NAIC Catastrophe Modeling Primer

December 2024

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Purpose of the Primer and Background of Catastrophe Modeling

The purpose of the Catastrophe Modeling Primer (Primer) is to provide information to state insurance regulators needing a basic understanding of catastrophe modeling. The Primer's intention is not to be all-inclusive; instead, it suggests considering and exploring the areas and concepts that will help state insurance regulators better understand the basics of probabilistic catastrophe models. This type of model forecasts the statistical characteristics of possible results by considering the random variance in one or more parameters across time. The Primer does not take a position as to the ultimate soundness of probabilistic catastrophe models or the interpretation of the results derived from their use.

The Primer introduces the fundamental concepts surrounding probabilistic catastrophe models and serves as a bridge to available training and materials offered by the Catastrophe Model Center of Excellence (COE). Since the COE provides training in the more technical aspects of catastrophe modeling, the Catastrophe Insurance Working Group of the Property and Casualty Insurance (C) Committee (Working Group) created the Primer to introduce state insurance regulators to basic catastrophe modeling concepts. For more advanced training, sign up for the COE Catastrophe Modeling Course, [CAT 101: Introduction to Catastrophe Modeling].

The COE within the Center for Insurance Policy and Research (CIPR) maintains a neutral viewpoint to build insights from data in an unbiased manner. The COE provides state insurance regulators with technical training and expertise in catastrophe models and their use in the insurance industry. Additionally, the COE facilitates an insurance department's (DOI) access to catastrophe modeling documentation, education, and tools on the mechanics of commercial catastrophe models and the treatment of perils and risk exposures.

The guidance offered in this Primer is advisory only and is not intended for state insurance regulators to prescribe mandatory guidelines, standards, or guidance for rate review or other regulatory procedures; instead, it is intended to objectively discuss the issues and ramifications of catastrophe models. The Primer will be revised as necessary to incorporate new developments and provide additional guidance and information.

The Evolution of Catastrophe Modeling

While the inception of probabilistic catastrophe risk modeling materialized in the late 1980s, the use of catastrophe models to monitor risks became more widely accepted in the 90s.[1] Models for catastrophes were initially created to assist insurers in assessing infrequent yet expensive catastrophic events.[2]

Hurricane Andrew made landfall in South Florida in 1992, and the Northridge Earthquake occurred in Southern California in 1994. Both events led actuaries to recognize that probabilistic computer simulation models would help estimate probable maximum losses for these severe events.

Andrew was the costliest natural disaster in U.S. history as insurance payouts for damaged homes, vehicles, and businesses damaged by the storm in both Florida and Louisiana.[3] Hurricane Andrew established that calculations based strictly on historical losses underestimated the projected losses. Before Hurricane Andrew, insurers depended only on historical claims experience to assess possible losses. The wake-up call delivered by Hurricane Andrew introduced the birth and rapid evolution of complex catastrophe modeling.[3]

[1] Grossi, P. and TeHennepe, C. (2008) *RMS – A Guide to Catastrophe Modeling,* Informa. https://forms2.rms.com/rs/729-DJX-565/images/rms_guide_catastrophe_modeling_2008.pdf.
[2] https://www.rms.com/catastrophe-modeling?contact-us=cat-modeling
[3]Insurance Information Institute, Hurricane Andrew and Insurance: The Enduring Impact of an Historic Storm
[4]Office of Insurance Regulation: The Property Insurance Market in Florida 2004: The Difference a Decade Makes

Following Andrew's landfall, catastrophe modelers projected the insured losses could cost insurers as much as $13 billion. Insurers managing their risks based entirely on historical data did not believe $13 billion could be an accurate estimation. Once the final numbers came in, Andrew's actual cost totaled $15.5 billion.[3]

The excessive losses from Andrew contributed to the insolvency of several insurers, requiring surviving companies to inject new capital or consider leaving the Florida market. Additionally, some insurers were technically insolvent as they relied on their parent company to transfer funds to pay claims. As a result, insurance rates and deductibles abruptly increased. Insurers canceled insurance policies or chose not to renew them. Some insurers decided to no longer write policies in Florida. The prices charged by reinsurers also increased.[4]

The 1994 Northridge earthquake, which measured 6.7 in magnitude, was the strongest earthquake to ever occur in an urban area. It caused tens of billions of dollars in damage and losses of life. This earthquake was another major catalyst for the use of catastrophe modeling in the United States.[5] The Northridge earthquake marked the end of an approach to assessing earthquake risk in California that was strictly based on loss experience.

Hurricane Andrew and the Northridge earthquake transformed insurers' views of risk management. Andrew established a critical turning point in the Florida insurance market and the Northridge earthquake in the California insurance market. Both events encouraged the use of catastrophe modeling, which paved the way for a new standard.[6]

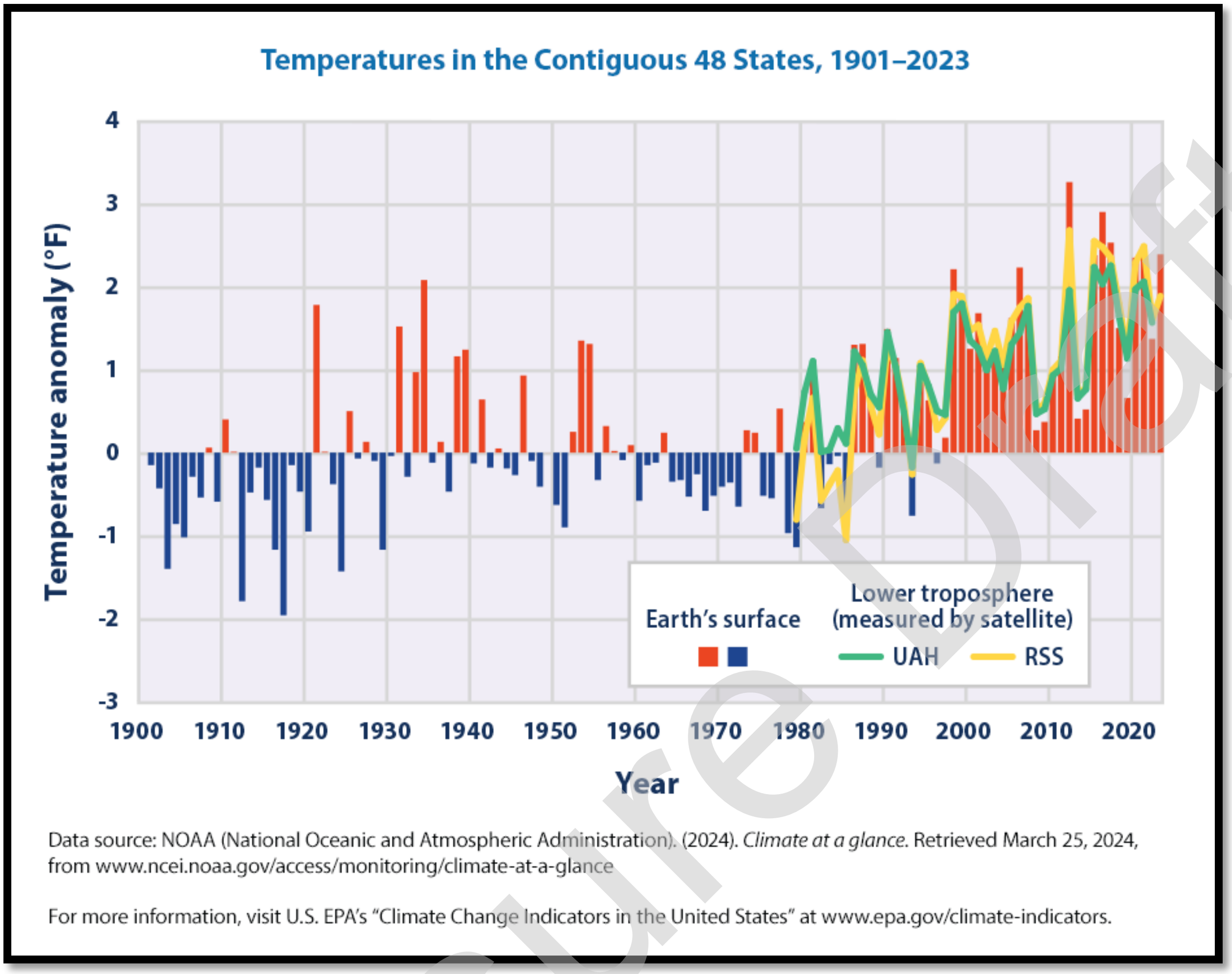
Observed Trends of Hazards and Losses

Hurricanes Ian, Katrina, and Harvey caused severe wind-driven and flood damage. Wildfires continue to grow more deadly due to rising temperatures and drought.

Since 1850, the Earth's temperature has increased by an average of 0.11 degrees Fahrenheit per decade, and the rate of warming has tripled since 1982. 2023 was the warmest year on record, and the ten warmest years have all occurred in the past decade.[7] The maps below in Figure 1 show how the annual average temperatures have changed throughout the decades.[8]

[3] https://www.insurancejournal.com/news/national/2022/06/01/669875.htm
[4] https://www.iii.org/sites/default/files/paper_HurricaneAndrew_final.pdf
[5] https://engineering.lehigh.edu/news/article/sharper-focus-catastrophe-modeling-0
[6] ibid
[7]https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature#:~:text=Highlights,0.20%C2%B0%20C)%20per%20decade
[8] https://www.noaa.gov/news/new-us-climate-normals-are-here-what-do-they-tell-us-about-climate-change

Figure 1.



Data source: NOAA (National Oceanic and Atmospheric Administration). (2024). *Climate at a glance*. Retrieved March 25, 2024, from www.ncei.noaa.gov/access/monitoring/climate-at-a-glance

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.

Wildfire

From 1983 to 2022, the National Interagency Fire Center recorded an average of 70,000 wildfires annually. The actual number of wildfires may have been even greater during the initial years nationwide data was collected, and the data does not show a clear trend during this time.[9]

Climate Central, an organization that conducts scientific research on the climate, recently studied weather records across the United States from 1973 to 2022, which showed that fire weather days have increased in numbers. This alarming trend is likely to continue due to rising temperatures and dry conditions, which increase the likelihood of more frequent and larger fires. Southern California, Texas, and New Mexico have seen some of the largest increases in annual fire weather days, with some areas experiencing about two more months of fire weather compared to 50 years ago[10].

In conjunction with increasing temperatures, the most dramatic impact due to wildfires has been observed mainly in the western and southwestern states.[11] Continued and increased development in the wildland-urban interface (WUI) across the country has led to increased frequency and costlier wildfires, tripling the

[9]https://www.epa.gov/climate-indicators/climate-change-indicators-wildfires#:~:text=The%20extent%20of%20area%20burned,have%20increased%20since%20the%201980s
[10] https://www.climatecentral.org/climate-matters/longer-more-intense-fire-weather-seasons
[11]https://www.dryad.net/post/understanding-the-wildland-urban-interface#:~:text=The%20expansion%20of%20the%20wildland,proximity%20with%20wildfire%2Dprone%20areas.

length of the wildfire season and causing more destructive fires.[12] While wildfire is considered a "natural disaster," 85-90% of wildfires occurring nationwide are caused by humans.[13] At any rate, no matter the cause of a fire, the increase in hot, dry, and windy conditions impacts the availability of materials that can burn, influencing how fire ignites, lasts, and spreads, and may hinder actions to control it.[14]

Figure 2 below depicts the number of billion-dollar wildfires for select time periods.

Figure 2

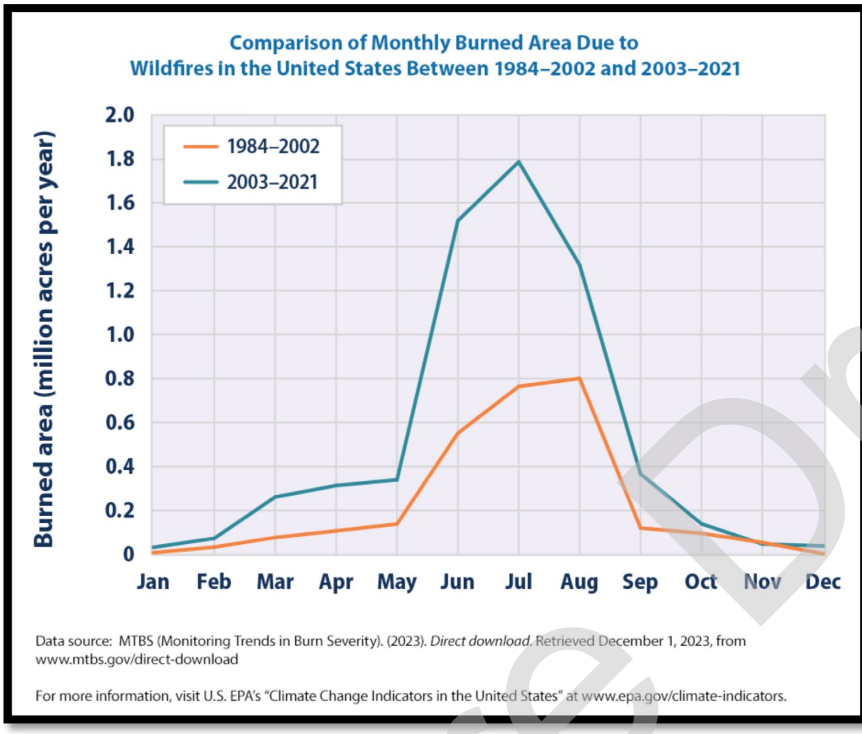
Select Time Period Comparisons of United States Billion-Dollar Wildfire Statistics (CPI-Adjusted)

Time Period	Billion-Dollar Disasters	Events/Year	Cost	Percent of Total Cost	Cost/Year	Deaths	Deaths/Year
1980s (1980-1989)	0	0.0	$0.0B	0%	$0.0B	0	0
1990s (1990-1999)	4	0.4	$13.8B	9.5%	$1.4B	46	5
2000s (2000-2009)	7	0.7	$20.6B	14.1%	$2.1B	109	11
2010s (2010-2019)	7	0.7	$70.5B	48.3%	$7.1B	209	21
Last 5 Years (2019-2023)	5	1.0	$46.5B	31.9%	$9.3B	174	35
Last 3 Years (2021-2023)	3	1.0	$21.1B	14.5%	$7.0B	125	42
Last Year (2023)	1	1.0	$5.7B	3.9%	$5.7B	100	100
All Years (1980-2024)	**22**	**0.5**	**$145.9B**	**100.0%**	**$3.2B**	**535**	**12**

[12] https://www.epa.gov/climate-indicators/climate-change-indicators-wildfires
[13]https://wfca.com/wildfire-articles/are-wildfires-natural-disasters/#:~:text=Although%20not%20all%20wildfires%20are,a%20result%20of%20human%20activity.
[14] https://www.climatecentral.org/toolkit-wildfire

Figure 3 below compares the difference in the amount of burned acres between certain time periods.

