Occurrence of Ridge-and-Runnel Beach Morphology at East Hampton, NY

Prepared by

Kathleen Fallon
School of Marine and Atmospheric Sciences
Stony Brook University
Stony Brook, NY

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Stony Brook University's COAST Institute

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Introduction

It is generally accepted that there are five major types of rip currents: Bar-gap, structurally controlled, flash, cusp-shore, and mega-rips (Leatherman 2012). Rip current classification however is a bit confused and most are difficult for the general public to understand. Leatherman (2012) lists and describes these all as surf-zone rip currents. Bar-gap rip currents form at a depression in the sand bar and can remain in place for long periods of time. They tend to occur when the surf is moderate and weather is ideal for swimming, making these the most dangerous rips. Structurally controlled rip currents are associated with either man-made or natural structures adjacent to the beach. Structurally controlled rip currents can result from either offshore rock formations or manmade structures that create an offshore-bound current. Due to the permanency of the features that control them, theses rip currents are also regularly occurring features of the surf zone. However wave condition must be just right for the rips to appear. Flash rip currents are transient and usually weak. They last for only a few minutes and can stay in one spot or move along the shore. Because flash rips are ephemeral and short-lived, they are, as yet**,** unpredictable. The ocean shoreline of New York is known to experience flash rip currents (Slattery 2010). Cusp-shore rip currents occur along crenulated shorelines. Lastly, mega-rip currents are usually structurally controlled; they can be very powerful and extend far offshore.

In addition to structurally controlled rip currents and flash rip currents, other classifications recognize permanent rip currents, as distinct from structurally controlled rip currents, as well as traveling rip currents (Brewster 1995), and swash rip currents (Dalrymple *et al*. 2011). Permanent rip currents are structurally controlled. They are encountered at groins along the New York ocean shoreline. Bar-gap rips are a common type of rip current in other places, but they do not seem to be common along New York's ocean coast. They are created by a break in the offshore, or shore-attached, sand bar. Bar-gap rips, however, can appear temporarily and episodically when ridge-and-runnel features are present.

Ridge-and-runnels are morphological features of the beach (Figure 1). They run parallel to the shoreline. The ridge is a long, low linear mound of sand at the swash zone. The runnel is an associated shallow trough, often filled with water between the ridge and the dry beach berm. They usually form after storms as eroded sand makes its way back onto the beach.

Figure 1. Ridge-and-runnel as seen looking seaward from the dune on Fire Island This feature appeared a few day after Hurricane Irene in 2012.

Rip currents might be expected to be more likely to appear and to persist when shore-attached ride-and-runnels are in place. These bar-gap rip currents form at a depression, gap, or hole in the ridge. They can remain in the same location for days, months, until the beach profile changes. (Leatherman 2012) With the ridge-and-runnel systems in place, the same conditions of wind, tide and waves might produce a higher risk of rip currents in months when ridges-and-runnels are statistically more prevalent, than they would in months when statistically few ridges-and-runnels are usually seen. Daily images from a beach at East Hampton, New York were examined to look for the occurrence of ridge-and-runnel morphology. It is a reasonable hypothesis that the probability for ridge-and-runnel formation and duration increases with the strength of a coastal storm affecting the region.

Previous Work

A particular study of the influence of ridge-and-runnel on the generation of bar-gap rip currents was done along the French Aquitania Coast (Castelle and Bonneton

2006; the paper is in French, but the published English summary is given here in the Appendix). Water levels were elevated in the runnel by a combination of wave overwash and tidal flooding. Rip currents then formed at the runnel outlet as flows longshore, "feeder" currents from the runnel escaped through the gaps in the ridge (Figure 2; Castelle and Bonneton 2006). The model simulations showed that shore-normal low-frequency waves were important causes of the rip currents. Bar-gap rip currents on the French Aquitanian Coast were strongly modulated by the tide with the strongest rip currents occurring around mid-tide for moderate waves with significant wave heights between 0.5 m and 1.5 m, and around high tide for energetic waves with significant wave heights greater than 2 m (Figure 3). The French Aquitanian Coast, however, is a marcotidal coast; the tidal range here is over three meters. Along the East Hampton coast the tidal range is only about one meter and no tidal modulation of (flash) rip-current occurrence had been seen (Slattery 2010).

