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A statistical model for predicting intensity of cyclones: A case study on North Indian Ocean

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Abstract
A tropical cyclone (TC) is a rapidly rotating atmospheric system that has a low-pressure center, namely an eye, strong winds, and a spiral arrangement of thunderstorms that produces heavy rain and causes severe destruction. Every year TC of the Northern Indian Ocean (NIO) basin affects South-eastern and Southwestern India significantly. Super Cyclone (1999), Mala (2006), Gonu (2007), Nargis (2008), Aila (2009), Giri (2010), Phailin (2013), Hudhud (2014), Fani (2019), Pabuk (2019), Amphan (2020), Yaas (2021) are the few such cyclones which affected the Indian coastal region at a large extent. Therefore, reliable forecasts of these events are very essential. It is the intensity, maximum wind speed of a storm, that causes damage to properties and lives. Therefore, along with track, intensity prediction of TCs should also be emphasized. In this study, a simple linear regression and an artificial neural network models are proposed for predicting the intensity of cyclones over NIO. The model parameters are estimated from the cyclone database that developed over the NIO basin during the period 2001-2019. Minimum Sea level Pressure (MSLP) and maximum sustained wind (VMAX) are selected as the parameters for the models. In the study we also compared the forecast results of considered the models with Indian Meteorological department (IMD) models. Simple regression model mostly outperforms all the model included in the study. The results indicate the suitability of the model for operational use.

Keywords: Intensity, North Indian Ocean, tropical cyclone

Introduction
A tropical cyclone (TC) is a rapidly rotating atmospheric system that has a low-pressure center, namely an eye, strong winds and a spiral arrangement of thunderstorms that produces heavy rain and causes severe destruction. TCs are noted for their devastating characters and impact on human activities. The main characteristics of tropical cyclones are strong winds, heavy rainfall, storm surge etc destructed properties and lives. India experiences tropical cyclones formed over the Northern Indian Ocean (NIO). NIO consists of two basins i.e. Bay of Bengal (BoB) and Arabian Sea (AS). India is a tropical country. The south-east and south-west coastal areas of India are more affected by the tropical cyclones formed over NIO. In the year 1999, the super cyclone of Odisha was the super cyclone with wind speeds exceeding 260-270 km/hr. There was massive destruction in Odisha, damage to 19 lakh houses, affected more than 25 lakhs people and nearly 10,000 humans lost their lives studied by Kalsi SR (Kalsi, 2006) [7]. The wind speed of very severe cyclone storm Phailin was 215 km/hr reported by IMD in 2013 (RMSC.2013). It affected many people and damaged properties as well. Extremely severe cyclonic storm Fani (2019) had the maximum wind speed 250km/hr. More than 6 lakh houses got damaged and nearly 3 lakh hectares of crop area were affected by the tropical cyclone Fani as reported in Regional Specialized Meteorological Centre (RMSC). The massive destruction was caused by winds, storm surges and rainfall. The destructive cyclones display the necessity for better prediction of tropical cyclone intensity. Because it is the intensity that causes the destruction. India Meteorological Department (IMD) functions as a Regional Specialized Meteorological Centre (RSMC) for tropical cyclones of NIO, as recognized by the World Meteorological Organization (WMO). Many Numerical Weather Prediction (NWP) models have been developed for TC forecast purposes. However, unlike track, intensity prediction accuracy is yet to reach a satisfactory level.

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Statistical models for such forecasts are generally developed considering the relationship between the dependent event and different variables affecting the event. A few statistical model/s are also developed for forecasting the intensity of tropical cyclones. The SHIFOR (Statistical Hurricane Intensity Forecast) model was used for forecasting the intensity of tropical cyclones in the Atlantic Ocean basin developed by Jarvinen B R and Neumann C J (Jarvinen& Neumann, 1979) [6]. This model was based on climatology and persistence. The SHIPS (Statistical Hurricane Intensity Prediction System) model has forecasted hurricane intensity in the Atlantic Ocean basin developed by DeMaria M and Kaplan J (DeMaria & Kaplan, 1994) [3]. Initially, it forecasted up to 72 hours but now forecasts up to 120 hours. This model is developed based on climatology, persistence, and synoptic predictors such as Absolute value of Julian Date-235(JDATE), Intial storm intensity (VMX), Intensity change during previous 12h (DVMX), Initial storm Latitude (LAT), Initial storm Longitude (LONG), Eastward component of storm motion vector (USM), Northward component of storm motion vector (VSM) and Magnitude of storm motion vector (CSM). An updated SHIPS model is also used for forecast hurricane intensity in the Atlantic and Eastern North Pacific Ocean basin by DeMaria M and Kaplan J (DeMaria & Kaplan, 1999) [2, 3]. Fitzpatrick P J (Fitzpatrick, 1997) [4] developed TIPS (Typhoon Intensity Prediction System) model for forecasting the intensity of tropical cyclones up to 48 hours in the western North Pacific Ocean basin. This model is used satellite data. A similar Statistical model was also developed for forecasting the intensity of tropical cyclones up to 72 hours in the Eastern North Pacific Ocean using 10 climatology and Persistence variables by Hogood JS (Hobgood, 1998) [5]. There are many statistical models developed for the Pacific and Atlantic basins, but no such type of models is developed for forecasting the intensity of tropical cyclones in North Indian Ocean basin. A simple empirical model has been proposed for forecasting tropical cyclone intensity in the Bay of Bengal by Roy Bhowmik *et al.* (Roy Bhowmik, Kotal, & Kalsi, 2007) [10]. A statistical-dynamical model (SCIP) for cyclone intensity has been implemented for real time forecasting 12 hourly intervals 12 to 120 hours for Bay of Bengal. The model parameters are derived based on model analysis fields on past cyclones. The parameters selected as predictors are: Initial Storm intensity, intensity changes during past 12 hours, storm motion speed, initial storm latitude positions, vertical wind shear averaged along the storm track, Vorticity at 850 hPa, Divergence at 200 hPa and sea surface temperature (SST). The model parameters are derived based on forecast fields of IMD-GFS (Global forecasting system) models for real time forecasting. IMD is also used Hurricane Weather Research and Forecasting (HWRF) model for forecasting track and intensity of cyclones. This model is run every 6hr intervals on real time basis like 00,06,12,18 UTC. This model is consequently operational by IMD for forecasting tropical cyclones like other national meteorological services. HWRF model has two different versions. They are Princeton Ocean Model (POM) and Hybrid coordinate Ocean Model (HYCOM). These two models are employed for real time forecasting tropical cyclones over NIO. SCIP (Statistical Cyclone Intensity Prediction) model is used to forecast cyclone intensity 12 to 120 hours in the Bay of Bengal developed by Kotal S D *et al.* (Kotal, Roy Bhowmik, Kundu, & Das Kumar, 2008) [8]. Sutapa Chaudhuri *et al.* showed (Chaudhuri, Dutta, Goswami, & Middey, 2013) [1] the prediction of cyclones intensity over

Arabian sea (AS) and Bay of Bengal (BoB) by using multilayer perceptron (MLP) model. In this model, Cental pressure (CP), Maximum sustained surface wind speed (MSWS), Pressure drop (PD), Total ozone column (TOC) and Sea surface temperature (SST) are considered as the input parameters. In most of the above works, it is seen that observational data on several variables have been used to predict the cyclone intensity. However, in reality, access to those observational data may not be always available for each basin. Moreover, here variables are more observations of each are required for every state which may not be always available for all the variables. Hence the data is suspected to suffer due to missing observations. Therefore, developing a simple intensity forecast model is necessary which would involve only one or two variables for which data availability may not be a challenge. In this study an effort has been input to forecast cyclone intensity using readily available observational data such as Minimum Sea Level Pressure (MSLP) and Maximum sustained wind (VMAX). Simple Linear Regression (SLR) and Artificial Neural network (ANN) models are considered in this study. The manuscript is organised following manner. The sources of data sample and area of study region are provided in section 2. In section 3, the methodology of the model is described. Results are discussed in section 4.

Study Area and Data Sources
The sample database of cyclones from 2001 to 2019 is used for the formulation of the statistical model. There are 40 numbers of tropical cyclones formed over the NIO during 2001-2019 are considered as formulation of the models and 12 number of cyclones are used for testing the model performance. Figure 1 showed the study area of the NIO with latitude 0^0N to 30^0 N and longitude 40^0 E to 100^0E. The red dots lines are the locations of tropical cyclones under study. IMD classified the cyclones into different tropical disturbances according their maximum sustained surface wind speed in knots (Intensity or VMAX). They are as follows:
1. Low-wind speed less than 17 knots
2. Depression-wind speed of 17-33 knots
3. Cyclonic storm-wind speed of 33-47 knots
4. Severe cyclonic storm-wind speed of 47-63 knots
5. Very severe cyclonic storm-wind speed of 64-119 knots
6. Supper cyclone-wind speed of more than 119 knots

In this study, VMAX and MSLP are obtained from the Joint Typhoon Warning (JTWC)(https://www.metoc.navy.mil/jtwc/jtwc.html?north-indian-ocean). The units of VMAX and MSLP are knots and hectoPascal (hPa) respectively. The VMAX of cyclones are collected from the RMSC (https://rsmcnewdelhi.imd.gov.in/report.php?internal menu=MjY) reports during 2015-2019.

