Forecast Verification over north Indian Ocean

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Need of Forecast Verification

- To monitor forecast quality
- To improve forecast quality
- To compare forecast of two systems and analyse of our strengths and weaknesses
- Confidence building among disaster managers, media and general public
- Plan for future

Presentation layout

Forecast Verification over north Indian Ocean

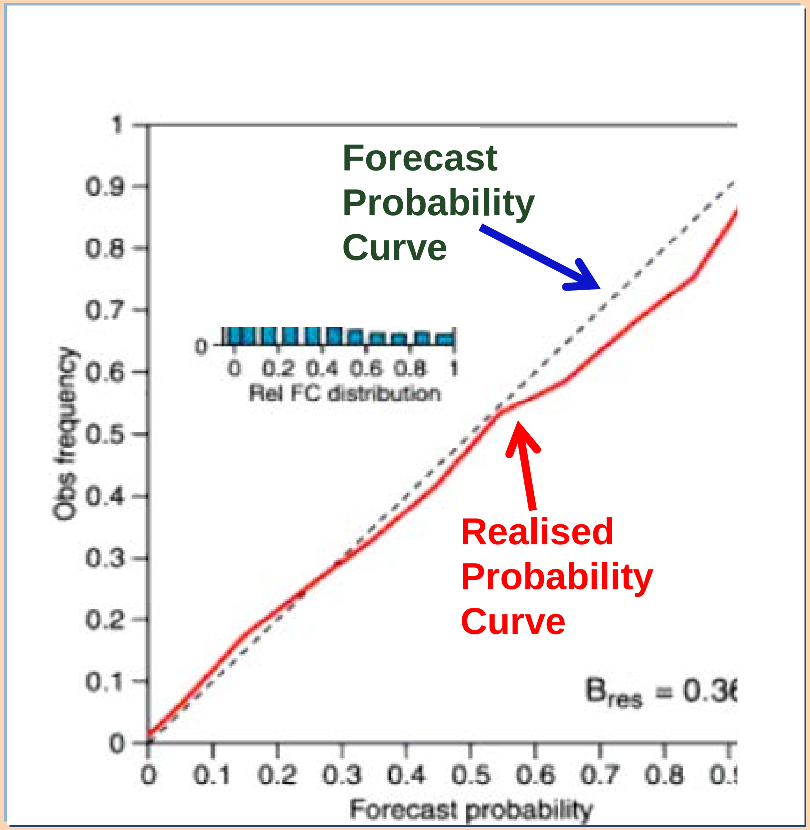
i. Genesis forecast error
ii. Track forecast error
iii. Track forecast skill
iv. Landfall forecast error
v. Intensity forecast error
vi. Intensity forecast skill
vii. Annual average track forecast error
viii. Annual average track forecast skill
ix. Annual average intensity forecast error and skill
x. Error in Cone of Uncertainty forecasts
xi. Five year mean error & skill in track and intensity forecasts
xii. Heavy rainfall forecast error
xiii. Storm surge forecast errors
xiv. Probabilistic cyclogenesis forecast

GENESIS PROBABILITY: SHORT RANGE FORECAST

- SOP for 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 forecast determined from NWP, synoptic, environmental, statistical and dynamical-statistical inputs.
- It provides probability of cyclogenesis during next 120 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.
- It commenced since 01 June 2014.
- Extended to 120 hrs since April 2018

➢Reliability Diagram

- ➢Graphical method for assessing reliability, resolution, and sharpness of a probabilistic forecast.
- ➢Plot between observed frequency & forecast probability.
- ➢Reliability is the agreement between forecast probability and mean observed frequency.
- ➢Realised curve closer to forecast curve indicate good forecast.



VERIFICATION OF CYCLOGENESIS FORECAST: METHODOLOGY

➢**Brier Score:**

$$BS = \frac{1}{n}\sum_{i=1}^{n}(f_i - o_i)^2$$

Oi= 0: if event has not occurred and Oi= 1: if event has occurred
Fi is the probability of occurrence according to the forecast system
(Here taken Fi as 0.165 for LOW, 0.495 for Moderate and 0.83 for High categories)

➢**Brier Score Reference:**
Replaced the probability of occurrence with the climatological probability.

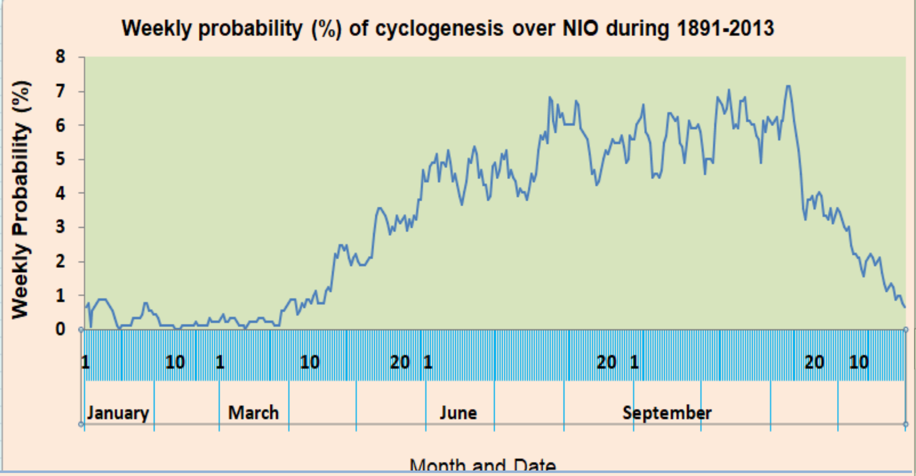
Note: BS can take on values in the range [0,1] For a perfect forecast BS = 0

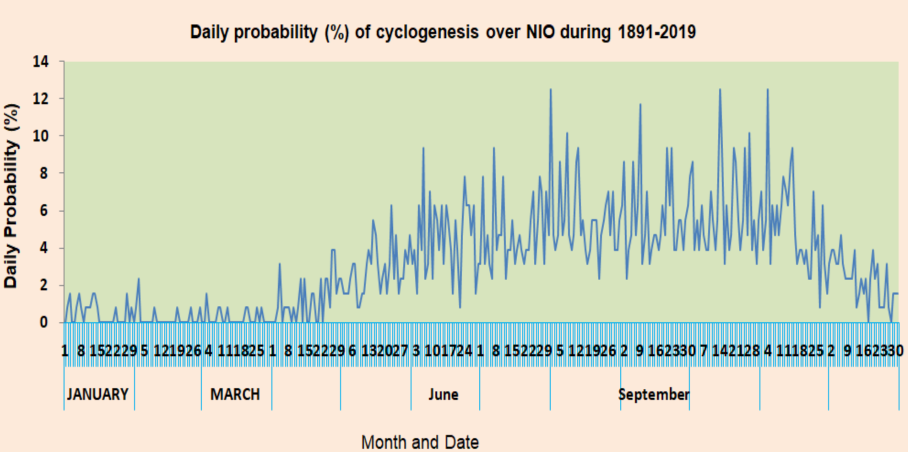
➢**Brier Skill:**

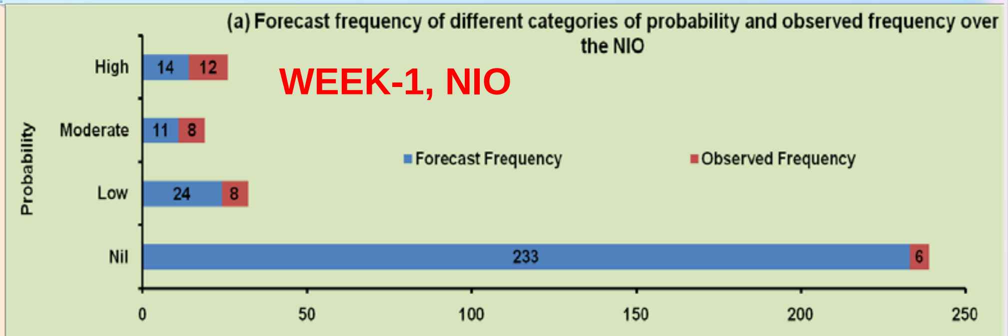
$$BSS = -\frac{BS - BS_{ref}}{BS_{ref}}$$

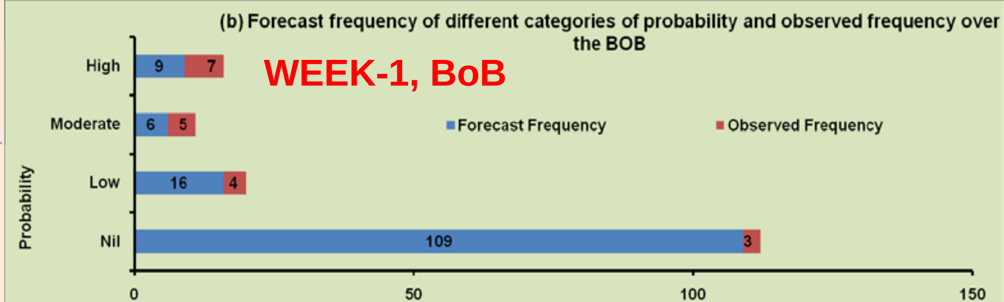
BSS can take value from 0-100%

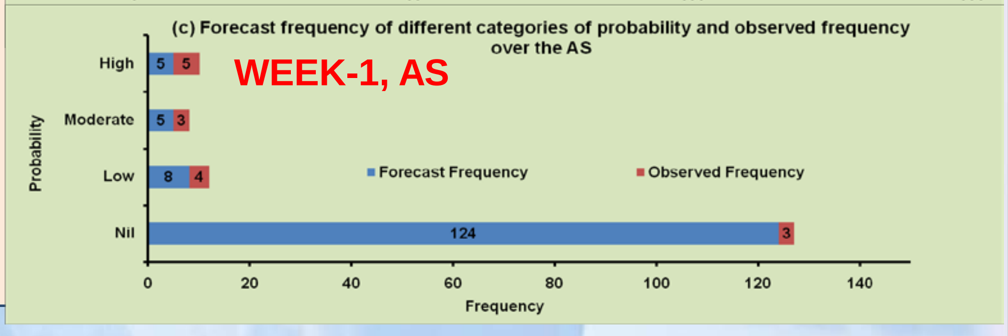
DATA & METHODOLOGY: CYCLOGENESIS PROBABILITY









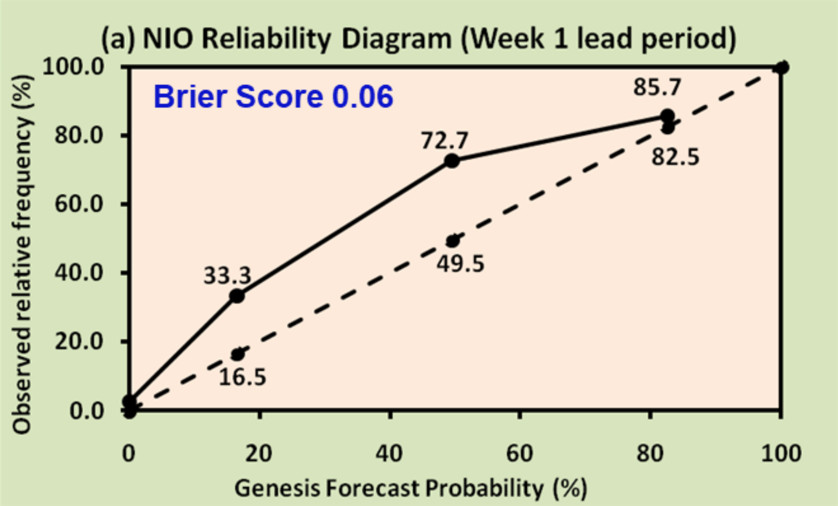


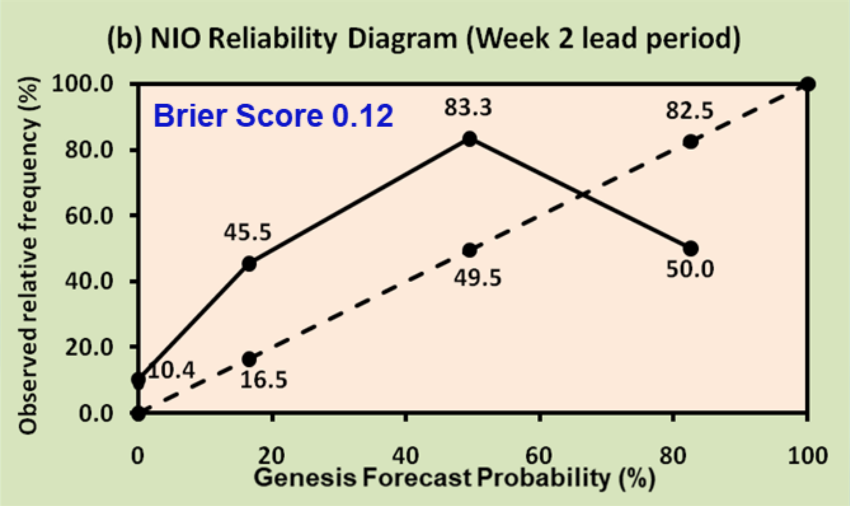
EXTENDED RANGE FORECAST VERIFICATION FOR NIO

Week1: Under warning for all categories. However, more prominent for Low & Moderate categories. Skilfull for Low & High category.

Week2: Under warning in case of Nil, Low & Moderate categories. Over warning for High category.

Week 1 (46% skill) forecast (BS:0.06) better than week 2 (11% skill) forecast (BS0.12)

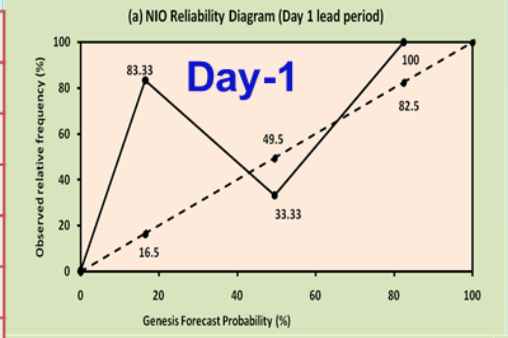


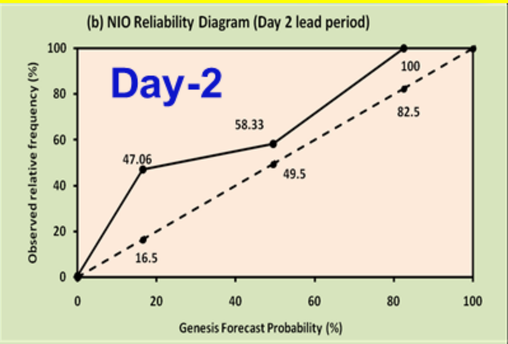


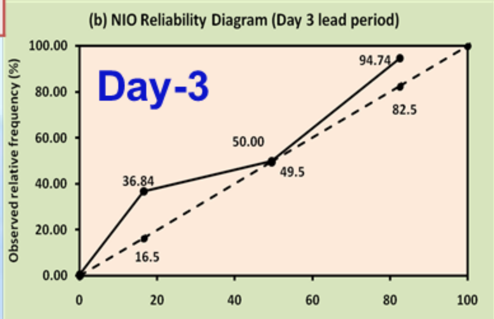
WEEK 1					WEEK 2				
BASIN	Bsi	BSr	BSS	BSS %	BASIN	Bsi	BSr	BSS	BSS %
NIO	0.06013	0.11137 3	0.46014	46.0139 9	NIO	0.12502	0.13998	0.10689	10.68945

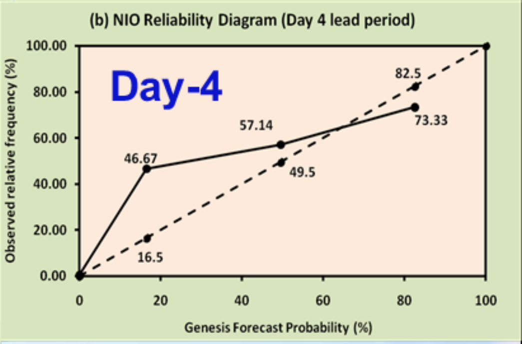
MEDIUM RANGE FORECAST VERIFICATION RESULTS FOR NIO

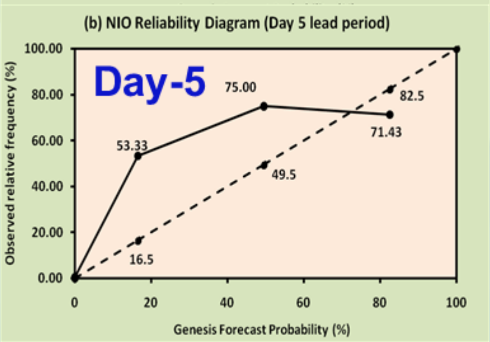
BASIN-NIO				
Parameter	BSi	BSr	BSS	BSS %
Day-1	0.014	0.02	0.25	25.5
Day-2	0.018	0.04	0.50	50.1
Day-3	0.032	0.06	0.44	44.0
Day-4	0.030	0.06	0.53	53.1
Day-5	0.027	0.08	0.65	64.9









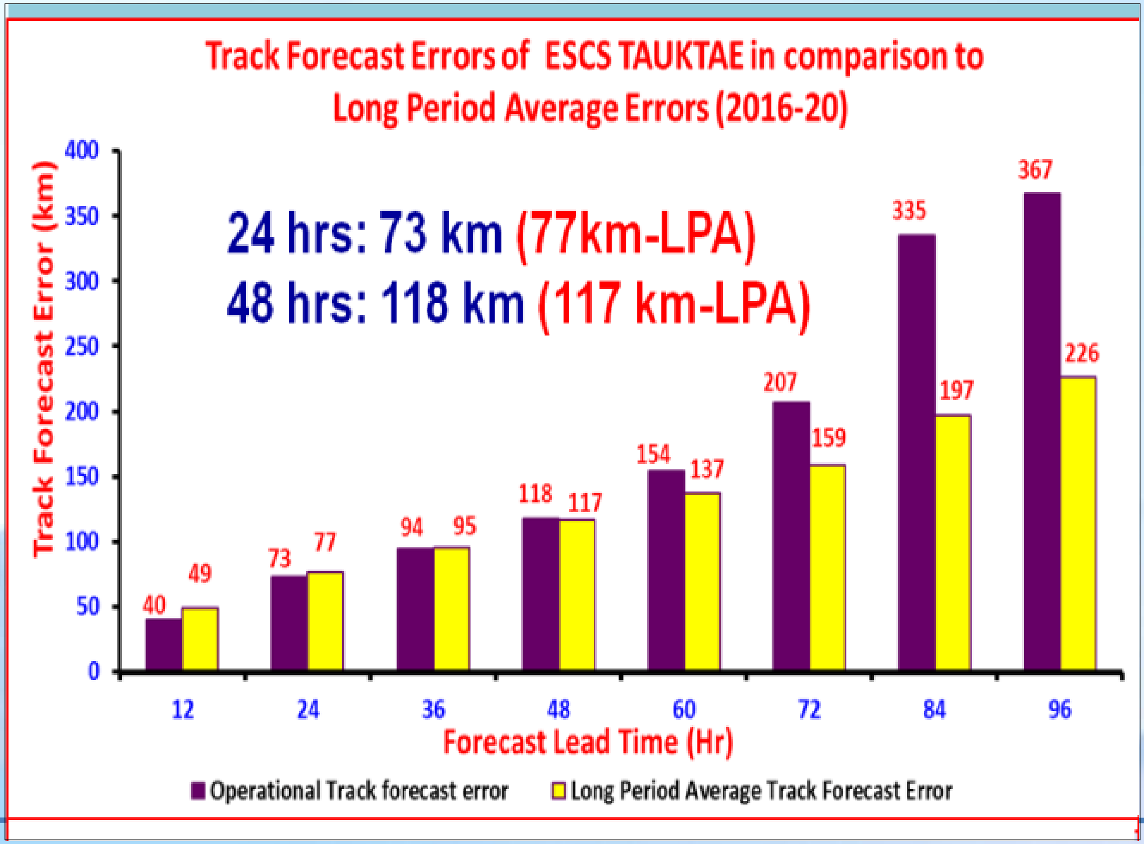


Results:

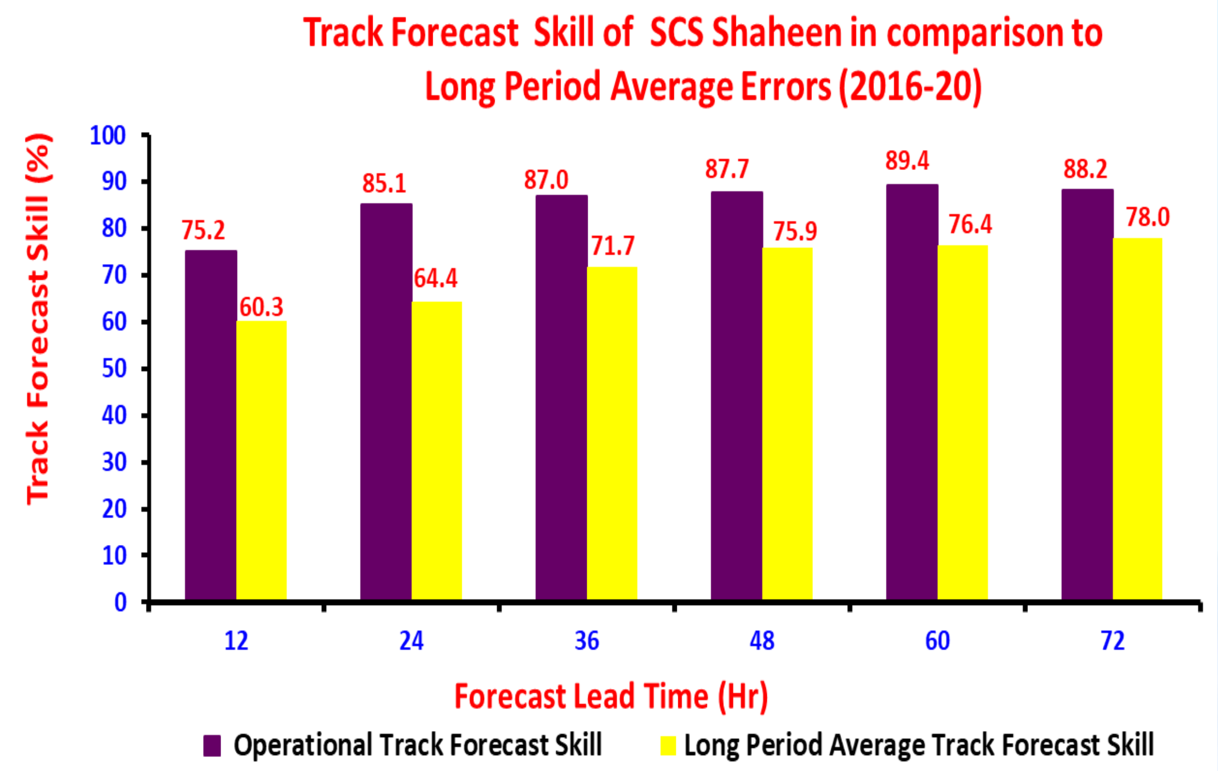
The BS for day1, day 2, day 3, day 4 and day 5 forecasts is 0.014, 0.018, 0.032, 0.030 and 0.027 respectively. The BSS varies from 25% to 65% during day1 to day5.

