Since the landmark Jim Lushine Rip Current Forecasting paper (1991) is not available electronically (personal communication), these scanned images of his paper are presented in this document.

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A STUDY OF RIP CURRENT DROWNINGS AND WEATHER RELATED FACTORS

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INTRODUCTION

Annually, tens of millions of beach-goers in the United States, 18 million alone in the two southeast Florida counties of Dade and Broward, are exposed to danger in the surf zone. Furthermore, the U.S. coastal population is increasing at a much faster rate than the population as a whole (NOAA, 1990). A literature search indicates that little has been published about the number of drownings caused by rip currents or about attempts to operationally forecast their occurrence.

A rip current is defined (Huschke, 1959) as "a strong water-surface current of short duration flowing seaward from the shore." Figure 1 shows a photograph and schematic of a rip current along the California coast. The rip current is popularly called a rip tide, runout, washout or seapuss, and erroneously called an undertow. Rip currents transport excess water ("set-up") in a narrow channel from the zone shoreward of the breakers into deeper water.

The "neck" region of the rip current (Figure 1), which is the narrow (usually 10 to 30 yards wide) channel of strongest current, has speeds measured by Sonu (1972) at four knots. Many drownings, especially those along the beaches of the Gulf of Mexico and portions of the U.S. East Coast, occur when a person on or inside of the nearshore sand bar is pulled into deeper water by a strong rip current. The rip current is fed by a longshore current which can nudge people, even those within a few yards of the beach, into the neck region.

Figure 1. Overhead photograph (left), and schematic (right), of a rip current, along the California coast. Courtesy of Robert L. Wiegel, Council on Wave Research, University of California.

DATA

A. County Medical Examiners' Records

The Medical Examiners' death records of Dade and Broward Counties in southeast Florida for the ten-year period 1979 through 1988 were examined for surf drownings. A death record includes, among other things, a police report and autopsy information. The death records for each of the approximately 210 drownings during this period were reviewed for information suggesting the drowning was primarily rip current related. Discarding those drownings unlikely to be rip current related reduced the potential number of victims to 148. In addition, information from death certificates of surf drowning victims, in all but one of the coastal counties of North Carolina and in both coastal counties of Alabama, were collected for the same period.

B. Beach Patrol Reports, Attendance Figures, and Newspaper Accounts

The beach patrol rescue logs for the cities of Miami Beach, Hollywood, Ft. Lauderdale, and for Dade County from January 1988 through July 1989 were tabulated. As noted from the rescue reports, most of these rescues involved rip currents (denoted on the rescue form as a runout). In addition, rescue reports for the years from 1987 back through 1979 were sampled (on a selective basis) at some of the beach patrol offices to help verify the likelihood of individual rip current drownings.

To normalize the number of rip current drownings with respect to the number of people at the beach, attendance totals at three Dade County beaches and one Broward County beach were collected for portions of the ten-year period 1979 through 1988.

To document rip current drownings elsewhere in Florida, a newspaper clipping service was utilized to collect information statewide. The period of collection extended from June 1989 through December 1990.

C. Meteorological and Oceanographic Data

Anecdotal information from beach patrol personnel suggested that three agents may be involved in making rip currents dangerous to people in the surf. These are wind waves, tides, and swells. Because real-time measurements of waves are not routinely available along the Florida coast, the wind rather than wave heights was chosen to be compared to rip currents in this study. The primary source of the wind observations was a National Weather Service (NWS) wind measuring instrument called located near the south end of Miami Beach, Florida. The site represented the closest wind measuring instrument to the ocean beaches of Dade and Broward counties.

The time and height of high and low tide and the speed and direction of the tidal current for the ten-year period were obtained from National Ocean Service (NOS) publications: *Tide Tables -- High and Low Water Predictions* and from the *Tidal Current Tables*. Tide data from the location at the Miami Harbor entrance about one mile south of the wind measurement on Miami Beach were also obtained from NOS.

A limited amount of data concerning swells along the northeast Florida coast and information about large swells along the United States West coast, were used for comparison to the occurrence of rip currents.

