Influence of Shoals on Spatial Variability of Storm Surge

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perspecta

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ABSTRACT

Idealized bathymetries were subjected to idealized cyclones in order to measure the storm surge response to a range of shoals, under various storm conditions, for the purpose of informing the development of bathymetry thinning algorithms. Nine bathymetries were considered, including eight shoals and a featureless reference domain. Six storm realizations (two different sizes/intensities and three different landfall directions) were used as meteorological forcing.

The shoals influenced the surge response in the following three ways: reduction of pre-peak setdown, change to the timing of surge arrival, and delay of surge recession. However, peak surge magnitude and surge at the coast were not meaningfully affected by the shoals considered.

The effect of three shoal parameters on surge response was analyzed (i.e., depth below mean sea level (MSL), cross-shore width, and distance from shore). Of these parameters, depth below mean sea level was the best predictor of whether a shoal will influence surge generation.

It appears that each shoal has a maximum area of influence. Once the areal extent is reached, the magnitude of its influence within that area increases with increasing severity of the storm conditions. Information on shoal depth and maximum area of influence can be used as criteria for bathymetry thinning.

1. Shoal Realizations

Figure 1

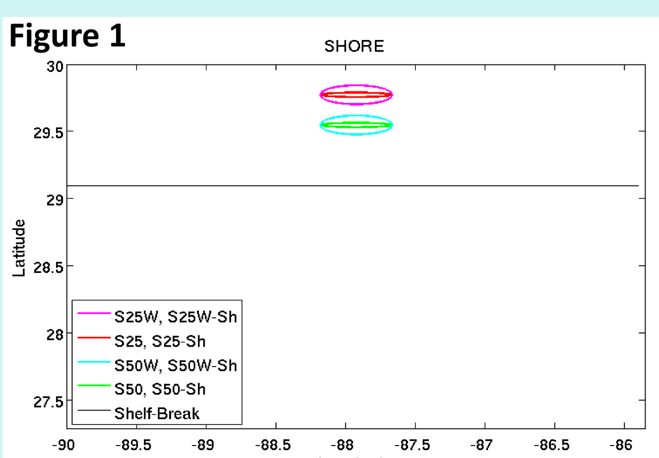


Figure 2

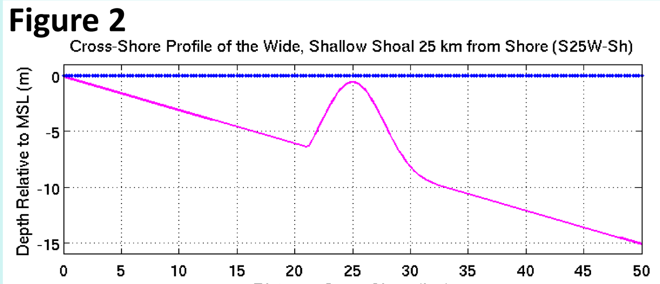


Table 1

Shoal/ Domain Name	Distance from Shore (km)	Cross-Shore Width at Seafloor (km)	Depth below MSL (m)
S25	25	3.75	3.0
S25-Sh	25	3.75	0.5
S25W	25	11.25	3.0
S25W-Sh	25	11.25	0.5
S50	50	3.75	3.0
S50-Sh	50	3.75	0.5
S50W	50	11.25	3.0
S50W-Sh	50	11.25	0.5

- The influence of three shoal parameters (**Table 1**) is investigated.
- There are two possible values for each parameter, resulting in eight unique shoals (**Table 1**).
- Shoal locations are shown in **Figure 1**.
- Shoal relief in the cross-shore direction (**Figure 2**) is modeled using a Gaussian curve over an ellipse.
- The **reference domain** has no shoal.

