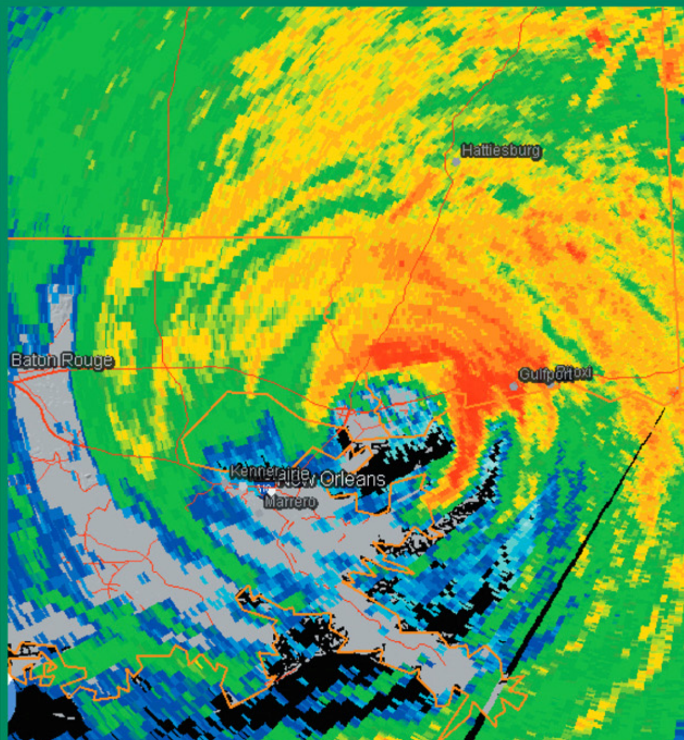
Technical Report 2005-01

NOAA's NATIONAL CLIMATIC DATA CENTER

Hurricane Katrina
A Climatological Perspective
Preliminary Report



Axel Graumann, Tamara Houston,
Jay Lawrimore, David Levinson, Neal Lott,
Sam McCown, Scott Stephens, David Wuertz

Asheville, NC 28801-5696
October 2005

US Department of Commerce
NOAA/NESDIS

Hurricane Katrina, A Climatological Perspective
October 2005, Updated August 2006

1. Introduction

Hurricane Katrina is the most costly natural disaster ever to strike the United States, and the deadliest since the Lake Okeechobee disaster (hurricane) of September, 1928. In addition, Katrina was one of the strongest storms to impact the coast of the United States during the last 100 years. At landfall, sustained winds were 127 mph (a strong Category 3 hurricane on the Saffir-Simpson scale—see Figure 2), and the minimum central pressure was the third lowest on record (920 mb). Katrina caused widespread, massive devastation along the central Gulf Coast states of the U.S. The flooding of New Orleans, LA following the passage of Katrina was catastrophic, resulting in the displacement of more than 250,000 people, a higher number than during the Dust Bowl years of the 1930's. As of early August 2006, the death toll exceeded 1800 and total damages/costs were estimated to be around $125 billion. For detailed information in addition to this climatological report, NOAA's National Hurricane Center has an excellent report online: http://www.nhc.noaa.gov/2005atlan.shtml

2. Description and Impacts

2.1 Storm Chronology

During August 25-31, 2005, Hurricane Katrina created a path of destruction across southern Florida, and caused devastation into parts of southeast Louisiana, Mississippi, and Alabama. The storm then tracked northward into Tennessee and Kentucky and points northeast from there, where heavy rainfall was the main impact of the storm.

Katrina began as a tropical depression 175 miles southeast of Nassau on August 23 and strengthened into Tropical Storm Katrina the next day as it moved erratically through the central Bahamas. (See Figure 1 for the path of Katrina.) Katrina began strengthening rapidly and a hurricane watch was issued for southeast Florida at 1700 EDT followed by a hurricane warning by 2300 EDT. Katrina moved slowly westward and became a minimal Category 1 hurricane 15 miles east northeast of Fort Lauderdale at 1700 EDT on August 25. At 1830 EDT, the hurricane made landfall between Hallandale Beach and North Miami Beach with sustained winds estimated at 80 mph and gusts of above 90 mph. Though the storm moved southwest across the tip of the Florida peninsula during the night, Katrina's winds decreased only slightly and it quickly re-intensified shortly after moving over the warm waters of the Gulf. In addition to the gusty winds, heavy rains accompanied Katrina in her trek across Florida. Although the storm over Florida never had sustained winds higher than 80 mph, substantial damage and flooding occurred and fourteen people lost their lives.

Katrina moved almost due westward after entering the Gulf of Mexico. A mid-level ridge centered over Texas weakened and moved westward allowing Katrina to gradually turn to the northwest and then north into the weakness in the ridging over the days that followed. Atmospheric and sea-surface conditions (an upper level anticyclone over the Gulf and warm sea surface temperatures – see Figure 7) were conducive to the cyclone's rapid intensification, which led to Katrina attaining 'major hurricane' status on the afternoon of the 26th.

Continuing to strengthen, a hurricane watch was issued by NOAA's National Hurricane Center for parts of Louisiana at 10:00 CDT on August 27 and a hurricane warning was issued for the north central Gulf from Morgan City eastward to the Alabama / Florida border at 22:00 CDT. By 07:00 CDT on Sunday, August 28, Hurricane Katrina reached Category 5 status with wind speeds of 160 mph and a pressure of 908 millibars. Three hours later, the maximum sustained wind speeds peaked near 175 mph and remained at that speed until the afternoon. At 16:00 CDT, Katrina's minimum central pressure dropped to 902 mb - the 4th lowest on record at that time for an Atlantic storm. (Note: Later in the season, Hurricane Rita reached an intensity of 897 millibars on September 22, and Hurricane Wilma set a new Atlantic record of 882 mb in October, knocking Katrina's record to the 6th lowest pressure.) By this time Katrina was at its peak strength with hurricane force winds extending outward up to 105 miles from the center and tropical storm force winds extending outward up to 230 miles. Sustained tropical storm force winds were already battering the southeast Louisiana coast. Though the storm was comparable to Camille's intensity, it was a significantly larger storm (see Figure 14). Ominously, the 16:00 CDT Bulletin from the National Hurricane Center warned of coastal storm surge flooding of 18 to 22 feet above normal tide levels … locally as high as 28 feet, and stated "Some levees in the Greater New Orleans Area could be overtopped."

Katrina advanced toward Louisiana during the night, and by 04:00 CDT on Monday, August 29, the center was 90 miles south southeast of New Orleans. Though winds near the center had dropped to 150 mph, gusts to hurricane force were occurring along the coast. NOAA Buoy 42040, located about 50 miles east of the mouth of the Mississippi River, reported a peak significant wave height of 55 feet at 06:00 CDT, which equals the highest ever measured by a National Data Buoy Center (NDBC) buoy.

At 06:10 CDT, Katrina made landfall in Plaquemines Parish just south of Buras (between Grand Isle and the mouth of the Mississippi River) as a strong Category 3 storm, despite entrainment of dryer air and an opening of the eyewall to the south and southwest. Landfalling wind speeds were approximately 127 mph with a central pressure of 920 millibars – the 3rd lowest pressure on record for a landfalling storm in the U.S. Winds at this time were gusting to 96 mph at the Naval Air Station at Belle Chasse, LA and to 85 mph at New Orleans Lakefront.

By 08:00 CDT, Katrina was only 40 miles southeast of New Orleans with hurricane force winds extending outward up to 125 miles. In the dangerous right front quadrant of the storm, Pascagoula Mississippi Civil Defense reported a wind gust to 119 mph and Gulfport Emergency Operations Center reported sustained winds of 94 mph with a gust to 100 mph. New Orleans Lakefront reported sustained winds of 69 mph with gusts to 86 mph. A little earlier, Belle Chasse reported a gust to 105 mph.

By 10:00 CDT, the eye of Katrina was making its second northern Gulf coast landfall near the Louisiana – Mississippi border. The northern eyewall was still reported to be very intense by WSR-88D radar data and the intensity was estimated to be near 121 mph. Even an hour later and far from the center, Dauphin Island, AL reported sustained winds of 76 mph with a gust to 102 mph, Mobile reported a gust to 83 mph, and Pensacola, FL reported a gust of 69 mph.

Katrina continued to weaken as it moved north northeastward during the remainder of the day. It was still at hurricane strength 100 miles inland near Laurel, MS. The storm was reduced to tropical storm status by 19:00 CDT when the storm was 30 miles northwest of Meridian, MS, and became a tropical depression near Clarkesville, TN on August 30.

South of the mainland and east of Louisiana, the Chandeleur Islands have been devastated during recent hurricane seasons. Hurricanes Lili (2002), Ivan (2004), and Dennis (2005) all did damage, but the surge from Hurricane Katrina (2005, the strongest and closest to the Chandeleurs) nearly destroyed the island chain.

Damage to homes and businesses in both Louisiana and Mississippi was catastrophic. The current estimate for overall damages and costs is approximately $125 billion, based on various figures including over $100 billion in U.S. Government expenditures and estimates from Munich Re. The death toll is now estimated as 1833, with several hundred people still listed as missing. Katrina was the third deadliest hurricane since 1900, being topped only by the Galveston hurricane of 1900 (at least 8000 deaths) and the Lake Okeechobee Hurricane of 1928 (over 2500 deaths). Following is the estimated death toll by state: Louisiana – 1577, Mississippi – 238, Florida – 14, Georgia – 2, Alabama – 2.

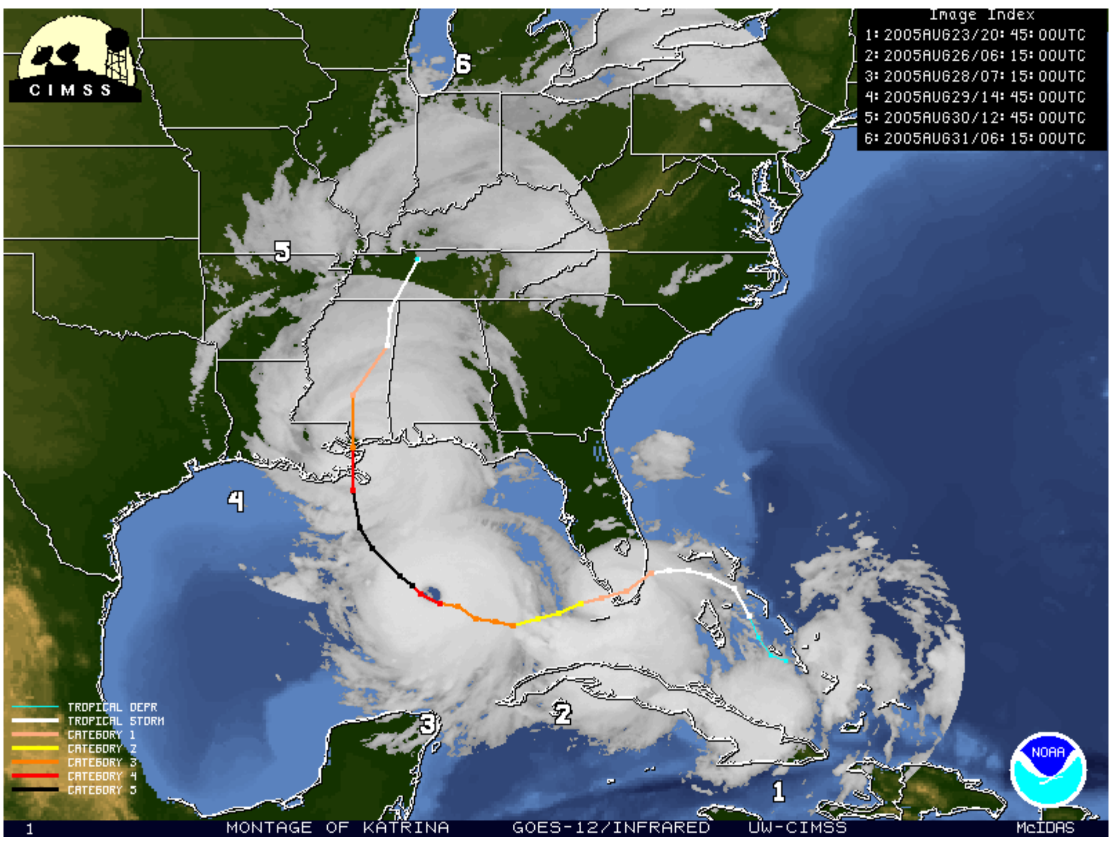


Figure 1. Path and Intensity of Hurricane Katrina.

