Inside the Black Box: Evaluating and Auditing Hurricane Loss Models*

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Abstract

The use of computerized simulated hurricane models has been generally accepted throughout the insurance industry. The widespread usage of hurricane loss models dates back to 1992 when losses from Hurricane Andrew highlighted the inadequacy of traditional actuarial methods in determining expected catastrophic hurricane losses. One common criticism levied against hurricane models (and more broadly, catastrophe models) was lack of transparency (the "black box"). The Florida Commission on Hurricane Loss Projection Methodology (Commission) was established to evaluate hurricane loss models used in the State of Florida. The Commission has used an on-site audit process to evaluate both proprietary and non-proprietary aspects of each model. More recently, the Commission has used closed sessions to evaluate the proprietary material related to the design and construction of the model. For a model to be found acceptable, it must meet all of the standards established by the Commission. The acceptance of models by the Commission forms the basis of model reviews performed by other organizations around the country as well. Given the unique nature of the Commission's activities and the weight given by the Commission's findings outside of Florida, this paper discusses the model evaluation process used by the Commission to provide insights into the key aspects of the auditing process. The paper also provides a review of the relevant catastrophe modeling literature published in insurance journals with a specific focus on the contributions appearing in the *Journal of Insurance Regulation*.

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Introduction

The use of computerized simulated hurricane models is accepted throughout the insurance industry. Hurricane catastrophe models are almost universally used by primary insurers and reinsurers, rating agencies and regulators, for ratemaking, risk analysis, catastrophic exposure and capacity management, reinsurance and catastrophe bond pricing, financial strength analyses, hazard mitigation analyses and other applications relating to the effects of hurricanes on properties.

The widespread usage of hurricane loss models dates back to 1992 when losses from Hurricane Andrew highlighted the inadequacy of traditional actuarial methods in determining expected catastrophic hurricane losses. Given the paucity of historical data related to losses from catastrophic events such as hurricanes and the substantial increase of both the number of coastal exposure units and insured values per exposure unit, probabilistic catastrophe modeling has emerged as a viable and preferred technique for modeling hurricane losses.

Recognizing the need for a process to evaluate hurricane loss model performance following Hurricane Andrew, the Florida Legislature in 1995 enacted legislation that created the Florida Commission on Hurricane Loss Projection Methodology (Commission). The Legislature recognized that "reliable projections of hurricane losses are necessary to assure that rates for residential insurance are neither excessive, inadequate, or unfairly discriminatory," and that "it is the public policy of this state to encourage the use of the most sophisticated actuarial methods to assure that consumers are charged lawful rates for residential property insurance coverage," Section 627.0628(1)(a), Florida Statutes. The Commission consists of a panel of independent experts to "provide the most actuarially sophisticated guidelines and standards for projection of hurricane losses possible." The Commission utilizes a Professional Team, consisting of individuals having professional credentials in actuarial science, statistics, meteorology, computer science, or structural engineering, in order to provide on-site audits of each model submitted for acceptance. The Professional Team's audit provides a review of the models at the level of detail considered necessary while allowing modelers to keep their trade secrets from becoming public information.

Catastrophe modeling is a complex process that involves the use of proprietary data and methods. For the private modeling firm, the business value of its model in part reflects the expertise that it has developed and the proprietary aspects of its operation and intellectual property**.** To protect this value, modeling firms do not disclose detailed information regarding the internal workings of their models to the general public. This reticence then leads to criticisms and concerns that catastrophe models are "black boxes" due to the lack of transparency. Some critics even have expressed significant reservations regarding whether the proprietary nature of the modeling process makes it unsuitable for ratemaking. For example, Whitehead (2007) in discussing proprietary earthquake models stated that their "use violates time-proven regulatory standards and practices" (pg 373).

The transition from the traditional actuarial approach of pricing catastrophe risk to the use of sophisticated computer models is supported by the Actuarial Standards of Practice (ASOP). Section 3.3.2 of ASOP #39 states in part:

> *If, after considering the items contained in section 3.3.1(a–f), the actuary believes that the available historical insurance data do not sufficiently represent the exposure to catastrophe losses, the actuary should consider doing one of the following:*
>
> *1. use noninsurance data to adjust the historical insurance data;*

2. use noninsurance data (including models based thereon) as input to ratemaking procedures; or

3. use models based on a combination of historical insurance data and noninsurance data.

