PREDICTION OF TRENDS OF TROPICAL STORMS IN THE NORTH ATLANTIC

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1. INTRODUCTION.

Usually, tropical storms and hurricanes start out as tropical disturbances, which are areas of unsettled weather and thunderstorms in the tropics. Hurricanes require having the appropriate conditions to develop and survive. Some of the most important conditions are warm ocean water, large moisture at low atmospheric levels and weak winds at high atmospheric levels. Thus, when conditions occur just on time, the tropical disturbance can grow from a large amount of thunderstorms into an organized system, which stats to circulate. Most Atlantic tropical storms are developed from atmospheric waves that propagate westward from Africa across the North Atlantic and Caribbean sea primarily from 10^o and 20^o N and this zone is called the main development region (MDR), (Goldenberg et al. 2001; Goldenberg and Shapiro 1996; Gray 1960). The major forcing factors that affect the MDR are classified as local and external factors. Local factors are inherent into the actual developing region and have a direct thermodynamic interaction to develop storms. However, external factors occur far away from the MDR and are related with regional conditions by means of some teleconnection. Some of the most factors that affect hurricane activity are: quasi-biennial oscillation index, sea surface temperature (SST), sea level pressure (SLP), lower troposphere moisture, and vertical wind shear (VWS).

It is known that ocean is the primary source of energy for tropical cyclones. Warm SST generates atmospheric instability, stimulating the penetration vortex, and inducing the development of tropical cyclone more resistance to VWS. It has been pointed out that local SST greater than 26.5^o C is a necessary condition for tropical cyclone development, and higher SST will increase the hurricane activity (Goldenberg et al. 2001). One of the most important factors to develop tropical cyclone activity is the magnitude of the vertical shear of the horizontal wind between the upper and lower troposphere (Gray 1960). Strong VWS inhibits the formation and intensification of tropical cyclones. Local VWS larger than 8 m/s is generally unfavorable for development of tropical storms.

It has been shown that hurricanes activity is physically related to some atmospheric variables. Gray et al. (2005) over the last 22 years had developed a statistical scheme to estimate the annual hurricane activity in the North Atlantic basin. Their forecast scheme is based on a variety of climate-related global and regional predictors associated with Atlantic Tropical Cyclone activity. They have identified some particular predictors related to upper air zones over Africa, South America, and Artic, as well as sea surface temperature on the Pacific, and Atlantic Ocean. These predictors are defined at a specific time and location. They also identified prior analog years which have similar global atmosphere and ocean precursor circulation features to the current studied year. Their prediction algorithm has been very successful for a short term forecast i.e., less than 12 months. However, society requires a tool to predict hurricane activity for longer period of time to estimate hurricane risk and formulate a strategic plan to mitigate the hurricane impact on social and economical development. Thus, in this study we are proposing an algorithm for predicting 20 years in advance the hurricane trends in the North Atlantic basin.

A proposed prediction algorithm relies on reanalysis and Global Circulation Models data to predict hurricane trends. A general and optimal variable selection algorithm is proposed to extract the best predictors that are related to hurricane

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activity from a large amount of possible meteorological variables.

2. METHODOLOGY.

A statistical model was developed to estimate the annual seasonal hurricane activity in the North Atlantic basin. The main purpose of this work is to estimate the expected hurricane activity during 2006 – 2025. The suggested methodology consists on four major steps: 1) identify the years with similar meteorological characteristics to the target year, 2) develop a statistical model, 3) adjust the GCM outputs to the NCEP/NCAR reanalysis data, and 4) predict the hurricane activity.

The first step consists on identifying the years that exhibit similar meteorological characteristics to the predicted year. The areas of the Earth that are likely to exhibit significant correlation with the number of tropical storms are selected and dimensionality reduction is applied over the vertical levels. The empirical orthogonal functions (EOF) are input into a self organized neural network to determine the years with similar characteristics to the predicted year.

