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Estimation of Tropical Cyclone Intensity from Satellite Data using GRU and DBN Approach

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Abstract: This research therefore seeks to fill this gap. The ways it can be applied, concerns the examination of GRU and DBN models and satellite imagery data for the assessment of the intensity of tropical cyclones. Not only can the findings of this research help understand the physical process of rapid intensity change of a storm, but it is also valuable to the ability to forecast the tropical cyclone intensity change – a factor incredibly important for local governments to develop their long-term strategies and avoid high losses. A continuous development over the modern computational technology as well as the numerical models have been developed over the several decades which invoked the great interest and extensive research in these specific areas that further enhances the understanding of the formation of tropical cyclones; track and intensity change. As a result of these advances in NWP there has been light shed in the advancements that now allows us to predict that path of a tropical cyclone in large accuracy. Nevertheless, the ability to predict the alteration of the intensity of a tropical cyclone is still one of the tough challenges which weather forecasters are facing up to. This is because there are times a tropical cyclone can intensify within the minimum time and with such intensification not easy to capture by numerical models. Moreover, the choice of the intensity forecast and its accuracy fully depends on the provided initial background information, as well as on the enormous information growth in the weather forecast and in a plenty of other application fields, the increase of which is always associated with the need for the development of more efficient algorithms and the increase in the amount of available computational resources. This paper will be designed to give a brief outline of the results achieved and to show how our approach has been used in two different case-studies. Then it will proceed towards explaining the values obtained through the model parameters and assess the performance of the model based on different conditions. In the last place, the model with largest performance will be used for the prediction of the tropical cyclone intensity of a case data. This work will give empirical evidence to define and solve the problems relevant to the current capability of the tropical cyclone intensity change forecast.

Keywords: *Tropical cyclones, GRU, DCN, forecasting, intensity*

1. Introduction

1.1 Background

Tropical cyclones are among the most disastrous natural phenomena in the world, and they relay devastating effects on human lives and infrastructure in the impacted areas. Also known as hurricanes or typhoons, the tropical cyclones are a natural calamity whereby various categories and their intensity are vital to many people in the scientific and operational communities. Tropical cyclones form over warm sea surfaces; given that they are primarily compelled to a great extent by the heat energy it is possible to release into the atmosphere through the condensation process of rain producers in such systems. Therefore, cyclones result in discomfort through the provision of heavy rains and wind, which lead to the destruction of aNy structures built by humans and even the geographic landscape. As technology in satellite remote sensing improves and the usage of high-performance computing grows with sophisticated equipment in meteorological departments, digital image processing and geography information systems. Satellites are now quite useful in observing the complete three-dimensional spatial patterns of tropical cyclones and providing detailed information about cyclone structural changes as well as the surrounding environment on a continuous basis. In turn, this has led to better and more timely forecasts and more accurate identification of one or more possible scenarios of the cyclone's track. Since tropical cyclones are typically in more remote regions of the world (e.g., the Western Pacific and the North Indian Ocean), where on-site observations are practically non-existent. Observed data and the results of scientific field campaigns are severely limited. Establishing a means to estimate the cyclone intensity from satellite data is really crucial in order to objectively monitor the trends and the patterns of the cyclone over a certain time period. Cyber infrastructure and high-performance computing offer scientists a great way of testing out models and the storage and manipulation of huge data sets like the satellite images and the numerical output from forecast models. Such facilities facilitate collaboration by allowing the results of research to be easily shared over the internet and open resources to semi-autonomous data analysis. This is really important because hurricane scientists working on the same hurricane at different times may each provide

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their own best path based on the observational data and personal experience. The development of automated systems for exploring alternative predictions has been a primary area of research and requires advanced algorithms and efficient computational routines. These will link up to the National Environmental Satellite Data and Information Service in which real-time data is sent to as a backup at this present moment but with the future prospects of being a provider of knowledge and data to the service. Such three entities namely data, models, and information technology support and interact with each other in defining the modern meteorological practice, which has a heavy emphasis on digitalization and interactivity. With the use of the satellite imagery in this essay to investigate the spatial distribution of the rainfall and the wind speed in a particular tropical storm, one can see how such technology can help us in evaluating and monitoring the intensities of the storm over a period of time. Also, it demonstrates well on how the satellite elements of the information technology in meteorology helps in our understanding of the weather.

