IMPROVING RIP CURRENT FORECASTING TECHNIQUES FOR THE EAST COAST OF FLORIDA

By

JASON ROLLAND CUMMINS

A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
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To Arthur and Mildred Cummins.

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Jason Rolland Cummins

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Major: Coastal and Oceanographic Engineering

This study documents the development of an improved rip current predictive index through the detailed examination of a long-term record of oceanographic and meteorological conditions with concurrent rip current events. Rip current rescue statistics are used as a proxy for actual *in situ* rip current measurements; the correlations of various meteorological and oceanographic parameters with the occurrence of rescues are used to establish the relative importance (and hence weighting) of these factors in the predictive scheme. The correlation analysis was conducted on a long-term data set consisting of rip-related rescues and hindcast wind and wave data in Volusia County, Florida, extending from 1997 to 2004. In addition to the established dependence on wave height and period (already incorporated in National Weather Service [NWS] predictions), the relative risk of daily rip current activity was found to increase during periods of shore-normal waves and when the occurrence of low tide coincided with times of peak beach attendance. The existing rip current forecasting methods practiced by the NWS were accordingly

modified to include both a wave direction parameter and a low tide parameter. After these adjustments, the modified predictive index exhibited significant improvements. Currently, the NOAA (National Oceanic and Atmospheric Association) wave buoys off the east coast of Florida (which are used on a same-day basis for NWS rip current warnings at present) are not equipped to measure the wave direction. To overcome this obstacle, the wave direction was incorporated into the rip current predictive scheme by implementing a readily available forecast (directional) wave model called WAVEWATCH III (currently used by NWS in other connections). An investigation of the performance of the modified index using oceanographic output information from the wave model was conducted in "blindfold" fashion using the Volusia County rescue information for the summer of 2005. The results indicate that the modified index outperforms the index currently employed by the NWS. These improvements in performance, as well as the advantages of advanced notice, justify the incorporation of a forecast wave model (WAVEWATCH III) into the operational rip current prediction process.

CHAPTER 1
INTRODUCTION

A rip current is a strong, channeled flow of water extending seaward from the shoreline. According to the United States Lifesaving Association rip currents are the cause of approximately 80% of their rescues nationwide. Since 1995, over 17,500 documented rescues in the U.S. were directly related to rip current activity. Rip current activity affects the safety of beach-goers visiting the coastal waters of this nation and others. As a result of these dangerous conditions, it is reported that in the U.S. alone over 100 deaths annually are attributed to rip currents.

An investigation was conducted at the University of Florida to examine the existing rip current prediction methods implemented by the National Weather Service. Analysis of rip-related rescues correlated with oceanographic conditions assisted in improving the accuracy of the presently employed rip current index. The index is a scale used to calculate the level of risk for ocean-goers due to local rip current formation. Knowledge of these conditions aids the local governmental authorities in the issuance of warnings to the public. Public awareness, as well as the talent and dedication of the beach lifeguards, plays a vital role in the prevention of rip-related drownings.

The development of a rip current prediction scheme began in south Florida with the Lushine Rip Current Scale (LURCS), which utilized wind speed and direction along with swell height and the time of low tide to assess the daily level of risk associated with rip currents (Lushine 1991). The LURCS prediction scheme was then later adapted for use on the central east coast of Florida (ECFL LURCS) with the inclusion of the swell period and a modification to the tidal parameter (Lascody 1998). The ECFL LURCS was later modified by Engle (2003). Engle (2003) eliminated the wind parameters and also incorporated the incident wave angle, directional spreading and the tidal level.

The intention of this study was to further justify the incorporation of a swell direction parameter and establish a way to integrate it into the prediction scheme, with the ultimate goal of using the index as an operational forecasting tool. An analysis using Volusia County rescue information extending from 1997 to 2004 was completed to establish the importance and respective range of each oceanographic parameter used in the rip current prediction scheme. The modifications were then individually tested against the performance of the existing ECFL LURCS method for the same time period. The incorporation of wave direction improved the accuracy of the rip current predictions. However, the NOAA (National Oceanic and Atmospheric Association) data buoys on the east coast of Florida are presently not capable of measuring wave direction; this represented a significant stumbling block in the implementation of the modified index as an operational tool. The application of the WAVEWATCH III model (Tolman 1997, 1999a) was introduced into the prediction scheme in order to resolve this quandary. The modified prediction index developed here used the oceanographic output information from the wave model to calculate the daily rip current threat levels for the summer of 2005. The results were then compared with the Volusia County rescue information and the completed ECFL LURCS worksheets to examine if the model could be used to accurately predict rip current conditions.

Previous research concerning the driving forces and theoretical underpinnings of rip current formation, as well as general characteristics of a rip are reviewed in Chapter 2.

An overview of the LURCS, ECFL LURCS and the Modified ECFL LURCS is presented in Chapter 3, along with motivation for improvements to the existing rip current prediction scheme. Chapter 4 discusses the data sources used during the analysis process of this study. The correlation between rescues and specific oceanographic parameters, and the subsequent modifications to the existing ECFL LURCS is presented in Chapter 5. A comparison between the resulting modified index implementing the WAVEWATCH III forecast model and the documented ECFL LURCS worksheets is presented Chapter 6. Finally, the summarized results of the study and overall conclusions are then presented in Chapter 7.

CHAPTER 2
RIP CURRENTS

Formation of a Rip Current

In 1936 the term "Rip Current" was suggested by F. P. Shepard to describe the phenomena observed by lifeguards and others on the coast of California. Originally, the phenomenon of seaward flow was referred to as a "Rip Tide". Yet the occurrence has little connection with the tidal flow itself, hence the recommendation by Shepard to rename the process. Rip currents are defined as narrow, seaward-directed currents that extend from the inner surf zone out through the line of breaking waves (Haller and Dalrymple 2001).

Five years later F. P. Shepard, along with K. O. Emery and E. C. Lafond (1941), reported various qualitative observations regarding rip currents. They divided the rip current, also referred to as a rip, into three specific parts: 1) the feeder currents, 2) the neck and 3) the head (Figure 2.1). The flow was perceived to be strongest in the nearshore through the surf zone, or "neck", and then the observed speeds reduced as the current traveled further offshore into the rip "head". Another important observation made by Shepard et al. was the association of rips with certain meteorological conditions. They noticed that an increase in rip current intensity was directly associated with an increase in wave height.

In a later study performed by Shepard and Inman (1950), it was found that rip currents are an integral component of a larger nearshore circulation system. They hypothesized the driving force of these circulation cells was the convergence and divergence of the incoming wave field due to the effect of the refraction, producing a longshore variation in breaking wave conditions. The resulting wave set-up field creates conditions where water is driven away from regions of the larger waves towards areas of smaller waves in the form of a longshore current. These currents eventually converge and turn seaward in the form of a rip current. The physics of the forcing mechanism was not completely understood until Longuet-Higgins and Stewart (1964) introduced the concept of radiation stress, and linked it analytically to the wave set-up. Radiation stress is defined as the excess momentum flux conveyed by a progressive wave. It is a function of the wave energy and therefore proportional to the square of the wave's height.

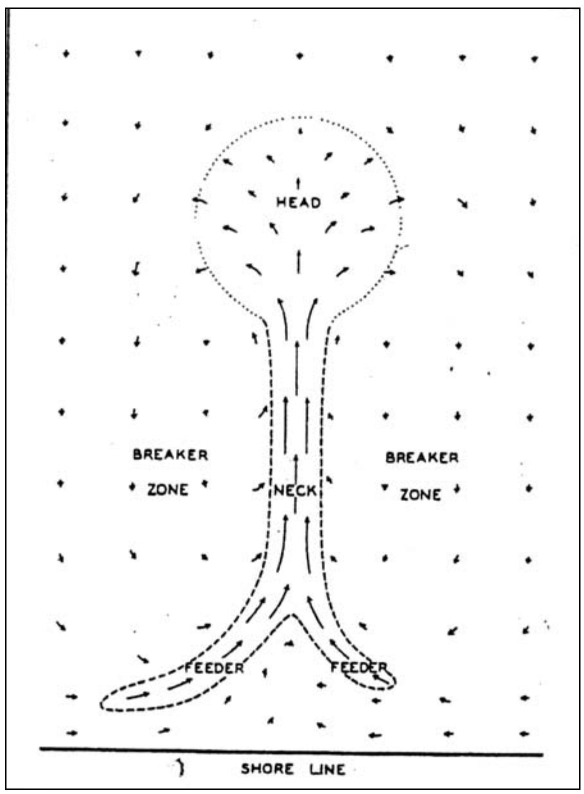

Figure 2-1. Rip current and its component parts (feeders, neck and head) as well as the commonly associated currents (represented by arrows) (from Shepard et al. 1941).

Originally the development of nearshore currents was attributed to the shoreward mass-transport of water by waves and the subsequent localized changes in sea level. In a qualitative field experiment, McKenzie (1958) observed that the water brought in toward the shore by breakers and translatory waves tends to cause longshore currents close to the beach. At variable intervals the longshore currents turn seaward and form outgoing rip currents. Longuet-Higgins and Stewart (1964) adopted a different approach by using the concept of radiation stress to analyze the conservation of momentum flux and observed changes in sea level. According to the theory, any change in the cross-shore radiation stress is balanced by a hydrostatic pressure gradient, or change in water level. In their study they theoretically predicted a decrease in the water level, know as set-down, when the waves approach the breaking point. Adhering to the continuity of momentum flux, the decrease in the water level is due to the increase in energy from the shoaling of a wave. They also predicted an increase in water level, known as set-up, shoreward of the breaking zone. The increase in water level is attributed to the energy dissipation, and subsequent decrease in radiation stress, of the wave during breaking. Figure 2.2 displays measurements from a lab experiment performed by Bowen et al. (1968) and their calculated results applying the theory developed by Longuet-Higgins and Stewart (1964).

Bowen (1969) investigated the observed nearshore circulation system using the concept of radiation stress developed by Longuet-Higgins and Stewart (1964). As mentioned earlier, cross-shore variations of the radiation stress is the cause of set-up and set-down. Since the radiation stress is proportional to the wave height, a longshore variation in the incident wave height will result in a longshore variation of set-up and set-down. The variation in set-up induces a pressure field, driving a flow of water in the surf zone away from regions of high waves toward the regions of low waves (Bowen 1969). When two of these flows converge on the same location exhibiting low wave energy, they turn offshore and exit the surf zone as a confined rip current (MacMahan 2006).

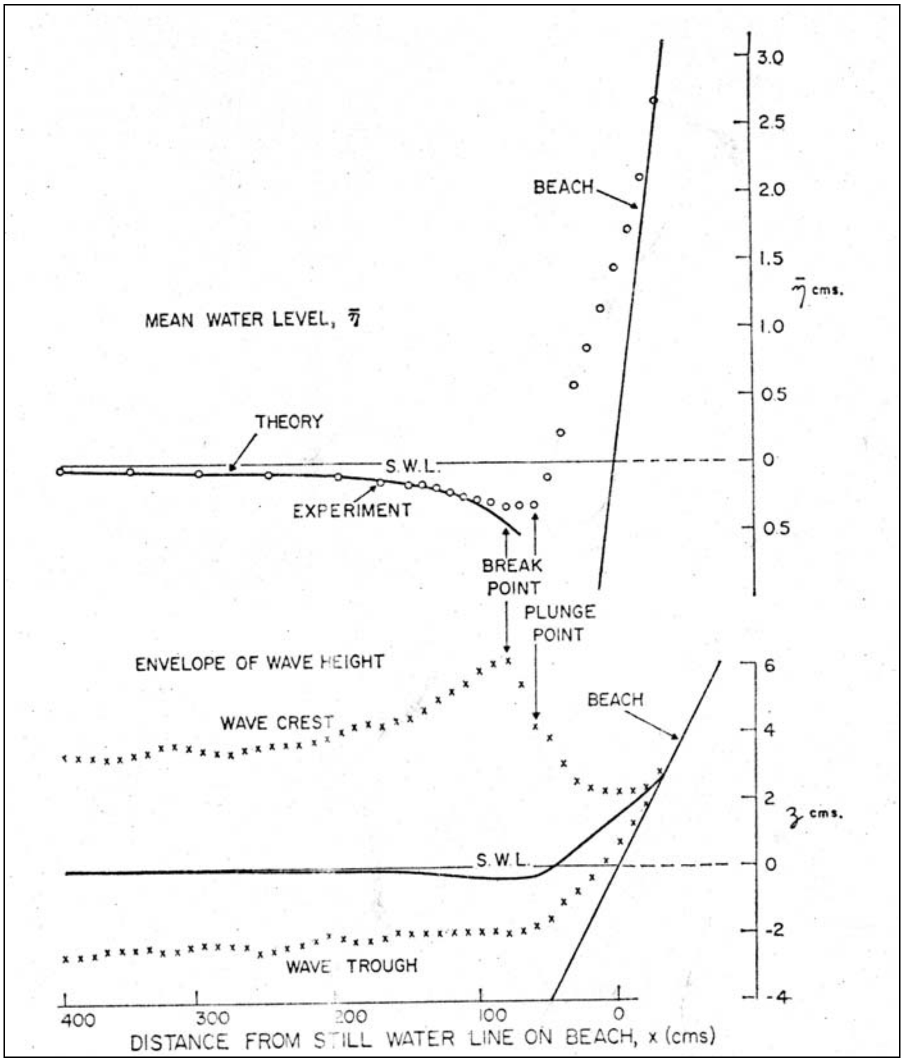

Figure 2-2. Profile of the mean water level and the envelope of the wave height for a typical experiment. Wave period, 1.14 sec; H_o = 6.45cm; H_b = 8.55cm; tan β = 0.082 (from Bowen et al. 1968).

In review, the generation of a rip current begins with longshore variations of the incoming wave field. These variations in wave height can be derived from incident and edge wave interactions (Bowen and Inman 1969), the convergence or divergence of wave rays over offshore bottom topography, and/or the induced variability in wave height caused by coastal structures (Dalrymple 1978). Independent of cause, the forcing disparity in the incident wave field drives nearshore circulation cells. These cells exhibit wide regions of shoreward flow separated by narrow regions of offshore flow. If the narrow regions are strong enough they will appear as rip currents (Haller and Dalrymple 2001).

Characteristics of a Rip

Rip currents are not confined to a specific type of beach and have been observed on the east and west coasts of Florida (Sonu 1972, Engle 2003), the coast of California (Shepard et al. 1941 & 1950, Bowen and Inman 1969, Cook 1970, MacMahan 2004) and on the coasts of Australia (McKenzie 1958, Short 1985, Brander 1999 & 2001, Haas 2002). Each location contains a different offshore topography and incoming wave field, yet the same phenomenon was seen in all. Rip currents have also been noted to occur around man-made structures, such as jetties, groins and piers. In this study the concentration is on the straight, typically barred beaches seen on the east coast of Florida. Rips have been observed in such locations and have been established in a similar controlled lab environment. Experiments conducted by Haller et al. (1997) at the University of Delaware demonstrated the occurrence of cell circulation on an alternating bar and channel configured shoreline, similar to the bathymetry on Florida's east coast.

On a barred beach the rip current is typically associated with a rip channel, or a gap in the bar where the out-flowing current is located. Since the rip itself can be unstable in its location, the associated channel can wander as well. However, if there is structural influence, the channel will tend to remain stationary. Generally, rip currents are not constant features, they can flow intermittently, the head swings back and forth, and their channels may migrate (Cook 1970). The migration of the channel can be the result of changing wave conditions. When the incident wave field increases in intensity, the rips tend to transform from many small rips to a few large rips (McKenzie 1958). Another mechanism for migration is the variability in strength of the feeder currents, which are rarely the same length and intensity. Uneven feeder currents can orient the rip obliquely to the shore, and cause the head to become unstable, moving from side to side. Rip currents have been known to form both orthogonally and diagonally across the surf zone (McKenzie 1958).

Due to the many variable factors influencing the nature of a rip current, the flow of the rip can also be highly unsteady, constantly varying in flow intensity. The changing speed or pulsation of the rip current is an important factor when evaluating the safety of beachgoers. A swimmer can be situated in a channel during a lull period and remain in control, yet when the rip pulsates and increases its flow the swimmer suddenly becomes in danger. Such unsteadiness has been observed on several occasions. Shepard and Inman (1950) noted that rip currents tend to register all variations in wave strength with a short time lag. Typical average rip current velocities are O(1.0)ft/s (0.3m/s), but on shorter time scales velocities can reach a max of 6.6ft/s (2.0m/s). Sonu (1972) observed pulsations at high tide corresponding to variance of the incoming swell, and at low tide corresponding with surf beat frequencies. Others have observed the latter phenomenon and generally associate the pulsations with wave groups at the infragravity level (0.004-0.04Hz) (Shepard et al. 1941, Shepard and Inman 1950, Brander and Short 2001, MacMahan et al. 2004). Field experiments performed by MacMahan et al. (2004) confirmed the pulsations were driven by infragravity cross-shore standing waves, also known as surf beat.

Although short-term pulsations can adversely affect ocean-goers, the overall strength and severity of a rip current is the primary determinant of ocean safety. It is almost uniformly agreed that an increase in wave height is directly correlated with an increase in rip current flow. An experiment conducted by Shepard et al. (1941) showed an increase of rip intensity with every period of larger waves. When conditions of larger swell occur, the surf zone increases in width and a system of larger and more active rips can establish itself (McKenzie 1958). Another important factor contributing to the intensity of a rip current is the tidal stage. During low tide there are two responses: (1) the breaking on the bar intensifies and (2) the flow concentrates in the rip channel. Both of these reactions contribute to the increased intensity of the rip current. Shepard (1941) first observed the concentration of seaward flow in the rip channel during low tide, preserving form even in less than ideal conditions. Additional field experiments conducted by Sonu (1972) helped validate the association of rip current strength with tidal stage, as well as a correlation with swell direction. During an experiment in Australia, Brander (1999) measured the greatest flow velocities at low tide. It has been noted and observed by many researchers, that there is a definite correlation between rip current intensity and wave height, as well as tidal stage. Therefore, both the wave height and tidal stage become crucial when attempting to interpret the severity of the rip current conditions, with an eventual goal of providing appropriate warnings to the public.

CHAPTER 3
FORECASTING

Researchers have long been examining rip currents to identify their forcing mechanisms and the conditions associated with their occurrence in nature. This information was incorporated into more recent works in an attempt to correlate rip currents with specific oceanographic parameters. With such knowledge one could accurately assess the rip current related hazards in the surf zone and then inform beach-goers. There are more rip-related deaths in Florida each year than hurricanes, tropical storms, tornados, severe thunderstorms and lighting combined (Lascody 1998). With a more accurate prediction system and adequate warning methods hopefully the number of rip current victims can be decreased.

In one of the first attempts at rip current predictions, Lushine (1991) examined the reported rip-related drownings and rescues in southeast Florida and the concurrent oceanographic and meteorological conditions. Since the availability of long-term records on rip current incidence is scarce, rip-related rescues proved to be a useful indicator of rip current events. Through his work, an experimental scale (Lushine Rip Current Scale, LURCS) was developed to calculate the risk level of the surf zone due to rip currents. The scale ranges from zero to five, zero corresponding to no weather-related rip current danger and five meaning high danger for all swimmers. In the development of the LURCS, Lushine (1991) found a strong correlation between rip current rescues and wind conditions. In southeast Florida wind is the primary source for wave generation, because the islands of the Bahamas intercept most of the distant swell. Wind then became the primary foundation of the scale, although it also includes swell height and small factors for tidal stage and persistence. An increase in wind and/or swell height will raise the scale's value respectively. The tidal stage factor is only added to the scale's value if the time is between two hours before and four hours after low tide. The persistence factor accounts for continuing rip current conditions.

Confirmation of the ability to accurately predict rip currents with the LURCS was achieved through testing on an independent data sample. Three parameters were used to interpret the results 1) Probability of Detection (POD), 2) False Alarm Ration (FAR), and 3) Critical Success Index (CSI). The results were convincing, and the LURCS was recognized as a beneficial approach to forecasting the occurrence of rip currents.

The scale developed by Lushine (1991) was intended for use in southeast Florida, an area dominated by locally generated wind waves. This is evident in the LURCS, because of the emphasis placed on wind conditions. The southeast division of the National Weather Service (NWS) implemented the forecasting technique, and warnings were issued when rip current activity was calculated high enough to pose a threat. Other sectors of the NWS noticed the advantage of the LURCS and a modified version was prepared for use along the central east coast of Florida.

The ECFL (East Central Florida) LURCS, developed by Lascody (1998), was derived from the original LURCS with the addition of a swell period factor and small changes to other parameters. Lascody (1998) realized the limitations of the LURCS application because of the dependence on wind waves, where east central Florida is more disposed to long period swell conditions. Less emphasis was placed on the wind conditions, and the inclusion of wave period into the scale assured dependence on swell conditions. The modified scale predicts well and is used today, yet a high false alarm ratio in testing showed the ECFL LURCS still needed some improvement (Lascody 1998).

A later investigation by Engle (2003) examined the ECFL LURCS and looked for such methods of improvement. Engle (2003) proposed two parameters, wave direction and tidal stage, to be particularly influential when attempting to assess rip current activity. The modified scale was based on the ECFL LURCS. The first change was removing the wind speed and direction parameters completely. Secondly, wave direction and tidal level were incorporated into the index. Tests were completed to compare the performance of the ECFL LURCS with the modified version, using rescue data and associated weather conditions. The modified scale showed improvements over the ECFL LURCS when using the POD and FAR for comparison. Alarm Ratio (AR) was another statistical parameter introduced by Engle (2003) to develop balance between the two scales. AR is the percentage of days the scale is predicting rip currents (Engle 2003). Engle's (2003) modified index showed promising improvements over the original ECFL LURCS. Another analysis was executed by Schrader (2004) to reinforce the accuracy of the modifications to the ECFL LURCS. This analysis applied a smaller independent data set, but still demonstrated the validity of the improvements claimed in earlier work by Engle (2003).

These more recent studies established the need to include wave direction in a predictive index, however there was no ready way to implement the new directional parameters. The existing rip current index applies information obtained from the NOAA weather buoys located off the east coast of Florida. These buoys measure the wave height and period, but provide no directional data. The aim of the present study is to overcome this shortcoming in an effort to make the predictive index operational. Through correspondence with the scientists operating the ECFL LURCS at the National Weather Service, the author determined what information was readily accessible to them during the forecasting process. One such asset is the output of the WAVEWATCH III model managed by the National Oceanographic and Atmospheric Association (NOAA). WAVEWATCH III is a global wave model used to predict height, period and direction at each of its grid points. It is executed every six hours (ex. 12am, 6am, 12pm, and 6pm) and the output is given on one-hour intervals for the following seven days. The resulting information could prove valuable by improving the index not only with the inclusion of wave direction but also through the extension of the forecast. Currently the rip current index calculation is prepared in the morning, and the rip current threat is ascertained for the same day. The conditions (and warnings if necessary) are distributed to the public through different avenues of the media, such as NOAA weather radio. Knowledge of the rip current threat a day in advance would help in the education and awareness of the public as well as establishing additional staffing needs of the local beach lifeguards.

This study built upon the previous work of Engle (2004), by the inclusion of a wave direction parameter and a modified tidal stage parameter. The modified index created here, and each of its parameters, was refined through testing on a long-term data set. This data consisted of rip-related rescues and hindcast oceanographic conditions. After finalization of the modified index, an investigation was conducted implementing the WAVEWATCH III forecast wave data (which includes wave direction) into the prediction methods. The WAVEWATCH III examination was completed to assess the forecasting capabilities of a modified prediction scheme.

CHAPTER 4
DATA

Site Description

The study site is separated into two sections, both of which are located on the central east coast of Florida (Figure 4-1). The northern section is comprised of the Volusia County beaches ranging from the North Ormond region south to New Smyrna. The southern section consists of the Brevard County beaches extending from Cape Canaveral south to Melbourne beach. The two sections are divided by the property of NASA's Kennedy Space Center.

The coastline of Volusia and Brevard County consists of sandy beaches with a mean sediment diameter of about 0.23mm and 0.33mm respectively (Charles et al. 1994). The nearshore bathymetry of both locations typically includes a single shore-parallel bar and trough configuration. The approximate azimuth of Volusia County is 62º East of North. The shoreline angle of Brevard County shifts due to a coastline perturbation at the location of the Kennedy Space Center. The azimuth therefore migrates gradually from 100º in Cape Canaveral to approximately 65º in Melbourne Beach (Figure 4-1). The continental shelf in the Volusia County region extends out approximately 80km from shore and the contours are relatively shore-parallel (Engle 2003). The continental shelf narrows further south on the Florida coastline, and therefore the width decreases to approximately 60km in Brevard County. However, the bottom contours remain relatively shore-parallel. The tides in Volusia and Brevard County are semidiurnal and have a maximum range of approximately 6-½ ft (2m).

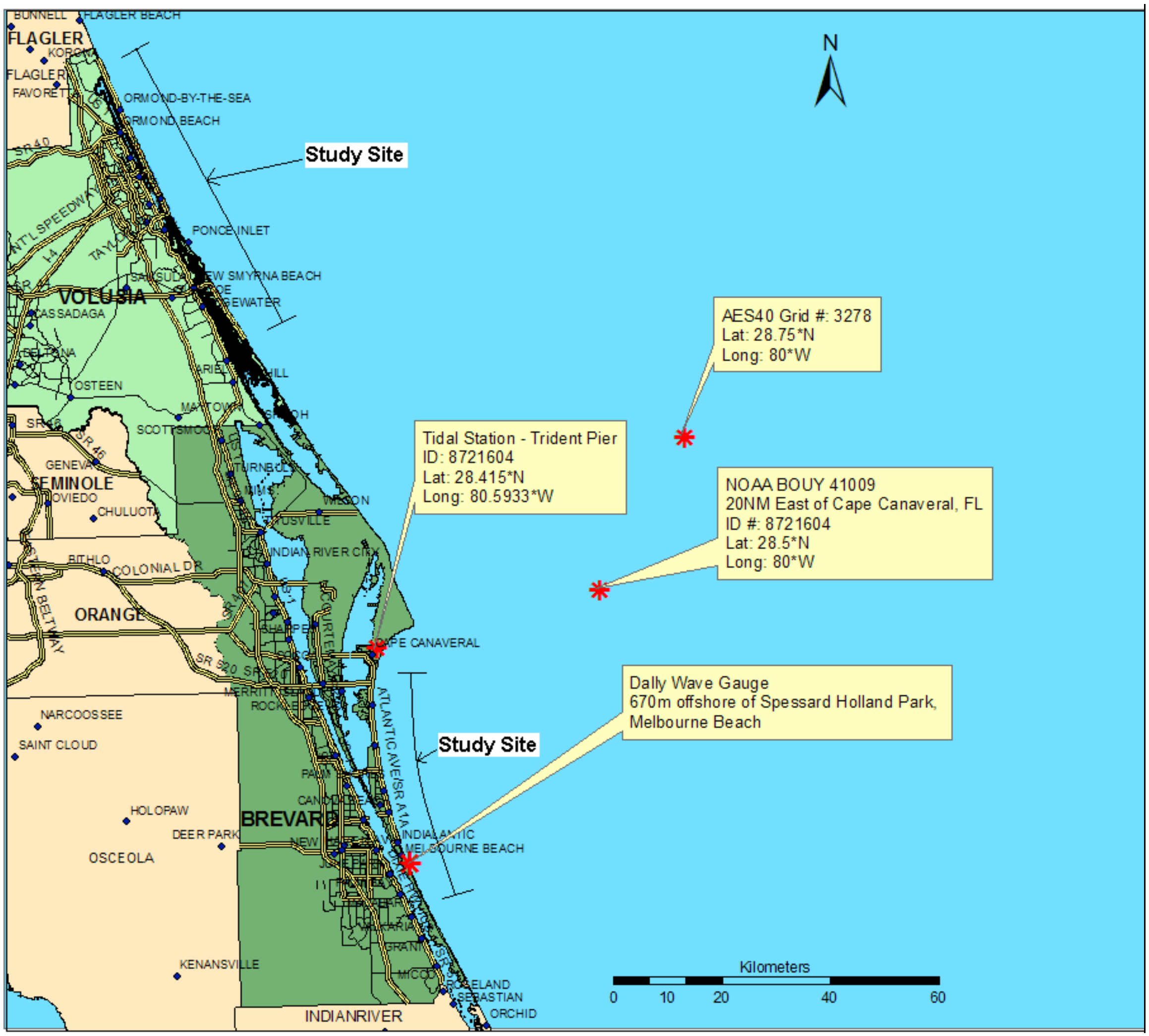

Figure 4-1. Map displaying the study site of Volusia and Brevard Counties as well as the locations of the tidal gauge, the AES40 grid point 3278, the NOAA buoy 41009, and the Melbourne Beach Wave Gauge.

Rip Current Rescues

Archived rescue logs were obtained from the Volusia County Beach Safety Division extending from 1997 through 2005. Each lifeguard reports their daily rescue activity including the date, location, type of rescue, and number of victims involved. This study utilizes both the number of daily rip related incidences and the number of victims rescued in each rip current incident. The reports are divided into six zones: (1) North Ormond to Flagler County line (2) Ormond Beach (3) Daytona Beach (4) Daytona Beach

Shores (5) Dunlawton Avenue south to Ponce Inlet jetty and (6) New Smyrna. The rip current predictive index has been formulated for application on the entire central east coast of Florida. In order to limit the possible spurious correlations due to localized effects, the present study does not account for the zones separately but compiles the rescue information from each zone into one comprehensive record.

Hindcast Data

Historic oceanographic (wave height, period, and direction) and meteorological (wind speed and direction) conditions were provided by the AES40 North Atlantic Wind and Wave Climatology hindcast model called OWI 3-G. The OWI 3-G model is a direct spectral type based from the WAM model (WAMDI Group 1988), and was originally developed by Oceanweather Inc. during a project for the Meteorological Service of Canada. The model grid spans from the equator in the south to the 75.625º latitude in the north, with the North American coastline representing the western boundary and the 20º longitude as the eastern boundary. The grid is spaced at 0.833º increments in the longitude and 0.625º increments in the latitude, therefore consisting of 9023 wet grid points. The information in this study was extracted from grid point #3278, which is located at 28.75º N latitude and 80º W longitude (Figure 4-1).

