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What is a Catastrophe Model? Primer #02
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What is a Catastrophe Model?

A catastrophe model is a simulation-based model of disasters to estimate potential economic losses

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Natural hazards, such as hurricanes, earthquakes, and wildfires, can cause widespread and devastating losses. To decide where to offer coverage and how much to charge, insurers and reinsurers must quantify the potential frequency and magnitude of claims. To stay solvent after a major disaster, they need to understand not just expected annual losses but also worst-case scenarios. To do this, they use catastrophe ("cat") models.

A catastrophe model is a mathematical framework that simulates hazards and estimates associated economic losses using three main components:

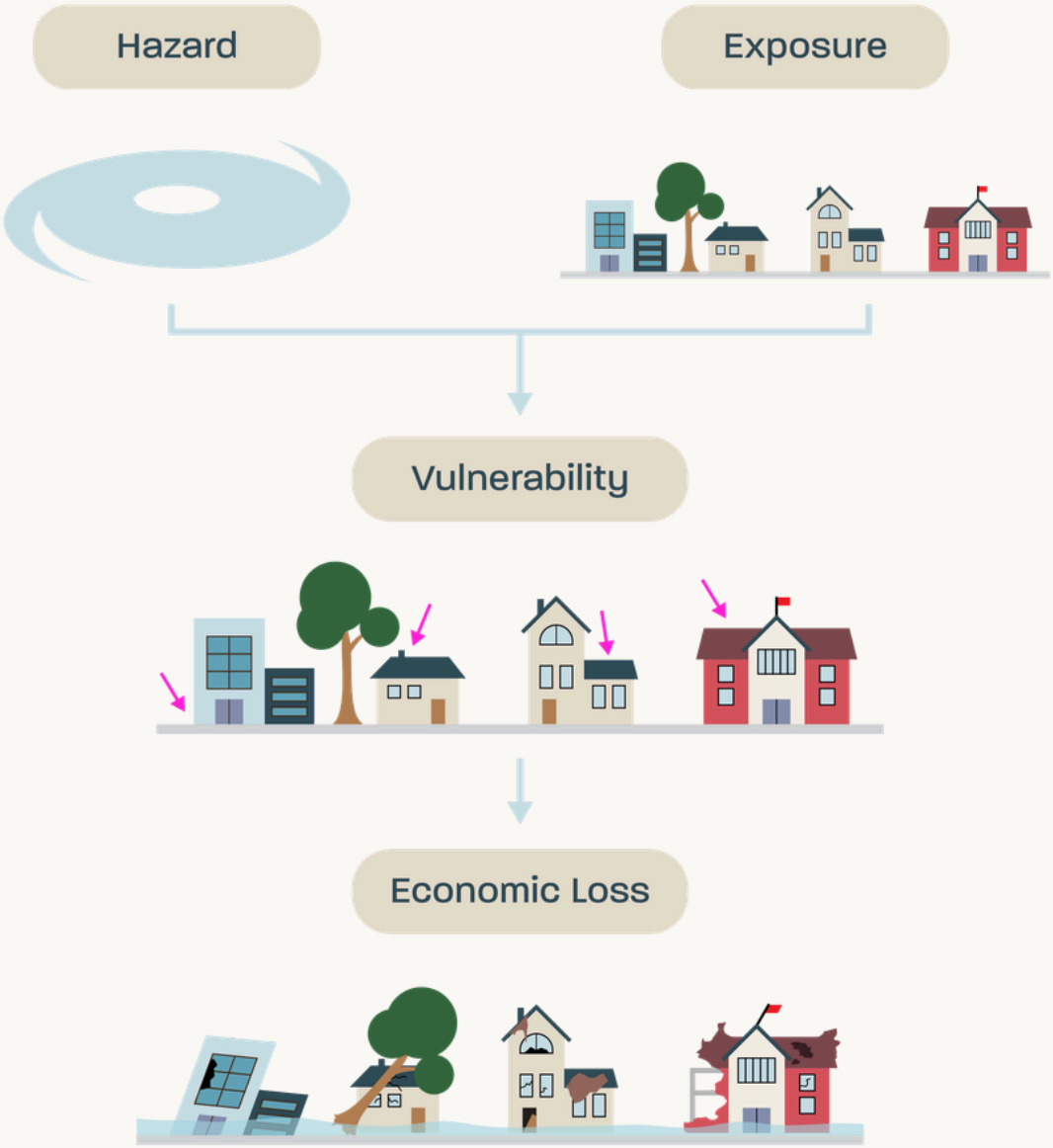
1. **a hazard module**
2. **an exposure database**
3. **a vulnerability module**

The **hazard module** runs thousands of simulations of the physical hazard to generate a probability distribution. Each model run produces one possible realization of the hazard, and enough runs are needed for the distribution to converge on a stable estimate. For example, in a hurricane model, each run generates a single simulated storm. Together, thousands of simulated storms define a probability distribution of wind speeds at different locations.

The results of these hazard simulations are then coupled to an **exposure database**. For an insurance company, this would identify all the properties they insure and the characteristics that influence losses, such as the type of roof, the building code used for construction, or the presence of a basement.

Finally, a **vulnerability module** estimates expected losses using functions that relate hazard levels to building characteristics. These functions, called *vulnerability curves* or *damage functions*, describe how much damage a structure would sustain at a given hazard intensity. For example, in a flood model, the damage function would relate flood depth to a percentage of structural damage.

Structure of a Catastrophe Model



What is the Output of a Catastrophe Model?

For a specific peril, cat models generate dollar amounts of potential losses that insurers and reinsurers may face at given hazard intensities, each with its own probability of occurrence. The model can then take those estimated losses and adjust based on insurance policy information, such as deductibles and coverage limits, to estimate potential claims for an insurance company. Losses are reported by return period and annual exceedance probability (AEP), two related measures used to describe the likelihood and associated impacts of hazard events.

