Wave Transformation and Nearshore Currents in the Vicinity of a Wide-Crested Submerged Reef

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Abstract:

Calculations of wave transmission over a submerged reef were performed to estimate the alongshore variability in local wave height across the surf zone. Measurements of incident and local wave heights were made in January 2005 in an attempt to verify previous calculations. No alongshore variation in local nearshore wave height was measured. Diver surveys indicated that a great deal of sand had been transported offshore and not only created a substantial sand bar, but also buried the most nearshore extent of the hard-bottom coral reef. Whereas the reef had supported topographic relief in August, 2004, it no longer did at the time of this study, and therefore it followed that wave transmission into the nearshore would be similar for the regions fronting Deerfield and Hillsboro Beaches. Calculations of local wave height and mean surface elevation did, however, give rise to alongshore variability in the cross-shore extent of wave transmission, and also gave rise to alongshore variability in mean sea-surface elevation. The gradient in elevation suggests that offshore flows will be driven in the region along FLDEP profile R7 as well as the region between FLDEP profiles R8 and R9, which also happens to be the region fronting Hillsboro Beach. Measured data and calculated parameters indicated that alongshore variability in local wave climate, sea-surface elevation and bottom topography can give rise to cross-shore flows which can act to transport sediments offshore from the beach. Although this region is characterized by an essentially unidirectional wave climate due to a shadowing effect of the Bahamian Islands, these calculations have demonstrated that alongshore variability in the local wave climate and bathymetry can give rise to important cross-shore processes.

Introduction:

Hillsboro Beach is part of the uninterrupted barrier island system that extends along the east coast of the United States from the Mid-Atlantic to the South Florida shoreline. It is located in southeast Florida in Broward County. Hillsboro Beach and the region directly to the north of Hillsboro Beach are characterized by a submerged hard-bottom reef system and the predominant littoral transport is to the south due to wave shadowing by the Bahamas. Such a uniform, relatively low-energy environment should lead to a fairly uniform beach along the stretch of barrier island that comprises Hillsboro and Deerfield Beaches. However, two significant erosional “hot spots” were identified in the four-year monitoring study of the recent 1998 beach nourishment project.

The reef system fronting the groin field at Deerfield Beach is effectively twice the width of that fronting Hillsboro Beach. The difference in reef characteristics, namely the local water depth at the location of the reef and the characteristic reef width, can lead to a difference in local incident wave climate. Typically, one would expect that the incident wave energy would be greatly reduced across such wide-crested reefs in shallow water, and that only a percentage of the incident wave energy would be transmitted across the reef. Owing to the different physical characteristics of the reef fronting Hillsboro and Deerfield Beaches, we would expect differences in wave energy arriving at the beaches. This should in turn produce persistent circulation and sediment transport patterns due to the fixed hard-substratum nearshore topography.

Background Data

Hillsboro Beach is located in southeast Florida in Broward County. Hillsboro Beach and Deerfield Beach, directly to the north, were nourished with approximately 550,000 yd^3 of sand in 1998, and have been continuously monitored between 1998 and 2002. During that time, the beach endured three hurricanes, Hurricanes Floyd, Irene and Michelle, and several northeasters during the winter months.

Site Description:

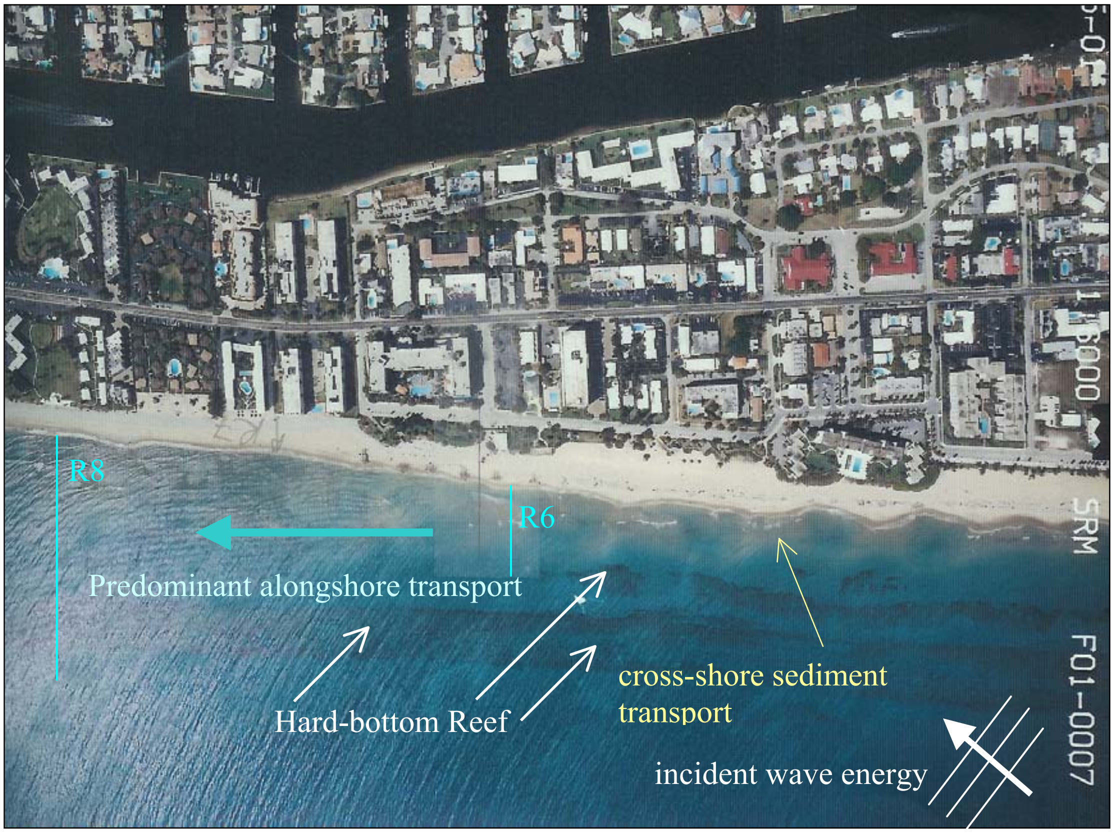

Figure 1: *Hillsboro and Deerfield Beaches: Note the fronting reef system, the Deerfield groin system, the direction of alongshore transport due to wave angle and cross-shore plumes of sediment as evidence of significant cross-shore processes.*

Hillsboro Beach and the region directly to the north of Hillsboro Beach is also characterized by a reef system and the predominant littoral transport due to wave angle is toward the south (see WIS data) (fig. 1; fig. 2). However, as reported by Coastal Systems International, Inc. (CSI), there appears to be significant cross-shore processes as can be seen from aerial photography (fig. 1).

Hindcast WIS data (USACE, http://frf.usace.army.mil/wis/) for the region was examined to investigate typical Significant Wave Heights and Wave Direction for the region. We downloaded data for year 1998 – 1999 from WIS STATION: 465 LAT: 26.25 N, LON:-79.92 W, DEPTH: 269 M to examine these parameters.

