Comparison of Observed and SLOSH model computed storm surge for hurricane Francis (2004) in Southwest Florida - November 2005

Under an OHS/FEMA requirement, post hurricane Francis high water mark surveys were conducted in Southwest Florida and a report was prepared (URS Group, Inc., Nov. 4 2004). The survey teams were instructed to obtain as many "coastal high water marks" as possible. These marks include "still water marks" inside of structures which mainly reflect the storm tide elevation without the effect of waves, and "outside debris lines" which generally reflect the combined effect of storm tide and wave set up and run up. Debris line elevations are usually higher than high water marks because of the added wave effects. Out of the 31 surveyed coastal high water marks along the Florida East Coast ten (10) were deemed to be mostly pure storm surge. Overall the coverage of the high water marks is fair for determination of the storm surge. Several of the marks are located near one another to show the difference in flooding between open ocean shoreline sites, which often have wave effects, and those on the bay, Intracoastal, or harbor side of islands. In addition to the 10 surge marks, 2 tide gage maxima were also available and were added to give a total of 12 storm surge values. The purpose of this report is to compare these observed high water marks to the SLOSH storm surge model calculated values at the same location. Table 1 shows the observed and calculated values. The report also compares the observed storm surge hydrograph at both tide gauge sites to the SLOSH storm surge model calculated hydrograph at the same locations.

The reference datum used for the high water marks in this study is the National Geodetic Vertical Datum of 1929 or NGVD. This is where sea-level was in 1929 and this was the "zero" elevation. Since 1929 the tide gages along the Southwest Florida coast have indicated a rise in sea-level on the average of about 0.7 feet. To take the rise in sea-level into account for the high water marks, the Francis SLOSH model simulation will include 0.7 feet in the initial water elevation. Also, during landfall the peak storm surge occurred approximately near the time of mean tide so that no correction was necessary for the tide elevation for high water mark comparisons.

During landfall the peak storm surge at Trident Pier occurred near the time of high tide, so that an additional 0.89 feet of water elevation will be necessary to correct for the tide at that site. Thus the total water elevation used to initiate the SLOSH model simulation at Trident Pier was 1.84 feet.

For the Bear Point Mitigation site the final SLOSH model run was initialized at 0.0 ft. water level. It is difficult to know for certain what the pre-storm anomaly in the ICW was and/or how the water level might have varied from the outer coast due to inland drainage and pumping. During landfall the peak storm surge occurred at Bear Point when the tide was approximately +0.6 feet.

THE FLORIDA "TREASURE COAST" SLOSH BASINS

The SLOSH model is a numerical storm surge model that computes water elevations generated by the wind and pressure forces in a tropical cyclone. Part of the model is a grid, covering the area of interest, which contains land elevations, water depths and vertical barriers which can impede storm tide flooding. All of these are referenced to NGVD. The grid is termed a basin and given a name. The basins covering the Florida Treasure Coast are called Cape Canaveral and Palm Beach. Figures 1a and 1b show the Cape Canaveral and Palm Beach SLOSH basins and their respective grids. Where the grids overlap, the one with the smaller grid cells (i.e. finer resolution) is usually used to compare against observed data. In the present circumstance it was decided to use the expanded Palm Beach basin, PB2, as all observation sites could be calculated and displayed in the same basin.

The SLOSH model uses as input a tropical cyclone track and intensity and creates a wind and pressure field which is passed through the grid. This, in turn, numerically moves the water in the grid and creates a storm surge flooding pattern. This is termed a SLOSH model run. The time history of the water elevation is saved in each grid cell and the maximum for each grid cell is displayed in what is termed the Envelope Of High Water (EOHW). The EOHW is commonly compared against high water mark observations.

Shown in Figure 2 are Frances' track and a circle representing the location of the maximum winds near the time of landfall. The radial distance of this circle is called the Radius of Maximum Winds (RMW) and is usually given in statute miles. The RMW for Francis near landfall and during its progression through the Palm Beach basin was approximately 35 statute miles. The wind arrows are blowing parallel to the wind. The barbs on the end of the arrow represent the wind speed in knots. A full barb is 10 knots, a half barb is 5 knots and a flag is 50 knots. The wind speed on any wind arrow is obtained by adding up the barbs and flags. For example, in Figure 3, the wind speed over Broward County is 70 knots and the wind speed at the RMW near Vero Beach is 85 knots.

