GUY CARPENTER

CATASTROPHE MODELING OVERVIEW

August 2019

MARSH & McLENNAN COMPANIES

Outline

- Intro to Catastrophe Modeling
  - Modeling Basics
  - Inside the Black Box
  - The Modeling Process
  - Other Considerations
- Model Uncertainty
- Appendix
  - 1: Definitions
  - 2: Event Loss Table

INTRO TO CATASTROPHE MODELING
MODELING BASICS

Intro to Catastrophe Modeling
What are Catastrophe Models?

WHAT

A tool that quantifies risk

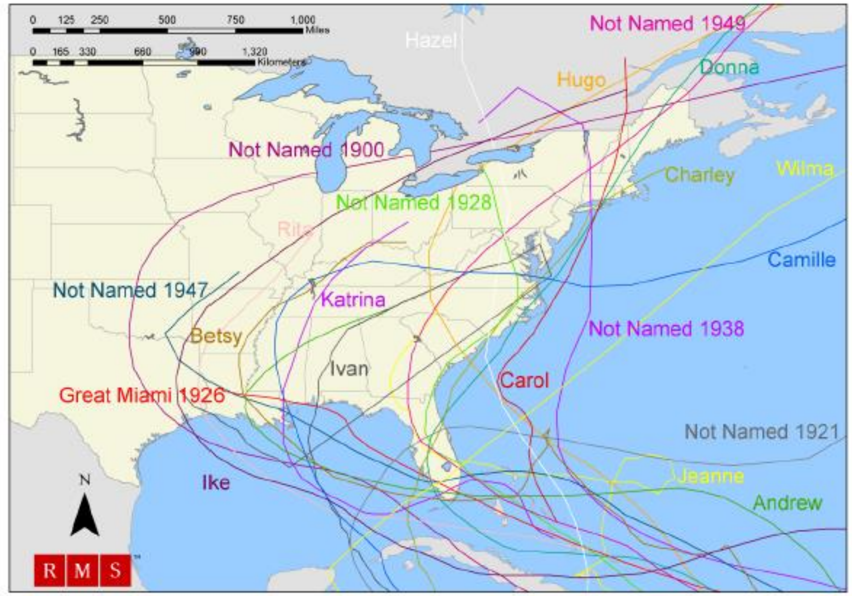
HOW

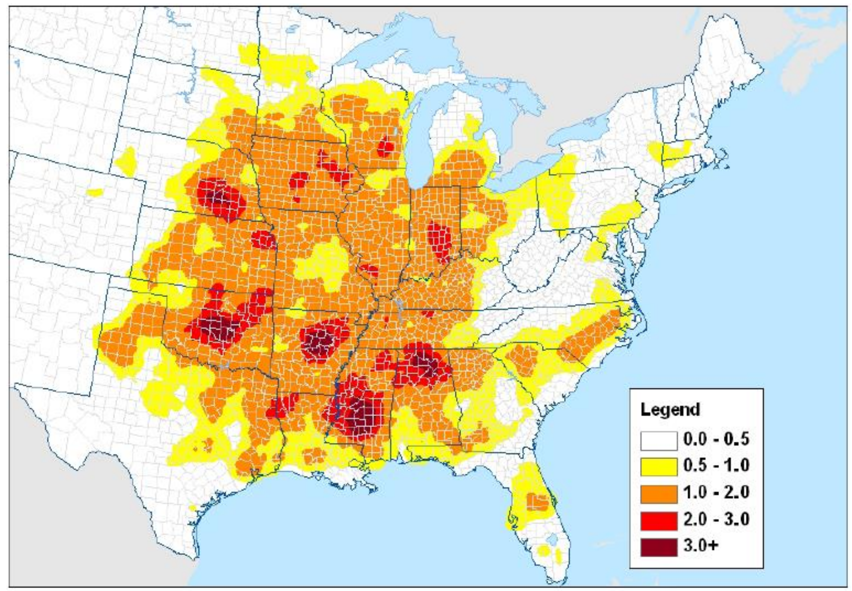
Examines insured values that are exposed to catastrophic perils such as hurricanes, earthquakes and terrorism

WHY

Aids management decision making on:

- Pricing and underwriting
- Reinsurance buying
- Rating agencies
- Portfolio management





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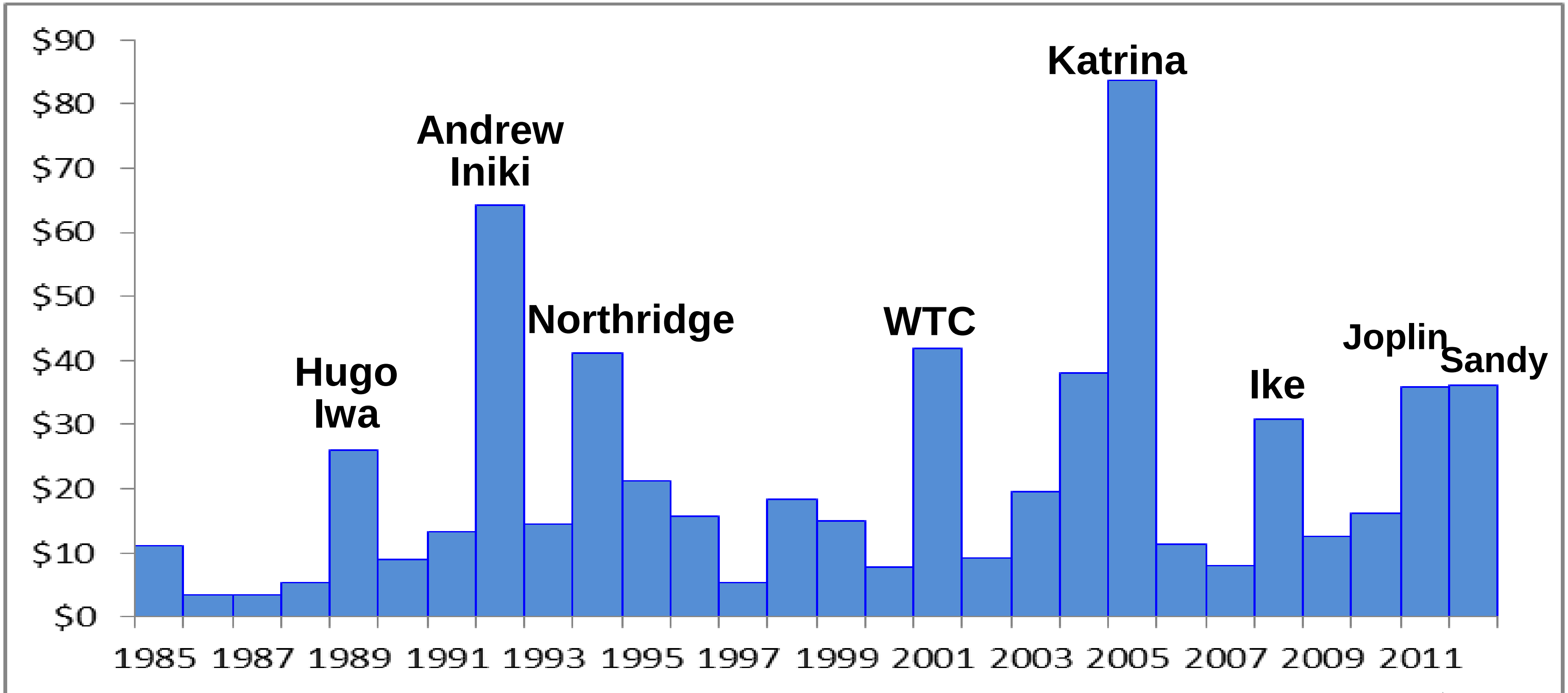
Intro to Catastrophe Modeling
The Evolution of Catastrophe Modeling



