How to Best Use Engineering Risk Analysis Models and Geographic Information Systems to Assess Financial Risk from Hurricanes

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BIOGRAPHIES

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Mr. Ulrich is a Project Manager for Risk Management Solutions, Inc. in Menlo Park, CA. His activities at RMS include the evaluation of the impact of natural phenomena hazards to large exposures for insurers and reinsurers across the world. He received a BS in Business Administration from the University of California at Berkeley in 1981, and an MBA from the University of Southern California in 1984. He is a Certified Public Accountant and a Certified Management Accountant.

ABSTRACT

In the past thirty years six hurricanes have caused over $1 billion of insured losses in the United States[1]. The impact of these events on the insurance industry has been staggering. These major events along with those of a more moderate nature have been particularly devastating to insurers with concentrations of exposure in coastal areas.

Due to the unpredictable nature of hurricanes, and the insufficient amount of reliable data, actuarial methods of analyzing risk are inappropriate for accurately assessing a company's potential hurricane exposure. The purpose of this paper is to present the benefits of utilizing both engineering and financial risk models with the latest developments of geographic information systems to better assess the financial risk from hurricanes.

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[1] See Table 8 of this paper.

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1. INTRODUCTION

Of all natural hazards, hurricanes are the major contributors of catastrophic losses to property insurance. Each year, on average, 100 tropical storms form in the world. About two-thirds of these storms grow into hurricanes, typhoons, or cyclones, and an average of about 2 hurricanes make landfall each year along the US coasts in the Gulf of Mexico and North Atlantic (Neumann, 1990). Generally speaking, the more intense the storm, the more extensive the resulting damage. Table 1 lists the Saffir-Simpson intensity scale used to rate hurricanes and includes a summary of the storm characteristics that are associated with each of the five intensity categories (Neumann, 1990).

While the number of hurricane casualties has decreased since the early 1900's as hurricane warning procedures and evacuation planning have improved, property damage resulting from hurricanes has increased dramatically. The main reason for the increase is the recent population and construction boom in coastal areas (Sparks, 1990). Although mitigation measures such as improving construction requirements may be taken, the existing building stock constitutes a huge liability to the insurance and reinsurance industry.

Table 1
Saffir-Simpson Intensity Scale

Saffir/Simpson Category	Wind Speed (mph)	Possible Tidal Surge (feet above sea level)	Damage Potential
1	74 - 95	4 - 5	minimal
2	95 - 110	5 - 8	moderate
3	110 - 130	8 - 12	extensive
4	130 - 155	12 - 18	extreme
5	155 and above	18 and above	catastrophic

Hurricanes and associated perils, having complex and incompletely understood causes, are notoriously difficult entities to quantify. Loss estimation methods which use historical property losses to project future hurricane impacts are inadequate because the exposure in hurricane-prone regions has changed drastically over the years. Even if the exposure was calibrated to current and projected trends, re-enactment of historical hurricane scenarios on a present-day portfolio does not provide the possible range of events (intensity and location) to assess hurricane risk in all geographic regions. Typically, companies use between 20 and 30 years of loss history for the purposes of risk assessment. Although re-enactment of past historical events on a company portfolio provides insight as to what might have happened if such events had occurred today, the available information on historical hurricanes is limited to a few events. Consequently, actuarial techniques cannot provide a full range of potential loss estimates.

To best understand the hurricane risk associated with a given location, one must analyze the affect of a wide range of hurricane events on the given location. As mentioned above, there are few, if any, locations which have experienced a complete spectrum of hurricane events, and most likely, no reliable recorded loss data or scientific storm data exist for all of the events. The solution to this problem is to ***simulate*** hurricane events.

Probabilistic techniques developed in engineering risk assessment of natural hazards are useful for dealing with low frequency-high consequence events because the physical process leading to the consequences (e.g. probability of failure or financial losses) is modeled rather than only the consequences themselves. Knowledge gained by the authors and their colleagues in the modeling of risk from the natural catastrophes is presented in this paper to illustrate salient points. The first two sections of this paper address at a high level the theories and methodologies used in the development and use of probabilistic hurricane models. The next two sections of the paper discuss the lessons learned through the practical applications of the models.

Accordingly, the remainder of this paper is organized as follows:

2. Overview of Probabilistic Hurricane Risk Models
3. Potential Uses of Probabilistic Hurricane Risk Models
4. Lessons Learned in Modeling Hurricane Risk
5. Lessons Learned Through Uses of Probabilistic Hurricane Risk Analyses
6. Summary

2. OVERVIEW OF PROBABILISTIC HURRICANE RISK MODELS

All probabilistic hurricane risk models developed for assessing property losses deal with two major questions: (1) How much damage would a hurricane with known properties cause to a given portfolio? and (2) How much damage would be expected in a given region (per annum or a given time frame) knowing the hurricane environment and financial risk structure of the exposed portfolio?

The first question deals with deterministic events because the characteristics of these storms are given prior to the analysis. These hurricanes may be selected either from a database of historical hurricanes having occurred in the region under study or simulated from a selection of potential storms likely to occur in the area. Although the deterministic event is well defined, there are still major gaps in the understanding of the process that governs how the hurricane energy affects structures. This means that when such an analysis is performed there are uncertainties in the results.

The second question is stochastic by nature because of the randomness in the occurrence, location, and nature of the events to be considered. The limited amount of historical data requires the analyst to make assumptions (for example the hypothesis of an homogeneous unit area rate of occurrence over geographic coastal areas), which in turn produce further uncertainties in the results.

To date, scientists have been unsuccessful in their attempt to predict when and where hurricanes may strike. The best estimate is a likelihood that hurricanes may strike a given area during a given time period. The methodologies that provide such estimates are probabilistic techniques developed in engineering risk assessment of natural hazards.

This section will provide a high level overview of each component of typical probabilistic hurricane risk models. Although most of the available risk models have similar structures, they may differ in the level of needed information to assess perils and losses. While some models assess hurricane impacts at a regional level, others assess these impacts at a site level, thus providing a more detailed representation of the relative risk across locations.

2.1 The Basic Probabilistic Model

Probabilistic hurricane risk models typically consist of four main components- a hazard model, a vulnerability model, an exposure model, and a financial model (See Figure 1). The hazard model calculates the probability of occurrence of different intensities of hurricane perils at a site or group of sites. These are fed into a vulnerability model and exposure model which calculate the corresponding damage level for particular construction types, building characteristics, and occupancy types. The resulting dollar loss amount is then allocated through the financial model to the insured and various insuring participants.

