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Monitoring the Storm Tide of Hurricane Wilma in Southwestern Florida, October 2005

Introduction

Residents in the southeastern United States were still recovering from Hurricanes Katrina and Rita when Hurricane Wilma appeared, the third category 5 storm of the 2005 Atlantic hurricane season and, at its peak, the most intense tropical cyclone ever recorded in the Atlantic Basin (fig. 1). The intensity of Wilma was reduced considerably by its travel over the Yucatán Peninsula on October 21-22, 2005, but reintensified into a category 3 storm as it moved into the Gulf of Mexico and approached Florida. Maximum sustained winds increased to 115 mi per hour and hurricane-force winds extended outward 85 mi from the center (Pasch and others, 2006). A storm surge of 9 to 17 ft above normal tide levels was predicted for the southwestern coast of Florida and areas south of the projected storm path.

On October 20, 2005, a team from the U.S. Geological Survey (USGS) in Ruston, Louisiana, was dispatched to Fort Myers, Florida, with enough pressure transducers (sensors) and housings to establish 30 temporary stations along the southwestern Florida coast where landfall was expected. Prior to team arrival, USGS employees in Fort Myers determined deployment locations for these stations based on preexisting structures, such as dock and bridge pilings. The monitored area extended from Boca Grande Pass, at the entrance to Charlotte Harbor, south to Everglades City at the northern edge of Everglades National Park. An existing USGS real-time coastal hydrologic monitoring network extends from Everglades City south into Florida Bay and, therefore, was already in place to monitor storm tide in that region (fig. 2). Where possible, sites were positioned to create a transect from the coast to interior estuarine bays and rivers.

Figure 1. Path of Hurricane Wilma during October 2005 (modified from Pasch and others, 2006). Filled and open circles represent the approximate eye position of Hurricane Wilma, respectively, at midnight and noon UTC (Coordinated Universal Time) on the dates shown. Local time (Eastern Daylight Time) is UTC time minus 4 hours.

All temporary stations were installed by October 22, 2005. Less than 48 hours later the hurricane made landfall south of Marco Island, where the magnitude, extent, and timing of the storm tide were recorded by the sensors. The temporary stations used for this effort and for Hurricane Rita have allowed the USGS to (1) extend the scope of data collection beyond that of existing networks, and (2) backup data collection at existing monitoring stations by utilizing nearby structures that are more likely to survive a major hurricane, such as bridge pilings. Data from this monitoring effort, conducted under severe conditions, can be used to improve the current understanding and prediction of storm tide.

Figure 3. Water-level sensor deployed at WS_26A Marco Island Bayside.

Purpose and Scope

This report documents the procedures used to collect storm tide data for Hurricane Wilma in southwestern Florida. Storm tide elevation data are presented for the 23 of 30 stations where storm tide was observed (arbitrary water-level data from the remaining 7 stations is made available but is not discussed). Data collected include date and time, temperature, and pressure (barometric and water), as well as all data used to adjust pressure data from inundated sensors to water-level elevation above NAVD 88. At one station where storm tide was substantial enough to leave a high-water mark, direct measurements of its elevation are compared to peak water levels measured at a nearby sensor. Storm tide data detected by the USGS real-time coastal monitoring stations in southwestern Everglades National Park and northeastern Florida Bay are also presented.

This report uses the term "storm tide" in place of "storm surge." As defined by the National Ocean and Atmospheric Administration, "storm tide" refers to the total water level above a datum generated by a storm. "Storm surge" refers to the component of the storm tide over and above the predicted astronomical tide (Jelesnianski and others, 1992). Additional information is available at: http://www.nhc.noaa.gov/HAW2/English/storm_surge.shtml and at http://www.asp.ucar.edu/colloquium/1988/Houston.jsp.

Pressure Transducer Deployment and Retrieval

Pressure transducers (or sensors) were programmed prior to deployment to measure and record time, temperature, and pressure every 30 seconds during the storm and for several days after passage of the storm. Sensors were deployed in 1.5 × 18 in. metal pipes and strapped to permanent objects, such as piers and power poles. Water-level sensors were deployed at elevations considered susceptible to storm tide inundation and barometric-pressure sensors were deployed at elevations considered not susceptible (figs. 3 and 4, respectively). During deployments, reference marks, consisting of driven nails or chiseled lines in concrete were created near each water-level sensor, and the vertical distance from the reference mark to the sensor (offset) was recorded (fig. 5). All sensors were retrieved less than 4 days after Hurricane Wilma passed, and offsets were checked to verify that the sensors had not moved relative to the reference mark.

