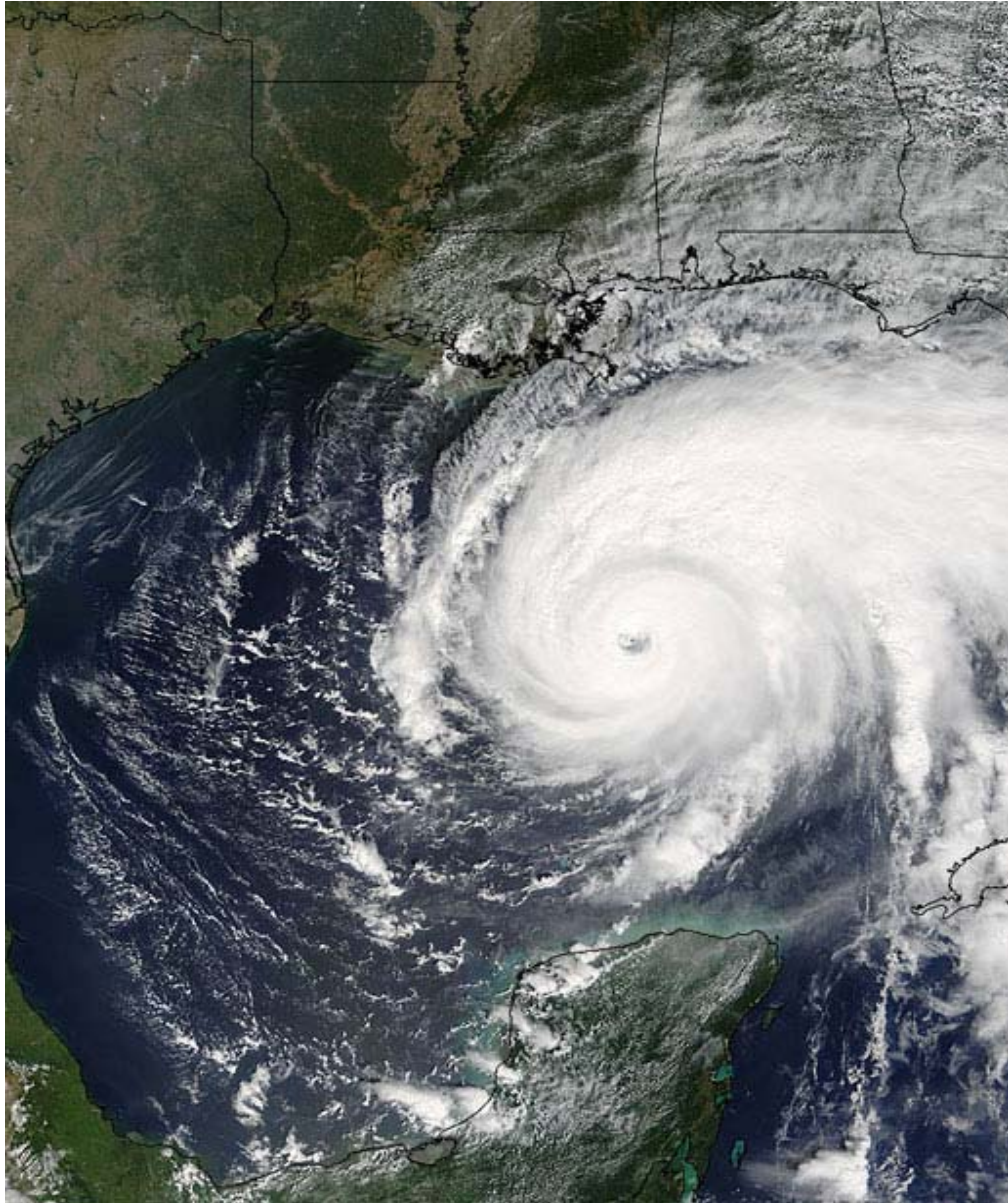


Hurricane Rita

September 18-26, 2005



Meteorologist

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Less than a month after one of the worst hurricane disasters in US history, the Gulf Coast was once again threatened by a monster hurricane. Breaking records set three weeks earlier by her predecessor Katrina, Rita became the strongest hurricane on record in the Gulf of Mexico. A potentially catastrophic category 5 hurricane with sustained winds of 180 mph took aim at the upper Texas and southwest Louisiana coast. Unprecedented evacuations were ordered along the threatened coastline with millions fleeing inland resulting in horrendous gridlock of evacuation routes. Luckily, for the Houston/Galveston area, Rita departed from the 3-day forecast track in the last 36 hours before landfall and spared the densely populated and high concentrations of petro-chemical plants in the region. The damage inflicted on southwest Louisiana was the worst experienced since category 4 hurricane Audrey plowed through the region in 1957 killing some 600 residents of Cameron Parish in her storm surge. Rita dealt a devastating blow to the state of Louisiana in the infancy of the hurricane Katrina recovery effort. The two hurricanes combined brought incredible destruction to the entire Louisiana coast. From the border of Texas to the border with Mississippi coastal towns, small fishing villages, barrier islands, and miles of marshlands were washed away by the combined forces of wind and water. The scars of the 2005 hurricane season will remain embedded in the Louisiana coast for decades to come.

Synoptic History

Rita's Birth

The area of disturbed weather that would eventually become Rita moved off the west coast of Africa on September 7th. At the same time a weak frontal trough dropped southward over the central Atlantic and became stationary from the southeastern Bahamas to north of the Leeward Islands on the 13th. The old tropical wave traveled quietly across the Atlantic through the deep tropics east of the Leeward Islands with little deep convection. On September 17th, the poorly organized tropical wave merged with the old surface trough north of the island of Puerto Rico. Convection gradually increased in intensity and coverage as the disorganized area of weather moved slowly westward. By 6:00 p.m. on September 17th, the area of disturbed weather had organized enough to be classified as a tropical depression about 70 miles east of the Turks and Caicos Islands in the southeastern Bahamas. Vertical wind shear from the southwest on the east side of an upper level low near Cuba resulted in poor organization through most of the 18th.

Tropical Storm

High resolution visible images along with observation sites in the southeast and central Bahamas indicated that the depression gained tropical storm status by noon on the 18th. Vertical wind shear continued to hamper the convective organization with the majority of the deep convection located near and to the north and east of the center. Although the surface center being tracked by satellite and reconnaissance aircraft was moving westward, reformations to the north due to convective induced pulling resulted in an overall west-northwest heading through the southeast Bahamas. On the 19th, the upper

level low responsible for the southerly shear over Rita weakened and shifted southwest allowing much more favorable conditions to develop. Convection quickly developed around the center with upper level outflow increasing in all quadrants. Rita passed through the southern Bahamas and entered into the Florida Straits early on the 20th. Global forecast models including the GFS, UKMET, and GFDL which had been predicting a northern Mexico or south Texas landfall on the 18th began to indicate that the ridge along the northern Gulf Coast would break down and allow Rita to turn poleward toward the middle Texas coast (Figure 1).

Hurricane Intensity / Florida Keys Impact

At 6:00 a.m. on the 20th, Rita became a hurricane about 100 miles east-southeast of Key West, FL. The hurricane began a period of rapid intensification as it passed just south of Key West. The Key West radar (NEXRAD) recorded 90 kt (105 mph) velocities at 5,000 ft which corresponds to about 80 mph at the surface when reduced for friction (NHC Report). Rita passed about 40 miles south of Key West around noon on the 20th battering the central and lower Keys with sustained tropical storm force winds with gusts to hurricane force. Rita gained category 2 status while passing south of the Keys during the afternoon of the 20th (Figure 2). Storm surge flooding of 2-4 ft was experienced on the windward side of the Florida Keys as Rita passed through the Florida Straits. Overall damage was mainly from large wave action and strong wind resulting in widespread power outages and downed trees.

Forecast Track

As Rita moved into the southeast Gulf of Mexico early on the 21st, eyes began to turn toward the growing threat to the Texas coast. A large ridge of high pressure was anchored along the US east coast with Rita embedded within the deep easterly flow on the south side of this high. Rita had tracked almost due west from the southern Bahamas into the area south of Key West and was either hitting or passing just south of the model projection points. The model consensus was actually in very good agreement with a clustering aimed at the Texas coast between Galveston and Matagorda Bay. The official NHC forecast track showed the center of Rita crossing the Texas coast just west of Palacios, TX early Saturday morning the 24th as a category 3 or 4 hurricane. The preparation for the landfall of a major hurricane on the middle or upper Texas coast was well underway by late on the 20th (Figure 3).

Category 5

Just like Katrina, Rita experienced an impressive period of extremely rapid deepening early on the 21st. The central pressure fell an astounding 70mb in a 24 hour period and the hurricane intensified from a 110 mph category 2 to a 165 mph category 5 in an 18 hour period. Rita fully utilized the excellent upper level conditions including great outflow in all quadrants and passage over the deep warm waters of the Gulf Loop Current containing high oceanic heat content. At 10:06 a.m. on the 21st, SFMR data recorded sustained wind speeds of 138 kt (160mph) supporting the category 5 intensity. At 1:35 p.m. on the 21st

flight level winds at 700 mb were measured at 161 kt (185 mph) with a surface reduction based on dropwindsonde profiles of 165 mph. Shortly after 1:30 p.m. two dropsondes measured 10 meter wind speeds of 163 mph and 171 mph respectively supporting the upgrade to a category 5 (NHC Report). By 6:00 p.m. the central pressure had fallen to a record 897mb with sustained surface winds of 170 mph making Rita one of the strongest Atlantic basin hurricanes on record and the strongest Gulf of Mexico hurricane (Figure 4). The reconnaissance aircraft departed Rita after 6:00 p.m. on the 21st and the next flight did not arrive until around midnight on the 22nd. It is estimated by satellite presentation that Rita bottomed out around 895mb around 9:00 p.m. on the 21st with sustained surface winds of 180 mph and gusts well over 200 mph (NHC Report). In fact, flight meteorologists recorded a peak wind gust of 237 mph during the period of rapid intensification. It should also be noted that Rita exhibited numerous “hot towers” or highly active convective cells reaching extremely high into the atmosphere in the eyewall as recorded by the TRMM satellite. It is interesting to note that a burst of two 18 km hot towers directly preceded the rapid intensification of Rita from a tropical storm to a category 4 hurricane. In addition, Rita along with Katrina were highly electrified which is unusual for tropical cyclones due to their warm core nature.

Late on the evening of the 21st, the forecast track along with the guidance clustering remained aimed at the upper Texas coast (Figure 5). The global forecast models including the GFDL and GFS were depicting a worst case track of a catastrophic hurricane into the upper Texas coast near Freeport. Massive evacuations were underway across large sections of coastal Texas including the Houston/Galveston area. A hurricane watch was issued at 4:00 p.m. on the 21st from Port Mansfield, TX to Cameron, LA.

Weakening

Early on Thursday, September 22nd, the inner eyewall of Rita collapsed and was replaced with a secondary outer eyewall some 30 miles across. These inner core changes which are not fully understood resulted in the gradual weakening of the hurricane up until landfall. In addition to the inner core changes, weak southwesterly wind shear and slightly drier air over Texas and Louisiana began to affect the system. Early morning visible images on the 22nd revealed some restriction of the upper level outflow pattern on the western side of the hurricane and a slow erosion of the western portion of the central dense overcast. As the central core of Rita weakened, the wind field greatly expanded. Tropical storm force winds expanded outward 180 miles from the center with hurricane force winds extending outward 75 miles from the center. Rita was yet another exceptionally large Gulf of Mexico hurricane, one common characteristic of many of the 2005 hurricanes. While Rita’s pressure inched up slowly, aircraft data indicated the wind maxima decreased rapidly, and like Katrina the low central pressure did not represent the wind field gradient. The large weak pressure gradient over the Gulf of Mexico and adjacent US coast resulted in wind speeds much lower than what would have been expected with pressures in the 910’s and 920’s as Rita approached the Louisiana and Texas coasts. Late on the 22nd, Rita passed just north and east of a large warm water eddy vortex over the northwestern Gulf of Mexico. Had Rita passed over this eddy, intensification may have occurred (Figure 6).