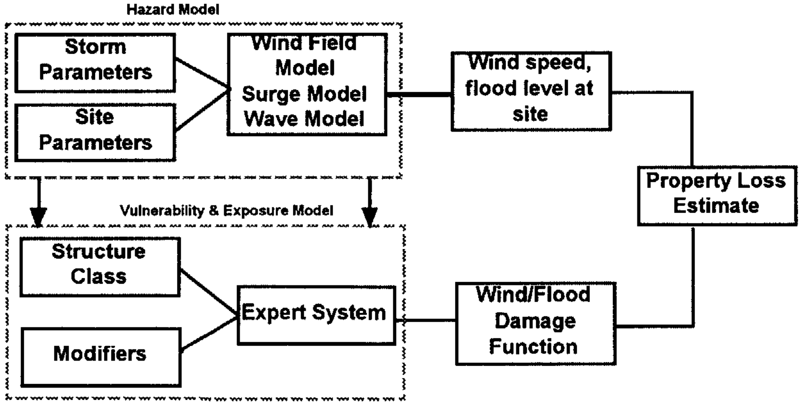

Figure 1
Hurricane Model Schematic Flow Chart

Typical probabilistic hurricane risk models develop a series of simulated storms that reproduce the range of possible meteorological events which may affect any hurricane-prone regions. This process can be broken down into four major steps.

STEP 1 - Development of a database of simulated hurricanes. This database should cover the range of theoretical possible hurricanes, and associate a probability of occurrence with each simulated hurricane.

STEP 2 - Development of a hurricane hazard model. Utilizing the database of simulated hurricanes developed in STEP 1, the hazard model calculates the intensity of associated perils (generally wind and surge) from the simulated hurricanes at a desired location (e.g. the address of the property to be insured) or a group of locations.

STEP 3 - Development of a vulnerability model. The vulnerability model calculates the damage to a given structure and its contents, as well as the time related loss utilizing the hazard results at the desired location of the structure developed in STEP 2.

STEP 4 - Development of a financial model to calculate losses to a structure or a group of structures.

2.2 Development of a Database of Simulated Hurricanes

The first step in modeling hurricanes is to simulate a range of physically possible hurricanes for all hurricane-prone regions. These simulated hurricanes are the tools with which expected losses are modeled. The typical process involved in developing a database of simulated hurricanes is as follows:

☐ Estimate the rate of occurrence of storms affecting discrete coastal areas

☐ Estimate the probability distribution of the climatological characteristics of hurricanes based on historical data and meteorological expertise

☐ Simulate the characteristics of hurricanes at coastal areas

☐ Simulate storm behaviors

2.2.1 Rates of Occurrence

The rates of occurrence of storms affecting coastal areas in a given region are estimated from historical rates of occurrence. Probabilistic distributions (e.g. Poisson, negative binomial distributions) are then fitted to this data to estimate the probability of occurrence of one or more events. Because storms do not need to make landfall to cause damage to properties, typical models estimate the rates of occurrence of land falling storms as well as storms passing within short distances from the coast.

2.2.2 Probability of Distribution

Given the occurrence of an event, key storm parameters are simulated using probability distributions derived for each event. The key storm parameters used in a typical model include the following.

- Central pressure difference. The difference between ambient pressure and minimum pressure, generally at the center of the storm.
- Forward velocity. A measure of the speed at which the storm travels across the earth.
- Track angle. The direction of the storm path.
- Landfall location. The point at which the storm effectively crosses the coastline or is at its closest distance and the point at which algorithms are used to predict the life of the storm system.
- Radius to maximum wind. The distance from the center of the storm to areas of greatest surface winds, generally at the very outer edge of the storm's eye -- the eye wall. Radius to maximum wind is dependent on the above parameters.

Central pressure difference has the greatest single correlation with storm intensity (wind speed and surge). Because of the limited amount of historical data available to develop statistical distributions of this parameter (as well as of the others), probabilistic models are developed and bounded with minimum and maximum values judged to be credible by meteorological experts.

2.2.3. Simulation of Hurricane Characteristics

The simulation of the characteristics of hurricanes within a given coastal segment is performed by either using a logic tree approach or a bootstrapping technique. A logic tree technique simulates characteristics of storms by selecting them jointly from probability distributions. These distributions are represented by a finite number of slices. These slices are defined to represent the entire population of possible values but still to retain the statistical parameters of the original distributions. A bootstrapping technique uses the same probability distributions as the logic tree technique, but randomly selects values from these distributions. In either method, meteorological characteristics of storms within a segment are simulated by selecting a series of joint values of the key storm parameters. Special care must be taken when selecting any of these approaches. In the logic tree approach, the probability distributions of the storm characteristics within each segment are segmented in unequal slices for which the sum of the associated weights are equal to 1.0. This segmentation must be fine enough to represent an adequate sampling of the total range of the parameter values. In the bootstrapping approach, there should be a large enough number of simulations to ensure convergence. Random simulations using Latin hyper cube techniques are sometimes used as a means to achieve this convergence.

2.2.4 Storm Behaviors

After simulation of the storms at a given location, a probabilistic model will model the storm behaviors. Generally speaking the parameters of the storms (including the track) change as the storms move inland. Central pressure difference rapidly decays while the forward velocity increases. The storm tracks are generally curved. Most models simulate land falling storms as straight lines and the central pressures decay using simplified relations (filling rates). More sophisticated models use behaviors of historical storms to simulate the behaviors of probabilistic storms. This is believed to better represent the inland hurricane risk. An example of a subset of simulated storms is given in Figure 2.

