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Atmospheric and Ocean Conditions and Social Aspects Associated with Rip Current Drownings in the United States

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Atmospheric and Ocean Conditions and Social Aspects Associated with Rip Current Drownings in the United States

by

Charles H. Paxton

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy School of Geosciences College of Arts and Sciences University of South Florida

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Keywords: waves, rip current, wave buoy, significant wave height, beach safety

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ABSTRACT

The purpose of this research is to provide a better understanding of the physical and social aspects of rip currents in ocean areas that will lead to better forecasts, better governmental policies in beach areas, and ultimately to save lives. A rip current is a nearshore circulation in which breaking waves run up onto the beach then retreat rapidly in deeper channels back toward the sea. Rip currents pose a significant threat to beachgoers and can pull even the strongest swimmers out to sea. The primary factors associated with rip current formation on unarmored beaches are variations in the local beach bathymetry, wind-generated longshore waves of varying height, and lower tidal stages. The rationale for this study is highlighted when rip current deaths are put in context with deaths from other weather related deaths. The average number of rip current deaths per year in the United States is 46 and in the year 2010 rip currents were responsible for 64 deaths which was higher than the deaths associated with lightning, tornadoes, hurricanes and the cold winter during the year. The methodology followed for this study includes a review of demographics from over 500 rip current drowning reports along the Atlantic Ocean, Pacific Ocean and Gulf of Mexico coasts of the United States from 1994-2012. This research indicates that tourists are often victims, and rescuers can become the victims. For each state or sub-state area where rip current drownings are prevalent, an analysis of social aspects, beach areas, and associated ocean and weather patterns was conducted using averaged wind and pressure fields over wave generation areas, buoy data, and tide data. It is important to understand the evolution of these drowning events and seek solutions to mitigate the problem.
CHAPTER 1: INTRODUCTION

Rip currents pose a significant threat to beachgoers. A rip current is a nearshore circulation pattern of accumulated water caused by wave run-up onto the beach then flowing rapidly back out to sea through narrow channels in the surf zone where waves break. In essence, waves break and run up onto the beach then retreat in deeper channels back toward the sea, except for the case of flash rip currents which are not bathymetrically controlled. Rip currents can pull even the strongest swimmers out to sea and depending on the size of the surf and the nearshore bathymetry, rip currents can extend past the breakers. The nearshore zone extends from the shoreline to a water depth where wave motion does not affect the ocean bottom. Much of the rip current research has focused on direct measurements of currents in and near the surf zone, wave tank modeling, or numerical simulations (Leatherman 2011). The primary factors associated with rip current formation are variations in the local beach bathymetry, longshore waves of varying height, and lower tidal stages. This study will review statistics of deaths and injuries from over 500 rip current reports along the coasts of the contiguous United States, analyze the social aspects and associated ocean and weather patterns, and provide a more clearly defined strategy for forecasting rip currents for ocean areas with the greatest number of rip current fatalities. The importance of this work is highlighted when rip current deaths are put in context with deaths from other severe weather. In 2010 rip current deaths were responsible for 64 deaths around the country which was higher than the deaths associated with lightning, tornadoes, hurricanes and the cold winter during 2010. Using National Weather Service (NWS 2014) statistics, Table 1.1 shows weather related fatalities from
2002 to 2012. Rip currents stand out as one of the prevalent weather related hazards with a 10 year average of 46 fatalities in the waters of the United States (U.S.).

Table 1.1 Weather related fatalities in the U.S. from 2002 to 2012 (NWS 2014).

<table>
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<tr>
<th>Year</th>
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<th>Tornado Fatalities</th>
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<th>Hurricane Fatalities</th>
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<th>Cold Fatalities</th>
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<td>45</td>
<td>33</td>
<td>28</td>
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</tr>
<tr>
<td>2010</td>
<td>29</td>
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<tr>
<td>2011</td>
<td>26</td>
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<td>41</td>
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</tr>
<tr>
<td>2012</td>
<td>28</td>
<td>70</td>
<td>29</td>
<td>4</td>
<td>155</td>
<td>8</td>
<td>28</td>
<td>42</td>
<td>104</td>
<td>528</td>
</tr>
<tr>
<td>Total</td>
<td>9235</td>
<td>7444</td>
<td>7507</td>
<td>3322</td>
<td>3727</td>
<td>710</td>
<td>1080</td>
<td>501</td>
<td>979</td>
<td>15,454</td>
</tr>
<tr>
<td>10-Yr. Avg</td>
<td>35</td>
<td>109</td>
<td>76</td>
<td>109</td>
<td>117</td>
<td>27</td>
<td>24</td>
<td>46</td>
<td>51</td>
<td>640</td>
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</tbody>
</table>

Previous studies examining rip current drownings have focused on localized areas or single beach locations. This research focuses on a broader scale national approach and then examines local differences. Currently the NWS uses “Low, Medium and High” descriptors to relate the danger levels associated with rip currents in forecasts but those descriptors do not have a standard set of ocean and meteorological based parameters associated with them. This project will identify oceanic, meteorological and geographic conditions to determine what factors influence conditions that lead to rip current drownings to provide guidance for longer term predictions out to 5 days. The typical NWS rip current forecasts are only valid for a 12-24 hour period. Identifying these typical patterns associated with rip currents in forecasts may enable forecasters to provide more lead time for ocean rescue services to plan for staffing. This research was initiated due to prior correspondence from U.S lifeguards expressing an urgent need for more detailed rip current forecast parameters and more collaboration with rip current researchers. In turn, the benefits of
these more accurate forecasts will help lifeguards better allocate their resources, with the overall goal of saving lives.

1.1 Rip Current Definition

Shepard (1936) first used the term “rip current” to describe a circulation pattern of accumulated water from ocean waves rapidly flowing back out to sea through narrow channels in the surf zone. Shepard et al. (1941) described the “feeder” currents (Figures 1.1 and 1.2) near the shoreline that funnel water into the “neck”, or primary section of the rip current, through the surf zone, then the “head” spreads out in deeper water. The neck of the rip current typically forms in a channel of deeper water called the rip channel. At some beaches the sandbars depicted in Figure 1.1 are more perpendicular or transverse to the shore.

During the late 1940s, John Isaacs describes meeting Willard Bascom and conducting pioneering surf zone research near Carmel, CA using an amphibious vehicle (Behrman and Isaacs 1994). They found that when higher than average groups of waves, which are commonly known as set waves, break in fast succession, the nearshore water level would rise then rush back in a narrow channel. Dalrymple (1978) described a rip current as a current of water moving rapidly seaward from the beach. Two primary factors associated with rip current formation are longshore variations in the local beach bathymetry and longshore waves of varying height (Bowen 1969, Dalrymple 1978, Haller et al. 1997). The surf zone bathymetry most favorable for rip current development depicted in Figure 1.1 is not always present but run-up from several waves may coincide to produce a rip current nonetheless. For example, a well-defined gap in the outer sandbar may not be present but beachgoers may be pulled into deeper water between sandbars or the rip current may continue to flow outward without the presence of deeper channels. Mean rip current
speeds may be up to 0.5 ms\(^{-1}\) (Garcez-Faria et al. 2000, Haines and Sallenger 1994). Maximum rip currents have been measured up to 2 ms\(^{-1}\) (Brander and MacMahan 2011).

![Figure 1.1 Rip current schematic diagram.](image1)

Figure 1.1 Rip current schematic diagram.

![Figure 1.2 Rip current feeder and neck areas at low tide at St. Augustine Beach, Florida (Photo by Charles Paxton).](image2)

Figure 1.2 Rip current feeder and neck areas at low tide at St. Augustine Beach, Florida (Photo by Charles Paxton).
Debate exists over the terminology. In the past, this phenomenon has been named “undertow” (Atwood and Goldthwait 1908) or “rip tides”. Rip tides are formally defined by Collins (2012) as “a current opposing other currents, producing violently disturbed water; esp., the strong, narrow flow of sea water that rushes seaward after incoming waves pile up on the shore.” The term adopted for this phenomenon by the National Oceanic and Atmospheric Administration (NOAA) and the United States Life Saving Association (USLA) is “rip current”. Brander and MacMahan (2011) suggested that the term “rip tide” be reserved for tidal fluctuations at inlets. Leatherman (2011) suggests that the term “beach rip” be used similarly as “rip current”. He also suggested that “rip tide”, sometimes known as “tidal jet” should be used to describe a tidal flow through an inlet, and “undertow” as a brief outgoing flow that does not extend beyond the next breaking wave.

Factors leading to rip currents are varied, such as wave height (McKenzie 1958), tidal fluctuation (MacMahan et al. 2011), wind velocity (Lascody 1998), and various other local parameters including beach slope, presence of tidal channels and sand grain type (Murray et al. 2003).

1.2 Rip Current Observations

Researchers have studied rip currents using a variety of methodologies. Individual elements of the rip currents such as sediment transport and bar morphology, wave angle, tidal influences and bathymetry may be studied with great detail. One of the most common methods of study is a direct observation with the naked eye. From that point of view many questions may arise. How can I better see the rip current? How strong is the rip current? How large are the waves offshore? How broad is the swash zone? Masselink and Hughes (1998) and Puleo et al. (2000) used the term “swash” to represent the oscillation of the water's edge on the beach where the
sediment exchange between the ocean and the beach take place. To highlight rip currents in the
water, researchers (Huntley et al. 1988, Brander and MacMahan 2011, Leatherman 2011) have
used dye as a tracer element.

The observations become more sophisticated with various in situ measuring devices
introduced such as current meters (Aagaard et al. 1997, Brander 1999, Brander and Short 2001),
pressure sensors, and GPS-equipped drifters. Video camera use began primarily during the 1970s
(Sonu 1972, Sasaki and Horikawa 1975, Sasaki and Horikawa 1978). As computer technology
developed and wireless communication improved, the use of remote cameras has increased greatly
and time lapse observations have been used by many researchers (Orzech et al. 2011). Wave fields
are remotely sensed using phase-array Doppler radar (Smith and Largier 1995). Water
characteristics are measured using horizontal Doppler sonars (Vagle et al. 2001). Away from
shore, spectral wave data are available from offshore buoys (NDBC 2013). From space,
geostationary satellites give a broad view of weather systems that produce waves over the oceans
where few surface observations exist. Some polar orbiting satellites are equipped with
scatterometers from which ocean wind fields are derived (Naderi et al. 1991). Satellite data
provides a method to verify numerical weather models that form the basis for wave forecast models
where no other observation data exists.

MacMahan (2011) describes his involvement with more than 10 comprehensive field
experiments around the world. During that 10 year period he and his colleagues used many
different observational techniques and model simulations to gain knowledge of rip currents. In one
such 44 day field experiment at Sand City, Monterey Bay, CA, rip current kinematics and beach
morphodynamics were measured using 15 instruments composed of co-located velocity and
pressure sensors, acoustic Doppler current profilers, and kinematic GPS surveys (MacMahan et al.
The researchers found an inverse relationship between sediment accretions on the transverse bar and rip channel erosion.

One of the drawbacks of a single point of observation is the representativeness of the location and associated conditions during the observation period. For example, the location may have unusually prolonged small or large incident wave action during the time of the study. The dynamics at each stretch of beach are different with varying: wave frequencies, initial sandbar structures, nearby geographical or man-made structures, sand and beach composition, and offshore bathymetry. For example, Bruneau et al. (2009) studied rip currents along the Aquitanian Coast of southwest France in a five day field experiment using a large array of sensors and under a wide range of wave conditions. The field study incorporated daily topographic surveys and video imaging to investigate beach morphodynamic evolution. During the experiment the significant wave heights offshore were 0.5 to 3m. With the varying wave heights, the researchers were able to see a difference in rip current activity on low and high wave energy days.

At times researchers may take characteristics of rip currents that were observed in the field or at the beach and try to replicate those actions by building or using a physical model such as a wave tank (Lamont-Smith and Waseda 2008). Another approach is mathematical, using the equations of motion and conservation to predict intensity and other characteristics of rip currents. The mathematical principles are then incorporated into high resolution (down to meters) numerical models. Typically, an ocean model is coupled with a nearshore wave model and the output from the ocean model provides initial and boundary conditions for the nearshore wave model that runs in sequence. Longuet-Higgins and Steward (1964) defined radiation stress as the excess flow of momentum onto the shore, due to the presence of the waves, that creates a water level gradient, where the stress is balanced by hydrostatic pressure, leading to an outflow of water. Kumar et al.
(2011) used the three-dimensional Regional Ocean Modeling System and coupled it to the Simulating Waves Nearshore (SWAN) and the refraction/diffraction (REF/DIF) wave propagation models in a variety of surf zone configurations to determine transport. They were able to improve the surf zone recirculation patterns over previous formulations based on radiation stress. Adding to the previous model configuration, Kumar et al. (2012) used a coupled ocean-atmosphere-wave-sediment transport modeling system to better determine the relationship of waves and circulation. Haas and Warner (2009) compared results and efficiencies of a faster running quasi-three-dimensional model to the ROMS and found ROMS more adaptable to a greater variety of scenarios. Westphalen et al. (2012) numerically simulated a physical model of a wave tank to better understand the dynamics that occur. Statistical approaches are another method to correlate different atmospheric and oceanographic variables to rip currents.

1.3 Ocean Conditions Associated with Rip Currents

Rip currents are primarily created by waves that are generated by wind blowing across the water, and wind is created by differences in atmospheric pressure. The pressure gradient force is balanced by the interactions of the Coriolis and centrifugal forces to produce the gradient wind (Wallace and Hobbs 1977). Stronger winds blowing across longer, wider, and deeper fetches of ocean for longer periods of time create larger waves with more energy (Young 1999). Capillary waves develop when wind begins to move over a water surface and small ripples are formed. These ripples or capillary waves have wavelengths less than 2 cm and periods between waves less than 0.1 s. Because of the short wavelength, the restoring force is the surface tension of the water. Capillary waves have a rounded crest and a V-shaped trough. As the wind continues to move across the water, the wave grows in length and height with higher pressure on the windward side
of the wave, thus moving the wave. As the wavelength exceeds 2 cm, gravity becomes the restoring force and the wave is termed a gravity wave. With enough wind duration, wind strength, and fetch (distance over which the wind blows), the waves become seas with a mixture of periods. The longer period (9 – 30 s), faster moving waves depart the development area as swells (Munk 1950). Table 1.2 from Munk (1950) shows ocean wave period classifications and development associations. Waves may also be created by geologic shifts within a body of water (a tsunami). Also, a sharp atmospheric pressure difference can create a rise in ocean level and through resonant feedback can grow if the speed is coincident with water of a constant favorable depth (Paxton and Sobien 1998). This type of wave development is sometimes known as a meteorological tsunami or meteotsunami (Monserrat et al. 2006).

<table>
<thead>
<tr>
<th>Period</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.1 s</td>
<td>Capillary waves (associated with wind)</td>
</tr>
<tr>
<td>0.1 - 1 s</td>
<td>Ultra-gravity waves (associated with wind)</td>
</tr>
<tr>
<td>1 - 30 s</td>
<td>Ordinary gravity waves (associated with wind)</td>
</tr>
<tr>
<td>30 s - 5 min.</td>
<td>Infra-gravity waves (associated wind and ordinary gravity waves)</td>
</tr>
<tr>
<td>5 min. - 12 hours</td>
<td>Long-period waves (associated with storms and earthquakes)</td>
</tr>
<tr>
<td>12 - 24 hours</td>
<td>Ordinary tides (associated with sun and moon)</td>
</tr>
<tr>
<td>&gt; 24 hours</td>
<td>Trans-tidal waves (associated with storms, sun and moon)</td>
</tr>
</tbody>
</table>

The overall mathematical principles of wave motion and fluid dynamics are well known, but in the shifting sands of a beach, exact mathematical replication of a particular rip current event is impossible. The group wave velocity is the speed of wave propagation but the wave phase velocity can be greater than the group velocity which is known as the dispersion relationship. For a wave of wavelength $\lambda$ and frequency $\omega$, the phase velocity $v_p$ is given by:
\[ v_p = \lambda \omega = \lambda / T \]  \hspace{1cm} (Eq. 1.1)

where \( T \) = period in seconds. The wave frequency \( \omega \) is defined in relation to period \( T \) by:

\[ \omega = 2 \pi / T \]  \hspace{1cm} (Eq. 1.2)

and

\[ T = \lambda / v \]  \hspace{1cm} (Eq. 1.3)

For a wave to grow, the wind velocity must be greater than or equal to the phase velocity. The group velocity is the velocity at which an envelope of waves moves and is also the velocity at which the wave energy propagates. Waves of different wavelengths travel at different phase speeds and this is known as frequency dispersion. Amplitude dispersion is a nonlinear effect where larger amplitude waves have a different phase velocity than smaller waves. Water depth in relation to wavelength is important in several different ways. Deep-water waves are defined as the depth \( (d) \geq \lambda / 2 \), intermediate-water waves are where \( \lambda / 20 < d < \lambda / 2 \) and shallow-water waves are where \( d \leq \lambda / 20 \). In deep water, waves are dispersive and shallow water waves are not dispersive. Gerstner (1802) postulated that waves in deep water have limits to size and period in relation to wind speed, duration and fetch. In deep water, when individual wave steepness or ratio of wave height \( (H) \) to wave length \( (H / \lambda) \) is larger than 0.17, the wave becomes unstable and breaks (Dean and Dalrymple 2002). When the input by the wind is balanced by wave breaking, the energy is balanced, and the waves have grown to maximum size for that wind velocity and fetch. This is termed a fully developed sea. In a fully developed sea, the greater wind speeds produce higher energy waves with longer periods and wavelengths, but at lower frequencies. Given a particular wind speed, fetch, and duration, wave size and period in deep water will only grow to a limit and this is known as a fully developed sea state (Gerstner 1802, Kinsman 1965, Müller et al. 2005). In
an analysis of fully developed wind seas, Pierson and Moskowitz (1964) substantiated earlier work by Phillips (1958) and Kitaigorodskii (1962) that, for a given fetch and wind velocity, the seas will reach an asymptotic limit. That relationship between wave energy distribution and the wind was further modified by Alves et al. (2003).

As waves approach shallow water, frictional effects of the ocean floor slow the waves and increase the wave height (Gunn 2001, Lindeburg and Baradar 2001). This is known as “shoaling”. As waves shoal, the wavelength decreases but the frequency remains constant resulting in a compensatory increase in wave height. When the water depth is small compared to the wavelength in shallow water, the waves break. As a wave shoals and increases in height the wave will break when the water depth (h) is less than or equal to 1.25 times the wave height or $H > 0.8h$ (Dean and Dalrymple 2002). This is dependent on individual wave characteristics and wind effects that can create a premature break if the wind is onshore or the converse with an offshore wind. Breaking waves dissipate wave energy which mixes the surface layers (Melville 1994). As a wave breaks, the wave energy is transformed into turbulent kinetic energy (Agrawal et al. 1992, Terray et al. 1996).

The wave continues toward the beach and, depending on the bottom characteristics, the wave may reform and break several times before reaching the shore. Momentum will carry the wave up the beach and then retreat back toward the sea, particularly funnelling into deeper channels when they exist. Longer period waves greater than 10s occur less frequently, but break with more energy and momentum and can push more water up the slope of the beach. Long period waves also travel from the generation area in groups or sets that create variability in the rip current strengths (Shepard and Inman 1950, Sonu 1972, MacMahan 2003). Shepard and Inman (1950) noted that rip current variability occurred on different timescales associated with wave ‘sets’ or
groups of higher waves. Therefore, the larger long period set waves may only occur every 10 to 20 minutes. This can catch swimmers by surprise. Dalrymple (1975) inferred that two intersecting wave trains of the same wavelength (period) will cancel each other spatially, creating a pattern of rip currents along spaced nodal lines. Dalrymple and Losano (1978) found refraction slowed waves near the rip current to create longshore currents in the shallow water that became the “base” of the rip.

Higher wave heights also are widely regarded as having a large impact on the presence of rip current-related drownings (McKenzie 1958). Larger waves create a larger surf zone region, which can lead to more rip currents due to strong longshore flow creating nearshore circulation (Murray and Reydellet 2001). In addition, larger wave heights contribute to exhaustion for those caught in a rip current, leading to panic and increased chances of drowning (McKenize 1958). Swell heights of over 3.1 m are generally very dangerous, and wave periods over 10 s also increase the likelihood of rip currents (Lascody 1998).

1.4 Bathymetry, Structures, and Tides

Characteristics such as bathymetry, beach slope, sand type, and other factors play a role in local rip current formation (Brander and Short 2001, Murray and Reydellet 2001, Aagard and Vinther 2008). On a broad scale, the width and depth of the continental shelf is important as it relates to frictional effects which affect wave heights. A long and shallow continental shelf, as seen off the west or northeast coasts of Florida, will decrease incoming wave sizes and a short continental shelf, such as that found in the Hawaiian Islands or parts of coastal California, will have less influence on wave size. The nearshore bathymetry that is affected by wave action dictates the nature of rip currents. Sandy beaches typically have a varied sea bottom with sandbars parallel
to the beach separated by deeper troughs. Sandbars are built as incoming surf creates a drift of sand towards the bar area where waves break and outgoing currents carrying sand also contribute to nearshore bar formation (King and Williams 1949, Aagaard et al. 1997, Dyhr-Nielsen and Sørensen 1970, Haines and Sallenger 1994). Brewster (1995) described flash rip currents as those resulting from the coincidence of waves at the shore creating a gradient leading to a brief outflow of water. The difference in depths between sandbars and deeper troughs can be quite drastic, with waist deep water dropping off to over 2 m deep within just a meter. In that scenario, poor swimmers who feel safe in the shallower water can be pulled outward slightly by a rip current and be overcome by a state of panic when their feet do not touch the sandy bottom.

Variations alongshore in sea depth may result in sandbars with small gaps between them. Wave momentum is directed parallel to the direction of wave propagation. As the wave approaches the sandbar, shoaling, breaking, and then wave run-up onto the beach occurs. This leads to water flowing toward lower water surfaces alongshore and then channeling seaward through gaps in the sandbar (Murray and Reydellet 2001). Large surf and strong longshore currents will create shifting sandbars with breaks or gaps. MacMahan (2003) analyzed three years of time averaged video images at Duck, North Carolina to study the stability and persistence of rip channels and concluded that only large storms with strong longshore currents have a significant impact on bar morphology. Aagaard and Vinther (2008) found that relatively small water depths across the bar crest were more likely to create rip circulations and conversely deeper water over the bar crest led to a brief undertow.

Short (1985) observed over 3500 rip currents and classified three types of rip currents: erosion, mega, and accretion. He described erosion rips as those widely spaced and produced in rising seas with beach erosion occurring. Erosion rips were described as variable carriers of
sediment up to 1 km offshore and persisting for around 24 hours or less. Mega rips were described as large-scale (>1 km) erosion rips that were topographically controlled. Accretion rips were described as those occurring after erosion rip formation during stable or decreasing wave conditions and, associated with beach accretion, become associated with crescentic bar patterns. These may persist in one location for days to weeks under favorable wave conditions. Crescentic bar patterns are naturally occurring beach patterns that tend to funnel wave run-up back out to sea leading to rip currents. Garnier et al. (2010) simulated the formation of crescentic bars from an initially straight shore-parallel bar and found during the evolution to crescentic that as the rip channels narrowed, the sand crests on the beach were created.

Field data indicate that decreasing water depths nearshore may increase rip current speed (MacMahan et al. 2005). This suggests that stronger, more dangerous rips are present during the trend from high tide to low tide. Lower tidal stages was another factor noted by McKenzie (1958), Sonu (1972), Brander (1999), Brander and Short (2001), and Dronen et al. (2002). In addition, a higher than normal tide (such as during a full moon) has also been attributed to an increase in rip current strength (Lascody 1998). This is may be related to a faster outgoing tide. Longuet-Higgins and Stewart (1964) found that rip current velocities reach a maximum near low tide. Upon observing rip currents for six years in New South Wales, Australia, McKenzie (1958) determined that larger waves at acute angles to the shore and lower tides produced more prominent longshore currents and stronger rip currents.

More studies conclude that beach slope may play a role in stronger rip currents as well. A steeper beach slope will result in a narrower surf zone region resulting in weaker longshore flows (Murray et al. 2003). More gradual sloping beaches with a wider surf zone and stronger feeder currents lead to an increase in rip current activity (Murray and Reydellet 2001, Dalrymple 1978).
Nearshore or intermediate transverse sandbars create the strongest feeder currents that become the strongest rip currents (Murray et al. 2003). Murray (2004) described the formation of rip channels in which short-lived jet-like rip currents develop in random locations creating local erosion and a trough-like channel. Guedes et al. (2012) evaluated swash motions on a beach using a multiple regression model using different combinations of independent variables to represent beach slope and breaking waves. Murray also found that when modeling, this lag in sediment transport was necessary to simulate the scenario. Guza and Inman (1975) and Sallenger (1979), through field experiments, determined that beach cusps were initially formed from longshore variations in edge waves or wave run-up and further modified through positive feedback.

Short and Hesp (1982) characterized beaches with fine to medium sand as dissipative, reflective, or intermediate. The dissipative beaches have gentle slopes, wide surf zones, and sandbars parallel to shore with channels running normal to shore. Reflective beaches have a steep slope with either cusps or berms without sandbars. The intermediate beaches have a moderate slope with broad cusps, crescentic-transverse bars and deeper rip current channels.

Other studies have determined the relationship between nearshore circulation patterns, long shore wave break heights, and the location of rip currents. Observations suggest that gaps in long shore wave heights can signal a rip current moving through the gap. If a gap in the breaking waves or a consistent area of lower wave heights is present, this could indicate a nearshore circulation system with a rip current moving seaward through the gap (Bowen 1969). Beachgoers are sometimes advised to look out for such gaps in long shore wave break heights (Leatherman 2011). Nielsen et al. (2001) found that rip current channels that are deeper tend to strengthen rip current and wave interaction but Kennedy et al. (2008) noted that the relationship between sandbar gap widths and the strength of rip current is unknown.
Wright and Short (1984) found that intermediate transverse sandbars create the strongest feeder currents that become the strongest rip currents. They also found a relationship between sandbar changeability (B), wave height (H), wave period (T), and sediment fall velocity (w), which is linked to sand grain size where:

\[ B = \frac{H}{wT} \]

They found that the most mobile or changeable sandbars were at beaches with a modest or meager medium-grained sediment supply and highly changeable wave conditions. Sandbars with lower mobility were at beaches with persistent high wave energy and fine-grained sediment or beaches with lower energy waves and with coarse-grained sediments. In a study along North Carolina beaches, Gallagher et al. (1998) determined that when wave energy was low, sandbars move slowly toward the beach and when wave energy was high, with significant wave heights over 2 m, sandbars moved rapidly about 130 m offshore.

Hard barriers like jetties are often placed at inlets to help keep navigational channels clear, and daily tidal fluctuations create strong currents within the inlet channel. When side-shore wind conditions are present and a long shore current parallel to the coast develops, the jetty barrier forces water seaward in strong rip currents. Piers typically create a deeper channel near the pilings that provides a funnel effect for rip currents of seagoing water. Although rip currents can happen at any beach, particularly if reefs or permanent structures such as piers or jetties jut out into the water, it is the gentle sloping beach areas that can temporarily contain and then funnel large amounts of water through a deeper channel into a strong and sustained rip current. This is particularly
aggravated at lower tides when more of the gently sloping beach is exposed. Additionally an outgoing tide can add to the general outward movement of the water.

Engle (2003) found that the frequency of rip current rescues increased with wave direction normal to the shore, mid to low tidal stages and narrow directional spreading. Narrow directional spreading (less than 35 degrees) accounted for 75 percent of rescues. Engle found that one quarter of the rip rescues occurred with smaller wave heights (less than 0.45 m). Intermediate wave heights (between 0.45 m and 0.85 m) resulted in increased rescues. From his results, Engle postulated that fewer rescues at higher wave heights may be due to fewer people venturing into the surf. Engle also found that most rip current rescues (62 percent) occurred with 7.5 to 9 s wave periods and wave periods less than 6.5 s accounted for only 10 percent of rip current rescues.

