Fatal Tradeoff?

Toward A Better Understanding of the Costs of Not Evacuating from a Hurricane in Landfall Counties

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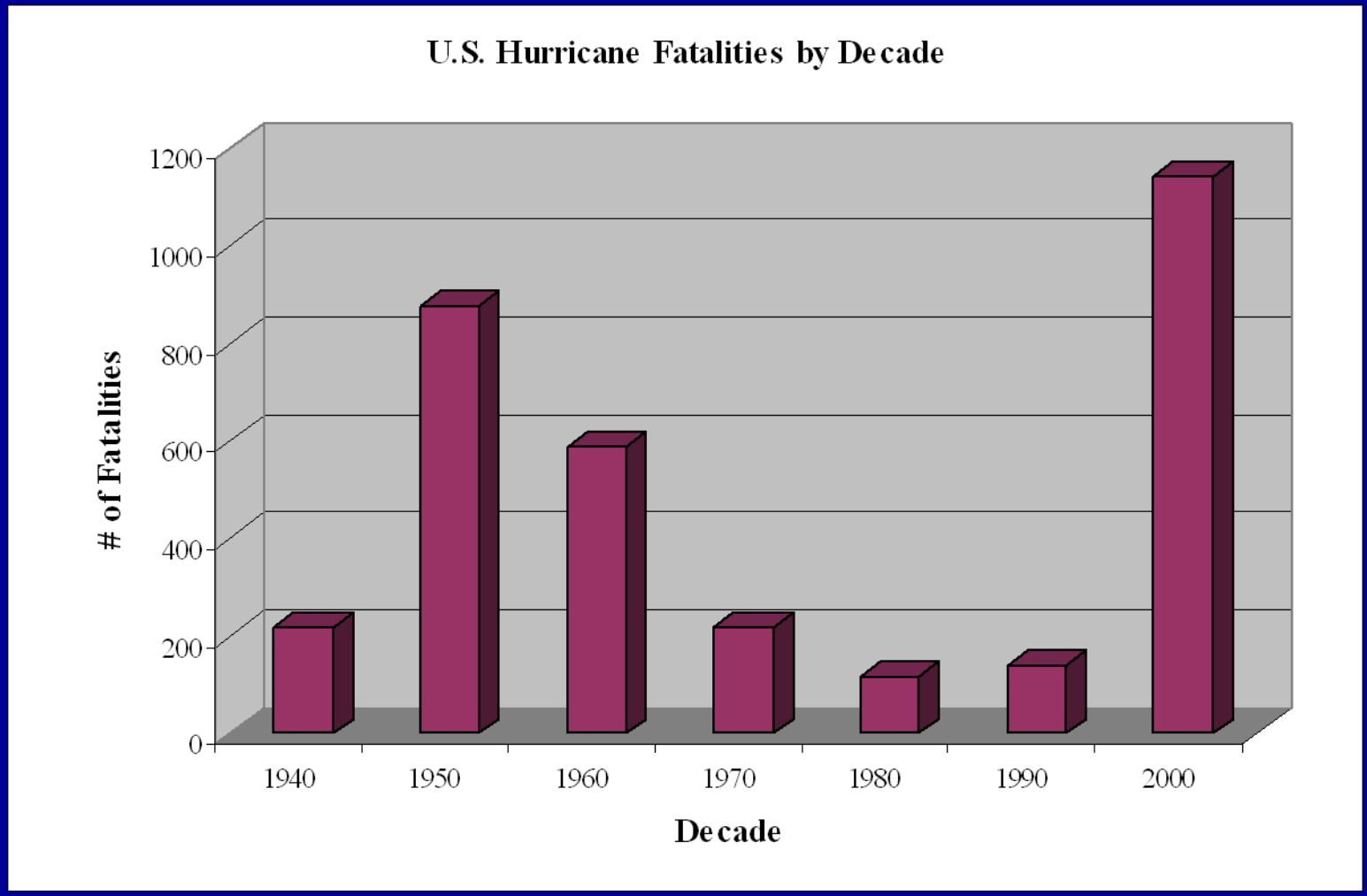
U.S. Landfall Hurricanes Less Lethal Over Time?



Source: http://www.nws.noaa.gov/om/hazstats/images/67-years.pdf

A New Reality of Hurricane Fatalities?

The "spike" from Katrina significant for at least two reasons:

1) Highlights the potential for disaster

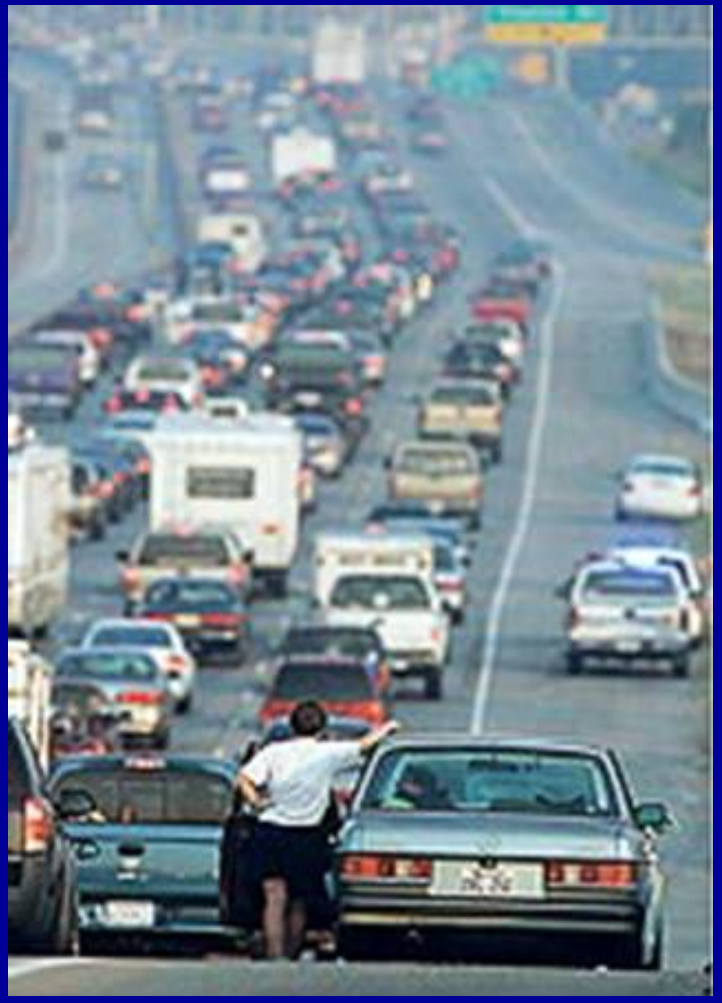
2) Underscores how perceived risk impacts mitigation => e.g., evacuation

Dynamic Model of Evacuation

For Each Forecast Period, Evacuate when:

Costs of Evacuating Now < *Expected Value of Waiting*

Hurricane Rita



Mitigation & Minimization of Fatalities

- *Requires an accurate assessment of potential hurricane-induced losses*

Texas mulls massive 'Ike Dike' to prevent flooding

"In order to justify something like this (i.e., $4 billion) … it has to be looking at protecting the entire bay, ***people's lives*** *and all the infrastructure"*

- *But what are accurate rates and what do they depend upon …?*

Rate for:	TS	Minor Hurricane	Major Hurricane
Loss of life in evacuation area	0.002%	0.02%	0.75%

(Centrec, 2007)

Vulnerability Index	Hurricane Frequency	Socio-Econ Factors	City Infrastructure	Physical Characteristics
U.S. Mainland Area	40%	20%	20%	20%

(Leatherman, 2007)

Empirically Modeling Hurricane Fatalities (1970 – 2007)

for directly or indirectly affected landfall county, *i*, landfalling hurricane, *j*, in year, *t*,

$$Fatalities_{i,j,t} = f\left(S_{j,t}, G_{i,j,t}, O_{j,t}, SE_{i,j,t}, F_{j,t}, E_{i,j,t}, T_t\right)$$

