An Examination of the Geographic Aggregation of Catastrophic Risk*

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Catastrophic Exposures and Risk Bearing

- Earthquake
  - California but much broader exposure
  - Tidal Wave/Tsunami
- Windstorm and Storm Surge
  - Hurricane/Tornadoes
  - Coastal and Inland
- Flood
  - Rainfall driven
  - Wind driven- Storm Surge
  - Tsunami
- Terrorism
- Pandemics
- Catastrophes and Risk Bearing
  - State: Private market, E&S, Residual market
  - Federal: Flood, Terrorism (ex-post financial support)

U.S. Federal Catastrophe Fund

- Proponents
  - Financial strength of federal government
  - Pool risks that are uncorrelated or have low correlation
  - Eliminate or reduce market dysfunctions
    - Coverage availability
    - Prompt claims payments
  - Eliminate or reduce underinsurance problem
  - Feds provide support ex-post anyhow!
- Opponents
  - Intrusion into private market
  - Concerns about governmental inefficiencies (e.g., NFIP performance)
  - Verification and triggers
  - "Why should [INSERT YOUR STATE HERE] pay for California earthquake losses/Florida hurricane losses/Texas hurricane losses/New York –New Jersey wind and flood losses??"
    - The subsidy problem
  - Path to unwanted federal regulation of insurance

Motivation

- Public policy debate about shifting additional catastrophic risk to the federal level
  - ongoing and often contentious
  - Little in the way of empirical analysis
- Research Questions:
  1) Do diversification benefits exist by aggregating catastrophic loss over larger geographic areas?
  2) If so, when and to what degree do these benefits exist?
- First Phase of Research
  - Coastal States- Texas to Virginia

Selected Literature Review on Geographic Diversification

- Lin and Wen (NAAJ, 2012)
  - Relationship between ERM adoption and reinsurance or geographic diversification.
- Klein and Wang (JRI, 2009)
  - Catastrophic risk financing in the US and EU
- Harrington (JRI, 2009)
  - Financial crises and systemic risk
- Klein and Krohm (JIR, 2008)
- Jaffee and Russell (JRI, 1998)

Study Details

- Methodology
- Experiment 1: Single exposures in single ZIP Codes
- Experiment 2: Aggregations of uniform exposures
- Experiment 3: Aggregations with Realistic Exposures
- Implications and Further Research.

Methodology

- Simulate all Atlantic storms (1851 to 2011; only using 1871 to 2011 for analysis since 1851 – 1870 is potentially missing significant numbers of weaker storms)
- TARU full physics tropical cyclone model – enhanced SLOSH wind model with trajectory based boundary layer, WISWAVE III wave model (incl. inshore refraction/breaking), 5 sigma layer hydrodynamic model (storm surge and riverine flooding), TRMM Climatology based rain model.
- ISTANU damage model (composite of multiple public domain damage functions).

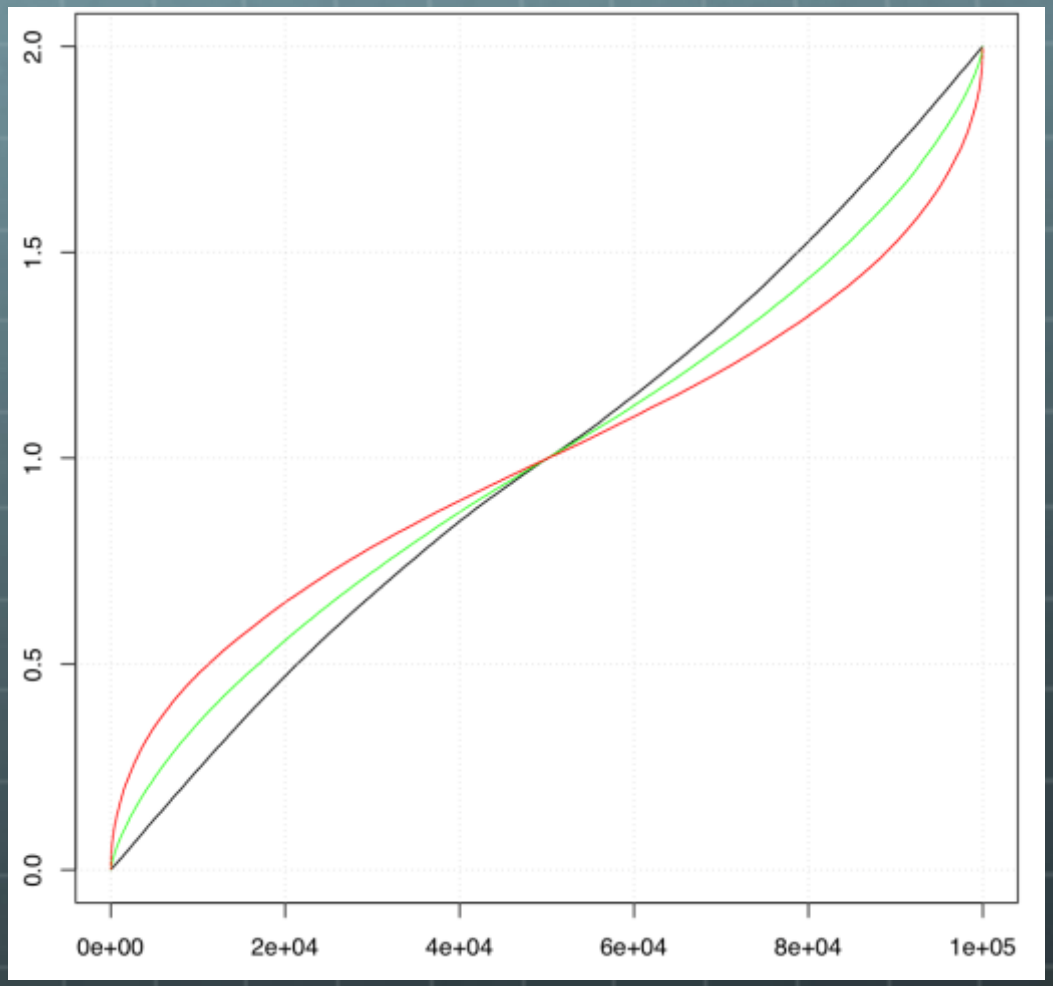
Data Sets

- Hypothetical exposures at each ZIP Code centroid:
  Structure Value: $100,000
  Contents Value: $60,000
  Standard US Single Family Construction (WF)
- Realistic exposures derived from 2010 American Community Survey at the Block Group level. All residential exposures (Manufactured Housing through Commercial Residential), roughly 10x more detailed than ZIP Codes.
- ATCF A Decks (storm tracks since 1871)
- WTC SRTM and MODIS derived terrain data sets (Spring 2012 land cover)

Coverages

- The current insurance system is split between flood, which is covered by FEMA, and wind and rain damage, which is covered by private insurance.
- Often causes problems for the consumer – what is covered, who pays? Differences between a "hurricane" and a "tropical storm"
- AAL's cover wind, wave, rain, and flood~ no loads/subsides