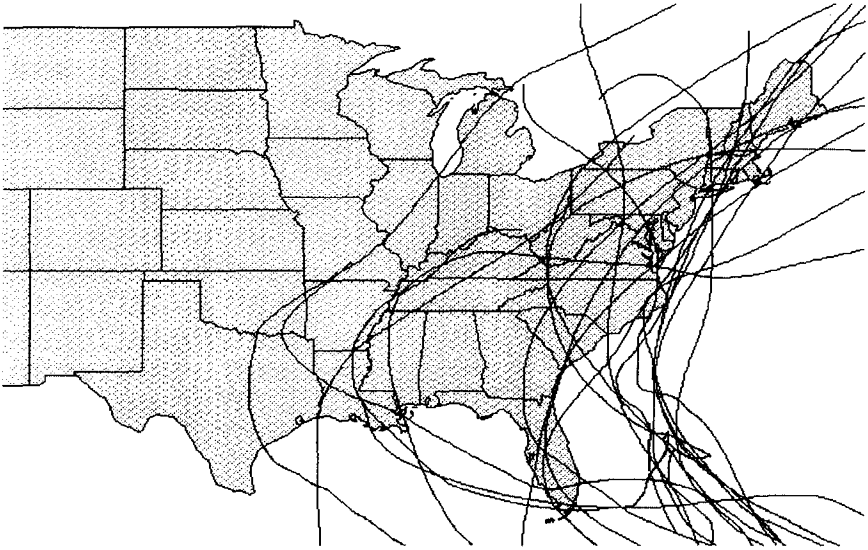

Figure 2
Sample Simulated Storm Tracks

2.3 Development of a Hurricane Hazard Model

Hurricane systems can bring a variety of associated perils in addition to high pressure winds. These perils include storm surge and waves, local flooding, missiles, and tornadoes or very localized highly turbulent wind conditions. In some historical cases, these collateral perils have been far more damaging than the direct effects of the storm itself. Estimation of hurricane hazard due to all perils is a critical part of a hurricane risk model. Most models locally assess hazards due to wind and surge (including waves). However there is not yet enough evidence to suggest that it is possible to model with relative confidence hazards associated with other perils. Sophisticated risk models represent these perils as "modifiers", that is parameters which adjust the hurricane risk as a function of the hurricane-prone regions and storm characteristics (for example the representation of "wet" storms within areas).

2.3.1 Wind Hazard

Wind hazard is generally represented by maximum wind speed and duration of the wind speed above a critical level, judged to be representative of the domain in which damage occurs. Wind speed is defined as a 2-3 second peak gust at ground level. These wind speeds are defined by the characteristics of the storm, which are pressure distribution, storm direction, forward velocity, radius to maximum wind speed, and latitude of the site (See Figure 3). In addition, distance from site to shore, and location of the site with respect to the storm track (Dmin) are incorporated in the estimate of the wind field. The choice of the wind profile model is important in the development of a hurricane risk model because it is used to directly correlate damage to hurricane wind hazard.

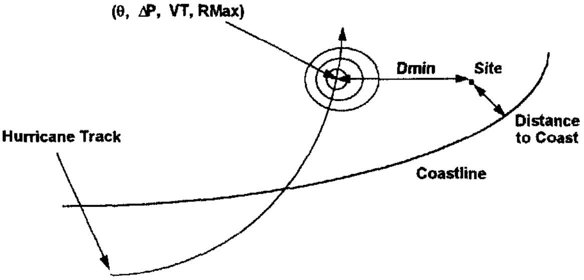

Figure 3
Wind Field Model

Although storms themselves are undeterred by ground level conditions (except in extreme conditions such as mountain ranges), wind speeds experienced at ground and building heights can be dramatically influenced by local terrain features, also known as roughness conditions. Broadly defined, roughness is a local condition which creates a disturbance in the passage of storm winds across a region. Models capable of predicting hurricane risk at a specific location incorporate this information at a site-specific location level. In general, the rougher the local area, the more friction acting on the storm's surface winds, causing turbulence and a slowing of the wind speeds. Table 2 splits roughness conditions into two distinct categories: natural roughness and man-made roughness (Boissonnade and Gunturi, 1994).

Table 2
Example of Roughness Conditions
(reprinted with permission from RMS, Inc.)

Natural Roughness	Man-made Roughness
Offshore	Scattered housing
Flat unobstructed areas to seaside	Suburban areas, towns, city outskirts
Open, fairly flat country; grassland, farmland	City centers
Wooded areas	

2.3.2 Surge Hazard

Surge hazard is characterized by its hydrostatic effect (surge level) and hydrodynamic consequences due to wave actions. Most hurricane risk models use simple surge hazard models, however, some use sophisticated models which account for the meteorological characteristics of the storm, storm direction with the coast, local fetch, bathymetric and topographic conditions, tide levels, and flood protection structures.

2.4 Validation of a Hurricane Hazard Model

Because probabilistic hurricane hazard models predict the likelihood of occurrence of hurricane intensities at given locations from a limited set of historical data, care must be provided to validate results obtained from such models. Several tests need to be performed for this purpose. Simple tests compare the rates of occurrence for simulated storms against historical rates. Other tests compare simulated hazard results with historical hazard results. Although validation data only exist for a limited number of years, this test ensures that the probabilistic hazard results are consistent with historical hazards.

2.5 Development of a Vulnerability Model

Estimates of damage to locations due to various hurricane perils are typically modeled in probabilistic hurricane risk models according to a variety of parameters. Methodologies differentiate structures in several types. This differentiation is generally based on the behavior of structures in wind. Some classifications differentiate structures on their structural ability to resist hurricane hazard while others use a discrimination based on building usage or line of business. This latter classification indirectly accounts for the structural wind resistance of structures but also for the consequences should the structure envelope fail. A complete classification should account for all of the above. Table 3 gives an example of such a classification.

Table 3
Example of a Building Classification
(printed with permission of RMS, Inc.)

Construction Material	Building Usage	Building Height	Unit Type
Wood frame	Residential	Single floor	Single family
Masonry	Commercial	Multi-floor	Multi-family
Reinforced Concrete			
Light Metal			
Steel Frame			
Mobile Homes			

Estimated damage is measured in terms of a Mean Damage Ratio (MDR). An MDR for a structure is defined as the ratio of the structure's repair cost divided by its replacement cost. Typically, three separate MDRs for a location are calculated: structure, contents, and time element losses (e.g. business interruption or additional living expenses).

Damage tables typically consist of a matrix of hazard levels (wind speeds or flood levels) by construction class, with the output as the corresponding MDRs. To calculate an MDR for a given location, a model first determines a hurricane hazard level, and then looks up the corresponding MDRs for building and contents based on the building classification.

The development of these damage functions draws on many disciplines, including wind engineering, structural engineering and forensic engineering. For example, one set of damage functions has been derived using a combination of engineering studies and actual loss data provided by insurance companies. Published engineering studies include those sponsored by the National Science Foundation, the Federal Emergency Management Agency, and the Army Corps of Engineers (Boissonnade and Gunturi, 1994). In addition to these studies, a substantial number of insurance companies have provided actual loss data from several historical hurricanes which has allowed for a comprehensive and thorough calibration of the damage curves for each building class. This process of calibrating the model with actual insurance industry loss data is repeated as new data becomes available. Special care must be taken to account for increases in materials and labor in the event of catastrophic events.

2.6 Hurricane Loss Development

From the observation of historical hurricanes, it is obvious a large variability exists in the performance of a construction class under wind hazards. Much of this variability can be accounted for by a proper modeling of the hurricane event, including consideration of the meteorological factors of the storm, local site conditions, and structural vulnerability. Given a hurricane of a specific intensity, the wind conditions at two given sites with similar local conditions and the same distance to the storm may be quite different. Furthermore, even if the sites were to experience similar wind conditions, the performance of two identical structures, one at each site, might be quite different.

