Note on the Influence of the Mississippi River Gulf Outlet on Hurricane Induced Storm Surge in New Orleans and Vicinity

Joannes Westerink
Department of Civil Engineering and Geological Sciences
University of Notre Dame, Notre Dame IN 46556

Bruce Ebersole
Coastal and Hydraulics Laboratory, U.S. Army Engineering Research and Development Center
Vicksburg, MS 39180

Harley Winer
New Orleans District, U.S. Army Corps of Engineers
New Orleans, LA 70160

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Concerns have been raised regarding the role of the Mississippi River Gulf Outlet (MRGO) on storm surge propagation into metropolitan New Orleans and vicinity. This note discusses hydrodynamic model simulations that evaluate the influence of the MRGO on flooding during major hurricane events.

The physical system here is very complex, one comprised of a network of estuaries, lakes, rivers, channels, and low lying wetlands, with topographic major relief defined by river banks and an extensive system of levees and raised roads. Water surface elevation response is driven by storm surge, tides, and wind-waves. Both storm surge and tides are characterized as forced very long wavelength inertial gravity waves, while wind-waves are gravity waves defined by their short period. All three types of waves propagate and experience various levels of local forcing which can further build amplitudes. In metropolitan New Orleans and vicinity, the amplitude of the tides is small; the maximum tide range is on the order of one half foot in Lake Pontchartrain and two feet in Chandeleur Sound. The amplitude of a storm surge can be much higher; for Hurricane Katrina, the peak storm surge along the MRGO adjacent to the St. Bernard Parish/Chalmette hurricane protection levee was computed to be as much as 18 ft. This note focuses on the relevant long period motion that dominates the circulation patterns in the area. In particular, the impact of the MRGO on large scale catastrophic storm surge development and propagation is examined.

The MRGO is a dredged channel that extends southeast to northwest from the Gulf of Mexico to a point where it first merges with the Gulf Intracoastal Waterway (GIWW), and then continues westward until it intersects the Inner Harbor Navigation Canal (IHNC) as shown in Figure 1. The first 9 miles, the bar channel, are in the open Gulf. The next 23 miles of the channel lie in the shallow open waters of Breton Sound. From there, the inland cut extends 14 miles to the northwest with open marsh on the northeast and a 4,000-ft wide dredged material placement bank on the southwest side. At this point the channel cuts across the ridge of a relict

distributary of the Mississippi River, Bayou La Loutre. For nearly the next 24 miles, there is a hurricane protection levee atop a dredged material placement bank on the southwest side of the channel and Lake Borgne and open marsh lie to the northeast. A portion of the levee protecting St. Bernard Parish/Chalmette and the portion of the hurricane protection levee along the south side of Orleans East Parish, north of the GIWW, form the "funnel" that is often referenced.   The point where the MRGO and GIWW channels merge is just to the east of the Paris Road Bridge (see Figure 1). From this point, the merged GIWW/MRGO channel continues west for about 6 miles to the point where it intersects the IHNC; this portion has hurricane protection levees on both banks. The IHNC extends from Lake Pontchartrain, to the north, to the Mississippi River to the south. The IHNC has levees or floodwalls along both banks. The IHNC Lock, which connects the IHNC to the Mississippi River, is located at the southern limit of the IHNC. The MRGO bar channel authorized depth is 38 ft; the authorized bottom width is 600 ft. The remainder of the channel has an authorized depth of 36 ft and an authorized bottom width of 400 or 450 ft, depending on location.

It is important to distinguish between two sections of the MRGO and the role each plays in tide and storm surge propagation. One is the east-west oriented section that runs between the IHNC and the confluence of the GIWW/MRGO near the Paris Road Bridge, labeled as the GIWW/MRGO in Figure 1, and hereafter referred to as Reach 1. The other is the much longer southeast-northwest section designated as the MRGO in Figure 1, and hereafter referred to as the Reach 2.

The critical section of the MRGO is Reach 1, the combined GIWW/MRGO. It is through this section of channel that Lake Pontchartrain and Lake Borgne are hydraulically connected to one another via the IHNC. Reach 1 existed as the GIWW prior to the construction of the MRGO, although the maintained depth was lower. Because of this connectivity, the local storm surge and astronomical tide in the IHNC and in the section designated GIWW/MRGO is influenced by the tide and storm surge in both Lake Pontchartrain and Lake Borgne. The two Lakes are also connected to each other via the Rigolets and Chef Menteur Pass; the IHNC is the smallest of the three connections. The Reach 1 GIWW/MRGO section of channel is very important in determining the magnitude of storm surge that reaches the IHNC from Lake Borgne and Breton Sound. If the hydraulic connectivity between Lake Pontchartrain and Lake Borgne is eliminated at a point within this section of channel, tide or surge to the west of this point will become primarily influenced by conditions at the IHNC entrance to Lake Pontchartrain; and tide or storm surge to the east of this point will become primarily influenced by conditions in Lake Borgne.

Much concern seems to be focused on MRGO/Reach 2 that runs from the GIWW/MRGO confluence, just east of the Paris Road Bridge, to the southeast. Past work, McAnally and Berger (1997), Carillo et al. (2001), and Tate et al. (2002) for example, has shown that this section of the MRGO channel, along with the critical section, the GIWW/MRGO/Reach 1, plays an important role in the propagation of the astronomical tide wave and in the flux of more saline water from Lake Borgne/Breton Sound into Lake Pontchartrain via the IHNC. The significant role of the MRGO in the propagation of the low-amplitude tide has been established.

Three previous studies have been performed to examine the influence of MRGO/Reach 2 on flooding in New Orleans and vicinity. The first of these studies, Bretschneider and Collins (1966), was performed for the U.S. Army Corps of Engineers, New Orleans District (USACE-MVN). The primary objective of the study was to determine the effects of the MRGO channel, and dredged material placement banks, and associated works, on the hurricane surge environment of an area to the east of the Mississippi River from the southern end of the MRGO to the IHNC. The study looked at Hurricane Betsy and six synthetic storms. Based on simplified one-dimensional numerical computations and estimates of channel conveyance effects, the report concluded that Betsy would have produced essentially the same surge elevations with or without the MRGO.

The second study was also commissioned by the USACE-MVN and involved "closing" the MRGO/Reach 2 with a barrier placed across the MRGO extending out from state road 624 and the La Loutre Ridge (U.S. Army Corps of Engineers, New Orleans District, 2003). That closure was located just to the southeast of Shell Beach in Figure 1. The study examined 9 synthetic storms with a track to the west of the Mississippi River running parallel to the MRGO with input strengths varying from 65 to 124 knots and forward speeds ranging from 5 to 20 knots. In addition, Hurricane Betsy input winds were examined. Each of the 10 storms was simulated with and without the MRGO closure along the La Loutre Ridge. The study applied the S08 high resolution unstructured finite element grid with detailed refinement of the MRGO, GIWW, IHNC, the Rigolets Inlet and Chef Menteur Pass (Feyen et al. 2005, Westerink et al. 2006). Resolution and domain definition requirements have been verified for the S08 grid and the resulting model has been validated (Blain et al. 1994, Blain et al. 1998, Westerink et al. 2000, Feyen et al. 2002, Feyen et al. 2005, Westerink et al. 2006). The S08 grid applies a larger approximation for the width of the MRGO/Reach 2 channel, thus leading to conservative estimates of the influence of the channel. A two dimensional depth integrated version of the ADCIRC model (Luettich et al. 1992, Luettich and Westerink 2004, Luettich and Westerink, 2005, Westerink et al. 2006), a finite element based shallow water equation code that is accurate, stable and robust, was used to perform the computations.

Results from this study showed that for low-amplitude storm surges (peak surge having a magnitude of 4 feet or less), the presence of MRGO/Reach 2 increased the storm surge by up to the following amounts: 0.5 ft at Shell Beach and Bayou Dupre, and 0.3 ft at Paris Road Bridge and the IHNC Lock. For nearly all situations that were examined (results for all ten storms at the four locations shown in Figure 1), the presence of the MRGO/Reach 2 either did not cause a significant change or the increase was less than 0.3 ft. In a few situations, notably a slow moving weak storm, the presence of the MRGO/Reach 2 channel actually led to a very small decrease in peak surge level at the four locations. For higher amplitude storm surges, peak surges on the order of 7 to 12 feet (which included Hurricane Betsy), changes induced by MRGO/Reach 2 were 0.3 ft or less for all situations. The MRGO did however considerably enhance drainage from Lake Pontchartrain through the IHNC/GIWW out to Breton Sound following passage of the storms.

A follow up study was commissioned by the State of Louisiana, Department of Natural Resources and implemented by URS Corporation (2006). This study applied the same unstructured S08 grid but filled in the MRGO/Reach 2 channel to surrounding

topographic/bathymetric levels. This study also applied the ADCIRC code and the results were similar to the USACE-MVN study. Reach 2 of the MRGO had a very limited impact on increasing storm surge for large storms, including Hurricanes Betsy and Katrina. All changes were less than 0.6 ft and most changes were less than 0.3 ft, in the vicinity of New Orleans. Results also indicated that the MRGO enhanced post storm drainage from portions of the system.

In general, the studies cited above reached consistent conclusions. The change in storm surge induced by MRGO/Reach 2 (computed as a percentage of the peak surge magnitude) is greatest when the amplitude of the storm surge is low, on the order of a few feet or less. In these situations, changes induced by the MRGO are rather small, 0.5 ft or less, but this amount is as much as 25% of the peak surge amplitude. When the long wave amplitude is very low, the surge is more limited to propagation via the channels. Once the surge amplitude increases to the point where the wetlands become inundated, this section of the MRGO plays a diminishing role in influencing the amplitude of storm surge that reaches the vicinity of metropolitan New Orleans. For storm surges of the magnitude produced by Hurricanes Betsy and Katrina, which overwhelmed the wetland system, the influence of MRGO/Reach 2 on storm surge propagation is rather small. When the expansive wetland is inundated, the storm surge propagates primarily through the water column over this much larger flooded area, and the channels become a much smaller contributor to water conveyance.

The results of these studies can be readily understood by considering in more detail the evolution of storm surge for critical hurricane tracks passing to the west of the Mississippi River. These storms blow wind across the region first from the northeast, then from the east, then from the southeast and south and finally from the west. The sustained northeasterly and especially easterly winds push water onto the wide and shallow Mississippi-Alabama Shelf into Breton and Chandeleur Sounds, and Lake Borgne. These winds build surge up regionally on the shelf and in particular against the Mississippi River and hurricane protection levees in Plaquemines Parish, against the St. Bernard Parish/Chalmette hurricane protection levee system and into the so called funnel defined by the levees protecting St. Bernard Parish/Chalmette and New Orleans East along the confluence of the GIWW/MRGO. As winds become southerly, the significant surge that has built up along the Mississippi River levees in southern Plaquemines Parish starts to propagate north as a constrained wave up the Mississippi River and as an unconstrained wave through Breton Sound, both influenced by the strength and direction of the winds. Finally, westerly winds blow surge away from these levees.