Impact of correlation on PML

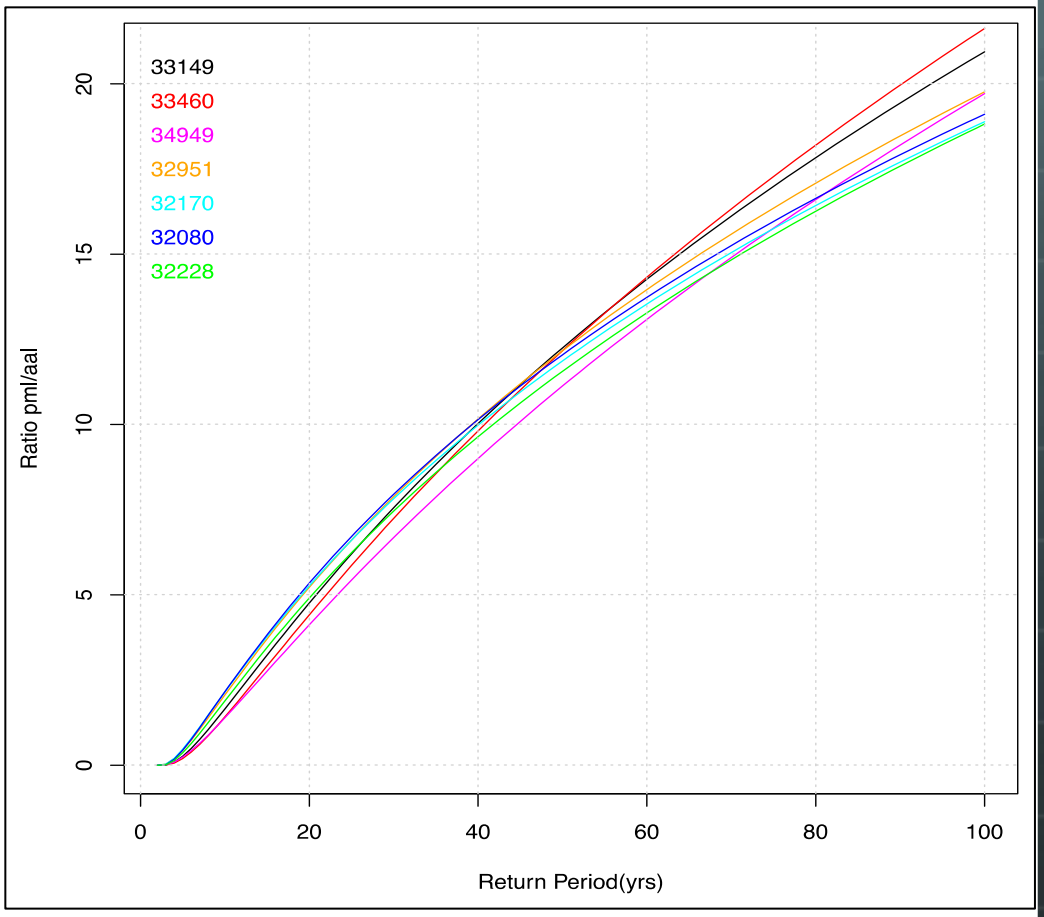


Plot of the sum of the probability of two variables (each from 0 to 1) with correlations of 1.0 (black), 0.5 (green), and 0.0 (red). This corresponds to two points located at the same location, then two points close enough to be impacted by some but not all events, and finally far enough apart to be unaffected by the same events.

Events (100,000) vs. cumulative "losses"

Terminology and Comparison Criteria

- Average Annual Loss (AAL)
- Probable Maximum Loss (PML)
  - Maximum Likelihood Estimate (MLE) loss at the specified return period.
- PML/AAL
  - Multiples of the annual premium that are required to cover the losses from an event of that return period
- Plot: PML/AAL to Return Period



Variability and Uncertainty

- Variability: What is the range of probable risk in a given year?
  - In catastrophic risk this can be an enormous range – from zero to a large number.
  - We usually look at this in terms of return periods, such as the 100 year event, or in annual terms, an event has a 1 in 100 chance of happening in a given year.
- Uncertainty: How good are the estimates of the risk?

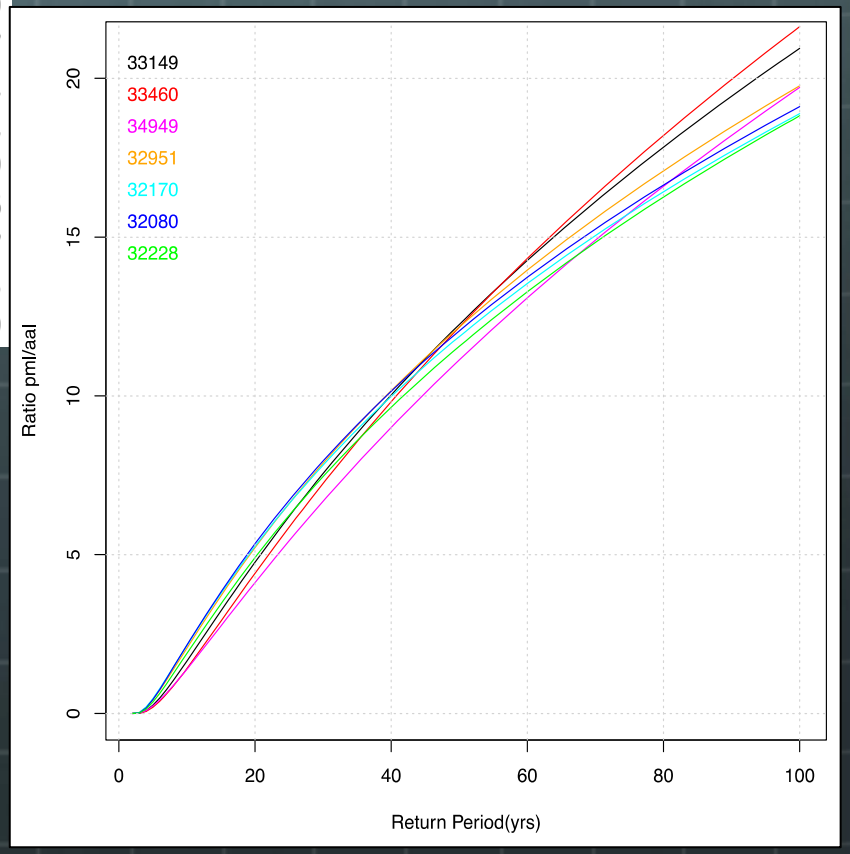
Experiment 1: Single Exposures

- Simplest case.
- What is the behavior of single exposures (one house) in disparate risk locations?
- What happens as we aggregate single exposures?
- What happens to AAL and PML as we aggregate geographically diverse exposures?

Experiment 1: Locations

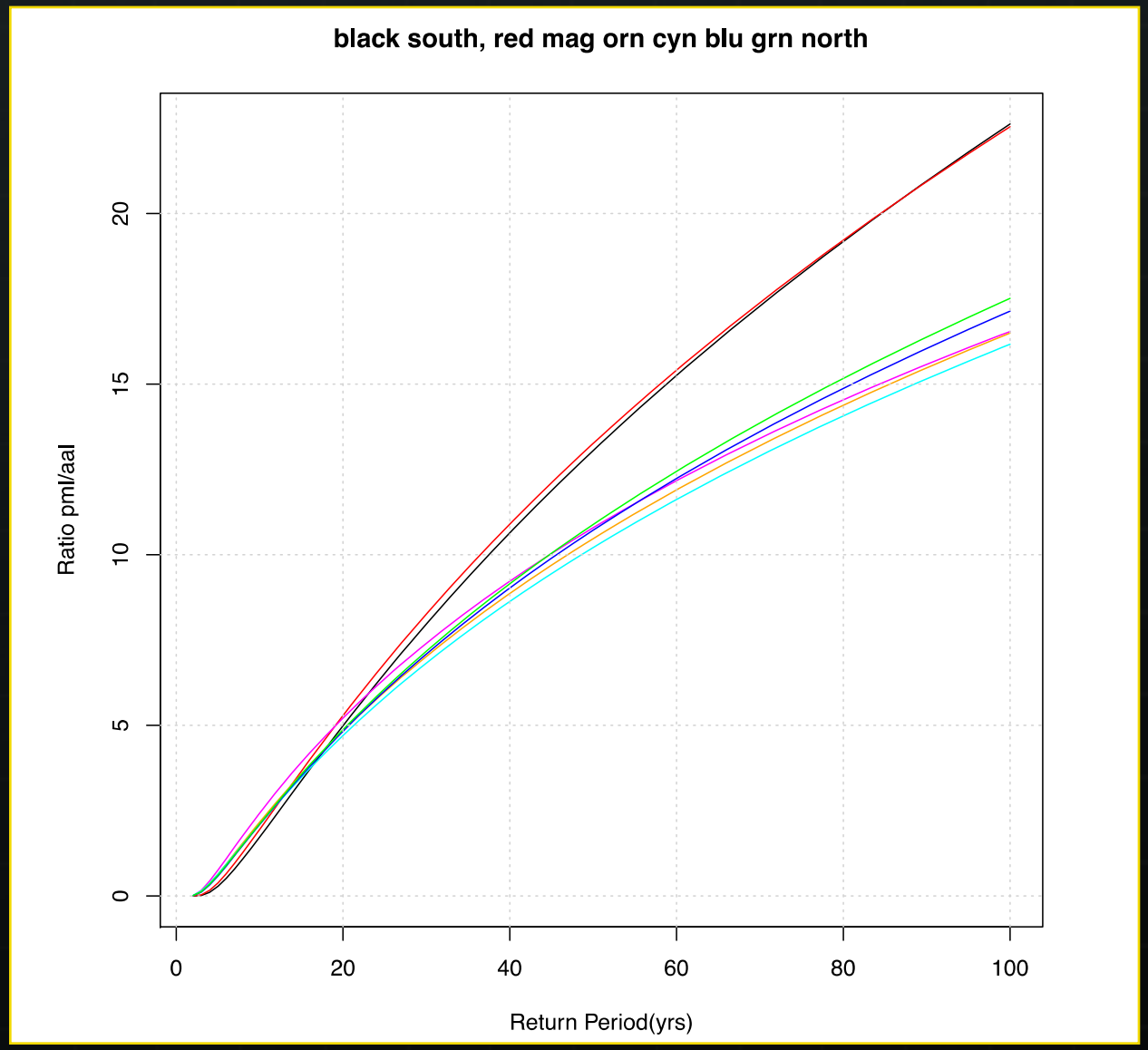
Exp 1: Single Exposure Results

criteria	exposure	aal	losscost	rp_aal	rp_1pct
33149	160000	2556.79	15.98	7.8	6.5
33316	160000	1211.84	7.57	8.5	9.6
33460	160000	1693.06	10.58	8.7	8.5
33455	160000	1967.76	12.30	8.2	7.4
34949	160000	1736.72	10.85	8.4	8.1
32971	160000	1384.78	8.65	7.3	7.9
32951	160000	779.88	4.87	6.8	9.9
32815	160000	367.32	2.30	6.5	16.7
32170	160000	508.75	3.18	6.9	14.1
32136	160000	499.39	3.12	6.6	13.1
32080	160000	456.71	2.85	6.7	13.9
32082	160000	349.22	2.18	7.2	17.6
32228	160000	401.73	2.51	7.2	16.7
32035	160000	529.69	3.31	7.6	15.3
31328	160000	905.52	5.66	6.6	8.9



The shapes of single exposure curves are remarkably similar even across widely different risk areas, terrain, hydrology, etc.