1.2 Problem Statement

The main objective of research is to investigate the performance of different machine learning techniques in cyclone intensity estimation from satellite data. Satellite images provide a direct way to observe cyclones and potential indicators associated with cyclone intensity. It was found in a previous study that cyclone intensity estimation from satellite imagery can be done using pattern recognition techniques. A multiple linear regression model was able to estimate the intensity of the cyclone represented in categories based on the Dvorak technique. This was done using best track data to provide guidance on estimating the expected change in intensity of a cyclone in a given time period and location. Results showed that the multiple regression model was successful at producing statistically significant findings with some predictors. An underlying theme of all of the above work is the idea of establishing the map-function of cyclone intensity on its environmental fields to gauge the environmental dependence of TC intensity. Another simplified regression-based model on a subset data of the above work also demonstrated encouraging outcomes of estimating intensity changes. A different angle was taken in work by Kossin concerning the estimation of potential intensity and Carnot efficiency on future and past projections of all tropical cyclones.

1.3 Objective

To foster an optimally organized case database of satellite-derived cyclone intensity changes, including much extended temporal and spatial resolution to conduct an in-depth examination of specific alterations of individual tropical cyclone intensity changes. This will involve the development and utilization of advanced objective Dvorak technique that will provide a more consistent and improved estimation of tropical cyclone intensity change. Also, the results of the CASE database analysis will be inter-compared with results of other climatologist to test the reliability and robustness of the various intensity changing trend estimations. This will strongly test the hypothesis that the recently identified transient increasing trend of global tropical cyclone intensity changes has been a prominent feature of the last 30 years and may be linked to recent climate change. Finally, it is expected that the representative results of this study will lead to an improved evaluation of the various regional and global climate models' ability to replicate tropical cyclone intensity changes.

