Loss of Life in the United States Associated with Recent Atlantic Tropical Cyclones

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ABSTRACT

A database was established for the period 1970–99 to assess the threat to life in the contiguous United States and adjacent coastal waters from Atlantic tropical cyclones. Freshwater floods caused more than one-half of the 600 U.S. deaths directly associated with tropical cyclones or their remnants during that 30-year period. More than three-quarters of the victims under age 13 died in rain-induced floods. Most fatalities occurred in inland counties. Storm surge losses were significantly (but perhaps only temporarily) less than in previous periods of comparable length. This paper presents a statistical summary of the casualties, explores reasons for the losses, and reviews efforts to mitigate the threats.

1. Introduction

Atlantic tropical cyclones have likely killed between one-third and one-half a million people since the discovery of the New World, including around 25,000 people in the United States after the American Revolution (Rappaport and Fernandez-Partagas 1995). The largest U.S. disasters occurred after 1880 (e.g., in South Carolina and Georgia in 1881 and 1893; in Louisiana in 1893; in Galveston, Texas, and its environs in 1900; near Lake Okeechobee in 1928) and, in nearly every instance, storm surge was the predominant killer. An American Meteorological Society (AMS) policy statement adopted in October 1972 noted that the combination of storm surge and accompanying waves was responsible for 90% of hurricane-related fatalities near the U.S. coast (AMS 1973). The vulnerable coastal population has grown since then, and the potential remains high for storm surge to cause another large loss of life (Sheets 1990).

Freshwater floods from rain present another great threat to life in tropical cyclones, and these effects occasionally exceed the coastal impact. Such floods, which can occur hundreds of miles inland, recently claimed up to thousands of lives in the Americas and the Caribbean (e.g., 1998 Hurricanes Mitch in Honduras and Nicaragua, and Georges in Hispaniola; 1994 Hurricane Gordon in Haiti; 1993 Tropical Storm Bret in Venezuela; 1988 Hurricane Gilbert in Mexico). These losses extend a centuries-long trend—for the location of tropical cyclone-related casualties in the Western Hemisphere to migrate with the population—from casualties at sea through the 1700s, to the shoreline and coastal zone through the mid-1900s, to some areas well inland during the past 50 years (cf. Rappaport and Fernandez-Partagas 1997). Worldwide, these events accrue to making floods the deadliest and costliest natural phenomenon (Scofield and Margottini 1999).

The 1972 AMS policy statement noted that about 500 lives had been lost in the United States due to freshwater floods associated with the passage of six tropical cyclones over the preceding 20-year period. One of these storms was Hurricane Diane (1955), which caused nearly 200 flood-related fatalities, likely the largest death toll incurred from rain-induced floods.
during a tropical cyclone in the United States during the twentieth century. As recently as 1999, however, inland floods claimed 50 lives in the United States during Hurricane Floyd. A massive rescue mission is credited with saving another 1400 people from Floyd’s flood waters [J. Cline, Raleigh, North Carolina, National Weather Service (NWS) Forecast Office, 1999, personal communication].

Some tropical cyclones cause large losses both near the coast and well inland. In the United States, Hurricane Camille (1969) provides the most recent example of great magnitude, killing 256 people (Hebert et al. 1997); about half of these fatalities occurred at the coast, with the remainder from floods inland. Camille represented a rather singular meteorological event, it being one of only two Atlantic hurricanes to strike the United States at category-5 intensity on the Saffir–Simpson Hurricane Scale (Simpson 1974) in more than 150 years (e.g., Neumann et al. 1993; Fernandez-Partagas and Diaz 1996) (the other struck the Florida Keys in 1935). Camille also marked a programmatic watershed. In its wake, national policies and procedures were revised and governmental responsibilities at the local, state, and national levels were clarified (see Simpson 1998).

This paper documents the loss of life in the United States attributed to Atlantic tropical cyclones during the 30-year post-Camille era from 1970 to 1999. Where possible, it identifies the causes and locations of losses, with the objective of providing a resource from which educational programs and tropical cyclone mitigation and preparedness activities can be developed to diminish tropical cyclone hazards.

2. Data

This study established a database of information about fatalities 1) in the contiguous United States and 2) at sea within 50 nautical miles of the U.S. coast occurring in association with Atlantic tropical cyclones. These losses were associated with a subset of 65 of the roughly 300 Atlantic tropical (or subtropical) storms and hurricanes and an uncertain number of tropical depressions (see Pasch et al. 1998, p. 1121) that formed during the study period.

