NCMRWF deterministic models for TC prediction

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- NCMRWF Modelling & DA Systems
  - Case of ESCS ‘Foni’
    - Track Forecast Verification
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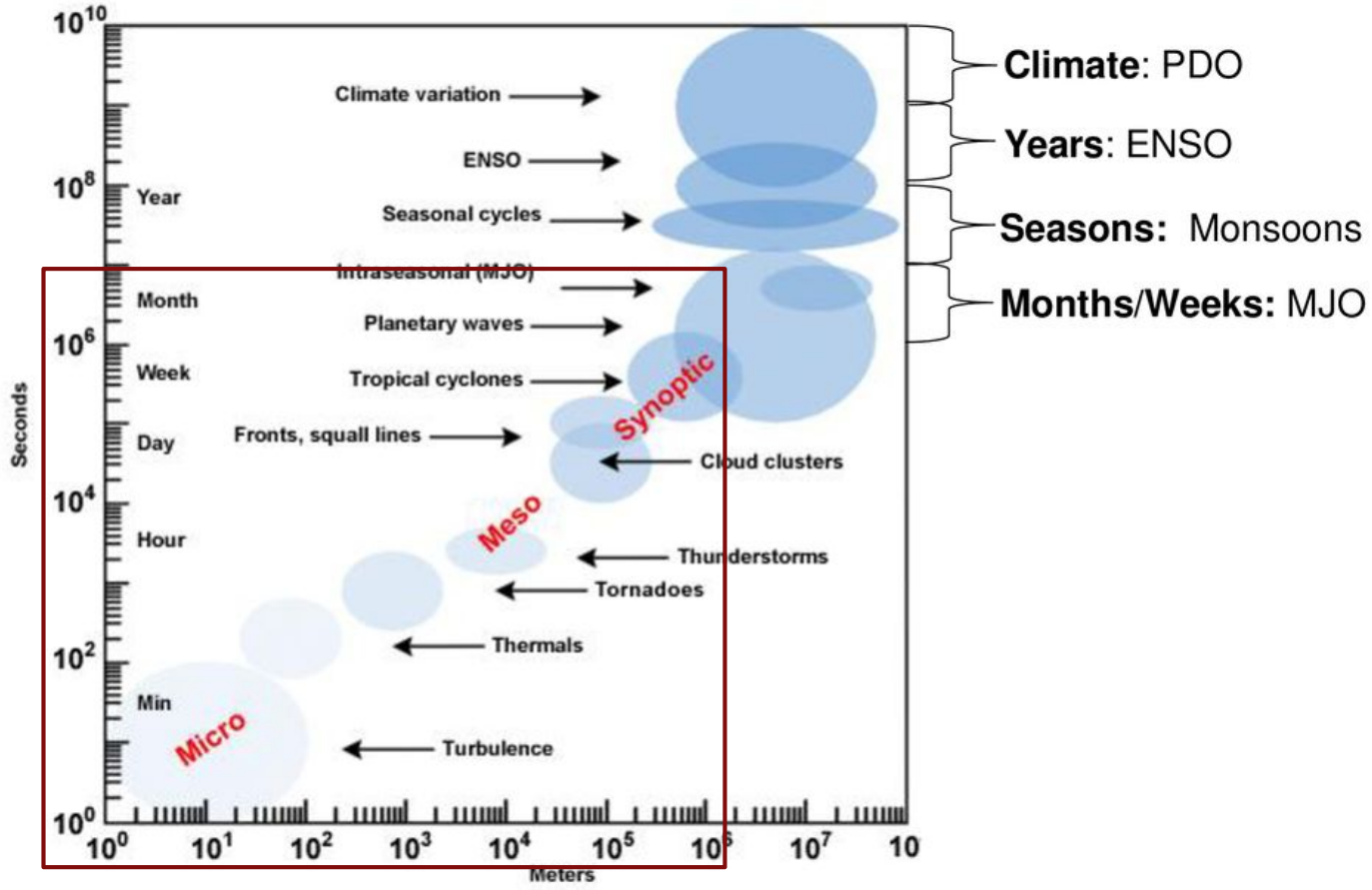
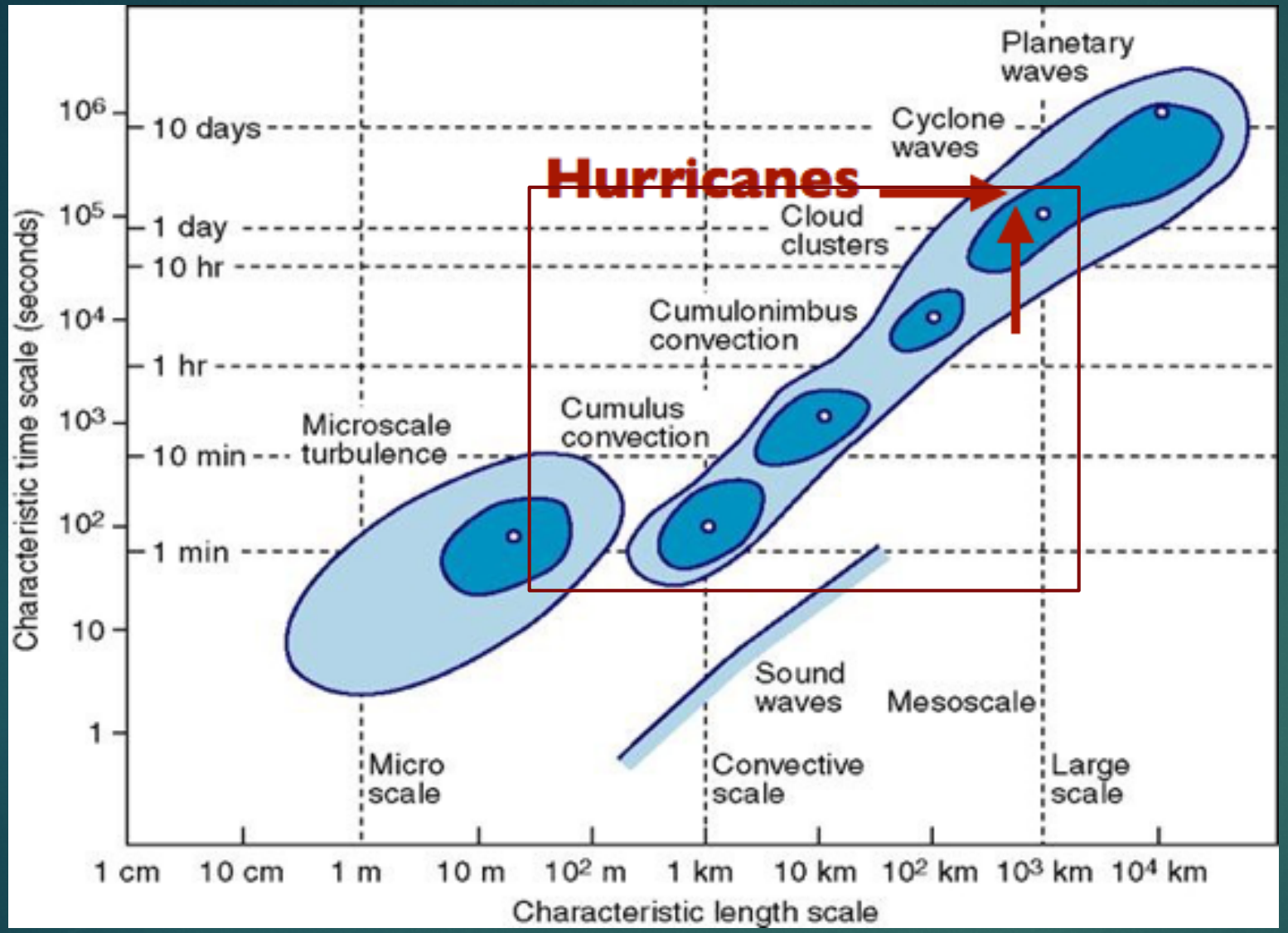
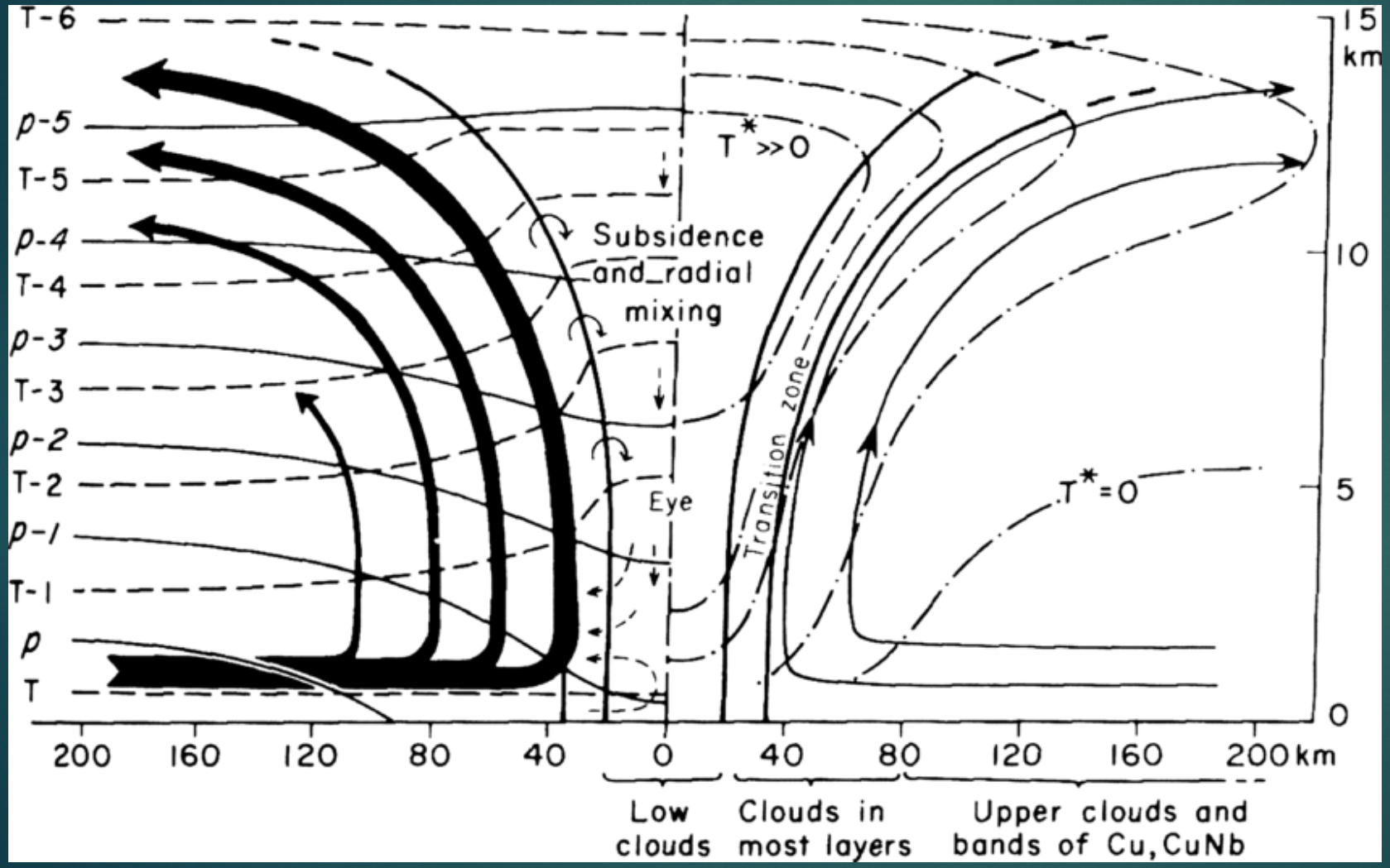
  - Case of SuCS ‘Amphan’
    - Track Forecast Verification
    - Intensity Forecast Verification

Atmospheric Scales of Motion



Space and time-scales of dynamical atmospheric processes. SOURCE: UCAR

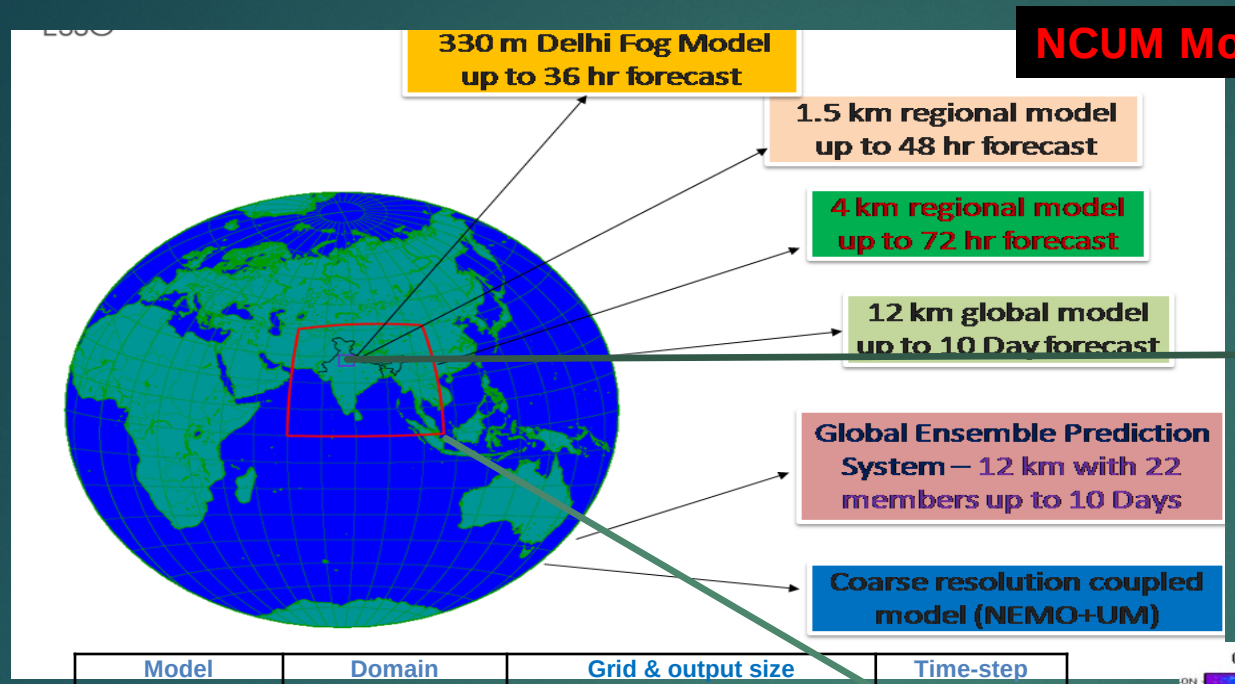

Planetary waves
Cyclone waves
Hurricanes
Cloud clusters
Cumulonimbus convection
Cumulus convection
Microscale turbulence
Sound waves
Mesoscale
Micro scale
Convective scale
Large scale
10 days
1 day
10 hr
1 hr
10 min
1 min
10^6
10^5
10^4
10^3
10^2
10
1
Characteristic time scale (seconds)
1 cm
10 cm
1 m
10 m
10^2 m
1 km
10 km
10^2 km
10^3 km
10^4 km
Characteristic length scale


T-6
p-5
T-5
p-4
T-4
p-3
T-3
p-2
T-2
p-1
T-1
p
T
T* >> 0
Subsidence and radial mixing
Eye
Transition zone
T* = 0
15 km
10
5
0
200
160
120
80
40
0
40
80
120
160
200 km
Low clouds
Clouds in most layers
Upper clouds and bands of Cu, CuNb

NCMRWF Models

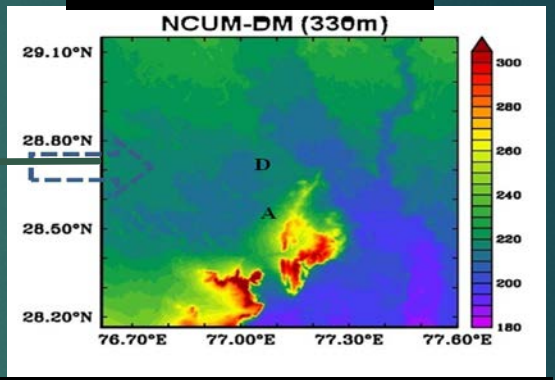
Model	Application & Domain	Resolution	Forecasts
NCUM	Global NWP Forecasts	N1024L70 (12km horizontal resolution with 70 vertical levels)	00UTC: Day0 to Day10 12UTC: Day0 to Day 10
NEPS	Global Ensemble Prediction	N1024L70 (12 km horizontal resolution; Control+ 11 member)	00UTC: Day0 to Day10 12UTC: Day0 to Day10
NCUM-R	Regional high resolution over Indian Region (5-40N and 65-100E)	4 km resolution Explicit convection	00UTC: Day0 to Day3
NCUM-1.5km	Regional convective scale modeling	1.5 km (experimental)	00UTC: Day0 to Day3 (experimental/hindcast)
NCUM-Coupled	Global Seamless Prediction (Days to Season)	NCUM Atmospheric Model (1.875˚ x 1.25˚; L85), Ocean Model NEMO (1˚ x 1˚), Sea Ice Model (CICE) and OASIS coupler	(experimental/hindcast)

NCMRWF Models

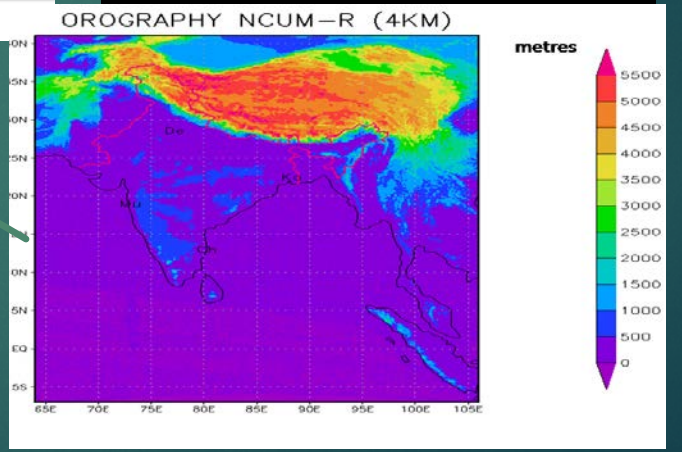


NCUM Model domains

330m orography



4km orography

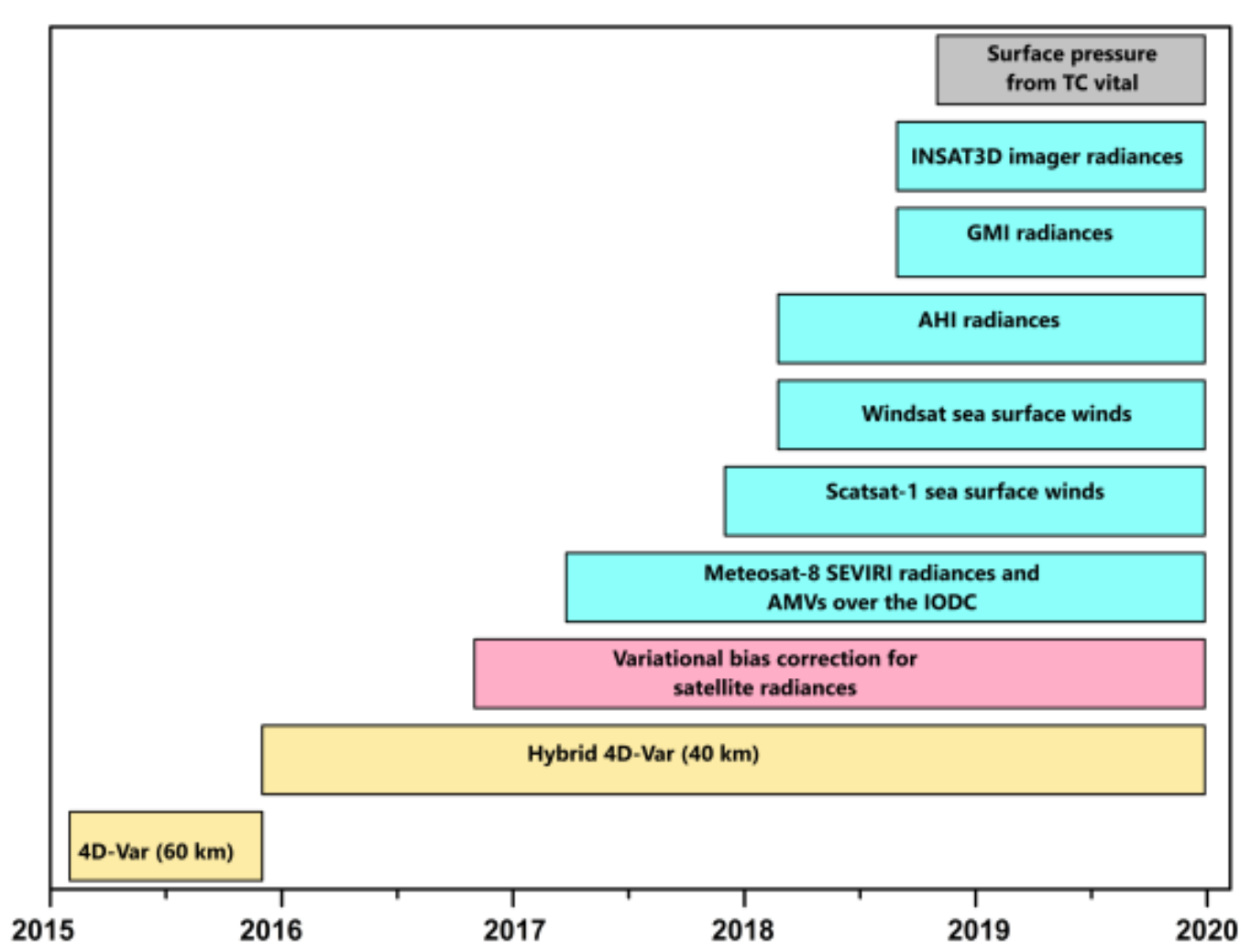


Model	Domain	Grid & output size	Time-step
NCUM-G, (N1024)	Global,12km 70 levels	2048x1536x70 1.1 TB	5 min (10 days)
NCUM-R (4KM)	BIMSTEC,4km 80 levels	1200x1200x80, 440GB	2 min (3 days)
NCUM-R (1.5KM)	Local, 1.5k 80 levels	500x500x80 39GB	60 sec (48 hrs)
NCUM-R (330m)	Delhi, 330m 80 levels	300x300x80 13GB	12 sec (36 hrs)

