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NAIC Catastrophe Modeling Primer

March 2025

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Purpose of the Primer and Background of Catastrophe Modeling

The purpose of the *NAIC Catastrophe Modeling Primer* (Primer) is to provide information to state insurance regulators who need a basic understanding of catastrophe modeling. The Primer's intention is not to be all-inclusive; instead, it suggests the consideration and exploration of areas and concepts that could 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 Modeling Center of Excellence (COE). Since the COE provides training on the more technical aspects of catastrophe modeling, the Catastrophe Insurance (C) Working Group of the Property and Casualty Insurance (C) Committee 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 a department of insurance's (DOI's) 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 (PMLs) for these severe events.

Hurricane Andrew was one of the costliest natural disasters in U.S. history, with extensive insurance payouts for homes, vehicles, and businesses damaged by the storm in both Florida and Louisiana.[3] Following Hurricane Andrew, it was established that calculations based strictly on historical losses may underestimate 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]

Following Hurricane Andrew's landfall, catastrophe modelers projected that 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, Hurricane Andrew's actual cost totaled $15.5 billion.[4]

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[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

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.[5]

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 numerous losses of life. This earthquake was another major catalyst for the use of catastrophe modeling in the United States.[6] The Northridge Earthquake marked the end of an approach to assessing earthquake risk in California 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.[7]

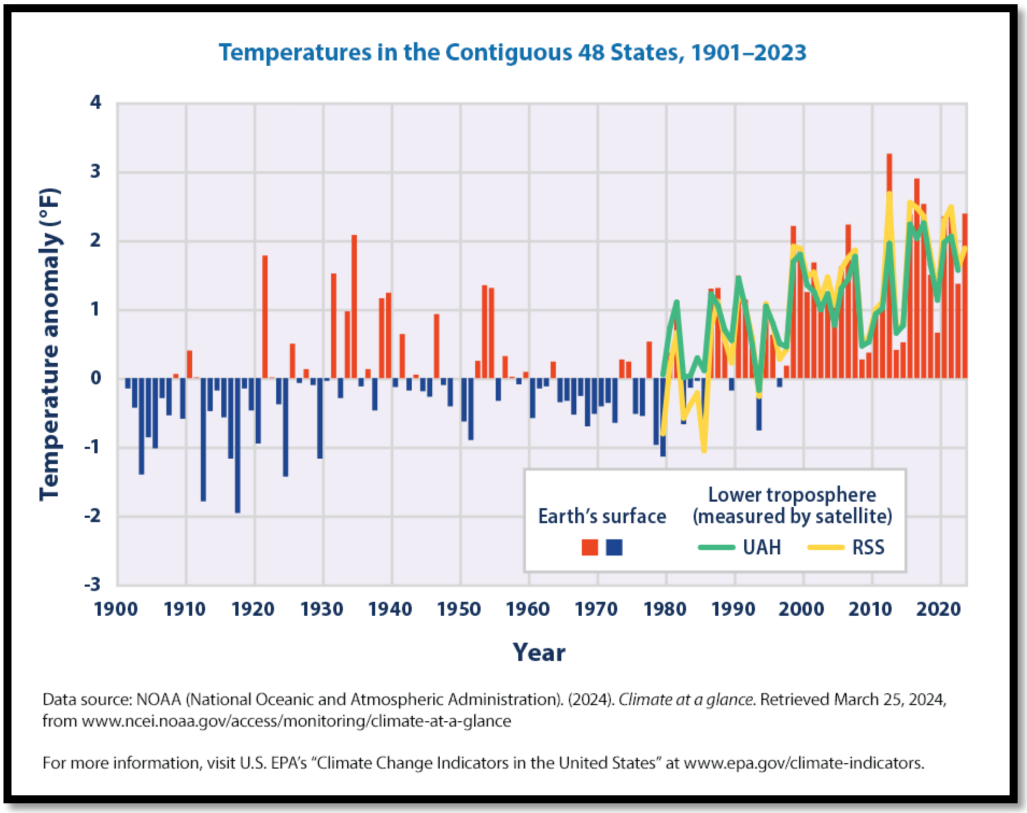
Observed Trends of Hazards and Losses

Hurricanes Ian, Katrina, and Harvey caused severe wind-driven and flood damage, while 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°F per decade, and the rate of warming has tripled since 1982. 2023 was the warmest year on record, and the 10 warmest years have all occurred in the past decade.[8] The data in Figure 1 shows how annual average temperatures have changed throughout the decades.[9]

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

Figure 1: Shifts in Annual Average Temperatures Over Time



Wildfire

From 1983 to 2022, the National Interagency Fire Center (NIFC) 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.[10]

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. 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.[11]