The OWI 3-G model has been tested to validate the precision of the model's deepwater wind and wave output. A quantile-quantile evaluation performed by Swail et al. (2000) compared the model hindcast with recorded satellite and buoy information. A quantile-quantile assessment is used to determine if two data sets are comprised of a common distribution. The study exhibited a good correlation in the 1^{st} to the 99^{th} percentile between the model output and the documented real-time data.

Tides

The tidal data used in analyzing the ECFL LURCS and the modified version was obtained through NOAA Tides Online Historical Data Retrieval. The tidal station ID is 8721604 (Trident Pier) and is located at 28.415º N and 80.5933º W (Figure 4-1). The local times of low tide were obtained on a daily basis for calculations in the modified rip current predictive index.

The moon phases for each year of the study were acquired from the U.S. Naval Observatory website “http://aa.usno.navy.mil/data/docs/MoonPhase.html”. The occurrence of the new and full moon phases were used during the calculations of the ECFL LURCS. For the days before, after, and during a full or new moon the astronomical tide factor was included in the rip current threat level.

WAVEWATCH III

The WAVEWATCH III (Tolman 1997, 1999a) model is a third generation wave model developed at the Ocean Modeling Branch of the National Center for Environmental Predictions (NCEP/NOAA). WAVEWATCH III solves the spectral action density balance equation for wavenumber-direction spectra. Assumptions within this method limit the model to application outside the surf zone and to spatial scales larger than 1km. The source terms for the model include wave growth and decay due to the actions of wind, nonlinear resonant interactions, dissipation due to white-capping and bottom friction. The model uses a regularly spaced longitude-latitude grid. The spectral discretization of the wave energy applies an invariant logarithmic intrinsic frequency grid to spatially vary the wavenumber (Tolman and Booij 1998). The directional increment of the wave energy spectra is constant and covers all directions. The output of the resulting wave spectra is at selected locations. In this study the output location used is identical to the position of the NOAA buoy 41009 (Figure 4-1).

Lifeguard Observations

In an agreement with the University of Florida Department of Coastal Engineering, Brevard County lifeguards were asked to document daily observations of the nearshore conditions. The protocol consisted of completing a prearranged worksheet containing various air and sea parameters (Figure 4-2). The beaches of Brevard County are usually heavily occupied, resulting in an excess of responsibilities for the lifeguards. Therefore, the observations are logged sporadically through October, November and December of 2004, along with May, June and July of 2005. Knowledge of the conditions from a first-hand observer can still prove to be qualitatively useful during the analysis process.

Completed ECFL LURCS Worksheets

Completed ECFL LURCS worksheets (Figure 4-3) were obtained from the National Weather Service (NWS) extending from April to October of 2005. These worksheets were filled out by NWS employees and used to distinguish if a warning should be issued.

Melbourne Beach and NOAA Data Buoys

There is one existing wave buoy on the central east coast of Florida that measures wave direction. This buoy is funded through the beaches and shores division of Florida State University (FSU) and maintained by Dally at Surfbreak Engineering. It was deployed off the coast of Melbourne Beach in a depth of approximately 8m (Figure 4-1). The nearshore wave information obtained from this buoy was used to corroborate the observations made by the Brevard County Lifeguards. The NOAA Data Buoy (# 41009,

Figure 4-1) was utilized as a qualitative reference for oceanographic and meteorological conditions throughout the study.

University of Florida Wave Conditions and Rip Current Checklist

Date: 8.15.05

Time: 1000

Observer: WYATT WERNETH

Location: LORI WILSON

Gator Engineering

Breaking Wave Height (ft): [0] [1] [2] [3] [4] [5] [6] [7] [8] [9] [10] [>10]

Wave Period (s): [4] [5] [6] [7] [8] [9] [10] [11] [12] [13] [>13]

Wave Direction: [Strong N-S] [Weak N-S] [Directly Onshore] [Weak S-N] [Strong S-N]

Rip Channel Development: [None] [Weak] [Moderate] [Strong]

Tidal Stage: [Extreme High] [High] [Mid-high] [Mid] [Mid-Low] [Low] [Extreme Low]

Tidal Direction: [Falling] [Stationary] [Rising]

Mid-Tide Bar Depth (ft): [No Bar] [0.5] [1] [1.5] [2] [2.5] [3] [3.5] [4] [4.5] [5] [5.5] [6] [>6]

Longshore Current (ft/s): [4 N-S] [3 N-S] [2 N-S] [1 N-S] [0] [1 S-N] [2 S-N] [3 S-N] [4 S-N]

Rip Current Danger: [None] [Low] [Moderate] [Significant] [High] [Extreme]

Surf Danger: [Very Mild] [Mild] [Moderate] [Rough] [Very Rough] [Extreme]

Weather: [Sunny] [Partially Cloudy] [Overcast] [Raining]

Air Temperature (˚F): [<50] [50-60] [60-65] [65-70] [70-75] [75-80] [80-85] [85-90] [90-95] [>95]

Water Temperature (˚F) [<50] [50-60] [60-65] [65-70] [70-75] [75-80] [80-85] [85-90]

Comments:

Figure 4-2. Lifeguard observation worksheet completed on August 15, 2005.

NAME LASCODY (check box if statement issued) ☐ DATE 9/2/05

CALCULATING DAILY RIP CURRENT THREAT-- ECFL LURCS

1. WIND FACTOR	**ONSHORE** (40-100°)	**LONGSHORE FACTOR** (110-160°, 340-30°)
10-14 kt	2.0	-0.5
15-19	3.0	-1.0
20-24	4.0	-2.0
25 +	5.0	-3.0

ONSHORE FACTOR ____________ **LONGSHORE FACTOR** ____________

2. SWELL FACTOR (Do not include WIND WAVE height)

a)	SWELL HEIGHT	SWELL HEIGHT FACTOR
	1 ft	0.5
	2	1.0
	3-4	2.0
	5-7	3.0
	8-10	4.0
b)	**SWELL PERIOD**	**SWELL PERIOD FACTOR**
	8 sec	0.5
	9-10	1.0
	11	1.5
	12-13	2.5
	>13	3.5

SWELL HEIGHT FACTOR + SWELL PERIOD FACTOR = **SWELL FACTOR** 1.0-2.0

3. MISCELLANEOUS FACTORS

If astronomical tides are higher than normal (i.e., near full/new moon), add 0.5

If previous day swell factor ≥ 1.5, add 0.5

MISC. FACTOR 0.5

4. TODAY'S RIP CURRENT THREAT is summation of **LONGSHORE, SWELL and MISC.** factors

Do not include ONSHORE FACTOR **RIP CURRENT THREAT** 1.5-2.5

5. IF RIP CURRENT THREAT is < 2.5, there is a LOW RISK of rip currents, and generic statement for rip currents near piers/jetties may be mentioned for values 1.5 - 2.5.

If RIP CURRENT THREAT is 3.0 - 4.5 (2.5 - 4.5 on weekends): issue statement for MODERATE RISK of rip currents.

If RIP CURRENT THREAT is ≥ 5.0: issue statement for HIGH RISK of rip currents (*coordinate with DAB Beach Patrol*).

IF ONSHORE FACTOR is ≥ 3.0 or **SWELL FACTOR** is ≥ 4.0, highlight rough surf.

IF ONSHORE FACTOR > 4.0 or **SWELL FACTOR** is ≥ 6.0, consider High Surf Advisory.

IF LONGSHORE FACTOR is ≤ -1, discuss longshore current threat in HWO (depicted as LOW RISK in gHWO). **(Z:\Randy\Marine\RipNew\Oct2003sheet.wpd)**

Figure 4-3. A completed ECFL LURCS worksheet from September 2, 2005.

CHAPTER 5
DEVELOPEMENT OF IMPROVED RIP CURRENT INDEX

Analysis

Lushine (1991), Lascody (1998) and Engle (2003) all used rescue and drowning incidences to develop and test their respective rip current predictive scales. Lushine (1991) obtained medical examiner's information, beach patrol rescue logs and newspaper clippings in Dade and Broward Counties from 1979 to 1988. Lascody (1998) acquired similar information in Volusia, Brevard, Indian River, St. Lucie and Martin Counties from 1989 to 1997. Engle (2003) utilized lifeguard rescue logs in Volusia County for only one year, 1996. The aim of this study is to verify the inclusion of wave direction, proposed by Engle (2003), and the adjustment of other parameters by exploring a long-term data set (1997–2004).

Lifeguard rescue logs have proved to be useful in developing a rip current prediction scheme. Lushine (1991) and Lascody (1998) showed that rip current rescues are a good qualitative representation of rip currents themselves. The obvious drawback to this method is that the data can be strongly dependent on the population of ocean-goers. If there are no people in the water, then there will be no evidence of a rip current. This doesn't necessarily mean there was no occurrence of a rip current; it might only mean there weren't any bathers to be rescued from one. A good example of this phenomenon is the winter season. On the central east coast of Florida, the water becomes relatively cold in the winter months. Therefore considerably less people enter the water and fewer rescues are logged. In examination of Figure 5-1, the majority of rescues occur during the summer months. This does not necessarily indicate a reduction of rip current activity in the winter months, but is far more likely the effect of the dependency of rip current rescues on ocean-goers.

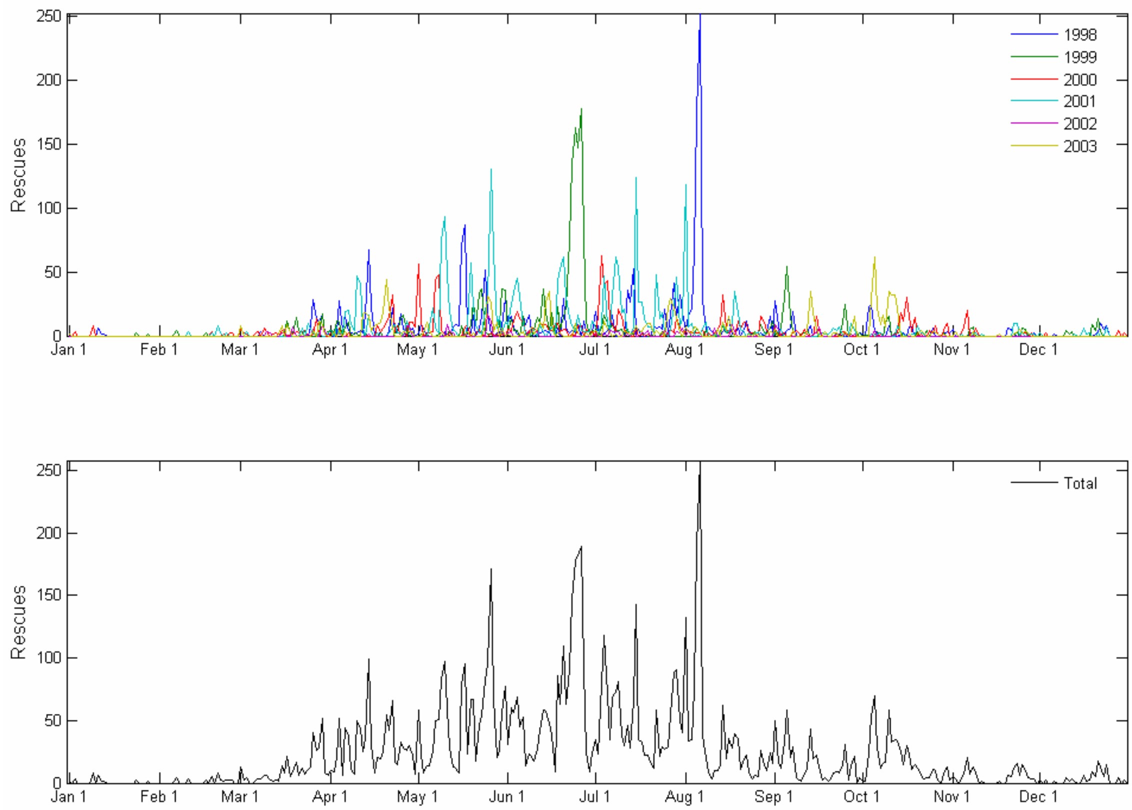

Figure 5-1. Time-series plot of daily rescues for each individual year (top) and the total daily rescues (bottom) as logged by the Volusia County lifeguards (1998–2003).

Limiting the examination and analysis of rip current rescues to the summer season mitigates the issue concerning a lack of bathers during the winter. The assumed peak days of attendance are from day 75 to day 250 of a given year. This time frame translates into mid-march until early September. The month of March signifies the start of spring break vacations and the east coast of Florida is considered a prime destination. The rising influx of tourists is directly associated with an increase in rescues (Figure 5-1). The rescues then become more inconsistent in September as the water temperature starts to decrease and hurricane season is ongoing. As seen in Table 5-1, the majority of the rescues occur during the previously defined summer season. When rescues are totaled over the years examined, excluding 2002 for reasons explained later, almost 87 percent of the rescues occurred in the summer.

Table 5-1. Percentage of rip-related rescues occurring in the summer (defined as day 75–250), 1998 to 2003.

	1998	1999	2000	2001	2002	2003
Total rescues	2058	1799	1232	2399	226	1135
Summer rescues	1887	1633	972	2256	201	723
Percent summer	0.92	0.91	0.79	0.94	0.89	0.64

This study was also quantitatively limited to the years 1998, 1999, 2000, 2001, and 2003. The exclusion of 1997 and 2004 is due to the lack of data coverage in both of these years. The rescue data from 1997 is limited and the hindcast data from 2004 is only available for the first half of the year. Both years were still examined on a daily basis, investigating the high rescue days and qualitative correlations, but overall summer statistics were withdrawn. The omission of 2002 is because of the significant lack of rescues occurring during this year. In Table 5-1 a dramatic decrease in rescues from the other years can be seen. The reason for this is unknown, but one assumption is the considerable decrease of tourism travel in the year following the September 11th terrorist attacks. Independent of cause, the data demonstrates an unnatural decrease in rescues for 2002, and consequently the year was removed from the study.

Another difficulty when using rescues to mark rips is the effect of rough water conditions and/or inclement weather. If the surf zone is violent people are hesitant to enter the water and if the weather conditions are poor (ex. rain, clouds) people are even less likely to make the trip to a beach. This predicament is not as easily remedied as the previous situation. The only assurance is that the ECFL LURCS and the newly modified index were exposed to the same problem. Therefore, any such disadvantages are assumed to equally challenge the predictive capability of both indexes.

The first step in improving the present index was to develop a preliminary new index. The new index was built on the same foundation as the two previous indexes. The LURCS and ECFL LURCS assess given input conditions and then return a rip current threat level. Each input parameter affects the index by increasing or decreasing the resulting threat level. An example of a completed ECFL LURCS worksheet is shown in chapter 4 (Figure 4-3). Approximate ranges for each parameter and their respective threat values are already established. When the conditions (e.g., Wave height) are found to lie in a given range, a value is assigned to that particular factor. After completing the list of factors, their respective values are summed to obtain a threat level. The severity of rip current danger is dependent on the threat level, and a predetermined threshold establishes if it is advisable to issue a warning.

The adjustments to the new index were loosely based on an approach established in previous work done by Engle (2003), which served to eliminate the wind parameter, incorporate wave direction, and modify the tide factor. The aforementioned data was then used to test the performance of the new rip current prediction index (RIPDEX) against the ECFL LURCS currently applied by the NWS. Each new (e.g., direction and tide) and old (e.g., swell height and period) parameter was tested and modified in a cyclic process to ensure the index reached maximum performance levels. The previous work by Engle (2003) initiated the idea of applying these new factors (e.g., wave direction) to increase the accuracy of the ECFL LURCS. Now a far longer data set can be used to better establish the correct ranges for each input parameter and to clarify each of their roles in a more optimal prediction scheme.

Ocean Correlations

The oceanographic parameters used in index computations were examined to determine their importance in the formation of rip currents. These parameters include wave direction, wave height, wave period and the time of low tide. Each parameter was first examined from a qualitative viewpoint. Figure 5-2 is a time-series plot of daily wave height, period and direction along with the amount of rip current incidents (rips) and the number of victims rescued from each rip (rescues) for 2001. The wave direction is given in meteorological convention, which is measured clockwise from true north (recall that 62º represents shore-normal for Volusia County). The "x" marks on the plots of height, period and direction correspond to days with more than 15 rescues. These days along with other spikes in the number of rescues were used to identify associations between the wave characteristics and rescues.

In Figure 5-2 the high rescue days tend to occur during peaks in the wave period. An example of this can be seen in the beginning of the month of May. The wave period increases from 7 to 11 seconds and the result is multiple days consisting of rescue numbers greater than 15. Another aspect possibly effecting the same time period is the synchronized spike in wave height. Larger waves with longer periods (e.g., distant swell) are directly attributed to an increase in rip current intensity (Shepard et al. 1941). An interesting observation is the successive days of high rescues during the subsidence of this wave height spike. A possible mechanism for such observations may include both physical and human behavioral effects. The increase in wave height and period may lead to the formation of rip channels in the bar, but it is probably too rough for most beach patrons to confidently enter the water. When the severity of the conditions begins to subside the people waiting become more inclined to enter the surf zone. However, the channels remain intact and the rip currents still pose a considerable threat to bathers. Such events indicate the importance of knowing the ocean conditions and rip current threat for the previous days and lend credence to the use of "persistence factors" in prediction.

Figure 5-2. Time-series plots of wave height (ft), wave period (sec), wave direction (deg) and rip current incidents with associated rescues for 2001. The "x" marks correspond to days with more than 15 rescues.

In 1998 there is a dramatic spike in rescues in the beginning of August and it seemed justified to investigate it further (Figure 5-3). On August 4^{th}, 5^{th}, and 6^{th} there were 65, 175, and 252 rescues respectively. These three days accounted for 24% of the rescues recorded in 1998. All of the days landed in the middle of the week, so the often-observed weekend population effect was not a relevant issue. The next logical step was to examine the conditions prior to the incident. In the days leading up to this spike there was a period of relatively consistent swell periods and heights, and the wave direction was slightly north of shore-normal. These consistent rip current generating conditions likely resulted in the formation of localized rip channels, and were verified by the rescues on days prior. Then, as seen in Figure 5-3, the wave direction suddenly changed to the southeast and as the direction migrates back to its original values the abnormal spike in rescues occurred. It is hypothesized that the large change in wave direction over a relatively short time period may magnify the instabilities of a longshore bar and rip current system. This magnification results in more hazardous conditions for beach-goers.

Similar plots were generated for the other 7 years included in this study (see appendix A). Each plot was also qualitatively examined to assist in investigating the connection between each parameter and the occurrence of rip-related rescues.

The parameters of the rip current predictive index were then further explored to find the range of conditions that constituted the greatest association with rip current development. Each parameter was dissected into distinct ranges, and then associated with the rips and rescues occurring on those days when the conditions are in their particular ranges. A histogram is plotted for every year, grouping the normalized frequency of the oceanographic parameter along with the rip current incidents and the related number of rescues.

Figure 5-3. Time-series plots of wave height (ft), wave period (sec), wave direction (deg) and rip current incidents with associated rescues for 1998. The “x” marks correspond to days with more than 15 rescues.

Wave height

The first correlation discussed is between rip currents and the offshore significant wave height (H_O). The record of wave height was divided into one-foot categories ranging from zero to ten feet (0–3.05m). Figure 5-4 displays three bars plotted in each range. The first (blue) bar represents the percentage of days the significant wave height provided from the hindcast was in the specified range. The second (green) bar represents the percentage of rip-related rescues occurring on the days when the associated wave height was in the respective range. The third (red) and final bar represents the percentage of rip current observations made by the lifeguards when a rescue occurred, which is independent of the number of rescue victims. A comparison of the latter two bars provides some insight of how severe the rip currents were in a specified condition range.

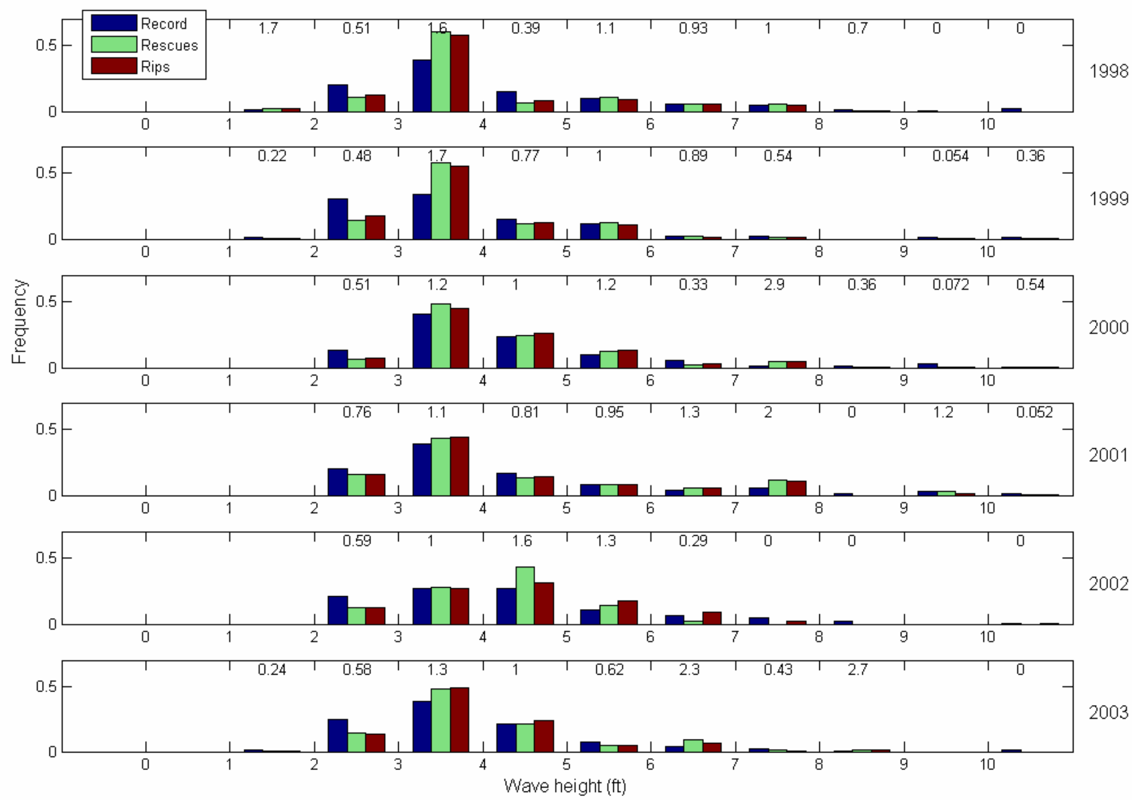

Figure 5-4. Correlation histogram-plot of offshore significant wave height (ft) along with rip current incidents and associated rescues for years 1998 to 2003. The blue (1^{st}) bar represents the percentage of days that the wave height was within the respective range. The green (2^{nd}) and red (3^{rd}) bars represent the percentage of total rescues and the percentage of rip current incidents respectively, that occurred when the wave height was within that range. The numbers on the top of each plot correspond to the ratio of the blue and green bar magnitudes.

A trend can be seen from year to year that the majority of the wave heights occur in the 2 to 6 foot (0.61–1.83m) range. An interesting characteristic of Figure 5-4 is the high number of rescues occurring in the 3 to 4 foot (0.91–1.22m) range of wave height. If the percentages are combined over all the years, excluding 2002, approx 52% of the rescues occur when the wave heights are between 3 and 4 feet. When examining the histograms, an important aspect is the difference in magnitude within each group of bars. If the rescue and/or rip current bar is greater than the actual occurrence of the parameter, then this constitutes a higher risk of rip-related rescues on days with those conditions. The difference in the magnitude of the first two bars is represented by the ratio value displayed above each group of bars. This ratio value is calculated as the magnitude of the green (2^{nd}) bar divided by the magnitude of the blue (1^{st}) bar. A ratio value greater than one corresponds to a higher relative risk of rip-related rescues occurring. In 1998 for example, 39% of the documented wave heights and 60% of the total rescues occurred in the 3 to 4 foot (0.91–1.22m) range. However, 20% of the wave heights occurred in the 2 to 3 foot (0.61–0.91m) range, along with only10% of the total rescues. Therefore, on days when the wave height range was 2 to 3 feet there was an average of 3.3 rescues, but on days with a height range of 3 to 4 feet there was an average of 10.4 rescues.

The relative importance of each range to the threat level is well represented in the ECFL LURCS and therefore was not changed. The contribution of the swell height parameter to the computation of the modified index is as follows:

- $H_O < 1$ft → swell height factor = 0
- 1 ft $\leq H_O <$ 2 ft → swell height factor = 0.5
- 2 ft $\leq H_O <$ 3 ft → swell height factor = 1
- 3 ft $\leq H_O <$ 5 ft → swell height factor = 2
- 5 ft $\leq H_O <$ 8 ft → swell height factor = 3
- 8 ft $\leq H_O$ → swell height factor = 4

Wave period

The next oceanographic parameter reviewed is the peak wave period associated with the incoming swell (T_P). In Figure 5-5 the wave period is divided into 1-second intervals ranging from 4 to 13 seconds. The groups displayed outside this range include all occasions below 4 seconds and above 13 seconds respectively. The majority of the recorded wave periods occur in the range of 5 to 9 seconds, approximately 77% of all the years combined. Remember the analysis is limited to the summer months when the average wave period is generally shorter in comparison with the winter. It is apparent there is a high ratio of rescues on days when the wave period is between 6 and 8 seconds. In 1999 and 2003 there is a high risk of rescues between 7 and 8 seconds, represented by ratio values of 1.7 and 1.5 respectively. In 1999, 2000, 2001, and 2002 there is a high risk of rescues between 6 and 7 seconds, represented by ratio values of 1.9, 1.4, 1.3 and 1.5 respectively. This trend varies a bit from year to year, but overall there was an average of 9.1 rescues per day in the 6 to 8 second range, which is slightly above normal. The average for all the summers combined, excluding 2002, was 8.5 rescues per day.

The ECFL LURCS only accounts for swells with periods longer than 8 seconds. However evidence has shown reason to include a slightly shorter period swell, especially as a result of the high beach attendance in the summer. The longer period swell remains an integral part in the progression of a hazardous surf environment (Figure 5-5). Basically the swell period factors were shifted down two seconds, still adhering to the structure of assigning a larger threat value for an increased swell period. The resulting contribution of the swell period parameter to the modified index calculation is as follows:

- $T_P < 6s \rightarrow$ swell period factor = 0
- $6s \leq T_P < 7s \rightarrow$ swell period factor = 0.5
- $7s \leq T_P < 9s \rightarrow$ swell period factor = 1
- $9s \leq T_P < 11s \rightarrow$ swell period factor = 2
- $11s \leq T_P \rightarrow$ swell period factor = 3

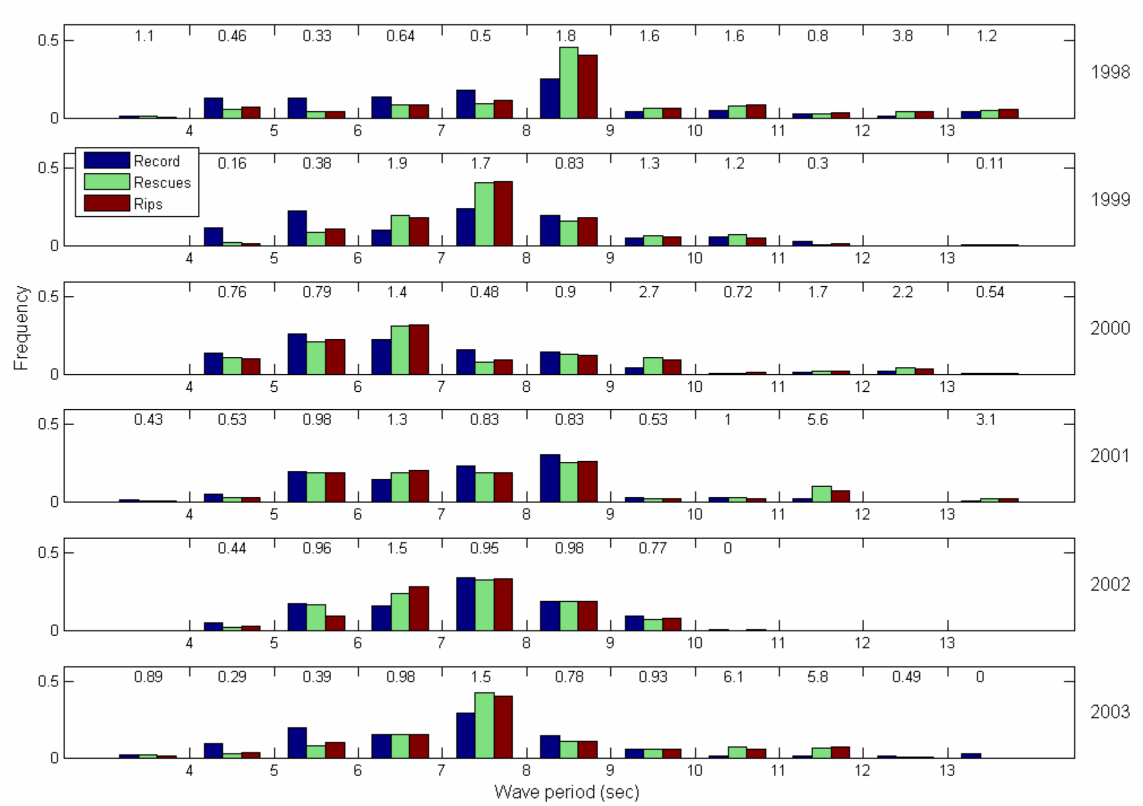

Figure 5-5. Correlation histogram-plot of peak wave period (sec) along with rip current incidents and associated rescues for years 1998 to 2003. The blue (1st) bar represents the percentage of days that the peak wave period was within the respective range. The green (2nd) and red (3rd) bars represent the percentage of total rescues and the percentage of rip current incidents respectively, that occurred when the peak wave period was within that range. The numbers on the top of each plot correspond to the ratio of the blue and green bar magnitudes.

Wave direction

The first additional parameter introduced to the new index is offshore wave direction (D_O). Direction is considered to be a valuable factor when determining the level of rip current formation and subsequent danger to ocean-goers (McKenzie 1958, Sonu 1972, and Engle 2003). The next step is achieving a way to include swell direction into the index and presumably improve the accuracy.