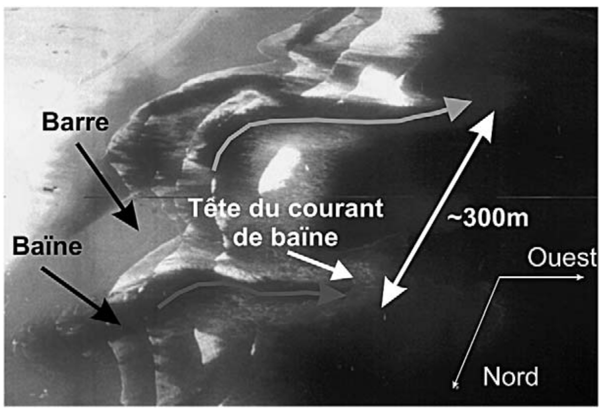

Figure 2. From: Castelle and Bonneton, 2006. Aerial photograph of a ridge and runnel system, Aquitanian Coast, France. Showing the location of gap-rip currents located at the runnel outlets.

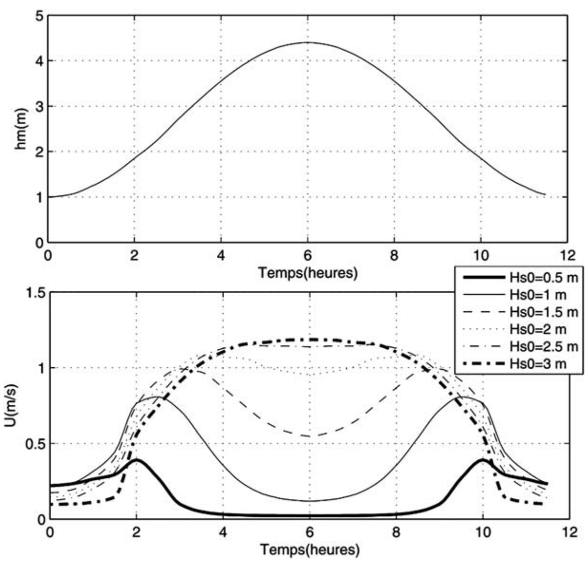

Figure 3. From: Castelle and Bonneton, 2006. Tide level h_m and rip current velocity U as a function of time for different significant

Methods

An Erdman Systems ® camera had been installed on the chimney of a private residence at the East Hampton shore in March, 2007. The camera is 15 m above mean sea level and about 120 m from shoreline. Images were recorded every 15 seconds between 6:00 A.M (EST) and 9:00 P.M (EST). From 6:00 A.M through 3:00 P.M. the camera is oriented 90 degrees to the ocean, but due to sun glare, from 3:00 P.M. through 9:00 P.M. it is oriented to look alongshore east. For this study, four images per day were examined in the period from October 2010 to November of 2012. Once a ridge and runnel event was identified, successive frames were looked at in order to determine the duration of each event.

NOAA's website <http://www.ndbc.noaa.gov/station_page.php?station=44025> was used to obtain historical wave data for the four days before each ridge and runnel event was first seen. Wave data was collected at Station 44025, which is thirty nautical miles off the coast south of Islip, New York. The maximum wave height was recorded and the significant dominant wave period was calculated for each day leading up to the events. This data was then divided by the wave period in order to estimate the wave steepness used to determine the severity of each event.

Results

Figure 4: Picture of a ridge and runnel event from the camera located in East Hampton, NY. 10 November 2007

Figure 4 is an example of an image showing a ridge-and-runnel. Six hundred and forty-three days of pictures were examined between October 2013 and November 2012. Ridge-and-runnels occurred thirty-five times. Of the six hundred and forty three days, a ridge and runnel was seen on one hundred days, or about 16% of the time. They lasted between one and eight days (Figure 5) and were most prevalent in the fall and early winter (Figure 6), but, in 2011, also showed up in the spring and late summer. It seems that they appear two or three days after an event of high wave steepness and it seems reasonable to assume that their duration depends on the magnitude of the event.

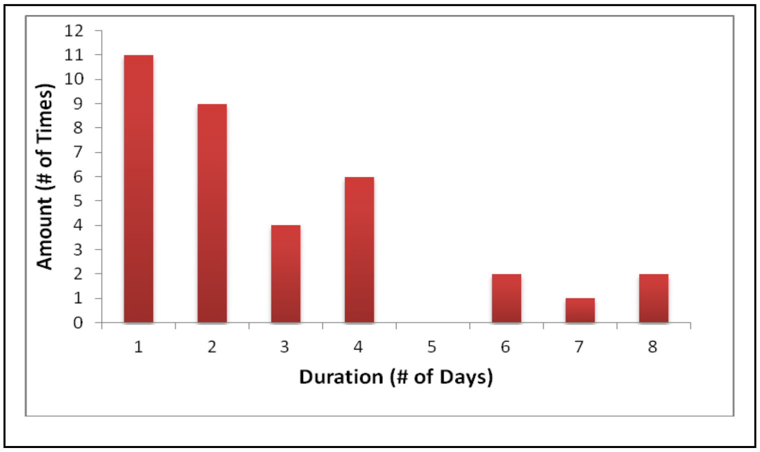

Figure 5: Graph showing the length of a ridge and runnel expressed in the number of days, versus the amount of time an event lasting a specific number of days was observed.