Section 3.1 of ASOP 38 provides that "an actuary may find it appropriate to use models that incorporate specialized knowledge outside of the actuary's own area of expertise." The purpose of ASOP 38 is to provide certain guidance and requirements that enable actuaries to use such models, specifically including catastrophe models.

Through its on-site audits and the ability to hold closed meetings to discuss proprietary or trade secret information, the Commission has access to proprietary data and methods and this serves to access the black box on behalf of the residents of the state of Florida.[4] The Commission's responsibility is to ensure that hurricane models produce outputs (hurricane loss costs) that are reasonable in nature and supported by the existing science. The unique role of the Commission is highlighted by the fact that while the Commission's focus is on hurricane models used in the state of Florida, its findings are broadly used by other states with hurricane exposure (e.g., Hawaii, South Carolina, and Louisiana).[5] Additionally, the American Academy of Actuaries (2008) called the Commission's review process the "gold standard for the review of hurricane models for producing property insurance loss costs" (page 4).

The purpose of this paper is to discuss the model evaluation process used by the Commission and to provide insights into the key aspects of the auditing process. As such, it extends the prior literature that includes discussions of the formation of the Commission and its basic function. By providing a deeper understanding of the evaluation process, this paper in part helps in the effort to bring further transparency to the process and move beyond the tendency to refer to the proprietary models as mere "black boxes." Finally, the paper provides a review of the relevant catastrophe modeling literature published in insurance journals with a specific focus on the contributions appearing in the *Journal of Insurance Regulation*. As such, the results of this paper should be of interest to those who operate in or have responsibility over markets impacted by and prone to hurricane wind loss. This would include insurance regulators, actuaries, public policy makers, individuals involved with developing hurricane loss models, end users of modeled hurricane loss costs, and academics who have an interest in research related to catastrophe modeling.

The paper commences with a review of the existing literature related to hurricane catastrophe modeling. This is followed by a brief overview of hurricane modeling and how the Commission's evaluation procedure aligns with that process. In the following section, we provide a discussion of important issues and concerns related to auditing hurricane loss models. The paper concludes with a summary of the main insights and observations made in the paper.

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[4] The Commission relies on the Professional Team to probe the models in great depth with an initial scrutiny of the public submission, a request for additional materials to be provided on-site and then ultimately a two and a half day on-site audit where all aspects of the model are exposed to and reviewed by the Professional Team. In the past three years, Commissioners have attended the on-site audits as observers and have the opportunity to ask further questions when the Professional Team adjourns each day. Consequently, the Commission does not rely solely on the Professional Team in arriving at its decision regarding compliance of the model to its standards.

[5] In 2001, the Hawaii Commissioner of Insurance established a process to enable the Hawaii Division of Insurance to review the loss costs produced by hurricane models in that State. One of the requirements for a model to be found acceptable in Hawaii is that the model must have been determined to be acceptable by the Florida Commission.

Literature Review

Given the multi-disciplinary nature of hurricane modeling, it is not surprising to see research related to hurricane modeling published in meteorological, statistical, actuarial, or engineering journals.[6] Examples include research investigating the relationship between climate change and hurricane characteristics, uncertainty analysis, or the effects of mitigation. In examining research published in the journals devoted to risk management and insurance, one finds the published research is less prevalent. Given the regulatory issues surrounding catastrophe modeling, the *Journal of Insurance Regulation* has published a number of articles on this topic area and a review of these articles is provided in this section.

From a historical perspective, the important early research was published by Friedman (1975, 1984). Clark (1986) built on the work of Friedman and provided arguments in a *Society of Actuaries Proceedings* article for using a simulation/probabilistic approach to assessing catastrophe risk. As noted above, Hurricane Andrew in 1992 was the transformative event that led to a sea change in how catastrophic risk was viewed and evaluated.