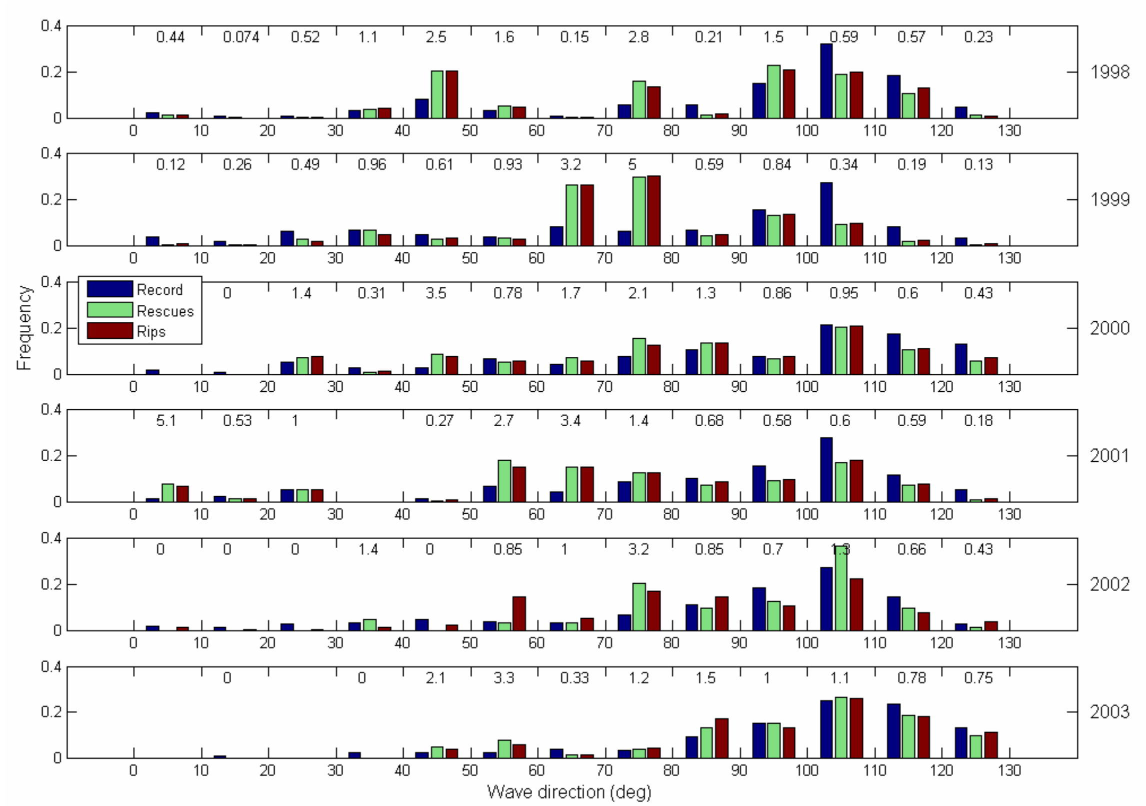

Figure 5-6. Correlation histogram-plot of offshore wave direction (deg) along with rip current incidents and associated rescues for years 1998 to 2003. The blue (1st) bar represents the percentage of days that the wave direction was within the respective range. The green (2nd) and red (3rd) bars represent the percentage of total rescues and the percentage of rip current incidents respectively, that occurred when the wave direction was within that range. The numbers on the top of each plot correspond to the ratio of the blue and green bar magnitudes.

The shoreline azimuth where the lifeguards rescue information was obtained (Volusia County) is approximately 62º. When viewing Figure 5-6, the incident wave field is considered orthogonal to shore if the angle is relatively close to this value. The figure shows a large number of incidences when the wave angle is greater than 90 degrees, accounting for the high number of southeast summer swells. Although more waves originate from the southeast in the summer, the greatest association with risk or danger to swimmers applies to shore normal conditions. Through general inspection of the size differences within bar groups, the greatest risk was associated with angles in the range of

40 to 80 degrees. This is justified by the high ratio values within this degree range, which translates to approximately 20 degrees north and south of shore-normal. In the summer of 1999, when the wave angle was between 60 and 80 degrees, there was an average of 37 rescues per day. Although 1999 is probably an extreme case in comparison to the other years, it still illustrates how large of an effect wave direction can have.

Direction was first incorporated into the new index in the same manner as wave height and period. The closer the wave direction was to shore normal, the larger the value of the direction factor. Then this factor was directly applied, through summation, to the rip current threat level. After the first couple of tests, which are discussed later in this chapter, there was little progression in the probability of detection and a slight increase in false alarms. The decision was then made to approach the inclusion of wave direction in another manner. The new approach consisted of using the wave direction factor as a multiplier of the other swell conditions (height and period). In this method the wave direction worked together with the other swell parameters to indirectly affect the threat level. The indirect association to the threat level was an attempt to decrease the false alarms occurring on days with an exceedingly small swell directed onshore. Also incorporated into the multiplicative parameter was a reduction of the threat level due to an oblique incident wave field. The results of the testing showed improvements in the overall performance of the index, not just the false alarm ratio. The positive response initiated additional effort to refine the method, and the contribution of the swell direction parameter was finalized as follows:

- $-20^{\circ} \leq D_O < 30^{\circ} \rightarrow$ swell direction multiplier = 0.75
- $30^{\circ} \leq D_O < 45^{\circ} \rightarrow$ swell direction multiplier = 1.5

- $45^{o} \leq D_O \leq 75^{o}$ → swell direction multiplier = 2
- $75^{o} < D_O \leq 100^{o}$ → swell direction multiplier = 1.5
- $100^{o} < D_O \leq 150^{o}$ → swell direction multiplier = 0.75
- Else → swell direction multiplier = 1

Low tide

In the ECFL LURCS the tidal factor only pertains to an increase in the tidal range due to astronomical effects (Figure 4-3). Rip current researchers agree that low tide directly affects the formation of rip currents on a barred beach (Shepard 1941 and Brander 1999). Additionally, if a rip channel was already established, the decrease in water depth will intensify the rip current flow (Shepard 1941, Sonu 1972 and Brander 1999). Both produce an increased hazard for ocean-goers. Engle (2003) attempted to change the tidal parameter through a relation to the actual tidal level. This proved valuable when analyzing rescues taking place at different times throughout the day. The conclusion was the majority of the rescues occurred during the rising tide. However, the incorporation of tidal level into the index is difficult because the threat assessment is on a daily basis and the tidal level is changing periodically throughout the day. To account for the effect of low tide, the new tide factor will adjust depending on the time of day low tide occurs.

In this study the greatest risk to swimmers occurs when low tide is between 10 a.m. and 12 p.m. (Figure 5-7). In 1998 there was an average of almost 21 rescues per day when low tide occurred between 10 a.m. and 12 p.m. This justifies the previous results from Engle (2003) because the rising tide would then occur during the middle of the day, when the beach is most populated.

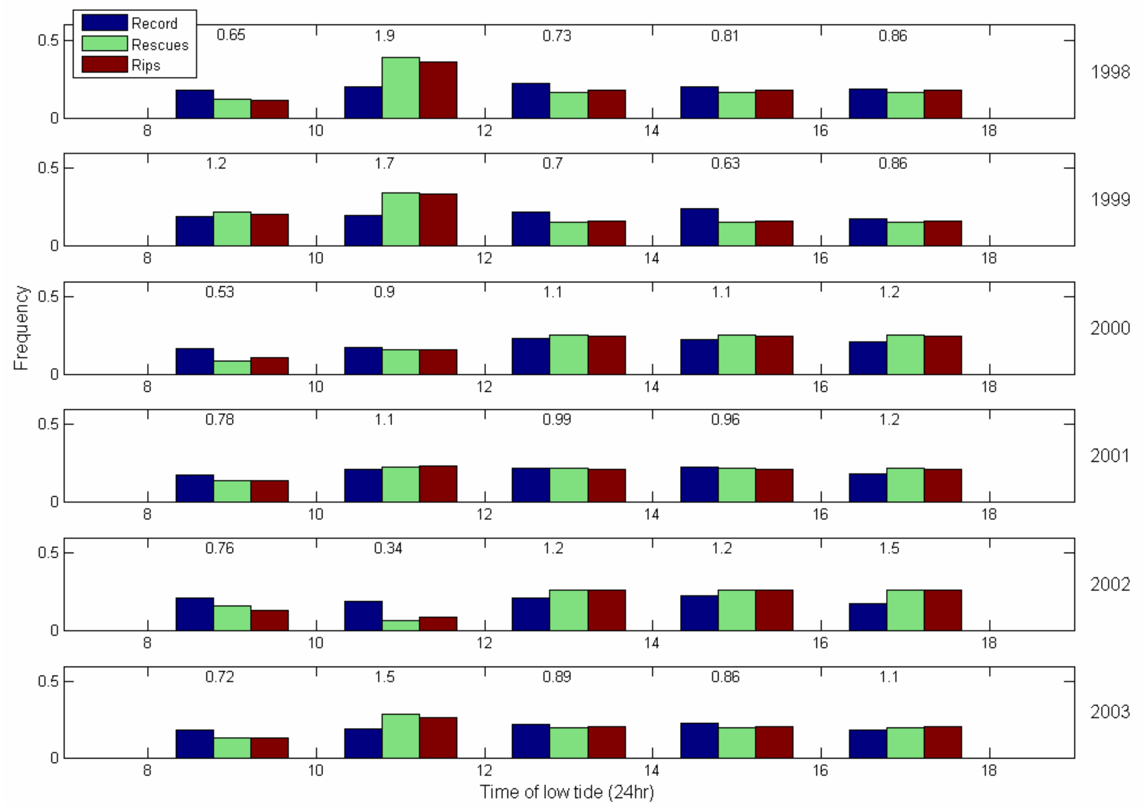

Figure 5-7. Correlation histogram-plot of the time of low tide (24hr) along with rip current incidents and associated rescues for each year from 1998 to 2003. The blue (1st) bar represents the percentage of days that low tide occurred within the respective time range. The green (2nd) and red (3rd) bars represent the percentage of total rescues and the percentage of rip current incidents respectively, that occurred when low tide occurred within that time range. The numbers on the top of each plot correspond to the ratio of the blue and green bar magnitudes.

The increased risk of rescues on the rising tide could be attributed to mental aspects as well as physical. During low tide the waves break more violently on the sandbar and aid in the development of rip channels. The intense breaking detours people from swimming, then when the tide slowly raises the breaking intensity visually decreases and people feel secure enough to enter the water. The incident wave conditions might have only experienced minimal changes, persistently forcing the nearshore circulation system. Yet, more people are entering the water in confidence, which leads to an increased number of rescues. The new tidal parameter was adjusted to raise the rip current threat level if low tide coincides with the daytime beach attendance. The scale is slightly asymmetrical due to the increased rescue dependence found on the rising tide, and the contribution to the index calculation is as follows:

- Low Tide < 9am → tidal factor = 0
- 9am ≤ Low Tide < 1pm → tidal factor = 1
- 1pm ≤ Low Tide < 5pm → tidal factor = 0.5
- 5pm ≤ Low Tide → tidal factor = 0

With the ranges of each parameter and their respective influence over the rip current index calculations established, the modified index was then tested against the existing form of the ECFL LURCS to validate the adjustments made, and observe any improvements.

Testing

The ECFL LURCS and the newly modified index, with the adjusted parameters discussed in the previous section, were tested on a data set ranging from 1998 to 2003. Each index was computed on a daily basis using the oceanographic and meteorological conditions given by the OWI 3-G hindcast. The daily rip current threat level was attained from each respective index and then compared with the lifeguard records of rip currents and their related rescues. Figure 5-8 is an example of the results of the index calculations and the concurrent lifeguard records for the year 1998, after the changes to each parameter were finalized (for remaining years see appendix B). The horizontal lines represent the respective warning thresholds. If the plot of each respective rip current index is above this threshold then it is recommended to issue a warning to the public.

The purpose of the testing process was to substantiate the inclusion of wave direction and the modifications made to the other parameters in the rip current predictive index. To assess the performance of both the ECFL LURCS and the modified index, six statistical parameters were used (1) Alarm Ratio, (2) False Alarm Ratio Method 1, (3) False Alarm Ratio Method 2, (4) Correct Alarm Ratio (CAR), (5) Probability of Detection Method 1, and (6) Probability of Detection Method 2. Each was computed using the rip current incidents as well as the related rescues documented by the Volusia County lifeguards.

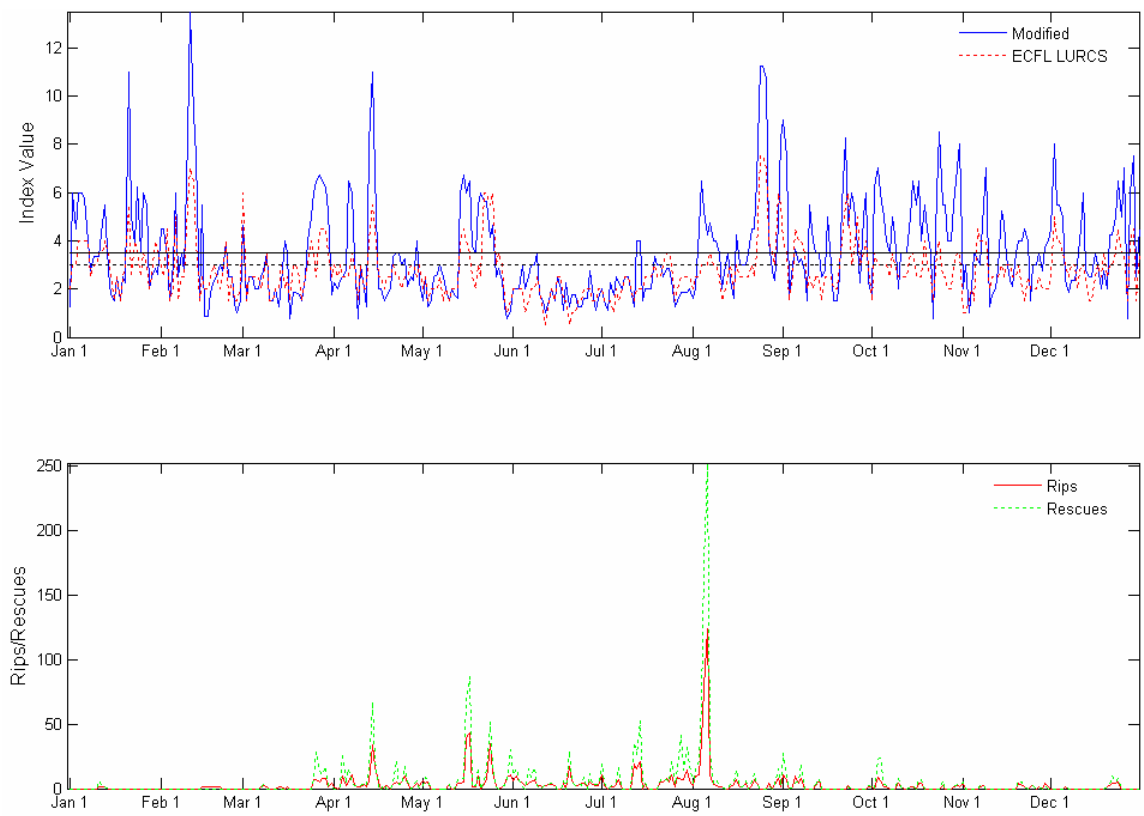

Figure 5-8. The daily-calculated threat values of both the ECFL LURCS and the modified index (top) along with the daily rip current incidents with associated rescues (bottom) for 1998. The horizontal lines represent the warning threshold for each respective index.

Engle (2003) introduced the Alarm Ratio (AR) as a control when comparing a modified rip current predictive scale with an existing scale. The AR is defined as the percentage of days each respective index would issue a warning.

$$\text{AR} = \frac{\text{Days Index } \geq \text{ Threshold}}{\text{Total Days}}$$

The False Alarm Ratio (FAR) is the measure of over warning. The first method (FAR1) is commonly used by the National Weather Service (NWS) and is calculated as the number of days an index issued a warning without the occurrence of rescues normalized by the total number of days the index issued a warning. The result is the percentage of warnings given by the respective rip current index when no rescues occurred.

$$\text{FAR1} = \frac{\text{Days Index } \geq \text{ Threshold w/ no Rescues}}{\text{Days Index } \geq \text{ Threshold}}$$

The Correct Alarm Ratio (CAR) is identified as the percent of warnings issued that coincide with rescues. The CAR is calculated as the number of days an index issued a warning and a rescue occurred normalized by the total number of days the index issued a warning. It is also calculated through the subtraction of FAR1 from 1.

$$\text{CAR} = \frac{\text{Days Index } \geq \text{ Threshold w/ Rescues}}{\text{Days Index } \geq \text{ Threshold}} = \text{FAR1 - 1}$$

The second method (FAR2) was developed by the author for use in the cyclic testing process as a measure of improvement or deterioration. The FAR2 is defined as the percent of the days in which no rescues occurred yet the index issued a warning.

$$\text{FAR2} = \frac{\text{Days Index } \geq \text{ Threshold w/ no Rescues}}{\text{Days w/ no Rescues}}$$

The Probability of Detection (POD) is approached through two methods. The first method (POD1) was developed to assess the importance of the events detected by the rip current index. The POD1 is computed as the sum of rip related rescues on days the index issued a warning, normalized by the total amount of rescues. This statistical parameter establishes the importance of detecting the days with high numbers of rescues.

$$\mathrm{POD1} = \frac{\text{Sum of Rescues on Days Index} \ \geq \ \text{Threshold}}{\text{Total Rescues}}$$

The second method (POD2) was directly adapted from the NWS and is defined as the percentage of rip current events detected by the index.

$$\mathrm{POD2} = \frac{\text{Sum of Days Index} \ \geq \ \text{Threshold w/ Rescues}}{\text{Sum of Days w/ Rescues}}$$

The percentage growth of the POD compared with the FAR is reflected through the additional POD/FAR ratio parameters. These ratios give the relative improvements of any adjustments made to the index, and were used to find a warning threshold that would produce the maximum levels of performance. The POD2/FAR2 ratio proved helpful due to the large number of rescues that occur during the summer season. Upon averaging all the years in the data set, excluding 2002, it was concluded that approximately 67% of days in the summer season (day 75–250) exhibited documented rescues. The POD2/FAR2 ratio compares the percent of rescue days detected with the percent of non-rescue days also detected. If this ratio value is greater than 1, then the rip current predictive index is identifying a higher percentage of the days with rescues than the days without rescues. Theoretically if a warning was issued everyday of the summer, a 100 percent probability of detection would result. However this would also result in a 100 percent of the false alarms. The POD2/FAR2 ratio helps to establish balance between the increases in the probability of detection and the false alarms.

During the testing process four trials were completed in which an individual parameter was adapted based on the correlation analysis discussed earlier. After each adjustment, the modified index was computed from 1998 to 2003. The results of the modified index were then compared with the performance of the ECFL LURCS to ascertain any improvements made by the adjusted parameter. Comparisons between the performances of each respective index were analyzed using the previously discussed statistical parameters. If the results were positive after each trial, the change remained and carried over to the next trial.

Trial 1: Extraction of the wind factor

The first of four trials in changing the ECFL LURCS was the removal of the wind factor. After the removal, the daily threat values were computed by modified index over all the years. The performance changes are represented by the statistical parameters displayed in Table 5-2. Each parameter was calculated for all the years and then averaged together. A positive “percent change” value is regarded as an improvement of the modified index over the ECFL LURCS. Again, the statistics were calculated for the year 2002 for qualitative inquisition but excluded from the averaging process.

After examination of Table 5-2, it is evident that this adjustment is detrimental to the performance of the index. The FAR1 for rescues increased from 0.25 to 0.35 (approx. 21%), and the FAR1 for rip currents increased from 0.21 to 0.29 (approx. 20%). A slight increase in false alarms is expected as the ECFL LURCS longshore wind factor only negates from the total threat value. Deleting this parameter will undoubtedly raise the index values. The warning threshold for the modified index was adjusted to 3.5 to account for the increase in threat values, yet the performance levels of the modified index remained significantly lower than the ECFL LURCS.

Table 5-2. Performance results of the modified index after trial 1 (extraction of the wind factor), and the original ECFL LURCS averaged over the years from 1998 to 2003 (excluding 2002). A positive % change corresponds to an improvement over the ECFL LURCS.

		Modified	ECFL	Difference	% Change
AR		0.28	0.31	-0.02	-05.4
FAR1	Rescues	0.35	0.25	-0.06	-21.4
	Rips	0.29	0.21	-0.05	-20.3
FAR2	Rescues	0.29	0.23	-0.06	-25.3
	Rips	0.24	0.18	-0.05	-26.9
POD2	Rescues	0.27	0.34	-0.05	-14.4
	Rips	0.28	0.34	-0.04	-12.7
POD1	Rescues	0.31	0.43	-0.09	-21.4
	Rips	0.30	0.42	-0.08	-21.7
CAR/ FAR1	Rescues	2.11	3.31	-1.20	-36.3
	Rips	3.16	4.59	-1.43	-31.2
POD2/ FAR2	Rescues	1.00	1.53	-0.54	-35.0
	Rips	1.39	2.00	-0.62	-30.8
POD2/ FAR1	Rescues	0.87	1.53	-0.65	-42.7
	Rips	1.19	1.96	-0.77	-39.3

Although the removal of the wind parameter was intended to improve the performance of the rip current predictive index, the opposite occurred. The longshore wind factor actually increases the accuracy of the ECFL LURCS predictions. These unexpected results might be the effect of human behavior in addition to unknown physical processes. The range of wind velocity that negates the rip current threat begins at 10 knots (11.5 mph) and extends to more than 25 knots (28.7 mph) (Figure 4-3). The elevated levels of wind intensity might detour people from visiting the beach and therefore correlate to lower rescue numbers. Further analysis of the wind conditions would be needed to verify this assumption. The limited examination of the correlation between the wind conditions and the rip current rescues in this study did not justify the exclusion of the wind parameter. Subsequently, it remained in the prediction scheme.

Trial 2: Inclusion of a wave direction factor

The second trial consisted of integrating the wave direction. The first attempt was the inclusion of a factor that directly added to the overall threat value, similar to the swell factors of height and period. This was achieved by increasing the direction factor as the waves became more orthogonal to the shoreline, with a maximum value of 4 depicting nearly shore-normal wave conditions. The approach was based on previous work done by Engle (2003). After the modification to the scale, the results showed an increase in the POD. However, the POD/FAR ratios were not convincing, denoting that the improvements in detection were counter-balanced by an increase in false alarms. The correlations in this study and previous studies (see Engle 2003), illustrate a good association between wave direction and rip current events. The difficulty is within the incorporation of the wave direction parameter.

After careful deliberation, the idea was developed to include the wave direction as a multiplier of the other swell parameters. The thought process behind the idea was to restrict an orthogonal incident wave field from offsetting the occurrence of swell conditions unfavorable for rip current formation. For example, assume the swell height and period factors are both less than or equal to one and the direction is completely onshore. In an additive scheme, the direction parameter itself would have the ability to push the threat level into warning status. However, the wave conditions are likely too small for rip current formation and the resulting effect could be a false alarm. If the direction was a multiplier, it will indirectly raise the threat level in concert with the swell conditions. The performance results of this modification are exhibited in Table 5-3. The warning threshold was kept at 3 to generate maximum performance levels represented in the values of the POD/FAR and the CAR/FAR ratios.

There were slight improvements in the FAR1, FAR2 and POD2, but considerable enhancement in the POD1 when compared with the ECFL LURCS. The modified index showed an increase of approximately 28% and 24% in the POD1 analysis for rescues and rips respectively. The larger increase in the POD1 symbolizes that the index is detecting a greater amount of the high-rescue days. The progress in both the false alarms and the detections is well portrayed by the POD2/FAR2 ratio values. There was an approximate increase of 10% and 19% in the ratio of general detections to false alarms (POD2/FAR2) for rescues and rip respectively. The ratio of detection importance to false alarms (POD2/FAR1) also experienced increases of 11% and almost 19% for rescue and rip analysis. This exemplifies the advances in the capability of the modified index to detect rip current events when the multiplicative direction factor is applied compared with the original ECFL LURCS, which contains no wave direction parameter.

Table 5-3. Performance results of the modified index after trial 2 (inclusion of wave direction), and the original ECFL LURCS averaged over the years from 1998 to 2003 (excluding 2002). A positive % change corresponds to an improvement over the ECFL LURCS.

		Modified	ECFL	Difference	% Change
AR		0.32	0.31	0.01	03.7
FAR1	Rescues	0.24	0.25	0.02	06.1
	Rips	0.20	0.21	0.01	04.9
FAR2	Rescues	0.22	0.23	0.00	02.1
	Rips	0.18	0.18	0.00	00.1
POD2	Rescues	0.36	0.34	0.02	05.7
	Rips	0.36	0.34	0.02	04.6
POD1	Rescues	0.55	0.43	0.12	28.1
	Rips	0.53	0.42	0.10	24.3
CAR/ FAR1	Rescues	3.64	3.31	0.32	09.7
	Rips	5.56	4.59	0.96	21.0
POD2/ FAR2	Rescues	1.69	1.53	0.16	10.4
	Rips	2.39	2.00	0.39	19.3
POD2/ FAR1	Rescues	1.70	1.53	0.17	11.2
	Rips	2.32	1.96	0.37	18.7

Trial 3: Modification of the swell period factor

The third trial included the modification of the wave period factor to account for slightly shorter period swells. It was shown in the previous section that there was a high risk for swimmers when the wave period is between 6 and 8 seconds. However, the ECFL LURCS assigns a zero to this factor for wave conditions with a period less than 8 seconds. The adjustment to the index begins the wave period factor with a value of 0.5 for a 6 second wave and increases accordingly. The statistical results after accounting for the shorter period waves are shown in Table 5-4. After a series of computations the warning threshold showed maximum performance at a value of 3.5, and was subsequently changed.

Table 5-4. Performance results of the modified index after trial 3 (modification of the swell period factor), and the original ECFL LURCS averaged over the years from 1998 to 2003 (excluding 2002). A positive % change corresponds to an improvement over the ECFL LURCS.

		Modified	ECFL	Difference	% Change
AR		0.34	0.31	0.03	09.6
FAR1	Rescues	0.26	0.25	-0.00	-01.5
	Rips	0.22	0.21	-0.01	-05.4
FAR2	Rescues	0.26	0.23	-0.03	-13.0
	Rips	0.22	0.18	-0.03	-18.0
POD2	Rescues	0.37	0.34	0.03	09.0
	Rips	0.37	0.34	0.03	07.9
POD1	Rescues	0.58	0.43	0.15	35.0
	Rips	0.56	0.42	0.13	31.7
CAR/ FAR1	Rescues	3.17	3.31	-0.15	-04.4
	Rips	4.28	4.59	-0.31	-06.8
POD2/ FAR2	Rescues	1.48	1.53	-0.05	-03.3
	Rips	1.86	2.00	-0.15	-07.5
POD2/ FAR1	Rescues	1.57	1.53	0.04	02.9
	Rips	1.92	1.96	-0.03	-01.7

The POD1 and POD2 for both rips and rescues are the only improvements over the results of trial 2. Both the FAR1 and the FAR2 experienced considerable deterioration. The simultaneous increases in the probability of detection and the false alarm ratio are best examined through the POD2/FAR ratios. All of the ratios demonstrated inferior performance compared with the ECFL LURCS, and even greater reductions from the results of trial 2. After interpretation of the yearly performance results summarized in Table 5-4, it was concluded that the reorganization of the swell period factor diminishes the quality of the rip current predictive index. Therefore, the changes of the wave period factor will not be incorporated into the modified index for the remaining trial.

Trial 4: Redevelopment of the tidal factor

The initial change in the fourth trial was the removal of the astronomical tide factor and the integration of a low tide parameter. However, after a series of preliminary tests the index exhibited superior results when both tidal factors were accounted for, and therefore the final trial was completed including both.

Rip currents are known to intensify during low tide, and if this occurs while the beaches are heavily populated then the result is an increase in rip current risk to ocean-goers. To account for the effect of low tide, a small factor was included into the index that is dependent on the time at which the low tide occurs. The max value of this factor is 1. Therefore, it does not have as much influence as the other factors. Its purpose is to raise the threat level when the conditions are only slightly favorable for rip formation, yet might need a lower water level to achieve potentially dangerous rip current activity. As shown by the scale presented in the previous section, the threat level is affected only if low tide occurs during the day.

The adjustments of the previous trial (wave period factor) were not retained and therefore comparisons should be made with the results of trial 2 in order to ascertain any improvements in the index due to the addition of a low tide parameter. For this trial, it was found favorable to keep the warning threshold to a value of 3.5. With the inclusion of the low tide factor, the overall performance of the modified index increased (Table 5-5). The FAR1 and FAR2 both improved from the results of trial 2 and continue to outperform the ECFL LURCS. The POD1 and POD2 values decreased slightly (approx. 2–4% each) from trial 2, however the POD1 values remain considerably higher than the ECFL LURCS. This illustrates the ability of the modified index to detect the days in which the rip current risk is greater.

Table 5-5. Performance results of the modified index after trial 4 (redevelopment of the tidal factor), and the original ECFL LURCS averaged over the years from 1998 to 2003 (excluding 2002). A positive % change corresponds to an improvement over the ECFL LURCS

		Modified	ECFL	Difference	% Change
AR		0.30	0.31	-0.00	-01.5
FAR1	Rescues	0.23	0.25	0.03	10.3
	Rips	0.19	0.21	0.02	09.0
FAR2	Rescues	0.21	0.23	0.02	09.4
	Rips	0.17	0.18	0.01	07.7
POD2	Rescues	0.35	0.34	0.01	02.2
	Rips	0.35	0.34	0.00	00.7
POD1	Rescues	0.55	0.43	0.12	26.7
	Rips	0.52	0.42	0.09	22.0
CAR/ FAR1	Rescues	3.72	3.31	0.41	12.4
	Rips	6.31	4.59	1.72	37.5
POD2/ FAR2	Rescues	1.78	1.53	0.24	15.7
	Rips	2.74	2.00	0.73	36.5
POD2/ FAR1	Rescues	1.66	1.53	0.13	08.7
	Rips	2.49	1.96	0.53	27.3

The relative improvement and/or worsening of the probability of detection and false alarm values is better viewed through the POD/FAR ratios. The POD2/FAR2 for rescues increased from 1.53 to 1.69 in trial 2, and then further improved to 1.78 in trial 4. This indicates that the advances in the FAR2 values surmounted the small decrease in the POD2 values from trial 2. There was significant progression in all the other ratios except the POD2/FAR1 for rescues, which decreased by only 2.5% from trial 2. However, this ratio value still remained almost 9% better than the ECFL LURCS. The outcome of trial 4 does reinforce the assertion that the occurrence of low tide during the day has an effect on the rip current risk towards ocean-goers. Therefore, the adjusted tidal factor was retained in the modified index.

