

# Mapping and Visualization of Storm-Surge Dynamics for Hurricane Katrina and Hurricane Rita

Scientific Investigations Report 2009–5230

U.S. Department of the Interior  
U.S. Geological Survey

**Cover.** Example of the barriers used to guide the spline surface interpolation routine for an area along the Mississippi coast for modeling storm surge from Hurricane Katrina.

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By Dean B. Gesch

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U.S. Geological Survey, Reston, Virginia: 2009

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*Suggested citation:*

Gesch, D.B., 2009, Mapping and visualization of storm-surge dynamics for Hurricane Katrina and Hurricane Rita: U.S. Geological Survey Scientific Investigations Report 2009–5230, 18 p.

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## Conversion Factors and Datums

<b>Multiply</b>	<b>By</b>	<b>To obtain</b>
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
mile, nautical (nmi)	1.852	kilometer (km)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

# Mapping and Visualization of Storm-Surge Dynamics for Hurricane Katrina and Hurricane Rita

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## Abstract

The damages caused by the storm surges from Hurricane Katrina and Hurricane Rita were significant and occurred over broad areas. Storm-surge maps are among the most useful geospatial datasets for hurricane recovery, impact assessments, and mitigation planning for future storms. Surveyed high-water marks were used to generate a maximum storm-surge surface for Hurricane Katrina extending from eastern Louisiana to Mobile Bay, Alabama. The interpolated surface was intersected with high-resolution lidar elevation data covering the study area to produce a highly detailed digital storm-surge inundation map. The storm-surge dataset and related data are available for display and query in a Web-based viewer application. A unique water-level dataset from a network of portable pressure sensors deployed in the days just prior to Hurricane Rita's landfall captured the hurricane's storm surge. The recorded sensor data provided water-level measurements with a very high temporal resolution at surveyed point locations. The resulting dataset was used to generate a time series of storm-surge surfaces that documents the surge dynamics in a new, spatially explicit way. The temporal information contained in the multiple storm-surge surfaces can be visualized in a number of ways to portray how the surge interacted with and was affected by land surface features. Spatially explicit storm-surge products can be useful for a variety of hurricane impact assessments, especially studies of wetland and land changes where knowledge of the extent and magnitude of storm-surge flooding is critical.

## Introduction

Hurricane Katrina and Hurricane Rita were two of the largest and most destructive tropical cyclones in the record-setting 2005 Atlantic hurricane season. Although each storm weakened before landfall, both storms intensified to Category 5 status over the Gulf of Mexico. Wind damage was significant, but the storm-surge destruction caused by each hurricane occurred over extensive areas and is the primary impact that will be long remembered (Graumann and others, 2005; Knabb and others, 2006). The storm surge

from Hurricane Katrina was centered around Bay Saint Louis, Mississippi, and extended about 6 miles inland from the coast (about 12 miles along bays and rivers; Farris and others, 2007; fig. 1). Hurricane Rita's storm surge propagated up the Calcasieu River causing flooding in the Lake Charles area nearly 25 miles inland from the coast (Farris and others, 2007).

Geospatial data are critical for hurricane response and recovery activities and were used extensively during and after Hurricane Katrina and Hurricane Rita (Conzelmann and others, 2007; Greenlee, 2007; Hartley, 2007; Wilson and Cretini, 2007). Light detection and ranging (lidar) is a remote sensing technology that has advanced significantly in recent years to become a standard survey tool used by the mapping industry to collect very detailed, high precision measurements of land surface elevations (Stoker and others, 2006). Because of their high level of spatial detail and vertical accuracy, lidar data are an excellent geospatial data resource for use in low-relief hurricane-prone coastal areas and were applied in numerous response and recovery activities for Hurricane Katrina and Hurricane Rita (Gesch, 2007b; Sallenger and others, 2007; Stockdon and others, 2007). In an ongoing effort to improve the quality of topographic data for scientific applications, the U.S. Geological Survey (USGS) has been integrating lidar elevation data into its primary topographic database, the National Elevation Dataset (NED; Gesch, 2007a). Fortunately, high-resolution lidar elevation data for southern Louisiana were integrated into the NED prior to the 2005 hurricane season and thus were readily available for response to Hurricane Katrina and Hurricane Rita.

The lidar elevation data along the northern gulf coast provided the requisite high-accuracy base layer for storm-surge mapping and analysis. The Federal Emergency Management Agency (FEMA) has produced a set of maps and geographic information system (GIS) products for recovery from Hurricane Katrina (see [http://www.fema.gov/hazard/flood/recoverydata/katrina/katrina\\_about.shtm](http://www.fema.gov/hazard/flood/recoverydata/katrina/katrina_about.shtm)) and Hurricane Rita (see <http://www.fema.gov/hazard/flood/recoverydata/rita/index.shtm>) including high-water marks, storm-surge inundation limits, and surge-elevation contours. The work reported here makes use of some of the same data sources as the FEMA products but extends the storm-surge mapping to larger areas and provides additional derived storm-surge datasets through different presentation methods.

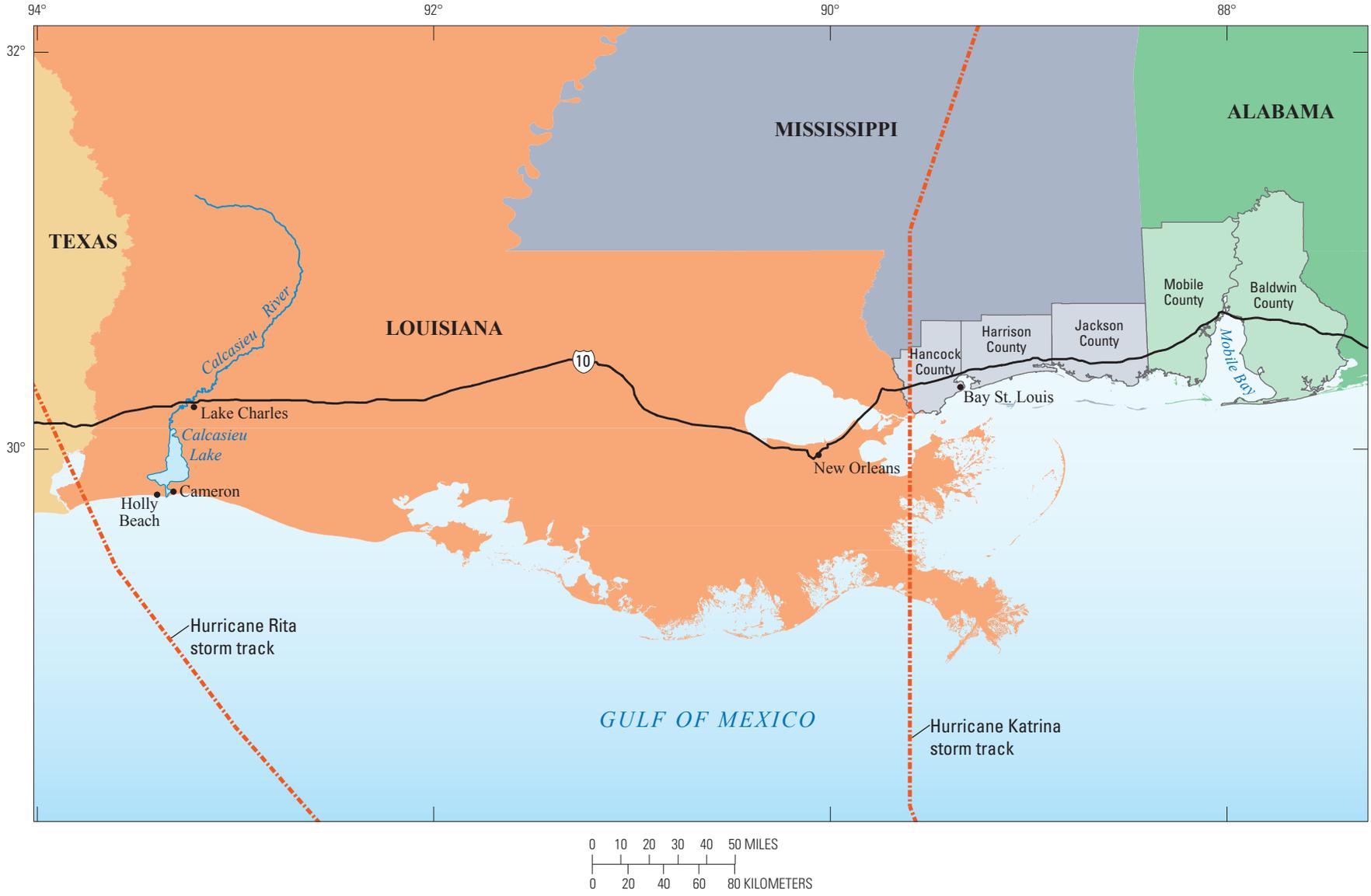


Figure 1. Location of study area and storm tracks of Hurricane Katrina and Hurricane Rita in 2005.