Sparing Houston/Galveston

A short wave trough passing through the mid Mississippi valley early on the 22nd dug far enough southward to tug Rita slightly northward during the morning hours of the 22nd. Forecast models did not grasp this trough correctly nor its effects on the hurricane and hence remained clustered at the Houston/Galveston area up until the 12Z (6:00 a.m.) September 22nd runs. By the 10:00 a.m. advisory it had become clear that the short wave along with a substantial wobble to the north had pushed Rita enough to the right that the track would have to be adjusted eastward along the Gulf coast toward the Beaumont and Lake Charles area (Figure 7). The forecast track now indicated a landfall over Jefferson County, TX about 70 miles northeast of the track projection 12 hours earlier. Although a small change by tropical forecasting standards, the model data and NHC track would now spare the Houston/Galveston area the much feared direct hit of a major hurricane. A hurricane warning was issued from Port O Connor, TX to Morgan City, LA with the 10:00 a.m. advisory package. Although the track had shifted up the coast yielding a better outcome for the highly populated Houston/Galveston area, evacuation gridlock was occurring on every interstate leaving southeast Texas. This track shift also put into motion mass evacuations for the Beaumont and Port Arthur area as well as the Lake Charles area.

Landfall

Rita rounded the western edge of a ridge of high pressure over the southern US and behaved as forecast models had predicted from midday on the 22nd up until landfall. Rita weakened steadily from the peak on the 21st up until landfall in extreme southwest Louisiana early on the 24th. The gradual weakening likely resulted from dry air ingestion from the north and west, weak upper level wind shear, and lower levels of oceanic heat content over the northwest Gulf of Mexico. These factors, along with internal core dynamics (eyewall replacement cycles) which are impossible to forecast, resulted in the fluctuations of intensity until landfall. Rita crossed the coast near Johnson's Bayou, LA in extreme southwestern Cameron Parish at 2:30 a.m. September 24th with sustained surface winds of 115 mph (Figure 8). Data from reconnaissance aircraft 3-4 hours before landfall along with velocity data from the Lake Charles NEXRAD support the category 3 wind classification at the time of landfall. This includes flight level wind records of 111-115 kts (127-132 mph) which reduced for surface friction yields between 100-105 kts (115-120 mph) at the surface. Velocity data from the Lake Charles NEXRAD indicated 120 kt (138mph) at 500 meters above the surface over the water and at the coastline just east of where the center made landfall (NHC Report). Even though Rita officially made landfall as a category 3 hurricane, only a very small area just east of the center likely experienced full category 3 wind conditions. Rita tracked north-northwest into southeast Texas and then nearly northward up the Sabine River while gradually weakening into a tropical storm.

Meteorological Impacts

Wind

Rita was a large hurricane with hurricane force winds extending outward 85 miles from the center at the time of landfall and tropical storm force winds extending outward 205 miles. An estimated 350 to 400 miles of coastline were affected by sustained tropical storm force winds as well as nearly 150 miles with hurricane force winds. Reconnaissance data and the NEXRAD radars out of Lake Charles and League City suggest that Rita crossed the coast with sustained winds near 115 mph. However, the majority of southwest Louisiana and extreme southeast Texas experienced category 1 wind conditions with pockets of sustained category 2 conditions across Cameron and Calcasieu Parishes. Sustained category 3 conditions were experienced in a small area where the eastern eyewall crossed the Cameron Parish coastline including the towns of Holly Beach, Cameron, and Hackberry. Both the Lake Charles and Beaumont area received sustained category 1 conditions with gusts well over 100 mph. Numerous observation sites were in the path of Rita's hurricane force winds, however many failed prior to the onset of the worst conditions due to power outages and wind damage to the equipment.

The Cameron, LA RAWS site recorded a peak gust of 108 mph near the time of landfall. A research tower from the Florida Coastal Monitoring Program in Port Arthur, TX recorded a peak gust of 129 mph, along with peak gust of 107 mph at both Nederland and Orange Texas. Texas Tech University research towers recorded 121 mph peak gust at the Regional Airport in Port Arthur and a 94 mph peak gust at Orange, TX before the tower was damaged. All surface data collected indicated 1-minute sustained winds of 75-80 mph within the western eyewall over southeast Texas with peak gusts into the low end category 3 range. Unofficial wind reports were received from various sources in the days following landfall. Storm chasers on HWY 84, 5 miles southwest of the Lake Charles regional airport, recorded a peak gust of 115 mph. The highest recorded wind gust was 133 mph with Davis wind equipment southwest of Grand Lake, LA at a height of 50 feet above the ground (Lake Charles Post Storm Report). Wind gusts of 120-135 mph were likely experienced west of HWY 27 across the western portions of Cameron Parish extending inland along Calcasieu Lake.

Wind damage was extensive to severe across Cameron and Calcasieu Parishes with major roof damage and some complete failure of buildings. Numerous trees were felled into structures and most of the power infrastructure was heavily damaged. Across southeast Texas, Hardin, Jasper, Jefferson, Newton, and Orange counties sustained major wind damage mainly from the downing of trees into structures. Structural wind damage including blown off roofs and overturned mobile homes were common across the Beaumont and Port Arthur area where the western eyewall tracked.

Outside of the hurricane force wind radius was a large area of tropical storm force winds which affected both the New Orleans and Houston/Galveston areas. Wind damage in the Houston area was mainly limited to downed trees, downed power lines, and blown over

signage. A peak wind gust of 61 mph was recorded at BUSH IAH, although higher gust to near hurricane force were recorded along the northern shore of Galveston Bay. Tropical storm force winds extended inland over 200 miles along the track of Rita affecting a large portion of western Louisiana and east Texas including a 59 mph wind gust at Terrell, TX.

Storm Surge

Rita produced a large and destructive storm surge along the majority of the Louisiana coast. The hardest hit locations were across Cameron and Vermillion Parishes where entire towns were swept away. Ekman transport and surge run-up resulted in widespread inundation along much of the Louisiana coast and throughout many of the coastal bayous and bays. High water marks left within the courthouse in Cameron, LA, near where the eastern eyewall moved ashore, reached the second story indicating a 15-18 ft rise in sea level. The storm surge flooded nearly the entire parish with high water marks at Herbert's Marina, near Grand Lake, LA, between 10-15 ft some 20 miles inland from the Gulf of Mexico. The surge penetrated northward up Calcasieu Lake into the Lake Charles area where protective levees were overtopped flooding portions of the downtown area with 3-6 ft of water. High water marks at I-10 over the Calcasieu River in Lake Charles were 6 ft above sea level some 30 miles inland. Based on debris marks in homes including, an NWS employee, the surge rose 10-15 ft south of Lake Charles near the northern edge of Calcasieu Lake. Every structure between Holly Beach, LA and the town of Grand Chenier, LA (about 20 miles of coastline) including 80% of Cameron and 70% of Creole were swept away (Figure 9).

Eastward along the Louisiana coast storm surge values exceeded 10-13 ft across Vermillion Parish and much of the Atchafalaya Bay basin. Extensive flooding of 8-12 ft occurred over large portions of Vermillion, Iberia, and St. Mary Parishes. In the southeast part of the state flooding of 4-7 ft overtopped some levees in Terrebonne and Lafourche Parishes and resulted in additional levee failures around the New Orleans area hampering the dewatering efforts from hurricane Katrina.

West of where the eye crossed the coast around the Sabine Lake area, storm surge values were on the order of 5-8 ft in the lake flooding portions of Sabine Pass and Port Arthur. Low lying homes and business near the lake as well as chemical plants sustained multiple feet of inundation.

Rainfall

Rainfall averaged 6-10 inches along the track of the core of Rita with peak amounts of 16.0 inches at Bunkie, LA and 14.0 inches at DeRidder, LA. In east Texas, 12.50 inches was recorded at Silsbee and 9.50 inches at Woodville. This rainfall resulted in flooding along multiple bayous and rivers across central and southwestern Louisiana during the week following Rita. A combination of the storm surge flooding and fresh water run-off resulted in portions of southwest Louisiana remaining flooded for up to a week and a half after the passage of the hurricane.

Tornadoes

Rita produced a number of devastating tornadoes across the State of Mississippi, southeast Arkansas, and northeast Louisiana over a 36 hour period on September 24th and 25th. 49 tornadoes were reported including an F3 and eight F2 tornadoes resulting in 15 injuries and 1 fatality. One of the tornadoes produced a 17 mile damage path across Humphreys and Sunflower counties in Mississippi. The Rita outbreak produced a record number of tornadoes across this area for an event lasting less than 48 hours. The previous record was 35 tornadoes on January 21-22, 1999.

Mini Swirls

Radar images during landfall, as well as storm chaser reports and a personal view of some of the wind damaged area, suggest the presence of mini swirls or vorticity maximas within the northern eyewall of Rita. Mini swirls were discovered in the aftermath of hurricane Andrew across south Florida where streaks of near total devastation were embedded within the overall wind damage. Although not fully understood, this phenomenon is hypothesized to be a result of vorticity stretching in supercell thunderstorms within the eyewall region of intense hurricanes. The swirls are very short duration wind maxes lasting usually less than 10 seconds, but can produce wind speeds as much as 40-50 mph greater than the sustained background wind. This produces narrow streaks of damage in a confined area and when the occurrence happens across a uniform pattern such as a subdivision or forest the results can be quite noticeable. On a personal travel to the impacted area, a clearly defined swath of heavy wind damage was noted in the pine forest along both sides of I-10 at the border of Texas and Louisiana. Compared to the surrounding tree damage eastward where the stronger eastern eyewall crossed reveals a small but severe swath of wind damage consistent with a meso vortex mini swirl. Additionally, at least two damage streaks were noted in the town of Hackberry, LA, one through a mobile home park which is somewhat suspect and the other on the south side of town where extensive damage occurred to a church. A review of the NEXRAD data from Lake Charles during landfall shows multiple supercell thunderstorms ringing the northern eyewall of Rita across Cameron Parish extending northward into western Calcasieu Parish and then into Orange County, TX (Figure 10). A more extensive ground and aerial survey would have likely found additional damage streaks across Cameron and Calcasieu Parishes in agreement with the track of the supercells noted on the Lake Charles NEXRAD data.

The Evacuation

Hurricane Rita resulted in a massive evacuation of coastal residents along the Texas and Louisiana coast. Upwards of 2.8-3.2 million residents fled the region in advance of Rita creating one of the largest evacuations in world history. Local and state road systems were heavily overwhelmed by the mass exodus resulting in incredible traffic delays on area interstates and severe fuel shortages throughout a large part of southeast Texas and southwest Louisiana. It was expected that 445,000 vehicles would evacuate southeast Texas in the event the region was threatened by a major hurricane, but 1.7 million

vehicles evacuated prior to the landfall of Hurricane Rita. It was estimated that 1.2 million residents would evacuate the area, but instead 2.8-3.2 million residents left, 47% of which were outside the storm surge inundation zones. Additionally, 1100 patients at UTMB in Galveston were air lifted to various hospitals around the state resulting in one of the largest air evacuations in US history.

Preparation

The first state conference call between the State of Texas and local jurisdictions was held at 10:00 a.m. Monday September 19th. It was decided that preparation for coastal evacuation was to begin and that local jurisdictions were to follow the plans developed by the State of Texas for such a hurricane threat as Rita. The 72 hour countdown for emergency management officials would begin at 2:00 p.m. September 20th, which was roughly 72 hours before the forecasted onset of tropical storm force winds. Monday the 19th and Tuesday the 20th were preparation days for the State of Texas with thousands of state personnel being pre-positioned to assist in the evacuation effort.

