EOS

EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION

VOLUME 91 NUMBER 7

16 FEBRUARY 2010

PAGES 65–72

Forecasting Hurricane Impact on Coastal Topography

PAGES 65–66

Extreme storms can have a profound impact on coastal topography and thus on ecosystems and human-built structures within coastal regions. For instance, landfalls of several recent major hurricanes have caused significant changes to the U.S. coastline, particularly along the Gulf of Mexico. Some of these hurricanes (e.g., Ivan in 2004, Katrina and Rita in 2005, and Gustav and Ike in 2008) led to shoreline position changes of about 100 meters. Sand dunes, which protect the coast from waves and surge, eroded, losing several meters of elevation in the course of a single storm. Observations during these events raise the question of how storm-related changes affect the future vulnerability of a coast.

Given the intensity of many processes that occur near coastlines, vulnerability can be assessed in terms of safety, economic factors, recreation, habitat, and even cultural assets. Anyone with an interest in one or more of these coastal variables will want to have updated information on the health of the underlying beach and dune system. They will want to know whether this system is presently changing and whether it is likely to change in the future.

The U.S. Geological Survey (USGS) has developed a research program to assess the vulnerability of the coast to extreme storms and ultimately to predict the extent of coastal topographic change and changes in vulnerability expected with future storms. In collaboration with the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Army Corps of Engineers (USACE), the USGS is predicting the likely interactions between storm forcing (e.g., surge and waves) and coastal topography (beaches, berms, and dunes) during hurricanes in near real time. This rapid response provides forecast, nowcast, and verification information that is used to focus research efforts, test predictive models, and provide updated information to the public, coastal managers, and emergency response teams regarding the poststorm state of the coastal environment.

To demonstrate this collaborative response, the predictive ability of a new system was tested for Hurricane Ike, which made landfall on 13 September 2008 near Galveston, Tex., as a powerful category 2 storm (Figure 1). The coastal impacts included severe erosion (and deposition) and destruction of homes, roads, and other structures (Figure 1). As this storm evolved, state-of-the art observations and modeling capabilities were used to advance knowledge of coastal topographic changes.

Coastal Topographic Change as a Function of Storm Regime

The approach to forecasting coastal topographic change due to extreme storms relies on determining the nature of storm-induced interactions between topography and hydrodynamic processes. These interactions can be categorized according to a storm-scale parameterization [*Sallenger,* 2000] that compares estimated storm surge and wave runup elevations with the local height of the dune or beach berm near the coastline. The ratio of surge and runup elevations to berm heights is much less than 1 when the storm surge elevation is low and waves interact only with the beach during mild conditions—such conditions, termed the swash regime, typically serve to sustain the coastline. The ratio approaches 1 when storm surge elevations increase and waves wash over the tops of dunes (termed the overwash regime). Finally, under more extreme conditions, the ratio far exceeds 1 when the surge elevation exceeds the dune elevation, allowing overland flow as well as waves to pass across the tops of the dunes (inundation regime). Figure 1 shows an example of severe erosion in response to fully inundated conditions.

The rationale for identifying storm regimes such as swash, overwash, and inundation is that the topographic, hydrodynamic, and sediment transport interactions are different in each regime, and therefore characterization of the storm regime serves as a proxy for coastal change. For example, predictions of the likelihood of an inundation regime can be used as a proxy for indicating the likelihood of severe erosion. This approach was applied to Hurricane Ike by defining the potential for inundation of the beach system (height of storm surge minus dune height). Estimates of dune and storm surge elevations were obtained using observational and modeling capabilities available from USGS, USACE, and NOAA.

Hurricane Ike: Scenario-Based Predictions

The USGS storm response methodology (Figure 2a) begins with a prestorm analysis (approximately 3 days prior to landfall) to determine the geographic region where hurricane conditions may cause significant coastal topographic change. The region of interest is broadly defined using NOAA's meteorological forecasts of the hurricane track and its uncertainty.