We note that the surge driven by the sustained northeasterly and easterly winds is not influenced by the MRGO, since the direction of water movement is from east to west across Breton and Chandeleur Sounds and Lake Borgne. The brief southeasterly and southerly winds do guide the substantial surge wave that has built up in Plaquemines Parish north across Breton Sound. In the case of Hurricane Betsy, the surge propagated in a northerly direction along the Mississippi River levees and was stopped by river levees at English Turn. In the case of Hurricane Katrina, the surge propagated in a northeasterly direction perpendicular to the MRGO towards Gulfport, Mississippi. In either case, the northerly movement of water is not significantly influenced by the MRGO since the size of the surge is substantially larger than the increased cross sectional area for flow, or conveyance, offered by the MRGO. Furthermore the

alignment of the MRGO does not coincide with the direction of propagation of the massive surge as it heads north and only briefly coincides with southeasterly winds which locally force flow.

We have simulated Hurricane Katrina both with the MRGO/Reach 2 in place as well as with the MRGO/Reach 2 filled to surrounding bathymetric and topographic levels. The hydrodynamic computations were performed with the TF01 ADCIRC model of Southern Louisiana which is a refinement of the earlier S08 model with added details and resolution for the coastal floodplains of the north shore of Lake Pontchartrain, Mississippi and Alabama (Interagency Performance Evaluation Task Force, 2006). We applied identical wind and pressure fields derived from a Planetary Boundary Layer (PBL) model to simulate the atmospheric forcing functions during the Katrina event (Thompson and Cardone, 1996). A sequence of hourly snapshots of water surface elevations with super-imposed winds (Figure 2) shows the evolution of storm surge with the MRGO in place. More detailed elevation values are given in corresponding labeled water elevation contour plots in Figure 3. Surge buildup starts with easterly winds blowing water from east to west against the Mississippi River levees in Plaquemines Parish as well against the hurricane protection levees of St. Bernard Parish/Chalmette in addition to driving water into the funnel defined by the levees protecting St. Bernard Parish/Chalmette and New Orleans East. When winds become southerly, the massive surge that has built up in Breton Sound propagates north. We note that the northeasterly propagating storm surge has a crown of more than 16 ft above NGVD 29 extending out more than 12 miles and water levels in the entire Mississippi-Alabama Shelf exceed 10 ft above NGVD 29.

The simulation without the MRGO/Reach 2 results in very similar water levels in most of the domain for the Katrina event. Differences in the maximum Katrina event water levels with and without the MRGO in place are shown in Figures 4a and 4b. Notable differences with the MRGO Reach 2 channel in place are as follows: there is a reduction of water level of up to 0.2 ft at the entrance to the MRGO's inland cut; there is an increase of 0.3 to 0.4 ft in the marshes west of the MRGO in the region delineated by Pointe a la Hache, Carlisle, Stella, Caernarvon and Verret; a maximum increase of approximately 1.1 ft locally east of English Turn; in Lake Borgne along the MRGO there is a 0.1 to 0.2 ft increase; there is a 0.1 to 0.2 ft decrease along the St. Bernard Parish/Chalmette protection levee; and finally there is a 0.1 to 0.2 ft increase in a portion of the GIWW/MRGO/Reach 1. In all other regions, including in the IHNC, differences are less than 0.1 ft. In addition, the New Orleans and vicinity protection system is not impacted more than 0.2 ft. These results coincide with those from the earlier studies. We note that the small increases in surge due to the presence of MRGO/Reach 2 can be traced to the alignment of the local southeasterly winds that briefly occur later in the storm and that do in fact drive more water up the MRGO/Reach 2. These waters then feed into the northward-propagating surge wave and spread laterally relative to the propagation direction. However due to fact that the alignment between the wind and the MRGO/Reach 2 is brief and in light of the shelf-wide high water levels at this stage of the storm, the impact on channel conveyance is small. The largest difference and its associated pattern seen at English Turn is related to this mechanism as well as small differences in the northward propagating waves' phasing properties coupled with the winds turning at this point as the eye of the storm moves across this area. The small decreases in maximum water elevations occur due to a small reduction in the local resistance to water being pushed by local winds in a northwesterly direction at the entrance to the MRGO/Reach 2 inland

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cut and due to increased water depths reducing local set-up against the St. Bernard Parish/ Chalmette protection levee (local wind driven set-up is inversely proportional to the depth of the water).

The reasons for the very limited influence of the MRGO/Reach 2 in the vicinity of New Orleans for strong storm events are clear. First, the MRGO does not influence the important preliminary east–west movement of water that drives the significant build up of surge in the early parts of the storm. Second, the northerly propagation of surge during the later stages of the storm are only minimally influenced by the MRGO because the increased hydraulic conveyance associated with the channel is very limited for large storms due to the large surge magnitude and especially due to the very large lateral extent of the high waters on the Mississippi-Alabama shelf that build up early on from the east. In addition, the propagation direction of this surge wave does not typically align with the MRGO and furthermore the southeasterly winds which align with the MRGO occur only very briefly.

The fact that all studies show a larger proportional influence of the presence of the MRGO/Reach 2 for low intensity (low peak surge magnitude) events is related to the fact that the proportional increase in conveyance due to Reach 2 is greater when the surge is small and the water levels in Breton Sound and Lake Borgne are generally low. This also explains why we see a more rapid drop in post-storm Lake Pontchartrain levels for large-scale events with the MRGO in place. Waters typically withdraw relatively rapidly from Breton Sound and Lake Borgne due to the direct connection to open waters. The total combined conveyance of the Rigolets, Chef Menteur Pass and the IHNC/GIWW/MRGO system is increased with the MRGO in place under the lower post-storm levels on the Mississippi-Alabama shelf.

While the simulations clearly show that the Reach 2 of the MRGO does not significantly influence the development of surge in the region for large storm events, the presence of the critical Reach 1 combined GIWW/MRGO and IHNC connection between Lake Borgne and Lake Pontchartrain as well as the funnel defined by the hurricane protection levees along the banks of the MRGO and GIWW locally collect and focus surge in the region, influencing all hydraulically-connected regions as well as New Orleans proper. The degree of focusing by the levees which form the funnel is a function of the wind speed and direction. Strong winds from the east tend to maximize the local funneling effect.

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Westerink, J.J., R.A. Luettich, J.C. Feyen, J.H. Atkinson, C. Dawson, M.D. Powell, J.P. Dunion, H.J. Roberts, E. J. Kubatko, H. Pourtaheri, 2006: A Basin to Channel Scale Unstructured Grid Hurricane Storm Surge Model for Southern Louisiana**.** *Monthly Weather Review*, To be submitted.
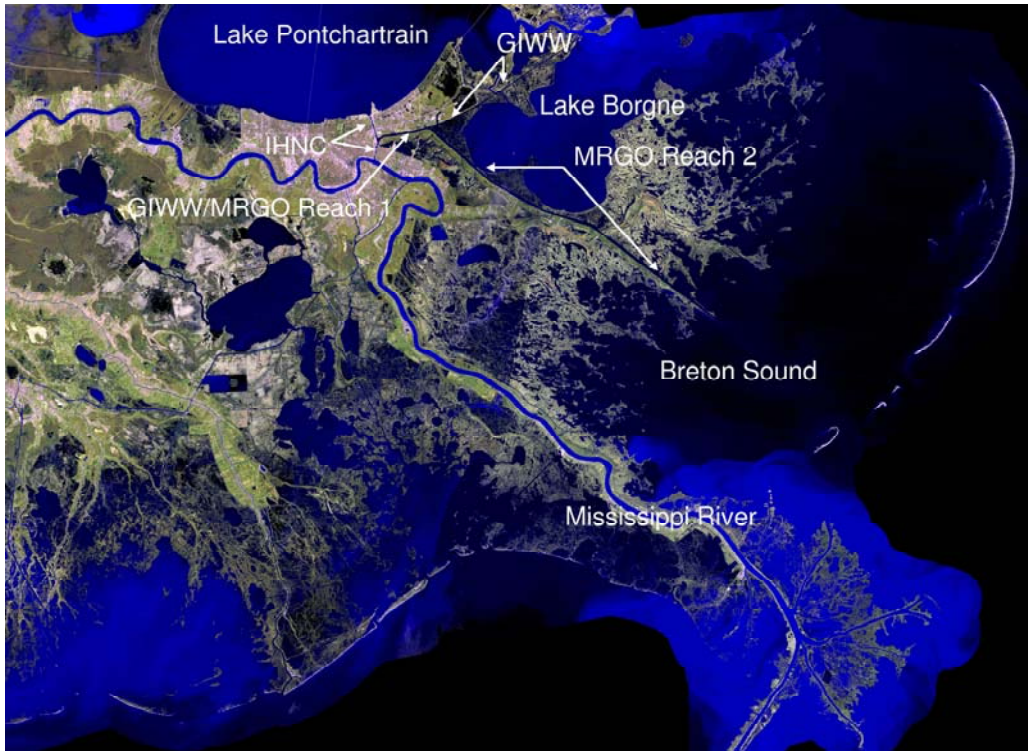
Figure 1a. Satellite image of Southeastern Louisiana.