Another factor in rip current formation is linked to wave and current interaction. Various mathematical models characterize the relationship of wave train, wave-current and incident-edge wave interaction (Dalrymple 1978). Incident-edge wave interaction involves the interaction between synchronous edge waves (traveling alongshore) creating a nearshore circulation dependent upon the wave period. This circulation can lead to the formation of rip currents. Wave train interaction between two synchronous wave trains may also induce a rip current according to a second mathematical model, but the percentage of occurrence for this type of interaction is not known (Dalrymple 1978). Dalrymple also studied the interaction between rip currents and waves in an attempt to determine rip current spacing, but these results were theoretical with the numerous uncertainties in energy dissipation and instability mechanisms. Interestingly though, Murray and Reydellet (2001) and Murray et al. (2003) contend that while conditions such as wave heights, tides, and other parameters are believed to have an effect on the formation of rip currents, there is no universal consensus on the cause.
Kumar et al. (2011) used the three-dimensional Regional Ocean Modeling System and coupled it to the SWAN and REF/DIF wave propagation models to use for surf zone applications. They were able to improve the surf zone recirculation patterns over previous formulations based on radiation stress (Haas and Warner 2009). Adding to the previous model configuration, Kumar et al. (2012) used a coupled ocean-atmosphere-wave-sediment transport modeling system to integrate the effect of waves on circulation and vice versa. Now, more sophistication and control has been obtained by numerically simulating physical models, such as a wave tank (Westphalen et al. 2012). Statistical approaches are another method to correlate different atmospheric and oceanographic variables to rip currents.

1.5 Weather Conditions Associated with Rip Currents

Gensini and Ashley (2010) looked at the synoptic-scale surface conditions in seven categories associated with rip current fatalities: high pressure created onshore winds; low pressure created onshore winds; thunderstorms in the vicinity; winds parallel to shore, tropical systems, onshore winds, and no significant synoptic-scale features present. They found that 70 percent of all rip current fatalities are associated with a surface high pressure system creating onshore winds. They noted that tropical cyclones produced the second highest frequency of rip current fatalities.

Hurricanes are a commonly noted weather factor related to rip current drowning and rescue incidents (Lascody 1998). A distant hurricane can become an unknown factor to beachgoers creating large but infrequent long period swells that can extend hundreds of miles from the center of the storm (Paxton 2011). Therefore, it is possible for strong rip currents to exist due to a hurricane generated swell on a fair-weather day. In addition to hurricanes, other synoptic scale phenomena, such as strong high and low pressure systems with interfacing frontal systems, may
also generate strong winds and large swells (Lascody 1998, Schrader 2004, Gensini and Ashley 2010).

Recent studies have focused more on meteorological phenomena being a primary factor for the cause of rip current-related drownings and rescues. Swells typically generated by large scale synoptic weather events such as hurricanes, strong high pressure systems, and frontal systems may be enhanced by smaller scale local phenomena such as onshore flow associated with the sea breeze (Lascody 1998, Paxton 2011). The presence of onshore wind was also noted in several other studies. Mollere et al. (2001) examined wind, tide, and swell measurements associated with rip current deaths in the Florida Panhandle region and concluded that 94 percent of the 18 cases occurred with an outgoing tide, the wind normal to the shore, and an average swell height of 0.7 m and period of 6-7 s. Schrader (2004) examined local meteorological conditions associated with rip currents in Volusia County, Florida and found that onshore wind flow created rip current prone conditions after cold fronts had pushed through the area. Schrader also found that rip currents in the Florida Panhandle are associated with cold fronts north of the state creating strong onshore winds with a southerly component and wave directions normal to the shore. Kent (2008) studied wave and weather patterns related to rip current events along the North Carolina coast and found conditions corresponding well to previous research that included: wave direction typically normal to shore; wind directions between 22.5 degrees and 90 degrees to shore; significant wave heights from 0.5 m and 1.5 m; and dominant wave periods from 5-10 s.

Increased swells and stronger wind speeds have been found to have a dramatically increased effect on the presence of rip currents. Lascody (1998) found that wind directions perpendicular to shore, moving in the direction of the shore (between 40 and 110 degrees on the East Coast of Florida), had a positive correlation with increased rip currents. He also found that
the stronger the wind speed, the stronger the rip in general, especially with winds exceeding 15-20 knots (7.5-10 ms⁻¹) though he contends that the swell wave period and swell wave height together factor for about 8 times the impact of the wind factor. Although previous research attributes onshore winds to greater rip current frequency, Paxton (2011) indicated that onshore winds create choppy disturbed waves that are more likely to catch a swimmer by surprise and rough conditions may also mask or hide someone in distress from potential rescuers.

Lascody (1998) also mentioned that synoptic scale phenomena, such as strong high and low pressure systems with interfacing frontal systems, may also generate strong winds and large swells. A strengthening of the pressure gradient around a semi-permanent area of high pressure such as the Bermuda High can create higher than normal waves. Around a strong area of high pressure, surface winds could easily exceed 25 knots (12.5ms⁻¹), which is above the threshold of dangerous wind speeds related to the formation of rip currents described by Lascody (1998). If the Bermuda High extends far enough to the west, its effects can impact beaches on the eastern coast of the United States, and even the Gulf of Mexico coastline. A tragic rip current event occurred in Panama City, Florida with a very strong Bermuda High extending into the Gulf of Mexico, causing strong swells to push onto Panama City Beach from south to north, perpendicular to the beach. The combination of these strong winds, wind direction and large swells attracted beachgoers, and also caused multiple rip deaths on the beach on July 25th, 2008 (Paxton 2011).

1.6 Rip Current Forecasting

Several techniques have been derived to improve forecasting and prediction for dangerous rip current events using wave height, meteorological data and bathymetrical characteristics. Lushine (1991) developed an empirical forecasting technique termed the Lushine Rip Current Scale (LURCS) that incorporated wind direction and speed, swell height, and the time of low tide
to forecast rip current danger in South Florida. Based on Lushine (1991), Lascody (1998) described four parameters used in the East Central Florida (ECFL) LURCS rip current threat forecasts that included wind speed and direction, and swell height and period. To improve upon the LURCS method, Engle (2003) devised a technique for forecasting rip currents at Daytona Beach, Florida by comparing rip current rescue records to both the NOAA National Data Buoy Center (NDBC) buoy wind data and the United States Army Corps of Engineers directional wave data that included significant wave height, peak wave period, peak wave direction, and mean water level and he found the frequency of rip current rescues increased with wave direction normal to the shore, mid to low tidal stages and narrow directional spreading. Forecasters at the Wilmington, North Carolina NWS office use a combined LURCS/ECFL method that accounts for wave periods less than 7 s (B. Rinehart, personal communication, 9 April 2014).

Alvarez-Ellacuria et al. (2010) developed a model to predict times of increased wave height, wave direction and consequently rip current threat. The forecasting system can predict wave heights and direction with a fairly strong degree of accuracy for up to three days. The model uses mathematical formulas from previously determined wave propagation methods laid out by Dalrymple (1978). It also accounts for bathymetry of the beach and other variables to determine the size of the surf zone, on top of the wave height and direction data (Alvarez-Ellacuria et al. 2010). Further examining and replicating their model for other beach locations may lead to improved forecasting for rip currents and safety for beachgoers. Argaard and Vinthner (2008) determined that their model could predict whether the entire bar area unit undergoes rip cell circulation or not but it could not predict whether coexisting lateral circulations would occur.

Wu et al. (2008) developed a rip current observation and monitoring tool to calibrate a rip current model for Southern California. Lifeguards working with meteorologists at the NWS Office
in San Diego, California took rip current observations that included coastal wave and tide data and found that rip currents were influenced by swells and local beach profile. They used the collected data to calibrate two empirical models developed by Wright and Short (1984) and Guza and Inman (1975) to aid in determining rip current threat at a specific beach.

1.7 Social Aspects and Demographics of Rip Current Victims

The NWS (2014) accounts for nine primary weather related hazards with heat being the most prevalent killer with a ten year average of 119 deaths per year. The other hazards, ranked in order with the ten year average of deaths are: hurricanes (114), tornado (108), flood (78) rip currents (46), wind (45), lightning (37), cold (27), and winter (23). Considering the ten year average; rip current fatalities fall into fifth place. Another measurement of hazard severity is the property damage estimate of which all of those hazards may produce except rip currents. More people died (1016) during the uncharacteristic 2005 hurricane season than any other since 1940 (NWS 2014). That was ten times the ten year average number of hurricane related deaths. Similarly, the 2011 tornado outbreak killed 553 people which was about five times the ten year average. For rip currents, the fluctuation is much less.

Like other weather hazards, rip current drownings are seasonal; primarily occurring during the summer season when more people gather at the beach. Florida is one exception with rip current drownings reported during every month. In Florida, roughly a third of the rip current-related drownings occurred during the November to April time frame. For Southeast Florida, influenced by the warm waters of the Gulf Stream, half of the days with rip current drownings occurred from November to April (Paxton 2011). Although the ocean water is typically colder than south Florida,
Paxton (2011) noted that California is also an exception with half of the drowning days occurring from November to April.

Compared to other weather hazards, rip currents more often impact tourists who are unfamiliar with the ocean. Like other hazards, rip currents occur regardless of the day of the week but unlike those hazards that can strike anywhere, rip currents only kill those at the beach who are in the water. Therefore unlike other hazards, most rip current-related deaths occur on weekends and Sunday has almost three times the deaths of an average weekday (Paxton 2011).

During 2011, 3555 people died from drowning in the U.S which was lower than the 2010 number of 3782 (Hoyert and Xu, 2012). Dietz and Baker (1974) found that approximately 50-75 percent of drownings occur in open water such as oceans, lakes, rivers, and ponds. In a report on drowning, Laosee et al. (2012) found the death rate among males was almost four times that for females (2.07 per 100,000 people vs. 0.54). In children aged 5–14 years the rates by racial or ethnic groups were: blacks, 1.34; Hispanics, 0.46; and whites, 0.48. For nonfatal drowning injuries that were 15 years or older, 21.8 percent were associated with alcohol use.

It is often thought that a drowning person will signal distress in the water by yelling or waving their arms. According to Pia (1974), who made observations of drowning non-swimmers, he illustrated that people who are in the process of drowning are often quiet while struggling to keep their mouth above the water and quickly succumb to the water. Pia (1974) labeled this as the Instinctive Drowning Response.

Gensini and Ashley (2010) analyzed rip current fatalities in the conterminous U.S for the period 1994-2007 and found an average of 35 deaths each year that are more likely to occur during summer season weekends. They also noted that males are over six times more likely to die than females. Studying accidental drowning in Pinellas County Florida, Nichter and Everett (1989)
found that bodies of salt water were the most common drowning site; three times more males drowned than females, and 59 percent of young adult victims had detectable blood alcohol levels. Copeland (1984) looked at Dade County drowning victims and found that almost 38 percent had detectable blood alcohol levels. Gulliver and Begg (2005) surveyed young New Zealand adults and found that males reported a higher level of water confidence, more exposure to risk behaviors, more exposure to unsafe locations, and more near-drowning incidents, than females. They also determined that water-confident males were more likely to drink alcohol before water activities.

It appears that males are greater risk takers and may not know their limits. Morgan et al. (2009) studied beachgoers in Australia and found that males visited surf beaches more frequently than females, expected to spend longer in the water, in deeper water, and more often entered the water after drinking alcohol.

The USLA (2012) oversees a standardized training program for lifeguards and compiles statistics for drownings that occur at about 95 percent of ocean beaches and at some non-ocean sites patrolled by lifeguards. The USLA was founded in 1979 as an expansion of the National Surf Life Saving Association of America to include any member of an ocean, bay, lake, river, or open water lifesaving or rescue service. The USLA (2012) web page defines drowning as “an unintentional death caused as the result of respiratory impairment from submersion/immersion in the water.” A guarded drowning is defined as “a drowning death(s) which occurs in an area under the protection of lifeguards, as determined by the lifeguard provider, or within a designated swimming area.” An unguarded drowning is defined as “any other drowning death(s) within the jurisdiction of the lifeguard provider at any time of day or year. Does not include fatalities discovered in the water, where the cause is unrelated to beach activity.” In a Center for Disease Control (CDC) report assessing lifeguard services, Branche and Stewart (2001) found that more
than three-quarters of drownings at USLA sites occurred when beaches were unguarded. The USLA (2012) statistics (Table 1.3) show the total 2011 beach attendance at 312,675,437 people with 63,019 rescues of which 32,140 were in rip current situations and 6,854 in the surf. The drowning deaths at unguarded beaches totaled 79 of which 16 were attributed to rip currents and 4 to large surf. At guarded beaches, the drowning death total was 20 with 3 attributed to rip currents and 3 to large surf. Based on the last ten years of reports from USLA affiliated lifeguard agencies, the USLA has calculated the chance that a person will drown at a beach protected by USLA affiliated lifeguards at 1 in 18 million (USLA 2012).

Table 1.3 USLA statistics for 2007-2011 from USLA (2012).

<table>
<thead>
<tr>
<th>Category</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beach Attendance</td>
<td>281,223,110</td>
<td>286,943,081</td>
<td>312,678,880</td>
<td>312,141,846</td>
<td>312,675,437</td>
</tr>
<tr>
<td>Rescues</td>
<td>74,463</td>
<td>79,208</td>
<td>83,471</td>
<td>56,934</td>
<td>63,019</td>
</tr>
<tr>
<td>Preventative Actions</td>
<td>4,918,770</td>
<td>4,792,017</td>
<td>6,457,403</td>
<td>5,599,108</td>
<td>5,665,344</td>
</tr>
<tr>
<td>Medical Aids</td>
<td>252,202</td>
<td>282,125</td>
<td>265,879</td>
<td>326,116</td>
<td>325,719</td>
</tr>
<tr>
<td>Boat Rescues</td>
<td>4,042</td>
<td>3,887</td>
<td>3,321</td>
<td>4,076</td>
<td>3,367</td>
</tr>
<tr>
<td>Passengers</td>
<td>9,203</td>
<td>8,890</td>
<td>7,425</td>
<td>10,160</td>
<td>6,722</td>
</tr>
<tr>
<td>Vessel Value</td>
<td>$145,023,860</td>
<td>$73,592,155</td>
<td>$82,396,415</td>
<td>$101,725,770</td>
<td>$131,858,516</td>
</tr>
<tr>
<td>Drowning Deaths</td>
<td>109</td>
<td>105</td>
<td>124</td>
<td>127</td>
<td>99</td>
</tr>
<tr>
<td>Drowning Deaths (Unguarded)</td>
<td>89</td>
<td>86</td>
<td>103</td>
<td>102</td>
<td>79</td>
</tr>
<tr>
<td>Drowning Deaths (Guarded)</td>
<td>20</td>
<td>19</td>
<td>21</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>Lost And Found Persons</td>
<td>16,729</td>
<td>11,374</td>
<td>15,222</td>
<td>12,948</td>
<td>11,301</td>
</tr>
<tr>
<td>Public Safety Lectures</td>
<td>22,184</td>
<td>9,652</td>
<td>10,780</td>
<td>14,074</td>
<td>6,968</td>
</tr>
<tr>
<td>Students Attending</td>
<td>448,316</td>
<td>354,259</td>
<td>293,714</td>
<td>383,333</td>
<td>232,263</td>
</tr>
<tr>
<td>Reporting Agencies</td>
<td>109</td>
<td>111</td>
<td>117</td>
<td>116</td>
<td>114</td>
</tr>
</tbody>
</table>
Can multiple rip current drownings occurring in a short time span over a narrow geographic area as described in Paxton (2011) be related to a disaster? In one day during 2003, eight fatalities occurred along Florida Panhandle beaches. During that summer 20 people died along that stretch of coastline. Wisner et al. (2004) describe a disaster as an extreme natural event or process. They portray disasters as the interaction of hazards and vulnerable situations compounded by the number of people exposed to the hazard. Rip currents are not typically thought of as a natural disaster and do not directly impact ones dwelling as other natural disasters may. Although rip currents are not specifically mentioned, the Pressure and Release (PAR) Model (Blaikie et al. 1994) has several indicators which are relevant toward rip current drownings. According to Wisner (2004), the primary alignments that create more vulnerability to a hazard are: 1) A natural environment with varied and infrequent but deadly hazards; 2) political and economic ideologies that lead to a lack of local investment; and 3) social characteristics and processes that provide unequal access to opportunities and unequal exposure to hazards (Fig.2). A collective example of these alignments is a popular beach without lifeguards or lifesaving equipment.

Therefore the risk of a rip current disaster becomes greater as the vulnerability factors increase. Beside a lack of lifeguards, surf conditions conducive to rip currents, and warmer weather, vulnerability is manifested in social factors such as class, gender and ethnicity that may contribute to ocean familiarity and swimming ability. As Wisner et al. (2004) mentions “to understand disasters we must not only know about the types of hazards that might affect people, but also the different levels of vulnerability of different groups of people” (p. 7).
1.8 Rip Current Education and Awareness

On average, rip currents kill more Floridians than tropical cyclones, tornadoes and lightning combined every year (Lascody 1998). Public outreach material related to rip currents has increased over the years, especially with media campaigns, flyers, pins, magnets, school education programs, and from government entities. Although governments, the media, and other groups have warned the public of rip current dangers, those warnings have not had a serious impact on the number of drowning deaths per year (Leatherman 2011).

While government sponsored programs such as NOAA’s “Break the Grip on the Rip!” have been successful at providing information to the public, lack of funding and analysis of the program hamper efforts at further progress towards educating and warning beachgoers. NOAA provides a daily rip current forecast for coastal locations, but in general, the public at large is not well informed on the dangers of rip currents. One program developed by NOAA and the USLA to help beachgoers become familiar with rip currents is signage located at beach access points which provides suggestions for identifying and surviving a rip current (Fig. 3). The signs provide information to beach visitors before they enter the water. NOAA’s “Break the Grip on the Rip!” campaign has clearly made some impact, as most popular beaches in the U.S now have signs with educational information to advise beachgoers what to do in the event they are caught in a rip current. However, two major areas of concern regarding campaigns such as “Break the Grip on the Rip!” have arisen: first, a lack of devoted funds from governments or the private sector limit the ability for beach safety lessons to be continually and properly taught to beachgoers (Brander and MacMahan 2011). Second, Brander and MacMahan (2011) also suggest that no analysis has been attempted to assess the effectiveness of the “Break the Grip of the Rip!” campaign or other
outreach programs. Without proper analysis, effective parts of the program remain undeterminable, and improvements cannot be made to better educate and inform the public.

Figure 1.3 Vulnerability to hazards (Wisner et al. 2004).

Other educational rip current material shows beachgoers how to spot rip currents by spotting discolorations in the water. This rip current information shows currents taking the form of a neck near the shore with a visible discoloration traveling from the shore outward to sea. At the end of the neck, a mushroom shaped head and discoloration may also be observed (Fletemeyer and Leatherman 2010). This informational program is intended to educate beachgoers and keep
them safe. However, problems exist with some rip current safety information that is widely distributed to beachgoers. Not all rip currents are visible, so methods such as signage may be less effective (Fletemeyer and Leatherman 2010). The common knowledge for swimmers to either ride the rip current offshore until it dissipates or swim parallel to shore may not be preventing rip current drowning. Often a long shore current will occur that is perpendicular to a rip current (Bowen 1969). This distorts the flow of the rip, and gives it a more curved or angled shape at times. So, swimming parallel to shore may actually result in swimming back into the rip, rather than away from it, causing further exhaustion and panic, and therefore drowning (Fletemeyer and Leatherman 2010). Riding the rip current offshore may not be the best option either, as the combination of being carried out by a strong current and breaking waves crashing onto a person, particularly on beaches without lifeguards, may be deadly (Brander and MacMahan 2011).

Figure 1.4 Rip current signage posted at beach cross-overs.
Another method of beach safety for beachgoers includes the presence of warning flags (Fletemeyer 2011, Houser et al. 2011). Prior to 2002, Florida beach areas had many different standards for beach safety and notification. In 2002 the Florida Legislature mandated the development of a uniform beach safety program and then in 2005, an amendment required standardized beach warning flags Florida Department of Environmental Protection (FDEP 2012). It was realized that the varied notifications of beach hazards could confuse beachgoers. The standardized flags and interpretive signs are given to local governments that provide public beach access by the FDEP Coastal Management Program. Other states such as Alabama and California have similar flag systems. The beach flags are not direct indicators of rip current presence but typically indicate general surf conditions. Near beach access points, descriptive signs indicate what various colors of flag mean. Also available are national comprehensive educational rip current signs that were developed through the NWS, SeaGrant, and USLA. These signs have a diagram of a typical rip current and suggest that swimmers caught in a rip current should not panic, and should not swim against the rip current but instead should swim parallel to the rip current and signal for help. Brander and MacMahan (2011) mention that lateral feeder or longshore currents may also impede someone swimming parallel to the rip current and lead to exhaustion and therefore strongly suggest swimming only in lifeguarded areas. This recommendation is not on most standardized national signage.

These signs and flags warning of rip currents that are present on many beaches often lack any real educational or informational value, and some do not use the term “rip current”. Also, there is no way of determining who does and does not read these signs to evaluate their effectiveness (Brander and MacMahan 2011). They found that it is also difficult to evaluate how educational and outreach material such as flyers, magnets and billboards effect the behavior of beachgoers.
Educational programs from elementary through high school are effective at teaching children the dangers of rip currents as most rip deaths occur within the young male adult group (Nichter and Everett 1989, Brander and MacMahan 2011).

Brander and MacMahan (2011) also note a lack of consistent rip current drowning reporting exists though the United States. They suggest that lifeguards are in a key position to document rip current data on surf conditions, beach attendance, and rescues. They also found a lack of consistent reporting globally making global rip current drowning estimates very unreliable. Unfortunately the USLA data are collected on an annual basis and individual reports or even monthly summaries are not available. Information that is lacking in existing reports from the USLA and NWS is detail about individual victims such as swimming ability, surf zone familiarity, evolution of the drowning event and how the rescue was accomplished. Other agencies are involved with collecting rip current data.

Mote Marine Laboratory (Mote 2012) in Sarasota Florida developed a system for beach lifeguards, park personnel, and beach patrol officers to report Karenia Brevis (red tide) symptoms such as dead fish and respiratory irritation, and surf condition reports including the presence of rip currents (Mote 2012). The reports come from 26 Florida Gulf Coast and Panhandle beach areas. Lifeguards report conditions each day through a special interface designed by Mote for smartphone devices. Each report has a time stamp indicating when it was last updated. The reports are available on the internet and in addition to rip current and red tide information, the reports include: the date and time, water color, wind direction, surf conditions, and presence of seaweed and red drift algae.

More recent development by computer scientists at Stevens Institute of Technology in New Jersey at the request of Professor Jon Miller, a coastal processes specialist, is a smartphone
application to assist lifeguards with identifying and cataloguing rip current occurrences (Stevens 2012). When a rip current is identified along the beach, the location is noted through the phone’s GPS and the lifeguard enters information such as size, strength, and nearby structures. The reports are then available in near real time on a map or in a list through a web interface.

The NWS Meteorological Development Laboratory (MDL 2012) also developed an interface for NWS and lifeguard collaborative reporting of surf conditions. This interface is being used at 15 beaches around the United States including San Diego and several areas along the East Coast and Great Lakes. Beach lifeguards submit reports containing beach characteristics, such as tide state and swell direction once or twice daily. The reports alert the NWS to rip current and surf conditions on the beach. The lifeguards also give feedback on the effectiveness of NWS rip current forecasts. MDL plans to develop a rip current forecast scheme for individual beaches to improve accuracy in rip current forecasts.

Assigned lifeguards at beaches save lives and is the single most effective way of preventing drowning deaths. The chances of drowning on a patrolled beach are 1 in 18 million (USLA 2012), with the vast majority of all rip current drowning deaths occurring on unsupervised beaches. Unfortunately, lifeguards are not employed at every beach at all times. Some drownings occur at beaches after lifeguards go off duty for the day. The consensus recommendation is to swim only at beaches with lifeguards on duty (Fletemeyer and Leatherman 2010, MacMahan et al. 2011). Laosee et al. (2012) suggest that everyone should learn survival swimming skills relevant to beachgoers: lifeguards should be present, alcohol use should be avoided, weaker swimmers should use a lifejacket and supervisors should have training in cardiopulmonary resuscitation.
1.9 Research Questions

Much of the rip current research has focused on direct measurements of currents within the nearshore waters or littoral zone, wave tank modeling, or numerical simulations. This study has a much broader approach comparing both the physical and social aspects of rip current drownings including the ocean conditions and similarities that drowning victims share. In the physical realm, the fundamental questions are:

- Where do rip current drownings occur?
- What beaches are most conducive to rip current drownings than others?
- For beaches where rip current drownings have occurred, what are the specific beach characteristics such as slope, bathymetry, and any other prominent features such as structures and reefs?
- What are the spatial wind vector and pressure patterns in wave development regions?
- What are the trends of wave height, and dominant and average wave periods on days with rip current drownings?
- Is a particular tidal trend occurring at the time of each drowning?
- Can a strategy be developed to identify high risk days for rip current drownings that leads to better planning for coastal lifeguards and other public safety officials?

Beyond the physical realm are the social aspects of rip current drownings.

- Are rip current drownings are related to chronological aspects such as time of year, day of the week, holidays, and time of the day?
- Do commonalities exist in demographics of victims such as sex, age and ocean experience?
• What behavioral patterns are evident that safety messages could address?

Other questions are linked to actions based on the research.

• Will this research provide information to the NWS, USLA, and local lifeguard agencies for standardized reporting of rip currents, rescues, and drownings?

• Are some messages not being understood by beachgoers regarding rip current safety?

• Besides lifeguards, are there other safety features that could be utilized to help save lives?
CHAPTER 2: METHODS

The fundamental step in this research was obtaining rip current drowning information from ocean beaches from the contiguous United States that includes locations, demographics and descriptions of each event. Those reports were analyzed and plotted. The beach characteristics were examined for the locations more prone to drownings. Next, atmospheric and oceanographic information was obtained from nearby buoys and local tide information gathered from tide tables. Finally, wind and pressure composites, from particular regions, were produced for the dates of the drownings.

The following describes the order of analysis:

1. Gather and map specific locations of rip current drownings based on Storm Data (2013) using ArcGIS software.

2. Identify the beach characteristics at drowning locations, and where known, find data associated with beach slope, bathymetry, and any other prominent features such as rock, reefs, piers, and jetties.

3. Collect the daily spatial surface wind velocity (m s\(^{-1}\)) and sea level pressure patterns (hPa) leading to rip current drownings using mean and anomaly data composites from the day of the event to 4 days prior which were generated through the Earth System Research Laboratory (ESRL 2013) website.

4. Plot and analyze wave trends of height, direction, period, and water temperature from buoy and nearshore measurements. Using data retrieved from NOAA’s National Data Buoy Center
from buoys near the sites of each rip current drowning, these data were compared with the other
data collected on meteorological conditions and beach types.

5. Graph tidal trends at the time of each drowning from NOAA tide predictions and
measurements using NOAA historical tidal data predictions available through the Center for
Operational Oceanographic Products and Services.

6. Perform descriptive statistical analyses on the buoy data (e.g., sample size, means,
correlations, and standard deviations) and inferential statistics (e.g., t tests, F tests, chi square tests).

2.1 Research Area

Rip current reporting methodology varies greatly between National Weather Service
Forecast Offices with some locations only reporting rip currents since 2007 and some with no
reports. The rip current drowning reports were plotted using ArcGIS with a Bing (2013) map
background where applicable.

These plots showed some natural clustering in locations; therefore the following areas were
selected for study because they have consistent rip current records that typically encompass ten
years or more. The areas are: California, Texas, Alabama, Florida, South Carolina, North Carolina,
New Jersey, New York, and (Figure 2.1).

Florida was further divided into four regions: the Florida Panhandle coast, Florida
southwest coast, Florida southeast coast, Florida east coast. The Florida Panhandle coast stretches
from the Alabama/Florida border to east Dog Island. The southwest coast stretches from Anclote
Key south to Marco Island. The southeast coast stretches from Key Largo to Vero Beach. The east
coast area extends from Vero Beach north to the Florida/Georgia border.
2.2 Rip Current Drowning Reports

Rip current death and injury reports from 1994-2012 were gathered from Storm Data (NCDC 2013). Although the extent of injuries associated with rip currents can vary, injuries are typically listed in Storm Data when a near drowning victim is taken to a hospital. Reports of deaths from lightning, floods, tornadoes and hurricanes go back several hundred years but rip current reporting to the NWS Storm Data Publication (NCDC 2013) began at some locations during 1994 and other areas such as Texas only in 2007 (Table 2.1).
Rip Current reporting is now processed at all NWS coastal offices. Storm Data rip current records are input by NWS Warning Coordination Meteorologists at the 27 coastal offices around the continental United States. The Warning Coordination Meteorologists receive reports from emergency managers, law enforcement, and from the media – primarily from newspaper clippings. The rip current reports fell within the Storm Data category of “Ocean and Lake Surf” events, but since a recent reorganization in 2012, they now have a separate rip current category. The Storm Data text highlighted in this research has not been modified from the original to correct typos or grammar.