Guided by forecast information, USGS successfully deployed storm surge sensors at 59 locations along the coast, including beach, inland, and riverine settings [*East et al.,* 2008]. NOAA's existing analysis of hurricane scenarios and numerically simulated surge elevations ("maximum of the maximum" surge, or MOMS) for hurricane categories 1–5 were used to characterize storm surge threats in the region of interest. In practice, the numerical simulations were driven with a range of wind fields (upon which the Saffir-Simpson categories for measuring the intensity of hurricanes are based) and depend on storm size and atmospheric pressure gradients [*Glahn et al.,* 2010; *Jelesnianski et al.,* 1992].

Simulated surge elevations were compared with measured dune elevations extracted from existing USGS and USACE data sets and were used to define the potential for dune inundation (Figure 2b). For the region expected to be affected by Hurricane Ike, inundation was predicted for category 3–5 storms.

By N. G. Plant, H. F. Stockdon, A. H. Sallenger Jr., M. J. Turco, J. W. East, A. A. Taylor, and W. A. Shaffer

Updated Predictions

After landfall, the prestorm forecasts based on category 1–5 hurricane scenarios may not be relevant because they are based on an ensemble of scenarios that do not necessarily reflect the details of a particular storm. Instead, actual pressure and wind fields are known after landfall, and improved storm surge predictions and observations are usually available [*Glahn et al.,* 2010].

The inundation prediction for Hurricane Ike was refined (Figure 2c) by replacing the MOM surge elevations with NOAA's probabilistic measure of modeled surge, based on winds, track, and forward speed specific to this storm. The probabilistic storm surge product issued approximately 24 hours prior to landfall (i.e., at 0900 UTC on 13 September for Hurricane Ike) was used. Several statistical definitions of surge elevation are available from this updated prediction, including probabilities of extreme values. A 10% exceedence level was selected to represent a worst-case scenario for dune inundation—that is, there is only a small chance (10%) that surge elevations would be higher than this value; dunes exceeding this elevation are unlikely to be inundated.

Hurricane Ike made landfall as a strong category 2 hurricane. However, the updated inundation prediction (Figure 2c) more closely resembles the prestorm prediction for a strong category 3 hurricane (Figure 2b). This illustrates a limitation of tying inundation and erosion predictions to the Saffir-Simpson scale, which is based on wind speed alone. Thus, improved numerical simulations of storm surge using realistic wind fields that capture storm size and atmospheric pressure gradients yield improved inundation predictions. For example, the updated prediction for Hurricane Ike suggests widespread inundation and a high likelihood of major topographic change, particularly to the east of the landfall location.

Updated Observations

The USGS used the updated inundation prediction for Hurricane Ike to help determine the geographic extent to be targeted in poststorm oblique photography and lidar (light detection and ranging) topographic survey missions. The purpose of the photography was to document changes caused by the storm (Figure 1) and to help interpret the topographic data [*Doran et al.,* 2009]. In the case of Hurricane Ike, extreme coastal erosion was expected over a broad region of eastern Texas and western Louisiana, establishing the priority areas for updating photography. The photographs confirmed the predictions of extreme erosion.

In a given storm season, topographic and bathymetric data used to estimate inundation potential may be out of date due to previous storm-driven erosion.

