

MORPHOLOGICAL CHARASTERISTICS OF RIP CURRENT EMBAYMENTS ON THE OREGON COAST

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Abstract: A methodology is presented to identify possible rip current embayments from lidar-derived shorelines along the U.S. Oregon coast. Analyses of these features include their location and their representative length scales in an effort to determine a desired orientation of the features. A total of 99 embayments were analyzed having an average length and amplitude of 575 meters and 17 meters. During the major El Niño event of 1997/1998 there is an increase in size; however, the total number of embayments remained unchanged. The locations of rip embayments in the respective surveys does not show any significant correlation and appears to be random.

INTRODUCTION

Natural shoreline morphologies are complex and often exhibit various types of cuspate and rhythmic features at both small and large scales. Recent advances in rapid, large scale surveying technologies such as lidar have provided the comprehensive topographic data necessary to quantify the occurrence and evolution of these shoreline features. Rip embayments are spatially localized areas of erosion, sometimes called an erosional "hotspot" (Komar 1998; Kraus and Galgano 2001), and are an example of a cuspate-type feature that is common on the winter shorelines of the Pacific Northwest. These embayments can occur as either rhythmic or independent forms and they generally have a longshore length scale on the order of hundreds of meters, similar to sand waves, arrhythmic giant cusps, or rhythmic giant cusps (Dolan 1971). Their cross-shore length scale (amplitude) can be as large as 50 meters and essentially represents their erosional impact. Rip embayments, as their name implies, are generally assumed to be the result of the hydrodynamics associated with rip currents. However, as with beach cusps and many other shoreline features, their hydrodynamic origin is not always certain.

The presence of rip embayments creates vulnerability within the natural beach defense system. Storm waves will preferentially attack the beach through the deeper areas along the rip channels leading to the embayments. This means they are also better able to reach backing dunes and cliffs, which are the last defense for most coastal developments. Extreme events such as these have been well documented in Oregon, at times accounting for up to 30 meters of dune erosion in 3 weeks and causing houses and property to succumb to the ocean (Komar and Rea 1976).

Observations have established that a rip current that persists and is reasonably stationary will carve out a channel along the main flow axis where the currents are the strongest. The rip current or “rip cell” is supplied by longshore feeder currents and the net result is often a net offshore transport of sand. As sand along the beachface is removed by these currents, a localized erosional feature termed a rip embayment is created (Komar 1971). Swash processes also play a role in the erosion leading to the formation of embayments; however, their exact contribution is not well understood. Nonetheless, much of the sediment is likely carried offshore within the rip current and can often be seen as a large plume of suspended sediment extending beyond the break point (Shepard et al 1941).

Field observations of rip current embayments are limited and mainly derived from the shorelines of the Pacific Northwest (e.g. Komar and Rea 1976; Komar et al 1989; Revell et al 2002). The frequent, long period swell found here is conducive to rip generation and hence, is the likely culprit. However, rip embayments have been noted in California (Shepard et al, 1941), the East coast of the United States (Dolan 1971; List et al 2006), New Zealand (Stephens et al. 1999; Shand et al, 2004) and Australia (Wright and Short 1984; Short and Hesp 1982). Though, it should be noted that those were mainly qualitative measurements that focused on the amount of dune erosion, while detailed measurements of the rip embayment morphologies were not undertaken. The observed length scales ranged from 300-800 meters and their amplitude was described in terms of the associated dune erosion (O(10) meters).

In the following sections we present a methodology for identifying rip embayments (or at least features with the characteristics of rip embayments, though their actual origin remains unknown). The developed methodology is then applied to a representative shoreline contour, in this case the Mean High Water (MHW) contour extracted from lidar surveys undertaken along Oregon coast in 1997, 1998, and 2002. From these data we examine the morphological and spatial characteristics of rip embayments and their frequency of occurrence on the Oregon coast. The analysis will also consider whether embayments form at preferential locations and whether the 1997-1998 El Niño played a role in increasing the frequency of embayments or contributed to their migration.

STUDY SITE

The Oregon coast can be divided into approximately 18 "pocket beach" littoral cells that are headland bounded. These cells can further be subdivided into sub-cells by the presence of inlets, jetties, and rocky promontories. In the present work we identify populations of shoreline features that are characteristic of rip current embayments from lidar surveys of four separate sub-cells. However, to be clear, we are unable to definitively establish the physics of embayment formation. Nevertheless, henceforth we will refer to them as rip current embayments and quantify their physical scales.

