NWP BASED OBJECTIVE CYCLONE PREDICTION SYSTEM

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STEP-III: Tropical Cyclone Intensity Prediction by SCIP model

[Kotal, S.D., Roy Bhowmik, S.K., Kundu, P.K. and Das, A.K., 2008. A Statistical Cyclone Intensity Prediction (SCIP) Model for Bay of Bengal. *Journal of Earth System Science (Springer) 117:157-168.*]

Objective:

Intensity prediction at 12-hr interval up to 72 hours

Statistical Cyclone Intensity Prediction (SCIP) Model

Data sample: 62 Tropical Cyclones during the period 1981 to 2000

The predictors:

S.No	Predictors	Symbol of Predictors	Unit
1.	Intensity change during last 12 hours	IC12	Knots
2.	Vorticity at 850 hPa	V850	$\times 10^5\ s^{-1}$
3.	Storm motion speed	SMS	ms^{-1}
4.	Divergence at 200 hPa	D200	$\times 10^5\ s^{-1}$
5.	Initial Storm intensity	ISI	Knots
6.	Initial Storm latitude position	ISL	°N
7.	Sea surface temperature	SST	°C
8.	Vertical wind shear	VWS	Knots

Formulation of the model:

The model is developed using multiple linear regression technique

$$y = a_o + a_1 x_1 + a_2 x_2 + \ldots\ldots\ldots + a_n x_n$$

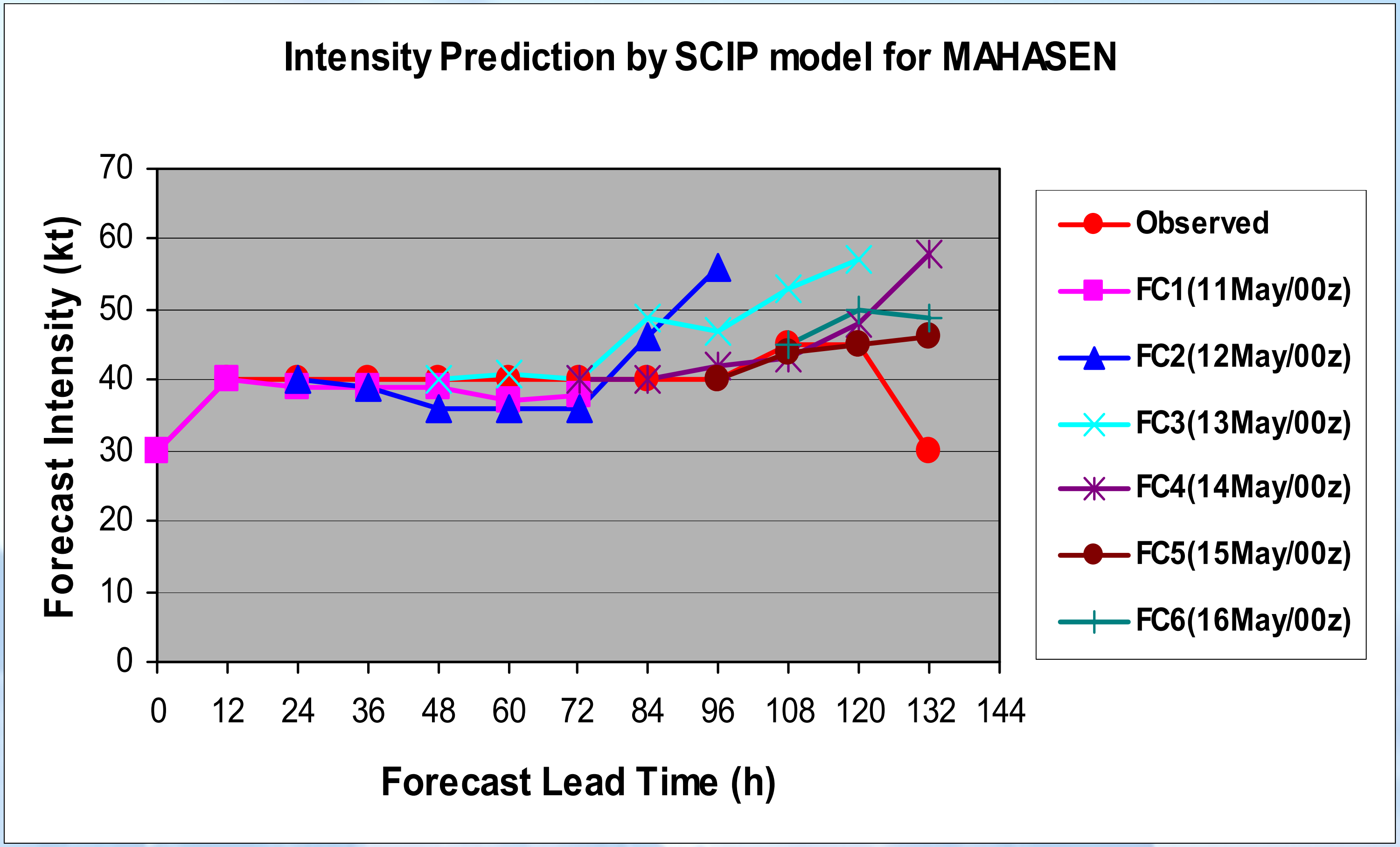
The SCIP model estimates changes of intensity at 12, 24, 36, 48, 60 and 72 hours. Six separate regression analyses are carried out for forecast interval 12, 24, 36, 48, 60 and 72 hour.

12 hours intensity change by multiple linear regression technique is defined as:

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

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

CS VIYARU: May 10-16


Intensity Prediction by SCIP model for MAHASEN
Forecast Intensity (kt)
0
10
20
30
40
50
60
70
0
12
24
36
48
60
72
84
96
108
120
132
144
Forecast Lead Time (h)
Observed
FC1(11May/00z)
FC2(12May/00z)
FC3(13May/00z)
FC4(14May/00z)
FC5(15May/00z)
FC6(16May/00z)

Intensity forecast error (kt)- VIYARU

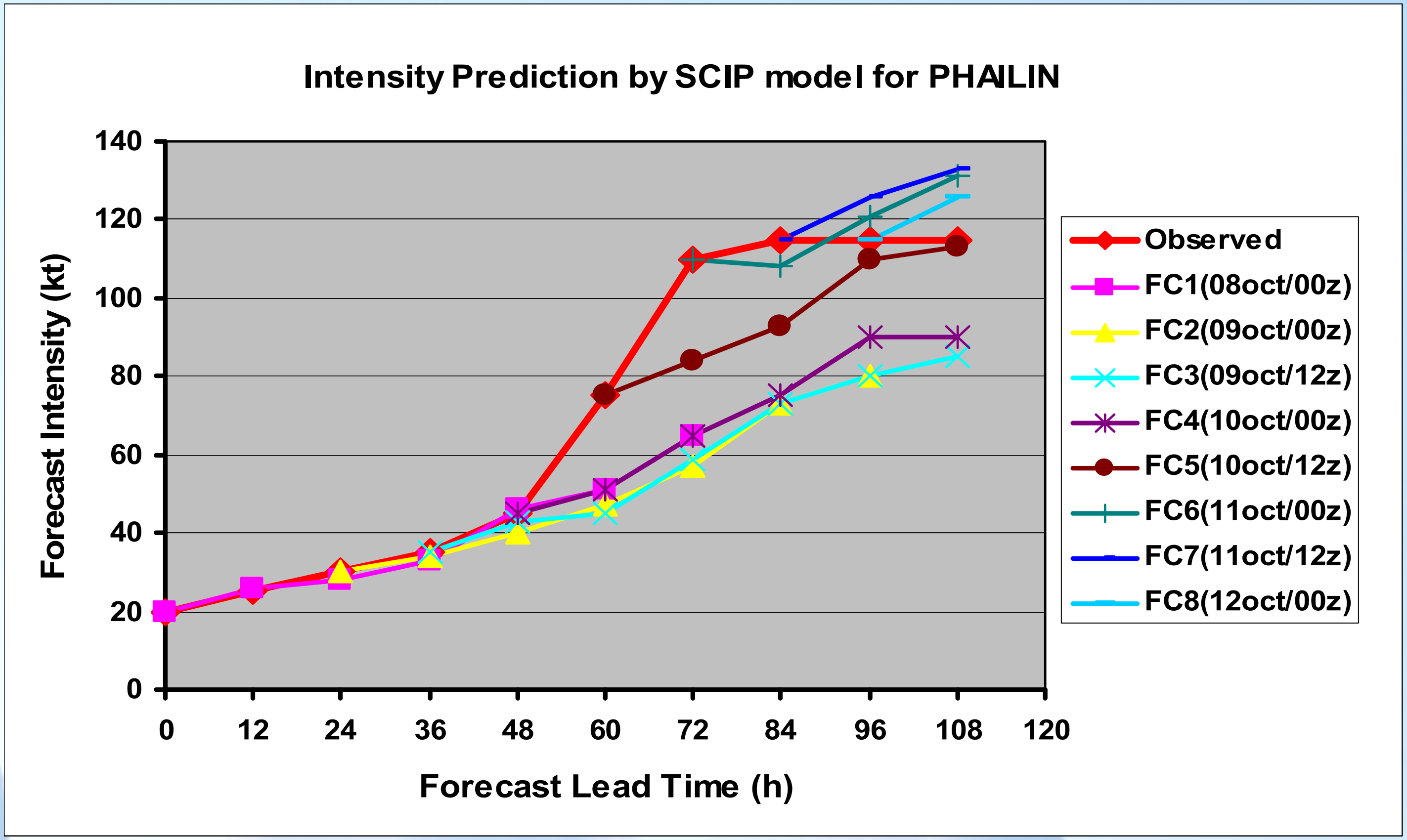
Average absolute errors (Number of forecasts verified is given in the parentheses)

Lead time →	12 hr	24 hr	36 hr	48 hr	60 hr	72 hr	84 hr	96 hr	108 hr	120 hr
IMD-SCIP	1.3 (6)	4.3 (6)	6.4 (5)	3.8 (4)	11.3 (4)	10.0 (3)	-	-	-	-
IMD-HWRF	27.2(10)	21.3(9)	8.6(8)	10.9(7)	19.2(6)	23.0(5)	29.5(4)	14.0(3)	22.0(2)	29.0(1)
OFFICIAL	3.6 (24)	6.8(22)	8.7(20)	10.0(18)	13.0(16)	15.0(14)	14(10)	13(8)	17(6)	14(4)