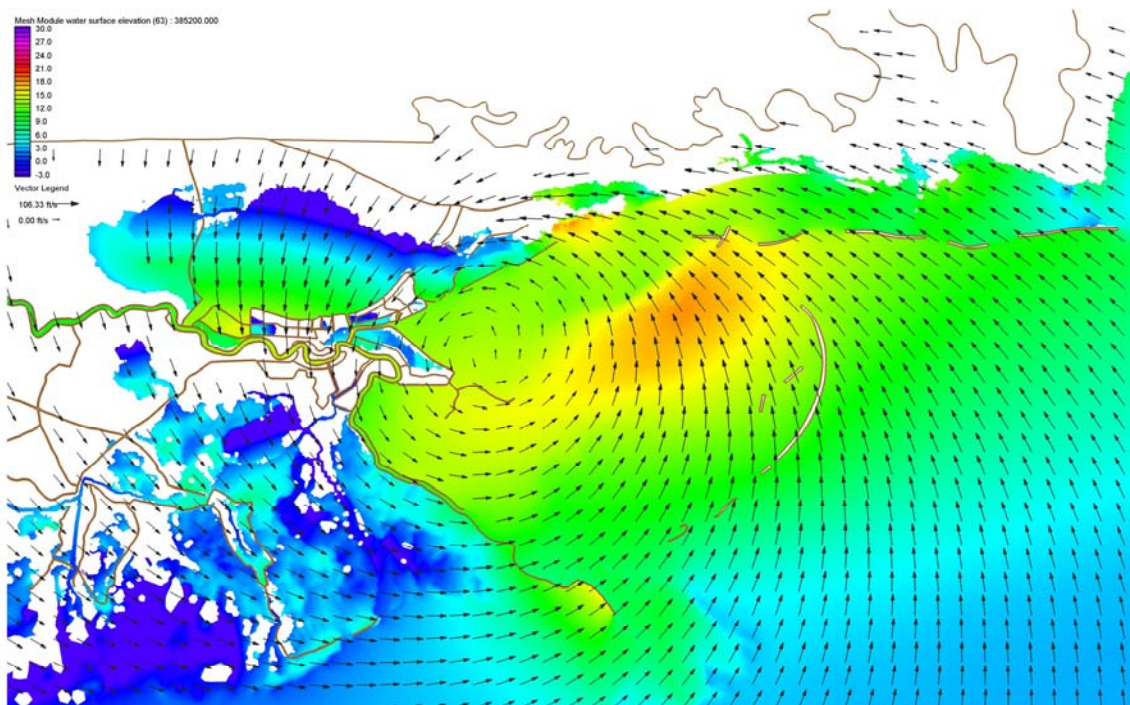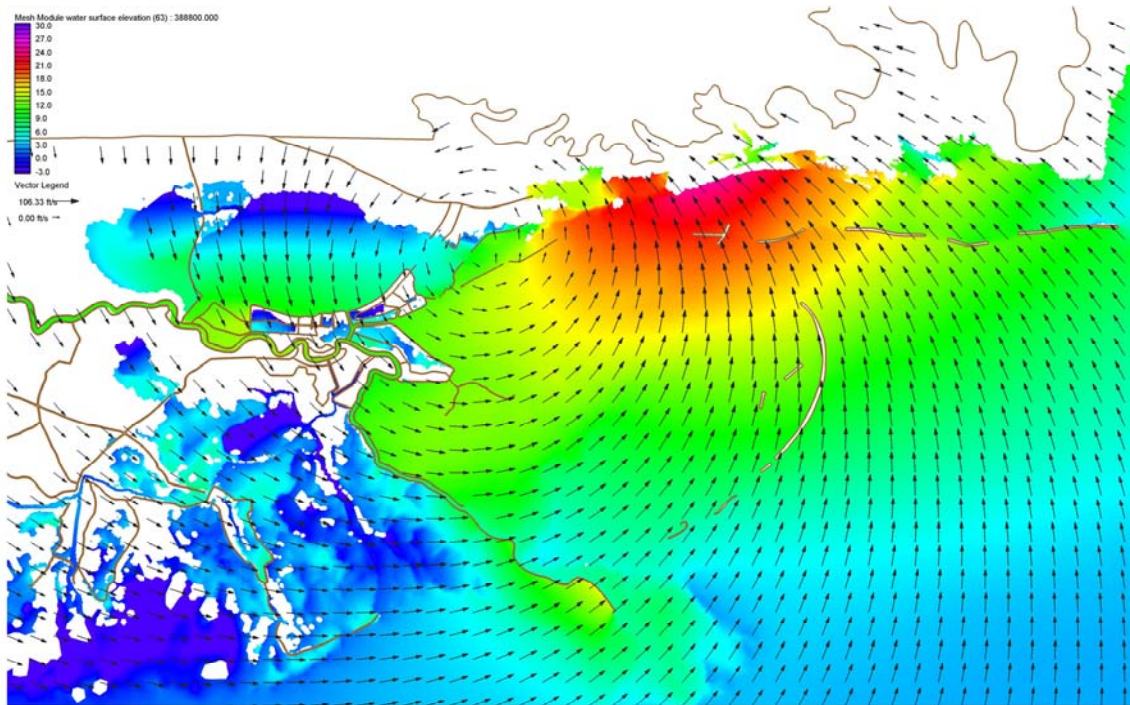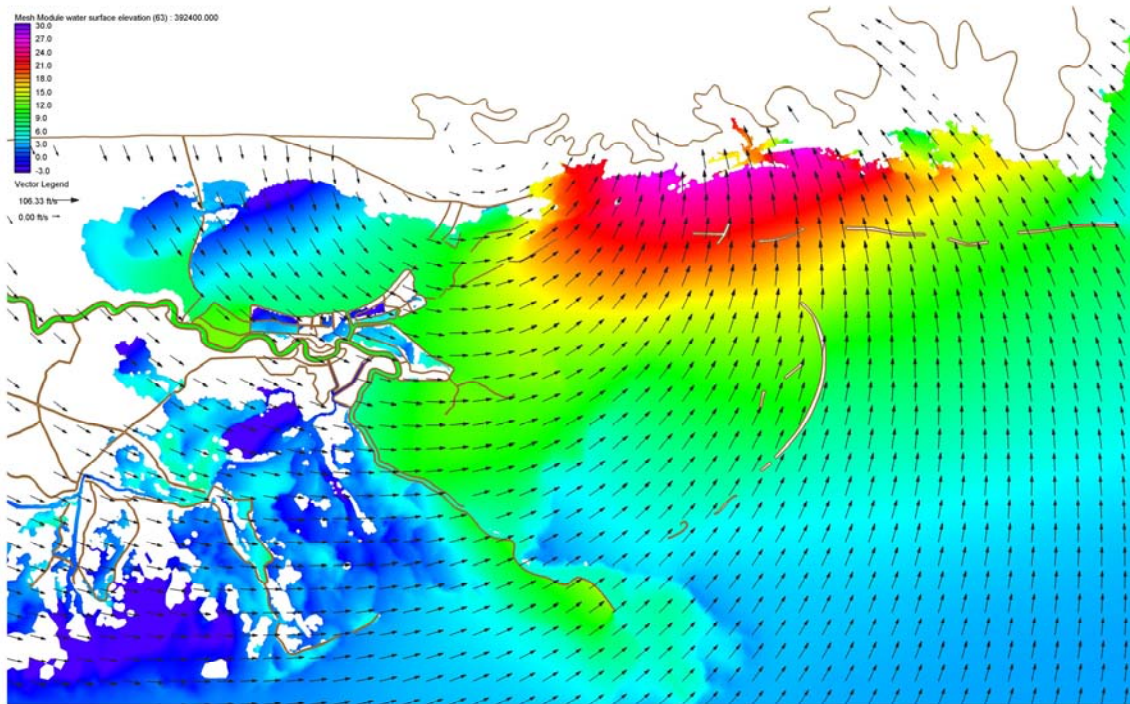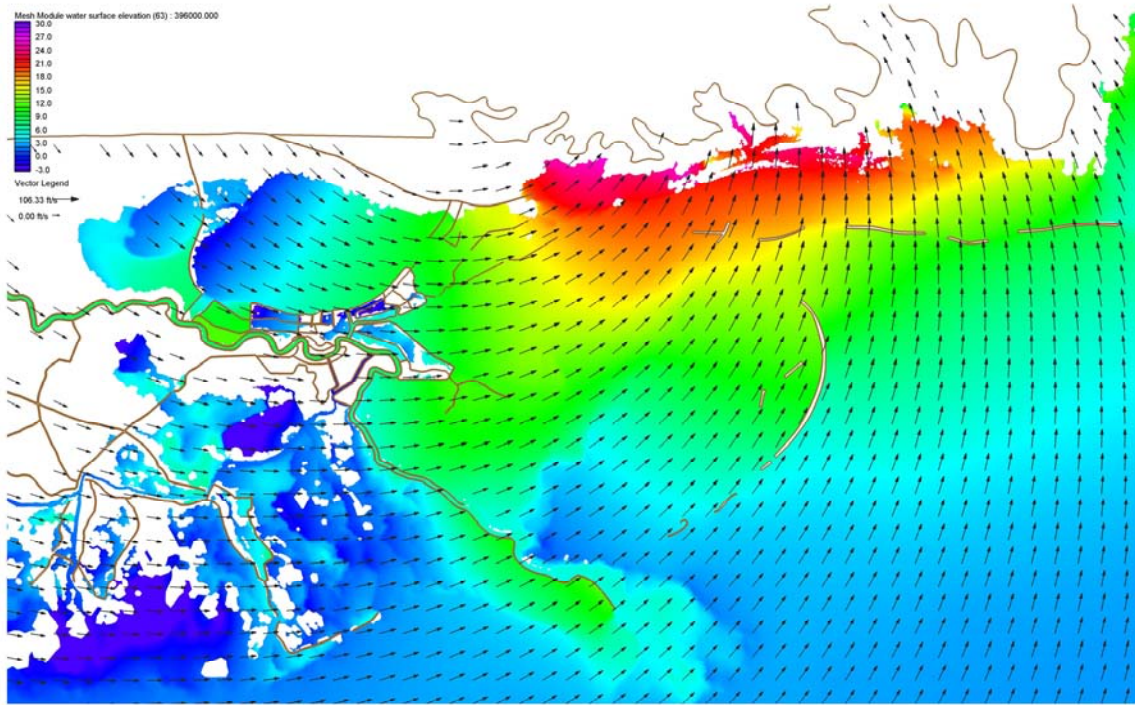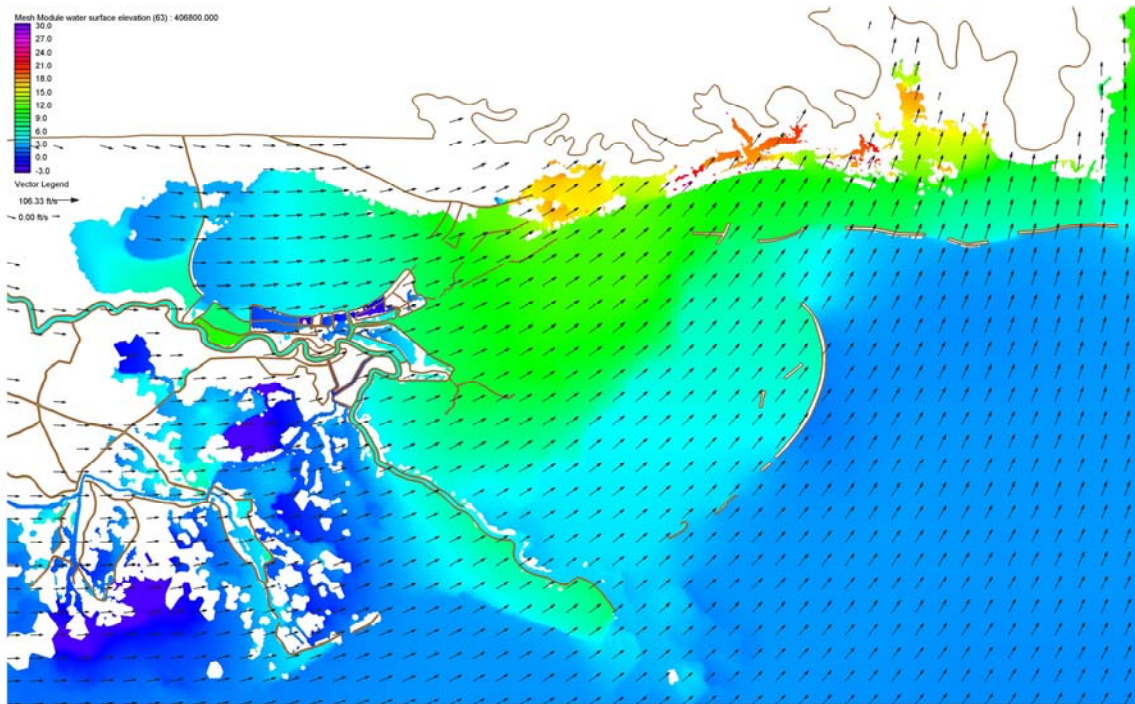Figure 1b. Satellite image of metropolitan New Orleans and vicinity.