2 Literature Review

The literature review was intended to focus on the updating of various aspect, primarily enclosed to the "intensity estimation of Tropical Cyclones". Kai Beven (2011) argued that it is high time to refrain from relying on Saffir-Simpson Hurricane scale in order to forecast the rate of formation of the tropical cyclones. The Saffir-Simpson scale is a scale which provides an estimate of the power of a hurricane by giving a rating from 1 to 5 in line with the sustaining wind velocity. This categorization is used in order to give some indication of the extent of the likely potential property damage and flooding that could be anticipated along the coast which might result from the hurricane making landfall. R Pradhan et al [2] utilized a single CNN based IR image from passive microwave sensors for evaluating TC intensity directly by weighting average formula based upon two higher categories to the CNN. It is or maybe wrong with respects to classifying TC concentrated. In later a long time, relapse examination is utilized by the examiner to reinforce TC estimation. A. Wimmers et al. connected a 2D-CNN calculation with input information from 37.85-93 GHz channels, accomplishing an RMSE of 14.31 ties in their approval. They too proposed the deviation-angle fluctuation method (DAV-T), which employments per-pixel brightness temperatures. The precision of gauges by the Joint Tropical storm Caution Center (JTWC) for cruel supported wind speed (MSW) was affirmed. Thus, DAV-T accomplished an RMSE of 12, showing that its gauges are solid. Inside the specific case of northwest Pacific tropical storms in between 2005 and 2011, an expected wind speed of around 72 kt has been recognized. The pooling, the convolutional and completely associated layers in a cCNN are perfect in profound highlight extraction (wherein highlights more profound than a thousand are likely to be obtained) in profound learning. There's no have to be extricate for starters the parameters suggesting the density of TCs within the infrared adj. photographs in connection to CNNs. [5]. Nevertheless, even in such balanced conditions, when the samples of different intensity of TC are taken into consideration, the explanation of the changes in TC by a single model can encounter significant difficulties due to the high variety of forms of TCs and the very broad amplitude of TC wind speed variations. Currently, there is a lack of studies using CNN methodologies to estimate TC intensities, and those that have been done utilize commonly, and very simple deep learning network structures such as AlexNet or VGGNet. For predicting tropical cyclone intensity, Boyo [7] proposed rotation-blended CNN by blending convolutional low-pass filters with rotation kernels. An experiment involves rain rate observation by passive-microwave , infrared data, and water vapor measurements. The Dvorak method of estimating cyclone intensity has been widely used in the past thirty years and newer techniques have been developed as advancements in technology have come about. ADT [8] uses algorithms in order to make binary symptoms of clouds instead of using expert's opinion. As tropical cyclone poses with various social and economical effects it is essential to forecast its intensity with precision for it aids in disaster risk reduction and increases knowledge in the scientific field. It is perhaps accurate to state that a TC has the potential to pose a massive threat to the lives and structures of affected individuals. These storms produce huge impacts on coasts and the inland regions, with potentialities for extreme rain and tornadoes in addition to storm surges. The damage that an TC can cause is influential with the strength size and location of the storm [9]. For these reasons, accurate measurements of these intensities are very important especially in real time TC prediction and disaster preparedness. In spite of critical headways in later a long time, evaluating tropical tornado (TC) acceleration remains a major challenge in TC examination. Zeng utilized hyperspectral information recoveries to improve storm figures [12] Moreover, profound learning procedures have been as often as possible connected to memorize properties from adjoining imaging information. Convolutional Neural Networks (CNNs) which previously were designed to work with images belong to a layered model type popular in deep learning. A recent CNN model developed to identify objects autonomously through satellite pictures and then estimate TCI has been based on LeNet-5 [13]. These networks when brought deeper and more fined tuned on larger datasets have resulted in better predictive models. As part of understanding the TC satellite images, low et al employed a VGG-16. When analyzing TC symmetry, there is a new and progressive measurement, the deviation angle variance (DAV)[15],[4] , or the measure of how much those angles deviate from the regular angles on the hexagonal grid.

The cloud top slant inside a 120 km sweep of a tropical tornado (TC) center, alongside the cruel and standard deviation of cloud beat temperature inside a 240 km ring around the TC, are utilized to parameterize the relationship between TC cloud highlights and TC escalated. T. Suthar et al. proposed a self-attentive TCNN BiGRU show for assessing TC escalated, illustrating its viability in TC estimation.

2.1 Role of Satellite Data in Cyclone Intensity Estimation

The peak CDO temperature in the oldest CDO region is the principal source of information on cyclone intensity in the 24-hour period. The Dvorak Technique involves using the pattern recognition method to analyze the cloud form, associate it with certain forms characteristic of storms of specific intensity of the developing tropical cyclone. It relies on the sovereignty of the intensity of a tropical cyclone that is reasoned by the cloud graphics of the storm. Decomposition of the warm core in a tropical cyclone is indicated at the development stage of a tropical cyclone where intensification and formation of the storm is noted. The intensity change is immediate, but the Satellite CI number may take 12-24 hours to fully reflect this. These changes have been documented in previous research on the life cycle of tropical cyclones. However, convective and stratiform precipitation aren't always available without 6 hourly Satellite Imagery data, and are also subjective observational tools. This makes automated objective estimation using satellite imagery very difficult.

2.2 GRU and DBN Models in Cyclone Intensity Estimation

The GRU has been assessed to be able to capture the relationship between the multiple channel satellite data (in our case between the brightness of temperature reading from infrared image and radar scattering index) and target variable (cyclone intensity) precisely compared to the recurrent multi-layer perception (RNN-MLP), recurrent autoregression (RAR), and the conventional feed-forward neural network. The performance improvement is accredited to its gating mechanisms: update and reset gate and its ability to store information over a long period of time. Gated mechanisms help to control the flow of information in the network and manage what information needs to be kept or discarded, meanwhile for the conventional RNN all of the previous information will be kept storing in the network. This makes the GRU more resilient to the degradation problem and can capture the relevant information more systematically. On top of that, it has been discovered during the eastward and westward propagating tropical cyclone experiment which involves a high temporal setting in predicting cyclone intensity, the GRU is less prone to overfit compared to the RAR. In short, GRU is able to provide a more systematic and precise relationship between the predictor and the target variable, less prone to overfit, and better in handling the high dimension and complex climate data compared to the conventional RNN and other types of neural networks. An example work illustrates the application of the GRU is the cyclone track projection by P Dong et al. [18]. Cross et al. (2019) also mentions that the GRU is a candidate for future climate modeling.