Losses in billions, adjusted to 2013, source: PCS

Experience and simple exposure rating used to quantify cat potential

The genesis of Catastrophe Modeling

Industry acceptance soars
New models emerge

Models come under extreme scrutiny

Intro to Catastrophe Modeling
Catastrophe Modeling Advantages

- **Minimizes reliance on historical data**
  - Adding an additional historical event to a small historical database can provide broad fluctuations in results
  - Historical results are not representative of future events in many areas
  - Exposures change over time (property values, population movement, building codes and construction techniques, topography, etc.) and on-leveling losses is challenging
- **Uses probabilistic distributions to properly address**
  - Low frequency but high severity events
  - Geographical distributions of events (fill in the holes)
- **Probabilistic distributions provide for robustness in the tail**
  - Compensate for little historical data
- **Process large volumes of data and complex calculations quickly**

Catastrophe Modeling Disadvantages

- **Model output is heavily influenced by three critical areas**
  - Quality of the source data (availability, completeness, accuracy)
  - Model methodology (difficult to quantify, different amongst vendors)
  - Model application (added complexity in decision process)
- **Model results can "take complete control" - often intended to be one of many decision tools but ends up as the ultimate and sometimes only answer**
- **Expensive and time-consuming to develop and operate**
  - Why many primary insurers do not develop models, license models or have cat modelers in-house
  - Why many of our clients rely on GC for these capabilities

Intro to Catastrophe Modeling
Vendor Models

RMS®

- Founded at Stanford University in 1988
- World's leading provider of products/services for the quantification and management of Cat risks.
- Grew in the 1990s, expanding services and perils covered
- Current version: RiskLink™ v.18

AIR

- Founded in 1987
- Pioneered the probabilistic catastrophe modeling technology
- Previous software product was CLASIC/2™
- Current version: Touchstone v6.0

CoreLogic®

- Known Previously as EQECAT
- Many large reinsurers and other risk management companies have developed their own in-house models
- Current version: RQE v18 (Risk Quantification and Engineering)

- Differences in assumptions and methodologies across vendors
- No one model is "right"
- Use multiple models for complete picture
- GC can provide expertise in understanding model differences (MSA®)

Intro to Catastrophe Modeling
Modeled Lines of Business

LOB's where catastrophe modeling is widely used by insurance companies for underwriting and portfolio management:

- Property
  - Personal Lines
  - Commercial Lines
  - Industrial Risk
  - Builders Risk
- Auto Physical Damage
- Marine (Yacht, Warehousing, Docks)

LOB's where catastrophe modeling used less frequently due to higher uncertainty in probabilistic results; commonly casualty risks are based on loss accumulations:

- Casualty
  - Workers Compensation
  - Life
  - Accident and Health

Intro to Catastrophe Modeling
Modeled Perils and Coverages

MODELED PERILS

- Hurricane
- Tornado/hail/wind
- Earthquake
- Terrorism/CNBR (NBCR)
- Infectious Disease
- Agricultural (crop)
- Flood (Europe)
- Winter storm
- Severe Convective Storm
- California Wildfire

NON-MODELED PERILS

- Flood (non-Europe)
- Volcanic hazards
- Landslide hazards
- Tsunami hazards
- Major earthquake aftershock

CAT Modeling

MODELED LOBs

- Personal lines property
- Commercial lines property
- Industrial property
- Builders risk
- Marine
- Personal auto/dealer Lot
- Workers compensation
- Lives at risk – A&H

MODELED COVERAGES

- Property
- Contents
- Time-Element
- Number of Employees
- Payroll

Intro to Catastrophe Modeling
Secondary Perils

Models recognize that when an event occurs, there is a range of possible loss results, which could stem from the occurrence of **Secondary Perils**

Secondary Perils

STORM SURGE

Quickly rising ocean water levels associated with hurricane that can cause widespread flooding

DEMAND SURGE (A.K.A. LOSS AMPLIFICATION)

The short term inflation in the prices of labor and materials following a catastrophe

