Rip Currents in the Great Lakes: An Unfortunate Truth

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Introduction

The Great Lakes are not characteristic of inland lakes; they are large Inland Seas, with typical dimensions for each lake of the five Great Lakes of over 500 km in length and 150 km in width. Located in the mid-continent interior, strong and rapidly changing wind fields produce correspondingly severe locally generated seas, reaching in extreme conditions, significant wave heights in excess of 7 meters. Many people associate rip currents only with ocean coastlines and are surprised to discover that they do indeed occur with unfortunate regularity along the coastlines of the Great Lakes, (Figure 1). Thus far in 2010 alone, the Great Lakes have experienced 25 rip-related deaths (Documented by National Weather Service). In a recent examination of rip current fatalities over the period of 1994-2007 (Gensini, 2009), the State of Michigan alone stands fourth in the list of greatest number of fatalities for all coastal states in the contiguous United States. Figure 2 displays the locations, and total number for that location, of Great Lakes fatalities due to rip currents that
have been documented by the National Weather Service (NWS) for the period of 2002-2009. During this period, the Great Lakes Basin experienced an average of 7 rip current fatalities a year. The 25 rip-related deaths in 2010 is the largest number of rip current fatalities recorded for the summer season since NWS first began documenting them in 2002.

![Figure 2. Great Lakes rip current fatalities for the period 2002-2009 (as recorded by NWS).](image)

The Great Lakes Basin encompasses over 17,500 km of coastline, almost 2000 km more than the US Atlantic and Pacific coasts combined, much of which is open for tourism. Given this vast amount of coastline and the corresponding large number of visitors, residents and guests, rip currents in the Great Lakes are a phenomenon that should not be overlooked.

Nationally, the general public, as well as the scientific community, has long recognized the significance of rip currents as a coastal hazard on ocean coasts. Over 80% of all surf related rescues are attributable to rip currents with over 20,000 rip-related rescues and approximately 150 fatalities along U.S. beaches in any given year (Lushine, 1991a and 1991b.). It is widely accepted that better forecasting and greater public awareness can mitigate this coastal hazard.
The National Weather Service produces full Surf Zone Forecasts for the Atlantic, Gulf and Pacific coasts, but did not begin issuing Great Lakes Surf Zone Forecasts with rip current risk information until 2006. Within the Great Lakes, several NWS offices are currently testing rip current advisory forecast methods developed in collaboration with the University of Michigan Marine Hydrodynamics Laboratories, based upon wind speed, fetch, duration and other inputs. However, NWS cites a need for better near-shore wave models to help describe the unique characteristics and physical dynamics of the enclosed Great Lake Basin.

Although Great Lakes drownings associated with strong visible cross-shore current structures have been well-documented, very little quantitative data exists to verify the presence of a rip-type flow regime at the time of the incident. A rip current is composed of transient features, requiring immediate data collection response to capture what amounts to “perishable” data. In addition, the unique hydrodynamic conditions which dominate Great Lakes rip current formation require further scientific understanding for the development of a robust regional predictive algorithm.

The following sections of this paper focus on hypothesis-driven, nearshore dynamics to explain the generation of rip currents associated with enclosed basins (such as the Great Lakes). The nearshore dynamics in operation in these basins differ from exposed open oceanic coasts in several important ways.

