Hurricane Vulnerability in Latin America and The Caribbean: Normalized Damage and Loss Potentials

Roger A. Pielke Jr.[1]; Jose Rubiera[2]; Christopher Landsea[3]; Mario L. Fernández[4]; and Roberta Klein[5]

Abstract: In late October 1998, the remnants of Hurricane Mitch stalled over Honduras and Nicaragua, killing more than 10,000 people and causing as much as $8.5 billion in damage. While Central America and the Caribbean have a history of natural disasters, the fatalities and destruction caused by Mitch were the greatest in at least several decades, prompting many questions including: What accounts for the extent of these losses? Is Mitch a harbinger of future disasters in the region? and What might be done in response? This paper seeks to shed light on these questions by examining the historical and geographic context of hurricane vulnerability in Latin America and the Caribbean. The paper examines trends in economic and other societal factors that increase vulnerability to hurricanes in Central America and the Caribbean and includes a case study of normalized hurricane losses in Cuba made possible by newly collected damage data published herein. The paper places its findings into the context of policies related to climate change and natural hazards.

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Introduction: Hurricane Mitch and Regional Vulnerability

In late October 1998, the remnants of Hurricane Mitch stalled over Honduras and Nicaragua, killing more than 10,000 people, affecting 6.7 million, and causing as much as $8.5 billion in damage (IFRCRCS 1999; U.S. House of Representatives Committee on International Relations 1999). Mitch was one of the deadliest Atlantic hurricanes in recorded history, ranking second to the 1780 "Great Hurricane" in the Lesser Antilles (Table 1).

The United States provided $300 million in aid in the immediate aftermath of Hurricane Mitch (White House 1999). Donor nations and nongovernmental organizations later pledged $9 billion in aid to the countries affected by Hurricane Mitch, including an additional $1 billion from the United States for reconstruction assistance, disaster mitigation, and debt relief. The Inter-American Development Bank and World Bank pledged $5.3 billion for debt relief and other projects (World Bank 2002).

[1]Director, Center for Science and Technology Policy Research, Cooperative Institute for Research in Environmental Sciences, Univ. of Colorado–Boulder, Campus Box 488, Boulder, CO 80309-0488.

[2]Chief, National Dept. of Predictions, San Bernardino 278; e/Serrano y Durege, Stos. Suarez, La Habana, Cuba.

[3]Research Meteorologist, Hurricane Research Division, Atlantic Oceanographic and Meteorological Laboratory, National Oceanic and Atmospheric Administration, 4301 Rickenbacker Causeway, Miami, FL 33149.

[4]Economist, Researcher, and Professor, World Economy Research Centre, No. 309, 22 St. and 5th Ave., Miramar, Havana, Cuba.

[5]Managing Director, Center for Science and Technology Policy Research, Cooperative Institute for Research in Environmental Sciences, Univ. of Colorado-Boulder, Campus Box 488, Boulder, CO 80309-0488.

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Mitch started out as a tropical wave and was upgraded to a Category 5 hurricane by October 26. The storm weakened by the time it made landfall on October 29 and was downgraded to a tropical storm by October 30. Although its winds decreased by landfall, Mitch produced heavy rains that approached a year's average rainfall in some areas (Ferraro et al. 1999; IFRCRCS 1999). These rains led to flash floods and landslides that killed thousands of people who inhabited exposed areas (Guiney and Lawrence 1999). While Mitch's impacts were greatest in Honduras and Nicaragua, it also affected El Salvador, Guatemala, Belize, and Costa Rica.

Central America and the Caribbean have a history of natural disasters, but the fatalities and destruction caused by Mitch were the greatest in at least several decades. The tremendous devastation and loss of life has prompted many questions, such as: What accounts for the extent of these losses? Is Mitch a harbinger of future disasters? and What might be done in response? This paper seeks to shed light on these questions by examining the historical and geographic context of hurricane vulnerability in Latin America and the Caribbean.

Several recent studies argue that understandings of societal impacts of hurricanes and other extreme events have at times been based on incorrect assumptions and misinterpreted data (e.g., Pielke and Landsea 1998; Kunkel et al. 1999; Pielke et al. 2000; Pielke and Downton 2000). Poor understandings are particularly significant when they form the basis for policy making in response to the growing impacts of weather and climate on society (Pielke and Pielke 1997; Pielke 1998; Pielke et al. 1999). A more accurate understanding of weather impacts necessarily acknowledges the actual and potential influences of *both* changes in climate and changes in society. In the United States, for example, economic impacts of hurricanes increased dramatically during a prolonged period of relatively benign hurricane activity (Pielke and Landsea 1998). The implication is that the single largest factor conditioning the growth in hurricane losses in the United States is rapidly increasing coastal population and wealth, *not* changes or variability in climate (Landsea et al. 1999).

Table 1. Loss of Life from Central American and Caribbean Hurricanes

Hurricane	Date	Area struck	Deaths
Great Hurricane	October 1780	Martinique, St. Eustatius, Barbados, Offshore	22,000
Hurricane Mitch	October–November 1998	Central America	10,000
Hurricane Fifi	September 1974	Honduras	3,000–10,000
Unnamed	September 1930	Dominican Republic	2,000–8,000
Hurricane Flora	September–October 1963	Haiti and Cuba	7,200–8,000
Unnamed	September 1776	Martinique	$>$6,000

Note: Data from Rappaport and Fernandez-Partagas (1997), NCDC (1999), and IFRCRCS (1999).

The case of hurricanes in the United States, however, is not necessarily representative of tropical cyclone impacts in other regions or of the impacts of other phenomena such as floods. This paper examines trends in economic and other societal factors that increase vulnerability to hurricanes in Central America and the Caribbean, introducing a simple normalization methodology that can be used to estimate the losses that would be associated with historical hurricanes if they occurred under current societal conditions. The findings are then placed in the context of policies related to climate change and natural hazards.

Regional Climatology

Hurricane activity varies greatly throughout Latin America and the Caribbean. All portions of Latin America (including Central America and South America) south of 10°N latitude had a less than 1% chance of a hurricane strike per year. The annual likelihood of hurricane activity increased farther from the equator to a maximum of $>$20% northeast of the Bahamas. While the coastal region with the greatest hurricane activity anywhere in the Atlantic basin was extreme South Florida (~15% annual chance), many locations throughout Latin America and the Caribbean had at least a 10% annual chance of experiencing a hurricane. These include: the Lesser Antilles from Martinique northward through the British and U.S. Virgin Islands, Puerto Rico, southern Haiti, Dominican Republic, the northern and central Bahamas, western Cuba, and the Cayman Islands. Locations with a moderate hurricane risk (5–10% annual chance) are the Lesser Antilles from Grenada to St. Lucia (including Barbados), northern Haiti, eastern and central Cuba, Jamaica, the southern Bahamas, Turks and Caicos Islands, Honduras, Belize, the Yucatan, and the western Gulf of Mexico coast of Mexico. Locations with a smaller risk of hurricane impacts (1–5% annual chance) are Trinidad and Tobago, northern Venezuela, northern Colombia, Panama, Costa Rica, Nicaragua, and the Bay of Campeche coast of Mexico. Clearly the hurricane risk varies tremendously (e.g., by a factor of 12 from Trinidad to the British Virgin Islands) throughout the region, but no coastal community north of 10°N is immune to the effects of hurricanes.

The hurricane tracks represented by Fig. 1 help illustrate how these empirical probabilities for Caribbean hurricanes can vary dramatically from one decade to another. These figures highlight the differences between the active 1940s to 1960s versus the quiet 1970s and 1980s. In general for the whole region, accurate records extend back to the mid-1940s, when aircraft reconnaissance provided reliable measures of intensity and position (Neumann et al. 1999).

Fig. 2 presents the yearly counts of hurricane strikes [from the National Hurricane Center's "best track" file; Jarvinen et al. (1984)] in subportions of the basin. Central American hurricanes [those striking Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama; Fig. 2(a)] show rather pronounced year-to-year variability from a peak of two hurricanes in 1961 and 1974 to none occurring in several years, but rather small decadal changes. The long-term average is 0.2 hurricane strikes per year. Extreme hurricane events occurred in 1955 (Janet), 1961 (Hattie), 1974 (Fifi), and 1998 (Mitch).

