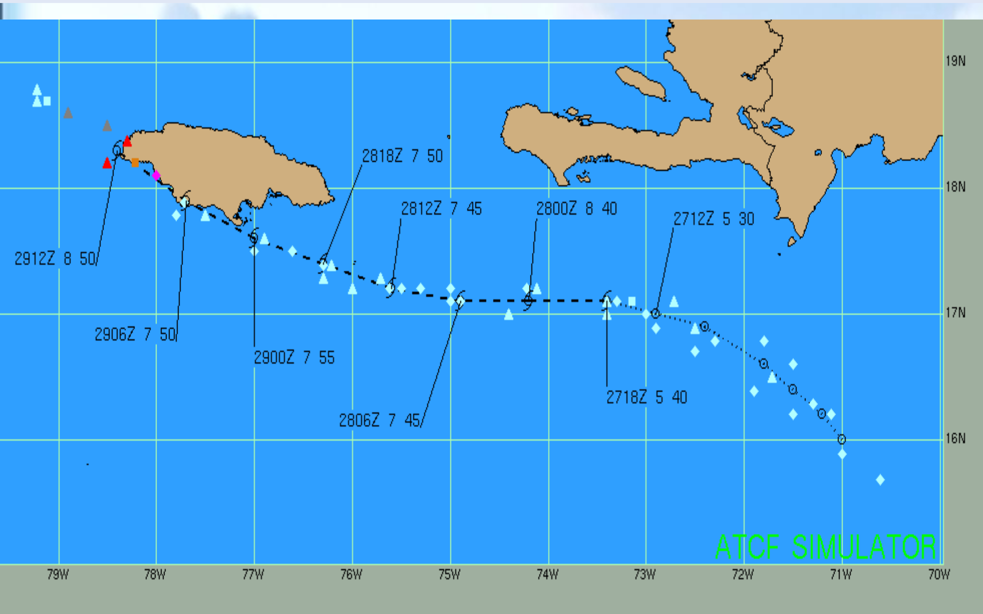
(c) Radar (within 300 km from coast)

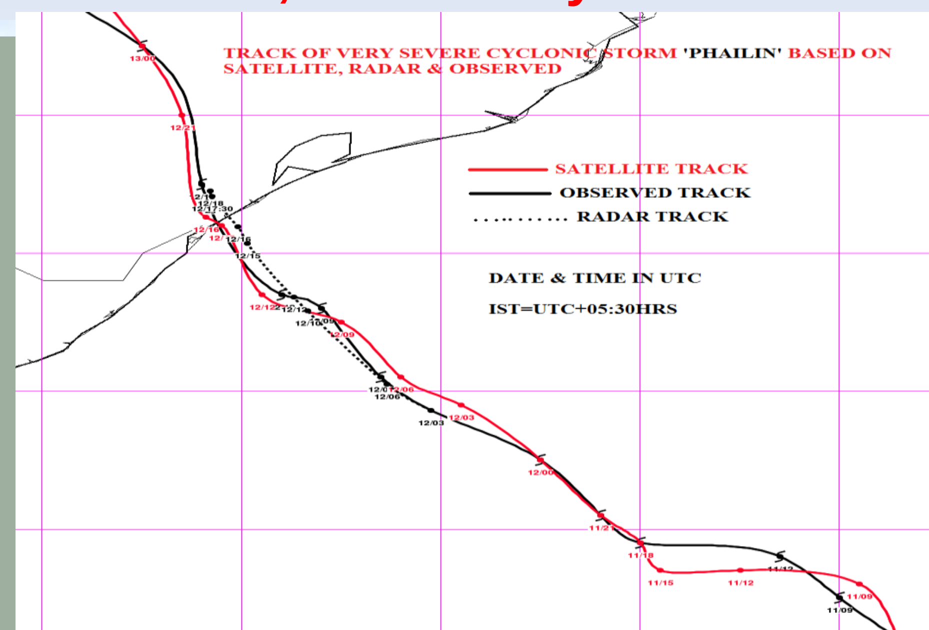
(d) **Surface observations**

- Ships, buoys, land stations (limited)

(e) Final consensus Location

In comparison, USA has Aircraft reconnaissance, better buoy network





Current Status of intensity monitoring vis-à-vis Global Scenario

(a) Geo-Satellite INSAT/METEOSAT (Dvorak Tachnique) ASCAT, Windsat(only twice a day)

(b) Polar sat (microwave imagery)

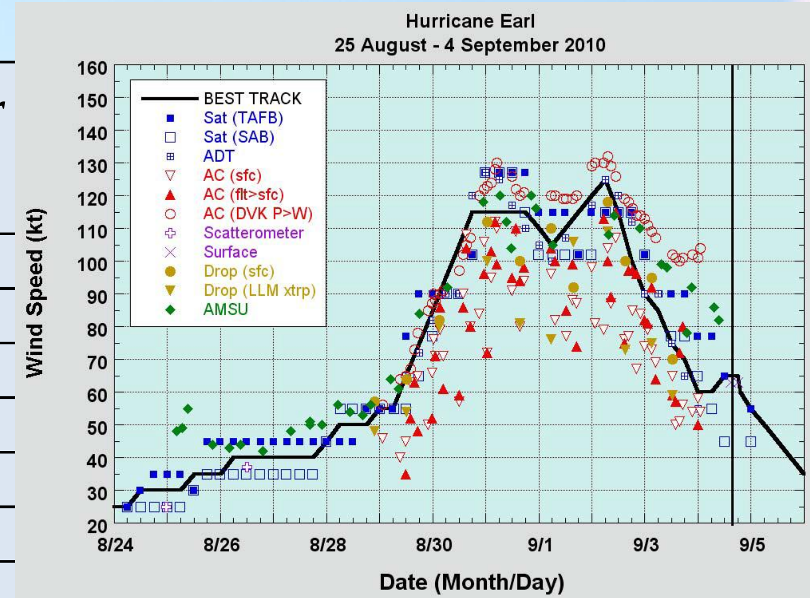
Radar (within 300 km from coast)

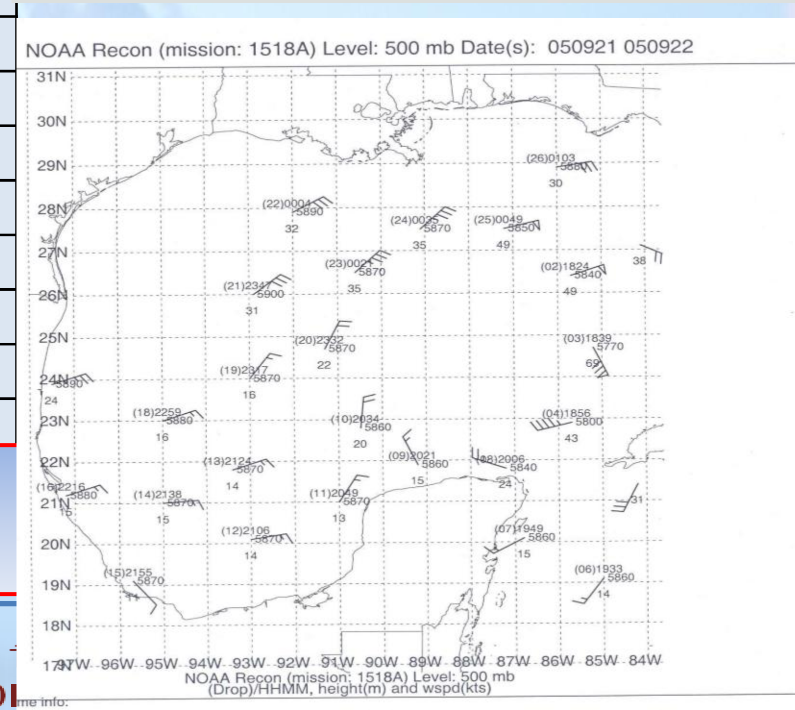
(c) Surface observation limited over Sea

(e) Final consensus

Comparison with USA indicates following issues

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





- **Issues : No aircraft reconnaissance**
- **Dvorak technique is not validated**