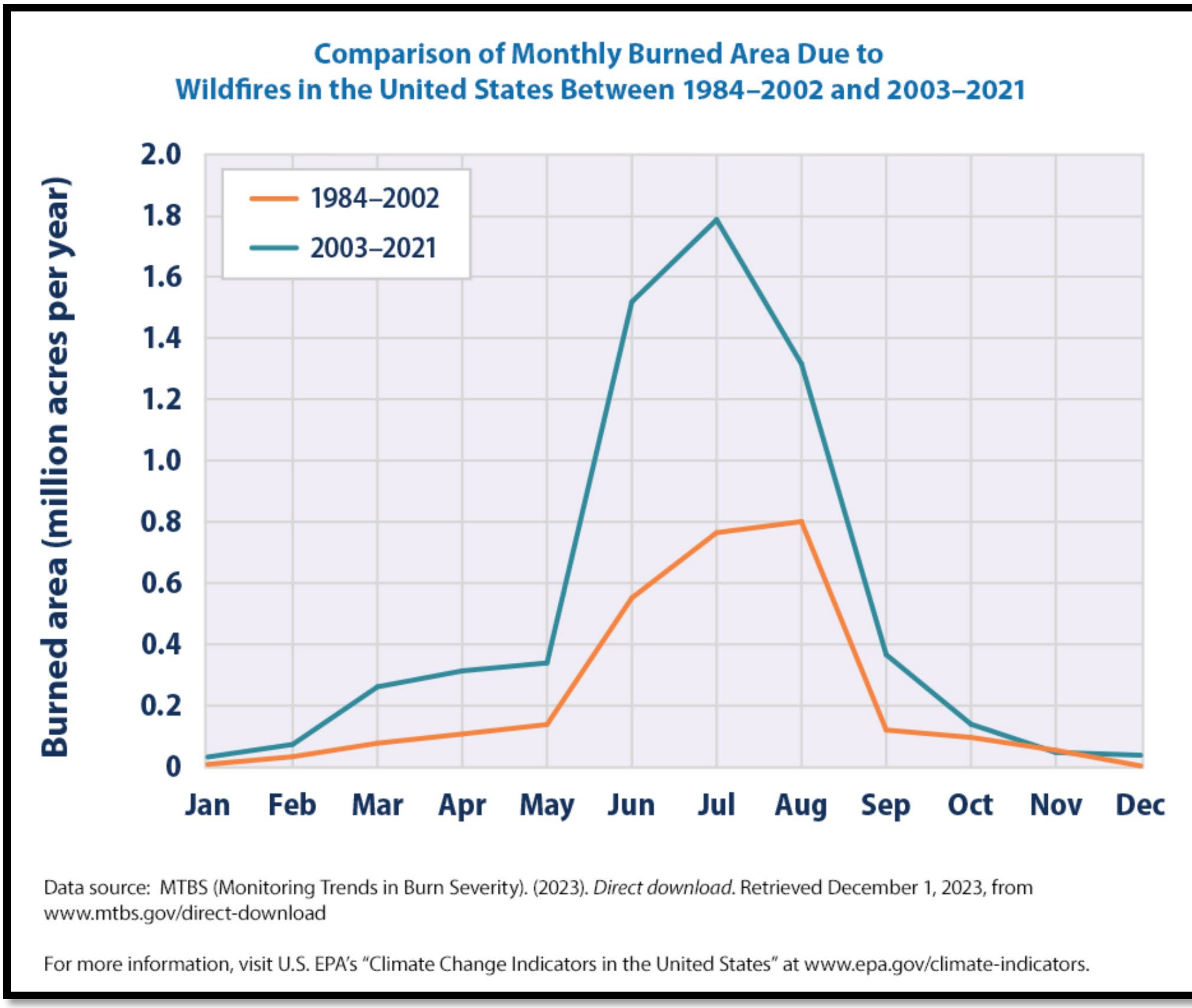
In conjunction with increasing temperatures, the most dramatic impact from wildfires has been observed mainly in the western and southwestern states.[12] Continued and increased development in the wildland-urban interface (WUI) across the country has led to increased frequency and costlier wildfires, tripling the length of the wildfire season and causing more destructive fires.[13] While wildfire is considered a "natural disaster," 85-90% of wildfires occurring nationwide are caused by humans.[14] No matter the cause of a fire, the increase in

[10] https://www.epa.gov/climate-indicators/climate-change-indicators-wildfires#:~:text=The%20extent%20of%20area%20burned,have%20increased%20since%20the%201980s
[11] https://www.climatecentral.org/climate-matters/longer-more-intense-fire-weather-seasons
[12] https://www.dryad.net/post/understanding-the-wildland-urban-interface#:~:text=The%20expansion%20of%20the%20wildland,proximity%20with%20wildfire%2Dprone%20areas.
[13] https://www.epa.gov/climate-indicators/climate-change-indicators-wildfires
[14] https://wfca.com/wildfire-articles/are-wildfires-natural-disasters/#:~:text=Although%20not%20all%20wildfires%20are,a%20result%20of%20human%20activity.

hot, dry, and windy conditions impacts the availability of materials that can burn. This influences how fire ignites, lasts, and spreads, and it may hinder actions to control it.[15]

In January 2025, Los Angeles faced one of the most devastating wildfires in history. The Palisades and Eaton Fires were particularly destructive, causing property damage estimated between $95 billion and $164 billion, with insured losses amounting to $75 billion.[16]

Figure 2: Comparison of the Difference in the Amount of Burned Acres Between Certain Time Periods