(i)Track forecast error

- Known as direct position error.
- It is calculated for each six hourly forecasts valid up 120 hrs during the life period of each cyclone.
- Then mean error is calculated for the given cyclone for 12, 24, 36, 48, 72, 84, 96, 108 and 120 hrs forecasts.



(ii)Track forecast skill



- ❖ Track forecast skill is calculated for a given cyclone by comparing the six hourly operational track forecast errors with track forecast errors of a reference model. The climatology and persistence (CLIPER) model is used as a reference model.

- ❖ Track forecast skill (%)= (CLIPER track forecast error-Operational track forecast error)/CLIPER track forecast error*100
- ❖ The average skill is calculated for 12, 24, 36, 48, 72, 84, 96, 108 and 120 hrs forecasts based on the life period of the cyclone.
- ❖ For a good forecast, skill should be at least positive.
- ❖ Higher the positive value of skill, better is the track forecast.

Scope for improvement in Track forecast skill

(i) Initial error / 00 hr forecast error is also calculated at present based on operational best track and the BT finalised at the time of verification.

(ii) BT data, which is the basis for track forecast verification, is prepared based on operational analysis. Due to absence of aircraft reconnaissance observations etc., the track in deep sea is mainly based on satellite based estimates. Goyal et al (2013) have shown that there can be an error of 0.5° (55 km) in such cases. Hence, reanalysis of best track can be carried out after the augmentation of observational network in sea areas.

(iii) The ensemble prediction system (EPS) which provides the strike probability and dynamical cone of uncertainty to be implemented.

(iv) CLIPER model to be updated with the latest past data to serve as a better reference model (Sharma et al, 2013 and Nayak et al, 2013).

(v) New approach like the Track Forecast Integral Deviation (TFID) integrates the track error over an entire forecast period (Yu et al., 2013). To be attempted over NIO.

iii. Landfall forecast error

Calculated as: (a) Landfall point forecast error (LPE) (km)
(b) Landfall time forecast error (LTE) (hrs)

(a) Landfall point forecast error

- defined as the direct position error between **forecast landfall point** & **actual landfall point**.
- forecast landfall point determined by applying linear interpolation to forecast location before & after landfall
- LPE is calculated for each six hourly forecasts valid upto 120 hrs

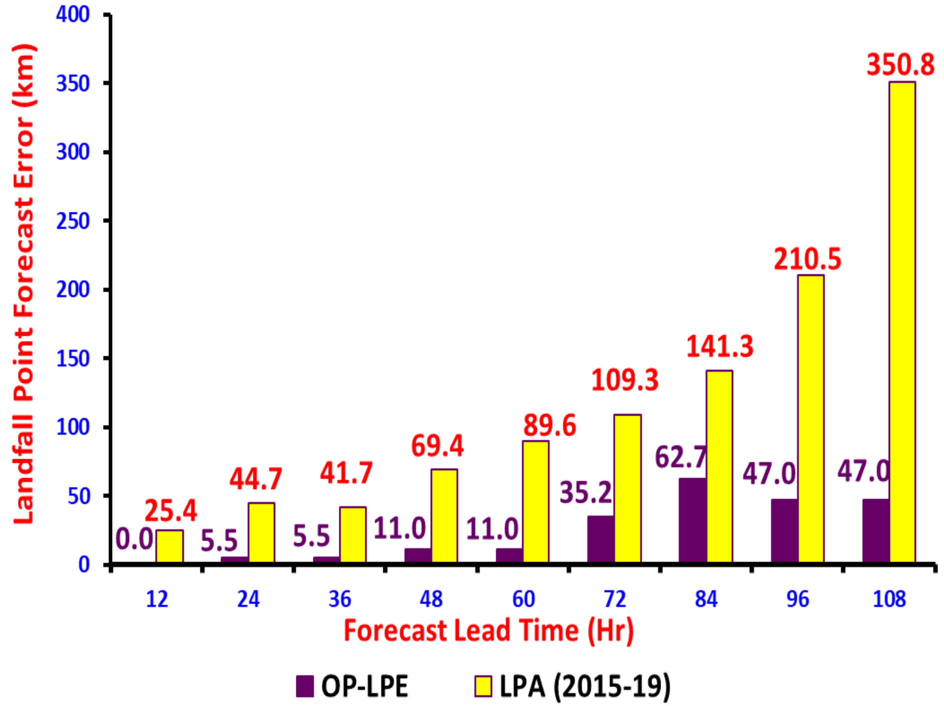
(b) Landfall time forecast error

- defined as difference in forecast landfall time and actual landfall time irrespective of landfall point.

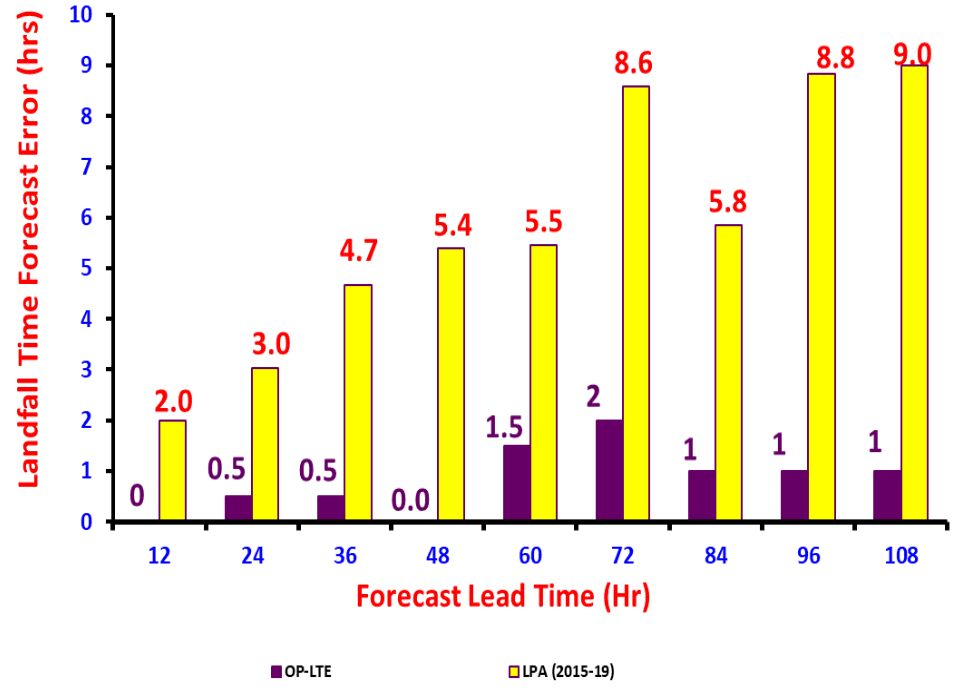
Landfall forecast error-SuCS Amphan

Excellent demonstration of zero landfall point and time error

(a) Landfall Point Forecast Errors of SuCS AMPHAN in comparison to Long Period Average Errors (2015-19)



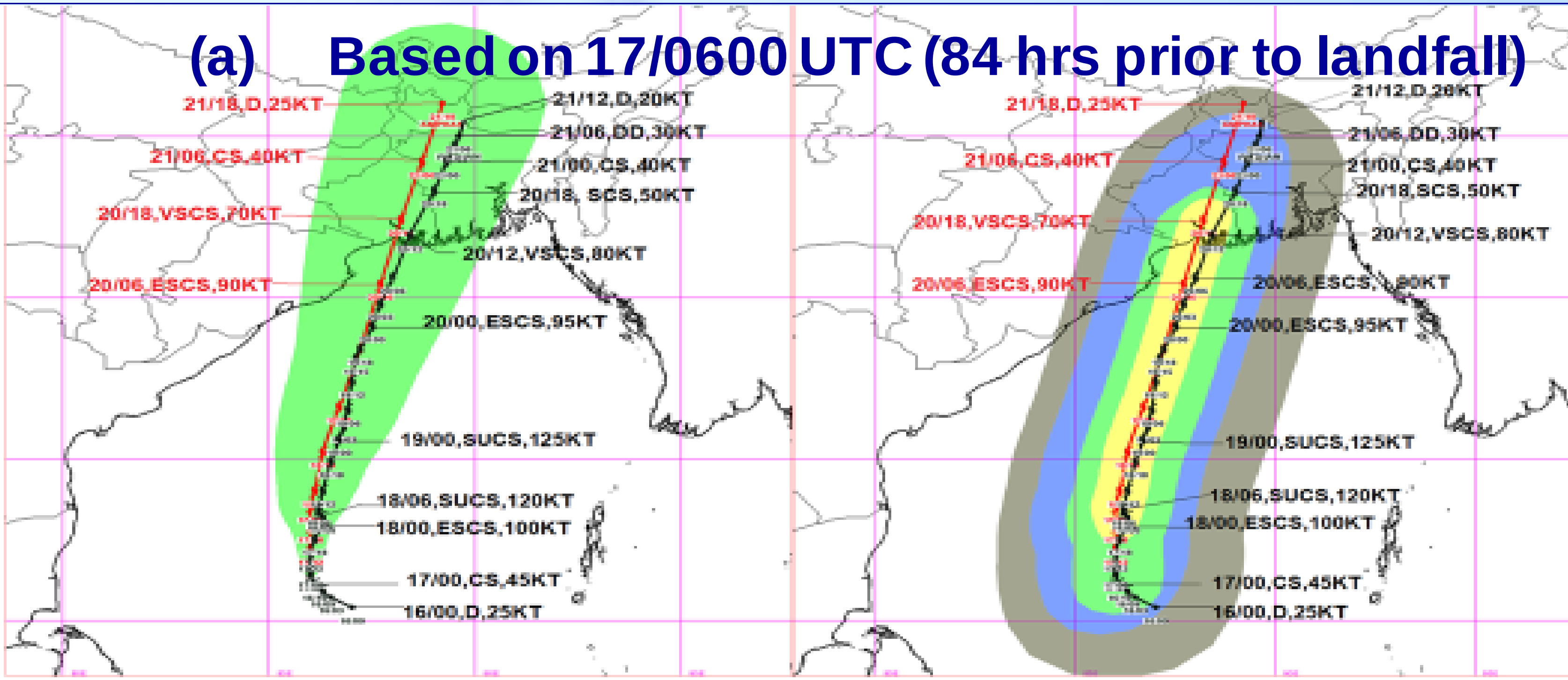
(b) Landfall Time Forecast Errors of SuCS AMPHAN in comparison to Long Period Average Errors (2015-19)



Landfall forecast error-SuCS Amphan

Excellent demonstration of zero landfall point and time error

(a) Based on 17/0600 UTC (84 hrs prior to landfall)



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

OBSERVED TRACK

FORECAST TRACK

CONE OF UNCERTAINTY

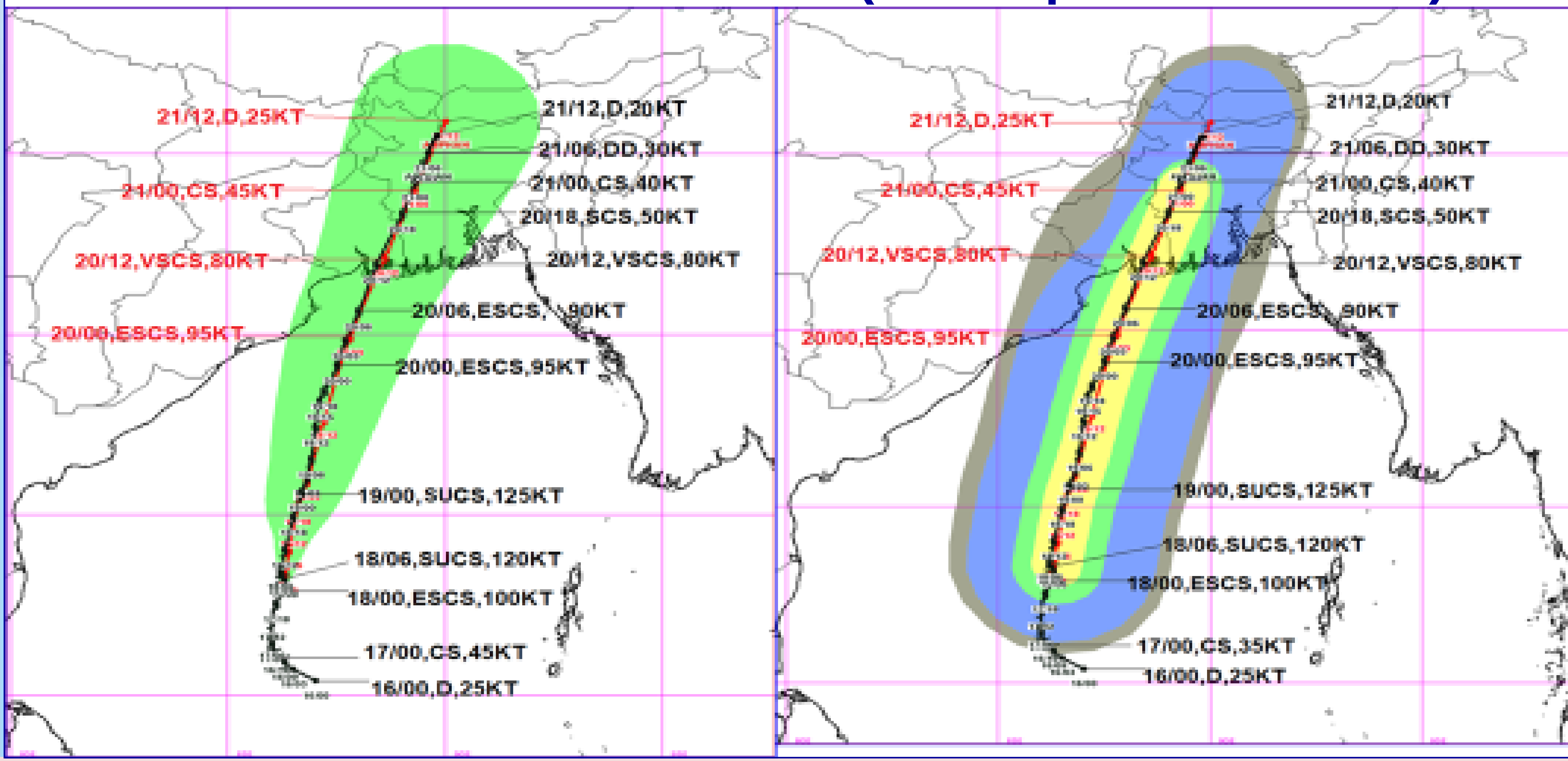
MSW(knot)(kmph)	Impact	Action
28-33 ((52-61)	Very rough seas.	Total suspension of fishing operations
34-40(62-74)	High to very high seas	Total suspension of fishing operations
41-63(75-117)	Very High seas	Total suspension of fishing operations
≥ 64 (≥118)	Phenomenal	Total suspension of fishing operations

Observed & forecast track along with COU and quadrant wind distribution based on 0600 UTC of 17th May (84 hrs prior to landfall) of SuCS AMPHAN indicating accuracy in landfall, track & intensity predictions

Landfall forecast error-SuCS Amphan

Excellent demonstration of zero landfall point and time error

- **Based on 18/0300 UTC (60 hrs prior to landfall)**

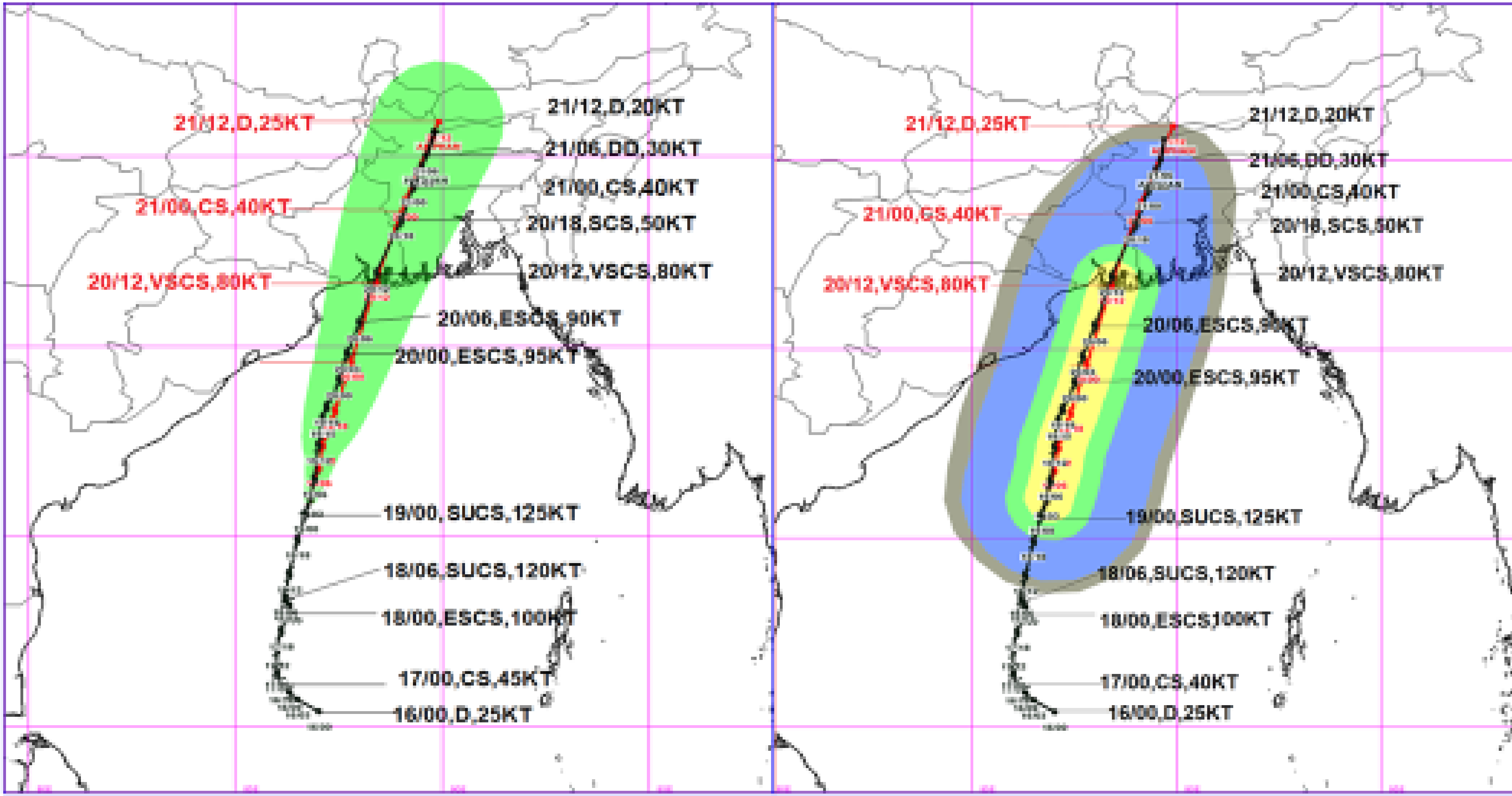


Observed & forecast track along with COU and quadrant wind distribution based on 0600 UTC of 17th May (84 hrs prior to landfall) of SuCS AMPHAN indicating accuracy in landfall, track & intensity predictions

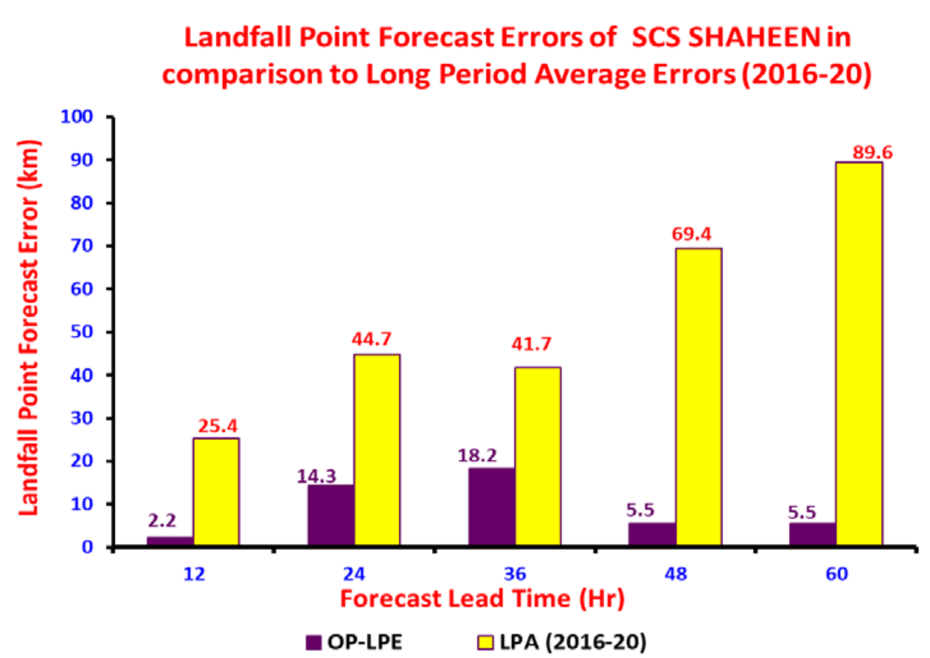
Landfall forecast error-SuCS Amphan

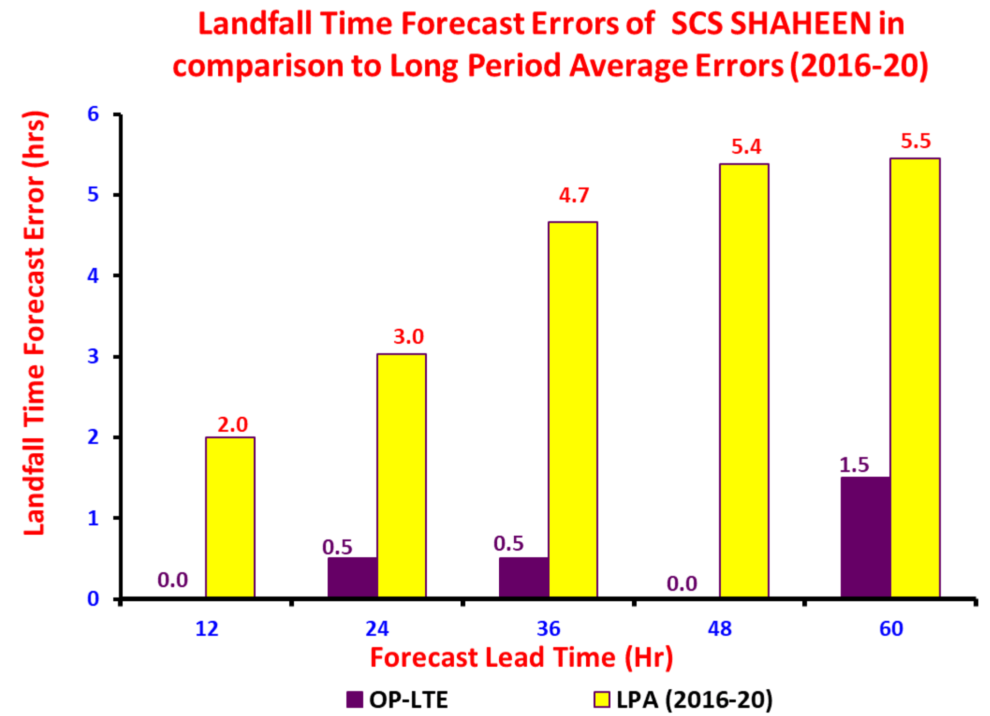
Excellent demonstration of zero landfall point and time error

Based on 19/0300 UTC (36 hrs prior to landfall)



Landfall forecast error-SCS Shaheen





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Scope for improvement in landfall forecast

(i) Improvements in observational network near the landfall locations and a denser network of HWSRs along the coast.