Methodology
Simple Linear Regression
Simple Linear regression (SLR) is a statistical method that summarizes and studies the relationship between two continuous variables. MSLP and VMAX are used to develop the model. The correlation between the variables is shown in Figure 2. The correlation between MSLP and VMAX is negative. The objective of the study is only one variable considered as predictor to forecast VMAX easily, while more variables are implicated then it is very complicated to forecast VAMX. The SLR model is easy to forecast VMAX compare with other Statistical and Dynamical models. Here the trial

has been made to keep the model the simplest. The ANN model is developed with same predictor with two hidden layers. The effectiveness of the models are also examined. In SLR One variable denoted by X, is regarded as the predictor or independent variable. The other variable denoted by Y, is regarded as the response or dependent variable. SLR is simple because it concerns the study of only one predictor variable. It is a linear regression model with a single independent variable. The model is developed by using the SLR technique shown in Equation 1. The coefficients and intercepts are determined using the data set of (40) tropical cyclones during 2001-2019. The SLR model estimates the changes in intensity with the changes in each 12h forecast leads up to 12- 120 hrs. There are 10 separate numbers of regression equations which carried out to forecast the VMAX.

$$Y_t = b_0 + b_1 * X_1 \qquad \text{Equation (1)}$$

Where X is denoted by MSLP, Y is the VMAX of cyclones (Intensity) and t is the forecast leads at 12 hours. The values of t are 12, 24, 36, 48, 60, 72, 84, 96, 108 and 120. Y is the dependent variable (VMAX) and X is the independent variable (MSLP), b_1 is the regression coefficients of the model and b_0 is the intercept.

Artificial Neural Network
Artificial Neural Networks (ANNs) are algorithms based on human brain function and issued complicated patterns and forecast issues. The ANN is a deep Machine Learning method that arose from the concept of human brain neural network. Regression, ANNs can be used to predict an output variable as a function of the inputs. The input features (independent variables) can be categorical or numerical types, however the regression ANNs, we require a numerical dependent variable. If the output variable is a categorical variable (or binary) the function as a classifier. Prediction using ANNs is similar to use to predict the value of dependent variables based on one or more independent variables. ANNs are trained on a data set that includes input and output values for a set of observations and can handle non-linear relationships between the dependent and independent variables too. The main purpose of using ANN for regression over linear regression is that linear regression represents the linear relationship between the independent and dependent variables and cannot learn the complex non-linear relationship between the above variables. So we need ANN technique is used examine the non-linear relationship between independent and dependent variables.
In this study, we consider a general ANN with one input dependent variable and two hidden layers to predict the VMAX. In this ANN, the weights are multiplying by independent variable and adding them and the bias is also added to the result. The Model is developed by using an ANN technique shown in Equation (2)

$$Y_t = b_0 + \sum_{i=0}^{n} w_i * X_t \qquad \text{Equation (2)}$$

Where, Y is the VMAX (Intensity) of cyclones, X is the MSLP, b_0 is the bias and w_i is the weights and t is the 12hr forecast leads. The values of t are 12 to 120hr.

Evaluation of Model Forecast
Mean Absolute Error (MAE) is used to evaluate the models forecast error. MAE is the average absolute difference between the forecasting values and the actual values. Errors in

forecasts have been computed using MAE. This is defined as Equation (3)

$$MAE = \sum_{i=1}^{n} \frac{|Y_i - \hat{Y}_i|}{n} \qquad \text{Equation (3)}$$

Where, $\hat{Y}_i$ = Forecasted Intensity.
Y_i = Observed Intensity.
n = Number of cases of forecasts.

Forecast results
In this section, the results of intensity forecasts for the seasons 2015, 2016, 2017, 2018 and 2019 are described. The first couple seasons from above given seasons are from training sets and the last three seasons are from testing sets. The SLR and ANN algorithm were running on the data obtained from JTWC (https://www.metoc.navy. mil/jtwc/jtwc.html?north-indian-ocean). A comparison study of MAEs of HWRF, SLR, ANN and SCIP models are also discussed in this section. The number of cases are different for different models so, firstly we study a comparison among the MAEs of SLR, ANN and HWRF models of above cyclone seasons are shown in the Figures 3, 4, 5, 6, 7 with respective given above the seasons. Then focused among the MAEs of SLR, ANN and SCIP models are shown in the Figure 8, 9, 10, 11, 7. MAEs are calculated for all of the cyclones between 2015 and 2019. The summary of results of 2015 cyclone season is shown in Figure 3. The results showed significant reduction intensity forecast errors. Interestingly SLR estimated very small errors, less than 3 knots between 12 and 120 forecast leads. But in ANN model these were more than 21 knots. HWRF produced 8 to 10 knots between 12 and 72 forecast leads and more than 10 knots fore remaining forecast leads. The number of cases vary between 92(12h) to 16 (120h) for different forecast intervals. The errors of SLR are 74, 74, 75, 76, 77, 79, 79, 79, 81, 79 percentage less than HWRF model between 12h and 120h forecast leads respectively. The details of number of cases are represented in the parenthesis of the Figure.
The summary the results cyclone season 2016 are shown in Figure 4. The number of cases are vary 86(12h) to 16(120h) for forecast leads. Interestingly, SLR is also giving very small error less than 5 knots between 12h and 120h forecast leads. ANN has a range 14 to 24 knots for all the forecast leads. HWRF produced below 10 knot errors for all the forecast leads expect 120 forecast lead.
Seasonal forecast errors for the season 2017 is represented in the Figure 5. The number of cases vary between 8(120h) and 46(12h). The numbers of cases are very small as compare to other season because there are only 3 number of cyclones originated in this season. In SLR model, errors were shown less than 5 knots in 12h and 24h forecast leads. It is also shown less than 7 knots in remaining forecast leads except 108h forecast lead. In ANN model, errors are vary from 8 to 16 knots between all the forecast leads. HWRF gives more error than SLR model in between 12h and 60h forecast leads but it gives less than 5 knots between 72h and 120h forecast leads. SLR gives 48, 43, 33, 27, 11 percentages of errors less than HWRF in 12h, 24h, 36h, 48h and 60h respectively and HWRF produces 22, 22, 73, 150, 92 percentages of errors less than SLR in 72h, 84h, 96h, 108 and 120h forecast leads respectively.
Figure 6 depicts the cyclone season 2018, the number of cases are vary from 43 to 155 in between 120h to 12h respectively. The errors are less than 5 knots in all the forecast leads were shown by SLR model. ANN model gives 10 to 15 knots in all the forecast leads. It gives more errors than HWRF in all the

forecast leads. The errors of HWRF vary from 6 to 9 knots in all the forecast leads. SLR gives 46, 46, 47, 48, 51, 50, 47, 46, 47and 52 percentage less error than HWRF model between 12h and 120h forecast leads respectively.

Figure 7 showed the forecast errors and corresponding number of cases in the parenthesis of the season 2019. In this season, the number of cases is between 66(120h) and 183(12h). The errors of SLR less than 8 knots between 12h and 120h forecast leads. HWRF produces around 7 knots errors in all the forecast leads. But in ANN the errors are higher than the above two models. SLR gives 9, 7, 6, 7, 8, 7, 2, 1, 1 and 5 percentages of errors less than HWRF in 12h, 24h, 36h, 48h, 60h, 72h, 84h, 96h, 108h and 120h forecast leads respectively.

Figures 8, 9, 10, 11, 12 showed the comparison study of errors among the SLR, ANN and SCIP model for the seasons 2015 to 2019. The summary of results of 2015 cyclone season is shown in Figure 8. The results show significant reduction intensity forecast errors. Interestingly SLR gives also very small errors, less than 3 knots between 12 and 120 forecast leads. But in ANN model these were more than 20 knots. SCIP gives 8 to 10 knots between 12 and 84 forecast leads and more than 10 knots for remaining forecast leads. The number of cases vary between 47(12h) to 9 (120h) for different forecast leads. The details of number of cases are in the parenthesis in this Figure. The summary the results cyclone season 2016 are shown in Figure 9. The number of cases are vary 45(12h) to 9(120h) for different forecast leads. Interestingly, SLR is also giving very small error less than 5 knots between 12h and 120h forecast leads. ANN has a range 14 to 23 knots for all the forecast leads. SCIP produces below 10 knot errors for all the forecast leads expect 120 forecast lead.

