A Review of Cyclone Track Forecasting Techniques

Raju Thapa*, Surya Parkash, Harjeet Kaur and Anil Kathait

Abstract

Over the past few decades, the tropical cyclone forecasting capacities and accuracies have improved considerably with the advancement in numerical weather prediction (NWP). With the improvement in monitoring technology, data collection and modeling techniques there are significant increased lead time forecasts. In this review work, an attempt has been made to understand various techniques used to produce forecast such as averaging across occurrences, statistical forecasting techniques, dynamical and numerical forecasting techniques, statistical-dynamical techniques, hybrid forecasting techniques, other forecasting techniques.

Keywords: *Tropical cyclone; Cyclone track forecasting techniques; Numerical Weather Prediction (NWP); India Meteorological Department (IMD)*

1. Introduction

Prediction of tropical cyclone is a complex process which includes prediction of several parameters such as location, wind speed, intensity, probable storm surges and accompanying rainfall etc. (Holland, 2009). Tropical cyclone forecasting techniques takes into consideration the behavior of previously encountered similar cyclone and/ or the recent-past behavior of the current cyclone. The similarity between cyclones may be attributed to the similar behavioral pattern, place of origin or time of origin. To forecast the track of the current cyclone, certain forces or factors are considered, also called predictors, with an assumption that these predictors would influence the previous and present cyclone in similar manner similarly. The cyclone track forecasting techniques that are implemented can be broadly categorized into various classes as represented figure 1.

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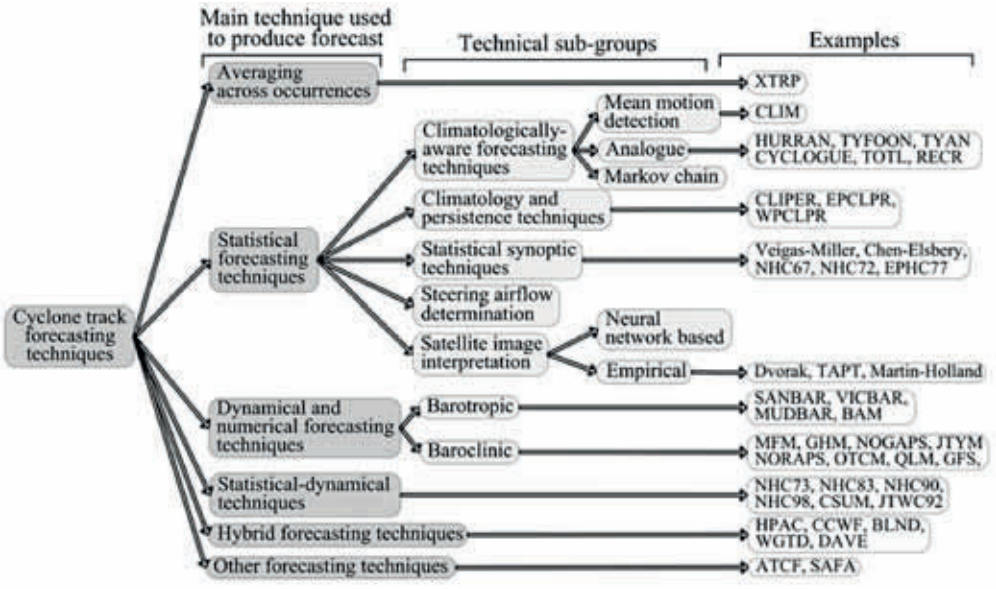

Figure 1: Details of various cyclone track forecasting techniques used (Roy and Kovordanyi 2012).

The Indian Seas have historically been the deadliest basin with several cyclones responsible for more than 1 lakh of causalities. The 1970 Bhola cyclone killed about 3 lakhs people, perhaps, the maximum number as per the recorded history. In the Bay of Bengal, number of devasting cycloning storms originated which made landfall in the eastern coast of India such as Cyclone Amphan 2020, extreme severe cyclonic storm Fani 2019, Cyclonic Storm Roanu 2016, extremely severe cyclonic storm Hudhud 2014 etc. Similarly number of devastating cycloning storms made landfall on the West coast of India originating in the Arabian Sea such as Cyclone Nisarga 2020, Very Severe Cyclonic Storm Ockhi 2017, Cyclonic Storm Phyan 2007 etc. The annual frequency of cyclone in India is represented in Figure 2.