NCUM-G – use 274 nodes for 10 day 12hr (Takes 1 hr 10min)

NCUM-R use 86 nodes for 75hr forecast (Takes 1 hr 4 minute)

Improved use of Data in Recent years

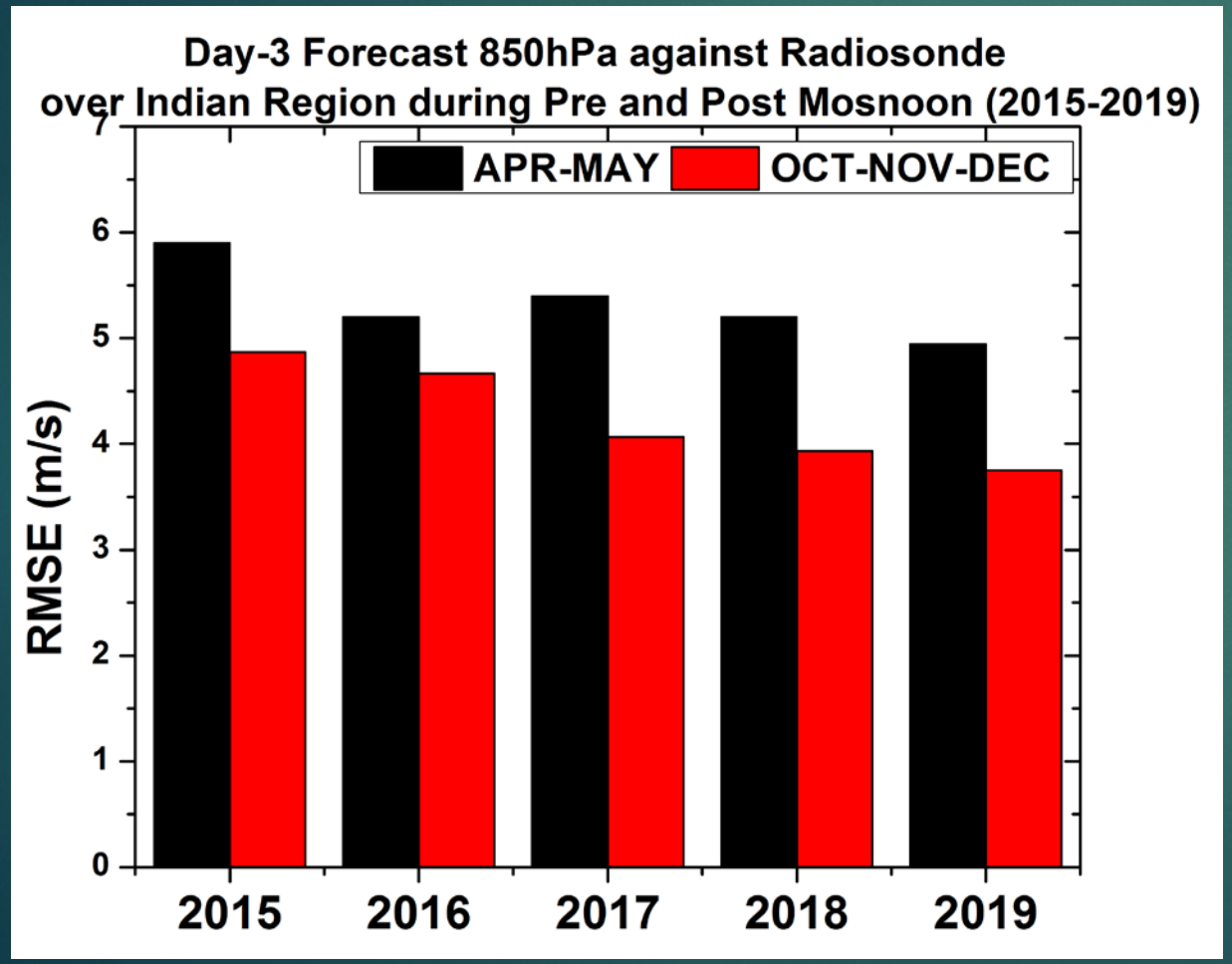


Hybrid 4D-Var Data Assimilation

Observation Type	Observation Description
AHIClear	Advanced Himawari Imager radiances from Himawari-8
Aircraft	Upper-air wind and temperature from aircraft
AIRS	Atmospheric Infrared Sounder of AQUA
AMSR	Radiances from AMSR-2 onboard GCOM satellite
ATOVS	AMSU-A, AMSU-B/MHS, HIRS from NOAA-18 &19, MetOp-A&B
ATMS	Advanced Technology Microwave Sounder in NPP satellite
CrIS	Cross-track Infrared Sensor observations in NPP satellite
GOESClear	Cloud clear Imager radiances from GOES
GPSRO	Global Positioning System Radio Occultation observations from various satellites
GroundGPS	Ground based GPS observations from various locations
IASI	Infrared Atmopheric Sounding Interferometer from MetOp-A&B
SAPHIR	SAPHIR microwave radiances from Megha-Tropiques
Satwind	Atmospheric Motion Vectors from various geostationary and polar orbiting satellites
Scatwind	Advanced Scattrometer in MetOp-A & B
SEVIRIClear	Cloud clear observations from SEVIRI of METEOSAT 11
Sonde	Radiosonde observations, upper-air wind profile from pilot balloons, wind profiles, VAD wind observation from Indian DWR
Surface	Surface observantions from Land and Ocean
SSMIS	SSMIS Radiances

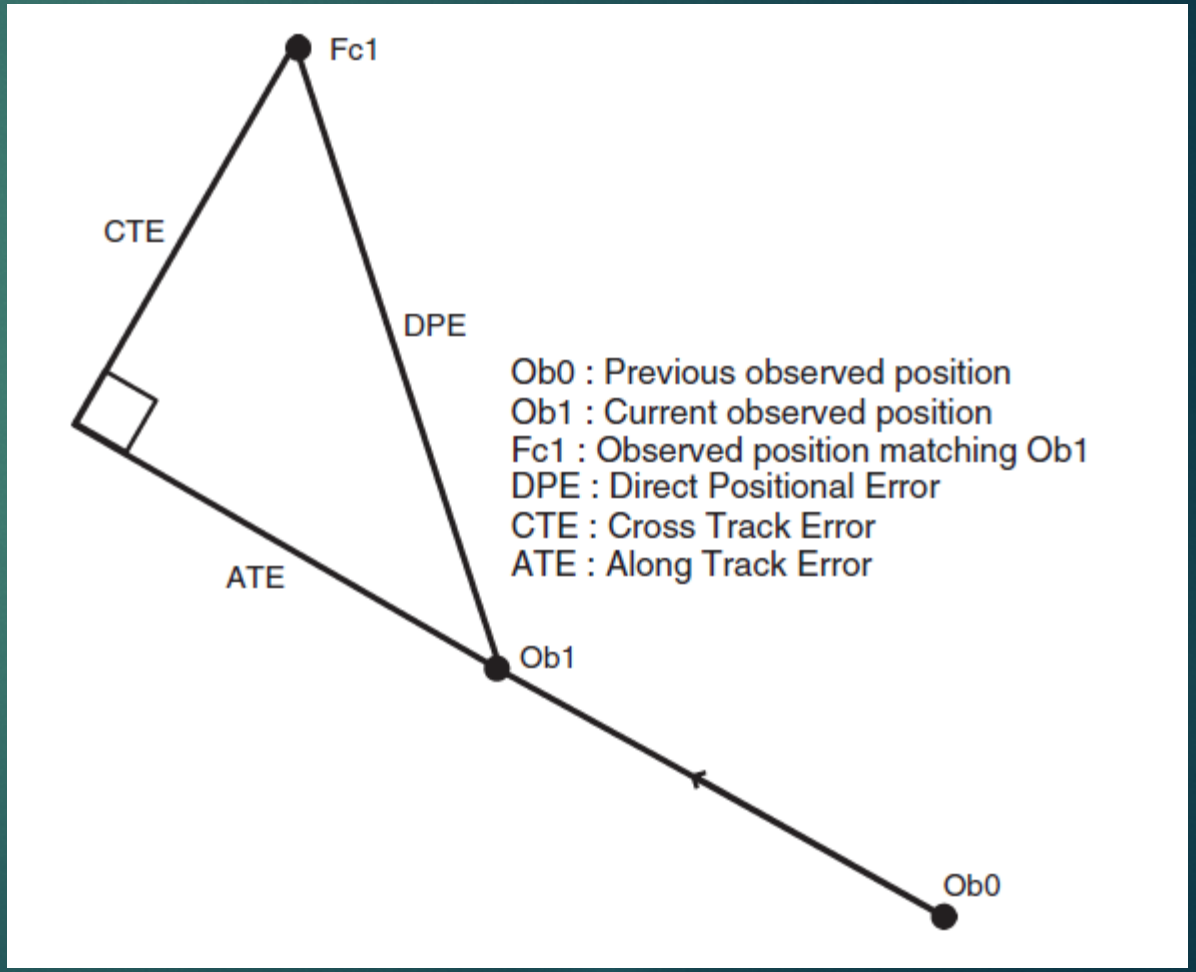
- The NCUM-G Hybrid 4D-Var assimilation system combines the flow dependent errors calculated from the Ensemble Transform Kalman Filter (ETKF) based NEPS forecasts with the climatological background errors.
- The hybrid approach is scientifically attractive as it elegantly combines the benefits of ensemble data assimilation with the benefits of 4D-Var within a single data assimilation system (Barker, 2011).

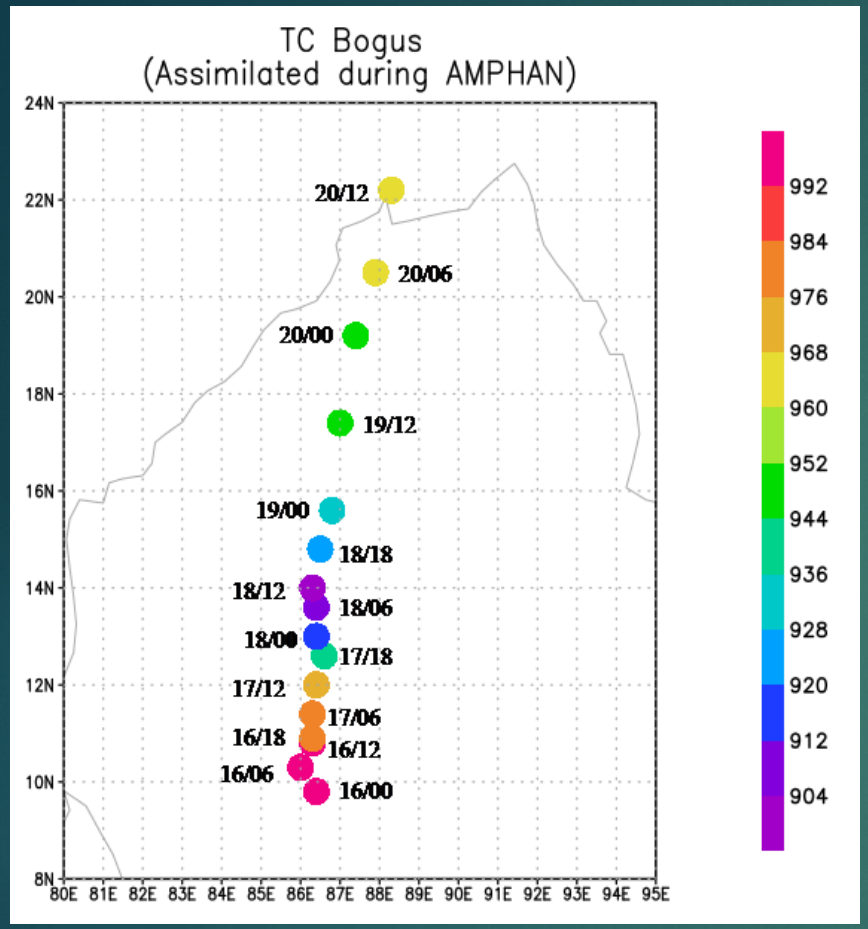
Reduced Errors during NIO TC Season



- Forecast verification of track & intensity are based on the IMD's Best Track data

- Track Forecast Verification
  - DPE, ATE and CTE
- Intensity
  - MinSLP and MaxWind

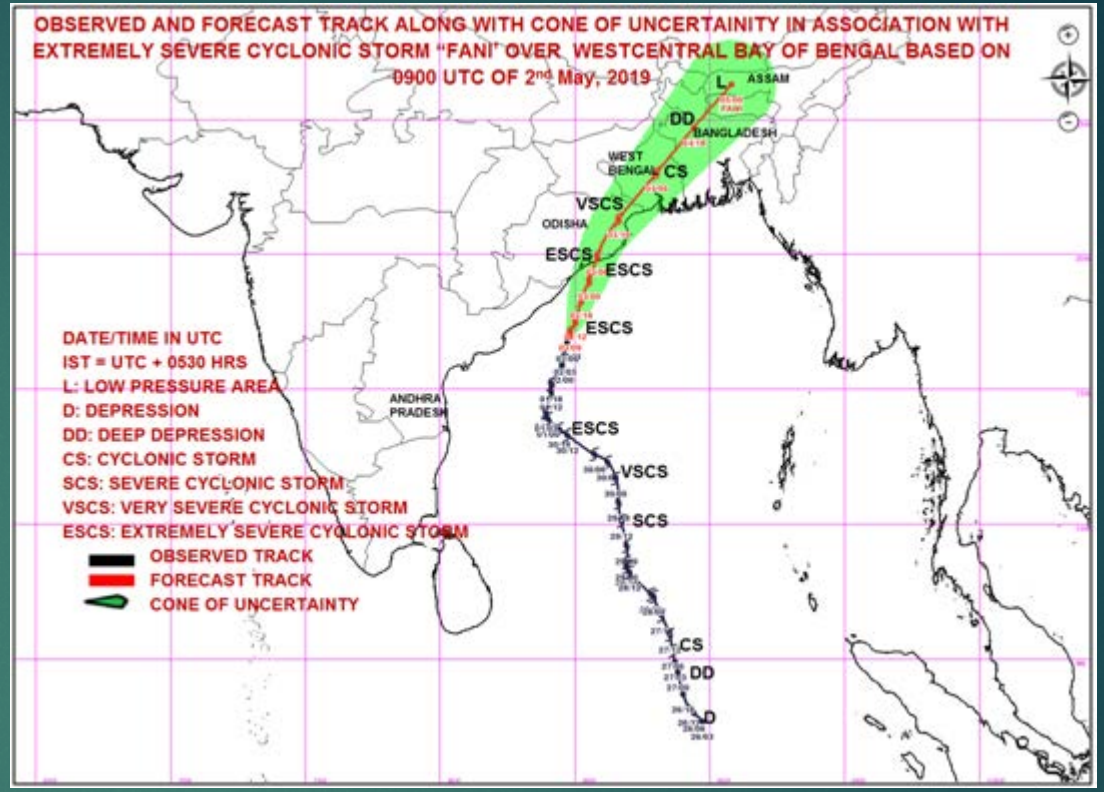




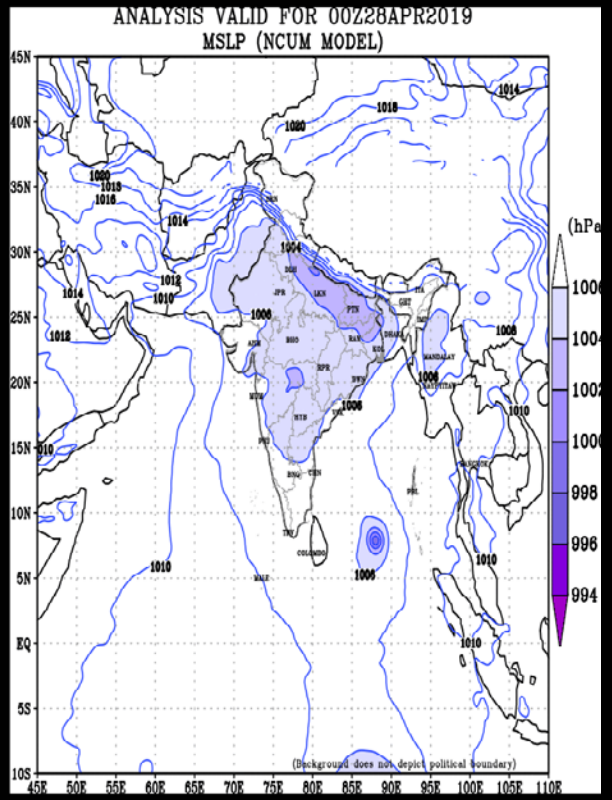
Location of pressure from TC vitals assimilated in the NCUM-G during AMPHAN cyclone

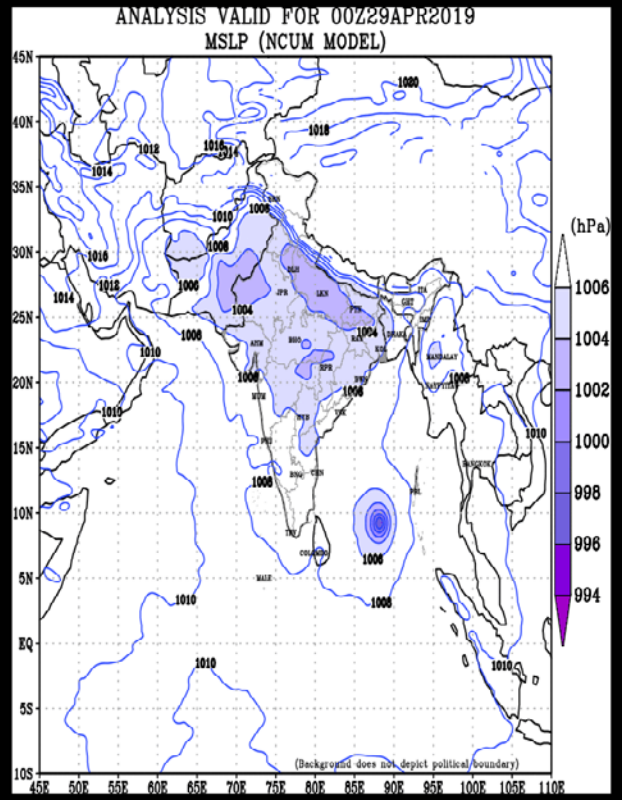
For realistic location and the magnitude of the low pressure in the model analysis the location and the minimum low pressure associated with the tropical cyclone is adjusted by assimilating the estimated surface pressure information from the Tropical Cyclone Vital (TC Vital) reports since October 2018.