Seasonal forecast errors for the season 2017 is shown in the Figure 10. The number of cases vary between 4(120h) and 24(12h). In SLR model, error was shown less than 5 knots only in 12h forecast leads. It is also shown less than 7 knots in 24h,36h,48h and 60h forecast leads and less than 10 knots for remaining forecast leads. In ANN model, errors are varying from 8 to 17 knots between all the forecast leads. SCIP gives more error than SLR model between 12h and 60h forecast leads but it gives less than 5 knots between 84h and 120h forecast leads. SLR gives 45, 42, 33, 24 and 20 percentages of errors less than SCIP in 12h, 24h, 36h, 48h, 60h respectively and HWRF produces 21, 40, 60, 130 and 105 percentages of errors less than SLR in 72h, 84h, 96h, 108 and 120h forecast leads respectively.

Figure 11 depicts the cyclone season 2018, the number of cases are vary from 43 to 155 in between 120h to 12h respectively. The errors are less than 5 knots in all the forecast leads were shown by SLR model. The errors of ANN are varying from 10 to 15 knots in all the forecast leads. It gives more errors than SCIP in all the forecast leads. The errors of SCIP are varying from 6 to 9 knots in all the forecast leads. SLR gives 45, 44, 47, 47, 49, 51, 45, 45, 38 and 48 percentages less error than SCIP model between 12h and 120h forecast leads respectively.

Figure 12 showed the forecast errors and corresponding number of cases in the parenthesis of the season 2019. In this season, the number of cases is between 33(120h) and 92(12h). The errors of SLR are less than 8 knots between 12h and 120h forecast leads. SCIP produces around 7 knots errors in all the forecast leads. But in ANN the errors are higher than the above two models. The errors of ANN are varying from 22 to 28 knots in all the forecast leads. SLR gives fewer errors than

all the leads except 96h and 108h. SLR gives 8, 8, 6, 6, 8, 5 and 3 percentages of errors less than SCIP in 12h, 24h, 36h, 48h, 60h, 72h, 84hand 120h forecast leads respectively. SCIP shows 1 percentage of errors less than SLR in both 96h and 108h forecast leads.

Performance with respect to some named storms
In this section, some individual storms forecasts for the year 2019 were studied. There were 7 number of cyclones originated in NIO. In this section we have focused only 4 cyclones. A comparison study of MAE of SLR, ANN, SCIP and HWRF model are also studied. The MAEs for cyclone VAMX (intensity) forecast for the named cyclones FANI, VAYU, HIKKA and KYARR of 2019 seasons are shown in the Figures 13, 14, 15, 16 and Figures 17, 18, 19, 20 respectively. The numbers of cases are different of different models so, firstly we study a comparison among the MAE of SLR, ANN and HWRF models of above-named cyclones, then among the MAE of SLR, ANN and SCIP models. The Figures 13, 14, 15, 16 showed the errors comparison among SLR,ANN and HWRF models and Figures 17, 18, 19, 20 showed the errors comparison among the SLR, ANN and SCIP models. Figure 13 depicted the MAE of named cyclone of FANI. The number of cases is varying 15-33 (120h-12h). HWRF showed below 10 knots error between 12h and 48h forecast leads and 10 to 13 knots in the remaining forecast leads. SLR model produced around 7 knots in each forecast leads. A range of 26 to 47 knots of errors in all forecast leads showed by ANN. SLR produces the smallest errors among the models and ANN had greatest errors. The MAE of very severe cyclone storm of VAYU is given in the Figure 14. The number of cases is vary 13 to 31 between 120 and 12 hour forecast leads. The maximum intensity of very sever cyclonic storm VAYU is 100 knots.

The MAE of SLR was less than 4 knots in all the forecast leads but HWRF showed around 10 knots in 12h, 24h and 36h leads. It was also shows less than 10 knots and more than 6 knots between 60h and 120h leads. The MAE of ANN is vary from 12 to 18 knots in all the forecast leads. The errors of SLR is very smallest than other two models for severe cyclone storm VAYU.

Figure 15 showed MAE severe cyclone storm HIKKA. The number of cases of vary from 1 (84h) to 13(12h). In this storm, SLR showed fewer errors than HWRF in 12h, 24h, 72h and 84h but it showed more errors than HWRF in 36h and 60h forecast leads. ANN showed more than 14 knots in all the forecast leads.

In Figure 16, the MAE of super cyclone KYARR is presented. The number of cases is vary from 20(12h) to 38(120h). The MAE of HWRF is less than 4 and SLR produced around 5 knots in all the forecast leads. ANN produced more than 18 knots in all the leads. In this super cyclone, HWRF model produced a smallest error with compare to other two models.

Figure 17presented MAEs of SLR, ANN and SCIP model of considered individual cyclones. It showed also the results of FANI. The number of cases is vary between 8(12h) and 17(120h). The forecast errors of SLR are around 7 knots and SCIP are lies between 8 to 12 knots in all the forecast leads. ANN produced 27 knots more in all the forecast leads. SLR had less error with compare to other considered model.

The MAE of cyclone VAYU showed in Figure 18. The number of cases are vary from 6(120h) and 15(12h). The errors of SLR are less than 5 knots. In comparison errors of models, SLR showed less than SCIP and ANN. The Figure 19 showed the MAE cyclone HIKKA. The number of cases is 1-

7 between 84h and 12h. SLR forecasts better than results than other models in all the forecast leads. But in case of KYARR, SCIP performed better than other models in all the forecast leads presented in the Figure 20. In this case SCIP produced less 5 knots and SLR around 6 knots in all the forecast leads. ANN produced more than 20 knots for all leads. Therefore, from the intensity errors of some important cyclones in 2019 season it may observed that only a single model SLR has uniformly minimum errors irrespective cyclones for all the forecast leads between 12h and 120h.

Forecast skills
In this section, we focused a comparison of forecast skills of different models. We calculated the forecast skills of HWRF, ANN and SLR models on the data only based on year 2019. The computations of skills were calculated by the formula given below

$$S_m\% = 100 \times (S_b - S_f)/S_b$$

Where S_m is the skill score of the models, S_b is the error of the base line model and S_f is the forecast error of the models. The formula above is one of the verification skill method used for MAE (Mohapatra, Bandyopadhyay, & Nayak, 2013) [9]. Figure 21 showed the percentage of skill scores of the models HWRF, SLR and ANN. Among these models, ANN showed very poor performance comparing other two models in each forecast leads between 12h and 120h. It shows that SLR has highest skill among all the models. SLR performed better than HWRF model by 8%, 5%, 3% and 1% at 12h, 24h, 36h and 120h forecast leads respectively. At 48h, 60h and 72h forecast leads SLR model performed better by 4%. But the skill of SLR and HWRF are same at 84h, 96h and 108h forecast leads. Similarly the skill scores of the SCIP, SLR and ANN

models are also considered. The SLR has given better performance comparing with other models.
Accuracy measures like bias (knots), correlation coefficient R between observed and the predicted intensity values, Root mean square errors (RMSE) and coefficient of variation (CV) are considered here. It noted in the Table 1 to understand the accuracy measures of the model SLR, ANN and HWRF. Table 2 represents the accuracy measures of SLR, ANN and SCIP model. The accuracy measures of models in table 1 and 2 are calculated on the data of year 2019. In Table 1, HWRF model adopted by IMD to forecast the intensity of cyclones here. The bias of SLR is always less than the HWRF. The lowest bias is 3.23 while highest is 5.31 for SLR. The lowest and highest biases are 4.7 and 5.73 for HWRF respectively. Correlation Coefficients of SLR are higher than or equal to HWRF model between 12h and 120h. The RMSEs of SLR are always less than of HWRF model in each forecast leads. The RMSEs of SLR are varying from 8.44 and 9.14 knots. Coefficient of Variation shows the less variance of forecast errors. The CV of SLR is less than HWRF model for all the forecast leads and it lays Between 12.09 to 13.29 with 12h-120h forecast leads.

