

An examination of rip current fatalities in the United States

Victor A. Gensini · Walker S. Ashley

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Abstract This study analyzes fatalities caused by rip currents in the conterminous United States for the period 1994–2007. Results include the frequency of fatalities from rip currents, their cause, and their unique spatial distributions. An analysis of historical hazard event data illustrate that, on average, 35 people reportedly die from rip currents each year in the United States. Also, similar to other hazard events where unique differences in gender vulnerability have been found, men are over six times more likely to fall victim to a deadly rip current than females. Rip current fatalities are most common in the southeastern United States, with a nonuniform spatial distribution along other Atlantic, Pacific, and Great Lakes coastlines. Physical vulnerabilities are suggested as the primary cause for the unique fatality distribution found. Temporally, summer season weekends are shown to have the more fatalities than any other time of the year. A classification scheme was developed to categorize synoptic-scale weather conditions present during deadly rip current events. More than 70% of all rip current fatalities are associated with onshore winds. Specifically, a rip current fatality is most likely when a surface high pressure system creates these onshore winds. The quality of the fatality reporting database available for researchers is also assessed.

Keywords Rip currents · Coastal hazards · Fatality distributions · Drownings

1 Introduction

According to the Center for Disease Control and Prevention (2009), drowning is the seventh leading cause of unintentional injury deaths for all ages in the United States. Contributing to the thousands of fatal drownings each year are deaths associated with natural hazards known as rip currents. Rip currents can turn a pleasant day at the beach into a perilous place for swimmers any time of the year.

V. A. Gensini (✉) · W. S. Ashley
Meteorology Program, Department of Geography, Northern Illinois University,
Davis Hall Rm. 118, DeKalb, IL 60115, USA
e-mail: vgensini@niu.edu

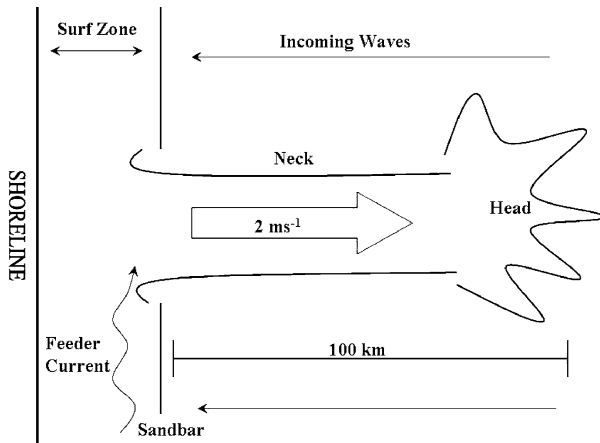


Fig. 1 Plan view schematic of a rip current. See text for discussion

A rip current is essentially a process to transport built up excess water in the surf zone back out into deeper water (Fig. 1). The lethal part of the rip current, known as the “neck”, obtains the fastest velocity that a rip current acquires [sometimes near 2 ms^{-1} (Sonu 1972)]. This quick-moving seaward channel is commonly 10–30 m wide and fed by a “feeder current.” This feeder current commonly sets up parallel to the shore, and normal to the direction of the neck. Rip currents typically form at low spots or breaks in sandbars, and also near structures such as piers, groins, or jetties. An easy way to visualize a rip current would be to imagine a dam separating water at two different elevations. If a hole forms in the dam, the water at a higher elevation (and therefore higher potential energy) will rush out toward lower water (known as the neck). The water at the higher elevation will begin to rush from both sides (known as the feeder current) to take the place of mass from exiting water. When the neck of the rip current finishes its task of transporting the excess water near the shore to deeper water; the “head” of the rip current forms, usually noticeable by the murky, stirred up water commonly found about 100 m offshore.

Typically, rip currents claim their victims due to exhaustion in the neck of the current, as the natural reaction of most people is to try to swim against the current back to shore. Unfortunately, this can lead to a downing fatality if the victim is not rescued by a lifeguard or other swimmer before the rip current subsides. In order to help mitigate these events in the future, there is a need for researchers and forecasters to understand how meteorological conditions give rise to rip currents, and the spatial distribution of these fatalities.

2 Background

Responsible for an estimated 150 deaths per year in the United States (Lushine 1991a, b), rip currents are a hazard to anyone in the water regardless of swimming experience. These currents are not commonly thought of as significant hazards in the United States due to their relative spatial isolation. In other words, rip currents are usually isolated in occurrence, and tend to last for small temporal periods, thus making them particularly dangerous and hard to predict. However, in 2003, approximately 153 million people (53% of the nation’s population) lived in the 673 United States’ coastal counties (NOAA 2008). These

densely populated counties provide residents and tourists with thousands of miles of coastline to enjoy each year. With an estimated 330 million visitors annually, beaches become a fatality prone area due to the magnitude of people in the water, and many of these beachgoers are unaware of the lethal risk that rip currents pose (Lushine 1991a, b).

Lushine (1991a, b) correlated rip current fatalities in two Florida counties to wind speed, wind direction, and tidal variation. The research revealed that the wind direction was onshore and within 30° of normal with a speed of 12 ms⁻¹ or greater during 90% of rip current rescues and drownings. These meteorological conditions are favorable for rip current formation because they initiate the process of mass water accumulation in the surf zone that greatly enhances the potential for rip current formation. From these observations, Lushine created the Lushine Rip Current Scale (LURCS). The LURCS uses an observationally driven, ingredients-based approach, as noted by Doswell et al. (1996), to forecast rip current risk. Using wind velocity and direction, tidal variations, swell heights, and a persistence factor, the LURCS can give forecasters situational awareness of the rip current risk for any given day. Forecasters can then issue timely mitigation products to emergency managers and citizens in order to mitigate rip current casualties. The LURCS has been modified for use in east central Florida (ECFL LURCS) by changing the tidal factor and including swell period (Lascody 1998).