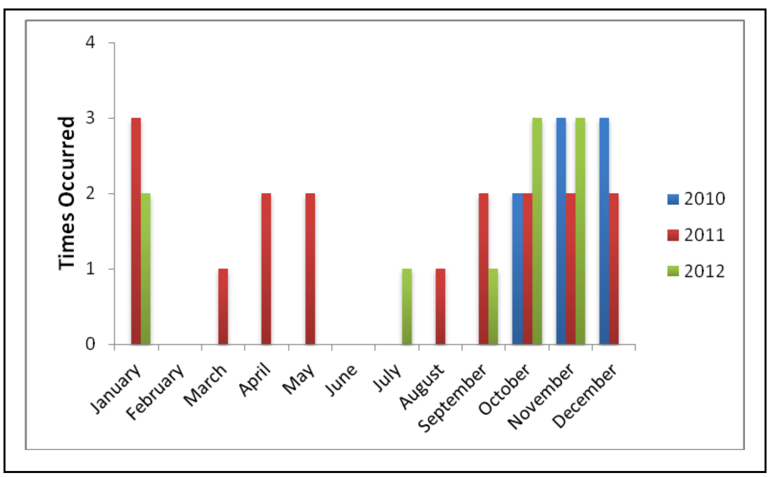

Figure 6: Graph of the number of times a ridge and runnel event occurred in each month from 2010-2012.

Discussion and Conclusions

An empirical predictor base on the wave condition might be developed from such data. Wave steepness (height over wavelength) seems a more promising predictor. In deep water, the wavelength is proportional to the wave period squared; wavelength is proportional to wave period in shallow water. Wavelength was not reported at Station 44025, so wave period was used as a surrogate. Data for 2012 seemed to show a direct, positive relationship between maximum wave steepness in the five days preceding the appearance of ridges-and-runnels and the duration of the features (Figure 7). Overall, the relationship is not definitive however (Figure 8). It may that the parameter based on offshore wave conditions would need to be for shallow-water transformations.

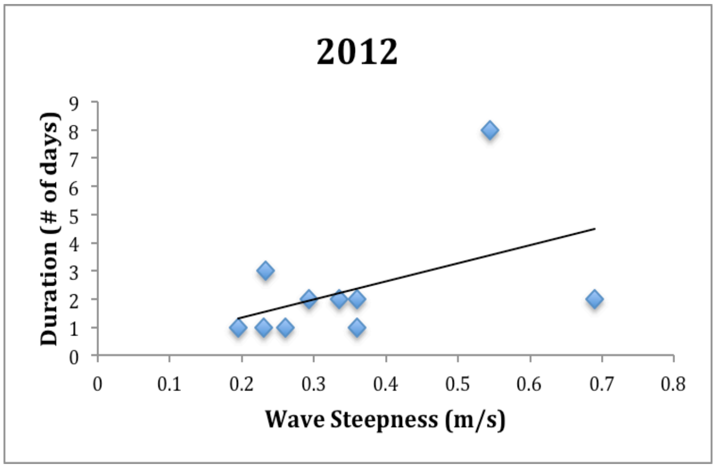

Figure 7: Graph of the greatest wave steepness, a calculation of maximum wave height divided by the significant dominant wave period, before a ridge and runnel event appeared compared to the length, in days, for each event that was observed in 2012.