Although many probabilistic hurricane risk models do not account for site uncertainties, a systematic account of these uncertainties and their effects on assessing hurricane risks is needed to better understand the limitations of the models.

Generally, complex hurricane hazard models calculate an expected value of the hazard and a coefficient of variation (COV) representing an estimate of the uncertainty around the expected value. COV values are typically of the order of 0.15 to 0.25.

Similarly, detailed engineering vulnerability models calculate an expected damage ratio value and a COV value. A review of empirical data on building performance reveals that while the damage ratios for structures in the same class are similar, a great deal of variability exists. For example the coefficient of variation for the damage ratios for residential structures during Hugo was about 0.55 for a mean damage ratio of 5.6%. Review of losses indicate that the COV value is large for low damage ratios and decreases as damage ratios increase. Note that loss variability decreases as the number of structures damaged during the same event increases.

2.6.1 Deterministic Event Analysis

Simple deterministic hurricane risk models assess the loss per location or geocode cell (for example Zip Code or county) as:

$$L_{ij} = D_{ij}\, E_{ij}$$

Where: L_{ij} is the expected loss for structures in class i and geocode cell j. D_{ij} and E_{ij} are the damage ratio and total insured values for structures in class i and cell j.

Total expected losses at cell j, regardless of the class of structure, are computed by addition of the losses in this cell as:

$$L_j = \Sigma_i\, L_{ij}$$

Finally, total losses over all cells are calculated as:

$$L = \Sigma_i\, L_i$$

Maps can also be produced which show the geographical distribution of losses.

Non-deterministic models not only calculate mean hazard and vulnerability estimates but also calculate the variability associated with these estimates. Expected losses are then calculated using a "distributed" loss model. In this model the marginal distribution of loss for structures in the ith class and within cell j is obtained by convoluting the uncertainty in wind speed and uncertainty in loss distribution given the specific wind speed. It can be written as follows:

$$f(L_{ij}) = \int f(L_{ij}/V_S) * f(V_S)\,dV_s$$

where: $f(L_{ij}/V_S)$ is the density function of the loss, L_{ij}, given the wind speed at the site with given local site conditions. This distribution is generally beta-distributed.

$f(V_S)$ is the density function of the site specific wind speed estimated, accounting for local site conditions, by the wind field model. This distribution is generally log-normally distributed.

Total expected losses at cell j, regardless of the class of structure, is computed as:

$$E\,(L_j) = \int f(L_j)\,dL_j$$

with

$$f(L_j) = f(L_{1j}) * f(L_{2j}) * \ldots * f(L_{nj})$$

Similarly, total losses over all cells are calculated as:

$$E\,(L) = \int f(L)\,dL$$

with

$$f(L) = f(L_1) * f(L_2) \ldots$$

The advantage of this technique becomes apparent in the estimates of expected losses through financial constraints such as deductibles. For example, assume the total value of exposures is \$200,000 and that the loss assessed using the simple deterministic model is calculated as L = \$20,000. For simplicity, the loss distribution estimated with the distributed loss model is assumed to have a mean value, E(L)=\$20,000 and a Coefficient of Variation, COV=0.20. With these numerical values Table 4 lists expected net losses after deductibles (ded.) of different magnitudes. Using the simple model the expected net loss is defined by:

$$E(NL) = L - ded.$$

The expected net loss calculated with the distributed model is calculated as:

$$E(NL) = \int \max\,(0, f(L) - ded.)\,dL$$

Although the difference between results from the two models is minimal for small deductibles, the difference becomes substantial as deductibles increase.

Table 4
Assessment of Expected Losses Using Simple and Distributed Loss Models

	Expected Net Loss after Deductible			
Method	**0%**	**2%**	**9%**	**10%**
Simple model (without uncertainty	$20,000	$16,000	$2,000	$0
Distributed loss model (with uncertainty	$20,000	$16,400	$3,040	$1,840
Difference	$0	$400	$1,040	$1,840

2.6.2 Probabilistic Wind Hazard Analysis

Most models calculate loss distribution by convoluting losses calculated for each simulated storm with the probability of occurrence of the storm. A complete representation of the loss distribution can be carried out by using a "distributed" loss model and calculating probabilities of exceeding a loss by convoluting the uncertainty in wind speed, uncertainty in loss distribution given the specific wind speed, and the likelihood of occurrence of the event generating the wind speed. It can be written as follows:

$$P\,(L > l) = \sum_{i} P(i) * F(L > l / i)$$

where:

P(i) is the annual probability of occurrence of the ith event

F(L>l/i) is the probability that the loss exceeds l. This value is calculated using the marginal distribution defined for the deterministic event case.

Although more complex, this methodology has the advantage of better propagating uncertainties within the analysis.

3. POTENTIAL USES OF PROBABILISTIC HURRICANE RISK MODELS

As discussed earlier, minimal historical data regarding hurricanes and resulting losses exist for actuaries to use for the analysis of risk. A hurricane simulation model provides actuaries with a tool that can "generate" sufficient data with which to accurately analyze hurricane risk. By simulating a spectrum of severity of storms at virtually all potential landfall sites, and assigning a probability of occurrence to each storm, the model is a tool which can be used to assess financial risk at any location in a hurricane prone area, not just in areas where sufficient historical data exist.

While there are numerous applications for probabilistic hurricane risk models, this section will focus on three key issues which insurance entities are not able to properly address without simulation models.

1. Diversification of Portfolio Risk
2. Assessment of Reinsurance Needs
3. Development of Hurricane Loss Costs & Rating Territories

3.1 Diversification of Portfolio Risk

As seen with recent hurricanes Andrew and Hugo, the combination of population growth and migration to the coastal areas in the hurricane-prone states can have disastrous consequences for insurance entities. Not only are insurers challenged with the task of assessing the risk of a specific property at a given location, but they also need to be able to analyze the risk associated with their portfolio as a whole under a spectrum of potential events. Complicating this challenge is the fact that insurers strive to diversify their books of business in a population that is not geographically diversified, and is in fact frequently concentrated in high risk areas.

As discussed above in Section 2, simulation models can use meteorological data collected by meteorologists to "recreate" historical storms. For example, an insurance company in Louisiana can use a simulation model to assess the potential damage to their current portfolio if the historical hurricane Camille (CAT 5, 1969) were to occur again today. The models can also run "what if" scenarios such as shifting the storm track of hurricane Andrew to the North so it makes landfall in Miami instead of Homestead and assessing the resulting damage.

