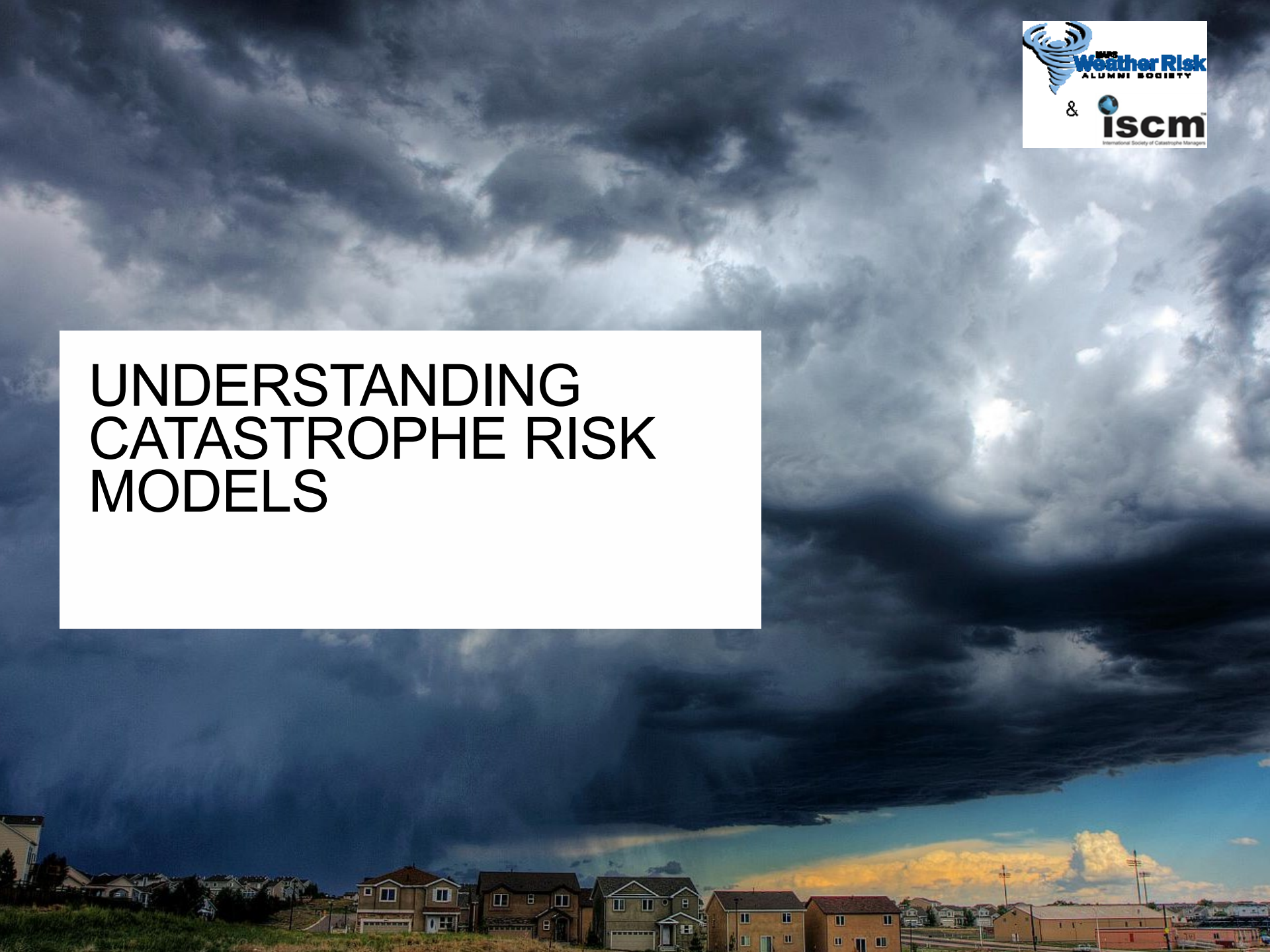
UNDERSTANDING CATASTROPHE RISK MODELS



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Mark is a Senior Research Meteorologist in the Risk Accumulation Department of Munich Reinsurance America. His responsibilities include evaluating commercially available catastrophe risk models and providing technical expertise on underwriting and risk accumulation issues.

Mr. Bove has been active in meteorological consulting and research for 20 years. Before joining Munich Reinsurance America in July 2000, Mark was a graduate research assistant at Florida State University in Tallahassee, Florida, where he conducted research on short-term climate variations and probabilistic modeling of extreme weather events. Mark's research included studies of ENSO's influence on Atlantic hurricane landfall frequencies and tornadic activity patterns in the United States. Other research and consulting topics included seasonal temperature and precipitation anomalies in the United States and Latin America. Mark's work made national headlines on several occasions and he was the 1998 recipient of the Father James B. Macelwane award for outstanding undergraduate research by the American Meteorological Society.

Mark holds Masters and Bachelors degrees in Meteorology from Florida State University and has earned the Chartered Property Casualty Underwriter (CPCU) and Associate in Reinsurance (ARe) professional designations. Mark is also a member of the American Meteorological Society (AMS) & International Society of Catastrophe Managers (ISCM).

AGENDA

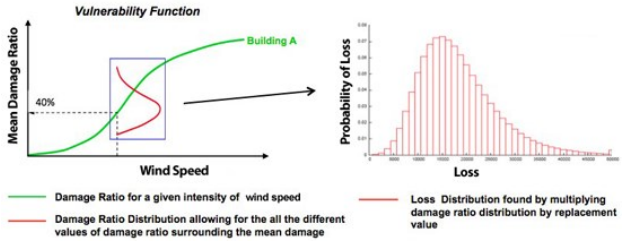
1. Review of Catastrophe Modeling 101
2. Insurance, Reinsurance, & Natural Catastrophes
3. What are Catastrophe Risk Models?
4. History of Cat Models
5. Model Vendor Overview
6. Building Blocks of Cat Models
7. Cat Model Output & Uses
8. Cat Model Limitations
9. Q & A

REVIEW: CAT MODELING 101
A FEW DEFINITIONS

- **Peril** = potential causes of loss or damage (ex. Earthquake or Windstorm)
- **Hazard** = the danger from the peril
- **Risk** = uncertainty leading to potential adverse outcomes OR shorthand for an insured object

VS

VS

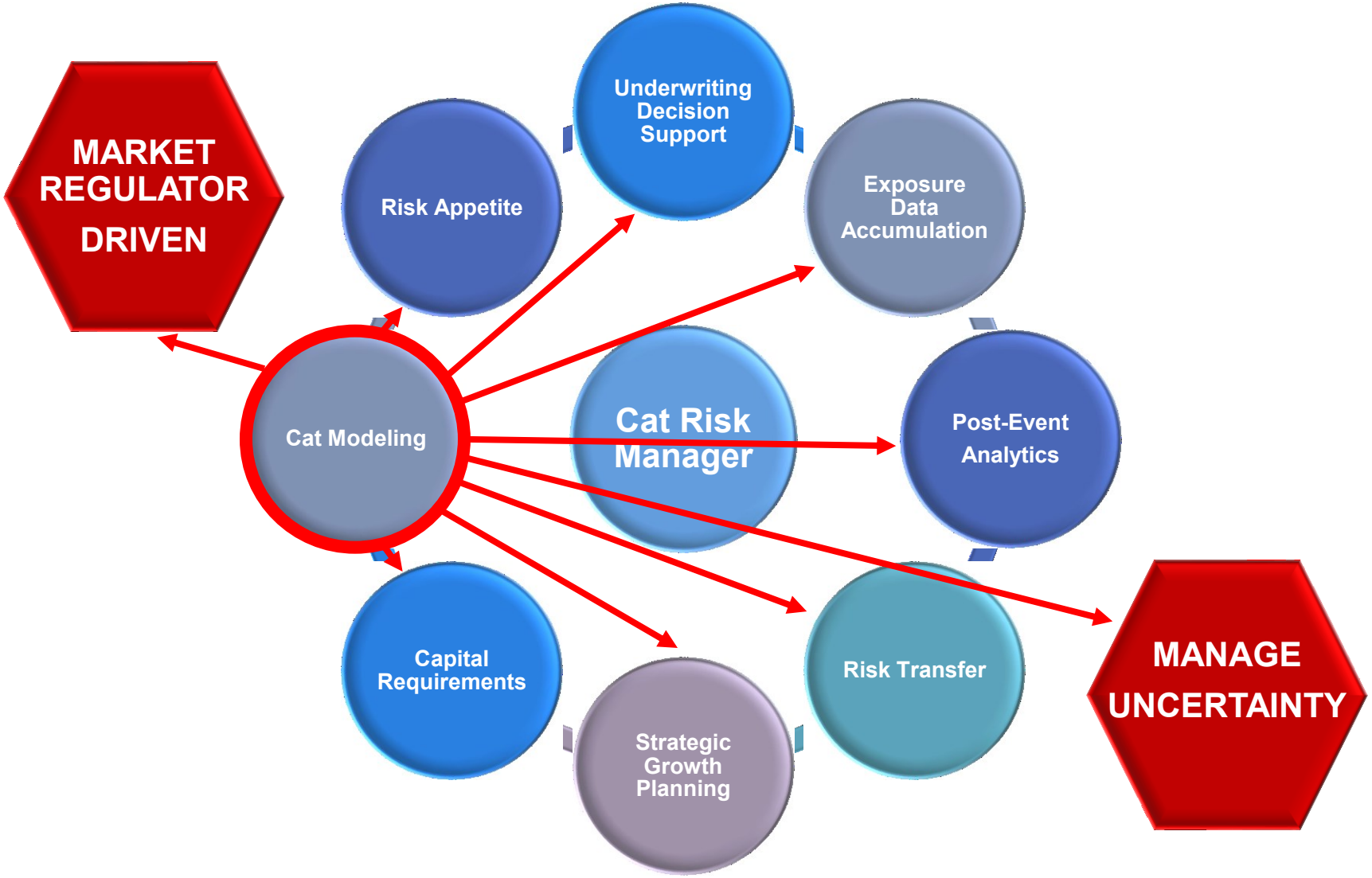


OR

- **Catastrophe Risk Management:**
  1) Identifying the catastrophe risk given the context of the organization
  2) Quantifying the risk
  3) Deciding what to do given the level of risk and risk appetite
  4) Monitoring the level of risk

