NWP BASED OBJECTIVE CYCLONE PREDICTION SYSTEM

Dr. S. D. Kotal

Scientist-F

NWP Division, New Delhi

भारत मौसम विज्ञान विभाग
INDIA METEOROLOGICAL DEPARTMENT

Operational NWP Models at IMD

- GFS T1534L64 (12 km)
- WRF (3DVAR -9 km, 3 km)
- HWRF (18 km, 6 km, 2 km)
- GEFS (T1534)
- GPP (Genesis Potential)
- SCIP (for cyclone intensity prediction)
- MME (for cyclone track)
- RI-Index (Rapid Intensification)
- Decay after landfall (Decay model)

NWP Model product from Other Centres

- ECMWF
- JMA
- NCEP GFS
- UKMO
- NCMRWF

Model configuration

HWRF:

- **v3.7 with GFS T1534 initial and boundary condition**
- **Triple Nested (18 Km, 6 Km, 2 Km) - Vertical level 61**
- **Run time 00, 06, 12, 18 UTC**

WRF:

- **V3.6 with RADAR data assimilation using 3DVAR**
- **Horizontal resolution 9km & 3km**
- **Vertical level 45**

GFS:

- **T1534L64 (12 Km)**
- **Run time 00, 12 UTC**

GEFS

- **Run time 00 UTC**

Dynamical models are providing very useful guidance to operational forecasters:

- Limitation of models.
- Variation of forecasts among NWP models.
- Requirements are also different for different forecast services.
- Need to generate more skillful, consensus, and requirement based products.

NWP BASED OBJECTIVE CYCLONE FORECAST SYSTEM

Kotal, S.D., Bhattacharya S.K. and Roy Bhowmik S.K. 2014. Development of NWP based objective Cyclone Prediction System (CPS) for North Indian Ocean Tropical Cyclones – Evaluation of performance. Tropical Cyclone Research and Review, 3(3), 162-177

STEP-I : CYCLOGENESIS

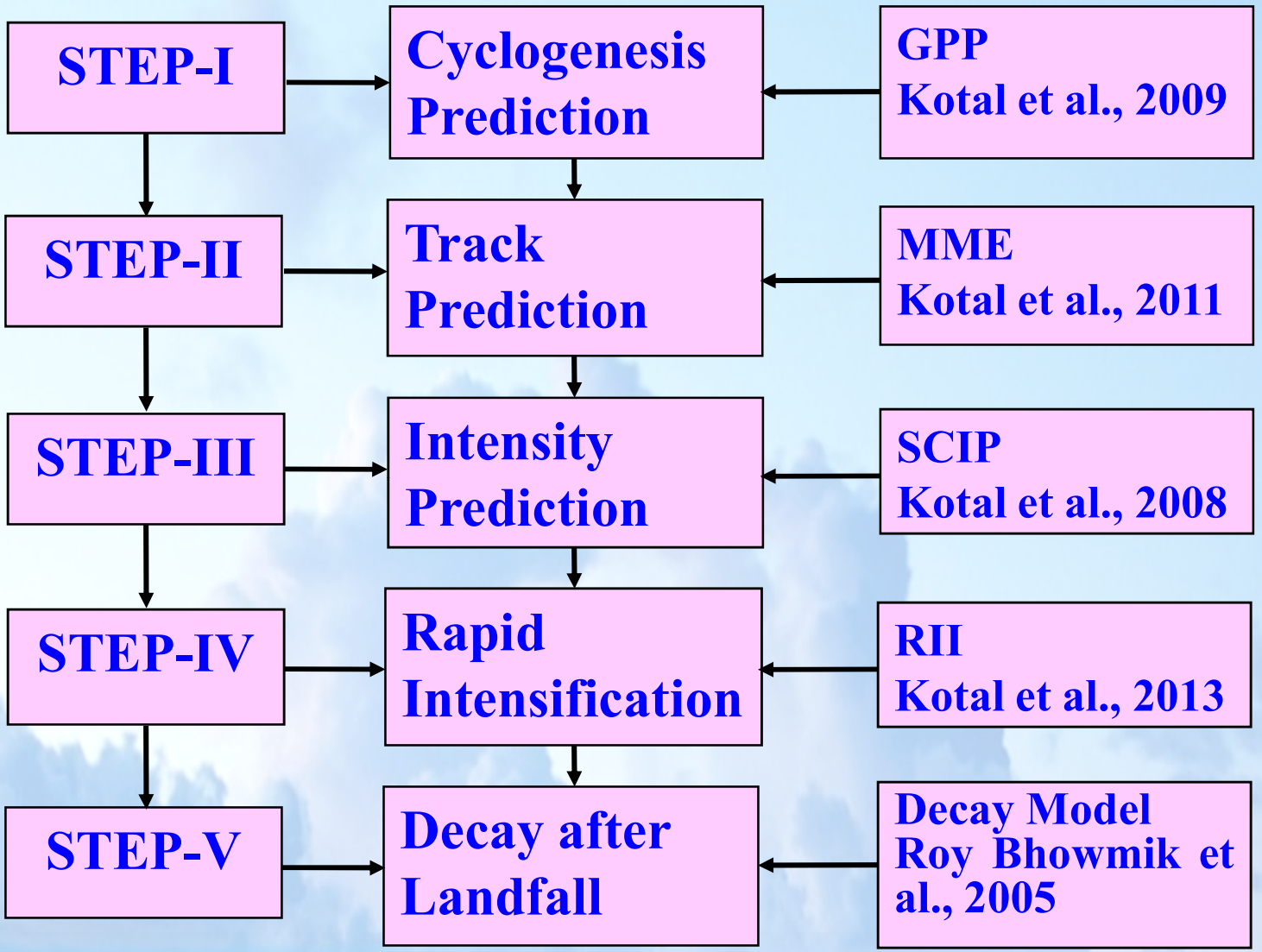
STEP-II : TRACK

STEP-III : INTENSITY

STEP-IV : RAPID INTENSIFICATION

STEP-V : DECAY AFTER LANDFALL

Cyclone Prediction System



GENESIS POTENTIAL PARAMETER (GPP)

STEP- I : Tropical Cyclogenesis

[Kotal S.D., Kundu P.K. and Roy Bhowmik S.K., 2009. Analysis of Cyclogenesis parameter for developing and non-developing low pressure systems over the Indian Sea. Natural hazards (Springer) 50:389-402.
Kotal, S.D. and Bhattacharya S.K. 2013. Tropical Cyclone Genesis Potential Parameter (GPP) and its application over the North Indian Sea. Mausam, 64(1):149-170]

Objective:

To understand the potential zone of cyclogenesis and potential for intensification of a system at early stages of development

Formulation of the Genesis potential parameter (GPP):

Two Dynamic variables :

(i) Low level relative vorticity (ζ_{850})

(ii)Vertical wind shear (S)

Two Thermo-dynamical variables:

(i) Middle troposphere relative humidity (M)

(ii) Middle-trpospheric instability (I)

The GPP is defined as:

(Natural Hazards, 2009, 50,389-402)

$$GPP = \frac{\xi_{850} x M x I}{S} \qquad \text{if } \zeta_{850} > 0,\ M > 0 \text{ and } I > 0$$

$$= 0 \qquad \text{if } \zeta_{850} \leq 0,\ M \leq 0 \text{ and } I \leq 0$$

Where , ζ_{850} = Low level relative vorticity (at 850 hPa) in 10^{-5} s^{-1}

S = Vertical wind shear between 200 and 850 hPa (ms^{-1})

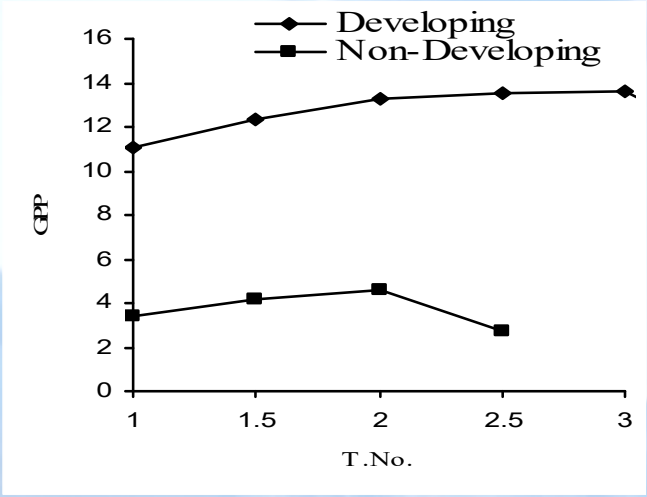
$$M = \frac{[RH - 40]}{30}$$ = Middle troposphere relative humidity

Where RH is the mean relative humidity between 700 and 500 hPa

I = ($T_{850} - T_{500}$) °C = Middle-trpospheric instability (Temperature difference between 850 hPa and 500 hPa)

Genesis potential parameter for developing versus non- developing systems:

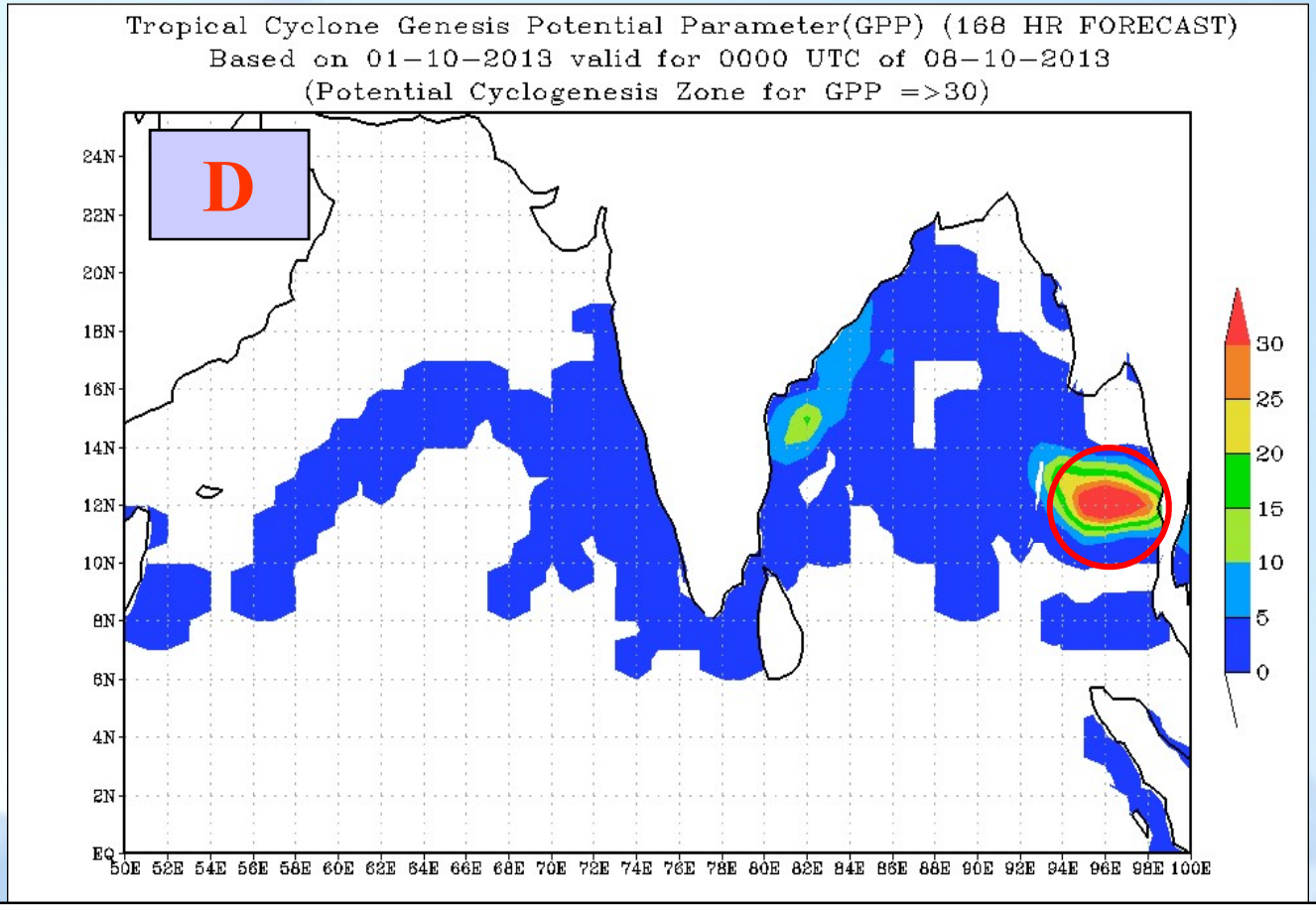
GPP($x10^{-5}$) →					
T.No. →	1.0	1.5	2.0	2.5	3.0
Developing	11.1	12.3	13.3	13.5	13.6
Non-Developing	3.4	4.2	4.6	2.7	-



Threshold value of GPP => 8.0

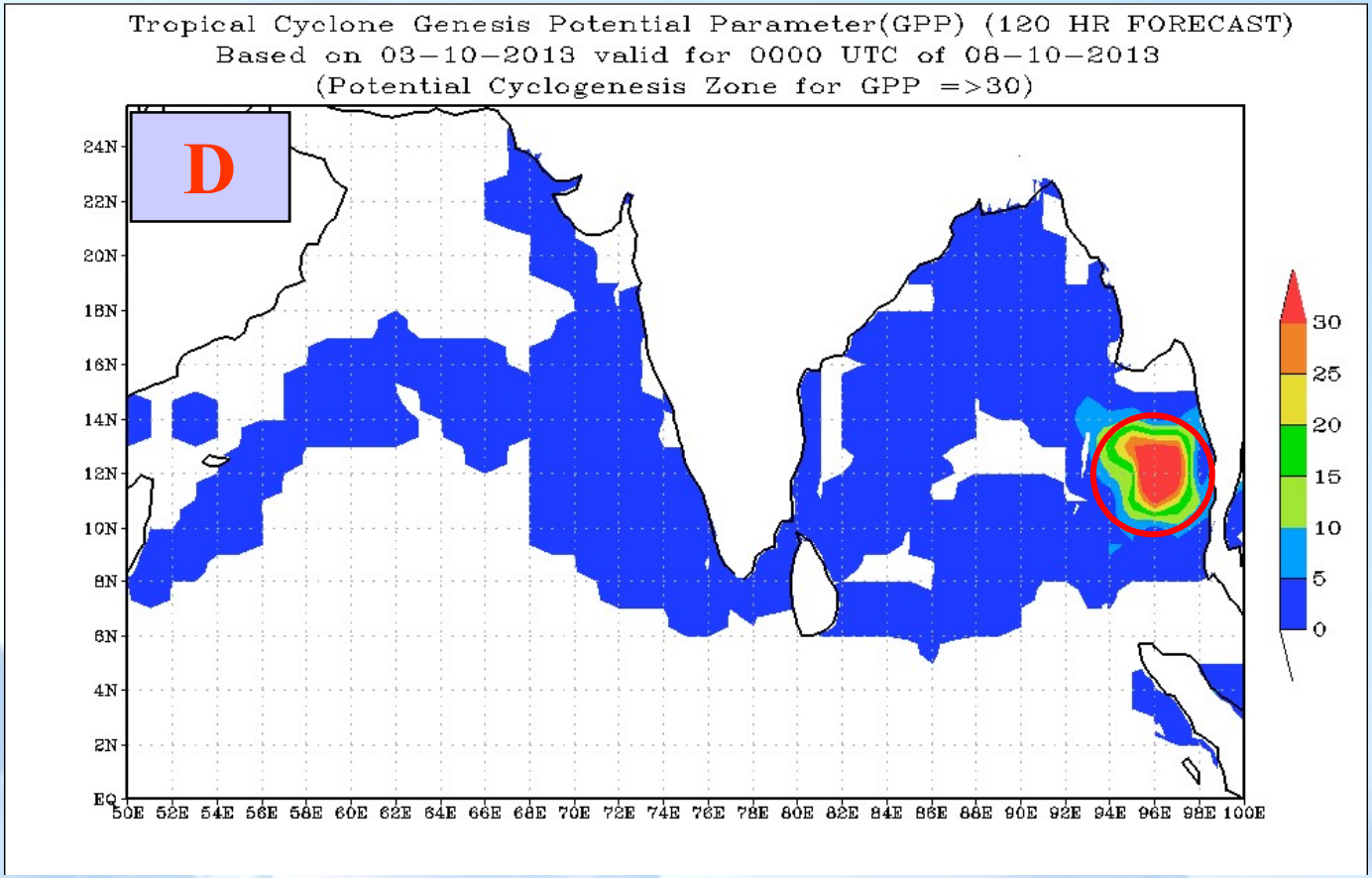
PHAILIN
(Bay of Bengal October 2013)

Grid Point Analysis of Genesis Potential Parameter (GPP)



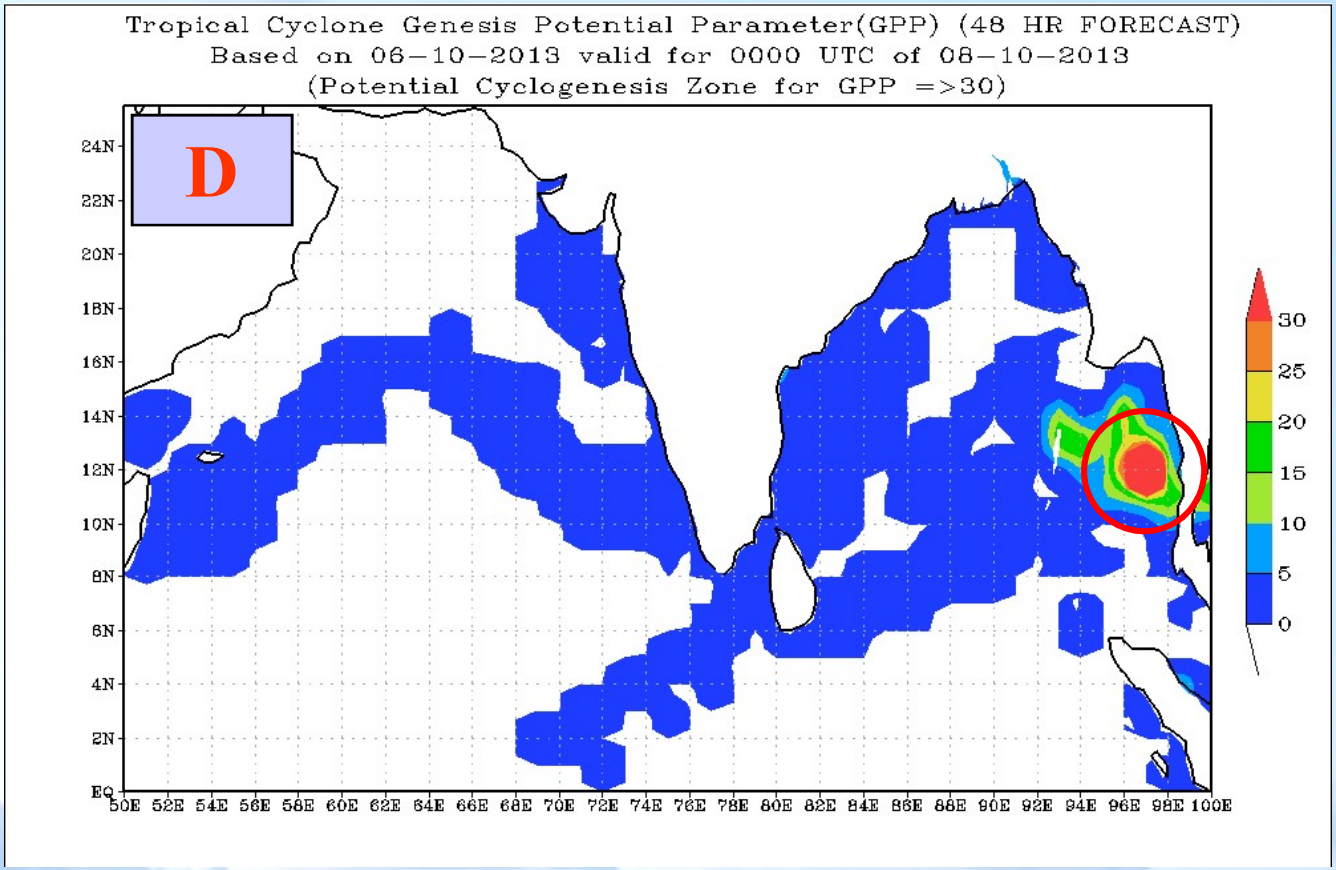
On 1 Oct. 2013: 168 hour forecast (7 days in advance) of GPP valid for 00 UTC 08 October 2013 correctly indicated the location of potential cyclogenesis zone, where Depression formed on that day.

Grid Point Analysis of Genesis Potential Parameter (GPP)



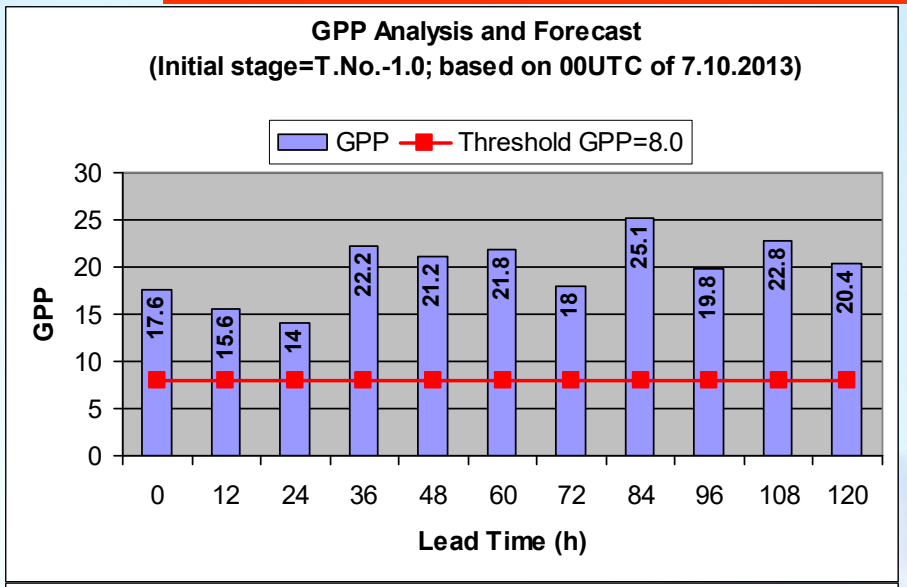
On 3 Oct. 2013: 120 hour forecast (5 days in advance) of GPP valid for 00 UTC 08 October 2013 correctly indicated the location of potential cyclogenesis zone, where Depression formed on that day.

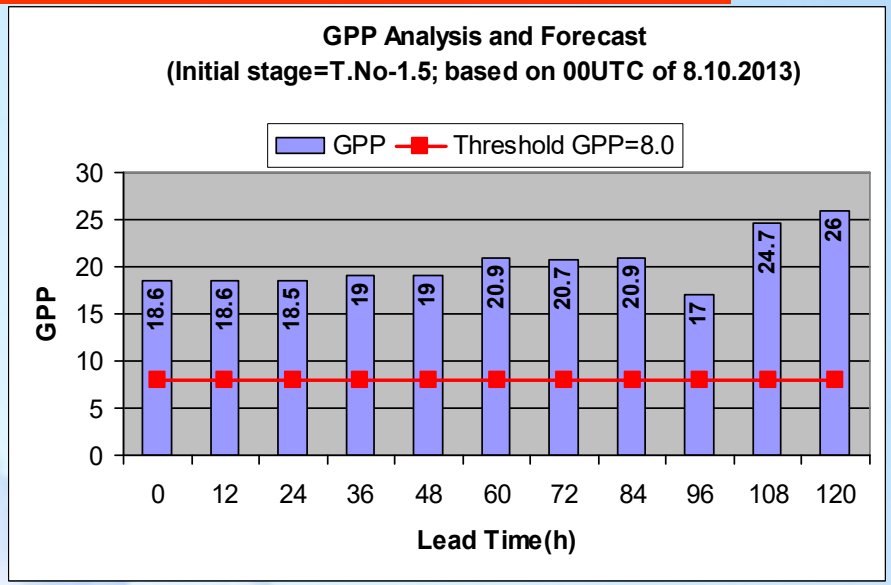
Grid Point Analysis of Genesis Potential Parameter (GPP)

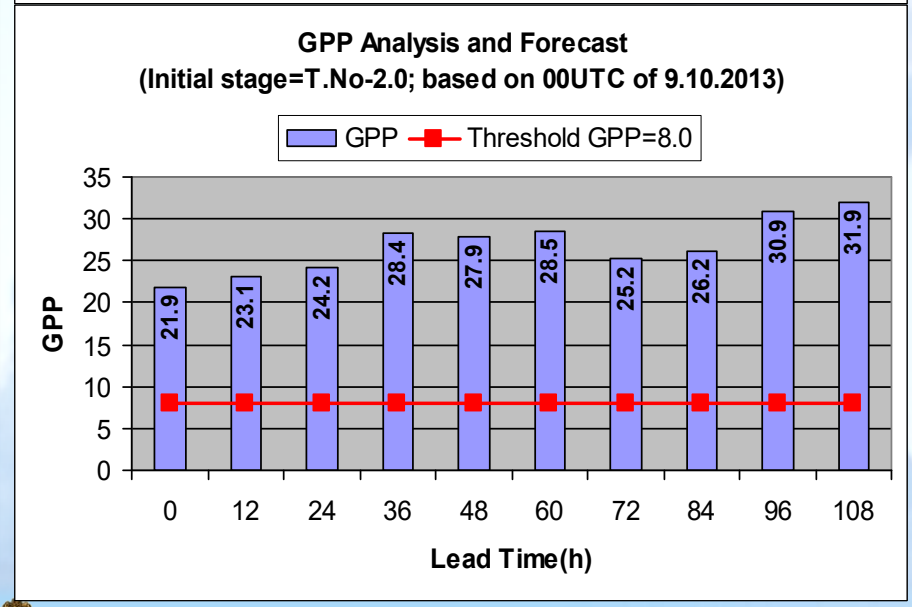


On 6 Oct. 2013: 48 hour forecast (2 days in advance) of GPP valid for 00 UTC 08 October 2013 correctly indicated the location of potential cyclogenesis zone, where Depression formed on that day.

