Social Vulnerability to Climate-Sensitive Hazards in the Southern United States

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ABSTRACT

The southern United States is no stranger to hazard and disaster events. Intense hurricanes, drought, flooding, and other climate-sensitive hazards are commonplace and have outnumbered similar events in other areas of the United States annually in both scale and magnitude by a ratio of almost 4:1 during the past 10 years. While losses from climate-sensitive hazards are forecast to increase in the coming years, not all of the populations residing within these hazard zones have the same capacity to prepare for, respond to, cope with, and rebound from disaster events. The identification of these vulnerable populations and their location relative to zones of known or probably future hazard exposure is necessary for the development and implementation of effective adaptation, mitigation, and emergency management strategies. This paper provides an approach to regional assessments of hazards vulnerability by describing and integrating hazard zone information on four climate-sensitive hazards with socioeconomic and demographic data to create an index showing both the areal extent of hazard exposure and social vulnerability for the southern United States. When examined together, these maps provide an assessment of the likely spatial impacts of these climate-sensitive hazards and their variability. The identification of hotspots—counties with elevated exposures and elevated social vulnerability—highlights the distribution of the most at risk counties and the driving factors behind them. Results provide the evidentiary basis for developing targeted strategic initiatives for disaster risk reduction including preparedness for response and recovery and longer-term adaptation in those most vulnerable and highly impacted areas.

1. Introduction

The southern United States is particularly at risk to extreme natural events associated with climate-sensitive hazards such as hurricanes, floods, droughts, and sea level rise. Even in the absence of climate change, exposure to climate variability and climate-related extremes (Goklany 2005; Thomalla et al. 2006) could mean potential increases in stronger hurricanes, heavier precipitation events leading to increased flooding, more frequent extensive droughts, and potential rises in sea level throughout the region. Planners, decision makers, and emergency managers within the region are considering these climate-sensitive hazards as part of their disaster risk management efforts. They are focusing on the hazard exposure as well as the vulnerability of residents to such hazard events. Social vulnerability captures the variability within the population to prepare for, respond to, mitigate, and recover from a hazard event. It is the geographic or spatial intersection of the exposure to climate-sensitive hazards and the vulnerable populations that turn events such as Hurricane Katrina (Cutter and Emrich 2006; Landphair 2007; Laska and Morrow 2006) or the annual flooding along the Mississippi River (Black 2008; Cannon 2000) into disasters.

This paper provides a spatial assessment of the social vulnerability of the southern United States to climate-sensitive hazards. For our purposes, the southern United States is defined broadly as the 13 states stretching from Maryland in the north to Texas in the west. This paper examines the spatial patterning of social vulnerability and hazard exposure for county, state, and regional geographies. In so doing, it provides the evidentiary basis for developing strategic initiatives aimed at disaster risk reduction and medium-term adaptation in those most vulnerable and highly impacted areas.

2. Background

a. Climate-sensitive hazards

The southern United States has frequent loss-causing flood events, chronic and long-lasting droughts, and

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periodic high wind, rain, and storm surge from hurricanes and tropical storms. While new and different threats related to climate change will become apparent in the coming years, climate-sensitive hazards are expected to increase in severity and impact (Diaz and Murnane 2008; Allison et al. 2009). Future hazard threats related to climate variability and extremes in the United States include more intense hurricanes with related increases in wind, rain, and storm surges, as well as drier conditions that will impact human health, water, agriculture, coastal areas, and many other aspects of society and the natural environment (Karl et al. 2009). There is considerable difficulty in anticipating what, when, and where these specific impacts of climate variability and extremes will occur and the populations most affected. One method for determining this is to take an analog approach and extrapolate past experience (hazard exposure and vulnerability) into the future. To that end, this research utilizes a combination of approaches (historical analogs, current probabilities, and future projections) to delineate the areal extent of exposure to climate-sensitive hazards in the study area. The goal is to develop a generalized spatial understanding of where the impacts are the greatest and who bears the consequences of those impacts.

The use of historical proxy data provides a reasonable indicator of the areal exposure and impacts from climate-sensitive hazards at the regional scale. Exposure is the frequency, severity, and areal extent of the hazard in question. For our purposes, we are only delineating the exposure zone (its areal dimension, using data on frequency and severity thresholds). Monetary damages to property and crops measure impacts, as do human losses such as injuries and fatalities. For example, during the past decade (2000–09), property and crop losses from flooding, drought, hurricanes, and other coastal hazards was $154 billion (in 2009 adjusted U.S. dollars) for the southern United States compared to merely $29.5 billion (in 2009 U.S. dollars) for the remainder of the country (Hazards and Vulnerability Research Institute 2011). Extending the comparison over a longer period of record (1960–2009) again shows a large disparity between the southern states and the rest of the United States. For the southern states, property and crop damages were $234 billion (adjusted to 2009 U.S. dollars), compared to the rest of the nation ($88 billion). Fatalities from these events are comparable between the South and the rest of the United States during the past decade (616 for the South, 492 for the rest of the United States) and over the longer period of record (2655 for the South, 2479 for the remainder of the United States) (Hazards and Vulnerability Research Institute 2011). Another way to measure impact is to examine the social burdens related to climate-sensitive hazards. This includes measuring not only which population subgroups are more or less susceptible to the hazards (social vulnerability) but where they live and work.

b. *Social vulnerability*

The concept of vulnerability, or the potential for harm, first introduced into the hazards and disasters literature in the 1970s, provides a means for understanding the interactions between social and natural systems that give rise to hazards and disasters (O'Keefe et al. 1976). Vulnerability is widely used in the hazards, disasters, and human dimensions of global change literature to describe the differential impacts of environmental threats on people and the places where they live and work (Heinz Center 2002; Wu et al. 2002; Cutter et al. 2003; Pelling 2003; O'Brien et al. 2004; Wisner et al. 2004; Adger 2006; Birkmann 2006; Cox et al. 2006; Eakin and Luers 2006; Enarson 2007; Fussell 2007; Polsky et al. 2007; Myers et al. 2008; Zahran et al. 2008; Ionescu et al. 2009). Vulnerability explains the differential impacts of shocks or stressors to natural systems and the ability of those systems to absorb and withstand impacts (physical vulnerability). A companion construct, social vulnerability, provides the societal context within which such stressors operate and highlights the uneven social capacity for preparedness, response, recovery, and adaptation to environmental threats. To fully understand and characterize the vulnerability of places requires the following two measures: attributes of the hazards exposure (areal extent, frequency, severity) and sensitivity of the population to impacts. The sensitivity (social vulnerability) is defined by those social, economic, and demographic characteristics that influence a community's ability to prepare for, respond to, cope with, recover from, and ultimately adapt to environmental hazards (Cutter et al. 2000).

It is important to note that social vulnerability is a preexisting condition within a place. Conceptually, we can think of social vulnerability as an ''all-hazards'' construct in emergency management, where its utility highlights the preevent differential capacity of social groups to prepare for, respond to, and recover from hazards, regardless of hazard origin. Detaching social vulnerability from the hazard context is important in delineating its variability across the landscape. However, it is only when we spatially integrate the exposure or hazard zones with the spatially defined social vulnerability that we can adequately represent the relative level of hazardousness among places (Cutter et al. 2000).