Although the LURCS (and its modifications) is a useful tool to indicate the threat of rip current formation, it does not take into account some physical variables (e.g., cloud cover or precipitation) and societal factors (e.g., weekends and holidays) that could change the risk of a rip current fatality. For example, low and high pressure systems off the east coast of the United States can produce onshore flow to many surf zones. Both systems may invoke a high rip current formation risk on the LURCS, but swimmers will be more inclined to enter the water on days when a high pressure system is offshore. The clear skies generally associated with large-scale subsidence of a high pressure system would provide beachgoers with favorable weather for beach activities as opposed to a day amid a low pressure system with stratus clouds and precipitation occurring. Therefore, forecasters could benefit by understanding surface synoptic meteorological conditions present during fatalities and make adjustments to their forecasts accordingly. Furthermore, social aspects play a role in rip current fatalities. Currently, there are no variables that account for these factors in the LURCS. However, many National Weather Service offices, such as the Newport, NC weather forecast office, will issue a higher categorical risk of rip currents, if all conditions are equal, on holidays and weekends. Such social-rating techniques can be employed over all areas where rip current forecasting takes place, even though coastal bathymetry may differ.

There is limited research into rip current fatalities, and often fatality tallies are estimated from sources that may have incomplete data. This study presents a comprehensive spatial and temporal analysis of rip current fatalities, with related demographic and meteorological data, for 1994–2007. Kent (2008) correlated synoptic-scale meteorological conditions present during rip current formation along the coast of North Carolina, and found that frontal passages creating onshore winds were the leading cause of rip current formation. This paper will extend this research methodology by examining synoptic-scale weather features present during rip current *fatalities* and the associated societal factors that set the stage for deadly rip current events.

The results of this study will help forecasters develop a conceptual model of meteorological features present during rip current fatalities, and aid researchers understanding of the spatial, temporal, and societal vulnerabilities associated with these fatalities. Areas that

are spatially vulnerable to rip current fatalities can then be targeted through mitigation efforts to assist in making citizens aware of the lethal risk of rip currents. This, in turn, will support the primary goal of the National Weather Service, which is to help protect lives and property. Ideally, this study will facilitate rip current awareness across the entire United States.

3 Methodology

3.1 Fatality catalog compilation

The National Climatic Data Center's (NCDC) *Storm Data* was queried to locate rip current fatalities across the United States from 1994 to 2007. This temporal period was chosen due to the absence of rip current fatality reports in *Storm Data* prior to this time. *Storm Data* is not a faultless or complete database (Doswell and Burgess 1988; S.A. Changnon and D. Changnon 1999; Curran et al. 2000; Ashley and Mote 2005; Ashley and Ashley 2008a, b; and Gall et al. 2009) because of the underreporting of both casualties and damage estimates. However, as also noted by Ashley and Ashley (2008b), fatal weather events are more likely to be reported due to enhanced media attention. Therefore, *Storm Data* provides researchers with an adequate first estimate of the actual number of fatalities for given oceanic and atmospheric events.

Lexis Nexis, a Web site archive of newspaper articles from local and national newspapers, was used to cross refer and supplement fatality and event information gathered from *Storm Data*. Fatalities from both *Storm Data* and *Lexis Nexis* were then tallied into a single comprehensive database. This database includes all deaths that are directly the result of a rip current. Therefore, *Storm Data* or *Lexis Nexis* had to specify that the casualty was directly the result of a rip current event (e.g., drowning or physical trauma within water). In *Storm Data*, this was indicated by a "rip current" fatality category under the event type "Ocean and Lake Surf." *Lexis Nexis* fatalities were added by searching for the terms "rip current," "rip tide," and "undertow," as keywords in news wire searches across the country. If an article contained information stating that a rip current was the cause, or believed to be the cause of a fatality, the event was then noted. If this fatality was not associated with any previous fatality reports in *Storm Data*, it was added to the database. Occasionally, multiple news sources across the nation reported the same fatality, especially when multiple people died at the same beach on the same day. In such cases, variables such as age, gender, and sometime names were used to avoid counting the same fatality multiple times. Each fatality report in the comprehensive database contains the following information (if provided from the sources examined):

1. state, county, and beach of the fatality;
2. date and time of the death;
3. demographic information of report (e.g., age and gender);
4. additional details and comments about the report (e.g., what the victim was doing surrounding the time of the fatality or meteorological features present during the day).

A third source of data was obtained from Mr. Dave Guenther, the rip current studies program manager at the National Weather Service in Marquette, MI. These data were gathered by generating internet queries for "Great Lakes rip current fatalities" for the temporal record 2002–2007. Information contained in this portion of the dataset is similar to the information found above in *Storm Data* and *Lexis Nexis*. Although these data only

exist for the latter part of the research period, inclusion of these events was desirable in order to make the most comprehensive fatal rip current database possible.

3.2 Spatial analysis

Using a geographic information system (GIS), fatality locations were mapped to depict the spatial distribution of fatal rip currents. Atlantic, Pacific, and Gulf of Mexico coastline fatalities were mapped in 100-km grid cells using the latitude and longitude of a fatality and summing the number of fatalities along a 100 km stretch of coastline. In the Great Lakes region, only Lake Michigan was analyzed due to the lack of multiple fatalities on other lakes (three on Lake Erie, two on Lake Superior, one on Lake Ontario). Latitude and longitude points were developed from city, beach, or county locations that were provided in *Storm Data*, *Lexis Nexis*, or internet queries.

3.3 Meteorological categorization

The National Oceanic and Atmospheric Administration's (NOAA) *Daily Weather Map Series* archive (<http://www.hpc.ncep.noaa.gov/dwm/dwm.shtml>) was used to determine the meteorological surface and upper-level weather features present leading up to, and during, the time of the fatality. On the day that a rip current fatality occurred, the synoptic-scale surface condition in relationship to the coast was recorded—e.g., high pressure center off the coast created onshore winds. These conditions were sorted into seven categories (Table 1). Categories used in this study are similar to those chosen by Kent (2008) and include: high pressure created onshore winds; low pressure created onshore winds; thunderstorms in the vicinity; winds parallel to shore; tropical systems; onshore winds other; and no significant synoptic-scale features present. Since rip currents (on the order of tens of meters) and synoptic-scale meteorological conditions (on the order of thousands of kilometers) are not on the same spatial or temporal scale, this method does contain some uncertainty, but as Lushine (1991a, b) noted, rip currents usually develop after favorable meteorological and oceanographic conditions persist over synoptic-scale time periods. To make this process more objective, a decision tree (Fig. 2) was used to answer simple questions to arrive at a categorical classification.