The Plan

For the first time in Texas history, local government was given the authority to issue mandatory evacuation orders before the start of the 2005 hurricane season. The state also developed a phased evacuation plan, traffic management plan, and corridor routing system for the Harris, Galveston, and Brazoria county area after the miserable hurricane Ivan evacuation of southeast Louisiana in September of 2004. The plan called for zone A to evacuate first, followed by zone B, and zone C with implementation of the traffic management plan as needed along the evacuation corridors. The evacuation corridors were developed to expedite traffic flow northward out of the storm surge zones and minimize bottlenecking by shutting off entrance ramps on to the corridors.

The Corridor Plan (Figure 11)

1. Residents of Galveston Island and those residents west of SH 3 were to use I-45 north to Huntsville, TX. Residents near the E Beltway 8 and in the Pasadena and southeast Houston area were to use SH 225 to the E Beltway 8 to the Hardy Toll Rd and then merge into I-45 near Spring, TX.
2. Residents east of SH 3 and in the Baytown, LaPorte, Kemah, and Clear Lake area were to use SH 146 to SH 321 and then merge into US 59 at Cleveland, TX.
3. Residents in western Galveston County west of I-45 were to use HWY 6 north to US 290 and then HWY 6 north to shelter locations in College Station, TX.
4. Residents of Brazoria County east of the Brazos River including the Freeport, Lake Jackson, and Clute areas were to use SH 288 to the south Beltway 8 then northward up the west Beltway 8 to HWY 290 then NW to HWY 6 to shelter locations in College Station, TX.
5. Residents of western Brazoria County west of the Brazos River were to use SH 36 north to shelter locations in Brenham, TX.

Preparations for the implementation of the traffic management plan and large scale evacuation for a major hurricane strike were largely in place by the evening of the 20th. This included suspending all construction on the evacuation corridors, emergency road construction to widen shoulders, re-striping of evacuation corridors, placement of electronic signage along the corridors, and pre-positioning of equipment and manpower to implement the traffic management plan.

Critical Decisions

Early on Tuesday, September 20th, the timeline for mandatory evacuations of the coastal storm surge zones was decided.

Special Needs Residents: mandatory evacuation to begin at 6:00 a.m. Wednesday the 21st.

Zone A: evacuation was to become mandatory at 6:00 p.m. Wednesday the 21st.

Zone B: evacuation was to become mandatory at 2:00 a.m. Thursday the 22nd.

Zone C: evacuation was to become mandatory at 6:00 a.m. Thursday the 22nd.

The traffic management plan was to go into effect for all corridor evacuation routes at 6:00 p.m. Wednesday in combination with the commencement of the mandatory evacuation orders.

The surrounding coastal counties with lesser population density were to begin voluntary evacuations Wednesday including: Chambers, Matagorda, Jackson, and Calhoun counties.

Voluntary Evacuations

At 2:00 p.m. September 20th, over 72 hours before the landfall of tropical storm force winds, the mayor of Galveston ordered a voluntary evacuation of Galveston Island with several other local cities and jurisdictions declaring additional voluntary evacuation orders during the afternoon and evening hours of the 20th.

Wednesday September 21st

Residents in the coastal storm surge zones began leaving in earnest early Wednesday morning with the cancellation of school in several districts. It is interesting to note that the cancelling of school appears to be a large driving force behind how residents will respond to an evacuation order. Various companies and businesses along with the petrochemical industry were in multiple stages of preparation and shut-down with the expectation that all preparations and release of employees would be completed by Wednesday evening.

A large number of residents heeded the voluntary evacuation orders and local evacuation routes became increasingly congestion by early afternoon on the 21st. TXDOT

implemented the traffic management plan for HWY 6 during the early afternoon hours several hours before the planned implementation was to take place due to increasing congestion. Outbound lanes on all the major interstates leaving Houston were heavily congested by late afternoon. A combination of early evacuation during the voluntary phase and industry allowing employees to leave early resulted in heavy congestion well before the mandatory evacuation orders were declared and the full extent of the traffic management plan implemented.

Mandatory Evacuation

At 6:00 p.m., with hurricane Rita still aimed at the upper Texas coast, mandatory evacuation orders were issued for Zone A and full implementation of the traffic management plan was put into effect for the evacuation corridors. Evacuation routes were already heavily congested with long lines of delays due to bottlenecks and choke points where freeway main lanes merged down or traffic entered the freeway. In addition, the Wednesday evening rush hour merged into the evacuation traffic resulting in increasing delays. By 10:00 p.m., as more residents left under the mandatory order, the evacuation corridors became parking lots. Traffic speeds were averaging 5-10 mph along I-45 north and US 290. Travel times that would normally take an hour were averaging 4-6 hours. A well planned and so far well executed evacuation had become gridlock as residents either disregarded or were not educated on the phased plan and attempted to leave all at once.

Early Thursday morning the forecast track of Rita had shifted eastward up the Texas coast with a landfall now progged over Chambers County. This required immediate mandatory evacuation orders for the golden triangle (Beaumont/Port Arthur areas) of southeast Texas and large sections of southwest Louisiana. These new evacuation orders added even more traffic to already heavily overwhelmed interstates increasing travel times into the 15-25 hour range.

Emergency Contraflow

At 4:08 a.m. Thursday September 22nd, under mounting pressure from local officials in the Houston/Galveston area, the state began planning for emergency lane reversal. With all interstates across southeast Texas in gridlock it was becoming clear that residents would not reach safety before Rita made landfall given the current state of the evacuation. At 6:00 a.m. the governor approved the plans for emergency contraflow and ordered the full implementation of hastily developed plans at the State Operations Center. Tremendous amounts of coordination were needed from hundreds of jurisdictions to open contraflow on three Texas interstates (I-45, I-10, and US 59).

At noon on the 22nd, 80 miles of I-45 north were contraflowed with an additional 35 miles opened at 1:00 p.m. and 34 miles opened at 2:30 p.m. By 2:30 p.m. 149 miles of I-45 were contraflowed from just north of The Woodlands, TX to Buffalo, TX. In central Montgomery County 17 traffic lanes were headed northbound with traffic at a standstill for over 35 miles to downtown Houston (Figure 12).

At 1:00 p.m. 110 miles of I-10 from near Katy, TX to Seguin, TX were contraflowed with an additional 31 miles opened at 3:00 p.m. The I-10 contraflow worked fairly well compared to the I-45 and US 59 contraflows, and this is believed to be a result of good loading of the contraflow lanes.

At 6:00 p.m. 80 miles of US 59 were contraflowed starting near Porter, TX with an additional 55 miles opened at 8:00 p.m. With as much as 6 lanes of traffic headed northbound, traffic remained extremely slow from San Jacinto and Polk counties over 100 miles into Harris County. This was due to the merging at multiple points of traffic from the Beaumont and Port Arthur areas.

Additional, smaller scale contraflows were conducted in extreme southeast Texas where Beaumont traffic was in gridlock. In total, TXDOT contraflowed 487 miles of Texas interstate in a 12 hour period, and deployed 1287 employees at the peak of the evacuation on the 22nd.

Fuel shortages

With travel times upwards of 18-25 hours from Houston to Dallas and 14-16 hours from Houston to San Antonio vehicles began to run low and in many instances out of fuel. Many service stations along the evacuation corridors were without fuel by late on Wednesday the 21st, and could not receive additional fuel shipments due to the traffic congestion, the evacuation, and shut down of multiple supply and distribution centers across southeast Texas. With state trooper escort, fuel trucks were brought in to refuel vehicles out of gas along the evacuation corridors late on the 22nd. Additionally, buses picked up stranded drivers along the evacuation corridors and brought them to safety well before the onset of tropical storm force conditions.

Evacuation Completion

Even with the horrendous travel times, the majority of the evacuation traffic had cleared the storm surge inundation zones by early Friday morning September 23rd. Surprisingly, some 85-90% of Galveston County had evacuated and compliance was closer to 100% across southwest Louisiana in Cameron Parish. The evacuation was completed well before the onset of tropical storm force winds and this is a direct result of early planning and preparation along with early evacuation orders well before hurricane Rita threatened.

A massive shelter operation was conducted to house those who had evacuated the coastal areas. In Texas alone, 393 shelters were opened with 46% of the shelters being opened in the northeast Texas cities of Lufkin (35), Nacogdoches (11), Longview (23), and Tyler (27). Additionally, 59 shelters were opened in the Austin and San Antonio area and 31 shelters in the Dallas/Fort Worth metro area.

Phased Return

After the large scale gridlock during the evacuation ahead of hurricane Rita, the State of Texas devised a phased re-entry plan back into southeast Texas. Residents north of I-10 and west of I-45 would return Sunday, September 25th. Residents south of I-10 west of Galveston Bay were to return home on Monday, September 26th, and lastly residents north of I-10 and east of I-45 as well as Chambers County were to return home on Tuesday, September 27th. Coordination with area school districts ensured classes would not start until Wednesday, September 28th to help alleviate returning traffic on Sunday the 25th. Minus a few locations on I-45 south of Dallas and I-10 east of San Antonio, the return of residents to the area did not result in the kind of traffic delays experienced before landfall.

The Damage

For the second time in a three week period the United States Gulf Coast suffered a significant hurricane disaster. Rita made landfall in extreme southwest Louisiana about 10 miles east of the Texas state line raking a large section of the Louisiana coast with a devastating storm surge and much of southeast and deep east Texas with hurricane force winds. It is estimated that Rita caused between 8 -10 billion dollars in damage across the region making it the 9th costliest hurricane in US history. Rita affected a total of 85,729 square miles across the states of Louisiana and Texas.

Death Toll

Due to large scale mass evacuations well in advance of Rita and excellent public response from citizens within the storm surge inundation zones, Rita's direct death toll was 7, a significant reduction from that of hurricane Katrina. 1 death was from drowning near Lake Charles, 1 person died in a tornado in one of the outer feeder bands, 3 deaths from falling trees, and 2 deaths from rip currents in Florida. Indirectly, 119 persons died, many during the epic evacuation due to high values of heat and humidity and lack of life sustaining medications. 24 residents from a Bellaire, TX nursing home perished in a fire on their charter bus in the evacuation on I-45 south of Dallas.

Texas

The main impacts to the State of Texas were hurricane force winds on the western side of the circulation. Since Rita made landfall just east of the border, most of the storm surge impacts were located near and to the right of where the center crossed the coast and mainly affected areas from the Sabine River eastward into Louisiana. Sustained hurricane force winds battered the greater Beaumont and Port Arthur areas and then spread north-northwest into deep east Texas resulting in extensive vegetation and structural damage from felled trees. 22 Texas counties were declared federal disaster areas opening the flow of federal aid into the region. 477,319 residents applied for disaster aid in the State of Texas alone including 329,191 residents requesting housing assistance.

Southeast Texas

Damage across the Houston/Galveston county warning area was 159.5 million dollars in property and crop damage with 49 indirect fatalities related to the evacuation and 3 injuries related to the hurricane (NWS Houston/Galveston Post Storm Report).

Harris County

Sustained tropical storm force winds were felt across the entire county from late the 23rd through mid morning on the 24th, including a wind gust to 61 mph at BUSH IAH at 1:29 a.m. on the 24th and 74 mph at Morgans Point. The majority of the damage was from falling tree limbs, downed power lines, blown out windows, and downed signage. Wind tunneling effects and wind loading on the upper floors of downtown Houston skyscrapers resulted in 48 windows being blown out of the JP Morgan Chase and Chase Tower buildings downtown. Damage estimates were 90 million dollars across Harris County along with 34 indirect fatalities due to the evacuation. Much of Harris County was without power early on the 24th, however power crews had restored nearly 80% of the power by Monday, the 26th with the exception of the far northeast part of the county near Kingwood and Huffman where power was out for up to six days. Across the county, 16 structures were destroyed with 1,163 sustaining minor damage.

