

Increasing Population Vulnerability to Hurricane Damage on the U.S. Gulf Coast, 1950 to 2009

John R. Logan¹ and Zengwang Xu²

Abstract

The societal impacts of natural disasters depend on the location of human settlements and the social vulnerability of populations at risk. We study hurricane risk on the U.S. Gulf Coast during 1950-2005, estimating the spatial extent of wind damage from every hurricane in this extended period. These estimates are calculated using the HURRECON model, based on the known path and wind speeds of individual storms and calibrated to fit actual damage reports for a sample of Gulf Coast storms. The estimates are analyzed in combination with population data, categorized by age, race, and poverty status, to determine how the settlement pattern in the Gulf region has shifted over time in relation to the cumulative risk of hurricane damage in the period. We provide evidence that despite continued coastal development and population growth, settlement has tended to shift away from higher risk zones. But the more vulnerable population groups – the elderly, African Americans, and poor – have shifted in the opposite direction, which we interpret as a cautionary sign of diminished capacity for resilience to disaster.

¹ Department of Sociology, Box 1916, Brown University, Providence, RI 02912, USA

² Department of Geography, University of Wisconsin - Milwaukee, Milwaukee, WI 53211 USA

Corresponding author: John R. Logan, Department of Sociology, Box 1916, Brown University, Providence, RI 02912. Phone 401-863-2267. Fax 401-863-3213. John_logan@brown.edu.

Acknowledgements: This research was supported by National Science Foundation through grant CMMI-0624088. Rima Wahab Twibell provided research assistance on application and validation of damage models with supervision by Steve Hamburg. Emory Boose provided technical advice on the application of HURRECON. Timmons Roberts, Michael White, Andrew Foster, Osvaldo Sala, and David Foster offered comments on the manuscript.

Keywords: Disaster, Vulnerability, Resilience, Risk assessment

In the United States, major hurricanes have caused more damage to human society and ecosystems than any other natural disasters (Pielke et al 2008; Pielke and Landsea 1998). Efforts to understand the impacts of hurricanes from the perspective of ecological systems are rooted in the concept of resilience (Folke 2006; Holling 1973). Adger et al (2005) summarize the mainstream theory. Natural hazards are endemic to coastal zones, but biodiversity, functional redundancy, and spatial heterogeneity confer a capacity to recover from catastrophic damage. Ecosystems are resilient, referring to their capacity “to absorb recurrent disturbances such as hurricanes or floods so as to retain essential structures, processes, and feedbacks” (2005, p. 1036).

Though many social scientists are wary of adopting ecological theory directly or by analogy, what Tierney, Lindell, and Perry (2001) call the classic sociological paradigm of disasters also presumes that there would be an automatic return to equilibrium in the society following disaster. A key concern in social systems, however, is that not all population groups and local communities can be expected to be equally resilient (Dash, Peacock and Morrow 1997, Peacock and Girard 1997, Smith et al 2006). Consequently a major focus of social science research on disasters has been the phenomenon of differential vulnerability. This is our subject, and we approach it through the study of hurricane risk on the United States Gulf Coast in the period 1950-2009.

We begin by reviewing the key concepts of locational and social vulnerability and summarizing the well developed literature on which population groups are understood to be vulnerable. The following section lays out our research design, which requires estimating the spatial extent of wind damage from all hurricanes on the Gulf Coast in the period 1950-2006 and linking those estimates with information on the resident population of those areas. We introduce an existing meteorological model that we adapted to the Gulf Coast and parameterized on the basis of newspaper reports of actual damage from a sample of hurricanes. This allows us to present maps of the cumulative risk of damage at various levels of intensity for the full period. It is then straightforward to identify the population size and composition of areas with more or less risk and to chart its change from 1950 through 2005. Finally we take advantage of damage estimates from Hurricanes Katrina and Rita in 2005 to determine the population impacts of these extraordinary events over the subsequent four years.

Locational and social vulnerability

Our research requires that we distinguish two dimensions of the potential harm that human populations face from hurricanes. The first is their risk by virtue of their residential location (broadly related to their proximity to the coast), which we refer to as **locational vulnerability**. The second is their capacity to deal with disaster, which we call **social vulnerability**. This dichotomy is well established in the literature on vulnerability, although there was a tendency for early writing from the perspective of the risk-hazard (RH) paradigm to think of hazards as exogenous and accidental agents and to underplay the social production of risk (Kates 1985; Burton et al 1978). Chambers (1989, p. 1; see also Hewitt 1997) defined vulnerability as having “two sides: an external side of risks, shocks and stress to which an individual or household is subject; and an internal side which is defencelessness, meaning a lack of means to cope without damaging loss.” The complementarity of these two dimensions is at the core of the pressure-and-release (PAR) model that has guided much of the research on this topic (Blaikie et al 1994). This formulation has led many scholars to the view that disasters, at

least in the distribution of their consequences (Mileti 1999; Moore et al 2004) and perhaps also in their production (Watts and Bohle 1993), are manmade.

Cutter (1996) emphasized the location of risk with her notion of the hazards of place, which takes into account both the biophysical risk of a given location and the social response that a given place or categories of people within it can mount. In a more recent review Cutter, Boruff, and Shirley (2003, p. 243) argue that the vulnerability of a place to harm depends on both the physical risks of the location and the social factors related to age, race and poverty that “shape the susceptibility of various groups to harm and that also govern their ability to respond.” Further, they identify a set of factors that influence social vulnerability: “lack of access to resources (including information, knowledge, and technology); limited access to political power and representation; social capital, including social networks and connections; beliefs and customs; building stock and age; frail and physically limited individuals; and type and density of infrastructure and lifelines” (p. 244).

Turner et al (2003, p. 8074) put forward a similar view, asserting that research has demonstrated that “vulnerability is registered not by exposure to hazards (perturbations and stresses) alone but also resides in the sensitivity and resilience of the system experiencing such hazards.” Further, they also argue for a place-based approach: “The strong variation in vulnerability by location, even to hazards created by global-scale processes and phenomena ... elevates the role of ‘place-based’ analysis. The term ‘place based’ implies a spatially continuous distinctive ‘ensemble’ of human and biophysical conditions or coupled human–environment systems” (p. 8076).

This emphasis on location is also found in a series of studies that seek to describe the spatial distribution of risks using historical data or future projections, based on data on climate, demography, or both. Dilley et al (2005) attempt to create a global ranking at a high level of spatial resolution for exposure of people and of economic production for six major natural hazards: earthquakes, volcanoes, landslides, floods, drought, and cyclones using data from 1980 through 2001. Ciscara et al (2011) offer projections of the costs in terms of human health and economic loss of climate change in Europe through 2080, making no assumptions about human adaptation of climate change during the period. McDonald et al (2011) analyze access to freshwater in cities of the developing world, looking at both the impacts of anticipated urban growth (which they find to be the larger factor) and climate change on the number of people with inadequate access within their urban area.

Who is vulnerable?

The vulnerability perspective draws upon and extends studies of spatial differentiation in urban and rural landscapes that have documented persistent racial residential segregation (Massey and Denton 1993) and concentration of poverty (Jargowski 1997), as well as limited residential mobility of older, poorer, and minority households (South and Crowder 1997). It incorporates findings about which social groups are most likely to be exposed to biophysical risk (locational vulnerability) as well as estimates of which groups are least capable of dealing effectively with disaster. Mcgranahan, Balk and Anderson (2007, p. 20) clearly have both aspects in mind: “On the one hand, affluent settlements and groups are in a better position to take protective measures and to adapt or escape when flooding does occur (as media coverage and research on hurricane Katrina and New Orleans amply demonstrated). On the other hand, the poorest residents of the cities of low-income countries are often forced (implicitly or explicitly)

to settle in flood plains or other hazard-prone locations, as they cannot afford more suitable alternatives.”

Though much research on locational disparities has focused on urban neighborhoods (Wilson 1987), similar issues arise in less densely populated settings (Lobao 2004). Scholars have probed various dimensions of unequal exposure to environmental risk (Bullard 1990; Bullard 1993), with particular interest in their community health impacts (Pastor, Sadd et al. 2001). Earlier work has demonstrated that measures of social capital are correlated with the likelihood of being proximate to certain hazardous sites and other indicators of neighborhood well-being (Diez-Roux 1997; Sampson, Morenoff et al 1999; Buka et al 2002; Morenoff 2003). Bolin (2006), drawing on the literature on environmental health, argues that the processes of marginalization, which could take many forms, result in inequalities in exposure to hazards and access to opportunities. Blacks were most heavily impacted by Hurricane Katrina (Logan 2008), in large part because historically they were segregated into low-lying areas known to be vulnerable to flooding (Colten 2005). These studies support the theory that routine processes of urban and rural development create cumulative disadvantages for many residents, constituting a stratification of places (Logan and Molotch 1987) that reinforces other dimensions of social inequality.