Advances in Cyclone Forecasting : Genesis

Seasonal prediction

1) **PCR model of seasonal forecast of frequency (OND) of cyclonic disturbances over the Bay of Bengal - (D.R. Pattanaik, NWP)**

2) **Seasonal Cyclonic disturbances days over NIO (*CD days) during OND season based on regression*. (S. Balachandran, RMC Chennai)**

Advances in Cyclone Forecasting : Genesis

Extended range Prediction

Multi-model ensemble based TC genesis forecast for 2/3 weeks - (D.R Pattanaik, NWP)

Medium Range Prediction

4. NWP models and dynamical statistical models

5. Short Range Prediction by Consensus

Extended Range Prediction of Cyclogenesis

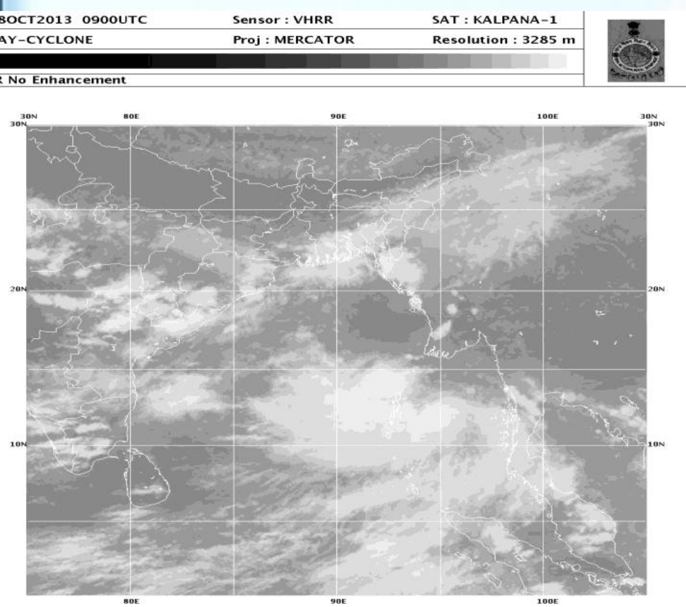
i) Dynamical Models : CFS

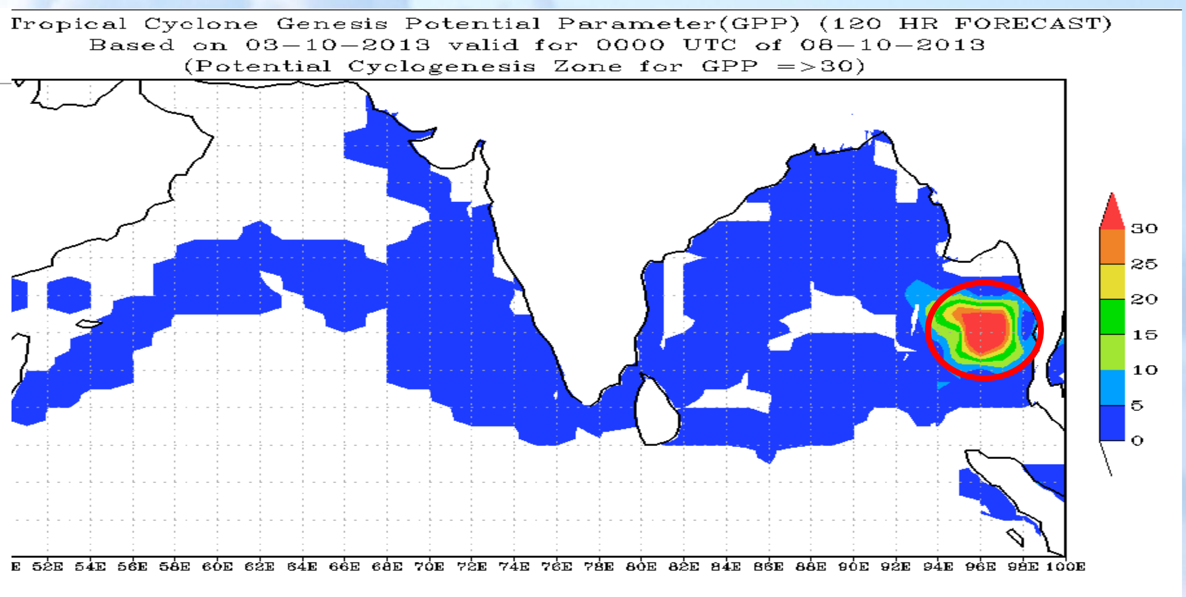
ii) Dynamical statistical models (IITM, CFAN etc)

iii) MJO Phase (IITM, other global deterministic and probabilistic models)

4. Medium Range prediction

- ❖Deterministic models
- ❖EPS
- ❖Dynamical statistical models (GPP) : Kotal et al, 2009





SHORT RANGE GENESIS FORECAST

- **Input :**
- **Observations (mainly satellite based) for synoptic and environmental conditions**
- **NWP models**
- **Dynamical statistical guidance**
- **The official forecast is based on a consensus determined from NWP, synoptic, environmental, statistical and dynamical-statistical inputs.**
- **It provides probability of cyclogenesis during next 72 hrs based on the observations at 0300 UTC of everyday and issued at 0600 UTC.**
- **This probabilistic forecast is issued in terms of nil, low, fair, moderate and high probability corresponding to 0, 1-25, 26-50, 51-75 and 76-100% probability of occurrence.**

TC track forecasting methods

Achievement:

i) Statistical Techniques : (Analogue, Persistence, Climatology, CLIPER

ii) Synoptic, satellite and Radar based subjective assessment

iii) NWP Models

- Individual models (Global and regional)
- IMDGFS (574), GFS (1534), NCUM, NCUM Regional Model, ARP (Meteo France), ECMWF, JMA, UKMO, NCEP, WRF (IMD), HWRF (IMD),
- MME (IMD) and MME based on Tropical Cyclone Module (TCM)
- EPS (Strike probability, Location specific probability :

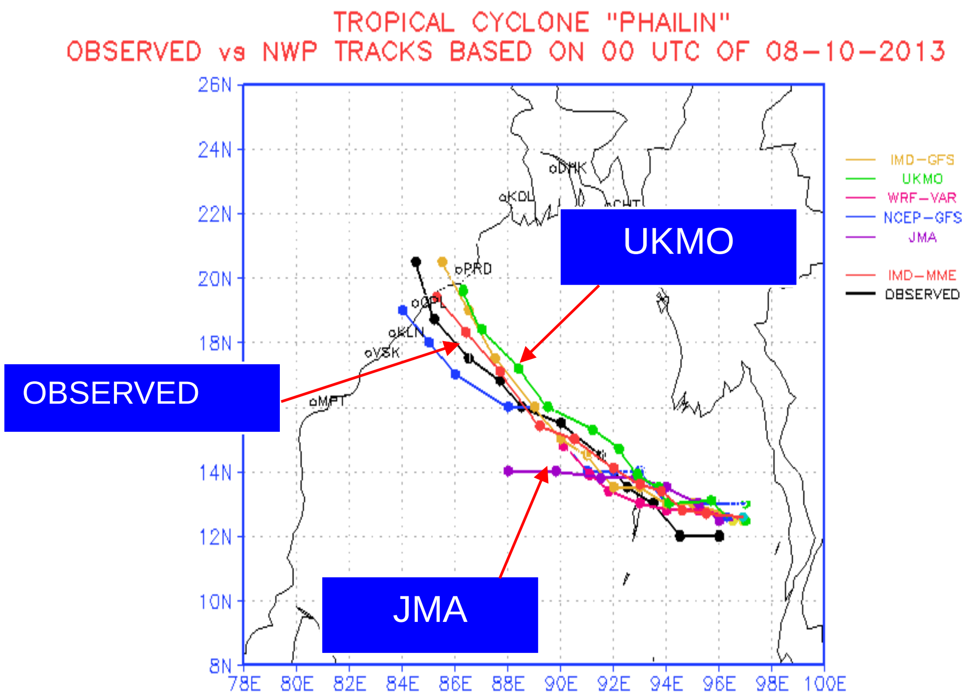
GEFS, UMEPS and TIGGE products are available