Figure 3.



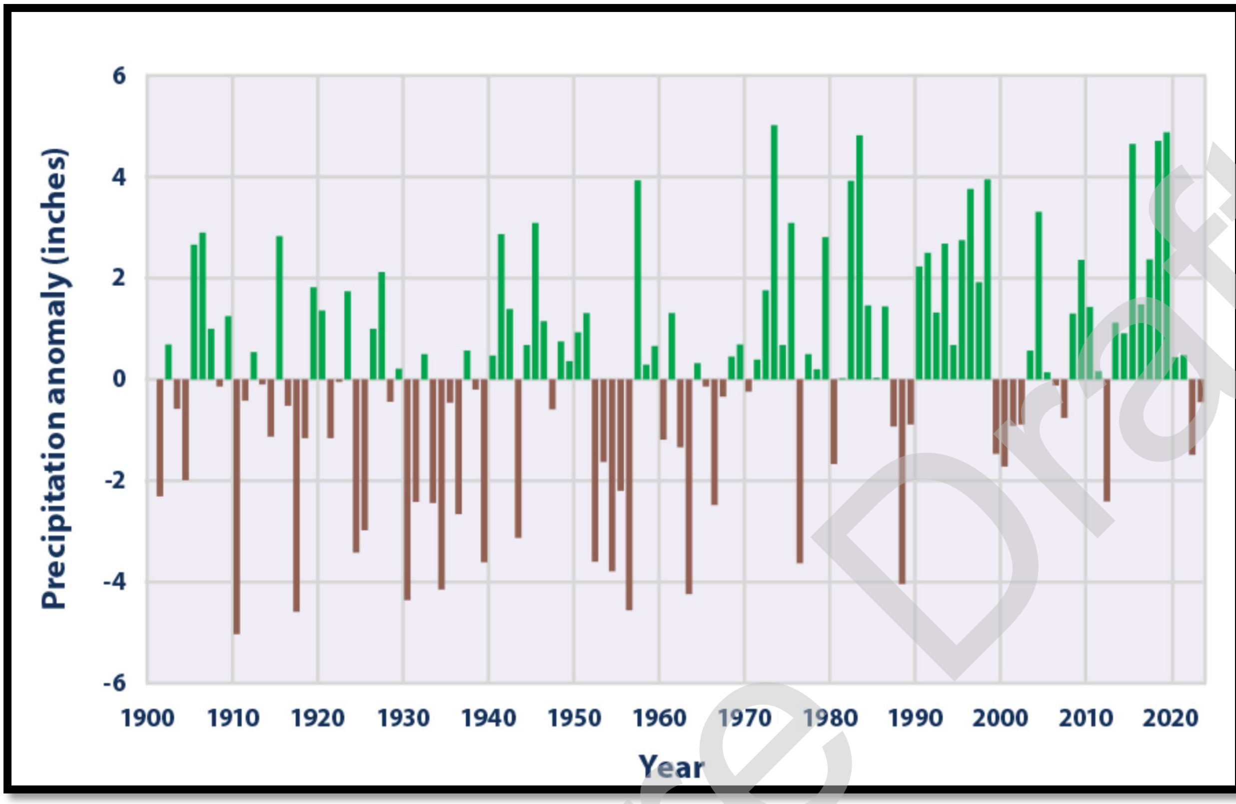
Precipitation

Billion-dollar inland flood events have increased in the U.S., and heavy rainfall events and their ensuing flood risks are increasing because warmer temperatures are "loading" the atmosphere with more water vapor. Over time, this increases the potential for extreme rainfall events.[15] Heavy rainfall is increasing in intensity and frequency across most of the United States, heightening the risk of floods and flash floods.[16]

[15]https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature#:~:text=Highlights,0.20%C2%B0%20C)%20per%20decade.

[16] https://www.globalchange.gov/indicators/heavy-precipitation

Figure 4. Precipitation in the Contiguous 48 States, 1901–2023



Data Source: NOAA (National Oceanic and Atmospheric Administration). (2024). *Climate as a glance.*[17]

In recent years, a more significant percentage of precipitation has come from intense single-day events.[18]

[17] *Retrieved March 25, 2024 from www.ncei.noaa.gov/access/monitoring/climate-at-a-glance*

[18] https://www.epa.gov/climate-indicators/climate-change-indicators-heavy-precipitation

Figure 5 illustrates the billion-dollar flooding events, which are based on the adjustments in the Consumer Price Index (CPI).[19]

Figure 5.

United States Billion Dollar Flooding Events (CPI-Adjusted)

Year	Flooding Count	Flooding Count Rank	Flooding Costs (Billions)	Flooding Costs Rank	Flooding Deaths	Flooding Deaths Rank
2023	1	12	$4.6	11	22	13
2022	1	12	$1.5	23	42	8
2021	2	4	$2.8	16	7	24
2020	0	44	$0.0	44	0	44
2019	3	2	$24.0	2	12	18
2018	0	44	$0.0	44	0	44

Source: Time Series | Billion-Dollar Weather and Climate Disasters | National Centers for Environmental Information (NCEI) (noaa.gov)[i]

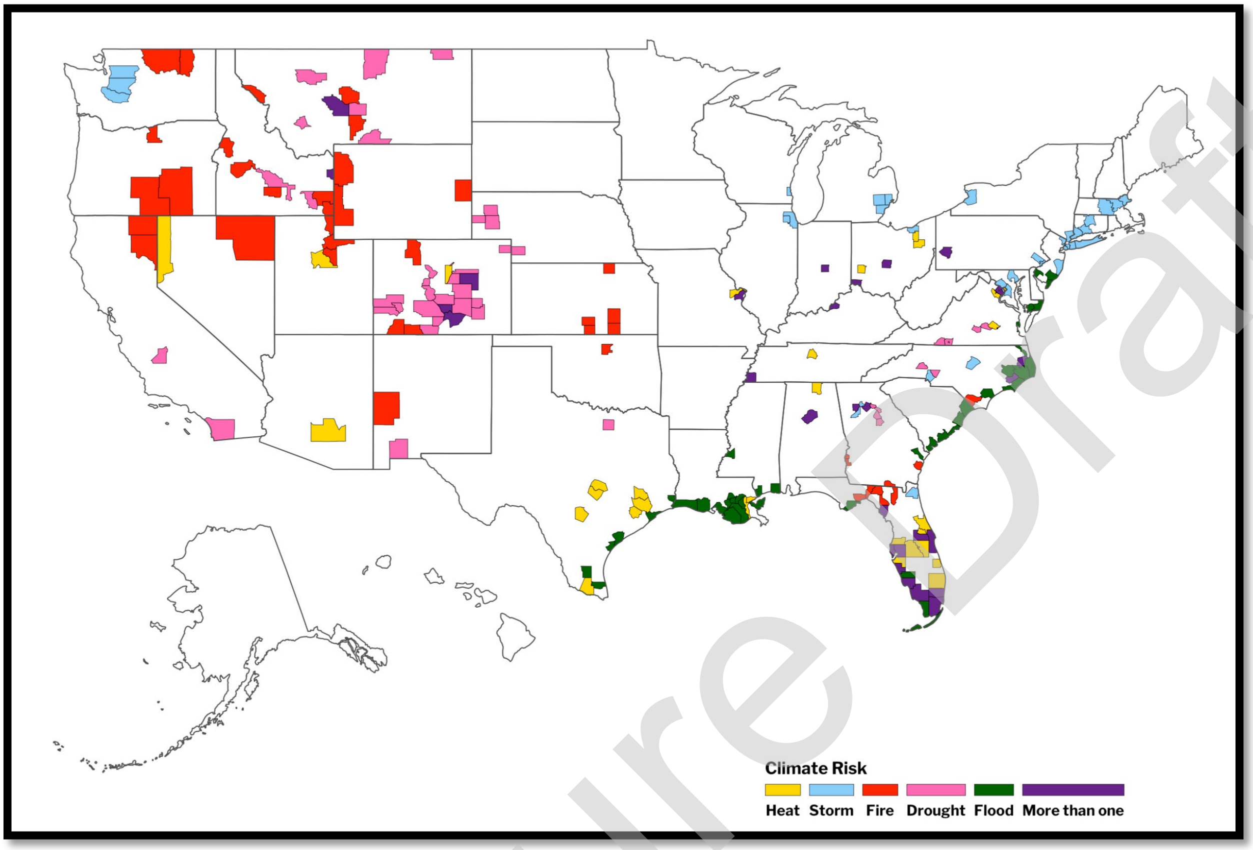
According to AON's 2024 NatCat report, globally, $380 billion of economic losses resulted from weather and climate events in 2023. Insurance covered only 31% of the weather and climate-related losses, a noteworthy decrease from the previous year. The protection gap, or uninsured losses in a country, presents a global challenge. The expected rise in the frequency and severity of weather events as larger populations live in disaster-prone areas further emphasizes the increased need for catastrophe models. The NatCat report is updated annually and can be found on AON's website.[20]

Additionally, the demographic and population shift since the 1970s is worth noting. For example, Florida's population grew by an average of 2.3% annually between 1970 and 2022.[21] People are moving to areas with high climate risk due to affordability, lower taxes, more housing choices, and access to nature. This has, in turn, led to a decline in the population in areas with lower climate risk.[22]

[19] CPI is a measure of the average change over time in the prices paid by consumers for a representative basket of consumer goods and services.
[20] https://www.aon.com/en/insights/reports/climate-and-catastrophe-report
[21] https://florida.reaproject.org/analysis/comparative-indicators/growth_by_decade/population/tools/
[22] https://www.redfin.com/news/climate-migration-real-estate-2021/

Figure 6 shows the top counties with the highest percentage of properties facing high-climate risk.[23]

Figure 6



A property is classified as having high climate risk when it faces a high, very high, or extreme climate risk score from ClimateCheck.[24]

Three counties in Florida, Lee County, Brevard County, and Hillsborough County, had the highest High-Storm-Risk County net migration rate in the 2016- 2020 Period.[25]

The frequency of natural disasters resulting in over $1 billion in costs has risen over the past 40 years, climbing from an average of three annually in the 1980s to 13 annually during the 2010s. Not only are natural disasters happening more often, but the average amount of damage and loss of life from each event has also increased.[26]

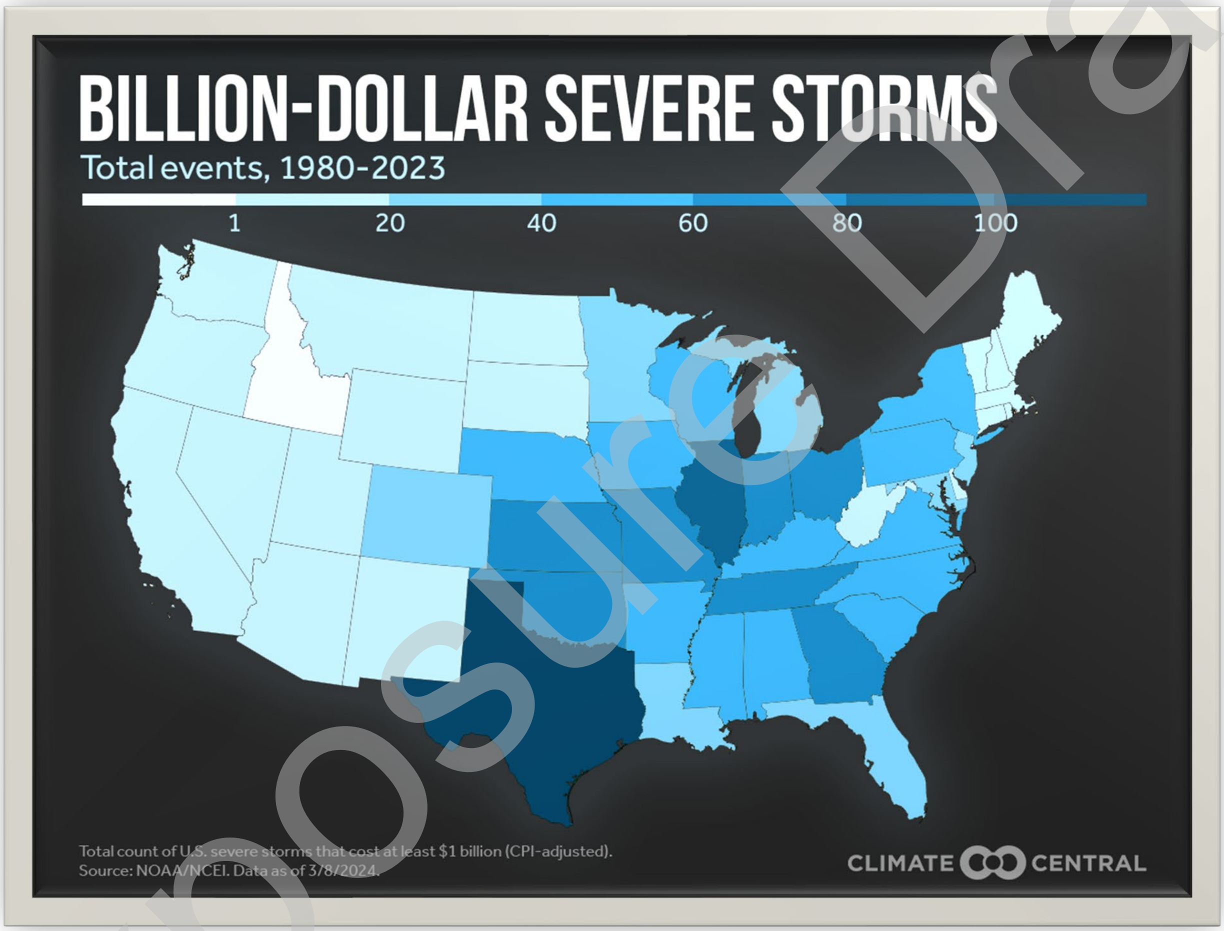
In recent years, the number of flooding and severe storm events has significantly increased compared to all other types of disasters.[27] In 2023, losses from severe convective storms surpassed $50 billion for the first time in a single year.[28]

[23] Picture from: https://www.redfin.com/news/climate-migration-real-estate-2021/ -- Source: ClimateCheck, county property records, MLS data, and 2020 population estimates from the U.S. Census Bureau.
[24] https://climatecheck.com/
[25] Source: ClimateCheck, county property records, MLS data, and 2020 population estimates from the U.S. Census Bureau
[26] ibid
[27] https://usafacts.org/articles/are-the-number-of-major-natural-disasters-increasing/
[28] https://www.swissre.com/press-release/Insured-losses-from-severe-thunderstorms-reach-new-all-time-high-of-USD-60-billion-in-2023-Swiss-Re-Institute-estimates/4a15acf7-64b4-4766-8662-1c35d268ab12

Figure 7, below, depicts the total count of U.S. severe storms that cost at least $1 billion (CPI-adjusted), as of March 8, 2024.