With respect to capacity for resilience, Cutler, Boruff and Shirley (2003, p. 244) claim “there is a general consensus within the social science community about some of the major factors that influence social vulnerability... Among the generally accepted are age, gender, race, and socioeconomic status.” Cochrane (1975) argues that lower income groups consistently bear a disproportionate share of the losses, even if they are not more likely to be placed in the path of disaster. They receive, in most instances, the smallest proportion of disaster relief; they are the least likely to be insured (for health, life or property); and they live in dwellings which are of the poorest construction and most subject to damage. Dash et al (1997) in their study of Hurricane Andrew concluded that housing, job, business, and tax revenue losses were proportionately greater in the minority community. Smith et al (2006), in their analysis of the same event, argue that the wealthy (for whom insurance and self-protection is most affordable) returned quickly to their prior locations. Middle income households, on the other hand, moved away to avoid risk, and were replaced by lower income households attracted by declining rents.

Aside from disparities in the immediate impacts of disaster, there may be differences in communities’ ability to command attention in the process of recovery. Bolin and Stanford (1998) find no evidence in the Northridge earthquake in Los Angeles that lower income households were over-represented in the victim pool; in this case, general exposure cut across race, ethnicity and class. But while relief efforts were focused on middle-class homeowners, 80% of the damage in that earthquake was sustained by multifamily and low-rent rental housing (Wu and Lindell 2004). Many believe that pre-disaster inequalities are inevitably reproduced during recovery. According to Tierney et al (2001, pp. 149-150), the classic view was that a disaster minimizes conflicts and divisions originating prior to the disaster event, and that the political system would mobilize at all levels to support recovery (Dynes 1970). The current view (Peacock et al 1997, see also Freudenburg 1997) is that the process of responding to a natural disaster occurs within an inherently competitive and conflictual atmosphere in which individuals, families, and communities compete for scarce resources.

Peacock and Girard (1997, p. 188), in their study of Hurricane Andrew, concluded that prior inequalities were exacerbated by the inequalities inherent in the market-based recovery

process itself. A series of obstacles built into the urban social structure place certain neighborhoods and households at substantially higher risk after disaster. Dash, Peacock, and Morrow (1997) found that a poorer community is less able than its more affluent counterpart to manage recovery efforts in the post-disaster period because of lack of experienced administrators and organizational deficits. Morrow and Peacock (1997) add a stronger political element to this analysis, pointing to policies by local governments to delay investing in affordable housing while landlords and real estate developers took advantage of opportunities to upgrade existing housing to higher rent levels. These observations support the “continuity principle” enunciated by Tierney et al. (2001) or Vale and Campanella’s (2005) idea of “the inertia of urban resilience.” Disasters disrupt the social order but they do not obliterate it, and while disasters may accelerate pre-disaster trends they rarely reverse them.

Research design: estimating locational vulnerability

We seek to identify how locational vulnerability to hurricanes has evolved since the mid-20th Century and to determine whether groups considered to be socially vulnerable are particularly exposed to risk. Within the 56-year period of study we treat hurricane risk as a constant, although recent research on Atlantic tropic cyclone activity (Mann et al 2009) and global mean temperature (Emanuel 2005) suggests a long-term trend of increasing frequency and intensity. In the near term it is more difficult to discern trends. There is a random component to where, when, and with what intensity hurricanes actually occur. To smooth out the random events we aggregate damage from all storms in the period and treat the result as a single spatial profile of hurricane risk for the region making the assumption that the experience of 56 years provides a reasonable reflection of the underlying pattern. The analysis includes 320 counties within 200 miles from the coastline in an area from Texas through the Florida Panhandle. The results presented here are based on all 43 hurricane-strength storms in the period 1950-2005; similar results are found in analyses including all 93 tropical storms.

On the population side we take advantage of time series data to track population movements. We begin with the spatial distribution of population and trace it decade by decade through 2000. Then, in order to capture the impact of Hurricanes Katrina and Rita in 2005 we provide annual population estimates for 2000-2009. Hence we can discover not only who is in the path of storms in general, but how that pattern may have shifted over several decades. Data through 2000 are from decennial censuses; subsequent data are annual population estimates made by the Census Bureau and poverty figures from the American Community Survey. The measures used here are at the county level: race (comparing whites to blacks), age (comparing young adults aged 20-34 to people of retirement age 65 and above), and social class (comparing people above and below the official poverty line).

For only a few recent storms are there detailed records of what areas were damaged and to what extent. Therefore in the first phase of this research our task was to reconstruct for the first time estimates of the land area that was affected by every hurricane, the gradient from higher to lower intensity of wind, and the implied level of damage on the ground. This is a major undertaking. The available data maintained by NOAA are the hurricane track records that can be represented as a series of line segments. For example Figure 1 shows that path of Hurricane Camille, an H5 hurricane in 1969. The line segments with windspeeds are the input data for our analysis. The figure displays our final estimates of the spatial pattern of wind speeds experienced in the affected area, identifying zones where wind speeds were at the F0 through F4 level.

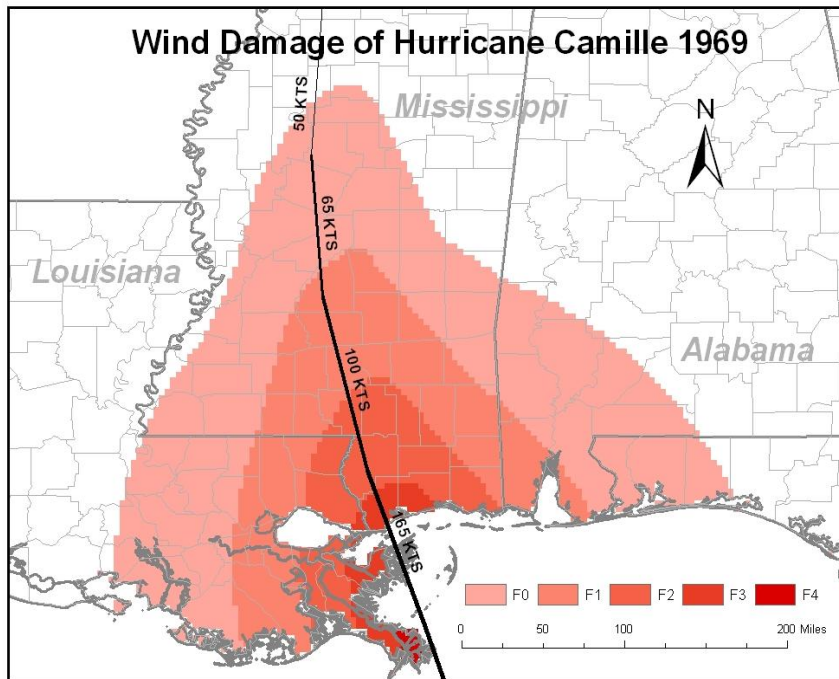


Figure 1 Given the known path and wind speeds of a hurricane, the purpose of modeling is to estimate the intensity and spatial extent of wind damage in terms of the widely used Fujita scale. Shown here are known parameters and estimated wind damage for Hurricane Camille 1969.

Results: the spatial extent of wind damage

To make comparable estimates for every hurricane in the period we apply a meteorological model (HURRECON) that has been parameterized and applied to the analysis of the Great New England Hurricane in 1938 and Hurricane Hugo in Puerto Rico as well as numerous other storms (Boose, Chamberlin, and Foster 2001; Boose, Serrano and Foster 2004). Although the wind velocity and direction in a hurricane is very dynamic, analysis of the aerial reconnaissance transects data for many hurricanes reveals common macro-structures in hurricane wind fields (Boose, Foster and Fluet 1994; Neumann 1987; Vickery, Skerlj, and Twisdale 2000). These common structures include: (1) in the northern hemisphere, wind rotates around the hurricane center in a counter clock wise direction as the hurricane eye moves along the track; and (2) wind velocity increases from the eye outward until reaching its maximum at the hurricane eye wall and then decaying exponentially.

HURRECON models the shape and extent of the hurricane's surface wind field (sustained wind speed, peak gust speed, and wind direction) based on meteorological data (location of the eye and intensity at every six hours along the track) and surface type (land or water). It requires setting two parameters that describe how the wind velocity and direction change with the radial distance away from the hurricane eye to the eyewall and beyond. These are the Radius of Maximum Wind (RMW, or the size of the hurricane eyewall), and a wind profile exponent b . These two parameters together describe how the wind velocity and direction change with the radial distance away from the hurricane eye to the eyewall and outward (Figure

2). Wind damage can also be affected by landscape factors such as elevation and topography and by characteristics of the built environment (such as quality of housing construction) that are not taken into account by this model.

