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Integrating Disparate Lidar Datasets for a Regional Storm Tide Inundation Analysis of Hurricane Katrina

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ABSTRACT

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Hurricane Katrina was one of the largest natural disasters in U.S. history. Due to the sheer size of the affected areas, an unprecedented regional analysis at very high resolution and accuracy was needed to properly quantify and understand the effects of the hurricane and the storm tide. Many disparate sources of lidar data were acquired and processed for varying environmental reasons by pre- and post-Katrina projects. The datasets were in several formats and projections and were processed to varying phases of completion, and as a result the task of producing a seamless digital elevation dataset required a high level of coordination, research, and revision. To create a seamless digital elevation dataset, many technical issues had to be resolved before producing the desired 1/9-arc-second (3meter) grid needed as the map base for projecting the Katrina peak storm tide throughout the affected coastal region. This report presents the methodology that was developed to construct seamless digital elevation datasets from multipurpose, multi-use, and disparate lidar datasets, and describes an easily accessible Web application for viewing the maximum storm tide caused by Hurricane Katrina in southeastern Louisiana, Mississippi, and Alabama.

ADDITIONAL INDEX WORDS: *lidar, data, Hurricane Katrina, digital elevation models, storm tide, Northern Gulf of Mexico*

INTRODUCTION

Hurricane Katrina caused the largest natural disaster in U.S. history after slamming into the Gulf Coast, with the eye of the storm hitting about 55 km east of New Orleans (Turnipseed *et al.*, 2007). Although the storm initially brought more destruction to areas along the Mississippi and Louisiana coast, several levees protecting New Orleans failed the following day, and the city, about 80% of which is below sea level, was flooded. The flooding in New Orleans and the hurricane storm tide that impacted the Gulf of Mexico coast in Mississippi and southeast Louisiana killed hundreds, made homeless tens of thousands more, and triggered a massive relief effort that is ongoing (Travis, 2005). It has been estimated that Hurricane Katrina caused the loss of more than 1,800 human lives and about $81 billion in damage (Turnipseed *et al.*, 2007).

In addition to the many rescue and recovery efforts that were initiated immediately after the storm, there was a strong need to quickly ascertain the areas inundated by storm tide waters for rescuers and assess wind and flood damage (Raber and Tullis, 2007). City planners, insurance companies, and other groups needed this type of information to make educated emergency response decisions. The U.S. Geological Survey (USGS) began flagging and surveying high-water marks (HWMs) along the Mississippi coast on September 1, 2005 to compare the peak surge to the peak surge of Hurricane Camille in 1969 (K.V. Wilson, Jr., USGS Mississippi Water Science Center, written com., 2005). After Hurricane Katrina, the USGS began the detailed task of obtaining and processing existing pre-Katrina Light Detection and Ranging (lidar) data throughout the region. Lidar mapping has been increasingly accepted as an effective and accurate technology for producing high-resolution elevation data for bare earth, vegetation, and structures (Lefsky *et al.* 2002; Stoker *et al.*, 2006). High level spatial detail and vertical accuracy of elevation measurements make lidar remote sensing an excellent mapping technology for use in low-relief hurricane-prone coastal areas (Farris *et al.*, 2007; Gesch, 2009).

By converting lidar data into bare ground topography, vegetation, or structural morphologic information, extremely accurate, high-resolution digital elevation models (DEMs) can be derived to visualize and quantitatively represent scenes in three dimensions. Farris *et al.* (2007) documented the many technologies, including lidar data mapping of New Orleans, used in the USGS response to the devastation caused by Katrina. In addition to high-resolution bare earth digital elevation models used in this effort, other lidar-derived products included quantitative estimates of vegetative features, such as canopy height, canopy closure, and biomass (Lefsky *et al.*, 2002), and models of urban areas such as building footprints and three-dimensional city models (Maas, 2001). However, bare ground topography accuracy can be adversely affected if flooding of stream channels and floodplains is taking place during lidar acquisition.

Many disparate sources of lidar data have been acquired and processed for varying environmental reasons by pre- and post-Katrina projects (Stockdon *et al.*, 2009). The datasets were in several formats and projections and were processed to varying phases of completion, and as a result the task of producing a seamless digital elevation dataset required a high level of coordination, research, and revision. To create a seamless digital elevation dataset, many technical issues had to be resolved before producing the desired

