Unit 7 Section 3 Computer Lab

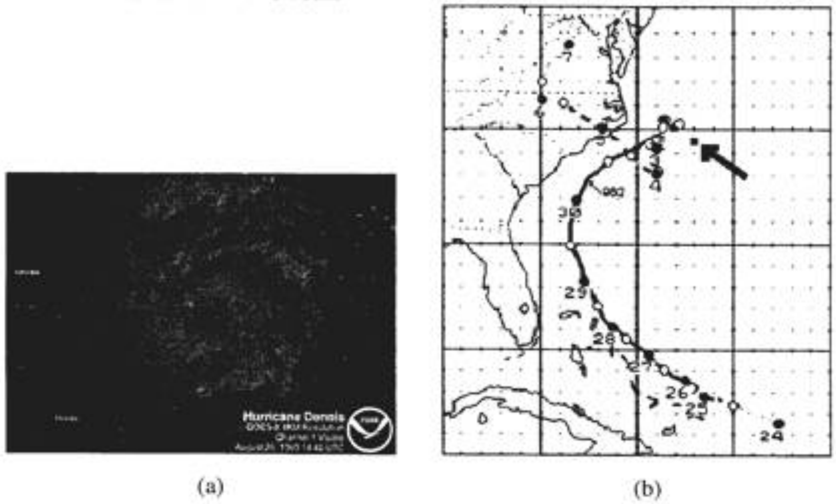
Part 1:

OPEN OCEAN AND COASTAL IMPACTS OF TROPICAL CYCLONES

Educational Outcomes: Tropical cyclones are significant phenomena in the Earth system. They are as much oceanic as they are atmospheric in open ocean and coastal areas. They form over warm ocean waters as heat and water vapor are transported into the atmosphere. Their atmospheric components including winds, precipitation, and air pressure bring about changes in the surface and upper layers of the ocean. If atmospheric conditions are favorable, a tropical disturbance intensifies into a named tropical storm with sustained surface wind speeds of 63 km per hr (39 mi per hr) and then a hurricane (so named in the Atlantic and eastern Pacific basins) with sustained winds of 119 km per hr (74 mi per hr) or higher. Coupling of tropical cyclones with the ocean impacts numerous ocean characteristics including sea level, water waves, and sea surface and upper layer temperatures, salinity, and structure. The latent and sensible heat of the ocean is converted to the kinetic energy of storm winds and moving water that can devastate the coastal zone.

A hurricane consists of an eye with relatively cloud-free skies and calm air about 10 to 65 km (6 to 40 mi) across. Surrounding the eye is the eyewall, a towering ring of intense thunderstorms responsible for the heaviest rain and strongest winds. Additional bands of heavy rain and thunderstorms spiral into the eyewall from the periphery of the storm. Viewed from above, the circulation of the winds about the surface low-pressure center of the hurricane eye is counterclockwise in the Northern Hemisphere.

Hurricanes Over the Ocean



(a) (b)

Figure I. Hurricane Dennis and its effects on the ocean surface layer. (a) Visible satellite image of Dennis at 1445Z on 29 August 1999. (b) Path of Dennis from 24 August to 7 September 1999. Arrow locates approximate position of Argo float shown with a (.). (c) Argo float 115 profile #052 on 22 August 1999 (following page). (d) Argo float profile #053 on 2 September 1999 (following page).

While the ocean supplies the energy for tropical cyclones, the spin of hurricanes as they progress across Earth's surface and accompanying precipitation impact the ocean over which they travel. Figure I provides information showing the impact of Hurricane Dennis (1999) on the surface layer of the underlying ocean. Figure I a is a satellite view of the hurricane when it was located to the east of Jacksonville, FL. Figure Ib shows the track of the storm from 24 August to 7 September 1999. Figures Ic and Id, on the next page, provide vertical temperature castings acquired via a University of Washington PALACE float that was located approximately at the "." position pointed to by an arrow on the Figure I b map.

The Figure Ic temperature profile acquired before the arrival of Hurricane Dennis at the float location indicates a surface water temperature of approximately _______ °c. The Figure I d temperature profile, after the arrival of the hurricane in the area where the float was located, indicates a surface water temperature of approximately ___________°C.