In response to the need to better understand this new methodology, the National Association of Insurance Commissioners (NAIC), began in 1993 to study the issues related to catastrophe modeling by establishing several working groups (Harrison and Nordman, 1997). This was followed by a symposium on catastrophe modeling in 1996 that was in part sponsored by the NAIC's Catastrophe Modeling Subgroup. Papers presented at this symposium were subsequently published in the *Journal of Insurance Regulation* in the spring of 1997. The papers and the subsequent response to the Whitehead paper illustrate the concerns regarding the use of proprietary catastrophic models. It is interesting to note that some of the criticism levied against catastrophic models more than ten years later continues to be related to their perceived lack of transparency.

In the introductory article, Harrison and Nordman (1997) acknowledged the developmental costs associated with proprietary catastrophic models and provided insights from the Catastrophic Modeling Subgroup regarding the evolving relationship between modelers and regulators. Whitehead (1997) took the position that propriety earthquake catastrophe models were not acceptable "as long as these models are unverifiable 'black boxes'" (1997, pg 372) and consequently, the proprietary nature of these models "renders them inappropriate for use in regulatory proceedings and their use violates time-proven regulatory standards and practices" (1997, pg 373). Refuting Whitehead's contention that the use of proprietary computer models results in a breach of actuarial standards, members of the Casualty Practice Council of the American Academy of Actuaries (CPC, 1997) described the professional responsibilities of actuaries who use proprietary computer modeling in insurance ratemaking and indicated why actuarial ratemaking principles support the use of computer models in determining rates for catastrophic exposures.

Musulin (1997) illustrated the problems associated with using the traditional actuarial approach to determining rates in areas with catastrophic loss exposures. The excess wind factor is based on a long-term average (e.g., over a 20 to 30 year period). For this factor to be viable, the time period would reflect normal catastrophic activity, stable population patterns, and no significant changes in policy coverage (e.g., ACV to replacement cost) or construction practices (Musulin, 1997). As noted above, losses from Hurricane Andrew provided a clear indication

[6] While the primary focus of this paper is on modeling hurricane risk, the initial articles discussed in this section focused on modeling catastrophic risks that included more than just wind (e.g., earthquake).

that these assumptions were invalid. As Musulin suggested, the challenge for the regulator in using simulation models relates to the complexity of the process, data quality, and transparency. These continue to be the challenges facing regulators today where the use of, and reliance upon, catastrophe models has grown considerably.

Nordman and Piazza (1997) provided context to the discussion regarding catastrophe modeling and the regulation of insurance products and companies when these models are used. In gauging or evaluating regulator reactions to catastrophe models, they noted the importance of understanding the regulatory environment in a particular state. This point continues to be valid as catastrophe models are at the center of a sometimes contentious debate over insurance rates in states such as Florida and Massachusetts. The authors described the activities related to finding regulatory solutions in California, Florida, Louisiana, New York, South Carolina, and Texas. They noted Florida's significant exposure to catastrophe losses, its decision to "adopt a public policy that encourages the use of sophisticated actuarial methods and models," (Nordman and Piazza, 1997, pg 367) and the subsequent creation of the Commission.

Two subsequent articles published in the *Journal of Insurance Regulation* also focused on hurricane catastrophe models but both provided a different perspective to modeling the hurricane catastrophe exposure. Pielke et al. (1999) suggested an approach involving normalized hurricane losses as an additional methodology to evaluate hurricane model performance. They argued that this approach would provide a baseline with which to evaluate model performance that was easily understood and transparent. Providing an alternative to the use of proprietary models, Watson, Johnson, and Simons (2004) used publicly available data sources to model hurricane risk in North Carolina.

The framework noted above was introduced by Watson and Johnson (2004) in a 2004 BAMS article. The framework has been used by the Commission in order to provide additional understanding of differences in model performance and it served as the basis for the Commission's report to the Florida House of Representatives in 2007 (Commission, 2007). Other related research using data from model submissions to the Commission includes evaluation of model sensitivity (Iman, Johnson, and Watson 2005a), model uncertainty (Iman Johnson, and Watson 2005b), and an interdisciplinary article by Iman, Johnson, and Watson (2006), that provides a detailed overview of hurricane modeling and uncertainty/sensitivity analysis.