ANALYSIS...RESULTS AND DISCUSSION

A. Number of Rip Current Drownings in Southeast Florida

To determine the probable number of rip current drownings in southeast Florida, the 148 surf drownings from 1979 through 1988 that were identified as potential rip current drownings were examined in closer detail. A three step approach was taken. First, eyewitness accounts from Medical Examiners' records that were consistent with the effects of rip currents identified 42 of the 148 deaths as probably rip current related. Second, beach patrol rescue records were examined; and if "runouts" were reported, it was assumed that drownings on that day were probably rip current related. This added another 30 cases for a total of 72. Third, after determining the wind and tide conditions with which rip currents were associated (see later sections for details), and comparing them to conditions on the day of the drowning, another 22 cases were deemed probable rip current drownings. **Thus, a total of 94 probable rip current drownings occurred from 1979 through 1988.**

These drownings usually occurred at a rate of one per day and at infrequent intervals. However, on nine occasions, two drownings occurred in one day. On six occasions, drownings occurred on two or three consecutive days.

Annual rip current drownings from 1979 through 1988 are plotted in Figure 2 (top). The correlation between rip current drownings and beach attendance were negative, and the apparent cycle in rip current drownings over about ten years is speculated to be associated with long-term weather patterns.

The monthly number of rip current surf drownings is shown in Figure 2 (middle). From this graph it can be seen that the highest incidence of rip current related drownings, 64 of the 94 (68%), occurred during the six-month period from March through August. This distribution is largely accounted for by the greater beach attendance during this time.

Figure 2 (bottom) shows a bimodal age distribution of the rip current drowning victims with one maximum in the age group from 16 to 25 years old, and the other from 55 to 75 years old. Eighty-seven percent of the victims were male. Thirty percent of the drownings occurred among tourists.

Nine of the drowning victims were diagnosed by autopsy to have had some degree of artery or heart disease which may have contributed to the death. Additionally, another seven of the drowning victims had blood alcohol or drug levels that might have impaired their ability to function normally in the water.