Galveston and Chambers Counties

Sustained tropical storm force winds onset across much of Galveston Island by mid afternoon on the 23rd and continued through the mid morning hours of the 24th including a wind gust of 66 mph at the Galveston Pleasure Pier and 60 mph on the Galveston Causeway. Wind gusts likely exceeded hurricane force along the western side of Galveston Bay where frictional effects across the bay were limited. Wind damage was mainly limited to downed tree limbs, power lines, wooden fences, and signage. Brief sustained hurricane force conditions were likely experienced across the Bolivar Peninsula where damage occurred to roofing materials and power poles were snapped. Of note was the buoy 20 miles east of Galveston which recorded sustained winds of 63 mph with a peak gust of 76 mph. Total damage was 15 million dollars over Galveston County and 8 million dollars over Chambers County. No deaths were reported in Galveston County with one indirect fatality in Chambers County. In Chambers County 497 structures sustained some form of damage with 7 completely destroyed.

Liberty, Polk, and San Jacinto Counties

These three counties sustained the most significant wind damage from hurricane Rita across the Houston/Galveston area. Sustained tropical storm force winds were felt throughout all of the counties with gusts well over hurricane force. In fact wind gusts likely exceeded 90 mph at multiple times throughout these counties during the early morning of the 24th as Rita moved inland just east of these counties. Moderate to at times major wind damage occurred across this area mainly from falling trees which impacted

structures below. Liberty County reported 2 direct fatalities when a couple was killed when a tree fell through their house while sleeping. Additionally, a three year old girl was killed while sleeping in her house in Point Blank, TX when a tree fell. Over the three county area, 297 structures were destroyed including 250 in San Jacinto County alone. A total of 6,160 structures across the three county area sustained some form of damage. Damages totaled 40 million dollars with 23 million across Polk County alone.

Houston, Trinity, and Walker Counties

The track of hurricane Rita resulted in stronger winds across these three northern counties than across coastal Brazoria County. Sustained tropical storm force winds with gust to 60 mph were recorded from I-45 eastward. Damage to the tall pine forest was moderate with some trees being snapped, but the majority losing tree limbs. Falling limbs resulted in roof damage to structures below and took down miles of power transmission lines across the area. Total damage for the three county area was 3.5 million dollars and one indirect death was reported in Houston County during the evacuation. In Trinity County, 36 structures were destroyed with a total of 792 damaged.

Montgomery County

Sustained tropical storm force winds with gusts to near hurricane force mainly east of I-45 occurred during the early morning of the 24th. Wind damage was primarily to trees and power lines and to structures from falling trees. Damage totaled 2.5 million dollars across the county. 10 fatalities were reported along I-45 during the evacuation mainly due to heat stress with an additional 3 fatalities resulting from carbon monoxide poisoning after the hurricane. Power was not fully restored to portions of eastern Montgomery County for up to two weeks after landfall.

Brazoria and Fort Bend Counties

Sustained tropical storm force winds were experienced across these counties with gusts up to 50 mph. Damage was minor and mainly resulted from downed tree limbs and sporadic power outages. Large wave action and wave run-up prior to the arrival of Rita caused minor beach erosion and overwash at times of high tide near Surfside, TX. Total damage across Brazoria County was 500,000 dollars.

Extreme Southeast and East Texas

Jefferson, Hardin, and Orange Counties

Located east of Chambers and Liberty counties eastward to the state line, these three counties took the brunt of Rita's strong winds. The western eyewall passed across this region with the center of Rita passing very near Orange, TX and then NNW over Deweyville and Jasper. Sustained winds across the three county area were at least 80-85 mph with gusts over 100 mph. A peak wind gust of 96 mph was recorded by a storm chaser in east Beaumont and a gust to 94 mph at Orange, TX. A Texas Tech research

wind tower in Port Arthur recorded a peak gust of 121 mph with a sustained 1 minute wind of 93 mph. Florida University research towers at Port Arthur, TX and Nederland, TX recorded 128 mph and 107 mph gust respectively. The majority of the region experienced sustained category 1 wind conditions with gusts well into the category 3 range. Significant wind damage occurred across the Beaumont and Port Arthur areas extending inland along the track of the core of Rita's eyewall for nearly 80 miles. Severe tree damage occurred along this path where many trees were snapped or uprooted (Figure 13). In the more populated areas, roofs were torn off buildings and metal airport hangers were lofted and blown away. Even strongly built hotels and downtown buildings in Beaumont suffered damage from wind drive debris and wind loading to the upper floors.

A storm surge of 5-8 ft was recorded in Sabine Lake impacting the Sabine Pass, Port Arthur, Bridge City, and Orange areas. The surge penetrated inland up the Sabine River past I-10 browning miles of pine forest near the river. Structures near the western side of Sabine Lake sustained extensive water damage from the storm surge and large sections of eastern and southern Port Arthur were flooded upwards of 2-4 ft. Luckily, Rita made landfall just east of Sabine Lake and the northerly flow on the west side of the hurricane helped reduce the surge into the lake. Had Rita tracked 20 miles to the west a catastrophic storm surge on the order of 18-22 ft would have heavily damaged much of Beaumont and Port Arthur and totally destroyed towns such as Sabine Pass, Bridge City, and West Orange.

A total of 10,576 structures were destroyed across the three county area. In Hardin County alone, 7,700 mobile homes were destroyed and 26,050 structures received some form of damage. Some form of damage was inflicted on 82,831 structures across this area of southeast Texas.

Newton, Tyler, Jasper, Angelina, and San Augustine Counties

Rita weakened into category 1 hurricane as she passed east of Lufkin during the late morning and early afternoon hours of the 24th. Winds across the five county area of deep east Texas were sustained in the category 1 range of 75 to 85 mph with gusts upwards of 90 mph. This resulted in significant amounts of tree damage across the pine forest of deep east Texas which in turn damaged numerous structures below (Figure 13). Hundreds of miles of power transmission lines were downed by the strong winds and falling trees. Many locations in this area were reachable only by air for several days following Rita due to the large amounts of downed trees blocking roadways. Across Jasper County, 1503 structures were damaged.

Structural Damage

Various degrees of damage occurred across east Texas from near total destruction of structures where the northern and western eyewall tracked to numerous locations with trees felled across and through the structures resulting in near total losses. 11,273 single family homes were completely destroyed across the State of Texas with the greatest number being found in the three county area of Hardin County (6,050), Orange County

(3,600), and Jefferson County (926) totaling 10,576 single family homes. 92% of the destroyed homes were found within the location heavily impacted by the northwest eyewall where sustained winds were in the 80-90 mph range. 23,648 single family homes received major damage and an additional 54,132 homes received minor damage. 9,577 mobile homes were completely destroyed along with 483 apartment units. 7,604 mobile homes and 3,969 apartment units received major damage and 5,612 mobile homes and 2,235 apartment units suffered minor damage.

A total of 21,333 structures were destroyed across the State of Texas due to hurricane Rita with an additional 35,221 having major damage, and 61,979 suffering minor damage. A total of 118,533 structures were adversely affected due to the impacts of Rita.

Louisiana

The State of Louisiana took the brunt of Rita's storm surge and high winds with 15 parishes being declared federal disaster areas. Damage was extensive and widespread where the right front quadrant crossed the coast. The entire small towns of Peveto Beach and Holly Beach were completely destroyed by the storm surge with nearly 80% of Cameron and 70% of Creole, LA destroyed. 460,000 households across Louisiana requested individual assistance after Rita. 76,500 residents across southwest and south-central Louisiana were left homeless with 45,000 jobs lost and over 10,000 businesses impacted. Insured damages to the State of Louisiana from Rita are at 2.4 billion dollars. Additionally, Rita impacted 53 critical and non critical care facilities across southwest and south-central Louisiana and 17 colleges and universities. 515 schools with a total of 230,000 students were impacted by Rita across the state of Louisiana, compared to 930 schools and 480,000 students due to hurricane Katrina.

Cameron Parish

Rita made landfall as a 115 mph category 3 hurricane in the extreme southwest portion of Cameron Parish near Johnson's Bayou (Figure 8). An extreme storm surge occurred across the entire parish completely destroying the coastal towns of Johnson's Bayou, Holly Beach, Peveto Beach, and Grand Chenier, along with 80% of the town of Cameron. Storm surge heights were between 14-16 ft across a large portion of the parish and much of the low lying marsh remained flooded for several days following the passage of Rita. In fact nearly the entire parish was flooded by the storm surge and virtually every structure was inundated or completely washed away. Sustained category 3 winds were experienced near and just east of where the eye crossed the coast across the Holly Beach and Cameron areas northward through the town of Hackberry and Grand Lake. Radar velocity data from the Lake Charles site was recording 120 kt (138 mph) at 500 meters above the surface near the time of landfall. A reduction of 75% for an altitude of 500 meters yields surface winds of 90 kt (104 mph). In addition, a reconnaissance aircraft dropwindsonde at 11:44 p.m. reported 92 kt (106 mph) surface winds as Rita was nearing the coast. Damage was extensive and the coastline moved an average of 100-200 ft landward as a result of the storm surge and wave action (Figure 14). It is estimated that 45% of buildings across the parish sustained severe damage or were completely

destroyed by the hurricane force winds. Luckily, the parish is home to only 1,900 residents and nearly all had evacuated before Rita made landfall resulting in no loss of life.

Vermillion Parish

Rita tracked well to the west of this parish but yielded a devastating blow. The large circulation along with angle of approach to the coast resulted in extensive storm surge flooding across this area. Storm surge flooding extended 20-25 miles inland across the low lying Vermillion Parish where water reached portions of HWY 14 over 30 miles north of the coast. In fact the surge flooding surpassed HWY 14 and extended some 40 miles inland into the Lake Arthur and Gueydan areas and the southern portions of Acadia and Jefferson Davis Parishes. Pecan Island and Intracoastal City sustained major damage from a 10-13 ft surge and large wave action. Data from high water marks obtained by FEMA suggests that water level run-up occurred throughout the northern portion of Vermillion Bay into Weeks Bay where surge values of 12 ft were noted. The storm surge inundation stopped a few miles short of the higher populated towns of Abbeville and Kaplan. Sustained category 1 wind conditions were experienced across the western half of Vermillion Parish which was located just east of the eastern eyewall region with gusts into the low end category 2 range. Unlike Cameron Parish where nearly all residents heeded the evacuation orders, upwards of 1,000 residents in Vermillion Parish needed rescue south of the Abbeville area.

Iberia and St Mary Parishes

The surge penetrated 10-15 miles inland across Iberia and St. Mary Parishes. Much of the coastal plains south and west of HWY 90 were inundated with water ranging in depths from 8-12 ft. Surge run-up in the West Cote Blanche Bay produced upwards of an 11 ft surge over the southwest portions of Iberia Parish. The surge also penetrated up the lower Atchafalaya River impacting the Amelia and Morgan City areas. Storm surges in this area were similar to those produced by hurricane Lili in 2002. The region experienced sustained tropical storm force winds with gusts over hurricane force resulting in widespread downed trees and power lines. However, the greatest amount of damage was caused by the storm surge flooding.

Calcasieu Parish

As Rita tracked inland over extreme southeast Texas, the eastern eyewall passed over much of Calcasieu Parish including the cities of Lake Charles, Westlake, and Sulphur. Wind damage was extensive with roofs blown off and numerous trees felled on structures. Data from the Lake Charles radar and available surface observation sites suggest sustained category 1 wind conditions were felt across much of the parish with gusts to near 100 mph. This is consistent with damage surveys both by air and ground after Rita. Strong south and south-southwest winds on the east and southeast sides of Rita resulted in a substantial storm surge northward up Calcasieu Lake flooding locations around the lake. Portions of the Lake Charles levee system were overtopped resulting in

flooding of downtown Lake Charles to depths of 3-6 ft. Water levels rose 8-12 ft within the lake and in the lower portion of the Calcasieu River inundating several casinos on the edge of the lake. Storm surge damage was noted along the Calcasieu River as far as 35 miles inland due to water level run-up through the river floodplain and reached well upstream of Moss Bluff about 10 miles north of the I-10 bridge. Areas south and southwest of Lake Charles recorded a 10-15 ft surge as noted by high water marks in residential structures at Grand Lake. In the western part of the parish, the surge penetrated inland to locations north of I-10 near the border and stopped just short of reaching to town of Vinton.

