Trends in U.S. Tropical Cyclone Mortality During the Past Century

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Hazard mitigation specialists in the United States, and particularly in Florida, are deeply concerned with hurricanes. Storm surge, heavy rainfall, and high winds combine to make them perilous events. Despite technological advances in monitoring and prediction, hurricanes retain their potential to cause severe damage and numerous deaths. Hurricane Mitch, which devastated Honduras and Guatemala in 1998 is a reminder that hurricanes can quickly kill thousands of people. Population and demographic shifts toward the coasts will make the problem worse.

The United States' coastal population is growing faster than the total population. Damage data from past storms support the notion that the United States is becoming increasingly vulnerable to hurricanes (Pielke and Landsea 1998). The five costliest U. S. hurricanes have occurred since 1965 (Elsner and Kara 1999). The average number of deaths from hurricanes has, however, decreased markedly over the past century (Simpson and Riehl 1981). This is due, in part, to technological advances (satellite and aircraft surveillance, numerical weather prediction models, etc.) and to effective communication of their destruction potential (Pielke and Pielke 1997). For example, efficient communication and transportation infrastructure allow effective warning and evacuation of coastal residents well in advance of the storm (Riebsame et al. 1986).

However, because the distribution of annual deaths is skewed, the mean annual death toll can be misleading. In fact, there is the intuitive notion that with more people in harm's way, there is an increasing threat of casualties. Here, instead of the *mean* we use the *median* value to ascertain the typical number of deaths per year. In addition we demonstrate that, similar to damage costs, the median

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number of deaths per hurricane has been larger during the second half of the century than during the first half.

Data and Method

Data used in this study are obtained from Hebert et al. (1996). They consist of estimated annual number of deaths in the mainland United States from North Atlantic tropical cyclones that reached land over the period 1900 through 1995 (see Table 1). The North Atlantic includes the Caribbean Sea and Gulf of Mexico. A tropical cyclone is a generic term referring to a disturbance or storm of tropical or subtropical origin. For the purpose of this study we use only the count of direct deaths from tropical cyclones (see also Fitzpatrick 1999). Direct deaths are those that occur from high winds, storm surge, or flooding accompanying the storm. Indirect deaths, including stress-related heart attacks or traffic accidents on rain-soaked highways, are not included. Historically, whenever there is a large loss of life from a tropical cyclone, the main cause of death is drowning, not wind or wind-blown objects or structural failure (Rappaport and Fernández-Partagás 1995). Inland flooding remains a significant threat to lives during a tropical cyclone landfall even after the storm's surface circulation diminishes. In fact, of the tropical cyclones affecting the United States since 1970, inland loss of life is relatively large (Rappaport et al. 1999).

To uncover trends in the data, the 96-year period is broken into six consecutive 16-year sub-periods: 1900–15, 1916–31, 1932–47, 1948–63, 1964–79, and 1980–95. The length of each sub-period is a compromise between smoothing and a reliable number of data points. Shorter sub-periods produce more points at the expense of less smoothing. Choosing a shorter or longer sub-period does not meaningfully change the results.

The mean annual number of deaths is tabulated for each sub-period, as well as the standard deviation and the coefficient of variation. Additionally, we determined the median annual mortality over each sub-period. A k -statistic is calculated as the number of years in which there are at least k deaths for different values of k . Note that earlier years may have had a greater accounting problem than the more recent years. With regards to the actual number of fatalities, this could influence the present results.

Mortality data on a per storm basis over the period 1966–95 are obtained from the seasonal tropical cyclone summaries published