Saffir-Simpson Hurricane Scale		
Category	**Knots**	**(MPH)**
1	64-82	(74-95)
2	83-95	(96-110)
3	96-113	(111-130)
4	114-135	(131-155)
5	136 and >	(156 and >)

Figure 2. Saffir-Simpson Scale for Hurricane Intensity.

2.2 Storm Surge

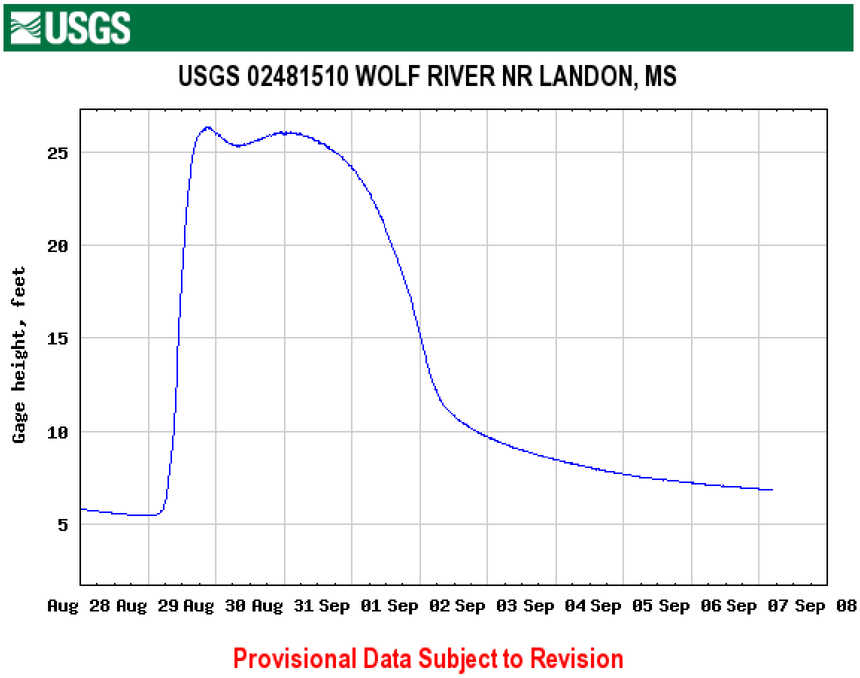
Though wind damage was significant, the legacy of Hurricane Katrina will be the horrific storm surge which accompanied the storm. A surge of 24-28 feet was estimated along the western Mississippi coast across a path of about 20 miles, tapering to a height of 17-22 feet along the eastern MS coast. The maximum high water mark observation was 27.8 feet at Pass Christian, MS. Alabama's coast experienced surges ranging from as high as 10 feet in the east to 15 feet in the west. Surges in eastern Louisiana generally ranged from 10 to 19 feet.

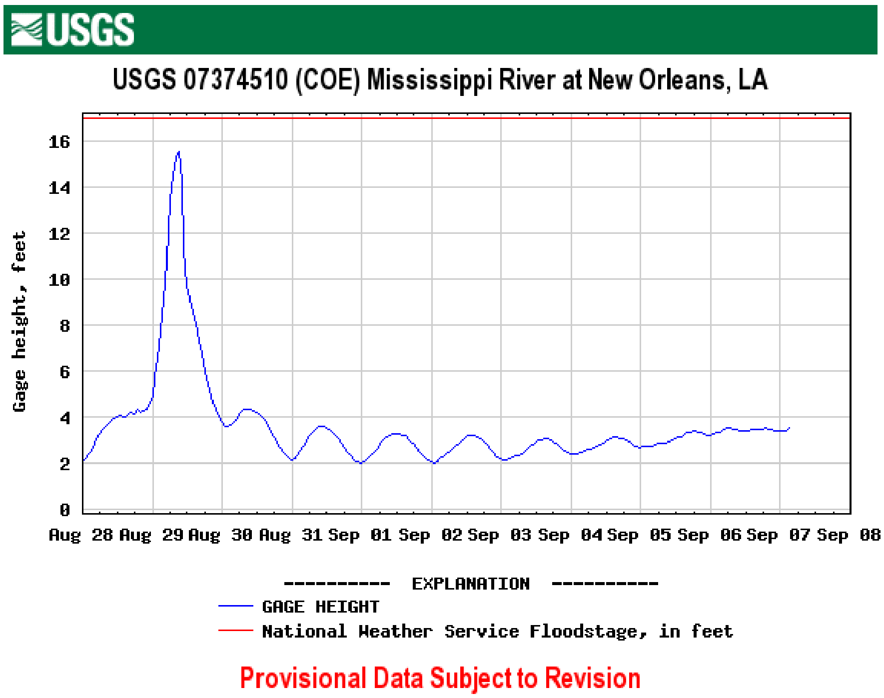
Even though weakening before landfall, several factors contributed to the extreme storm surge: a) the massive size of the storm, b) the strength of the system (Category 5) just prior to landfall, c) the 920 mb central pressure at landfall, and d) the shallow offshore waters. Sweeping through the delta country southeast of New Orleans, several small towns were virtually obliterated and Plaquemines and St. Bernard parishes were devastated. (See Figure 4 for the preliminary US Geological Survey (USGS) stage height of the Mississippi River at New Orleans). The surge caused the level of Lake Pontchartrain to rise, straining the levee system protecting New Orleans. Significant failures in the levee system occurred on August 30 on the 17th Street Canal, Industrial Canal, and London Avenue Canal levees. Water poured into the city which sits mostly below sea level. Eventually 80 percent of the city was underwater at depths of up to 20 feet. Though the city was essentially pumped dry by September 20, the approaching storm surge from Hurricane Rita on September 23 caused a new breach in the repaired Industrial Canal levee and many of the areas of the city were flooded again.

Surges on the Mississippi coast, to the right of Katrina's second landfall, also nearly obliterated towns. The Hancock Emergency Operations Center reported an estimated surge level of 27 feet at their location. The damage and high water marks indicate that the surge reached from 6 to as far as 12 miles inland in some areas, especially along bays and rivers. In Waveland, 80 percent of all the dwellings were declared uninhabitable. The surge in the Saint Louis Bay area was similar to that accompanying Hurricane Camille in 1969. (See Figure 4 for preliminary USGS river stage height for the Wolf River station west of Landon, MS.) Further east in the Gulfport and Biloxi areas, the surges were unprecedented, topping those of Camille by approximately 5 to 10 feet or more. (See Figure 4 for the USGS stage height for the Biloxi River.) Along much of the spans of the Bay St. Louis Bridge and the Biloxi-Ocean Springs Bridge, only pylons remain. Refer to Figure 3 for a before and after photo in Biloxi, MS (courtesy of USGS -- http://coastal.er.usgs.gov/hurricanes/katrina/).

Figure 3. USGS Before and After Photo in Biloxi, MS, Along the Coast.

The USGS has river gauge data online (http://waterdata.usgs.gov/nwis) which provides a good perspective on the impact of the surge, rainfall, and levee breaks, along the "mouth" of several rivers—see Figure 4. Note that these data are showing the surge of water from the Gulf of Mexico into the entrance zone for each river into the Gulf. The rises (from previous levels) for the Wolf, Mississippi, and Biloxi Rivers are 22, 13, and 24 feet, respectively.





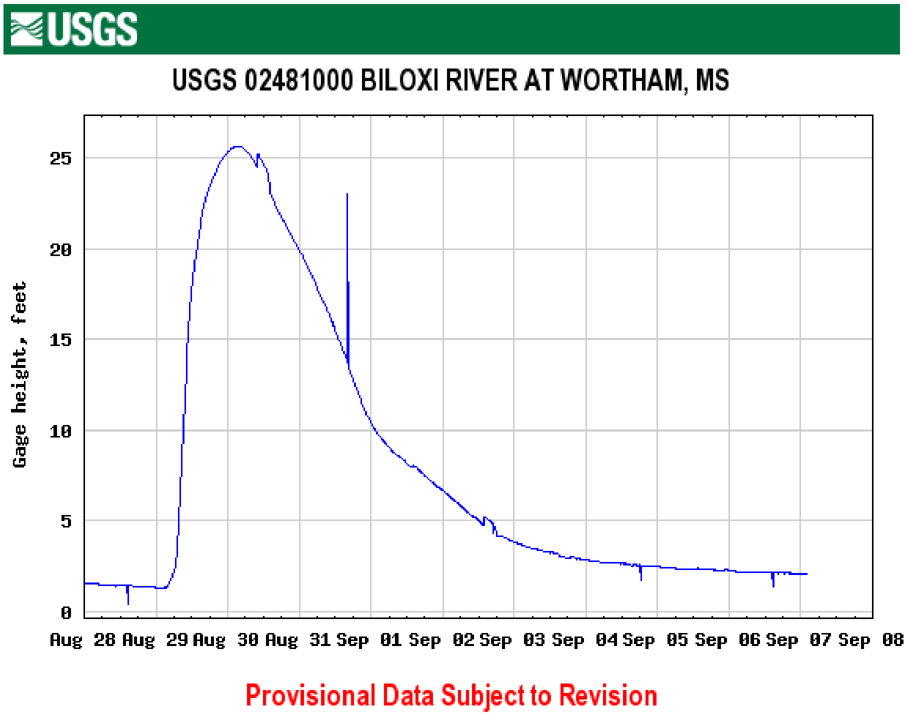


Figure 4. USGS River Gauge Data Showing Affects of Katrina's Storm Surge, Rainfall, and Levee Breaks, at Landon, New Orleans, and Wortham.

2.3 Rainfall Data

The rainfall amounts from Katrina, though rather high in some places, were not the main impact of the storm. The table below shows the preliminary storm totals (in inches) for the period affected by Katrina (August 24-30, 2005), for locations with at least six inches of rain. The data were provided by NOAA's Climate Prediction Center. Please note that due to the affects of the storm, some totals are incomplete, and many stations along the immediate Gulf coast are not listed for this reason.