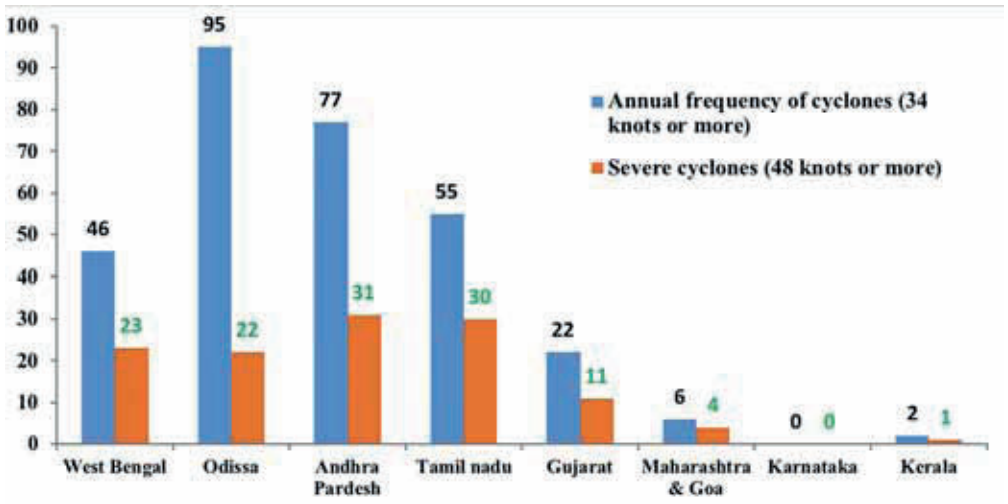

Figure 2: Annual Frequency of Cyclone

(Source: https://mausam.imd.gov.in/)

1.1 Averaging Across Cyclones

Averaging across cyclones are the simplest cyclone track forecasting techniques (Holland, 2009). In this technique, current and recent-past movement of cyclone are extrapolate and average to generate forecast the details of future cyclone and are also called as extrapolation techniques (Roy and Kovordanyi 2012). Only two factors i.e., direction and previous positions of the current cyclone governs the future movement of cyclone, the accuracy of the forecast depends on precise selection of time-tagged positions (including recent-past position) of the current cyclone. Even though this technique provide satisfactory extrapolation for short-term forecast i.e., 12 to 24 hours ahead, but they are not adequate and preferable for making long-term forecasting (Jeffries et al., 1993; Roy and Kovordanyi 2012).

1.2 Statistical Forecasting Techniques

These techniques are mostly based on regression analysis and can be used for producing both short-term (24 hours) and long-term (72 hours) cyclone forecasting (Miller and Chase, 1966). Some of major types of statistical forecasting techniques are statistical synoptic techniques, climatologically-aware forecasting techniques, steering airflow

determination, climatology and persistence forecasting techniques and statistical-dynamical techniques (Jeffries et al., 1993; Neumann, 1979; Roy and Kovordanyi 2012). Details of present or previous storm, numerical simulations or synoptic analysis can be used to obtain the predictor data set used for cyclone track forecasting. In comparison to dynamical and numerical forecasting techniques, statistical techniques require fairly low computational resources. In addition, any number of combinations of variable can be considered in the observed data (Neumann, 1985; Lee and Liu, 2004; Roy and Kovordanyi 2012). This technique reflects the average behavior of storms and the prediction of the model varies greatly when the present synoptic situation departs greatly from the normal climatology (Keenan, 1985). Additionally, this quality of data influences the output of the prediction of these techniques making it quite unreliable in data-sparse regions (Jeffries et al., 1993).

1.3 Dynamical and Numerical Cyclone Forecasting Techniques

Dynamical cyclone forecasting are carried out in two different processes i.e., using equations to forecast the track of the tropical cyclone vortex and determining the suitable pressure level using wind prognoses at different air pressure levels from global or regional models (Jeffries et al., 1993). This technique doesn't depend on climatological data of the basin since the different environmental factors that influence the cyclone are incorporated in the model enabling this technique to execute reliable forecasting even in data scarce environment. To run these modeling multi-kernel computers are required as these models cannot be run on desktop PCs (Lee and Liu, 2004, Neumann, 1985).

1.4 Statistical-dynamical Techniques

In this technique, predictors are determined to use statistical screening of past storms followed by combining with forecasts produced by a dynamical technique resulting in a final forecast (Neumann, 1979). In statistical-dynamical techniques, the output obtained from both from statistical and dynamical techniques are integrated. Statistical-dynamical technique is also known as NHC73 and is used by the NHC.