Area average Genesis potential parameter (GPP)





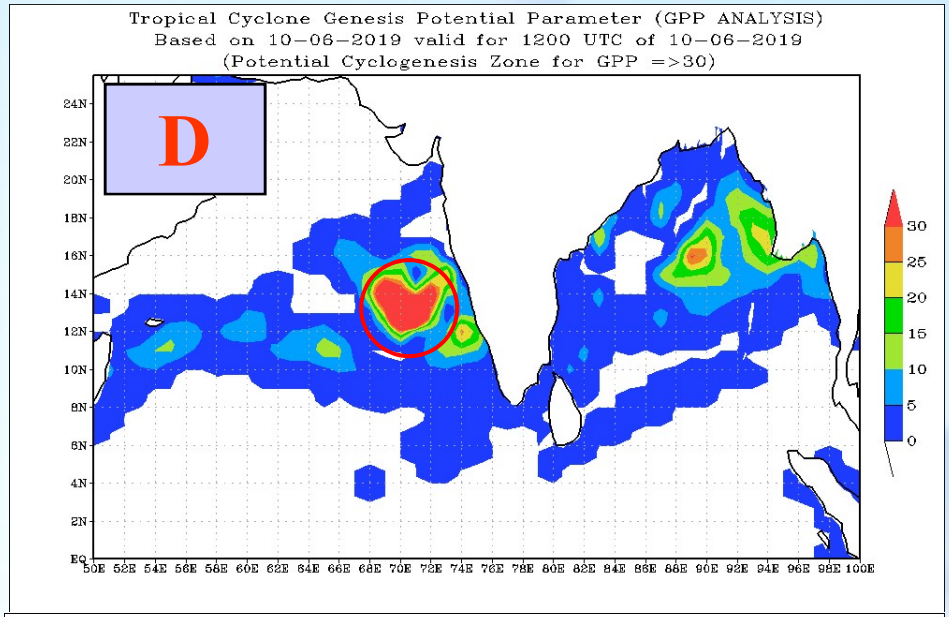


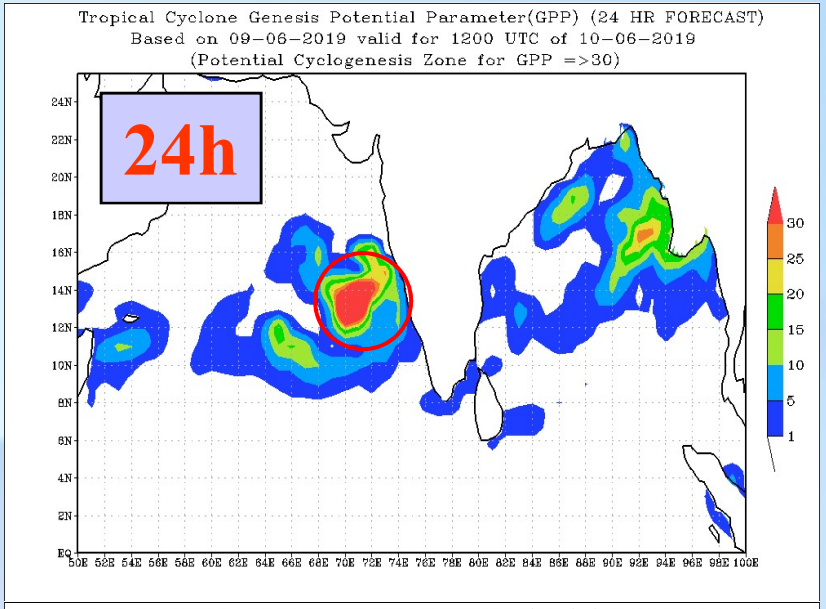
Inference: Analysis and forecasts of GPP show that GPP ≥ 8.0 (threshold value for intensification into cyclone) indicated its potentential to intensify into a cyclone at early stages of development (T.No. 1.0, 1.5, 2.0).

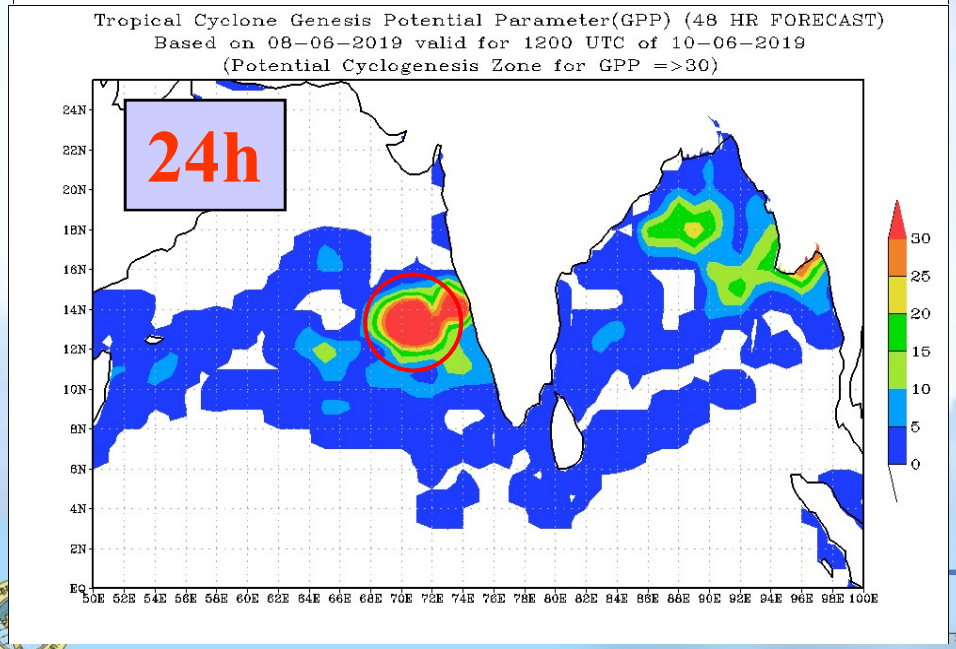
Very Severe Cyclonic Storm 'VAYU'

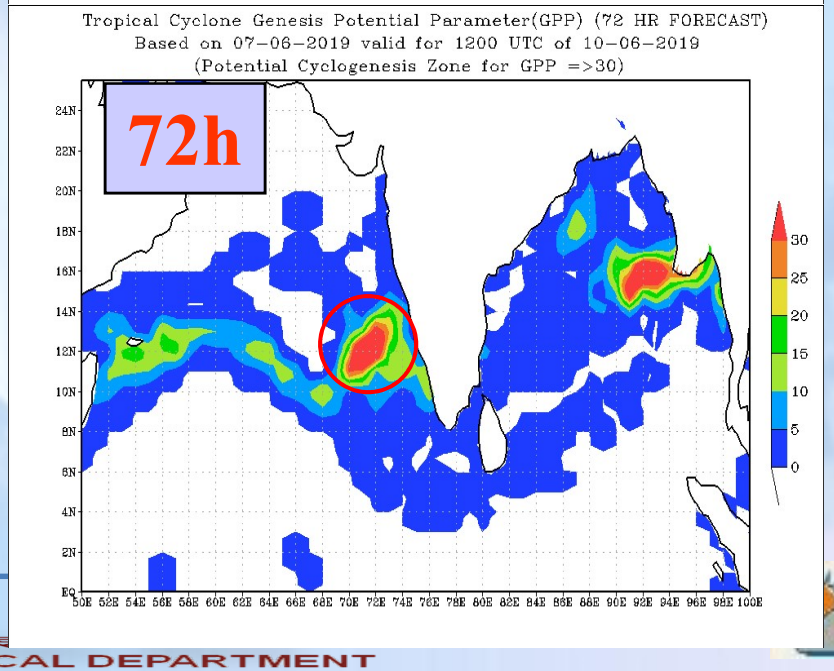
Arabian Sea during (10-17) June 2019

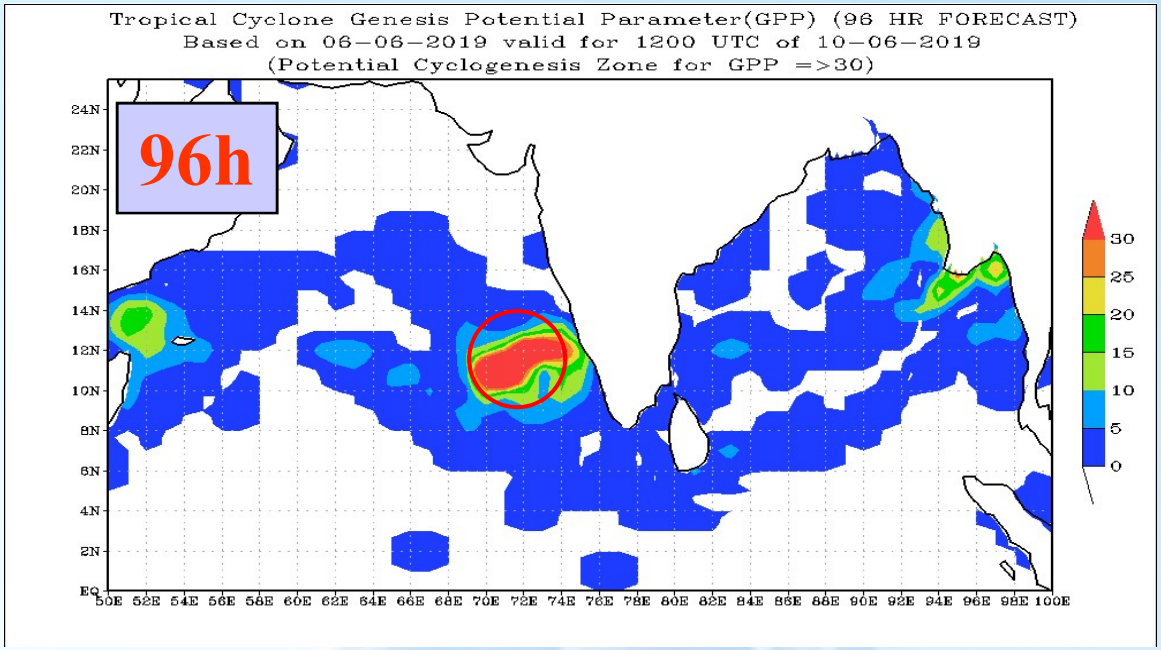
Genesis potential parameter (VAYU)

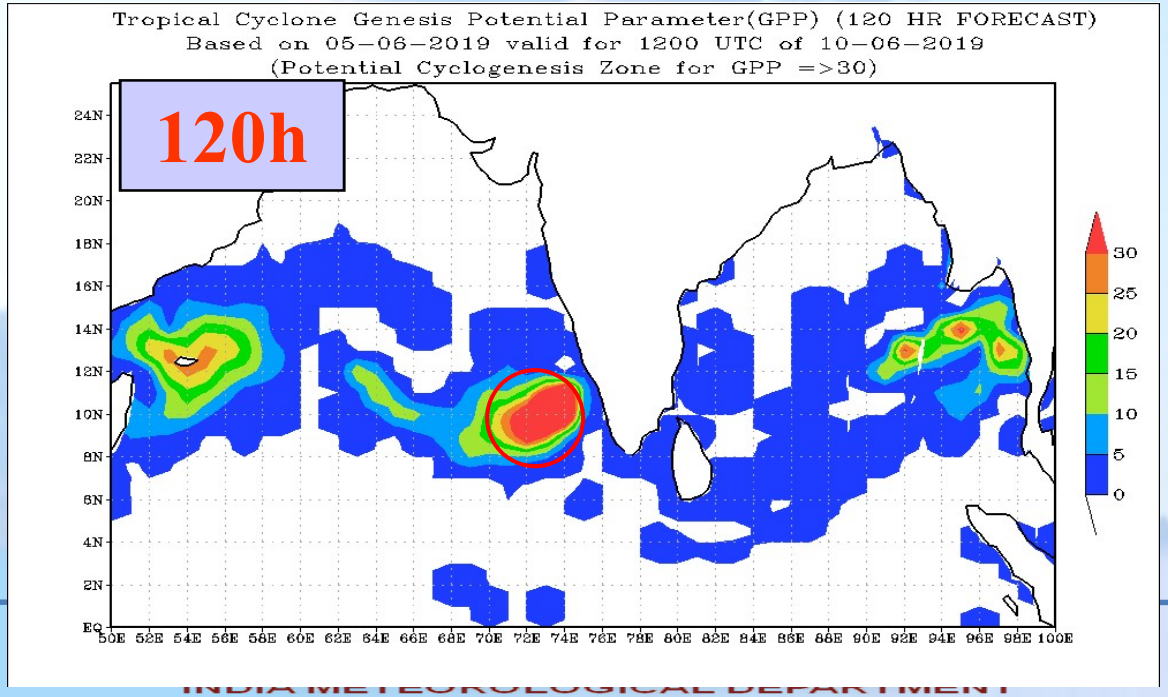




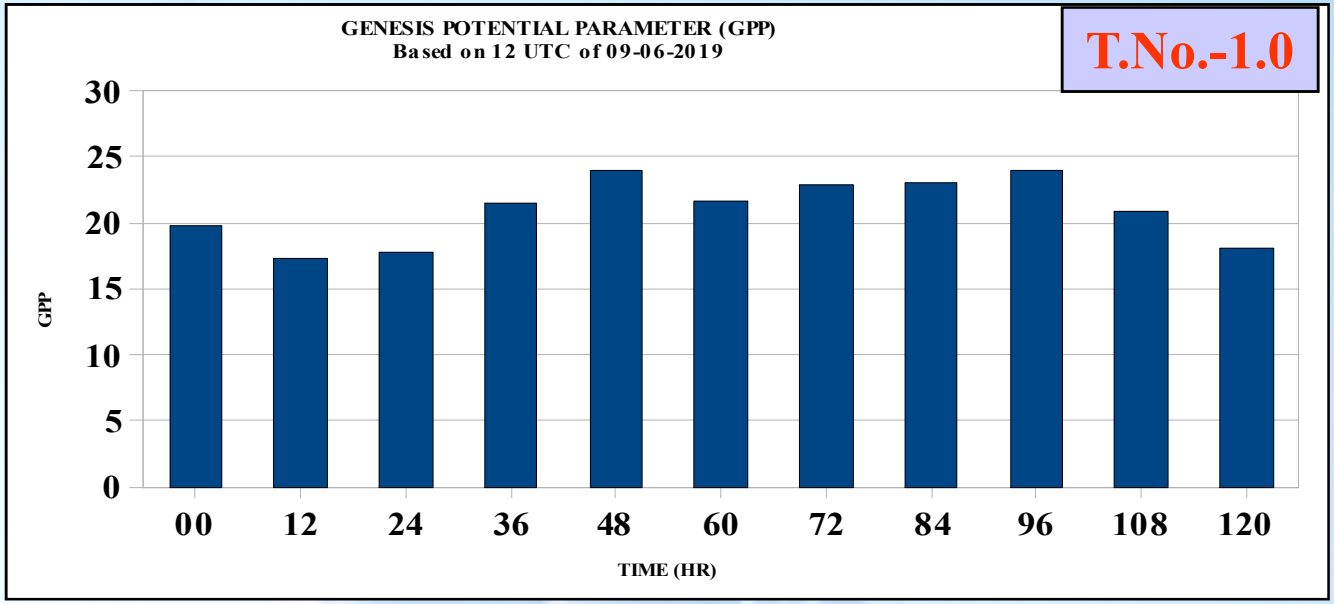


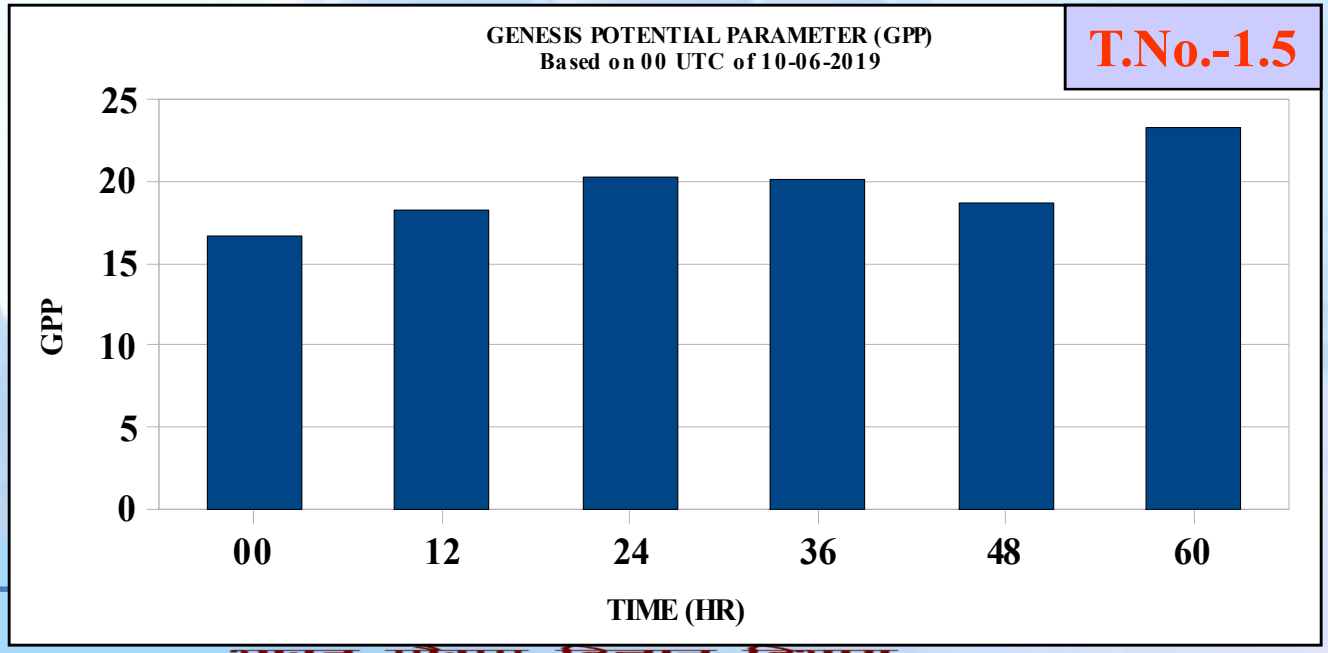


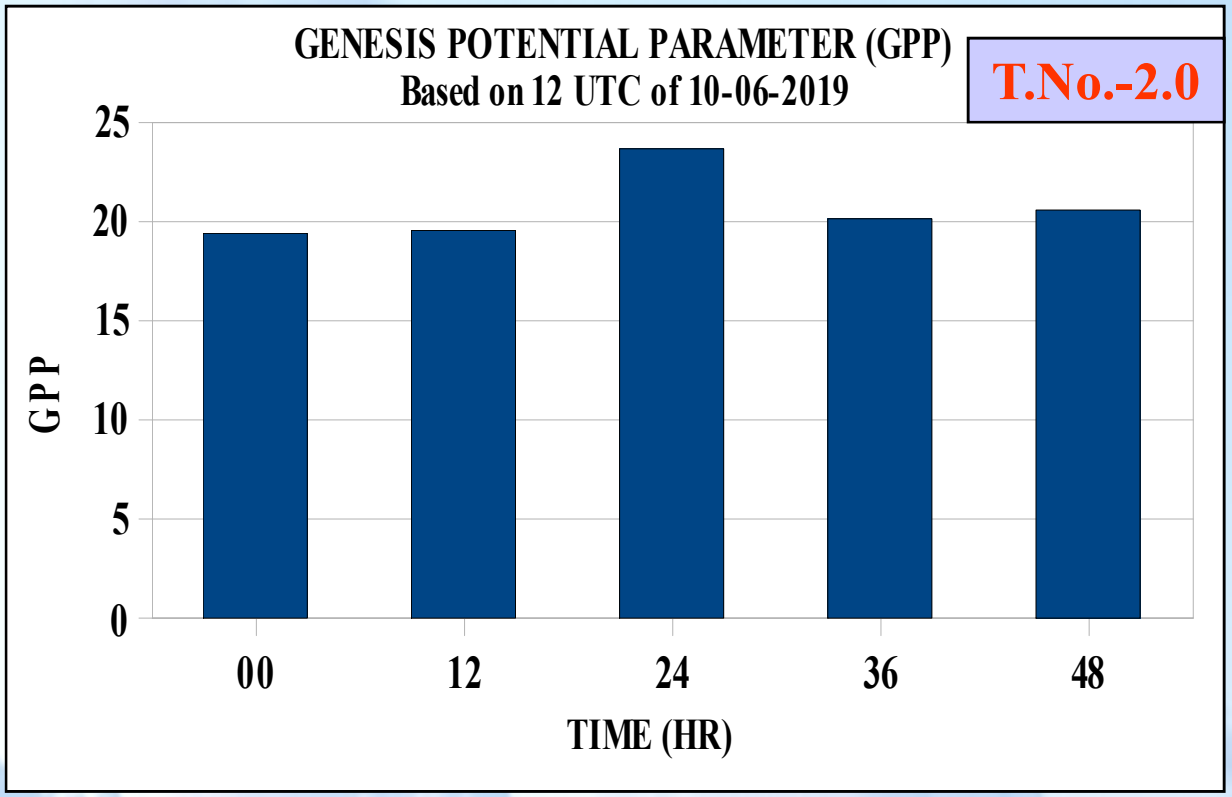

Tropical Cyclone Genesis Potential Parameter(GPP) (96 HR FORECAST)
Based on 06-06-2019 valid for 1200 UTC of 10-06-2019
(Potential Cyclogenesis Zone for GPP =>30)
96h
24N
22N
20N
18N
16N
14N
12N
10N
8N
6N
4N
2N
EQ
50E 52E 54E 56E 58E 60E 62E 64E 66E 68E 70E 72E 74E 76E 78E 80E 82E 84E 86E 88E 90E 92E 94E 96E 98E 100E
30
25
20
15
10
5
0


Tropical Cyclone Genesis Potential Parameter(GPP) (120 HR FORECAST)
Based on 05-06-2019 valid for 1200 UTC of 10-06-2019
(Potential Cyclogenesis Zone for GPP =>30)
120h
24N
22N
20N
18N
16N
14N
12N
10N
8N
6N
4N
2N
EQ
50E 52E 54E 56E 58E 60E 62E 64E 66E 68E 70E 72E 74E 76E 78E 80E 82E 84E 86E 88E 90E 92E 94E 96E 98E 100E
30
25
20
15
10
5
0

Area average Genesis potential parameter (GPP)

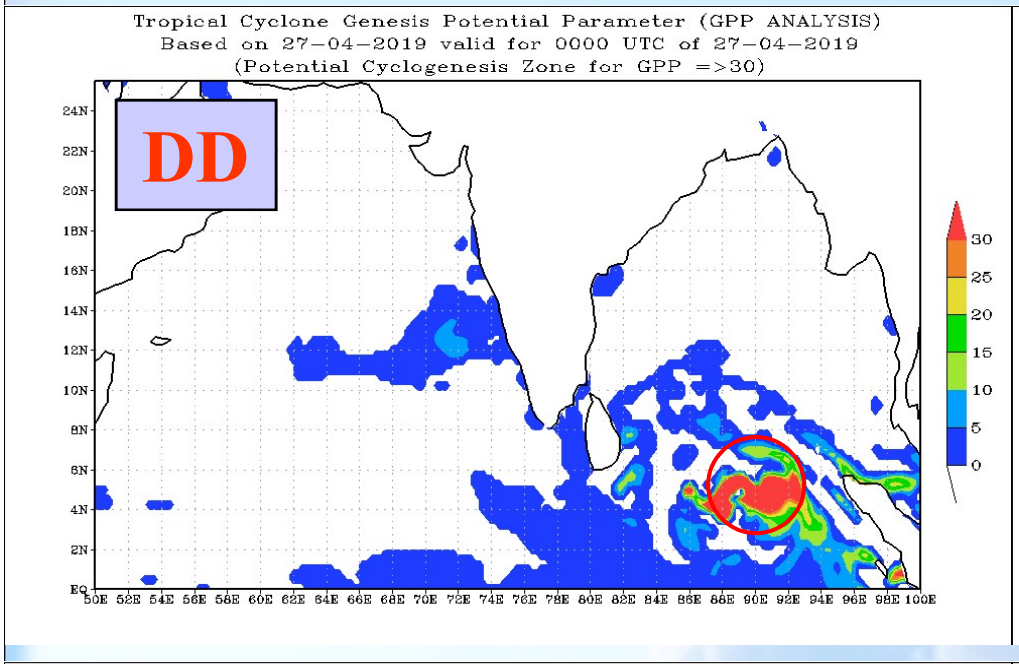


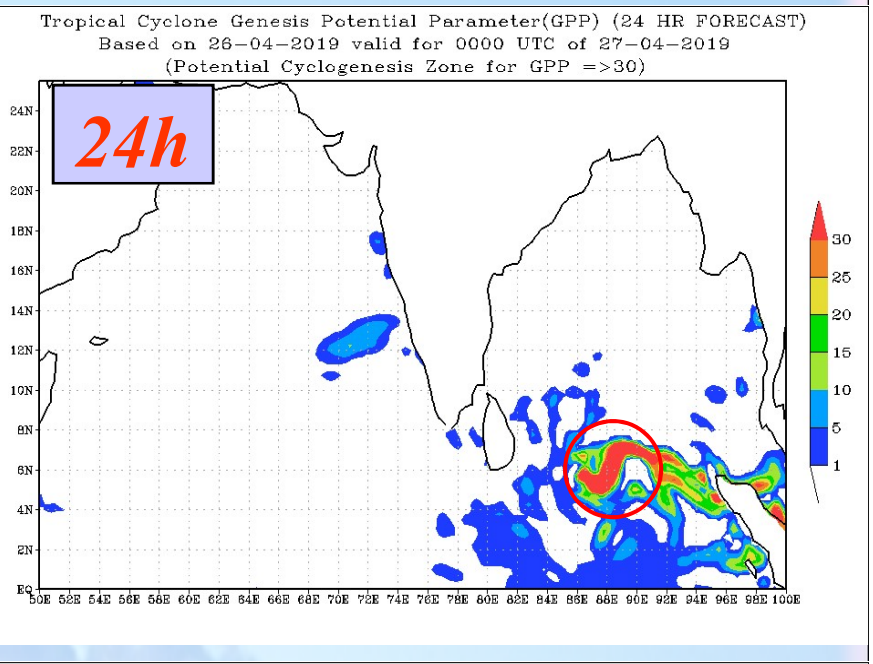


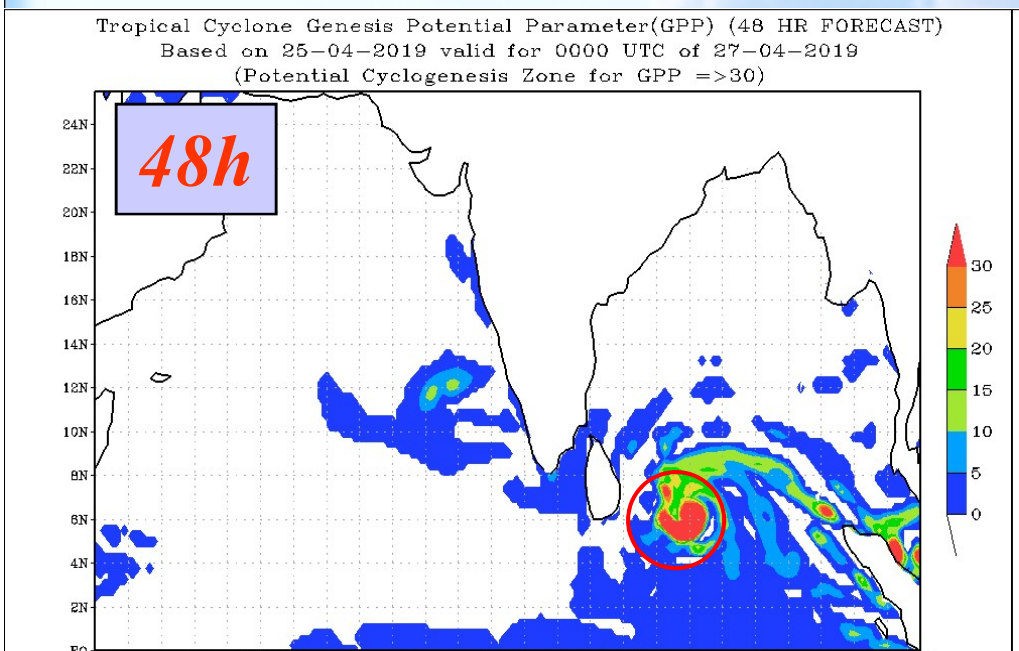

GENESIS POTENTIAL PARAMETER (GPP)
Based on 12 UTC of 10-06-2019
T.No.-2.0
GPP
25
20
15
10
5
0
00
12
24
36
48
TIME (HR)