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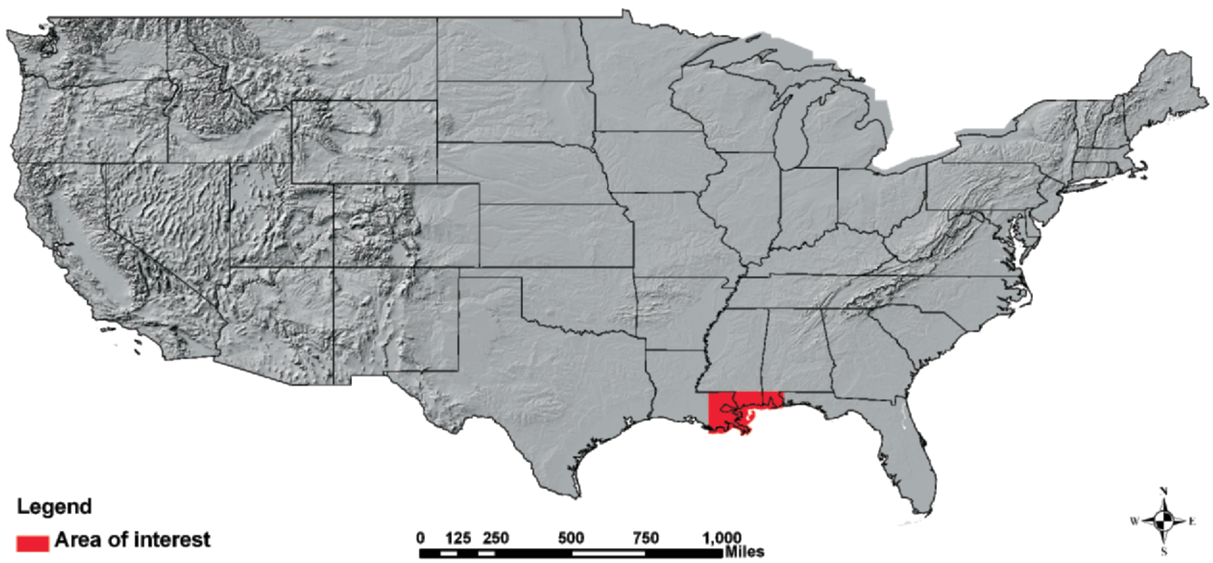

Figure 1. Area of southeastern Louisiana, Mississippi, and Alabama for which a high-resolution elevation and maximum storm tide dome dataset was created.

1/9-arc-second (3 meter) grid needed as the map base for projecting the Katrina peak storm tide in the affected coastal region. This report presents the methodology that was developed to construct seamless DEMs from multipurpose, multiuse, and disparate lidar datasets and describes an easily accessible Web application for viewing the maximum storm tide caused by Hurricane Katrina in southeastern Louisiana, Mississippi, and Alabama.

Background and History of the Storm

Hurricane Katrina made initial landfall on the northern Gulf of Mexico coast early on August 29, 2005, first slamming into the Mississippi River delta near Buras, Louisiana, and later, the Pearl River delta at the Louisiana-Mississippi border (Knabb *et al.*, 2005).

Four days earlier in the late evening of August 25, 2005, less than two hours before Tropical Storm Katrina made first landfall on the southeastern Atlantic coast of Florida, the storm was upgraded to a Category 1 (Saffir-Simpson Hurricane Scale) hurricane after forming as a tropical depression over the Bahamas on August 19 (Knabb *et al.*, 2005). After spending only six hours over land in southern Florida, Tropical Storm Katrina reentered open water in the southeastern Gulf of Mexico in the early morning of August 26, just north of Cape Sable (Knabb *et al.*, 2005). During the next three days, Katrina rapidly intensified from a tropical storm to a Category 5 hurricane by late in the afternoon of August 28 with a maximum peak wind speed intensity of greater than 170 miles per hour (mph). This maximum intensity occurred about 170 nautical miles southeast of the mouth of the Mississippi River and helps explain the extreme magnitude of the storm tide height that occurred when Hurricane Katrina made landfall (Knabb *et al.*, 2005). During Katrina's maximum intensity, tropical storm and hurricane force winds extended 200 and 90 nautical miles from the eye, respectively (Knabb *et al.*, 2005). These conditions defined Hurricane Katrina as one of the most intense and largest storms to ever form in the northern region of the Gulf of Mexico (Knabb *et al.*, 2005).

After some erosion of the eye wall late on August 28, Hurricane Katrina turned northward to make landfall near Buras, Louisiana, with sustained winds of about 125 mph, making the storm a strong Category 3 hurricane. Hurricane Katrina then continued northward, briefly reentering the Gulf of Mexico before making final landfall near the mouth of the Pearl River at the Louisiana-Mississippi boundary as a very dangerous Category 3 storm with an estimated intensity of 120 mph sustained winds. Knabb *et al.* (2005) explained that although Hurricane Katrina had weakened from a Category 5 to a Category 3 hurricane in the last eighteen hours before landfall, the radial extent of tropical storm and hurricane force winds remained about the same, which further explains the extreme storm tide in southeastern Louisiana and the Mississippi Gulf coastal region. Katrina weakened rapidly after its final landfall near the Louisiana-Mississippi border, becoming a Category 1 storm by 1800 UTC on August 29 in central Mississippi. The storm was downgraded to tropical storm status early on August 30, after five days as a hurricane in the Gulf of Mexico (Knabb *et al.*, 2005).

Study Area

Due to the sheer size of Hurricane Katrina, an unprecedented regional analysis at very high resolution and accuracy was needed to properly quantify and understand the effects of the hurricane and the entire storm tide. Lidar data from disparate sources existed for Baldwin and Mobile Counties in Alabama, for Jackson, Hancock, and Harrison Counties in Mississippi, and for the eastern parishes in Louisiana (Figure 1). These separate datasets encompassed the majority of the affected area of Hurricane Katrina and its associated storm tide and compose the region addressed in this report.