3 Methodologies

Author presents an innovative new method for estimating the intensity of a tropical cyclone The current best method for intensity estimation does not use all the available observations; it uses a local regression in the neighborhood of the cyclone center, which means that it cannot measure intensity without presence of eye. This novel approach employs a machine learning technique known as a Gated Recurrent Unit (GRU) along with Deep Belief Networks (DBN) within a supervised learning framework. This means that it is trained/tested on historical cyclones for which we have intensity estimates. This method provides intensity estimates at every time-stamp of the input data and therefore can provide a time-series of intensity, which the current best technological approaches cannot with the same confidence. Ultimately, we can use all data from a tropical cyclone to estimate intensity. The specific technique described here uses an input sequence of SSMIS brightness temperatures in the life-cycle of a cyclone. Future work will seek to extend the spatiotemporal field to utilize multiple channels and different sensors.

3. 1 Architecture of GRU and Deep belief network (DBN)

Most of the pattern recognition techniques or single-stage regression/classification techniques such as logistic regression, support vector machines, etc. are not capable of memorizing the previous input data once a prediction output is generated. However, since for a sequence of intensity measurements we need the value at each time step, we use GRU, utilizing its recurrent architecture. A GRU is another form of recurrent neural network or a type of LSTM type of network but with added features. The fact that an LSTM or GRU network is able to adapt the memory in use also has great benefits. An LSTM comprises the chain formed from repeating modules of neural networks. Each module has four layers but these layers are reconfigured neural networks in this case. In a typical neural network all these layers have specific fixed weights (parameters) obtained during a training phase of the network while in an LSTM network these parameters are not fixed and are different in every module of the network. This architecture is suitable for our problem as it can understand/retain information for long periods of time.

DBN Model Architecture

Using RBM as the building blocks, the DBN is comprised of two stages. The first stage builds an unsupervised, layer-by-layer generative model of the input. To obtain an efficient learning process and effective model, the layers are trained one at a time. This involves learning the distribution of a layer of latent variables given the observed variables through iterative training of the RBM with Contrastive Divergence. The second stage of the model is where we form the conditional model using a Hurricane condition-hide approach. This involves modifying the weights of the connections to the visible layer nodes made during the unsupervised pre-training. For the data considered, the observed variables are intensity change over a specified time period, while the conditions are the environmental variables at each time and location. This stage trains an RBM to learn the joint distribution over the visible and latent variables, given a fixed observation of the visible variables. Finally, to generate a prediction of intensity change given the environmental conditions, the model runs the RBM up to predict the latent variables given a certain observation of the visible variables, then runs back down to generate a reconstruction of the visible variables to input into the equation for intensity change.