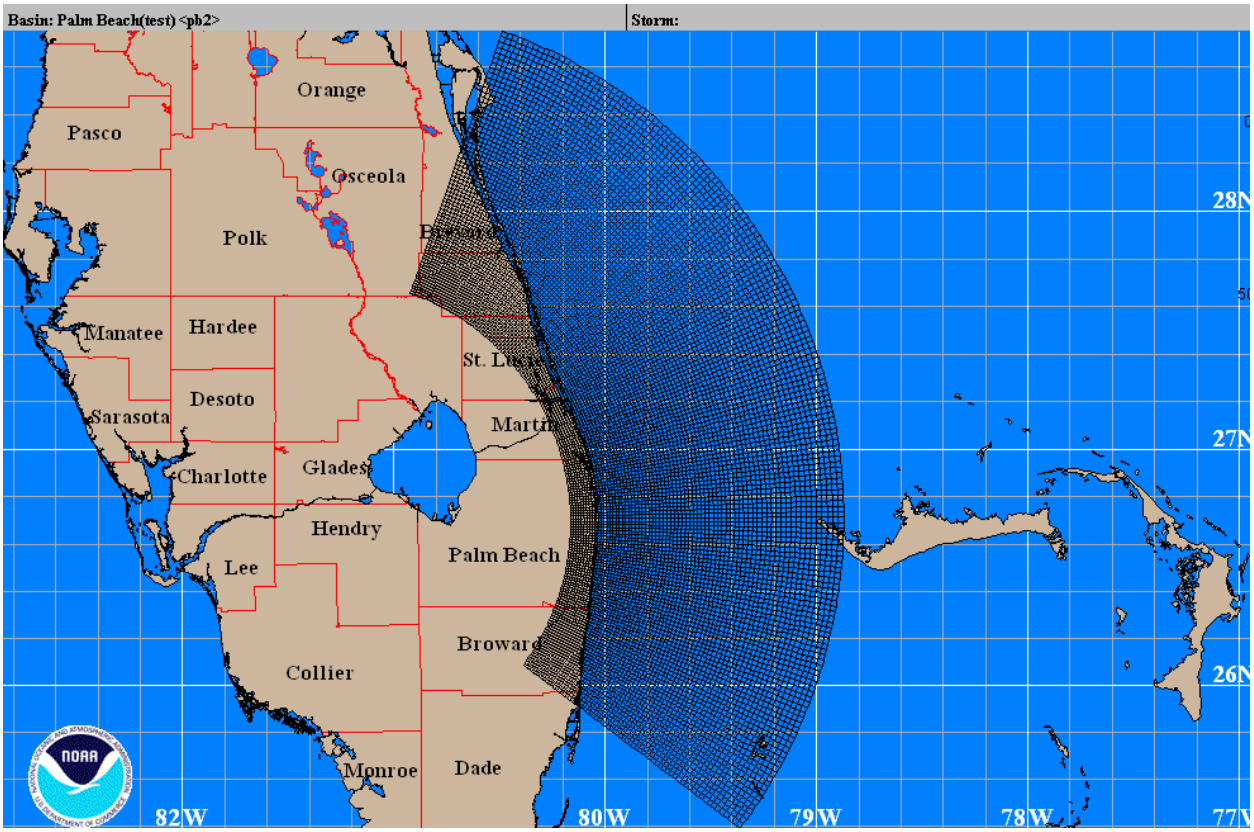

Figure 1a. Palm Beach SLOSH domain.