There is a need for more regular observation of the losses caused by secondary perils and sharing of the associated results. For example, severe convective storms pose a risk to solar and wind energy projects, which are newer technologies. It is essential to update data sets and models more frequently to address changing exposures. Updated data sets will reduce the accumulation of risk and provide a better understanding of loss trends.[29]

Figure 7.



Source: [Climate Central]

[29] https://www.iii.org/sites/default/files/docs/pdf/triple-i_state_of_the_risk_convective_storms_10232023.pdf

Figure 8.

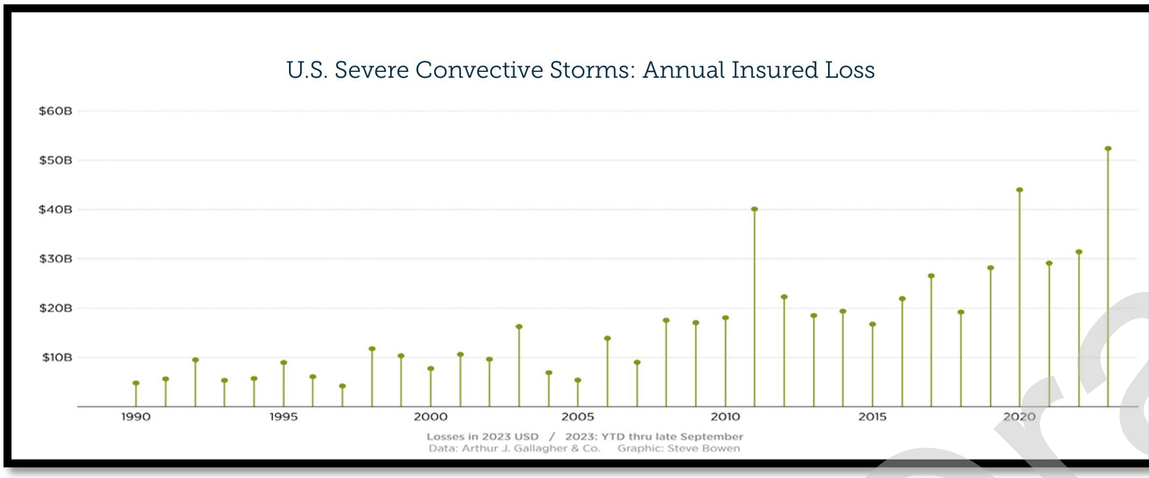
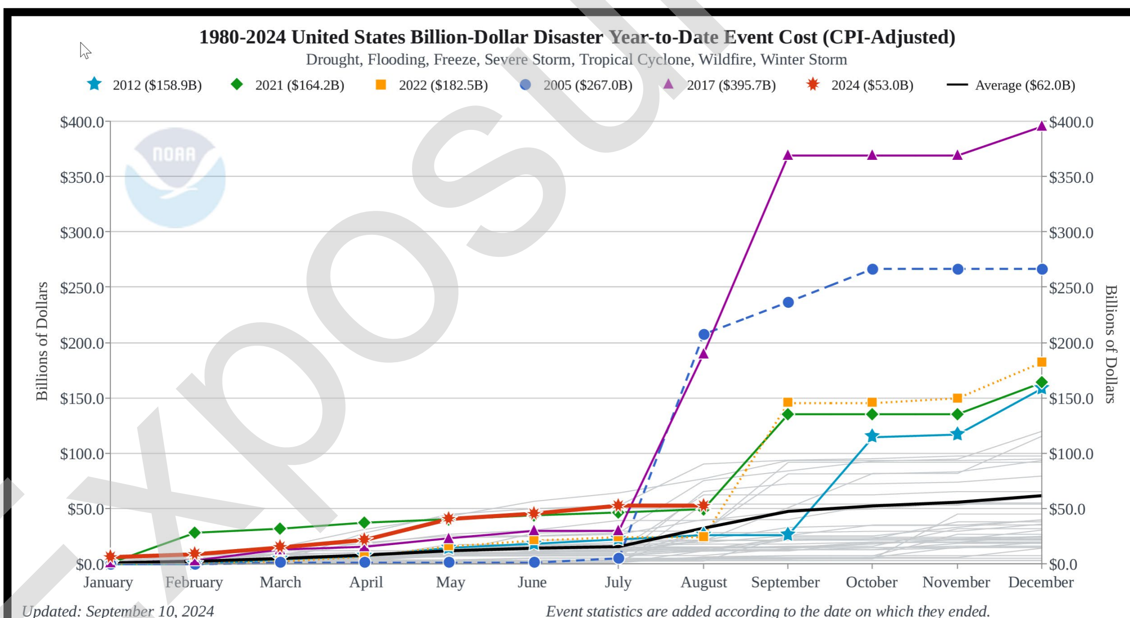


Figure 8 above visualizes the increased severity of yearly U.S. severe convective storm events. Between 2013 and 2022, severe storm events accounted for 54% of disasters.[30]

As of April 8, 2024, the U.S. has seen 378 disasters of $1 billion or greater with losses due to weather and climate-related disasters since 1980, averaging 20.4 yearly events for the most recent five years (2019 – 2023). The numbers are CPI-adjusted, and yearly summaries can be found by visiting NOAA Summary Stats. Figure 9 represents the types of these disasters.[31]

Figure 9.



The National Centers for Environmental Information (NCEI) uses documented history to track historical severe weather and climate events. Currently, the NCEI monitors and assesses the costs and impacts of crop freeze events, drought, hurricanes, inland flooding, severe convective regional storms, wildfires, and winter

[30] ibid

[31] Source: NOAA National Centers for Environmental Information (NCEI) U.S. Billion Dollar Weather and Climate Disasters (2024)[31]

storms.[32] Figure 11 below illustrates the number of events associated with each disaster event from 1980 to 2024 (as of April 8, 2024). The summary data can be found on the NCEI's state-summary page.

Figure 10.

Billion-dollar events to affect the United States from 1980 to 2024 (CPI-Adjusted)*

Disaster Type	Events	Events/ Year	Percent Frequency	Total Costs	Percent of Total Costs	Cost/ Event	Cost/ Year	Deaths	Deaths/ Year
Drought	31	0.7	8.2%	$356.4B	13.2%	$11.5B	$7.9B	4,522	100
Flooding	44	1.0	11.6%	$198.3B	7.4%	$4.5B	$4.4B	738	16
Freeze	9	0.2	2.4%	$36.6B	1.4%	$4.1B	$0.8B	162	4
Severe Storm	188	4.2	49.7%	$465.1B	17.3%	$2.5B	$10.3B	2,100	47
Tropical Cyclone	62	1.4	16.4%	$1,395.4B	51.8%	$22.5B	$31.0B	6,897	153
Wildfire	22	0.5	5.8%	$144.0B	5.3%	$6.5B	$3.2B	535	12
Winter Storm	22	0.5	5.8%	$99.3B	3.7%	$4.5B	$2.2B	1,402	31
All Disasters	**378**	**8.4**	**100.0%**	**$2,695.1B**	**100.0%**	**$7.1B**	**$59.9B**	**16,356**	**363**

The chart above includes the following caveats[33]:

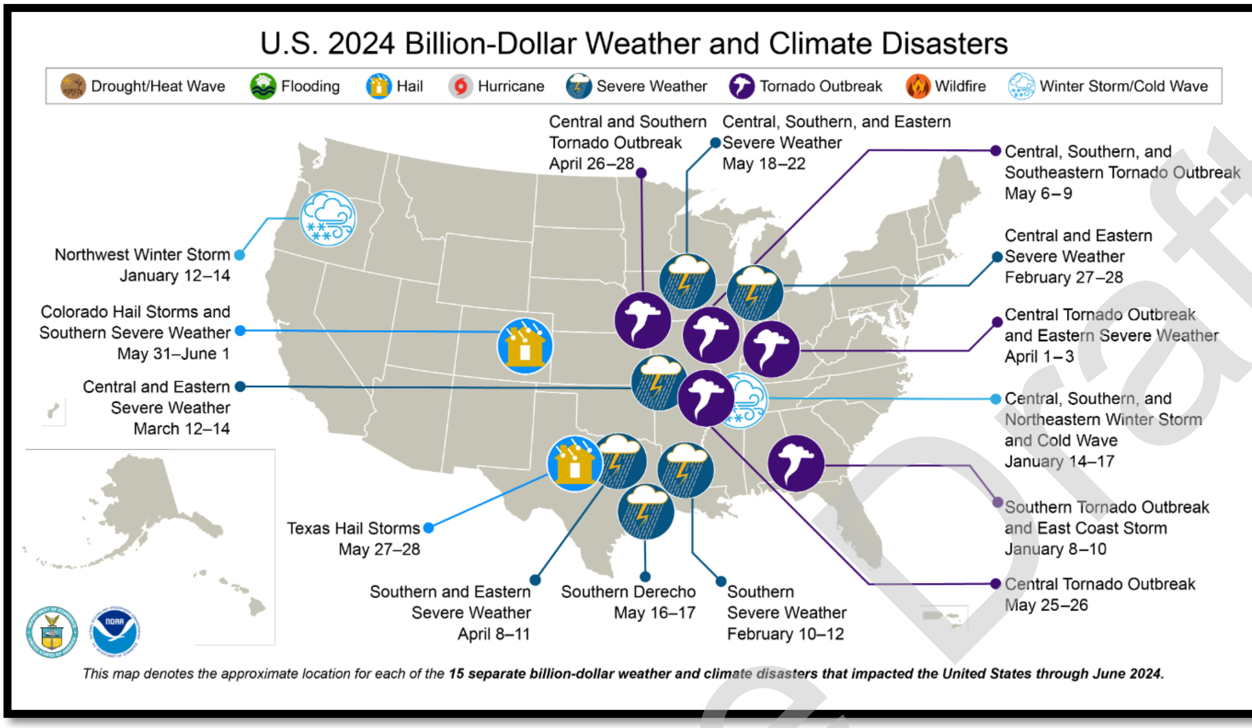
- Deaths associated with drought are the result of heat waves. (Not all droughts are accompanied by extreme heat waves.)
- Flooding events (river basin or urban flooding from excessive rainfall) are separate from inland flood damage caused by tropical cyclone events.

The National Hurricane Center, reinsurance industry, and catastrophe modelers all use the NCEI's data by integrating NCEI's findings into their assessments to consider the risk and loss possibilities throughout the country.[34]

Catastrophic events are occurring more frequently and are becoming more severe, reminding property insurers that they are at significant risk of incurring losses from disasters. The increase in frequency and severity highlights the importance of using catastrophe models. Figure 11 illustrates the 2024 billion-dollar weather and climate disasters through June 2024.

[32] Billion-Dollar Disasters: Calculating the Costs | Did You Know? | National Centers for Environmental Information (NCEI) (noaa.gov).
[33] NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2024). https://www.ncei.noaa.gov/access/billions/, DOI: 10.25921/stkw-7w73
[34] ibid

Figure 11. (including CPI adjustment to 2024)[35].



What is a Catastrophe Model?

Like any other real-world model, catastrophe models represent plausible event scenarios that could happen in the future. By simulating possible events, catastrophe models help inform the user of areas where future events will likely occur, even if there have been no historical events.

Catastrophe models are designed to answer some of the following questions:

- Where are future catastrophic events likely to occur?
- How intense is the catastrophic event likely to be?
- For each potential event, what is the estimated range of damages and insured losses?
- What is the probability (likelihood of loss) of a given loss level (size of loss) for an insurer's book of business based on a wide range of plausible catastrophe scenarios?

Why Use a Catastrophe Model?

Catastrophes, like hurricanes and earthquakes, are infrequent events that can pose a significant financial hazard to an insurer, including solvency risk, reduction in earnings, and a rating downgrade. Insurers typically use actuarial models based on historical experience to price and manage for non-catastrophic risk. For example, insurance companies generally use historical data to calculate car insurance premiums because insurers rely on historical data to estimate the frequency and severity of common occurrences like car accidents. A historical approach is only considered successful when there is sufficient data and when previous events reliably predict future claims payments. These traditional methods may not be suitable for low-frequency and high-severity catastrophic events.[36]

[35] Source: https://www.ncei.noaa.gov/news/national-climate-202406

[36] https://www.milliman.com/en/insight/taking-catastrophe -models-out-of-the-black-box

Historical loss experience is difficult to adjust to reflect current conditions, such as portfolio changes or societal changes. For example, building codes, construction practices, and materials change over time, so the damage from a previous catastrophic event that occurred many years ago may not provide accurate details for a current loss.[37]

Since the inception of catastrophe models in the late 1980s, these models are now being used across the insurance industry for ratemaking, buying reinsurance, managing catastrophe exposures, and meeting regulatory and rating agency standards. Other stakeholders increasingly use catastrophe models for new purposes, including loss mitigation studies and quantification, forward-looking climate scenario modeling, and addressing other climate-related impacts. However, as their use becomes more widespread, it is important to understand how a catastrophe model can be used and to help decision-makers learn how to evaluate them effectively.[38]

Catastrophe Models Versus Historical Approaches

Extreme weather events occur less frequently, so past information does not include all possible and plausible events.[39] As discovered following Hurricane Andrew, loss estimates using traditional actuarial techniques based on historical loss experience were much lower than the actual losses.[40] However, this does not mean historical experience consistently understates the expected losses. Following a large hurricane, the use of historical losses may overstate the future expected losses.

A study by Milliman found infrequent wildfires before 2017 and the use of historical losses, likely understated rate indications. However, historical losses after the extreme wildfire seasons that followed may have overstated rate indications.[41]

Catastrophe models consider multiple factors, including the underlying physical science of the peril and historical data, to estimate the frequency of events, the intensity of hazards, and their proximity to specific locations. These models also incorporate engineering principles and building vulnerability data to assess expected property damage based on the local hazard intensity. By combining these elements, catastrophe models provide insights that go beyond conventional historical data, offering a more comprehensive understanding of potential risks.