FIRE FOLLOWING

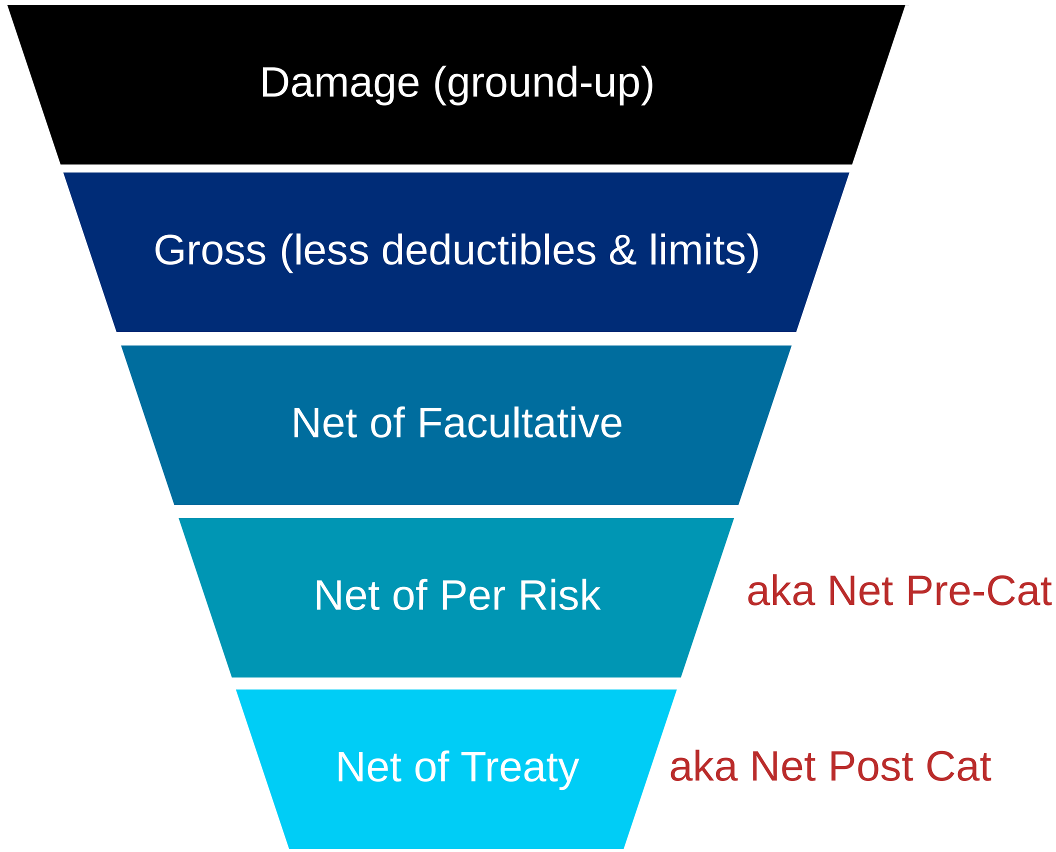
Fires which commonly occur following an earthquake, typically due to the rupture of natural gas lines or other structures carrying combustible materials

EARTHQUAKE SPRINKLER LEAKAGE

Building Sprinklers that can split or burst from shaking and cause water damage

Secondary Perils may contribute substantially to portfolio loss estimate

Intro to Catastrophe Modeling
Financial Perspectives



- Account for deductibles, limits and risk treaties within cat model and prior to simulation analysis
- Changes to inuring reinsurance structure require re-run of catastrophe models

Intro to Catastrophe Modeling
Types of Models

Deterministic Model

- Modeling using a **single** discrete event
- Commonly seen as recreations of historic events or single hypothetical analysis
- Event is assumed to happen without regard to probability

Probabilistic Model

- Uses as series of **simulated events**
- Accounts for the probability of those events over time

Intro to Catastrophe Modeling
How the Output is Used

- Evaluate Reinsurance Needs
- Portfolio Management
  - Monitor Exposure Growth / Geographic Spread
  - Evaluate Impact of Portfolio Expansion / Contraction
  - Mapping
- Underwriting on New/Renewal Books of Business; Deductible Scenarios
- Pricing
  - Insurance Policies
  - Reinsurance Treaties
- Rating Agency (e.g. A.M. Best) Requirements
- Real-time Event Analysis

INTRO TO CATASTROPHE MODELING
INSIDE THE BLACK BOX

How Does a Catastrophe Model Work?

Company Portfolio

Hazard Module

Used to generate the pattern of physical disturbance that is produced by a particular geophysical event

Engineering / Vulnerability Module

Estimates physical damage to structures and contents

Financial Module

Evaluates insured losses, given the damage level and values as well as the applicable insurance and reinsurance structures

The Three Catastrophe Model Components

1

Hazard Module

Site Intensity

- Generates the pattern of physical disturbance from an event (HU, EQ, tornado/hail, etc.)
- Important elements: Geocoding, distance to coast
- Stochastic event database

2

Vulnerability Module

Vulnerability of Property

- A set of relationships that defines how structural damage varies with exposure to differing levels of hazard (such as ground motion or wind speed)
- Important elements: Value of risk, construction, occupancy, year built, number of stories