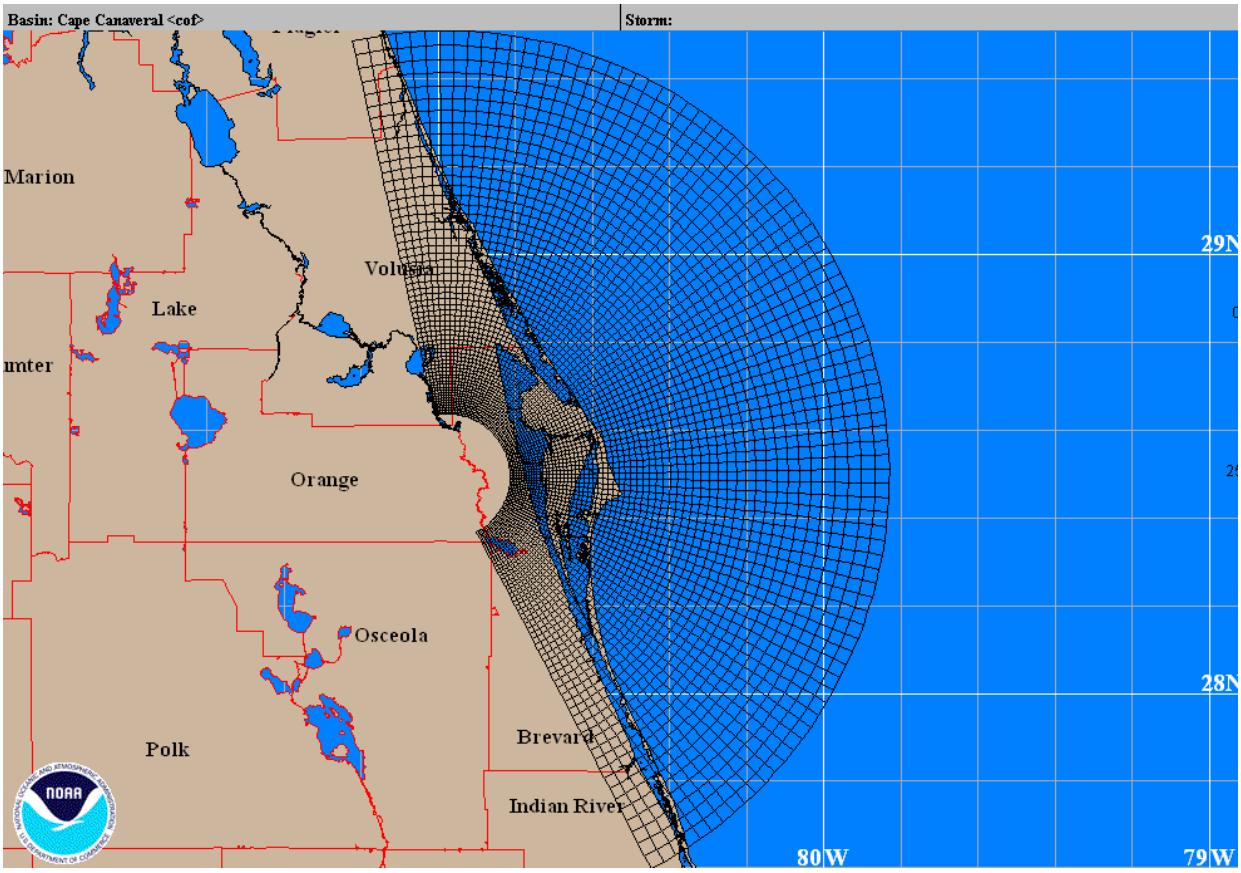

Figure 1b. Cape Canaveral SLOSH domain.