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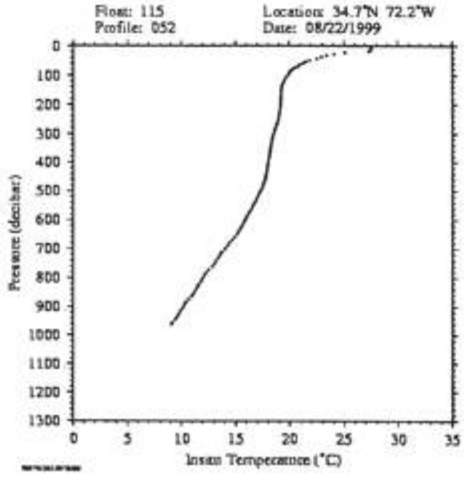
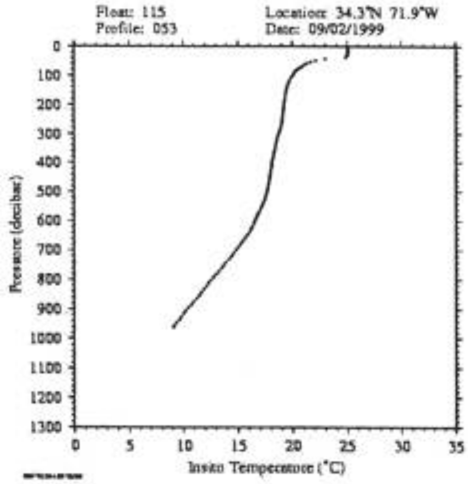


(c)



(d)

2. Comparison of the two temperature profiles shows that the passage of Hurricane Dennis was accompanied by [(an increase) (no change) (a decrease)] in sea surface temperature.

3. Further comparison of the two temperature profiles shows that the thickness of the uppermost layer of the ocean where the temperature is uniform (isothermal) [(increased) (did not change) (decreased)] because of the passage of the hurricane. Based on the temperature data provided, it appears that the hurricane winds [(did) (did not)] force vertical mixing of the seawater in this upper layer.

Impacts of Hurricanes on Coastal Regions

The most serious threat to coastal locations from a hurricane is the storm surge. A storm surge is a dome of ocean water that travels with the hurricane, from the eye to the right of the track in the Northern Hemisphere (where onshore winds are strongest). The low air pressure near the hurricane eye causes sea level to rise about 0.5 m (1.6 ft) for every 50-millibar drop in air pressure. Wind-driven water topped by waves also pushes forward on the right side of the path of the storm. Added to this is the normal sea level variation due to tides. These factors combine to generate a storm surge that can range in height from I m to more than 6 m (3 ft to more than 20 ft), depending on the storm strength (wind speed).

As the storm nears shore, the sea bottom topography becomes a factor. The on-coming water volume may be negligible over a deep-sea bottom but becomes monumental with a gently sloping, shallow bottom. The density of water is 1000 kilograms per cubic meter. That is one metric ton of mass per cubic meter hitting the shore at speeds of IS to 25 km (9 to 16 ft) per hr. And this surge dome may extend 40 km (25 mi) or more along the shore making for millions of cubic meters of water volume. This can be a devastating knockout punch!

Meteorologists at NOAA's National Hurricane Center (NHC) use special numerical models to predict hurricane tracks based on atmospheric data including air pressure patterns and upper-level winds. The atmospheric conditions that are input to these models come from regular observations and from special aircraft that fly through the storms. When a coastal locality is targeted by a tropical cyclone, another type of numerical model is employed to estimate the effect of the storm at landfall.

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NHC's Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model predicts water level surges, typically within 20% of the values of actual occurrences. [For those interested, the basins along the Gulf of Mexico, Caribbean and Atlantic Coasts that have been modeled by SLOSH are identified at http://www.nws.gov/mdl/marine/basins.htm.] Stored in the model are detailed topographic data on major coastal cities and their surroundings. Using this topographic database, the model examines hundreds of hurricanes of varying intensity, forward speed, direction, and location of landfall within the area of interest. From this the model predicts water level changes. Emergency managers with knowledge of local elevations and the location of structures can use information on the maximum predicted water levels to follow a plan of action to protect life and property.