## Methods and Results: Hurricane Katrina

The storm surge from Hurricane Katrina had the highest peak of any surge that has been observed in the Gulf of Mexico (Turnipseed and others, 2007). In addition to the peak height, the significance of the storm surge is further evidenced by the extensive area that was impacted. FEMA flood recovery maps and corresponding products have been produced for Louisiana and Mississippi (<http://www.fema.gov/hazard/flood/recoverydata/katrina/index.shtm>), but the effects of the hurricane were significant along the Alabama coast as well (Knabb and others, 2006). In addition to the lidar elevation data available in the NED for Louisiana, lidar data for the three coastal counties in Mississippi and the two coastal counties in Alabama were also available as source data. However, the lidar data for Mississippi and Alabama were not yet processed to NED standards and had not been integrated into the seamless dataset. Working with five distinct lidar collections to produce a coherent high-resolution elevation base for storm-surge mapping was a significant challenge, but the successful completion of the processing was a key to providing the required regional data coverage (Stoker and others, in press). The need for storm-surge inundation maps can be immediate during hurricane recovery, and such data were developed quickly in response to Hurricane Katrina (Raber and Tullis, 2007). The work described here produced a maximum storm-surge dataset that covered a larger area than previous efforts and was based on surveyed high-water-mark elevations and tide-gage data that had been rigorously quality assured (Turnipseed and others, 2007).

To accurately map the extent and magnitude of the Hurricane Katrina storm surge onto the land surface, scientists needed a high-resolution, high-accuracy base-elevation layer. The statewide Louisiana lidar collection (Cunningham and others, 2004) provided data for the eastern Louisiana parishes affected by Katrina, whereas county-based lidar collections provided data for Mississippi and Alabama. A gridded (raster) elevation layer with a grid spacing of 1/9 arc-second (about

10 feet) was produced for integration into the NED. Details of the processing required to integrate the five diverse county-based lidar collections (table 1 and fig. 1) are described by Stoker and others (in press). Figure 2 shows a shaded relief portrayal of the seamless 1/9-arc-second NED layer that served as the high-resolution elevation base for Hurricane Katrina storm-surge mapping and analysis.

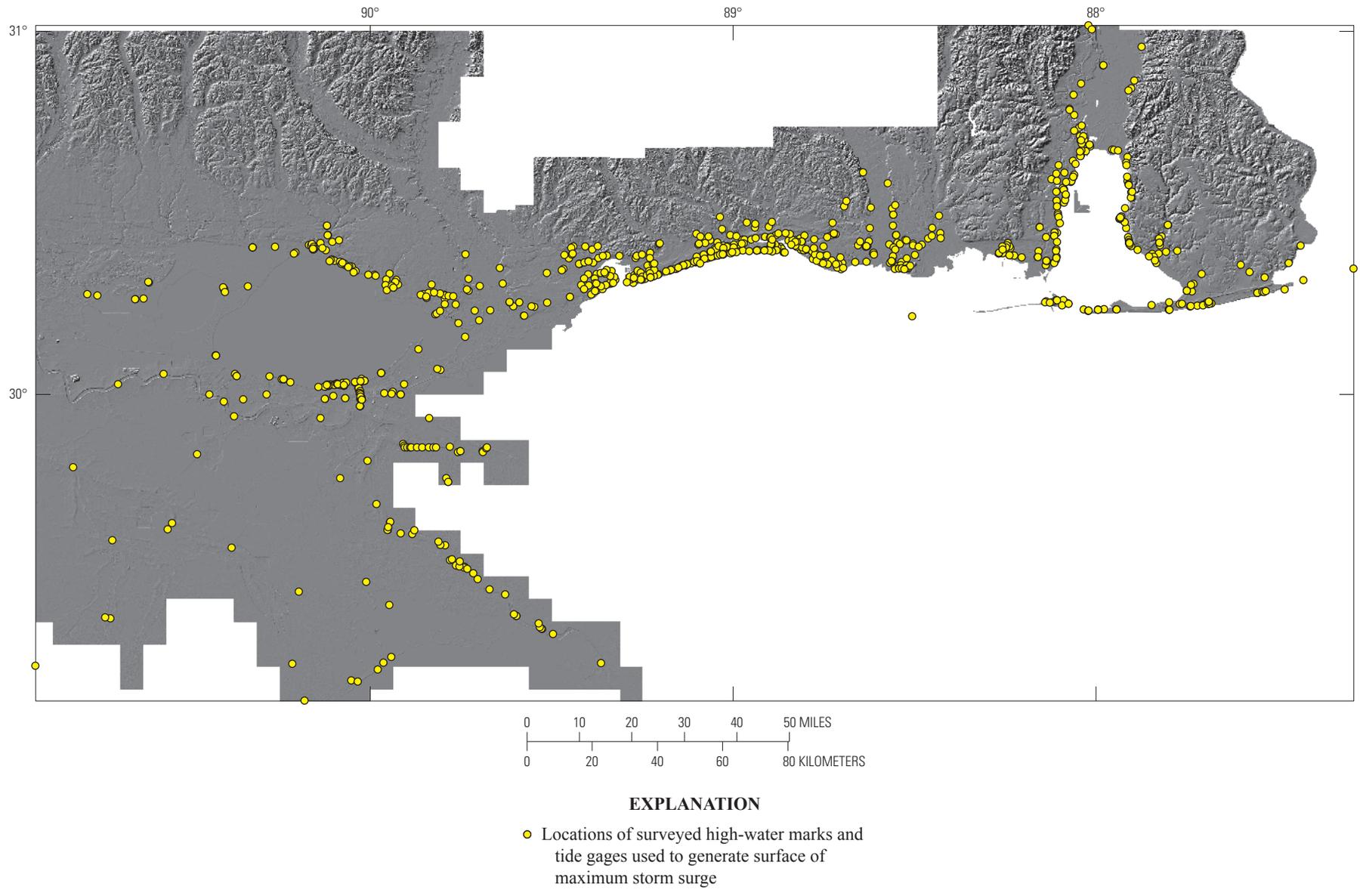
Shortly following landfall of Hurricane Katrina, survey crews from the USGS, FEMA, and U.S. Army Corps of Engineers began collecting data to document the storm surge. High-water marks were flagged and surveyed, and when combined with tide-gage data, these points formed a dataset of high-water elevations for more than 1,500 locations. Review and quality assurance of the points reduced this dataset to 842 elevations (fig. 2) that were used for subsequent GIS processing (Turnipseed and others, 2007; Stoker and others, in press). A continuous surface representing the peak storm surge (fig. 3) was interpolated from the 842 input elevation points by using the spline with barriers algorithm in ArcGIS. The barriers used to guide the surface generation were selected levees and natural drainage-basin divides. Use of the barriers resulted in an interpolated surface that modeled the actual attenuation of storm-surge heights and routing of the surge as it moved into the back bays and estuaries (Turnipseed and others, 2007; Stoker and others, in press). Figure 4 shows the effect of the barriers on the surface interpolation for an area along the Mississippi coast. The landward propagation of the modeled storm surge is hindered by the barriers; consequently, the water must flow around the end of the barriers to inundate the area behind the barriers (fig. 4). The study of Hurricane Katrina storm-surge inundation by Raber and Tullis (2007) also demonstrated the advantages of incorporating local barriers into area interpolation.