1.5 Hybrid Forecasting Techniques

As the name suggests, in hybrid forecasting techniques the output generated from two or more different techniques are combined statistically. In this technique, all the strength of the combining techniques will be inherited by the hybrid model and will be able to handle a broader set of predictors. However, in addition to strength, weakness of each constituent technique will get aggregated (Jeffries et al., 1993; Chu, 1999).

1.6 Other Cyclone Forecasting Techniques

In addition to the above mentioned techniques of cyclone forecasting, several other techniques are employed to tract and forecast cyclone movement but cannot be classified under above classification. Some examples includes intelligent decision support framework developed by Pedro et al. (2005), Systematic Approach and Forecast Aid (SAFA), Automated Tropical Cyclone Forecasting System (ATCF), Analysis and Forecast Integration System (TAFIS) (Roy and Kovordanyi 2012).

1.7 Tropical Cyclone Forecasting by IMD

IMD is the Nodal agency for cyclone forecasting in India. During forecasting of tropical cyclone, genesis, location, probable path, wind speed, duration are predicted along with heavy rain, storm surge, gale wind, coastal inundation and other associated adverse weather condition. IMD follows a specific systematic procedure to implement all the aspects of early warning of cyclone. Scientifically based conceptual models, meteorological datasets, dynamical & statistical models, advance technology, skill and expertise are employed to carry out analysis, prediction and decision-making process of tropical cyclone. The detail schematic diagram of early warning system used by IMD is represented in figure 3. Conventional observational network, Doppler Weather Radars and satellites, buoy & ship observations, climatological, statistical and Numerical Weather Prediction (NWP) are used for the above purpose. IMD is constantly working to upgrade all its early warning component and technology to increase its efficiency and effective management of tropical cyclone. In this regard, IMD has commenced introducing the state-of-the art Doppler Weather Radar (DWRs) along the coastline in replacement of existing cyclone detection radars (CDRs) as part of their modernisation programme (Rathore et al., 2017).

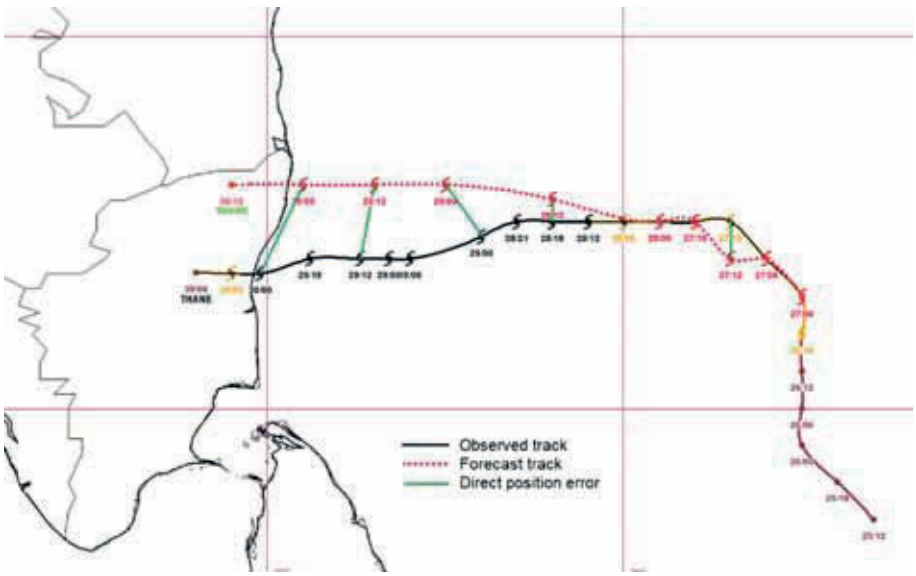

Figure 3: An example of forecast track based on 0000 UTC of 27 December 2011, observed track of very severe cyclonic storm, Thane (25–30 December 2011) and the direct position error at different forecast verification time.

(Source: https://mausam.imd.gov.in/)

For forecasting the intensity of tropical cyclone, both satellite method and radar technique are used. In radar technique, radial velocity measurements are collected via direct wind observations. In addition, data collected from Buoy, Ships, Scatterometry wind from satellite etc can be used to calculate the Maximum sustained surface wind apart from Dvorak technique. A statistical–dynamical model is implemented for real time forecasting of 12 h to 72 h intensity, where IMD GFS model are used for derivation of model parameters (Kotal et al. 2014; Rathore et al., 2017).