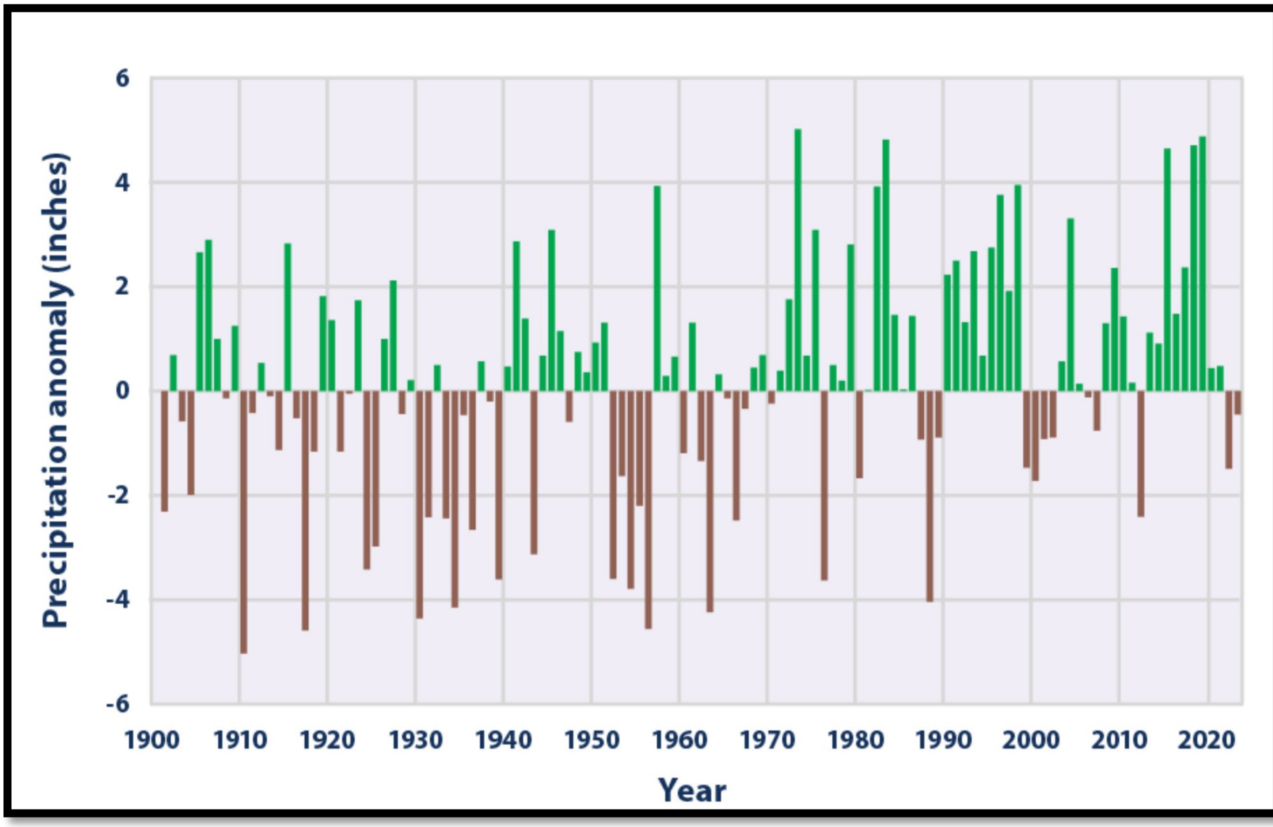
Precipitation

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.[17] Heavy rainfall is increasing in intensity and frequency across most of the United States, heightening the risk of floods and flash floods.[18]

[15] https://www.climatecentral.org/toolkit-wildfire
[16] https://www.anderson.ucla.edu/about/centers/ucla-anderson-forecast/economic-impact-los-angeles-wildfires
[17] https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature#:~:text=Highlights,0.20%C2%B0%20C)%20per%20decade.
[18] https://www.globalchange.gov/indicators/heavy-precipitation

In recent years, a more significant percentage of precipitation has stemmed from intense single-day events.[19]

Figure 3: Precipitation in the Contiguous 48 States, 1901–2023



Data Source: NOAA (National Oceanic and Atmospheric Administration). (2024). ***Climate at a Glance.***[20]

According to AON's 2025 *Weather, Climate and Catastrophe Insight*, globally, $368 billion of economic losses resulted from weather and climate events in 2024. Insurance covered only 52% of the weather- and climate-related losses, a noteworthy increase from the previous year. The protection gap, which refers to uninsured losses within a country, is a global challenge. rates of insurance coverage. The expected rise in the frequency and severity of weather events is expected to continue as population growth continues in disaster-prone areas. This further emphasizes the increased need for catastrophe models.[21]

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.[22] People are moving to areas with high climate risk due to affordability, lower taxes, and more housing choices. This has, in turn, led to a decline in the population in areas with lower climate risk.[23]

A property is classified as having high climate risk when it faces a high, very high, or extreme climate risk score from ClimateCheck.[24] The U.S. Climate Vulnerability Index is an interactive map tool that allows the user to apply specific impacts. The tool lets policymakers see which communities face the most significant impacts due to the changing climate. It shows what is driving the challenges so policymakers and communities

[19] https://www.epa.gov/climate-indicators/climate-change-indicators-heavy-precipitation
[20] *Retrieved March 25, 2024, from www.ncei.noaa.gov/access/monitoring/climate-at-a-glance*
[21] https://assets.aon.com/-/media/files/aon/reports/2025/2025-climate-catastrophe-insight.pdf
[22] https://florida.reaproject.org/analysis/comparative-indicators/growth_by_decade/population/tools/
[23] https://www.redfin.com/news/climate-migration-real-estate-2021/
[24] https://climatecheck.com/

can take action to build climate resilience where it is needed the most. To view this information in detail, visit the U.S. Climate Vulnerability Index to view data by location.

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.[25]

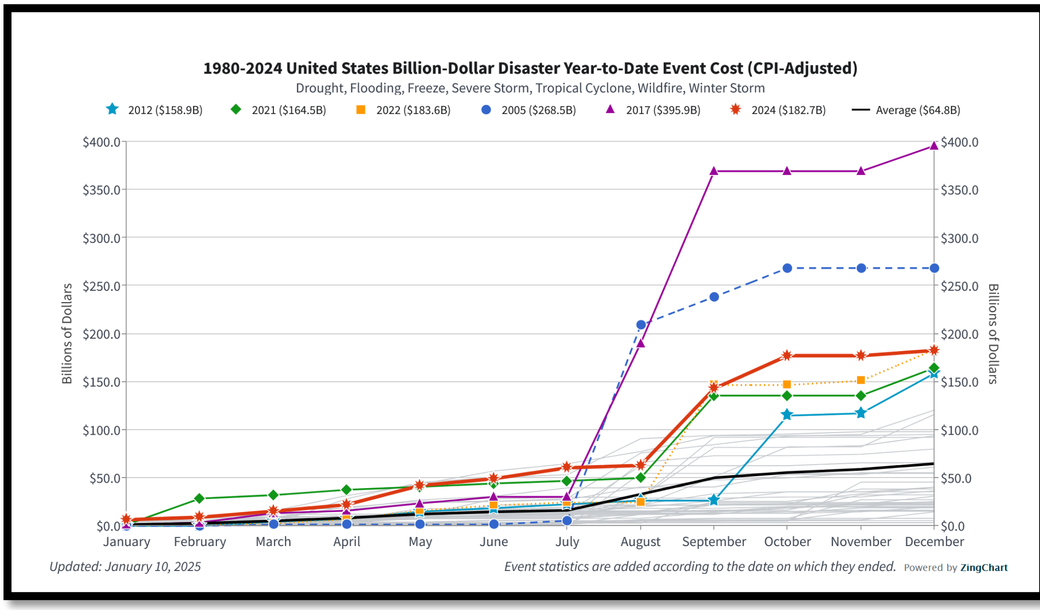
In recent years, the number of flooding and severe storm events has significantly increased compared to all other types of disasters.[26] In 2023, losses from severe convective storms surpassed $50 billion for the first time in a single year.[27]

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.[28]

As of January 2025, the U.S. has seen 403 disasters of $1 billion or greater with losses due to weather and climate-related disasters since 1980, averaging 23 yearly events for the most recent five years (2020–2024). The numbers are CPI-adjusted, and yearly summaries can be found by visiting NOAA Summary Stats. Figure 6 represents these disaster types.[29]

[25] Ibid.
[26] https://usafacts.org/articles/are-the-number-of-major-natural-disasters-increasing/
[27] 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
[28] https://www.iii.org/sites/default/files/docs/pdf/triple-i_state_of_the_risk_convective_storms_10232023.pdf
[29] Source: NOAA National Centers for Environmental Information (NCEI) U.S. Billion Dollar Weather and Climate Disasters (2024)[29]

Figure 4: Graphic Representation of Billion-Dollar Climate-Related Disasters in the U.S. Since 1980



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 storms.[30] Figure 5 illustrates the number of events associated with each disaster type from 1980 to 2024. The summary data can be found on the NCEI's state-summary page.