A Web viewer application ([http://topotools.cr.usgs.gov/Katrina\\_viewer/](http://topotools.cr.usgs.gov/Katrina_viewer/)) was developed for presentation of the Hurricane Katrina storm-surge datasets, including the base-elevation layer, the high-water marks, and the derived maximum storm-surge surface (fig. 5). The application makes use of Open Geospatial Consortium/Web Map Service technology,

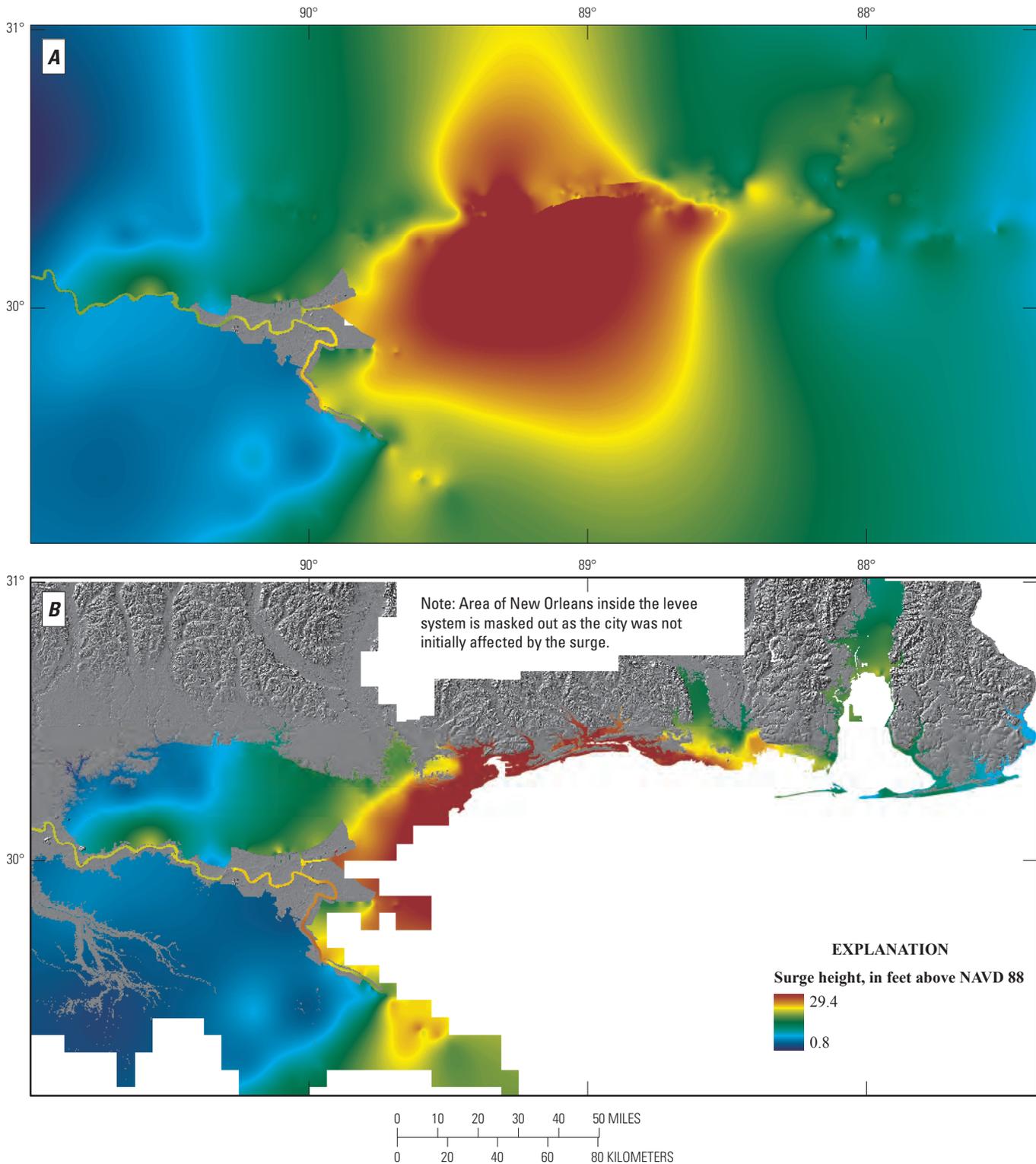
**Table 1.** Source data used to develop a high-resolution elevation base layer for Hurricane Katrina storm-surge mapping.

[Data included gridded digital elevation model (DEM) data, lidar point data in the industry standard LAS file format and in ASCII text format, and mass points and breakline (MPBL) data in the geographic information system industry standard Shapefile format]

Area	Format	Projection	Elevation units	Metadata available
Louisiana	5-meter DEM (raster)	Universal Transverse Mercator	Feet	Yes
Hancock County, Miss.	LAS binary (points)	Mississippi State Plane (meters)	Feet	Yes
Harrison County, Miss.	ASCII XYZ (points)	Mississippi State Plane (feet)	Meters	No
Jackson County, Miss.	LAS binary (points)	Mississippi State Plane (meters)	Feet	Yes
Mobile County, Ala.	LAS binary (points)	Alabama State Plane (feet)	Feet	Partial
Baldwin County, Ala.	Shapefile (MPBL)	Alabama State Plane (feet)	Meters	Partial

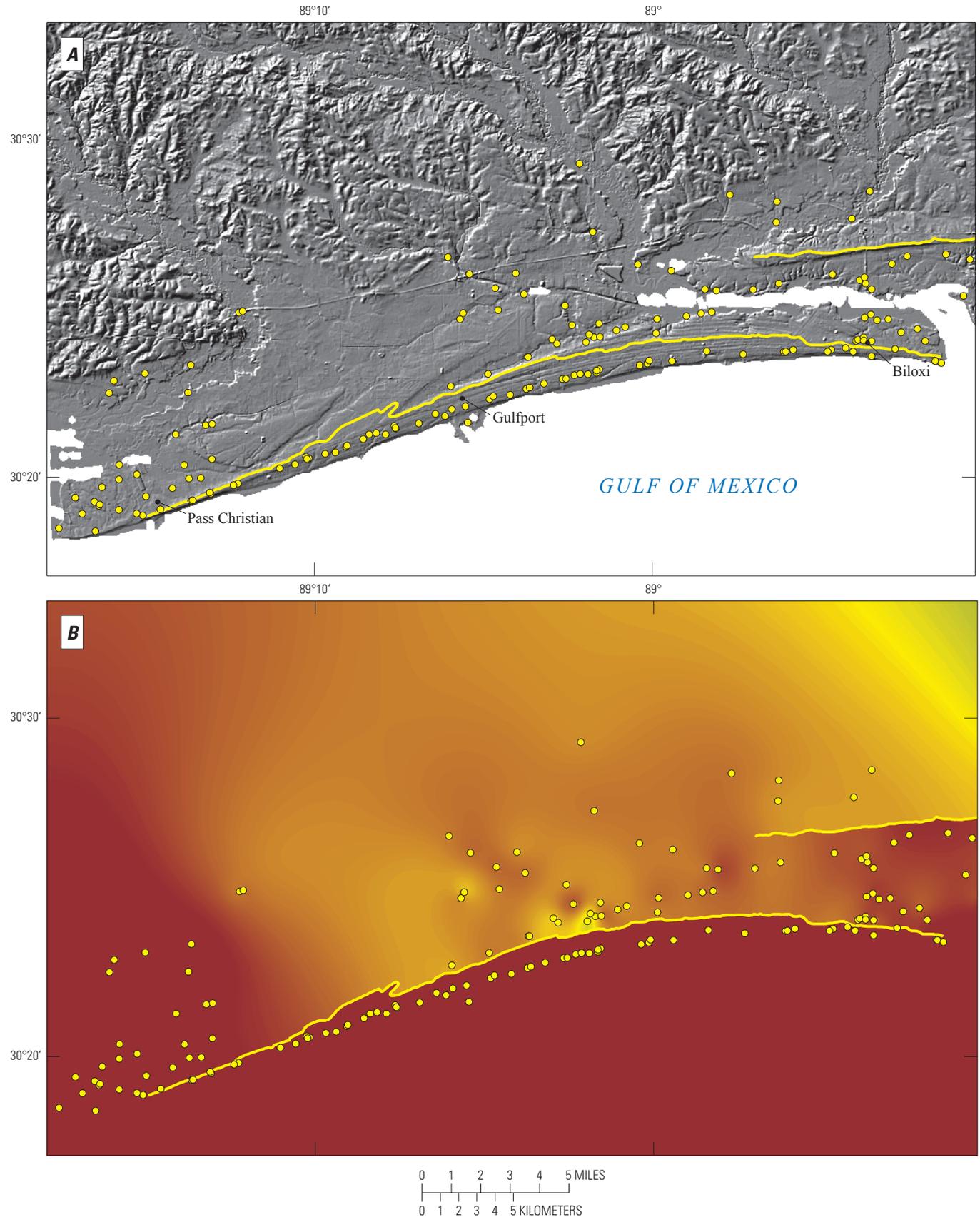


**Figure 2.** Shaded relief image of the 1/9-arc-second National Elevation Dataset (NED) layer for the Hurricane Katrina storm-surge impact zone in the northern Gulf of Mexico.



**Figure 3.** Surface of peak storm surge for Hurricane Katrina in the northern Gulf of Mexico area interpolated from high-water mark elevations. *A*, Output surface from the spline with barriers algorithm. *B*, The same surface after having been intersected with the lidar-derived elevation layer to depict the extent and magnitude of storm-surge inundation.