3

Financial Module

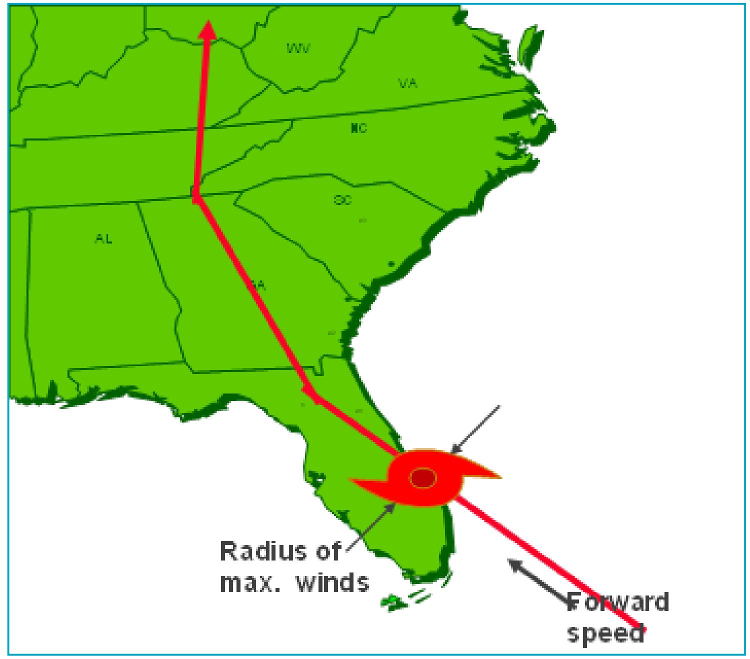
Loss Calculation

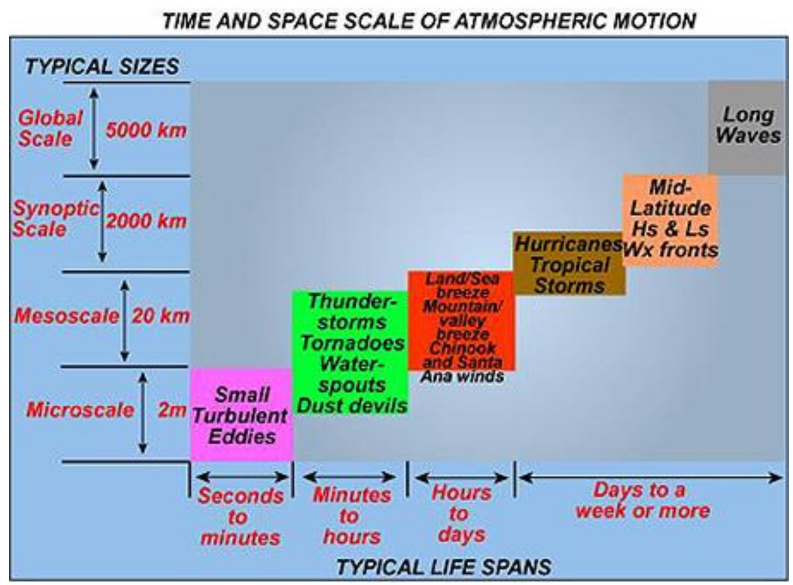
- Evaluates insured loss given structural values as well as the applicable insurance and reinsurance structures
- Important elements: Limit, deductible, reinsurance information

HAZARD MODULE

- Frequency (How often?)
- Severity (How big?)
  - Landfall location
  - Central pressure difference
  - Maximum wind speed
  - Forward speed
  - Filling rate after landfall
  - Storm path/wind field
  - Wind peak gusts
  - Single cell, supercell or multi-state
  - Terrain roughness

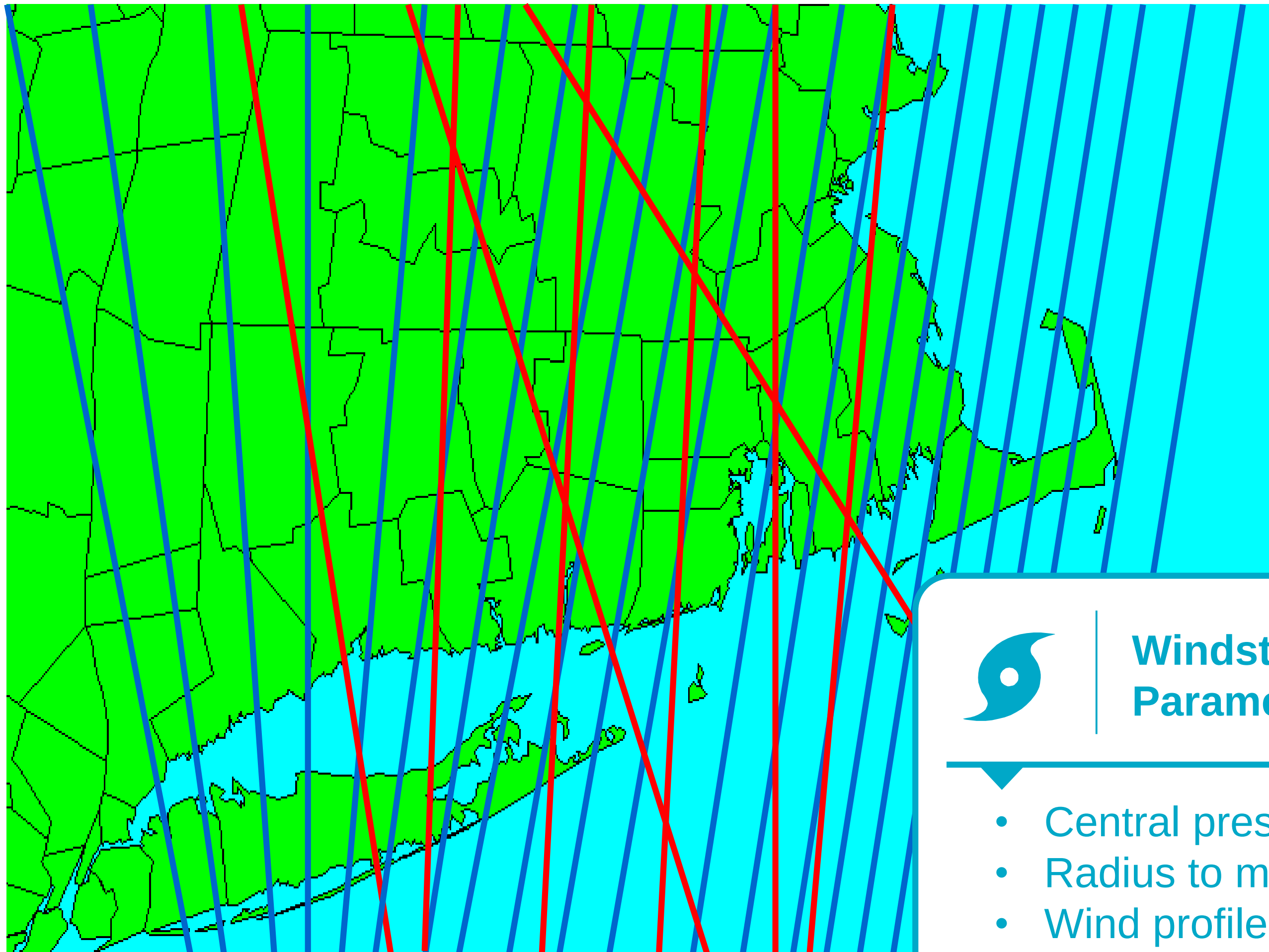
Site Intensity
Hurricane: Site Wind Speed
Earthquake: Ground Motion
Tornado/ Hail: Event Intensity