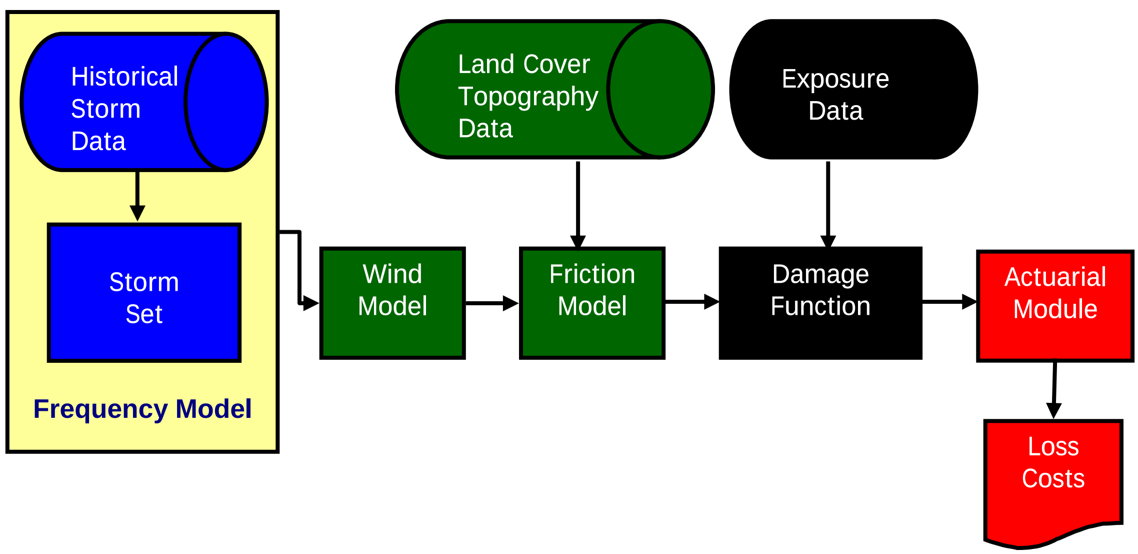
Hurricane Loss Models and Evaluation Standards

Overview of Process and Standards

Since the extant literature provides detailed descriptions of the functional aspects of catastrophic models (Kozlowski and Mathewson, 1997) and hurricane loss models (e.g., Clark, 1986; Watson and Johnson, 2004; Born and Martin, 2004), we will focus our discussion on how the standards established by the Commission to evaluate hurricane loss models relate to hurricane loss model components and the operational aspects of the model. We will pay particular attention to the review process that is widely recognized as rigorous and comprehensive (e.g., via heavy consideration of Florida findings by other states such as Hawaii, South Carolina and Massachusetts) and has contributed to advancing the state of the art of hurricane modeling.

Figure 1 provides a structure diagram relating the components of traditional hurricane loss models. The starting point in developing a loss model is consideration of the historical record (drawn from the National Hurricane Center's Archive of Hurricane Seasons (HURDAT) and other sources) from which a stochastic storm set is developed to reflect future hurricane activity. Storms in the stochastic set are generated in the computer model to produce winds at the locations of insured properties, taking into account the dissipating impacts of storms weakening over land and friction effects. Winds acting on structures produce damage based on modeler vulnerability functions which is then converted to insured losses according to policy provisions and other assumptions integrated into the model.

Figure 1
Traditional Hurricane Loss Models



To determine that the proprietary models achieve the goals of the Commission (i.e., models produce loss costs that are reasonable), the Commission has developed computer simulation model standards that must be met by modeling firms in order to be found acceptable by the Commission. Table 1 provides a high-level perspective of the areas covered by the Commission standards with respect to the model components described above.[7]

[7] Complete details of the standards can be found in the Report of Activities issued by the Commission every year on the first of November (www.sbfla.com/methodology).