2. Method of Quantifying Shoal Parameter Influence

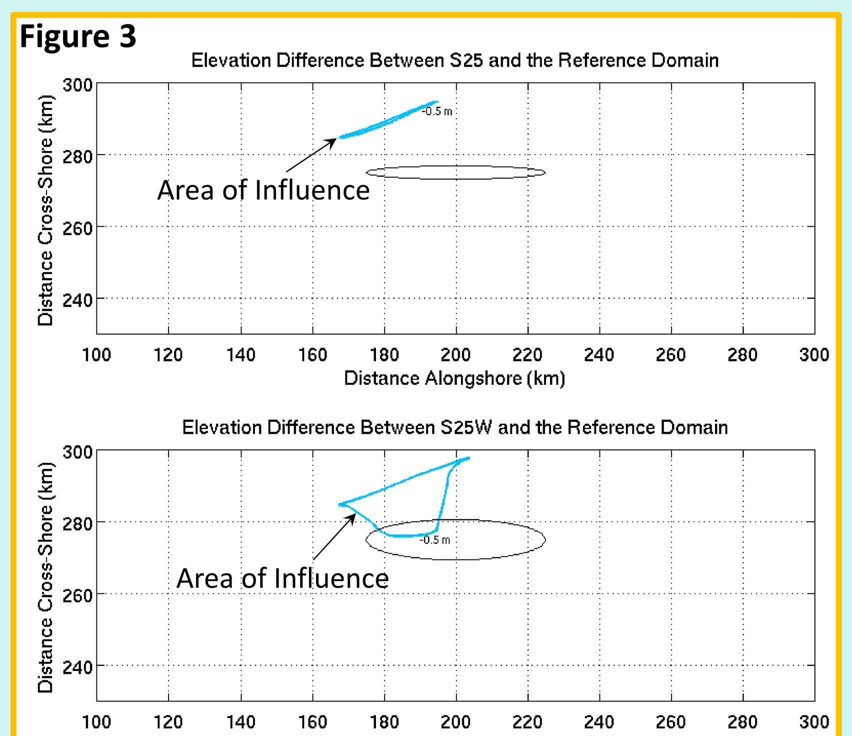
Table 2

Pairings for Calculating Shoal Parameter Influence					
Depth Below MSL		**Distance from Shore**		**Cross-Shore Width**	
S25-Sh	S25	S25	S50	S25W	S25
S25W-Sh	S25W	S25W	S50W	S25W-Sh	S25-Sh
S50-Sh	S50	S25-Sh	S50-Sh	S50W	S50
S50W-Sh	S50W	S25W-Sh	S50W-Sh	S50W-Sh	S50-Sh

Table 3

Convention for Determining Shoal Parameter Influence		
Parameter Assessed	**Value of Result**	
	+	**–**
Depth below MSL	Shallow Shoals More Influential	Deep Shoals More Influential
Distance from Shore	Close Shoals More Influential	Distant Shoals More Influential
Cross-Shore Width	Wide Shoals More Influential	Narrow Shoals More Influential

