Essentials of Hurricane Cat Modeling

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Outline

- Specifics of hurricane hazard modeling
  - stochastic event set
  - windfield, local conditions
- Key hurricane risk modeling issues
  - near term frequencies
  - storm surge
  - offshore energy
- Secondary structural characteristics
  - construction codes, characteristics most important to capture
- Risk metrics
  - stochastic risk atlas, creating EP curves, average annual loss, volatility, CROL, correlation, TVAR, etc.

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How is Loss Cost Generated?

- It is the sum of losses from all events affecting a location divided by the number of sampling years

$$\frac{1}{109 \text{ Years}} \sum_{\text{Storm Year}=1900}^{2008} \text{Site Loss (all storms)}$$

- It is the sum over all potential events of the product of the damage from an event times the annual frequency of each event

$$\int_{\text{Storm\_t}} \text{Site Loss (Storm\_t)} * f_t(t)\,dt$$

Where $f_t(t)$= the annual frequency of one storm from all potential events

- How is this done? A simplified example

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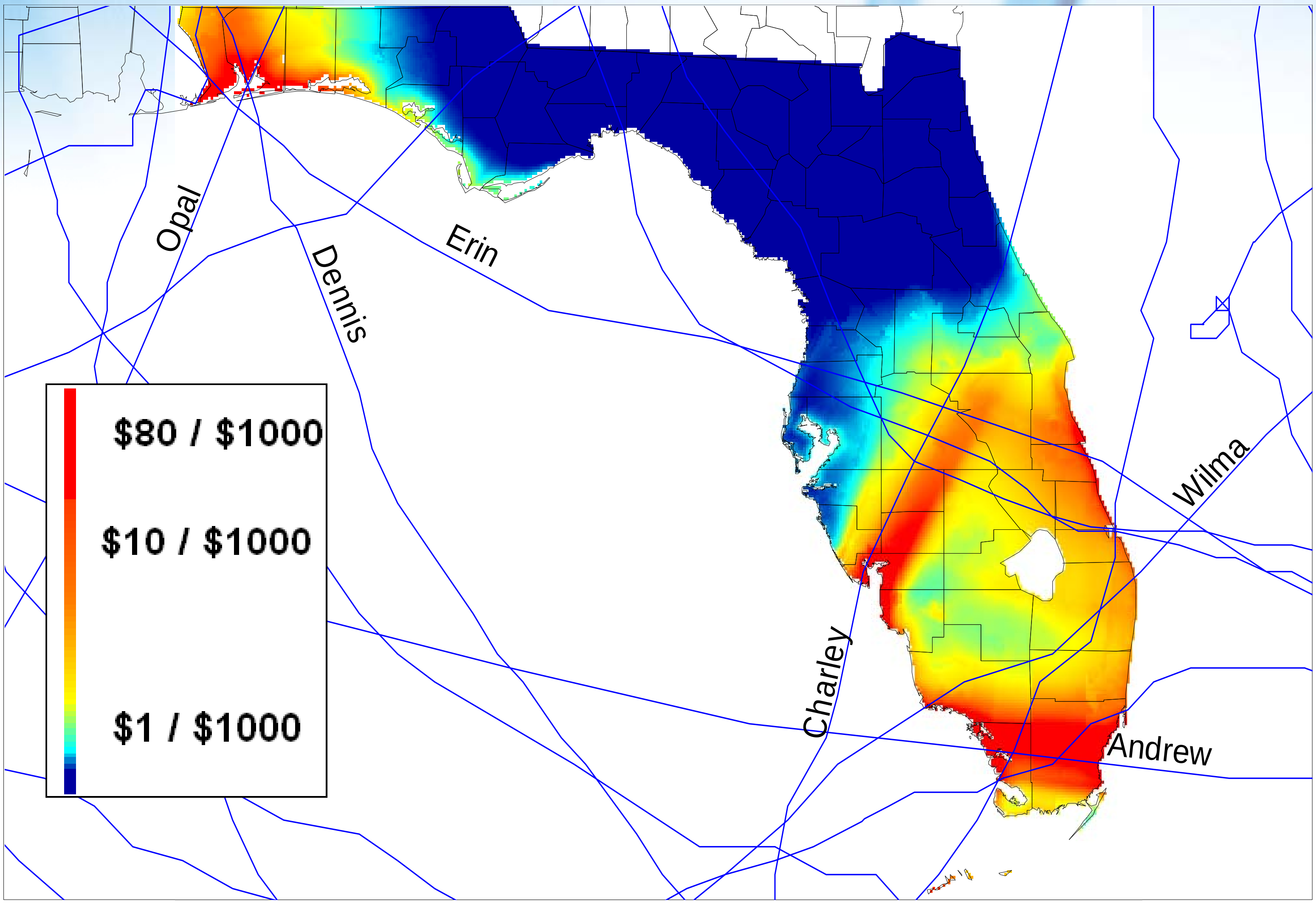
Loss Cost, 1990 to 2008 Storms



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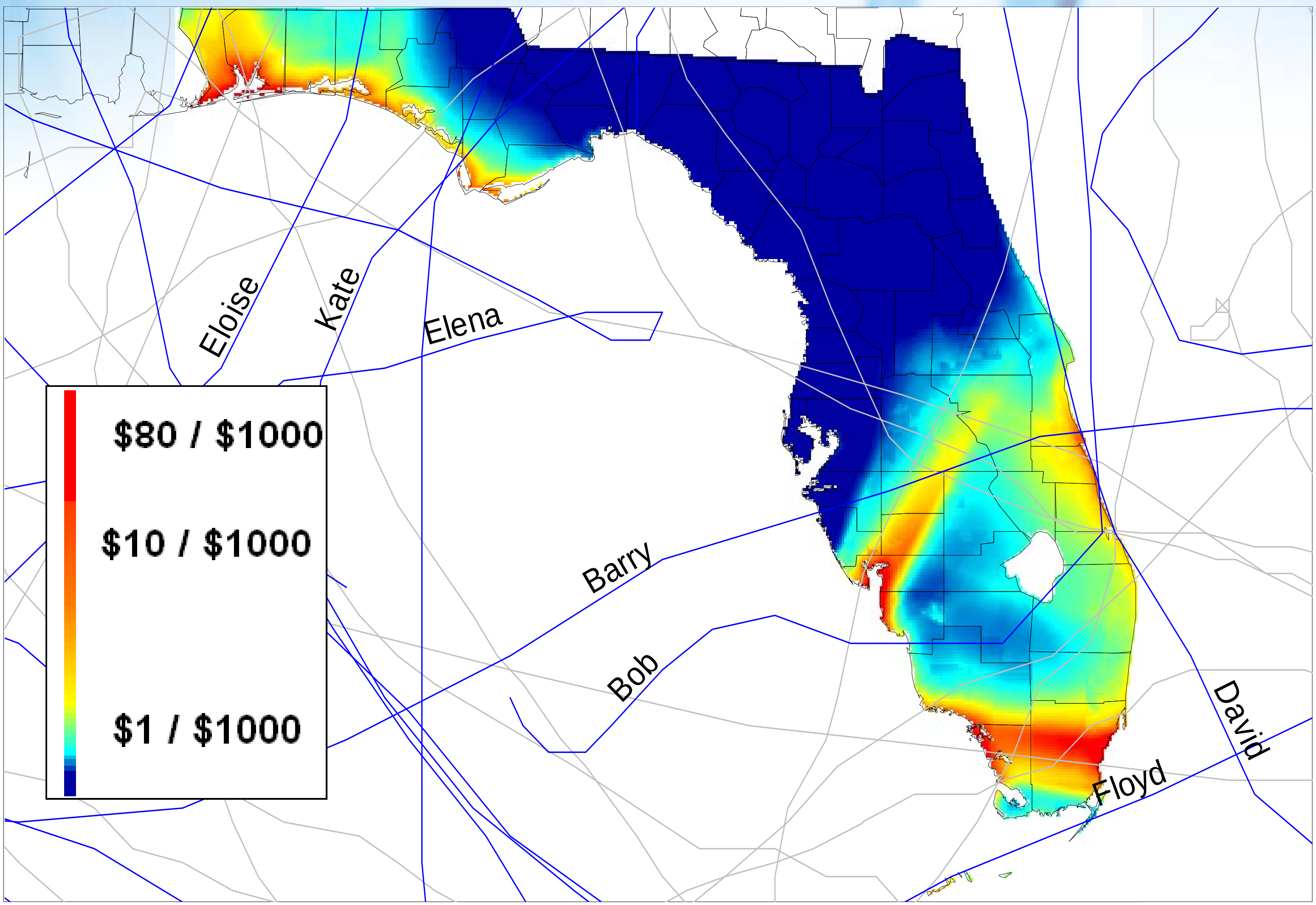
Loss Cost, 1970 to 2008 Storms



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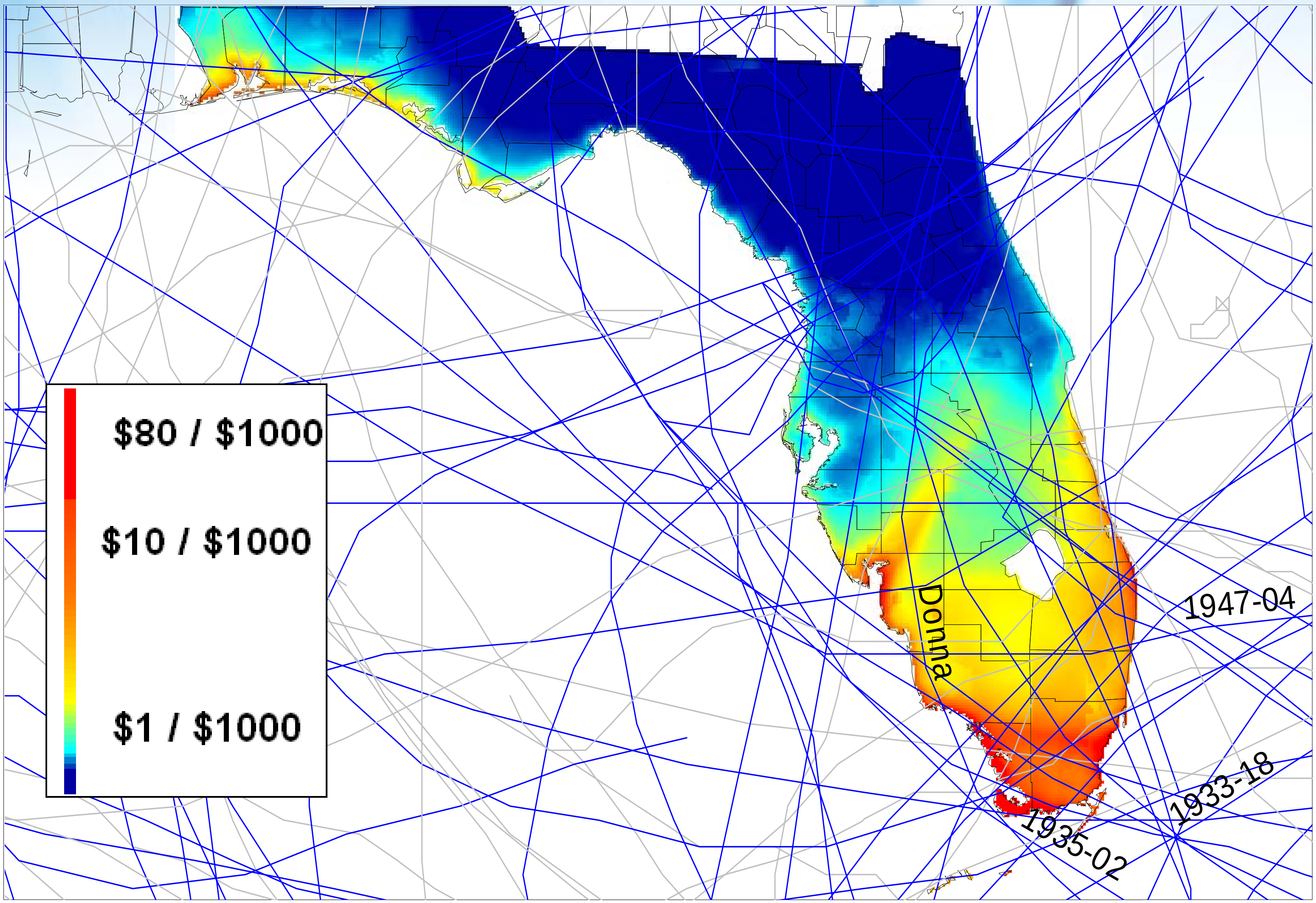
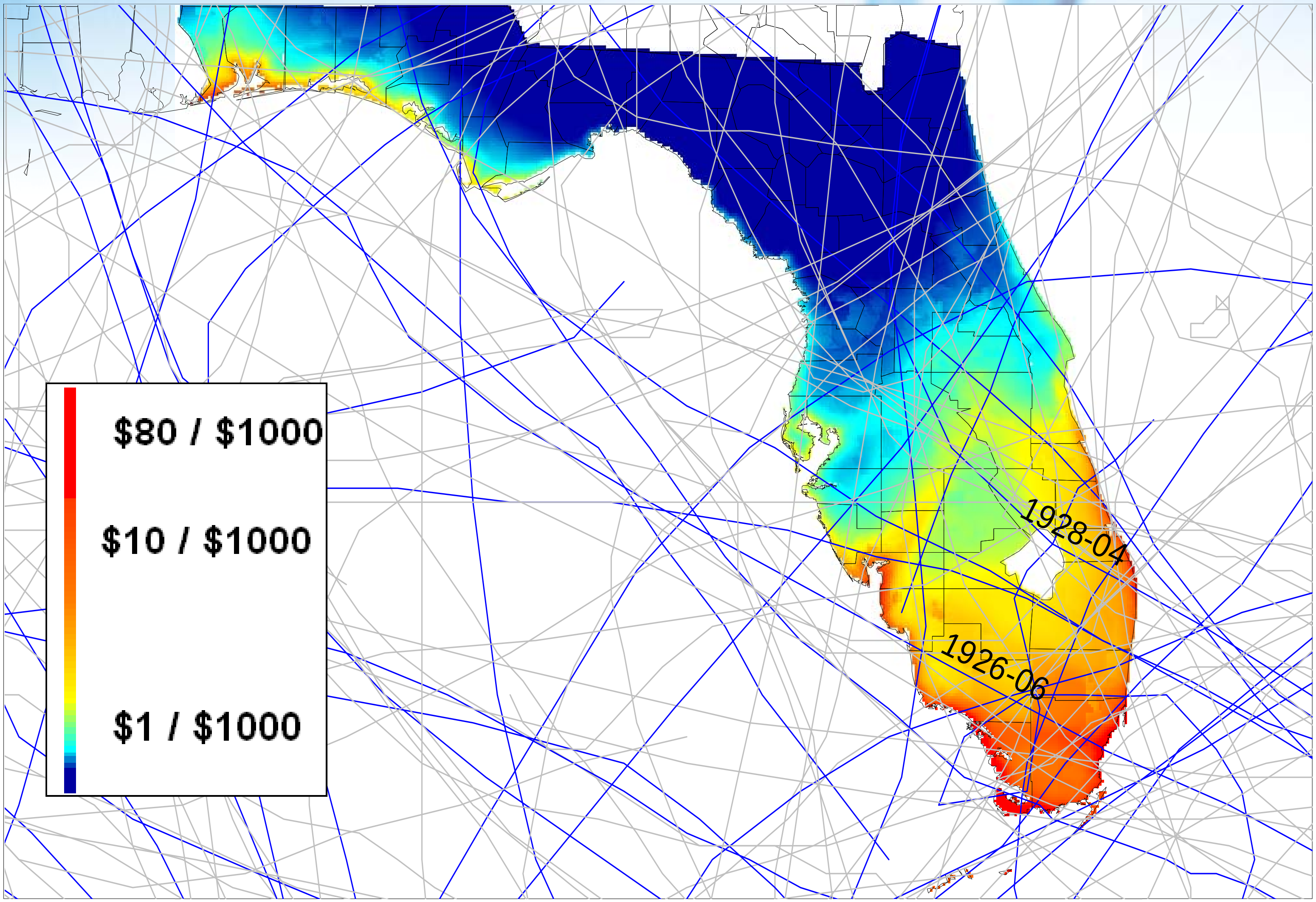
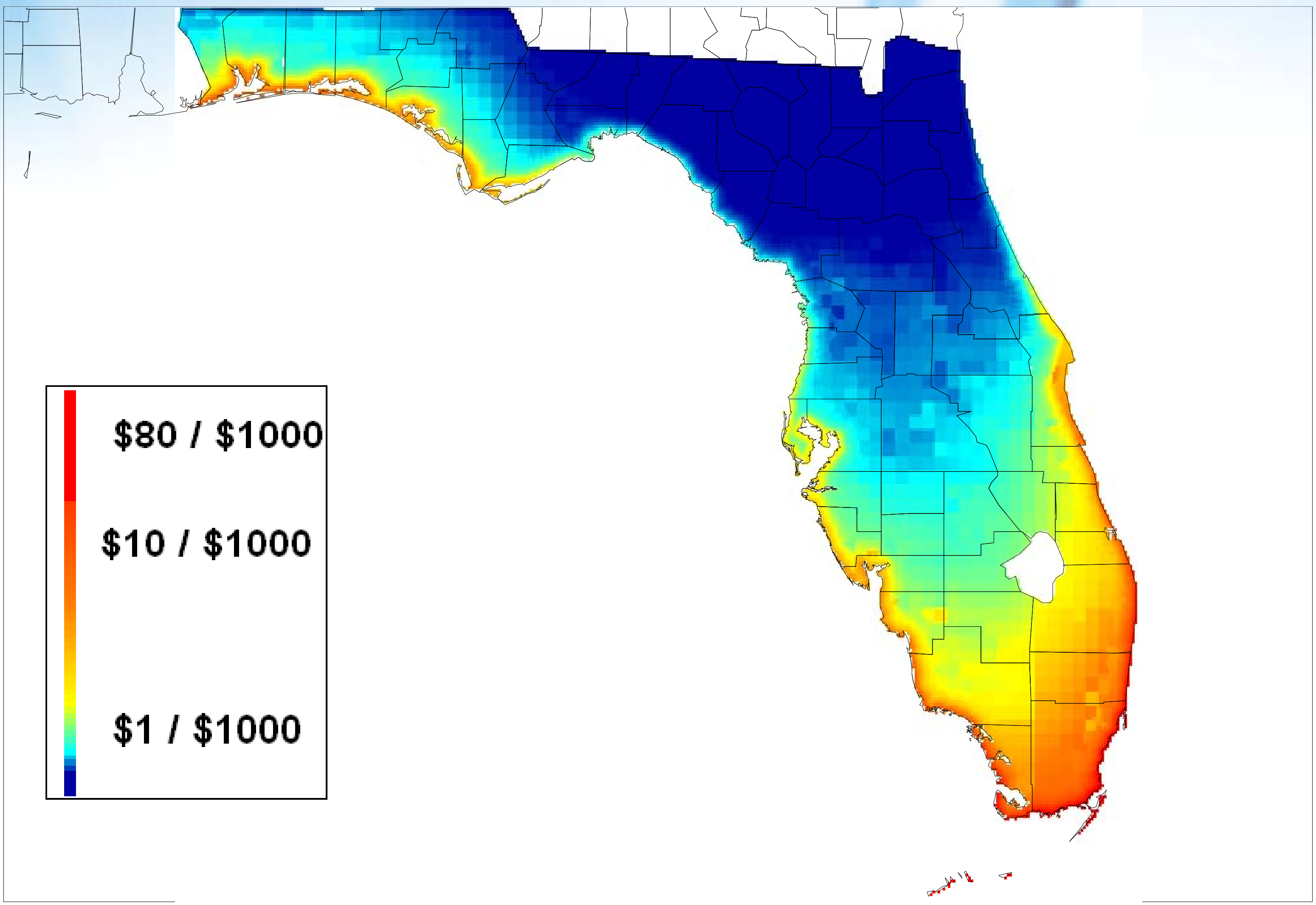
Loss Cost, 1930 to 2008 Storms