3. Methodology

a. *Study area*

The focus of this research is on a broadly defined southern region of the United States. The study area

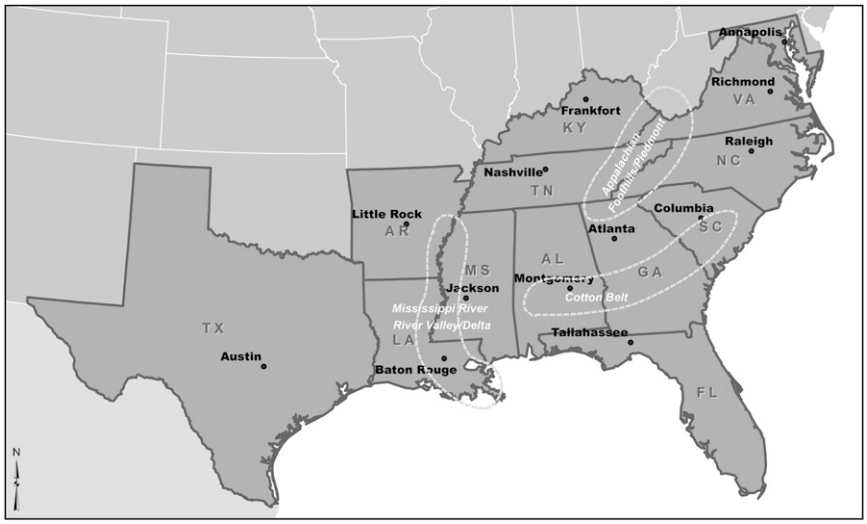

FIG. 1. Study area with states, selected historical/geographic regions, and state capitals.

includes 1288 counties, along the Gulf of Mexico and Atlantic Coast as well as interior states in the South. Historically the Mason-Dixon Line, which forms part of the border between Pennsylvania, Maryland, Delaware, and West Virginia, marked a geographic boundary delineating the free and slave states and defined "the South" or the southern region of the United States. Contained within this region are numerous subregions such as the Cotton Belt, Mississippi River Delta/Valley, and Appalachian Foothills and Piedmont (Fig. 1).

We used the county as our analysis unit. There were several reasons for this. First, many of the social vulnerability variables were only available at this scale. Second, in order to combine several different datasets and normalize the hazard exposure data, we aggregated to the county unit of analysis. Finally, many emergency management functions and decisions begin at the administrative level of a county. As a means to influence decision-making at the local (county) and state level, we felt the county unit of analysis was the most appropriate.

b. Social Vulnerability Index (SoVI)

The Social Vulnerability Index (SoVI) is a quantitative measure of social vulnerability to environmental hazards. Originally developed in 2003 and applied to U.S. counties, SoVI provides an empirically based comparative measure that facilitates the geographic examination of relative differences in levels of social vulnerability across states and regions (Cutter et al. 2003). The index synthesized socioeconomic variables known to influence vulnerability (National Research Council 2006) into multiple dimensions using a principal components analysis. These dimensions were equally weighted and summed to produce the overall score for the particular spatial unit (e.g., county, census tract) of interest. In the absence of any theoretical justification for the weighting of dimensions, the equal weighting and additive approach seemed the most prudent (Cutter et al. 2003; Schmidtlein et al. 2008). Conceptually, SoVI relates well to indices of social well-being and inequality, but its focus is on environmental hazards and the capacity of social groups to prepare for, respond to, and recover from disasters. It also captures the multidimensional aspects of social vulnerability, especially the dynamic intersection of race, class, and gender.

The methods in this paper augment the SoVI, which originally included variables related to the built environment. For this paper, only those social and demographic variables more reflective of social well-being were used. In this regard, the SoVI score for the southern United States (SoVI-SE) provides a better snapshot of those characteristics of social groups (and not the built environment) associated with vulnerability that are known to either enhance or retard hazard preparedness, response, recovery, and mitigation/adaptation to hazards.

c. Identifying social vulnerability at the county level

Thirty-two socioeconomic and demographic variables from the original SoVI method provided the input to the SoVI-SE computation (Table 1). To maintain comparable across the region, we used Census 2000 data to represent a mixture of true counts and estimates of the population and their characteristics. The use of 2000 Census data in 2010 is problematic, but it does provide the most consistent coverage across the region and for our variable set at this time. The 2010 Census data only have six or so primary variables (age, sex, race, Hispanic or Latino origin, relationship status, housing tenure)

TABLE 1. Categorical grouping of variables utilized in the creation of SoVI-SE.

Socioeconomic or demographic category	Variable description
Race/ethnicity	% black population, % Native American Indian population, % Asian or Pacific Islander population, % Hispanic population, % recent international migration
Wealth	Per capita income, % households earning more than $100,000 (U.S. dollars) in 2000, % living in poverty, median dollar value of owner-occupied housing units, median gross rent ($) for renter-occupied housing units
Housing type and tenure	% housing units that are mobile homes, no. housing units per square mile, % rural farm population, % urban population
Education and employment	% population over 25 yr old with less than 12 yr of education, % of civilian labor force unemployed, % civilian labor force participation, % female participation in civilian labor force, % employed in primary industry (farming, fishing, mining, forestry), % employed in transportation, communications, and other public utilities, % employment in service occupations
Age, gender, and health	% population under 5 yr old, % population 65 yr or older, average number of people per household, Social Security recipients, nursing home residents per capita, number of physicians per 100 000 population, number of hospitals per capita
Gender and family structure	% female population, % female-headed households, % renter-occupied housing units, % international migration

that were collected from the short form (actual counts) that went to all households. Past decennial censuses used the long form for more detailed information based on counts but it has been replaced by the American Community Survey (ACS). More recent data (2005–07) are available, but these are either based on projections, not actual counts, or are derived from sample surveys such as those used in the ACS product by the U.S. Census. One drawback of the ACS statistical portrait at the time of writing this paper was the population threshold of 20 000. Counties, cities, and towns with less than 20 000 inhabitants are not included in ACS, effectively precluding 518 of 1288 counties (or 40%) from our analysis. For the purposes of SoVI, ACS data pose problems because of the lack of statistical coverage of all counties in the southern United States, and the fact that many of the specific variables needed to compute SoVI are not available. To mix and match different years of data for the same geography will not produce the comparable scientific, spatial, or statistical results that we desired.

The 32 variables were normalized (percentages, density functions, per capita), standardized (z scores), and then input into a principal components analysis (PCA) to reduce the number of variables into a smaller set of multidimensional factors or components. Adjustments to the component's directionality insured that positive values were associated with increasing social vulnerability and negative values associated with decreasing social vulnerability. If a factor included negative and positive values that both influenced vulnerability (such as the age component with high values for elderly and the young), then the absolute value was used. Once the directionality was established, the equally weighted components summed to produce the final SoVI-SE (see Cutter et al. 2003 and http://sovius.org for specific details on the construction).

Eight distinct components explain 74% of the variance in the data for the SoVI-SE (Table 2). These components include wealth (not poverty); age (older persons); race and gender (Black populations and female-headed households); ethnicity (Hispanic populations); rural farm populations; special needs populations; gender; and employment in the utility, transportation, or communications sectors, which we label infrastructure employment. There is considerable sensitivity testing of the SoVI metric to monitor its robustness at different spatial scales and in different places (Schmidtlein et al. 2008). The multidimensional components and the level of explained variance in this present study are consistent with other SoVI studies for different regions and for the United States as a whole (see http://sovius.org).