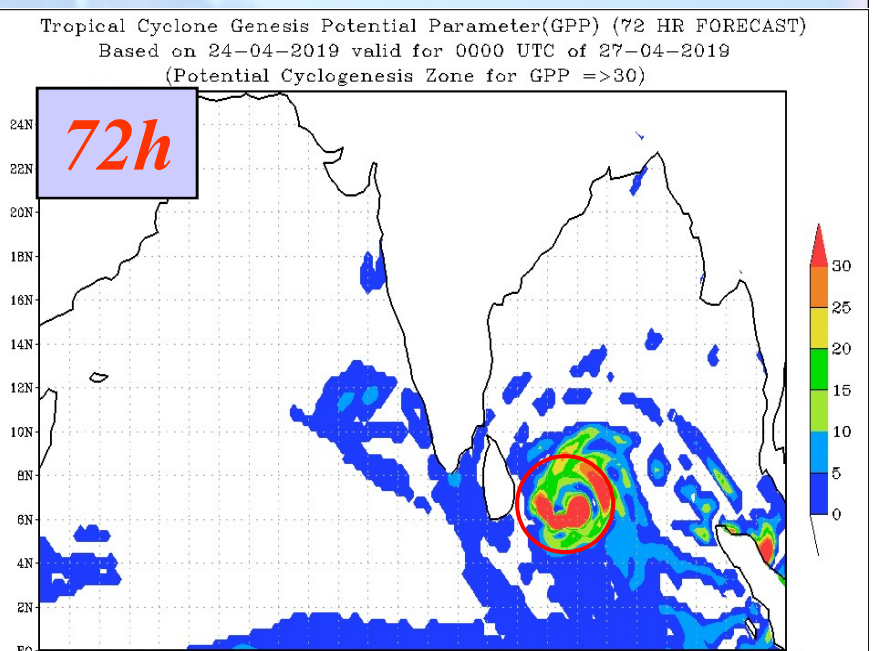
ESCS FANI: 26April-04 May 2019

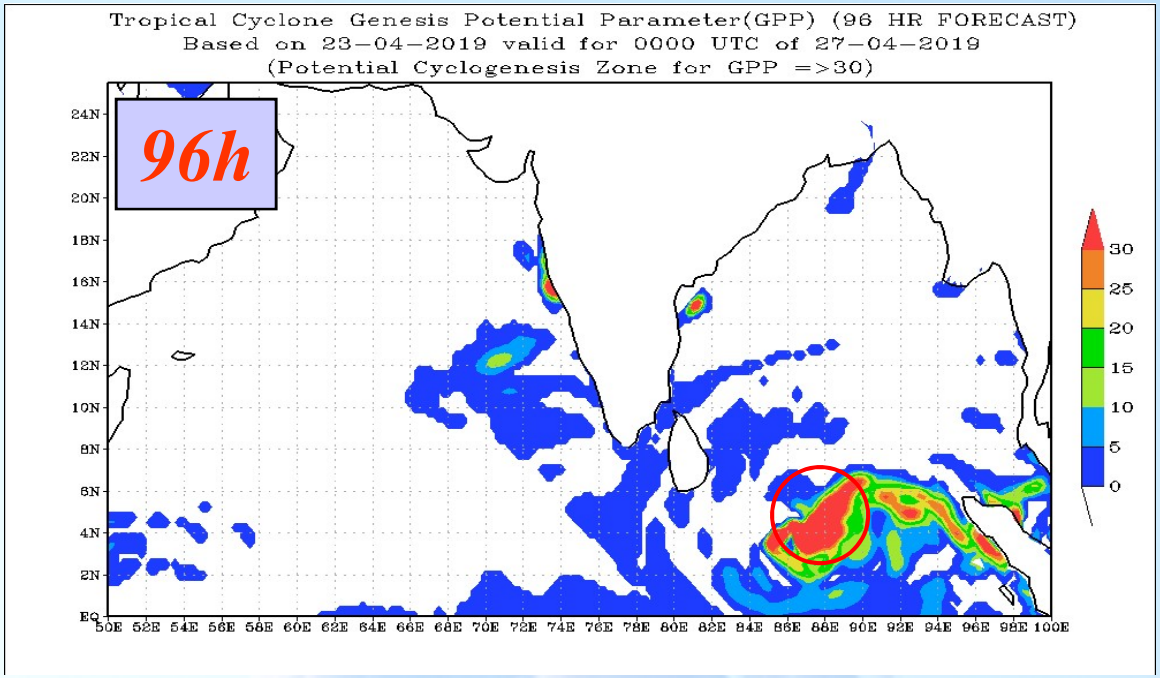
Genesis forecasts by GPP FANI

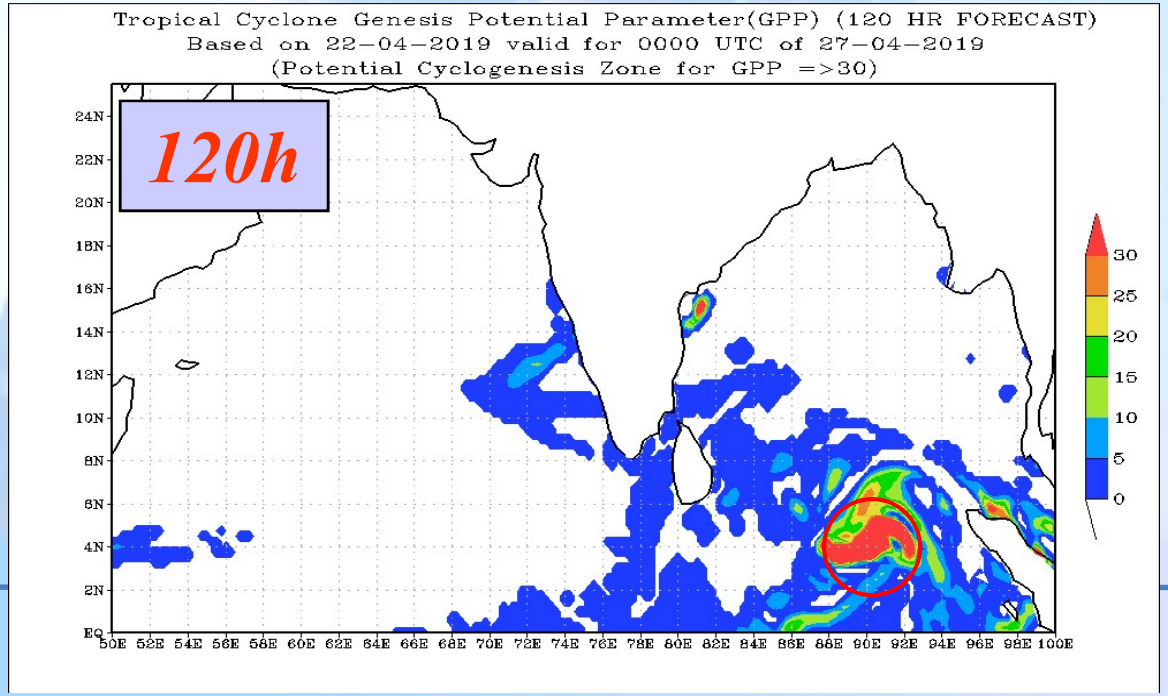




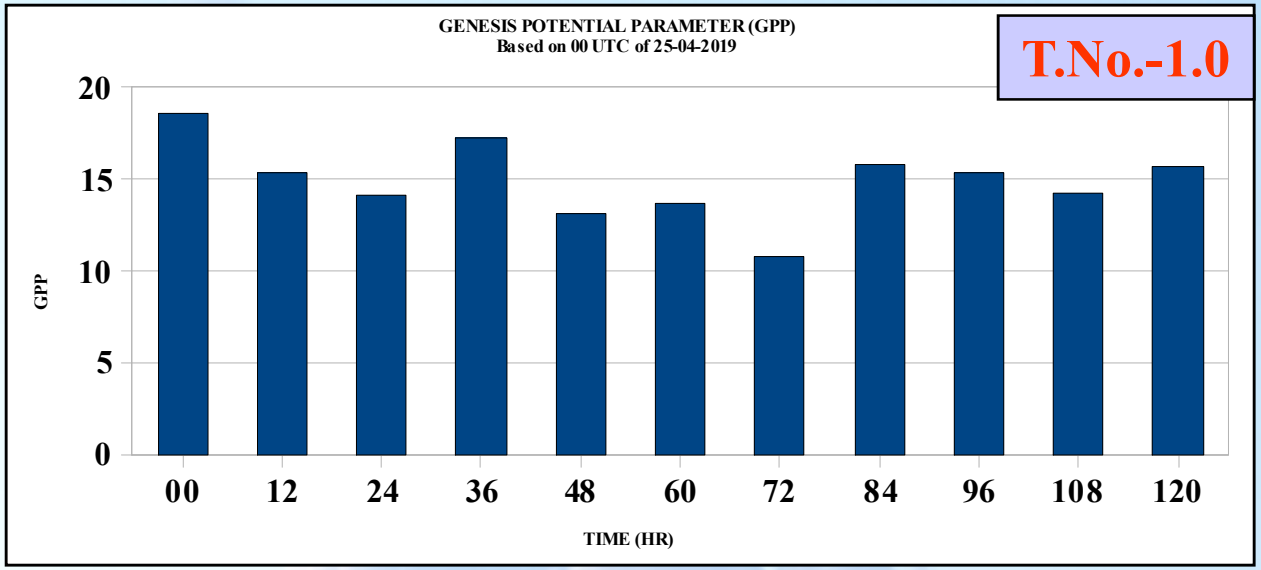




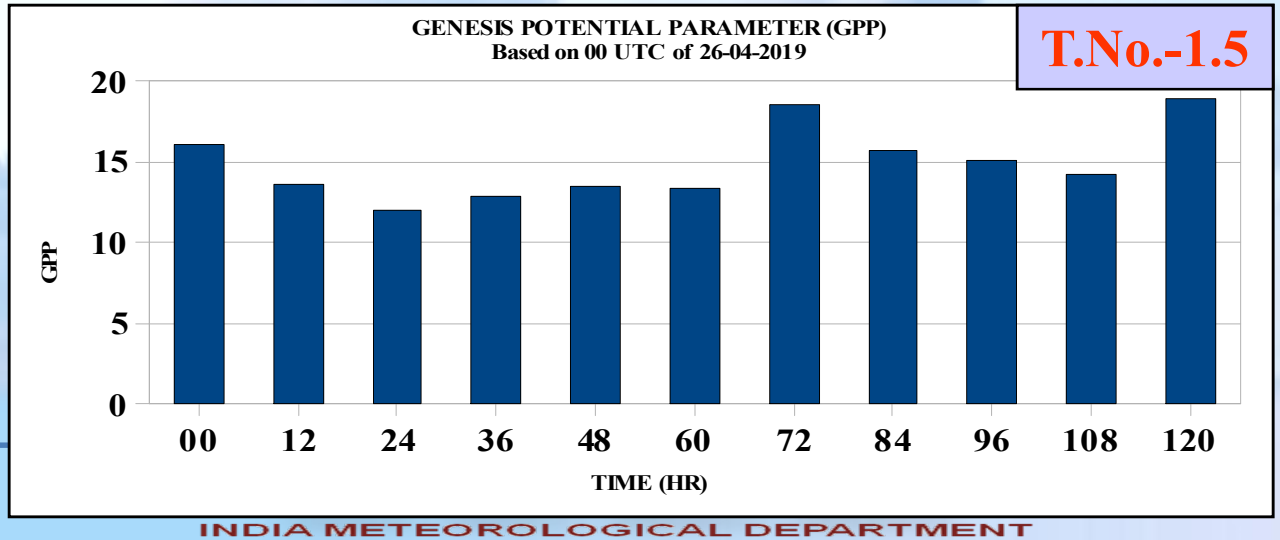

Tropical Cyclone Genesis Potential Parameter(GPP) (96 HR FORECAST)
Based on 23-04-2019 valid for 0000 UTC of 27-04-2019
(Potential Cyclogenesis Zone for GPP =>30)
96h
24N
22N
20N
18N
16N
14N
12N
10N
8N
6N
4N
2N
EQ
50E 52E 54E 56E 58E 60E 62E 64E 66E 68E 70E 72E 74E 76E 78E 80E 82E 84E 86E 88E 90E 92E 94E 96E 98E 100E
30
25
20
15
10
5
0


Tropical Cyclone Genesis Potential Parameter(GPP) (120 HR FORECAST)
Based on 22-04-2019 valid for 0000 UTC of 27-04-2019
(Potential Cyclogenesis Zone for GPP =>30)
120h
24N
22N
20N
18N
16N
14N
12N
10N
8N
6N
4N
2N
EQ
50E 52E 54E 56E 58E 60E 62E 64E 66E 68E 70E 72E 74E 76E 78E 80E 82E 84E 86E 88E 90E 92E 94E 96E 98E 100E
30
25
20
15
10
5
0

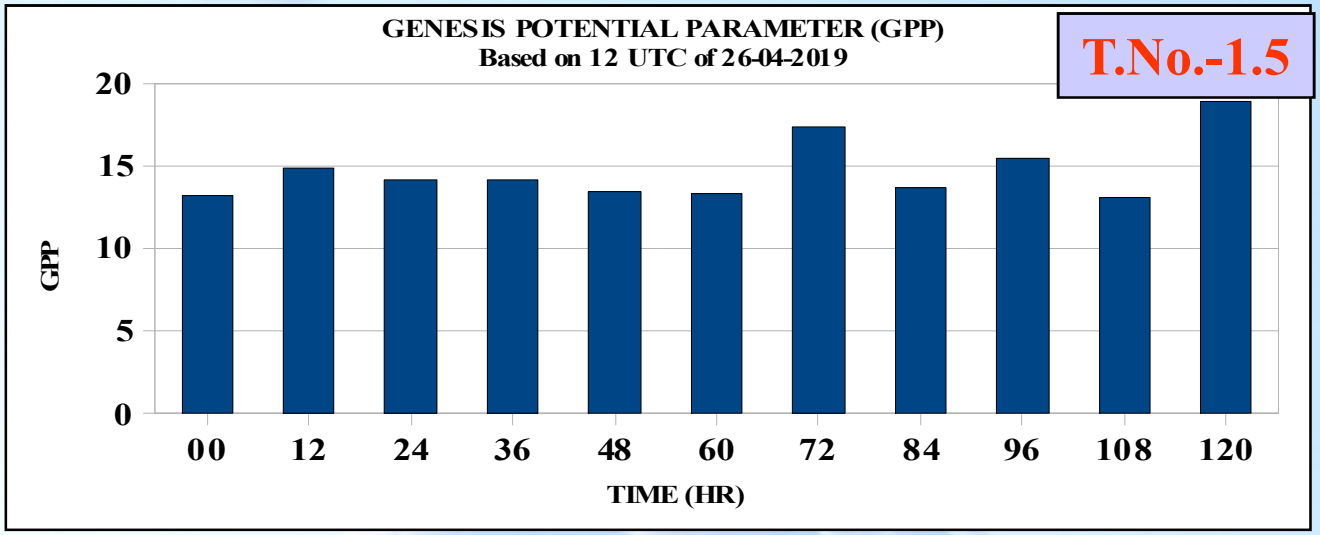
Mean GPP forecasts forecasts based on 00 UTC of 25.04.2019 (FANI)



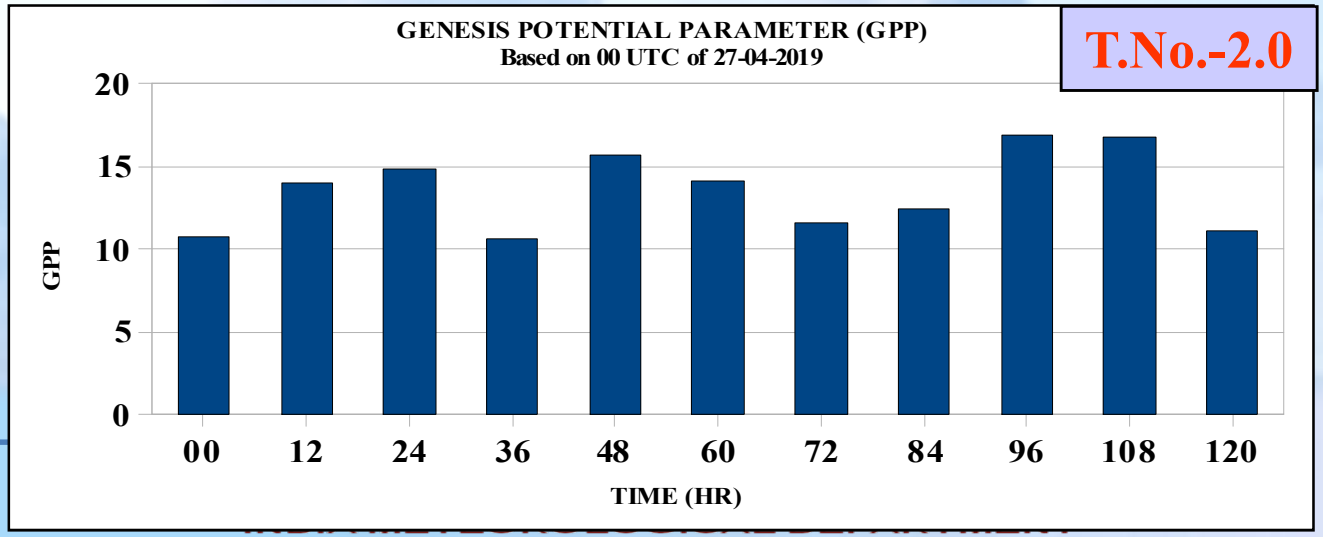
Mean GPP forecasts forecasts based on 00 UTC of 26.04.2019 (FANI)



Mean GPP forecasts forecasts based on 1200 UTC of 26.04.2019 (FANI)

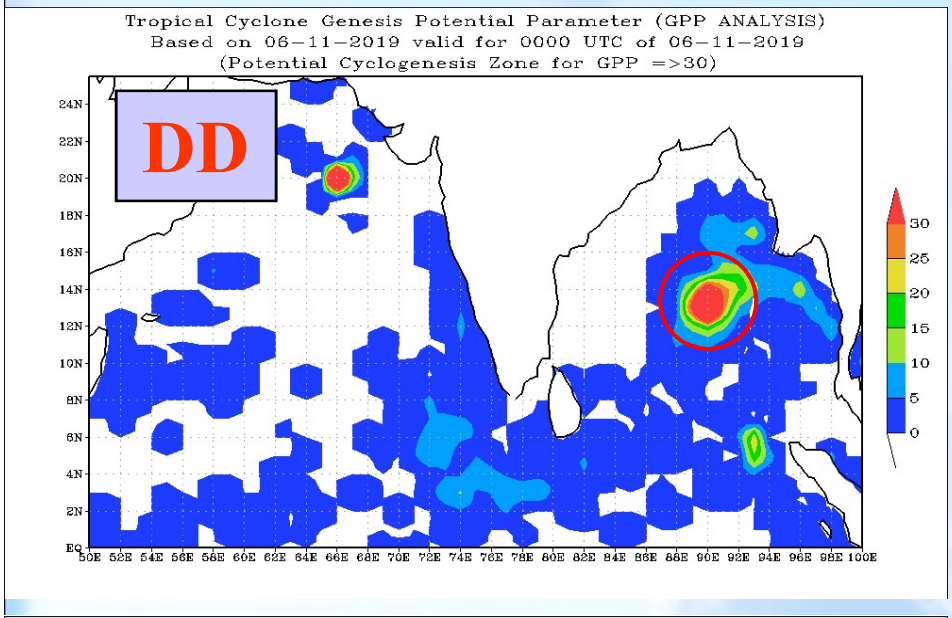


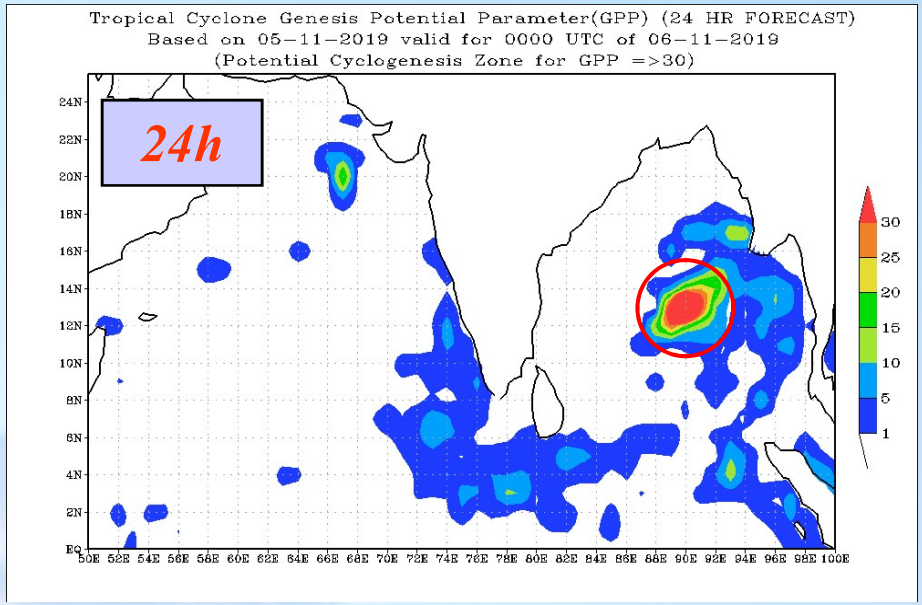
Mean GPP forecasts forecasts based on 0000 UTC of 27.04.2019 (FANI)

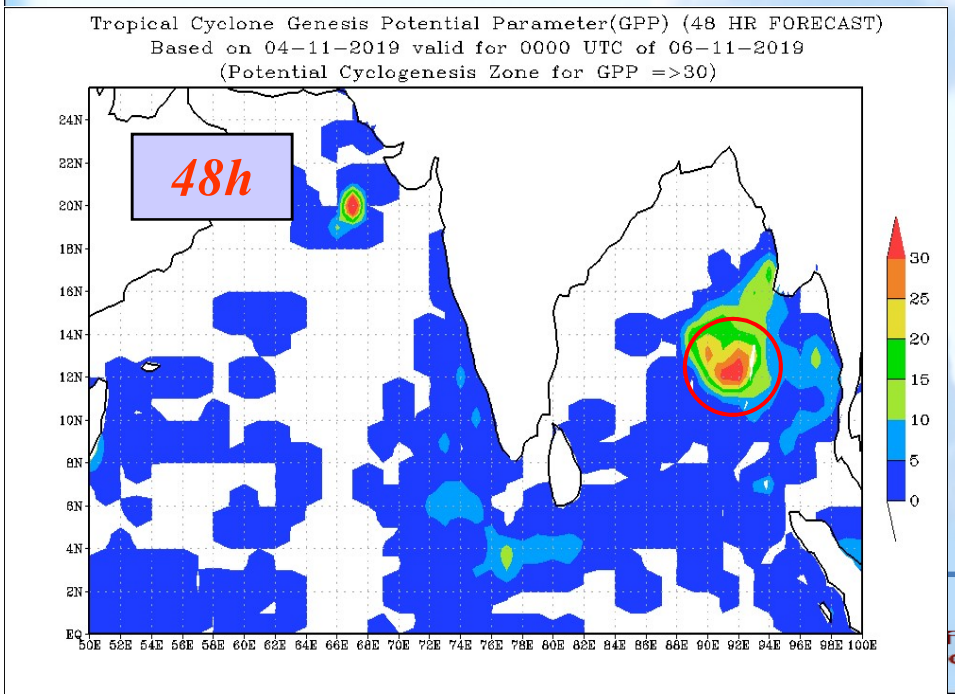


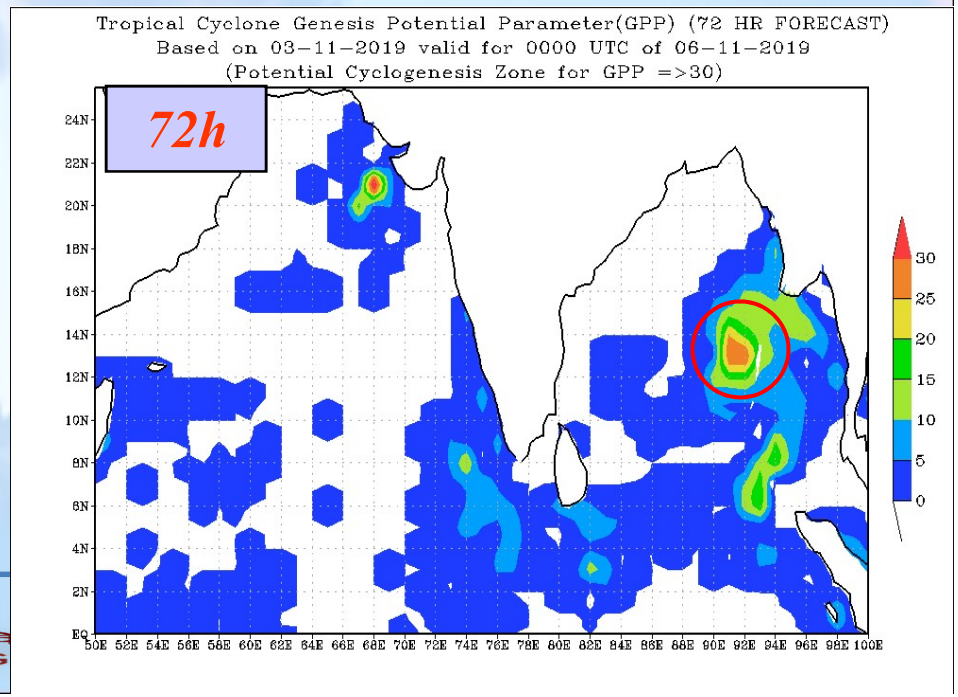
Cyclonic Storm 'BULBUL' over the Bay of Bengal during 5-11 November 2019

Genesis forecasts by GPP (BULBUL)

