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Idealized Marsh Simulations: Sensitivity of Hurricane Surge Elevation and Wave Height to Marsh Continuity

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PURPOSE: The purpose of this CHETN is to assess changes in peak surge elevation and wave height with changes in the continuity (degree of segmentation) of an idealized marsh-like coastal feature. Application of varying elevation and bottom friction in model simulations is used to represent a non-continuous marsh delineated by channels. The analysis isolates the sensitivity of the modeled storm surge to changes in the continuity of an idealized marsh, and qualitatively indicates the degree to which a segmented marsh may influence the storm surge protection compared to a fully continuous marsh. This is the fourth in a series of technical notes on the influence of marshes on storm surge and waves.

METHODOLOGY: A set of idealized surge simulations using ADCIRC (Westerink et al. 1992) and STWAVE (Smith et al. 2001) were made to examine changes in storm surge elevation and wave height with changes in various marsh characteristics, such as elevation, vegetation cover, shape, and continuity (degree of segmentation). This note presents results for changes in marsh continuity, while accompanying technical notes evaluate other marsh characteristics. The modeling process involved an ADCIRC simulation followed by an STWAVE simulation, and finally a re-simulation of ADCIRC that included wave-radiation stress obtained from the STWAVE results. The modeling system applied is described by Bunya et al. (2009) and Wamsley et al. (2009). Results presented in this note depict wave conditions and total surge levels driven by wind, atmospheric pressure, and wave radiation stress.

The idealized grid domain applied in this study includes straight and parallel bathymetric contours on a 1:1000 continental shelf with a single perturbation (landscape feature representative of a marsh) positioned along the northern Gulf of Mexico, in the vicinity of southeastern Louisiana (Figure 1). The landscape feature is represented by a 400 km^2 portion of the coastline (the approximate size of Biloxi Marsh in southeastern Louisiana). A non-continuous marsh is achieved by delineating a marsh feature into 16 identical square segments. Each square segment is positioned at an elevation of 0.5 m above mean sea level, representative of a high-water marsh. Within each marsh segment, bottom friction is represented by a Manning's *n* value of 0.035, representative of a saline marsh (Bunya et al. 2009). Channels delineating the marsh segments have a depth of 2.0 m, and bottom friction of 0.020 Manning's *n*, representative of a sandy surface with no vegetation (Chow 1959). Figures 2 and 3 provide a plan and cross section view. Marsh continuity (*c*) is numerically defined as the percentage of area having increased bottom friction and elevation within the total area of the marsh limits (in this case, 400 km^2). The marsh is backed by a non-overtopping wall representative of a levee.

Six hurricanes of varying size and intensity were simulated with each of the marsh configurations to examine the surge response to varying meteorological conditions. Table 1 lists the characteristics of the idealized storms applied in this study. Each storm track was selected such that the maximum winds impact the center of the marsh with a storm forward speed of 5.6 m/s (20.2 km/h). Landfall pressures range from 900 to 975 mb, while radii of pressure range from 20.4 to 74.1 km. The simulation of varying storm intensity and size provides further insight into how marsh segmentation influences the surge and wave height for storms of varying intensities.