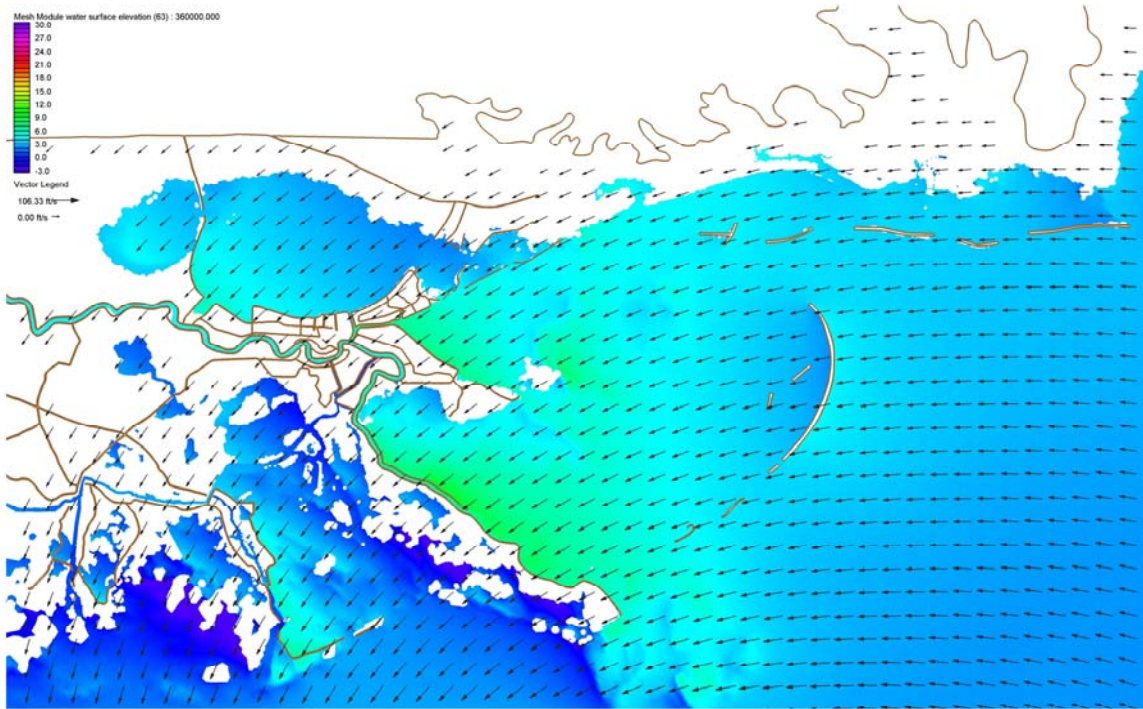
Figure 2a. Water surface elevation with respect to the NGVD29 (ft) with boundary layer adjusted wind velocity vectors (knots) during Hurricane Katrina on August 29, 2005 at 0700UTC.
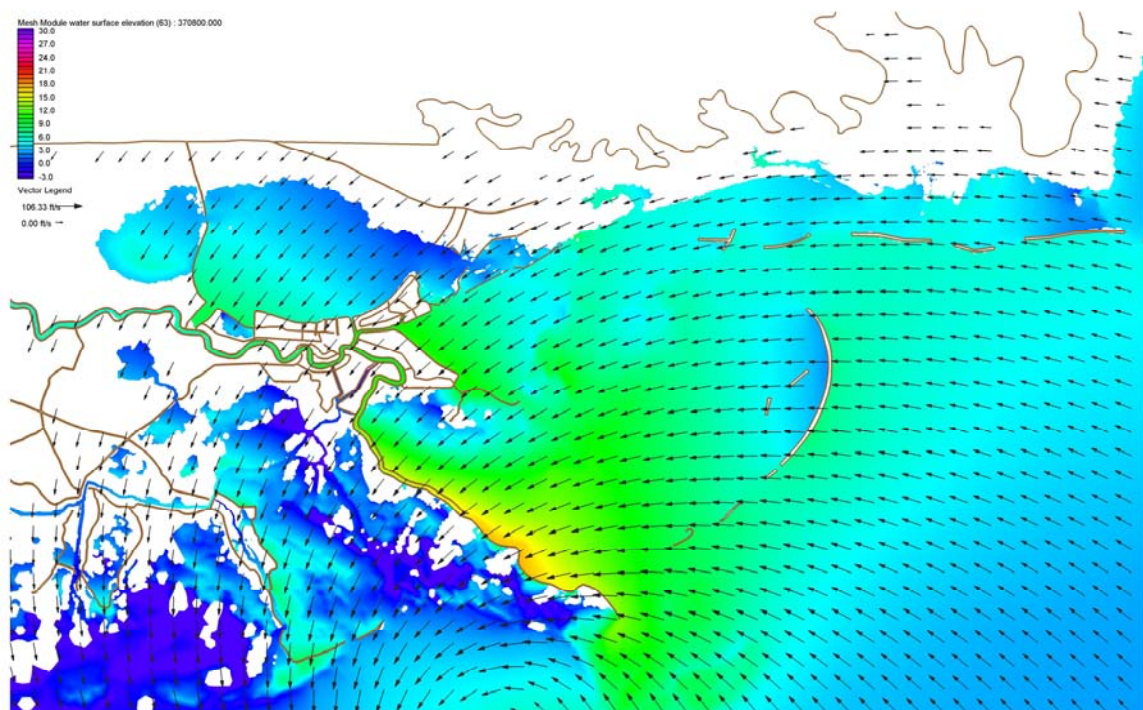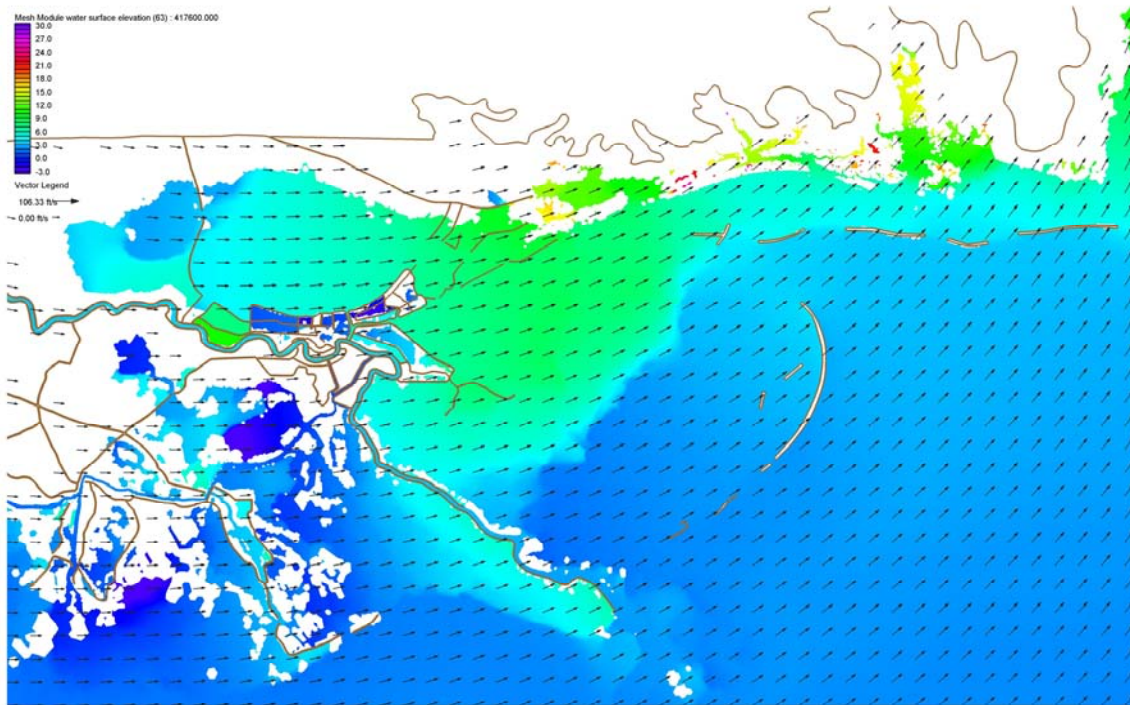