Figure 5: Number of Events by Disaster Since 1980

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	32	0.7	7.9%	$367.5B	12.6%	$11.5B	$8.2B	4,658	104
Flooding	45	1.0	11.2%	$203.0B	7.0%	$4.5B	$4.5B	742	16
Freeze	9	0.2	2.2%	$37.4B	1.3%	$4.2B	$0.8B	162	4
Severe Storm	203	4.5	50.4%	$514.3B	17.6%	$2.5B	$11.4B	2,145	48
Tropical Cyclone	67	1.5	16.6%	$1,543.2B	52.9%	$23.0B	$34.3B	7,211	160
Wildfire	23	0.5	5.7%	$147.9B	5.1%	$6.4B	$3.3B	537	12
Winter Storm	24	0.5	6.0%	$104.2B	3.6%	$4.3B	$2.3B	1,463	33
All Disasters	**403**	**9.0**	**100.0%**	**$2,917.5B**	**100.0%**	**$7.2B**	**$64.8B**	**16,918**	**376**

[30] Billion-Dollar Disasters: Calculating the Costs | Did You Know? | National Centers for Environmental Information (NCEI) (noaa.gov).

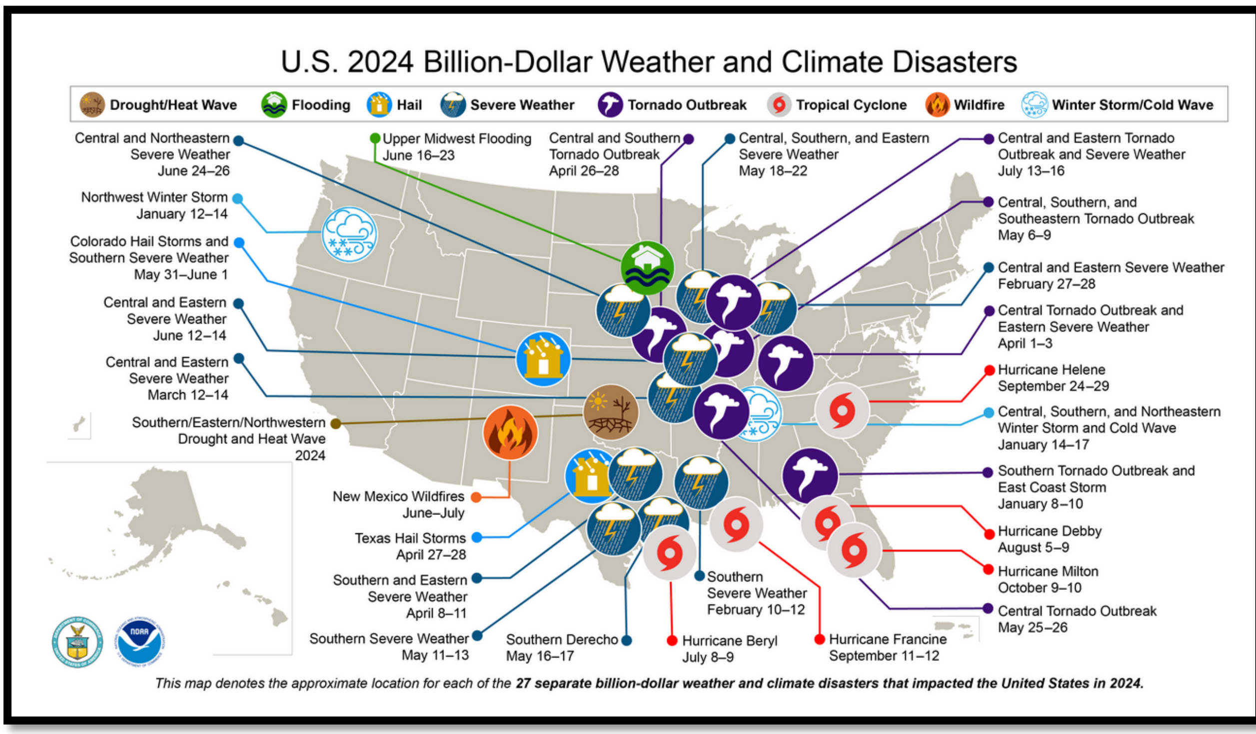
Figure 5 includes the following caveats:[31]

- 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 (NHC), reinsurance industry, and catastrophe modelers all use the NCEI's data by integrating the NCEI's findings into their assessments to consider the risk and loss possibilities throughout the country.[32]

Catastrophic events are occurring more frequently and 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 6 illustrates the billion-dollar weather and climate disasters for 2024.

Figure 6: U.S. 2024 Billion-Dollar Weather and Climate Disasters (CPI adjusted)[33]



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.

It is necessary to distinguish between providing the probability of future events and predicting the future. Catastrophe models provide the probability of potential losses from events that could occur. The stochastic

[31] 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
[32] Ibid.
[33] Source: https://www.ncei.noaa.gov/news/national-climate-202406

catalogs are meant to be robust enough to cover what's possible in terms of future events, but they don't predict future events. This distinction applies to event frequency, location, and severity.

Like any other real-world model, catastrophe models help us to understand the likelihood of scenarios that could happen in the future. By simulating a robust catalog of possible events, catastrophe models help inform the user of the risk of future events, even with a limited historical record.

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

- How likely is an area to be affected by a future event?
- Given a severity threshold, how likely could events exceeding the threshold occur?

Why Use a Catastrophe Model?

Catastrophes, such as 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.[34]

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.[35]

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.[36]

Catastrophe Models Versus Historical Approaches

Extreme weather events occur less frequently, so past information does not include all possible and plausible events.[37] As discovered following Hurricane Andrew, loss estimates using traditional actuarial techniques based on historical loss experience were much lower than the actual losses.[38] 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.