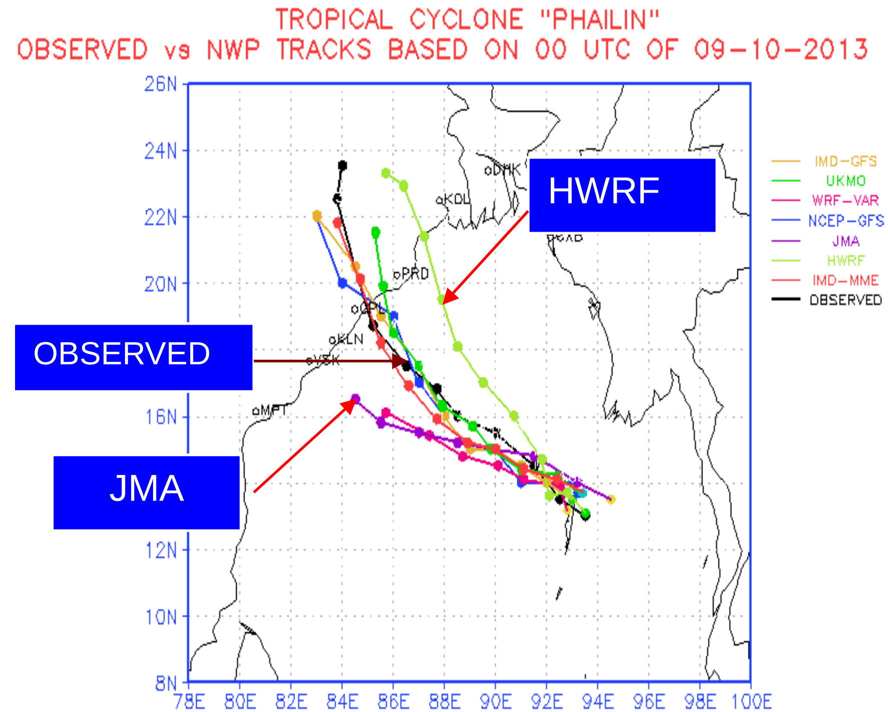
Operational forecast is consensus based mainly dependent on MME

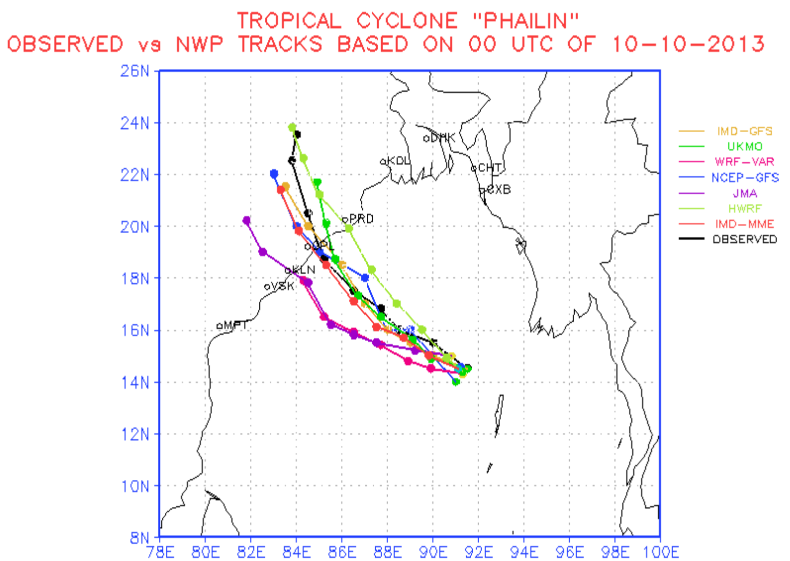
Challenges :

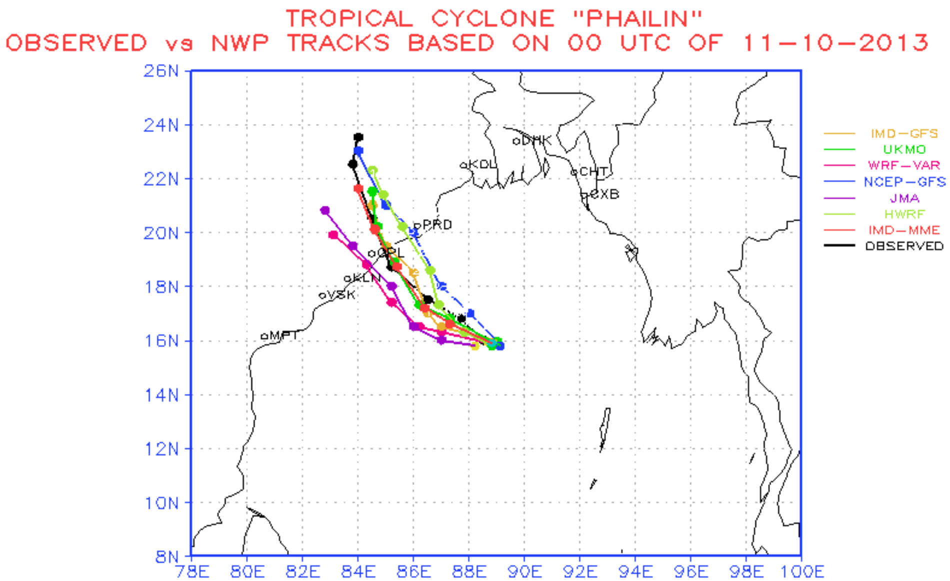
1. To utilize late models guidance on real time
2. Development of EPS of regional models
3. Utilisation of EPS for development of Dynamic Cone of Uncertainty
4. Pregenesis track forecast

Track and intensity forecast for Phailin









TC intensity Forecasting methods

Achievements

i) Statistical Techniques (Analogue, Persistence, Climatology)

ii) Synoptic, satellite and radar based subjective assessment

iii) Dynamic Models

v) Dynamical Statistical Model (SCIP)