In addition to modeling historical storms, models can simulate hypothetical storms to analyze the expected losses to a book of business resulting from thousands of possible events. The possible analyses include maximum credible events, a 100 year storm, and the average annual loss. All of these analyses are valuable tools for identifying areas of potential risk within a specific portfolio. The following table shows the results of the analyses of the average annual loss and losses from hurricane Andrew for a hypothetical portfolio at company ABC.

Table 5
Company ABC - Modeled Losses

Total Insured Value	Average Annual Loss	Hurricane Andrew Losses
$3.5 Billion	$5.4 Million	$17.9 Million

Areas of high potential risk can be caused by extreme concentrations of exposure, a high risk of hurricanes occurring in the specified region, or a combination of both. In the example shown in Table 5, a risk manager for Company ABC can readily identify discrete geographic regions (e.g. Zip Code, city or county) of portfolio-specific high risk by breaking down the total modeled losses shown above into losses by geographic regions. While the results of these types of analyses are somewhat intuitive at times, with the use of models, risk managers have the ability to actually quantify results for which they formerly had to rely upon their best judgment.

To continue with the example from Table 5, hypothetical Company ABC writes business in just four regions. The average annual loss of $5.4 million has been broken down for each of the four regions and is shown below in Table 6 along with the Total Insured Value (TIV) of each location.

Table 6
Company ABC - Modeled Losses by Region

Region	TIV	% of Portfolio	Ave. Annual Loss	% of Loss
Columbia, SC	$1.4 Billion	40%	$0.03 Million	1%
Charleston, SC	$1.0 Billion	29%	$3.00 Million	55%
Orlando, FL	$800 Million	23%	$0.60 Million	11%
Miami Beach, FL	$300 Million	8%	$1.80 Million	33%
TOTAL	$3.5 Billion	100%	$5.43 Million	100%

In this simple example, 40% of the portfolio exposure is located in Columbia, but as it is located well inland, it only accounts for 1% of the average annual loss. Conversely, Charleston and Miami Beach account for only 37% of the portfolio's TIV, but 88% of the risk on an average annual loss basis. This highlights that while Charleston and Miami Beach can readily be identified as the two regions having the greatest risk within this portfolio, without a simulation model it would not be possible to ***quantify the magnitude*** of the portfolio's risk that is captured in these two regions. Having identified geographic areas of concern, the next step is to diversify the current exposure in these areas. Diversification of the risk can be accomplished through the use of underwriting guidelines, pricing, marketing efforts such as promotional campaigns, or by reducing the exposure through the use of reinsurance.

The same methodology used to identify areas of high risk can be used to identify areas of relatively low risk which constitute potential market opportunities (e.g. Orlando and Columbia in this example). Low risk areas occur as a result of either small dollar exposure within the portfolio, or low risk of hazard. The goal of the overall process is to diversify the book of business to the extent that expected losses and worst case losses do not endanger the solvency of the company.

Along with diversification of portfolio risk, the use of simulation models can also increase the efficient utilization of a company's capacity. This is achieved through the analysis of the risk of a given area in connection with an analysis of the company's current premium rates for the area. Areas with high premium levels in relation to the hurricane risk can potentially become target areas for marketing efforts. These same concepts apply to the assessment of a company's reinsurance needs.

3.2 Assessment of Reinsurance Needs

In the wake of the catastrophes causing multi-billion dollar losses to the insurance industry, a frequently asked question among risk managers is "are we adequately covered?" Clearly every company has their own definition of what "adequately covered" means, but it definitely entails a function of company-specific risk tolerance and level of reserves, along with other factors. Prior to the development of hurricane simulation models, a risk manager could not accurately assess the potential danger to a company's solvency resulting from a potential hurricane.

A simulation of virtually every credible hurricane event, which takes into account the probability of occurrence of each hurricane, can be run against a given book of business. The result of such an analysis is a series of points forming a curve of the probability of sustaining specified loss levels.

Given a company's current level of reserves, a "risk threshold", or amount they can afford to lose should be established. The exceeding probability curve is the ideal tool for assessing the amount of reinsurance to cede. The following figure shows an exceeding probability curve for a sample portfolio along with its three Cat Layers and attachment points (e.g. Cat Layer 1=$30,000 excess of $20,000). Each point on the curve represents a discrete event. The loss associated with the event is plotted on the X axis. The probability of exceeding this loss is shown on the Y axis.

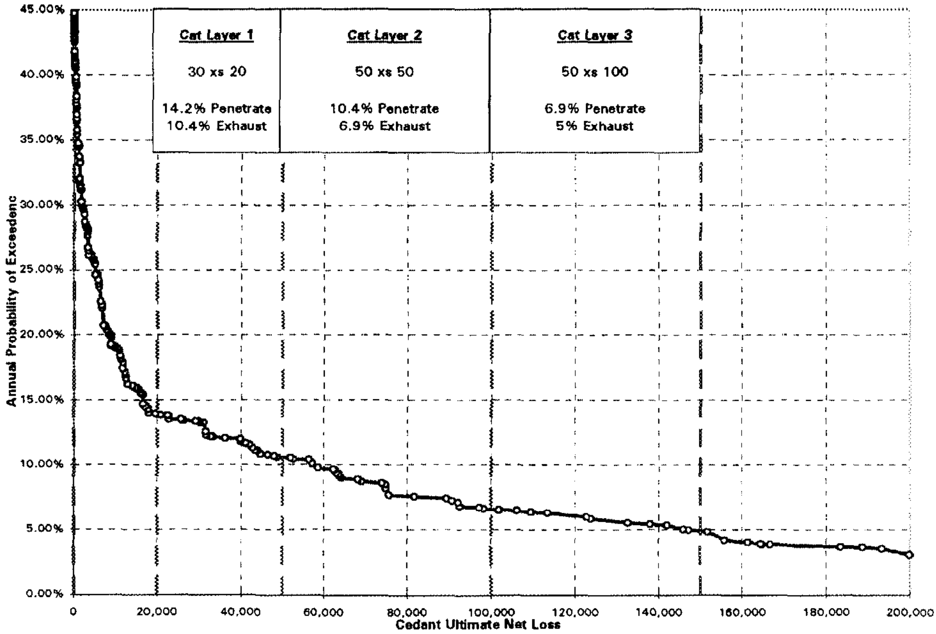

Figure 4
Exceeding Probability Curve

Given the scarcity and cost of catastrophe reinsurance, a key feature of hurricane simulation models is the ability to analyze the potential need for reinsurance. Given the need for reinsurance, the pricing of various layers can then be analyzed. By modeling expected losses, an insurer can assess the probability of a particular layer of reinsurance being accessed, and the corresponding expected loss to the layer under various scenarios. For example, as shown in Figure 4 above, there is a 14.2% chance of Cat Layer 1 (30 excess 20) being penetrated, and a 10.4% chance of the layer being exhausted. There is a 5% chance of all three Cat Layers being exhausted.