METHODS

The USGS and its partners began acquiring, collating, and preprocessing lidar datasets immediately following the landfall of Hurricane Katrina. Lidar data were obtained from multiple

Table 1. *Area location, format, projection, elevation units, and existence of metadata for lidar datasets used in the construction of a seamless high-resolution elevation dataset for areas in Louisiana, Mississippi, and Alabama affected by storm tide from Hurricane Katrina.*

Area	Format	Projection	Elevation Units	Metadata?
Eastern Louisiana Parishes	5-m DEM (raster)	UTM	Feet	Yes
Hancock County, MS	LAS binary (points): Reprocessed with breaklines added	MS State Plane (meters)	Feet	Yes
Harrison County, MS	ASCII XYZ (points) & EBN binary: Reprocessed with breaklines added	MS State Plane (feet)	Meters	No
Jackson County, MS	LAS binary (points): Reprocessed with breaklines added	MS State Plane (meters)	Feet	Yes
Mobile County, AL	LAS binary (points) w/ CAD breaklines	AL State Plane (feet)	Feet	Partial
Baldwin County, AL	ESRI Shapefiles: Mass points and breaklines	Al State Plane (feet)	Meters	Partial

sources, including a private company, local and state agencies, and Federal bureaus, such as the National Oceanic and Atmospheric Administration (NOAA), the USGS, and the U.S. Army Corps of Engineers (USACE).

Many disparate sources of lidar data were acquired and processed for individual projects to accomplish various tasks pre- and post-Katrina. The original datasets were in several different formats and projections and were processed to varying phases of completion before they were acquired for this project. Some of these data sets already existed in a bare earth, ready-to-use format, and were easily downloadable from the USGS National Elevation Dataset (NED) (Gesch *et al.*, 2002). Some of the raw point cloud data were already available and being processed for the USGS Center for Lidar Information Coordination and Knowledge (CLICK) database (Stoker *et al.*, 2006).

The lidar data were in various file formats and projections and represented different levels of processing. The task of producing a seamless digital elevation dataset required a high level of development, coordination, and revision. To create a seamless digital elevation dataset, many technical issues had to be resolved before producing the desired 1/9-arc-second (3-meter) grid needed as the map base for projecting the Katrina maximum storm tide in the affected coastal region. Differences in datums, projections, units, and file types created a need to standardize the inputs in order to create a regional product. The end product was an ESRI ArcGIS GRID in a geographic coordinate system, which is the standard deliverable format for the NED.

Southeastern Louisiana Datasets

Lidar data that were already bare-earth processed and gridded into an acceptable Digital Elevation Model (DEM) format were available from southeastern Louisiana parishes. The Louisiana data were projected in Universal Transverse Mercator (UTM) Zone 15-North-Meters, North American Datum of 1983 (NAD 83). The original source DEM resolution was 5 m x 5 m, and the data were resampled to 1/9-arc-second grids in ArcGIS to be consistent in resolution (3 meters) with the other datasets. Although the datasets were resampled to a 3-m resolution, the data were originally acquired and processed at a 5-m resolution.

Mississippi Gulf Coast Datasets

This project created a seamless dataset for the three counties that border the Gulf of Mexico in Mississippi (i.e., Hancock, Harrison, and Jackson Counties) by processing lidar data of each county separately and then merging them into a single dataset. The Hancock and Jackson County lidar data were delivered as binary laser file format (LAS) files in State Plane Meters Mississippi East NAD 83, with elevation data (z-values) in feet. Initially, these LAS files were preprocessed and point data were classified as bare or non-bare. Because of the large size of the LAS files, the data were tiled to more efficiently manage the processing. Each tile was interpolated to a raster format using the Natural Neighbor algorithm in ArcGIS to convert the data from points to 1/9-arc-second grids (ESRI, 2004).

The Harrison County lidar data were delivered as bare earth ASCII comma-delimited text files, as well as proprietary Earthdata* binary (EBN) files. These data were projected in State Plane Feet Mississippi East feet NAD 83, although the z-values were in meters and not feet. These data were converted to feet for compliance with vertical units in the Jackson and Hancock Counties' datasets before being preprocessed, tiled, and interpolated into 1/9-arc-second grids. These data were processed using software to process the data to surfaces, and then to lattices, which were converted into 1/9-arc-second grids for use in ArcGIS*.

Alabama Datasets

Two coastal Alabama counties (Baldwin and Mobile) were significantly affected by the Hurricane Katrina storm tide. The Mobile County, Alabama lidar data obtained by the USGS were LAS binary files with breaklines as computer-aided drafting files. The data were in State Plane Feet Alabama West NAD83 with z-values in feet. The files were processed using Terrascan* and Terramodel* to create surfaces with breaklines, and then output into lattice grid formats for conversion into ArcGIS compliant grids. The Baldwin County, Alabama lidar data were acquired as mass points and breaklines using ArcGIS shapefile format. These data were projected in State Plane Feet Alabama West NAD83 with z-values in feet. The data were converted to Triangulated Irregular Networks (TINs), and breaklines were added before they could be converted to grids. Table 1 summarizes the differences among datasets for Louisiana, Mississippi, and Alabama.

Postprocessing Techniques

After the Mississippi data were completely processed once, the lidar points were completely reprocessed to add in the breakline information. Instead of using the Natural Neighbor interpolation in this process, each binary dataset was converted to an ArcGIS shapefile, and then converted to TINs. The breakline data were then incorporated into the TINs, and the files were converted to ArcGIS 1/9-arc-second grids.