Figure 4. Barometric-pressure sensor deployed at WS_19 Imperial River.

Figure 5. Water-level sensor deployment at WS_30 Everglades City.

Abstract

Temporary monitoring stations employing nonvented pressure transducers were used to augment an existing U.S. Geological Survey coastal monitoring network to document the inland water levels related to the storm tide of Hurricane Wilma on the southwestern coast of Florida. On October 22, 2005, an experimental network consisting of 30 temporary stations was deployed over 90 miles of coastline to record the magnitude, extent, and timing of hurricane storm tide and coastal flooding. Sensors were programmed to record time, temperature, and barometric or water pressure. Water pressure was adjusted for changes in barometric pressure and salinity, and then converted to feet of water above the sensor. Elevation surveys using optical levels were conducted to reference storm tide water-level data and high-water marks to the North American Vertical Datum of 1988 (NAVD 88). Storm tide water levels more than 5 feet above NAVD 88 were recorded by sensors at several locations along the southwestern Florida coast. Temporary storm tide monitoring stations used for this effort have demonstrated their value in: (1) furthering the understanding of storm tide by allowing the U.S. Geological Survey to extend the scope of data collection beyond that of existing networks, and (2) serving as backup data collection at existing monitoring stations by utilizing nearby structures that are more likely to survive a major hurricane.

