State of Florida Hurricane Loss Projection Model: Atmospheric Science Component

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ABSTRACT: The State of Florida is in the process of developing an open, public model for the purpose of probabilistic assessment of risk to insured residential property associated with wind damage from hurricanes. The model comprises atmospheric science, engineering, and financial/actuarial components and is planned for 2004 submission to the Florida Commission on Hurricane Loss Projection Methodology. The atmospheric component includes the modeling of the complete track and intensity life cycle of each simulated hurricane. When a storm approaches within 200 km of the Florida coastline, the wind field is computed by a slab model of the hurricane boundary layer coupled with a surface layer model based on the results of recent GPS sonde research. A time series of open terrain surface winds is then computed for each zip code in the threatened area. Depending on wind direction, an effective roughness length is assigned to each zip code based on the upstream roughness as determined from land cover/ land use products. Thousands of storms are simulated allowing determination of the wind risk for all zip codes in Florida. The wind risk information is then provided to the engineering and loss models to assess damage and average annual loss, respectively.

Keywords: Hurricane, risk, loss, insurance

INTRODUCTION

The historical record for establishing the risk of hurricanes throughout the coastal United States is limited to a period of about 100 years. Unfortunately this period is not sufficient to establish risk without large errors so alternative methods have been used since the 1970's (Russell 1971). Hurricane risk models are currently used to conduct simulations of thousands of years of storms based on statistical probability distributions of important historically observed parameters. This method is often referred to as the joint probability method since the probability of having an event is coupled with the probability that the event is of a given intensity. Commercial modeling interests have developed several versions of these, which are used to advise the insurance industry for ratemaking. Unfortunately the models are proprietary so customers whose rates have increased on the basis of model calculations have no way of examining or questioning the results. The State of Florida is developing a public model to provide an understandable baseline for comparison to the commercial models. The model will be open and transparent; in which results can be examined in great detail. This paper will describe the atmospheric component of the model.

ANNUAL OCCURRENCE AND STORM GENESIS

The model has the capability of simulating climate cycles and tropical cyclone activity according to different periods of the historical record. The period 1851-2002 is the latest available but the period 1900-2002 is frequently used due to uncertainties about 19th century storms, especially for Florida. There are also uncertainties about the first half of the 20th century since aircraft reconnaissance only began in the 1940's so another choice in the period of record is the period 1944-2002. Four additional choices are available which simulate the warm (El Nino, fewer hurricanes) and neutral or cold (La Nina, more hurricanes) interannual climate cycles in tropical cyclone activity, as well as the cold or warm phases of the Multi-decadal climate cycles. These choices constrain the historical record from which the fit of annual tropical cyclone occurrence is made. Two fits are tested, the negative binomial and the Poisson model (Fig. 1). Goodness of fit tests determine which fit is used for the subsequent simulations. Once the number of tropical cyclones for a given year is determined, the historical seasonal genesis frequency is empirically fit to determine the date and time of genesis for each storm.

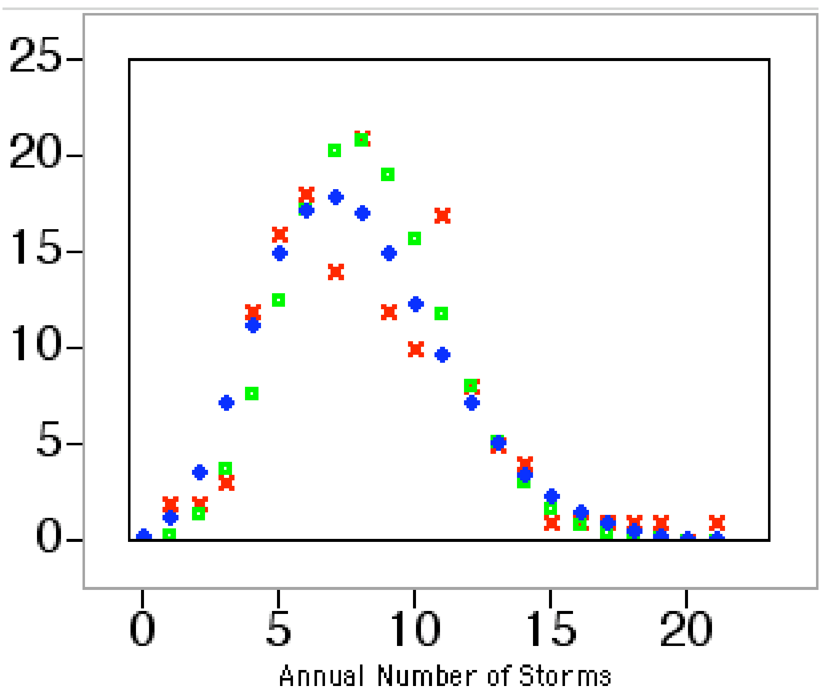

Figure 1. Annual number of storms observed (crosses), Poisson model (squares), and negative Binomial model (diamonds).