Hazard Module – Stochastic Database

Thousands of Hypothetical Events

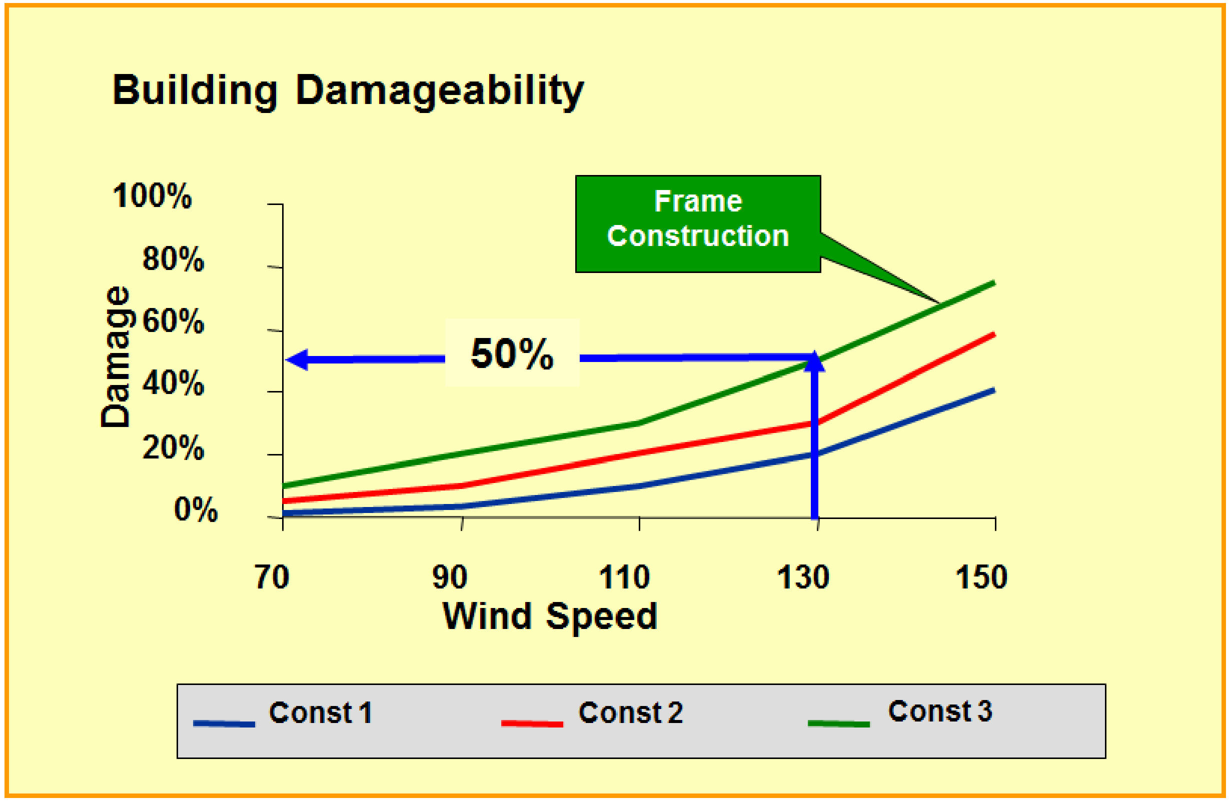


Windstorm Parameters

- Central pressure
- Radius to max. wind
- Wind profile
- Terrain, etc.

VULNERABILITY MODULE

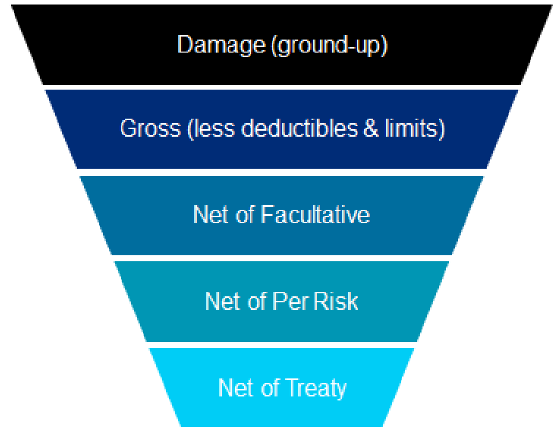
- Vulnerability function (aka damage curve) relates expected amount of damage to severity of the hazard
  - For hurricane, hazard is peak wind gust
  - Estimate Mean Damage Ratio (MDR)
    - ratio of loss to replacement value of building (contents)



Damage Rates are for illustration only and are not selected from any particular model

FINANCIAL MODULE

- Estimates insured losses, given the damage level and values as well as the applicable insurance and reinsurance structures
- Evaluates multiple financial perspectives
  - Ground up: damage prior to coverage limits and deductibles
  - Gross: loss after deductibles, limits, attachment points
  - Net: loss after treaty cessions, facultative, etc.



- Values
  - By coverage
- Deductibles
  - By coverage, location, and/or policy level
  - Differ by peril
- Limits
  - By coverage, location, and/or policy level
  - Differ by peril

- Reinsurance
  - Facultative
  - Surplus Share
  - Per Risk Excess
  - Quota Share
  - Catastrophe Excess

Catastrophe Modeling Input – It's All About the Data

- Hazard Module
  - Location of Risk
- Vulnerability Module
  - Occupancy
  - Construction
  - Number of Stories
  - Year Built
  - Square Footage
- Financial Module
  - Replacement Value of Risk
  - Limits and Attachments
  - Deductibles
  - Reinsurance

Understand the impact on model output due to lack of data or data assumptions

Pulling it All Together

1. Select an event in the event set
   – Event ID 111234
2. For each location in the portfolio, determine peak-wind gust windspeed for that event
   – At 101 Main Street, peak-gust windspeed = **120 mph**
3. Determine mean damage ratio (MDR) using vulnerability curve
   – Peak gust windspeed of 120 mph = **MDR of 40%**
4. Determine ground-up loss (damage) for location
   – $1,000,000 Value * 40% MDR = **$400,000 damage for location**
5. Apply policy terms to calculate loss for Company
   – $50,000 Deductible = **$350,000 loss for location**
6. Repeat Steps 1-5 for each location and sum across all locations to determine Company loss for Event ID 111234

Repeat Steps 1-6 for each event to create table of thousands of event losses.