ESCS ‘Fani’

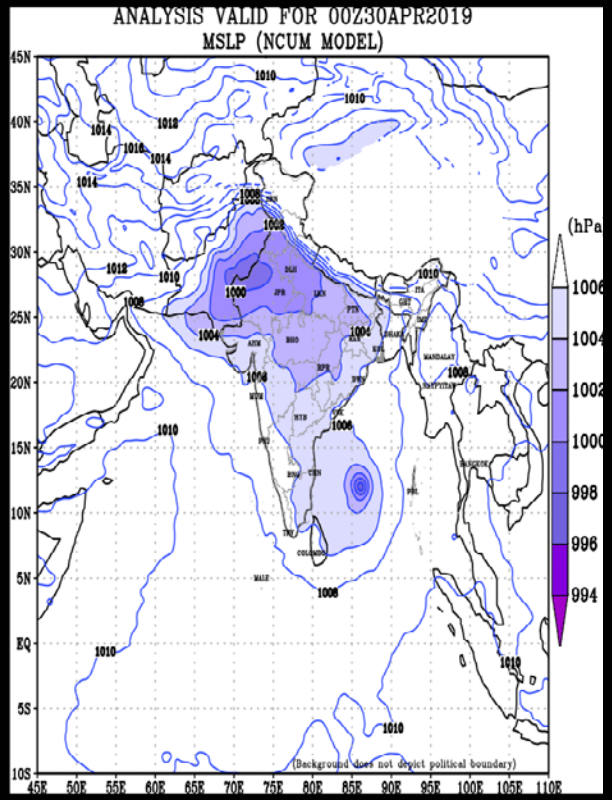

OBSERVED AND FORECAST TRACK ALONG WITH CONE OF UNCERTAINITY IN ASSOCIATION WITH EXTREMELY SEVERE CYCLONIC STORM "FANI" OVER WESTCENTRAL BAY OF BENGAL BASED ON 0900 UTC OF 2nd May, 2019
L
ASSAM
DD
BANGLADESH
WEST BENGAL
CS
VSCS
ODISHA
ESCS
ESCS
ESCS
ANDHRA PRADESH
ESCS
VSCS
SCS
CS
DD
D
DATE/TIME IN UTC
IST = UTC + 0530 HRS
L: LOW PRESSURE AREA
D: DEPRESSION
DD: DEEP DEPRESSION
CS: CYCLONIC STORM
SCS: SEVERE CYCLONIC STORM
VSCS: VERY SEVERE CYCLONIC STORM
ESCS: EXTREMELY SEVERE CYCLONIC STORM
OBSERVED TRACK
FORECAST TRACK
CONE OF UNCERTAINTY

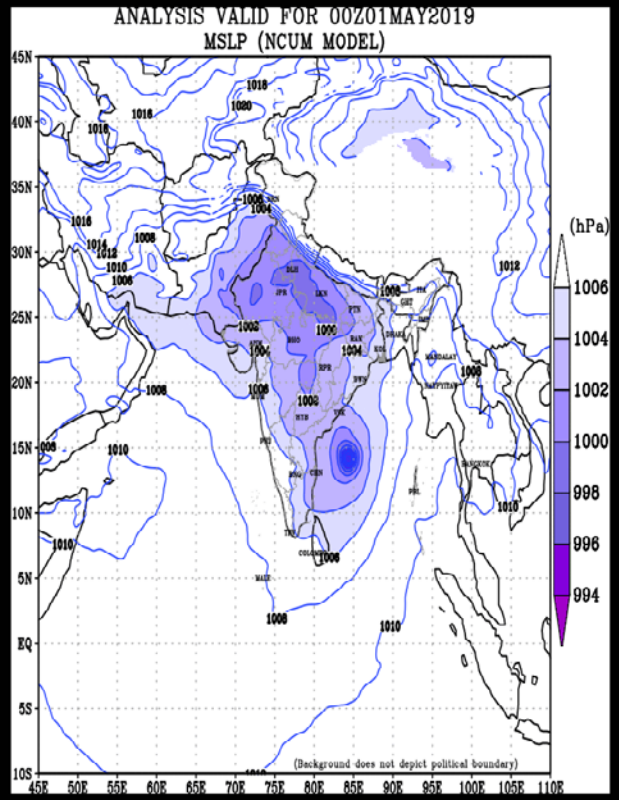
NCUM


ANALYSIS VALID FOR 00Z28APR2019
MSLP (NCUM MODEL)
(hPa)
1006
1004
1002
1000
998
996
994
(Background does not depict political boundary)

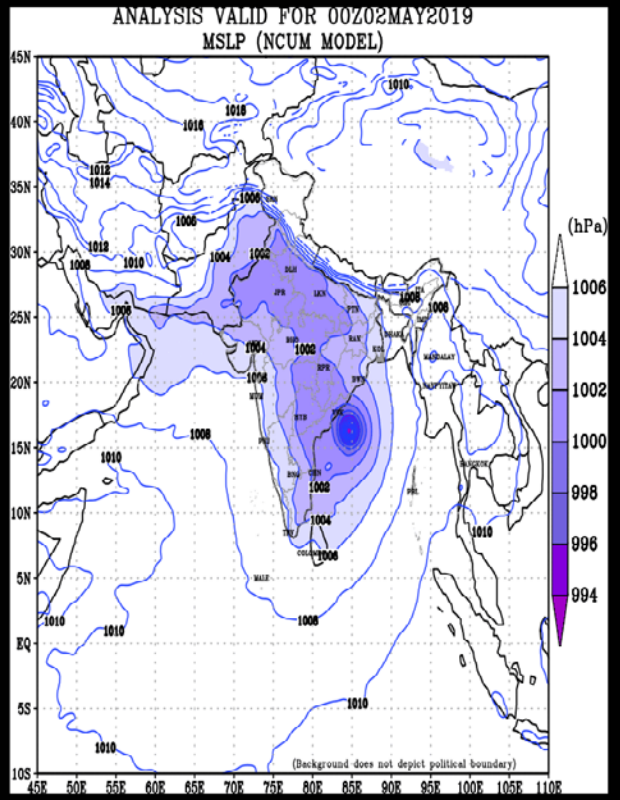

ANALYSIS VALID FOR 00Z29APR2019
MSLP (NCUM MODEL)
(hPa)
1006
1004
1002
1000
998
996
994
(Background does not depict political boundary)

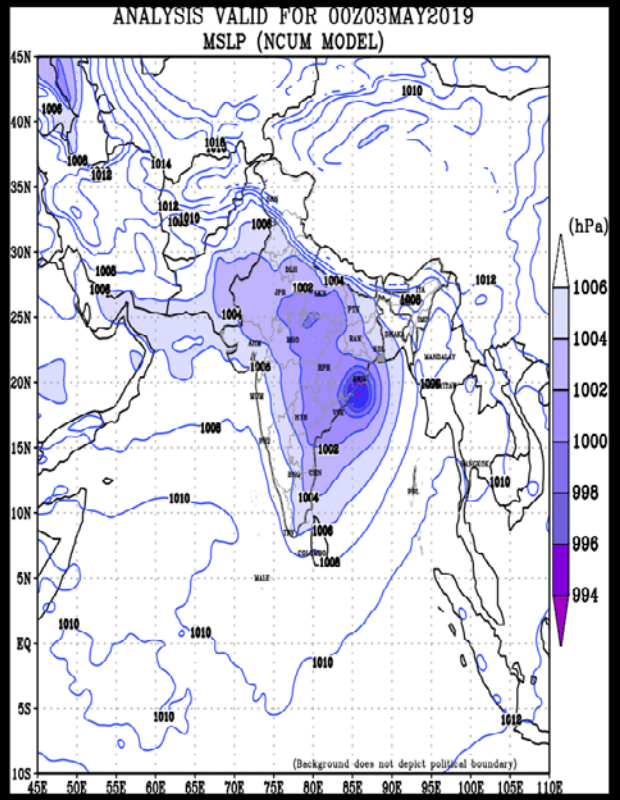
NCUM


ANALYSIS VALID FOR 00Z30APR2019
MSLP (NCUM MODEL)
(hPa)
1006
1004
1002
1000
998
996
994
(Background does not depict political boundary)


ANALYSIS VALID FOR 00Z01MAY2019
MSLP (NCUM MODEL)
(hPa)
1006
1004
1002
1000
998
996
994
(Background does not depict political boundary)

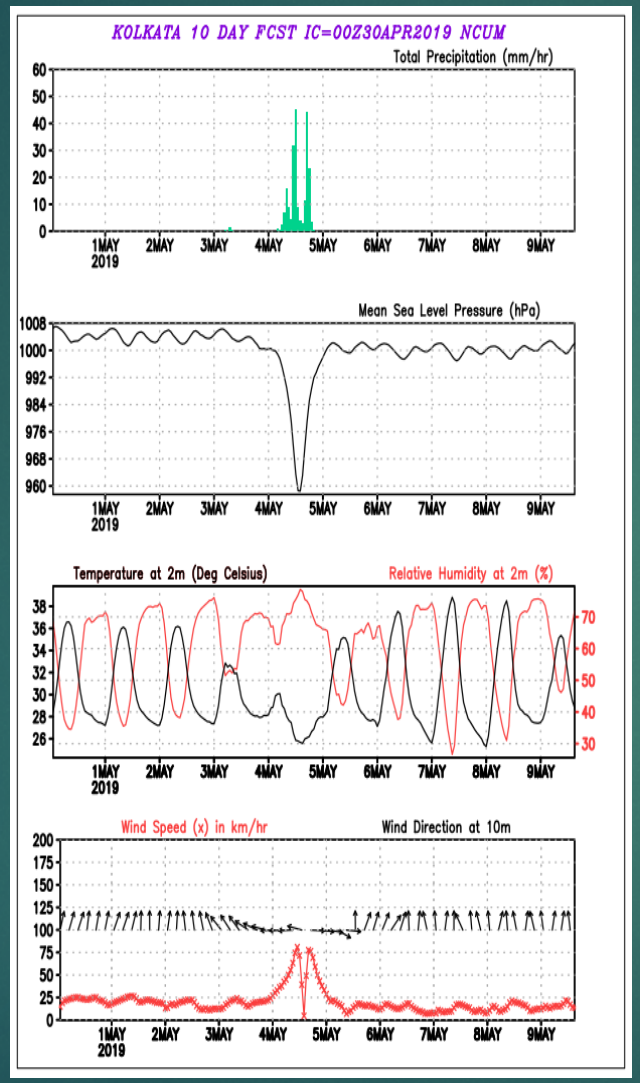
NCUM


ANALYSIS VALID FOR 00Z02MAY2019
MSLP (NCUM MODEL)
(hPa)
1006
1004
1002
1000
998
996
994
(Background does not depict political boundary)

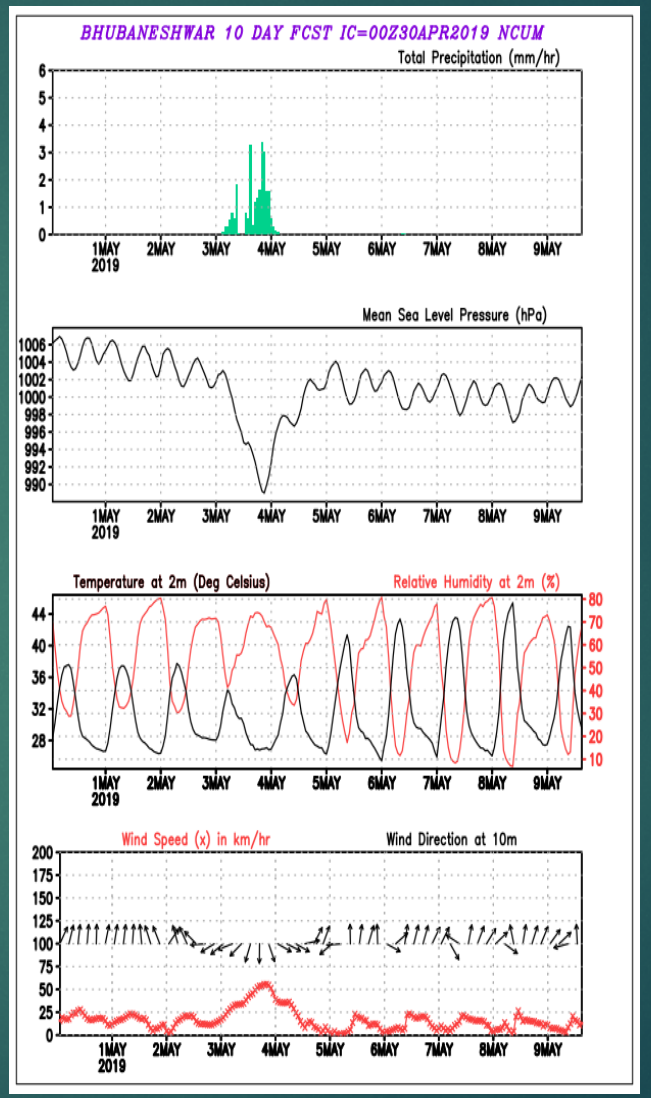

ANALYSIS VALID FOR 00Z03MAY2019
MSLP (NCUM MODEL)
(hPa)
1006
1004
1002
1000
998
996
994
(Background does not depict political boundary)

FANI CYCLONE EYE FOOTPRINTS IN THE NCUM FOERCAST METEOGRAM (IC:00Z 30 APR 2019)

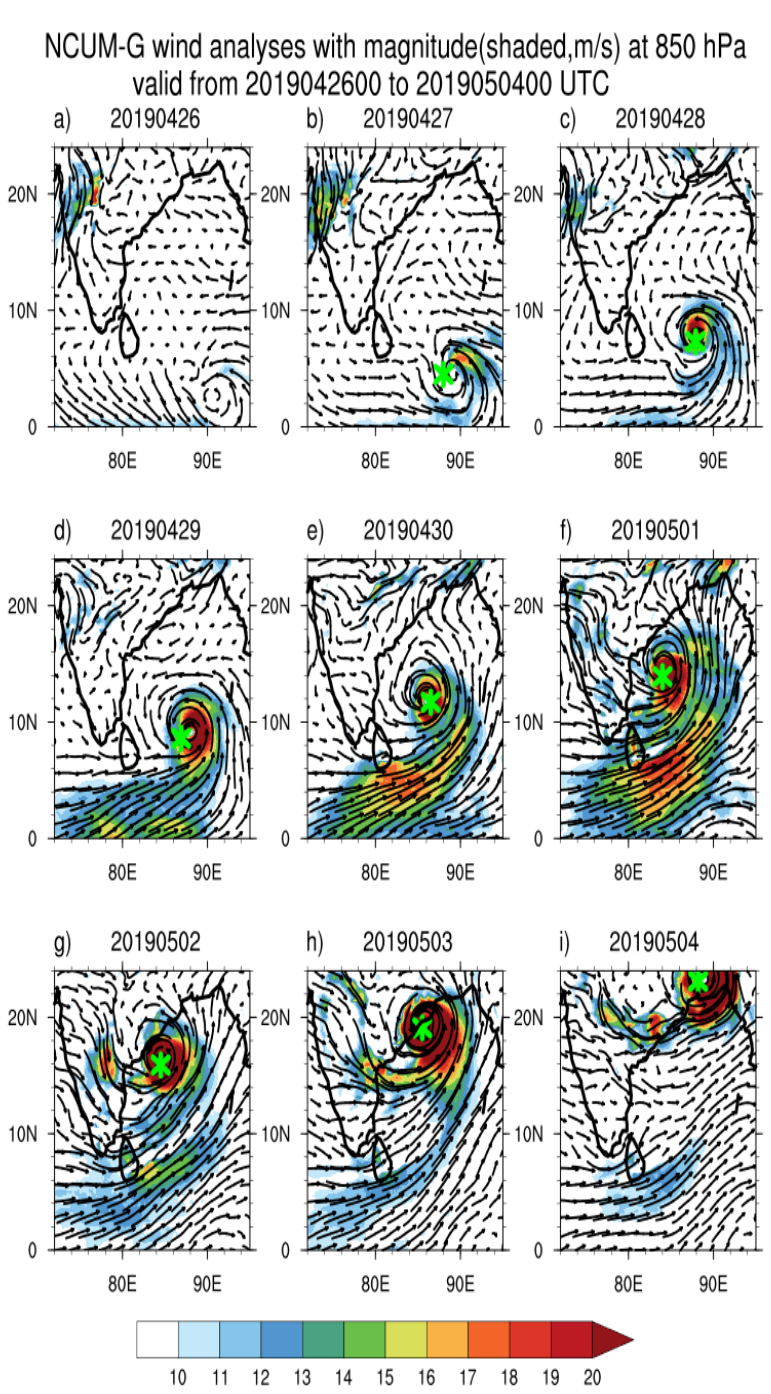
(KOLKATA)



(BHUBANESHWAR)



*But TC Fani dissipated fast after landfall and hence crossed to West Bengal as only a depres



