Fidelity of AI Model in Representing the Different Types of Cyclone Track Estimation

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Abstract - *Tropical cyclones have devastating effects on human life and the natural environment and cause great economic losses. There are traditional methods such as numerical weather forecast models for tracking cyclones, but these are complex, require high computing power,are time consuming, and are costly. In today's era of remote sensing, satellites and radars are widely used to collect weather data in the form of grids and images. In this study, this visual imagery will be used to predict the trajectory of cyclones that have formed over the Arabian Sea (AS) and the Bay of Bengal (BoB) using the Artificial Intelligence Convolutional Neural Network (CNN) technique. The cyclone trajectory simulated by the traditional PNT and AI models was compared to the observation trajectory to see the accuracy of the AI models for the two different cases of cyclones formed. across two different seas, i.e. AS and BoB, which have different characteristics and opposite cyclone traces.*

Key Words: Convolutional Neural Network (CNN), Numerical Weather Prediction(NWP), Cyclones, Linear Regression, Data Analysis, Global Forecast system (GFS), European centre for Medium range Weather forecast (ECMWF), Meteorological and Oceanographic Satellite Data Archival Center (MOSDAC).

1.INTRODUCTION

Cyclone is the weather phenomenon, The System of winds rotating inwards to an area of the low barometric pressure, with the anticlockwise or fierce rotation. Cyclones are classified on basis of the wind speed as follow:-

Deep Depression (50-61 km/h), Cyclonic Storm (62-88 km/h), Severe Cyclonic Storm (89-117 km/h), Very Severe Cyclonic Storm(118-166 km/h), Extremely Severe Cyclonic Storm (166-221 km/h), Super Cyclonic Storm (> 222km/h).

In this paper two cyclones discussed, they are:-

1. Cyclone Nisarga 2. Cyclone Amphan

Cyclone Nisarga was a strong cyclone current (SCS) with a high wind speed of 110 km / hr near Ratnagiri on June 2, 2020 and was the strongest tropical cyclone to hit the Indian state of Maharashtra in June since 1891. It was formed in the Arabian Sea (AS). Nisarga Cyclonic Route followed by traditional methods such as Arabian Sea - Mumbai - Ratnagiri- Gujarat.

The super cyclone storm Amphan was a very strong, powerful and deadly tropical cyclone that caused widespread damage in the East Indies, particularly in West Bengal and Odisha. This cyclone formed in the Bay of Bengal (BoB) followed by the traditional method as the Bay of Bengal–West Bengal–Odisha.

Visual imaging data is used to predict the trajectory of cyclones that have formed over the Arabian Sea (AS) and the Bay of Bengal (BoB) using the Artificial Intelligence Convolutional Neural Network (CNN) technique simulated by traditional NWP and AI models. with observation tracking to see the accuracy of the AI models for the two different cases of cyclones formed in two different seas, i.e. AS and BoB with different characteristics and opposite cyclone traces.

The effects and devastation of the cyclones are the sea brought into the city by the strong cyclone winds, the waves rustle with fear, the church roofs are broken and the huge stones carry enormous distances, two thousand people died. This shows cyclones. They have economic and social effects that can be reduced by using better forecasting systems and accurate estimates of the course of cyclones. This explores the importance of artificial intelligence techniques in predicting cyclone trail estimation, which is time efficient, cheaper and simpler compared to conventional numerical weather forecasting (NWP).

2. LITERATURE SURVEY

Tropical cyclones (TC) are considered to be extreme climatic events with strong winds, storms and floods that can cause great damage to coasts around the world. Over the past century, numerous meteorologists and warning centers have devoted themselves to researching advances in observation technology,the interactions of the atmospheric environment, the atmospheric boundary layer and the air-sea interface as well as forecasting techniques. However, there are many problems with the remaining forecasting capabilities, particularly with forecasting the eruption, intensity and risk of the tropical cyclone.