How Catastrophe Models Work

The development of catastrophe models has occurred over decade-long processes of combining the various components of hazard, vulnerability, exposure, and loss geospatially. These models simulate catastrophic events using a probabilistic framework that generates a stochastic event set to determine the likelihood and severity of each event scenario and the hazard intensity at the local geographical level over the lifecycle and path of those event scenarios. The models use physical vulnerabilities for estimating the damages, using an insurer's business portfolio as it currently exists as the input to the model. Each simulated event scenario has expected damage, which is the mean loss, and uncertainty, which is the standard deviation, around the damage estimate.[42]

A catastrophe model produces an event loss table or a year loss table with a list of simulated events and associated loss amounts. Event losses can be generated at varying resolution levels (aggregated vs. most

[37] Nov. 3, 2020 Insurance Summit Event Development of a Private Flood Market, Brandon Katz.
[38] https://www.milliman.com/en/insight/taking-catastrophe-models-out-of-the-black-box
[39] https://www.milliman.com/en/insight/taking-catastrophe-models-out-of-the-black-box
[40] https://www.insurancejournal.com/magazines/mag-features/2022/05/16/667461.htm
[41] https://www.milliman.com/-/media/milliman/pdfs/2022-articles/10-19-22_pci-pifc-cdi-summary.ashx
[42] (Nov. 3, 2020 Insurance Summit Event Development of a Private Flood Market, Brandon Katz)

detailed) depending upon the use case, such as county, state, or postal code level or at the individual location level.[43]

Catastrophe model results can vary significantly, even with the same exposure data input, due to differences in data specifications and underlying assumptions. These variations and uncertainties often motivate companies to use model settings that best suit their book of business, adjust the modeled output, or combine the results from multiple models, producing a range of outcomes tailored to their specific needs.

How Catastrophe Models Are Used

The development of catastrophe models continues to transform how insurers quantify, price, transfer, and manage risk. Today, catastrophe models are prevalent throughout the property and casualty insurance industry, helping insurers and other entities manage catastrophic risks from various perils. They also play a significant role in the pricing and underwriting process by allowing insurers to see the risks associated with a particular geographic area. For example, reinsurers can use a catastrophe model to consider which risks they are best suited to undertake.[44]

Rating agencies rely on catastrophe models to assess the primary risk to an insurer's financial health. By examining the insurer's overall use of catastrophe models. The insurer's rating can be affected by its level of exposure, as the rating is impacted by the cumulative exposure level.[45]

Finally, catastrophe models allow insurers to project possible financial losses arising from adverse, naturally occurring catastrophic events. The probable maximum losses derived from catastrophe models allow companies to stress test associated exposure to determine the financial impact and assist companies in determining the appropriate reinsurance program structure to transfer the risk to third parties and limit the company's exposure to natural disasters.[46]

Some common questions that the output of catastrophe models can help answer include:

- What would be a reasonable premium for the catastrophe component of an insurance or reinsurance policy?
- What new business opportunities (territories and/or lines of business) should the insurer consider adding?
- How much could the insurer potentially lose in a worst-case scenario, and what is the likelihood of that loss size?
- How can the insurer best mitigate these risks?
- Does the insurer have sufficient capital to stay solvent for a worst-case scenario?
- Is the insurer operating within the capital constraints set by the board, rating agencies, and regulatory agencies?

Model Components

Catastrophe models exist for natural catastrophes such as hurricanes, earthquakes, floods, and convective storms, like tornadoes, hail, and wildfires, as well as for man-made catastrophes like terrorism and emerging risks like cyber.[47]

[45] Kob, J.J. (2022) Realising catastrophe: The financial ontology of the Anthropocene. https://doi.org/10.7488/era/2366
[46] Ibid
[47] Walker, Joanna Faur. (2020, September 1). *Catastrophe Modelling – So much more than a tool for insurers* [Video]. YouTube. https://www.youtube.com/watch?v=jfvVnpUnGJo

The basic framework for modeling the impacts of natural hazards on a portfolio of exposures can be broken down into the following modules *(Note: The exact terminology used by each model vendor may vary slightly from what is described below):*

- Hazard Module (also known as the local intensity calculation module or event footprint generation);
- Vulnerability Module;
- Exposure Module; and
- Financial Module

The Hazard Module

Hazard is defined as the danger caused by a peril to a community within the impacted area; for example, damaging winds from a hurricane might be a peril. The main function of the hazard module is to generate various event scenarios, determine the path associated with each scenario, and assess the local impact as the event progresses in both time and space for specific perils such as hurricanes or earthquakes.

The hazard module consists of two sub-components, as listed below.

1. Event Catalog
2. Event Footprint

An event catalog consists of a probabilistic event set, which is a database of simulated scenario events.[48] Each event sets events draw upon data from meteorological history, geology, and geography.[49]. The simulation uses logical and scientific data principles to replicate several types of events. Each event is defined by its probability of happening and the area it affects. It generates numerous potential event scenarios based on realistic parameters and historical data to forecast plausible future outcomes with varying probabilities.[50] Each event in the simulation represents a specific magnitude or intensity, trajectory or path, probability of occurrence, and event footprint, which contains an associated hazard intensity footprint for each simulated event.

Additionally, the event catalog contains information about the event's hazard intensity. For example, if the event is a windstorm, the hazard parameters might include sustained wind speed or peak gust speeds. The parameters for a flood might consist of flood depth, flood extent, and velocity.[51]

Each event in the event catalog is characterized by a specific strength or size, location, path, and annual probability of occurrence (also known as event rate). Every event scenario in the catalog is associated with a unique event footprint reflecting the relative intensity and extent of the hazard over the event's path during the event duration, considering the impact of local terrain as the event progresses. This information is stored in the event footprint component of the hazard module.

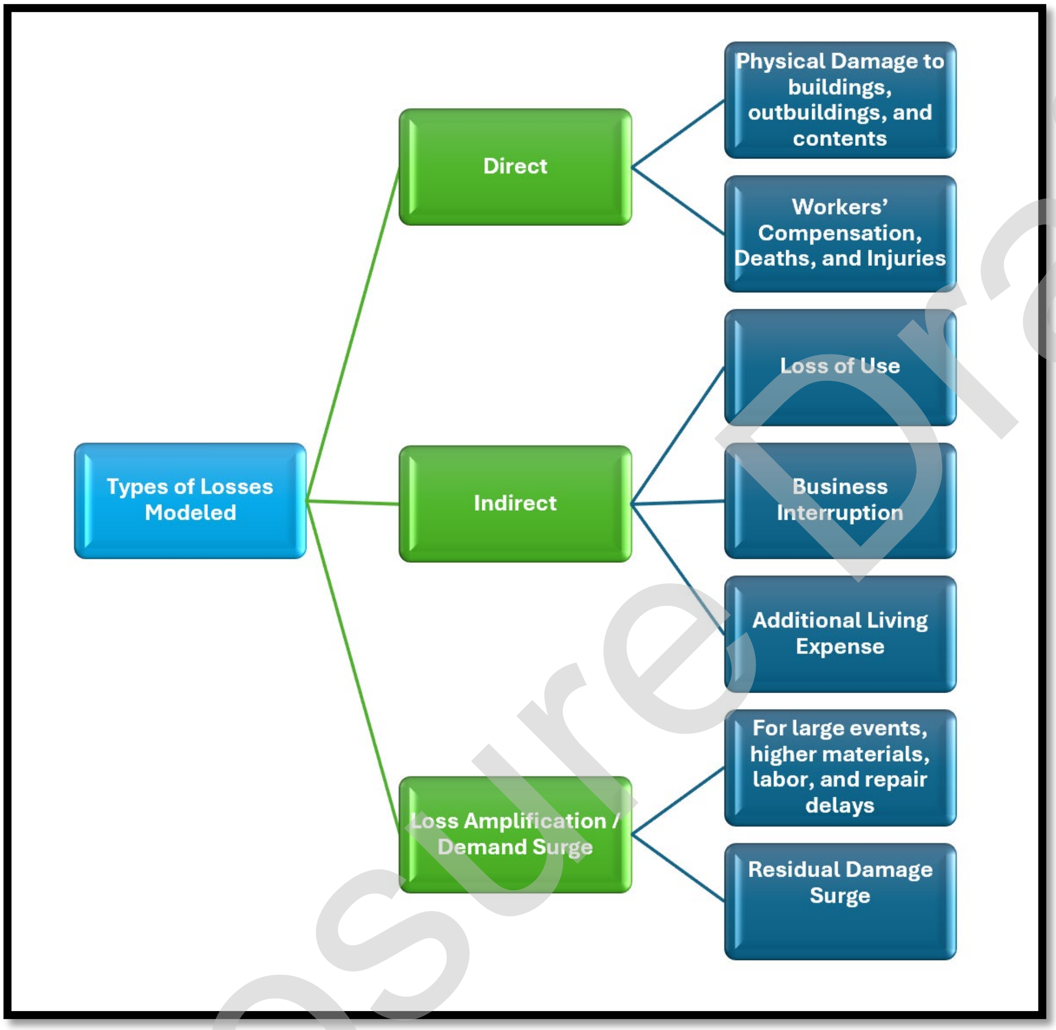
The Vulnerability Module

The vulnerability module calculates the expected damage to the properties at risk, given the hazard intensity, using damage functions. Damage functions are essentially equations that compute the amount of expected damage for a given hazard intensity (such as wind speeds). This could be, for example, the vulnerability of a building and its contents (direct damage), indicating how likely it is for a building to experience a certain

[48] Grossi, P. and TeHennepe, C. (2008) *RMS – A Guide to Catastrophe Modeling,* Informa. https://forms2.rms.com/rs/729-DJX-565/images/rms_guide_catastrophe_modeling_2008.pdf.
[49] Walker, Joanna Faur. (2020, September 1). *Catastrophe Modelling – So much more than a tool for insurers* [Video]. YouTube. https://www.youtube.com/watch?v=jfvVnpUnGJo
[50] https://www.rms.com/catastrophe-modeling?contact-us=cat-modeling
[51] Walker, Joanna Faur. (2020, September 1). *Catastrophe Modelling – So much more than a tool for insurers* [Video]. YouTube. https://www.youtube.com/watch?v=jfvVnpUnGJo

amount of damage or a collapse from a given hazard intensity.[52] This module also calculates Additional Living Expenses (ALE) or Business Interruption losses (indirect loss).

Figure 12 – Types of Losses Modeled



The vulnerability matrix generally varies depending upon the building's risk characteristics, such as occupancy (residential, commercial, or industrial), building construction (wood, masonry, or steel), age of the building, height of the building, and many more, such as the age of roof, roof to wall connection and opening protection.[53]

The vulnerability framework of the catastrophe models considers the regional variation in building code adoption and enforcement and differences in the regional building inventory. A catastrophe model is one tool that demonstrates how stricter building codes and mitigation features could help reduce losses. Catastrophe models use distinct characteristics representing building hardening features to reflect lower damage than a building that has not been mitigated. These features are peril dependent. For example, mitigating hail damage is the use of hail-resistant roofing. When mitigation data elements such as roof-to-wall connections, type of opening protection, and pressure-treated garage doors are specified in the

[52] Grossi, P. and TeHennepe, C. (2008) *RMS – A Guide to Catastrophe Modeling,* Informa. https://forms2.rms.com/rs/729-DJX-565/images/rms_guide_catastrophe_modeling_2008.pdf.

[53] Grossi, P. and TeHennepe, C. (2008) *RMS – A Guide to Catastrophe Modeling,* Informa. https://forms2.rms.com/rs/729-DJX-565/images/rms_guide_catastrophe_modeling_2008.pdf.

exposure data, most catastrophe models can reflect the impact of these elements through vulnerability curves.

The Exposure Module

While the hazard module estimates the hazard intensity footprint for a specific event, the exposure module houses the portfolio data, such as location-specific information, the building's complete physical address or latitude/longitude, risk characteristics, and insured values.

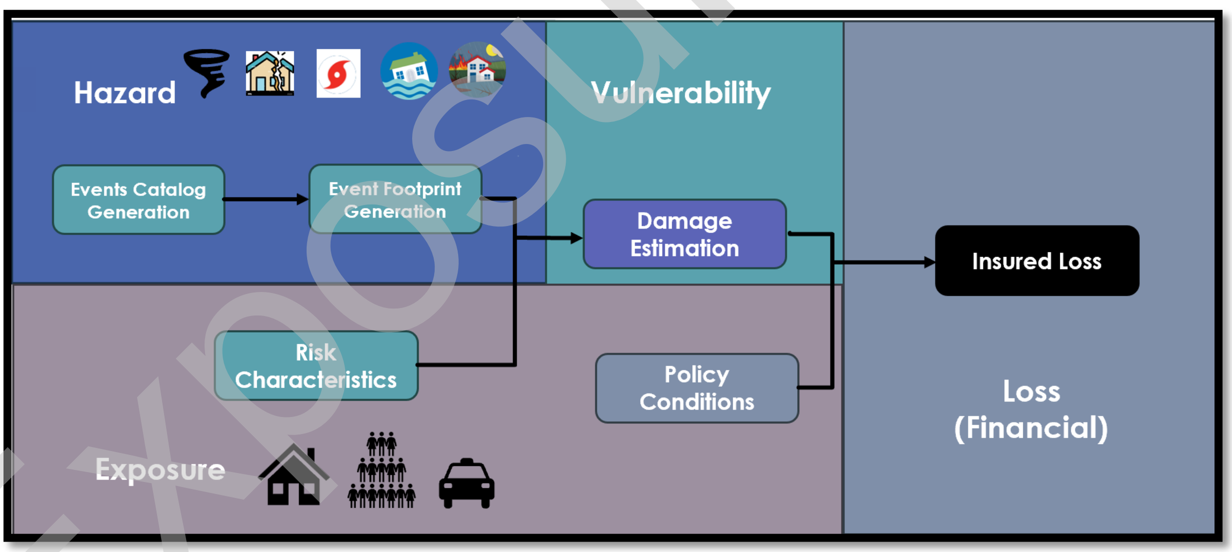
The exposure module also includes information about insurance policy terms and conditions, such as deductibles, limits, and any applicable reinsurance.

Catastrophe models are sensitive to the data input by the insurer, or the entity designated by the insurer for data input for running through the model to produce the modeled results. Catastrophe models include a framework to use default assumptions to fill in some of the missing information, such as the use of a default year band based on the occupancy in a certain geographical area using the model vendor's proprietary building inventory database. However, the uncertainty of the modeled output increases when the input data is not accurate or has material gaps and relies on assumptions.[54]

The Financial Module

The financial module translates the physical damage calculated in the vulnerability module to provide the dollar amount of financial loss. The module translates physical damage into total monetary loss by computing an estimate of insured losses. This process applies policy conditions, like deductibles and limits, to reach these loss estimates.[55] All event scenarios' losses are aggregated to create a loss probability distribution. Loss distribution is used to derive expected losses and the likelihood of different loss levels.