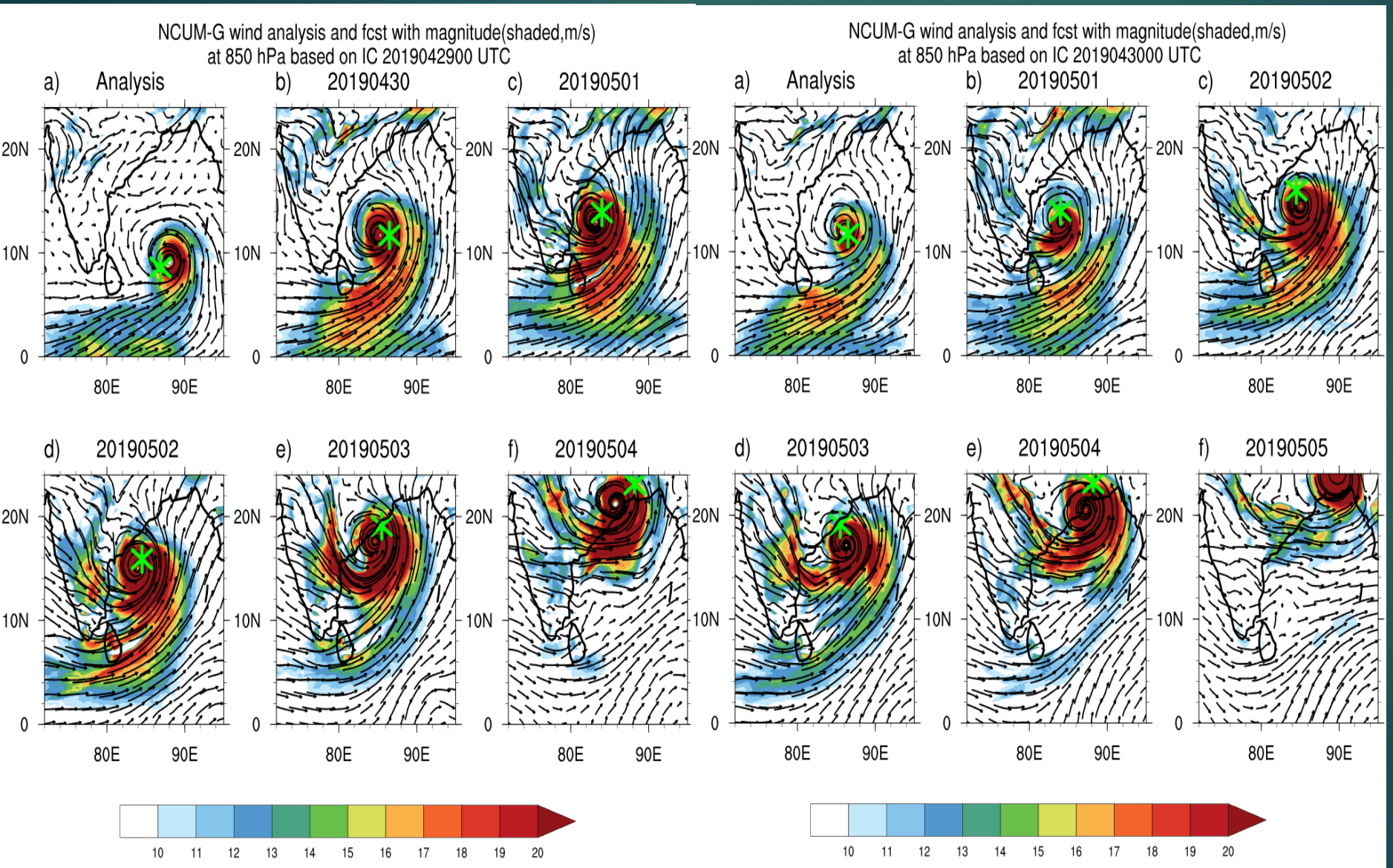
NCUM Analysis

Accurate representation of the cyclone location in the initial Analysis

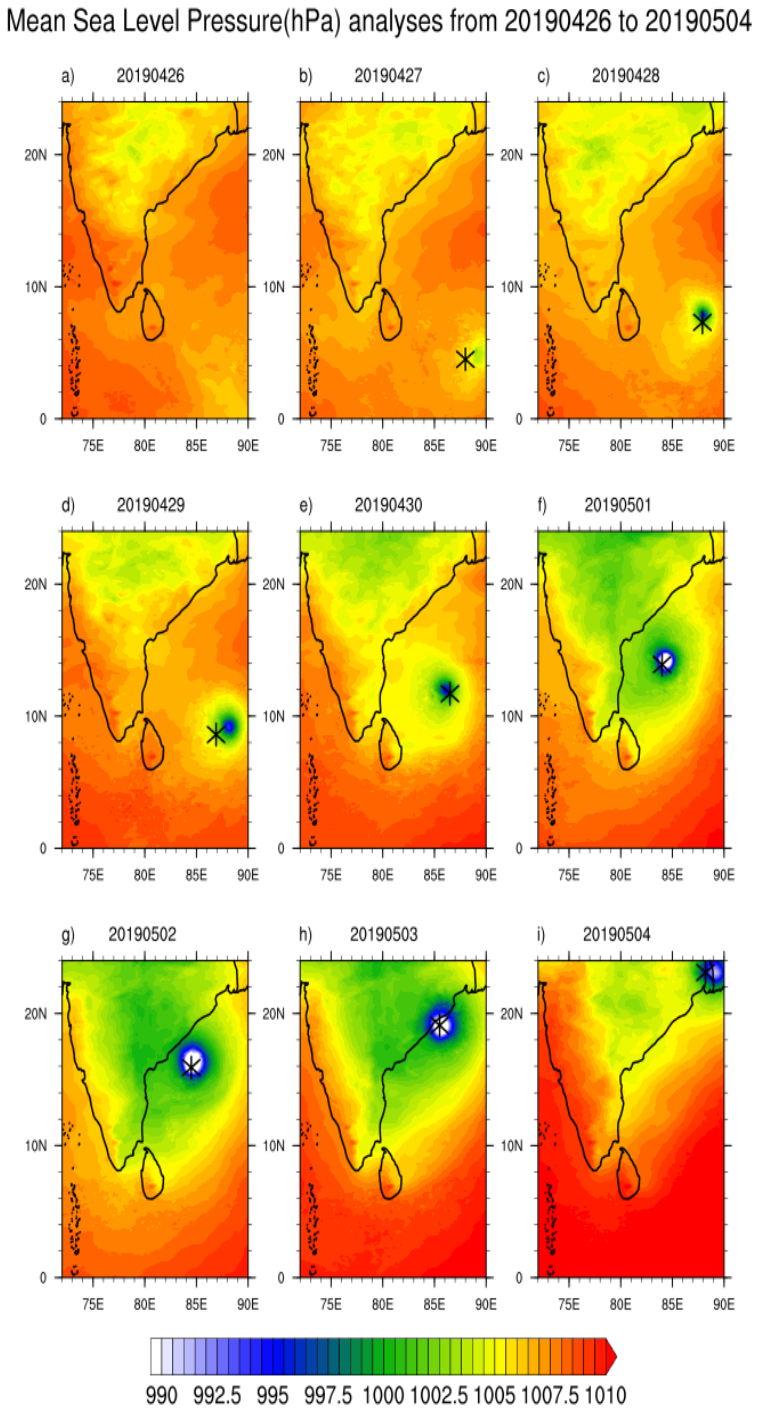
Winds at 850 hPa – Forecasts

IC: 00Z 29 APR 2019

IC: 00Z 30 APR 2019



Observed and forecast cyclone centre

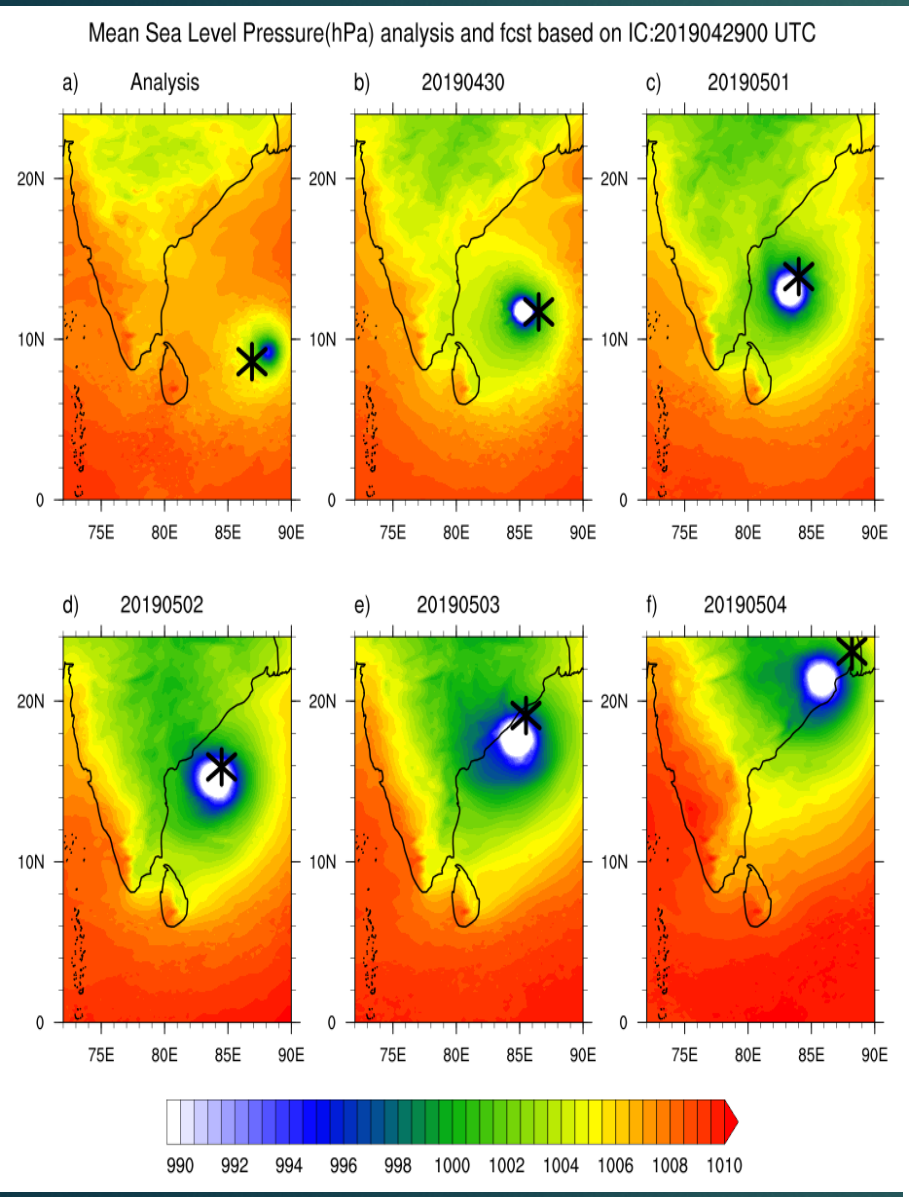


NCUM Analysis

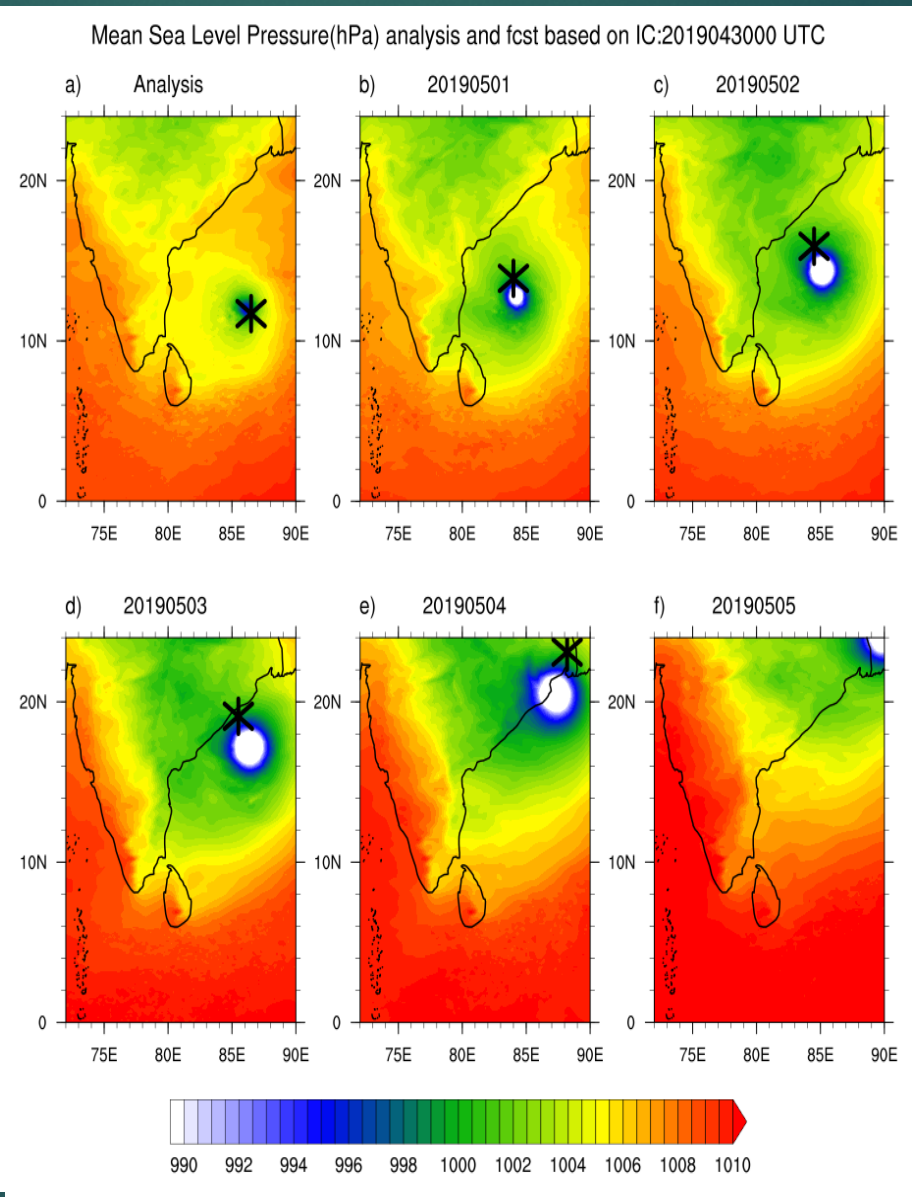
Accurate representation of the cyclone location in the initial Analysis

MSLP – Forecasts

IC: 00Z 29 APR 2019



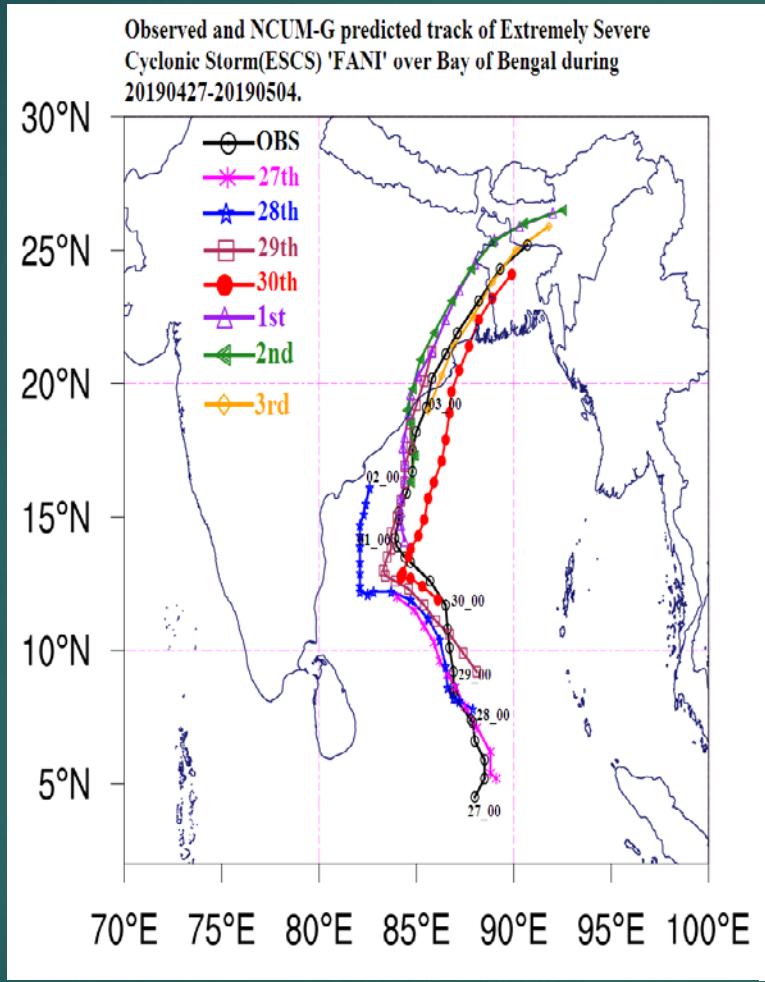
IC: 00Z 30 APR 2019



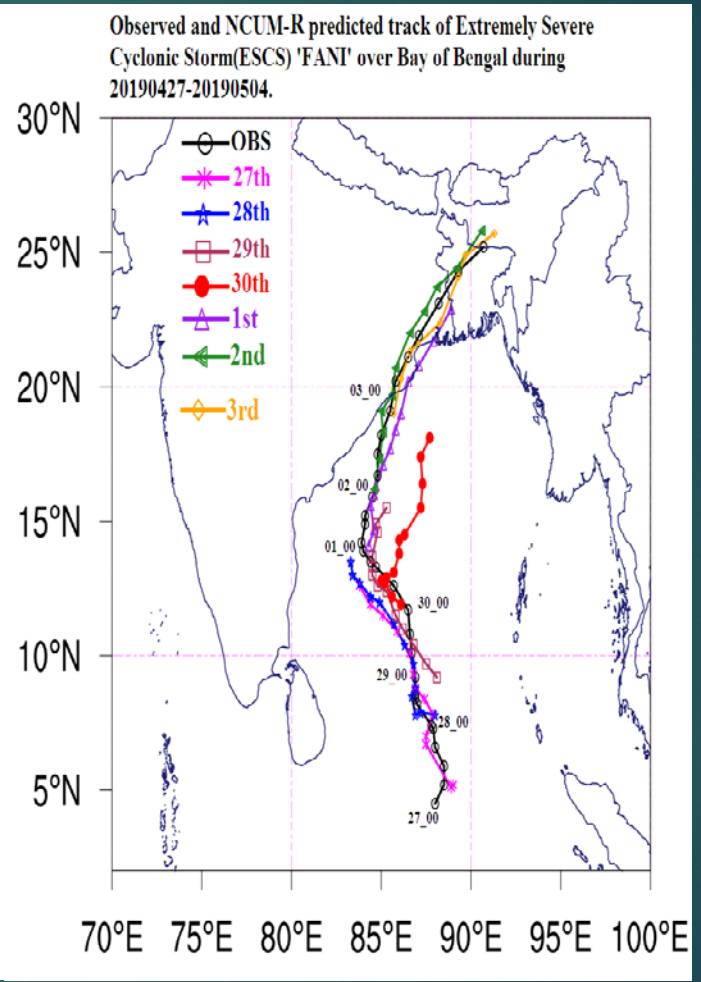
Observed and forecast cyclone centre

TC FANI – Observed and predicted tracks

NCUM-G (5 days fcst)



NCUM-R (3 days fcst)



Forecast Track Errors for ESCS 'Fani'

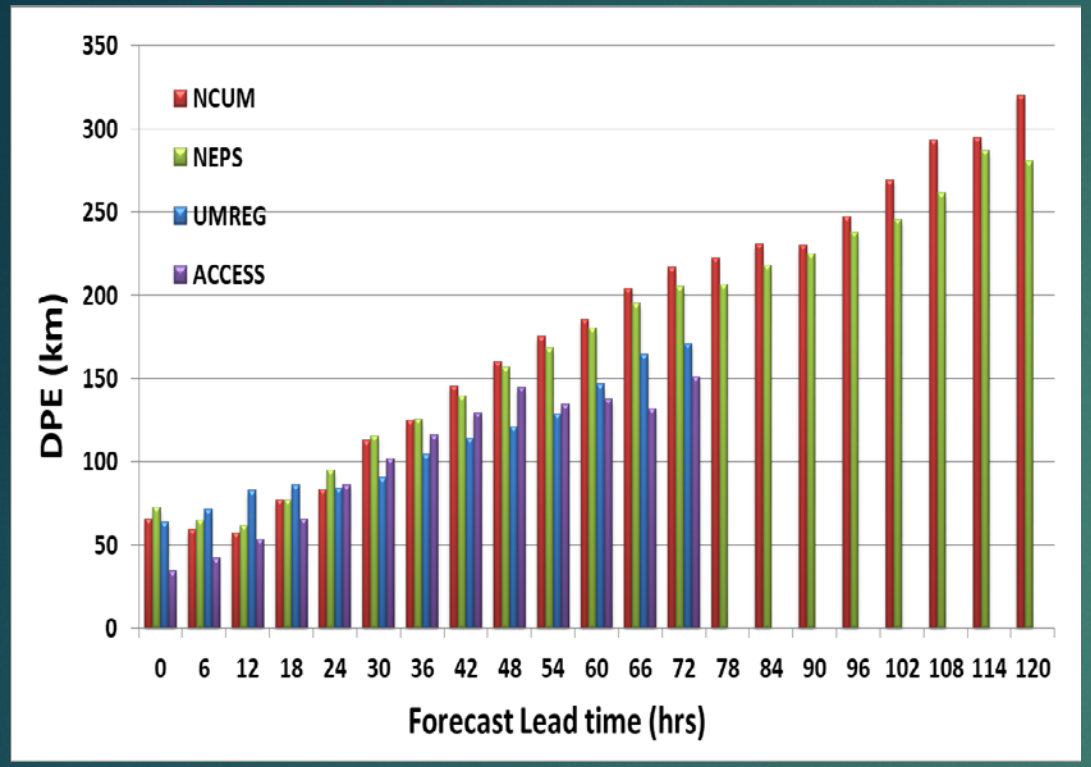


Table 1. Forecast Track Errors for ESCS Fani from 00Z26Apr-12Z04May 2019.
[ACCESS model tracks are available from 12Z27Apr-00Z04May2019]

	0	24	48	72	96	120
NCUM	**66**	**83**	**160**	**217**	**248**	**320**
No. of cases	*15*	*15*	*13*	*12*	*11*	*9*
NEPS	**73**	**95**	**157**	**205**	**238**	**280**
No. of cases	*15*	*15*	*13*	*12*	*10*	*8*
UMREG	**68**	**100**	**129**	**179**		
No. of cases	*15*	*16*	*15*	*13*		
ACCESS	**34**	**86**	**144**	**151**		
No. of cases	*14*	*13*	*11*	*9*		

Forecast Track Errors for ESCS 'Fani'

- Initial Position Errors (IPE):
  - Lowest mean IPE ACCESS (34km)
    - [min 10.8km on 00z01May and max 71km on 00Z27Apr]
  - NCUM and UMReg are second best with 66 and 68km IPE
  - Highest mean IPE NEPS (mean) (73km)
    - [min 16.8km on 00z03May and max 147km on 00Z27Apr]

Table 1. Forecast Track Errors for ESCS Fani from 00Z26Apr-12Z04May 2019.
[ACCESS model tracks are available from 12Z27Apr-00Z04May2019]

	0	24	48	72	96	120
NCUM	**66**	**83**	**160**	**217**	**248**	**320**
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UMREG	**68**	**100**	**129**	**179**		
No. of cases	*15*	*16*	*15*	*13*		
ACCESS	**34**	**86**	**144**	**151**		
No. of cases	*14*	*13*	*11*	*9*		

Forecast Track Errors for ESCS 'Fani'

- Direct Position Error (DPE):
  - Lowest Day-1 DPE in NCUM (83km)and ACCESS(86km)
    - NCUM Day-1 DPE 14 of 15 values <85km except on 00z30Apr (123km)
    - ACCESS Day-1 DPE 7 of 13 values >100km
  - Lowest Day-2 DPE in UMReg (129km)
    - UMReg Day-2 DPE 5 of 15 values <100km and 5 of 15 values >150km
  - Lowest Day-3 DPE in ACCESS (151km)
    - ACCESS Day-3 DPE 6 of the 9 values >150km

Table 1. Forecast Track Errors for ESCS Fani from 00Z26Apr-12Z04May 2019.
[ACCESS model tracks are available from 12Z27Apr-00Z04May2019]

	0	24	48	72	96	120
NCUM	**66**	**83**	**160**	**217**	**248**	**320**
No. of cases	*15*	*15*	*13*	*12*	*11*	*9*
NEPS	**73**	**95**	**157**	**205**	**238**	**280**
No. of cases	*15*	*15*	*13*	*12*	*10*	*8*
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No. of cases	*15*	*16*	*15*	*13*		
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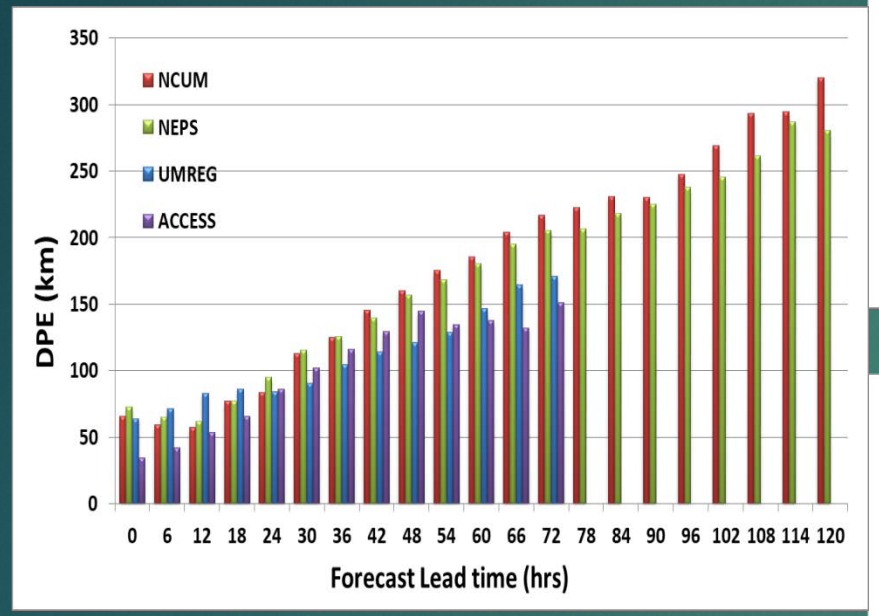
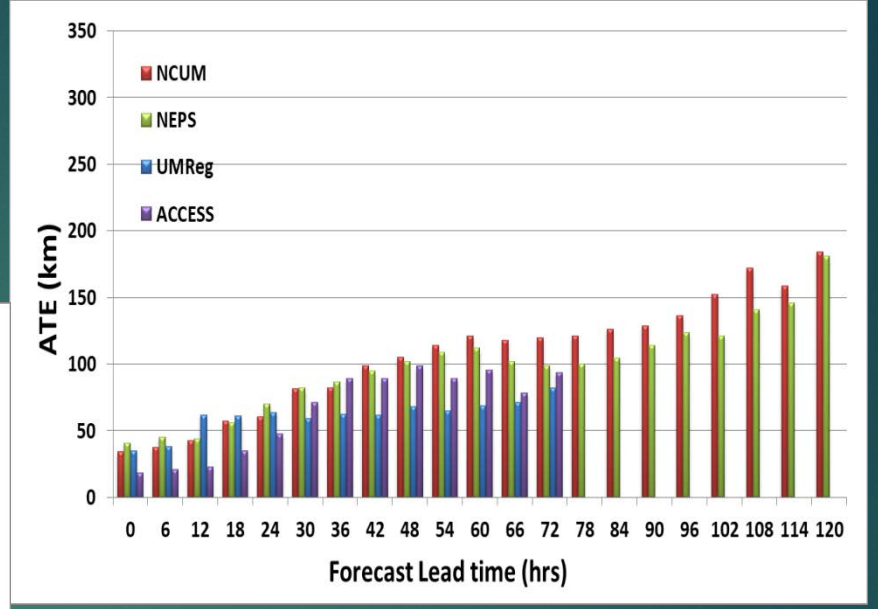
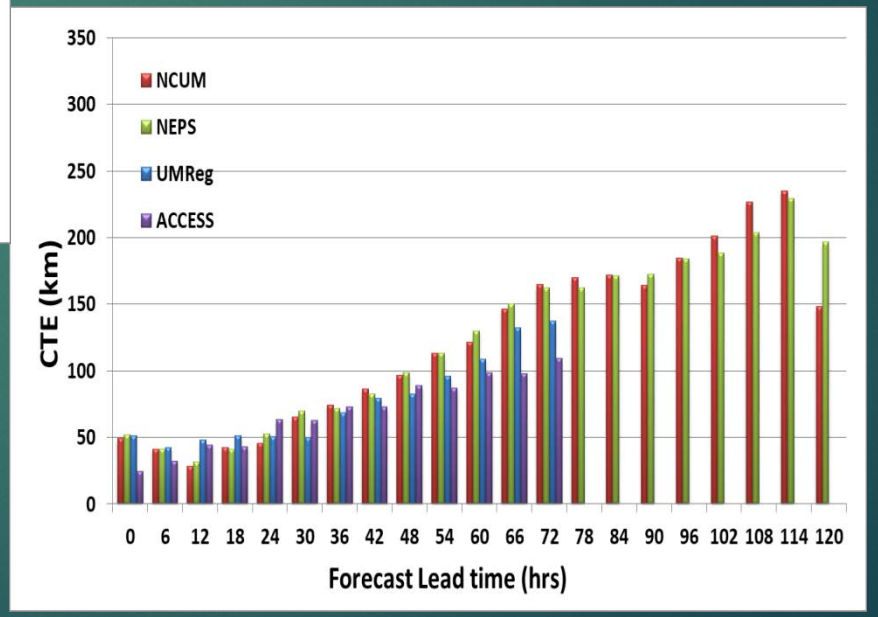
No. of cases	*14*	*13*	*11*	*9*		