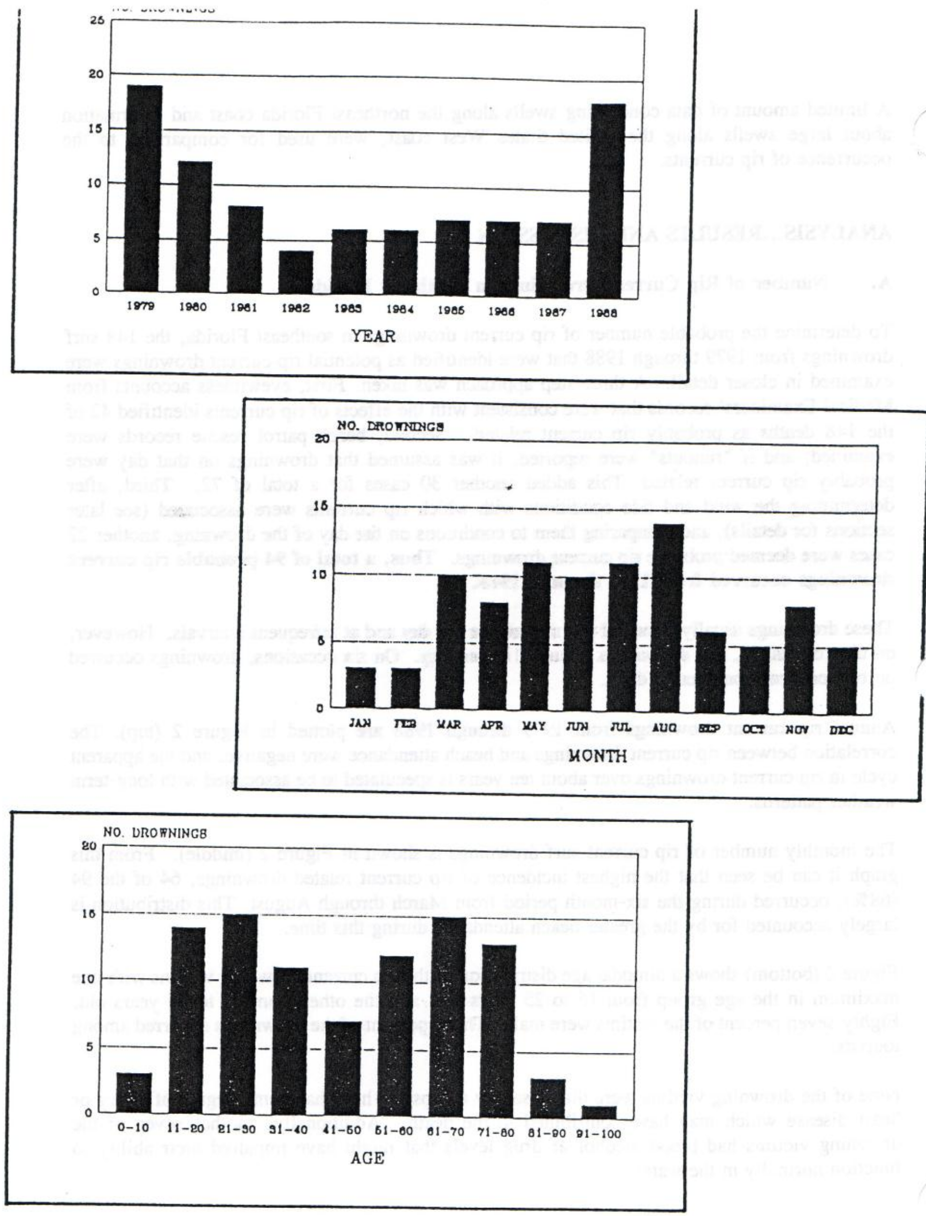


Figure 2. Rip current drownings in Dade and Broward counties of southeast Florida 1979-1988, (top) by year, (middle) by month, (bottom) by age.