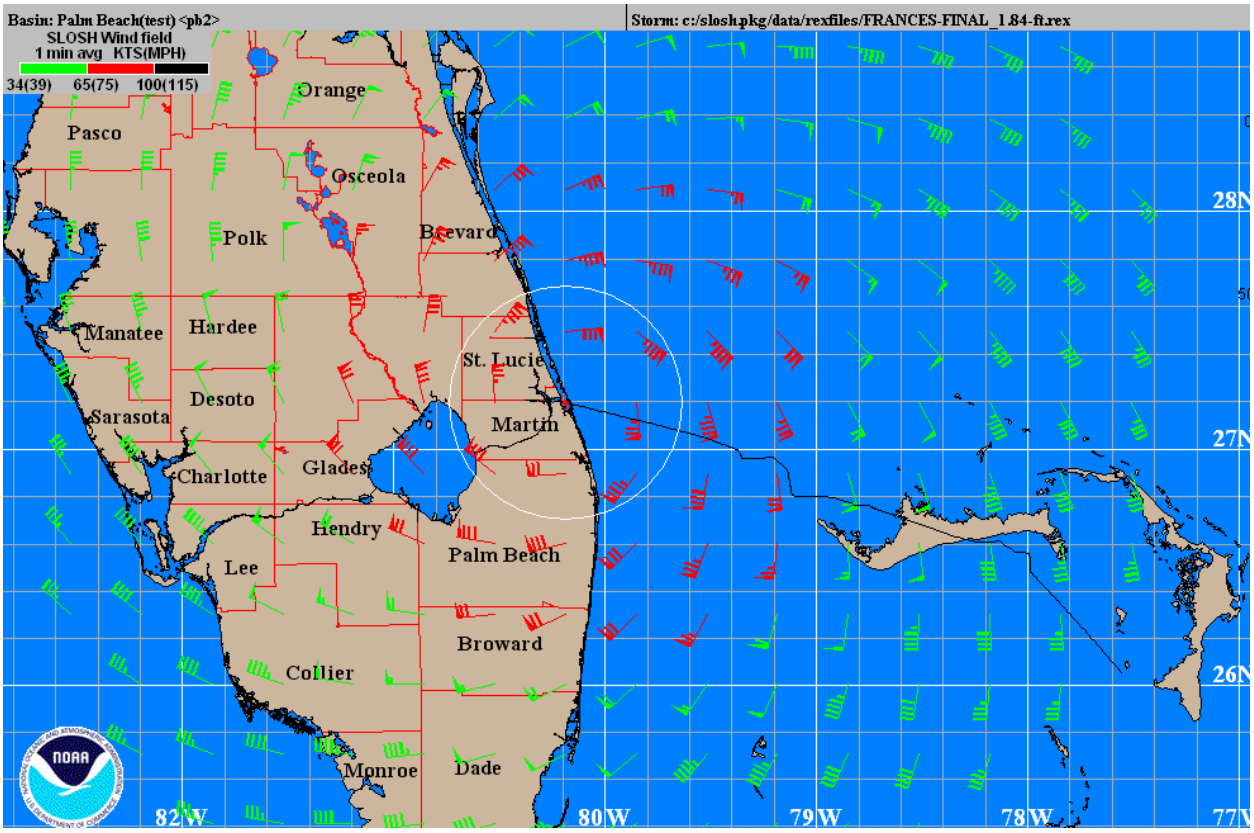

Figure 2. Hurricane Francis winds at landfall.

Comparison of the Trident Pier and Bear Point Observed High Water Marks to SLOSH Values

SLOSH model runs were made in the Palm Beach basin (PB2) using best-track Francis track and intensity data as input. The EOHW for the final best-track/intensity SLOSH model run is shown in Figure 3. The display shows a model initialization at 1.84 ft., appropriate for Trident Pier. The EOHW shows the storm surge that was largely generated by the strong wind field on the right hand side of the hurricane. These strong winds created currents in the Atlantic Ocean that moved toward the shoreline and piled water up on the barrier islands and mainland. The height of the water, referenced to NGVD, is given by a color code. A large area of ocean shoreline experienced water elevations of 6 feet or greater. The SLOSH model calculated that the maximum occurred near Vero Beach, Florida and Stuart, Florida – near 8 feet.