In Table 2, SCIP model adopted by IMD to forecast the intensity of cyclones here. The bias of SLR is less than SCIP in 12h, 84h, 96h, 108h and 120h otherwise reverse. The lowest bias is 3.6 while highest is 5.4 for SLR. The lowest and highest biases are 4.3 and 5.3 for SCIP respectively. Correlation Coefficients of SLR are higher than or equal to SCIP model between 12h and 120h. The RMSEs of SLR are always less than of SCIP model in each forecast leads. The RMSEs of SLR are vary from 8.4 and 9.3knots. Coefficient of Variation shows the less variance of forecast errors. The CV of SLR are less than SCIP model for all the forecast leads and it lies Between 13.1 to 15.1 with 12h-120h forecast leads.
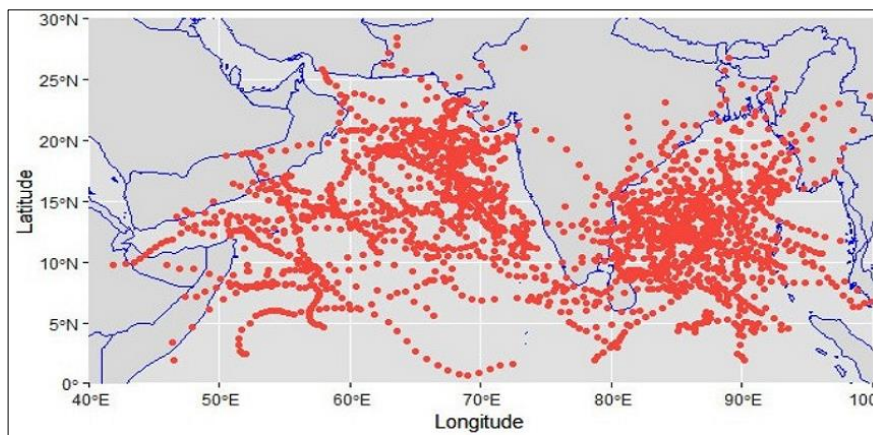

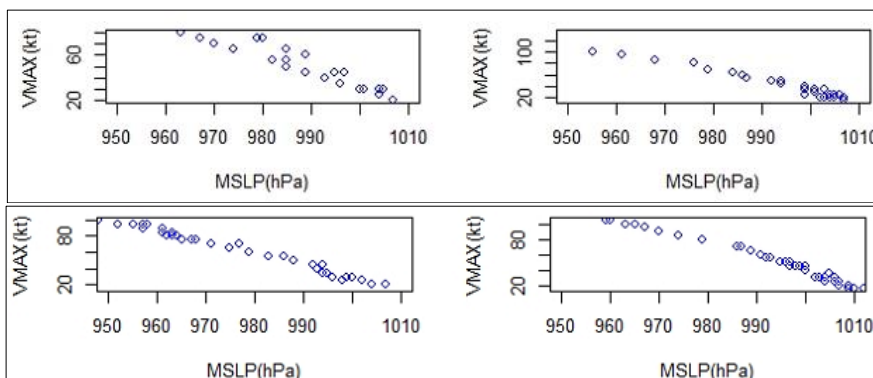**Fig 1:** Cyclones in NIO during 2001-2019. The red dots lines denote path of the cyclones

Fig 2: Scatter plot of MSLP vs VMAX. The correlation between MSLP and VMAX is negative
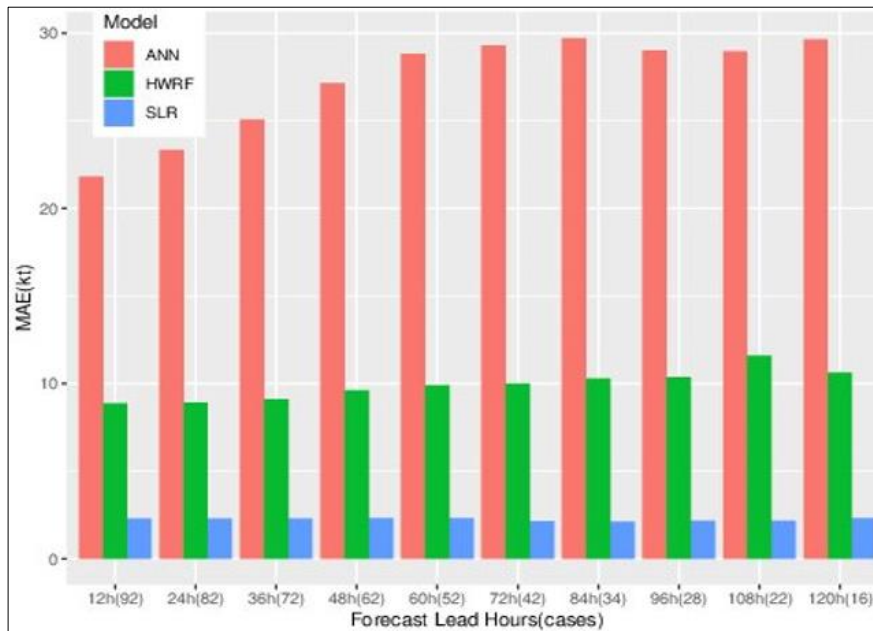
Fig 3: Seasonal Cyclones Intensity Forecast Errors during 2015. The SLR model is producing least forecast errors for all the forecast leads.
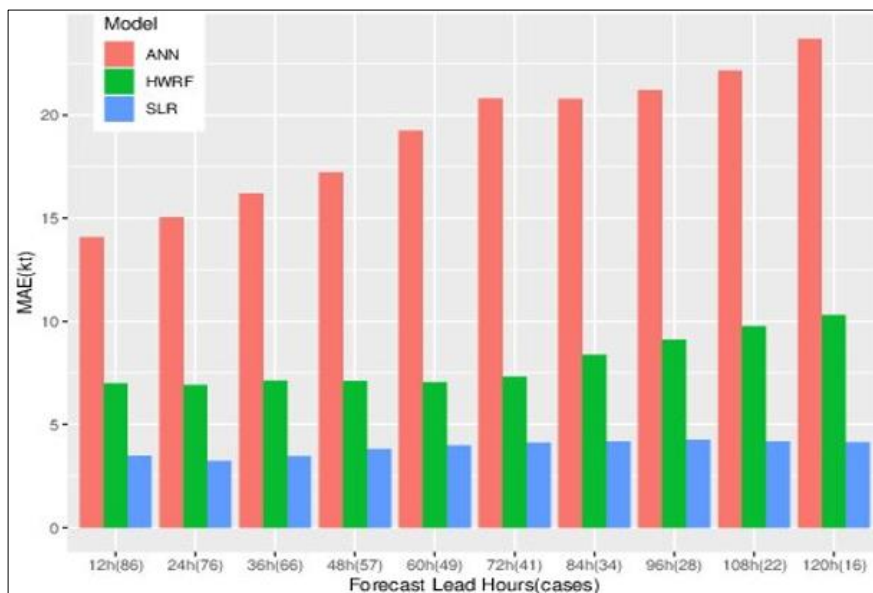