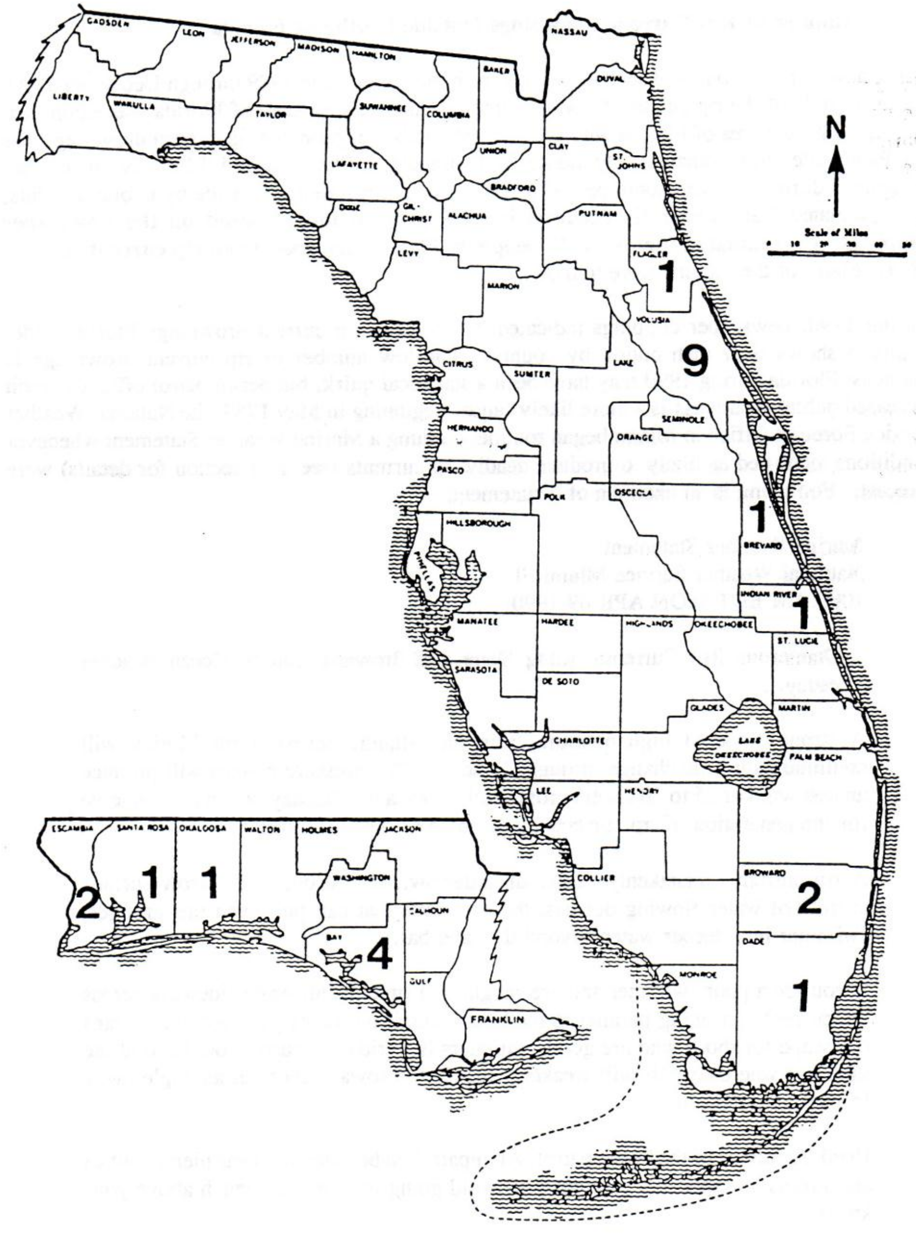


Figure 3. Rip current drownings in Florida during 1990 by county.

Other areas of the United States experience rip current drownings (personal communications, John Fletemeyer and Bill Richardson, 1989). Death certificate data from coastal North Carolina indicates an average of nearly ten probable rip current drownings each year from 1979 through 1988. In coastal Alabama during the same period, about three drownings a year are probably rip current related. Based on a comparison between drowning statistics gathered by the Metropolitan Life Insurance Company (1977) and the National Safety Council (1990) and the rip current drowning data in Florida, North Carolina and Alabama, **it is estimated that an average of 150 people drown annually in rip currents in the United States.**

C. Wind Relationship to the Occurrence of Rip Current

The hourly wind observation closest in time to the rip current event was determined. To obtain the best relationship between the wind direction and speed and the incidence of rip currents, a number of factors were considered. The 72 drownings, previously determined to have been rip current related based on information from Medical Examiners' reports and beach rescue logs, were compared to the Miami Beach wind measurements closest in time to the drowning. Figure 4a is a wind rose constructed from these data showing the frequency of direction and the average speed. Note that all of the wind directions were onshore near times of rip current drownings. Since the southeast Florida coast is oriented between north-south and 20 degrees clockwise to this direction, a large majority of the winds were nearly normal to the coast. The average of the sustained wind speeds closest in time to the drowning was 13 knots.

Looking more closely at the hourly wind data, it was observed that sometimes the wind was strong overnight, but then weakened and veered (turned clockwise) during the following daylight period (approximately 12 hours). This often occurred at the end of a several day period of moderate to strong onshore wind flow. Such rip currents that took place during the period of weaker winds following an episode of strong winds were designated as "residual" rip currents. If the wind during these residual events was deleted, an even stronger relationship between strong onshore wind nearly normal to the coast and likely rip current drownings was noted (Figure 4b). The average wind speed for this sample was 14 knots.

As seen in Figure 4b, in cases excluding residual rip currents, a very strong relationship between rip currents and wind direction exists. **When rip current drownings took place, the wind direction was onshore 100% of the time. Furthermore, the direction was onshore and within 30 degrees of normal to the coastline about 90% of the time.**

With respect to wind speed, the relationship is not as consistent as with the wind direction. Using wind speeds and excluding residual cases, a frequency plot was drawn for the combined rescue and drowning reports from 1979 through 1988 (Figure 5, top). This plot shows 90% of all rip current drownings and rescues occurred with a wind of 10 knots or greater and 67% with 12 knots or greater. Considering just the drownings (Figure 5, bottom), 75% of the wind speeds were 10 knots or greater. Of the 25% below 10 knots, the age of the victim was 20 years or younger or 60 years or older implying (Figure 5, bottom), implying that these rip currents may have been weaker.