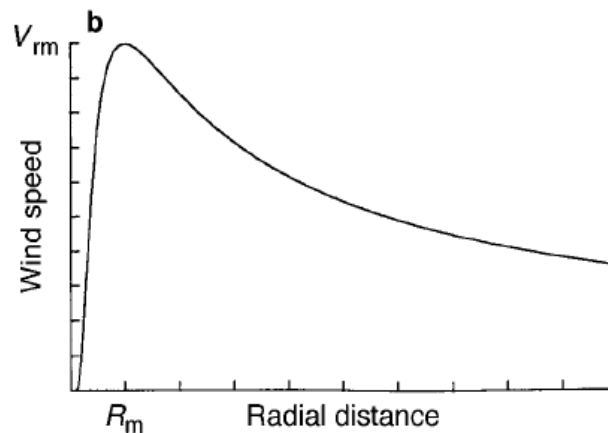


Figure 2 The estimated wind speed at a given location is a function of the distance to the storm center. The function is characterized by the Radius of Maximum Wind (RMW) and the wind speed decay exponent, b . RMW could be measured through aerial reconnaissance and b could be measured from weather station or aerial reconnaissance transects, but these are most often not available and must be estimated.

Because HURRECON has not been applied in the Gulf region, additional research was required in order to select appropriate parameters. To calibrate the model we collected data on 20 hurricanes in three states (Table 1) selected to represent cases with varying intensity from H1 to H5 on the Saffir/Simpson scale. Local newspapers across Texas, Louisiana, and Mississippi were reviewed for the week of each hurricane that passed near their area of coverage and reports of damage were collected and coded for damage level on the Fujita scale (Fujita 1971, 1987). For example, it was reported in the *Daily Corinthian* (Corinth, MS) on 8/19/69 that “the destructive force of Camille was felt this far inland as this tree in City Park was the victim of high winds and heavy rain which moved to this end of the state.” The damage was coded on the Fujita scale (Table 2) as F0 at this location. We obtained a total of 1276 damage reports (including some reports coded as no damage). Damage reports from nine hurricanes were used to select the model parameters that provided the best fit between reported and estimated damage. Five measures of fit were used (for example the average correlation between estimated and observed damage at the county level for the validation hurricanes is 0.68). The best fitting model choice is based on a composite of all five measures. Reports from the remaining eleven hurricanes were used to verify the selected parameters (for example, the average correlation of estimated and observed damage for the verification hurricanes is 0.59; discounting two hurricanes with a perfect match but observations in only four counties the average correlation is 0.50). The model was then applied uniformly to all 43 hurricanes in the period.

Hurricane	Year	Landfall State	Intensity at Landfall	Impact States	Wind Damage Reports
Calibration sample:					
Baker	1950	AL	H1	Alabama	32
Betsy	1965	LA	H4	Louisiana/Mississippi	65
Camille	1969	MS	H5	Mississippi/ Louisiana/ Alabama	178
Erin	1995	FL	H1	FL Panhandle/Alabama/Mississippi	53
Opal	1995	FL	H3	FL Panhandle/ Alabama	147
Georges	1998	MS	H2	Mississippi/Alabama	72
Lili	2002	LA	H1	Louisiana/Mississippi	43
Ivan	2004	AL	H3	Alabama	100
Katrina	2005	LA	H3	Louisiana/Mississippi/Alabama	128
Verification sample:					
Hilda	1964	LA	H2	Louisiana	15
Beulah	1967	TX	H5	Texas	28
Eloise	1975	FL	H3	FL Panhandle/Alabama	80
Frederic	1979	AL	H4	Alabama/Mississippi	156
Alicia	1983	TX	H3	Texas	21
Elena	1985	MS	H3	Mississippi/ Louisiana/ Alabama	63
Kate	1985	FL	H2	Florida	6
Danny	1985	LA	H1	Louisiana	11
Chantal	1989	TX	H1	Texas	7
Claudette	2003	TX	H1	Texas	12
Dennis	2005	FL	H3	FL Panhandle/Alabama	59

Table 1 Hurricanes selected for gathering of damage reports for calibration and verification of the HURRECON model

To reduce the effect of random error in measurement and spatial location for the newspaper reports, we created a measure of the maximum reported damage in every county in the following way. Damage reports were converted to a continuous damage surface using Kriging interpolation, which was overlaid with counties, and the maximum damage from this surface was used as the measure for the county. For hurricanes without enough damage reports to support such interpolation, we simply assigned the maximum reported damage to each county and made no estimate for neighboring counties.

	Fujita Rating				
Measure	F0 damage	F1 damage	F2 damage	F3 damage	F4 damage
Trees	Leaves and fruits off, branches broken, trees damaged	Trees blown down, broken or uprooted	Extensive blown down, large trees snapped, uprooted or broken	Most trees down, uprooted (if supported by comparable damage to	Tree uprooted and carried some distance
Crops	Damaged or blown down				
Buildings (unspecified)	Minor damage (some damage to chimneys, awnings, TV antennas, roof shingles, and windows)	Unroofed or damaged	Blown down or destroyed	50% or more blown down or destroyed (in the town)	
Masonry buildings	Minor damage (some damage to chimneys, awnings, TV antennas, roof shingles, and windows)	Roof peeled, windows broken, chimneys down, loss of awnings	Unroofed	Blown down or destroyed	Well constructed houses leveled. Structures with weak foundations blown away some distance
Wood houses	Minor damage (some damage to chimneys, awnings, TV antennas, roof shingles, and windows)	Roof peeled, windows broken, chimneys down, loss of awnings	Unroofed or destroyed	3+ blown down or destroyed- whole subdivision	Well constructed houses leveled. Structures with weak foundations blown away some distance
Mobile Homes		mobile homes pushed off foundations or overturned	mobile homes demolished		
Barns, cottages, churches, town halls	Minor damage	Unroofed, steeple blown down	Blown down or destroyed		
Carports, Cabins, shacks, sheds, outbuildings, warehouses, huts	minor damage	unroofed, blown down or destroyed			
Furniture, bedding, clothes	Not moved	Blown down			
Masonry (brick or block) walls, radio towers	No damage	Blown down			
Utility poles	Wires down	Poles damaged or blown down			
Signs, traffic signs, fences, billboards	Some damage	Blown down			
Autos	No damage	Moving autos pushed off road	Stationary autos moved or pushed over	Heavy autos lifted and thrown	Cars thrown
Trains	No damage	Pushed along tracks	Boxcars pushed over	Trains overturned	
Marinas, small airplanes	Minor damage	Destroyed			
Small boats	Blown off mooring	Sunk			

Table 2 The rating criteria of wind damage reports (mainly based on Fujita-scale wind damage with modifications.

We used reports from nine hurricanes for a detailed exploratory study to determine the parameter or range of parameters that provide the best fit between the spatial extent of maximum estimated wind damage (from HURRECON) and reported damage at the county level. For each of these nine hurricanes we tested every combination of the following parameters as suggested from prior research: RMW (25, 50, 75, and 100km) and b (1.1, 1.2, 1.3, 1.4, 1.5, and 1.6). For a given combination of RMW and b , the HURRECON model can be executed on an equally divided raster space in IDRISI raster file format, which is converted from a model extent defined in GIS. For individual hurricanes, 10 kilometer is used as the resolution. For the whole Gulf

Coast, 20 kilometer is used as the resolution. Having determined the best fitting combination, we applied those parameters to the remaining eleven hurricanes and again tested the fit between the model and damage reports. Judging that the fit was acceptable, we then applied this calibrated model to all hurricanes in the Gulf Coast between 1950 and 2005.

Evaluation of alternative parameters was based on the performance of five different measures of fit. Several indices have been proposed in the literature (Wilmott et al 1985). We calculated the following measures: Spearman's rank order coefficient(r), index of determination (r^2), root mean square error (RMSE), mean square error (MSE), and index of agreement (d). Each index has slightly different characteristics; for example the correlation coefficients can measure collinearity but are insensitive to the additive and proportional differences between predicted and observed values. High values of correlation (r), index of agreement (r^2), and index of determination(d) indicate good correspondence and agreement between modeled and reported damages in terms of variability and magnitude. Low values of RMSE and MSE indicate a good overall agreement with a large percentage of error being random. The model with the best overall performance should have high correlation measures and low difference measures.

We calculated all five indices for every combination of values of RMW and b . In order to evaluate results on a common scale, we developed a standardized measure of fit on each index. For each of the initial nine hurricanes we determined which combination was the best fit on each index (i.e., the highest value of correlation measures or the lowest value of difference measures). That value was then used as the basis for assessing the fit for other combinations of parameters. More precisely the standardized measure was defined as $R_{std} = |R - R_{bestfit}| / R_{bestfit}$, where R_{std} denotes the standardized value; R is the calculated index value; and $R_{bestfit}$ is the value for the best fit model. Then in order to select a single "best" combination of parameters, we take the average of the five standardized indices for all nine hurricanes (this implies that we weight each index equally). Figure 3 presents a graph of these averages, showing that the model with RMW of 25km and b of 1.4 has the best overall performance.