where

S = relevant storm strength

G = geographical

O = overall storm characteristics

SE = socio-economic

F = Forecasting Technology

E = Evacuation

T = Time

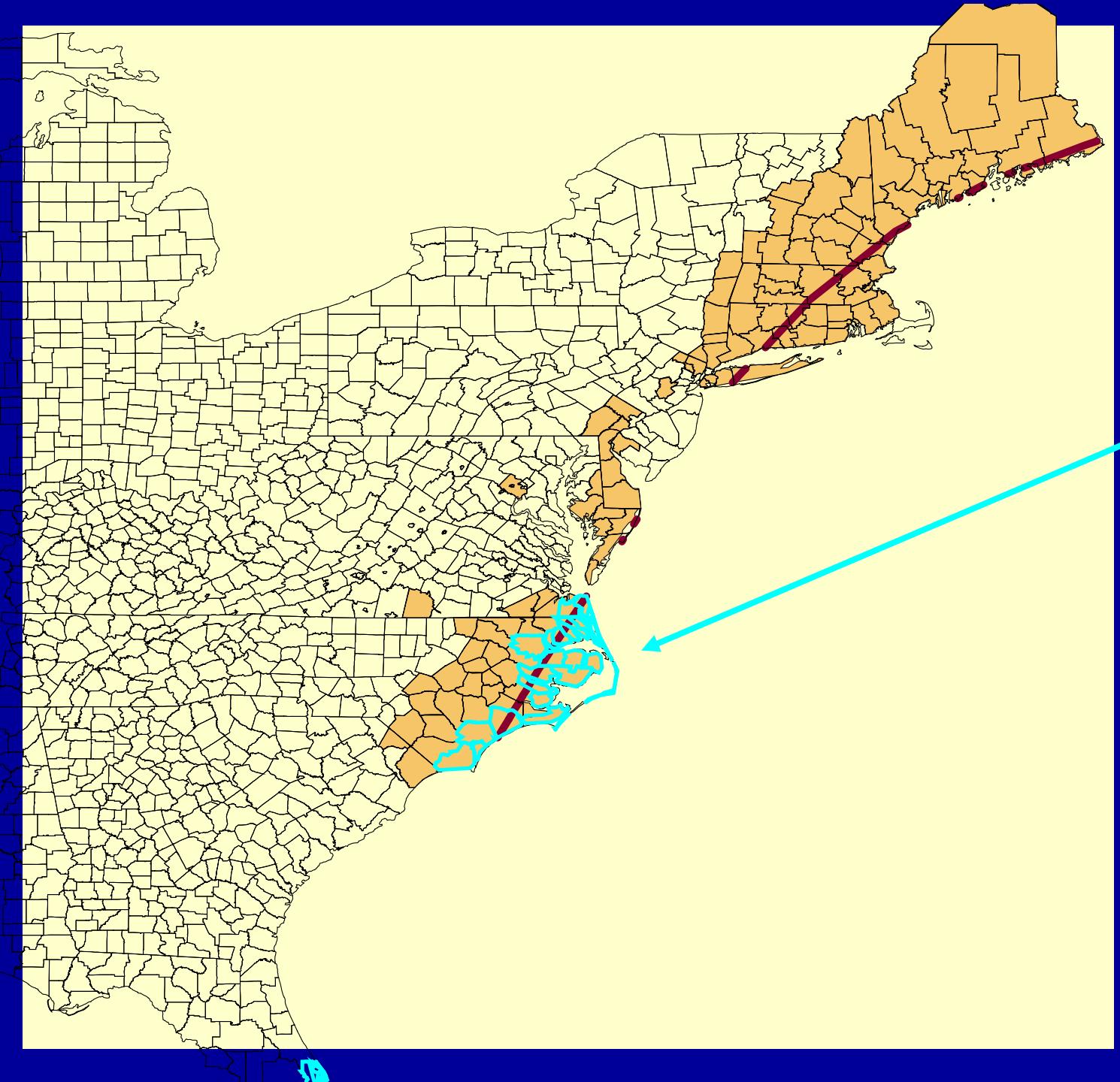
Hurricane Fatality Data Issues

- Direct vs. indirect deaths
- Coastal vs. Inland Fatalities

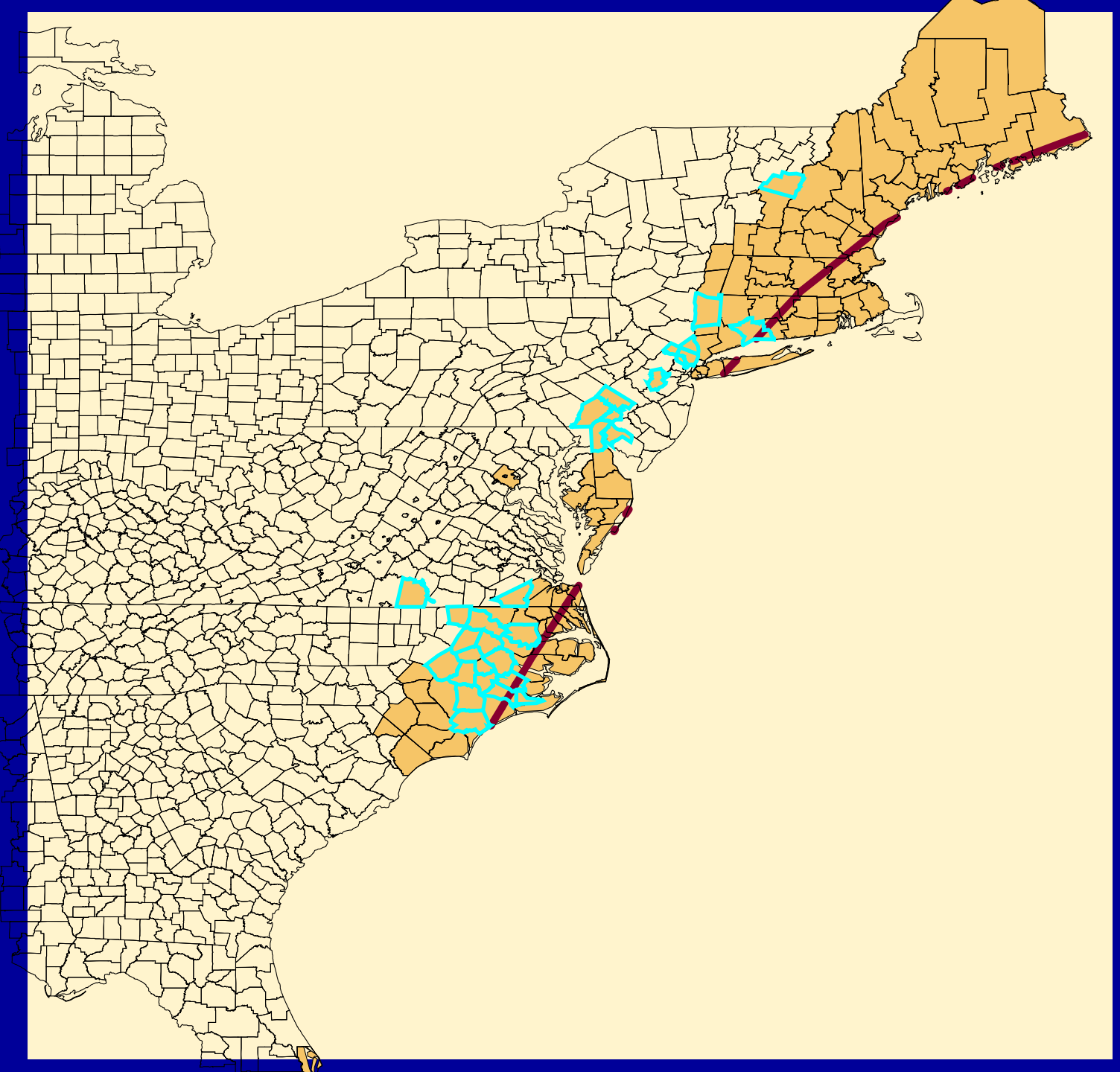
We use Rappaport (2000) as our data baseline to account for these issues

As an example from Hurricane Floyd:

- EM-DAT = **70** vs. Rappaport = **56**
- Of the 56 direct fatalities, nearly 95% occurred outside of the NHC designated directly or indirectly affected landfall counties



Floyd
Affected
Landfall
Counties



Floyd Counties Incurring Fatalities

During 1970 – 2007, *84 total fatalities* for affected landfall counties

	SSHS Category								
Decade	**0**	**1**	**2**	**3**	**4**	**5**	**Total Fatalities**	**Total # of Hurricanes**	**Fatalities Per Storm**
1970		3		12			15	12	1.3
1980		7	2	14	5		28	18	1.6
1990	3	1	5	7		15	31	17	1.8
2000 - 07	1	2		2	5		10	21	0.5
Total	4	13	7	35	10	15	84	68	1.2

- 494 county observations => 93% with zero fatality
- More fatalities in general for:
  - Stronger storms
  - Direct hit
- Excludes 1087 fatalities from Hurricane Katrina

Hurricane Fatality Data Issues (Cont'd)

- Direct vs. indirect deaths
- Coastal vs. Inland Fatalities

- Accounting for (amongst other things):
  - Evacuation
  - Mitigation
  - Improved Forecasting & Warnings