Only deaths occurring as a direct result of the forces of tropical cyclones or their remnants were cataloged. Such “direct” deaths include those persons who drowned in storm surge, rough seas, rip currents, and freshwater floods. Direct deaths also include casualties resulting from lightning and wind-related events (e.g., flying debris, collapsing structures), with a subset of statistics kept for losses in tornadoes. Deaths incurring “indirectly,” from such factors as heart attacks, housefires (e.g., from untended candles), electrocution from downed power lines, and vehicle accidents on wet roads, were not included in the database.

For each tropical cyclone-related fatality, the study attempted to identify:

• name of cyclone,
• date and time of injury leading to death,
• cause of death,
• county or parish of occurrence,
• strength of cyclone at landfall and at date and time of fatal incident,
• age of deceased,
• gender of deceased,
• source(s) of information, and
• supplemental notes.

To do so, the study used information primarily found in newspapers and the following NWS publications:

1) Natural Disaster Survey Reports,
2) Service Assessments,
3) Preliminary Post-storm Reports from Weather Forecast Offices (WFOs),
4) Preliminary Reports from the Tropical Prediction Center/National Hurricane Center (henceforth NHC),
5) Storm Data, and

Not all the incidents cited could be completely or unambiguously documented. For example, while the primary publications stated that there were about 50 deaths in Pennsylvania due to Hurricane Agnes in 1972, and that most victims drowned, they provided rather limited information about individual incidents. A search of secondary documentation continues for that storm and others. In another example, the NHC Preliminary Report, and the Natural Disaster Survey Report and Monthly Weather Review articles that borrowed from that report, attribute six deaths in Virginia to Hurricane Hugo in 1989. Those publications provided no other information about those losses. Storm Data shows no deaths during Hugo in Virginia. A
search through several area newspapers and a magazine published on the event did find reference to five or six fatalities, but it is unclear whether those accounts refer to the same people counted in the Preliminary Report. In fact, the fatalities tracked down are considered to be indirect losses. In cases like this, subjective and, it is hoped, judicious decisions were made about the use of the data in this study. It is acknowledged that other researchers looking at the same data might come to different conclusions about some individual events, but the overall findings and inferences would likely not be significantly altered. (For Hugo, the author chose to exclude the six possible fatalities in Virginia from the database pending possible discovery of information supporting the direct nature of those losses.)

3. Results

a. Overview

A total of 600 fatalities occurred in the contiguous United States and its coastal waters associated with Atlantic tropical cyclones during 1970-99. Cause of death was found or could be concluded with some certainty for all but seven cases. Drowning accounted for 479 deaths, or 82% of the fatalities, with wind-related events responsible for most of the others (Fig. 1). Of those whose age was known (304), 18% were 12 years of age or younger. This is comparable to the percentage of preteens in the population of the affected states (U.S. Bureau of the Census 1998).

For the 392 instances where gender was known, men accounted for 71% and women 29%. This disparity is pervasive across many incident types and, as noted below, is even larger for victims engaged in outdoor work or recreational activities. The limited record for the subset of preteens indicates a smaller disparity, 56% boys and 44% girls.

The largest loss occurred in association with Agnes. More than 100 people died during the cyclone’s overland passage (Table 1). Like Agnes, the most deadly storms were usually among the first in a season to form. For example, 5 of the 11 deadliest tropical cyclones were “A” storms and 3 others were “Cs” (On average, 10 named storms formed annually during the study period; i.e., the season reached the “J” storm.) While this could be a statistical aberration, the tendency for the first storms of a season to be the deadliest, with few exceptions, applies back to at least 1950.

The relatively weak steering currents common to the eastern United States during the months of June, July, and August likely factored into the large losses incurred in these cyclones of the early part of the hurricane season. Tropical cyclones embedded in weak flow move relatively slowly. This can prolong their impact along the coast and increase their potential to generate excessive rain and life-threatening freshwater floods.

The data do not show a straightforward relationship between number of deaths and the intensity of a tropical cyclone at landfall (or at the closest point of approach for the few deadly systems whose center’s remained offshore.) Tropical storms and category-1, -2, and -3 hurricanes each eventually contributed to more than 100 deaths.

The most severe weather usually covers a small area near the circulation center that diminishes in extent when a tropical cyclone moves inland. For the 1970–99 period, most of the deaths occurred apparently at the time when local wind speeds were below the 64-kt threshold of hurricane intensity. In fact, large loss of life occurred in several instances after a cyclone moved far enough inland that it contained little or no surface circulation [e.g., Tropical Storms Charley (1998), Alberto (1994), and Amelia (1978)]. For these systems, freshwater floods were the primary killer.