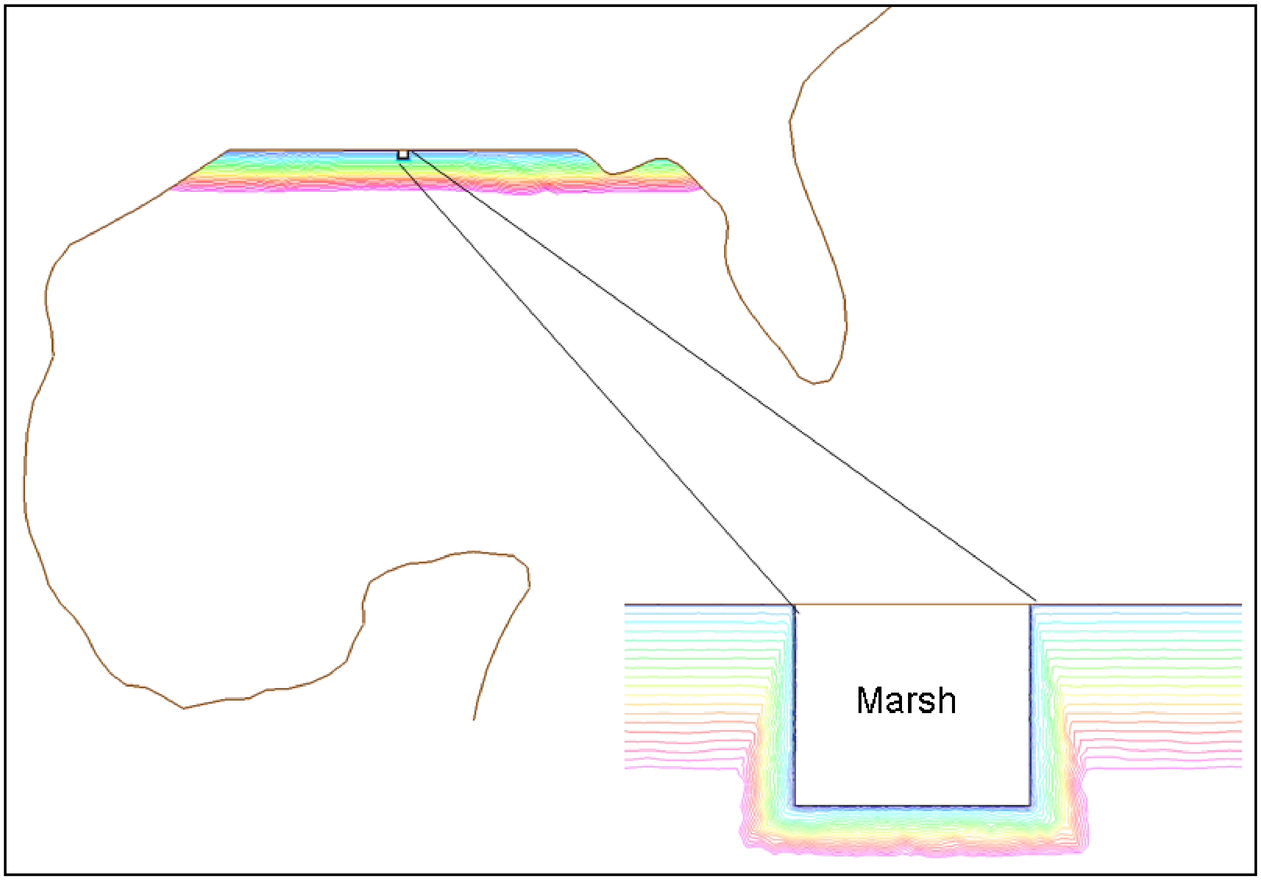

Figure 1. Idealized marsh within ADCIRC domain

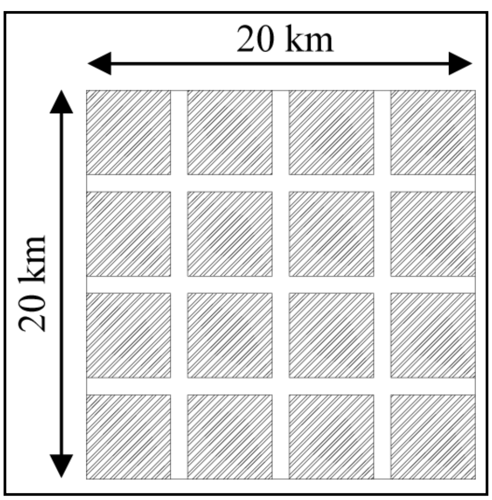

Figure 2. Sample sketch of a non-continuous marsh (c = 75%) in plan view. Shading depicts marsh segments, with Manning's *n* of 0.035 and elevation 0.5 m above sea level.