Handled through the empirical modeling

Initial Zero-Inflated Poisson Results

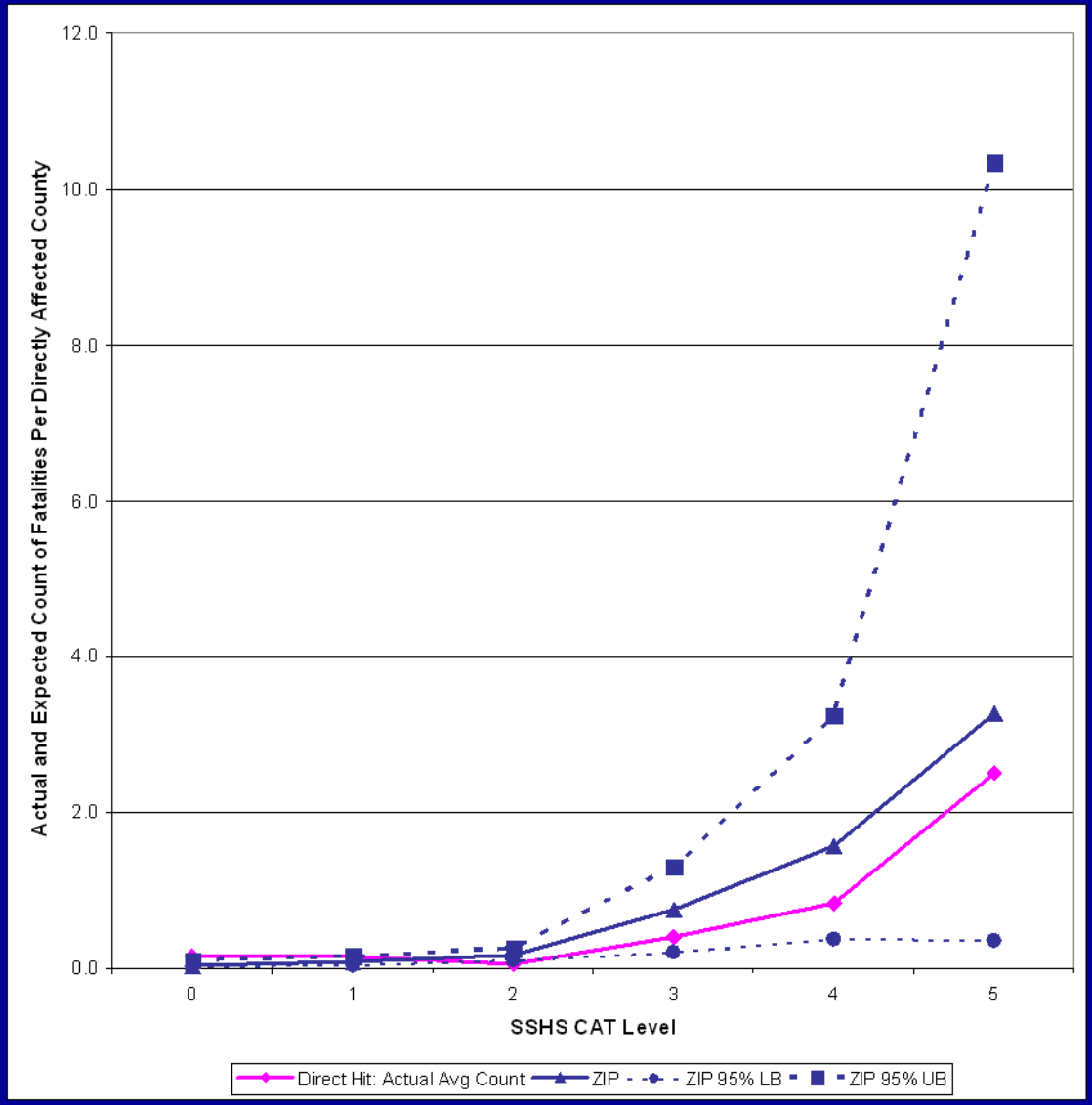
Independet Variable	***ZIP***	
Directly affected County	0.88	
	(0.62)	
SSHS	0.73	***
	(0.14)	
Population Total (000's)	0.00	***
	(0.00)	
1970 decade dummy	1.48	***
	(0.55)	
1980 decade dummy	1.25	***
	(0.46)	
1990 decade dummy	1.05	**
	(0.47)	
Constant	-3.66	***
	(0.76)	
Zero Inflated Logit		
Directly affected County	-1.07	
	(0.68)	
Major Hurricane dummy	-2.19	*
	(1.25)	
Evacuation Percentage	0.07	*
	(0.04)	
Constant	-0.65	
	(2.05)	

Indication of lower lethality over time – an outcome of improved mitigation?

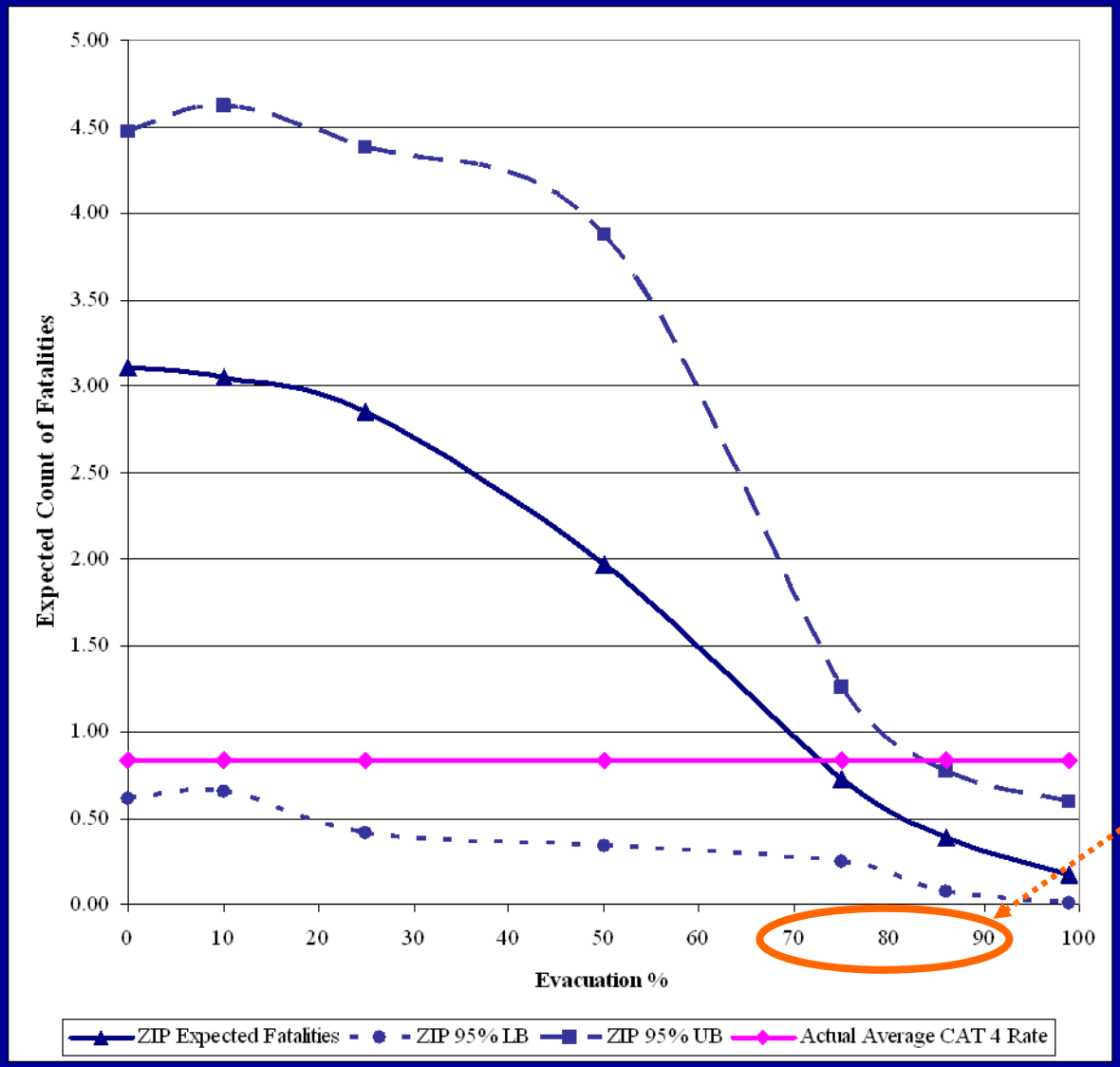
* p<.1; ** p<.05; *** p<.01

Standard errors below in parentheses

Actual vs. Predicted Average Rates of Fatality by SSHS for Directly Affected Counties



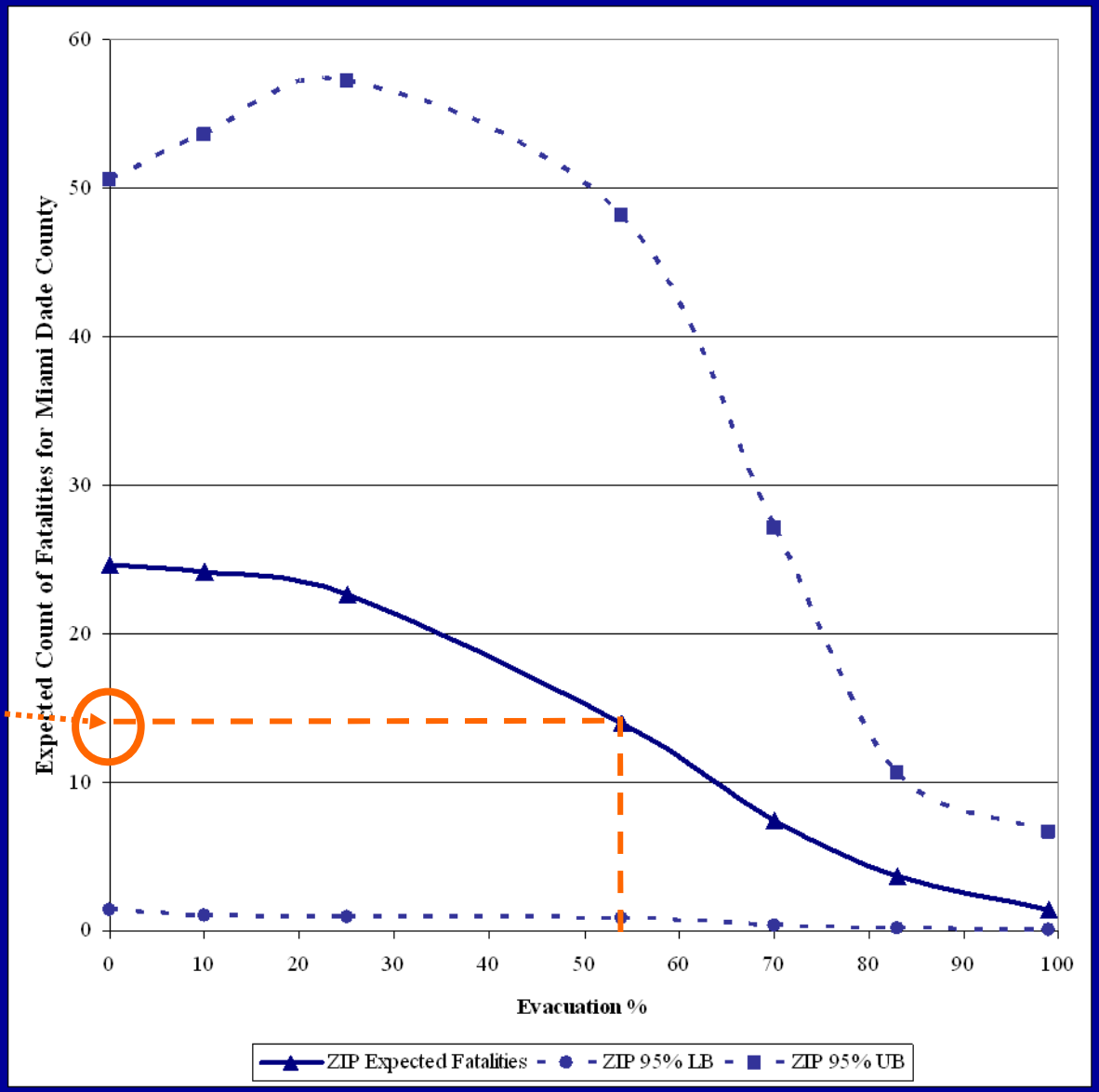
The Effect of Varying Levels of Evacuation on Expected Fatalities for a CAT 4 hurricane & 500,000 county population