Preparing such an analysis provides an insurer with an effective bargaining position for the negotiation of reinsurance pricing. In addition to negotiating a reasonable price, a company can more efficiently reinsure their exposures. For example, rather than establishing guidelines for exposure limits per geographic region based on the size of the region, the exposure limits can be based on the relative risk of the region.

The exceeding probability curve is also used to define events representing losses associated with a given annual probability of exceedance (or associated return periods). Detailed analysis of these events is often used to characterize the variability associated with losses for given return periods. PML estimates can be derived from these type of analyses.

3.3 Computation of Hurricane Loss Costs

As discussed earlier, the use of smoothing techniques will not fully eliminate the potentially huge variability in actuarially computed hurricane loss costs. Rates will be subject to the results of recent historical events which may or may not reflect the true risk of a given region in the long term. Hurricane simulation models allow users to simulate thousands of storms along with their associated probability of occurrence to determine an average annual loss for a given property. While the simulation models will continually be improved over time through the incorporation of new technology and new meteorological data, the resulting loss costs should remain fairly consistent. The following is a brief discussion of potential methodologies to be utilized in computing loss costs.

3.3.1 Overview of Loss Cost Methodology

In computing loss costs, hurricane models analyze thousands of simulated hurricanes. For each of the potential events, the resulting damage to the structure analyzed and the probability of the event occurring are taken into account. This analysis does not require any of a user's historical hurricane loss data. For a personal lines example, using company-specific information regarding policy forms, coverage amounts, and associated deductibles, the construction class of the structure (including age and other engineering specifics, if available), and the location of the dwelling, the model can compute the expected annual loss (e.g. loss cost or pure premium) to the dwelling resulting from the entire database of simulated hurricanes.

The result of this analysis for a dwelling is a loss cost which includes damage to structure, contents and additional living expense, and is expressed as a percentage of the structure's

Coverage A amount. For example, a company may wish to know the loss cost for the following building.

Location - 2410 Collins Ave, Miami Beach, FL 33140
Construction type -Masonry
Year built - 1960
Number of floors - 2
Occupancy - single family dwelling
Coverage - A - 100%, B - 10%, C - 50%, D - 20%
Deductible - $500 applied to all coverages except D

The model will compute a hurricane loss cost of perhaps 0.75% for this building category, independent of the building value. Because the result is expressed as a percentage, the same loss cost can be applied to another building with similar characteristics and in the same geographic area. Hurricane loss costs can be computed for any combination of construction class, coverage weights and deductible levels desired, and this loss cost methodology can be implemented in a number of approaches.

Given the ability to compute a long term average annual loss for a given property, this theory can be expanded to compute an expected average annual loss for a geographic region, and thus, for the computation of territory rates. The following two sections of this paper address methodologies for computing hurricane loss costs for territories. The "building block approach" computes generic loss costs suitable for use by any company, while the second approach is a company specific approach. The methodologies are explained using personal lines examples, but the same basic methodologies apply to other lines of business with only minor modifications.

3.3.2 Building Block Approach

In this approach, loss costs are computed first on a Zip Code level[2]. This is done by modeling one hypothetical building for each permutation of construction class, policy type and deductible level in each Zip Code. There are several potential locations for the placement of the hypothetical building. The most readily available location is the geographic centroid of the Zip Code. However, taking into account the actual land-usage information within a particular Zip Code, a "population-weighted" centroid can be developed. This land-use weighted centroid provides a more realistic approximation of where the relevant exposures within a Zip Code are actually located. The land-use centroids make the biggest impact in the high risk coastal areas. As people tend to live near the beach, the population in many coastal Zip Codes tends to be skewed to the coast; thus leading to higher modeled losses than if geographic centroids are used.

After determining the location of the hypothetical buildings, the model then computes the average annual loss to each of the buildings within each Zip Code. The result of this step is a

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[2] Zip codes are chosen for their relatively fine resolution and the ease with which boundary file and population information can be obtained.

loss cost, expressed as a percentage of a structure's coverage A amount, for each category of building analyzed for each Zip Code.

The second step of this process is to aggregate the Zip Code level loss costs into loss costs by desired territory. The territories can be Zip Codes, cities, counties, or user-defined regions. The aggregation process is performed by first determining which Zip Codes map to each territory, and then aggregating the Zip Code level values by weighting them by the relative population within each Zip Code.

This methodology has advantages in that it models hurricane risk at a high resolution basis (Zip Codes) and is a fairly straightforward application of the modeling technology. The loss costs reflect geographic averages for building location and census averages for population distribution, and then incorporate user-specific information regarding the types of policies and deductibles offered. The results of this methodology provide a realistic quantification of risk for most companies. However, some "specialty" companies may have a book of business (e.g. "high end" homes only) which could conceivably have loss costs which are different than the loss costs computed using the averaging techniques of this scenario (e.g. the location of the high-end homes within a Zip Code may differ significantly from the population-weighted centroid, and/or the high-end population distribution between Zip Codes may differ from the total population distribution). For cases such as this, a user may want to determine loss costs using portfolio specific information.

3.3.3 Portfolio-Specific Exposure and Territory Approach

Under this methodology the loss costs are computed by first determining the average annual loss to each policy in the user's portfolio. These values are then aggregated by policy category (construction class, structure age, coverage amount and deductible level), and into the user's desired geographic territories. Average annual losses by policy category and by territory are then converted to loss cost percentages by dividing each average annual loss amount by the total associated coverage amount.

The resulting loss costs will be based on the exact location, type and value of every policy in the user's book of business at the time of the computation. In this methodology, no "averaging" occurs through the use of Zip Code centroids for the modeling of locations, or through the use of population distribution data to weight Zip Code loss costs as in the building block approach. However, certain Zip Codes may not have sufficient data to accurately reflect risk across the entire Zip Code, and thus skew rates for "new policies" underwritten within the Zip Code.

3.3.4 Definition of Rating Territories

Historically, rating territories have frequently been defined using relatively large geographic boundaries such as counties. This is due in part to a lack of hurricane loss data, and in part to simplify the underwriter's job. For example, when rating territories align with counties, it is easy to look up a rate for a potential new policy given its address. However, when modeling location-specific loss costs, there can be significant variation in the actual risk to various properties located within a single county rating territory.

The variation of risk within a territory leads to several problems. It is difficult to assign an "average" rate for a county in which there are a wide range of risks. Insurers can potentially unknowingly accumulate concentrations of exposures in the high risk portion of the county. From a rate payer's viewpoint, the policyholders in the relatively low risk portions of the county are in effect subsidizing the policyholders in the high risk portion of the county through the payment of a county-average premium.