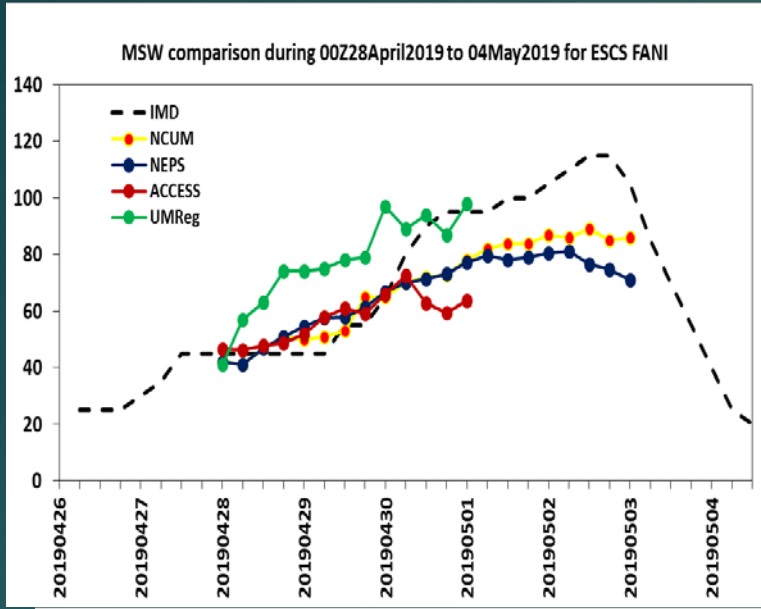


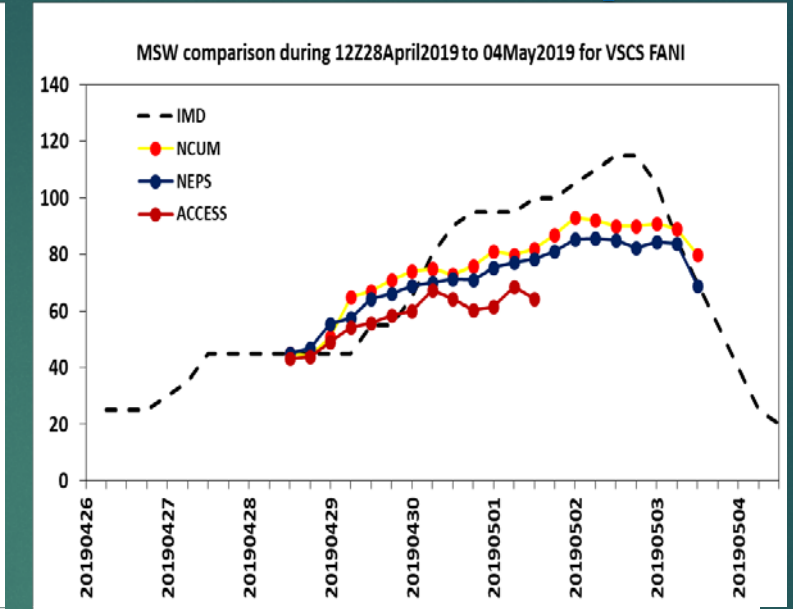


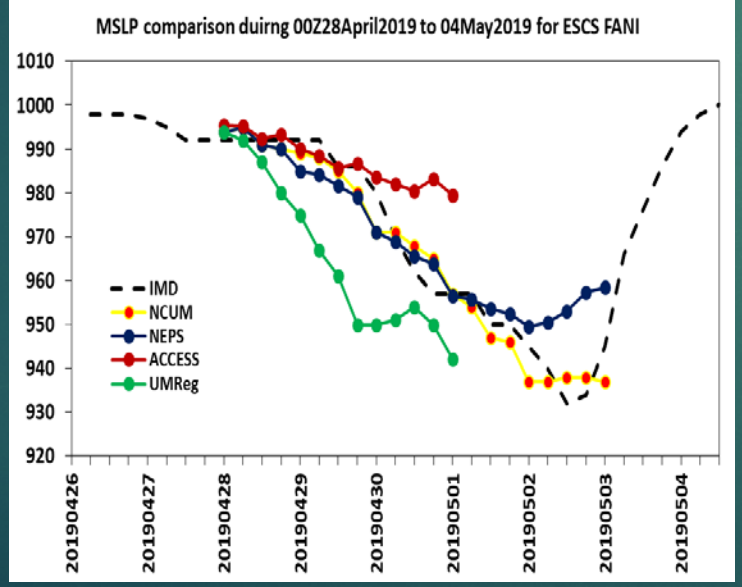
- ATE <50km and CTE ~ 50km in the initial position.
- Error contribution in DPE mainly due to CTE

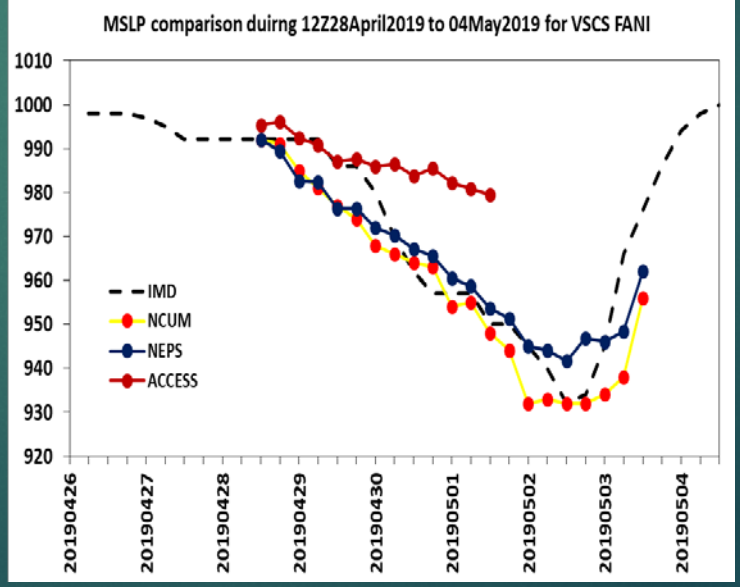
00UTC 28th Apr

12UTC 28th Apr









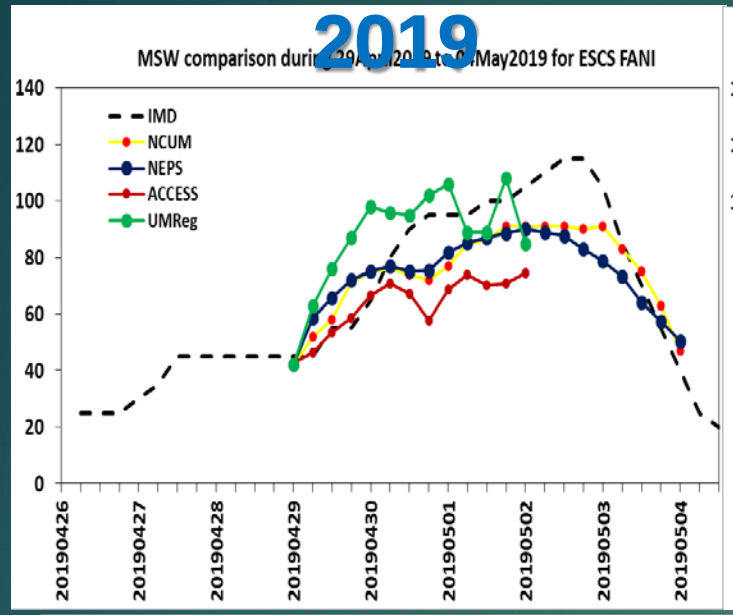
Strong Intensity in NCUM, NEPS and UMReg

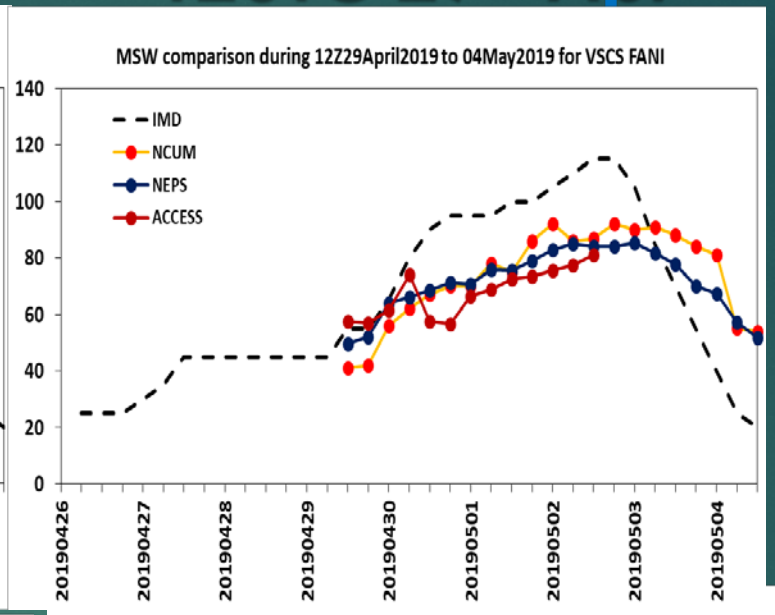
Max Wind: Underestimated at higher lead time Overestimated in UMReg

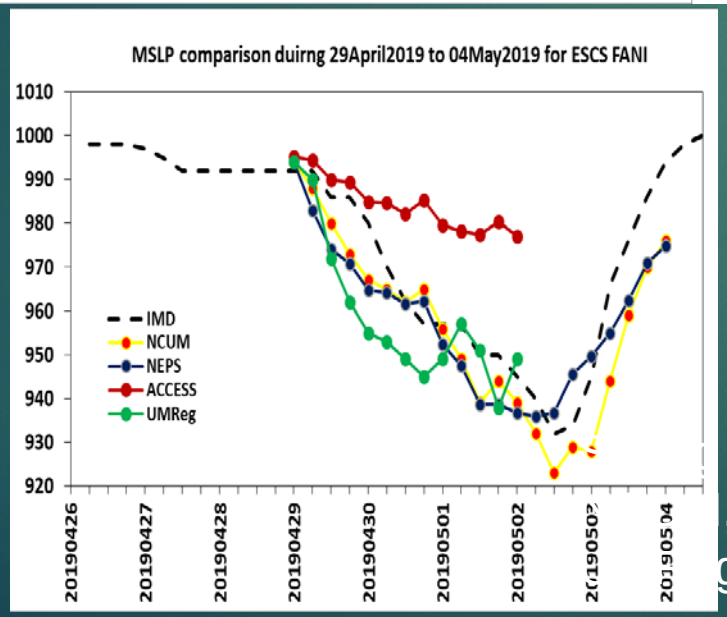
MinSLP: Accurately predicted in NCUM and NEPS Underestimated in ACCESS Overestimated in UMReg

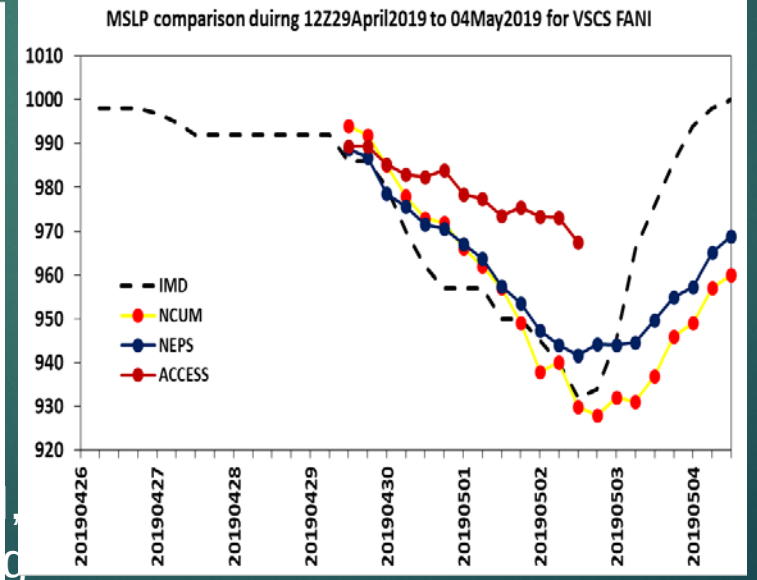
00UTC 29th Apr 2019

12UTC 29th Apr







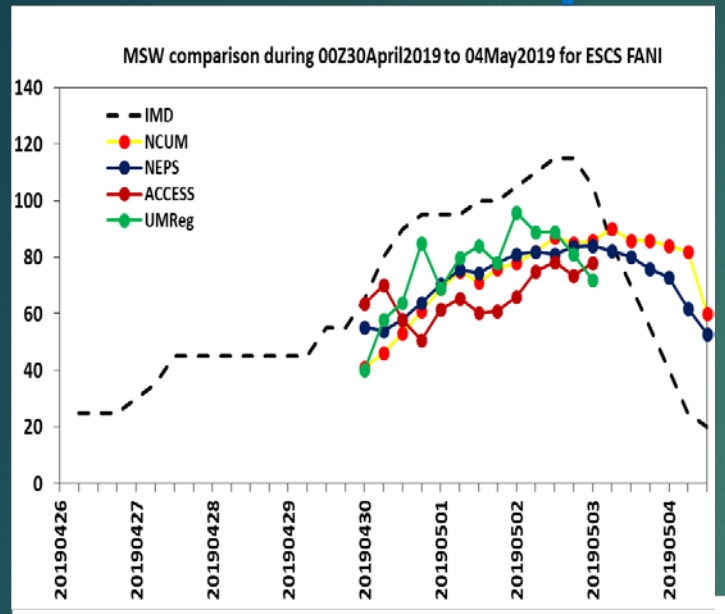


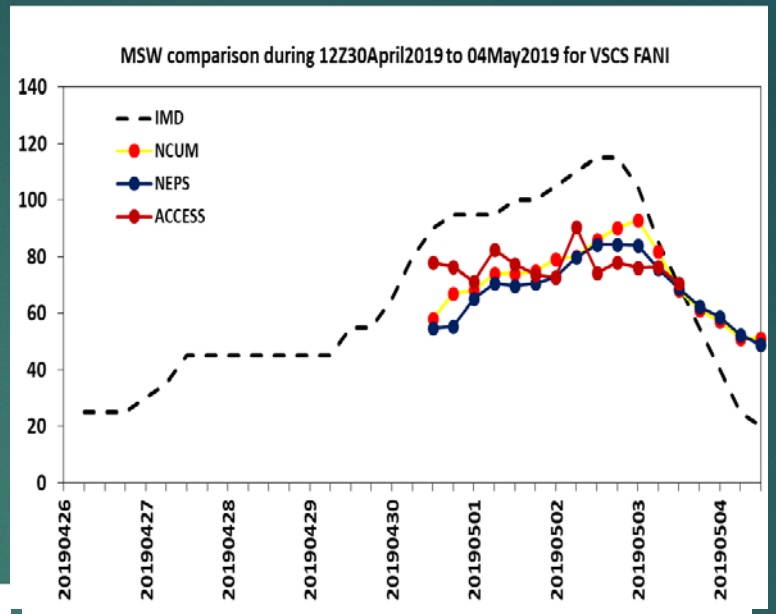
Max Wind: Underestimated at higher lead time Overestimated in UMReg

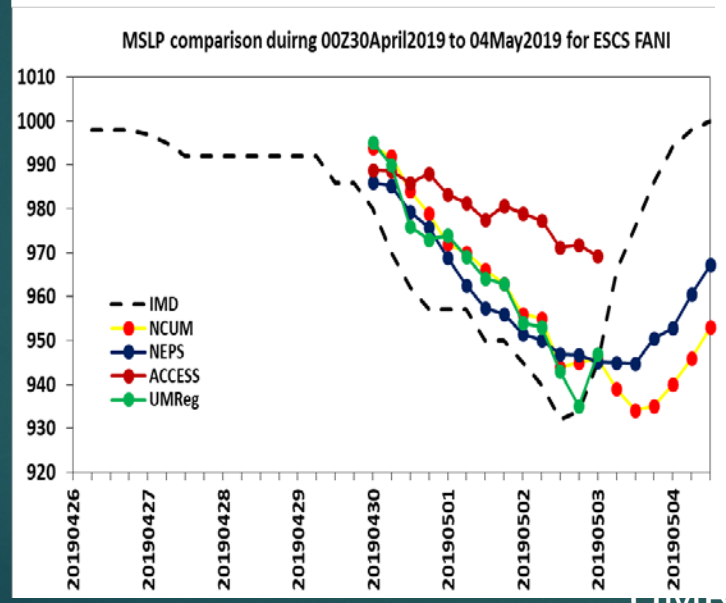
MinSLP: Accurately predicted in NCUM and NEPS Peak overestimated in NCUM Underestimated in