**Rip Current Research**

The first scientific observations of rip current circulations were made by (Shepard et al., 1941) off the coast of La Jolla, California. For this site, Shepard and Inman (1950) determined that wave refraction over the offshore topography (i.e. submarine canyons) created strong longshore wave height gradients that led to rip current generation. Other mechanisms for rip current generation were identified through later studies: longshore wave height variation due to standing edge waves (Bowen, 1969; Bowen and Inman, 1969); intersecting wave trains of identical frequency leading to longshore variations in water level (Dalrymple, 1975); nearshore bathymetric variations (Haller et al., 2002); coupled hydrodynamic/morphodynamic systems with variable a longshore bathymetry and hydrodynamics (Hino, 1974).
Scientific observations of rip currents have been hampered by the difficulty in deploying sensitive instrumentation in this harsh flow environment. Despite limited observation sets, detailed examination of currents within rip channels commonly demonstrates pulsations on relatively long timescales. Several explanations exist for this phenomenon. First, rip current pulsations have been shown to be related to infragravity motions on the order of 0.004 to 0.04 Hz (for example, Sonu, 1972; Suhayda, 1974; Wood and Meadows, 1975; Guza and Thornton, 1985; MacMahan et al., 2004a). Second, the mass transport and wave setup produced by the larger waves within a wave group can cause significant “puddling” of water within the surf zone, which returns to the sea via rip channels when the smaller group waves arrive (Munk, 1949; Shepard and Inman, 1950). In addition, longer period motions (≥ 15 mins) of non-gravity waves associated with rip current shear instabilities have been identified as driving rip current pulsations (Smith and Largier, 1995; Brander and Short, 2001; Haller and Dalrymple, 2001). Finally, wave group-induced vortices may also contribute to rip current pulsations (Reniers et al., 2004; MacMahan et al., 2004b).

Within the Great Lakes, Wood and Meadows (1975) made the first field measurements of unsteadiness in longshore currents and observed long period wave induced motions in the 30 to 90 second period ranges. The fluctuations were persistent across the active surf zone and with depth throughout the water column. This quantitative documentation provided details of the longshore feeder flows to periodic rip currents developed through the multiple bar nearshore topography. In 1982, the spatial pattern in Lake Michigan of these wave motions was shown to be observable from space using Synthetic Aperture Radar observations (Meadows et al., 1982).

A secondary aspect of rip current research has focused on the development of the morphological rip channel features through laboratory, field, and numerical studies (see Van Enckevort et al., 2004 and MacMahan et al., 2006 for literature reviews). As mentioned above, in some cases, rip channels are established through interaction of waves with offshore topographic features, such as submarine canyons (Long and Ozkan-Haller, 2005). On many barred beaches, rip channels are expressed as quasi-regularly spaced channels flanked by crescentic bars, and research has focused on the spacing of these channels as related to the incident wave conditions or
morphodynamic dimensions. However, this area of research has been unfruitful (for example, Huntley and Short, 1992). More recent studies using time-lapsed video images of the surf zone, although proven as a successful method for data retrieval (Van Enckevort et al., 2004; Holman et al., 2006), have failed to support any causal relationships. Numerical investigations also fall short in providing robust estimates of rip channel spacing (for example, Damgaard et al., 2002). Calvete et al. (2007), through a numerical sensitivity analysis, show that the lack of predictability of rip channel development and spacing is an inherent property of the coastal system, related to the sensitivity of the channel development to the pre-existing bathymetry of the nearshore zone. Thus, a secondary need to fully understand Great Lakes rips is to seek the acquisition of time-sensitive “perishable” data before, during, and after a rip event to determine if any morphodynamic influences of nearshore features may be playing a role in rip current generation. As an example of the importance of this phenomenon, Figure 3 shows a pair of aerial photographs along the same section of Lake Michigan coastline. These two photographs were taken seconds apart as the aircraft proceeded along the shoreline. Hence, the incident wave field is nearly identical in both photographs. The photograph on the left clearly shows a long linear, three bar system in the nearshore region and the photograph on the right shows a complex rip current system in full operation.

Rip currents have also been observed to vary with tidal elevation on the ocean coast. Although the misnomer of “rip tides” would indicate a relationship with tidal currents, in actuality, the tidal influence is due to the changes in water level accompanying the tidal cycle. Rip currents are tidally modulated such that decreases in tidal elevation increase rip current flows to a relative
maximum (Sonu, 1972; Brander and Short, 2001; MacMahan et al., 2005). In the Great Lakes, the astronomical tides are minimal, however, a secondary flow of magnitude and duration similar to ocean coastal tides is the seiche. Seiches are the result of a consistent wind blowing over an enclosed basin, resulting in a mass transport of surface water towards the downwind coast (Figure 4) and resultant increase in water level. When the wind ultimately decreases or shifts,

Figure 4. A seiche caused by water buildup due to wind stress or pressure gradient in an enclosed basin (modified from Great Lakes Atlas: http://www.epa.gov/glnpo/atlas/index.html).

this buildup of water is free to flow back, resulting in a complex rotational wave within the basin, not dissimilar from a tidal bulge along an exposed ocean coastline. For example seiching (wind tides) both contribute excess water to the nearshore zone and can significantly change wave elevation over relatively short time periods.