Hurricane Hugo

The SLOSH model can be demonstrated through its application to the Charleston, SC SLOSH basin. Near midnight on 22 September 1989, Hurricane Hugo swept onshore in Charleston with winds of 194 km (120 mi) per hr and heavy rains causing 21 U.S. mainland deaths and $7 billion in damage-the costliest U.S. hurricane landfall to that date. Figure 2 displays the Charleston SLOSH basin, a roughly semi-circular area with a grid plotted over land surfaces that include those places most likely to be subjected to flooding associated with hurricane landfall. In this view, Hurricane Hugo's eye had entered the SLOSH basin area. The thin line from the lower right to the eye's position represents the storm's path (from the southeast to the northwest). [Note: Figures 2 and 3 are derived from a color animation that can be viewed at your option at httv://www.nws.noaa.gov/mdl/marine/hugolhtm. We recommend a visit to it.]

4. Arrows with feathers and flags depicting the wind field at the time, reveal the counterclockwise circulation of the storm as seen from above. The wind pattern show winds blowing onshore to the [(left) (right)] of the eye's path when looking towards shore. The lighter gray shadings within the water portion of the basin view indicate higher water levels in the region centered on the eye (probably due to lower

atmospheric pressure at the center of the hurricane) and to the forward right of the advancing storm due to the wind pattern. The model output was probably showing coastal flooding to the [(left) (right)] of the hurricane's path when looking towards shore.

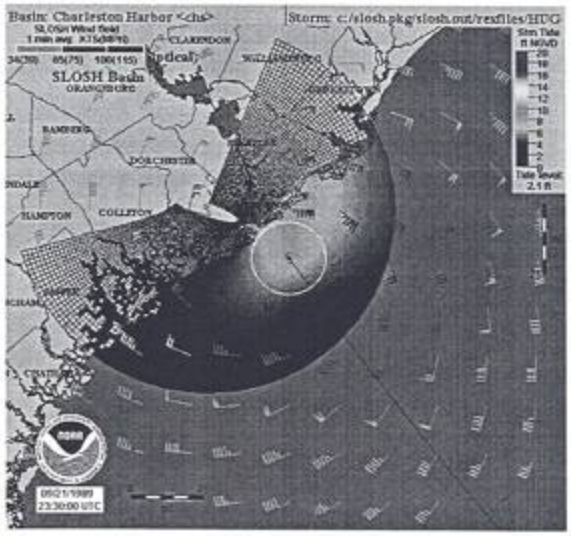

Figure 2. Model view of Hurricane Hugo approaching Charleston Harbor

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Figure 4. Locations of observed storm surge heights from Hurricane Hugo.

Table 1. Heights of SLOSH storm surge predictions and observed values (in feet) a locations shown in Figure 4.

	Location	SLOSH	Obs.
A	Folly Beach	8	11
B	Charleston	10	8
C	Bulls Bay	20	20
D	McClellanville	12	15

7. Note the location of the highest water levels in Figure 3. The greatest storm surge, as indicated by the shading, was predicted to occur to the [(left)(center)(right)] of the track of Hugo. From the observed heights in Table I, the highest storm surge actually occurred to the [(left)(center)(right)] of the track of Hugo as it came ashore.

8. Compare the predicted surge heights from the SLOSH model with those actually observed for the different locations. The predicted heights were [(within a few feet) (five or more feet different)] from the actual occurrences. The prediction at the location of highest actual surge was [(poor) (good)].

9. Use of the SLOSH model's predicted storm surge levels [(can be) (is not)] helpful in providing emergency management personnel with information that enables them to take action in avoiding death and injury and minimizing property damage.

Part 2:

OPEN OCEAN AND COASTAL IMPACTS OF TROPICAL CYCLONES

The first part of this investigation primarily focused on the interactions between tropical cyclones in the open-ocean and coastal environments. In this part of the investigation, we take a closer look at the coastal zone impacts of recent hurricanes as they made landfall.

Hurricane Katrina

On Sunday evening, 28 August 2005, the effects of the approaching Hurricane Katrina were beginning to be felt along the north central Gulf Coast as the storm's outer rain bands swept ashore. Within 24 hours, Katrina's ferocious winds, storm surge, and torrential rains would devastate the Gulf Coast of Louisiana and Mississippi, obliterating coastal communities and devastating New Orleans. According to the National Weather Service, Katrina was the third most intense hurricane (minimum central air pressure of 920 mb) to make landfall on the U.S. since reliable records began in 1851. More than 1300 people lost their lives and in terms of economic loss, Katrina would rank as the most destructive hurricane to strike the United States.