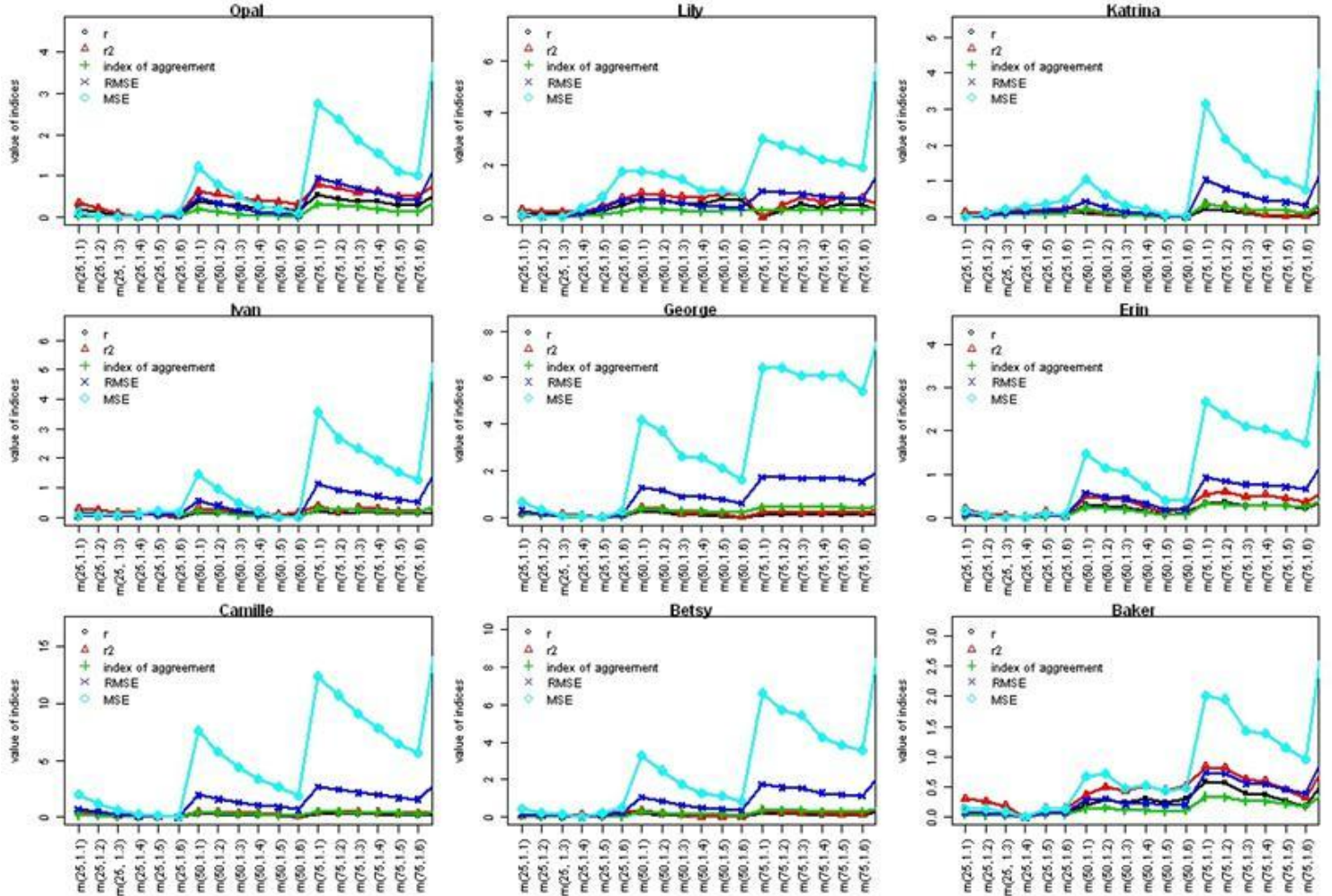


Figure 3 comparison of the performance of HURRECON models of different parameters

We illustrate the procedure followed for the nine calibration hurricanes with the case of Camille (1969). Figure 4 shows visually the close correspondence between reported damage and estimates based on the calibrated HURRECON model. The pattern is consistent with meteorological expectations as the intensity of damages lessened and the extension of damage narrowed along the storm track from the shoreline to the north, and there is typically greater damage on the east side of the track. However, there exists a significant amount of spatial heterogeneity in the point-based damage reports that we consider to be artifactual. The values at the county level are more reliable, leading us to prefer to analyze results at this scale.

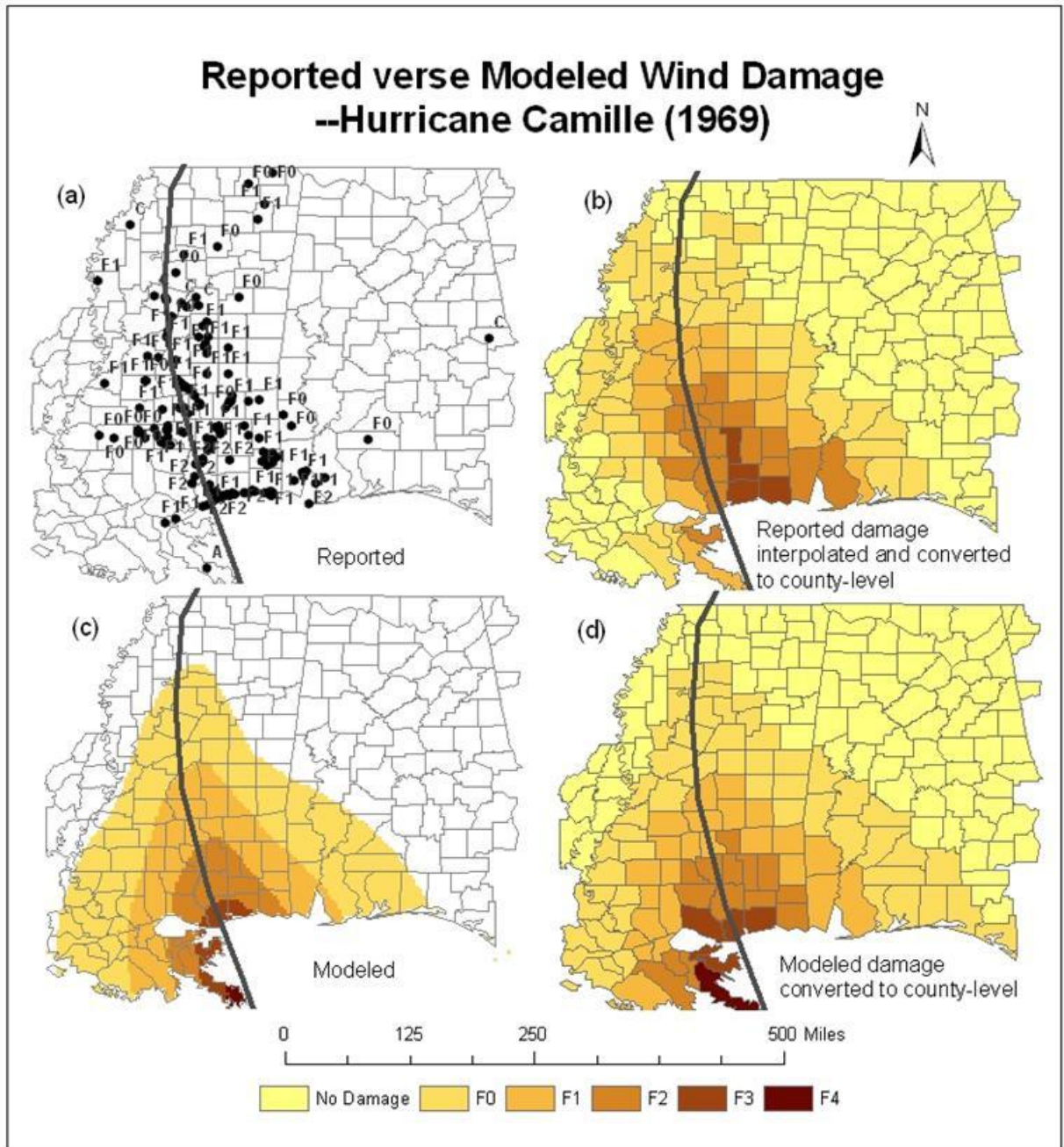


Figure 4 Comparison of reported damage(a) and damage estimated from the best fitting model (c)for Camille (1969), showing interpolation (b) and conversion to the county level(d).

Having calibrated the model with data from nine hurricanes, we then verified the results by applying the best-fit parameters of RMW (25KM) and b (1.4) to eleven additional hurricanes for which we had gathered damage reports from local media (results are shown for nine calibration hurricanes and eleven verification hurricanes in Table 3). For each hurricane we calculated the number of counties for which the estimated damage was the same as the reported damage, and the number where there were differences of one or two points in either direction. For all hurricanes there is a tendency for reported damage to be greater than estimated damage,

which is consistent with Boose's observations (Boose et al 2001). But in two of the verification cases there appears to be a poor model fit. In the case of Frederick (1979) there is exact agreement for only 5 of 62 counties, and 25 counties have reports of damage that are 2 points higher than estimated by the model. Further analysis shows that many reported damage locations are farther to the north than anticipated by the model. Boose (Boose et al 2001; Boose et al 1994) dealt with a similar situation by increasing wind speed along the hurricane track, but this solution would not generally be satisfactory for Gulf Coast hurricanes. Hurricane Dennis (2005) generated many damage reports in east and central Alabama that are quite far away from the hurricane track, which veered quickly westward toward Mississippi after landfall. In this case we interpret the discrepancy as mainly due to error in reported damage. In the remaining nine cases, exact correspondence ranged from 23.1% to 100% of counties, and discrepancies of one or less in the Fujita scale ranged from 62.5% to 100% of cases.