REVIEW: CAT MODELING 101
ROLE OF CATASTROPHE MANAGER

REVIEW: CAT MODELING 101
ROLE OF CATASTROPHE MANAGER



REVIEW: CAT MODELING 101
INSURANCE PRICING

Typical Good

- Fixed and variables costs are well-known
- Little uncertainty

Insurance Policy

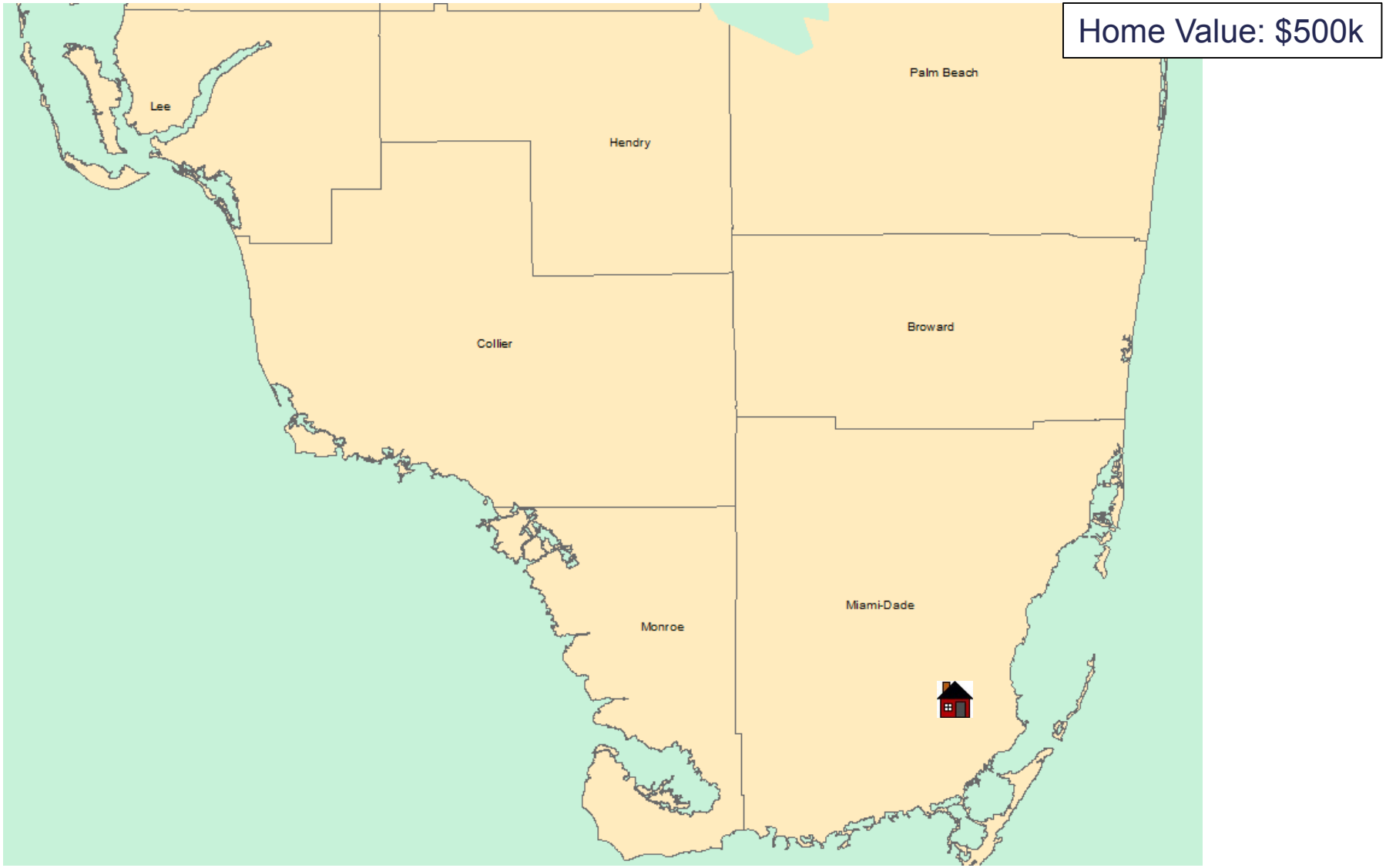
- Uncertainty in final cost
- Premiums collected with a promise to pay in the future
- Actuaries use historical loss data to determine future losses (experience rating)
- CAT presents other challenges

INSURANCE, REINSURANCE, AND NATURAL CATASTROPHES

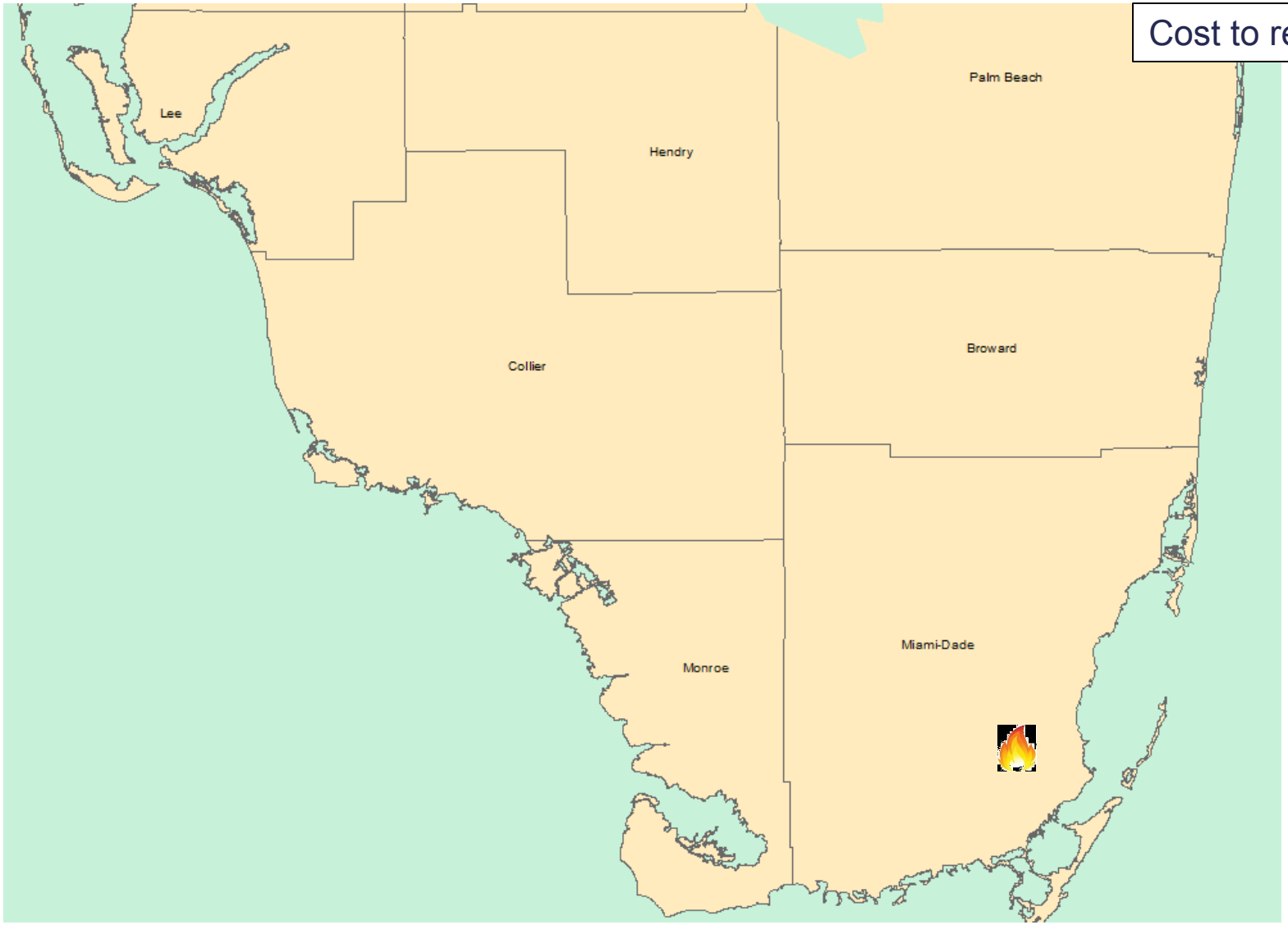
Primary insurance is not well-suited to handle natural catastrophes.

Reinsurance is the true risk transfer mechanism for large, catastrophic loss events.

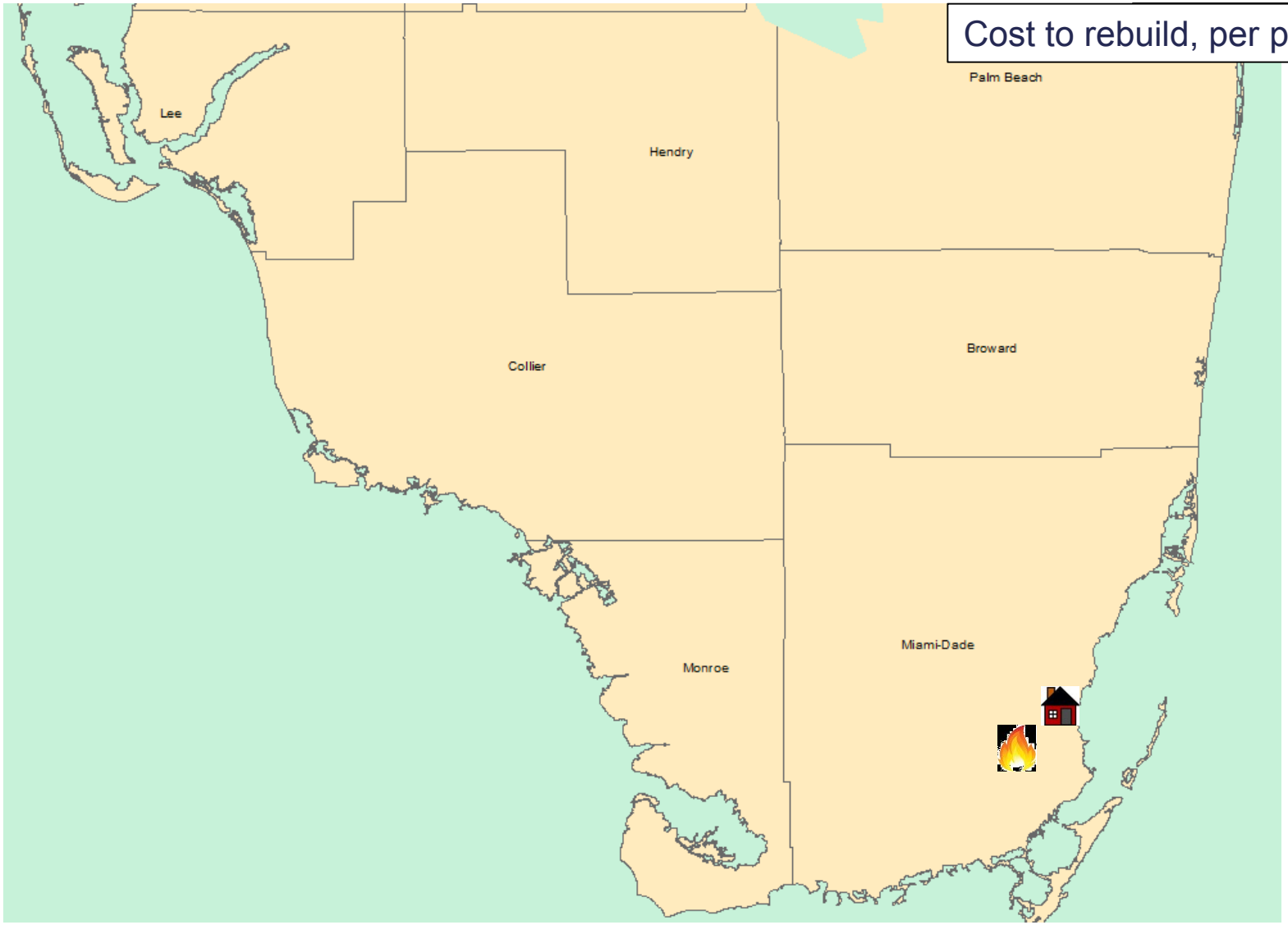
INSURANCE, REINSURANCE, AND NATURAL CATASTROPHES



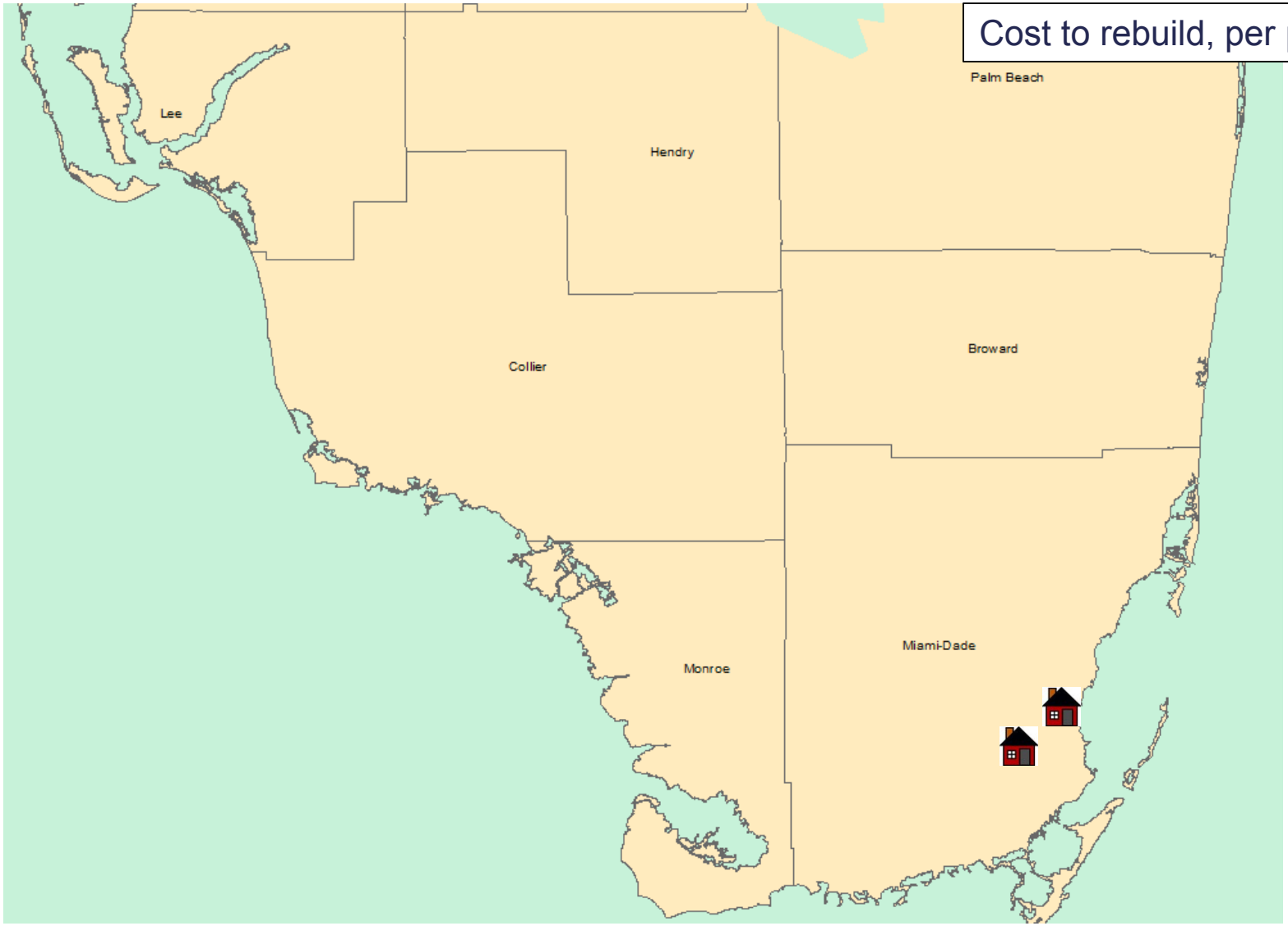
INSURANCE, REINSURANCE, AND NATURAL CATASTROPHES