Jefferson Davis, Beauregard, and Acadia Parishes

These parishes sustained upper level tropical storm force sustained winds with gusts well over hurricane force. Some of the lower portions of Jefferson Davis parish sustained storm surge flooding of 2-4 ft from water level run-up throughout the lower portion of the Bayou Nezpique basin and Lake Arthur area. Structural damage was mainly limited to numerous downed trees, power lines, and roof damage.

Southeast Louisiana including New Orleans

Less than one month after hurricane Katrina, Rita gave southeast Louisiana a glancing blow. Storm surge flooding of 6-8 ft resulted in overtopping of levees in Terrebonne Parish where an estimated 9,900 homes were damaged in the Houma area. Shallow surge flooding of 2-4 ft inundated a large portion of St. Charles Parish and nearly all of Lafourche Parish. Levees protecting portions of southern Lafourche Parish were not overtopped and prevented flooding in the Larose and Galliano areas. A storm surge of 4-5 ft was forced into Lake Pontchartrain early on Friday September 23rd as Rita passed well south and west of New Orleans. The surge resulted in renewed flooding at the Industrial Canal breach point inundating portions of New Orleans and St. Bernard Parishes. Additional flooding was noted on the north side of Lake Pontchartrain in the southern part of St. Tammany Parish where homes heavily damaged from hurricane Katrina in the Slidell area were flooded again. Portions of Plaquemines Parish which suffered catastrophic damage from Katrina were overwashed again by a 4-6 ft storm surge and wave action delaying the recovery effort. Sustained tropical storm force winds were felt across much of southeast Louisiana including peak a wind gust of 53 mph at Baton Rouge

Economic Impact

396,080 (12%) of the Texas labor force was directly impacted by hurricane Rita and 1.56 million (48%) of the state of Louisiana's labor force was directly affected by both hurricanes Rita and Katrina. In the Houston area, the evacuation closed most local industry for four working days including all of the regions petro-chemical industry and the port of Houston.

Oil and Natural Gas Industry

Only three weeks after being heavily impacted by hurricane Katrina, hurricane Rita stormed across the heart of the Gulf of Mexico oil and natural gas industry causing substantial damage to offshore platforms and coastal refineries. Rita destroyed 69 platforms and damaged 40 others and resulted in damages to 83 pipelines in the offshore waters. 13 rigs were set adrift and 3 are missing and were likely sunk in the Gulf of Mexico. A total of 108 oil and natural gas platforms were destroyed by Rita with an additional 53 significantly damaged. 100% of Gulf oil production (1.5 million barrels) was offline just before and during hurricane Rita with 81% of the manned platforms evacuated. Resultant damages from hurricane Rita continued to shut in 396,000 barrels of oil and 1,804 cubic feet of gas as of January 16, 2006. Long term projections indicate that 225,000 barrels per day of oil and 400 million cubic feet of gas per day will not be restored to operation before the start of the 2006 hurricane season.

Refinery Industry

30% of the total US refining capabilities are located in the region where Rita made landfall. 21 major refineries along the Texas and Louisiana coast were closed and evacuated prior to the landfall of hurricane Rita. The 9 major refineries in the Houston/Galveston area sustained little to no damage from Rita and were back to normal operations within a week after landfall. The 7 major refineries in the Port Arthur and Lake Charles area sustained wind damage and widespread power outages along with rainfall and storm surge inundation. The hardest hit location was the Valero plant in Port Arthur where significant wind damage occurred to two cooling towers and a flare stack closing the refining operations up to one month for repairs. Damage to the other refineries in the area was mainly minor and closures were heavily related to long lasting power outages instead of inflicted wind and storm surge damages. A total of 60 natural gas processing plants were shut down ahead of Rita and at least half sustained minor wind and flood damage. The overall impact of hurricane Rita on the petro-chemical refining industry was relatively light and would have been substantially greater had Rita tracked further west into the Galveston Bay area.

Insurance Industry

Insured losses from hurricane Rita have totaled 4.97 billion dollars with over 381,000 claims being filed. The combined claims of the entire 2005 hurricane season has resulted in a record 3.2 million insurance claims with 55% being from hurricane Katrina. With respect to insured losses, Rita becomes the 7th costliest hurricane behind hurricane Hugo (1989) and just ahead of hurricane Frances (2004). Overall damage estimates of 9.4 billion dollars makes Rita the 9th costliest hurricane in US history. 48.6% (185,000 claims) were filed in the State of Louisiana totaling 2.91 billion dollars. 44.4% (169,000 claims) were filed in the State of Texas totaling 1.97 billion dollars with additional smaller scale losses in Mississippi, Florida, Alabama, Arkansas, and Tennessee. An additional 2-3 billion dollars worth of insured damages was inflicted on the offshore industry in the Gulf of Mexico. The damage distribution was 2.94 billion (59%) to

personal property, 1.85 billion (37%) to commercial property, and 186 million (4%) to vehicles. It should be noted that the annual average insurance loss from tropical cyclone damages in the State of Texas is 615 million dollars or second in the nation behind the State of Florida, and Texas has an estimated 740 billion dollars of insured coastal exposure with 302 billion being coastal residential properties (Hartwig). The Texas Windstorm Insurance Association currently has upwards of 26 billion dollars of coverage along the Texas coast.

Louisiana Casino Industry

Unlike the total destruction of the casino barges along the Mississippi coast from hurricane Katrina, the casinos of southwest Louisiana escaped with only minor to moderate damage. Delta Downs in Vinton, LA suffered wind damage to the roof of the building resulting in water damage to the lower floors. The new 365 million dollar L'Auberge du Lac along the east bank of the Calcasieu River just south of Lake Charles survived the hurricane with only minor water and wind damage. An advanced system of water level control and protective berms kept the casino out of Rita's 6-8 ft surge in the river. Due to the light amounts of damage the L'Auberge du Lac became the staging area for 600 Entergy workers restoring electricity to the region. Just south of I-10 both Harrah's and Isle of Capri sustained storm surge flooding from the Calcasieu River.

Agricultural Impacts

Rita's hurricane force winds and storm surge cut through the heart of the timber industry of east Texas and the agricultural heart of southwest Louisiana. Extensive damage occurred to all aspects of the agricultural industry from timber to cattle to fishing. Total agricultural impacts to the State of Louisiana from hurricane Rita are near 590 million dollars compared to over 1 billion due to hurricane Katrina.

Timber Industry

The wide expanse of hurricane force winds felled thousands of acres of pine and hardwood forest across east Texas and western Louisiana. In the State of Texas alone, 967 million cubic feet of timber was damaged or affected over a 771,000 acre area. Economic losses from timber damage are estimated at 371 million dollars. Orange County lost nearly 43% of its timber to Rita's winds while Jasper County lost the greatest amount of cubic feet 148,457. The majority of the pine and hardwood forest within the core winds of the eyewall were either felled by snapping or being uprooted. Hundreds of acres of coastal pine forest near the Louisiana border extending east through Cameron and Vermillion Parishes were either killed or browned by the inland penetration of the storm surge and the influx of salt into the root system. In the western part of Louisiana, damages inflicted on the timber industry were near 225 million dollars including 1.4 million to the Christmas tree industry.

Crops and Livestock

Southwest Louisiana is home to a vast sugarcane crop and large amounts of coastal cattle herding. Rita dealt a significant blow to both aspects of this part of the southwest Louisiana economy. Thousands of head of cattle drowned in the storm surge when it swept inland across the coastal parishes resulting in decaying carcasses throughout the coastal parishes for many weeks after landfall. Total cattle losses were nearly 52 million dollars. Sugarcane losses totaled 141.5 million dollars and total crop losses exceeded 200 million dollars.

Fisheries

Much of south-central and southwest Louisiana has a large amount of shrimping and commercial fisheries industry. Due to their location near the Gulf of Mexico or along low lying inland bayous and rivers, Rita's storm surge caused heavy damage to this industry. Thousands of boats were washed miles inland, some as far as 20 miles, due to the storm surge, while coastal docking and processing locations were wiped away by a combination of the storm surge, wave action, and wind. 18 million dollars in damage was sustained to the shrimping industry with a total damage dollar amount of just over 34 million to the fisheries industry.

Power Outages

Rita's large expanse of hurricane force winds over thousands of acres of tall pine forest resulted in extensive damage to the power grid and transmission line system across east Texas and western Louisiana. In the hours following landfall various power companies reported upwards of 2 to 3 million customers without power. The majority of those customers were in the highly populated Houston area where power poles and lines were taken down by falling limbs and trees. By September 25th, roughly 1.5 million customers remained without power across Louisiana and Texas, with 775,298 from the State of Texas. CenterPoint brought in 4,000 personnel from across the country to help restore power. Entergy was harder hit with 153 large transmission lines and 120 substations knocked out of service between New Caney, TX and Lafayette, LA. Due to the substantial amount of wind damage to transmission lines and blocked roads from fallen trees, some parts of east Texas and western Louisiana were not fully restored for 4-6 weeks following the landfall of Rita. The majority of the Houston area, which received relatively minor wind effects, were restored within a week of landfall, however areas of Liberty, Polk, San Jacinto, and Trinity counties were not restored to full service for 2-3 weeks. In Louisiana severe damage to the electrical system resulted in the loss of power to 700,000 homes in 41 of the state's 64 parishes.

Education

Hundreds of school districts across Texas and Louisiana were out of school for an extended period of time. Classes were dismissed throughout much of the

Houston/Galveston area starting on Thursday, the 22nd due to the large scale evacuation. School districts surrounding the point of landfall were heavily damaged by wind and storm surge flooding and many did not reopen for up to one month after landfall. All 26 districts in Harris County were out of school Thursday and Friday, the 22nd and 23rd and then again Monday and Tuesday, the 26th and 27th, largely due to the evacuation and fuel shortage situation. In the State of Louisiana 111,964 students out of 661,246 were displaced by both hurricanes Rita and Katrina. In hard hit Cameron Parish where nearly the entire parish was submerged under Rita's 14-16 ft storm surge, 1,427 out of 1,499 (92%) students were displaced. The school district reported 62% of their infrastructure was completely destroyed by the storm surge and the return to class at the end of October was made possible through bussing of students to nearby parishes that were not as damaged (Figure 14). In Calcasieu Parish 30,026 out of 32,192 (93%) students were displaced. At Lake Charles's Boston High School, storm surge flooding resulted in the loss of 19,000 books in the library and extensive water damage to multiple schools through the community. Calcasieu Parish schools reopened on October 25th, nearly a month after Rita struck and mainly in temporary buildings or neighboring schools that were not as heavily damaged. Schools across east and southeast Texas reopened within 2-3 weeks after Rita's landfall, many of which would have opened sooner had power been restored. A total of 78.2 million dollars has been made available to the state of Texas through the Hurricane Education Recovery Act to help schools recover.

Lake Livingston

In the early morning hours of September 24th, as Rita made landfall across east Texas, hurricane force winds were felt across Lake Livingston and tropical storm force winds across Lake Conroe. The north to south alignment of the lakes allowed for north and north-northeast winds on the west side of the circulation to extend down the length of the lakes. With a wind gust to 117 mph at Lake Livingston and sustained 60-75 mph winds for many hours, large wave action and minor storm surges (1.5ft) were created on the south and southwest shores of the lake. Wave action was large enough to damage the 30 inch diameter rip rap stone along the dam's embankment resulting in significant amounts of erosion and scour along the north side of the Lake Livingston dam (Figure 15). The integrity of the dam came into question by mid morning and the Trinity River Authority released 79,200 cfs into the Trinity River Saturday and Sunday to lower the lake water level. A complete evaluation of the dam was conducted the week following Rita and determined the dam remained structurally sound. 20 million dollars in damage occurred to the Lake Livingston dam as a result of hurricane Rita.

