

## Normalized Hurricane Damages in the United States: 1925–95

ROGER A. PIELKE JR.

*Environmental and Societal Impacts Group, National Center for Atmospheric Research, Boulder, Colorado*

CHRISTOPHER W. LANDSEA

*Hurricane Research Division, NOAA/AOML, Miami, Florida*

(Manuscript received 5 September 1997, in final form 4 March 1998)

### ABSTRACT

Hurricanes are the costliest natural disasters in the United States. Understanding how both hurricane frequencies and intensities vary from year to year as well as how this is manifested in changes in damages that occur is a topic of great interest to meteorologists, public and private decision makers, and the general public alike. Previous research into long-term trends in hurricane-caused damage along the U.S. coast has suggested that damage has been quickly increasing within the last two decades, even after considering inflation. However, to best capture the year-to-year variability in tropical cyclone damage, consideration must also be given toward two additional factors: coastal population changes and changes in wealth. Both population and wealth have increased dramatically over the last several decades and act to enhance the recent hurricane damages preferentially over those occurring previously. More appropriate trends in the United States hurricane damages can be calculated when a normalization of the damages are done to take into account inflation and changes in coastal population and wealth.

With this normalization, the trend of increasing damage amounts in recent decades disappears. Instead, substantial multidecadal variations in normalized damages are observed: the 1970s and 1980s actually incurred less damages than in the preceding few decades. Only during the early 1990s does damage approach the high level of impact seen back in the 1940s through the 1960s, showing that what has been observed recently is not unprecedented. Over the long term, the average annual impact of damages in the continental United States is about \$4.8 billion (1995 \$), substantially more than previous estimates. Of these damages, over 83% are accounted for by the intense hurricanes (Saffir–Simpson categories 3, 4, and 5), yet these make up only 21% of the U.S.-landfalling tropical cyclones.

---

### 1. Introduction: Why trends matter

In recent years, decision makers in government, insurance, and other sectors have demonstrated increasing concern about the actual and potential impacts of weather and climate on society. To a significant degree, concern has been motivated by expectations that human-induced climate change will result in increasingly greater weather-related impacts to society. Concern has also been motivated by actual increases in weather-related impacts documented in recent years. Understanding these impacts in terms of trends, causes, and projections has significance for a range of policy decisions related to disaster mitigation and the international negotiations on climate change.

This paper focuses on trends in hurricane impacts in the United States because of the relatively well-docu-

mented information available on trends in hurricane climatology, economic impacts, and societal factors underlying those impacts.<sup>1</sup> Recent increases in the impacts of hurricanes in the United States have focused attention on them. In addition, the increased damages related to hurricanes have been attributed to climate change by the U.S. Senate, many in the insurance industry, and *Newsweek* magazine, among many others (U.S. Senate Bipartisan Task Force on Funding Disaster Relief 1995, hereafter BTFFDR; Dlugolecki 1996; cover of *Newsweek*, 21 January 1996). Recent research indicates that this attribution has been made incorrectly, leading to a conclusion that the factors responsible for documented trends in hurricane impacts are widely misunderstood (Landsea et al. 1996; Pielke 1997). The purpose of this paper is to examine trends in hurricane impacts in the United States in order to provide researchers and policy

---

*Corresponding author address:* Dr. Roger A. Pielke Jr., Environmental and Societal Impacts Group, National Center for Atmospheric Research, P.O. Box 3000, Boulder, CO 80307-3000.  
E-mail: rogerp@ucar.edu

---

<sup>1</sup> The term “hurricane” is used throughout the paper as a generic term to include subtropical storms, tropical storms, and hurricanes (Landsea 1993).

TABLE 1. Damage estimates in south Florida associated with Hurricane Andrew. Current dollar estimates of \$30 billion in damages directly related to Hurricane Andrew in south Florida. Original sources are located in Pielke (1995).

Type of loss	Amount (\$ billions)
Common insured private property	16.5
Uninsured homes	0.35
Federal disaster package	6.5
Public infrastructure	
state	0.050
county	0.287
city	0.060
schools	1.0
Agriculture	
damages	1.04
lost sales	0.48
Environment	2.124
Aircraft	0.02
Flood claims	0.096
Red Cross	0.070
Defense Department	1.412
Total	30.0

makers with reliable information on which to base their expectations of future impacts.

**2. Trend data**

The impacts of weather on society have been defined according to a three-tiered sequence (Changnon 1996): “Direct impacts” are those most closely related to the event, such as property losses associated with wind damage. “Secondary impacts” are those related to the direct impacts. For example, an increase in medical problems or disease following a hurricane would be a secondary impact. “Tertiary impacts” are those that follow long after the storm has passed. A change in property tax revenues collected in the years following a storm is an example of a tertiary impact. The impacts discussed in this paper are direct impacts. Table 1 shows the direct impacts associated with Hurricane Andrew’s landfall in south Florida in 1992.

Data on the economic impacts of hurricanes are published annually in *Monthly Weather Review* and are