Root Mean Square (RMSE) errors (Number of forecasts verified is given in the parentheses)

Lead time →	12 hr	24 hr	36 hr	48 hr	60 hr	72 hr	84 hr	96 hr	108 hr	120 hr
IMD-SCIP	2.2 (6)	8.0 (6)	8.5 (5)	4.3 (4)	14.9 (4)	11.6 (3)	-	-	-	-
IMD-HWRF	30.0(10)	24.3(9)	12.2(8)	12.8(7)	22.8(6)	28.0(5)	31.5(4)	14.3(3)	22.4(2)	29.0(1)
OFFICIAL	4.6 (24)	8.9(22)	10.8(20)	12.5(18)	16.1(16)	17.8(14)	16.1(10)	15.7(8)	17.5(6)	16.4(4)

VSCS PHAILIN: October 8-14



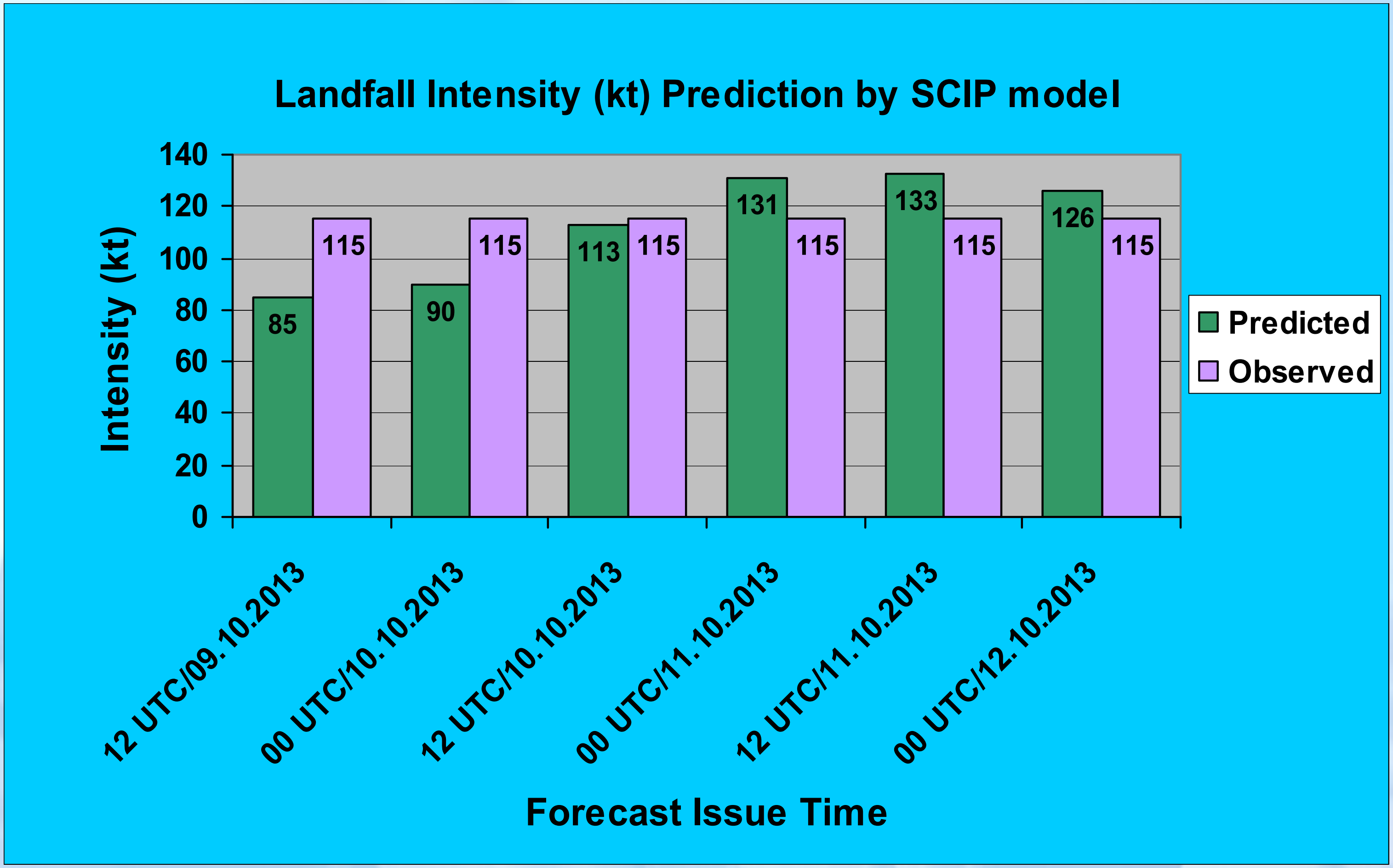
Intensity Prediction by SCIP model for PHAILIN
Forecast Intensity (kt)
140
120
100
80
60
40
20
0
0
12
24
36
48
60
72
84
96
108
120
Forecast Lead Time (h)
Observed
FC1(08oct/00z)
FC2(09oct/00z)
FC3(09oct/12z)
FC4(10oct/00z)
FC5(10oct/12z)
FC6(11oct/00z)
FC7(11oct/12z)
FC8(12oct/00z)

Average absolute errors (PHAILIN)
(Number of forecasts verified is given in t he parentheses)

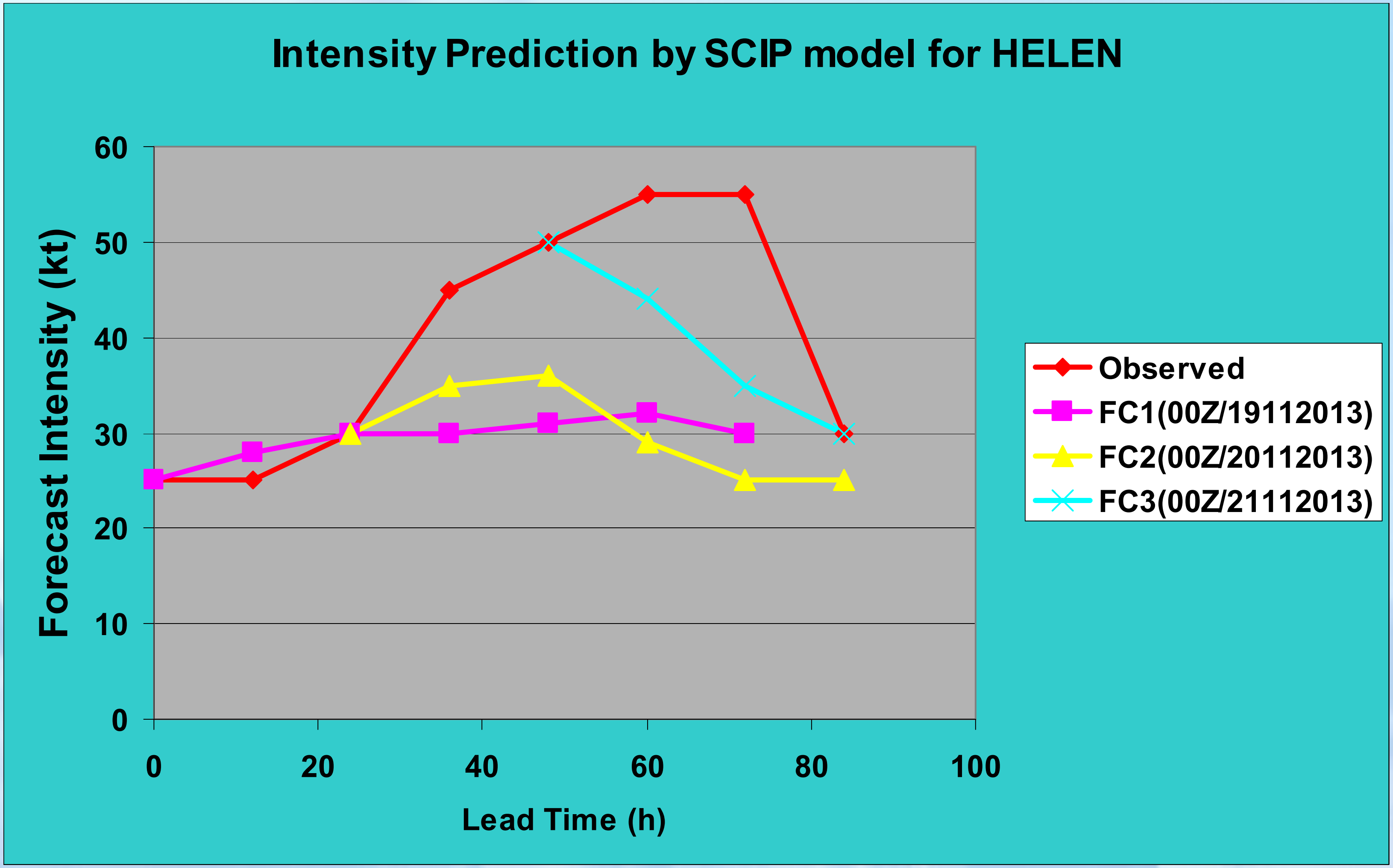
Lead time →	12 hr	24 hr	36 hr	48 hr	60 hr	72 hr	84 hr
IMD-SCIP	10.4(8)	18.3(7)	23.7(6)	24.6(5)	31.5(4)	36.7(3)	-
IMD-HWRF	17.0(6)	21.0(5)	27.8(5)	30.5(4)	28.3(3)	19.5(2)	11.0(1)

Root Mean Square (RMSE) errors
(Number of forecasts verified is given in the parentheses)

Lead time →	12 hr	24 hr	36 hr	48 hr	60 hr	72 hr	84 hr
IMD-SCIP	13.9(8)	23.3(7)	29.6(6)	32.3(5)	32.4(4)	37.2(3)	-
IMD-HWRF	19.0(6)	24.2(5)	31.7(5)	31.2(4)	28.6(3)	20.0(2)	14.9(1)


Landfall Intensity (kt) Prediction by SCIP model
Intensity (kt)
0
20
40
60
80
100
120
140
85
115
90
115
113
115
131
115
133
115
126
115
Predicted
Observed
12 UTC/09.10.2013
00 UTC/10.10.2013
12 UTC/10.10.2013
00 UTC/11.10.2013
12 UTC/11.10.2013
00 UTC/12.10.2013
Forecast Issue Time