As per the requirement of the ship, cyclone wind radii are generated in each quadrant (NW, NE, SE and SW) for wind reaching 34 knots (kts), 50 (kts) and 64 (kts). With recent advancement in technology and techniques such as Special Sensor Microwave Imager (SSMI), ocean satellite, multi satellite surface winds, Doppler Weather Radar (DWR) etc., the monitor and prediction of IMD have been more accurate and efficient (Mohapatra and Sharma 2015; IMD 2013; Rathore et al., 2017). Figure 4 show an example of wind radii forecast of tropical cyclone Phailin issued by IMD.

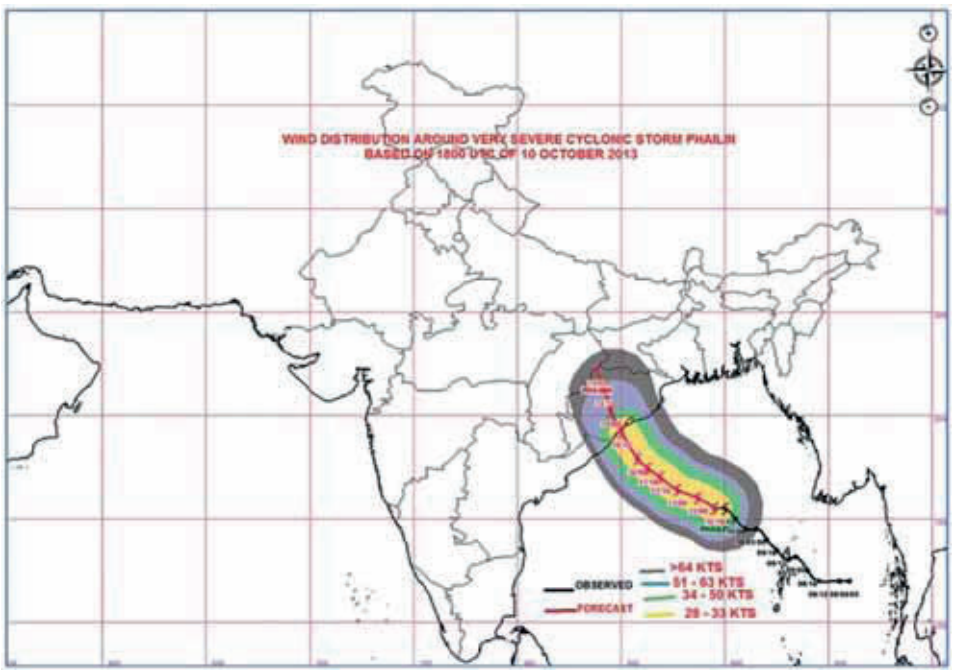

Fig. 4 An example of wind radii forecast

Generally, there are 3 types of adverse weather i.e., heavy rain, gale wind and storm surge that are associated with tropical cyclone during its landfall. Heavy rainfall forecasting is provided based on climatological, synoptic, Radar, satellite, and NWP techniques where, forecast issued contain details such as time, intensity, location and duration of heavy rainfall. Forecast of gale wind contain vital informations such as area of occurrence, duration, commencement time and magnitude of gale wind. The prediction is carried out using climatological, synoptic, radar, satellite, NWP and dynamical statistical techniques. (Source: https://mausam.imd.gov.in/)

Storm surge is the rise of sea due to the cyclone and depends upon radius of maximum wind, rainfall, river run off, pressure drop at centre, interaction with sea waves, point of landfall, bathymetry, astronomical tide, coastal geometry, etc. The forecast of storm surge includes information such as time, location and duration magnitude of storm surge. The technique used for storm surge prediction includes IMD Nomogram, IIT

Delhi Storm surge model and Indian National Centre for Ocean Information Services (INCOIS), Hyderabad Storm surge and coastal inundation model (Ghosh 1977; Dube et al. 2009; Rao et al. 2012).

1.8 Nowcasting

The forecasting and prediction techniques and instrumentation are constantly improving. Some of recent introduction includes dense automatic weather station (AWS) network, good network of Doppler Weather Radars, Kalpana and INSAT satellites observations, advancement in analysis tools, availability of nowcast models, computational and communication capabilities etc. for nowcasting of convective weather major stations/cities falling under the coverage of DWR and with the expansion of DWR networks, more number of cities will be brought under nowcasting.

2. Conclusion

With the advancement in science and technology, sophisticated numerical models are implemented for prediction and forecast of tropical cyclone. Though there have been significant achievement in recent time but still much work needs to be done in understanding force influencing cyclone position, direction etc. The exact importance of various conditions necessary for formation of cyclone is not clear.

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