Table 1 Categories of surface meteorological conditions used in this study to determine the primary weather situation associated with a rip current fatality

Meteorological setting	Description
1 High pressure	A synoptic-scale low pressure created onshore winds
2 Low pressure	A synoptic-scale high pressure created onshore winds
3 Thunderstorms	Data source specifically indicated that thunderstorms were occurring around the time of the fatality
4 Winds parallel to shore	Synoptic-scale setting created winds parallel to shore favorable for long shore currents to develop
5 Tropical systems	A tropical cyclone was affecting the area or waves from a distant cyclone were influencing the surf zone
6 Onshore winds other	Synoptic-scale winds were directed onshore by some other mechanism (e.g., pressure trough, frontal passage)
7 No significant weather	No significant synoptic-scale weather or convective phenomena were present during the time of the fatality

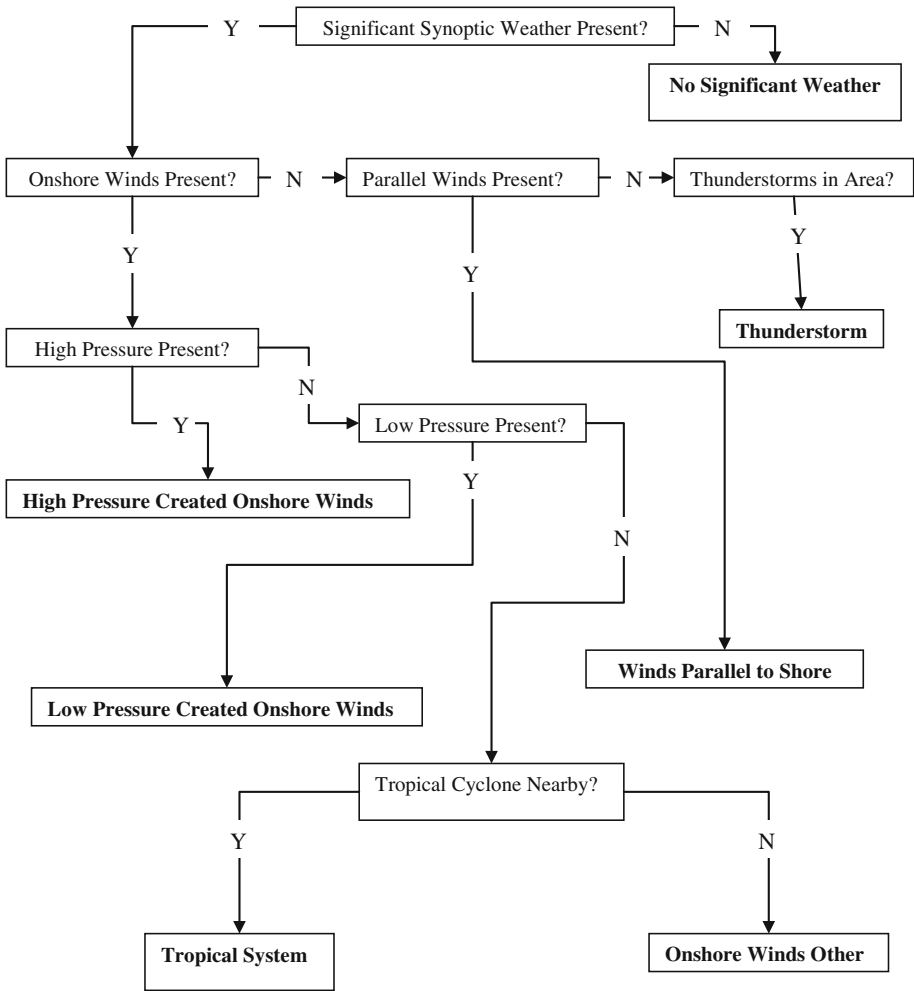


Fig. 2 Flow chart for determining synoptic-scale environments highlighted in Table 1. *Bold font* indicates a category used for this study

4 Results

4.1 Fatality distributions

As anticipated, *Storm Data* did not capture all reported rip current fatalities in the coterminous United States for the period 1994–2007. Examination of *Lexis Nexis* and internet queries, identified an additional 106 fatalities over this period, bringing the total number of fatalities for this study to 480. On average, approximately 35 people are reportedly killed each year from a rip current along United States shorelines (Fig. 3). This value is much lower than Lushine (1991a, b) previous estimate of 150 fatalities per year. However, because *Storm Data* did miss as many as 13 deaths in one of the sample years, it is apparent that underreporting rip current fatalities is a problem in *Storm Data*. Assuming

