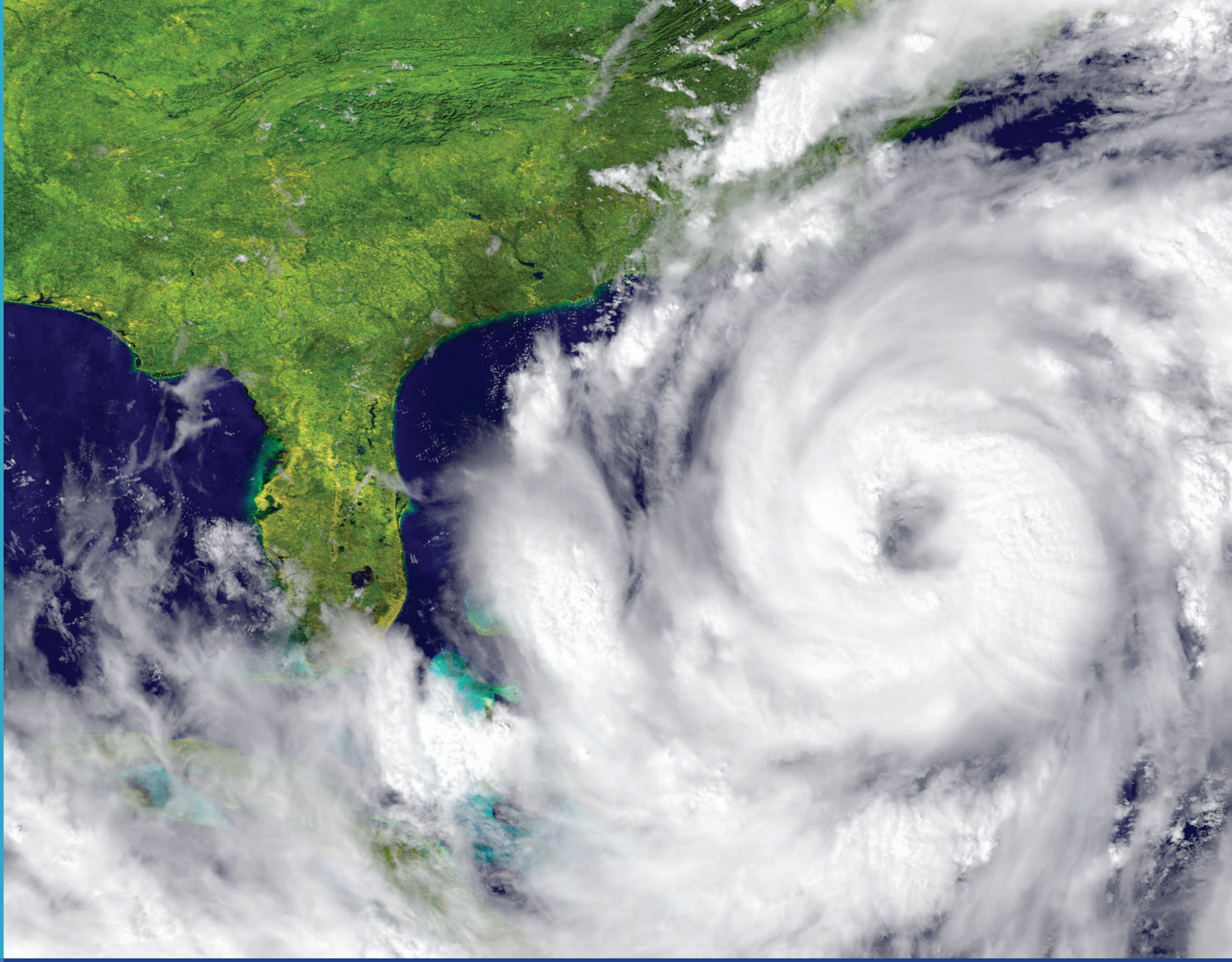

JULY 2018

USES OF CATASTROPHE MODEL OUTPUT

American Academy of Actuaries
Extreme Events and Property Lines Committee

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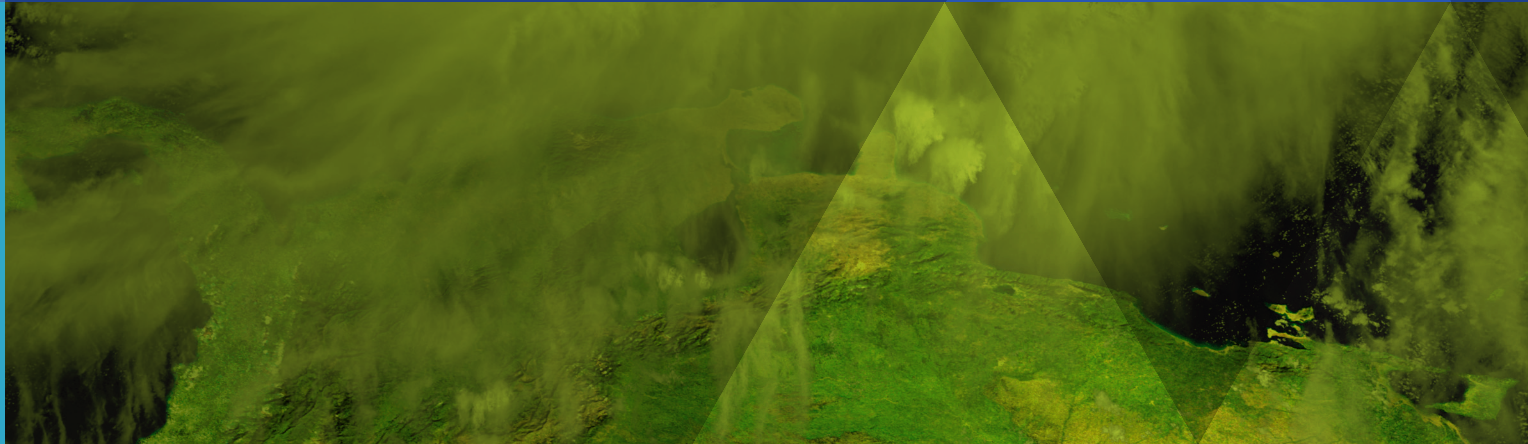

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The American Academy of Actuaries is a 19,000-member professional association whose mission is to serve the public and the U.S. actuarial profession. For more than 50 years, the Academy has assisted public policymakers on all levels by providing leadership, objective expertise, and actuarial advice on risk and financial security issues. The Academy also sets qualification, practice, and professionalism standards for actuaries in the United States.

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Executive Summary

Historical information is generally insufficient for predictions related to future catastrophes. As a result, catastrophe modeling—which is more accurate, stable, and flexible—has been developed. Catastrophe models have become an important element in actuarial practice. This paper reviews four basic uses: ratemaking, loss mitigation, risk selection, and reinsurance. The review uses four of the many possible events as illustrations: Hurricane Wind, Storm Surge, Inland Flood, and Tornado and Straight Line Wind.

As these models proliferate, various organizations have established requirements governing their use. American Academy of Actuaries members are required to follow applicable actuarial standards of practice (ASOPs)[1] as adopted by the Actuarial Standards Board. Regulatory and standard-setting bodies—most notably the Florida Commission on Hurricane Loss Projection Methodology and the National Association of Insurance Commissioners—have taken a lead in analyzing the appropriateness of catastrophe models.

Models dealing with different catastrophes have several similar components:

1. Probability of the particular catastrophe occurring;
2. Intensity of the catastrophe;
3. Corresponding damage; and
4. Allocation of loss amounts among the various impacted entities.

Each of these components becomes a module in a catastrophe model.

In the first module, a mathematical simulation with a large number of iterations is undertaken. The process produces probabilities of the event occurring, and is concerned with answering the question: What is the chance of this event occurring?

The second module concerns the intensity of the occurrence. It answers the question: What are event conditions (such as windspeed or water depth) inside the footprint (the area impacted by the event)?

The third module quantifies the impact of the event on the structures (and related property, such as building contents). It answers the question: How badly damaged is the insured structure?

1 Actuarial Standards Board; Actuarial Standards of Practice; available at http://www.actuarialstandardsboard.org.

The final allocates the damage among various parties (policyholder, insurance company, reinsurer) according to the terms of the insurance contract.

Models can be used in many applications. Common areas include ratemaking, risk selection, mitigation, and reinsurance. Expected losses, along with the associated volatility, are key building blocks in these and many other areas. Among other things, more accurate premiums can be determined, the potential benefit of mitigation features can be quantified, and changes to exposure characteristics and policy terms can be assessed.

Both state and federal public policymakers are using catastrophe models to address public policy issues. These efforts include analysis of the size of potential loss, the cost of a potential loss, appropriateness of territory and classifications, mitigation efforts, and insurance coverage modifications.

Catastrophe models offer many advantages compared to historical loss-based projections. Like any tool, understanding both their capabilities and shortcomings is of paramount importance.

Purpose

This paper is intended to provide an overview of how catastrophe models have developed and demonstrate how catastrophe model output can be used in selected actuarial tasks.

