Forecasting Hurricane Storm Surge on the Mississippi River

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Introduction

The National Weather Service (NWS) is responsible for forecasting stages for the major rivers in the United States. The Lower Mississippi River Forecast Center (LMRFC) is responsible for forecasting river stages on the Mississippi River below Chester, IL, on the Ohio River below Smithland Lock and Dam, IL, and continuing from the confluence of the Ohio-Mississippi to the Gulf of Mexico. The LMRFC prepares and issues daily forecasts for twenty-one locations along the mainstems of the lower Ohio and Mississippi Rivers. A unique forecast problem is the forecasting of stages on the lower Mississippi River when a hurricane induced storm surge is present. Storm surge waves move rapidly upstream and can cause significant damage and delays to barge traffic along the Mississippi River.

The LMRFC has combined the NWS Dynamic Wave Operational Model (DWOPER), a one-dimensional unsteady state flow model, on the Mississippi River with output from the Sea, Lake, and Overland Surge Heights (SLOSH) model. The SLOSH model generates a storm surge hydrograph on the Mississippi River at a pre-selected grid point near West Pointe a la Hache, LA. This hydrograph is used as a downstream boundary in DWOPER to produce stage forecasts as a hurricane storm surge travels upstream on the Mississippi River.

Dynamic Wave Operation Model on the Mississippi River

The LMRFC employs the National Weather Service River Forecast System (NWSRFS) Version 5.0 as its operational forecast system (National Weather Service, 2004). The NWSRFS is a complete set of software designed to perform all necessary tasks to enable a River Forecast Center to prepare and issue river forecasts. One of the model components in the NWSRFS is the Dynamic Wave Operational Model (DWOPER), a one-dimensional unsteady state flow model (Fread, 1978). DWOPER is used to model unsteady flows in rivers, reservoirs, and estuaries by solving the complete one-dimensional Saint-Venant` equations of unsteady flow using an implicit finite-difference scheme (Fread, 1974).

DWOPER was developed during the mid 1970's and was initially implemented on the lower reaches of the Mississippi River. During the 1990's, the NWS Flood Wave (FLDWAV) program was developed to house hydrodynamic models (NWS, 2004). The FLDWAV program combines the capabilities of both DWOPER and the NWS Dam Break program. However, DWOPER is still available as a stand-alone

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tool for use in modeling complex hydraulic conditions that exist on many rivers across the United States; including, the modeling of backwater profiles and resultant effects from hurricane induced storm surges.

During the late 1970's through the mid 1980's and for the purpose of improving river forecast accuracy, the LMRFC implemented DWOPER on the lower Ohio and lower Mississippi Rivers. To simplify its operational application, the lower Ohio/Mississippi River complex was modeled as four different DWOPER segments or components as shown in Figure 1.