The mean significant wave height (Hs) for that year was calculated to be 0.93 m. A histogram of wave direction was computed and presented in a rose plot (fig. 2).

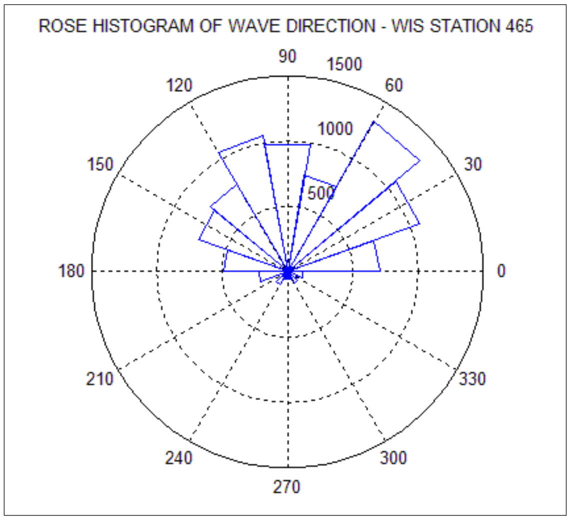

***Figure 2**: Rose Histogram of Wave Direction (from which): A significant amount of the wave energy arrives from the North of East quadrant (between 0 and 90 degrees) due to the wave shadowing caused by the Bahamas.*

Here, it is easily seen that most of the wave energy arrives from the northeast due to the wave shadowing of the Bahamian Islands, and, hence the predominant alongshore transport is toward the south.

Such a uniform, relatively low-energy ($\overline{H_s} = 0.93m$) environment should lead to a fairly uniform beach along the stretch of barrier island that comprises Hillsboro and Deerfield Beaches. However, it was found that there are two significant erosional "hot spots" as identified by Coastal Systems International. One is at the most northern extent of Hillsboro Beach, directly south of the Deerfield groin field and the other is to the south, at the southernmost extent of the 1998 nourishment project.

Preliminary Site Visit / Analytical Calculations

Bathymetry:

A preliminary reconnaissance study was conducted on 15 August 2004 via SCUBA. Two divers swam transects along FLDEP Profiles R6 and R8 (fig. 1) to qualitatively examine the nearshore bathymetry, and to estimate the width and elevation of the hardbottom reef relative to the sand bed. It was determined that characteristic reef widths for Deerfield and Hillsboro Beaches were 250 and 100 ft., respectively. The approximate water depth at the sand bed at the onshore and offshore extent of the reef was measured at 20 ft. using a dive computer. The reef itself was 15 to 18 ft. below the water surface, again as measured via dive computer.

Submerged Reef System and Incident Wave Energy:

Figure 1 illustrates the hard-bottom reef system that fronts both Hillsboro and Deerfield Beaches. However, it can be seen from Figure 1 that the reef fronting Deerfield Beach is effectively twice the width of that fronting Hillsboro Beach. The wave-breaking pattern induced by the reef can be easily viewed by examination of aerial photographs during time periods of significant incident wave energy. Figure 3 was produced by superimposing Figure 1 with an additional USACE aerial of the region taken during a time of high wave energy, in order to illustrate the ability of the reef to reduce incident wave energy through wave breaking and nearshore turbulence. Through examination of Figure 3, it is observed that waves break across the reef and continue to break across the nearshore reef fronting the southernmost extent of Deerfield Beach, as evidenced by the white breaker line across the reef in that region.

***Figure 3**. Two aerial photographs (courtesy of the USACE Jacksonville District) superimposed to illustrate the pattern of wave breaking across the submerged hard-bottom reef fronting Hillsboro and Deerfield Beaches. The white breaker line is the result of wave breaking and nearshore turbulence across the reef. This photograph demonstrates that the reef is effective in inducing wave breaking and reducing local wave energy across the reef for elevated wave energy conditions.*

Figure 3 illustrates that the reef is effective in reducing local wave energy during times of elevated wave energy conditions. It is observed here that waves break across the leeward edge of the contiguous reef section fronting Deerfield Beach and waves continue to break across the most nearshore fringing reef at that same location. The reef is not as effective for the same wave conditions in front of Hillsboro Beach because the distance between the reef and the subaerial beach is larger at Hillsboro Beach than at Deerfield Beach, and the characteristic reef width is greatly reduced at Hillsboro Beach.

The difference in reef characteristics, namely the local water depth at the location of the reef and the characteristic reef width, will lead to a difference in local incident wave climate. Typically, the incident wave energy is greatly reduced for wide-crested reefs that are in shallow water, and only a percentage of the incident wave energy is transmitted across the reef. Owing to the different physical characteristics of the reef fronting Hillsboro and Deerfield Beaches, we expect differences in wave energy arriving at the beaches. In this instance, we expect to observe persistent circulation and sediment transport patterns due to the fixed hard-substratum nearshore topography.

In the following, we will examine the wave energy that is transmitted across the reef at Hillsboro Beach and the reef at Deerfield Beach for the same incident offshore wave conditions, and the resulting currents induced by the transmitted wave energy.

Analytical Calculations:

WAVE TRANSMISSION: Wave Transmission across a wide-crested submerged reef is a function of reef width, reef depth, incident wave height and local wavelength. Wide-crested reefs that support characteristic widths on the same order as typical incident wavelengths (tens to hundreds of meters) are especially effective at reducing the energy of low-frequency (high wave period) swell and storm waves. Similarly, reefs that are in shallow water are very effective in reducing the energy of waves with wave heights that are on the same order as the reef depth (typically 1 – 3 meters).

Here, we write the equation for wave transmission across a wide-crested submerged breakwater as (Friebel and Harris, 2004):

$$K_t = -0.4969\exp\left(\frac{R_c}{H_{oi}}\right) - 0.0292\left(\frac{B}{d}\right) - 0.4257\left(\frac{h}{d}\right) - 0.0696\ln\left(\frac{B}{L}\right) + 0.1359\left(\frac{R_c}{B}\right) + 1.0905 \tag{1}$$

where B is the crest width of the submerged reef, d is the local water depth, h is the height of the structure from the seabed, R_c is the depth of water over the structure (h-d) (referred to as negative freeboard), H_{oi} is the incident wave height, and L is the wavelength at the local water depth.

To solve Equation 1, we chose characteristic reef widths for Deerfield Beach and Hillsboro Beach as 250 ft and 100 ft, respectively. Here, we set the water depth at 20 feet. Solving Equation 1, we find that, in water depths of approximately 20 feet, a reef that stands 5 feet above the sea-floor with a characteristic width of 70 meters (approximately 230 feet) will reduce incident wave heights by 25 percent (75 percent of the wave energy passes across the reef). Similarly, a reef that has a characteristic width of 30 meters (approximately 100 feet) will reduce incident wave heights by only 10 percent (90 percent of the wave energy passes across the reef). We also find that the reef becomes more effective at reducing wave energy with an increase in wave height (Hi) or a reduction in wave length (L) (or alternatively, wave period, T). In other words, submerged wide-crested breakwaters are more effective in reducing the energy of steep, incident waves (H/L is large), as shown in Figure 4.