Much has been written about catastrophe models used for insurance. Modelers have published detailed information related to specific models including how they were developed and validated. High-level summaries have come out of the insurance sector's comparisons of output from model to model and to historical events. Practitioners have published papers highlighting and others discussing specific aspects of using model output for a given task. This paper was developed to help fill the gap between overviews and detailed description by describing some practical applications.

Catastrophe models were initially developed to address the shortcomings inherent in using historical data to project potential losses from infrequent, severe events that impacted many properties that were not geographically diverse. Knowledge about and acceptance of these models by risk-bearing entities and regulators have expanded along with the development of more and increasingly sophisticated models.

Model use has become required in many areas beyond those considered "traditional" areas of actuarial practice. These uses demonstrate the power and pervasiveness of models. Some of these are described in the Governance and Public Policy Uses section of this paper, while others have been espoused by the private market.

Also included are concrete examples of how expected losses and related metrics from catastrophe models can be used by private insurance companies, public policy experts, and others. Four basic use cases—ratemaking, loss mitigation, underwriting or risk selection, and reinsurance—are developed for four types of catastrophic events:

- Hurricane Wind (does not include tropical storms or Storm Surge)
- Flood: Storm Surge
- Flood: Inland
- Tornado and Straight-Line Wind (Tornado/SLW)

These types of events were selected as useful illustrations. Models also exist for many other causes of loss (earthquake, severe convective storm, wildfire, pandemic, etc.)

Appendices to this paper provide additional details on how the examples were developed.

Introduction

In perils where losses are dominated by reasonably predictable and frequent events, actuaries can use recent historical loss experience, adjusted for inflation and other appropriate changes, to estimate future losses. Where losses are infrequent events, such as those that arise from catastrophes, the available historical information may not be sufficient to reliably predict future loss potential. This problem has led to the development of sophisticated loss simulation models for perils such as hurricane, earthquake, and flood.

The actuarial profession has recognized the limitations of relying on historical data and has taken steps to incorporate model analyses into their work. Model development, expanding and enhancing their uses, and understanding their current and future potential contributions to analyses will continue for the foreseeable future.

History

Catastrophe modeling combines natural science with risk management practices, using computer power. Since the 1800s, property insurers have been visualizing exposure by mapping covered property. Likewise, scientists have been measuring wind speed and ground motion since the 1800s. In recent decades, many studies have been published asserting theories about the causes and expected frequency of natural disasters. "These two separate developments—mapping risk and measuring hazard—came together in a definitive way in the late 1980's and early 1990's" to create catastrophe models.[2] Increasing computer capabilities in that period were critical to model development.

Commercial modeling software was developed to estimate the potential cost of natural disasters. Initially, the use of these models was limited. However, in 1989, the $4 billion price tag for Hurricane Hugo and $6 billion for the Loma Prieta earthquake helped increase attention given to catastrophe models. In 1992, Hurricane Andrew ($15.5 billion) clarified the critical need to manage risk and the importance of catastrophe models. A few hours after Hurricane Andrew struck southern Florida, one of the modelers shared its real-time modeling estimate of $13 billion. Hurricane Andrew losses led to nine insurance company insolvencies.[3]

2 *Catastrophe Modeling: A New Approach to Managing Risk*; edited by Patricia Grossi and Howard Kunreuther; 2005.
3 Ibid.

The insurance industry's use of catastrophe models to estimate potential future catastrophe losses has gained momentum and has become a standard risk management practice. Several additional factors contributed to the advancement of the catastrophe models. The primary driver was the realization that commonly used actuarial methods relying on five to 25 years of historical catastrophe losses were inadequate for pricing and risk management. Combined with the substantial improvement in computing power and sophistication, models became the tool of choice for helping to manage catastrophic risk.

The continuing development and increasing reliance on catastrophe models is evidence of their value and suggests catastrophe models are here to stay and will continue to play an important role in measuring catastrophe risk.

Governance of Models

Catastrophe models have expanded into many areas of actuarial practice and are available for an increasing number of perils and potentially impacted regions. As the use of and reliance on catastrophe models has increased, the need for appropriate guidance and oversight has also increased. Various requirements have been established to govern the use of models. In addition, indirect oversight is occurring through scrutiny of models and model results by the business parties involved. Model analyses and output are required by various entities.

The American Academy of Actuaries and insurance regulatory bodies have developed requirements and guidance for actuaries in their development, use, and reliance on catastrophe models. Enterprise Risk Management (ERM), rating agencies, and state insurance regulators mandate certain model output to be provided for use in evaluation of risk-bearing entities. Reinsurers and capital markets rely on the standard language and definitions developed by modelers, and the output is key in designing products, defining terms, and negotiating costs. The reliance on model metrics creates an incentive for robust, current, and useful model results. While this is true for any tool used to manage risk, the level of financial impact and inability to ascertain the "right" answer result in application of additional scrutiny.

Actuarial Standards of Practice

All actuaries who are members of the U.S. actuarial organizations that have adopted the Code of Professional Conduct are required to follow actuarial standards of practice (ASOPs), which are established by the Actuarial Standards Board. The ASOPs provide guidance for what an actuary should consider, document, and disclose when performing an actuarial assignment. Actuaries may wish to review the applicability guidelines for assistance in determining standards of practice relevant to the task being performed. Specifically focused on catastrophe model use are:

- ASOP No. 38, *Using Models Outside the Actuary's Area of Expertise (Property and Casualty)*, provides guidance to an actuary in using models that incorporate specialized knowledge outside of the actuary's own area of expertise.
- ASOP No. 39, *Treatment of Catastrophe Losses in Property/Casualty Insurance Ratemaking*, indicates that an actuary should consider models based on noninsurance data when available historical insurance data does not sufficiently represent the exposure to catastrophe losses. In addition, this ASOP provides guidance for acceptable use of such models.

Florida Commission on Hurricane Loss Projection Methodology.

In the 1995 Florida Legislative session, the Florida Commission on Hurricane Loss Projection Methodology (FCHLPM) was created to evaluate hurricane models. "The Legislature specifically determined that reliable projections of hurricane losses for residential property insurance are necessary to assure rates are neither excessive nor inadequate, and that computer modeling has made it possible to improve upon the accuracy of hurricane loss projections."[4] The FCHLPM's remit was expended in 2014 to include the flood peril.

The FCHLPM publishes standards and related information in salient scientific disciplines as well as supporting activities such as software and security. The information submitted to the FCHLPM by the modeling firms is reviewed by an independent panel of experts. A company submitting a rate filing for residential property insurance in the state of Florida that relies on the results of a hurricane model is limited to those models that have been found acceptable by the FCHLPM. Several other states have interrogatories or questionnaires related to catastrophe models used in rate filing indications. Many of the states exposed to hurricanes request information about the FCHLPM review of any hurricane model used. Models that have been approved by the FCHLPM have been more likely to be found acceptable by other states than are non-FCHLPM accepted models.

4 Florida Commission on Hurricane Loss Projection Methodology website: www.sbafla.com/methodology.

The National Association of Insurance Commissioners

The National Association of Insurance Commissioners (NAIC), representing the nation's state, territorial, and possession insurance regulators, certifies insurance regulatory sections of state government as being in compliance with its model laws (through an accreditation process), which creates an incentive for local regulators to follow what the NAIC has adopted. One requirement is assuring that companies have sufficient capital to withstand adverse events. While the review and determination of financial stability is up to a company's domiciliary state regulator, the NAIC has published a property/casualty risk-based capital (RBC) formula that quantifies many of the risks facing companies and relates it to solvency levels. One of the factors in the formula is catastrophic losses, and probable maximum losses (PMLs) at specified levels are required as input to this formula. Model use and results are also required in the completion of an Own Risk and Solvency Assessment (ORSA), which is a key part of Enterprise Risk Management (ERM)—discussed in more detail below).

The NAIC also offers educational sessions related to various topics of interest, including catastrophe models. It has provided a list of questions state regulators might ask.

Insurance regulators and policymakers recognize the importance of promoting insurance markets and supporting the use of models when historical data is limited or non-predictive of the future. For example, in 2015 the Florida Legislature wanted to stimulate growth of private flood insurance as an alternative to the National Flood Insurance Program (NFIP). The Florida Legislature passed a statute allowing private insurance companies to write flood insurance, beyond what can be offered via the NFIP's Write-Your-Own program. The Florida Office of Insurance regulation continues to review flood product and rate filings; however, insurance companies can introduce flood coverage without sharing specific details about how the flood rates were determined. The statute indicates that in 2025, insurance companies will be required to submit details of their models. This illustrates a recognition by regulators of the importance of models and how the regulatory environment can stimulate insurance coverage for a product that insurers have been historically reluctant to write. As mentioned above, the FCHLPM is responsible for developing flood standards designed to assure regulators that the flood models being used are accurate and reliable.