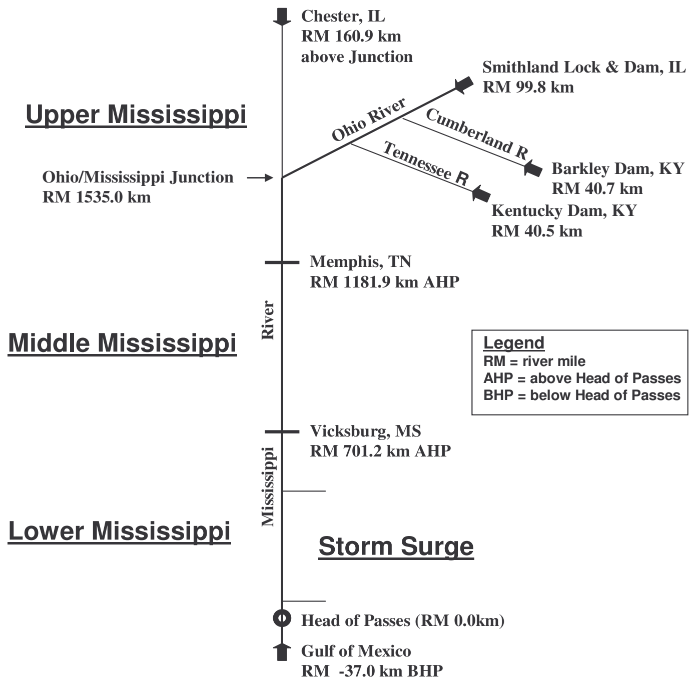

Figure 1. **LMRFC Modeled DWOPER segments (underlined)**

The Upper Mississippi River segment consists of its main channel plus three dynamic tributaries. The main channel is defined as extending from Smithland Lock and Dam, IL, on the Ohio River to its downstream boundary at Memphis, TN, on the Mississippi River. The upstream boundaries of the three dynamic tributaries are: 1) Barkley Dam, KY, on the Cumberland River, 2) Kentucky Dam, KY, on the Tennessee River, and 3) Chester, IL, on the Mississippi River. The Middle Mississippi segment runs from Memphis to Vicksburg, MS, and the Lower Mississippi component is modeled from Vicksburg downstream to the Gulf of Mexico.

Upstream boundary conditions on the Upper Mississippi segment are observed and forecasted flows at Chester, Smithland Lock and Dam, Barkley Dam, and Kentucky Dam. Downstream at Memphis, a single valued rating curve provides the downstream discharge boundary condition. Model computed flows at Memphis serve as the upstream boundary for the Middle Mississippi segment. A single valued rating curve is also used at Vicksburg as the downstream boundary for the Middle Mississippi; and, model computed flow at Vicksburg becomes the upstream boundary for the lower Mississippi segment. Water surface elevations in the Gulf of Mexico serve as the lower Mississippi downstream boundary. The Upper, Middle, and Lower DWOPER segments each operate on a six-hour time step.

This paper will focus on the fourth and final segment developed for handling hurricane induced storm surges propagating upstream. While this segment is shown in Figure 1 to be a subset of the Lower Mississippi component, it is modeled as a stand-alone mode. This segment operates on an hourly time step with its upstream boundary located at Red River Landing, LA, (RRLL1) and its downstream boundary at West Pointe a la Hache, LA (WPHL1). This 408.3km reach of the river was chosen because continuous levees border both sides of the Mississippi River. WPHL1 is the last gauging site having continuous levees on both sides of the Mississippi making it a desirable downstream boundary location.

The type of downstream boundary used at WPHL1 is an hourly stage time series, or a SLOSH generated surge hydrograph; and, the upstream boundary is the observed and forecasted streamflow time series at RRLL1. Thus, real time SLOSH predicted storm surge elevations on the Mississippi River at WPHL1 serve as the downstream boundary condition. See Figure 2 for a schematic of the DWOPER storm surge segment.