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

[34] https://www.milliman.com/en/insight/taking-catastrophe -models-out-of-the-black-box
[35] Nov. 3, 2020, Insurance Summit Event Development of a Private Flood Market, Brandon Katz
[36] https://www.milliman.com/en/insight/taking-catastrophe-models-out-of-the-black-box
[37] https://www.milliman.com/en/insight/taking-catastrophe-models-out-of-the-black-box
[38] https://www.insurancejournal.com/magazines/mag-features/2022/05/16/667461.htm

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 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.[39]

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 versus most detailed) depending upon the use case, such as county, state, or postal code level or at the individual location level.[40]

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 books 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/casualty (P/C) insurance industry, helping insurers and other entities manage catastrophic risks from various perils. Catastrophe models 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.[41]

Rating agencies rely on catastrophe models to aid in their assessment of an insurer's solvency risk. Catastrophe models evaluate whether catastrophe-exposed insurers can effectively manage the associated risk, whether they have the potential to sustain potential losses, and whether they can have the financial strength to sustain potential losses.[42]

Finally, catastrophe models allow insurers to project possible financial losses arising from catastrophes. 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.[43]

The PML represents the estimated loss value associated with a low-probability, high-impact event. This probability threshold is often expressed as the event's return period. The choice of a specific return period depends on the company's approach to catastrophe risk management and its defined risk appetite.

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?

[39] (Nov. 3, 2020 Insurance Summit Event Development of a Private Flood Market, Brandon Katz)
[40] https://www.iii.org/article/catastrophe-modeling-vital-tool-risk-management-box
[41] Ibid.
[42] Ibid.
[43] Ibid.

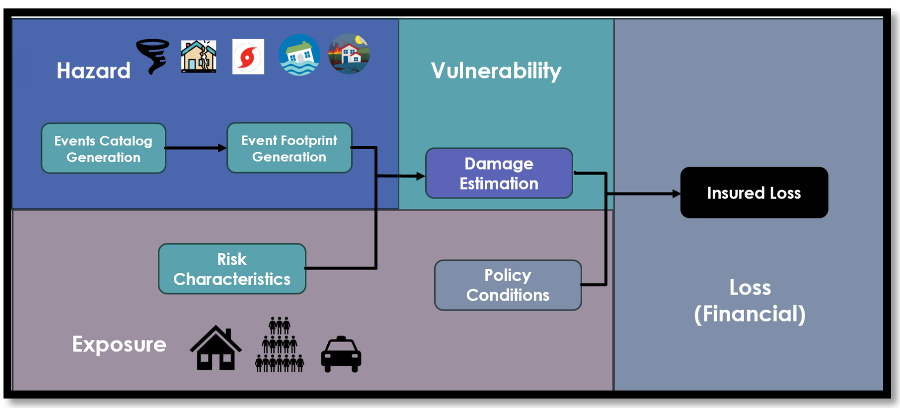
- What new business opportunities (territories and/or lines of business) should the insurer consider adding?
- How much could the insurer potentially lose in low probability scenarios, such as a 1 in 100-year event?
- How can the insurer best mitigate these risks?
- Does the insurer have sufficient capital 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, which include tornadoes, hail, and wildfires. They also exist for man-made catastrophes like terrorism and emerging risks like cyber.[44]

Figure 7 shows the basic framework for modeling the impacts of natural hazards on a portfolio of exposures, which can be divided into four modules.

Figure 7. Components of Catastrophe Models



1. Hazard module (also known as the local intensity calculation module or event footprint generation)
2. Vulnerability module
3. Exposure module
4. Financial module

Note that the exact terminology used by each model vendor may vary slightly from what is described above.

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:

1. Event catalog

[44] 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

2. Event footprint

An event catalog consists of a probabilistic event set, which is a database of simulated scenario events.[45] Each event set draws upon data from meteorological history, geology, and geography.[46] 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.[47] 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.[48]

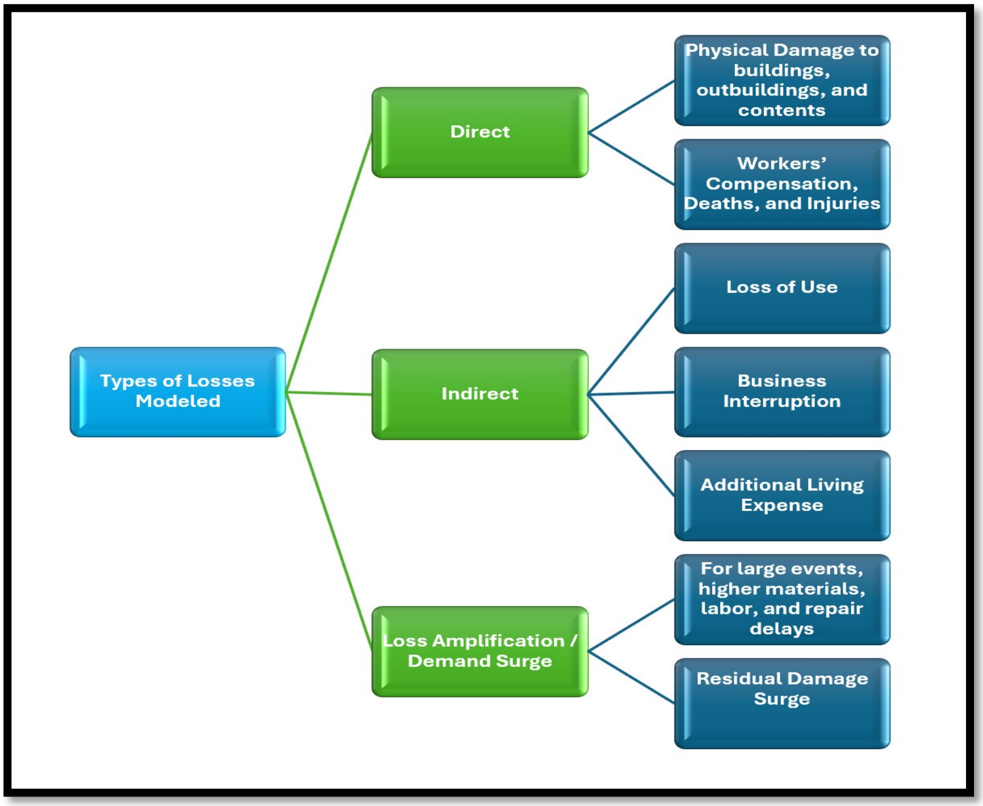
Each event in the event catalog is characterized by a specific strength or size, location, path, and annual probability of occurrence (also known as event rate). Every event scenario in the catalog is associated with a unique event footprint reflecting the relative intensity and extent of the hazard 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 amount of damage or a collapse from a given hazard intensity.[49] This module also calculates additional living expenses (ALE) or business interruption losses (indirect loss). (Refer to Figure 8)

[45] 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
[46] 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
[47] https://www.rms.com/catastrophe-modeling?contact-us=cat-modeling
[48] 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
[49] 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

Figure 8: 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 the roof, roof-to-wall connection, and opening protection.[50]

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 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.