(ii) Use of mobile wind profilers, doppler on wheels etc. as being used in other parts of the globe for improving the accuracy in determination of landfall.

(iii) Determination of skill of the landfall forecasts using CLIPER.

(iv) Verification of probabilistic forecasts generated by models and strike probablility generated by the EPS need to be verified.

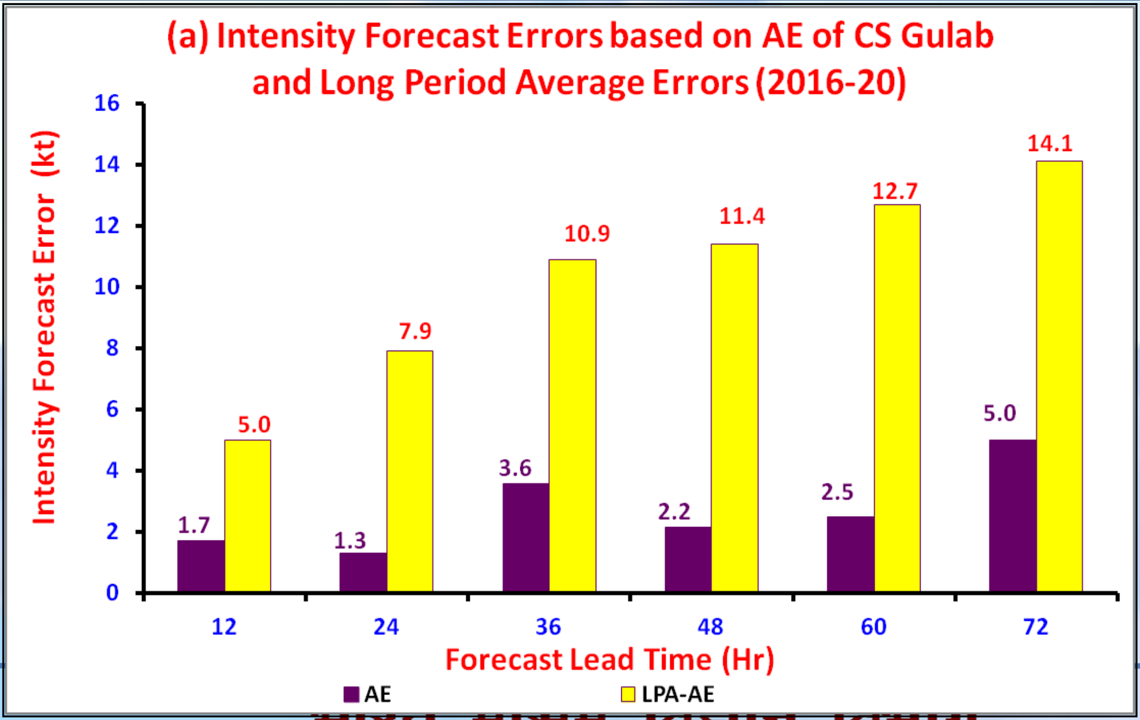
(v) Currently, the landfall forecast is verified only for the cases for which actual landfall occurred. However, there are cases when there is forecast for landfall, but, landfall does not occur and vice versa. Verification of such cases to be carried out as per the methodology adopted by Dupont et al (2006).

(vi) Improved intensity prediction could also reduce such cases in future.

(iv) Intensity forecast error

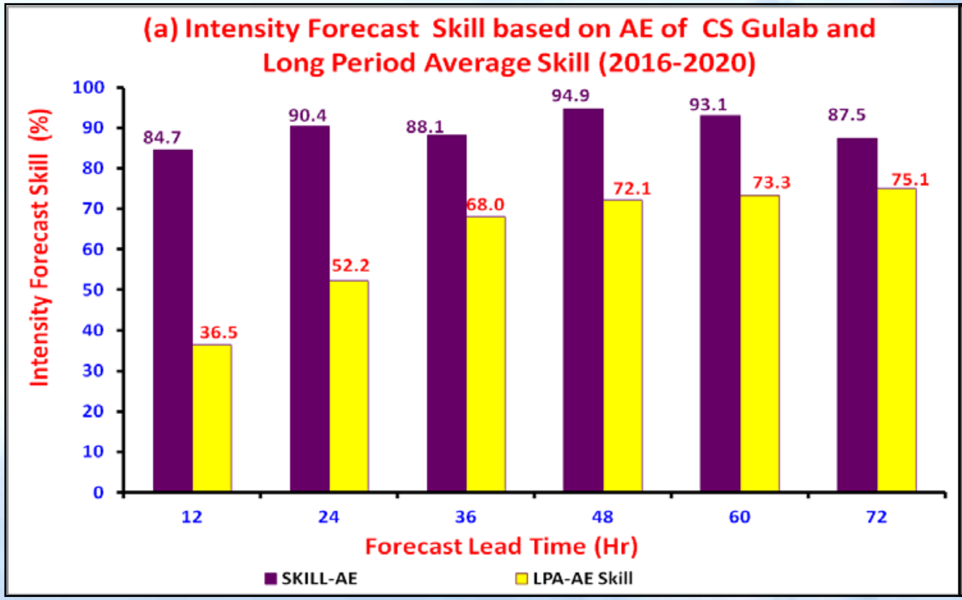
Intensity forecast error (kt):

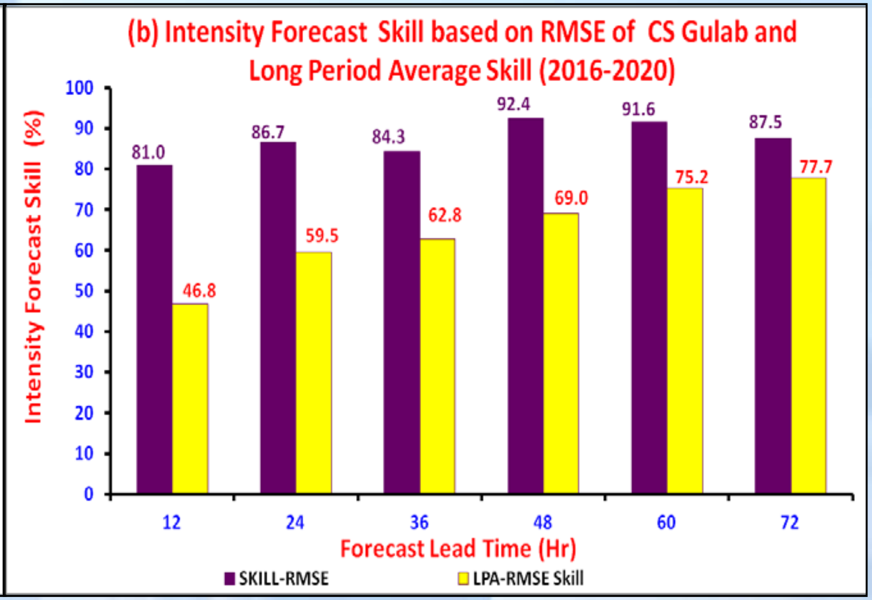
- **Calculated based on the forecast maximum sustained surface wind speed (MSW) and actual MSW.**
- **We calculate (a) absolute mean error and (AAE) (ii) Root Mean Square (RMSE) error.**
- **Data base includes six hourly forecasts with validity period of 120 hrs.**
- **We calculate intensity forecast errors for 12, 24, 36, 48, 60, 72, 84, 96, 108 & 120 hrs forecasts.**



(v) Intensity forecast skill (%)

- Calculated by comparing the operational intensity forecast error like AAE & RSME with that of reference model.
- Forecast based on persistence method is used as reference model.
- Skill is calculated for 12, 24, 36, 48, 60, 72, 84, 96, 108 and 120 hrs lead periods.
- Gain (loss) in skill (%) = $\frac{\text{Persistence Error- Operational Error}}{\text{Operational Error}}$





(vi) Annual average track forecast error & Skill

- **Annual average track forecast error and skill are calculated by taking the track forecast errors of all the cyclones during the year.**

- **It is calculated for 12, 24, 36, 48, 72, 84, 96, 108 and 120 hrs lead periods.**

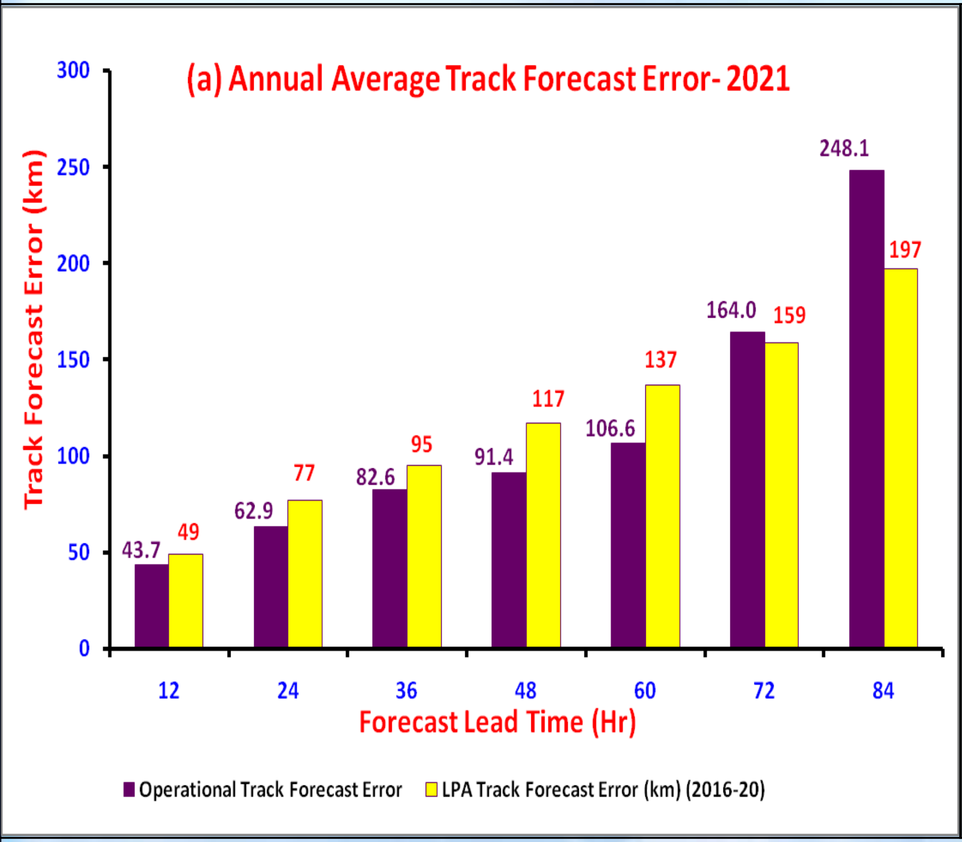
- **Annual average error = (n1*E1+n2*E2+n3*E3+....) / (n1+n2+n3+...)**

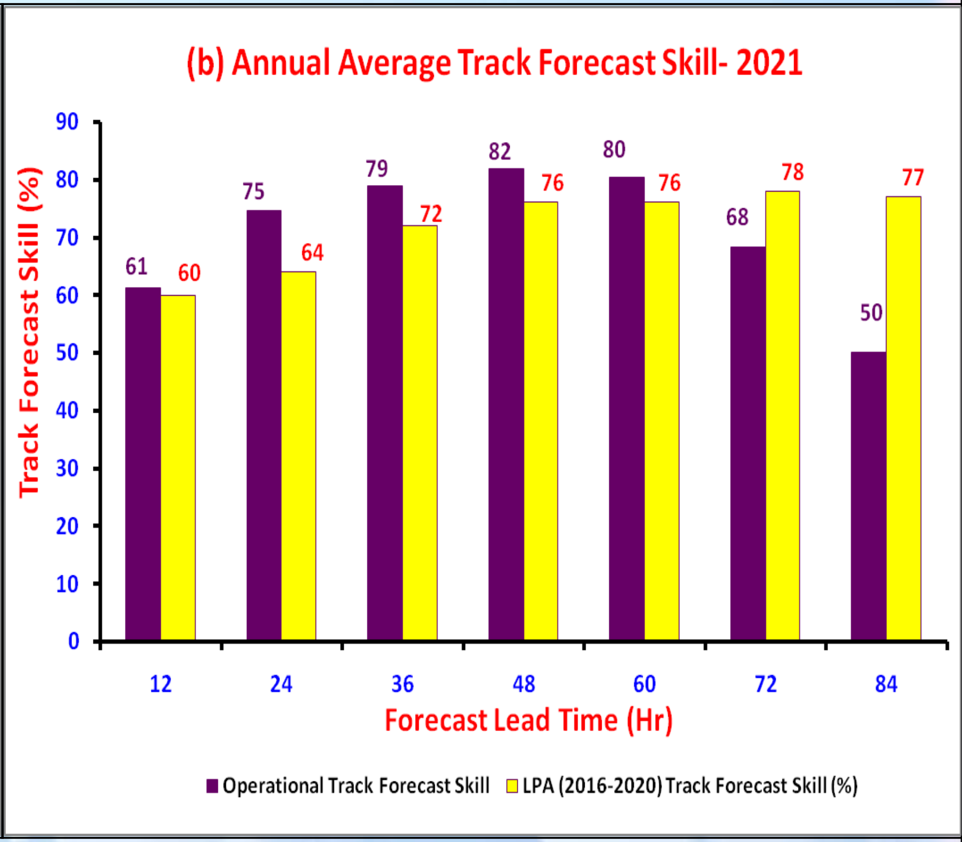
where n1, n2, n3... are number of six hrly forecasts verified for cyclone 1, 2, 3... and

E1, E2, E3... are the average error for cyclone n1, n2, n3….

- **Annual average track forecast skill = (weighted average CLIPER error-weighted average Operational error)/ weighted average CLIPER**

(vi) Annual average track forecast error & Skill





(vi) Annual average landfall point & time forecast error

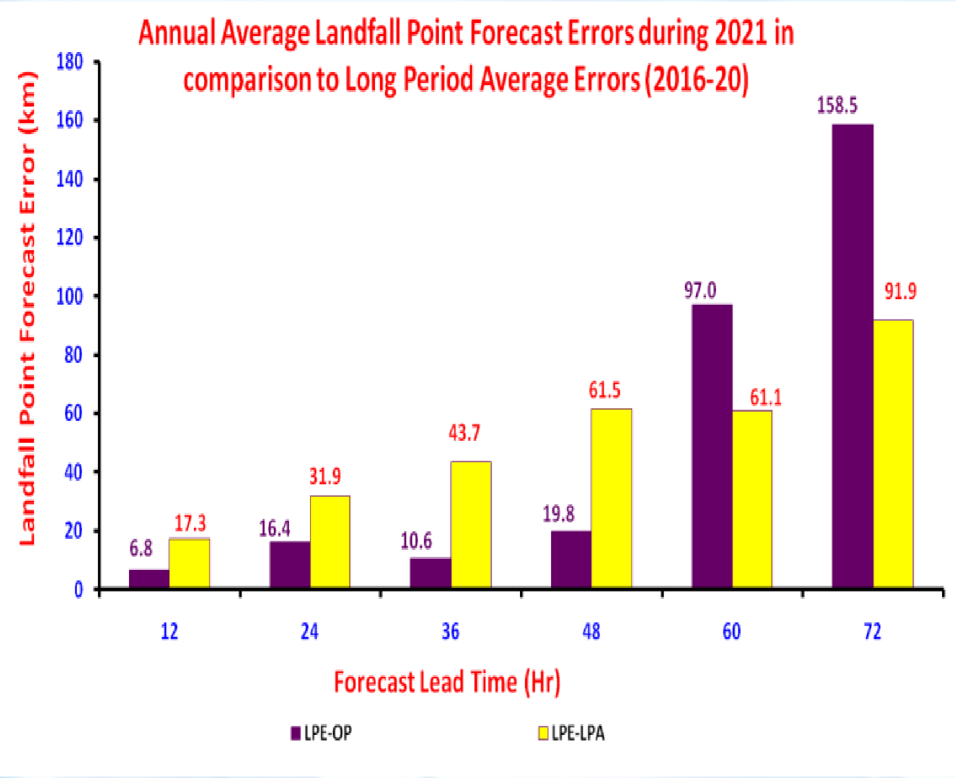
- **Annual average point & time forecast errors are calculated by taking the forecast errors of all the cyclones during the year.**

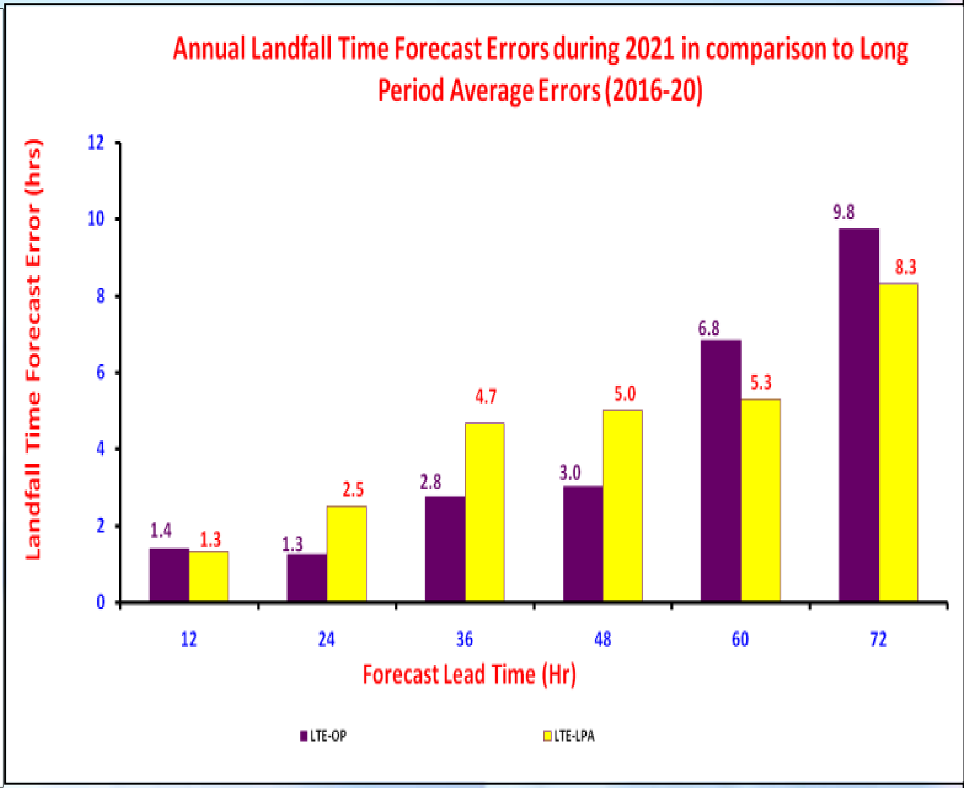
- **It is calculated for 12, 24, 36, 48, 72, 84, 96, 108 and 120 hrs lead periods.**

- **Annual average error** $= \dfrac{(E1+E2+E3+....)}{\text{total no. of cyclones}}$

E1, E2, E3... are the average error for n cyclones

(vi) Annual average landfall point & time forecast error





(vii) Annual average intensity forecast error and skill

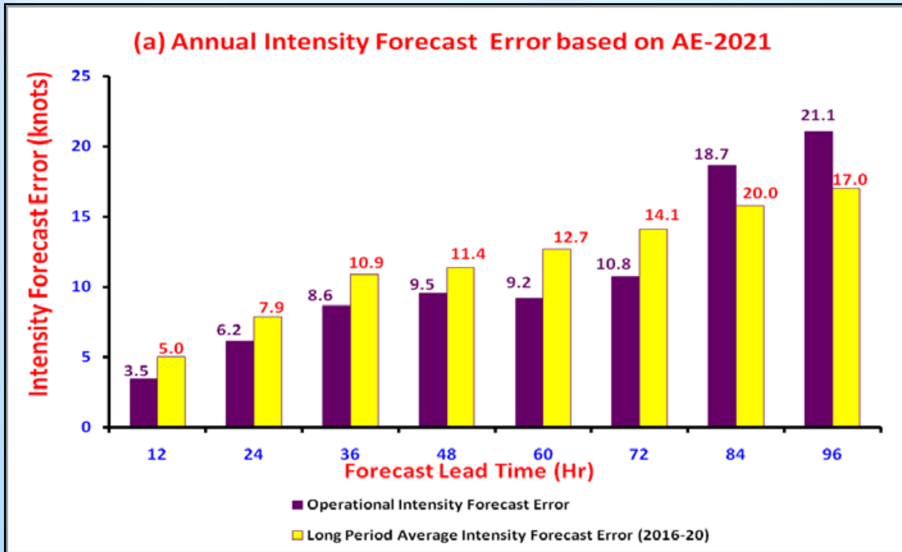
- Annual average intensity forecast error based on absolute error is calculated by taking the mean intensity forecast errors of all the cyclones during a year and the No. of observations verified.
- It is calculated for 12, 24, 36, 48, 60, 72, 84, 96, 108 and 120 hrs lead periods.
- Annual average error based on absolute error =