			Modeled minus reported damage					Total	% counties	% counties with
Hurricane	Year	SS	-2	-1	0	1	2	counties	with exact	difference of 1
								affected	agreement	point or less on
										F scale
Calibration sample:										
Georges	1998	H2	0	14	46	6	0	66	69.7	100
Erin	1995	H1	0	20	42	3	0	65	64.6	100
Betsy	1965	H4	0	18	52	17	0	87	59.8	100
Baker	1950	H1	0	19	49	5	0	73	67.1	100
Katrina	2005	H3	2	67	108	12	2	191	56.5	97.9
Ivan	2004	H3	4	49	107	3	0	163	65.6	97.6
Lili	2002	H1	1	8	19	4	0	32	59.4	96.9
Opal	1995	H3	12	61	188	5	0	266	70.7	95.5
Camille	1969	H5	0	29	129	22	10	190	67.9	94.7
Verification sample:										
Alicia	1983	H3	0	2	6	1	0	9	66.7	100
Chantal	1989	H1	0	2	2	0	0	4	50	100
Claudette	2003	H1	0	5	2	0	0	7	28.6	100
Kate	1985	H2	0	0	4	0	0	4	100	100
Elena	1985	H3	2	12	9	1	0	24	37.5	91.7
Hilda	1964	H2	2	6	3	2	0	13	23.1	84.6
Danny	1985	H1	2	2	3	0	0	7	42.9	71.4
Beulah	1967	H5	3	1	6	1	1	12	50	66.7
Eloise	1975	H3	9	9	6	0	0	24	25	62.5
Frederick	1979	H4	25	31	5	1	0	62	8.1	59.7
Dennis	2005	H3	13	13	2	1	0	29	6.9	55.2

Table 3 Summary of the difference between the estimated and reported county-level damage (using RMW=25KM and b=1.4).

It is natural that the fit for verification cases would be somewhat lower than for the calibration cases, and we conclude that the HURRECON model as applied here provides reasonable estimates of the spatial extent of wind damage.

Our estimates of the spatial pattern of cumulative risk of hurricane damage on the Gulf Coast are presented here in four ways (Figure 5). Panel (a) maps the 270 counties with at least an F0 level of damage experienced over the 56-year period and shows the number of such hurricanes in the county. As expected the incidence is greater near the coast, but there is considerable additional variation – less along the Texas coast than in Louisiana, Mississippi, and the Florida Panhandle. Panel (b) maps the 170 counties with at least F1 level of damage. It is considerably reduced in extent compared to F0 impacts and more closely hugs the coastline. Panel (c) considers only damage of F2 or above, and is even more clearly geographically restricted, including 67 counties mostly on the coast and again especially in Louisiana and Mississippi. Finally, panel (d) identifies the maximum damage level from any hurricane over the 56 years examined. F3 or F4 intensity is found only in eight landfall counties at the Mexican-Texas border and in Louisiana and Mississippi, but there are 162 counties that at some point experienced F1 or F2 damage, and many of these are inland.

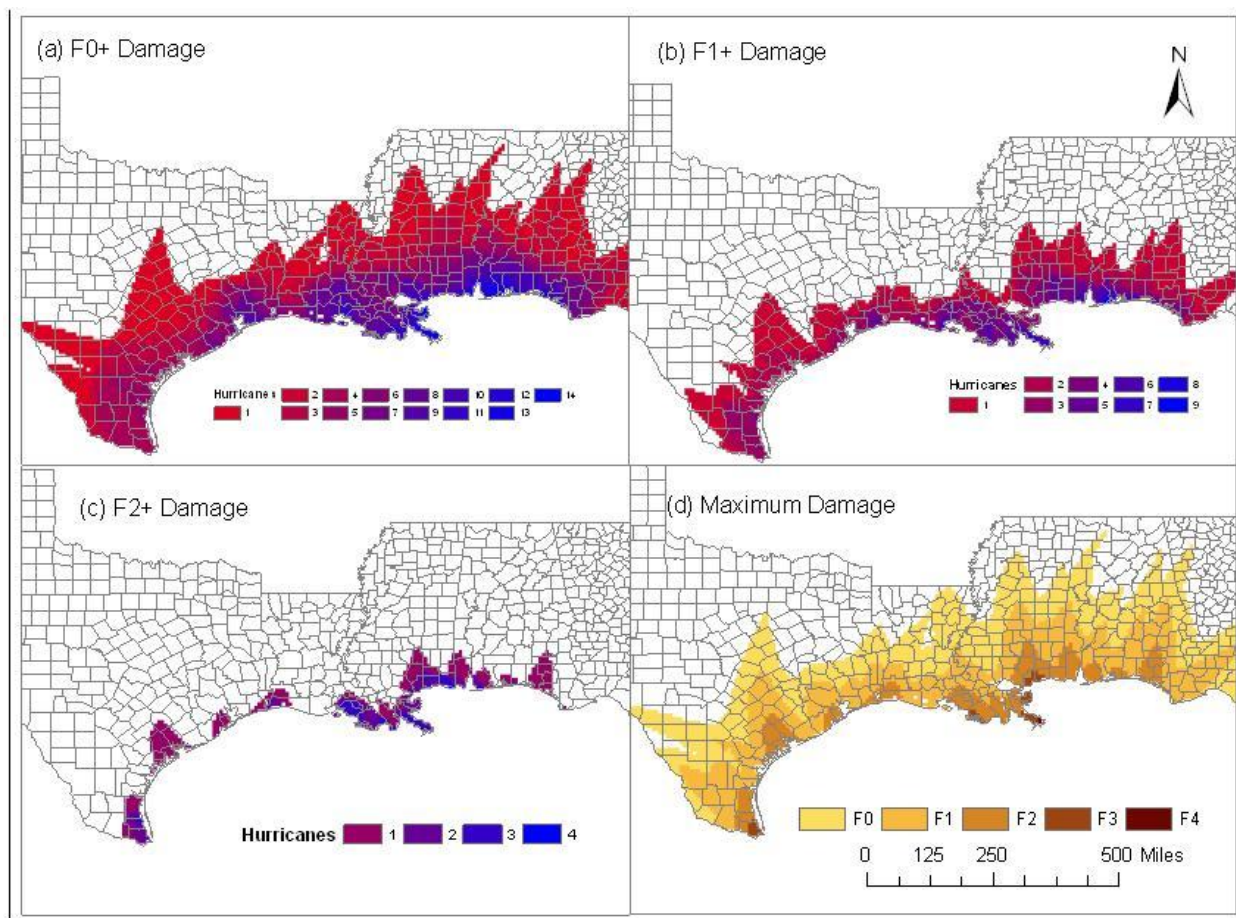


Figure 5 Modeled damage frequency and intensity, using best-fit values for the radius of maximum winds (RMW=25km) and wind profile exponent($b=1.4$) : (a) F0+ damage; (b)F1+ damage; (c) F2+ damage; (d) maximum damage experienced since 1950.

Who was at risk?

These damage estimates make it possible for the first time to address questions about how population shifts over a half-century change people's risk from hurricanes. As noted above, our assumption is that hurricanes in this period are an exogenous phenomenon with random variation

across time and space, and that the aggregated observed result for 1950-2005 is an unbiased estimate for any period in the recent past or near future.

Given the spatial extent of damage for counties, we used decennial census figures and annual population estimates to calculate the number and composition of persons living in areas with differing risks of wind damage in each decade. In many cases counties are divided into two or more zones of estimated damage, and we have allocated population to each zone according to its share of the county's land area. The standard inclusive geographic unit available for subcounty areas is the census tract, which could provide more geographically precise population measures, but tract data are not available for most rural areas prior to 1980.

We find that about three quarters of the population in the study region in 2000 lived in areas that are at risk of at least one hurricane with damage of F0 or higher in a 56-year period. More telling, nearly one person in six was in an area with a risk of F2 damage or greater, which would involve buildings blown down and destroyed, roofs lost from masonry buildings, and stationary cars or railroad boxcars pushed over. More than a third of the population lived in areas that experienced five or more hurricanes, an average of at least one per decade (Table 4).