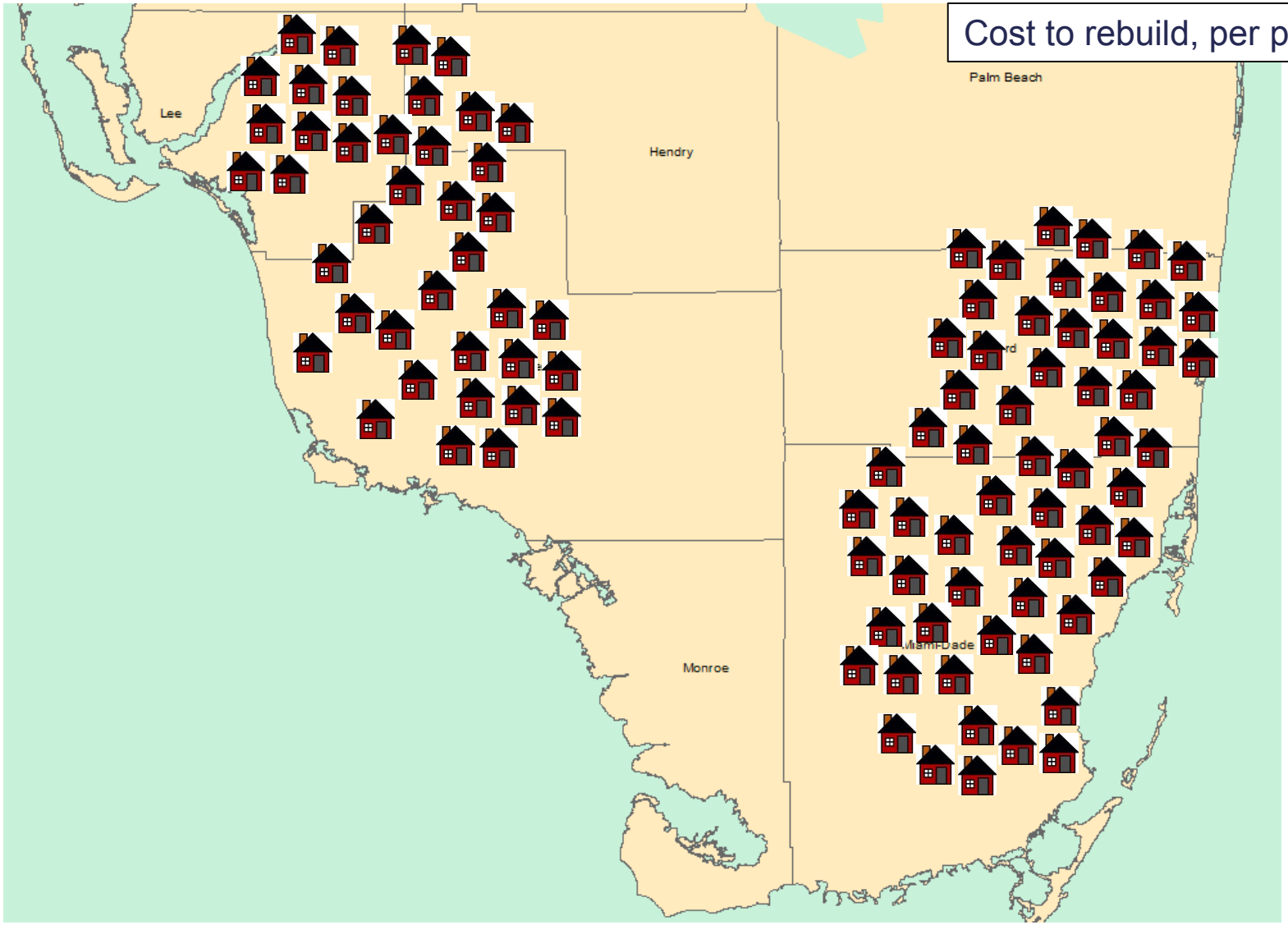
INSURANCE, REINSURANCE, AND NATURAL CATASTROPHES



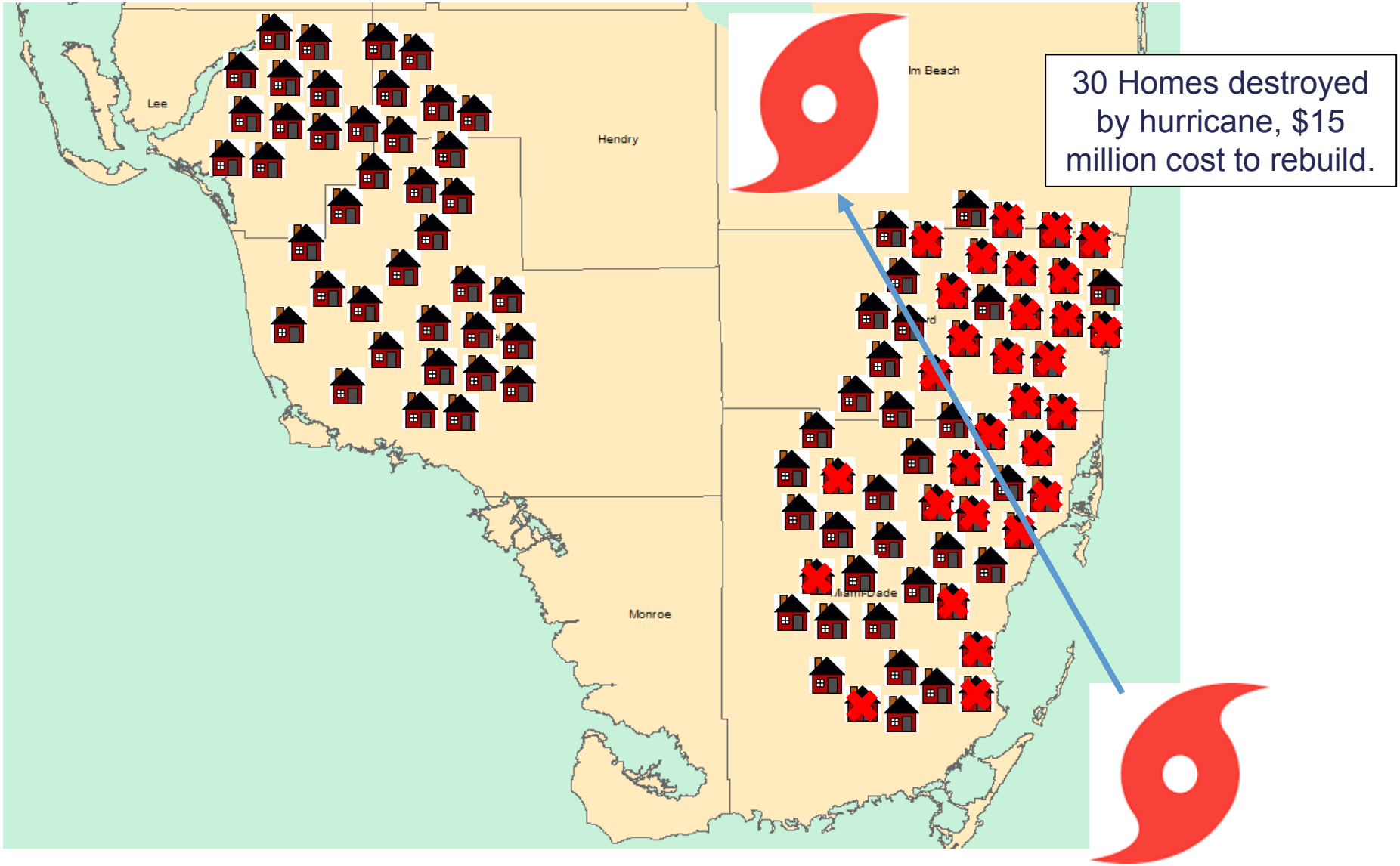
INSURANCE, REINSURANCE, AND NATURAL CATASTROPHES



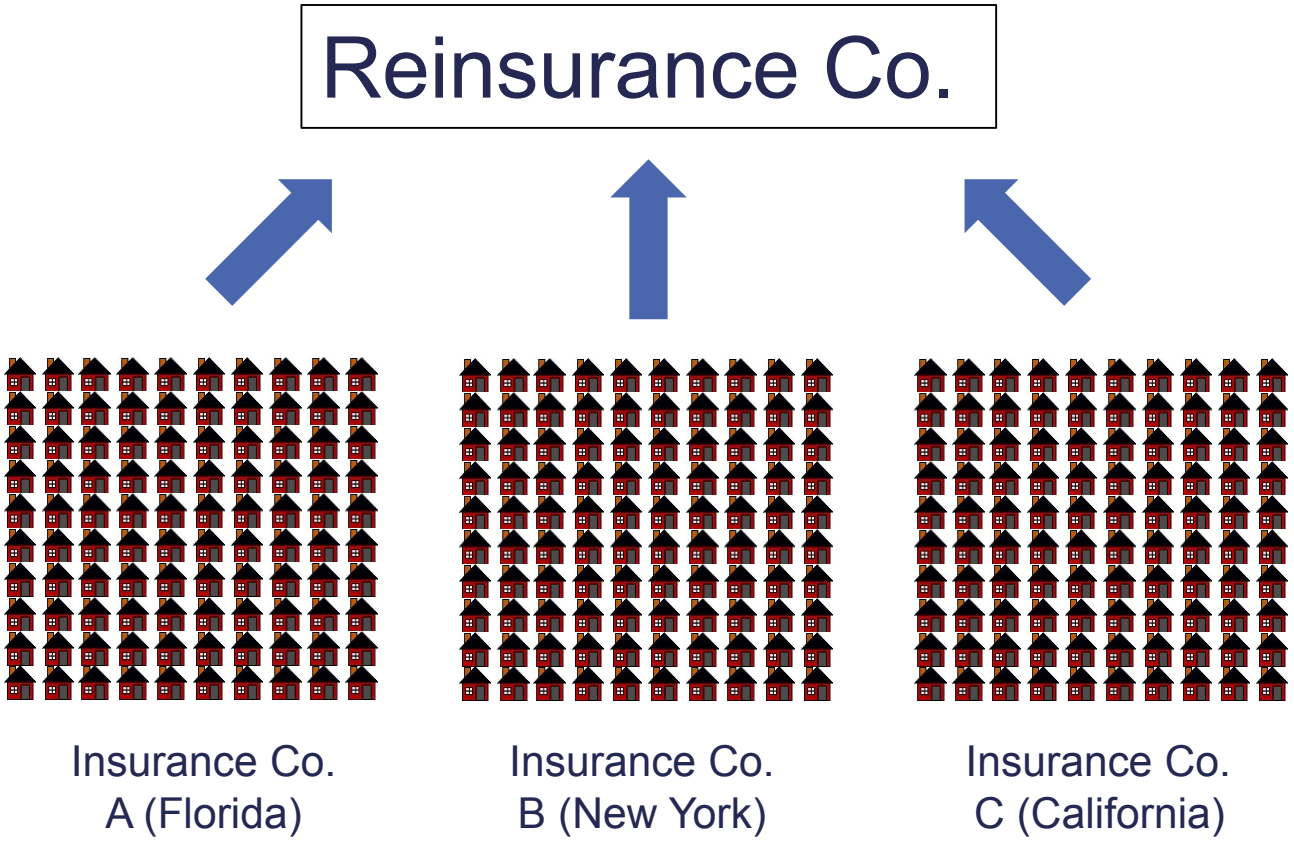
INSURANCE, REINSURANCE, AND NATURAL CATASTROPHES



INSURANCE, REINSURANCE, AND NATURAL CATASTROPHES



INSURANCE, REINSURANCE, AND NATURAL CATASTROPHES (2)



One of the primary functions of reinsurance is to keep insurance companies in business after a disaster, like hurricanes and earthquakes.