A total of 138 victims reportedly died in, or attempting to abandon, their vehicles (Fig. 2). Almost all these incidents occurred in association with freshwater-flooded roads. The number of these losses could be much higher because documentation of such incidents was frequently not available in the early part of the study period. Therefore, at least 23% of all victims died in this manner. Indeed, during 1999 Hurricane Floyd, 32 of 56 (57%) of the deaths were associated with drowning and vehicles. (Traffic accidents on wet roads were considered indirect losses and did not contribute to these statistics.)

Stratification by geographical area and cause (e.g., Table 1) provides some additional insight into the losses.
The offshore area of interest for this study extended seaward from just beyond the breakers to 50 n mi from the coast. For historical perspective, it is important to note that tropical cyclones have claimed tens of thousands of lives over the more expansive open waters of the Atlantic hurricane basin since the discovery of the New World (Rappaport and Fernandez-Partagas 1997). Most of those victims drowned when their vessels sank. Many of the losses, including the several offshore incidents where more than 1000 people perished, occurred prior to 1800. Several factors contributed to their peril.

For instance, the concept of storm track and the difference between storm motion and circulation remained obscure until Benjamin Franklin’s observations and conclusions of the mid-eighteenth century (Ludlum 1963) were extended and formalized by Redfield (1836), Reid (1841), and others.

In addition, with communications generally limited for centuries to the line of sight, storms almost always moved faster than did the information about them. While Redfield (1846) suggested that the then-expanding electric telegraph could be used to alert mariners of approaching bad weather, not until 1909 was the first in situ ship report of hurricane conditions received on land to be recommmunicated to others (Garriott 1909).

Concomitant advances in meteorology, communication, navigation, and the seaworthiness of ships over the years make such losses less frequent today. A total of 60 people, or 10% of all this study’s documented casualties between 1970 and 1999, died in the offshore focus area of this paper. Most of these offshore incidents involved the drowning of one or two people. Casualties occurred generally from capsized or wave-swept small- to medium-sized vessels including a tugboat, a trawler and other fishing boats, sailboats, and an inflatable boat. No large ships—such as freighters or cruise liners—or military watercraft were lost with casualties. In three instances, oil rig workmen died in the northern Gulf of Mexico. During one of these events, a lift boat overturned in 1989 Hurricane Chantal, leading to the loss of 10 men, the largest loss in the offshore study area during the period.

In the maritime trades, many more men than women died at sea through the centuries. That was also

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<tr>
<th>Rank</th>
<th>Name</th>
<th>Month/Year</th>
<th>Total</th>
<th>Surge</th>
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*Rough surf, rip currents, and undertow.
the case during the most recent 30 years in the offshore zone. Men accounted for more than 90% (40 of 44) of the offshore casualties, where gender was known.

c. Coastal counties

Loss-of-life information was usually available by county (or parish). This stratification conveniently coincides with the domain of many local emergency management officials and services. For coastal counties, storm surge has represented historically the primary tropical cyclone threat to the littoral zone. The dangers from surge apply along the coast, to bays, sounds, and to coastal sections of rivers. The severity of the surge, as measured by the depth and onshore penetration of water, depends on a number of such natural factors as cyclone intensity (surface wind speed) and forward speed of motion, local bathymetry, coastal topographic gradients, and barrier (e.g., dune) structure. Loss of life is a function of these factors as well as storm frequency and many sociological conditions, including population density, land use, design and implementation of local and regional preparedness plans, past storm experience, communication, forecast accuracy, and options for egress. While the United States suffered numerous storm surge disasters with losses in the hundreds or the thousands from 1870 to 1940, only six people, all adults, succumbed to surge during the last 30 years. Two surge-related deaths were reported from Hurricane Allen (1980), and one each from Hurricane Celia (1970), Charley (1986), Hugo (1989), and Fran (1996). The role of surge, if any, in about five other fatalities is uncertain.