## Annual Hurricane Damage 1900-1995

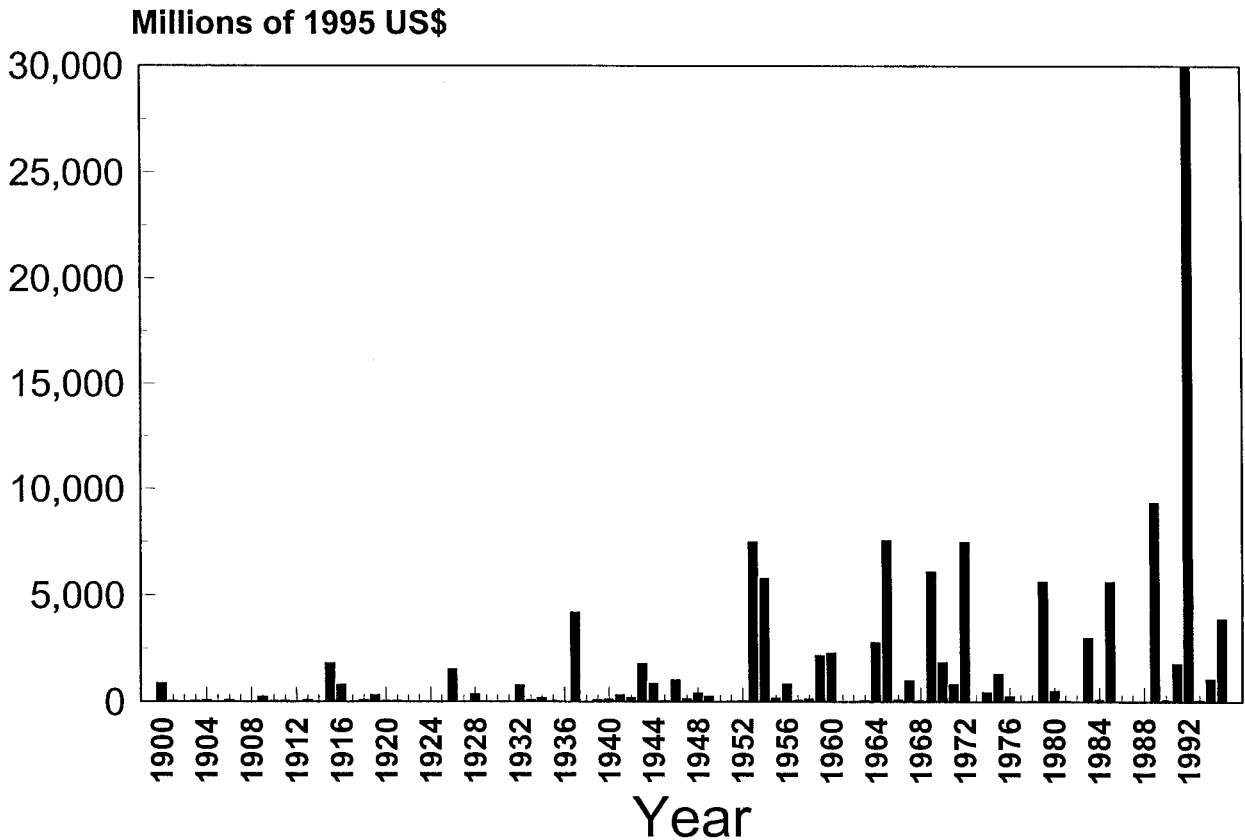


FIG. 1. Time series of U.S. hurricane-related losses (direct damages in millions of 1995 U.S. dollars) from 1900 to 1995 (source from Hebert et al. 1996).

## U.S. Insured Losses to Hurricanes: 1950-1995

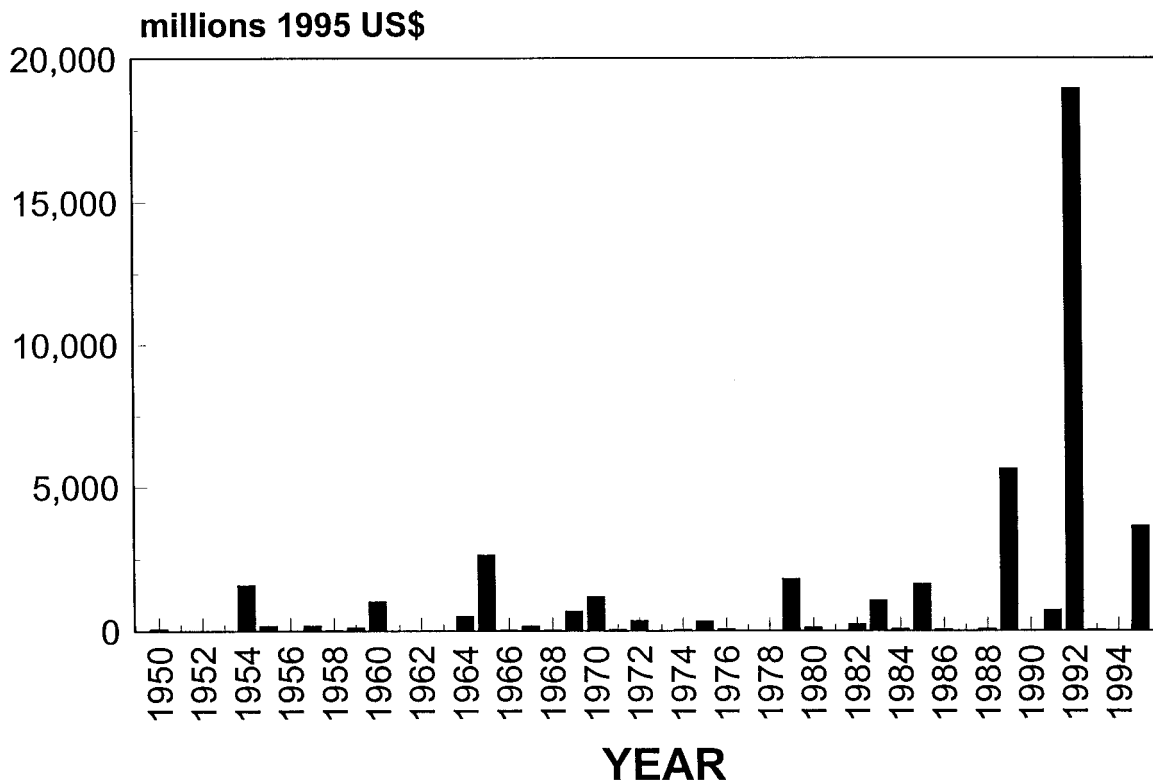


FIG. 2. Time series of hurricane-related insured losses in the United States (in millions of 1995 U.S. dollars) from 1950 to 1995 (data provided courtesy of Property Claims Services, Inc.).

summarized in Hebert et al. (1996).<sup>2</sup> Figure 1 shows the annual record of total hurricane losses (direct damages, inflation adjusted) in the United States from 1900 to 1995. An independent record of estimated losses to the insurance industry is kept by Property Claims Services, Inc., and is shown for the period 1950–95 in Fig. 2. Both figures show more events and more extreme events in recent decades and years. Viewing these trend data, it would seem logical to conclude that hurricanes have become more frequent and severe as compared to earlier this century. Indeed, a 1995 U.S. Senate report asserted that hurricanes, “have become increasingly frequent and severe over the last four decades as climatic conditions have changed in the tropics” (BTFFDR, p. 23). Many insurers, as well, have concluded that hurricanes have become more frequent (Dlugolecki et al. 1996). In fact, the past several decades have seen a *decrease* in the frequency of intense hurricanes and the period of 1991–94 was the least active 4-yr period in at least 50 yr

(Landsea et al. 1996). This trend means that more frequent or more intense hurricanes are not the cause of increasing hurricane-related damages, rather society has become more vulnerable to the effects of hurricanes (Pielke 1997).