CAT 4 Expected Evacuation Range

The Effect of Varying Levels of Evacuation on Expected Count of Fatalities for *Hurricane Andrew*

15 Actual vs. 13.98 Predicted



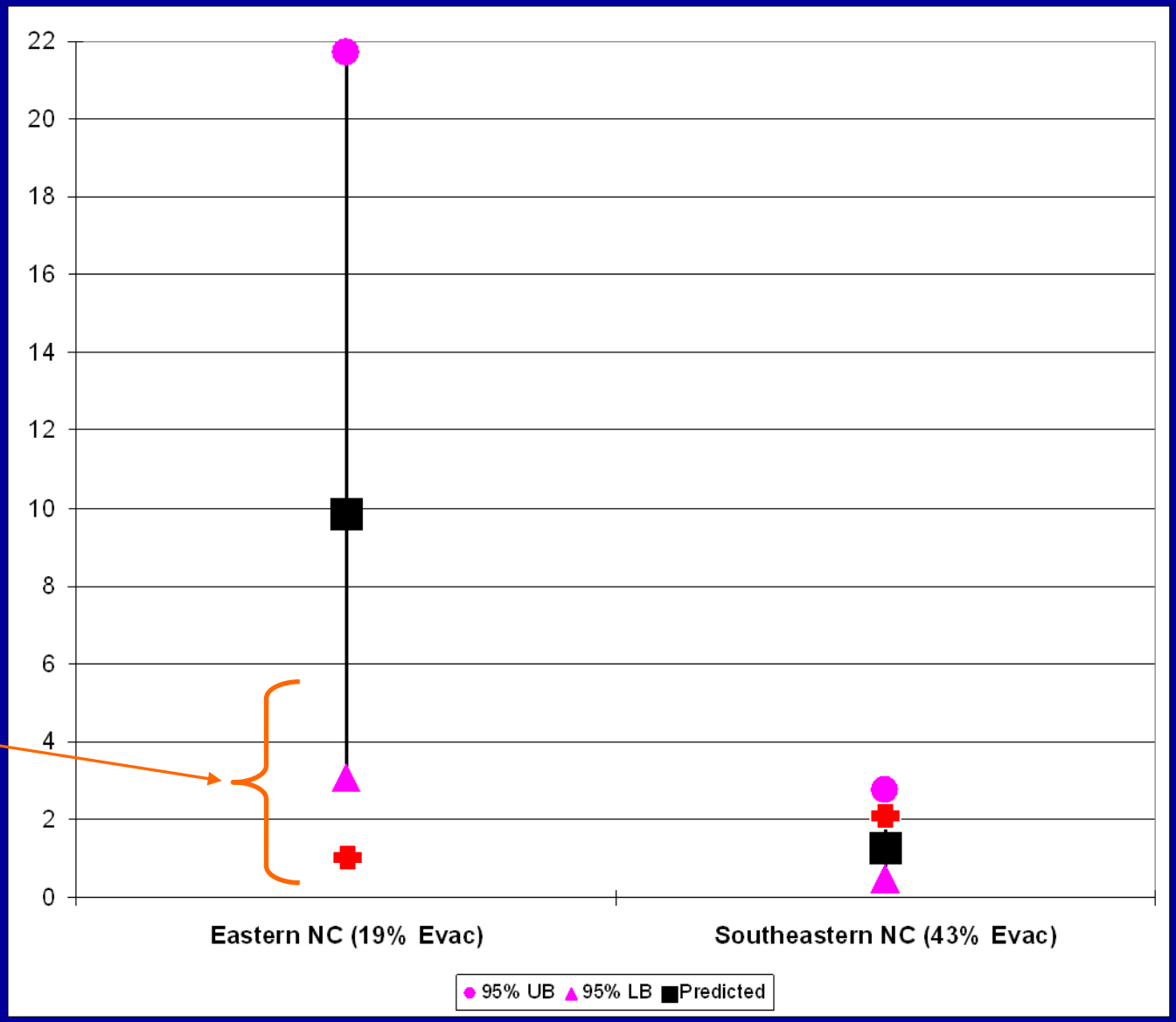
Hurricane Floyd Related Data

- Landfall at Cape Fear, NC as a CAT 2 Hurricane
- Evacuation Rates

	Coastal County Zones	
County Location	**Surge**	**Non-Surge**
Eastern NC	18-20%	15%
Southeastern NC	43-57%	30%

- County population ranging from 4,100 to 156,000
- 16 directly affected counties, 1 indirectly affected
- 3 total direct fatalities in these affected counties

Hurricane Floyd Predicted vs. Actual Fatalities



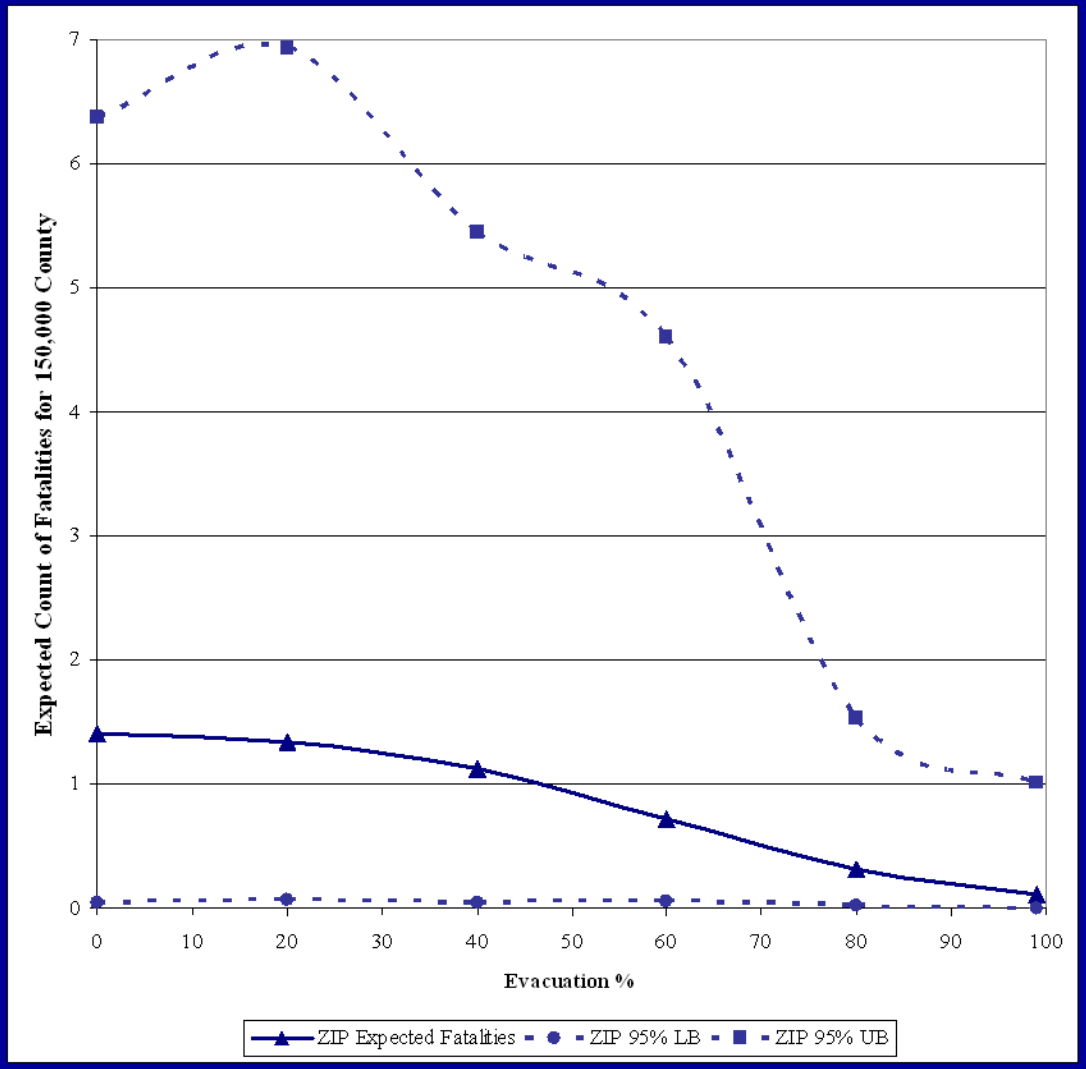
Given the low evacuation rate, model predicts a higher count of fatalities than realized