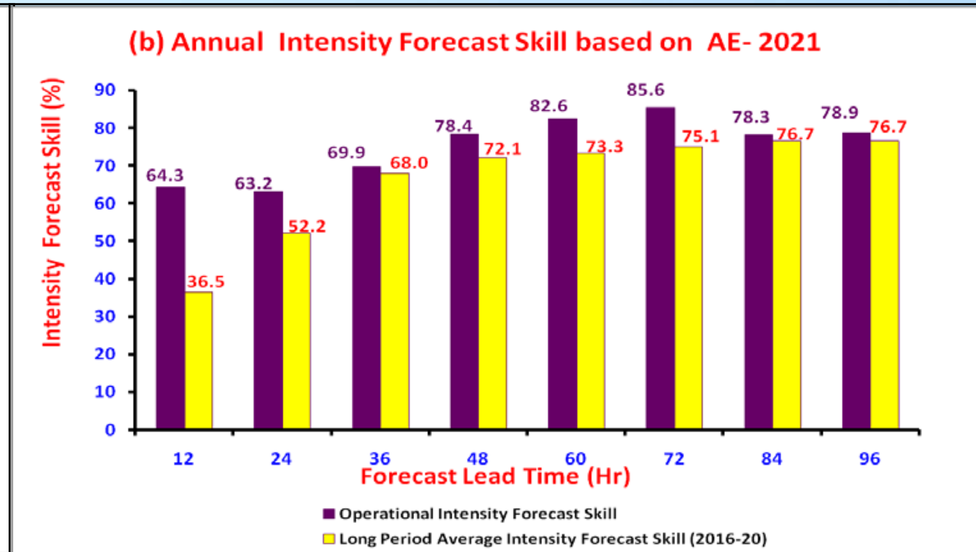
$$\frac{(n1*E1+n2*E2+n3*E3+....)}{(n1+n2+n3+...)}$$

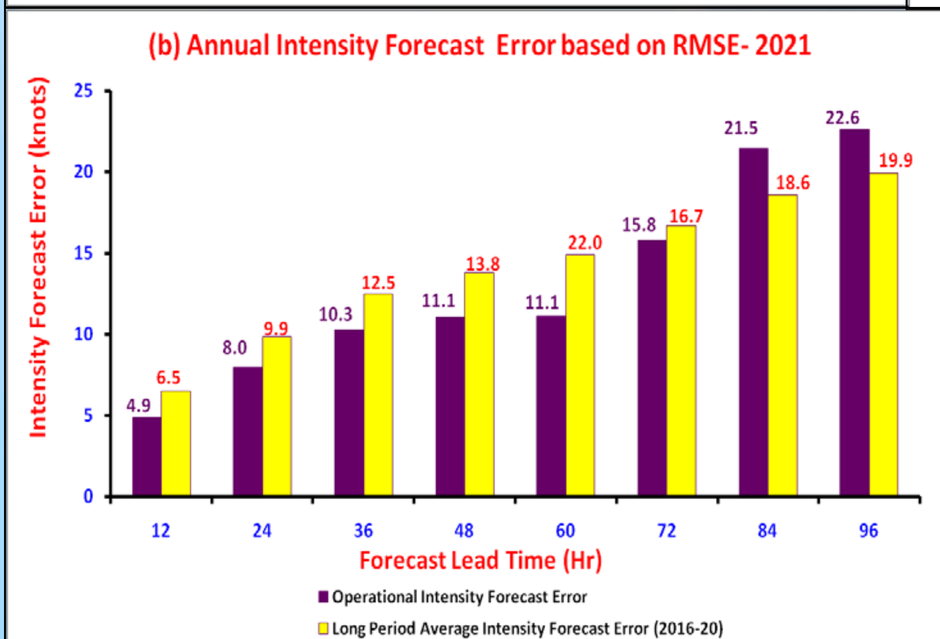
  n1, n2, .. are No. of six hrly forecasts verified for cyclone 1, 2, ... &
  E1, E2, .. are the mean intensity forecast errors for cyclone n1, n2….
- Similarly, annual average intensity forecast through persistence based on absolute error is calculated.
- Skill in annual average intensity forecast based on absolute error is calculated w.r.t. persistence forecast for 12, 24, 36, 48,60, 72, 84, 96, 108 & 120 as lead period.

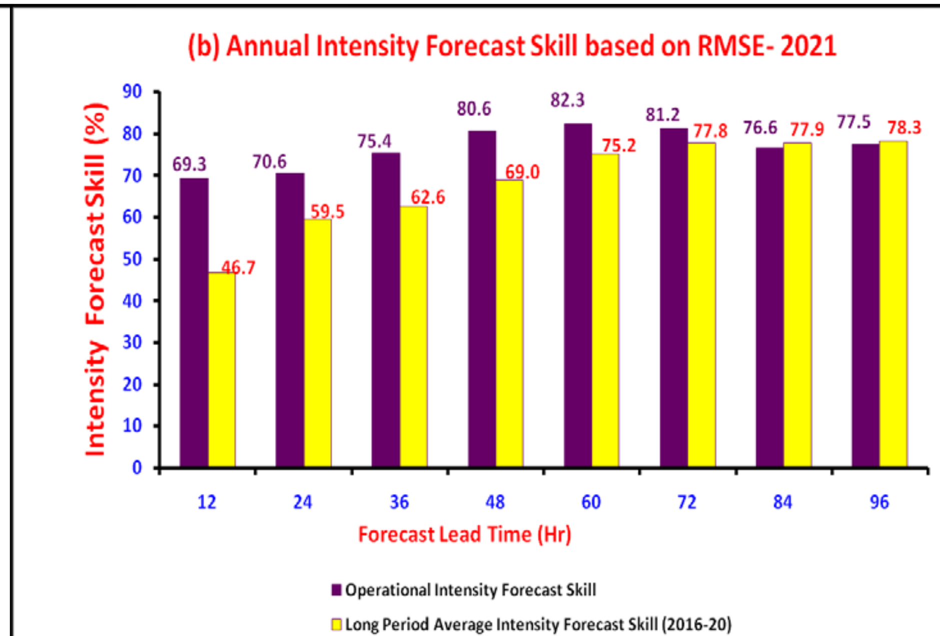
  Gain (loss) in skill (%) = $\frac{\text{Persistence Error- Operational Error}}{\text{Operational Error}}$
- Similarly, annual average intensity forecast error and skill based on root mean square error are calculated.

(vii) Annual average intensity forecast error and skill





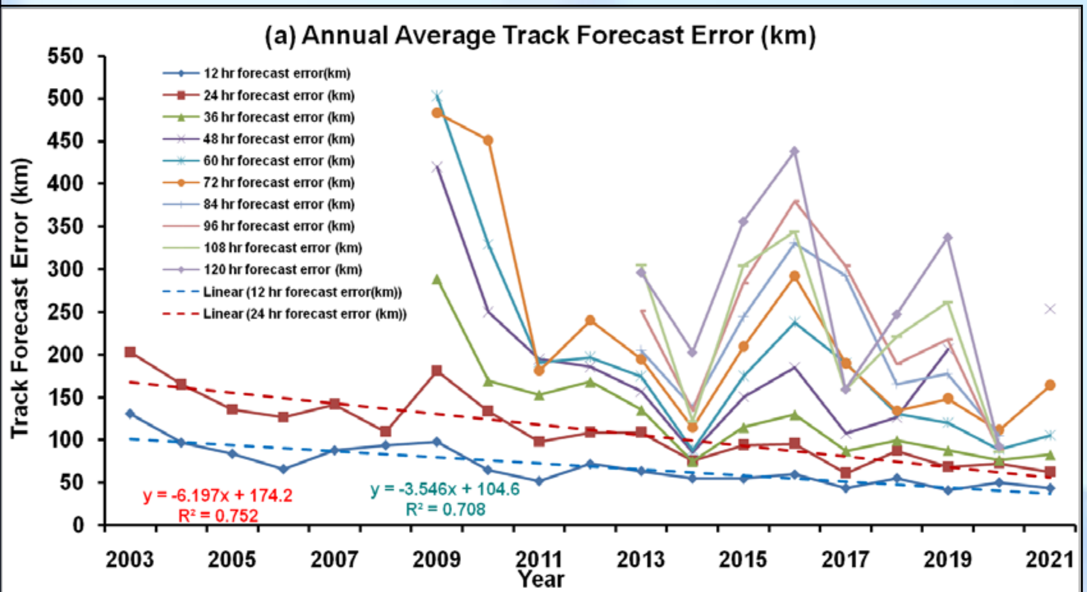


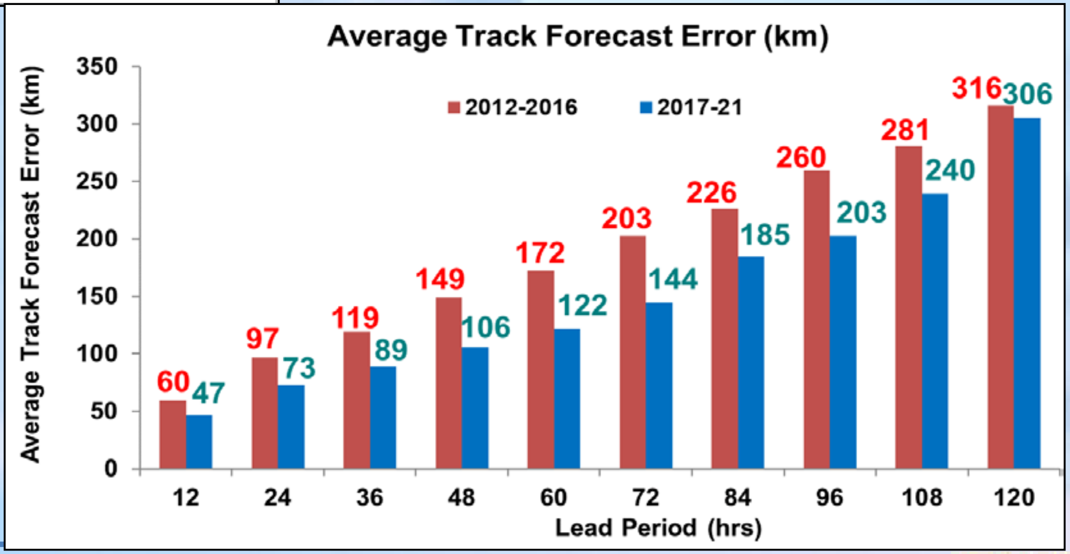


(viii) Five year mean error and skill in landfall, track & intensity forecasts

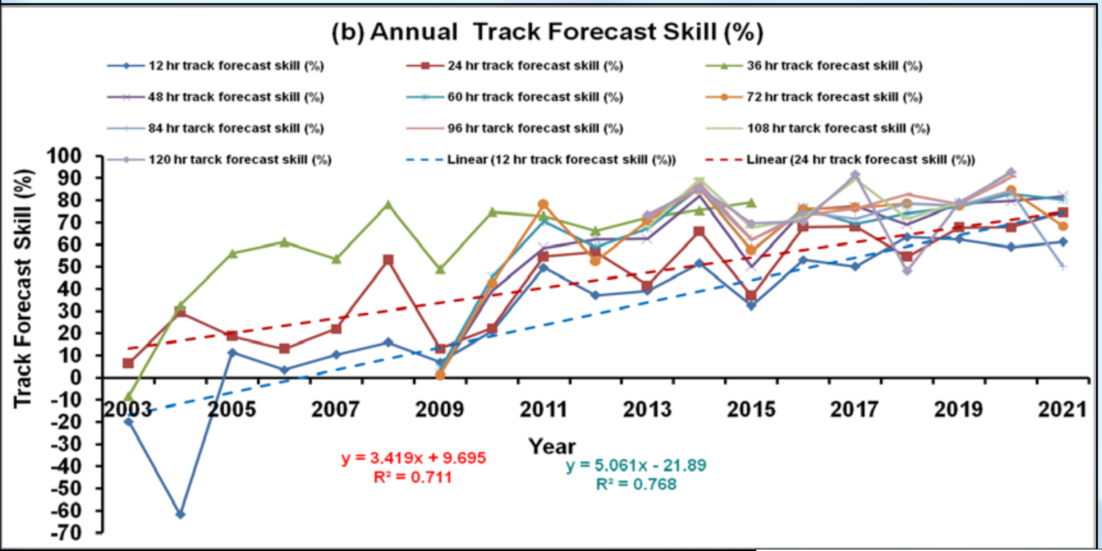
- Five year mean error in track forecast and intensity forecasts are calculated by the weighted mean approach.
- The annual average error are weighted by number of forecasts verified in the year for this purpose.
- Errors and skills are calculated for 12, 24, 36, 48, 60, 72, 84, 96, 108 and 120 hour forecasts.

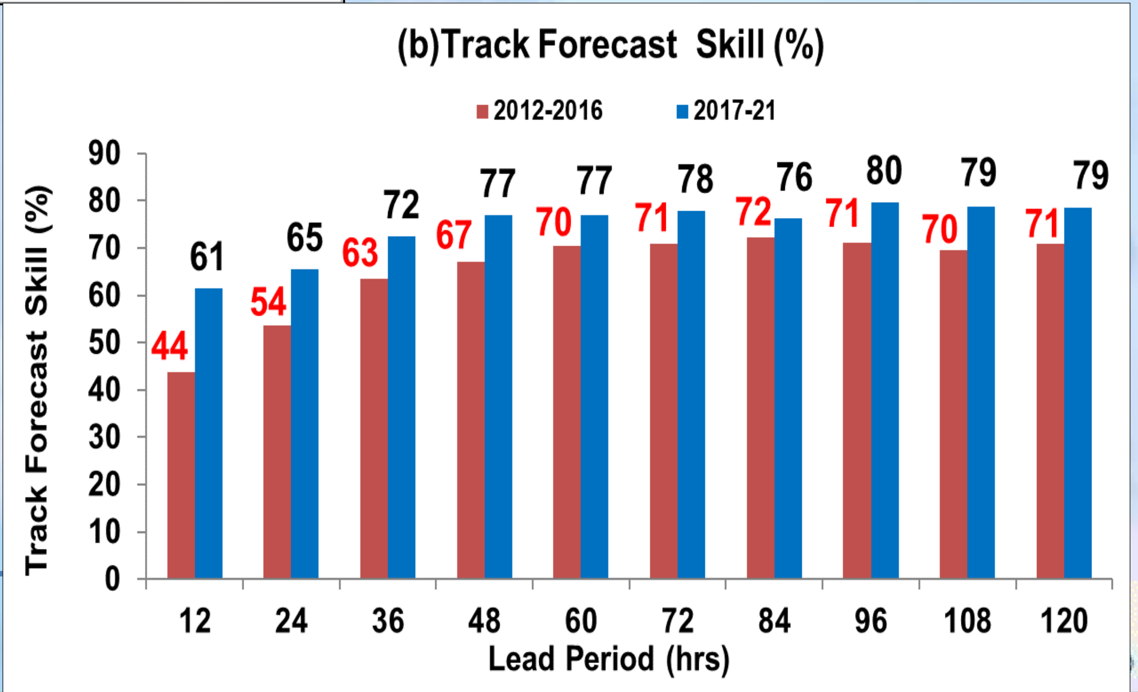
Advances in Cyclone Forecasting :
Improvement in Track forecast accuracy





Advances in Cyclone Forecasting :
Improvement in Track forecast skill accuracy





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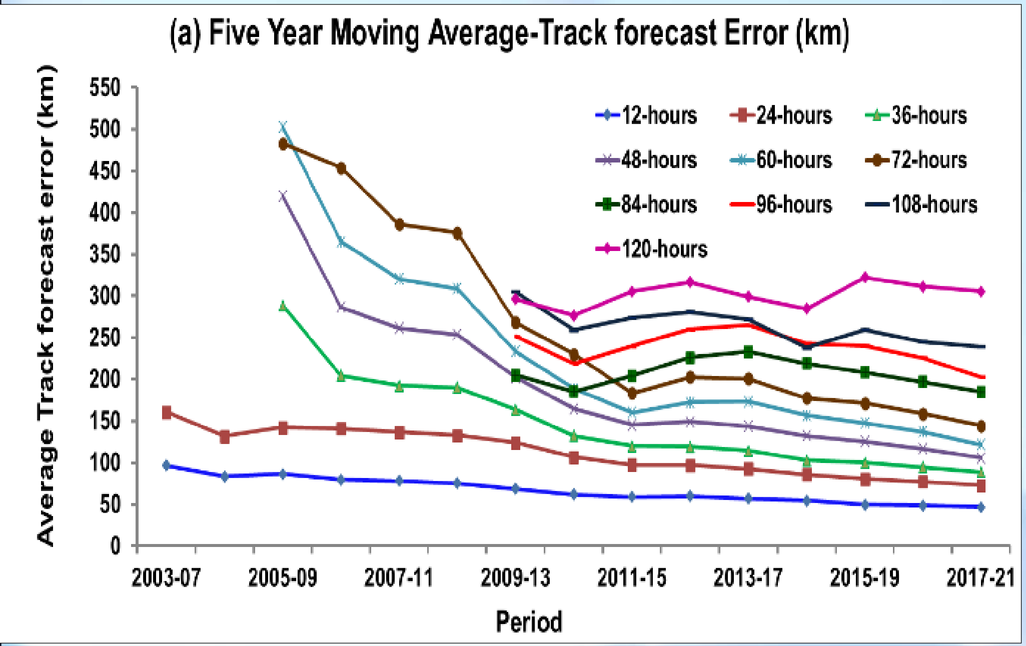
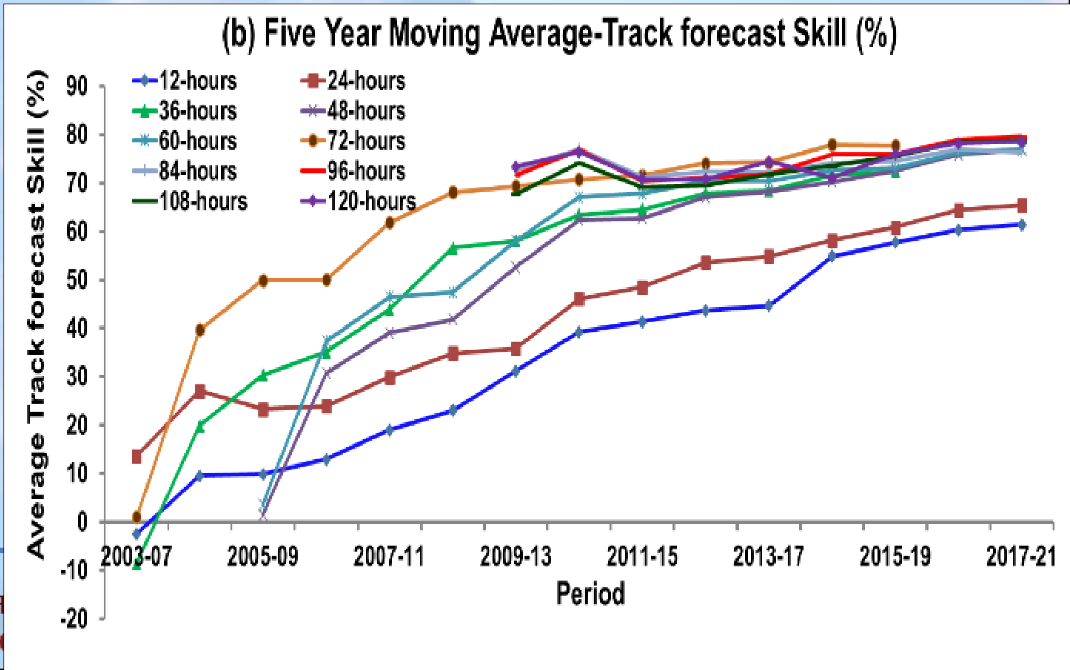
Five Year Moving Average- Track Forecast Error & Skill