Damage 1950- 2005:		1950		1960		1970		1980		1990		2000	
F2 damage or higher	White	1,442	11.9%	1,868	12.8%	2,091	12.2%	2,113	11.4%	2,127	10.6%	2,210	10.2%
	Black	441	9.8%	570	11.7%	635	12.6%	738	12.7%	781	12.0%	876	11.2%
	Age 20-34	466	12.1%	485	13.0%	524	12.0%	851	11.8%	827	10.4%	791	9.6%
	Age 65+	112	10.1%	160	10.5%	198	10.8%	296	11.0%	378	11.5%	442	11.5%
	Non-poor	279	19.2%	412	19.9%	2,208	18.5%	2,676	17.7%	2,670	16.6%	3,193	15.9%
	Poor	181	13.6%	169	14.6%	533	16.6%	576	17.2%	761	17.9%	661	17.7%
5 or more hurricanes	White	2,869	23.6%	3,779	25.9%	4,480	26.0%	4,944	26.8%	5,098	25.3%	5,328	24.5%
	Black	999	22.1%	1,263	25.9%	1,402	27.9%	1,644	28.2%	1,781	27.3%	2,050	26.1%
	Age 20-34	953	24.6%	1,007	27.0%	1,161	26.5%	1,969	27.4%	1,957	24.7%	1,894	22.9%
	Age 65+	225	20.2%	327	21.4%	410	22.3%	618	23.0%	793	24.1%	943	24.4%
	Non-poor	565	38.7%	854	41.3%	4,841	40.5%	6,091	40.3%	6,277	38.9%	7,582	37.8%
	Poor	385	28.9%	358	30.8%	1,071	33.3%	1,135	34.0%	1,519	35.7%	1,321	35.4%

Table 4 Number (in thousands) and percentages of persons living in zones with above average hurricane risk in Gulf Coast counties, based on 1950-2005 experience, for selected population groups. The time trend shows that socially vulnerable populations were at greater risk in 2000 than in 1950.

The total population of the Gulf Coast region as defined here grew between 1950 and 2000, from under 11.5 million to over 23.8 million (more than doubling, while in the same period the U.S. population increased by 81%, shifting from the Northeast and Midwest to the South and West). Consequently the number of persons at risk also grew in absolute terms. However our focus is not on overall population growth but on how the share of the population exposed to various levels of damage changed over time. The findings in this respect are different for different levels

of damage. There was an increase in the share of people living in areas that had at least one hurricane with F0 damage or higher in the period, from 73.1% to 76.7%, most of which had occurred by 1980. The share of people exposed to F1 damage or higher and to three or more hurricanes increased more sharply (from 47.3% to 55.0% and from 47.4% to 53.8%, respectively). Exposure to higher levels (F2 or above) followed a curvilinear trend, rising during 1950-1970, but declining again so that it returned to about its 1950 level in 2000. There was also a curvilinear trend in exposure to five or more and to eight or more hurricanes. These data suggest some turning away from areas with the greatest locational vulnerability in favor of areas with risks in a more moderate range, a process that ecologists might interpret as adaptation.

A closer examination of exposure to F2 or greater damage, which has the most significant impacts on residents, reveals substantial differences in exposure among subgroups of the population defined by age, race and poverty status as well as different trend lines (Figure 6).

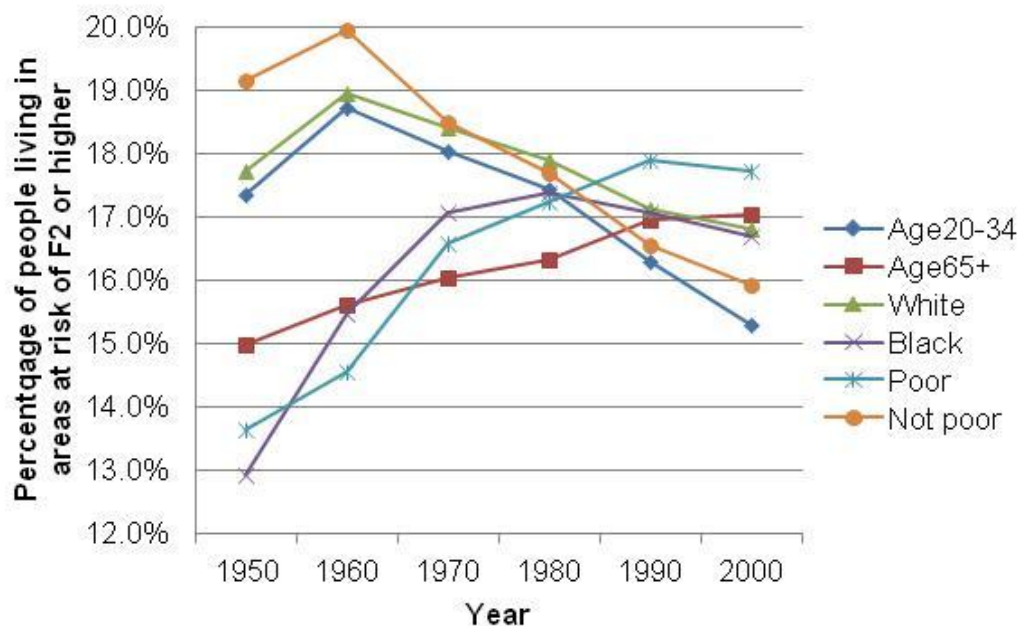


Figure 6. Trends in the exposure of different population groups on the Gulf Coast during 1950-2000. The Y-axis is the percentage of each groups' members who lived in areas at risk of F2 damage or higher. A larger share of older, black and poor residents were at risk in 2000 compared to 1950, while vulnerability declined for younger, white, non-poor residents.

The selected age categories are persons 20-34, the prime early adulthood period that most distinguishes areas that are losing or gaining population through migration, and persons over 65, who are considered to have the most difficulty coping with natural disasters. A very large proportion (77.4% in 2000) of the total population in this region is white or black, with reliable population estimates not possible prior to 1980 for Hispanics. Therefore we limit our comparison to whites and blacks (counting only non-Hispanic whites and blacks in 1980-2009, when census reports make this possible, but all persons of white or black race in 1950-1970). Poverty is based on the official federal poverty level in each year.

There was a sharp reversal in relative risk for young adults and older residents. In 1950 a higher share of young adults than older persons lived in risky areas (17.3% vs. 15.0%). The share of young adults at risk peaked in 1960 and began a steady decline, while the over 65

population shifted toward higher risk areas through 1990. By then older persons were more exposed than young adults at the F2 damage level. There was an even larger disparity in exposure at the F1 damage level in 1950 (49.3% of young adults vs. 42.7% of seniors). Although the share of seniors exposed to F1 damage increased faster over time than that of young adults, they were still slightly less exposed at this level by 2000 (52.0% for seniors, 54.6% for those aged 20-34).

Initial differences by race were greater: in 1950, 17.7% of whites but only 12.9% of blacks were in areas of F2 or greater damage. White exposure increased slightly through 1980 but then declined. However black exposure increased substantially through 1980, almost reaching the same level as whites, and was virtually the same as whites in 1990 and 2000. At the F1 level, whites were much more exposed than blacks at the beginning of the period (50.8% vs. 38.8%), but the difference was much reduced by 2000 (53.9% vs. 51.0%).

The pattern by poverty status is similar to the pattern by race. Figure 6 shows that non-poor persons were at higher risk of F2 damage in 1950 (19.2% vs. 13.6%). But by 1960 this exposure had peaked and it declined to 15.9% by 2000. Exposure of poor residents increased steadily through 1990, and by 2000 was nearly two percentage points higher (at 17.7%) than non-poor exposure. Again the data at lower damage levels shows a somewhat different trend: a greater disparity in the beginning (52.2% of the non-poor had F1 exposure in 1950, compared to 42.7% of the poor). The exposure of the non-poor changed very little after that time, but it increased steadily for the poor, and it was actually higher for the poor (55.7%) than for the non-poor (54.8%) by 2000.

These findings show a shifting relationship between locational vulnerability and social vulnerability on the Gulf Coast. Immediately after World War II, the least socially vulnerable residents lived disproportionately in the areas closer to the coast where there was greater exposure to the highest levels of potential hurricane damage. Within two decades their residential pattern was shifting toward areas of moderate risk, while socially more vulnerable seniors, blacks, and poor residents shifted toward areas of higher risk. We are not yet able to explain why these changes took place, but certainly the net effect raises a concern about whether the most exposed Gulf Coast communities may have become less resilient as a result.

Population impacts of extraordinary events

Although there were several major hurricanes during the period of study, their impacts seem to have been cumulative and to show up in relatively modest but continuing shifts in the population pattern. The experience in 2005 of Hurricanes Katrina and Rita at the end of our study period offers a different phenomenon because, as is well known, these hurricanes (and associated flooding of New Orleans) displaced very large numbers of people. And as we will show, this displacement partly reversed the longer term trends.

The relevant data are displayed in Figure 7, tracing population changes since 2000 for areas of F2 damage or higher. Between 2000 and 2005 the only changes for the total population or any of the population groups that we tracked were toward slightly lower exposure. There was, however, a substantial population displacement between 2005 and 2006. In a single year the share of the total population in areas of F2 damage or greater dropped from 15.9% to 14.6% (a loss of nearly 300,000 people in this zone). The decline was similar for both young adults and seniors and for poor and non-poor. However it was particularly sharp for blacks (down by 3.1%,

from 16.4% to 13.3%) compared to whites (from 16.6% to 15.7%). This is because of the highly localized impacts on New Orleans (Logan 2008).

