

Fatalities in the United States from Atlantic Tropical Cyclones

New Data and Interpretation

BY EDWARD N. RAPPAPORT

A 2000 *Bulletin* article by Rappaport (henceforth R0) identified the causes and provided analysis of the loss of life in the United States from Atlantic tropical cyclones during the period 1970 to 1999. That study focused on “direct deaths,” defined as fatalities attributable to the forces of the storms and their remnants. It covered a relatively quiet period in the Atlantic hurricane basin, averaging six hurricanes

annually, of which one to two made U.S. landfall. R0 found for that period that rain-related incidents were the most common. There were no storm-surge disasters during that period (i.e., storms that took tens to hundreds of lives), as had occurred in previous decades.¹ Only six people *in total* died as a result of storm surge during the 30 years in the R0 study. Any hopes that storm-surge impacts had come under control, however, were soon dashed.

A significant uptick in activity began shortly before the end of that period and continues as of this writing. For example, 12 hurricanes, including 7 major hurricanes [those of at least category 3 on the Saffir-Simpson Hurricane Wind Scale (SSHWS)], made landfall on the U.S. Gulf or Atlantic coast in just the two-year period of 2004–05.

This paper describes the findings obtained by extending the record to cover a longer period: 50 years, from 1963 to 2012. During that period, about 650–700 Atlantic tropical cyclones occurred, comprising 578 hurricanes and tropical and subtropical storms and around 100 tropical depressions. These additional cases add confidence to findings and conclusions. For context, while operational breakthroughs occur intermittently, several critical components of today’s operational tropical cyclone forecast and warning program started or had their origins in innovations that took place near the beginning of the extended study period, making that period to some degree representative of the current era. For example, satellite images first became available routinely to operational forecasters in 1966. Also, the first operational tropical cyclone forecast models (e.g., NHC67) using predictors

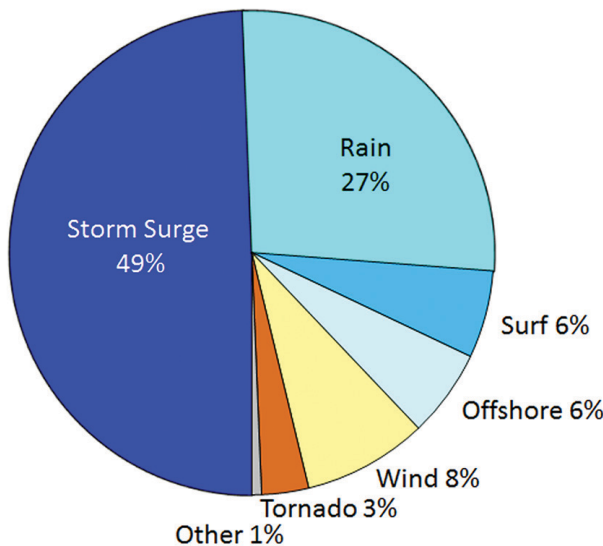


FIG. 1. Cause of death in the United States directly attributable to Atlantic tropical cyclones, 1963–2012.

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¹ While such everyday terms as “rain,” “storm surge,” “wind,” “tornado,” etc., would not be identified as a technical cause of death by medical practitioners, their use is customary for this application. The terms are employed in R0 and here to identify the storm’s physical attribute leading to loss of life.

derived from observations and numerically forecast fields were introduced at the beginning of the period. In the mid-1960s, what had been known as the Miami Weather Bureau Office became the National Hurricane Center. During Hurricane Betsy in 1965, the NHC first exploited television as a communication medium to provide information to the public as the event unfolded.

This update applied R0's approach for the additional Atlantic tropical cyclones. Two hurricanes, Camille (1969) and Katrina (2005), required special procedures discussed later to estimate losses.

The following section and Figs. 1 and 2 present the most significant findings.

KEY STATISTICS.

- One out of every five or six Atlantic basin tropical cyclones caused loss of life in the United States.
- Two to three tropical cyclones per year caused U.S. fatalities, on average.
- Around 2,544 people died in the United States or its coastal waters from tropical cyclones in the 50-year period of 1963–2012. (This estimate likely represents a modest underestimate of the total because it does not fully account for people who died but were reported as missing.)
- The total equates to about 50 deaths per year on average, but the number of deaths varied greatly by year and storm.