STATION NAME	ID	STATE	LAT	LON	RAINFALL
RED_BAY_12_NNE	CCTA1	AL	34.55	-87.99	6.6
PERRINE_5_WSW	PRRF1	FL	25.58	-80.44	16.3
HOMESTEAD	HST	FL	25.48	-80.38	14.6
HOMESTEAD_5_W	HGAF1	FL	25.48	-80.56	14.4
FLORIDA_CITY_8_SSW	SDAF1	FL	25.33	-80.53	12.3
CUTLER_RIDGE_3_SSE	BCPF1	FL	25.54	-80.33	11.1
KEY_WEST	EYW	FL	24.56	-81.76	10.4
CUTLER_RIDGE_3_NE	CTRF1	FL	25.61	-80.31	9.7
MARATHON	MTH	FL	24.73	-81.05	9.7
MIAMI	TMB	FL	25.65	-80.43	9.6
RICHMOND_HEIGHTS_13_W	CHKF1	FL	25.63	-80.58	9.1
SWEETWATER_14_WSW	SHAF1	FL	25.69	-80.63	8.6
PORT_SALERNO_9_WSW	PTSF1	FL	27.09	-80.33	6.6
HOMESTEAD_24_NW	ENPF1	FL	25.61	-80.85	6.1

CUTLER_RIDGE_4_S	BBBF1	FL	25.52	-80.35	6.0
MOUNT_VERNON	MTVI3	IN	37.95	-87.88	7.6
POSEYVILLE	POSI3	IN	38.17	-87.78	6.9
HOPKINSVILLE_4_SW	HOPK2	KY	36.85	-87.55	11.9
COBB	CBBK2	KY	36.98	-87.78	9.1
FINNEY	BRRK2	KY	36.90	-86.13	8.7
ABERDEEN	ABEK2	KY	37.23	-86.68	7.2
BARDSTOWN	BTNK2	KY	37.80	-85.47	7.1
BOWLING_GREEN	BWG	KY	36.96	-86.42	7.1
DAM_49_UNION	UNWK2	KY	37.80	-87.98	7.1
NOLIN	NOLK2	KY	37.28	-86.25	7.0
BOSTON_6_SW	BOSK2	KY	37.75	-85.75	6.5
PROVIDENCE	PDNK2	KY	37.40	-87.77	6.5
BROOKSVILLE_2_SW	PWVK2	KY	38.65	-84.10	6.1
BIG_BRANCH		LA	30.55	-89.93	14.8
NEW_ORLEANS	NORL1	LA	29.93	-90.14	13.6
LAPLACE_5_NE	WSLL1	LA	30.10	-90.42	12.9
HAMMOND_5_E	ROBL1	LA	30.51	-90.36	11.9
NATALBANY		LA	30.55	-90.48	10.5
BUSH	BSHL1	LA	30.63	-89.90	10.3
PEARL_RIVER	PERL1	LA	30.39	-89.74	9.8
KENNER		LA	30.13	-90.23	9.7
COVINGTON	CVEL1	LA	30.48	-90.09	9.6
COVINGTON	CUSL1	LA	30.49	-90.17	9.6
VENICE	VNCL1	LA	29.28	-89.35	8.8
VENICE	BVE	LA	29.33	-89.42	8.8
SLIDELL_10_SSW	LIBL1	LA	30.14	-89.86	7.4
NEW_ORLEANS	MSY	LA	29.99	-90.26	7.2
COVINGTON		LA	30.48	-90.11	7.2
FRANKLINTON	FRNL1	LA	30.84	-90.16	7.1
DULAC_5_E	PCDL1	LA	29.39	-90.62	6.8
YCLOSKEY	BLYL1	LA	29.84	-89.69	6.2
COVINGTON_7_NW	CGSL1	LA	30.56	-90.15	6.0
NECAISE_1_N	NNHM6	MS	30.62	-89.41	10.1
HANCOCK		MS	30.39	-89.47	9.8
TROY_2_SE	TROM6	MS	34.09	-88.86	8.6
SARAH_1_W	SARM6	MS	34.58	-90.22	8.5
NOXAPATER_1_N	NXPM6	MS	33.02	-89.05	8.3
COLUMBIA_6_WSW	RMAM6	MS	31.21	-89.92	8.2
IUKA_5_S	IKAM6	MS	34.73	-88.18	8.1
CAESAR_3_WSW	CREM6	MS	30.57	-89.59	7.8
WIGGINS_6_E	BLCM6	MS	30.85	-89.03	7.6
HOLCUT	HCTM6	MS	34.73	-88.30	7.5
ACKERMAN_3_SE	TNFM6	MS	33.28	-89.14	7.5
HATTIESBURG	HBG	MS	31.27	-89.25	7.3
KOSCIUSKO	KOSM6	MS	33.05	-89.60	6.9
BROOKLYN_1_SW	BKNM6	MS	31.05	-89.20	6.8
KOSCIUSKO_13_SE	KSOM6	MS	32.98	-89.39	6.8
CONEHATTA		MS	32.46	-89.27	6.8
PHILADELPHIA_5_N	PLAM6	MS	32.84	-89.10	6.7

FOREST_7_N	FSTM6	MS	32.31	-89.49	6.5
PHILADELPHIA_3_SSE	RNEM6	MS	32.73	-89.10	6.5
YAZOO_CITY_5_NNE	YAZM6	MS	32.90	-90.38	6.5
YAZOO_CITY		MS	32.86	-90.41	6.5
BRUCE_2_W	BRUM6	MS	34.00	-89.37	6.3
DENNIS_6_WSW	DNNM6	MS	34.52	-88.32	6.2
WIGGINS_13_E	WGAM6	MS	30.85	-88.91	6.2
ABERDEEN	ABEM6	MS	33.83	-88.52	6.2
ARKABUTLA	ARKM6	MS	34.76	-90.12	6.2
EDINBURG	ENBM6	MS	32.80	-89.33	6.1
SANFORD	OKCM6	MS	31.49	-89.43	6.1
LAUREL_17_SE	LAUM6	MS	31.53	-88.89	6.0
THREE_RIVERS	PCBM6	MS	30.58	-88.57	6.0
CORINTH	CORM6	MS	34.92	-88.52	6.0
BLACK_MOUNTAIN_10_NNE	MMTN7	NC	35.76	-82.27	7.6
NASHVILLE	NSHO1	OH	40.61	-82.16	6.5
PHARISBURG	PBGO1	OH	40.35	-83.30	6.2
NEWARK	NWKO1	OH	40.05	-82.39	6.0
GEORGETOWN_2_NE	BCAO1	OH	38.88	-83.89	6.0
MASTEN_1_S	MASP1	PA	41.50	-76.82	6.0
OBION_2_SW	OBNT1	TN	36.24	-89.22	7.3
FAIRVIEW	FBNT1	TN	35.99	-87.12	6.9
WHITE_HOUSE_1_S	WHST1	TN	36.45	-86.65	6.4
DYERSBURG_10_W	MGLT1	TN	36.05	-89.56	6.4
BETHPAGE_1_S	BETT1	TN	36.47	-86.32	6.3
SPRINGFIELD_3_SE	SPRT1	TN	36.47	-86.83	6.3
COLLINWOOD	CLLT1	TN	35.17	-87.75	6.2
BOGOTA	BOGT1	TN	36.13	-89.43	6.1
ORLINDA	ODAT1	TN	36.60	-86.70	6.0
WINFIELD	WINW2	WV	38.53	-81.92	6.0

Figure 5 from NOAA's Climate Prediction Center provides a general picture of the rainfall amounts. Heaviest rainfall occurred in southeast Louisiana, then across parts of Mississippi, western Tennessee, and western Kentucky.

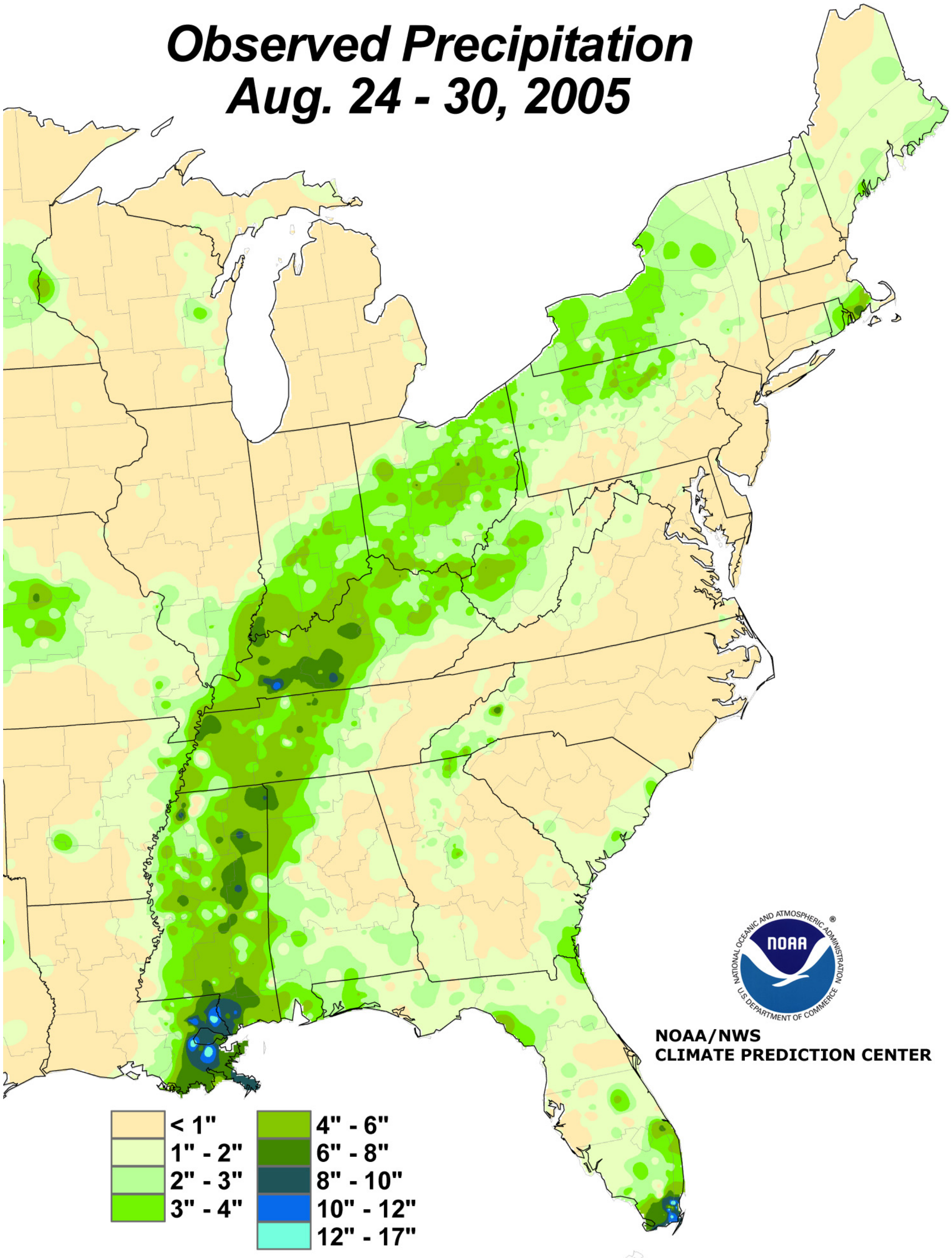


Figure 5. Preliminary Estimate of Rainfall Amounts Associated with Katrina.

2.4 High Winds

Very high winds occurred along a rather large swath in Katrina's path, due to the size of the storm, with highest winds in the eyewall near landfall, especially in the right-front quadrant. However, due to the severe affects of the storm, many reporting stations in the areas of highest winds did not observe/report observations during the time of maximum winds. NEXRAD radial velocity data indicated peak winds near the surface of around 140 mph in the eyewall at time of landfall. The tables below show the peak wind gusts recorded by land stations (first table) along with Coastal Marine (CMAN) and buoy stations (second table), for locations which recorded speeds of at least 60 mph. Figure 6 provides a map of the estimated maximum wind gusts.