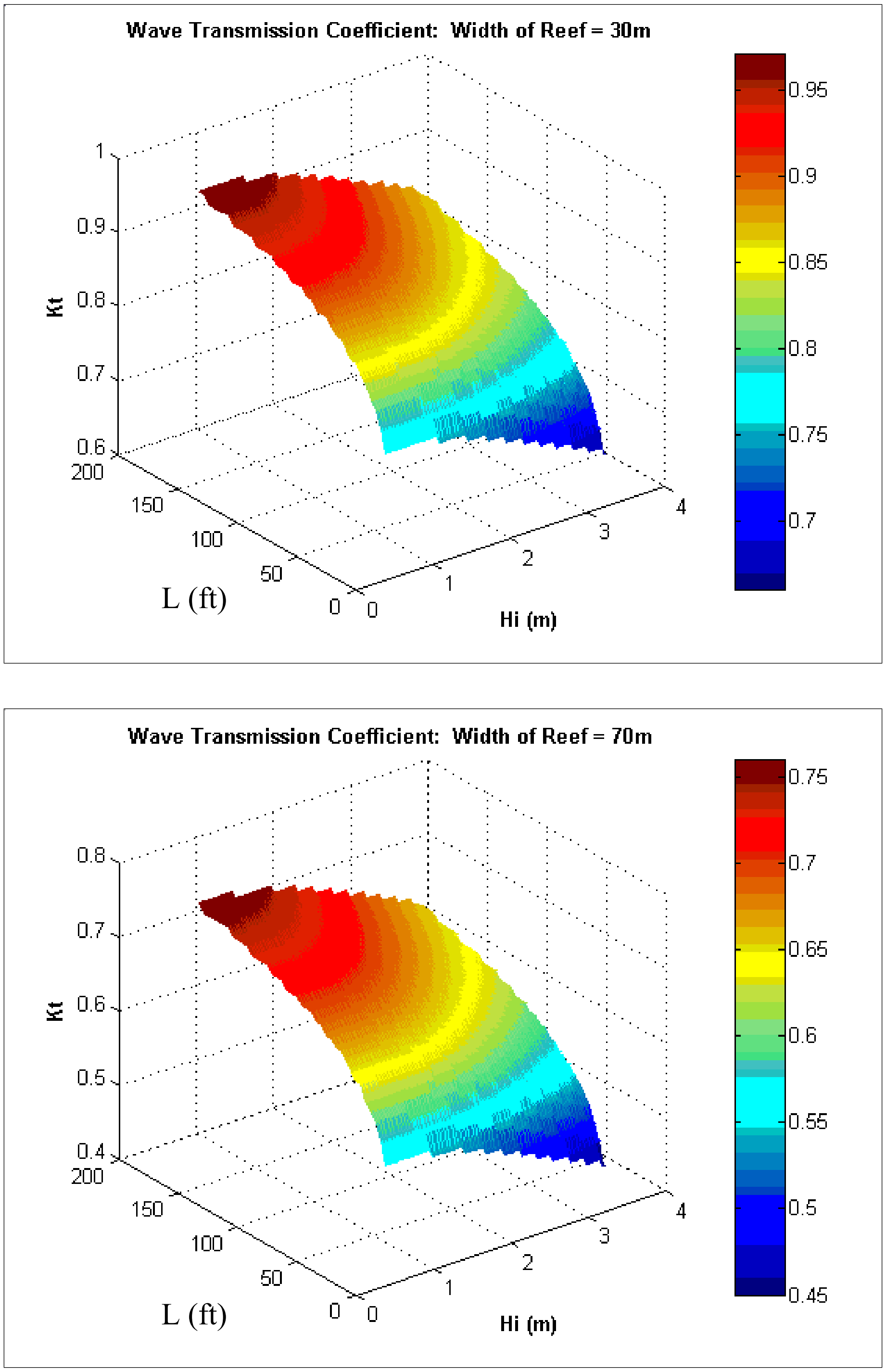

***Figure 4a-b**: Calculation of the Wave Transmission Coefficient (Kt) as a function of wave height and wave length, from Equation 1. Wave energy transmitted across the submerged reef is decreased with increasing incident wave height and decreasing wavelength. Essentially, the reef is more efficient at reducing incident wave energy with increasing wave steepness (H/L). Here, a reef with a characteristic width of 70 meters reduces typical incident wave heights by 25% or more whereas a reef with a characteristic width of 30 meters reduces typical incident wave heights by 10% or more. (Water depth = 20ft, reef elevation = 5ft above the seafloor)*

ALONGSHORE VARIATION IN BREAKING WAVE HEIGHT / SEA LEVEL SLOPE: As a mass of water moves shoreward via breaking waves, the mean sea surface level is elevated in the form of wave set-up. This elevation in mean sea level causes a hydrostatic pressure gradient in the offshore direction that balances shoreward-directed wave momentum and drives a return near-bottom flow, or undertow.

We can write the equations for wave set down, which is a depression in mean sea-level at the region of wave breaking, as:

$$\eta_b = -\frac{kH^2}{8\sinh(2kh)} \tag{2}$$

where η_b is the mean sea surface elevation at wave set-down, k is the local wave number, H is the local wave height, and h is the local water depth.

Similarly, we can write the equation for wave set-up, which is a region of elevated mean sea-level across the surf zone, with a maximum elevation in the swash zone:

$$\frac{\partial\overline{\eta}}{\partial x} = -\left[\frac{1}{1+8/3\gamma^2}\right]\frac{\partial h}{\partial x} \tag{3}$$

where $\overline{\eta}$ is the mean sea surface elevation across the surf zone, x is the cross-shore distance and γ is the ratio of local wave height to local water depth, usually set at 0.78.

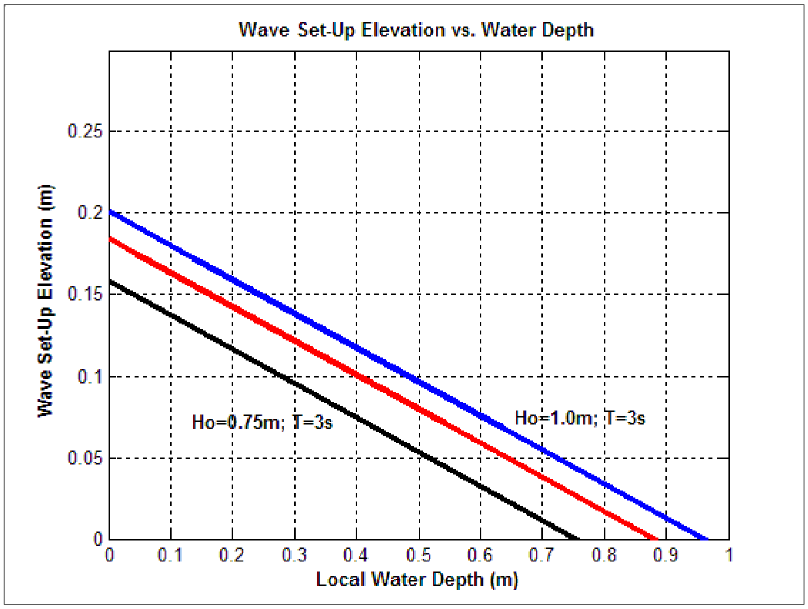

***Figure 5**: Wave set-up: Mean water elevations at the still water level (SWL) are 0.2m, 0.188m, and 0.155m for no reef, a 30m wide reef and a 70 m wide reef, respectively.*