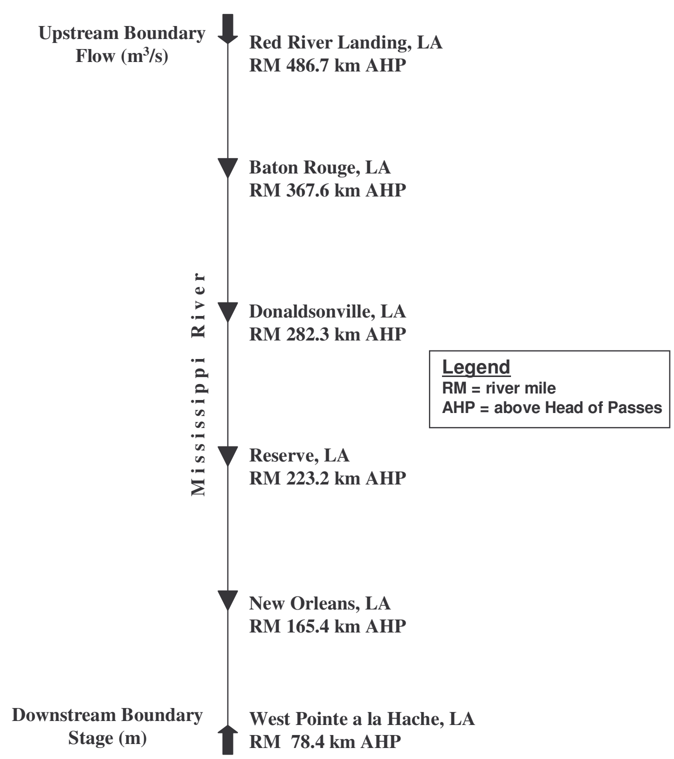

Figure 2 – Mississippi River Storm Surge Segment

Sea, Lake, and Overland Surge from Hurricanes (SLOSH) Model

The SLOSH model was developed by the NWS (Jelesnianski, Chen, and Shaffer, 1992) to simulate water surface elevations due to a storm surge associated with hurricanes impacting the Gulf of Mexico or Atlantic coastal areas. SLOSH is used in advance of a land-falling hurricane to forecast storm surge elevations in an operational environment. The SLOSH model basin grid is a continuously changing polar grid. This allows for detailed computations near the center of the grid where elevations and conditions change rapidly and a coarser grid where conditions change less rapidly.

As shown in Figure 3, the NWS Marine Development Laboratory has developed grid coordinate systems for 35 different SLOSH basins starting from near Brownsville, TX, to Portland, ME. Topographic and bathymetric elevation data are determined for each basin grid and data are referenced to the 1929 National Geodetic Vertical Datum (NGVD). For all grids, the NWS has developed the NGVD surface elevations for each grid cell within each of the 35 SLOSH basins.

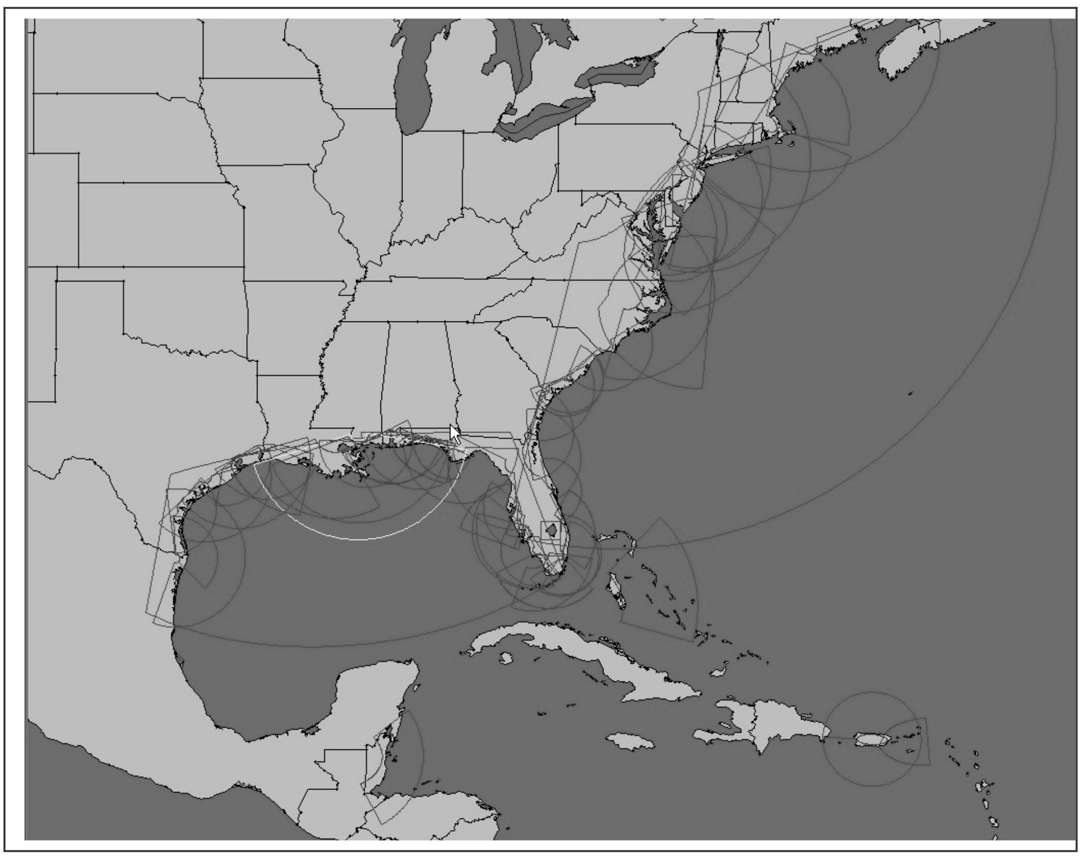

Figure 3 – Outlines of the 35 SLOSH basins along the Gulf of Mexico and Atlantic coasts

The grid boundary used for the southeast Louisiana coast is shown in white in Figure 3. This SLOSH grid is labeled the Lake Ponchartrain Basin with its full grid shown in Figure 4. The southeast Louisiana coastline is faintly visible within the Lake Ponchartrain Basin grid along with the protruding Mississippi River delta. Data for levee heights within this Basin were obtained from the New Orleans District, US Army Corps of Engineers, bathymetric data from National Ocean Services (NOS) bathymetric charts, and topographic information from the US Geological Survey (USGS) topographic maps.