[50] 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

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.[51]

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, such as deductibles and limits, to reach these loss estimates.[52] 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.

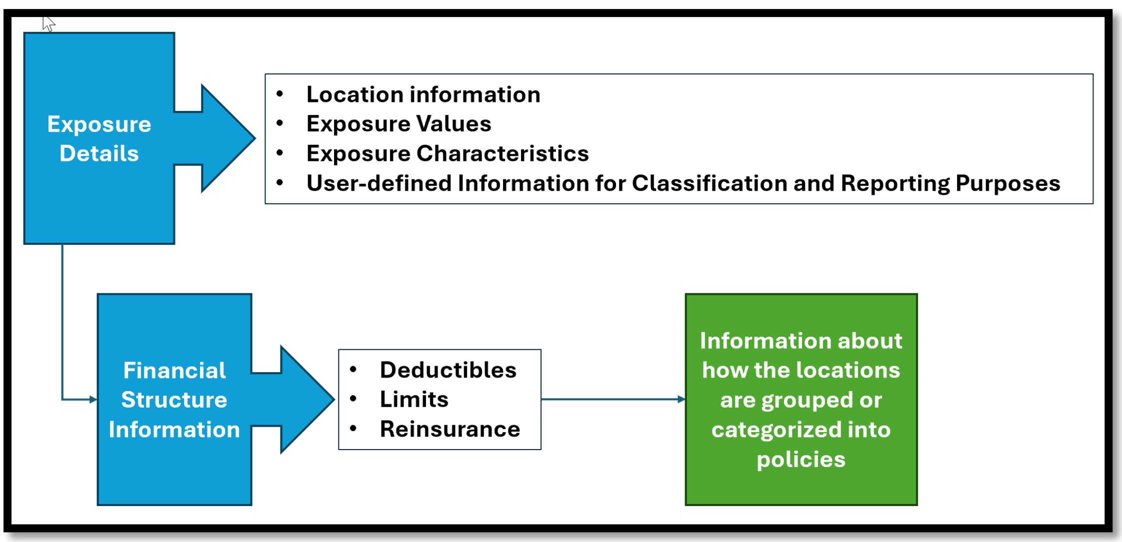
Inputs

Catastrophe event simulations require a broad combination of inputs. Exposure details required by a catastrophe model must include detailed location information, total insured value (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 9: 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.

[51] 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
[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

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.

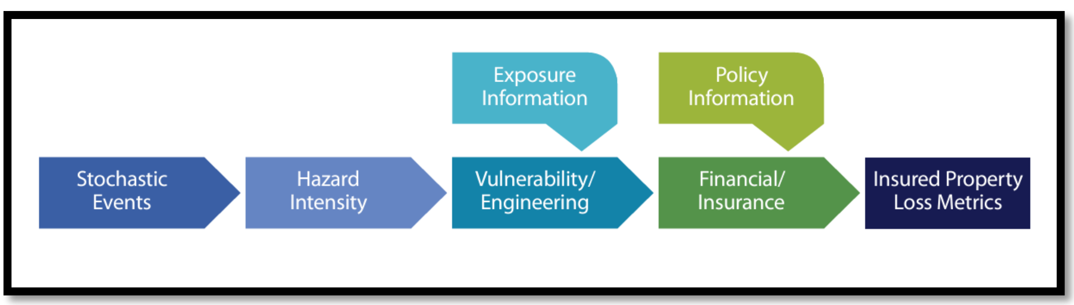
The catastrophe model evaluates the given coordinates' accuracy based on the input address's quality. The model indicates the level of detail in the match, distinguishing between a high-resolution match (e.g., street, building, or parcel) and a low-resolution match (e.g., postal code or city). Catastrophe 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. [53]

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.[54]

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. 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.[55] Figure 10 illustrates the process used to obtain the output.

Figure 10: How Catastrophe Model Components Interact[56]



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

Key Metrics and Outputs

Average Annual Loss

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

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

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

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.[57] It is important to note that AALs can even be calculated down to the single risk level, and insurers may consider that to determine whether a policy is likely to be profitable.

Exceedance Probability Curves

Catastrophe models produce exceedance probability (EP) curves. These curves represent loss distribution based on 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

The occurrence exceedance probability (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

The aggregate exceedance probability (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 the return period. 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 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.