Here we examine differences in wave set-up for a characteristic incident wave with a wave height of 1 meter and wave period of 3 seconds. Allowing for 10% wave height reduction for a wave translating across a 30 meter wide reef and, additionally, allowing for a 25 percent wave height reduction for a wave translating across a 70 meter wide reef, we calculate resulting wave set-up elevations at the still water level (SWL) h=0. We find that for the case where all of the energy is transmitted across the reef (Kt = 1), the set-up elevation is 0.2m. For the case where 90% of the incident wave height is transmitted across the reef, (Kt=0.9), the resulting set-up is 0.19m. Finally, for the case where 75% of the incident wave height is transmitted across the reef, the resulting set-up is 0.155m. (fig. 5) The resulting alongshore gradient in mean sea-surface level $\partial\bar{\eta}/\partial y$ over a 0.1 km stretch of beach is 0.0003, which is typical for beaches with longshore bar systems (see Komar, 1998).

NEARSHORE CIRCULATION: Nearshore circulation is induced by the mass of water carried shoreward by breaking waves. This mass must be balanced by a return flow seaward, which can take the form of an undertow or a rip current, and/or it can be carried alongshore in the form of an alongshore current.

Typically, alongshore currents are driven by waves arriving at the shoreline at an angle. As waves break at an angle, the shore-parallel component of moving water carried within the breaking wave induces an alongshore current. However, alongshore currents can be induced by alongshore differences in breaking wave elevation and the resulting sea-surface set-up. A nearshore sea-surface elevation gradient, $\partial\bar{\eta}/\partial y$, can drive alongshore currents even if waves are arriving directly from offshore.

The significance of this result is that there may be a divergence in sediment transport at the alongshore location where breaking waves are the largest. The resulting flows from this type of alongshore variation in breaking wave height can cause the sediment to be transported away from regions of greatest breaking wave height to regions where the breaking wave height is smaller (fig. 6). This divergence will reveal itself as an erosional hot spot.

Figure 6: Description of circulation system at Hillsboro and Deerfield Beach. The variation in breaking wave height induces an alongshore variation in wave set-up at the shoreline. This variation creates a sea-surface slope down toward Deerfield Beach. The sea surface slope induces a pressure gradient toward Deerfield Beach, and water and entrained sediments will tend to move toward Deerfield Beach. The current induced by the variation in alongshore sea-surface elevation must be added to the current induced by waves arriving to the shoreline at an angle.

Relating the alongshore sea surface gradient, $\partial\bar{\eta}/\partial y$, to breaking wave heights through Equations 3 and 4, Komar (1998) developed an equation for the alongshore velocity at the mid-surf position owing to waves arriving to the shoreline at an angle and owing to alongshore gradients in breaking wave height. The alongshore velocity is written as:

$$v_l = 1.17\sqrt{gH_b}\sin\alpha_b\cos\alpha_b - a\sqrt{gH_b}\frac{\partial H_b}{\partial y} \tag{4}$$

where $a = \dfrac{\pi\sqrt{2}}{C_f\gamma^{5/2}}\left(1+\dfrac{\gamma^2}{8}\right)$

Here, g is the acceleration due to gravity, H_b is the breaking wave height, α_b is the breaking wave angle, y is the characteristic alongshore distance over which there is an appreciable change in incident wave energy, and C_f is a friction factor typically set at 0.010. We find that for ∂H_b of 0.15m (0.5ft) over a distance of 1000 ft, and $C_f = 0.01$, the alongshore current generated by this effect *alone*, is on the order of 1 m/s (1.29 m/s).

January 2005 Field Study:

Nearshore Bathymetry

Extensive bathymetry data exist for the region (CSI, Inc., 2002) through the acquisition of traditional survey data from hydrographic surveys and also through LIght Detection And Ranging (LIDAR) / Laser Airborne Depth Survey (LADS) surveys that were sponsored by Dade and Broward Counties (JCR, 2003). We employed nearshore profiles obtained on 26 February 2002 to describe the site because they most accurately reflected the "winter profile" configuration of the beach. Specifically, FLDEP profile at monument R6 was used to describe the beach fronting Deerfield Beach, and FLDEP profile at monument R8 was used to describe the beach fronting Hillsboro Beach (fig. 7).

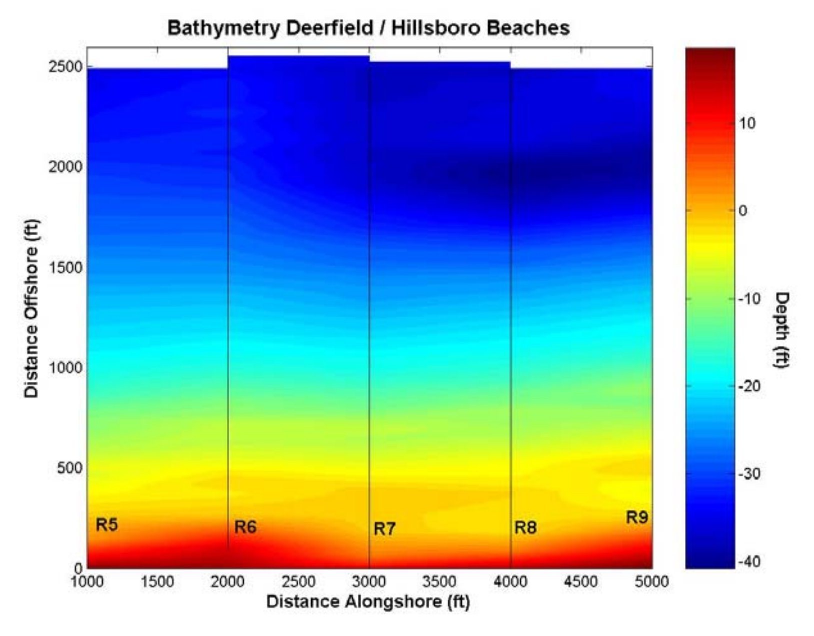

***Figure** 7: FLDEP Profiles R6 and R8 were used to examine the effect of the variation of coastal bathymetry on nearshore circulation*

Methods:

Field instrumentation was deployed from 6 through 9 January 2005 to obtain data describing the wave energy arriving at the shoreline at Deerfield and Hillsboro Beaches. For this study, an Acoustic Doppler Profiler (ADP) was deployed offshore (approx. 1500 ft offshore of MLW) to obtain incident wave and current information at that location (fig. 9). This data were used to measure the incident wave climate to later describe wave transformation across the surf zone. In addition, two S4 electro-magnetic current meters were deployed in the surf zone in 10 ft. of water, directly along FLDEP profile line R6 and R8 (approximately 500 ft offshore of MLW), respectively, to obtain significant wave height and direction as waves were entering the surf zone (fig. 9). The S4 current meters were placed inshore of the hard-bottom coral reef as well as the pronounced sand bar that had developed as part of the winter beach profile.