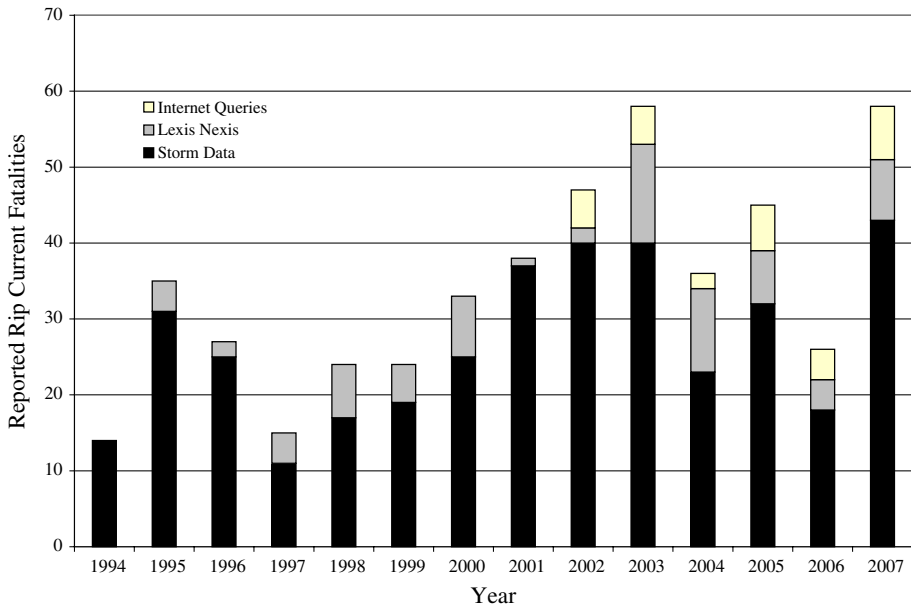


Fig. 3 Reported rip current fatalities by year

Storm Data, *Lexis Nexis*, and internet queries together account for all rip current fatalities in the United States, *Storm Data* still only captures 78% of the fatalities. Despite this underreporting issue with *Storm Data*, if coupled with another data source such as *Lexis Nexis*, the result is a more accurate portrayal of the actual number of fatalities. However, it is still likely that some fatal rip current events may have gone undocumented in both data sources because fatal rip current events are typically isolated and are not associated with damage that may attract media attention. Similarly, it is well known that fatal lighting events are underreported due to their singularity and lack of large-scale damage (e.g., see discussions in Curran et al. (2000) and Ashley and Gilson (2009)). Thus, it is plausible that the number fatalities associated with rip currents could be higher, yet we have no competing dataset to confirm this assumption.

Florida possesses more coastlines (over 2,000 km) than any other state in the contiguous United States. With a tourist industry grossing over \$35 billion in 1999 (FDEP 2008), it is explicable that Florida has more deadly rip currents than all other states combined (Table 2). Data from 1994 to 2007 suggest that nearly 16 people die each year in Florida rip currents as compared to Lushine (1991a, b) estimate of 25–35 deaths per year in the state of Florida. However, analyzing only the last 5 years of the record indicates that an average of 20 people die in Florida killer rip currents each year. Therefore, Lushine’s estimate of the number of rip current fatalities in Florida each year is likely a satisfactory approximation. However, when normalizing the number of fatal rip current events by dividing the number of fatalities by the length (km) of the states coastline, Alabama is actually the deadliest of states. The deadliest-segments of United States coastlines will be discussed in more depth in the geographic analysis section.

July is the peak month for fatal rip currents in the United States with the crest of the distribution encompassing Northern Hemisphere summer months (Fig. 4). This is due to the favorable beach conditions (i.e., water and air temperature) that exist during this

Table 2 Total number of reported rip current fatalities by state (1994–2007)

State	Deaths	% of total	Normalized fatalities
Florida	230	47.83	0.1059
California	56	11.80	0.0414
North Carolina	44	9.11	0.0908
Michigan	34	7.04	0.0069
Alabama	18	3.73	0.2110
New Jersey	18	3.73	0.0860
New York	16	3.31	0.0783
South Carolina	13	2.69	0.0432
Indiana	9	1.86	0.1243
Ohio	7	1.45	0.0139
Washington	5	1.04	0.0198
Texas	5	1.04	0.0085
Delaware	4	0.83	0.0888
Maryland	4	0.83	0.0802
Illinois	4	0.83	0.0395
Oregon	3	0.62	0.0063
Virginia	2	0.62	0.0111
Connecticut	2	0.41	0.0129
New Hampshire	2	0.41	0.0956
Georgia	1	0.21	0.0062
Louisiana	1	0.21	0.0016
Wisconsin	1	0.21	0.0008
Minnesota	1	0.21	0.0033

Normalized fatalities were calculated by dividing the number of fatalities by the length (km) of the state's coastline. The top five normalized rip current fatality states are shown in *bold*. Coastline length was provided by CRS (2006) and Michigan (2009)

temporal period which attract many beach tourists. Many of these fatalities occurred on weekends when beach tourism and population of people in the water are at their highest (Fig. 5).

Results also indicate that men are much more likely to be a victim of a fatal rip current; more specifically, men between the ages of 10 and 29 (Fig. 6). Males account for 84% of all rip current fatalities in the United States (Fig. 7). This is similar to other hazards (e.g., lightning) where 84% of all lightning deaths in the United States were attributable to males (Curran et al. 2000). According to Howland et al. (1996), the most drowning victims are male due to their likeliness to engage in activities in which water is present, and their increased use of alcohol. In addition, numerous newspaper articles referenced that many males drowned in rip currents while trying to save others who were swept up in the current. All of these factors combined formulate the asymmetrical gender distribution of fatal rip currents found in Fig. 7.

4.2 Meteorological relationship to rip current fatalities

United States rip current fatalities occur most often when a synoptic-scale surface high pressure directs winds onshore (Fig. 8). Interestingly, synoptic-scale surface high pressure