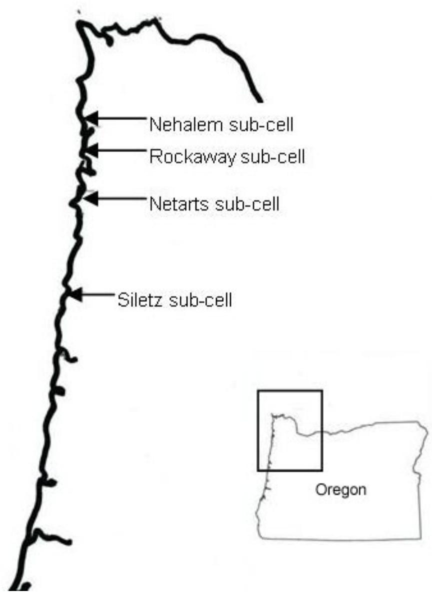

Figure 1 – Locations of the sub-cells used in this study.

The lidar data utilized herein are from portions of the Netarts, Siltetz, Nehalem, and Rockaway littoral cells. The Netarts sub-cell encompasses Cape Lookout State Park and extends ~9 km north to the Netarts Bay inlet. The Siletz sub-cell extends ~10 km from Government Point north to the inlet to Siletz Bay. The Rockaway sub-cell extends ~9 km north from the Tillamook Bay to Nehalem Bay, while the Nehalem sub-cell extends ~8 km north of Nehalem Bay to Neahkahnie Mountain. The morphodynamic characteristics of three of the sub-cells, Netarts, Rockaway, and Netarts, are similar and typified by wide, gently sloping (~2.3°) fine sand beaches, making them fully dissipative in the morphodynamic classification of Wright and Short (1984). In contrast, beaches along the Siletz littoral cell are characterized by coarse sand, and steeper beach slopes so they are classified as intermediate to reflective.

Wave conditions on the central to northern Oregon coast are much the same. During the winter, the wave regime is characterized by long period high energy waves (~3 meters wave height, ~12 second wave period) from the southwest accompanied with elevated water levels. The summer months have relatively calmer conditions with waves (~1 meter height and 8 second period) arriving from the northwest on lower water levels (Ruggiero et al, 2005). Rip embayments are thought to be less prevalent in the summer months (Komar et al 1989), whether they remain throughout the year has not been documented.

DATA

Anticipating the 1997-1998 El Niño event, the USGS conducted lidar surveys along the Washington, Oregon and California coastline in the fall of 1997 and again in the spring of 1998 (Revell et al 2002). Specific flights within our area of interest were carried out on 17 October, 1997 and on 28 April, 1998. Lidar data from a flight on 20 September 2002 are also examined as part of this study.

The most prevalent source of error in lidar data arises from reflections off the water surface, which creates a noisy topographic signal. These points are eliminated by establishing the tidal elevation during the flight time and removing data points taken from areas below this elevation (Stockton et al 2002). To establish the water elevation, data from nearby tide gages during the approximate times of the lidar flights were used.

As noted by Revell et al (2002), the 1997 surveys were conducted during mid-tide. This tidal elevation is less than a meter from our desired datum, which caused noise similar to that found in Stockdon et al (2002). Due to this effect only the shoreline from the Netarts sub-cell was resolved. The 1998 and 2002 surveys were flown during low tide where tidal elevations were at least a meter below our shoreline datum. Thus a shoreline was able to be extracted from all locations.

The presence of rip current embayments (as with most morphologic features) is dependant in some fashion on the antecedent wave conditions. As context for the lidar determined shorelines from 1997, 1998, and 2002, the antecedent wave conditions for Oregon are shown in Figure 2. Continuous wave height and period data were collected from the National Data Buoy Center station 46002 located 275NM West of Coos Bay, OR. As can be seen in Figure 2, the October 1997 LIDAR was preceded by two major storms, characterized by significant wave heights that exceed 8 m with the capability of transporting large quantities of sediment. A period of nearly five months of low energy conditions preceded the September 2002 survey.