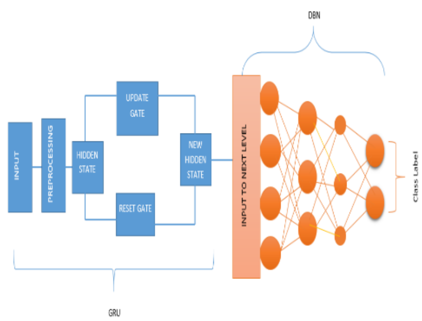


Fig 1 Proposed GRU-DBN Architecture

4 Experimental Setups

To construct the track information, the leading track is isolated into 70% for demonstrate training,15 % for show approval, and 15% for show testing. Information is given to the GRU-DBN demonstrated in subsequences where a subsequence involves the data of the tropical violent wind at the interval of each M hours. The stream F and temperature T are then forecasted for another M hours and after that a concentration is anticipated. The fetched work depicts the distinction or the blunder that exists between the label data and the yield of the neural arrangement shown amid preparation. This is often done by utilizing the cost work and passing it back through the demonstration and the free parameters are adjusted in such a way that the cost work is kept to a least. After the prepared show has been tried, and passed any comparing ability at the foresee the concentration of tropical tornados will be utilized at foreseeing the concentration of tropical violent winds in climate show information. A possible application of this work is using the predictive intensity of overseas tropical cyclones to determine if their remnants will have a significant impact on medium to long-range weather in the Pacific region. This may better inform people in countries that are likely to be affected by the remnants of tropical cyclones to prepare for increased chances of extreme weather.

4.1 Dataset Description

The historical TC track database employed is based on the International Best Track Archive for Climate Stewardship (IBTrACS) dataset (Knapp et al. , 2010)[19], which is accessible at the National Hurricane Center webpage (http://Home http://www.nhc.noaa.gov/gis/). The IBTrACS compilation is suitable because it is a digital format that can be accessed freely where IBTrACS contains records all the tropical cyclones that occurred from late 1980s to present and reconstructs the intensity of the TCs. Once the data was obtained it was cleansed and prepared as time-ordered sequences where each sequence represents a single storm. Storms that lasted less than 48 hours are labelled as "short-lived" and given the intensity value of 0 since it was considered impractical to try and estimate the intensity of these storms as they are less likely to have a noticeable impact and tend to show erratic intensity changes due to their lifespan. Using the global CSFR dataset as a guide, a 2.5x2.5 degree gridded layer was defined which encompasses the entire globe. The coordinates in the TC track were then converted to a grid cell location and the intensity of the storm at that time-stamped location was inserted into the corresponding grid cell in the sequences. This methodology aligns with the global field analysis. A minor data reduction takes place during the mapping process of storm positions to grid cells, as some storm paths come close to overlapping each other. The result is a large dataset consisting of a diverse range of storm sequences, each containing anywhere from a few to several hundred time-stamped intensity data points.

4.2 Experimental setup

To assess the quality of the introduced two methods, the GRU-DBN method is referred to as GR-BN that with only a single layer of GRU; the other is the stacked bidirectional network with the flowing and antipodal GRU noted as GRUA, the experiments are conducted based on the center locations of TCs. This is because besides the identification of the location where a TC will occur at some arbitrary time in the future, the position at time t + 6h may also be of comparable use in disaster preparedness while the strength of a TC is one determinant in the possible change in direction of the TC. However, because there is no information available on the environmental SST during the era-interim period, further experiments are conducted by inputting information about the current environmental SST into the GRU in order to demonstrate the effect of conditioning the hidden state update of the GRU on the additional input. The estimation of the intensity of TCs provides a useful tool for risk management and disaster prevention/mitigation, as it is known that an increase in the intensity of a TC increases the potential risk of harm to people and damage to property. With increase in global warming, it can be expected that the intensity of TCs will increase in the future and thus the understanding the change in the behavior will provide a useful guide for future trends in TCs.

5 Results and Analysis

We use the methods described above to estimate the TC intensity from the datset during the life cycle of the TC. The input to the model is defined by the datset for any given TC at the particular time. Output is the estimated TC intensity. The models are trained and tested with the best track data.

5.1 Sensitivity Analysis of Model Parameters

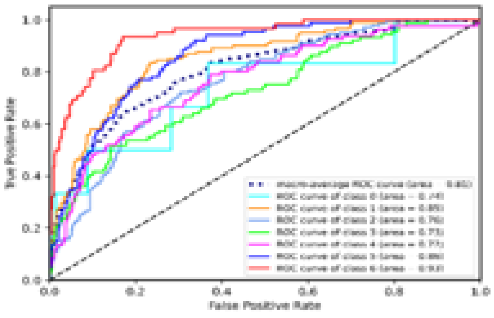
Because a specific parameter has independent and/or combined impact on TC intensity estimate, it is crucial that we perform sensitivity analysis on each model parameter. Sensitivity analysis is carried out by estimating model performance while varying the input parameter of choice, with all other parameters held constant. A typical unsophisticated method is to vary the parameter over a user-defined range and perform N-many cross validation experiments, measuring some composite performance metric in each case and finally produce a graph of model performance against parameter value