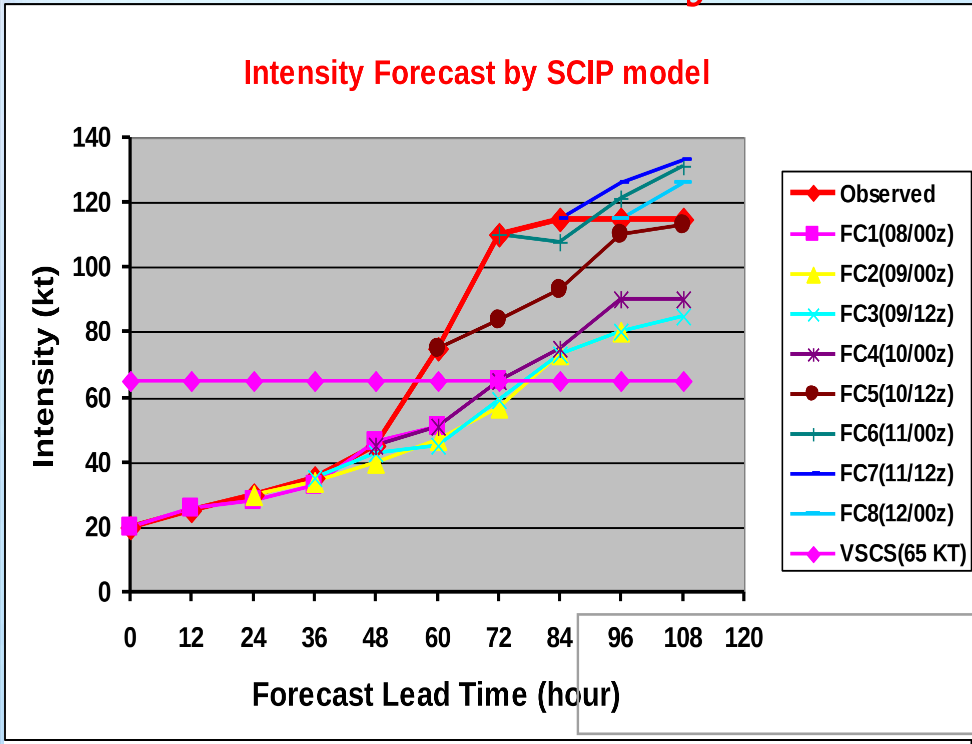
vi) RI technique

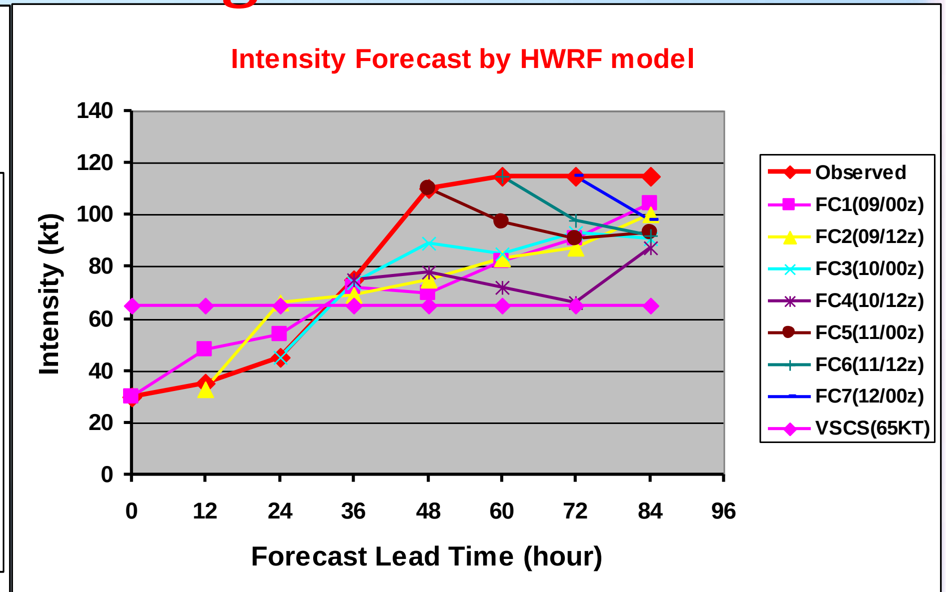
Operational forecast is subjective consensus based mainly on SCIP

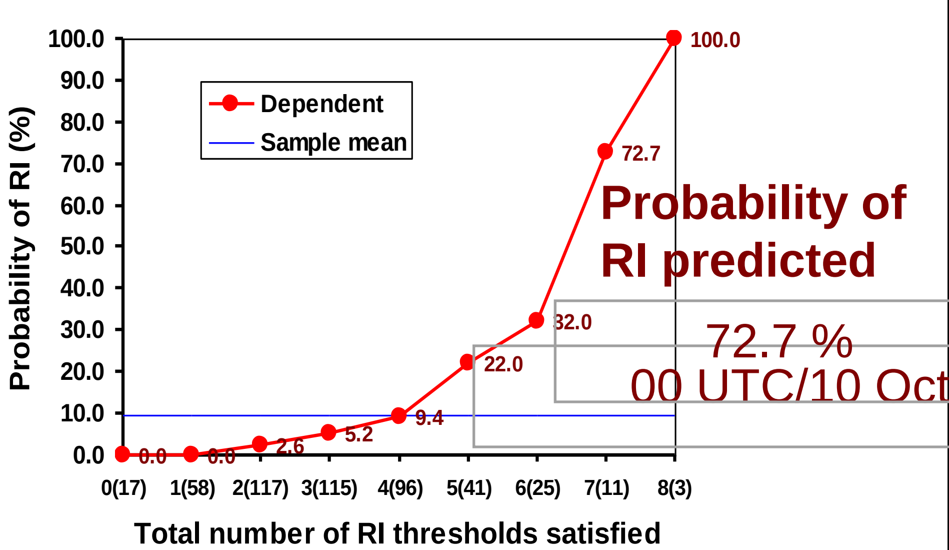
CHallenges:

1. CLIPER model for intensity prediction
2. SCIP has its own limitation, as it fails in RI/RW cases as in recent cyclones of Phailin, Chapala and Megh. Hence needs improvement.
3. Existing RI technique is based on environmental conditions
4. Techniques to ingest Internal dynamics of the system in dynamical statistical models for RI and RW cases
5. About 20% cases undergo RI/RW
6. Eye wall replacement cycles are further less over this basin . However no forecasting technique
7. Forecast of uncertainty in intensity.