Table 1
Tropical Cyclone Deaths

Year	Deaths	Year	Deaths	Year	Deaths
1900	8000	1932	0	1964	49
1901	10	1933	63	1965	75
1902	0	1934	17	1966	54
1903	15	1935	414	1967	18
1904	5	1936	9	1968	9
1905	0	1937	0	1969	256
1906	298	1938	600	1970	11
1907	0	1939	3	1971	8
1908	0	1940	51	1972	122
1909	406	1941	10	1973	5
1910	30	1942	8	1974	1
1911	17	1943	16	1975	21
1912	1	1944	64	1976	9
1913	5	1945	7	1977	0
1914	0	1946	0	1978	36
1915	550	1947	53	1979	22
1916	107	1948	3	1980	2
1917	5	1949	4	1981	0
1918	34	1950	19	1982	0
1919	287	1951	0	1983	22
1920	2	1952	3	1984	4
1921	6	1953	2	1985	30
1922	0	1954	193	1986	9
1923	0	1955	218	1987	0
1924	2	1956	19	1988	6
1925	6	1957	400	1989	56
1926	269	1958	2	1990	13
1927	0	1959	24	1991	16
1928	1836	1960	65	1992	24
1929	3	1961	46	1993	4
1930	0	1962	3	1994	38
1931	0	1963	10	1995	29

Values are estimated annual deaths (direct) from tropical cyclones in the United States 1900–95. Data are from Hebert et al. (1996). The horizontal line divides the data into the six equal duration sub-periods used in the analysis.

routinely by the American Meteorological Society in the Monthly Weather Review for the purpose of determining the percentage of U. S. tropical-cyclone deaths from storms of hurricane intensity or greater. These are used to justify our calculation of the typical number of deaths per hurricane, which is obtained by multiplying the median number of deaths by 16 years and dividing by the hurricane frequency. State population data from the U. S. Bureau of the Census are used to calculate the population increases in coastal counties along the hurricane coast.

Results

The average annual death toll from tropical cyclones in the United States has decreased over the 20th century (Table 2). The average annual death count dropped from 584 in the first sub-period to 16 in the last sub-period. The standard deviation fell from 1985 to 16. The coefficient of variation, defined as the ratio of the standard deviation to the mean, decreased from 340% in the earliest sub-period to 103% in the most recent sub-period. This analysis suggests a decreasing problem with regard to hurricane-related deaths in the United States. In other words, despite substantial increases in population during the century, the annual number of tropical cyclone-related deaths is declining.

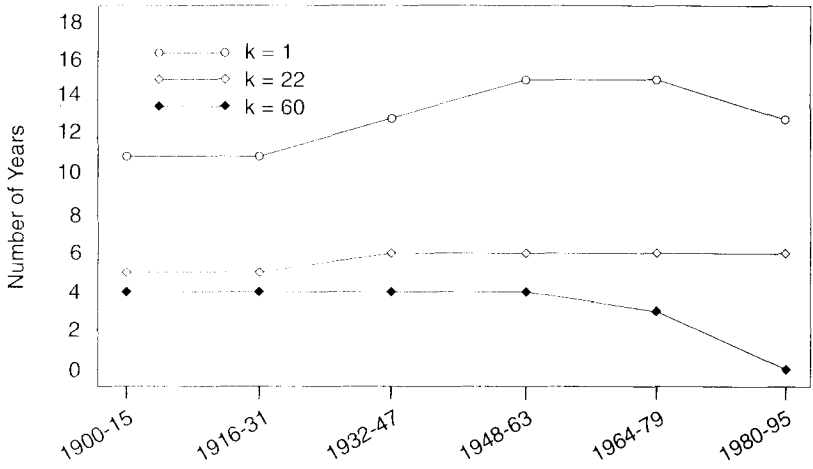
The above analysis is somewhat misleading as it fails to consider the full range of mortality data. For instance, Figure 1 shows

Table 2
Annual U.S. Hurricane Mortality Statistics

Sub-period	Mean	S.D.	C.V.(%)	Median	U.S. hurricane	Median deaths/ hurricane
1900-15	583.6	1985.1	340	7.5	26	4.6
1916-31	159.8	456.8	286	4.0	24	2.7
1932-47	82.2	170.8	208	13.0	34	6.1
1948-63	63.2	112.2	177	14.5	28	8.3
1964-79	43.5	65.3	150	19.5	23	13.6
1980-95	15.8	16.2	103	11.0	21	8.4

Values include mean, standard deviation, coefficient of variation, median, number of U.S. hurricanes, and the median number of deaths per hurricane.