Loss Cost, 1900 to 2008 Storms



Probabilistic Loss Cost



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Developing a high quality probabilistic model

- Historic set of events is insufficient
  - In spatial distribution (large stretches of coast with few or no events)
  - In severity distribution (very few severe hurricanes)
- Generating a probabilistic event set
  - Event set must have sufficient numbers to adequately simulate all severities and geometries
- Important aspects to test
  - Spatial distribution of AAL
  - Sensitivity of OEP / AEP to model granularity
  - Spatial correlations

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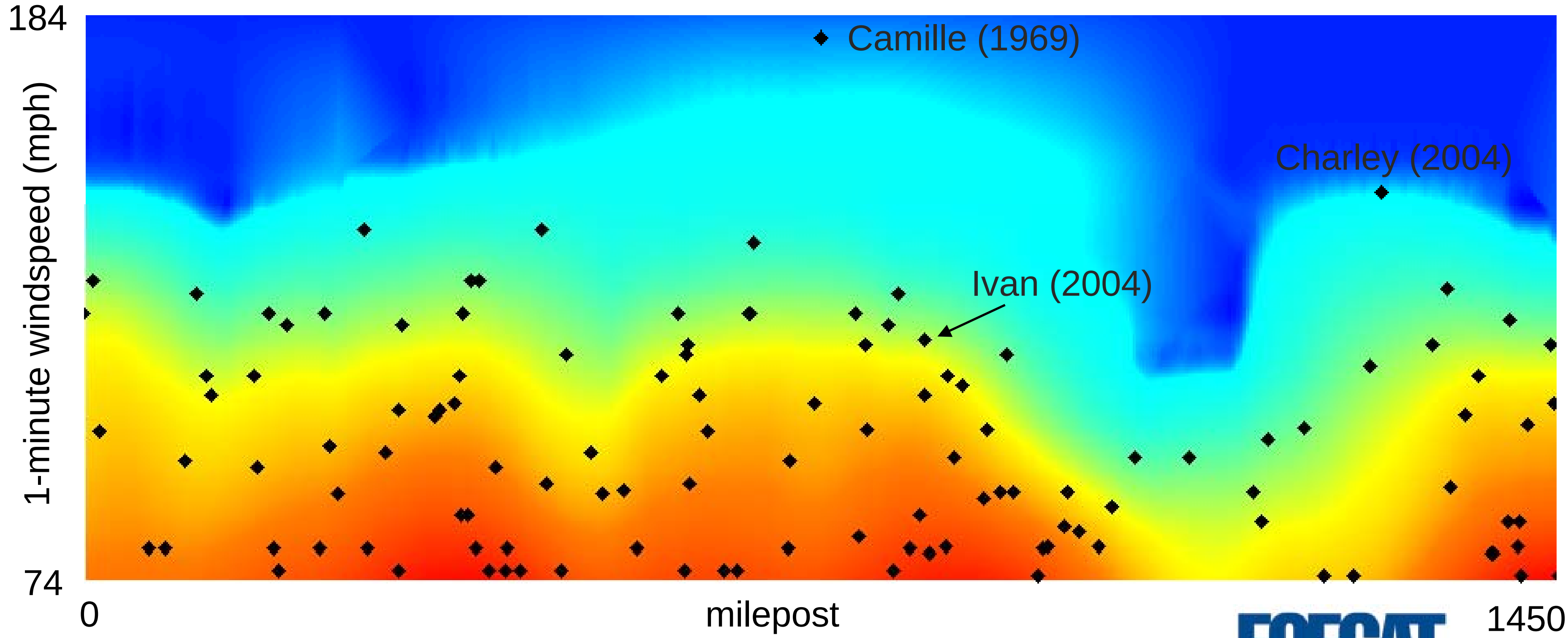
Develop Stochastic Event Set to Represent Full Range of Potential Hurricanes

- Create smooth distribution of hurricane occurrence:
  - Shading indicates annual exceedance frequency
  - Red is highest, dark blue is lowest



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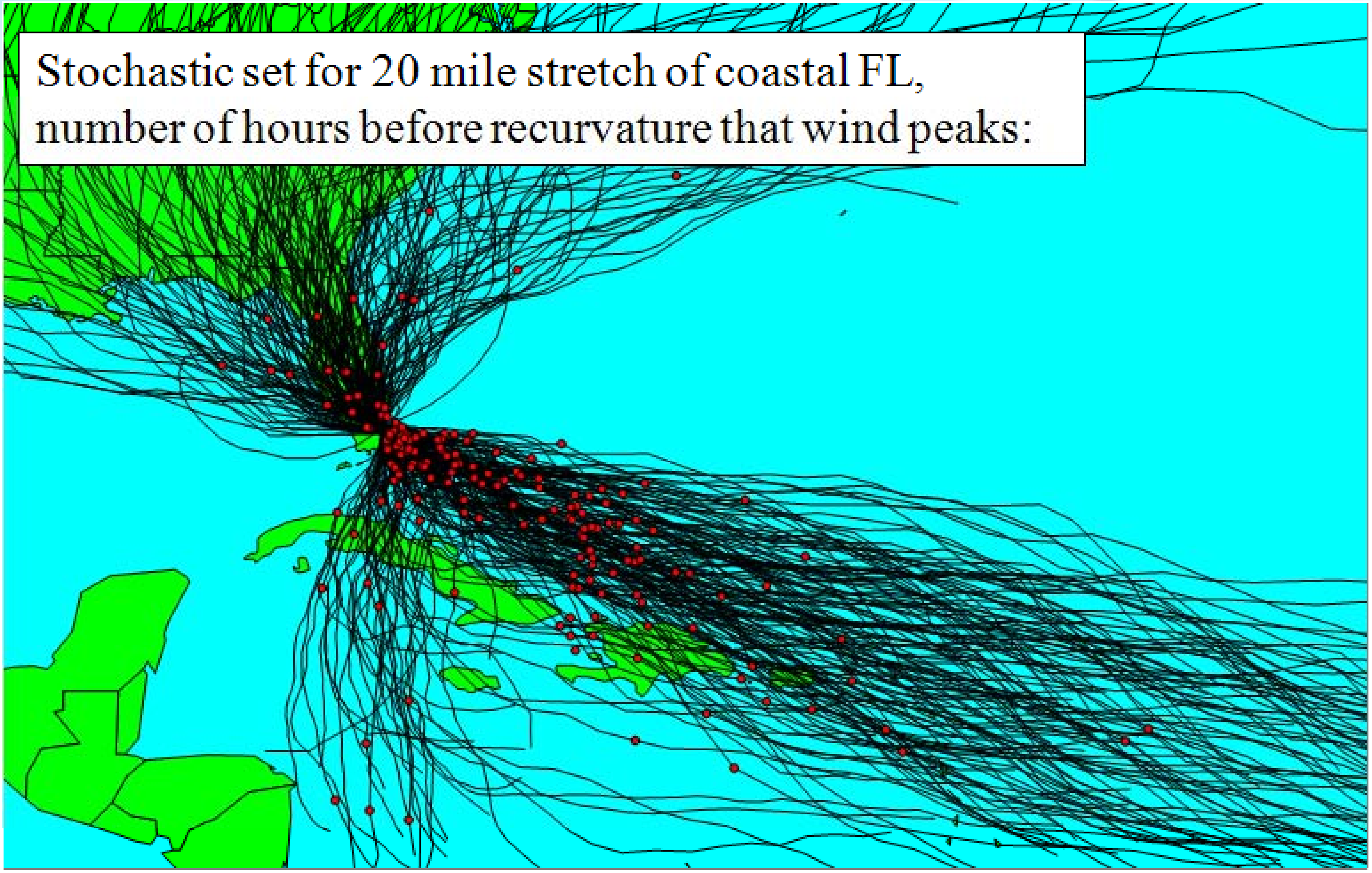
Evaluation of a Stochastic Set – Meteorological Validation

Recurvature versus location of maximum sustained winds



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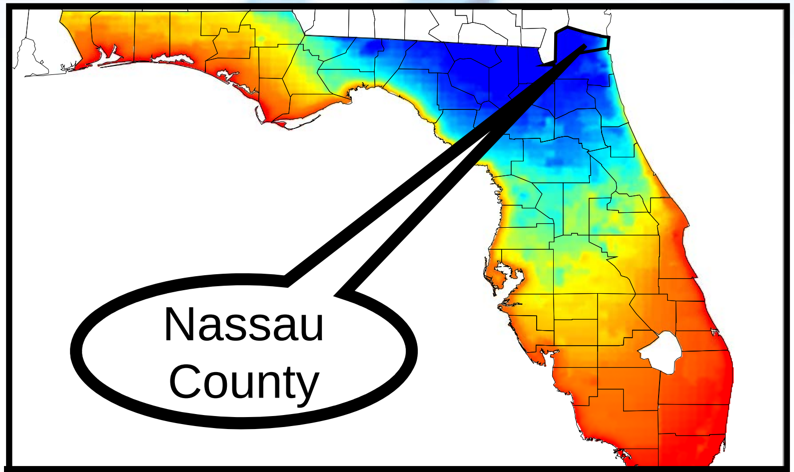
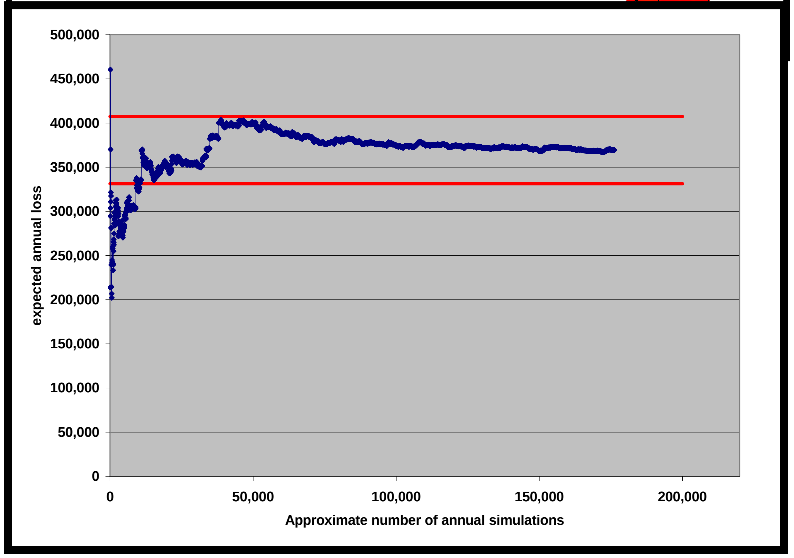
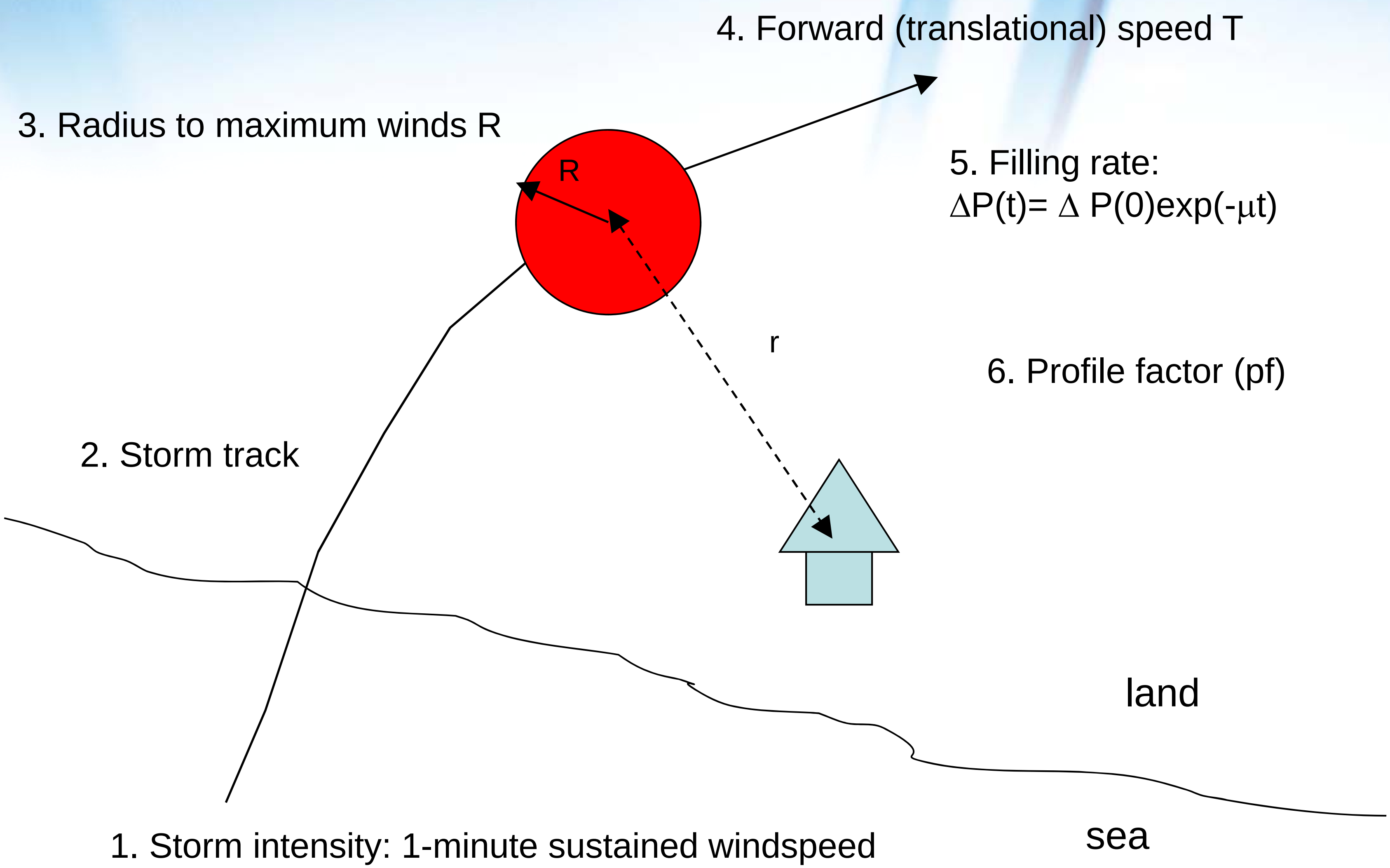
How many years of simulations are necessary?

- There are differences between the historically derived loss costs and the probabilistic loss costs
- Goal is to produce results that do not change if the sampling period is increased
- The number of simulations is a function of the frequency and severity of loss inducing events





Hurricane parameters



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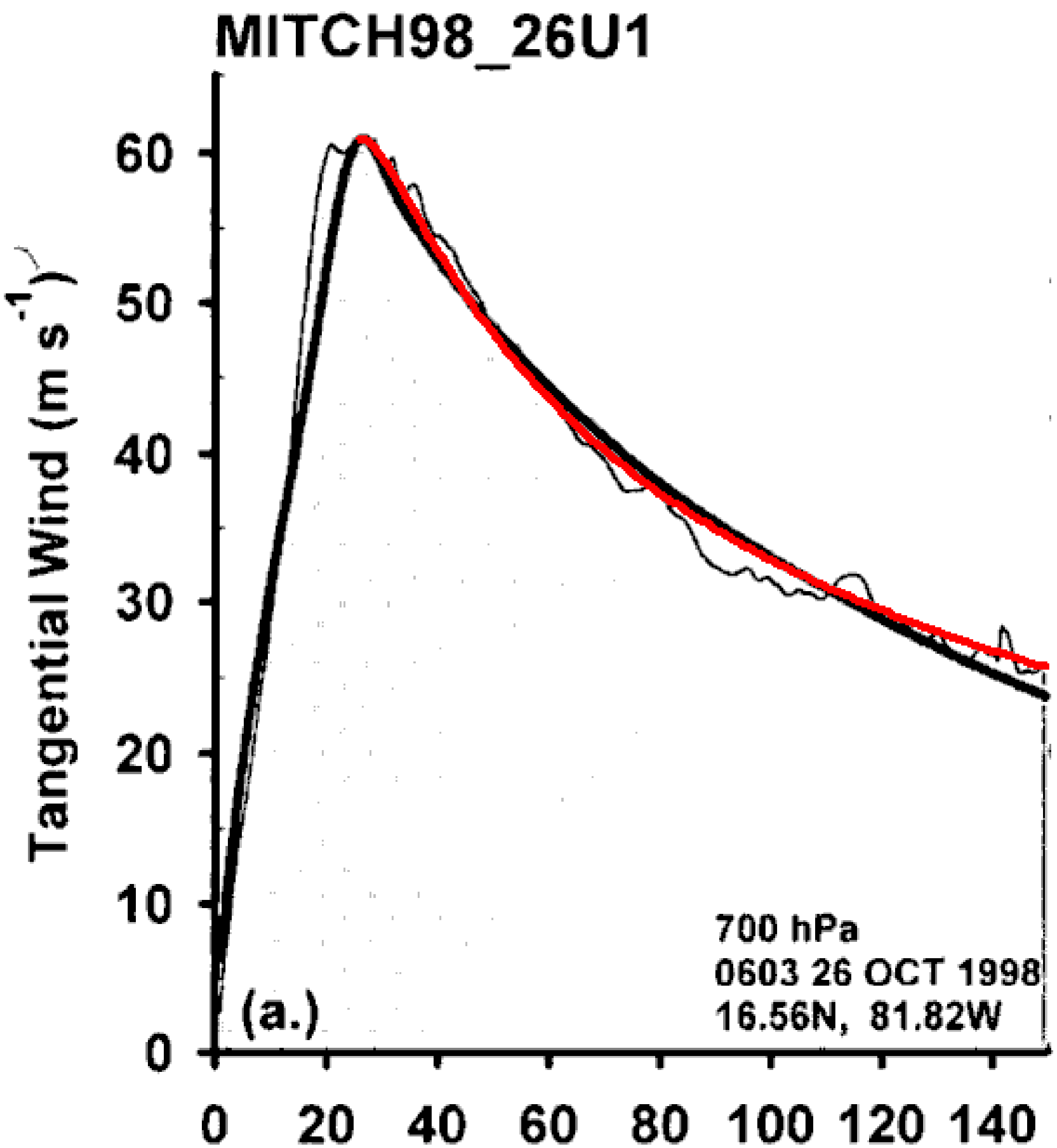
Profile factor – Hurricane Mitch (1998)



EQECAT (red)
Willoughby (heavy black)
Observed (thin black)

Local Wind Effects

- <u>Distance to Coast</u> - including left/right asymmetry and fetch
- <u>Land use and Land cover</u> - based on National Land Cover Database 2001 (NLCD 2001) at a resolution of approximately 30 meters
  - vegetation (forest types, agricultural uses, open land types, etc.)
  - density of built environment
- <u>Local topography</u> - based on GTOPO30 database (resolution approximately 900 meters)