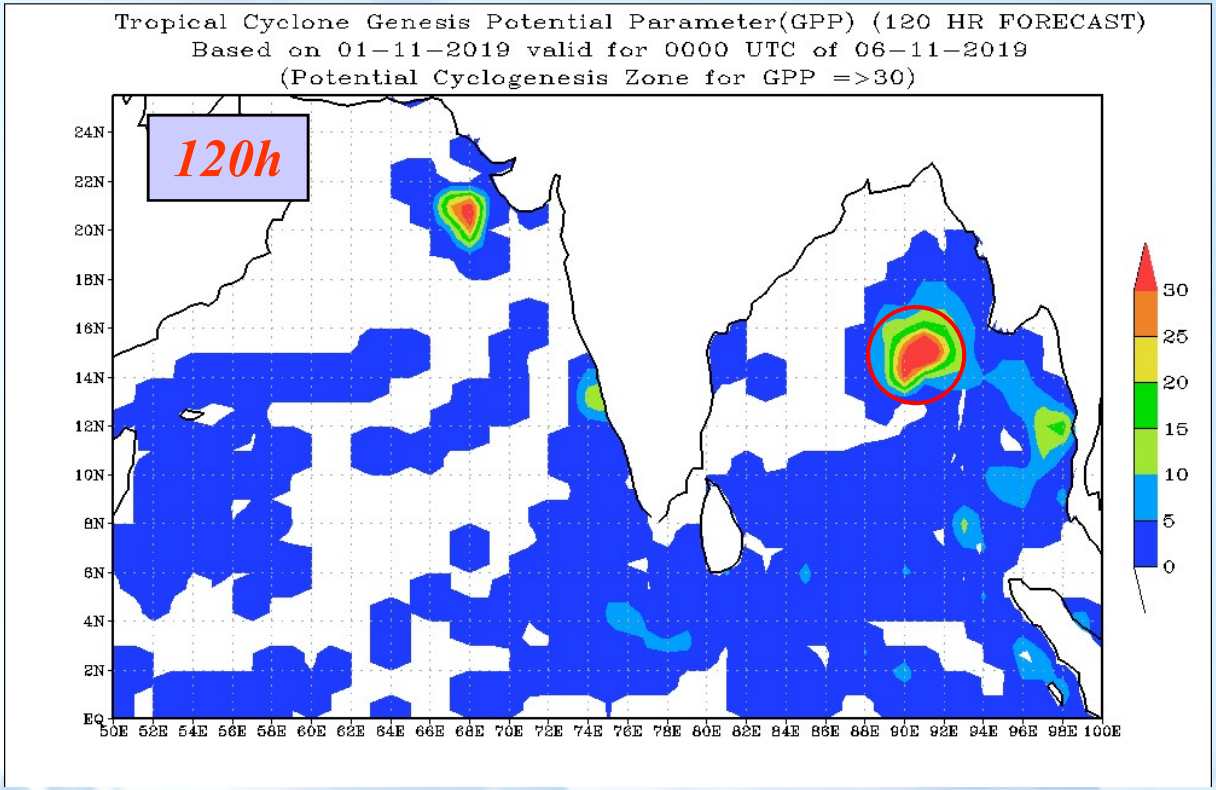




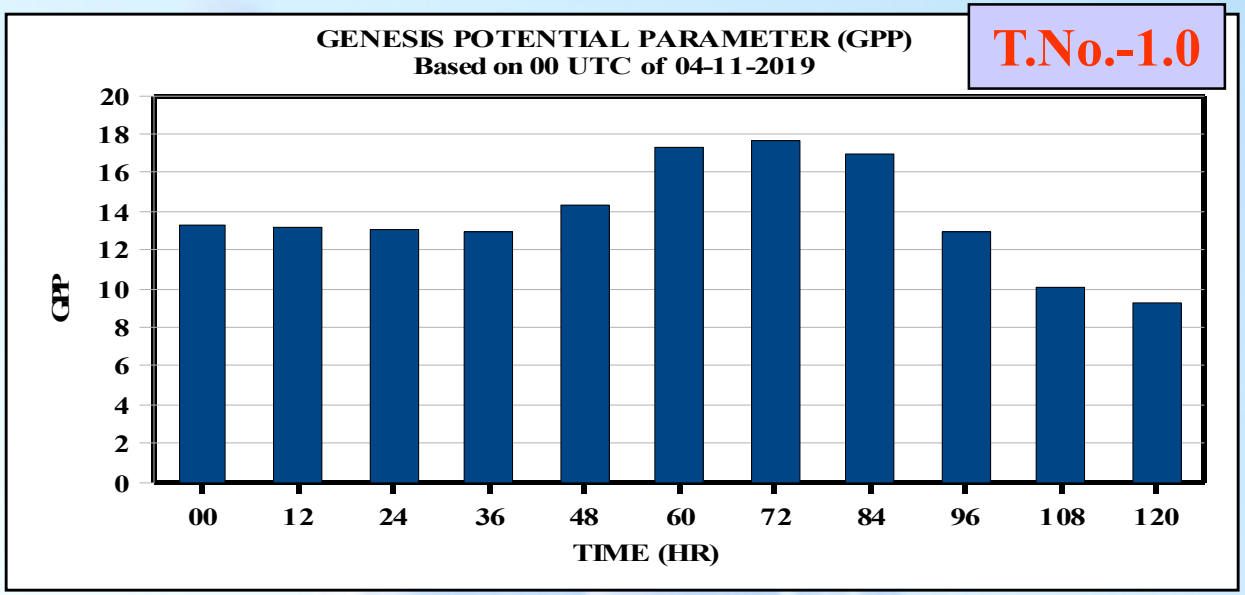




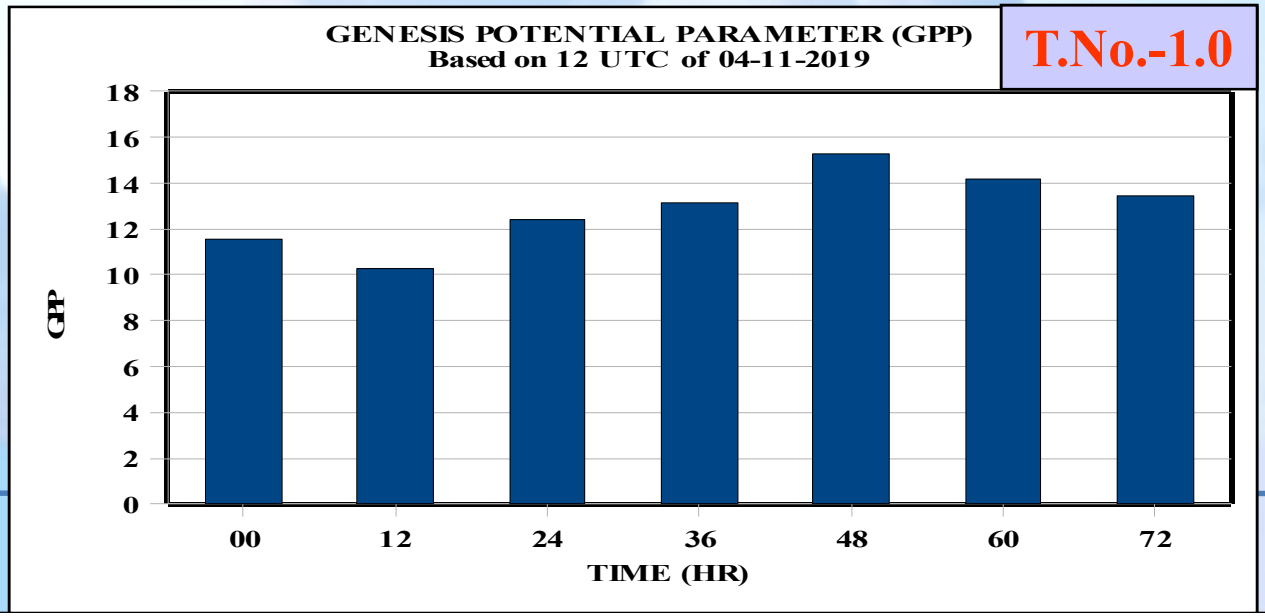
Genesis forecasts by GPP (BULBUL)



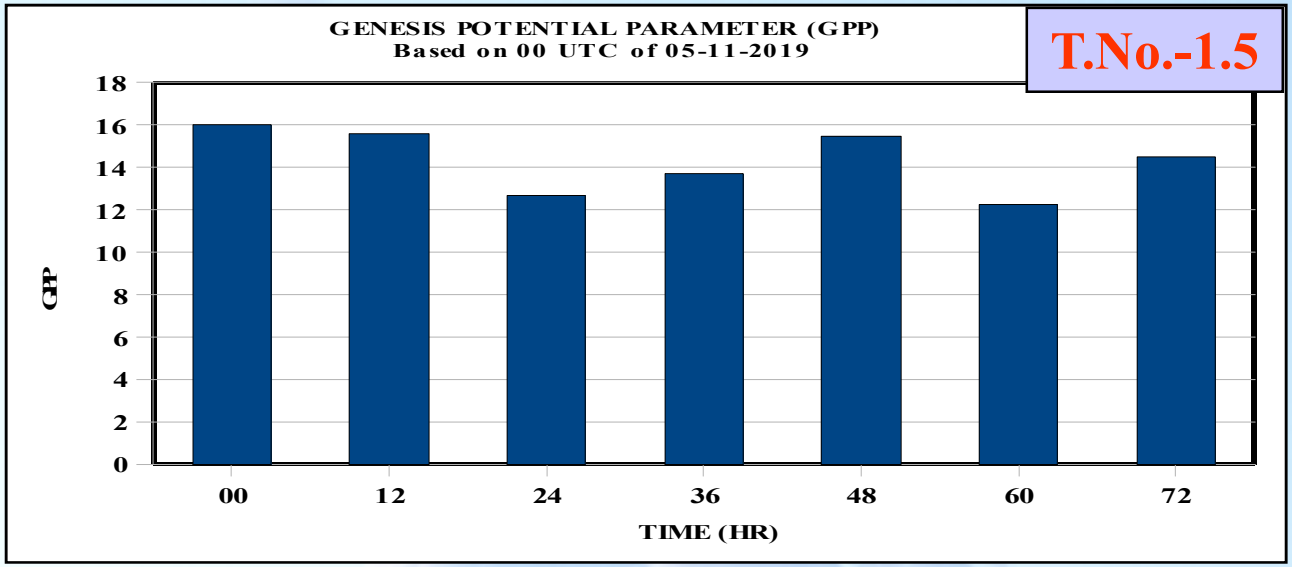
Mean GPP forecasts forecasts based on 00 UTC of 04.11.2019 (BULBUL)



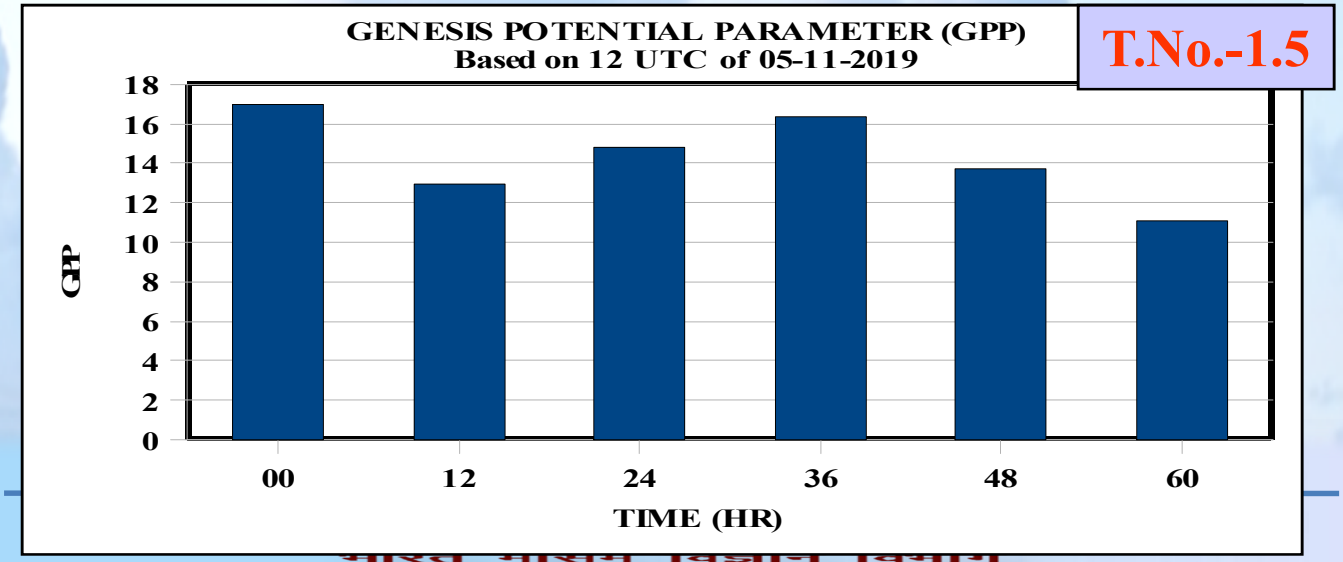
Mean GPP forecasts forecasts based on 12UTC of 04.11.2019 (BULBUL)



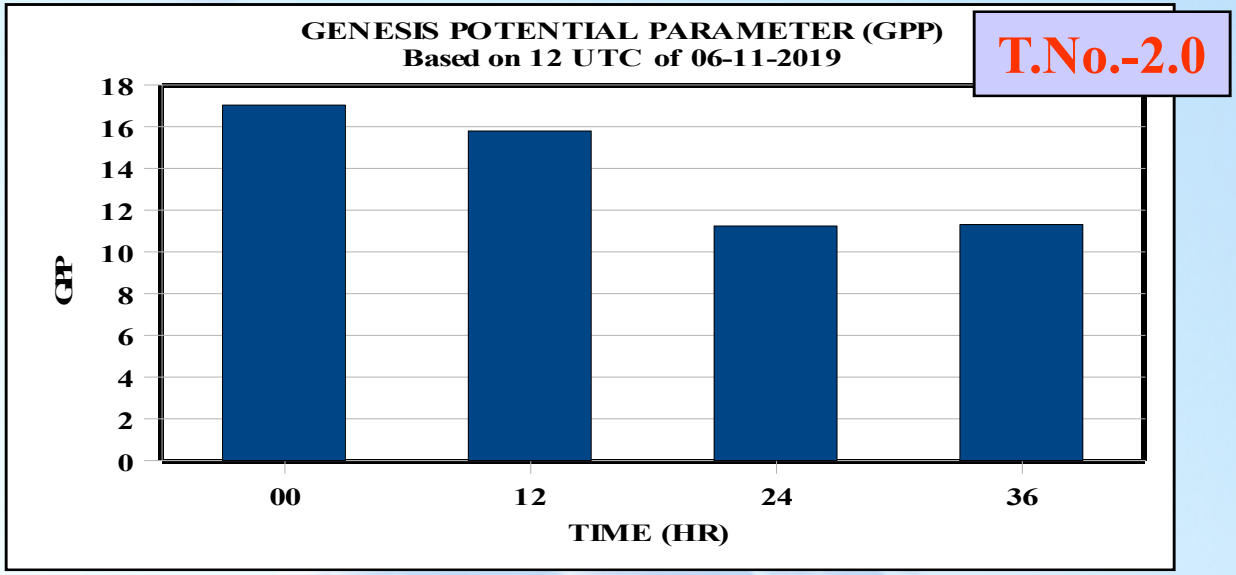
Mean GPP forecasts forecasts based on 00 UTC of 05.11.2019 (BULBUL)



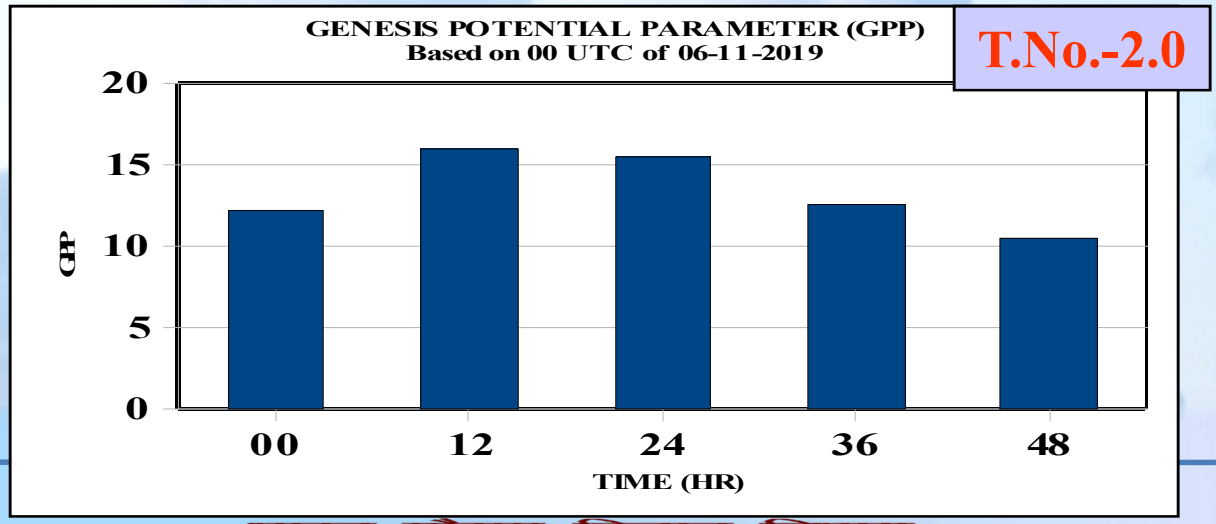
Mean GPP forecasts forecasts based on 12 UTC of 05.11.2019 (BULBUL)



Mean GPP forecasts forecasts based on 00 UTC of 05.11.2019 (BULBUL)

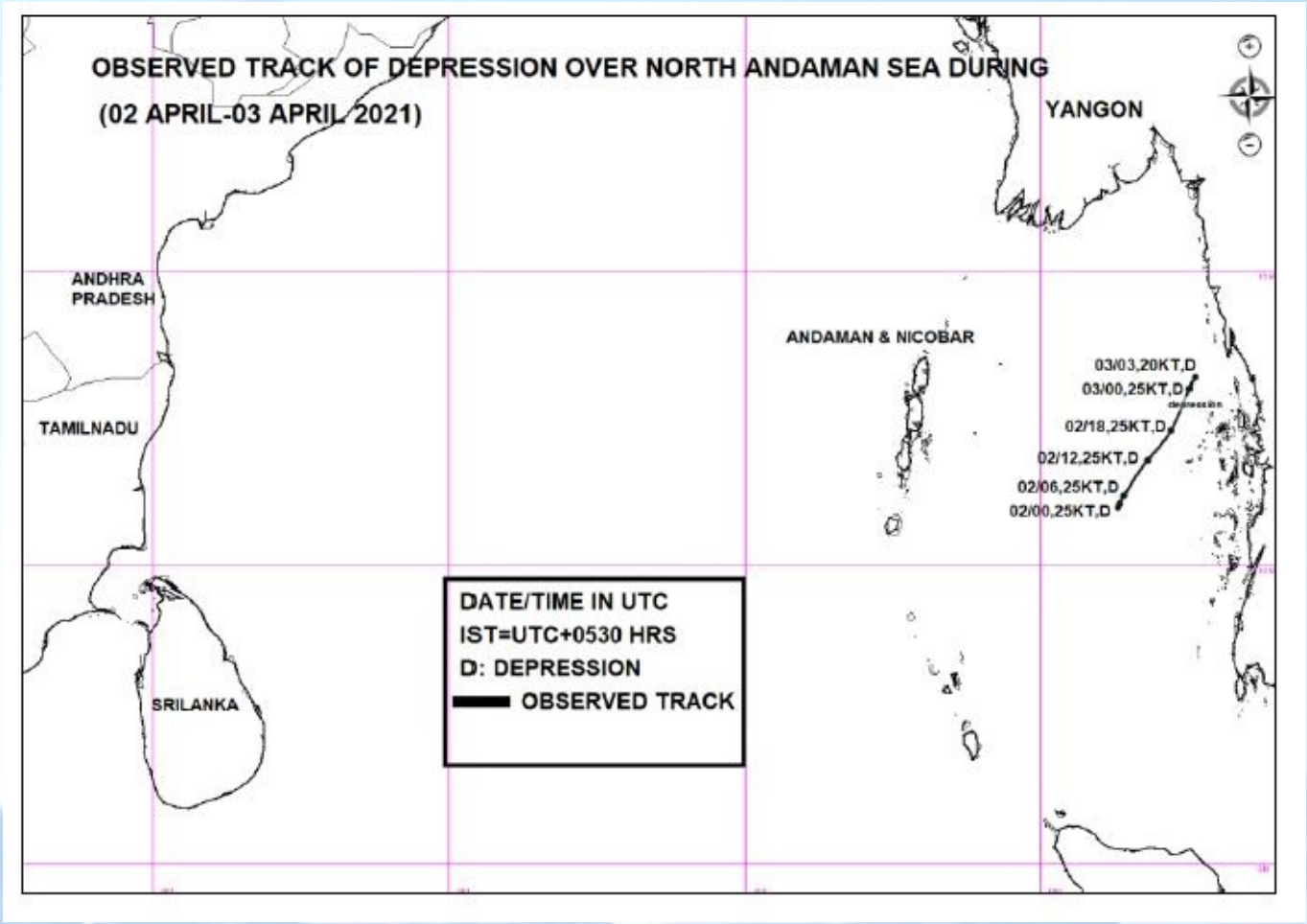


Mean GPP forecasts forecasts based on 12 UTC of 05.11.2019 (BULBUL)

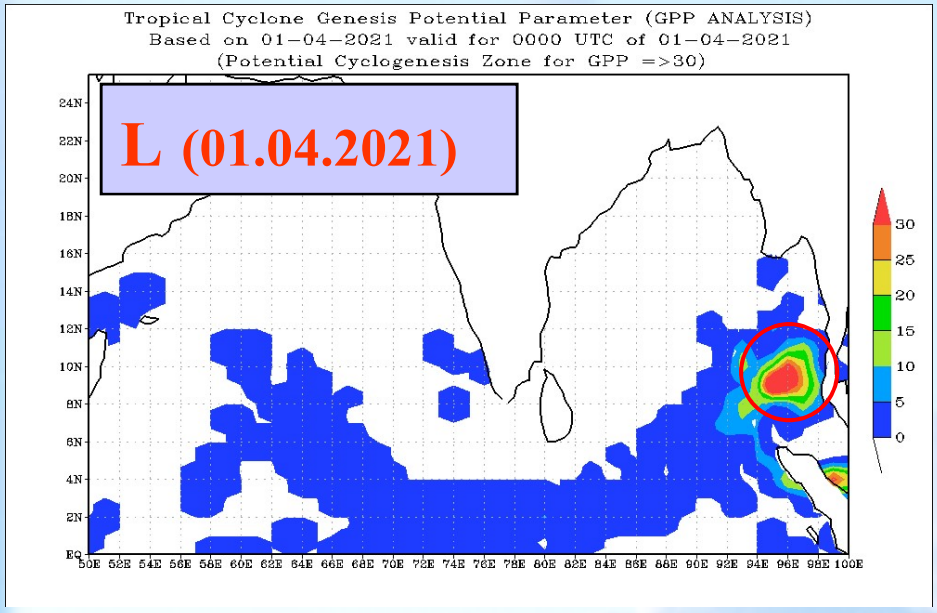


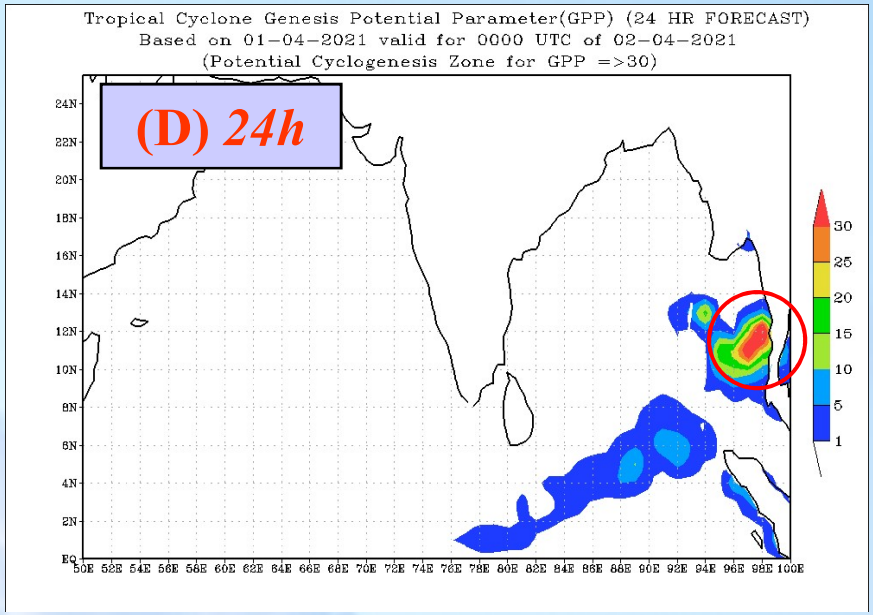
DEPRESSION over the Bay of Bengal during 2-3 April 2021

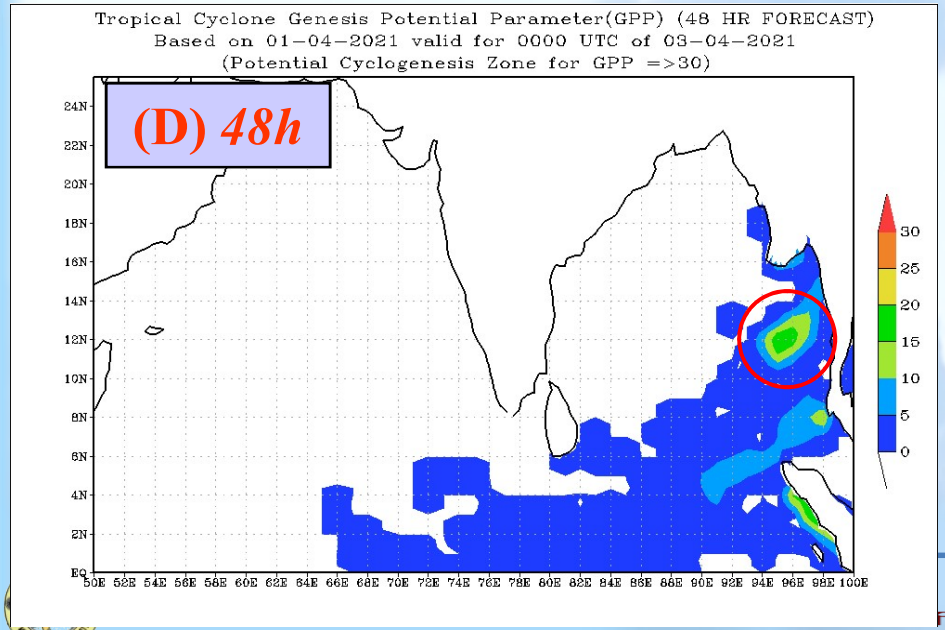
DEPRESSION over the Bay of Bengal during 2-3 April 2021

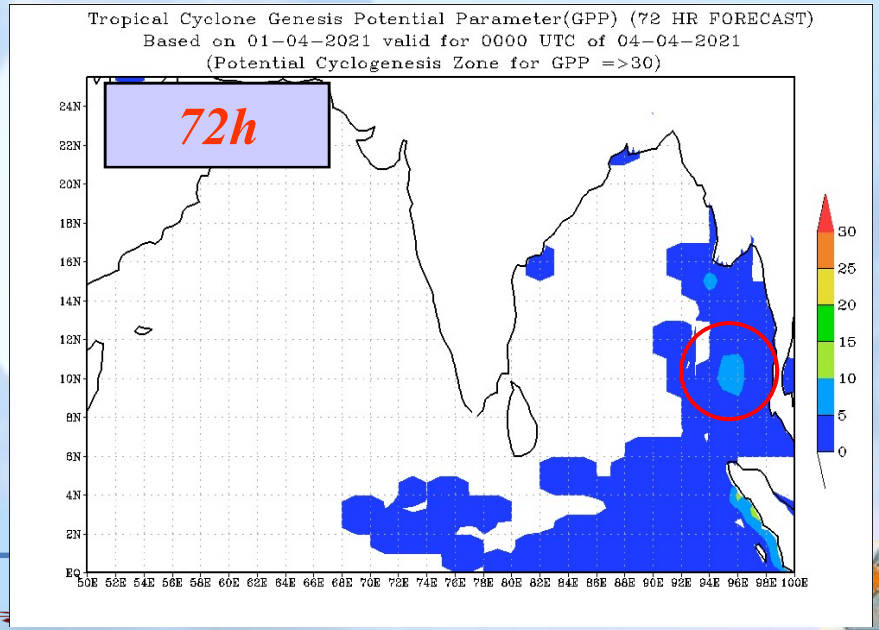


Genesis forecasts by GPP (DEPRESSION)