Figure 1
Number of Years with at Least k Deaths

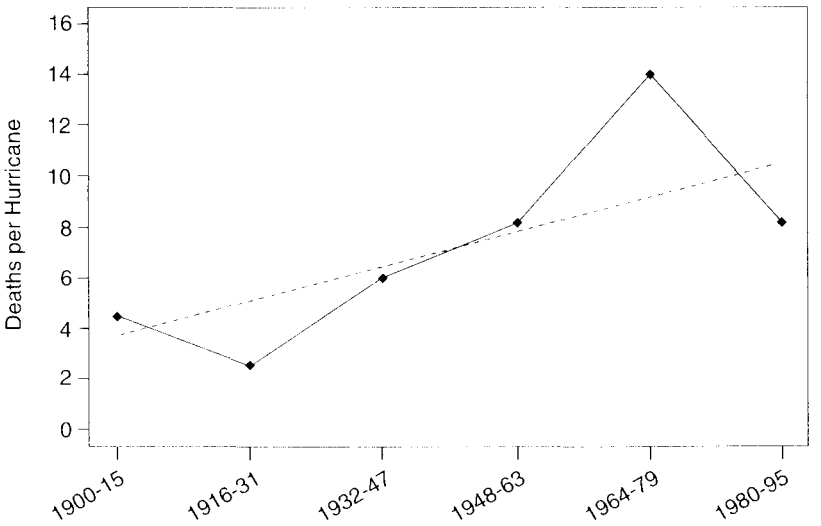


Trends in U.S. tropical cyclone deaths. Each point represents the number of years in the sub-period in which there were at least **k** direct tropical cyclone fatalities. Note that the general trend are different for different values of **k**.

the frequency of years in each sub-period with at least k tropical-cyclone related deaths. The overall trends on these curves are different for different values of k . The frequency of years with at least one hurricane fatality has increased since the first half of the century. However, the number of years with a large annual death toll has decreased. At about k=22 , the six sub-periods yield similar values indicating no change over the century. That is, all six sub-periods have approximately six years with more than 21 deaths.

The mean and median are widely used measures of central tendency. In general, sample means vary less than medians except in the case of a skewed distribution caused by extreme values. Figure 2 suggests a highly skewed distribution of annual tropical-cyclone deaths for which the median better reflects the central tendency. As an illustration, the mean and median annual death toll over the 96-year period is 158 and 10, respectively. If 1900—the year in which an estimated 8000 people died in the Galveston hurricane—is eliminated from the analysis, the mean (over the period 1901–95) drops to 75, whereas the median remains at 10.

Figure 2
Typical Mortality per US Hurricane



Mortality per hurricane during each sub-period. Values are obtained by multiplying the median by 16 (number of years in the sub-period) and dividing by the number of hurricanes. The dashed line represents a linear regression of the data points.

Table 2 lists the median number of deaths during each sub-period. Here we observe a general increase over the century. Thus, while the annual mean number of deaths has fallen dramatically, the median number has risen. The result is striking when considering that there were fewer hurricane landfalls over the past several decades. Most tropical cyclone-related deaths occur with hurricanes. Mortality data on a per storm basis over the period 1966–95 indicate that 85% of U. S. tropical cyclone deaths were due to hurricanes, although, as mentioned, a substantial portion of these deaths occurred inland from flooding after the storm weakening. The relatively more frequent catastrophic events earlier in the century would likely make this percentage even higher over the entire century. On the other hand, the bias related to counting deaths from inland flooding during earlier years is not considered.

Table 2 also lists the number of U. S. hurricanes in each sub-period. A U. S. hurricane is defined as a tropical cyclone with winds of hurricane strength at the point of landfall (all or part of