The second step includes implementing an optimal variable selection algorithm to develop a parsimonious regression model with the largest coefficient of multiple determination as well as avoiding the multicolinearity problem. The variable selection algorithm is based on a combination of a stepwise regression with a parsimonious principle to select the minimum set of the best predictors. The variable selection algorithm identifies the best predictors over a horizontal and vertical search. The third step is to adjust the outputs from the Global Numerical Model (GCM) to the NCEP/NCAR reanalysis data. The GCMs are a set of couple climate change simulation models, which each individual model addressed specific atmospheric process. It solves the primitive equations to simulate the possible atmospheric conditions under a selected scenario. The GCM simulates the atmospheric conditions by using a scenario postulated by the Intergovernmental Panel on Climate Change (IPCC). The World Meteorological Organization and the United Nations jointly established the IPCC in 1988. Due to significant climate changes that have been occurred over the earth the IPCC conducted a scientific and socioeconomic study to determine the risk of occurring climate changes generated by human activity. In 1992 the IPCC postulated several world scenarios. The IS92a scenario, which is also in known as the Business as Usual (BAUS), was selected and considers the expected variation of the CO_2 concentration during 1900 to 2100. This scenario also takes in to account the following elements: technology development, population growth, land-use change, water resources, industrial activity, and other human related factors. GCM simulation over the BAUS scenario shows the possibility of controlling the CO_2 emissions in the next years using renewable energy, by the commitment of the highly industrialized countries in reducing the dependency of the petroleum. According to the results of this simulation, the sea surface temperature will stay an increasing tendency, given to greenhouse effect. In addition, these results indicate that rainfall average in the planet did not change significantly; however, the periods of drought of high rain levels will be more intense. Therefore, the variability of the synoptic conditions, in the surface and the atmosphere in the future will be different from the past.

The third step is the statistical adjustment of the GCM data and is accomplished by using a regression model that includes two correction factors. The first factor is additive and the second factor is multiplicative to correct the first and the second moments of the process, respectively. The correction factors are derive during the overlapping period (1995-2005) and applied during the remaining part of the series.

The fourth step consists on using the improved GCM outputs to evaluate the developed regression models. The final output presents the ensemble prediction for the trends of intense hurricanes during the period of 2006-2025.

3. PRELIMINARY RESULTS

The proposed prediction scheme has partially been developed, i.e., we have not been able to implement the proposed methodology, since this is an ongoing research project. The prediction algorithm will include local and external factors that have been proved to affect the hurricane activity. The local factors that directly affect the main developing region are VWS, SLP and SST. The local factors will be studied at 2.5^o of horizontal resolution over the MDR. External factors were studied at global scale by means of identifying some teleconnetions between the large-scale patterns of atmospheric instability. It is well known that atmospheric instability is related to reaction of a parcel displaced from the original position. The vertical acceleration along the path of a raising parcel is related to the temperature difference between the parcel and its environment. It has been identified that sever thunderstorms occur when air is unstable and sufficient moisture is lifted. In this study two large scale stability indexes were studied: the K and total totals (TT) index. The K index measures the thunderstorm potential based on vertical temperature lapse rate, moisture content of the lower atmosphere, and vertical extent of the moisture layer. The greater the K index the larger the likelihood of the thunderstorm development (McNulty, 1983). The TT index identifies the potential areas of thunderstorm development and is defined as the sum of two convective indexes, the vertical totals and cross totals (Miller 1972). TT index must be used with careful attention because the cross total cannot be larger than the vertical totals. In addition to the stability indexes the following large-scale indexes will also be studied: North Atlantic Oscillation, Southern Oscillation, wind components and geopotential height at several vertical levels.

The implemented strategy consists of developing a statistical prediction algorithm. The surface of the Earth was divided into seventy two regions of 30x30 degrees each one (Figure 1). The statistical algorithm determines the location of the meteorological variable that is highly correlated with the cyclone activity in the North Atlantic basin. An optimum variable selection algorithm was developed to select a linear function with the minimum number of predictors and with the largest correlation between predictors and predictand. Upper air data was obtained from NCEP/NCAR reanalysis project covering the following period from 1950 to 2005. Reanalysis data was used to perform model validation and GCMs simulation data was used to develop the prediction scheme. Model validation was conducted to asses the performances of the prediction algorithm. The first 36 years (1950-1985) was used to develop the statistical model and the last 20 years (1986-2005) was used to predict hurricane activity and compare with the actual observed values to measure the prediction skill (Figures 5 and 6). Figure 1 shows the studied 72 regions. Figure 2, 3, and 4 show the monthly time series of the 72 regions of the vertical wind shear, the K index, and the TT from 1950-2025, respectively. Figure 5 shows the model fitting results using only teleconnection with external factors, i.e., the implemented methodology does not include the analog concept and the local factors. Blue line in Figure 5 shows the observed intense hurricane and the red line represents the fitted trend of the hurricanes. Figure 6 shows the validation of the preliminary model. Blue line represents the observed hurricanes. The dots in Figure 6 represent individual predictions generated by using different sets of predictors. The green line on Figure 6 is the predicted hurricane trend and was obtained by computing the median of the individual set of predictions for every year.