Fig 4: Seasonal Cyclones Intensity Forecast Errors during 2016. The SLR model is producing least forecast errors for all the forecast leads.
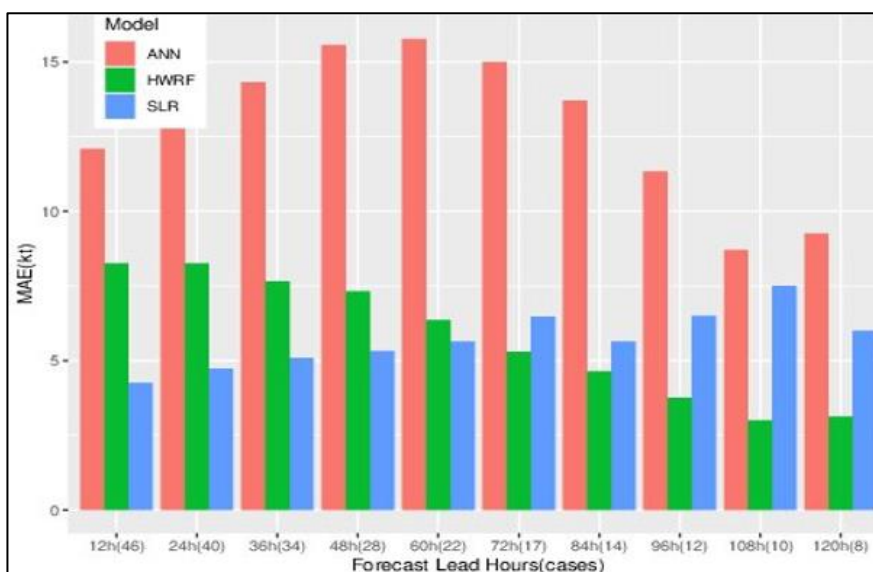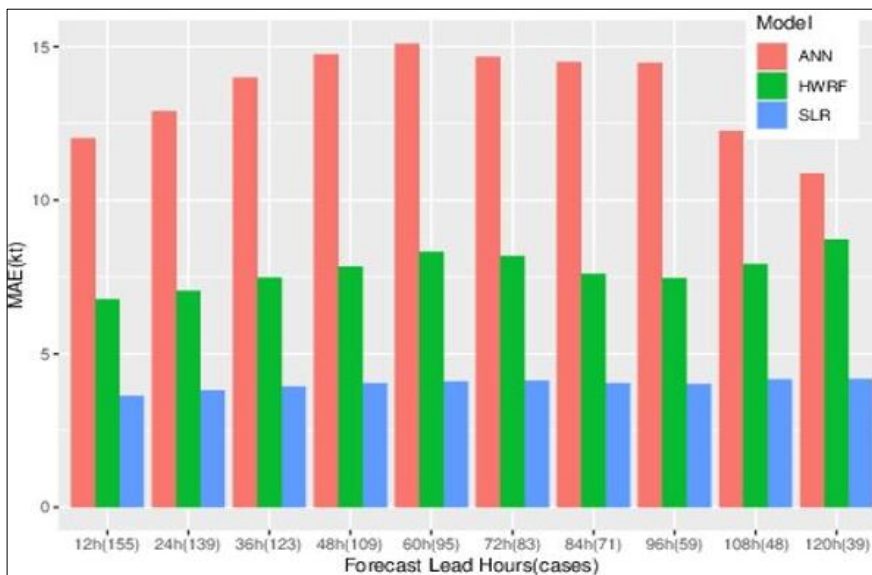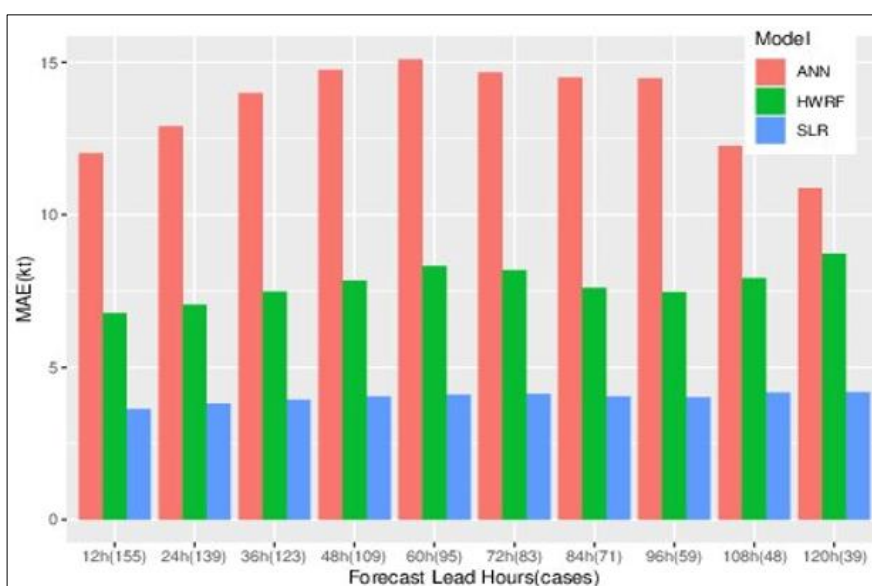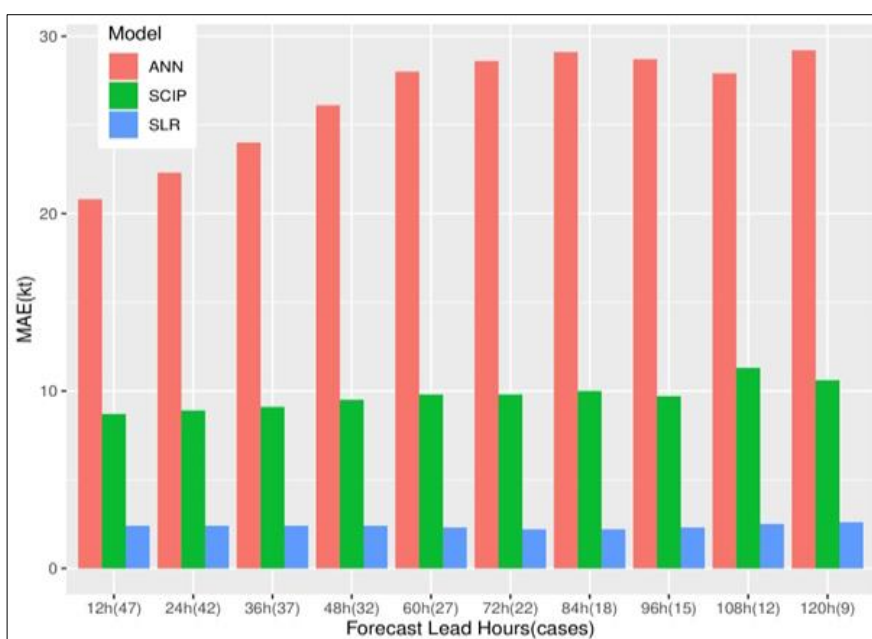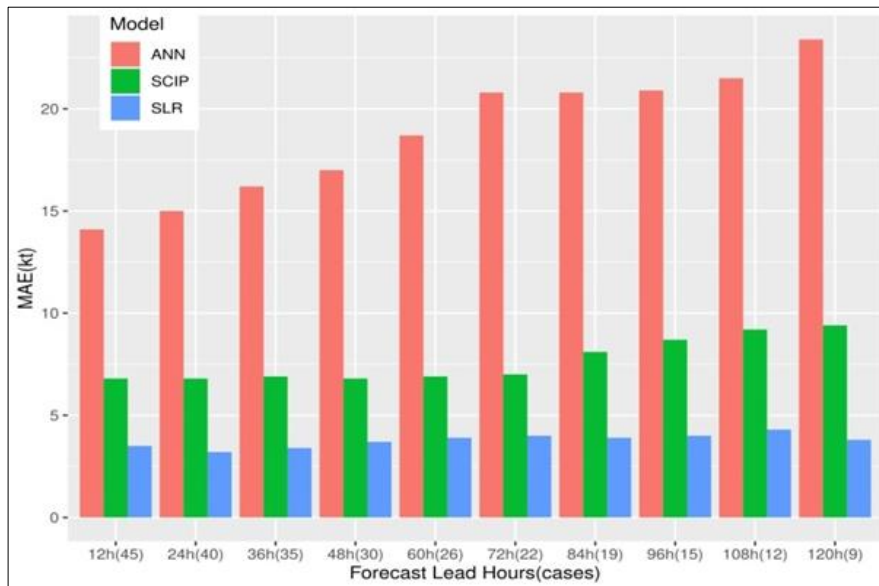

Fig 5: Seasonal Cyclones Intensity Forecast Errors during 2017. SLR model is producing least Forecast errors for 12-60 forecast leads and HWRF is producing least forecast errors for 72-120 forecast leads

Fig 6: Seasonal Cyclones Intensity Forecast Errors during 2018. The SLR model is producing least Forecast errors for all the forecast leads
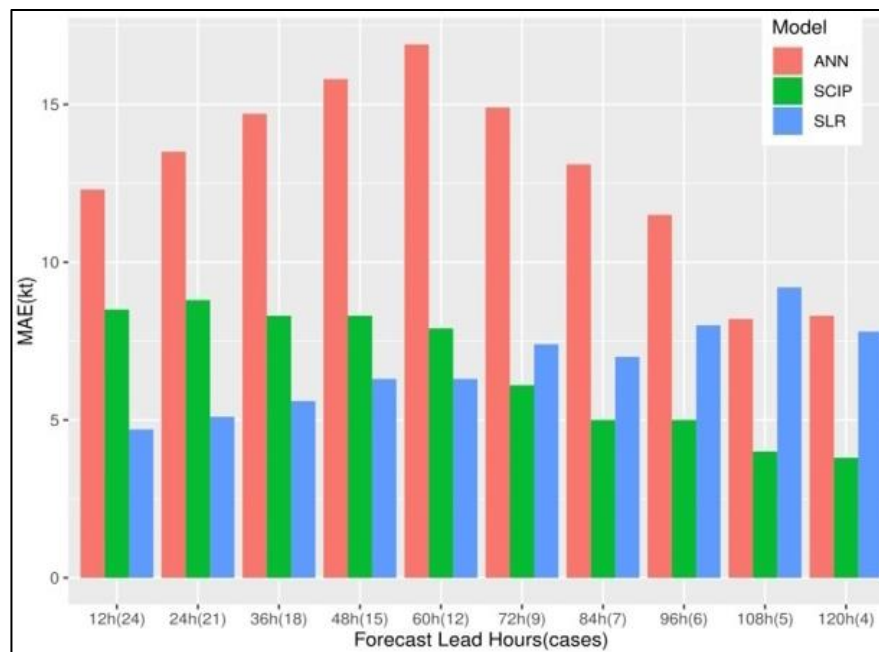

Fig 7: Seasonal Cyclones Intensity Forecast Errors during 2019. The SLR model is producing least Forecast errors for all the forecast leads