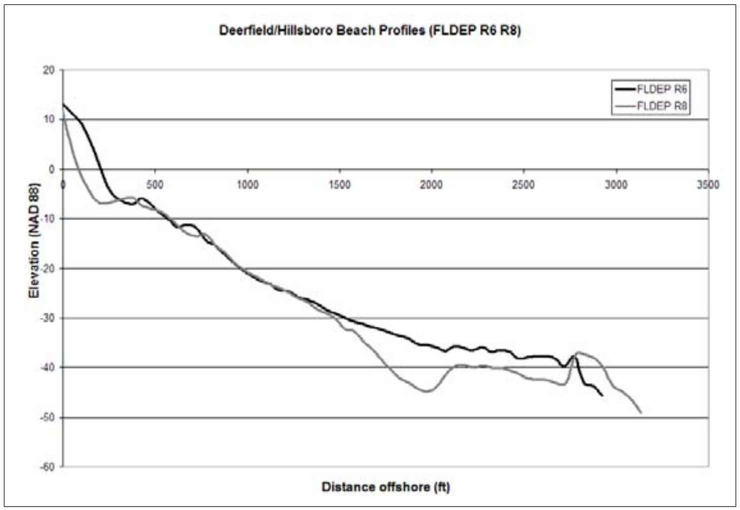

***Figure 8**: FLDEP Profiles R5 – R9*

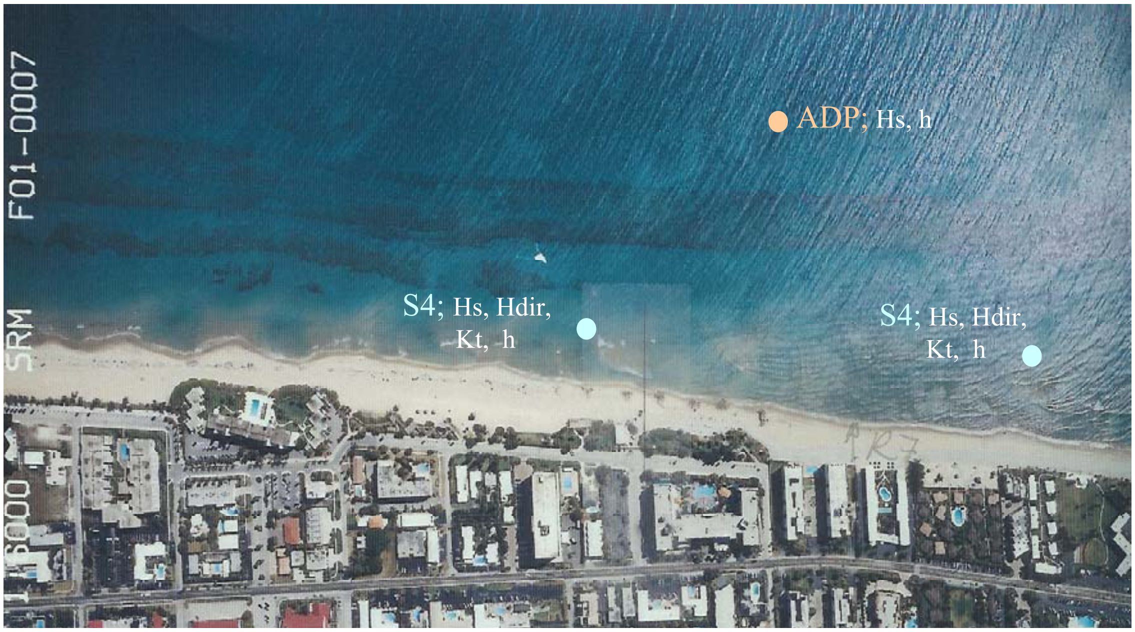

***Figure 9**. Instrument locations for Hillsboro Beach Field Study. One ADP and two S4 ECMs were deployed to measure incident wave height (Hs), transmitted wave height (Hs), wave direction (Hdir), wave transmission coefficient (Kt), and local water depth (h).*

The ADP was programmed to burst sample at 2 Hz for twenty (20) minute intervals, continuously. Each hour, three 20-minute samples were input into a Fast Fourier Transform to obtain significant wave height and peak spectral period. Wave direction was not measured due do a hardware installation error. The water column was binned into 0.3m bins so that 2-minute ensemble averages of the measurement of north, east and vertical velocities were obtained for each bin. The two S4s were programmed to obtain 18-minute samples at 2Hz to obtain a minimum of 2048 points as input for a Fast Fourier Transform to obtain directional wave spectra. Here, the S4 measured water depth, north, east and vertical velocities for 18-minute burst samples every hour.

Results:

The observations were conducted during a period of moderate wave action from the south-east, specifically with waves arriving from between 85 – 120 degrees, and persistent winds in excess of 10 knots, primarily from between 100 and 150 degrees (fig. 10). Incident wave heights were between 0.3 and 1.5 meters (between 1 and 5 ft) over the sampling period (fig. 11). Peak spectral periods were consistent at approximately 4.3 seconds. Nearshore wave heights increased during low tide as waves shoaled and broke on the sand bar, re-formed and then broke again directly offshore of the swash zone. Wave heights were slightly greater at Deerfield Beach than at Hillsboro Beach. During high tide, waves passed over the bar and the surf zone was restricted to the region directly offshore of the swash zone (fig. 11). Currents measured with the ADP and the two S4's were consistently below 10 cm/s with no coherent pattern, thus indicating that the S4's were not placed in the dissipative region of the surf zone.

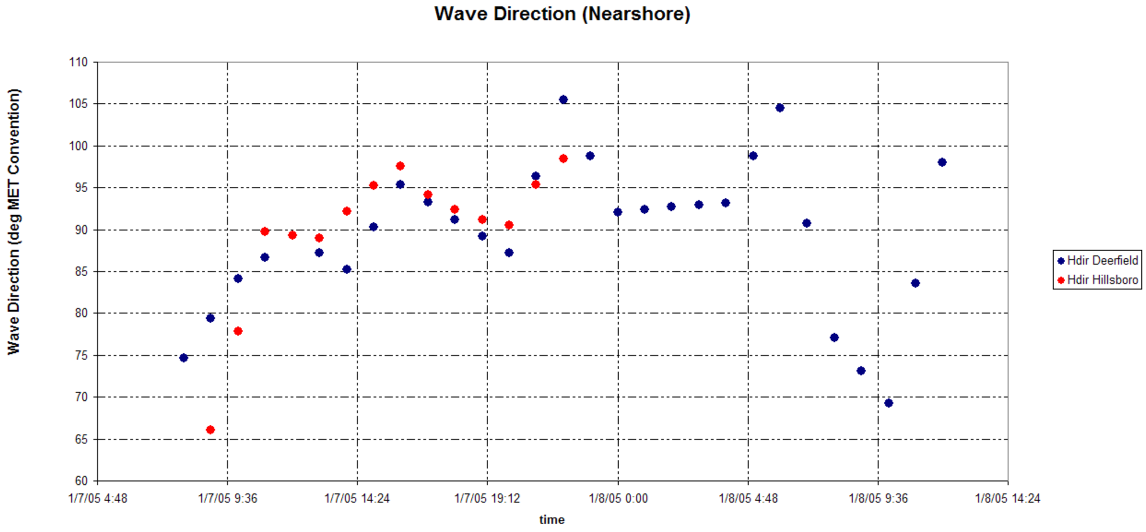

Figure 10: *Nearshore wave direction (MET convention) measured with the two S4 current meters.*