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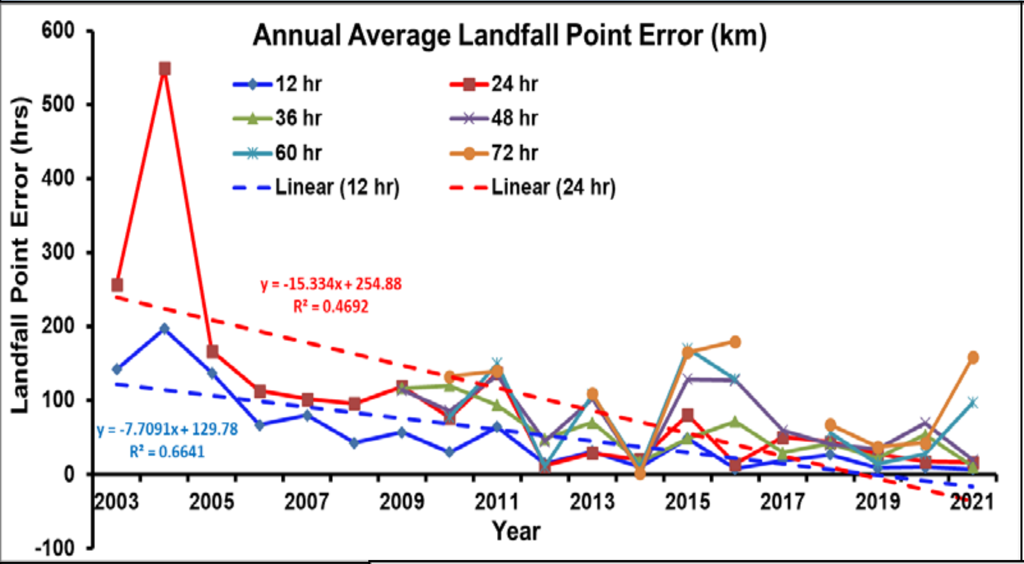
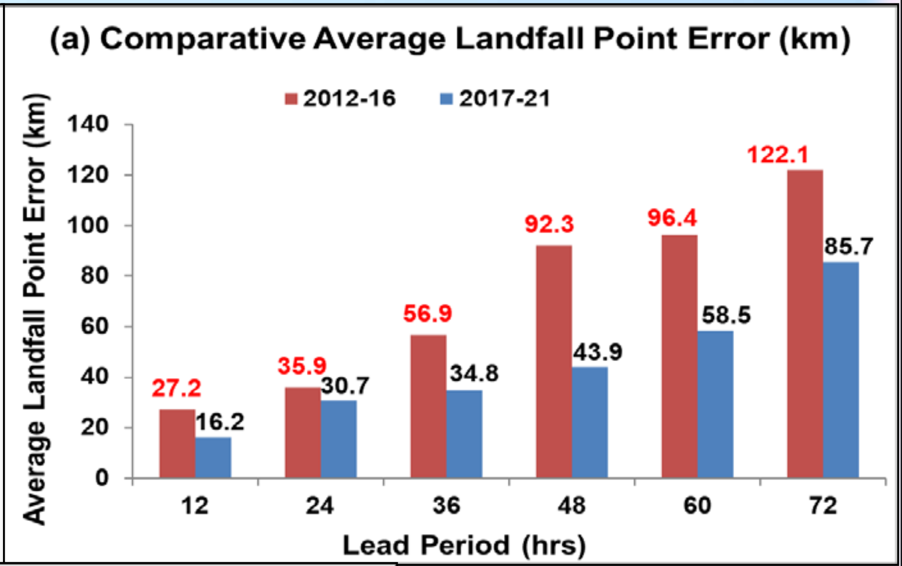
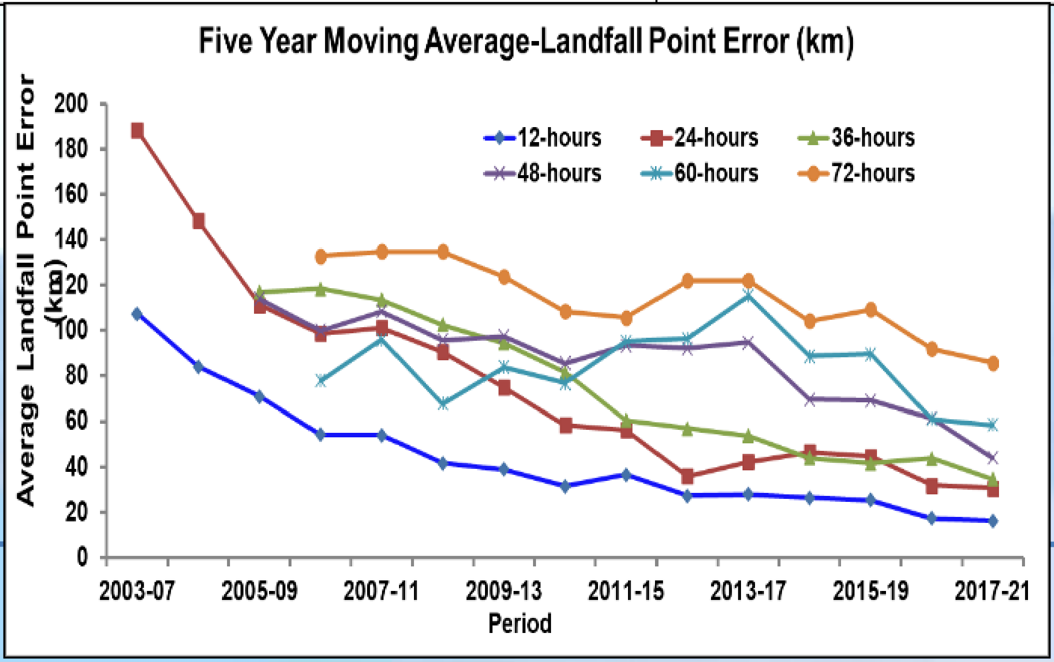
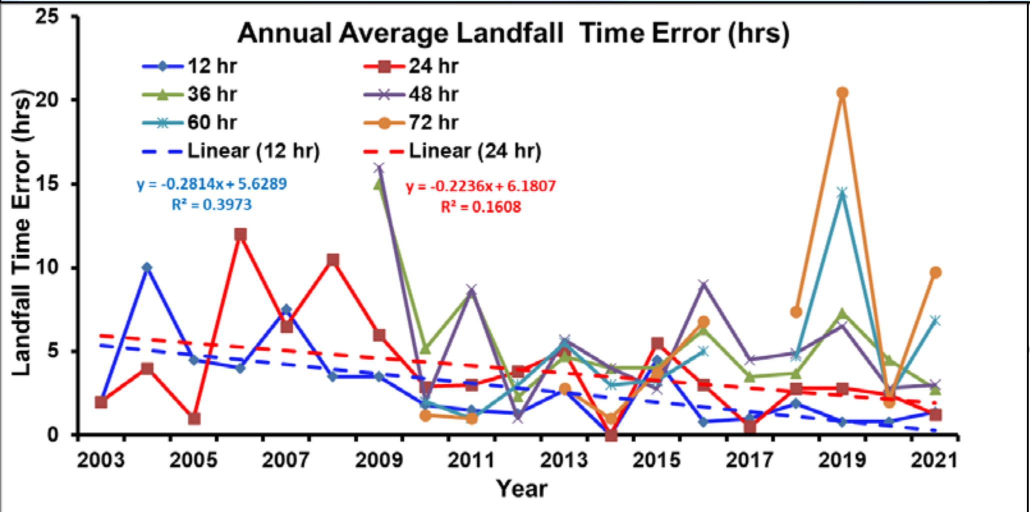
Advances in Cyclone Forecasting :
Improvement in Landfall Point forecast

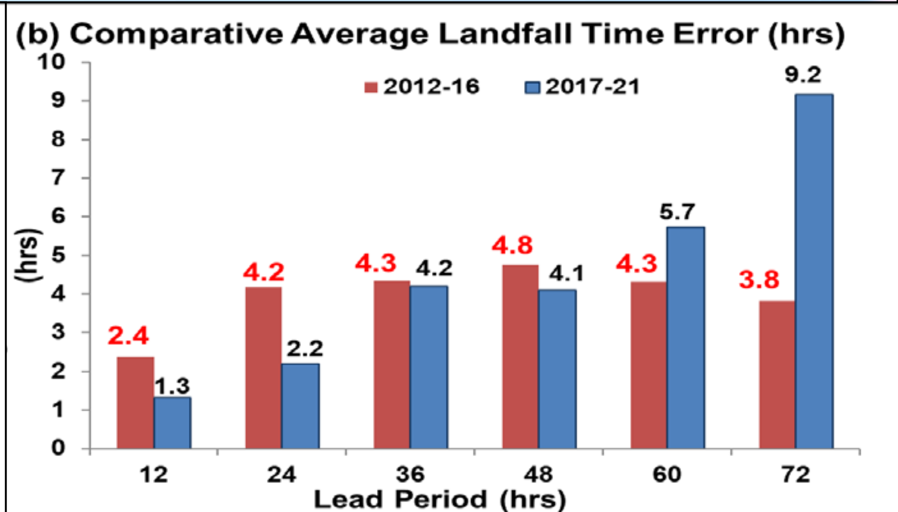


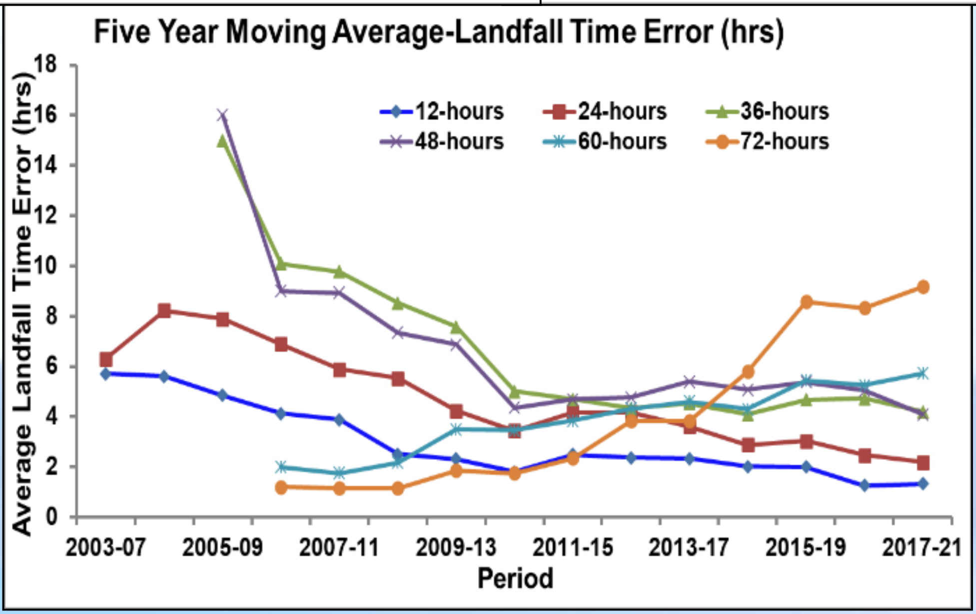




Advances in Cyclone Forecasting :
Improvement in Landfall Time forecast





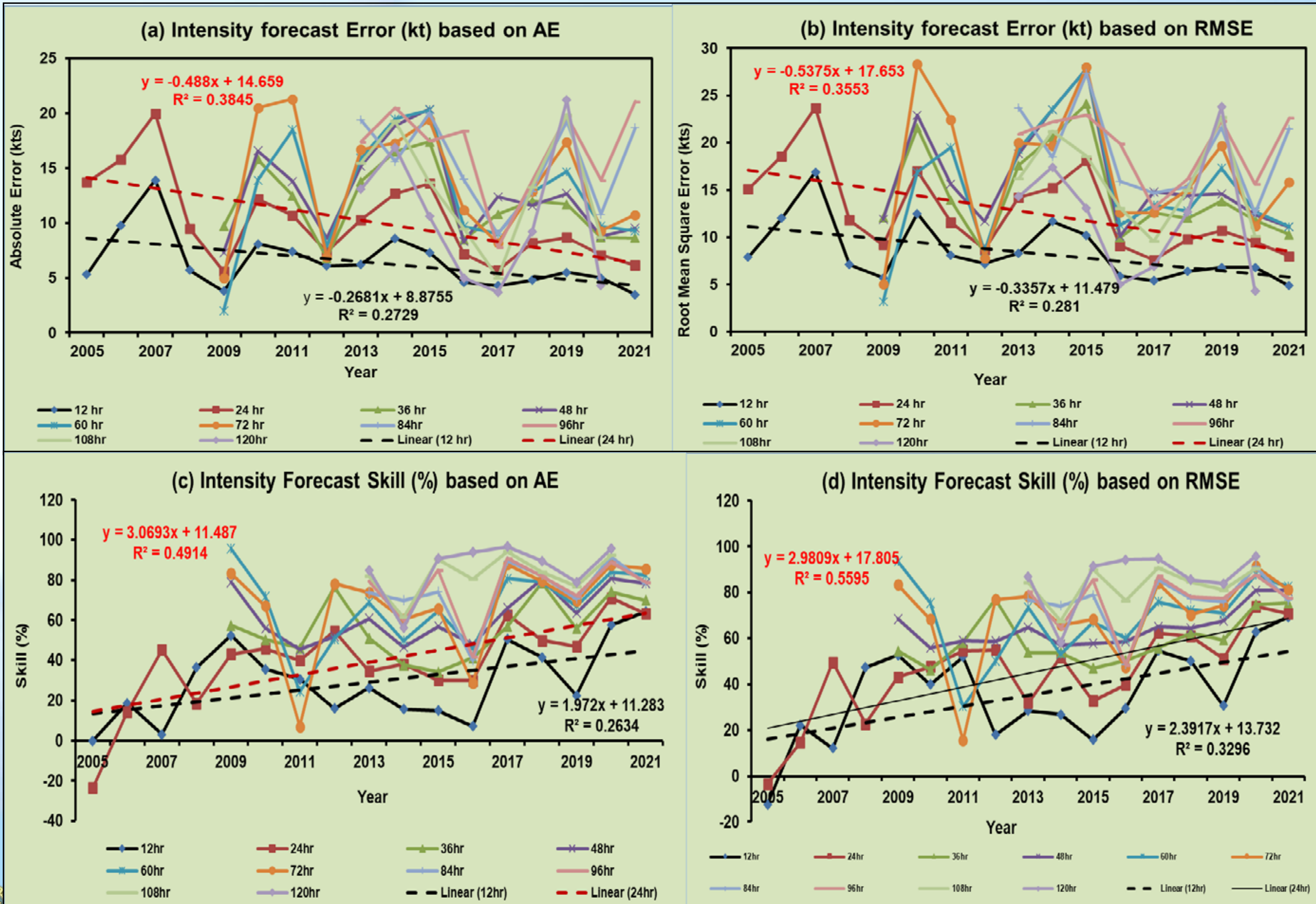


भारत मौसम विज्ञान विभाग

INDIA METEOROLOGICAL DEPARTMENT

Advances in Cyclone Forecasting :

AE & RMSE of maximum sustained surface wind forecast



Advances in Cyclone Forecasting :
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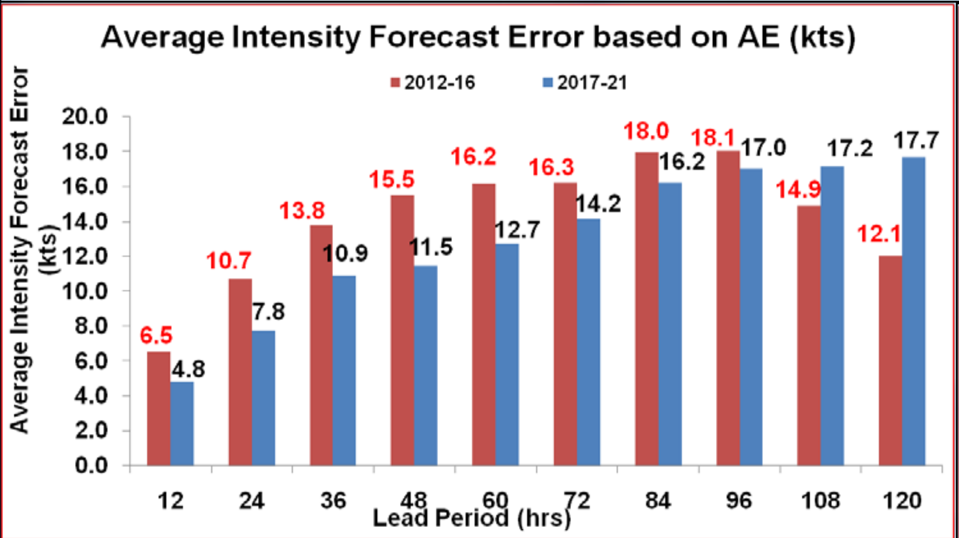
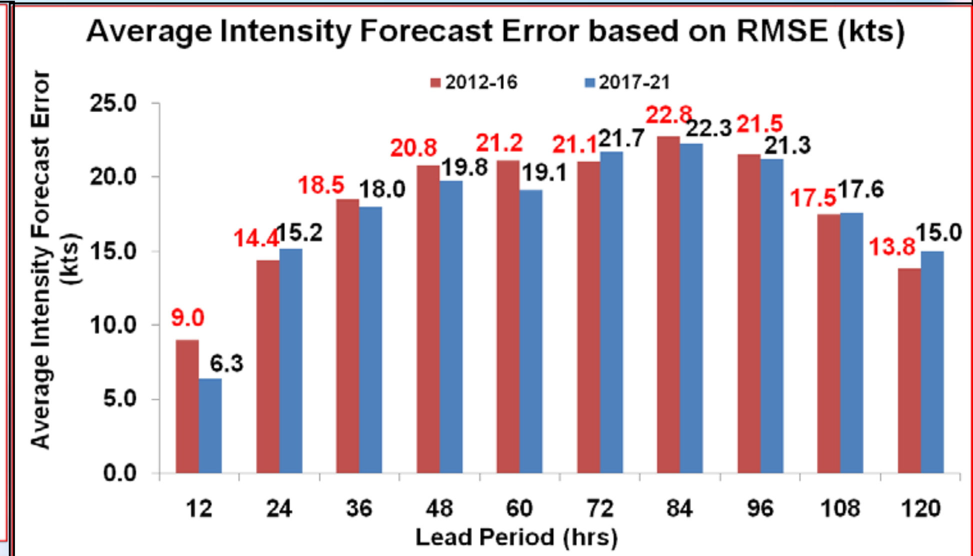
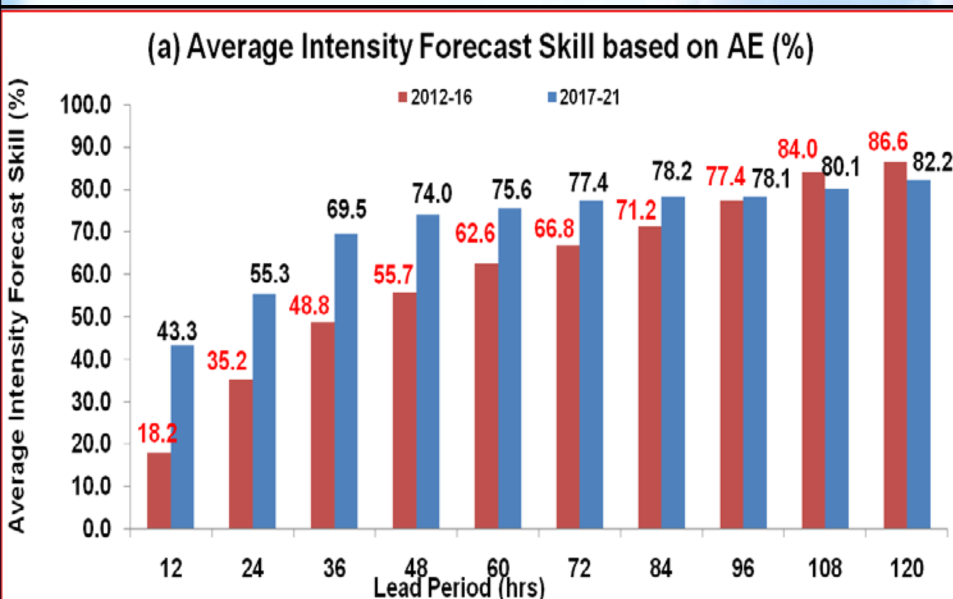
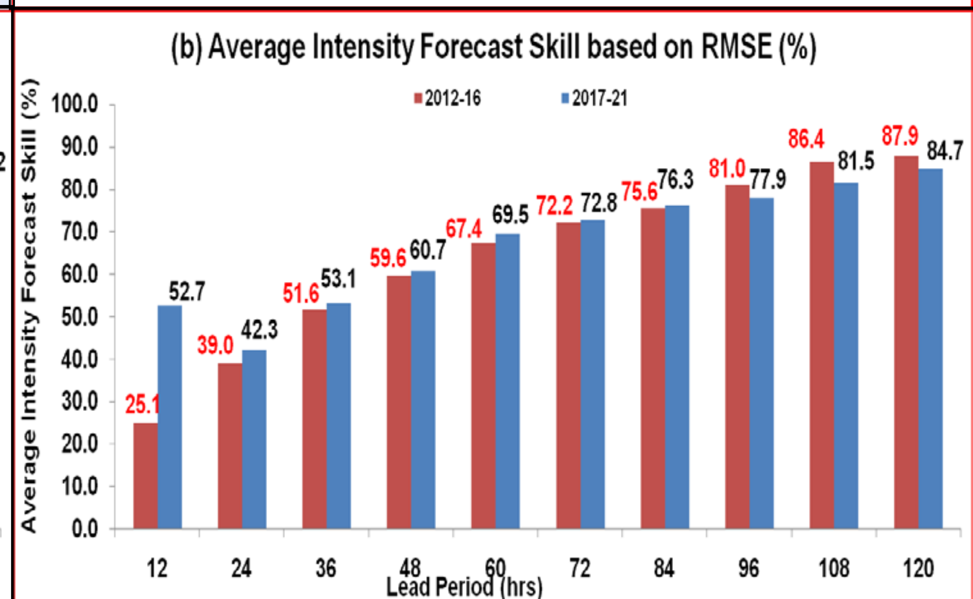
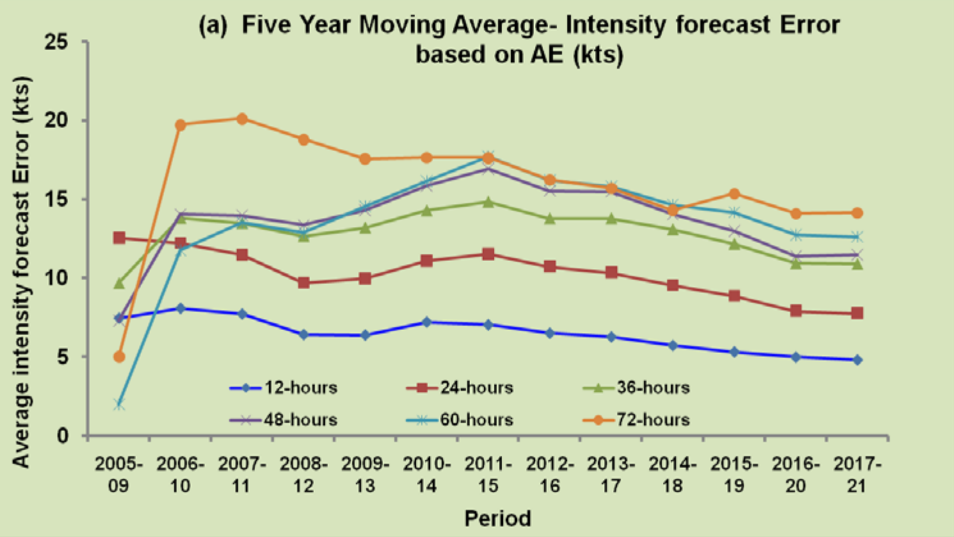