Cat Modeling Output – Typical Results & Definitions (Event Loss Table)

- The data underlying any cat model output is the event loss table
- Consists of each event simulated along with the resulting loss
- Sample event output:

Event ID	Loss	Event Description	Landfall State	Landfall County	SSI
437812	4,400,000,000	FL-NE_Cat5	FL	Indian River	5
437830	4,000,000,000	FL-SE_Cat5, MA-CC_Cat0	FL	Broward	5
438632	3,750,000,000	FL-SE_Cat5	FL	Palm Beach	5
437676	3,600,000,000	FL-SE_Cat5	FL	Palm Beach	5
438622	2,750,000,000	NC_Cat5, MA_Cat4	NC	Brunswick	5
438489	2,500,000,000	FL-SE_Cat5, MA_Cat0	FL	Dade	5
438451	2,400,000,000	FL-SE_Cat5, FL-SW_Cat0, NY_	FL	Broward	5
438351	2,250,000,000	FL-SE_Cat5	FL	Palm Beach	5
438248	2,240,000,000	FL-SE_Cat4, SC_Cat3	FL	Palm Beach	4

Catastrophe Modeling Output

- OEP - Occurrence Exceeding Probability: Probability that a single occurrence will exceed a certain threshold
- AEP - Aggregate Exceeding Probability: Probability that one or more occurrences will combine in a year to exceed the threshold

Exceedance Probability	Return Period (Years)	Occurrence Loss (000)	Aggregate Loss (000)
10.0%	10	$3,000	$5,000
5.0%	20	$15,000	$22,000
2.0%	50	$85,000	$87,000
1.0%	100	$200,000	$202,000
0.5%	200	$300,000	$310,000
0.4%	250	$500,000	$520,000
0.2%	500	$600,000	$610,000
0.1%	1,000	$900,000	$910,000
Average Annual Loss (000)			$9,000

- According to the OEP curve, there is a 1% chance each year that the Company will see a single occurrence causing gross loss of or greater than $200M
- According to the AEP curve, there is a 0.4% chance each year that the Company's gross aggregate losses for the year (from one or more events) will meet or exceed $520M

Catastrophe Modeling Output

- Average Annual Loss (AAL)
  - The long term average loss expected in any one year for the book of business for the peril being modeled. Represents the loss cost or pure premium for the book of business for the peril being modeled.

- AAL is an additive statistic
  - Can be used to subdivide the losses for a portfolio by categories of interest
  - Can be used to determine loss drivers
    - Geography (state, county, etc.)
    - Line of Business
    - Region/Territory
    - Peril
    - Producing Agent
    - Risk Characteristics

County	Average Annual Loss (000)	Percent to Total
Suffolk, NY	$1,500	16.7%
Queens, NY	$1,000	11.1%
Worcester, MA	$800	8.9%
Ocean, NJ	$720	8.0%
Bucks, PA	$640	7.1%
Lancaster, PA	$570	6.3%
Middlesex, MA	$520	5.8%
Allegheny, PA	$500	5.6%
Allegany, NY	$480	5.3%
Salem, NJ	$320	3.6%
Subtotal Top 10	$7,050	78.3%
Subtotal All Other	$1,950	21.7%
Total	$9,000	100.0%

Catastrophe Modeling Output

- Average Annual Loss (AAL) is an additive statistic but....
  - The values on the AEP and OEP curves are not additive:

$$OEP(250)_{A+B} \neq OEP(250)_{A} + OEP(250)_{B}$$

- Note that models may need to be re-run for every additional cut or grouping of data
- Multiple portfolios will need to be grouped through MetaRisk® or other GC tools

INTRO TO CATASTROPHE MODELING
OTHER CONSIDERATIONS

Other Considerations
Hurricane Frequency -- Near-Term vs Long-Term

- Long-Term Frequency
  - Based on hurricane historic landfall record of over 100 years
  - In AIR: aka Standard Catalog
- Near-Term Frequency
  - Otherwise known as Medium-Term Frequency, Atlantic Multi-Decadal Oscillation (AMO), Warm SST Catalog (AIR)
  - Introduced in 2006 hurricane models following active 2004-2005 hurricane seasons
  - Recognition of the “warm phase,” characterized by a well-accepted meteorological phenomenon, AMO and it’s resultant increase in hurricane frequencies
  - In RMS, represents expected average annual landfall rates along the Atlantic and Gulf coastlines on a rolling 5-year time horizon

GC recommends Long-Term Freq as a more reliable and stable view of risk

Other Considerations
Demand Surge

- What is Demand Surge?
  - Economic Demand Surge (EDS)
    - Rapid increase in the cost of building materials and labor cost as demand for repair exceeds supply or capacity of the construction sector following a major hurricane
  - Triggered in models based on size of Industry Loss for an event
- **RMS**
  - Post Loss Amplification (PLA) (aka Demand Surge Plus)
    - Includes EDS plus Claims Inflation plus Super Cat adjustments
      - To account for Katrina-type claims increases due to adjustment delays, levee breaches, etc.
  - Available for Hurricane and Earthquake perils
- **AIR**
  - Reflects EDS only
  - Available for all perils

Other Considerations
Storm Surge

- Fully probabilistic physical numerical model to estimate water driven on land by a combination of pressure drop and wind stress over the lifetime of a storm
- **RMS:** Default Assumptions
  - Single Family Dwellings, Low-Rise Multi-Family Dwellings and Commercial Occupancies
    - Assumes a portion of storm-surge related damage not covered by the NFIP are paid by wind policies as a result of coverage leakage
    - Take-up rates vary by state and flood zone
      - Take-up rate for Low-rise Commercial is half of SFD and MFD rate
    - Flat 20% Leakage factor also included for SFD and low-rise MFD
  - Mid and High-Rise Multi-Family Dwellings and Commercial Occupancies
    - Assumes NFIP is not applicable and policies cover surge losses
  - MDR_surge_modified = MDR_surge x Covg Leakage Factor x (1-Scaled NFIP Take-Up Rate)
- **AIR:** Default Assumptions
  - Take-up rate of 5% for storm surge coverage for both residential and small commercial exposures
  - 100% for automobiles and large commercial (building ≥$10M)

Other Considerations
What is Not Contemplated in the Modeled Loss Estimates?