In all, 182 gigabytes (GB) of lidar data were processed for five counties in Mississippi and Alabama. The datasets for Mississippi and Louisiana were seamlessly integrated using ASSEMBLE, a custom program used for processing the National Elevation Dataset (NED) and ArcSDE (Gesch *et al.*, 2002). All datasets were projected into a geographic coordinate system for use in the ASSEMBLE program. The ASSEMBLE program mitigated all noticeable dataset seams and other edge boundary anomalies. For example, a root mean square error (RMSE) of +/- 15 cm for two adjoining projects could equate to a difference of 30 cm at the boundaries of the two datasets, producing an obvious edge. Edge matching routines in the ASSEMBLE program reconcile discontinuities by forcing a fit at the seam and spreading the residuals over a large area. The degree of mismatch at each point along a seam is computed by comparing the observed slope across the boundary to the anticipated slope, as estimated from the nearby terrain. Half of this estimated mismatch is subtracted from the high posting and added to the low posting. The change at each border cell is then smoothly spread out and away from the seam by adding the surrounding cells as an inverse distance weighted portion of the adjustment. The cumulative effect of these adjustments along a seam is similar to that produced by nonlinear "rubber-sheeting" techniques developed for planimetric data, although in this case only z-values are shifted. This method necessarily introduces fairly large shifts near large discontinuities; changes in relative elevation are actually quite small. At the end of the process, slight second-order discontinuities may remain, both because the act of adjusting postings in the neighborhood of a seam has changed the definition of "anticipated slope" and because of slope errors in the DEMs. Finally, the Mean Profiler filter is run over the seams to restore these slopes to a more reasonable value. The visibility of seams in mapped edges can be further reduced by the specified overlay order of the county-based grids. The order was determined by visual inspection. The values from each successive grid replaced data that were previously placed as follows: Eastern Louisiana parishes, Harrison County, Mobile County, Jackson County, Hancock County, and Baldwin County.

After the data were seamlessly integrated, a shaded relief image was created and used for quality assurance and quality control of the processing methods. Initial quality assurance checks revealed that a few tiles needed to be reprocessed, and some differences in the Geoid model used by the projects that created the multiple source datasets were detected and corrected. After the initial quality control was completed, the datasets were finalized in the ArcSDE Program of ArcGIS for use in the Web-based mapping application.

In subsequent ArcGIS processing, the tiled grids were merged into county-based grids. The shaded relief grids for each county were also merged into county-based grids.

ArcGIS/IMS* relies on the use of pregenerated pyramid raster grids to reduce display times for very large images. Unfortunately, the ArcGIS internal resampling method does not create pyramids from shaded relief layers that are optimized for visualization. Therefore, custom pyramid layers were created for study by the U.S. Geological Survey and were used for displaying in ArcGIS/IMS. The full resolution lidar layer was resampled using bilinear interpolation to create elevation layers that have cell sizes in multiples of 2. Shaded-relief grids were then generated from each of the custom pyramid layers. These custom pyramid layers are made visible in the Web-based mapping application by using minimum and maximum scale viewing thresholds. This creates the most efficient rendering possible depending on the scale of the web map application.

A mosaic of the elevation grids for datasets of all five counties and for the southeastern Louisiana Parishes was created. Loading the elevation grid data to ArcSDE resulted in a 31.5 GB GIS layer. Further pyramid layering was done, and then statistics for the datasets were computed. In the final datasets, all elevations are in feet above North American Vertical Datum of 1988 (NAVD88).

Data Analysis

Storm surge is the onshore rush of water caused by the high wind and low pressure centers associated with a hurricane or other intense storm (NOAA, 2008). The amplitude of the storm surge at any given location is dependent upon the orientation of the coastline with the storm track, the intensity, size and speed of the storm, and the local bathymetry. In practice, storm surge is usually estimated by subtracting the local astronomical tide (including regional sea-level variations) from the observed storm tide.

Storm tide is the maximum water-level elevation measured by a gaging station during the storm or determined from a qualified high-water mark (HWM) after the storm (NOAA, 2008). Storm tide used in this report is the combination of storm surge, local astronomical tide, and regional sea-level variations. The total instantaneous water-level elevation may greatly exceed the storm tide elevations since wind generated waves ride on top of the storm surge.

In the wake of Hurricane Katrina's destruction, HWMs representing Katrina's maximum storm tide were flagged, surveyed, and documented by the Federal Emergency Management Agency (FEMA), NOAA, USACE, USGS, and Louisiana State University (LSU). These data were supplemented by available USGS, USACE, and Interagency Performance Evaluation Task Force (IPET) tidal gage and HWM data (IPET, 2008) to compile high-water elevations at more than 1,500 locations. These high-water mark elevation data representing the maximum storm tide elevation caused by Hurricane Katrina were processed and filtered, and eventually 842 high-water marks were used to generate the maximum storm tide GIS coverage for the affected coastal region (Figure 2). A few points were repositioned slightly to ensure that each point was contributing to the correct side of the given barrier in the Louisiana and Mississippi Gulf Coast regions and directly affect how the storm tide is routed inland. Points in the New Orleans area were deleted because the initial storm tide from Hurricane Katrina did not affect the city. Points in the New Orleans area were not used to generate the peak storm tide surface in order to approximate the peak surge that approached the city levees.