Lake Conroe

Similar erosion occurred on the south and southeast shores of Lake Conroe. Sustained tropical storm force winds occurred across Lake Conroe for 4-6 hours early Saturday morning as Rita moved inland including a sustained 2 minute wind of 56 mph at 6:30 a.m. September 24th. Lesser wind velocities than what were recorded at Lake Livingston resulted in less damage to the dam. Wave action was estimated to have been near 6 ft and created a 3,000 foot gash across the dam's interior face removing the rip rap protection

and eating into the clay core. This was the most significant damage to the Lake Conroe dam since its completion in 1974 and required the San Jacinto River Authority to reduce the level of the lake by 5 ft during the winter of 2005-2006. On March 7th, 2006 crews had fully repaired the damage caused by hurricane Rita at a cost of 1.5 million dollars.

Recovery Effort

As of January 7th, 2006, 478,151 residents across Louisiana and Texas had applied for individual assistance with 558,402,638 dollars being paid out by FEMA. 367,036 residents have visited local disaster recovery centers and 336,643 (99%) home inspections have been completed. 2,697 travel trailers have been provided out of 3,441 requested. The US Army Corps of Engineers along with local counties and cities have removed 7.5 million cubic yards of debris or about 86% of all the debris generated by the hurricane. An additional 1.2 million cubic yards is still in need of removal. Due to the widespread devastation of the 2005 hurricane season, response groups such as the Red Cross, United Way, and Salvation Army lumped together much of the response effort into a general hurricane relief. Hence, the breakdown for the hurricane Rita response is blurred within the hurricane Katrina and hurricane Wilma efforts.

Comparison to Hurricane Audrey

On June 27th, 1957 a powerful category 4 hurricane with sustained winds near 145 mph made landfall in Cameron Parish, LA causing a devastating storm surge that claimed 600 lives across southwest Louisiana. Storm surge flooding of 12.4 ft was recorded at Cameron and much of Cameron, Vermillion, and St. Mary Parishes were submerged under sea water with 10-15 ft wave action on top of the surge. Lack of preparation and evacuation resulted in a substantial loss of life from drowning as the storm surge swept inland. A result of the devastation was a strong partnership between the local forecast office in Lake Charles and the local emergency managers across southeast Texas and southwest Louisiana. Extensive evacuation and hurricane preparedness drills and education were held annually across the region with close working relationships between the NWS forecasters and the local emergency planners. Near misses by hurricane Andrew (1992) and an indirect impact by hurricane Lili (2002) yielded the execution of the regions disaster response plans and evacuation procedures. When hurricane Rita became a threat and eventually devastated the area, advanced and well coordinated emergency planning resulted in no loss of life from storm surge flooding. Conference calls between the forecast office and multiple emergency response organizations were held four times a day in addition to the public release of the hurricane local statements (HLS) detailing the expected impacts from Rita. The flow of information between various agencies resulted in coordinated and planned decision making and clearly worded advice and orders to the public. Even though Rita produced a substantially higher surge than Audrey, a near total evacuation of the residents at risk long before the onset of tropical storm conditions saved thousands of lives.

Lessons

Lesson 1: Phased Evacuation

It is clear after the mass evacuation with hurricane Rita that phasing of the evacuation into zones does not work well. By Wednesday evening at the time when the mandatory evacuation was to begin for zone A, many residents from all across the region were flooding area freeways creating gridlock conditions. Better planning is needed with respect to who needs to evacuate and how to educate the public about when to evacuate.

Lesson 2: Residents at Risk

Of the 2.5 million people that fled the Houston/Galveston area ahead of Rita, an amazing 47% were outside the storm surge inundation zones and did not need to evacuate. The purpose of an evacuation is to move those within the risk area of being flooded by storm surge out of the surge zones, the “run from the water and hide from the wind” concept. However, during Rita over 1 million residents left that did not need to leave impeding the evacuation of those that were in danger from storm surge flooding. It is likely that the near continuous coverage of the devastation caused by hurricane Katrina only weeks earlier played a large part in the response to the threat of hurricane Rita. Strong and consistent public education of the storm surge zones is needed and these zones need to be clearly marked in public places. This aspect of the evacuation process is likely the single most important due to the fact that if only the residents who needed to leave actually left, traffic congestion would be reduced.

Lesson 3: Contraflow

In August 2005, evacuation consultants for the State of Texas informed the state that contraflow would not be needed due to Houston’s robust transportation system. Real life experience proved otherwise as evacuation routes became gridlocked early in the evacuation implementation. It is now understood after the Rita evacuation that our coastal populations have to a degree outgrown our evacuation interstate system especially when the majority of the residents leave within a confined time period. The rapid increase in coastal populations in the last 20 years has resulted in the necessity for contraflow in multiple areas along the US coastline. Implementation of contraflow plans is strongly needed along with early and proper loading of the contraflowed lanes and multiple exit strategies along the contraflow routes. It is also imperative that local residents as well as localities along the contraflow routes fully understand how contraflow will be conducted and the far reaching impacts to local traffic flow.

Lesson 4: Evacuation Survey

In the weeks following Rita’s impact on the region, KHOU Channel 11, along with the Houston Chronicle, the University of Houston, and Rice University conducted a survey of residents across Chambers, Galveston, Harris, Montgomery, Brazoria, Fort Bend, Matagorda, and Waller counties with respect to their evacuation experiences. A total of

351 residents out of 647 responded to the survey. 32.3% of those who evacuated headed for Austin, San Antonio or Dallas with 51.6% going to smaller Texas towns to stay with family (58.3%) or friends (20.4%). 24.5% left the area because they were scared of the impact of a hurricane with a surprising 3.0% being afraid of flooding. Over half (52.9%) evacuated on Thursday, September 22nd with 34.2% leaving Wednesday, the 21st. 18.1% of the persons who responded to the survey used I-45 north as their evacuation route with 10.2% using I-10 west, and 9.5% using HWY 290. 53.2% spent over 200 dollars on the evacuation and provisions. 59.9% of those who responded that evacuated were **NOT** in an evacuation zone or told to evacuate by public officials. Surprisingly, many residents did not make their evacuation decisions based on statements by public officials, but instead based their decisions on the media (45.3%). The media coverage of Rita was rated excellent by 51.8% and the quality of weather reports from the local media and NWS offices were rated excellent by 68.6%. One of the most amazing findings is that 61.5% of those surveyed said they would evacuate again if threatened by a category 4 hurricane.

Lesson 5: Essential Personnel

Private industry and public service officials need to clearly define their essential personnel and make it clearly understood what is expected during an emergency such as a hurricane landfall. Various public service organizations from police and fire to public works reported significant loss of their workforce prior to the landfall of hurricane Rita. Such personnel are vital to the immediate response and recovery effort following a hurricane and are critically needed to maintain life sustaining services. It is important that supervisors and managers convey the importance of service to their essential personnel and explain the consequences of leaving when service is required. Essential personnel should be chosen wisely as critical decisions, stressful work loads, and extremely long hours may be required before, during, and after a hurricane landfall.

Lesson 6: Forecast Track Error

Residents along the coast should understand the amount of forecast track error at each time step of the forecast. Focus should not be applied to the black line on the NHC graphics, but instead the overall error cone provided with each forecast package. The average forecast track error on day 4 of the forecast is upwards of 250 miles and 325 miles for 5 day forecast. The 3 day average forecast track error is 150 miles. Coastal residents should understand that due to our large coastal population growth along the upper Texas coast, critical decisions with respect to evacuation must be determined as much as 72 hours before the onset of tropical storm force winds. The average error at this time span may be as much as 150 miles. Hurricane Rita made landfall within the 4 day error cone issued at 5:00 p.m. Tuesday, September 20th. Rita also made landfall within the hurricane watch area issued on the afternoon of the 21st and well within the hurricane warning area. The fact is that coastal residents must be willing to evacuate and have nothing happen. It is the price paid for living on the coast in a hurricane threat zone.

Lesson 7: Preparation, Planning, and Drills

The key to surviving the impact of a major hurricane is preparation and planning. All residents, private industry, public services, and response groups need to have well rehearsed hurricane plans. These plans should be drilled often with frequent corrections when needed. Clearly defined rolls of responsibility, the location of essential equipment such as fuel and tools, and strong redundancy with respect to outside services is highly recommended. Coastal residents should completely stock a hurricane supply kit at the start of hurricane season, not when a hurricane enters the Gulf of Mexico. In addition a detailed personal evacuation plan tailored to the specific needs of each individual should be developed for those residents in the surge inundation zones.

Final Comment

Had Rita tracked 100 miles to the west the devastation along the upper Texas coast, including Galveston and the many communities along the shores of Galveston Bay, would have been tremendous. The Houston/Galveston area should be fortunate that the hurricane turned hard enough to spare the area the impacts of a major hurricane landfall. Rita's storm surge would have penetrated up to 20 miles inland across Galveston and Brazoria counties inundating most of the highly populated areas east of I-45. The western end of Galveston Island and the Bolivar Peninsula currently experiencing rapid growth would have been reduced to nothing more than concrete slabs and wooden pilings in a scene not at all different from Holly Beach or Gulfport. As coastal populations continue to increase multi billion dollar hurricane disasters will occur more frequently. The luck of the upper Texas coast since the landfall of hurricane Alicia in 1983 will end in the future. At some point in time this area will suffer what Louisiana and Mississippi suffered from hurricanes Katrina and Rita, and the area must be prepared when the time comes.

Fast Facts

15-20 ft storm surge in Cameron Parish
Storm surge inundation extended 15-20 miles inland at places
9.4 billion dollars in damage
4.97 billion dollars in insured losses
2-3 million residents without power immediately after landfall
Largest evacuation in world history (2.8-3.2 million residents)
8.7 million cubic yards of debris generated
478,151 residents applied for assistance
336,643 home inspections
2,697 travel trailers provided by FEMA
20 million dollars in damage to Lake Livingston
1.5 million dollars in damage to Lake Conroe
95% of Cameron Parish school students were displaced
62% of Cameron Parish school infrastructure was destroyed
771,000 acres of Texas timber was affected
148,457 cubic feet of timber lost in Jasper Co., TX
1.4 million dollars in damage to the Christmas tree industry
596 million dollars lost in timber damage
354,000 insurance claims
21 major refineries in the path of Rita
69 oil platforms destroyed with 40 damaged
369,080 (12%) of the TX workforce impacted by Rita
21,333 structures destroyed in the state of TX
118,533 structures with some form of damage in the state of TX
9,577 mobile homes destroyed in the state of TX
76,500 LA residents left homeless
45,000 LA jobs lost
515 schools in LA impacted.