## 6 Mapping and Visualization of Storm-Surge Dynamics for Hurricane Katrina and Hurricane Rita



**Figure 4.** Example of the barriers used to guide the spline surface interpolation routine for an area along the Mississippi coast for modeling storm surge from Hurricane Katrina. *A*, Lidar elevation data with barriers (yellow lines) and high-water marks (yellow dots). *B*, Interpolated storm-surge surface (red represents the highest storm-surge elevations).

the industry standard for serving raster and vector GIS datasets on the Internet (Turnipseed and others, 2007; Stoker and others, in press). In addition to standard viewer functions to zoom, pan, and toggle layers and legends on and off, the Web application includes tools to read and display elevations from the lidar data and the storm-surge surface (fig. 6) and to display coincident land-elevation and storm-surge profiles for user-specified locations (fig. 7).

## Methods and Results: Hurricane Rita

The storm surge from Hurricane Rita reached well inland in southwestern Louisiana, affecting areas around Lake Charles and beyond to Interstate 10, more than 30 miles from the coast. The Louisiana communities of Holly Beach and Cameron were completely destroyed. The surge also affected areas in southeastern Louisiana that had been inundated during Hurricane Katrina (Farris and others, 2007).

FEMA has produced standard flood-recovery products for the parishes in southern Louisiana affected by Hurricane Rita, including surveyed high-water marks, surge-inundation limits, and surge-elevation contours (<http://www.fema.gov/hazard/flood/recoverydata/rita/index.shtml>). Hurricane Rita's storm surge has also been documented with an additional unique method. In the days prior to landfall, the USGS Louisiana Water Science Center deployed a network of portable sensors to record water levels and barometric pressure at sites along the gulf coast in eastern Texas and western Louisiana where Hurricane Rita was predicted to strike (fig. 8). The sensors recorded absolute pressure, either the force exerted by air (barometric pressure) or the weight of the water. In the case of inundation, the force exerted by the overlying water is converted to water levels (height measurements). Because the locations of the sensors are precisely surveyed after postsurge instrument recovery, the recorded water levels can be related to an absolute vertical datum, in this case NAVD 88. Collocated sensors that were not inundated recorded barometric pressure data that were used to correct the recorded water levels for changes in barometric pressure. Comparisons with high-quality manually surveyed high-water marks and USGS stream-gage data verified the accuracy of the sensor data. Details of the sensor deployment and recovery, data processing, and quality assurance of the storm-surge data from this experimental network are provided by McGee, Goree, and others (2006), and McGee and others (2007). The recorded water-level data and additional related information are available at <http://www.rustla.er.usgs.gov/surge/rita.htm>.

The sensors began recording pressure before hurricane landfall and continued recording every 30 seconds throughout the duration of the storm. The resulting dataset is an unprecedented documentation of storm-surge dynamics at a very fine temporal resolution over a broad area. In contrast to the surveyed high-water marks that had no timing or duration attributes, the water-level data from the sensor network

explicitly describe the magnitude of the surge at specific locations as a function of time. Maximum storm-surge heights of more than 14 feet were recorded east of Calcasieu Lake (sites LA11 and LA12 on figure 8) at about 2 a.m. on September 24, 2005.

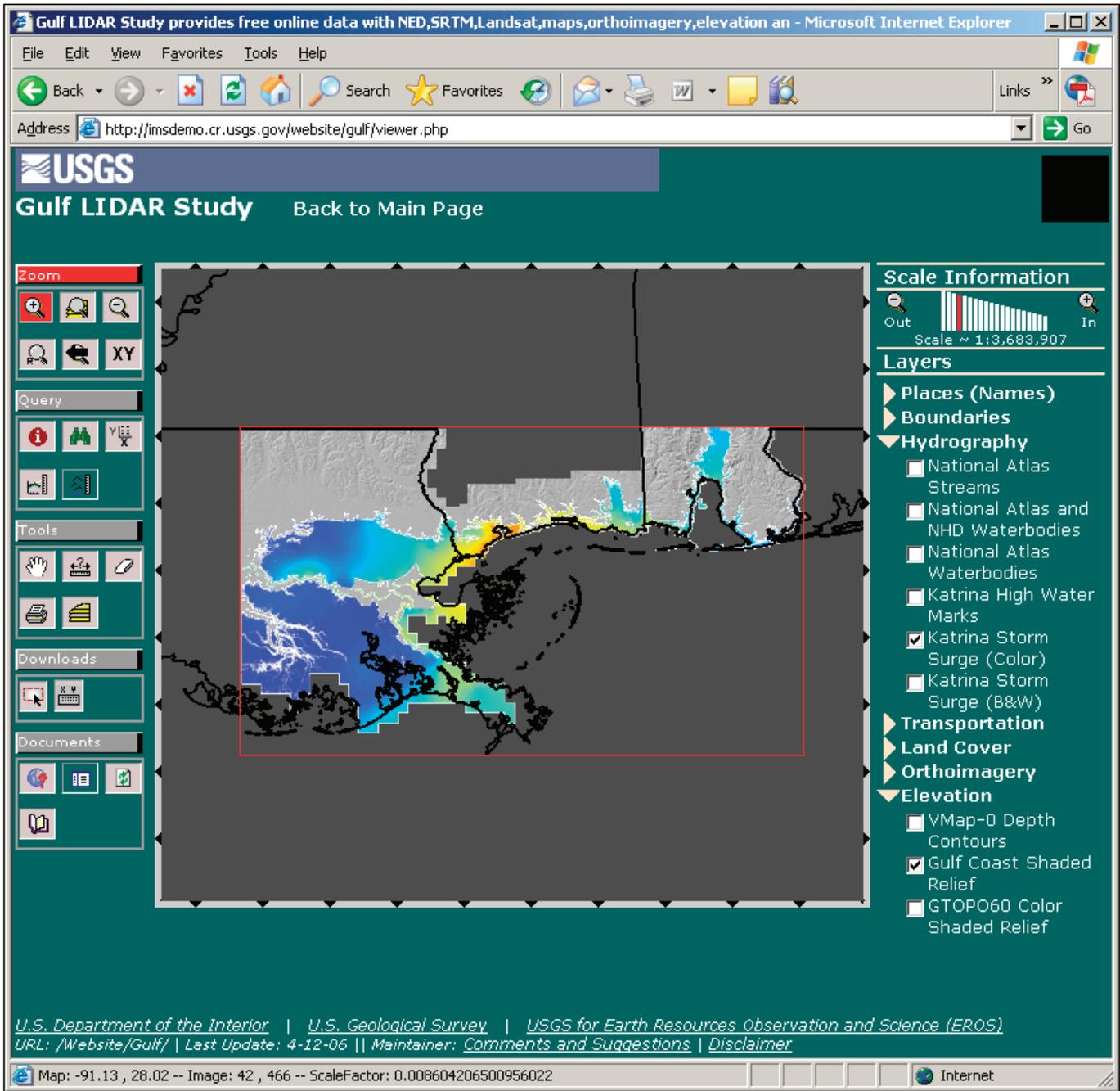
Because the temporal element of the storm surge is available in the sensor network dataset, which is unavailable in traditional storm-surge measurements, the propagation of the surge onto the land surface can be displayed as a time series of images (fig. 9). The water-level data from selected time slices were interpolated with a spline surface generation algorithm to create individual storm-surge surfaces tied to specific times. Each of these surfaces was intersected with elevation data from the NED, which included the Louisiana statewide lidar data, to generate storm-surge maps that indicated extent and depth of inundation. As depicted in Figure 9, the peak surge (orange to red colors on figure 9) came ashore between 1 a.m. and 4 a.m.

The temporal component of the water-level network dataset enables the analysis of storm-surge characteristics, such as calculating the propagation of peak water levels across the landscape (table 2; B. McGee, personal commun., 2006), that cannot be done with traditional surveyed high-water mark data. Standard data-visualization methods, such as the development of perspective views and contour maps, can also be used to display the temporal dynamics of the storm surge (fig. 10). Each technique offers a unique view of how the surge interacted with the landscape and offers clues about how the inundation was affected by natural and man-made features on the land surface.