A primary insurer's reinsurance cover may be participated on by dozens of reinsurers, helping spread the risk (and potential losses) globally.

WHAT IS A CATASTROPHE LOSS MODEL?

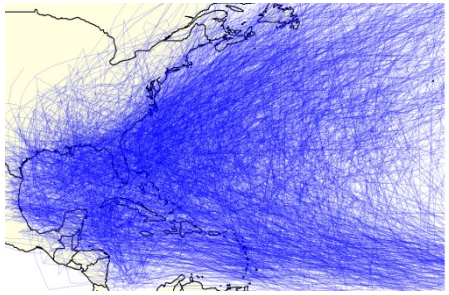
Catastrophe models are computer programs that estimate the financial impacts from a given peril to a single risk or collection (portfolio) of risks.

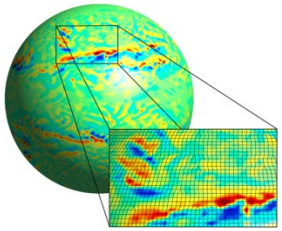
Cat models use pre-compiled stochastic event sets to calculate financial losses to a risk based upon (1) event intensity at the site, (2) the risk's physical characteristics, and (3) the terms of the financial contract (insurance and/or reinsurance).

Source: Munich Re

WHAT IS A CATASTROPHE LOSS MODEL?
WHAT THEY ARE AND ARE NOT

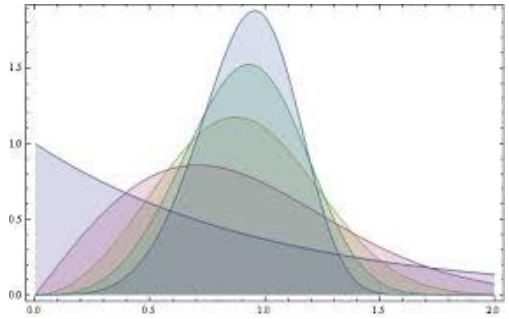
- **They are not predictive (i.e. not forecast models)**

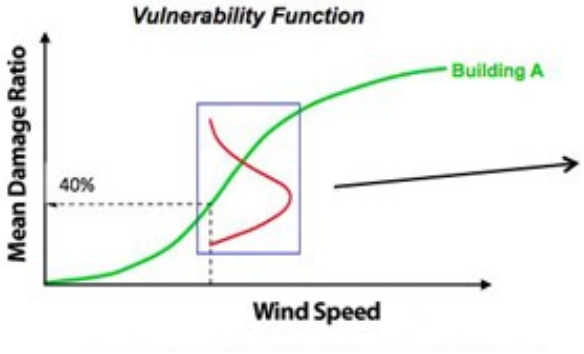




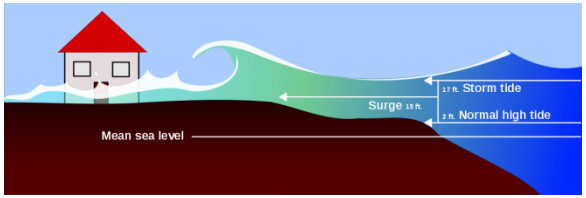
- **They use statistics**

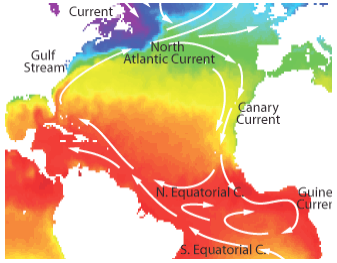
- **They all make different assumptions**

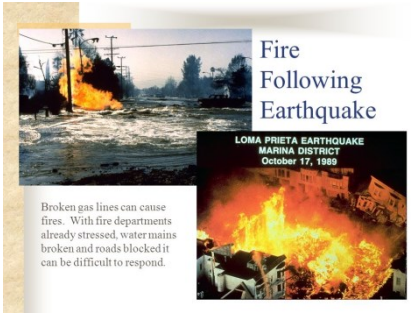




- **They allow for different user-defined views of risk**



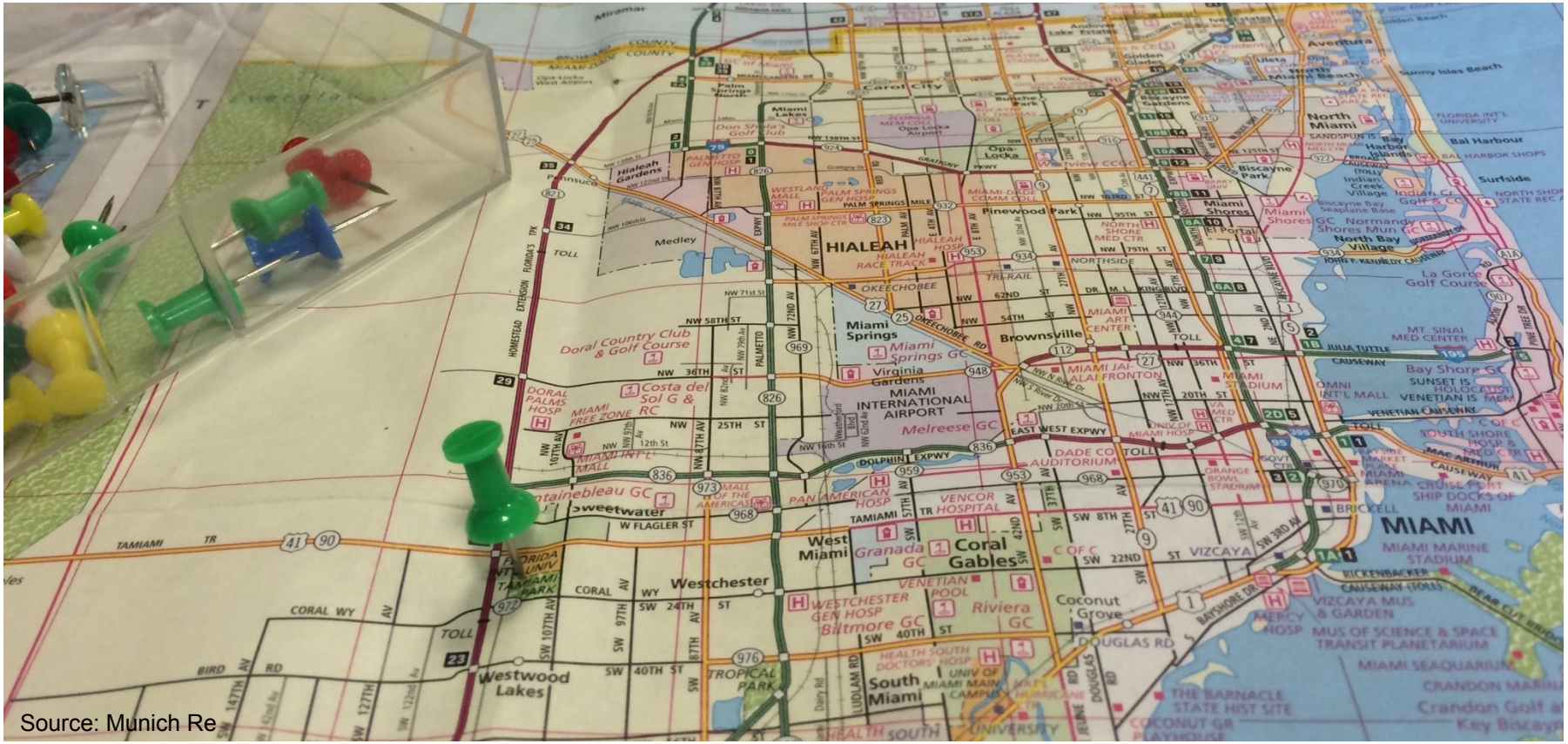




HISTORY OF CATASTROPHE RISK MODELS

Inception: 1980s

Before the PC age, the insurance industry lacked usable risk accumulation information



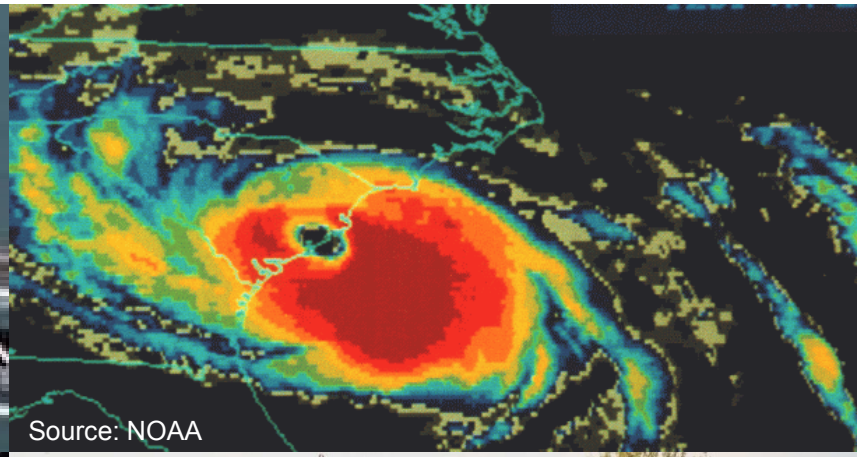
Source: Munich Re

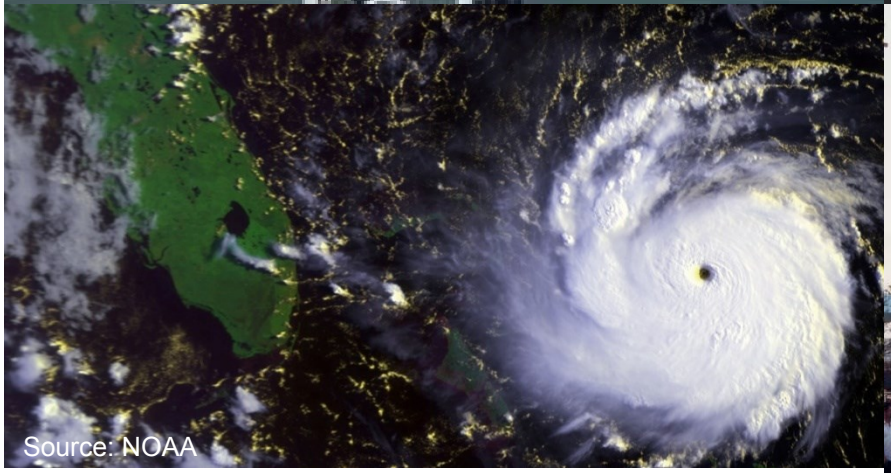
HISTORY OF CATASTROPHE RISK MODELS

Acceptance: 1990s

Major events in the United States accelerated model adoption

Source: Munich Re


Source: NOAA


Source: NOAA

Source: Munich Re

HISTORY OF CATASTROPHE RISK MODELS

Expansion: 2000s

- New peril models for emerging risks:
  - Terrorism (Property & Workers Compensation)
    - Conventional (Non-WMD)
    - Nuclear, Biological, Chemical, & Radiological (NBCR)
  - Pandemic (Influenza, SARS, etc.)
- New views of risk for existing models
  - “Long Term” and “Short Term” rates for Tropical Cyclones, largely conditioned on AMO state
  - Sensitivity testing of model components