The Northern Caribbean [Bahamas, British Virgin Islands, Cayman Islands, Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico, Turks and Caicos and U.S. Virgin Islands; Fig. 2(b)] hurricanes, in contrast, show high interannual variability as well as large multidecadal changes. Hurricane activity was relatively high from the 1940s to the late 1960s and in the late 1990s, while the period from the early 1970s until the mid-1990s was by contrast relatively quiet. Of the five large-impact hurricane events for this region, four [Charlie (1951), Fox (1952), Flora (1963), and Inez (1966)] were in the earlier active period, while only one [David (1979)] occurred during the quieter decades. The long-term average for the Northern Caribbean is 1.0 hurricane strikes per year.

The Southern Caribbean [Antigua and Barbuda, Barbados, Dominica, Grenada, Guadeloupe, Martinique, Montserrat, Nether-

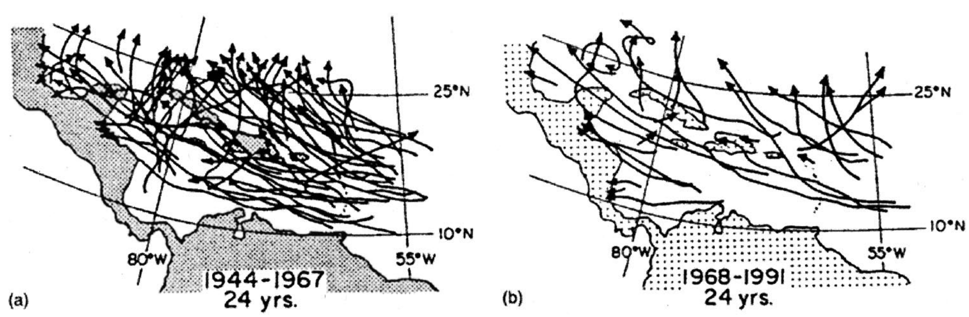

Fig. 1. Contrast of hurricane tracks in the Caribbean for multidecadal periods of: (a) 1944–1967; (b) 1968–1991 (Landsea 2000a)

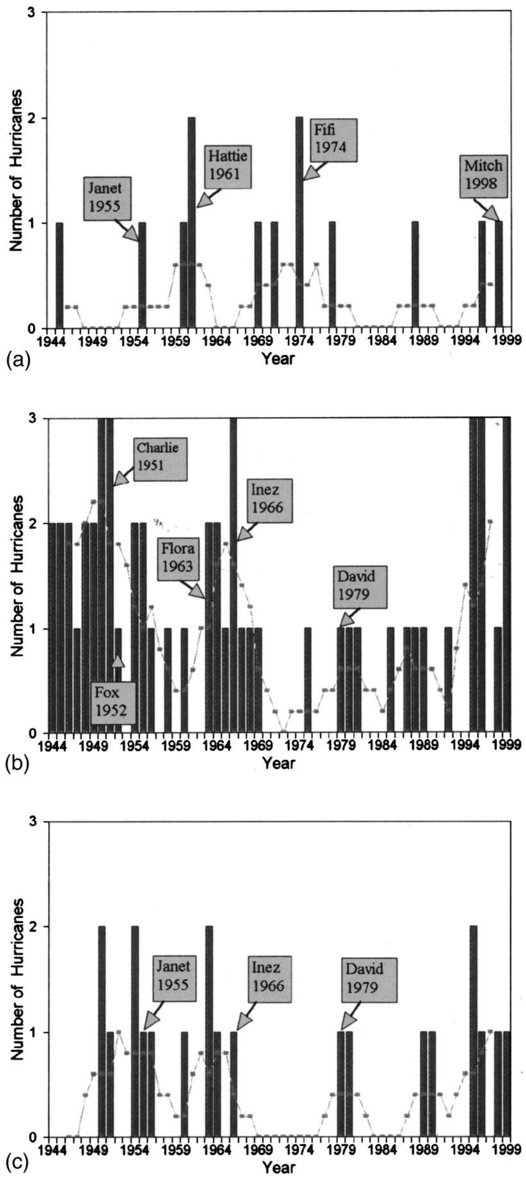

Fig. 2. 1944–1999 time series of (a) Central American, (b) Northern Caribbean, and (c) Southern Caribbean hurricanes (line represents moving 5-year average)

lands Antilles including St. Kitts and Nevis, St. Lucia, St. Vincent, and the Grenadines, and Trinidad and Tobago; Fig. 2(c)] experiences hurricanes at a lower rate than the Northern Caribbean with only 0.4 hurricane strikes per year. Though the region has the lowest total frequency of events in the Caribbean, it also shows pronounced variability as observed in the Northern Caribbean: active in the 1950s to mid-1960s, relatively quiet from the late 1960s through the mid-1990s, with only two interruptions in 1978–79 and 1988–89, and then active from 1995–1999. This region has been hit by three large-impact hurricane events since the mid-1940s: Janet (1955), Inez (1966), and David (1979).

On an interannual timescale, La Niña events, low vertical windshear, the west phase of the stratospheric quasibiennial oscillation, low sea-level pressures, and warm tropical North Atlantic/Caribbean sea surface temperatures (SSTs) favor enhanced activity throughout Latin America and the Caribbean (Gray 1984; Gray et al. 1994; 1997; Goldenberg and Shapiro 1996; Knaff 1997; Saunders and Harris 1997; Landsea et al. 1999). In contrast, Caribbean hurricanes were reduced during seasons with an El Niño event, high vertical windshear, east stratospheric quasibiennial oscillation, high sea-level pressures, and cool SSTs. Decadal variation is predominantly observed in the Northern and Southern Caribbean, and much less so in Central America [Figs. 2(a–c)].

In recent years, the documented variability of hurricanes in the region suggests the beginnings of a more active regime. Goldenberg et al. (2001) provide evidence from Atlantic Ocean sea surface temperatures, atmospheric circulation patterns, and the time series of Atlantic hurricanes themselves that 1995 marked a distinct switch back to active conditions last seen in the 1940s to 1960s. If conditions persist as they did last century, high levels of hurricane activity may prevail for the next two to three decades. Such a change would be most evident in the Northern Caribbean (1.3 hurricanes per year in the active era versus only 0.4 hurricanes per year that occurred in the quiet era of 1971–1994) and the Southern Caribbean (0.4 versus 0.2 hurricanes per year), but would not cause a significant change in Central American hurricanes (0.2 hurricanes per year in both regimes).

Normalized Losses and Economic Loss Potentials

As the previous section indicates, in the early years of the twenty-first century, Central America and the Caribbean may be in a more active hurricane period similar to that of the 1940s through 1960s. If so, this would undoubtedly result in increased potential for economic and human losses in the region, with Hurricane Mitch as a possible harbinger of things to come. But would a change in climate tell the whole story? This section explains the importance of societal factors for understanding increases in hurricane-related damage and loss of life.

Data and Methodology

Consider the case of hurricane losses in the United States as an introduction to the concept of normalized losses (NL). Extensive research has been conducted on normalized hurricane and flood losses in the United States (e.g., Pielke and Landsea 1998; Pielke et al. 1999, 2000; Pielke and Landsea 1999; Pielke and Downton 2000; Brooks and Doswell 2001). The National Oceanic and Atmospheric Administration's National Hurricane Center has kept records of total continental U.S. damage related to hurricanes since 1900 (Hebert et al. 1997). The raw data are inappropriate for trend analysis, because large societal changes have resulted in dramatic growth in recorded losses, even as hurricane landfalls decreased during the later decades of the twentieth century (Landsea 1993; Pielke and Landsea 1998). Nevertheless, it is possible to identify a climate signal in the damage data by normalizing the dataset to present-day values by accounting for the most significant societal changes (Pielke et al. 1999; Pielke and Landsea 1999).