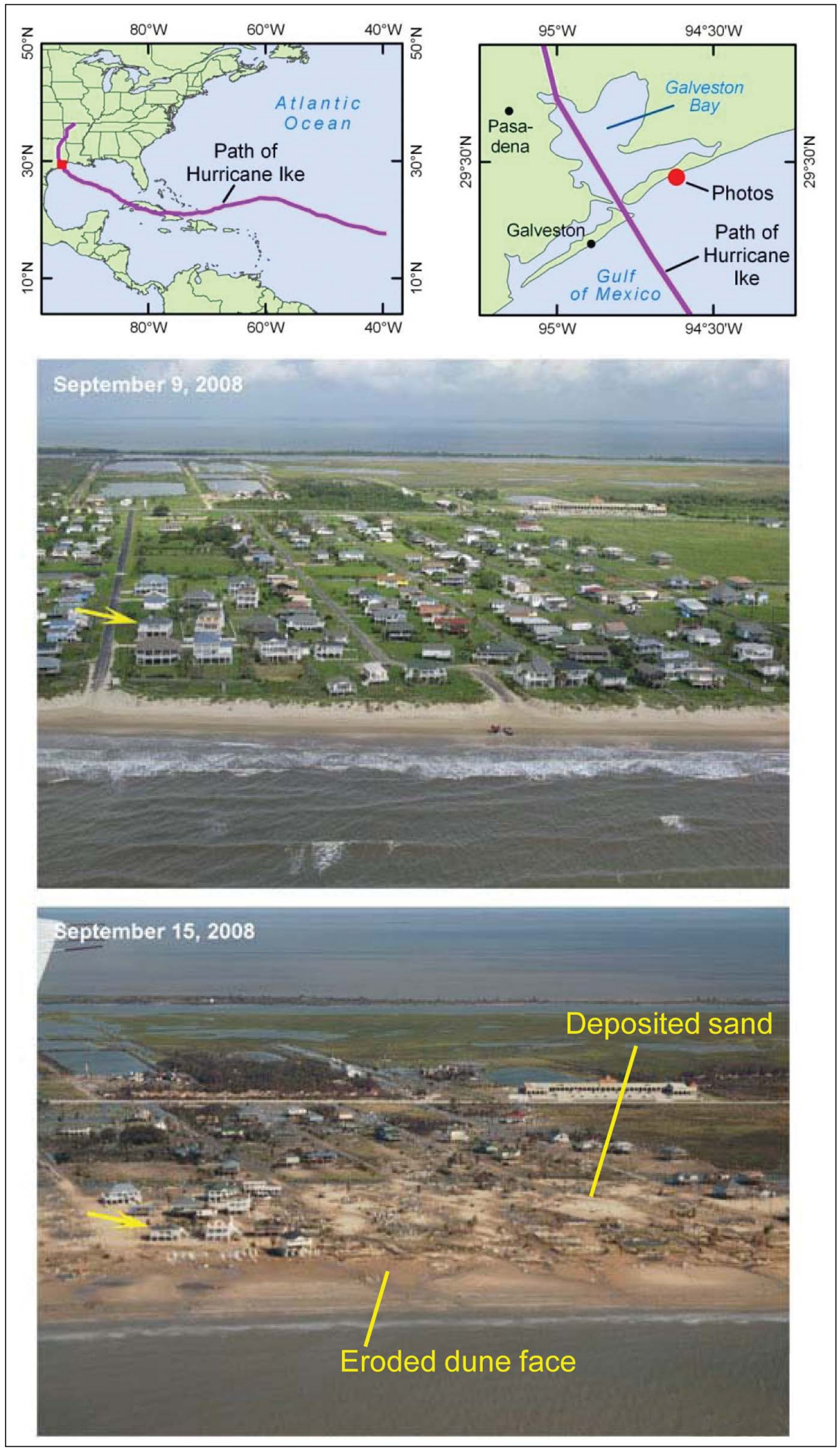

Fig. 1. (top) Maps showing the path of Hurricane Ike (purple curves). The red square indicates the location of the map to the right; the red dot indicates the location of the two photographs below. (bottom) Oblique aerial photographs of Bolivar Peninsula, Tex., on 9 September 2008 (photo acquired by researchers at University of New Orleans) and 15 September 2008. Yellow arrows mark a common feature in each image. In addition to the loss of houses, the evidence of inundation of the peninsula includes eroded dune faces and sand deposited well inland of the shoreline.

As a result, collection of new dune and beach elevation data is necessary to document actual topographic changes and to support vulnerability updates for future storms. For Hurricane Ike, the USGS conducted a poststorm lidar survey mission along the affected stretch of the coastline. A striking feature of the topographic response was catastrophic dune failure—meaning that dunes were completely leveled—over a long stretch of coast (Figure 2d). This response was consistent with the prediction (Figure 2c), based on a high potential for dune inundation.