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Key Risk Modeling Issues:

- Near Term Frequencies
- Storm Surge
- Offshore Energy

Climate-conditioned Frequencies: Atlantic Hurricane

- Traditional view was long-term
  - Scientists have been looking at elevated Atlantic hurricane activity since the mid 1990's
  - It took 2004-5 for mainstream cat modeling to move beyond long-term view
- If a period of elevated (or diminished) activity is likely to last several years or more, the long-term view may not be appropriate for managing risk
- Many relevant financial transactions (reinsurance contracts, cat bonds, etc.) have periods of 1 to 3 years
- Statistical methods can credibly correlate key aspects of the climate state with hurricane frequencies

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Relevant Time Scales

- North Atlantic Oscillation (NAO)
  - ~months
  - Significant impact on steering, but difficult to forecast beyond several weeks
- ENSO - El Nino / Southern Oscillation
  - ~3 to 7 year cycle
  - Difficult to forecast beyond several months
- AMO - Atlantic Multidecadal Oscillation
  - ~50 to 70 year cycle
  - Strong tie to hurricane activity
- Global warming
  - Impact on hurricane frequencies is relatively speculative

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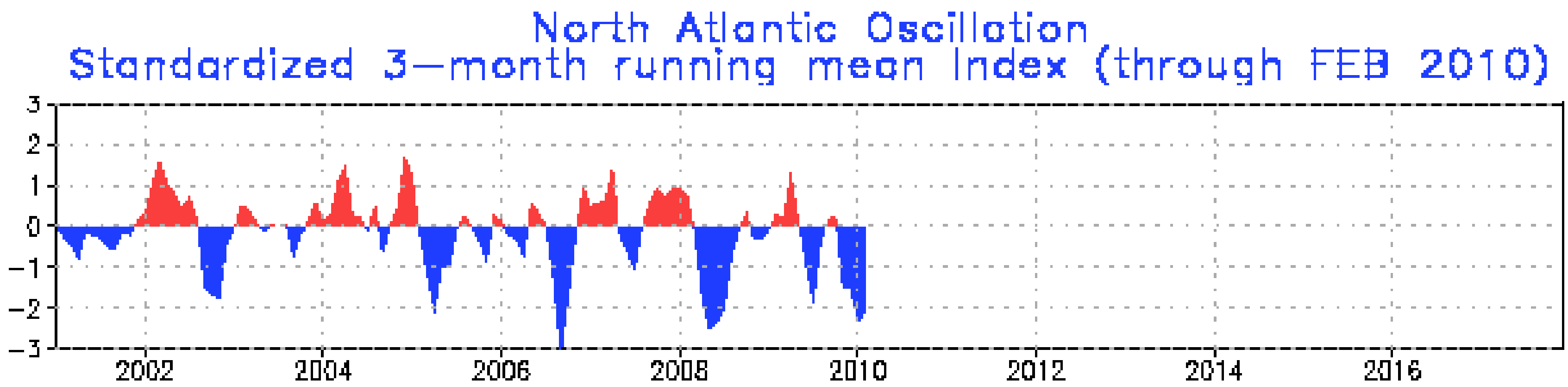
NAO (North Atlantic Oscillation)



- Positive NAO index phase shows a stronger than usual subtropical high pressure center and a deeper than normal Icelandic low
- The increased pressure difference results in more and stronger winter storms crossing the Atlantic Ocean on a more northerly track
- Influence on hurricane tracks: strong positive NAO associated with eastward displaced anticyclone, which favors re-curving at sea and not US landfalls
- Small negative correlation with AMO

http://www.cpc.noaa.gov/data/teledoc/nao.shtml

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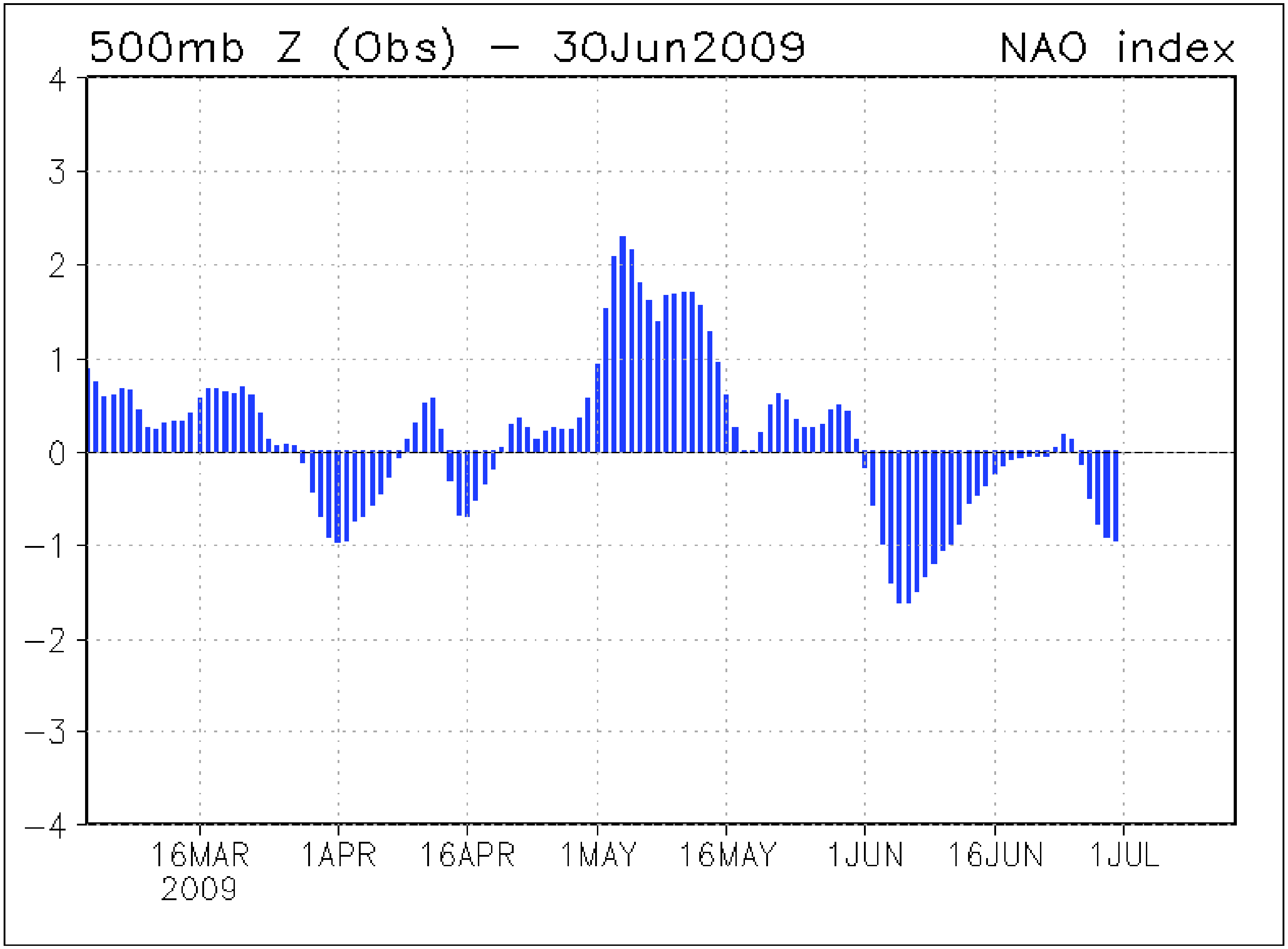
NAO – Daily data shows short period fluctuations - difficult to forecast



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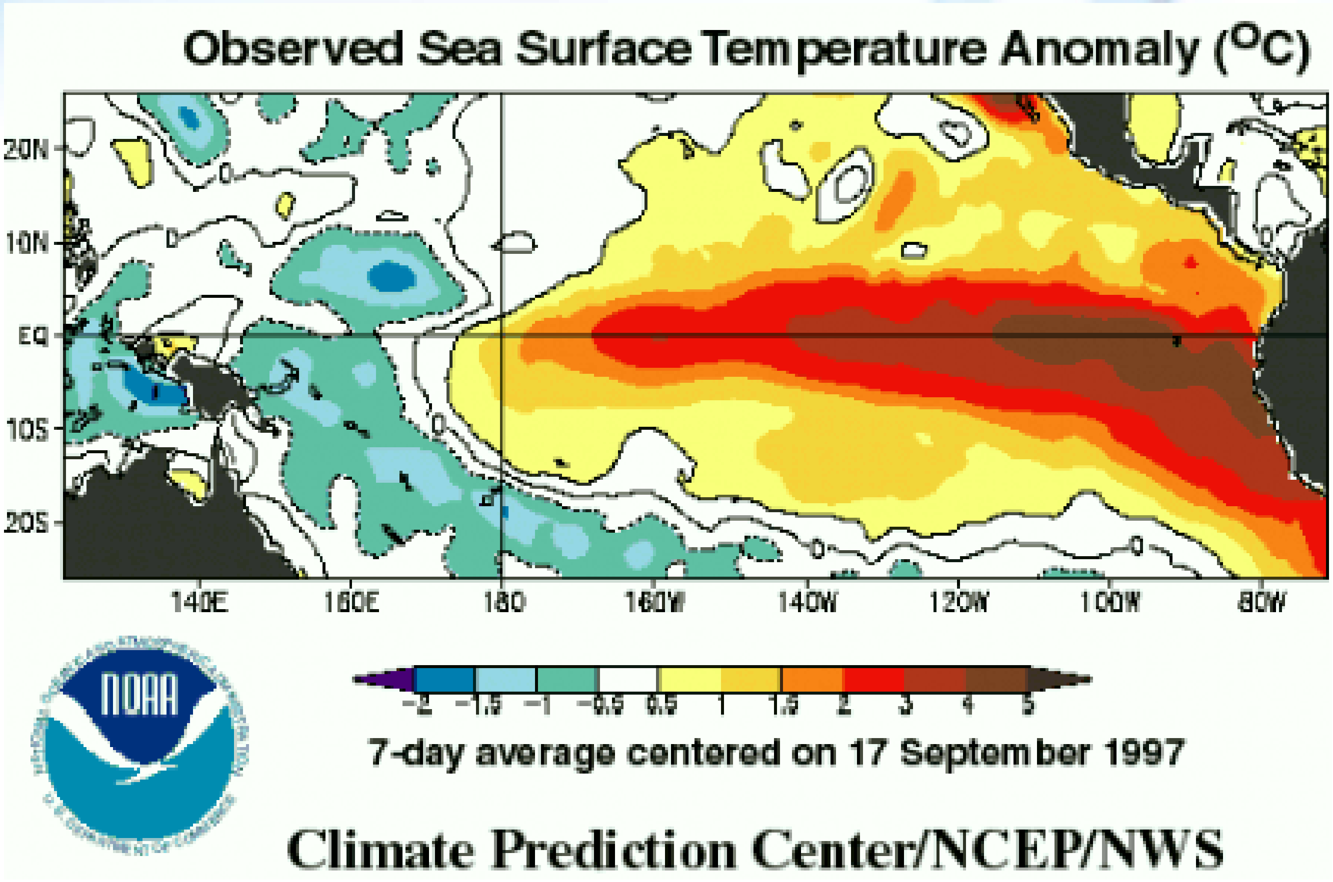
ENSO / El Niño – cyclical warming of equatorial Pacific Ocean



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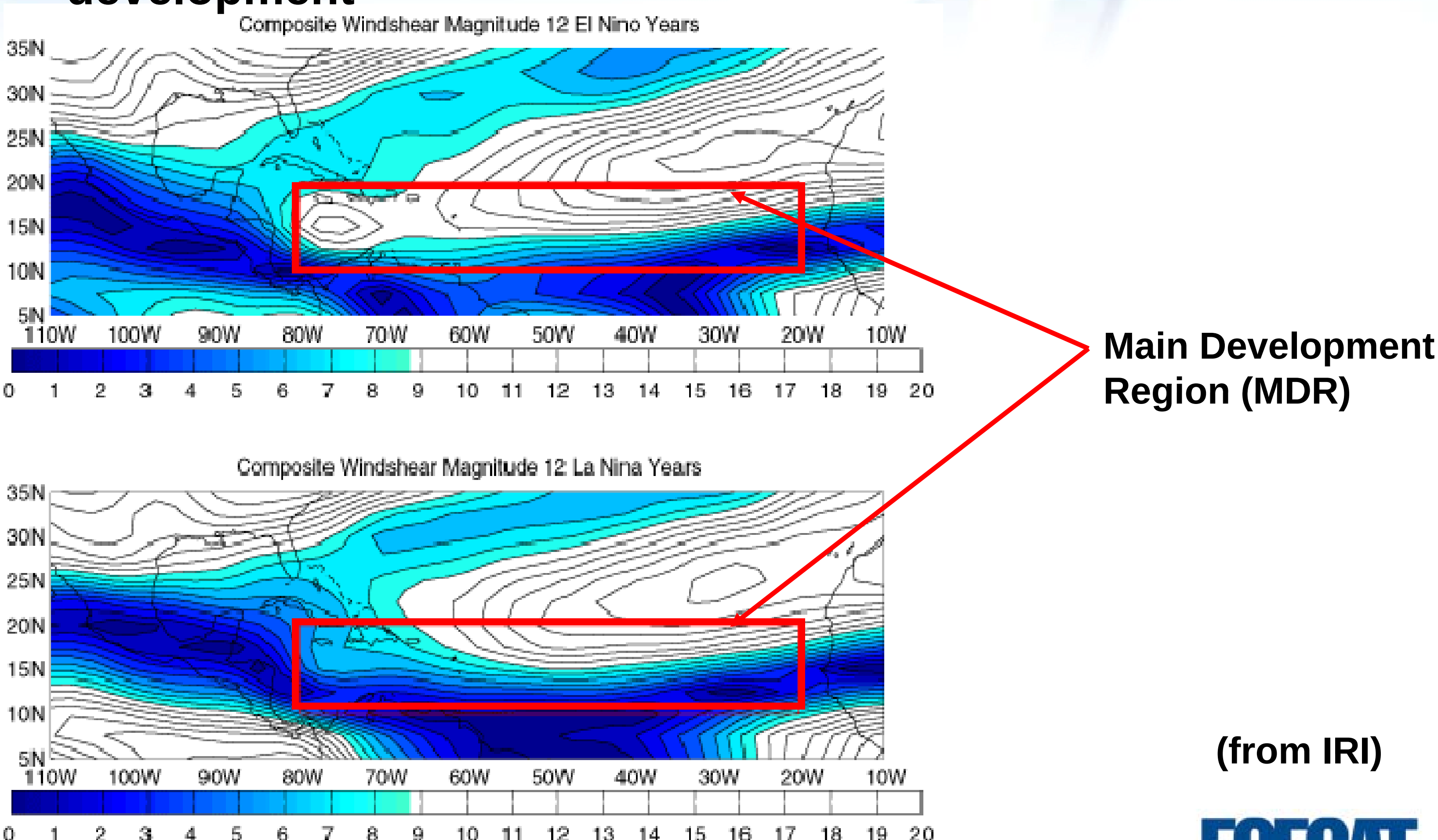
Wind Shear and ENSO

- **El Niño: HIGH wind shear; La Niña: LOW wind shear**
- **Wind shear magnitudes > 7.5 – 10 m/s in the Main Development Region (MDR) are unfavorable for hurricane development**



Composite wind shear magnitude (August to October, 1950-2001)

(from IRI)

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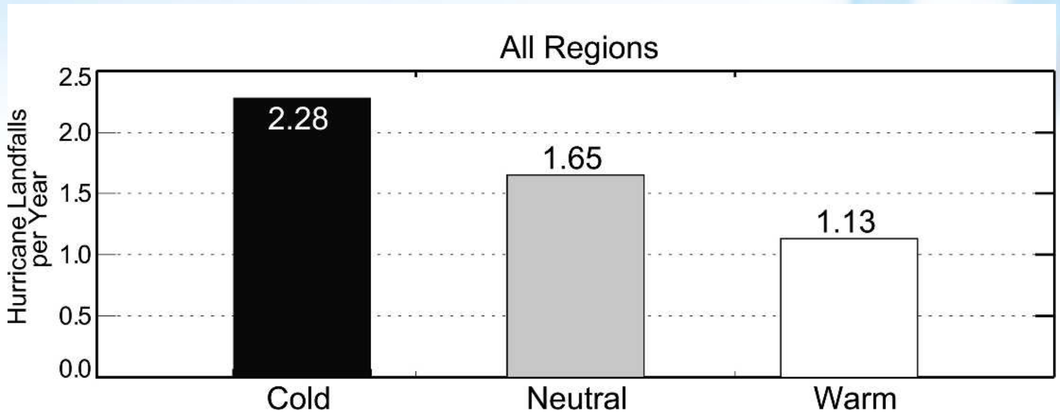
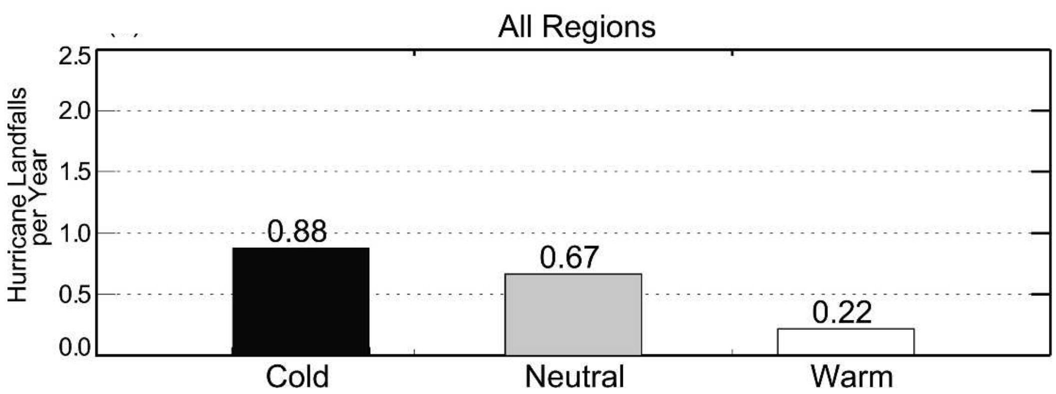
Impact of El Niño on number of U.S. hurricane landfalls



Average number of U.S. hurricane landfalls per year (1900-2004)



Average number of <u>major</u> U.S. hurricane landfalls (cat 3-5) per year (1900-2004)

From Smith et al, J. Climate (2006)