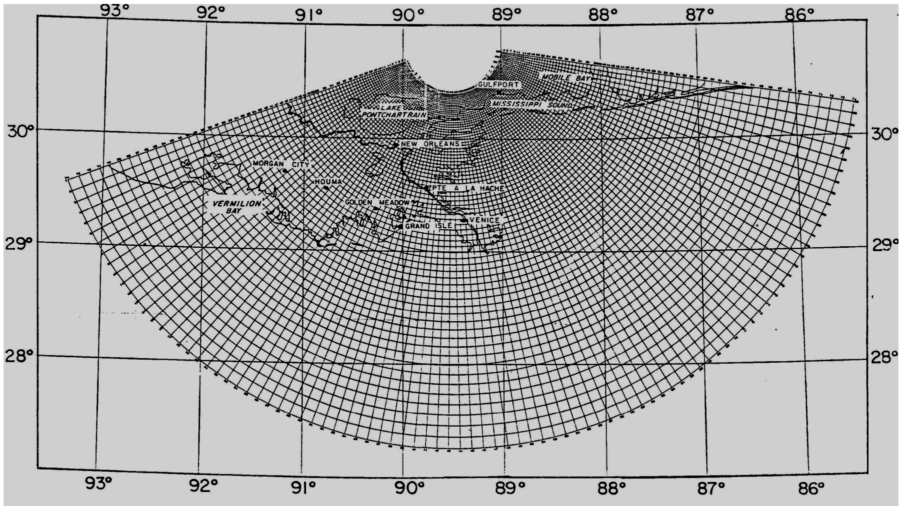

Figure 4 – Lake Ponchartrain Basin SLOSH Grid

Any operational tool such as SLOSH must have simple real-time inputs to meet the tight time constraints of the warning process for affective hurricane forecasting. SLOSH model input includes, but not limited to, storm central pressure, storm track (forward speed and direction), and the radius of maximum winds. SLOSH computes water surface elevations over time for each of the basin grid cells. SLOSH output of simulated storm surge data is converted to a binary file (called a rex file), which is sent to coastal NWS offices. Weather Service Forecast (WFO) offices and River Forecast Centers have software available to animate the rex binary file to see how the storm surge will vary in space and time for any given grid location.

Operational Procedures to Link DWOPER and SLOSH

In 1985, the LMRFC recognized the need to merge the SLOSH output with DWOPER to determine how a surge wave will propagate up the Mississippi River while contained within the levee system. SLOSH output produces surge heights at WPHL1, which can be used as direct input to DWOPER as a downstream boundary condition. Originally in the 1980s, the SLOSH output was transferred to the RFC via a dedicated synchronous communications line. At the RFC, this data was entered into DWOPER by hand and model runs were made. These procedures survived until the mid 90s when the Internet was used to transfer the data and automated procedures were developed to transfer SLOSH output to DWOPER.

When a hurricane is within 24 hours of making landfall, the NHC officials make several SLOSH model runs based on the NHC forecasted track. These data are made available to coastal NWS offices but are not available to the general public. The LMRFC has developed automated procedures that extract the projected storm surge heights at West Pointe a la Hache from SLOSH output files and reformats them for input to DWOPER. DWOPER is then run operationally to generate forecast stage hydrographs at five NWS official locations on the Mississippi River, at and below Red River Landing.

Sample Results

The LMRFC has utilized SLOSH output time series as operational input to DWOPER during several land-falling hurricanes to prepare river surge forecasts along the lower Mississippi River. One case presented here is the riverine induced surge caused by Hurricane Georges of 1998 and the computed SLOSH predictions at WPHL1 after he brushed the Mouth of the Mississippi River, 24 hours prior to landfall (see Figure 5).