Individually, and in combination, storm surge, waves, and wind are most violent and typically pose their most extreme dangers near the center of a hurricane. Some tropical cyclone–induced hazards, however, such as breaking waves from long-lived ocean swells, and rip currents and strong undertow, can occur along the coast as far as hundreds of miles from a cyclone’s center. There, many victims from 1970 to 1999 who were involved in recreational activities—swimming or wading, surfing, and sightseeing—apparently underestimated the risk in otherwise tranquil weather. For example, eight people drowned along the U.S. northeast coast in early September 1989 from rough surf generated by Hurricane Gabrielle, a large and intense storm whose center never came farther west than 65°W longitude. In total, 42 shoreline deaths were reported in association with rough surf or large coastal swells, with another 15 due to rip currents and/or undertow. The actual mortality totals for these threats could be larger because information identifying and associating losses at such large storm radii was sometimes not well publicized. Where gender was known, almost all (32 of 35) of these victims were male.

In the coastal counties, 30 people died in nontor- nadic events directly related to the wind. Some of these fatalities occurred in homes or other structures destroyed or otherwise compromised by the wind, or from being struck by wind-borne debris. The largest such loss was 13 people in South Florida during Hurricane Andrew. About a dozen of the wind-related deaths in the coastal zone resulted from falling trees. Tornadoes killed three or four people in coastal counties during the past three decades.

Freshwater floods killed somewhat more than 25–30 people in coastal counties (Another 30–40 freshwater fatalities could not be resolved by county). The severity of flooding in coastal areas can be exacerbated by the combination of storm surge and rainwater.

In all, about one-quarter of the deaths from 1970 to 1999 occurred in coastal counties.
d. Inland counties

Figure 3 shows the geographical distribution of losses by county, where known. It indicates loss of life from Atlantic tropical cyclones has occurred inland hundreds of miles from the coast. The map should not be used as an indicator of hurricane-safe regions. While most deaths in the eastern United States occurred from the Appalachian Mountains eastward, many locations not suffering losses from 1970 to 1999 (white areas on the map) were simply fortunate to be out of harm's way during this 30-year period. For example, Camille caused large loss of life in West Virginia after its center had moved about 700 n mi over land, and Hurricane Hazel (1954) caused inland deaths northward from North Carolina into Canada. In total, about 63% of the deaths from 1970 to 1999 occurred in inland counties.

Storm surge is usually not a threat to life more than a few miles from the coast, with such important exceptions as the Everglades region of southernmost Florida, the coastal marshlands of southern Louisiana, the sounds of North Carolina, and a few large lakes like Okeechobee and Ponchartrain (where some man-made barriers to surge have been erected). There were no surge deaths in inland counties or parishes from 1970 to 1999.

As tropical cyclones move inland, their environments, structures, and risks can change markedly from their marine forms. Surface winds and attendant hazards usually diminish gradually. Indeed, the NHC "best track" database shows no hurricanes centered farther inland over the United States than about 175 n mi. Nevertheless, 35 lives were lost to winds in inland counties since 1970. Falling trees (see Fig. 4) contributed to most of these deaths. Tornadoes took about another 20 lives.

Freshwater floods from excessive tropical cyclone-related rains led to about 300 deaths in inland counties and dominate the fatality total for those areas. A disproportionately large percentage (75%–80%) of the children killed by tropical cyclones drowned in fresh-
water floods (see Fig. 5). Such meteorological and hydrological factors as storm speed (e.g., Alberto’s near stall over Georgia), size and character of the precipitation field, orography, interactions with other weather features including low-level frontal zones (e.g., Floyd) or disturbances aloft (e.g., Agnes), soil nature, and wetness (e.g., Hurricane Dennis’ rains preceding Floyd in North Carolina) were important. Like storm surge, numerous and complex social issues factor into freshwater flood deaths.

Combining coastal and inland statistics indicates 59% (351 of 593) of all the deaths during the study period occurred by drowning in freshwater. In perspective, however, at an annual rate of about 12 deaths, these losses constitute a relatively small portion of the 225 flood-related deaths recorded each year in the United States (Scofield and Margottini 1999).

4. Discussion

The 600 lives lost in the United States and its coastal waters to Atlantic tropical cyclones since 1970 represent a large human toll. From a historical perspective, however, this total is small relative to previous periods of comparable length and is smaller than the losses occasioned by several individual tropical cyclones during the first half of this century. [In fact, the cumulative loss over the past 30 years is small enough that the next large disaster, particularly if attributable to storm surge, could skew (or unskew) some of the statistics presented in this paper.]