Figure 13 – Modules of a Catastrophe Model



Inputs

Catastrophe models are exposure-based and do not use historical claims data or claims experience from a specific location or policy being modeled. Catastrophe event simulations require a broad combination of inputs. Exposure details required by a catastrophe model must include detailed location information,

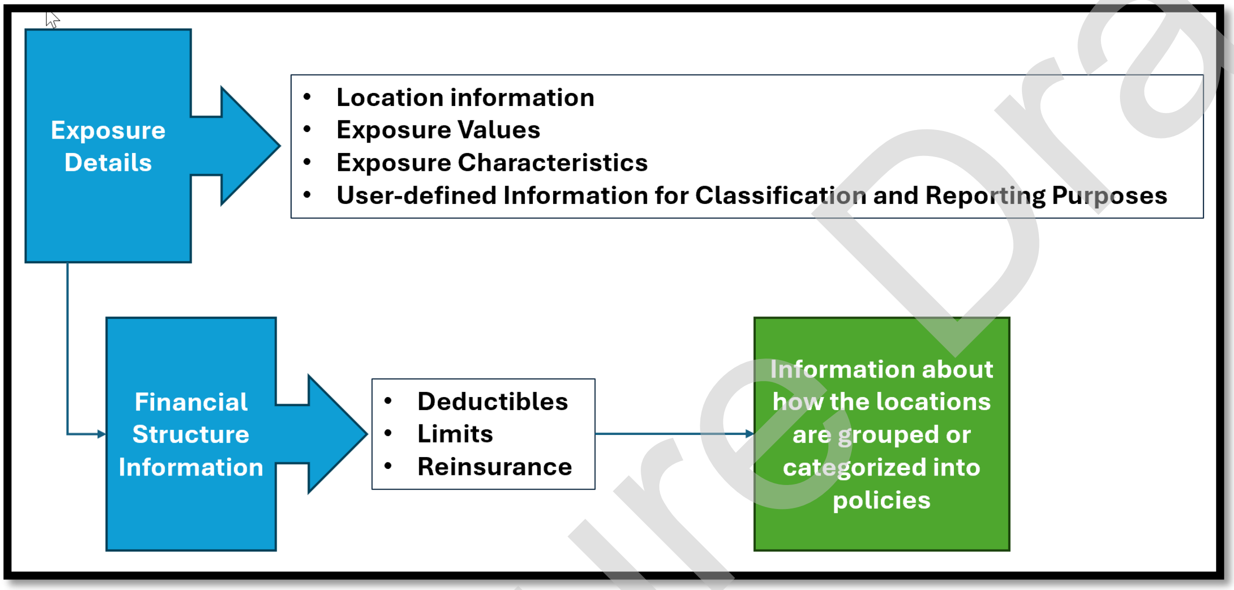
[54] Lavakare, A. and Mawk, K. (2008) *RMS – A Guide to Catastrophe Modeling,* Informa. https://forms2.rms.com/rs/729-DJX-565/images/rms_guide_catastrophe_modeling_2008.pdf
[55] Grossi, P. and TeHennepe, C. (2008) *RMS – A Guide to Catastrophe Modeling,* Informa. https://forms2.rms.com/rs/729-DJX-565/images/rms_guide_catastrophe_modeling_2008.pdf

exposure values also known as sum insured, exposure characteristics, and user-defined information for classification and reporting purposes.

While exposure values are essential to the modeling process, obtaining consistent and accurate values remains challenging. These values also need to be adjusted periodically to account for inflation trends. Therefore, it is important to validate and benchmark these values accordingly.

Financial structure information, like deductibles, limits, and reinsurance, need to be entered into a model, just as information about how the locations are grouped or categorized into a policy should be entered.

Figure 14 – Input Example



A catastrophe model's input depends on the peril being modeled. For example, hurricane deductibles may be different from those for earthquake or wildfire perils. Additionally, the mitigation element coding that the model considers depends on the peril being modeled.

For models to correctly reflect a peril's risk, multiple data inputs are required during each step. To protect against uncertainty, the model user must use reliable information to assess the input correctly. Exposure data includes exposure details, like address information. Geographic coordinates can also be used. Address granularity impacts the calculation of model uncertainty. Therefore, location validation is important, as it may affect the computation of model uncertainty. The catastrophe model evaluates the given coordinates' accuracy based on the input address's quality. The model indicates the level of detail in the match, distinguishing between a high-resolution match (e.g., street, building, or parcel) and a low-resolution match (e.g., postal code or city). Catastrophe models use this coordinate information to retrieve location-specific details to estimate the modeled losses. Depending upon the specific peril model, this generally includes retrieving geospatial hazards (e.g., soil characteristics, ground elevation) and, in some cases, selecting region-specific vulnerability information. The uncertainty in the model's loss estimates increases as the geocoding resolution decreases from high to low. For low-resolution matches, the catastrophe model makes assumptions to calculate losses for that location, which may not accurately reflect the actual hazard or vulnerability. This uncertainty is particularly true for high gradient perils like wildfires and floods, as the hazard varies greatly over short distances. [56]

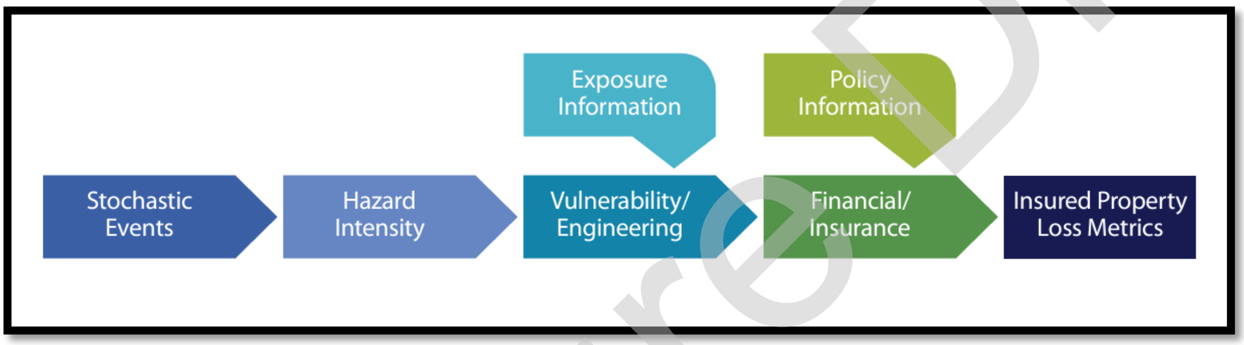
[56] Ibid

It is important to note that the catastrophe model is sensitive to the data input into it. The data quality of the information on the risk, such as address and building characteristic data, is important. However, better data quality does not guarantee a lower modeled loss, but it does ensure a more accurate representation of the risk. The better the data, the less there is a need to rely on assumptions, which reduces uncertainty. [57]

Outputs

Catastrophe models produce outputs that can be used by insurance industry professionals in numerous ways when it comes to catastrophe exposure management. The output derived from catastrophe models is widely used for ratemaking, premium mitigation credit quantification, reinsurance purchase, capital, and solvency assessment. In July 2018, the American Academy of Actuaries developed a paper, "Uses of Catastrophe Model Output." It is important to note that output is heavily influenced by the quality of the source data, the model methodology, and the model application. Additionally, catastrophe models should be continually improved through ongoing testing and rebuilding based on lessons learned.[58]

Figure 15: How Catastrophe Model Components Interact.[59]



Key Metrics and Outputs

Average Annual Loss (AAL)

Catastrophe model catalogs have many years of simulated activity reflecting the modelers' understanding of possible future events. The AAL can be calculated at various levels of detail like geography, type of policy form, line of business, exposure (house) level, etc.

[57] Donavan, M. (2020, April 22). *Oasis LMF Webinar 1: Fundamentals of Catastrophe Modelling* [Video]. YouTube. https://www.youtube.com/watch?v=OCRG0q2UVAs
[58] Natural Catastrophe Risk Management and Modeling (p. 11-12)
[59] https://www.actuary.org/sites/default/files/files/publications/Catastrophe_Modeling_Monograph_07.25.2018.pdf

The AAL represents a long-term average, the expected value occurring in any given year. The calculation used to obtain the aggregate AAL is:

$$\frac{\textit{sum of the losses from each year in the catalog}}{\textit{the number of years in the catalog}}$$

The AAL is simply the average of all the simulated iterations. AAL is synonymous with pure premium or expected loss. AAL is the most common metric used in catastrophe ratemaking and pricing.[60]

Exceedance Probability (EP) Curves

Catastrophe models produce EP curves. These curves represent loss distribution in terms of the likelihood and severity of the loss. They provide the probability of exceeding a certain loss size for the modeled portfolio of exposures in a given year. A catastrophe model generates an EP curve by running the event catalog against exposures for each event and year and providing losses for each event and year. The model generates the probability of exceedance of various loss levels on either an annual aggregate or annual occurrence basis.

Occurrence Exceedance Probability (OEP)

The OEP refers to the likelihood that the financial loss from a single catastrophic event will exceed a specified amount in any given year. For example, if you have an OEP of 1% for losses above $100 million, it means there's a 1% chance that at least one event in a year will cause losses greater than $100 million.

Aggregate Exceedance Probability (AEP)

The AEP measures the likelihood that the total financial loss from all catastrophic events occurring in a single year will exceed a specified amount. For example, if the AEP is 5% for losses above $50 million, this means there's a 5% chance that the combined losses from all catastrophes in a year will exceed $50 million.

Return Period

Another metric produced by catastrophe models is called return period (RP). The return period is simply the reciprocal of the exceedance probability and is a statistical measure of the frequency of a certain magnitude of event. For example, a 100-year return period indicates that, on average, an event of that magnitude or greater will occur once every 100 years. A frequent misconception is the belief that an event with a 100-year return period will happen precisely once every 100 years. Such an event could happen in consecutive years or not at all for many centuries. The return period only indicates an average likelihood, not a schedule.

Insurers often use catastrophe models to help them determine the appropriate level of reinsurance coverage the insurance company should purchase for natural catastrophe perils by looking at the return period of a certain loss size.[61] The return period helps companies set the attachment/retention and exhaustion levels.

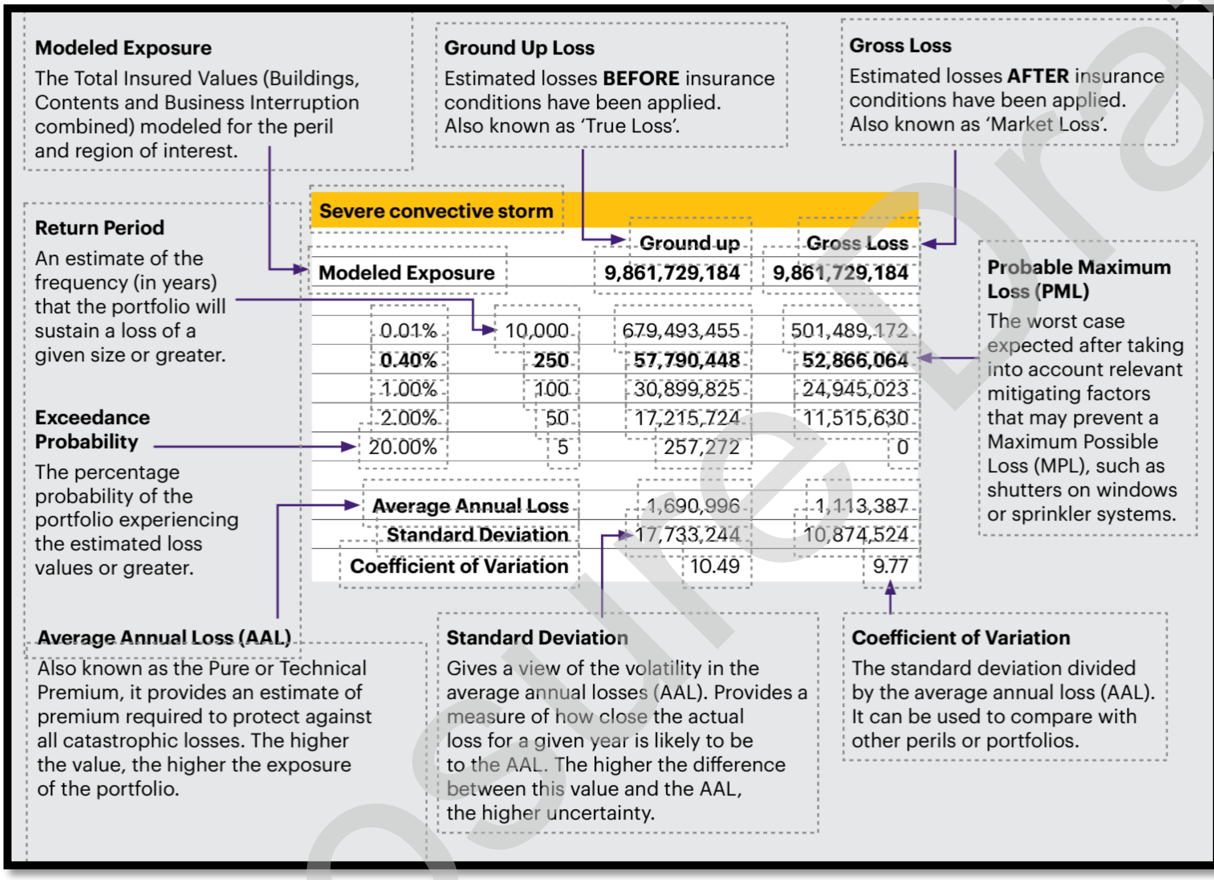
$$\textit{Loss Return Period} = \frac{1}{\textit{Exceedance Probability}}$$

[60] https://insnerds.com/using-catastrophe-models/
[61] https://www.marsh.com/pr/en/services/property-risk-management/insights/catastrophe-modeling.html

Probable Maximum Loss (PML)

The PML, or probability of exceeding a specified loss, shows how likely it is to exceed a certain amount of loss. This is the loss level at a certain probability threshold level or, in other words, at a specific return period. The PML represents the estimated maximum amount of loss a company could face from a single catastrophic event based on a specific probability or return period. It is used to assess the potential impact of extreme events, helping companies understand and prepare for the worst-case scenarios.

Figure 16 – A typical modeled-loss calculation [62]



Modeled Hazards

Since 2010, when the *NAIC Catastrophe Computer Modeling Handbook* (now referred to as the Primer) was published, new perils have been modeled, including catastrophic events like cyber, flooding, terrorism, and wildfire.

Natural Catastrophes

Various experts, including meteorologists, seismologists, geologists, structural engineers, mathematicians, and actuaries, create and evaluate these models.[63]

Earthquake

Earthquake risk assessment is challenging since historical data is limited and insufficient to predict future loss estimates and establish insurance rates. However, catastrophe loss models can be used to address this

[62] (Source: Managing Convective Storm Risks)
[63] https://www.doi.sc.gov/DocumentCenter/View/7001/Catastrophe-Models-FINAL-07232013?bidId=

challenge. These models rely on the expertise of scientists in relevant fields such as geology, seismology, and structural engineering and draw on information from the United States Geological Survey (USGS) National Seismic Hazard Model. EUSGS regularly updates hazard model to account for the frequency and severity of earthquakes (i.e., hazard). Two types of scientific models are used to assess earthquake losses: the Earthquake Rupture Forecast, which shows where and when the Earth might slip along a state's faults, and the Ground Motion Prediction model, which estimates the subsequent shaking given one of the fault ruptures. The USGS has been publishing hazard models for the United States and its territories since 1996, and a hazard toolbox is also available for querying and computing hazards from the USGS national seismic hazard models.[64]

Hurricane

Hurricane models use various pieces of information, such as historical disaster data, current population and building statistics, scientific knowledge, and financial data, to estimate the potential cost of hurricanes for a specific area. [65]

Once a model is built, a computer program analyzes it. It is important to recognize that hurricane models do not predict the exact number of hurricanes that will occur in a given year. Instead, they calculate the average potential impact of hurricanes over a longer period. Models provide the expected average annual hurricane loss and the probability of events of a certain size.[66]

Think of it like flipping a coin. Just because a fair coin is expected to land heads half the time, it does not mean that it will alternate between heads and tails with each flip. Similarly, hurricane models estimate the long-term average impacts rather than making predictions about the specific activity of any single year.[67]

Some models include storm surge flooding within their hurricane models and have a separate inland flood model that covers pluvial and fluvial flooding, while other models have a single flood model covering surge and inland flood.