Deaths from other short duration weather hazards, such as a tornado, wind, lightning, and flood, are gathered in a manner similar to rip current reports – through emergency managers, law
enforcement, and from the media. Reports of deaths from heat, cold, and winter weather are more elusive and are typically gathered from medical examiners long after the occurrence (D. Noah, personal communication, 19 December 2012). Although rip related current deaths and injuries have been reported in the Great Lakes region, that area was not examined for this study because this is a study of rip currents in larger basin ocean areas. In Hawaii, the Storm Data reports listed 25 combined ocean deaths since 1995 under the heavy surf or high surf categories without making distinctions of rip currents. Therefore the Hawaii reports were not used.

The advantage of this data set is that it is official data that documents rip current drownings and injuries for the United States. The data set has drawbacks in that the lengths of records vary by geographical area and the descriptive sections may lack detail for some of the reports.

2.3 Buoy and Nearshore Data

For a consistent overview, offshore NDBC buoys were used exclusively for this study. The buoys were selected by length of record, location, and data availability. For consistency, the buoys selected were in deep water areas to encompass incoming swells for a broader area and negate local effects such as island swell blocking. Nearshore buoys with long term records were not available for all areas. These moored buoys measure and transmit a variety of data but most commonly surface pressure, wind velocity, gusts, temperatures of the air and sea, and wave energy spectra from which significant wave height, dominant wave period (DPD), average wave period (APD) are derived. Additional information for each buoy used in this research is listed in Appendix A. For future follow-on studies, wave model data and buoys closer to the actual drowning locations will be used to provide a more detailed picture of the ocean conditions.
2.4 Morphodynamic Beach Data

Beach aerial images associated with drowning locations in this research were derived from Google Maps (2013) and Bing Maps (2013). Those images depict the beach area at the time the images were taken and most structures are permanent fixtures in the areas. The images do not necessarily depict the beach areas around the time of the drownings. The beaches could have been quite different based on renourishment projects, the building or removal of structures, and the frequency of major storms which could all impact the local bathymetry. The data associated with USGS National Assessment of Coastal Change Project (USGS 2012) and subsets (Hapke et al. 2010 and Benedet et al. 2006) provide morphodynamic classification of beaches. Those studies provide detailed information beyond the scope of this research. The datasets include beach width, dune elevations, emergent sandbars, presence of overwash (sand dune breached by high water and waves) zones, beach stability, stabilization structures such as jetties and sea walls, and density of development.

2.5 NCEP/NCAR Reanalysis Data

Surface pressure and wind vector composites from the day of the event to four days prior were generated from the NCEP/NCAR Reanalysis data (Kalnay et al. 1996) through the Earth System Research Laboratory (ESRL 2013) web interface. The web site provides methods to interactively input event dates and produce composite plots or averages of weather patterns associated with those dates. Those composite averages are also compared to the current 30 year climatology to produce an anomaly plot of the data. The ESRL (2013) web interface provides for input of various atmospheric fields, dates and image manipulations. When a request is submitted, the web interface calculates field averages for the submitted dates, and then returns a GrADS
composite image. To examine precursor wind and pressure patterns the data were examined from Day 0, the day of the event, to Day -4 which is 5 days before the event day. The plots provide a reference of consistent patterns associated with rip current days over an area but may not adequately show any particular event. The temporally and spatially averaged winds show the generation regions of ocean waves that create the hazardous conditions, but because of the averaging, are typically lower than the actual events. Events that are driven by typically smaller tropical cyclones show less consistency and weaker patterns. Those events are often better viewed on a case by case basis.

The NCEP/NCAR Reanalysis Project uses historical data to produce new atmospheric analyses from 1948 to the present. Unlike initial analyses taken from real-time weather forecasting, these analyses incorporate improved data assimilation techniques that include: 1) more observations; 2) better quality control; 3) consistent model/data assimilation for each year; 4) more available fields; 5) global vs. hemispheric analyses; 6) better vertical resolution. Virmani (2005) has shown that this reanalysis is not accurate close to the coast because of land contamination in the grid, however it is the best broadly available data set at this time and is therefore used in this study.

2.6 Tidal Data

NOAA historical tidal data predictions are available from the Center for Operational Oceanographic Products and Services (CO-OPS 2013). These data are readily available to the public for all beach areas and were used to determine tide phase within 6 hours of the time of drowning.
2.7 Beach Attendance Data

Table 2.2 shows beach attendance data for the top 25 attended beaches within the area of this study (Travel and Leisure 2012). The reports for each area were obtained from the USLA, Los Angeles Beaches and Harbors (LABH), Daytona Beach Area Convention and Visitors Bureau (DBACVB), New York State Parks Department (NYSPD). Nine of the top ten are in three of the most populated states. Ocean City, MD had only one reported drowning (Storm Data 2013) but a cursory check of newspaper articles indicates more drownings have occurred. The percentage of drownings compared to attendance is very low. The attendance figures do not indicate the percentage of visitors that actually went into the water. Additionally, some areas, such as Myrtle Beach, with 13 drownings, may not be represented.

Table 2.2 Top 25 attended beaches (Travel and Leisure 2012) and number of rip current drownings (Storm Data 2013).

<table>
<thead>
<tr>
<th>Beaches with Highest Beach Attendance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
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<td>6</td>
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<td>8</td>
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<td>9</td>
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<tr>
<td>10</td>
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<tr>
<td>11</td>
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<tr>
<td>12</td>
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<tr>
<td>13</td>
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<td>15</td>
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<td>16</td>
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<td>21</td>
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<tr>
<td>22</td>
</tr>
<tr>
<td>23</td>
</tr>
<tr>
<td>24</td>
</tr>
<tr>
<td>25</td>
</tr>
</tbody>
</table>
CHAPTER 3: SOCIAL ASPECTS AND DEMOGRAPHICS OF RIP CURRENT VICTIMS

Figure 3.1 shows the locations of rip current drownings and death totals by state. The top state by far was Florida with 277 deaths with California and North Carolina coming in with 47 and 42 respectively. New York had 31 drownings, New Jersey 30 and the narrow sliver of coastline in Alabama had 29 deaths.

![Figure 3.1 Locations and numbers of rip current deaths by state.](image)

Florida was divided into four sections (Figure 3.2). The Florida Panhandle coast stretches from the Florida border to Dog Island where 102 deaths occurred. Appalachee Bay is east of this area where the beaches fade to salt marsh and large waves become nonexistent in the very shallow waters. The southwest coast stretches from Anclote Key where the barrier islands and beaches
resume, south through the Tampa Bay area and extending south to Marco Island. Nineteen deaths occurred in this region. The shallow water of Florida Bay, between the Florida Keys and the mainland and protective outer reefs of the Keys greatly reduces the threat for rip currents in that region. The southeast coast stretches from Key Largo to Vero Beach where 83 deaths occurred. Most swells coming into the southeast coast, except north swells, are blocked by the islands of the Bahamas to the east across the Gulf Stream. A rare exception was documented by Davis and Paxton (2005) in which large hurricane swells propagated through the Providence Channel of the Bahamas. The east coast area that runs from Vero Beach north to the Florida border had 74 deaths.

Figure 3.2 Florida divided into four regions; Panhandle, Southwest, Southeast, and East.
3.1 Demographics of Drowning Victims

As expected the most rip current drownings occur during the summer months when waters are warmer (Figure 3.3). Drownings during the months of November, December, January, and February were all in either California or Florida. During March most of the drownings (15) were in Florida but seven occurred in California and interestingly another 4 occurred in the chilly waters of Oregon. The times of death varied but most occurred during the afternoon. This is important because in the absence of stronger ambient flow, an onshore sea breeze will dominate during the afternoon.

From the Storm Events (NCDC 2013) data, 519 people died in the ocean waters of the contiguous United States during the period of record ending in 2012. Of those for which the genders were known, 445 were males (87%) and 58 were females (13%). The youngest was 3 years old and the oldest was 85. The average age was 34.7, the median, 32 and the mode 18. The
age breakdown (Table 3.1) shows 11 children below the age of 10, 133 from 10 to 19 years old, 105 in their 20s, 71 in their 30s, 87 in the 40s, 68 people in their 50s, 40 in their 60s, 18 in their 70s, and one in the 80s. Teenagers, by far make up the largest decadal age group of rip current drowning victims. Another 40 people died in the waters of the Great Lakes in Michigan, Illinois, and Indiana of which 12% of the known sexes were females. The average age for Great Lakes drownings was lower at 26.6.

Table 3.1 Age breakdown of United States coastal area deaths.

<table>
<thead>
<tr>
<th>Age Breakdown of United States Coastal Area Deaths</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Younger than 10</td>
<td>11</td>
</tr>
<tr>
<td>10-19</td>
<td>133</td>
</tr>
<tr>
<td>20-29</td>
<td>105</td>
</tr>
<tr>
<td>30-39</td>
<td>71</td>
</tr>
<tr>
<td>40-49</td>
<td>87</td>
</tr>
<tr>
<td>50-59</td>
<td>68</td>
</tr>
<tr>
<td>60-69</td>
<td>40</td>
</tr>
<tr>
<td>70-79</td>
<td>18</td>
</tr>
<tr>
<td>80-89</td>
<td>1</td>
</tr>
</tbody>
</table>

Out of the 519 deaths noted in Storm Data (2013), 126 or 24% were noted to be tourists. Many of the Storm Data reports lack detail therefore the total number of tourists is likely much higher. The reports also indicated that 9% of the drownings were associated with tropical cyclone swells. Sadly 11% of the drownings, and possibly more, were people who dashed, poorly prepared, into the water to rescue someone struggling in the water and became victims themselves. It is
unknown from Storm Data (2013) how many successful recues were made but the USLA (2012) data indicate that over 32,000 rip current rescues were made by lifeguards during 2011.

3.2 Deadliest United States Beaches

The periods of record varied from state to state and within the different areas of Florida. Therefore, to gain a better understanding, the frequency by year of rip current deaths was determined for each state. Table 3.2 shows the number of deaths per state, the period of record and the number of deaths per year. Three of the top four locations were in Florida with four or more deaths per year. With only five years of data, Texas fell into third place. California averages nearly three deaths per year. Predominant easterly flow across the beaches and very few swells from storms makes Southwest Florida the safest location for beachgoers averaging about one death per year.

Table 3.2 Rip current drowning frequency per year by state or area.

<table>
<thead>
<tr>
<th>Period of Record by State</th>
<th>Number of Deaths</th>
<th>Years of Record</th>
<th>Deaths per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Florida Panhandle</td>
<td>102</td>
<td>19</td>
<td>5.37</td>
</tr>
<tr>
<td>Florida Southeast</td>
<td>83</td>
<td>18</td>
<td>4.61</td>
</tr>
<tr>
<td>Texas</td>
<td>22</td>
<td>5</td>
<td>4.40</td>
</tr>
<tr>
<td>Florida East</td>
<td>74</td>
<td>19</td>
<td>3.89</td>
</tr>
<tr>
<td>California</td>
<td>47</td>
<td>17</td>
<td>2.76</td>
</tr>
<tr>
<td>North Carolina</td>
<td>42</td>
<td>18</td>
<td>2.33</td>
</tr>
<tr>
<td>South Carolina</td>
<td>22</td>
<td>10</td>
<td>2.20</td>
</tr>
<tr>
<td>New York</td>
<td>31</td>
<td>15</td>
<td>2.07</td>
</tr>
<tr>
<td>New Jersey</td>
<td>30</td>
<td>18</td>
<td>1.67</td>
</tr>
<tr>
<td>Alabama</td>
<td>29</td>
<td>18</td>
<td>1.61</td>
</tr>
<tr>
<td>Florida Southwest</td>
<td>19</td>
<td>17</td>
<td>1.12</td>
</tr>
</tbody>
</table>
Although the physical length of named beach areas varies, the top four deadliest beach areas were in Florida (Table 3.3); particularly in the Florida Panhandle (Pensacola and Panama City beaches) and along the southeast coast (Miami and Ft Lauderdale beaches). The next three were outside of Florida in Gulf Shores Alabama, South Padre Island Texas, and Myrtle Beach South Carolina. Myrtle Beach was the farthest north location in the top ten deadliest beach areas in the United States. The last three beach areas in the top ten were in Florida on the east coast at Daytona Beach and in the Florida Panhandle at Miramar and Navarre beaches.

Table 3.3 Deadliest beach areas in the United States.

<table>
<thead>
<tr>
<th>Rank (deaths)</th>
<th>Beach Area</th>
<th>State</th>
<th>Deaths</th>
<th>Deaths per Year</th>
<th>Beach Length (km)</th>
<th>Deaths per km</th>
<th>Deaths per year per km</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pensacola Beach</td>
<td>Florida</td>
<td>28</td>
<td>1.65</td>
<td>29</td>
<td>0.97</td>
<td>0.057</td>
</tr>
<tr>
<td>2</td>
<td>Panama City Beach</td>
<td>Florida</td>
<td>23</td>
<td>1.21</td>
<td>30</td>
<td>0.77</td>
<td>0.040</td>
</tr>
<tr>
<td>3</td>
<td>Miami Beach</td>
<td>Florida</td>
<td>20</td>
<td>1.05</td>
<td>19</td>
<td>1.05</td>
<td>0.055</td>
</tr>
<tr>
<td>4</td>
<td>Ft. Lauderdale Beach</td>
<td>Florida</td>
<td>17</td>
<td>0.89</td>
<td>10</td>
<td>1.70</td>
<td>0.089</td>
</tr>
<tr>
<td>5</td>
<td>Gulf Shores</td>
<td>Alabama</td>
<td>17</td>
<td>0.89</td>
<td>16</td>
<td>1.06</td>
<td>0.056</td>
</tr>
<tr>
<td>6</td>
<td>South Padre Island</td>
<td>Texas</td>
<td>13</td>
<td>1.86</td>
<td>16</td>
<td>0.81</td>
<td>0.116</td>
</tr>
<tr>
<td>7</td>
<td>Myrtle Beach</td>
<td>South Carolina</td>
<td>13</td>
<td>1.30</td>
<td>19</td>
<td>0.68</td>
<td>0.068</td>
</tr>
<tr>
<td>8</td>
<td>Daytona Beach</td>
<td>Florida</td>
<td>12</td>
<td>0.63</td>
<td>11</td>
<td>1.09</td>
<td>0.057</td>
</tr>
<tr>
<td>9</td>
<td>Miramar Beach</td>
<td>Florida</td>
<td>11</td>
<td>0.58</td>
<td>8</td>
<td>1.38</td>
<td>0.072</td>
</tr>
<tr>
<td>10</td>
<td>Navarre Beach</td>
<td>Florida</td>
<td>10</td>
<td>0.53</td>
<td>16</td>
<td>0.63</td>
<td>0.033</td>
</tr>
</tbody>
</table>
CHAPTER 4: DROWNING DETAILS IN THE WESTERN UNITED STATES

Rip current deaths were noted within all three of the Pacific coastal states but the greatest concentration was in Southern California (Figure 4.1). The California events are studied in detail below. According to the National Oceanographic Data Center (NODC 2013), the average ocean water temperatures in Washington and Oregon range from the around 6 °C during the winter months to around 12 °C during the summer. Northern and central California ocean water temperatures range from around 12 °C to 16 °C. In Southern California, where most of the drownings occur, ocean water temperatures range from around 13 °C to as warm as 20 °C in the San Diego area.

Only two rip current drownings were reported in Washington. One was a 17 year old male on a boogie board at Long Beach who was pulled out to sea by a rip current. The other drowning was an adult male who drowned one mile south of Seaview Oregon.

In Oregon, only four records of drownings were found in the rip current section of Storm Data. Those deaths occurred in 2007 and 2008. The victims in the three events were 26 years old, two were 16 and the fourth was 11 years old. Two other reports from 2011 were erroneously listed as no deaths or injuries but two juvenile males drowned in one event after being swept away on rocks jutting into the surf by high waves and a juvenile female in the second event was with three other children on a floatation toy in the surf about 30 feet from the shore as a wave swept the toy out from underneath them and one drowned.
4.1 Demographics of Drowning Victims

In California 47 people were overcome by rip currents from 1996-2012. Several of the drownings though were in northern California near Preston Island, Big Lagoon, and Shelter Cove (Figure 4.1). Most of the drownings were in Southern California near Los Angeles and San Diego (Figure 4.2) with another four drownings south of San Francisco near Carmel on the Monterey Peninsula.
Figure 4.2 Southern California drowning locations.

Of those who drowned in California whose sex was indicated, 38 (85%) were males and 6 (15%) were females. The average age was 29 and the most frequent time of drowning was during the mid-afternoon. Several of the reports indicate people were initially on a jetty or rocks, in very shallow water, or on the beach and were pulled into the water by larger waves. Two event descriptions indicated that would-be rescuers had drowned.

Figure 4.3 shows that in California, the number of rip current drownings by month does not follow the national trend with March and August being the highest two months with 7 and 6 drownings respectively. The months of drownings clearly do not indicate a seasonal aspect as seen in other locations around the country.
### 4.2 The Deadliest Beach Areas

The beaches with the most drownings were in Orange County at Huntington and Newport Beaches (Table 4.1) with six and four drownings respectively. Huntington Beach has almost 8 million visitors per year and Newport Beach has over 9 million visitors annually (Table 2.2). Unlike some beach areas around the country with a huge number of visitors, these locations typically have lifeguards on duty during daytime hours. Therefore the drowning numbers are relatively low. Other notable beaches linked to rip current drownings are Ocean Beach near San Diego and Shelter Cove in northern California.
Table 4.1 Deadliest Beach Areas in California.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Beach Area</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Huntington Beach</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>Newport Beach</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Ocean Beach</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>Shelter Cove</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>Many beaches</td>
<td>2</td>
</tr>
</tbody>
</table>

4.3 Beach Characteristics

Coastal California has a narrow continental shelf that extends out around 50 km in the Southern California area, the continental shelf is more sloped and there are several prominent islands just offshore. Huntington Beach (Figure 4.4) has many features that are common to locations with a large number of drownings. It has several large parking lots, an adjacent bustling downtown area, a moderate to steep beach slope a long pier that provides a semi-permanent rip current.

Newport Beach is a long stretch of beach along a bending coastline with two long piers jutting into the Pacific Ocean. Figure 4.5 shows the northernmost pier, Newport Pier, at the bend in the beach. The figure also shows rock groins north of the pier that are notorious for creating rip currents. Newport Beach also has a jetty that under particular conditions refracts or bounces swells off the jetty and becomes a dangerously large peaking wave that breaks very close to the shore due to the steep beach slope. This location named “The Wedge” is a very popular location for body surfers and boogie boarders.
Figure 4.4 Huntington Beach (Bing Maps).

Figure 4.5 Newport Beach California (Bing Maps). The ovals indicate the groins and pier.
Figure 4.6 illustrates why Ocean Beach near San Diego has had rip current drownings. The image shows part of a large parking lot to accommodate the many visitors on the beach which is common in areas with multiple drownings. It also reveals a large shallow area for wave run-up to temporarily accumulate, a smaller rock groin at the shore break to help focus rip currents and a rip current in the water defined by the large swirl beyond the breakers. What the image doesn’t show are two other structures often associated with rip currents - a pier to the south and the large jetty to the north.

![Figure 4.6 Ocean Beach near San Diego (Google Maps). Note the yellow arrow pointing to a large swirl beyond the breakers indicating a rip current. The oval indicates a short rock groin.](image)

4.4 Spatial Surface Wind Velocity and Pressure Pattern Composites

The following series of sea level pressure and wind speed and vector composite images for the California drowning events (Figures 4.7a-b) shows the time frame from the day of the event
(Day 0) to four days prior to the event (Day -4). The areas represented in the composites are drowning events that occurred in northern California and Southern California. The surface pressure gradients directly influence the surface wind speed and direction which in turn produces the waves over the ocean. For the sea level pressure images, higher pressure is indicated by the warm colors (yellow-red) and lower pressures are indicated by the cool colors (blue-purple). In the wind representations, lower speeds are indicated by light blue shades and stronger winds are indicated by green, yellow, and red shades.

The composite images representing the average of pressure and wind patterns for drownings in the northern California area are shown in Figure 4.7a. This averaged scenario shows an increasing pressure gradient as the low pressure area over the North Pacific Ocean migrates eastward. This results in stronger westerly winds north of the subtropical high pressure and a corresponding fetch that migrates eastward several days before the events. This fetch, capable of creating large long period waves, nears the Pacific Northwest coastline by the event day. This composite also suggests that the subtropical high pressure gradient increases near coastal California resulting in an increase in northerly winds along the coast by the event day.

The composite analyses for sea level pressure and surface wind for the Southern California drowning events is shown in Figure 4.7b. The overall pattern depicted by the images shows much weaker pressure patterns than the northern California events. In these scenarios, it is the increased pressure gradient on the east side of the subtropical high and the desert low pressure area that creates stronger northerly winds prior to the event days. This increased wind over the limited fetch area would create an increased moderate swell prior to and during the drowning events.
<table>
<thead>
<tr>
<th>Day</th>
<th>Sea Level Pressure</th>
<th>Wind Speed and Vectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 0</td>
<td><img src="image0" alt="Image" /></td>
<td></td>
</tr>
<tr>
<td>Day -1</td>
<td><img src="image1" alt="Image" /></td>
<td></td>
</tr>
<tr>
<td>Day -2</td>
<td><img src="image2" alt="Image" /></td>
<td></td>
</tr>
<tr>
<td>Day -3</td>
<td><img src="image3" alt="Image" /></td>
<td></td>
</tr>
<tr>
<td>Day -4</td>
<td><img src="image4" alt="Image" /></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.7a Northern California sea level pressure (hPa) and wind speed (m s$^{-1}$) and vector composite images.
Southern California

<table>
<thead>
<tr>
<th>Day</th>
<th>Sea Level Pressure</th>
<th>Wind Speed and Vectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 0</td>
<td><img src="image1" alt="Sea Level Pressure" /></td>
<td><img src="image2" alt="Wind Speed and Vectors" /></td>
</tr>
<tr>
<td>Day -1</td>
<td><img src="image3" alt="Sea Level Pressure" /></td>
<td><img src="image4" alt="Wind Speed and Vectors" /></td>
</tr>
<tr>
<td>Day -2</td>
<td><img src="image5" alt="Sea Level Pressure" /></td>
<td><img src="image6" alt="Wind Speed and Vectors" /></td>
</tr>
<tr>
<td>Day -3</td>
<td><img src="image7" alt="Sea Level Pressure" /></td>
<td><img src="image8" alt="Wind Speed and Vectors" /></td>
</tr>
<tr>
<td>Day -4</td>
<td><img src="image9" alt="Sea Level Pressure" /></td>
<td><img src="image10" alt="Wind Speed and Vectors" /></td>
</tr>
</tbody>
</table>

Figure 4.7b Southern California sea level pressure (hPa) and wind speed (m s\(^{-1}\)) and vector composite images.
4.5 Wave Height and Period Trends

The primary buoy used for determining wave height, period, and direction for the Monterey Bay drownings was NDBC Station 46042 (50 km WNW of Monterey, California). For Southern California wave measurements, NDBC Station 46047 (224 km west of San Diego, California) was used as the primary buoy with a long-term record that is unobstructed from the islands near the Southern California coast. The islands may block swells from reaching the coast and near coastal buoys in certain areas.

Figures 4.8a-b show long term average box plots of significant wave height and dominant wave periods representing the period from September 1987 to December 2008. The round circles at either end of the lines indicate the maximum and minimum wave height. The thicker (red) line indicates +/- 1 standard deviation and the circle within that area is the mean.

Figure 4.8a primarily shows that the higher wave heights, average over 2 m, occur during the cool months with January having the highest maximum near 10 m and July having the lowest maximum of 3.8 m. The dominant wave period maxima (Figure 4.8b) for every month reached at least 20 s. In several months the dominant wave periods reached the peak of the measurement of 25 s. The average dominant wave periods range from around 13 s during the cool seasons to around 9 s during the months of July and August. These long term average wave heights and dominant wave periods are much higher than those measured by buoys in the Gulf of Mexico and North Atlantic Ocean coastal areas.
Figure 4.8a California Buoy 46042 significant wave height (m) mean and standard deviation plot.

Figure 4.8b California Buoy 46042 dominant wave period (s) mean and standard deviation plot.

Figure 4.9 shows averages for each of the Monterey Bay area drownings of the wave height, dominant period, and average period for California Buoy 46042 for 5 days prior to the day
of the drowning events. It is apparent that the wave heights double in size from around 2 m two days before the events to 4 m on the event days. The average wave period also increases from around 7 s two days prior to 10 s on the event day. The dominant wave period is around 14 s on the event day.

Figure 4.9 Averages of wave height, dominant period (DPD), and average period (APD) for California Buoy 46047 for each of the Northern California drownings from 5 days prior to the day of the drowning events.

Figures 4.10a-b show long term average box plots of significant wave height and dominant wave periods representing the period from December 1991 to December 2008. Figure 4.10a shows that the maximum wave heights increase from 3.7 m in August to 8.8 m in December. The average long term wave heights are between 2 and 3 m for all of the months except July, August, and September. The dominant wave period maxima (Figure 4.10b) for every month reached at least 20 s. The average dominant wave periods consistently range from around 11 to 13 s year round.
Figure 4.10a California Buoy 46047 significant wave height (m) mean and standard deviation plot.

Figure 4.10b California Buoy 46047 dominant wave period (s) mean and standard deviation plot.

Figure 4.11 shows averages for each of the Southern California area drownings of the wave height, dominant period, and average period from California Buoy 46047 for 5 days prior to the day of the drowning events. The wave heights remain relatively static throughout the time frame.
at 2-2.5 m. The average wave period increases slightly from 7 s to near 8 s at times on the event day. The dominant wave period also has a slight increase from 11 s one day prior to near 12 s on the event day.

![Figure 4.1](image)

Figure 4.11 Averages of wave height, dominant period (DPD), and average period (APD) for California Buoy 46047 for each of the Southern California area drownings from 5 days prior to the day of the drowning events.

**4.6 Tidal Trends**

Figure 4.12 shows the average of tidal trends for all of the California rip current drowning events within 6 hours of the noted time. In the figure, hour 0 is the time of drowning. This clearly shows that the most prevalent time of drowning is around low tide.
Figure 4.12 The average of tidal trends within 6 hours of the drowning events. Hour 0 is the time of drowning.

4.7 Case Studies

Case Study 1

Date: 25 March 2000

Time of incident: 1235 PST

Location: Shelter Cove, Humboldt County, California.

Victims: 45 year old female and two 17 year old males

Storm Data Report:

*A school group from Calgary, Alberta was visiting Black Sands Beach near Shelter Cove. A rogue wave swept the female victim out to sea. Four other members of the group attempted a rescue but were overcome by waves and currents. Two were later rescued by a fishing vessel and the Coast Guard. Two teenage boys were not found.*
This incident was related to a strong pressure gradient over the North Pacific Ocean. Low pressure over the Aleutian Islands at day -4 migrated eastward towards an area of high pressure off the coast of California (Figure 4.13). This scenario created a persistent fetch of strong winds over 20 ms\(^{-1}\) at times. Figure 4.14 shows the wave height, dominant period, and average period for northern California Buoy 46014 from 5 days prior to the day of the drowning event. Although the wave heights had spiked at 5 m several days earlier, the trend indicated decreasing wave heights. Even though the buoy indicated 2 m wave heights on the day of the drownings, the wave period jumped from around 12 s to 25 s. This sharp increase in period indicated the forerunners of a new swell generated by the strong fetch over the north Pacific was approaching. The increased period and increased wave length would have changed the character of the waves breaking in the shallow waters near the shore. These waves would have shoaled to higher heights and would have had more energy and more run-up onto the beach and thus be more capable of sweeping victims into the sea.

This type of incident is not as rare as it may seem particularly along the Pacific Ocean coasts of northern California, Oregon and Washington. Because these incidents don’t involve swimmers, these are not always noted as rip current drownings. Two other similar incidents occurred in northern California that year. These long period waves are typically infrequent and can sweep an unknowing person off their feet and flush them out to sea in bitterly cold water. The infrequency of these waves have earned them the term sneaker waves. During 2013 at least three similar incidents were reported by the Associated Press in Northern California.
## Table: Sea Level Pressure and Wind Speed and Vectors

<table>
<thead>
<tr>
<th>Day</th>
<th>Sea Level Pressure</th>
<th>Wind Speed and Vectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 0</td>
<td><img src="image1.png" alt="Image" /></td>
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<td>Day -4</td>
<td><img src="image9.png" alt="Image" /></td>
<td><img src="image10.png" alt="Image" /></td>
</tr>
</tbody>
</table>

Figure 4.13 Sea level pressure (hPa) and wind speed (m s\(^{-1}\)) and vector images.
Figure 4.14 Wave height, dominant period (DPD), and average period (APD) for northern California Buoy 46014 from 5 days prior to the day of the drowning event.