Wave transmission coefficients were calculated for the region fronting Deerfield Beach and Hillsboro Beach (fig. 12). Here it was found that when incident waves were greater than four feet, transmission coefficients dropped to between 0.8 and 0.6. Eighty percent of the wave energy was transmitted across the reef and sand bar when incident waves were at four feet and sixty percent of the wave energy was transmitted into the nearshore when incident waves were greater than six feet. There was no appreciable difference measured between the wave transmission for the region in the vicinity of Deerfield Beach and that of Hillsboro Beach.

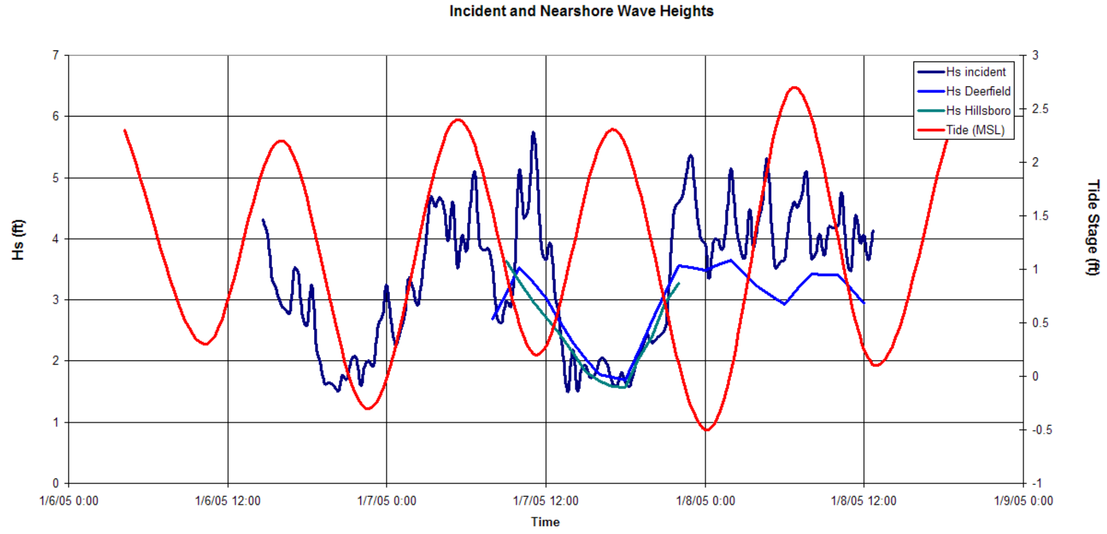

***Figure 11**: Incident wave height, nearshore wave heights for Deerfield and Hillsboro Beaches and Tide Stage. Wave heights at Deerfield Beach were slightly greater than those at Hillsboro Beach.*

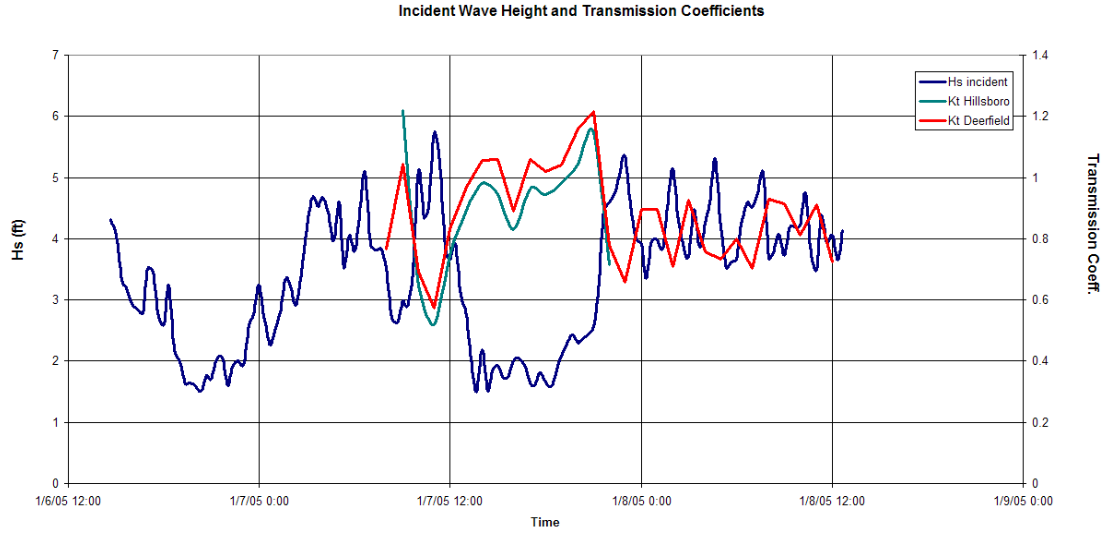

***Figure 12**. Wave Transmission Coefficients for Hillsboro and Deerfield Beaches. Transmission Coefficient is inversely proportional to incident wave height.*

Discussion:

We examined the slight differences in transmitted wave energy, and any resultant low-frequency flows for Deerfield and Hillsboro Beaches using the energy dissipation model constructed by DALLY et al. (1985). Essentially, local energy dissipation on a sloping beach is proportional to the difference between the actual wave energy flux and the stable wave energy flux across the surf zone.

This idea is expressed as:

$$\frac{\partial\left(EC_g\right)}{\partial x}=-\frac{-K_1}{D}\left[F-F_s\right] \tag{5}$$

where E is the wave energy, expressed as $\frac{\rho g H_s^{\ 2}}{8}$, K_1 is a coefficient typically between 0.15 and 0.17, D is the local water depth, C_g is the local wave celerity, F is the actual wave energy flux and F_s is the stable wave energy flux as a function of the water depth.

$$\frac{\partial\left(EC_g\right)}{\partial x}=-\frac{-K_1}{D}\left[\left(EC_g\right)-\left(EC_g\right)_{stable}\right] \tag{6}$$

and the energy flux is $EC_g=\frac{\rho g H_s^{\ 2}}{8}\sqrt{gD}$ in shallow water.