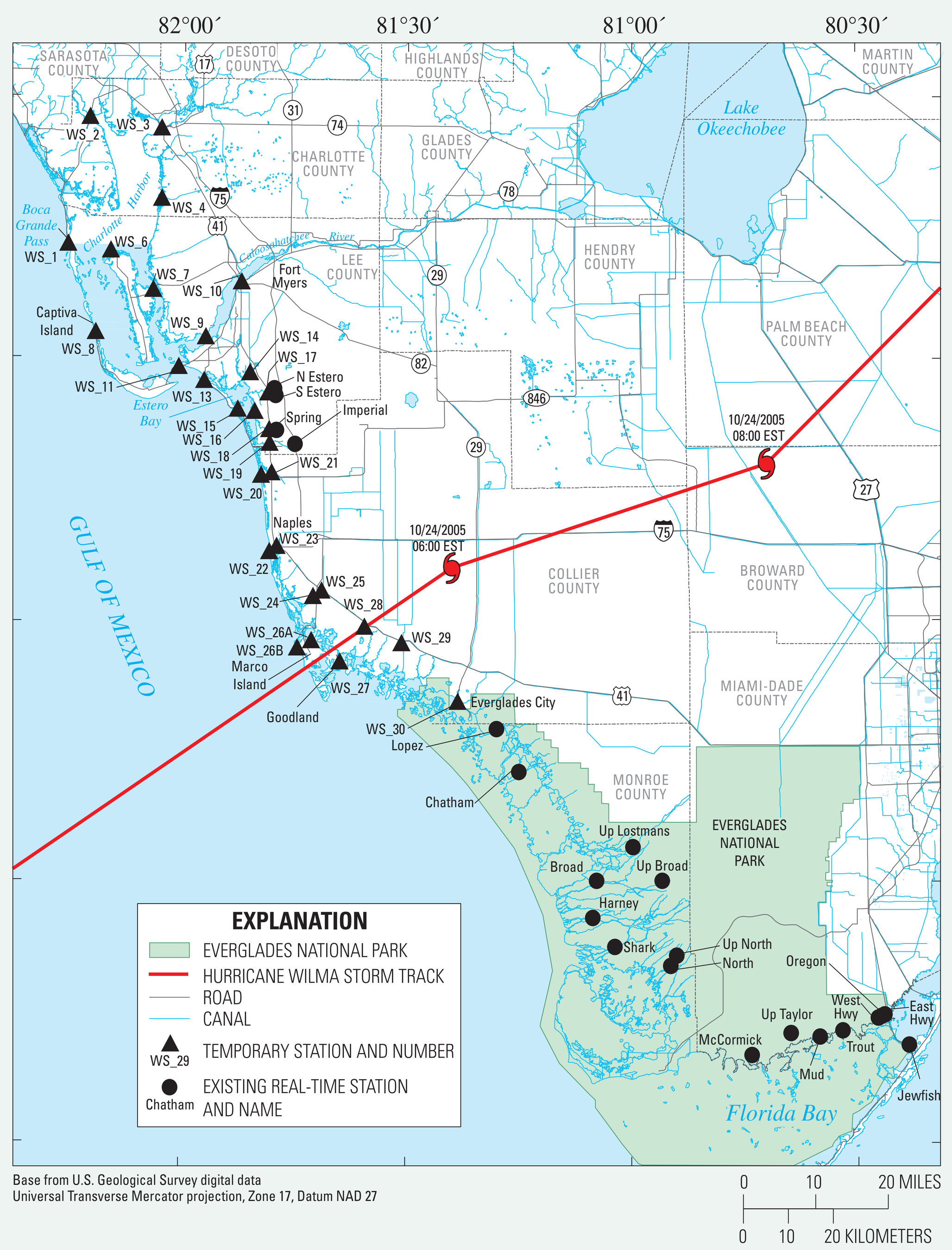

Figure 2. Temporary and real-time monitoring stations used in this study.

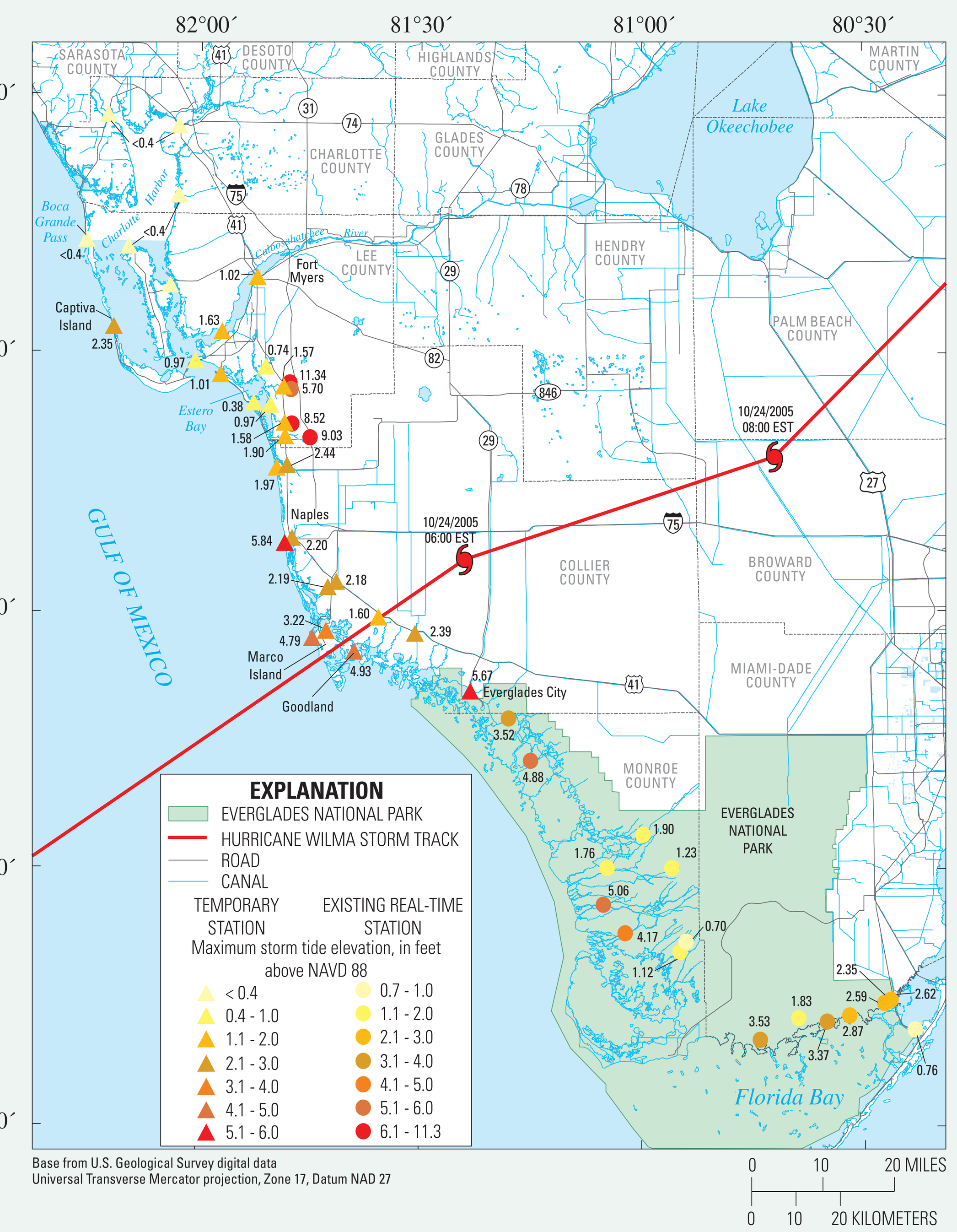

Figure 6. Storm tide measured at temporary and real-time monitoring stations.