Figure 2b. Water surface elevation with respect to the NGVD 29 (ft) with boundary layer adjusted wind velocity vectors (knots) during Hurricane Katrina on August 29, 2005 at 1000UTC.
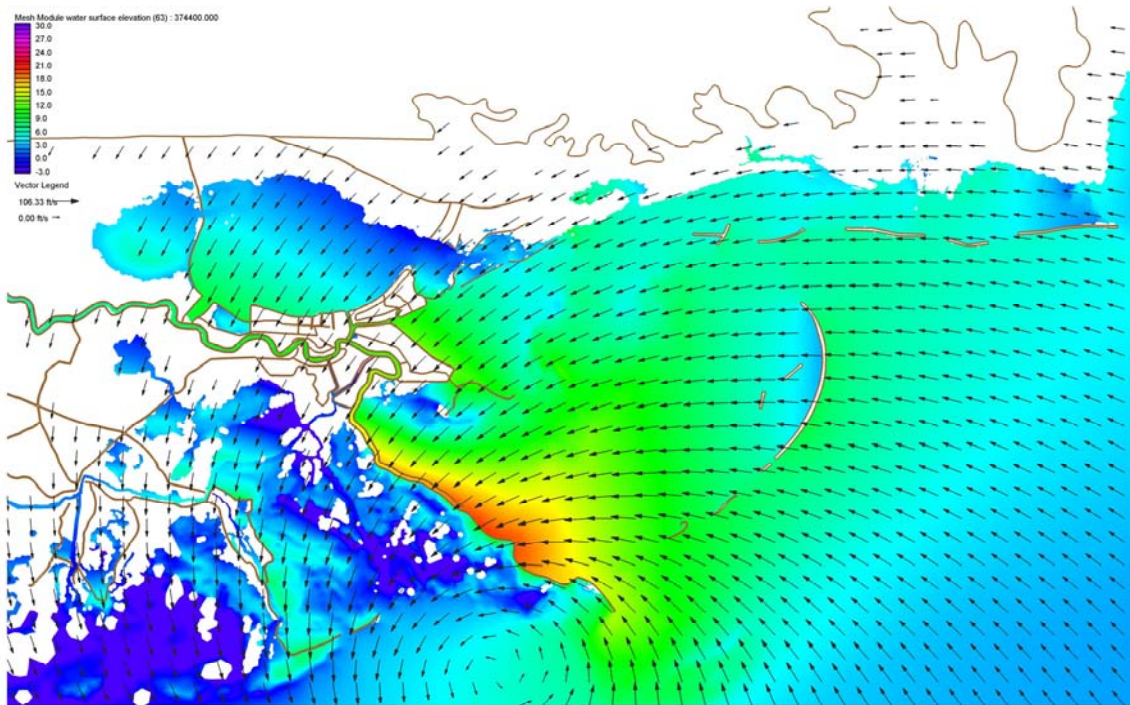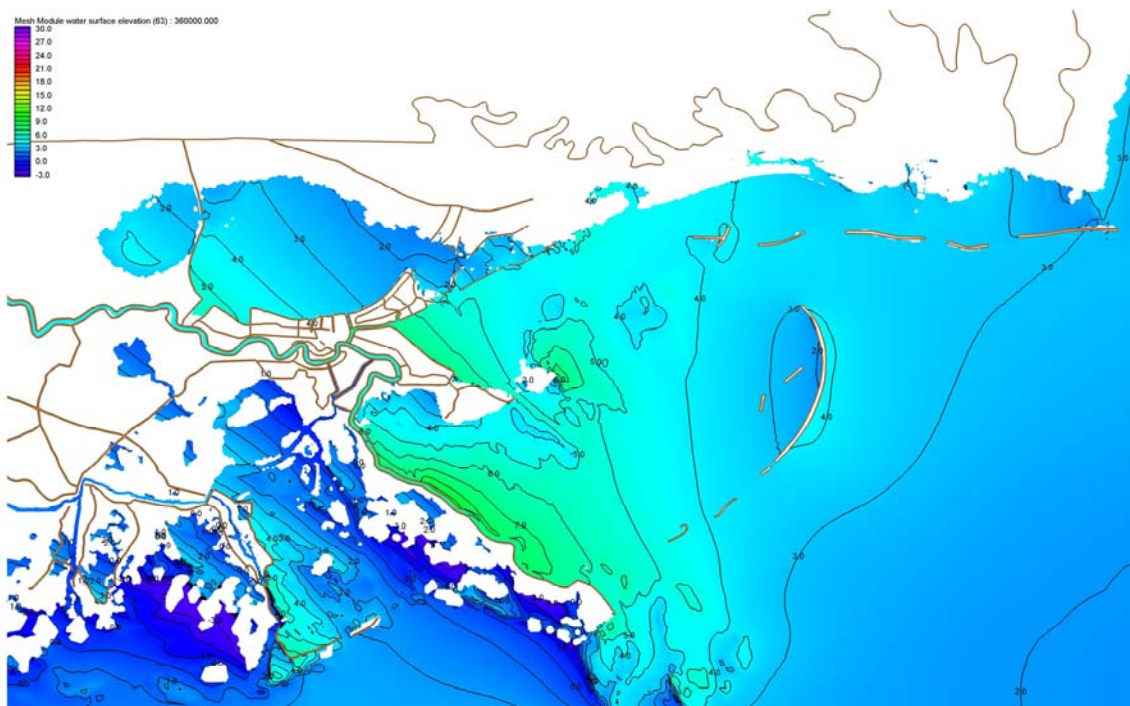
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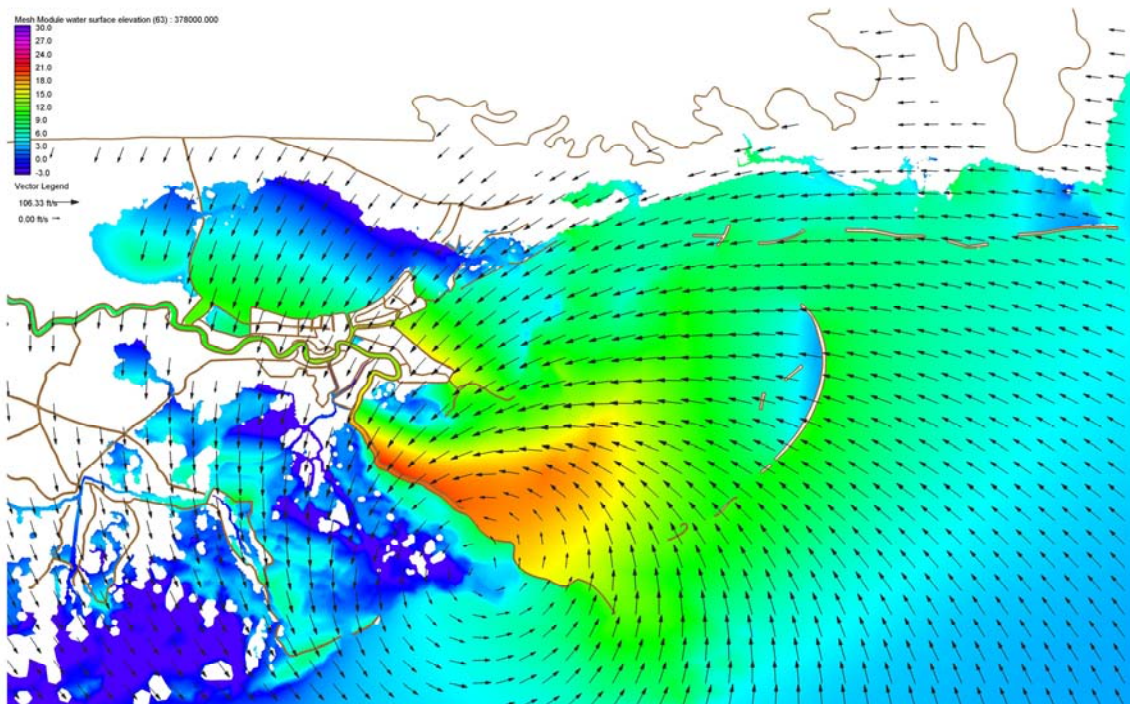
Figure 2d. Water surface elevation with respect to the NGVD 29 (ft) with boundary layer adjusted wind velocity vectors (knots) during Hurricane Katrina on August 29, 2005 at 1200UTC.
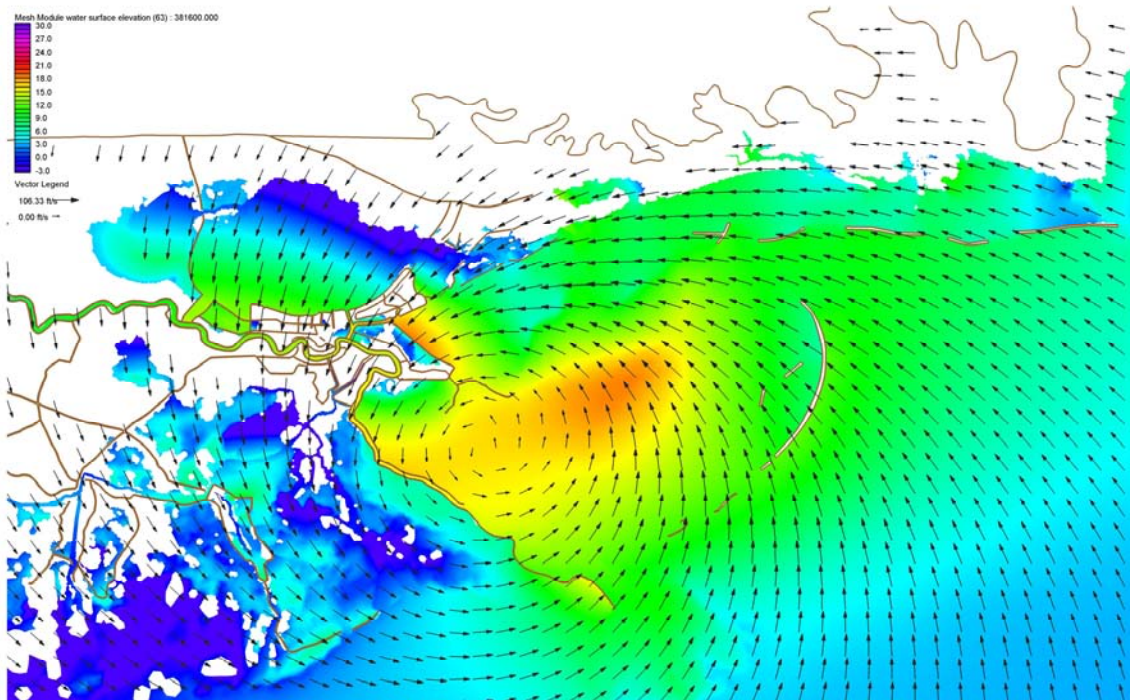
Figure 2e. Water surface elevation with respect to the NGVD 29 (ft) with boundary layer adjusted wind velocity vectors (knots) during Hurricane Katrina on August 29, 2005 at 1300UTC.