Table 1.
Major Model Components

Component Areas	**Frequency Model**	**Wind, Friction, Topography (Intensity)**	**Exposure Data, Damage Function**	**Actuarial Module**
Component Details	Base Hurricane Storm Set, Hurricane Probabilities	Hurricane Characteristics, Wind Field Structure, Hurricane Weakening	Derivation of Vulnerability Functions, Mitigation Measures	Actuarial Assumptions and Coverage, Commission Specified Calculations, Modeler Supporting Calculations
Logical Inter-Relationships	Hurricane Characteristics		Construction Practices	Loss Costs
Pervasive Aspects Across Areas	General Standards: Scope, Modeler Qualifications, Component Independence, Editorial Compliance Statistical Standards Computer Standards			
Key Results	Output Ranges			

The four major model component areas in Table 1 relate to frequency of hurricanes, the wind field, physical damage to structures exposed and the consequent insured losses expected. The specific model aspects listed directly below the four model component column headings are directly related to the respective areas. Logical relationships of hurricane characteristics require some consideration of the joint impacts of frequency and intensity. Several general standards have been developed that relate to all components of the model (personnel involved in the development of the model and their qualifications). Statistical and computer standards cross boundaries of the model as they are pervasive in the model development, implementation and testing/validation process. A key product from each modeler's annual submission is a set of tables of output ranges that provide average annual loss costs by county, structure type, and deductible limits. The output ranges receive a great deal of scrutiny throughout the review process as well as upon the ultimate acceptability of a model.

With this overview of the Commission standards process, some individual standards will be considered in more detail to address the key similarities and differences in models that have been evaluated and to demonstrate the transparency achieved through the review process. Standards from the general, meteorology, vulnerability, and actuarial areas will be considered in turn.

Discussion of General Standards

The scope of the computer model and its implementation is addressed in standard G-1 which states, "*The computer model shall project loss costs and probable maximum loss levels for personal lines residential property insured damage from hurricane events*." In auditing against this standard, the Commission identifies a series of disclosure items that mandate the modeler to reveal various aspects of their model. This standard provides the most transparent description of the model (at least the 30,000 foot view) and the Commission can insist on more detail as it deems appropriate by declaring incomplete or vague material as a deficiency that must be corrected prior to launching the on-site audits. The disclosure level of detail in the modeler submissions, from the overview in standard G-1 through the subsequent topical standards, has tended to increase, especially since 2000 when Applied Research Associates (ARA) entered the review process and again in 2007 with the participation of the Florida Public Hurricane Loss Model. Much of the basis of ARA's model has appeared in the open wind engineering literature to which it has contributed, although it must be emphasized that the Commission reviews the implemented model in depth—not relying solely on the existence of published papers which the submission may contend constitutes the model. The computer standards in particular provide the impetus in the audit to ensure that the implementation matches the model description in standard G-1.

Standard G-3 mandates that, "*ZIP Codes used in the model shall be updated at least every 24 months using information originating from the United States Postal Service*." Depending on the specific data source vintage (ZIP Codes are updated continuously by the USPS), the modelers can differ amongst themselves regarding specific ZIP Codes while meeting the Commission standards. For example, with population growth a coastal ZIP Code could be split into a new ZIP Code that is coastal and another that is entirely inland. If the old identifying number is identified with the new inland location, its population centroid in turn could change from being less than a mile from the coastline to possibly twenty or thirty miles inland. This change in location can have a considerable impact on hurricane risk and in turn, loss cost per $1000 exposure for various structure types. The audit requires consideration of population ZIP Code centroids, which are relevant in the absence of specified street-address exposure locations. ZIP Codes and population centroids are also relevant here since this is the resolution used by the Florida Hurricane Catastrophe Fund in basing insurance rates while preserving the proprietary nature of the modeler's calculations. Population centroids are surrogates for average ZIP Code location which is also appropriate for unknown or unspecified exposure location. All modelers are required to verify that the population centroid locations are meaningful (not over water, for example) which is a labor intensive task. In an ideal modeling world, one might prefer that individual exposures be "modeled" rather than pretending, as is done in some models, that residential structures within a ZIP Code are co-located at the centroid. For purposes of computational efficiency without loss of sufficient accuracy, centroids provide a viable simplification to the modeling process.