In general, the most popular dynamic tropical cyclone forecast models have relatively poor accuracy, an incomplete representation of complex physical processes, and approximate resolution. There are few studies showing that the lack of representations of air-sea energy exchange at very high wind speeds prevents more effective simulation of CT intensity.

Satellite imagery is key data for weather forecast modeling. With the deep learning approach, the automatic image processing requires large data sets, which are explained with the various properties for training purposes. The accuracy of the weather forecast is best with data with a relatively dense temporal resolution. There are three optical flow methods using 14 different constraint optimization techniques, and the five error estimates are tested here.Cyclone data sets of another class) were used for training. The artificially enriched data (optimal combination from the previous exercise) are used as a training set for a neural convolution network to classify images in terms of thunderstorms or no clouds.

A strong tropical cyclone can turn into a typhoon or hurricane, a very devastating and unstoppable natural disaster that is responsible for death and property every year. For example, in 2017 alone, there were eight typhoons that landed in China, affecting around 6 million people and scarring around $ 5 billion in financial terms.Typhoons have multiplied, making tropical cyclone forecasting even more valuable and citizens and governments accept that they are better prepared when faced with such a calamity. Seascape, the coastline of the marine areas and the landscape of the inland areas. In addition, when a tropical cyclone forms, it can be influenced by a number of factors, including the meteorological environment, thermodynamics, and kinetics of the tropical cyclone system.All of the difficult problems make predicting the course of tropical cyclones a major challenge. Given the impact of tropical Cyclones in society and the complexity of their prediction, it is therefore important to research and apply new techniques for forecasting the course of tropical cyclones. There are many studies that use artificial intelligence techniques to detect typhoons, cyclones, and hurricanes around the world; Few studies have highlighted so far, but smaller or no studies found that examined the two different categories and different trajectory of cyclones over the Indian Ocean.

Typhoon trails are predicted using the Generative Adversarial Network (GAN) with the satellite imagery as inputs. The trained opposing generative network (GAN) is fought in order to generate a typhoon trace in the next 6 hours, for which the opposing generative network is not capable. To train the neural network, the time series of data from satellite images of typhoons that have recently occurred on the Korean peninsula are used. Predicting sudden changes in trajectory west or north is identified as a challenging task, while predicting is significant. Improved when speed fields are used in conjunction with the satellite imagery. The image of the forecast runway of a passing typhoon identifies the future location of the typhoon center and deformed cloud structures.

Many places around the world are exposed to tropical cyclones and the associated storm flow. Despite huge efforts, a great number of people pass away each year as a result of the cyclone events. To lighten damage, the improved prediction techniques must be developed. The technique presented uses artificial neural networks to interpret NOAA-AVHRR satellite imagery data. A multi-layer neural network, favouring the human visual system, was trained to forecast the movement of cyclones based on the satellite imagery data. The trained network produced correct directional forecasts for 98% of test images, that shows a good generalization capability. Future work will include extension of the present network to handle the wide range of cyclones and to take into account supplementary information, such as wind speeds, humidity, air pressure and water temperature.

The probability of using air temperature and moisture profiles for the resolution of pressure in the tropical cyclones (TC). The Tropical Cyclone middle pressure values calculated from the satellite data were compared with the estimates of the Japan Meteorological Agency. The accuracy of an air temperature and moisture profile renewal from the radiometer data is verified using the direct radiosonde measurements together with the weather station data for the Northwest Pacific. The comparison with the estimates of a Joint Typhoon Warning Center (USA) demonstrates bad agreement.

A convolutional neural network (CNN) and Deep Learning method was evolved to predict the movement direction of tropical cyclones or typhoons over the Northwestern Pacific basin from Himawari-8 (H-8) satellite imagery data.