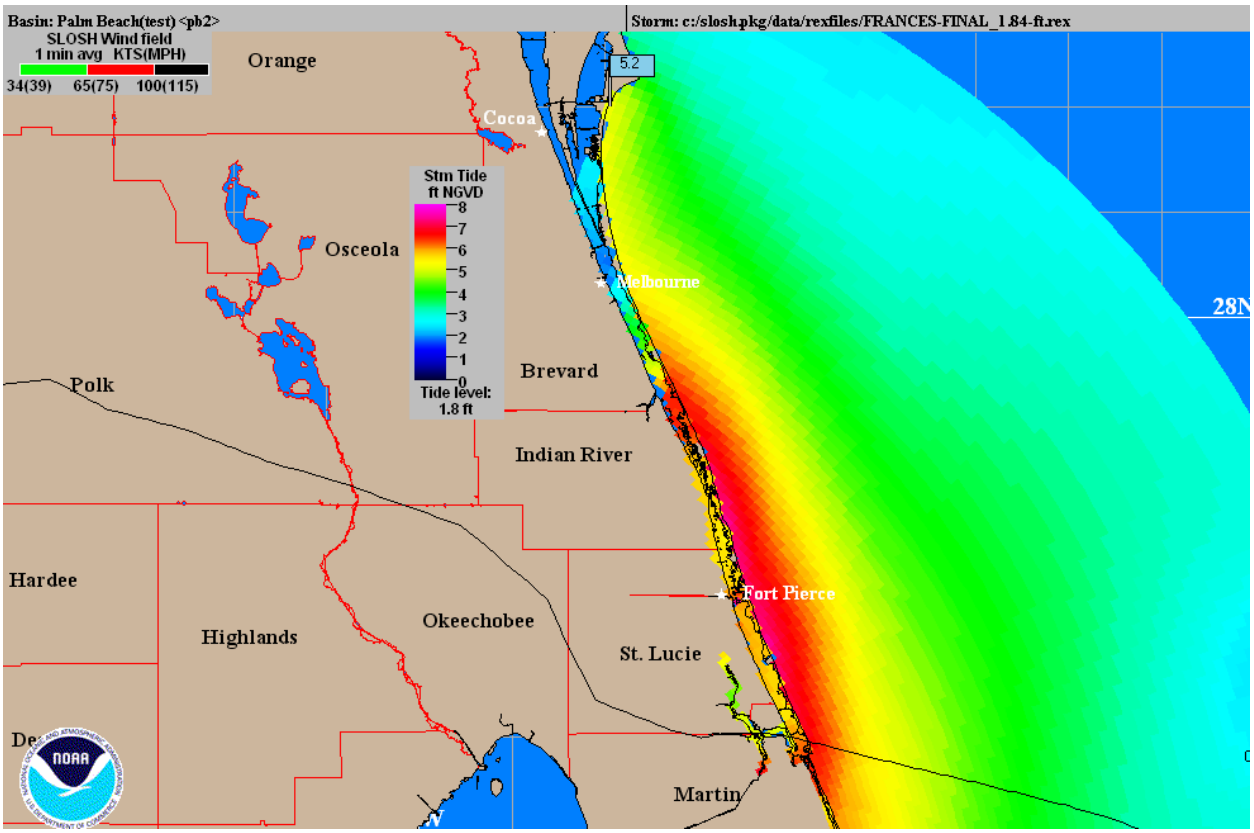

Figure 3. EOHW at Trident Pier, SLOSH initialized at +1.84 ft.

Further examination of Figure 3 shows that the hurricane pushed water into the Indian River and some high water elevations are occurring there. The Trident Pier tide gauge location is noted by a flag showing the EOHW. The observed high water mark at the Trident Pier was compared to the SLOSH generated high water obtained from the output EOHW. The comparison gives a SLOSH value of +5.2 feet NGVD versus an observed value of +5.4 feet NGVD.

As previously noted, for the comparison of Bear Point Mitigation site gauge with SLOSH the model run was initialized at 0.0 ft. Figure 4 shows +3.9 ft. NGVD at Bear Point and +3.5 ft. NGVD at Trident Pier. The pre-storm anomaly of +0.7 ft and MSL adjustment of +0.25 ft. that were used for Trident Pier were also used for Bear Point. The calculated tide at Bear Point was +0.6 ft. The total adjustment for Bear Point therefore was +1.66 feet, yielding a calculated total elevation of +5.6

ft. NGVD. The observed elevation at the Bear Point gauge was +6.0 ft. NGVD. A check on the utility of this technique can be had by adding the Trident Pier adjustments to the 0.0 ft. initialized SLOSH run at Trident Pier. The result is +1.84 plus (computed) +3.5 ft., total +5.34 ft. NGVD versus an observed height of +5.44 ft. NGVD. As noted above, initiation of the model at +1.84 produced a very similar result of +5.1 at Trident Pier.