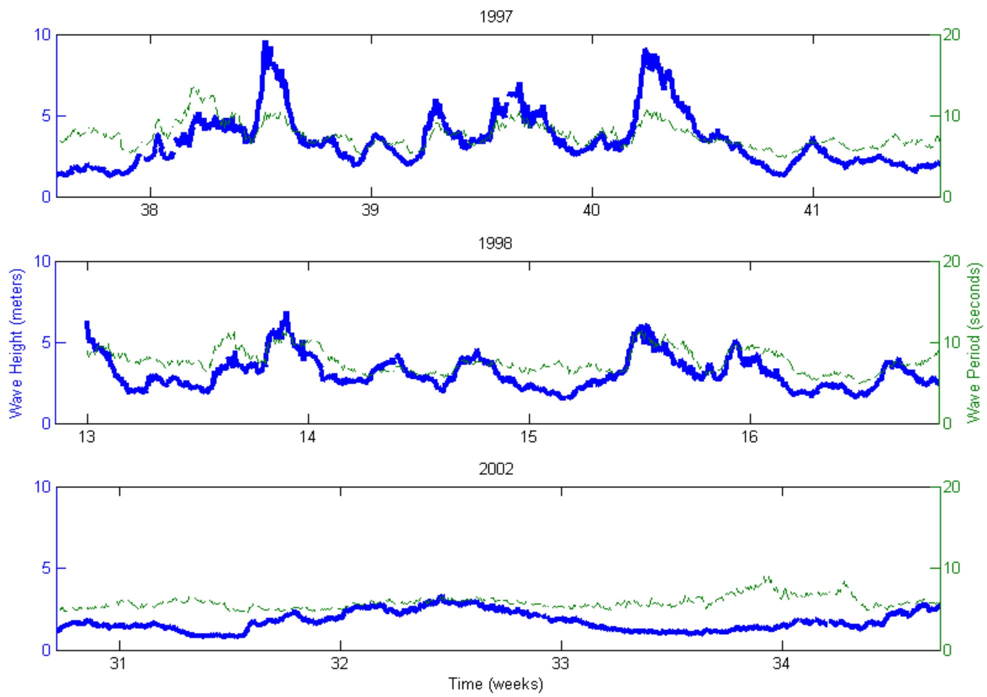

Figure 2 – Antecedent wave conditions prior to lidar surveys, wave height (solid blue line), wave period (dotted green line), x-axis represents weeks (lidar surveys took place at the end of each respective record).

METHODOLOGY

As a representative shoreline contour, we utilize the MHW level. Using a datum based shoreline provides unbiased repeatability whereas proxy shorelines based on visual cues are highly subjective. The study sites have a constant value for MHW that has been established at 2.1 meters NGVD88 (Weber et al 2005).

The raw lidar data was obtained from the NOAA Coastal Services Center (http://maps.csc.noaa.gov/TCM/). In post-processing NOAA has modified the data into a 5 meter grid within the Oregon State Plane North projection oriented in Northings and Eastings. This provides a series of beach profiles along the Eastings and with a profile located every 5 meters in the Northings direction. On average, the beaches were oriented with a six degree offset from true north and thus an Easting cross-shore profile closely resembled a true profile oriented normal to shore. For each profile, the cross-shore location of the most seaward MHW elevation is found through simple interpolation. Through these cross shore profiles a beach face slope is calculated for the portion within on meter of the MHW elevation. Once the location of MHW is found for each profile the MHW shoreline contour can be determined.

In order to establish the rip embayment locations we must identify local areas of erosion relative to the overall mean shoreline (baseline). The baseline is established by lowpass filtering the raw MHW contour. This filter consists of a running average filter applied twice with a window size of 1500 m and then demeaning the signal. Applying the filter twice results in a sharp cutoff, whereby only features with length scales larger than 1500 m remain. A second signal is then created with short scale features such as beach cusps (and remnant noise), removed from the raw shoreline by another lowpass filtering operation (100 m window size, applied twice) and again demeaned. The first signal is subtracted from the second, resulting in a bandpassed signal with bandpass limits of 100 m and 1500 m. An example of the bandpassed MHW shoreline contour that results from this method is shown in the middle of Figure 3 (bold line) where positive values are indicative of erosion.