Enterprise Risk Management

Enterprise Risk Management (ERM) is defined as "*[T]he discipline by which an organization in any industry assesses, controls, exploits, finances and monitors risks from all sources for the purpose of increasing the organization's short- and long-term value to its stakeholders.*"[5]

Companies are becoming increasingly aware of the need for systematic evaluation of the risks faced. ERM is useful for any enterprise and is not limited to insurance-related entities. Many companies have departments dedicated to evaluation of risk. Such evaluations for property/casualty insurance companies often rely heavily on catastrophe models. Simulations can increase a company's understanding of the range of possibilities, concentration of risk, exposure overall, and the impact of any risk-transference mechanisms. The importance of catastrophe models in assessing an insurance company's risk is substantiated by rigorous use of models by reinsurers and rating agencies. The reinsurers' and rating agencies' reliance on such models also provides a form of governance of the models used, since more useful models provide superior understanding of catastrophic risk.

As catastrophe models continue to develop and their use expands and deepens, direct and indirect requirements and influences are likely to become more sophisticated.

5 Actuarial Standard of Practice No. 46, *Risk Evaluation in Enterprise Risk Management.*

Model Overview and Components

While each peril model reflects multiple factors specific to the peril being modeled, catastrophe models have similar components:

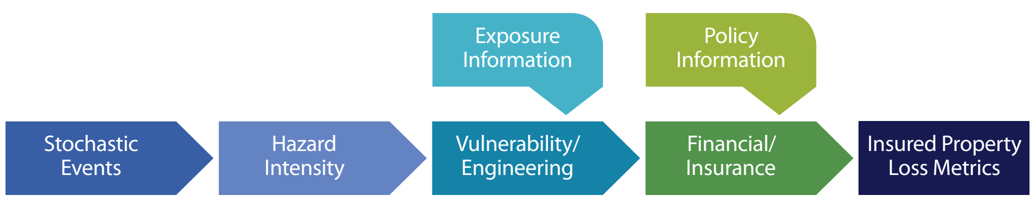
Stochastic Event Generation. Contains event information generated by the model, including probability of occurring (known as event rate), or the sequence of the event within the simulated year.

Hazard/Local Intensity. Local intensity of the event; what conditions are inside the event footprint. For example, inundation depth of a flood, wind speed of a hurricane, or ground movement accelerations of an earthquake.

Vulnerability/Engineering. How the intensity impacts the structure and contents. The salient structure characteristics are specific to a peril, although some (such as the age of a building) are likely to be applicable to many perils.

Financial/Insurance. How the loss is allocated among those responsible for payment. Applies the insurance contract terms to the loss, assigning portions of the amount to policyholders (via deductibles), insurance, and reinsurance companies.

The modules listed proceed sequentially. Each module creates data. Some key information is passed on to the next module to enable the process to continue. Some module output is useful on its own for validation and other purposes. The flowchart below illustrates how the model components interact.



The first stage of catastrophe modeling is to generate a stochastic event set, which is a database of simulated events. The events follow logical scientific rules related to the type of event. Each event is characterized by a probability of occurrence (event rate) and geographic area affected. Thousands of possible event scenarios are simulated, based on realistic parameters and historical data, to probabilistically model what could happen in the future.

The hazard component of catastrophe models quantifies the severity of each event in a geographical area, once the event has occurred. An event footprint is generated, which is a spatial representation of hazard intensity from a specific event. For example, the model calculates the peak wind speeds at each location affected by the storm for hurricane wind.

Catastrophe models capture property vulnerability. Mean damage ratios (MDRs) are losses expressed as a percent of value, for a given hazard level (e.g., ground motion or wind speed) and location. These are the average percentages of damage that are expected for a structure with the characteristics input into the model. The uncertainty around the estimated property loss (sometimes referred to as secondary uncertainty) is often expressed in terms of a standard deviation or a coefficient of variation (CV). Standard deviations are used in the examples in this monograph.

Finally, a financial or insurance module quantifies the financial consequences of each event from various financial perspectives. The policy terms such as deductibles, limits, and reinsurance are applied to the damage from each insured property from the vulnerability model to calculate the allocation of the loss amount.

While some analysis settings can be selected by the user (such as whether demand surge will apply), most of the model workings have been developed by the modeling company scientists and can't be altered. Users must input information about the policies potentially impacted and characteristics about each property. Individual policies, groups of policies (termed portfolios), and subsets of portfolios can be analyzed.

Use Cases

This section gives explanations and numeric examples of how catastrophe model output can be used in several typical actuarial tasks. A hypothetical set of policies in the state of Florida was defined for use in this paper and used as input to a catastrophe model. Details on this portfolio of policies and on the model settings used can be found in the appendices.

Ratemaking. The annual cost of catastrophic events needs to be determined because most policy terms are for a year. Models generate Average Annual Loss (AAL) for each insured property. The cost of an insurance policy is comprised of AAL, expenses, and risk load. Appropriate reinsurance costs must be included, and their assignment to an expense category depends on what those costs consist of and how they are treated by the primary company. The examples, which use a methodology chosen for its simplicity, does not include reinsurance costs. The risk load depends on the variability (i.e., standard deviation or CV) or uncertainty in the loss estimates. The premiums developed in this paper are for the catastrophe peril risk only and do not contemplate any non-catastrophe causes of loss.

Underwriting and Risk Selection. Nearly any property can be insured if an appropriate rate can be calculated and charged. However, an insurance company must consider the financial health of its entire book of business, and some risks are a better component for any given portfolio than others. In addition, companies typically specialize in types of property and/or geographic areas. So, while a price that is commensurate with expected loss is critical, there are other factors to be taken into consideration. The impact of adding a given property to what an insurer already has on its books depends not only on the individual property, but also on how that property's potential for loss interacts with existing policies. Measures such as Probable Maximum Losses (PML) are considered. A PML, also known as a Return Period Loss (RPL), gives two pieces of information—an amount and a probability. It is an amount that is expected to be exceeded with a given probability by an event or in a year. For example, a 100-year occurrence PML of $6 million ($6M) means that there is a 1-in-100 (1 percent) chance of a loss of at least $6M.

Loss Mitigation. Some characteristics that modelers have included have been shown to lessen the severity of loss. The impacts of these mitigation features can be evaluated by seeing how AALs and other measures react to the presence or absence of these features. Cost/Benefit tradeoffs can be evaluated. Strategies to encourage desired choices can be tied to potential loss dollar changes.

Catastrophe Reinsurance. Many insurance companies will themselves buy insurance (called catastrophe reinsurance) to assist in paying losses following a catastrophic event. In the case of a catastrophic event, insurance companies (primary insurers) are likely to quickly need large sums of money—more than what makes sense to accumulate. Because model output uses language and metrics that have become common among primary insurers, reinsurers, and others, transactions can be efficiently analyzed and terms agreed upon. Many reinsurers and reinsurance contracts are not focused on individual properties or everyday losses, but instead look at providing loss coverage to portfolios of policies. This allows primary companies to protect themselves from extreme events in accordance to their risk tolerance.

Ratemaking

Determine Rate Level

The ratemaking formula and assumptions used here are based on methods used by many property/casualty insurers. Simplifying assumptions have been made to facilitate understanding and highlight model output use. The price of insurance is based on the sum of three basic components. Companies may subdivide these three components and categorize the total premium in various ways. However, the basic principle is the same, which is to calculate the premium that is sufficient to cover expected loss, expenses, and risk load:

$$\text{Premium} = \text{AAL} + \text{Expense Load} + \text{Risk Load}$$

Catastrophe models are essential to calculate AAL and risk load. As noted above, AAL stands for Average Annual Loss; it is the expected loss per year, averaged over many years. AAL is calculated as the annualized cost of all potential stochastic events in a year:

$$AAL = \sum_i p_i L_i$$

Where: p_i is the annual probability of an event(i) occurring, and L_i is the expected loss of the event.

To adequately insure a risk, an insurer must commit a certain level of capital beyond the expected annual loss to cover the potential for catastrophic loss. This risk load should be sufficient to cover the cost of capital including a profit provision. Because catastrophe risk is volatile, the risk load can be multiples of AAL. The higher the volatilities, the higher the likelihood of insolvency, therefore the higher the risk load. There are different ways to develop the risk load. The standard deviation of the modeled losses (σ) is commonly used.

$$\sigma = \sqrt{\sum_i (p_i L_i^2) - AAL^2}$$

Table 1 shows the rate per $1,000 of building coverage for our portfolio of hypothetical policies for hurricane wind losses. It is shown as AAL / $1,000 building coverage. Tables 2, 3, and 4 show the same information for Tornado/Straight-Line Wind, Inland Flood, and Coastal Storm Surge. Nine counties in Florida and the entire state are shown to illustrate the potential variation of the costs. Insurance companies may use higher resolutions such as ZIP code or smaller grids in a rating plan to recognize the variations in the results.

The 27 percent expense load used in this example was judgmentally selected. An average building coverage limit of $207,500 is used in developing premium examples. The risk load is presumed to include a provision for profit.