Case Study 2

Date: 06 July 2007

Time of incident: 1640 PDT

Location: Huntington Beach, California.

Victim: 20 year old male

Storm Data Report:

At approximately 1640 hours PDT, two people at Huntington City Beach were caught in a rip current. One person was quickly rescued, but it took lifeguards about an hour to locate the second person and pull him ashore. Lifeguards treated the man but were unable to revive him. It was reported that he did not know how to swim.
Figure 4.15 shows the wave height, dominant period, and average period for Southern California Buoy 46047 from 5 days prior to the day of the drowning event. The wave heights were moderate - slightly over 2 m at times and the dominant period had been steadily increasing. The victim, a non-swimmer, drowned during a rip current spawned by waves of increasing energy.

Figure 4.15 Wave height, dominant period (DPD), and average period (APD) for Southern California Buoy 46047 from 5 days prior to the day of the drowning event.
CHAPTER 5: DROWNING DETAILS IN THE GULF COAST STATES

The Gulf of Mexico states included in the section are Texas, Louisiana, Mississippi, and Alabama. Florida is in separate sections. In Mississippi no rip current drownings were reported. In Louisiana, where beaches are scarce, one of the two drowning events occurred during large swells from Hurricane Isidore. An overwhelming majority of the drowning cases occurred in Texas with 22 deaths, and Alabama with 29 deaths. Therefore, incidents in those two states will be studied more closely. Figure 5.1 shows the drowning locations in Texas and Louisiana. In Texas the number one location was spring break destination South Padre Island. Other drownings occurred on the northern part of Padre Island and Galveston Island. Figure 5.2 shows the drowning locations in Alabama. Alabama has the highest density of drownings along the very short stretch of coastline.

![Map of Gulf Coast drowning locations](image)

Figure 5.1 Drowning locations in Texas and Louisiana.
5.1 Demographics of Drowning Victims

Although the records only go back to 2007, Texas has averaged 3-4 drownings per year for a total of 22 deaths. The most frequent time of drowning in Texas was during the mid-afternoon. Of those whose sex was known, 90 percent (19) were males. The average age was one of the lowest by state at 28. The youngest victim was 12 and the oldest was 66 years old. The rip current drownings in Texas are seasonal from April to August with the peak in June and July (Figure 5.3).

Rip current drowning records in Alabama go back to 1995 when these types of records were formally begun. Storm Data (2013) indicates that 29 people died along the short coastline of Alabama. Of those whose sex was noted in the reports, six were female (28%) and 21 male (72%). This was the highest percentage of female deaths of the states studied in greater detail. The most frequent time of drowning was midafternoon. The average age was 33 years old with the youngest...
victim 3 years old and the oldest 67. Two event descriptions indicated that would-be rescuers had drowned. Figure 5.4 shows a somewhat atypical pattern in the rip current deaths by month. Although the deaths are clustered around the warm season from April to October, the distribution is bi-modal with early season peaks in April and May and another peak in September.

![Deaths by Month in Texas](image)

Figure 5.3 Drownings by month in Texas.

### 5.2 The Deadliest Beach Areas

In Texas, the most deaths, by far, were on South Padre Island (Table 5.1). According to the City of South Padre Island (myspi.org 2013) due to the long narrow beaches, instead of traditional stationary lifeguards, the beach patrol is mobile. The second ranking is the North Padre Island
locations of the Packery Channel and Mustang Island near Corpus Christi with six deaths. Galveston Island near Houston had two reported drownings.

![Deaths by Month in Alabama](image)

On the east side of Mobile Bay, the stretch of beach at Gulf Shores had the most (17) drownings in Alabama (Table 5.2). Nearby, Orange Beach had six rip current deaths recorded. Dauphin Island and Fort Morgan had four and two deaths recorded respectively.
Table 5.1 Deadliest Beach Areas in Texas.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Beach Area</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>South Padre Island</td>
<td>13</td>
</tr>
<tr>
<td>2</td>
<td>Padre Island/Packery Channel/ Mustang Island</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>Galveston Island</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Freeport</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 5.2 Deadliest Beach Areas in Alabama.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Beach Area</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gulf Shores</td>
<td>17</td>
</tr>
<tr>
<td>2</td>
<td>Orange Beach</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>Dauphin Island</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>Fort Morgan</td>
<td>2</td>
</tr>
</tbody>
</table>

5.3 Beach Characteristics

Much of the Texas coastline is undeveloped. Padre Island is a barrier island that is very long, around 180 km, and quite narrow. Much of the island is barren with sand dunes and scrub and only accessible by boat. The town of South Padre (Figure 5.5) Island has a population of less than 3000 but is a prime tourist destination. Figure 5.5 shows three distinct linear areas where waves are breaking with deeper water in-between. It is those deeper water areas where people are more likely to drown. A linear sandbar structure on the shallow sloped beach continues to the northern end of Padre Island, another hot-spot for drowning, and north to Galveston where a seawall and groins line the seashore.
Gulf Shores, Alabama has white sand beaches with a wide array of beach front hotels for vacationers and large beach parking lots to accommodate day trippers (Figure 5.6). The figure shows crescentic patterns on the shore that are a factor in funneling wave run-up into rip currents. This stretch of coastline is characterized with low to moderately sloped beaches with a moderate
continental shelf out to 100 km. Gulf Shores provides seasonal lifeguard services at only three locations.

Figure 5.6: Gulf Shores, AL (Google Maps).

Dauphin Island Alabama (Figure 5.7) is an oddly shaped barrier island with a Pleistocene core and a sand spit at the mouth of Mobile Bay which is accessible by a bridge. The island’s location is in an area where strong tidal currents associated with Mobile Bay are often present. Some of the drownings in that area occurred when the offshore wave measurements were small (<0.5 m) and could be attributed to tidal currents instead.

5.4 Spatial Surface Wind Velocity and Pressure Pattern Composites

For Texas rip current drownings, composite average images of the sea level pressure and wind patterns derived from ESRL (2013) for the drowning dates are shown in Figure 5.8. The subtropical ridge persistently extends across the northern Gulf of Mexico creating an east wind flow across the Caribbean Sea and a more southeast wind flow in the western Gulf. An increasing
pressure gradient over the Gulf of Mexico creates an area of stronger winds to the west of the Yucatan Peninsula. This area of stronger winds remains persistent for several days prior to the drownings which would produce moderate seas around along the Texas coast.

![Dauphin Island, Alabama](image)

Figure 5.7 Dauphin Island, Alabama (Google Maps). The circle indicates Dauphin Island.

The composite images of sea level pressure and wind vectors are shown in Figure 5.9. In this scenario, the subtropical ridge over the Gulf of Mexico at Day -4 lifts northward as time progresses. This general pattern creates a more southerly onshore flow leading to larger waves along the narrow stretch of Alabama beaches. The irregularity of the patterns depicted in these composite images though leave some doubt that this is a consistent pattern. Section 5.7 contains a case study for one event that indicates a completely different weather scenario.
Figure 5.8 Texas sea level pressure (hPa) and wind speed (m s$^{-1}$) and vector composite images.
<table>
<thead>
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</table>

Figure 5.9 Alabama sea level pressure (hPa) and wind speed ($\text{m s}^{-1}$) and vector composite images.
5.5 Wave Height and Period Trends

The buoy used for determining wave height and period as the primary buoy in an unobstructed location with a long-term record for the Texas drownings was NDBC Station 42019 (111 km South of Freeport, Texas). For the Alabama beach drownings, wave measurements were taken from NDBC Station 42040 (119 km South of Dauphin Island, Alabama).

Figures 5.10a-b show long term average box plots of significant wave height and dominant wave periods representing the period from May 1990 to December 2008 for Buoy 42019. The round circles at either end of the lines indicate the maximum and minimum wave height. The thicker (red) line indicates +/- 1 standard deviation and the circle within that area is the mean.

Figure 5.10a shows that the wave heights averaging over 1 m every month except July and August. The highest maximum significant wave heights over 5 m are spread out in an erratic pattern. May had the lowest maximum of 3.5 m. The dominant wave period maxima (Figure 5.10b) have reached 25 s during the hurricane season months of June, July, August and November. The average dominant wave periods are consistently around 6 s year round.

Figure 5.11 shows the averages of wave height, dominant period, and average period for Texas Buoy 42019 for each of the drownings from 5 days prior to the day of the drowning events. The wave heights were very persistent, around 1-1.5 m for the entire time span. The average and dominant wave periods slowly increased marginally, by 1 s, during the time frame. This indicates that the conditions associated with the drownings were persistent but perhaps other factors such as the day of the week or weather kept people out of the water on the preceding days.
Figure 5.10a Texas Buoy 42019 significant wave height (m) mean and standard deviation plot.

Figure 5.10b Texas Buoy 42019 dominant wave period (s) mean and standard deviation plot.
Figure 5.11 Averages of wave height, dominant period (DPD), and average period (APD) for Texas Buoy 42019 for each of the drownings from 5 days prior to the day of the drownings.

Figures 5.12a-b show long term average box plots of significant wave height and dominant wave periods representing the period from December 1995 to December 2008 for Alabama NDBC Buoy 42040. Figure 5.12a shows that the wave heights averaged slightly over 1 m every month except May, June, July and August. The highest maximum significant wave heights over 16 m were associated with hurricanes during August and September. April and May had the lowest maximums of 3.9 m. The dominant wave period maxima (Figure 5.12b) shows a rise from 11 s during the late winter and spring beginning in June to a maximum of 20 s in September, then a decline. The average dominant wave periods consistently range between 5 and 6 s year round.

The averages of wave height, dominant period, and average period for Alabama Buoy 42040 for the drowning events show a 1 m increase in wave height from Day -3 to the day of the event. The average period increases by 1 s and the dominant wave period increases by nearly 2 s
from the lowest point at Day -3. Although this was just a subtle increase in the average, it indicates an upward trend of wave activity during the days with rip current drownings.

Figure 5.12a Alabama Buoy 42040 significant wave height (m) mean and standard deviation plot.

Figure 5.12b Alabama Buoy 42040 dominant wave period (s) mean and standard deviation plot.
Figure 5.13 Averages of wave height, dominant period (DPD), and average period (APD) for Alabama Buoy 42040 for each of the drownings from 5 days prior to the day of the drowning events.

5.6. Tidal Trends

The average tidal trends within six hours of the Texas drowning events (Figure 5.14) indicated an outgoing tide with a low tide 2-3 h after the time of drowning. Alabama waters have a major high tide and a major low tide with minor high and low tides on a daily basis. During the Alabama drowning events (Figure 5.15), the tide was outgoing with low tides occurring around 6 hours after the time of drowning.
Figure 5.14 The average of tidal trends in Texas within 6 hours of the drowning events. Hour 0 is the time of drowning.

Figure 5.15 The average of tidal trends in Alabama within 6 hours of the drowning events. Hour 0 is the time of drowning.
5.7 Case Studies

Case study 1

Date: 27 April 2011

Time of incident: 1700 CST

Location: South Padre Island, TX.

Victims: Three males aged 22, 18 and 12 years old.

Storm Data Report:

*Three young men from northern Mexico were swept to their deaths in dangerous rip currents near the Isla Blanca jetties on South Padre Island. The men took advantage of the warming surf temperatures to venture into the water, only to drown due to the strength of the current and a combination of lack of swimming ability in dangerous surf, and potential panic. Conditions were ripe for rip currents. A front had shifted winds to the north and northeast, and swell period increased to 8 and 9 seconds, with average period rising to 6.9 seconds at the NOAA Buoy about 35 NM east northeast of Port Mansfield. Surf heights were likely 4 to 6 feet, and the swell direction was from a favorable east-southeast direction. The swimmers ventured out at around 6 PM. A 22 year old was pulled out of the water during the mid evening and taken to Valley Baptist Medical Center, where he was pronounced dead. An 18 year old was last seen in distress and unable to be rescued Wednesday evening; the Coast Guard found him early on the 29th at Boca Chica Beach, several miles south of the location where he entered the water. A third victim, 12, was never found after several days of Coast Guard searches, which ended on May 1st.*
This well described incident related several key factors. As noted in other reports, the swimming ability of the victims was poor. The swell and period increased during the day leading to more vigorous surf. Northerly winds, which were mentioned in the report, likely influenced a longshore current that was diverted offshore along the long jetty jutting out into the Gulf of Mexico creating a rip current.

Figure 5.16 Isla Blanca beach and jetty on South Padre Island. (Google Maps).

Case Study 2
Date: 24 May 2008
Time of incidents: 1800 and 1805 CST
Location: Dauphin Island, AL
Victim: 54 year old male and 12 year old male.
Storm Data Report:

Two people drowned along the Alabama beaches. The first was swimming in rough water near Gulf State Park in Foley. Red flags were flying warning of dangerous surf. He was pulled from the water and died. A young boy drowned in swift current near the public beach on Dauphin Island. He was pulled away from the shore by the current and was not found until the following day.

These incidents occurred within 5 minutes in two separate areas along the Alabama shoreline. Figure 5.17 shows the record of wave height, dominant period, and average period for Alabama Buoy 42040 from 19 May 2008 to 24 May 2008. The wave heights show an abrupt rise of over a meter two days before the incident. At the time of the incident the wave height was 1 m. What changed even more were the average and dominant periods prior to, and during the day of the event. The average period rose from around 3.5 s to over 5 s and the dominant period rose from around 3.5 s to over 8 s on the event day.

Figure 5.18 shows sea level pressure and wind speed and vector images from 19-24 May 2008 for the Alabama case study. This pattern is very different from the average with low pressure indicated by the purple shades over the northeast United States and a frontal system along the axis of low pressure extending to Texas and New Mexico at Day -4. As time progresses, the east coast low pressure area weakens and a developing low over north Texas and Colorado becomes the dominant feature. This evolution creates stronger winds over the Yucatan Channel from Day -2 to Day -1 which would promote more vigorous waves in the direction of Alabama.
Figure 5.17 Alabama Buoy 42040 wave height, dominant period, and average period from 19 May 2008 to 24 May 2008.
Figure 5.18 Alabama sea level pressure (hPa) and wind speed (m s$^{-1}$) and vector images from 24-19 May 2008
CHAPTER 6: DROWNING DETAILS IN THE FLORIDA PANHANDLE

The white-sand beaches of the Florida Panhandle stretching from Pensacola to Panama City (Figure 6.1) had the highest incidence of rip current drownings of all the beach locations studied. The area has some unique features that make it dangerous. The offshore bathymetry is unique for the Gulf of Mexico in that the continental shelf is narrower in this area. The narrower shelf means that there is less interaction with the seafloor and hence less frictional dissipation, so the waves will retain more height as they move into shallower water and break in beach areas. Many beaches along the Florida Panhandle do not have life guards and alcohol use is legal in many beach areas (R. Davis, personal communication, 12 April 2013).

Figure 6.1 Drowning locations along the Florida Panhandle.
6.1 Demographics of Drowning Victims

Drowning deaths by month along the Florida Panhandle (Figure 6.2) show that no drownings occurred during January and February. During March, six people drowned and the number jumped up to 14 during April but dipped in May to 10 before the peak of 20 in June.

Out of the drowning victims whose sex was known, only five (5.4%) were females. The other 95.6 percent (93) were males. The average age was 38 and the ages ranged between 3 and 73 years old. Figure 6.3 shows the age breakdown by age groups. Although the average age was 38 years old, the thirties age group was lower than the two next younger and two next older groups.

Eleven of the reports mentioned a tropical storm or hurricane responsible for the rough surf. Sadly 18 of the 92 (19.6%) reports indicated that the supposed rescuer had become a victim. One might think that during college spring break the victims would be mostly in their teens and twenties but the March and April average ages were 38 and 41. Figure 6.4 shows that most drownings occur near the weekends and Sunday was the most prominent day when people died in rip currents.

6.2 The Deadliest Beach Areas

Pensacola beach tops the rankings for the deadliest beach area along the Florida Panhandle beaches with 28 deaths (Table 6.1). Panama City Beach was ranked second with 24 deaths. Other prominent drowning locations were Navarre Beach, Miramar Beach and Destin. The area has a narrow to moderate continental shelf that extends out 75-150 km. The beach has a prominent sandbar structure (Figure 6.6) of a shore break area and inner sandbars and outer sandbars where the water is relatively shallow with deep troughs in between. People wade to the middle sandbar
to frolic in the surf but a brief rip current will pull swimmers off the middle sandbar to where the water is quite deep (R. Davis, personal communication, 12 April 2013).

Figure 6.2 Drowning deaths by month along the Florida Panhandle.

Figure 6.3 Number of victims by age group.
Table 6.1 Deadliest beach areas in the Florida Panhandle.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Beach Area</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pensacola Beach</td>
<td>28</td>
</tr>
<tr>
<td>2</td>
<td>Panama City Beach</td>
<td>24</td>
</tr>
<tr>
<td>3</td>
<td>Navarre Beach</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>Miramar Beach</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>Destin</td>
<td>7</td>
</tr>
</tbody>
</table>

6.3 Beach Characteristics

The area has a continental shelf that extends out 75–150 km. The white-sand gulf shores of Panama City Beach have many large hotels that stretch along the beach area. Additionally, large parking lots accommodate a number of day visitors in some areas. St Andrews State Park is one of those areas with large parking lots that provide beach access near a jetty and a pier (Figure 6.5). Two other long fishing piers, where rip currents are more likely to form, exist along the Panama City beaches. The beach has a prominent sand bar structure (Figure 6.6) with a shore break area...
and middle and outer sandbars where the water is relatively shallow with deep troughs in between. People wade to the middle sandbar to frolic in the surf but a brief rip current will pull swimmers off the middle sandbar and out to deeper water (R. Davis, personal communication, 12 April 2013).

Figure 6.5 St. Andrews State Park, Panama City Beach (Bing Maps).

Figure 6.6 Panama City Beach sandbar structure (Google Maps).
The sandbar structure at Pensacola Beach is similar to Panama City Beach with long shallow bars parallel to the beach and deep water adjacent to the bar. Unlike Panama City Beach, Pensacola beach has fewer hotels. It is more likely that Pensacola beach has more day visitors with several large parking lots as seen in Figure 6.7. The figure also reveals crescentic patterns along the shore that have been noted to be indicative of rip current development areas. At either end of the developed part of Pensacola Beach, which has been ravaged at times by hurricanes, are very desolate stretches of the barrier island.

Figure 6.8 shows an unusual view of an overflowing pond draining into the Gulf of Mexico near Inlet Beach west of Panama City. The pond water is a dark brown color that contrasts with the white sand and the greenish gulf water and constitutes a tracer of a rip current indicated by the blue arrow. Just beyond the rip current, into the gulf, is an area of deep water.
Figure 6.8 Pond drainage into the Gulf of Mexico near Inlet Beach (Bing Maps).

6.4 Spatial Surface Wind Velocity and Pressure Pattern Composites

Figure 6.9 shows the sea level pressure and wind speed and vector composite images for the rip current drownings that occurred along the Florida Panhandle. The characteristic pressure pattern for rip current drownings along the Florida Panhandle is the subtropical ridge poking across Florida over the Gulf of Mexico. Around Day -2 the ridge intensifies slightly the flow to a more southerly direction and increases the winds across the eastern Gulf of Mexico.
### Florida Panhandle

<table>
<thead>
<tr>
<th>Day</th>
<th>Sea Level Pressure</th>
<th>Wind Speed and Vectors</th>
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<td><img src="image" alt="Sea Level Pressure Day -4" /></td>
<td><img src="image" alt="Wind Speed and Vectors Day -4" /></td>
</tr>
</tbody>
</table>

Figure 6.9 Sea level pressure (hPa) and wind speed (m s\(^{-1}\)) and vector composite images.
6.5 Wave Height and Period Trends

The primary buoy used for determining wave height and period for the Florida Panhandle drownings was NDBC Station 42039 (213 km ESE of Pensacola, Florida). Figures 6.10a-b show long term average box plots of significant wave height and dominant wave periods from buoy 42039 representing the period from December 1995 to December 2008. The round circles at either end of the lines indicate the maximum and minimum wave height. The thicker (red) line indicates +/- 1 standard deviation and the circle within that area is the mean.

Figure 6.10a indicates that the long-term mean of the significant wave height for Florida Panhandle Buoy 42039 is below 1 m for the warm season months of May through August. By September the mean increases above 1 m and remains above 1 m until the next summer. The maximum wave heights during that period of record were over 10 m in July and over 12 m in September associated with hurricane activity. With the stormy tropical weather that occurred in the Gulf of Mexico during September, the largest standard deviation also occurred during that month. The lowest maximum wave heights of around 3 m occurred during May when high pressure and light winds typically dominate the Gulf of Mexico weather. The mean dominant wave period of just under 6 s, attributable to the common locally generated waves in the restricted gulf fetch area, varied very little throughout the year (Figure 6.10b). The maximum dominant wave periods varied considerably from month to month with the highest of 20 s occurring in April and the lowest maximum of 10 s occurring in November.
Figure 6.10a Panhandle Florida Buoy 42039 significant wave height (m) mean and standard deviation plot.

Figure 6.10b Florida Panhandle Buoy 42039 dominant wave period (s) mean and standard deviation plot.
Figure 6.11 shows the averages of wave height, dominant period, and average period for the Panhandle Florida Buoy 42039 for each of the drownings from 5 days prior to the day of the drowning events. Although the trends in this average plot are subtle, likely due to the large number of inputs, the three variables all increased during the time frame. The significant wave heights increased to over 1 m on the days before the drownings. The average wave period increased from near 4 s to near 5 s on the drowning days. The dominant wave period increased from a low of 5 s to over 6 s on the days of the drownings. These increases all represent a greater threat for more vigorous surf and a greater chance for rip currents.

Figure 6.11 Averages of wave height, dominant period (DPD), and average period (APD) for Panhandle Florida Buoy 42039 for each of the drownings from 5 days prior to the day of the drowning events.
6.6 Tidal Trends

The tidal trends along the Florida Panhandle beaches within 6 hours of the drowning events (Figure 6.12) indicate an outgoing tide at the time of drownings. This is consistent with other cases noted where the decreasing tide exposes more of the middle and outer sandbars to surf and exposes more rip current channels.

![Mean Tide During Rip Currents in the Florida Panhandle](image)

Figure 6.12 The average of tidal trends within 6 hours of the drowning events. Hour 0 is the time of drowning.

6.7 Case Study

This case study follows a chain of ten drownings along the Florida Panhandle beaches during July 1996. The victims, whose age and sex were known, were males under 51 years old (Table 6.2).
Table 6.2 Florida Panhandle drowning victims during July 1996. (*It is a common misconception that rip currents will pull a victim underwater.) The reports were not changed from the originals to correct typos or grammar.

<table>
<thead>
<tr>
<th>Date Time (CST)</th>
<th>Florida Panhandle drowning victims during July 1996</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200 July 6 Navarre Beach, 27 year old male</td>
<td>A 27 year old male was swimming near Navarre Beach when he was pulled under the water* by a strong rip current. He drowned in the rough surf before he could be rescued.</td>
</tr>
<tr>
<td>1500, July 7, Inlet Beach, FL, 23 year old male</td>
<td>A man drowned when he got caught in severe rip currents in the Gulf of Mexico. His body washed ashore the next day at Panama City Beach, east of where he drowned.</td>
</tr>
<tr>
<td>1200, July 7, Navarre Beach, FL, 35 year old male</td>
<td>A 35 year old male was scuba diving in the gulf just offshore of Navarre Beach. A strong rip current ripped his mask off and he was overcome by the water. He was brought to shore and taken to a local hospital but died later that day.</td>
</tr>
<tr>
<td>1400, July 7, Seagrove Beach, FL, 43 year old male</td>
<td>A man was caught in severe rip currents and drowned while swimming in the Gulf of Mexico at Seagrove Beach.</td>
</tr>
<tr>
<td>1400, July 19, Seagrove Beach, FL, Male - unknown age</td>
<td>A man drowned after being caught in a severe rip current in the Gulf of Mexico.</td>
</tr>
<tr>
<td>1500, July 26, Inlet Beach, FL, 50 year old male</td>
<td>A man was caught in a severe rip current and drowned in the Gulf of Mexico, while trying to retrieve 2 children who had floated out in the gulf on a raft.</td>
</tr>
<tr>
<td>1830, July 27, Sandestin, FL, 14 year old – sex unknown</td>
<td>A teenager drowned after being caught in a rip current while swimming in the Gulf of Mexico.</td>
</tr>
<tr>
<td>1200, July 28, Navarre Beach, FL, Male – age unknown</td>
<td>A visitor to Navarre Beach drowned in a strong rip current while swimming in the gulf on Navarre Beach.</td>
</tr>
<tr>
<td>1045, July 29, Pensacola Beach, FL, 15 year old male</td>
<td>A 15 year old male was swimming near Casino Beach on Pensacola Beach when he was pulled under the water by a strong rip current and drowned in the rough surf.</td>
</tr>
<tr>
<td>1435, July 30, Sandestin, FL, 48 year old male</td>
<td>A 48 year old Louisiana man man was drowned after apparently being caught in a rip current.</td>
</tr>
</tbody>
</table>
Figure 6.13 shows the wave height, dominant period, and average period for Panhandle Florida Buoy 42039 for the month of July 1996. During the first set of rip current drownings, the significant wave heights had increased several days before to nearly 2 m. During July 6th and 7th the dominant wave period spiked above 8 s. This was also the weekend after the Fourth of July holiday when more people would be expected to visit the beach. The wave heights were over a meter for several days after the first drownings and then decreased prior to the next weekend. By July 17, the waves increased to over 1 m again and the next rip current victim died on Friday July 19. This drowning also coincided with an increase in dominant and average wave period during the day indicating a swell reaching the area. The final set of deaths again occurred during the span of a weekend each day from Friday July 26 to Tuesday July 30. The significant wave heights were fairly steady near 1 m but the dominant period jumped from 4 s to 8 s and as high as 10 s.

Figure 6.13 Wave height, dominant period, and period for Panhandle Florida Buoy 42039 for the month of July 1996. The red vertical lines indicate the dates of drownings. The letter “S” indicates that the day of the week is Sunday.
CHAPTER 7: DROWNING DETAILS IN SOUTHWEST FLORIDA

Southwest Florida beaches exist between salt marshes to the north over the “Big Bend” area of Florida and salt marshes to the south adjacent to the Everglades, Big Cypress National Park and Florida Bay. Southwest Florida beaches stretch from the shores of Pinellas County southward into Collier County (Figure 7.1). During the time of this study, nineteen people drowned in rip currents along the often placid Southwest Florida coast.

Figure 7.1 Drowning locations along Southwest Florida beaches.
7.1 Demographics of Drowning Victims

The most frequent time of drowning was mid afternoon. This particular area of Florida had a much higher percentage of female drownings. Out of those whose sex was noted, 36 percent (7) were female and 64 percent (11) were male. The average age was higher than many regions at 41. Although the numbers were small, the breakdown by age group (Table 7.1) shows that more people in their 60s drowned than any other decadal age group. Water temperatures often dip below 15 °C during the winter and that limits drownings with no deaths from October through February (Figure 7.2). For the months where drownings were reported, the pattern is rather erratic with May and August having the most deaths.

Table 7.1 Deaths by age group.

<table>
<thead>
<tr>
<th>Years of Age</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-9</td>
<td>1</td>
</tr>
<tr>
<td>10-19</td>
<td>3</td>
</tr>
<tr>
<td>20-29</td>
<td>2</td>
</tr>
<tr>
<td>30-39</td>
<td>2</td>
</tr>
<tr>
<td>40-49</td>
<td>3</td>
</tr>
<tr>
<td>50-59</td>
<td>2</td>
</tr>
<tr>
<td>60-69</td>
<td>4</td>
</tr>
<tr>
<td>70-79</td>
<td>1</td>
</tr>
<tr>
<td>80-89</td>
<td>0</td>
</tr>
</tbody>
</table>
7.2 The Deadliest Beach Areas

Drownings in the typically calm waters of the Southwest Florida region are rare considering the number of visitors to the area’s beaches during the year. The beaches that stand out are Anna Maria Island and Marco Island, both with only two recorded incidents with 3 drownings at each location (Table 7.2). Other areas with two deaths are Long Boat Key, Treasure Island, and Fort Myers Beach.