HISTORY OF CATASTROPHE RISK MODELS

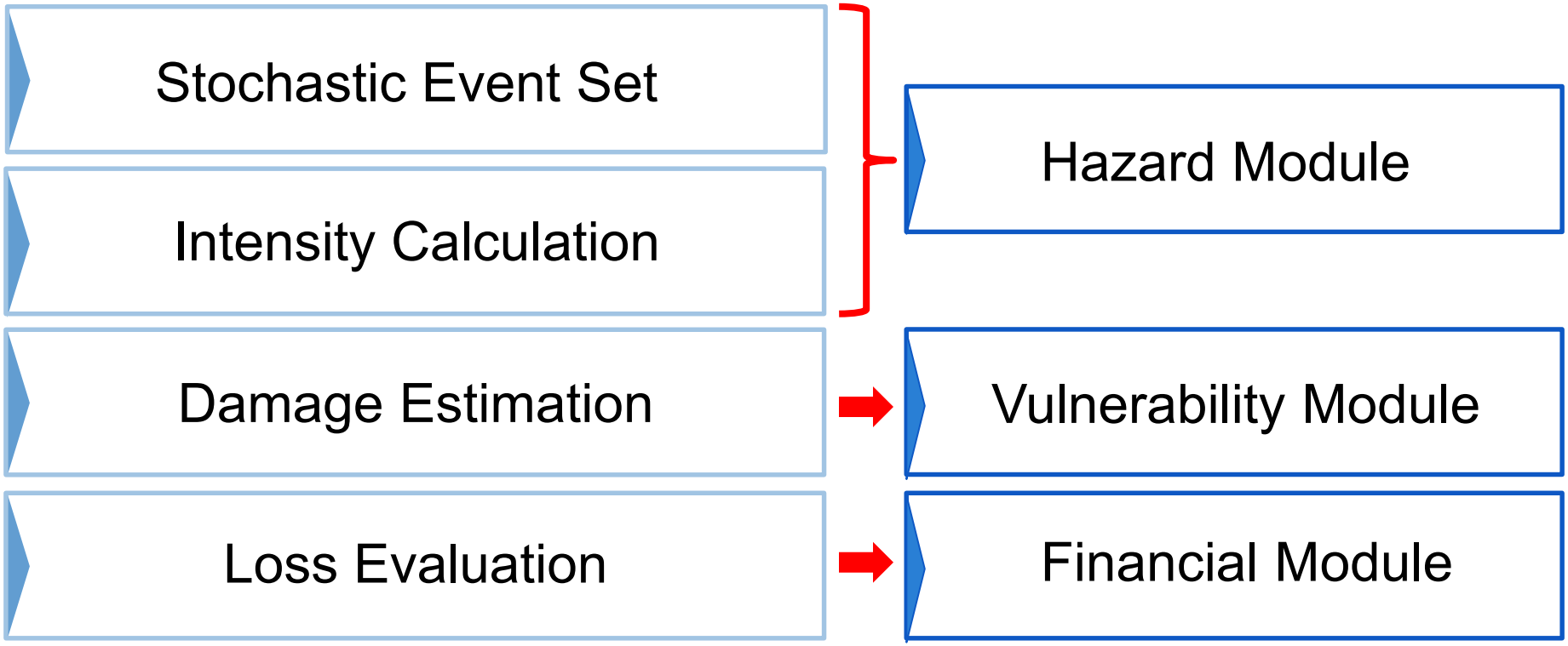
Evolution: 2010s

- Increased used of NWP modeling by model vendors:
    - Storm surge for both tropical & extratropical cyclone
    - Increased use of reanalysis data / physical models to inform model development
    - WRF runs informing meteorological peril models where little historical data are available
- Increased ability to customize model components; development of plug-and-play modeling platforms
    - Model vendors want to be one-stop source for all of their customer's modeling needs
    - Introduction of cloud computing to improve model resolution, run time, analytics, etc.

CAT MODEL VENDORS
(NON-EXHAUSTIVE LIST)

BASICS OF CATASTROPHE RISK MODELS
BUILDING BLOCKS

There are four basic components to all catastrophe models, regardless of the peril being modeled.



BASICS OF CATASTROPHE RISK MODELS
STOCHASTIC EVENT SET

A set of discrete events covering all the important combinations of location, size, and other pertinent characteristics of the peril in question, as well as the (annual) probability of each event.

A model's Stochastic Event Set should:

- Account for all locations that are impacted by peril of interest.
- Have a sufficient number of events to cover all possible sizes and intensities that are possible in a given location.
- Consider the probability of a given event occurring.
- Have enough events to produce loss results that are geographically consistent & statistically stable.

BASICS OF CATASTROPHE RISK MODELS
INTENSITY CALCULATION

Catastrophe models must calculate the intensity of each event at every site of interest (individual risk locations affected by an event in the Stochastic Event Set.

A model's Intensity Calculation component should:

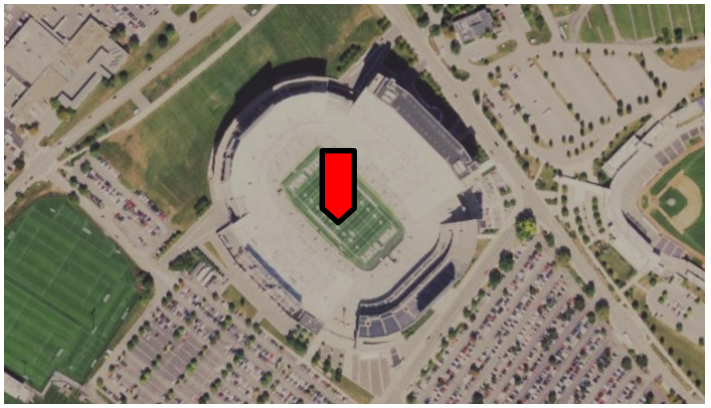
- Be based on established physics of the hazard being modeled
- Consider the **source** characteristics of the event
- Consider the **path** characteristics of the event
- Consider environmental influences at or around **site** of interest

To calculate event intensities at each location of interest, the model requires Geocoding and the relevant Geospatial Hazard Databases for the peril being modeled. Both of these tools are included in the model.

BASICS OF CATASTROPHE RISK MODELS
GEOCODING & GEOSPATIAL HAZARD DATABASES

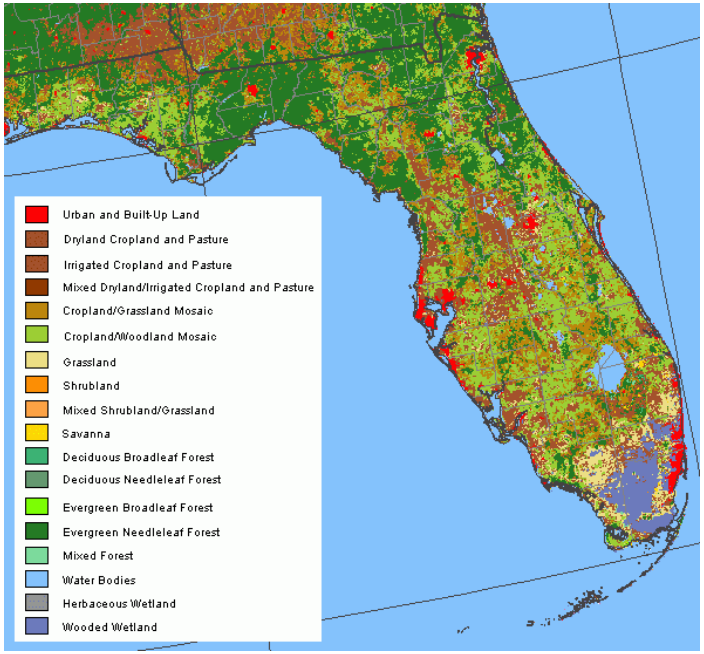
Geocoding

Computer program that transforms location information contained in exposure data (building number, street, city, state, and postal code) into latitude/longitude coordinates.



Map: ESRI

1 Beaver Stadium, University Park, PA 16802
= 40.812 ºN, 77.856 ºW



Geospatial Hazard Databases

Information on the local environmental and/or physical factors that can influence an event's intensity at the site.

The relevant information depends on the peril; With respect to tropical cyclones: topography and surface roughness.

BASICS OF CATASTROPHE RISK MODELS

EXAMPLE: ATLANTIC HURRICANE EVENT SET DEVELOPMENT

All cat modelers use HURDAT / Best Track data as the first-order source in calibrating the frequency & severity of landfalling tropical cyclone (TC) events in the Atlantic. It is also used to extract TC parameters for statistical modeling.

Event Tree:
Modelling a range of hurricane parameters (different combinations of intensity, landfall angle, R_{max}, etc.) at thousands of pre-defined points along the U.S. coastline, without regard to overall basin behavior, except for landfall rates.

Basin Simulation:
Modelling entire Atlantic Basin to recreate realistic hurricane event sets using tens of thousands of model iterations (years). Can be done with either numerical weather prediction (NWP) or statistical models. Historical landfall frequency/severity relationships along coastal segments (“gates”) must be closely approximated by the model.

TC Windfield:
Several different equations or mathematical approximations can be used to simulate a hurricane wind field. Examples include NWP models, Gradient Wind Equation, Holland B Parameter, and Rankine Vortex. Max 3-sec gust typically used to related wind intensity to damage, duration of wind may also be considered.

TC Storm Surge:
Due to complexity of modeling coastal flooding, NWP is typically used for storm surge footprints (SLOSH, MIKE, etc.), forced by the stochastic event’s wind field.

BASICS OF CATASTROPHE RISK MODELS

EXAMPLE: ATLANTIC HURRICANE EVENT SET DEVELOPMENT

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Florida Commission on Hurricane Loss Projection Methodology:

https://www.sbafla.com/method/

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BASICS OF CATASTROPHE RISK MODELS
DAMAGE ESTIMATION

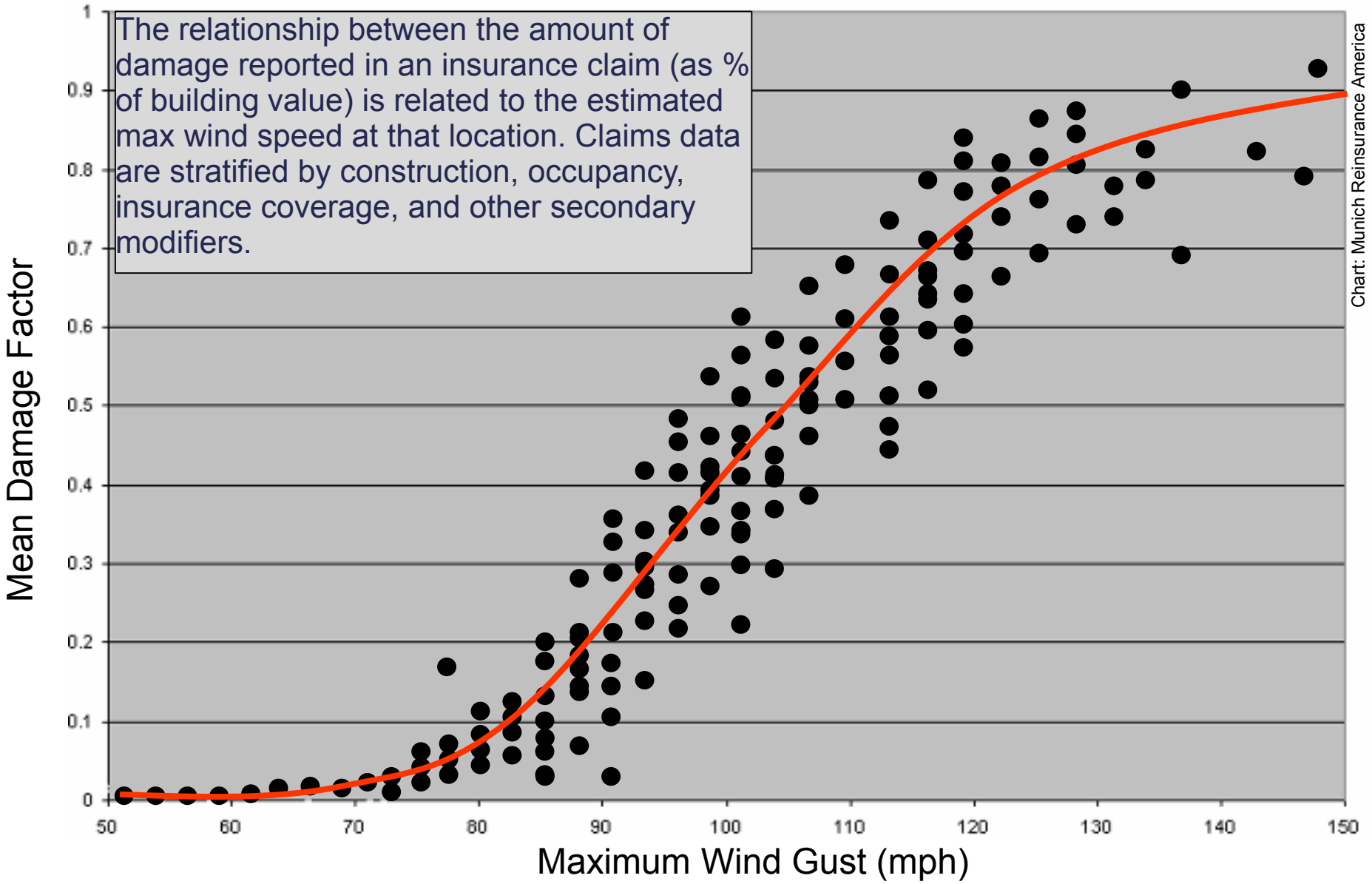
A set of functions that estimate the damage level of every structure, given its vulnerability to the particular peril and the event's intensity at the site