The social vulnerability scores, ranging from 12.8 indicating the most vulnerable (Webb County, Texas) to −19.8, the least vulnerable (Robeson County, NC), were mapped using a three-class standard deviation method. Use of standard deviations preserves the underlying distribution of the data (mean of zero and one-half standard deviation on either side). The moderate category represents the mean; the elevated category is greater than one-half standard deviation above the mean; and the limited is less than one-half standard deviation below the mean. This classification method permits the best balance between interpretation (3 classes) and the identification and visualization of the extremes (high and low vulnerability that are of the most interest).

Extrapolation of SoVI scores from 2000 data does pose some potential issues in terms of social vulnerability to future threats because of migrations as well as

TABLE 2. SoVI-SE.

Component	Label	% Variance explained	Most influential variable/correlation
1	Wealth	23.1	Per capita income (0.93), median rent (0.90), % poverty (−0.67)
2	Age	14.6	People per housing unit (0.84), pop over 65 (−0.88), median age (−0.89)
3	Race	10.8	% African American (0.87), % female-headed household (0.84)
4	Ethnicity	6.6	% Hispanic (0.72)
5	Rural	5.1	% employed in natural resources extraction (0.55), % rural farm residents (0.50)
6	Special needs populations	5.0	Hospitals per capita (0.70); nursing home residents (0.62)
7	Gender	4.6	% females (0.91)
8	Infrastructure employment	4.6	% employed in utilities, transportation, or communications (0.73)
Total variance explained		74.4	
Equation for SoVI-SE = (-) Factor 1 + (ll) Factor 2 + Factor 3 + Factor 4 + Factor 5 + Factor 6 + Factor 7 + (-) Factor 8			

changes in composition of the population. However, demographic projections routinely cast population growth into the future (in 10, 20, or 50 yr) based on historic and present trends. Cutter and Finch (2008) used the same principle of extrapolation using 1960–2000 county-level SoVI scores to predict county SoVI scores for 2010. The accuracy of the projection is unknown at present, as the requisite variables from the 2010 Census data are no longer comparable. However, extending the trend line out to future years does provide a reasonable basis to drawn general conclusions about likely future county level social vulnerabilities for the study area.

d. Spatial measures of hazard exposure

Climate-sensitive hazards, especially those related to water (or the lack of water) are among the most costly threats that face the United States. In fact, tropical storms/hurricanes, heat waves/drought, and flooding top the Billion Dollar Climate and Weather Disasters list for the time period 1980–2009 (National Oceanic and Atmospheric Administration 2010). Even without the influence of climate change to exacerbate their impacts, climate-sensitive events will continue to threaten lives and livelihoods (Diaz and Murnane 2008). There is a likely link between climate change and increases in climate extreme and severe hazard events (McCarthy et al. 2001; Parry et al. 2007; Allison et al. 2009; Karl et al. 2009). Understanding past and present exposure to climate-sensitive hazards can assist in planning for and mitigating against the impacts of future climate-sensitive threats such as heat and drought (Schär et al. 2004; Scott et al. 2004), flooding (Milly et al. 2002, 2005), and more intense hurricanes and tropical storms (Knutson and Tuleya 2008).

Using hazard exposure data on intense drought occurrence, hurricane winds, current flood risk, and projected sea level rise and inundation provides a set of measureable and geographically defined impact areas. To spatially compare the exposure across the different climate-sensitive hazards at the geographic scale of interest (the county), we standardized the exposure as an aggregate areal measure: the percentage of land area in each county affected by the individual hazard. While we recognize that the results lack precision at subcounty scales, it does provide a first approximation of the level of historic and future geospatial exposure to climate-sensitive hazards.

1) DROUGHT

Drought is a difficult hazard to define and measure because of the diverse geographical distribution, temporal nature of the event, and modifications of climate zones designations within the United States. Broadly speaking, drought is a deficiency of precipitation over an extended time period resulting in a water shortage for specific geographic areas, groups, or activities. Generally, the definition of drought in an arid or semiarid environment (west Texas, for example) is different from the definition of drought in a more humid climate (South Florida). There are also short-term droughts (lasting a few weeks or months) to longer-term droughts that last several months to years. One standard method for measuring the duration and intensity of long-term drought is the Palmer drought severity index (PDSI or PDI). The PSDI values range from −4 or below (extreme drought conditions) to +4 and above (extremely moist conditions), where 0 is deemed normal. For our analysis, we used values of −4 or below to identify counties experiencing extreme drought conditions. The PSDI monthly means were obtained online from the National Oceanographic and Atmospheric Administration (NOAA) Earth Systems Research Laboratory's Physical Science Division from 1978–2007 for each climate division in the study area (National Oceanic and Atmospheric Administration 2009). Using the data from the climate divisions, we computed the number of months that experienced severe to extreme drought (−4 or below on the PSDI) for

each county to derive an overall frequency of drought. We then used a three-class standard deviation method to differentiate between low, medium, and high frequencies of extreme drought months based on the raw counts by climate forecast zone. Since climate zone boundaries are sometimes different from county boundaries, spatial adjustments reconciled the geography so each county was spatially associated with intersecting climate zones. For each county, we computed the county area within the high category of extreme drought. We then took the county area in high extreme drought/total county land area and mapped the percentages using the three-class standard deviation method. This produced the county-level extreme drought hazard exposure classed into limited, moderate, and elevated categories.

2) Flooding

Geospatial data associated with the Federal Emergency Management Agency (FEMA)'s National Flood Risk Report (Federal Emergency Management Agency 2009) provided the input data for computing flood hazard areas. This report calculated the areal extent of each flood zone within every enumeration unit (U.S. Census block group) in the United States through a spatial intersect process. Data reflect the land area in the Special Flood Hazard Area (SFHA) by specific zones (e.g., A, AE, A1, A30, AH, AO, AR, A99, V, VE, V1–30). From these data, we calculated the total land area within the SFHA (more commonly known as the 100-yr flood zone) for each county in the study area. To compute the flood exposure area, we took the amount of land area within the SFHA as a percentage of the total land area within each county. Again, the map of flood hazard exposure used the three-class standard deviation method mentioned above.

3) Hurricane winds

There are two primary hazards associated with hurricanes: storm surge and wind. Storm surge is geographically restricted and accounts for a higher potential for loss of life. Hurricane winds have a broader geographic impact area and effect both coastal and inland areas. Given the overlap between flood zone delineations and storm surge inundation zones, we selected wind to characterize hurricanes. The creation of hurricane winds zones entailed the collection of storm tracks for all hurricanes during the past 30 yr (1978–2007) that either made landfall or were located within 100 miles of the U.S. mainland. These data came from the historical hurricane track data archive (National Oceanic and Atmospheric Administration 2007). Research indicates that the average diameter of hurricane force winds is 100 miles (Willoughby 2007). Accordingly, we defined the hurricane wind impact areas as 50 miles on either side of the linear historic hurricane track. After mapping the tracks, we created a 50-mile spatial buffer and computed the amount of land area within the hurricane wind impact zone for each county. The amount of land in the hurricane wind zone divided by the total land area in the county produced the percentage of land area affected. As before, the mapping of hurricane wind exposure used the three-class standard deviation method.

4) Sea level rise

We derived sea level rise hazard zones from digital elevation model (DEM) data available from the United States Geological Survey (USGS) 1/3 arcsecond national elevation dataset (NED). The size of the study area and the need for consistent and complete data at the subcounty level required the use 1/3 arcsecond NED data for this assessment. While better elevation data are available for individual states, this is not true for all the relevant coastal states in our study area. Because our primary concern was in the areal extent of potential exposure to the sea level rise hazard, we felt the use of USGS dataset provided an acceptable balance between spatial coverage, resolution, and accuracy.