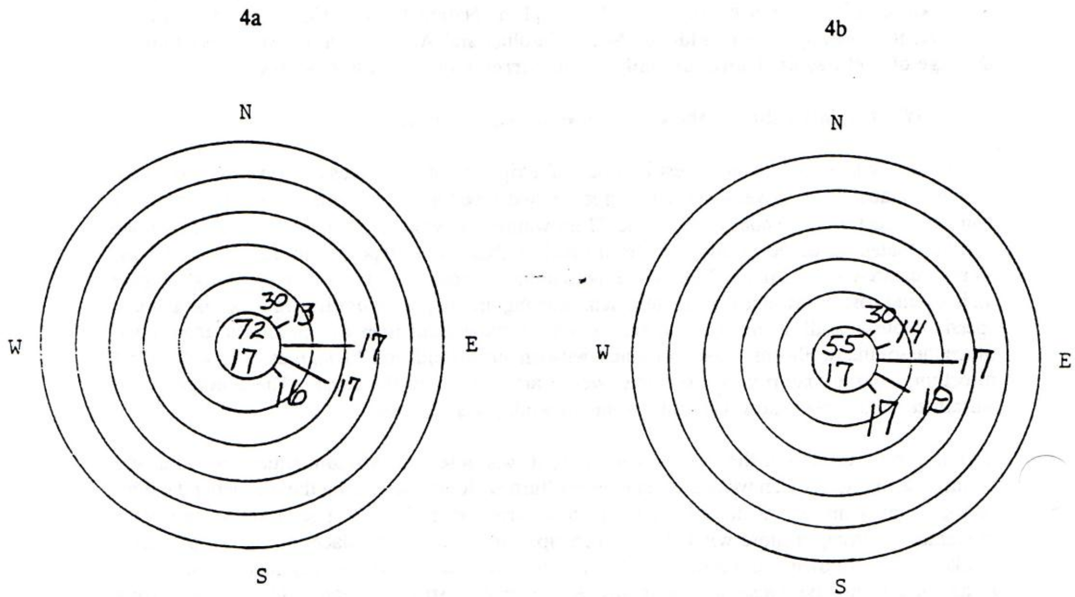
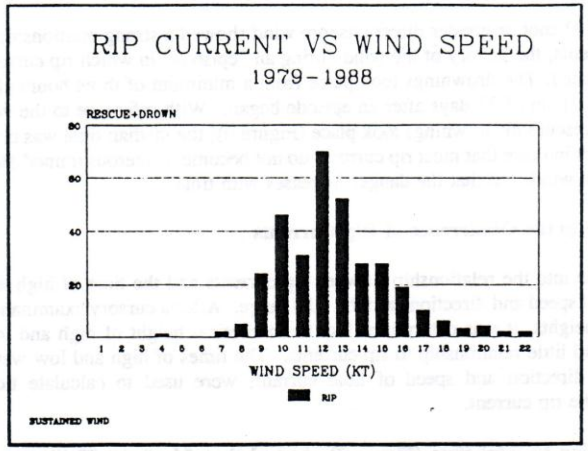


Figure 4. Wind rose during rip current drownings along southeast Florida ocean beaches, 1979-1988, (a) residuals included, (b) residuals excluded. Each ring represents 20% frequency of direction with the number at the outer end of each line being the average scaler wind speed (knots) for that direction. Inside the center are the number of observations (top) and the average scaler wind speed for all the directions (bottom).