TABLE 1 Hurricane Wind Rate and Premium Example

County	Modeled Gross Hurricane Wind Loss$ Per $1000 Cov A	Selected Risk Load (Standard Deviation)	Expense Load $	Hurricane Wind Premium $ Per $1000 Cov A	Hurricane Wind Premium $ for $207.5K Cov A Home
(A)	(B)	(C)	(D) = ((B)+(C))/.73-((B)+(C))	(E) = (B)+(C)+(D)	(F) = (E) * 207.5
Monroe	13.82	27.65	15.34	56.81	11,788.23
Broward	5.54	11.08	6.15	22.77	4,723.82
Palm Beach	5.26	10.51	5.83	21.60	4,482.44
Miami-Dade	7.60	15.21	8.44	31.25	6,484.54
Hillsborough	0.75	1.51	0.83	3.09	641.70
Orange	0.36	0.72	0.40	1.48	306.28
Okeechobee	1.91	3.81	2.11	7.83	1,624.67
Duval	0.25	0.49	0.27	1.01	209.96
Sarasota	1.74	3.48	1.93	7.14	1,481.68
Statewide	2.64	5.29	2.93	10.86	2,253.96

TABLE 2 Tornado/Straight-Line Wind Rate Premium Example

County	Modeled Gross Tornado/Straight-Line Wind Loss$ Per $1000 Cov A	Selected Risk Load (Standard Deviation)	Expense Load $	Tornado/Straight-Line Wind Premium $ Per $1000 Cov A	Tornado/Straight-Line Wind Premium $ for $207.5K Cov A Home
(A)	(B)	(C)	(D) = ((B)+(C))/.73-((B)+(C))	(E) = (B)+(C)+(D)	(F) = (E) * 207.5
Monroe	0.02	0.01	0.01	0.05	9.76
Broward	0.06	0.03	0.04	0.13	27.52
Palm Beach	0.08	0.04	0.04	0.16	33.49
Miami-Dade	0.06	0.03	0.03	0.12	24.84
Hillsborough	0.17	0.08	0.09	0.34	71.14
Orange	0.20	0.10	0.11	0.41	85.57
Okeechobee	0.13	0.06	0.07	0.26	54.25
Duval	0.16	0.08	0.09	0.32	67.18
Sarasota	0.13	0.06	0.07	0.26	53.90
Statewide	0.14	0.07	0.08	0.28	58.92

TABLE 3 Inland Flood Rate and Premium Example

County	Modeled Gross Inland Flood Loss$ Per $1000 Cov A	Selected Risk Load (Standard Deviation)	Expense Load $	Inland Flood Premium $ Per $1000 Cov A	Inland Flood Premium $ for $207.5K Cov A Home
(A)	(B)	(C)	(D) = ((B)+(C))/.73-((B)+(C))	(E) = (B)+(C)+(D)	(F) = (E) * 207.5
Monroe	0.18	0.28	0.17	0.63	131.29
Broward	0.65	0.98	0.61	2.24	465.14
Palm Beach	0.56	0.84	0.52	1.92	398.48
Miami-Dade	0.97	1.45	0.90	3.32	687.94
Hillsborough	0.25	0.38	0.23	0.86	178.72
Orange	0.40	0.59	0.37	1.36	281.65
Okeechobee	1.02	1.53	0.94	3.48	722.78
Duval	0.69	1.03	0.64	2.36	489.99
Sarasota	0.15	0.23	0.14	0.52	107.20
Statewide	0.59	0.89	0.55	2.04	422.64

TABLE 4 Storm Surge Rate and Premium Example

County	Modeled Gross Storm Surge Loss$ Per $1000 Cov A	Selected Risk Load (Standard Deviation)	Expense Load $	Storm Surge Premium $ Per $1000 Cov A	Storm Surge Premium $ for $207.5K Cov A Home
(A)	(B)	(C)	(D) = ((B)+(C))/.73-((B)+(C))	(E) = (B)+(C)+(D)	(F) = (E) * 207.5
Monroe	2.05	3.08	1.90	7.02	1,457.25
Broward	0.32	0.48	0.30	1.10	227.97
Palm Beach	0.05	0.07	0.04	0.17	34.25
Miami-Dade	0.23	0.34	0.21	0.79	162.97
Hillsborough	0.07	0.10	0.06	0.23	47.10
Orange*	—	—	—	—	—
Okeechobee*	—	—	—	—	—
Duval	0.70	1.05	0.65	2.40	498.68
Sarasota	0.26	0.39	0.24	0.89	184.26
Statewide	0.27	0.40	0.25	0.91	189.01

*These counties are inland, and not exposed to coastal storm surge.

Determine Risk Relativities and Rating Factors

An insured risk's potential insured loss propensity in a catastrophic event varies by many factors, including geographic location, physical characteristics of the building, and policy terms. Catastrophe models can be used to determine the impact of each rating factor, such as construction, year built, occupancy, and territory relativities.

Deductible Relativities

A deductible is the amount "deducted" from an insured loss before payment is made. Deductibles have been an essential part of insurance contracts for many years and are a sharing of the risk between the insurance company and the policyholder. When repairing a damaged home or replacing personal possessions, the amount of the deductible would come out of policyholder's own pocket.

Deductible relativities can be estimated by models using gross losses (loss after application of the deductible) divided by ground up losses (total amount of loss without any adjustments).

$$\text{Deductible loss elimination ratio} = 1 - (\text{Gross Loss}/\text{Ground Up loss}).$$

Deductible relativity examples for 2 percent deductibles for Hurricane Wind, Tornado/Straight-Line Wind, Inland Flood, and Storm Surge are shown in tables 5 through 8. Two percent deductibles are standard in Florida for hurricane wind and are shown here for the other perils for comparison.

For hurricane wind deductible relativities in Table 5, non-coastal counties, such as Orange and Okeechobee, have higher deductible loss elimination ratios than coastal counties. This is because coastal regions experience higher wind speeds and losses are more likely to be severe, so deductibles tend to be a smaller portion of the overall loss. Because inland counties' hurricane wind losses are likely to be lower, deductibles tend to be a higher percentage of overall loss.

TABLE 5 Hurricane Wind Deductible Loss Elimination Ratio

County	Avg Hurricane Wind Ground Up AAL $	Avg Hurricane Wind Gross AAL $ @2% Deductible	2% Deductible Hurricane Wind Loss Elimination Ratio
(A)	(B)	(C)	(D) = 1-(C)/(B)
Monroe	3,577.20	2,868.47	19.8%
Broward	1,704.98	1,149.46	32.6%
Palm Beach	1,636.70	1,090.73	33.4%
Miami-Dade	2,190.53	1,577.90	28.0%
Hillsborough	365.76	156.15	57.3%
Orange	274.57	74.53	72.9%
Okeechobee	796.42	395.34	50.4%
Duval	182.22	51.09	72.0%
Sarasota	629.12	360.54	42.7%
Statewide	885.65	548.46	38.1%

TABLE 6 Tornado/Straight-Line Wind Deductible Loss Elimination Ratio

County	Avg Tornado/ Straight-Line Wind Ground Up AAL $	Avg Tornado/ Straight-Line Wind Gross AAL $ @2% Deductible	2% Deductible Tornado/Straight-Line Wind Loss Elimination Ratio
(A)	(B)	(C)	(D) = 1-(C)/(B)
Monroe	5.56	4.75	14.6%
Broward	15.80	13.39	15.2%
Palm Beach	18.98	16.30	14.1%
Miami-Dade	14.28	12.09	15.4%
Hillsborough	40.24	34.62	14.0%
Orange	47.58	41.64	12.5%
Okeechobee	29.64	26.40	10.9%
Duval	37.39	32.70	12.6%
Sarasota	30.27	26.23	13.4%
Statewide	33.00	28.67	13.1%

TABLE 7 Inland Flood Deductible Loss Elimination Ratio

County	Avg Inland Flood Ground Up AAL $	Avg Inland Flood Gross AAL $ @2% Deductible	2% Deductible Inland Flood Loss Elimination Ratio
(A)	(B)	(C)	(D) = 1-(C)/(B)
Monroe	55.37	38.34	30.8%
Broward	172.41	135.82	21.2%
Palm Beach	148.83	116.36	21.8%
Miami-Dade	250.88	200.88	19.9%
Hillsborough	64.38	52.19	18.9%
Orange	101.51	82.24	19.0%
Okeechobee	269.06	211.05	21.6%
Duval	164.52	143.08	13.0%
Sarasota	40.17	31.30	22.1%
Statewide	151.07	123.41	18.3%

TABLE 8 Storm Surge Deductible Loss Elimination Ratio

County	Avg Storm Surge Ground Up AAL $	Avg Storm Surge Gross AAL $ @2% Deductible	2% Deductible Storm Surge Loss Elimination Ratio
(A)	(B)	(C)	(D) = 1-(C)/(B)
Monroe	469.04	425.52	9.3%
Broward	70.67	66.57	5.8%
Palm Beach	10.56	10.00	5.3%
Miami-Dade	50.50	47.59	5.8%
Hillsborough	15.38	13.75	10.6%
Orange	—	—	—
Okeechobee	—	—	—
Duval	159.58	145.62	8.8%
Sarasota	58.88	53.81	8.6%
Statewide	60.48	55.19	8.7%

Geographic Location Relativities

The propensity for catastrophe damage depends highly on geographic locations. Models can be used to determine the location relativities under various resolutions. The relative frequency and severity of events are critical to determining rating territories, rate levels, and underwriting/risk selection criteria. The granularity of the meaningful variation is different for the various perils. For example, storm surge damage is generally more severe for properties closest to the coast. However, depending on the elevation, the expected damage can be quite different for areas near each other. Table 9 shows the geographic relativities for selected counties in Florida for Hurricane Wind, Tornado/Straight-Line Wind, Inland Flood, and Coastal Storm Surge risks.