For the model to be coherent overall, it is imperative that the primary components be individually sound and operate independently. To this end, standard G-4, "*The meteorological, vulnerability, and actuarial components of the model shall each be theoretically sound without compensation for potential bias from the other two components.*" precludes artificial manipulation for empirical expediency. For example, a model that contained adjustments to the damage function to correct for possible inadequacies in the wind field would fail this standard.

Discussion of Meteorological Standards

Commission standards are *evaluative* rather than *prescriptive*—the Commission reacts to the models rather than dictating mathematical models used in components. With respect to the suitability of supporting data bases, however, the Commission specifies one data base in particular—namely the National Hurricane Center's Archive of Hurricane Seasons (HURDAT) data base to serve as the required, common basis for establishing annual frequencies of events. Deviations from HURDAT are allowed if the modeler can successfully provide support via an argument that relates to the currently accepted scientific literature and statistical techniques. The use of HURDAT replaced a long standing use of the official Commission historical storm set which was onerous to develop and to maintain and which potentially inhibited modelers from embarking on their own research efforts on historical events. Although all modelers now use HURDAT as a source data base for frequencies, their specific model implementations vary relative to the amount of subsequent "smoothing" used to fill in gaps with respect to hurricane intensity in coastal areas receiving little hurricane activity (e.g., northeast Florida) since 1900.

For hurricane characteristics beyond frequencies, consideration of hurricanes in other basins (eastern or western Pacific) can be used to improve estimation of hurricane characteristics (e.g., the relationship of radius of maximum winds to central pressure for very intense storms). Modelers take different approaches regarding the construction of the wind field and its transformation at the coast and over land. Simple wind fields trace their origins to NWS 23 (Schwerdt et al., 1979) and NWS 38 (Ho et al., 1987) while other alternatives draw on the more recent atmospheric science literature. Watson and Johnson (2004) survey a number of wind field models suitable for hurricane risk modeling (as well as friction models and damage functions).

As hurricanes approach the coast and make landfall, the loss of energy from the warm water source and friction effects owing to surface roughness weakens the intensity of storms. For the manner that this phenomena occurs, the modelers employ various approaches to incorporate these phenomena which is addressed in the meteorological standard M-5 on landfall and over-land weakening methodologies. In particular, for surface roughness, land use and land cover needs to be determined and an adjustment factor applied accordingly. Many possibilities for doing so exist, with the Commission open to those supported by appropriate geographic information system data. There is no "HURDAT" equivalent generally accepted source for this data so each modeler has developed its own internal methodology. In reviewing these models, the Commission looks at results from a third party (Kinetic Analysis Corporation) who generates land use/land cover data annually using satellite imaging methods. Impacts from wildfires or real estate development (converting forested land to smoother open terrain) are thus accommodated in the data base. The impacts on loss costs have been found to be significant for land use/land cover data that is not consistent with the more current terrain (Watson and Johnson, 2004), thus necessitating the importance of this standard.

Discussion of Vulnerability Standards

Standards related to damage (vulnerability) functions have historically contained the most proprietary aspects of the private computer models and need to be assessed during the professional team on-site audit and more recently, during Commission closed sessions. Development of damage functions is an expensive process which draws from historical data, tests (e.g., wind tunnel experiments), structural calculations, expert opinion and site inspections (post event).[8]

The effort that modelers expend related to vulnerability is clearly indicated during the audit process and in the closed session Commission meetings. The vulnerability area highlights the challenge that any modeler faces in differentiating its model based on value that is proprietary in nature. For example, Watson and Johnson (2004) showed that a simple cubic damage function performs similarly to the more sophisticated damage functions with respect to specific historical storm modeled versus actual losses. While this may refute Einstein's aphorism that models should be simple but not too simple, it does illustrate the challenge of using a more expensive and defendable proprietary process versus an approach that is inexpensive and widely available.

[8] Following hurricane events, modelers send their engineers to impacted areas to assess the losses both quantitatively (via surveys of roof damage, for example) and qualitatively (types of damage such as pool enclosures).