High-risk examination

After the testing process and subsequent verification of the two modifications (direction and tide) made to the index, further analysis was completed to asses its capability in detecting the particularly important high-risk days. Table 5-6 displays the percentage of high rescue/rip days detected by each index for years 1998 to 2003. The classification of a high-risk day is broken into three categories (1) Days with at least 5 rescues/rips, (2) Days with at least 15 rescues/rips, and (3) days with at least 25 rescues/rips.

For days with at least 5 rescues the modified index detection percentage is an average of 49.5%, and the ECFL LURCS forecasted 39.3%. The average detection value is appropriately weighted for each year depending on how many rescues occurred in that year. Over the next two rescue categories both indexes increase their detection rates. However, the percentages of the modified index remain higher than the ECFL LURCS. The modified index detected 64.9% of the days when there was at least 15 rescues, compared to 50.4% by the ECFL LURCS. The modified index, but not the ECFL LURCS, detected the single rescue day in this category for 2002. In the final category, days with more than 25 rescues are examined. This category is associated with extremely dangerous rip current conditions. The modified index detected an average of 70.3% of those days, and the ECFL LURCS detected 52.7%. Overall, the modified index outperformed the ECFL LURCS by approximately 10% in the first category. In the final high-risk category the modified index increased to almost 20% better performance.

Table 5-6: The percentage of the high rip current rescue and incident days for each year from 1998 to 2003. As well as the average of all the years weighted by the number of rips/rescues for each year.

	1998	1999	2000	2001	2002	2003	Average / Total
Rescues >= 5							
ECFL Rescues	43.2	46.3	32.2	43.0	35.7	38.6	39.3
Mod. Rescues	55.4	66.7	49.2	40.7	64.3	52.3	49.5
# of days	74	54	59	86	14	44	331
Rips >= 5							
ECFL Rips	46.8	52.8	32.5	42.6	42.3	44.1	35.8
Mod. Rips	59.7	77.8	57.5	45.9	50.0	55.9	47.4
# of days	62	36	40	61	52	34	285
Rescues >= 15							
ECFL Rescues	46.2	59.1	46.2	47.6	00.0	64.3	50.4
Mod. Rescues	64.1	90.9	76.9	47.6	100	71.4	64.9
# of days	39	22	13	42	01	14	131
Rips >= 15							
ECFL Rips	66.7	46.2	42.9	53.8	35.7	50.0	43.6
Mod. Rips	83.3	100	100	50.0	71.4	50.0	59.0
# of days	12	13	07	26	14	06	78
Rescues >= 25							
ECFL Rescues	50.0	57.1	50.0	53.6	—	50.0	52.7
Mod. Rescues	66.7	100	100	53.6	—	50.0	70.3
# of days	18	14	08	28	00	06	74
Rips >= 25							
ECFL Rips	100	16.7	00.0	33.3	50.0	—	37.5
Mod. Rips	100	100	100	50.0	100	—	62.5
# of days	07	06	01	12	06	00	32

Another facet of the high rescue examination was the determination of a warning threshold for higher risk rip current conditions. The daily threat level of the modified index within each rescue category was determined. Figure 5-9 and Figure 5-10 display the threat values of each year for the days in which there were more than 15 and 25 rescues respectively. The average threat value for the days with more than 15 rescues was approximately 5.4 and the average for the days with more than 25 rescues was approximately 5.8. It was ascertained that the majority of high-rescue days occurred when the threat level was close to 5.5. As a result, it is recommended to issue a severe rip current warning if the index value is 5.5 or greater.

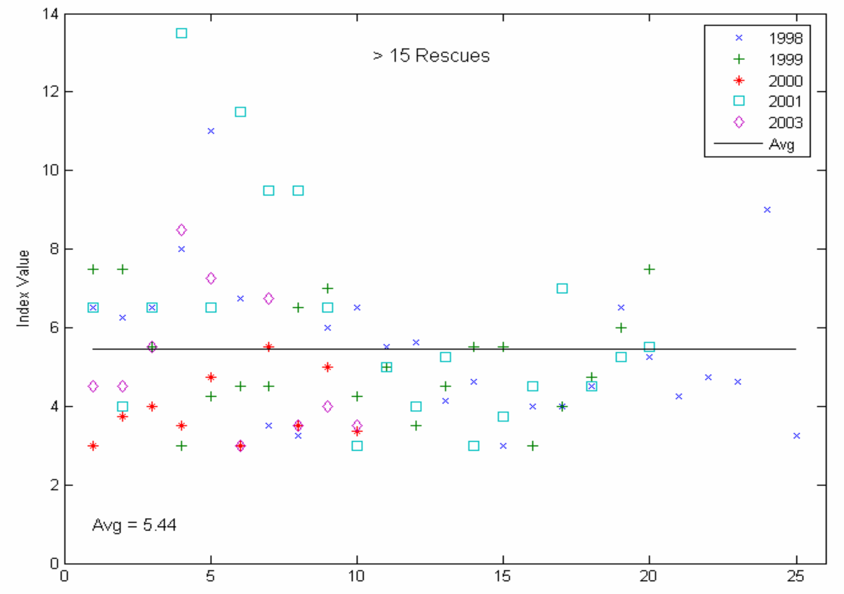

Figure 5-9. Calculated rip current threat values for days with more than 15 rescues (1998–2003). The horizontal line represents the weighted average value.

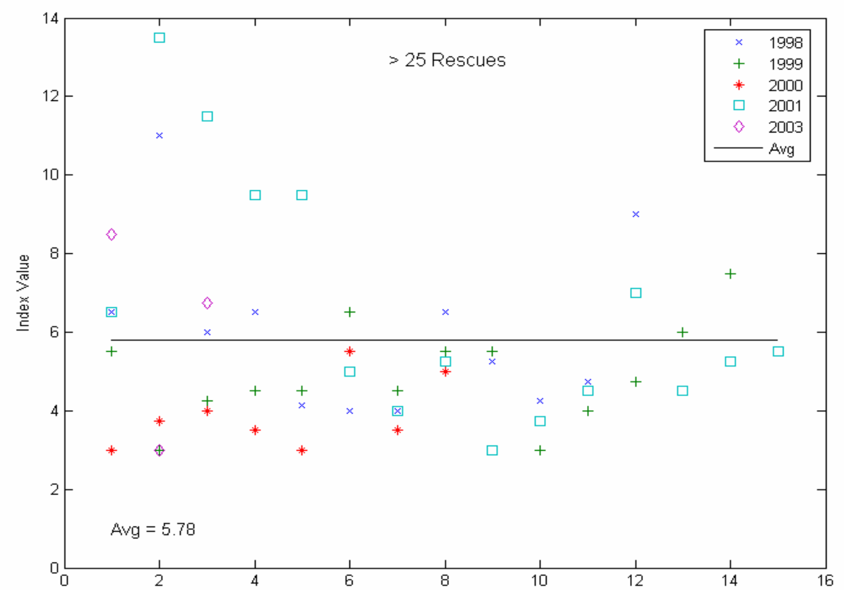

Figure 5-10. Calculated rip current threat values for days with more than 25 rescues (1998–2003). The horizontal line represents the weighted average value.

Summary

The parameters and their respective ranges were first analyzed through a subjective histogram approach. The summation of all the years for each parameter is presented in Figure 5-12. The swell height was found to have greatest rip current risk to ocean-goers in the 3 to 4 foot (0.91–1.22m) range. The swell period exhibited an increase in risk starting above 6 seconds, which differs from the 8-second cutoff used in the ECFL LURCS. The wave direction showed a high risk associated with a shore-normal incident wave field, which was in agreement with previous theory and observations. Figure 4-10 displays the increased risk associated with the direction of the incident wave field ranging from 40° to 80°, or within 20° North or South of shore-normal. This high risk is exemplified by exhibiting the greatest overall ratio values as compared with the other parameters. As a result, wave direction has proven to be a crucial component when ascertaining hazardous rip current conditions. However, complications arose when attempting to include wave direction into the index, but were eventually overcome with the use of a multiplicative (rather than an additive) factor. The tidal influence differed from year to year, but in examination of the overall trend the greatest risk to ocean-goers occurred when low tide was in the late morning (10–12 a.m.).

After each parameter change was incorporated into the modified index, it was then tested against the performance of the original ECFL LURCS. As a result of the testing procedure, the wind parameter and wave period factor remained unchanged. Reversely, the inclusion of the wave direction factor and the low tide parameter were justified. The final results of the testing process summarized over the years 1998 to 2003 (excluding 2002) are observed in Table 5-6. The performance of the newly developed rip current predictive index has shown considerable improvements when compared with the ECFL

LURCS. To visually ascertain the difference between the two indexes the daily forecasts computed by the ECFL LURCS and the modified index for 1998 are displayed graphically in Figure 4-13 and Figure 4-14 respectively. The horizontal line represents the warning threshold, and each marker is a daily rip current threat value. The different markers signify the amount of rescues documented for that day.

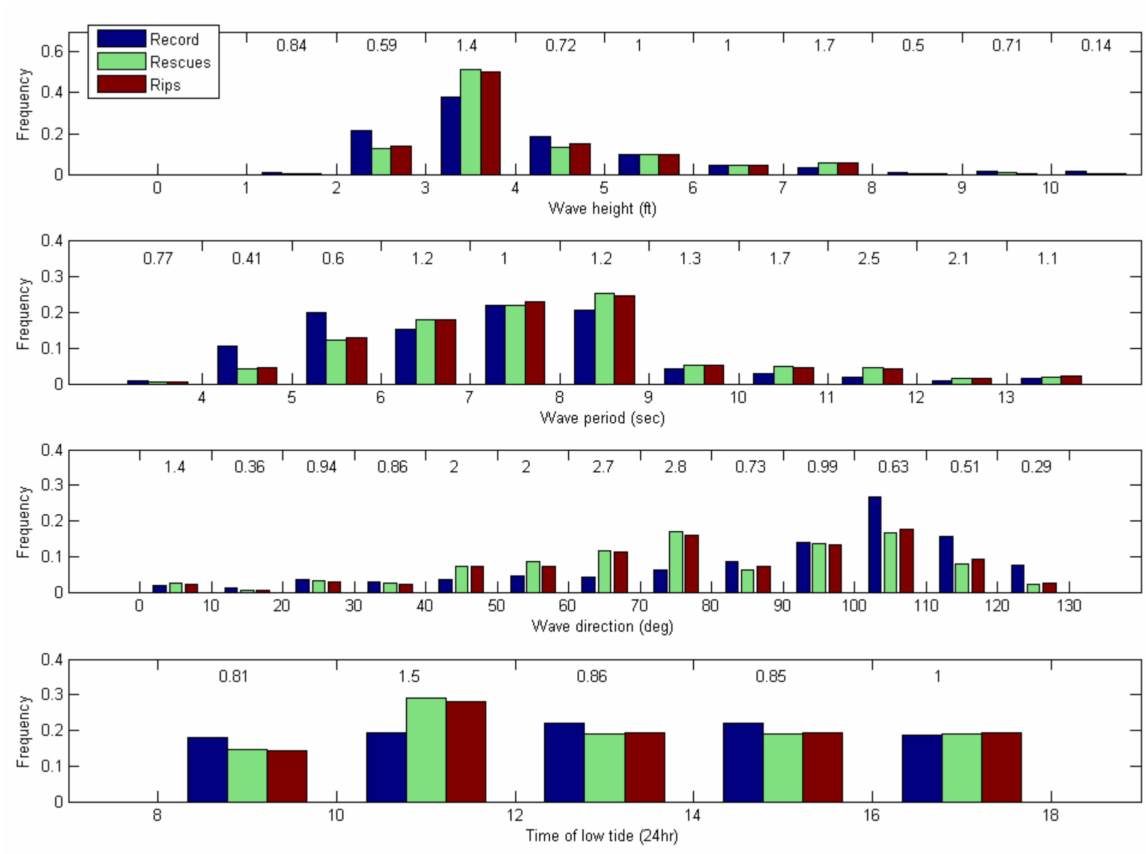

Figure 5-12. Correlation histogram-plot of the offshore wave height (ft), peak wave period (sec), offshore wave direction (deg), and time of low tide (24hr) along with rip current incidents and associated rescues combined over the years from 1998 to 2003 (excluding 2002). The blue (1st) bar represents the percentage of days that each parameter occurred within the respective range. The green (2nd) and red (3rd) bars represent the percentage of total rescues and the percentage of rip current incidents respectively, that occurred when the parameter occurred within that range. The numbers on the top of each plot correspond to the ratio of the blue and green bar magnitudes.

A difference is noticed between the two indexes after examination of the higher risk days. The threat values calculated by the modified index have shifted vertically, accounting for the severity of conditions on those days. Also observed is the large number of the zero rescue days that remained under the warning threshold. There are some increases in threat values for the zero rescue days, but since the statistics are based on rescues and therefore ocean-goers, these anomalies could be the effect of inclement weather conditions. For similar plots of the remaining years (including separate analysis of both rip current incidents and rescues) see appendix-D.

Although, not all the initially assumed parameter changes were incorporated into the modified index, the important assumptions of wave direction and low tide having an effect on rip current formation were resolved. The resulting rip current predictive index (RIPDEX) incorporating all observations can be seen in Figure 5-15.

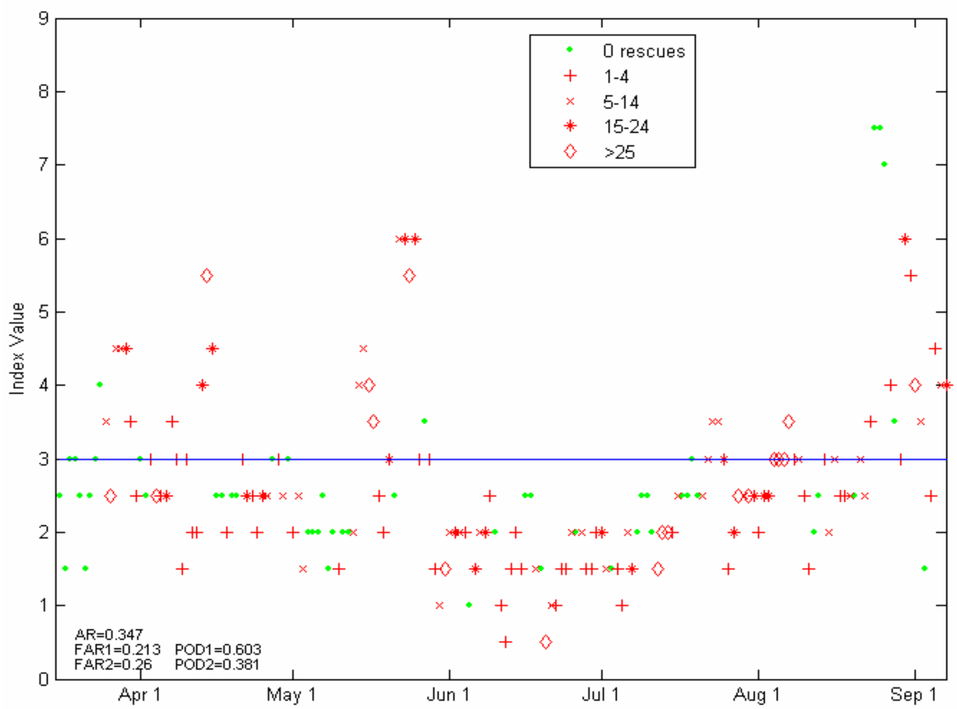

Figure 5-13. ECFL LURCS daily rip current threat levels for the summer of 1998. The daily rip current rescue totals are indicated by the marker symbols.

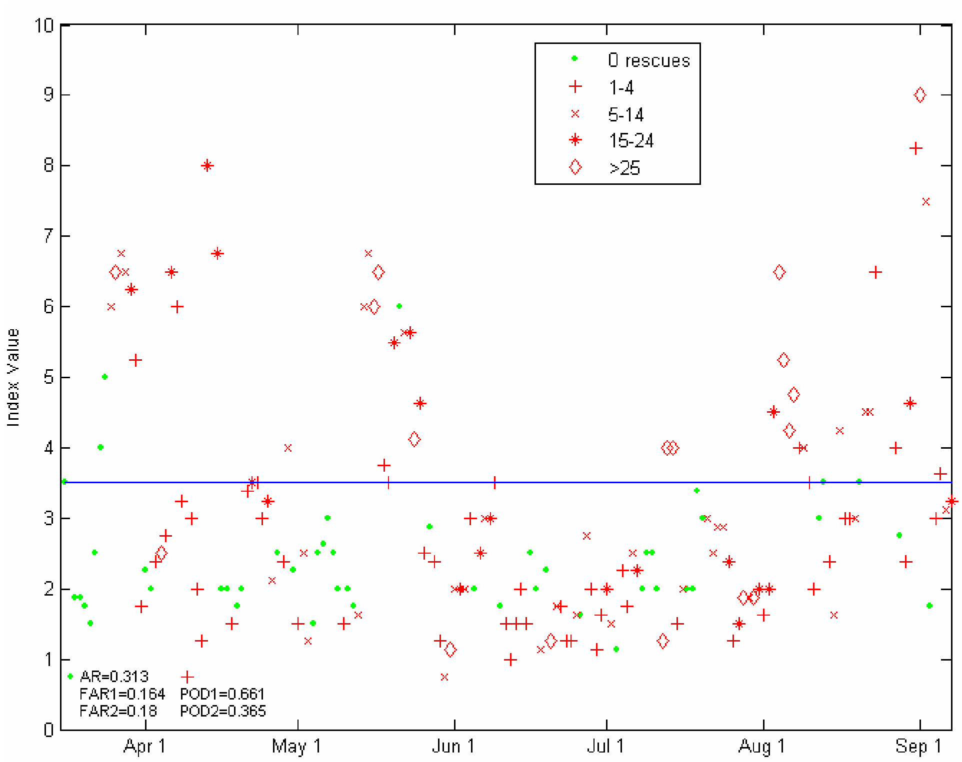

Figure 5-14. The modified index daily rip current threat levels for the summer of 1998. The daily rip current rescue totals are indicated by the marker symbols.

RIPDEX

1)

SWELL HEIGHT	
Height, Ho (ft)	Factor
Ho < 1	0
1 <= Ho < 2	0.5
2 <= Ho < 3	1
3 <= Ho < 5	2
5 <= Ho < 8	3
8 <= Ho	4
Swell Heght Factor	

2)

SWELL PERIOD	
Period, T (sec)	Factor
T < 8	0
8 <= T < 9	0.5
9 <= T < 11	1
11 <= T < 12	1.5
12 <= T < 13	2.5
13 <= T	3.5
Swell Period Factor	

3) Swell Height Factor + Swell Period Factor = **Swell Factor** ________

4)

SWELL DIRECTION	
Direction, Do (deg)	Multiplier
340 (-20) <= Do < 30	0.75
30 <= Do < 45	1.5
45 <= Do <= 75	2
75 < Do <= 100	1.5
100 < Do <= 150	0.75
other	1
Swell Direction Multiplier	

5)

TIDE	
Time of Low Tide, LT (LST)	Factor
9<=LT<13	1
13<=LT<17	0.5
LT<9 or LT>17	0
Tide Factor	

6)

WIND FACTOR	
Longshore only (110-160°, 340-30°)	
Wind Speed, Ws (kt)	Factor
10 <= Ws < 15	-0.5
15 <= Ws < 20	-1
20 <= Ws < 25	-2
25 <= Ws	-3
Wind Factor	

7)

MISCELLANEOUS FACTOR	
Condition	Factor
If astronomical tides are higher than normal (i.e. near full/new moon)	0.5
If previous day swell factor (3) >= 1.5	0.5
Misc. Factor	

Rip Current Threat = (Swell Factor x Swell Direction Multiplier) + Wind Factor + Tide Factor + Misc. Factor

RIP CURRENT THREAT = _______

If **RIP CURRENT THREAT** is 3.5 - 5.5 (3.0 - 5.0 on weekends and holidays):
------issue statement for MODERATE RISK of rip currents.

If **RIP CURRENT THREAT** is >= 5.5:
-------issue statement for HIGH RISK of rip currents.

Figure 5-15. RIPDEX (rip current predictive index) worksheet.

CHAPTER 6
USE OF INDEX AS FORECASTING TOOL

Analysis

The purpose of this project was not only to improve the existing rip current index (ECFL LURCS), but also to discover more efficient methods of implementing it as a forecasting tool. The use of the WAVEWATCH III model as an input to the index incorporates a forecasting ability, as well as the inclusion of wave direction; the latter of which proved to be beneficial to the performance of the index (see Chapter 5), and both of which had proved to be significant stumbling blocks previously. Application of the WAVEWATCH III model makes it possible to forecast the rip current threat in advance. With this capability the National Weather Service will have additional options when alerting the public of upcoming severe conditions. Since the forecasts are computed in advance, any warnings can be issued the day before a severe rip current event. Therefore the warning can be publicized on the evening news and in the daily newspaper. The knowledge of dangerous conditions in advance allows people to either change their plans accordingly, or at least be more prepared for the situation. Another advantage is the ability to re-establish staffing needs of the local lifeguards. If the index forecasts extreme rip current conditions, the beach safety division has the opportunity to place additional lifeguards on duty to compensate for the expected additional number of rescues.

In this study the WAVEWATCH III outputs of wave height, period and direction were used to compute daily rip current threat levels with the modified index for the summer of 2005. The results of the 12pm model simulation from the day prior to the forecast day were used in the calculation of the rip current threat level. Due to the irregularity of the WAVEWATCH III output, the modified index values were calculated by the author. The moon phase and time of low tide was also integrated into the calculations, but the wind field was not included. The analysis was again limited to the summer season to minimize the spurious effects of low beach population issues. In 2005 there were 2,657 rip-related rescues documented by the Volusia County Lifeguards, with approximately 89% of those rescues occurring in the summer season. The summer season for this study is defined as day 79 until day 250, which translates into March 20th until September 7th. The 4 day lag in the start of the summer season, when compared with the previous study, is due to the lack of WAVEWATCH III data for days prior. The resulting daily threat levels were then compared with the documented rip current rescues in Volusia County, along with the completed ECFL LURCS worksheets (Figure 4-3) and lifeguard observations (Figure 4-2) for the same time period. The ECFL LURCS worksheets and the lifeguard observations are sporadic over the summer of 2005 and consequently, the comparison with these two data sets was restricted to the days with a high number of rescues.

The first analysis of the WAVEWATCH III rip current forecasting capabilities was an assessment of the overall performance using the statistical parameters described in chapter 5 (e.g., AR, FAR, POD…). The results are displayed in Table 6-1. The Alarm Ratio was approximately 0.48, which is higher than the results of the ECFL LURCS and the modified index from the previous study (see chapter 5). However, the percentage of days with rip-related rescues in 2005 was higher than the average for 1998 to 2003 (89% compared with 68%). The value of the False Alarm Ratio Method 1 remained low at

0.17, yet the value of the False Alarm Ratio Method 2 increased to 0.38. This was expected because of the increase in the number of days with rescues, and corresponding decrease in the number of non-rescue days. The Probability of Detection Method 2 showed considerable improvement over the results from chapter 5, increasing to 0.51. The Probability of Detection Method 1 also showed improvements, increasing to 0.61 and 0.57 for rescues and rips respectively. The POD/FAR ratio values were comparable to those from the previous multi-year analysis. The POD2/FAR2 ratio decreased slightly, yet it was expected because of the high FAR2 value resulting from a decrease in days in which no rescues occurred. The POD2/FAR ratio increased, representing an enhancement in the detection of days with a greater amount of rescues.

Table 6-1. Performance results of the WAVEWATCH III forecasting the daily rip current threat levels for the summer of 2005.

		WAVEWATCH III
AR		0.48
FAR1	Rescues	0.17
	Rips	0.17
FAR2	Rescues	0.38
	Rips	0.38
POD2	Rescues	0.51
	Rips	0.51
POD1	Rescues	0.61
	Rips	0.57
CAR/FAR1	Rescues	4.88
	Rips	4.88
POD2/FAR2	Rescues	1.35
	Rips	1.35
POD2/FAR1	Rescues	3.03
	Rips	3.03

Overall, the performance results appear to compare well with the statistical values obtained in the multi-year study discussed in chapter 5. A plot containing the daily threat levels and concurrent rescues is presented in Figure 6-1. The horizontal line represents the warning threshold and each marker signifies the index value as well as the amount of rescues occurring on that specific day. A large majority of the higher rescue days are above the warning threshold, and many of the non-rescue days remain below. In general, this represents a good performance by the modified index and the WAVEWATCH III data. There is a noticeable discrepancy occurring in the month of April, in which there are a few non-rescue days that have high index values. The ECFL LURCS worksheets displayed similar heightened threat levels for these days as well. This could be the result of stormy conditions, in which the rough surf made it unappealing for beach-goers to enter the ocean. Another possibility could be that the inclement weather kept them from going to the beach altogether. Independent of cause, the lack of rescues may likely represent a decrease in ocean-goers and does not necessarily guarantee an absence of rip current activity.

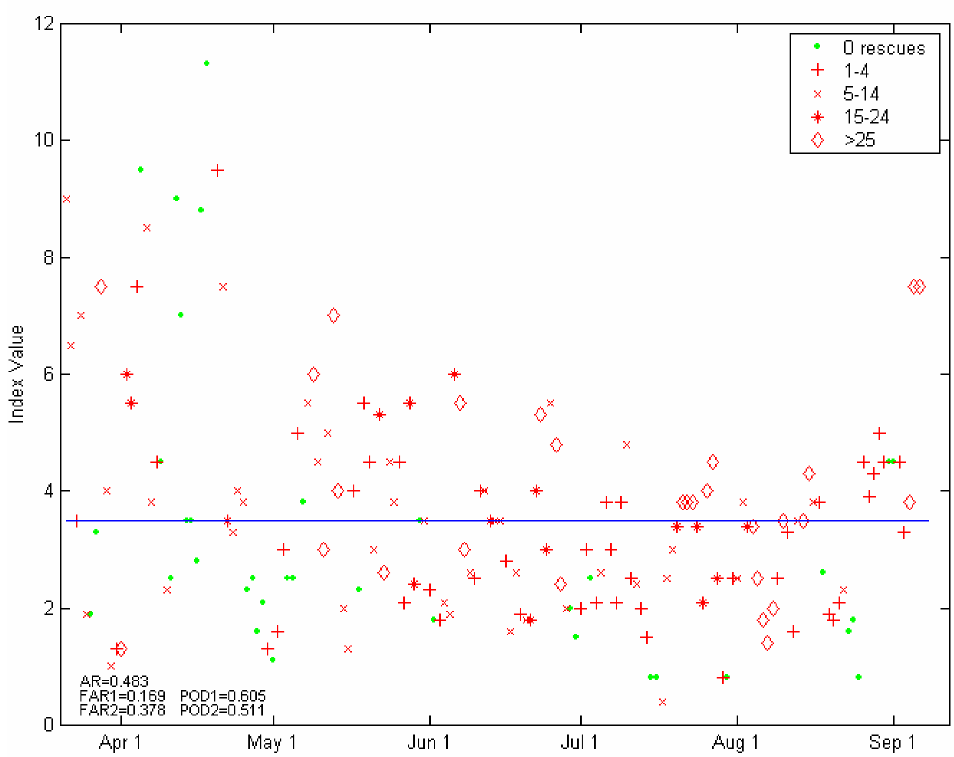

Figure 6-1. Daily rip current threat levels computed with the modified index using the WAVEWATCH III oceanographic output information for the summer of 2005. The daily rip current rescue totals are indicated by the marker symbols.

In order to further validate the use of the WAVEWATCH III data in the rip current prediction scheme an evaluation with existing methods (ECFL LURCS) for the same time period was needed. However, the ECFL LURCS worksheets recorded by the National Weather Service are discontinuous. Therefore, the comparison between the documented ECFL LURCS worksheets and the results from the modified index implementing the WAVEWATCH III data was limited to the high-rescue days. The lifeguard observations are even more intermittent than the worksheets. Subsequently, they were only used as a qualitative confirmation of dangerous rip current conditions.

A total of 36 days occurred over the summer of 2005 in which there were more than 15 rescues and also an available ECFL LURCS worksheet. Examination of these days was used to determine if the application of the WAVEWATCH III model is a viable method of forecasting rip current conditions. Table 6-2 presents a summary of the WAVEWATCH III output conditions and subsequent threat levels, along with the threat levels of the ECFL LURCS worksheets for the high rescue days. In addition, the table also displays whether or not each respective index recommends the issuance of a warning. If a “yes” is followed by a “w” it indicates the weekend and therefore a lower warning threshold was used.

The ECFL LURCS worksheets detected 22 of the 36 high-rescue days (approx. 61%) and the WAVEWATCH III forecasts detected 23 out of the 36 days (approx. 64%). Therefore, the forecasts using the WAVEWATCH III data actually performed slightly better than existing methods represented by the worksheets. In addition to the improved prediction quality, the WAVEWATCH III forecast gives the benefit of advanced notice. The analysis of the high-rescue days also emphasized the importance of incorporating wave direction into the prediction scheme. The average deviation of the wave direction from shore-normal (Volusia County, 62º) on all 36 high-rescue days, weighted by the number of rescues, is approximately 23 degrees.

Table 6-2. The WAVEWATCH III forecasted wave conditions and associated rip current threat levels, as well as the threat levels documented by the National Weather Service on the ECFL LURCS worksheets for the high-rescue days in the summer of 2005 ("w" corresponds to a weekend and subsequent decrease in the warning threshold).