Wind Gust (mph)	Station ID	Station Name	State
83	MOB	MOBILE/BATES FIELD	AL
79	BFM	MOBILE DOWNTOWN	AL
82	FLL	FT LAUDERDALE/HOLLY	FL
80	TMB	MIAMI/KENDALL-TAMIA	FL
78	MIA	MIAMI INTL AIRPORT	FL
74	EYW	KEY WEST INTL ARPT	FL
71	NPA	PENSACOLA NAS	FL
69	PNS	PENSACOLA REGIONAL	FL
68	OPF	MIAMI/OPA LOCKA	FL
66	FXE	FORT LAUDERDALE	FL
64	BCT	BOCA RATON AIRPORT	FL
64	PMP	POMPANO BEACH	FL
60	HRT	HURLBURT FIELD (AF)	FL
86	NEW	NEW ORLEANS/LAKEFRO	LA
90	BIX	KEESLER AFB/BILOXI	MS
80	NMM	MERIDIAN NAS/MCCAIN	MS

Wind Gust (mph)	CMAN or Buoy ID	Lat	Lon
114	GDIL1	29.27	-89.95
105	DRYF1	24.63	-82.86
101	BURL1	28.89	-89.43
98	DPIA1	30.25	-88.06
89	42003	26.00	-85.90
83	42040	29.20	-88.20
80	42007	30.10	-88.80
79	FWYF1	25.59	-80.09
79	SMKF1	24.62	-81.11
79	TAML1	29.19	-90.66
77	MLRF1	25.01	-80.37
77	SANF1	24.45	-81.87
72	42001	25.80	-89.70
69	LONF1	24.84	-80.86
62	LUML1	29.25	-90.66

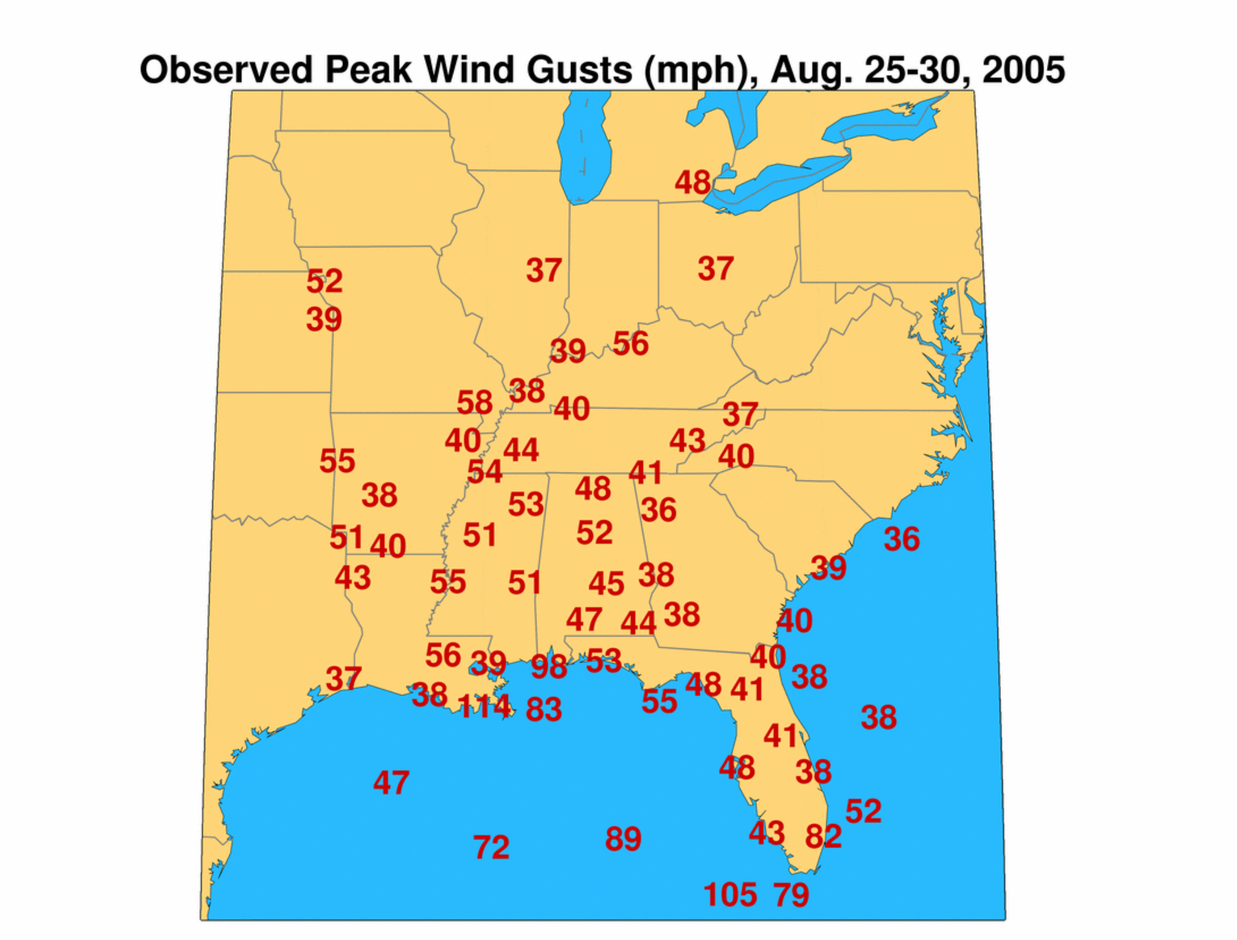


Figure 6. Preliminary Observations for Maximum Wind Gusts Associated with Katrina.

3. Contributing Factors

A number of factors contributed to making Katrina a strong Category 5 hurricane (though weakening to Category 3 just prior to landfall). Sea surface temperatures (SST) in the Gulf of Mexico were one to two degrees Celsius above normal (see Figure 7), and the warm temperatures extended to a considerable depth through the upper ocean layer. Also, Katrina crossed the "loop current" (belt of even warmer water), during which time explosive intensification occurred. The temperature of the ocean surface is a critical element in the formation and strength of hurricanes. As shown in Figure 8, there has been an overall increasing trend in July-September Atlantic and Gulf of Mexico SSTs during the past 100 years marked by two distinct periods of increasing temperatures (1910-1945; 1976-present). This pattern is similar to that observed across global land and ocean surfaces.

Also, vertical wind shear was less than normal, which allowed for the storm to develop quickly. Figure 9 illustrates the wind shear in the area, using the 200 mb to 850 mb zonal shear anomaly for the month of August 2005, with negative zonal shear anomalies.

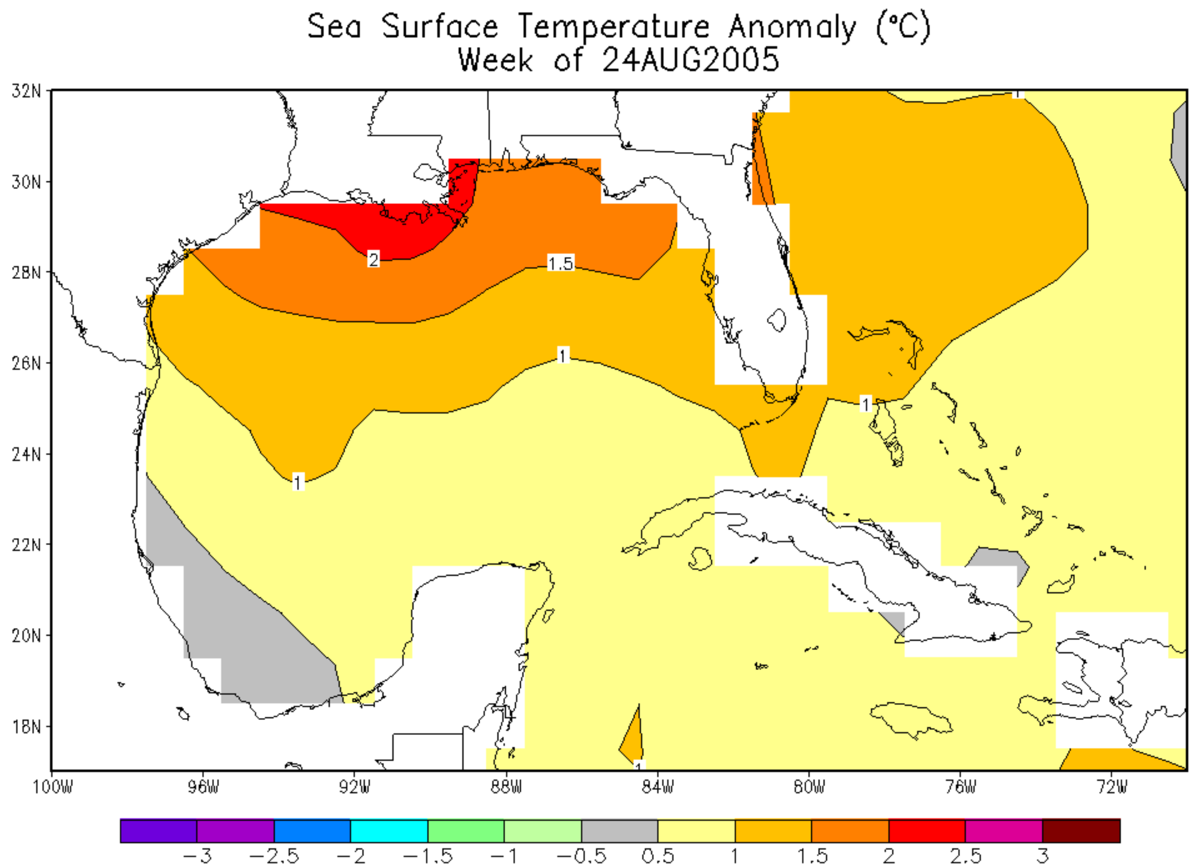
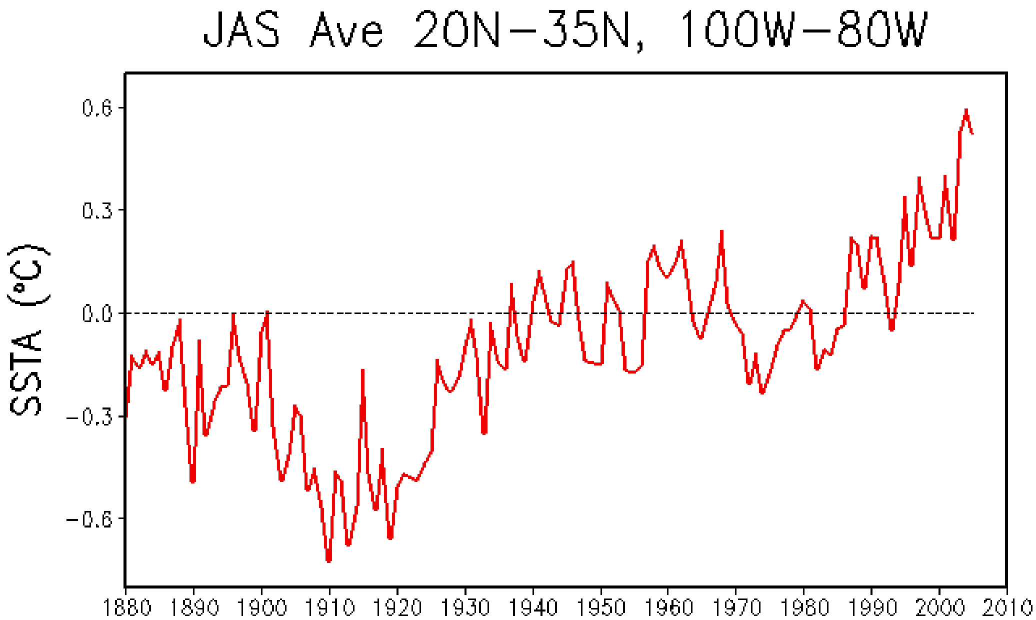


Figure 7. Gulf of Mexico SST Anomaly (Departure from Normal) During Katrina's Development.