Exp 1: aggregation of two points



Starting at ZIP Code 33149 (in Dade County), computing the values for combinations of that exposure and one other ZIP code, moving up the coast.

Why the break at 120 miles/20 years?

- Related to the damage swath of a typical hurricane (typically 120 miles), correlation between sites, and frequency of occurrence (if two sites within that width get hit, it is likely by the same storm, which happens on the order of once in 20 years.

Experiment 2: County Level Aggregation of single exposures

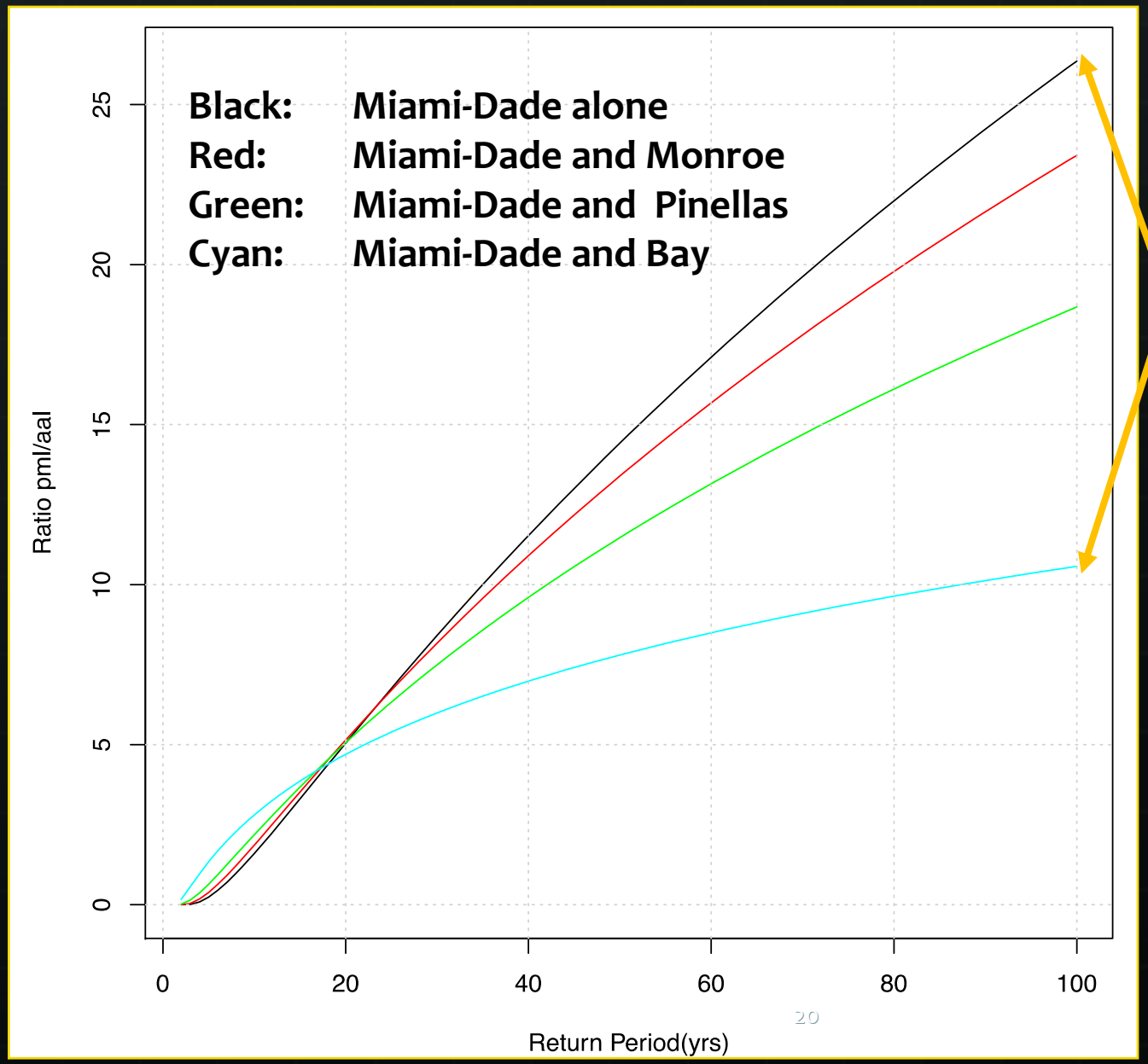
- What happens as we expand from a single point in a county to the full county?
- What happens as we combine counties that are increasingly far apart?

Exp2: Individual Counties

- Similar results to individual ZIP code test
- Loss cost varied from 0.99/1000 to 12.57/1000, widely scattered across the entire range.
- Return Period of AAL only varied from 5.60 to 8.70, with most clustered near the average (7.03)
- Curves all similar to ZIP curves (flat).

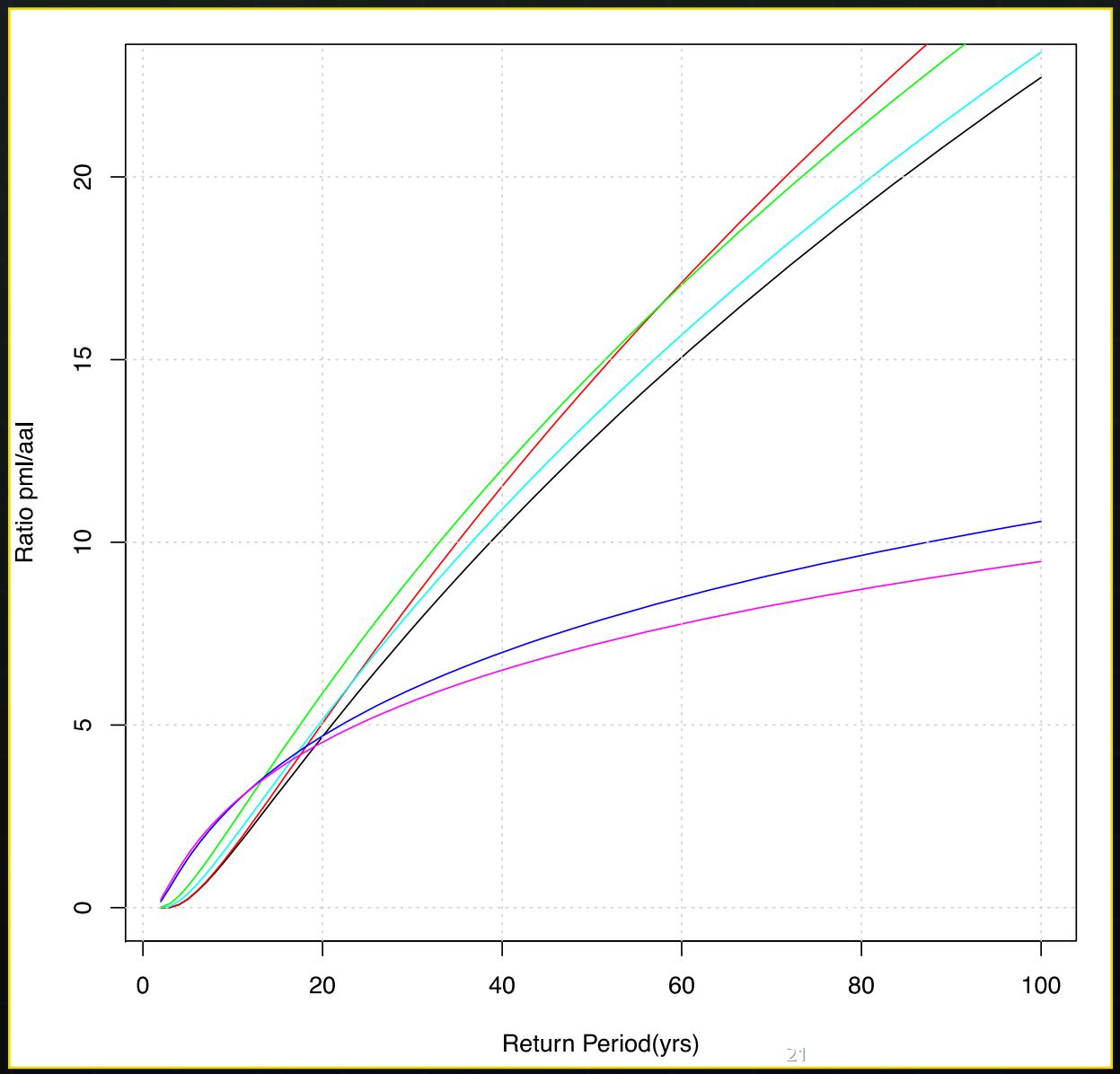
Note: using single exposure in each ZIP Code centroid ($160K WF)