[57] https://insnerds.com/using-catastrophe-models/

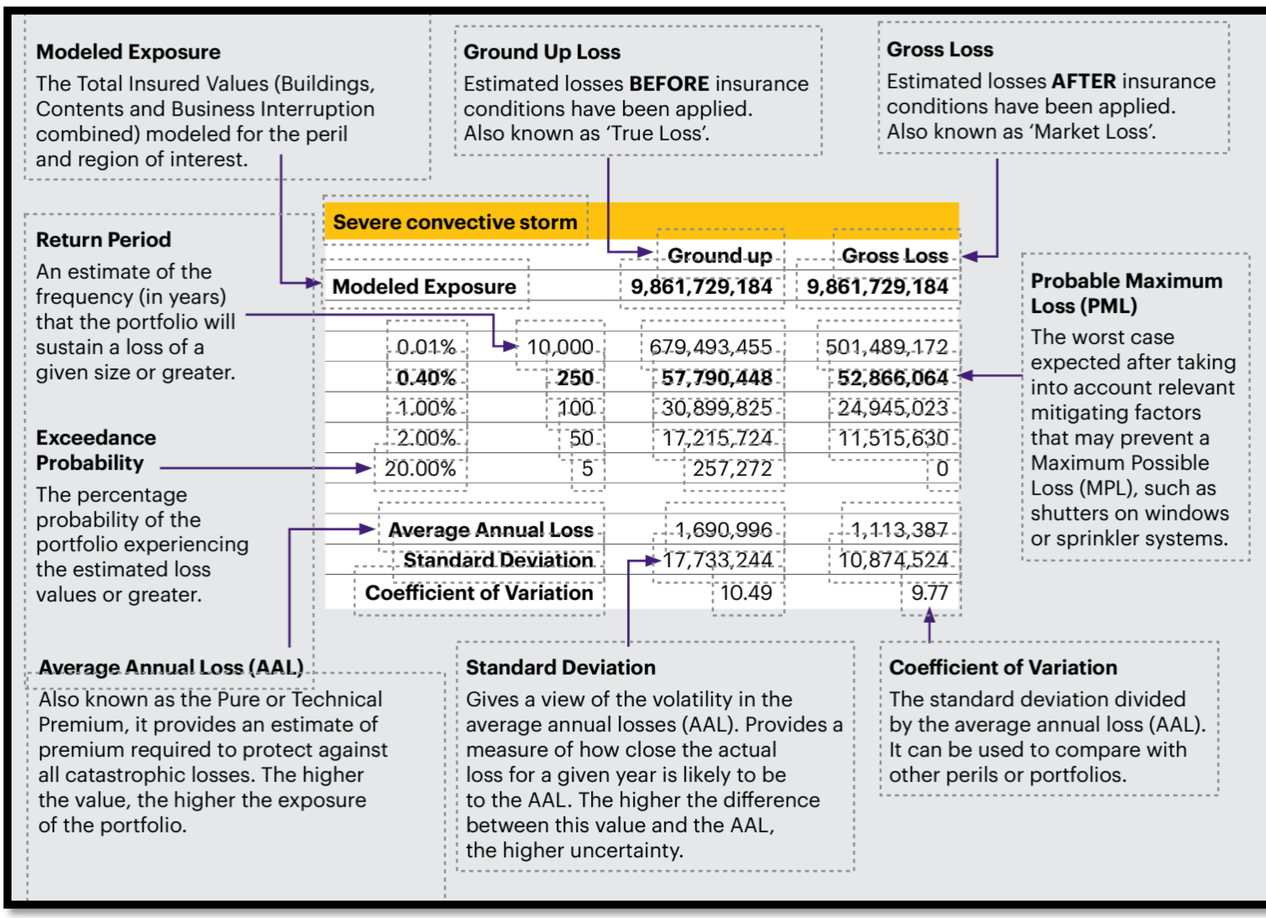
Insurers often use catastrophe models to help them determine the appropriate level of reinsurance coverage the insurance company should purchase for natural catastrophe perils by looking at the return period of a certain loss size.[58] The return period helps companies set the attachment/retention and exhaustion levels.

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

Probable Maximum Loss

The PML, or probability of exceeding a specified loss, shows how likely it is to exceed a certain amount of loss. (Refer to Figure 11) 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 11: A Typical Modeled-Loss Calculation[59]



Modeled Hazards

Since 2010, when the *NAIC Catastrophe Computer Modeling Handbook* (now referred to as the *Catastrophe Modeling Primer*) was published, new perils have been modeled, including catastrophic events such as cyber, flooding, terrorism, and wildfire. Various experts create and evaluate these models.[60]

[58] https://www.marsh.com/pr/en/services/property-risk-management/insights/catastrophe-modeling.html
[59] Source: Managing Convective Storm Risks
[60] https://www.doi.sc.gov/DocumentCenter/View/7001/Catastrophe-Models-FINAL-07232013?bidId=

Catastrophes

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 challenge. Model vendors offer two types of earthquake catalogs: time-dependent and time-independent. In the time-dependent catalog, the likelihood of an earthquake changes over time to reflect shifts in the seismic environment. For example, after a major earthquake, the probability of another large earthquake occurring along the same fault line decreases because much of the stored energy has already been released.

These models rely on the expertise of scientists in relevant fields, such as geology, seismology, and structural engineering, to draw on information from the United States Geological Survey (USGS) National Seismic Hazard Model. USGS regularly updates the hazard model to account for the frequency and severity of earthquakes.

The USGS has been publishing hazard models for the United States and its territories since 1996, and a hazard toolbox is available for querying and computing hazards from the USGS's hazard models.[61]

Hurricane

Hurricane models use various 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.[62]

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.[63]

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.[64]

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 is 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.[65]

There are four types of flooding: 1) fluvial floods (river floods); 2) pluvial floods (flash floods); 3) coastal floods (storm surges); and 4) tsunamis (inundation).[66]

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[61] USGS Earthquake Hazard Toolbox
[62] https://www.doi.sc.gov/DocumentCenter/View/7001/Catastrophe-Models-FINAL-07232013?bidId=
[63] Ibid.
[64] Ibid.
[65] https://www.air-worldwide.com/blog/posts/2019/3/the-role-of-catastrophe-models-in-the-evolution-of-the-flood-insurance-market/
[66] 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

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.[67]

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 suddenly releases water or by excessive snowmelt. Flash floods are particularly dangerous because the water moves with great force, making it difficult to navigate.[68]

Coastal flooding occurs when seawater rises and covers the land along the coast. This happens due to strong windstorms and may be exacerbated by high tide. Storm surge is an abnormal rise of water generated by a storm over and above the predicted astronomical tides and is often related to a hurricane or typhoon.[69]

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.[70]

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.[71]

If a convective storm contains at least one of the following, it is considered a severe convective storm: 1) hail that is one inch or larger; 2) over 57.5 mph wind gusts; or 3) a tornado.[72] 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.[73]

Due to the complex nature of severe convective storms, modeling the peril of these weather events presents several challenges. The severe convective storm 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.

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.[74]

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.

[67] Ibid.
[68] Ibid.
[69] Ibid.
[70] https://aegaea.com/flood-modelling/#:~:text=Flood%20modelling%20uses%20predicted%20river,flood%20levels%2C%20and%20hazards
[71] https://www.wtwco.com/en-us/insights/2024/01/a-guide-to-managing-severe-convective-storm-risks
[72] https://www.assetworks.com/convective-storm-modeling-details-rm20/
[73] Ibid.
[74] 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.[75]

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.[76]

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 and firefighting suppression efforts when these events occur.[77]

Winter Storms

Winter storms can take three forms: 1) freezing rain; 2) sleet; or 3) 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, such as 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.

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. 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.[78]

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[75] 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
[76] 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
[77] 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
[78] https://www.insurancethoughtleadership.com/cyber/how-cat-models-are-extending-cyber

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.[79]

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.[80]

Terrorism

When it comes to predicting terrorism, there is 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 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.

[79] Ibid.
[80] Ibid.