Letting $H_s=KD$ where K is the stable spilling breaker assumption (H is a function of water depth only) usually set at 0.40, equation X becomes,

$$\frac{\partial\left(EC_g\right)}{\partial x}=-\frac{-K_1}{D}\left[\frac{\rho g H_s^2}{8}\sqrt{gD}-\frac{\rho g}{8}K^2D^2\sqrt{gD}\right] \tag{7}$$

Assuming shallow water, equation 5 finally becomes,

$$\frac{\partial\left(H_s^2\sqrt{D}\right)}{\partial x}=-\frac{-K_1}{D}\left[H_s^2\sqrt{D}-K^2D^2\sqrt{D}\right] \tag{8}$$

The resulting energy flux and wave transformation for FLDEP Profiles R5 through R9 are shown in Figure 13. The cross-shore location of wave breaking and resultant transmission across the surf zone is closely linked to fine differences in the nearshore bathymetry. The local wave heights across the nearshore region are shown in Figure 14, and here it can be seen that wave heights are greater in the offshore depression in Profiles R7, R8 and R9. Further, whereas waves break further offshore for these same profiles, there is wave transmission further up the beach. This is due to the milder beach slope fronting Hillsboro Beach which supports a wide surf zone. The beach fronting Deerfield beach is very steep, is coarse grained and supports a narrow surf zone. Waves are not transmitted as far inshore as those at Hillsboro Beach (fig. 14).

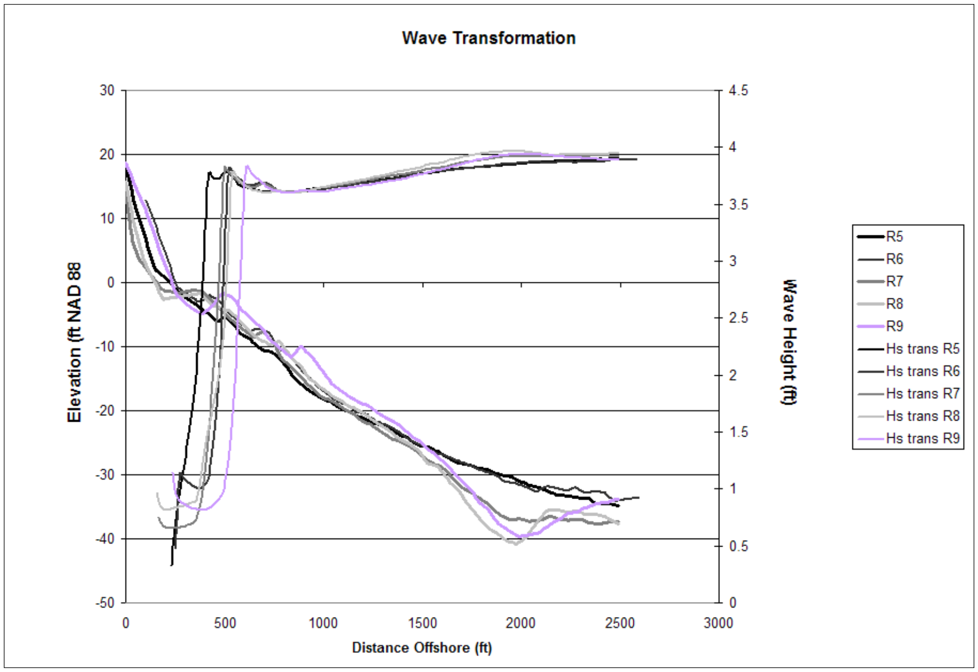

Figure 13: *Nearshore bathymetry and wave transmission (DALLY 1985) into the surf zone*

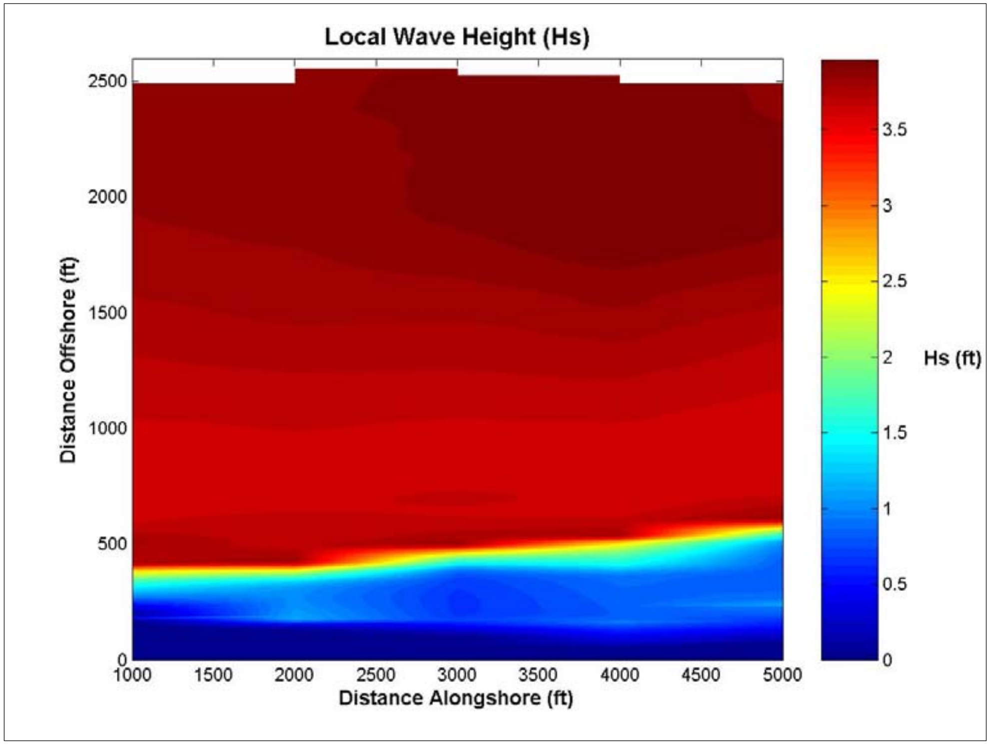

Figure 14:*Local wave heights in the nearshore and across the surf zone (DALLY 1985)*

We calculated the local set-down and set-up using Equations 2 and 3. Here we find the regions of maximum set-up in the vicinity of R7 and between regions R8 and R9 (fig. 15). The gradient in mean sea-surface elevation will drive low-frequency nearshore flows. Despite the fact that there were no measurable differences in the nearshore wave climate, variations in nearshore bathymetry lead to differences in mean sea-surface elevation in the alongshore. We calculated the gradient in sea-surface elevation to illustrate the location and direction of low frequency flows resulting from differential set-up in the alongshore (fig. 16).