				WAVEWATCH III			Modified Index		ECFL LURCS	
Month	Day	Rips	Rescues	Height (ft)	Period (sec)	Direction (deg)	Threat	Warning?	Threat	Warning?
4	21	8	17	1	8	57	3.5	yes	2.5	no
5	8	16	38	3	10	40	6.0	yes	5	yes
5	10	15	27	1	8	38	3.0	no	3.5	yes
5	12	11	25	3	9	48	7.0	yes	3.5	yes
5	13	8	27	2	8	50	4.0	yes	3	yes
5	22	19	35	2	8	102	2.6	no	3	yes
5	27	10	21	3	10	38	5.5	yes	3.5	yes
6	5	7	16	2	11	60	6.0	yes	2	no
6	6	28	90	2	10	60	5.5	yes	3	yes
6	7	49	113	2	9	103	3.0	no	3.5	yes
6	12	9	15	3	7	82	3.5	yes	2	no
6	21	13	21	3	7	30	4.0	yes	3.5	yes
6	22	22	47	3	8	40	5.3	yes	4	yes
6	23	11	17	2	7	44	3.0	no	2.5	no
6	25	36	66	4	8	88	4.8	yes	1	no
6	26	22	35	3	8	102	2.4	no	2	no
7	19	11	22	3	8	103	3.4	no	2.5	no
7	20	18	43	3	10	100	3.8	yes	3	yes
7	21	23	47	4	9	101	3.8	yes	4	yes
7	22	25	46	3	9	101	3.8	yes	3.5	yes
7	23	13	23	3	8	101	3.4	yes (w)	4	yes
7	24	8	15	1	9	103	2.1	no	2.5	yes (w)
7	25	22	40	3	6	31	4.0	yes	1.5	no
7	26	74	136	3	7	47	4.5	yes	2.5	no
8	2	10	16	3	8	101	3.4	no	3.5	yes
8	3	20	41	3	8	101	3.4	no	3	yes
8	4	40	74	2	7	99	2.5	no	3	yes
8	5	26	44	1	8	105	1.8	no	2.5	no
8	6	30	48	1	7	107	1.4	no	2	no
8	7	46	88	1	7	68	2.0	no	2.5	yes (w)
8	9	16	28	1	9	73	3.5	yes	3	yes
8	13	17	44	2	9	97	3.5	yes	3	yes
8	14	21	39	3	8	98	4.3	yes	4	yes
9	3	18	37	1	9	98	3.8	yes	1.5	no
9	4	39	73	5	6	60	7.5	yes	2	no
9	5	77	147	7	6	60	7.5	yes	2	no

Scrutiny of the high-rescue days that were undetected by the modified index revealed an interesting characteristic. In the study, some of high-rescue days (May 22nd; June 7th and 26th; July 19th and 24th; August 2nd, 3rd, 5th and 6th) that went undetected by the index exhibited a wave direction slightly above 100 degrees, representing a southeast swell. If the wave direction is between 100º and 150º, the result is a swell reduction multiplier of 0.75. Rip currents are not entirely understood and although shore normal waves were shown to have a large effect on the formation of a rip (see chapter 5), a consistent long period swell from any direction could contribute to rip-rescue conditions. It can be seen that when there is a constant swell for multiple days, there are usually rescues somewhat independent of the wave direction (e.g., July 19th to the 24th, Table 6-2). After further deliberation it was decided to lift the destructive multiplier if the period factor was greater than 0. This was an attempt to isolate the longer period swell and ignore the locally generated wind waves. As a result of the changes, the overall performance of the index improved (Table 6-3). The FAR and FAR2 values did not change, but both the POD1 and POD2 increased from the previous results. This enhancement in the detection capability of the modified index is better elucidated through the POD/FAR ratios. The POD2/FAR2 ratio increased from 1.35 to 1.47 (approx. 8.9%), and the POD2/FAR ratio increased from 3.03 to 3.53 (approx. 16.5%).

The slight modification to the WAVEWATCH III index calculations also increased the detection of the previously discussed high-rescue days. Table 6-4 presents the WAVEWATCH III forecasts after the modification of the direction multiplier. The updated index detected 29 out of the 36 days (approx 81%), increasing 6 days from before. The results of the index after the modifications are also displayed graphically in Figure 6-2.

Table 6-3. Performance results of the WAVEWATCH III forecasting the daily rip current threat levels for the summer of 2005, after the modification to the multiplicative direction factor.

		WAVEWATCH III
AR		0.52
FAR	Rescues	0.16
	Rips	0.16
FAR2	Rescues	0.38
	Rips	0.38
POD2	Rescues	0.56
	Rips	0.56
POD1	Rescues	0.70
	Rips	0.66
CAR/FAR	Rescues	5.25
	Rips	5.25
POD2/FAR2	Rescues	1.47
	Rips	1.47
POD2/FAR	Rescues	3.53
	Rips	3.53

Another interesting aspect of the results was the accuracy of employing both indexes in the rip current prediction scheme. Of the 36 high rescue days examined, only 3 days were undetected by both indexes (almost 92% accuracy). Implementation of the WAVEWATCH III model has exhibited promising results in comparison with the ECFL LURCS, however complete dependency on this new method is not yet recommended. At present utilizing both methods collectively can further increase the accuracy of the overall process. It seems each method possesses similar as well as dissimilar deficiencies; therefore it would prove beneficial to exercise both methods, with the result that the high-risk days undetected by one index would have the chance to be detected by the other index.

Table 6-4. The WAVEWATCH III forecasted wave conditions and associated rip current threat levels (after modification to the multiplicative direction factor), as well as the threat levels documented by the National Weather Service on the ECFL LURCS worksheets for the high-rescue days in the summer of 2005 ("w" corresponds to a weekend and subsequent decrease in the warning threshold).

				WAVEWATCH III			Modified Index		ECFL LURCS	
Month	Day	Rips	Rescues	Height (ft)	Period (sec)	Direction (deg)	Threat	Warning?	Threat	Warning?
4	21	8	17	1	8	57	3.5	yes	2.5	no
5	8	16	38	3	10	40	6.0	yes	5	yes
5	10	15	27	1	8	38	3.0	no	3.5	yes
5	12	11	25	3	9	48	7.0	yes	3.5	yes
5	13	8	27	2	8	50	4.0	yes	3	yes
5	22	19	35	2	8	102	3.0	yes (w)	3	yes
5	27	10	21	3	10	38	5.5	yes	3.5	yes
6	5	7	16	2	11	60	6.0	yes	2	no
6	6	28	90	2	10	60	5.5	yes	3	yes
6	7	49	113	2	9	103	3.5	yes	3.5	yes
6	12	9	15	3	7	82	3.5	yes	2	no
6	21	13	21	3	7	30	4.0	yes	3.5	yes
6	22	22	47	3	8	40	5.3	yes	4	yes
6	23	11	17	2	7	44	3.0	no	2.5	no
6	25	36	66	4	8	88	4.8	yes	1	no
6	26	22	35	3	8	102	3.0	yes (w)	2	no
7	19	11	22	3	8	103	4.0	yes	2.5	no
7	20	18	43	3	10	100	4.5	yes	3	yes
7	21	23	47	4	9	101	4.5	yes	4	yes
7	22	25	46	3	9	101	4.5	yes	3.5	yes
7	23	13	23	3	8	101	4.0	yes	4	yes
7	24	8	15	1	9	103	2.5	no	2.5	yes (w)
7	25	22	40	3	6	31	4.0	yes	1.5	no
7	26	74	136	3	7	47	4.5	yes	2.5	no
8	2	10	16	3	8	101	4.0	yes	3.5	yes
8	3	20	41	3	8	101	4.0	yes	3	yes
8	4	40	74	2	7	99	2.5	no	3	yes
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8	7	46	88	1	7	68	2.0	no	2.5	yes (w)
8	9	16	28	1	9	73	3.5	yes	3	yes
8	13	17	44	2	9	97	3.5	yes	3	yes
8	14	21	39	3	8	98	4.3	yes	4	yes
9	3	18	37	1	9	98	3.8	yes	1.5	no
9	4	39	73	5	6	60	7.5	yes	2	no
9	5	77	147	7	6	60	7.5	yes	2	no

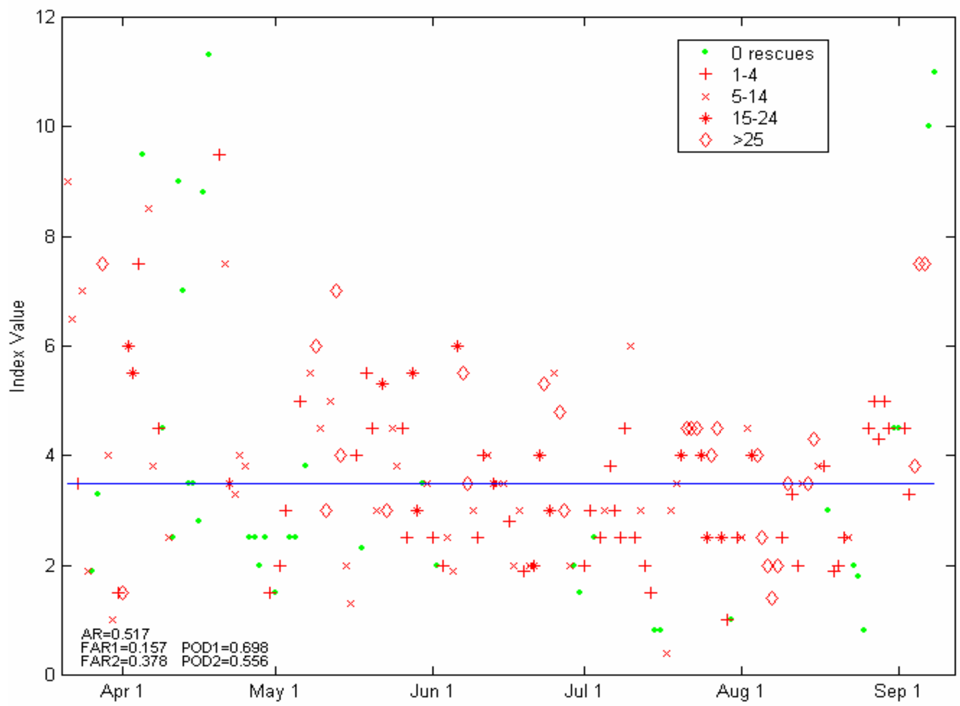

Figure 6-2. Daily rip current threat levels computed with the modified index using the WAVEWATCH III data for the summer of 2005 (after modification to the multiplicative direction factor). The daily rip current rescue totals are indicated by the marker symbols.

Summary

The newly developed index (Figure 5-15) was tested on an independent data set using the WAVEWATCH III forecasts from the previous day. The purposes of this analysis was to verify the improvements made to the ECFL LURCS and assess the forecasting capabilities of a rip current predictive index implementing readily available wave model forecasts. The investigation covered the summer of 2005 for the general performance of the WAVEWATCH III forecasts, but was limited to 36 high-rescue days for comparison with the recorded ECFL LURCS worksheets.

The modified index outperformed the ECFL LURCS worksheets for the 36 considered days. Initially the new prediction method correctly detected approximately 64% of the days in which more than 15 rescues occurred. This performance was a slight improvement over the 61% detection rate of the ECFL LURCS worksheets for the same days. Then after improvements, the new method correctly detected over 80% of the high-rescue days. The modified index calculations for the 2005 summer resulted in a POD2/FAR2 ratio of 1.47 and a POD2/FAR ratio of 3.53. The resulting daily threat levels from the index calculations and the concurrent lifeguard records for the summer of 2005 are displayed in Figure 6-3. Almost every surge in the rips and/or rescues is associated with a rise in the calculated threat level. This parallel movement depicted in the graph explains the increase in the POD2/FAR ratio when compared with the results from the analysis in chapter 5. An increase in the POD2/FAR ratio accounts for an improvement in the detection of days with dangerous rip current activity, illustrated by the surge in rescues. The observed increases in the level of performance as well as the advantages of advanced notice justify the use of the WAVEWATCH III model as an input to the index calculations. However, it was noted that this new method of incorporating wave direction through the WAVEWATCH III model should not yet fully replace the existing ECFL LURCS worksheets. Instead the new method should be an additional tool in the rip current forecasting process to help increase accuracy as well as provide greater lead time for public warnings.

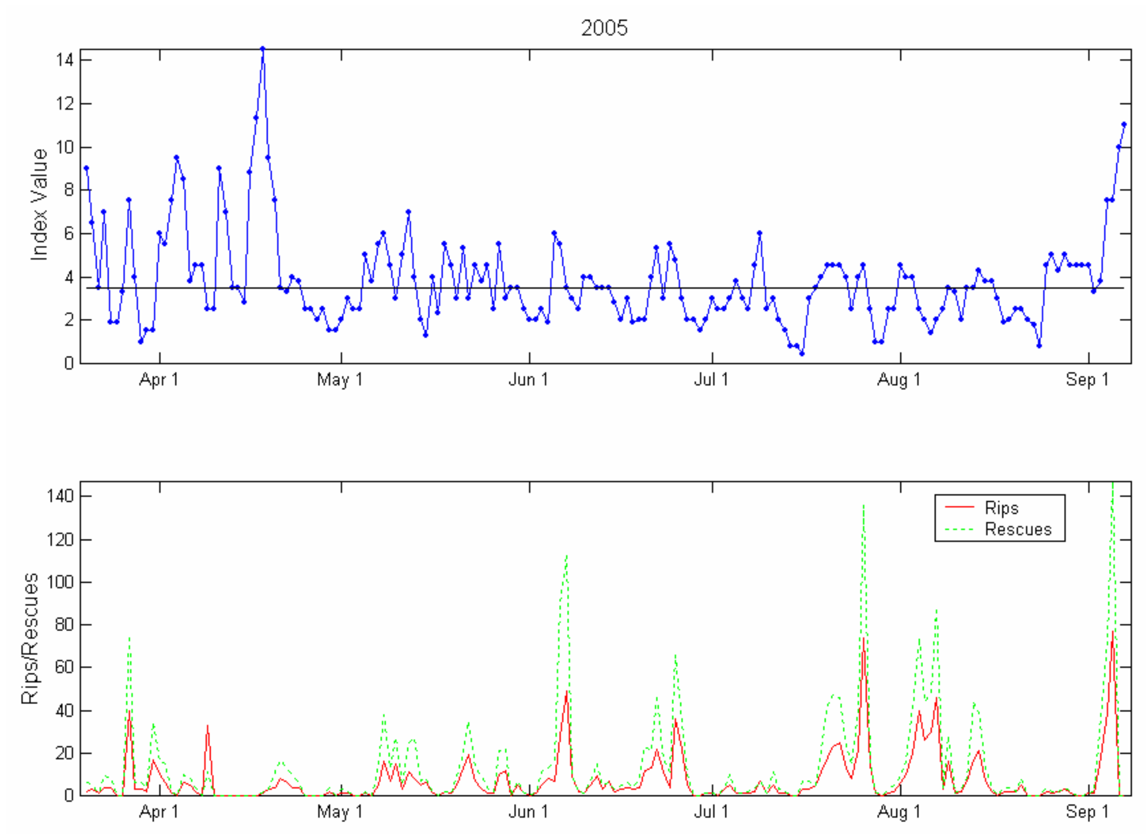

Figure 6-3. The daily-calculated threat values of both the modified index using the WAVEWATCH III oceanographic output information (top) along with the daily rip current incidents with associated rescues (bottom) for the summer of 2005. The horizontal lines represent the warning threshold.

CHAPTER 7
SUMMARY AND CONCLUSIONS

The first part of this study focused on the development of a modified index for the prediction of rip currents, in which wave direction was included as a primary parameter. An examination of all parameters and their correlation with rip-related rescues was completed to establish the relative importance (and hence appropriate weighting values) of each in the modified rip current index. The swell parameter data indicated the greatest relative rip current risk when the swell height ranged between 3 and 4 feet and the swell period was above 6 seconds. The swell height range was well represented in the existing ECFL LURCS and therefore remained unchanged. A slight shift in the swell period factor was thought to improve the performance of the index, yet the testing results proved otherwise. As a result the swell period parameter also remained unchanged. The incident wave direction exhibited the greatest risk to ocean-goers when the angle was between 40 and 80 degrees, representing a range within approximately 20 degrees north and south of shore-normal in the area of Volusia County. These results reinforce the importance of wave direction as an indicator of rip current threat previously noted in a study by Engle (2003). The swell direction was included into the modified index as a multiplicative factor. The tide data indicated the greatest risk for rip currents when low tide occurred during the day, especially between 10 a.m. and 12 p.m. The time of low tide was included into the index in addition to the existing astronomical tide factor.

Rip current formation is also influenced by the beach morphology. This becomes a problem for the prediction scheme because the nearshore bathymetry can be inconsistent along the coast of Florida, and transform with varying wave conditions. Therefore some variability will always be present in the correlation and testing results. This is due to the fact that the lifeguard records cover the entire coast of Volusia county, yet there is a near complete absence of time-dependent bathymetry data for the same area. However, the morphological dependence is indirectly incorporated into the index through the persistent swell factor. If there is consistent swell conditions that assist in the formation of a longshore bar, trough and rip channel system, then the index threat value for the days following will be subsequently increased.

The overall trends in each parameter are well represented in the modified rip current predictive index, and each change was proven through the testing process. Some of the parameters may appear artificially oriented towards the summer season, which is expected because the analysis was restricted to the summer. The winter season does pose a threat for rip current formation, but there is a considerable decrease in the number of ocean-goers. The analysis was dependent on rip-related rescues serving as a proxy for rip current formation and therefore the examination was limited to the summer season (Day 75–250). This period corresponds to the highest population of beach-goers and subsequently the majority of the annual rescues. From 1998 to 2005 over 80% of all rip-related rescues occurred during the summer (as defined above).

It must be noted that the use of rip current rescues as an indicator or proxy for actual rip current events is not without its drawbacks. This method suffers from the spurious effects of beach population as noted earlier (a lack of swimmers in bad weather may lead to no rescues, but this is not a guarantee that rip currents did not occur). However, in the absence of any direct long-term measurements of rip currents, this approach provides the best long-term data set to enable the correlation of rip current activity to the relevant meteorological and oceanographic forcing. The restriction of analysis to the summer months (when beach populations are generally large) helps in the reduction of these spurious effects.

The new index demonstrated considerable improvements over the original ECFL LURCS when tested on the documented lifeguard rescues from 1998 to 2003. The Probability of Detection Method 1 increased 26.7% and 22.0% for rescues and rips respectively. However, the Probability of Detection Method 2 increased only marginally (2.2% and 0.7%), signifying that the existing ECFL LURCS system detected a similar amount of rescue events. The False Alarm Ratio Method 1 decreased (improved) 10.3% and 9.0% for the rescues and rips. The False Alarm Ratio Method 2 also displayed improvement with decreases of 9.4% for rescues and 7.7% for rips. The combined progression of the False Alarm Ratio and the Probability of Detection is illustrated by each ratio value. The POD2/FAR2 increased 15.7% for rescues and 36.5% for rips. The POD2/FAR increased 8.7% for rescues and 27.3% for rips. In general, the modified index performed more accurately than the ECFL LURCS. There was a decrease in the false alarms and an increase in the detection of the higher risk days, which are represented by an increased number of rescues.

The second part of this study was geared toward the implementation of the predictive index as a forecasting tool. This was accomplished by employing a forecast (directional) wave model called WAVEWATCH III, which is a significant step since the east coast of Florida lacks a long-term network of directional wave measurements. The performance of the modified index employing oceanographic conditions given by

WAVEWATCH III compared well with the statistical values obtained from the analysis executed in the first part of the study. The new method was also compared with the ECFL LURCS worksheets on days in which there were more than 15 rescues. After improvements, the modified index detected 81% of the high-rescue days, while the ECFL LURCS worksheets only detected 61% of those same events.

Although this new system of rip current prediction shows significant improvements over the existing method, there is still difficulty within the process of creating a rip current forecast. The main problem is the interpretation of the WAVEWATCH III output parameters. Evaluating these parameters can become rather subjective, particularly if there is not an explicitly dominant swell. Care must be taken during this phase and therefore the user should be somewhat aware of the mechanics of rip current formation, as well as other important factors. These factors include, but are not limited to, the swell conditions and the number of rescues occurring in days prior to the forecasted day. To achieve the most consistent results, those who calculate the rip current threat level using the WAVEWATCH III model and the modified index should implement similar protocol.

The new method is not intended to replace the existing system completely, however it would certainly assist in the overall process of rip current prediction. It has been shown that shore-normal waves frequently result in a higher risk environment. Therefore, it is beneficial to use the WAVEWATCH III model to incorporate wave direction (which is otherwise unavailable from any real-time measurement platforms). Another significant advantage to this new method is the advanced notice of severe rip current conditions. By using the forecast wave field rather than same-day measurements, the extra time allows for earlier and maybe more effective issuance of warnings to the public through the media and other venues. It also allows for the beach safety division to staff the local lifeguard stations accordingly, in preparation for the additional rescues anticipated with heightened threat levels. These advancements would hopefully decrease the number of rip current drownings in Florida.

The addition of wave direction might also assist in the extension of the application of a rip current predictive index to other coastal locations outside East Central Florida as well. However, further study would likely be needed to re-calibrate the other index parameters in order to reflect local wave and tidal conditions. For now, the next logical step in this process is to use the new predictive index incorporating WAVEWATCH III in an operational mode (perhaps side by side with the ECFL LURC worksheets) to make forecasts and comparative tests on a daily basis.

APPENDIX A
WAVE CONDITIONS AND RIP CURRENT RESCUES

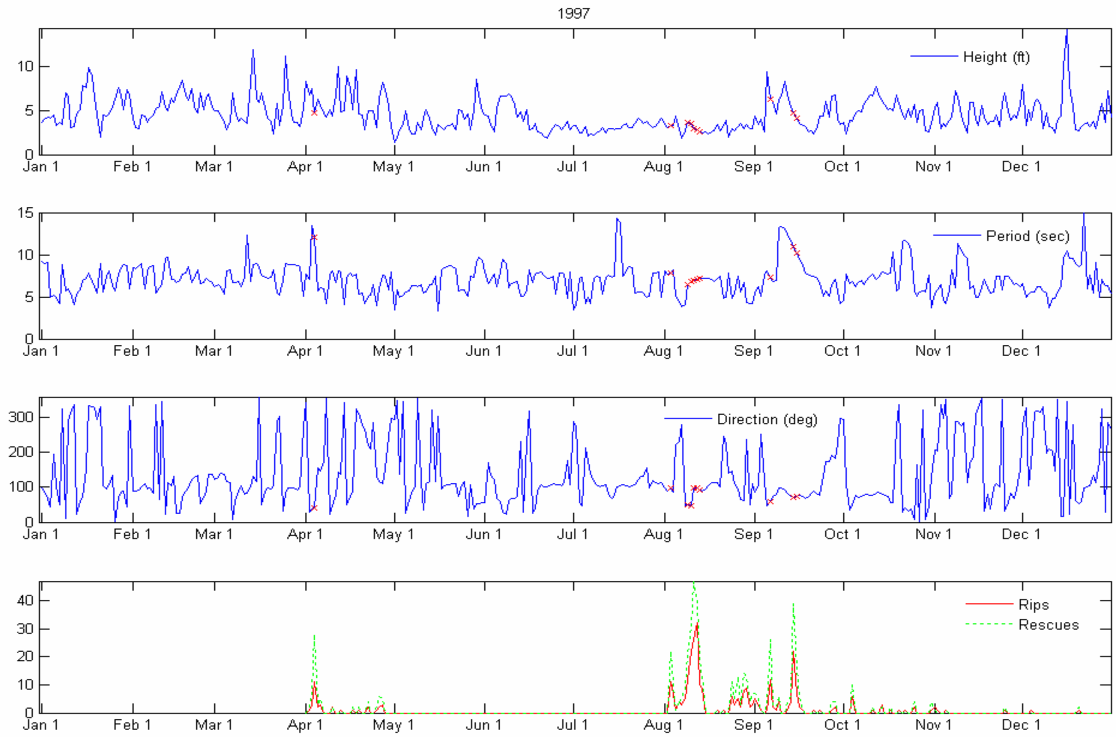

Figure A-1. Time-series plots of wave height (ft), wave period (sec), wave direction (deg) and rip current incidents with associated rescues for 1997. The “x” marks correspond to days with more than 15 rescues.

Figure A-2. Time-series plots of wave height (ft), wave period (sec), wave direction (deg) and rip current incidents with associated rescues for 1998. The "x" marks correspond to days with more than 15 rescues.

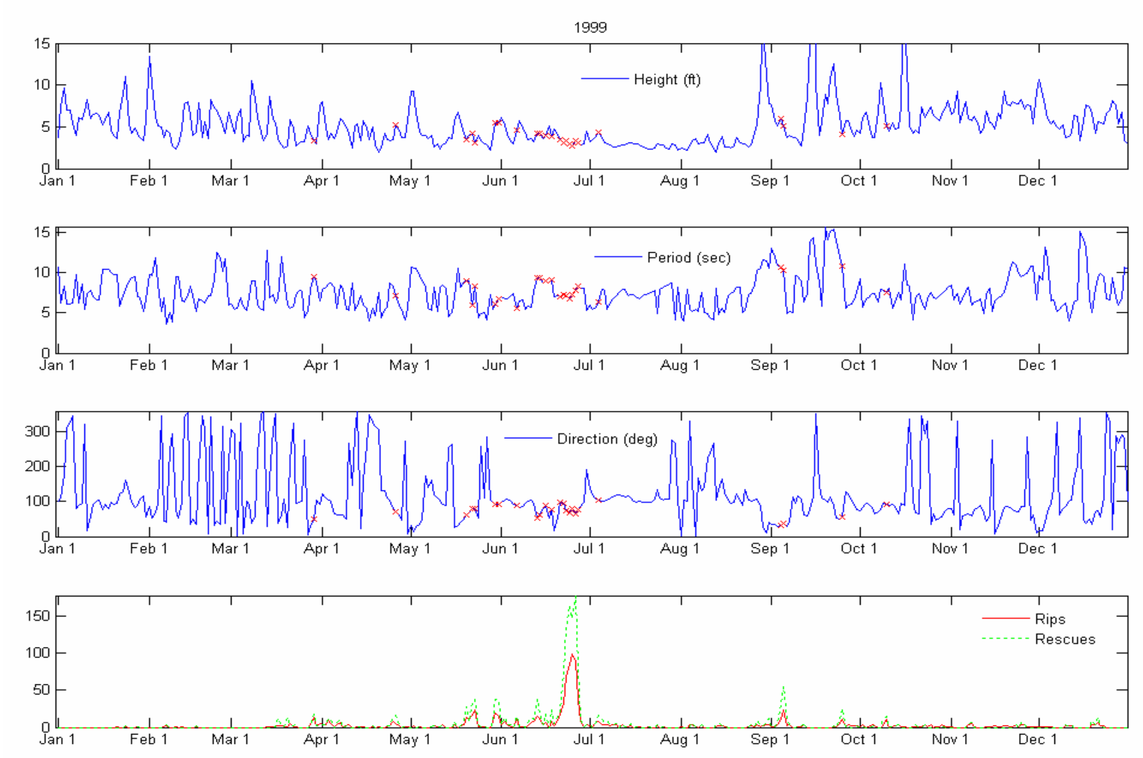

Figure A-3. Time-series plots of wave height (ft), wave period (sec), wave direction (deg) and rip current incidents with associated rescues for 1999. The “x” marks correspond to days with more than 15 rescues.

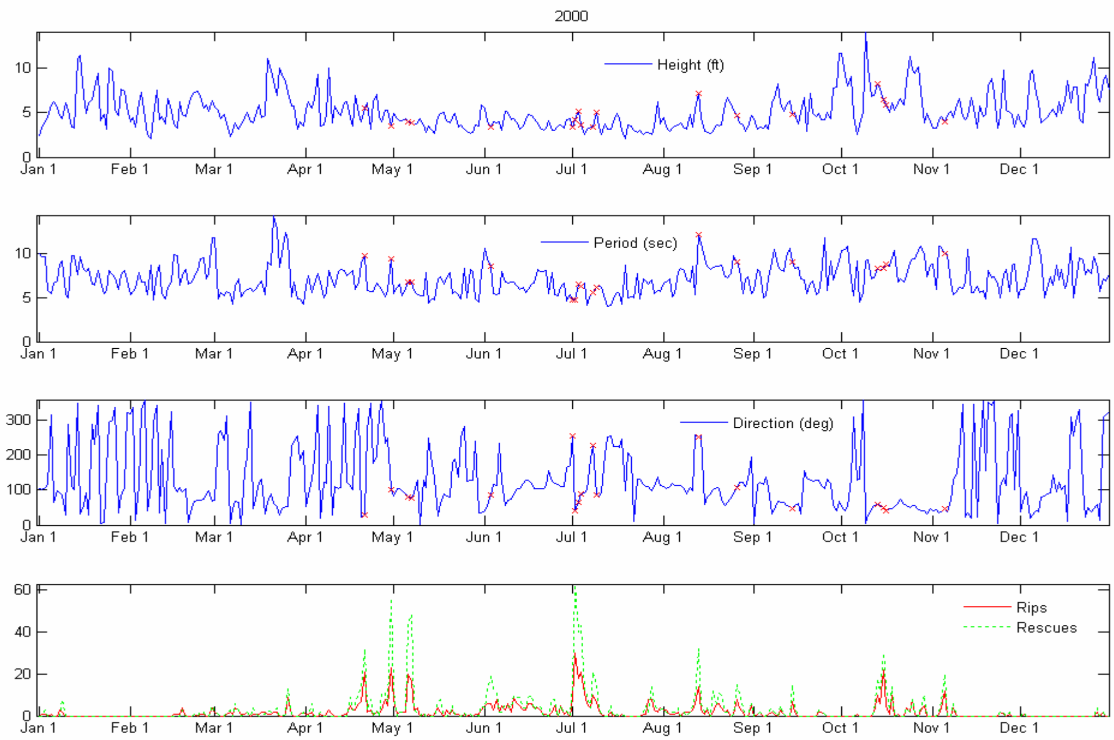

Figure A-4. Time-series plots of wave height (ft), wave period (sec), wave direction (deg) and rip current incidents with associated rescues for 2000. The “x” marks correspond to days with more than 15 rescues.

Figure A-5. Time-series plots of wave height (ft), wave period (sec), wave direction (deg) and rip current incidents with associated rescues for 2001. The “x” marks correspond to days with more than 15 rescues.