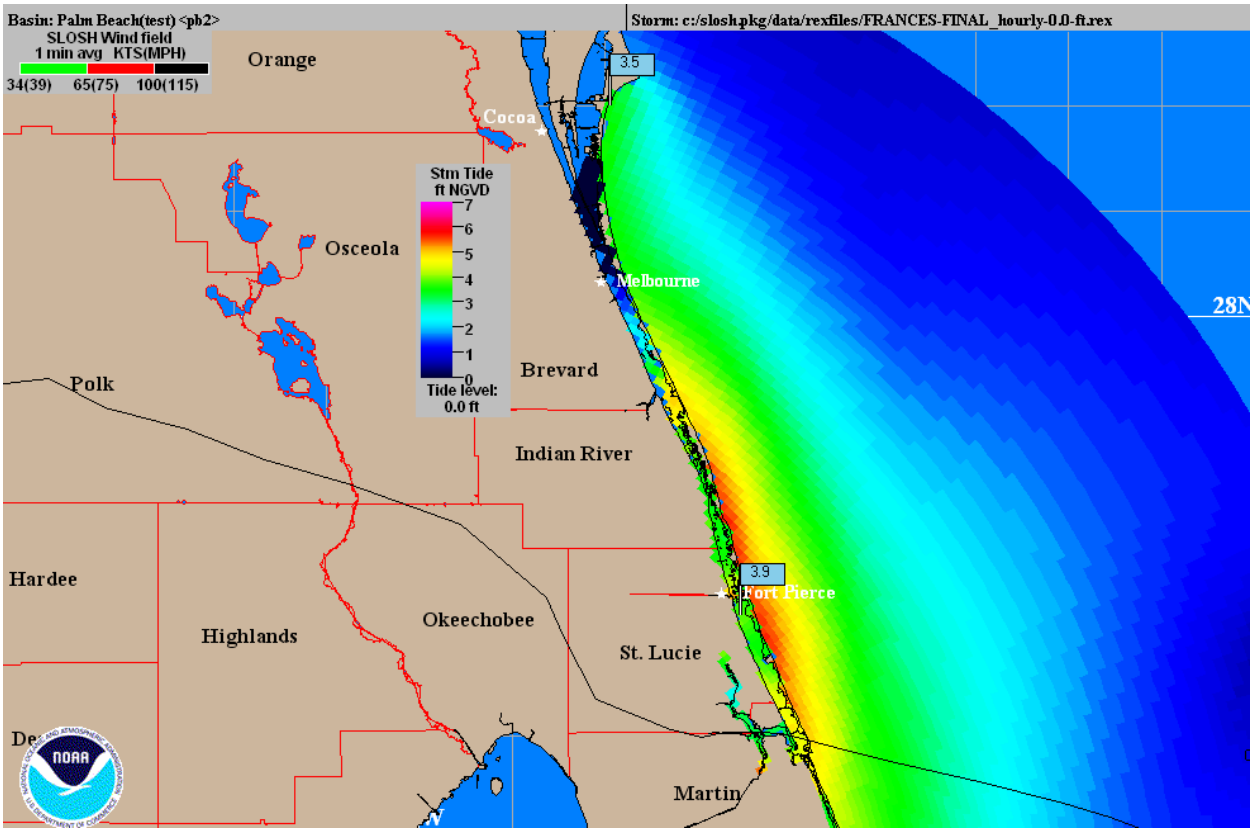

Figure 4. EOHW, SLOSH initialized at 0.0 ft.

Comparison of the Trident Pier and Bear Point Gauges with SLOSH Storm Surge Hydrographs

The hydrographic records at the Trident Pier and Bear Point tide gauges were obtained and were compared to the SLOSH model-generated storm surge hydrographs for the same locations using hurricane Francis input parameters. Figures 5 and 6 show the comparisons. Overall the comparison is very good.