A cause of death was identified for 2,325 individuals. For them:

- Roughly 90% of the deaths occurred in water-related incidents, most by drowning.
- Storm surge was responsible for about half of the fatalities (49%).
- Rainfall-induced freshwater floods and mudslides accounted for about one-quarter of the deaths (27%).
- Rainfall-induced flood deaths occurred in more tropical cyclones than any other hazard.
- Between 100 and 150 people perished near the shoreline from rip currents, large waves, etc.
- About the same number, between 100 to 150 people, drowned in marine incidents offshore within 50 miles of the coast.
- Between 5% and 10% of the fatalities were caused by nontornadic winds.
- Around 3% of victims succumbed to tornadoes.
- The deadliest six storms—about 1% of the total number of storms—accounted for about two-

thirds of the deaths; Katrina in one day was responsible for more than 40% of the fatalities in the past 50 years.

- The deadliest storms were not necessarily the strongest at landfall. Only 3 of the 10 deadliest were “major hurricanes” (Category 3 or higher on the SSHWS) when they came ashore. Six of the 10 were tropical storms or Category 1 hurricanes at landfall.

CHARACTERISTICS OF THE DEADLIEST STORMS. In terms of fatalities, the five largest losses, in descending order, occurred in Katrina, Camille, Agnes (1972), Betsy (1965), and Sandy (2012). (For a more in-depth discussion of these storms, see NHC tropical cyclone reports at www.nhc.noaa.gov/data/#tcr.)

These storms shared some characteristics. Each came ashore at hurricane strength. Drowning predominated as the cause of death. Storm surge was the primary killer in Katrina, Betsy, and Sandy. About the same number of people died from Camille's surge as from its rain. Rainfall was the primary culprit in Agnes.

Katrina took around 1,100 lives. It stands apart not just for the enormity of the losses, but for the ways in which most of the deaths occurred. Research published by Brunkard and colleagues in 2008 found that 84% of the deaths in Louisiana occurred in Orleans and neighboring St. Bernard Parishes. There, levee failures allowed water to fill parts of the New Orleans area to great depth, leading to the deaths of hundreds of people by drowning, expiring in home attics sought as refuge, and from “blunt trauma.” Simulations by Jonkman et al. (2009) show storm surge flooded parts of those parishes with great rapidity and to depths of 15 to 20 ft:

Various eyewitness accounts tell how the floodwater entered the [lower 9th Ward] neighborhood through the breaches with great force and how it caused death and destruction in the areas near the breaches. Typical death causes for people exposed to the floodwaters include drowning (in a building or in the street) or physical trauma due to impacts from debris and/or building collapse.

With this knowledge, the deaths in Orleans and St. Bernard Parishes are attributed to storm surge in this study. That attribution likely overestimates by a little the contribution of surge. Again, according to

the 2009 Jonkman et al. study, “A limited number of fatalities in the flooded area might be caused by wind effects. However, it is expected that the number of wind fatalities will be limited as (a) most people found shelter during the passage of the storm; (b) storms in the past with comparable strength and no flooding have caused much fewer fatalities.” A relatively small number of deaths could also have been the result of rain, but in this study rain was relegated to an exacerbating factor in the storm-surge zone.

This study classifies the remaining 16% of the deaths in Louisiana as indeterminate, though none were likely due to tornadoes (no tornadoes were reported in the state), and any deaths in landlocked parishes would not have been from surge.

The Katrina disaster took a different form some 50 miles northeast of New Orleans along the Mississippi coast. There, large losses occurred when the Gulf of Mexico surged across the shoreline to a U.S. record depth of 28 ft. The surge penetrated inland as far as 6–12 miles. The surge was built and driven ashore by a much larger than normal surface wind field that at landfall had peak wind speeds near the Category 2–3 threshold. The winds had been even stronger—Category 5—less than 12 hours earlier over the northern Gulf. Just 75 miles from shore, these winds generated huge waves, reaching “significant wave heights” of 55 ft, the highest ever recorded in the Gulf by the National Data Buoy Center. At landfall, the residual waves rode atop the surge onto land. This devastating combination of swift and deep waters razed dwellings and produced fatalities across miles of Mississippi coast. Mississippi coroners’ records indicate around 180 direct deaths occurred in that state during Katrina. Most of them are attributed to surge.

Camille, like Katrina, produced a storm surge that killed more than 100 people along the Mississippi coast. Both hurricanes reached Category 5 intensity over the northern Gulf. Their centers came ashore in almost the same place. Camille, unlike Katrina, remained at Category 5 status until landfall, making it the second strongest U.S. hurricane behind only the 1935 Labor Day hurricane in the Florida Keys. Camille’s winds generated the record U.S. storm-surge depth to that time, surpassed so far only by Katrina. But, because Camille’s wind field covered a much smaller area than Katrina’s, the lateral extent of Camille’s surge was also much smaller than Katrina’s. The number of deaths in Mississippi was based on the review of 123 death certificates by Wilkinson and Ross in a 1970 study (p. 10). Except for five people who

died of head injuries caused by flying debris or falling objects (attributed to wind in this study), victims “. . . drowned [from storm surge] while trying to ride out the storm in a residence near the waterfront.”