TABLE 9 Territory Relativities

County	Hurricane Wind Gross Avg AAL $	Hurricane Territory Relativities	Tornado/ Straight-Line Wind Avg Gross AAL $	Tornado/ Straight-Line Wind Territory Relativities	Inland Flood Avg Gross AAL $	Inland Flood Territory Relativities	Storm Surge Avg Gross AAL $	Storm Surge Territory Relativities
(A)	(B)	(C) = (B)/ Statewide(B)	(D)	(E) = (D)/ Statewide(D)	(F)	G) = (F)/ Statewide(F)	(H)	(I) = (H)/ Statewide(H)
Monroe	2,868.47	5.230	4.75	0.166	38.34	0.311	425.52	7.710
Broward	1,149.46	2.096	13.39	0.467	135.82	1.101	66.57	1.206
Palm Beach	1,090.73	1.989	16.30	0.568	116.36	0.943	10.00	0.181
Miami-Dade	1,577.90	2.877	12.09	0.422	200.88	1.628	47.59	0.862
Hillsborough	156.15	0.285	34.62	1.207	52.19	0.423	13.75	0.249
Orange	74.53	0.136	41.64	1.452	82.24	0.666	—	—
Okeechobee	395.34	0.721	26.40	0.921	211.05	1.710	—	—
Duval	51.09	0.093	32.70	1.140	143.08	1.159	145.62	2.638
Sarasota	360.54	0.657	26.23	0.915	31.30	0.254	53.81	0.975
Statewide	548.46	1.000	28.67	1.000	123.41	1.000	55.19	1.000

Underwriting and Risk Selection

Insurance premiums commensurate with risk are critical to a robust insurance market and to the continuing ability of companies to remain solvent and provide needed protection to policyholders. Besides the business need for accurate premiums, insurance premiums that reflect risk can inform individuals as to how safe or exposed they are and can promote mitigating behavior. Along with adequate rates, companies monitor how much business they write and their aggregate exposure to loss from extreme events. For catastrophic events, this can be critical because many properties may be damaged from one event. Insuring 1,000 homes around the state of Florida may not be problematic while insuring 1,000 homes in the coastal Miami-Dade area may expose the company to an unacceptable level of loss. Managing aggregate risk minimizes the risk of insolvency. In addition, minimizing the concentration of risk may help reduce reinsurance costs and limit the number of claims following an event to a manageable level.

Risk selection initially was used as a binary decision tool—a property was acceptable to insure based only on its characteristics, or it was not acceptable. Catastrophe models also allow a property to be evaluated based on its risk in the context of a company's entire book of business. In some cases, catastrophe models may also facilitate premium changes or coverage adjustments to make the premium commensurate with the associated risk. Rather than yes/no decisions, these coverage and premium adjustments allow previously uninsurable properties to obtain coverage. More accurate premiums can be determined and charged for all risks.

Loss Metrics for an Insured Property at an Individual Location

Underwriters and risk selection algorithms can use many metrics, or combinations of them, to provide additional information to help understand the risk for an individual insured property location. Models consider both environmental and building characteristic variables to provide information relevant to the property being reviewed. Companies may set up guidelines around various ranges of these metrics, with these ranges set based on the risk tolerance that the company has decided to follow. A few examples of these metrics are:

1. AAL/TIV: The ratio of the AAL to the Total Insured Value (TIV) provides a metric that shows the long-term risk at a location. This can be useful in evaluating how properties that are close geographically can have significantly different expected losses AAL. Some examples are given in the tables that follow. Because all our hypothetical policies have been defined as having the same TIV, the division to put our metrics on a comparable basis is not needed.

Tables 10 through 13 demonstrate the importance of accurate detailed geographic information. For each catastrophic peril, ZIP-level AALs vary significantly from state-level, and location-level information within a ZIP also varies. This can be helpful in determining, for example, how large rating territories should be. In the tables below, Inland Flood and Storm Surge show the widest ranges of AAL values, compared to Tornado/Straight-Line Wind. One possible conclusion could be that differentiating Tornado/Straight-Line Wind loss potential by territory does not add much value. Inland Flood loss potential appears to be concentrated in fewer than a third of the locations within one ZIP code. Comparing this information to a map would be informative and could provide additional information besides proximity to a water source.

Other metrics besides AAL provide more depth, and it should be emphasized that relying solely on information such as that shown in the tables is not recommended. In addition, the ZIP codes shown below were selected to illustrate the variability among loss costs.

TABLE 10 **Hurricane Wind AAL**

ZIP Code	# Locations	Average AAL	Lowest AAL	Highest AAL
(A)	(B)	(C)	(D)	(E)
32327	121	$156.83	$85.20	$505.54
All (Statewide)	100,000	$885.65	$61.07	$5,931.26

TABLE 11 **Inland Flood AAL**

ZIP Code	# Locations	Average AAL	Lowest AAL	Highest AAL
(A)	(B)	(C)	(D)	(E)
32043	155	$218.86	$0.00	$9,927.00
32043	105 of the 155	$0.00	$0.00	$0.00
All (Statewide)	100,000	$151.07	$0.00	$21,632.46

TABLE 12 **Storm Surge AAL**

ZIP Code	# Locations	Average AAL	Lowest AAL	Highest AAL
(A)	(B)	(C)	(D)	(E)
34689	123	$403.51	$0.00	$4,708.26
34689	3 of 123	$0.00	$0.00	$0.00
All (Statewide)	100,000	$60.48	$0.00	$19,686.13

TABLE 13 **Tornado / Straight-Line Wind AAL**

ZIP Code	# Locations	Average AAL	Lowest AAL	Highest AAL
(A)	(B)	(C)	(D)	(E)
32534	79	$81.09	$75.11	$117.70
All (Statewide)	100,000	$33.00	$1.88	$157.78

2. PML/TIV ratio: The ratio of a PML at a specified return period, to the TIV gives an indication of the possible severity at a location. Combining this view with locations that have similar AAL/TIV ratios gives an indication of the variability of risk at a location.

Hurricane wind example: Here are two locations from different parts of the state with similar AALs but different 250-year PML/AAL ratios. As this example shows, a location in ZIP code 32053 has a slightly higher AAL, but the PML for ZIP code 32311 has a PML that is 20 percent larger (suggesting higher loss potential from extreme events).

TABLE 14 **Hurricane Wind PML/TIV**

ZIP Code	AAL	250-year PML	PML / AAL
(A)	(B)	(C)	(D)
32053	$98.16	$5,024.54	51.19
32311	$91.88	$6,025.14	65.58

Portfolio Metrics

It can be instructive to see how adding or removing a property affects PML for a book of business. A property could have a relatively high AAL, but if it's in an area with low concentration in the current book, and doesn't impact the total book's PML and resulting reinsurance costs, the property could still be acceptable to an insurer, especially if capital allocated to writing property insurance is limited. Another way that some companies do this is to review their Tail Value at Risk (TVaR). Like the PML process, a company may review its TVaR to see if adding locations has a significant impact on the tail/extreme risk at various return periods.

An extension of the process described above is portfolio optimization. In this process, the insurance company chooses the modeled metric that is important to it, and then builds a geographically distributed portfolio that optimizes that metric relative to premium or insurance values (exposure). For example, if a company has the capital allocated to be able to write $100 million in premiums in a state, it may design a portfolio that minimizes a specified return period PML (like a 100-year PML).

Consider two separate insurance carriers in a state having similar 100-year PMLs, even though they have very different distribution of risk across the state. Both are considering acquiring a portfolio of locations. However, given their different current distributions, the acquisition could cause significantly different marginal changes to their PMLs.

Mitigation

Mitigation involves efforts to prevent hazards from developing into disasters and to reduce the effects of disasters when they occur. There are many different types of mitigation efforts. Some apply to individuals and some to communities, and they can be structural (e.g., window shutters, flood levees) or nonstructural (e.g., land-use planning). In all these situations, catastrophe models can help quantify the costs and benefits.

In the case of an individual structure, mitigation decisions often occur when insurance for the home is purchased. As an example, consider a hypothetical homeowner in Monroe County, Florida, who is debating whether to install hurricane shutters on her home. From Table 1 in the Ratemaking section above, she would be considering a premium (based on the hypothetical portfolio) of $11,788 for hurricane wind coverage. A catastrophe model used to calculate the premium can also be used to explore the savings from installing shutters. The following table shows output of this analysis.