## Discussion

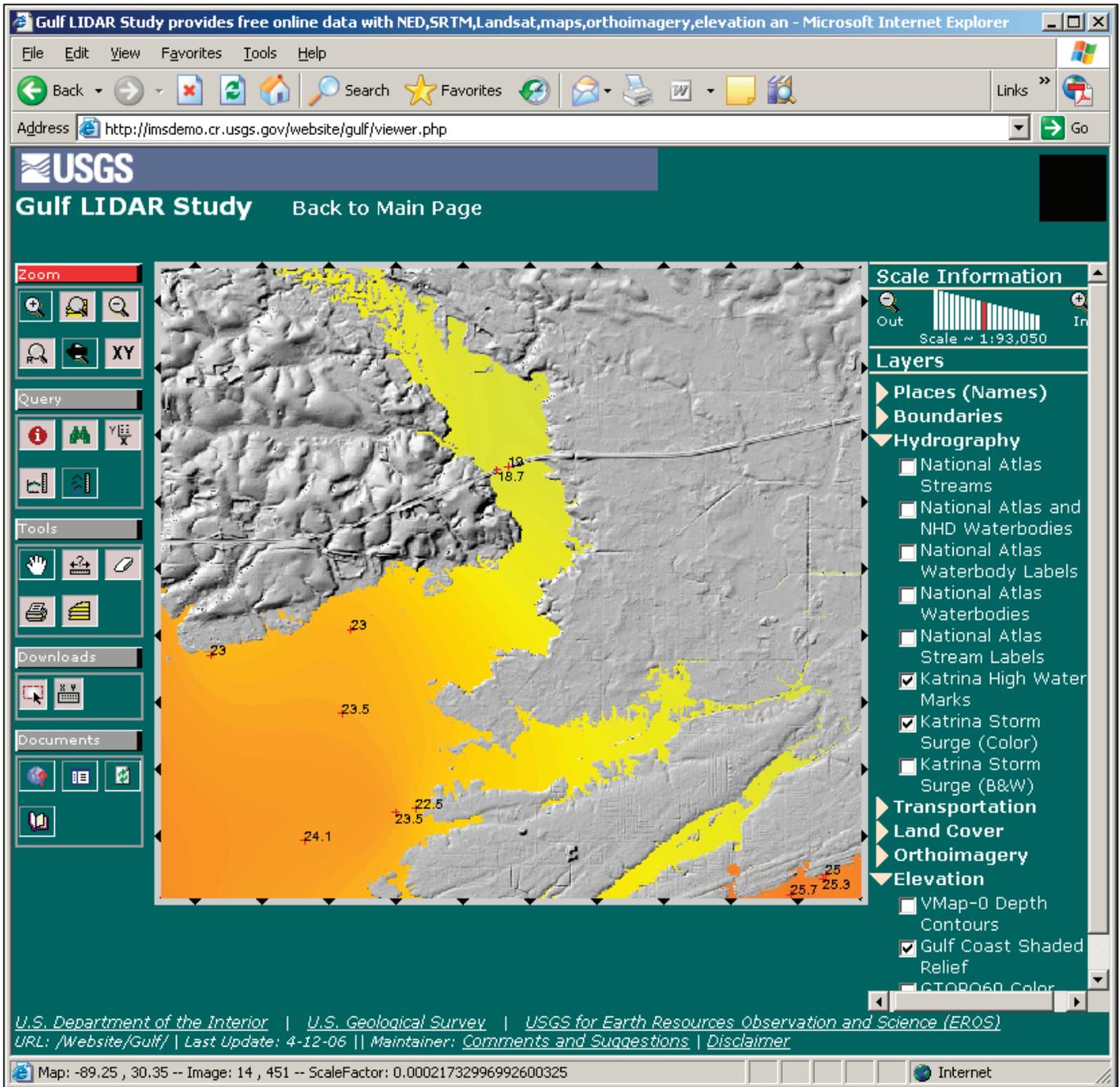
Because so much of a hurricane's impact results from the storm surge, it is important to know the extent and magnitude of the surge as accurately as possible. In the case of Hurricane Katrina, traditional map-based products derived from high-water surveys were produced by FEMA, but they do not cover the full extent of the storm-surge impact area. The peak storm-surge surface described here is a digital geospatial dataset that is GIS ready and covers a larger area than other map products. The Hurricane Katrina high-resolution storm-surge surface interpolated from quality-assured high-water marks allows spatially explicit overlay analysis to be done for studies of the surge's impact. It also facilitates simple dissemination of information about the storm surge as demonstrated in the data-display and elevation-query tools on the Web viewer application (figs. 5–7).

The temporal water-level dataset collected by a network of absolute-pressure sensors for Hurricane Rita is a unique resource that allows for development of derivative products and analyses that characterize the surge and aid in studies of its impacts. Traditionally, studies of a storm surge rely on visual flood evidence such as high-water marks, damage



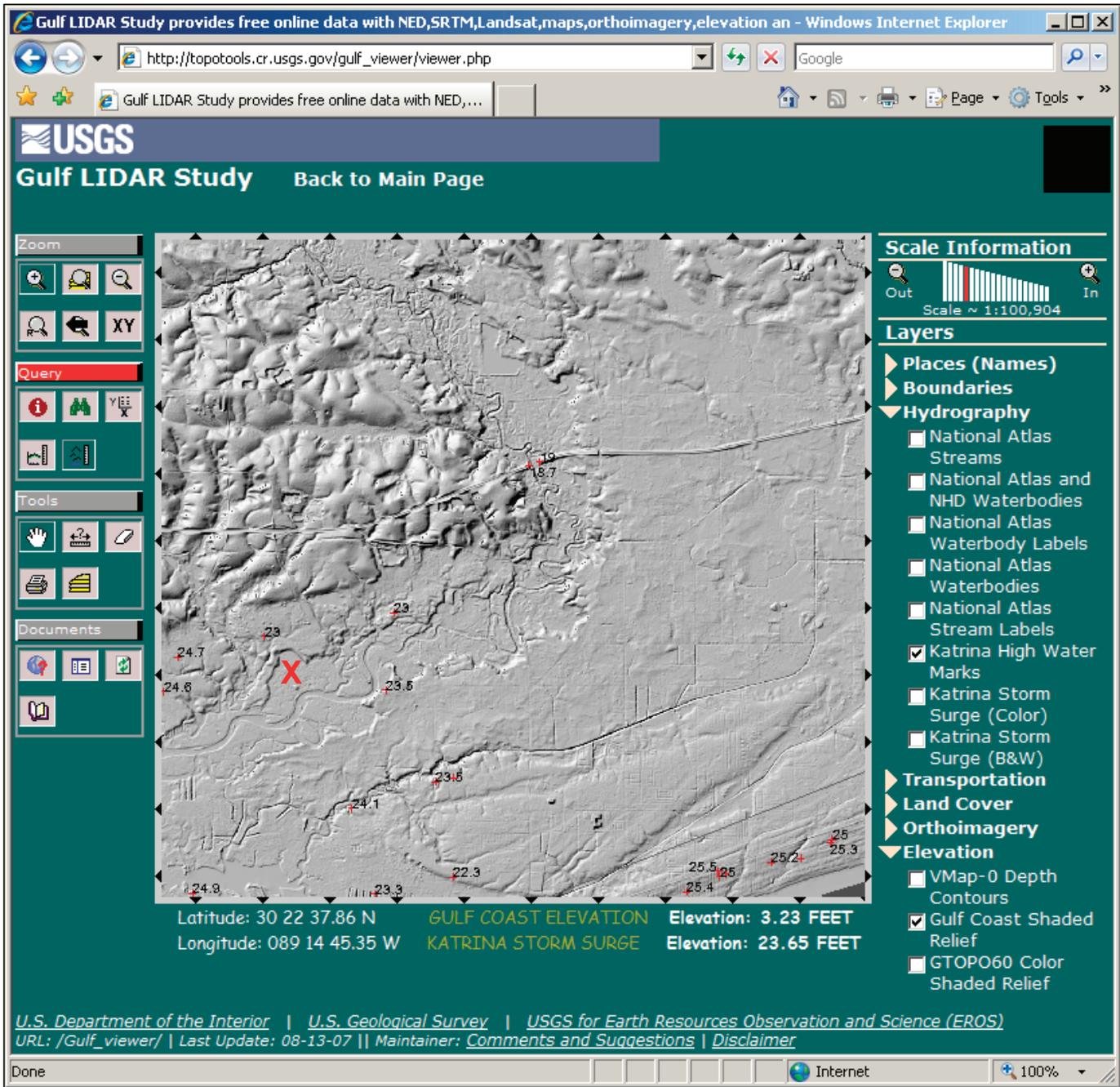
Initial screen view

Figure 5. Web viewer application ([http://topotools.cr.usgs.gov/Katrina\\_viewer/](http://topotools.cr.usgs.gov/Katrina_viewer/)) for display and manipulation of Hurricane Katrina storm-surge datasets.