Recovery of USGS in situ storm surge sensors took place in the week after landfall [*East et al.*, 2008]. Figure 2d compares the probabilistic (10% exceedence) storm surge prediction with the observations. The observed surge levels at most locations were nearly equal to the probabilistic surge forecast level that was used in the updated inundation prediction.

A Case for Synergy

Many data sets and model simulations were needed to develop predictions of Hurricane Ike's impact on coastal topography. These diverse data sets were developed by different agencies for various specific purposes, including public safety, engineering design, and geologic studies. Thus, the integration required for the predictions presented here leveraged this prior investment of resources. It is expected that coastal topographic change predictions will in turn support a wide range of future activities. For instance, coastal change forecasts will continue to be needed immediately after landfall to plan the efficient deployment of poststorm observational resources used to survey the actual topographic response. Such forecasts and observations of topographic changes will continually be needed to update storm surge models. Together these advances contribute to updated assessments of vulnerability due to erosion by future storms.

Hurricane Ike is just one example of the major storms that have battered the world's coasts. By using this approach to prediction of storm-induced geomorphic coastal change, the effects of hurricanes and other extreme storms can be quantified in other locations on U.S. coasts. A similar model could also be adopted to help anticipate the effects of cyclones in the Indian Ocean or typhoons in the Pacific.