Intensity forecast during Phailin



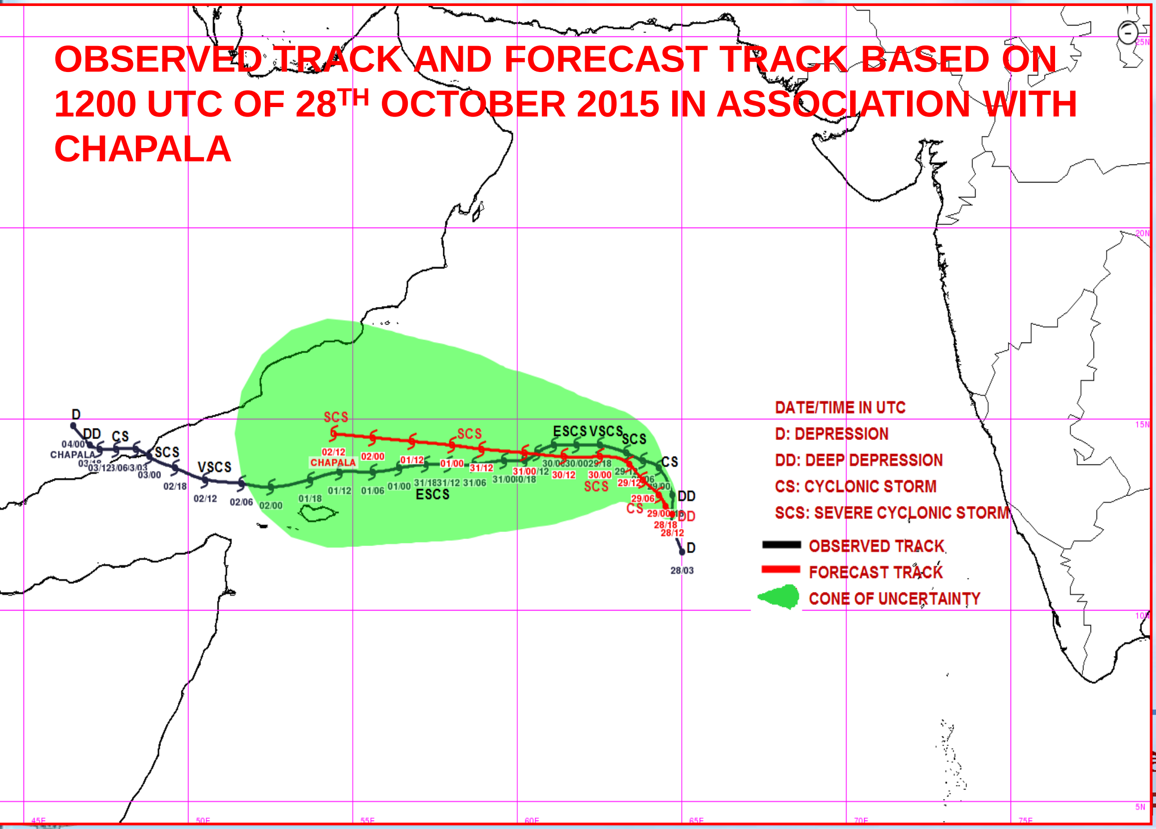


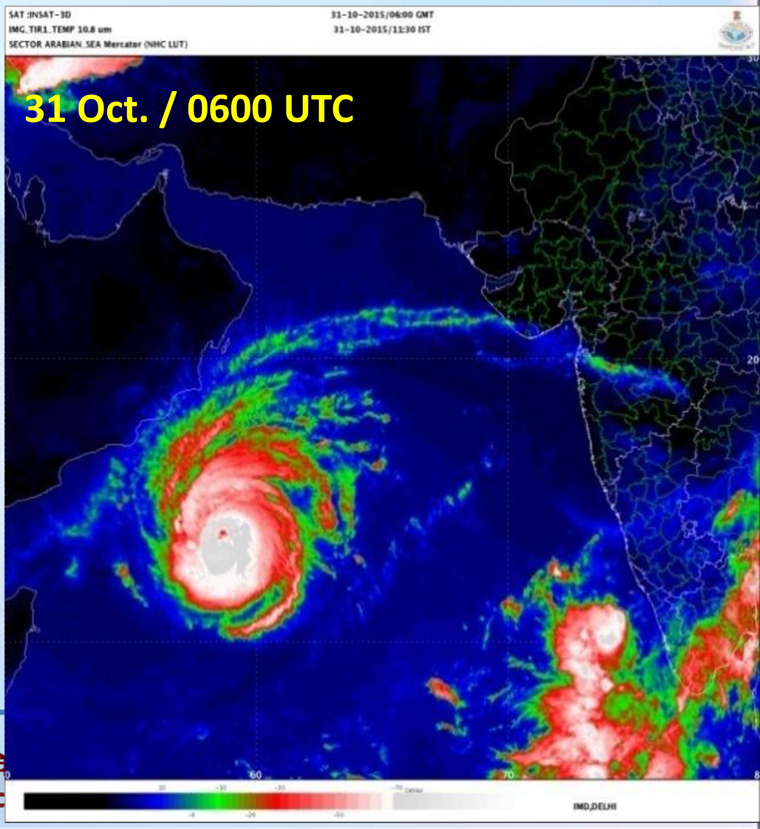


No. of RI- Indices satisfied	Probability(%) of RI	Chances of occurrence
0	0	NIL
1	0	NIL
2	2.6	VERY LOW
3	5.2	VERY LOW
4	9.4	VERY LOW
5	22.0	LOW
6	32.0	MODERATE
7	72.7	HIGH
8	100	VERY HIGH

FORECASTING CHALLENGES-ESCS CHAPALA

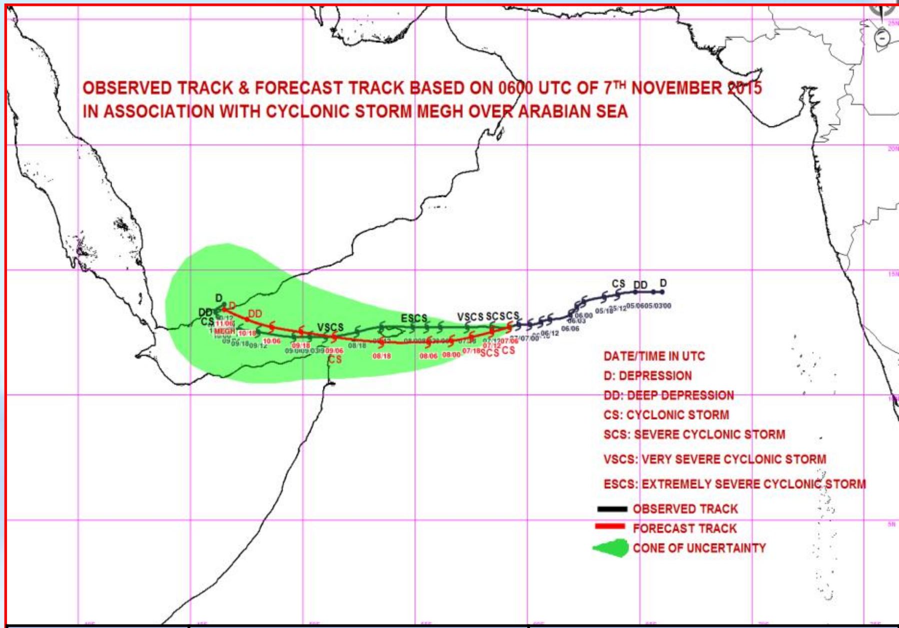
- It had the maximum intensity of 115 kts (215 kmph) and crossed Yemen coast with a speed of 65 kts (120 kmph).
- The system rapidly intensified from 29th morning (35 kts) to 30th afternoon (90 kts).
- The SCIP and RII model failed to predict rapid intensification of ESCS CHAPALA.

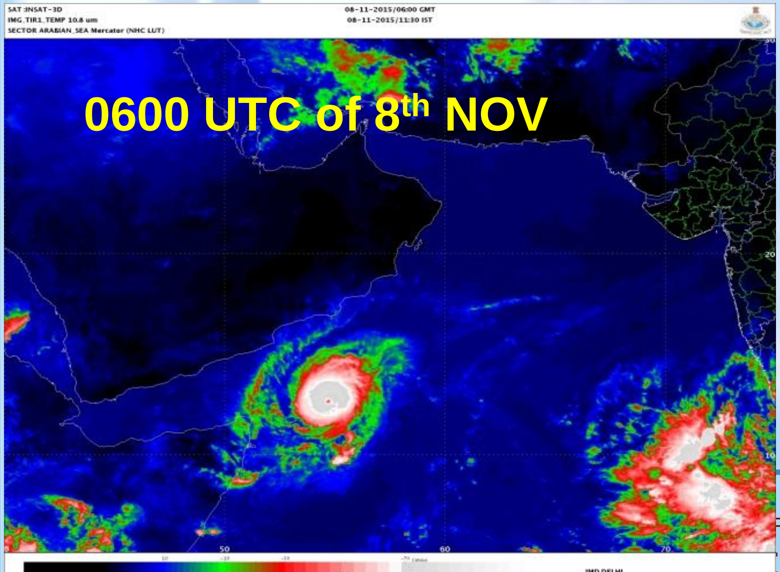




FORECASTING CHALLENGES- ESCS MEGH

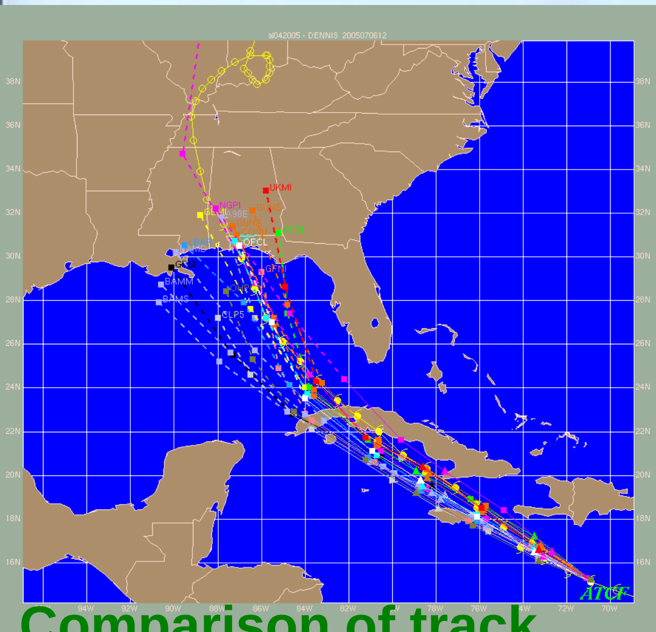
- Megh experienced rapid intensification during 0000 UTC of 7th (45 kts) to 0000 UTC of 8th (85 kts).
- Megh experienced rapid weakening over Gulf of Aden from 1800 UTC of 9th (65 kts) to 0600 UTC of 10th (35 kts).
- The SCIP and RII models failed to predict the Rapid Intensification and weakening of the system.