Exp 2: Combine two counties



To cover a 100 year event requires **27 times** the AAL in Dade county, but only requires **11 times** the AAL for a combined portfolio of Dade and Bay

Exp2: Multi-County Combos

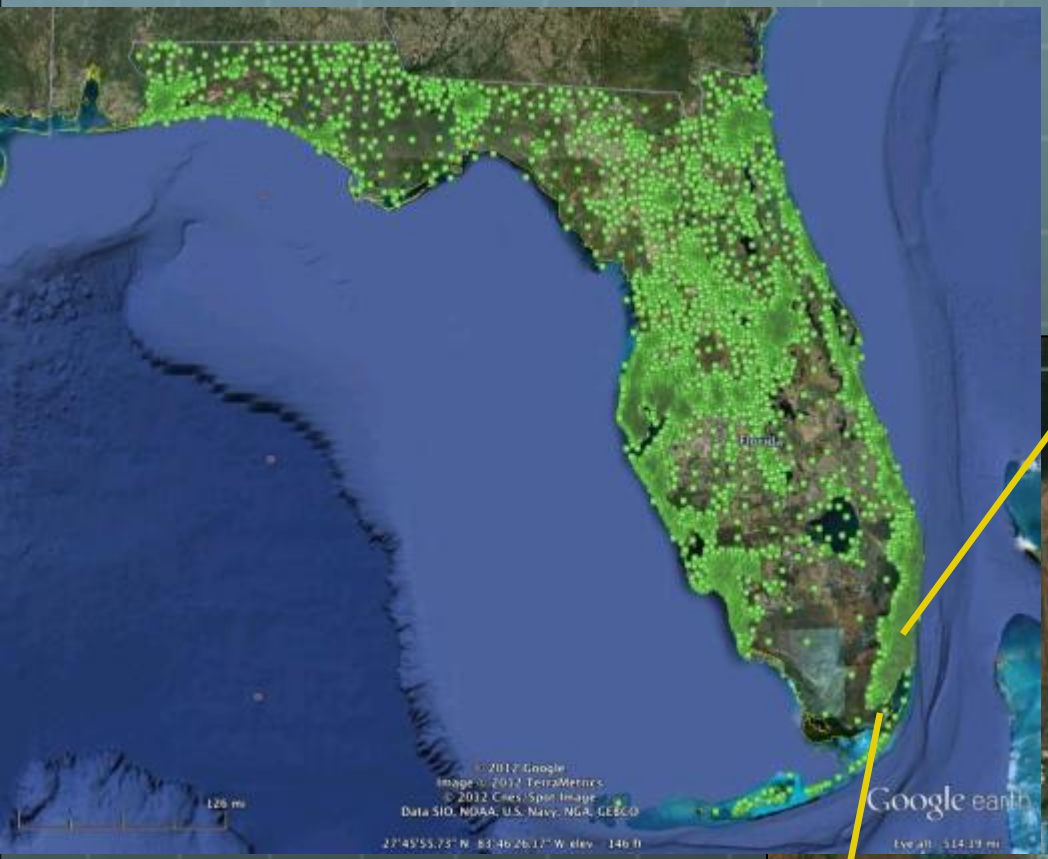


Black: Zip 33186
Red: Miami-Dade
Cyan: Monroe/Dade
Green: FL South of 27
Blue: FL South of 28
Magenta: All of Florida

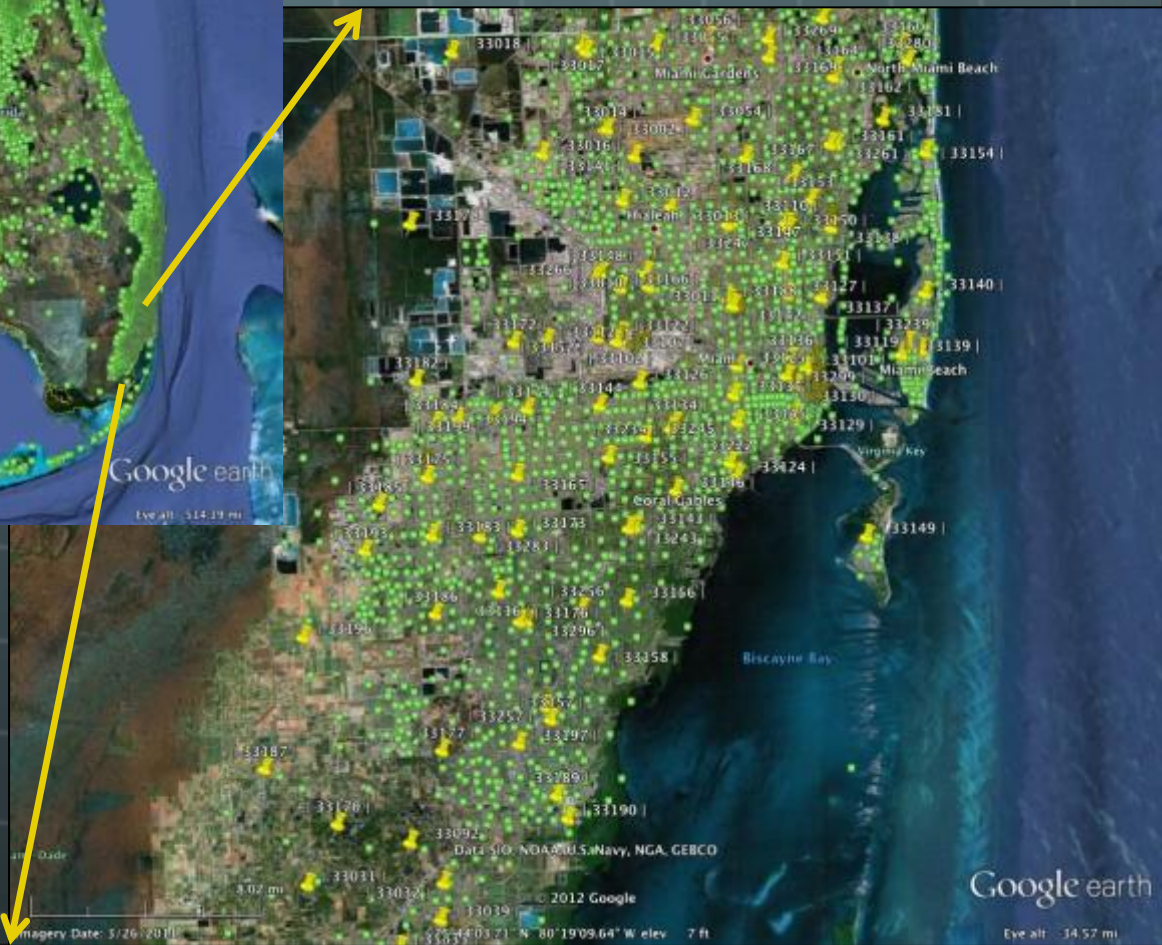
Experiment 3: Realistic Exposures

- How do realistic exposures behave at the county level, and how does that compare with our simplified exposure data set?
- What happens to AAL and the PML curves as we create increasingly diverse portfolios?