In developing vulnerability functions, modelers must consider mitigation factors (e.g., hurricane shutters and manufactured home tie-downs). Given the resources required to develop these factors the private modelers consider the impact of mitigation proprietary in nature. The Florida Public Hurricane Loss Model does provide explicit vulnerability functions which facilitate the public's understanding of damage functions. The mitigation efforts are an outgrowth of legislation passed during the 2005 legislative session which required property insurers to clearly notify policyholders at each renewal of premium discounts, credits, other rate differential, or reduction in deductibles for properties on which fixtures or construction techniques demonstrated to reduce the amount of loss in a windstorm can or have been installed or implemented.

Discussion of Actuarial Standards

Actuarial standards collect a number of conditions related to estimated insured losses following the determination of physical damage to structures. There are several standards involving basic requirements or restrictions to the actuarial component (e.g., expenses, risk loads, investment income, premium reserves, taxes, assessments and profit margin are not to be allowed in loss cost projections). In the audits, each model's actuary attests to the absence of these contributions which can be further audited through detailed examination of the computer model structure and code. Examination of user input forms to the model also provide assurance with regard to these matters.

Models differ with respect to the insurance data at their disposal and how the data is used for model development through validation. A model that does not have access to insurance exposure and loss data cannot meet the actuarial standards. One modeling company who initiated the review process eventually withdrew when it became apparent that data shortages could not be overcome. The Florida public model needed a special data call from the Office of Insurance Regulation to acquire the necessary data. For every model reviewed, the Commission investigates (primarily through the Professional Team) processes used in examining data from insurance companies that are involved in developing, refining and validating various functions used in model components. Exposure and claims data are notoriously messy and hence, the modelers expend considerable effort in processing it for developing specific model components or in validating the model with respect to historical loss data.

Demand surge (an increase in the cost of claims due to amplified payments following a hurricane or a series of hurricane events) became the basis for a standard in the 2006 Report of Activities with the recognition that data from the 2004 and 2005 hurricane seasons were sufficient to establish viable demand surge models. A standard A-4 on Demand Surge was created that states:

A. *Demand surge shall be included in the model's calculation of loss costs using relevant data;*

B. *The methods, data, and assumptions used in the estimation of demand surge shall be actuarially sound*.

Since the inclusion of the demand surge component in the Standards, the Commission has reviewed it in closed session.. Demand surge functions are analogous to vulnerability functions in that modelers invest resources in developing these functions and prefer to keep them proprietary. As there is little published literature on demand surge, the Commission continues to review modeler-specific depictions of demand surge. During the first year of reviews of demand surge in 2006, the Commission found that the five submissions met the demand surge standard A-4, but indicated that the modelers needed to incorporate the 2004 and 2005 hurricane seasons in the development and validation of the demand surge model. In other words, results from Hurricane Hugo (1989) and Hurricane Andrew (1992) were not sufficient for this component. The modelers complied during the review against the 2007 standards.

Additional living expense (ALE) relates to coverage for the extra costs of housing, dining expenses, and so forth up to the policy limits, in the event that a home becomes uninhabitable due to a covered loss. The specific Commission standard on ALE is A-9 and it states that:

A. The methods used in the development of ALE loss costs shall be actuarially sound;

B. ALE loss cost derivations shall consider the estimated time required to repair or replace the property;

C. The relationship between the modeled structure and ALE loss costs shall be reasonable, based on the relationship between historical structure and ALE losses;

D. ALE loss costs produced by the model shall appropriately consider ALE claims arising from damage to the infrastructure.

Modelers use insurance loss data as the basis for determining ALE. From a modeling standpoint, ALE is imbedded in the historical insurance data and this adds ever greater importance to the review of the modeler's handling of insurance data.

The output ranges mentioned in Table 1 are reviewed in the context of the actuarial standards. The logical relationships to risk are thoroughly examined; from the submissions themselves, maps of loss costs per thousand can reveal sensible sets of results (inland versus coastal counties, northern counties versus southern counties, and so forth). Even though the explicit creation of the loss costs is not available to the general public, the inter-relationships among submitted values can be assessed during the audit process.