The **return period** is the average interval between events of a given magnitude (for example, a 100-year, or 1-in-100-year, event), with longer return periods indicating rarer and generally more severe events. The **annual exceedance probability** (AEP) is the chance that an event associated with a given return period occurs in any single year. For example, a 100-year return period event has an AEP of 1% (0.01), meaning it has a 1-in-100 chance of being equaled or exceeded in any given year. Over the long term, such events occur once every 100 years on average.

Summarizing across event magnitudes and their associated probabilities yields several different metrics of loss. The most widely used is the average annual loss (AAL), which estimates the loss expected in a typical year. However, a single average provides little insight into losses induced by rare, extreme events that could threaten an insurer's solvency. Catastrophe models therefore also report losses at long return periods, such as the 100-, 200-, and 500-year loss levels, against which regulators and rating agencies require insurers to hold capital to ensure financial resilience.

How are Catastrophe Models Different from Climate Models and Weather Forecasting Models?

Cat models, climate models, and weather forecasting models are designed to answer different questions over different time periods. Cat models estimate potential economic losses from specific hazard events, typically over a near-term horizon, such as one year. Climate models simulate the Earth system over decades to centuries, including future climate-scenario based projections and past climate reconstructions, to describe the evolution of climate variables, such as temperature, precipitation, and large-scale atmospheric and oceanic conditions. Weather models use current conditions to predict local weather conditions over hours or days.

While all three are physics-based mathematical models, they differ substantially in methods, scale, and intended purpose. Cat models use a combination of physics (hazard generation), engineering information on structural vulnerability (property damage), and statistics (economic loss calculations) to estimate potential losses from simulated hazard events. The inputs for cat models include exposure data and financial information—for example, structure location, building characteristics, and insurance policy terms—along with simulated hazards. Outputs include loss estimates and probability distributions of losses for the current year.

Climate models primarily solve physical equations governing the Earth system to simulate large-scale climate behavior over long time horizons, rather than individual hazard events. Simulations begin with an observed baseline state of the atmosphere, ocean, and land. During each run of a climate model, physical equations are solved to project how climate variables change over time under different greenhouse gas (GHG) and solar forcing scenarios. They output simulated trajectories of Earth system variables such as temperature, precipitation, and

ocean conditions at various time stamps for each resolved point across the globe for 50 to 100 years. Models have different spatial resolutions that can span from 30 to 250 kilometers. Because they operate at relatively coarse resolutions across space and time, they do not explicitly resolve localized extreme events, such as hurricanes, tornadoes, or wildfire ignition. Instead, they represent changes in large-scale climate conditions from which variations in hazard frequency and intensity may be indirectly inferred.

Weather forecasting models solve similar physics-based equations to climate models, but operate at much finer resolutions in time and space, using real-time observations to predict very near-term changes in local weather. They require "data assimilation" to run, which continuously integrates observations from satellites, ground stations, and other instruments into the model state to produce hourly-to-daily forecasts of local weather conditions.

Cat models are primarily used for insurance and reinsurance risk evaluation, while climate models are primarily used to research the Earth system in its past and future states, and can be applied to climate mitigation and adaptation planning. Weather models are used for daily forecasting and emergency management applications.

Comparing Models

	Catastrophe Model	Climate Model	Weather Forecasting Model
Inputs	• Insurance policy information • Exposure data (location and building characteristics) • Peril simulations	Preliminary environmental conditions at a global scale	Recent weather observations
Outputs	Metrics of economic loss	Simulated global atmospheric and ocean conditions	Local weather forecasts
Timescale	Current year	50–100 years	Hours or days
Common Application	Insurance and reinsurance assessment and pricing	Understanding historical and future climates; Adaptation and mitigation planning	Daily planning and emergency management
Sample Question Model Can Answer	Over the next year, what level of economic loss can we expect from a severe storm in this community?	How will storm-related climate conditions change over the next century under increasing greenhouse gas emissions?	Will there be a severe storm over the next few days in this place?

Glossary

Catastrophe model	A catastrophe model is a simulation-based model of disasters to estimate potential economic losses
Climate model	A computer simulation of the Earth's climate system, including the atmosphere, ocean, land, and ice, used to recreate the past climate or predict the future climate
Weather model	Computer models that process current weather observations to forecast future weather
Return period	The average interval between events of a given magnitude
Average annual loss (AAL)	The probability that an event associated with a given return period will occur in any single year. For example, a 100-year return period event has an AEP of 1% (0.01), meaning it has a 1-in-100 chance of being equaled or exceeded in any given year.

Resources

1. Haitham Nobanee, Xuan-Hoa Nghiem. 2024. Climate Catastrophe Insurance for Climate Change: What Do We Know and What Lies Ahead? *Current Opinion in Environmental Sustainability.* 66: 101395, https://doi.org/10.1016/j.cosust.2023.101395.
2. Duncan Ellis. 2012. Catastrophe Modeling, Why All the Fuss? *Marsh Insights Property*, Fall: 2–3. https://www.marsh.com/en/services/property-risk-management/insights/catastrophe-modeling.html.
3. Moody's. Insurance Solutions Developer Portal , Cat Modeling. https://developer.rms.com/risk-modeler/docs/cat-modeling.
4. National Center for Atmospheric Modeling. Modeling + Data Simulation: Simulating a Complex World. https://ncar.ucar.edu/what-we-offer/models.
5. National Centers for Environmental Information. https://www.ncei.noaa.gov/.
6. Verisk. What is Catastrophe Modeling? https://www.verisk.com/resources/about-catastrophe-modeling/