Peak intensity of 180 mph (895mb) at 24.7 N / 87.3 W (9:00 p.m. on the 22nd)
Landfall intensity of 115 mph at Johnson's Bayou, LA at 2:40 a.m. on the 24th

Peak wind gust of 133 mph at Herbert's Marina near Grand Lake, LA
Peak wind gust of 105 mph at Beaumont, TX (KBPT)
Peak wind gust of 116 mph at Port Arthur, TX (FCMP)
Peak wind gust of 117 mph at Lake Livingston dam
Peak wind gust of 137 mph at buoy 42001 (25.8 N / 89.7 W)
Highest recorded rainfall total of 16.0 inches at Bunkie, LA
Lowest land pressure recorded: 939.1mb (27.73 in) at Johnson's Bayou, LA
950mb (28.05 in) recorded at Cameron, LA
952.3mb (28.12 in) recorded at Beaumont, TX
988.1 (29.18 in) recorded at Houston, TX (KIAH)

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Figures

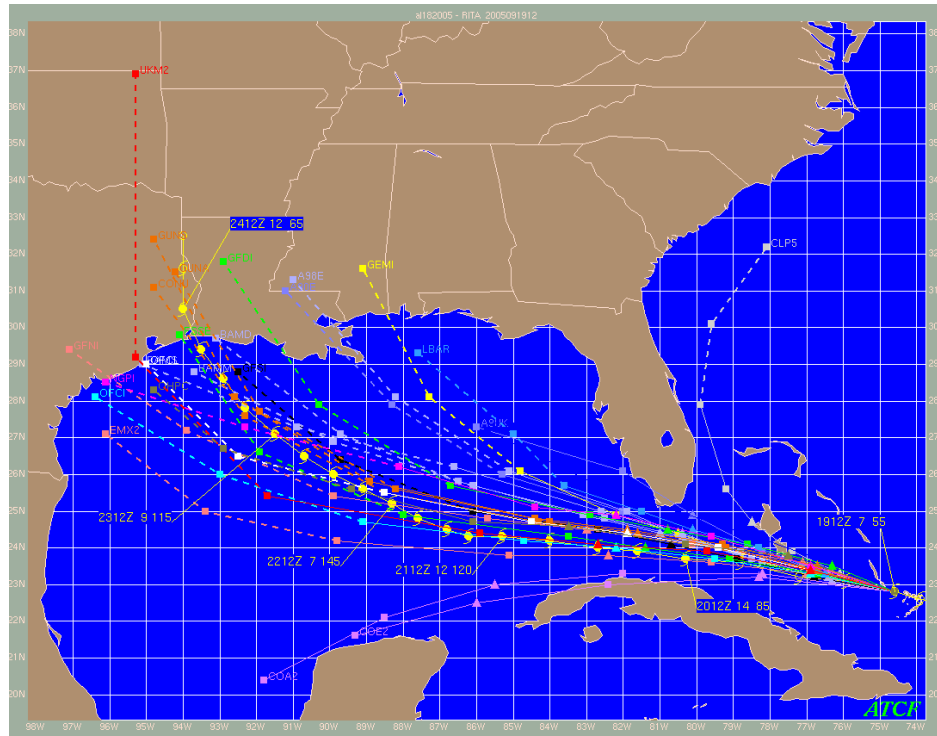


Figure 1: Forecast guidance tracks early on Monday, Sept. 19th, 2005. Source: Bill Read, NWS Houston/Galveston.

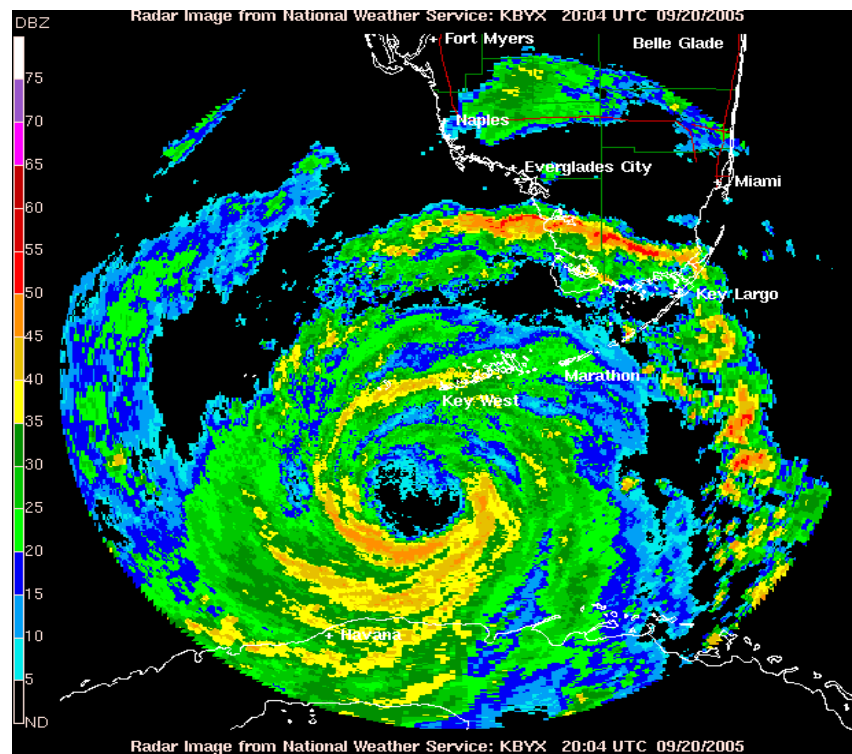


Figure 2: NEXRAD image from Key West with 100 mph sustained winds. Source: NWS Key West

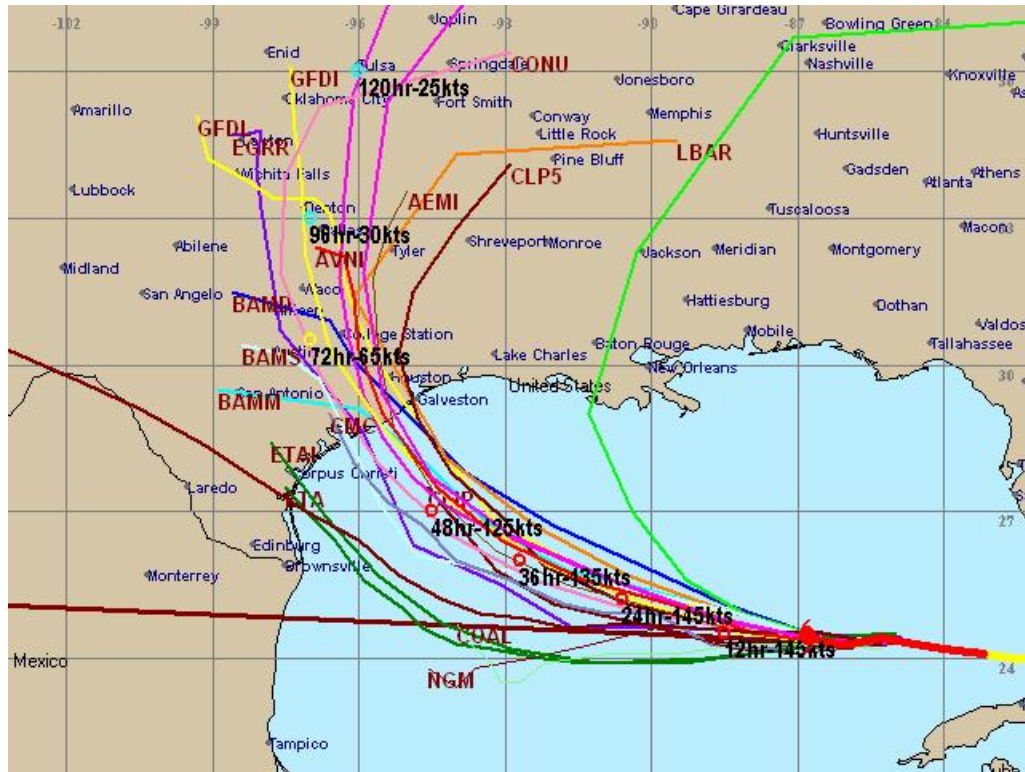


Figure 3: Forecast model guidance early Wednesday, Sept. 21st.

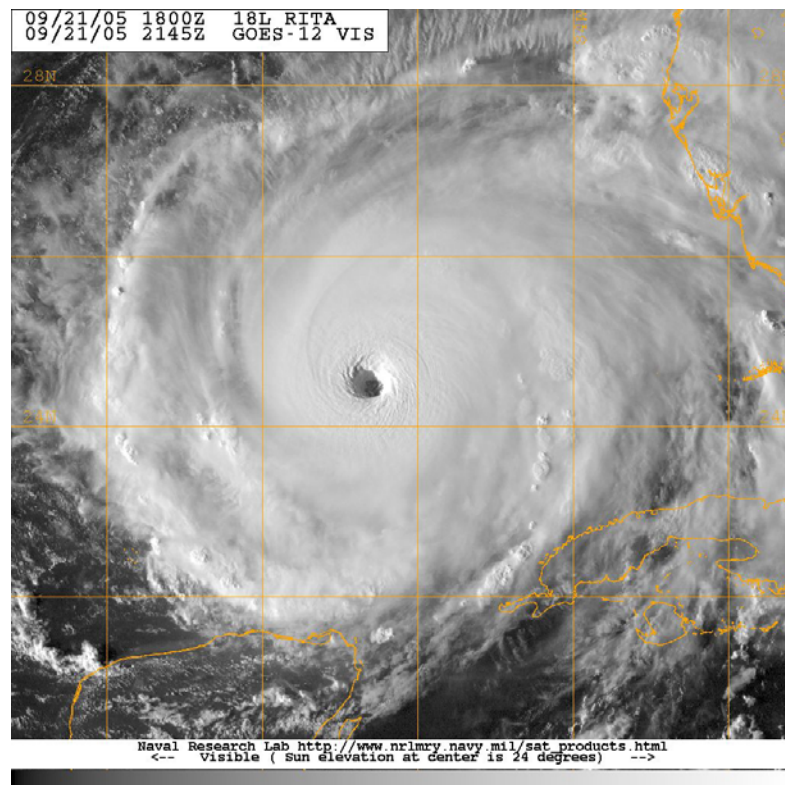


Figure 4: Visible image of category 5 hurricane Rita on the afternoon of Wednesday, Sept. 21st.
Source: Navy Research Laboratory

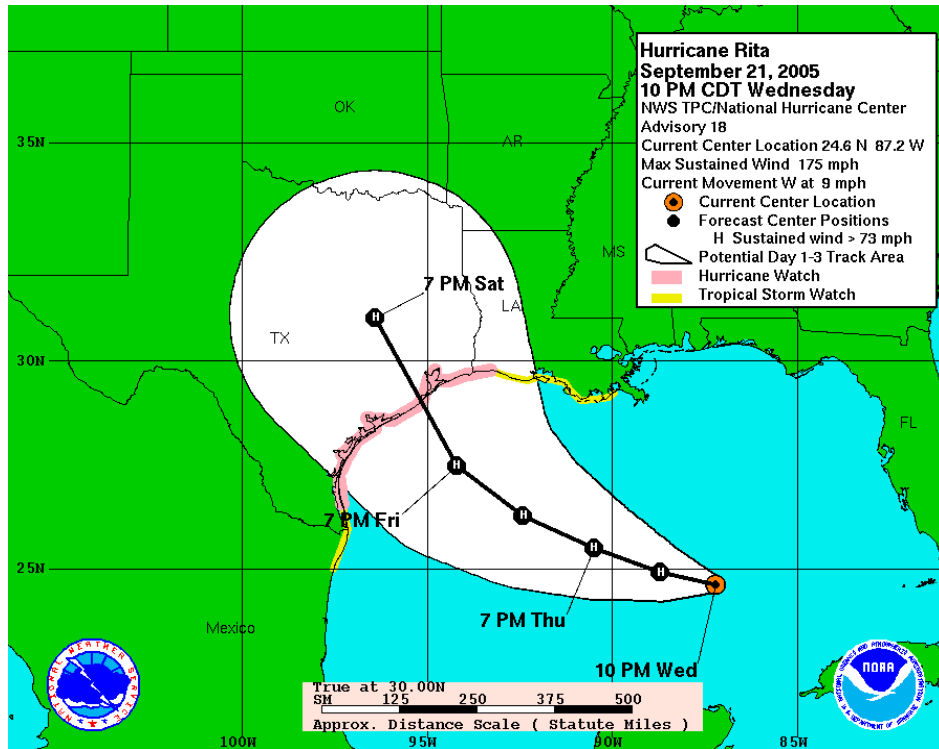


Figure 5: NHC forecast track at with the 10:00 p.m. advisory package on Wednesday, Sept. 21st.
 Source NHC