We downloaded NED imagery from the USGS Seamless Data Server (http://seamless.usgs.gov/index.php). The files were entered into an ArcGIS Image Service to compensate for the sheer volume of data associated with this portion of the research (60+ GB for base imagery alone). Geo-rectified images for each state created from this regional image service enabled efficient spatial analysis at the state and substate levels. The projected sea level rise analysis utilized a 120-cm threshold based on the study by Titus and Narayanan (1995), which found a 1% chance of a 120-cm sea level rise along the eastern seaboard of the United States by 2100. Corroboration of this conservative estimate of near-term sea level rise is both in Rahmstorf (2007) and in news reports stemming from the International Scientific Congress on Climate Change in Copenhagen (Copenhagen Post 2009; Fahrenthold 2009). The approximation of sea level rise inundation follows a simple bathtub model adapted from Titus and Richman (2001) where the DEM is simply flooded until reaching the desired level of sea level rise. However, this approach is only as accurate as the underlying DEM. The vertical accuracy of NED data relies on coarse sources of elevation data (e.g., contour maps). Thus, the subsequent DEM and the modeled SLR are only very rough approximations of the areal extent of future inundation. When measured against the total amount of land subject to tidal flows and influences, the total percentage of land area in the projected sea level rise zone is equally a rough approximation.

Each state SLR subset was reclassified using a binary classification method. This allowed the identification of

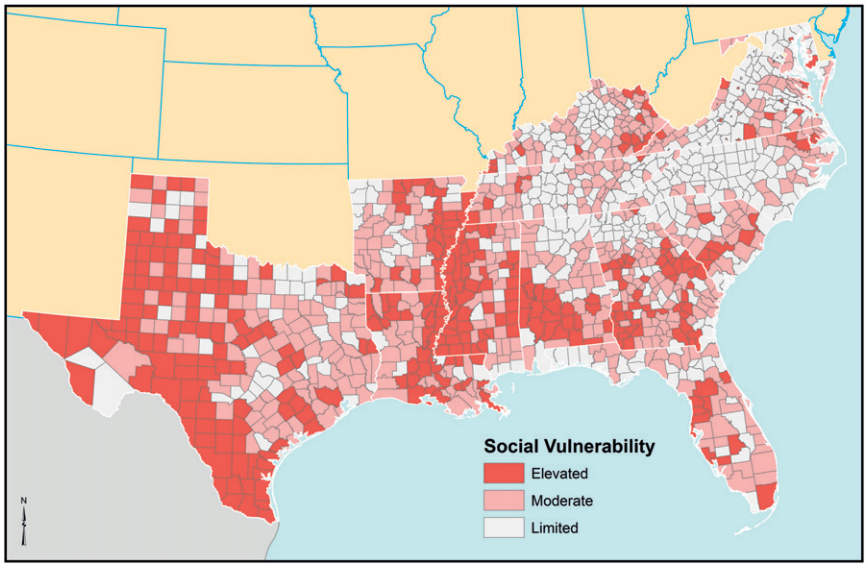

FIG. 2. Social vulnerability in the southern United States.

areas below the 120-cm sea level rise threshold. These were counted and then multiplied by the size of each pixel in the dataset (roughly 100 m^2), producing an estimate of the land area within potential sea level rise zones for each coastal county. The estimates divided by the total area within the coastal county produce the percentage of land in each county within a likely sea level rise inundation zone. These mapped percentages also used the three standard deviation scheme to maintain comparability with the other hazards of interest and the representation of social vulnerability.

4. Regional vulnerability to individual hazards

Irrespective of hazards, the geography of social vulnerability within the southern United States (Fig. 2) highlights concentrations of elevated levels in three primary areas. The first is the traditional cotton belt extending in an arc along the inland coastal plain from South Carolina through Georgia to southern Alabama. These socially vulnerable places are characterized by rural populations, a general lack of wealth, and higher than average special needs populations. A secondary cluster of elevated social vulnerability is present along Mississippi River Valley/Delta region. Here, the social vulnerability is a function of rural poverty, race, gender, and age (children and the elderly). A third major cluster of counties exhibiting elevated social vulnerability is in west Texas. The social vulnerability in this cluster is driven by ethnicity, gender, age (children), and poverty. Regions with comparatively lower levels of social vulnerability are in central Kentucky, central Tennessee stretching into northern Alabama, and along the Appalachian foothills and Piedmont region stretching from north Georgia through South Carolina, North Carolina, and Virginia. Many of the region's coastal counties, especially in southern Mississippi, southern Alabama, and in Florida's panhandle are also in the limited social vulnerability category. Similarly, many of the Atlantic coastal counties from St. Johns, Florida, to Dare County, North Carolina, also exhibit low social vulnerability, ostensibly due to more affluence, greater employment, and less racial and ethnic diversity within the counties.

a. Hazards exposure

Nearly a third of the study area experienced extreme drought hazards (<-4 PDSI values) during the past 30 yr, with 27% of the regional land area in an extreme drought zone. However, the pattern of drought was not uniformly distributed (Fig. 3a). The first concentration of elevated drought hazard exposure occurs in Appalachia, especially eastern Tennessee, north Georgia, north Alabama, and western North Carolina. This region had a persistent drought that averaged 21 months or the equivalent of 1.75 yr in the extreme drought category. Another cluster includes South Carolina, where 73% of the state experienced extreme drought during the past three decades (Fig. 4, darkest bar). Another large cluster is in central and west Texas, a semiarid region to begin with, but one that averaged more than 10 months in the extreme drought category according to the PDSI. Smaller clusters of elevated drought are present in central Florida, southern Mississippi, southern Louisiana, northern Kentucky, and Maryland. The case of Florida is interesting

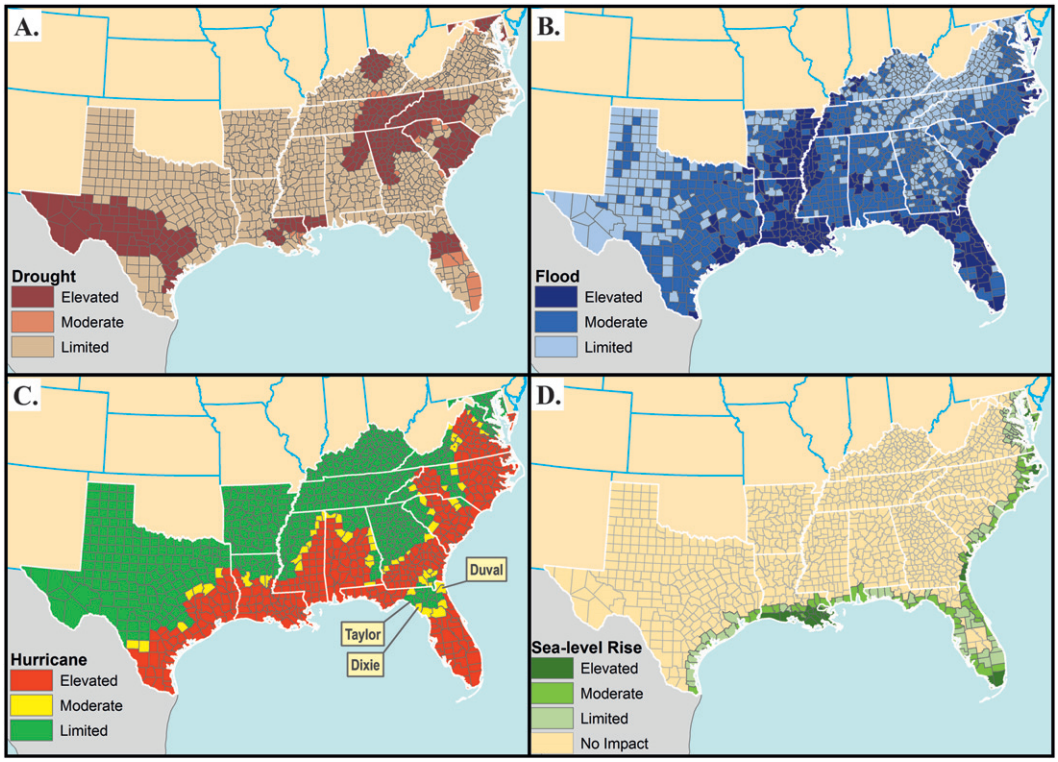

FIG. 3. (a) Drought hazard zones, (b) flood hazard zones, (c) hurricane wind hazard zones, and (d) sea level rise hazard zones for the southern United States.