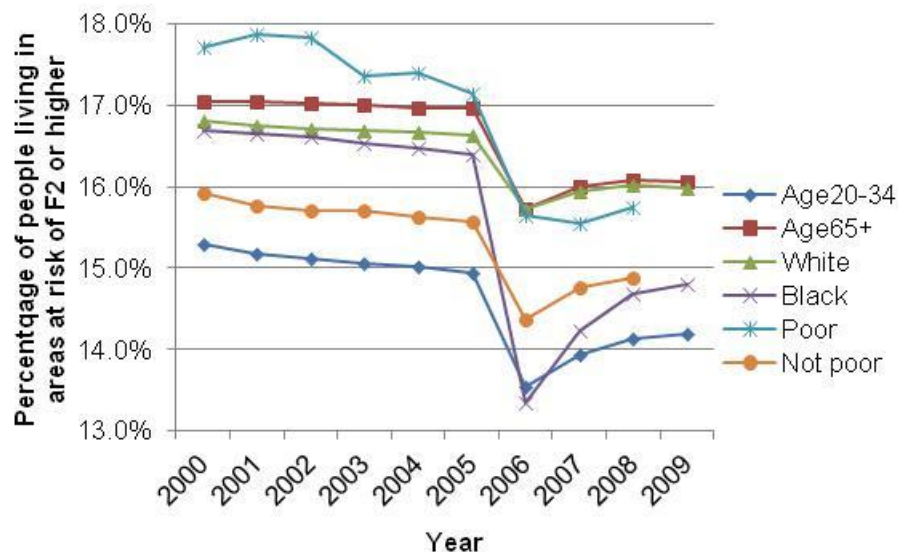


Figure 7. Trends in the exposure of different population groups on the Gulf Coast during 2000-2009. The annual figures reveal the sudden population displacements and slow return from Hurricanes Katrina and Rita after 2005.

Through 2009 the total population returned partially to the prior level, and partial return was the experience of most population subgroups that we have tracked. Two population groups stand out. One is the black population, which experienced the most extreme decline in the first year (a drop of over three percentage points). Despite a sharp rebound after 2006, the net loss by blacks remained the largest of any group. The other exceptional case is residents below the poverty line. Their population share dropped less than blacks but somewhat more than the remaining categories. More disturbing, there was almost no return for poor residents (the share in F2 areas grew only from 15.7% in 2006 to 15.8% in 2008, the latest date for which data are available). In fact, the number of poor residents in this zone dropped by 85,000 between 2005 and 2006 and by another 19,000 in the following year. From 2007 to 2008 the number increased by a mere 1,000. These results suggest a differential pattern of vulnerability after Katrina and Rita – the black population was most heavily impacted in the first year, while poor residents were least likely to return.

Discussion

The at-risk population in the Gulf region has grown substantially in absolute numbers but has declined as a share of the total population in the region. Our focus has been on whether some subgroups of the population faced disproportionate risk. The changing pattern of population distribution in the Gulf Coast region tended to move more socially vulnerable populations into risky locations through 2005. Because older persons, blacks and the poor are likely to have fewer personal resources to cope with displacement or damage, their disproportionate movement over time to areas of higher risk (until the massive displacement after 2005) is particularly disturbing. Studying the impacts of Katrina and Rita offers additional clues to which groups may be more socially vulnerable, since blacks and poor people were more

heavily affected or for a longer duration than were seniors. It will be valuable to investigate whether there are also differences based on other characteristics such as education, home ownership, and family composition, all of which have been shown to be related to people's ability to recover from natural disasters. Being aware of these patterns will be key to averting the man-made disaster of placing vulnerable people in harm's way.

This is a purely descriptive study, an accounting of who lived where and how that changed over time. However the results merit more interpretation. One view, already mentioned above, is that the relative shift of population out of areas that have proved more risky in the last 50 years represents a successful adaptation of population to its environment. It is possible that communities are becoming more aware of risk, that the costs of hurricane damage are being factored into decisions about where to live by families and by insurance companies and that government has also begun to favor living in more secure locations. An alternative view is that the economy adjacent to the Gulf Coast is being restructured over time, favoring a low-wage second-home, tourist and casino economy along with offshore oil production that employs few workers but suffers intermittent environmental risks. By this reasoning one might expect some abandonment of the coastal zone by those population groups who are most mobile and/or are most interested in employment opportunities (white, young, and non-poor). There is likely some truth to both scenarios. Either way, the result is clearly a trend toward greater confluence of locational and social vulnerability.

Our success in modeling damage is of value in itself. This research demonstrates that wind damage can be reliably reconstructed from information on the path and wind speeds of historical hurricanes, yielding estimates that are highly correlated with published damage reports. Hurricane impacts along the Gulf Coast from 1950 to 2005 were spatially skewed, with areas of Louisiana and Mississippi being much more vulnerable than those on the Texas coast. The inland reach of wind damage is also variable. Incorporating information on storm surge, another component of hurricane damage, will be another useful step for future research.

Progress in modeling damage for historical hurricanes creates a potential for better estimates of their impacts. For example time-series models that take into account spatial dependence can evaluate whether individual hurricanes have effects, or whether only the most severe storms make a difference, or whether it is the cumulative effect over many years that matters. Are effects temporary or lasting? Such models can also be used to compare a range of outcomes, such as demographic (e.g., population displacement), economic (e.g., employment shifts), or environmental (e.g., forest cover) changes. A central question for theories of disaster and resilience is how effects may differ between human and natural systems – for example, are effects on human communities effectively buffered through public assistance and insurance systems, is the extent and timing of recovery similar in each domain, and is there evidence of greater adaptation to vulnerability over time in one domain or the other? Estimation of parallel models for both social and physical characteristics of the landscape is a feasible method for addressing such questions and is a useful direction for future research.

References

Adger, W. N., Hughes, T. P., Folke, C., Carpenter, S. R. and Rockstrom, J. 2005. Social-Ecological Resilience to Coastal Disasters. *Science* 309:1036-1039.

- Blaikie, Piers, Terry Cannon, Ian Davis and Ben Wisner. 1994. *At Risk: Natural Hazards, people's vulnerability, and disasters*. London: Routledge.
- Bolin, Robert and L. Stanford. 1998. The Northridge earthquake: Community-based approaches to unmet recovery needs. *Disasters* 22(1):21-38.
- Bolin, Robert. 2006. Race, Class, Ethnicity, and Disaster Vulnerability. In *Handbook for Disaster Research*, ed. Juan Rodríguez, Enrico L. Quarantelli and Russell R. Dynes, 113-129. New York: Springer Press.
- Boose, E. R., Chamberlin, K. E. and Foster, D. R. 2001. Landscape and Regional Impacts of Hurricanes in New England. *Ecological Monographs* 71:27-48.
- Boose, E. R., Foster, D. R. and Fluet, M. 1994. Hurricane Impacts to Tropical and Temperate Forest Landscapes. *Ecological Monographs* 64:369-400.
- Boose, E. R., Serrano, M. I. and Foster, D. R. 2004. Landscape and Regional Impacts of Hurricanes in Puerto Rico. *Ecological Monographs* 74:335-352 .
- Buka, S., R. T. Brennan, Janet W. Rich-Edwards, Stephen W. Raudenbush, and Felton Earls. 2002. Neighborhood support and the birth weight of urban infants. *American Journal of Epidemiology* 157:1-8.
- Bullard, Robert D. 1990. *Dumping in Dixie: Race, Class, and Environmental Quality*. Boulder, CO: Westview.
- Bullard, Robert D. 1993. Anatomy of Environmental Racism and the Environmental Justice Movement. In *Confronting Environmental Racism: Voices from the Grassroots*, ed. Bullard, Robert D., 15-41. Cambridge, Mass.: South End Press.
- Burton, Ian, Robert W. Kates, and Gilbert F. White. 1993. *The environment as hazard*. 2nd ed. New York: Guildford Press.
- Chambers., R. 1989. *Vulnerability, coping and policy*. IDS Bulletin 20, 2: 1-7.
- Ciscara, Juan-Carlos, Ana Iglesias, Luc Feyen, László Szabó, Denise Van Regemortera, Bas Amelunge, Robert Nicholls, Paul Watkiss, Ole B. Christensen, Rutger Dankersc, Luis Garrote, Clare M. Goodess, Alistair Hunt, Alvaro Moreno, Julie Richardson, and Antonio Soria. Physical and economic consequences of climate change in Europe. 2011 *Proceedings of the National Academy of Sciences of USA* 108(7): 2678-83.
- Cochrane, H.C. 1975. *Natural hazards and their distributive effects: A research assessment*. Boulder: Institute of Behavioral Science University of Colorado.
- Colten, Craig E. 2005. *An Unnatural Metropolis: Wrestling New Orleans from Nature*. Baton Rouge, Louisiana: Louisiana State University Press.
- Cutter, S. L., Boruff, B. J. and Shirley, W. L. 2003. Social Vulnerability to Environmental Hazards. *Social Science Quarterly* 84:242-261.
- Cutter, Susan L. 1996. Vulnerability to environmental hazards. *Progress in Human Geography* 20(4):529-539.
- Dash, N., W. G. Peacock, and B. H. Morrow. 1997. And the poor get poorer: A neglected Black community. In *Hurricane Andrew: Ethnicity, Gender and the Sociology of Disaster*, ed. W. G. Peacock, B. H. Morrow, and H. Gladwin, 206– 225. London: Routledge.
- Diez-Roux, A. 1997. Neighborhood environments and coronary heart disease: A multilevel analysis. *American Journal of Epidemiology* 146:48-63.