TABLE 15 **Hurricane Wind Shutter Impact on AAL**

County	Hurricane Wind Gross AAL $ Without Shutter	Hurricane Wind Gross AAL $ With Shutter	Hurricane Shutter Discount
(A)	(B)	(C)	(D) = 1-(C) /(B)
Monroe	2,872.35	2,479.14	13.7%
Broward	1,377.11	1,154.62	16.2%
Palm Beach	1,170.99	970.26	17.1%
Miami-Dade	1,732.43	1,459.86	15.7%
Hillsborough	169.17	131.77	22.1%
Orange	77.21	54.90	28.9%
Okeechobee	420.06	326.71	22.2%
Duval	53.94	39.41	26.9%
Sarasota	440.52	363.29	17.5%
Statewide	483.87	398.29	17.7%

Recalculating the premium to reflect the hurricane wind savings would proceed as follows:

AAL with savings = (Col C from Table 15, per thousand) + Risk Load Expenses (Col C from Table 1), loaded for expenses.

$$= ((2{,}479 / 207.50) + 27.65) / (1-0.27) = \$54.23 \text{ per thousand}$$

Compared to the calculated Hurricane Wind premium per thousand from Table 1 of $56.81, this results in savings of 4.5% (54.23/56.81 -1). The premium savings would be 0.045 x $11,788.23 = $534.

The company may decide to adjust loss elimination ratios (LER) and expenses for mitigated properties as well. To the degree expenses vary with claim costs, additional savings could be realized. LERs could be increased or decreased. Because there tend to be more minor losses than extreme losses, more relative weight would be in the LER.

A community can also use a catastrophe model to weigh public policy decisions. Because a model can easily be applied to groups of individual risks, it can help a community understand aggregate costs and benefits stemming from a widespread implementation of a mitigation effort (e.g., a building code change).

As part of its review, the Florida Commission on Hurricane Loss Projection Methodology requires catastrophe modeling firms to make extensive regular submissions which, among many other things, must include the modeling firm's measurement of various mitigation measures. A copy of the relevant table for the model used in this paper from the April 2017 submissions is shown in Appendix 2. The first few rows are reproduced here to demonstrate the high level of detail that a catastrophe model can provide policymakers. With aggregated calculations like those used in the individual case above, a community can use these rates to measure the effect of mitigation efforts on its housing stock.

Figure 1: Response to FCHLPM Form V-2

INDIVIDUAL MITIGATION MEASURES			PERCENTAGE CHANGES IN DAMAGE* (REFERENCE DAMAGE RATE - MITIGATED DAMAGE RATE) / REFERENCE DAMAGE RATE * 100									
			FRAME STRUCTURE					MASONRY STRUCTURE				
			WINDSPEED (MPH)					WINDSPEED (MPH)				
			60	85	110	135	160	60	85	110	135	160
	REFERENCE STRUCTURE		0	0	0	0	0	0	0	0	0	0
ROOF STRENGTH	BRACED GABLE ENDS		15.1%	14.6%	12.4%	9.9%	4.8%	13.6%	13.4%	11.6%	9.4%	5.9%
	HIP ROOF		19.0%	18.2%	15.5%	12.5%	6.2%	17.3%	16.8%	14.5%	11.9%	7.5%
ROOF COVERING	METAL		-8.7%	-8.6%	-7.3%	-5.7%	-2.7%	-8.1%	-8.3%	-7.1%	-5.6%	-3.4%
	ASTM D7158 CLASS H SHINGLES (150 MPH)		1.9%	1.9%	1.6%	1.2%	0.6%	1.7%	1.7%	1.5%	1.2%	0.7%
	MEMBRANE		-5.2%	-5.1%	-4.3%	-3.4%	-1.6%	-5.0%	-5.1%	-4.4%	-3.5%	-2.1%
	NAILING OF DECK	8d	1.9%	1.9%	1.6%	1.2%	0.6%	1.7%	1.7%	1.5%	1.2%	0.7%

Reinsurance

Reinsurance and other risk transfer mechanisms play a valuable role in the insurance market. The risk of insolvency increases for primary insurance companies when many policies are likely to have a claim at the same time. For many types of claims, the correlation between policies is low (e.g., slip-and-fall claims). However, catastrophes increase the likelihood of many claims in close geographic proximity occurring all at once. Primary insurance companies manage this exposure by transferring the risk to other parties. Other parties with less concentrated exposure (e.g., investors or reinsurers with worldwide portfolios) are in a better position to manage this risk. This process expands the capacity of the insurance market by adding capital and efficiently managing risk.

Reinsurance pricing for catastrophe losses relies heavily on model results. Clearly defined measures and terms facilitate communication and negotiation of contract terms between various parties.

For example, a catastrophe reinsurance contract may cover losses between the 100-year and 250-year PMLs for specific causes of loss. As stated earlier, a PML or Return Period Loss is an amount that is expected to be exceeded by an event with a given probability. Table I6 shows 100-year and 250-year PMLs for our hypothetical policies for each of our four causes of loss. The probabilities in column (B) are the reciprocals of the Return Period years, (e.g., 1.0% = 1 / 100 and 0.4% = 1 / 250.) The PMLs in columns (C) through (G), shown in millions USD, are the model-generated expected loss amounts. As shown in Table 16, there is a 1.0% chance of hurricane wind causing damage costing at least $1,315 million, and a 0.4% chance of hurricane wind causing damage of at least $1,902 million. As expected, lower probabilities are associated with higher PMLs. For our hypothetical group of policies, at the probabilities shown, Hurricane Wind is likely to cause the most severe loss, followed by Inland Flood, Storm Surge (Coastal Flood), and finally Tornado/Straight-Line Wind.

TABLE 16 **PML Amounts in $ millions by Peril**

Return Period	Probability	Hurricane Wind	Flood Inland	Flood Storm Surge	Tornado/ SLW	All Causes Combined
(A)	(B)	(C)	(D)	(E)	(F)	(G)
100-year	1.0%	1,315	202	97	37	1,458
250-year	0.4%	1,902	384	157	52	2,031

Although AALs are additive, PMLs are not. Note that the PML for All Causes Combined is less than the sum of the PMLs from each cause of loss. To illustrate why PMLs are not additive, consider the probability that a one in 100-year event occurs for each cause of loss. The probability that all causes have a one in 100-year event in the same year is much less than 1 percent; therefore, the sum of the one in 100-year PMLs is associated with a much longer return period.

A reinsurance company may decide to sell coverage for a loss of at least $1,315M up to $1,902M to a primary company for wind damage from hurricane wind. This layer can be evaluated based on the AALs and standard deviations. Reinsurance pricing discussions often begin with the AAL plus a factor times the standard deviation for the layer. The factors used vary over time and under differing circumstances, but for a given layer at a fixed point in time, factors from similarly exposed companies and/or similar market conditions can serve as useful benchmarks.

Table I7 shows AALs, standard deviations, and coefficients of variation for the 100-year PML to the 250-year PML layer for the same causes of loss as in Table 16. The probability of reaching an amount of loss that activates the reinsurance coverage, called the layer retention, is 1.0 percent, and the probability of a loss using the entire layer, known as hitting the layer limit, is 0.4 percent.

TABLE 17 **Layer Statistics for 100- to 250-year PML**

	Hurricane Wind	Flood Inland	Flood Storm Surge	Tornado/ SLW	All Causes Combined
(A)	(B)	(C)	(D)	(E)	(F)
AAL in layer 100-year to 250-year	3,412	248	161	0	3,821
Standard Deviation in layer 100-year to 250-year	39,649	8,385	2,652	0	43,441
Coefficient of Variation 100-year to 250-year layer	11.6	33.8	16.5	na	11.4

Table 18 adds a layer covering expected losses in the 250-year to the 500-year return periods. Note that as the probability of loss to a layer decreases, the AAL also decreases and the coefficient of variation increases. This makes intuitive sense by recognizing:

- the probability of a loss in the 100- to 250-year layer return period is 1.0 percent;
- the probability of a loss in the 250- to 500-year layer return period is 0.4 percent; and
- layers with less frequent occurrences are less predictable, thus, volatility is higher.

TABLE 18 **Layer Statistics for 100- to 250- and 250- to 500-year PMLs**

	Hurricane Wind	Flood Inland	Flood Storm Surge	Tornado/ SLW	All Causes Combined
(A)	(B)	(C)	(D)	(E)	(F)
AAL in layer 100-year to 250-year	3,412	248	161	0	3,821
Standard deviation in layer 100-year to 250-year	39,649	8,385	2,652	0	43,441
Coefficient of Variation in layer 100-year to 250-year	11.6	33.8	16.5	na	11.4
AAL in layer 250-year to 500-year	1,348	35	64	0	1,448
Standard deviation in layer 250-year to 500-year	23,863	1,808	1,548	0	25,331
Coefficient of Variation in layer 250-year to 500-year	17.7	51.7	24.2	na	17.5

Reinsurance costs are often negotiated and can be influenced by market conditions. More judgment is applied to pricing reinsurance compared to primary coverage. Pricing and availability of coverage is information that is disseminated throughout the market. Catastrophe modeling provides an important source of quantitative information to evaluate risk and objectively evaluate reinsurance pricing. Moreover, catastrophe modeling provides quantitative information to financial markets in developing catastrophe bonds and other risk-linked securities.