This brings into question the definition of a rating territory. Clearly, politically defined regions do not always make appropriate hurricane territories. Hurricane simulation models can be used to re-define existing rating territories taking into account actual catastrophic risk rather than convenient geographic boundaries.

The creation of realistic rating territories can be a by-product of the "building-block" approach to computing loss costs discussed above. After computing the loss costs by Zip Code, the resulting values can be mapped to show the relative variation between geographic regions. Being able to visualize these risks geographically allows the definition of rating territories to be performed with relative ease. Territories can conceivably be comprised of non-contiguous Zip Codes grouped on the basis of similar risk.

The next question to be answered is how many rating territories should be developed. Ideally, every specific location should be rated individually. Unfortunately this is not a realistic solution from an administrative stand point. The goal is to reach a reasonable middle ground between developing territories with relatively homogenous risk within the territory, and developing a number of territories that is manageable by the insurance entity. While different insurance entities are able to handle different levels of complexities in terms of the number and definition of rating territories, it is possible to provide guidance on where the maximum benefits of finely defined territories can be obtained.

After a hurricane makes landfall it rapidly loses force as it moves inland. The greatest decreases in expected damage occur within the first few miles from the coast. To illustrate this point, the following figure shows the exposure and average annual loss to a sample portfolio broken down into five segments based on the location's distance to coast.

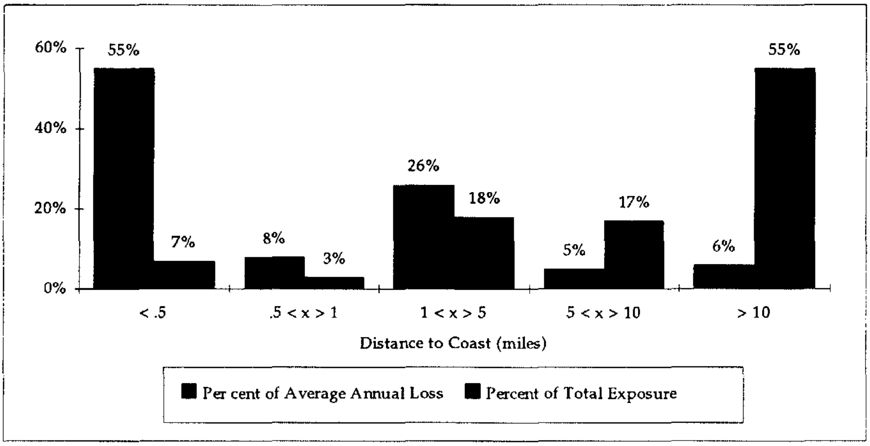

Figure 5
Exposure & Average Annual Loss vs. Distance to Coast

In Figure 5 a disproportionate amount of the loss is expected to occur in the area within 0.5 miles from the coast. Therefore, in this example it is apparent that hurricane rating territories need to be narrowly defined near the coast, but once you move ten miles from the coast, grosser definition such as counties is probably sufficient.

Along the coast of the Southeastern United States, it is possible that even a Zip Code is too "deep" a boundary. As there is significant change in the risk in even the first few blocks from the beach, a user may want to consider the use of census tracks or user-defined areas for territories.

4. LESSONS LEARNED IN MODELING HURRICANE RISK

While use of probabilistic hurricane risk models to estimate losses is an effective form of analysis, one should understand the limitations associated with the process. These limitations can be broken down into the following categories:

1. Inherent hurricane hazard modeling limitations
2. Inherent hurricane vulnerability modeling limitations
3. Insurance data limitations

4.1 Inherent Hurricane Hazard Modeling Limitations

There are several limitations inherent in the modeling of hurricanes. The first is the unpredictability of hurricanes. For example, it is not unusual to observe within areas of high hurricane damage a block of houses that has been totally destroyed, while a neighboring block of houses has remained virtually undamaged. A second limitation is the inability to perfectly capture the local conditions (terrain roughness, density of structures) around the site of interest. A third limitation is due to a lack of actual meteorological data. While measurements are recorded at a minimum of every six hours, data for the time in between measurements must be interpolated. Because hurricanes don't necessarily follow "smooth" paths, this is a potential source of error. In addition, recorded data is not always reliable.

A fourth important limitation in hurricane hazard modeling is the limited number of years of observation that have been recorded. Detailed meteorological observations have only been reported for the last 40 to 50 years and detailed historical reports of events are only available for the last century or slightly more for some parts of the world. This limited set of data inherently limits a hazard model. Substitute sources of information, such as meteorological expertise, are needed to develop probabilistic models.

4.2 Inherent Hurricane Vulnerability Modeling Limitations

Although damage functions can be estimated using available loss data and engineering expertise, reported loss data is limited. Even if reports of losses exist after each event, these losses are often in a format that is not usable for analysts. Indeed, the finer the possibility of discriminating losses between types of structures (structural type, age, height, etc.) and coverage (structures, contents, time expenses, etc.), the more reliable the vulnerability model can be in predicting future losses.

4.3 Insurance Data Limitations

There are several limitations in the process due to insurance company data. In certain cases, exposure and loss data provided by insurers appear reasonable in total. However, certain anomalies in the data often exist on a location-specific basis. For example, loss information is often tracked through the location where the claim was actually processed, rather than where the claim actually occurred.

Another potential limitation due to insurance company data is the lack of detailed exposure information. While some models incorporate many variables such as number of floors, year of construction, roof type, etc., insurance companies frequently do not track this level of detail. Therefore assumptions must be made where the data is incomplete. These assumptions may or may not lead to modeling inaccuracies.

5. LESSONS LEARNED THROUGH PROBABILISTIC HURRICANE RISK ANALYSES

This section presents some of the findings the authors and their colleagues have made through the analysis of numerous insurance company's books of business. Specifically addressed are the following topics.

- ☐ The appropriateness of the current level of wind deductibles
- ☐ The adequacy of currently filed hurricane loss costs
- ☐ Risk due to concentration of exposure in a small geographic area
- ☐ The need for improved bookkeeping of insured exposures

The ideas contained in this section are generalities based on our experience in relatively high risk regions. The actual results for different geographic regions and for a given insurance entity may differ.

5.1 Current Level of Wind Deductibles

Personal lines wind deductibles in states with a high risk of hurricanes are typically around $500 applied separately to each coverage type. This is significantly different than the level of deductibles for earthquake risk in California, where deductibles are frequently 10% or more. Clearly, a 10% deductible makes a significant impact in reducing an insurer's exposure. The $500 wind deductibles eliminate some of the minor claims that would cause administrative headaches, but do little to reduce a company's hurricane exposure in a major event. Hurricane simulation models allow a company to run "what if" scenarios comparing the portfolio losses they would sustain under various deductible levels. The following table shows the impact of varying deductible levels on losses sustained from hurricane Andrew to hypothetical Company XYZ.