Figure 3



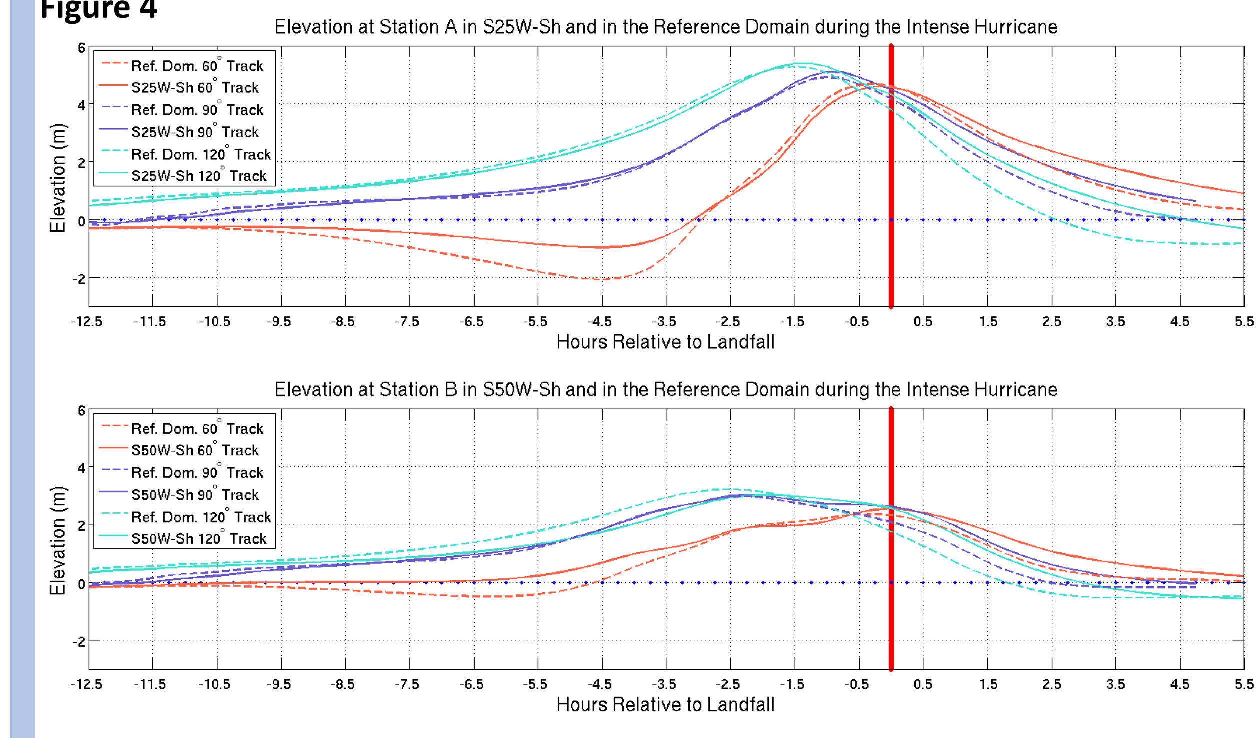
- A shoal's **area of influence** is defined as the area within a given elevation difference contour (**Figure 3**).
- The shoals' areas of influence are used to determine the effect of their geometric characteristics (**parameters**) on storm surge.
- Groupings are constructed to isolate the influence of each of the three parameters (**Table 2**).
- **Table 3** provides for the interpretation of the results of the shoal parameter influence calculations.

The areas of influence for the two shoals pictured in **Figure 3**, S25 and S25W, are shown under identical conditions; therefore, any difference in storm surge can be attributed to the shoals' difference in width.

3. Results: Time Series of Elevation and Difference in Elevation

Elevation in Domains with Shoals (Solid Lines) and in the Reference Domain (Dashed Lines)

