Mapping Hurricane Katrina Peak Storm Surge in Alabama, Mississippi, and Louisiana

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ABSTRACT

Hurricane Katrina produced the largest peak storm surge observed in the Gulf of Mexico. Hurricane Katrina made landfall on the northern Gulf of Mexico Coast early on August 29, 2005, first slamming into the Mississippi River delta near Buras, Louisiana, and then overwhelming the Pearl River delta at the Louisiana-Mississippi border. Riverine flooding from Katrina-induced rainfall was minimal in the region, but the storm devastated the Gulf of Mexico coastal region of southeastern Louisiana, Mississippi, and Alabama. Katrina has been estimated to have caused the loss of more than 1,800 human lives, and about $81 billion in damages.

In the wake of Katrina's destruction, high water marks–representing Katrina's peak storm surge–were flagged, surveyed, and documented by teams representing the Federal Emergency Management Agency, the U.S. Geological Survey, U.S. Army Corps of Engineers, and others. Peak storm surge of about 29 feet was documented near Bay St. Louis, Mississippi, confirming that Katrina was more than 4 feet greater than Hurricane Camille (previous largest known peak storm surge).

In the months that followed, the U.S. Geological Survey began developing an internet-based geographic information system (GIS) application that will allow a user to pinpoint depths of the Hurricane Katrina peak storm surge in the affected states. Pre-Katrina flown Light Detection and Ranging (LiDAR) data were seamlessly conjugated to form a high-resolution digital elevation model (DEM) that served as the base for the mapping. The Federal Emergency Management Agency also contributed pre-Katrina LiDAR-based DEMs and inundation polygons, and high water marks for Louisiana, Mississippi, and Alabama. These data were supplemented by available U.S. Geological Survey, U.S. Army Corps of Engineers, and Interagency Performance Evaluation Task Force tide gage and high water mark data to compile high water elevations at more than 1,500 locations to be used in generating a peak storm surge GIS coverage for the affected coastal region. In addition, the U.S. Geological Survey Earth Resources Observation and Science Center obtained U.S. Army Corps of Engineers Mobile District post-Katrina LiDAR for further use in computing planform changes of barrier islands/coastlines in the region and developing methods to estimate debris volume caused by the storm.

Keywords: Floods, Hydrology, Surface Water, Wetlands, Methods

History of Hurricane Katrina

In the late evening of August 25, 2005, less than 2 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. After spending only 6 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. Throughout the next 3 days, Katrina rapidly intensified from a tropical storm to a Category 5 Hurricane with a maximum peak wind speed intensity of greater than 170 miles per hour (mph) late in the afternoon of August 28. This maximum intensity occurred about 170 nautical miles southeast of the mouth of the Mississippi River and helps explain the extreme proportions of the storm surge height that occurred from Hurricane Katrina when it made landfall. During Katrina's maximum intensity, tropical storm and hurricane force winds extended 200 and 90 nautical miles from the eye, respectively (Knabb and others 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.

After some erosion of the eye wall late on August 28, Hurricane Katrina turned northward to make landfall near Buras, Louisiana, about 1110 Universal Time Coordinated (UTC) with about 125 mph sustained winds, making the storm a strong Category 3. 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 and others (2005) explained that although Hurricane Katrina had weakened from a Category 5 to a Category 3 in approximately the last 18 hours before landfall, the radial extent of tropical storm and hurricane force winds remained about the same, which helps explain the extreme storm surge 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, and was then downgraded to a tropical storm early on August 30, after only 5 days as a hurricane in the Gulf of Mexico.

Study Area Description

Alabama, Mississippi, and Louisiana are located within the East Gulf Coastal Plain physiographic province; the Hurricane Katrina storm surge-affected region (fig. 1) generally is within 30 miles of the Gulf of Mexico coast. Land-surface elevations in the affected region range from sea level near the coast to more than 50 feet above sea level. The climate varies from humid to sub-tropical. Average annual rainfall is almost 70 inches near the coast (Wax, 1990).

Objectives

This paper describes the methods used in the development of a Web-based geographic information system (GIS) mapping application that allows users to pinpoint maximum storm surge depths across regions of Alabama, Mississippi, and Louisiana affected by Gulf flooding from Hurricane Katrina and presents examples of provisional results of this mapping project. The paper also discusses the development of the digital elevation model (DEM) derived from pre-Katrina acquired LiDAR for this coastal region. The paper does not present the extent or magnitude of subsequent flooding of the metropolitan area of New Orleans, La., caused by breaches and breaks of the levee system that occurred after the initial Hurricane Katrina storm surge passed. The data presented in this paper are provisional and subject to change upon further review by the USGS.

