USGS HURRICANE STORM-SURGE MONITORING NETWORKS: An example from Hurricane Rita

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Abstract. Preventing coastal flood hazards, such as hurricane-induced storm surge, from becoming human disasters requires an understanding of the relative risks floods pose to communities and knowledge of the processes by which flood waters rise, converge, and abate. The timing, magnitude, and duration are critical to accurately measure hurricane storm surge. The U.S. Geological Survey has developed a mobile network of rapidly deployable water-level and barometric-pressure sensors to better observe and document the timing, magnitude, and duration of hurricane-induced storm surge dynamics as they make landfall and interact with coastal features. Such understanding can lead to improvements in the design of bridges, dams, and levees and other infrastructure, aid the delineation of flood-plain boundaries and evacuation routes, and serve as the basis for informed land-use planning.

INTRODUCTION

Historically, hurricane-induced storm surge has been documented through analysis of structural or vegetative damage and by using water lines, called high-water marks, left behind by flood waters. Identifying and qualifying high-water marks and determining how well these marks represent maximum flood levels are often subjective. The quality of the high-water mark depends upon the type of mark, such as debris, seed, mud, or stain, and on whether the mark was created in a protected environment, such as the interior wall of a building, or in an unprotected environment, such as an exposed bridge piling or fence post. These sources rarely provide quantitative information about the timing of the inundation, nor do they facilitate reconstruction of the sequencing of multiple flow paths by which the storm-surge waters arrived, or the magnitude of waves and wave run-up comprising flood waters. In addition, high-water marks can not be used to evaluate storm-surge model performance along the dynamic track of a hurricane with its accompanying changes in wind strength and direction.
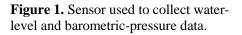
In response to these deficiencies, the U.S. Geological Survey (USGS) has developed and deployed a mobile storm-surge monitoring network to provide detailed time-series data for selected hurricane landfalls (URL: http://water.usgs.gov/waterwatch/hsss/). As part of this program, water-level, and barometric-pressure sensors are deployed to areas of hurricane landfall to create a concentrated network of as many as 80 temporary storm-surge gages along water channels and throughout nearby overland features such as beaches, barrier islands, wetlands, and constructed environments.

Through May, 2010, USGS storm-surge networks have been successfully deployed for Hurricanes Rita (2005, 32 water-level monitoring sites); Wilma (2005, 30), Gustav (2008, 80); Ike (2008, 65); and Tropical Storm Ernesto (2006, 40 sites for which the data were not published). Data were collected as frequently as every 30 seconds for 24-48 hours before hurricane landfall and for as long as two weeks after landfall. At selected sites in southwest Louisiana, data were collected for multiple hurricanes (Rita, Gustav, and Ike). The data are available at (URL: http://water.usgs.gov/osw/programs/storm_surge.html).

DEPLOYMENT OF STORM SURGE SENSORS

Typical USGS storm-surge networks utilize water-level sensors to document the timing, extent, and magnitude of hurricane storm surge. Selected sites also include a second sensor, called a barometric sensor, which collects atmospheric pressure data that is used to correct water-level data for changes in atmospheric pressure with the passing of the hurricane. Figure 1 shows an example of a sensor used to collect water-level and barometric-pressure data. The sensors are placed at locations distributed throughout the projected areas of coastal flooding. Locations may be determined from forecasts (surge model analysis), previously reconnoitered or deployed sites, input from State and local agencies, or even opportunistic sites may be added that provide spatial coverage in the network. Other factors that affect site placement are expected surge height, proximity to populated communities and existing real-time gages, datum control, and accessibility.

Figure 1. Sensor used to collect water-level and barometric-pressure data.

Figure 2. Water-level sensor device attached to power pole.

The sensors are programmed prior to deployment to record data at short time intervals (usually one minute or less) to capture the combined effects of downstream river flows, storm-water outfalls, tides, and wind-driven ocean surge and waves during the storm and for up to two weeks after the storm has passed. Each sensor is placed in a perforated metal housing for protection and temporarily attached to power poles, bridge pilings, or other structures that are unlikely to be damaged or destroyed by the storm surge (fig. 2). The water-level sensors are deployed at elevations considered susceptible to storm surge inundation and the barometric-pressure sensors are positioned above the highest anticipated storm-surge in the area. During deployment, temporary elevation benchmarks are established on to the same or near-by structures to serve as elevation controls for the sensors and high-water marks expected to result from the hurricane induced flooding.