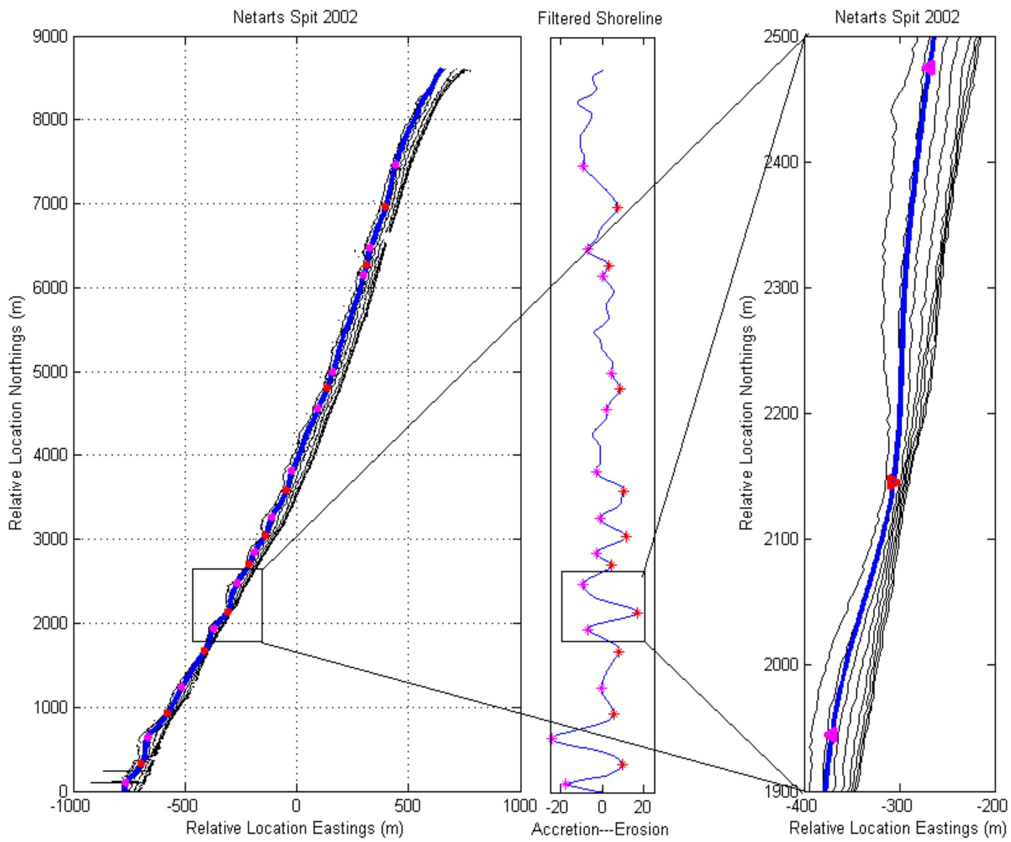

Figure 3 – (left panel) Elevation contours from lidar data, filtered MHW shoreline shown in bold, contour interval is 0.5 meters; (middle panel) filtered MHW shoreline (right panel) expanded view of a single rip embayment. In all panels, stars represent the locations of embayments and horns.

Individual embayments and horns are identified by applying a local maximum-minimum method (Koptenko 2003) on the bandpassed shoreline with a threshold that ignores small scale features less than 100 meters in length and less than 5 meters in amplitude (marked in the center panel of figure 3).

Using a datum based shoreline allows consistent and repeatable measurements of the features. A simple diagram of the scale definitions we have employed for rip embayments is shown in Figure 4. The length of the embayment is measured as the linear distance between adjacent horns located on the bandpassed shoreline (bold line in right and left panel figure 3. The amplitude of the embayment is the perpendicular distance from the maximum point of erosion within the embayment to the line of length.

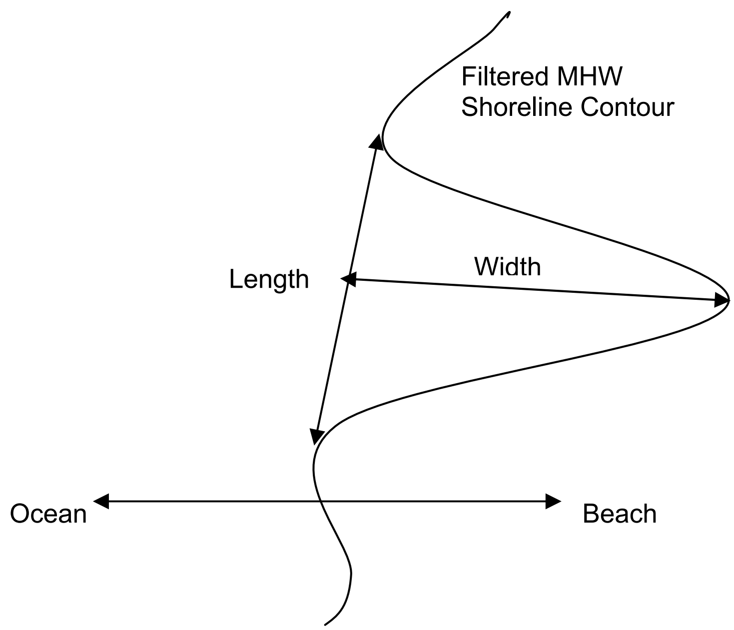

Figure 4 – Definition sketch for rip embayment scales.