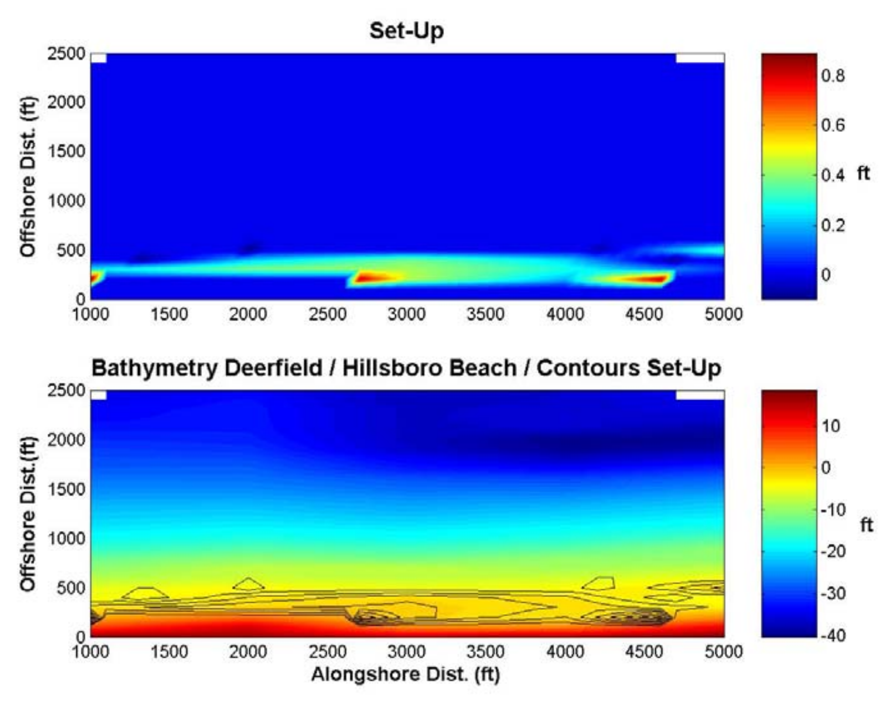

***Figure 15a&b**: Set-up across the surf zone. Regions of greatest set-up are in the vicinity of R7 through R9, fronting Hillsboro Beach. Dense contours show the regions of greatest set-up.*

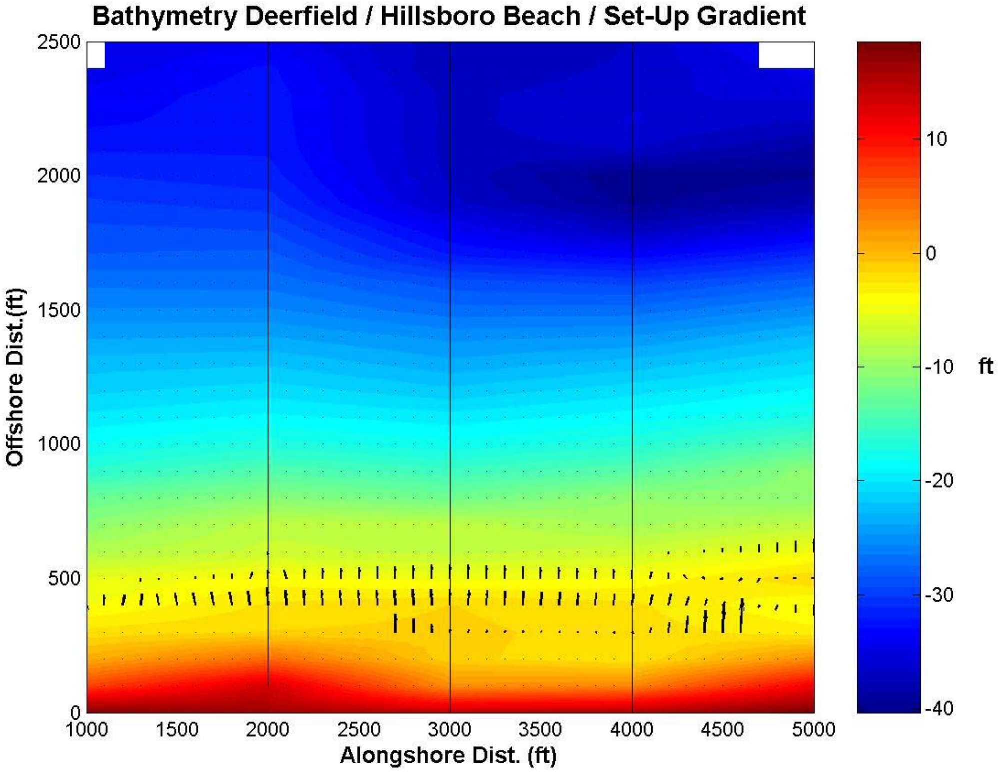

***Figure 16**: Calculation of the gradient in set-up across the surf zone shows that low-frequency currents will be directed offshore in the vicinity of R7 and the region between R8 and R9. Complexities in nearshore bathymetry have given rise to alongshore variability in the mean surface elevation and resulting flows.*

Calculation of the gradient in set-up across the surf zone shows that low-frequency currents will be directed offshore in the vicinity of R7 and the region between R8 and R9. Complexities in nearshore bathymetry have given rise to alongshore variability in the mean surface elevation and resulting flows.

Conclusions:

Wave transmission into the nearshore, across the coral reef and across the sand bar, was inversely proportional to incident wave height, as the effectiveness of the reef and bar in reducing wave energy increased as offshore wave heights increased.

No alongshore variation in local nearshore wave height was measured. Diver surveys indicated that a great deal of sand had been transported offshore and not only created a substantial sand bar, but also buried the most nearshore extent of the hard-bottom coral reef. Whereas the reef had supported topographic relief in August, 2004, it no longer did at the time of this study, and therefore it followed that wave transmission into the nearshore would be similar for the regions fronting Deerfield and Hillsboro Beaches.

Calculations of local wave height and mean surface elevation did, however, indicate alongshore variability in the cross-shore extent of wave transmission, and also indicated alongshore variability in mean sea-surface elevation. The gradient in elevation suggests that offshore flows will be driven in the region along FLDEP profile R7 as well as the region between FLDEP profiles R8 and R9, which also happens to be the region fronting Hillsboro Beach.

Measured data and calculated parameters indicate that alongshore variability in local wave climate, sea-surface elevation and bottom topography can give rise to cross-shore flows which can act to transport sediments offshore from the beach. Although this region is characterized by an essentially unidirectional wave climate due to the shadowing effect of the Bahamian Islands, these calculations have demonstrated that alongshore variability in the local wave climate and bathymetry can give rise to important cross-shore processes.

References:

Dally, W.R, Dean, R.G. and Dalrymple, R.A.,1985: Wave height variation across beaches of arbitary profile, J. Geophysical Research, 90 (C6): 11917-11927

Finkl, C.W. et al. (2004) Laser airborne depth sounder (LADS): a new bathymetric survey technique in the service of coastal engineering, environmental studies and coastal zone management. *Journal of Coastal Research.*

Friebel, H.C. and Harris, L.E., (2004) A new wave transmission coefficient model for submerged breakwaters. 29th International Conference on Coastal Engineering. Lisbon, Portugal. September 19-24, 2004.

Komar, P.D.,1998. Beach Processes and Sedimentation. 2nd ed. Prentice Hall. Upper Saddle River, NJ.

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