Camille was also similar to Katrina in causing great loss of life in a second mode in a second location. While Camille’s small size allowed New Orleans to escape the kind of losses it would later suffer during Katrina, its great intensity at landfall and its rather rapid movement made possible its second great disaster. Camille gradually weakened into a tropical depression on its two-and-a-half-day trek over the eastern United States to the mid-Atlantic coast. While Camille had maximum wind speeds of only 30 mph when its center reached the Appalachian Mountains, it dropped as much as 30 inches of rain (and unofficially more) in the upslope flow over western Virginia. These rains triggered mudslides that killed more than 100 people. Fatalities attributed to mudslides occurred in only one other tropical cyclone during the period, Hurricane Ivan (2004), with four deaths.

Katrina and Camille provide examples of the relatively great threat to life from tropical cyclone storm surge in Louisiana and Mississippi. Many of the worst U.S. hurricane disasters have occurred there. In fact, the largest loss by far in the quarter-century preceding the start of this analysis period occurred only six years earlier when around 400 people died in coastal southwestern Louisiana during Hurricane Audrey (1957).

More than half of the U. S. tropical cyclone deaths from 1963 to 2012 occurred in either Louisiana or Mississippi (LA-MS). Even excluding the fatalities associated with the levee failure in New Orleans, LA-MS had almost one-quarter of the deaths. In contrast, Florida (FL) and Alabama (AL) together incurred only about 5% of the deaths even though they experienced about two-and-a-half times the number of hurricane and tropical storm landfalls as LA-MS. This means that there were about 25 times as many deaths in LA-MS per landfall event as in FL-AL (and still about 10 times more when leaving out Katrina’s New Orleans impact). A similar comparison shows LA-MS having fewer landfalls than Texas, but more than seven times the number of deaths as in Texas (still three times more when excluding New Orleans in Katrina).

Reasons for the differences between LA-MS and the areas either side of them include their respective bathymetry and coastal topography, which affect storm-surge height and inland penetration. For example, while all of coastal Florida is at risk from dangerous storm surge, the relatively steep Florida

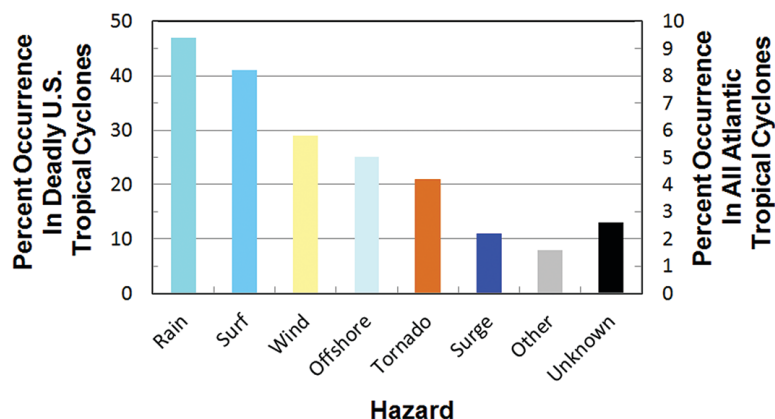


FIG. 2. Percentage of 1963–2012 Atlantic tropical cyclones (right scale) and deadly U.S. tropical cyclones (left scale) in which noted types of fatalities occurred in the United States.

Atlantic littoral does not allow for as high a surge as along the Florida's Gulf Coast under otherwise identical conditions. Other factors include population density, previous experiences with tropical cyclones, and such social vulnerabilities as discussed in the 2009 review paper by Cutter et al. The above statistics highlight the extreme vulnerability of the central Gulf Coast. They should not be interpreted as minimizing the still-high risk along the Gulf Coast outside of LA-MS.

INTERPRETATION AND IMPLICATIONS.

The data show that significant risks to life in the United States from Atlantic tropical cyclones persist, even for relatively "weak" systems. To the extent the study period reflects current risk, as well as preparedness activities and real-time responses, these findings provide possible insights for public education and outreach efforts, and to operational products and services intended to minimize tropical cyclone fatalities in the United States.

To that end, wind (speed) has historically defined the strength of a tropical cyclone. It also provides energy to the ocean to build and drive waves and storm surge, helps organize and concentrate the rainfall features that contribute to freshwater flooding, and is what many—perhaps most—people think of first about hurricanes. Yet, nontornadic wind directly causes a very small percentage (8%) of the fatalities, and tornadoes even fewer. R0 identified an important exception noted as well by Schmidlin in a 2009 study. Falling trees can pose a significant wind-related risk to life. Hurricane Sandy provided the most recent

example, with 20 of its 72 deaths attributable to falling trees.