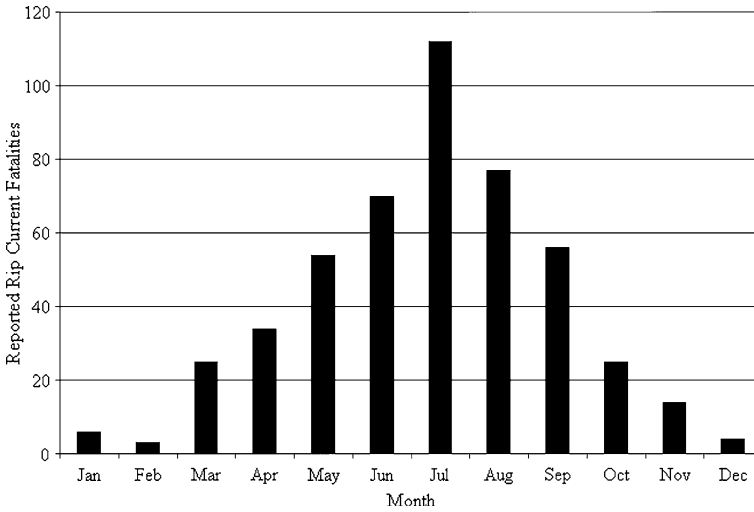


Fig. 4 Reported rip current fatalities by month

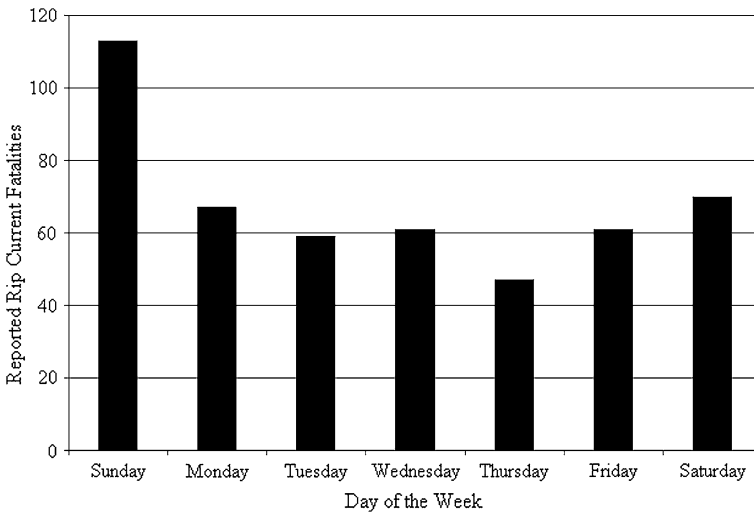


Fig. 5 Same as Fig. 4, except by day of the week. The dates of three reports were unknown

systems are usually not associated with other natural hazards such as hurricanes, tornadoes, etc., but account for a large proportion (over 40%) of rip current fatalities. Off the southeast coast of the United States, these semi-permanent, subtropical, warm-season high pressure centers provide easterly winds at the surface that are normal to shorelines (Fig. 9b). Depending on the pressure gradient force, these onshore winds can be quite strong and allow for favorable conditions for the development of rip currents. Typically, these slow-moving (sometimes stationary) high pressure centers create favorable rip current conditions for days at a time, and are associated with fair-weather skies that make ideal days for tourists or locals to travel to the beach. Please note that these meteorological

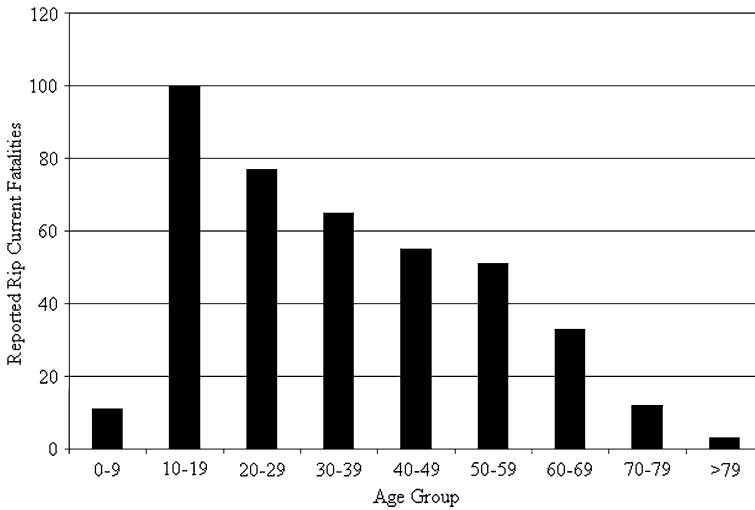
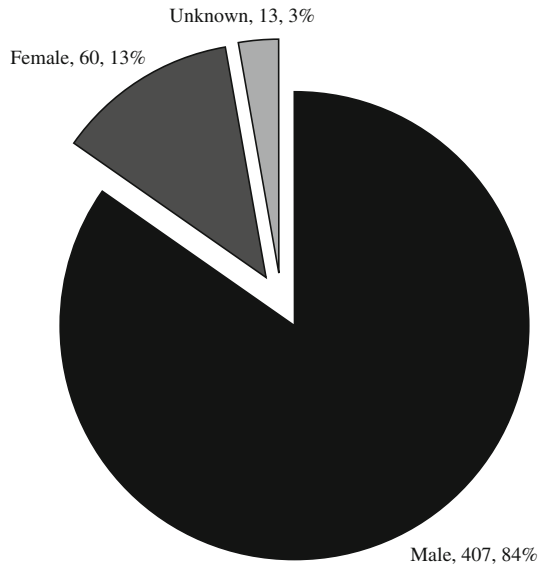


Fig. 6 Percent of reported rip current fatalities (1994–2007) and percent of United States population (US Census Bureau 2009) by age segments. Sixteen percent of reported fatalities during this period did not contain age information and are thus not represented in the graph

Fig. 7 Total number/percentages of reported rip current fatalities by gender



conditions differ from those of only rip current formation. For example, Kent (2008) described that rip current formation was most likely off the coast of North Carolina from postfrontal winds behind a front that directed winds onshore. It is hypothesized that California (ranked 2nd in the United States for total reported rip current fatalities, 13th normalized) does not see as many rip current fatalities as Florida, because Northern Hemisphere high pressure systems off the West Coast creating ideal beach visiting

conditions, would direct synoptic-scale winds offshore, which are unfavorable for the development rip currents.

Meteorological settings containing a tropical system account for the second highest frequency of reported rip current fatalities. Waves associated with a tropical system can propagate far from the center of the low pressure and impact coastlines not directly affected by the tropical system’s precipitation or cloud shield. These waves can last for many days, even after the tropical system makes landfall. Meteorological conditions hundreds of kilometers away from these systems may be vastly different and more favorable for beach visitors than conditions present in the vicinity of the tropical system. Therefore, it is logical that these events account for the second highest frequency of rip current fatalities. Rip current forecasters should be aware of surface meteorological conditions similar to Fig. 9a that may pose a risk to beaches in their forecast area.