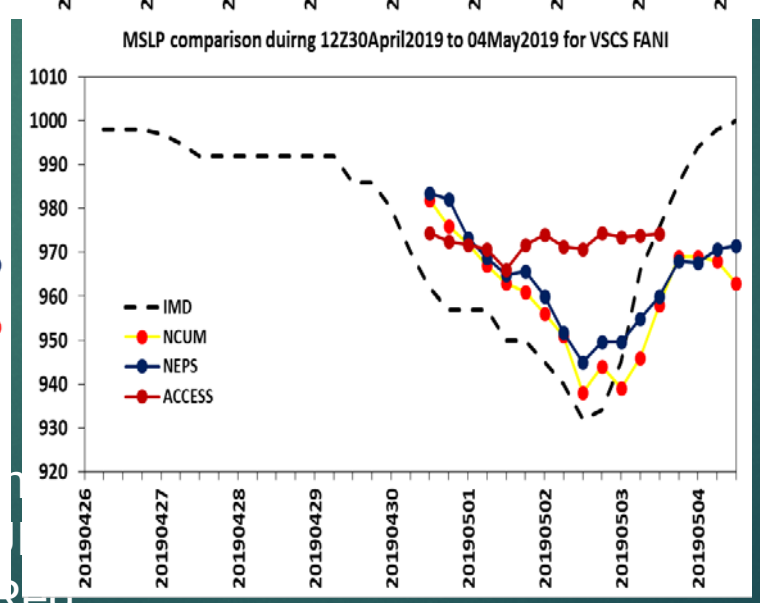
00UTC 30th Apr

12UTC 30th Apr







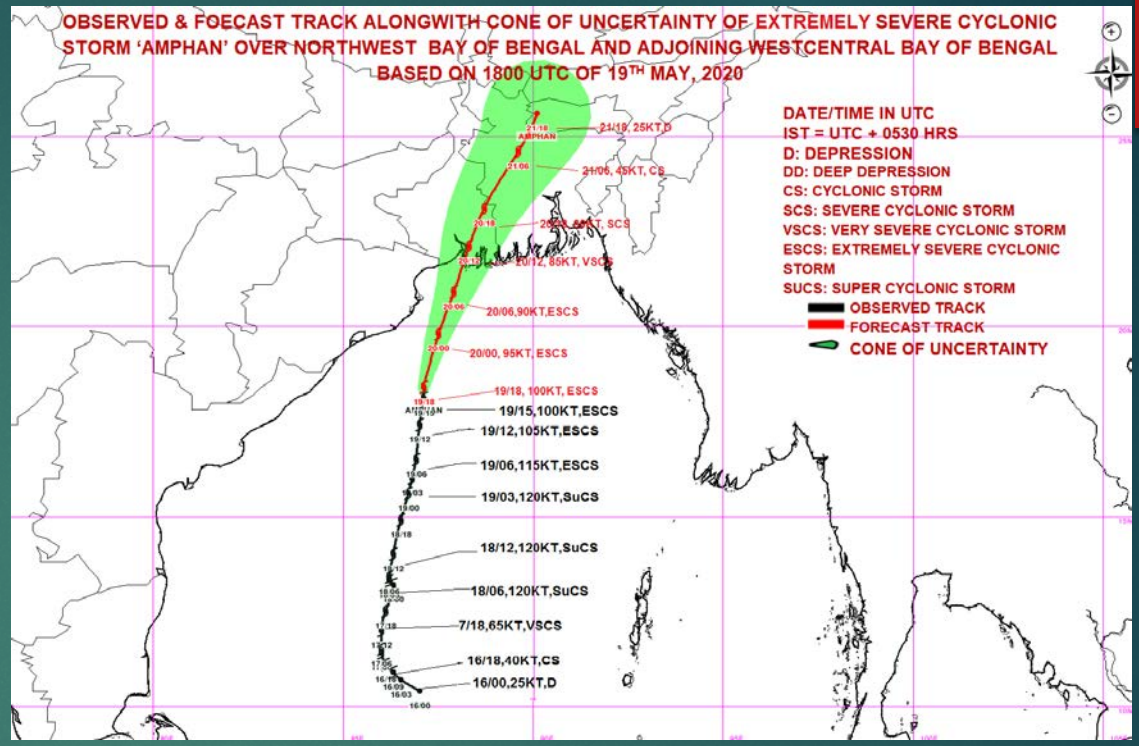


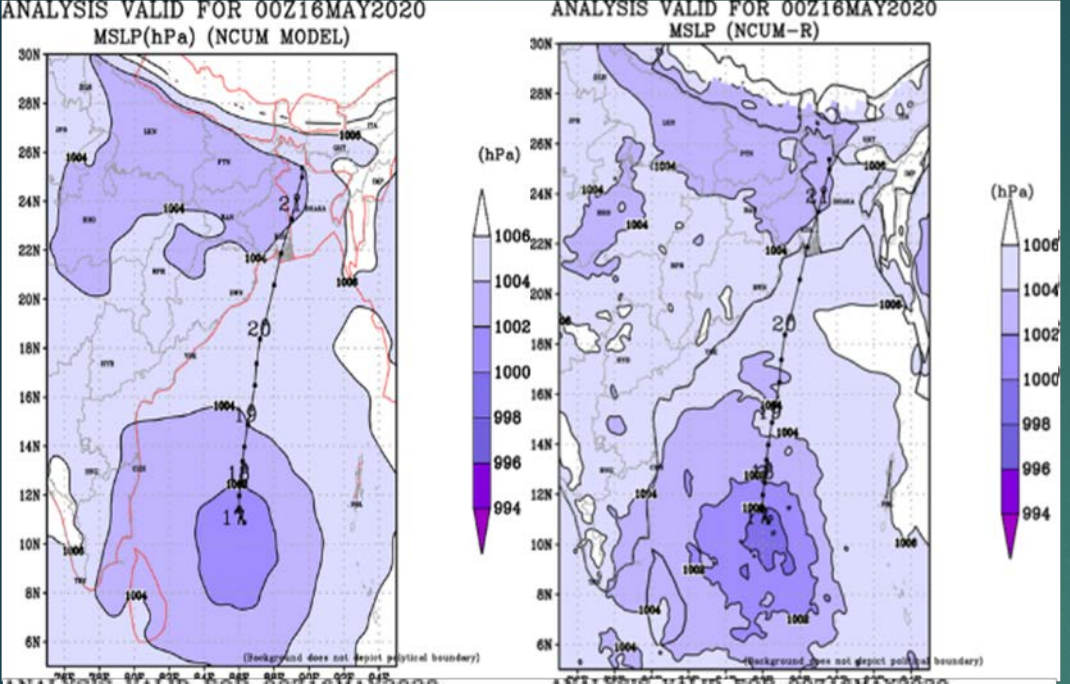
UMReg

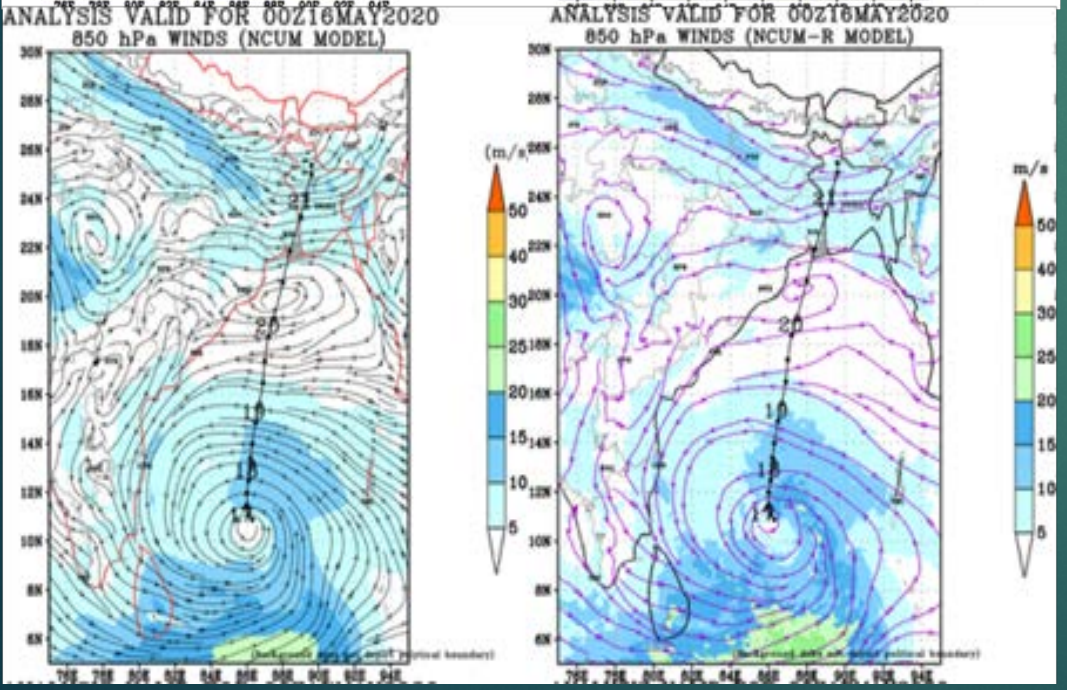
Max Wind: Underestimated at all lead time Overestimated at higher lead times

MinSLP: underestimated in all lead times Overestimated at higher lead times

SuCS ‘Amphan’

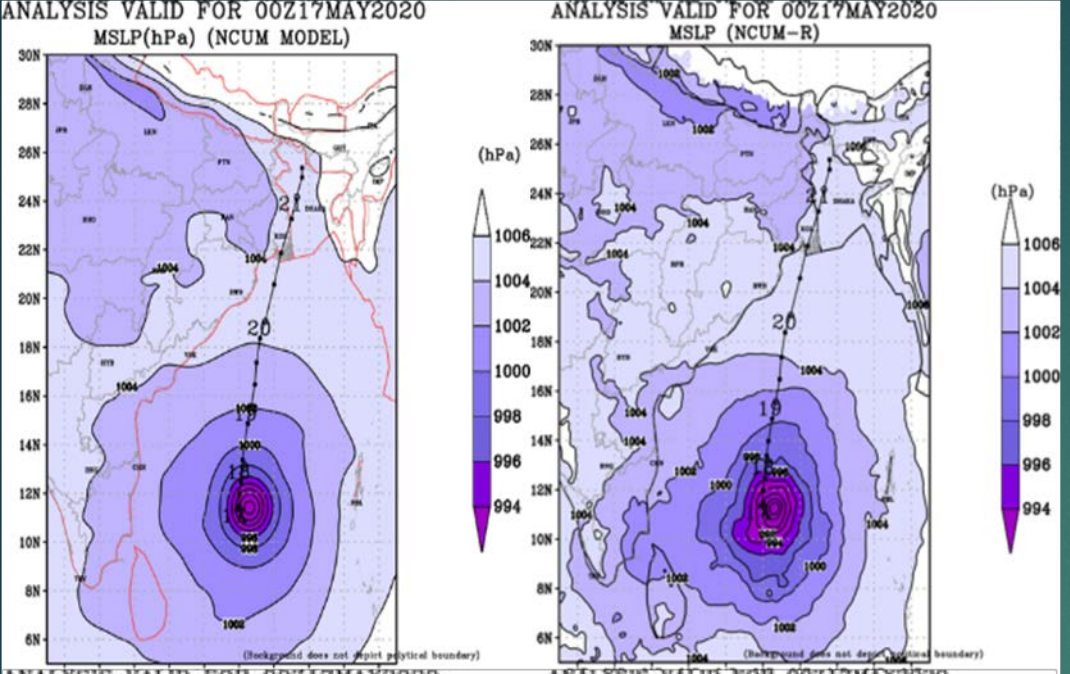

OBSERVED & FOECAST TRACK ALONGWITH CONE OF UNCERTAINTY OF EXTREMELY SEVERE CYCLONIC STORM ‘AMPHAN’ OVER NORTHWEST BAY OF BENGAL AND ADJOINING WESTCENTRAL BAY OF BENGAL BASED ON 1800 UTC OF 19TH MAY, 2020
DATE/TIME IN UTC
IST = UTC + 0530 HRS
D: DEPRESSION
DD: DEEP DEPRESSION
CS: CYCLONIC STORM
SCS: SEVERE CYCLONIC STORM
VSCS: VERY SEVERE CYCLONIC STORM
ESCS: EXTREMELY SEVERE CYCLONIC STORM
SUCS: SUPER CYCLONIC STORM
OBSERVED TRACK
FORECAST TRACK
CONE OF UNCERTAINTY
21/18, 25KT,D
21/06, 45KT, CS
20/06,90KT,ESCS
20/00, 95KT, ESCS
19/18, 100KT, ESCS
19/15,100KT,ESCS
19/12,105KT,ESCS
19/06,115KT,ESCS
19/03,120KT,SuCS
18/12,120KT,SuCS
18/06,120KT,SuCS
7/18,65KT,VSCS
16/18,40KT,CS
16/00,25KT,D

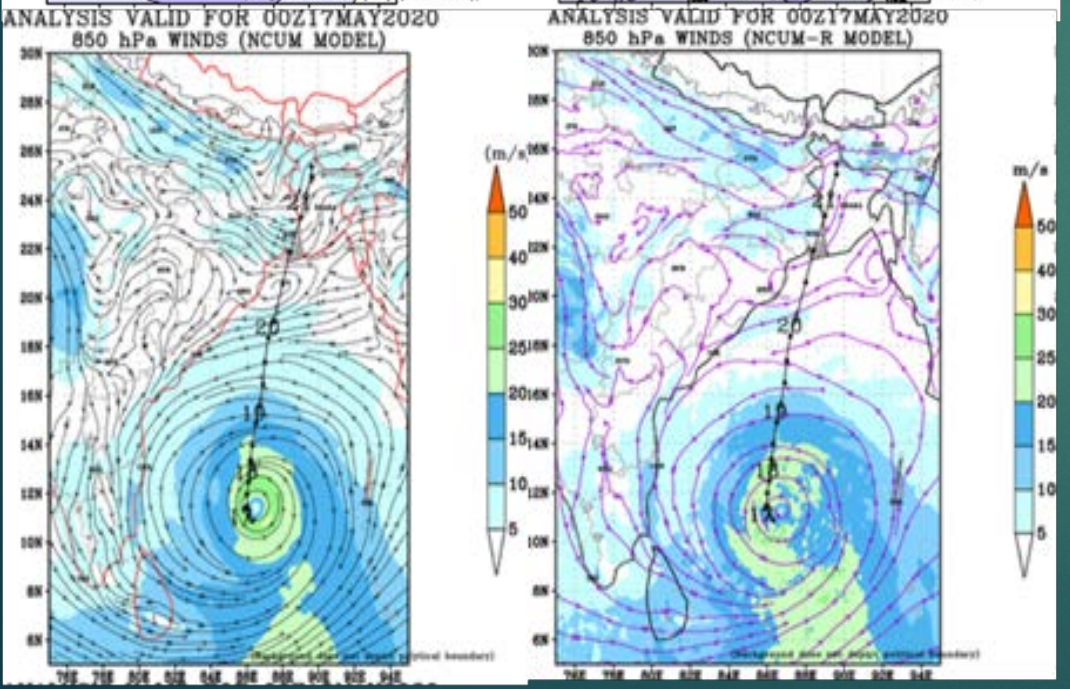




Cyclonic System in BoB

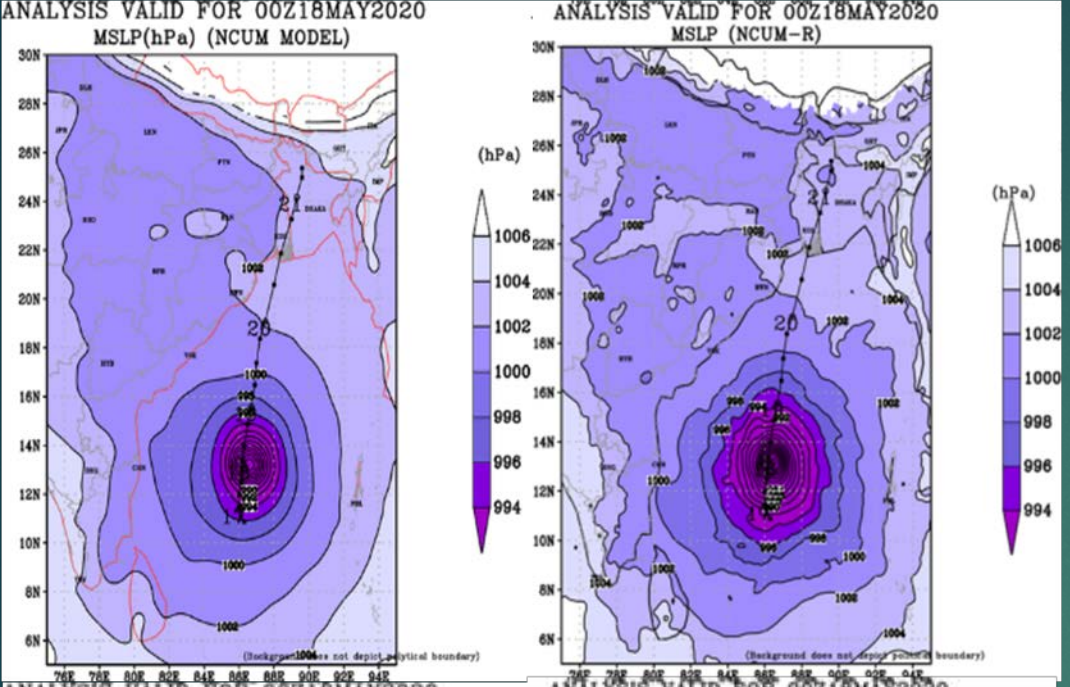
NCUM-G and NCUM-R : High resolution analysis

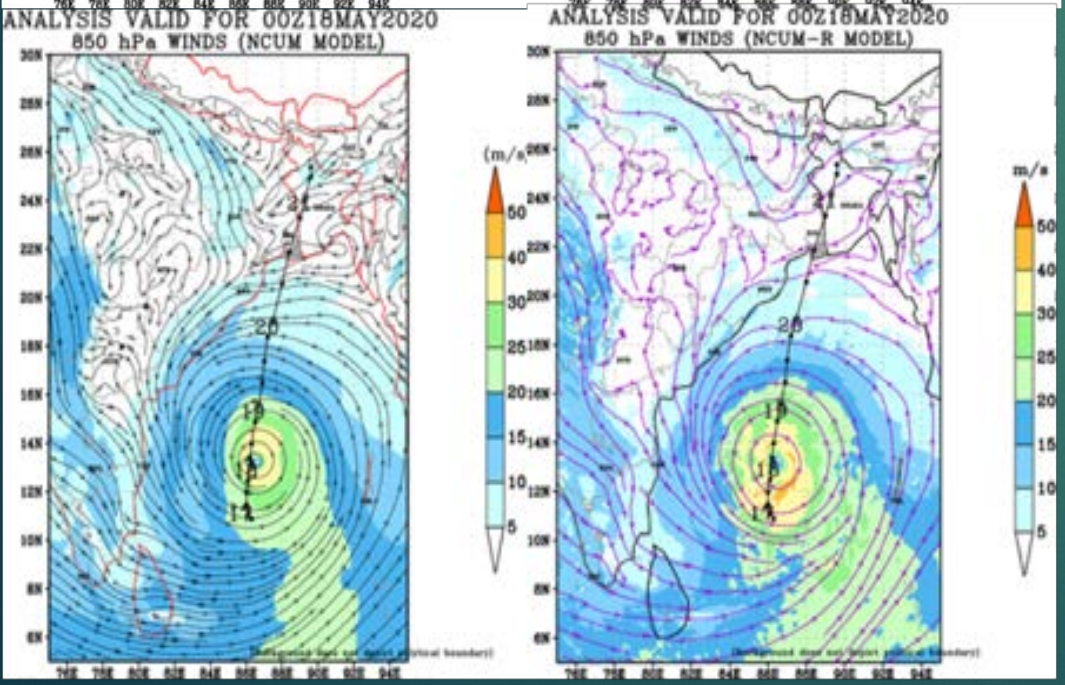




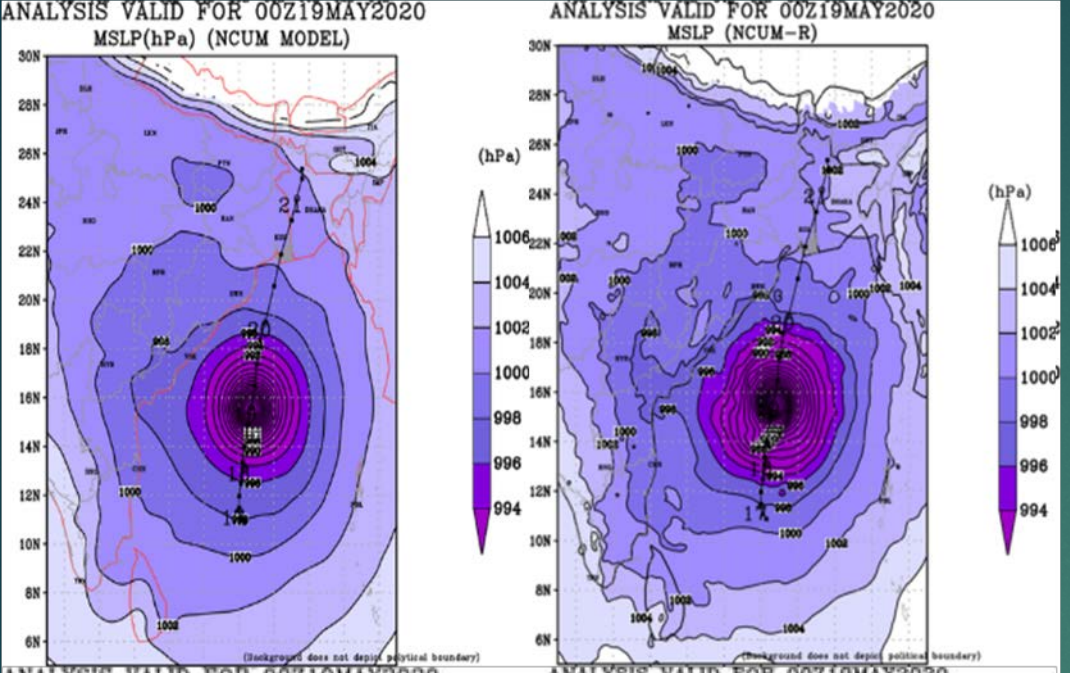
Cyclonic System in BoB

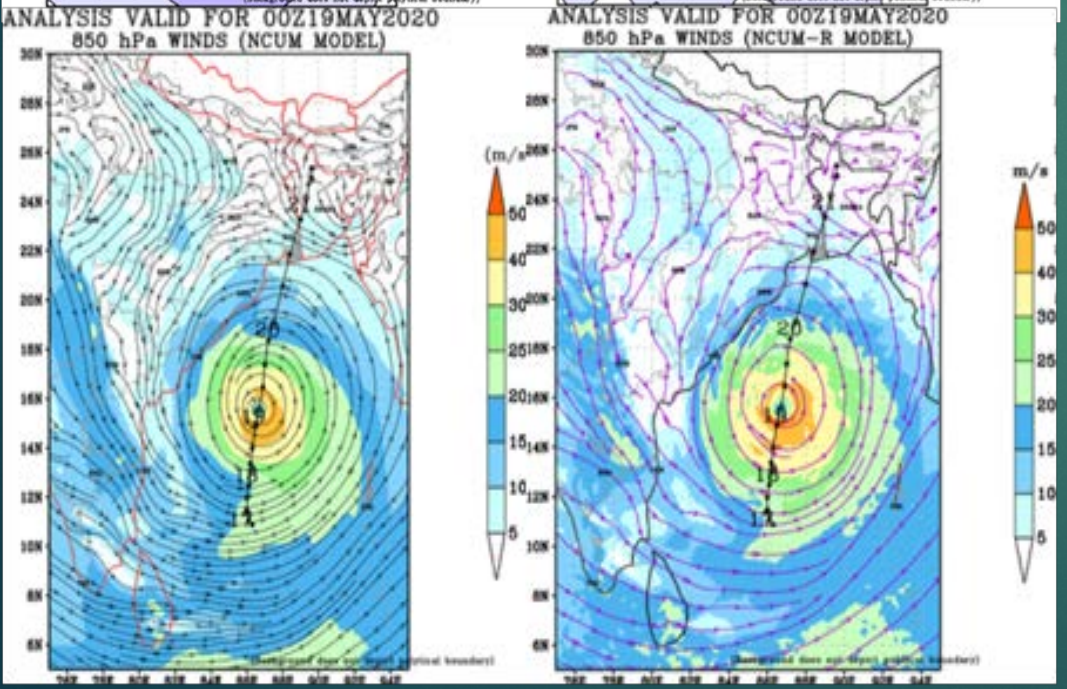
NCUM-G and NCUM-R : High resolution analysis





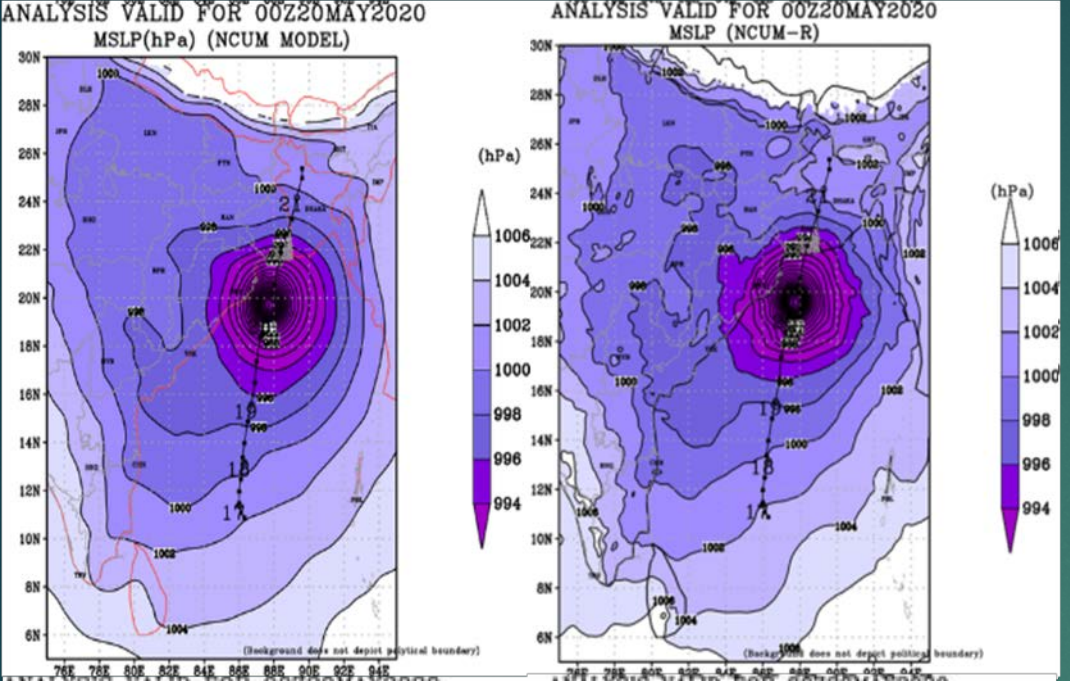
Cyclonic System in BoB
NCUM-G and NCUM-R : High resolution analysis