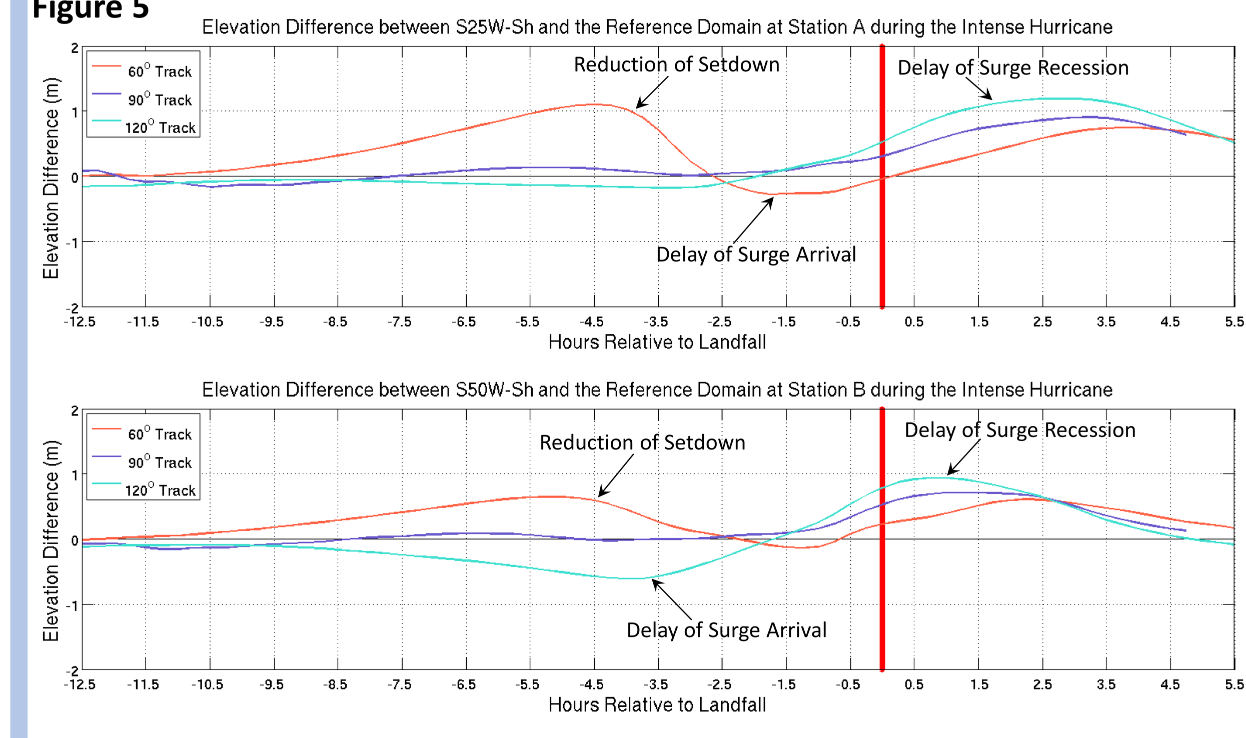
Figure 4



- **Figure 4** shows the elevation time series near the largest shoal at each location (solid lines).
- Dotted lines show elevation at the same location in the reference domain.
- **Top** plot is near the shoal 25 km from shore; **bottom** plot is near the shoal 50 km from shore.
- Colors correspond to storm track.
- Red vertical lines indicate the time of landfall.

Difference between Elevation in Domains with Shoals and in the Reference Domain

Figure 5



- **Figure 5** shows the difference between elevation near each shoal and in the reference domain.
- **Top** plot is near the shoal 25 km from shore; **bottom** plot is near the shoal 50 km from shore.
- Colors correspond to storm track.
- Red vertical lines indicate the time of landfall.
- Prominent influences of the shoals on surge are labeled.

5. Results: Maximum Area of Shoal Influence

During Surge Recession (All 6 Storm Realizations)