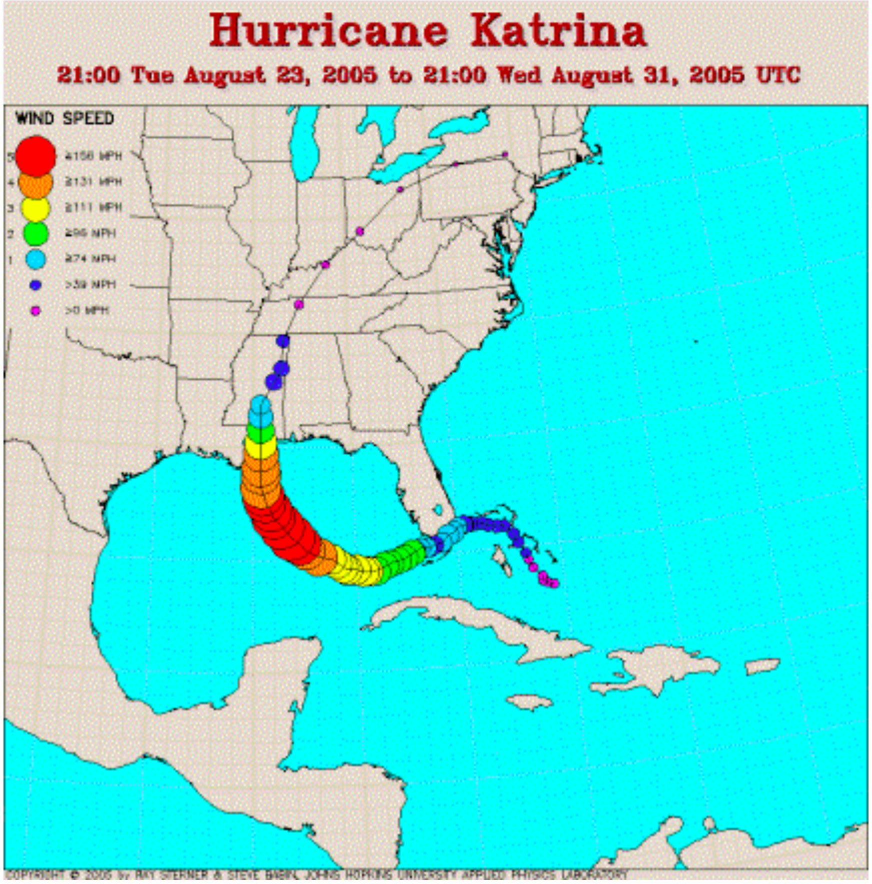

Image 1

As shown in Image 1, Katrina formed in the southeastern Bahamas on 23 August 2005; the next day the system strengthened to a tropical storm and was assigned its name. Changes in the intensity of Katrina are indicated by the color-coded circles. The system's ranking on the Saffir-Simpson Hurricane Intensity Scale (1 to 5) is listed to the left of the colored circles and the corresponding sustained surface wind speeds in miles per hour (MPH) are listed to the right of the colored circles. (For information on the Saffir-Simpson Scale, refer to page 190-191 in your textbook.)

On Thursday, 25 August, Katrina made landfall as a category 1 hurricane, producing strong winds and heavy rain over southeast Florida. Katrina lost some strength during the seven hours it took to pass over the southern tip of the Florida peninsula. Tracking almost due west and fueled by the warm waters of the Gulf of Mexico, the storm system quickly intensified and then gradually turned toward the northwest and then north. By the afternoon of 26 August, Katrina was a major hurricane. As a precaution, public officials issued mandatory evacuation orders for the people of New Orleans, LA, Gulfport, MS, and sections of Mobile, AL. Earlier, personnel on platforms and oil rigs in the Gulf were evacuated.

10. When most intense, Katrina was a category **[(*3*) (*4*) (*5*)]** hurricane with maximum sustained surface winds of 282 km per hr (175 mph).

11. As shown in Image 1, Katrina attained this maximum intensity **[(*over east-central Gulf of Mexico*) (*when the system made landfall*)]**.