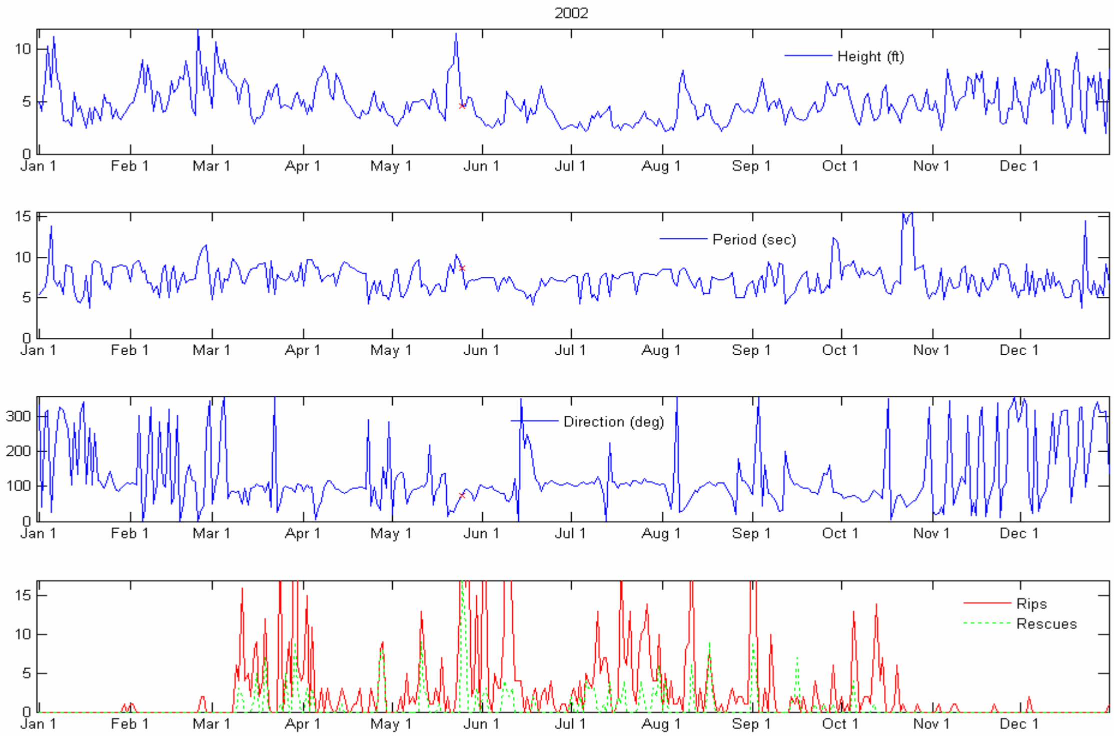

Figure A-6. Time-series plots of wave height (ft), wave period (sec), wave direction (deg) and rip current incidents with associated rescues for 2002. The “x” marks correspond to days with more than 15 rescues.

Figure A-7. Time-series plots of wave height (ft), wave period (sec), wave direction (deg) and rip current incidents with associated rescues for 2003. The “x” marks correspond to days with more than 15 rescues.

Figure A-8. Time-series plots of wave height (ft), wave period (sec), wave direction (deg) and rip current incidents with associated rescues for 2004. The “x” marks correspond to days with more than 15 rescues.

APPENDIX B
RIP CURRENT THREAT VALUES AND RESCUES

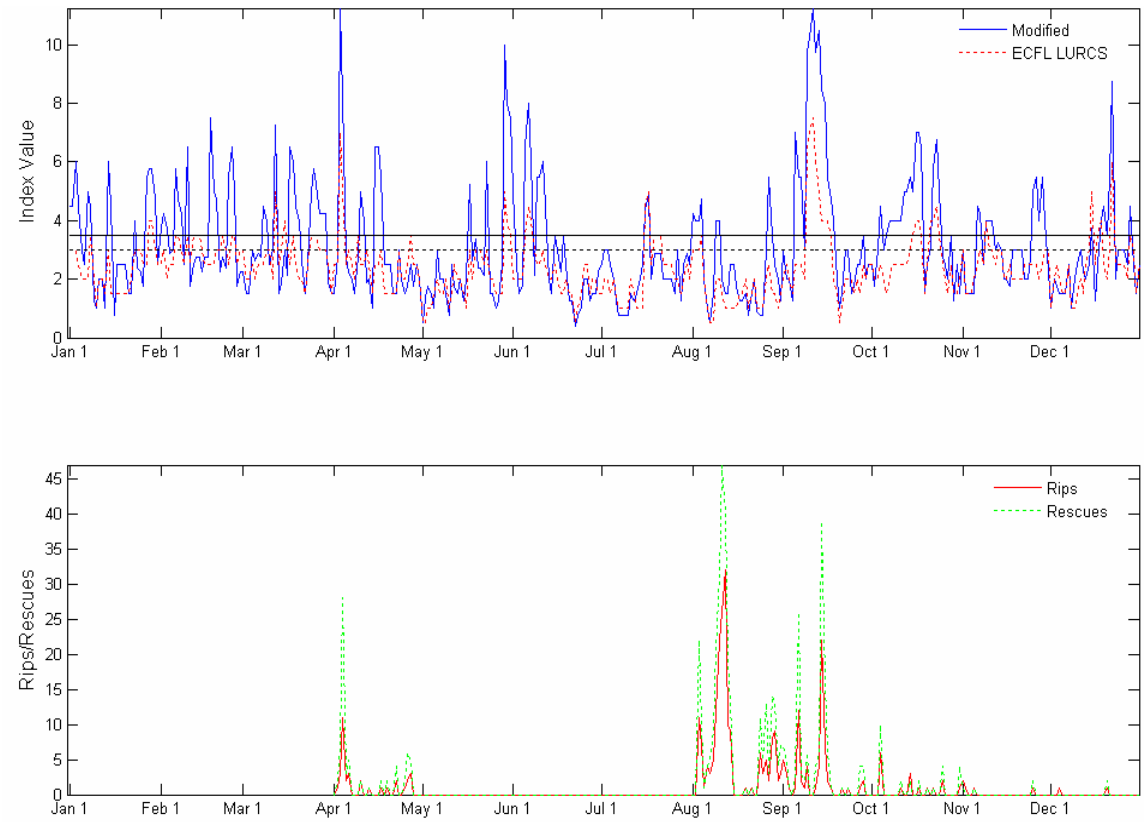

Figure B-1. The daily-calculated threat values of both the ECFL LURCS and the modified index (top) along with the daily rip current incidents with associated rescues (bottom) for 1997. The horizontal lines represent the warning threshold for each respective index.

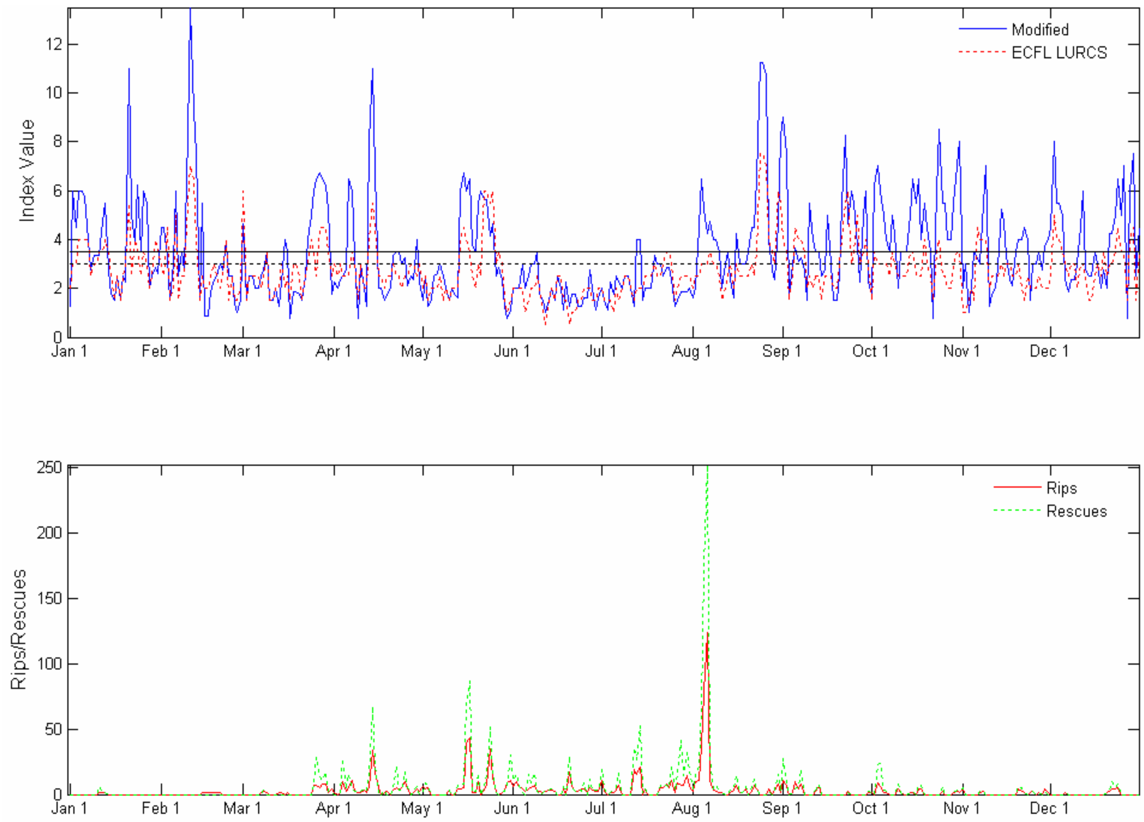

Figure B-2. The daily-calculated threat values of both the ECFL LURCS and the modified index (top) along with the daily rip current incidents with associated rescues (bottom) for 1998. The horizontal lines represent the warning threshold for each respective index.

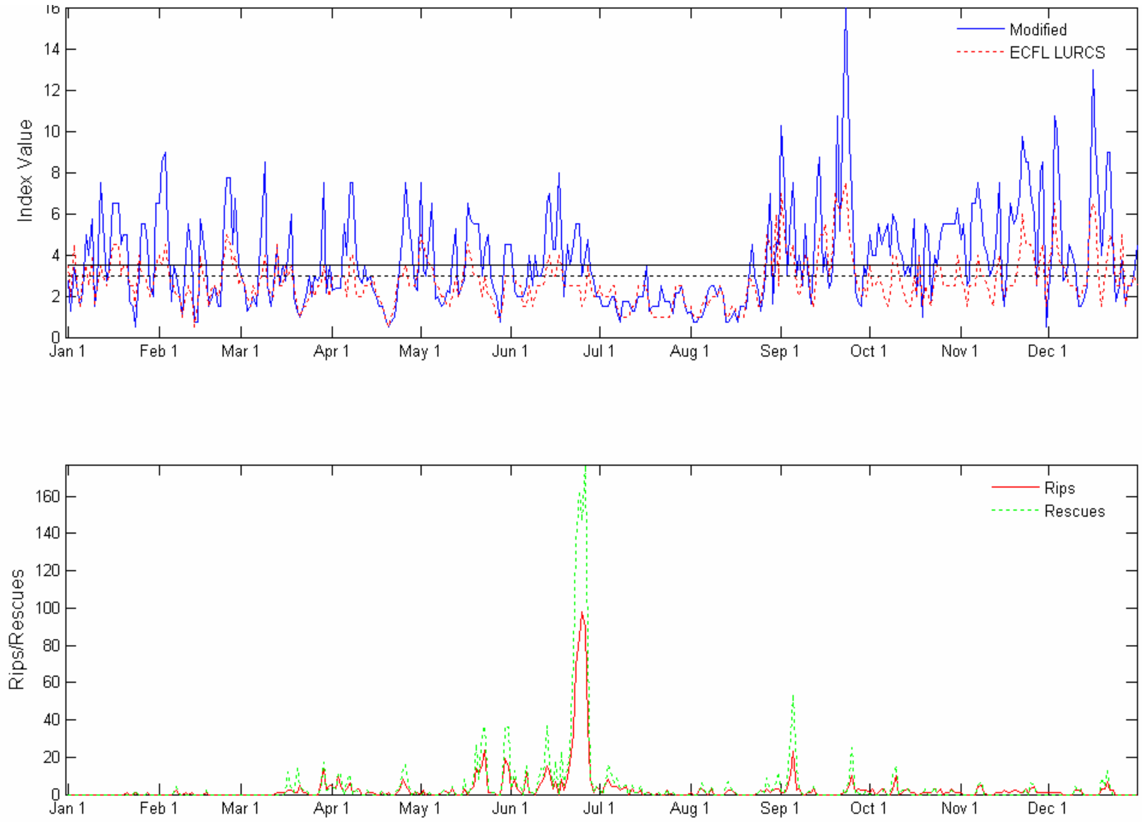

Figure B-3. The daily-calculated threat values of both the ECFL LURCS and the modified index (top) along with the daily rip current incidents with associated rescues (bottom) for 1999. The horizontal lines represent the warning threshold for each respective index.

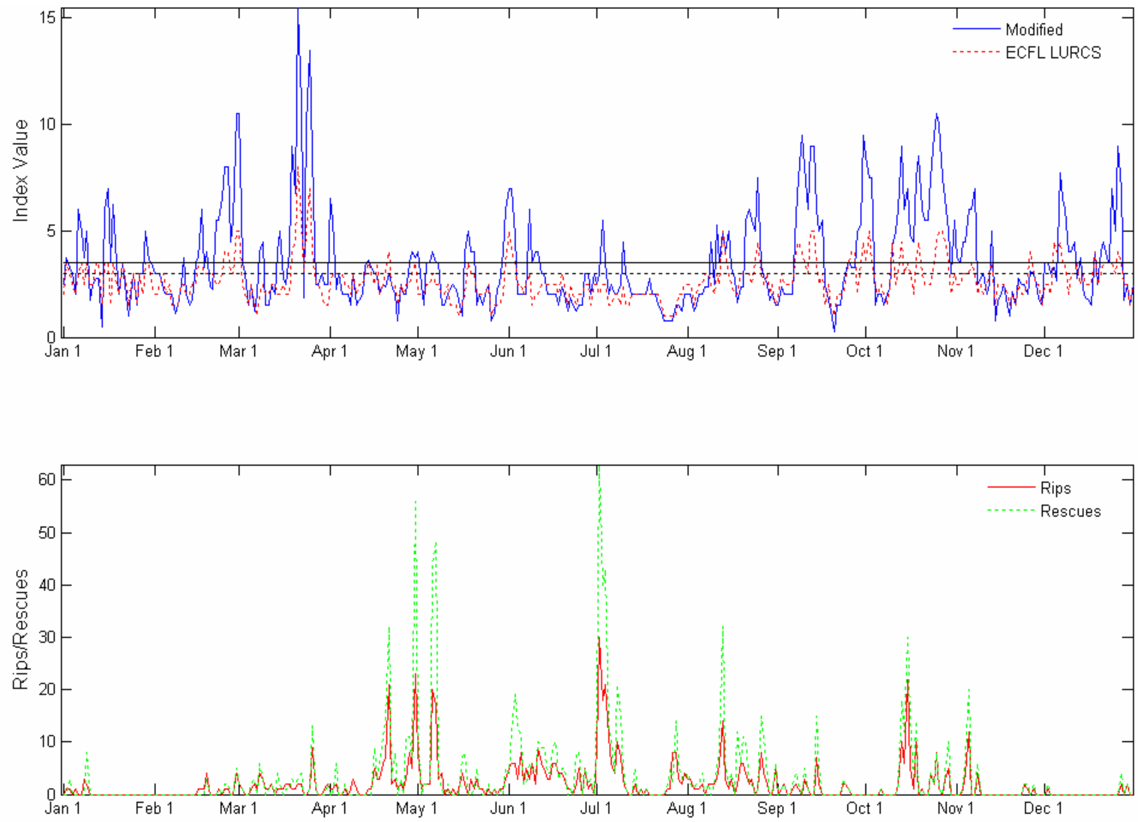

Figure B-4. The daily-calculated threat values of both the ECFL LURCS and the modified index (top) along with the daily rip current incidents with associated rescues (bottom) for 2000. The horizontal lines represent the warning threshold for each respective index.

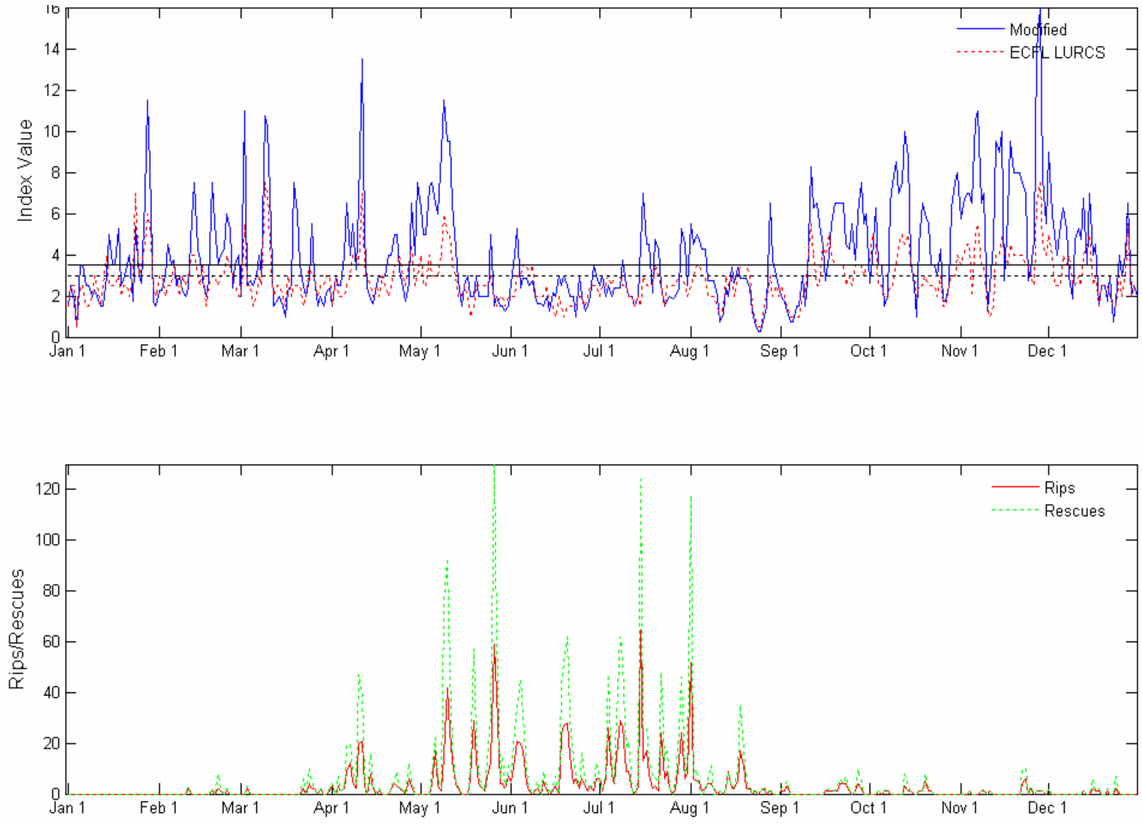

Figure B-5. The daily-calculated threat values of both the ECFL LURCS and the modified index (top) along with the daily rip current incidents with associated rescues (bottom) for 2001. The horizontal lines represent the warning threshold for each respective index.

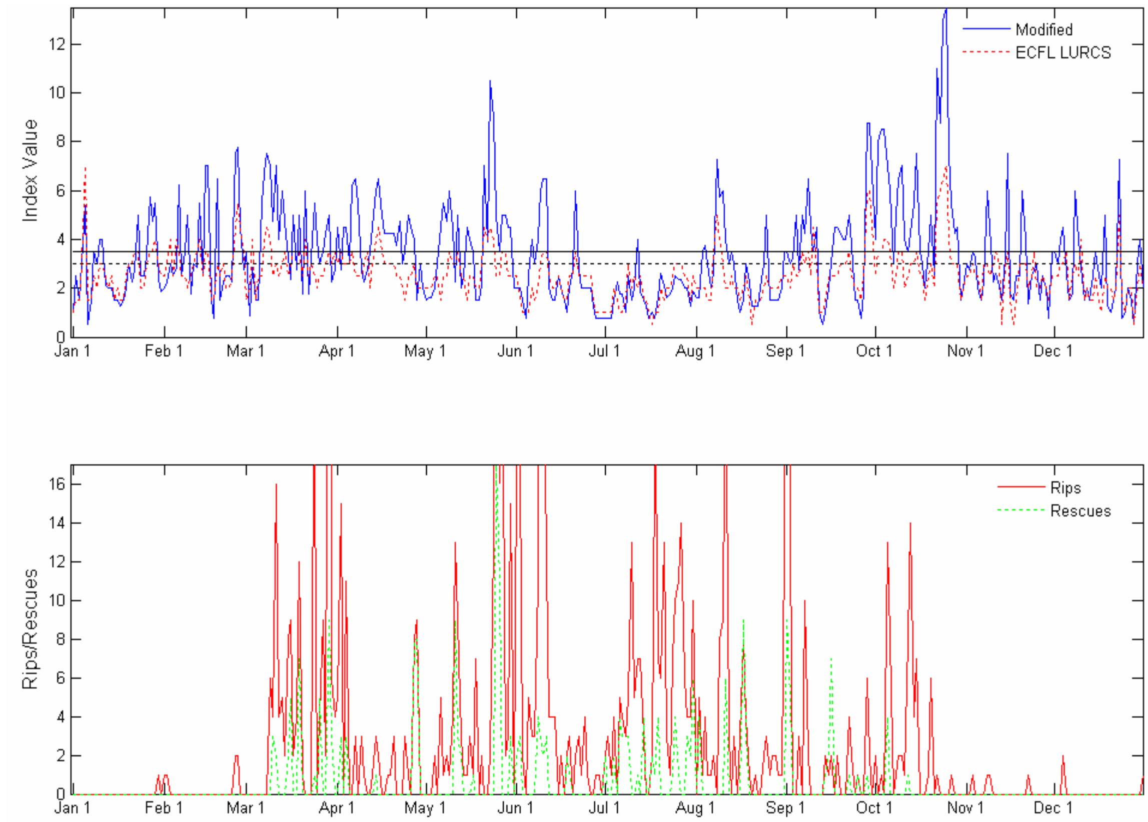

Figure B-6. The daily-calculated threat values of both the ECFL LURCS and the modified index (top) along with the daily rip current incidents with associated rescues (bottom) for 2002. The horizontal lines represent the warning threshold for each respective index.

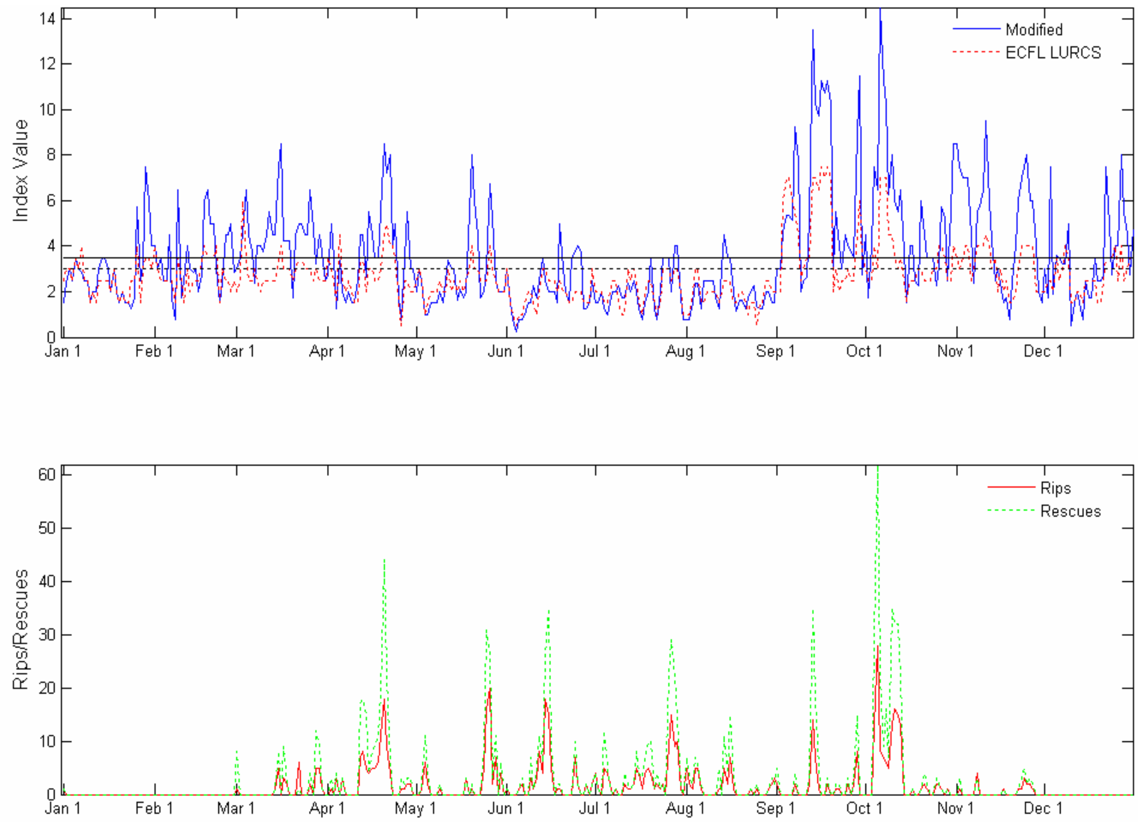

Figure B-7. The daily-calculated threat values of both the ECFL LURCS and the modified index (top) along with the daily rip current incidents with associated rescues (bottom) for 2003. The horizontal lines represent the warning threshold for each respective index.

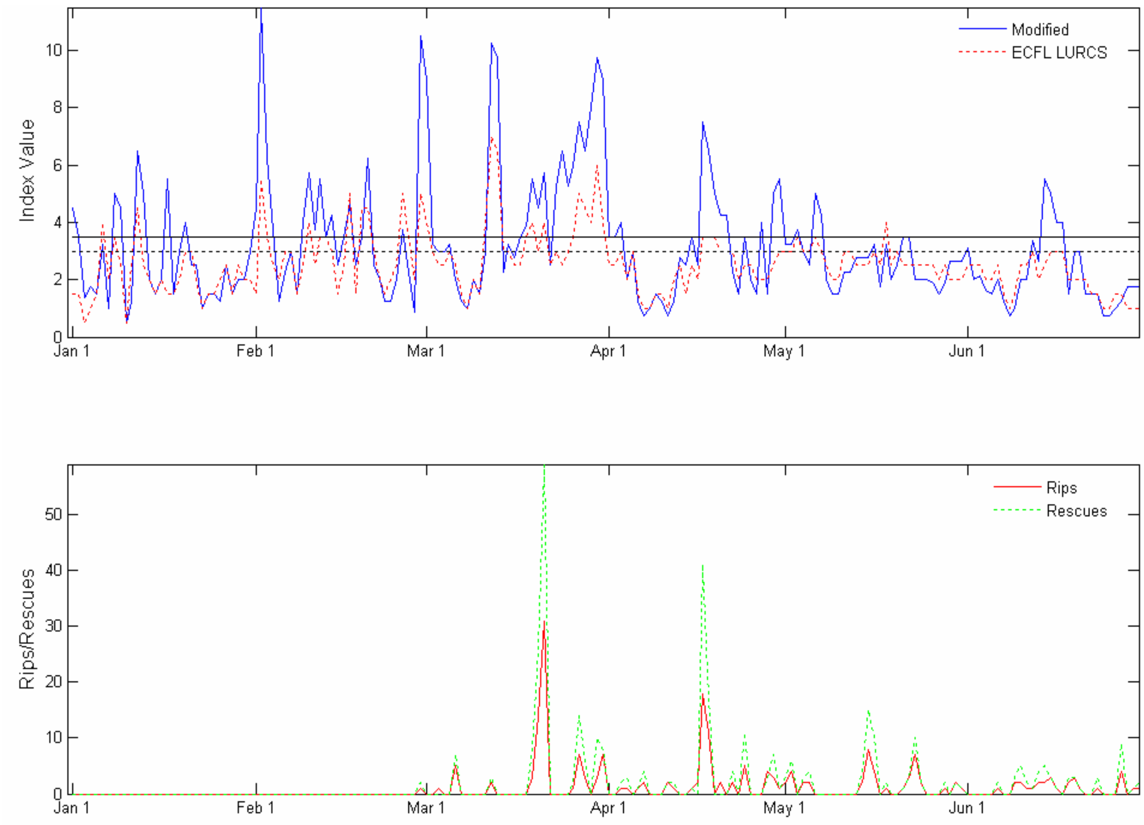

Figure B-8. The daily-calculated threat values of both the ECFL LURCS and the modified index (top) along with the daily rip current incidents with associated rescues (bottom) for 2004. The horizontal lines represent the warning threshold for each respective index.

APPENDIX C
DAILY SUMMER THREAT VALUES, DAILY RESCUE TOTALS AND RESULTING PERFORMANCE STATISTICS

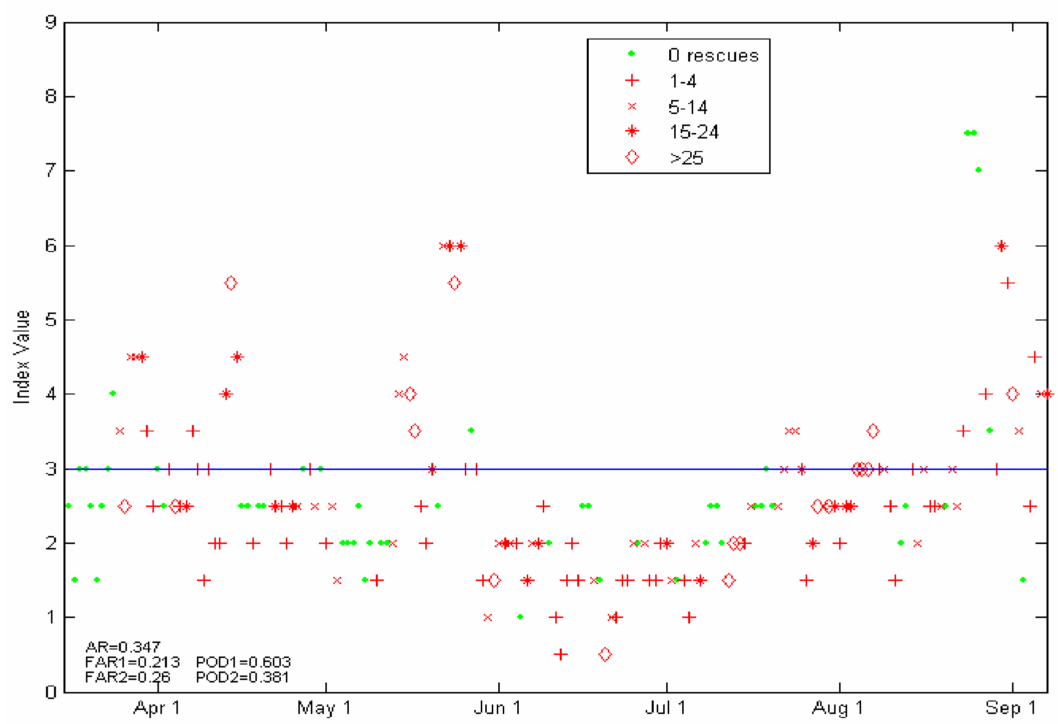

Figure C-1. ECFL LURCS daily rip current threat levels for the summer of 1998. The daily rip current rescue totals are indicated by the marker symbols.