Florida Hurricane Catastrophe Fund

Following Hurricane Andrew in 1992, the state of Florida created the Florida Hurricane Catastrophe Fund (FHCF) in a special legislative session to "provide a stable and ongoing source of reimbursement to insurers for a portion of their catastrophic hurricane losses; (to) create additional insurance capacity sufficient to ameliorate the current dangers to the state's economy and to the public health, safety, and welfare." (F.S. 215.555). The Fund operates as an independent state-run reinsurer for primary insurance companies selling residential property insurance in the state. Each company must participate in the Fund, but can select from various participation percentages. The Fund's capacity, retention, and limits are set by statute, and are adjusted annually based on specified Fund and market demographics. Statewide capacity was originally set to $17 billion for a hurricane season, and was later amended to include an additional $17 billion for a subsequent season, based on exposure growth and capacity.

The FHCF is required to use the results of all models found acceptable by the Florida Commission on Hurricane Loss Projection Methodology in determining the premiums charged to participants.

Public Policy and Catastrophe Models

The value of catastrophe models is recognized by public policymakers and those who provide them with analyses. As mentioned above, the Florida Hurricane Catastrophe Fund is required to use FCHLPM's approved models in its determining the premium it charges to participants.

On the federal level, the Congressional Budget Office's September 2017 study "The National Flood Insurance Program: Financial Soundness and Affordability"[6] made use of models in quantifying its analyses and conclusions. The Federal Emergency Management Agency is working with a private catastrophe modeling firm to "leverage a probabilistic modeling approach to assess the flood program's overall risk and potential payouts to property owners. The model will also be used to help the NFIP evaluate actuarially sound rates for its policies and to assess the impacts of major flooding events in real time."

All the use cases cited above, as well as many other applications, can inform public policy issues. Some policy questions that can be addressed include:

1. What is the probability of an event occurring that is too big for an entity to handle?
2. Do the premiums reflect an actuarially sound estimate of the expected value of all future costs associated with an individual risk transfer?
3. Have appropriate rating territories and classifications been identified?
4. Are there mitigation features that would reduce the costs to the entity in an advantageous cost/benefit way?
5. Are there reasonable coverage modifications (such as increasing deductibles) that could be useful?

Improvements in federal, statewide, and regional programs require the cooperation of several stakeholders. Objective quantification of potential losses can facilitate these efforts. Mitigation features, once identified and deemed feasible, can eventually become standards. One such example is the Insurance Services Office's Building Code Effectiveness Grading Schedule (BCEGS®).[7] Building codes and their enforcement can be considered in catastrophe models. For example, it was discovered that a significant amount of the damage from Hurricane Andrew could have been avoided if the building codes in effect had been more rigorously enforced. Hurricane models highlighted the pervasiveness of the issue, demonstrated the cost savings that could be generated, and facilitated decisions to improve building codes.

6 Congressional Budget Office; "The National Flood Insurance Program: Financial Soundness and Affordability"; September 2017.
7 ISO Mitigation; "What Determines a Municipality's Code Effectiveness Classification?"; Undated.

Advantages and Limitations of Historical Data and Catastrophe Models

Limitations of relying on historical data

1. Frequency and severity of catastrophe activity has not been constant over time. Climate conditions and sea surface temperatures, among other things, influence tropical cyclone activities. Although far better understood than in the previous century, there is still much that remains unknown about tropical cyclones. How much reliance is appropriate for data from past cycles and how long do those cycles tend to last? Damaging earthquake activity occurrence data is even sparser. The last major earthquakes in the New Madrid seismic zone happened in 1811 and 1812. Clearly, five to 25 years' experience is not nearly enough to evaluate the expected catastrophe costs.

2. In addition to limitations associated with historical frequency and severity, the attributes of historical events may be quite different from future events. Storm surge heights and the resulting damage from Hurricane Katrina, Hurricane Ike, Superstorm Sandy, and Hurricane Harvey were much greater than what would be expected from a surge estimation strictly tied to a wind event. Because this is a relatively recent recognition, historical records are unlikely to provide helpful experience that accurately separates wind and surge.

3. Geographical patterns and physical characteristics of the historical record do not reflect the full range of possible catastrophe events. Many areas may not have had any historical losses at all, but are clearly at risk. For example, a Texas 150-year experience period does not include a Category 5 hurricane. As a result, the frequency and severity of such an event would not be anticipated in the loss experience. Inland flood has catastrophic event potential across large areas, but there are usually specific places within those areas that experience a loss. Focusing on historical damage would overstate the loss potential in some areas and understate the potential in areas that are in very close proximity and equally likely to experience a loss.

4. Property distributions and characteristics have changed. Population has increased in high-risk areas near the coast, lakes, and rivers. Housing units have grown significantly in high-risk areas during the last few decades. Construction methods and building codes have changed. Modern building codes require wind- and water-resistive design elements that will reduce the likelihood of damage in the catastrophe. Historical

losses based on old exposure distribution can't be used without appropriate actuarial adjustments. Adjustments based on assumptions introduce more uncertainties to the process.

5. Many important property characteristics are not available in historical records. Expected catastrophe loss is highly dependent on a property's specific characteristics. Flood loss, for example, is affected by elevation, proximity to rivers or oceans, whether the building site is on the ground or on stilts, the bathymetry or contour of the ocean floors, the local flood mitigation features, etc. It is likely that two houses next to each other may have very different damage ratios from the same flood event due to their unique characteristics. This type of information may not have been collected in the past, and may not lend itself to reliable reconstruction.

6. Claim payment records may be limited or inaccurate and claim practices may have changed over time. In addition, exposure information related to the claim may not have been kept. Exposure information about properties exposed to loss but not damaged or having only negligible damage (especially below the deductible) may not be available. Understandably, claims adjusters focus on making policyholders whole following an event and may not be as meticulous as they might otherwise be in their documentation.

7. Information related to older events is not always reliable. Extreme events might have damaged or destroyed instruments. Events that occurred where the population was sparse or limited may have only the most general information recorded or may not have been noted at all. The exposure information related to the insured losses may not contain information that allows matching to claim payments, and, as noted above, exposure information for properties that did not suffer damage may not have been kept.

8. For these reasons and others, while historical data does bring valuable insight about catastrophe losses, it is insufficient in many cases to make proper projections for future catastrophe losses. This has led to extensive efforts to develop catastrophe models, which are a better alternative for estimating catastrophe losses.

Advantages of Using Catastrophe Models

Catastrophe models overcome the limitations of the historical records in several ways.

1. Catastrophe models simulate significantly more realistically plausible events than are contained in the historical record. Catastrophe simulation models use a database of scenario events that are designed to be comprehensive and realistic. The frequency of each event is calibrated to reflect the scientific view of the likelihood of that event. For example, if a coastal segment has experienced more Category 3 storms than category 4 or 5 storms, then the event database will take this into account. Category 3 storms would make up a bigger portion of the storms affecting the area in the model analysis. These event parameters are smoothed to minimize the gaps in the historical records. Similar scientific knowledge is incorporated into each of the model modules as appropriate.
2. Catastrophe models allow users to import and analyze the current exposure and settlement terms, therefore avoiding the pitfalls in adjusting historical experience to reflect changes in the number, types, and values of structures exposed to the hazard. The models can also account for changes in building practices, building code, and loss-mitigation features.
3. Catastrophe models are updated regularly and often. This enables catastrophe models to incorporate the most advanced science in meteorology, hydrology, seismology, statistics, and structural engineering into the models. Catastrophe models incorporate the most current information on land use/land cover, surface roughness, soil type, flood defense, flood control measures, ZIP code boundary, etc.
4. Catastrophe models allow the insurance industry to develop forward-looking views. It allows users to analyze "what if" scenarios to assess the impact of certain catastrophe risk management strategies.
5. Catastrophe models encourage sensitivity testing, which leads to more frequent and thorough testing. These analyses can provide valuable information about characteristics to investigate more thoroughly, provide additional viewpoints to consider, and stress-test scenarios.
6. There are several catastrophe models available to the insurance industry. Having several viewpoints can provide additional, valuable information related to risk management.

Limitations of Catastrophe Models

1. There are significant uncertainties around model estimates and large ranges of output values among different models. Many assumptions are involved in creating catastrophe models. A large range of output does not mean that any model is inaccurate or unreliable. The uncertainty is, to a large degree, expected, and its sources understood by actuaries. Uncertainties in alternate methods of estimating catastrophe damage are likely to be even larger and more difficult or impossible to quantify. However, a wide range of model output can cause concerns with consumers, regulators, and executives.
2. Collecting important building characteristics is not an easy task for an insurance company and may require a substantial financial output before any benefit is realized.
3. There may be damage or causes of loss that happen due to or concurrent with a catastrophic event that are not included in model output. These need to be treated separately. This is not usually problematic, but does emphasize the importance of understanding what the model assumptions are.
4. Model changes with software update can cause stability concerns. As science continues to evolve, and more data becomes available, modeling vendors have opportunities to incorporate new sciences and learnings into the models. As a result, the industry may experience large swings in the estimates from year to year. However, these changes are far smaller than what could happen when relying on historical experience.
5. Given the complexity of catastrophe models, using models requires either reliance on a company's reinsurance broker or other third party, or significant investment in training, software, and hardware to develop and maintain internal expertise.
6. While the technical documentation of the models is available to users for their general knowledge, some core assumptions are considered proprietary and are not readily accessible to users. A catastrophe model is developed by a group of scientists (meteorologist, seismologist, hydrologist, statisticians, engineers, actuaries, computer scientist, etc.) with specialized knowledge in different fields. It is not an easy task for model users to develop even a basic understanding of the model, as required by U.S. actuaries' standards of practice.[8]
7. Catastrophe models are tools to help insurers assess and understand catastrophe risks. Like other tools, catastrophe models have limitations. Due to the uncertainties discussed above, it is impossible and unrealistic to expect a catastrophe model to produce perfect answers. However, this is not a reason to discredit a modeling approach, as relying solely on historical records is less reliable.