Methods

LiDAR Data Processing

Immediately following Hurricane Katrina, the USGS Earth Resources Observations and Science (EROS) Data Center began the detailed task of processing pre-Katrina LiDAR data for Baldwin and Mobile Counties in Alabama, for Jackson, Hancock, and Harrison Counties in Mississippi, and for the eastern parishes in Louisiana. Data were obtained from multiple sources, including a private company, and local, State, and Federal entities [such as the National

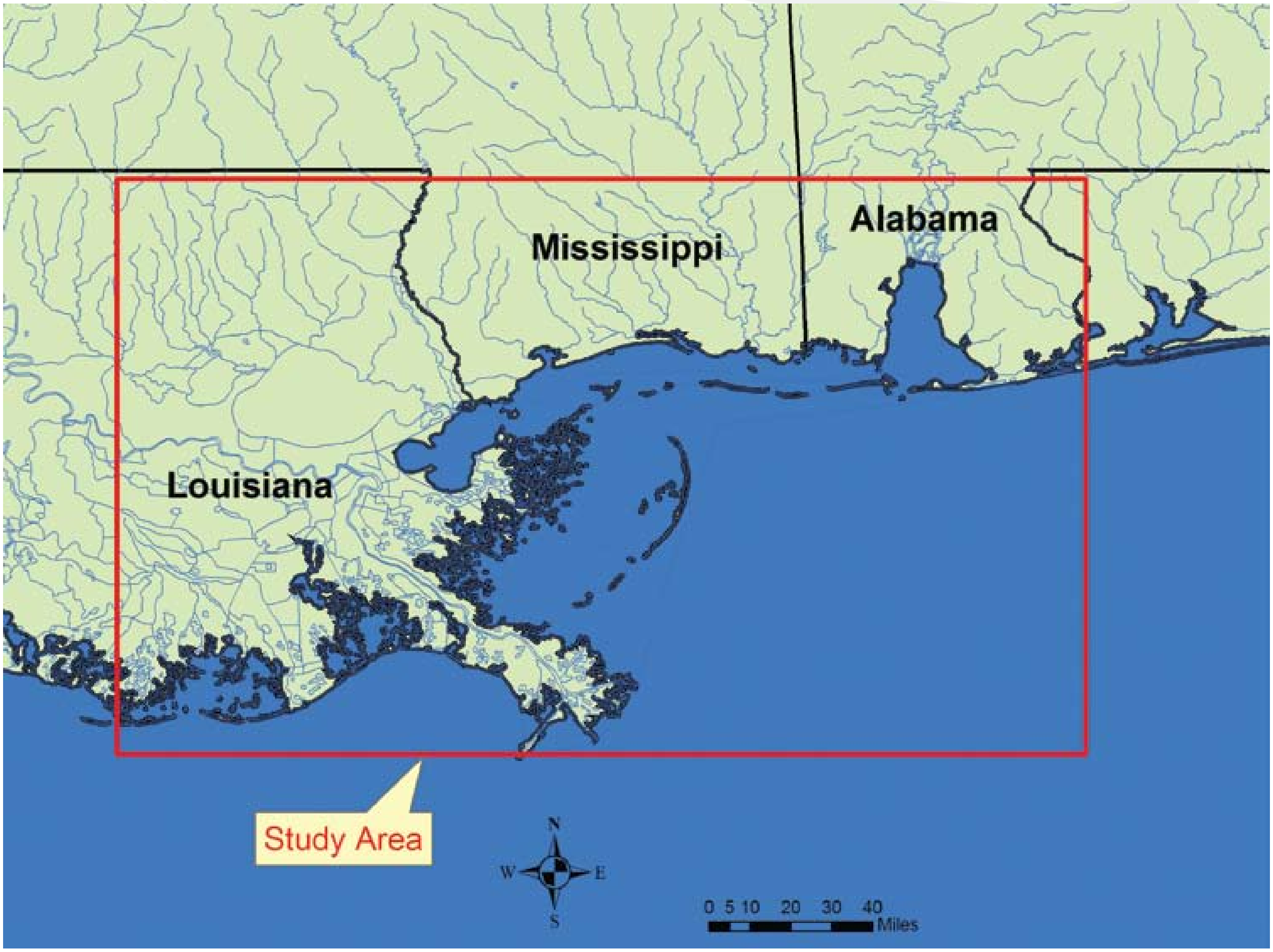

Figure 1. Map of the coastal region of Louisiana, Mississippi, and Alabama affected by Hurricane Katrina.