Table 7.2 Deadliest beach areas in Southwest Florida.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Beach Area</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Anna Maria Island</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>Marco Island</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Long Boat Key</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Treasure Island</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>Fort Myers Beach</td>
<td>2</td>
</tr>
</tbody>
</table>
7.3 Beach Characteristics

The Southwest Florida area has a broad continental shelf that extends out 250-300 km. At the south end of the mouth of Tampa Bay, Anna Maria Island has a varying bathymetry. At the tip of the island is deeper water associated with Passage Key Inlet (Figure 7.3). To the west of the tip are sandy shoals that are manipulated by the tides and currents. At the shoals, the waves break far offshore and lose energy as they move towards the coast. South of the shoal area is a unique area of transverse sandbars aligned perpendicular to shore. When swells are present, this area typically has less significant wave action. Rip currents may develop south of the transverse bars where peaky waves form. The waves change from peaks to more linear farther south. Two of the deaths were near the interface of the shoal and transverse wave area. The other death was farther south in surf generated from Hurricane Isidore located near the Yucatan Peninsula.

Figure 7.3 Northern Anna Maria Island (Google Maps).
Marco Island has the beach that is the farthest south in Southwest Florida. It is small but heavily populated. It is situated near a very complex network of islands, marsh, and tidal waterways. West facing beaches wrap around to the north side of the island. All three drownings, where the victims were overcome by waves and currents, occurred on the northwest portion of the island named Tigertail Beach (Figure 7.4).

![Tigertail Beach](Figure 7.4 Marco Island Florida (Google Maps)).

### 7.4 Spatial Surface Wind Velocity and Pressure Pattern Composites

The composite sea level pressure and wind velocity images (Figure 7.5) show a subtle pattern of the subtropical ridge drifting south and creating a southwest wind flow and moderate wave action by the day of the event - Day 0.
Southwest Florida

<table>
<thead>
<tr>
<th>Day</th>
<th>Sea Level Pressure</th>
<th>Wind Speed and Vectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 0</td>
<td><img src="image1" alt="Map" /></td>
<td><img src="image2" alt="Map" /></td>
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<tr>
<td>Day -1</td>
<td><img src="image3" alt="Map" /></td>
<td><img src="image4" alt="Map" /></td>
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<tr>
<td>Day -2</td>
<td><img src="image5" alt="Map" /></td>
<td><img src="image6" alt="Map" /></td>
</tr>
<tr>
<td>Day -3</td>
<td><img src="image7" alt="Map" /></td>
<td><img src="image8" alt="Map" /></td>
</tr>
<tr>
<td>Day -4</td>
<td><img src="image9" alt="Map" /></td>
<td><img src="image10" alt="Map" /></td>
</tr>
</tbody>
</table>

Figure 7.5 Sea level pressure (hPa) and wind speed (m s\(^{-1}\)) and vector composite images
7.5 Wave Height and Period Trends

For Southwest Florida wave measurements, NDBC Station 42036 (207 km west-northwest of Tampa, Florida) was used as the primary buoy in an unobstructed location with a long-term record. Figures 7.6a-b show long term average box plots of significant wave height and dominant wave periods for Southwest Florida Buoy 42036 representing the period from January 1994 to December 2008. The round circles at either end of the lines indicate the maximum and minimum wave height. The thicker (red) line indicates +/- 1 standard deviation and the circle within that area is the mean.

Figure 7.6a shows that the mean significant wave height during the warm months (May-Aug) is below 1 m. The rest of the year the mean wave height is 1 to 1.2 m. The maximum wave heights range from 3 m in May to over 8 m in October. The mean dominant wave periods are consistent between 5 and 6 s year round. The maximum dominant wave periods range from only 10 s in April to 25 s in August and September related to hurricane activity.

The averages of wave height, dominant period, and average period for Southwest Florida Buoy 42036 for each of the drownings from 5 days prior to the day of the drowning events are shown in Figure 7.7. The data show that, in the typical scenario, the wave period increases from the average 5 to 6 s to around 7 s on the event days. The figure also shows an increase in significant wave height from below 1 m to around 1.5 m associated with the rip current deaths on the event days.

7.6 Tidal Trends

Figure 7.8 shows the average of tidal trends within 6 hours of the drowning events. Hour 0 is the time of drowning. This clearly shows that the drownings typically occur during an outgoing
tide. This is consistent with prior research and with most other locations in this study that either indicated a low tide or an outgoing tide.

Figure 7.6a Southwest Florida Buoy 42036 significant wave height (m) mean and standard deviation plot.

Figure 7.6b Southwest Florida Buoy 42036 dominant wave period (s) mean and standard deviation plot.
Figure 7.7 Averages of wave height, dominant period (DPD), and average period (APD) for Southwest Florida Buoy 42036 for each of the drownings from 5 days prior to the day of the drowning events.

Figure 7.8 The average of tidal trends within 6 hours of the drowning events. Hour 0 is the time of drowning.
Case Study 1

Date: 25 June 2013

Time of incident: 1200 EST

Location: Pass-a-Grill Beach, Florida

 Victim: 41 year old female

Storm Data Report:

Four people, some vacationing from Alabama became caught in rip currents as they were swimming in the Gulf of Mexico after Tropical Storm Debby. A relative who attempted to save them became the fifth person caught in the rip currents. Bystanders pulled all five people back to shore, but one of them, a 41 year old woman, was unconscious and not breathing, and died as a result.

This is another tragic account of a family losing a loved one. Tropical Storm Debby created waves at Buoy 42036 as high as 5 m with dominant wave periods over 10 s in the Gulf of Mexico the day and night before the incident. During the day of the rip current drowning at Pass-a-Grille Beach, the wave height and period had begun to subside but wave action continued at the gulf beaches.

The series of screen captures from WFTS-Tampa video (2013) shows some key aspects of the drowning. Figure 7.10 shows the buoy the victims were said to be swimming by when they began to have problems. The image shows a time when waves were relatively calm between wave sets. Figure 7.11 shows one of the several rescuers, Alison Howard, a trained lifeguard, who
rescued two victims. While it is common for rescuers to become victims, Ms. Howard followed her lifeguard training and took a surfboard as a flotation device. Figure 7.12 shows several of the victims being tended to by medical personnel on the beach. The image also shows that even though the tide was incoming, quite a bit of the beach was exposed. It also shows a deep area with breakers on the sandbar where the victims encountered the rip current.

Figure 7.9 Wave height, dominant period (DPD), and average period (APD) for Southwest Florida Buoy 42036 from 5 days prior to the day of the drowning at Pass-a-Grille Beach on 25 June 2012.
Figure 7.10 The family was swimming near this buoy at Pass-a-Grille Beach (WFTS-Tampa video).

Figure 7.11 Alison Howard, a trained lifeguard, rescued two victims on a surfboard at Pass-a-Grille Beach (WFTS-Tampa video).
Figure 7.12 Drowning and near drowning victims being tended to at Pass-a-Grille Beach (WFTS-Tampa video).

Case Study 2

Date: 7 July 2013

Time of incident: 1300 EST

Location: Siesta Key, Florida

Victim: No drowning victims

This is an account of an incident that was witnessed at the North end of Siesta Key on Sunday July 7, 2013 (K. Pyne, personal communication, 12 July 2013).

“My sisters and I stopped to take a picture in front of an old sailboat at the beach (Figure 7.13). We were down at the end of the beach and far from the lifeguards. While trying to take the picture we started to hear a lot of screaming. A young girl, about ten years old, swimming with
her father had apparently gotten pulled past the drop-off by a wave. The father tried to help her but was struggling himself because he could not stand. Another man in the water swam over to help, and still the two of them were struggling to get the girls head out of the water. The mother and her friend ran from the shore to them, and the four of them were finally able to get girl and bring her back to shore.”

Figure 7.14 shows a wave-less beach profile at Siesta Key, near where the incident occurred, with the shore break area on the beach, a deep trough, and an outer sandbar before dropping off into deeper water. This drop-off area, just offshore of the shallow sandbar, is where the young girl had been pulled out into deeper water. Luckily there were no drowning victims – just survivors. This first-hand account illuminates how difficult it is to rescue a child, or any panicking–person, in deep water without a flotation device.
Figure 7.14 Beach profile at the north end of Siesta Key (Google Maps).
CHAPTER 8: DROWNING DETAILS IN SOUTHEAST FLORIDA

The Southeast Florida coast stretches from Vero Beach in Indian River County south through Palm Beach and Broward Counties to the beaches of Miami-Dade County (Figure 8.1). Along this heavily populated expanse of coastline popular with tourists, 83 people lost their lives in the North Atlantic Ocean.

8.1 Demographics of Drowning Victims

The average age of the drowning victims (44) was the highest of all the areas studied. Of those whose sex was known, 9 (13%) were female and 69 (87%) were male. Figure 8.2 shows that most of the victims fell into the 40-49 age group. It is of note that the older age groups were much better represented while the youngest age group had no victims. The most frequent time of drownings was in the afternoon at early afternoon.

The warm waters of Southeast Florida are inviting to swimmers year round with average water temperatures ranging from around 21 °C in January to as warm as 30 °C during July and August. Therefore, rip current drownings have occurred during every month (Figure 8.3). As might be expected, the most drownings occur during the warm season but show a bimodal distribution with maxima during April and May and July and August. This is likely coincidental with seasonal tourist migrations.
Figure 8.1 Southeast Florida drowning locations.

Considering drownings by day of the week, one might think that an older representation of drowning victims might have a more even distribution throughout the week. This is not the case (Figure 8.4). Sunday, with 24 drowning events, is the most common day for drowning along the Southeast Florida coast. Saturday and Monday each had 50 percent fewer deaths than Sunday, with 13 and 12 incidents respectively.
Figure 8.2 Number of victims by age group.

Figure 8.3 Drownings by month.
Figure 8.4 Drownings by day of the week.

8.2 The Deadliest Beach Areas

Miami Beach is in the top position for number of deaths with 20. Ft Lauderdale Beach is not far behind with 17 rip current drownings. Other notable locations are Palm Beach, Hollywood and Lauderdale by the Sea.

Table 8.1 Deadliest Beach Areas

<table>
<thead>
<tr>
<th>Rank</th>
<th>Beach Area</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Miami Beach</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>Ft Lauderdale Beach</td>
<td>17</td>
</tr>
<tr>
<td>3</td>
<td>Palm Beach</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>Hollywood</td>
<td>7</td>
</tr>
<tr>
<td>5</td>
<td>Lauderdale by the Sea</td>
<td>5</td>
</tr>
</tbody>
</table>
8.3 Beach Characteristics

Southeast Florida is mostly sheltered from swells by the Bahamas islands to the east. Although the Bahamas often render the seas calm, rare swells from the north can generate wave action over Southeast Florida. Davis and Paxton (2005) documented an unusually large and localized swell from Hurricane Isabel in 2003 that propagated through the Providence Channel (Figure 8.5) and produced 3-4 m surf near Boynton Beach and Delray Beach. More typical wave action is more locally generated in the gap between Southeast Florida and the Bahamas under the predominant easterly wind flow.

With the Gulf Stream just offshore, the Southeast Florida area has a very narrow continental shelf that extends out less than 50 km in the northernmost area, decreasing to around
10 km over the rest of the area. The beaches of Southeast Florida are adjacent to very urbanized land areas. Several piers and inlets with jetties exist that are known locations for enhanced rip currents. Figure 8.6 shows the location of deeper water associated with a rip current channel. The waves are not breaking in this location. By the appearance of the wave run-up on the beach, the tide is high. Figure 8.7 shows a series of gaps in the bar extending into the breakers associated with potential rip current areas on North Miami Beach.

Figure 8.6 Miami’s South Beach. Arrow shows location of rip current (Google Maps).
8.4 Spatial Surface Wind Velocity and Pressure Pattern Composites

The sea level pressure, and wind speed and vector, composite images from the day of the event (Day 0) to Day –4 are shown in Figure 8.8. Several days prior to the event, the subtropical high over the North Atlantic Ocean was ridging over central Florida with rather weak pressure gradients resulting in light wind over the area. As time progressed toward the day of the event the center of the subtropical high over the eastern Atlantic weakened as the ridge on the west side of the high drifts northward and intensifies. This increase in pressure gradient over the Atlantic increased the wind speeds over eastern Cuba on Day -2. This area of enhanced wind drifted north on Day -1 to central Cuba and the southern Bahamas. On the day of the event, the area of enhanced wind extended northward around the northern Bahamas and Southeast Florida. This increase in wind increased the generation of wind waves over the region.
### Southeast Florida

<table>
<thead>
<tr>
<th>Day</th>
<th>Sea Level Pressure</th>
<th>Wind Speed and Vectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 0</td>
<td><img src="image1" alt="Sea Level Pressure" /></td>
<td><img src="image2" alt="Wind Speed and Vectors" /></td>
</tr>
<tr>
<td>Day -1</td>
<td><img src="image3" alt="Sea Level Pressure" /></td>
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</tr>
<tr>
<td>Day -2</td>
<td><img src="image5" alt="Sea Level Pressure" /></td>
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<tr>
<td>Day -3</td>
<td><img src="image7" alt="Sea Level Pressure" /></td>
<td><img src="image8" alt="Wind Speed and Vectors" /></td>
</tr>
<tr>
<td>Day -4</td>
<td><img src="image9" alt="Sea Level Pressure" /></td>
<td><img src="image10" alt="Wind Speed and Vectors" /></td>
</tr>
</tbody>
</table>

Figure 8.8 Sea level pressure (hPa) and wind speed (m s\(^{-1}\)) and vector composite images.
8.5 Wave Height and Period Trends

No buoys that record wave data exist near the coastline of Southeast Florida therefore buoy data are not shown.

8.6 Tidal Trends

The average tides for all of the rip current cases (Figure 8.9) show that the events were most likely to occur at low tide. This is consistent with most other areas in the study and other local studies.

![Mean Tide During Rip Currents in Southeast Florida](image)

Figure 8.9 The average of tidal trends within 6 hours of the drowning events. Hour 0 is the time of drowning.

8.7 Case Studies

Case Study 1

Date: 30 May 2007
Time of incident: 1315 AM EST
Location: Palm Beach, Florida
Victim: 32 year old Male

Storm Data Report:
A 56-year-old Slovakian man visiting on business drowned at the beach behind The Breakers in Palm Beach. Hotel lifeguards pulled the man out of the water but could not revive him. EPISODE NARRATIVE: Three people drowned at Southeast Florida beaches over the Memorial Day weekend as a result of rip currents. East winds of 15 to 20 mph persisted for several days and caused favorable conditions for numerous rip currents. A total of 30 rescues were performed along Palm Beach County beaches alone, with many more likely to have occurred across all of Southeast Florida.

This is just one death out of five that occurred during the 2007 Memorial Day weekend along the southeast coast of Florida. Giancarlo Squicimari was staying at a Hotel in Palm Beach, Florida over Memorial Day weekend and was caught in a rip current trying to rescue two young girls. The following is an excerpt from an article published in The Palm Beach Post on May 29, 2007:

A stranger yelled for someone to help her drowning daughters, and Michael Sagaro bolted from his beach chair to the ocean. His best friend, Giankarlo Squicimari, stopped building a sand castle with Sagaro’s 3-year-old and followed him. Maybe 50 yards out, a desperate 12-year-old held out her hand and Sagaro grabbed it. Exhausted, he saw Squicimari a few yards away with
the girl's sister. And then, Sagaro felt death coming. He couldn't get back. "I'm kicking my feet, kicking my feet, kicking my feet," he said. "I'm trying to hold us together. The waves pull you and pull you. These rip tides grab you and grab you." Sagaro didn't know it then, but his stronger best friend was enduring the same struggle. "You're viewing death as it comes. Your body is saying there's nothing else to do. My legs couldn't hold any more, the waves are flipping me under," Sagaro said. Except he was saved. Squicimari, 31, drowned. On a beautiful Sunday afternoon, behind the Four Seasons on Palm Beach, five people would carry his body out of the water.

Giancarlo’s friends and family, like so many others whose loved ones have died in tragic situations, were called to action. They developed an information page to help people understand rip current risks (Figure 8.10). The web page image contains a key element that should be at every beach location with signage on how to use it, particularly in the absence of lifeguards. The throw ring (or other flotation device) is a necessity for water rescues.
Case Study 2

Date: 17 October 1998

Time of incident: Unknown

Location: Boynton Beach, Florida

Victim: 20 Year old Male

Storm Data Report:

*Strong easterly winds resulted in rip currents. 20 year old man was last seen surfing but time of drowning is unknown. Lifeguards reported several rescues.*

Figure 8.1 shows pressure and wind patterns from the day of the event (Day 0) to four days prior to the drowning. This October case illustrates the conditions that are typical for a northerly swell to propagate into Southeast Florida. On Day -4, a strong low pressure area was over the Atlantic Ocean with an elongated area of high pressure situated along the Atlantic coastline. These two features were creating a strong northerly flow in which swells would develop. As that low pressure area moves off to the northeast, another low pressure area, but weaker, moves over the Atlantic by Day 0. Behind that low pressure area is a stronger high pressure area with a long fetch area over the Atlantic Ocean. Waves generated in this area then propagated into Southeast Florida. Figure 8.12 shows the wave height, dominant period, and average period for East Florida Buoy 41010 from 5 days prior to the day of the drowning. The wave height on the day of the drowning rose to over 2.5 m with a period between 7 and 8 s in association with the strengthening high pressure moving over the Atlantic Ocean.
<table>
<thead>
<tr>
<th>Day</th>
<th>Sea Level Pressure</th>
<th>Wind Speed and Vectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 0</td>
<td><img src="image" alt="Sea Level Pressure" /></td>
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</tr>
<tr>
<td>Day -3</td>
<td><img src="image" alt="Sea Level Pressure" /></td>
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<tr>
<td>Day -4</td>
<td><img src="image" alt="Sea Level Pressure" /></td>
<td><img src="image" alt="Wind Speed and Vectors" /></td>
</tr>
</tbody>
</table>

Figure 8.11 Sea level pressure (hPa) and wind speed (m s\(^{-1}\)) and composite images 13-17 October 1998.
Figure 8.12 Wave height, dominant period (DPD), and average period (APD) for East Florida Buoy 41010 from 5 days prior to the day of the drowning.
Along the east coast of Florida (Figure 9.1), from the state border south to Sebastian Inlet, 74 people died from drowning in rip currents during the period of record from 1994 to 2012. With the islands of the Bahamas to the southeast, the southern part of this long stretch of coastline is partially blocked from swells coming from the southeast or south.

9.1 Demographics of Drowning Victims

The average age of the rip current victims was 36. It is notable that the decadal age groupings were not evenly distributed (Figure 9.2). The group containing youths from 10-19 years of age had almost one third of the victims. Of those whose sex was known, 65 (94%) of the victims were males and only four were females (6%). In twelve (16%) of the cases, the potential rescuer became the victim.

Figure 9.3 shows the rip current drownings by month. January and February had no reported rip current drownings. The number of drownings increased from March onward with a peak in September that continued into October. A sharp drop occurred in November into December. The most common days of the week for rip current drownings (Figure 9.4) were over the weekend with Sunday being the primary day. The most frequent time of drowning was midafternoon.
Figure 9.1 Drowning locations along East Florida.
Figure 9.2 Number of victims by age group.

Figure 9.3 Drowning deaths by month.
9.2 The Deadliest Beach Areas

Daytona Beach, a well-known tourist destination, had the most rip current deaths with 15 (Table 9.1). St Augustine was ranked second with 10 drownings. Other notable locations were Crescent Beach, just south of St. Augustine Beach, and Cocoa Beach.

Table 9.1 Deadliest Beach Areas in East Florida

<table>
<thead>
<tr>
<th>Rank</th>
<th>Beach Area</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Daytona Beach/Daytona Beach Shores</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>St. Augustine</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>Crescent Beach</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>Cocoa Beach</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>Many beaches</td>
<td>5</td>
</tr>
</tbody>
</table>
9.3 Beach Characteristics

The area has a moderate continental shelf that extends out 50 km in the southernmost area to around 100 km over most of the area. Aerial photography illustrates rip current channels at the shallow to moderately sloped, highly populated beaches along the east coast of Florida. Two areas are highlighted in Figure 9.5 at St. Augustine Beach. The area circled near the top of the image (north) is an area of deeper water associated with a rip current area. The area to the south near the bottom of the image is a much larger rip current structure with an elongated feeder area on the south end and a broad wave-free area out to sea. Also note the smaller crescentic patterns at the high tide line but the much broader crescent pattern associated with the southern rip current area. Figure 9.6 shows two more rip current areas with elongated inside feeder current areas and gaps in wave action where water is deeper associated with a rip current. At Daytona Beach (Figure 9.7), where driving on the beach is permitted, a rip current is present in the water adjacent to the northernmost parked cars on the beach.

9.4 Spatial Surface Wind Velocity and Pressure Pattern Composites

The sea level pressure and wind speed and vector composite images in Figure 9.8 indicate that the dominant sea level pressure pattern for rip current cases along the east coast of Florida is persistent ridging of the high north of Florida into the Mid-Atlantic States. This ridge intensifies closer to the days of the events. The wind response is a stronger onshore wind toward and on the day of the event. This onshore wind will create higher and choppier surf.
Figure 9.5 St. Augustine Beach (Bing Maps). Circles indicate rip current areas.
Figure 9.6 Crescent Beach (Bing Maps). Circles indicate rip current areas.
Figure 9.7 Daytona Beach (Bing Maps). Circle indicates rip current areas.
East Florida

<table>
<thead>
<tr>
<th>Day</th>
<th>Sea Level Pressure</th>
<th>Wind Speed and Vectors</th>
</tr>
</thead>
<tbody>
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<td>Day 0</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>Day -1</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>Day -2</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>Day -3</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>Day -4</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
</tbody>
</table>

Figure 9.8 Sea level pressure (hPa) and wind speed (m s\(^{-1}\)) and vector composite images.
9.5 Wave Height and Period Trends

For the area of east central Florida, the NDBC Buoy Station 41009 (37 km east of Cape Canaveral, Florida) was used. Figures 9.9a-b show long term average box plots of significant wave height and dominant wave periods for Cape Canaveral Florida Buoy 41009 representing the period from August 1988 to December 2008. The round circles at either end of the lines indicate the maximum and minimum wave height. The thicker (red) line indicates +/- 1 standard deviation and the circle within that area is the mean. Figure 9.9a shows that the mean significant wave height fluctuates seasonally. The lowest mean wave heights are near 1 m or below from May through August. The rest of the year, the mean wave heights are near 1.5 m. The maximum wave heights vary with the lowest in July around 3.5 m and the highest during September near 10 m. The dominant wave period fluctuates between 7 and 9 s annually with the lowest in June and highest in September.

The averages of wave height, dominant period, and average period for the Cape Canaveral Florida Buoy 41009 for each of the drownings from 5 days prior to the day of the drowning events are shown in Figure 9.10. The subtly evolving pattern illustrated by the sea level pressure and resulting wind show an increase in the wave height to 1.5 m at Day -4. The wave heights then decrease on Day -3 then increase on the event day to around 1.8 m. The average period is steady around 5 s and increases to near 6 s on Day -1. The dominant period doesn’t indicate a trend.

9.6 Tidal Trends

The mean tide occurring at the time of rip current drownings along the east coast of Florida is a low tide (Figure 9.11). Lower tides will expose more of the gently sloped beach creating a broader area for feeder currents to obtain water resulting in stronger rip currents.
Figure 9.9a East Florida Buoy 41009 significant wave height (m) mean and standard deviation plot.

Figure 9.9b East Florida Buoy 41009 dominant wave period (s) mean and standard deviation plot.
Figure 9.10 Averages of wave height, dominant period (DPD), and average period (APD) for Cape Canaveral Florida Buoy 41009 for each of the drownings from 5 days prior to the day of the drowning events.

Figure 9.11 The average of tidal trends within 6 hours of the drowning events. Hour 0 is the time of drowning.
9.7 Case Study

Date: 3 September 2010
Time of incident: 1000 EST
Location: Daytona Beach, Florida
Victim: 19 year old male

Storm Data Report:

*Over two hundred swimmers were rescued by Volusia County Beach Patrol on September 4 alone.*

*Around 1000 LST, two teenagers were caught in a rip current and rescued by bystanders. One of the teenagers was transported to a local hospital were she later died. Around 2000 LST, a 19 year old was found face down in the ocean after being trapped in a rip current. The victim was transported to a local hospital, where he remained in a coma.*

*Strong rip currents persisted across the east-central Florida waters in the aftermath of Hurricane Earl. Rough surf on September 1 and 2 kept most swimmers out of the ocean, but once swell heights lessened and more swimmers entered the water, life guards rescued several hundred people who became caught in rip currents. One drowning and one serious injury resulted from the rip currents in Volusia County.*

Tropical surface analyses from National Environmental Satellite, Data, and Information Service (NESDIS) from 1-3 September 2010 are shown in Figures 9.12a-c. The images show Hurricane Earl initially just east of the central Bahamas islands on September 1st. On September
2nd, Hurricane Earl had moved north-northeast and was east of central Florida. By the 3rd, Earl had moved north to a position just offshore of South Carolina.

Figure 9.13 shows the 5 day record of wave height, dominant period, and average period for East Florida Buoy 41009 from 29 August to 3 September 2010. During most of the period, the significant wave heights were above 2 m. As Hurricane Earl approached on September 2nd, the wave heights increased to over 4 m, the average wave period increased from 5.5 s to over 10 s, and the dominant wave period increased as high as 19.5 s. On September 3rd, the wave heights began to decrease but were still above 1 m as Earl moved north of the area. The average and dominant periods also decreased on the day of the drowning to 7-8 s and 9-13 s respectively.
Figure 9.12a-c Tropical analysis showing location of Hurricane Earl 1-3 September 2010 (NESDIS).
Figure 9.13 Wave height, dominant period (DPD), and average period (APD) for Cape Canaveral Florida Buoy 41009 from 29 August to 3 September 2010.
CHAPTER 10: DROWNING DETAILS IN THE SOUTHEAST TO MID-ATLANTIC STATES

Rip current drownings in the Mid-Atlantic States from Georgia north to Delaware are typically seasonal as Atlantic Ocean water temperatures warm to tolerable ranges. Georgia has a rather sparse beachfront available to the public with remote islands and few bridges. Only one drowning has been reported since 2005. Tybee Island is the primary beach area in Georgia. Numerous reports have come from Tybee Island on rip current rescues since 2005, but, with an active lifeguard force, only one rip current drowning has been reported. South and North Carolina (Figure 10.1) have a more robust beach tourist season and many more drowning incidents. The three states to the north, Virginia, Maryland, and Delaware, had four, one and four rip current drownings respectively.

Figure 10.1 Drowning locations from Georgia to Virginia.
10.1 Demographics of Drowning Victims in the Carolinas

South Carolina waters had 20 drowning incidents reported in Storm Data since the first report in 1997 but there were no reports between 1997 and 2004. It is unlikely that no one drowned in rip current incidents during those years. Of the deaths reported, 19, or 95% were males. The average age was 33 with victims ranging from 9-59 years old. The most frequent time of drowning was early afternoon. Figure 10.2 shows the rip current drowning deaths by month. The deaths increase as ocean temperatures warm from typical values below 10 °C in the winter to above 15 °C in April to above 20 °C in May and up to an average of 28 °C in July. The abrupt drop in deaths to zero in August and one death in September, when average water temperatures are still in the comfortable range, may be due to the lack of reports from 1997 to 2004.

Figure 10.2 Rip Current drownings by month in South Carolina.
Since 1995, North Carolina ocean waters had over twice as many drowning incidents (42) when compared to South Carolina. Where the sex was known, 32, or 82% were males and 7, or 18% female. The average age was 35 with victims ranging from 10-51 years old, with the most deaths occurring in the 30-39 age range. (Figure 10.3). The most frequent time of drowning was early afternoon.

![Number of Victims by Age Group](image)

**Figure 10.3 Number of victims by age group in North Carolina.**

With ocean temperatures slightly cooler than summer, the onset of rip current drownings in North Carolina is May with a peak in August (Figure 10.4). Water temperatures typically remain at comfortable levels (around 25 °C) into September.
10.2 The Deadliest Beach Areas in the Carolinas

Myrtle Beach is a long stretch of beach and the top beach destination for tourists in South Carolina. Most of the South Carolina deaths (13) occurred at Myrtle Beach. Pawleys Island and Garden City Beach each had two reported rip current drownings.

Table 10.1 Deadliest beach areas in South Carolina.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Beach Area</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Myrtle Beach</td>
<td>13</td>
</tr>
<tr>
<td>2</td>
<td>Pawleys Island</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Garden City Beach</td>
<td>2</td>
</tr>
</tbody>
</table>
Rip current drownings in North Carolina are spread out over more beach areas than South Carolina. Kure Beach had the most drowning incidents with six. Rodanthe had five drownings, Nags head, Okracoke Island and Fort Fisher had four and Carolina Beach had three deaths (Table 10.2).