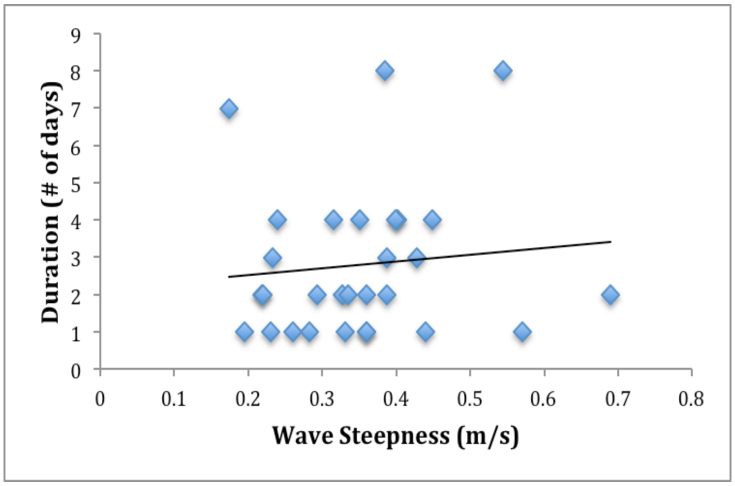

Figure 8: Graph of the greatest wave steepness, a calculation of maximum wave height divided by the significant dominant wave period, before a ridge and runnel event appeared compared to the length, in days, of the event. Each plotted point

Acknowledgments

The East Hampton Beach Preservation is thanked for providing the funding for the Erdman Systems ® camera used to obtain all the data, and special thanks for Mr. Matthew Howe at SoMAS for downloading all of the images.

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Brewster, B.C. (editor). 1995. *The United States Lifesaving Association Manual of Open Water Lifesaving.* Upper Saddle River, NJ: Prentice Hall Pages 43-45.

Castelle, B., and P. Bonneton. 2006. "Modeling of a rip current induced by waves over a ridge and runnel system on the Aquitanian Coast, France.." *Comptes Rendus Geoscience*. 338.10: 711-717.

Dalrymple, R.A., J.H. MacMahan, A.J. Reniers, and V. Nelko 2011. "Rip currents." Annual Review of Fluid Mechanics, 43, 551-581.

Leatherman, S.P. 2012. "Rip currents: types and identification." *Beach and Shore*. 80.3: 5

Slattery, M.P. 2010. Assessing the nature of rip currents along the south shore of Long Island, NY: Dominant rip type and insights into possible forcing mechanisms, Ph.D.Dissertation, School of Marine and Atmospheric Science, Stony Brook University: 141pp.

Appendix

Abridged English version of Castelle, B., and P. Bonneton. 2006. "Modeling of a rip current induced by waves over a ridge and runnel system on the Aquitanian Coast, France.." Comptes Rendus Geoscience. 338.10: 711-717.

“Rip currents are intense and narrow seaward-oriented currents being part of nearshore circulation patterns that play a key role in nearshore morphodynamics. Strong rip currents are induced by breaking waves over the ridge and runnel system on the French Aquitanian Coast (Fig. 1). The time- and depth-averaged flow model MORPHODYN is used to simulate wave-induced currents over a ridge and runnel system. This flow model is forced by SWAN wave rider. Computations show the presence of a strongly tidal-modulated rip current located at the runnel outlet associated with circulation eddies and feeder currents (Fig. 2). The forcing of the feeder currents is the pressure gradients, i.e. is the third term of Eq. (1). A strong setup is generated over the bar and in the trough, and is weaker in channel (Fig. 3).

This longshore pressure gradient drives the feeder currents toward the channel and contributes to the formation of a rip current. Pressure gradients are not the only driving force. The major driving mechanism for circulation eddies and rip currents is the combination of radiation stress spatial gradients and pressure gradients. Therefore, the residual forcing Fr (Damgaard et al. 2002) is defined to help in describing the net forcing available to drive currents. Simulations show that, for shore-normal incidence swells, radiation stress gradients Fv are mostly balanced by pressure gradient Fp (Fig. 4.1 and 4.2). At the runnel outlet, the two forcings do not balance and a significant amount of residual forcing is available to drive a circulation eddy associated with a rip current (Fig. 4.3 and 4.4). The maximum of residual forcing is located where the beach topography is strongly tridimensional. The sensitivity of this rip current to offshore wave conditions and tide level are investigated. Simulations show that the rip current is favored by the presence of shore-normal low-frequency waves. For oblique incidence waves, the entire longshore component of the radiation stress gradient is available to drive longshore current that oscillates over the ridge and runnel system (Fig. 5). For short-period swells, refraction due to the three-dimensional behavior of the topography is weaker, which leads to less intense residual forcing and a weaker rip current. The magnitude of the rip current depends on both residual forcing intensity and the cross-section area of the runnel outlet, thus on tide level. Tidal modulation of the rip current is intense, with maximum flow velocity occurring around mid-tide for moderate energy conditions (0.5 m < Hs < 1.5 m), and around high tide for energetic conditions (Hs > 2 m) (Fig. 6). Simulations highlight that the Aquitanian coast rip currents are controlled by the local topography, offshore wave conditions and tide level”.