Results also indicate that low pressure systems creating onshore winds to a particular beach can also lead to fatal rip currents. Over the period of analysis, nearly 70 deaths occurred when a low pressure system was creating onshore winds to the beach where the fatality occurred. However, as depicted by Fig. 9c, these fatalities were often spatially displaced from the center of the low pressure system where beach visiting conditions would likely be unfavorable. Fatalities associated with this category were generally found along the Gulf of Mexico shoreline, where southerly winds in advance of a cold front directed warmer onshore flow to the Gulf States. This conveyor belt of onshore flow ahead of a cold front would also lead to favorable beach conditions, albeit for a smaller temporal scale than other categories previously discussed.

The “Onshore Winds Other” category is a rather unique classification that was formed to capture events that did not quite fit with the features associated with synoptic-scale low or high pressure systems. These events contain surface meteorological characteristics such as inverted pressure troughs or wind shifts not associated with major low or high pressure systems. Interestingly, offshore, inverted surface pressure troughs were noted during 30 out of the 52 rip current fatalities in California. This distinctive surface feature was not present

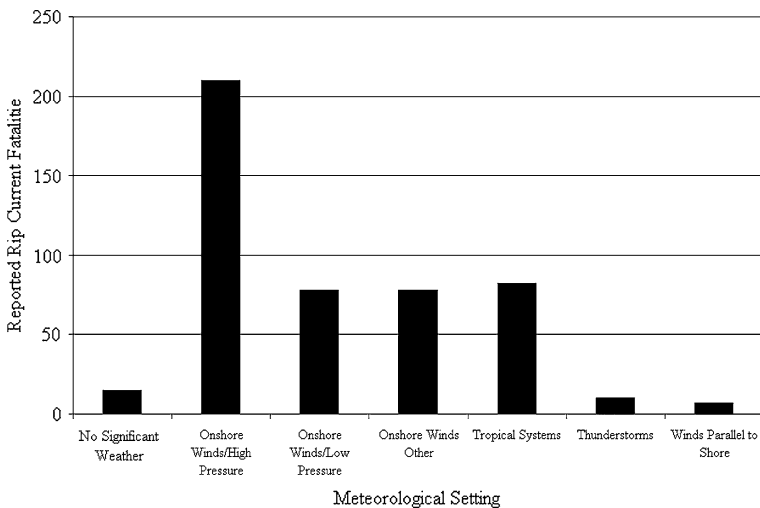


Fig. 8 Synoptic-scale meteorological features associated with rip current fatalities. Three meteorological settings were unidentified due to an unknown date. See Table 1; Figs. 2, 9, and the text for additional information on the settings

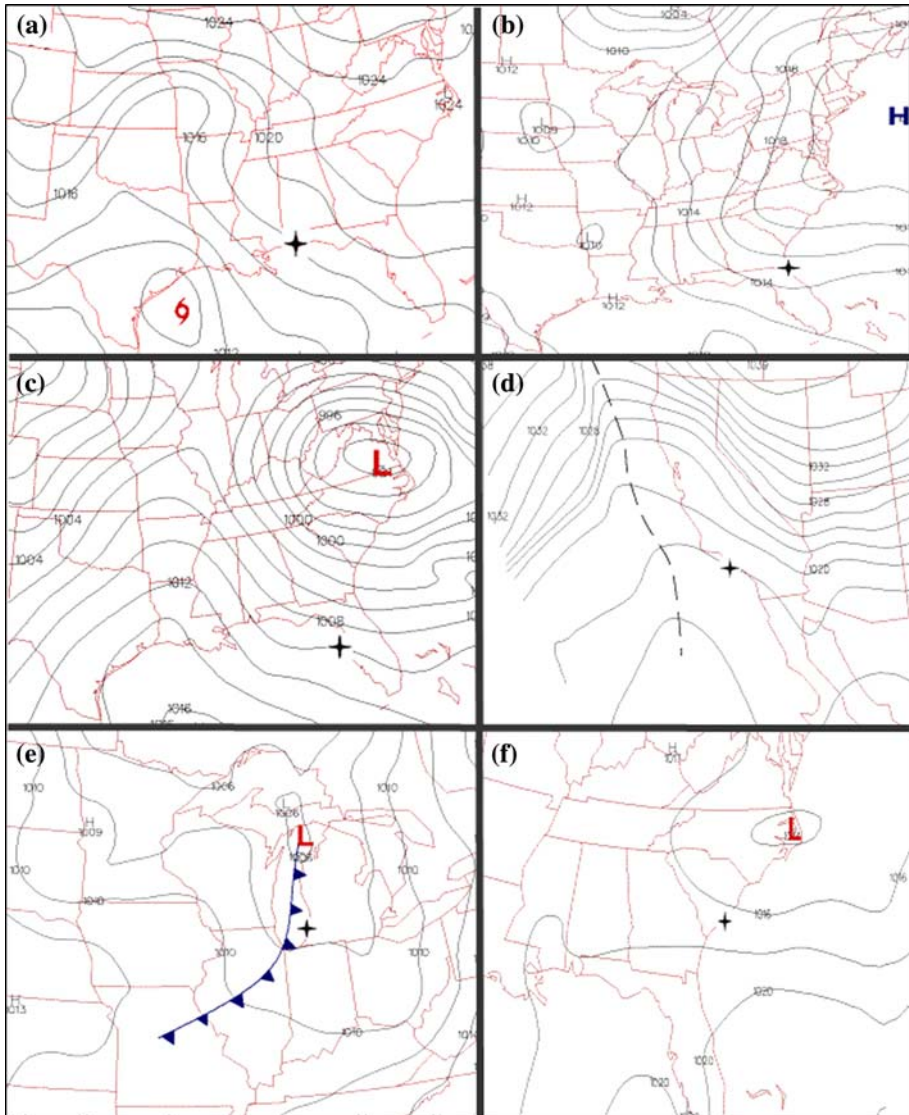


Fig. 9 Examples of the different meteorological classifications used in this study (cf. Table 1 and Fig. 2), including: **a** August 31, 2003, ‘tropical system’ **b** July 30, 2004, ‘High pressure created onshore winds’ **c** March 28, 2005, ‘low pressure created onshore winds’, **d** June 26, 2003, ‘onshore winds other’, **e** August 27, 2005, ‘thunderstorms’, and **f** June 24, 2004, ‘winds parallel to shore’. Black “+” indicates the location of the fatality or fatalities on the day illustrated. Red “L” indicates a center of surface low pressure. Blue “H” represents a center of surface high pressure. Blue line with triangles represents a surface cold front. Black dashed line indicates a surface pressure trough axis

in fatal rip current events elsewhere in the United States. These inverted troughs are common to California in the summer season, as differential heating between California’s Central Valley and the Pacific Ocean induces surface pressure troughs to form. Ulrickson and Mass (1990) modeled these inverted troughs in the Central Valley, and found that their “Summer A” type synoptic settings (which correspond to an inverted trough at the surface)