Even though just a few storm-surge fatalities occurred from 1970 to 1999, the enveloping 50-year period had a disproportionately large number of storm-surge deaths compared to other tropical cyclone hazards. While U. S. storm-surge deaths accounted for about half of the total number of deaths, storm surge killed people in fewer than 1 in 10 of the tropical cyclones causing deaths in the United States, and in less than 1 in 50 Atlantic tropical cyclones. These data are consistent with a less detailed, but longer-period review and remind us that, except for the 1940s, every

decade from the 1870s through the 1960s contained at least one instance with hundreds or thousands of surge-related deaths in the United States.

The near absence of storm-surge deaths from 1970 to 1999 represented a welcome respite from this threat. It also revealed as a byproduct the significant risk in the United States from tropical cyclone rains.

The additional data in the current study show, as found earlier, that drowning from excessive rainfall occurs in *more tropical cyclones* than from any other cause; Fig. 2 shows that almost half of the deadly U.S. tropical cyclones had a death in flooding from rain. On the other hand, the *total number of fatalities* from storm surge approaches about double the total attributed to excessive rain. While the strongest winds and deepest storm surge usually occur near the center of intense tropical cyclones, rainfall events often take place far from the center, sometimes long after central storm features have significantly weakened or dissipated.

THE MESSAGE ON STORM SURGE. R0 emphasized the risk to inland areas from tropical cyclone rains for the 30-year period ending in 1999. Near the end of that period, the NWS initiated several activities intended to lessen the impact of rain (see R0). Additional efforts, like the NWS-led "Turn Around, Don't Drown" campaign, followed.

This study, while reaffirming the threat from rain, makes clear that the potential for massive loss of life due to storm surge persists. It provides a call to action for the nation's hurricane research and operations program to develop and implement new storm-surge mitigation strategies.

A natural place to focus such efforts is on forecast accuracy. Katrina and Sandy are the two most recent storms of note for the large magnitude of losses, both occurring in the past nine years. Forecast verification statistics (not shown) indicate that track and intensity forecast errors were smaller than average in both storms. Storm-surge forecasts were quantitatively very good for both storms. Consistent NWS forecasts of an exceptional, life-threatening surge, and its location, were available at least two days prior to landfall for each storm. It can be argued that the forecasts and lead times were good enough that large losses of life could have been averted. So, while we still need and are developing better forecasts, forecast accuracy for these two storms does not appear to have been a key contributor to the storm-surge losses.

Another area to consider that is largely under control of the hurricane program is what and how storm-surge information is communicated to the public. On this topic, social scientists assisting the NWS have identified a fundamental problem from recent surveys of coastal residents:

... Nearly three out of five [respondents] have never heard or read an estimate of the potential storm surge risk in their area. ... A significant portion of the U.S. coastal population is not fully aware of their storm surge vulnerability. (Lazo and Morrow 2013)

To address this deficiency, the NWS is making product changes. For example, it removed reference to storm surge from the Saffir-Simpson scale. This was necessary because the categories on the scale, defined by wind speed, called for corresponding storm-surge heights that differed significantly from what occurred in some important storms, including Katrina and Charley (2004), misrepresenting the threat.

The NWS plans to introduce a new storm-surge graphic, which would enable an individual to determine from a high-resolution map the forecast peak storm-surge water level at any location of interest, presented as height about ground (i.e., inundation).

Preparing for hurricane storm surge often requires taking different protective actions than employed for wind, as captured for example by the catchphrase “Run from the water (i.e., evacuate), hide from the wind (shelter locally).” The current NWS warning system does not distinguish clearly between the two threats. In particular, while the NWS issues public warnings for many atmospheric and oceanographic threats, it does not do so explic-

itly for storm surge—the phenomenon that takes the largest number of lives in single-day weather-related events in the United States. Recognizing this inadequacy, the NWS has been working toward establishing U.S. storm-surge warnings by about 2015. The storm-surge warning would be triggered by a life-threatening surge, with its location and timing often differing from the NWS hurricane warnings that are based on wind speed. The additional warning type would provide emergency managers and the public with more impact-specific forecast guidance. Surveys indicate strong support for a storm-surge warning among emergency managers, the media, and the public. Once employed, this country would join others that have implemented operational storm-surge warnings for their sovereign lands (e.g., Canada, Japan, and Bangladesh).

The goal of reducing storm-surge losses extends to high levels in the U.S. government. NOAA’s work toward the goal is described in its Storm Surge Roadmap. This effort includes sponsoring storm-surge scientific research and development, and related social science work through its Hurricane Forecast Improvement Project. The commitment supports improving not only the forecast but also forecast mes-



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saging about storm surge, with the goal of minimizing loss of life from the most deadly of storm hazards by magnitude in this country.

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