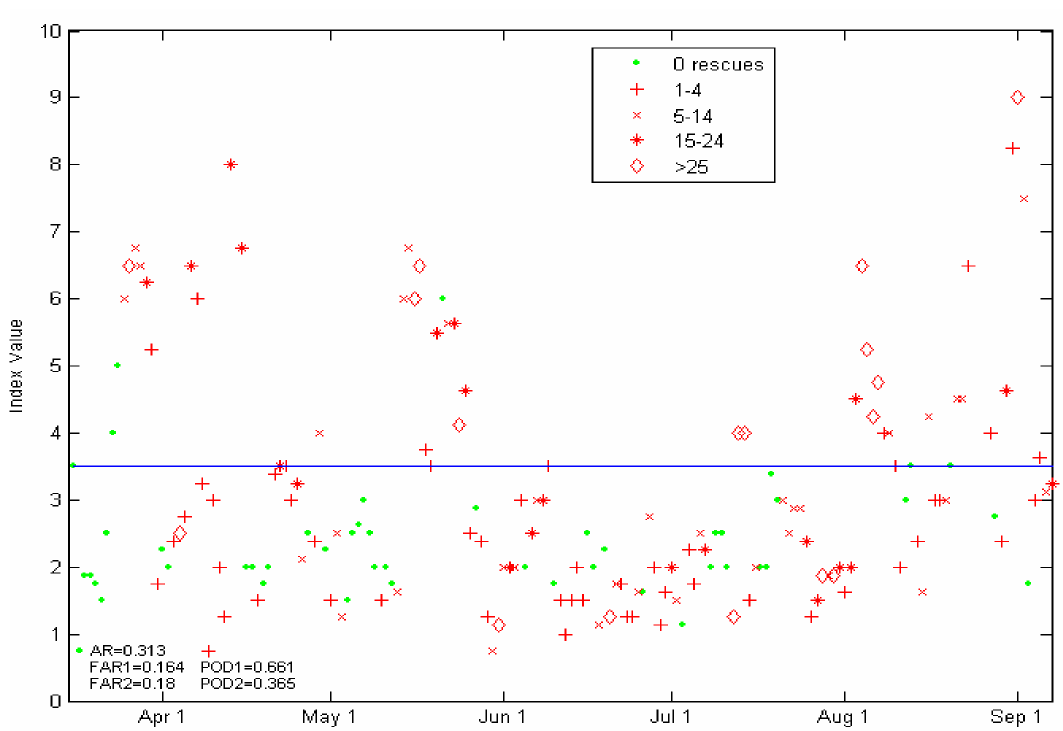

Figure C-2. The modified index daily rip current threat levels for the summer of 1998. The daily rip current rescue totals are indicated by the marker symbols.

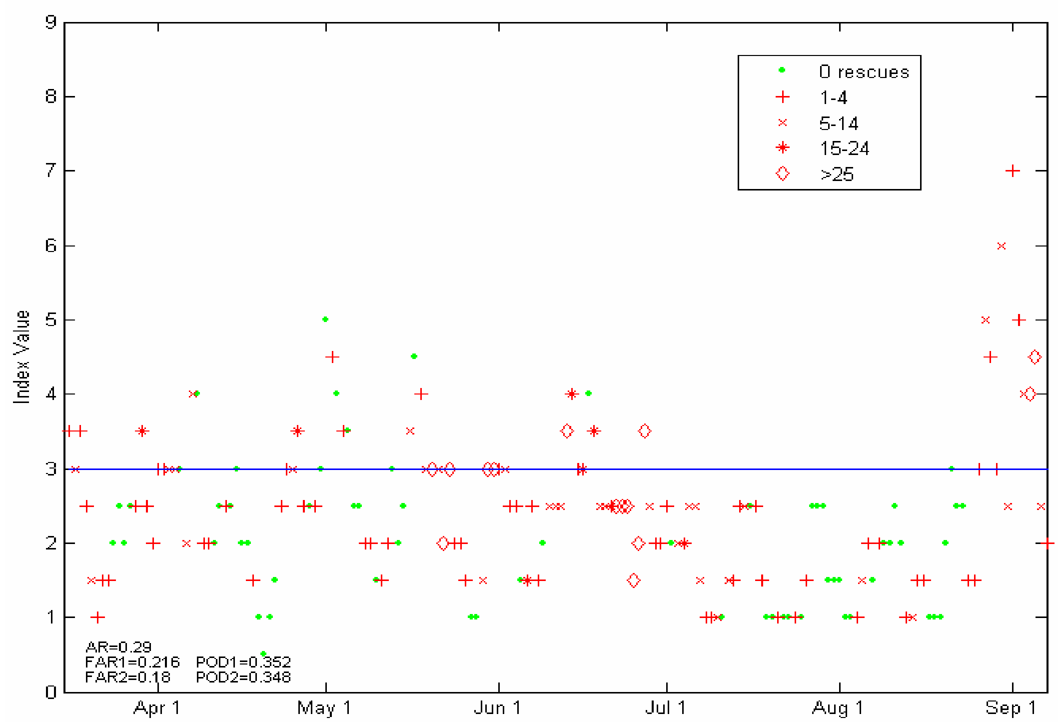

Figure C-3. ECFL LURCS daily rip current threat levels for the summer of 1999. The daily rip current rescue totals are indicated by the marker symbols.

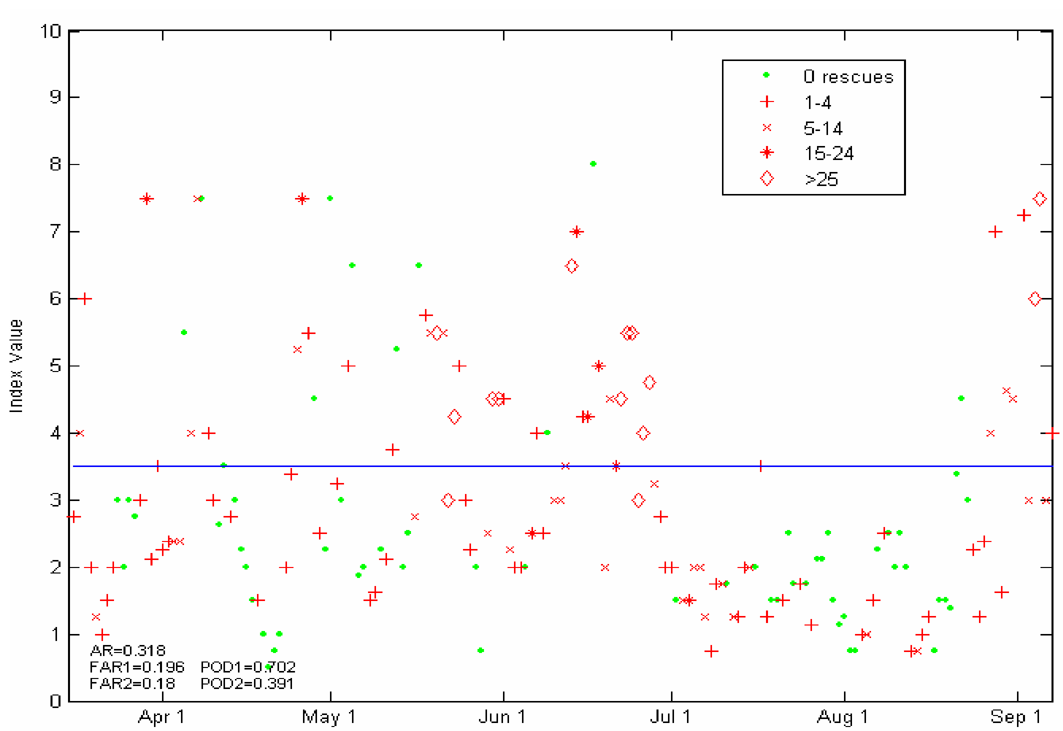

Figure C-4. The modified index daily rip current threat levels for the summer of 1999. The daily rip current rescue totals are indicated by the marker symbols.

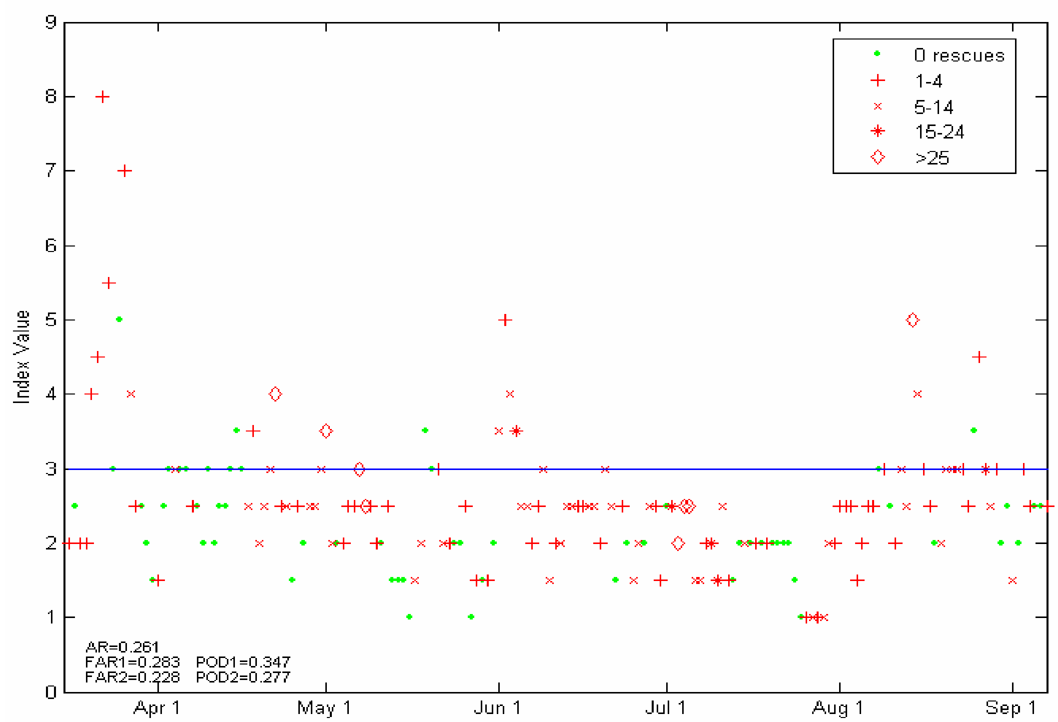

Figure C-5. ECFL LURCS daily rip current threat levels for the summer of 2000. The daily rip current rescue totals are indicated by the marker symbols.

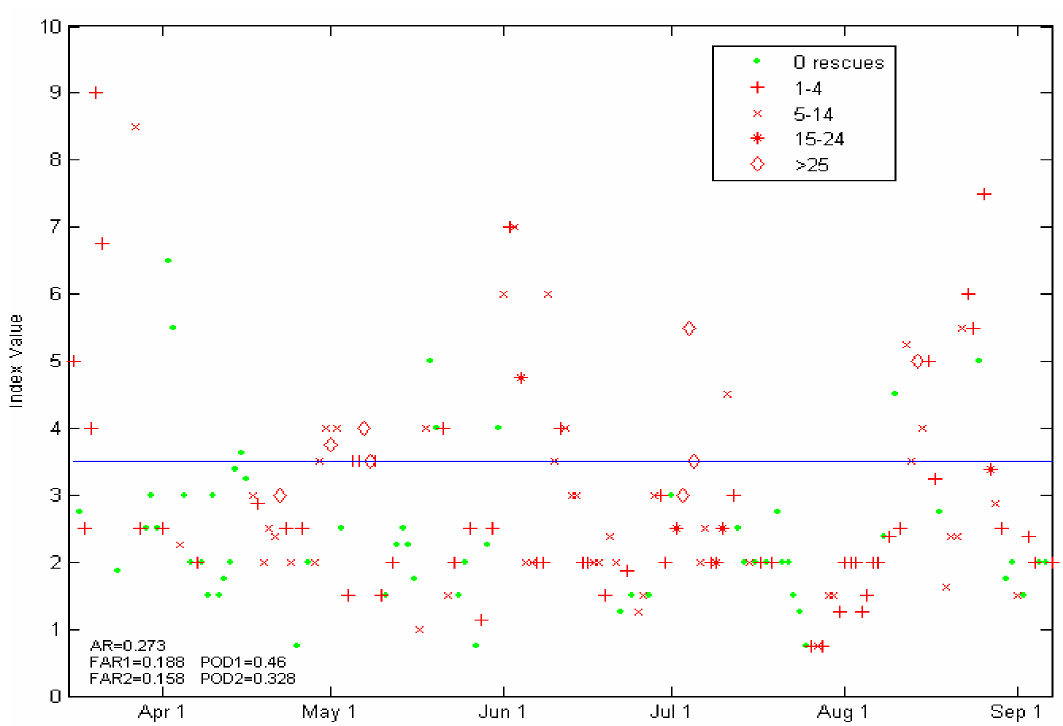

Figure C-6. The modified index daily rip current threat levels for the summer of 2000. The daily rip current rescue totals are indicated by the marker symbols.

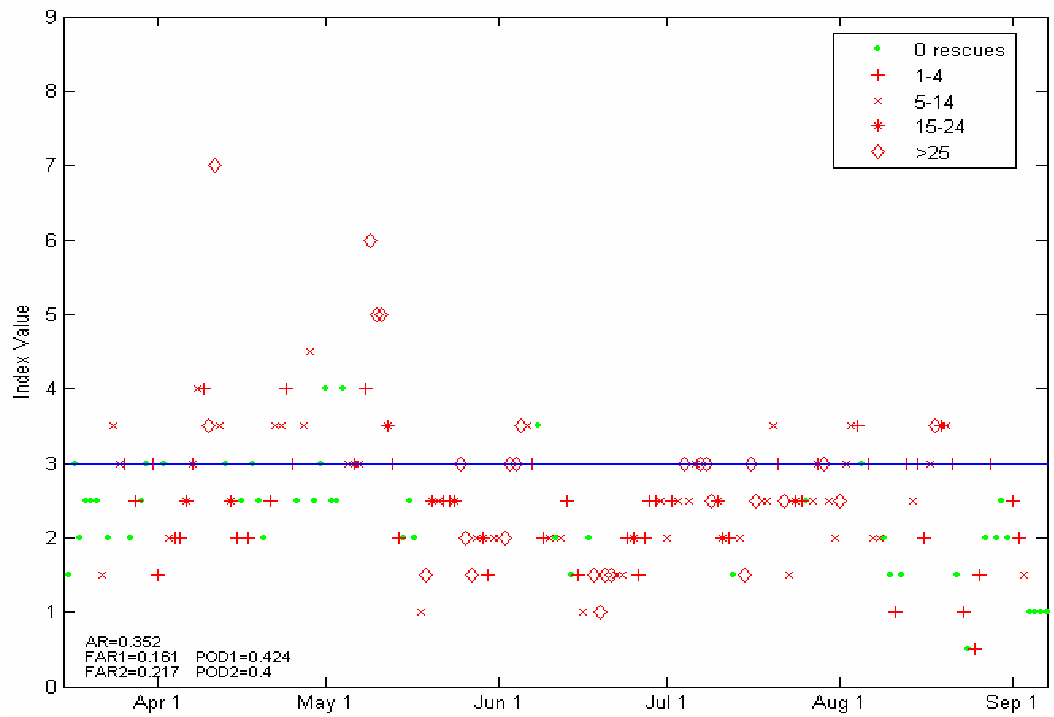

Figure C-7. ECFL LURCS daily rip current threat levels for the summer of 2001. The daily rip current rescue totals are indicated by the marker symbols.

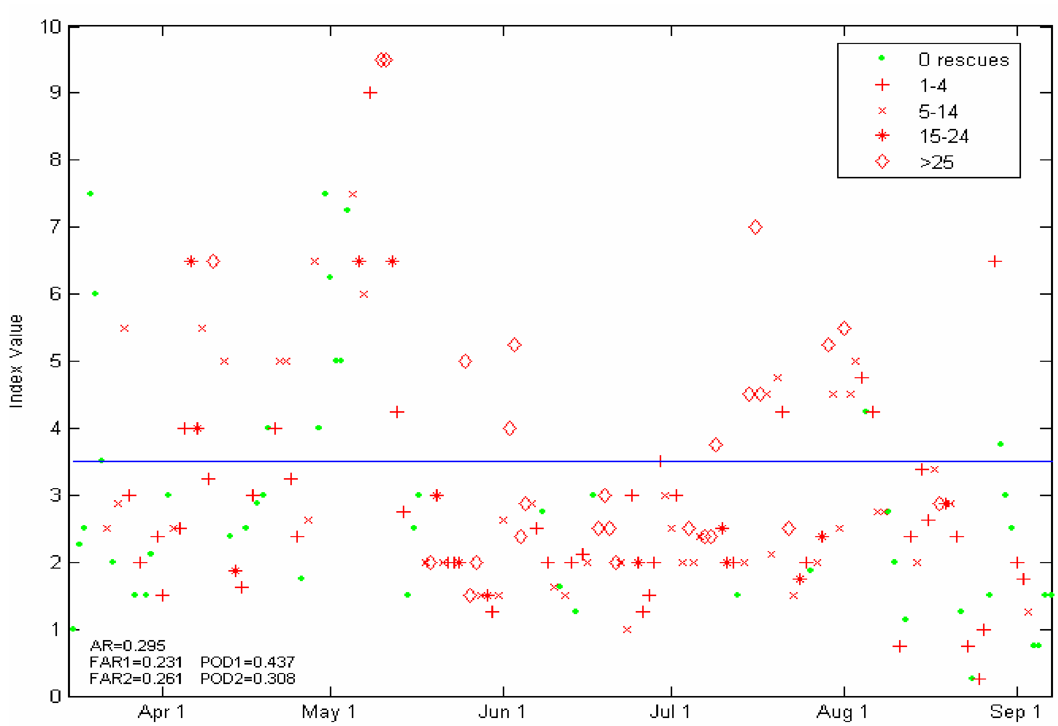

Figure C-8. The modified index daily rip current threat levels for the summer of 2001. The daily rip current rescue totals are indicated by the marker symbols.

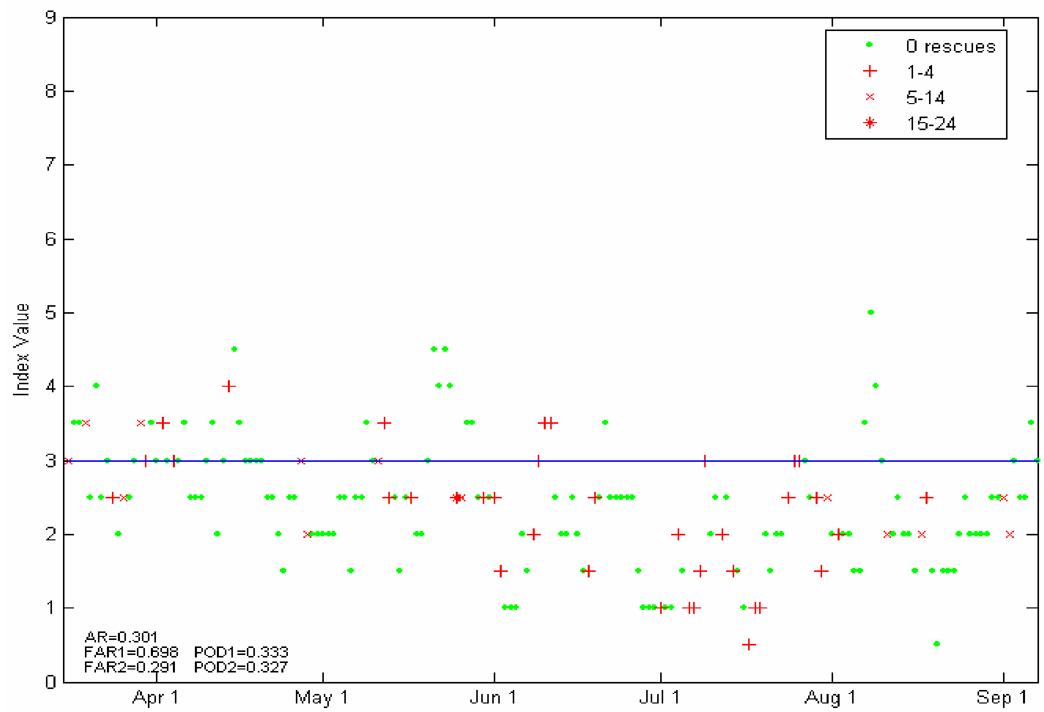

Figure C-9. ECFL LURCS daily rip current threat levels for the summer of 2002. The daily rip current rescue totals are indicated by the marker symbols.

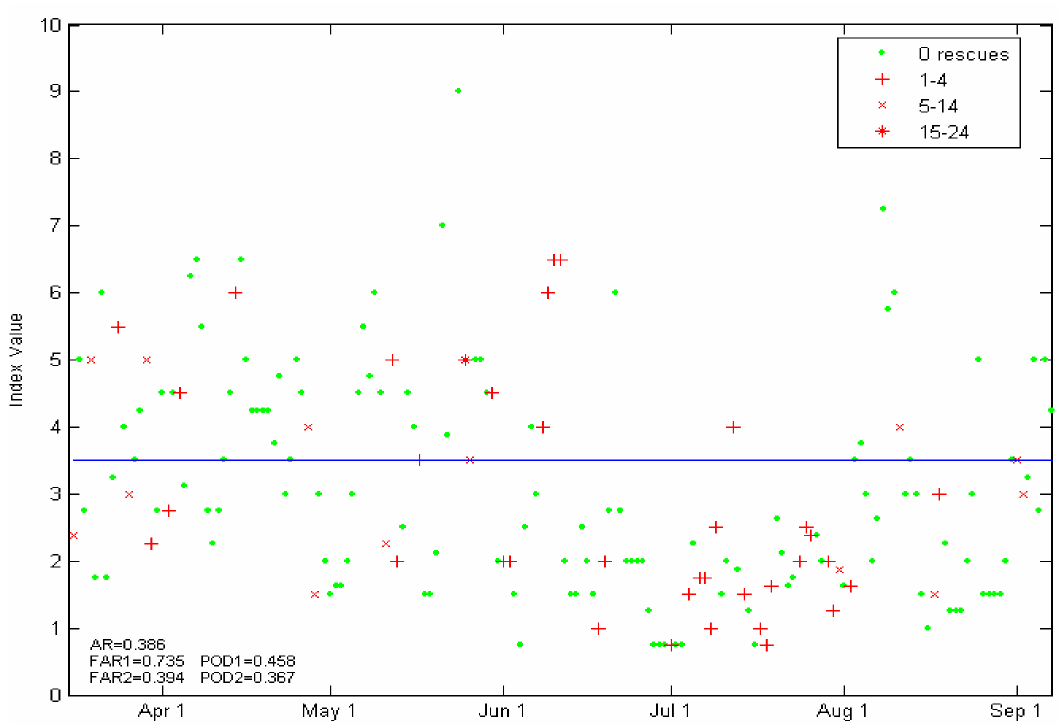

Figure C-10. The modified index daily rip current threat levels for the summer of 2002. The daily rip current rescue totals are indicated by the marker symbols.

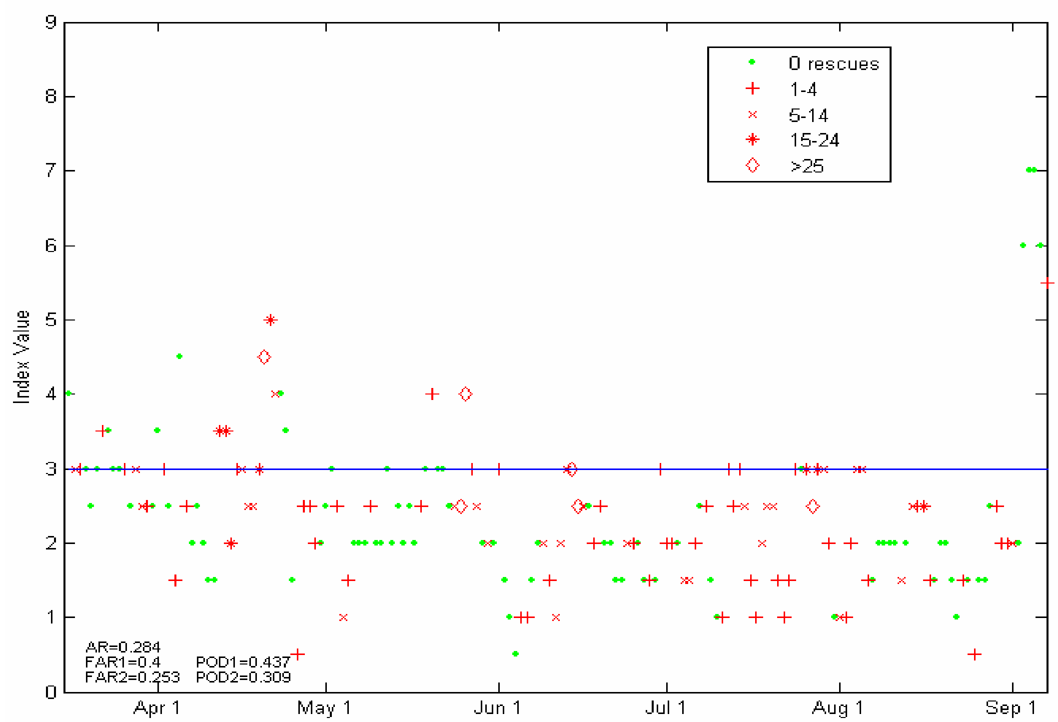

Figure C-11. ECFL LURCS daily rip current threat levels for the summer of 2003. The daily rip current rescue totals are indicated by the marker symbols.

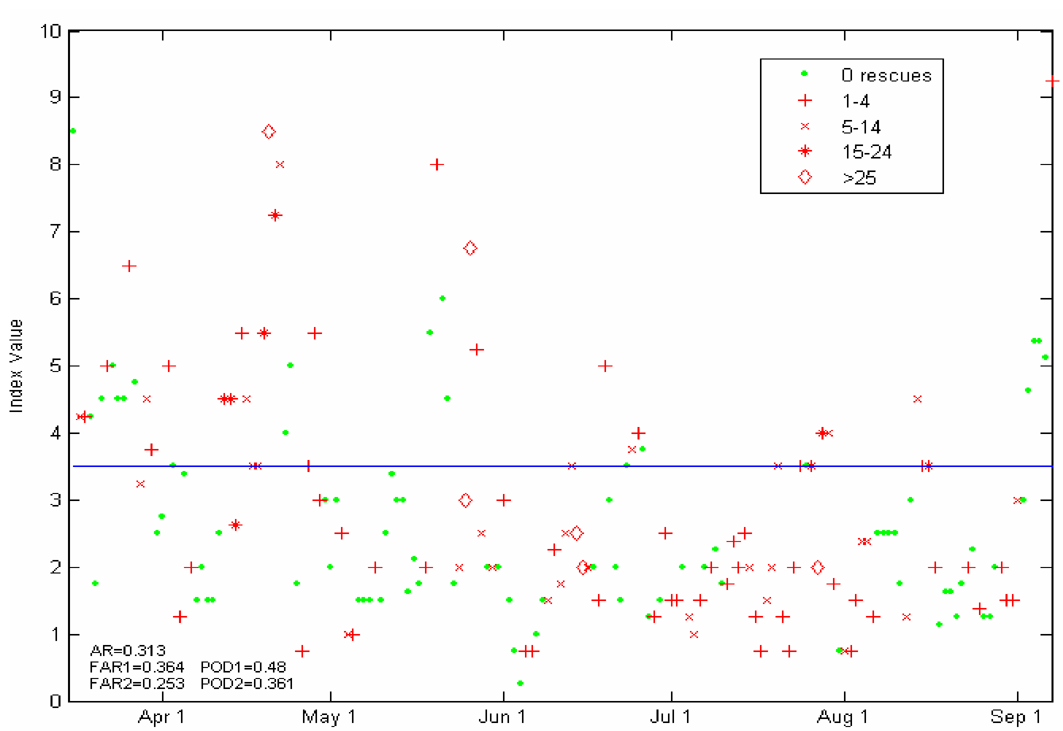

Figure C-12. The modified index daily rip current threat levels for the summer of 2003. The daily rip current rescue totals are indicated by the marker symbols.

APPENDIX D
DAILY SUMMER THREAT VALUES, DAILY RIP TOTALS AND RESULTING PERFORMANCE STATISTICS

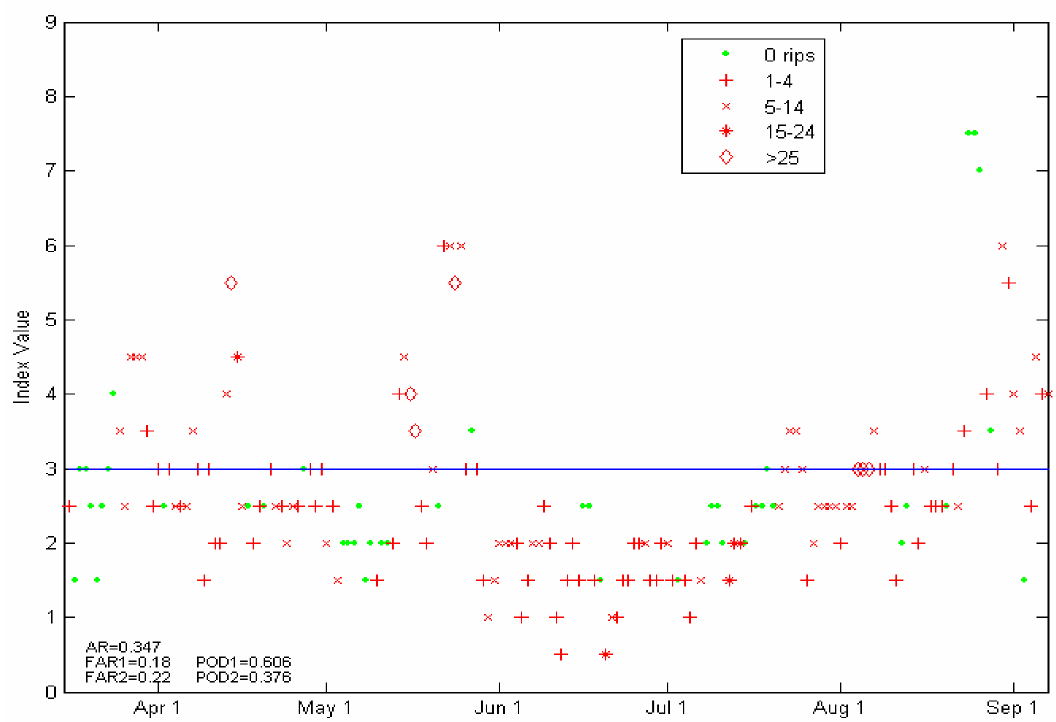

Figure D-1. ECFL LURCS daily rip current threat levels for the summer of 1998. The daily rip current incident totals are indicated by the marker symbols.