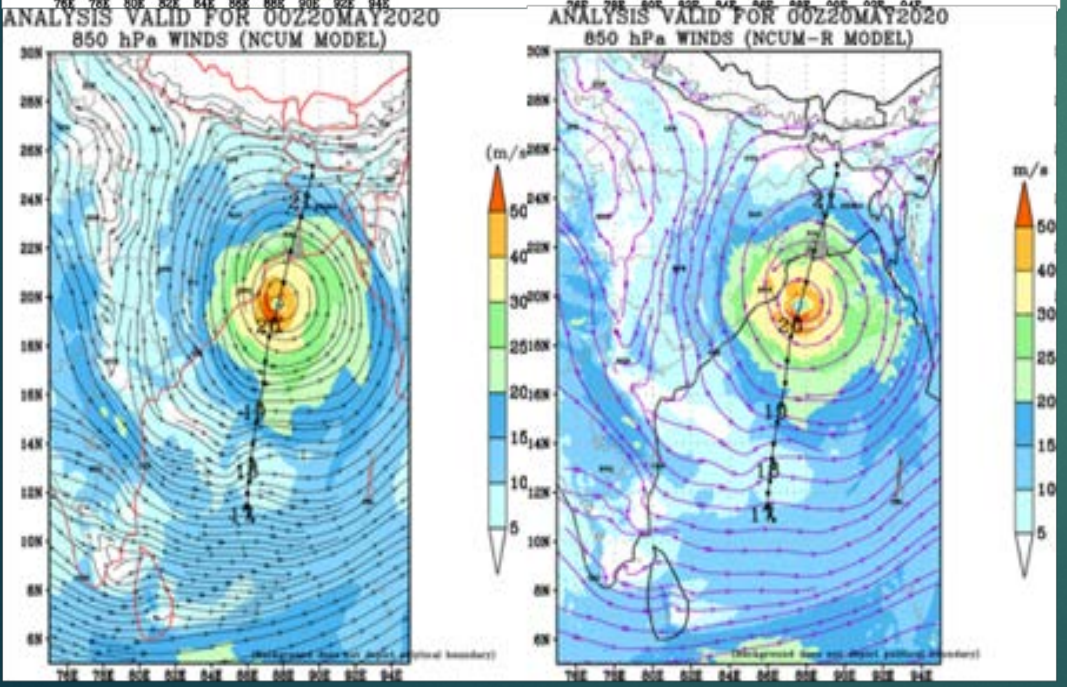




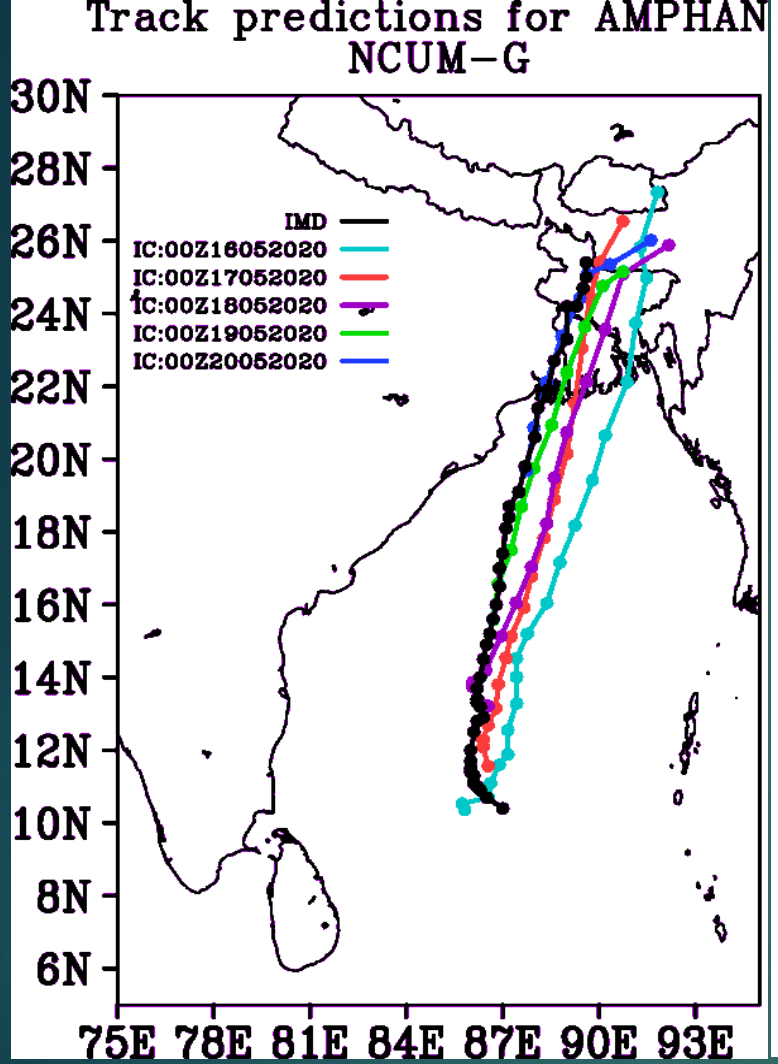
Cyclonic System in BoB

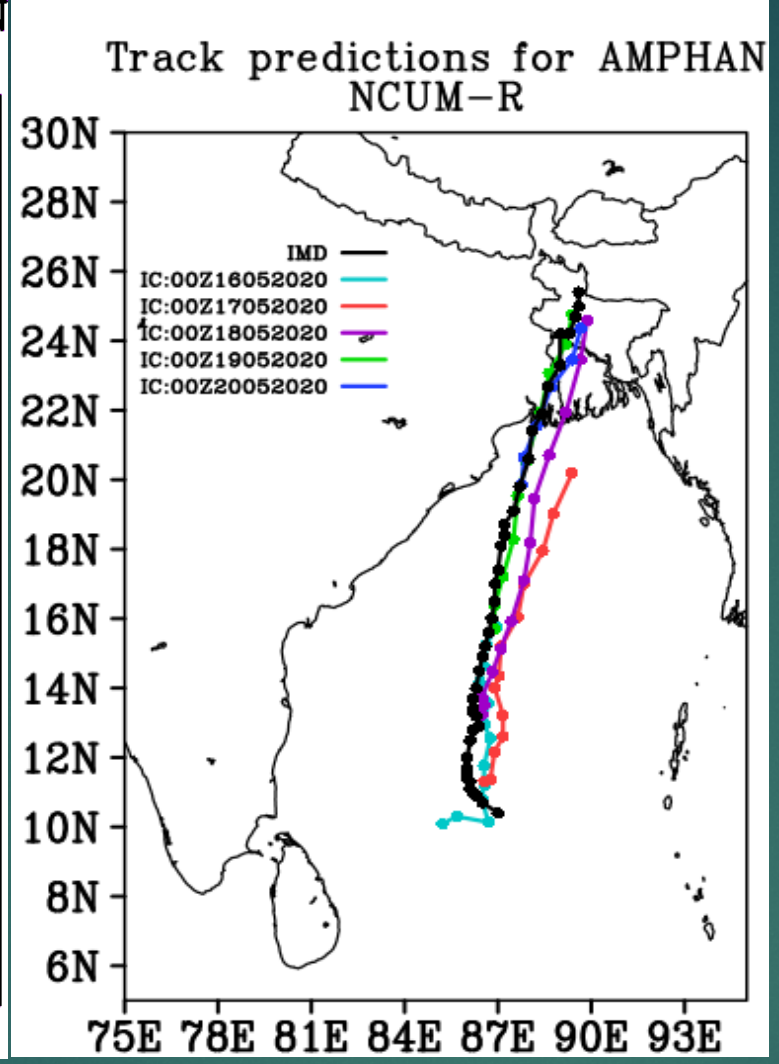
NCUM-G and NCUM-R : High resolution analysis





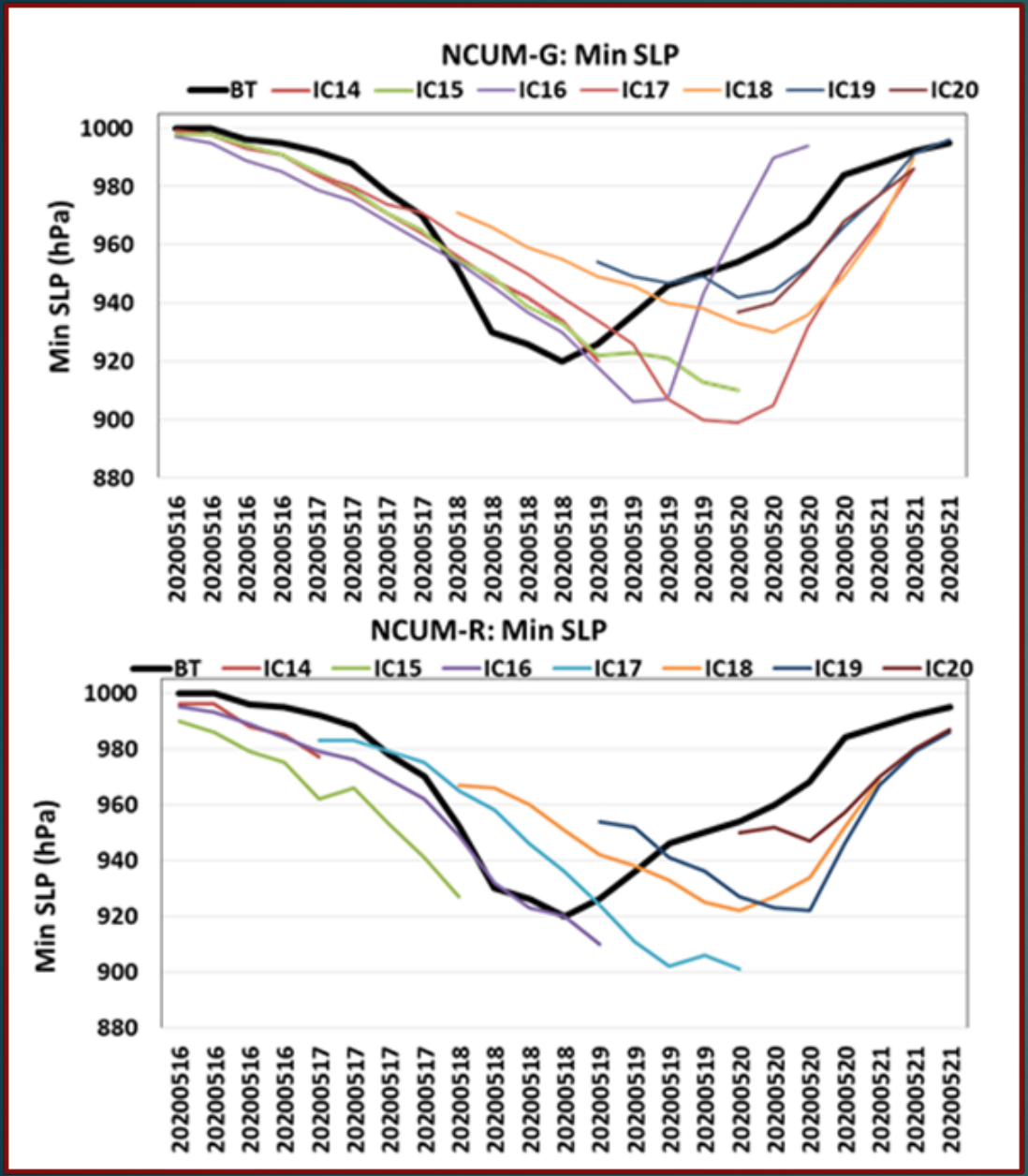
Cyclonic System in BoB
NCUM-G and NCUM-R : High resolution analysis


Track predictions for AMPHAN
NCUM-G
IMD
IC:00Z16052020
IC:00Z17052020
IC:00Z18052020
IC:00Z19052020
IC:00Z20052020
30N
28N
26N
24N
22N
20N
18N
16N
14N
12N
10N
8N
6N
75E 78E 81E 84E 87E 90E 93E

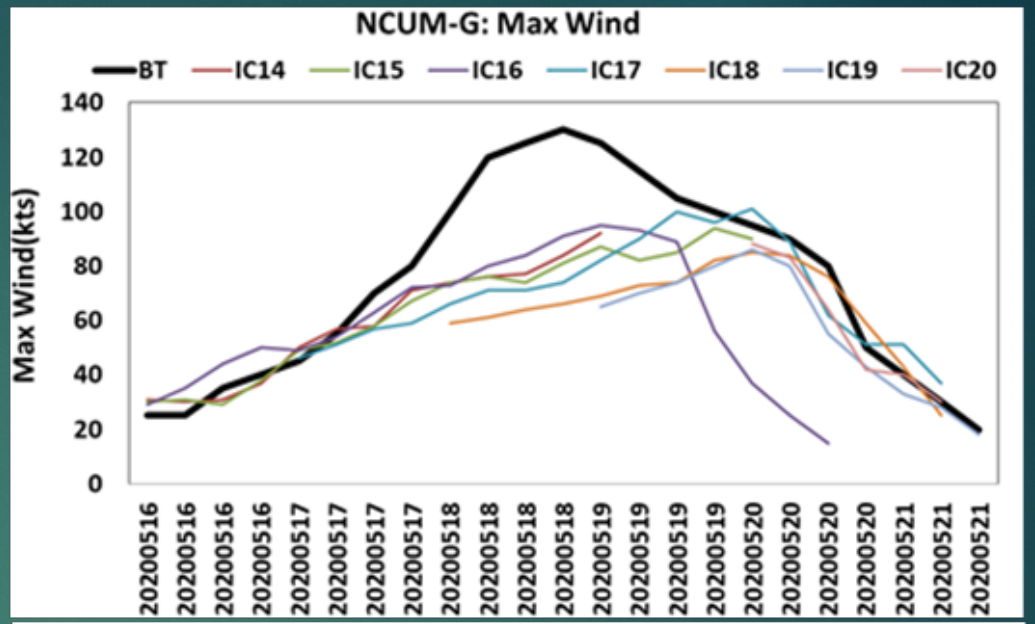

Track predictions for AMPHAN
NCUM-R
IMD
IC:00Z16052020
IC:00Z17052020
IC:00Z18052020
IC:00Z19052020
IC:00Z20052020
30N
28N
26N
24N
22N
20N
18N
16N
14N
12N
10N
8N
6N
75E 78E 81E 84E 87E 90E 93E

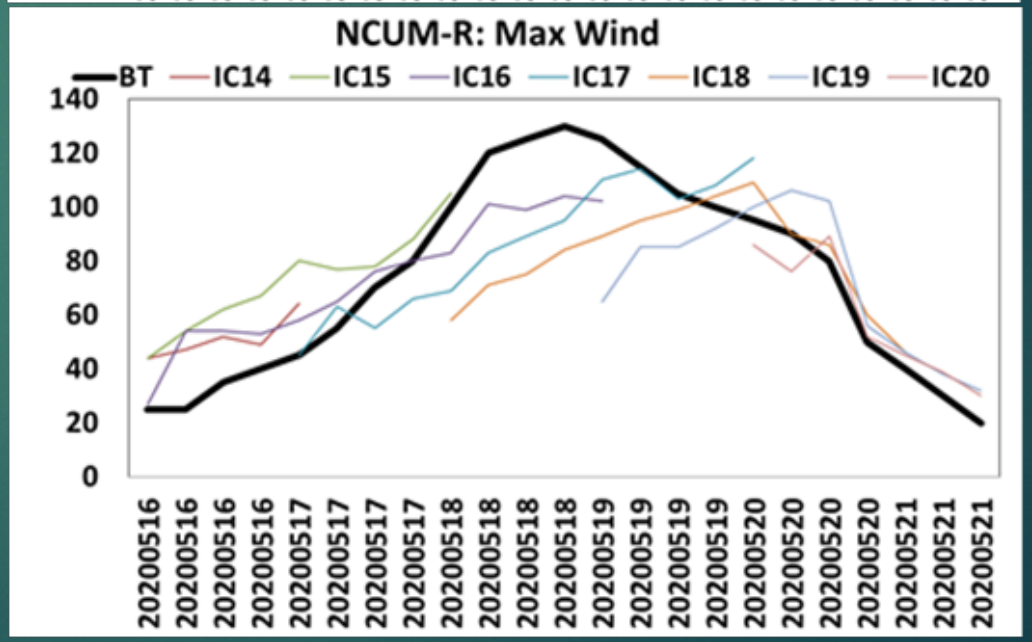
Forecast track errors before the naming of the cyclone (13-15 May 2020) and after the naming of cyclone (16-21 May2020)

Forecasts Based on 13-21 May 2020											
Fcst Hour	**0**	**12**	**24**	**36**	**48**	**60**	**72**	**84**	**96**	**108**	**120**
NUCM-G	43	65	68	94	112	148	183	205	210	227	250
NCUM-R	48	72	78	86	99	118	153				
Forecasts Based on 13-15 May 2020											
NUCM-G		144	94	70	86	81	140	146	139	159	171
NCUM-R		80	63	59	93	103	138				
Forecasts based on 16-21May 2020											
NUCM-G	43	58	62	98	124	187	237	294	326	429	
NCUM-R	48	71	81	95	102	131	169				


NCUM-G: Min SLP
BT IC14 IC15 IC16 IC17 IC18 IC19 IC20
Min SLP (hPa)
1000
980
960
940
920
900
880
20200516 20200516 20200516 20200516 20200517 20200517 20200517 20200517 20200518 20200518 20200518 20200518 20200519 20200519 20200519 20200519 20200520 20200520 20200520 20200520 20200521 20200521 20200521

NCUM-R: Min SLP
BT IC14 IC15 IC16 IC17 IC18 IC19 IC20
Min SLP (hPa)
1000
980
960
940
920
900
880
20200516 20200516 20200516 20200516 20200517 20200517 20200517 20200517 20200518 20200518 20200518 20200518 20200519 20200519 20200519 20200519 20200520 20200520 20200520 20200520 20200521 20200521 20200521


NCUM-G: Max Wind
BT IC14 IC15 IC16 IC17 IC18 IC19 IC20
Max Wind(kts)
140
120
100
80
60
40
20
0
20200516 20200516 20200516 20200516 20200517 20200517 20200517 20200517 20200518 20200518 20200518 20200518 20200519 20200519 20200519 20200519 20200520 20200520 20200520 20200520 20200521 20200521 20200521


NCUM-R: Max Wind
BT IC14 IC15 IC16 IC17 IC18 IC19 IC20
140
120
100
80
60
40
20
0
20200516 20200516 20200516 20200516 20200517 20200517 20200517 20200517 20200518 20200518 20200518 20200518 20200519 20200519 20200519 20200519 20200520 20200520 20200520 20200520 20200521 20200521 20200521

Improved Track & Intensity in NCUM-G Forecasts in recent years

NCMUG-V4

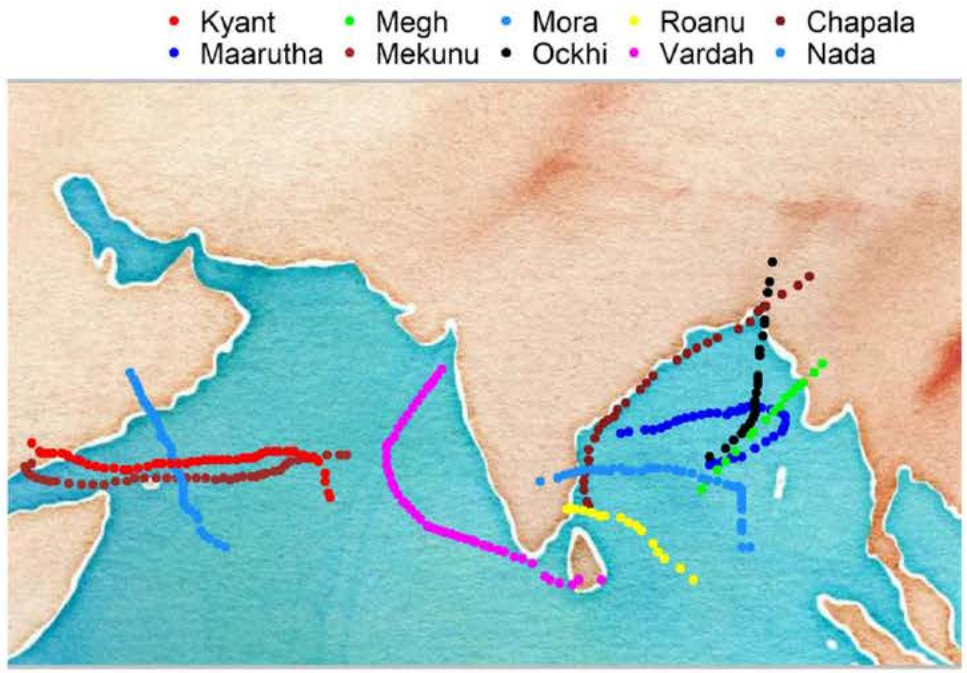
22 TCs formed over NOI during 2015-2019

NCMUG-V5

Table 4. *List of tropical cyclones studied and their details.*

Sl No.	Name	Dates	Basin of formation	Classification	MSW (kt)	MinSLP(hPa)	Life (days)	Landfall
1	Chapala	28 Oct-04 Nov 2015	AS	ESCS	115	940	8	Yes
2	Megh	05-10 Nov 2015	AS	ESCS	95	964	6	Yes
3	Roanu	17-22 May 2016	BoB	CS	45	983	6	Yes
4	Kyant	21-28 Oct 2016	BoB	CS	40	996	8	No
5	Nada	29 Nov-2 Dec 2016	BoB	CS	40	1000	4	Yes
6	Vardah	6-13 Dec 2016	BoB	VSCS	70	975	8	Yes
7	Maarutha	15-17 April 2017	BoB	CS	40	996	3	Yes
8	Mora	28-31 May 2017	BoB	SCS	60	978	4	Yes
9	Ockhi	29 Nov-6 Dec 2017	BoB	VSCS	85	976	8	No
10	Mekunu	21-27 May 2018	AS	ESCS	95	960	7	Yes
11	Daye	19-22 Sep 2018	BoB	CS	35	992	9	Yes
12	Luban	6-15 Oct 2018	AS	VSCS	75	978	10	Yes
13	Titli	8-12 Oct 2018	BoB	VSCS	80	972	5	Yes
14	Gaja	10-19 Nov 2018	BoB	VSCS	70	976	10	Yes
15	Phethai	13-18 Dec 2018	BoB	SCS	55	992	6	No
16	Fani	26 Apr-04 May 2019	BoB	ESCS	115	932	9	Yes
17	Vayu	10-17 Jun 2019	AS	VSCS	80	970	8	No
18	Hikaa	22-25 Sep 2019	AS	VSCS	75	978	4	Yes
19	Kyarr	24 Oct-02 Nov 2019	AS	SuCS	130	922	10	No
20	Maha	30 Oct-07 Nov 2019	AS	ESCS	100	956	9	No
21	Bulbul	05-11 Nov 2019	BoB	VSCS	75	976	7	Yes
22	Pawan	02-07 Dec 2019	AS	CS	40	998	6	Yes