Damgaard, J., N. Dodd, L. Hall, and T. Chesher. 2002. “Morphodynamic modeling of rip channel growth.” *Coastal Engineering.* 45. 199-221.

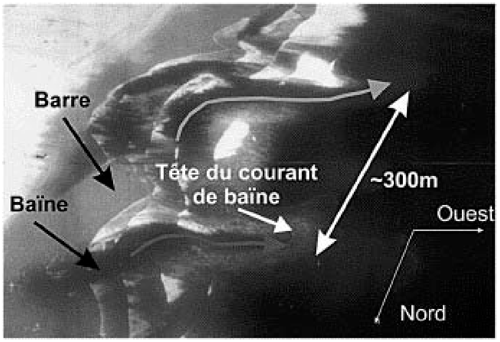

Figure 1: Aerial photograph of a ridge and runnel system, Aquitanian Coast. Showing the location of gap-rip currents located at the runnel outlets.

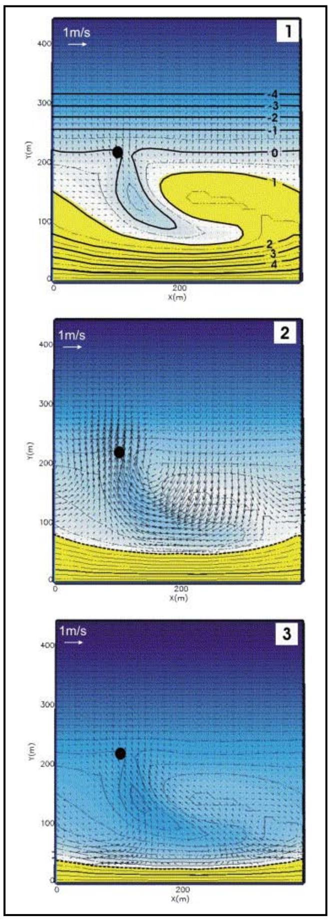

Figure 2: A strongly tidal-modulated rip current that is located at the runnel outlet is associated with circulation eddies and feeder currents.

$$\frac{\partial \bar{Q}_i}{\partial t} + \frac{\partial}{\partial x_j}\left(\frac{\bar{Q}_i \bar{Q}_j}{\bar{h}}\right) = -g\bar{h}\frac{\partial \bar{\eta}}{\partial x_i} - \frac{1}{\rho}\frac{\partial S_{ij}}{\partial x_j} - \frac{1}{\rho}\frac{\partial R_{ij}}{\partial x_j} + \frac{1}{\rho}\frac{\partial T_{ij}}{\partial x_j} - \frac{\tau_i^{b}}{\rho}$$

Equation 1: Forcing of the feeder currents is the pressure gradients.

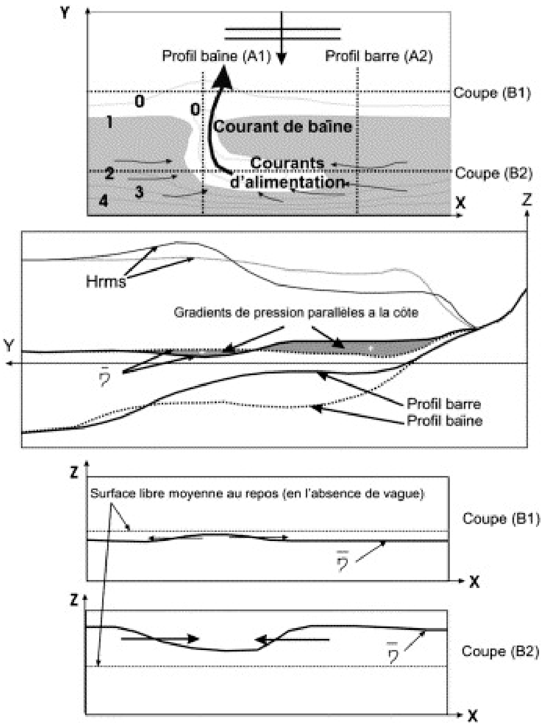

Figure 3: A strong setup is generated over the bar and in the trough, and is weaker in channel.

