How Do Buildings Fail in a Hurricane?
US Damage Mechanisms by Decade

Total damage normalized to 2018 for economic changes
Wind Flowing Over a House

Pressure on windward walls
Suction on roof & lee walls

Flying debris causes failure in addition to the dynamic pressure of the wind.
Breaching the Building Envelope Adds Internal Pressure to External Suction
Structural Failure(s)

- Shingles or roof tiles fail
- Rainwater enters
- Windows, entryway doors & garage doors fail
- Soffits blow upward
- Interior walls collapse
- Roof sheathing blows off
- More rainwater enters
High Velocity Hurricane Zone Building Code

10 ft

Tie Beam

Concrete Block

Foundation

Reinforcing Steel

Negative Load Path to Ground

Hurricane straps around trusses
Failures “Prevented” by High Velocity Hurricane Zone Building Code

- Failure of doors & windows
- Collapse of interior walls
- Roof detachment from walls
- Toppling of unreinforced exterior masonry walls
- “Prevented” really means failure moves to higher wind speed
Vulnerability curves define percent damage as a function of wind speed.
Progressive Failure

Threshold of Damage

Complete Destruction

ENVELOPE BREACHED

Percent Destroyed

Wind Speed

0%

25 m/s

50%

100%

100 m/s

windows & doors

roof sheathing & gable ends

pool enclosures & fences, tiles & shingles

walls
Where the Vulnerability Curve Starts to Ramp Up
Farther Up the Curve
Devastation
Schematic Effect of Construction Standards on Vulnerability
How Do Insurance Companies Set Rates?

- Inventory of insured structures (*Book of Business*)
- Climatology of hurricanes
- Vulnerability curves for various kinds of construction
- Costs of claims based upon damage and terms of policies
- Regulation by state and federal governments
Structure of a Catastrophe (CAT) Model

- Hazard
- Inventory
- Vulnerability
- LOSS
Inventory Module

- Digital list of insured structures (Book of Business)
- Information
  - Location (zip or Lat/Lon)
  - Insured value
  - Type of construction
  - Size
  - Number of stories
  - Year built
  - History—losses, remodeling
  - Coverage…
Hazard Modules are Based Upon the Redfield-Reid Paradigm
Statistics From HURDAT File

- Record of Atlantic TCs back to 1851
- Not complete before 1900 (or maybe 1944)
- Tabulates Lat, Lon, Pmin, Vmax, landfall every 6 hours
- Developed for forecast verification
- Has taken on the status of a legal document

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Synthetic Hurricane Seasons

- Generate ~1000 virtual hurricane seasons
- Go through each season day-by-day
- For each 10° (or 5°) square generate (or not) a random starting intensity and motion
- Generate history of track, intensity & size
- Combine the cyclones and repeat for another virtual season
Model Track and Intensity Using a Markov Process

- Every six hours adds a random $Dx$ and $Dy$ to previous position
- Also add increments of intensity and size
- With mean and standard deviation calculated from HURDAT
- Probabilities depend upon position, day of year, etc.
Many CAT Models Use the “Holland” Parametric Wind Profile

- Parameters are
  - Minimum Pressure,
  - Radius of Maximum Wind
  - B, the “Width Parameter”

- Monte-Carlo model of changes

- Generate winds for each virtual hurricane
Vertical structure of the wind depends upon surface roughness.

Logarithmic Wind Law

\[ u(z) = \frac{u_* \ln \frac{z}{z_0}}{0.41} \]
Virtual Storms Impact on Actual Insured Property

Need to consider only landfalling storms
Cost Module

• Converts damage to repair/replacement costs---i.e. to claims
• Depends upon
  – Kind and extent of damage
  – Cost of labor and materials
  – Post-storm demand surge
• Generally includes
  – Structure contents
  – Temporary accommodations
CAT Model Summary

• Generate many (~1000) random hurricane seasons with the same climatology as HURDAT

• Calculate damage and claims for the company’s Book of Business

• Count from most damaging to least damaging and sort from least damaging to most damaging

• Divide count by number of seasons and tabulate as a function of predicted claims to get *Exceedance Probability* curve
Exceedance Probability Curve

- The Curve gives the probability of each potential “Loss Cost” or greater
GDP Detrended Damage, 1900-2018

Mean: 2.884, SD: 1.068.
Skew: -0.159, Kurt: 2.637
These are US nationally aggregated losses. Insurers will use their own “Book of Business”
How do Insurance Companies Use Exceedance Probabilities?
Reinsurance is Used to Transfer Risk

1% - 0.5%
Study Questions

1. Most primary insurance companies buy _____ to protect themselves against catastrophic losses much greater than the annual average.
   a. Flood insurance  c. PML
   b. Reinsurance      d. Credit Default Swap

2. The _____ component of a Hurricane Catastrophe model relates wind speed or flood water depth to the fraction of an insured structure destroyed
   a. Vulnerability  c. Loss
   b. Hazard         d. Inventory

3. Probable Maximum Loss represents the largest expected total claims that a primary insurance company might pay during an unusually destructive year. PML typically has annual probability _____.
   a. 50%  c. 1-0.5%
   b. 33-66%  d. < 0.1%

4. Because of its fundamental nature, the reinsurance industry must be_____
   a. Cooked as hell  c. Subject to local regulation
   b. Profitable every year  d. International in scope
Summary

- Damage caused by
  - Dynamic Pressure
  - Flying Debris
  - Water penetration
- Failure of building envelope progresses to structural failure
- Mitigation
  - Negative load path
  - Protection of windows and doors
- Vulnerability Curves: Percent damage as a function of wind speed
- Catastrophe model modules
  - Hazard: Hurricane number, intensity, size …
  - Vulnerability: Amount of insured property in harm’s way
  - Loss: Models failure of structure
  - Cost: Combines damage and policy terms to estimate claims
- Exceedance Probability: Probability of a given Loss Cost or more
- Reinsurance: Insurance for insurers--covers loss above some (large) deductible and below policy limit
- Maximum Probable Loss
  - 1% or 0.5% on XP curve
  - Larger losses may cause insolvency
Thank you for your attention. Questions?