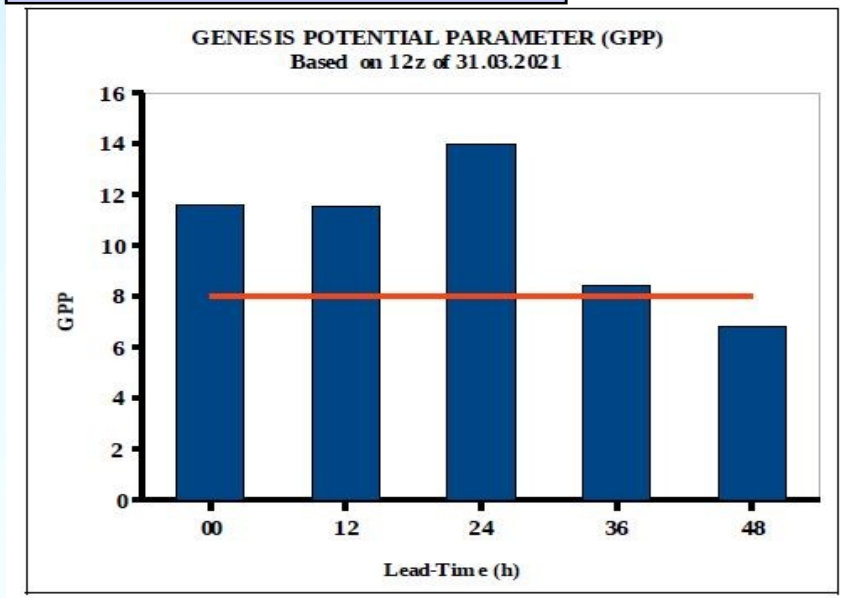


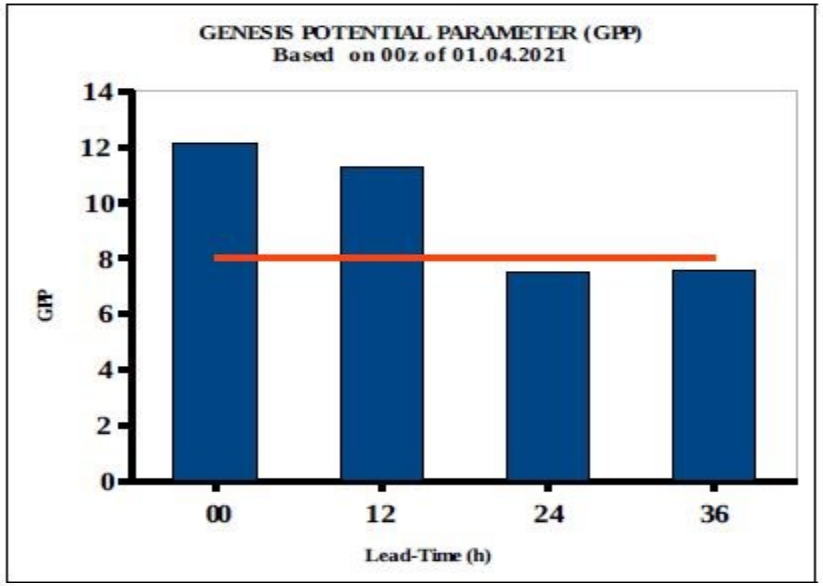


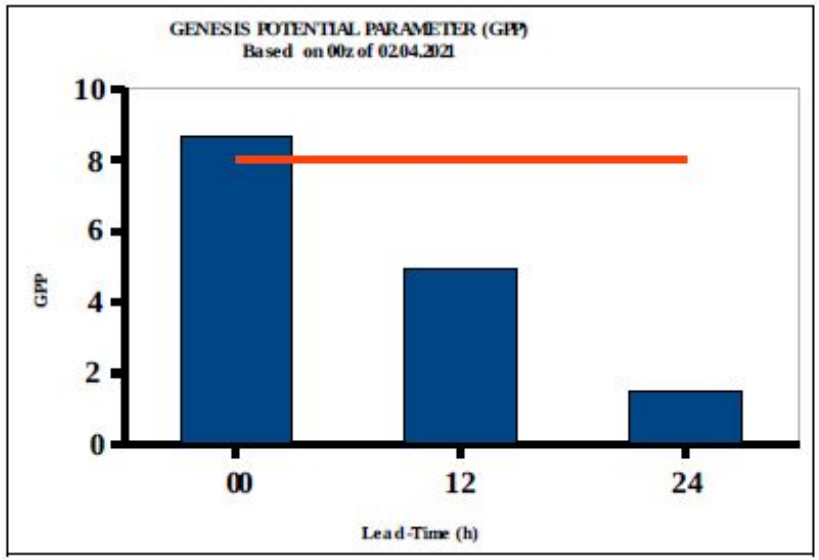
L(31.03.2021/12 UTC)

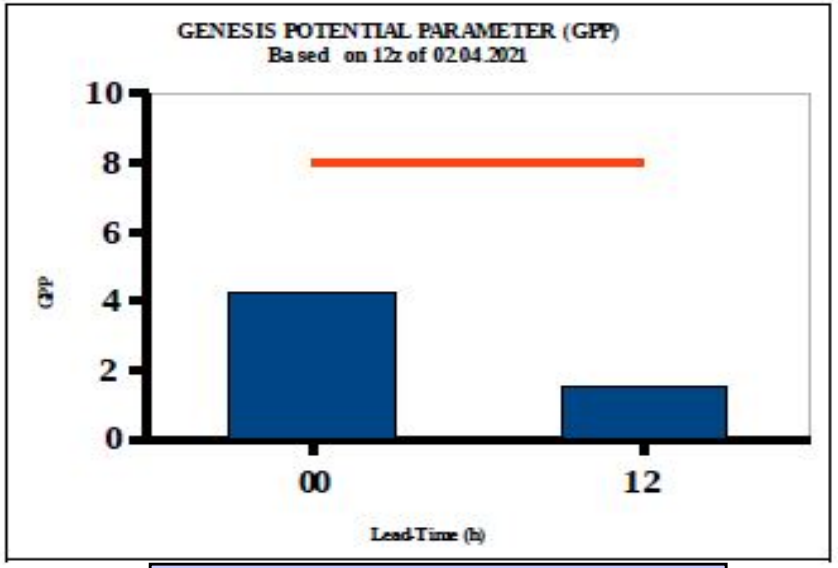
Genesis forecasts by GPP

L(01.04.2021/00 UTC)





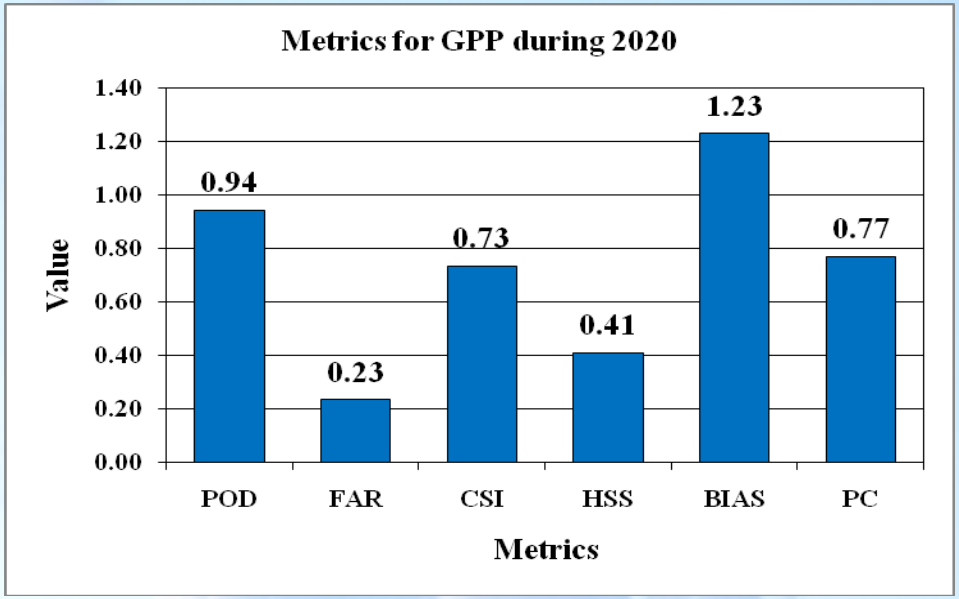




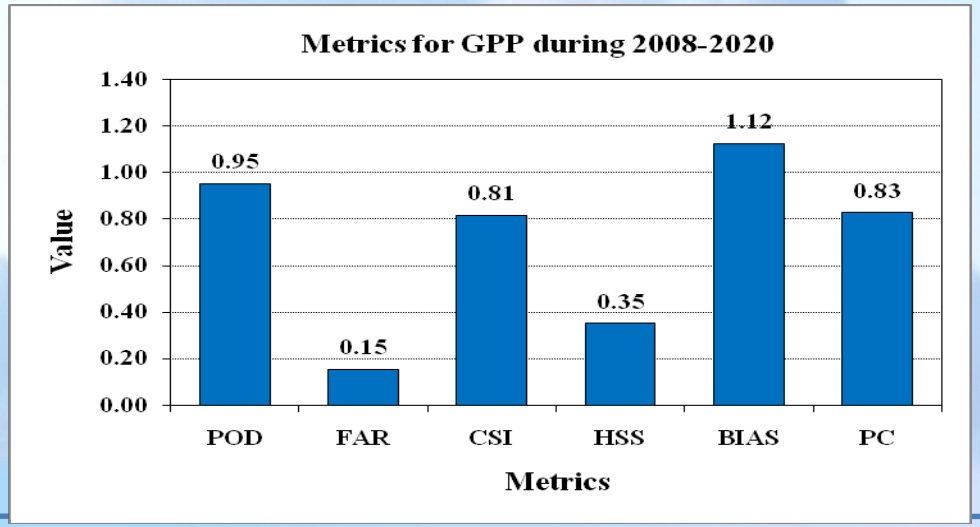
D(02.04.2021/00 UTC)

D(01.04.2021/12 UTC)

Forecast Skill of Genesis potential parameter (GPP) during 2020



Forecast Skill of Genesis potential parameter (GPP) during 2008-2020

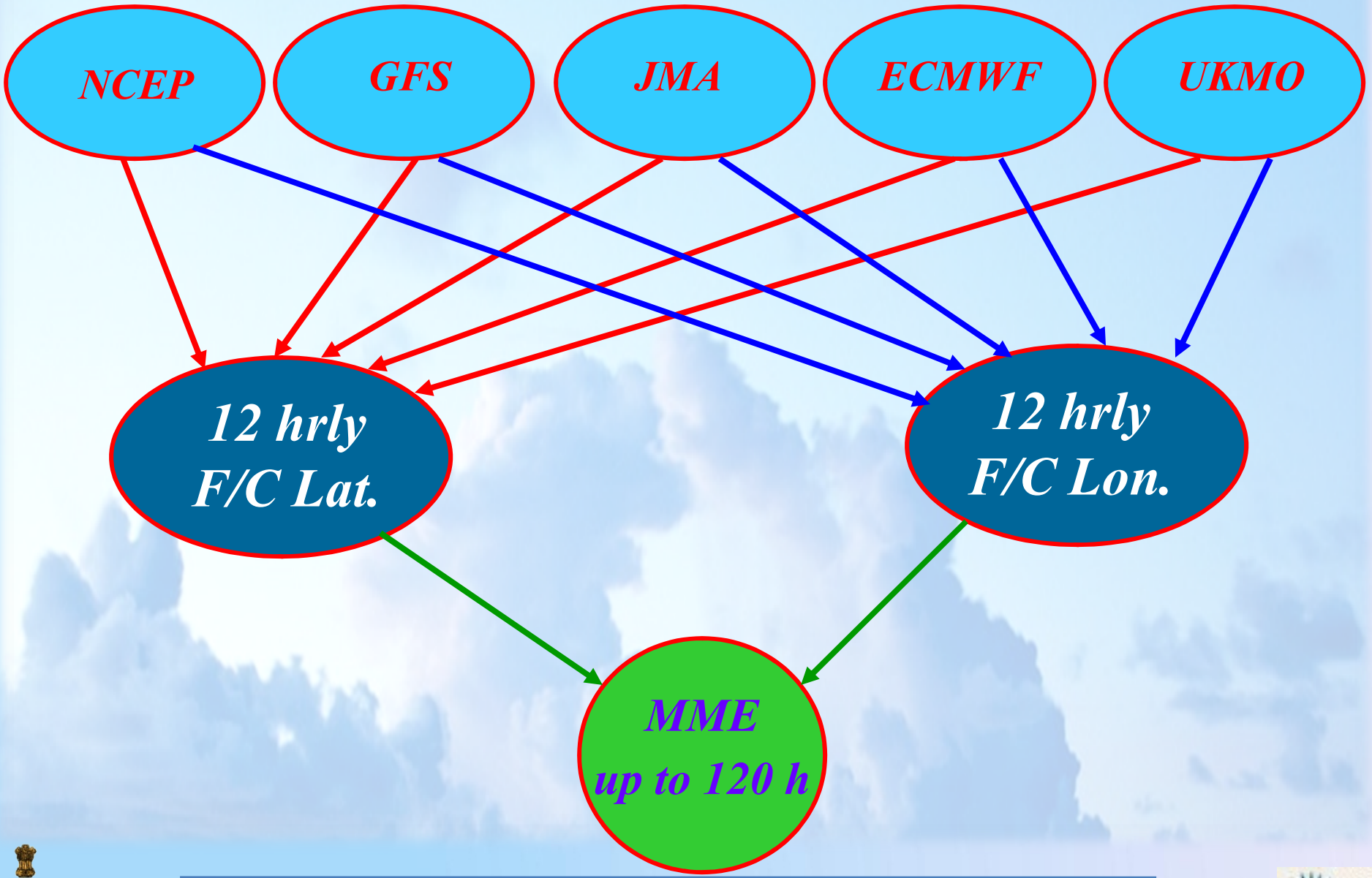


STEP-II: TRACK PREDICTION BY MME

[Kotal, S.D. and Roy Bhowmik S.K. 2011. A Multimodel Ensemble (MME) Technique for Cyclone Track Prediction over the North Indian Sea. *Geofizika*, 28(2): 275-291]

Objective: To generate a consensus track forecast of NWP models by collective bias correction

TRACK PREDICTION BY NWP MODELS AND MME



MME Cyclone Track Prediction

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

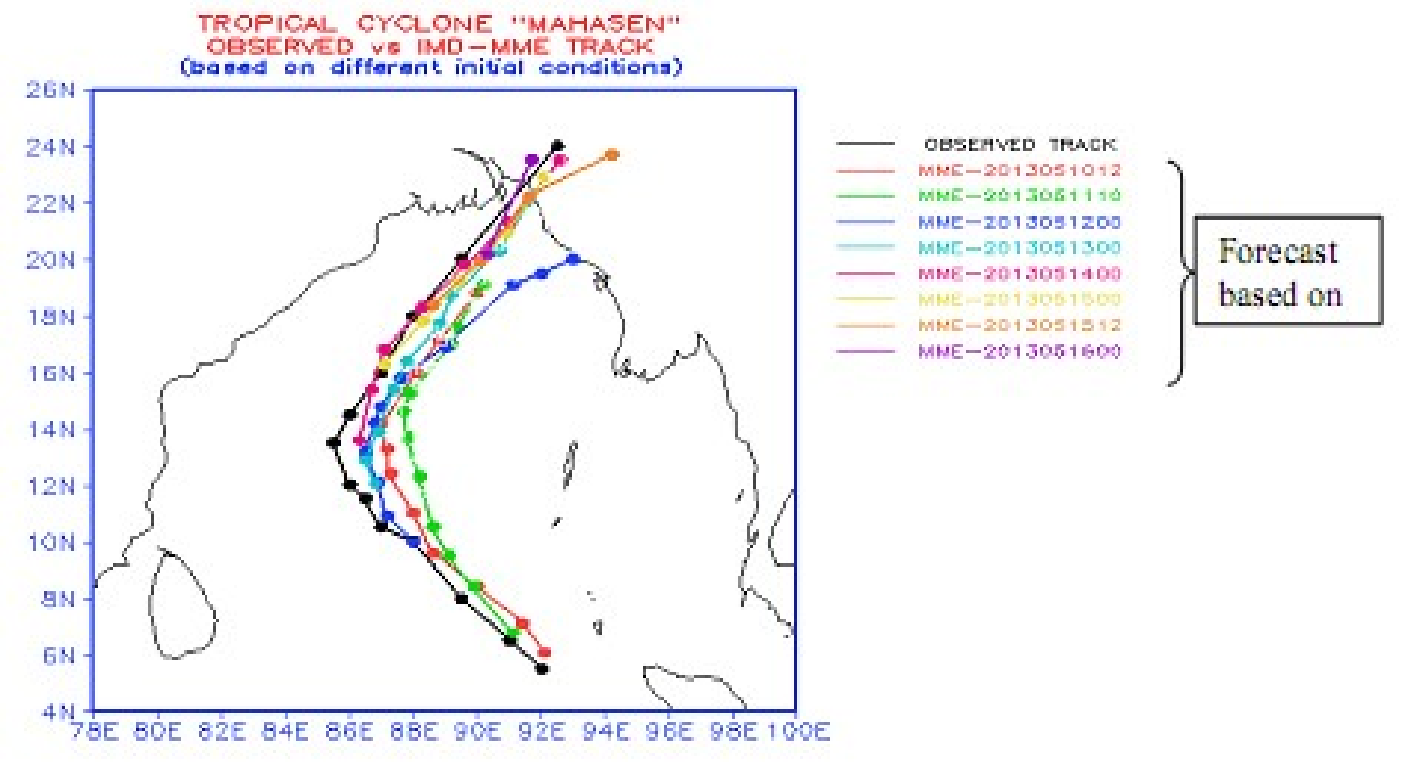
$$LAT^f_t = a_o + a_1 NCEP_t^{lat} + a_2 GFS_t^{lat} + a_3 JMA_t^{lat} + a_4 ECMWF_t^{lat} + a_5 UKMO_t^{lat}$$

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

for t = forecast hour 12, 24, 36, 48, 60, 72, 84, 96, 108 and 120 h

VIYARU
(Bay of Bengal May 2012)

MME track forecasts based on different initial conditions

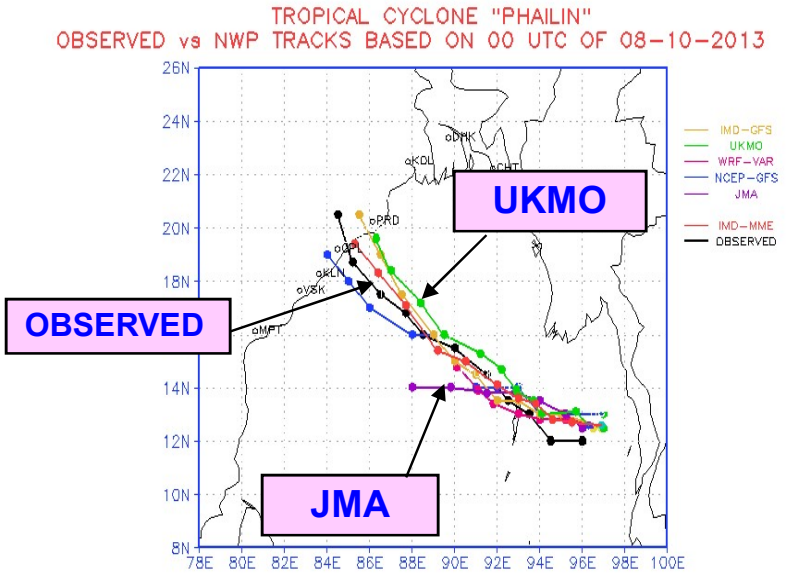


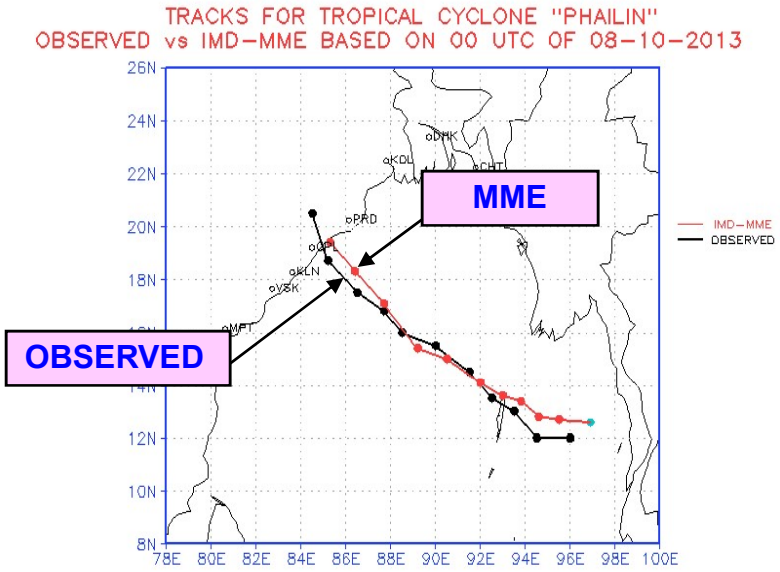
Landfall point error (km)- VIYARU

Model	FC based on 00 UTC/14.05.2013	FC based on 00 UTC/15.05.2013	FC based on 12 UTC/15.05.2013	FC based on 00 UTC/16.05.2013
	Lead time: 56 h	Lead time: 32 h	Lead time: 20 h	Lead time: 8 h
IMD-GFS	NO LF	NO LF	136	-
IMD-WRF	NO LF	147	49	45
IMD-QLM	NO LF	63	137	243
JMA	137	63	98	49
NCEP-GFS	289	169	136	136
ECMWF	259	274	127	15
IMD-MME	63	63	63	25
IMD-HWRF	84	174	121	-

PHAILIN
(Bay of Bengal October 2013)

NWP model and consensus NWP (Multi-model ensemble) track forecasts based on 00 UTC of 08.10.2013 for cyclone PHAILIN

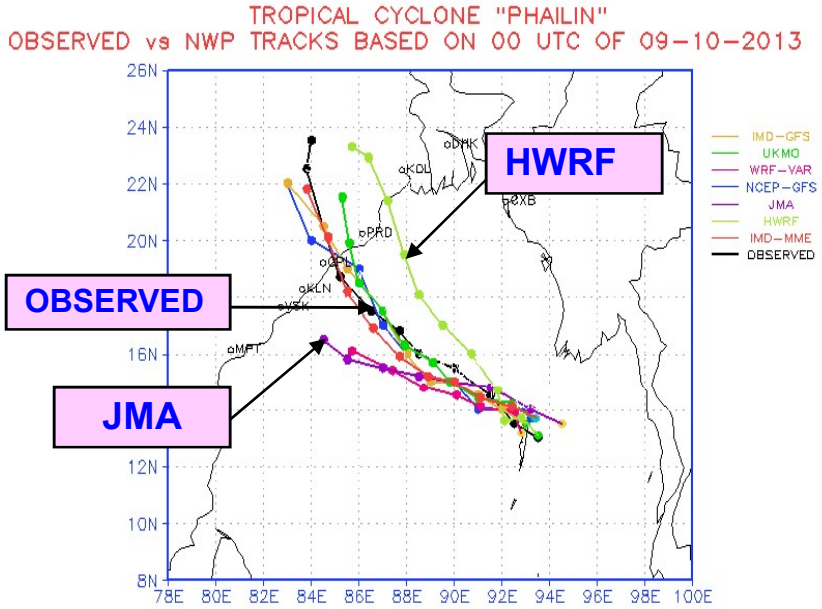


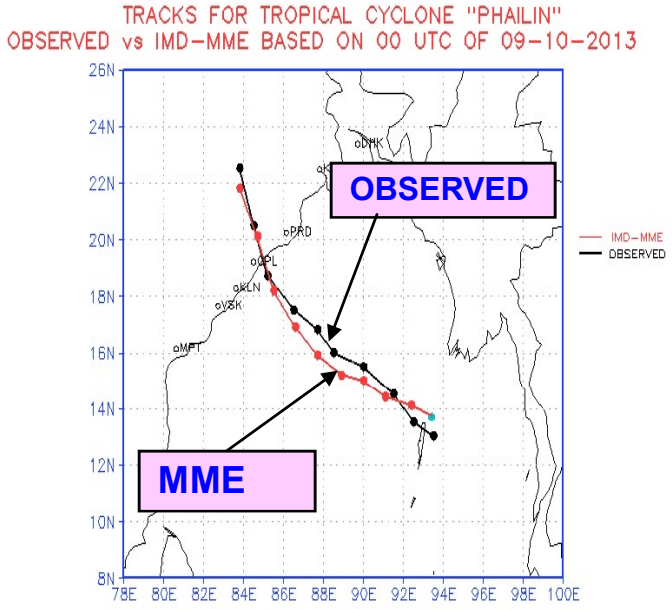


All model landfall point forecasts varied from north AP to Paradip(Odisha)

Consensus track forecast correctly predicted landfall at GOPALPUR(Odisha)

NWP model and Multi-model ensemble track forecasts based on 00 UTC of 09.10.2013

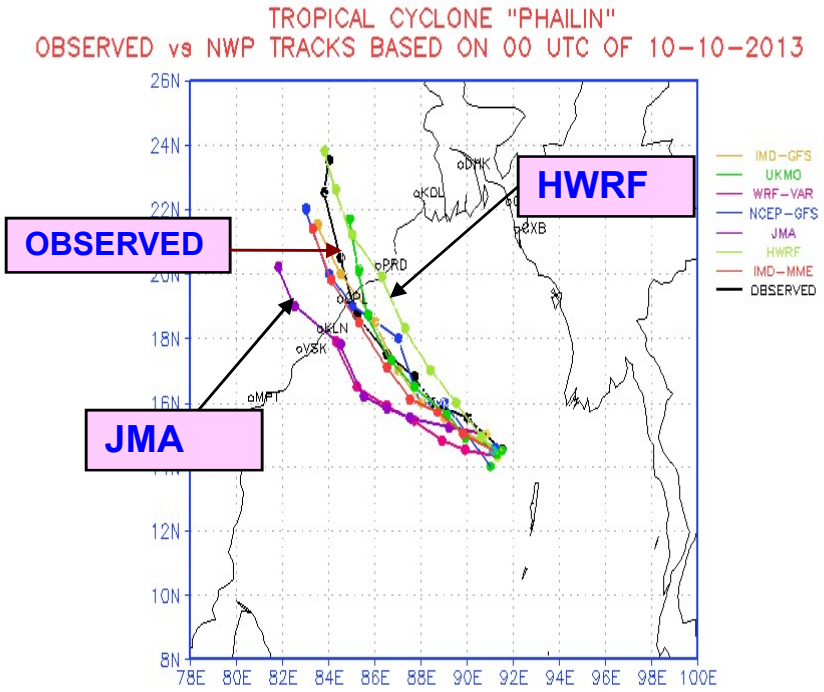


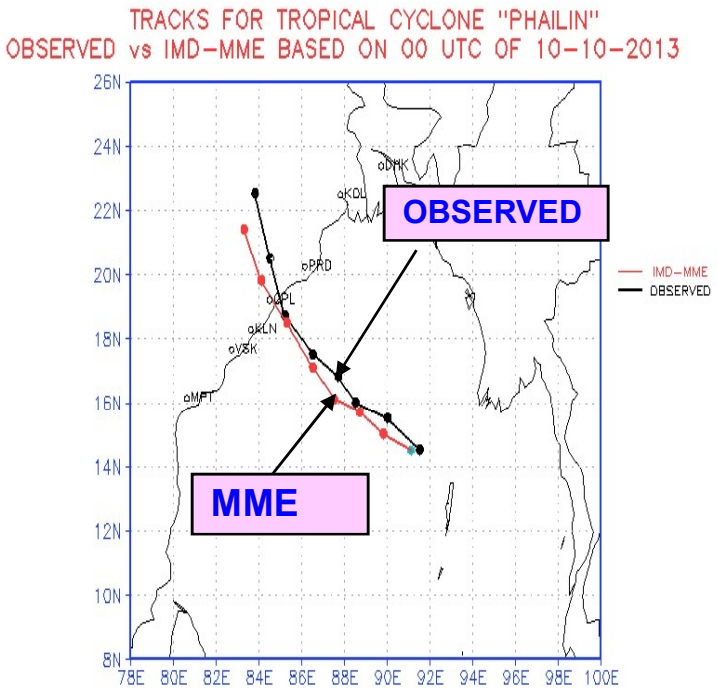


All model landfall point forecasts varied from North AP to Sagar Island(west Bengal)