At least three factors account for the apparent misreading of the historical record. First, in 1997 a dollar is worth less than one-tenth what it was 50 yr ago due to inflation. Yet, even when one accounts for inflation, a trend of exponentially increasing losses remains as is shown in Figs. 1 and 2. A second factor is changing population patterns and demographics that underlie the loss record. A storm that made landfall many years ago would cause significantly greater damage today simply because there are more people and property located in vulnerable coastal locations. Consider that in 1990, Dade and Broward Counties in south Florida were home to more than the number of people who lived in 1930 in *all* 109 counties from Texas through Virginia along the gulf and Atlantic coasts (Pielke 1995). Figure 3 illustrates the rapid growth that has occurred in southeast Florida. A third and final factor for the misreading of the historical record is that people today are simply

<sup>2</sup> References to primary sources can be found in Landsea (1991) for 1949–89 and Pielke and Pielke (1997) for 1981–96.

### Florida Coastal Population 1900 to 1990

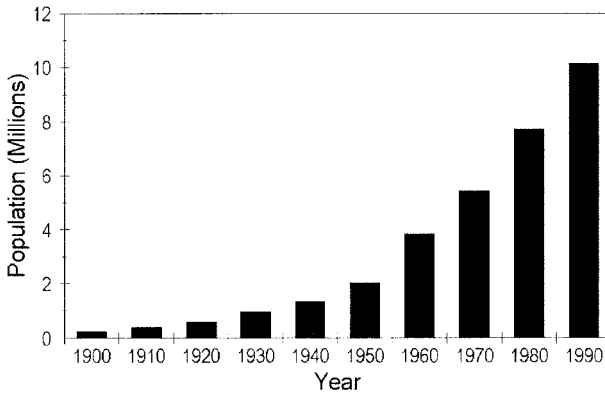


FIG. 3. Growth in Florida's coastal population 1900–90.  
Source: U.S. Census.

wealthier in terms of their possessions than were people years ago. Coastal residents today have more to lose. For these important reasons, interpreting the hurricane loss record is fraught with difficulties.

It is possible to “normalize” the historical loss record to values that are more representative in today's context (Changnon et al. 1997). Researchers have used several types of tools to improve upon the actual loss record to better understand past impacts (Dlugolecki et al. 1996). In a “stage damage” approach, people or property subject to risk of hurricane impacts are inventoried based on a number of key dimensions (e.g., number, type, and location of structures) and then, based on the inventory, a computer model is created to estimate losses from a particular event's impact. A number of companies (such as Property Claims Services) run these models (Banham 1993). Table 2 illustrates the output of one such model. In “simulation” approaches modeling is used as well, but the focus is not on a particular event but instead on a family of events and the corresponding frequency and magnitude distribution of impacts. Companies such as Applied Insurance Research and EQE International run these sorts of models (Banham 1993), an example of which is shown in Table 3.

Catastrophe models are only as good as the assumptions that underlie them. For instance, prior to Hurricane Andrew, models such as these led hurricane loss experts to conclude that the worst-case scenario for a hurricane impact along the U.S. coast would be around \$10 billion (e.g., Senate Committee on Banking, Housing, and Urban Affairs, Subcommittee on Housing and Urban Affairs 1992).<sup>3</sup> Even in the im-

<sup>3</sup> In 1992, Robert Sheets, then director of the National Hurricane Center, stated prior to Hurricane Andrew's impact, before a Congressional committee that the 1926 Miami hurricane would likely result in up to \$35 billion in damages, but that many thought this number too high (Senate Committee on Banking, Housing, and Urban Affairs, Subcommittee on Housing and Urban Affairs 1992).

TABLE 2. Example of a stage damage approach. Damages are adjusted to 1992 estimates based on inflation and increased housing density. Source: Englehardt and Peng (1996).

Storm			1992 damages (U.S.\$ billion)
Name	Location	Year	
Unnamed/cat. 4	Miami	1926	39
Andrew/cat. 4	S. Florida	1992	24
Betsy/cat. 3	S. Florida	1965	15
Donna/cat. 4	Sombrero Key	1960	10
Unnamed/cat. 4	Pompano Beach	1947	9
Unnamed/cat. 3	Homestead	1941	5
Unnamed/cat. 4	Palm Beach	1928	3.5
Cleo/cat. 2	Miami	1964	2.7
Unnamed/cat. 3	Palm Beach	1949	2.6
Inez/cat. 1	S. Florida	1966	2.2

mediate aftermath of Andrew many estimates of damages were off by significant amounts (Noonan 1993). The primary reason that the model estimates were off for this particular event was a number of important factors not included in the models that only became apparent in the wake of the disaster. Of course, these models are designed for specific use by the insurance industry and, thus, may not meet the needs of other decision makers. While different decision makers have different needs for impact information (i.e., timeliness, accuracy, etc.), large errors in impact estimates can have significant negative influences on specific decisions. Conversely, certain decisions can be improved with accurate impact information. West and Lenze (1994, 145) ask “how do we determine whether a model has ‘correctly’ simulated an impact?” They find that “at present, most evaluation in regional impact analysis is confined to the fairly simple and nonrigorous step of asking whether the results look ‘reasonable’” and they recommend further research in the area of model evaluation.

In order to provide researchers and decision makers with a more accurate picture of trends in hurricane impacts in the United States, we have normalized past

TABLE 3. Example of a simulation approach. Hurricane loss projections for category 4 or 5 hurricanes at key points along the coastline. Source: Applied Insurance Research in IIPLR/IRC (1995).

Saffir– Simpson scale	Location	Total insured loss (billions U.S.\$ 1993)
5	Miami, FL	52.5
5	Ft. Lauderdale, FL	51.9
5	Galveston, TX	42.5
5	Hampton, VA	33.5
5	New Orleans, LA	25.6
4	Asbury Park, NJ	52.3
4	New York City, NY	45.0
4	Long Island, NY	40.8
4	Ocean City, MD	20.1