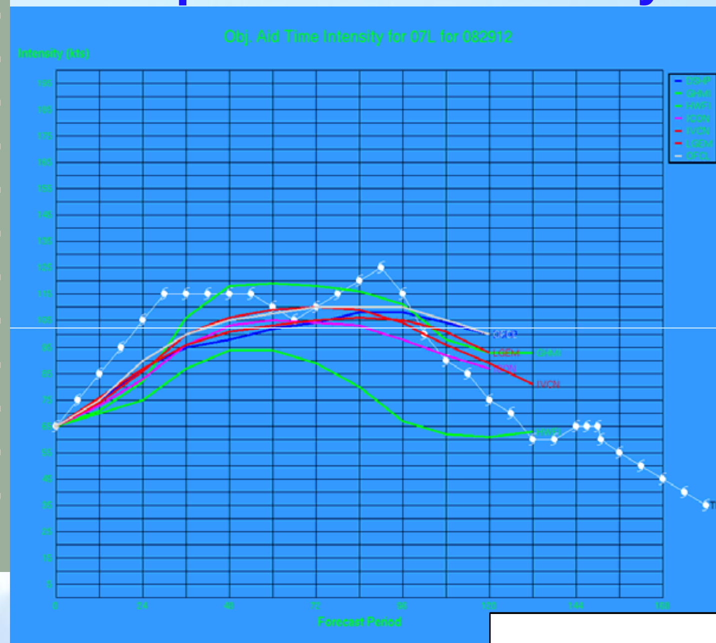


Lead Period (hrs)	Operational Error (kt)		IMD-SCIP (kt)	
	AE	RMSE	AE	RMSE
12	8.0	10.3	12.7	14.2
24	17.2	22.7	21.5	23.3
36	25.1	32.1	31.3	34.5
48	31.1	38.1	38.8	42.4
60	35.9	38.1	43.7	46.3
72	40.1	41.7	48.6	50.7

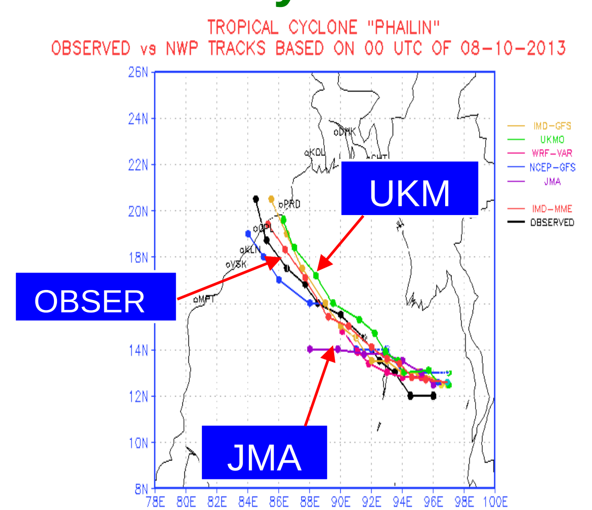
Comparison of Track Forecasting in India and USA

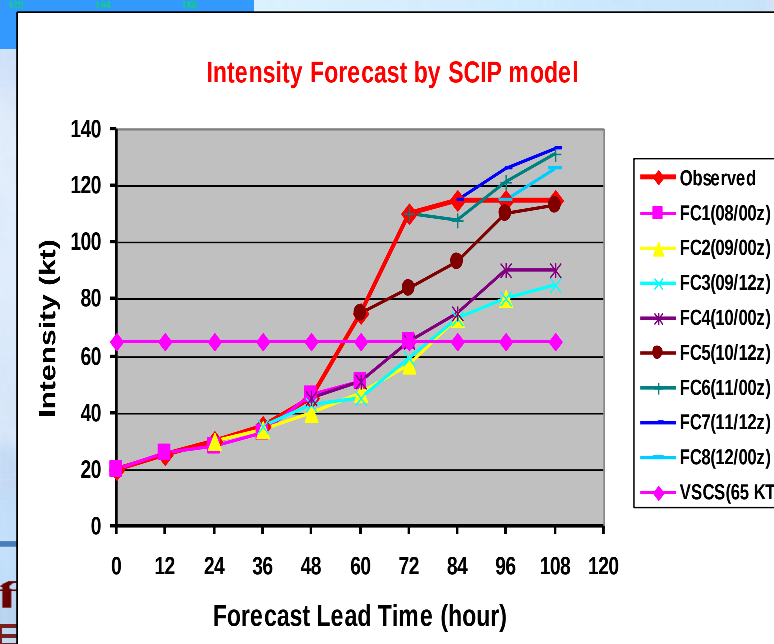


Comparison of intensity forecast by models



Comparison of track forecast by models





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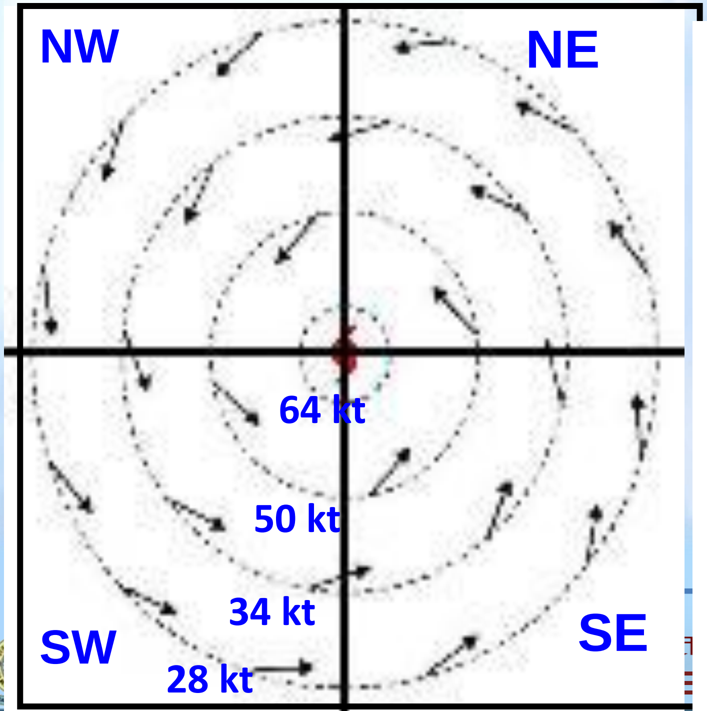
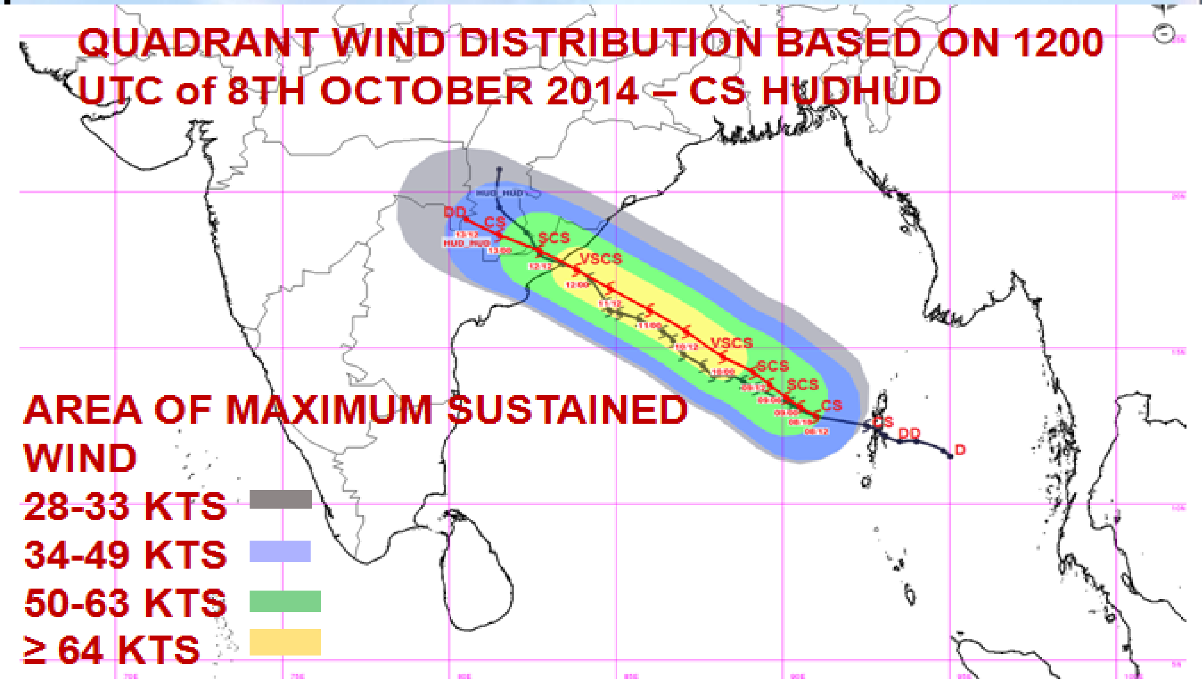
Quadrant wind radii monitoring and forecast

