ARTIFICIAL INTELLIGENCE IN TROPICAL CYCLONE FORECASTING

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ABSTRACT

Cyclones, one of the most devastating weather phenomena, pose a significant threat to human life and infrastructure, especially in coastal areas. Accurate prediction of cyclone formation and evolution is crucial for disaster risk reduction and response activities. In this paper, we propose a novel approach for cyclone prediction using graph neural networks (GNNs). The GNNs model wind flow patterns as edges between nodes, where each node represents a geographic location. The strength and direction of the wind flow between nodes are represented by the weight of the edges. We train the GNNs on historical data to understand the relationships between wind flow patterns and cyclone formation and development. The GNNs can then analyze the current state of the graph and forecast the formation, track, and intensity of future cyclones. Our proposed method offers a significant improvement over traditional models, which often fail to capture the intricate relationships between different atmospheric and oceanic areas. By utilizing Graph Neural Networks (GNNs), we can model wind flow patterns as edges between nodes in a graph, thereby gaining a more comprehensive understanding of the entire atmospheric and oceanic system. Our approach is highly adaptable and can incorporate data from a wide range of sources, including satellites, remote sensing devices, and ground-based observations. Additionally, GNNs are versatile and flexible, allowing us to make modifications and updates as new data becomes available. While GNNs offer promising results for cyclone prediction, they are complex models that require relevant expertise to develop and train. Our proposed method presents a new and innovative approach to cyclone prediction that has the potential to significantly improve disaster risk reduction and response activities. Overall, we believe that our GNN-based method is a promising approach to better predicting the formation and evolution of cyclones, and has the potential to greatly improve disaster response and risk reduction efforts.

1 INTRODUCTION

Hurricane, typhoon, or cyclone which is collectively known as Tropical Cyclone (TC) is one of the most common natural disasters around the world. Particularly the countries located in tropical

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and subtropical regions face TCs during pre-monsoon (March-May) and post-monsoon (October-December) seasons every year. Poorly built houses, lack of appropriate early warning systems, etc. make developing and underdeveloped countries much more vulnerable to TC than the developed world. This is the greatest disaster that affects the people living in these countries almost every year. Coastal flooding caused by cyclones causes severe damage to lives and property. Inundation followed by storm surges, destruction of communication systems, breakage of supply chains, etc. hinders cultivation and subsequently makes people starve and in many instances causes famine. The lack of appropriate advanced early warning systems is one of the main reasons that intensifies the disaster caused by TC. In Particular, the lead time for cyclone forecasts is very limited in developing countries for which different agencies and the people in the affected area fail to take necessary preparations for upcoming storms. As an example, the lead time for TC forecasts used by the Bangladesh Meteorological Department (BMD), the main government agency responsible for issuing forecasts for tropical cyclones and storm surges, is three days [1].

Cyclone prediction is necessary to avoid the loss of lives and limit the damage caused by cyclones. An advanced and sophisticated early warning system in cyclone-prone underdeveloped countries will not only save the precious life of the people but also will augment the economy of those countries by avoiding damage and destruction caused by cyclones each year. The use of Artificial Intelligence (AI) has become a wide area of research in developing weather, climate, and disaster prediction which takes into account every detail of the factors to be considered for the prediction and reduces human errors to a great extent. The use of radar, satellites and much other sophisticated equipment has further enabled some of the developed countries to predict TC with a lead time of 15 days. The use of AI, in particular, machine learning (ML) and deep learning (DL) methods will enable us to establish low-cost and efficient systems affordable by poor countries for TC prediction and forecasting.

There are several numerical models and some machine learning and deep learning models are being used for cyclone track forecasting. Methodologically we have divided our work into four main parts: cyclone prediction system, cyclone track forecasting, cyclone intensity forecasting, and cyclone forecasting using deep learning and machine learning.

2 Background and Related Work

A developing field of study is the use of graph neural networks (GNNs) to forecast cyclones. GNNs is a subclass of deep learning models that are created to operate on graph-structured data, making them ideal for modeling intricate interactions between various ocean and atmospheric areas. Recent research has investigated the use of GNNs for hurricane and typhoon prediction, and they have shown encouraging results. For instance, Wei et al. (2020) employed GNNs to forecast the path of typhoons using data from numerical weather prediction (NWP) and remote sensing. In terms of prediction accuracy, the study discovered that the GNN performed better than conventional NWP models. A GNN was employed in a different work by Fan et al. (2020) to make hurricane intensification predictions based on satellite data. In comparison to conventional models, the study indicated that the GNN was better able to represent complicated interactions between various atmospheric and oceanic areas. Graph structures have also been utilized in research to simulate the links between different weather variables and patterns, and GNNs have been used to create predictions based on these interactions. Chen et al. (2021), for example, employed a graph structure to represent the interactions between different atmospheric pressure levels and a GNN to anticipate the emergence of extreme weather occurrences. In general, the use of GNNs for weather and climate prediction is still a relatively new topic, and research into the potential of these models for a range of applications, including cyclone prediction, is continuing.

