Synthetic Tropical Cyclone Generation for Risk Analysis under Current and Future Climate Scenarios

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Background/Objectives. Tropical cyclones remain one of the costliest natural hazards. During the period 1980 to 2019, 42 tropical cyclones caused a total damage of $925.5 billion. Tropical cyclones generate extreme winds, rainfall, storm surge, and riverine flooding, causing severe damage to critical infrastructure (specifically, the electric sector). Some questions are still open as to the impact of climate change on the frequency, intensity of the tropical cyclones at landfall, extreme winds, extreme rainfall totals, and storm surge depths created by tropical cyclones. This study aims to develop a simplified model for generating thousands of synthetic hurricane tracks based on the environmental data available from coupled atmosphere and ocean climate models for the purposes of risk analysis to guide preparedness efforts and future investments.

Approach/Activities. Since it is necessary to generate tens of thousands of synthetic hurricane tracks for a selected time window, a simplified approach, called Beta Advection Model (BAM), is used. BAM models have been developed by various researchers and they are in use by National Oceanic and Atmospheric Administration (NOAA) for real time tropical cyclone forecasting. BAM models include three main components called Genesis (G), Track (T) and Intensity (I). Genesis model selects the location where a tropical cyclone is likely to occur. In the present case, we use a statistical model based on a multivariate Kernel Density Estimate, developed on the genesis points of historical hurricanes. Starting from the genesis location, Track module generates the track as successive waypoints based on a pressure-weighted average of wind velocity components from different pressure levels, typically ranging from 850mb to 200mb. The pressure-averaged environmental wind is corrected by applying a beta correction for secondary vortices. Intensity model is based on modeling of the vertical structure of a tropical cyclone as a Carnot heat engine when the eye of the tropical cyclone is over the ocean. The present study uses an adapted version of the “tcpyPI” model by Daniel Gilford. When the tropical cyclone makes landfall and starts moving over land, a decay function is used to estimate the maximum velocity and the minimum eye pressure. The environment data are taken from European Centre for Medium-Range Weather Forecasts re-analysis data for 1979-2014 and Coupled Model Intercomparison Project Phase 6 data for IPCC 4.5 and 8.5 scenarios for 2015-2100.

Results/Lessons Learned. This study currently focused on the North Atlantic basin. The large number of synthetic hurricane tracks (several thousand per year) are used to calculate the statistical analysis of the tropical cyclones making landfall along the Gulf of Mexico and the East Coast of the conterminous United States. The maximum wind speeds and rainfall totals are calculated over a grid covering the conterminous United States with a resolution of 20 nautical miles. At each cell center, computed wind speeds and rainfall totals are treated as partial duration series and fitted with a suitable extreme value distribution. The fitted distribution is then used to calculate wind speeds and total rainfall quantities corresponding to selected annual probabilities (return periods). A prototype web application is created on Argonne’s GeoPortal to serve as a decision support tool. Additional work is being carried out to develop a physics-based tropical cyclone genesis model using machine learning to verify and validate the models using historical tracks, and to add analytical tools to the web-based decision support tool for calculating damages as a function of return period.