The storm tide coverage was generated using a spline with barrier algorithm in ArcGIS* (ESRI, 2004). The barriers used to help define how the storm tide created by Hurricane Katrina came ashore were selected levees and natural basin divides in the region significantly affected. These barriers helped to better attenuate and route the surge as it moved inland into the back bays and estuaries (Figure 3). The New Orleans area was masked out in the final surface, and this version of the storm tide coverage was then overlaid and fitted to the lidar DEM of the region by using the ArcGIS raster calculator to determine flooded and nonflooded areas. The flooded area polygon was used to define the inundation boundaries, which were then used to clip the maximum storm tide surface as shown. All elevations are presented in feet above NAVD88.

Inspection of the flooded areas, high-water marks, and lidar-based DEM revealed some areas of the Mississippi River and West Pearl River in Louisiana in which the bare earth DEM elevations were too high, or above the true bare earth. The Louisiana lidar were collected by different flight lines taken at different times and different water levels. Some of the lidar were collected when the Mississippi and Pearl Rivers stages were above normal. Varying water levels are a problem at certain times of lidar collection, especially in this low-relief terrain area. The correction of the DEM in these areas based upon river bathymetric and additional lidar surveys during low-water

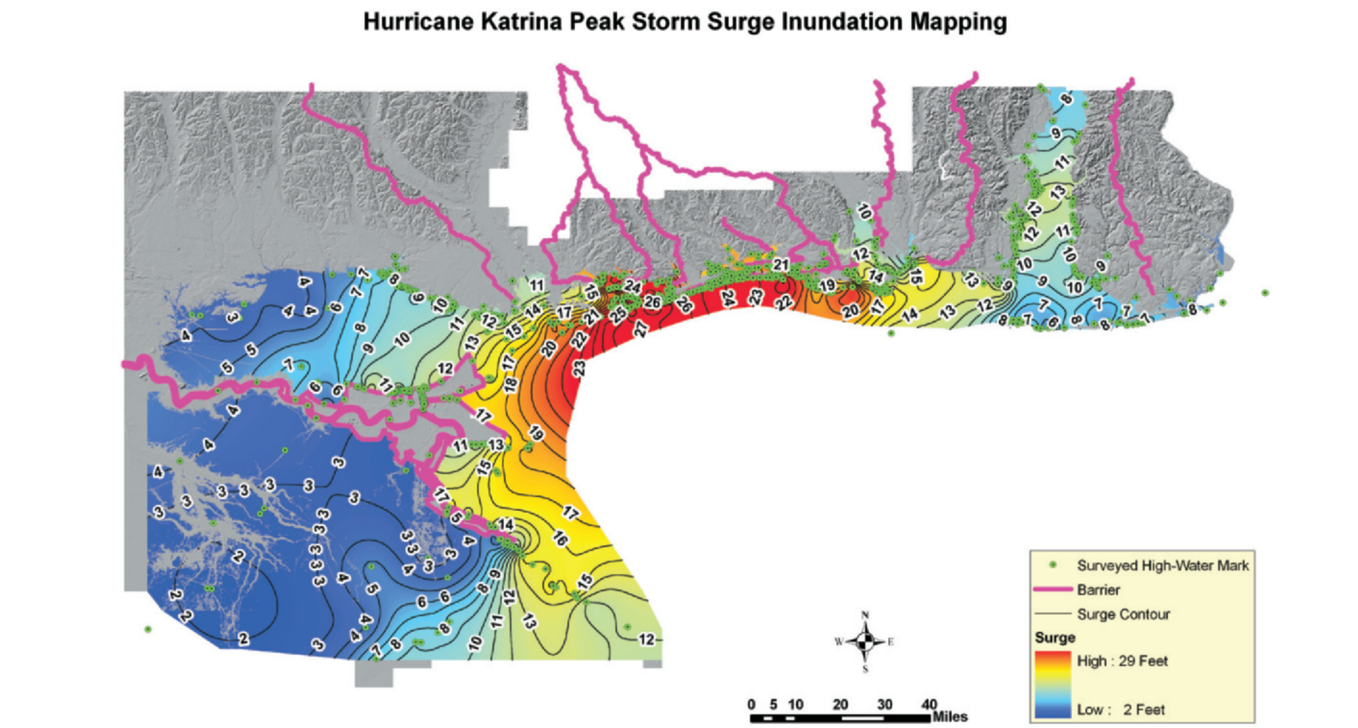

Figure 2. High-water mark elevation data used to generate the peak storm tide geographic information system coverage for the areas in southeastern Louisiana, Mississippi, and Alabama affected by Hurricane Katrina.