Table 10.2 Deadliest beach areas in North Carolina.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Beach Area</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kure Beach</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>Rodanthe</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>Nags Head</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Ocracoke Island</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Fort Fisher</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>Carolina Beach</td>
<td>3</td>
</tr>
</tbody>
</table>

10.3 Beach Characteristics in the Carolinas

The Georgia coastline has a moderate continental shelf that is 130 km wide with a gentle slope of about 38 cm per km (Henry and Hoyt 1968). The continental shelf narrows to about 100 km offshore of South Carolina with shallow sloped beaches. Along the North Carolina coast, the continental shelf extends out around 100 km over the south and north areas, but near the Outer Banks the shelf has a moderate slope and the continental shelf drops off rapidly within about 30 km. Coastal South Carolina has few barrier islands and most of those are near inlet areas. The greater Myrtle Beach area is a long stretch of coast, attached to the mainland, around 40 km in length from Surfside Beach to North Myrtle Beach. Several fishing piers extend into the waters and small creeks feed into the Atlantic Ocean in various locations (Figure 10.5). Two of the drownings occurred at Pawleys Island (Figure 10.6) which is a narrow barrier island with inlets that can create strong tidal currents on either end.
Figure 10.5 Myrtle Beach, SC (Bing Maps). The red circles indicate piers and the yellow circle indicates a creek mouth. The blue dot indicates the drowning location of Jeffrey Dinkins described in the case study in section 10.7.

Three of the deadliest beaches in North Carolina (Carolina Beach, Kure Beach and Fort Fisher) are shown in Figure 10.7. These beach areas are on a broad to narrowing strip of land with the Atlantic Ocean to the east and the Cape Fear River to the west. Fort Fisher, at the south end, has a rocky reinforced beachfront. A long shore current, from south to north, could push people toward rocks which would then hamper exiting the water when the waves are high (Figure 10.8). The image shows an outer surf break with gaps that could accommodate rip currents. The image also shows a large parking lot which is a feature common with locations where drownings are more likely.
Figure 10.6 Pawleys Island, South Carolina (Bing Maps).
Figure 10.7 North Carolina’s coast including Fort Fisher, Kure Beach, and Carolina Beach (Bing Maps).
Figure 10.8 Fort Fisher, North Carolina (Bing Maps).
10.4 Spatial Surface Wind Velocity and Pressure Pattern Composites

The composite images of sea level pressure and wind speed and vectors from the day of the drownings (Day 0) back in time to 4 days prior (Figure 10.9) shows a rather placid summertime scenario. The subtropical high pressure area dominates the mid-Atlantic Ocean and ridges over the mid-Atlantic coastline. As a cold front approaches the eastern seaboard, the ridge retracts eastward. Changes in this pattern are very subtle, with an increase in the pressure gradient east of the Bahamas and a resulting increase in southeasterly winds in that region several days prior to the event. This pattern generates the waves in typical drownings.

The sea level pressure and wind speed and vector composite image patterns associated with the North Carolina cases (Figure 10.10) show a similar but more subtle scenario. The gap or break on the west side of the subtropical high indicates that, in the typical event, a frontal boundary is intersecting with the subtropical high. This creates a persistent southerly wind flow over a sizeable fetch that would send moderate waves toward the North Carolina coastline. The lower pressures in the composite images could also indicate more transient low pressure areas that could increase wave heights and wave periods as is shown in the case study below.
<table>
<thead>
<tr>
<th>Day</th>
<th>Sea Level Pressure</th>
<th>Wind Speed and Vectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 0</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>Day -1</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>Day -2</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>Day -3</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>Day -4</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
</tbody>
</table>

Figure 10.9 South Carolina sea level pressure (hPa) and wind speed (m s\(^{-1}\)) and vector composite images.
### North Carolina

<table>
<thead>
<tr>
<th>Day</th>
<th>Sea Level Pressure</th>
<th>Wind Speed and Vectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 0</td>
<td><img src="#" alt="Image" /></td>
<td><img src="#" alt="Image" /></td>
</tr>
<tr>
<td>Day -1</td>
<td><img src="#" alt="Image" /></td>
<td><img src="#" alt="Image" /></td>
</tr>
<tr>
<td>Day -2</td>
<td><img src="#" alt="Image" /></td>
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<tr>
<td>Day -3</td>
<td><img src="#" alt="Image" /></td>
<td><img src="#" alt="Image" /></td>
</tr>
<tr>
<td>Day -4</td>
<td><img src="#" alt="Image" /></td>
<td><img src="#" alt="Image" /></td>
</tr>
</tbody>
</table>

Figure 10.10 North Carolina sea level pressure (hPa) and wind speed (m s\(^{-1}\)) and vector composite images.
10.5 Wave Height and Period Trends

NDBC Buoy Station 41004 (76 km Southeast of Charleston, South Carolina) was used for South Carolina comparisons. For North Carolina, NDBC Buoy Station 41025 at Diamond Shoals (34 km southeast of Hatteras North Carolina) was used.

Figures 10.11a-b show long term average box plots of significant wave height and dominant wave periods representing the period from May 1980 to December 2008 for Buoy 41004. The round circles at either end of the lines indicate the maximum and minimum wave height. The thicker (red) line indicates +/- 1 standard deviation and the circle within that area is the mean. Figure 10.11a shows that the long term average significant wave height is consistently between 1-1.5 m year round. The highest maximum wave height, over 12 m during September, stands out above the rest which range from near 5.5 m to 10.8 m. July had the lowest maximum wave height of 3.8 m. The dominant wave period maxima (Figure 10.11b) shows a September maximum at 20 s. During the other months, the dominant wave periods range between 14 and 17 s. The long term average dominant wave period consistently ranges between 7 and 8 s, except during September when the average climbs just above 8 s.

Figure 10.12 shows the average characteristics of wave height, dominant period, and average period for Buoy 41004 for each of the South Carolina rip current drowning cases from 5 days prior to the day of the drowning events. The wave heights increase by a half meter the day prior to the events and there is only a slight indication of a rise in average and dominant wave periods.
Figure 10.11a South Carolina Buoy 41004 significant wave height (m) mean and standard deviation plot.

Figure 10.11b South Carolina Buoy 41004 dominant wave period (s) mean and standard deviation plot.
Figure 10.12 Averages of wave height, dominant period (DPD), and average period (APD) for South Carolina Buoy 41004 for each of the rip current drownings from 5 days prior to the day of the drowning events.

Figures 10.13a-b show long term average box plots of significant wave height and dominant wave periods representing the period from March 2003 to December 2008 for Buoy 41025. Figure 10.13a shows that long term average significant wave height is consistently between 1-1.5 m year round. The highest maximum wave height was near 14 m during September and the lowest maximum, only around 3 m, was in July. The rest of the months range from near 4.8 to 8.3 m. The dominant wave period (Figure 10.13b) spiked at 31 s during October. The maximum dominant wave periods during the other months range from 14 to 17 s. The average dominant wave period is between 7 and 8 s.
Figure 10.13a South Carolina Buoy 41004 significant wave height (m) mean and standard deviation plot.

Figure 10.13b North Carolina Buoy 41025 dominant wave period (s) mean and standard deviation plot.
The average characteristics of wave height, dominant period, and average period for North Carolina Buoy 41025 for each of the North Carolina rip current drowning cases from 5 days prior to the day of the drowning events is shown in Figure 10.14. The significant wave heights show very little change during the days leading up to the events. Through the entire time span, the average period increases to near 6 s. The dominant wave period, for this composite of rip current drowning cases, increases from a low of 7 s to 9 s on the day of the event. This increase in period would typically invigorate the waves at the coastline.

Figure 10.14 Averages of wave height, dominant period (DPD), and average period (APD) for North Carolina Buoy 41025 for each of the North Carolina drownings from 5 days prior to the day of the drowning events.

10.6 Tidal Trends

The average tidal trends in South Carolina (Figure 10.15) occur around low tide and are consistent with the literature. It is during lower tides that more of the gently sloped beach is exposed and provides a broad area for wave run-up that can be focused into outgoing rip current
channels. The same pattern exists for North Carolina (Figure 10.16). The average rip current drownings in North Carolina, depicted as hour 0, occur at the time of low tide.

Figure 10.15 The average of tidal trends within 6 hours of the drowning events in South Carolina. Hour 0 is the time of drowning.

Figure 10.16 The average of tidal trends within 6 hours of the drowning events in North Carolina. Hour 0 is the time of drowning.
10.7 Case Studies

Case Study 1

Date: 7 July 2011

Time of incident: 1800 EST

Location: Myrtle Beach, South Carolina

Victims: 41 and 42 year old males.

Storm Data Report:

Two men, 41 year old Jeffrey Dinkins, and 42 year old Johnny Ward, died in a rip current while attempting to rescue a six year girl. Two other people were involved and were rescued by an Horry County officer. Two men drowned in a rip current while attempting to save a six year old child.

This case was not unlike others with increasing wave height and period, leading up to, and on the day of the rip current deaths. The swell increased from less than a 1 m to 1.5 m. The average wave period also increased from around 4 s to over 6 s and the dominant wave period remained between 8 s and 9 s (Figure 10.17). The dominant wave period appears to be incorrect on Day -1 and Day -2.
Storm Data reports can be misleading. Newspaper reports following the drowning provided more information than the Storm Data entry above. First, the two drownings were separate incidents. Johnny Ward was from Pound, Virginia and drowned in the ocean near 71st Avenue North in Myrtle Beach around 8:15 p.m. Jeffrey Dinkins from Lewisville, North Carolina, drowned around 7 p.m. near 9550 Shore Drive. This location is shown in Figure 10.5. Mr. Dinkins was in the ocean with his 6 year old son, Zane, and with a family friend and his 6-year-old daughter. The father and daughter were caught in a rip current that began to pull them away from shore. Dinkins and another man who was 62 years old came to the rescue of the 6 year old and her 40 year old father who were caught in a rip current. The father and daughter made it to shore but Dinkins drowned. The 62 year old rescuer was being swept away as others on site pulled Dinkins from the ocean. The other rescuer had taken a cooler-- as a spur-of-the-moment flotation device-- into the
ocean for the rescue and had drifted about 150 m off shore when he was rescued (myrtlebeachonline.com, 2013). The cooler likely saved that man’s life. Two years later, in 2013, Jeffrey Dinkins (Figure 10.18) was awarded a Carnegie Medal for extraordinary civilian heroism (wsjournal.com, 2013).

Figure 10.18 Jeffrey Dinkins died saving a friend and the friend’s daughter as his 6 year old son watched. (Photo: Dinkins family)

Since those drownings, and the potential impact on tourism, the Myrtle Beach Fire Department conducted a study to find strategies to reduce ocean drowning occurrences (Gwyer 2012). Four research questions in the Myrtle Beach study were evaluated and they were: 1) what are the ocean risks and hazards that may contribute to drowning incidents, 2) what commonalities do drowning victims share, 3) what do public safety organizations do to lessen the risk of ocean drowning, 4) what are the attitudes and views of local residents and visitors toward ocean drowning. Interestingly, at Myrtle Beach only every tenth lifeguard stand was required to be watching beachgoers in the water which meant the lifeguards could be renting beach equipment to visitors. For 2013, this policy was changed to every fifth lifeguard stand being lifeguard only.

The study was comprised of expert input and surveys. Only 29% of the visitors and 20% of the residents preferred to stay near a lifeguard. Only 35% of visitors and 43% the residents
believe the ocean is very dangerous although less than 10% thought that the ocean posed no danger. Only 16% of visitors said they would attend a short ocean safety program. Both residents and visitors did pay attention to warning flags on the beach and safety messages on radio and television. A majority of residents (86%) thought that ocean safety should be taught in schools.

Case Study 2
Date: 13 September 2000
Time of incidents: 1330, 1430 and 1500 EDT
Location: Kure Beach and Carolina Beach, North Carolina
 Victims: 23 year old male and a male and female of unknown ages.

Storm Data Report:

*Large swell waves from distant Hurricane Florence generated rip currents along Pleasure Island Beaches. Deaths by drowning occurred at 1:30 and 2:30 PM EDT at Kure Beach, and at 3 PM EDT at Carolina Beach.*

Figure 10.19 shows the wave height, dominant period, and average period for North Carolina Buoy 41002 from 5 days prior to the day of the drowning event. The buoy record shows that Hurricane Florence generated large swells over 3 m five days before the drownings that subsided to 2 m then increased again over 3 m early on the event day. The average wave period subsided from 7 to 6 s on the event day while the dominant wave period decreased from a high of 11 s on the day prior to 8 s late on the event day. Figure 10.20 shows the sea level pressure and wind speed and vectors associated with Hurricane Florence that is centered south of Cape Hatteras. It is important to note that the 2.5 degree resolution of the reanalysis only shows broad patterns
and not fine detail associated with smaller scale systems such as hurricanes. Figure 10.21 is a
NOAA satellite image of a poorly developed Hurricane Florence on 13 September 2000 off the
Florida coast and southeast of North Carolina.

![North Carolina Buoy 41002](image)

Figure 10.19 Wave height, dominant period (DPD), and average period (APD) for North Carolina
Buoy 41002 from 5 days prior to the day of the drowning event (13 September 2000).
Figure 10.20 Sea level pressure (hPa) and wind speed (m s$^{-1}$) and vectors associated with Hurricane Florence on 13 September 2000.

Figure 10.21 Visible satellite image of Hurricane Florence on 19 September 2000 (NOAA)
CHAPTER 11: DROWNING DETAILS IN THE NORTHEAST UNITED STATES

In Massachusetts, only one drowning was reported: in a supposed rip current at Anthony's Beach in Dartmouth (Figure 11.1). Although officials at other beaches in the area reported numerous rescues and moderate rip currents on this day, it is unlikely that this drowning was associated with a rip current due to the sheltered nature of the location. Only one event was reported in Rhode Island and it was a successful rescue. In the only report from Connecticut, two deaths were attributed to rip current drownings, in New Haven, but the details attribute the drowning to a capsized boat. No rip current drownings were noted along the tiny strip of the New Hampshire coastline. Most of the New York incidents were on Long Island, with a southern exposure, while the New Jersey beaches have an eastern exposure with many rock groins extending into the ocean.

Frigid waters lap the coastal areas of the northeastern United States during the winter but as summer approaches the water temperatures warm to more tolerable ranges. Average water temperatures in Maine and New Hampshire warm from around 10 °C in May to around 17 °C in July and August. In Massachusetts, Rhode Island, and Connecticut, average water temperatures warm to a more comfortable range, from 12 °C in May to 22 °C in July and August. In New York and New Jersey, the water temperatures average 15 °C in May, and warm to 23 °C in July and August.
11.1 Demographics of Drowning Victims

Rip current drowning incidents in New York and New Jersey were the most frequent of the northeast states and were examined in detail. In New York, of those whose sex was known, 31 deaths occurred involving 23 (79%) males and 6 (21%) females. In New Jersey, 34 deaths occurred all of which were males (100%). The average age of victims in New Jersey was 27 and the average age in New York was 23.

Figure 11.2 indicates that the deaths by month for New York and New Jersey occur only during the warm season, beginning as waters warm in May and ending in September as waters cool. The peak month for rip current drownings is July, with 20 deaths, followed closely with August (18), and June (15).
11.2 The Deadliest Beach Areas in New Jersey and New York

Of the deadliest beaches in New Jersey (Table 11.1), the touristy Atlantic City area and the Seaside areas ranked first with five deaths each. Deal had four deaths all associated with the same episode. Bradley Beach also had four cases and Asbury Park had three drowning victims.

Table 11.1 The deadliest beach areas in New Jersey.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Beach Area</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Atlantic City Area</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>Seaside Heights/Seaside Park</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>Deal</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>Bradley Beach</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Asbury Park</td>
<td>3</td>
</tr>
</tbody>
</table>
Two beach areas in New York stand out amongst the rest as the deadliest (Table 11.2). They are Rockaway Beach, with nine fatalities, and Long Beach with 11. Several other locations had two drownings: Cupsogue Beach, East Quogue, Jacob Riis Park in Queens, Jones Beach, and Montauk.

Table 11.2 The deadliest beach areas in New York.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Beach Area</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rockaway Beach</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>Long Beach</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>Several locations</td>
<td>2</td>
</tr>
</tbody>
</table>

11.3. Beach characteristics in New Jersey and New York

The New York and New Jersey coastal area has a long continental shelf that extends out 150-200 km. Many of the New York and New Jersey beaches are adjacent to urbanized areas with large populations, and many of the beaches have moderate slopes and groin or jetty control structures that are likely to create rip currents. The Storm Data reports typically do not have enough detail to show whether these structures played a role in the incidents. Rockaway Beach, NY (Figure 11.3) has a number of groins extending into the ocean. Wildwood Crest Beach, NJ (Figure 11.4) has a long groin structure that is visible in the image taken at a time of very low tide. Deal Beach, NJ (Figure 11.5) has many structures extending into the water, and at the time the image was taken, very little beach was evident. Before Extratropical Storm Sandy struck the area during October 2012, Seaside Heights (Figure 11.6) had an amusement park situated on a large pier. The pier may have been a source for enhanced rip currents associated with rip current drownings.
Figure 11.3 Rockaway Beach, NY (Bing Maps).

Figure 11.4 Wildwood Crest Beach, NJ. (Bing Maps).
Figure 11.5 Deal, NJ. (Bing Maps).

Figure 11.6 Seaside Heights, NJ. (Bing Maps).
11.4. Spatial Surface Wind Velocity and Sea Level Pressure Pattern Composites

The drownings in New Jersey and New York all took place during the warm season. This is typically when the subtropical high pressure is the dominant feature over the mid-Atlantic Ocean. Figures 11.7 and 11.8 shows a series of sea level pressure and wind speed and vector composite images for the New Jersey and New York drowning events. The figures show the time frame from the day of the event (Day 0) to four days prior to the event (Day -4). In these averaged images, where important weather systems may be in different locations on different days, it is important to understand that the overall pattern is more important than the actual magnitudes.

For the New Jersey drownings (Figure 11.7), the subtropical high was in place over the central Atlantic Ocean, but lower pressure intruding into the west side of the high indicates frontal boundaries or transient low pressure areas. Some of the low pressure areas that transited the region were of tropical nature, as illustrated in the case study at the end of this chapter. The wind vectors show higher velocities associated with the trade wind region and provide indication of weak southerly winds from the Leeward Islands northward along the east coast that would create some swell into the region. The wind vectors near and east of New Jersey present a weak and more random pattern associated with more transient weather systems.

The composite images for New York (Figure 11.8) tell a different story than those from the New Jersey drownings. The subtropical high is much more consolidated on the west side related to a more persistent pressure pattern. The associated long and persistent fetch of increasing southerly wind creating waves is blowing in the direction of New York beaches.
<table>
<thead>
<tr>
<th>Day</th>
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<th>Wind Speed and Vectors</th>
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Figure 11.7 New Jersey area sea level pressure (hPa) and wind speed (m s\(^{-1}\)) and vector composite images.
### New York

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</table>

Figure 11.8 New York area sea level pressure (hPa) and wind speed (m s\(^{-1}\)) and vector composite images.
11.5. Wave Height and Period Trends

NDBC Buoy Station 44009 (48 km southeast of Cape May, New Jersey) was used for the New Jersey wave measurements. Figures 11.9a-b show long term average box plots of significant wave height and dominant wave periods representing the period from May 1986 to December 2008. The round circles at either end of the lines indicate the maximum and minimum wave height. The thicker (red) line indicates +/- 1 standard deviation and the circle within that area is the mean. The higher wave heights, averaging over 2 m, occur during the late autumn and winter months. The lowest long term average wave heights of less than 1 m occur during the summer (Figure 11.9a). The highest maximum wave heights were between 7 and 8 m in January and February, with the lowest maximum near 4 m during June. The long term average dominant wave periods (Figure 11.9b) are very consistent throughout the year, ranging between 7 and 8 s maxima, except slightly higher (11.2 s) in September. The long term maximum dominant wave periods have reached the 20 s and all are 16 s and above.

The New Jersey wave characteristic averages of height, average period, and dominant period (Figure 11.10) for each of the drownings, from 5 days prior to the day of the drowning events, shows very little change in wave height of 1 m, or average period which was around 5-6 s. The only noticeable feature is a slight uptick in dominant period on the event days from around 8 s to slightly over 9 s. The lack of variability in the fields may be due to the transitory nature of the systems generating waves.
Figure 11.9a New Jersey Buoy 44009 significant wave height (m) mean and standard deviation plot.

Figure 11.9b New Jersey Buoy 44009 dominant wave period (s) mean and standard deviation plot.
For New York incidents, NDBC Buoy Station 44025 (56 km South of Islip, New York) was used. Figures 11.11a-b show long term average box plots of significant wave height and dominant wave periods representing the period from April 1991 to December 2008. Figure 11.11a indicates that the maximum wave heights are variable depending on the month, but range from 3.5 m in June to 9.2 m in December. The average wave heights, averaging around 1 m, occur during the summer months, with a slight increase to 1.5 m the rest of the year. The dominant wave period maxima (Figure 11.11b) was the lowest in February (14 s) and highest in January (25 s). The average dominant wave periods are very consistent around 7 s.
Figure 11.1a New York Buoy 44025 significant wave height (m) mean and standard deviation plot.

Figure 11.1b New York Buoy 44025 dominant wave period (s) mean and standard deviation plot.
The New York Buoy (Figure 11.12) showed a very slight increase in wave height above 1 m and a slight increase in average period from 5 s to near 6 s. The dominant period increased about 2 s, from a low of 6.7 s the day prior, to around 8.2 s on the event day. This is consistent with the steady southerly fetch south of the New York area.

![Graph](image11.png)

Figure 11.12 Averages of wave height, dominant period (DPD), and average period (APD) for New York Buoy 44025 for each of the drownings from 5 days prior to the day of the drowning events.

11.6. Tidal trends in New Jersey and New York

The New Jersey tidal trend (Figure 11.13) averages show an outgoing tide in progress at the times of the drownings. The average time of drowning is about 1-2 h prior to low tide. This falls in line with tidal trends at the time of rip current deaths for most other locations around the country.
The average of tidal trends within 6 hours of the New Jersey drowning events. Hour 0 is the time of drowning.

In New York, the tidal profile is much different than other locations. Figure 11.14 shows that the average tidal profile is a rising tide during the drowning events. Figure 11.15 shows the individual tidal profiles with the outgoing tides indicated in green and the incoming events indicated in red. The figure shows that most of the events occurred with an incoming tide. This is considerably different than the norm for this study, although many of the tides that were incoming were still near low tide at the event times. The reason for this phenomenon has several possibilities. The most likely explanation is that the specific beach locations where the drownings occurred had structures that could produce rip currents with most tidal profiles.
Figure 11.14 The average of tidal trends within 6 hours of the New York drowning events. Hour 0 is the time of drowning.

Figure 11.15 The tidal trends for each of the New York drowning events. Hour 0 is the time of drowning. Green lines indicate outgoing tide and time of drowning and red lines indicate incoming tide at the time of drowning.
11.7 Case Studies

Case Study 1

Date: Multiple Days 14, 17,-19 August 1995

Time of incident: Multiple times

Multiple Locations in New Jersey: Deal, Point Pleasant, Avon, Atlantic City

Victims: Five males aged 17, 11, 13, 37 and 45.

Storm Data Report:

Swells associated with Hurricane Felix generated rough surf and rip currents for about one week along the New Jersey shore. Five drownings occurred. A 17-year-old surfer drowned off Deal (Monmouth County) the night of the 14th. Two boys were swept off the beach by a large wave the around 1830 on the 17th at Point Pleasant Beach (Monmouth County). One body was not found until the next day. The same night a 45-year-old male drowned at Avon (Monmouth County) around 1930. The last drowning occurred at 1515 on the 19th when a 37-year-old surfer was knocked over by a large wave and was pinned underwater by a jetty in Atlantic City. Numerous injuries were reported, five alone in Long Beach Township on the 13th. The heavy surf inflicted a serious neck injury to a Wildwood man on the 15th. Heavy surf and rip currents started affecting the southern New Jersey shore on the 13th. In Cape May City, 79 water rescues occurred on the 13th, 76 more on the 14th as persons became trapped within rip tides. The rough surf spread to Monmouth County by the 14th and municipalities along the shore began restricting bathing. Hundreds of persons were drenched by a large wave in Atlantic City during the annual "Wedding of the Sea" ceremony at the JFK Plaza on the 15th. By the middle of the week (16th), waves reached ten feet at Atlantic City and up to eight feet at Sandy Hook and most bathing was prohibited. For
Atlantic City, this was the first time bathing was prohibited since Hurricane Gloria in 1985. As Felix floundered and weakened offshore, bathing restrictions began to be lifted on the 20th. While tidal flooding was only minor, the weeklong pounding by the heavy surf caused considerable beach erosion. Erosion in Cape May County was described as moderate to heavy. The beach in Ocean City suffered considerable erosion as 80 yards of beach disappeared and a 10 foot cliff was created by the surf at 5th street. In Ventnor (Atlantic County) ten to fifteen feet of beach was eroded.

This was a prolonged event associated with Hurricane Felix. Unfortunately, those that drowned in the heavy surf did not understand the power of the ocean until it was too late. Figure 11.15 shows the wave height, dominant period, and average period for New Jersey Buoy 44009 during the drowning events. Note that the buoy is the closest buoy to New Jersey with a long term record. The buoy times are in UTC and 4 hours earlier and it is the trend of the buoy that is important. The first drowning occurred on 4 August in the evening at the peak of the average period – over 11 s. The wave height had increased as high as 2 m within the time of drowning. The dominant period had increased from around 6 s to over 16 s the day prior and remained above 12 s until 18 August. The significant wave height was near 4 m late on 17 August when the next three drownings occurred. The last death was on 19 August as the period increased above 12 s and the wave height increased again to 4 m. For the first two dates the tides were outgoing and for the third date, the tide was incoming.
Figure 11.16 Wave height (m), dominant period (DPD) (s), and average period (APD) (s) for New Jersey Buoy 44009 from 12 August 1995 to 20 Aug 1995. The general time frames of the drownings are indicated by the broad yellow line. The day of the week is indicated for the drowning days.

Figure 11.16 shows the sea level pressure and wind patterns associated with Hurricane Felix. Indications of a closed low pressure circulation appear on Day -3 northeast of the Windward Islands, which continued to intensify and move northwest until it was east of Florida on Day 0. The pressure gradient between Hurricane Felix and the subtropical high pressure to the east was steep and created strong easterly winds in that area. Those winds created the 4 m waves that hit the shores of New Jersey and the rest of the east coast of the United States.
<table>
<thead>
<tr>
<th>Day</th>
<th>Sea Level Pressure</th>
<th>Wind Speed and Vectors</th>
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</thead>
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<td><img src="image" alt="Image of Day-4" /></td>
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</tbody>
</table>

Figure 11.17 New Jersey area sea level pressure (hPa) and wind speed (m s⁻¹) and vector composite images associated with Hurricane Felix.
Case Study 2

Date: 23 July 2001

Time of incident: 0900 EDT

Location: Rockaway Beach, New York

Victims: Three Females aged 13, 16 and 14.