Figure 2f. Water surface elevation with respect to the NGVD 29 (ft) with boundary layer adjusted wind velocity vectors (knots) during Hurricane Katrina on August 29, 2005 at 1400UTC.

Figure 2g. Water surface elevation with respect to the NGVD 29 (ft) with boundary layer adjusted wind velocity vectors (knots) during Hurricane Katrina on August 29, 2005 at 1500UTC.

Figure 2h. Water surface elevation with respect to the NGVD 29 (ft) with boundary layer adjusted wind velocity vectors (knots) during Hurricane Katrina on August 29, 2005 at 1600UTC.

Figure 2i. Water surface elevation with respect to the NGVD 29 (ft) with boundary layer adjusted wind velocity vectors (knots) during Hurricane Katrina on August 29, 2005 at 1700UTC.

Figure 2j. Water surface elevation with respect to the NGVD 29 (ft) with boundary layer adjusted wind velocity vectors (knots) during Hurricane Katrina on August 29, 2005 at 2000UTC.

Figure 2k. Water surface elevation with respect to the NGVD 29 (ft) with boundary layer adjusted wind velocity vectors (knots) during Hurricane Katrina on August 29, 2005 at 2300UTC.
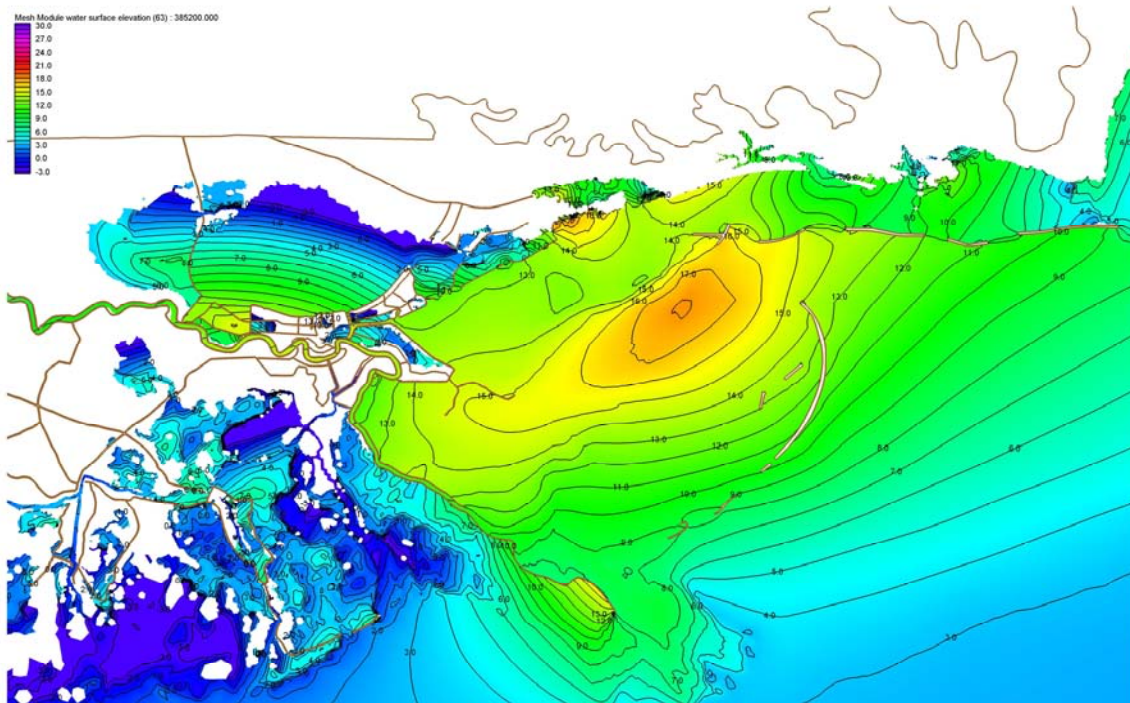