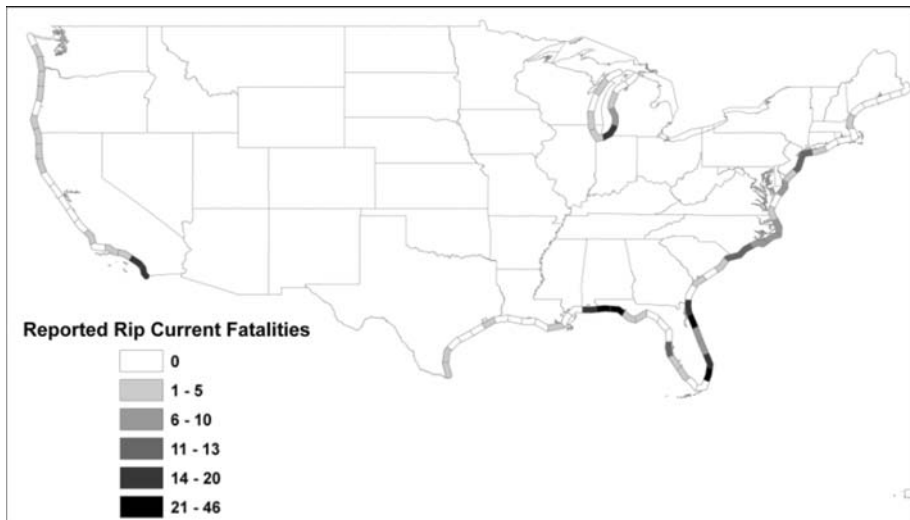


Fig. 10 Number of reported rip current fatalities along 100-km segments of United States' coastline. Additional fatalities occurred on other Great Lakes (three on Lake Erie, two on Lake Superior, one on Lake Ontario), but are not spatially represented here due to lack of space

produce onshore sea breeze-induced flow over a majority of their domain. Although strength of these winds (5 ms^{-1}) would not be consistent with a major rip current threat according to Lushine (1991a, b), the direct onshore flow from these circulations appears to be enough to produce a notable fatal rip current risk in the region. Forecasters should become aware of this risk when weak synoptic flow patterns develop and allow mesoscale flows and features to dominate the sensible surface weather.

The final two categories are less frequent events, but worth noting as their own category due to their less obvious ability to produce fatal rip currents. Although “Thunderstorm” and “Winds Parallel to Shore” categories account for only 7% of the deaths over the period, they are often unexpected and coexist with surface conditions not generally associated with rip currents in current literature. As an example, on July 4, 2003, eight rip current fatalities were recorded on Lake Michigan. Generally, Lake Michigan does not have many rip current fatalities because synoptic-scale features that direct onshore winds to beaches are not stationary for a long enough period of time to build up surplus water in the surf zone. However, as noted by Lushine (1991a, b), rip currents are most common around the time of low tide. On the Great Lakes, forecasters consider thunderstorm-induced seiches in lieu of tides. On July 4, 2003, a complex of thunderstorms along a cold front induced a seiche on Lake Michigan that caused rip currents to form along several Lake Michigan beaches.¹ This proved to be the deadliest day due to rip currents anywhere in the United States over the period 1993–2007.

The surface winds in the “Winds Parallel to Shore” category are known to be favorable for the development of long shore currents that can lead to the development of rip currents (Sonu 1972). This is especially true if a pier or jetty is present on the coastline. These features can funnel the water back out to sea forming a rip current. Unfortunately, *Storm*

¹ Verified in discussions with Mr. Dave Guenther. See Mr. Guenther's informal manuscript online at http://www.meted.ucar.edu/marine/ripcurrents/forecasting/content/Case_Study_070403.pdf

Data and *Lexis Nexis* rarely provided explicit details on the exact location of the fatality, making it difficult to tell if the death occurred near a pier or jetty. Although categorizing deaths in this category contains the highest amount of subjectivity, these deaths only account for 5% of all rip current fatalities from 1993 to 2007.

4.3 Geographic analysis

The spatial distribution of United States rip current fatalities is nonuniform and favors particular geographic areas (Fig. 10). The highest frequency of fatalities due to rip currents is located in the 100-km section from Miami Beach, FL northward to West Palm Beach, FL. This area tallied 46 fatalities during the period 1994–2007. On a larger scale, a regional maximum of fatal rip currents can be found along the east Florida I-95 corridor from Jacksonville to Miami, FL. This corridor tallied an average of 23 fatalities per 100-km segment. The west coast of the Florida peninsula shows relative maximum around the Tampa-St. Petersburg area, but in terms of totals, the west coast has far fewer fatalities than its eastern counterpart (Fig. 11c). This is to be expected as coastal bathymetry, land use, and beach visitation frequency differ profoundly from the west to east coast. Also, as