Conventional Wisdom

Geographical Considerations

Explanatory Variable	Expected Fatalities
County Landfall probability	(+)
Western & Central Gulf States	(+)
“Early” Storms	(+)
# of track observations	(-)
Median HH income	(-)
% > 65, < 18, poverty, male	(-)
Forecast track error	(-)
Forecast intensity error	(+)

CAT 4 Hurricane Directly Striking NC Coastal County Today with 150,000 population



The Prospect for Preparation

Explanatory Variable	Expected Fatalities
County Landfall probability	(+)
Western & Central Gulf States	(+)
“Early” Storms	(+)
# of track observations	(-)
Median HH income	(-)
% > 65, < 18, poverty, male	(-)
Forecast track error	(-)
Forecast intensity error	(+)

Socio-Economic Characteristics

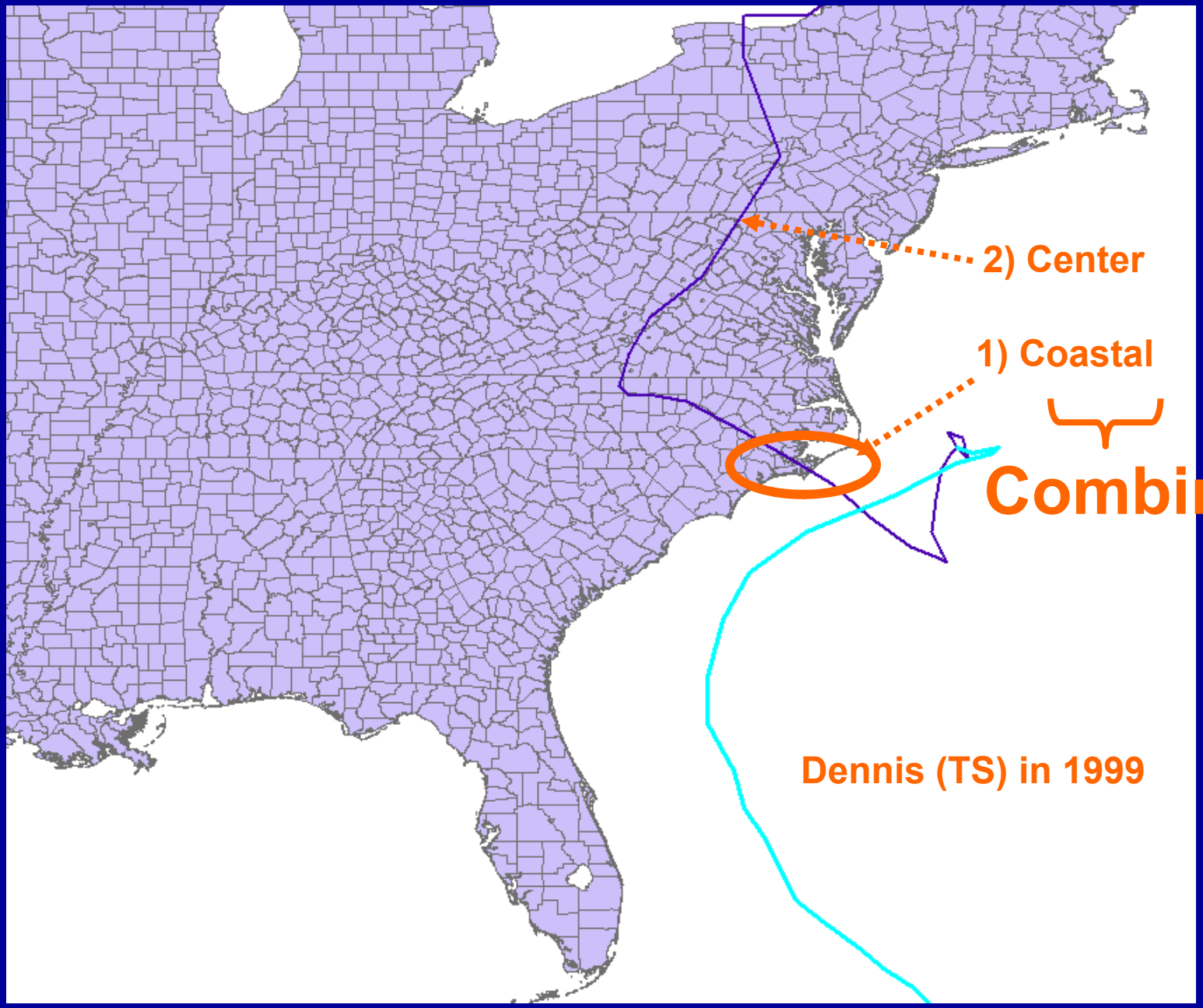
Explanatory Variable	Expected Fatalities
County Landfall probability	(+)
Western & Central Gulf States	(+)
“Early” Storms	(+)
# of track observations	(-)
Median HH income	(-)
% > 65, < 18, poverty, male	(-)
Forecast track error	(-)
Forecast intensity error	(+)

Forecasting Technology

Explanatory Variable	Expected Fatalities
County Landfall probability	(+)
Western & Central Gulf States	(+)
“Early” Storms	(+)
# of track observations	(-)
Median HH income	(-)
% > 65, < 18, poverty, male	(-)
Forecast track error	(-)
Forecast intensity error	(+)

Extending the Research

(Czajkowski, Simmons, & Sutter)