Exp 3: Florida ACS Exposure

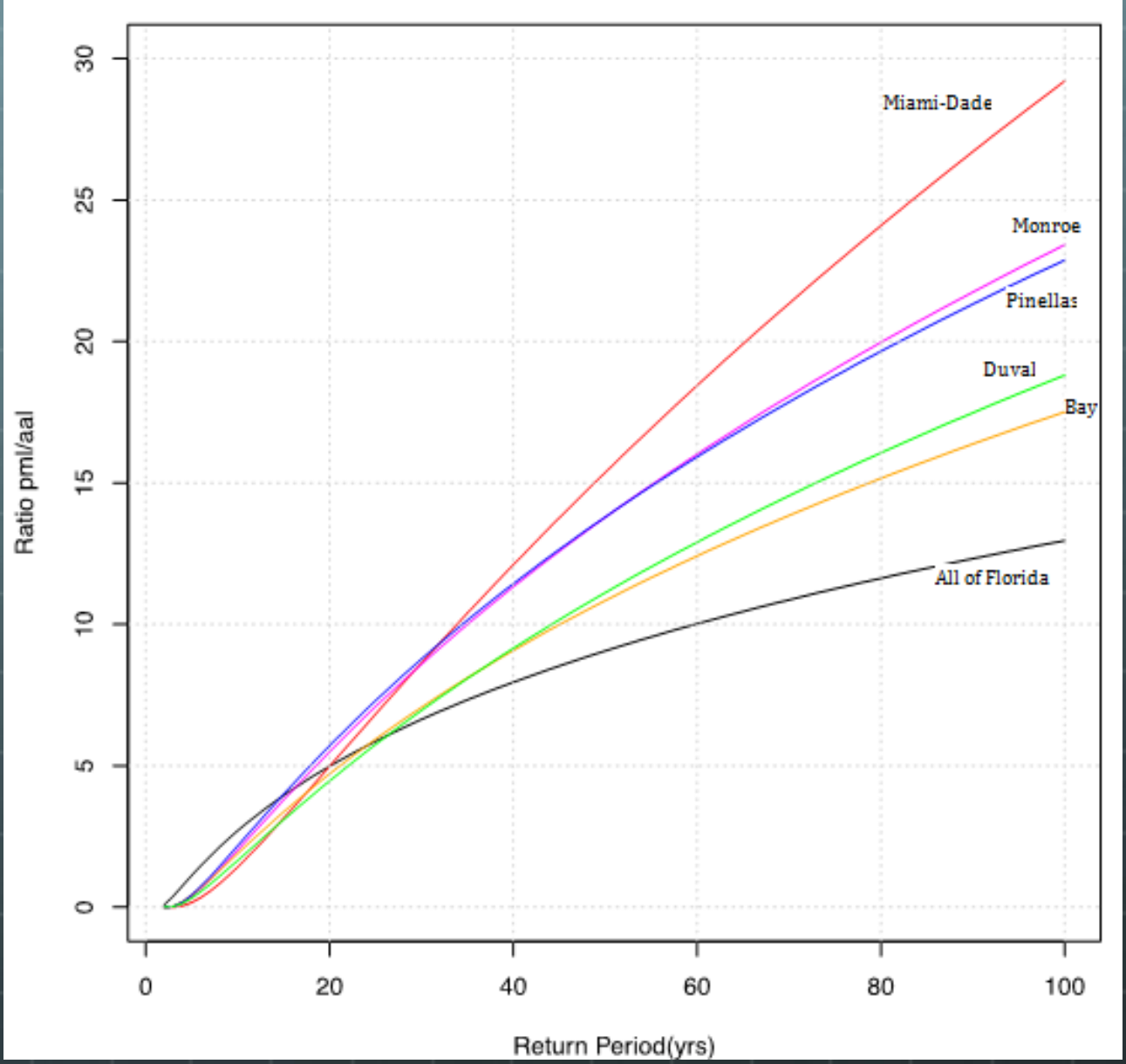


Pushpins are ZIP Codes
Green dots are ACS BG Centroids



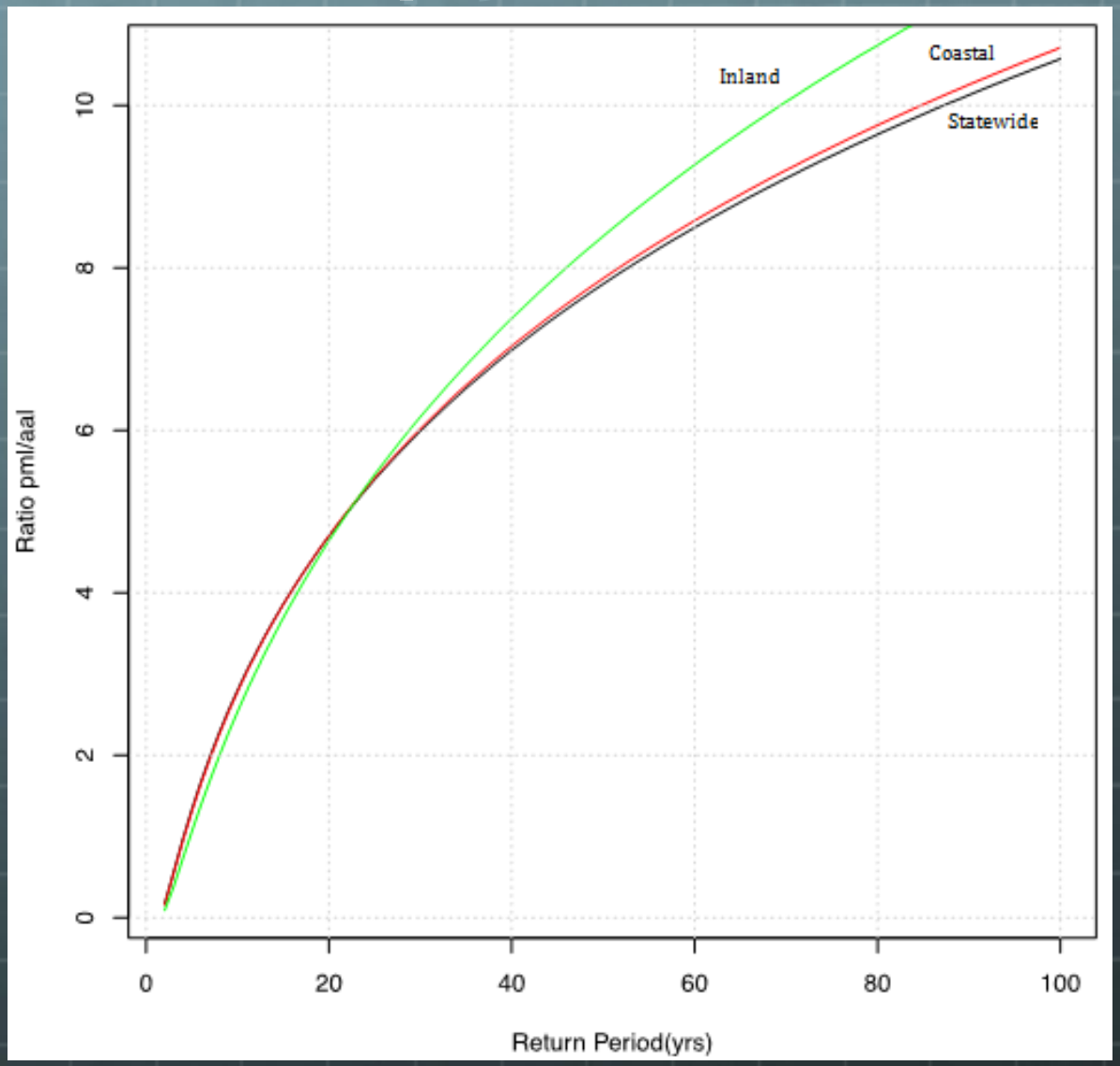
ACS data is approximately 10 times as dense as ZIP Codes are in urban areas geographically. Diverse portfolio – Manufactured Housing, Wood Frame, Masonry, Duplexes, Condos, etc.

Exp 3: Florida



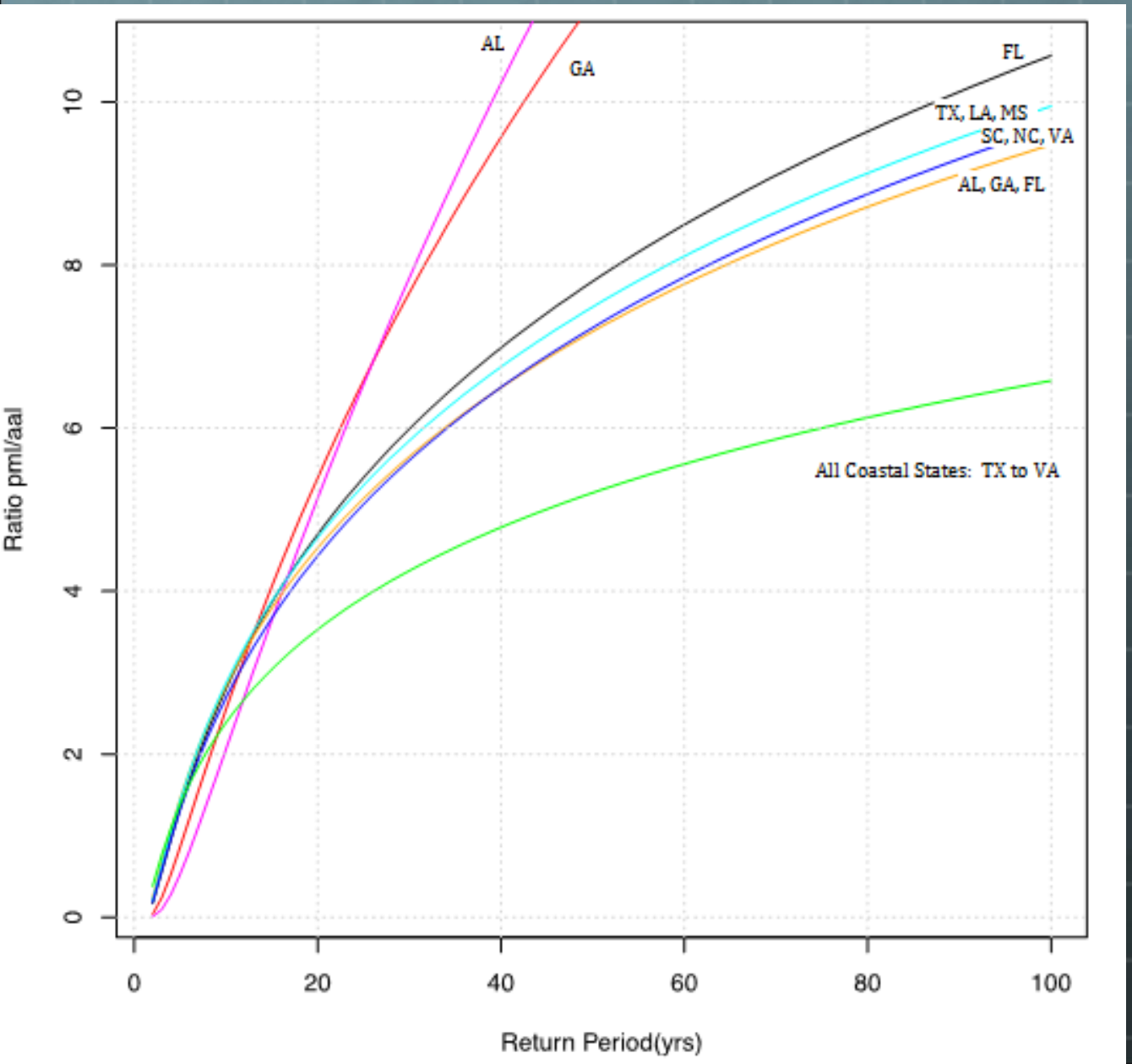
As with the hypothetical ZIP Code curves based on the simple exposure, the curve for small geographic areas have a different shape than the statewide portfolio.