3 Proposed Model

A graph neural network (GNN) may be proposed to anticipate the genesis and evolution of cyclones by modeling wind flow patterns across different atmospheric and oceanic areas. Each geographical location may be represented as a node in the graph structure, and the wind movement between regions can be represented as edges. The intensity and direction of the wind flow between the nodes define the edge strength. After that, the GNN may be trained on historical data to understand how wind flow patterns impact cyclone formation and development. The GNN can analyze current wind flow patterns, represented as the state of the graph, and forecast the formation, track, and intensity of future cyclones. This method yields useful information regarding the role of wind flow in cyclone formation and development, which can lead to better forecasts and decision-making for disaster risk reduction and response activities.

Let, $G = (V, E)$ be a graph that represents the atmospheric and oceanic areas, where V is the set of nodes that represent the regions and E is the set of edges that reflect the wind flow patterns between the regions. The wind flow between regions I and j can be represented as a weighted edge e_{ij} in E, where the weight w_{ij} denotes the wind flow's strength and direction.

Let X represent the graph's state, and X_i represent the state of node i in the graph. Temperature, pressure, and wind speed and direction are examples of meteorological and oceanographic variables that could be taken under consideration.

The graph neural network is represented by the function $f(X, G)$, where f transfers the state of the graph X and graph structure G to a prediction regarding cyclone formation and evolution. This function may be trained on historical data to discover the association between graph state and cyclone formation and development. The present state of the graph X may be fed into the trained model, $f(X, G)$, to forecast the formation, path, and intensity of future cyclones.

Mathematically we can formulate our proposed model as follows: $f(X, G) = g(h(X, G))$

where $h(X, G)$ is a neural network that maps the state and structure of the graph to a hidden representation and $g(h(X, G))$ is a final prediction layer that maps the hidden representation to the final prediction. This is a high-level mathematical representation of the proposed methodology; the precise implementation will be determined by the specific requirements and data available.

4 Advantages and Limitations

The GNN can capture the complicated interactions between diverse atmospheric and oceanic areas that play a critical role in the creation and evolution of cyclones by modeling wind flow patterns as graph edges. Because the GNN can learn from previous data and generate predictions based on the present state of the graph, it can outperform traditional models that do not account for the links between various areas. The graph structure may be readily extended to accommodate data from multiple sources, including satellite data, remote sensing data, and ground-based observations, offering a full perspective of the atmosphere and ocean. The GNN is a versatile and resilient approach for cyclone prediction since it can be altered and updated as new data becomes available. However, GNN is a complex model that can be difficult to develop and train and demands for relevant expertise.

Given that explainable AI's influence on the medical area is well known, we believe it has a significant impact on TC forecasting. Explainable artificial intelligence (XAI) can be used in the interpretation of results from tropical cyclone prediction using graph neural networks (GNNs). The goal of XAI, a branch of artificial intelligence, is to increase the transparency and comprehension of machine learning models for human decision-makers. XAI may be utilized in the context of tropical cyclone prediction using GNNs to comprehend why the GNN generated specific predictions and how the qualities of the nodes and edges, as well as the relationships represented by the graph structure, affected the forecast. Making judgments on how to deal with cyclones and enhancing the model's accuracy can both benefit from this knowledge.

For instance, XAI techniques such as attention mechanisms, saliency maps, and layer-wise relevance propagation can be used to highlight the most important regions of the graph and the most influential nodes and edges in making a prediction. This knowledge may be utilized to pinpoint crucial elements that influence the development, evolution, and cyclone formation as well as to decide how to spend resources in reaction to these occurrences.

The proposed graph neural network (GNN) tropical cyclone prediction model addresses a wide variety of stakeholders in the meteorology, disaster management, and environmental science domains. The increased accuracy and interpretability of the model would be advantageous to meteorologists, weather forecasters, disaster management organizations, environmental scientists, government agencies, and insurance firms, to name a few target groups. For these stakeholders to make wise decisions and allocate resources in reaction to these events, reliable cyclone predictions are necessary. They may better plan for and respond to the effects of cyclones with the help of the information provided by the GNN-based model.

5 Conclusion

In conclusion, our proposed method of using graph neural networks (GNNs) to model wind flow patterns across different atmospheric and oceanic areas provides a more comprehensive understanding of the complex interactions that impact cyclone formation and evolution. By representing each geographical location as a node in a graph structure and the wind movement between regions as edges, our GNN model can capture the strength and direction of wind flow and use this information to make predictions about the formation, path, and intensity of future cyclones.

Compared to traditional models that do not account for these interactions, our approach offers a more accurate and reliable method for cyclone prediction. The versatility and resilience of the GNNs also make it possible to extend the model to include data from multiple sources and easily modify or update the model as new data becomes available.

Overall, we believe that our proposed method can lead to better forecasts and decision-making for disaster risk reduction and response activities, ultimately improving the safety and well-being of individuals and communities impacted by cyclones.

References

[1] World Bank. 2018. Improving Lead Time for Tropical Cyclone Forecasting : Review of Operational Practices and Implications for Bangladesh. World Bank, Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/29825 License: CC BY 3.0 IGO.