6 Discussions

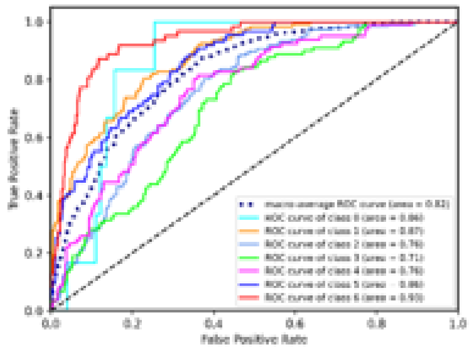
To detect the rapidly changing tropical cyclone intensity, we applied an RNN model, namely Gated Recurrent Unit (GRU)-DBN, to the dataset of tropical cyclones, and compared it with the conventional Dvorak Technique. We first focused on the Rapid Intensification (RI) of the tropical cyclone, where it could affect the surroundings significantly with its present and future intensity. We defined RI as a significant increase in intensity over 24 kt in 24 hours or a mere increment of 30 kt in 24 hours, which was adopted from previous studies. RI is a challenging problem for the forecasters because most tropical cyclones do not undergo RI during warnings issued from the RSMC, and it occurs in a shorter time than the usual intensification, giving less time for the decision of warnings. RI classification has no universal standards but the critical increment of intensity is widely accepted.

6.1 Interpretation of Results

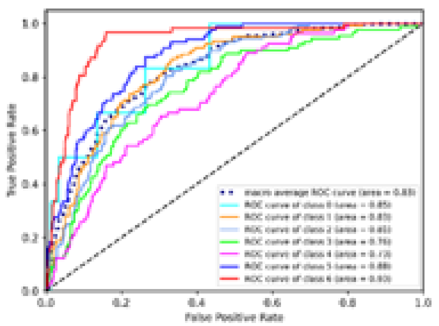
To begin with, let's get it the comes about of the Tropical Cyclone Intensity that can be anticipated within the ROC bend showed up in Figure 2. The ROC bend was made by plotting the genuine positive rate (measurement: hit rate) against the untrue positive rate (measurement: false alert rate) of parallel expectation at each limit esteem. ROC bend is exceptionally well known for the utilization in design acknowledgment and machine learning regions. It is developed by graphing the likelihood of genuine positives among all positive cases on the Y pivot and wrong positives among all negative cases on X pivot. ROC space is decided in terms of Genuine Positive Rate (TPR) along the x-axis and False Positive Rate (FPR) along the y- pivot. These demonstrate classification execution. From the ROC bend, ready to decide the likelihood of rectify classification through the range beneath the bend (AUC). AUC stands for region beneath the bend that appears the execution of the classifier and is utilized for the most part as an sign to appear how great the classifier is.



(a) ROC for GRU based Architecture



(b) ROC for DBN based Architecture



(c) ROC for proposed GRU-DBN Architecture

Fig 2 ROC Curve

7 Conclusions

Based on evaluation and also some of the aspects, the original objective in tropical cyclone intensity estimation through satellite data is to develop a theoretical framework for cyclone intensity. This approach can be essential for the future forecast or nowcast of the cyclone intensity in certain time. From the original objective, our experimental results showed a pretty good improvement in all aspects in different conditions of cyclone intensity level. This approach acts as an estimation for the real cyclone intensity. During the research, the main problem is to assess the statistical method to estimate the probability of detection in classifying the wind speed level and rate the wind speed for the certain interval. This must be proven in different samples and approaches, and it also needs to do comparison. There are still too many areas that need to be explored and upgraded, but we have the greatest goal to provide precise and reliable estimations of the cyclone intensity right now at any place.

Conflicts of interest

The authors declare no conflicts of interest.

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