because, as drought conditions persist in this humid region, there is an increased threat of wildfires due to the parched vegetation. While difficult to document accurately (wildfire data are not as readily available as other hazard data), there is speculation that Florida has seen an increase in the number of drought-induced wildfires during the past 30 yr and in all likelihood, an increase in property losses associated with them (Buckley et al. 2006; Pye et al. 2010).

Roughly 16 percent of the study region is in a FEMA-designated SFHA (100-yr flood zone). There is a distinctive regional pattern, with elevated exposure to flooding occurring in counties along the Mississippi River and its tributaries, and along the hurricane coast stretching from central coastal Texas through North Carolina (Fig. 3b). Within the elevated category, the percentage of county land area in FEMA-designated flood zones category ranges from 24% to 98%. Relatively low exposure to flood hazards dominates the arid region of west Texas and in the mountainous terrain along the Appalachians. While the percentage of land area in flood zones is near zero in these areas, both arid and mountainous places are subject to flash flooding, which could significantly affect residents outside the 100-yr flood plain areal designation. Summarizing this indicator to a statewide scale, the greatest flood hazard exposure based on land area in the SFHA is in Louisiana (48%) and the least in Virginia and Kentucky (8%) (Fig. 4—light gray bar).

The pattern of hurricane wind exposure clearly has a coastal bias stretching from south Texas to the Delmarva Peninsula in Maryland (Fig. 3c). Nearly 38% of the land area in the study area, including many inland and noncoastal counties, is within an elevated zone of hurricane wind exposure (Fig. 4—white bar). Yet there are a few interesting findings. First, the big bend region of Florida from Taylor and Lafayette counties across the state to Duval County (Jacksonville) is noticeable by the relative absence of elevated hurricane wind exposure. Within the past 30 yr, this swath of land has not experienced hurricane force winds. The second finding is the frequent penetration of hurricane force winds hundreds of miles inland, well beyond the coastal counties. This is especially significant in South Carolina (Hurricane Hugo in 1989), in Alabama and Mississippi (Hurricane Camille in 1969, Hurricane Frederick in 1979, and Hurricane Katrina in 2005), and in northern Virginia (Hurricane Isabel in 2003). This pattern of areal exposure to hurricanes shows that this climate-sensitive hazard is not just a problem for coastal counties, but for inland counties as well.

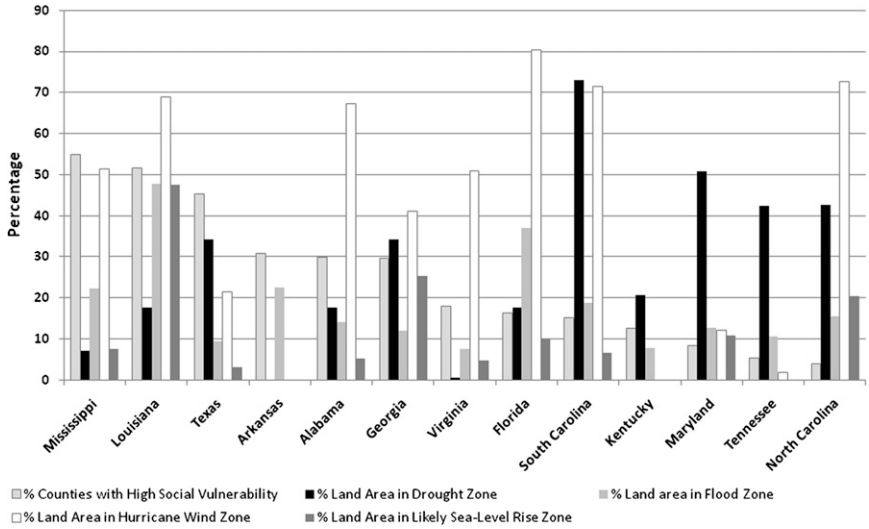

FIG. 4. The percentage of counties (by state) with elevated social vulnerability and the percentage of land area located within each of the four hazards analyzed.

Initial exposure to the potential effects of sea level rise will occur primarily in those counties immediately adjacent to the coast and in low-lying neighboring counties with tidal rivers. In this respect, the sea level rise hazard does not have an immediately perceptible impact on the vast majority of counties outside the immediate coast (Fig. 3d). For the 186 coastal (or near coastal) counties, stretching from south Texas to the Chesapeake, the impact of any significant amount of sea level rise will lead to a drastically different story. These counties include approximately 115 000 square miles of land area, nearly 16% of which is subject to probable inundation by the projected 120-cm rise in sea levels using the most current Intergovernmental Panel on Climate Change (IPCC) projections (Fig. 4—dark gray bar). There is considerable regional variability, with Louisiana having the greatest overall areal exposure, followed by Georgia and North Carolina. The lower areal exposure for Florida is a function of multiple instances where larger counties (by area) only have a fractional portion of the county with a tidal river segment, or a low-lying inland marsh, which is subject to sea level rise based on the modeling.

We fully recognize the scale of our analysis precludes the detailed level of study that can more accurately examine the areal extent of hazard exposure at localized levels. However, our intent was to draw singular and multihazard views of the region at a comparable scale, in this case the county. Our goal is a general depiction of social vulnerability and hazard exposure, one that provides a broad overview of which counties are the most vulnerable to climate-sensitive hazards and why (social factors or hazard exposure).

b. Intersection of social vulnerability and hazards exposure

To examine the relationship between social vulnerability and climate-sensitive hazard exposure, we employ a bivariate mapping technique. This procedure permits the visualization of the relationship between social vulnerability and hazard exposure for each county. This integration permits the overall assessment of vulnerability to climate-sensitive hazards based on hazard exposure and sensitivity (or social vulnerability).

County vulnerability to drought hazards is highest in Texas, followed by a concentration in Florida, South Carolina, and western Georgia (Fig. 5a). In Texas, the combination of the elevated exposure to extreme drought and the elevated social vulnerability driven by ethnicity, poverty, young families, and immigrant populations combine in the elevated category (shaded burgundy). In Florida, the counties in the elevated category (also shaded burgundy) have not only elevated exposures, but also elevated social vulnerability as a function of ethnicity and a large elderly population in these rural counties north of Tampa (Citrus, Hernando, Pasco, Marion). In South Carolina, the pattern of extreme drought and elevated social vulnerability is driven by counties with low income, minority, and female-headed households with limited education and employment. The impacts of the drought hazard may be greater in these counties because the disadvantaged populations have less capacity and ability to adequately prepare for, respond to, or adapt to the hazard.