Oceanic and Atmospheric Administration (NOAA)] and were developed for varying purposes and in accordance with differing criteria designed to meet the needs of the end use of the agency or entity contracting for the collection of the data. Because the data were collected independently in various file formats, projections, and levels of processing, the task of producing a seamless digital elevation dataset required a high level of research, coordination, and revision. Many technical issues were resolved before EROS was able to produce the seamless digital elevation dataset (1/9th arc-second (3-meter) grid) used as the map base for projecting the Katrina peak storm surge in the affected coastal region.

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 Geoid projections used were detected and corrected. After the data were initially quality assured, the datasets were finalized in ArcSDE to be used in the Web-based mapping application.

After the 0.5 x 0.5 degree grids (ArcGIS GRID format) were generated via the ASSEMBLE program, the z-values (elevation data) were converted from meters to feet. Map projections were defined for each grid to reduce error messages in subsequent ArcGIS processing. The tiled grids were then 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 pre-generated 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, EROS created custom pyramid layers and used those for displaying in ArcGIS/IMS . This was accomplished by resampling the full-resolution LiDAR layer 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.

A mosaic of the elevation grids for all five counties and for eastern Louisiana was then 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. All elevations are in feet above North American Vertical Datum of 1988 (NAVD88).

Many technical issues were encountered and solved as necessary. For example, the various Windows/ArcGIS temporary directory variables had to be set large enough to avoid running out of disk space during processing. Another example requiring a "work-a-round" was discovered when increasing the size of the study area. Theoretically, preferably, logically, and historically, when performing this operation with ArcInfo , any new pixels in a larger geographic window for which there are no input values would be set to NODATA. In ArcGIS , however, these pixels are assigned a value of zero, necessitating further intermediate processing to eliminate the division operand errors involved in computing datasets with zero.

Peak Storm Surge Elevation

Almost immediately after the landfall of Hurricane Katrina, survey crews from the USGS, FEMA, USACE and others were dispatched to flag, survey, and document the peak storm surge caused by the storm. FEMA contributed inundation polygons and high-water marks for Alabama, Mississippi, and Louisiana. These data were supplemented by available USGS, USACE, and Interagency Performance Evaluation Task Force tidal gage and high-water mark data to compile high-water elevations at more than 1,500 locations. These data were processed further, filtered, and eventually 842 high-water marks were used to generate the peak storm surge GIS coverage for the affected coastal region (figure 2). The storm surge coverage was generated using the spline with barrier algorithm in ArcGIS . The barriers used were selected levees and basin divides to better attenuate the surge as it moved inland into the back bays and estuaries (figure 2). The mapping was for areas outside the New Orleans, La., levees to approximate the peak storm surge that approached the levees. This storm surge coverage was then carefully overlaid and fitted to the LiDAR DEM of the region by using the ArcGIS raster calculator to determine flooded and non-flooded areas. The flooded area polygon was used to define the inundation boundaries, which were then used to clip the peak storm surge surface as shown in figure 2. All elevations are in feet above North American Vertical Datum of 1988 (NAVD88).

Peak storm surge elevations of greater than 29 feet were documented near Bay St. Louis, Miss., confirming that the Katrina storm surge was more than 4 feet greater than storm surge caused by Hurricane Camille (highest known peak storm surge to hit the region prior to Hurricane Katrina).

Web-based Mapping Application Development

The Web mapping application for the 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. The following paragraphs outline the methods used in creating the Web-based mapping application.

One of the major advantages to using the WMS approach is a tool that allows collapsing groups of layers - particularly helpful when dealing with large numbers of layers.

Another advantage is the option of using the transparency characteristic of Graphic Information Files (gifs); for example, the amount of transparency for layers such as the color Katrina storm surge surface can be easily adjusted.

There are currently four tools on the website:

1) Elevation Query Tool, which uses the USGS National Elevation Dataset (NED) 1/3rd 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 surge surface,
3) U.S. National Grid Query Tool, which returns the National Grid coordinates for a specified point, and
4) Profile Comparison Tool, which displays a graph or text listing of the profile points for any two of the four source elevation layers.