A normalized loss dataset is based on three factors: inflation, wealth, and population. These factors are used for several reasons [see Pielke and Landsea (1998) for discussion]. First, accounting for inflation/deflation is necessary because the value of a currency changes over time. Second, increases in wealth and population mean more people and more property located in exposed areas, so that, consequently, more can be lost. Data on all three factors for the United States are kept by the U.S. government and allow for the creation of a normalized loss dataset for 1925–2001 [and alternatively back to 1900 with simplifying assumptions, after

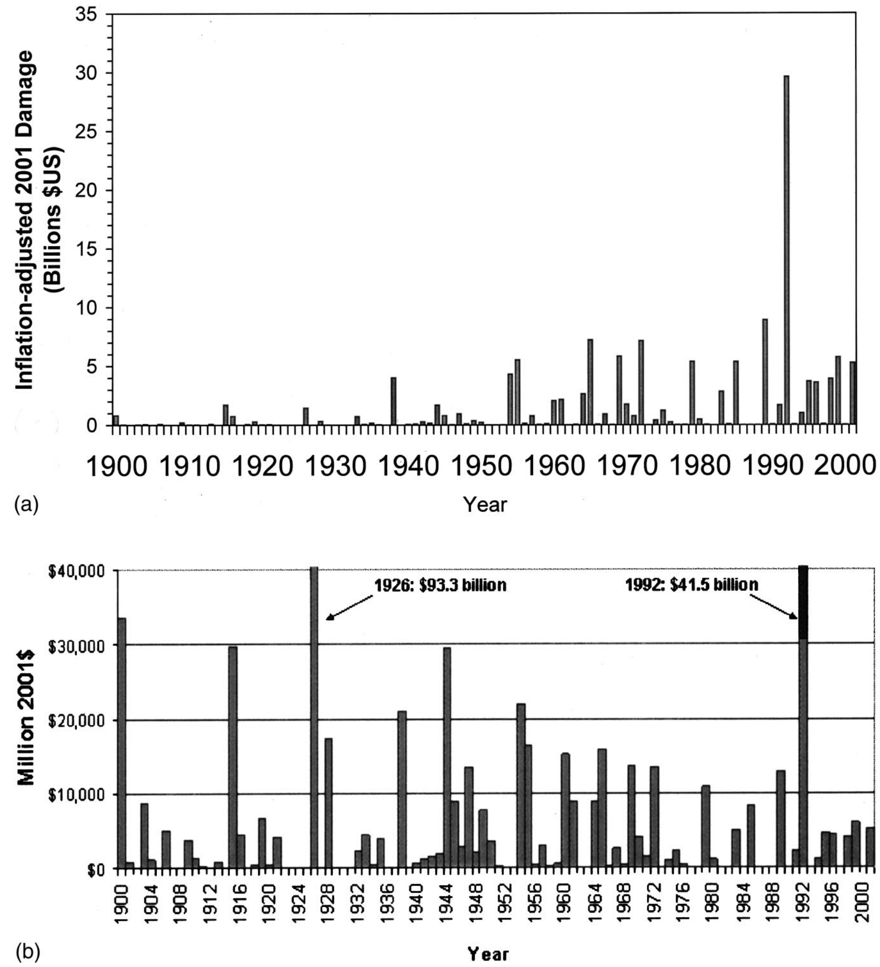

Fig. 3. 1900–2001 U.S. hurricane damage: (a) adjusted for inflation; (b) normalized to 2001 values

Pielke and Landsea (1998)]. The result of normalization is an estimate of the economic impact of any storm had it made landfall in 2001. Fig. 3(a) shows growth in inflation-adjusted losses from hurricanes in the United States from 1900–2001. This figure shows more damaging events as the twentieth century progressed. When these losses are normalized by adjusting for increases in population, wealth, and inflation, as shown in Fig. 3(b), it is readily apparent that more frequent events with greater associated losses would have occurred earlier in the century had the societal context of today existed at that time. One implication of this work, largely unrecognized in discussion of climate policy, is that societal factors dominate trends and projections related to the impacts of extreme climate events (cf. Pielke et al. 2000).

Pielke and Landsea (1999) provide support for the validity of the assumption that hurricane losses increase in proportion to increases in population, wealth, and inflation by comparing the normalized record of hurricane losses with climatological data on the El Niño/Southern Oscillation (ENSO), which has a well-established relationship to hurricane activity in the Atlantic (Landsea 2000a, b). During El Niño years, hurricane activity tends to be suppressed in the Atlantic, while during La Niña years it is enhanced. When normalized hurricane damage in the various phases of the ENSO cycle very closely resembles overall variations in hurricane activity within the ENSO cycle documented from climatological data (Bove et al. 1998; Pielke and Landsea 1999). In addition, Pielke et al. (1999) provide data showing that a normalized damage record compares favorably with the output of catastrophe models the insurance industry uses to estimate damage. These findings lend support to the notion that a normalization methodology can account in large part for the societal changes that underlie trend data on hurricane impacts, creating a data series that more accurately identifies the unique effects of climate variability and thereby presents a more realistic view of trends in past damage.

Economic data on hurricane damage in Central America and the Caribbean are even more limited than in the United States. Data since 1950 suggest that hurricanes in recent decades have caused greater economic losses than those of past decades [cf. Rodriguez (1997) and the data used in the Cuban case study presented later in this paper]. The more complete U.S. record (non-normalized) shows a similar trend of increasingly damaging hurricanes. While intense Atlantic hurricanes were more common between the 1940s and 1960s, they were in comparison much reduced in the 1970s through the early 1990s (Landsea et al. 1999). Thus, it is logical to hypothesize that increasing societal vulnerability, rather than more frequent or intense hurricanes, is the primary cause of increasing hurricane-related losses in Central America and the Caribbean, as has been shown to be the case in the United States.

Fig. 4 shows population growth in selected Central American countries, Northern Caribbean islands, and Southern Caribbean islands. Mexico is not included in this study, even though it has considerable historical losses and vulnerability to hurricanes. Mexico's geographic extent would require a detailed examination

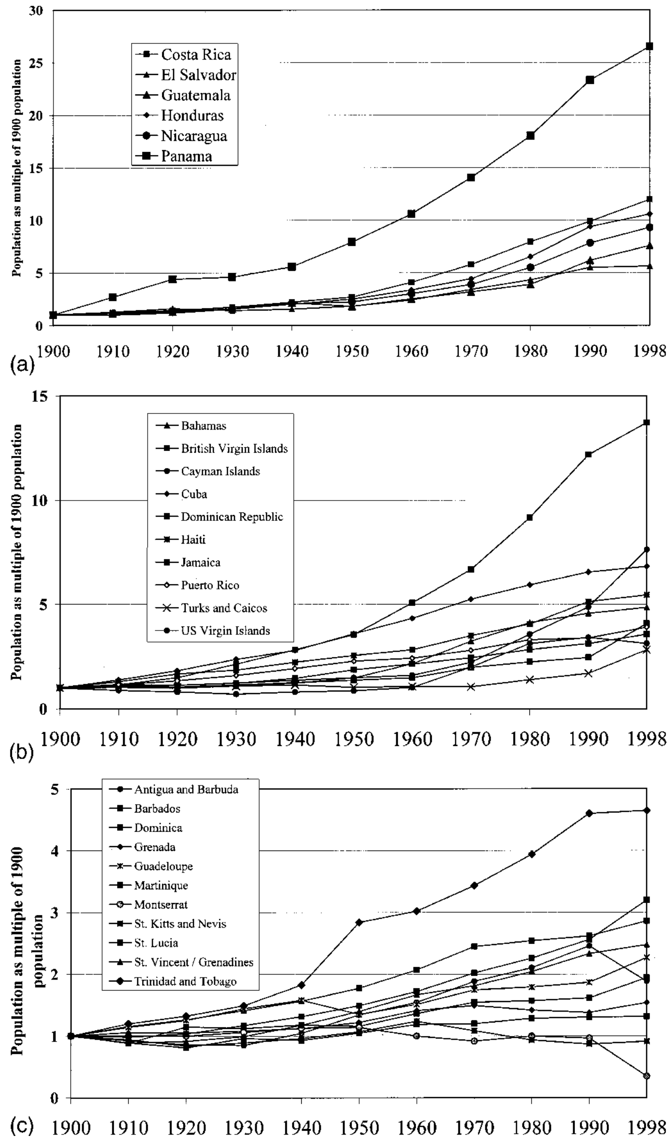

Fig. 4. 1900–1998 population as multiple of 1900 population for selected (a) Central American countries; (b) Northern Caribbean islands; (c) Southern Caribbean islands [data from *Encyclopedic World Atlas* (1997); *The Economist* (1990); Mitchell (1998); World Almanac (1900, 1906, 1916, 1926, 1936, 1946, 1956, 1976, 1988, 1990, 1998); Anuario Estadistico de Cuba (1987, 1997); *Cuba en Cifras* (1998)]