Exp 3: FL Coastal vs. Interior



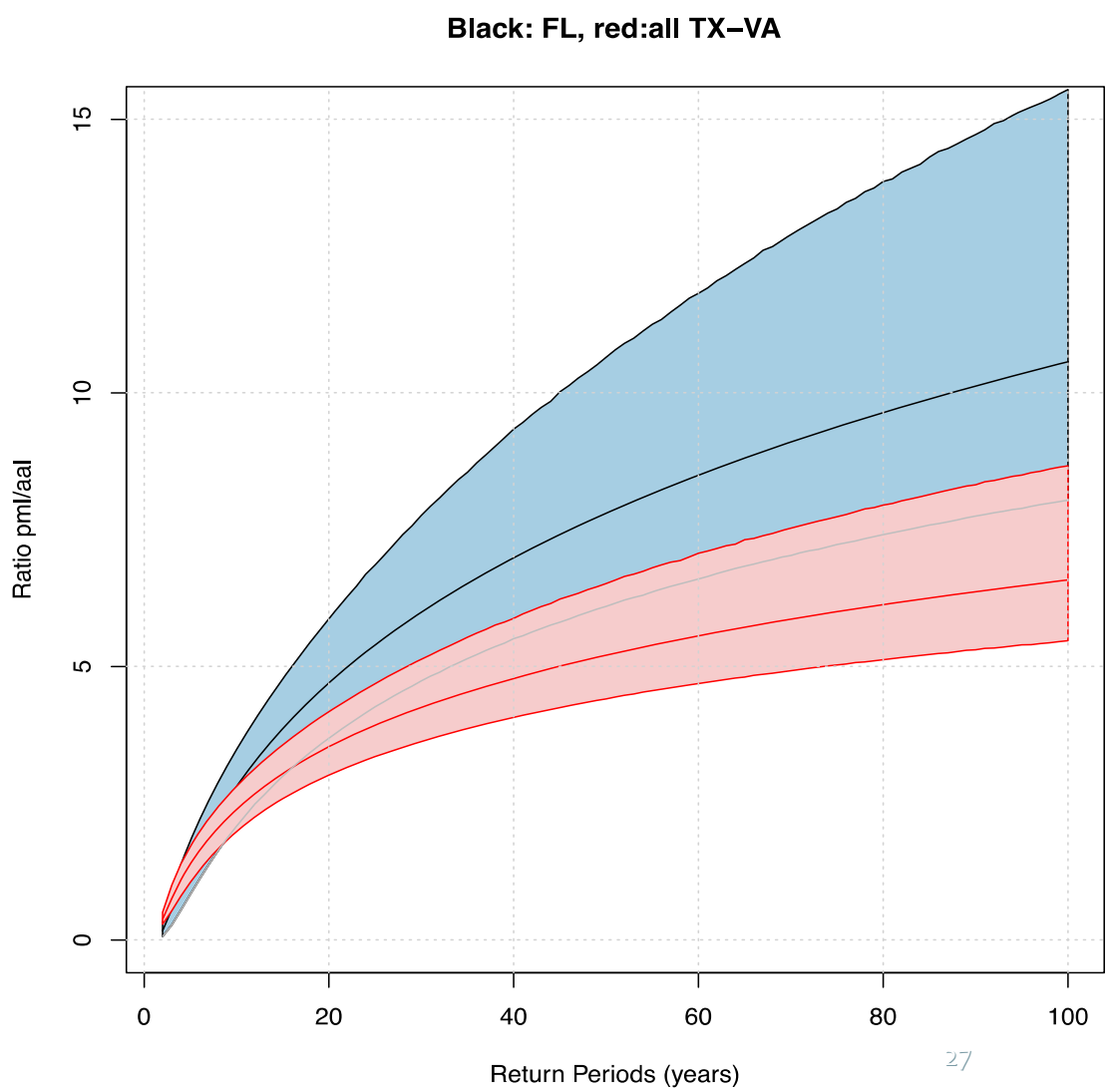
Due to the geometry of the state of Florida, the "interior" category is somewhat correlated – thus that curve is intermediate between a geographically diverse portfolio and one or two county groups.

Exp 3: Multistate Portfolios



Note that GA and AL (as well as MS, not shown) act more like Counties due to the limited direct coastal exposure.

Uncertainty



How good are the loss estimates? This figure shows the range of possible values for the State of Florida (blue shaded area bounded by black lines), and for the entire coast from Texas t o Virginia (pink shaded area bounded by red lines). In both cases the shaded area represents the upper 90% and lower 10% prediction limits. In other words, there is a 10% chance the correct value is above the shaded area, and a 10% chance the correct value is below the shaded area.

Reserves required

Territory	100 Year Loss
Texas	$26,495,700,000
Louisiana	$18,337,501,250
Mississippi	$4,751,439,400
South Carolina	$5,624,569,400
North Carolina	$8,231,516,250
Virginia	$4,810,914,050
Florida	$49,483,235,000
Georgia	$3,349,056,550
Alabama	$8,955,484,400
Sum of each state:	$130,039,416,300
Multi-state Aggregate:	$71,110,875,000
Percent aggregate:	54.7%
Ratio aggregate to individual:	1.83

Main Results

- Clear benefit of pooling catastrophic wind/water risk more broadly
  - Geographic diversification benefits for the less frequent/more severe events
    - > 20-25 year return period
    - 54% of individual aggregate
  - Benefit would accrue to all state combinations examined in this study.
    - Natural boundaries instead of state borders
  - Results are independent of premium: No subsidy issue
  - Diversification reduces risk and uncertainty
  - Model transparency should help to address black box concerns
    - Modeled loss results include storm surge