- Not Modeled (Explicitly)
  - Loss Adjustment Expense
  - Precipitation
    - Impact of Wind-driven rain and saturated soils
  - Tree Damage
  - Supplemental Coverages
    - Water or sewer back-up
    - Debris removal
    - Ordinance or law
    - Contamination and associated clean-up costs

MODEL UNCERTAINTY

Uncertainty in Catastrophe Models

When a cat model says
“Your 100 year return period loss is
$1,117,243,572,” what it really means is that
your 100 year return period loss is about a
billion dollars but it could be 600 million dollars
or maybe two billion dollars…
or something like that. *

•Guy Carpenter Briefing “Managing Catastrophe Model Uncertainty” John Major December 2011

Sources of Uncertainty within the Models
The Three Catastrophe Model Components

1
Hazard Module

- Limited historical data on hurricane, earthquake and tornado/hail events
- Unreliable data quality for old records
- Lack of understanding of physical phenomena underlying hurricane and earthquake behavior

2
Vulnerability Module

- Limited claims data (model calibration)
- Valuation
- Improper coding of risk characteristics
- Lack of understanding of structural behavior under severe loads

3
Financial Module

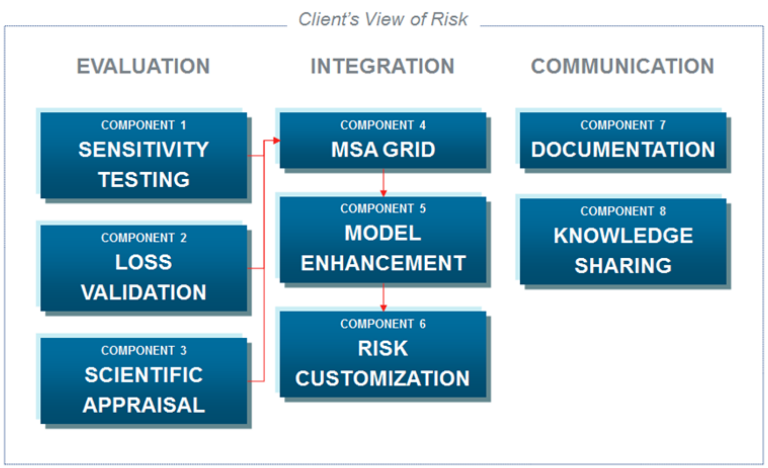
- Real-life application of terms/reinsurance
- Model limitations, depending on level of "terms" versus the level at which the reinsurance applies

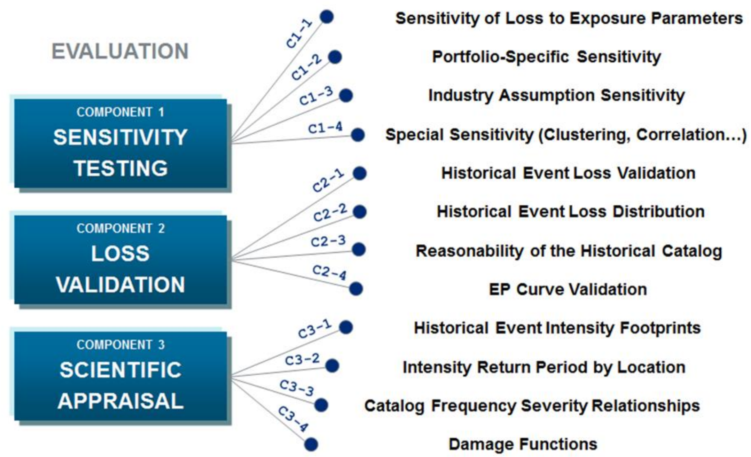
Model Uncertainty
Manage Through Multiple Models

- Model vendors differ in
  - Interpretation of the historical record
  - Interpretation of detailed scientific data
  - Sources of vulnerability
  - Site conditions data
- Using multiple models and blending results
  - Can help to
    - Narrow the uncertainty band
    - Smooth impact of individual model version changes
    - Better estimate risk and control uncertainty
    - Diversification of error sources
  - Can not
    - Overcome the limitations of historical data
    - Overcome data errors

Model Suitability Analysis (MSA)®

- Provides a rigorous, systematic assessment of the many available cat models, helping clients formulate their view of catastrophe risk, complete with documentation for communication to stakeholders
  - Evaluation components include sensitivity testing, loss validation and scientific appraisal
  - Tests currently available within the GC framework for US North Atlantic Hurricane are
    - event frequency by severity (Test C3-3)
    - model sensitivity to exposure inputs (Test C1-1)





APPENDIX 1
Definitions

Important Definitions

- **Deterministic Model**: A model that assesses the impact of a hazard by investigating the severity of a single possible outcome.
- **Probabilistic Model**: A model that assesses the impact of a hazard and assigns probabilities to a whole range of possible outcomes.
- **Primary Uncertainty**: Uncertainty in the likelihood that a particular event occurs.
- **Secondary Uncertainty**: While primary uncertainty measures uncertainty in the likelihood that a particular event occurs, secondary uncertainty incorporates the distribution of potential loss amounts for the event. In other words, it recognizes that when an event occurs, there is a range of possible loss values.
- **EP (Exceeding Probability)**: The probability of exceeding specified loss thresholds. In risk analysis, this probability relationship is commonly represented as a curve (the EP curve) that defines the probability of various levels of potential loss for a defined structure or portfolio of assets at risk of loss from natural hazards.
- **TVaR (Tail Value at Risk) or TCE**: The conditional expectation of losses that are greater than or equal to a specified return period loss (RPLα, where α is the selected risk tolerance threshold). In other words, TVaR is the expected value of loss given that a loss at least as large as RPLα has occurred.

Important Definitions

- **Return Period**: The expected length of time between recurrences of two events with similar characteristics. The return period can refer to hazard events such as hurricanes or earthquakes, or it can refer to specific levels of loss (e.g. a $100 million loss in this territory has a return period of 50 years).
- **Occurrence Exceeding Probability (OEP)**: A measure of the probability that a single occurrence will exceed a certain threshold.
- **Aggregate Exceeding Probability (AEP)**: A measure of the probability that one or more occurrences will combine in a year to exceed the threshold.
- **Average Annual Loss:** The long term average loss expected in any one year for the book of business for the peril being modeled. Represents the loss cost or pure premium for the book of business for the peril being modeled.

Important Definitions

- **Damage:** Any economic loss or destruction caused by an earthquake, windstorm, or other peril.
- **Ground Up Loss**: The gross amount of loss occurring to an insured and subject to the insured's insurance policy, beginning with the first dollar of loss and prior to the application to the deductible or deduction, if any, required by the policy.
- **Gross Loss**: The amount of a ceding company's loss irrespective of any reinsurance recoveries due. It is calculated by taking the ground-up loss less any deductibles.
- **Net Loss**: The amount of loss which an insurer keeps for its own account and does not pass on to another insurer (or reinsurer).