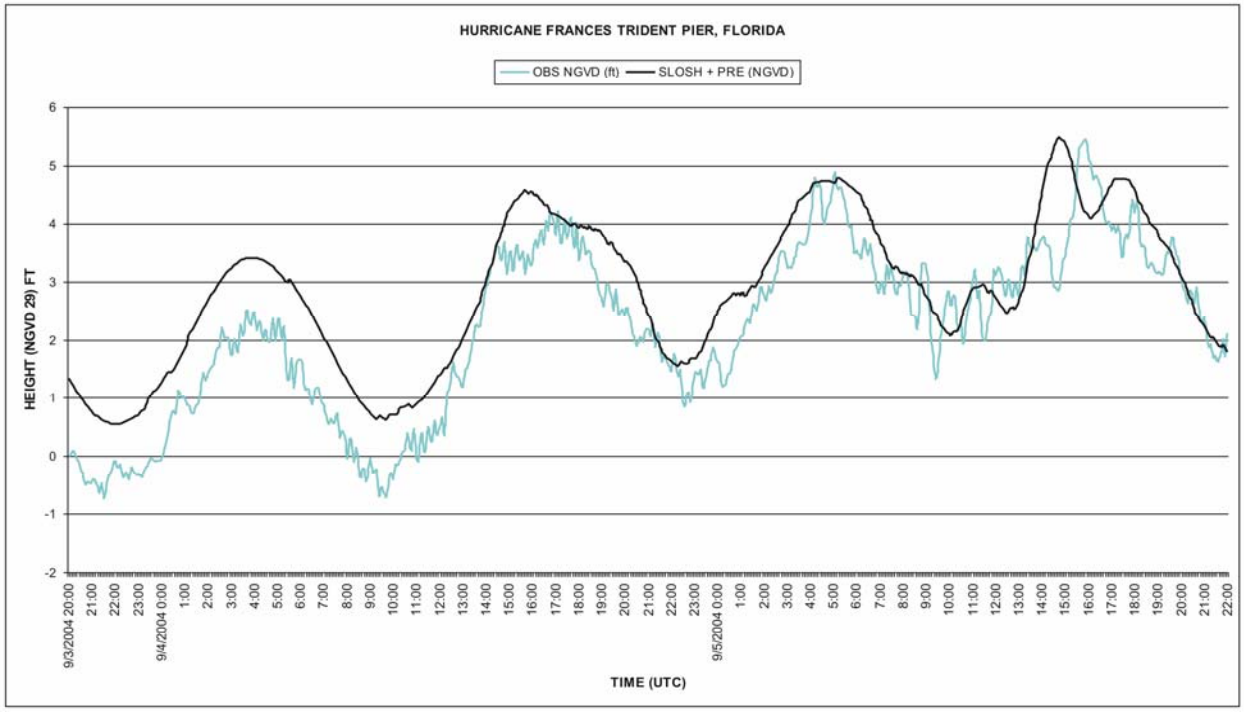

Figure 5. Observed vs. SLOSH hydrographs, Trident Pier.