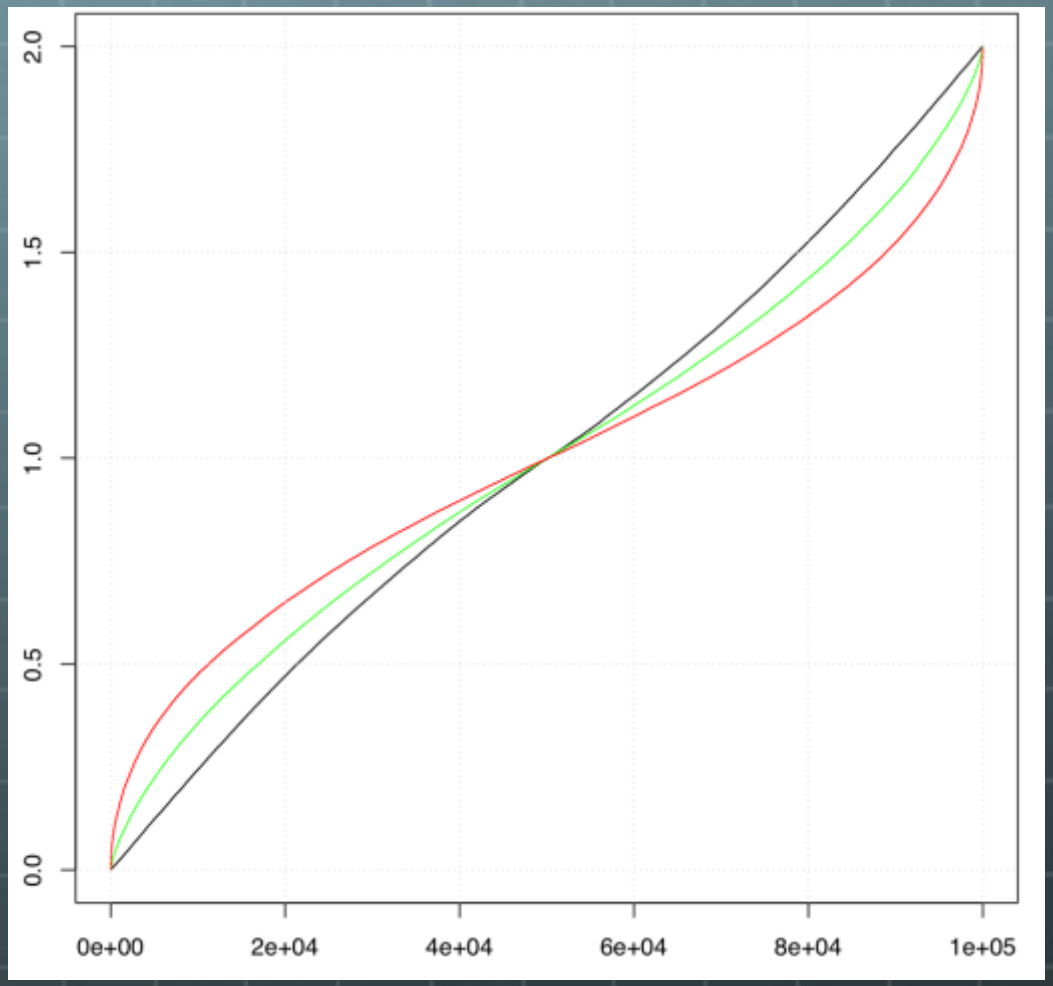
Implications and Future Direction

- Pooling implications
  - Two Tier System
    - Multi-state (coastal) compact, national wind risk pools
  - Challenges
    - Need for long-term perspective
      - AALs across time
      - Year to year variation in experience across states
    - Triggers and Managers
- Future Direction
  - Additional analysis related to diversification benefits
  - Evaluate whether geographic diversification benefits exists for pools with different catastrophic exposures (i.e., wind, earthquake, flood).
- Catastrophic Storm Risk Management Center
  - www.strormrisk.org

Appendix Slides

- Subsequent slides focus on some auxiliary calculations that are intended to suggest why the empirical results (individual sites, expanded to two sites; aggregated diverse sites) exhibit the behavior that they do.
- Focus is on the correlation (i.e., distance) between sites—basically 1 if the sites are the same and declining as they move apart.
- Material on Weibull distribution in support of the estimated shape parameters on hypothetical and actual exposures.

Impact of correlation on PML



Events (100,000) vs. cumulative "losses"

Plot of the sum of the probability of two variables (each from 0 to 1) with correlations of 1.0 (black), 0.5 (green), and 0.0 (red). This corresponds to two points located at the same location, then two points close enough to be impacted by some but not all events, and finally far enough apart to be unaffected by the same events.

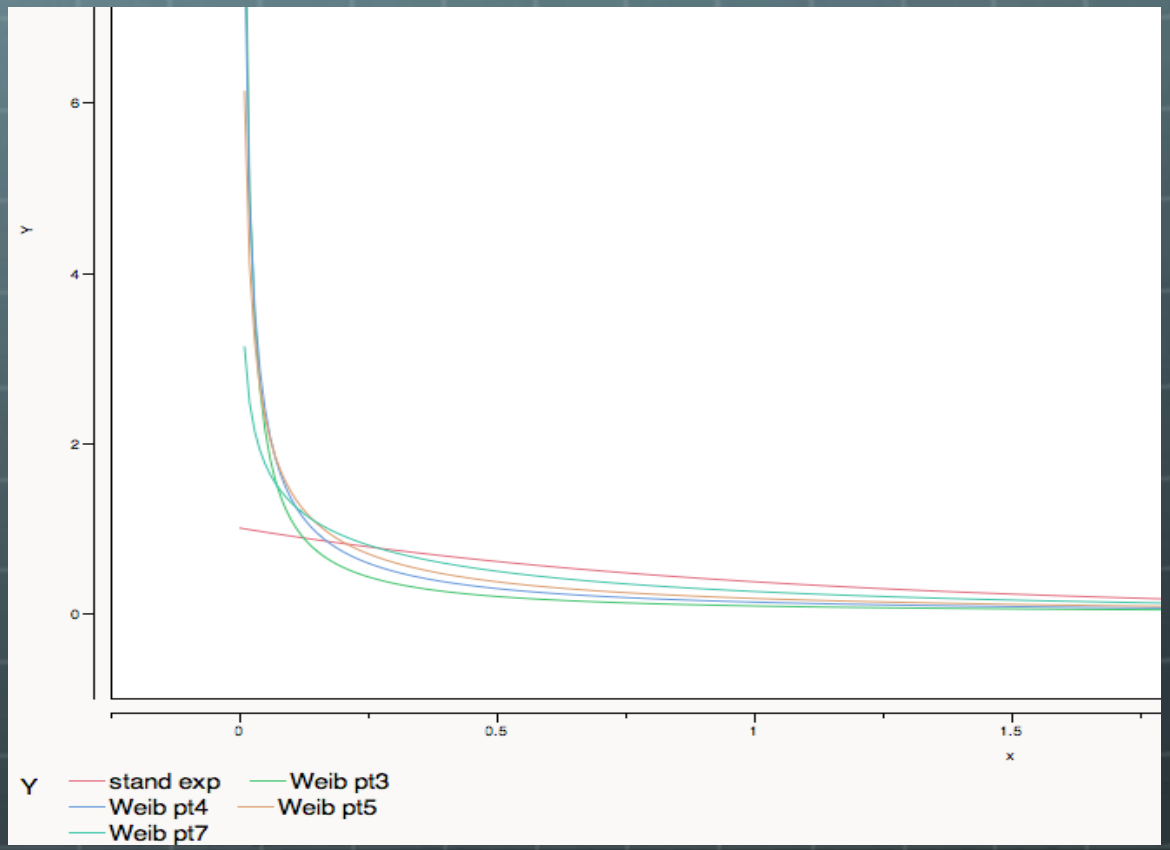
Weibull Shape Parameter

- We are fitting the loss data using the two parameter Weibull distribution, having shape parameter α and scale parameter β.
- Density function:

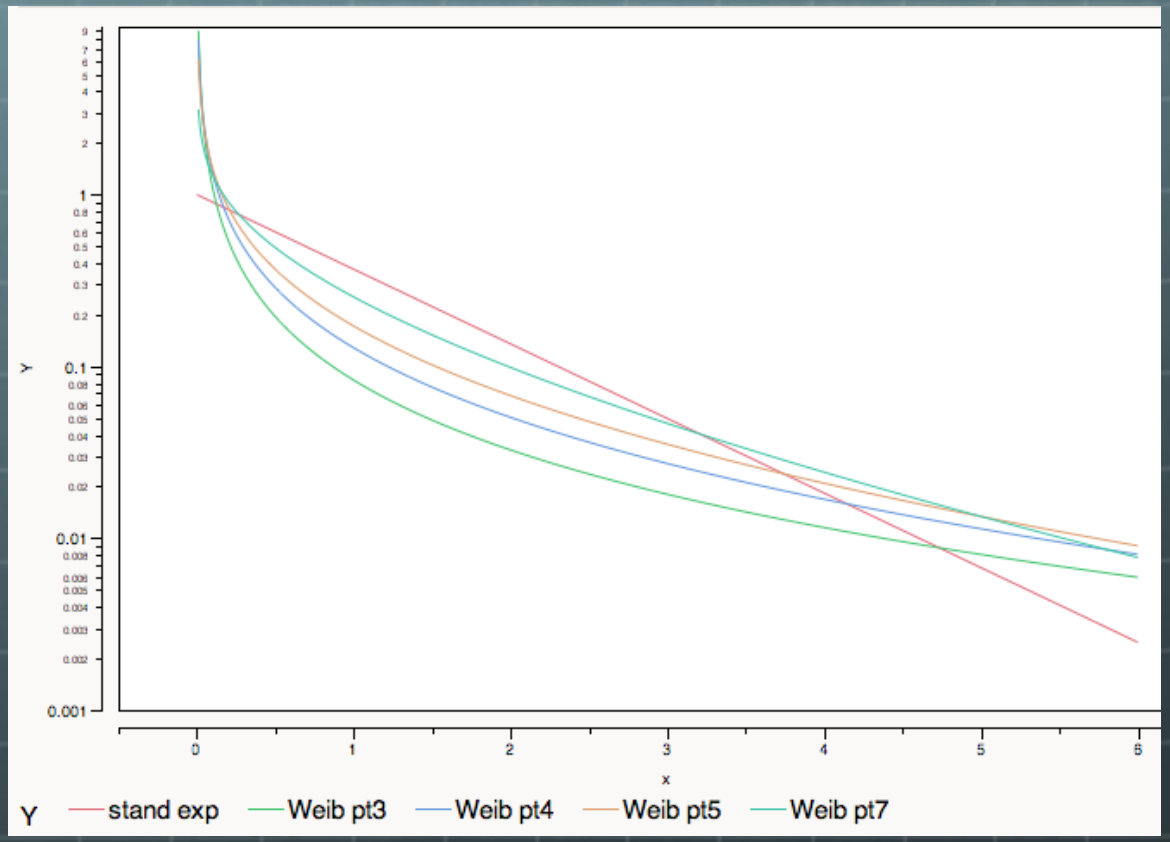
$$f(x) \propto x^{\alpha-1} \exp\left[-\left(\frac{x}{\beta}\right)^{\alpha}\right]$$

- The shape parameter α tells us what the curve looks like.
  - α in the range 0.31 to 0.55 for individual sites, average 0.42
  - α of 0.61 to 0.75 for geographically dispersed, average 0.65
  - α of 1.0 for the baseline exponential distribution (Weibull is a power transformation of an exponential)

Weibull Density Functions



Density Functions with log vertical scale



Parameters of Weibulls Plotted

α	Mean with $\beta = 1$	β to get mean of 1	Resultant variance	Corresponding standard deviation
1.0	1	1	1	1
0.3	9.26	0.108	29.2	5.41
0.4	3.32	0.301	9.9	3.14
0.5	2.00	0.500	5	2.24
0.7	1.26	0.790	2.14	1.46

Suppose a Pearson correlation ρ for a bivariate normal distribution.