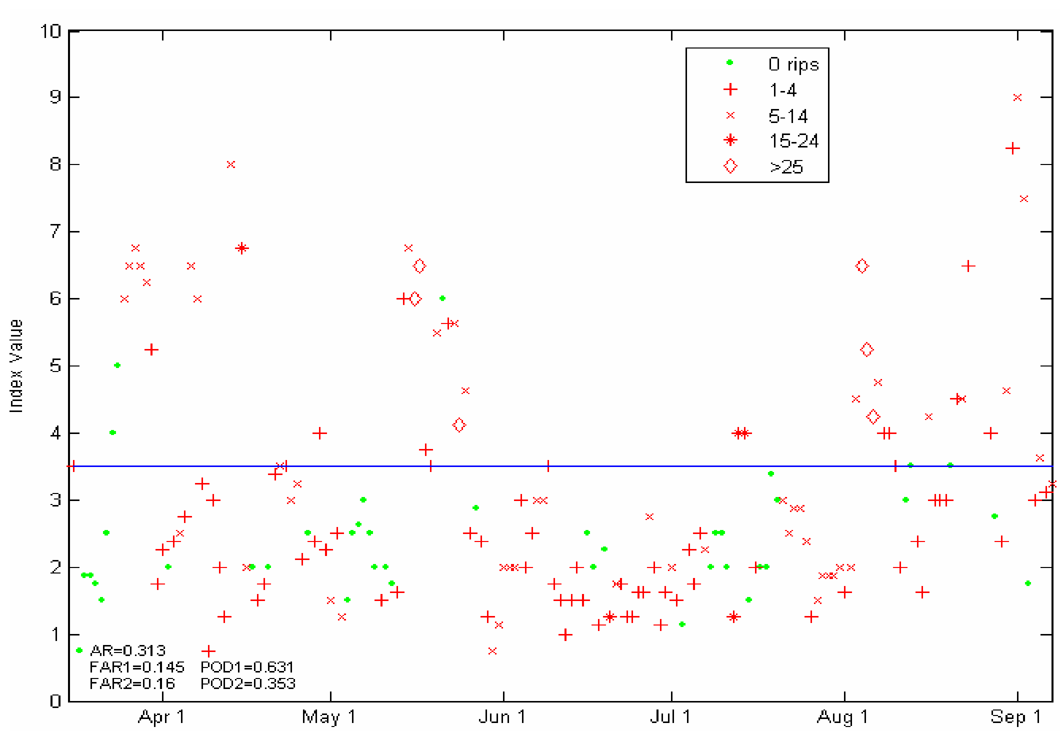

Figure D-2. The modified index daily rip current threat levels for the summer of 1998. The daily rip current incident totals are indicated by the marker symbols.

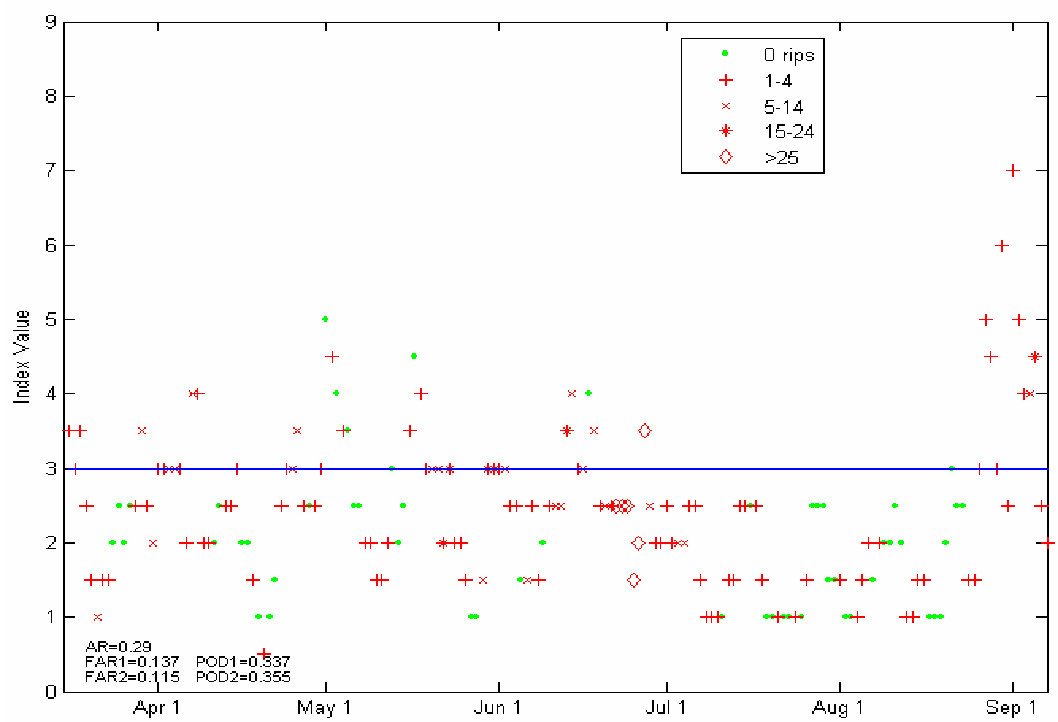

Figure D-3. ECFL LURCS daily rip current threat levels for the summer of 1999. The daily rip current incident totals are indicated by the marker symbols.

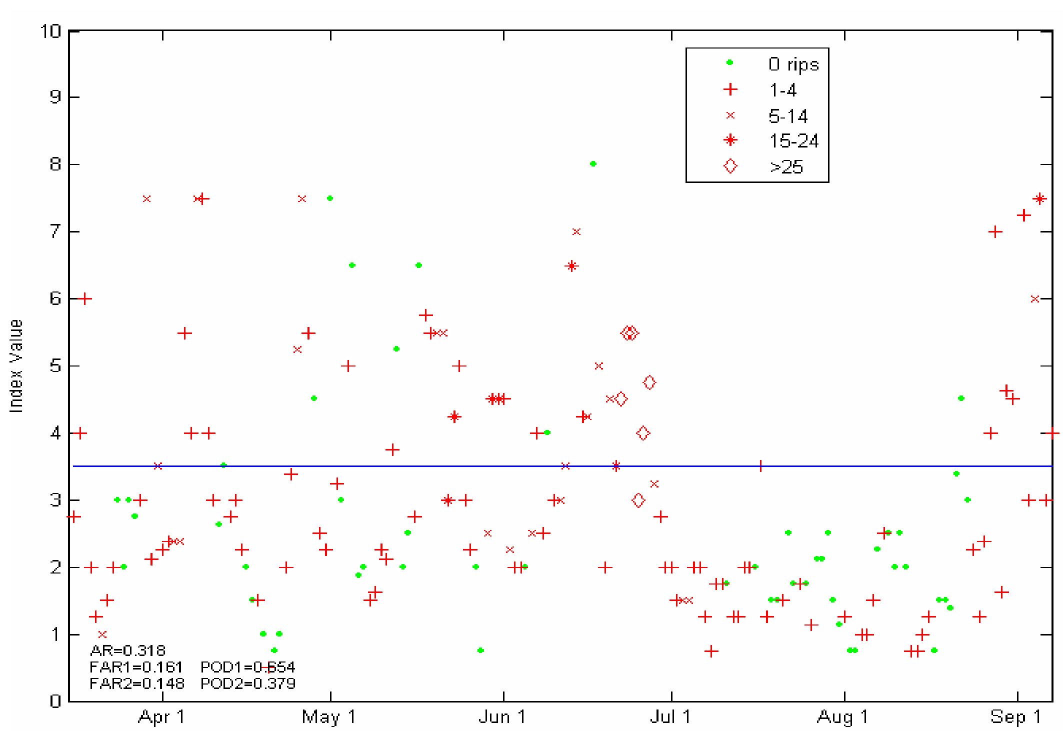

Figure D-4. The modified index daily rip current threat levels for the summer of 1999. The daily rip current incident totals are indicated by the marker symbols.

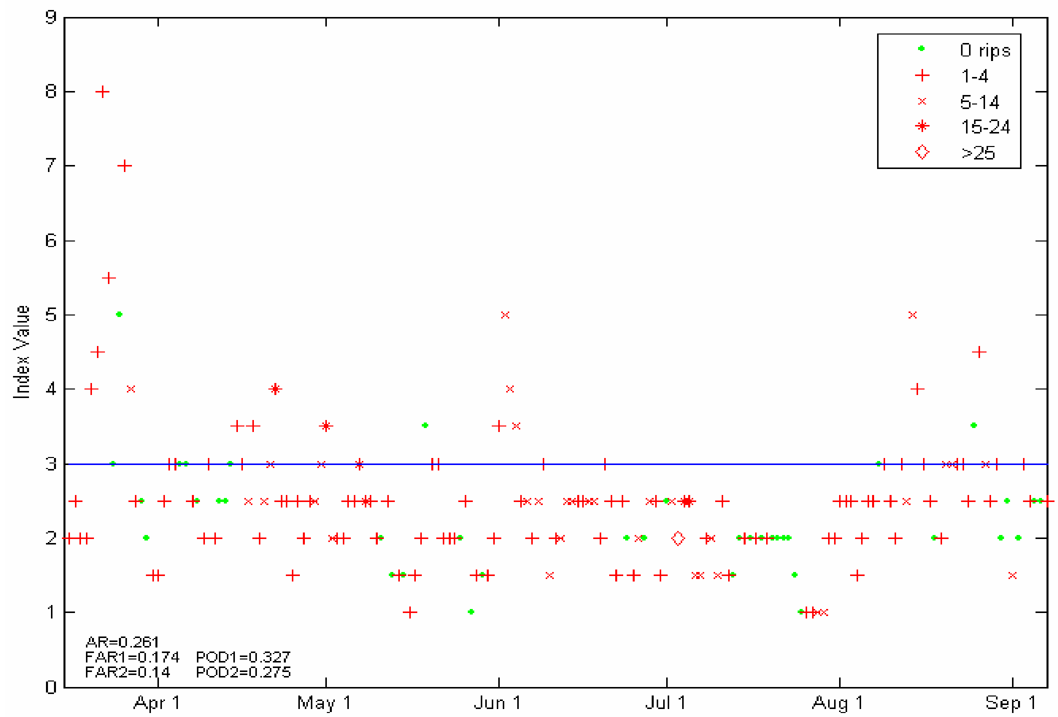

Figure D-5. ECFL LURCS daily rip current threat levels for the summer of 2000. The daily rip current incident totals are indicated by the marker symbols.

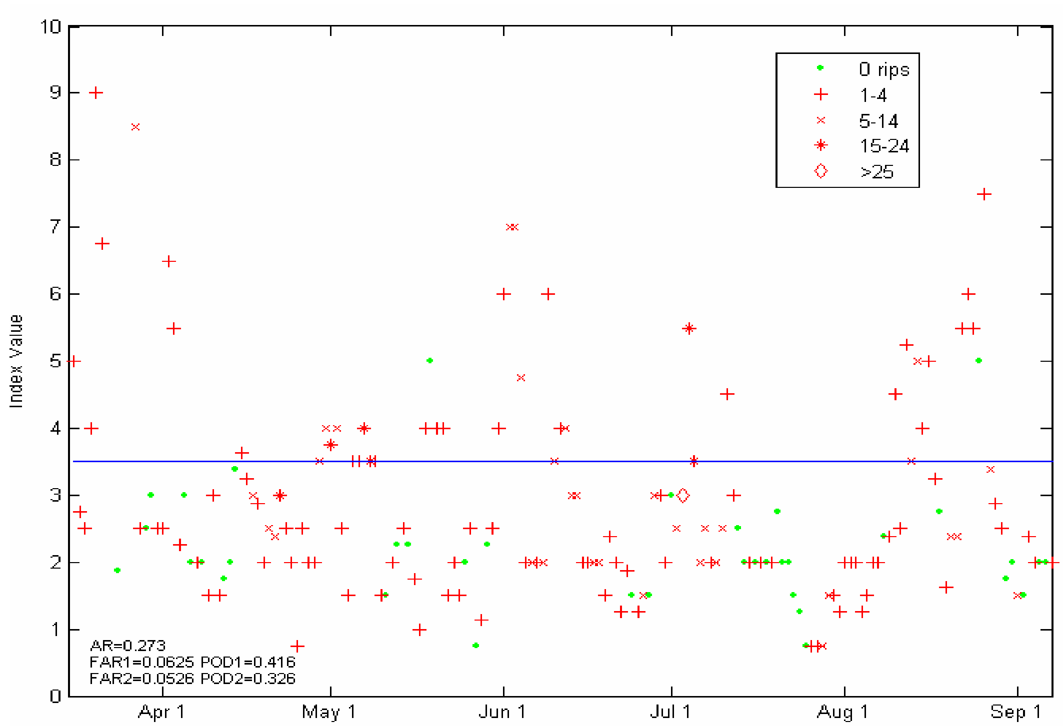

Figure D-6. The modified index daily rip current threat levels for the summer of 2000. The daily rip current incident totals are indicated by the marker symbols.

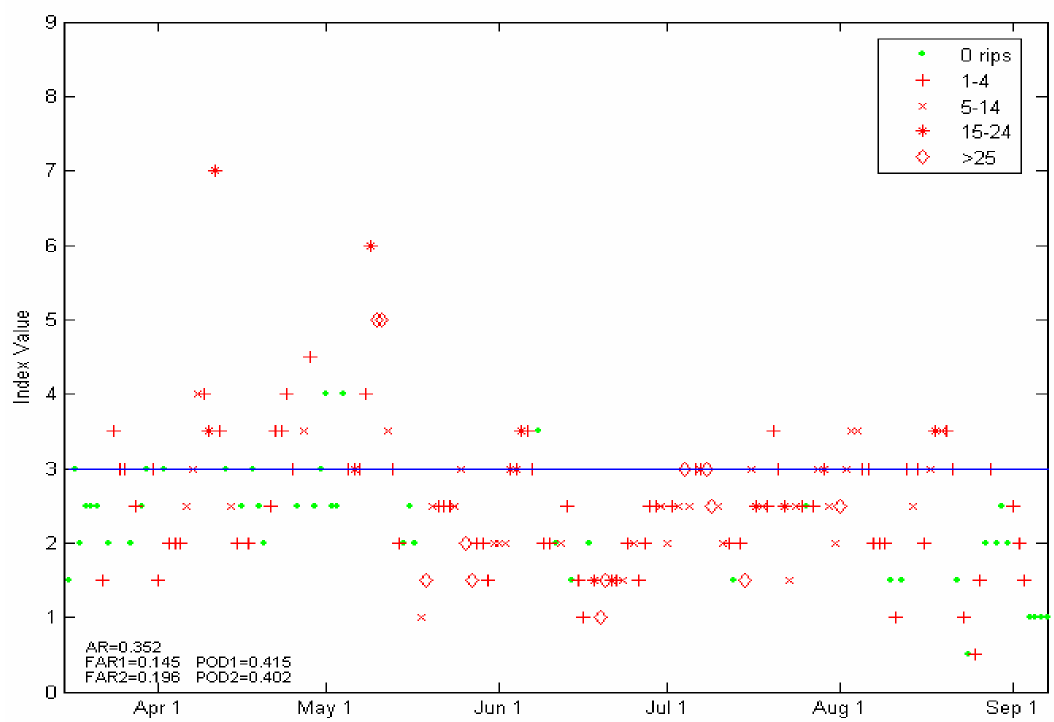

Figure D-7. ECFL LURCS daily rip current threat levels for the summer of 2001. The daily rip current incident totals are indicated by the marker symbols.

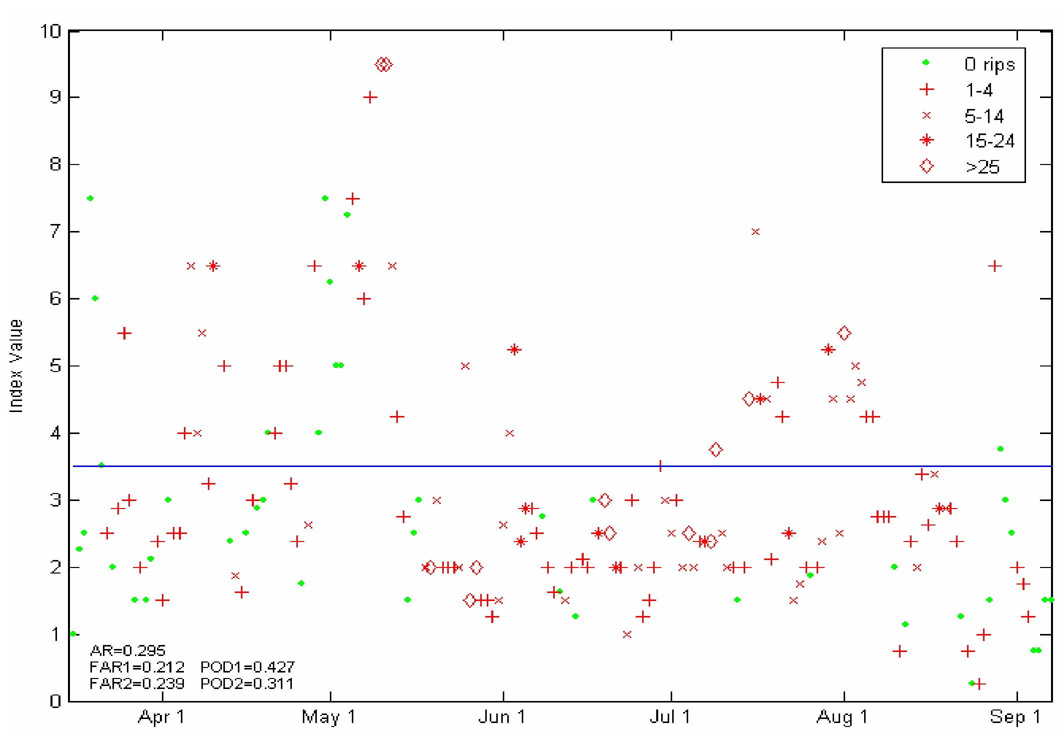

Figure D-8. The modified index daily rip current threat levels for the summer of 2001. The daily rip current incident totals are indicated by the marker symbols.

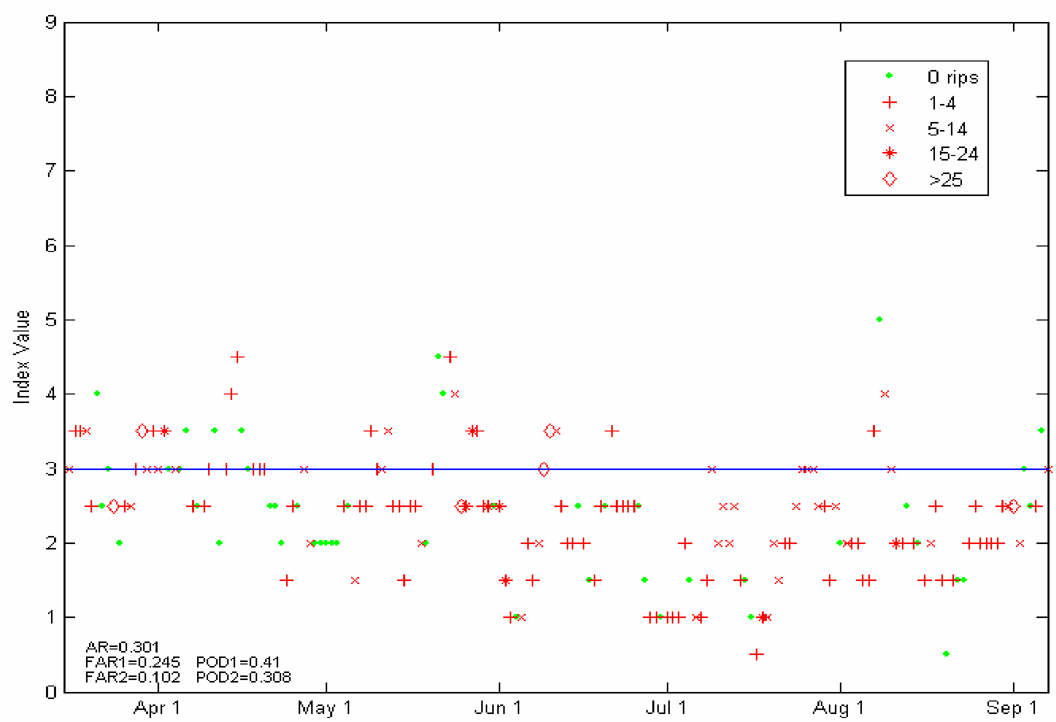

Figure D-9. ECFL LURCS daily rip current threat levels for the summer of 2002. The daily rip current incident totals are indicated by the marker symbols.

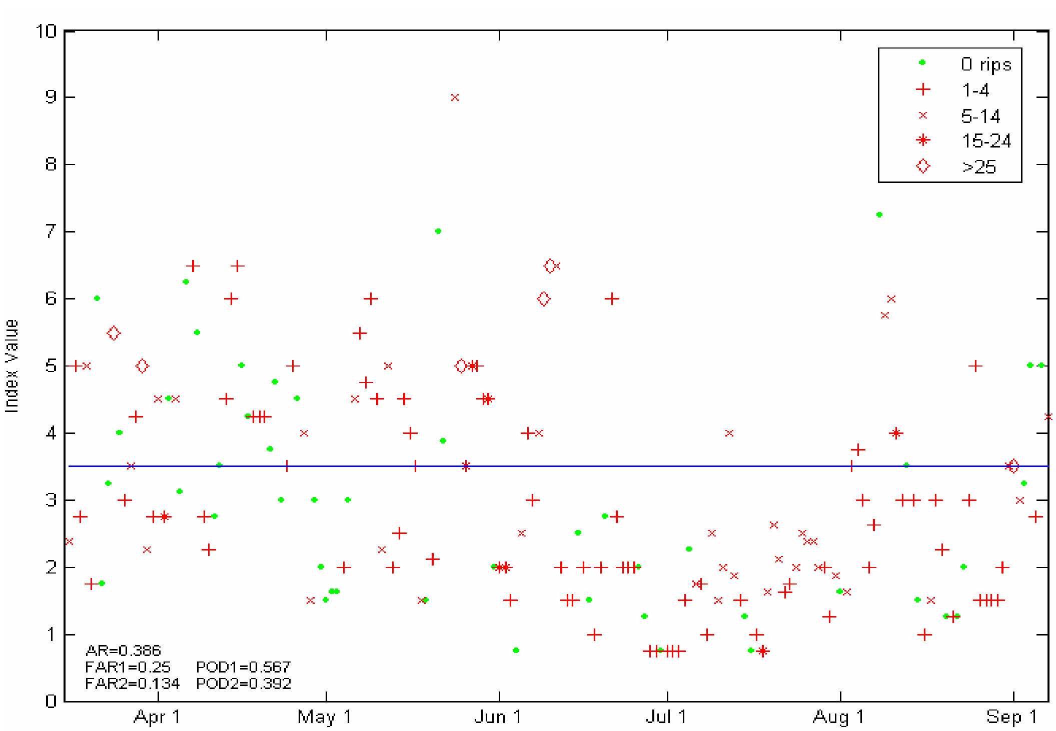

Figure D-10. The modified index daily rip current threat levels for the summer of 2002. The daily rip current incident totals are indicated by the marker symbols.

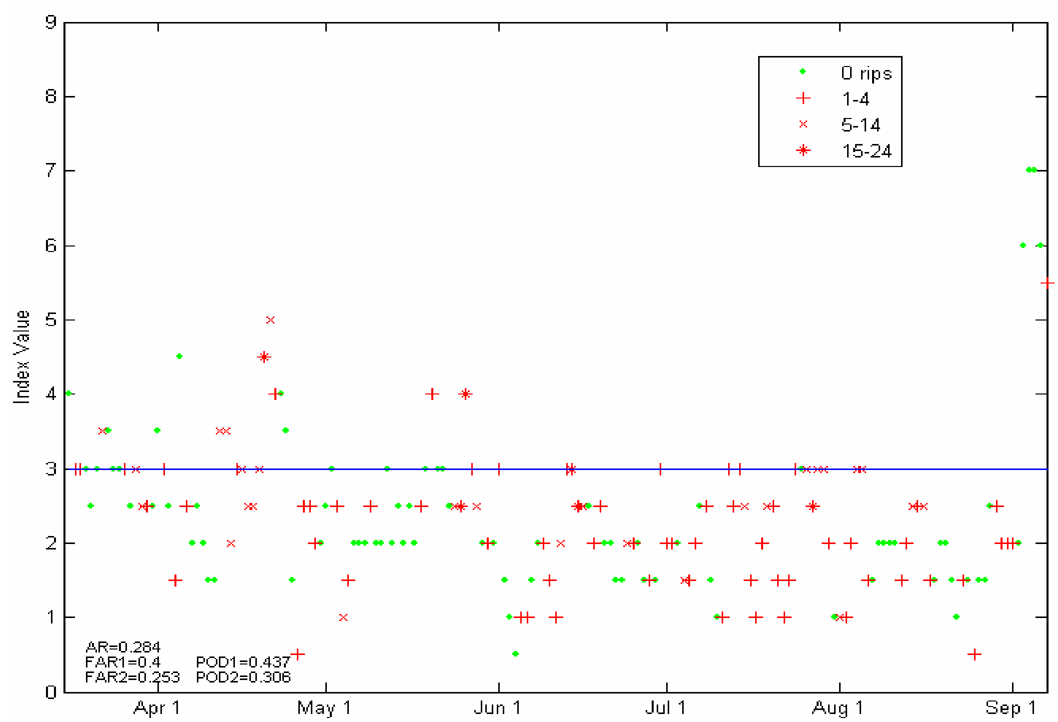

Figure D-11. ECFL LURCS daily rip current threat levels for the summer of 2003. The daily rip current incident totals are indicated by the marker symbols.

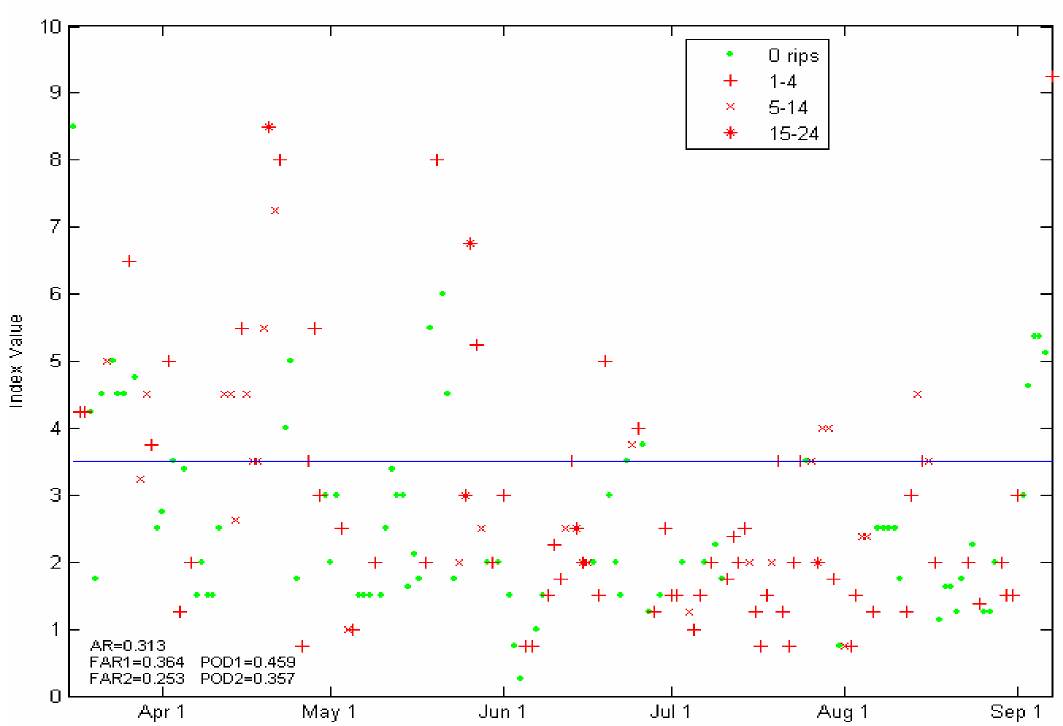

Figure D-12. The modified index daily rip current threat levels for the summer of 2003. The daily rip current incident totals are indicated by the marker symbols.

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BIOGRAPHICAL SKETCH

Jason Cummins was born on January 1, 1982 in Fort Lauderdale, Florida. Although it was a difficult decision to depart from the coast, in 2000, he moved to Gainesville, Florida to become a gator and an engineer. After four years of football in the swamp and some studying, he graduated with a Bachelor's degree in Civil Engineering. He was then presented the opportunity to do research on rip currents under the supervision of Dr. Robert Thieke. The idea of learning about the coastal processes he has been witness to his whole life, as well as the promise of regular visits to the beach definitely caught his attention. He gladly accepted and the research he completed at the University of Florida led to a Master of Science degree in Coastal and Oceanographic Engineering. His future work will certainly involve the application of the knowledge he gained during his six years in Gainesville, as well as his love of the ocean.