SCS HELEN: Nov 19-23



Intensity Prediction by SCIP model for HELEN
Forecast Intensity (kt)
0
10
20
30
40
50
60
0
20
40
60
80
100
Lead Time (h)
Observed
FC1(00Z/19112013)
FC2(00Z/20112013)
FC3(00Z/21112013)

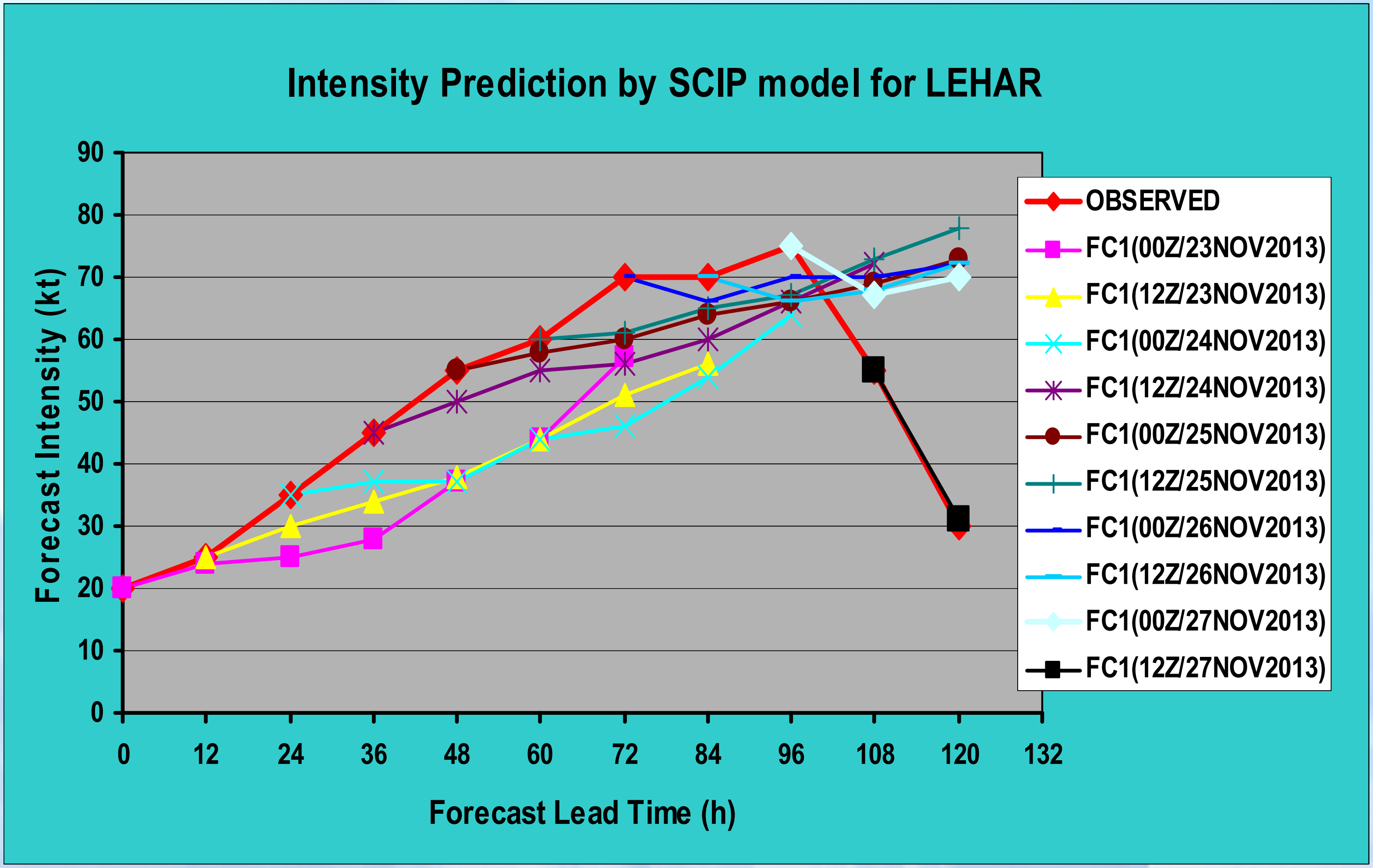
Average absolute errors (HELEN)
(Number of forecasts verified is given in t he parentheses)

Lead time →	12 hr	24 hr	36 hr	48 hr	60 hr	72 hr	84 hr
IMD-SCIP	8.0(3)	11.3(3)	20.5(2)	24.5(2)	14.0(2)	25.0(1)	-
IMD-HWRF	5.3(4)	11.0(4)	7.0(3)	6.0(2)	-	-	-

Root Mean Square (RMSE) errors
(Number of forecasts verified is given in the parentheses)

Lead time →	12 hr	24 hr	36 hr	48 hr	60 hr	72 hr	84 hr
IMD-SCIP	8.8(3)	14.1(3)	21.2(2)	25.1(2)	16.6(2)	25.0(1)	-
IMD-HWRF	7.9(4)	11.6(4)	8.2(3)	6.7(3)	-	-	-

VSCS LEHAR: Nov 23-28


Intensity Prediction by SCIP model for LEHAR
Forecast Intensity (kt)
90
80
70
60
50
40
30
20
10
0
0
12
24
36
48
60
72
84
96
108
120
132
Forecast Lead Time (h)
OBSERVED
FC1(00Z/23NOV2013)
FC1(12Z/23NOV2013)
FC1(00Z/24NOV2013)
FC1(12Z/24NOV2013)
FC1(00Z/25NOV2013)
FC1(12Z/25NOV2013)
FC1(00Z/26NOV2013)
FC1(12Z/26NOV2013)
FC1(00Z/27NOV2013)
FC1(12Z/27NOV2013)

Average absolute errors (LEHAR)
(Number of forecasts verified is given in the parentheses)

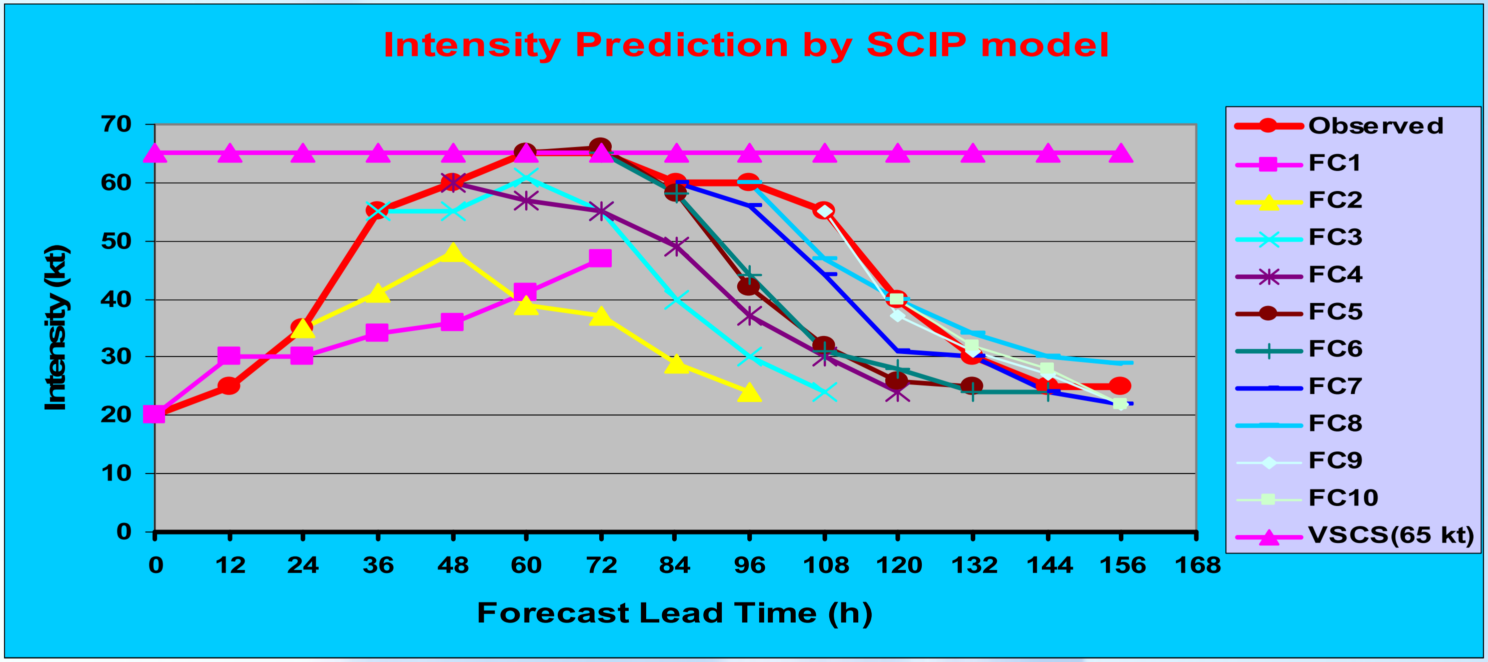
Lead time →	12 hr	24 hr	36 hr	48 hr	60 hr	72 hr	84 hr	96 hr	108 hr	120 hr
IMD-SCIP	5.6 (10)	13.0 (9)	16.9 (8)	19.6 (7)	20.3 (6)	19.6 (5)	-	-	-	-
IMD-HWRF	23.4(9)	12.9(8)	12.4(7)	12.7(7)	7.3(6)	13.6(5)	21.3(4)	22.7(3)	30.5(2)	57(1)

Root Mean Square (RMSE) errors
(Number of forecasts verified is given in the parentheses)

Lead time →	12 hr	24 hr	36 hr	48 hr	60 hr	72 hr	84 hr	96 hr	108 hr	120 hr
IMD-SCIP	6.6 (10)	16.6 (9)	19.7 (8)	22.1 (7)	24.0 (6)	22.9 (5)	-	-	-	-
IMD-HWRF	25.7(9)	17.1(8)	15.5(7)	13.6(7)	9.7(6)	19.2(5)	28.3(4)	29.5(3)	31.2(2)	57(1)