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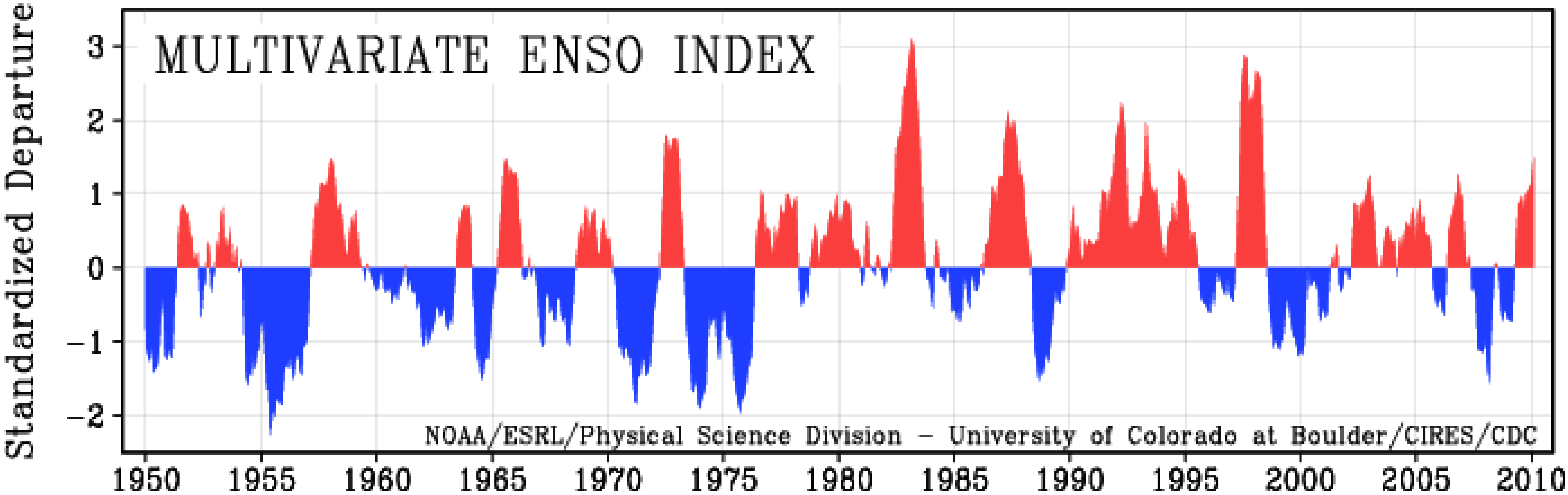
ENSO (El Nino / Southern Oscillation)



- El Niño conditions present early 2002 - late 2005 **(incl. 2004-5 seasons)**
- Weak La Niña conditions late 2005 - early 2006
- El Niño conditions early 2006 - early 2007
- Neutral / La Niña conditions early 2007 - ~May 2009
- Current El Niño developed starting ~ May 2009
- El Niño conditions expected to continue into spring (issued 7 Jan 2010)

http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory

http://www.cdc.noaa.gov/enso/enso.mei_index.html

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Latest ENSO Forecasts (17 Dec 2009)

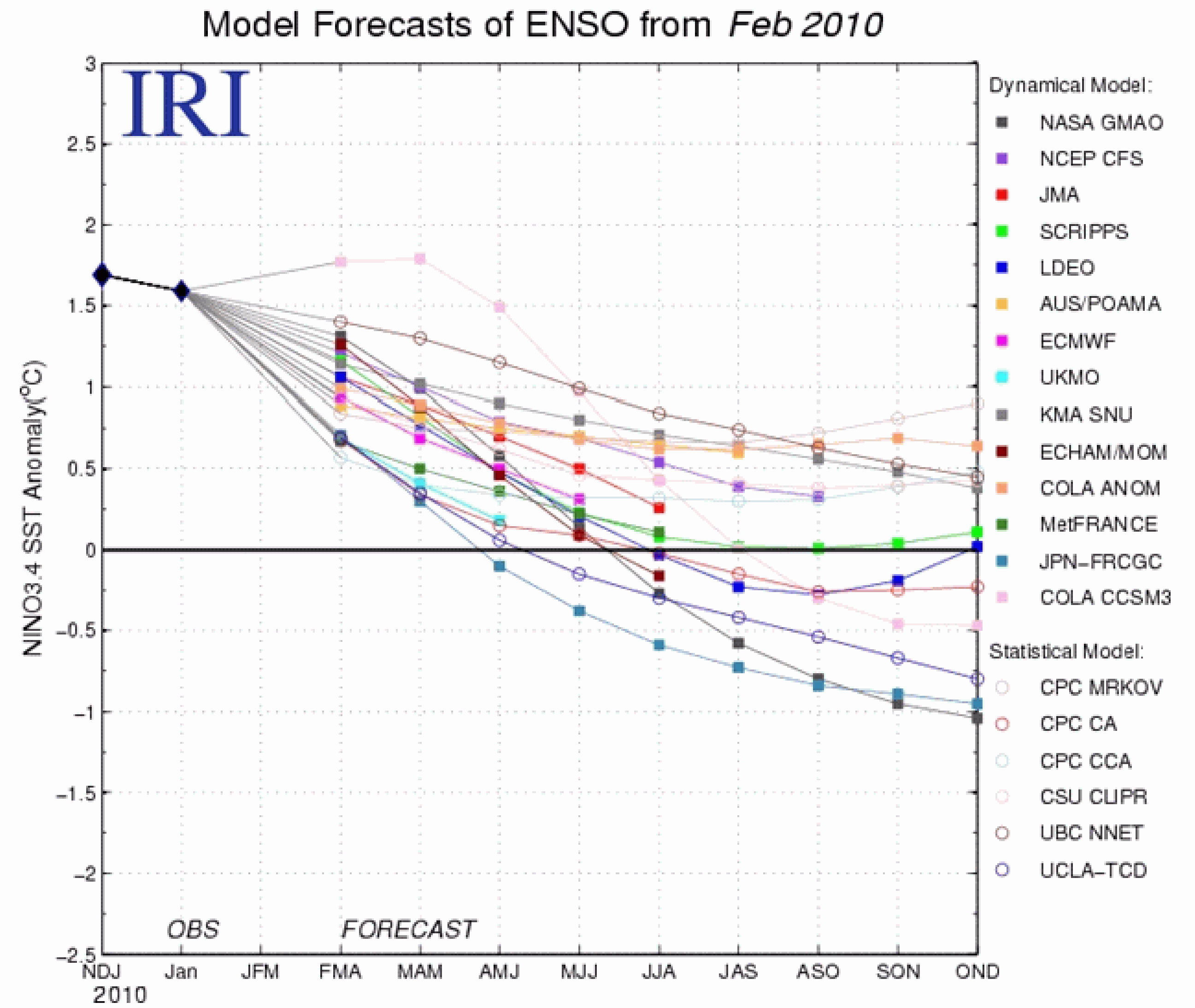

Figure 6. Forecasts of sea surface temperature (SST) anomalies for the Niño 3.4 region (5°N-5°S, 120°W-170°W). Figure courtesy of the International Research Institute (IRI) for Climate and Society. Figure updated 16 February 2010.

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AMO (Atlantic Multidecadal Oscillation)

- COOL Phase
  - Cooler SSTs
  - Increased shear above tropical surface easterlies
  - Unfavorable environment for hurricanes
- WARM Phase
  - Warmer SSTs
  - Reduced shear above tropical surface easterlies
  - Favorable environment for hurricanes
- Roughly 25-40 years in each mode
  - 1900-1925: COOL - decreased activity
  - 1926-1969: WARM - increased activity
  - 1970-1994: COOL - decreased activity
  - 1995-????: WARM - increased activity

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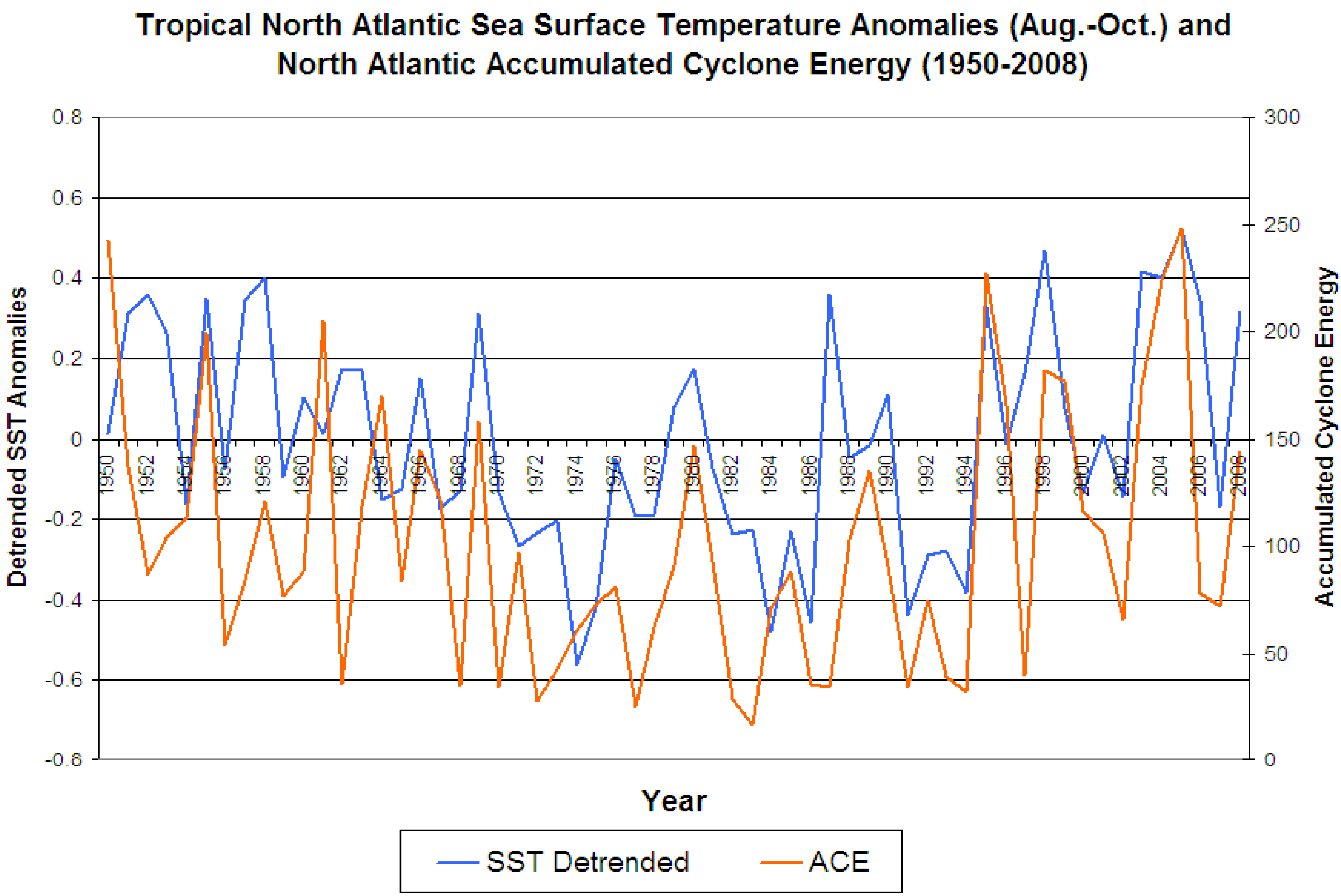
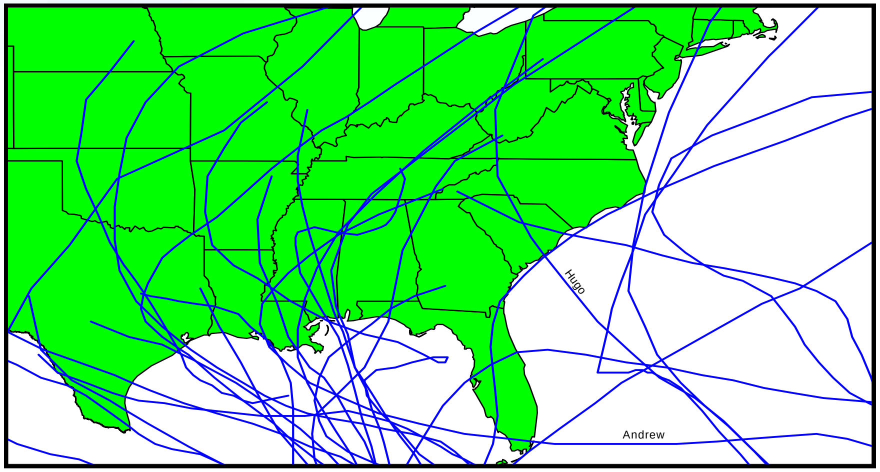
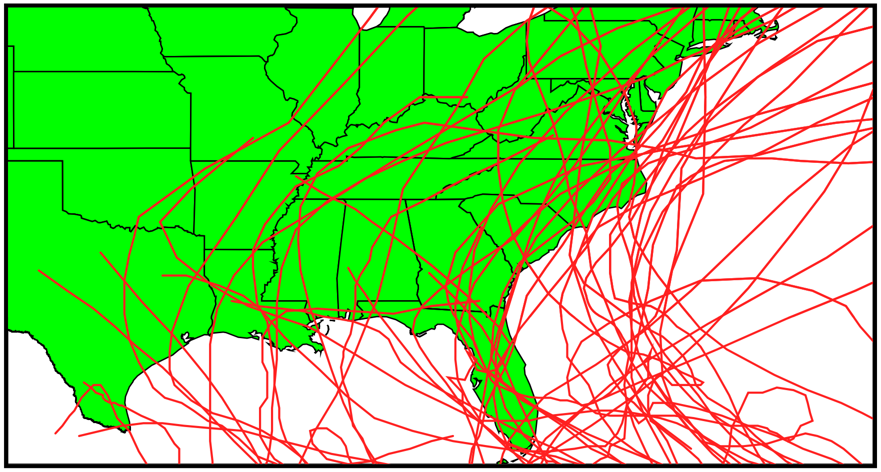
Historical AMO & Atlantic Activity



Cat 3+ Hurricane Activity During AMO Cycles



Cool AMO
28 CAT 3+ events in 51 years
Frequency of 0.55 per year



Warm AMO
49 CAT 3+ events in 58 years
Frequency of 0.84 per year

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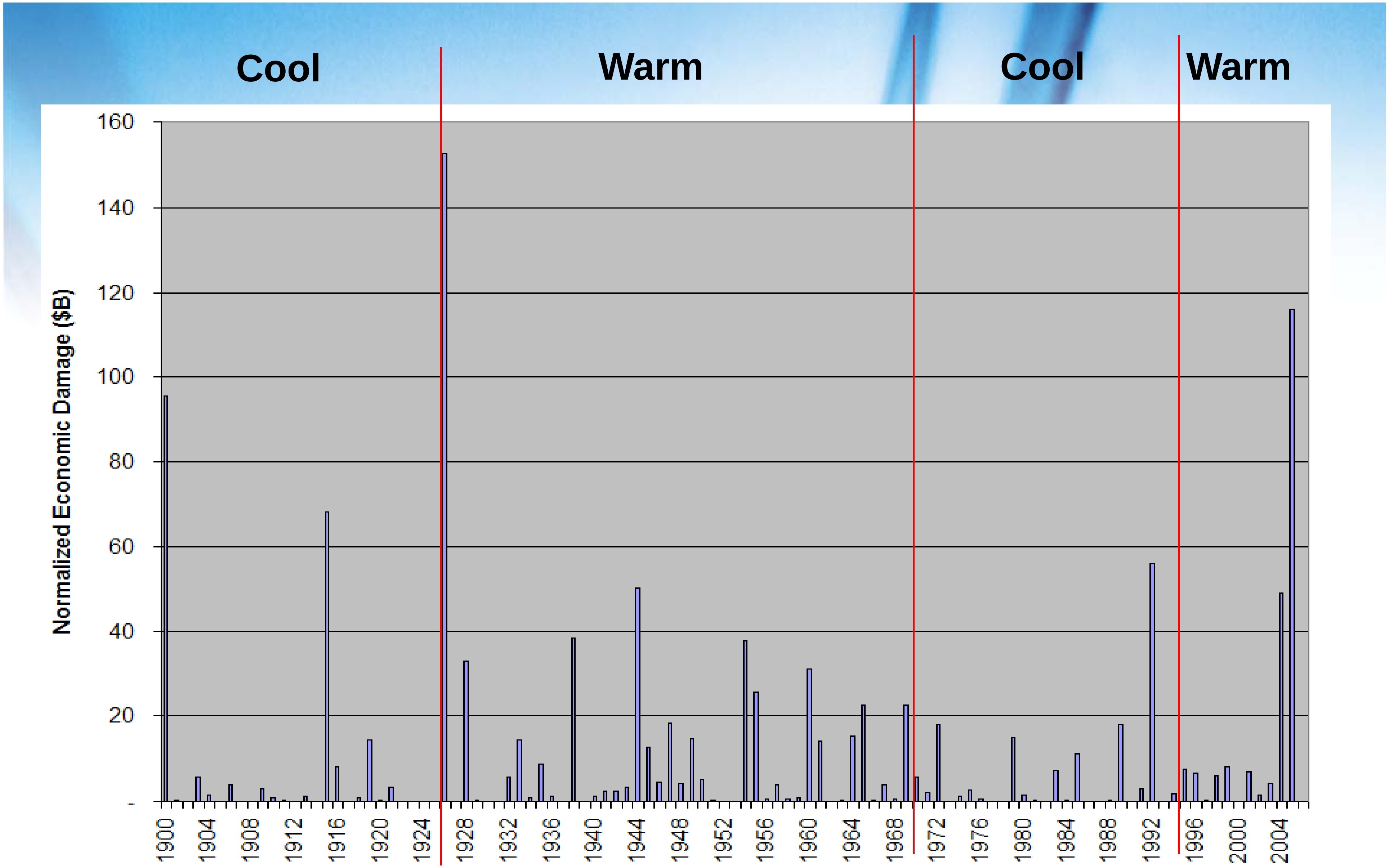

From Pielke et al, Normalized Hurricane Damages in the United States: 1900-2005

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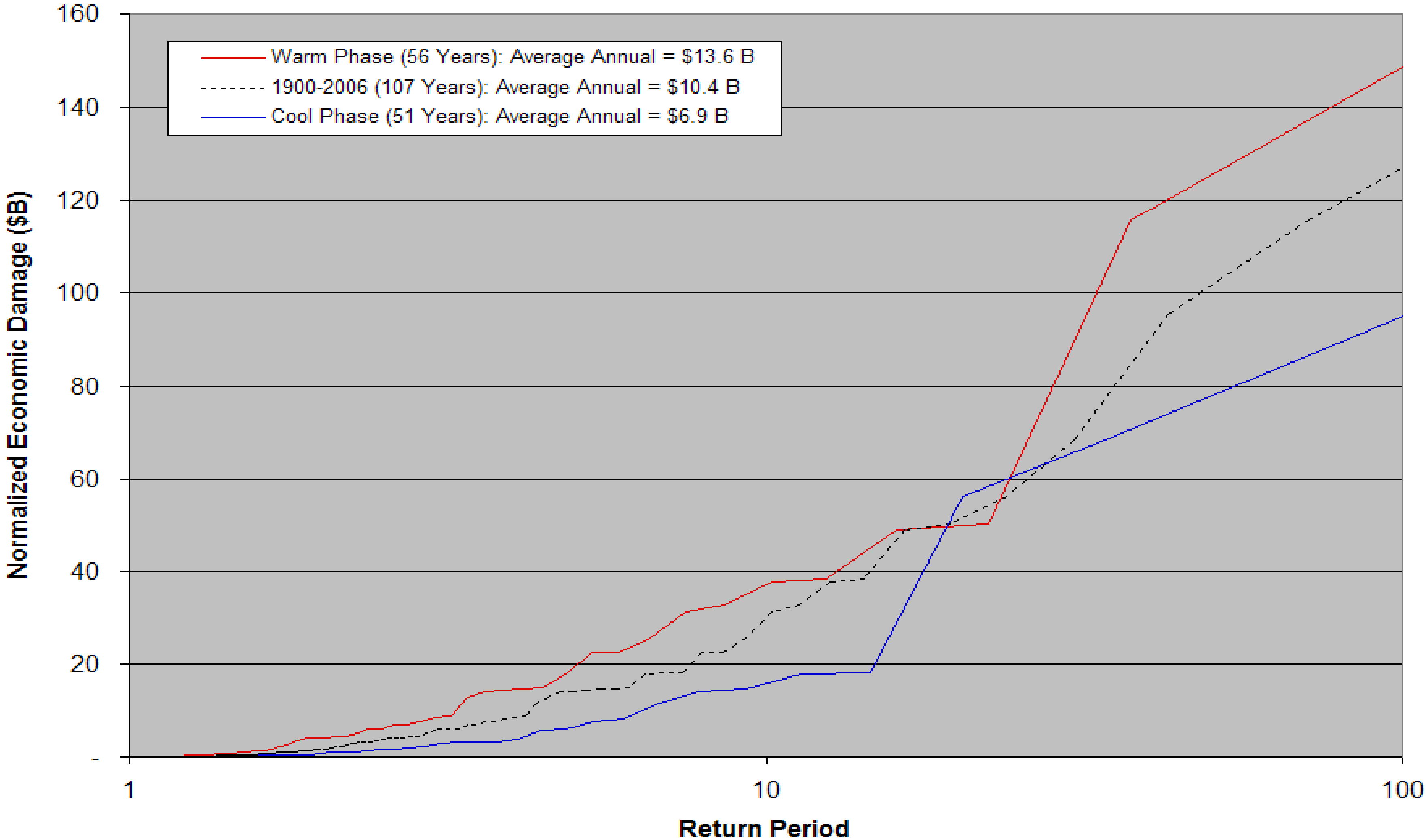