## Annual Hurricane Damage: 1925-1995 Normalized to 1995 values

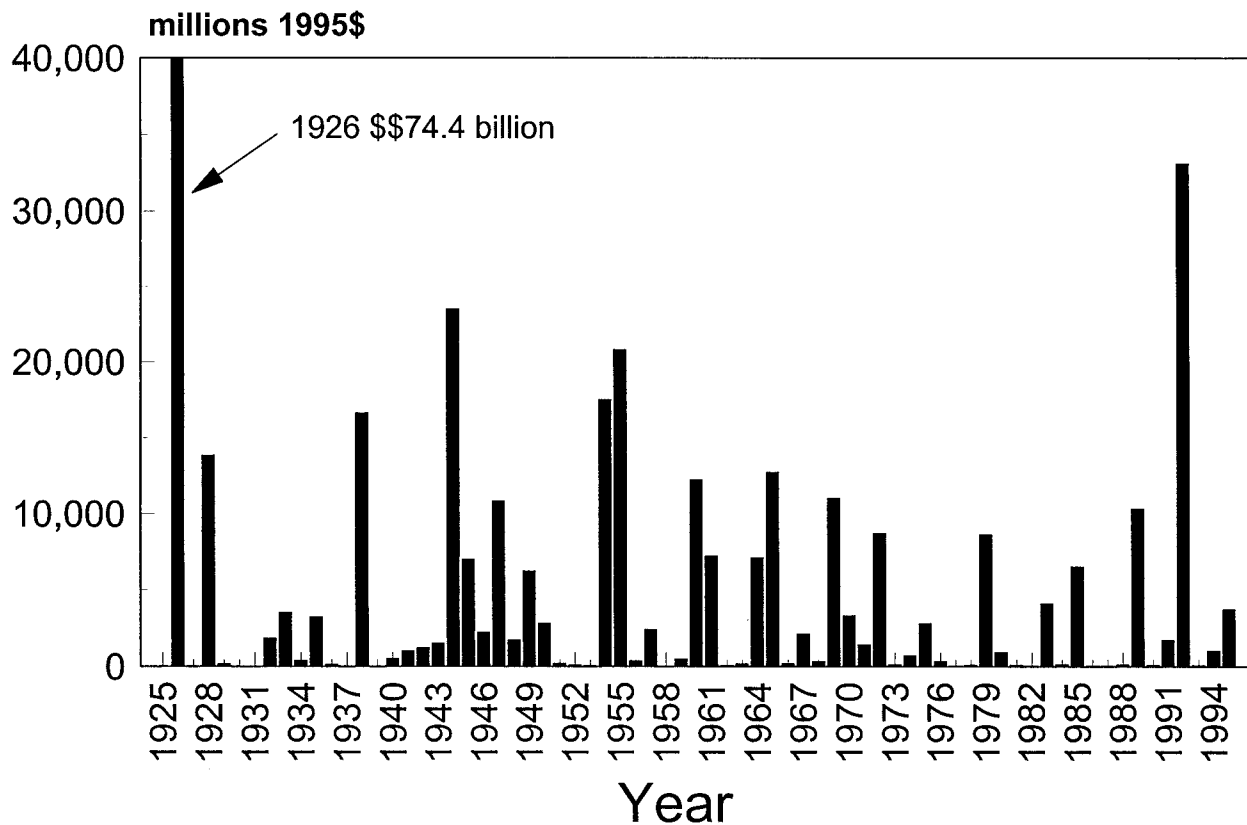


FIG. 4. Time series of United States hurricane-related losses (direct damages in millions of 1995 U.S. dollars) from 1925 to 1995 in normalized 1995 damage amounts (utilizing inflation, coastal county population changes, and changes in wealth).

damages to 1995 values using a simple, transparent methodology (Behn and Vaupel 1982; Patton and Sawicki 1986). This methodology may also be useful as an independent check on the output of the more complex catastrophe models.

TABLE 4. Number of years with extremely high (>\$1 billion, >\$5 billion, and >\$10 billion) normalized damage amounts for each decade. The column at the far right presents the annual average normalized damage for that particular decade.

Years	>\$1 billion	>\$5 billion	>\$10 billion	Per year (\$ billions)
1925-29	2	2	2	17.7
1930s	4	1	1	2.6
1940s	8	4	2	5.6
1950s	4	2	2	3.7
1960s	6	5	3	5.2
1970s	5	2	1	2.7
1980s	3	2	1	2.2
1990-95	4	1	1	6.6

### 3. Normalized data

To normalize past impacts data to 1995 values, it is assumed that losses are proportional to three factors: inflation, wealth, and population. The result of normalizing the data will be to produce the estimated impact of any storm as if it had made landfall in 1995 (cf. Changnon et al. 1997).

Inflation is accounted for using the implicit price deflator for gross national product, as reported in the Economic Report of the President (Office of the President 1950, 1996). Wealth is measured using an economic statistic kept by the U.S. Bureau of Economic Analysis called "fixed reproducible tangible wealth" and includes equipment and structures owned by private business, owner-occupied housing, nonprofit institutions, durable goods owned by consumers, as well as government-owned equipment and structures (BEA 1993). Wealth is accounted for in the normalization using a ratio (inflation adjusted) of today's wealth to that of past years [end of year gross stock from Table A15 of BEA

TABLE 5. Summary of normalized 1995 damage amounts (in millions of U.S. dollars) for the U.S. tropical cyclones from 1925 to 1995. Categories of the storm are from the Saffir–Simpson hurricane scale (Simpson 1974). The parentheses indicate the number of each category that has struck the United States. “Potential damage” provides a relative scale for the median damage amount given that a category 1 hurricane is scaled as “1.” Values in the brackets are likely not representative of the true amounts because of the very small sample (two) available.

Category of storm	Mean damage	Median damage	Potential damage	Total damage (%)	Total for each storm (%)
Trop. and subtrop. (118)	59	0	0	2.0	0.02
Hurr. cat. 1 (45)	624	33	1	8.3	0.18
Hurr. cat. 2 (29)	698	336	10	6.0	0.21
Hurr. cat 3 (40)	2978	1412	50	35.0	0.88
Hurr. cat. 4 (10)	15 358	8224	250	45.2	4.52
Hurr. cat. 5 (2)	(5973)	(5973)	500	3.5	(1.75)

(1993)].<sup>4</sup> Because the measure of wealth is based on national figures, we have adjusted it back to per capita by removing from it the relative change in the entire U.S. population. Wealth data are available from 1925, consequently the normalization begins with that year.

The final factor is population change based on data from the U.S. Census for each of the 168 coastal counties that lie along the coast from Texas to Maine.<sup>5</sup> The population factor is defined as the change in population of the affected coastal county (or counties).