Fig 8: Seasonal Cyclones Intensity Forecast Errors during 2015. The SLR model is producing least Forecast errors for all the forecast leads

Fig 9: Seasonal Cyclones Intensity Forecast Errors during 2016. The SLR model is producing least Forecast errors for all the forecast leads

Fig 10: Seasonal Cyclones Intensity Forecast Errors during 2017. The SLR model is producing least Forecast errors for 12-60 forecast leads and SCIP model is producing least forecast errors for 72-120 Forecast leads.
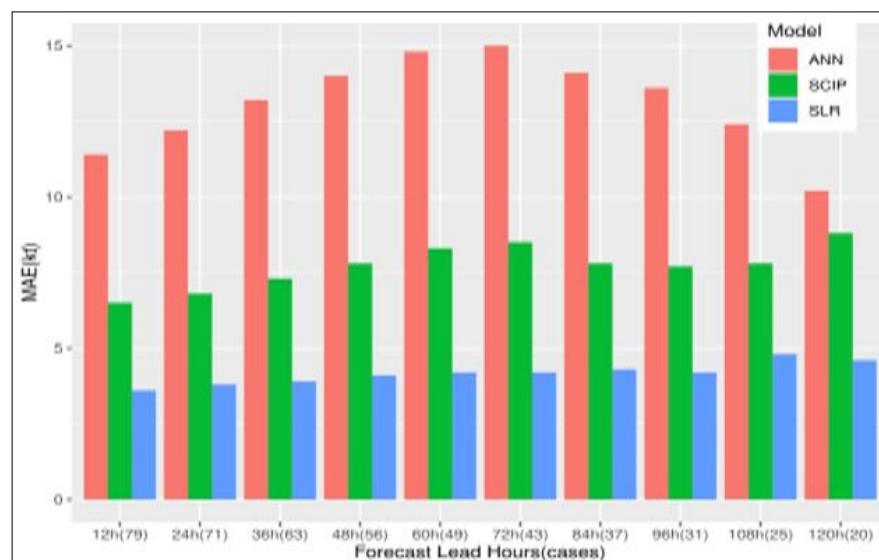

Fig 11: Seasonal Cyclones Intensity Forecast Errors during 2018. The SLR model is producing least Forecast errors for all the forecast leads
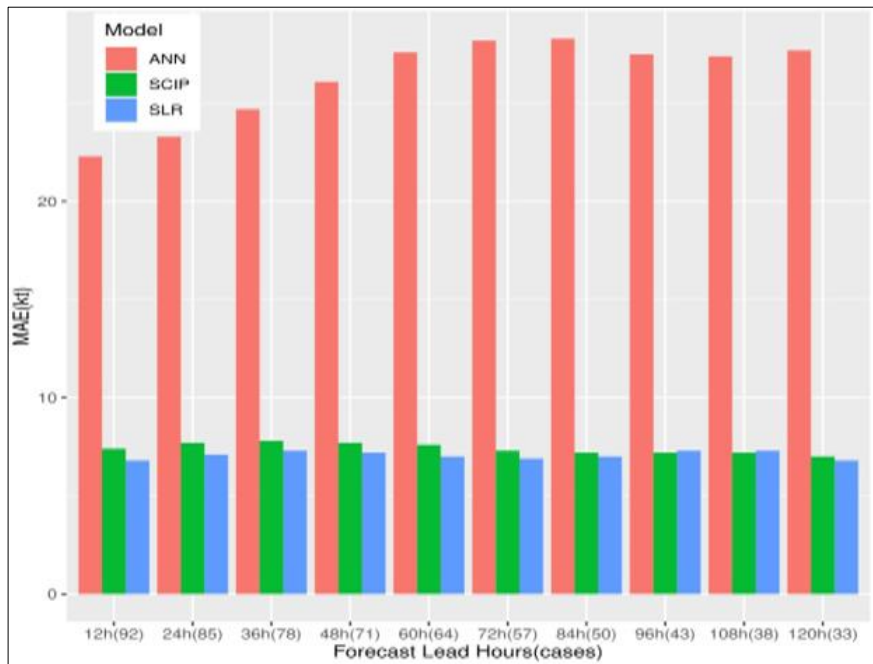
Fig 12: Seasonal Cyclones Intensity Forecast Errors during 2019. The SLR model is producing least Forecast errors except 96 and 108 forecast leads
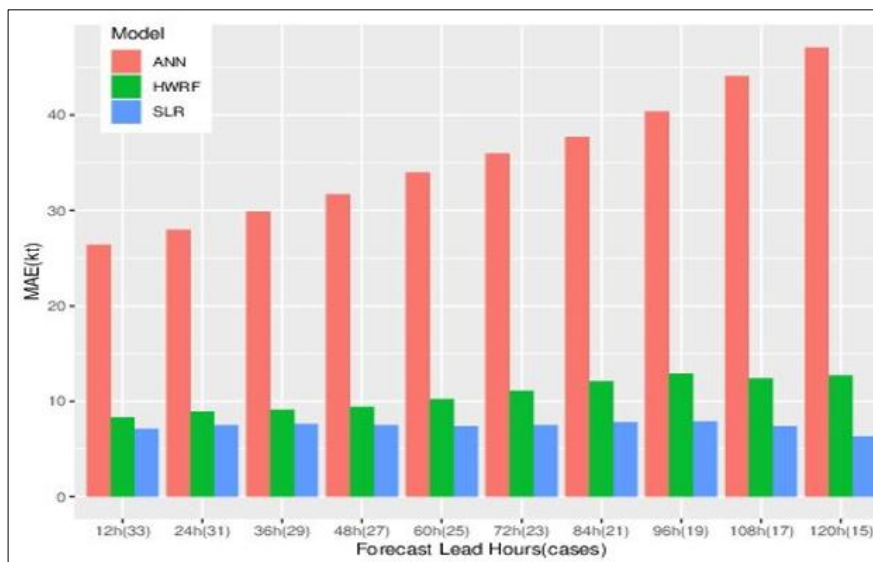

Fig 13: Intensity forecast errors of FANI during 2019. The SLR model is producing least forecast errors for all the forecast leads
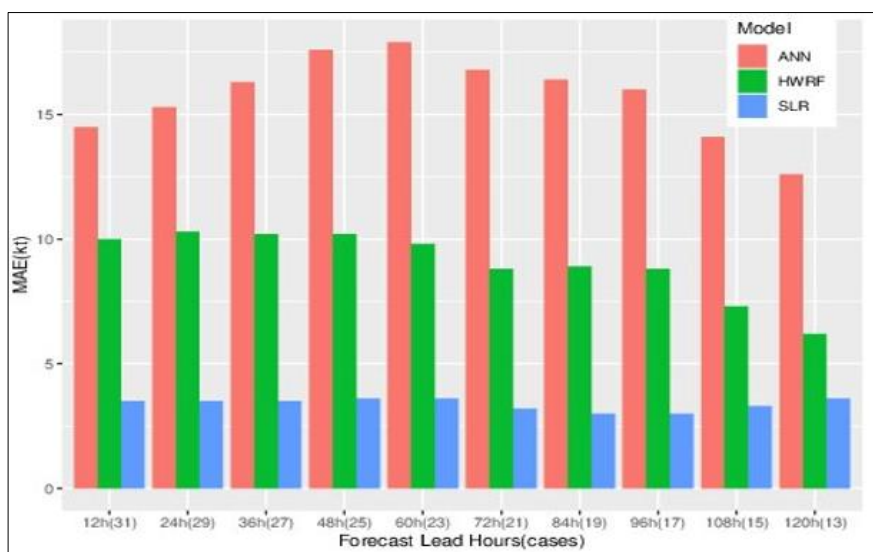