Predicting the course of a tropical cyclone is critical to the safety of people and property. Even though dynamic predictive models can provide very accurate short term predictions and are computationally intensive, current statistical predictive models offer plenty of room for improvement as the database of past hurricanes is constantly growing and compound relationships have only recently been tested for this application. A new proposal is a neural network model that brings together data from past routes and re-analyzes the atmospheric image data in 3D. A moving frame of reference that follows the center of the storm is also used for the 24-hour follow-up forecast. The network is trained to estimate the latitude and longitude of tropical cyclones and depressions from a huge database from both hemispheres. The superiority of the merged network has been proven and a comparison with current predictive models shows that deep learning methods predict complimentary and complementary forecasts. In addition, the method can provide a forecast for a new storm in a few moments, which is the most valuable advantage for real-time forecasts compared to conventional forecasts.

3. METHODOLOGY

The forecast tracks of cyclones in IMD result from a manually analyzed forecasting process, which relies on output from several NWP models (RSMC 2010) including IMD Global Forecast system (GFS), European centre for Medium range Weather forecast (ECMWF), the UK Meteorological Office, Japan Meteorological Agency (JMA), ARP-Meteo-France, National Centre for Environmental Prediction (NCEP) GFS and some ensemble means like multi-model ensemble (MME). Consensus forecasts that gather all or part of the numerical forecast tracks and use synoptic and statistical guidance are used to issue official forecasts. Deep Learning showed encouraging performance for the characterization of complex patterns such as storm classification. We deploy the CNN framework using Keras (open source neural network library) for the classification of storm images into the five categories specified by IMD. The satellite images (infrared and visual) of cyclones from IMD are fed as input to the CNN and the model is trained on Google collaborator platform to extract relevant features from these images. Raw image from the dataset was cropped to remove header files and white edges. Subsequently, image binarization with some additional changes was applied to the images. Objective of this step was to remove the unnecessary information like grid lines, geographical boundaries, and landscape. In classic image binarization, the image is converted into a binary image with pixel intensities above a certain threshold are converted to one and others to zero. In our algorithm, the output was still an RGB image and the pixels with intensities above a threshold retained their original values while the other pixels were converted to the lowest minimum, i.e., zero. As a result, only the vortex and peripheral cloud patches were retained with original pixel values and other features were removed. The threshold was taken to be suitably optimized multiple (generally 1.4) of median of the pixel intensities of the image. Subsequently, image erosion was applied on the processed image. Model outputs i.e. cyclone track estimated/predicted from the output of the IMD operational NWP global model (Global Forecast Model; GFS), cyclone track estimation from AI/ML model are compared with observational track of cyclones (Amphan and Nisarga) from IMD. To assess the fidelity of the AI model in predicting the future cyclone track, comparative analysis techniques Like Root Mean Square Error (RMSE) and Track forecast error are used and these are explained as below. The track forecast errors (Forecast position – Actual position) of Cyclone centre.

3.1 Prediction of Storm

Cyclone is a system of winds rotating about a center of low atmospheric pressure termed as "eye" having wind velocity above a certain limit. There are many techniques for tropical cyclone forecasting but these can be grouped into three main classes of forecasting models. First is statistical models which are based on an analysis of storm behavior using climatology and correlate a storm's position and date to produce a forecast that is not based on the physics of the atmosphere at the time. Secondly dynamical models which are numerical models, solves the governing equations of fluid flow in the atmosphere; these models are based on the same principles as other limited-area numerical weather prediction models (NWP model) but may include special computational techniques such as refined spatial domains that move along with the cyclone and third models uses elements of both approaches of above mentioned models are called statistical-dynamical models. Here, we are presenting an AI model to track the eye (or the center) of the cyclone and predict its track. The aim of our model is to analyze the patterns present in its movement and then use it to predict the path of the cyclone. For testing, we used the archived cyclone images provided by the Indian Meteorological Department. These satellite images were captured over a half an hour interval, over different spectra (visible, infrared). Different channels images obtained from weather satellites are used in track and intensity forecasting of tropical cyclones.