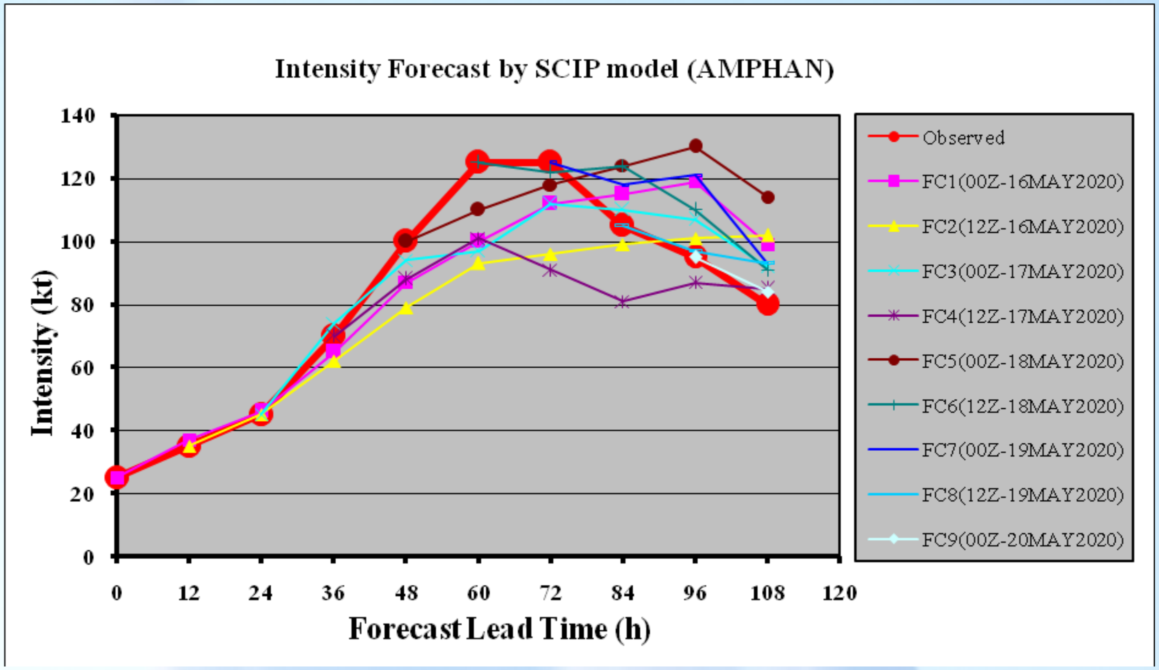
VSCS MADI: Dec 6-13

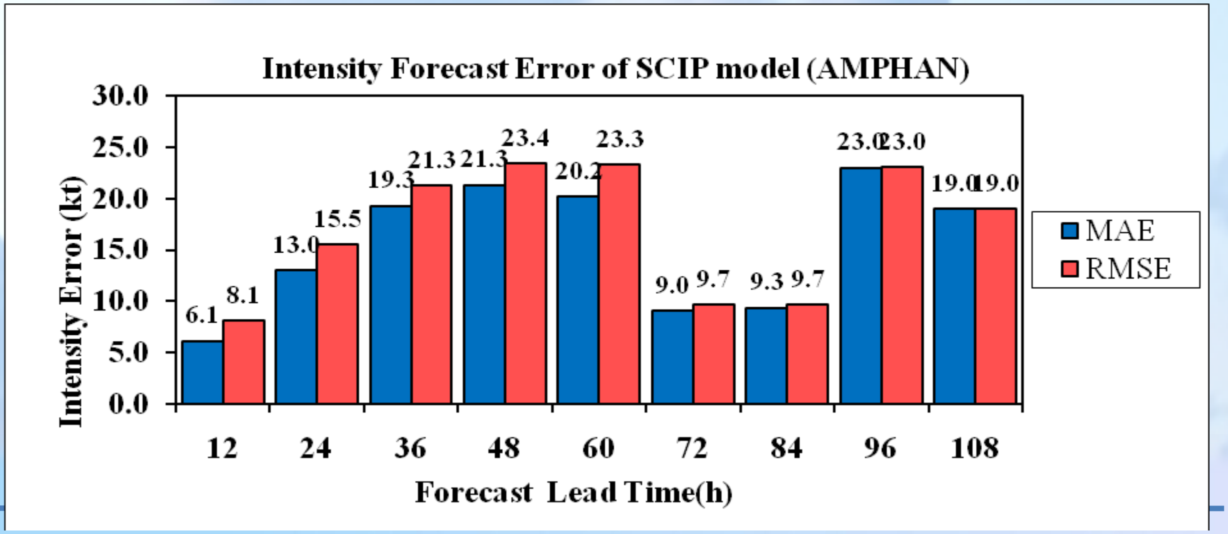
INTENSITY FORECASTS BY SCIP (MADI)



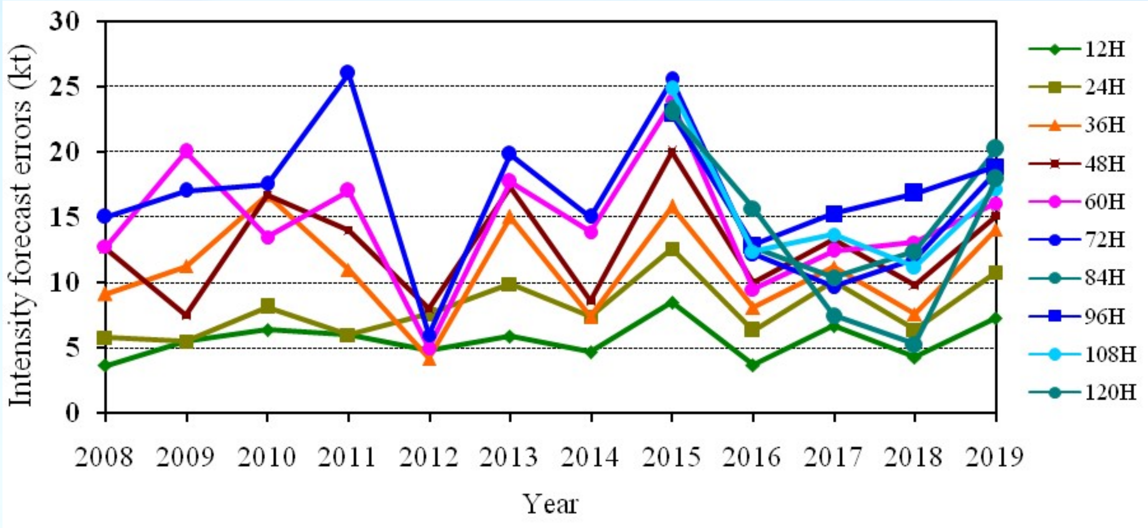
Lead time →	12 hr	24 hr	36 hr	48 hr	60 hr	72 hr
AAE	5.2 (10)	6.4 (10)	12.8(10)	15.3 (9)	16.9 (8)	15.7 (7)
RMSE	6.4 (10)	8.2 (10)	15.3(10)	18.2 (9)	20.3 (8)	20.3 (7)

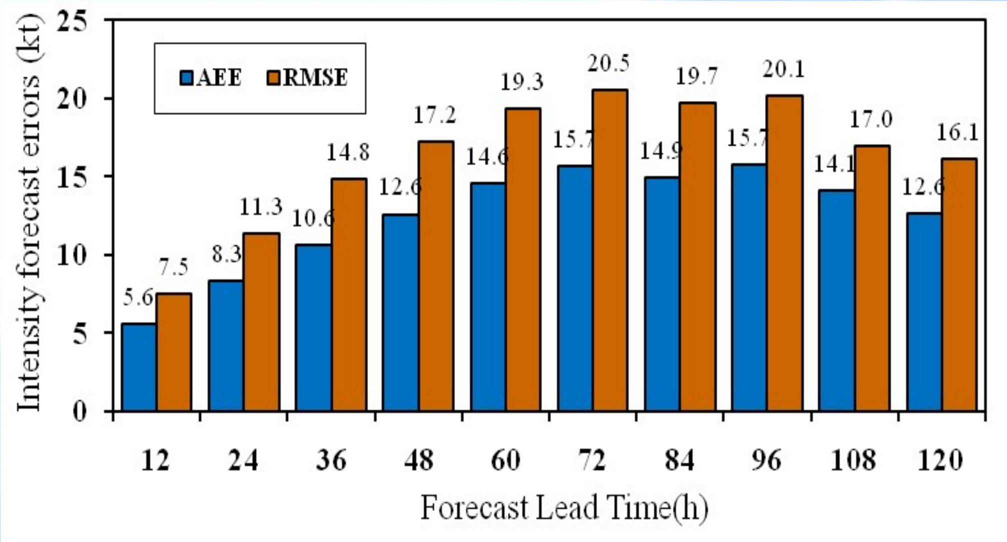
INTENSITY FORECASTS BY SCIP (AMPHAN)