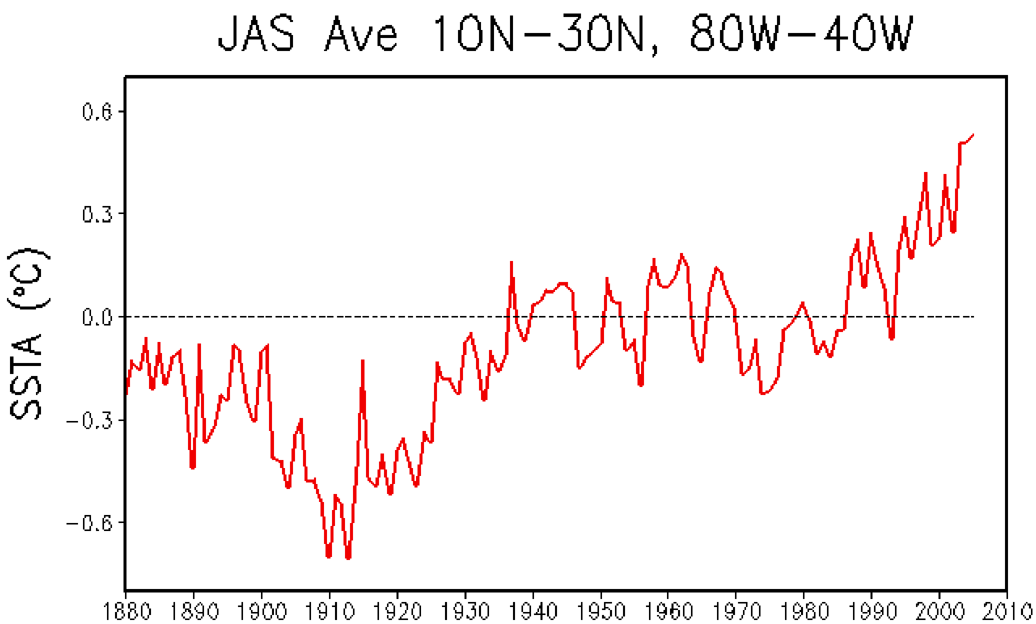


Figure 8. July – September SST Anomalies for 1880-Present, for the Gulf of Mexico (top graph) and Atlantic (bottom graph), (Smith and Reynolds, 2004 with updates).

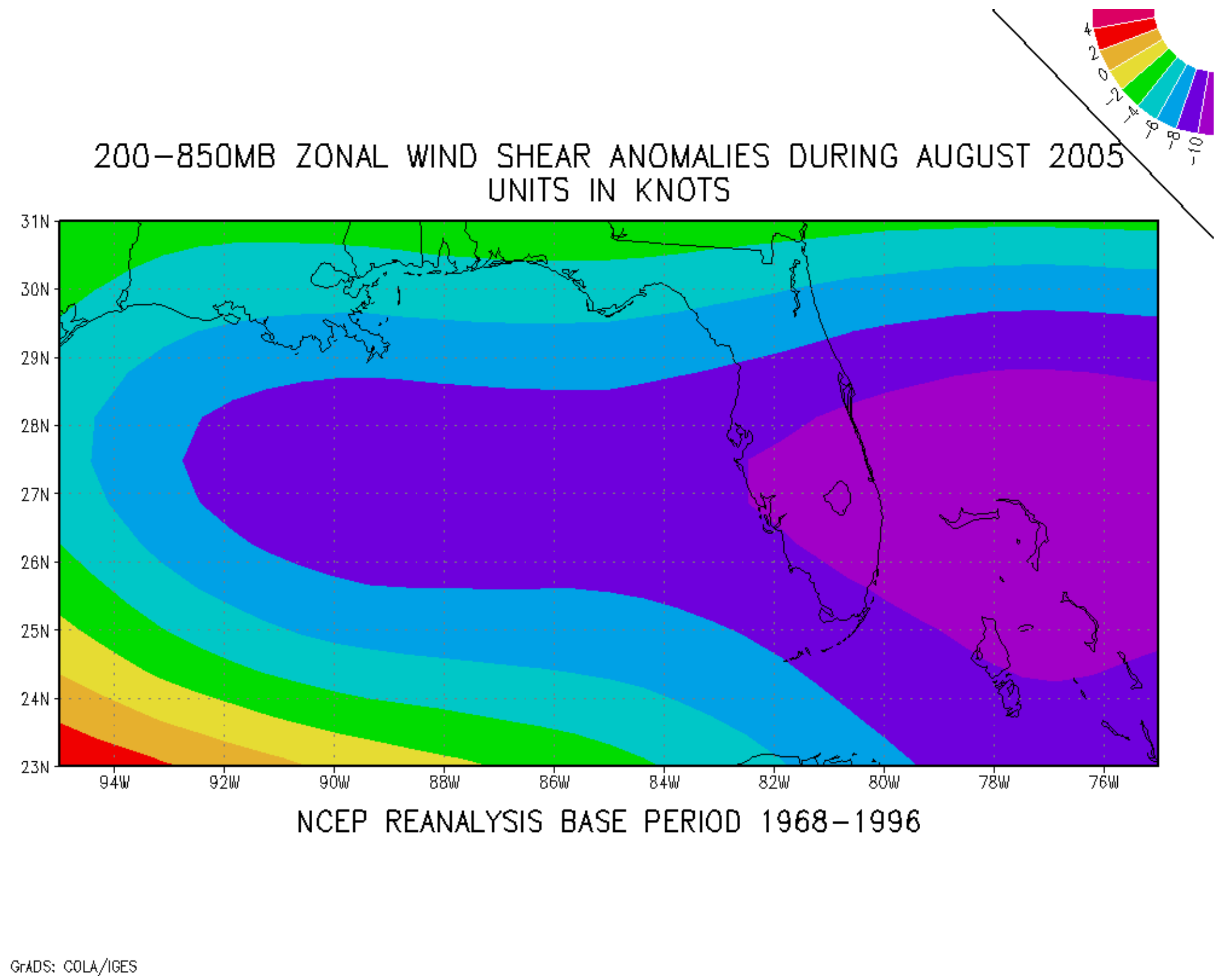


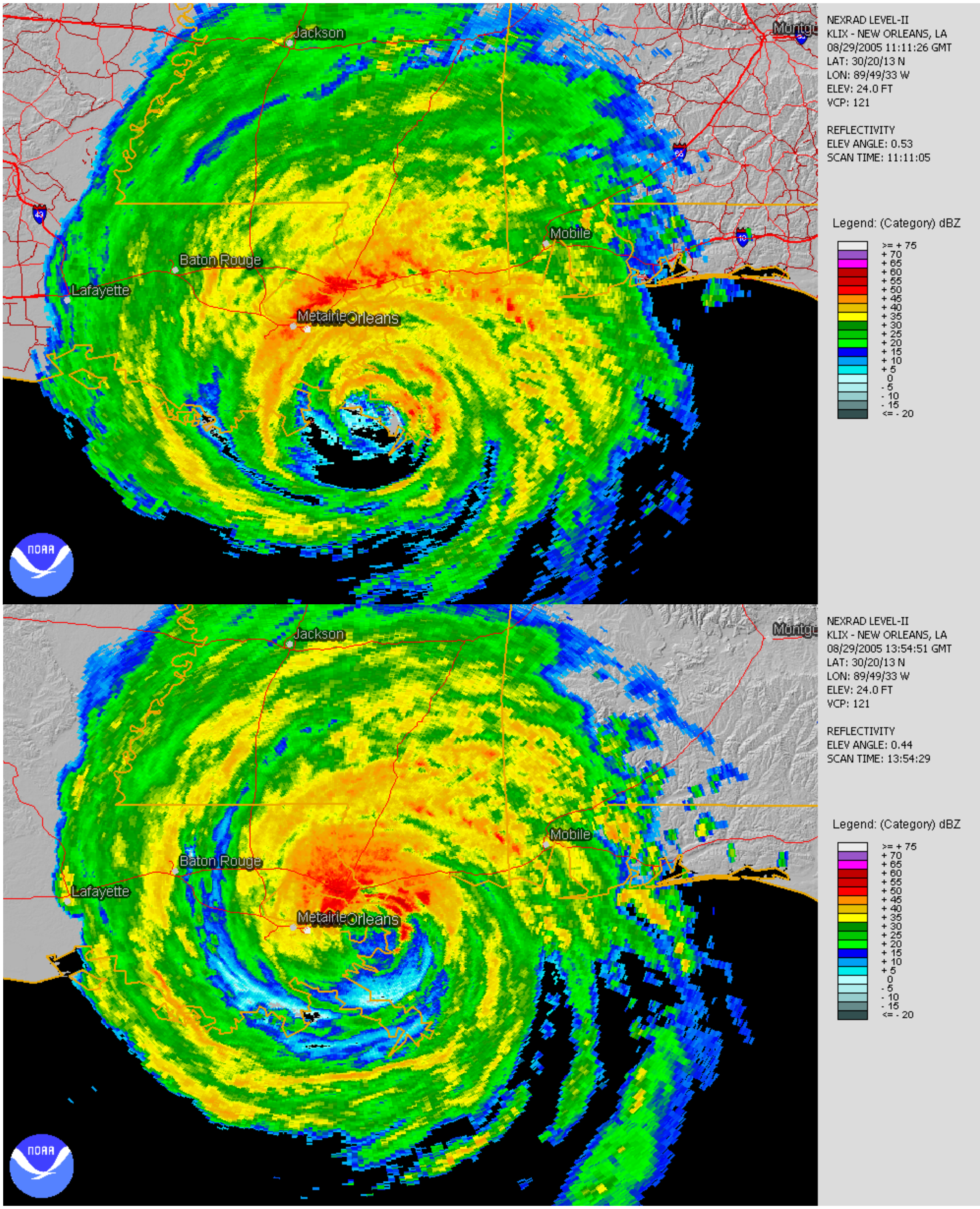
Figure 9. 200 mb to 850 mb Zonal Wind Shear Anomaly for August 2005.

4. Views Via Remote Sensing

Satellite and radar images of Katrina provide an excellent view of the storm from space and as seen by local NEXRAD sites along the Gulf coast. Figures 10-13 show the very well organized nature of the storm. These images include NEXRAD reflectivity from New Orleans and Mobile, along with NOAA's Geostationary Operational Environmental Satellites (GOES) and Polar-orbiting Operational Environmental Satellites (POES) images.

The heaviest bands of rainfall shown on radar coincide with the strongest wind gusts at the surface, as the heavy rain and thunderstorms transfer momentum from the level of highest winds (above the surface) down closer to the surface. Although Katrina weakened somewhat just prior to landfall, the height and extent of the storm surge was not affected much by this trend, as the "buildup" of the ocean surface not only relates to storm strength but storm duration and size, along with the shape and ocean water depth along the coastline.

Finally, Figure 14 shows a satellite comparison of Camille vs Katrina, which provides a good perspective of Katrina's large size.