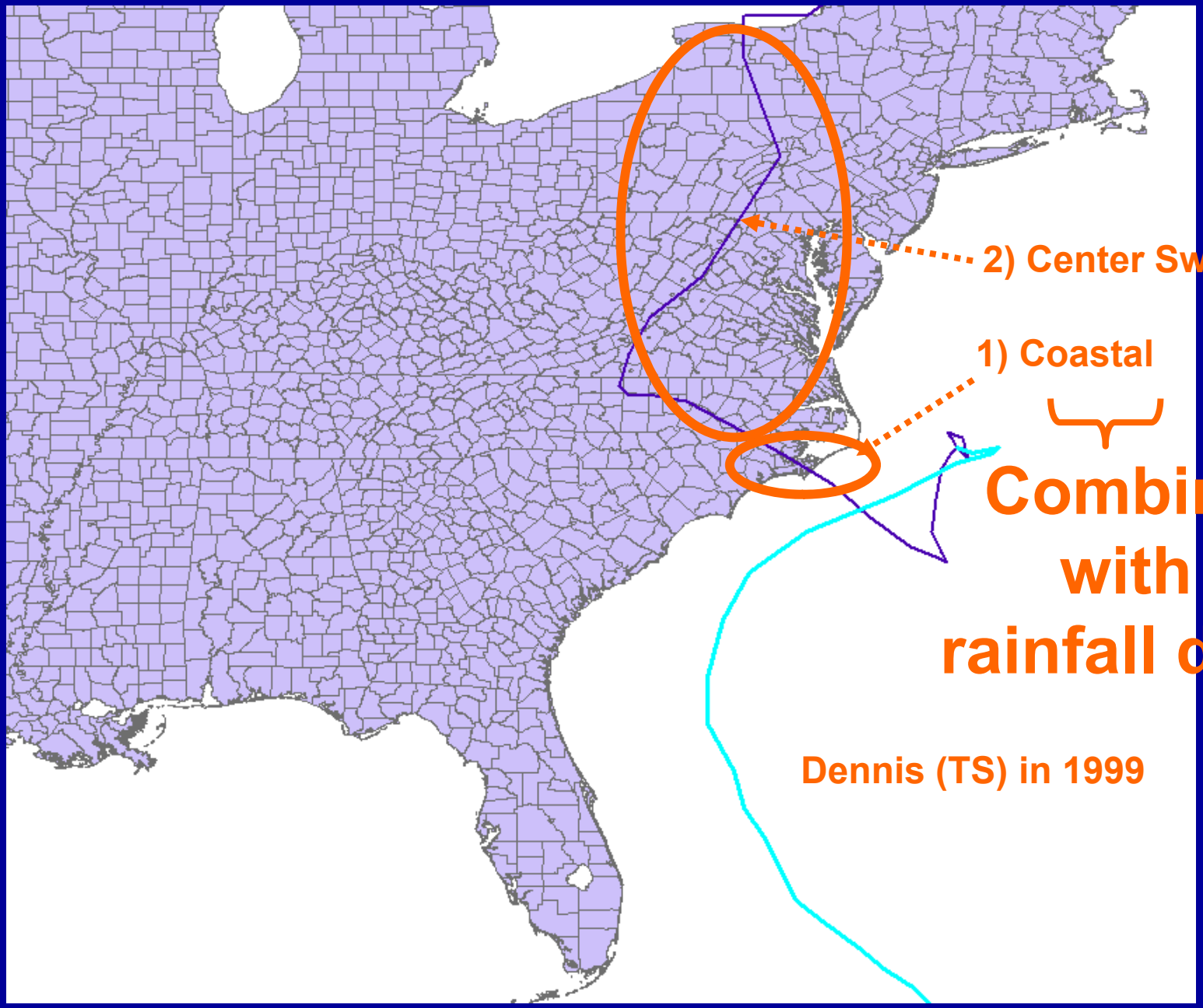

2) Center
1) Coastal
Combine
Dennis (TS) in 1999

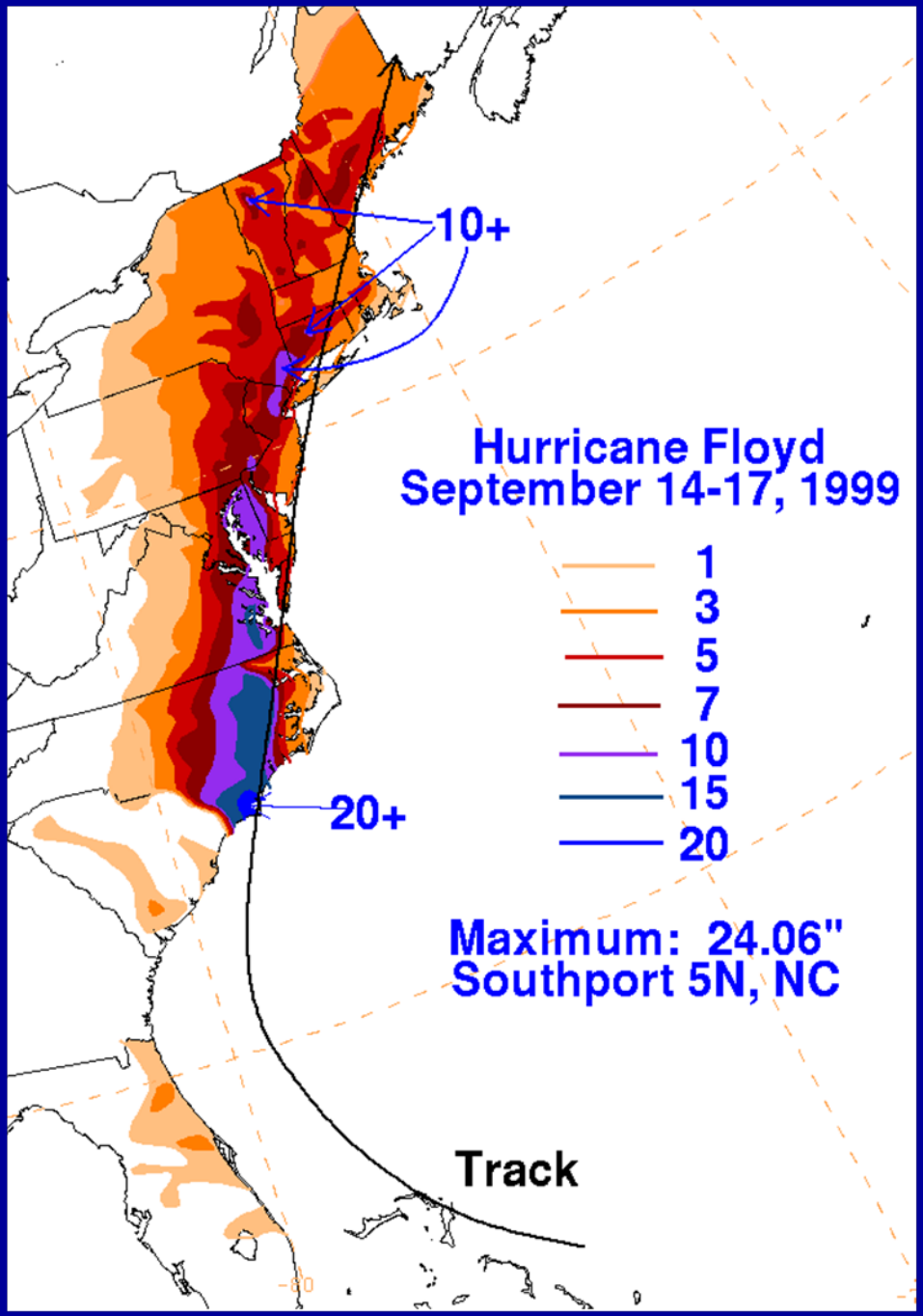
Results: Direct & Indirect coastal with center of storm inland (≈ 130 fatalities)

- No distinction of expected fatalities between
  - coastal and inland counties
  - directly and indirectly hit coastal counties
- The 2000's were actually *less lethal* => emphasis on inland flooding working?
- Storm strength

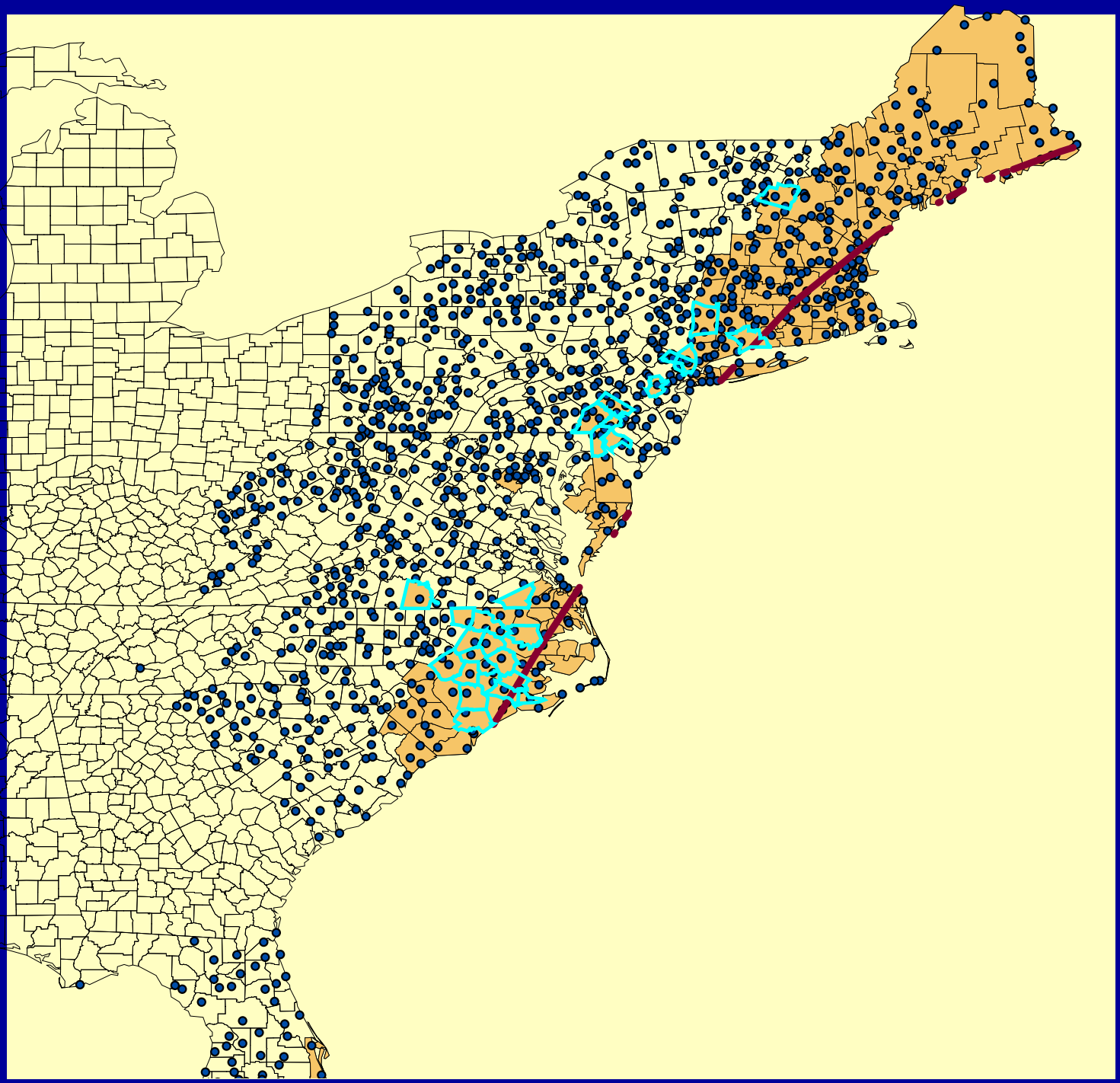
Strength	More fatalities by factor of:
TS	3.8
Minor	5.5
Major	44.3

- Storms striking overnight are more deadly
- Minor hurricanes and more evacuation lead to a higher probability of zero fatalities occurring, while being a coastal county does not