Storm Data Report:

*Three girls were playing in knee-deep surf near Beach 17th street on Rockaway Beach around 9 am EDT, when they were swept away by rip currents. The inlet between Rockaway and Atlantic Beach was dredged to accommodate boat travel. The steep slope of the Continental Shelf, coupled with the tides, created a dangerous funnel effect.*

Although this was labeled as a rip current death, this was not clearly attributable to a rip current. The portion of Rockaway Beach where the drownings were said to occur is sheltered from the Atlantic Ocean swells by Atlantic Beach (Figure 11.17). From the report, the body of water in which the girls drowned was a tidal channel that likely had a strong current moving through it. If the girls were in a less sheltered area, the weather patterns would be relevant. The buoy record (Figure 11.18) shows increasing wave heights and period on Day -4 as the low pressure develops along the Atlantic Seaboard and moves northeast. On the event day, the wave heights were less than 1 m with an erratic dominant period of 7-9 s. Figure 11.19 shows that a cold front had moved offshore on Day -4 and slowly dissipated. On Day -4 and Day -3 the winds on the south side of the front were southerly and that likely produced the swell that gradually dissipated as the dominant fetch changed orientation away from New York.
Figure 11.18 Rockaway Beach 23 July 2001 drowning location indicated by red dot. (Bing Maps)

Figure 11.19 Averages of wave height, dominant period (DPD), and average period (APD) for New York Buoy 44025 from 5 days prior to the day of the drowning (23 July 2001).
<table>
<thead>
<tr>
<th>Day</th>
<th>Sea Level Pressure</th>
<th>Wind Speed and Vectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 0</td>
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<td>Day -2</td>
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<tr>
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<tr>
<td>Day -4</td>
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<td><img src="image10" alt="Map" /></td>
</tr>
</tbody>
</table>

Figure 11.20 Sea level pressure (hPa) and wind speed (m s\(^{-1}\)) and vector images associated with an area of low pressure.
CHAPTER 12: STATISTICAL ANALYSIS OF WAVE PATTERNS

For this portion of the study, significant wave height (m) was examined from four NDBC buoys to study differences in wave heights and wave periods in the Pacific Ocean, Gulf of Mexico, and the Atlantic Ocean offshore from Florida and New York. The NDBC buoys used were: Station 46047 in the Pacific Ocean (224 km west of San Diego, California); Station 42039 in the Gulf of Mexico (213 km east-southeast of Pensacola, Florida); Station 41010 in the Atlantic Ocean (222 km east of Cape Canaveral, Florida); Station 44025 in the Atlantic Ocean (56 km south of Islip, New York). The hourly buoy data reports stretched over a span of 11 years from 1999 to 2009, except for the New York buoy where the year 1998 was substituted for 1999 (which was mostly missing). This amounts to over 84,000 individual observations for each buoy used. At various times, data were missing from the sites, but overall the sources were very useable.

The statistical analysis and graphing was accomplished using a combination of Excel and SAS statistical software. The extremes were notable in that the Pacific Ocean site, off the coast of California, had the highest average of wave height, but the lowest extreme height at 8 m. The Gulf of Mexico had the lowest average wave height, but the highest wave events (12 m) that were associated with hurricanes. The highest event for the Atlantic off New York was 10 m, with 9 m for the Atlantic Ocean off the coast of Florida. The buoy graph data (Figures 12.1a-d) shows a cyclical pattern of lower wave heights during the summer and higher wave heights during the winter. The primary exceptions are summer hurricane swells that can be exceptionally higher, particularly noted in the Gulf of Mexico.
Figure 12.1a Significant wave height (m) – Buoy 46047 Pacific Ocean, California - 224 km west of San Diego, CA.

Figure 12.1b Significant wave height (m) – Buoy 42039 Gulf of Mexico - 213 km ESE of Pensacola.
Figure 12.1c Significant wave height (m) - Buoy 41010 Atlantic Ocean Florida – 222 km east of Cape Canaveral.

Figure 12.1d Significant wave height (m) - Buoy 44025 Atlantic Ocean, New York – 56 km south of Islip, NY.
12.1 Wave Frequencies

Figure 12.2, the wave height frequency at buoy locations, shows the number of reports or observations and the associated wave height up to 5 m. The Gulf of Mexico Buoy 42039 had the highest number of zero observations with over 600, and the highest frequency of wave heights was 0.4 m with 8263 observations. The highest frequency for the Atlantic – New York Buoy 44025 was 0.8 m with nearly 7000 observations and a slight secondary peak at 1.1 m. The Atlantic – Florida buoy 41010 had a broader range of maximum frequency between 0.9 m and 1.2 m. The Pacific Ocean – California Buoy 46047 had fewer smaller wave heights and a greater number of wave heights above 2 m than the other locations. The highest frequencies, above 5000 observations, were from 1.6 m to 1.8 m. Although it is not shown on the graph, the Gulf of Mexico buoy had the highest frequency of extreme waves above 8 m. Tables 12.1 and 12.2 show the wave height quantiles and frequencies for the four buoys and reflects the frequencies shown in Figure 12.2 that were rounded to the nearest whole meter.

![Wave Height Frequency at Buoy Locations](image)

Figure 12.2 Wave height (m) frequencies at buoy locations (truncated at 5 m).
Figure 12.3 shows the wave period frequency at the four buoy locations. The periods were rounded to the nearest second. The Gulf of Mexico Buoy 42039 had the highest number of lower wave period observations peaking at 6 s. The Atlantic Florida buoy had a peak at 8 s. The Atlantic New York buoy had a bimodal distribution with peaks at 6 s and 8 s. The Pacific Ocean – California Buoy 46047 had a very broad distribution of longer wave periods than the other locations with several peaks at 8s, 11 s, 14 s, 17 s and 20 s. The highest frequency for the Pacific Ocean buoy was at 14 s.

Figure 12.3 Wave period (s) frequencies at buoy locations.
Table 12.1 Wave height quantiles (%) for the four buoy locations.

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<th>Pacific California</th>
<th>Wave Height (m)</th>
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Table 12.2 Wave height frequencies for the four buoy locations.

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<td>941</td>
<td>1.13</td>
<td>83124</td>
<td>99.57</td>
</tr>
<tr>
<td>5</td>
<td>199</td>
<td>0.24</td>
<td>83323</td>
<td>99.81</td>
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<tr>
<td>6</td>
<td>71</td>
<td>0.09</td>
<td>83394</td>
<td>99.89</td>
</tr>
<tr>
<td>7</td>
<td>51</td>
<td>0.06</td>
<td>83445</td>
<td>99.95</td>
</tr>
<tr>
<td>8</td>
<td>16</td>
<td>0.02</td>
<td>83461</td>
<td>99.97</td>
</tr>
<tr>
<td>9</td>
<td>5</td>
<td>0.01</td>
<td>83466</td>
<td>99.98</td>
</tr>
<tr>
<td>10</td>
<td>12</td>
<td>0.01</td>
<td>83478</td>
<td>99.99</td>
</tr>
<tr>
<td>11</td>
<td>6</td>
<td>0.01</td>
<td>83484</td>
<td>100.00</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>0.00</td>
<td>83485</td>
<td>100.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Atlantic New York</th>
<th>Freq</th>
<th>Percent</th>
<th>Cum Freq</th>
<th>Cum %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4404</td>
<td>5.20</td>
<td>4404</td>
<td>5.20</td>
</tr>
<tr>
<td>1</td>
<td>55659</td>
<td>65.67</td>
<td>60663</td>
<td>70.86</td>
</tr>
<tr>
<td>2</td>
<td>18907</td>
<td>22.31</td>
<td>78970</td>
<td>93.17</td>
</tr>
<tr>
<td>3</td>
<td>4390</td>
<td>5.18</td>
<td>83360</td>
<td>98.35</td>
</tr>
<tr>
<td>4</td>
<td>1078</td>
<td>1.27</td>
<td>84438</td>
<td>99.62</td>
</tr>
<tr>
<td>5</td>
<td>271</td>
<td>0.32</td>
<td>84709</td>
<td>99.94</td>
</tr>
<tr>
<td>6</td>
<td>36</td>
<td>0.04</td>
<td>84745</td>
<td>99.98</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
<td>0.01</td>
<td>84753</td>
<td>99.99</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>0.00</td>
<td>84757</td>
<td>100.00</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>0.00</td>
<td>84758</td>
<td>100.00</td>
</tr>
</tbody>
</table>
12.2 Buoy Descriptive Statistics

Table 12.3 shows the descriptive statistical measures for wave height, which include the central tendencies, variability, and profile shape indicators for the four buoys. The mean was highest (2.173 m) for the Pacific California record and lowest for the Gulf of Mexico (1.024 m). The mean standard error is small for these four samples because N > 84,000. The mode for the Gulf of Mexico was only 0.4 m indicating the tendency for smaller waves. The standard deviation of 0.860 m is highest for the Pacific buoy, indicating more of a range from the mean, and it is lowest for the Atlantic – New York buoy at 0.715 m. The data sets are all positively skewed with the bulk of the observations at the lower end of the spectrum. Kurtosis values indicate the shape of the distribution (flat or peaked) to that of the normal distribution. The kurtosis for the four buoy locations shows leptokurtic distributions. The Pacific California buoy has the lowest value which indicates this is closer to the shape of a normal distribution than the others. The Gulf of Mexico buoy has the highest kurtosis value indicating a more peaked distribution.

Table 12.3 Descriptive statistical measures for wave height (m) for the four buoy locations.

<table>
<thead>
<tr>
<th></th>
<th>Pacific California</th>
<th>Gulf of Mexico</th>
<th>Atlantic Florida</th>
<th>Atlantic New York</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>2.173</td>
<td>1.024</td>
<td>1.544</td>
<td>1.278</td>
</tr>
<tr>
<td>Standard Error</td>
<td>0.003</td>
<td>0.003</td>
<td>0.003</td>
<td>0.002</td>
</tr>
<tr>
<td>Median</td>
<td>2.0</td>
<td>0.8</td>
<td>1.4</td>
<td>1.1</td>
</tr>
<tr>
<td>Mode</td>
<td>1.7</td>
<td>0.4</td>
<td>1.1</td>
<td>0.8</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.860</td>
<td>0.750</td>
<td>0.812</td>
<td>0.715</td>
</tr>
<tr>
<td>Sample Variance</td>
<td>0.739</td>
<td>0.562</td>
<td>0.659</td>
<td>0.511</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>2.107</td>
<td>13.899</td>
<td>4.858</td>
<td>3.595</td>
</tr>
<tr>
<td>Skewness</td>
<td>1.199</td>
<td>2.501</td>
<td>1.618</td>
<td>1.552</td>
</tr>
<tr>
<td>Range</td>
<td>8.7</td>
<td>12.1</td>
<td>10.2</td>
<td>6.1</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Maximum</td>
<td>8.7</td>
<td>12.1</td>
<td>10.2</td>
<td>6.1</td>
</tr>
<tr>
<td>Count (N)</td>
<td>89024</td>
<td>87779</td>
<td>92413</td>
<td>84503</td>
</tr>
</tbody>
</table>
Table 12.4 shows the descriptive statistical measures for wave period. The mean was highest (12.03 s) for the Pacific California measurements and lowest for the Gulf of Mexico (5.61 s). Similar to the wave height, the mean standard error is small for these four samples because of the large number of observations. For the Gulf of Mexico, the average, median, and mode were within one second at 5.61 s, 5.56 s and 6.25 s respectively. The means for the Atlantic Florida and Atlantic New York buoys were 8.09 s and 7.30 s, with the same modes of 9.09 s. The standard deviation of 3.383 s for Pacific California buoy is the highest of all with the Atlantic Florida and New York buoys at 2.256 s and 2.487 s. The lowest standard deviation was in the Gulf of Mexico with 1.558 s. The data sets are all positively skewed, with a greater number of lower wave period measurements than higher wave period measurements. The kurtosis value for the California buoy location indicates a broad distribution. The kurtosis for the Gulf of Mexico and Atlantic Florida buoy locations shows leptokurtic distributions and to a lesser degree for the Atlantic New York buoy location.

Table 12.4 Descriptive statistical measures for dominant wave period (s) for the buoy locations.

<table>
<thead>
<tr>
<th></th>
<th>Pacific California</th>
<th>Gulf of Mexico</th>
<th>Atlantic Florida</th>
<th>Atlantic New York</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>12.03</td>
<td>5.61</td>
<td>8.09</td>
<td>7.30</td>
</tr>
<tr>
<td>Standard Error</td>
<td>0.011</td>
<td>0.005</td>
<td>0.007</td>
<td>0.008</td>
</tr>
<tr>
<td>Median</td>
<td>12.12</td>
<td>5.56</td>
<td>8.33</td>
<td>7.14</td>
</tr>
<tr>
<td>Mode</td>
<td>14.29</td>
<td>6.25</td>
<td>9.09</td>
<td>9.09</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>3.383</td>
<td>1.558</td>
<td>2.256</td>
<td>2.487</td>
</tr>
<tr>
<td>Sample Variance</td>
<td>11.446</td>
<td>2.428</td>
<td>5.090</td>
<td>6.183</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>-0.561</td>
<td>2.229</td>
<td>0.216</td>
<td>0.188</td>
</tr>
<tr>
<td>Skewness</td>
<td>0.103</td>
<td>0.570</td>
<td>0.418</td>
<td>0.625</td>
</tr>
<tr>
<td>Range</td>
<td>25</td>
<td>20</td>
<td>14.53</td>
<td>19.05</td>
</tr>
<tr>
<td>Minimum</td>
<td>0</td>
<td>0</td>
<td>2.86</td>
<td>0</td>
</tr>
<tr>
<td>Maximum</td>
<td>25</td>
<td>20</td>
<td>17.39</td>
<td>19.05</td>
</tr>
<tr>
<td>Count (N)</td>
<td>95363</td>
<td>85500</td>
<td>96432</td>
<td>87444</td>
</tr>
</tbody>
</table>
Tables 12.5a-d show the wave height tests for location assuming the null hypothesis Mu0=0. Because these large samples are very representative of the population, the p-values are very low and the Student’s t values are very high. The results indicate a very low p value linked to the very high number of samples. Therefore the null hypothesis is rejected at the 5 percent level of significance.

Table 12.5a Pacific Ocean California tests for location: Mu0=0.

<table>
<thead>
<tr>
<th>Test</th>
<th>Statistic</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student's t</td>
<td>t</td>
<td>659.3713</td>
</tr>
<tr>
<td>Sign</td>
<td>M</td>
<td>41378.5</td>
</tr>
<tr>
<td>Signed Rank</td>
<td>S</td>
<td>1.7122E9</td>
</tr>
</tbody>
</table>

Table 12.5b Gulf of Mexico tests for location: Mu0=0.

<table>
<thead>
<tr>
<th>Test</th>
<th>Statistic</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student's t</td>
<td>t</td>
<td>351.1623</td>
</tr>
<tr>
<td>Sign</td>
<td>M</td>
<td>32040.5</td>
</tr>
<tr>
<td>Signed Rank</td>
<td>S</td>
<td>1.0266E9</td>
</tr>
</tbody>
</table>

Table 12.5c Atlantic Ocean - Florida tests for location: Mu0=0.

<table>
<thead>
<tr>
<th>Test</th>
<th>Statistic</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student's t</td>
<td>t</td>
<td>553.3565</td>
</tr>
<tr>
<td>Sign</td>
<td>M</td>
<td>41933</td>
</tr>
<tr>
<td>Signed Rank</td>
<td>S</td>
<td>1.7584E9</td>
</tr>
</tbody>
</table>

Table 12.5d Atlantic Ocean - New York tests for location: Mu0=0.

<table>
<thead>
<tr>
<th>Test</th>
<th>Statistic</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student's t</td>
<td>t</td>
<td>518.3225</td>
</tr>
<tr>
<td>Sign</td>
<td>M</td>
<td>40177</td>
</tr>
<tr>
<td>Signed Rank</td>
<td>S</td>
<td>1.6142E9</td>
</tr>
</tbody>
</table>

The SAS System analysis of variance, or ANOVA Procedure, was used with significant wave height as the dependent variable (Table 12.6). The ANOVA is used instead of computing several sets of two-sample t-tests that would increase the chance for type I error. The ANOVA provides an indication that the means of several groups are all equal or not, and abridges the t-test
for more than two groups. The ANOVA results also indicate a very low $p$-value linked to the very high N value. Therefore the null hypothesis is rejected at the 5 percent level of significance. The F value which is the *between group variability / within group variability* is also much higher than the critical F value of 0.043, and therefore the null hypothesis is rejected.

Table 12.6 ANOVA results for the four buoy samples.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F (P Value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>3</td>
<td>54802.68</td>
<td>18267.56</td>
<td>24715.6</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Error</td>
<td>344208</td>
<td>254407.46</td>
<td>0.74</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrected Total</td>
<td>344211</td>
<td>309210.14</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>R-Square</th>
<th>Coeff Var</th>
<th>Root MSE</th>
<th>WaveHeight Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.177</td>
<td>55.83</td>
<td>0.856</td>
<td>1.54</td>
</tr>
</tbody>
</table>

### 12.3 Relationship of Drownings to Wave Characteristics

Regression analyses were run for wave characteristics over a 10 year period for Alabama and Florida Panhandle beaches where the waves were often less vigorous. Those regression analyses provided no significant results. The wave data were pared down to only daytime hours and to only the months that drownings occurred – also with no significant results.

The descriptive statistical measure for the 24 hours of wave height measurements during the drowning event days are listed in Table 12.7. This shows that the average significant wave height increases to over 1 m occur on days when people perish in rip current drownings. The averaging of many cases will lower the most important significant wave heights during the day of
the drownings. The mean wave heights range from the lowest of 1.06 m in New Jersey to 2.42 m in Southern California. The median and the mode are lower from the mean in Southwest Florida and the standard deviation is higher than any other location, indicating the brief nature of the wave activity. This location also has the broadest range of confidence interval at 0.14. The Monterey area buoy with only four cases is not shown.

Table 12.8 shows the descriptive statistical measures for the 24 hours of dominant wave period (s) readings during the drowning event days. Southern California stands out with the longest periods. In the Gulf of Mexico, the mean periods are between 6 and 7 s. In the Atlantic Ocean, the mean periods are in the 7 to 9 s range. The standard deviation was over 3 s for Southern California and under 1 s for Texas where the wave periods vary less on drowning event days. Interestingly the minimum periods reported were just over 5 s for Southern California, but 4 s or under elsewhere. The maximum period reported during the Texas and Alabama days with drownings was under 10 s and elsewhere over 11 s.

Table 12.7 Descriptive statistical measures for wave height for drowning event days.

<table>
<thead>
<tr>
<th>Wave Height</th>
<th>CA</th>
<th>TX</th>
<th>AL</th>
<th>FL Pan</th>
<th>FL SW</th>
<th>FL E</th>
<th>SC</th>
<th>NC</th>
<th>NJ</th>
<th>NY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>2.42</td>
<td>1.46</td>
<td>1.64</td>
<td>1.27</td>
<td>1.35</td>
<td>1.49</td>
<td>1.52</td>
<td>1.22</td>
<td>1.06</td>
<td>1.19</td>
</tr>
<tr>
<td>Standard Error</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.02</td>
<td>0.07</td>
<td>0.03</td>
<td>0.03</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Median</td>
<td>2.33</td>
<td>1.39</td>
<td>1.64</td>
<td>1.10</td>
<td>0.79</td>
<td>1.45</td>
<td>1.38</td>
<td>1.19</td>
<td>0.96</td>
<td>1.16</td>
</tr>
<tr>
<td>Mode</td>
<td>1.37</td>
<td>1.41</td>
<td>1.30</td>
<td>0.89</td>
<td>0.26</td>
<td>1.52</td>
<td>1.11</td>
<td>0.81</td>
<td>1.10</td>
<td>1.02</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.88</td>
<td>0.45</td>
<td>0.63</td>
<td>0.66</td>
<td>1.20</td>
<td>0.59</td>
<td>0.57</td>
<td>0.37</td>
<td>0.52</td>
<td>0.39</td>
</tr>
<tr>
<td>Sample Variance</td>
<td>0.77</td>
<td>0.20</td>
<td>0.39</td>
<td>0.43</td>
<td>1.44</td>
<td>0.35</td>
<td>0.32</td>
<td>0.14</td>
<td>0.27</td>
<td>0.15</td>
</tr>
<tr>
<td>Range</td>
<td>4.61</td>
<td>2.45</td>
<td>2.56</td>
<td>3.77</td>
<td>4.98</td>
<td>3.59</td>
<td>2.83</td>
<td>1.89</td>
<td>3.20</td>
<td>2.01</td>
</tr>
<tr>
<td>Minimum</td>
<td>1.00</td>
<td>0.70</td>
<td>0.37</td>
<td>0.29</td>
<td>0.21</td>
<td>0.48</td>
<td>0.76</td>
<td>0.57</td>
<td>0.38</td>
<td>0.43</td>
</tr>
<tr>
<td>Maximum</td>
<td>5.61</td>
<td>3.15</td>
<td>2.93</td>
<td>4.06</td>
<td>5.19</td>
<td>4.07</td>
<td>3.59</td>
<td>2.46</td>
<td>3.58</td>
<td>2.44</td>
</tr>
<tr>
<td>Confidence Level (95.0%)</td>
<td>0.07</td>
<td>0.07</td>
<td>0.06</td>
<td>0.05</td>
<td>0.14</td>
<td>0.06</td>
<td>0.06</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
</tr>
</tbody>
</table>
In addition to the average analysis for each location, the maximum wave heights on each of the drowning days were collected and averaged (Table 12.9). The maximum significant wave heights for the Monterey area rip current drownings were much higher (5.0 m) than all other locations and so were the dominant wave periods (15-20 s). The waves of that magnitude were vigorous enough to sweep people off the beach and carry them into the cold water to their deaths. The average maximum significant wave heights, and associated dominant and average periods, for Southern California drowning events were also higher than any of the Gulf of Mexico or Atlantic Ocean buoy measurements. The Florida Panhandle and Alabama buoys had the highest average maximum significant wave heights, around 2 m, in the Gulf of Mexico and the Atlantic Ocean. The dominant wave periods were moderate to low compared to other locations. New Jersey had the lowest average maximum significant wave heights (1.4 m) in the areas studied in the Atlantic Ocean and the Gulf of Mexico and had a more moderate average dominant wave period of 11.1 s. New York also had an average maximum significant wave height at 1.5 m. The lowest average

---

Table 12.8 Descriptive statistical measures for dominant wave period (s) for drowning event days.

<table>
<thead>
<tr>
<th>Wave Period</th>
<th>CA</th>
<th>TS</th>
<th>FL</th>
<th>FL</th>
<th>FL</th>
<th>SC</th>
<th>NC</th>
<th>NJ</th>
<th>NY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>12.25</td>
<td>6.65</td>
<td>6.79</td>
<td>6.72</td>
<td>6.09</td>
<td>8.34</td>
<td>7.69</td>
<td>8.87</td>
<td>8.77</td>
</tr>
<tr>
<td>Standard Error</td>
<td>0.13</td>
<td>0.07</td>
<td>0.07</td>
<td>0.06</td>
<td>0.12</td>
<td>0.12</td>
<td>0.09</td>
<td>0.16</td>
<td>0.12</td>
</tr>
<tr>
<td>Median</td>
<td>12.31</td>
<td>6.67</td>
<td>6.67</td>
<td>6.67</td>
<td>5.88</td>
<td>8.33</td>
<td>7.69</td>
<td>8.33</td>
<td>8.33</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>3.39</td>
<td>0.87</td>
<td>1.29</td>
<td>1.53</td>
<td>2.06</td>
<td>2.21</td>
<td>1.65</td>
<td>3.00</td>
<td>2.90</td>
</tr>
<tr>
<td>Sample Variance</td>
<td>11.52</td>
<td>0.76</td>
<td>1.66</td>
<td>2.33</td>
<td>4.25</td>
<td>4.89</td>
<td>2.71</td>
<td>9.03</td>
<td>8.40</td>
</tr>
<tr>
<td>Range</td>
<td>14.74</td>
<td>5.24</td>
<td>5.76</td>
<td>11.35</td>
<td>8.55</td>
<td>11.11</td>
<td>8.50</td>
<td>12.67</td>
<td>13.57</td>
</tr>
<tr>
<td>Minimum</td>
<td>5.26</td>
<td>3.85</td>
<td>3.33</td>
<td>2.94</td>
<td>2.56</td>
<td>3.70</td>
<td>4.00</td>
<td>3.33</td>
<td>3.13</td>
</tr>
<tr>
<td>Maximum</td>
<td>20.00</td>
<td>9.09</td>
<td>9.09</td>
<td>14.29</td>
<td>11.11</td>
<td>14.81</td>
<td>12.50</td>
<td>16.00</td>
<td>16.70</td>
</tr>
<tr>
<td>Confidence Level(95.0%)</td>
<td>0.26</td>
<td>0.13</td>
<td>0.13</td>
<td>0.11</td>
<td>0.24</td>
<td>0.24</td>
<td>0.17</td>
<td>0.31</td>
<td>0.24</td>
</tr>
</tbody>
</table>
maximum dominant periods were in the Gulf of Mexico at the Southwest Florida, Alabama, and Texas buoys. All of these values are higher than the long term average wave heights and periods noted in Tables 12.3 and 12.4 and in the long term averages for each buoy in the respective chapters.

With all other conditions the same, a longer period wave will result in a larger breaking wave at the beaches. In other words, longer period waves that are smaller will provide similar impacts on rip current strength in the surf zone. With that notion, a simple formula was developed and will be tested on future cases.

To gain a more comprehensive value when considering the wave height (H) and period (T), the wave length (L) was determined by:

\[ L = \frac{T^2 g}{2\pi} \]  \hspace{1cm} (Eq. 12.1)

The cross-section pseudo wave area (A_c) was determined by:

\[ A_c = H \times L \]  \hspace{1cm} (Eq. 12.2)

Considering the maximum pseudo wave areas computed from average wave height and period on the days with rip current deaths (Table 12.10), the lowest values of cross-section area were in the Gulf of Mexico with an average of 108 m². The Atlantic area had an average of 165 m² and Southern California with 606 m².
Table 12.9 Average maximum significant wave height, dominant period, and average period.

<table>
<thead>
<tr>
<th>Buoy Location</th>
<th>Buoy Number</th>
<th>Average Maximum Height (m)</th>
<th>Average Maximum Dominant Period (s)</th>
<th>Average Maximum Average Period (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monterey</td>
<td>46042</td>
<td>5.0</td>
<td>15.2</td>
<td>10.4</td>
</tr>
<tr>
<td>S. California</td>
<td>46047</td>
<td>2.9</td>
<td>13.9</td>
<td>8.5</td>
</tr>
<tr>
<td>Texas</td>
<td>42019</td>
<td>1.8</td>
<td>7.4</td>
<td>5.3</td>
</tr>
<tr>
<td>Alabama</td>
<td>42040</td>
<td>2.0</td>
<td>7.3</td>
<td>5.2</td>
</tr>
<tr>
<td>Florida Panhandle</td>
<td>42039</td>
<td>2.1</td>
<td>9.0</td>
<td>5.9</td>
</tr>
<tr>
<td>Southwest Florida</td>
<td>42036</td>
<td>2.0</td>
<td>7.4</td>
<td>5.4</td>
</tr>
<tr>
<td>Southeast Florida</td>
<td>41010</td>
<td>1.6</td>
<td>9.0</td>
<td>5.6</td>
</tr>
<tr>
<td>East Florida</td>
<td>41010</td>
<td>1.9</td>
<td>10.0</td>
<td>6.4</td>
</tr>
<tr>
<td>South Carolina</td>
<td>41004</td>
<td>1.8</td>
<td>9.0</td>
<td>5.8</td>
</tr>
<tr>
<td>North Carolina</td>
<td>41025</td>
<td>1.6</td>
<td>10.1</td>
<td>6.4</td>
</tr>
<tr>
<td>New Jersey</td>
<td>44009</td>
<td>1.4</td>
<td>11.1</td>
<td>6.4</td>
</tr>
<tr>
<td>New York</td>
<td>44025</td>
<td>1.5</td>
<td>9.3</td>
<td>6.3</td>
</tr>
</tbody>
</table>
Table 12.10 Pseudo wave area (m$^2$) from average hourly wave height and period on days with rip current deaths.

<table>
<thead>
<tr>
<th>Location</th>
<th>Buoy</th>
<th>Pseudo Wave Area (m$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Florida Panhandle</td>
<td>42039</td>
<td>98.5</td>
</tr>
<tr>
<td>Texas</td>
<td>42019</td>
<td>104.6</td>
</tr>
<tr>
<td>Southwest Florida</td>
<td>42036</td>
<td>114.2</td>
</tr>
<tr>
<td>Alabama</td>
<td>42040</td>
<td>115.3</td>
</tr>
<tr>
<td>New York</td>
<td>44025</td>
<td>127.6</td>
</tr>
<tr>
<td>New Jersey</td>
<td>44009</td>
<td>146.9</td>
</tr>
<tr>
<td>Southeast Florida</td>
<td>41010</td>
<td>153.0</td>
</tr>
<tr>
<td>North Carolina</td>
<td>41025</td>
<td>158.8</td>
</tr>
<tr>
<td>South Carolina</td>
<td>41004</td>
<td>174.1</td>
</tr>
<tr>
<td>East Florida</td>
<td>41009</td>
<td>191.8</td>
</tr>
<tr>
<td>Southern California</td>
<td>46047</td>
<td>605.7</td>
</tr>
</tbody>
</table>
CHAPTER 13: DISCUSSION AND CONCLUSIONS

The goal of this rip current research is to avert tragedy. While families should have had a wonderful day at the beach, many lives have been needlessly lost to rip currents over the years. The physical aspects of rip current drownings, such as trends in wave height and period, tides, and beach areas were explored in this research. The social aspects of rip current drownings were also explored, including: the victim’s age and sex, common behavioral characteristics, and the event chronologies. The American Meteorological Society (AMS 2014) released a Professional Guidance Statement stating the need for more research that combines physical and social science elements to help reduce vulnerability to natural hazards. Some suggestions were also made for additional fields to be added to official rip current reports that may lead to a greater understanding of the rip current drowning dilemma. Furthermore, some simple modifications can be made to rip current literature and signage that will help save lives. Finally, some recommended actions that could be taken by municipalities are mentioned.