Data Corrections

Pressure data from inundated sensors were corrected for changes in barometric pressure using data from barometric-pressure sensors and the following formula:

$$Pw - Pb = Pc$$

where:
Pw is water pressure, in pounds per square inch
Pb is barometric pressure, in pounds per square inch
Pc is corrected water pressure, in pounds per square inch

If a barometric-pressure sensor was not co-located with a water-level sensor, the data from the nearest barometric-pressure sensor was used to correct the water-level data. Water-level data from sensors also were corrected for salinity (water density) as:

$$(Pc \times 144) / Dw = Hw$$

where
144 is a conversion factor to compute pounds per square inch to pounds per cubic foot
Dw is water density in pounds per cubic foot
Hw is water height above the transducer in feet

Corrections for salinity were based upon the location of the sensor in proximity to the coast. In general, sensors located at the coast were categorized as saltwater (density of saltwater is 63.9887 lb/ft3), and sensors located at estuarine bays and tributaries were categorized as brackish (density of brackish water is 63.0522 lb/ft3).

Acknowledgments

The authors wish to thank the USGS personnel for their dedication in making this monitoring effort possible, including Ben McGee and Burl Goree (Ruston, Louisiana), Kevin Hubbs and Ray Dupuis (Tampa, Florida), Gene Krupp, Sara Hammermeister, Craig Thompson, Jessica Flanigin, and Eduardo Patino (Fort Myers, Florida), Scott Prinos (Fort Lauderdale, Florida), and Robert Mason (Reston, Virginia). The authors also wish to thank Kim Swidarski (USGS, Fort Lauderdale, Florida) for preparing the illustrations and GIS maps used in this poster and accompanying report. The authors would also like to thank Cliff Merz from the University of South Florida for providing data from the Coastal Ocean Monitoring and Observation System, as well as Tim Howard from the South Florida Water Management District Big Cypress Basin for providing data from their monitoring network.

Hurricane Wilma Data Series Report and data files available at http://pubs.usgs.gov/ds/2007/294

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Hurricane Wilma Storm Tide Data

Measurable storm tide occurred at all temporary stations from Captiva Island south to Everglades City (figs. 6 and 7). Storm tide was also detected at all USGS real-time coastal monitoring stations in southwestern Everglades National Park and northeastern Florida Bay (fig. 8). A storm tide of about 1 ft was observed at the northernmost stations in the Caloosahatchee River and Estero Bay. A storm tide of 1.5 to 2.0 ft was observed at bridges along Highway U.S. 41 over tributaries to Estero Bay. The highest storm tide occurred at stations directly south of Marco Island (where Hurricane Wilma made landfall), with a maximum storm tide of 5.67 ± 0.5 ft above NAVD 88 recorded at Everglades City (WS_30). Storm tide was 4 to 5 ft at major coastal rivers along the southwestern coast of Everglades National Park, decreasing to 1 to 2 ft above NAVD 88 as the storm tide traveled inland. Storm tide of about 3 ft was measured along the coastal creeks of northeastern Florida Bay.

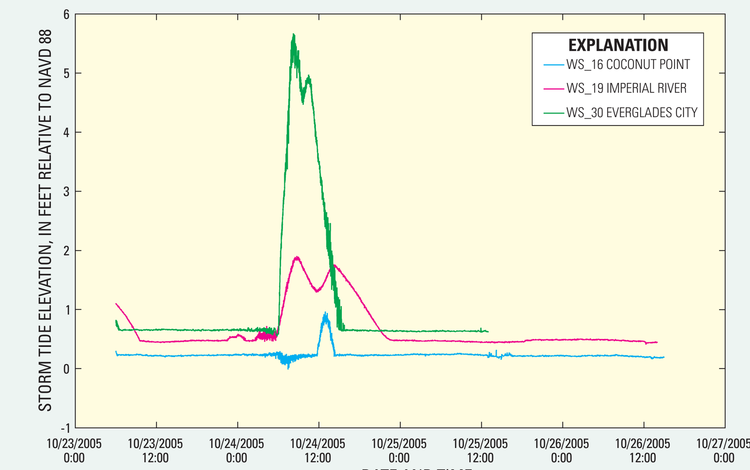

Figure 7. Hurricane Wilma storm tide elevations at selected temporary stations.