From data in Pielke et al, Normalized Hurricane Damages in the United States: 1900-2005

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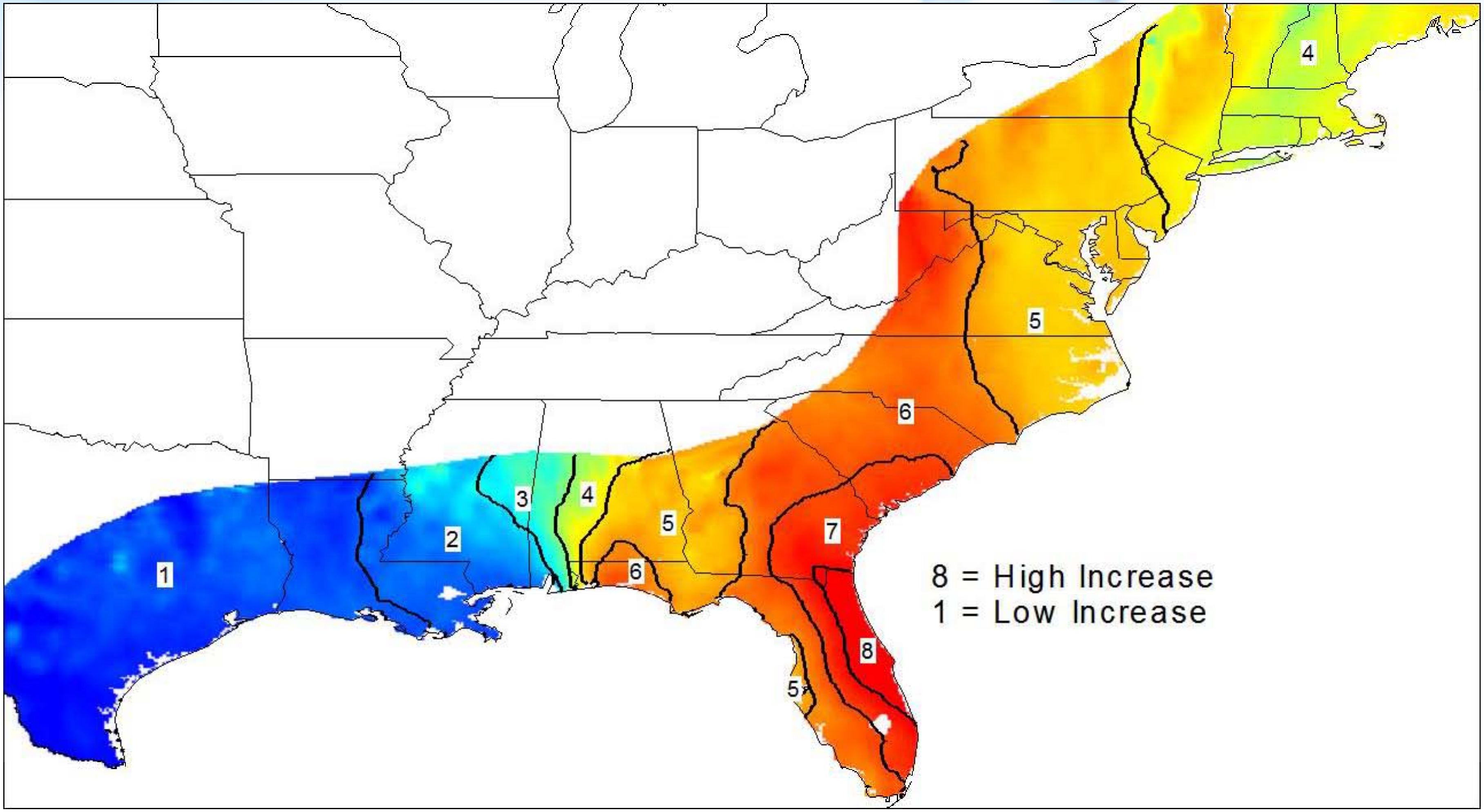
Near-Term vs. Long-Term - AAL



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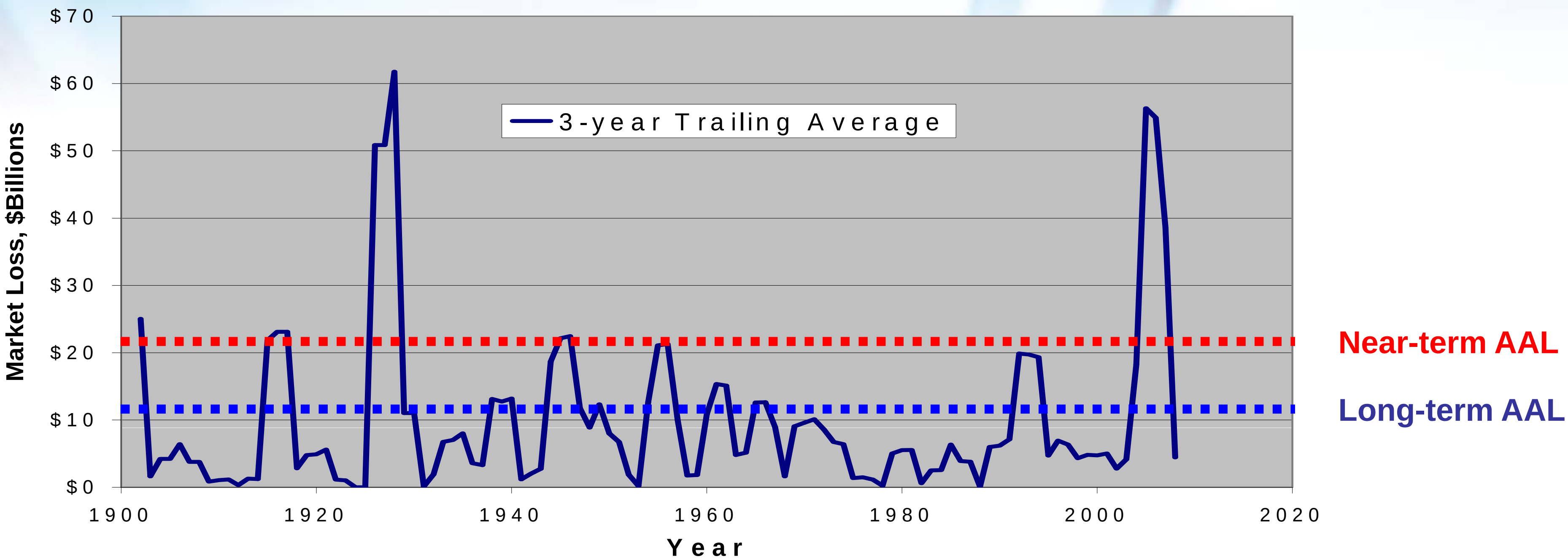
Annual hurricane losses are volatile



The trailing 3 year average is highly variable

Average annual loss ~ $11 billion
Standard deviation ~ $22 billion
More Than 2/3 of the Losses Have Come From a Dozen Seasons

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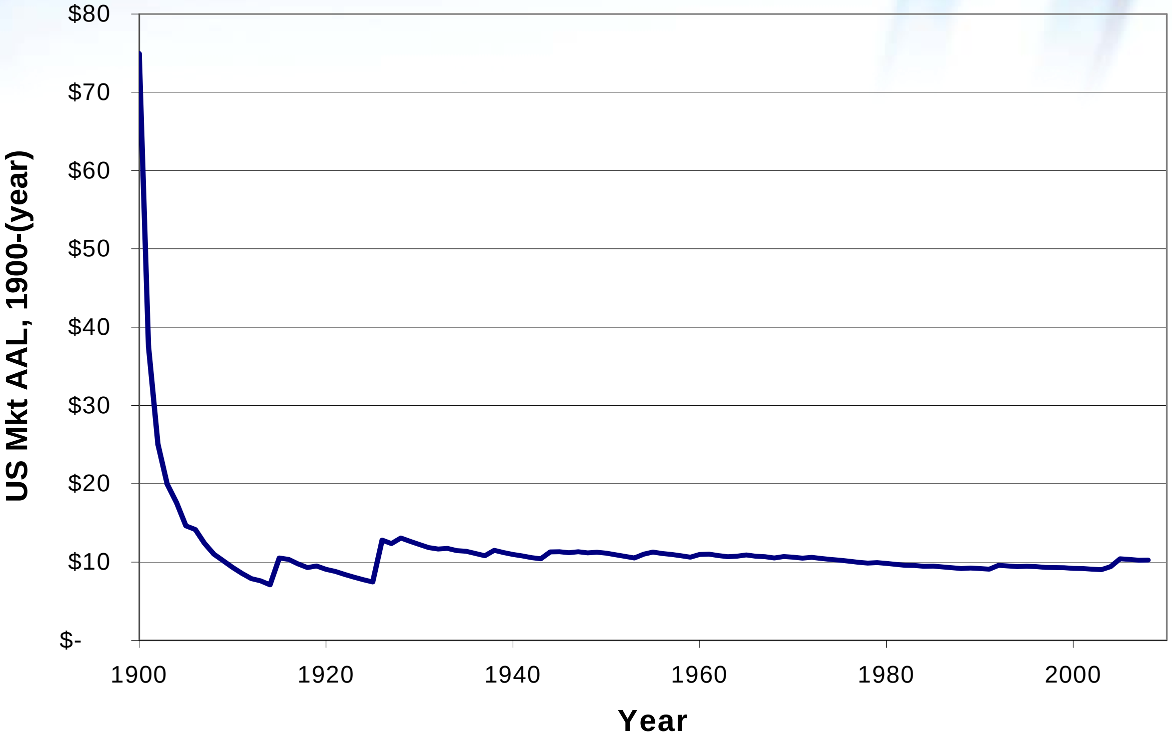
Annual hurricane losses are volatile



Historical AAL stabilizes at about 40 years

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Near Term Frequencies: Summary

- 3 years of data is insufficient to assess the adequacy of a hurricane frequency model
- Regardless of whether AMO is truly a physical cycle likely to repeat, current conditions are similar to prior warm 'phases', which correlate well with increased activity
- Statistical methods are by no means the final answer (e.g. downscaling from AOGCMs), but they have merit in quantifying climate-conditioned frequencies

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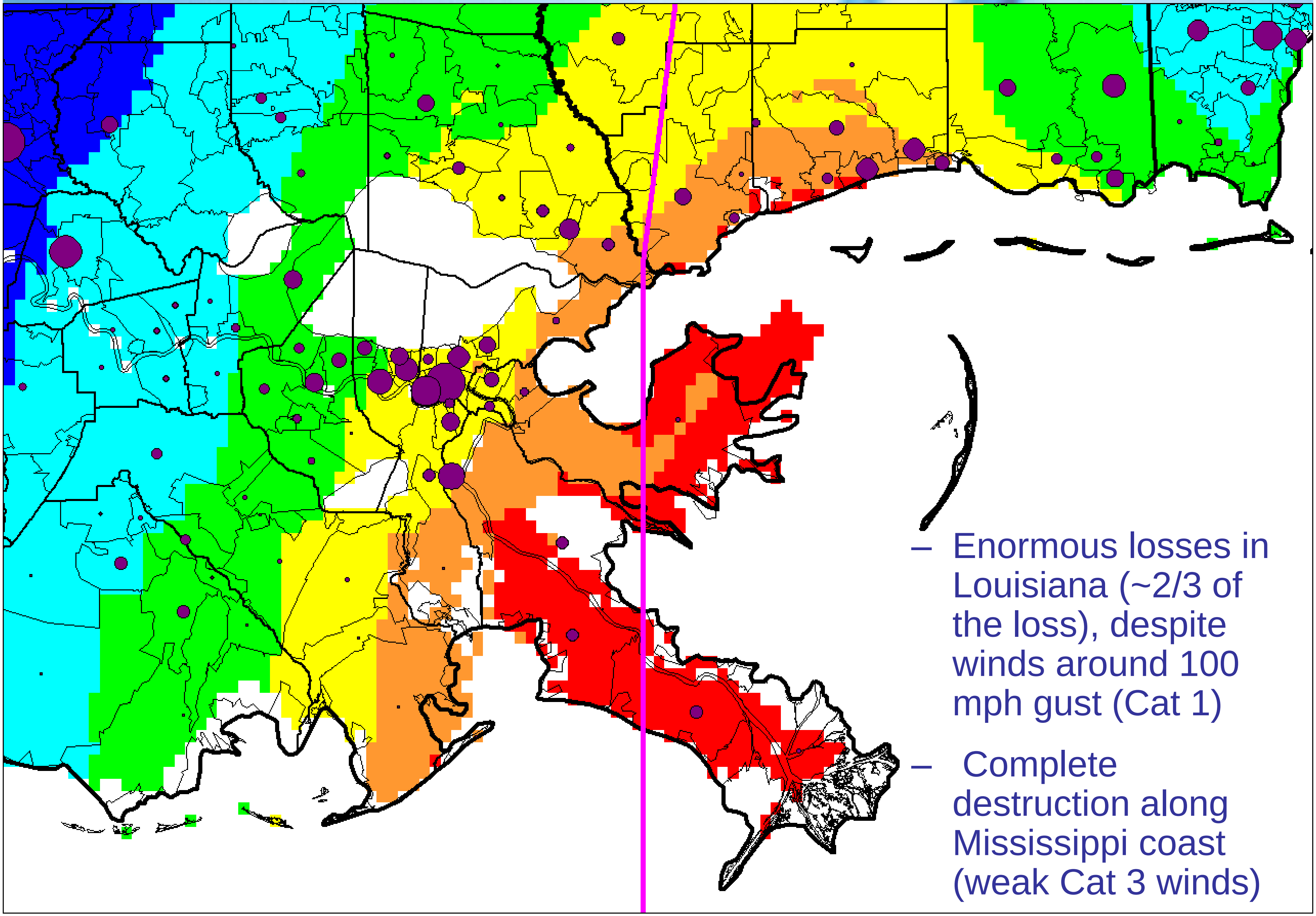
Key Risk Modeling Issues:

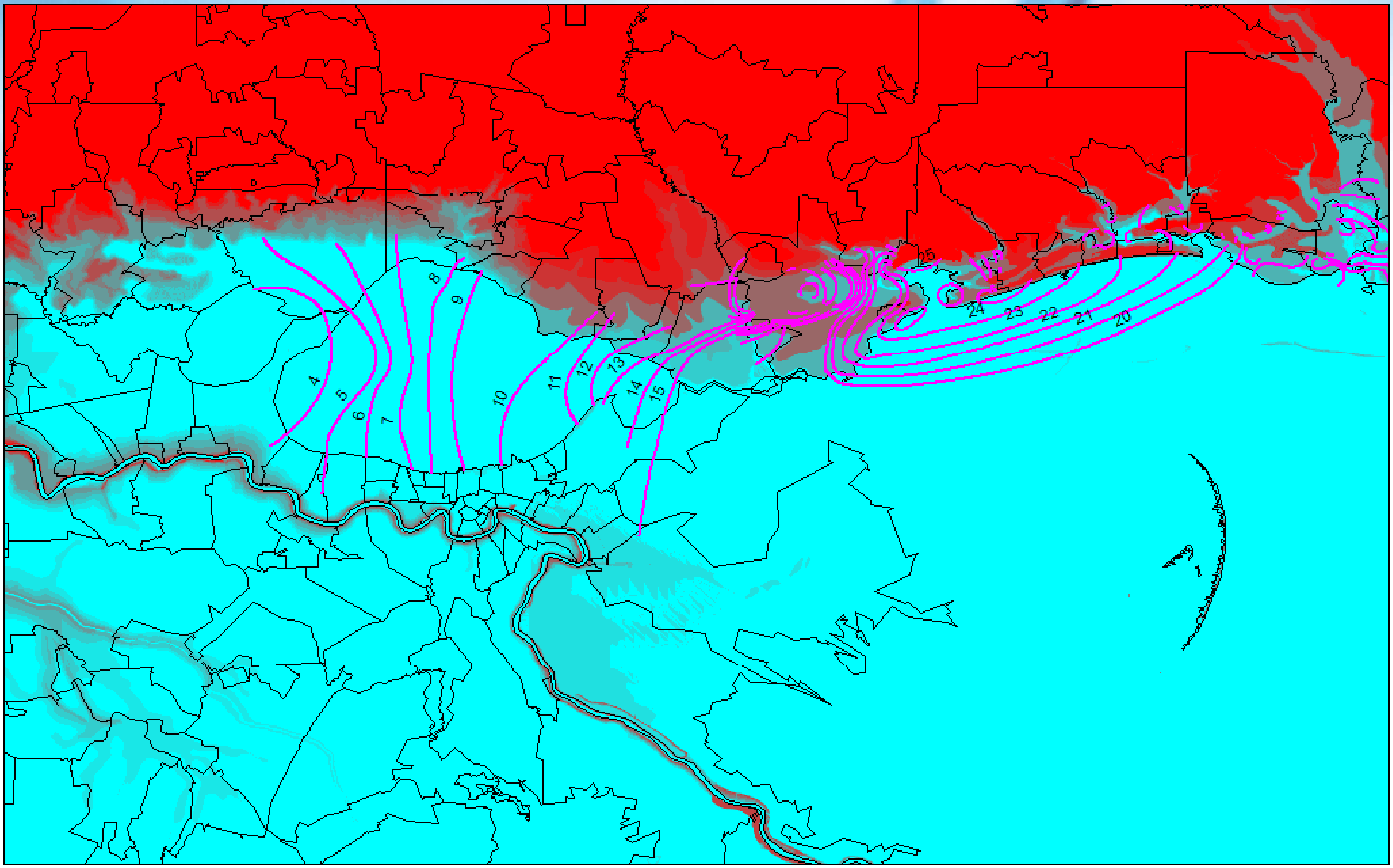
- Near Term Frequencies
- Storm Surge
- Offshore Energy

Wind vs. Flood - Katrina



- Enormous losses in Louisiana (~2/3 of the loss), despite winds around 100 mph gust (Cat 1)
- Complete destruction along Mississippi coast (weak Cat 3 winds)