Excessive water level variations are also common to the Great Lakes Basin on a variety of time scales not seen on open ocean coasts. Water level variations on the order of 0.3 meters occur seasonally with variations as large as 0.5 meters annually and extremes approaching 2 meters on decadal time scales. These longer term fluctuations change beach and nearshore slopes, cause migration of semi-permanent sand bars and alter the nearshore sediment supply (Meadows et. al., 1997). Since the waters that fill the Great Lakes are primarily the result of evaporation and precipitation over the basin, even the incident wave climate varies with the frequency and
intensity of the storms on these same decadal time scales. Figure 5, depicts a representative section of the long term water level record for Lake Michigan and Huron from 1918 through 2002. This water level history clearly demonstrates the multiple scales of Great lakes water elevation variation.

![Figure 5](image_url) A representative section of the Lake Michigan-Huron water level record (1918 – 2002) from NOAA.

Finally, the wind generated wave systems of these enclosed basins are primary locally generated (resulting from the cyclones present over the basins themselves). Locally generated seas are complex, unsorted, steep, widely distributed in direction, and often accompanied by strong longshore components of wind. All of these factors combine to contribute to strong and difficult-to-predict nearshore circulations along the coastlines of the Great lakes.

**Enclosed Basin Nearshore Dynamics**

Although the Great Lakes are similar to the ocean in many ways, there are pointed differences between the two that make rip current generation in the Great Lakes somewhat unique. As previously mentioned, the changing water levels (on many time scales) of the Great Lakes affect the location and movement of near shore sandbars, in turn affecting the location and formation of rip current channels. It has been observed that increased wind and higher wave energy precedes an increase in long term water levels (Meadows et al., 1997), which may set the “bathymetric
stage” for increased rip current frequency. In general, these conditions lead to a steeper, more mobile nearshore zone. Also, the Great Lakes Basin are enclosed, which creates the unique condition mentioned earlier, the seiche. Although common to all of the Great Lakes, the most extreme seiches occur in Lake Erie (relatively shallow basin, oriented east-west into the prevailing wind) with recorded elevation differences between Toledo, Ohio and Buffalo, New York of 4.9 meters. These seiches oscillate in the longitudinal mode with a period of approximately 16 hours. Seiching both contributes excess water to the nearshore zone and can significantly change water elevation over relatively short time periods. For example, the series of seven drownings along the southeast shoreline of Lake Michigan on July 4th of 2003 were associated with a moderate to strong seiche of the basin (Guenther, 2003). During this single event, seven rip-related drownings were reported within a three-hour period along a concentrated three mile section of State Park beach between 16:30 and 19:30 Z. Fortuitously the location of these tragic events is ringed by NOAA / National Ocean Service’s (NOS) water level gauges. The location of these gauging stations is presented in Figure 6, with corresponding water level records provided in Figure 7.

Figure 6. July 4, 2003 drowning event location in Lake Michigan, showing surrounding data stations.
It is evident from these records that both a transverse and longitudinal seiche were present in southern Lake Michigan at the time of the fatalities. These seiche modes were excited by the passage of an intense squall line and corresponding wind shift.

In 2002 four men drowned in a strong rip current off Nickel Plate Beach in Huron, Ohio. Once again, the records from the NOS gauging stations indicate that a seiche had occurred spanning the times of the drowning. The two records, shown in Figure 8, are from NOS stations at Marblehead, OH and Sturgeon Point, New York.
Figure 8. NOS water level records for Lake Erie for July 9-11, 2002. The arrow points to the water level at the time of the rip current drownings.