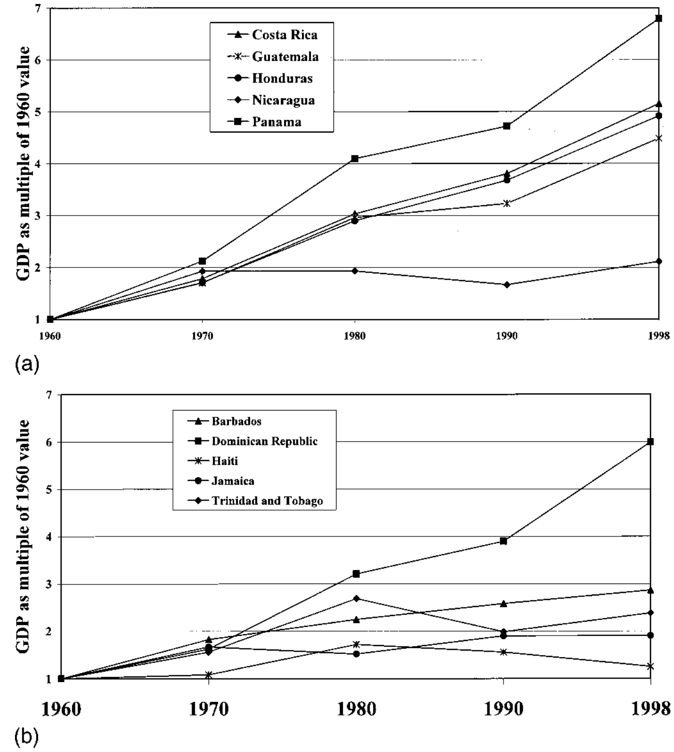

Fig. 5. 1960–1998 GDP as multiple of 1960 GDP for selected (a) Central American countries; (b) Caribbean countries (data provided to writers by Inter-American Development Bank Statistics and Quantitative Analysis Unit, Integration and Regional Programs Department)

of historical economic and demographic data that goes well beyond the scope of this study. Thus, an exploration of trends in hurricane vulnerability in Mexico awaits further study.

To facilitate comparison of population growth among these countries, the graphs set the 1900 population at 1, with population for successive periods shown as a multiple of the 1900 population. For example, Costa Rica's 1998 population was approximately 12 times larger than its 1900 population [Fig. 4(a)] and the Dominican Republic's 1998 population was almost 14 times as great as its 1900 population [Fig. 4(b)].

Figs. 5 and 6 show changes in wealth, as measured by gross domestic product (GDP) and per capita GDP, in selected Central American and Caribbean countries. [On GDP as a measure of wealth, see World Bank (1993) and Moulton et al. (1999); on its limitations, see Cobb et al. (1995).] In the analysis described as follows, because of the limitations of available data, GDP is used instead of direct measurements of aggregate national wealth under an assumption that changes in GDP will be highly correlated with measures of changes in national wealth; per capita GDP factors out the effects of population growth. For example, Fig. 5(a) shows that, from 1960 to 1998, national GDP in Costa Rica increased by a factor of about 5. Fig. 6(a) shows that the average per person GDP in Costa Rica increased by only about 1.5 times during the same period. The difference is accounted for by the overall growth in Costa Rica's population. For purposes of normalizing hurricane damage, more precise explanations for growth (or declines) in vulnerability are possible by differentiating between growth in population and growth in wealth. Thus, where data are available, we seek to separate out population growth from overall GDP growth.

Data on growth in population, wealth, and inflation allow for normalization of hurricane damage from any given year to estimate roughly what the economic losses would have been if the storm occurred in a different year under different societal conditions. The general approach for normalizing losses from a single storm that impacts several countries is as follows:

$$NL_x = \sum L_{y,c} \cdot I_{y,c} \cdot W_{y,c} \cdot P_{y,c}$$

where x = year in which losses are to be estimated; y = year of storm's actual impact; c = country of storm's impact; NL_x = storm loss normalized to year x; $L_{y,c}$ = storm's actual losses in country c, in current-year dollars (not adjusted for inflation); $I_{y,c}$ = inflation factor, determined by the ratio of the implicit price deflator for country c in year x to that of year y; $W_{y,c}$ = wealth

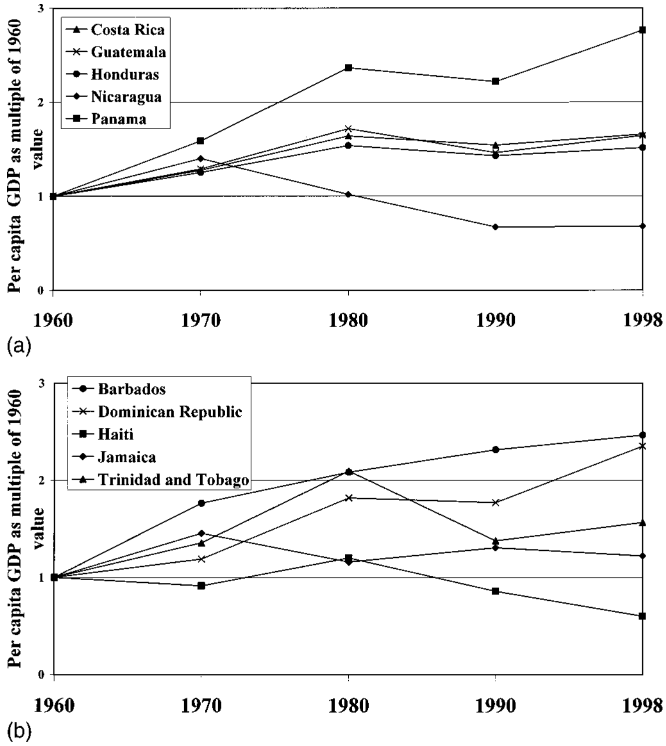

Fig. 6. 1960–1998 per capita GDP as multiple of 1960 per capita GDP for selected (a) Central American countries; (b) Caribbean countries (data provided to writers by Inter-American Development Bank Statistics and Quantitative Analysis Unit, Integration and Regional Programs Department)

factor, determined for country *c* by the ratio of its inflation-adjusted, per capita Gross Domestic Product in year *x* to that of year *y*; and $P_{y,c}$ = population factor, determined for country *c* by the ratio of its population in year *x* to that of year *y*.

Inflation in the United States is accounted for using the implicit price deflator for the Gross National Product, as derived from the Handbook of Labor Statistics (U.S. Bureau of Labor Statistics 1971), the Economic Report of the President (Office of the President 1960, 1997), and the U.S. Department of Commerce Bureau of Economic Analysis website (BEA 1999). For the United States, Pielke and Landsea (1998) use a measure of national wealth more accurate than GDP, called Fixed Reproducible Tangible Wealth. This measure was adjusted to a per capita basis based on the population of the coastal counties affected. This allowed for a normalization that more precisely and more accurately reflects the changes occurring in the regions most affected by hurricanes. The size of the countries in Central America and the Caribbean that are the focus of this paper makes such a calculation less necessary, while data availability makes it unrealistic. It would, of course, be possible to develop other normalization methods that use other factors that might be related to growth in impacts.

Using this methodology, Table 2 shows losses normalized to 1998 for selected Central American and Caribbean hurricanes since 1960. As this table illustrates, each of these storms would cause considerably more damage if they occurred in 1998 rather than in the year in which they occurred.

Until data become readily available for all storms and all countries, it will not be possible to present a complete trend of normalized hurricane losses in Central America and the Caribbean. The next two sections present (1) a complete normalization analysis for Cuba; and (2) for a number of other countries, an analysis of trends in Economic Loss Potential that can be used as a foundation to normalize loss data, should they become more readily available.

Normalized Losses in Cuba: 1900–1998

We single out Cuba for detailed analysis because of the availability of a new dataset on historical hurricane losses in Cuba created by the second author and published here for the first time. This dataset allows for a complete normalization of the Cuban hurricane loss record. Fig. 7 shows the number of landfalling hurricanes in Cuba from 1900 to 1998 (Rubiera, from Coleccion de Publicaciones Cubanas, Biblioteca Instituto de Meteorologia, La Habana, Cuba). Table 3 and Fig. 8 show the economic losses associated with these storms, in millions of current-year and inflation-adjusted U.S. dollars. United States inflation rates are used because the original hurricane loss figures are expressed in current U.S. dollars. Even with relatively few events, the time series shows that more recent storms have tended to cause greater damage than those of the more distant past, just as has been the case in the United States.

To adjust for changes in the Cuban economy since 1903, we use three sets of data. The various datasets are necessary because of disagreement among economists about how to represent trends in inflation and wealth in the Cuban economy. While these disagreements may well have important implications for other areas of analysis, conclusions based on normalized hurricane losses are insensitive to the dataset chosen. Thus, the following analysis uses a range of datasets (see Table 4 for data sources and comments). The United Nations (UN) data are in both current-year pesos and equivalent U.S. dollars, assuming an official exchange rate of one Cuban peso to one U.S. dollar. The 1960–1997 Cuban data are in current-year pesos.