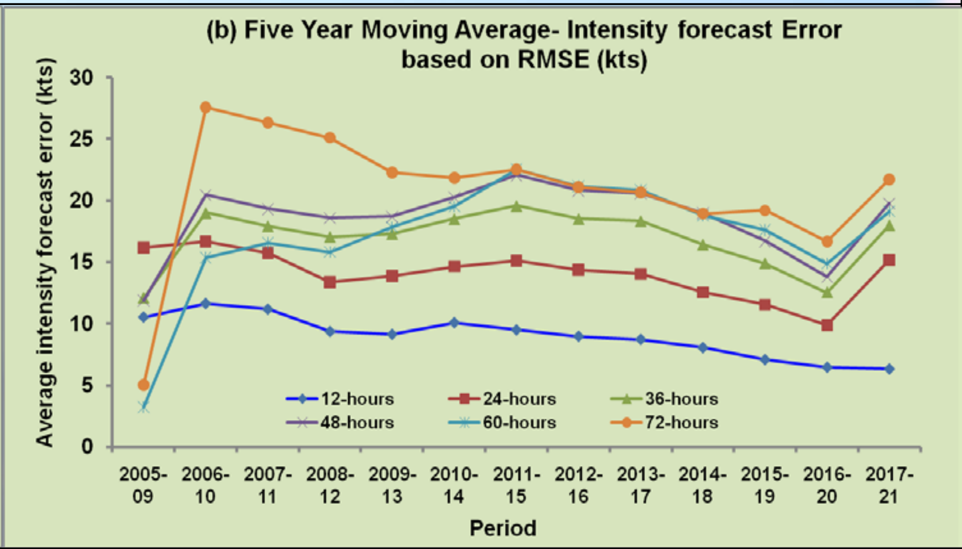


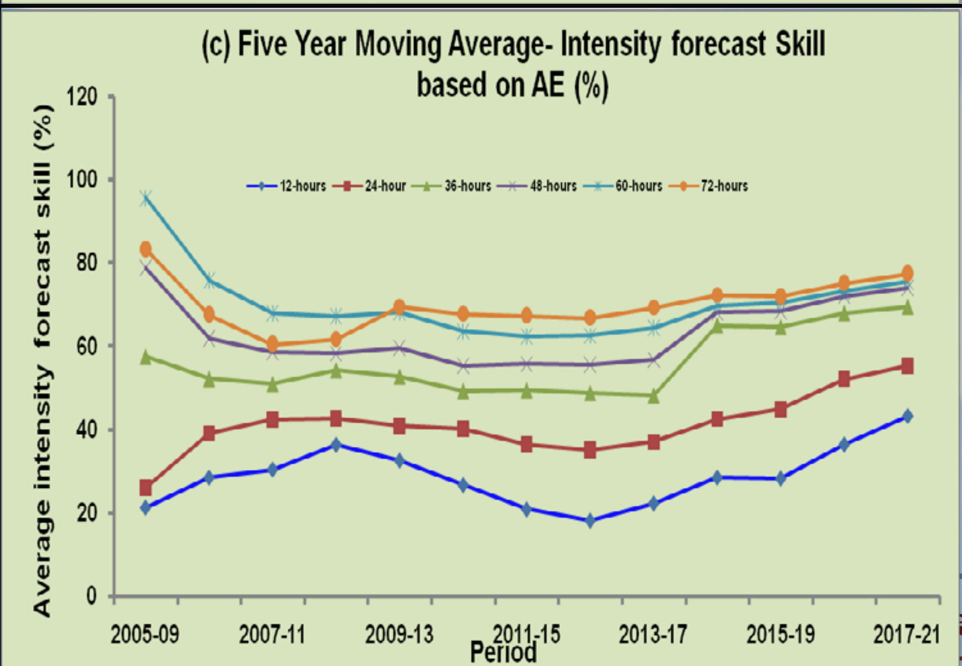


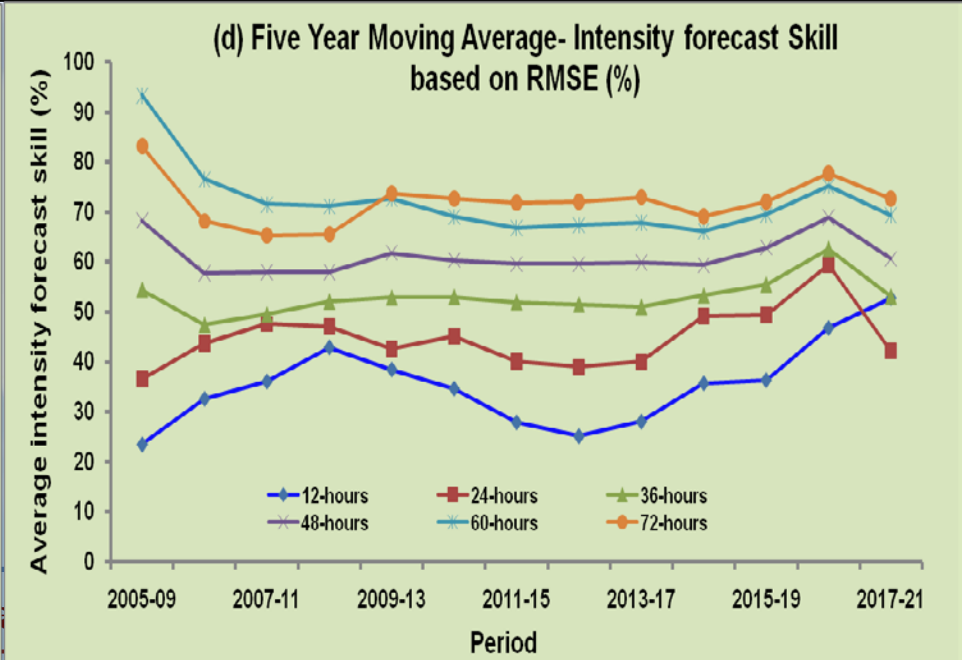


Advances in Cyclone Forecasting :
AE & RMSE of maximum sustained surface wind forecast





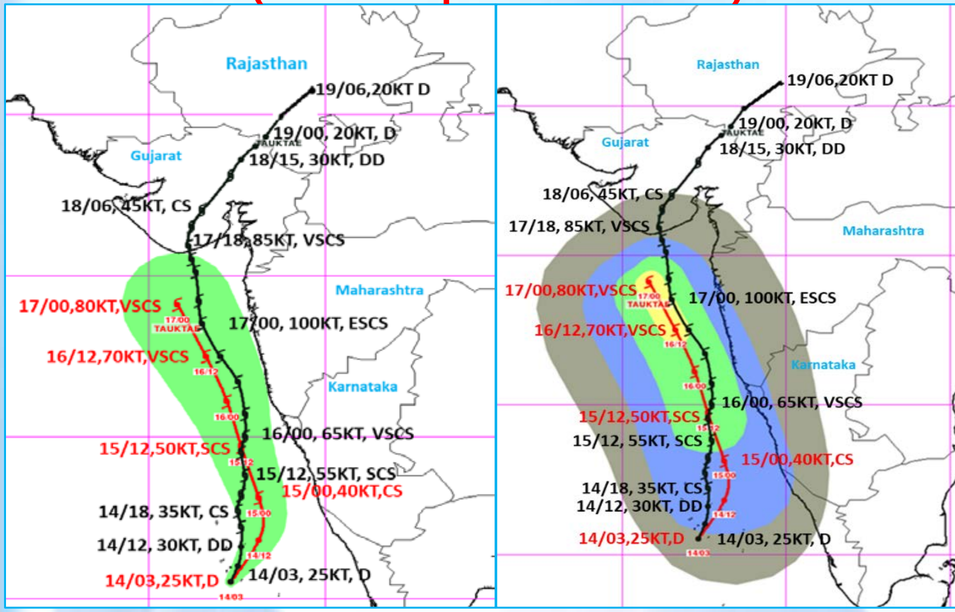




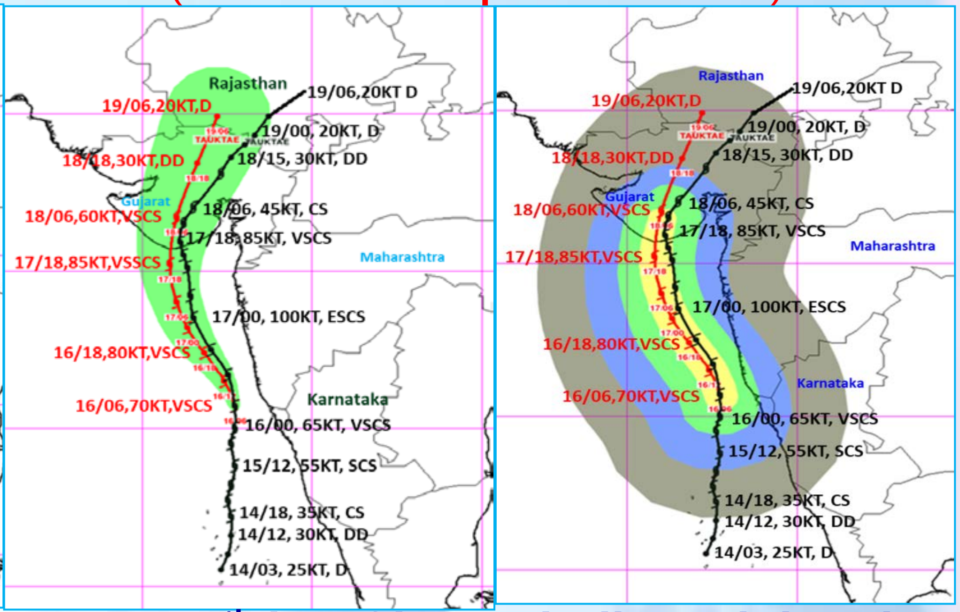
ESCS TAUKTAE

FORECAST ACCURACY- TRACK, LANDFALL & INTENSITY

Forecast issued at 1245 hours IST of 14th May
(80 hours prior to landfall)



Forecast issued at 1430 hours IST of 16th May
(about 36 hours prior to landfall)



From 14th itself it was indicated that system would move parallel to west coast of India and affect all states from Kerala-Gujarat

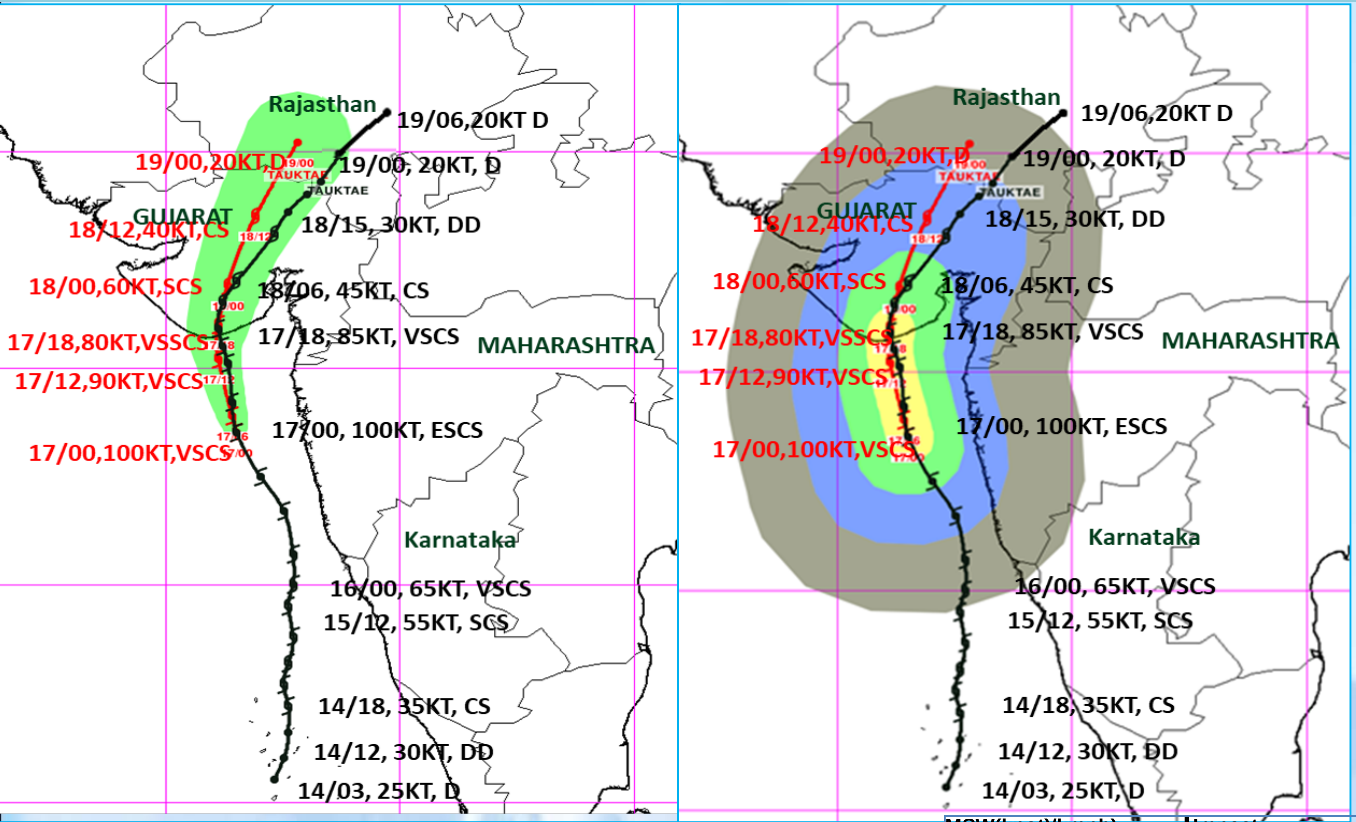
From 16th itself it was indicated that the system would cross south Gujarat coast between Porbander & Mahuva around 18th early morning

DATE/TIME IN UTC, IST = UTC + 0530 HRS, D: DEPRESSION, DD: DEEP DEPRESSION, CS: CYCLONIC STORM, SCS: SEVERE CYCLONIC STORM, VSCS: VERY SEVERE CYCLONIC STORM, OBSERVED TRACK, FORECAST TRACK, CONE OF UNCERTAINTY

MSW(knot)/kmph)	Impact	Action
28-33 /(52–61)	Very rough seas.	Total suspension of fishing operations
34-40/(62-74)	High to very high seas	Total suspension of fishing operations
41-63/(75-117)	Very High seas	Total suspension of fishing operations
≥ 64 (≥118)	Phenomenal	Total suspension of fishing operations

ESCS TAUKTAE

FORECAST ACCURACY- TRACK, LANDFALL & INTENSITY



Forecast issued at 0830 hours IST of 17th May (about 18 hours prior to landfall) demonstrating accuracy in track, intensity and landfall.

It was indicated that the system would cross coast between Porbander & Mahuva between 2030-2230 IST of 17th with wind speed 155-165 gusting to 185 kmph.

DATE/TIME IN UTC, IST = UTC + 0530 HRS, D: DEPRESSION, DD: DEEP DEPRESSION, CS: CYCLONIC STORM, SCS: SEVERE CYCLONIC STORM, VSCS: VERY SEVERE CYCLONIC STORM, OBSERVED TRACK, FORECAST (, CONE OI UNCERTAINTY

MSW(knot)/kmph)	Impact	Action
28-33 /(52–61)	Very rough seas.	Total suspension of fishing operations
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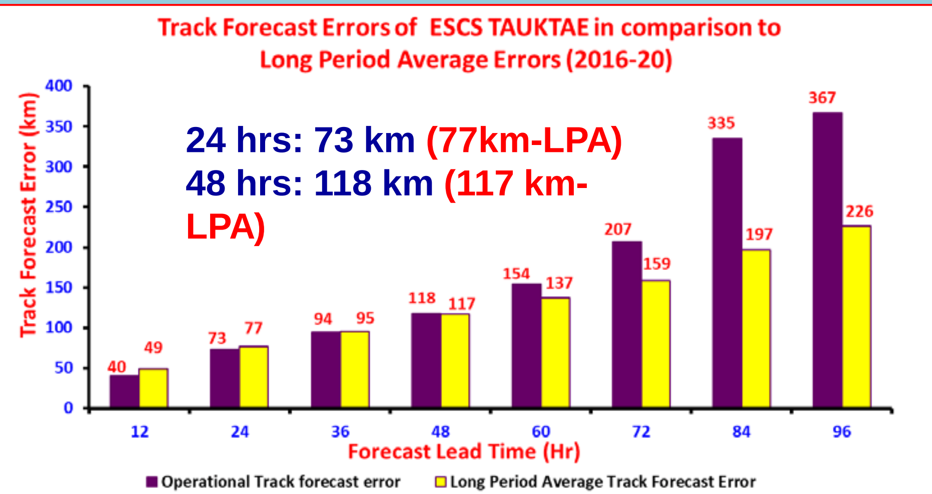
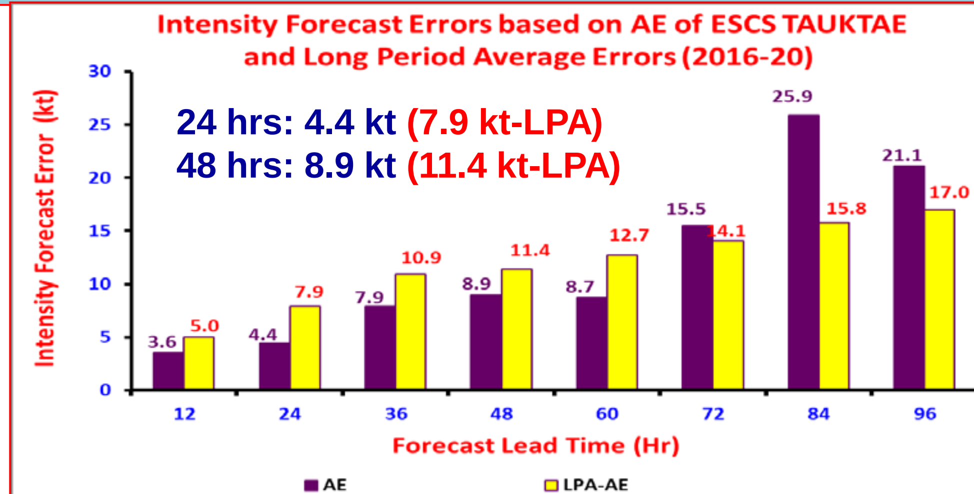
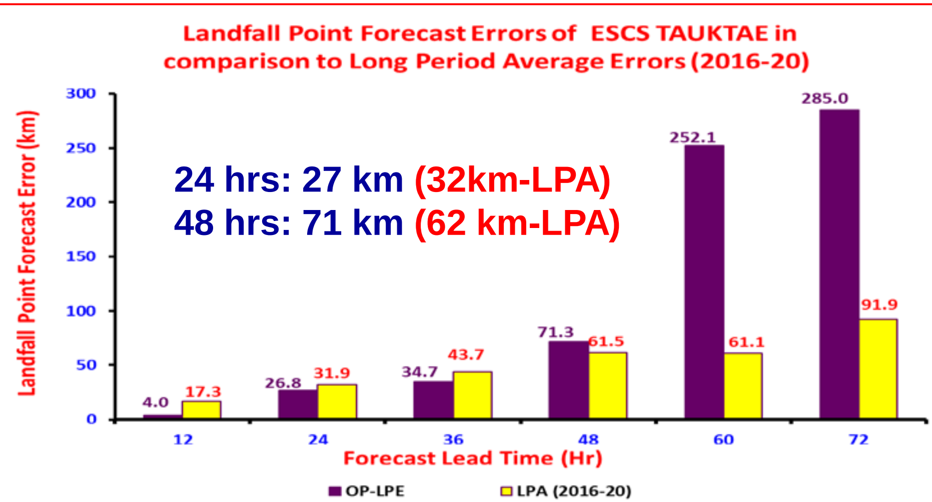
≥ 64 (≥118)	Phenomenal	Total suspension of fishing operations

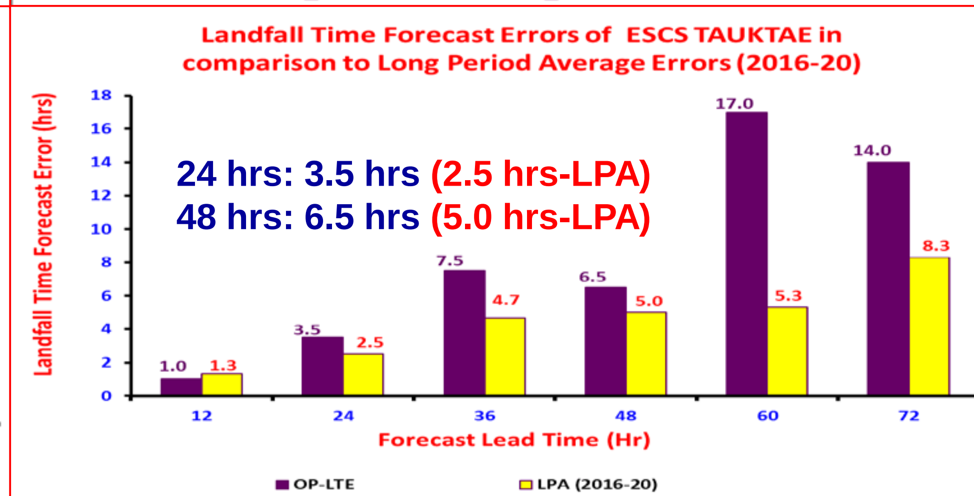
ESCS TAUKTAE

OPERATIONAL FORECAST ACCURACY- TRACK, LANDFALL &





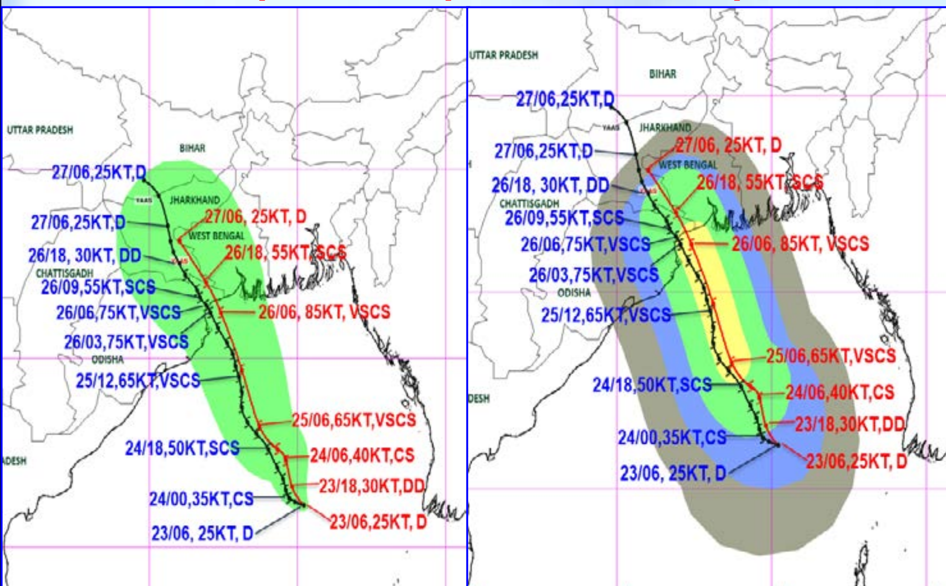


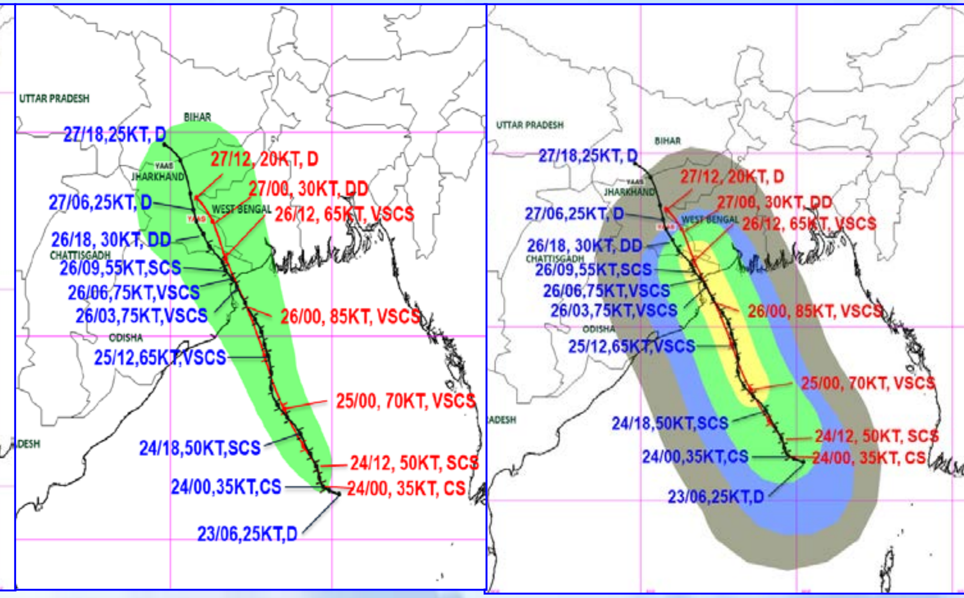


FORECAST ACCURACY- TRACK, LANDFALL & INTENSITY

Forecast issued at 1350 hours IST of 23rd May
(72 hours prior to landfall)