Consensus track forecast correctly predicted landfall at GOPALPUR

NWP model and Multi-model ensemble track forecasts based on 00 UTC of 10.10.2013

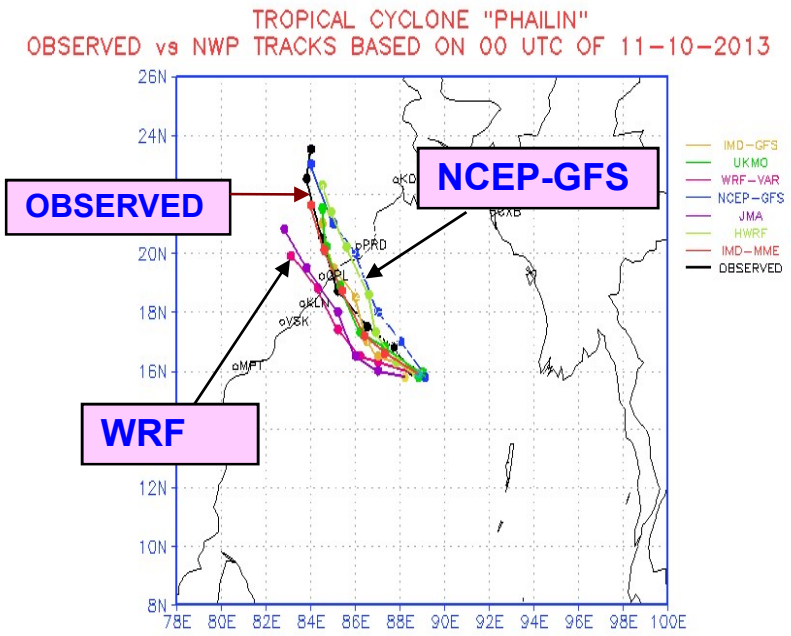


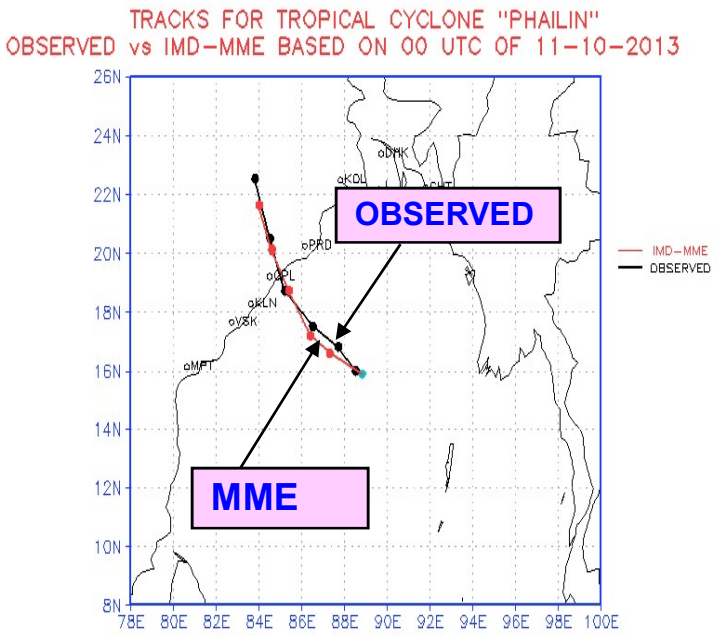


All model landfall point forecasts varied from Kalingapattanam(North AP) to Paradip(Odisha)

Consensus track forecast correctly predicted landfall at GOPALPUR

NWP model and Multi-model ensemble track forecasts based on 00 UTC of 11.10.2013

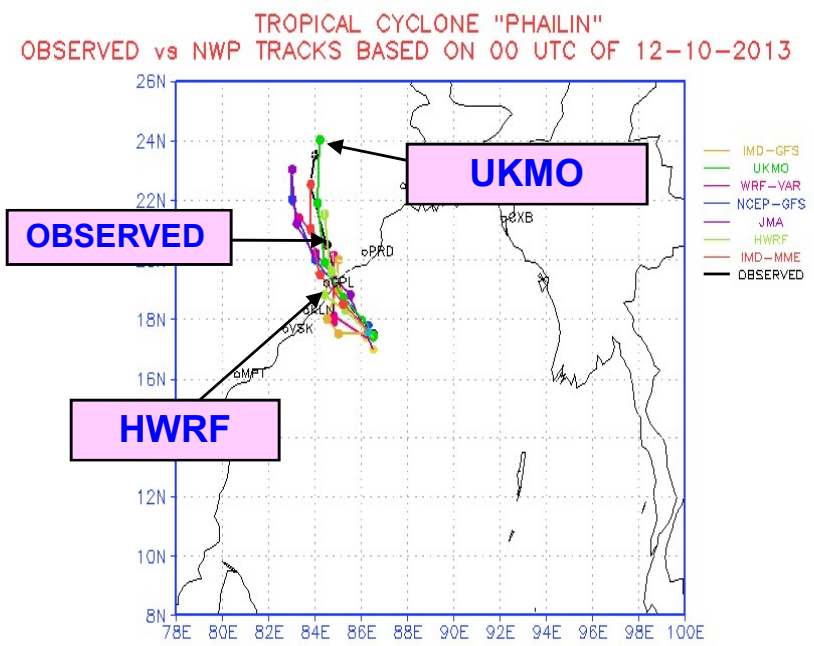


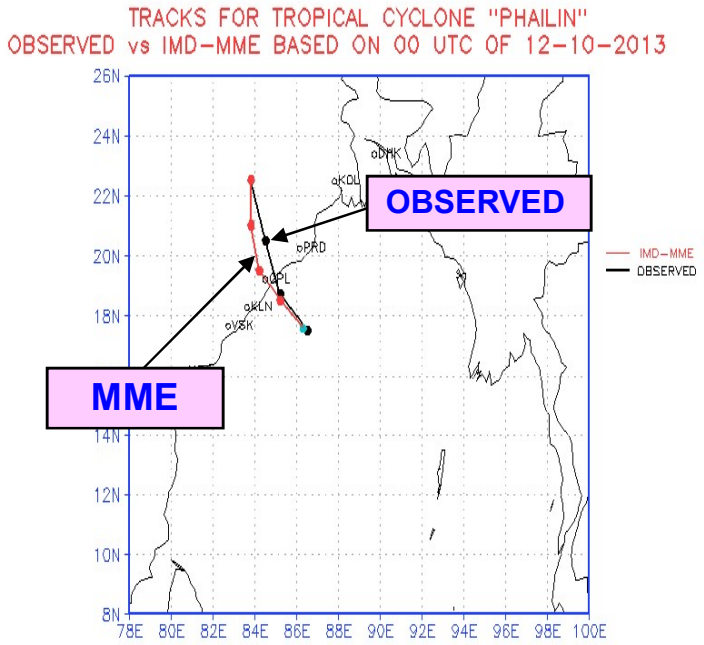


All model landfall point forecasts varied from Kalingapattanam(North AP) to Paradip(Odisha)

Consensus track forecast correctly predicted landfall at GOPALPUR

NWP model and Multi-model ensemble track forecasts based on 00 UTC of 12.10.2013

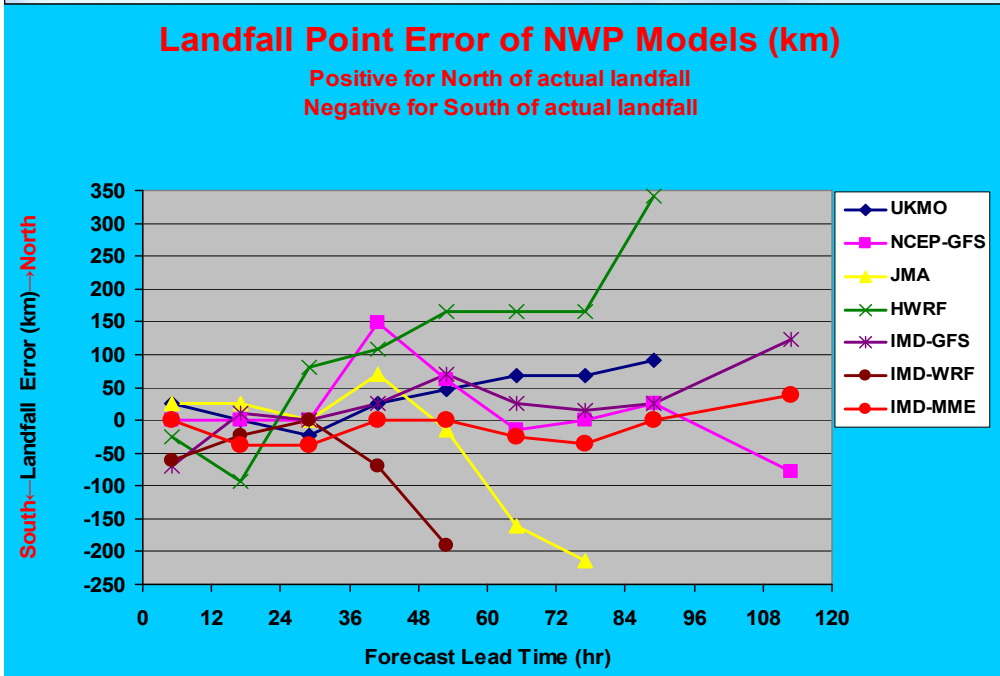


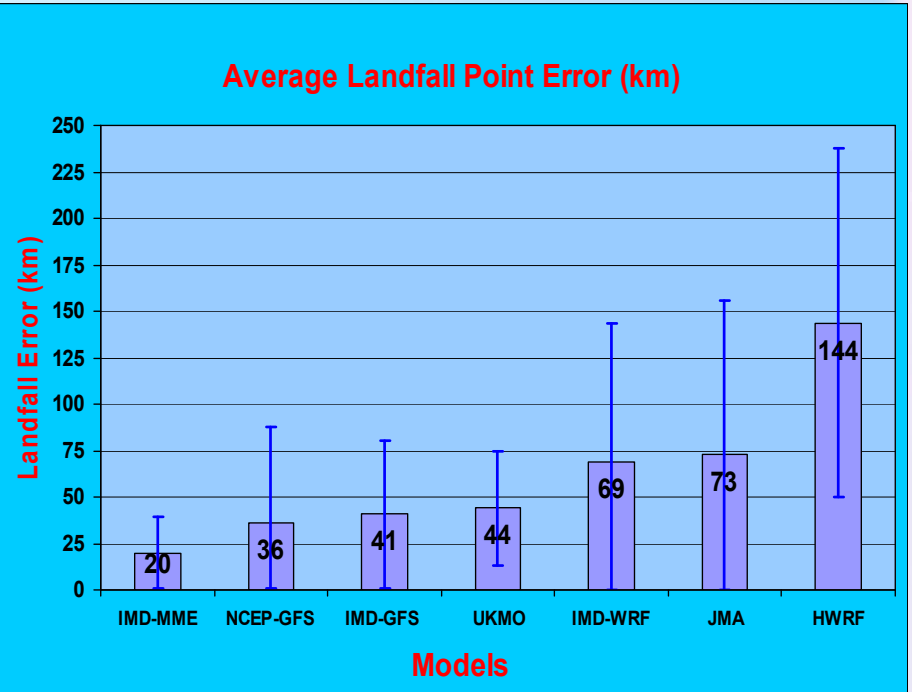


All model landfall point forecasts varied from Kalingapattanam(North AP) to Gopalpur(Odisha)

Consensus track forecast correctly predicted landfall at GOPALPUR

Landfall Point Error (km) of NWP Models





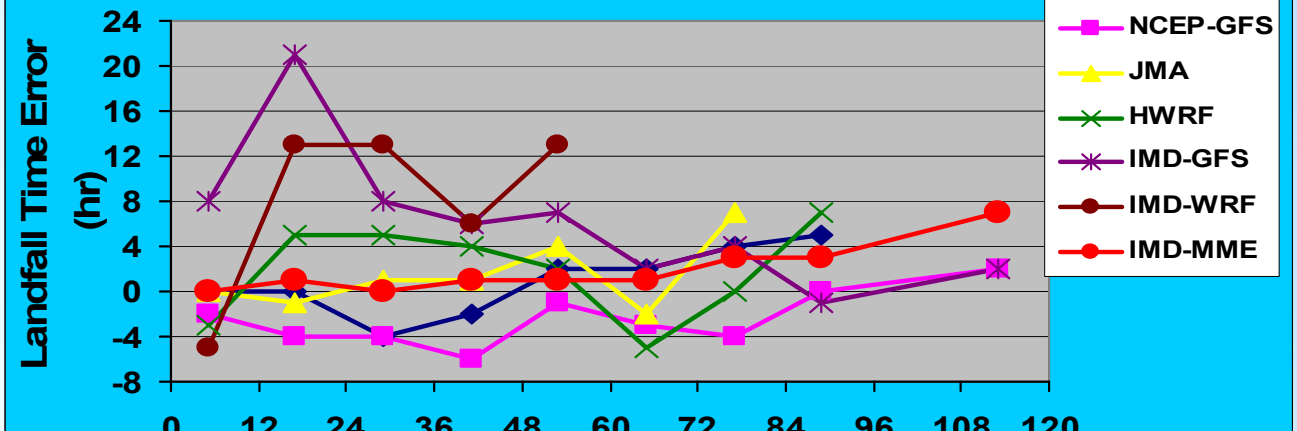
MME landfall forecast errors were consistently low at all lead time

Average landfall forecast error was lowest for MME

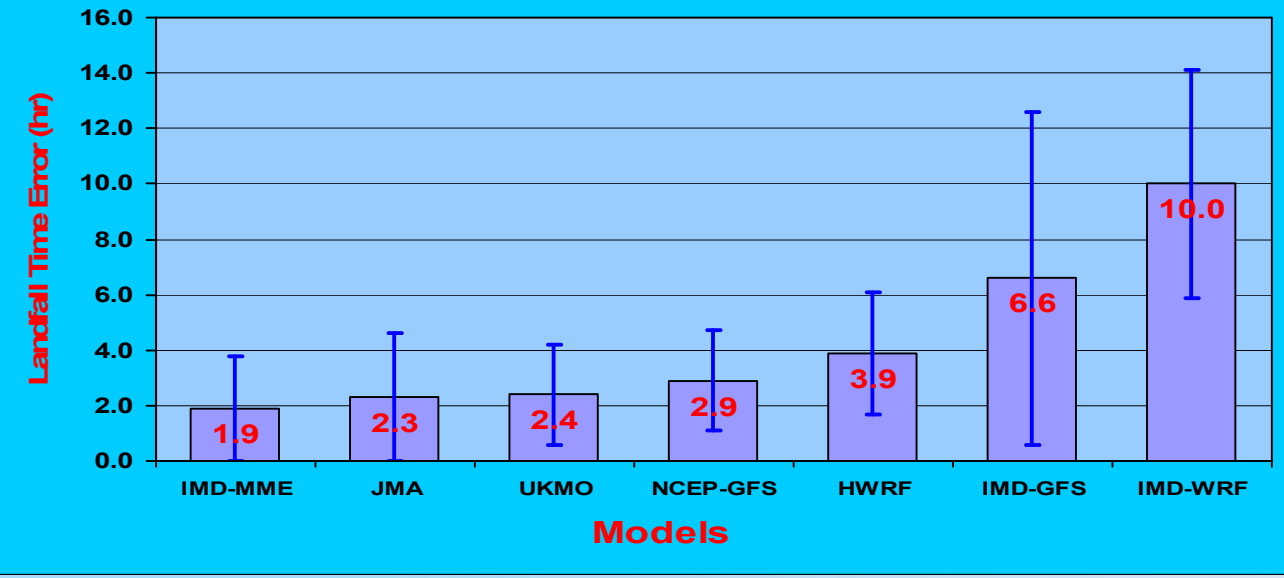
Landfall Time Error of NWP Models (hr)

Negative for Early landfall

Positive for Delayed landfall

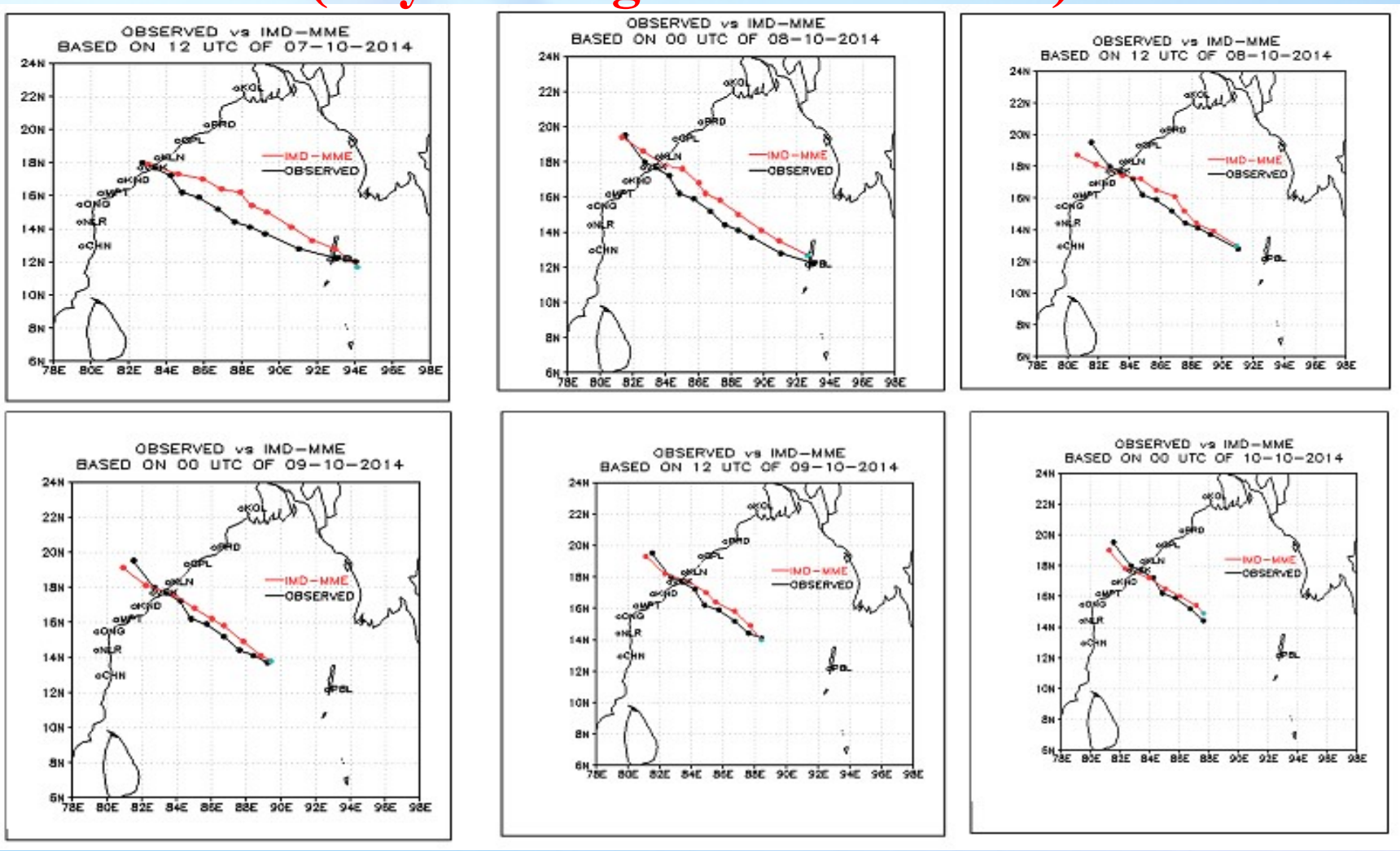


Average Absolute Landfall Time Error (hr)

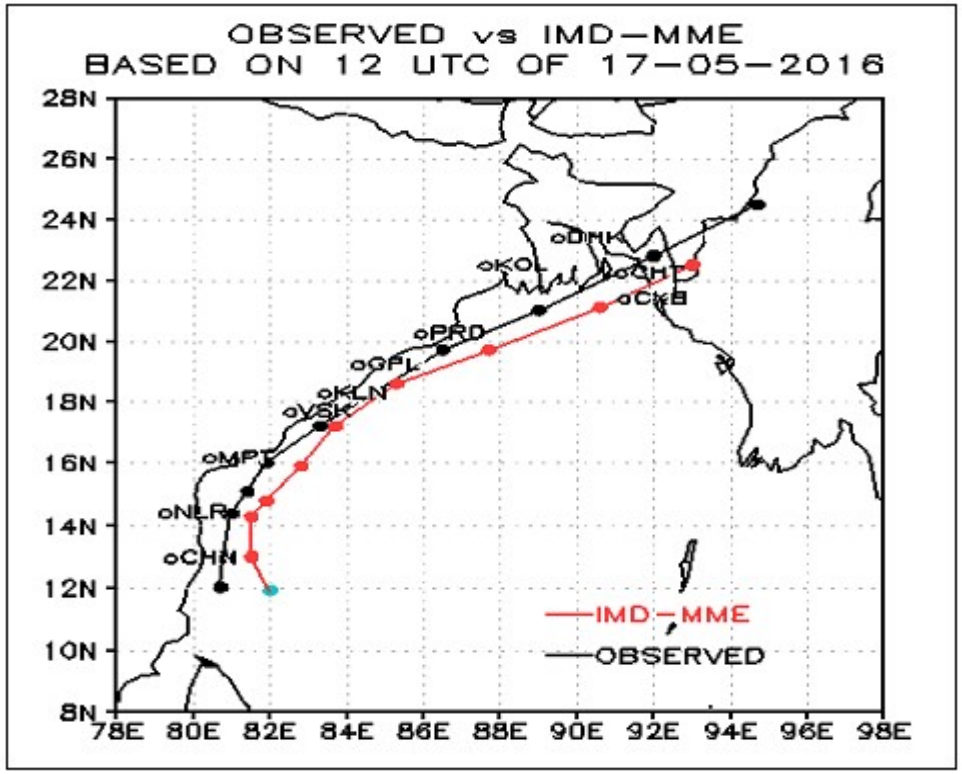


MME forecasts track for cyclone HUDHUD

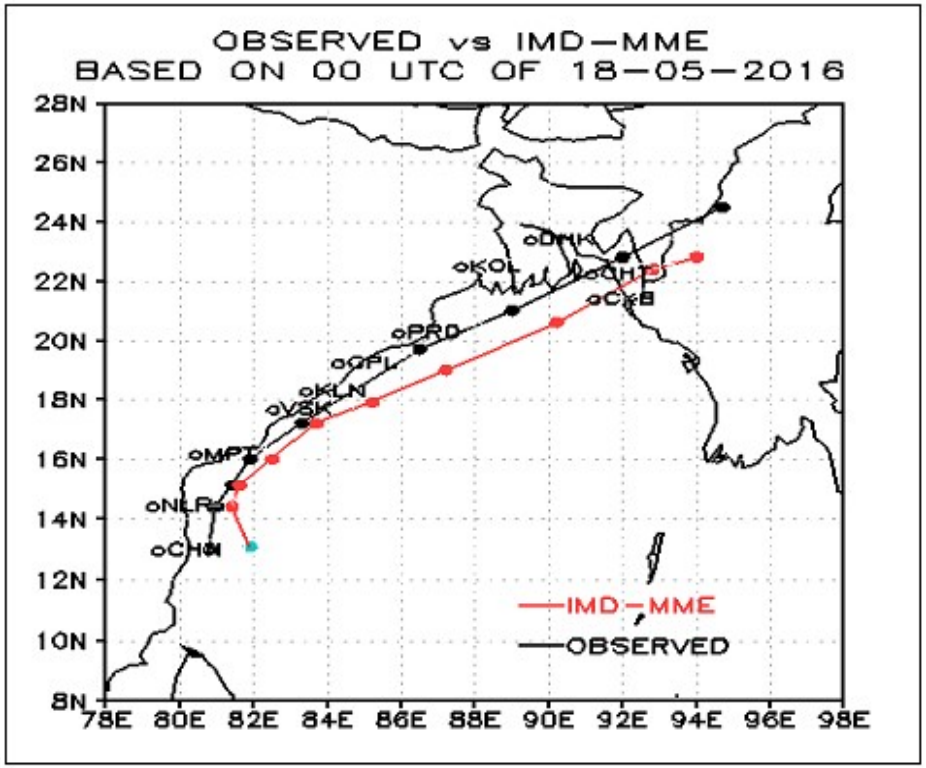
(Bay of Bengal October 2014)



NWP model and consensus NWP (Multi-model ensemble) track forecasts based on 12 UTC of 17.05.2016 and 00 UTC of 18.05.2016 for cyclone ROANU (Landfall Time-10 UTC 21.5.2016)