Measurements of the rip embayments are dependant upon the chosen datum used for the analysis. As an example, a more complete topographic survey of a rip embayment, obtained from a land-based technique May 2005 (see e.g. http://www.oregongeology.com/sub/Nanoos1/index.htm) is shown in Figure 5. This feature was surveyed using a Trimble 5700/5800 RTK-DGPS surveying system mounted on an ATV and extends further offshore than the lidar survey. This feature remained through July 2005 but was erased by October 2005. It is evident from Figure 5 the survey that estimated embayment amplitudes would effectively increase if lower contours were used for the analysis, and at the upper levels of the beach face there is very little signal of the embayment. However, the longshore scale of the embayment appears less dependent on the chosen contour. The filtering process applied to the lidar data also inherently reduces the amplitude of the embayments. However, for comparison, using the MHW contour for the data in Figure 5, the observed embayment is approximately 450 meters in length with an amplitude of about 25 meters, which compares favorably with the scales estimated from the lidar data in this sub-cell.

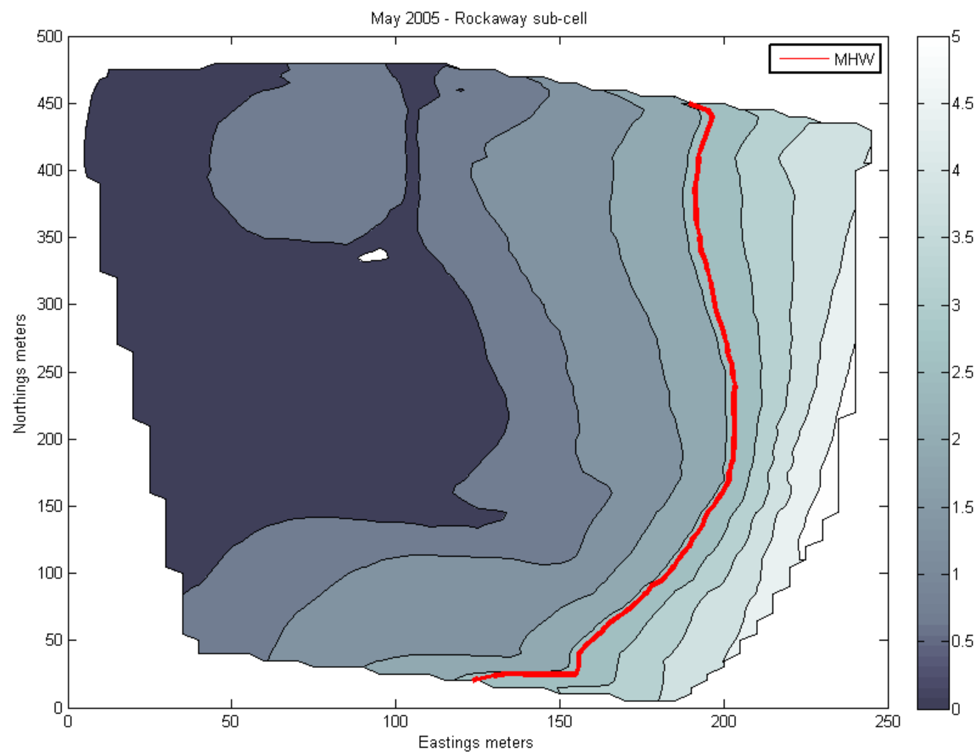

Figure 5 – Land-based survey of rip current embayment, located at 2231500 X 224910 Y in Oregon State Plane North.

RESULTS

Following the method described above plausible rip current embayment length, amplitude, slope, and spatial location were analyzed for four sections of coast for the three years in which lidar data is available. A summary of all features is first provided, followed by an examination of the temporal relationships and particularly the response pf the embayments to the 1997-1998 El Niño in the Netarts sub-cell.

A total of 99 rip current embayments were detected and measured along sandy shorelines totaling approximately 90 km, with an average of eleven embayments per year, per study site. Table 1 provides a summary of the results for each sub-cell throughout the study period. As defined, the embayments exhibit a mean length and amplitude of 575 meters and 17 meters respectively. These values are located near the center of the expected range; however, the scales have a large standard deviation. Nonetheless, the majority of the features had a length and amplitude less than 1000 meters and 30 meters.