Forecast issued at 0900 hours IST of 24th May
(about 54 hours prior to landfall)





From 1st Bulletin it was indicated that system would intensify upto VSCS stage, affect Odisha-West Bengal States and cross North Odisha coast on 26th A/N

Forecast issued on 24th morning demonstrating accuracy in track, landfall & intensity prediction

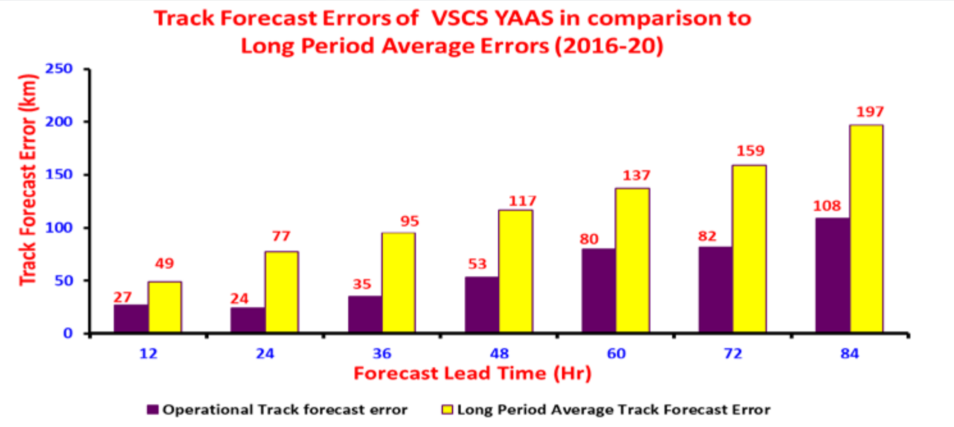
DATE/TIME IN UTC, IST = UTC + 0530 HRS, D: DEPRESSION, DD: DEEP DEPRESSION, CS: CYCLONIC STORM, SCS: SEVERE CYCLONIC STORM, VSCS: VERY SEVERE CYCLONIC STORM, OBSERVED TRACK, FORECAST ... , CONE OF UNCERTAINTY

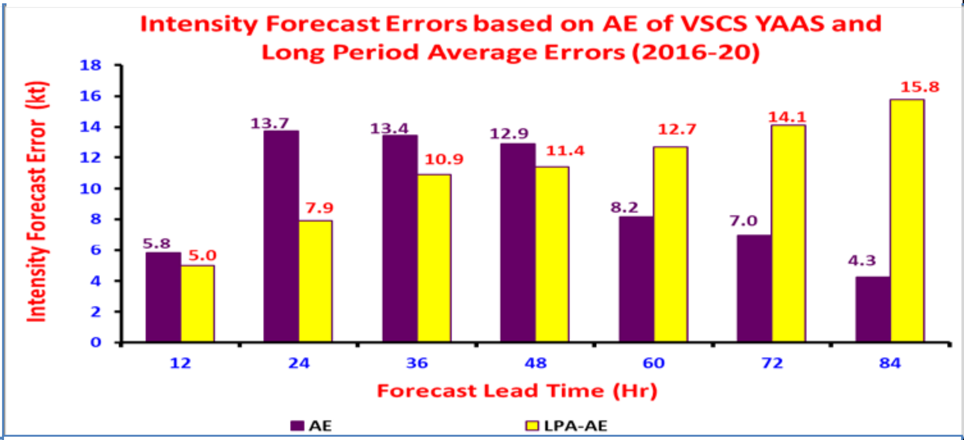
MSW(knot)/kmph)	Impact	Action
28-33 /(52–61)	Very rough seas.	Total suspension of fishing operations
34-40/(62-74)	High to very high seas	Total suspension of fishing operations
41-63/(75-117)	Very High seas	Total suspension of fishing operations
≥ 64 (≥118)	Phenomenal	Total suspension of fishing operations

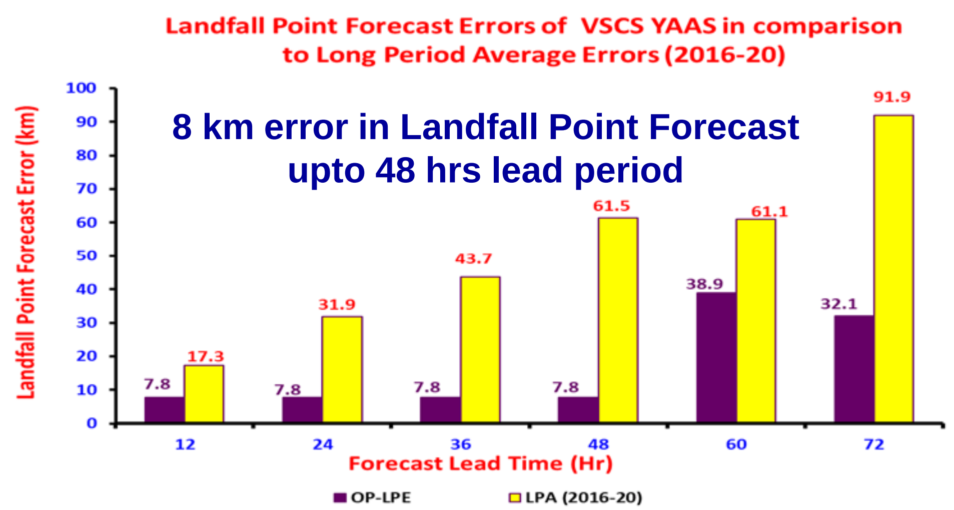
OPERATIONAL FORECAST ACCURACY- TRACK, LANDFALL &

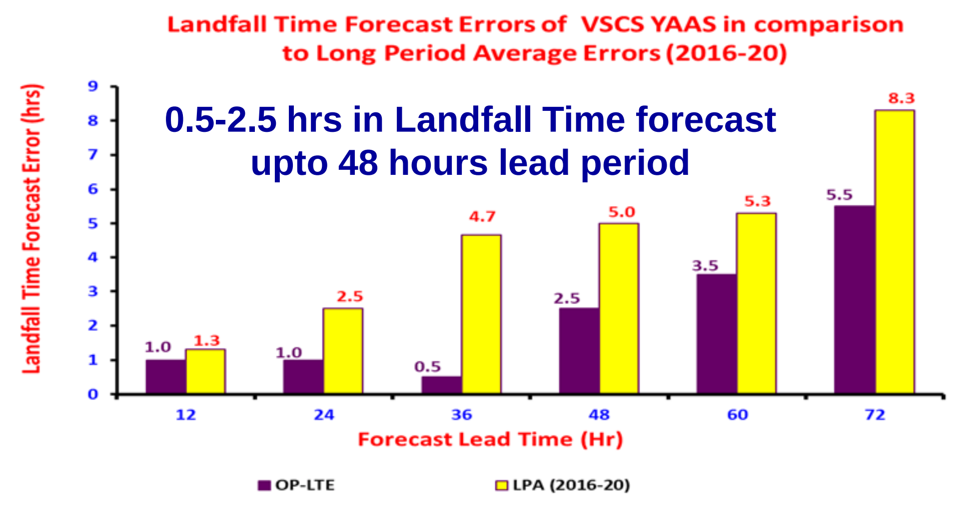
24 hrs: 24 km (77km-LPA), 48 hrs: 58 km (117 km-LPA)

24 hrs: 13.7 kt (7.9 kt-LPA), 48 hrs: 12.9 kt (11.4 kt-LPA)



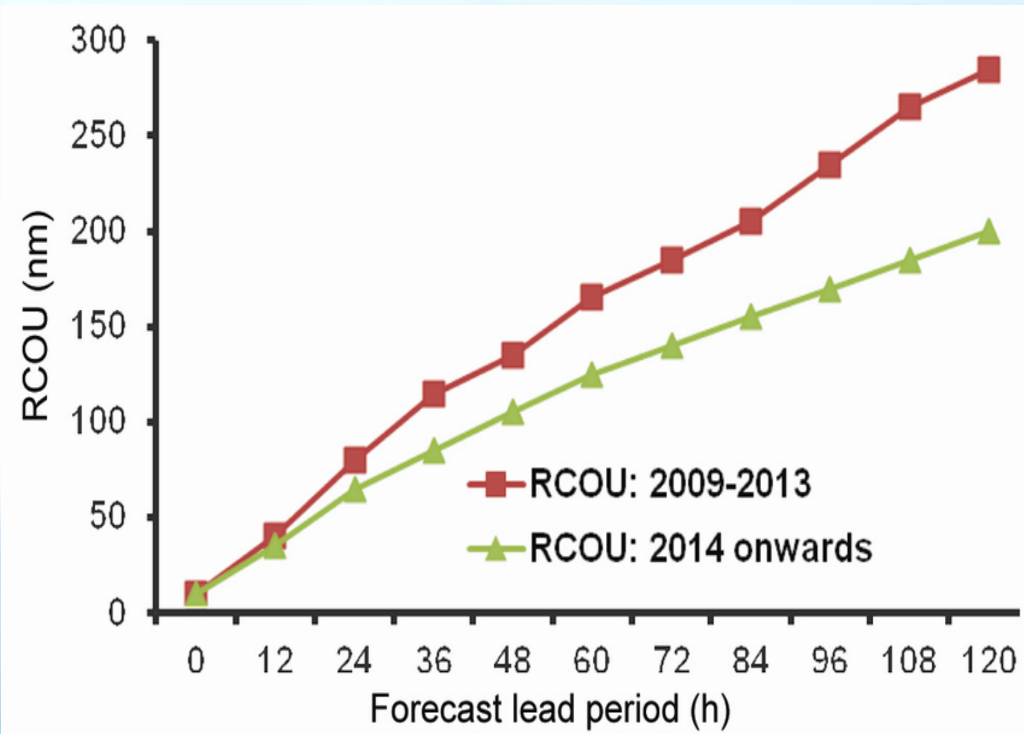


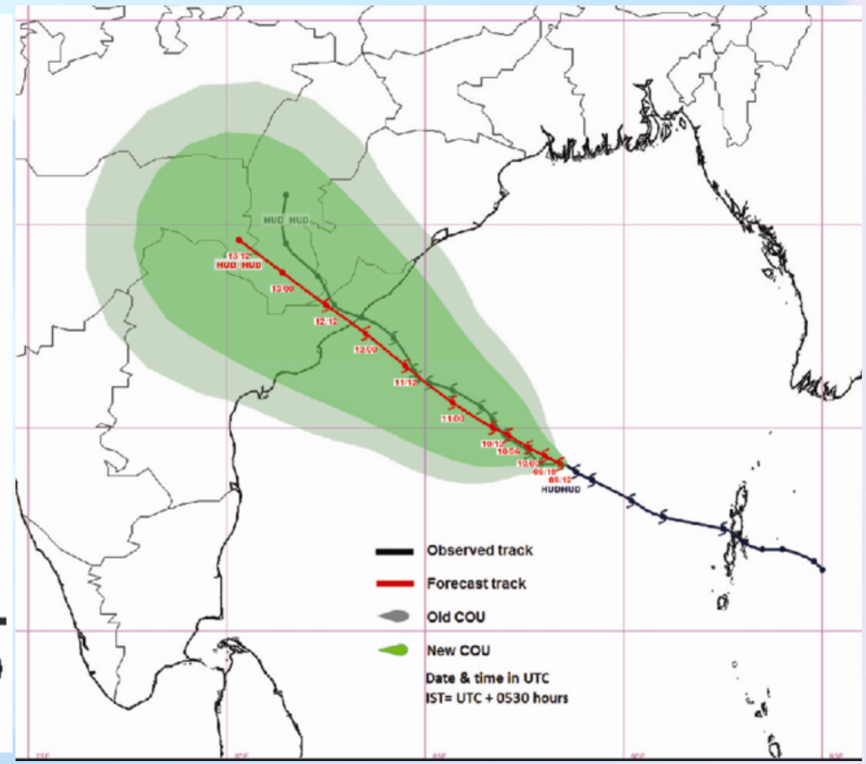




(viii) Error in Cone of Uncertainty forecasts

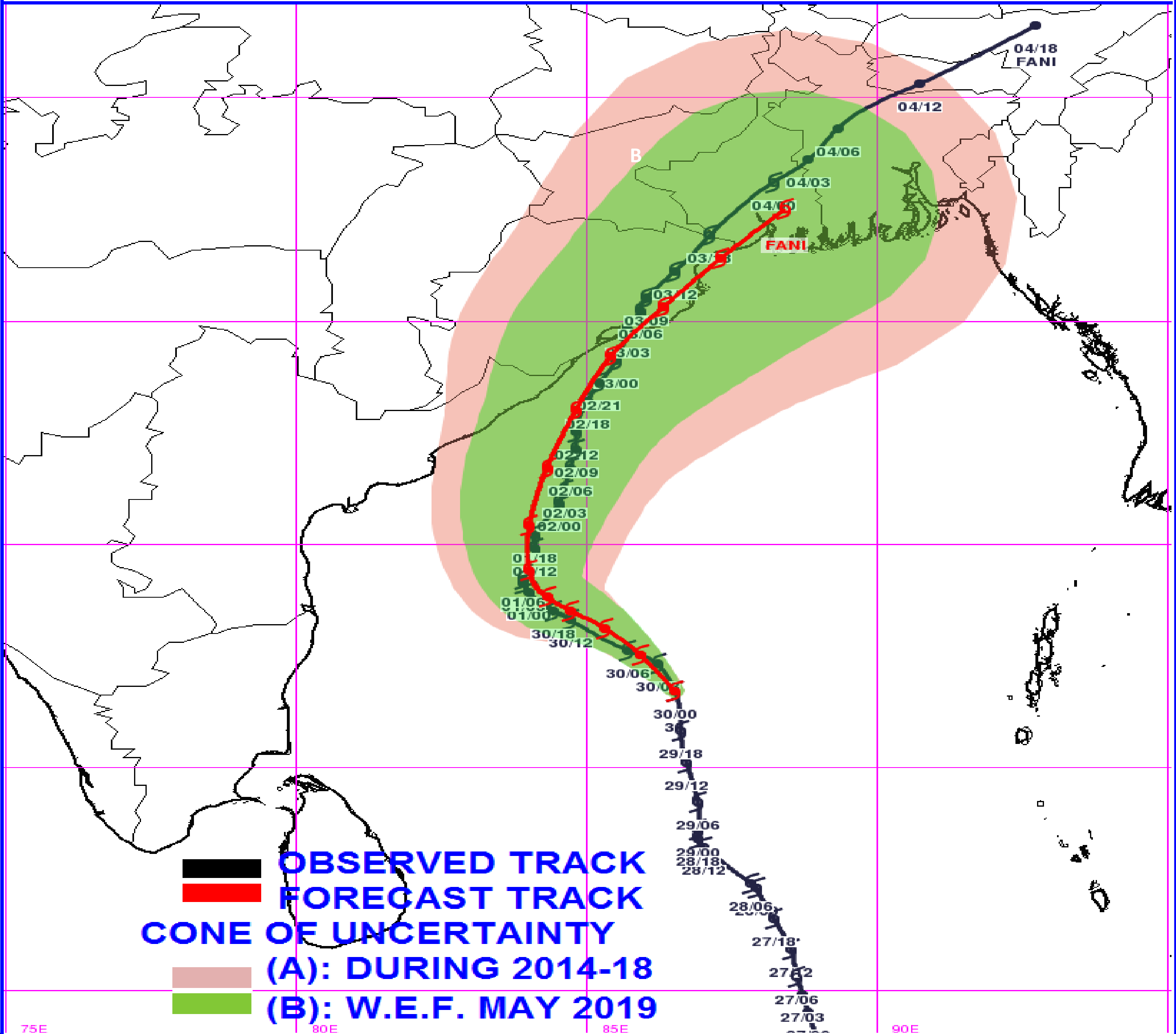
- The cone of uncertainty forecasts issued alongwith the track forecasts are also verified to find out the percentage of track forecasts lying within the forecast cone of uncertainty. It is calculated for each cyclone and also for the year as a whole.
- Errors are calculated for 12, 24, 36, 48, 60, 72, 84, 96, 108 and 120 hrs lead period.





Mohapatra et al, 2017, Current Science

OBSERVED & FORECAST TRACK ALONGWITH CONE OF UNCERTAINTY (A) DURING 2014-18 & (B) W.E.F. MAY, 2019



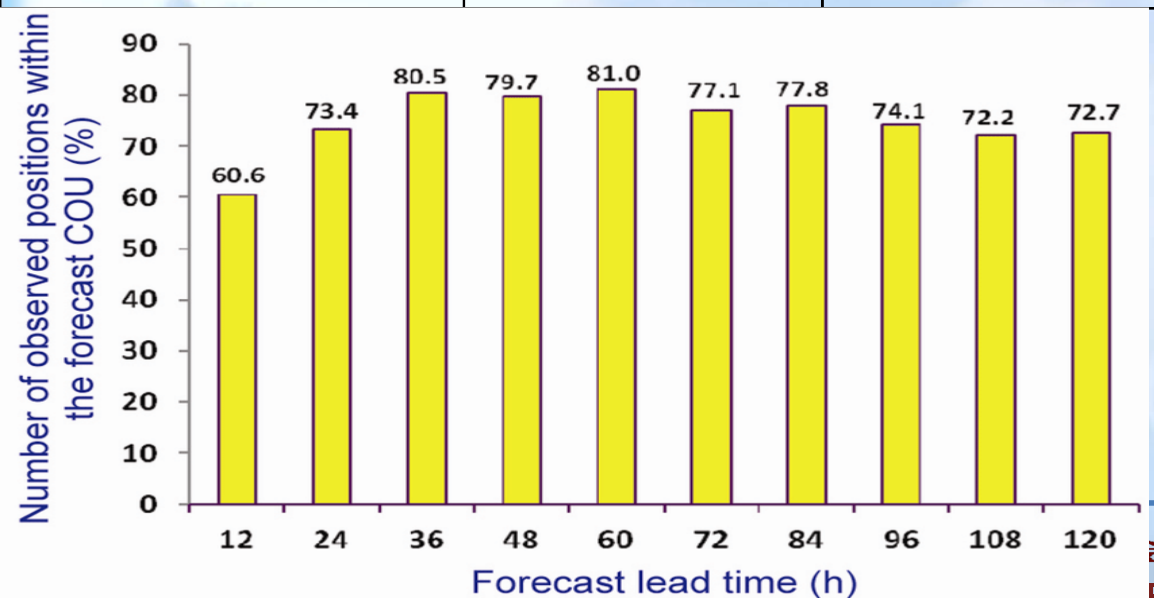
Verification of Cone of uncertainty forecast

Lead Period (hrs)	Viyaru			Phailin		
	W	B	T	W	W	T
12	10	14	24	16	4	20
24	12	10	22	14	4	18
36	13	7	20	14	0	14
48	15	3	18	13	0	13
60	13	3	16	11	0	11
72	8	6	14	9	0	9
84	7	3	10	7	0	7
96	8	0	8	5	0	5
108	6	0	6	3	0	3
120	4	0	4	1	0	1

W- within range, B- Beyond range, T- Total

Verification of cone of uncertainty (COU) in track forecast issued by IMD during 2013

Lead period (hrs)	Within COU	Outside COU	Total	Percentage Correct
24	57	26	83	68.7
36	51	20	71	71.8
48	48	16	64	75.0
60	39	15	54	72.2
72	28	15	43	65.1
84	23	9	32	71.9
96	19	6	25	76.0
108	13	4	17	76.5
120	06	2	8	66.7



Verification of COU during 2014-15

Mohapatra et al, 2017, Current Science

(ix) Heavy rainfall forecast error

Spatial distribution and intensity forecasts of heavy rainfall issued sub-division wise are verified in a tabular form for each date and time of forecast by comparing the actual occurrence of heavy rainfall.

Date/ Time(UTC)	Forecast Rainfall in association with VSVS Hudhud	Observed Rainfall
06.10.14/ (0300)	**Andaman and Nicobar Islands**: Isolated heavy to very heavy rainfall during the **next 24 hours.** Intensity would increase thereafter with heavy to very heavy rainfall at a few places and isolated extremely heavy falls (>=25 cm) during **subsequent 48 hours**.	**08 October 2014:** Andaman & Nicobar Islands: Isolated heavy to very heavy rainfall
07.10.14/ (0300)	**Andaman and Nicobar Islands:** Heavy to very heavy rainfall at a few places and isolated extremely heavy falls (>=25 cm) would occur over during **subsequent 48 hours.**	
08.10.14/ (0300)	**(i) Andaman and Nicobar Islands:** Heavy to very heavy rainfall at a few places and isolated extremely heavy falls (≥25 cm) during next 24 hours.	

(ix) Heavy rainfall forecast error

Date/ Time(UTC)	Forecast Rainfall	Observed Rainfall
08.10.14/ (0300)	**(ii) <u>North Andhra Pradesh and South Odisha:</u>** Heavy to very heavy falls at a few places with isolated extremely heavy falls over south Odisha from **11th evening onwards.** Heavy rain to very heavy rainfall would also commence at a few places over Visakhapatnam, Vizianagaram. Srikakulam districts of north coastal Andhra Pradesh and districts of north coastal Odisha **during the same period.**	**08 October 2014:** Andaman & Nicobar Islands: Isolated heavy to very heavy rainfall **12 October 2014:** North Andhra Pradesh: Heavy to very heavy rainfall at a few places Odisha: Isolated heavy to very heavy rainfall
09.10.14/ (0300)	**<u>North Andhra Pradesh and South Odisha coasts:</u>** (i) Heavy to very heavy falls at a few places and isolated extremely heavy falls over East Godavari, Visakhapatnam, Vizianagaram and Srikakulam districts of North Coastal Andhra Pradesh and South Odisha from **11th evening onwards.** Heavy to very heavy rainfall at isolated places over remaining districts of Andhra Pradesh and North Coastal Odisha during the same period.	