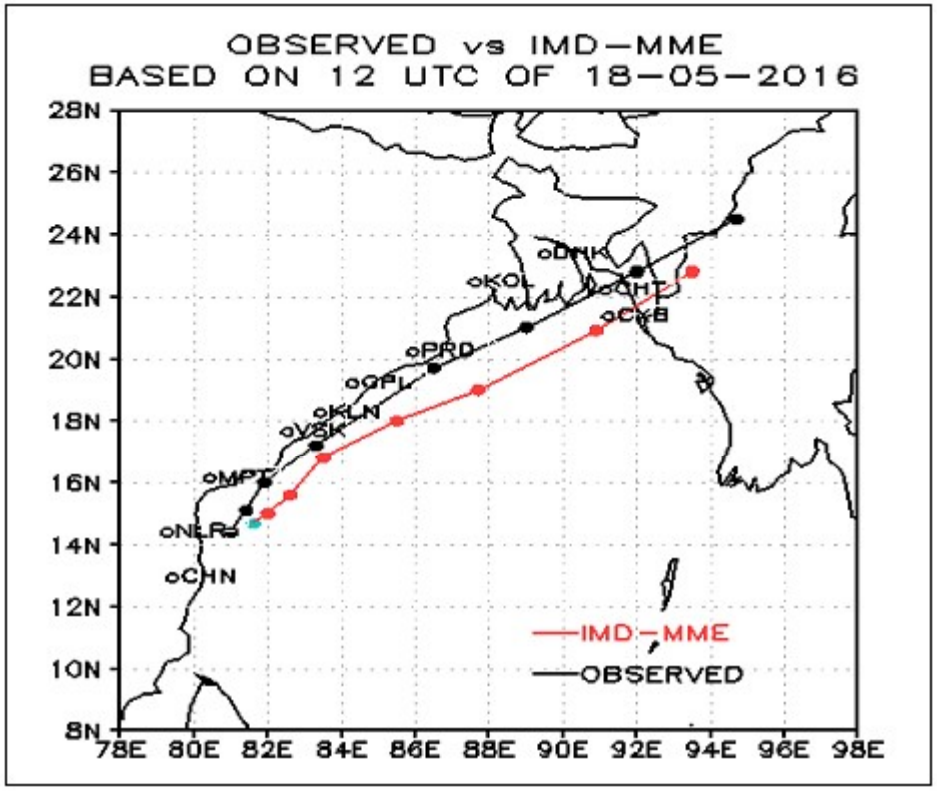


Landfall forecast Lead Time -94 h

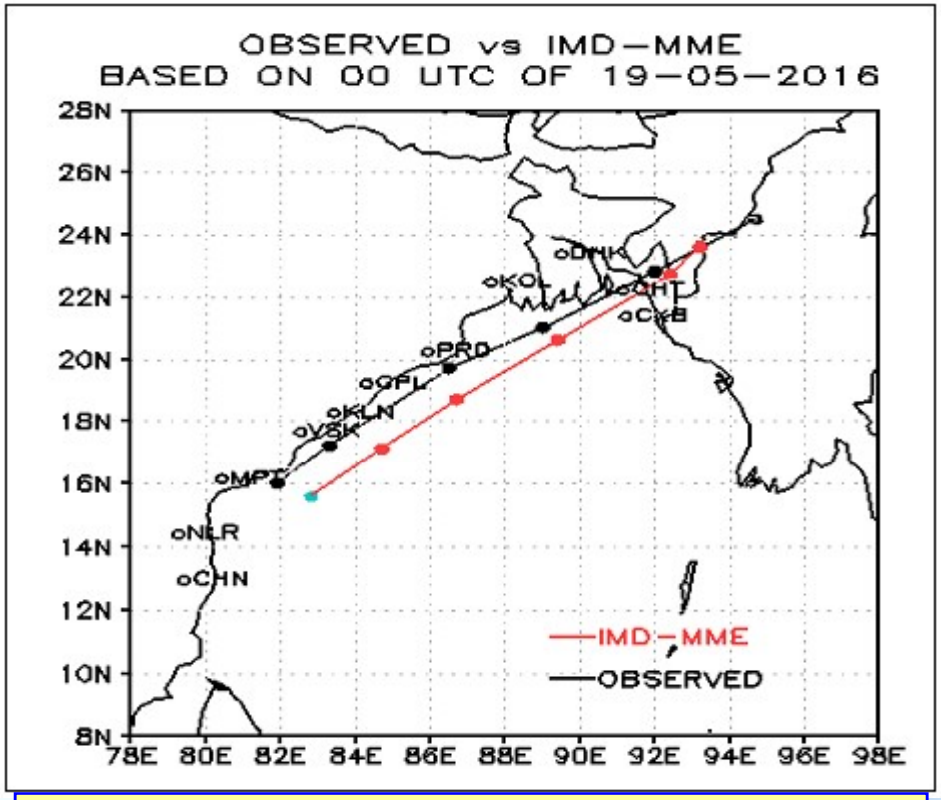


Landfall forecast Lead Time -82 h

NWP model and consensus NWP (Multi-model ensemble) track forecasts based on 12 UTC of 18.05.2016 and 00 UTC of 19.05.2016 for cyclone ROANU

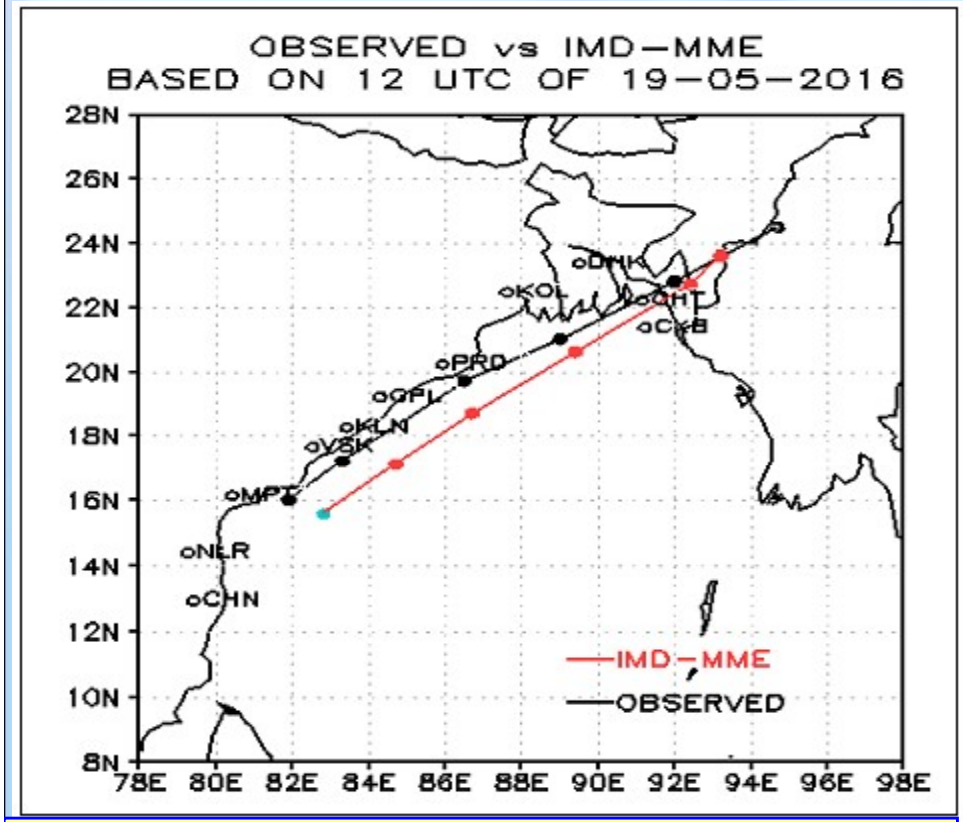


Landfall forecast Lead Time -70 h

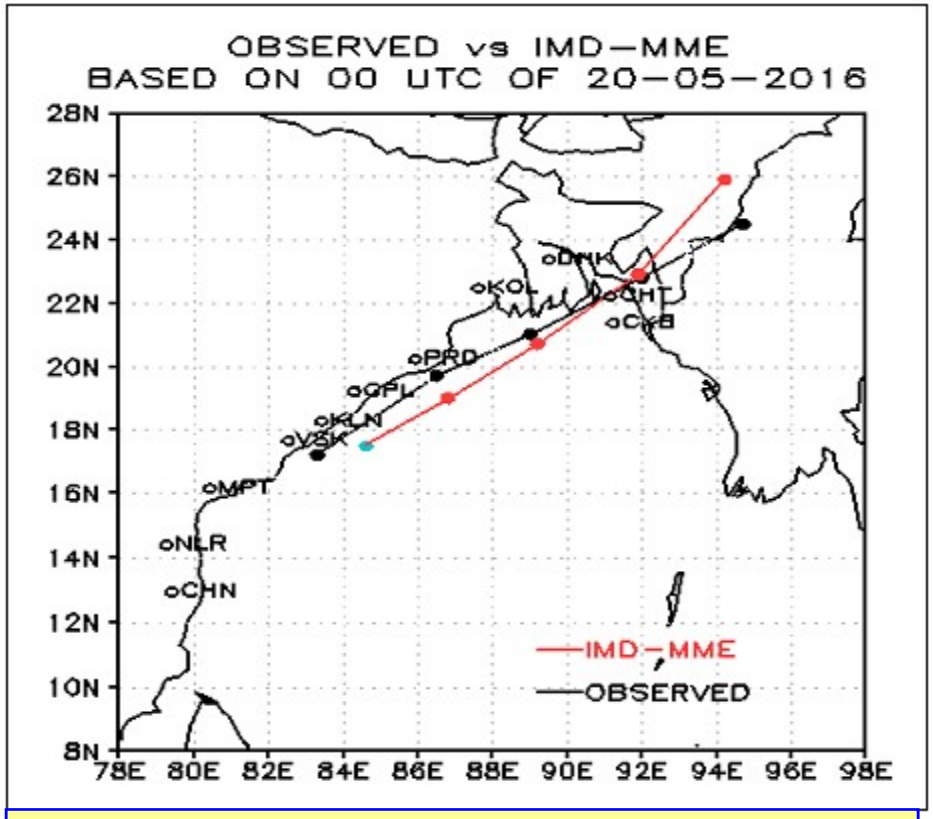


Landfall forecast Lead Time -58 h

NWP model and consensus NWP (Multi-model ensemble) track forecasts based on 12 UTC of 19.05.2016 and 00 UTC of 20.05.2016 for cyclone ROANU

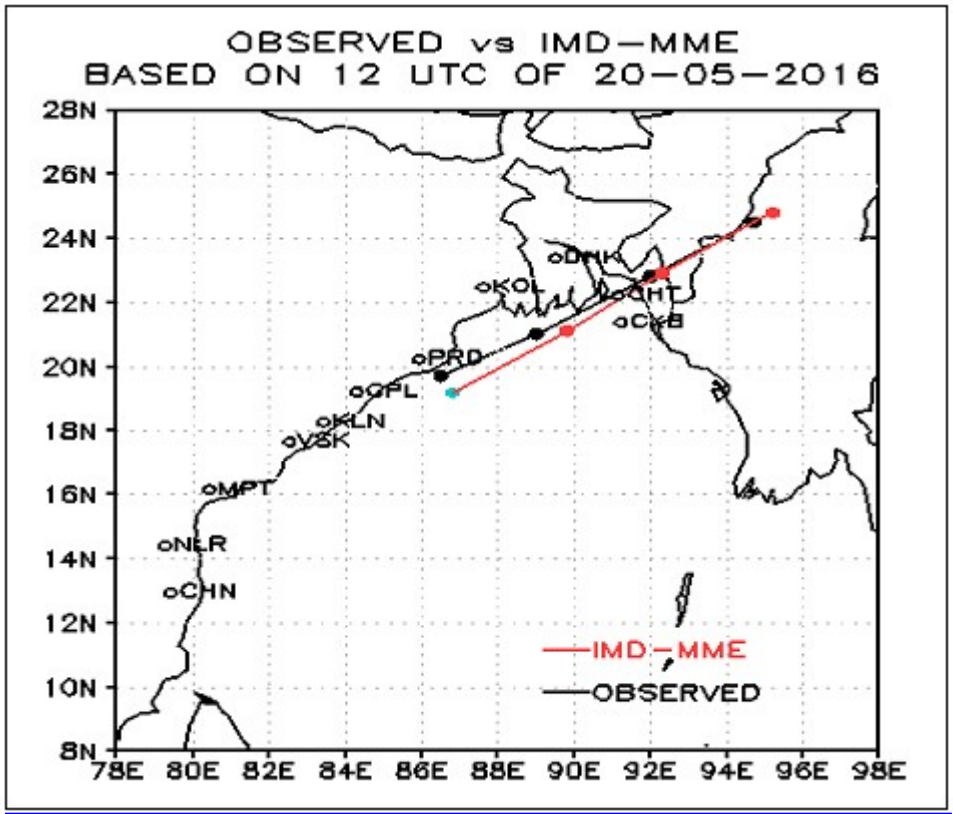


Landfall forecast Lead Time -46 h

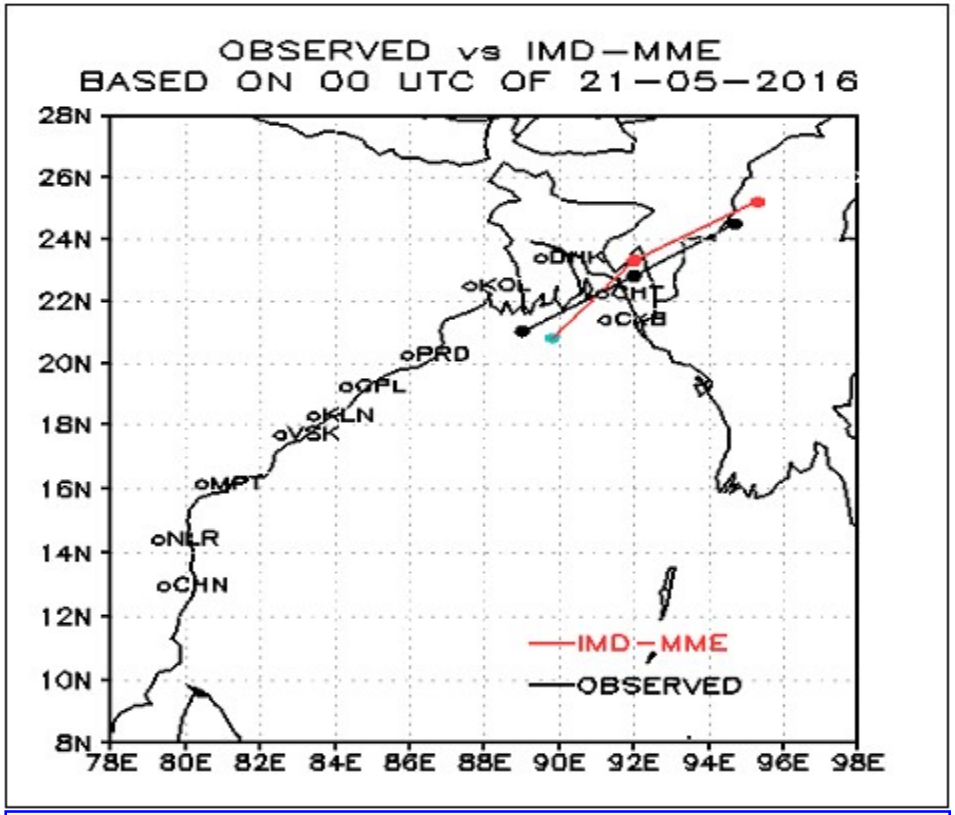


Landfall forecast Lead Time -34 h

NWP model and consensus NWP (Multi-model ensemble) track forecasts based on 12 UTC of 20.05.2016 and 00 TUC 21.05.2016 for cyclone ROANU



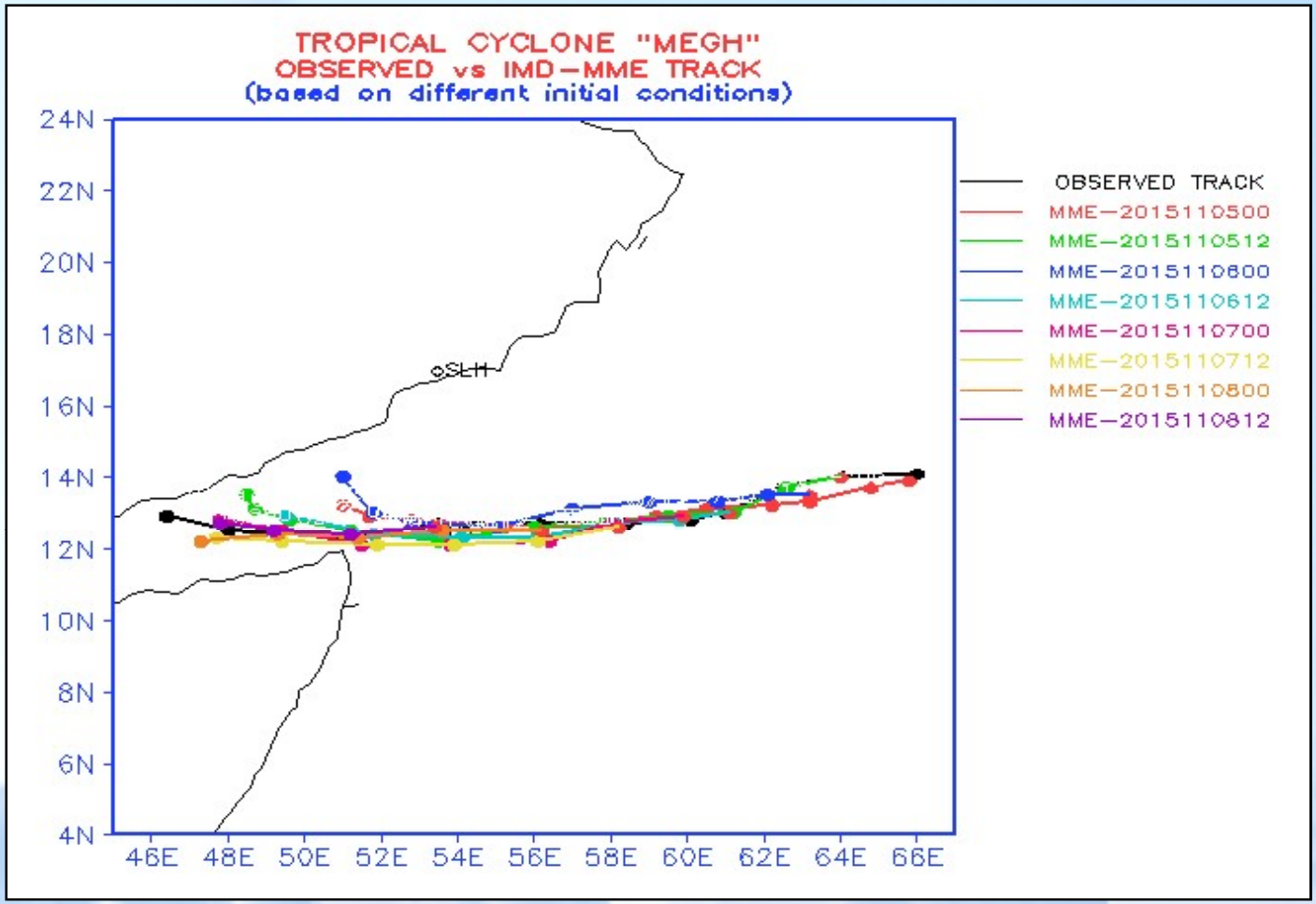
Landfall forecast Lead Time -22 h



Landfall forecast Lead Time -10 h

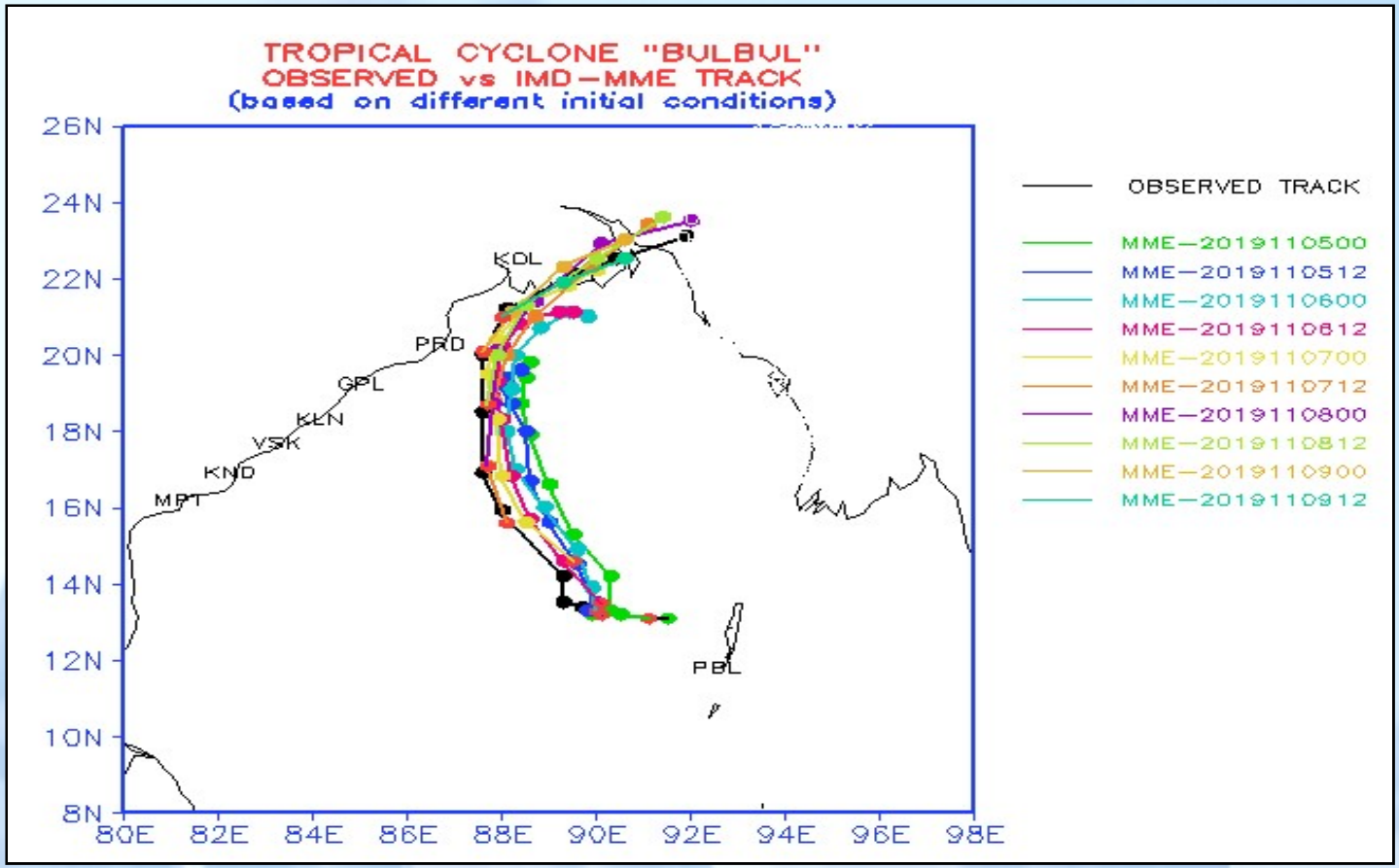
ESCS MEGH: 05-10 November 2015

(Arabian Sea)

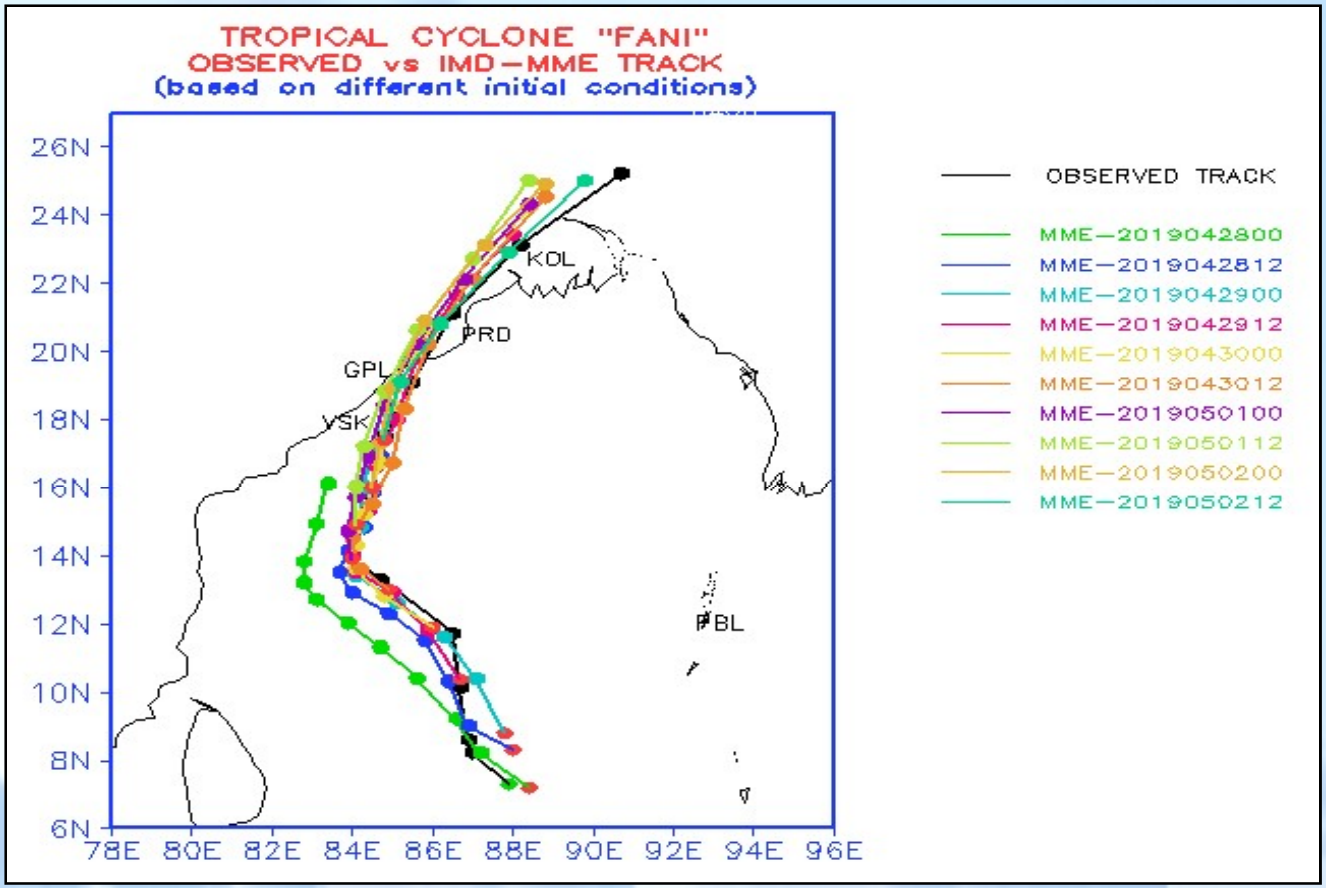

TROPICAL CYCLONE "MEGH"
OBSERVED vs IMD-MME TRACK
(based on different initial conditions)
24N
22N
20N
18N
16N
14N
12N
10N
8N
6N
4N
46E
48E
50E
52E
54E
56E
58E
60E
62E
64E
66E
OBSERVED TRACK
MME-2015110500
MME-2015110512
MME-2015110600
MME-2015110612
MME-2015110700
MME-2015110712
MME-2015110800
MME-2015110812

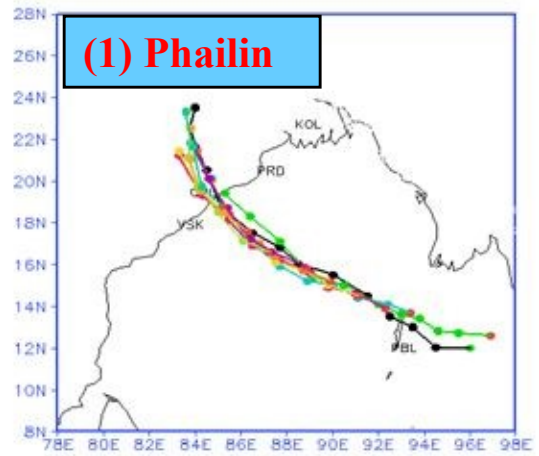
All Track forecasts by MME vs Observed Track (BULBUL)

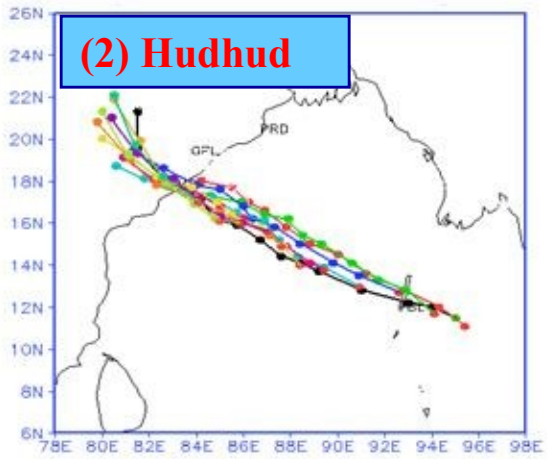
(Bay of Bengal November 2019)