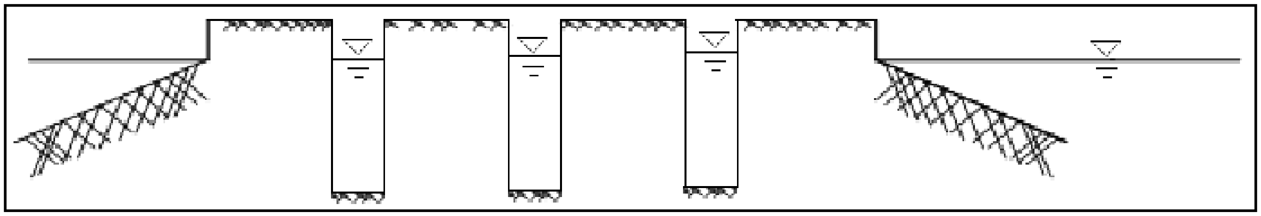

Figure 3. Sample sketch of non-continuous marsh cross-section. Marsh segments are characterized by a Manning's *n* of 0.035 and an elevation of 0.5 m above sea level. Channels are characterized by a Manning's *n* of 0.020, at a depth of 2.0 m. Channel width is dependent upon marsh continuity (900 m for 75% continuous, and 2000 m for 50% continuous)

Table 1. Storm Suite.

Landfall Pressure Radius (km)	Pressure at Landfall (mb)	Surge Potential, ζ_{base} (average peak surge for base configuration, m)	Wave Potential, H_{base} (average peak wave height for base configuration, m)
20.4	975	1.6	0.2
38.9	975	2.0	0.3
38.9	941	3.4	0.9
20.4	900	4.2	1.4
38.9	900	5.1	2.0
74.1	900	6.0	2.4

RESULTS: Figures 4 and 5 illustrate the sensitivity of surge and wave response to marsh continuity. These figures indicate surge and wave height differences between a non-continuous marsh and a fully continuous marsh (c = 100%) having a constant elevation of 0.5 m and Manning's n of 0.035. In this study, two marsh layouts are investigated, having continuities of 75 percent (narrow gaps) and 50 percent (wide gaps). Percent changes in surge levels outside the limits of the marsh feature are limited to less than +/- 10 percent, a result of the shifting of surge waters due to increased flow conveyance through the marsh. Surge results indicate areas of increased peak surge (less than 10 percent) along the western edge of the marsh. This is a result of excess water traversing the marsh from east to west, when westward surge propagation dominates peak surge levels. Storms of high surge potential are characterized by less defined changes outside the marsh boundaries. Peak wave heights were unaffected in areas outside the marsh area.

Significant changes in peak surge are observed within the limits of the marsh, as revealed in Figure 4. For the storm of lowest surge potential (ζ_{base} = 1.6 m), surge is increased by 50 percent along the coast due to a decreased marsh continuity of 75 percent. For the same storm, reducing continuity to 50 percent results in a shoreward increase in surge of 70 percent. This is due to the conveyance of water through the 2-meter deep channels. As marsh continuity is decreased from 75 percent to 50 percent, the channels delineating marsh segments increase in width (from 900 m to 2000 m), resulting in greater conveyance of water throughout the marsh. This causes more noticeable changes in peak surge as marsh continuity decreases. Decreases in surge levels along the outer boundaries of the marsh are also indicated in Figure 4. For the storm of lowest surge potential, surge levels are decreased by less than 10 percent within the seaward row of marsh segments. This is also a result of increased conveyance within the marsh, as water is distributed from the outer limits of the marsh to the inner marsh segments. This effect is most evident for the four storms of lowest surge potential, as illustrated in the first four rows of Figure 4. As surge potential increases, effects of marsh continuity become less significant.