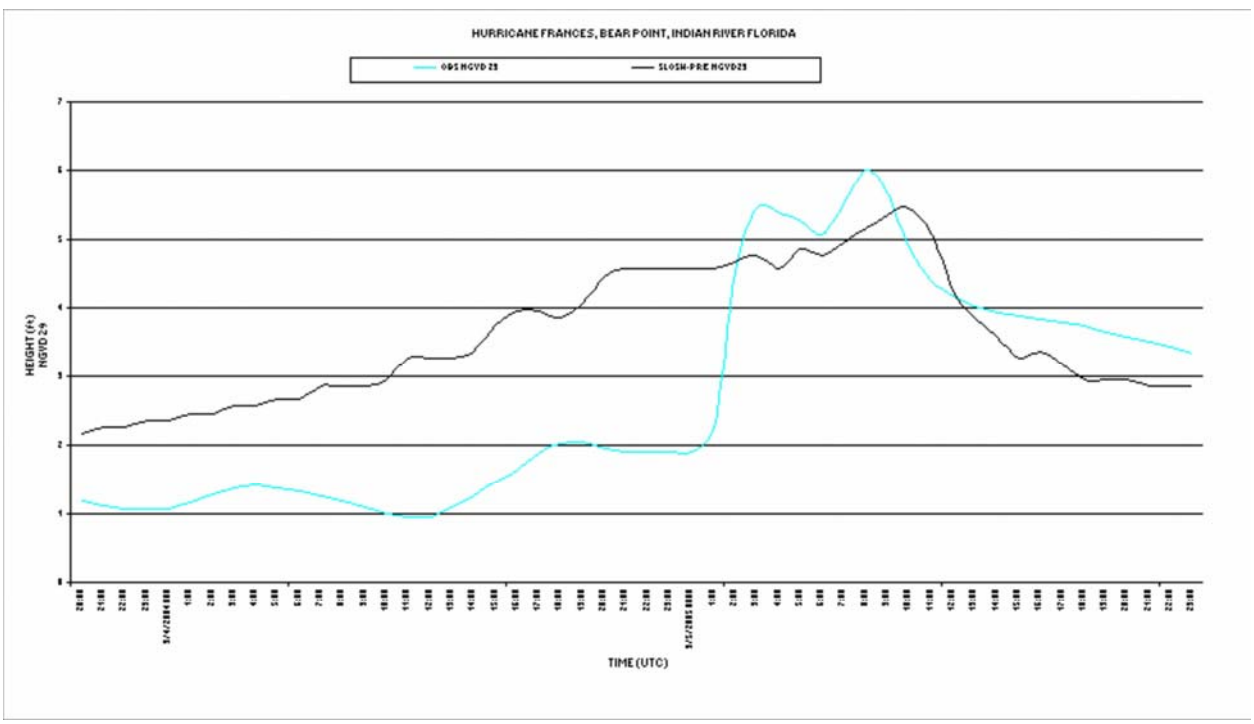

Figure 6. Observed vs. SLOSH hydrographs, Bear Point

STORM SURGE MARKS FOR THE EAST COAST OF FLORIDA HURRICANE FRANCES						
FLOOD SOURCE	SURVEY ELEVATION (ft) NGVD29	SLOSH HEIGHT (ft) NGVD29	LOCATION	LATITUDE	LONGITUDE	COUNTY
Indian River	6.0	6.0	13380 N. Indian River Dr.	27° 50.2′ N	080° 28.7′W	Indian River
Indian River	5.9	6.0	13340 Indian River Dr.	27° 50.2′ N	080° 28.7′W	Indian River
Indian River	5.8	5.6	680 SE 23rd St.	27° 33.67′ N	080° 21.7′W	Indian River
Indian River	6.6	5.7	106 East Harbor Dr.	27°37.8′ N	080° 22.5′W	Indian River
Indian River	5.0	6.4	5210 93rd Lane	27°45.9′ N	080° 26.2′W	Indian River
Indian River	5.6	5.7	2701 N. Indian River Dr.	27° 29.1′ N	080° 20.1′W	St. Lucie
Hobe Sound	4.7	5.5	12140 SE Indian River Dr.	27° 03.4′ N	080° 07.3′W	Martin
Hobe Sound	4.7	5.7	103 River Rd.	27° 03.0′ N	080° 06.7′W	Martin
Lake Worth	6.0	5.0	Park Ranger Home off of A1A	27° 50.1′ N	080° 03.0′W	Palm Beach
Jupiter Inlet	7.4	5.9	79 Lighthouse Dr.	27° 56.7′ N	080° 04.5′W	Palm Beach

Table 1. Storm surge marks for Hurricane Frances, East Coast of Florida

Including the Trident Pier and Bear Point tide gauges with the points shown in Table 1. yields the statistical results:

Mean difference between observed and calculated storm surge heights: -0.04 ft: Standard deviation of the mean: 0.8 ft. These values are in line with the SLOSH long-term record.

Conclusions

For hurricane Francis (2004) the observed and SLOSH calculated high water mark comparison was good at the Trident Pier and Bear Point locations. The statistics of the coastal surge values are in line with long-term variance with the SLOSH model.

Likewise, a comparison of the observed storm surge hydrographs from the Trident Pier and Bear Point to the SLOSH model calculated storm surge hydrographs showed reasonable results.

Recommendations

Based upon the above results it is recommended that the following be done:

1. The SLOSH basins for Palm Beach (and the contiguous Cape Canaveral basin) are reconfigured with a finer mesh of grid cells and that the latest measured water depths and land elevations are used to do this. Ground controlled LIDAR data should be utilized if available.

2. A series of hypothetical hurricanes, based upon hurricane climatology, are run using the new Palm Beach and Cape Canaveral SLOSH basins to determine the hurricane storm tide flood plain.

We thank Hazen and Sawyer, Inc. for the provision of Bear Point tide gauge data.