Katrina - Surge Contours (feet)



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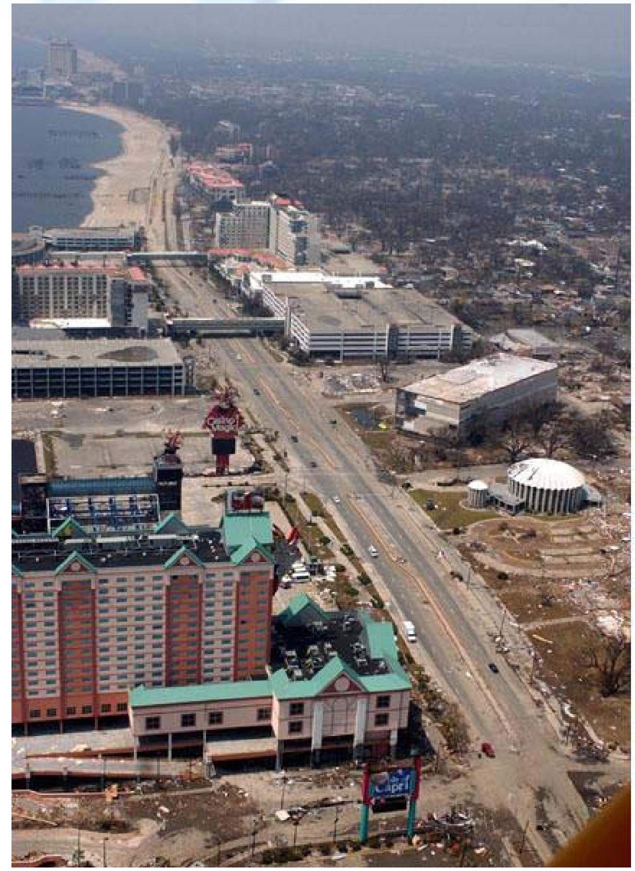
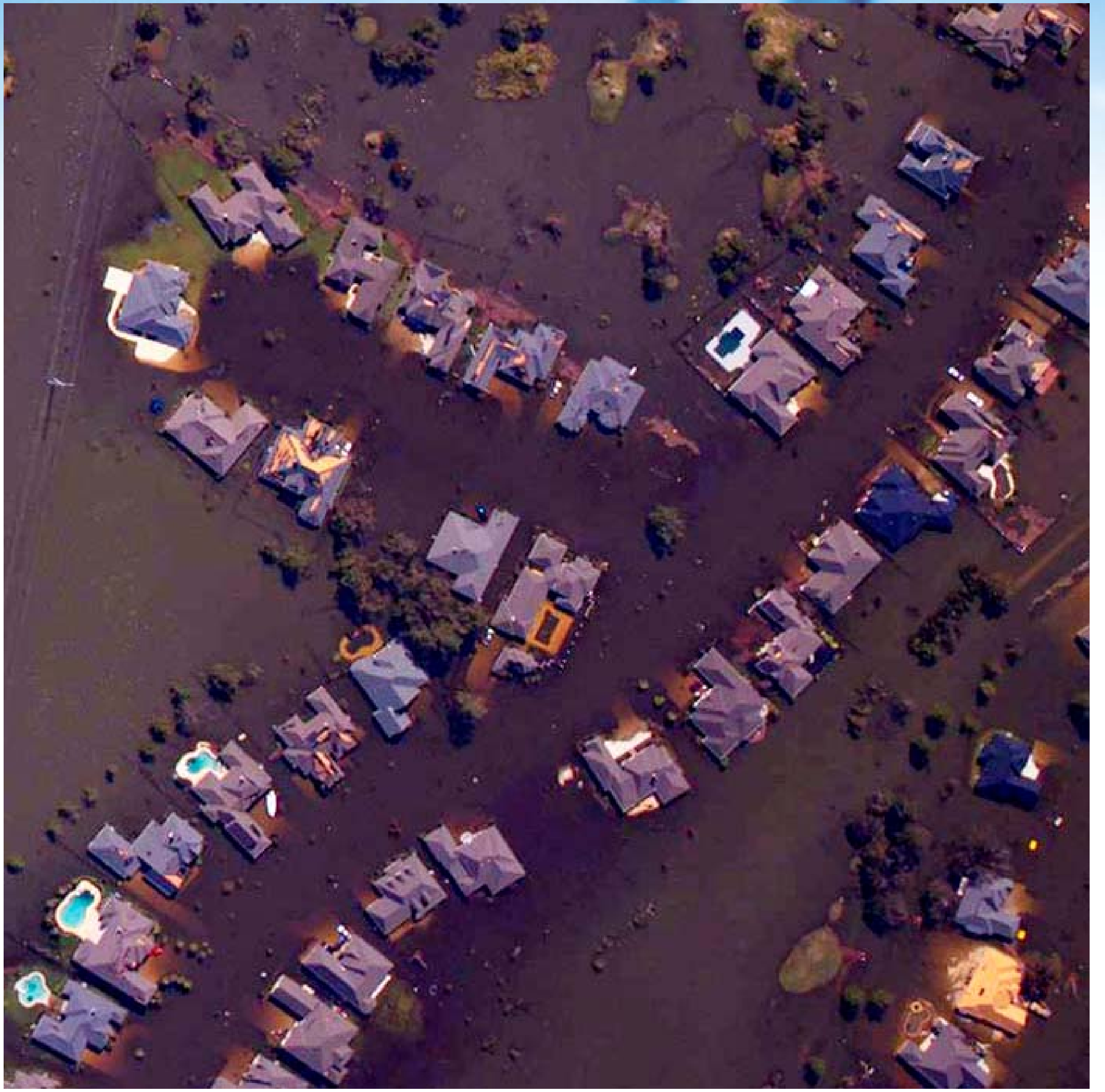
Beachwalk Condos in Long Beach, MS

Casino Row
Biloxi, MS



New Orleans



Storm Surge Components

- Surge height is combination of:
  - Storm tide
    - Water pushed toward the shore by the force of the winds in the hurricane (wind stress) acting on the sea surface
    - **Gently sloping seafloor (bathymetry) allows for higher surge**
    - (minor) Lower atmospheric pressure increases height
  - Wind driven waves
  - Astronomical tide level, independent of the storm
- Modeling methodology:
  - Finite Element Method with bathymetry (depth) specified, solving the governing equations, including wind stress and bottom stress
  - Incorporate tidal effect as a random variable (+/- tidal range, specified at each coastal boundary point)
- Inundation and damage occur in 2 zones:
  - Velocity zone (first few hundred meters), where wave action and debris can completely destroy structures
  - Farther inland, where the main problem is flooding as opposed to structural damage

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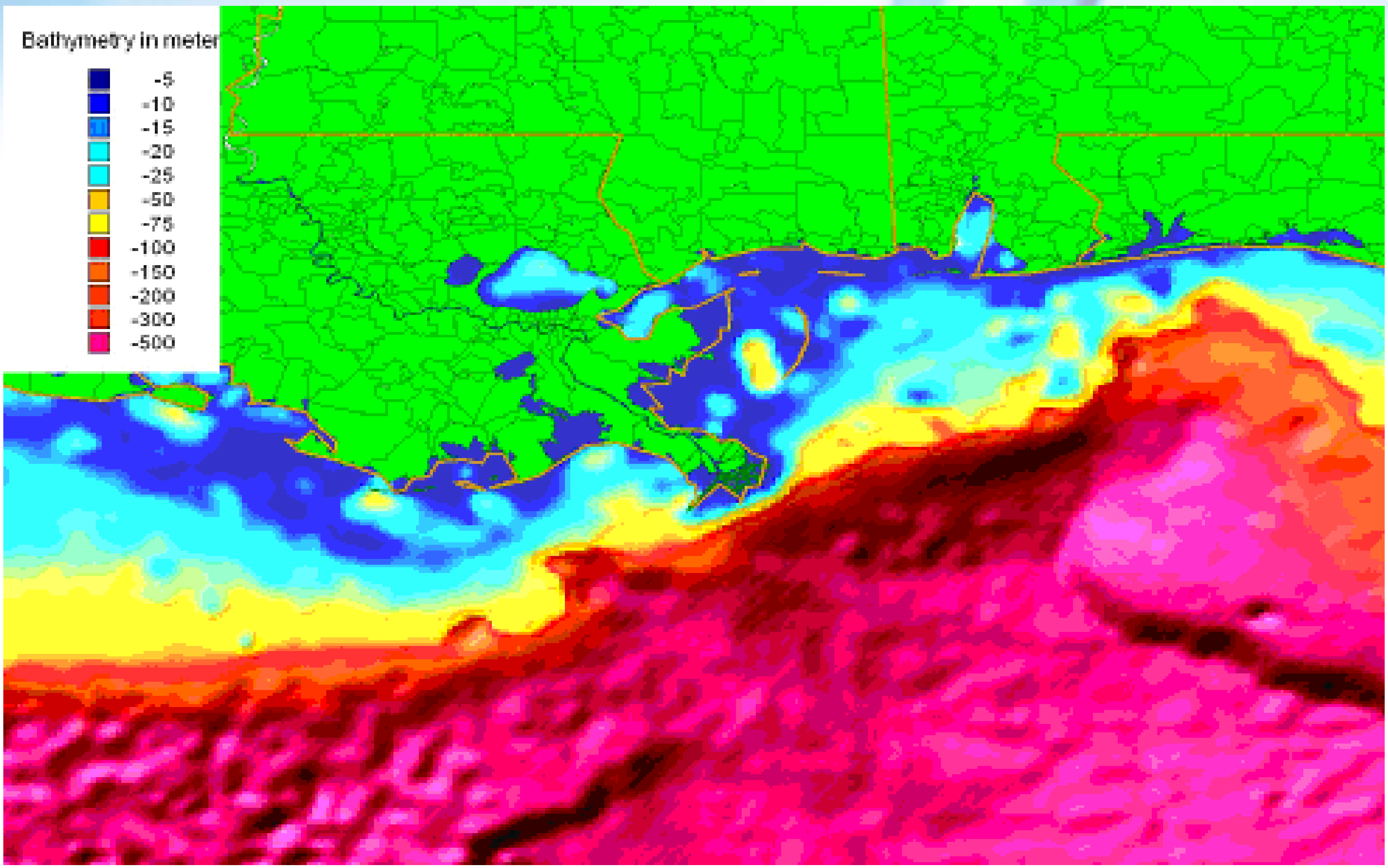
Digitized bathymetry in the Gulf of Mexico used in the EQECAT storm surge model



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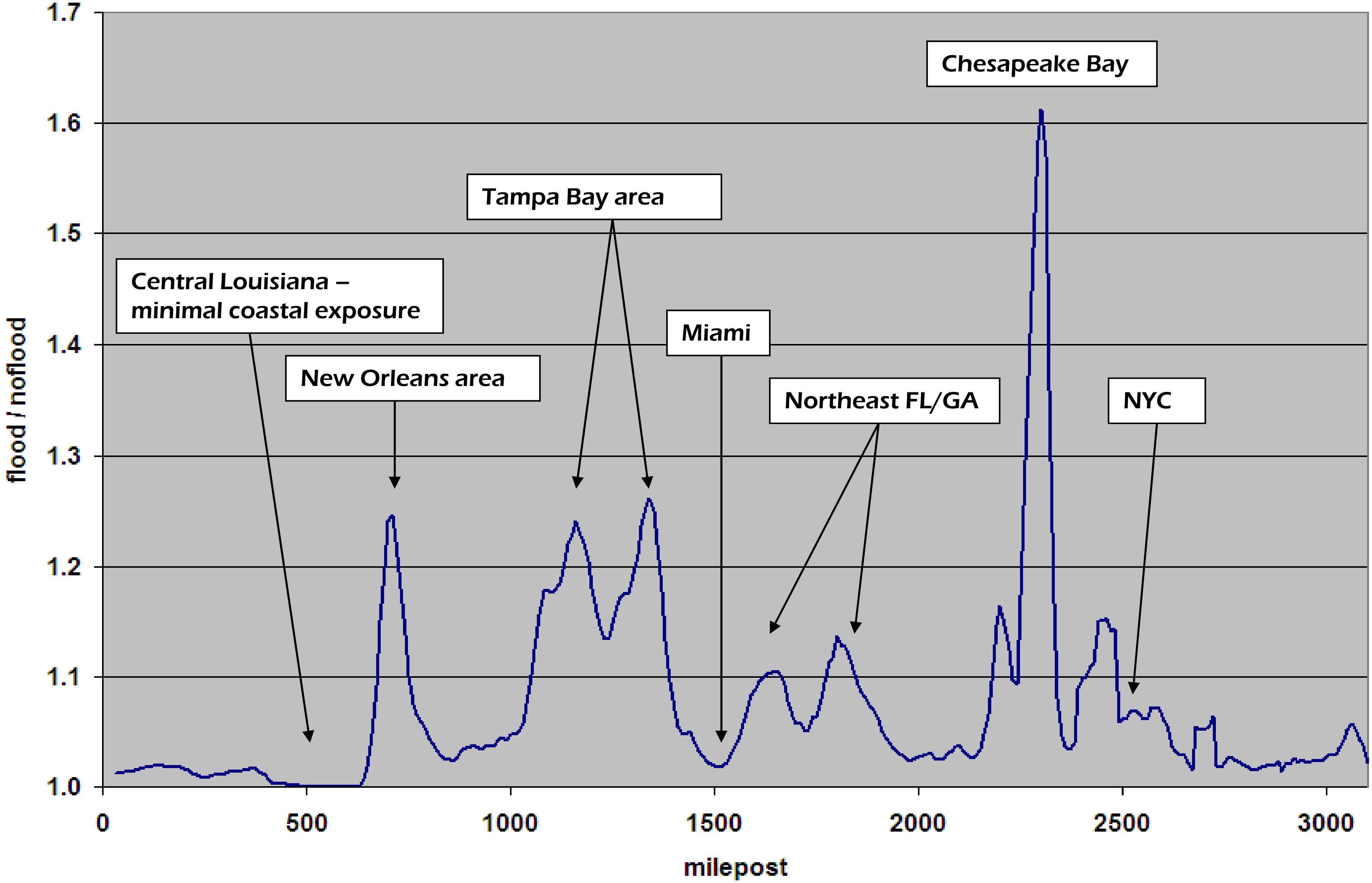
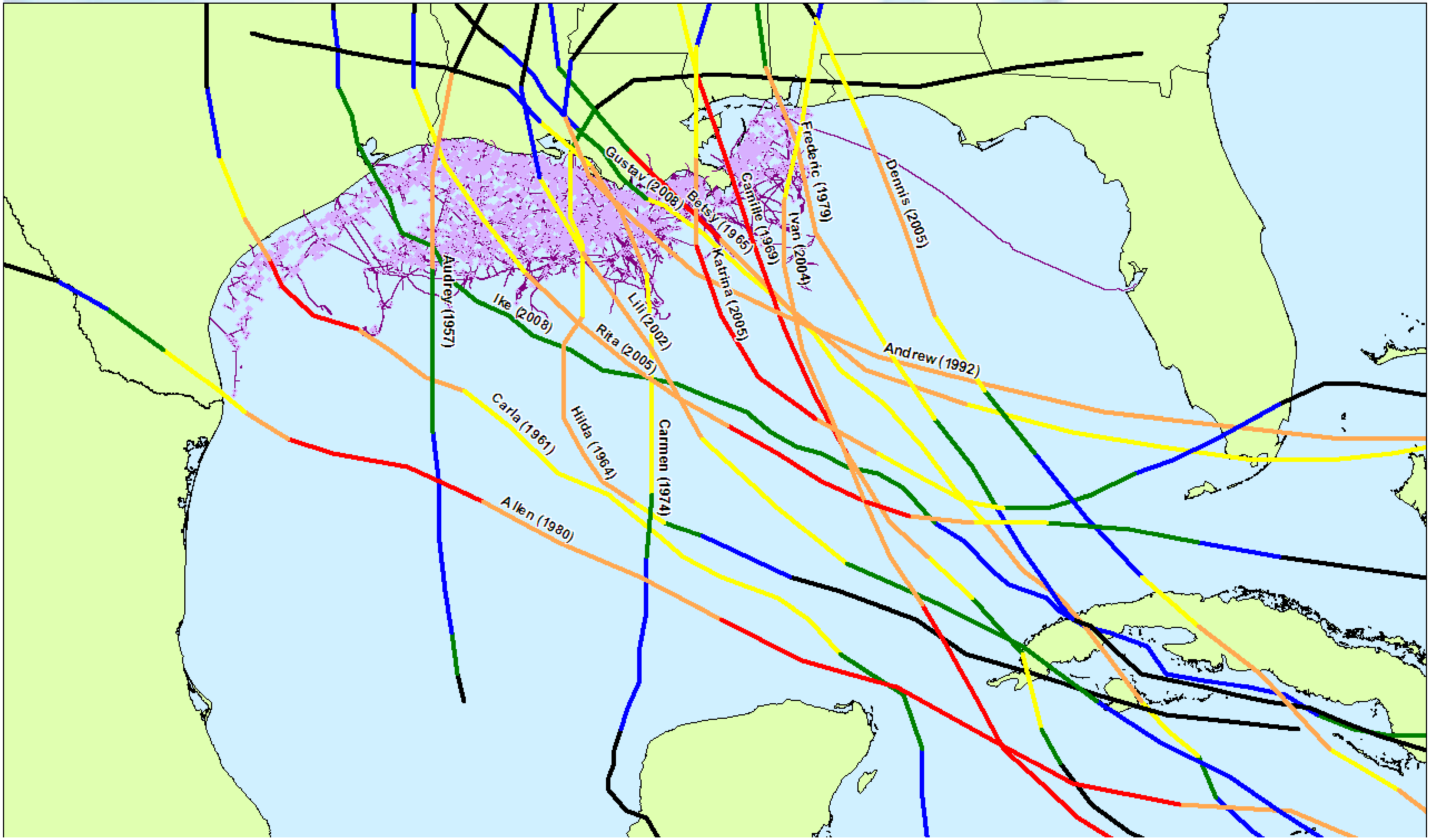
Relative storm surge impact by coastal location



Key Risk Modeling Issues:

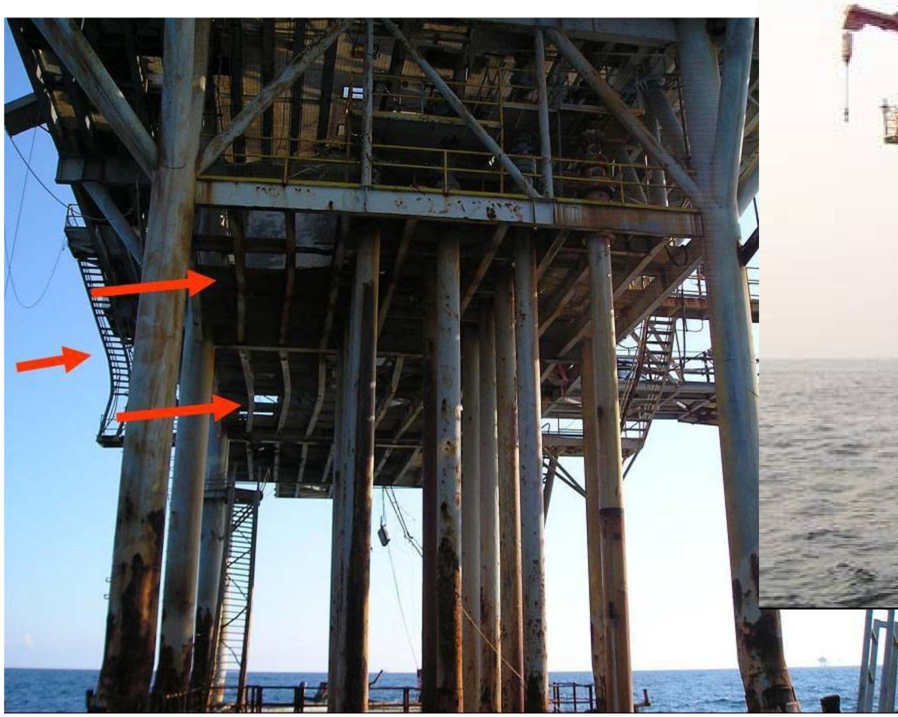
- Near Term Frequencies
- Storm Surge
- Offshore Energy