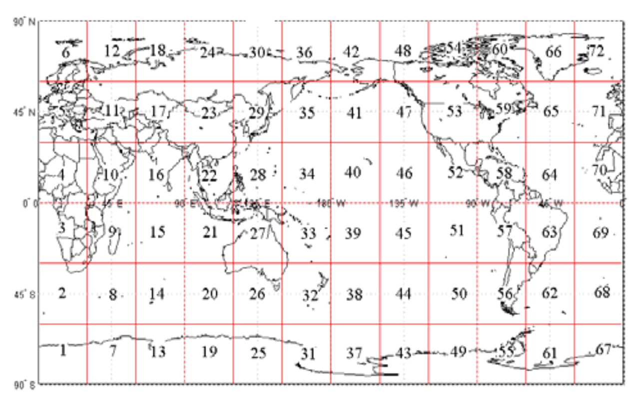

Figure 1. The selected areas of study.

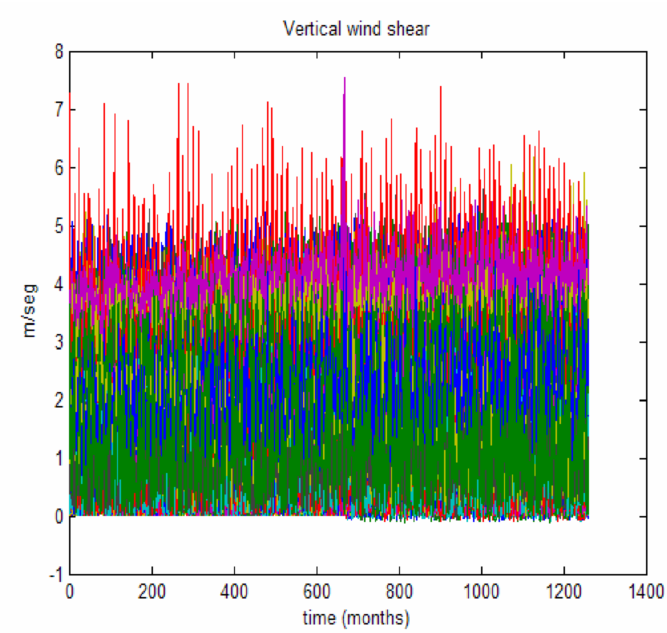

Figure 2. The vertical wind shear (m/s) (1950-2025).

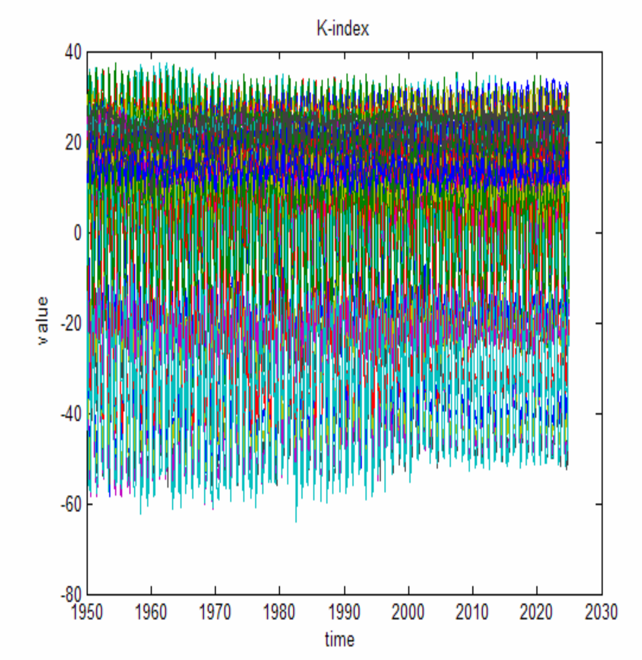

Figure 3. The K index (1950-2025).