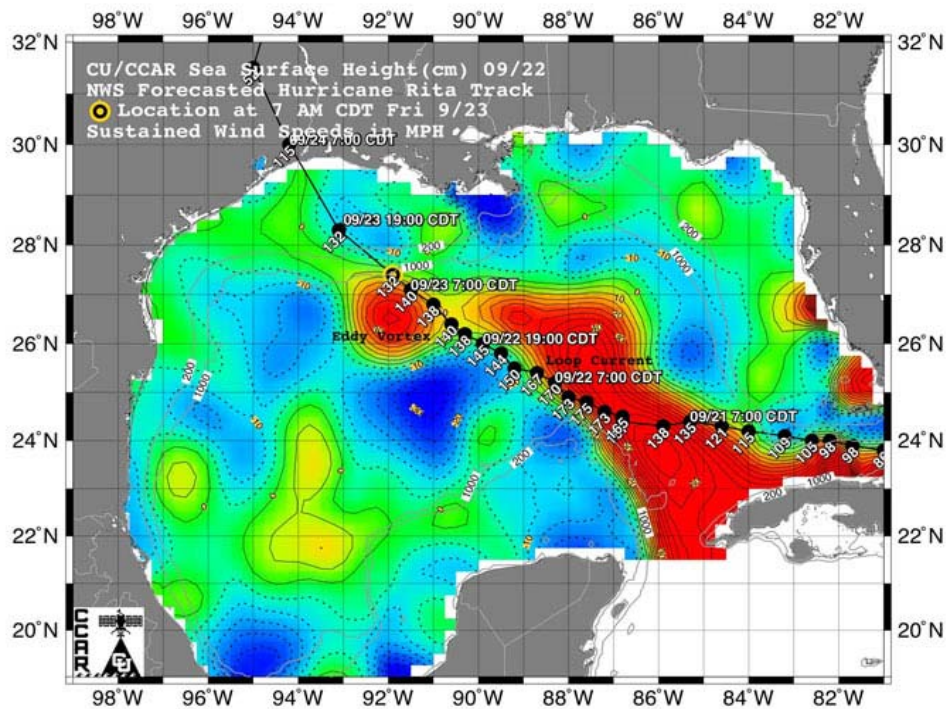


Figure 6: The track of Rita overlaid across a sea level map of the Gulf of Mexico. Red areas are higher sea level corresponding to higher water temperatures and high oceanic heat content. Source NASA



Figure 7: NHC forecast track with the 10:00 a.m. advisory on Friday, Sept. 23rd. Source NHC

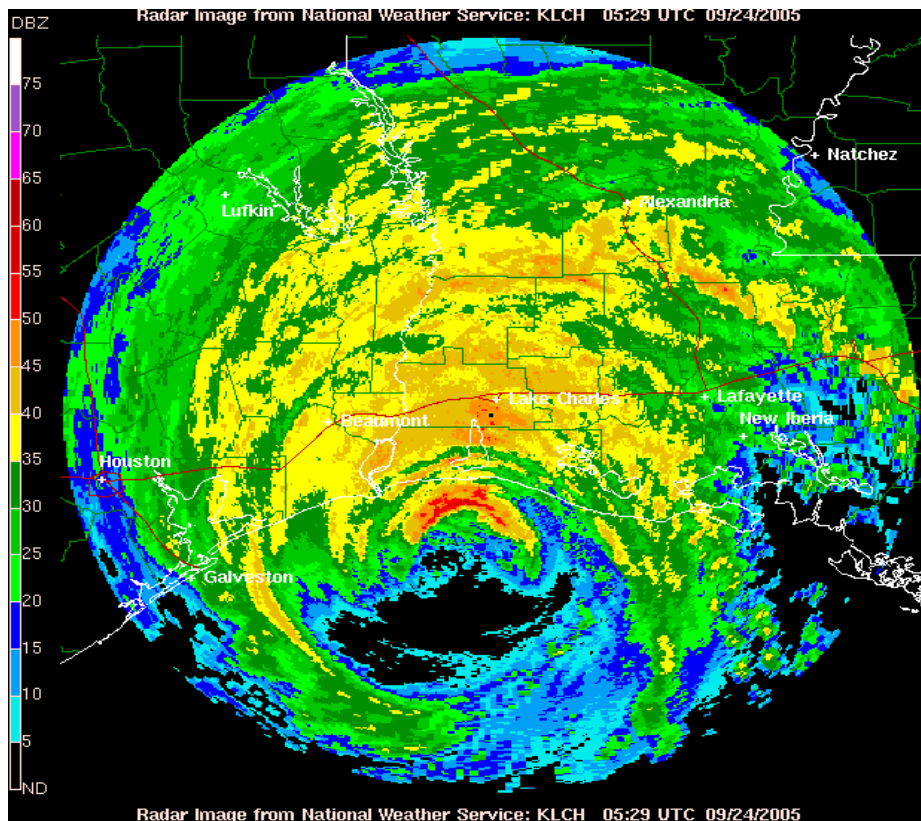


Figure 8: Hurricane Rita just prior to landfall over Cameron Parish. Source: NWS Lake Charles



Figure 9: Aerial before and after images of Holly Beach, Louisiana showing the complete destruction of structures along the coastline. This area went through the eastern eyewall and suffered a storm surge of 15-18 ft resulting in total devastation. Source USGS

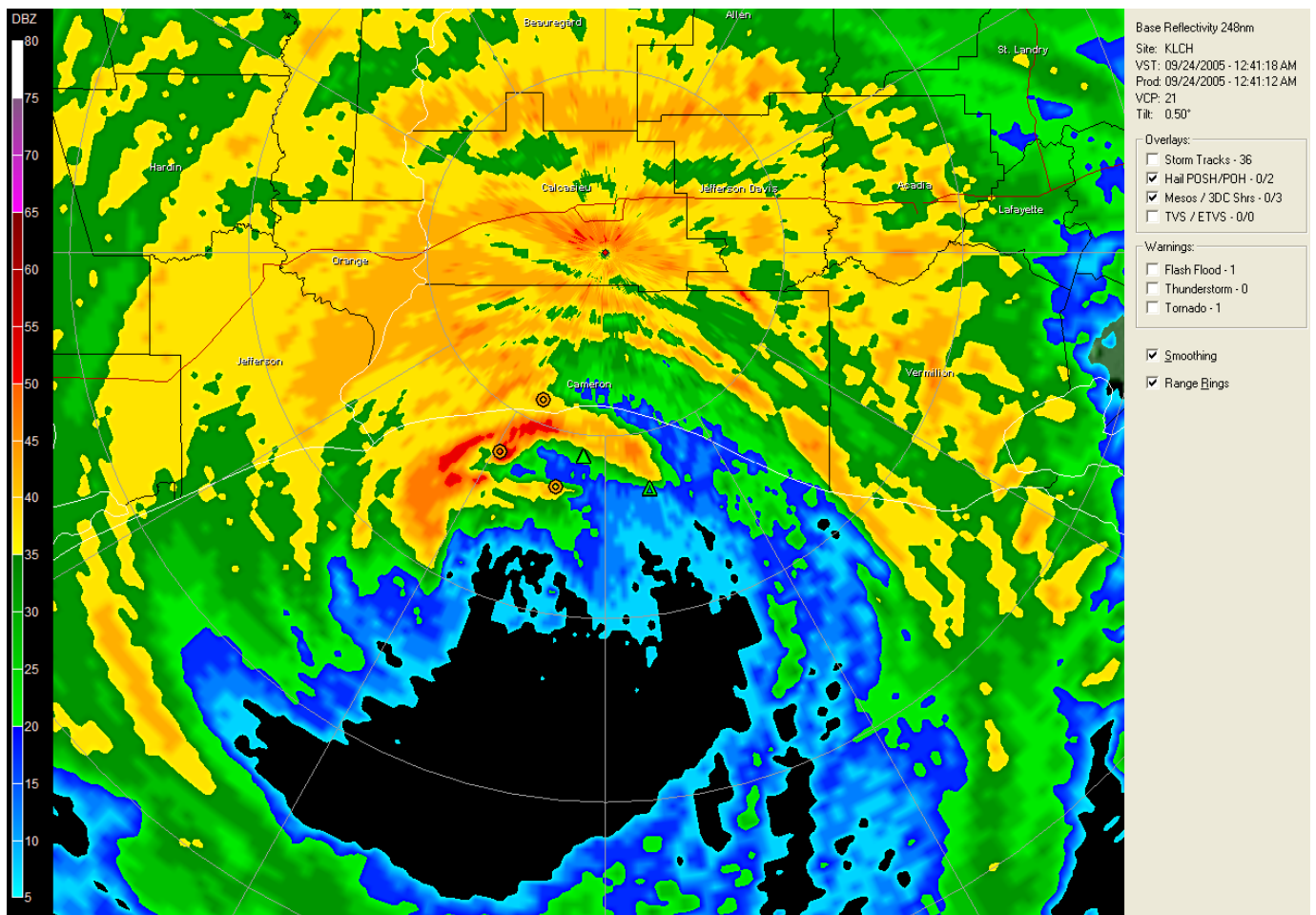


Figure 10: Level III radar image with meso vortex indicators (orange circles) highlighted, shows potential “mini swirls” or gustnadoes within the northern eyewall of Rita at the time the northern eyewall was crossing the coast.

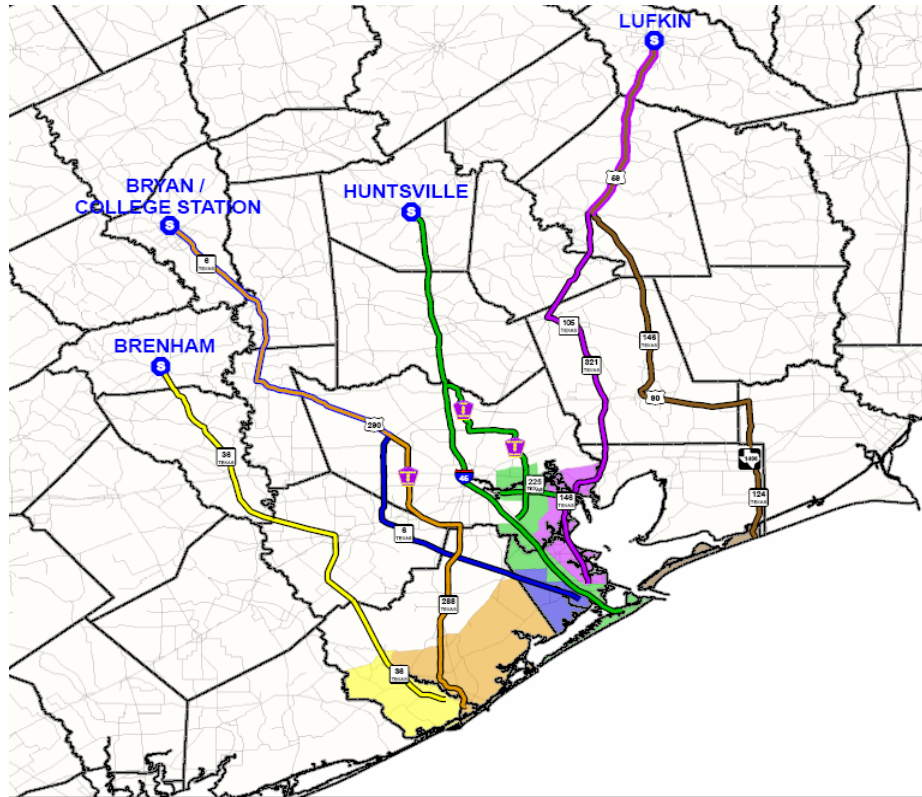


Figure 11: Color coded corridor evacuation plan for southeast Texas. The shaded areas were to take the appropriate shaded interstate to the indicated shelter location. Source: NWS Houston/Galveston



Figure 12: I-45 Contraflow at HWY 242 north of The Woodlands. 17 lanes of northbound traffic. Source: Time



Figure 13: Common wind damage from sustained category 1 winds across east Texas and western Louisiana.



Figure 14:
 Top two: Remains of Holly Beach, LA
 Middle Two: Cameron, LA
 Bottom Two: Cameron Elementary School (left) and south Cameron Elementary School (right)
 These areas went through the eastern eyewall of Rita and experienced sustained category 3 wind conditions and a storm surge of 14-16 ft.
 Sources: Cameron Parish School District, Associated Press



Figure 15: Lake Livingston Dam erosion and rip rap removal due to wave action. Source: NWS Houston/Galveston