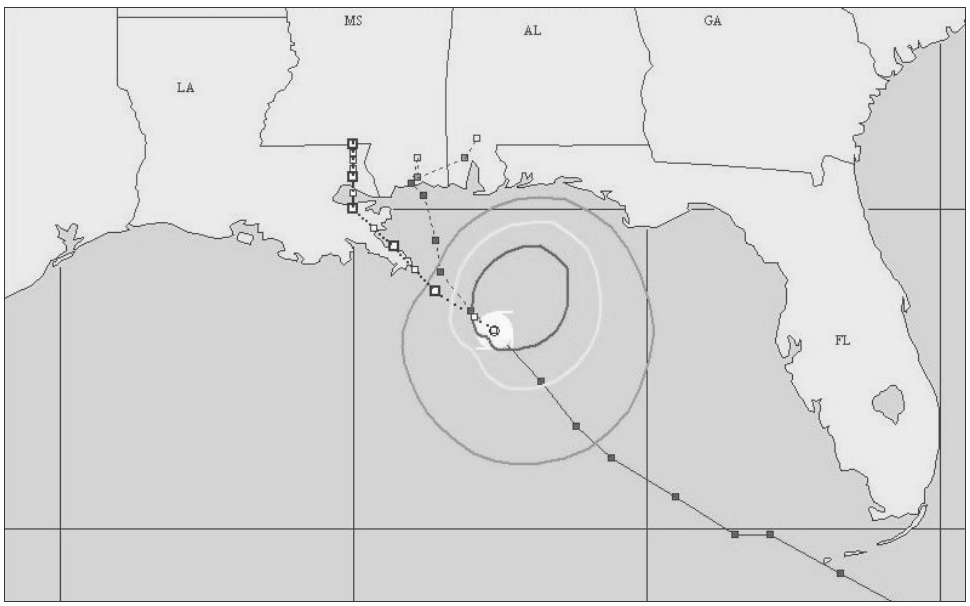

Figure 5 – Hurricane Georges observed (black boxes) and forecasted forecasted track (white boxes) 24 hours prior to landfall.

Twenty-four hours prior to Georges making landfall, the NHC made a real-time SLOSH run for the Lake Ponchartrain Basin. The forecasted movement according to NHC Advisory #48 was a northwest track along the Mississippi Delta and across Lake Ponchartrain. The SLOSH model generated a full surge hydrograph at West Pointe a la Hache with a predicted surge crest of over 3.0 meters NGVD. The River's baseflow surface elevation at WPHL1 prior to the approaching surge wave was 0.61 meters. The storm surge hydrograph generated by SLOSH is shown in Figure 6 and labeled as the SLOSH computed surge.

The WPHL1 surge stage hydrograph was used as the downstream boundary in DWOPER. Running of DWOPER produced simulated forecasts at the six gauging sites on the Mississippi River as is shown in Figure 2. DWOPER real-time simulation examples for WPHL1, NORL1, and BTRL1 are presented in Figures 6, 7, and 8 in upstream order. Time is given as Greenwich Mean Time (GMT).