A model's Damage Estimation component should:

- Consider a building's main characteristics, such as construction material, occupancy, year of construction, number of stories, etc. ("primary modifiers")
- Consider other building characteristics that either increase or decrease its vulnerability to the peril in question. ("secondary modifiers")
- Consider the initial quality of construction, including the adoption and enforcement of building codes, as well as the age and the maintenance of the building.
- Have different damage functions / vulnerability curves for each insurance coverage: buildings (structural and nonstructural elements), contents, and time element.
- Use a consistent measure to correlate event intensity with building damage.
- Also provide vulnerability functions for secondary hazards, such as storm surge.

BASICS OF CATASTROPHE RISK MODELS

IDEALIZED VULNERABILITY CURVE (DAMAGE FUNCTION)



BASICS OF CATASTROPHE RISK MODELS
LOSS EVALUATION

Calculate insurance losses to individual locations, policies, and portfolios, given the damage level & values, as well as the applicable insurance and reinsurance structures.

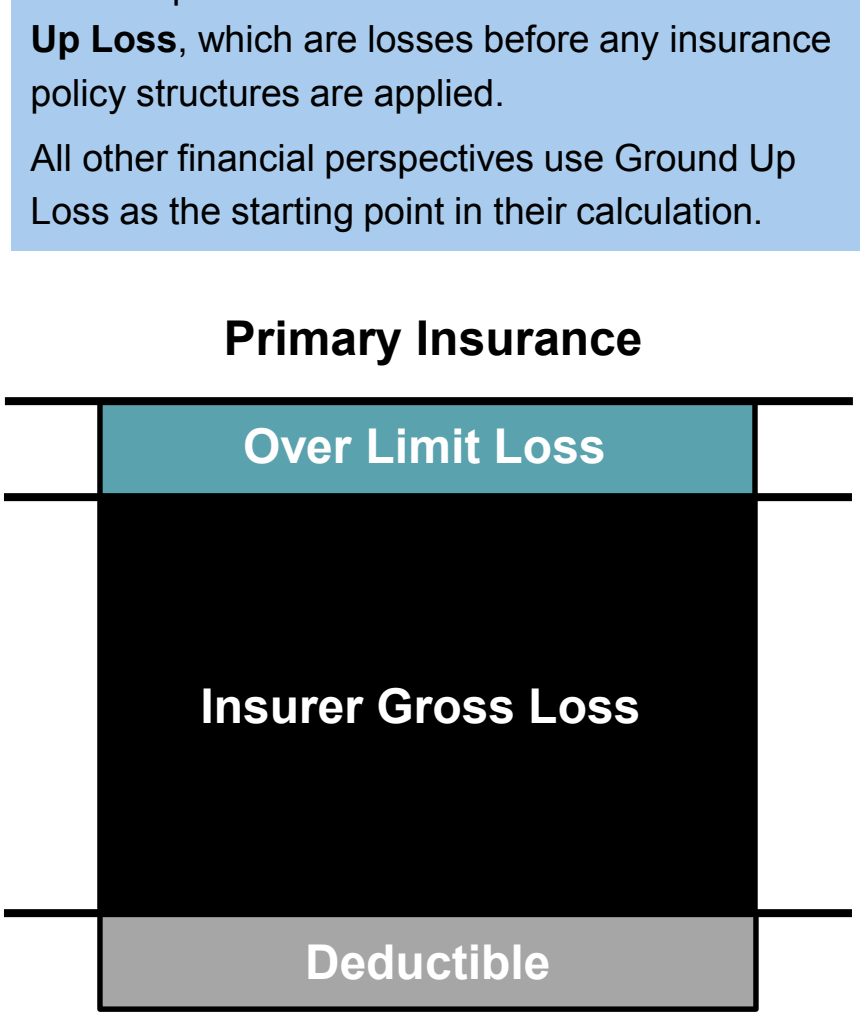
A model's Loss Evaluation component should:

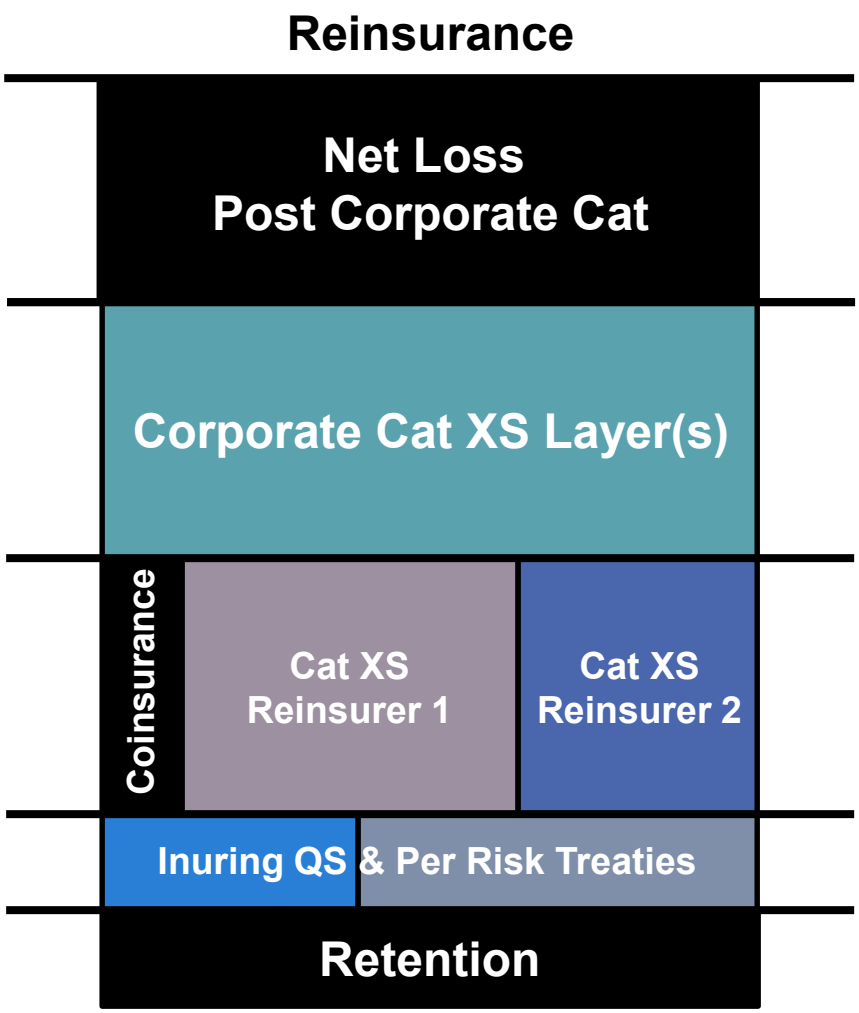
- Determine how building damage translates into insurance loss.
- Calculate insurance/reinsurance losses for individual locations, accounts, and entire portfolios
- Determine whether or how to account for:
  - Demand surge
  - Price gouging
  - Inflated claims
  - Aggressive construction contractors
  - Questionable claims settlement

BASICS OF CATASTROPHE RISK MODELS
FINANCIAL LOSS PERSPECTIVES

Catastrophe Loss Models first calculate **Ground Up Loss**, which are losses before any insurance policy structures are applied.

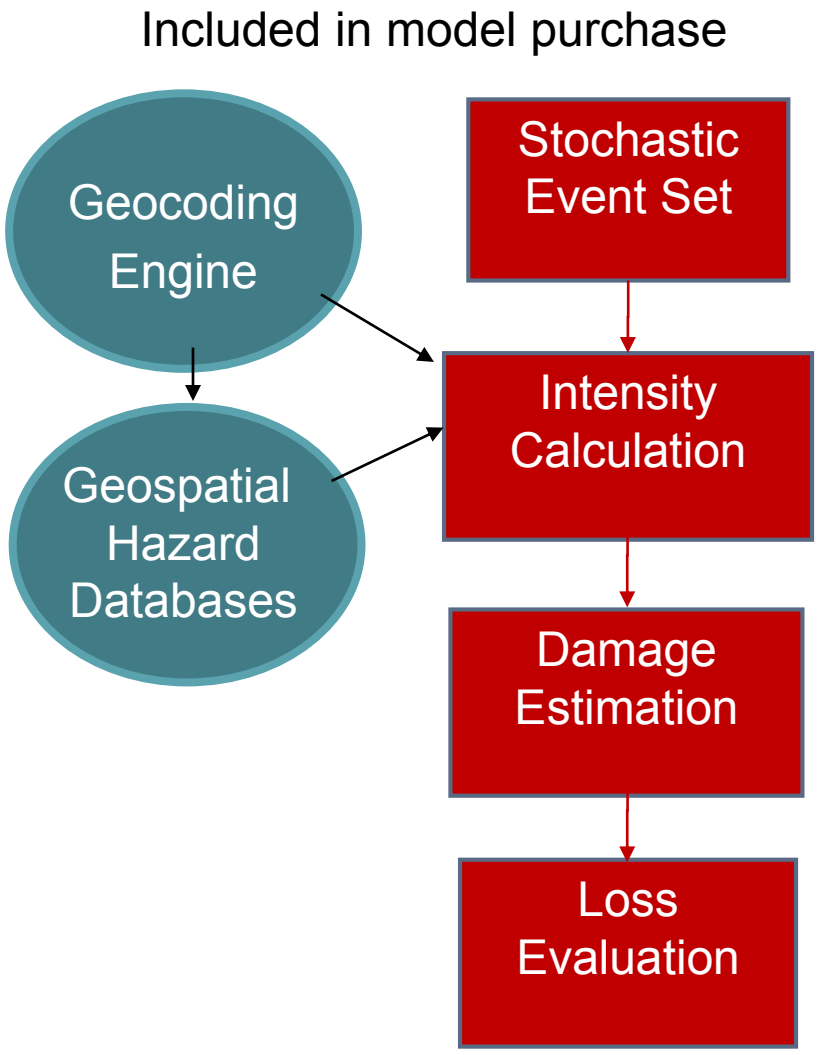
All other financial perspectives use Ground Up Loss as the starting point in their calculation.