Flood

Flood modeling is an emerging science that helps insurers estimate flood risks. It's also helpful in evaluating building codes and land use. Experts use various data to create flood models, including land topography, river channel surveys, historical records of water levels, rainfall, previous floods, land use, and other general information about drainage areas or watersheds. With advancing technology, flood models will improve, enabling the models to better capture uncertainty.[68]

There are four types of flooding: fluvial floods (river floods), pluvial floods (flash floods), coastal floods (storm surges), and tsunamis (inundation).[69]

Cities can experience surface flooding during heavy rains when the drainage system gets overwhelmed by water, causing it to overflow onto streets and nearby structures.[70]

Flash floods occur when there is a significant amount of heavy rainfall in a short period of time within a particular area or on an elevated surface nearby. They may also happen when an upstream dam or levee

[64] USGS Earthquake Hazard Toolbox
[65] https://www.doi.sc.gov/DocumentCenter/View/7001/Catastrophe-Models-FINAL-07232013?bidId=
[66] Ibid
[67] Ibid
[68] https://www.air-worldwide.com/blog/posts/2019/3/the-role-of-catastrophe-models-in-the-evolution-of-the-flood-insurance-market/
[69] https://www.zurich.com/en/knowledge/topics/flood-and-water-damage/three-common-types-offlood#:~:text=There%20are%20three%20common%20flood,is%20forecast%20in%20different%20ways
[70] Ibid

suddenly releases water or by excessive snowmelt. Flash floods are particularly dangerous because the water moves with great force, making it difficult to navigate.[71]

Coastal flooding happens when seawater rises and covers the land along the coast. This occurs due to strong windstorms and may be exacerbated by high tide. A storm surge, as it is called, is often related to a hurricane or typhoon.[72]

A flood model can evaluate a property's flood risk by considering factors such as anticipated river flows, rainfall, and coastal levels, as well as topographical data and flow equations. It then generates flood risk data, including depth, flood levels, hazards, and velocity.[73] Once considered uninsurable by the private market, flood insurance is a viable product offering with rate and rating plans developed using catastrophic flood models.

Severe Convective Storms

Sophisticated radar and satellite technology are now used to detect and track developing storms, unlike in the past when observation and reports from members of the public were relied upon. Unfortunately, events in sparsely populated areas often went unrecorded, leading to an incomplete record of severe convective storm history in many areas.[74]

If a convective storm contains at least one of the following: 1) hail that is one inch or larger; 2) over 57.5 mph wind gusts; or 3) a tornado, the storm is considered a severe convective storm.[75]

Severe convective storms are intense weather events that can be incredibly destructive. Several sub-perils characterize them, including hail, tornadoes, straight-line winds, and lightning. Each of these sub-perils can cause significant damage to property and pose a threat to human safety.[76]

Due to the complex nature of severe convective storms (SCS), modeling the peril of these weather events presents several challenges. The SCS model needs a robust framework to handle the challenging task of reflecting sub-peril contribution and correlation accordingly. The model methodology and framework need to capture both types of catastrophic events—localized and larger outbreaks. The model's resolution, both temporal and spatial, depends heavily on the resolution of satellite and radar imagery observations that underlie the footprint generation and calibration framework.

For more information, view A Guide To Managing Severe Convective Storm Risks.

Wildfire/Drought and Heat Events

Long periods of drought and heat waves can impact the environment but also affect people. For example, wildfire, tree mortality, and crop losses may be more severe when drought and heat waves happen simultaneously.[77]

Both crop and wildfire models are available, and the impact of these perils on wildfire is one part of the equation, along with other parameters in a wildfire model.

[71] Ibid
[72] Ibid
[73] https://aegaea.com/flood-modelling/#:~:text=Flood%20modelling%20uses%20predicted%20river,flood%20levels%2C%20and%20hazards
[74] https://www.wtwco.com/en-us/insights/2024/01/a-guide-to-managing-severe-convective-storm-risks
[75] https://www.assetworks.com/convective-storm-modeling-details-rm20/
[76] Ibid
[77] https://www.preventionweb.net/news/two-extremes-same-time-how-often-droughts-and-heat-waves-will-occur-together#:~:text=Prolonged%20droughts%20and%20heat%20waves,can%20be%20even%20more%20severe.

Like flood models, wildfire models are less mature in their development than other catastrophe models. Nevertheless, several models have been developed to estimate the risk of loss due to wildfire, whether caused by human or natural factors. [78]

The more common components considered in wildfire models are historical fire incidents, weather (e.g., wind speed and direction, relative humidity/drought, temperature), land characteristics, topography (e.g., elevation, slope, or aspect - the direction the slope faces), and fuel (type of vegetation). Some models also consider mitigation measures taken to reduce the risk of wildfire loss in the area. These models estimate wildfire behavior, such as how far embers travel, how and where the fire is expected to ignite, and how quickly and in which direction the fire is expected to spread once ignited. Additionally, some models include components to estimate damage from smoke associated with wildfire.[79]

Like other catastrophe models, results from these wildfire models can be used in insurance and reinsurance pricing, risk management, and underwriting. The development of enhanced wildfire models will significantly impact town planning and construction practices in areas prone to wildfires, as well as firefighting suppression efforts when these events occur.[80]

Winter Storms (snow, ice, freezing rain)

Winter storms can take three forms: freezing rain, sleet, or snow. Winter storm models use weather prediction technology to get a representation of potential storms. This technology utilizes advanced mathematical models and computational power to provide detailed insights into the development, movement, and impact of these storms in specific areas. Winter storms have various characteristics, like windstorms, ice storms, blizzards, etc., and they appear differently in various regions based on the climate conditions.

Winter storms can damage buildings, vehicles, and infrastructure. Wind speeds exceeding 160 km/h, and heavy snowfall or freezing rain can occur. Business interruption losses can also occur when storm damage or snow and ice disrupt infrastructure.

Winter storms can cause a range of secondary hazards that vary depending on the region. These hazards include warm air, sudden temperature changes, heavy snow, rain or freezing rain, and ice drifts in rivers or coastal areas. A winter storm can also cause extreme frost. When a storm closes an airport, flights can be canceled, which can greatly impact businesses and commercial enterprises, causing significant losses affecting large geographic regions.

Man-made Catastrophes

This type of catastrophe is beyond the scope of this paper. For technical training needs surrounding catastrophe modeling, visit the COE's website.

Cyber

"Cyber" is a newer risk that has emerged due to the widespread use of information technology (IT) and global interconnectedness in the modern world. It threatens individuals and businesses and can result in various adverse consequences, such as data loss, decreased revenue, physical harm, or harm to one's reputation.

78 Karels, J. (2022, June). Wildland urban interface: A look at issues and resolutions. U.S. Fire Administration. https://www.usfa.fema.gov/downloads/pdf/publications/wui-issues-resolutions-report.pdf

79 Karels, J. (2022, June). Wildland urban interface: A look at issues and resolutions. U.S. Fire Administration. https://www.usfa.fema.gov/downloads/pdf/publications/wui-issues-resolutions-report.pdf

80 Penney, G., & Richardson, S. (2019, January 7). *Modelling of the radiant heat flux and rate of spread of wildfire within the urban environment*. MDPI. https://www.mdpi.com/2571-6255/2/1/4

The term "cyber" encompasses a range of effects, including business disruption, hardware or software malfunctions, regulatory penalties, and data theft resulting from security breaches.

While cyber catastrophe models have evolved, they differ from traditional catastrophe models. The output from cyber catastrophe models continues to be especially sensitive to the input used in the model. Cyber risk does not have geographical boundaries, so significant discrepancies exist in a vendor's methodologies used to quantify risk. Consequently, it's common to notice considerable inconsistencies in the methods adopted by different vendors for quantifying cyber risk. These discrepancies include scenario definitions, the coverages in a cyber insurance policy, event generation, vulnerability indicators, and estimated resulting damage costs.[81]

More information can be found in "[How Cyber Catastrophe Models Evolved with the Cyber Insurance Market](#)."

Systemic risks from natural catastrophes and cyber events are different. One of the most significant contrasts is that cyber perils occur when attackers seek to damage businesses and individuals worldwide. Modeling for a cyber event must consider factors such as geopolitical threats, the use of computers for criminal activities, and a business's reliance on interconnected technologies. Models employ scenarios representing systemic events involving multiple businesses and a single point of failure, such as reliance on the same cloud service providers.[82]

Cyber risk models are not without uncertainty. However, these models are a helpful tool for managing capital planning, reinsurance, and undertaking regulatory issues. Knowing about past events helps support stable and robust cyber insurance.[83]

Terrorism

When it comes to predicting terrorism, there is much uncertainty as compared to natural disasters. Factors like how often it may happen, where it might occur, and how severe it could be are hard to predict. Since there is not much historical data to use for making these predictions, experts must rely on judgment. Aside from using probabilities, another common way to predict terrorism is to create "what-if" scenarios. These scenarios help pinpoint high-risk areas, known as "hot spots," in specific regions like Lower Manhattan in New York or the central district of Chicago.

Terrorism events can impact various insurance lines. These models are used to estimate damages from a wide range of attack modes for property and workers' compensation lines.

For example, a terrorism model can be used to estimate workers' compensation losses by considering the extent of damage to individual buildings to estimate the number and severity of injuries, including partial, permanent, temporary, and fatalities. The model creates distributions of injury severity for each damage state, building, and occupancy type and combines these with corresponding severity payouts based on the type of injury.

The State Insurance Regulators' Perspective

State DOIs do not all take the same approach to an insurer's use of catastrophe models.

State insurance regulators are obligated to ensure that the resulting rates are appropriate. Models for perils, like wildfire and flood, have emerged more recently. Since large losses from catastrophic events can

[81] https://www.insurancethoughtleadership.com/cyber/how-cat-models-are-extending-cyber
[82] ibid
[83] Ibid

potentially threaten insurer solvency, state insurance regulators must consider the advantages or disadvantages of replacing the conventional models with a newer methodology.

State insurance regulators continually update risk-based capital (RBC) charges to address the evolving risk landscape. For example, in 2017, the NAIC expanded the risks quantified in the RBC formula to include a specific charge for hurricane and earthquake catastrophe risk to recognize increased exposure to catastrophic events. Additionally, in 2022, the Catastrophe Risk (E) Subgroup of the Property and Casualty Risk-Based Capital (E) Working Group recommended that wildfires be added to the RBC framework for catastrophe risk exposures.[84]

Financial Solvency

For financial solvency, 100-year PML CAT model outputs from the list of CAT model vendors for Earthquake and Hurricane perils are currently calculated in the Rcat risk charge. There are also CAT models for wildfire and severe convective storm perils that were adopted separately for the 2023 and 2024 yearend informational reporting.

Ratemaking

As part of the rate filing process, an insurer often gets a set of follow-up questions from a DOI. During this process, state insurance regulators might ask questions about a model's assumptions or methodologies used in a rate filing. Understanding how the insurers' actuaries reach new rate levels is needed to confirm the new rates are reasonable (i.e. not excessive or inadequate) and not unfairly discriminatory. In many states, rates related to catastrophe risk are an important element. Splitting the rate dollar into segments like profit, taxes, commissions, cost of capital (reinsurance), expected catastrophe losses, expected non-catastrophe losses, and fixed overhead shows how material the catastrophe risk component can be. The assumptions used in the estimation of these components are at times of interest to state insurance regulators.[85]

Catastrophe vendors support their clients when they have questions about a catastrophe model. Often, the catastrophe modeler interacts directly with state insurance regulators to educate them about their models. Some modelers also work with state insurance regulators to regulate the models themselves.

In ratemaking, actuaries generally use historical data or modeled losses to form the basis for determining future cost estimates. The absence or presence of catastrophes in any historical data used to form future cost estimates can create biases that diminish the appropriateness of using the data as the basis for future cost estimates. The actuary should address such biases by adjusting the historical data to form future cost estimates and determining a provision for catastrophe losses (after considering the issues and practices found in sections 3.1–3.3 of ASOP 39).

The actuary may use other considerations and methods to adjust for catastrophes associated with casualty insurance coverages. For example, the adjustments may include limiting losses in the underlying data and using increased limits or excess loss factors based on industry data or other sources.

Adjustments could also involve legislative changes, legal decisions, changes in the distribution of policy limits, and coverage provisions. Additional adjustments may be appropriate, including supplementing state-specific data with countrywide or company-specific data with industry information. For details, refer to [ASOP 39 - Treatment of Catastrophe Losses in Property/Casualty Insurance Ratemaking].

Currently, a few states have specific requirements related to the submission, review, and/or acceptance of catastrophe models for use in ratemaking. Each state varies in what a modeler must provide for review and what they do with the information.

[84] Birraine, K. (2022, September 8). *Senate*. United States Committee on Banking, Housing, and Urban Affairs. https://www.banking.senate.gov/imo/media/doc/Birrane%20Testimony%209-8-22.pdf h
[85] https://www.air-worldwide.com/blog/posts/2015/8/insurers-and-cat-models-under-the-regulatory-lens/

Regulatory Concerns

Model Variability

The variability in results between models is only one concern regulators hold as they review catastrophe models and their outputs.

Another concern related to variability in model results is that the same model's results can change dramatically with an update to a new version, either on an aggregate basis or by segment (e.g., county).[86]

Catastrophe models for more recently modeled perils do not have the same maturity level as those for perils that have been modeled for 20+ years. For example, hurricane and earthquake models have existed longer than wildfire models.

Results from the more mature models, such as hurricane and earthquake models, are more consistent and exhibit less variability than results from less mature models, like wildfire, which itself is a complex peril to start with. However, this does not mean that less mature models are necessarily unreliable. Effective use of less mature models may require more analysis about how the results were reached, and modifications may be required.[87]

State Specific Information

State insurance regulators are not always equipped with the expertise to contradict or confirm the findings of catastrophe models.