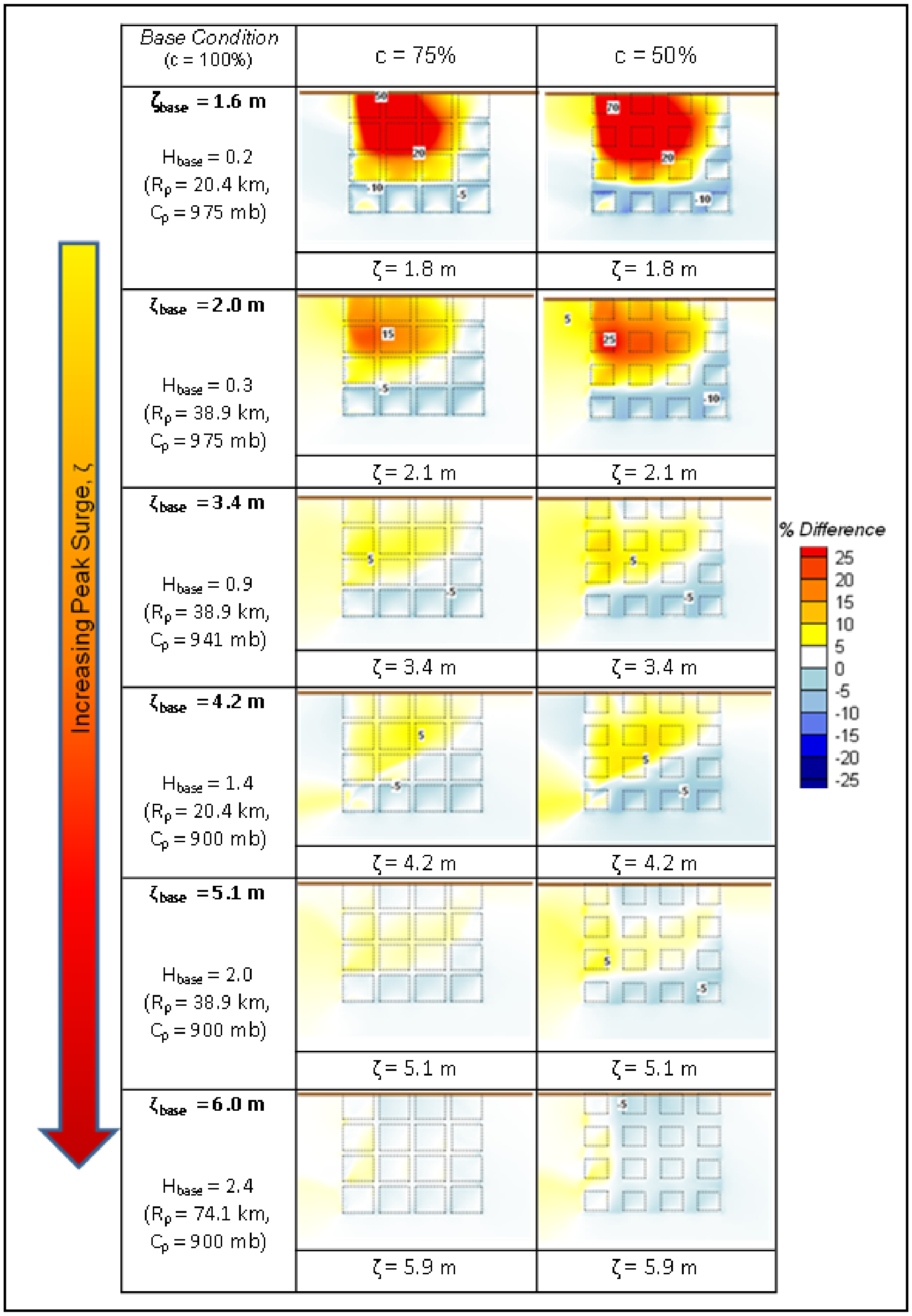

Figure 4. Percent change of peak surge response due to decreased marsh continuity, compared to a fully continuous marsh. Hot colors indicate surge increases, while cool colors indicate surge decreases. Top of square represents coastline. Marsh segments are denoted by dotted lines. Average peak surge within each base case square is represented by ζ_{base}. Average peak surge within each experimental marsh square is denoted by ζ.