While the flood hazard has both inland and coastal components, elevated county vulnerability to flooding

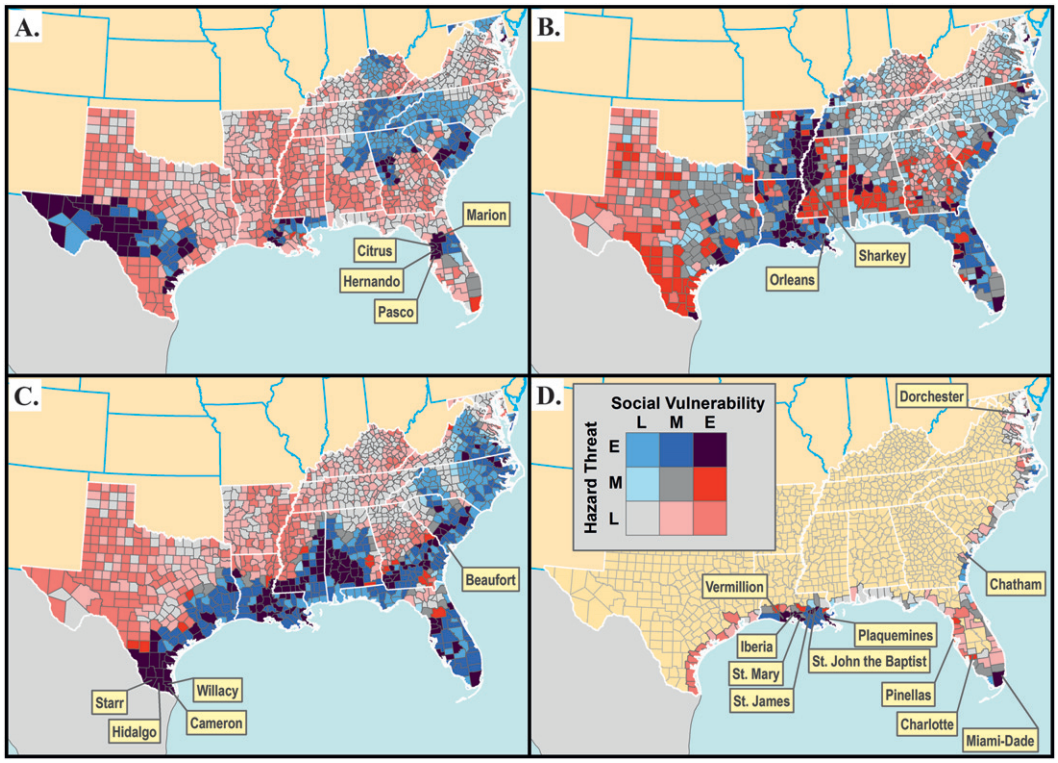

FIG. 5. Bivariate maps depicting place vulnerability to (a) drought hazard, (b) flood hazard, (c) hurricane wind hazard, and (d) sea level rise hazard for the southern United States (L = limited; M = moderate; and E = elevated).

(Fig. 5b) is concentrated in the lower Mississippi Valley, in western Alabama, and in a few coastal counties in Texas, Florida, and Maryland. For example, the concentration of vulnerability in the Mississippi River Delta region is a product of the elevated levels of social vulnerability and large percentages of land in the 100-yr flood zone. Specifically, in Orleans Parish, 88% of the land area lies within the SFHA. In combination with the elevated levels of social vulnerability characterized by race and gender, ethnicity (Hispanic), and special needs populations, this parish ranks among the most vulnerable in the nation. In Sharkey County, Mississippi, 79% of the county lies within the 100-yr flood plain. Coupled with equally elevated levels of social vulnerability, in this case attributed to race, gender, lack of wealth, and age, Sharkey County is also among the most vulnerable counties in the South to flood hazards.

While coastal counties contain most of the hurricane wind exposure, many inland counties also exhibit the highest level of county vulnerability to hurricane winds (Fig. 5c). The vast majority of the U.S. coastal counties exhibit limited to moderate levels of social vulnerability, largely due to the accumulation of wealth in these highly desirable locations. For example, Beaufort County, South Carolina, is one of the least socially vulnerable counties in the state and in the region. Home to Hilton Head Island, the county's social vulnerability is low because of the high per capita incomes, high house values, and a relative lack of significant special needs populations or renters. This lower level of social vulnerability attenuates the effect of the elevated exposure and suggests an inherent capacity within that county to adequately prepare for and respond to the hurricane wind hazard. In contrast, the rural coastal plain counties in South Carolina, which lie within the I-95 corridor, are among the most socially vulnerable in the state. The interaction of race, gender, lack of wealth, and rural populations coupled with the hurricane exposure produces greater impacts on these populations than those residing in coastal counties. This is also true in inland Mississippi and Alabama. Finally, there is a concentration of elevated levels of social vulnerability and hurricane wind hazards in the south Texas border region as a function of immigrant populations, females, young families, and lack of wealth (Cameron, Willacy, Hildago, and Starr). These counties have roughly the same level of wind exposure as other coastal counties but less capacity to prepare for, respond to, and recover from the impacts because of the elevated social vulnerability in the county.

Given the extreme exposure, coupled with the elevated levels of social vulnerability, the impact of sea level rise is greatest in southern Louisiana, specifically Plaquemines and the parishes adjacent to Vermillion and Atchafalaya Bays (St. Mary, Iberia, and Vermillion) (Fig. 5d). St. John the Baptist and St. Johns, containing Lake Maurepas and Lac Des Allemands, are also in the elevated category. Elsewhere, Miami-Dade, Florida (given the elevated social vulnerability), and Dorcester, Maryland (elevated exposure and elevated social vulnerability), complete the counties with elevated sea level rise vulnerability. Despite the potential for inundation, the remaining coastal counties either have limited exposures but elevated social vulnerability (areas shaded in dark red such as Pinellas and Charlotte Counties on Florida's west coast) or elevated exposures with limited levels of social vulnerability (areas shaded in dark blue such as Chatham County (Savannah, Georgia).

5. Multihazard exposure

Each of the climate-sensitive hazards has a different geography of exposure. While one can examine these individually, it is useful to gain an overall snapshot of the spatial variation in the cumulative area exposure. A summary of the areal extent of exposure for all four exceeds the total land area (e.g., adds up to more than 100%). Since we only have aggregate information for the entire county not the exact location of the hazard zone itself, we could not use a simple spatial overlay to compute the affected area. Taking a mean percentage exposure skews the distributions especially those that are bimodal (all or none of the county in the exposed hazard zones). Therefore, to produce the all-hazards or multiple-hazards perspective required a different statistical approach.

We used the exposure classifications and assigned a value of one to all counties in the limited category; a value of two for those in the moderate category; and a value of three for counties in the elevated category for each of the four hazard threats. We summed these scores to create a multihazard score (producing a ranking of the ranks). Each hazard is given an equal weight since there is currently no scientific evidence to support differential weighting for each of the four hazards analyzed here. The multihazard score has a theoretical range from 3 to 12 (a maximum value of 3 for each of the four hazards—flood, hurricane wind, drought, and sea level rise; and a minimum value of 1 for each them, plus a value of zero for sea level rise for the interior counties). The multihazard score was then classified into three categories using a standard deviation classification (limited = <-5 standard deviation, moderate = between -0.5 and $+0.5$ standard deviation, and elevated = >0.5 standard deviation) and mapped. This method allows for the simple disaggregation of county level scores for a comparative assessment of areas with elevated levels of hazard exposure. The approach also enables the intersection of multihazard exposure zones with social vulnerability.