Following the passage of the storm, the sensors are recovered and the data are downloaded and processed. Water-level data are corrected for changes in barometric pressure using data from a co-located or nearby barometric-pressure sensor. Water-level data also may be corrected for salinity. Corrections for salinity are based upon the location of the sensor in proximity to the coast, as either saltwater (density of 64.0 lbs/ft^3 [pounds per cubic foot]), brackish water (density of 63.1 lbs/ft^3), or freshwater (density of 62.4 lbs/ft^3) (McGee and others, 2006). Vertical distances to the water surface and to available high-water marks are measured relative to the temporary elevation benchmarks to confirm water-level sensor accuracy. Traditional line-of-sight leveling is

employed to adjust the relative elevation of the sensors, the high-water marks, and the temporary benchmarks to a common datum. This datum is then tied to the North American Vertical Datum of 1988 (NAVD 88) through the use of Global Positioning System (GPS) equipment or traditional line-of-sight leveling is employed to tie the data to a benchmark of known elevation.

HURRICANE RITA STORM-SURGE MONITORING RESULTS

The storm-surge monitoring network idea was created by staff members at the USGS Water Science Center in Ruston, Louisiana following Hurricane Katrina in August 2005. The first deployment of such storm-surge network was for Hurricane Rita in September 2005. As Hurricane Rita approached landfall, the network was quickly deployed to areas of southwestern Louisiana and southern Texas. Sensor locations were selected based on storm-surge forecasts, topography, and accessibility. The sensors were deployed by strapping the sensor housing to permanent objects such as bridge piers and power poles. Water-level and barometric-pressure sensors were deployed at 33 sites along various waterways and coastal marshes along the coast to approximately 30 miles inland. The sensors were programmed to record the date and time, temperature, and water-level or atmospheric pressure during the storm and for several days after the storm had passed.

After Hurricane Rita had passed, 32 sensors (one sensor was destroyed) were recovered and the data were downloaded and processed. Water-level data were corrected for changes in barometric pressure and also were corrected for salinity based upon the location of the sensor in proximity to the coast.

The storm-surge network data shows that the highest surge elevations were recorded near the coast and the lowest elevations were recorded inland. Analysis of the storm-surge data defined the highest water-levels, the duration, and timing of the storm-surge as Hurricane Rita moved across the coast and inland. The storm-surge data also are useful when used to create maps of the affected communities and (or) areas. Figure 3 is a map that was generated from the Hurricane Rita storm-surge data that shows the storm-surge elevations along the coasts of southeast Texas and southwest Louisiana at 3-hour intervals from midnight (0000 hours) through noon (1200 hours) on September 24, 2005. The resulting storm-surge elevations (fig. 3) clearly indicate the influences of coastal orientation with respect to the hurricane path and relative elevations of streams, marshes, roads, and uplands, especially in early sequences before many of these features were inundated as storm-surge increases (Berenbrock and others, 2008). This information provides scientists with a better understanding of storm-surge dynamics and aids emergency officials in preparation and response to these events.

CONCLUSIONS

In the United States each year, natural hazards, such as the hurricane-induced storm surge, cause deaths and costs billions of dollars in disaster aid, disruption of commerce, and destruction of homes and critical infrastructure. Although the number of lives lost each year to natural hazards has generally decreased, the economic cost of major disasters response and recovery continues to rise. Historical studies of the hurricane-induced storm surge have rarely provided useful information about the timing of the storm surge, the sequencing of the paths by which the surge waters arrive, or the duration of the storm-surge event. The storm surge network developed by the USGS has been successfully deployed for several Hurricanes since its inception in 2005. These data enable water- and land-resources personnel to study storm-surge inundation and visualize its interaction with the coastal features such as beaches, barrier islands, and streams. Additionally, the major paths of penetration, the duration, and the height and frequency of waves that make landfall and destroy homes and critical infrastructure can be determined.

Data of this nature are rare and very valuable for all sectors of society. The data from a hurricane storm surge network provides valuable data for engineers to improve structural design of coastal infrastructure, emergency preparedness agencies to better protect public safety, and scientists to evaluate and improve hurricane storm-surge models for more accurate forecasts.
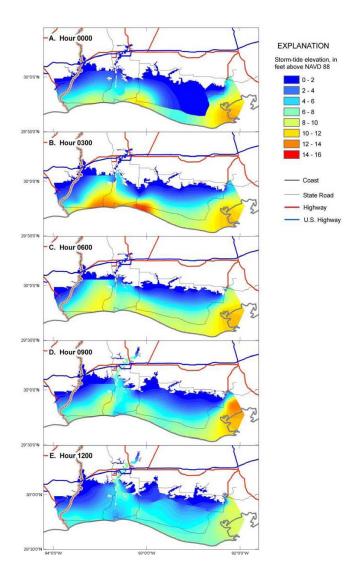

Figure 3. Hurricane Rita storm-surge elevations along the coasts of southeast Texas and southwest Louisiana at 3-hour intervals from midnight (0000 hours) through noon (1200 hours) on September 24, 2005 (from Berenbrock and others, 2008).

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