12. Hurricanes acquire their energy from the latent heat released when water vapor evaporated from the ocean surface condenses in the storm system. Sea-surface temperature (SST) largely governs the rate of evaporation; the higher the temperature, the greater the evaporation. Hurricanes

require a sea-surface temperature of at least 26.5 °C (80 °F) through an ocean depth of 60 m (200 ft) or more. Observed changes in the intensity of Katrina as it tracked from Florida into the east-central Gulf indicate relatively **[(*warm*) (*cool*)]** surface waters.

Katrina weakened to a strong category 3 hurricane as it made landfall on the morning of 29 August in southern Plaquemines Parish just south of the town of Buras, LA at the mouth of the Mississippi River. Maximum sustained winds were near 205 km per hr (125 mph) to the east of the storm center with hurricane force winds extending 195 km (120 mi) from its center, driving a 6-9 m (20-30 ft) storm surge that reached well inland along the Louisiana and Mississippi Gulf coast and as far east as Mobile, AL, flooding parts of the city. Several hours later, after passing over Breton Sound and Lake Borgne, the eye of the storm made another landfall at the mouth of the Pearl River on the Louisiana-Mississippi border.

13. Image 1 shows that after Katrina made landfall in coastal Louisiana and tracked northward, its sustained wind speed **[(*diminished*) (*remained the same*) (*strengthened*)]**.
14. As a tropical cyclone tracks from sea to land, its source of energy (latent heat) **[(*increases*) (*remains the same*) (*decreases*)]**.

Storm Surge

As noted in the first part of this investigation, in the coastal zone potentially the most devastating impact of tropical (and extra-tropical) cyclones is the *storm surge*, a dome of ocean water driven ashore by strong onshore winds and topped by wind-driven waves. Strong winds coupled with low air pressure pile seawater into a dome that can be 80 to 160 km (50 to 100 mi) across that sweeps over the coastline bringing floodwaters that can take lives, cause considerable property damage, and modify the coast. Typically, the storm surge's highest water levels are to the right of the place of landfall of the storm's advancing eye. In general, a storm surge of 1 to 2 m (3 to 6.5 ft) can be expected with a weak hurricane, whereas an intense hurricane may produce a storm surge greater than 5 m (16 ft).

Consider, for example, the impact of Hurricane Wilma on water levels along the southeast coast of the Florida Peninsula. After lingering for several days in the northwest Caribbean near and over Mexico's Yucatan Peninsula, Wilma tracked toward south Florida making landfall as a category 3 hurricane about 35 km (22 mi) south of Naples, FL at 6:30 a.m. EDT on 24 October 2005. In the following six hours, Wilma streaked across southern Florida, weakened to category 2, and moved offshore just north of West Palm Beach by mid-afternoon. Over warm waters again, Wilma intensified to a category 3 hurricane.

Image 2 is a NOAA/NOS CO-OPS plot of the ocean water level (red) in meters relative to the MLLW (Mean Lower Low Water) datum at Virginia Key, FL (south of Miami Beach) for the period 22-26 October 2005. The predicted variation in water level due to astronomical tides is plotted in blue. This image is best viewed online or as a color print. If printed in black and white, color code or label the red and blue curves.

15. According to Image 2, Wilma produced a maximum storm surge height at Virginia Key, FL of **[(*0.4*) (*1.45*) (*almost 2*)]** meters above MLLW.
16. This maximum surge height occurred at __________ UTC, about 1.5 hours after Wilma's eye had made landfall to the west near Naples, FL.
17. The water level at this time was about **[(*2.0*) (*1.2*)]** meters above the predicted low tide.

Compare the actual water levels (heights) with the astronomically predicted tides. As Hurricane Wilma swept northeastward across southern Florida, the storm's surface winds were blowing in a counterclockwise and slightly inward direction about the center (eye) of the storm system. For much of the hurricane's advance across Florida, the winds along the southeastern coast where Virginia Key is located pushed water towards land to produce the elevated water levels shown in Image 2. As the storm exited Florida, it produced winds pushing water away from shore, as evidenced by the water levels lower than the astronomical tide.