2) Center Swath
1) Coastal
Combine with rainfall data
Dennis (TS) in 1999



David Roth - Hydrometeorological Prediction Center Rainfall Data

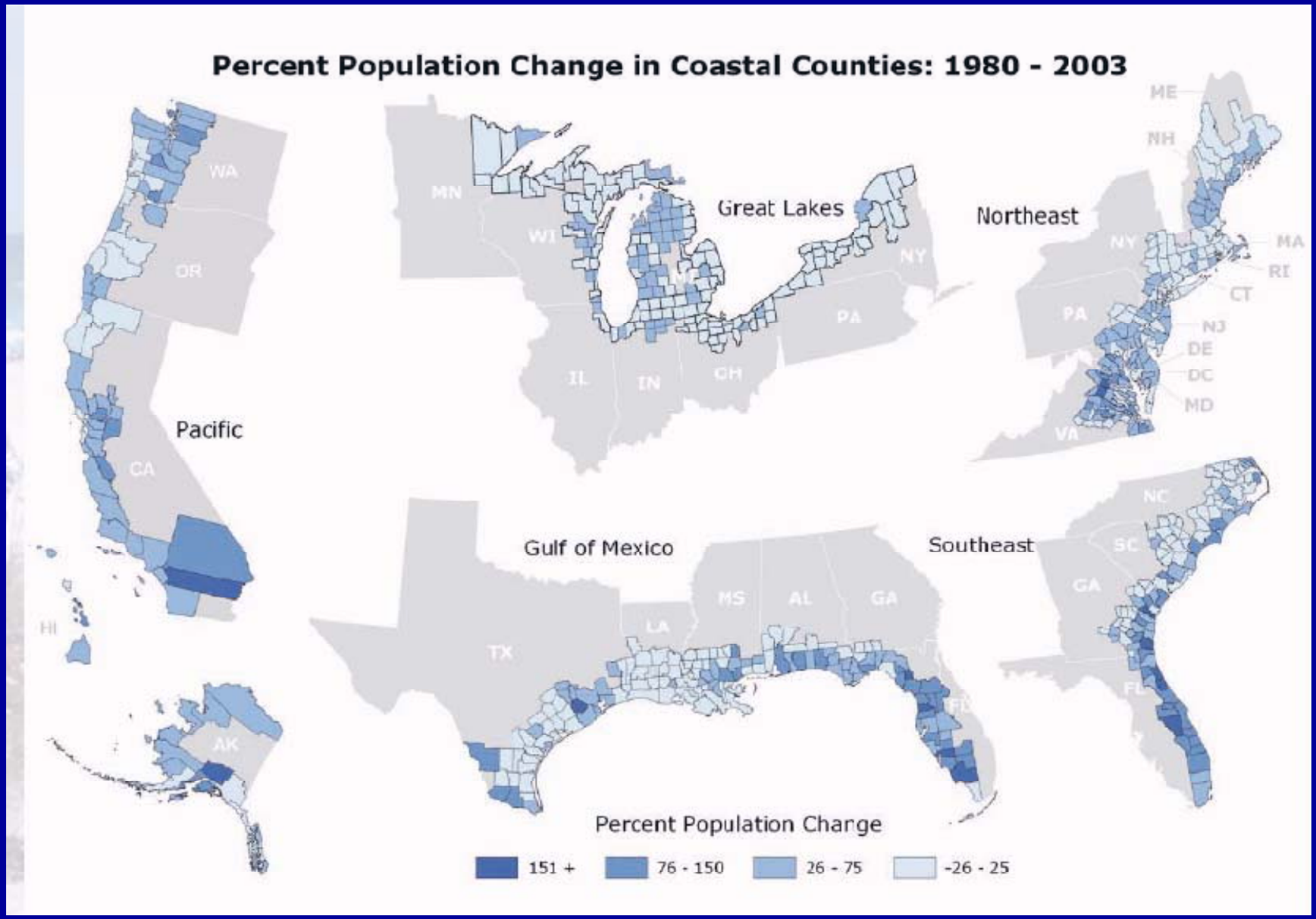


Floyd Affected Counties, Fatalities, & Rainfall data

Thank you
Questions / Comments?

Other Slides

Coastal Population Growth



Source: NOAA (2004)

Related Disaster Fatality Modeling

- Hurricanes:
  - Sadowski & Sutter (2005, 2008)
  - Perez-Maqueo, Intralawan, Martinez (2007)
  - Price (2008)
- Tornadoes, Earthquakes, Tsunamis:
  - Simmons & Sutter (2005, 2006, 2008)
  - Anbarci, Escaleras, Register (2005)
  - Escaleras, Register (2008)
- General Disasters:
  - Kahn (2005)
  - Neumayer & Plumper (2007)
  - Kellenberg & Mobarak (2008)

Fatality Data

Data for Analysis

Fatality Data:

- **Rappaport (2000)** => constructed comprehensive database of *600 total tropical cyclone* fatalities for (1970– 1999) that identified by tropical cyclone:
  - cause of death
  - county or parish of occurrence
  - strength of cyclone at landfall and at date and time of fatal incident
- Supplemented for (2000–2007) from NHC Annual Summaries of North Atlantic Storms & Tropical Cyclone Reports
- Verified vs. other fatality sources such as: EM-DAT, NCDC Events Database, Sadowski & Sutter (2008), etc.

Associated Storms:

68 *hurricanes* from 1970 – 2007 * which *affected the continental U.S.* as per Blake et al. (2007) & Pielke et al. (2006)

Decade	Total Fatalities*	Fatalities per landfalling Hurricane*
1970	187	15.6
1980	82	4.6
1990	154	9.1
2000-07	98	4.7
Total	521	7.7

(*Excludes 1507 deaths associated with Katrina)

Data for Analysis

Decade	TS	1	2	3	4	5	Total Fatalities*	Fatalities per landfalling Hurricane*
1970		135	5	47			187	15.6
1980	3	30	4	28	17		82	4.6
1990	14	8	78	31		23	154	9.1
2000-07	8	13	22	45	10		98	4.7
Total	25	186	109	151	27	23	521	7.7

(*Excludes 1507 deaths associated with Katrina)

Data Comparison – vs. EM-Dat, etc

Year	Hurricane	Region of Landfall	Intensity @ Landfall	Rappaport	NHC	S&S	EmDat
1980	Allen	1	3	5	2	2	0
1985	Danny	2	1	2	1	2	0
1985	Elena	3	3	2	4	0	4
1985	Gloria	9	2	8	8	11	11
1985	Juan	3	1	9	12	12	12
1985	Kate	4	2	4	5	6	5
1989	Chantal	2	1	13	13	13	
1989	Hugo	8	4	17	21	21	51
1989	Jerry	1	1	3	3	3	2
1993	Emily	6	3	3	3	2	1
1995	Erin	7	1	3	3	3	11
1995	Opal	3	3	9	9	9	19
1996	Bertha	8	2	6	7	8	
1996	Fran	8	3	19	26	34	39
1998	Bonnie	8	2	2	3	3	2
1998	Earl	4	1	3	3	3	
1998	Georges	6	2	1	1	1	4
1999	Dennis	8	2	4	4	4	3
1999	Floyd	8	2	56	56	56	70
	Total			**170**	**184**	**193**	**234**

Distribution of Affected Counties by Count of Fatality and SSHS

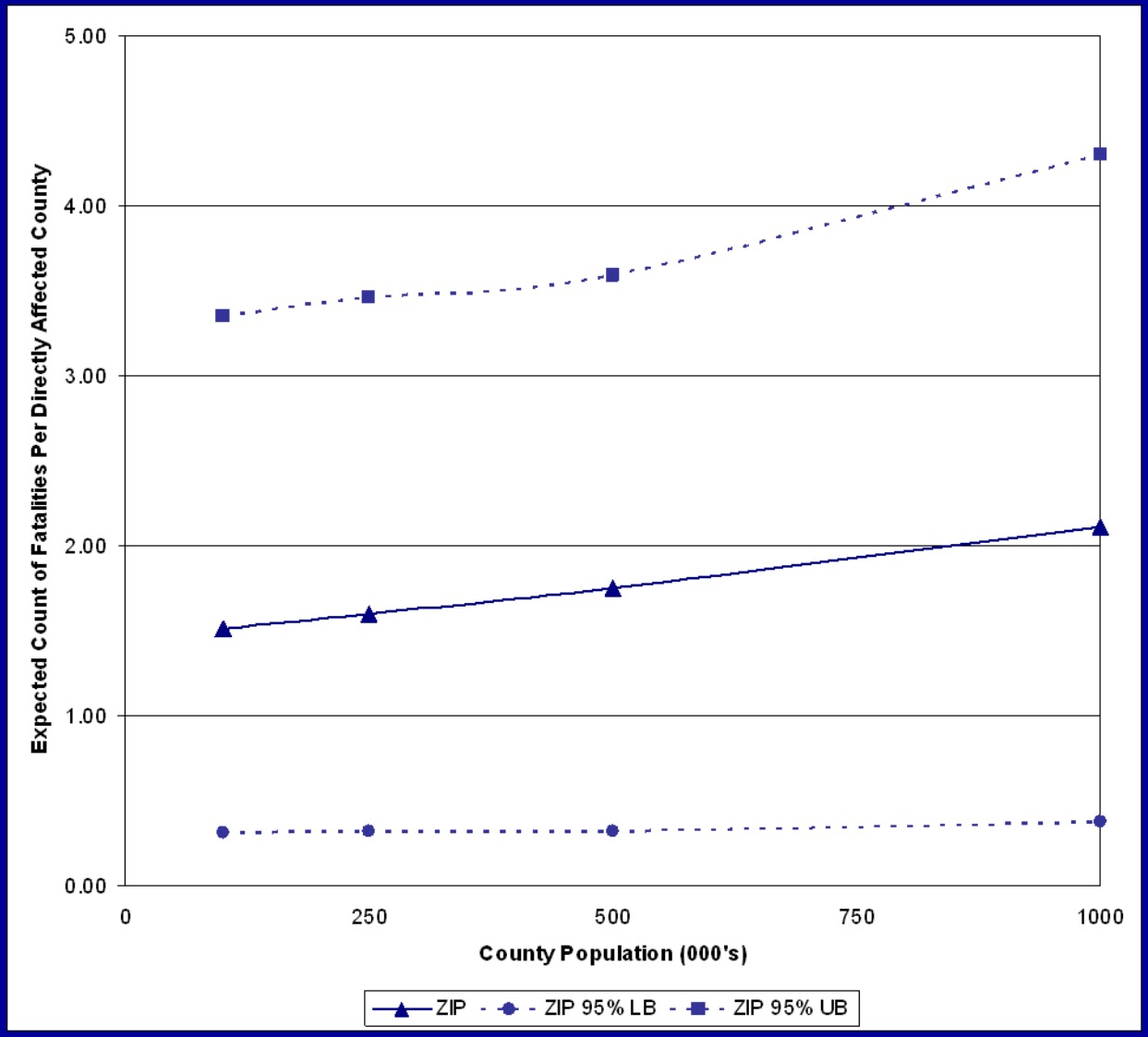
	SSHS Category						
Count of Fatality	**0**	**1**	**2**	**3**	**4**	**5**	**Total # of Affected Counties by Count**
0	38	96	129	172	10	10	455
1	2	10	3	8	1		24
2	1		2	4			7
3		1		1			2
4					1		1
5				2	1		3
6				1			1
15						1	1
Total Affected Counties by SSHS	41	107	134	188	13	11	494
Avg Fatalities per Affected County Per storm	0.10	0.12	0.05	0.19	0.77	1.36	