Spearman's rank correlation coefficient is related to this via:

$$\rho_S = \frac{6}{\pi}\sin^{-1}\left(\frac{\rho}{2}\right)$$

while Kendall's rank correlation coefficient is given via

$$\tau = \frac{2}{\pi}\sin^{-1}(\rho)$$

Joint Distribution Extremes

- What is the range of correlation/association coefficients for specific choices of marginal distributions that are positive and highly skewed?
- Pearson correlations are limited, with minimums for Weibulls, as follows:
  - $\alpha = \ldots$

Exp2: Combine Two Counties (table)

criteria	exposure	aal	losscost	rp_aal	rp_1pct
Monroe Only	1.92E+06	21298.18	11.09	6.80	6.50
Monroe and Dade	2.22E+07	213288.67	9.59	7.20	7.40
Monroe and Broward	1.60E+07	142278.96	8.89	6.90	7.30
Monroe and Palm Beach	1.42E+07	141429.22	9.93	6.80	6.90
Monroe and Martin	3.84E+06	45424.05	11.83	6.00	5.60
Monroe and St. Lucie	4.96E+06	57958.02	11.69	6.00	5.60
Monroe and Indian River	4.48E+06	43798.31	9.78	5.60	5.60
Monroe and Brevard	9.44E+06	48676.32	5.16	5.20	7.60
Monroe and Volusia	9.44E+06	40102.97	4.25	5.00	8.80
Monroe and Flagler	2.88E+06	23650.74	8.21	5.80	6.50
Monroe and St Johns	4.00E+06	26089.73	6.52	5.50	7.00
Monroe and Duval	1.07E+07	39820.10	3.71	5.40	10.00
Monroe and Nassau	3.04E+06	23609.87	7.77	6.00	6.90

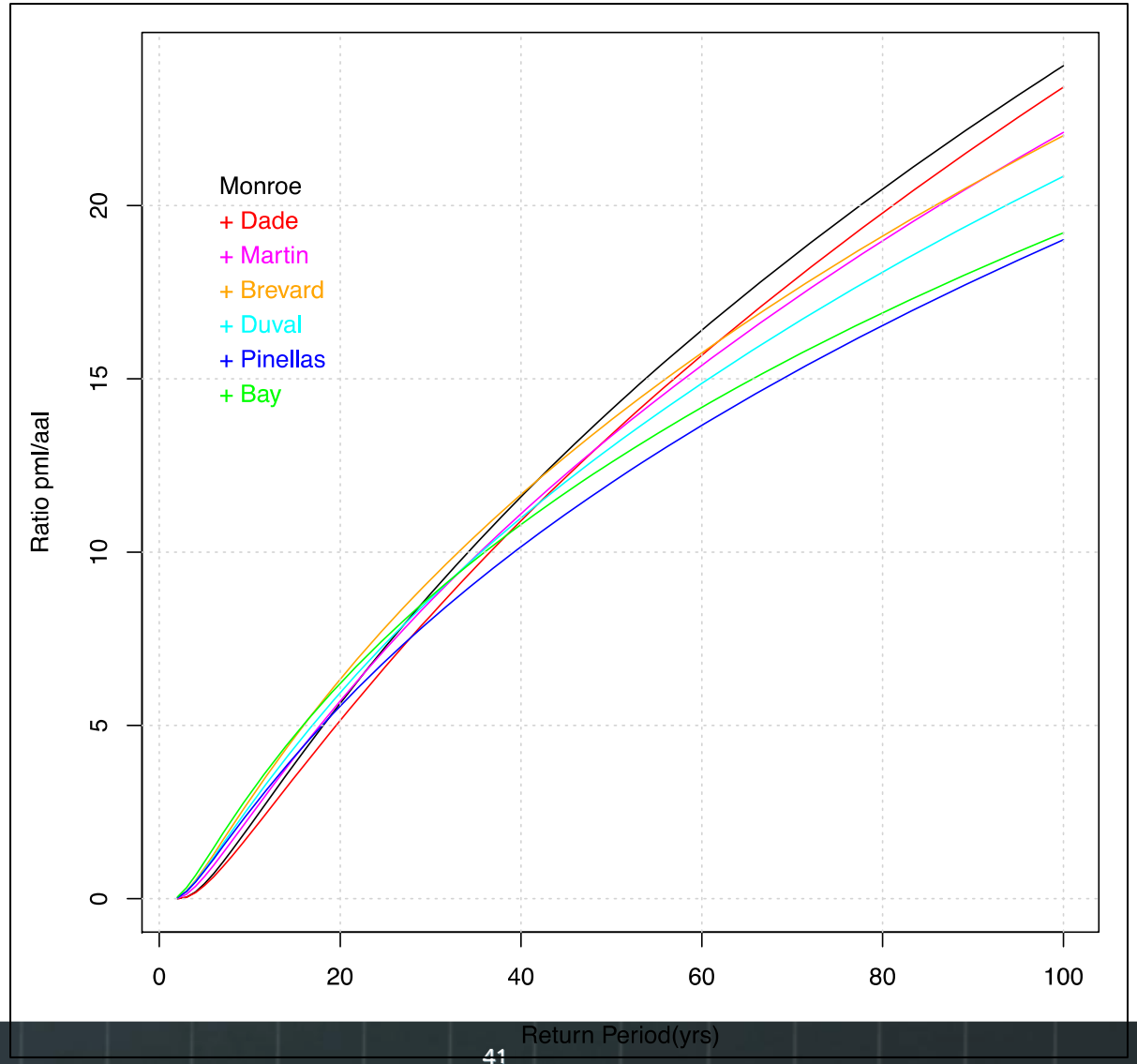
Note that as seen with individual exposures, as the geographic diversity increases, the return period of the AAL tends to decrease.

Caution: Monroe and Nassau is a bit misleading due to the distribution of ZIP Codes in Nassau County.

Note: using single exposure in each ZIP Code centroid ($160K WF)

Exp2: Multi-County/State Aggregations

criteria	exposure	aal	losscost	rp_aal	rp_1pct
ZIP 33186	160000	2561.24	16.01	8.1	6.7
Miami-Dade	2.03E+07	191990.52	9.45	8.0	8.2
Monroe	1.92E+06	21298.18	11.09	6.8	6.5
Miami-Dade and Monroe	2.22E+07	213288.67	9.59	7.2	7.4
Florida south of 27 North	6.37E+07	604994.21	9.50	6.3	6.4
Florida south of 28 North	1.10E+08	853047.55	7.73	5.1	6.0
Florida south of 29 North	1.69E+08	1046963.97	6.20	4.8	6.6
Florida	2.38E+08	1268467.18	5.34	4.0	6.6
Georgia	1.55E+08	59671.64	0.38	5.4	212.9
Alabama	1.34E+08	144753.96	1.08	6.6	35.7
Texas	4.24E+08	445075.63	1.05	5.3	36.7
Lousiana	1.16E+08	326215.66	2.81	5.7	14.0
Mississippi	8.56E+07	98171.60	1.15	7.3	43.9
South Carolina	8.62E+07	99621.91	1.16	5.8	35.4
North Carolina	1.75E+08	203517.45	1.17	4.3	56.2
Virginia	1.99E+08	85552.97	0.43	7.0	135.6
Florida/Georgia	3.93E+08	1328138.89	3.38	3.9	10.6
Alabama/Florida/Georgia	5.27E+08	1472892.60	2.79	3.8	13.7
Texas/Lousiana/Mississippi	6.25E+08	869462.87	1.39	3.8	45.7
North and South Carolina, Virginia	4.60E+08	388692.37	0.85	4.0	172.4
All coast Texas to Virginia	1.61E+09	2731047.72	1.69	3.6	71.4

Note: using single exposure in each ZIP Code centroid ($160K WF)
Orange line indicates point at which correlation decreases radically.

Exp 2: Multi-County Combinations