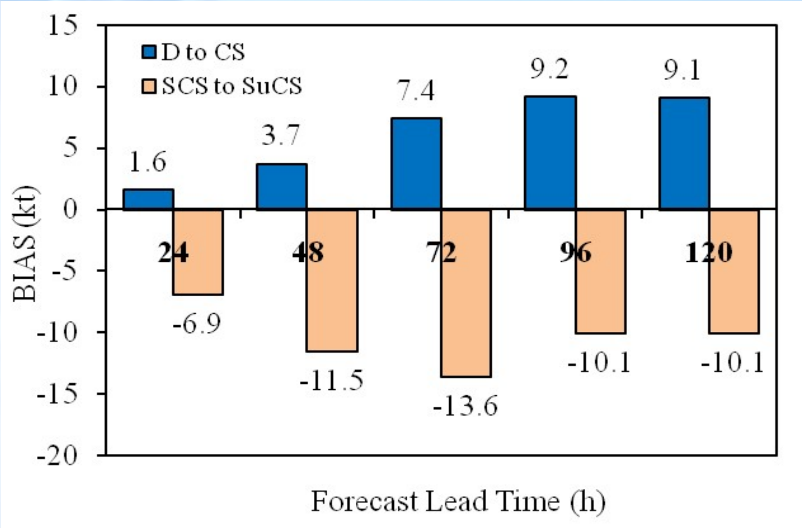




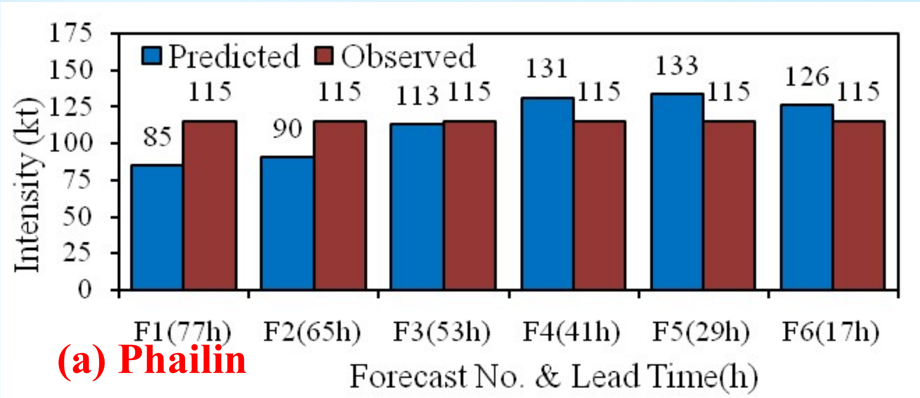
MEAN FORECAST ERRORS : 2010-2019



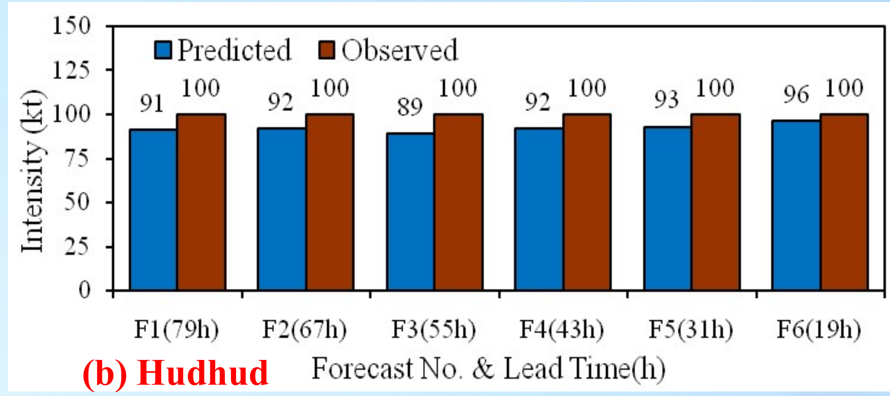




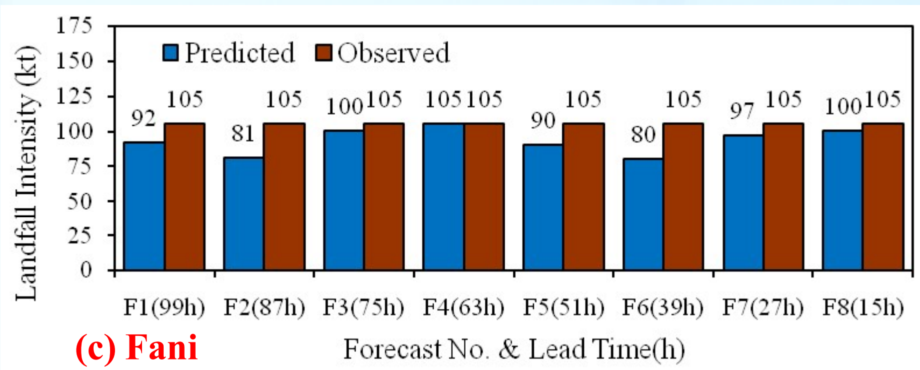
LANDFALL INTENSITY FORECASTS BY SCIP



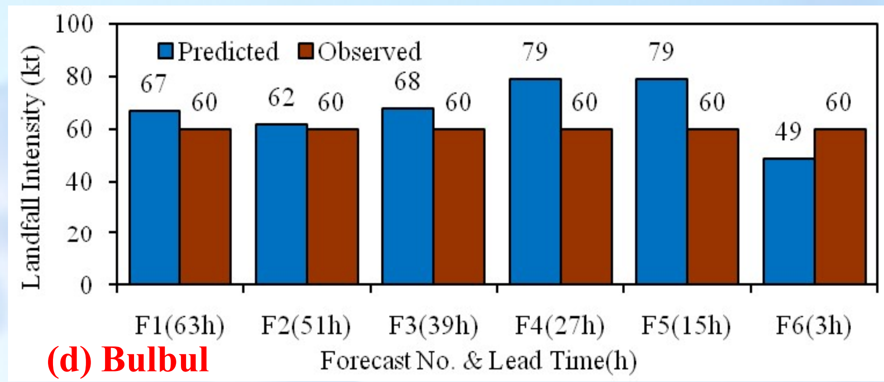
(a) Phailin



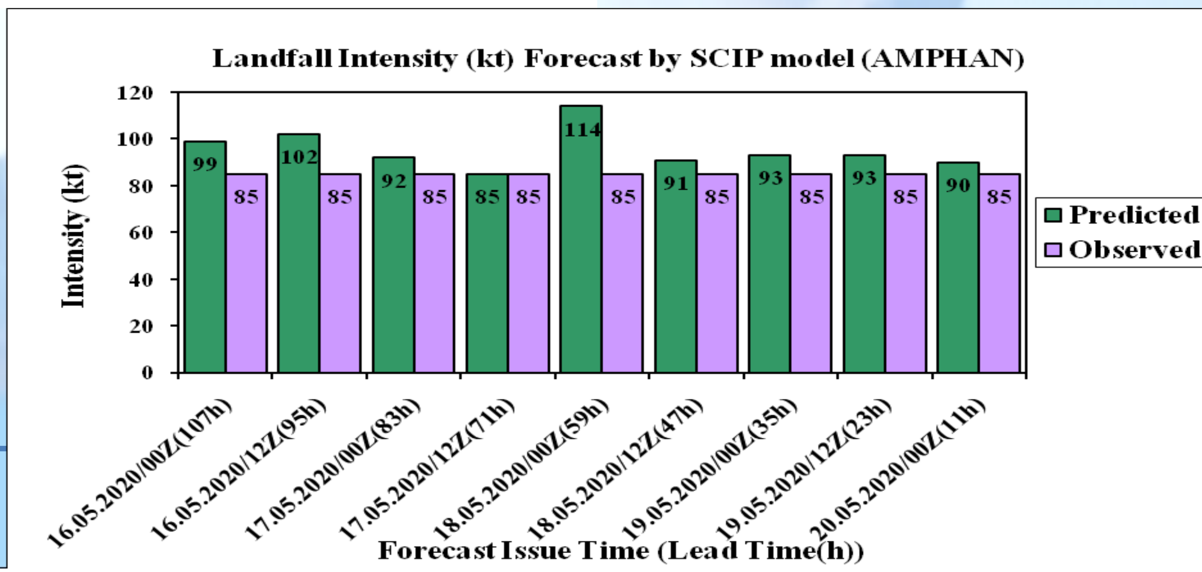
(b) Hudhud

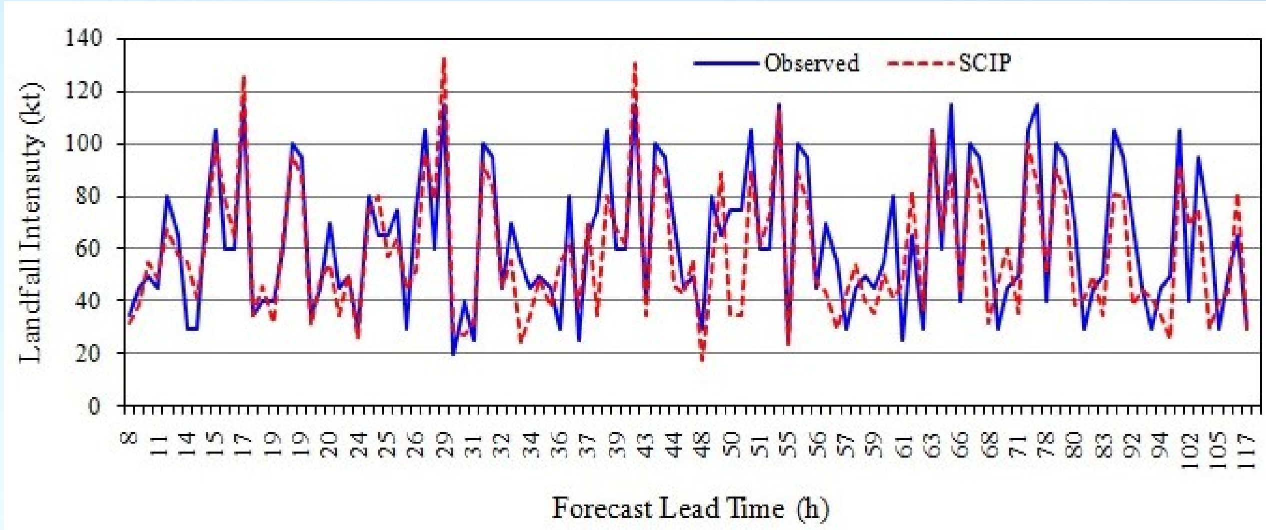


(c) Fani

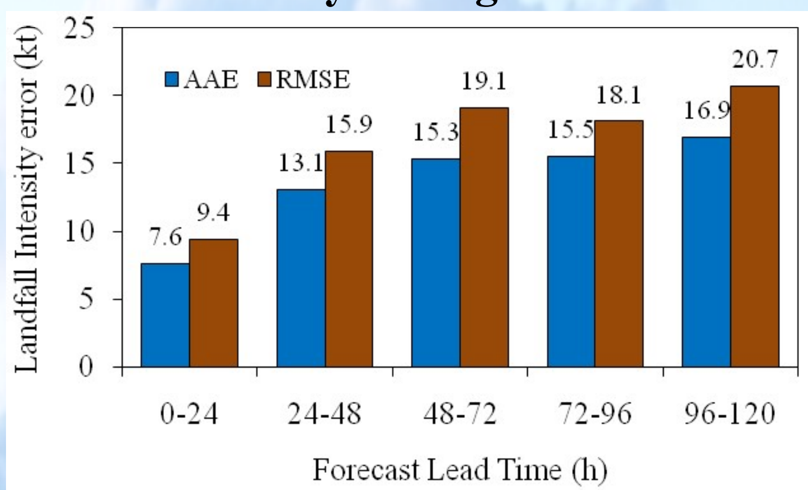


(d) Bulbul





Landfall intensity forecast by SCIP versus Observed intensity during 2010-2019



Mean landfall intensity error(h) of SCIP model during 2010-2019

STEP-IV: Rapid Intensification(RI)

[Kotal, S.D. and Roy Bhowmik S.K. 2013. Large-Scale Characteristics of Rapidly Intensifying Tropical Cyclones over the Bay of Bengal and a Rapid Intensification (RI) Index. *Mausam,* 64(1):13-24.]