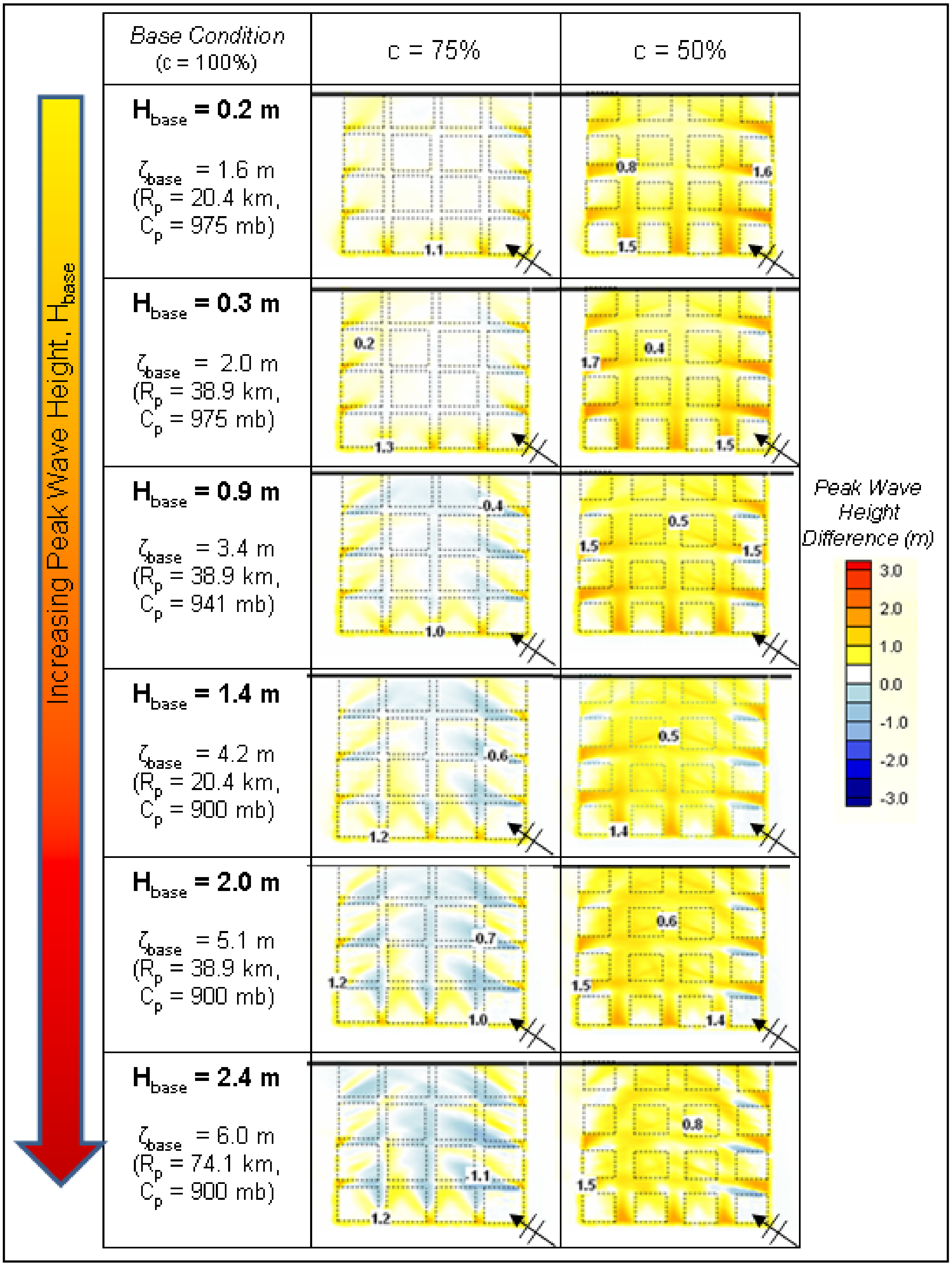

Figure 5. Change in maximum wave height (in meters) due to decreased marsh continuity, compared to a fully continuous marsh. Hot colors indicate wave height increases, while cool colors indicate wave height decreases. Average peak wave height within the marsh for the base case is represented by H_{base}. Top of square represents coastline. Marsh segments are denoted by dotted lines. Average peak surge for within each base case square is represented by ζ_{base}.

Slight decreases in peak surge (less than 5 percent) are observed along the coast for the two storms of highest surge potential, as shown in the bottom two lines of Figure 4, a result of increased conveyance allowing surge waters to flow out of the marsh during the peak of the storm. As with the low surge potential events, increased areas of surge are still observed in areas central to the marsh due to channeling from the seaward edge of the feature.

A comparison of surge results both including and excluding wave radiation stress indicates a set-up of the water levels at the seaward edge of the marsh due to wave breaking. A set-down of water levels is observed just seaward of the marsh, prior to breaking. For the storm of highest potential, base case water levels are displaced by 0.4 m due to wave set-up and 0.1 m due to wave set-down. A narrow band of wave setup is also evident adjacent to the coastal boundary of the grid, stemming from wave breakage along the coast.