Not surprising, once the climate-sensitive hazards aggregate to a multihazard exposure, elevated levels are found along the coasts, but not exclusively so. With the exception of a few north central Florida counties, Florida stands out with the greatest susceptibility to climate-sensitive hazards (Fig. 6a) based on its historic experience (hurricane/drought), current risk (flood), and projected sea level rise areal exposure as identified in this paper.

Despite the elevated levels of exposure to these hazards in the coastal counties, each of them has a different capacity to prepare for, respond to, or adapt to those hazards associated with climate extremes and variability. When paired with the social indicators, the individual county vulnerability becomes apparent (Fig. 6b). For example, counties in both the elevated exposure and elevated social vulnerability (shaded in burgundy) include most of coastal south Texas, portions of south Louisiana in the Atchafalaya basin, western Florida north of Tampa, in western Alabama, and the coastal plains of South Carolina. Many of the remaining coastal counties, are characterized by elevated exposures and moderate levels of social vulnerability (dark blue shades). However, other counties (in dark red), such as those in western Mississippi or west Texas, stand in stark contrast to this pattern with moderate levels of hazard exposure and elevated social vulnerability.

Because county vulnerability is a product of both the social vulnerability and hazard exposure, a broader range of underlying driving forces can be identified. Consequently, a one-size-fits-all intervention strategy for risk reduction, mitigation, and adaptation may not be as effective as one customized to the particular county. The geographic distribution of the hazard exposure, the social vulnerability, and the combination of the two provides a mechanism for targeted investments in mitigation and adaptation that are place specific. Hazard mitigation (regulating development in high-risk zones, improved building codes, mandated insurance) could reduce the impact of climate-sensitive hazards in those counties whose vulnerability is predominately based on hazard exposure (counties in burgundy or dark blue). For example, with the drought hazard, some states have implemented actions to improve water storage and collection capabilities as well as actions to reduce water usage of expanding populations through targeted water conservation programs (South Carolina Emergency Management Division 2009). Social mitigation (improved education, workforce development, enhanced economic opportunities)

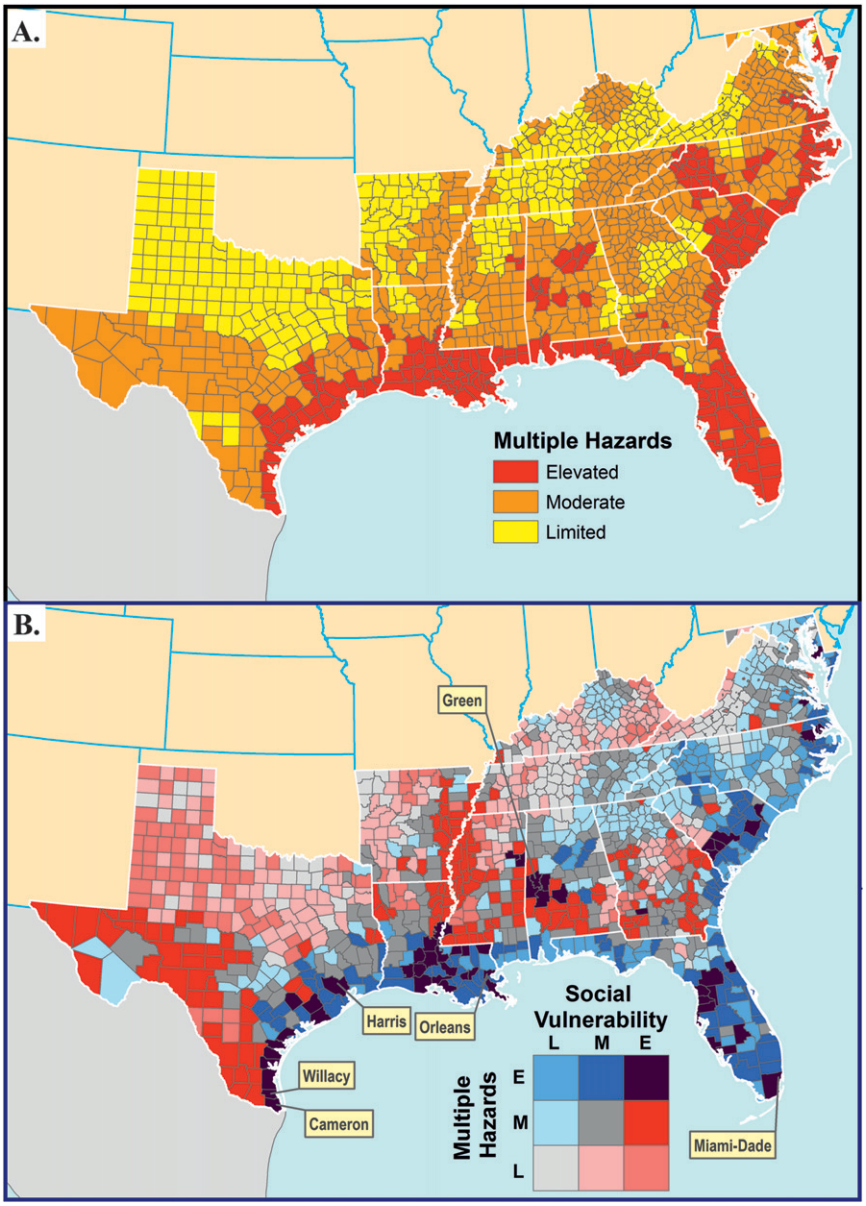

FIG. 6. (a) Combination of drought, hurricane wind, flooding, and sea level rise hazards into one multihazard map and (b) bivariate depiction of social vulnerability to multihazards for the southern United States (L = limited; M = moderate; and E = elevated).

might be more effective in those counties where the overall vulnerability is primarily a function of social conditions (counties in burgundy or red). Again using a drought example, social mitigation, especially in rural agricultural areas, could include provision of alternative (nonfarm related) employment opportunities or markets for selling nonproductive assets at fair value (Wilhite and Buchanan-Smith 2005). As Fig. 6b illustrates, the bivariate mapping approach clearly shows the variability in county vulnerability to climate-sensitive hazards. Further, the mapping also graphically illustrates the driving factor behind it—mostly hazard exposure, mostly social vulnerability, or a combination of elevated levels of both. Simply put, geographic space matters and the intervention strategies employed can vary depending on the social vulnerability of the population and the hazards exposure unique to that place.