APPENDIX 2
Event Loss Table

Catastrophe Modeling Output
The Event Loss Table -- RMS

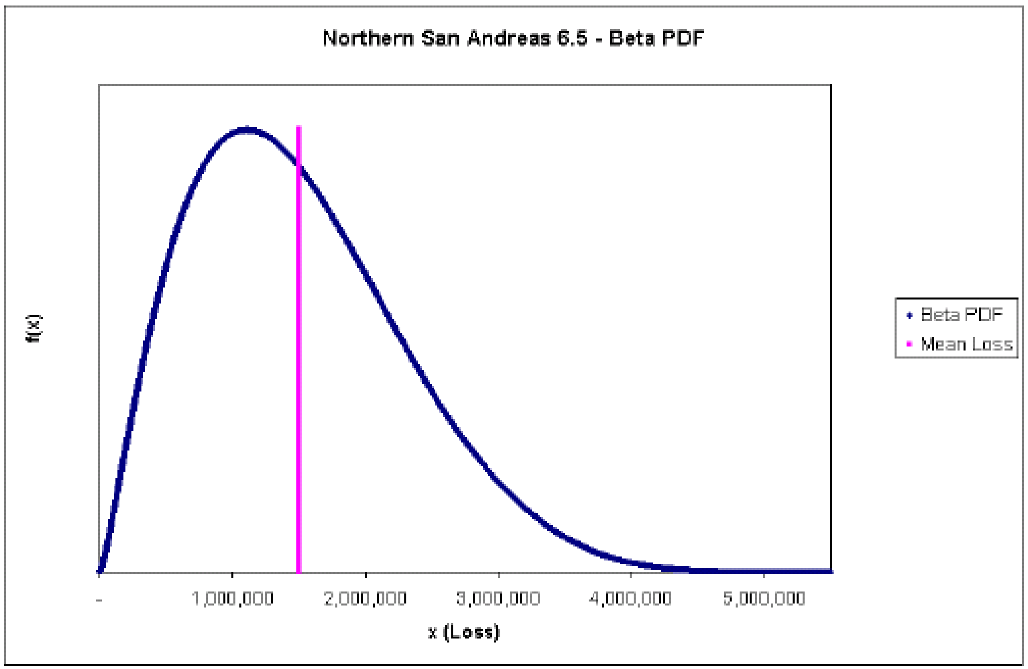
EVENTID	RATE	PERSPVALUE	STDDEVI	STDDEVC	EXPVALUE
2851447	3.62E-05	2,137,938,177	21,534,064	1,059,183,643	30,595,850,974
2860627	1.72E-06	1,905,158,933	20,259,204	1,063,278,547	29,743,955,823
2857920	7.74E-06	1,752,507,360	20,046,812	829,307,598	29,637,977,380
2855099	2.24E-06	1,646,938,079	18,502,454	956,966,648	29,817,265,423
2868768	1.50E-07	1,595,762,960	17,842,249	752,169,047	28,743,536,057
2849767	3.09E-06	1,490,782,680	17,252,134	866,837,579	29,150,008,923
2871086	1.51E-05	1,458,307,300	17,393,044	772,378,676	27,121,751,636
2863301	1.65E-07	1,455,730,844	17,579,336	835,033,786	30,270,029,509
2857230	6.65E-07	1,423,726,589	18,843,018	533,757,597	29,743,432,843
2862970	2.77E-07	1,363,130,451	16,296,276	865,423,686	28,462,240,877
2848794	1.24E-05	1,350,356,311	17,019,626	851,795,261	29,698,290,422
2877212	4.83E-06	1,235,284,769	16,165,948	691,593,767	23,421,483,121
2868396	6.57E-06	1,169,387,686	14,745,859	793,755,727	30,206,635,529
2850211	5.49E-06	1,168,801,575	17,171,897	454,832,205	30,351,581,784
2870736	4.37E-06	1,101,407,594	16,727,763	465,557,151	30,039,274,364
2877164	4.70E-05	1,095,272,887	16,762,448	451,325,517	29,856,244,396

- **EVENTID**: Unique identifier for each event
- **RATE**: Rate of occurrence of each event
- **PERSPVALUE**: Mean loss for each event
- **STDDEVI**: Independent Standard Deviation
- **STDDEVC**: Correlated Standard Deviation
- **EXPVALUE**: Exposed value to the event
- **Average Annual Loss**: AAL = Σ(RATE * PERSPVALUE)

Catastrophe Modeling Output
The Event Loss Table – RMS – Secondary Uncertainty

- Model Uncertainty
  - **Primary Uncertainty** - uncertainty around whether an event will occur
  - **Secondary Uncertainty** - uncertainty in the amount of loss, given that a certain event has occurred

- It is assumed that each event on the ELT has a probability density function that follows a Beta distribution.



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Catastrophe Modeling Output
The Event Loss Table -- AIR

- **EVENTID**: Unique identifier for each event
- **YEAR**: Simulation year
- **LOSS**: Mean loss for each event
- Note: Standard deviation is not provided by default in AIR
- **Average Annual Loss** is equal to the total loss for all events divided by the number of simulation years (which is most typically 10,000)

EVENTID	YEAR	LOSS
2754	106	989,966,831
90991	3383	919,778,429
234119	8678	723,302,295
19227	720	600,527,281
155045	5744	595,583,222
107597	3995	575,357,197
194372	7204	531,210,726
39393	1464	504,472,536
23446	876	497,642,204
228600	8470	477,846,185
169199	6256	468,302,656
29380	1093	431,140,754
149760	5549	424,157,015
189811	7028	423,191,930
262342	9725	422,595,941
170874	6317	416,960,947

Catastrophe Modeling Output
The Event Loss Table

- Forms of ELT used in MetaRisk
  - .rm2 files for RMS
  - .vnt files for AIR
  - .eld files for both
    - Current preferred file type
      - Especially for AIR because includes “Year”
- Cat modeling team generally creates using EventBuilder tool
- Can include multiple “loss causes”

Questions/Wrap Up

GUY CARPENTER

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