Key Hurricanes in the Gulf of Mexico (1950-2008)



Agents of Offshore Hurricane Damage

- Wind
  - Most significant for some mobile offshore assets, onshore assets and offshore topsides facilities
- Waves and current
  - Most significant for fixed offshore structures and some mobile structures
- Landslides
  - Highly damaging to fixed assets and pipelines but in localized areas



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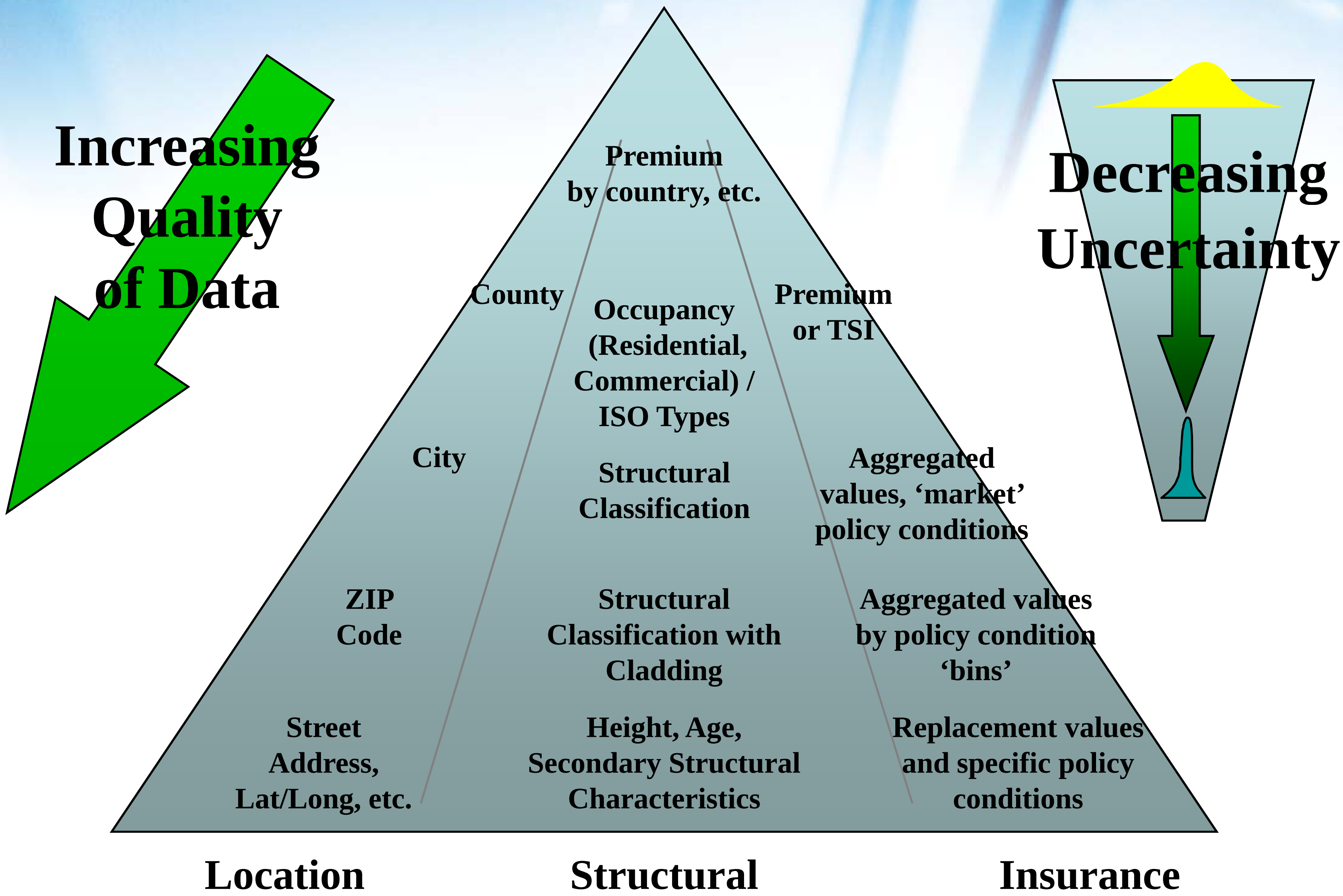
Secondary Structural Characteristics

Modeling Issue: Data Quality



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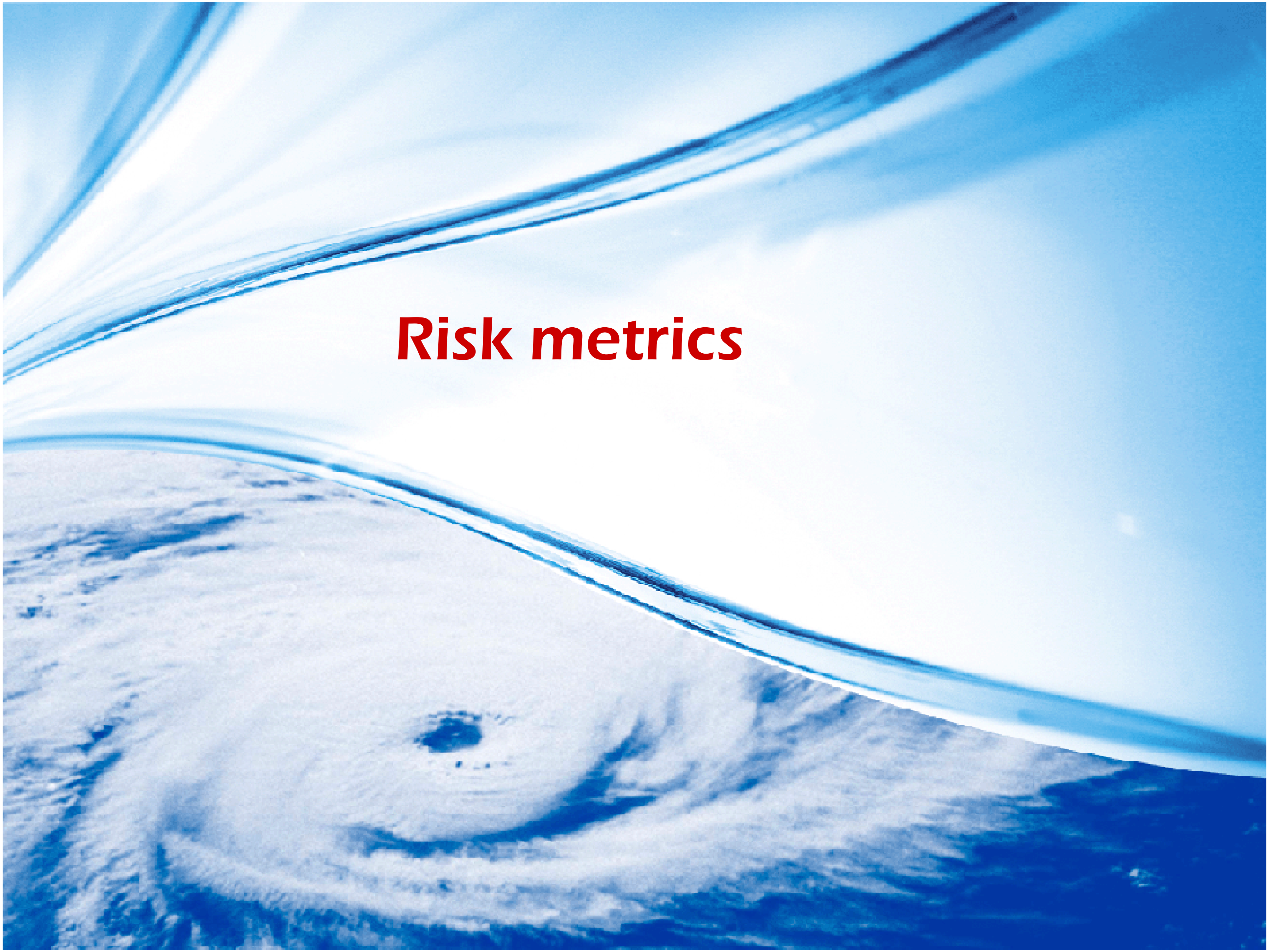
FCHLPM Form V-2

INDIVIDUAL MITIGATION MEASURES		PERCENTAGE CHANGES IN DAMAGE* (REFERENCE DAMAGE RATE - MITIGATED DAMAGE RATE) / REFERENCE DAMAGE RATE * 100									
		FRAME STRUCTURE					MASONRY STRUCTURE				
		WINDSPEED (MPH)					WINDSPEED (MPH)				
		60	85	110	135	160	60	85	110	135	160
	REFERENCE STRUCTURE	0	0	0	0	0	0	0	0	0	0
ROOF STRENGTH	BRACED GABLE ENDS	15.4%	15.1%	13.0%	10.5%	5.2%	13.1%	13.5%	11.8%	9.6%	6.1%
	HIP ROOF	19.5%	18.9%	16.2%	13.3%	6.7%	17.3%	17.4%	15.2%	12.5%	8.1%
ROOF COVERING	METAL	0.0%	0.0%	0.0%	0.0%	0.0%	-2.6%	-2.7%	-2.4%	-1.9%	-1.2%
	RATED SHINGLES (110 MPH)	8.0%	8.0%	6.8%	5.5%	2.6%	5.2%	5.4%	4.7%	3.8%	2.4%
	MEMBRANE	2.7%	2.7%	2.3%	1.8%	0.9%	0.0%	0.0%	0.0%	0.0%	0.0%
	NAILING OF DECK 8d	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ROOF-WALL STRENGTH	CLIPS	19.5%	18.9%	16.2%	13.3%	6.7%	15.2%	15.4%	13.5%	11.0%	7.1%
	STRAPS	19.5%	18.9%	16.2%	13.3%	6.7%	15.2%	15.4%	13.5%	11.0%	7.1%
WALL-FLOOR STRENGTH	TIES OR CLIPS	8.0%	8.0%	6.8%	5.5%	2.6%	5.2%	5.4%	4.7%	3.8%	2.4%
	STRAPS	8.0%	8.0%	6.8%	5.5%	2.6%	5.2%	5.4%	4.7%	3.8%	2.4%
WALL-FOUNDATION STRENGTH	LARGER ANCHORS OR CLOSER SPACING	0.0%	0.0%	0.0%	0.0%	0.0%	-	-	-	-	-
	STRAPS	8.0%	8.0%	6.8%	5.5%	2.6%	-	-	-	-	-
	VERTICAL REINFORCING	-	-	-	-	-	-	-	-	-	-
OPENING PROTECTION	WINDOW SHUTTERS PLYWOOD	10.7%	10.6%	9.1%	7.3%	3.5%	10.5%	10.8%	9.5%	7.7%	4.9%
	WINDOW SHUTTERS STEEL	10.7%	10.6%	9.1%	7.3%	3.5%	10.5%	10.8%	9.5%	7.7%	4.9%
	WINDOW SHUTTERS ENGINEERED	17.4%	17.0%	14.6%	11.9%	5.9%	17.3%	17.4%	15.2%	12.5%	8.1%
	DOOR AND SKYLIGHT COVERS	15.4%	15.1%	13.0%	10.5%	5.2%	10.5%	10.8%	9.5%	7.7%	4.9%
WINDOW, DOOR, SKYLIGHT STRENGTH	WINDOWS LAMINATED	10.7%	10.6%	9.1%	7.3%	3.5%	7.9%	8.1%	7.1%	5.8%	3.6%
	WINDOWS IMPACT GLASS	10.7%	10.6%	9.1%	7.3%	3.5%	7.9%	8.1%	7.1%	5.8%	3.6%

MITIGATION MEASURES IN COMBINATION		PERCENTAGE CHANGES IN DAMAGE* (REFERENCE DAMAGE RATE - MITIGATED DAMAGE RATE) / REFERENCE DAMAGE RATE * 100									
		FRAME STRUCTURE					MASONRY STRUCTURE				
		WINDSPEED (MPH)					WINDSPEED (MPH)				
		60	85	110	135	160	60	85	110	135	160
STRUCTURE	MITIGATED STRUCTURE	25.7%	24.4%	21.1%	17.5%	9.0%	23.5%	23.1%	20.3%	16.8%	11.1%


Risk metrics

Probabilistic vs. EBE

- 'Event by Event' aka 'EBE' (or event loss table) results provide:
  - Event id, event description, mean and sigma loss, frequency
  - For all events in the stochastic event set that affect the portfolio
- But by themselves they do not provide very many useful metrics describing the portfolio risk
  - Average annual loss as sum product of mean loss and frequency is about all you get
- Need a frequency model to convert them to probabilistic results
  - e.g. 100-year per occurrence, annual aggregate, TVAR, etc.
- Examples of frequency models:
  - Poisson (arrival times are independent)
  - Negative binomial (can reflect temporal clustering)

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Stochastic Risk Atlas

- Simulation of all events from all models / perils, considering their geography and frequency
- Takes event outcomes and frequencies and turns them into something more useful – financial impacts in the time domain
- Robust method to calculate annual aggregate losses
- Provides the ability to model time domain aspects of insurance/reinsurance contracts – e.g. annual attachments and limits, 2nd and 3rd event covers, etc.
- Basis of all financial calculations
- Currently consists of 150,000 simulated years

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Stochastic risk atlas - metrics

- Go through the 150k years
- For year (and each model) determine number of events that year (drawn from the relevant freq distribution)
- For each event, draw a random sample from all of the EBE outcomes
- For each year keep track of
  - Sum of the event losses
  - Maximum of the event losses
- AAL (average annual loss) = average of the 150k sums
- 1-in-100 or '100 year' Per occurrence (OEP) = 99th percentile of the (150k) maximums (i.e. 1500th highest)
- 1-in-100 or '100 year' Annual aggregate (AEP) = 99th percentile of the (150k) sums (i.e. 1500th highest)

Definition: return period = 1/annual exceedance probability

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ROL / CROL

- ROL = rate on line
  - Premium divided by limit, for a layer
- CROL = calculated rate on line
  - Formula by which modeled results can be compared with ROL, generally considering at least the following:
    - Average annual loss
    - Standard deviation of annual loss
    - Expense load
- Decision as to whether contract is a good idea can be based (partially) on comparison of CROL to ROL
- However: correlation of contracts/risks within a portfolio is also fundamental to the decision (portfolio optimization) – 'reference portfolio' analysis

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Why correlation is important

Simple example of the effect

- 50 events, each with annual frequency = 0.01
- 2 policies, each with the same risk (i.e. the same 50 distinct loss outcomes), but possibly caused by different events
- 3 cases:
  - – Perfect correlation
  - – High correlation
  - – Low correlation

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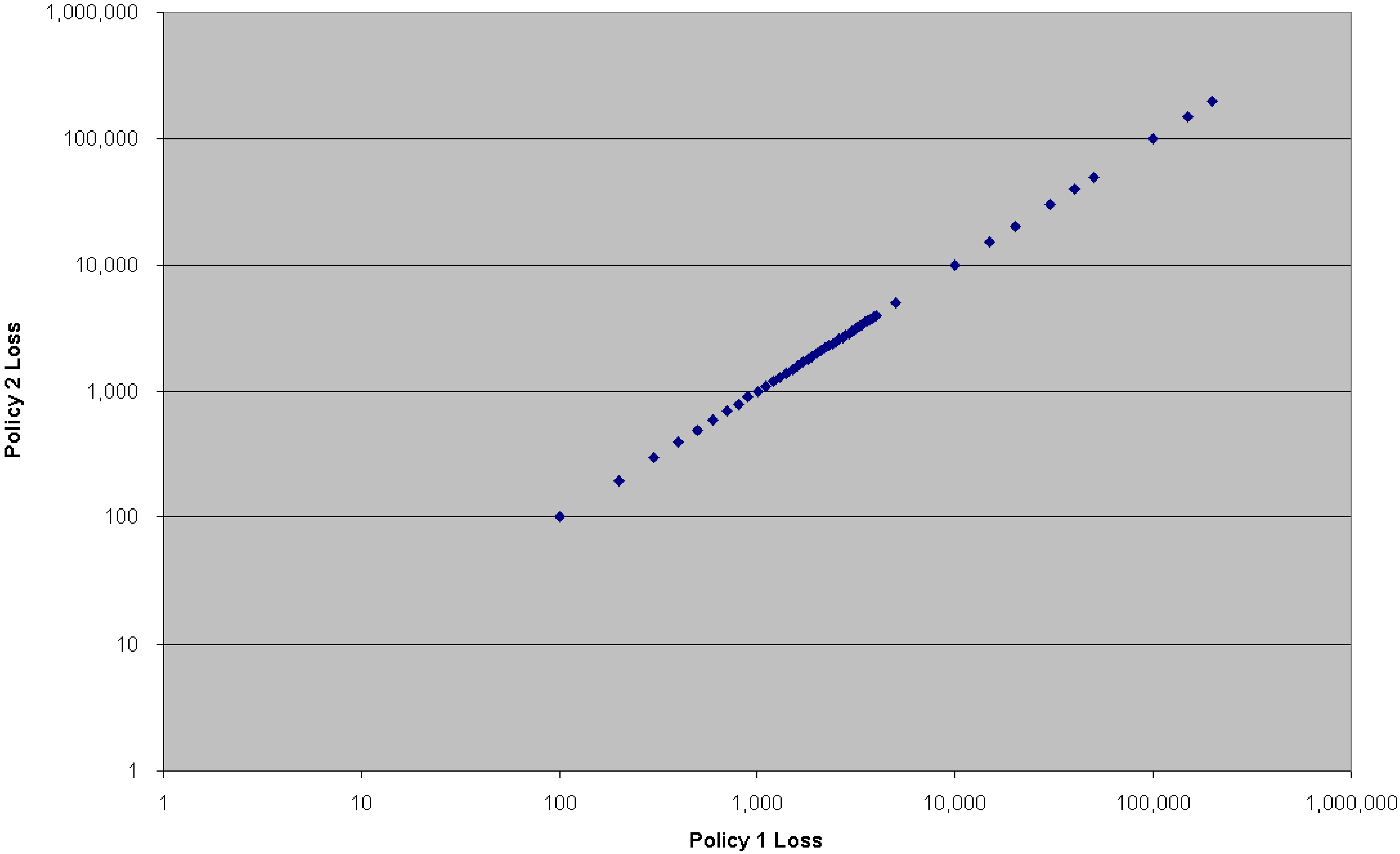
Perfect Correlation