Objective: Probability forecast of Rapid Intensification

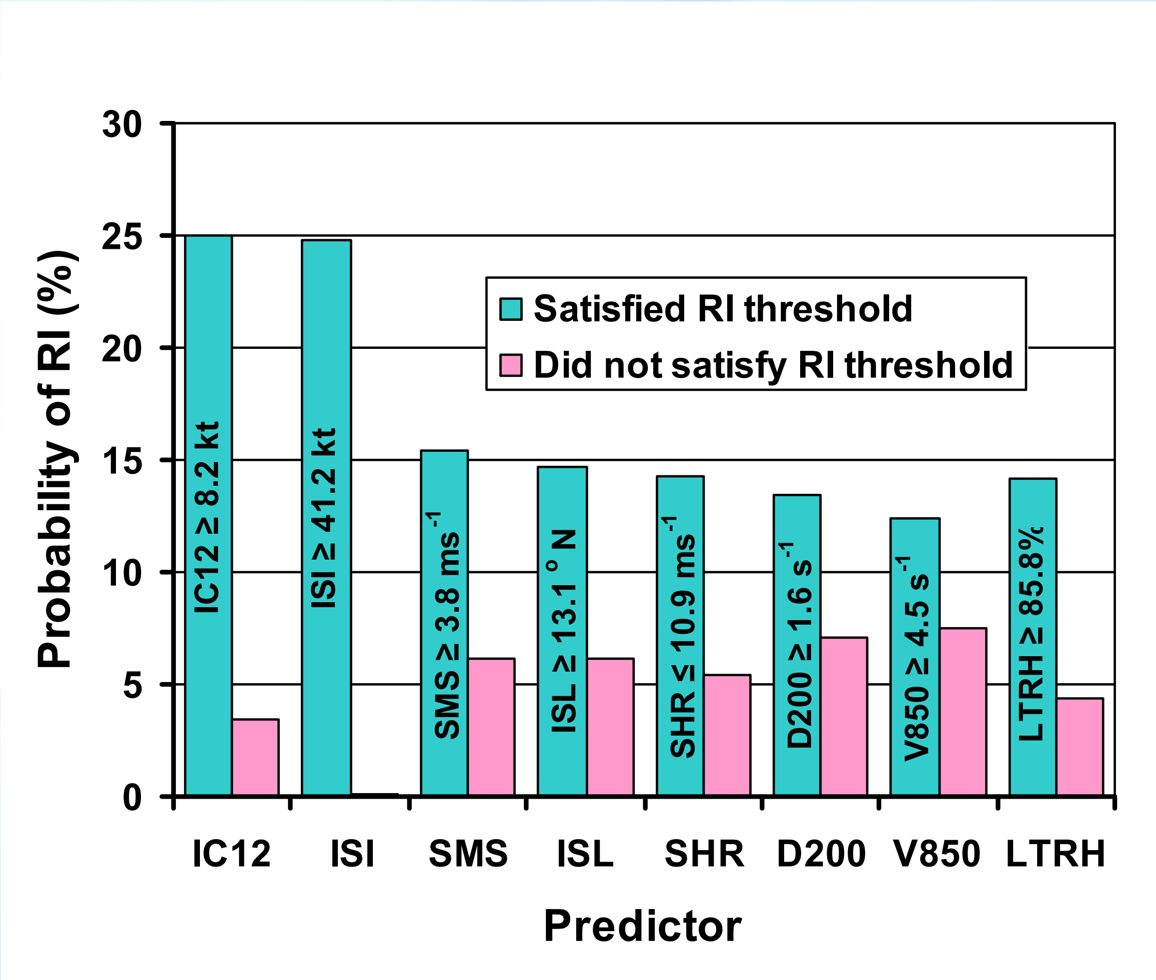
Rapid Intensification: Increase of intensity by 30 kt during 24 h

Data sample: 88 Tropical Cyclones during the period 1981 to 2010

Rapid Intensification

S.No.	Variables	Symbol of Variables	Unit
1.	Previous 12-h intensity change	IC12	kt
2.	Vorticity at 850 hPa	V850	10^{-5} s^{-1}
3.	Storm motion speed	SMS	ms^{-1}
4.	Divergence at 200 hPa	D200	10^{-5} s^{-1}
5.	Initial Storm intensity	ISI	kt
6.	Initial Storm latitude position	ISL	°N
7.	850-700 hPa average relative humidity	LTRH	%
8.	850-200 hPa vertical wind shear	SHR	ms^{-1}
9.	Sea Surface Temperature	SST	°C

Rapid Intensification Index (RII)



- Data Period - 1981-2010
- No. of TC - 88
- No. of data sample - 483
- No. of parameter - 8

Composite probability of Rapid Intensification

The composite probability of RI (P_n) is defined as:

$$P_n = \left(\frac{n_1}{(n_1 + n_2)} \right) \times 100\%$$

Where,

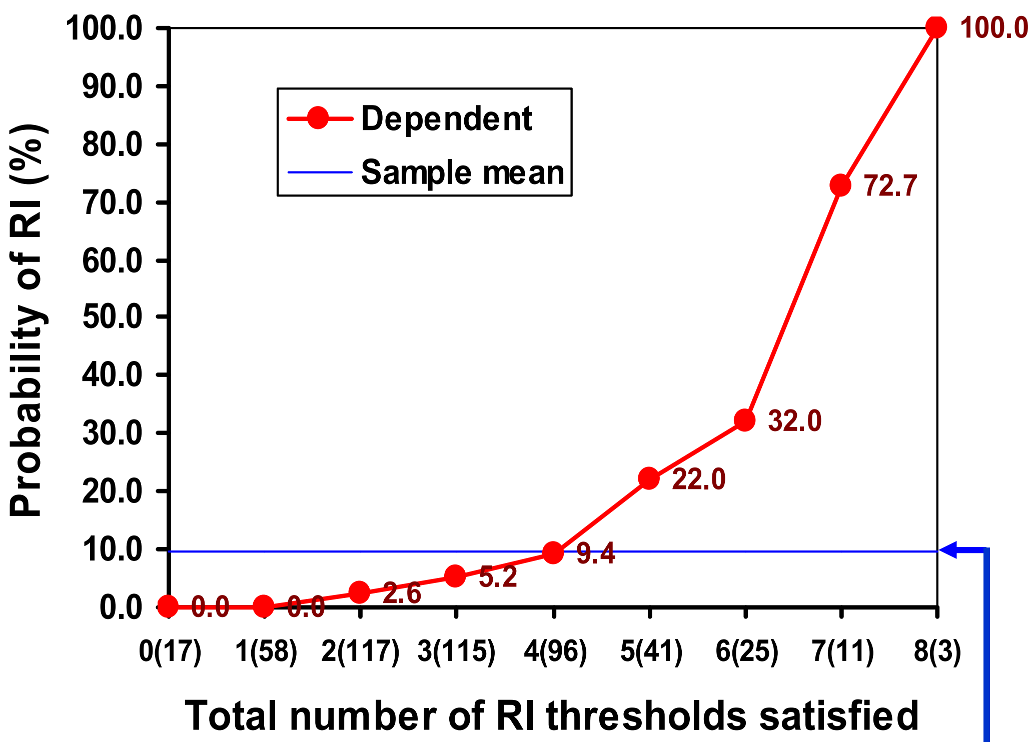
P_n = RI probability for n number of variables that satisfied their respective thresholds

n_1 = Number of RI cases that satisfied the n number thresholds

n_2 = Number of non-RI cases that satisfied the n number thresholds

n = 0, 1, 2, 3, 4, 5, 6, 7, 8 (number of variables)

Composite probability of Rapid Intensification



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

Climatological Probability of RI=9.5%

Probability of Rapid intensification (by RI-Index)

Rapid intensification (RI) is defined as: Increase of intensity by 30 kts or more during subsequent 24 hour.

Forecast based on	Probability of RI predicted	Chances of occurrence predicted	Occurrence
00 UTC/11.05.2013	9.4 %	VERY LOW	NO
00 UTC/12.05.2013	5.2 %	VERY LOW	NO
00 UTC/13.05.2013	2.6 %	VERY LOW	NO
00 UTC/14.05.2013	5.2 %	VERY LOW	NO
00 UTC/15.05.2013	9.4 %	VERY LOW	NO
12 UTC/15.05.2013	22.0 %	LOW	NO
Inference: RI-Index could able to predict non-occurrence of Rapid Intensification of cyclone VIYARU during its lifetime.			

Probability of Rapid intensification (by RI-Index)-PHAILIN

Rapid intensification (RI) is defined as: Increase of intensity by 30 kts or more during subsequent 24 hour.

Forecast based on	Probability of RI predicted	Chances of occurrence predicted	Intensity changes (kt) in 24h	Occurrence
00 UTC/08.10.2013	9.4 %	VERY LOW	5	NO
00 UTC/09.10.2013	9.4 %	VERY LOW	15	NO
12 UTC/09.10.2013	9.4 %	VERY LOW	40	YES
00 UTC/10.10.2013	72.7 %	HIGH	65	YES
12 UTC/10.10.2013	72.7 %	HIGH	40	YES
00 UTC/11.10.2013	72.7 %	HIGH	5	NO
12 UTC/11.10.2013	32.0 %	MODERATE	0	NO

Inference: RI-Index could able to predict OCCURENCE as well as NON-OCCURENCE of Rapid Intensification of cyclone PHAILIN during its lifetime except forecast for 12 UTC of 09.10.2013 and 00 UTC of 11.10.2013.

Probability of Rapid intensification (by RI-Index)-HELEN

Forecast based on	Probability of RI predicted	Chances of occurrence predicted	Intensity changes (kt) in 24h	Occurrence
00 UTC/19.12.2013	**5.2 %**	**VERY LOW**	**5**	**NO**
00 UTC/20.12.2013	**9.4 %**	**VERY LOW**	**20**	**NO**
00 UTC/21.10.2013	**9.4 %**	**VERY LOW**	5	NO
Inference: RI-Index was able to predict NON-OCCURENCE of Rapid Intensification of cyclone HELEN during its lifetime.				