As illustrated in Figure 5, wave heights are also affected by changes in marsh continuity. Peak wave height response is characterized by sharp increases within the channels at the seaward edges of the marsh. Within these channels, wave heights are increased by as much as 1.7 m due to decreased marsh continuity. The increased total water depth within the channels allows the waves to propagate into the marsh with minimal damping. For the mash configuration of 75 percent continuity, sharp and localized decreases in peak wave height are noted within the marsh, a result of shadowing and refraction as waves propagate across the seaward marsh segments. Figure 6 shows the relationship between marsh continuity and average peak wave height within the idealized feature. It should be noted that the wave model applied has not been validated for storm waves in wetlands, due to a lack of available data. Additional data is needed on waves in extreme events. Deployments during hurricanes Gustav and Ike during the 2008 hurricane season have obtained valuable data that, once analyzed, should improve our understanding of wave attenuation over wetlands.

Figures 7 and 8 depict the relationship between marsh continuity and surge response in graphical form. Figure 7 reveals the relationship between peak surge volume (volume above sea level in the marsh area) and marsh continuity. As marsh continuity is decreased, storms of low surge potential result in an increase of surge storage within the marsh. This increase in storage becomes less sharp as storm potential increases, shifting to a decrease in storage with decreasing continuity for storms of high surge potential. These relationships suggest a threshold peak surge potential that marks a balance between surge storage within the marsh and surge conveyance through the marsh. Figure 8 illustrates the effects of marsh continuity on peak surge levels at the coast. For storms of low surge potential, decreasing marsh continuity results in an increase in coastal peak surge levels. Conversely, storms of high surge potential result in a decrease in coastal peak surge. This shows that a non-continuous marsh may offer comparable surge protection at the coast given a surge event of high magnitude.

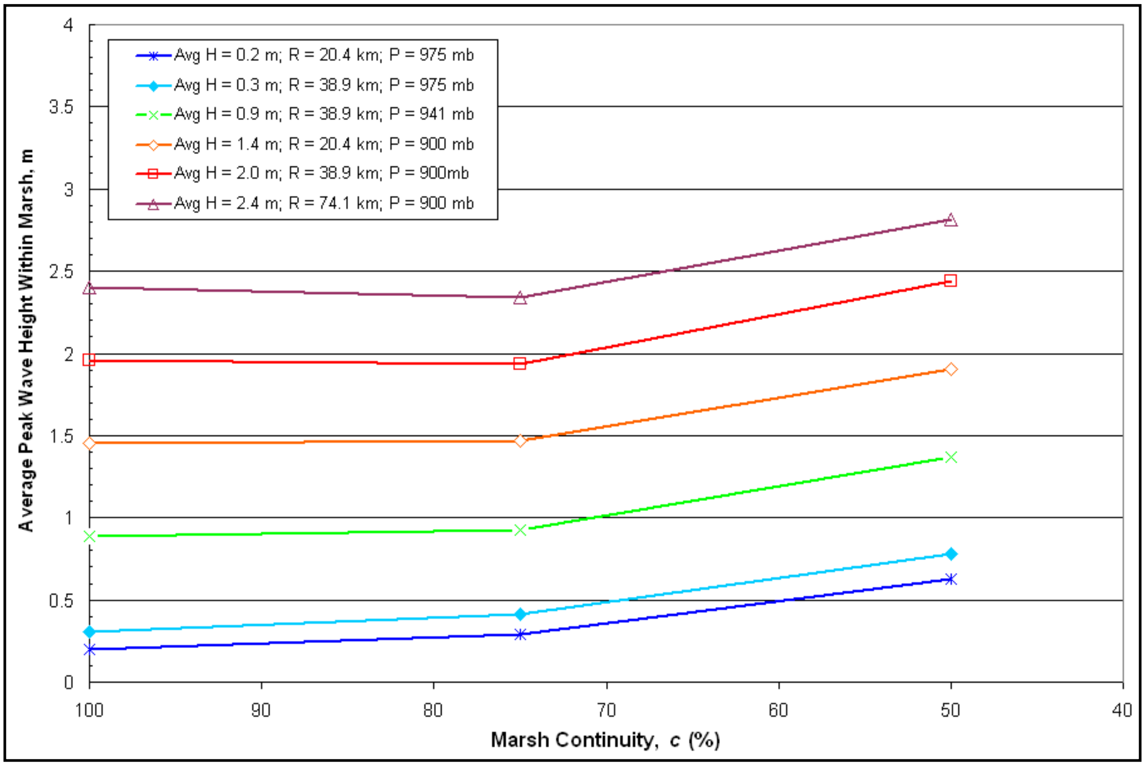

Figure 6. Change in average peak wave height within the marsh due to decreasing continuity.