After zooming in and displaying high-water marks

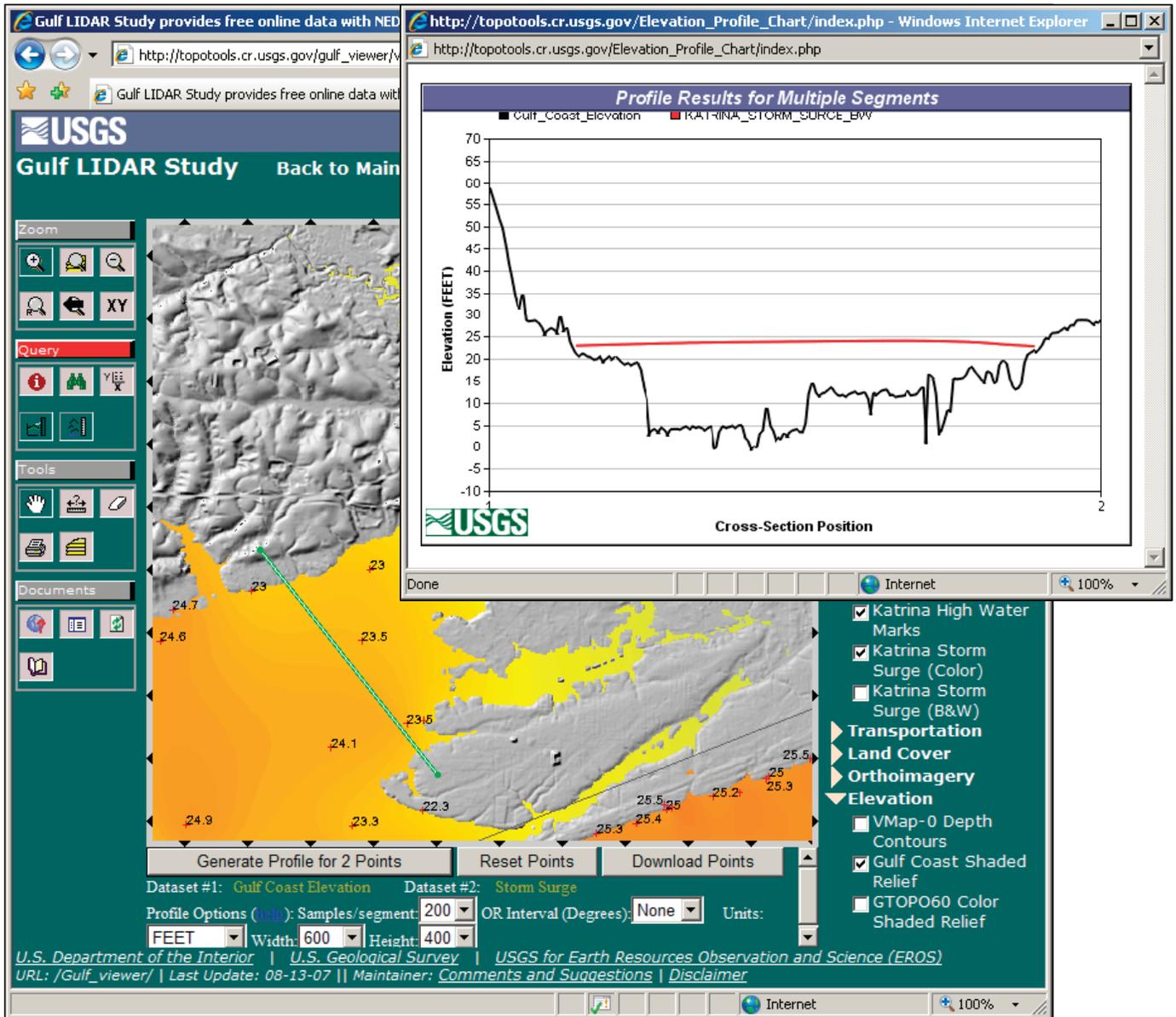
**Figure 5.** Web viewer application ([http://topotools.cr.usgs.gov/Katrina\\_viewer/](http://topotools.cr.usgs.gov/Katrina_viewer/)) for display and manipulation of Hurricane Katrina storm-surge datasets.—Continued



**EXPLANATION**

- Latitude and longitude are shown for location noted by “X”
- GULF COAST ELEVATION – Elevation from lidar base layer at location noted by “X”
- KATRINA STORM SURGE – Height of storm surge surface at location noted by “X”
- Difference between GULF COAST ELEVATION and KATRINA STORM SURGE (20.42 feet) is maximum depth of inundation at location noted by “X”

**Figure 6.** Elevation-query tool on the Web viewer application for display and manipulation of Hurricane Katrina storm-surge datasets.



**EXPLANATION**

- Profile trace from user-specified points. Only two points are represented in this example. Multiple points can be selected to define the profile trace. Pop-up window shows elevation profile between selected points.

**Figure 7.** Elevation-profile tool on the Web viewer application for display and manipulation of Hurricane Katrina storm-surge datasets.

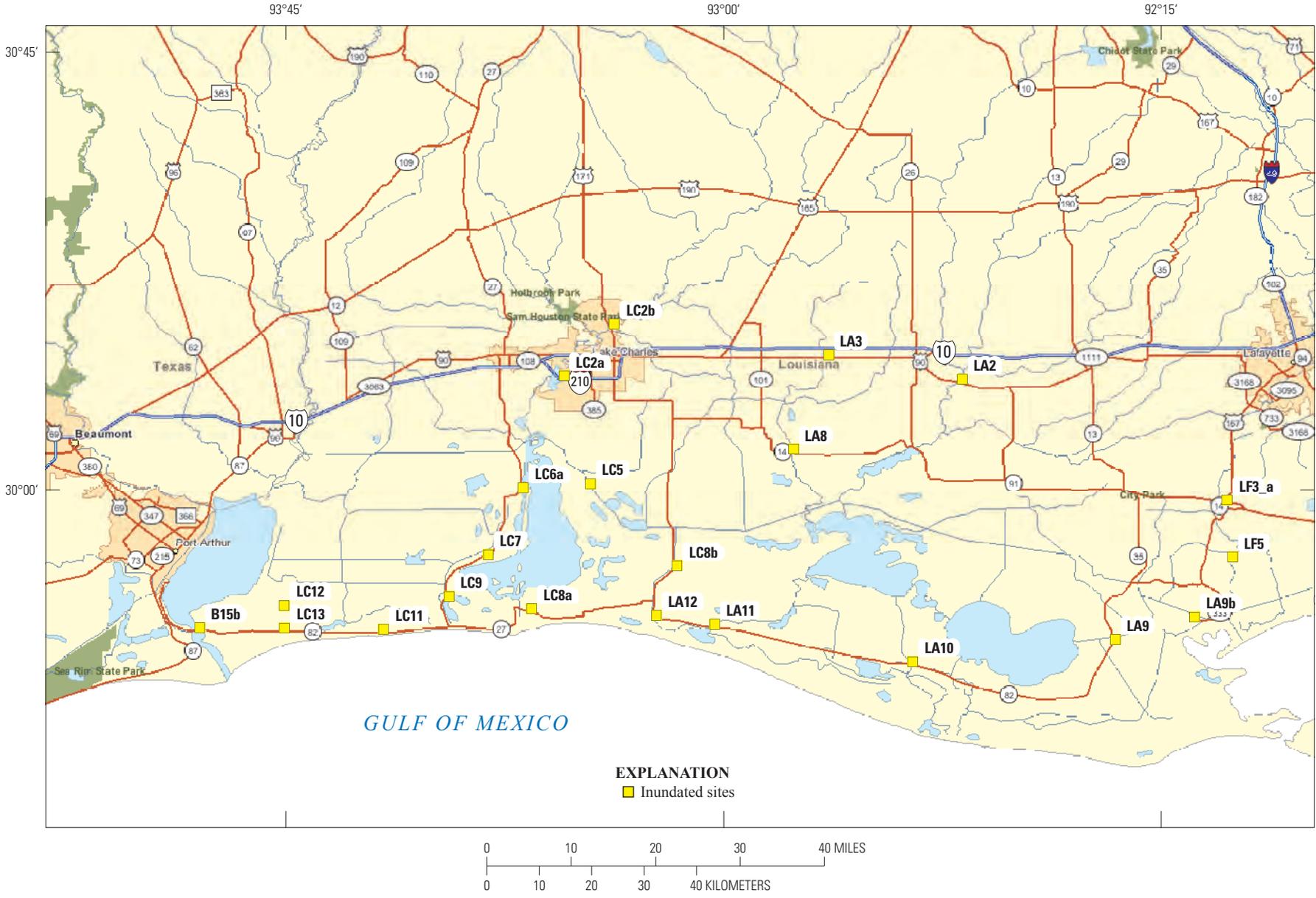
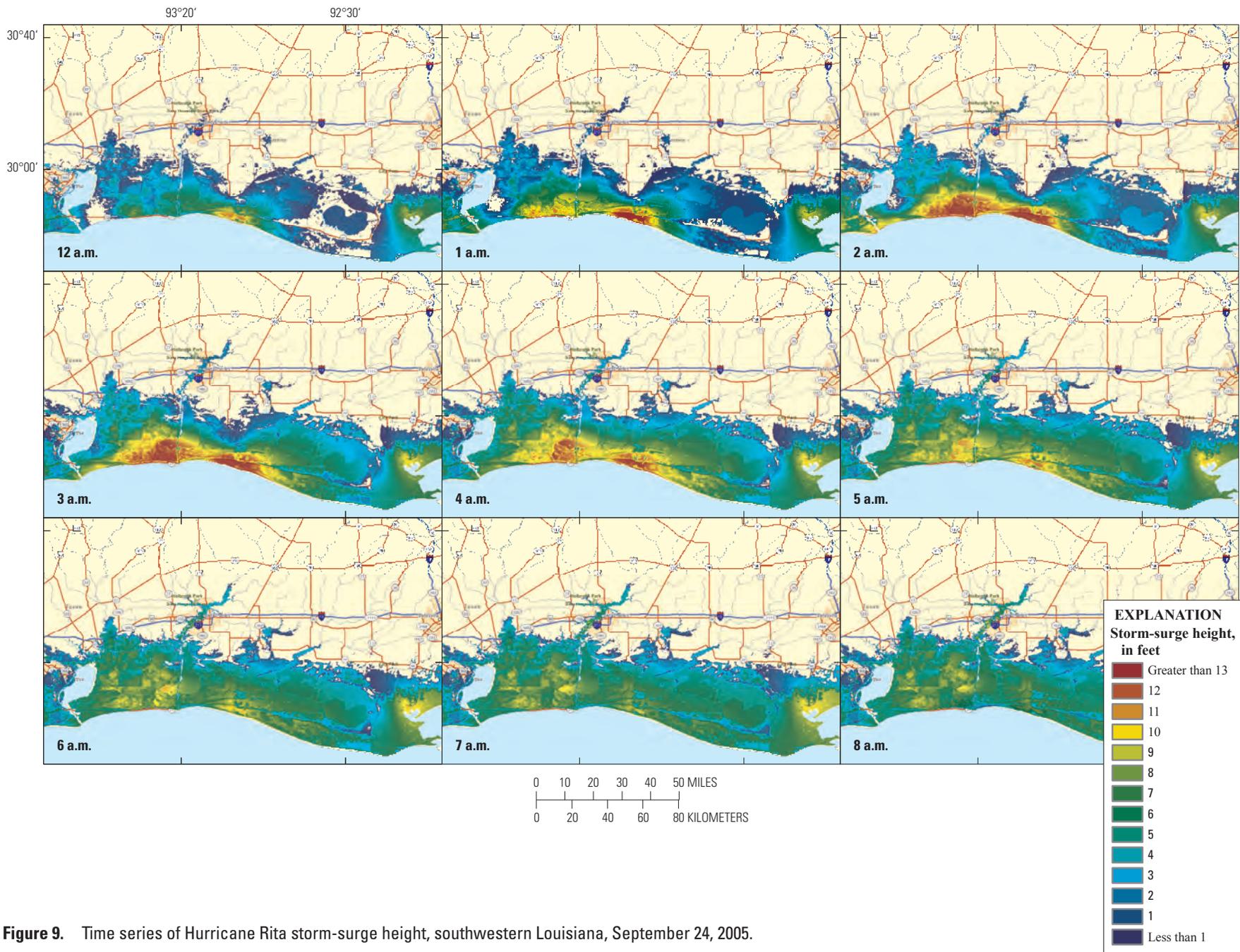