Figure 9

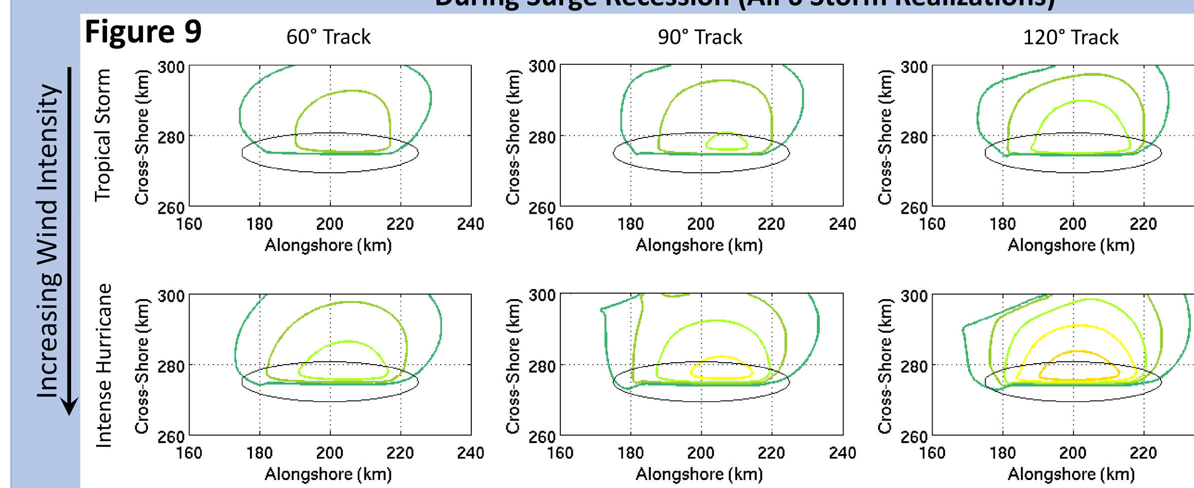


Figure 9 depicts the influence of S25W-Sh on surge recession during all six storm realizations.

Table 6

Shoal S25W-Sh Area of Influence Area (km²) in Contours: Tropical Storm				Shoal S25W-Sh Area of Influence Area (km²) in Contours: Intense Hurricane			
Contour	**60° Track**	**90° Track**	**120° Track**	**Contour**	**60° Track**	**90° Track**	**120° Track**
0.25 m	1,207.40	1,188.26	1,230.33	**0.25 m**	1,368.44	1,444.68	1,475.45
0.50 m	401.80	561.54	746.77	**0.50 m**	736.73	997.43	1,116.42
0.75 m	0.00	44.53	312.07	**0.75 m**	207.62	447.50	763.52