Some states may prohibit the use of catastrophe models to project fire risk in the overall level of an insurer's prospective rates. California is the only state that has a regulation that directs fire risk reflected in the overall rate level to be calculated using historical losses, although modeled wildfire losses are acceptable in the determination of rate segmentation (e.g., establishing rate relativities by territory or wildfire score).

Some modelers provide standard reports to state insurance regulators. These reports offer basic assumptions, data, and inputs for the model. Many modelers share basic information with state insurance regulators who request it.[88]

Modelers have allowed state insurance regulators to view model input and output and review some of the model's formulas and algorithms. Modelers form agreements with state insurance regulators stating that this information must remain confidential.[89]

State insurance regulators recognize the freedom of information laws may necessitate that all information they receive requires public disclosure of all information received.[90]

State insurance regulators and modelers continue to work on meeting the challenge of providing adequate disclosures to make educated decisions while maintaining the confidentiality of a modeler's proprietary elements.[91]

State insurance regulators continuously pursue new sources of information and accurate recommendations to help them understand model input, output, and methods.[92]

[86] From the original NAIC Catastrophe Modeling Handbook
[87] https://www.milliman.com/en/insight/taking-catastrophe-models-out-of-the-black-box
[88] Original NAIC Catastrophe Modeling Handbook
[89] ibid
[90] ibid
[91] ibid
[92] ibid

California

California Code of Regulations, 10 CCR § 2644.4 (e) specifies allowance of models for Earthquake and Fire Following Earthquake (FFEQ) for ratemaking in California. California also allows models for other perils in developing rating relativities, such as territorial and wildfire relativities.

California Code of Regulations 10 CCR § 2644.9 requires that insurers develop or update their homeowner's insurance rating plans and consider and apply mitigation credits, discounts, or other rate differentials for properties that employ recognized wildfire mitigation measures.

California also requests that the insurer complete its model review checklist, which has recently been revised to improve support for both catastrophe and non-catastrophe models.

Florida

The Florida Commission on Hurricane Loss Projection Methodology (FCHLPM) was established to evaluate models per Florida statute. For the residential property line of business, only the use of accepted models is required to support hurricane rates in rate filings submitted to the Florida Office of Insurance Regulation (FLOIR). The FCHLPM also evaluates flood models, though rate filings are informational.[93]

The FCHLPM is independent of FLOIR. However, Florida statute requires that FCHLPM membership includes a FLOIR actuary responsible for property insurance rate filings, who is appointed by the Commissioner of FLOIR.

The FCHLPM consists of technical experts specializing in meteorology, engineering, actuarial, and computer science.

In Florida, a public hurricane loss projection model incorporating detailed loss data is utilized to review rate filings. This model is subject to FCHLPM review. When companies select an accepted model to use in rate filings, detailed policy exposures and building characteristics are provided for balancing.

Per the FCHLPM's website, the FCHLPM posts information about the accepted models and the FCHLPM's review requirements.

Hawaii

Commissioners Memorandum 2022-9R provides guidance on supplemental rate filing requirements for property insurance and supersedes Memorandum 2003-3R. Hawaii does not have a formal body that reviews models. Its insurance law specifies the DOI must review the model. If a model vendor updates its model and the update is not on the list, it cannot be used.

Louisiana

The Louisiana Department of Insurance (LDI) issued Bulletin No. 2013-04, which provides assistance to Property and Casualty insurers using catastrophe models to support proposed rates filed with the LDI. This bulletin focuses on modeling specific to the hurricane peril; however, the guidance provided should be used for other perils where applicable.[94]

Maryland

Maryland requires insurers to fill out a questionnaire for rates and forms when using a catastrophe model. The questionnaire asks for information about the model, insurance data sources, vendor model elements and criteria, catastrophe sources, data validation and updates, property coding and accuracy, model output, and sensitivity testing. See Appendix 3 for the questionnaire Maryland uses.

[93] Florida Statute 627.0628

[94] https://www.ldi.la.gov/docs/default-source/documents/legaldocs/bulletins/bul2013-04-cur-catastrophemodelinte.pdf?sfvrsn=38e67c52_14

South Carolina

South Carolina law, S.C. Code Ann. § 38-75-1140 (2007), authorizes the Director of Insurance to evaluate the use of any natural catastrophe model in property insurance rate filings in South Carolina. South Carolina has a review process for hurricane models used in ratemaking for property insurance for South Carolina properties, but they do not review models for other perils.

The South Carolina Department of Insurance issued Bulletin Number 2014-03 in 2014. This bulletin provides background for an independent panel's initial review of hurricane models. It also sets forth the direction that SC DOI would take going forward and how the industry should respond regarding the making of SC property rates for damage by hurricanes.

Throughout the model review process, it has become clear that the models' results depend on the input data from companies using them. This is why insurers are required to provide a description of the input data used to run the models. [95]

The South Carolina DOI's website provides information about the hurricane models that are approved in the state and when they are set to expire. If a company is using an unapproved model, then it needs to provide the following information:

- An explanation of why the company is using the selected model;
- The differences between the approved and selected model;
- The impact of the model selection on loss costs and indication calculation; and
- The approval and expiration dates set by the Florida Commission on Hurricane Loss Projection methodology.

Companies must complete the CAT-Property exhibit included in the Property Actuarial Exhibits workbook for any property rate filing submission. The actuarial exhibits can be found on the South Carolina DOI's website.[96]

Consumers' Perspective

Most consumers are unaware of catastrophe models' role in developing their insurance rates. However, consumers are aware of the yearly increases in their insurance premiums, leading to many questions about their insurance costs. Usually, consumer advocates are not privy to the actual impact of catastrophe modeling on the consumer's rate and are limited in the information they can give to the consumer. As a result, consumers have little understanding of the role catastrophe modeling plays in developing insurance premiums.

Consumer advocacy groups have a much greater understanding of the role of catastrophe modeling and are likely to be skeptical about applying computer models to property insurance rates and underwriting decisions. There has been a perception that the insurers are hiding behind a cloak of mystery that is held by the catastrophe modelers. Consumer advocates know that a great deal of public information goes into the models. Yet, the modelers claim the models are confidential and will not show consumer advocates how they work. This cloak of mystery and the varying results produced by catastrophe models tend to make consumers and consumer advocates wary. They often oppose including a catastrophe rate based on confidential models. In states where consumer advocates are allowed to intervene in rate cases, they have sometimes hired their own experts to challenge the rates filed by an insurer.

[95] https://doi.sc.gov/DocumentCenter/View/7478/2014-03-Hurricane-Cat-Models-in-Property-Rate-Filings?bidId=
[96] https://www.doi.sc.gov/432/Property-Casualty

Rates are already increasing due to the increasing frequency and severity of catastrophic events. Consumer advocates believe the increases related to computer models and their effect on insurance bills should be disclosed. Additionally, there are still many areas where availability and affordability remain problematic.

Summary

Despite the challenges and complexities that come with catastrophe models, their usefulness and value in risk management cannot be overstated. These models are the cornerstone of informed decision-making in the insurance and reinsurance industries. They provide a structured framework to quantify risk, which is essential for developing sound strategies in underwriting, pricing, and portfolio management. While uncertainties do exist, catastrophe models are constantly evolving to incorporate new data, science, and technology. Today, catastrophe modeling serves the insurance market in a profound way. For the past 30 years, catastrophe models have played a major role in shaping the insurance industry for insurers and reinsurers. Their use extends beyond predicting insured losses. Insurers and reinsurers depend on catastrophe models for ratemaking, financial solvency, reinsurance placement, and more. The intricate nature of catastrophe modeling considers changing global climate conditions and insured exposure, creating the need for catastrophe models to implement updates to their data sets consistently. The insurance industry's reliance on catastrophe models continues to grow and underscores the critical importance of catastrophe models.

For technical training needs surrounding catastrophe modeling, visit the COE's website.

Appendix 1 – California Regulations – Links

- Cal. Code Regs. Tit. 10, § 2644.4 - Projected Losses
- Cal. Code Regs. Tit. 10, § 2644.9 - Consideration of Mitigation Factors; Wildfire Risk Models

Appendix 2 – Hawaii Memorandum

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COLIN M. HAYASHIDA
INSURANCE COMMISSIONER

September 23, 2022

2022–9R

To: All Licensed Insurers Offering Property Insurance

in Hawaii From:Colin M. Hayashida, Insurance Commissioner

Subject: Catastrophe Models for Hurricane Exposure in Hawaii ("Hurricane Models")

The purpose of this memorandum is to provide guidance on supplemental rate filing requirements for property insurance and to supersede memorandum 2003-3R dated July 30, 2003.

The Insurance Division has reviewed and approved for use, effective November 1, 2022, the following hurricane models in Hawaii:

- AIR Tropical Cyclone Model, Version 3.10 [1]
- Core Logic Hawaii Hurricane Model [2]
- RMS NA Hurricane Model, Version 18.1.1 [3]

Insurers with previously approved property rating programs which use formerly approved hurricane models are not required to refile.

Insurers who wish to use these newly approved models may do so, effective November 1, 2022. Additional filing instructions will be posted on the Insurance Division's website and in the electronic filing system by this date.

Be advised that the Insurance Division will be reviewing the appropriateness of the impact to the Hawaii policyholder, and shock increases on an overall or by-insured basis are discouraged. We encourage insurers to speak with the RPA Branch before making a new filing.

For questions regarding regarding this memorandum, please contact the RPA Branch Manager at (808) 586-2809 or email InsRpa@dcca.hawaii.gov.

[1] Released June 14, 2013, implemented in AIR Touchstone through 8.10

[2] Released July 31, 2019, implemented in RQE v 19

[3] North Atlantic Hurricane Model (Build 1945)

Appendix 3 – Maryland Regulations

Maryland Insurance Administration
Property and Casualty Rates and Forms Catastrophe Model Questionnaire

Provide your responses prior to the meeting. Your representative should be prepared to discuss the information provided as well as answer any additional questions that may be asked by MIA staff.

FILING COMPANY: ____

SERFF TRACKING NUM: _____________________ COMPANY TRACKING NUM: _________________

QUESTIONNAIRE COMPLETETION DATE: ______________________

A. **MODELS**

1. Identify the vendor(s) and model version(s) that was used in the development of this rate filing.
2. If this model version(s) has been use a previous Rate/Rule filing(s) please provide the SERFF (s) Tracking Number(s).
3. Provide the reason you chose this vendor(s) over the other vendors on the list.
4. Provide the date this model was put into effect by your company.
5. List the reason/purpose for using the model identified in Item 1 above.
6. Advise if this version differs from the vendor's model used in your previous filing.
7. If the answer to #6 is yes, provide the previous vendor and model version.
8. Provide an explanation for using this updated model version versus the previous model version.
9. What guidance, if any, was provided by the vendor to use this model appropriately?

B. **DATA SOURCES**

This section deals only with insurance data, and NOT actual or modeled catastrophe events.

1. Identify the Insurance data sources required by the current model in use.
2. Identify the Insurance data sources used by the company for this rate filing.
3. Have any modifications been made to the model to accommodate this rate filing?
4. For data sources that have been modified, explain the deviation.
5. Identify which are bulk coded, and which are proxy based.
6. Has any data been summarized or bulk coded? For example, construction type is unknown where the default criteria are frame?
7. With respect to the insurance data sources mentioned above, identify which are company based data, and which are external based data.
8. Describe which data is real/actual and which data is the result of default coding.
9. Discuss the appropriateness of data that may differ from the vendor's suggestions.
10. Input Data inaccuracies – Are there any coding mismatches between company data and the information required by model? For example, Modeler data codes: Storm Shutters, Bolted Shutters and Hurricane-Resistant Storm Shutters are individually coded but the Company

data combines the three types of shutters and codes them as one.

11. How does the company determine these inaccuracies and how are they corrected and/or adjusted prior to a model run?

C. **VENDOR MODEL Elements/Criteria**

The vendor has certain criteria as part of its model. Some are allowed to be modified while others have “switches” which may be turned off.

1. List all model criteria required by the vendor.
2. For all criteria in number 1, list any that have been modified and provide a brief explanation indicating why it was modified.
3. For all criteria in item #1, list all those “switches” that were turned off before running the model for this rate filing.
4. Provide a brief explanation as to why the criteria were switched off. For example, was storm surge, demand surge or hurricane frequency distribution not used in this particular model?

D. **CATASTROPHE SOURCES**

This section deals only with the event sets used in the model.

1. Which Modeled Events did the Company use in determining the output for this rate filing?
2. Did the company use actual or historical events in determining the output for this rate filing?
3. Did the company solely rely on the event data which adversely affect the company for this rate filing?
4. If yes to answer number 3 above, explain why.
5. Provide any additional comments relevant to this section.

E. **DATA VALIDATION AND UPDATES**

1. How recently did the company update its insurance data before running the model for this rate filing?
2. What is the time difference between entering the data into the model and running the model report?
3. Does the company code certain input insurance data sources that are inconsistent with the model?

F. **PROPERTY CODING AND ACCURACY**

1. Explain in detail how the company geocodes property locations.
2. How complete is the information *(*exact vs. zip code vs. street level*)*
3. What percentage of the insured properties was coded to street address, zip code, city or county?

G. **MODEL OUTPUT**

1. List and briefly explain/define all the model outputs that were used to develop this rate filing. For example, what were the model outputs for pure premium and the event loss curve for this rate filing?
2. Explain how the model outputs were used in the development of this rate filing.
3. Explain how answers provided in Section C, **Vendor Model Elements/Criteria** impact the output of your model, if possible.
4. Is a loss adjustment expense applied to your model? If so, explain.
5. What role if any does the model play in the calculation of net cost of reinsurance?
6. Explain how the net cost of reinsurance was used in the development of this rate filing.

H. **SENSITIVITY TESTING**

1. Does the company perform any sensitivity testing? If yes, describe the testing. Is there guidance from the vendor?
2. Which input data sources are most sensitive to assumption adjustments?
3. With respect to Section C, **Vendor Model Elements/Criteria,** does the company compare results based on the criteria used in the model? How sensitive are these "switch" adjustments?

Appendix 4 – Questions for Regulators Following a Preliminary Assessment of Catastrophe Models

Please note that this section primarily relates to hurricane and earthquake property loss. The suggested questions could be adapted for other catastrophic events (tornado, hail, freeze, etc) and for other types of loss such as workers compensation. Readers are directed to the Working Definitions section of this handbook for further clarification of terms.

The questions and interrogatories in this section should not be viewed as a recommended requirement for first response on a submission by a company or modeling firm. Prior to action on a submission the regulator may ask these questions of him or her self to determine what areas of attention are most relevant for further exploration. Following such a preliminary assessment the regulator is likely to be in a better position to conduct an effective and efficient review.

EVALUATING MODELS

This section contains three sets of questions. Section A: General Questions contains questions that can be applied to earthquakes and hurricanes; Section B: Questions Specific to Earthquakes contains questions that are specific to earthquake modelers; Section C: Questions Specific to Hurricanes contains questions that are specific to hurricane modelers.