- Dilley, Maxx, Robert S. Chen, Uwe Deichmann, Arthur L. Lerner-Lam, Margaret Arnold, Jonathan Agwe, Piet Buys, Oddvar Kjekstad, Bradfield Lyon and Gregory Yetman. 2005. *Natural Disaster Hotspots: A Global Risk Analysis Synthesis Report*. Center for Hazards and Risk Research, Columbia University.
- Dynes, R. R. 1970. *Organized Behavior in Disaster*. Lexington, MA: D.C. Heath
- Emanuel, K. 2005. Increasing destructiveness of tropical cyclones over the past 30 years. *Nature* 436:686-688.
- Folke, C. 2006. Resilience: The emergence of a perspective for social-ecological systems analyses. *Global Environmental Change* 16:253-267.
- Freudenburg, William. 1997. Contamination, Corrosion and the Social Order. *Social Forces* 71:909-932.
- Fujita, T. T. 1971. *Proposed characterization of tornadoes and hurricanes by area and intensity*. Chicago, Illinois : Univeristy of Chicago.
- Fujita, T. T. 1987. *U.S. Tornadoes: part one, 70-year statistics*. Chicago, Illinois: University of Chicago.
- Hewitt, Kenneth. 1997. *Regions of risk: a geographical introduction to disasters*. Essex, U.K.: Longman Pub Group.
- Holling, C. S. 1973. Resilience and Stability of Ecological Systems. *Annual Review of Ecology and Systematics* 4:1-23.
- Jargowsky, Paul A. 1997. *Poverty and Place: Ghettos, Barrios, and the American City*. New York: Russell Sage Foundation.
- Kates, Robert W. 1971. Natural hazard in human ecological perspectives: hypotheses and models. *Economic Geography* 47(3):438-451.
- Lobao, Linda. 2004. Continuity and Change in Place Stratifications: Spatial Inequality and Middle-Range Territorial Units. *Rural Sociology* 69:1-30.
- Logan, John R. 2008. Unnatural Disaster: Social Impacts and Policy Choices after Katrina. In *Natural Disaster Analysis After Hurricane Katrina: Risk Assessment, Economic Impacts and Social Implications*, ed. Harry W. Richardson, Peter Gordon, and James E. Moore, 279-297. London: Edward Elgar Publications.
- Logan, John R. and Harvey Molotch. 1987. *Urban Fortunes: The Political Economy of Place*. Berkeley: University of California Press.
- Mann, M. E., Woodruff, J. D., Donnelly, J. P. and Zhang, Z. 2009. Atlantic hurricanes and climate over the past 1,500 years. *Nature* 460:880-883.
- Massey, Douglas and Nancy Denton. 1993. *American Apartheid*. Cambridge, MA: Harvard University Press.
- McDonald, Robert I., Pamela Green, Deborah Balk, Balazs M. Fekete, Carmen Revenga, Megan Todd, and Mark Montgomery. 2011. Urban growth, climate change, and freshwater availability. *Proceedings of National Academy of Sciences of USA* 108:6312-6317.
- Mcgranahan, Gordon, Deborah Balk and Bridget Anderson. 2007. The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. *Environment & Urbanization* 19(1): 17-37.
- Mileti, D. 1999. *Disasters by Design: A Reassessment of Natural Hazards in the United States*. Washington DC: Joseph Henry Press.

- Moore, Spencer, Laura Linnan, and Salli Benedict. 2004. After Hurricane Floyd Passed: Investigating the Social Determinants of Disaster Preparedness and Recovery. *Family & Community Health* 27:204-217.
- Morenoff, Jeffrey. 2003. Neighborhood mechanisms and the spatial dynamics of birth weight. *American Journal of Sociology* 108:976-1017.
- Morrow, Betty Hearn and W. G. Peacock. 1997. Disasters and Social Change: Hurricane Andrew and the Reshaping of Miami? In *Hurricane Andrew: Ethnicity, gender, and the sociology of disasters*, ed. W. G. Peacock, B. H. Morrow & H. Gladwin, 226-242. London; New York: Routledge.
- Neumann, C. 1987. *The National Hurricane Center Risk Analysis Program (HURISK)*. Coral Gables, FL:National Hurricane Center.
- Pastor, Manuel, James Sadd, and John Hipp. 2001. Which came first? Toxic facilities, minority move-in, and environmental justice. *Journal of Urban Affairs* 23(1):1-21.
- Peacock, W. G. and C. Girard. 1997. Ethnic and racial inequalities in hurricane damage and insurance settlements. In *Hurricane Andrew: Ethnicity, gender, and the sociology of disasters*, ed. W. G. Peacock, B. H. Morrow & H. Gladwin, 171-190. London; New York: Routledge.
- Peacock, W. G., B.H. Morrow and H. Gladwin. 1997. *Hurricane Andrew: Ethnicity, gender, and the sociology of disasters*. London; New York: Routledge.
- Pielke, R. A. and Landsea, C. W. 1998. Normalized Hurricane Damages in the United States: 1925-1995. *Weather and Forecasting* 13:621-631.
- Pielke, R. A., Gratz, J., Landsea, C. W., Collins, D., Saunders, M. A. and Musulin, R. 2008. Normalized Hurricane Damages in the United States: 1900-2005. *Natural Hazards Review* 9:29-42 .
- Sampson, Robert J., Jeffrey Morenoff and Felton Earls. 1999. Beyond social capital: spatial dynamics of collective efficacy for children. *American Sociological Review* 64: 633-660.
- Smith, V., Carbone, J., Pope, J., Hallstrom, D. and Darden, M. 2006. Adjusting to natural disasters. *Journal of Risk and Uncertainty* 33:37-54.
- South, Scott and Kyle Crowder. 1997. Escaping Distressed Communities: Individual, Community, and Metropolitan Influences. *American Journal of Sociology* 102:1040-1084.
- Tierney, K. J., Lindell, M. K. and Perry, R. W. 2001. *Facing the Unexpected: Disaster Preparedness and Response in the United States*. Washing D. C.: Joseph Henry Press.
- Tierney, Kathleen, Michael Lindell and Ronald Perry. 2001. *Facing the Unexpected: Disaster Preparedness and Response in the United States*. Washington, D.C.: Joseph Henry Press.
- Turner, B. L., Roger E. Kasperson, Pamela A. Matson, James J. McCarthy, Robert W. Corell, Lindsey Christensen, Noelle Eckley, Jeanne X. Kasperson, Amy Luers, Marybeth L. Martello, Colin Polskya, Alexander Pulsiphera and Andrew Schiller. 2003. A framework for vulnerability analysis in sustainability science. *Proceedings of National Academy of Science of USA* 100(14):8074-8079.
- Vale, Lawrence J. and Thomas J. Campanella. 2005. Axioms of Resilience. in *The Resilient city: How modern cities recover from disaster*, ed. Lawrence J. Vale and Thomas J. Campanella, 335-357. New York: Oxford University Press.
- Vickery, P. J., Skerlj, P. F. and Twisdale, L. A. 2000. Simulation of Hurricane Risk in the U.S. Using Empirical Track Model. *Journal of Structural Engineering* 126:1222-1237.
- Watts. Michael J. and Hans G. Bohle. 1993. Hunger, Famine and the Space of Vulnerability. *GeoJournal* 30(2):117-125.

- Wilson, William J. 1987. *The Truly Disadvantaged: The Inner City, The Underclass, and Public Policy*. Chicago: University of Chicago Press.
- Willmott, C. J., Steven G. Ackleson, Robert E. Davis, Johannes J. Feddema, Katherine M. Klink, David R. Legates, James O'Donnell, and Clinton M. Rowe. 1985. Statistics for the Evaluation and Comparison of Models. *Journal of Geophysical Research* 90:8995-9005.
- Wu, Jie Ying and Michael K. Lindell. 2004. Housing Reconstruction after Two Major Earthquakes: The 1994 Northridge Earthquake in the United States and the 1999 Chi-Chi Earthquake in Taiwan. *Disaster* 28:63-81.