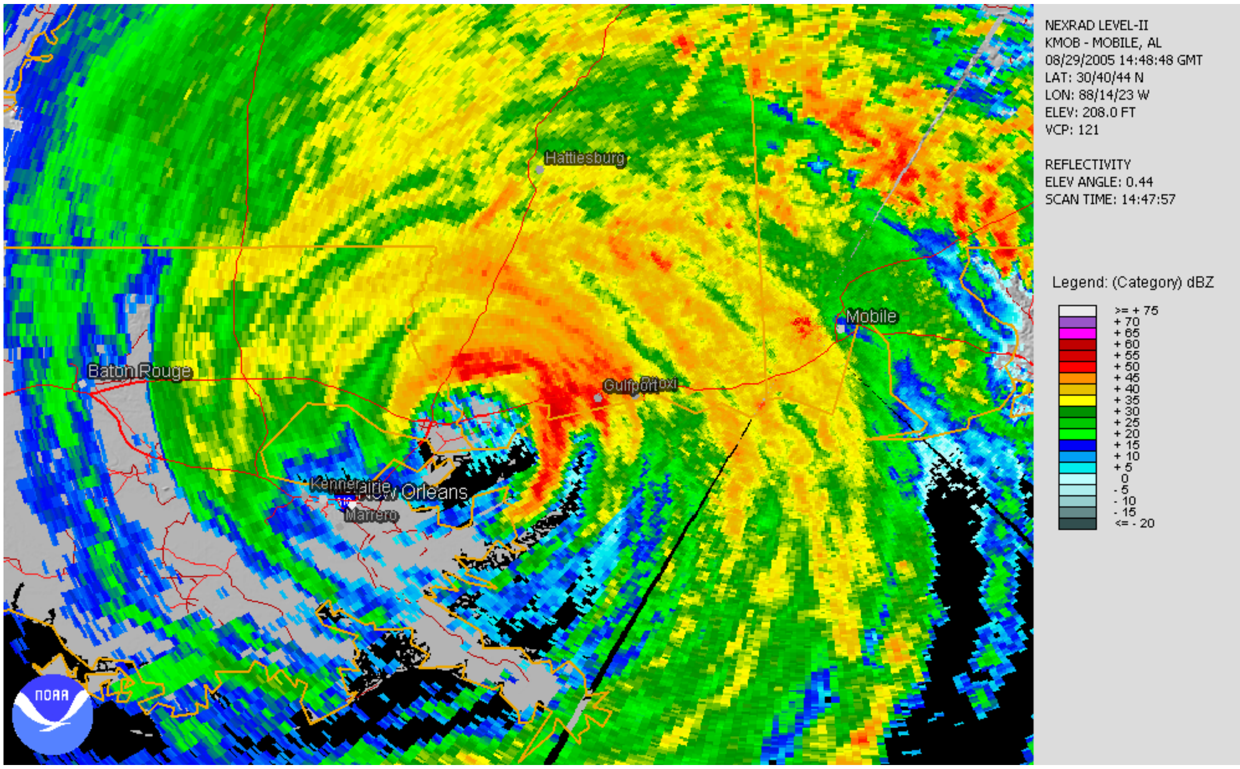


Figure 10. NEXRAD Images Prior to, During, and After Landfall.

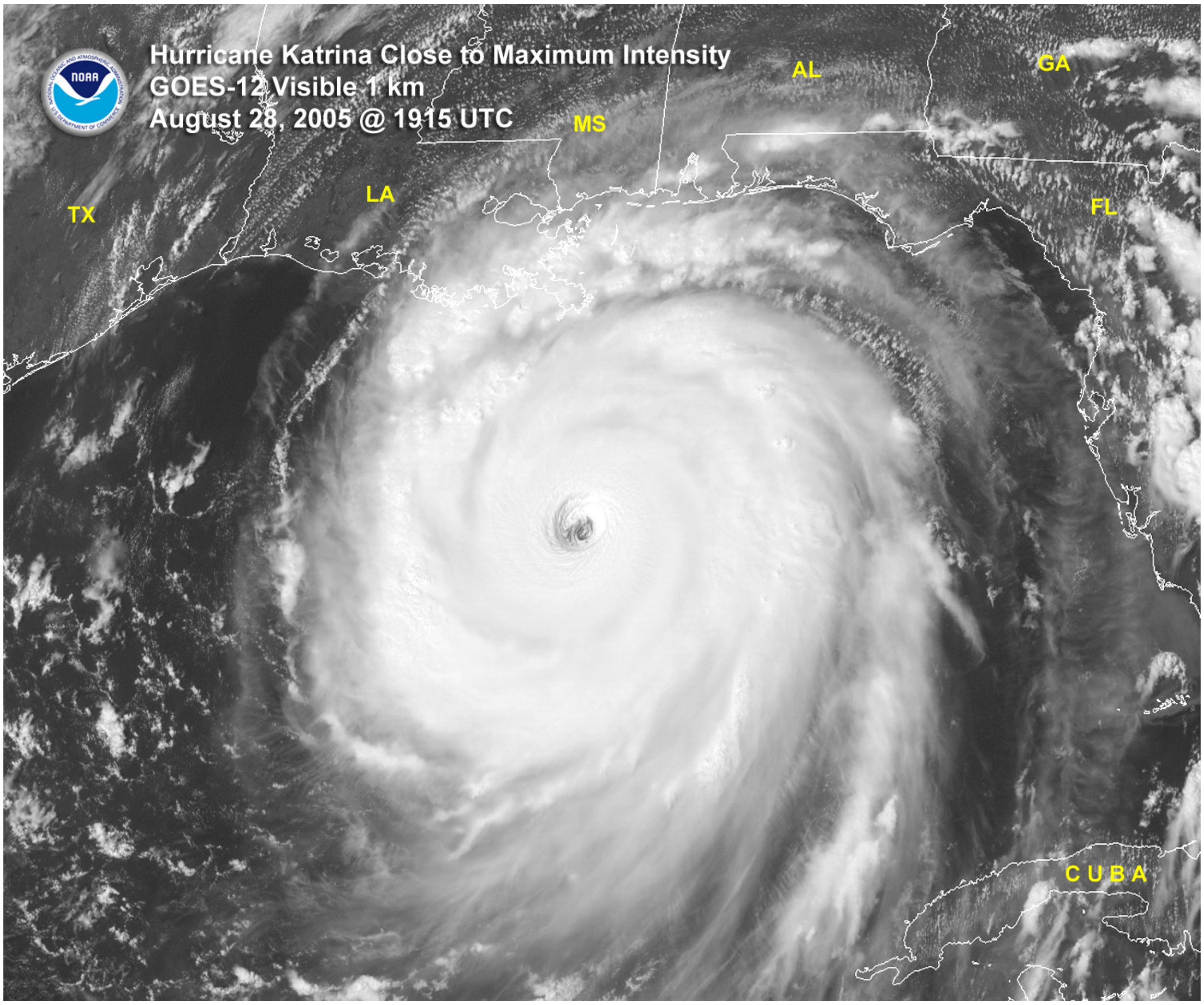


Figure 11. GOES-12 Visible Image of Katrina.

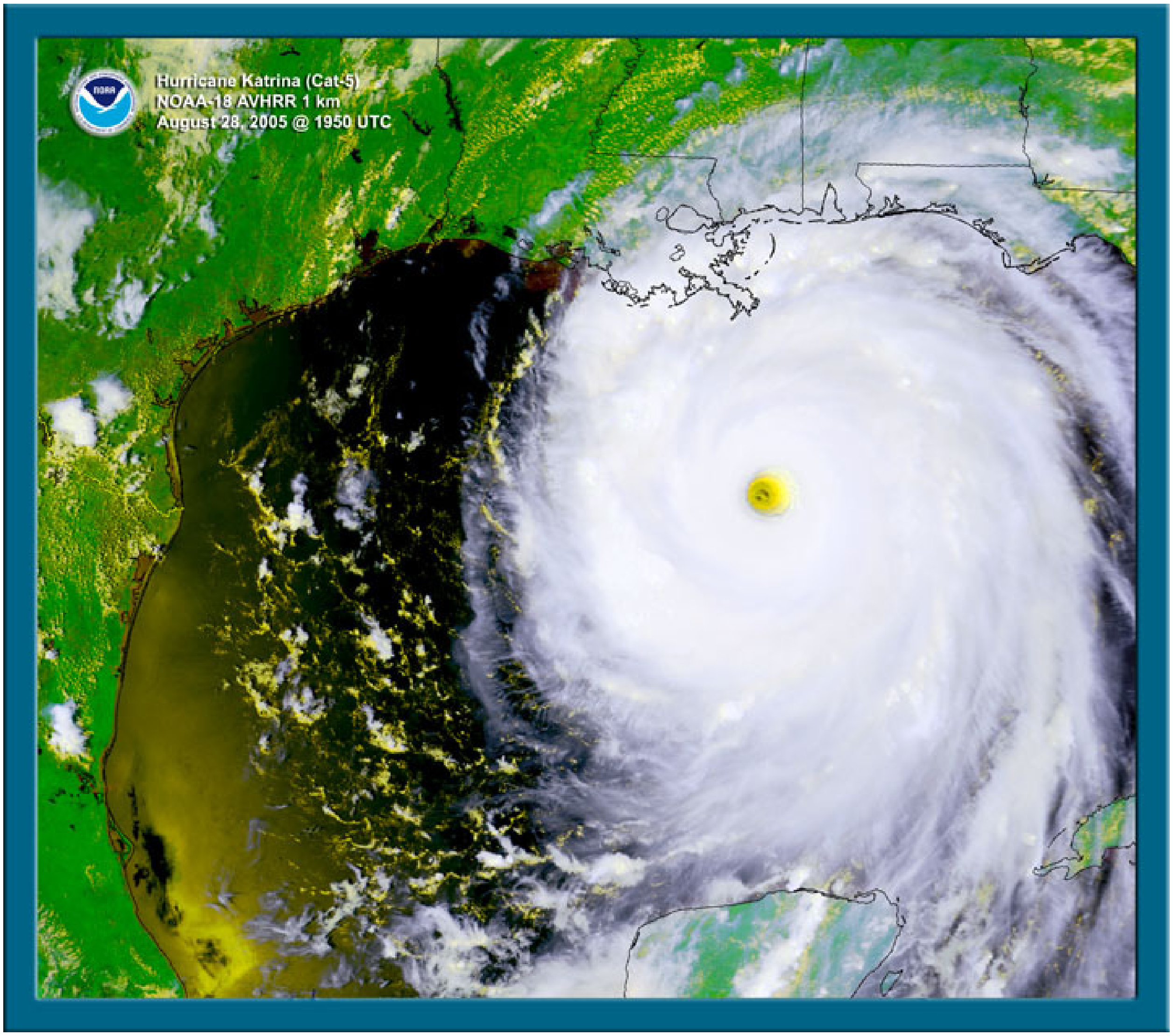


Figure 12. NOAA-18 (Polar Orbiter) Image of Katrina.