Thus, it is hypothesized that long period dynamics in the Great Lakes, especially those of seiche mode frequency, (with periods on the order of hours) may contribute to the generation of rip currents.

A second important difference between Great Lakes coastlines and that of exposed ocean coastal regions lies with the incident wave field. The dimensions of the Great Lakes Basin are comparable in spatial scale to the atmospheric low and high pressure system that traverse the
region. This produces an incident wave climate composed primarily of locally-generated fetch limited seas. Locally generated seas are complex, with unsorted, steep waves that are widely distributed in direction, and often accompanied by a strong longshore wind component. This is in stark contrast to the conventional wisdom of rip current generation, requiring a well organized wave field to produce a correspondingly well organized nearshore circulation. All of these factors contribute to strong and difficult-to-predict Great Lakes nearshore circulations.

Furthermore, in the fall, strong air/sea temperature differences develop as the Lakes warm. Cold outbreaks of Canadian polar air drive large and rapid wave growth, resulting in the infamous November storms of the Great Lakes (“the Gales of November”). In a brief review of notable major Great Lakes shipwrecks, it is observed that:

- **M/V Edund Fitzgerrald**: 29 crew/29 lost November 10, 1975
- **M/V Carl D. Bradley**: 35 crew/33 lost November 18, 1958
- **Great Storm of 1913**: 251 lost from 12 ships November 7-11.

Obviously, the combination of warm Lake temperature coupled with strong outbreaks of wind in November, combine to produce very dangerous Great Lakes wave conditions. Although still present, this threat is less in the late summer months (August – September) when the beaches are still very active. Under these unstable atmospheric conditions, wave growth is alarmingly fast, often catching bathers, surfers and first responders off guard.

A vivid example of this phenomenon is provided by the dedicated work of the Great Lakes Environmental Research Laboratoy (GLERL) of NOAA in numerical wind and wave forecasting. The Great Lakes Coastal Forecasting System (http://www.glerl.noaa.gov/res/glclfs/) provides twice daily predictions of wind, wave, circulation, temperature structure and water level elevation for all five of the Great Lakes. Figures 9 and 10 provide an example of rapid and severe wave growth for a late year (November), large air/sea temperature difference, wind outbreak as described above. Note, significant wave heights are presented in feet.
Figure 9. Strong, late season, outbreak of Canadian air over the Great Lakes Basin

Figure 10. Resulting Great Lakes wave field (Significant wave height in feet).
Great Lakes Rip Current Forecasts

The dynamics of the Great Lakes enclosed basin and the locally generated seas provide many difficulties for the forecasting of rip currents. In 2006, the NWS Great Lakes offices began issuing Surf Zone Forecasts which included rip current risk information. Forecasting Great Lakes rip currents is a three step process. First, the forecaster collects data on the observed conditions. The Great Lakes are surrounded by a comprehensive network of observing platforms where ground truth information can be obtained to verify forecasts and update as needed. These include but are not limited to:

1. Buoys – The United States National Data Buoy Center (NDBC), Environment Canada, and most recently added, the Great Lakes Observing System (GLOS) coastal monitoring network with directional wave capability, all maintain buoys on the Great Lakes. These buoys provide wave heights, wind speed and directions, and periods of the waves. The GLOS buoys and a few of the NDBC buoys also provide wave directional information. The NDBC and Environment Canada buoys are located mid lake, while the GLOS buoys are located along the Great Lakes’ coasts. All buoys give valuable real time data.

2. NOS Gauges – National Ocean Services maintains a network of 54 tide gauges around the Great Lakes, which measures the lake levels at 6 minute intervals as well as providing wind data, air temperature, relative humidity, and barometric pressure. These are particularly helpful in monitoring for seiches.

3. Doppler Radar - The National Weather Service and Environment Canada blanket the Great Lakes with Doppler radar coverage, providing real time precipitation and wind data aloft.