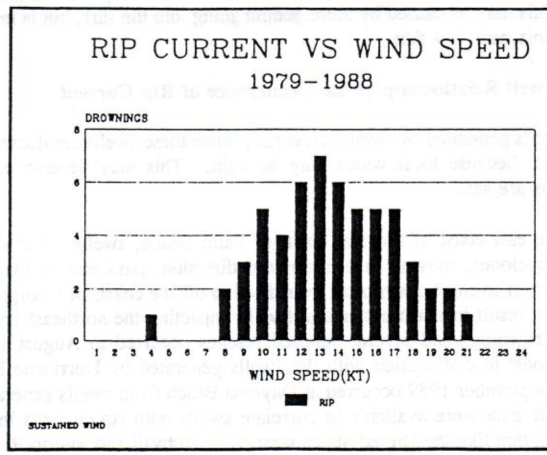


Figure 5. Frequency of wind speed along southeast Florida beaches, 1979-1988 during (top) combined rip current rescues and drownings, and (bottom) rip current drownings only.

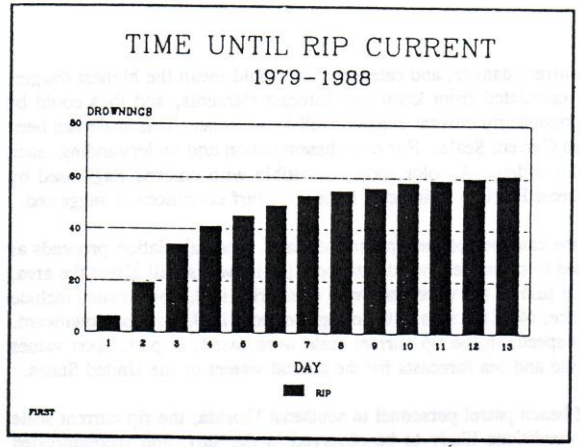


Figure 6. Time between beginning of rip current conditions and the occurrence of drowning at southeast Florida ocean beaches, 1979-1988.

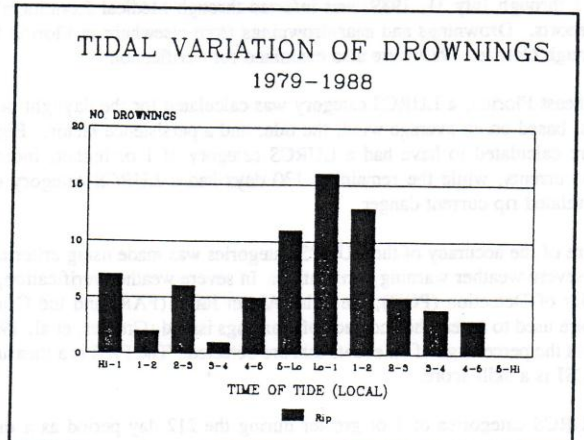


Figure 7. Rip current drownings at southeast Florida ocean beaches, 1979-1988, relative to time of high and low tide.

mean no weather-related rip current danger, and category five would mean the highest danger. The scale could be routinely calculated from known or forecast elements, and thus could be used to alert beach-goers of possible rip current dangers well in advance. This scale has been called LURCS for Lushine Rip Current Scale. For easy dissemination and understanding, each LURCS category may be color-coded. A color code compatible with colored flags used by beach patrols (at least in southeast Florida) to indicate hazardous surf conditions is suggested.

Table 1a is used to calculate the category of the rip current scale. The calculation proceeds as follows: (1) use the wind speed to calculate a wind category; (2) if swells will affect the area, add a swell category; (3) if the sum of the wind and swell categories is 0.5 or greater, include the effects of tide and persistence; (4) if the sum of the categories ends in 0.5, round downward. The values and range of wind speeds in the rip current scale were based, in part, upon values used operationally in NWS wind and sea forecasts for the coastal waters of the United States.

Drawing on the experience of beach patrol personnel in southeast Florida, the rip current scale numbers were matched with conditions likely to be observed in the surf, and recommended actions to be taken by the bather under these conditions were given (Table 1b). Each rip current scale number is assigned a color code for easy recognition by, and distribution to, the public.