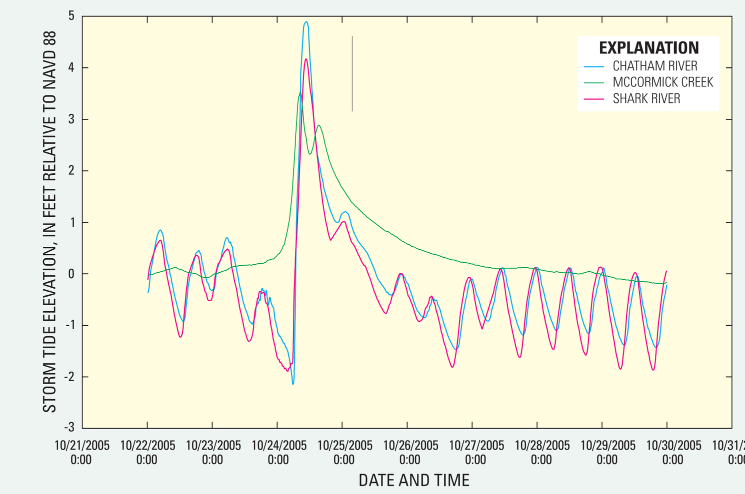

Figure 8. Hurricane Wilma storm tide elevations at selected real-time stations in Everglades National Park.

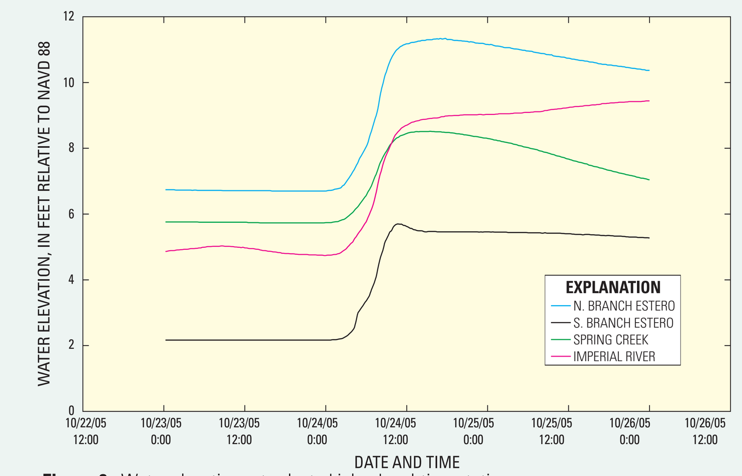

Figure 9. Water elevations at selected inland real-time stations.

The maximum recorded water levels occurred at N. Estero River, Spring Creek, and Imperial River (fig. 6). These permanent stations are located on tributaries to Estero Bay upstream from tidal effects under normal conditions. The magnitude of the water levels observed was influenced by the elevation of the streams at that point. Water levels increased sharply at all three stations (fig. 9), with the smallest increase of 2.79 ft occurring at Spring Creek and the greatest increase of 4.64 ft occurring at N. Estero River. Water levels in these streams increase rapidly during significant rain events, as occurred during the passing of Hurricane Wilma. The maximum water levels are likely more a function of flooding and stream elevations than storm tide. A similar increase in water levels was observed at S. Estero River (fig. 6).

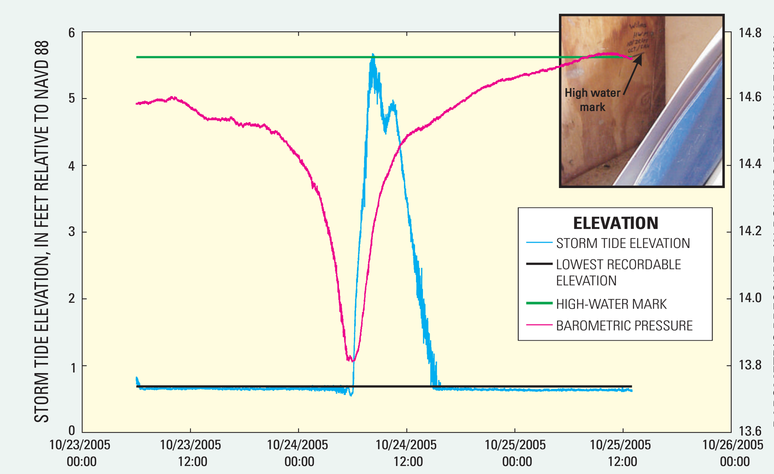

Figure 10. Hurricane Wilma storm tide elevations at WS_30 Everglades City, including high-water mark.