- Achievements :
- Wind radii monitored and forecast since 2010.
- Based on subjective consensus forecast and adjustment with initial observations by multiple satellite products.
- Challenges
- We do not have any objective method for this product.
- Dynamical statistical model may be developed for forecasting.
- Not verified due to lack of adequate observation
- Probabilistic wind (location specific) :





Rainfall Monitoring

- Factors affecting rainfall
- Storm track (location and translation speed)
- Storm size (positive)
- Wind shear (negative) – leads to a quicker dropoff in rainfall for inland TCs
- Topography – Positive in the upslope areas, but negative past the spine of the mountains
- Nearby synoptic-scale features
- Time of day – core rainfall overnight/ outer band rainfall during day

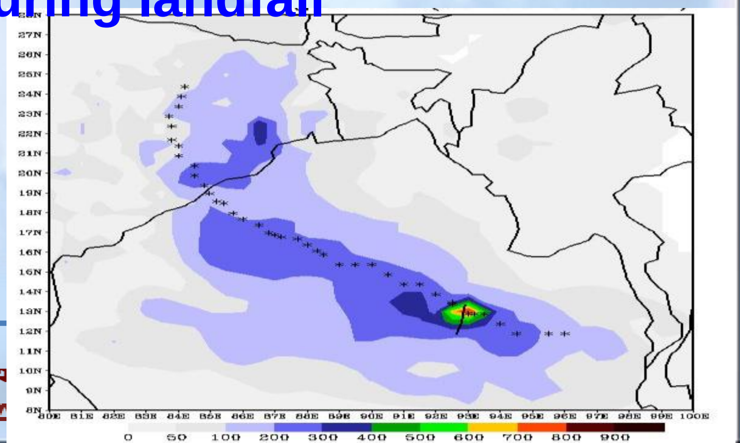
Achievement :

Raingauge and satellite based merged rainfall analysis

Challenges : Radar estimates to calibrated and merged

Preparation of TC related rainfall dataset

Accumulated rainfall (8-14 Oct, 2013 with track of Phailin showing rainfall belt shift during landfall



❖ Heavy rainfall forecasting

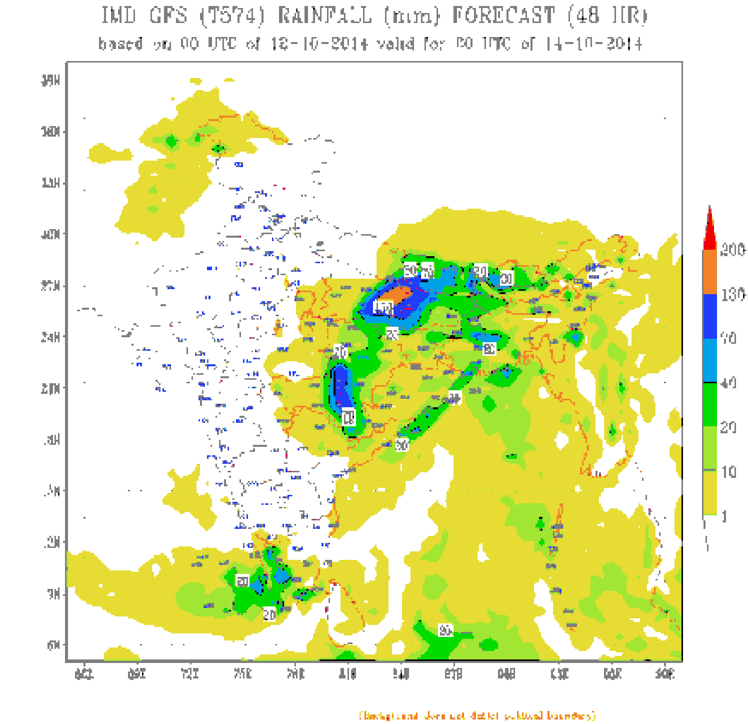
Synoptic method, Climatological method, topography, analog method

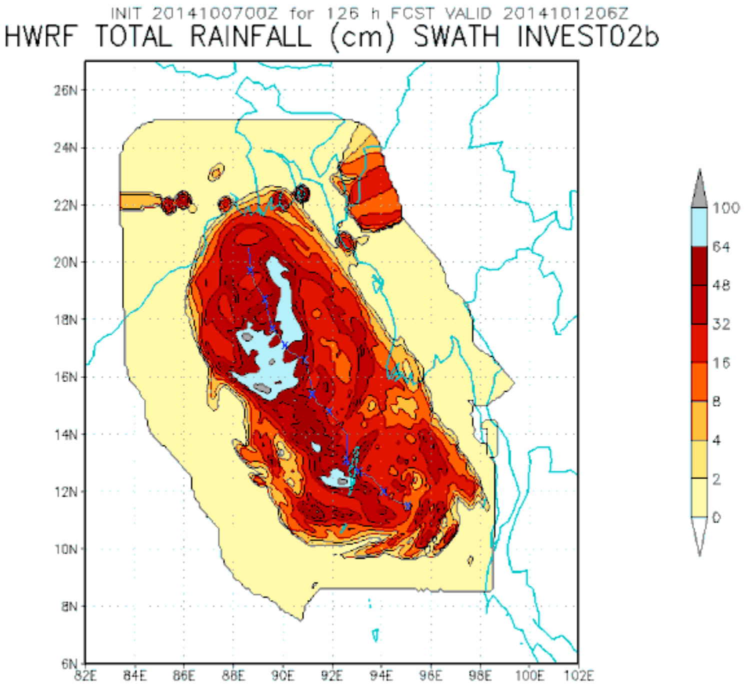
Satellite, Radar and NWP Method

Ensemble method

Challenges :

- NWP models mainly underestimate heavy rainfall
- Location specific rainfall
- forecast more challenging
- Models to improve QPF for river catchments and smaller regions through
- dynamical statistical downscaling and
- bias corrections etc
- Grid-point rainfall forecast for Hydrodynamical model based flood prediction is needed.





Heavy Rainfall

Komen

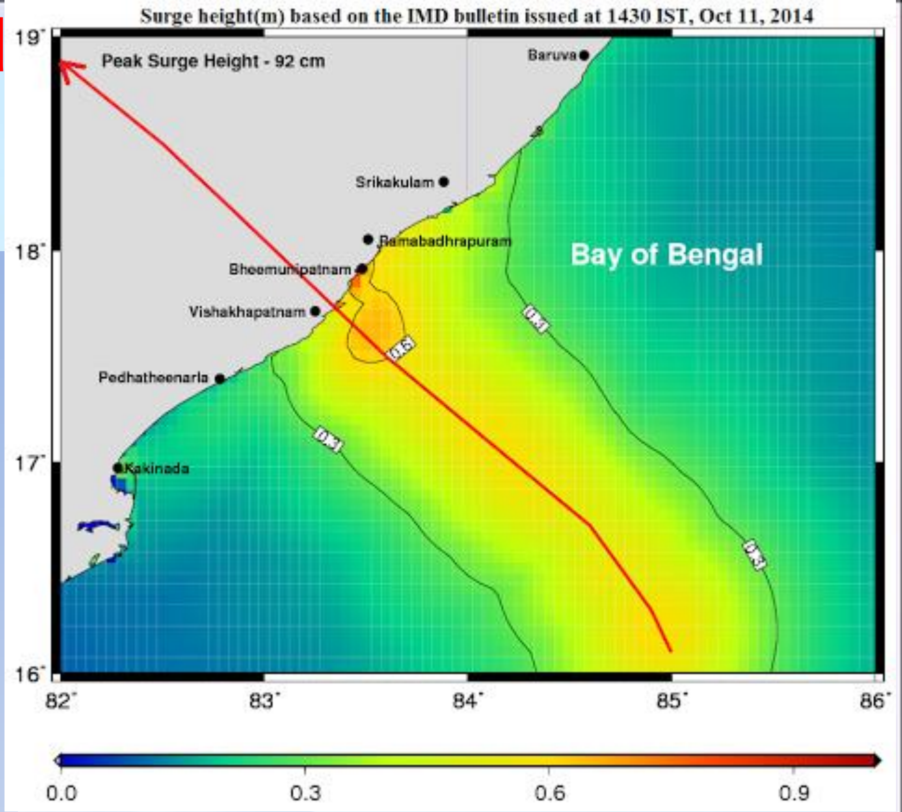
Skill Parameter	24 hr forecast	48 hr forecast
Probability of detection(POD)	0.9	0.9
False alarm rate (FAR)	0.4	0.2
Missing rate (MR)	0.1	0.1
Correct non-occurrence (C-NON)	0.2	0.7
Critical success index (CSI)	0.6	0.7
Bias for occurrence	1.4	1.1
Percentage correct (PC)	61.5	79.1
Heidke skill score (HSS)	0.1	0.6