G. Verification

Using the LURCS derived criteria for rip current dangers, a verification of an independent data sample was done. The presence of rip currents in southeast Florida during the 212 days from January 1 through July 31, 1989, was inferred through Medical Examiners' reports and beach rescue reports. Drownings and near-drownings from elsewhere in Florida for the period from June through October 1989 were also examined for verification.

For southeast Florida, a LURCS category was calculated for the daylight period of each of the 212 days, based on an average wind, the tide, and a persistence factor. Eighty-two of the 212 days were calculated to have had a LURCS category of 1 or higher, indicating some danger from rip currents, while the remaining 130 days had a LURCS category of 0, indicating no weather-related rip current danger.

A measure of the accuracy of the LURCS categories was made using criteria frequently applied to NWS severe weather warning verification. In severe weather verification, three values -- the Probability of Detection (POD), the False Alarm Ratio (FAR) and the Critical Success Index (CSI) -- are used to assess the accuracy of warnings issued (Grenier, et al. 1989). Basically, the POD gives the percentage of all events that are detected. The FAR is a measure of overwarning, and the CSI is a skill score.

Using LURCS categories of 1 or greater during the 212 day period as a measure of the need for a warning, the POD was calculated to be 92%, the FAR was 56%, and the CSI was 42%. By comparison, the statistics for tornado and severe thunderstorm warnings in the United States for 1988 (Grenier, et al., 1989) showed a POD of 57%, a FAR of 58%, and a CSI of 32%. The

Table 1a

Derivation of LURCS Categories
Category Numbers

Wind Speed (Knots)	Wind Direction Direct Onshore	Wind Direction Oblique Onshore
<10	0.0	0.0
10	0.5	0.0
10-15	1.0	0.5
15	2.0	1.0
15-20	3.0	2.0
20	4.0	3.0
20-25	4.5	3.5
25-35	5.0	4.5
35-50	5.0	5.0

Swell Ht (Feet)	
>2-4	Add 2 Categories
>4-7	Add 3 Categories
>7-10	Add 4 Categories
>10	Add 5 Categories

Tidal Factor	Add 1.0 Category within -2 to +4 hours of low tide
Persistence Factor	Subtract 0.5 Category on first day LURCS is >0.0; add 1.0 Category for second or subsequent day if LURCS increases 2.0 or more categories

1. Use the observed or forecast wind to the nearest 5 knots and nearest Cardinal direction to determine the wind category.
2. If any swells will affect the area, add swell categories.
3. For wind or swell categories of 0.5 or greater, include tidal factor.
4. If yesterdays LURCS category was >0.0, include persistence factor.
5. Round off the sum of these numbers downward to the nearest whole category.

Definitions and limitations:

1. Wind is the prevalent wind (i.e., excluding the sea breeze)
2. Wind directions are defined as:
   (a) Direct onshore=within 30 degrees of normal to coast.
   (b) Oblique onshore=more than 30 degrees normal to coast.
4. If direct onshore wind, and strong at night, use this wind during the entire ensuing daytime period.
5. Maximum category is 5.

FAR (overwarning) for forecasts of rip current conditions may be misleading in that rip currents may well have been present, but no drowning or rescue occurred, and thus the forecasts did not "verify."

Although the information on rip current drownings elsewhere in Florida was not nearly as complete as those in southeast Florida, all 12 events during the period June through October 1989 had a LURCS category of 3 or higher, indicating the applicability of the LURCS derived criteria outside southeast Florida. No determination of the POD, FAR or CSI could be made from these data.

Table 1b

LURCS Description

Category	Color Code	Description	Recommended Action
		No weather-related rip current danger	None
1	Yellow	Caution for weak or non-swimmers Weak rip currents possible	Weak swimmers stay in shallow water
2	Yellow	Caution for all Moderate rip currents possible	All swimmers stay in shallow water
3	Red	Danger for weak or non-swimmers Moderate rip currents likely	Weak swimmers don't enter water above knees
4	Red	Danger for all Strong rip currents possible	All swimmers don't enter water above knees
5	Black	High Danger for All Strong rip currents likely	Stay out of water

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