The center of erosion of the embayments in not often located equidistant from its horns. For each study period there is no predisposition to be skewed to the north or the south. This asymmetric nature may be the result of some form of minor migration of the embayment. Another possibility is that the rip current channel is directed at an oblique angle to the shoreline causing a preferred side of erosion.

Examining the embayments from a given site, it is evident that under the same offshore wave conditions individual embayment response was not consistent. Some embayments were characterized by an increase in both their length and amplitude, while other embayments exhibited a decrease in their morphological dimensions; still others experienced an increase in their length and a decrease in amplitude.

Table 1 – Numerical summary of rip current embayment measurements

	Embayment Count	Mean Length [m]	Std Length [m]	Mean Amplitude [m]	Std Amplitude [m]	Mean Space [m]	Std Space [m]
Netarts Spit							
1997	10	556	112	9	5	662	334
1998	10	641	207	14	6	814	438
2002	10	557	195	15	7	738	367
Siletz Spit							
1998	14	542	195	21	16	533	202
2002	10	467	135	16	7	686	393
Nehalem Spit							
1998	10	564	121	18	8	667	336
2002	12	621	257	22	12	651	289
Rockaway Beach							
1998	11	596	254	20	16	745	300
2002	12	630	203	22	15	654	226

It is expected that rip current size scales with rip current strength and, correspondingly, rip embayment amplitude would scale with length. Indeed, there is an apparent linear relationship between the length and amplitude of the embayments as shown in Figure 6. At the Siletz sub-cell, the embayments are relatively shorter than those at other sites (or equivalently, the Siletz embayments are of larger amplitude). It is possible this is due to the coarser grained sediments and steeper beach face found at this site

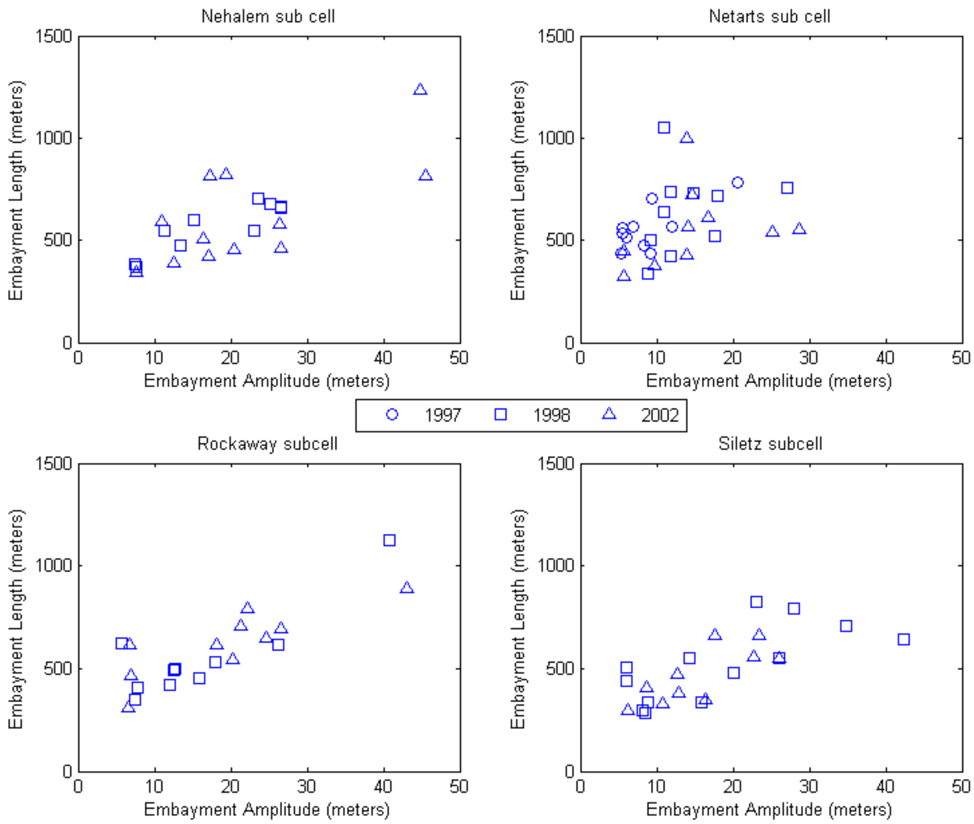

Figure 6 – Summary of Observed Embayments

Although the number of embayments at each site did not vary significantly between the different years, there was some change in the characteristic dimensions of the features. For example, in the Netarts sub-cell data that spans the major 1997-98 El Niño, there is a general increase in the spatial scale of the embayments. The embayment length scale increased 15% and the amplitude of the embayments increased by 55%.