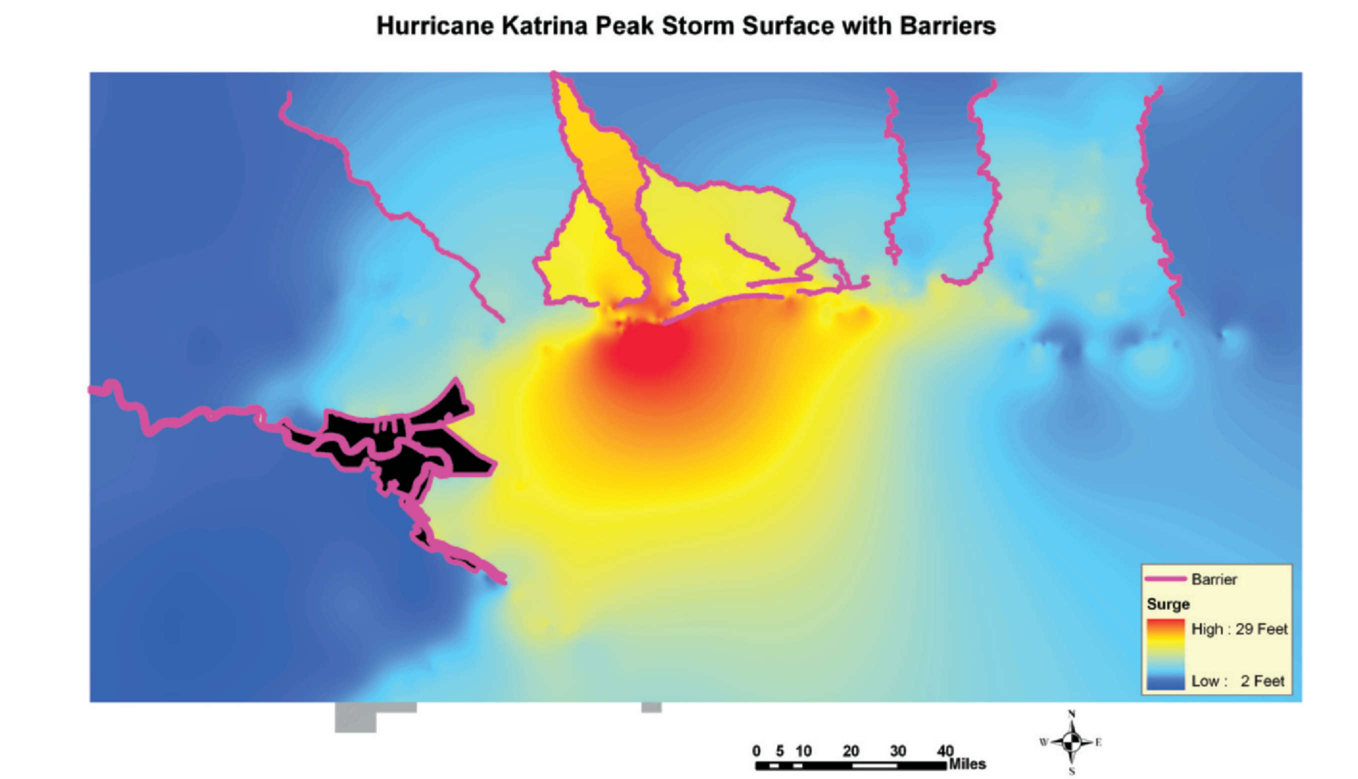

Figure 3. Hurricane Katrina maximum storm tide surface with barrier lines (e.g., levees and natural basin barriers used to help route the flood inland).

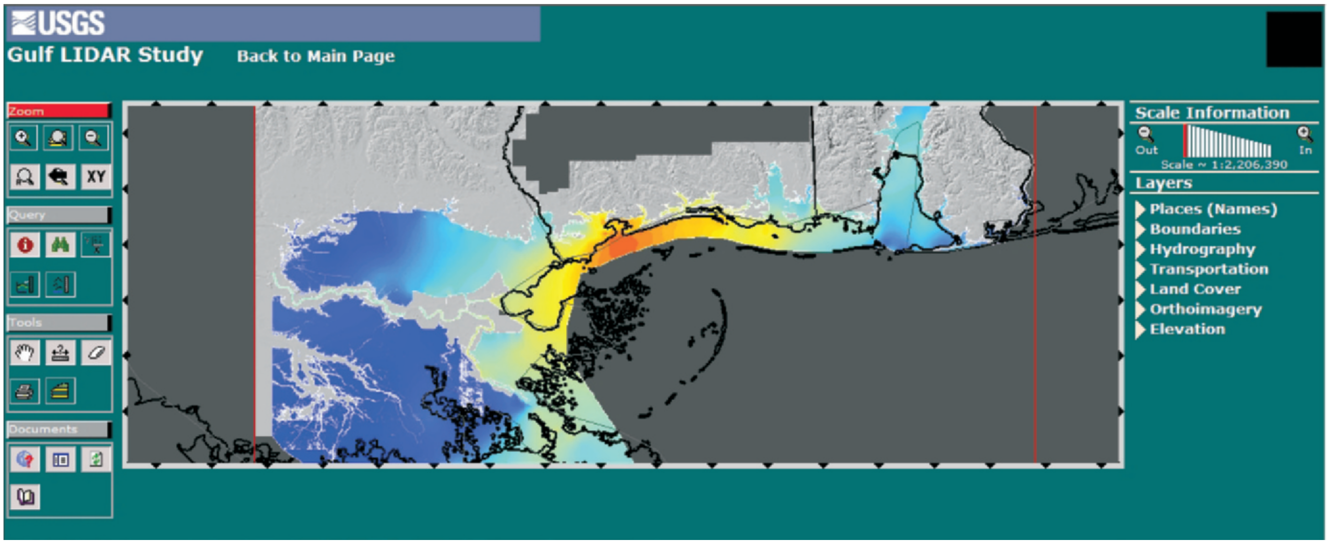

Figure 4. Internet map server screen capture of the USGS Hurricane Katrina maximum storm tide web application in southeastern Louisiana, Mississippi, and Alabama.

conditions was beyond the scope of this work.

Maximum storm tide elevations of greater than 29 feet were documented near Bay St. Louis, Mississippi. This confirmed that the Katrina storm tide was more than four feet greater than the storm tide caused by Hurricane Camille, the highest known storm tide to hit the region prior to Hurricane Katrina (Turnipseed et al., 2007).