One reason for the relatively small total is that only six people, 1% of the 30-year total, died as a result of storm surge since Camille. In part, this remarkably low total could be attributed to good luck [e.g., a disaster was narrowly averted in the Galveston area during Hurricane Alicia in 1983 (see Sheets 1990)] and to natural variations in the landfall location and strength of storms. For example, the number of strong hurricanes striking the United States during the last three decades was somewhat smaller than in previous 30-year periods (Hebert et al. 1997); 46 tropical storms and 18 category-1, 10 category-2, 12 category-3, and 2 category-4 hurricanes made landfall in the United States from 1970 to 1999. Nevertheless, much of the credit for the decrease in storm surge deaths should be given to the changes in hurricane-related policies and operations beginning shortly after Camille. These efforts initiated particularly important advances in the field of emergency management. This included the start of a professionalization of such local emergency management governmental units and a shift in their emphasis from a wartime fallout-shelter management function to one of emergency management for natural or other man-made disasters [R. Sheets, NHC (retired), 1999, personal communication].

The need to better communicate the hurricane threat to life and property was also first highlighted in the 1970s (Simpson 1998). The cooperative and successful working relationship established since then among the NHC, the emergency management community including the Federal Emergency Management Agency, the U.S. Army Corps of Engineers, and the media has proven invaluable (e.g., Sheets 1990). These lines of communication remain open and strong. The interaction takes place year-round. In the off-season, it includes training, preparedness, and mitigation activities that help both the public, and decision makers learn appropriate responses to tropical cyclones approaching vulnerable communities. During the hurricane season, these interactions help increase visibility of tropical cyclone threats and expedite the communication of potentially lifesaving information.

Many of the post-Camille hurricane mitigation activities focused on minimizing the impact of hurricanes on coastal communities, where the cyclones were strongest, the population concentrated and growing, and the potential for a catastrophic loss of life.
great. For example, the NWS accelerated its efforts to develop techniques to model storm surge inundations (e.g., Jelesnianski 1972). A Storm Surge Unit was established at the NHC and it helped refine those applications and develop surge projections for the U.S. east coast and Gulf Coast (e.g., Jelesnianski et al. 1992). This program continues today, and the information provided by these, now more enhanced, simulations remains a fundamental component of emergency preparedness plans and actions along the coast.

In combination, these efforts and technological advances in forecasting and communication helped stave off the seemingly inevitable large storm surge disasters during the past 30 years.

5. Conclusions

In contrast to the storm surge successes, the 351 freshwater flood deaths identified since 1970, taken with the statement on previous losses (AMS 1973), indicate only relatively modest gains in reducing loss of life in the United States due to excessive rainfall in tropical cyclones. Many deaths occur after a tropical cyclone moves inland and weakens from its landfall intensity. Often, it appears that the media spotlight and public attention diffuse and shift away from the ending drama at the coast to other current events—rather than following the usually weakening tropical cyclone while it moves inland. This suggests that the partnerships, aggressive year-round continuing education, and high visibility given to the coastal storm surge problem represent a model from which efforts to decrease inland loss of life might make further gains.

Partly in response to a preliminary version of this work (Rappaport et al. 1999), the NWS is implementing several changes to its operational procedures designed to reduce the threat posed by freshwater floods from tropical cyclones. For example, the NHC has elevated its emphasis on inland flooding in its advisories and in media interviews it provides during the event. To improve NWS internal communication, several River Forecast Centers and first-tier inland WFOs are being added to the “hurricane hotline” (Lawrence 1999) used to coordinate the content of NWS tropical cyclone advisories. In addition, the frequency of those advisories for inland systems has been increased to once every six hours (as occurs for Atlantic tropical cyclones centered elsewhere) from every 12 hours (WSOM 1999). (When a tropical cyclone moves inland over the United States and the threat becomes mainly precipitation, these advisories, then known as “storm summaries,” are issued by the Hydrometeorological Prediction Center rather than by the NHC.) The NWS has also planned off-season workshops to further improve operational procedures and to identify potential improvements in its public awareness activities and training materials.

Further progress could come from intensified meteorological research and from societal impact studies. For example, “Hurricane Landfall” and “Quantitative Precipitation Forecasts” constitute two foci of the U.S. Weather Research Program. Their prominent place in that program indicates the national significance carried by the tropical cyclone threat to this country and the focused commitment to minimize that threat.

Acknowledgments. Much of the great reduction in storm surge fatalities over the past 30 years can be attributed to the leadership and hard work of NHC directors whose terms spanned that period. For those efforts, and for comments they provided on this work, Robert Simpson, Neil Frank, Robert Sheets, Robert Burpee, and Jerry Jarrell are gratefully acknowledged.

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