4. Ship Observations/Volunteer Ship Observations - Numerous boats and ships on the Great Lakes volunteer to submit observations at regular intervals as they travel the Great Lakes. They provide weather, temperature, wind data, and wave information.

5. Nearshore Automated Observation Platforms - Numerous automated aviation and marine observing stations are also available near shore within a few miles of the lakes.

6. Satellite Information - Satellites provide sky cover, ice conditions and temperature profiles over the lake.
7. Rawinsonde Stations - Numerous rawinsonde stations are in close proximity to the Great Lakes and provide wind and temperature profiles of the air mass over the lakes. Each rawinsonde station takes readings twice a day.

After the observed data is collected, forecasts of the wind speed and directions over the Great Lakes are made by the operational forecasters at each NWS forecast office in the Great Lakes region. The wind forecasts are then used to predict the wind wave characteristics on the Great Lakes (including wave height, period and direction).

Once the wind and wave forecasts are completed, forecasters then determine the rip current risk for their area by applying the Great Lakes Rip Current Checklist (GLRCC) (Figure 11). This GLRCC was first developed for the Great Lakes by modifying the East Central Florida Lushine Rip Current Scale (ECFL LURCS) (Engle, et al., 2002) and the Lushine Rip Current Scale (LURCS) (Lushine, 1991) using parameters unique to the Great Lakes. This checklist works well for the long fetch parts of the Great Lakes with sandy beaches. For the breakwaters and groins, forecasters follow the general assumption that onshore wind will create a flow that will pile water onshore that will then flow parallel to shore. That flow condition combined with waves of 0.6 m or higher will produce a moderate or high risk of rip currents. The forecasters will adjust their criteria based on feedback from local users at specific beaches and around specific coastal engineering structures (e.g. breakwaters, harbor jetties, etc.).

After the rip current risk has been assessed, the Great Lakes office disseminates this and other relevant information using the Advanced Weather Interactive Processing System (AWIPS)
The Great Lakes possess both the breadth and power to develop the dynamics necessary for the production of rip currents, which pose a significant threat to the recreational community.

To date, most rip current research has been conducted in the ocean environment, in order to best serve the Great Lakes region, the enclosed basin dynamics unique to the Great Lakes should be investigated more thoroughly. Time sensitive “perishable” data needs to be collected before, during and after documented rip current events to determine if any morphodynamic influences play a role in rip current generation. Seiches (wind tides), which have been recorded in conjunction with a number of documented rip current drownings, leading to hypothesis that the long period dynamics of these seiches may contribute to the generation of rip currents, requires further study. The various scales of changing water levels, and locally generated seas, must be further examined in order to better determine how these dynamics influence the formation and correspondingly the forecasts of rip currents on the Great Lakes. Using the data collected from (Glahn, et al. 2003) which routes the forecasts through the family of services network to the media and through the Internet to all other interested users.

Products, including the Surf Forecast (Figure 12) are produced by six offices throughout the Great Lakes that seem to have the largest threat of rip currents.

The Surf Forecast provides additional information on air and lake temperatures, wind and wave conditions, rip current risk and other relevant information for end users. Other lake shore offices that do not experience a serious rip current threat in their county warned area, have opted to produce Lakeshore Hazard Messages whenever conditions for a moderate or higher risk of rip currents exists in their nearshore area of responsibility. All offices also provide information in the Hazard Weather Outlooks whenever there is a moderate or high risk of rip currents.

**Conclusions**

**Figure 12.** Example of Surf Zone Forecasts

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this research, The Great Lakes sector of NWS will be able to refine their rip current forecasting capabilities, making Great Lakes beaches safer and more attractive to residents and tourists alike.

References


Appendix A

Case Study of Great Lakes rip current at Huron, Ohio.