The State Insurance Regulator Perspective

State DOIs do not 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, such as wildfire and flood, have emerged more recently. Since large losses from catastrophic events can 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.[81]

Financial Solvency

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

Ratemaking

As part of the rate filing process, an insurer often receives 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 insurer's 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, including 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.[82]

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 *Actuarial Standard of Practice [ASOP] No. 39, Treatment of Catastrophe Losses in Property/Casualty Insurance Ratemaking*).

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-

[81] 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
[82] https://www.air-worldwide.com/blog/posts/2015/8/insurers-and-cat-models-under-the-regulatory-lens/

specific data with countrywide or company-specific data with industry information. For details, refer to ASOP No. 39.

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.

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).[83]

Catastrophe models for more recently modeled perils do not have the same maturity level as those for perils that have been modeled for 20 or more 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, such as wildfire, which itself is a complex peril. However, this does not mean that less mature models are unreliable. Effective use of less mature models may require more analysis about how the results were reached, and modifications may be required.[84]

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.[85]

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.[86]

State insurance regulators recognize the freedom of information laws may necessitate that all information they receive requires public disclosure of all information received.[87]

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.[88]

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[83] From the original NAIC Catastrophe Modeling Handbook
[84] https://www.milliman.com/en/insight/taking-catastrophe-models-out-of-the-black-box
[85] Original NAIC Catastrophe Modeling Handbook
[86] Ibid.
[87] Ibid.
[88] Ibid.

State insurance regulators continuously pursue new sources of information and accurate recommendations to help them understand model input, output, and methods.[89]

California

As of December 12, 2024, California passed regulations that allow insurers to use catastrophe models to project fire risk reflected in the overall rate level. It should be noted that California has always accepted modeled wildfire losses in the determination of rate segmentation (e.g., establishing rate relatives by territory or wildfire score).

California Code of Regulations 10 CCR § 2644.4.5 allows models for earthquake, flood, fire following earthquake (FFEQ), terrorism, and wildfire ratemaking in California.

California Code of Regulations 10 CCR § 2644.9 requires that insurers develop or update their homeowners 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.[90]

The FCHLPM is independent of FLOIR. However, Florida statute requires that FCHLPM membership include 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 P/C insurers using catastrophe models to support proposed rates filed with the LDI. This bulletin focuses on

[89] Ibid.
[90] Florida Statute 627.0628

modeling specific to the hurricane peril; however, the guidance provided should be used for other perils where applicable.[91]

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. Refer to Appendix 3 for the questionnaire Maryland uses.

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 it does 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 the DOI would take going forward and how the industry should respond regarding the making of South Carolina 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. [92]

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.
- The approval and expiration dates set by the Florida Commission on Hurricane Loss Projection Methodology (FCHLPM).

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.[93]

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 profoundly serves the insurance market. 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.

[91] https://www.ldi.la.gov/docs/default-source/documents/legaldocs/bulletins/bul2013-04-cur-catastrophemodelinte.pdf?sfvrsn=38e67c52_14
[92] https://doi.sc.gov/DocumentCenter/View/7478/2014-03-Hurricane-Cat-Models-in-Property-Rate-Filings?bidId=
[93] https://www.doi.sc.gov/432/Property-Casualty

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

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

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[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?

PROJECT HISTORY - 2025

NAIC CATASTROPHE MODELING PRIMER

1. Description of the Project, Issues Addressed, etc.

The *NAIC Catastrophe Modeling Primer* (Primer) was referred to the Catastrophe Insurance (C) Working Group of the Property and Casualty Insurance (C) Committee by the Climate and Resiliency (EX) Task Force. Updating the *Catastrophe Computer Modeling Handbook* (Handbook), now known as the Primer, was an existing charge for the Working Group. The Handbook was last updated in 2011.

The Primer provides the fundamental concepts surrounding probabilistic catastrophe models. It serves as a bridge to available training from the Center for Insurance Policy and Research's (CIPR's) Center of Excellence (COE).

The Primer provides background on catastrophe models and their use by regulators who need an introduction to catastrophe modeling. It is advisory only and is not intended to provide mandatory guidelines.

Topics covered in the Primer include:

- The evolution of catastrophe modeling
- What a catastrophe model is
- How catastrophe models work
- Model components
- Key metrics
- Regulatory interaction

The Primer is not intended to replace any work completed by the COE, but to serve as a high-level introduction to catastrophe modeling. The COE provides state insurance regulators with technical training and expertise regarding catastrophe models and information about their use within the insurance industry. The Primer will be particularly useful to employees entering the department of insurance (DOI) workforce.

2. Name of Group Responsible for Drafting the Model and States Participating

The Catastrophe Insurance (C) Working Group of the Property and Casualty Insurance (C) Committee was responsible for drafting the Primer. Participating states included California, Connecticut, Florida, Iowa, Missouri, North Carolina, and Pennsylvania.

3. Project Authorized by What Charge and Date First Given to the Group

The project was authorized by the Catastrophe Insurance (C) Working Group's charge to: "Consider revisions to the *Catastrophe Computer Modeling Handbook*." The charge was given to the Working Group in late 2021 and first addressed in 2022.

4. A General Description of the Drafting Process (e.g., drafted by a subgroup, interested parties, the full group, etc). Include any parties outside the members who participated

A drafting group was formed in April 2022 to begin drafting the Primer. Prior to drafting the document, the Working Group distributed a survey to the states to get an idea of how they were currently using the Handbook. The survey revealed that the Handbook was not used regularly.

After discussing the Handbook with the COE and stakeholders, the Working Group settled on simplifying it and creating a Primer.

This project created an entirely new 39-page document. The drafting group met regularly starting in 2024.

5. **A General Description of the Due Process (e.g., exposure periods, public hearings, or any other means by which widespread input from industry, consumers, and legislators was solicited)**

The Working Group exposed the Primer on Oct. 23, 2024, for a 30-day public comment period ending Nov. 22. The Primer was finalized in January 2025, and the Working Group adopted it March 25 during the Spring National Meeting. The Property and Casualty Insurance (C) Committee adopted the Primer March 26.

6. **A Discussion of the Significant Issues (items of some controversy raised during the due process and the group's response)**

The COE and the drafting group reviewed the Primer before it was finalized.

7. **List the key provisions of the model (sections considered most essential to state adoption)**

N**/A**

8. **Any Other Important Information (e.g., amending an accreditation standard)**

N/A