3.2 S/W and H/W Requirement

1. **H/W Requirement**

   • Processor: GPU

   • RAM: 8 gigabyte (GB)

   • Hard Disk Space: 1 TB

   • core:Keras 2.0 and TensorFlow 1.2

2. **S/W Requirement**

   • Language :Python 3.5.2, NCL(NCAR Command Language)

   • IDE : Jupyter Notebook (Anaconda Navigator)

3.3 Datasets Used

Observed and forecast intensity and track data of cyclones and other information are taken from the records of the Cyclone Warning Division of the Regional Specialized Meteorological Centre (RSMC), New Delhi operating at the headquarters of the India Meteorological Department (IMD). For providing cyclone warning advisories for the NIO, World Meteorological Organization (WMO) recognizes this office as the Regional Specialized Meteorological Centre (RSMC). RSMC, New Delhi issues the track forecast from deep depression stage onwards since 2009 for 12, 24, 36, 48, 60 and 72 hr forecast periods. The data table includes information like date, time, position in latitude and longitude, central pressure, pressure drop at centre, T-number and intensity (maximum sustained surface winds in knots). Images of cyclones data from the year 1990 until recent times with increased accuracy and coverage in recent years downloaded from IMD archives. With the advancement in technology infrared, mid infrared, short- wavelength infrared, water vapor images of the recent cyclones were also included in the archive. Raw data are selected for the analysis. For prediction, we trained the model with several random cyclone images downloaded from the Internet. Also, we downloaded images from Meteorological and Oceanographic Satellite Data Archival Center (MOSDAC). We tested the model on the Fani cyclone that occurred from April 26 – May 4 2019. Python codes and libraries are used for creating the labels.The resolution of each image is 1024 * 1200 pixels.

Also the raw storm track data used in this study is composed of more than 3,000 tropical and extratropical storm tracks since 1979, extracted from the NOAA database IBTrACS (International Best Track Archive for Climate Stewardship, Knapp et al., 2010).

4. RESULTS AND DISCUSSION

In this segment we can describe the results, i.eTraining was made to run in Epochs. Each epoch consisted of 1 spherical presentation of the entire training set of about 1025 snap shots (around 96 randomly 4 were permuted, to avoid sequence self-learning effects. A peak validation accuracy of 97% obtained for classifying the typhoon or non storm. Standard CNN model is carried out at the preprocessed dataset using Keras applications. To check the predicting performance of the model, cyclone Fani data (not used in training of the model) are fed to the version. A peak validation accuracy of 65% is acquired while 95 snapshots of cyclone Fani are fed into the version. Because of confined computational resources, the extra variables had been now no longer blanketed within the gift study, which additionally limits the predicting accuracy of the version. Error in community performance is described because of the distinction among accurate output and the output produced with the aid of using the community that 39% calculated for every output unit and squared and summed into an ordinary blunders measure. Mean tune forecast blunders are generally better range cyclones in westerly winds and for the ones which might be recurving than for smaller for decrease range cyclones transferring westward. In general, suggest tune forecast mistakes generally tend to boom with the forecast duration and may be as an awful lot as 30 % of the cyclone motion inside this identical duration. Hence, the forecasted tune can deviate with the aid of using as an awful lot as 20 stages from the cyclone's real tune.