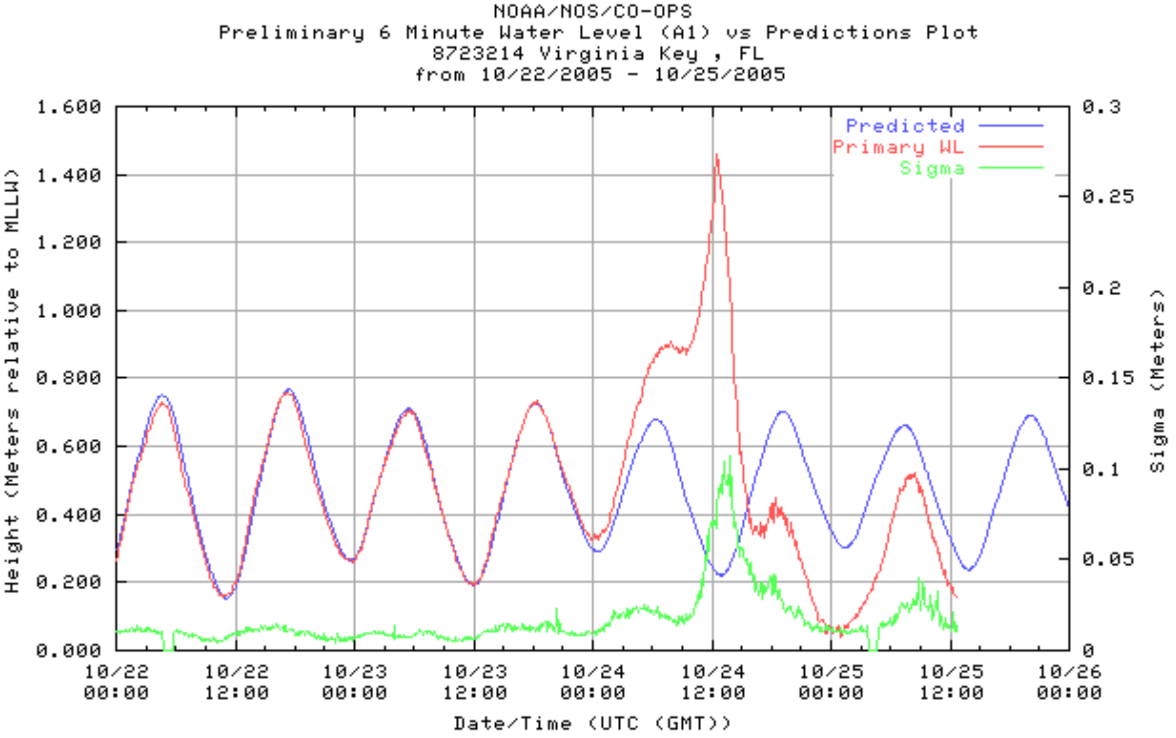

Image 2

18. According to Image 2, Hurricane Wilma's maximum storm surge at Virginia Key coincidentally occurred at **[(*high*) (*low*)]** tide.

19. If the maximum storm surge had occurred about 6 hours earlier or later, the storm surge height would have been about **[(*1.0*) (*1.45*) (*2.0*)]** meter(s).

20. Under these circumstances, the damage caused by the surging waters likely would have been **[(*less than*) (*the same as*) (*more than*)]** it actually was.

Barrier Islands

The initial target of a hurricane storm surge along the Gulf Coast is the series of long, narrow barrier islands that parallel the coast. These islands are subject to considerable erosion and in some cases the surge washes over the entire width of the island and may cut a new inlet. On 17 September 2004, the US Geological Survey conducted an aerial photographic survey of the barrier islands of Alabama and Florida that were impacted by Hurricane Ivan. Image 3 displays aerial photos of a section of a barrier island at Pine Beach, FL before and after the island was severed by a breach that developed in association with the passage of Hurricane Ivan. It can be assumed that the owners of the house pointed to by the arrow were both surprised and relieved by what they saw when they returned to the island after the storm.

Breach through barrier island, Pine Beach, FL: The island was severed by a breach that may have developed as the back bay drained excess water following the peak of the storm surge, although the breach could have been initiated by waves and surge from the Gulf side.

Image 3

21. The new inlet across the Pine Beach barrier island is **[(*likely*) (*unlikely*)]** to influence subsequent tidal and storm-induced water motions in the coastal waters between the barrier island and the mainland. If left to nature, longshore currents and associated littoral drift that maintains barrier islands could eventually close off the new inlet.

For more information on Hurricane Katrina, including animations, go to NOAA's National Climatic Data Center at http://www.ncdc.noaa.gov/oa/climate/research/2005/aug/hazards.html. Click on "Tropical Cyclones" and scroll down to the discussion of Hurricane Katrina.