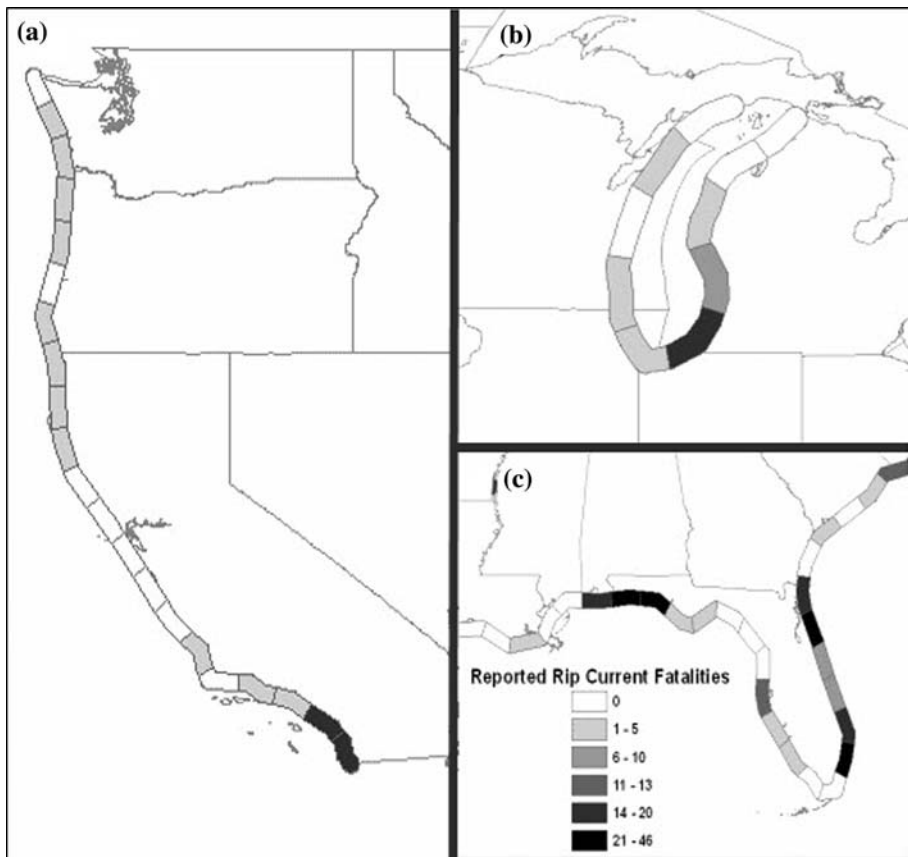


Fig. 11 1994–2007 reported rip current fatalities for **a** United States Pacific coast **b** Lake Michigan and **c** Florida

previously mentioned, semi-permanent surface high pressure centers off the East Coast of the United States provide onshore flow to Florida's Atlantic beaches. Another Florida maximum is found in the coastal Florida panhandle near Pensacola (Santa Rosa Island). This area has coastal characteristics (i.e., beaches and population centers) similar to Florida's eastern coast.

Elsewhere, an average of 10 deaths per 100 km exists along a long stretch of the Atlantic Coast roughly from Long Island, NY to Cape Island, SC. On the Pacific Coast, most of the fatalities are concentrated from San Diego to Long Beach, CA (Fig. 11a). Unique coastal bathymetry in this area is favorable for the development of rip currents during the onshore winds other meteorological setting (Fig. 9d). Coupled with a high population density, this area shows a relative maximum of rip current fatalities. As previously stated, in the Great Lake region, only Lake Michigan was mapped in a GIS because of the lack of multiple fatalities on other Great Lakes (Fig. 11b). Nearly 80% of Lake Michigan rip current fatalities occur from Porter, IN northward to Grand Haven, MI. Located between these two points is Warren Dunes State Park in Berrien County, MI. This area is a popular tourist destination for people in the Great Lakes region. Nearly 20 fatalities have been reported at the beaches of Warren Dunes State Park over the period of record.

5 Discussion and conclusion

Rip currents were previously estimated to cause approximately 150 deaths per year in the United States. An assessment of reported fatalities collected from both governmental and nongovernmental data sources illustrates that the likely number of rip current fatalities in the United States is previously lower than thought. Sources presented in this study suggest that about 30–40 people fall victim to rip current hazards each year. However, as previously stated, there are reporting problems in *Storm Data*; most notably in the quality of these reports. Some reports had no location, age, gender, or even time of death. A report of a fatality with no metadata serves very little use to researchers conducting spatiotemporal specific research. Occasionally, the description section of the *Storm Data* report contained important background information relevant to the fatality that was very beneficial for this study. Further, it is plausible that rip current fatalities are undercounted in the United States, but we have no competing dataset to draw a definitive conclusion to this hypothesis. It is also plausible that the efforts of Lushine and others in the early 1990s has helped to raise awareness of the hazard, and has thus decreased the number of fatalities since then.

Results illustrate that the east coast of Florida has the highest number of rip current fatalities in the United States. There are three main factors that make this area the rip current fatality capital of the United States: (1) semi-permanent high pressure centers off the east coast of the United States provide onshore winds that aid in the development of rip currents; (2) favorable beach visiting conditions exist when high pressure systems dominate the sensible weather; and (3) the Gulf Stream ocean current provides the east Florida coast with relatively warm ocean temperatures that are enjoyable to many beach visitors. Temporally, most fatalities occur on weekends in the summer months when beach populations are at their highest. This study also indicates males are six times likelier to fall victim to a rip current than women, which may be attributable to the higher likelihood of men engaging in water activities and their increased use of alcohol (Howland et al. 1996).

It is recommended that a more universal, and streamlined, process be developed to report and enter natural hazard damage and casualty information into *Storm Data*. Gall

et al. (2009) suggest the development of an “open access comprehensive data clearing-house for natural hazard loss information.” This is necessary to improve the ability to accurately access the losses from natural hazards in the United States. Without such a database, researchers are left to piece together data—likely incomplete—from multiple agencies or organizations that may have different reporting guidelines.

Lushine (2005) has provided a comprehensive set of suggestions that may be used to mitigate against rip current casualties. These mitigation techniques involve the use of expanded observational data, improvements of forecasts and warnings, expanded education and training of the public and scientists, increased beach patrol personnel, as well as reduction in the hazard through physical modification of the surf zone. The proposals set forth in Lushine (2005) are undoubtedly worth pursuing to reduce rip current fatalities in the United States. In addition, forecasters responsible for issuing marine products to the public should become aware of the spatial and temporal distributions, as well as the variety of meteorological conditions, associated with rip current fatalities in the United States. A conceptual model approach coupled with ingredients-based observational data will allow forecasters to issue timely products to help emergency managers, beach officials, and lifeguards reduce the number of future rip current casualties in the United States.

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