Figure 3a. Water surface elevation with respect to the NGVD 29 (ft) with labeled contours during Hurricane Katrina on August 29, 2005 at 0700UTC.
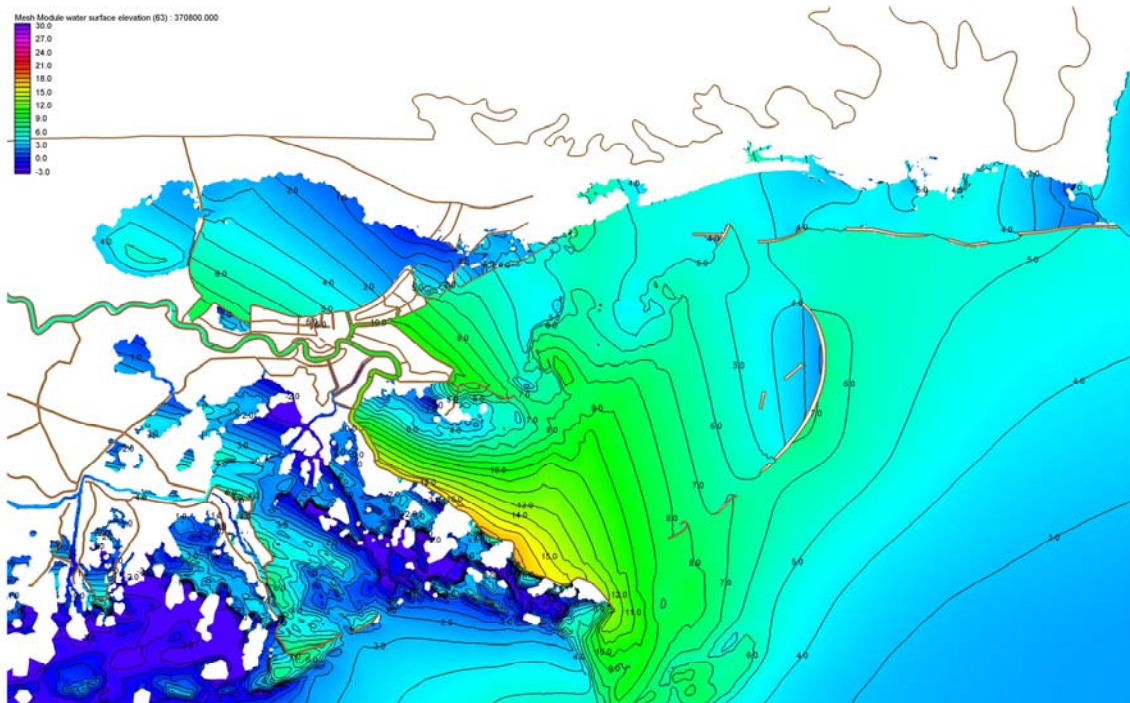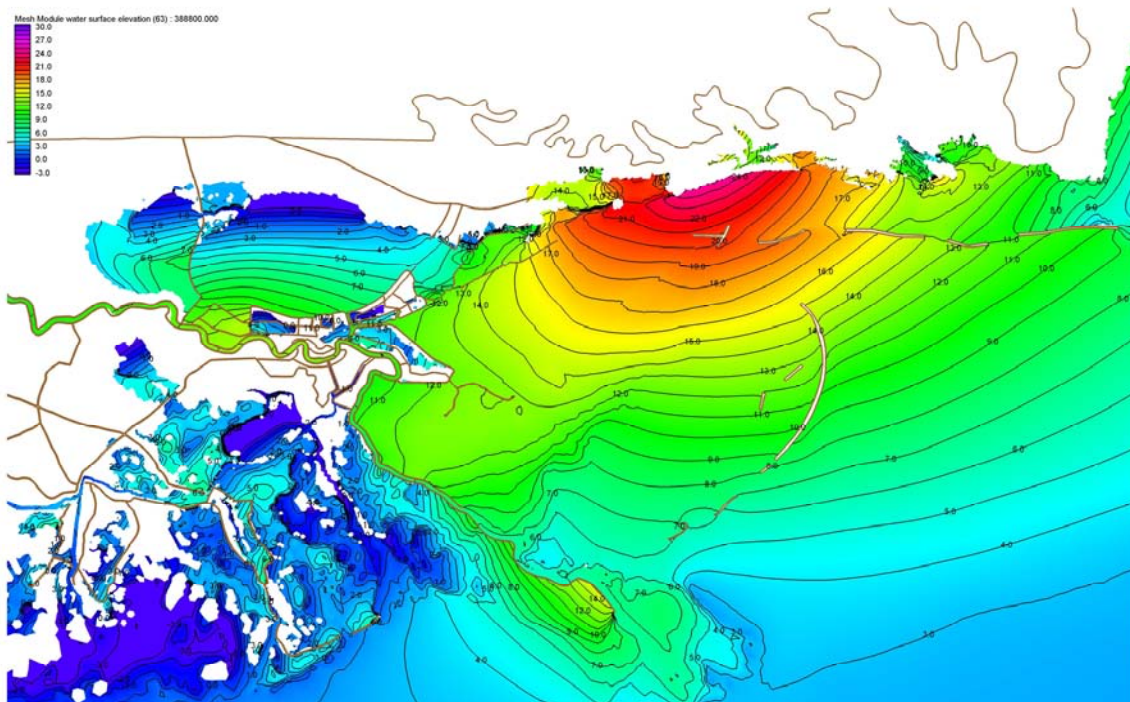
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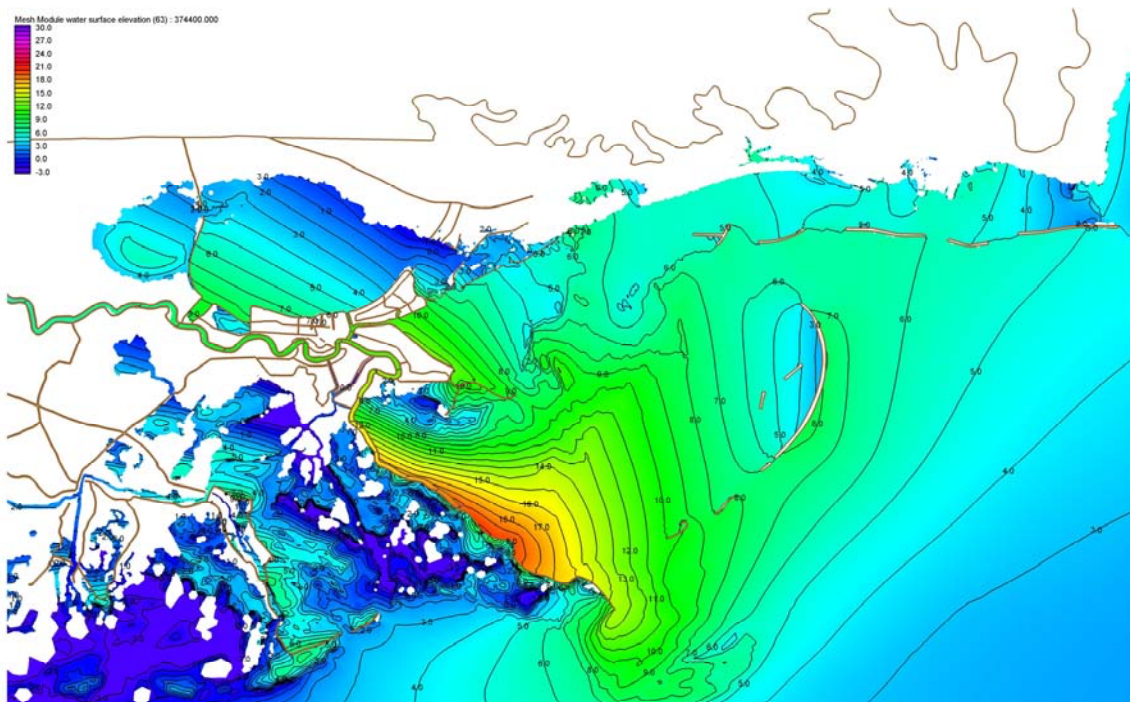
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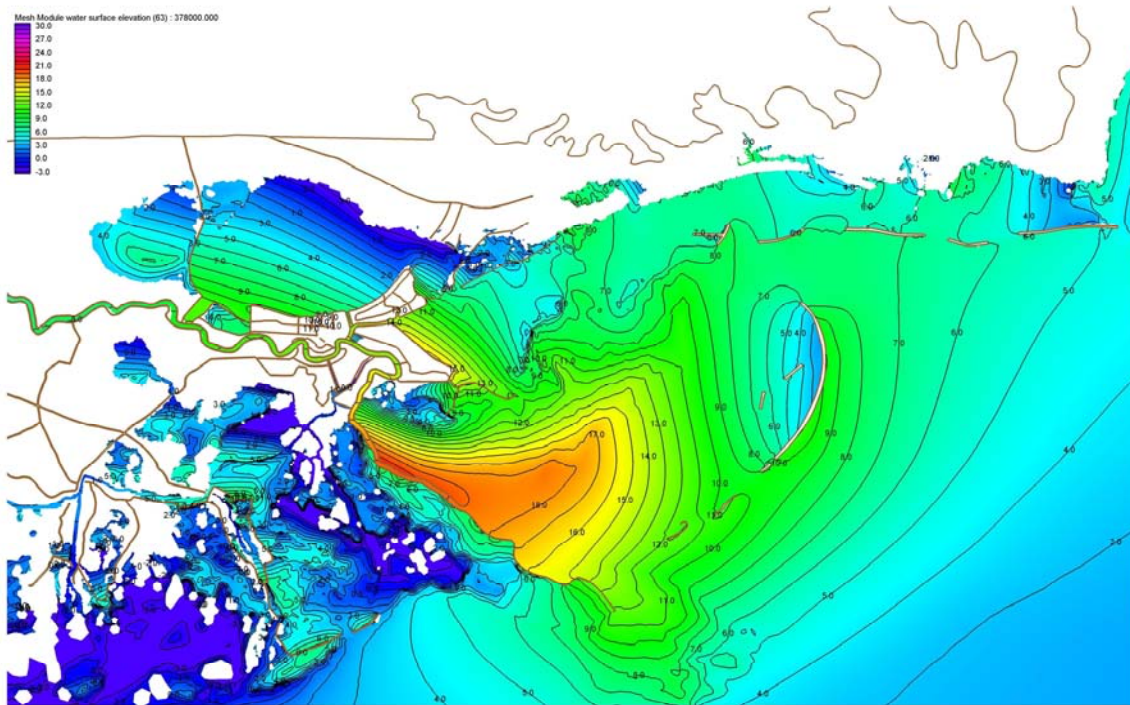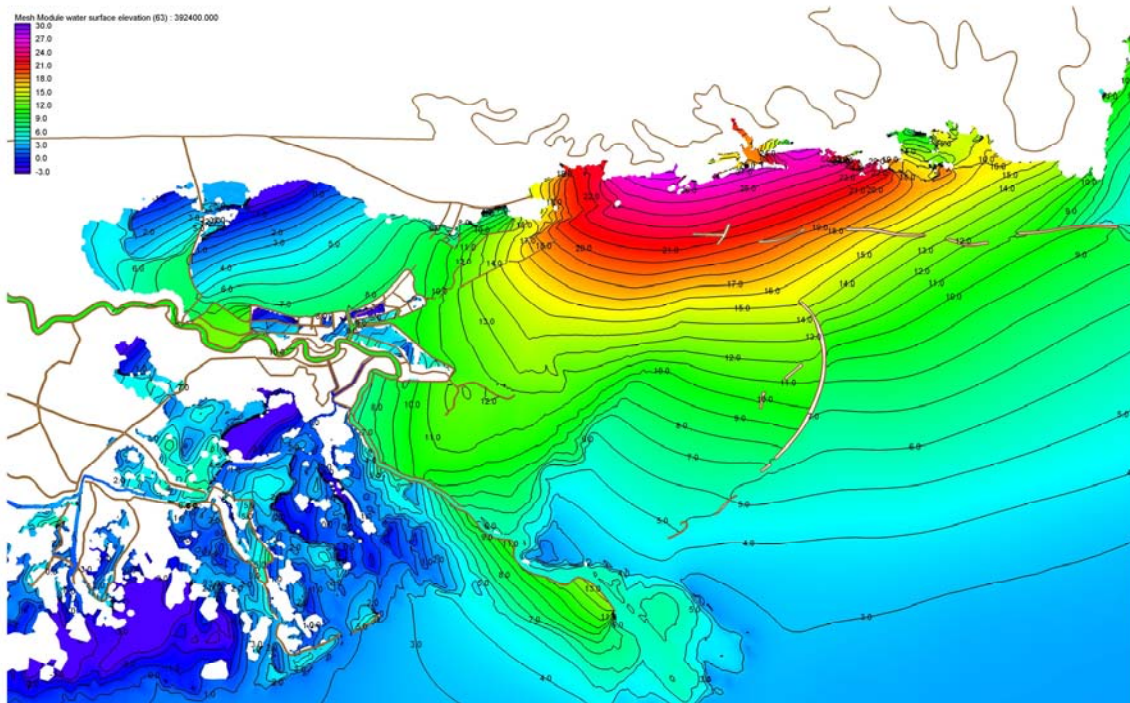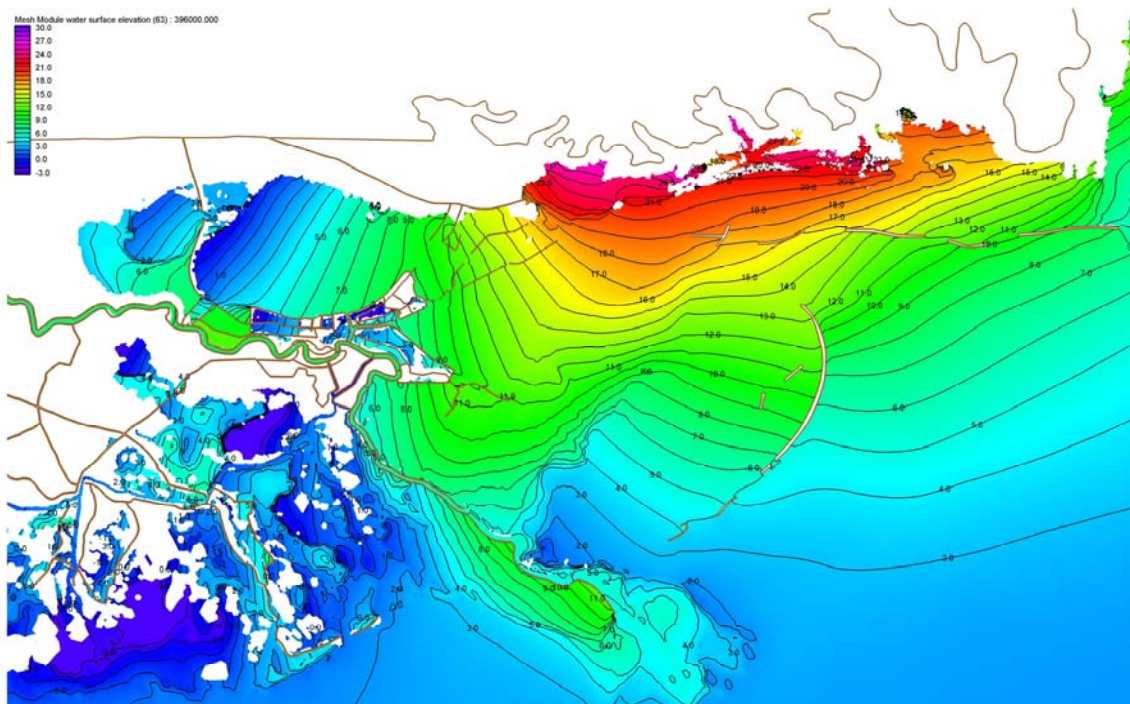
Figure 3d. Water surface elevation with respect to the NGVD 29 (ft) with labeled contours during Hurricane Katrina on August 29, 2005 at 1200UTC.
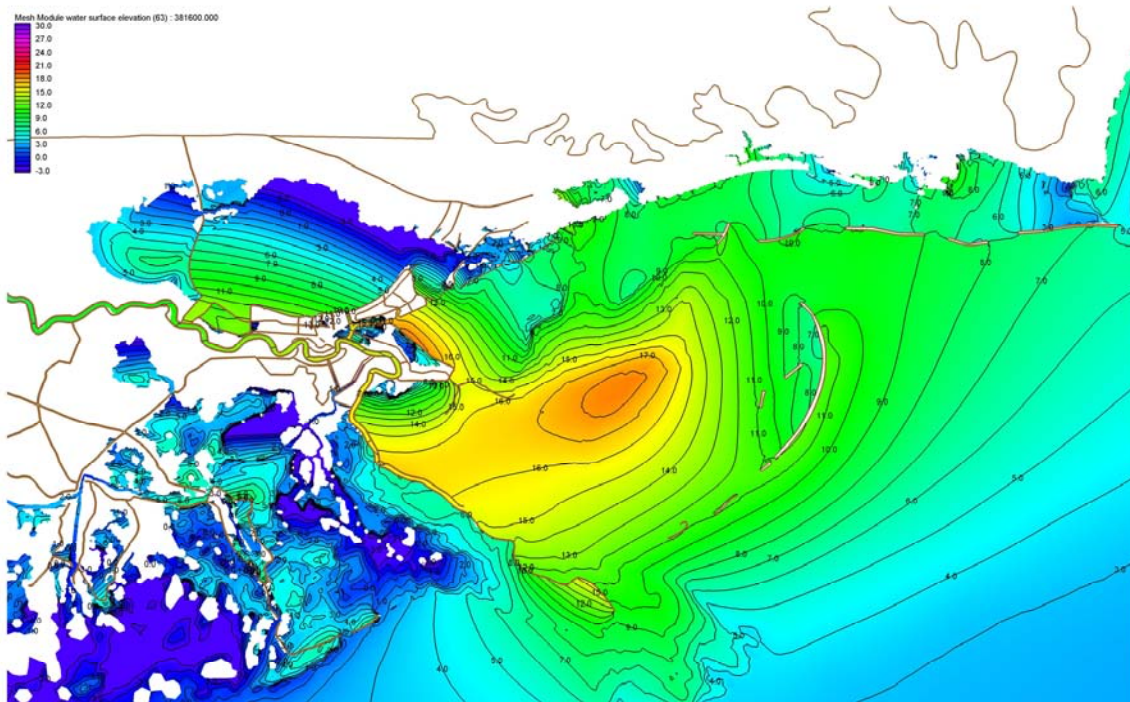
Figure 3e. Water surface elevation with respect to the NGVD 29 (ft) with labeled contours during Hurricane Katrina on August 29, 2005 at 1300UTC.