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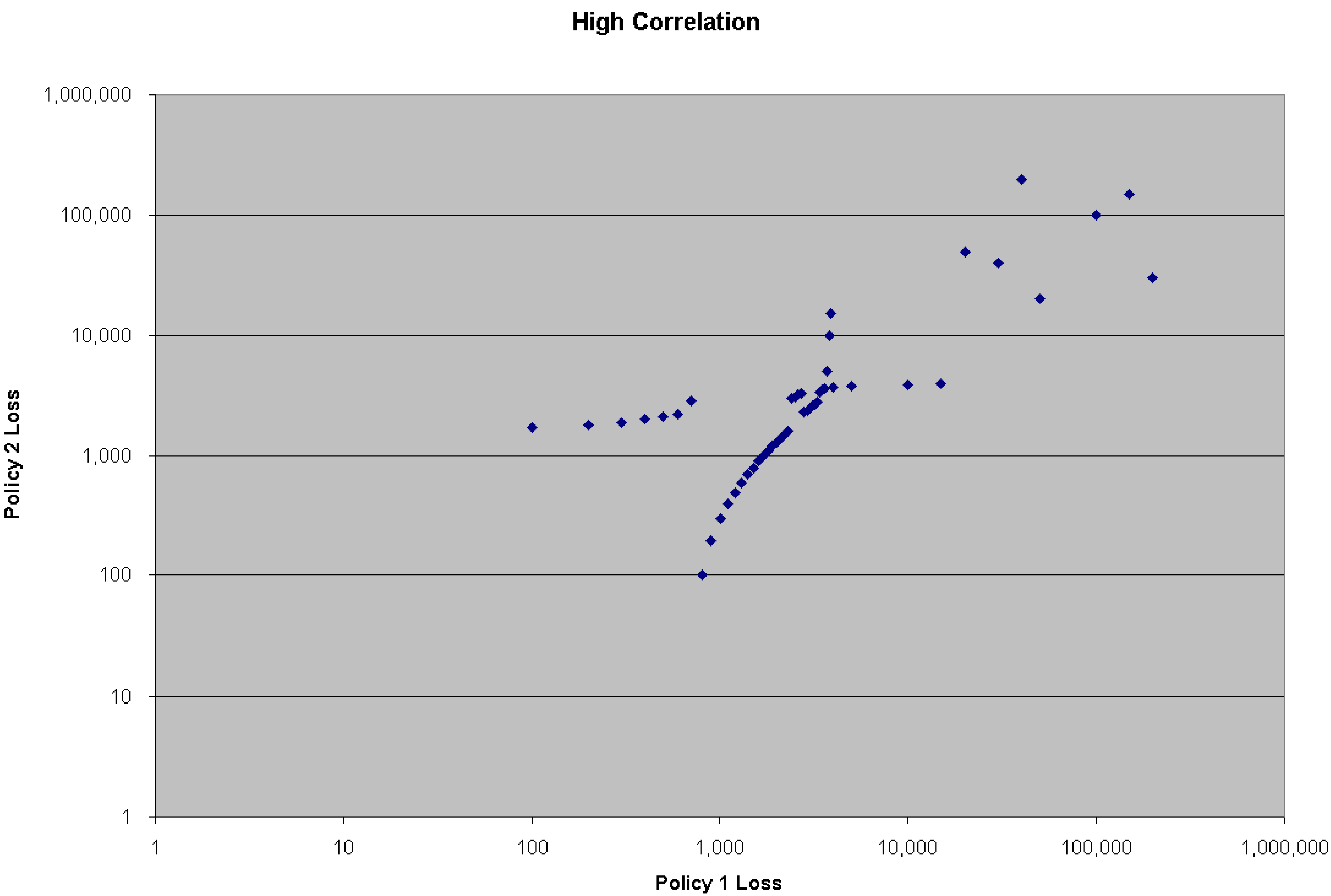

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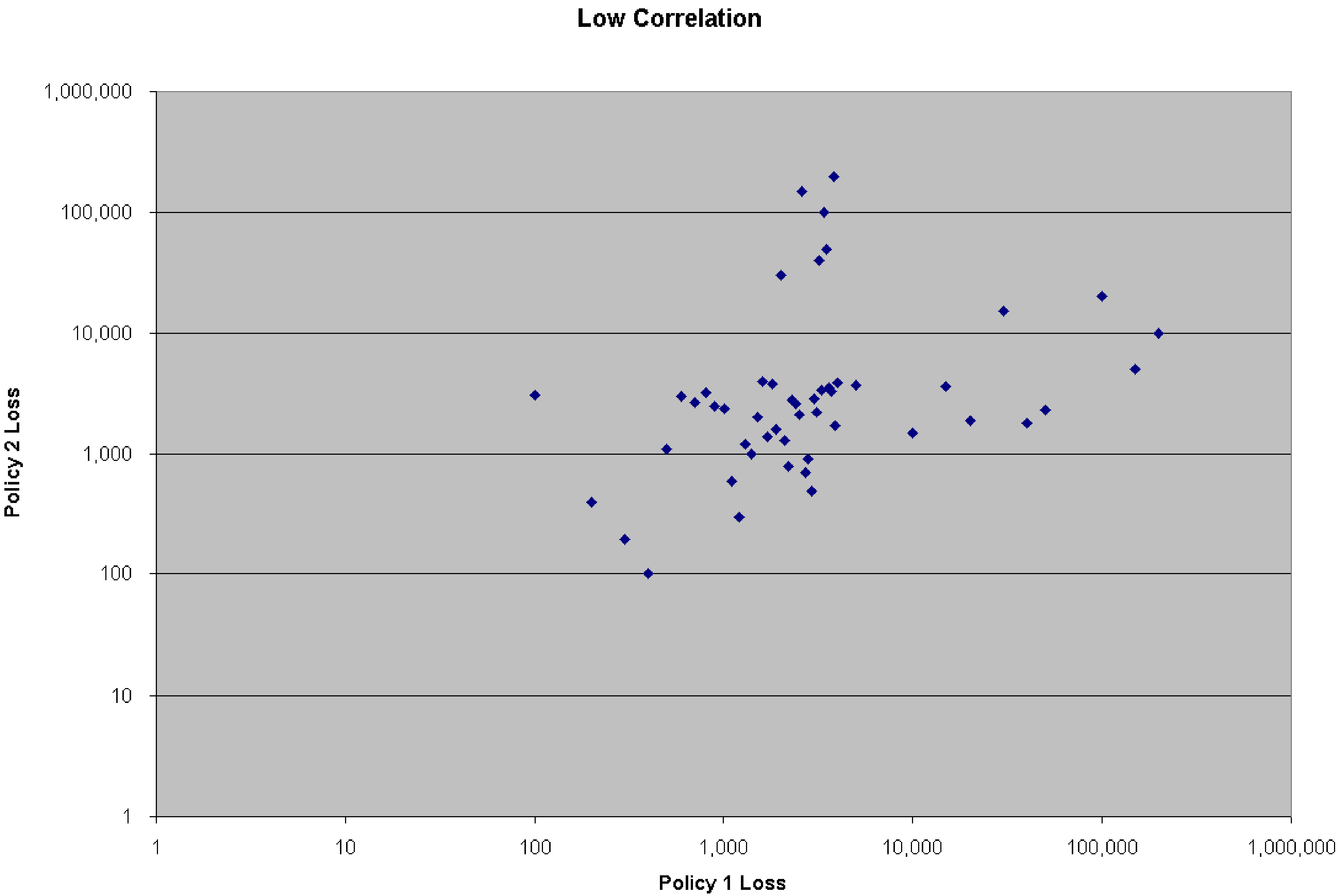

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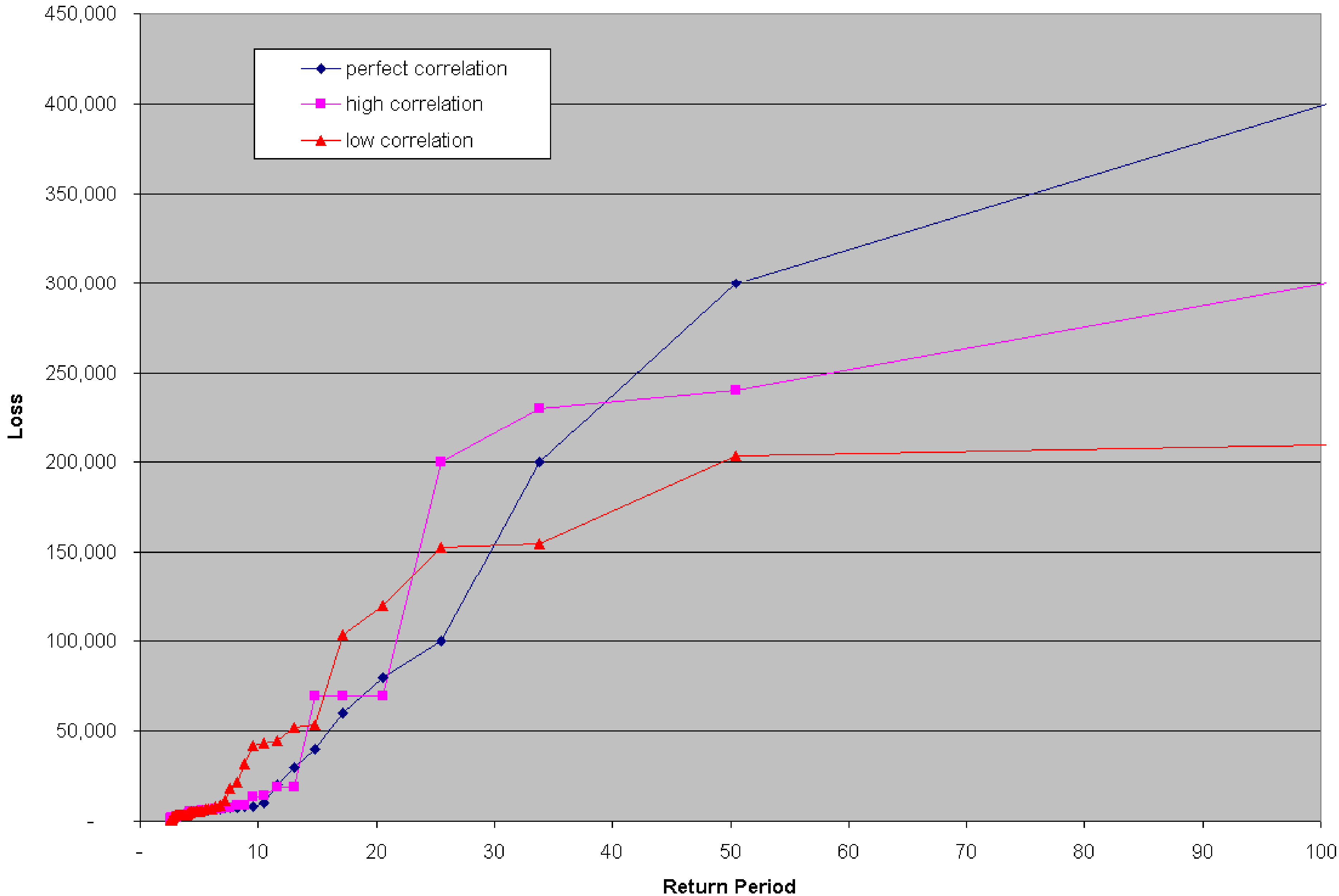
	Perfect Correlation				High Correlation				Low Correlation			
event	policy 1	policy 2	sum	sum sorted	policy 1	policy 2	sum	sum sorted	policy 1	policy 2	sum	sum sorted
1	200,000	200,000	400,000	400,000	200,000	30,000	230,000	300,000	200,000	10,000	210,000	210,000
2	150,000	150,000	300,000	300,000	150,000	150,000	300,000	240,000	150,000	5,000	155,000	203,800
3	100,000	100,000	200,000	200,000	100,000	100,000	200,000	230,000	100,000	20,000	120,000	155,000
4	50,000	50,000	100,000	100,000	50,000	20,000	70,000	200,000	50,000	2,300	52,300	152,600
5	40,000	40,000	80,000	80,000	40,000	200,000	240,000	70,000	40,000	1,800	41,800	120,000
6	30,000	30,000	60,000	60,000	30,000	40,000	70,000	70,000	30,000	15,000	45,000	103,400
7	20,000	20,000	40,000	40,000	20,000	50,000	70,000	70,000	20,000	1,900	21,900	53,500
8	15,000	15,000	30,000	30,000	15,000	4,000	19,000	19,000	15,000	3,600	18,600	52,300
9	10,000	10,000	20,000	20,000	10,000	3,900	13,900	18,900	10,000	1,500	11,500	45,000
10	5,000	5,000	10,000	10,000	5,000	3,800	8,800	13,900	5,000	3,700	8,700	43,200
11	4,000	4,000	8,000	8,000	4,000	3,700	7,700	13,800	4,000	3,900	7,900	41,800
12	3,900	3,900	7,800	7,800	3,900	15,000	18,900	8,800	3,900	1,700	5,600	32,000
13	3,800	3,800	7,600	7,600	3,800	10,000	13,800	8,700	3,800	200,000	203,800	21,900
14	3,700	3,700	7,400	7,400	3,700	5,000	8,700	7,700	3,700	3,300	7,000	18,600
15	3,600	3,600	7,200	7,200	3,600	3,600	7,200	7,200	3,600	3,500	7,100	11,500
16	3,500	3,500	7,000	7,000	3,500	3,500	7,000	7,000	3,500	50,000	53,500	8,700
17	3,400	3,400	6,800	6,800	3,400	3,400	6,800	6,800	3,400	100,000	103,400	7,900
18	3,300	3,300	6,600	6,600	3,300	2,800	6,100	6,100	3,300	3,400	6,700	7,100
19	3,200	3,200	6,400	6,400	3,200	2,700	5,900	6,000	3,200	40,000	43,200	7,000
20	3,100	3,100	6,200	6,200	3,100	2,600	5,700	5,900	3,100	2,200	5,300	6,700
21	3,000	3,000	6,000	6,000	3,000	2,500	5,500	5,800	3,000	2,900	5,900	5,900
22	2,900	2,900	5,800	5,800	2,900	2,400	5,300	5,700	2,900	500	3,400	5,600
23	2,800	2,800	5,600	5,600	2,800	2,300	5,100	5,600	2,800	900	3,700	5,600
24	2,700	2,700	5,400	5,400	2,700	3,300	6,000	5,500	2,700	700	3,400	5,600
25	2,600	2,600	5,200	5,200	2,600	3,200	5,800	5,400	2,600	150,000	152,600	5,300
26	2,500	2,500	5,000	5,000	2,500	3,100	5,600	5,300	2,500	2,100	4,600	5,100
27	2,400	2,400	4,800	4,800	2,400	3,000	5,400	5,100	2,400	2,600	5,000	5,000
28	2,300	2,300	4,600	4,600	2,300	1,600	3,900	3,900	2,300	2,800	5,100	4,600
29	2,200	2,200	4,400	4,400	2,200	1,500	3,700	3,700	2,200	800	3,000	4,000
30	2,100	2,100	4,200	4,200	2,100	1,400	3,500	3,600	2,100	1,300	3,400	3,700
31	2,000	2,000	4,000	4,000	2,000	1,300	3,300	3,500	2,000	30,000	32,000	3,600
32	1,900	1,900	3,800	3,800	1,900	1,200	3,100	3,300	1,900	1,600	3,500	3,500
33	1,800	1,800	3,600	3,600	1,800	1,100	2,900	3,100	1,800	3,800	5,600	3,500
34	1,700	1,700	3,400	3,400	1,700	1,000	2,700	2,900	1,700	1,400	3,100	3,400
35	1,600	1,600	3,200	3,200	1,600	900	2,500	2,800	1,600	4,000	5,600	3,400
36	1,500	1,500	3,000	3,000	1,500	800	2,300	2,700	1,500	2,000	3,500	3,400
37	1,400	1,400	2,800	2,800	1,400	700	2,100	2,600	1,400	1,000	2,400	3,400
38	1,300	1,300	2,600	2,600	1,300	600	1,900	2,500	1,300	1,200	2,500	3,400
39	1,200	1,200	2,400	2,400	1,200	500	1,700	2,400	1,200	300	1,500	3,400
40	1,100	1,100	2,200	2,200	1,100	400	1,500	2,300	1,100	600	1,700	3,200
41	1,000	1,000	2,000	2,000	1,000	300	1,300	2,200	1,000	2,400	3,400	3,100
42	900	900	1,800	1,800	900	200	1,100	2,100	900	2,500	3,400	3,000
43	800	800	1,600	1,600	800	100	900	2,000	800	3,200	4,000	2,500
44	700	700	1,400	1,400	700	2,900	3,600	1,900	700	2,700	3,400	2,400
45	600	600	1,200	1,200	600	2,200	2,800	1,800	600	3,000	3,600	1,700
46	500	500	1,000	1,000	500	2,100	2,600	1,700	500	1,100	1,600	1,600
47	400	400	800	800	400	2,000	2,400	1,500	400	100	500	1,500
48	300	300	600	600	300	1,900	2,200	1,300	300	200	500	600
49	200	200	400	400	200	1,800	2,000	1,100	200	400	600	500
50	100	100	200	200	100	1,700	1,800	900	100	3,100	3,200	500



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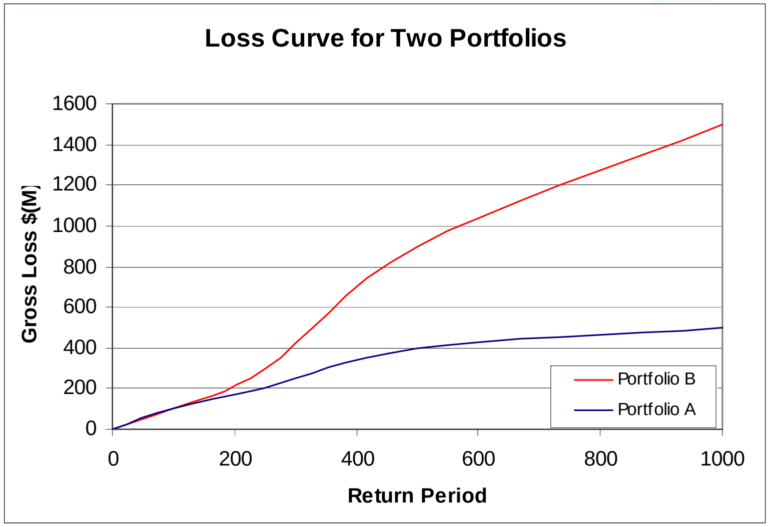
Tail Value at Risk (TVAR)

aka Tail Conditional Expectation (TCE)

- TVAR considers not only the loss level associated with an exceedance probability (sometimes called ‘probable maximum loss’ or PML), but also the shape / severity of the tail
- TVAR is the average of all losses greater than or equal to a specified exceedance probability

Why is TVAR a Better Metric?

- Consider the following example of two portfolios having the same 100 year Gross Loss:



Return Period	Portfolio A OEP Loss	Portfolio B OEP Loss
100	$100M	$100M
250	$200M	$300M
500	$400M	$900M
1000	$500M	$1.5B

Risk Measure	Portfolio A	Portfolio B
100 yr OEP	$100M	$100M
100 yr TCE	$160M	$250M

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How is TVAR Calculated?

- TVAR is equal to the return period loss plus the area underneath the exceedance curve to the right of the specified return period which can be expressed as follows:
  - TVAR= Loss at $RP_{\alpha\%}$ + Area underneath the exceedance curve to the right of $RP_{\alpha\%}$

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