To illustrate the normalization methodology, consider Hurricane Flora (1963) as an example. Flora resulted in an estimated current-year damage of U.S. $300 million in Cuba. The first normalization method relies on the change in Cuban wealth from 1963 to 1997, based on a combination of the Mitchell and UN data sets. We normalize to 1997 values because 1997 is the latest year for which Cuban wealth data are available.

The Cuban GDP in 1963 was 3,450 million pesos, in 1970 it was 5,420 pesos, and by 1997 it was 23,200 million pesos. Because the first normalization method combines two different GDP datasets (Mitchell from 1903 to 1969; UN from 1970 to 1997), we multiplied $300 million by the ratio of 1970 GDP, the first year of the UN dataset, to 1963 GDP, the year of Hurricane Flora, times the ratio of 1997 GDP, the last year of the UN dataset, to 1970 GDP, the first year of the UN dataset:

$$\mathrm{NL}_{97} = \$300\ \ \mathrm{million}_{63} \cdot (\mathrm{GDP}_{70}/\mathrm{GDP}_{63} \cdot \mathrm{GDP}_{97}/\mathrm{GDP}_{70})$$

The normalized damage that 1963 Hurricane Flora would cause if it struck Cuba in 1997 is

$$\$2{,}017\ \ \mathrm{million}_{1997} = \$300\ \ \mathrm{million}_{1963} \cdot 6.72$$

The second method adjusts Cuban hurricane damage to 1989 values, the last year of the 1903–1989 Mitchell (1998) dataset, then adjusts these values for inflation to 1997 U.S. dollars. The Cuban GDP was 12,791 million pesos in 1989, an increase of a

Table 2. Normalized Hurricane Losses from Selected Central American and Caribbean Hurricanes since 1960

Hurricane/date	Country affected	Reported damage	Damage normalized to 1998 U.S. dollars[a]
Mitch/October 1998	Honduras	$5–7 billion	$5–7 billion
	Nicaragua		
	El Salvador		
	Guatemala		
Georges/September–October 1998	St Kitts and Nevis	$800 million	$800 million
	U.S.V.I.	$100 million	$100 million
	Puerto Rico	$3.5 billion	$3.5 billion
	Dom Rep	$2 billion	$2 billion
Marilyn/September 1995	U.S.V.I.	$3 billion	$3.1 billion
Luis/August–September 1995	St. Maartin	$2.5 billion	$2.7 billion
	St. Martin		
	Antigua		
	Barbuda		
Hugo/September 1989	Puerto Rico	$1 billion	$1.5 billion
Joan/October 1988	Nicaragua	$2 billion	$3.3 billion
	Costa Rica	($1 billion Nicaragua)	($1.5 billion Nicaragua)[b]
	Colombia		
	Venezuela		
	Panama		
Allen/August 1980	St. Lucia	$235 million	$617 million
Claudette/July 1979	Puerto Rico	$750,000	$2 million
David/August–September 1979	Dominican Republic	$1 billion	$4 billion
Kendra/October–November 1978	Puerto Rico	$6 million	$17 million
Eloise/September 1975	Puerto Rico	$125 million	$458 million
Carmen/August–September 1974	Puerto Rico	$2 million	$8 million
Francelia/September 1969	Guatemala	$4.7 million	$71 million
Hattie/October 1961	Belize	$60 million	$1 billion
Abby/July 1960	Belize	$600,000	$11 million

[a]Due to a lack of per capita GDP for Puerto Rico, St. Lucia, St. Martin, St. Maartin, U.S. Virgin Islands, and Belize, we used the average of known per capita GDP for the relevant region. We also used an average of the Southern Caribbean population to measure population growth in normalizing Hurricane Luis damages.

[b]Our information does not disclose in which of the remaining countries $1 billion of these losses were incurred, so we have normalized these damages using average Central America values. References for Table 2.

factor of 3.71 since 1963. The inflation factor from 1989 to 1997 is approximately 1.244. For Hurricane Flora, the calculation is as follows:

$$\$1{,}384 \text{ million}_{1997} = \$300 \text{ million}_{1963} \cdot 3.71 \cdot 1.244$$

A third method relies on changes in Cuban wealth as indicated by a combination of the Mitchell dataset for 1903–1959 and Cuban datasets for 1960–1997. Under this method, the Cuban GDP in 1963 was 3,795 million pesos; in 1997 it was 22,952 million pesos, an increase of 6.05. For Hurricane Flora, the calculation is as follows:

$$\$1{,}814 \text{ million}_{1997} = \$300 \text{ million}_{1963} \cdot 6.05$$

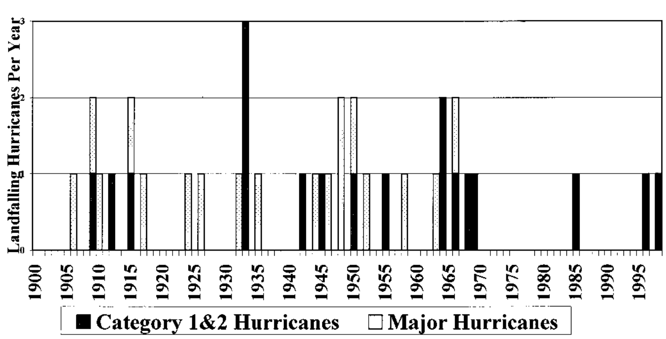

Fig. 7. Number of hurricanes that made landfall in Cuba, 1900–1998

Because of uncertainty in the wealth adjustment, damage also can be normalized using a fourth method that relies only on changes in inflation and population. U.S. inflation rates are used because the original hurricane loss figures are expressed in current U.S. dollars. This method is useful for calibrating the other normalization methods. The normalized losses (NL) that would be attributed to Hurricane Flora if it had struck Cuba in 1997 are computed as follows:

$$\text{NL}_{1997} = \$300 \text{ million}_{1963} \cdot I_{1963} \cdot P_{1963}$$

Cuba's population increased by a factor of 1.48, from 7,512,000 in 1963 to 11,093,000 in 1997. In 1963 a dollar in the United States was worth about 4.61 times its value in 1997. Normalizing Flora's damage to 1997 values using this approach results in slightly over $2 billion in losses ($\$300\text{ million} \cdot 1.477 \cdot 4.61 = \$2{,}043\text{ million}$). This result is somewhat higher than several of the results produced using the second and third normalization methods based on increases in wealth. This could illustrate that wealth and population in the Caribbean and Central America

Table 3. Hurricanes that Made Landfall over Cuba (1901–1998) [Unadjusted Data from Rodriguez (1997), NCDC (1999), and NCC (1974, 1975, 1976, 1978, 1979, 1980)]

Hurricane name or number	Year	Month	Day	SS category	Maximum wind (kt)	Region	Deaths	Damages (million U.S. dollars)	Remarks
8	1906	10	16–17	3	110	W	0	5	—
7	1909	09	17–18	1	75	W	0	1	—
9	1909	10	10–11	3	105	W	33	10	—
4	1910	10	14–17	3	105	W	10	10	—
6	1912	11	21	1	75	E	0	Minor	—
2	1915	08	14	3	105	W	0	Minor	a
4	1915	09	2	1	85	W	0	Minor	—
3	1917	09	25	3	105	W	0	10	—
7	1924	10	19	5	140	W	0	5	b
7	1926	10	20	3	105	W	600	100	—
10	1932	11	9	5	135	E	3,033	40	c
2	1933	07	3	1	80	W	22	4	—
11	1933	09	1	2	85	C	70	11	—
18	1933	10	4	2	95	W	0	Minor	—
4	1935	09	28	3	105	C	43	12	—
10	1942	11	6	1	70	E	0	Minor	—
11	1944	10	17–18	4	120	W	318	100	—
11	1945	10	12	2	85	C	3	1	—
5	1946	10	6–7	3	100	W	5	5	—
7	1948	09	20	3	100	W	30	7	—
8	1948	10	5	3	110	W	13	6	—
Easy	1950	09	2–3	1	70	W	0	Minor	—
King	1950	10	16–17	3	105	E	7	2	—
Fox	1952	10	24	4	120	C	40	10	d
Hilda	1955	09	13	1	65	E	4	2	—
Ella	1958	09	1–2	3	100	E	16	3	—
Flora	1963	10	4–8	3	110	E	1,150	300	e
Oleo	1964	08	25–26	1	65	E	0	Minor	—
Isbell	1964	10	13	2	95	W	3	10	—
Alma	1966	06	8	2	90	W	11	65	—
Inez	1966	09/10	30–02	3	100	E–C	4	5	—
Gladys	1968	10	16	1	65	W	6	12	—
Camille	1969	08	15	2	95	W	5	5	—
Kate	1985	11	19	2	95	C–W	2	400	—
Lili	1996	10	17–18	2	85	C	0	362	—
Georges	1998	09	24–25	1	65	E	6	40	f

Note: Only landfalling hurricanes have been taken into account in this work. Cuba has been divided into three regions: W=western region; C=central region; E=eastern region. (Coleccion de Publicaciones Cubanas, Biblioteca Instituto de Meteorologia, La Habana, Cuba).