Figure 8. Locations of the absolute-pressure sensors deployed to record the Hurricane Rita storm surge, southwestern Louisiana.



**Figure 9.** Time series of Hurricane Rita storm-surge height, southwestern Louisiana, September 24, 2005.

**Table 2.** Propagation velocity of the peak water level of the storm surge from Hurricane Rita.

[See figure 8 for site locations. The velocity of the peak water level moving across the landscape was calculated from site LC8a at the coast, across Calcasieu Lake to site LC7, to site LC2a near Lake Charles, and up the Calcasieu River north of Interstate 10 to site LC2b]

Site	Time of peak	Travel time of peak from previous site (seconds)	Distance from previous site (feet)	Velocity from previous site (feet per second)
LC8a	9/24/2005 2:25:27	--	--	--
LC7	9/24/2005 3:32:27	4,020	35,013.1	8.7
LC2a	9/24/2005 9:49:57	22,650	116,625.7	5.1
LC2b	9/24/2005 14:08:57	15,540	42,991.4	2.8

assessments, and debris piles, none of which contain information about the timing, duration, or routing of the flood waters. The first-of-a-kind temporal water-level dataset for Hurricane Rita provides a wealth of information about how natural and man-made features affect storm-surge flooding (Berenbrock and others, 2008). Specialized maps of surge characteristics, such as depth, duration, and timing of peak arrival and water recession, can be generated and used in analyses to better understand surge behavior. Another potential use of the temporal data is for calibration and validation of computer storm-surge models, leading to better predictive capabilities for the models for future storms. An understanding of storm-surge dynamics is important for fully assessing observed hurricane impacts (Luther and others, 2007) and validating model predictions (Blain and Preller, 2007), and geostatistical approaches have been used to simulate a time series of storm-surge surfaces (Halford, 1995). With the advent of sensor deployment and distributed temporal storm-surge monitoring for Hurricane Rita, collection and analysis of data on storm-surge dynamics have become operational, and such monitoring has been employed for Hurricane Gustav (McGee and others, 2008) and Hurricane Ike (East and others, 2008) in 2008. An inventory of deployable water-level sensors is now staged in several locations in hurricane-prone areas in anticipation of future storms (R. Mason, personal commun., 2006). The possibility of using real-time telemetry from the sensor network to transmit water-level data is being considered for future deployments (McGee, Tollet, and Mason, 2006).