(ix) Heavy rainfall forecast error

Date/ Time(UTC)	Forecast Rainfall	Observed Rainfall
10.10.14/ (0300)	**North Andhra Pradesh and South Odisha coasts:** Heavy to very heavy falls at a few places and isolated extremely heavy falls would occur over West and East Godavari, Visakhapatnam, Vizianagaram and Srikakulam districts of North Coastal Andhra Pradesh and Ganjam, Gajapati, Koraput, Rayagada, Nabarangpur, Malkangiri, Kalahandi, Phulbani districts of South Odisha commencing from **11th onwards.** Heavy to very heavy rainfall at isolated places over Krishna, Guntur and Prakasham districts of Andhra Pradesh and North Coastal Odisha **during the same period.**	**12 October 2014:** North Andhra Pradesh: Heavy to very heavy rainfall at a few places Odisha: Isolated heavy to very heavy rainfall

Heavy rainfall forecast is considered to be correct for a given subdivision, if there is occurrence of heavy rainfall over atleast two stations in that sub-division. For the purpose of verification a 3X3 contigency table has been prepared namely for no heavy rainfall (≤ 64.4 mm), heavy to very heavy rainfall (64.5-244.4 mm) and extremely heavy rainfall (≥ 244.5 mm).

24 hr observed class of heavy rainfallarial	24 hr forecast class of heavy rainfall			Total
	No heavy rainfall	Heavy to very heavy Rainfall	Extremely heavy Rainfall	
No heavy rainfall	3	2	0	5
Heavy to very heavy rainfall	6	10	3	19
Extremely heavy rainfall	0	0	2	2
Total	9	12	5	26
CSI (%)	27.3	47.6	40.0	
PC (%)	57.7			
HSS	0.3			

To find out the biases in the forecast, this 3X3 contigency table is reduced to 2X2 contigency table for verification of (i) heavy rainfall or higher intensity & no heavy rainfall and (ii) extremely heavy rainfall & no extremely heavy rainfall.

Observed rainfall	24 hr forecast for heavy rainfall or higher and no heavy rainfall		Total	24 hr forecast for extremely heavy rainfall & no extremely heavy rainfall		Total
	YES	NO		YES	NO	
YES	15	6	21	2	0	2
NO	2	3	5	3	21	24
Total	17	9	26	5	21	26
POD	0.7			1.0		
FAR	0.1			0.6		
MR	0.3			0.0		
C-NON	0.6			0.9		
CSI	0.7			0.4		
BIAS Occ.	0.8			2.5		
PC (%)	69.2			88.5		
TSS	0.3			0.9		
HSS	0.2			0.5		

Scope for improvements in TC rainfall forecast verification

- Current procedure involved rigorous statistical verification procedure
- Rainfall associated with a TC when it is out in the sea also needs to be understood for improving our warnings
- Daily satellite gauge merged rainfall dataset is being generated since 2013 by IMD and NCMRWF
- A rainfall forecast model such as R-CLIPER (based on rainfall climatology and persistence) using the satellite based rain estimates could be developed for the NIO basin to serve as the baseline for verification of the skill of forecast
- Verification of EPSgram is not carried out at present.
- Similarly, the location specific meteogram and local forecasts for TC related rainfall needs to be verified
- NWP based QPFs could be verified based on errors in the location as well as in the intensity of rainfall

(x) Gale wind forecast error

Spatial distribution and intensity forecasts of gale wind issued sub-division wise are verified in a tabular form for each date and time of forecast by comparing the actual occurrence of gale wind.

Date/ Time	Gale wind Forecast	Recorded wind
06.10.14 (0300)	Andaman and Nicobar Islands: Squally wind speed reaching 45-55 kmph during next 24 hours. The wind speed would increase gradually reaching gale wind speed upto 70-80 kmph on 8th October 2014.	**08 October 2014:** Port Blair: 88 kmph **09 October 2014:** Port Blair: 60 kmph **10 October 2014:** Port Blair: 64 kmph **11 October 2014:** Machilipatnam: 88 kmph Visakhapatnam: 74 kmph **12 October 2014:** Visakhapatnam: 185 kmph
07.10.14/ (0300)	Andaman and Nicobar Islands: Squally wind speed reaching 45-55 kmph during next 12 hours. The wind speed would increase gradually reaching gale wind speed of 70-80 kmph by 8th morning, October 2014.	
08.10.14/ (0300)	North Andhra Pradesh and Odisha coasts: Squally wind speed reaching 50-60 kmph gusting to 70 kmph would commence from 11th morning onwards. The wind speed would increase to 130-140 kmph gusting to 150 from 12th morning.	

(xi) Storm surge forecast error

Both spatial distribution and intensity forecasts of storm surge heaight issued district-wise are verified in a tabular form for each date and time of forecast by comparing with the actual storm surge, which is estimated by survey team or observed by tide gauge.

Forecast Storm surge above astronomical tide and area to be affected	Actual Storm Surge
09.10.14/0300 UTC Storm surge of about 1-2 meters above astronomical tide would inundate low lying areas of East Godavari, Visakhapatnam, Vizianagaram and Srikakulam districts of north coastal Andhra Pradesh at the time of landfall (12 Oct 2014/ Around noon) **10.10.14/0300 UTC** Storm surge of about 1-2 meters above astronomical tide would inundate low lying areas of Visakhapatnam, Vizianagaram and Srikakulam districts of north coastal Andhra Pradesh at the time of landfall (12 Oct 2014/ Around noon)	Observed Storm Surge recorded by the tide gauge at Visakhapatnam was 1.4 m.

(xi) Storm surge forecast error (2009-14)

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

Outcome

Due to above improvements, there has been increase in confidence of disaster managers and public leading to

i. Minimum loss of human lives (limited to double digits) in recent years (Amphan-76, FANI -64, Titli-85, Hudhud-46 and Phailin-21 against 10,000 deaths during Odisha Super Cyclone in 1999)

ii. Decrease in area of evacuation by 300 km in 20 years and hence evacuation cost by 60 percent.

iii. Decrease in ex-gratia paid by Govt. to survivors by 99% as compared to 1999.

iv. Significant gains to various sectors as power sector saved around 500 crores each from cyclone warnings during Phailin and Hudhud.

Outcome

v. Thus around 1100 crores are saved due to accurate forecast of one cyclone (Rs 590 crores in ex gratia payments, 32 crores in evacuation and 500 crores by power sector) which is more than double the entire cost of modernisation programme of IMD during 2008 to 12 (about 437 crores).

vi. Accurate cyclone warnings have not only benefitted India, but also residents of 13 Bay of Bengal and Arabian Sea countries. The number of deaths due to cyclones hitting these countries in recent years is limited to less than 100 in recent years [Sagar-53 (Somalia) , Mekunu-26 (Oman), Luban- 14 (Yemen), Chapala-5 (Yemen), Megh-18 (Yemen), Bulbul-6 (Bangladesh), Amphan-18 (Bangladesh)] against deaths in lakhs ten years back (1,40,000 deaths due to Nargis that hit Myanmar in 2008).

vii. Increase in number of WMO/ESCAP Panel member countries from 8 (2015) to 13 (2018).

viii. Awards and Appreciations to India and IMD from various national and international agencies.

Appreciations Received

Excerpts of PM Manmohan Singh's Address at

101st Indian Science Congress held at Jammu during 3rd-7th February 2014

Our advances in meteorology were evident during the recent cyclone in Odisha, when we received accurate forecasts of the landfall point that were more accurate than the forecasts of well known international bodies.

VSCS HUDHUD, 2014

In this cyclone, India Meteorological Department made excellent utilisation of Technology and from 6th October itself, this cyclone was predicted. The actual wind speed due to cyclone was same as the predicted wind speed. The track of the cyclone was same as that predicted. The time of landfall of cyclone was also same as that predicted by IMD.

Appreciations Received

Excerpt of 294th Report of the Department-related Parliamentary Standing Committee on Science & Technology.

The track record of the Ministry has been above par in the case of cyclone predictions which has been seen in the case of Hudhud and Vardah

104th INDIAN SCIENCE CONGRESS

Excerpt of Presidential Address

Among our many-sided advances in meteorology, important outcomes during the recent cyclones in Odisha, Andhra Pradesh and Tamilnadu, when we received accurate forecasts of landfall points that were more accurate than the forecasts of international agencies are notable.

Appreciations Received

Excerpt of Ho'ble Prime Minister's Maan Ki Baat on 31st July, 2017

Weather forecasts are available these days and the concerned technology has become so advanced these days, and space science also plays a very big role, that these weather forecasts turn out to be mostly accurate now. We should also gradually make it our nature to set our work patterns according to the weather predictions, which could safeguard us against losses

Appreciations Received

WMO OMM

World Meteorological Organization
Organisation météorologique mondiale
Organización Meteorológica Mundial
Всемирная метеорологическая организация
المنظمة العالمية للأرصاد الجوية
世界气象组织

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Fax: +41 (0) 22 730 81 81
wmo@wmo.int – public.wmo.int

Our ref.: 17451/2018 /WDS/TCP/Mekunu

Dr Kanduri Jayaram Ramesh
Permanent Representative of India
with WMO
India Meteorological Department
Ministry of Earth Sciences (GOI),
Mausam Bhawan, Lodi Road
NEW DELHI
India

19 June 2018

Subject: Severe Tropical Cyclone "Sagar" and Extreme Severe Tropical Cyclone "Mekunu"

Dear Dr Ramesh,

I wish to refer to the recent severe tropical cyclone "Sagar" and the extreme severe tropical cyclone "Mekunu", which happened consecutively in the Arabian Sea, from 17 to 28 May 2018.

I wish to express my sincere gratitude and appreciation to the RSMC Tropical Cyclone Centre, New Delhi, India that provided its advisory bulletins every three hours, during these two events.

The advisory bulletins were well distributed to all Members of the WMO/ESCAP Panel on Tropical Cyclones (PTC) and Somalia, for their early preparedness. They were also distributed to WMO Secretariat in Geneva, and forwarded to WMO Regional Offices in Bahrain and New York.

In addition to benefiting PTC Members and Somalia, those bulletins were well utilized by WMO Regional Office in Bahrain, to communicate and coordinate with both PTC and other Members neighboring Oman for their early preparation and necessary actions in response to the tropical cyclones. At the same time, all members of the Inter- Agency Standing Committee (IASC) with the key UN and non-UN humanitarian partners were informed and WMO representative in New York used the bulletins to provide a daily briefing to the United Nations (UN) Operations and Crisis Center at UN Headquarter, and informed the UN Secretary-General's Executive Office on the development of the tropical cyclones and their potential impacts.

It is vitally important and effective practice to distribute and communicate RSMC Dew Delhi's advisory bulletins with Members, WMO, UN and its humanitarian agencies in a timely manner, to enable all those concerned to take necessary and appropriate actions. I shall appreciate it very much if such a practice will be continued and strengthened.

I look forward to your continued support to the WMO Tropical Cyclone Programme and activities to reduce risks of disasters by tropical cyclones.

Yours sincerely,

(P. Talaas)
Secretary-General

Appreciation from WMO for Sagar and Mekunu in 2018

Appreciation from President of India for FANI in 2019

President of India
@rashtrapatibhvn

Our expertise in accurate weather forecast has improved. This was evidenced during the recent #CycloneFani that struck the eastern coast of the country. Due to accurate information and timely preparation, large scale destruction to life and property was averted #PresidentKovind

12:55 PM · Jun 20, 2019 · Twitter Web Client

232 Retweets **1.1K** Likes

Appreciation from United Nations for FANI in 2019

Excerpt of Appreciation from United Nations Office for Disaster Risk Reduction

The government's zero casualty policy for natural disasters and the near accuracy of the India Meteorological Department's early warning system have helped reduce the possibility of deaths from cyclone "FANI".

Appreciation from WMO for Amphan

Appreciation from the World Meteorological Organisation for accurate prediction of Super Cyclonic Storm "AMPHAN" that immensely helped in early response and actions. The services provided by IMD/RSMC New Delhi, showcased excellent lesson and best practices in tropical cyclone forecasting & warning services and response actions for effective mitigation of disaster.

WMO OMM

World Meteorological Organization
Organisation météorologique mondiale
Organización Meteorológica Mundial
Всемирная метеорологическая организация
المنظمة العالمية للأرصاد الجوية
世界气象组织

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Ref.: 10944/2020-1.6 S/DPS

Our ref.: 10944/2020/S/DPS/TCP-Storm-Amphan

Dr Mrutyunjay Mohapatra
Permanent Representative
of India with WMO
India Meteorological Department
Mausam Bhawan, Lodi Road
110003
NEW DELHI
India

2 June 2020

Subject: On Provision of RSMC New Delhi Tropical Cyclone Advisories for Super Cyclonic Storm "Amphan" in the Bay of Bengal, 16–21 May 2020

Dear Dr Mohapatra,

I refer to the recent super cyclonic storm "Amphan" , which happened in the Bay of Bengal, from 16 to 21 May 2020.

I wish to express my sincere gratitude and appreciation to India Meteorological Department and especially the RSMC Tropical Cyclone Centre, New Delhi, India, that provided its advisory bulletins every three hours, during the super cyclonic storm "Amphan".

The advisory bulletins were well distributed to all Members of the WMO/ESCAP Panel on Tropical Cyclones, in particular Bangladesh, to provide accurate and consistent forecasting information from genesis until the demise of the super cyclonic storm "Amphan'.
The accurate prediction of genesis, track, intensity, landfall point and time, as well as associated adverse weather like storm surge, rainfall and wind, by IMD/RSMC New Delhi with lead period of more than three days, has immensely helped in their early response and actions. The services thus provided by concerned Members have been showcased as excellent lesson and best practice in tropical cyclone forecasting and warning services and response actions leading to sufficient preparedness for mitigation of losses and damages.

The advisories were also distributed to the WMO Secretariat in Geneva, and shared with the WMO Regional Offices in Singapore, Bahrain, and the WMO Coordination Hub. WMO Secretary-General used the information extracted from the bulletins to communicate with the UN Secretary-General about "Amphan." Those bulletins were also well utilized by the WMO officer in New Yorkto daily brief the relevant entities of the United Nations (UN) at its Headquarter on the status and potential impacts of the cyclone "Amphan."

Evidently, it is vitally important and effective practice to distribute and communicate RSMC Dew Delhi's advisory bulletins with Members, WMO, the United Nations and its humanitarian agencies in a timely manner, thus enabling all those concerned to take necessary and appropriate actions. I should appreciate it very much that such a practice be continued and strengthened.

I would like to express my appreciation, and look forward to your continued support to the WMO Tropical Cyclone Programme and activities to reduce risks of disasters due to tropical cyclones.

Yours sincerely,

(E. Manaenkova)
for the Secretary-General

Ref.: 10944/2020-1.6 S/DPS

Excerpt of Appreciation from World Meteorological Organisation

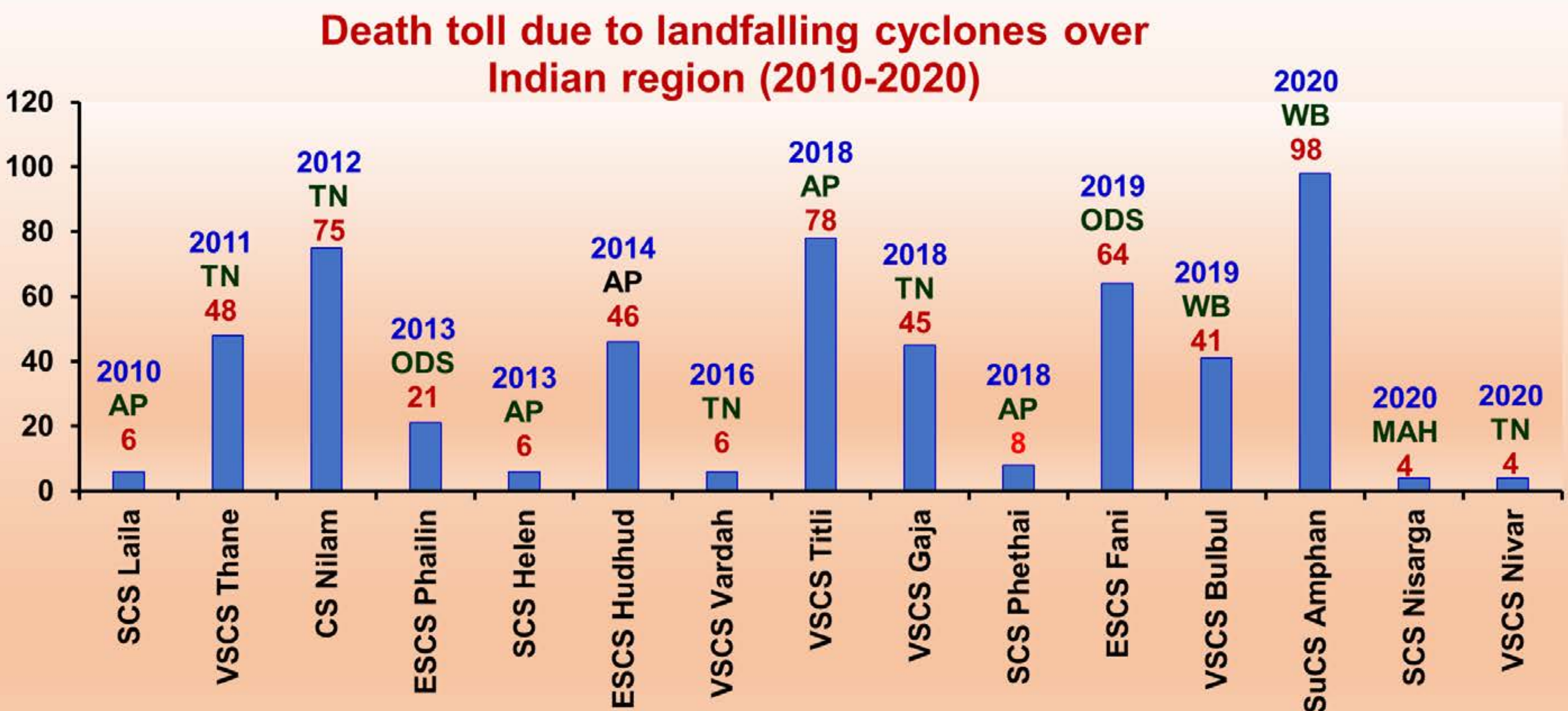
The accurate prediction of Super Cyclonic Storm "AMPHAN" immensely helped in early response & actions. The services provided by the India Meteorological Department/Regional Specialised Meteorological Centre, New Delhi showcased excellent lesson and best practices in tropical cyclone forecasting & warning services and response actions for effective mitigation of disaster.

Excerpt of Survey by NCAER, 2015

Based on independent Survey by National Centre for Applied Economic Research (NCAER) in Andhra Pradesh and West Bengal in 2015, more than 95 percent population believe and appreciate cyclone warnings by IMD.

Minimum annual socioeconomic benefits of weather prediction amounts to atleast US$160 billion and going to go more in years to come

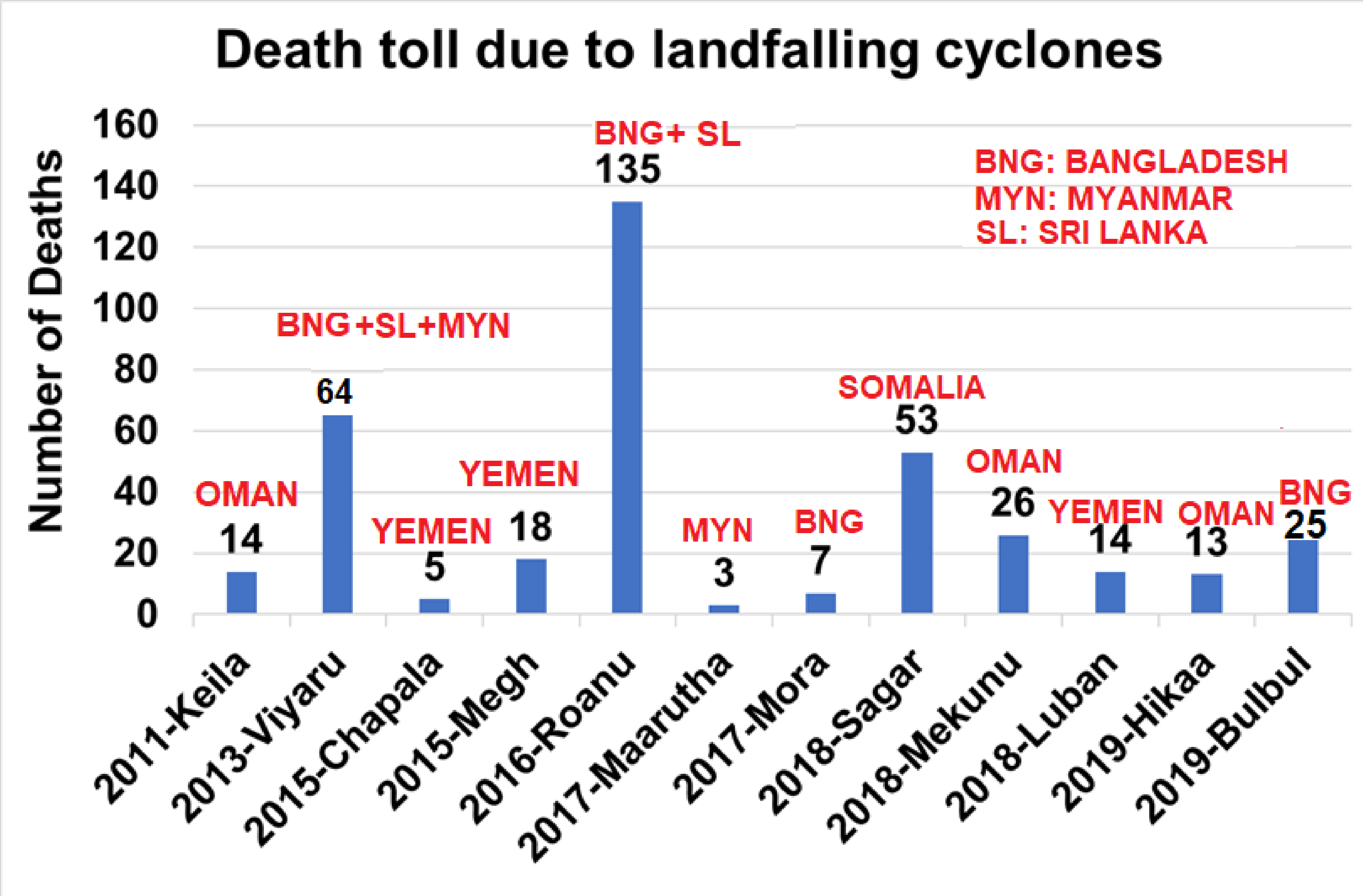
Death Toll over India



AP: Andhra Pradesh, TN: Tamilnadu, ODS: Odisha, WB: West Bengal, MAH: Maharashtra

TCs not shown: Bandu, Phet & Jal (2010), Lehar & Madi (2013), Ockhi (2017), Burevi (2020) due to weakening prior to landfall. Death due to landfalling TCs (MSW≥34 knot)

Death Toll over Member Countries



Thank you