To summarize, the normalization method is determined as follows:

- NL<sub>95</sub> = a storm’s loss normalized to 1995 value;
- y = year of storm’s impact;
- c = county(ies) of storm’s maximum intensity at landfall<sup>6</sup>;
- L<sub>y</sub> = storm’s loss in year y, in current dollars (i.e., not adjusted for inflation);
- I<sub>y</sub> = inflation factor, determined by the ratio of the 1995 implicit price deflator for gross national product to that of year y;

W<sub>y</sub> = wealth factor, determined by the ratio of the inflation-adjusted 1995 fixed reproducible tangible wealth expressed as per capita to that of year y; and

P<sub>y,c</sub> = population factor, determined by the ratio of the change in the population of the coastal county(ies) most affected by the storm from year y to 1995. County(ies) affected by the storm are defined by Jarrell et al. (1992).<sup>7</sup>

The general formula for y = 1925 to 1995 is, thus,

$$NL_{95} = L_y \times I_y \times W_y \times P_{y,c}.$$

For example, the 1938 New England hurricane made landfall as a category 3 hurricane through the states of New York, Connecticut, Rhode Island, and Massachusetts causing an estimated \$306 million damage.<sup>8</sup> The population of the coastal counties impacted [Suffolk (NY); New London, Middlesex, New Haven, Fairfield (CT); Newport, Bristol, Providence, Kent, Washington (RI); Bristol (MA)] at that time was 2.336 million, while the 1995 estimated population had increased to 4.860 million, a factor of 2.08. The inflation and wealth factors

<sup>4</sup> The data are provided 1925 through 1989. For the period 1990–95 we assume a constant annual increase in wealth equal to the average annual increase from 1980 to 1989.

<sup>5</sup> Because the U.S. Census is taken every 10 years, we have interpolated to estimate population for particular years.

<sup>6</sup> Five storms in particular caused most of their significant damage inland due to flooding: Diane (1955), Doria (1971), Agnes (1972), Eloise (1975), and Alberto (1994). We have used the inland county population data for these cases.

<sup>7</sup> We utilized the county(ies) that Jarrell et al. (1992) listed with the highest category of impact for each storm. Some hurricanes affected with the highest category just one county [e.g., Andrew (1992), Dade County], while others impacted many counties (see the example of the New England 1938 hurricane).

<sup>8</sup> The methodology is very sensitive to the accuracy of the reported damage at the time of the original event. Reliable data that show that past storms had a greater or lesser impact would alter our results.

TABLE 6. Same as in Table 5 except to categorize the median damage amounts by whether the tropical cyclone struck a coastal region that is currently (1995) sparsely (less than 250 000 people), medium (250 000–1 000 000) and highly (greater than 1 000 000) populated.

Category of storm	Median damage	Median damage by 1995 populations values		
		0–250 000	250 000–1 000 000	>1 000 000
Trop. and subtrop.	0	0 (60)	0 (37)	0 (20)
Hurr. cat. 1	33	16 (21)	17 (15)	232 (9)
Hurr. cat. 2	336	140 (10)	158 (7)	1380 (12)
Hurr. cat. 3	1412	1108 (13)	2050 (12)	2118 (15)
Hurr. cat. 4	8224	2105 (2)	8224 (4)	22 886 (4)
Hurr. cat. 5	(5973)	5973 (2)	— (0)	— (0)

TABLE 7. Top 30 damaging hurricanes, normalized to 1995 dollars by inflation, personal property increases, and coastal county population changes (1925–95). Note that Andrew is no longer the most destructive hurricane on record. Also note that 23 of the top 30 destructive hurricanes were intense hurricanes of Saffir–Simpson scale 3 or higher. Most of the very destructive category 1 and 2 hurricanes caused their damage through rainfall-induced flooding, often well away from the coast.

Rank	Hurricane	Year	Category	Damage U.S. billions \$
1	SE Florida/Alabama	1926	4	72.303
2	Andrew (SE FL–LA)	1992	4	33.094
3	SW Florida	1944	3	16.864
4	New England	1938	3	16.629
5	SE Florida/Lake Okeechobee	1928	4	13.795
6	Betsy (SE FL–LA)	1965	3	12.434
7	Donna (FL–eastern United States)	1960	4	12.048
8	Camille (MS–LA–VA)	1969	5	10.965
9	Agnes (NW FL, NE United States)	1972	1	10.705
10	Diane (NE United States)	1955	1	10.232
11	Hugo (SC)	1989	4	9.380
12	Carol (NE United States)	1954	3	9.066
13	SE FL–LA–AL	1947	4	8.308
14	Carla (N and central TX)	1961	4	7.069
15	Hazel (SC–NC)	1954	4	7.039
16	NE United States	1944	3	6.536
17	SE Florida	1945	3	6.313
18	Frederic (AL–MS)	1979	3	6.293
19	SE FL	1949	3	5.838
20	Alicia (N TX)	1983	3	4.056
21	Celia (S TX)	1970	3	3.338
22	Dora (NE FL)	1964	2	3.108
23	Opal (NW FL–AL)	1995	3	3.000
24	Cleo (SE FL)	1964	2	2.435
25	Juan (LA)	1985	1	2.399
26	Audrey (LA–N TX)	1957	4	2.396
27	King (SE FL)	1950	3	2.266
28	SE FL–GA–SC	1947	2	2.263
29	SE FL	1935	2	2.191
30	Elena (MS–AL–NW FL)	1985	3	2.064

are 11.75 and 2.224, respectively, between 1938 and 1995. Thus, the normalized damage that would be attributed to the 1938 New England hurricane if it struck in 1995 is the following:

$$\begin{aligned}
 & \$306 \text{ million}_{38} \times 11.75 \times 2.224 \times 2.080 \\
 & = \$16,629 \text{ million}_{95}.
 \end{aligned}$$

#### 4. Interpretation of the data

The normalized trend data on annual hurricane impacts from 1925 to 1995 is shown in Figure 4. It shows the estimated losses associated with each year’s hurricane activity, as if each year’s storms had made landfall in 1995.<sup>9</sup> It presents a much different picture than the non-normalized data. It shows that in the 1940s, 1950s, and 1960s more frequent and costly landfalls occurred than in the 1970s and 1980s, consistent with the climatology of hurricane landfalls (Neumann et al. 1993; Landsea 1993; Hebert et al. 1996). The normalized data

<sup>9</sup> Note that the normalized estimates are conservative because the adjustment for population neglects coastal development resulting from vacation properties.

also show that years with multibillion dollar losses have been the norm rather than the exception.

In terms of the normalized data, in aggregate, hurricanes caused >\$339 billion in losses over 71 years, or an annual average of about \$4.8 billion, with a maximum of >\$74 billion in 1926 and numerous years with no reported damage.<sup>10</sup> Note that the annual average is significantly higher than the \$2 billion per year reported in Landsea (1993) and (Hebert et al. 1996). Of the 71 yr, 35 yr (about 50%) had less than \$1 billion in dam-

<sup>10</sup> We considered the possibility that a hurricane making landfall years ago in a remote, sparsely populated area might result in no reported damages, yet would cause significant damage today, especially if that region was now more populated. In the historical record we identified 16 storms that made landfall with no reported damages. Of these, 12 were category 1 storms that made landfall in regions that are only sparsely or moderately populated today and, thus, would likely cause minimal damages. Four storms, 1928, 1929, 1933, and 1939, made landfall as category 2 storms, three in sparsely populated regions and one in a densely populated region. Based on our normalization, the three landfalls over sparse population would likely result in >\$100 million and the one landfall over dense population would likely result in >\$1 billion (dollar estimates from Table 5). The addition of these data would not significantly alter the summary data.