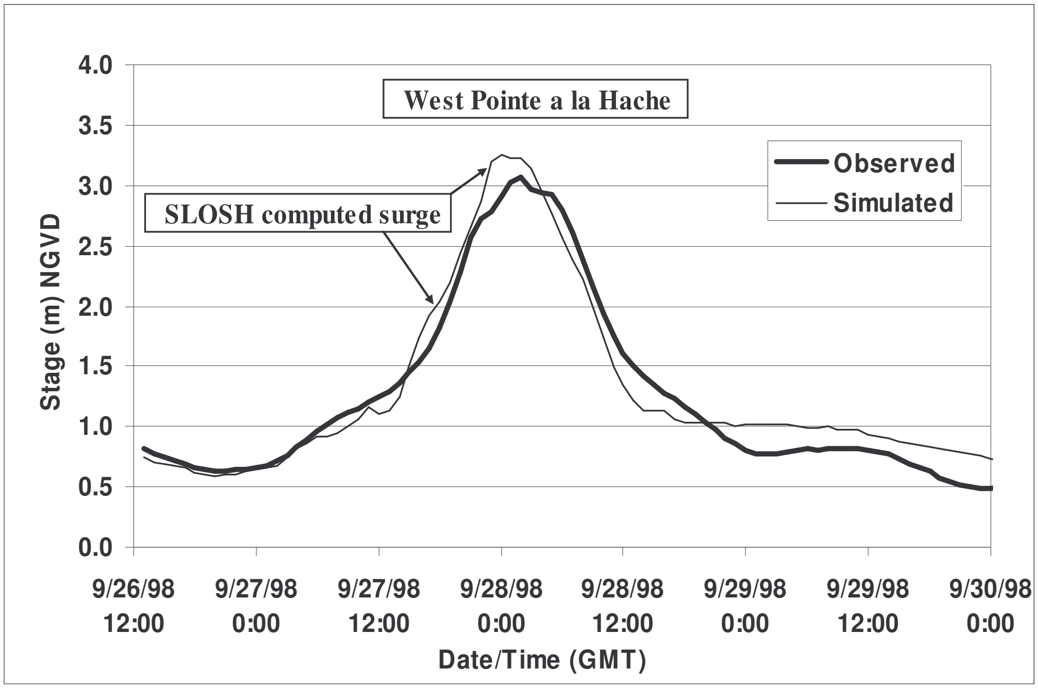

Figure 6. – Comparison of observed and SLOSH computed stages (thin line) at West Pointe a la Hache