[a]It crossed the Western tip of Cuba, mostly uninhabited at that time.

[b]Same as previous remark, except that the 1924 hurricane was called "the unprecedented hurricane" for it was a powerful Category 5 hurricane with lowest pressure 921.8 mb.

[c]The 1932 hurricane was also a Category 5 hurricane. Lowest pressure on a ship south of Cuba was 914.6 mb. It was remarkable for the huge storm surge of 6.5 m at Santa Cruz del Sur, Camaguey. The town was swept away. There were 2,870 deaths out of a population of 4,800 in that coastal town. Estimated winds at landfall were 140 kt, gusting up to 180 kt.

[d]"Fox" was a Category 4 hurricane at the time it passed Cayo Guano del Este, a Cuban small key South of Cienfuegos where the Cuban Meteorological Service had a first-order land station. Lowest pressure was 934 mb. Highest winds were estimated at 125 kt, gusting to 156 kt. However, "Fox" diminished strength rapidly before landfall. On exiting Cuba's northern coast, it was only a Category 2 hurricane with 85 kt winds.

[e]"Flora" was famous for the loops it made, staying up to 72 hours over Cuba's eastern region. It was a weakening storm over the mountains, but it had torrential rains with much flooding. Greatest amounts of rain were over 1,600 mm, with some points over 2,000 mm.

[f]Figures for economic losses for "Georges" are estimated from only preliminary figures. Insured losses in agriculture were $15 million U.S. dollars.

do not always move in the same direction, as has been the case in the United States. For example, if a country has a population of 10 with a per capita GDP of $1, its overall wealth is $10. If its population grows to 20 but its per capita GDP falls to $.75, the population is larger and the country is richer with an overall GDP of $15, but its inhabitants are poorer. It also could reflect the inadequacies of the wealth data.

Fig. 9 shows the range of estimates of Cuban hurricane damage in normalized 1997 U.S. dollars using these methods. Although the values for individual storms are somewhat different for each of the methods, the overall pattern is quite similar and thus relatively insensitive to the choice of wealth dataset. Regardless of the method used, all methods show that most normalized hurricane losses in Cuba occurred between the mid-1920s and

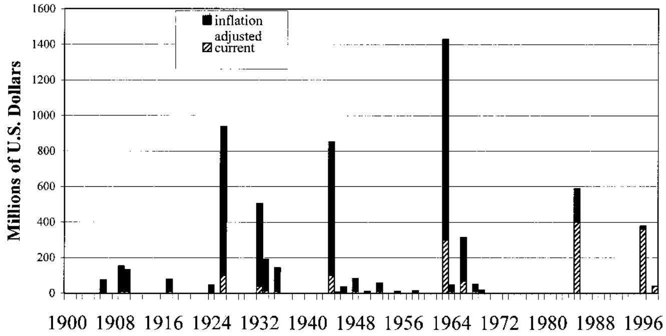

Fig. 8. Comparison of current year and inflation-adjusted hurricane losses in Cuba, 1900–1998

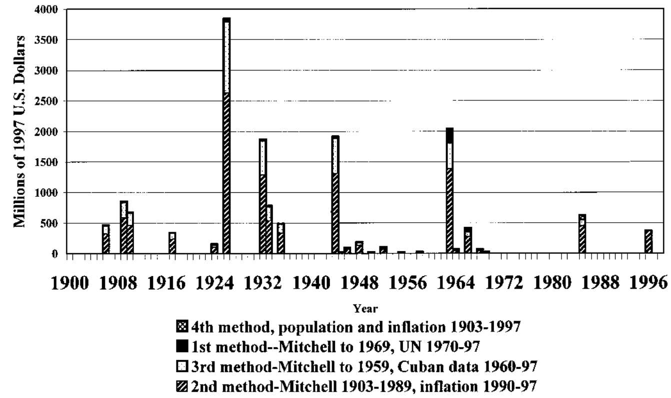

Fig. 9. Comparison of four alternative methods for normalizing Cuban hurricane damages to 1997 values

mid-1960s. Any trend of increasingly damaging storms has disappeared, consistent with the incidence of landfalling hurricanes shown in Fig. 7. The findings are consistent with the results of Pielke and Landsea (1998) for the United States.

In November 2001, following the completion of this case study, Hurricane Michelle struck Cuba. As a Category 4 hurricane, Michelle is the strongest hurricane to strike the island since 1952. Michelle caused about $2.0 billion in agricultural and property damage, which places it as the most destructive hurricane in Cuba's history based on actual damage. However, Michelle's destruction is quite similar to that which would have been caused by the more violent hurricanes of the past if they struck Cuba today.

Table 4. Sources of Data for Years Covered

Years covered	Sources of data and comments
1903–1989	International Historical Statistics: The Americas 1750–1993 (Mitchell 1998). Cuban wealth was reported on a national basis as Net National Product (NNP) until 1950, as Gross Domestic Product (GDP) from 1950 through 1958, and as Gross/Net Material Product since 1962. The Mitchell data set did not include wealth values for 1929, 1931, 1932, 1934, 1935, 1937, 1959, 1960, and 1961. These values have been interpolated. The Mitchell data set reported both NNP and GDP for 1950; we used the GDP figure for that year, which was somewhat higher than the NNP figure.
1970–1997	United Nations Statistical Division (personal correspondence, 1999)
1960–1997	1960–1975: Estimated from *Reconstrucción y Análisis de las Series Estadísticas de la Economía Cubana 1960–1975*, Junta Central de Planificación Cuba (1977), taking into consideration methodological differences between the Material Product System that was used in Cuba between 1960 and 1989 and the United Nations National Account System. 1976–1985: These data were calculated in terms of GDP from the yearly publication *Anuario Estadístico de Cuba*, Comité Estatal de Estadísticas (1987, 1997) 1986–1988: *La Economía Cubana. Reformas Estructurales y Desempeño en los Noventa*, Comisión Económica para América Latina (1997). 1989–1997: Oficina Nacional de Estadísticas de Cuba (1998).

Economic Loss Potential

A complete record of economic losses associated with hurricanes is not readily available for other Caribbean and Central American countries. Consequently, it is not possible to produce a complete record of normalized hurricane losses for these countries in the same manner presented herein for Cuba. One way around this data limitation is to calculate economic loss potential (ELP). ELP is a comparison of changes in the potential for hurricane losses, again based on the assumption that increases in wealth, population, and inflation will increase hurricane losses. The growth in ELP since 1960 (when the available data record begins) to the present can be computed by multiplying the change in per capita wealth since 1960, measured in constant U.S. dollars, by the change in population, by an inflation multiplier.

For example, economic loss potential for the Dominican Republic for 1980 is calculated as follows:

$$ELP_{1980}=1.82\cdot 2.59\cdot 1.8=8.52$$

The change in wealth equals 1980 per capita income divided by 1960 per capita income, or 865/475=1.82. The inflation factor equals the 1980 U.S. implicit price deflator divided by the 1960 implicit price deflator, or 0.56134/0.21654=2.59. Finally, the change in population equals the 1980 population divided by the 1960 population, or 5,499,000/3,047,000=1.8. The product of these figures can be used to estimate that a hurricane that occurred in 1980 in the Dominican Republic would cause approximately 8.5 times the damage it would have caused had it occurred in 1960. Fig. 10 shows the ELP for selected Caribbean and Central American countries between 1960 and 1990. (Economic loss potential is interpolated for years that data were not available.) Fig. 11 shows the ELP for Cuba using the four normalization methods, with 1903 as the base year. We compute Cuban ELP beginning in 1903 because that is the earliest year for which we have wealth data. Should historical trend data on economic losses become available, the calculation of a normalized loss record using the ELP is straightforward.