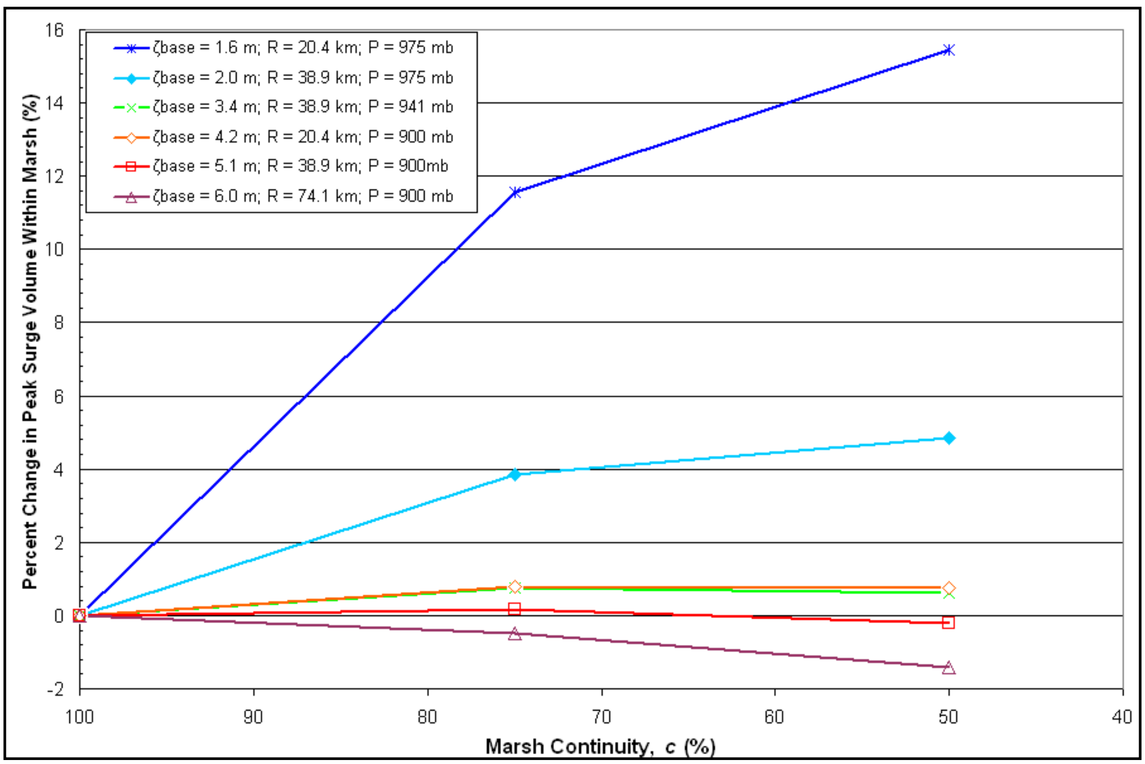

Figure 7. Change in peak surge volume (above sea level) within the marsh due to decreasing continuity.