13.1 Physical Aspects Associated with Rip Current Drownings

Rip currents may be elusive or a well-known artifact of a beach. Rip current time scales vary from a few seconds in a flash rip, absent of a rip current channel, to a semi-permanent rip current feature associated with a structure such as a jetty. Rip currents are influenced by several
factors including: beach location (reefs, rocks, sand type, and beach slope), tide, wave characteristics (height, period, frequency, and shoaling characteristics), and how these interact.

13.2 Wave Characteristics

Typical wave measurements from offshore deep water buoys are analyzed through algorithms to calculate the significant wave height, dominant period, and average period. Many factors are important including the location of the buoy in relation to beach areas and the bathymetry, particularly the length and depth of the continental shelf and the beach area itself including sandbar structure and manmade structures. It is not possible to attribute any single wave measurement to a particular drowning incident. Furthermore, the significant wave height is the average of the one-third highest waves. That means that the highest waves may be higher than the significant wave height by a factor of 2. Those maximum wave heights are not included in the buoy data.

Significant wave height (m) was examined from four NDBC buoys to study differences in wave heights in the Pacific Ocean, Gulf of Mexico, and the Atlantic offshore from Florida and New York. Over 10 years of hourly buoy data reports, with over 84,000 individual observations for each buoy, were used to examine the differences in wave height distributions. California had the highest average of wave heights but the lowest extreme, while the Gulf of Mexico had the lowest average wave height but the highest wave events that were associated with hurricanes. The results from running the SAS ANOVA procedure indicate a very low $p$ value linked to the very high $N$ value. The null hypothesis was rejected at the 5 percent level of significance with the $F$ value much higher than the critical $F$ value. No significant relationships were found using a
regression analysis comparing drownings to wave characteristics. The variability of the human element makes the analysis more divergent.

The average significant wave height increased to over 1 m on days when people perished in rip current drownings. The maximum wave heights on each of the drowning days varied by location. For the Monterey area, the wave heights (5.0 m) and dominant wave periods (15.2 s) were much higher than all other locations, which is higher than the highest long term buoy average of just under 3 m and 13 s which occur in the winter months. The wave characteristics for Southern California drowning events were also high, with wave heights of 2.9 m and periods of 13.9 s. Those numbers are just slightly higher than the long term buoy averages during the winter months of 2.5 m and 13 s. In the Gulf of Mexico, the Florida Panhandle and Alabama buoys had the highest average maximum significant wave heights, around 2 m but the dominant wave periods were moderate to low compared to other locations. These measurements were higher than the average swell height of 0.7 m, but closer to the 6-7 s wave periods that Mollere et al. (2001) found in the 18 cases studied. The long term average wave heights for the Alabama buoy during the months that drownings were reported were 1 m or less with periods less than 6 s. The lowest average maximum significant wave heights of 1.4 m were at the New Jersey buoy, but the average dominant wave period was a moderate 11.1 s. The long term wave height averages for the New Jersey buoy were lower during the months of drownings, and ranged from 1.3 during May to 0.8 m in June and July and back up to 1.2 m in September. The long term wave periods were several seconds lower around 8 s. The average maximum significant wave height for the New York buoy was 1.5 m with a period of 8.2 s, both of which were slightly higher than the long term averages. Southwest Florida, Alabama, and Texas buoys had the lowest average maximum dominant periods. Interestingly, the values of wave height and dominant period were higher in this study
than what Engle (2003) found. Engle noted that wave heights ranging from 0.45 to 0.85 m resulted in more rescues by lifeguards and that fewer people were in larger surf. The difference may be that this study looked at drownings instead of rescues. The maximum wave areas computed from wave height and period on the days with rip current deaths indicated that the lowest values were in the Gulf of Mexico with an average of 108 m$^2$. The Atlantic Ocean area average was 165 m$^2$ in, but Southern California was much larger at 606 m$^2$.

### 13.3 Wave Development Areas

Another factor in producing the swells that lead to rip currents is the longer term forecast of changes in the typical source regions of the swells. Some cases are obvious and linked to more dynamic systems like tropical storms and hurricanes, mid-latitude low pressure areas, or strong areas of high pressure. Most of the cases occur during the summer when weather patterns are weak. It is often the subtle movement and intensification of the Atlantic or Pacific subtropical high that creates a fetch leading to moderate waves that have enough power to create strong rip currents. The broad scale weather patterns that generate the incoming swells at the beach vary with latitude. Over the southern areas, it is an increase in the pressure gradient of the subtropical high pressure area that creates a longer and stronger fetch region. Near the California coast it is the pressure gradient on the east side of the subtropical ridge that often sends swells to Southern California. In the Gulf of Mexico it is the extension of the ridge westward and increasing gradient of the Atlantic subtropical high that generates swells. For Florida the gradient on the southern side of the subtropical high increases to produce higher swells. For northern California and northward along the east coast, the patterns indicate more transient areas of low pressure. For northern California it is low pressure over the North Pacific that produces large swells. For the Eastern Seaboard, the
wave producers are often tropical and extratropical cyclones. The operational wave models are only as good as the global spectral model that drives the surface wind stresses that create the waves.

### 13.4 Tidal Influences

Except for the New York beaches, this research compares favorably to other more localized studies (McKenzie 1958, Longuet-Higgins and Stewart 1964, Sonu 1972, Brander 1999, Brander and Short 2001, Mollere et al. 2001, Dronen et al. 2002, MacMahan et al. 2005) that indicated rip currents increase in strength when the tide is outgoing or low. The New York drownings were most prevalent at Long Beach and Rockaway Beach. Both of these beaches have many short rock groins extending into the ocean that create adjacent deep channels favorable for rip currents. At lower tides when these groins are fully exposed they may be less of a factor.

### 13.5 Beach Characteristics

Many factors may influence decisions on which beach to visit for an outing or vacation. Several common features were seen in aerial images and may attract similar minded people to a beach. These common features included hotels, large parking lots, and points of interest, such as piers. Natural features at the beach that may affect rip current development and strength area varied. Bar gaps or a crescentic beach with transverse bars jutting into the water provide channels for rip currents if other aspects are in place. Deep areas between bars can create a hazard if a non-swimmer is pulled into that area by a rip current. A low beach gradient allows more water to collect
in the shallow areas during wave sets. As the set waves wane, the collected water that runs out through channels creates or intensifies rip currents.

13.6 Social Aspects Associated with Rip Current Drownings

The social aspects of rip current drownings are just as relevant as the physical aspects. During the period of this study, 517 rip current deaths were reported, and because of underreporting, that number is likely higher. Of the victims whose sex was known, 87 percent were male and 13 percent were female.

The average age of all the known victims was 33. The age groups that are more likely to drown vary by region. Teenagers (10-19 years old) are in the most prevalent age group to die in California, East Florida, New Jersey and New York. New York had the youngest average age of victims at 23 years of age (Table 13.1). In Southwest Florida and Southeast Florida the average age is over 40. The oldest average age is along the southeast coast of Florida at 44. Although the total numbers are lower, the most prevalent age group of victims in Southwest Florida is 60-69 years old.

In most parts of the country, this is primarily a summer phenomenon, but in California and Florida drownings have occurred during every month. Many people drown on major summer holiday weekends (Memorial Day, Fourth of July, Labor Day). More people drown around the weekend, but Sunday is the most prevalent day that rip current drownings occur. In Southeast Florida, some warm months have fewer victims than other months. Is it due to the beach attendance or is it because of fewer days with hazardous rip currents? The most prevalent time of rip current drownings is during the midafternoon, but some occur during the morning, and some late at night.
Table 13.1 Average ages of rip current victims.

<table>
<thead>
<tr>
<th>Location</th>
<th>Average Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>California</td>
<td>29</td>
</tr>
<tr>
<td>Texas</td>
<td>28</td>
</tr>
<tr>
<td>Alabama</td>
<td>33</td>
</tr>
<tr>
<td>Florida Panhandle</td>
<td>38</td>
</tr>
<tr>
<td>Southwest Florida</td>
<td>41</td>
</tr>
<tr>
<td>Southeast Florida</td>
<td>44</td>
</tr>
<tr>
<td>East Florida</td>
<td>36</td>
</tr>
<tr>
<td>South Carolina</td>
<td>33</td>
</tr>
<tr>
<td>North Carolina</td>
<td>35</td>
</tr>
<tr>
<td>New Jersey</td>
<td>27</td>
</tr>
<tr>
<td>New York</td>
<td>23</td>
</tr>
</tbody>
</table>

13.7 Beach Reports

It is clear from this research that the NWS reports are often miscategorized, lacking data, or incorrect in the description of the event. The author is motivated to promote a better defined structure and content for rip current drowning reports by the NWS. The author is an active participant in determining a plan of action for a USLA/NWS/Sea Grant Rip Current Pilot Project for interactive reporting between NWS forecasters and USLA officials. The goal of this project is to have a daily exchange of information between forecasters and lifeguards leading to a greater understanding of rip current forecasting and more detailed reports of rescues and drownings – if they occur at a beach with lifeguards. Descriptions of participating beach areas will consist of information on beach location, natural and man-made conditions that contribute to rip current formation, description of seasonal changes in bathymetry, and baseline information. The primary goal is to have a daily exchange of information between the NWS and USLA lifeguards. A
proposed reporting frequency of twice per day (morning and evening) was determined for NWS forecasts, and core criteria parameters for lifeguards to provide. Those core and optional lifeguard reporting parameters are:

Core parameters
- strength of rip currents (none, weak, moderate, strong); in context to the respective beach
- surf height (average - highest breaking wave) (e.g. 2-4 feet)
- observation date and time
- today’s rescue activity (none, low, med, high) [seasonally adjusted]
- water attendance (low, med, high) [seasonally adjusted]
- comments (e.g. other hazards, slews, sandbars, water depth over the bar, bottom conditions contributing to rip current formation)
- reporter ID

Optional parameters (if lifeguards can provide the information)
- the number of rescues
- the number of rescues attributable to rip currents
- the peak time range of rescue activity
- longshore/lateral current strength (none, weak, moderate, strong) and originating direction (e.g. - from the south)
- rip current quantity (low, med, high) relative to normal baseline
- flag color - mainly Florida
- photos and possible video
- swell direction / angle of waves
- surf zone water temperature
• lifeguard predicted rip strength for the next 24 hours (none, weak, moderate, strong) (e.g.
the morning report might contain rip risk for current day, while the late afternoon report
might contain rip risk for following day)

This project will enhance the relationship between lifeguards and NWS forecasters and the
exchange of information will be invaluable for verification of rip current forecasts.

13.8 Education

The best rip current research in the world is useless unless it is used to make better
forecasts. The most accurate rip current forecast in the world is worthless unless there are
accompanying safety messages. The best rip current safety information is worthless if no one sees
it and it is not compelling enough to change behavior.

The goal is to turn this research into understandable safety information aimed at safety
professionals and to beachgoers. The National Drowning Prevention Alliance (NDPA) is
comprised of water safety professionals, scientists, and those who have lost loved ones to drowning
and their goal is to help avert tragedies when families visit water areas. The NDPA provides
outreach information and hosts annual meetings to bring a greater awareness to drowning issues.
The NWS also provides rip current information on web pages. The USLA is on the frontline
actually protecting beach visitors. The individual states, counties, and municipalities have the
power to make lifesaving changes. The media should be an active partner in disseminating
information, especially on high risk days. In the social science realm, it is important to learn the
effectiveness of safety information by obtaining feedback on safety programs, signage, and
literature.
Like other hazards, some knowledge can assist in making life saving decisions. For tornadoes, the recurring safety message is to seek shelter in a basement or interior room with no windows, such as a bathroom or closet. For lightning safety, most people know to go inside, away from trees and towers. For flash floods, the NWS slogan “Turn around don’t drown” suggests that people not enter fast moving water. Unlike other hazards that may strike someone at home or work, rip currents are avoidable. Fletemeyer and Leatherman (2010) indicate that rip currents may not be recognized by the general public. If caught in a rip current, the safest place to be is at a lifeguarded beach or wearing a personal flotation device, but nationally distributed signage does not mention this.

A drowning is particularly tragic when the rescuer becomes the victim. This was documented in about 11 percent of the cases and because of incomplete reports, this number is likely higher. The current signage should have more information than how a strong swimmer should escape a rip current. The existing signage is valid only if the person is a strong swimmer and does not panic. One missing piece of information on signage is a recommendation to swim near lifeguards, particularly for those unfamiliar with the ocean. Signs should also indicate where the nearest beach with lifeguards is located. Signage should also indicate that children will be safer in the water with an approved flotation device. Flotation devices are required for children on boats – why not when they are in the ocean? Since so many would-be rescuers drown because of a lack of information and training, another missing piece of information for beachgoers on signage is a list of items that may aid in potential rescue of someone in distress when no lifeguards are present. These items would be a plastic cooler, surfboard, boogie board, or similar item that floats. Signage should also stress that rescuing a panicking person in the water is extremely dangerous.
Beyond life-saving information, beach-goers should have tools that are available to perform a rescue in the absence of lifeguards. Figures 13.1a-b show that the Welsh have installed throw rings near water areas. Figure 13.1a shows one of many regularly spaced seaside throw rings. Figure 13.1b shows a throw ring at a very small pond at an abandoned slate mine – almost in the middle of nowhere. These should be a fixture on United States beaches. Throw rings are required at all public pools in the United States – why not public beaches? Other devices are available such as rescue tubes and rescue cans that are more adapted to ocean rescues. This recommendation could go a step further by placing an alarm in the throw ring compartment that sounds when the door is opened. This would not only alert other beachgoers, and possibly lifesaving personnel, to a potential drowning victim but would also be a theft deterrent.

13.9 Limitations of this Study

One of the primary limitations associated with this study is the Storm Data reports. Many of the Storm Data reports used for this study contained valuable information, but many lacked detail. Many of the reports were incorrectly categorized as rip currents, such as someone falling from a bridge, a boat capsizing, and drowning in smaller bodies of water that could not produce rip current circulations. Some reports were somewhat ambiguous and could have been due to tidal currents at an inlet or pass, and not rip currents. Even the more detailed reports lacked some data that could be important such as the victim’s swimming ability, the presence of lifeguards, alcohol use, and the actual cause of death (drowning, heart attack, etc.). The last two might only be available from medical examiner records.
To gather more complete reports, a new format should be instituted that has required fields and all attempts should be made to gather the required information. In this information age, the information is out there. To help provide the data, the author is working with a group of core partners to provide better reports of beach and ocean conditions and details of rip current rescues on a daily basis.

The other primary limitation with this study was the lack of specific ocean and weather data at each beach area. The buoys with long term consistent data were chosen. The distance and direction from the drowning locations varied. As mentioned previously, it is not possible to attribute any single wave measurement to a particular drowning incident. The significant wave height is an average of the highest third of the waves. The highest waves, which are more significant, are not noted in the buoy data. Furthermore, the highest waves may be higher than the significant wave height by a factor of two. Waves with longer periods may also not be significant enough to be noted in the dominant period record.
The NCEP/NCAR composite graphics reveal consistent atmospheric patterns in wave generation areas, but the inconsistent strength and location of more transient systems will not necessarily show a pattern. It is also important to note that the 2.5 degree resolution of the NCEP/NCAR reanalysis graphics only shows broad patterns and not fine detail associated with smaller scale systems such as hurricanes.

13.10 Areas of Future Work

On the physical side, a more detailed buoy analysis could be helpful. This analysis would incorporate data from more buoys, including nearshore buoys, for the state or sub-state areas. A more detailed buoy analysis using buoys with shorter records may limit the number of rip current cases. Wave model data that is more widely available for recent cases can be used to associate wave characteristics related to rip current drownings to provide greater insight into the evolution of these events. Future work will also involve using a wave area calculated from wave height and period.

On the social side, continuing partnerships with lifesaving agencies will provide a greater dialog, and the two-way feedback will help each agency understand problem areas and ultimately save beachgoers from drowning. Hopefully, in the future, those partnerships can be expanded to governmental agencies that have responsibility for the beach areas. Working with those agencies could be a catalyst for positive change of signage and lifesaving tools at the beach.

Future work could also include revamping the Storm Data reports to offer more information on the drownings gathered from news reports. Those updated reports would indicate where the
tourists were from, or if they were residents. Other useful information would be more detailed numbers on beach attendance with a higher temporal resolution.

13.11 Final Comments

This study will help increase operational meteorologists’ awareness of rip current prone days and will provide a guide for producing more comprehensive and longer term Surf Zone Forecasts for the coastal ocean areas including:

- Longer lead times for notification of high risk rip current days
- More accuracy in forecasting the intensity of rip current hazards in the Surf Zone Forecast
- More detailed digital marine forecasts.

The resulting more accurate, longer term predictions, will provide important information to coastal lifeguards and other public safety officials in the United States. This study will also be useful in the social realm by providing information to bring about positive change.

What people learn at United States beaches may save their lives in other counties. Unfortunately, in the two cases described below, college students were caught off guard and unaware of the dangers lurking in the sea. During 2011, five students from Ohio were on a mission trip in Costa Rica, working in orphanages and building churches for a week. The last day of the mission trip was spent at the beach where they encountered a rip current that pulled all of them out. Two of the students were saved by bystanders, but the other three drowned in the ocean.
newspaper article posted on Thursday May 5, 2011, by Alex Leff, stated that the third body had been recovered after U.S. teens drowned off Costa Rica’s Pacific coast.

Another drowning occurred in Costa Rica while a group of students was on a volunteer service trip. One of the students was standing in waist to chest deep water and was pulled into deeper water by a rip current and drowned. The student was Aly Zain Lakdawala (Figure 13.2), and he had been on the mission trip teaching English, volunteering at an orphanage, and saving sea turtle nests. The author received a stirring-motivating email from Jennifer Espinola regarding this drowning.

“I have read about your work on rip currents in the USF Magazine and want to offer my sincere gratitude for the impact your research can have. I work at USF as Director of the Center for Leadership and Civic Engagement, and took a group of students on a volunteer service trip to Costa Rica two years ago. One of our beloved students, Aly Lakdawala, got caught in a rip current and drowned while we were there and it was the most devastating experience of all our lives. We were warned about what rip currents are and told some basic techniques for avoiding and even getting out safely, but it is obviously a much more threatening situation than most people probably give credit to. Our students were wading in what felt like relatively calm waters up to their waists-chests when the waves began and swept the group of four into aggressive currents. The other three students barely made it out of the water, and we lost Aly. Rip currents took Aly two years ago this past Monday - the same day I received a note in my email about your research. I honestly could not believe the coincidence - it felt like a hopeful outcome of making a positive difference. I tell you this story to offer you great support for the work you are doing. It is important and can save lives. In fact, the surviving students and I have discussed the possibility of creating an online video to share more information about rip currents/tides - what they are, where they happen and
when, and what to do to avoid them or survive them if needed. If pieces from your research offer this information and you are willing to share, I will gladly explore this idea again with the students. Again, thank you for dedicating the time and effort to understanding this phenomenon, and to shedding light that can help protect the lives exposed. It is critically impactful to our world.”

Figure 13.2 Aly Zain Lakdawala was on a mission trip to teach English, volunteer at an orphanage and save sea turtle nests. (Photo USF)
CHAPTER 14: REFERENCES


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Appendix A: NDBC Buoy Information

Six types of moored buoys are used by the NDBC (2013) (Figure A.1) depending on measurement requirements, location, and water depth. They include: 3 m, 10 m, and 12 m discus hulls; 6 m boat-shaped (NOMAD) hulls; and the Coastal Buoy and the Coastal Oceanographic Line-of-Sight (COLOS) buoy.

Figure A.1 Types of moored buoys (NDBC 2013).

For this research, records were used from the 10 m discus buoy (Figure A.14), the 3 m discus buoys (Figure A.15) and the 6 m Nomad buoy (Figure A.16).
NDBC Station 46047 (LLNR 82) - TANNER BANK – 224 km west of San Diego, CA
- Owned and maintained by National Data Buoy Center
- Lat/Lon: 32.403 N 119.536 W (Figure A.2)
- 3-meter discus buoy
- ARES 4.4 payload
- Site elevation: sea level
- Air temp height: 4 m above site elevation
- Anemometer height: 5 m above site elevation
- Barometer elevation: sea level
- Sea temp depth: 0.6 m below site elevation
- Water depth: 1399 m
- Watch circle radius: 1554 m

Figure A.2 Location of Station 46047.
**NDBC Station 46042 (LLNR 297) - MONTEREY – 50 km WNW of Monterey, CA**

- Owned and maintained by National Data Buoy Center
- 36.785 N 122.469 W (Figure A.3)
- 3-meter discus buoy
- ARES payload
- Site elevation: sea level
- Air temp height: 4 m above site elevation
- Anemometer height: 5 m above site elevation
- Barometer elevation: sea level
- Sea temp depth: 0.6 m below site elevation
- Water depth: 2098 m
- Watch circle radius: 1141 m

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**Figure A.3 Location of Station 46042.**
NDBC Station 42019 (LLNR 1205) - FREEPORT, TX – 111 km south of Freeport, TX

- Owned and maintained by National Data Buoy Center
- 3-meter discus buoy
- AMPS payload
- 27.913 N 95.353 W (Figure A.4)
- Site elevation: sea level
- Air temp height: 4 m above site elevation
- Anemometer height: 5 m above site elevation
- Barometer elevation: sea level
- Sea temp depth: 0.6 m below site elevation
- Water depth: 78.9 m
- Watch circle radius: 114 m

Figure A.4 Location of Station 42019.
NDRC Station 42040 (LLNR 293) - LUKE OFFSHORE TEST PLATFORM – 119 km south of Dauphin Island, AL

- Owned and maintained by National Data Buoy Center
- 10-meter discus buoy
- ARES 4.4 payload
- 29.212 N 88.207 W (Figure A.5)
- Site elevation: sea level
- Air temp height: 10 m above site elevation
- Anemometer height: 10 m above site elevation
- Barometer elevation: sea level
- Sea temp depth: 1 m below site elevation
- Water depth: 164.6 m
- Watch circle radius: 263 m

Figure A.5 Location of Station 42040.
NDBC Station 42039 (LLNR 141) - PENSACOLA - 213 km ESE of Pensacola, FL
- Owned and maintained by National Data Buoy Center
- 3-meter discus buoy
- ARES payload
- 28.794 N 86.006 W (Figure A.6)
- Site elevation: sea level
- Air temp height: 4 m above site elevation
- Anemometer height: 5 m above site elevation
- Barometer elevation: sea level
- Sea temp depth: 0.6 m below site elevation
- Water depth: 274.3 m
- Watch circle radius: 487 m

Figure A.6 Location of Station 42039.
NDBC Station 42036 (LLNR 855) - WEST TAMPA – 207 km WNW of Tampa, FL
- Owned and maintained by National Data Buoy Center
- 3-meter discus buoy
- ARES 4.4 payload
- 28.500 N 84.517 W (Figure A.7)
- Site elevation: sea level
- Air temp height: 4 m above site elevation
- Anemometer height: 5 m above site elevation
- Barometer elevation: sea level
- Sea temp depth: 0.6 m below site elevation
- Water depth: 50.6 m
- Watch circle radius: 116 m

Figure A.7 Location of Station 42036.
NDBC Station 41010 (LLNR 845) - CANAVERAL EAST – 222 km east of Cape Canaveral

- Funding provided by the National Aeronautics and Space Administration
- Owned and maintained by National Data Buoy Center
- 6-meter NOMAD buoy
- ARES payload
- 28.906 N 78.471 W (Figure A.8)
- Site elevation: sea level
- Air temp height: 4 m above site elevation
- Anemometer height: 5 m above site elevation
- Barometer elevation: sea level
- Sea temp depth: 1 m below site elevation
- Water depth: 872.6 m
- Watch circle radius: 1279 m

Figure A.8 Location of Station 41010.
NDBC Station 41009 (LLNR 840) – CANAVERAL 37 km east of Cape Canaveral, FL

- Funding provided by the National Aeronautics and Space Administration
- Owned and maintained by National Data Buoy Center
- 3-meter discus buoy
- AMPS payload
- 28.523 N 80.184 W (Figure A.9)
- Site elevation: sea level
- Air temp height: 4 m above site elevation
- Anemometer height: 5 m above site elevation
- Barometer elevation: sea level
- Sea temp depth: 1 m below site elevation
- Water depth: 40.5 m
- Watch circle radius: 107 m

Figure A.9 Location of Station 41009.
NDBC Station 41004 (LLNR 825) - EDISTO – 76 km southeast of Charleston, SC

- Owned and maintained by National Data Buoy Center
- 3-meter discus buoy
- AMPS payload
- 32.501 N 79.099 W (Figure A.10)
- Site elevation: sea level
- Air temp height: 4 m above site elevation
- Anemometer height: 5 m above site elevation
- Barometer elevation: sea level
- Sea temp depth: 0.6 m below site elevation
- Water depth: 38.4 m
- Watch circle radius: 101m

Figure A.10 Location of Station 41004.
NDBC Station 41025 (LLNR 640) - Diamond Shoals 34 km southeast of Cape Hatteras

- Owned and maintained by National Data Buoy Center
- 3-meter discus buoy
- ARES payload
- 35.006 N 75.402 W (Figure A.11)
- Site elevation: sea level
- Air temp height: 4 m above site elevation
- Anemometer height: 5 m above site elevation
- Barometer elevation: sea level
- Sea temp depth: 0.6 m below site elevation
- Water depth: 68.6 m
- Watch circle radius: 112 m

Figure A.11 Location of Station 41025.
NDBC Station 44009 (LLNR 168) - DELAWARE BAY 48 km southeast of Cape May, NJ

- Owned and maintained by National Data Buoy Center
- 3-meter discus buoy
- AMPS payload
- 38.461 N 74.703 W (Figure A.12)
- Site elevation: sea level
- Air temp height: 4 m above site elevation
- Anemometer height: 5 m above site elevation
- Barometer elevation: sea level
- Sea temp depth: 0.6 m below site elevation
- Water depth: 30.5 m
- Watch circle radius: 63 m

Figure A.12 Location of Station 44009.
NDBC Station 44025 (LLNR 830) - LONG ISLAND – 56 km south of Islip, NY
Owned and maintained by National Data Buoy Center
3-meter discus buoy
AMPS payload
40.250 N 73.167 W (Figure A.13)
Site elevation: sea level
Air temp height: 4 m above site elevation
Anemometer height: 5 m above site elevation
Barometer elevation: sea level
Sea temp depth: 0.6 m below site elevation
Water depth: 40 m
Watch circle radius: 75 m

Figure A.13 Location of Station 44025.
Figure A.14 Ten meter discus buoy (Photo NDBC).

Figure A.15 Three meter discus buoy (Photo NDBC).
Figure A.16 Six meter Nomad buoy (Photo NDBC).
ABOUT THE AUTHOR

As a scientist, Charlie Paxton is constantly exploring ways to improve forecast processes and communication. He became interested in weather growing up near the Kennedy Space Center after encountering tornadoes, waterspouts, tropical storms, and lightning. Charlie began surfing as a teenager and forecasting the waves and weather became a primary interest. After graduating from Merritt Island High School, he joined the U.S. Navy and attended weather school in Lakehurst New Jersey and was then stationed at Mayport Florida and Adak Alaska. After the Navy he earned an undergraduate degree in meteorology with a minor in math from the Florida State University (FSU). Charlie started working for the National Weather Service as an intern in Huntington, WV. Charlie then accepted an offer to work at the Tampa Bay Area National Weather Service office in 1986. He later went back to FSU for a master’s degree in meteorology. After working on several meteorological research projects with Dr. Jennifer Collins he found inspiration to tackle a Ph.D. program in Environmental Science and Policy at the University of South Florida. His NWS work encompasses a blend of weather forecasting, weather research, computer programming and numerical modeling, public speaking and teaching. His research has explored ocean processes including rip currents and rogue waves, lightning, hail, tornadoes and deadly smoke and fog on the interstate highways. During his career at the NWS office in Ruskin, FL, Charlie experienced massive rainfall and flooding during 1988, record cold in 1989, deadly tornadoes in Pinellas County in 1992, the Storm of the Century during March of 1993, the 1995 meteotsunami, the 2004 hurricane season, and countless severe thunderstorms,