While transparency is one of the key issues related to catastrophe modeling, there are times when the publicly available information in the submission is used incorrectly. For example, the output ranges require the reporting of low, high and a weighted average across ZIP Codes in a county for a given structure type and deductible. Drawing loss costs from two modelers from two different ZIP Codes in the same county (one low and one high for large deductibles) can generate very large percentage differences that provide little in the way of valid comparative value between these two models and yet this difference sometimes serves as the basis for criticism from parties outside the model review process (e.g., popular press or public policy makers).

Besides the forms that contain the output ranges, there are several forms that the modelers complete that provide additional insight as to model performance. Historical storms since 1900 that have affected Florida are simulated as individual storms and the total losses are accumulated (Forms A-3 and S-5 in the 2008 Standards) and compared to the modeler's long run simulation results. The correspondence of results gives an excellent indication of the extent of "smoothing" performed by the model as well as the inherent variability from year to year in the historical record. Whether we consider these forms or others required in the submission, in general, the results reported help to shed light on model performance and add transparency to the model review process.

Comments on the First and Subsequent Submissions

All of the standards and forms considered thus far are relevant to first time submissions and submissions from companies that have been reviewed in the previous year. The effort for the first submission is substantial. In the years following the initial review, the submission also is examined for year to year changes. These changes should reflect changes to the standards and to the model itself. The focus on modelers undergoing subsequent reviews is on the updates to the model. All standards are reviewed but particular attention is paid to changes to the model (i.e., improvements to reflect new developments, data sources or improved mathematical representations). Form A-7 calls for the percentage change in output ranges for a fixed exposure to be mapped by the modeler (and audited by the Commission). For modelers who require a second audit by the Professional Team prior to going before the Commission, this form is crucial for providing credence to the "final" version of the model.

Evolution of Standards

The previous section considered the Commission standards as a yearly snapshot (according to the 2008 Report of Activities). The standards have evolved since their original development in 1995-1997. Likewise in parallel, the models under review have become more sophisticated as the amount of data has expanded and methodologies have improved. Hurricane models have been updated and refined on a regular basis in response to changes in knowledge, technology, and the property insurance marketplace. Such changes have been attributable in part to:

1) Continual updating of historical hurricane data repositories operated by weather agencies such as The National Hurricane Center, which provides information relative to each hurricane affecting the Caribbean, the Gulf of Mexico, and the Atlantic coastline;
2) Improvements in the scientific knowledge relating to hurricanes;
3) Competition among modelers;
4) Advances in the engineering knowledge relative to building damageability and a greater volume of data on damageability from subsequent hurricanes;
5) Engineering site inspections following an expanded history of hurricane events, and the ability to compare modeled damage with actual storm damage as models have been tested against an increasing number of events;
6) Engineering tests of damageability from wind (i.e., wind tunnel tests);
7) Changes in building code requirements;
8) Added modeling requirements of public agencies reviewing hurricane models, such as the Commission or the Hawaii Division of Insurance;
9) The demand for more information by investment and insurance industry rating agencies such as A.M. Best, Standard and Poors, and Moody's;
10) The need for updating models to account for shifts in population densities in hurricane prone states; and
11) The development of new data sources and databases (e.g., additional claims data from the 2004 and 2005 hurricane seasons, and revised land use and land cover databases).

Summary and Conclusions

The use of computerized simulated hurricane models is accepted throughout the insurance industry. Hurricane catastrophe models are almost universally used by primary insurers and reinsurers, rating agencies and regulators, for ratemaking, risk analysis, catastrophic exposure and capacity management, reinsurance and catastrophe bond pricing, financial strength analyses, hazard mitigation analyses and other applications relating to the effects of hurricanes on properties.

For a model to be found acceptable, it must meet all of the standards established by the Commission. The acceptance of models by the Commission forms the basis of model reviews performed by other organizations around the country as well. This paper discusses the model evaluation process used by the Commission and provides insights into the key aspects of the auditing process. The paper also provides a review of the relevant catastrophe modeling literature published in insurance journals with a specific focus on the contributions appearing in the *Journal of Insurance Regulation*.

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