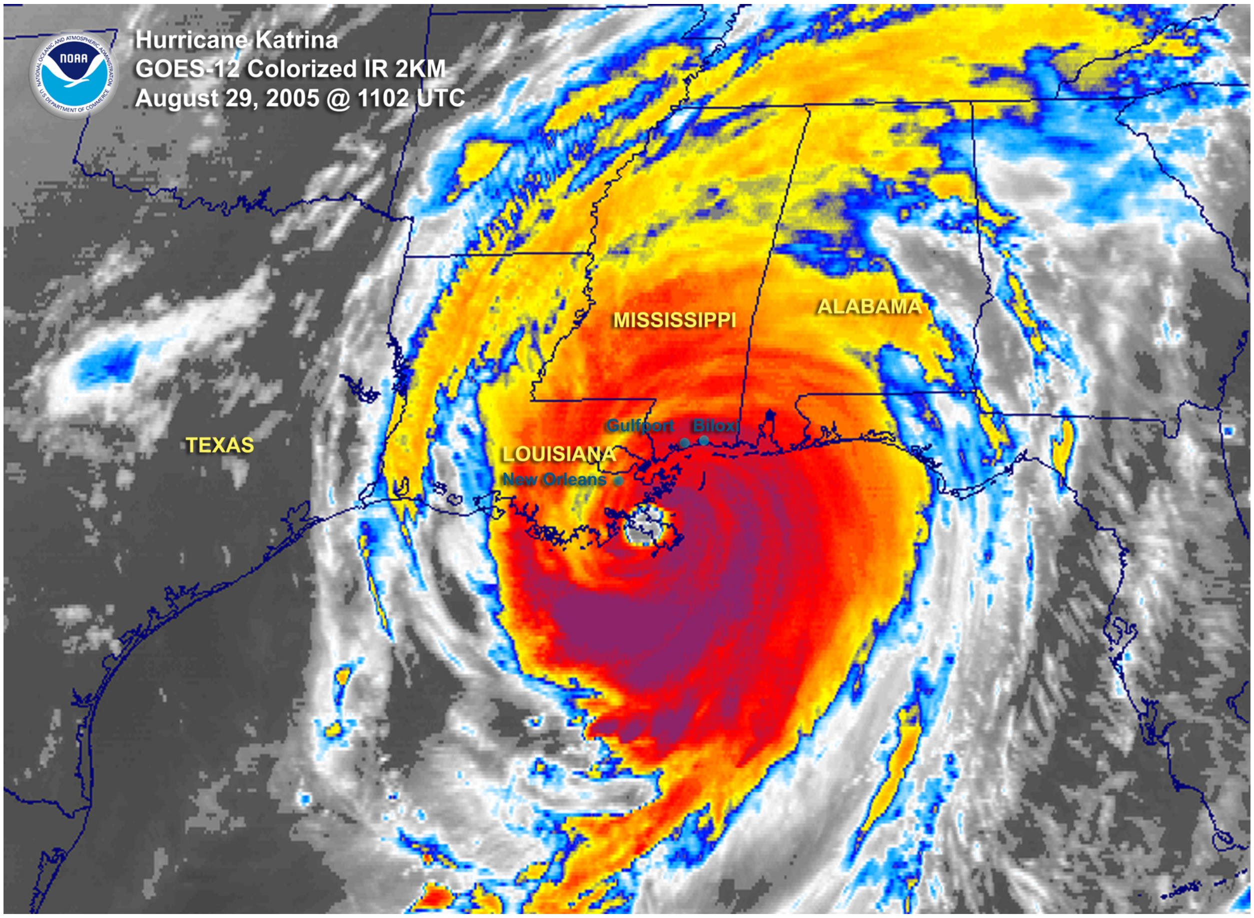


Figure 13. GOES-12 Colorized Infrared Image of Katrina.

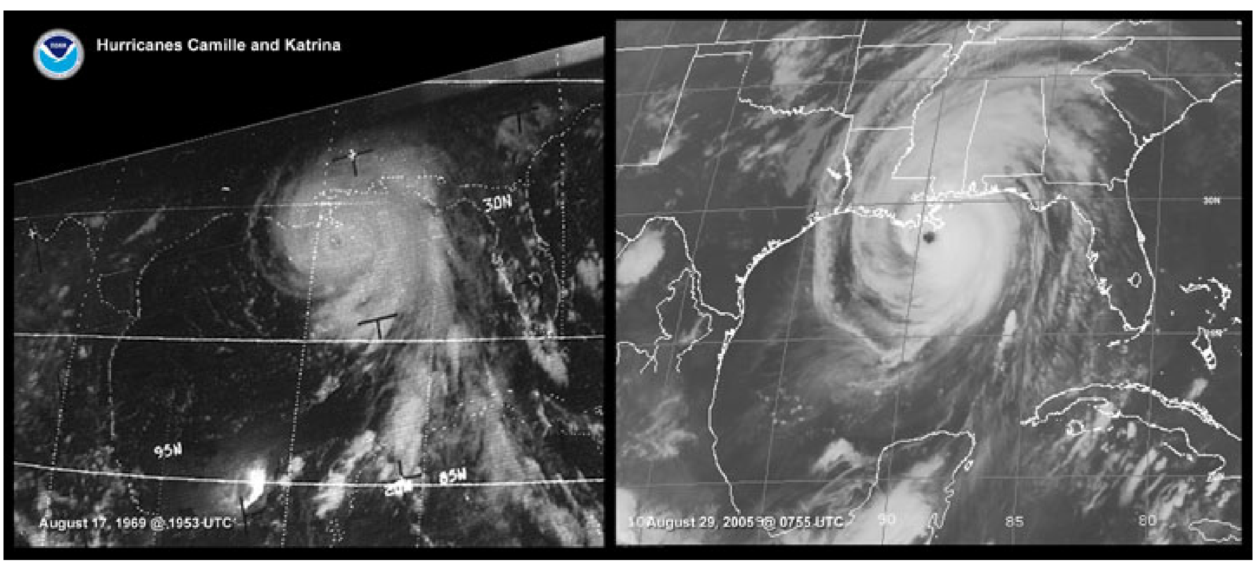


Figure 14. Side-by-side Images of Camille (left) vs Katrina (right).

5. Historical Perspective

5.1 Previous Hurricanes

Hurricane Katrina, while likely being the most costly hurricane on record, was not the most intense U.S. landfalling hurricane. Hurricane Camille, which followed a similar path to Katrina, was a much stronger storm when it made landfall along the Mississippi coast in 1969. The most costly hurricane to strike the U.S. prior to Katrina was Hurricane Andrew, which made landfall in southern Florida in 1992. These storms, as well as 4 major hurricanes in 2004 that led to the most costly hurricane season on record at the time, are briefly discussed below. Landfalling hurricanes in 2004 created approximately $45 billion in estimated losses in the U.S., along with 168 fatalities from direct and indirect causes related to the hurricanes.

Hurricane Camille: Hurricane Camille ravaged the Mississippi coastline when it made landfall on the night of August 17, 1969 with winds approaching 190 mph and a storm surge of 24.2 feet. The storm was an extremely strong Category 5 hurricane which caused 144 deaths in Mississippi and Louisiana and another 112 flood-related deaths in Virginia where up to 27 inches of rain fell within about 8 hours. Total damage was $1.42 billion in 1969, which equates to approximately $8.9 billion when adjusted for inflation. Only one hurricane to make landfall in the U.S. has had wind speeds estimated to be higher: the Labor Day hurricane of 1935 that struck the Florida Keys with sustained winds approaching 200 mph. Although Hurricane Camille took a path similar to Hurricane Katrina, and its estimated maximum wind speeds were greater than those of Katrina, the extent of hurricane force winds was much less, stretching only 75 miles from the center of the storm, as compared to well over 100 miles for Katrina. The smaller size of this category 5 hurricane resulted in damage that was more localized than that from Katrina. See Figure 14 for satellite images of Katrina vs Camille.

Hurricane Andrew: Prior to 2005, the most costly hurricane to strike the U.S. was Hurricane Andrew, which made landfall in southern Florida south of Miami on August 24, 1992. It caused $25 billion damage in Florida and was the most expensive of all natural disasters in United States history until Hurricane Katrina. Total damages equate to approximately $43.7 billion when adjusted for inflation. Maximum sustained winds at the time of landfall were estimated at 165 mph, a category 5 storm. The central pressure was 922 millibars, which is the third lowest on record for a landfalling hurricane in the U.S (after the 1935 Florida Keys Labor Day storm and Hurricane Camille in 1969). After striking Florida, Andrew moved northwest across the Gulf of Mexico to make a second landfall in a sparsely populated area of south-central Louisiana as a Category 3 storm.

Hurricane Charley: In August 2004, this Category 4 hurricane made landfall in southwest Florida, resulting in major wind and some storm surge damage in Florida, along with some damage in the states of South Carolina and North Carolina. The total damages exceeded $15 billion, with at least 35 deaths.

Hurricane Frances: In September 2004, this Category 2 hurricane made landfall in east-central Florida, causing significant wind, storm surge, and flooding damage in Florida, along with considerable flood damage in the states of Georgia, South Carolina, North Carolina, and New York, due to 5 to 15-inch rains. The total damages exceeded $9 billion, with at least 48 deaths.

Hurricane Ivan: In September 2004, this Category 3 hurricane made landfall on the Gulf coast of Alabama, with significant wind, storm surge, and flooding damage in coastal Alabama and the Florida panhandle, along with wind/flood damage in the states of Georgia, Mississippi, Louisiana, South Carolina, North Carolina, Virginia, West Virginia, Maryland, Tennessee, Kentucky, Ohio, Delaware, New Jersey, Pennsylvania, and New York. The estimated damages exceeded $14 billion, and there were at least 57 deaths.

Hurricane Jeanne: In September 2004, this Category 3 hurricane made landfall in east-central Florida, causing considerable wind, storm surge, and flooding damage in Florida, with some flood damage also in the states of Georgia, South Carolina, North Carolina, Virginia, Maryland, Delaware, New Jersey, Pennsylvania, and New York, along with Puerto Rico. The estimated damages exceeded $7 billion, and there were at least 28 deaths.

For additional information and statistics on historic storms, see:
- National Hurricane Center – http://www.nhc.noaa.gov/pastall.shtml
- National Climatic Data Center -- http://www.ncdc.noaa.gov/oa/reports/billionz.html
- National Climatic Data Center -- http://www.ncdc.noaa.gov/oa/climate/severeweather/hurricanes.html

5.2 Hurricanes Along the Central Gulf Coast

The central Gulf Coast has been impacted by a large number of topical cyclones over the years. From 1722-2005, 45 hurricanes made landfall between Houma, LA and Mobile, AL (see table below). Literature sites additional storms prior to the 20th Century but little information is available to confirm these events (Ludlum, 1963; Sullivan, 1986; and Roth, 1998). The area has also felt the affects of several more hurricanes and tropical storms that have passed or made landfall nearby.

Hurricanes that have made landfall between Houma, LA and Mobile, AL, 1722 to 2005

Date	Category	Hurricane Name
September, 1722		
September, 1740 (Mid-month)		
September, 1740 (A week later)		
Fall, 1746		
August/September, 1772		
October, 1778		
August, 1779		
August, 1780		
August, 1794		
August, 1812		
July, 1819		
September, 1821		
August, 1831		
August, 1848		
August 19-30, 1852	Major Hurricane	
September 15-17, 1855	Major Hurricane	
September 15-18, 1859	Hurricane	
August 8-16, 1860	Major Hurricane	
September 11-16, 1860	Hurricane	

October 2-9, 1867	Hurricane	
July 30, 1870	Hurricane	
September 14-21, 1877	Hurricane	
October 9-22, 1887	Hurricane	
September 11-26, 1889	Hurricane	
September 27 – October 5, 1893	Major Hurricane	
August 2-18, 1901	2	
September 19-30, 1906	3	
September 10-21, 1909	4	
September 11-14, 1912	1	
September 22 – October 1, 1915	4	
June 29 – July 10, 1916	3	
August 26 – September 3, 1932	1	
September 4-21, 1947	3	
September 1-6, 1948	1	
August 20 – September 1, 1950	1	Baker
September 21- 30, 1956	2	Flossy
September 14-17, 1960	1	Ethel
August 26 – September 12, 1965	3	Betsy
August 14-22, 1969	5	Camille
July 9-16, 1979	1	Bob
August 29 – September 14, 1979	3	Frederic
August 27 – September 4, 1985	3	Elena
September 7-11, 1988	1	Florence
July 16-26, 1997	1	Danny
September 15 – October 1, 1998	1	Georges

5.3 Indices and Trends

The Accumulated Cyclone Energy (ACE) index is one method to describe trends in tropical cyclone activity. This index uses a combination of the tropical cyclone's duration in a particular ocean basin, along with the strength of each storm. Figure 15 shows the recent upward trend, which appears to be part of a long-term cycle in activity, with the 1950's-1960's also being an active period. Of course, during that time, there was much less commercial and residential development along our coastlines. Figures 16-17 show the number of tropical cyclones, number of hurricane-days, and number of days with hurricanes, from 1960 through 2005.