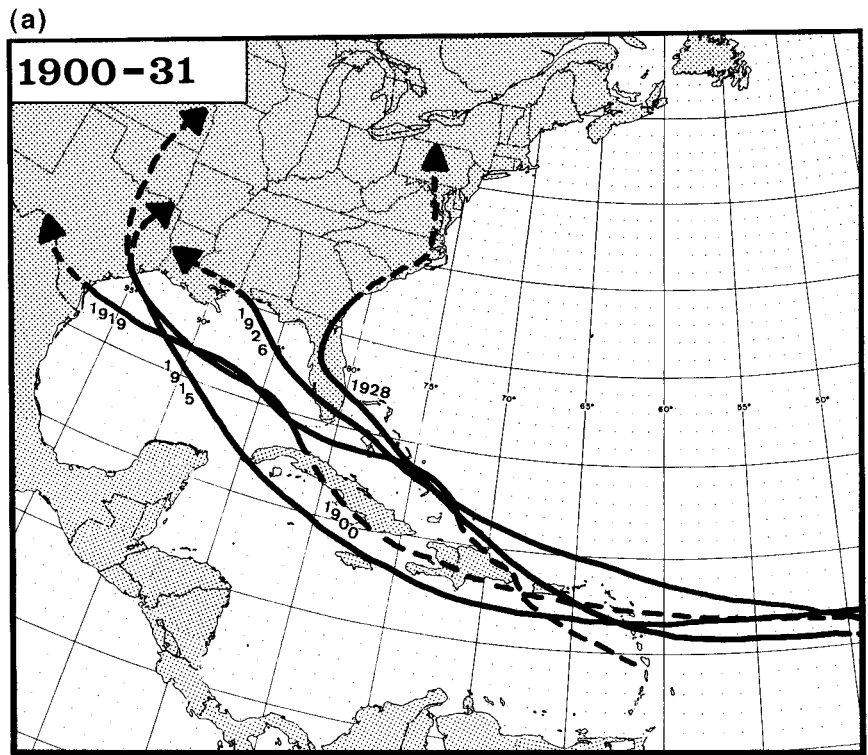


FIG. 5. Tracks of U.S. top 30 damaging hurricanes after normalization to 1995 dollars for the years (a) 1900-31, (b) 1932-63, (c) 1964-95. Solid lines indicate hurricane force conditions and dashed lines indicate tropical storms force intensity.

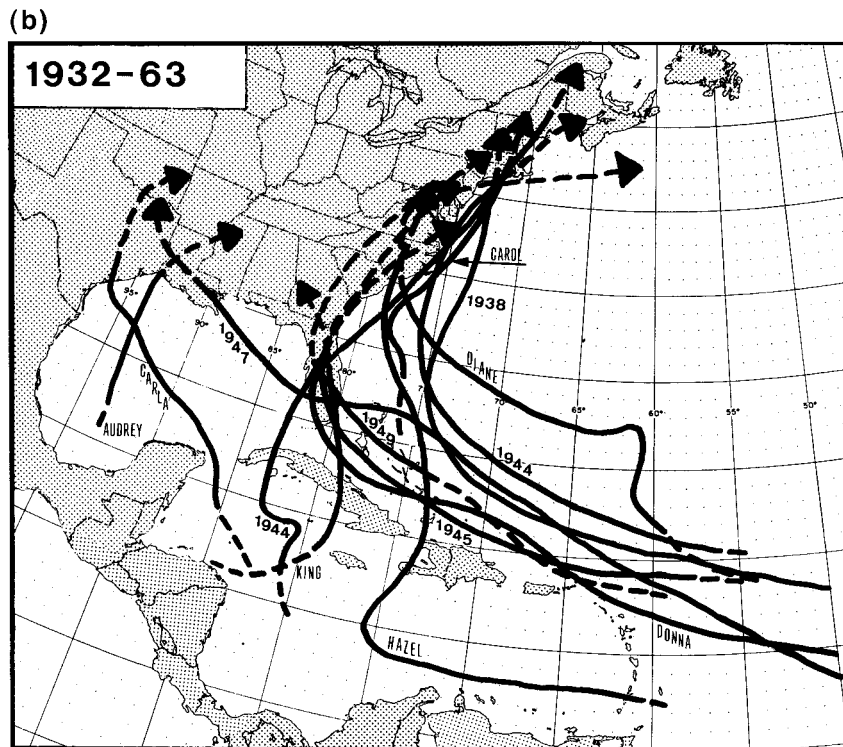


FIG. 5. (Continued)



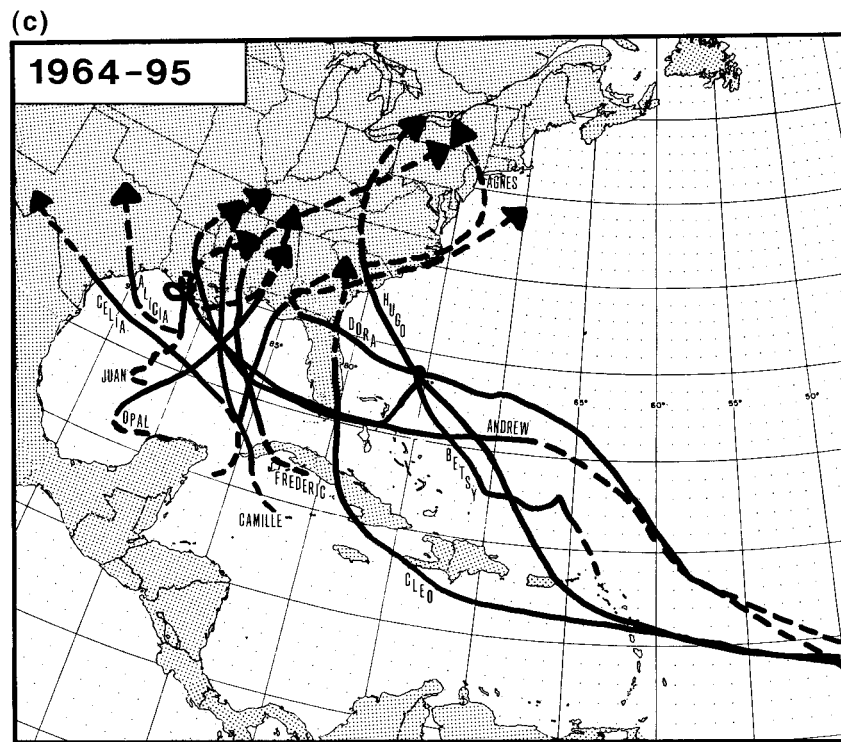


FIG. 5. (Continued)