SECTION A: GENERAL QUESTIONS
This section contains some questions a regulator may want to consider when reviewing a filing. The intent is to assist a regulator in formulating and implementing a set of questions and procedures that will be appropriate for the task at hand. Some questions may not be applicable for the filing or model under review.

The perspective taken is that of a regulator reviewing a rate filing that involves the use of a catastrophe model output. The questions are divided into three categories: those about input to the model, those about the model itself, and those about model output. The categories were not designed to be either mutually exclusive or all-inclusive, but provide a method of organizing questions and information.

<u>Data Sources</u>

1. What are the sources of the data, both within and outside the company? Where appropriate, do the various sources reconcile with each other?

2. To what extent has the company relied on data supplied by others? How did the company review the data for reasonableness and consistency?

3. Describe the exposure data provided to the modeling firm(s) by XX. Which data elements are modified or not used by the modeling firm(s)? Was bulk coding used?

4. At what level of detail is the data being supplied to the model?

5. Has the data been summarized or block coded in some way—how much is real data and how much is default coding? (Example: If don't know construction type, the default is "frame")

6. Is the output of the model in less detail than the model input? (Example – street address input; output by entire territory)

7. Is the data comprehensive (does it include all data elements required by the model)?
8. Were all data elements summaries of raw data, or were interpolations, estimations, or other inferences or assumptions made to provide the model with the required input?
9. If there are estimates, describe the estimates. What percentage of the property values has been assigned estimated characteristics? For hurricanes and earthquakes, what percentage of the property values within XX miles (i.e. 20 miles) of the coast and/or fault have estimated characteristics (geocode, construction, property value, etc)

10. Is the type of data appropriate for the analysis and model being used? Is the data over a year old? If so, how old is the data and why isn't it more recent? How have changes in exposure been accounted for in evaluating the results?

11. Does the data appear appropriate when compared to similar data from other companies?

12. Will the company provide the regulator with an electronic copy and/or summary of the data supplied to the modeler(s)? If not, why not? [Note: This is a good question particularly if the regulator has a catastrophe model for comparison.]

<u>Accuracy of Data</u>

1. Are there material inaccuracies due to imperfect data?
2. What elements of the data set used in the analyses were evaluated for materiality?
3. What is the threshold of materiality and whose threshold is it?
4. Are there any inaccuracies that could affect the output of the model and the expected range of possible outcomes?
5. Are there limitations to the data?
6. For example, have some buildings and locations been left out?
7. How have other coverage's, such as business interruption been accounted for?
8. How accurately are properties located, by zip code, geocode, county, etc.?
9. Are there limitations of the types of construction allowed in the model?

<u>Insurance Data</u>

Addressing/Geocoding:

1. What percentages of insured properties were coded to the following levels of detail: street address, zip code, city, or county?
2. Is the model based on exposures by zonal aggregates or at geocodable street level data?
3. Is the type of construction included in the model? Was the occupancy class included? When was this last reviewed? How was the building stock determined and evaluated?
4. Is the commercial property insured in a single location or does it have multiple locations? If it is a multi-location policy were all addresses included in the model?

For the homeowners policy form, please provide the number of policies, the average amount of insurance, the current average premiums and average rate changes for each of the categories below. Please calculate the premiums and rate changes.

By county and deductible

By county and with/without masonry veneer

By county and year built

1. Are there significant deductibles? If so, how are these handled by the model?
2. What role if any does the model play in the calculation of the net cost of reinsurance?
3. Is pre-event preparedness and post-event loss minimization taken into account? Was post event cost surge taken into account?

ASSUMPTIONS IN MODEL AND CALCULATION

<u>Appropriateness of Model Selection</u>

1. How did the company evaluate the model for appropriateness and applicability to the problem at hand?
2. Have any modifications been made to the model to accommodate the rate filing in question?
3. Has the model been updated or changed in any way since the rate filing analysis was done? Have all applicable catastrophic events been incorporated in the model?
4. Have actual events been compared to the model. If the results of the model differ materially from actual losses, explain what subsequent changes to the model have been made.
5. What simulation model(s) did XX utilize for the currently effective XX's Homeowner's coverage rates?
6. Are the results based on one model or an average of multiple models? If multiple models:
    a. What are the individual answers to each model?
    b. Was one of the models an internal model?
    c. Was any model excluded? Why?
    d. What are the advantages and disadvantages of each model?
7. Has the company disclosed the extent of reliance on experts in the use of the model? What is the level of expertise in the applicable field of those experts?
8. What is the insurer's largest probable maximum loss (PML)? Is a 1-in-100 year standard or 1-in-250 year standard or some other standard being used?
9. What threshold is used for calculating PML, 1-in-100, 1-in-250, or some other standard?
10. Which model was used? Was more than one model used? If so what is the PML from the other model?

Assumptions: (Note highly unlikely will get answers as detail trade secret for Hurricane or other weather models)

1. What are the major scientific assumptions of the model? (What scientific papers, etc., have been relied upon as a foundation for the model? Also, are there other reasonable, alternative assumptions that have been rejected? Who made the selection, and why?)

2. What are the major actuarial assumptions of the model? (Also, are there other reasonable, alternative assumptions, which have been rejected? Who made the decision and why?)

3. What are the model's basic algorithms? (How are the major components inter-related?) [Note: This also would tell how the model is structured.]

4. What are the material limitations of the model? Are there some types of loss that are excluded from the model? Are some catastrophic events excluded? Are some property locations, large property values, or construction types excluded from the model?

5. Does the model simulate and isolate appropriate causes of loss? For example, a model may produce both hurricane and other windstorm loss costs. In a rate filing, each of these components may have separate provisions.

6. Was the target a mean value or some other parameter (e.g. a probability distribution)? Do the iterations performed in the modeling reflect the mean values, stay within one standard deviation of the mean, or reflect the entire distribution? What is the range of modeled catastrophic events in terms of standard deviations from the mean?

7. Did the model take into account successive events (e.g. multiple hurricanes in a short timeframe, aftershocks in earthquake) in a region?

8. How has demand surge been taken into account? If so, what is the expected % increase in costs due to the demand surge? Describe how demand surge is used in the models. Provide the data and methods used to determine the effects of demand surge. What is the impact of demand surge?

9. Because not all damage is included in a standard model, has your company taken into account how these items will affect your overall catastrophe risk? If so how, and which perils are not in the model and which ones where accounted for?

10. Will any of the following "switches" be turned "on"? What switches are in the model?
    a. Time dependency
    b. Demand Surge
    c. Storm Surge
    d. Fire following earthquake
    e. Secondary uncertainty
    f. Business interruption
    g. Automobile damage
    h. Loss Adjustment Factors

Validation

1. What validation and testing has been performed with the model?

2. How long has the model been in production? Who has reviewed the model? Have any enhancements been made to the model?

3. Are there any significant differences of opinion among experts concerning material aspects of the model?

4. Describe sensitivity tests of the models. What was the most sensitive aspect of each model and the basis for making this determination? What is the degree to which these sensitivities affect expected loss costs results?

5. Has the model been certified or acknowledged to comply with a specified set of standards. If so, who certified it and what are the standards with which the model was required to comply?

6. Is the model based on generally accepted practices within the applicable field of expertise? [Note: This is more than just an actuarial question…structural engineering, etc.]

OUTPUT

What are the Outputs?

1. What are the outputs of the model? (Are the model outputs reasonable and what analysis or evaluation was performed to evaluate the reasonableness of the output? How were the model's calculations verified? Have the model and its outputs been peer-reviewed? Has the model output been validated? To what extent has other data been used in verifying the reasonableness of the output data?)

2. Were any other models evaluated? Are the results being relied upon consistent with similar output provided by different vendors? If not, please explain the differences. Please explain the differences between the historical indications and the model results? Please provide a summary of the modeled homeowners loss estimates produced by each of the simulation models by policy form, territory, and deductible. Please explain if one model was used or if more than one model was used and if so please provide a comparison of those models.

Adjustments to Outputs

1. Please describe the adjustments made for changes in risk, such as the coverage provided or the insurer's geographic distribution, to reflect the anticipated exposure for the period being priced? How was the model recalibrated to account for changes in the coverage provided?

2. Does the model produce loss costs for all classes or is a base loss cost produced and then adjusted for various risk characteristics? If adjustments are made, are they made by the model or afterward? Please provide support for any classification adjustments?

3. Is the level of detail in the filing the same as the model output? If not, what adjustments were made?

4. Have there been changes to the output data provided? What are the reasons for and effects of these modifications? Is the company willing to provide the output of the model before any changes were made as well as what is contained in the rate filing? If not, why?

5. Did the model vendor make any interpretations of the model output? If so, what were those interpretations and how were they incorporated into the filing?

6. How sensitive are the output results to changes in the input data, assumptions and model parameters?

Application of Outputs in Filing

1. How has the model output been used in the filing? Are results used for statewide indications, territorial indications, etc.?

2. What credibility is being assigned to the model output? How is the credibility determined? What is used as the complement of credibility?

3. How was Loss Adjustment Expenses (LAE) treated? How does the catastrophe LAE compare to the non-catastrophe LAE?

4. Other than the results of the simulation models, are there any changes to the data or assumptions that resulted in the overall average rate change to XX's Homeowners coverage?

5. To what extent is XX relying on the data, methods and assumptions underlying the currently effective Homeowners coverage rates?

SECTION B: QUESTIONS SPECIFIC TO EARTHQUAKE MODELERS (Note: Unlikely to get answers other than general trade secret)

1. Describe external independent peer reviews that have been performed on the following components as currently functioning in the models:
    a. Seismology
    b. Engineering (resulting damage or vulnerability)
    c. Actuarial Science

2. Are the model estimates of earthquake frequency, earthquake intensity, and earthquake loss costs time-independent or time-dependent? Please provide a comparison of the results if more than one model is used or if both time dependent and time independent assumptions were considered.

3. How are shake intensity and duration measured? What is the minimum shake intensity that could generate property damage in your state? How do the models determine shake intensity and duration at one location for an earthquake occurring at another location? How does this compare with currently accepted scientific literature depicting land composition? What database was used by the models? Are the modeled results logical and consistent? How do the modeled shake intensities compare to the historic record?

4. In modeling earthquake risk, how are the parameters for the seismic activity and attenuation determined?
5. What are the seismic attenuation relationships used? Do they differ throughout the state (perhaps by earthquake source depths)?
6. What are the impacts on the parameters from other seismology and geology influences (other than the summary of historic earthquakes)?

7. What is the model's "track record?" (How has the model performed in predicting the recurrence and magnitude of earthquakes, both in the mid-continent U.S. and elsewhere? Has well has the model predicted the insured damage caused by these earthquakes?)

8. How sensitive are the model estimates to assumptions about tectonic plate movement? Please state the tectonic plate movements that were incorporated and their affect on the modeled estimates.

9. Did the model take into account or apply only one type of earthquake? For instance, strike slip or dip slip.

10. How were the following factors taken into consideration in the earthquake model?
    a. Building construction – unreinforced masonry vs. seismic designed
    b. Building height
    c. Building location – soil type

1. What analyses have been done on different soil types?

2. Provide a list of past earthquakes that were capable of causing property damage in your state. What other characteristics are used to model earthquake frequency, location, intensity and duration?

3. Describe the historical earthquake data used for each of these characteristics identifying all earthquakes data included. Describe the dependencies among variables and how these are represented in the model. For the earthquake characteristics modeled as random variables, describe the probability distributions being considered in the covariance or dependency among the variables. Identify the:
    a. date
    b. location and intensity
    c. appropriate parameters
    d. data source
    e. earthquakes whose parameters are uncertain, in dispute or based on approximations.

4. How does the probability of earthquake occurrence compare to the historical and geological records with respect to frequency, intensity and geographical locations?

5. Please provide a table that shows the relationship between shake intensity and expected losses.

Use of Output

1. How were the epicenter locations, selected for iterations?

2. How has the model output been used in the filing? Are results used for statewide indications, territorial indications, etc.?

3. What data adjustments have been made for earthquakes from other regions that are incorporated in the model?

SECTION C: QUESTIONS SPECIFIC TO HURRICANE MODELERS
Unlikely to get answers other than general is trade secret

Model

1. Are the model results near term or long term results? What definition of near term and long term is being used?

2. In hurricanes, construction, location and secondary modifiers play a role in insurer's risks. How were these factors included in the hurricane model? What secondary modifiers are not being questioned relevant to building codes, mitigation features, and demand surge coverage?

3. When looking at the construction of a building in a hurricane prone area, does it have:
    a. Bracing Gable – ends in roof framing
    b. Upgraded exterior wall opening protections
    c. Upgraded exterior doors
    d. Shutters
    e. Building Code
    f. Roof to wall connection
    g. Year Built
    h. Age of Roof Type of Roof
    i. Secondary Water resistance

1. How is wind intensity and duration measured? How do the models determine wind intensity and duration at one location for a hurricane that makes land fall at another location? What database was used by the models? How do modeled results for wind intensities compare to the historical record?

2. What is the probable cost of loss of insured property after such a large hurricane – cite assumptions needed and used?

3. Were storm surge, demand surge, hurricane frequency distribution, off shore oil rig losses and Caribbean Clash Modeling included in the hurricane model?

4. Does meteorology reflect historical storm parameters not losses? What are the meteorology characteristics and is their statistical simulation reflecting uncertainty?

5. Is vulnerability reflected with engineering support and loss support?

6. Is there a statistical part that shows uncertainty analysis?

7. Does the actuarial portion reflect uncertainty and coverage?

8. Does the model identify location using latitude/longitude? If geocoded, how accurate is the

geocoding? If the location is less detailed, such as census block or zip code, how can it be accurate?

9. How is surface roughness, buildings, trees, etc. reflected and what data is used? Is the data current?

10. Provide a comparison of actual to modeled storms adjusting for change in exposure and explain the differences

<u>Historical Validation</u>

1. Provide a list of past hurricanes that were capable of causing property damage in your state. Identify the date, location and intensity, and appropriate parameters. Identify the data source. Identify hurricanes whose parameters are uncertain, in dispute or based on approximations.

2. What other characteristics are used to model hurricane frequency, location, intensity and duration? Describe the historical hurricane data used for each of these characteristics and identify all the hurricanes used. Describe the dependencies among variables and how they are represented in the model. For hurricane characteristics modeled as random variables, describe the probability distributions.

3. How do the modeled probability distributions of hurricane characteristics compare to those in the currently accepted scientific literature. How does the probability of occurrence of hurricanes compare to the historical record for frequency, intensity and geographical locations.

4. How do the modeled results compare to the historical results for the recurrence and size of hurricanes, both in Florida, the Gulf of Mexico and coastal areas? How do the modeled results compare to the historical losses caused by these hurricanes?