Probability of Rapid intensification (by RI-Index)-LEHAR

Forecast based on	Probability of RI predicted	Chances of occurrence predicted	Intensity changes (kt) in 24h	Occurrence
00 UTC/23.11.2013	5.2 %	VERY LOW	5	NO
12 UTC/23.11.2013	5.2 %	VERY LOW	20	NO
00 UTC/24.11.2013	22.0 %	LOW	20	NO
12 UTC/24.11.2013	22.0 %	LOW	15	NO
00UTC/25.11.2013	32.0 %	MODERATE	15	NO
12 UTC/25.11.2013	9.4 %	VERY LOW	10	NO
00 UTC/26.11.2013	9.4%	VERY LOW	5	NO
12 UTC/26.11.2013	5.2%	VERY LOW	-15	NO
00 UTC/27.11.2013	9.4%	VERY LOW	-45	NO
12 UTC/27.11.2013	0.0%	NIL	-30	NO
Inference: RI-Index was able to predict NON-OCCURENCE of Rapid Intensification of cyclone LEHAR during its lifetime.				

Probability of Rapid intensification (by RI-Index)-MADI

Forecast based on	Probability of RI predicted	Chances of occurrence predicted	Intensity changes (kt) in 24h	Occurrence
00 UTC/06.12.2013	5.2 %	VERY LOW	10	NO
00 UTC/07.12.2013	22.0 %	LOW	25	NO
12 UTC/07.12.2013	5.2 %	VERY LOW	10	NO
00 UTC/08.12.2013	22.0 %	LOW	5	NO
12 UTC/08.12.2013	9.4 %	VERY LOW	-5	NO
00 UTC/09.12.2013	9.4 %	VERY LOW	-5	NO
12 UTC/09.12.2013	22.0 %	LOW	-5	NO
00 UTC/10.12.2013	9.4 %	VERY LOW	-20	NO
12 UTC/10.12.2013	0 %	NIL	-25	NO
00 UTC/11.12.2013	0 %	NIL	-15	NO

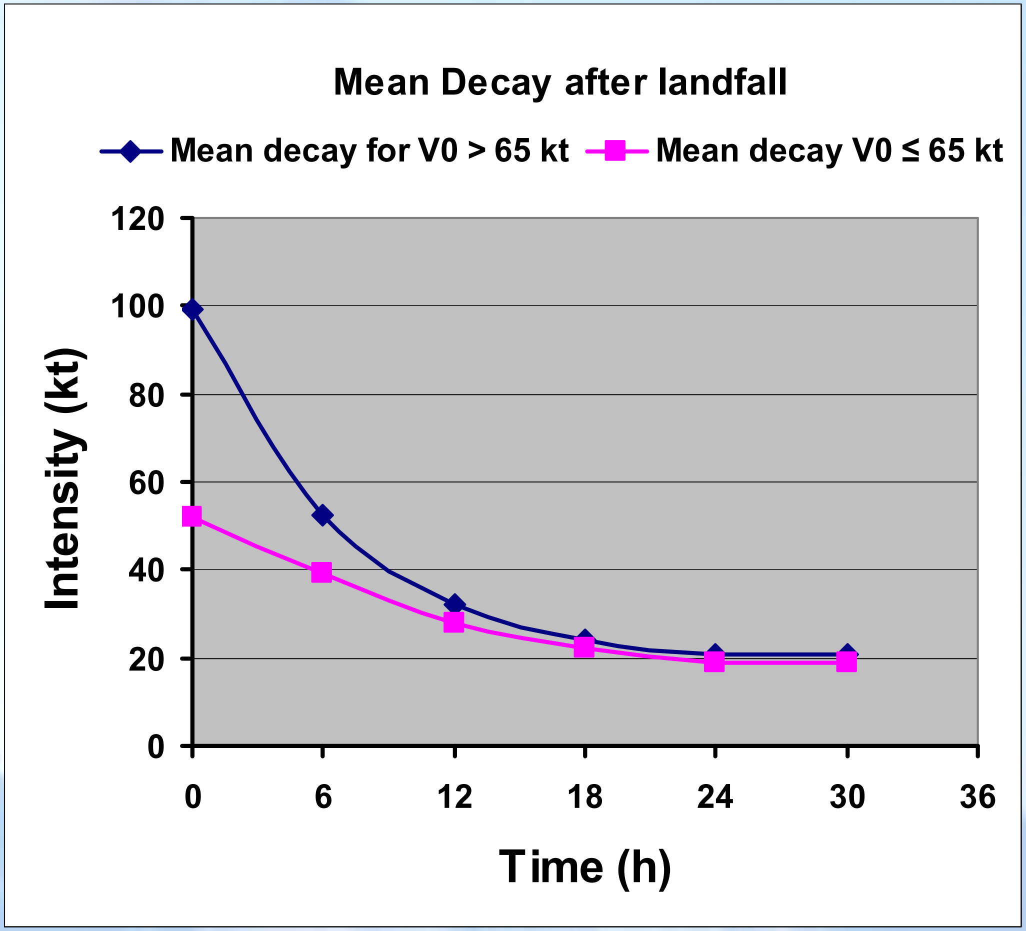
Inference: RI-Index was able to predict NON-OCCURENCE of Rapid Intensification of cyclone MADI during its lifetime by all ten forecasts issued.

STEP-V: Decay of Tropical Cyclone after landfall

[Roy Bhowmik S.K., Kotal, S.D. and Kalsi S.R, 2005. An empirical model for predicting decaying rate of tropical cyclone wind speed after landfall over Indian region. *Journal of Applied Meteorology,* 44:179-185]

Objective: **Prediction of Decaying Intensity after landfall at 6-h interval upto 24-h.**

Formulation of the model



$$\frac{dv}{dt} = -av$$

where a is termed as decay constant, V_0 is the maximum sustained surface wind speed at the time of landfall, V_t is the wind speed at time t after the landfall.

V_b is the background wind speed.

$\frac{dv}{dt} = -a(v-v_b)$ or, $\ln(v-v_b) = -at+c$ where c is integration constant.

at $t = 0, v = v_0$ i.e. $C = \ln(v_0 - v_b)$

so $\ln(v-v_b) = -at + \ln(v_0 - v_b)$

$$v_t = v_b + (v_0 - v_b)\exp(-at)$$

Decay constant: $a_1 = [\ln \{(V_o - V_b)/(V_6 - V_b)\}]/6$

Decay constant: $a_2 = [\ln \{(V_6 - V_b)/(V_{18} - V_b)\}]/12$

Reduction factors:

$$\begin{cases} R_1 = \exp(-a_1 * 6.0) \text{ for first 6-h} \\ R_2 = \exp(-a_2 * 6.0) \text{ for 12h to 24 h} \end{cases}$$

The decay equation for six hourly forecasts:

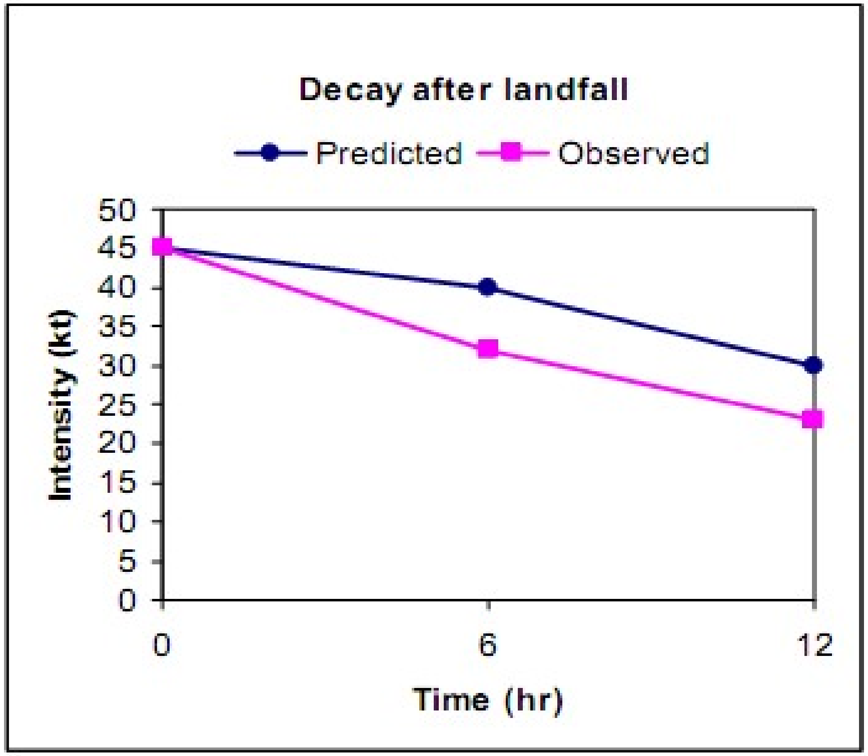
$$V_{t+6} = V_b + (V_t - V_b) * R_1 \text{ , for } t=0$$