Figure 3f. Water surface elevation with respect to the NGVD 29 (ft) with labeled contours during Hurricane Katrina on August 29, 2005 at 1400UTC.
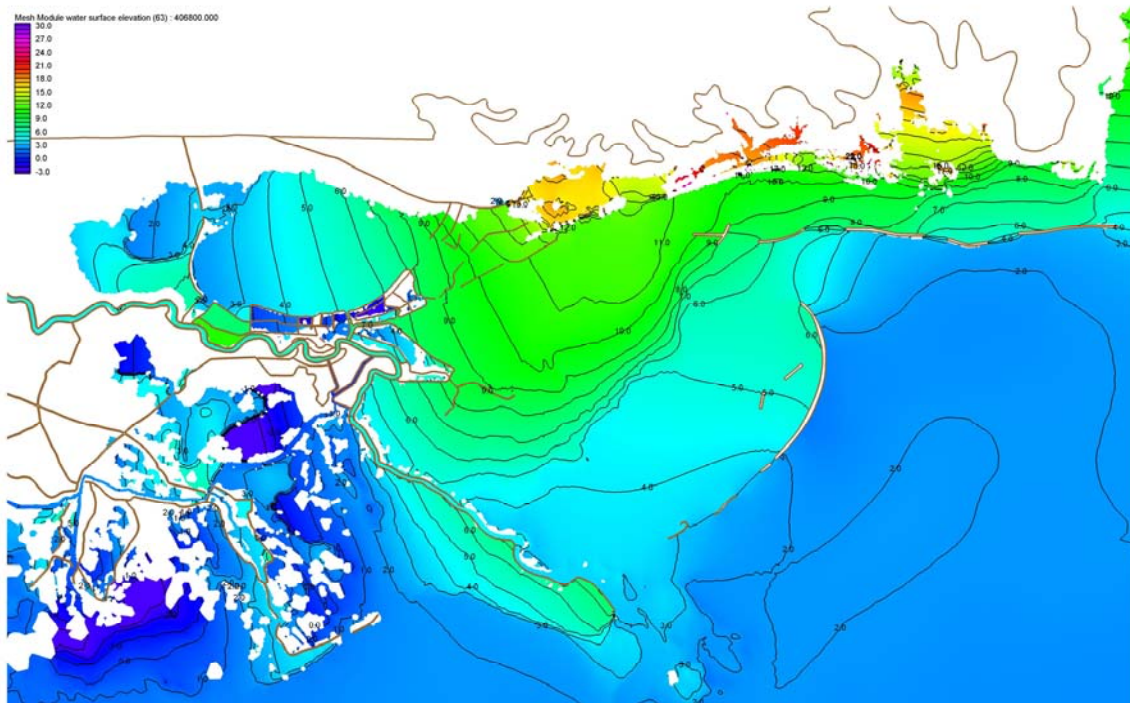

Figure 3g. Water surface elevation with respect to the NGVD 29 (ft) with labeled contours during Hurricane Katrina on August 29, 2005 at 1500UTC.
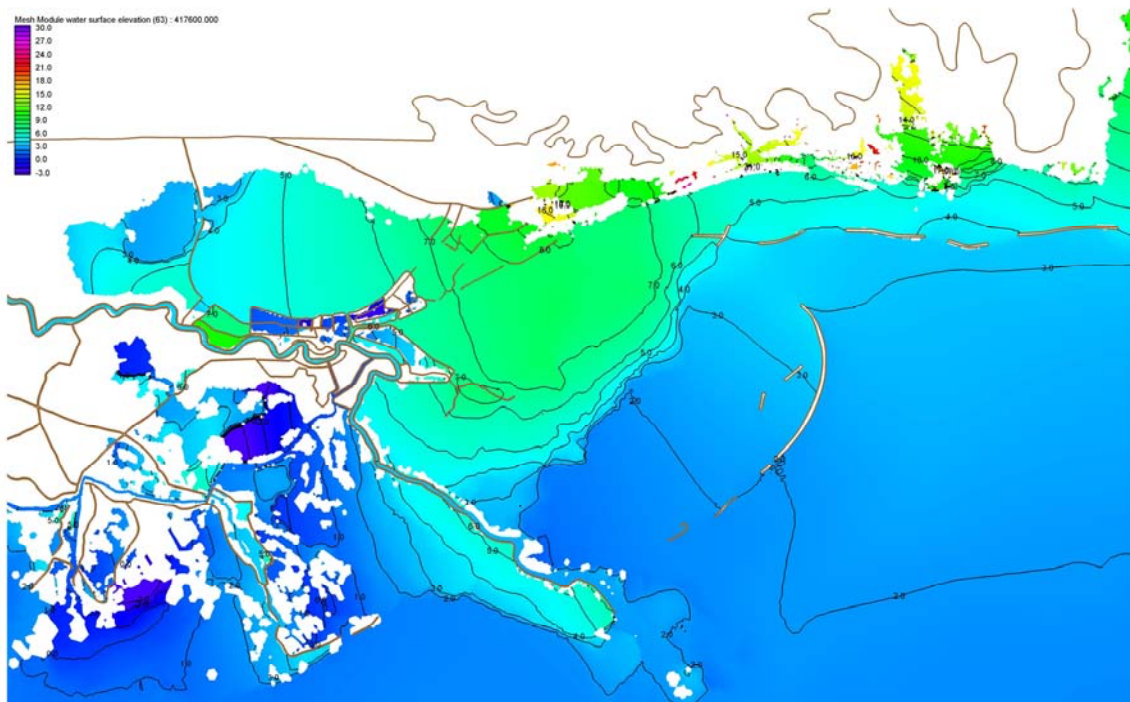
Figure 3h. Water surface elevation with respect to the NGVD 29 (ft) with labeled contours during Hurricane Katrina on August 29, 2005 at 1600UTC.

Figure 3i. Water surface elevation with respect to the NGVD 29 (ft) with labeled contours during Hurricane Katrina on August 29, 2005 at 1700UTC.

Figure 3j. Water surface elevation with respect to the NGVD 29 (ft) with labeled contours during Hurricane Katrina on August 29, 2005 at 2000UTC.

Figure 3k. Water surface elevation with respect to the NGVD 29 (ft) with labeled contours during Hurricane Katrina on August 29, 2005 at 2300UTC.
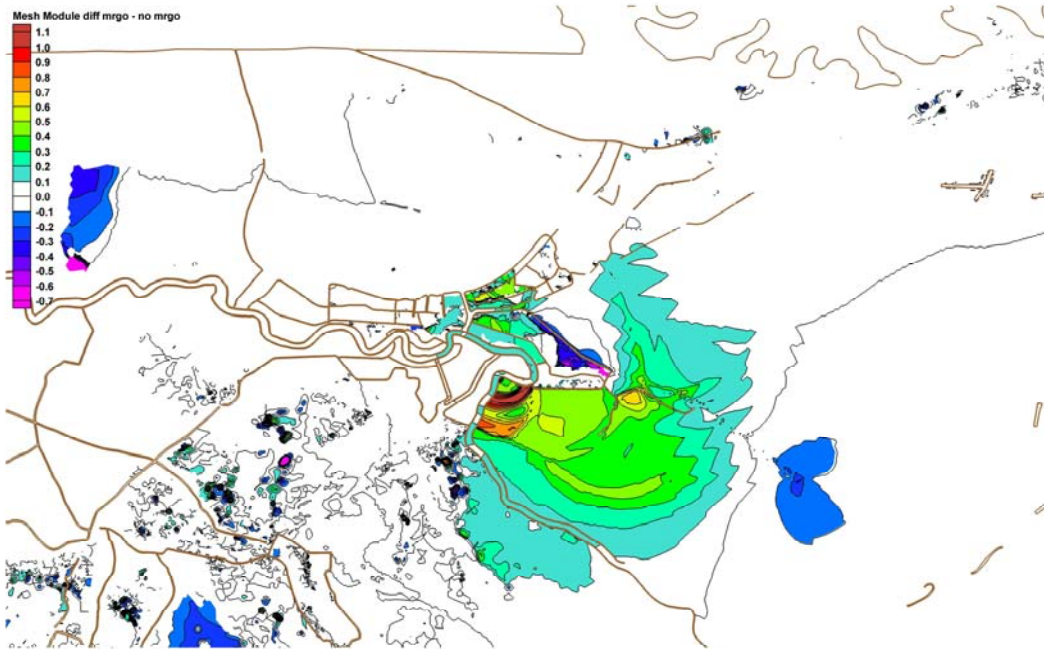
Figure 4a. Maximum Hurricane Katrina event differences in ft, for simulations with and without the MRGO in place. Positive differences indicate increased elevations with the MRGO in place while negative differences indicate decreased water levels with the MRGO in place.
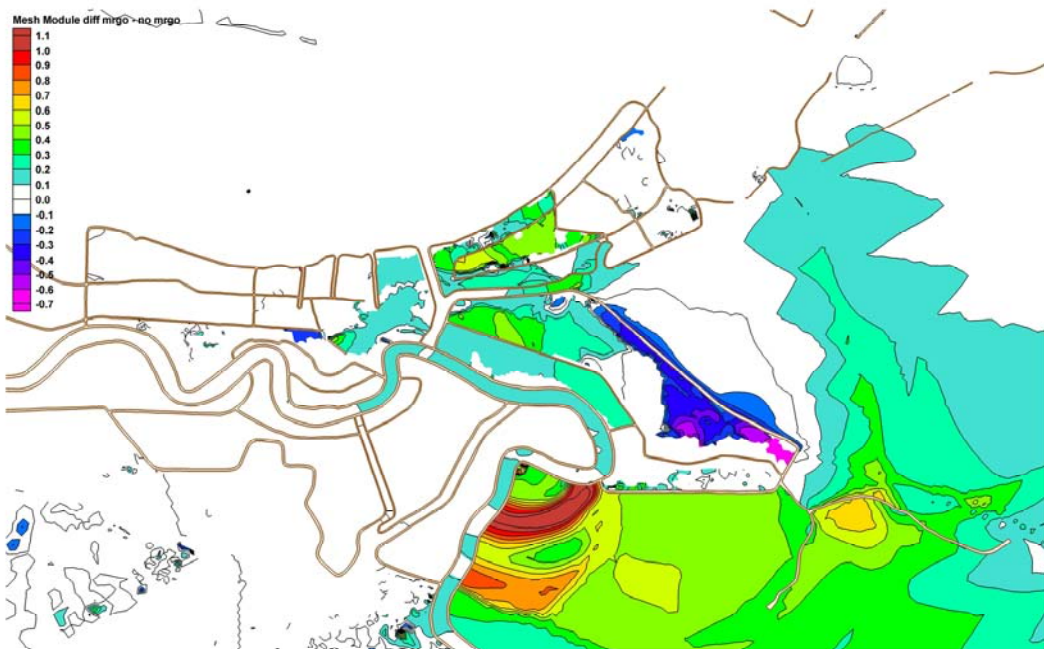

Figure 4b. Maximum Hurricane Katrina event differences in ft in metropolitan New Orleans and vicinity, for simulations with and without the MRGO in place. Positive differences indicate increased elevations with the MRGO in place while negative differences indicate decreased water levels with the MRGO in place.