Fig. 12 compares the growth in economic loss potential for the United States (using national figures) and Cuba (using the four normalization methods) beginning with 1925, the earliest year of our U.S. wealth data set. The U.S. growth in economic loss potential began exceeding that of Cuba around 1958.

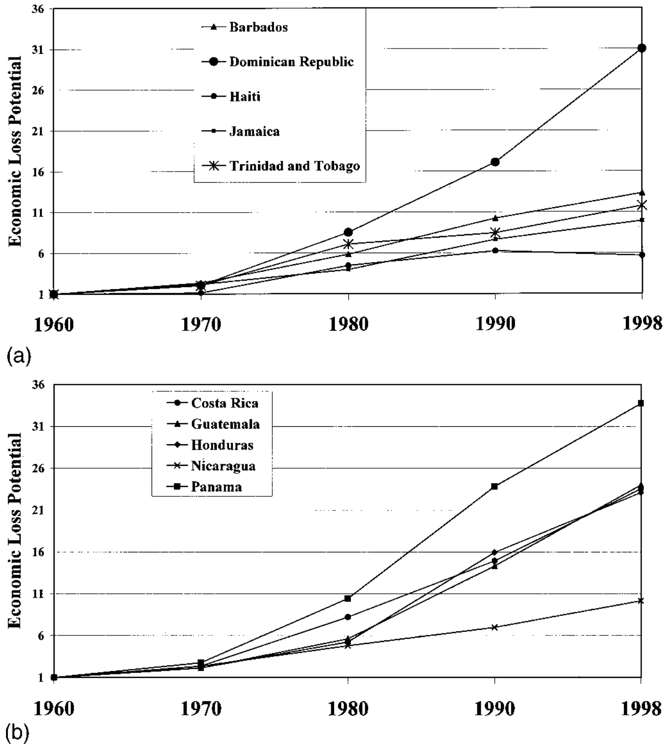

Fig. 10. Economic loss potential for (a) selected Caribbean countries, and (b) selected Central American countries, 1960–1998

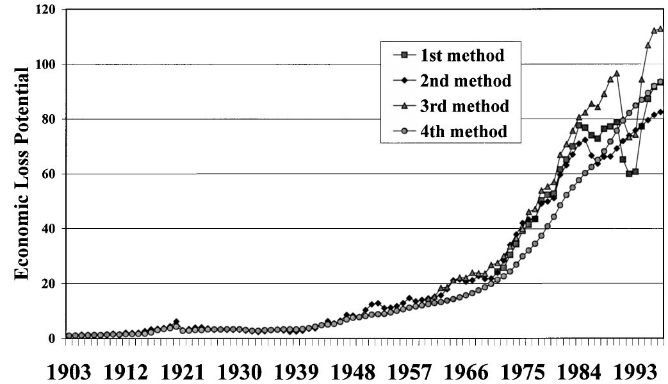

Fig. 11. Cuban economic loss potential using four normalization methods, 1903–1997

Loss of Life

To shape expectations about the possible exceptional nature of the human losses associated with Hurricane Mitch, a normalization methodology also can be used, in principle, to estimate the loss of life related to a hurricane had the storm occurred in a different year, based on the simple assumption that hurricane deaths increase in proportion to population. This assumption would be less relevant in countries such as the United States and Cuba that have seen dramatic improvements in preparedness, technology, and infrastructure. However, for many Caribbean and Latin American countries, such improvements have yet to occur (Degg 1992; IFRCRCS 1999).

A simple normalization of loss of life is computed by multiplying the number of deaths caused by the hurricane in the year that the hurricane struck (year *x*) by the change in population from the year of the hurricane to year *y* (year *y* population/year *x* population). Table 5 compares actual death tolls from several 20th century Central American and Caribbean hurricanes to normalized estimates of the number of deaths that these hurricanes would have caused had they struck in 1998. This table makes all too clear a startling point: If storms of comparable intensity to those that hit the Caribbean and Central America many years ago struck today, death tolls could be comparable to, and in some cases could exceed, those associated with Hurricane Mitch. Hurricane Mitch was by no means unique.

These figures might even be conservative. As populations rapidly grow, the proportion of people living in disaster-prone areas such as flash-flood zones, mudslide-prone valleys, and storm surge-threatened lowlands goes up even faster (Degg 1992). The point of this simple exercise is to complement more rigorous approaches to understanding mortality. The simple exercise suggests that Hurricane Mitch was likely not a unique or even a rare event.

Discussion

The data and analysis in this paper suggest that the impacts of Hurricane Mitch were not anomalous when compared with a nor-

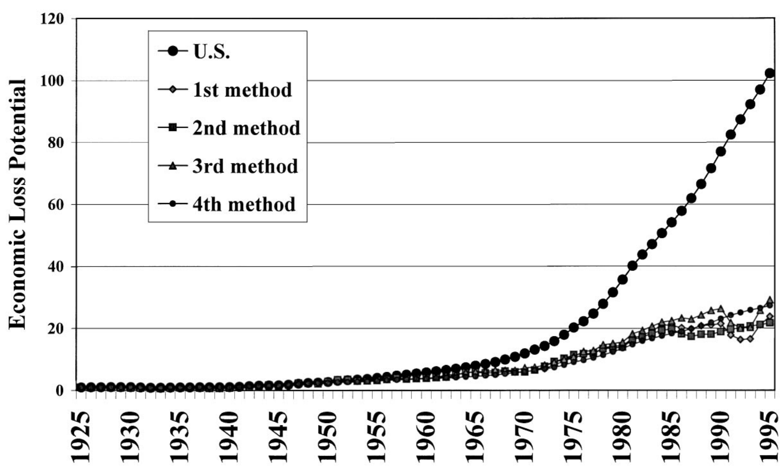

Fig. 12. Comparison of U.S. and Cuban economic loss potential, 1925–1995

Table 5. 1998 Estimated Deaths from Selected Historically Deadly Central American and Caribbean Hurricanes of the Twentieth Century

Name of hurricane	Date	Country	Deaths caused by hurricane[a]	Estimated hurricane-caused deaths in 1998
Unnamed	September 1–6, 1930	Dominican Republic	4,700 (estimated)	30,000
Unnamed	September 6–10, 1931	Belize	1,800 (estimated)	3,400
Unnamed	September 26–27, 1932	Puerto Rico	250 (estimated)	600
Unnamed	June 4–8, 1934	El Salvador, Honduras	2,250 (estimated)	10,500
Charlie	August 15–20, 1951	Jamaica, Mexico	250 (estimated)	900
Janet	September 28, 1955	Mexico, Belize, Grenada, Barbados, Carriacou	701	2,200
Hattie	October 31, 1961	Belize, Honduras	274	800
Flora	September 30–October 8, 1963	Haiti	7,400 (estimated)	12,000
Inez	September 27–October 11, 1966	Mexico, Dominican Republic, Guadelope, Haiti, Bahamas	1,000	2,000
Fifi	September 14–19, 1974	Honduras	6,200 (estimated)	12,000
David	August 25–September 7, 1979	Dominica, Puerto Rico, Dominican Republic	1,263	1,800
Mitch	October 27–29, 1998	Honduras, Nicaragua, El Salvador, Guatemala	10,000	10,000
Total	—	—	35,000 (estimated)	87,000 (estimated)

[a]Average of deaths reported in Rappaport and Fernandez-Partagas (1997). [Unadjusted data from IFRCRCS (1999), Rappaport and Fernandez-Partagas (1997), and NCC (1975, 1979, 1980)].

malized record of past losses. Rather than being a freak climate event, ''human intervention lies at the root of much of [Mitch's] damage'' (OCHA et al. 1999). Some of the interrelated human-caused factors that increase vulnerability to natural disasters such as Mitch include rapidly increasing populations, widespread poverty, lack of access to adequate land, deforestation, and urbanization. Hurricane Mitch should thus direct our attention to the broader dimensions of hurricane vulnerability in Latin America and the Caribbean.

Central America's population is growing rapidly, with average annual growth rates over the past ten years ranging from 1.6% in Panama to 2.6% in Costa Rica, Honduras, and Nicaragua (data provided by Inter-American Development Bank). Population growth increases vulnerability because there are more people for a disaster to impact and because more people settle in exposed areas. [Fig. 4(a) shows population growth in selected Central American countries.] In addition, population growth is related to poverty. In some countries an inverse relationship has been demonstrated between per capita GNP and total fertility rates, with countries having some of the highest fertility rates among the poorest (World Bank 1993). Poverty is a critical factor underlying vulnerability (Lavell 1994; Peacock et al. 1997; Pulwarty and Riebsame 1997; Morrow 2000).