RESULTS AND DISCUSSION

All of the lidar integration, high-resolution digital elevation creation, and storm tide elevation development were incorporated into a web application for public use (http://gisdata.usgs.gov/website/gulf/). The web mapping application for the Hurricane Katrina-affected coastal region of the Gulf of Mexico in Alabama, Mississippi, and Louisiana was developed based on Open Geospatial Consortium, Inc. Web Map Service (OGC/WMS) ArcIMS technology, accessing vector and raster layers stored in ArcSDE. This technology is an industry standard for serving GIS data to the Internet. One of the major advantages to using the WMS approach is a tool that allows collapsing groups of layers, which is particularly helpful when dealing with large numbers of layers (Figure 4).

Another web feature of this work is the use of the transparency

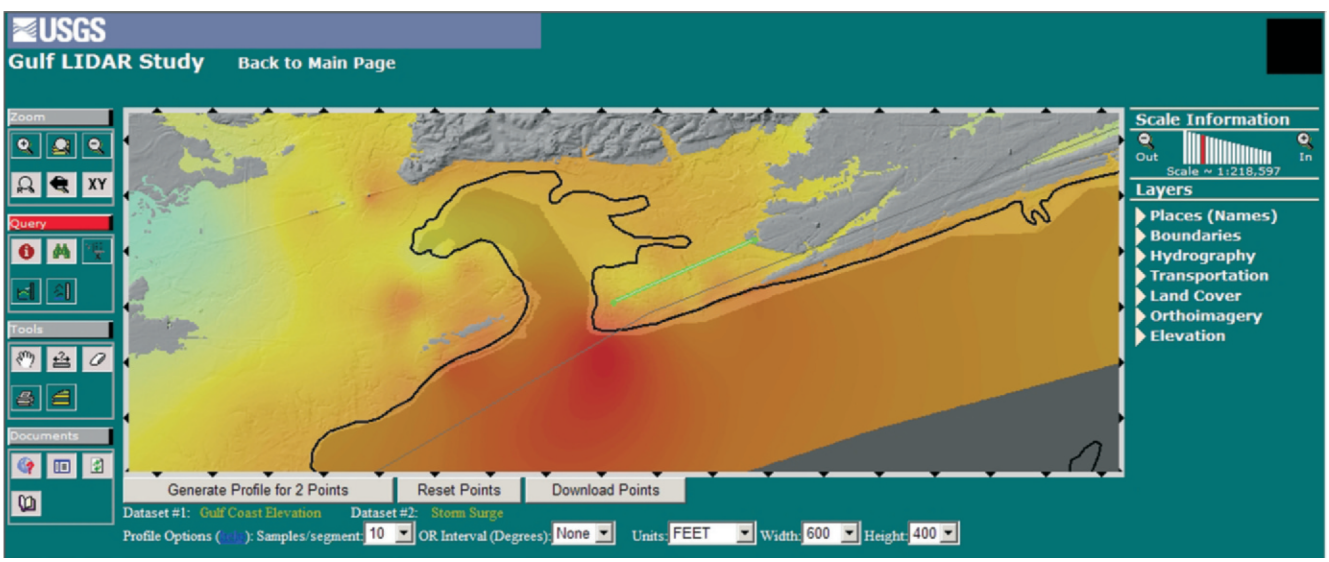

Figure 5. Example of a cross-section of storm tide and elevation generated from the USGS Hurricane Katrina maximum storm tide web application in southeastern Louisiana, Mississippi, and Alabama.

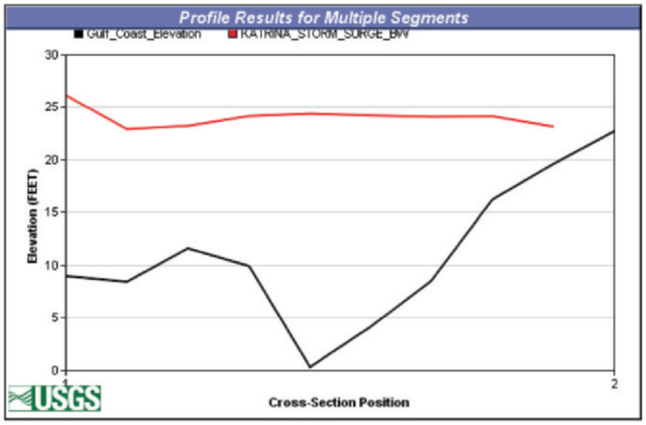

Figure 6. Example of an elevation profile comparison generated from the USGS Hurricane Katrina maximum storm tide web application in southeastern Louisiana, Mississippi, and Alabama.

characteristic of Graphic Information Files (gifs). For example, the amount of transparency for layers such as the color of the Katrina storm tide surface can be easily adjusted.

There are currently four tools on the Web site:

1) Elevation Query Tool, which uses the USGS National Elevation Dataset (NED) 1/3-arc-second grid data as the elevation source.

2) Gulf Elevation Query Tool, which returns the elevation of a point for both the lidar elevation and the storm tide surface.

3) U.S. National Grid Query Tool, which returns the National Grid coordinates for a specified point.

4) Profile Comparison Tool, which displays a graph or text listing of the profile points for any two of the four sources of elevation layers (Figures 5 and 6).