The data also indicate a correlation between beach slope and the location of the rip embayments. Figure 7 shows the bandpassed MHW shorelines along with the local cross-shore beach slope at the MHW contour. It is evident from the figure that within most of the embayments the slope increases to a maximum at the center of the embayment. This appears to be a characteristic of rip embayments, and may possibly be used as an additional criterion for distinguishing erosive embayment features from other shoreline variability.

The spacing and location of embayments on a given shoreline is shown in Figure 8 and appears to be random. A few embayments are found directly adjacent to one another creating localized rhythmic behavior, while at other locations a single embayment is isolated in a long stretch of straight beach. Due to the differences in the locations of the embayments from year to year, it is likely that embayments are not preferentially occurring at a given location. Even in the 1998 survey, which took place only 6 months after the 1997, there does not appear to be any correlation with the embayment locations from the 1997 survey. It is likely that the largest storms that occurred that winter wiped clean the shoreline embayment signals. Although there may be evidence of preferential dune erosion at the site of rip embayments that remains in the 1998 data. As yet, we have not examined this hypothesis.

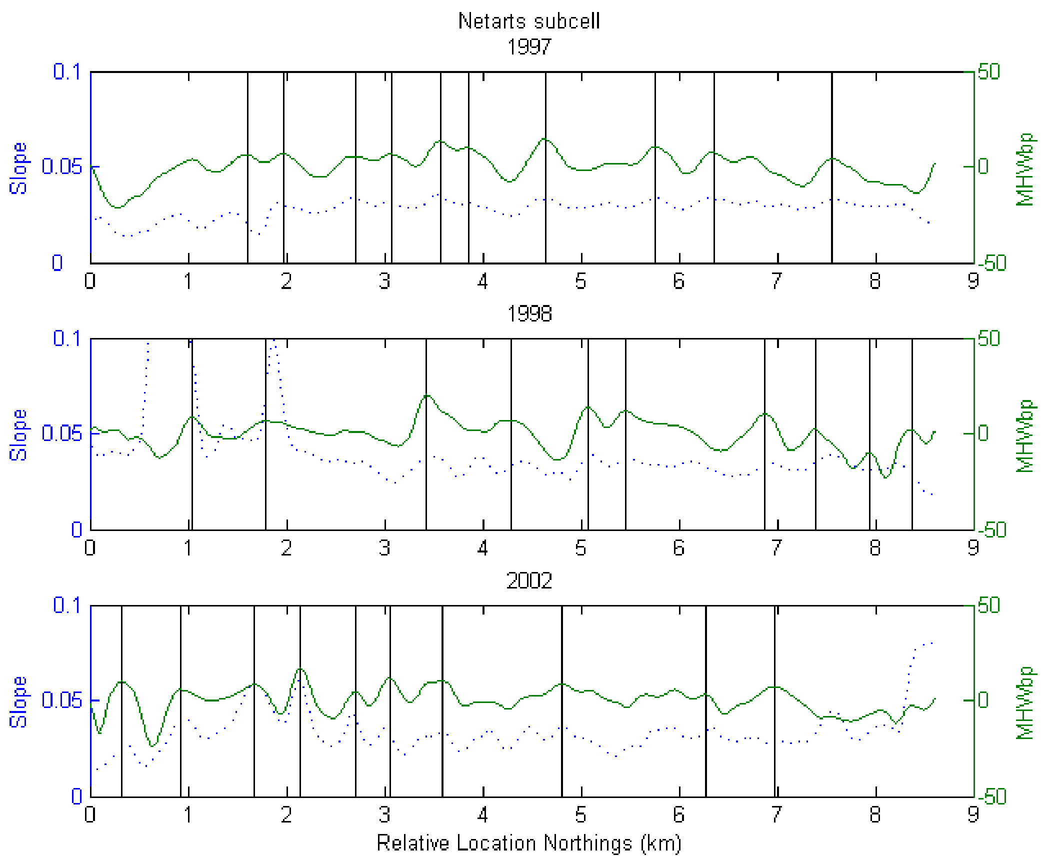

Figure 7 – Correlation between embayments and slope. The solid line represents the filtered MHW shoreline. The dotted line represents the slope. The vertical lines represent the center of the embayments.