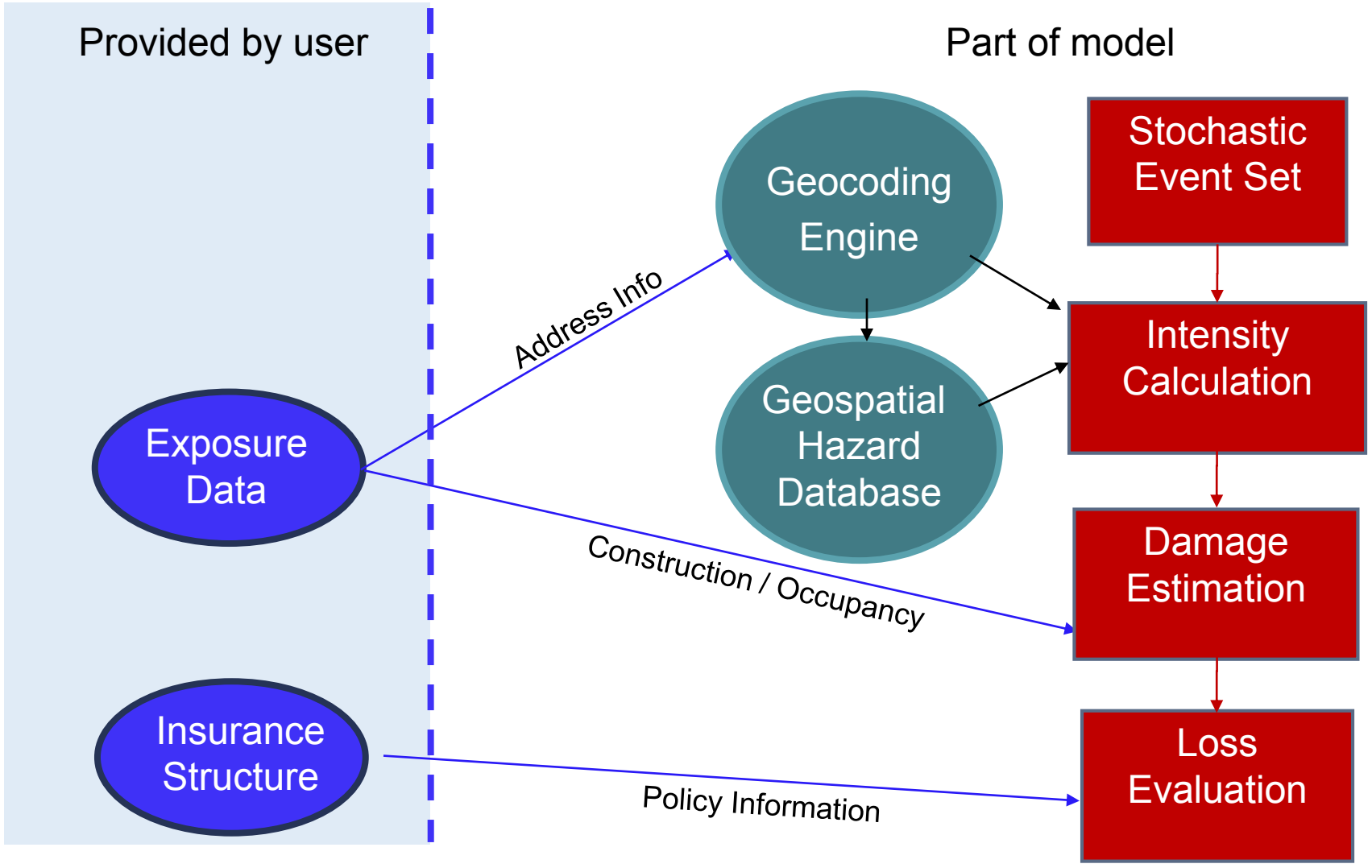
BASICS OF CATASTROPHE RISK MODELS

SIMPLE MODEL FLOWCHART



BASICS OF CATASTROPHE RISK MODELS

SIMPLE MODEL FLOWCHART

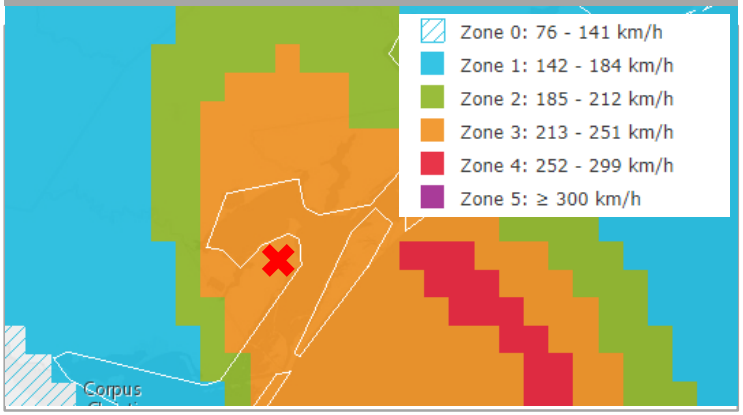


BASIC OF CATASTROPHE RISK MODELS
DETAILED MODEL FLOWCHART

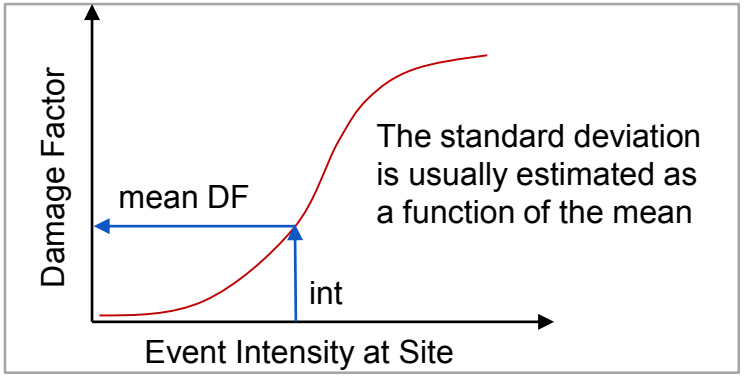
1. Stochastic Event Set

- Let *x*=1 & *n* = Number of Events in Set.
  - If Event *x* footprint impacts any location of interest, go to step 2.
  - If not, go to Event *x+1*.
  - Complete when all *n* events are assessed.

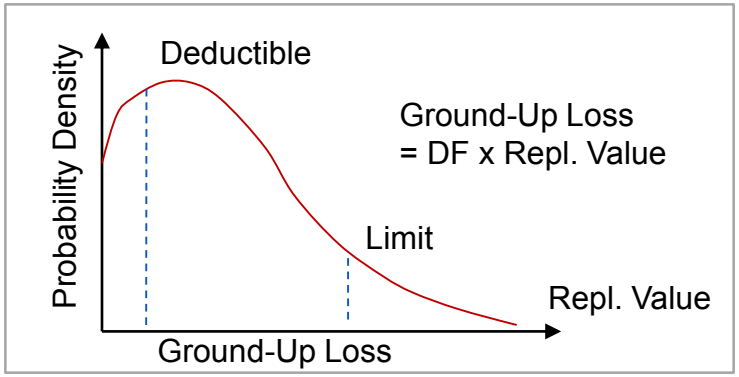
2. Intensity Calculation



3. Damage Estimation



4. Loss Evaluation



CATASTROPHE RISK MODEL OUTPUT
LOCATION-LEVEL EVENT LOSS TABLES

Expected (mean) losses are stored for each simulated event and location in an Event Loss Table (ELT) together with associated occurrence rates (probabilities). May also be called a Year Loss Table (YLT), depending on vendor and event set methodology.

Events		Location Losses			
		Policy 1		Policy 2	
ID	Rate	Location 1	Location 2	Location 3	Location 4
1	0.00008	$10,000	$20,000	$40,000	$0
2	0.00001	$20,000	$0	$100,000	$30,000
3	0.00003	$30,000	$0	$20,000	$30,000
4	0.00005	$40,000	$20,000	$30,000	$40,000
5	0.00005	$10,000	$0	$40,000	$10,000
6	0.00008	$30,000	$40,000	$10,000	$0
7	0.00001	$0	$10,000	$30,000	$50,000
8	0.00003	$0	$30,000	$30,000	$0
9	0.00001	$0	$0	$40,000	$70,000
10	0.00003	$0	$10,000	$0	$0

CATASTROPHE RISK MODEL OUTPUT
POLICY & PORTFOLIO EVENT LOSS TABLES

Aggregating Location Level Losses to Higher-Level Financial Perspectives

- Location-level coverage losses (for building, contents, time element) can be summed to obtain the location ELT, as the coverages at the same location are perfectly correlated.
- However, ELT creation for multi-location policies and entire portfolios requires information regarding the correlation of losses between locations, as well as applying the appropriate deductibles and limits from the insurance and/or reinsurance policy.

Events		Location Losses				Policy Losses		Portfolio Losses
ID	Rate	Policy 1		Policy 2		Policy 1 Loss	Policy 2 Loss	
		Location 1	Location 2	Location 3	Location 4	Limit: $40,000	Limit: $100,000	
1	0.00008	$10,000	$20,000	$40,000	$0	$30,000	$40,000	$70,000
2	0.00001	$20,000	$0	$100,000	$30,000	$20,000	$100,000	$120,000
3	0.00003	$30,000	$0	$20,000	$30,000	$30,000	$50,000	$80,000
4	0.00005	$40,000	$20,000	$30,000	$40,000	$40,000	$70,000	$110,000
5	0.00005	$10,000	$0	$40,000	$10,000	$10,000	$50,000	$60,000
6	0.00008	$30,000	$40,000	$10,000	$0	$40,000	$10,000	$50,000
7	0.00001	$0	$10,000	$30,000	$50,000	$10,000	$80,000	$90,000
8	0.00003	$0	$30,000	$30,000	$0	$30,000	$30,000	$60,000
9	0.00001	$0	$0	$40,000	$70,000	$0	$100,000	$100,000
10	0.00003	$0	$10,000	$0	$0	$10,000	$0	$10,000

CATASTROPHE RISK MODEL OUTPUT
ANNUAL LOSS DISTRIBUTIONS

Creating an Annual Loss Distribution

- Foundation of Exceedance Probability (EP) curves, the key output of Cat Modeling.
- "Annual" because most insurance contracts are for one year, so models reflect this.

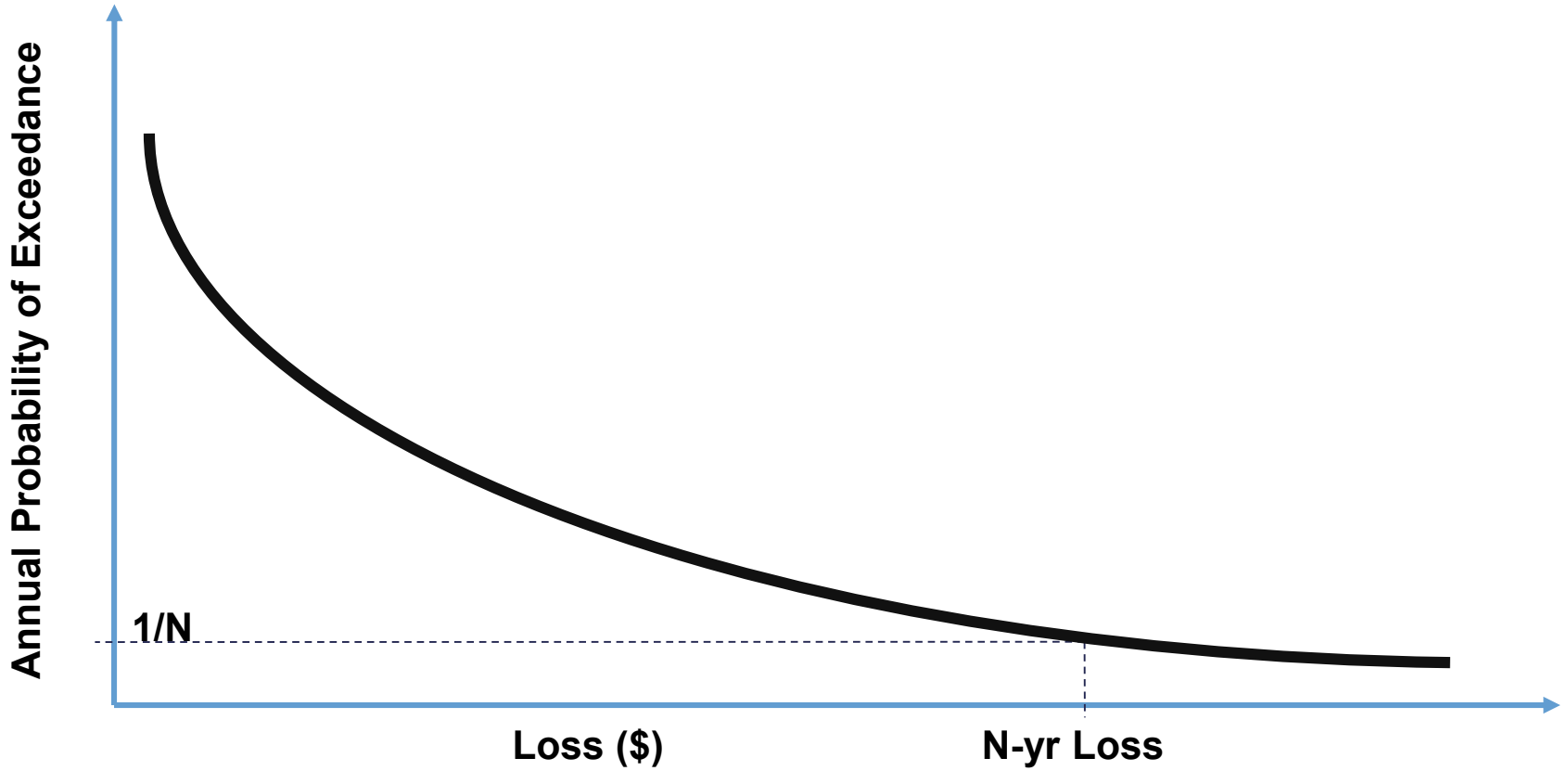
- The portfolio-level ELT is sorted by loss severity, in descending order.
- Using the event rate information, the models then calculate an annualized loss distribution by evaluating the probability that the loss from any given event can exceed a certain financial threshold.