STORM MOVEMENT AND INTENSITY

Following the method similar to that described by Vickery and Twisdale (2000b), the Atlantic and Caribbean basins are divided into five-degree boxes, which contain the historical and seasonal characteristics of storm motion and intensity change. Genesis location, Initial intensity, and motion for each storm are based on the geographic probability distributions of each quantity. This is an advantage over other models that constrain storms to form only where historical storm tracks originate. Intensity change is modeled by using the observed geographic probability distribution of six-hour changes of central pressure through modeling the potential intensity (Darling 1991). The potential intensity takes into account the concept of the hurricane as a heat engine constrained by the input (sea surface) and outflow (stratosphere) temperatures. Intensity change is limited so as to not exceed the maximum observed change for a particular geographic region. The entire track of each tropical cyclone for each year is simulated. When a storm center crosses the coastline (landfall) the intensity change follows a pressure decay model. If the storm moves back over the sea, the former intensity change model is reinstated. This approach has a great advantage over early models that considered a circular approach region surrounding coastal cities. Storms that parallel the coast or make several landfalls can be properly simulated with this method.

WIND FIELD AT LANDFALL

Once a simulated hurricane moves to within 200 km of the Florida coastline, the wind field model is turned on. The model is based on the slab boundary layer concept originally conceived by Ooyama (1969) and implemented by Shapiro (1983). Similar models based on this concept were developed by Thompson and Cardone (1996) and Vickery et al. (2000a,b). A gradient balance wind field is built given a radius of maximum wind (Rmax) and a central pressure. The central pressure comes from the intensity model while the radius of maximum wind is chosen from a log normal distribution in which the mean is weakly dependent on latitude and the difference between the central pressure and a peripheral pressure assumed to be 1013 kPa. The shape of the pressure profile is described by the Holland (1980) formula in which the sharpness of the pressure profile depends on an exponent, which has a dependence on Rmax and deltaP. The equations of motion are integrated for the steady state assumption; hence there is an assumed balance of pressure gradient, Coriolis, eddy diffusion, centripetal, and frictional forces in the slab boundary layer. Radial advection of tangential momentum acts to shift the maximum wind in the boundary layer inward relative to the storm center and greater than the gradient value. The mean surface wind for marine exposure is assumed to be 78% of the slab boundary layer wind, in accordance with recent results from over 300 boundary layer wind profiles observed in tropical cyclones (Powell et al 2003). The height and exposure of the model surface wind is 10 m and "open" in accordance with ASTM 1996. Marine winds are converted to open terrain using the methods described in Powell et al 1996. A gust factor (Powell et al 1996) is used to convert the mean wind to a maximum sustained one min wind, and then to a peak 3s gust as required for the engineering component damage calculations (see conference papers by Simiu, Pinelli, and Gurley). For each 10 min segment of storm motion, the open terrain exposure surface wind speed and direction is determined for all population-weighted zip code centroid locations within 200 km of the storm