Fig 14: Intensity forecast errors of VAYU during 2019. The SLR model is producing least forecast errors for all the forecast leads
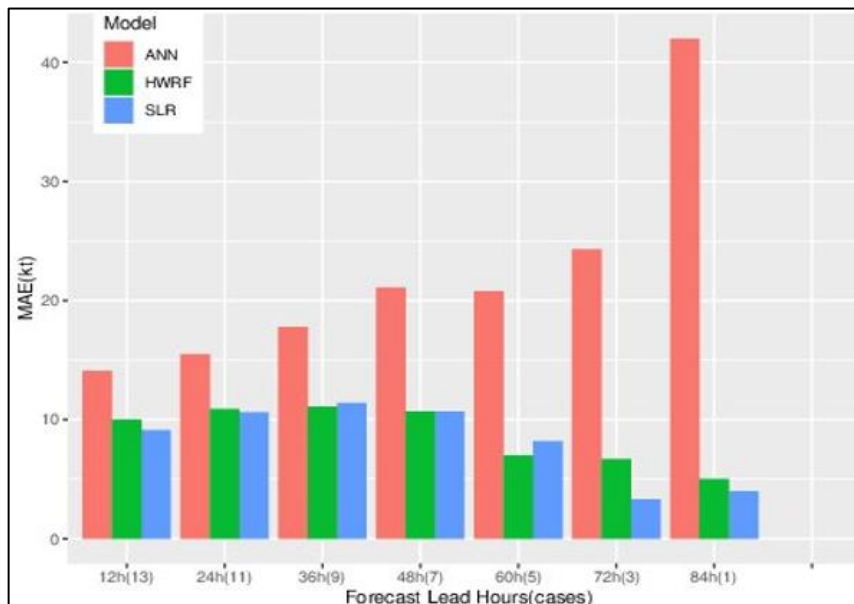
Fig 15: Intensity forecast errors of HIKKA during 2019. The SLR model is producing least forecast errors except 36 and 60 forecast leads
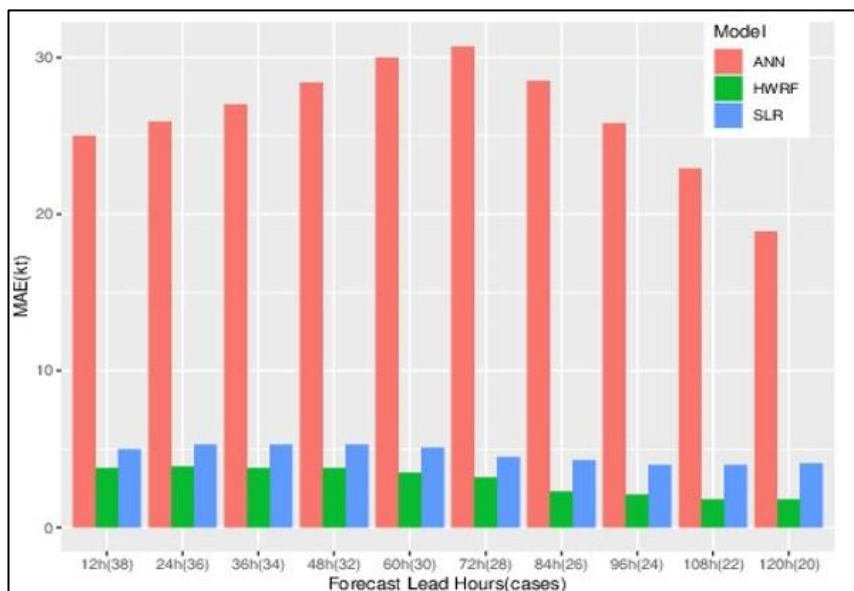

Fig 16: Intensity forecast errors of KYARR during 2019.The HWRF model is producing least forecast errors for all the forecast leads

Fig 17: Intensity forecast errors of FANI during 2019.The SLR model is producing least forecast errors for all the forecast leads

Fig 18: Intensity forecast errors of VAYU during 2019. The SLR model is producing least forecast errors for all the forecast leads

Fig 19: Intensity forecast errors of HIKKA during 2019. The SLR model is producing least forecast errors for all the forecast leads

Fig 20: Intensity forecast errors of KYARR during 2019. The SCIP model is producing least forecast errors for all the forecast leads
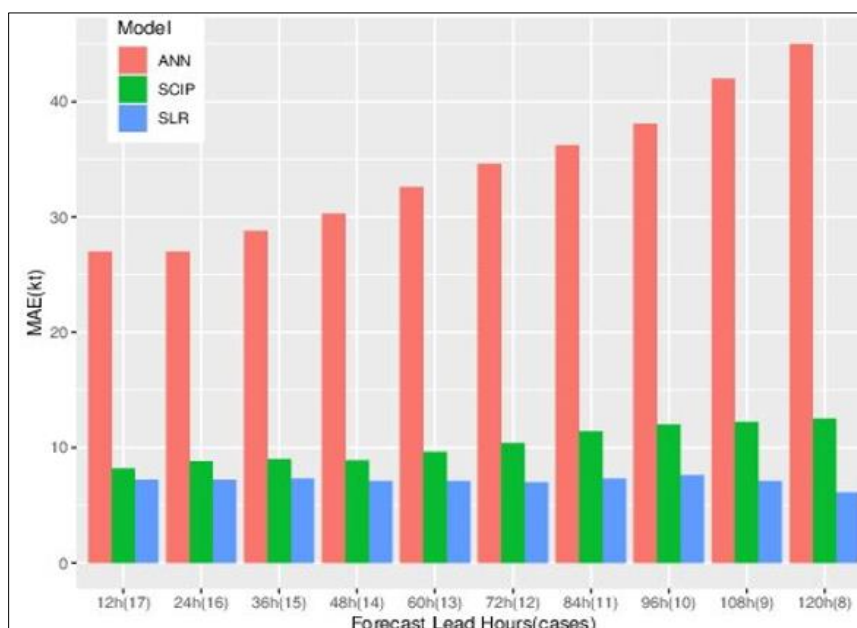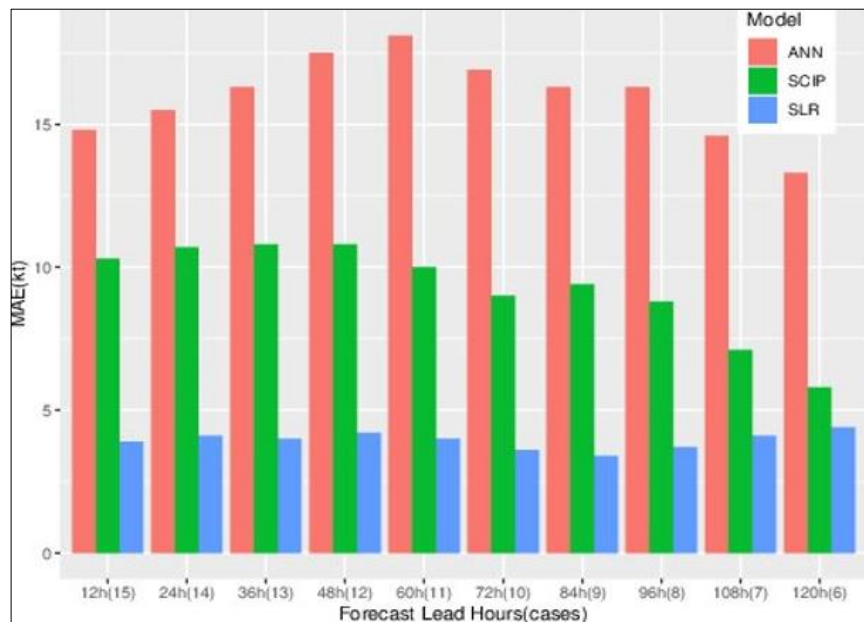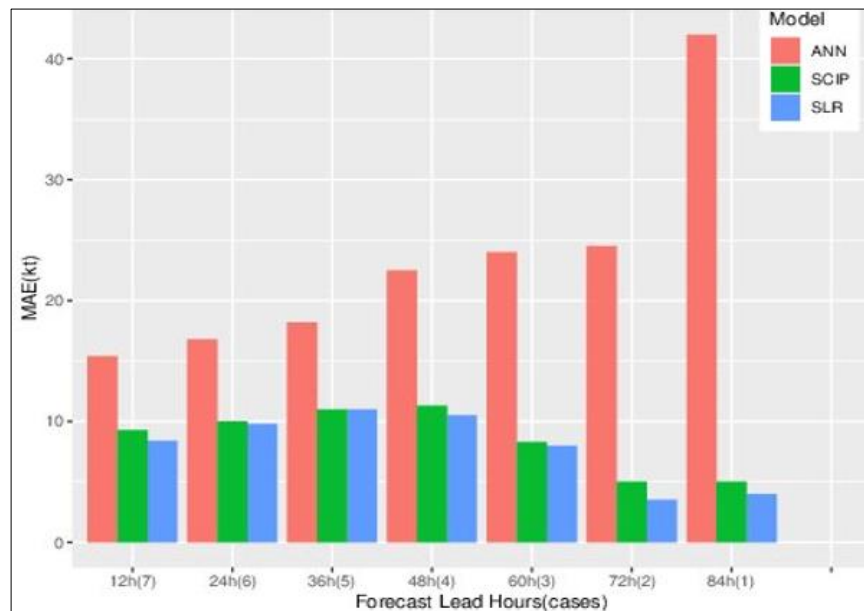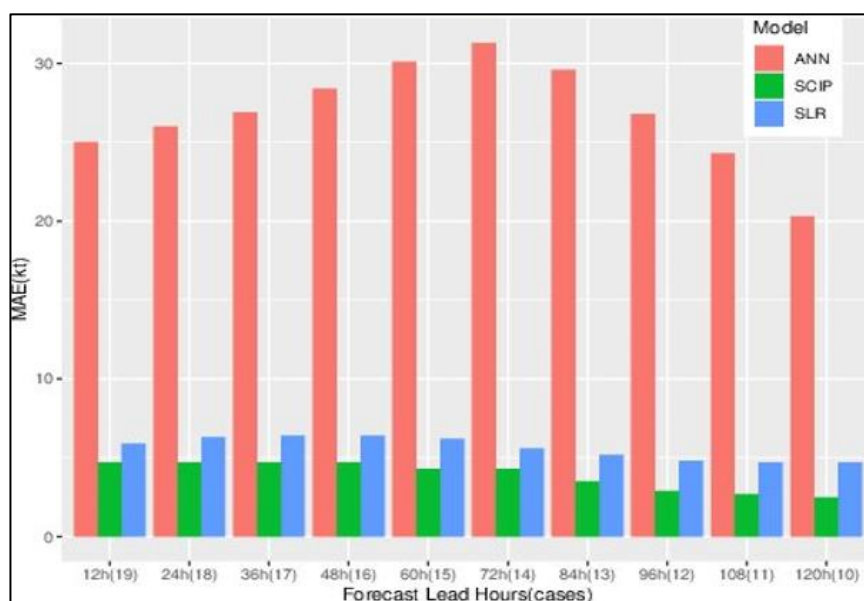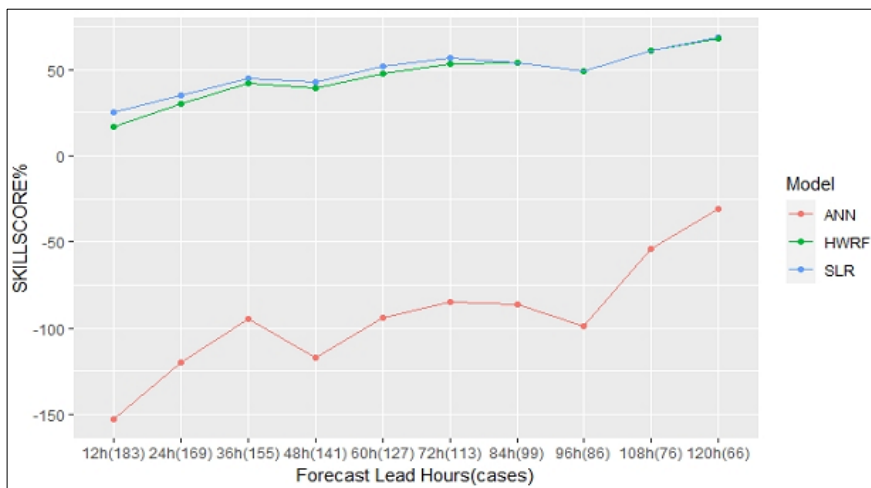
Fig 21: Skills of forecast models during 2019. The skill score of SLR is more for all forecast leads expect 84, 96 and 108 forecast leads