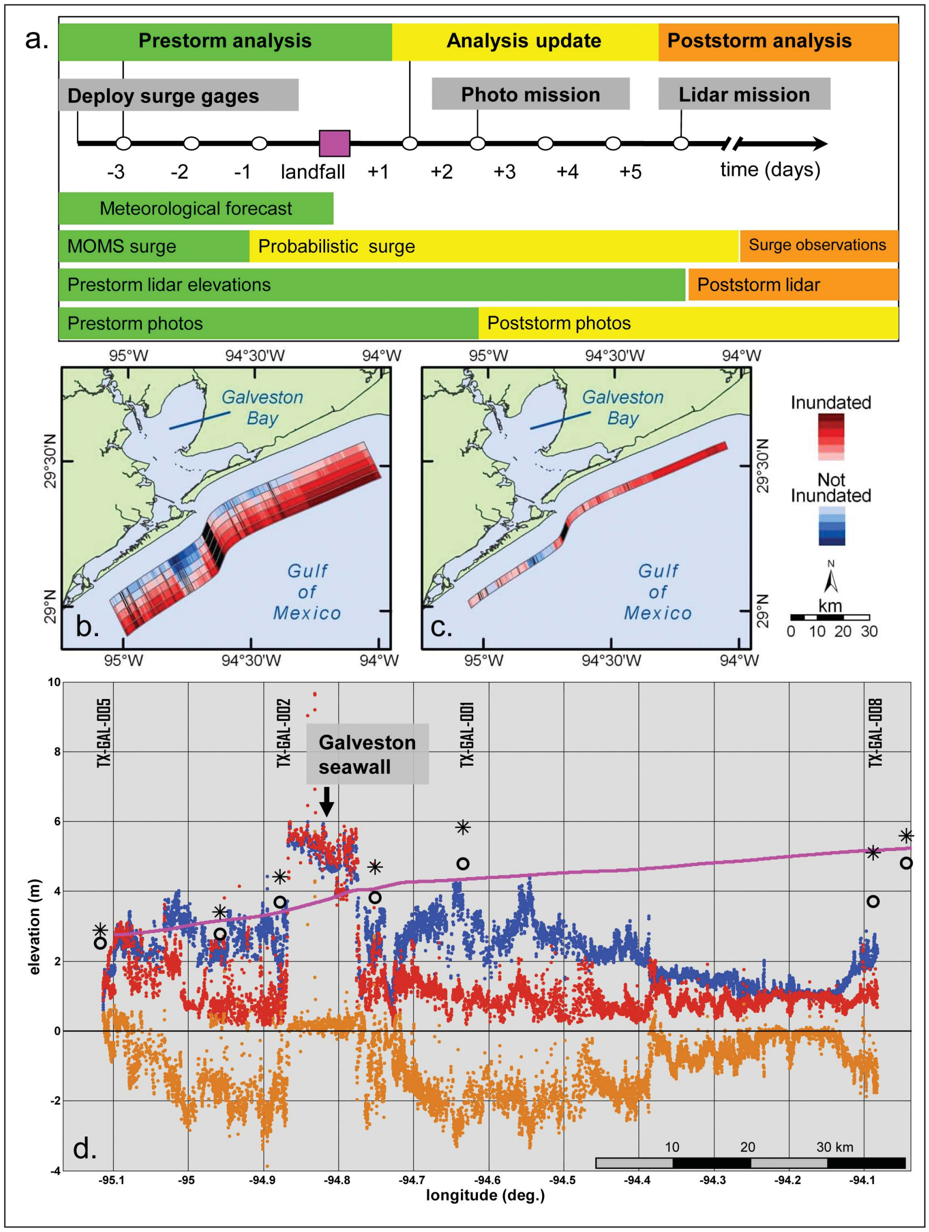

Fig. 2. Coastal topographic change response to Hurricane Ike. (a) Time line for analysis and observational deployments. Bars indicate model and data availability for prestorm forecast (green), forecast update (yellow), and poststorm analysis (orange). (b) Prestorm assessment of dune inundation potential for Galveston, Tex., for category 1–5 hurricanes, shown offset from the actual dune. Results for each modeled hurricane category are shown in parallel bands (category 1 is closest to the shore and category 5 is farthest offshore). Red colors indicate areas where maximum surge elevations based on "maximum of the maximum" surge (MOMS) exceed the elevations of the primary dunes. (c) Updated dune inundation based on National Oceanic and Atmospheric Administration's (NOAA) probabilistic storm surge forecast at landfall. (d) Comparison of topographic and storm surge elevation data. Topographic change is described by the prestorm dune height (blue), poststorm elevation at the location of the prestorm dune (red), and the elevation change (orange). Surge values include NOAA's probabilistic forecast (magenta line) and in situ observations (asterisks include wave height, and circles are the same data filtered to remove wave heights). TX-GAL labels indicate individual sensor names.

References

Doran, K. S., N. G. Plant, H. F. Stockdon, A. H. Sallenger, and K. A. Serafin (2009), Hurricane Ike: Observations and analysis of coastal change, *U.S. Geol. Surv. Open File Rep., OFR-2009-1061,* 35 pp.

East, J. W., M. J. Turco, and R. R. Mason Jr. (2008), Monitoring inland storm surge and flooding from Hurricane Ike in Texas and Louisiana, September 2008, *U.S. Geol. Surv. Open File Rep., 2008-1365,* 38 pp.

Glahn, B., A. Taylor, N. Kurkowski, and W. A. Shaffer (2010), The role of the SLOSH model in National Weather Service storm surge forecasting, *Natl. Weather Dig.,* in press.

Jelesnianski, C. P., J. Chen, and W. A. Shaffer (1992), SLOSH: Sea, lake, and overland surges from hurricanes, *Tech. Rep. NWS 48,* Natl. Oceanic and Atmos. Admin., U.S. Dep. of Commer., Washington, D. C.

Sallenger, A. H., Jr. (2000), Storm impact scale for barrier islands, *J. Coastal Res., 16*(3), 890–895.

Author Information

Nathaniel G. Plant, Hilary F. Stockdon, and Asbury H. Sallenger Jr., St. Petersburg Science Center, U.S. Geological Survey (USGS), St. Petersburg, Fla.; E-mail: nplant@usgs.gov; Michael J. Turco and Jeffery W. East, Texas Water Science Center Gulf Coast Program, USGS, Shenandoah; and Arthur A. Taylor and Wilson A. Shaffer, Meteorological Development Laboratory, National Weather Service, Silver Spring, Md.