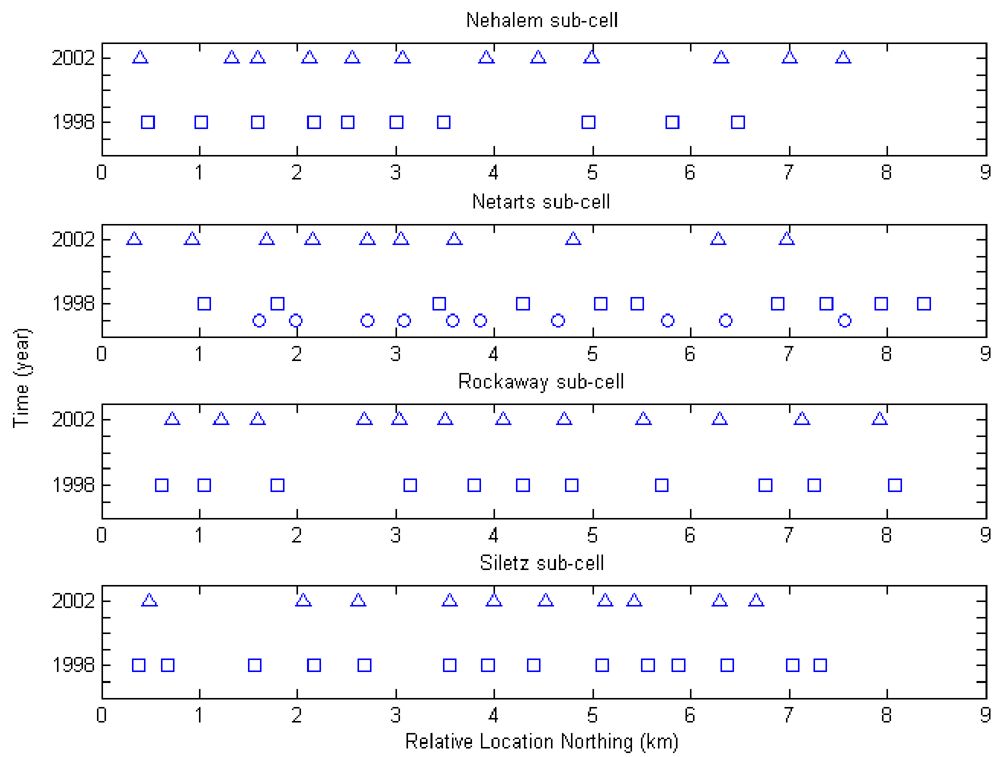

Figure 8 – Locations of embayment center versus survey time.

It is not clear yet if the antecedent wave conditions (Figure 2) for each survey has played a significant role in the embayment results. The wave data show that prior to the October 1997 survey there were two significant storm events with offshore wave heights of nearly 10 meters. Prior to the April 1998 survey there were two moderate storm events with wave heights around 5 meters. Prior to the September 2002 survey wave conditions there were five months of low energy conditions. Given these differences in the antecedent wave conditions, the only significant difference we have discerned in the rip embayments is the aforementioned general increase in embayment scales at the Netarts site for the 1998 data. Clearly further work is necessary to better understand the link between the wave conditions and the creation of rip embayments.

CONCLUSIONS

Using a bandpass filtered, datum based shoreline, morphologic features characteristic of rip current embayments with longshore length scales in the range of 100—1500 meters were extracted and analyzed. These erosional features are fairly common along the Oregon coast. In total, 99 embayments were found in shoreline data from four sites and three different years (9 shorelines total, ~90 km of sandy coastline). Consistent measurements of embayment length and amplitude made along the filtered shoreline had a mean length and amplitude of 500-700 meters and 10-20 meters respectively. The features appear to be distributed randomly along the coastline with no correlation in the locations from year to year. However, there does appear to be a correlation between the location of the embayments and the local slope in the cross-shore profile, with the slope tending to reach a maximum at the centers of the embayments.

FUTURE WORK

In order to better establish the hydrodynamic origin of rip embayments and their relationship to the prevailing wave conditions, our plan is to simulate the hydrodynamics of these morphologies with a sophisticated wave-driven circulation model. However, a prerequisite to this modeling effort will be to first obtain comprehensive bathymetric surveys (full surf zone coverage) of representative rip current embayments. We are presently developing a bathymetric survey system based on a personal watercraft in order to achieve this. Once obtained, the nearshore circulation field induced by these representative embayments will be simulated numerically. Finally, we will establish which wave conditions are necessary for rip circulations to develop.

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