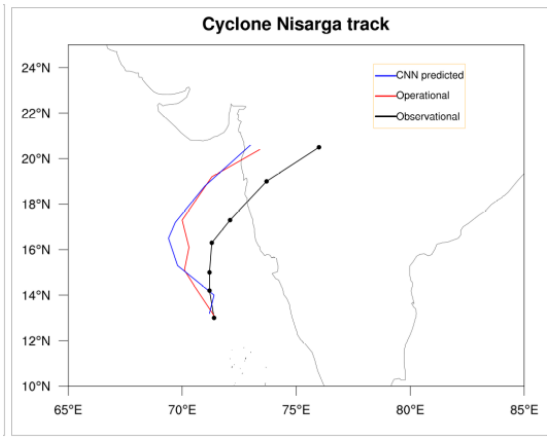
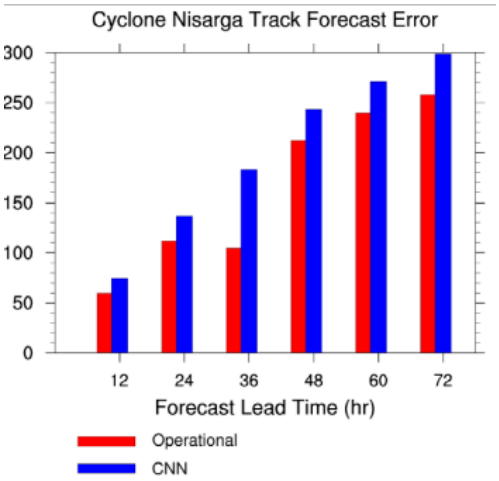


Fig -1: Cycling Nisarga Track (By NCL Software)



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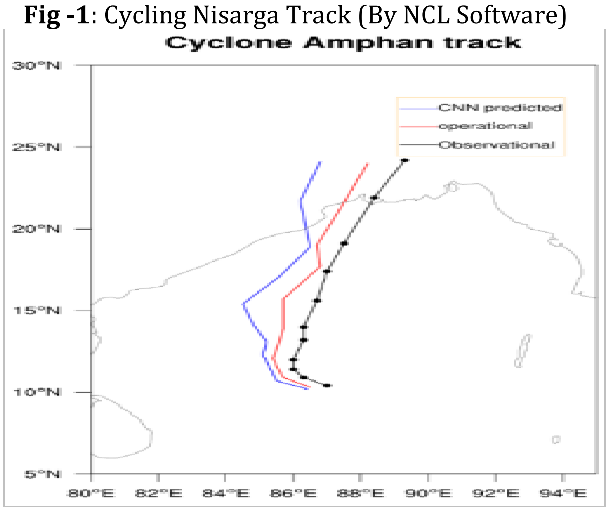

Fig -3: Cyclone Amphan Track (By NCL Software)

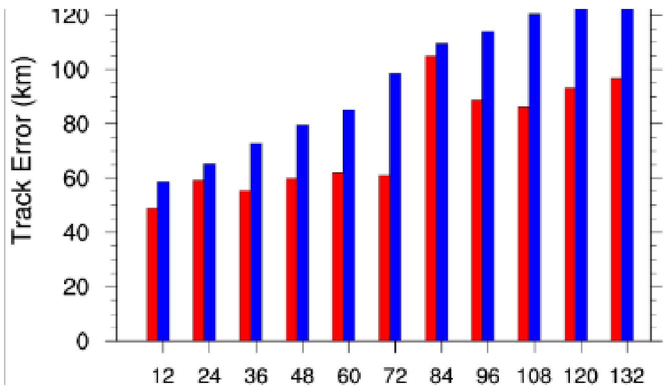

Fig -4: Cyclone Amphan Track Forecast Error

Figure 1 and 3 shows the tracks of cyclone Amphan and Nisarga respec-tively, in observations and models. Tracks forecasted by the both IMD operational forecast model and CNN model are similar with the actual observational track but with significant track forecast error in both of the cyclones. The cyclone Amphan track estimated by CNN model is more deviated than the operational forecasted track in comparison with actual track. But the case is different in cyclone Nisarga. CNN and operational predicted cyclone tracks are going hand to hand but with high track forecast error compared to cyclone Amphan. This shows the ability of CNN model to well predict the track of the cyclone (direction) but with higher forecast error than the operational model as compared to actual tracks. This may be overcome by adding more predictive variables like winds, temperature, Pressure etc.