DD(8-10 Nov 2015)

Skill Parameter	24 hr forecast	48 hr forecast
Probability of detection(POD)	1.0	0.6
False alarm rate (FAR)	0.3	0.6
Missing rate (MR)	0.0	0.4
Correct non-occurrence (C-NON)	0.5	0.5
Critical success index (CSI)	0.7	0.3
Bias for occurrence	1.5	1.3
Percentage correct (PC)	75.0	54.2
Heidke skill score (HSS)	0.5	0.1

Mohapatra (2015), TCRR

Storm surge monitoring and Prediction



- ❖ **Storm Surge prediction -**

  Nomograms, IITD model

  INCIOS Coastal Inundation Model

- ❖ **Predicts tide and surge only**

- ❖ **Does not consider past rainfall, future rainfall, river run off/ discharge etc.**

- ❖ **Probabilistic storm surge need to be introduced**

Storm Surge (2009-2014)

Observed class of storm surge (m)	24 hour foreast class of storm surge (m)					
	0	0.1-1.0	1.1-2.0	2.1-3.0	3.1-4.0	Total
0	5	2	2	2	0	11
0.1-1.0	0	0	2	0	0	2
1.1-2.0	0	0	1	0	0	1
2.1-3.0	0	0	0	1	2	3
3.1-4.0	0	0	0	0	0	0
Total	5	2	5	3	2	17
CSI	0.46	0	0.20	0.20	0	
PC (%)	41.2					
HSS	0.2					

Mohapatra (2015), TCRR

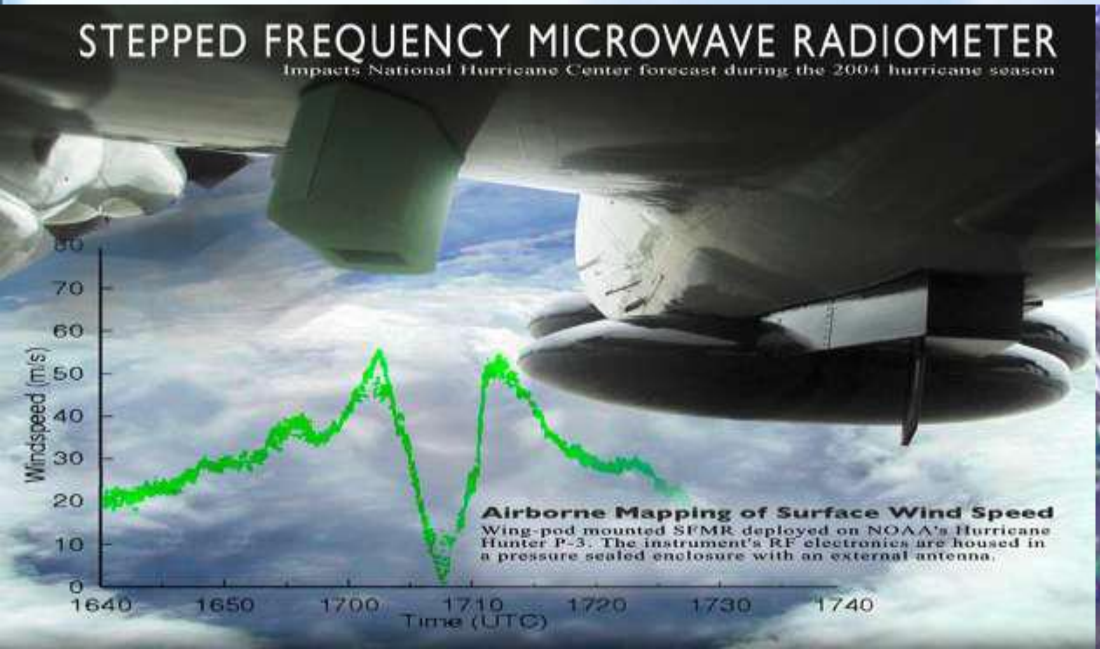
Area where improvement is needed: Observation and Modeling

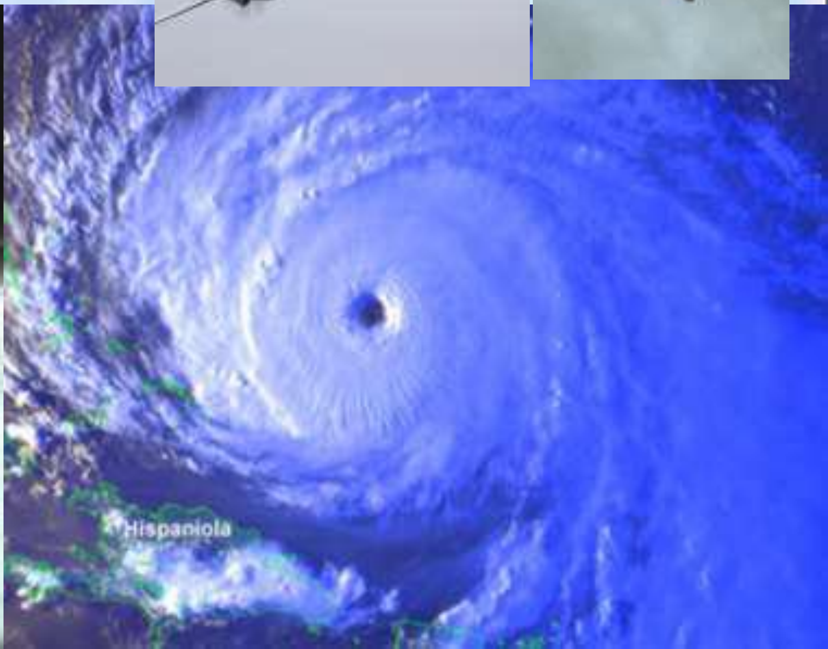
- ❖ Still there are gaps in technology vis-a-vis capability.
- ❖ Gap in scientific understanding required for better forecasting of :
  - Detailed structure and dynamics of cyclones over the NIO unlike Atlantic and Pacific Oceans.
  - Interaction between cyclone, Ocean, the surrounding environment
  - Internal physical and dynamical processes in clouds.
- ❖ Gap in observational and modeling systems for forecasting with high spatial resolution
- ❖ Forecast skill still can be improved by 20-30% in next 10 years
- ❖ Role of other Institutes :

- National Institutes : ISRO, INCOIS, NIOT, NCAOR, Ministry of Defence for observation, IITs, Universities for R&D,
- International Institutes for capacity development, technology transfer

TECHNOLOGICAL NEED :
AIR BORNE OBSERVATIONS:

- **Aircraft should be qualified for flying through thunderstorms and into the peripheral regions of severe cyclones, with a provision for Drop sonde release.**
- **Unmanned Aerial Vehicles (UAV) need to be used for measurements during occurrence of specific atmospheric events.**
- **India is planning for the above**





Impact based Forecasting (from static to dynamic)

Translating hazard information into impact scenarios

Hazard | Exposure | Vulnerability | Impact/Risk

Value at Risk

Statistical - census and survey data

GIS/Geospatial– Infrastructure, settlements, land use..

Cartographic, Geological, Hydro-meteorological ..
Geospatial Data – Vector and Raster

Source: Modified from Francis Ghesquiere, The Word Bank

Thank you