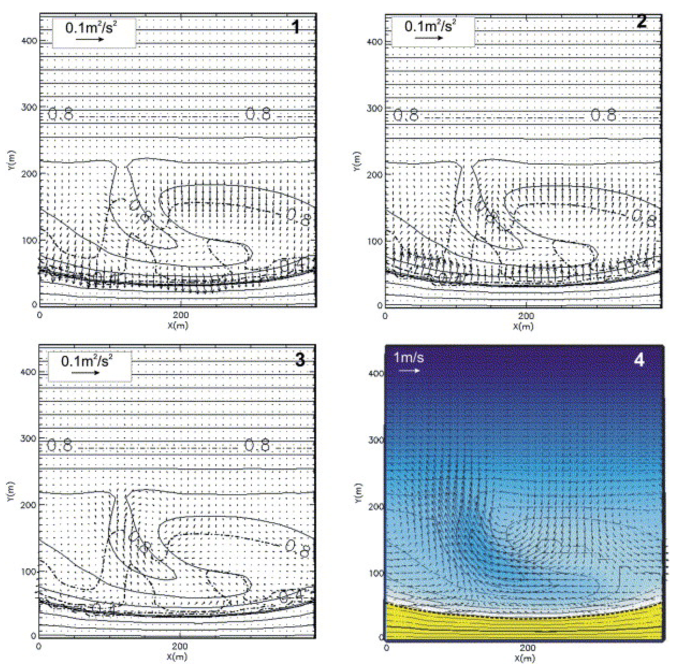

Figure 4.1, 4.2 4.3, and 4.4: For shore-normal incidence swells, radiation stress gradients Fv are mostly balanced by pressure gradient Fp. At the runnel outlet, the two forcings do not balance and a significant amount of residual forcing is available to drive a circulation eddy associated with a rip current.

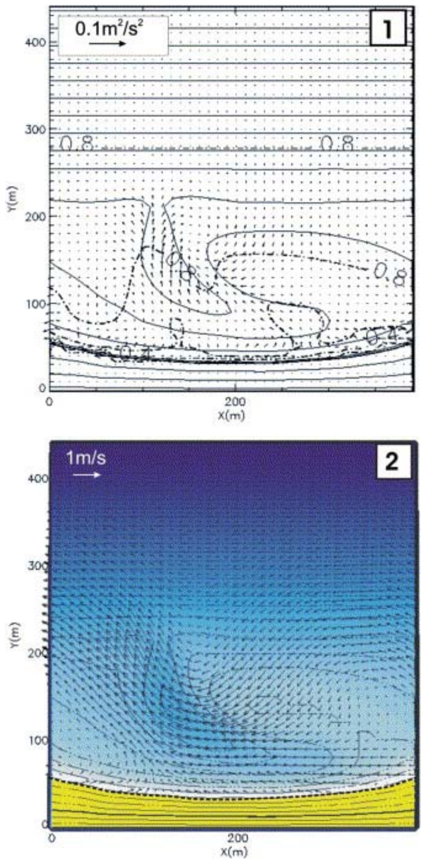

Figure 5: For oblique incidence waves, the entire longshore component of the radiation stress gradient is available to drive longshore current that oscillates over the ridge and runnel system

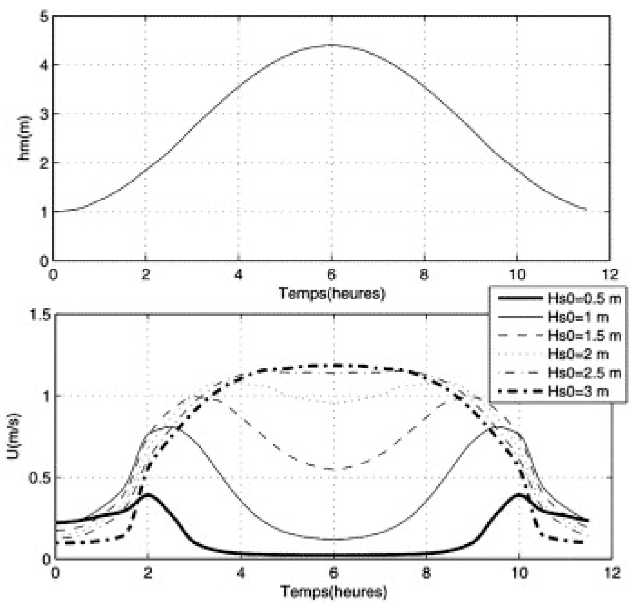

Figure 6: Tidal modulation of the rip current is intense, with maximum flow velocity occurring around mid-tide for moderate energy conditions (0.5 m < Hs < 1.5 m), and around high tide for energetic conditions (Hs > 2 m).