The Web application is user-friendly and allows for a variety of tools. Due to this application development, this study was the first to show that the storm tide dome extended from southeastern Louisiana east to Baldwin County, Alabama.

CONCLUSIONS

The use of lidar data for mapping on a project-level basis has increased dramatically for hydrologic and hydraulic modeling of flood inundation mapping projects, not only for natural disaster response, recovery, and mitigation, but also for a multitude of uses all over the world. This report demonstrates a methodology for the integration of multiple sources of lidar datasets that were collected for numerous applications. The work resulted in the construction of a publicly accessible seamless dataset for the region of southeastern Louisiana, Mississippi, and Alabama affected by Hurricane Katrina's historic storm tide from disparate highly accurate high-resolution project-level datasets.

Faced with a natural disaster as large in scope as Hurricane Katrina, local-level projects would not normally encompass such synoptic views, nor undertake the immense amount of processing needed to derive seamless, consistent elevation products from disparate local-level lidar collections. A seamless, consistent lidar dataset that is optimized and standardized would be preferable for large-scale data integration efforts so that regional analyses such as these could be performed easily and quickly. By developing a consistent baseline elevation dataset from lidar, more time could be used performing analyses and assessments and helping the public in an emergency instead of data preparation.

This report presents a synopsis that outlines the methodology needed to construct seamless DEMs from multipurpose, multiuse, and disparate lidar datasets and describes an easily accessible Web application for viewing the maximum storm tide caused by Hurricane Katrina in southeastern Louisiana, Mississippi, and Alabama. Accurate storm tide data will assist water resource managers, developers, and emergency officials to prepare, warn, and respond to tropical storm disasters in the future. These data can also be used for planning and design as the region slowly recovers from the recent devastation over the next few years.

*The use of trade or product names is for identification purposes only and does not constitute endorsement by the U.S. Government.

LITERATURE CITED

ESRI, 2004. *ArcGIS User's Guide*. ESRI Press, Redlands, CA, 598p.

Farris, G.S.; Smith, G.J.; Crane, M.P.; Demas, C.R.; Robbins, L.L., and Lavoie, D.L., eds., 2007. Science and the storms—the USGS response to the hurricanes of 2005: *U.S. Geological Survey Circular 1306*, 283p.

Gesch, D., 2009. Analysis of lidar elevation data for improved identification and delineation of lands vulnerable to sea-level rise. *Journal of Coastal Research*, SI(53), 49-58.

Gesch, D.; Oimoen, M.; Greenlee, S.; Nelson, C.; Steuck, M., and Tyler, D., 2002. The National Elevation Dataset. *Photogrammetric Engineering and Remote Sensing*, 68(1), 5-11.

Interagency Performance Evaluation Taskforce (IPET), 2008. *Performance evaluation of the New Orleans and southeast Louisiana hurricane protection system: Final report of the Interagency Performance Evaluation Task Force*. Vicksburg, Mississippi: U.S. Army Corps of Engineers, 9v. URL: https://ipet.wes.army.mil/

Knabb, R.D.; Rhome, J.R., and Brown, D.P., 2005. *Tropical cyclone report: Hurricane Katrina 23-30 August 2005*. Miami, Florida: National Oceanic and Atmospheric Administration, National Hurricane Center, 43 p. URL: http://www.nhc.noaa.gov/pdf/TCR-AL122005_Katrina.pdf

Lefsky, M.A.; Cohen, W.B.; Parker, G.G., and Harding, D.J., 2002. Lidar remote sensing for ecosystem studies. *Bioscience*, 52(1), 19-30.

Maas, H.G., 2001. The suitability of airborne laser scanner data for automatic 3D object reconstruction. *In*: Baltsavias, E.P., Gruen, A. and Van Gool, L. (eds.), *Automatic Extraction of Man-Made Objects from Aerial and Space Images (III)*. Ascona, Switzerland: A.A. Balkema Publishers, pp. 291-296.

National Oceanic and Atmospheric Administration (NOAA), 2008. *Center for Operational Oceanographic Products and Services: What is the difference between storm surge and storm tide?* Silver Spring, Maryland: National Oceanic and Atmospheric Administration, National Ocean Service. URL: http://co-ops.nos.noaa.gov/quicklook_faqs.shtml

Raber, G.T. and Tullis, J.A., 2007. Rapid assessment of storm-surge inundation after Hurricane Katrina utilizing a modified distance interpolation approach. *GIScience and Remote Sensing*, 44(3), 220-236.

Stockdon, H.; Doran, K.S., and Sallenger, A.H., Jr., 2009. Extraction of lidar-based dune-crest elevations for use in examining the vulnerability of beaches to inundation during hurricanes. *Journal of Coastal Research*, SI(53), 59-65.

Stoker, J.M.; Greenlee, S.K.; Gesch, D.B., and Menig, J.C., 2006. CLICK: The new USGS center for lidar information coordination and knowledge. *Photogrammetric Engineering and Remote Sensing*, 72(6), 613-616.

Travis, J., 2005. Hurricane Katrina: Scientists' fears come true as hurricane floods New Orleans. *Science*, 309, 1656-1659.

Turnipseed, D.P.; Wilson, K.V., Jr.; Stoker, J., and Tyler, D., 2007. Mapping hurricane Katrina peak storm surge in Alabama, Mississippi, and Louisiana. *Proceedings of the 37th Mississippi Water Resources Conference* (Jackson, Mississippi), pp. 202-207.