8 ASOP No. 38, Op. cit.

Summary

Use of computer models to estimate catastrophe losses for the insurance industry has gained momentum and has become a standard risk management practice. Hurricane Andrew in 1992 highlighted the shortcomings of processes used up until that time and how those shortcomings could create problems for the industry. Hurricane and earthquake models were introduced first to the market, followed by severe convective storm, wildfire, flood, terrorism, and pandemics. Several factors contributed to the advancement of the catastrophe models. The primary driver was the realization that the unpredictability of catastrophe events and limitations of traditional actuarial methods that rely on five to 25 years' historical records were not adequate to plan for future extreme events. Combined with the substantial improvement in computing power and sophistication, models became the tool of choice for managing catastrophic risk.

This monograph is offered to provide the reader with an overview of how actuaries use catastrophe model output for various analyses. Examples based on defined exposure input for selected causes of loss provide insight into these applications and show uses of modeled output.

Appendix 1
Hypothetical Policies and Model Settings

Construction of Hypothetical Policies

We distributed 100,000 single-residential policies geographically throughout the state of Florida, representing approximately 1 percent of the market's policy count.[9] The 100,000 policies were assigned to ZIP codes in proportion to the population of that ZIP.[10] Random parcels within the ZIP were assigned to each policy that had been allocated to that ZIP. The building value for each structure is $207,500.[11] Appurtenant structure values were 10 percent of building value ($20,750); Contents coverage value was set to 50 percent of building value ($103,750); and Additional Living Expense was 20 percent of building coverage, or $41,500. Each policy had a 2 percent blanket deductible (2 percent of the sum of all coverages combined, applied against losses from all coverages combined). Note that Florida requires 2 percent of building value be offered, and that choice is virtually universal in the admitted market in that state.

Construction, year of construction, and foundation type were left as default values. No basement or NFIP coverage was assumed to exist.

Model Settings

CoreLogic's RQE (Risk Quantification and Engineering) catastrophe model was used to generate the metrics shown in the tables.

Settings were selected that are, in the authors' experience, typical for model use. The expected losses include potential impacts of demand surge. All residential property coverages were included: Building, Appurtenant Structures, Contents, and Additional Living Expense. Except where otherwise indicated, the expected losses are ground-up, occurrence losses.

9 SNL data
10 IRS data
11 Median value per Zillow.com

Appendix 2
2017 Florida Hurricane Mitigation Measures

INDIVIDUAL MITIGATION MEASURES			PERCENTAGE CHANGES IN DAMAGE* (REFERENCE DAMAGE RATE - MITIGATED DAMAGE RATE) / REFERENCE DAMAGE RATE * 100									
			FRAME STRUCTURE					MASONRY STRUCTURE				
			WINDSPEED (MPH)					WINDSPEED (MPH)				
			60	85	110	135	160	60	85	110	135	160
	REFERENCE STRUCTURE		0	0	0	0	0	0	0	0	0	0
ROOF STRENGTH	BRACED GABLE ENDS		15.1%	14.6%	12.4%	9.9%	4.8%	13.6%	13.4%	11.6%	9.4%	5.9%
ROOF STRENGTH	HIP ROOF		19.0%	18.2%	15.5%	12.5%	6.2%	17.3%	16.8%	14.5%	11.9%	7.5%
ROOF COVERING	METAL		-8.7%	-8.6%	-7.3%	-5.7%	-2.7%	-8.1%	-8.3%	-7.1%	-5.6%	-3.4%
ROOF COVERING	ASTM D7158 Class H Shingles (150 MPH)		1.9%	1.9%	1.6%	1.2%	0.6%	1.7%	1.7%	1.5%	1.2%	0.7%
ROOF COVERING	MEMBRANE		-5.2%	-5.1%	-4.3%	-3.4%	-1.6%	-5.0%	-5.1%	-4.4%	-3.5%	-2.1%
ROOF COVERING	NAILING OF DECK	8d	1.9%	1.9%	1.6%	1.2%	0.6%	1.7%	1.7%	1.5%	1.2%	0.7%
ROOF-WALL STRENGTH	CLIPS		17.8%	17.1%	14.6%	11.6%	5.8%	16.2%	15.8%	13.7%	11.1%	7.1%
ROOF-WALL STRENGTH	STRAPS		17.8%	17.1%	14.6%	11.6%	5.8%	16.2%	15.8%	13.7%	11.1%	7.1%
WALL-FLOOR STRENGTH	TIES OR CLIPS		4.6%	4.6%	3.9%	3.0%	1.4%	0.0%	0.0%	0.0%	0.0%	0.0%
WALL-FLOOR STRENGTH	STRAPS		4.6%	4.6%	3.9%	3.0%	1.4%	0.0%	0.0%	0.0%	0.0%	0.0%
WALL-FOUNDATION STRENGTH	LARGER ANCHORS OR CLOSER SPACING		0.0%	0.0%	0.0%	0.0%	0.0%	-	-	-	-	-
WALL-FOUNDATION STRENGTH	STRAPS		4.6%	4.6%	3.9%	3.0%	1.4%	-	-	-	-	-
WALL-FOUNDATION STRENGTH	VERTICAL REINFORCING		-	-	-	-	-	-	-	-	-	-
OPENING PROTECTION	WINDOW SHUTTERS	PLYWOOD	12.1%	12.0%	10.1%	7.9%	3.8%	11.0%	11.0%	9.4%	7.6%	4.7%
OPENING PROTECTION	WINDOW SHUTTERS	METAL	12.1%	12.0%	10.1%	7.9%	3.8%	11.0%	11.0%	9.4%	7.6%	4.7%
OPENING PROTECTION	DOOR AND SKYLIGHT COVERS		21.8%	20.6%	17.7%	14.3%	7.2%	19.9%	19.2%	16.6%	13.6%	8.7%
OPENING PROTECTION	WINDOW	IMPACT RATED	10.6%	10.5%	8.9%	7.0%	3.3%	9.7%	9.8%	8.4%	6.7%	4.1%
OPENING PROTECTION	ENTRY DOORS	MEETS WINDBORNE DEBRIS REQUIREMENTS	10.6%	10.5%	8.9%	7.0%	3.3%	9.7%	9.8%	8.4%	6.7%	4.1%
OPENING PROTECTION	GARAGE DOORS	MEETS WINDBORNE DEBRIS REQUIREMENTS	10.6%	10.5%	8.9%	7.0%	3.3%	9.7%	9.8%	8.4%	6.7%	4.1%
OPENING PROTECTION	SLIDING GLASS DOORS	MEETS WINDBORNE DEBRIS REQUIREMENTS	18.8%	18.0%	15.4%	12.3%	6.2%	17.3%	16.8%	14.5%	11.9%	7.5%
OPENING PROTECTION	SKYLIGHT	IMPACT RATED	13.8%	13.5%	11.4%	9.0%	4.4%	12.3%	12.2%	10.5%	8.5%	5.3%

MITIGATION MEASURES IN COMBINATION		PERCENTAGE CHANGES IN DAMAGE* (REFERENCE DAMAGE RATE - MITIGATED DAMAGE RATE) / REFERENCE DAMAGE RATE * 100									
		FRAME STRUCTURE					MASONRY STRUCTURE				
		WINDSPEED (MPH)					WINDSPEED (MPH)				
		60	85	110	135	160	60	85	110	135	160
STRUCTURE	MITIGATED STRUCTURE	27.2%	25.6%	22.0%	17.8%	9.1%	25.2%	24.0%	20.8%	17.2%	11.1%

* Note: Larger or closer spaced anchor bolts: not currently distinguished in the model, as other aspects are deemed more important; also difficult to ascertain vertical reinforcing for masonry walls: this feature is accounted for through the selection of the base structure; vertically reinforced masonry walls are considered by the CoreLogic model as Reinforced Masonry (RM).

The input one-minute sustained 10-meter wind speeds were assumed to be over-water and were converted to over-land peak gust wind speeds using the minimum direction-dependent roughness length for the ZIP Code centroid and the model's standard gust factor formulation.

Source: FCHLPM; CoreLogic

Appendix 3
Disclaimers

This paper is not intended to be an interpretation of the actuarial standards of practice and is not meant to be a codification of generally accepted or appropriate actuarial practice. Actuaries are not in any way bound to comply with this paper or to conform their work to the practices described herein.

The use of the CoreLogic RQE model does not imply any recommendation or preference of that model over any other model.

The results shown in this paper have been derived as described. While accurate based on the exposures and assumptions described here, they are not realistic quantifications of expected loss and are not meant to be used for any purpose other than illustration.

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