Events		Portfolio Loss	Exceedance Prob.	Return Period
ID	Frequency			
2	0.00001	$120,000	0.00001	100,000
4	0.00005	$110,000	0.00006	16,667
9	0.00001	$100,000	0.00007	14,286
7	0.00001	$90,000	0.00008	12,500
3	0.00003	$80,000	0.00011	9,091
1	0.00008	$70,000	0.00019	5,263
5	0.00005	$60,000	0.00024	4,167
8	0.00003	$60,000	0.00027	3,704
6	0.00008	$50,000	0.00035	2,857
#	0.00003	$10,000	0.00038	2,632

CATASTROPHE RISK MODEL OUTPUT

EXCEEDANCE PROBABILITY (EP) CURVE

- EP curves are the ultimate and most important financial output for catastrophe risk models.
- EP curves give the annual probability of losses exceeding a given loss threshold.
- EP curves can be generated at the location, policy, or portfolio level, to which different insurance and / or financial structures can be applied for a single event or annual aggregate basis.



CATASTROPHE RISK MODEL OUTPUT

TYPES OF EP CURVES

- An **Occurrence EP Curve (OEP)** provides the probability that the maximum event loss from a given peril in any year will exceed a given loss threshold.
- An **Aggregate EP Curve (AEP)** provides the probability that the sum of all event losses from a given peril in any year will exceed a given loss threshold.

Example: Assume the 2017 Hurricane Season was simulated as part of a model stochastic event set. The insurance industry's insured losses from each U.S. event are:

Storm Name	Industry Insured Loss ($bn)
Harvey	$15.9 bn
Irma	$18.0 bn
Maria	$21.5 bn
Nate	$0.1 bn

Source: Property Claims Services (PCS)

The OEP loss for 2017 would be the largest single hurricane loss during the year, $21.5 bn.

The AEP loss for 2017 would be the sum of all US hurricane losses during the year, $55.5 bn.

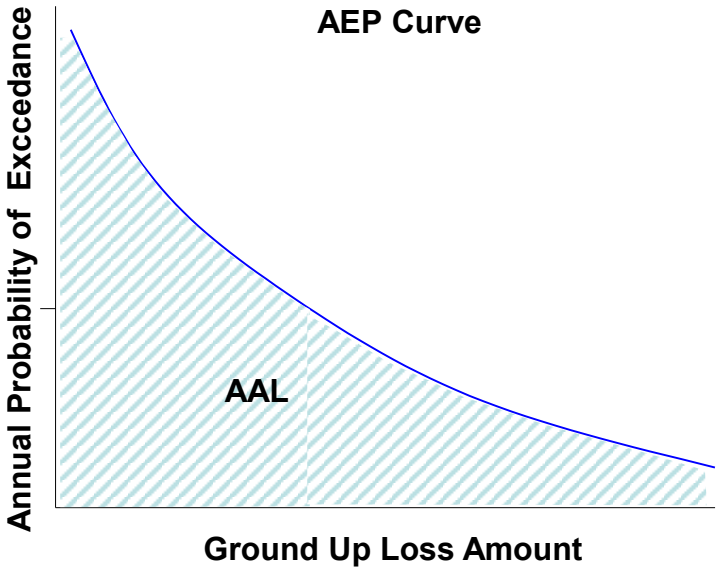
If you run U.S. industry exposure data through Cat Model, you can use OEP/ AEP curves to determine annual probability of exceeding these levels of insured loss.

CATASTROPHE RISK MODEL OUTPUT
AVERAGE ANNUAL LOSS

- **Average Annual Loss (AAL)** is a measurement of overall catastrophe risk.
- AAL is the (very) long-term average loss to a portfolio each year for a given peril.
- Also known as: Loss Cost, Pure Premium
- Calculated by summing (mean loss * event rate) for all events in a stochastic event set.
- Graphically, Ground Up AAL is represented by the area under the AEP curve.
- If a policy is occurrence-based, the AAL is the area under the OEP curve. For example, for an occurrence-based reinsurance policy providing $10 million of coverage in excess of $10 million, the AAL is the finite integral of the OEP curve from $10 to $20 million.

Example:

Event	Rate	Loss	Rate * Loss
A	0.2	$50,000	$10,000
B	0.1	$30,000	$3,000
C	0.4	$20,000	$8,000
		Total AAL:	$21,000



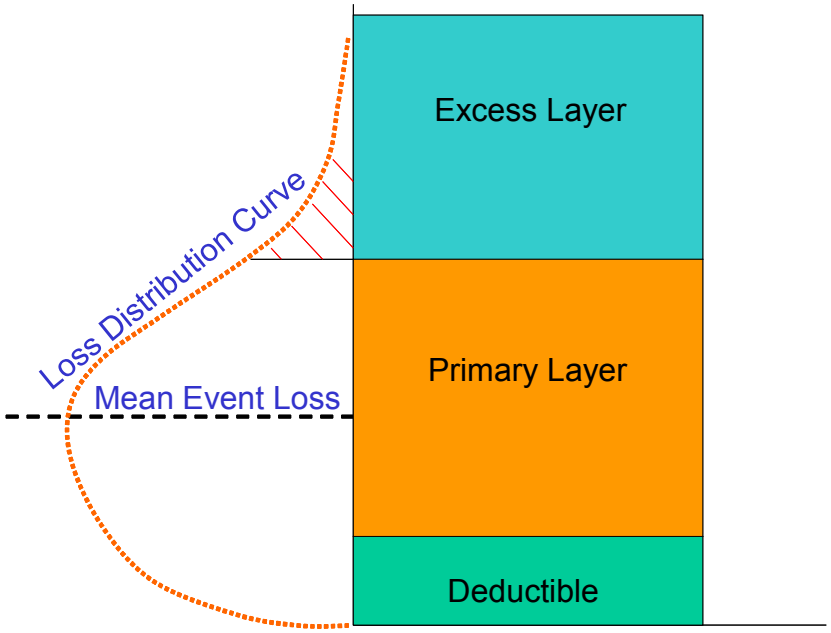
CATASTROPHE RISK MODEL OUTPUT
MODEL UNCERTAINTY

Primary Uncertainty – measures the uncertainty in the likelihood that a particular event occurs. For a given event, primary uncertainty is represented by the event rate and associated mean loss at a given location.

Secondary Uncertainty – the uncertainty in the amount of loss, given that a certain event has occurred. For a given event, secondary uncertainty is represented by the variation around the event mean loss.

Sources of Secondary Uncertainty:

- Hazard Uncertainty (Size & shape of windfield; terrain effects, etc.)
- Vulnerability Uncertainty (Range of possible damage states)
- Specification Uncertainty (Geographic resolution, construction, etc., of model)
- Portfolio Data Uncertainty (Geographic resolution, accuracy and timeliness of exposure data, etc.)

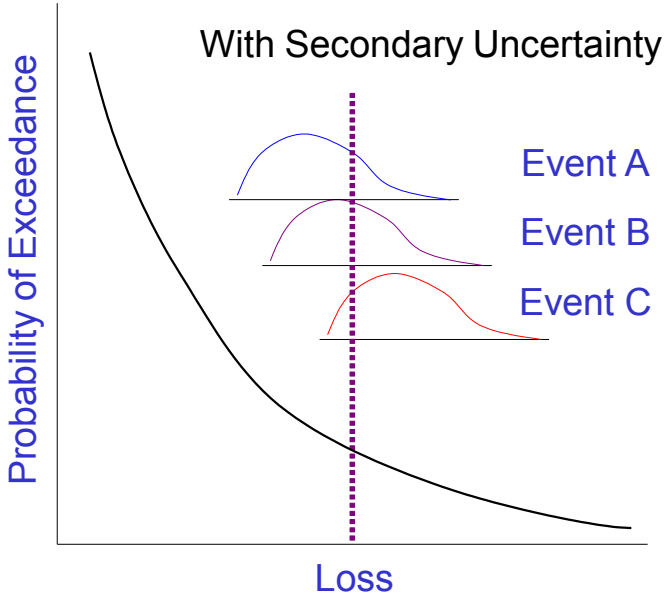


Expected Loss Methodology – Financial Output (including EP curves) only consider expected (mean) losses.

Distributed Loss Methodology – Financial Output (including EP curves) consider both expected (mean) losses and the uncertainty around the mean loss.

CATASTROPHE RISK MODEL OUTPUT:
EP CURVES & MODEL UNCERTAINTY

- EP curves can be generated both with and without secondary uncertainty.
- EP curves without secondary uncertainty tend to resemble step functions, particularly in extreme tail of distribution. EP losses can't exceed the greatest mean loss from a single event (OEP) or year (AEP).
- EP curves with secondary uncertainty tend to be very smooth, and maximum losses can greatly exceed that of the largest mean loss.
- This is due to model considering a range of potential loss outcomes from each event in determining EP values.



CATASTROPHE RISK MODEL LIMITATIONS
(NON-EXHAUSTIVE, THERE ARE MANY…)

- Accuracy & timeliness of exposure data
- Accuracy of geocoding engine
- Accuracy & resolution of geospatial hazard databases
- Event set size vs. Model run time
- Not all hazards associated with each peril are modelled
- Not all types of damage from included hazards are explicitly modelled
- Assumptions of peril rate / intensities in areas of limited historical data
- Assumptions in shape / size / parameter assumptions of event footprints
- Assumption of stationarity of peril frequency / severity
- Limited claims data to calibrate vulnerability curves for some perils or hazards
- Limited claims data to calibrate vulnerability curves for uncommon occupancy types
- Lack of hazard intensity data at claim locations: issues with curve calibration
- Vulnerability curve slope: small change in intensity = big change in estimated damage
- Assumptions on building code effectiveness and enforcement
- Losses to a location are always the mean loss for a given event intensity
- May not be able to correctly process complex insurance structures
- Model definition of event may not match contractual definition of an “event”
- Assumptions on socioeconomic influences on insured losses (demand surge, etc.)

CATASTROPHE RISK MODEL LIMITATIONS

THINGS TO REMEMBER

- Models are not exact, are always wrong, and will always change.
- Despite this, models provide a consistent way to monitor and assess exposures to and loss potential from catastrophic events.
- Models are complex probabilistic tools based on science, engineering, and expert judgment.
- Models do not replace underwriting but support the underwriting process.
- Models have been designed for the insurance/reinsurance industries and are calibrated to reflect the financial risk sharing in the contract.
- Model results are the “currency” used to trade risk.
- Beware of the “delusional exactitude” when dealing with model financial output.
- Models are essential tools in the insurance industry. Demand for geoscientists who can build models / assess models / interpret model output / perform data analytics, and can communicate clearly and effectively on these topics, are in increasing demand.

THANKS FOR YOUR ATTENTION!

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