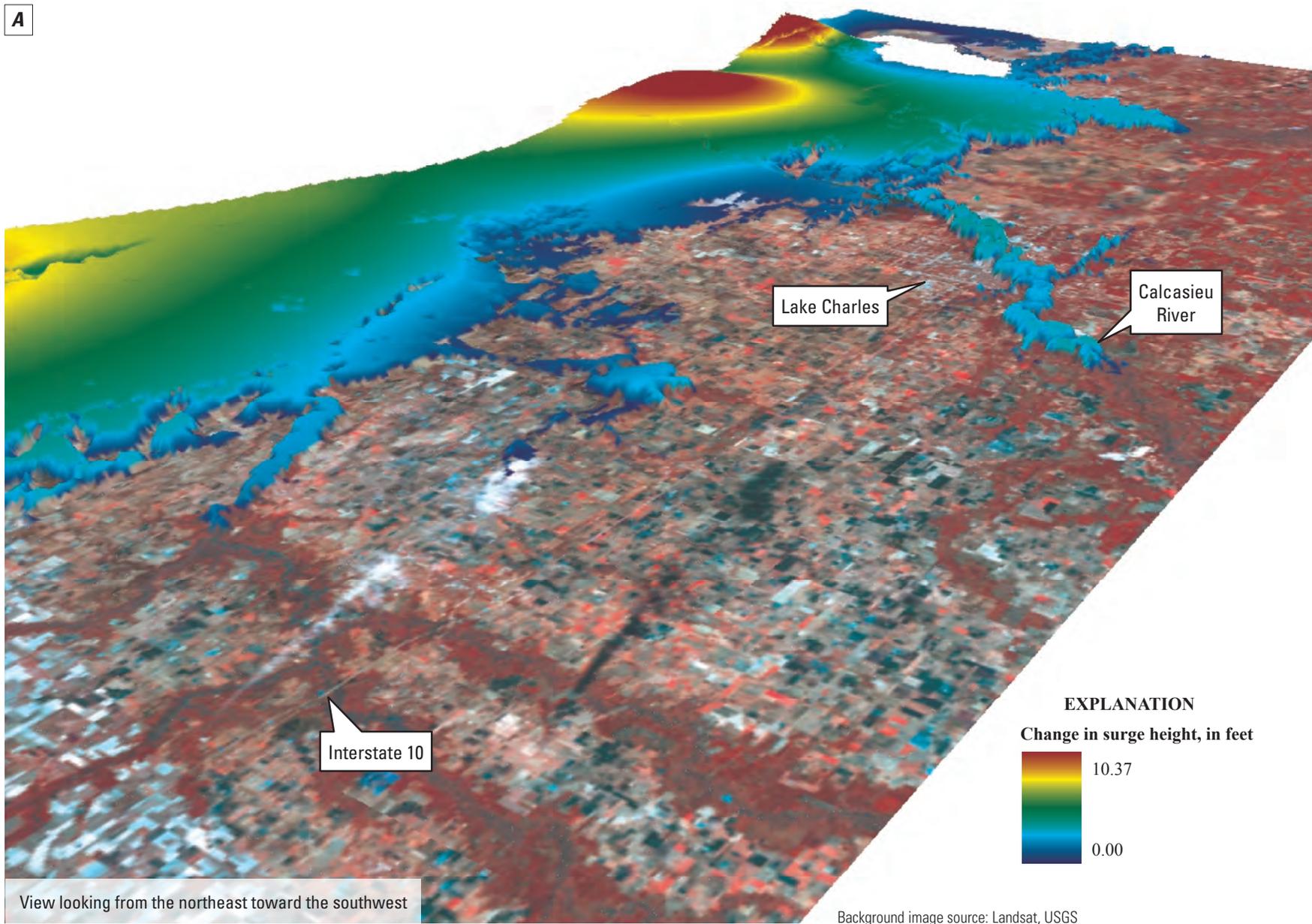
## Conclusions

The types of storm-surge maps, datasets, and visualizations demonstrated here can be useful for many studies of hurricane impacts, including ecological impact studies and assessments. The amount, timing, and duration of storm-surge floodwaters can have significant control over sediment transport, sediment deposition, and salinity conditions for wetland vegetation communities during and immediately following a storm. Spatially explicit storm-surge datasets can be advantageous for assessments of wetland impacts, especially if the

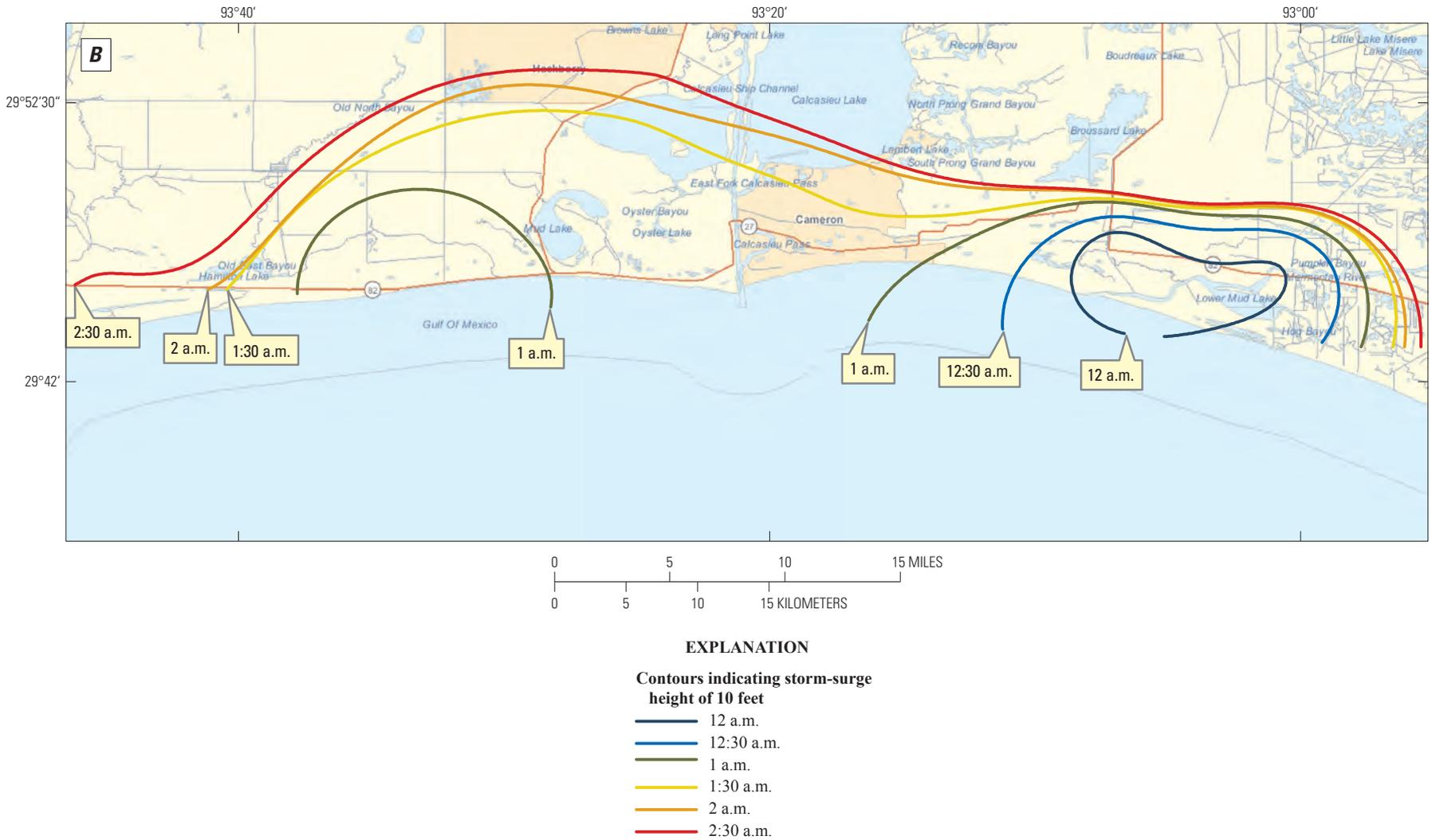
temporal components of the surge can be modeled as well. Temporal storm-surge maps could be especially useful for correlating with remote sensing measurements of land-surface and vegetation changes following storms (Barras, 2007). The continuous nature of modeled storm-surge surfaces interpolated from high quality point measurements overcomes the limitations of using only sparse point data to characterize storm surge over a broad area. The generation of regional storm-surge surfaces, in contrast to existing county-based products, allows production of more consistent derivatives like surge-height contours. The use of high-resolution, high-accuracy lidar elevation data in combination with precise storm-surge measurements allows detailed knowledge of the depth and extent of inundation to be brought into impact assessments and future mitigation planning scenarios. The ready availability of preassembled, consistent regional coverage of high quality lidar data facilitates their timely usage in hurricane response and recovery operations. The geospatial-data user community has recognized the usefulness of lidar as a means to provide highly detailed and accurate data for base-elevation mapping and vegetation studies, and there is significant interest in developing an initiative for a national lidar collection for the United States (Stoker and others, 2007, 2008). Such an initiative would provide invaluable data for hurricane recovery, impact assessments, and mitigation planning over the entire area of the United States subject to tropical cyclones.

## Acknowledgments

The contributions of the following individuals are gratefully acknowledged: Van Wilson (USGS) and Phil Turnipseed (USGS) for help with Hurricane Katrina data processing and project initiation; Robert Mason (USGS), Ben McGee (USGS), and Charles Berenbrock (USGS) for advice and encouragement on processing of the Hurricane Rita data and for help with graphics; Dean Tyler (USGS) and Matt Cast (SGT, Inc.) for dataset and Web viewer development; and Jordan Menig (SGT, Inc.), Jason Stoker (USGS), Chuck Nelson (SGT, Inc.), and Mike Oimoen (SGT, Inc.) for lidar data collection, lidar processing, and NED production.



**Figure 10.** Perspective view and contours used to display storm-surge features. *A*, Perspective view of the change in the Hurricane Rita storm-surge height over a 3-hour period (12 a.m. to 3 a.m.) on September 24, 2005. The surge came ashore in two distinct domes that inundated areas with up to 10 feet of water in only 3 hours. Sensors along the Calcasieu River measured increasing water levels from not only the surge but also runoff from the storm's precipitation. *B*, Contours derived from interpolated storm-surge surfaces for specific time slices during early advance of the surge. In this case, the contours show the location of 10 feet of water at indicated times.



**Figure 10.** Perspective view and contours used to display storm-surge features. *A*, Perspective view of the change in the Hurricane Rita storm-surge height over a 3-hour period (12 a.m. to 3 a.m.) on September 24, 2005. The surge came ashore in two distinct domes that inundated areas with up to 10 feet of water in only 3 hours. Sensors along the Calcasieu River measured increasing water levels from not only the surge but also runoff from the storm’s precipitation. *B*, Contours derived from interpolated storm-surge surfaces for specific time slices during early advance of the surge. In this case, the contours show the location of 10 feet of water at indicated times.—Continued

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Publishing support provided by:  
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