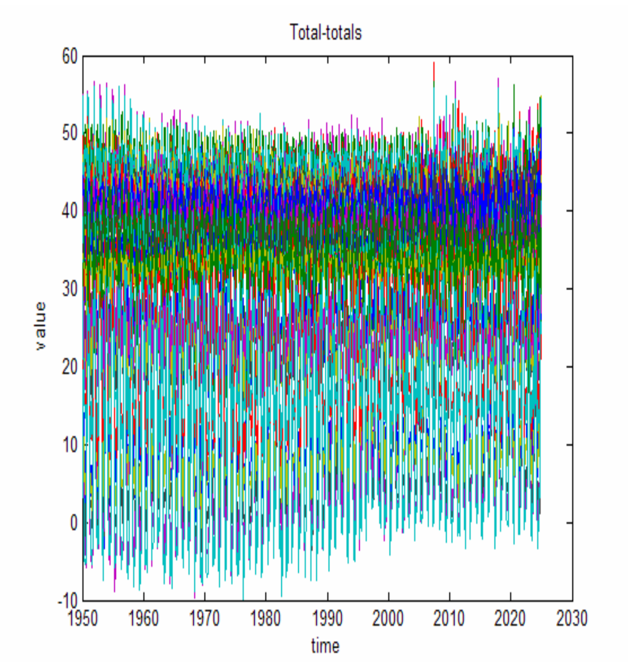

Figure 4. The total totals index (1950-2025).

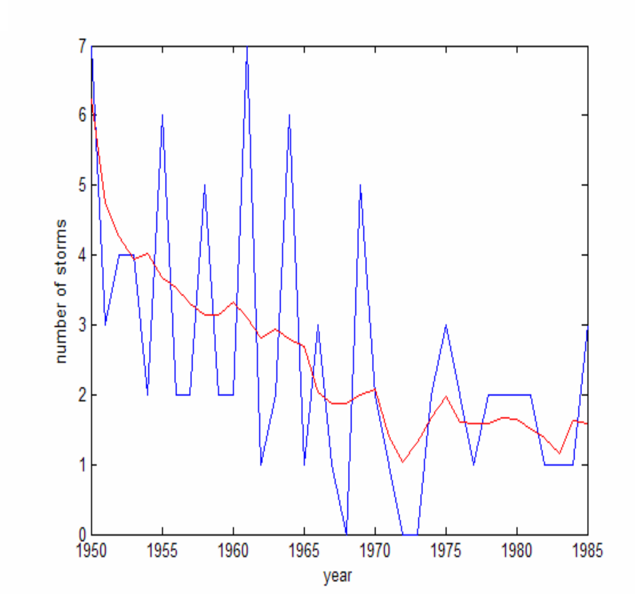

Figure 5. Model fitting for hurricanes with category 3, 4, and 5 (1950–1985).

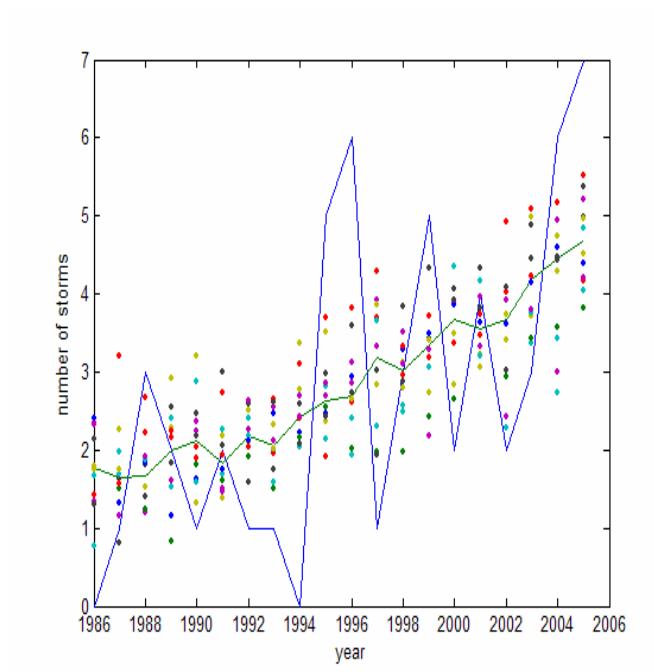

Figure 6. Observed and predicted hurricanes with category 3, 4 and 5 (1986-2005).