Poverty is endemic in the region affected by Mitch. For example, 48% of El Salvador's population was living in poverty in 1994, poverty being defined as having ''a monthly income level insufficient to purchase two basic food baskets'' (World Bank 1999a); approximately 75% of Guatemala's population was living below the poverty line in 1995, thus defined as the amount needed to purchase a basic basket of goods and services (World Bank 1999b); and half of Nicaragua's population fell below the poverty line in 1995, defined as the level of total per capita monthly expenditures at which one obtains the minimum daily caloric requirement of 2,226 calories per adult (World Bank 1999c). The percentages of Central Americans living below the international poverty line, defined as making less than $1 per day at 1985 international prices, adjusted for purchasing power parity, were: Guatemala (1989), 53%; Honduras (1992), 47%; Panama (1989), 27%; and Costa Rica (1989), 19% (World Bank 1999d).

Poverty can increase natural disaster vulnerability in at least three ways. First, impoverished people often lack access to land that is relatively unexposed to disasters. When Hurricane Fifi hit Honduras in 1974, land ownership had become highly concentrated, with 63% of Honduran farmers having access to only 6% of arable land. This was due to a variety of factors: large landowners driving out small farmers from their land to create large cotton estates, growth in land-intensive livestock production, ownership of large tracts of land by banana companies, and use of valley floors for large-scale irrigation projects (Painter and Durham 1995; Pulwarty and Riebsame 1997). Peasants were forced onto steep hillsides where agricultural practices increased soil erosion and siltation of rivers. Fifi killed as many as 10,000 Hondurans. In one town alone, 2,300 were killed when a dam created by landslides into a river gave way (Pulwarty and Riebsame 1997). Yet after Fifi, trends continued, setting the stage for Mitch; the Honduran Central Bank estimated that, by 1988, 48% of valley lands in the country were sown in pasture for cattle (DeWalt 1999).

Second, poor people migrate to urban areas in search of economically gainful activity if they are displaced from the land for whatever reason. Lacking access to safe building sites, they choose the remaining alternatives, which are frequently on steep hillsides or in flood-prone areas (Vermeiren 1989; Lavell 1994). Development of urban slopes and hilltops increases the risk of flooding lower-lying areas, where many Central American urban poor reside (Lavell 1994). Between 1980 and 1997 the percentages of Central Americans living in urban areas increased by anywhere from 3% in Guatemala to 10% in Nicaragua and Honduras (World Bank 1999d). The following percentages of Central Americans lived in urban areas in 1997: Costa Rica, 50%; El Salvador, 46%; Guatemala, 40%; Honduras, 45%; Nicaragua, 63%; and Panama, 56% (World Bank 1999d).

Finally, although deforestation is caused by many factors, such as conversion of forests to grazing and farming uses, road building and settlement, mining, and logging (Thrupp 1993), poverty can also force the clearing of forests for agriculture, homebuilding, and fuel gathering. Deforestation adds to vulnerability by increasing soil erosion, which can enhance the incidence of landslides, mudslides, and flooding. Average annual deforestation rates for Central America from 1990 to 1995—Costa Rica, 3%; El Salvador, 3.3%; Guatemala, 2%; Honduras, 2.3%; and Panama, 2.1%—were some of the highest in the world (World Bank 1999d).

Many of the factors that have increased vulnerability in Central America also exist in the Caribbean. While the rates of population growth are generally not as high as in Central America, countries such as Haiti, the Dominican Republic, and the Bahamas experienced average annual growth rates of 1.6 and 1.7% in the last decade (data provided by Inter-America Development Bank). [Figs. 4(b and c) show population growth in selected Caribbean countries.] The incidence of poverty in the Caribbean varies widely. In 1989, 48% of Dominican Republicans lived on less than $2 per day; in 1993, 25% of Jamaicans lived at this level (World Bank 1999d).

As in Central America, land is inequitably distributed in parts of the Caribbean. For example, 82% of Dominican Republic farmers have access to 12% of the agricultural land; 59% of farmers in Haiti occupy 22% of land, a pattern seen in Jamaica as well (World Bank 1993). Much of the land occupied by small farmers is either in mountainous areas or on hillsides (World Bank 1993). Some of the most substantial Caribbean losses from hurricanes in the last 50 years—Flora, 1963 (approximately 8,000 deaths), and Gordon, 1994 (1,145 deaths)—occurred because of floods, mudslides, and landslides on hilly terrain (Rappaport and Fernandez-Partagas 1997).

Deforestation is also occurring at a rapid rate in parts of the Caribbean. Between 1990 and 1995, Jamaica had an average annual deforestation rate of 7.2%; Haiti's was 3.4% (World Bank 1999d). Between 1978 and 1988, Haiti's forested land decreased at a rate ''bordering on desertification'' (World Bank 1993). Jamaica suffered unprecedented landslides from Hurricane Gilbert in 1988 due, in part, to the extensive removal of tree cover from steep slopes by several large-scale coffee projects (Pulwarty and Riebsame 1997). And urbanization is rapidly increasing in many Caribbean countries due to high fertility rates, restrictions on migration, and internal migration of the rural poor (Berke and Beatley 1997). Between 1970 and 1995, the percentages of the population living in urban areas increased by as much as 33% in Trinidad/Tobago and Saint Vincent/the Grenadines (ECLAC 1997). By 2000, over 64% of the Caribbean basin population is expected to be living in urban areas, up from 38% in 1960 (Berke and Beatley 1997).

Conclusion

The introduction asked: What accounts for the extent of the losses experienced in Hurricane Mitch? Is Mitch a harbinger of future disasters? What might be done in response? The analysis presented in this paper shows dramatically that the impacts of Hurricane Mitch were the result of a powerful storm that encountered profound human vulnerability. The data and analysis presented in this paper suggest that Hurricane Mitch is indeed a harbinger of future disasters unless actions are taken to reduce societal vulnerability. Such actions will be most effective if focused on processes of sustainable development.

In the area of sustainable development, the issues of poverty, land use, and environmental stewardship are certainly not new. But to some degree, in the context of hurricane impacts in particular, these issues arguably have been overshadowed by concern about global climate change (Pielke et al. 2000). Some have asserted that deadly and damaging storms like Mitch are a result of ''global warming.'' For example, the International Federation of Red Cross and Red Crescent Societies (IFRCRCS) reported that the intense level of North Atlantic hurricane activity between 1995 and 1998 that culminated in Mitch ''appear[s] to be linked to ''global warming'' (IFRCRCS 1999). J. Bryan Atwood, former director of the U.S. Agency for International Development, cited Mitch as an example of a ''classic greenhouse effect'' (Atwood 1998). Others extrapolate that more frequent or intense tropical cyclones will be a byproduct of global climate change (e.g., Berke and Beatley 1997; Sachs 1999).

These attributions, and others like them, are more than marketing devices in an increasingly polarized debate about energy policies. They are also the ideas that underlie policy recommendations for how society should allocate and use its finite resources to address the issue of future hurricane impacts. Some have suggested that Hurricane Mitch and possible future storms mean that society must redouble its efforts to reduce emissions in order to modulate future hurricane frequencies or intensities (e.g., Sachs 1999). Others have suggested that reducing societal vulnerability to hurricane impacts deserves greater attention (Pulwarty and Riebsame 1997).

The data presented in this paper support directing greater attention to reducing vulnerability, in accordance with Landsea et al. (1999): ''There is no evidence that society can intentionally modulate tropical cyclone frequencies and magnitudes through energy policies... . If a policy objective is to reduce society's vulnerability to hurricane impacts, then decision makers would be wiser to consider better adapting to documented variability, rather than preventing storms from occurring.'' Because tremendous population growth occurred during the last inactive period from the early 1970s to the mid-1990s, the countries of the Caribbean will likely experience large hurricane impacts in the next couple of decades, regardless of future storm incidence.

It is perhaps seductive to think that there exists a ''silver bullet'' solution to reducing the future impacts of hurricanes in Latin America and the Caribbean. Ample evidence suggests this is but wishful thinking. Scholars and practitioners have historically faced tremendous difficulties in addressing factors conditioning hurricane losses, particularly in developing countries. Attention diverted in hopes of a ''silver bullet'' solution only creates delay and distraction from the political, institutional, and intellectual steps that need to be taken. One prediction can be made with confidence, however. If present trends continue, events like Mitch will become more common, irrespective of the future climate.

Acknowledgments

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