ages. There were 19 yr (about 25%) with at least \$5 billion and 13 yr (about 18%) with at least \$10 billion. *From this analysis, all else being equal, each year the United States has at least a 1 in 6 chance of experiencing losses related to hurricanes of at least \$10 billion (in normalized 1995 dollars).* Of course, in particular years climate patterns can significantly alter these odds (Gray et al. 1997), and in every year beyond 1995 the stakes rise due to inexorable coastal population growth and development. Table 4 shows the breakdown of storms by decade and by the amount of damage caused. It shows that the 1940s had 8 yr with more than a billion in damages, as compared to the 1980s with only 3. *Perhaps more importantly, it shows that the 1940s–60s had 7 yr of greater than \$10 billion in damages, as compared with 1 in the 1970s and 1 in the 1980s.* Through 1995, the 1990s have unfolded more like the 1940s than the 1980s. However, it does seem that the United States has been fortunate with respect to the more extreme losses from the standpoint of relatively few hurricanes making landfall during the recent period of greatest development. Table 5 shows the summary results, broken down by category of storm. Table 6 further breaks down the data by segregating losses according to the population of the county in which the storm made landfall.

The intense hurricanes (Saffir–Simpson categories 3, 4, and 5) make up only about 21% of U.S.-landfalling tropical cyclones, yet account for about 83% of the normalized damage. This is a substantially higher per-

centage of the damage than reported by Landsea (1993), which utilized only inflation and coastal county population changes. The study by Landsea took place prior to Andrew’s landfall in 1992. The 52 intense hurricanes that struck the United States from 1925 to 1995 resulted in an average of \$5.5 billion in damages per storm. Within the hurricane season, 94% of normalized damages occurred in August or later, underscoring the impacts of the intense storms.

The 30 storms with the greatest losses over the 71-yr period are shown in Table 7. Figures 5a–c shows the tracks of these 30 storms. Hurricane Andrew (1992) ranks second to another category 4 storm that made landfall just to the north in 1926, causing >\$63 billion in damages, and then made a second landfall as a category 3 storm on the Florida and Alabama gulf coasts, causing >\$9 billion in damages. Third on the list is a 1944 south Florida storm (category 3), followed by the New England hurricane of 1938 (category 3), both causing >\$16 billion in losses.

If one uses actual coastal county population changes and conservatively assumes a 2% increase per year in combined inflation and wealth, then the list of great hurricane losses can be extended back to include three category 4 storms that made landfall in Texas in 1900, 1915, and 1919 (Table 8). Two of these storms made landfall in the Galveston area (1900, 1915) and would appear as third and fourth on the revised list with >\$26 billion and >\$22 billion in losses, respectively. The

TABLE 8. Top 30 damaging hurricanes, normalized to 1995 dollars by inflation, personal property increases, and coastal county population changes (1900–95). If one uses actual coastal county population changes and assumes a 2% increase per year in the combined GNP inflation and personal property index back to 1900, then this list can be supplemented by destructive hurricanes in 1900, 1915, and 1919. (These hurricanes are noted by asterisks in the table).

Rank	Hurricane	Year	Category	Damage U.S. Billions \$
1	SE FL–AL	1926	4	72.303
2	Andrew (SE FL–LA)	1992	4	33.094
3	*N TX (Galveston)	1900	4	26.619
4	*N TX (Galveston)	1915	4	22.602
5	SW FL	1944	3	16.864
6	New England	1938	3	16.629
7	SE FL–Lake Okeechobee	1928	4	13.795
8	Betsy (SE FL–LA)	1965	3	12.434
9	Donna (FL–E United States)	1960	4	12.048
10	Camille (MS–LA–VA)	1969	5	10.965
11	Agnes (NW FL, NE United States)	1972	1	10.705
12	Diane (NE United States)	1955	1	10.232
13	Hugo (SC)	1989	4	9.380
14	Carol (NE United States)	1954	3	9.066
15	SE FL–LA–AL	1947	4	8.308
16	Carla (N and central TX)	1961	4	7.069
17	Hazel (SC–NC)	1954	4	7.039
18	NE United States	1944	3	6.536
19	SE FL	1945	3	6.313
20	Frederic (AL–MS)	1979	3	6.293
21	SE FL	1949	3	5.838
22	*S Texas	1919	4	5.368
23	Alicia (N TX)	1983	3	4.056
24	Celia (S TX)	1970	3	3.338
25	Dora (NE FL)	1964	2	3.108
26	Opal (NW FL–AL)	1995	3	3.000
27	Cleo (SE FL)	1964	2	2.435
28	Juan (LA)	1985	1	2.399
29	Audrey (LA–N TX)	1957	4	2.396
30	King (SE FL)	1950	3	2.266

1919 storm would have resulted in >\$5 billion in losses, placing it at 22d on the revised list.

## 5. Conclusions

The normalized data indicate clearly that the United States has been fortunate in recent decades with regard to storm losses as compared with earlier decades. The data further refute recent claims that the rapid increase in non-normalized damages are due to climatic changes (cf. Changnon et al. 1997). When inflation, wealth, and population changes are taken into account, instead of increases, normalized damages actually decreased in the 1970s and 1980s. The 1990s, so far, are more akin to the normalized damages that occurred during the 1940s and 1960s, and are by no means unprecedented. Thus, caution is urged in interpreting statements regarding the increasing number of “billion-dollar losses” or other such measures (e.g., Flavin 1994). With respect to hurricanes, the clearest evidence that explains increases in losses is changes in society, not in climate fluctuations. Indeed, a climate signal is present in the normalized data, and this is of *decreased* impacts in recent decades.