$$= V_b + (V_t - V_b) * R_2 \text{ , for } t=6,12,18 \text{ h}$$

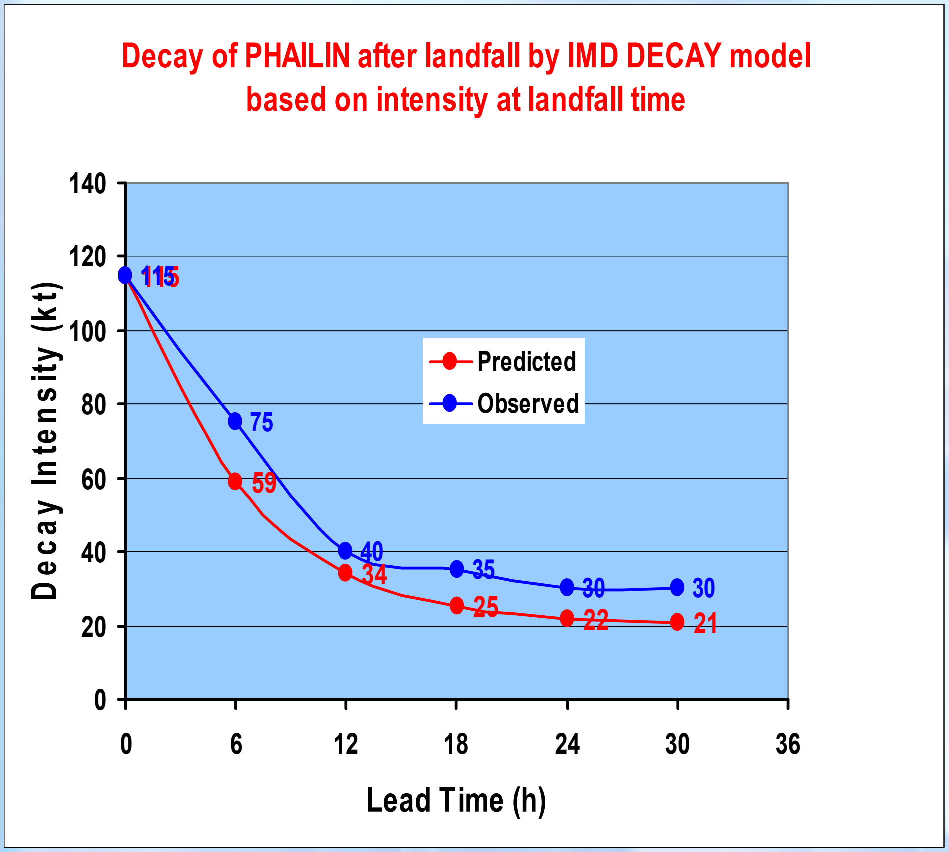
MSSW (knots)	a_1 (h^{-1})	R_1 $(6\ h)^{-1}$	a_2 (h^{-1})	R_2 $(6\ h)^{-1}$	V_b (knots)
≤ 65	0.099	0.552	0.149	0.408	19.0
> 65	0.154	0.339	0.194	0.311	21.0

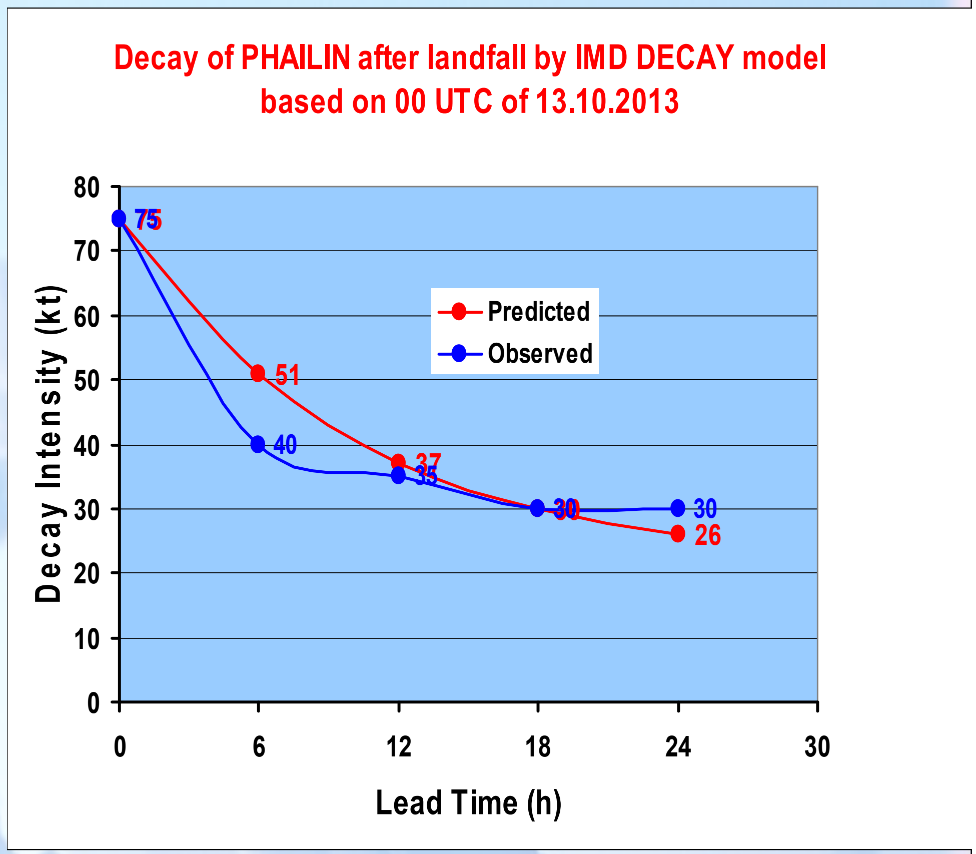
DECAY AFTER LANDFALL

Decay (after landfall) prediction curve (6-hourly) (Fig. 5) shows slow decay compared to observed decay. The error is -8 kt and -7 kt at 6 h and 12 h respectively.



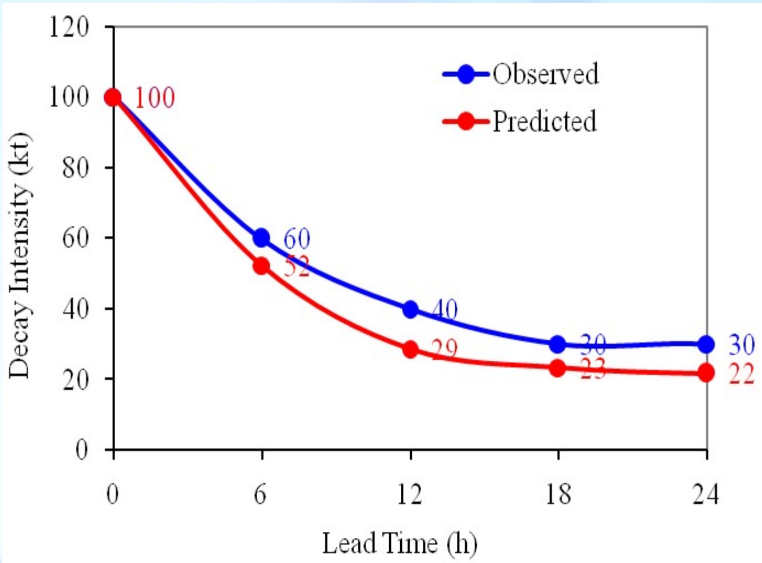
Decay after landfall of PHAILIN



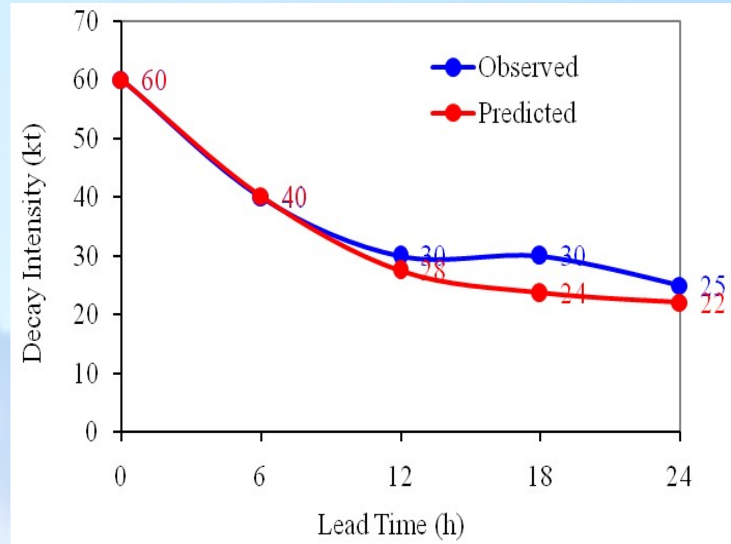


Decay model could correctly predict the decaying nature of the PHAILIN after landfall

DECAY AFTER LANDFALL (HUDHUD)

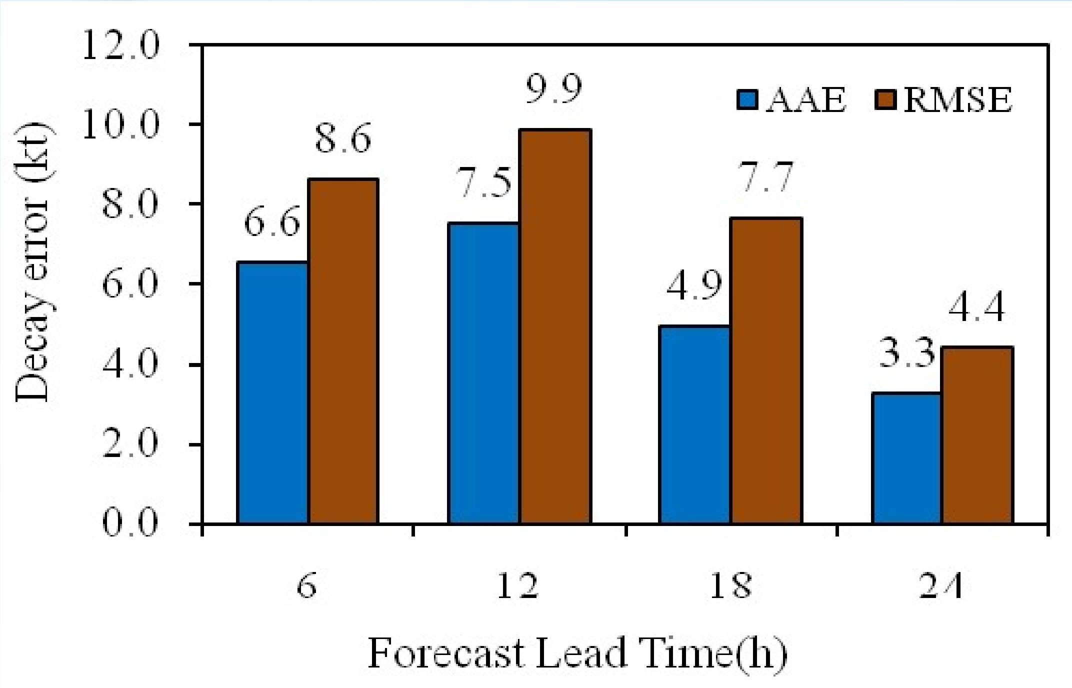


(a)



(b)

(a) Hudhud at the time of landfall, (b) Hudhud updated after 6h of landfall.



Average absolute error (AAE) and root mean square error (RMSE) of decay (kt) after landfall during 2010-2019.

भारत मौसम विज्ञान विभाग
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