Table 7

Company XYZ - Hurricane Andrew Losses

Deductible	Ground-Up Loss	Loss Net of Deductible	Impact of Deductible
$500	$27.7 Million	$27.0 Million	2.5% Loss Reduction
2%	$27.7 Million	$24.4 Million	11.9% Loss Reduction
5%	$27.7 Million	$21.2 Million	23.5% Loss Reduction
10%	$27.7 Million	$17.3 Million	37.5% Loss Reduction

Given the level of losses sustained from several recent hurricanes, insurers may want to consider moving to a higher level of deductibles than is currently in place.

5.2 Adequacy of Currently Filed Hurricane Loss Costs

The two issues addressed in this section are 1) Are the filed rates adequate with respect to the hurricane risk of the territory? and 2) Are the rating territories comprised of relatively homogeneous risk? If the current rates are actuarially determined, then the adequacy of the rates is largely dependent on the recent hurricane history in the area. For regions with no recent hurricane history, these rates will probably be too low, and for areas with significant recent hurricane activity, the rates may be too high. Overall we have found that hurricane rates tend to be a bit low, largely because without the use of a simulation model, the impact of extreme events is rarely considered. Thus, reliance on historical data for the determination of rates could potentially lead to the severe under-funding of risk.

A methodology for the development of rating territories was discussed in Section 3.3.4 above. We have found that insurers frequently develop rating territories that are too broad and encompass a wide range of risks within a single territory. While counties located inland are comprised of relatively homogeneous risk and thus are reasonable boundaries for use as rating territories, regions within about five miles of the coast require finer resolution of rating territories. As the greatest reduction in wind speeds occur in the first few miles from the coastline[3], the first territory should reach from the coastline to no further inland than a half mile to a mile. Subsequent territories should each be 2 to 3 miles "deep" until they reach about 10 miles inland. At this point counties or other large geographic regions are usually sufficient for territory definition.

5.3 Risk Due to Concentration of Exposure in a Small Geographic Area

Table 8 shows the insured loss payments for the ten most costly hurricanes in U.S. history. While hurricane Hugo caused the second most damage of any hurricane, it was a relatively moderate (CAT 3) hurricane. The amount of damage was due to the fact that Hugo made landfall in a major city - Charleston SC. Rarely have hurricanes made landfall in major cities. Hurricane Andrew, the U.S.'s most destructive hurricane made landfall in Homestead FL, but if it had made landfall in Miami, just to the north, the damage would have been significantly greater.

Table 8
Insured Loss Payments for the Ten Most Costly Hurricanes[4]

Name	Saffir Simpson	Date	Place	Estimated Insured Losses (1992 Dollars)
Andrew	4	August 1992	FL, LA	15,000,000,000
Hugo	4	September 1989	GA, VA, NC, SC	4,787,900,000
Betsy	3	September 1965	FL, LA, MS	2,389,700,000
Frederic	3	September 1979	AL, FL, KY, LA, MS, NY, OH, PA, TN, WV	1,517,800,000
Celia	3	August 1970	TX	1,168,800,000
Alicia	3	August 1983	TX	1,004,100,000
Carol	3	August 1954	CT, ME, MA, NH, NJ, NY, RI	758,700,000
Elena	3	Aug-Sep 1985	AL, FL, LA, MS	746,130,000
Camille	5	August 1969	AL, FL, LA, MS	647,800,000
Gloria	3	September 1985	CT, DE, ME, MD, MA, NH, NY, NC, PA, RI, VT, VA	575,080,000

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[3] The reduction in wind speeds is greatly affected by the local terrain features. High rise buildings serve to reduce wind speeds significantly, while open grassy areas have little impact on wind speeds.

[4] Source: Property Claims Service Division, American Insurance Services Group, Inc.

Without hurricane simulation models, insurers have no way to quantify the potential losses to their portfolios. Most companies are surprised at the results of a "worst case" analysis of their portfolio performed using hurricane simulation models, and are shocked to learn that numerous credible events exist which could endanger the solvency of their company. These types of analyses highlight the need to perform portfolio analyses using hurricane simulation models.

5.4 The Need for Improved Bookkeeping of Portfolio Information

As discussed in Section 2, there is a certain degree of uncertainty involved in the modeling of hurricanes due to the nature of hurricanes and to the limited amount of historical data on hurricanes. Over time, as more hurricanes occur and meteorologists gather new information on hurricanes, this modeling process will improve. However, there is one area in which insurers can make an immediate impact in terms of improving the modeled results of hurricane simulation models, and that area is in the quality of the data they capture.

The results of an analysis using a hurricane simulation model are only as good as the portfolio information input into the model. It is important that the portfolio data be both correct and complete. While the models can deal with incomplete portfolio information by making intelligent assumptions, this only introduces additional uncertainty into the model and potentially reduces the quality of the output.

The most important data elements to be supplied by the insurers are the following.

- ☐ Value of building
- ☐ Address (street number, city, Zip Code)
- ☐ Limit of policy
- ☐ Construction class (including number of floors)
- ☐ Deductible level
- ☐ Occupancy type

While numerous other factors are considered by the simulation models, these are the most sensitive variables, and will make a significant impact on the modeled results. Other variables which can be considered by the simulation models include year of construction, contents damageability and local building practices.

Not only must insurers do an accurate, complete job of capturing exposure information, but they need to capture detailed loss information after a hurricane occurs. Hurricane simulation models are theoretical models which require actual loss data with which to validate and calibrate the models' results. Many insurers do an inaccurate job of tracking losses by address or losses by coverage type. This information is needed to assist the analysts in the continual improvement of the models.

6. SUMMARY

In the wake of multi-billion dollar losses to the insurance industry from catastrophic events, the need for the widespread use of risk analysis tools has lead to the development of probabilistic modeling. The probabilistic hurricane risk assessment model incorporates knowledge from a wide range of disciplines including meteorology, civil engineering, statistics, actuarial science, mathematics, insurance and software development. Risk analysts have incorporated the work of this multi-disciplinary team to create probabilistic models.

As these tools are now PC-based, the insurance industry has the opportunity to access these probabilistic hurricane models. This allows for the quantification and dissemination of key information regarding the assessment of the hurricane exposure of a given book of business.

While probabilistic hurricane risk models do not predict the future, they can provide insurance entities with the ability to assess the likelihood of occurrence and financial impact of hurricane events - something insurance entities were previously unable to do.

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