The reference mark at site WS_30 was lost prior to the elevation survey due to construction activity at the site, so its elevation had to be estimated based on photographs taken at the time of deployment. The maximum storm tide recorded at WS_30, however, agreed well with the 5.62-ft elevation of the high-water mark (rated excellent) found near the station (fig. 10).

Data from WS_25 agreed well with data from the South Florida Water Management District BCB Hendersen Creek monitoring station located 10 ft downstream from the US-41 bridge (fig. 11). Data from WS_15 agreed well with data from the University of South Florida Coastal Ocean Monitoring and Observation System (COMPS) Big Carlos Pass station located about 800 ft away near the center of the pass (fig. 12). The increased variability in the data from the temporary station in comparison to the COMPS station is due to the shorter data collection interval (30 seconds, compared to 6 minutes) at the temporary station, and because the COMPS station has a stilling well that substantially dampened the wave action during the storm. In addition, the COMPS water-level data represent a mean value of 3-minute data collected at 1-second intervals.

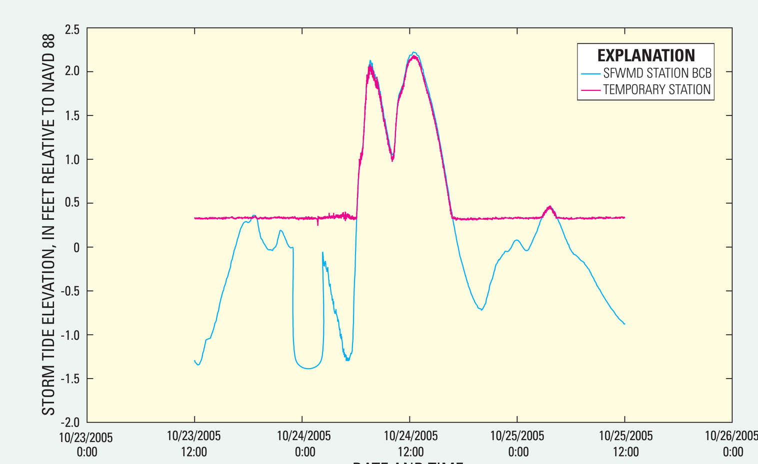

Figure 11. Comparison of Hurricane Wilma storm tide elevations at Hendersen Creek as measured by South Florida Water Management District station BCB and U.S. Geological Survey temporary station WS_25. The BCB data were obtained from the DBHYDRO database.

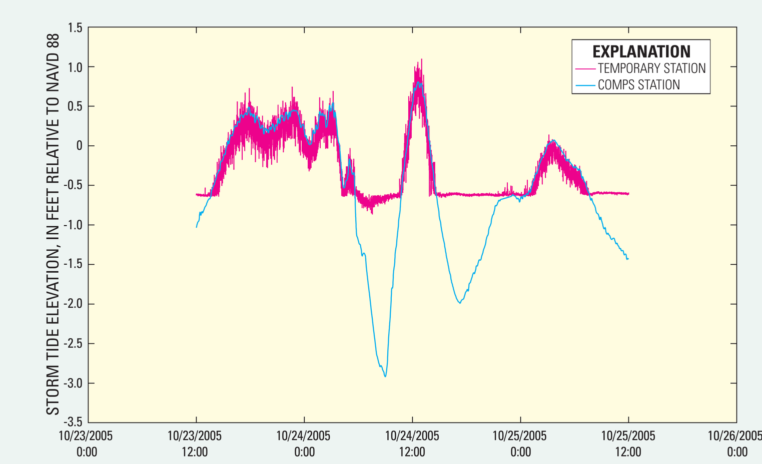

Figure 12. Comparison of Hurricane Wilma storm tide elevations at Big Carlos Pass as measured by the University of South Florida COMPS station and U.S. Geological Survey temporary station WS_15. Data for the COMPS station are from University of South Florida Department of Marine Science (undated).

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