1.00 m	0.00	0.00	0.00	**1.00 m**	0.00	84.96	416.61
1.25 m	0.00	0.00	0.00	**1.25 m**	0.00	0.00	139.97

The areas in the contours shown in **Figure 9** are quantified in **Table 6**.

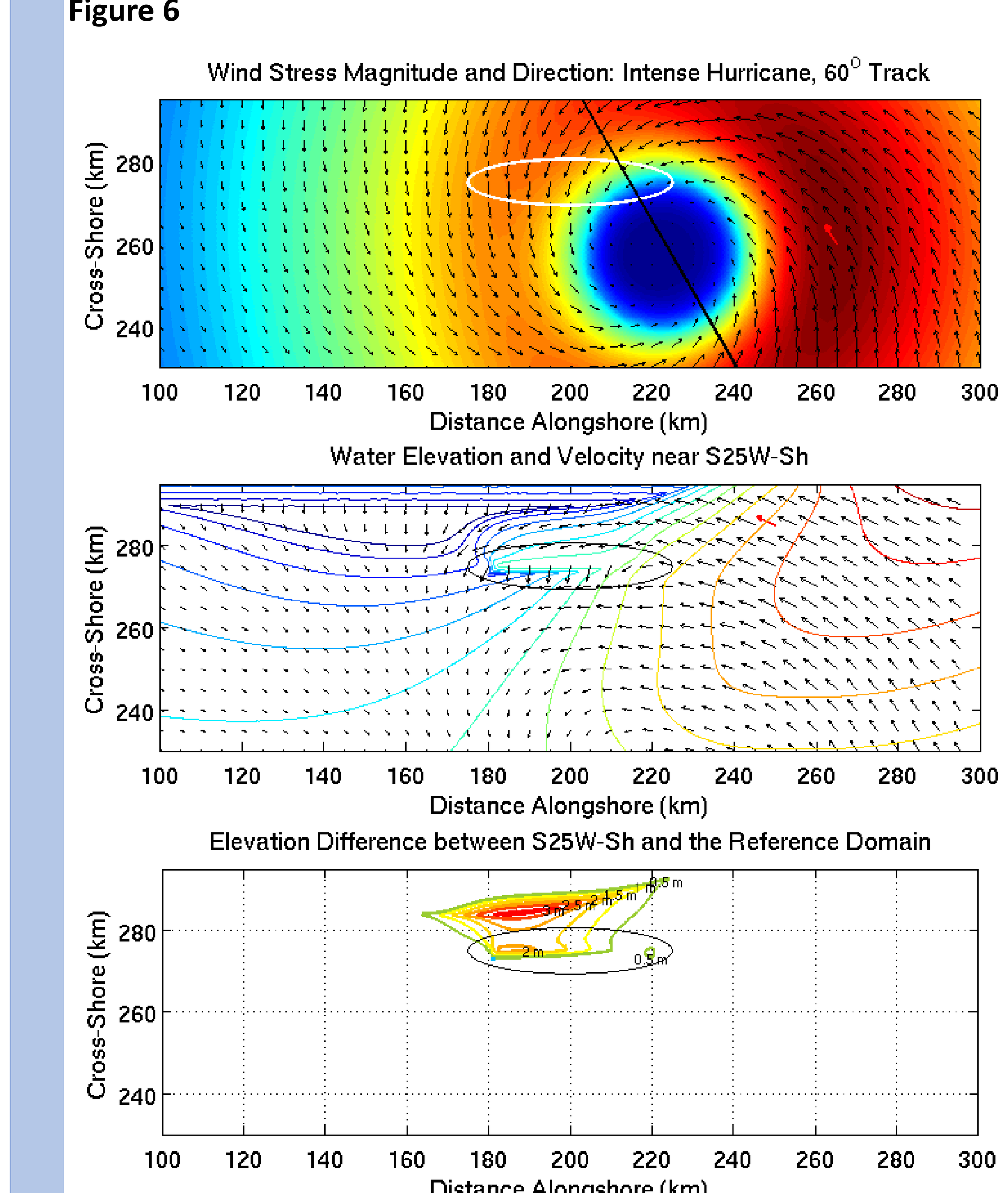
- Shoals appear to have a maximum area of influence.
- Once the maximum area is reached, its bounds remain stable regardless of any increase in storm conditions.
- Elevation difference from the reference domain over that area increases with increasing severity of the storm conditions, such as increased wind intensity or duration.