Distribution of Directly (D) & Indirectly (I) Affected Counties by Count of Fatality and SSHS

	SSHS Category												
	0		1		2		3		4		5		
Count of Fatality	D	I	D	I	D	I	D	I	D	I	D	I	Total # of Affected Counties
0	23	15	65	31	85	44	65	107	9	1	5	5	455
1	2		8	2	2	1	6	2	1				24
2	1				1	1	3	1					7
3			1				1						2
4									1				1
5							2		1				3
6							1						1
15											1		1
													494

Fatality Modeling

The Effect of Varying Levels of Population on Expected Fatalities for a CAT 4 hurricane



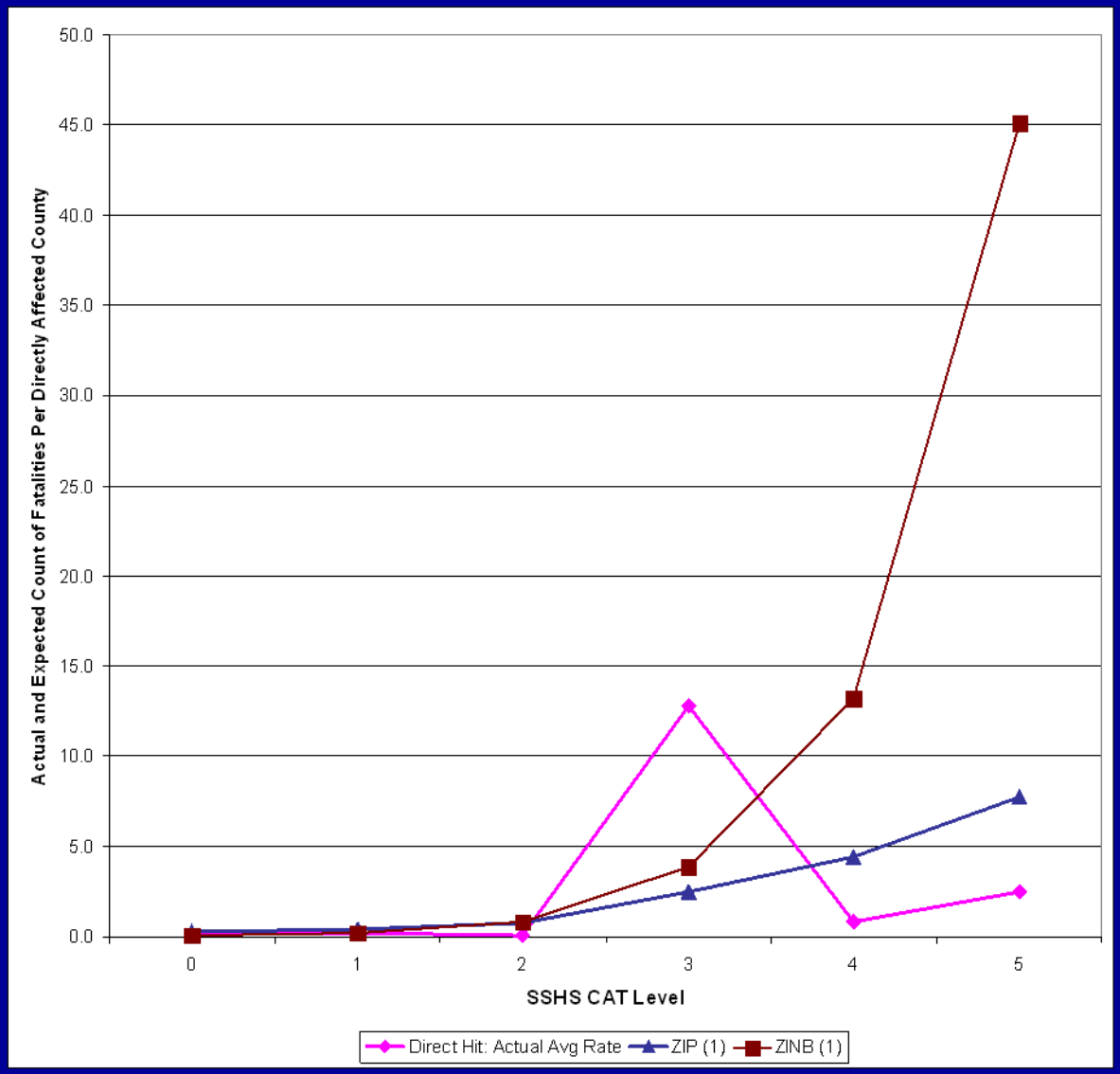
Hurricane Katrina Results

Independet Variable	***ZIP (1)***		***ZINB (1))***		***ZIP (2)***		***ZINB (2)***	
Directly Affected County	0.56		1.51	**	0.85	**	1.57	*
	(0.48)		(0.76)		(0.35)		(0.83)	
SSHS	0.56	**	1.23	***	0.52	***	0.97	**
	(0.26)		(0.40)		(0.18)		(0.39)	
Population Total (000's)	0.00		0.00		0.00		0.00	
	(0.00)		(0.00)		(0.00)		(0.00)	
1970 decade dummy	-3.21	***	-2.27	***	-1.82	***	-1.08	*
	(0.67)		(0.58)		(0.62)		(0.6)	
1980 decade dummy	-3.33	***	-1.86	***	-1.78	***	-0.83	
	(0.77)		(0.69)		(0.57)		(0.63)	
1990 decade dummy	-3.37	***	-1.81	***	-1.77	***	-0.9	
	(0.88)		(0.68)		(0.58)		(0.6)	
Constant	1.96	**	-2.72	***	0.54		-3.27	***
	(0.77)		(0.79)		(0.75)		(0.88)	
Zero Inflated Logit								
Directly affected County	-1.68	***	-1.82	*	-1.42	***	-1.24	
	(0.47)		(0.95)		(0.47)		(0.87)	
Major Hurricane dummy	-1.43	**	-5.09	**	-1.25	**	-4.13	*
	(0.59)		(2.52)		(0.58)		(2.19)	
Evacuation Percentage	0.02	*	0.15	**	0.02		0.12	**
	(0.01)		(0.07)		(0.01)		(0.06)	
Constant	2.96	***	-4.76		2.8	***	-4.16	
	(0.61)		(3.48)		(0.64)		(3.3)	
N	511		511		504		504	
Log pseudo-likelihood	-1758.5		-265.0		-398.6		-219.2	
LR chi-squared(α) ^			2987.0	***			358.8	***
Wald chi2	56.4		56.0		33.0		52.4	
McFadden's R2	0.38		0.12		0.30		0.10	
AIC	3539.0		554.0		819.2		462.4	
BIC	3585.6		604.8		865.6		513.0	

* p<.1; ** p<.05; *** p<.01

Robust standard errors are below coefficient estimates in parentheses
Models (1) includes fatality data from LA, MS, AL & FL
Models (2) include fatality data from MS, AL, & FL
^ Test statistic based upon default standard errors in STATA 9.2

Actual vs. Predicted Average Rates of Fatality by SSHS for Directly Affected Counties (including Hurricane Katrina Data)



The Effect of Varying Levels of Evacuation on Expected Count of Fatalities for *Hurricane Andrew* (including Hurricane Katrina data)