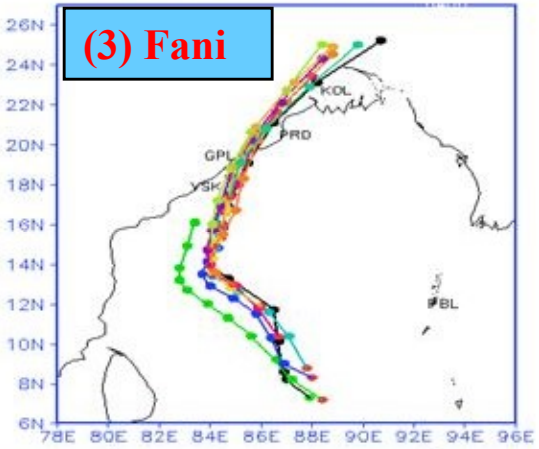


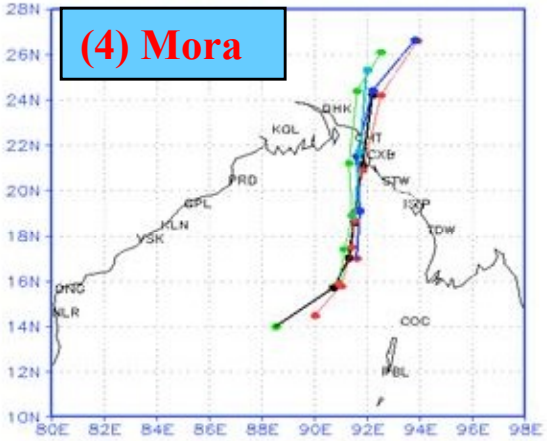
All Track forecasts by MME vs Observed Track (FANI)
(Bay of Bengal April 2019)

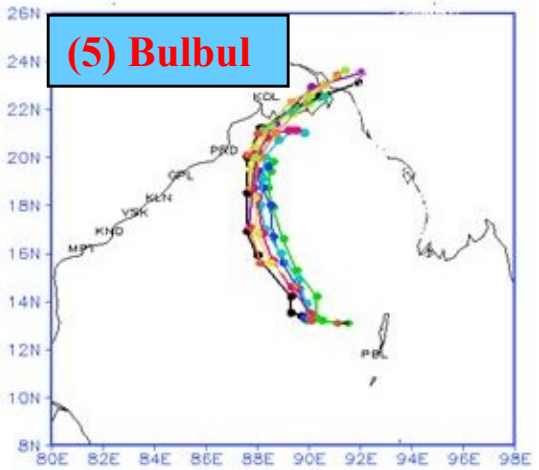


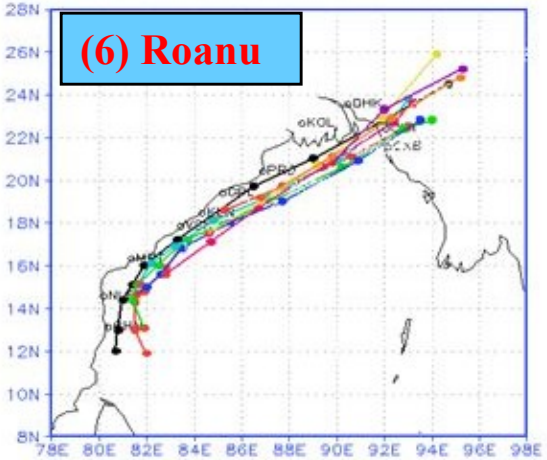

(1) Phailin
KOL
PRD
VSK
PBL

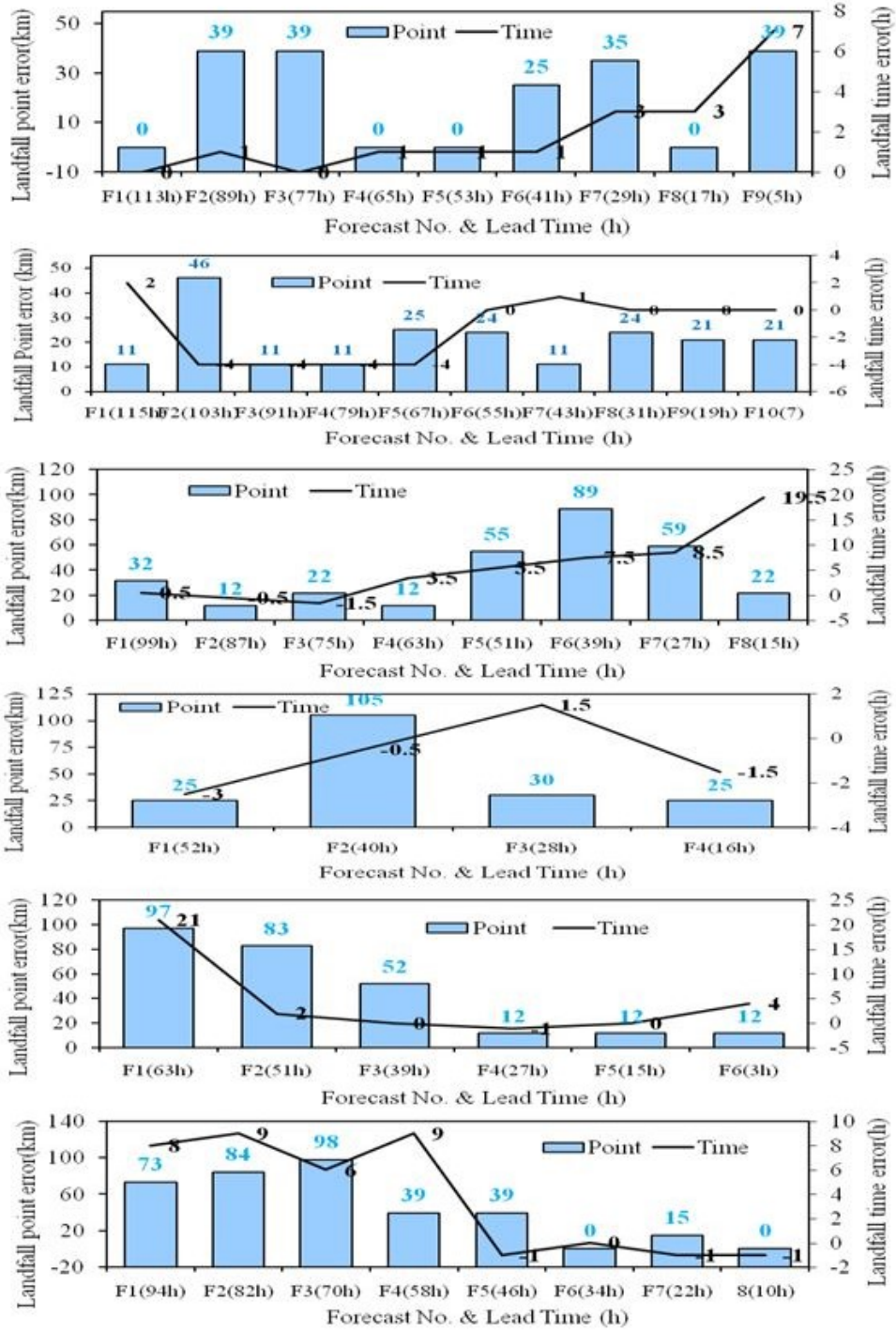

(2) Hudhud
PRD
GPL


(3) Fani
KOL
PRD
GPL
VSK
PBL


(4) Mora
DHK
KOL
PRD
GPL
KLN
VSK
TDW
DNC
NLR
COC
PBL

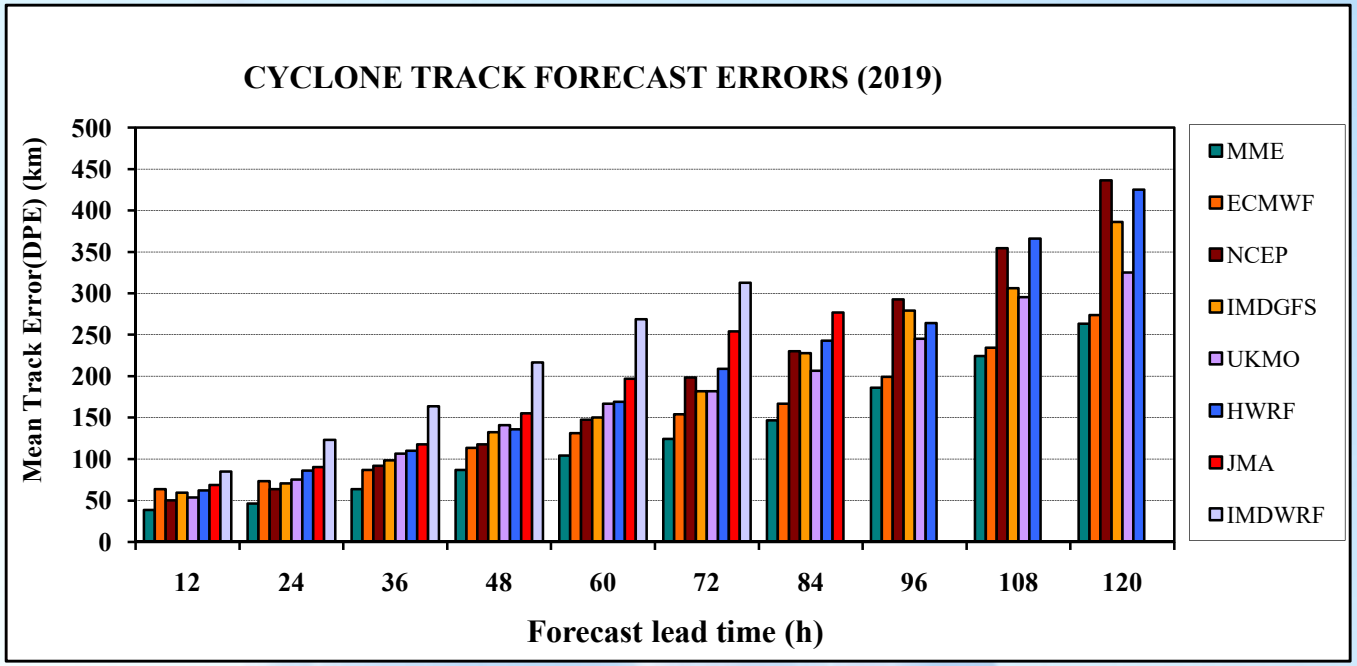

(5) Bulbul
KOL
PRD
GPL
KLN
VSK
KND
MPT
PBL

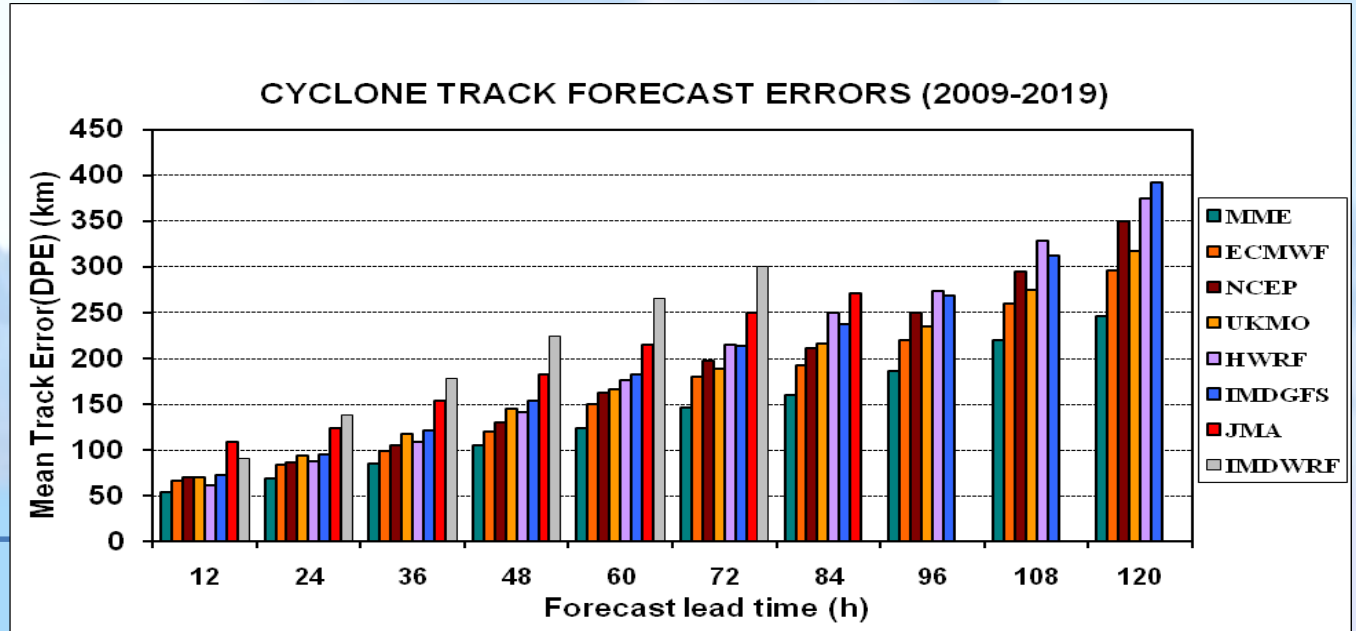

(6) Roanu



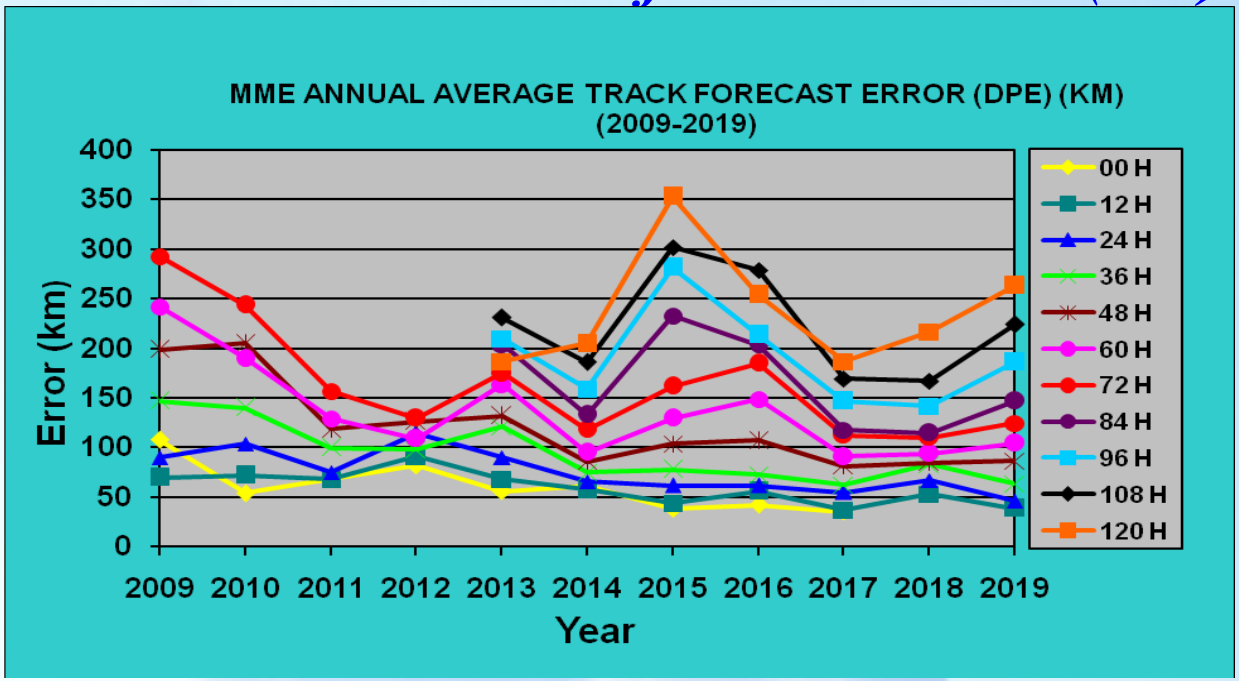
TCs (a) Phailin, (b) Hudhud, (c) Fani, (d) Mora, (e) Bulbul, and (f) Roanu.

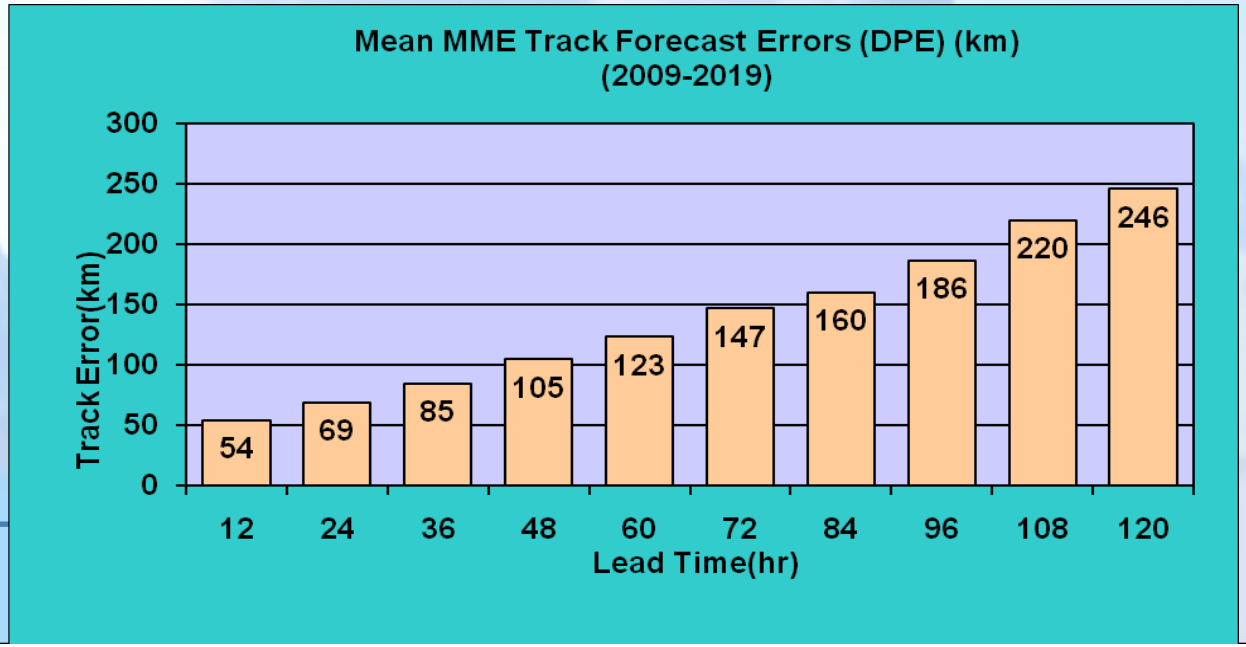
Mean track forecast error (km) - 2019



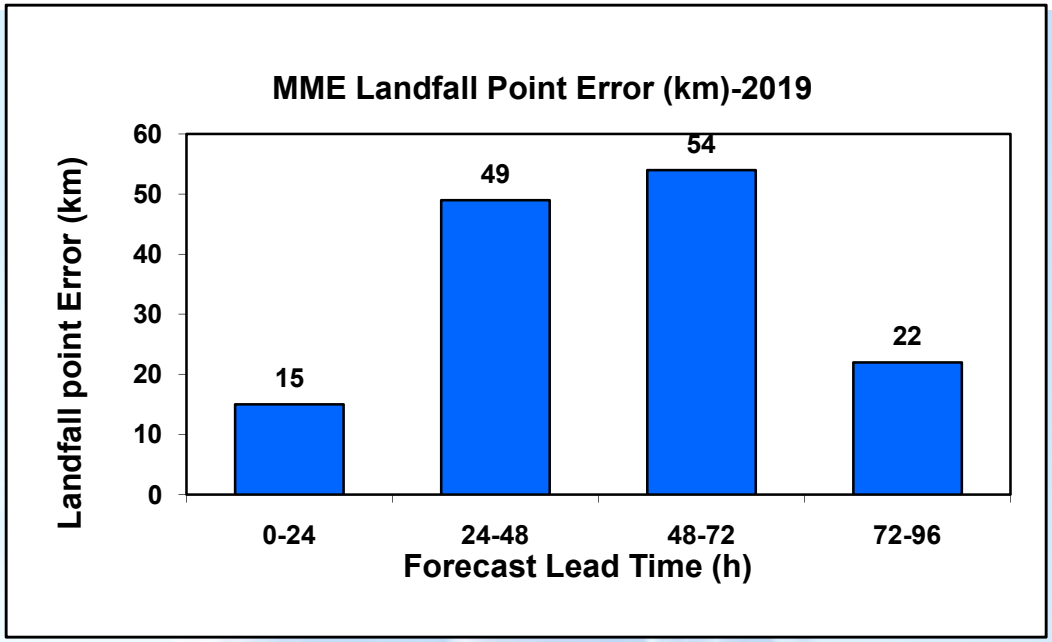


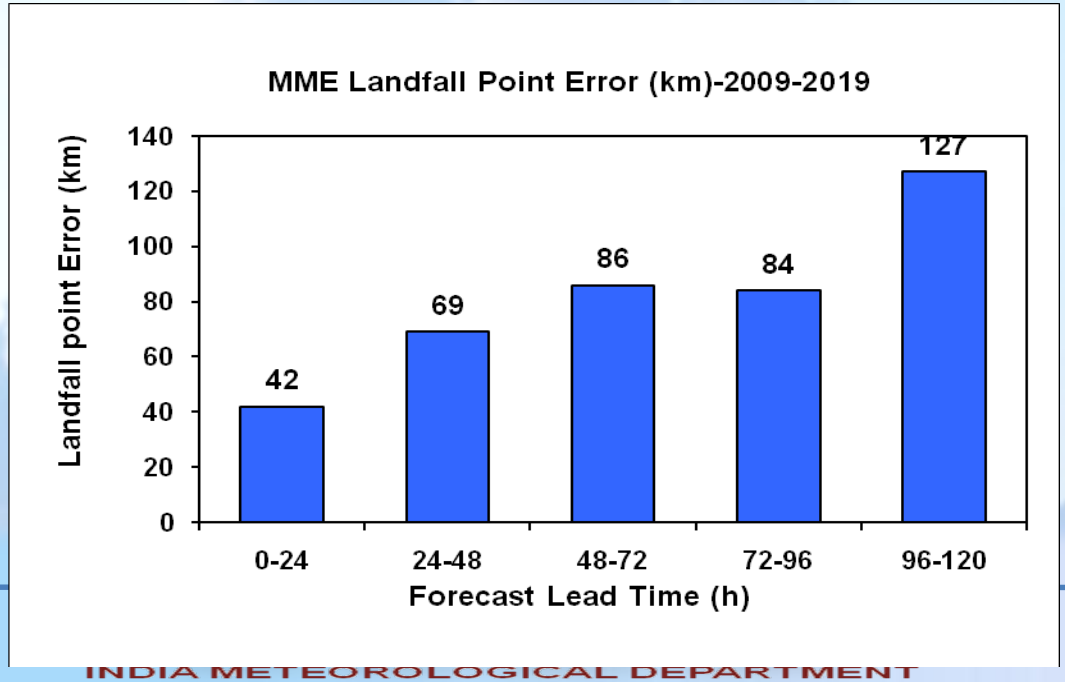
Year wise MME track forecast error (km)



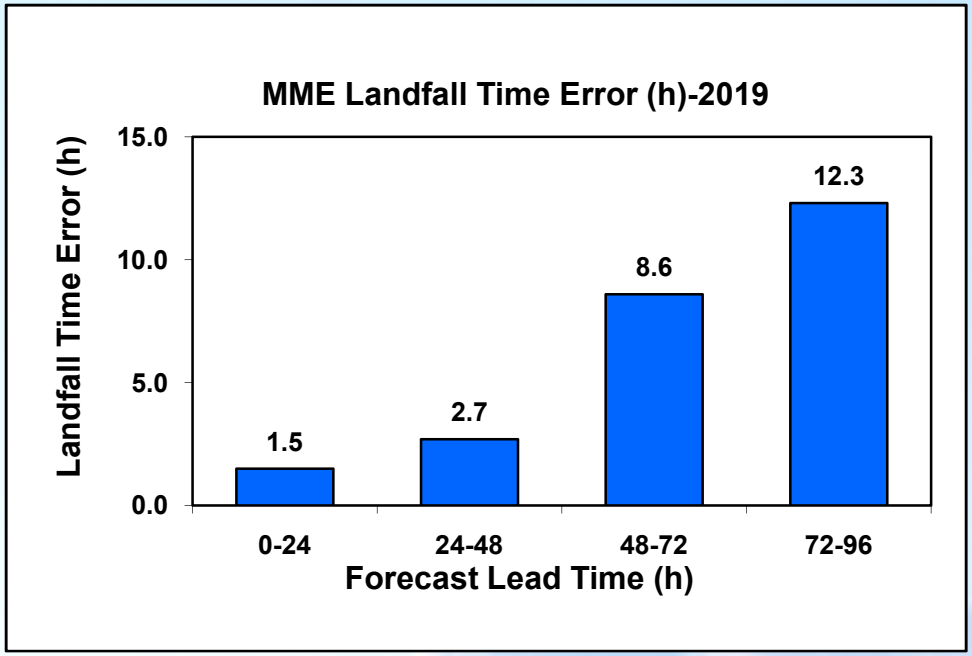


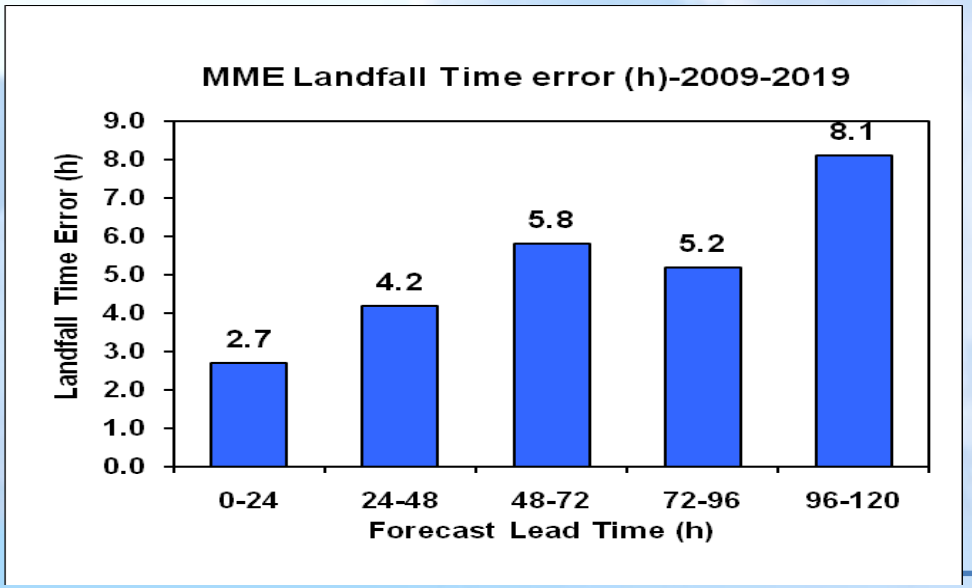
Landfall Point error (km)





Landfall Time error (h)





Kotal, S.D., and Bhattacharya S.K., 2021. "Evolution of Tropical Cyclone Forecasts of Dynamical-statistical Cyclone Prediction System (CPS) over the North Indian Ocean during the decade (2010-2019)". ***MAUSAM, 72(1):87-106. January 2021 (17 April 2021).***

भारत मौसम विज्ञान विभाग
INDIA METEOROLOGICAL DEPARTMENT