Figure 2 and 4 displays the cyclone track forecast error in kilo-meter with respect to forecast lead time(hr) of cyclone Amphan and Nisarga respectively. In both cases of the cyclone forecasted track error is increasing with respect to increasing in forecast time. But this error is higher in case of CCN track forecast than the operational track in both the cases. Nisarga CNN modeled track forecast error is higher than the Amphan and this has to be explored further in detail which is beyond the scope of our study. The RMSE of both cyclones track forecast by CNN model is higher than the operational forecast indicated the CNN model algorithms need to be further improved in image data processing like two cyclones in a single image, two elongated ends etc. which limits the cyclone track forecast prediction using AI/ML techniques.

5. CONCLUSIONS

The results that we have obtained are promising. To the extent that cyclone movement direction is reliably indicated by satellite data in the visible range, neural network techniques seem to be effective in extracting this information. We have successfully implemented and tested DL model for the prediction of cyclone track estimation using CNN for two different categories of cyclones originating over two different ocean basins i.e. AS and BoB gave satellite images as an input to CNN model.

The main points of the study are-

- CNN model is able to predict the track of different types of cyclones similar to the actual observational track but with some forecast track error.

- The cyclone's track estimated by CNN model is more deviated than the operational forecasted track issued by IMD but this may be improved by adding more variables in CNN model.

- In both cases of operational and CCN model, cyclones forecasted track error is increasing with respect to increasing in forecast time.

For future work, it would be interesting to develop a scaled-up version of the network, and compare its performance with the present network to see if higher resolution images contain additional information that is useful for recognizing cloud patterns and determining movement direction.

REFERENCES

[1] S. Hong, S. Kim, M. Joh and S.-K. Song, Globenet: Convolutional neural networks for typhoon eye tracking from remote sensing imagery, 2017.

[2] Matsuoka, D., Nakano, M., Sugiyama, D. et al. Deep learning approach for detecting tropical cyclones and their precursors in the simulation by a cloud-resolving global nonhydrostatic atmospheric model. Prog Earth Planet Sci 5, 80 (2018).https://doi.org/10.1186/s40645-018-0245-y.

[3] Chong Wang,Quing Zu, " CNN-Based Tropical Cyclone Track Forecasting from Satellite Infrared Images", IGARSS 2020 - 2020 IEEE International Geoscience and Remote Sensing Symposium

[4] Snehlata Shakya,Sanjeev Kumar, "Deep Learning Algorithm for Satellite Imaging Based Cyclone Detection", IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing (Volume: 13), pp. 827-839, 2020, doi: 10.1109/JSTARS.2020.2970253.

[5] http://ibtracs.unca.edu/index.php?name=v04r00-2020138N10086

[6] http://ibtracs.unca.edu/index.php?name=v04r00-2020155N17072

[7] Fett, R.W. and Brand, S., 1975, Tropical cyclone movement forecasts based on observations from satellites, Journal of Applied Meteorology, 14, 4, 452-465.

[8] J. Lian, P. Dong, Y. Zhang, J. Pan and K. Liu, "A Novel Data-Driven Tropical Cyclone Track Prediction Model Based on CNN and GRU With Multi-Dimensional Feature Selection," in IEEE Access, vol. 8, pp. 97114-97128, 2020, doi: 10.1109/ACCESS.2020.2992083.

[9] Lajoie, F. A., 1976, on the direction of movement of tropical cyclones, Australian Meteorological Magazine, 24, 95-104.

[10] Sophie Giffard,Mo Yang, "Tropical Cyclone Track Forecasting Using Fused Deep Learning From Aligned Reanalysis Data",ORIGINAL RESEARCH article Front. Big Data, 28 January 2020 — https://doi.org/10.3389/fdata.2020.00001

[11] Kossin J. 2003, A user's guide to the UW-CIMSS Tropical Cyclone Intensity Estimation (TIE) Model. Cooperative Institute for Meteorological Satellite Studies (CIMSS), University of Wisconsin-Madison.