If the normalization methodology produces valid results, the data provide some evidence at a very general

level that numbers generated through the more complex catastrophe models are reliable. This would lead to the conclusion that it is only a matter of time before the nation experiences a \$50 billion or greater storm, with multibillion dollar losses becoming increasingly frequent. Climate fluctuations that return the Atlantic basin to a period of more frequent storms will enhance the chances that this time occurs sooner, rather than later.<sup>11</sup>

*Acknowledgments.* We would like to acknowledge useful comments and suggestions from Marilyn Baker, Bob Burpee, Stan Changnon, Bill Gray, Paul Hebert, Jerry Jarrell, Bill Landsea, Donna Bahr-Landsea, Kathy Miller, Rade Thomas Muslin, Richard Roth, and Bob Sheets as well as those of the anonymous reviewers. Thanks also to John Cole at the Corpus Christi NWS Office for providing updated damage estimates from the 1932 hurricane. Thanks also to officials at Property Claims Services, Inc., for providing insurance loss data.

<sup>11</sup> A companion paper (Landsea et al. 1998, manuscript submitted to *Climate Change*) will put these results into the context of the observed variations of Atlantic basin and U.S.-landfalling tropical cyclone frequencies.

The text was ably prepared by Jan Hopper and D. Jan Stewart. All errors in the text are the responsibility of the authors. This research was partially supported by a grant from the Bermuda Biological Research Station's Risk Prediction Initiative on the topic of interannual tropical cyclone variability. This paper was initially prepared for a Panel on Social, Economic, and Policy Aspects of Hurricanes at the 22d Conference on Hurricanes and Tropical Meteorology in Fort Collins, Colorado.

## REFERENCES

- Banham, R., 1993: Reinsurers seek relief in computer predictions. *Risk Management* (August), 14–19. [Available from Risk Management, Inc., 205 E. 42nd St., New York, NY 10017.]
- BEA, 1993: Fixed reproducible tangible wealth in the *United States, 1925–1989* (January). Bureau of Economic Analysis, U.S. Government Printing Office, 337 pp. [Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.]
- Behn, R. D., and J. W. Vaupel 1982: *Quick Analysis for Busy Decision Makers*. Basic Books, 415 pp.
- Changnon, S. A., Ed., 1996: *The Great Flood of 1993: Causes, Impacts, and Responses*. Westview Press, 319 pp.
- , D. Changnon, E. R. Fosse, D. C. Hoganson, R. J. Roth Sr., and J. M. Totsch, 1997: Effects of recent weather extremes on the insurance industry: Major implications for the atmospheric sciences. *Bull. Amer. Meteor. Soc.*, **78**, 425–431.
- Dlugolecki, A. F., Ed. 1996: Financial services. *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses*. Cambridge University Press, 539–560.
- Englehardt, J., and C. Peng, 1996: A Bayesian benefit–risk model applied to the south Florida building code. *Risk Analysis*, **16**, 81–91.
- Flavin, C., 1994: Storm warnings. *Worldwatch*, **7**, 10–20.
- Gray, W. M., J. D. Sheaffer, and C. W. Landsea, 1997: Climate trends associated with multidecadal variability of Atlantic hurricane activity. *Hurricanes, Climate and Socioeconomic Impacts*, H. F. Diaz and R. S. Pulwarty, Eds., Springer, 15–53.
- Hebert, P. J., J. D. Jarrell, and M. Mayfield, 1996: The deadliest, costliest, and most intense United States hurricanes of this century (and other frequently requested hurricane facts). NOAA Tech. Memo. NWS NHC-31 (February), 41 pp. [Available from National Hurricane Center, 11691 SW17th St., Miami, FL 33165.]
- IIPLR/IRC, 1995: Coastal exposure and community protection: Hurricane Andrew's legacy. Insurance Institute for Property Loss Reduction/Insurance Resource Council Boston, MA, 48 pp. [Available from IRC, 211 S. Wheaton Ave., Suite 410, Wheaton, IL 60187.]
- Jarrell, J. D., P. J. Hebert, and M. Mayfield, 1992: Hurricane experience levels of coastal county populations from Texas to Maine. NOAA Tech. Memo. NWS NHC-46 (August), 152 pp. [Available from National Hurricane Center, 11691 SW17th St., Miami, FL 33165.]
- Landsea, C. W., 1991: West African monsoonal rainfall and intense hurricane associations. Colorado State University Dept. of Atmospheric Science Paper 484, 272 pp. [Available from Dept. of Atmospheric Sciences, CSU, Fort Collins, CO 80523.]
- , 1993: A climatology of intense (or major) Atlantic hurricanes. *Mon. Wea. Rev.*, **121**, 1703–1713.
- , N. Nicholls, W. M. Gray, and L. A. Avila, 1996: Downward trends in the frequency of intense Atlantic hurricanes during the past five decades. *Geophys. Res. Lett.*, **23**, 1697–1700.
- Neumann, C. J., B. R. Jarvinen, C. J. McAdie, and J. D. Elms, 1993: *Tropical Cyclones of the North Atlantic Ocean, 1871–1992* (fourth revision). NCDC/NHC Historical Climatology Series 6-2, 193 pp. [Available from NESDIS, Federal Bldg., 151 Patton Ave., Asheville, NC 28801-5001.]
- Noonan, B., 1993. Catastrophes: The new math. *Best's Review*, Property/Casualty edition, 41–83.
- Office of the President, 1950: Economic report of the President. U.S. Government Printing Office, Washington, D.C.
- , 1996: Economic report of the President. U.S. Government Printing Office, Washington, D.C.
- Patton, C. V., and D. S. Sawicki, 1986: *Basic Methods of Policy Analysis and Planning*. Prentice-Hall, 450 pp.
- Pielke, R. A., Jr., 1995: *Hurricane Andrew in South Florida: Mesoscale Weather and Societal Responses*. National Center for Atmospheric Research, 212 pp.
- , 1997: Reframing the U.S. hurricane problem. *Soc. Nat. Resour.*, **10**, 485–499.
- Pielke, R. A., Jr., and R. A. Pielke Sr., 1997: *Hurricanes: Their Nature and Impacts on Society*. John Wiley, 279 pp.
- Senate Committee on Banking, Housing, and Urban Affairs, Subcommittee on Housing and Urban Affairs, 1992: *The National Flood Insurance Reform Act of 1992*. 102–913.
- Simpson, R. H., 1974: The hurricane disaster potential scale. *Weatherwise*, **27**, 169, 186.
- U.S. Senate Bipartisan Task Force on Funding Disaster Relief, 1995: *Federal Disaster Assistance*. 104-4.
- West, C., and D. Lenze, 1994: Modeling the regional impact of natural disaster and recovery: A general framework and an application of Hurricane Andrew. *Int. Reg. Sci. Rev.*, **17**, 121–150.