4. Results: Times of Shoal Influence on Storm Surge

Prior to Peak Surge

(Intense Hurricane Approaching from the Southeast)

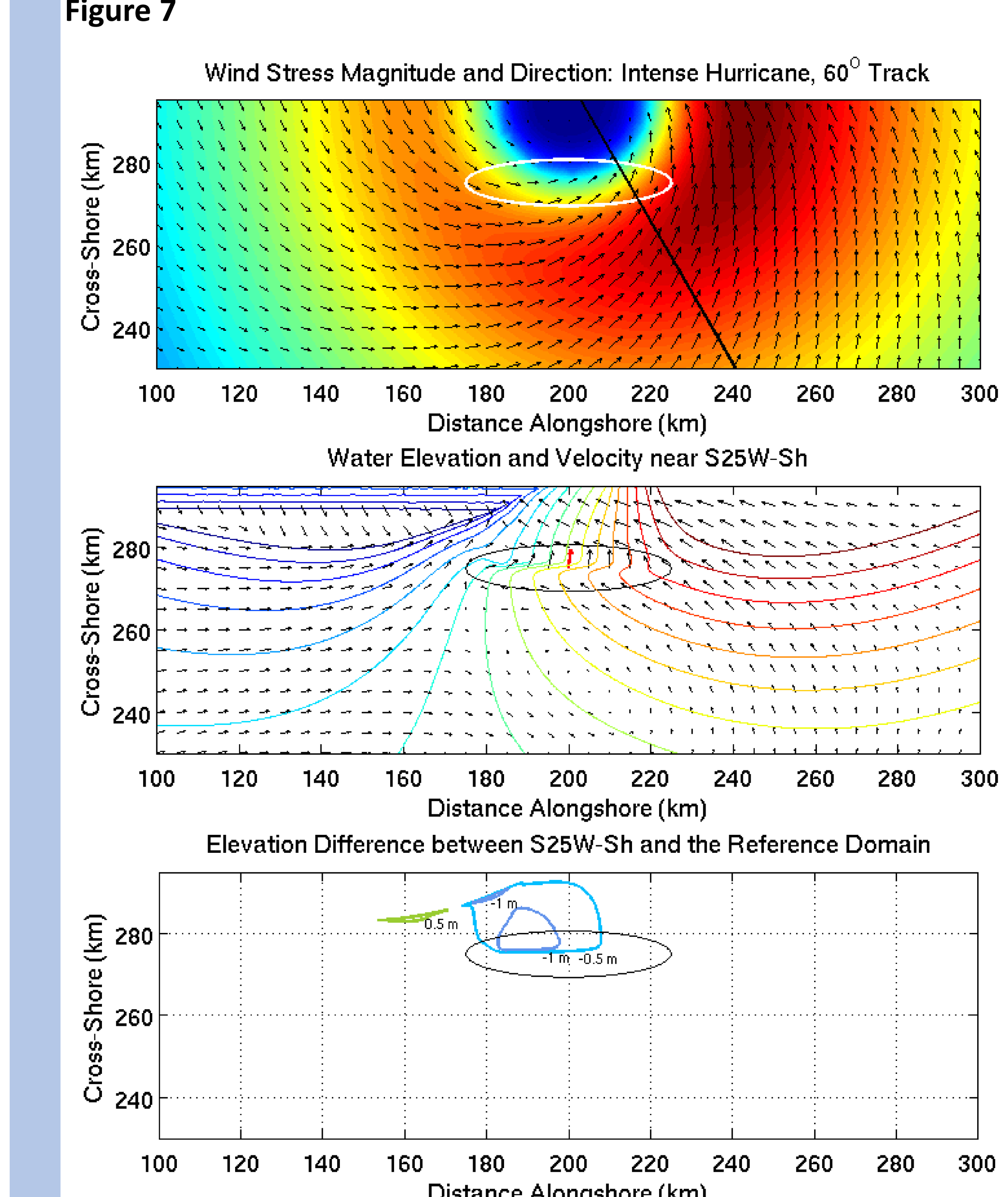
Figure 6



During Arrival of Peak Surge

(All 6 Storm Realizations)

Figure 7



During Surge Recession

(All 6 Storm Realizations)