Improved Skill of NCMRWF Unified Model (NCUM-G) in forecasting tropical cyclones over NIO during 2015–2019 (Kumar et al 2022)



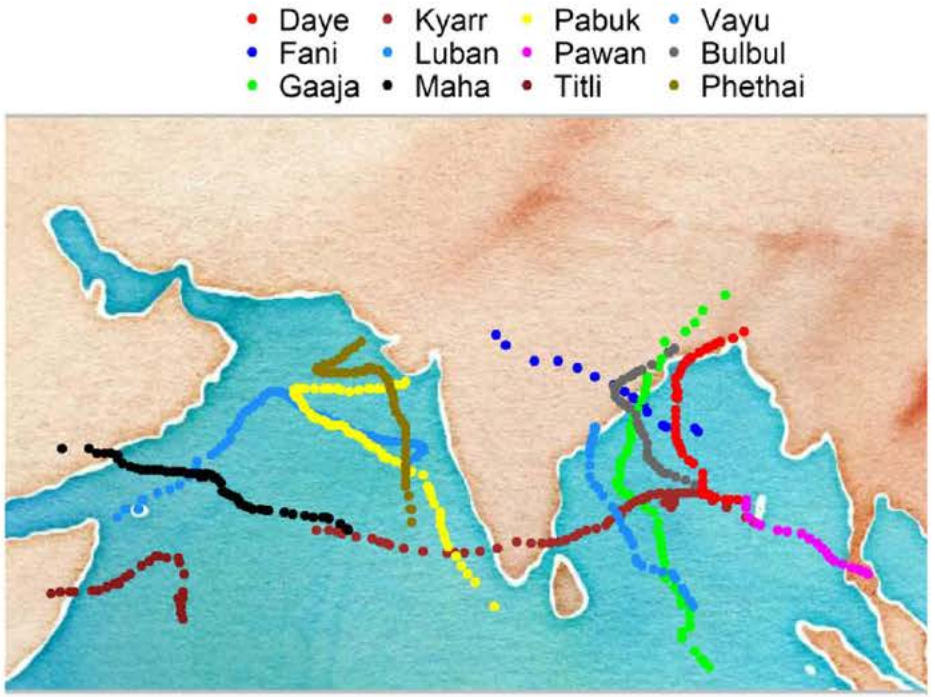
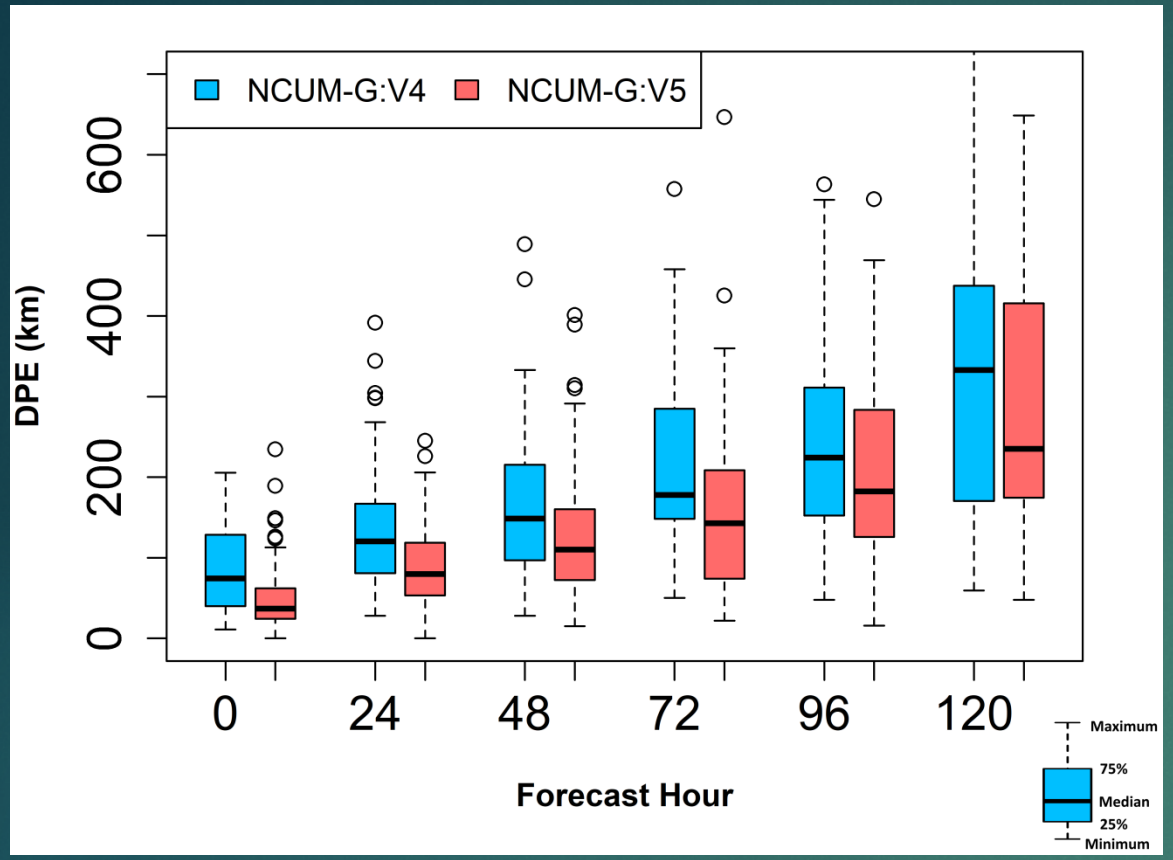
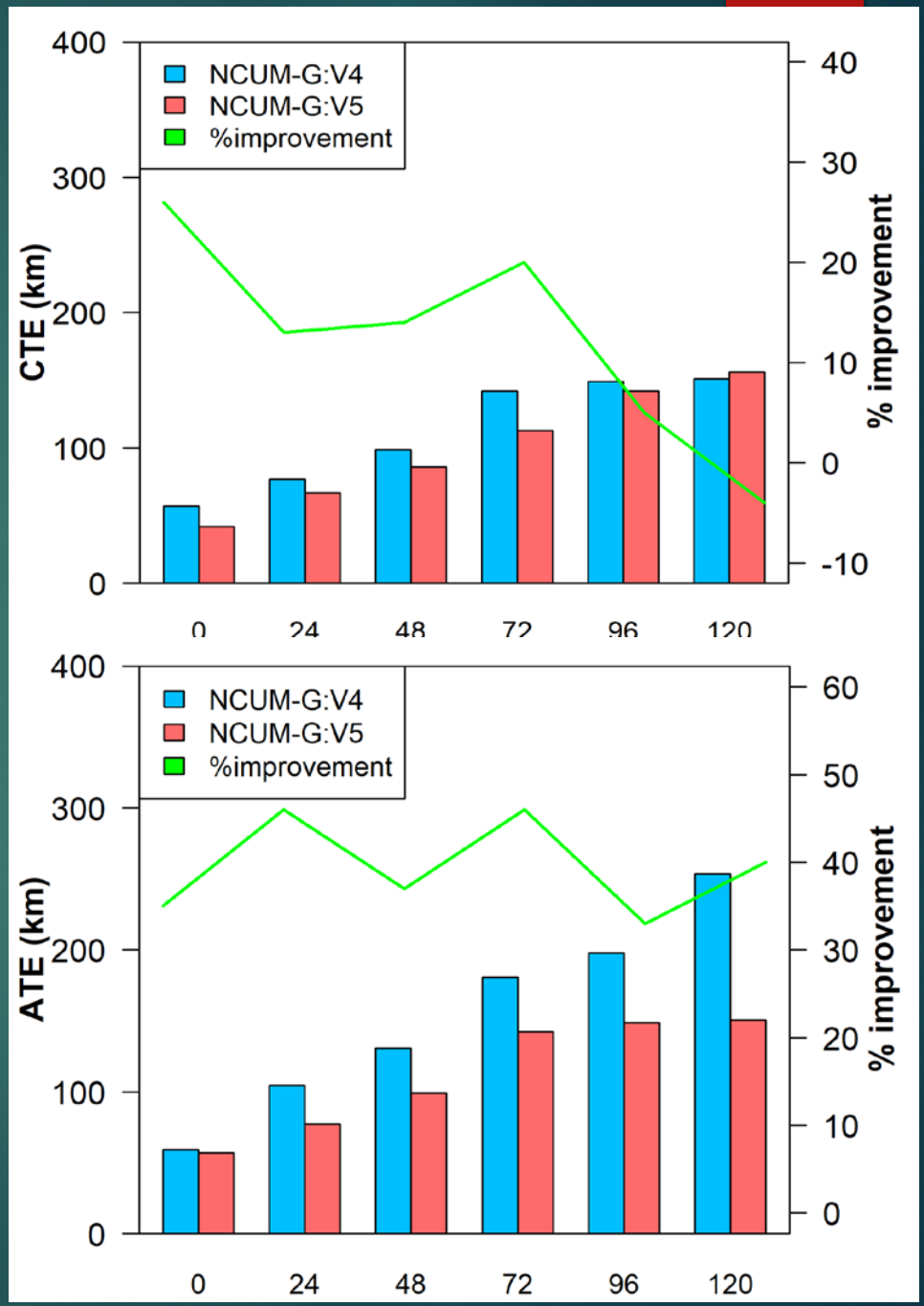


Figure 2. Best track plot of tropical cyclones as obtained from IMD for (a) 2015-May 2018 (b) June 2018-2019.

Improved Skill of NCMRWF Unified Model (NCUM-G) in forecasting tropical cyclones over NIO during 2015–2019 (Kumar et al 2022)





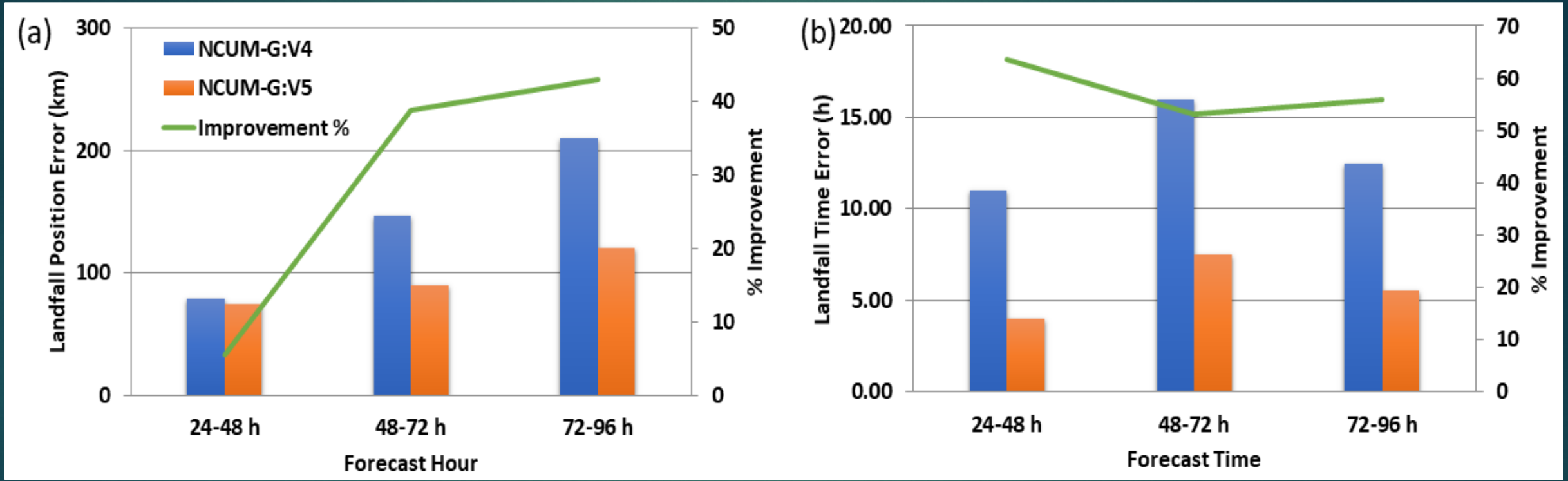
Improved forecast skill of the initial position of TCs with decrease in DPE by 44%.

Reduction in DPE at 48, 72, 96, 120 h are 34, 25, 27, 19, 26%.

Overall V5 shows gain in skill by approximately 24 h (1-day).

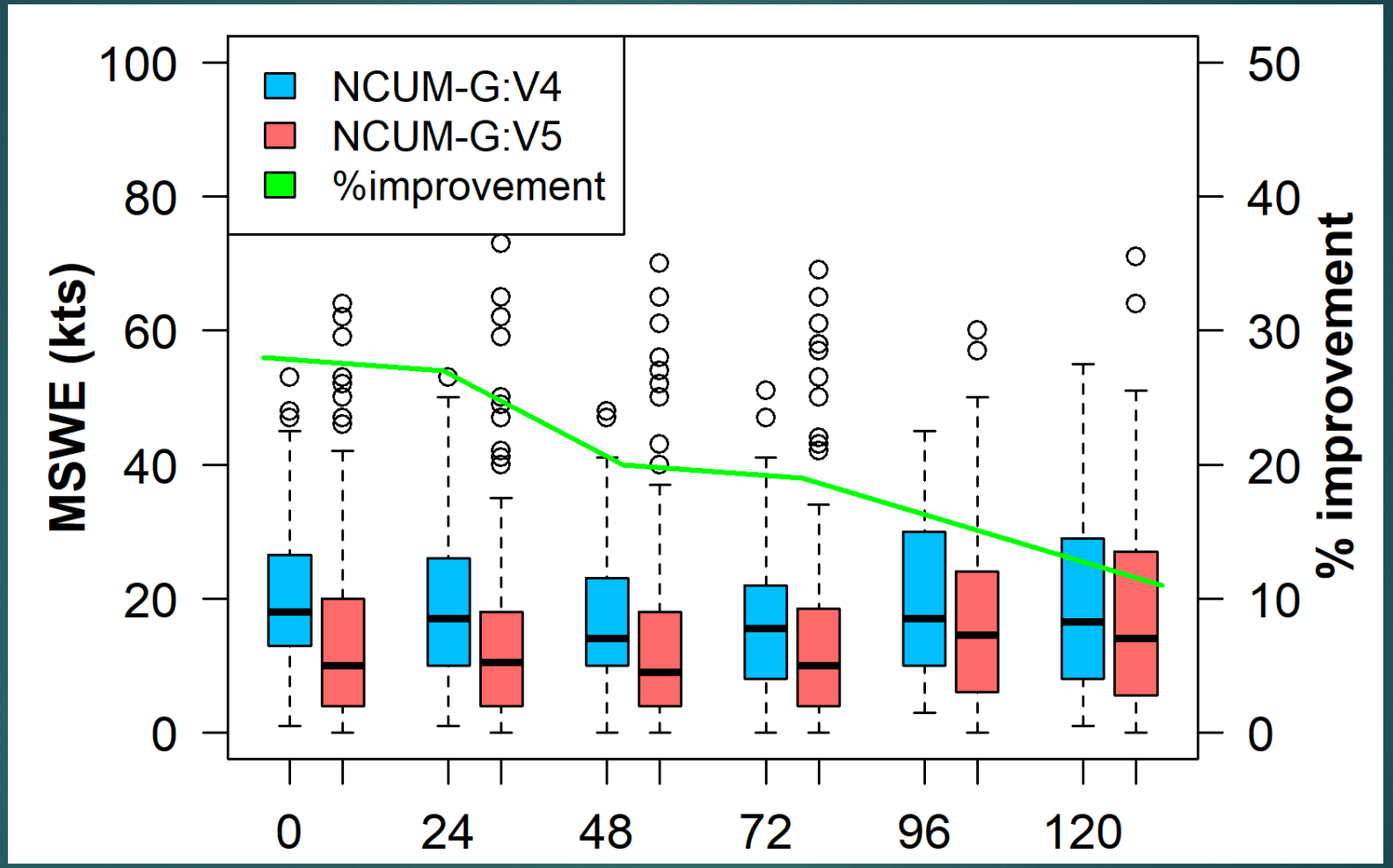
The improvement is majorly contributed by ATE

Improved Skill of NCMRWF Unified Model (NCUM-G) in forecasting tropical cyclones over NIO during 2015–2019 (Kumar et al 2022)



Comparison of mean landfall error from NCUM-G: V4 and NCUM-G: V5 (a) in landfall position (km) and percentage improvement (b) landfall time (h)

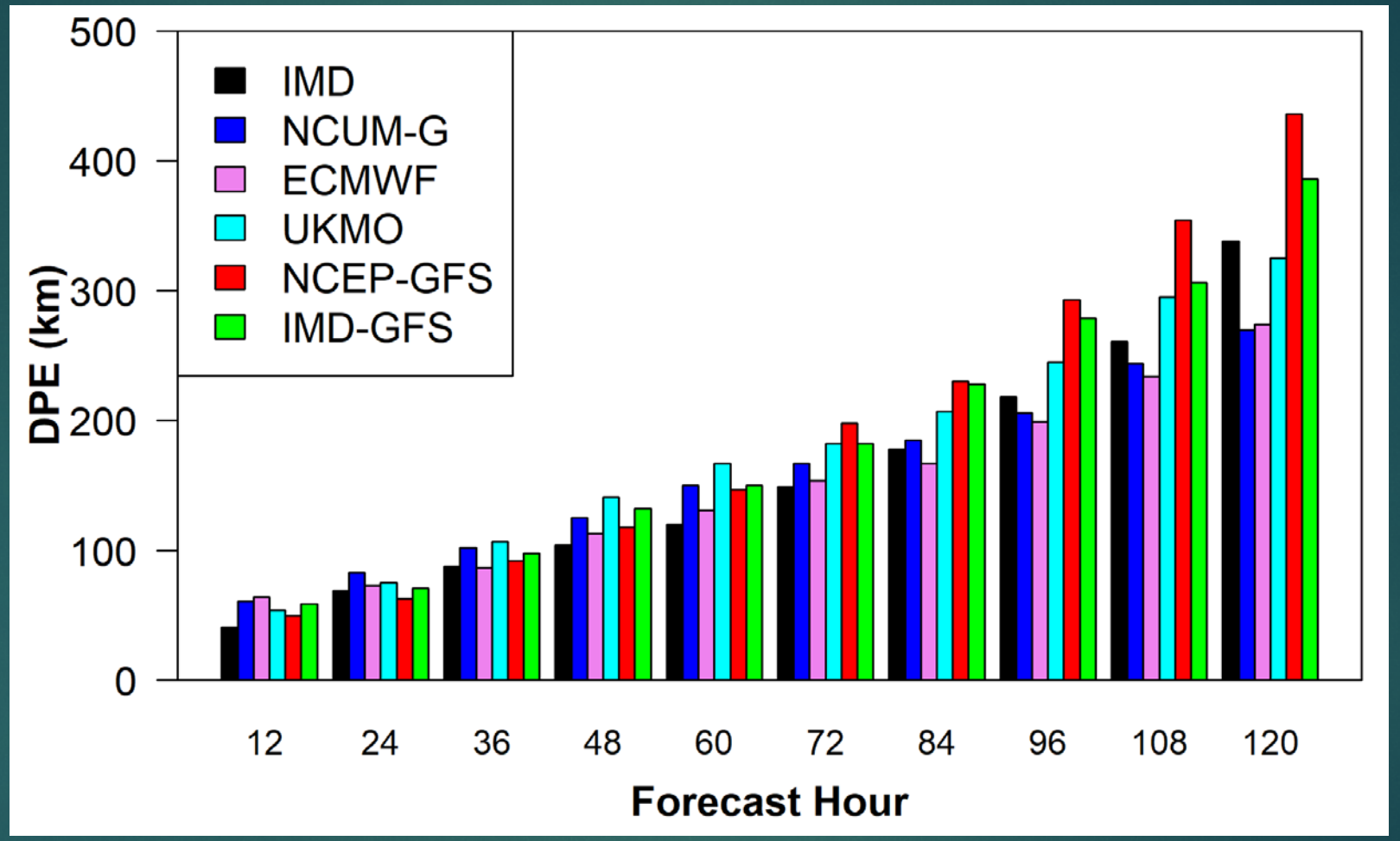
Improved Skill of NCMRWF Unified Model (NCUM-G) in forecasting tropical cyclones over NIO during 2015–2019 (Kumar et al 2022)



Comparison of errors in model (NCUM-G: V4 and V5) predicted mean intensity in terms of maximum sustained wind speed (MSWE)

Model show s the improvement at all lead times but more at shorter lead times

Improved Skill of NCMRWF Unified Model (NCUM-G) in forecasting tropical cyclones over NIO during 2015–2019 (Kumar et al 2022)



Comparison of DPE from different NWP models with IMD official forecast error in 2019
At higher lead times (96-h and above) NCUM-G and ECMWF show lower DPEs than IMD

Summary

- NCMRWF Modelling & DA Systems
  - Improved representation of initial position and intensity of TC
  - Case of ESCS ‘Foni’
    - Track Forecast Verification
    - Intensity Forecast Verification
    - Severe Weather Indices
  - Case of SuCS ‘Amphan’
    - Track Forecast Verification
    - Intensity Forecast Verification
  - Reduced initial position errors in NCUMG-V5
  - Significant reduction in the DPE at all lead times up to 120 h
  - Improved prediction of landfall time and position in NCUM-V5
  - Improved prediction of intensity in NCUM-V5