On July 10, 2002, four men between the ages of 18 to 34, drowned in a strong rip current while attempting to rescue a young woman from the waters off Nickel Plate Beach, located on the northeast side of Huron, Ohio at the west end of Lake Erie (Figure A1). At 18:30 UTC, a woman swimming at a sandbar yelled for help. She was approximately 23 m from shore in about 1.5 m of water. The rip current was pulling her northeast, away from the shoreline. The men entered the water in an attempt to rescue her and drowned. An off-duty firefighter eventually reached the young woman, and was able to rescue her with the help of others from the fire department. Waves, reported to be 1.2 - 1.8 m high, were strong enough to damage a boat used by the fire department during the rescue. Prior to the incident, red flags were posted by the City of Huron to warn swimmers to stay out of the water. Normally, a life guard is on duty, however, once the red flags are posted the life guard is permitted to leave the beach.

NDBC buoy 45005, located 32 km north of the city of Huron in western Lake Erie, reported winds from 040 to 050 degrees (northeast) at approximately 11 m/s for 5 hours prior to the incident. The winds were out of the north and northeast up to 21 hours prior to the incident. During the same time period, the buoy reported waves 1.5 to 2.1 m high and a water temperature of 23 degrees C. The Automated Surface Observing System (ASOS) station at Cleveland, approximately 80 km east of Huron, reported winds from 030 degrees at 7.5 m/s at 15:00 UTC. By 18:00 UTC the winds increased to 12.5 m/s from 040 degrees. At Mansfield, Ohio, approximately 110 km south of Huron, weather observing equipment reported winds between
030 and 040 degrees for four hours prior to the accident and varying between 27 and 32 m/s. At 14:00 UTC, the winds diminished rapidly to 5.3 m/s. The Marblehead water level data gauge, about 25 km northwest of Nickel Plate Beach, indicated the lake reached a peak of 174.60 m Mean Surface Level (MSL) at 15:00 UTC which dropped to 174.44 m by 19:00 UTC and to 174.08 m by 22:00 UTC. After 22:00 UTC, the lake level started increasing again to peak out at 174.45 m at 08:00 UTC.

Note in Figure A1, the Nickel Plate Beach is oriented northwest to southeast, allowing it to be highly exposed to northeast winds. Winds measured at buoy 45005 and at Cleveland airport appear to be most representative for the winds over Nickel Plate Beach at the time of the incident. Studies by Lushine (1991), Lascody (1998), and others have shown that a wind normal to shore would have a much higher probability of producing a dangerous rip current than one from any other direction. In addition to the high waves, reports from people at the beach indicated there was a strong undertow. Surface water temperatures of around 23 degrees C would indicate that hypothermia would not have been an issue.

Gary Packan (2002 personal communication), the director of the Parks and Recreation Department for the city of Huron, Ohio, stated there is no specific criterion for posting Red Flag Alerts other than when the waves look high. The decision to post alerts is up to the City Manager, Parks Director, and/or the Fire Chief with input from local personnel.

The falling lake level indicated by the Marblehead gauge seems to indicate that a seiche had occurred. Studies by Lushine (1991), noted tidal effects play an important role in the enhancement of rip currents. This seiche may have further enhanced the strength of the rip current similar to that which happens on ocean beaches during low tides. The breakwaters that run north of the area may also have caused some channeling and enhanced the waves and subsequent rip currents. Gary Packan said submerged sand dunes off shore change regularly and are not mapped. Channels may have developed in these sand dunes, causing an acceleration of the rip current.

Applying data from the west end of Lake Erie buoy to the rip current checklist, we find that the wave factor would be 3.0, and wind speed factor based on the Cleveland, Ohio airport’s Automated Surface Observing System (ASOS) would be 5.0. Estimating wave period based on
wave heights at the buoy we find a period of 4 seconds and a factor of 0. According to the Corp of Engineers (2010), the average lake level for Lake Erie for July, 2002 was 174.24 m and the Marblehead gauge showed a lake level of 174.44 m. We find even though a seiche was occurring and the lake level at Marblehead had dropped .16m, the lake level at the time of drowning was still above the monthly average. Therefore, the lake level factor would then be -0.5. Adding these values together yielded a rip current risk of 7.5. This is classified as a high risk.