Figure 8

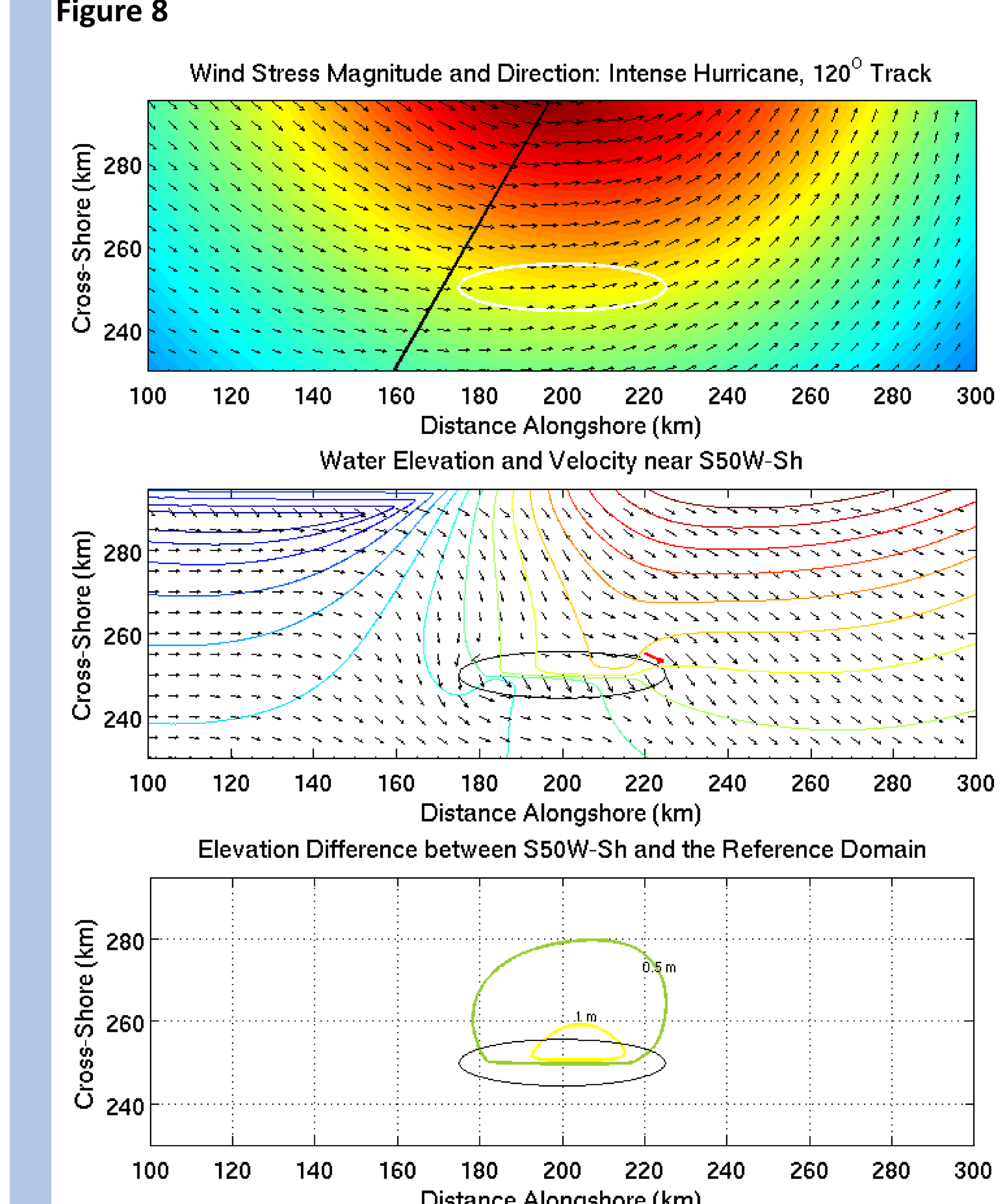


Table 4

Reduction of Setdown		
Intense Hurricane, 60° Track		
Parameter Assessed	**km² in 0.5 m Contour**	**km² in 1.0 m Contour**
Depth below MSL	4,130.81	988.43
Distance from Shore	-1,753.65	784.15
Cross-Shore Width	158.97	10.17

Three examples of the observed types of shoal influence on surge are shown in **Figures 6-8**.

- **Figure 6** shows the reduction of setdown by S25W-Sh.
- **Figure 7** shows the impact on peak surge arrival by S25W-Sh.
- **Figure 8** shows the delay of surge recession caused by S50W-Sh.

- **Top** plots show wind stress magnitude and direction with respect to the shoal location.
- **Middle** plots show water elevation and velocity near the shoal.
- **Bottom** plots show the difference in elevation caused by a shoal's presence as compared with elevation in its absence (i.e., in the reference domain) under identical conditions.

The results contained in **Tables 4** and **5** are obtained by summing the results of each parameter's pair-wise comparisons in **Table 2**. The convention described in **Table 3** should be used to interpret their meaning.

Table 5

Delay of Surge Recession			
Intense Hurricane (km² in 0.5 m Contour)			
Parameter Assessed	**60° Track**	**90° Track**	**120° Track**
Depth below MSL	1,419.42	2,536.03	3,153.04
Distance from Shore	158.95	65.41	-463.08
Cross-Shore Width	1,112.43	1,220.79	1,496.91
Tropical Storm (km² in 0.25 m Contour)			
Parameter Assessed	**60° Track**	**90° Track**	**120° Track**
Depth below MSL	2,959.83	3,648.15	4,164.52
Distance from Shore	1,157.15	592.75	-3.69
Cross-Shore Width	834.66	762.58	1,232.06