6. Hotspots

There are a number of counties in the region labeled ''hotspots'' because they contain elevated hazard exposures and elevated levels of social vulnerability

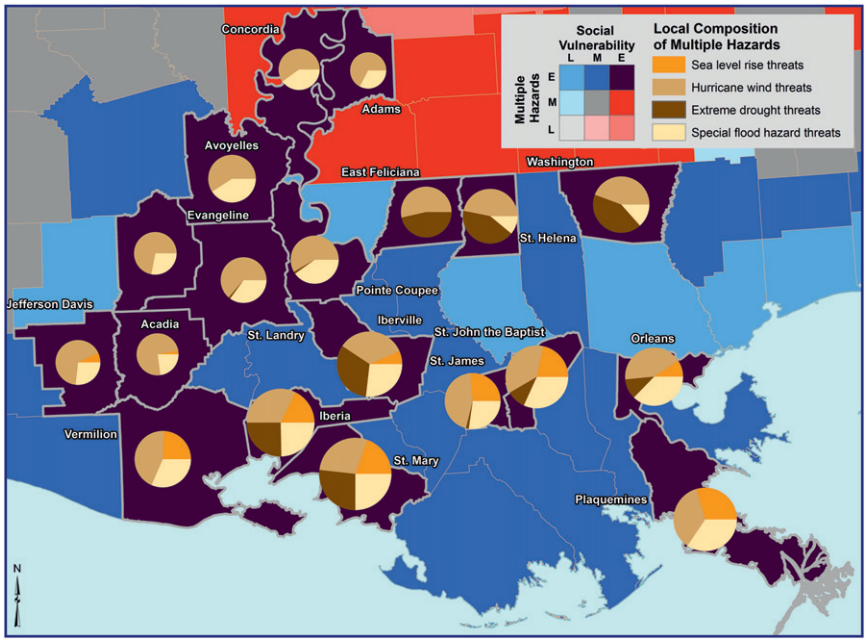

FIG. 7. Downscaling of hotspot analysis for southern Louisiana. Note that the size of each pie chart is representative of the percentage of land area within the four hazards analyzed, and the slices represent the relative proportions of exposure by each hazard.

(depicted in burgundy in Fig. 6b). There are two distinct patterns that are evident when examining these counties as a group: highly urbanized and densely populated counties that contain the extremes of wealth and inequalities (very rich to poverty populations; educated to less educated); and rural counties that contain mostly disadvantaged populations based on poverty, race and ethnicity, age, and gender. Based on 2010 population estimates, approximately 12.4 million people (or 11.6% of the southern U.S. population) live in these hotspots. Over half of the region's population in the hotspots live in two urban counties—Harris, Texas (metropolitan Houston), and Miami-Dade, Florida (metropolitan Miami). On a state-by-state comparative basis, Louisiana has 23% of its population living in these hotspot counties, 29% of Florida residents reside in elevated hazard and social vulnerability zones, and about 20% of Texans live in elevated hazard and social vulnerability areas.

In the urban counties, all of them coastal, the factors contributing to social vulnerability are varied. For example, in Cameron County, Texas (Brownsville), poverty is one of the driving factors increasing the social vulnerability along with ethnicity, gender, and age (children). In Orleans Parish (New Orleans) race, ethnicity, and special needs populations are the most significant contributors, but wealth reduces the overall score. The same is true in Harris County, Texas (Houston), where age (children), ethnicity, and single sector employment (oil and gas) contribute to social vulnerability within the county, but again wealth reduces the score. Finally, Miami-Dade, Florida, is the last example of urban social vulnerability where the drivers are ethnicity and gender, but wealth moderates the overall score. In terms of hazard exposure, it is hurricane winds (100% area coverage for the urban counties mentioned above), coupled with flooding (and in the case of Orleans Parish and Miami-Dade, sea level rise) that is contributing to county vulnerability.

In the rural hotspot counties, the factors producing the social vulnerability are more homogenous and include poverty, race and ethnicity, age, and gender. For example, in Willacy, Texas, ethnicity (Hispanic), age (children), and poverty contribute to its elevated score on the SoVI. In Greene, Alabama, the social vulnerability score is a function of race, rural agricultural residents, and poverty, in that order.

Taking a closer look at the driving forces of hazard exposure for those places characterized by elevated levels of vulnerability provides a more comprehensive understanding at a substate level. For example, hotspots in Southern Louisiana are compared to each other through a visualization of the combined threats for each parish (Fig. 7). Every "hotspot" parish has elevated social vulnerability but each has a different set of hazard exposures driving the overall vulnerability related to climate-sensitive hazards. For example, parishes such as Adams,

Concordia, Avoyelles, and Evangeline only have two main hazards (flooding and hurricane wind threats) as a potential focus for hazard mitigation, others such as Orleans, St. John the Baptist, St. Mary, Iberia, and Iberville continue to contend with all four climate-sensitive hazards. This visualization also provides a unique way of displaying the total land area within each hazard zone. Larger pie charts indicate more parish land area in each of the hour hazard zones. Therefore, although neighboring Acadia, Vermillion, and Jefferson Davis Parishes are exposed to the same hazards, the percentage of land total land area threatened in Vermillion is double that of Acadia and Jefferson Davis. Further, the proportional distribution of the areal extent of hazards exposure is different as well.

These examples of hotspots serve to identify where intervention strategies may garner the most success. In the rural hotspot counties, improvements in housing (making existing housing more resistant to wind; construction of affordable single family detached housing instead of relying on manufactured housing or mobile homes), may lessen the impact of hurricane winds. Redirecting development away from high-hazard areas through land use and growth management planning, especially along the hurricane coasts, is another strategy (Deyle et al. 2008). Purchase of homes and relocation out of the floodplain (especially for low-income communities) is another intervention for reducing the hazard impact. Conversely, subsidizing federal flood insurance for disadvantaged populations is another opportunity for both hazard and social mitigation. In urban areas, the differential provision of preparedness resources (transportation during evacuations, individual assistance for sheltering) to the most vulnerable populations, and differential assistance postdisaster could ease the burdens on these populations who lack the capacity and resources to recover from hazards and disasters in a timely fashion. Lastly, fostering a culture of self-sufficiency and empowering communities to be on their own for a week or more during the emergency period would go a long way toward building disaster resilience in both urban and rural hotspots.

7. Conclusions

This paper provides a broad overview of social vulnerability to climate-sensitive hazards in the southern United States. As we have demonstrated, geography matters, and there are considerable differences not only in the patterns of social vulnerability but in the patterns of hazards exposure as well. From a regional- or state-level perspective, we see distinct clusters of exposure and social vulnerability, yet one should not assume that all individuals or places within that broad region conform to those descriptors or generalizations. Instead, the appropriate use of this analysis is as a filter for determining where strategic initiatives and investments at the county level might be most productive. To assess specific mitigation opportunities would require better geospatial understanding of the intersection between localized patterns of social vulnerability (at a subcounty level) and the identification of the spatial interactions between populated places and hazard zones (not measured in percentage area covered) so the true nature of the hazard exposure and the social vulnerability is more accurately represented.

We know that the patterns of social vulnerability vary across the landscape. We also know that the likely impact of hazard events related to climate variability and change is not an exact science at present. However, creating useful information for emergency management, hazard mitigation, public policy, and community education by mapping known and probable impacts from hazard events and the socioeconomic characteristics of the population is the first step. The idea of place vulnerability is not a new concept, but it does provide a powerful impetus for how we deal with disaster events now and into the future. As a nation, we generally understand that certain disaster events occur in specific geographic areas. We are less aware of the specific spatial impact areas for the major disaster events that unfold year after year in this nation—in other words, the geography of hazards vulnerability. We also know that certain segments of the population are better able to respond to and recovery from the impacts of these disaster events than others. What is lacking is the ability to determine how these two processes interact with one another to produce place-specific vulnerability to hazards, and to present this information in a useful form to decision-makers, planners, and advocates. This paper demonstrates the ability, in very broad terms, to represent the geographical patterns of climate-sensitive hazards and social vulnerability, as the first step toward developing hazard reduction strategies and improving disaster resilience for some of the nation's most disadvantaged areas. Failure to produce effective mitigation and adaptation plans or a lack of understanding of those hazards associated with climate change variability and the likely populations most affected is no longer a viable excuse for inaction. With the methods and information provided in this paper serving as the scientific basis for planning and intervention, a failure to plan now is equal to planned failure during the next major disaster event.

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