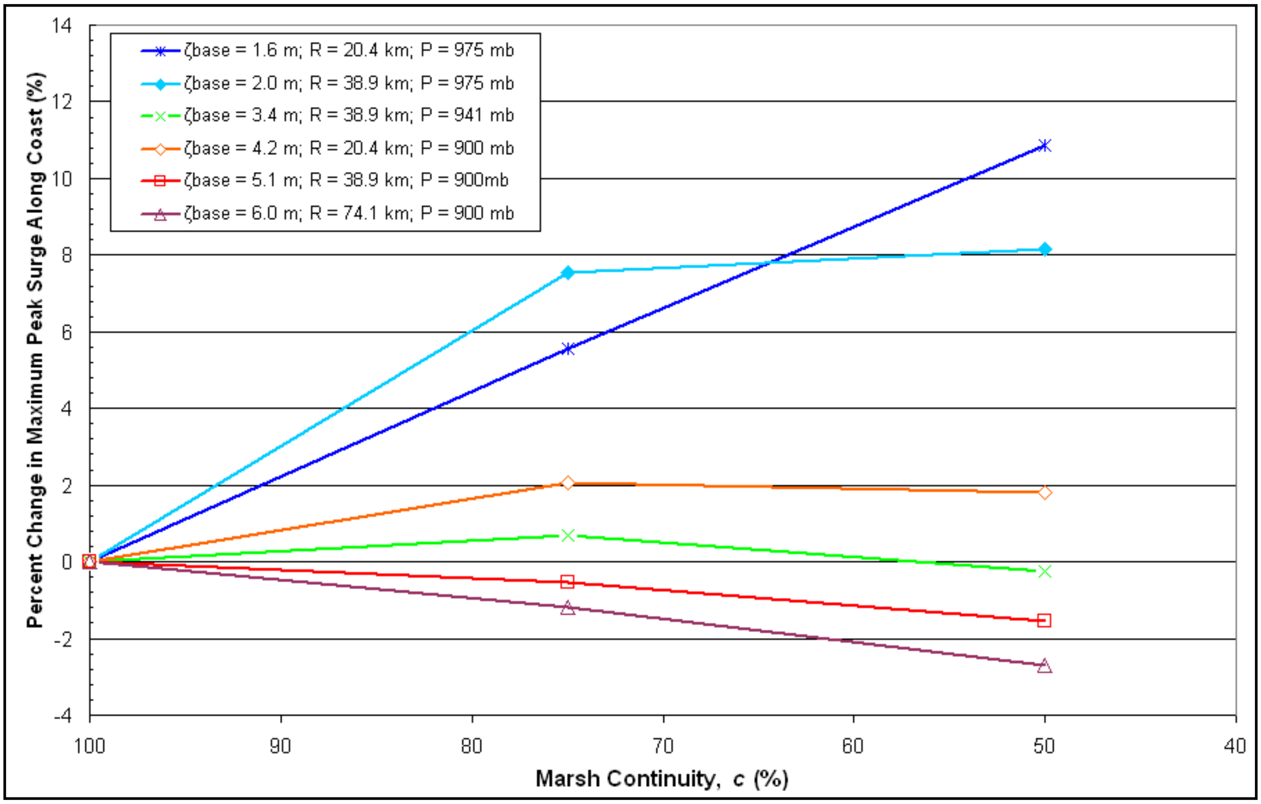

Figure 8. Change in peak surge along the coast due to decreasing marsh continuity.

SUMMARY: Due to the increased conveyance within a non-continuous marsh, surge is increased by as much as 70 percent along the coast for a storm of low surge potential (ζ_{base} = 1.6 m). Accompanied with this increase is a decrease in peak surge in seaward portions of the marsh, a result of the distribution of surge waters within the marsh. In this study, a low continuity marsh results in the greatest conveyance of water, and therefore the most significant changes in peak surge levels. Peak wave heights are higher within marsh channels, and locally decreased due to refraction around marsh segments. As surge and wave potential increases, the relative impact of marsh continuity diminishes. For storms of high surge potential (ζ_{base} = 6.0 m and 5.1 m), changes in peak surge within the marsh limits are limited to +/- 5 percent. These two storms of highest surge potential result in a slight decrease in coastal surge due to decreased marsh continuity. This indicates that water is being channeled out of the marsh limits during the time of peak surge. Findings in this study suggest that a non-continuous marsh may offer comparable levels of storm surge protection, given a storm of high surge and wave potential.

It should be noted that the shelf slope and shoreline irregularity exerts great influence on the surge. The results presented here are from and idealized landscape where shoreline irregularities do not exist and only one shelf slope is considered. Ultimately, the potential of wetlands to attenuate surges is dependant not only on wetland characteristics (evaluated here), but also on the surrounding coastal landscape and the strength and duration of the storm forcing.

ADDITIONAL INFORMATION: Questions about this CHETN can be addressed to Mary A. Cialone (601-634-2139, email: *mary.a.cialone@usace.army.mil*). This Technical Note should be referenced as follows:

> Loder, N. M., M. A. Cialone, J. L. Irish, and T. V. Wamsley. 2009. *Idealized Marsh Simulations: Sensitivity of Storm Surge Elevation to Marsh Continuity*, Coastal and Hydraulics Engineering Technical Note ERDC/CHL CHETN-I-79. Vicksburg, MS: U.S. Army Engineer Research and Development Center. *http://chl.wes.army.mil/library/publications/chetn/*

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