Table 1: Performance of different models during 2019. The number of cases in each forecast leads in the parentheses

		Forecast Leads(h)									
		12h(183)	24h(159)	36h(155)	48h(141)	60h(127)	72h(113)	84h(99)	96h(86)	108h(76)	120h(66)
Bias	SLR	4.98	5.31	5.27	5.22	4.96	4.5	4.53	4.48	4.09	3.23
	ANN	10.02	11.33	12.74	14.41	15.97	17.63	20.01	22.62	24.22	24.85
	HWRF	5.62	5.73	5.59	5.6	5.41	5.37	5.41	5.52	5.26	4.7
R	SLR	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.97	0.97	0.97
	ANN	0.47	0.42	0.4	0.4	0.43	0.46	0.53	0.63	0.71	0.75
	HWRF	0.97	0.97	0.97	0.97	0.97	0.98	0.97	0.97	0.97	0.97
RMSE	SLR	8.44	8.78	8.86	8.9	8.81	8.66	8.94	9.14	9.14	8.53
	ANN	29.82	30.85	32.11	33.14	34.25	35.32	35.68	35.81	36.13	36.6
	HWRF	9.48	9.74	9.84	10.03	9.93	9.76	9.94	10.3	10.03	10.04
CV	SLR	13.29	13.17	12.99	12.71	12.4	12.09	12.37	12.59	12.75	12.24
	ANN	46.95	46.71	47.08	47.34	48.22	49.32	49.37	49.31	50.38	52.51
	HWRF	14.92	14.75	14.43	14.33	13.98	13.63	13.75	13.81	13.99	14.4

Table 2: Performance of different models during 2019. The number of cases in each forecast leads in the parentheses

		Forecast Leads (h)									
		12h(93)	24h(86)	36h(79)	48h(72)	60h(65)	72h(58)	84h(51)	96h(44)	108h(39)	120h(34)
Bias	SLR	5	5.4	5.3	5.2	4.8	4.4	4.3	4.7	4.4	3.6
	ANN	8	9	10.2	11.4	13	14.9	17.8	22.4	24.3	19.2
	SCIP	5.1	5.2	5	4.7	4.3	4.3	4.7	5.2	5.3	4.7
R	SLR	0.98	0.98	0.97	0.98	0.98	0.98	0.98	0.97	0.97	0.97
	ANN	0.42	0.36	0.32	0.31	0.32	0.34	0.41	0.53	0.63	0.71
	SCIP	0.97	0.96	0.96	0.97	0.97	0.97	0.97	0.97	0.97	0.97
RMSE	SLR	8.4	8.7	8.9	8.9	8.8	8.6	8.8	9.2	9.3	8.8
	ANN	29.4	30.5	31.7	32.9	34.3	35.3	35.9	35.6	35.9	36.4
	SCIP	9.9	10.2	10.4	10.3	10.1	9.9	9.9	10	10	10
CV	SLR	15.1	15.1	14.8	14.3	13.8	13.2	13.2	13.5	13.7	13.1
	ANN	55.8	56.3	57.3	59	61.7	64.4	67.5	70.4	74.6	80.2
	SCIP	17.8	17.6	17.2	16.5	15.7	15.2	14.9	14.8	14.9	15.2

Concluding Remarks

The construction of Simple Linear Regression (SLR) and Artificial Neural Network (ANN) models were considered here. The SLR and ANN models were developed by using intensity (VMAX) and Minimum Sea Level Pressure (MSLP) of the tropical cyclones on North Indian Ocean. ANN model runs in different hidden layers. Here we considered only two hidden layer output because the forecasting intensities are same with change in layers. In this study, we have compared the forecasting intensity of the cyclones of the constructed models with IMD models (HWRF and SCIP). In the both seasonal forecasting and individual cyclones the SLR model gave better results than ANN, HWRF and SCIP. But ANN gave more forecast errors among the considered models cause for only MSLP is taken as input variable. Here VMAX and MSLP are linearly related. So SLR gave better forecasts compare with other models.

References

1. Chaudhuri S, Dutta D, Goswami S, Middey A. Intensity forecast of tropical cyclones over north Indian Ocean using multilayer perceptron model: Skill and performance verification. Nat Hazards. 2013;65:97–113.
2. DeMaria M, Kaplan J. A statistical hurricane intensity prediction scheme (SHIPS) for the Atlantic basin. Weather Forecast. 1994;9(2):209–220.
3. DeMaria M, Kaplan J. An updated statistical hurricane intensity prediction scheme (SHIPS) for the Atlantic and eastern north pacific basins. Weather Forecast. 1999;14(3):326–337.

4. Fitzpatrick PJ. Understanding and forecasting tropical cyclone intensity change with the Typhoon Intensity Prediction Scheme (TIPS). Weather Forecast. 1997;12(4):826–846.
5. Hobgood JS. The effects of climatological and persistence variables on the intensities of tropical cyclones over the eastern North Pacific Ocean. Weather Forecast. 1998;13(3):632–639.
6. Jarvinen BR, Neumann CJ. Statistical forecasts of tropical cyclone intensity for the North Atlantic basin; c1979.
7. Kalsi S. Orissa super cyclone—a synopsis. Mausam. 2006;57(1):1.
8. Kotal S, Roy Bhowmik S, Kundu P, Das Kumar A. A statistical cyclone intensity prediction (SCIP) model for the Bay of Bengal. J Earth Syst Sci. 2008;117:157–168.
9. Mohapatra M, Bandyopadhyay B, Nayak D. Evaluation of operational tropical cyclone intensity forecasts over north Indian Ocean issued by India Meteorological Department. Nat Hazards. 2013;68:433–451.
10. Roy Bhowmik S, Kotal S, Kalsi S. Operational tropical cyclone intensity prediction—an empirical technique. Nat Hazards. 2007;41:447–455.