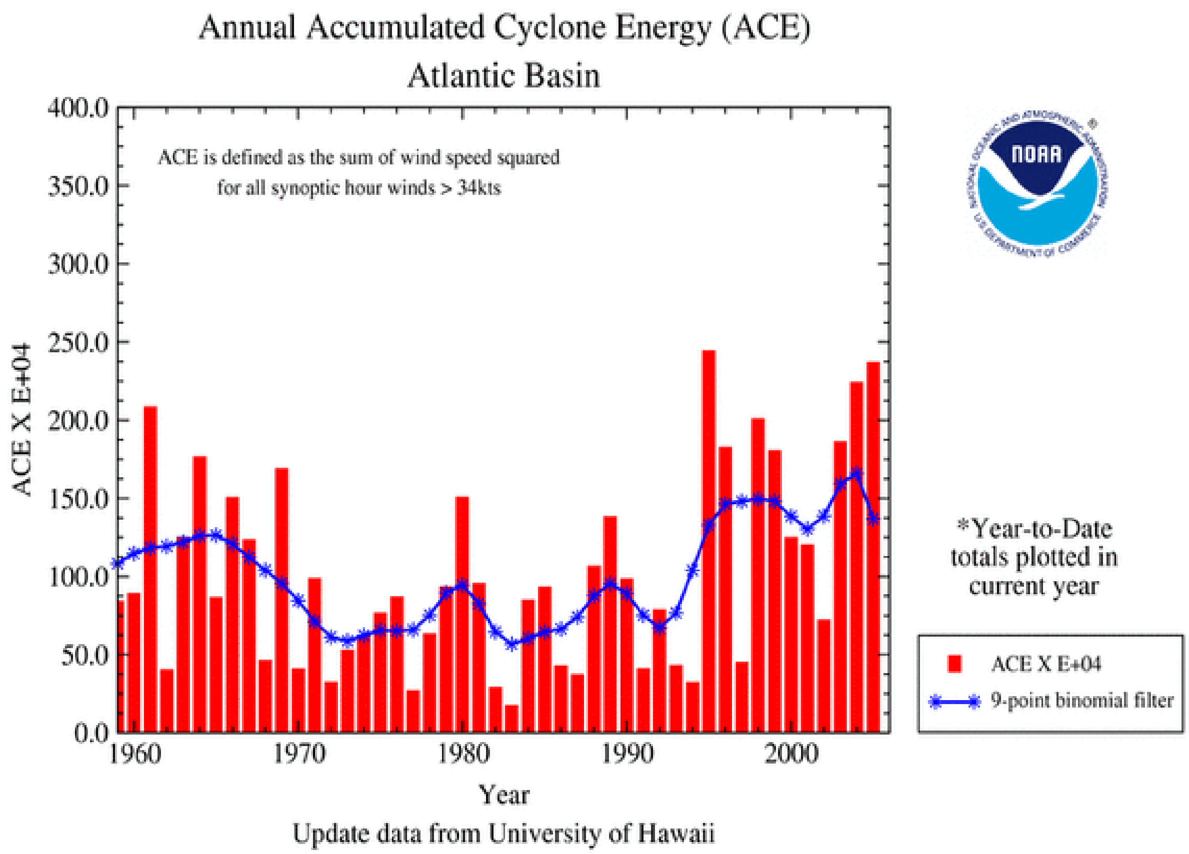


Figure 15. Accumulated Cyclone Energy (ACE) for 1960 through 2005.

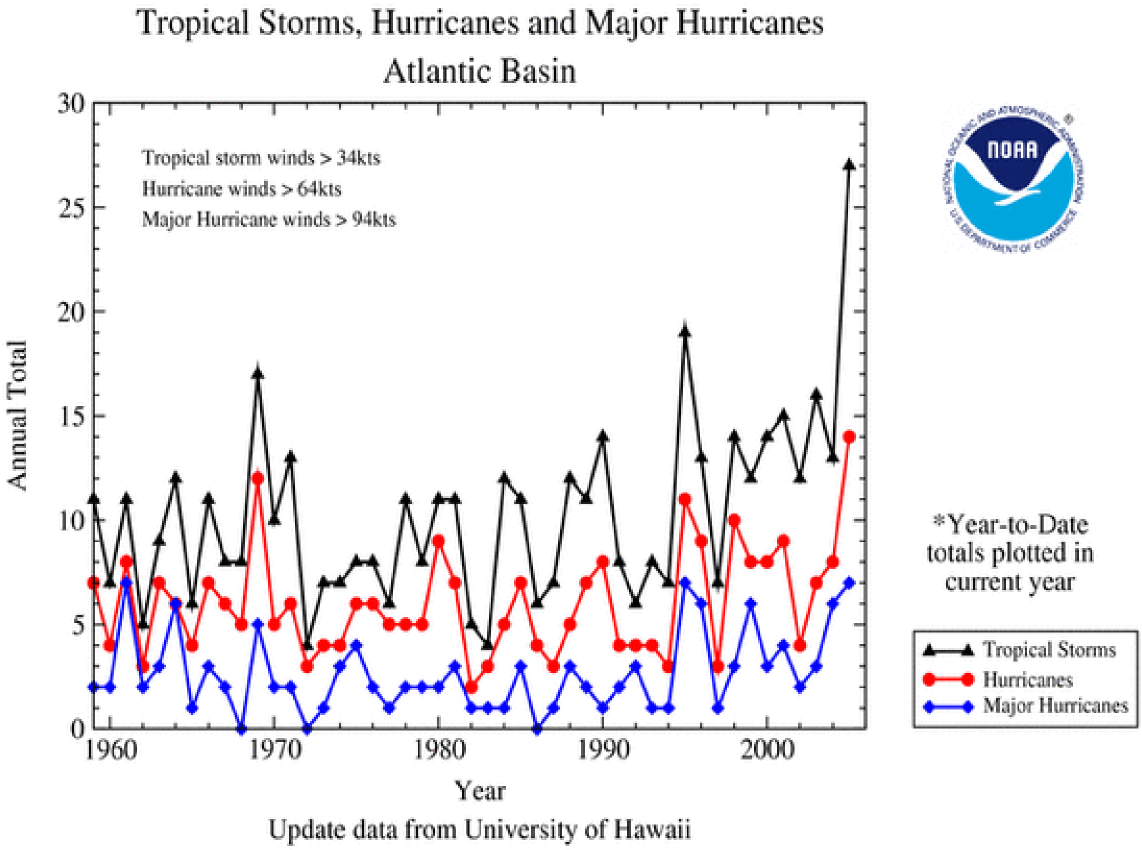


Figure 16. Number of Tropical Cyclones by Year for 1960 through 2005.

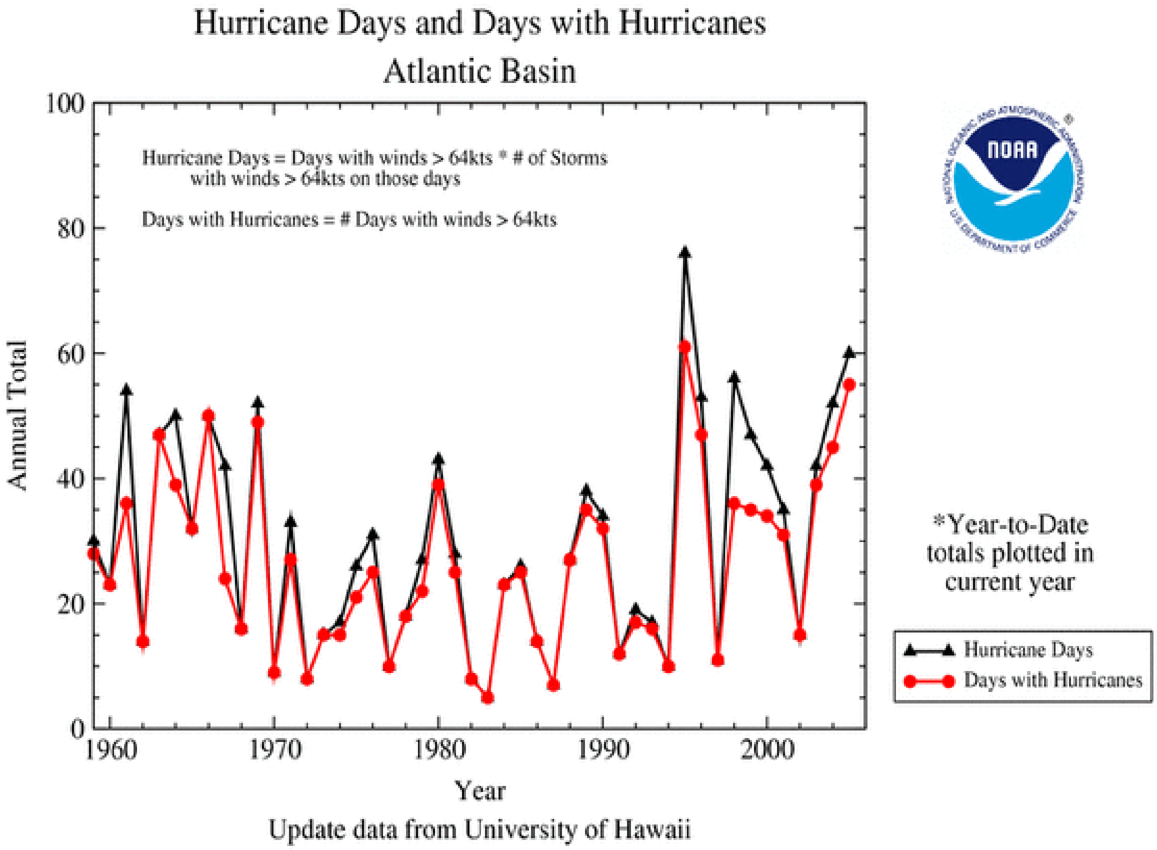


Figure 17. Number of Hurricane Days and Days with Hurricanes, 1960 through 2005.

6. Additional Resources

NWS Jackson, MS images of Katrina Damage: http://www.srh.noaa.gov/jan/katrina/
NWS Mobile/Pensacola images of Katrina Damage: http://www.srh.noaa.gov/mob/0805Katrina/
FEMA Photo Library: http://www.photolibrary.fema.gov/photolibrary/index.jsp
NOAA aerial photos of Katrina damage: http://www.noaanews.noaa.gov/stories2005/s2500.htm
NOAA hurricane hunter images of Katrina:
http://www.noaanews.noaa.gov/stories2005/s2496.htm
USGS photos and other information: http://coastal.er.usgs.gov/hurricanes/katrina/
National Hurricane Center – http://www.nhc.noaa.gov
National Climatic Data Center -- http://www.ncdc.noaa.gov/oa/reports/billionz.html
National Climatic Data Center --
http://www.ncdc.noaa.gov/oa/climate/severeweather/hurricanes.html

7. References

Ludlum, D.M. 1963. Early American Hurricanes, 1492-1870. Amer. Met. Soc. Boston, MA. 198 p.p.

NOAA, 1999. Tropical Cyclones of the North Atlantic Ocean, 1871-1998. Historical Climatology Series 6-2. National Climatic Data Center, Asheville, NC. 206 p.p.

NOAA, 2005. Track Maps, 1851- 2004. Atlantic Oceanographic and Meteorological Laboratory Reanalysis Project. [http://www.aoml.noaa.gov/hrd/hurdat/Track-Maps.htm]

NOAA, 2005. 1901-2003 United States Landfalling Hurricanes. National Climatic Data Center. [http://www.ncdc.noaa.gov/oa/climate/severeweather/hurricanes.html]

Roth, D. 1998. Louisiana Hurricanes. NOAA National Weather Service, Lake Charles, LA. [http://www.srh.noaa.gov/lch/research/lahur.htm]

Smith, T.M., and R.W. Reynolds, 2004: Improved extended reconstruction of SST (1854-1997). *Journal of climate*, 17 (12), 2466-2477.

Sullivan, C.L. 1986. Hurricanes of the Mississippi Gulf Coast, 1717 to Present. Gulf Publishing Company – The Sun Herald. 139 p.p.