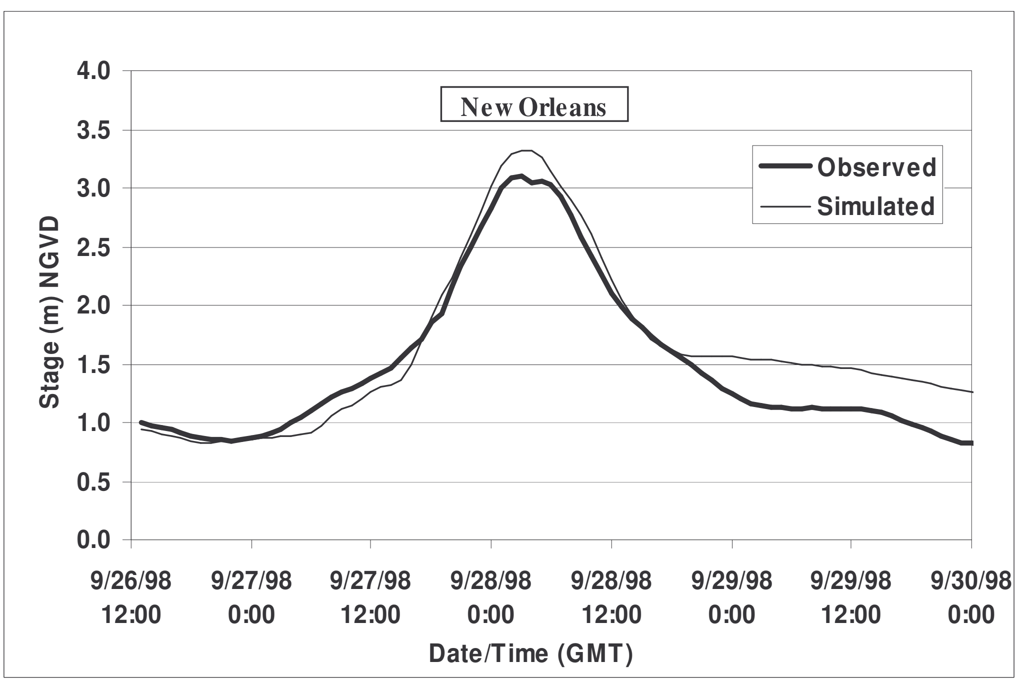

Figure 7. – Comparison of observed and DWOPER simulated stages at New Orleans

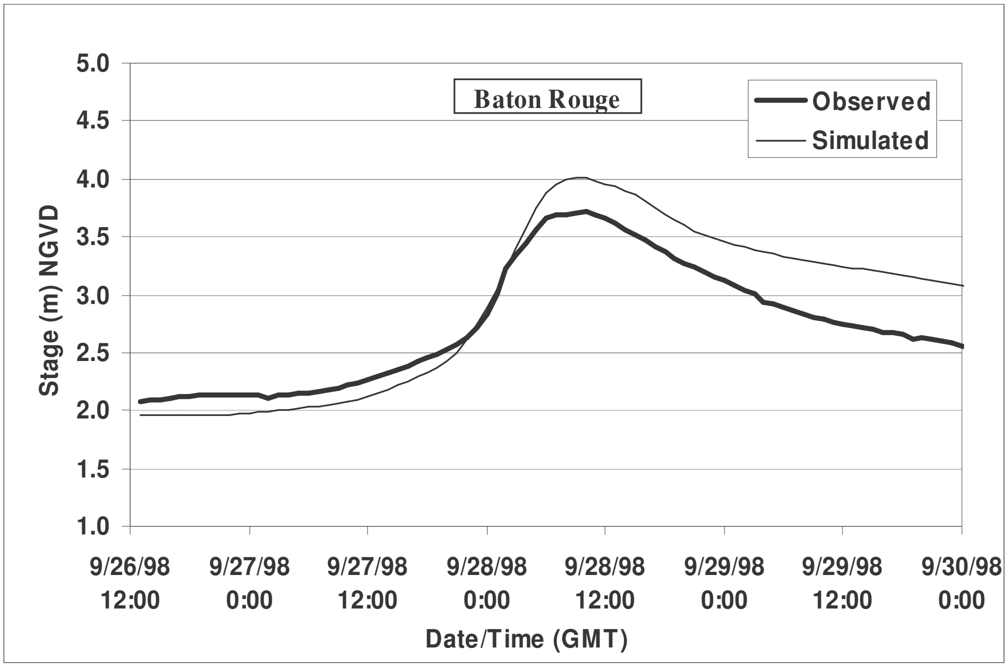

Figure 8. – Comparison of observed and DWOPER simulated stages at Baton Rouge, LA

Finally, Table 1 shows a partial set of real-time official forecasts issued by the LMRFC on September 27, 1998, at 10:20AM CDT, and which were based on the SLOSH predicted Hurricane Georges` storm surge at WPHL1. WPHL1 is not an official NWS forecast location and is not included (see Figure 7) below in Table 1. A condensed and replicated version of the last five official forecast locations on the Mississippi River is reproduced here.

Table 1. – Real time LMRFC forecasts issued for the lower Mississippi River based on the forecasted Hurricane Georges storm surge

RIVER FORECAST…LOWER OHIO/MISSISSIPPI RIVER
LOWER MISSISSIPPI RIVER FORECAST CENTER
NATIONAL WEATHER SERVICE SLIDELL LA
1020AM CDT SUN SEP 27 1998
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STATION	FS	7AM STG	24HR CHG	……F O R E C A S T…… 0928	0929	0930	1001	1002	CREST/DATE/TIME
MISSISSIPPI RIVER									
RED RIVER LANDING	48	20.4	+1.1	21.9	21.4	20.9	20.9	20.7	22.5 9/28 7 PM CDT
BATON ROUGE	35	7.5	MSG	12.3	9.4	8.9	8.5	8.4	13.0 9/28 9AM CDT
DONALDSONVILLE	27	5.5	+0.9	12.0	7.1	6.8	6.4	6.4	12.0 9/28 7AM CDT
RESERVE	22	4.8	+0.9	11.0	6.0	5.8	5.7	5.7	11.2 9/28 6AM CDT
NEW ORLEANS	17	4.5	+1.1	10.2	5.8	5.6	5.5	5.5	10.8 9/28 4AM CDT

FS = FLOOD STAGE IN FEET NGVD
STG = STAGE IN FEET NGVD
MSG = MISSING

Conclusion

The LMRFC has successfully utilized SLOSH model output as input to DWOPER for forecasting storm surges propagating up the Mississippi River. These unique procedures have provided valuable lead-time and river forecast information to shipping and commercial interests along the Mississippi assisting them in taking appropriate precautions prior to storm surge impacts.

The real-time application of SLOSH output used as boundary input to DWOPER has generally produced excellent results. The coupling of these two models is considered a valued asset to the LMRFC operations when preparing and issuing surge induced river forecasts. It should also be noted that hurricane induced surges on the lower Mississippi can propagate rapidly upstream at nearly 40 kilometers per hour.

References

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