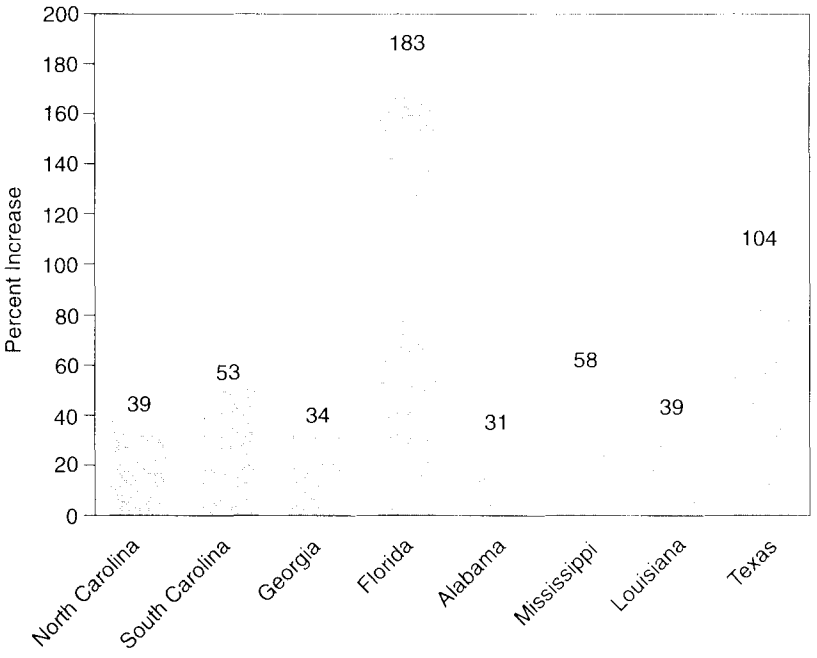
the eye-wall over land). A hurricane land falling more than once is counted as a single U. S. hurricane. Note the relative abundance of U. S. hurricanes during the 1930s and 1940s compared to the frequency during the latter third of the century. Multiplying the median number of deaths by the number of years in each sub-period and dividing by the number of U. S. hurricanes gives the typical mortality per hurricane (last column of Table 2). Although tropical cyclones of lesser intensity cause deaths, hurricanes have accounted for a significant portion of all casualties since 1966. The mortality per hurricane in the United States, which takes into account the median death toll and hurricane frequency, is shown in Figure 2 for each sub-period. As anticipated we see an increase over the period of record. In fact, a linear regression gives an R - squared value of 0.58 with a p -value on the slope coefficient of 0.079.

Discussion

Tropical cyclones in the United States have killed on the order of 15,000 citizens during the past century. Approximately half of these occurred during the 1900 Galveston catastrophe. After this tragedy there are sixteen years in the record with more than 100 deaths from tropical cyclones giving an average of one catastrophic year every six years. Yet, the last time the annual tropical cyclone death toll surpassed the century mark was back in 1972 with hurricane Agnes. Historically, largest losses are due to drowning from hurricane-generated storm surge. The decrease in storm-surge deaths during the latter part of the 20th century is attributable to a cooperative relationship between the National Weather Service/Tropical Prediction Center (National Hurricane Center), emergency management community, U. S. Army Corps of Engineers, and the media (Sheets 1990, Rappaport et al. 1999). However, the increasingly rare catastrophic event makes a trend analysis based on averages suspect. It is our view that the median value is a better metric of the typical annual death toll and that by this measure, an increase in deaths per hurricane has occurred during the 20th century.

The increase in mortality per hurricane is likely related to population increases along the hurricane coast. Figure 3 shows the coastal population increases between 1960 and 1994 for North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, and Texas. Although hurricanes and other tropical

Figure 3
Coastal Population Increase, 1960–94



Coastal population changes over the period 1960-94 expressed as a percentage increase. Values are from the U.S. Bureau of the Census for coastal counties as defined by the National Oceanic and Atmospheric Administration.

cyclones occasionally make landfall between Virginia and Maine, 85% of U. S. hurricanes between 1900 and 1995 made landfall along the coastline from Texas to North Carolina (Elsner and Kara 1999). Between 1960 and 1994, the U.S. population increased by 45%, with the population in the eight aforementioned most hurricane-prone states increasing by 80%. More troubling however is that coastal population in these states rose 103% during this time period. While advanced warnings (in particular, warnings of high winds and surge at the coast) have reduced the occurrence of a massive loss of life from a single event, the increased coastal population of the United States is raising the anticipated loss per hurricane. The problem is acute in densely populated areas where the evacuation clearance times are substantially longer than the storm warning time.

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