The proposed algorithm was used to predict the trend of the next two decades of intense hurricanes (2006 - 2025). These predictions was based on the postulated BASU scenario, which has been widely used as a forcing factor for global circulation models (GCMs) to analyze the possible impact of future climate change. Due to the fact that the analog process and predictors from the inside of the main developing region are not implemented yet, we present a preliminary result. In the near future we will derive a prediction including the local factors and the analog principle. The blue line on Figure 7 shows the observed intense hurricanes since 1950 to 2005. The red line from 1950 to 2005 shows the fitted trend of intense hurricanes and the red line from 2006 to 2025 shows the predicted trend of intense hurricanes.

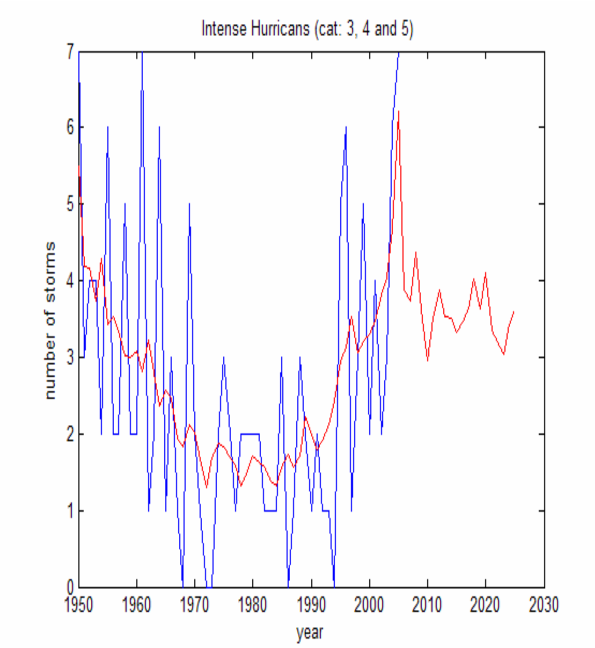

Figure 7. Prediction of intense hurricane trend (2006-2025)

4. CONCLUSIONS

A hurricane prediction algorithm has been developed to determine the possible trend of the hurricanes under the categories 3, 4, and 5. The current prediction scheme only takes into account predictors over the 72 regions to identify some teleconections at global scale between the observed intense hurricanes with the vertical wind shear, the K index and the total totals index. The implemented prediction scheme is incomplete. This prediction scheme does not take in to account the analog process which is very important for the identification of particular meteorological properties (El Nino status) of a given target year. The prediction scheme cannot include predictor extracted from the inside of the main developing region. Therefore, at this stage we are not able to derive definitive prediction results. Result presented here are at the very early and preliminary stage.

6. ACKNOWLEDDGEMENTS

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7. REFERENCES.

Goldenberg, S.B., Landsea, C.W., Metas-Nunez, A.M., and Gray, W.M. (2001). The Recent Increase in Atlantic Hurricane Activity: Causes and Implications.

Goldenberg, S. B., and L. J. Shapiro. (1996). Physical Mechanisms for the Association of El Nino and West African Rainfall with Atlantic Major Hurricane Activity. *Journal of Climate,* Vol. 6, pp 1169-1187.

Gray, W. M. and Klotzbach, P. J. (2005). Extended Range Forecast of Atlantic Seasonal Hurricane Activity. http://hurricane.atmos.colostate.edu/Forecasts.

Gray, W. M. (1968). Global View of the Origin of Tropical Disturbances and Storms. *Monthly Weather Review.* Vol. 96, No. 10, pp 669-700.

McNulty, R. P. (1983). Some Basic Elements of Thunderstorm Forecasting. NOAA Tech Memo NWS CR-69, Kansas City, MO.

Miller, R. C. (1972). Notes on Analysis and Severe-Storm Forecasting Procedures of the Air Force Global Weather Central. AWS Tech. Rpt. 200 (rev). Air Weather Service, Scott AFB, Il 190 pp.