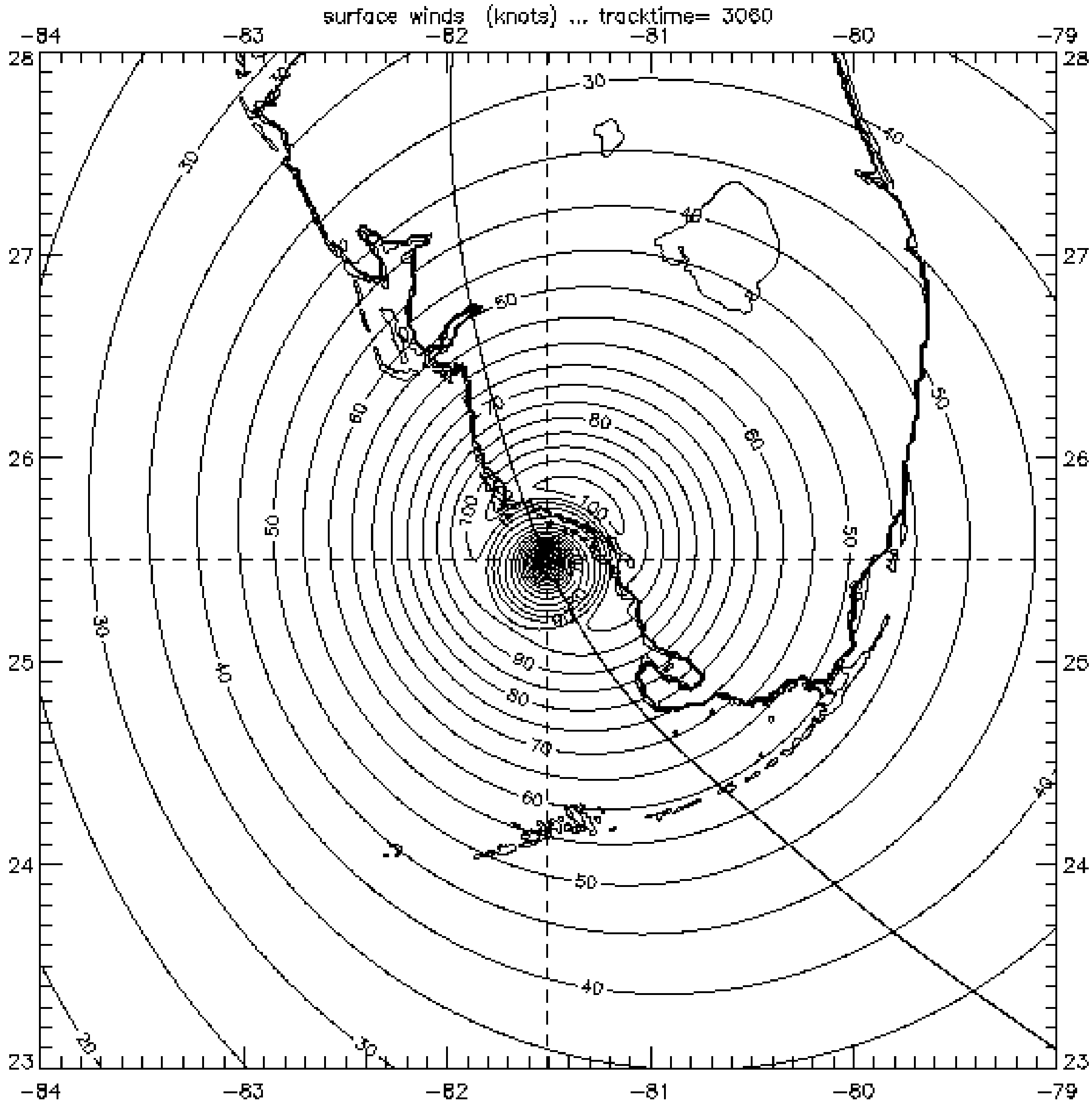

Fig. 2 Hurricane Donna (1960) surface wind field (kts) simulated by the model at landfall.

center. At the end of a simulation, time series of wind speed and direction exist for all zip codes in Florida for which hurricanes (or hurricanes that have decayed to a weaker status) have passed within 200 km. Land falling tropical storms and hurricanes that have decayed post-landfall to a tropical storm with maximum winds of <18 m/s are not considered. The great advantage of our approach over other models is that the full time series of the wind is retained at high resolution. Retaining this information will allow investigation of damage-relevant parameters such as duration of winds exceeding hurricane force and wind steadiness. Powell et al (1995) suggested that damage to the building envelope was associated with small values of wind direction steadiness and large values of duration. These parameters capture the physical torque effects of thousands of gust-lull cycles as well as the fact that, given the susceptibility of residential buildings to damage at roof corners and gables, the more the wind direction changes during a strong wind event, the greater the chance that a given wind direction will occur for which a structure is susceptible.

TREATMENT OF ROUGHNESS

The open terrain wind at each zip code centroid is corrected to the observed terrain using a fetch-dependent virtual roughness for that particular direction and zip code. The virtual roughness takes into account the flow over upstream changes in roughness and assumes that internal boundary layer development prevents the flow from reaching complete equilibrium with its surroundings (Petersen 1964, Powell et al., 1996). The flow is most influenced by the roughness of the terrain 3 km upstream of the zip code centroid, but the flow is still influenced by terrain further upstream. The approach we use is based on the Source Area Model (SAM) described in Schmidt and Oke (1990). SAM takes into account turbulence created by patchy terrain and determines the relative importance of the turbulence source area to a downstream wind sensor located at the zip code centroid. This approach is an improvement over current models that consider zip code roughness constant for all wind directions. Our method is especially advantageous for coastal zip code locations since flow with an upstream fetch over the sea can be significantly stronger than flow over a constant land roughness. The roughness is associated with a classification of the land use / land cover in a particular region according to LANDSAT imagery used to develop the National Multi-Resolution Land Cover database (http://www.epa.gov/mrlc/nlcd.html). Determination of the roughness for each LU/LC classification was conducted by FEMA's multi hazard damage mitigation model (HAZUS) project under the auspices of the National Institute for Building Sciences.

CONCLUSIONS

In order to achieve stable results, a very large simulation of ~100,000 years of activity is prescribed. It is expected that the model would be run once per year to take advantage of the latest historical data for ratemaking guidance to the Department of Insurance, although there are many other research uses for the model and it is expected that the model will undergo periodic enhancements to attempt to keep up with the latest advances in science and engineering. The model will reside at Florida International University's Hurricane Research Center in Miami. Complete documentation of the model algorithms and code will be available for public examination. Given that there may be one Florida hurricane landfall per year, this large number of storms will be contained in our database. Each storm may effect as many as 40 zip codes so it is expected that the database could contain several million time series instances, as well as track, intensity, and landfall wind field information on each storm. The database could then be queried for details on simulated storms and probability distributions relevant to a given zip code or county in Florida. The model is scheduled for submission in 2004 to the State of Florida Commission on Hurricane Wind Loss Projection.

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