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

Summary

The USGS, in cooperation with several other Federal, State, and local agencies, completed development of a Web-based geographic information system (GIS) mapping

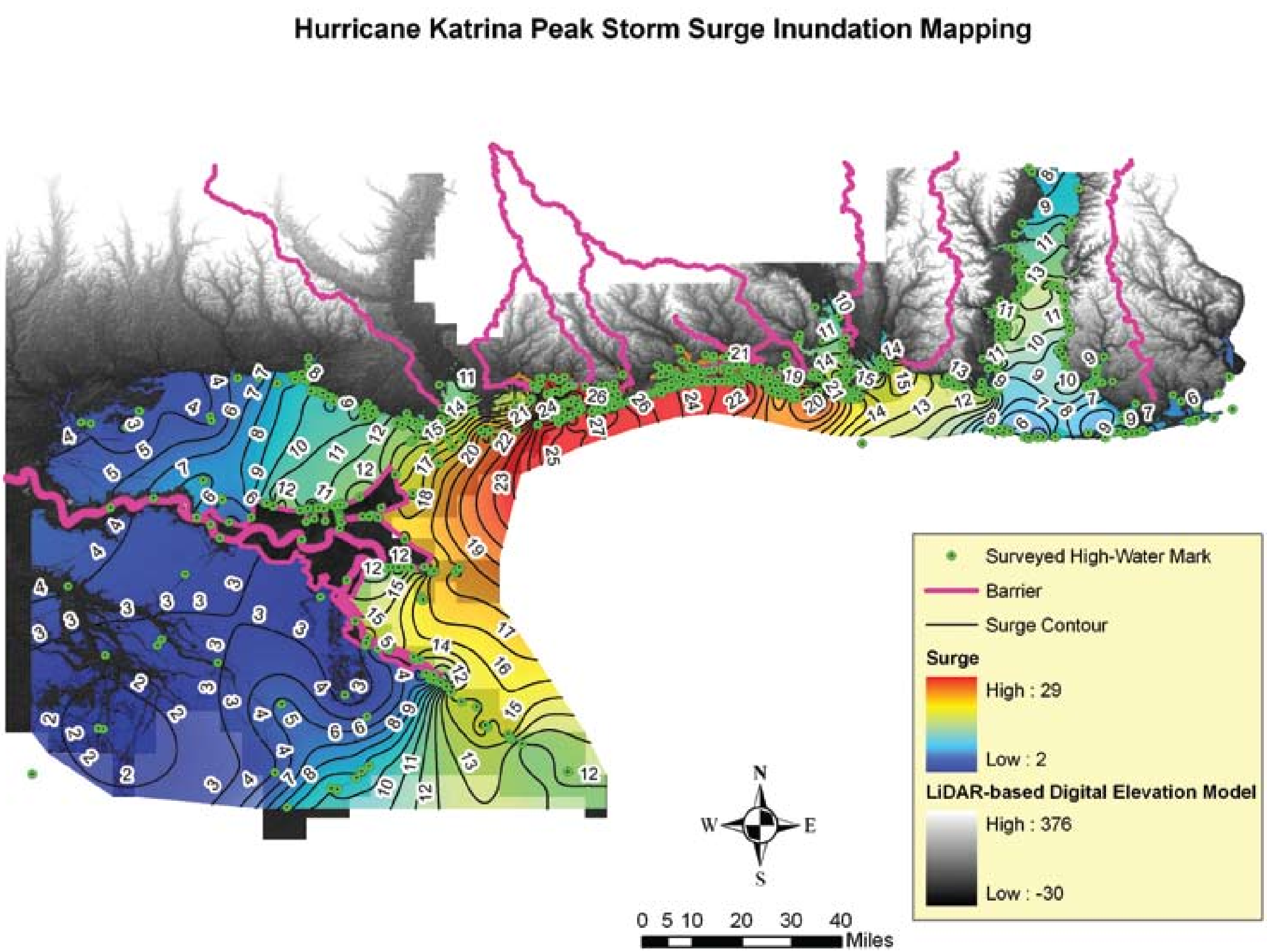

Figure 2. Peak storm surge inundation map generated from 842 surveyed high-water marks and LiDAR-based Digital Elevation Model.

application to allow a given user to pinpoint depths of the Hurricane Katrina peak storm surge in the storm-affected States of Alabama, Mississippi, and Louisiana. Pre-Katrina flown Light Detection and Ranging (LiDAR) data were seamlessly integrated to form a high-resolution digital elevation model (DEM) that served as the base for the mapping.

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