Post Storm Data Acquisition
Aerial Wind Analysis and Damage Assessment
Hurricane Katrina

October 31, 2005

1. OVERVIEW

Katrina was the eleventh named storm, fourth hurricane, third major hurricane, and first category five hurricane of the 2005 Atlantic Hurricane Season. Katrina's 902 mb central pressure was the fifth lowest on record for the Atlantic basin. The estimated minimum central pressure of 920 mb at landfall, just south of Buras, Louisiana, is the third lowest landfall pressure on record for the United States. The estimated death toll from Katrina is 1242 making it the deadliest storm to hit the United States in 77 years. Katrina is expected to become the costliest natural disaster in United States history with estimated insured property loss in excess of $200 billion*.

Katrina formed from a tropical wave and became a tropical depression about 175 miles southeast of Nassau in the Bahamas on August 23. The following day, it strengthened to a tropical storm. Katrina moved northwestward through the Bahamas, and then turned westward toward South Florida and gradually strengthened. Katrina became a Category 1 hurricane and made landfall on the Miami-Dade/Broward county line in south Florida during the evening of August 25. Katrina moved southwestward across south Florida dumping over a foot of rain, toppling trees and power lines and damaging homes and businesses across south Florida. Katrina also brought heavy rains and sustained tropical storm force winds to portions of the Florida Keys. After crossing south Florida and entering the Gulf of Mexico, Katrina began to strengthen reaching Category 5 strength on August 28 about 250 miles south-southeast of the mouth of the Mississippi river. Katrina's winds reached their estimated peak intensity of 175 mph winds and the pressure fell to 902 mb, the fifth lowest pressure on record, later that day. Katrina turned to the northwest and then north making landfall in Plaquemines Parish, Louisiana just south of Buras with estimated minimum central pressure of 920 mb, the third lowest landfall pressure on record in the United States, and sustained winds of 140 mph winds, Category 4, at 6:10 AM CDT on August 29. Katrina continued northward and made its second landfall near the Louisiana/Mississippi border at 10:00 AM CDT with estimated maximum sustained winds of near 125 mph, Category 3 (Figure 2). Katrina weakened as it moved inland to the north-northeast but was still a hurricane 100 miles inland near Laurel, Mississippi. Katrina continued to weaken and became a tropical depression near Clarksville, Tennessee on August 30. By mid morning on August 31, Katrina transitioned to an extra-tropical low in upstate New York. Figure 1 shows the preliminary track and intensity of Katrina.

Katrina's impact along the central and eastern Gulf coast was enormous. The maximum storm tides (combination of storm surge and tidal surge) occurred along the southern Mississippi coast. The National Weather Service Weather Forecast Office (WFO) in Lake Charles, LA, which performed the survey for WFO New Orleans/Baton Rouge, LA, estimated a 30 foot (above MSL) storm tide at the Hancock, MS Emergency Operations Center and a 26 foot (above MSL) storm tide at Wortham, MS along the Biloxi River.

** The data contained in this report are preliminary and subject to change. Please refer to the Tropical Cyclone Report on Hurricane Katrina issued by the NOAA/NWS/NCEP Tropical Prediction Center/National Hurricane Center for official information on Katrina.*

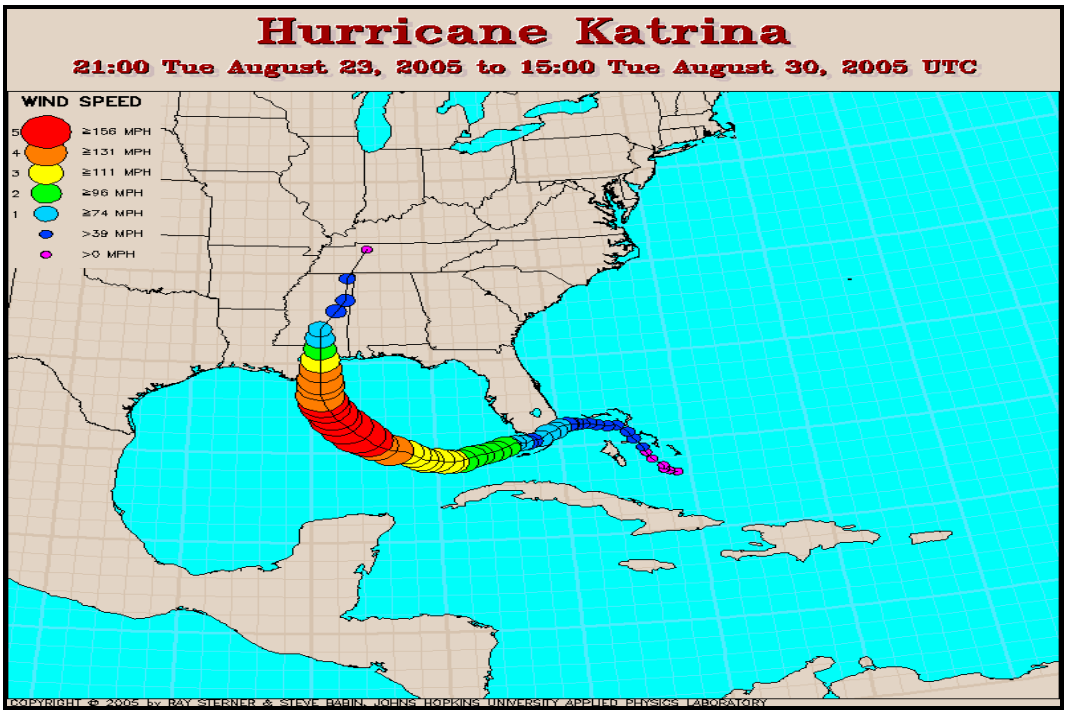

Figure 1. Path of Hurricane Katrina during the period August 23 – 30, 2005. Purple indicates tropical depression stage, dark blue tropical storm stage, light blue category 1 hurricane stage, green category 2, yellow category 3, orange category 4, and red category 5.

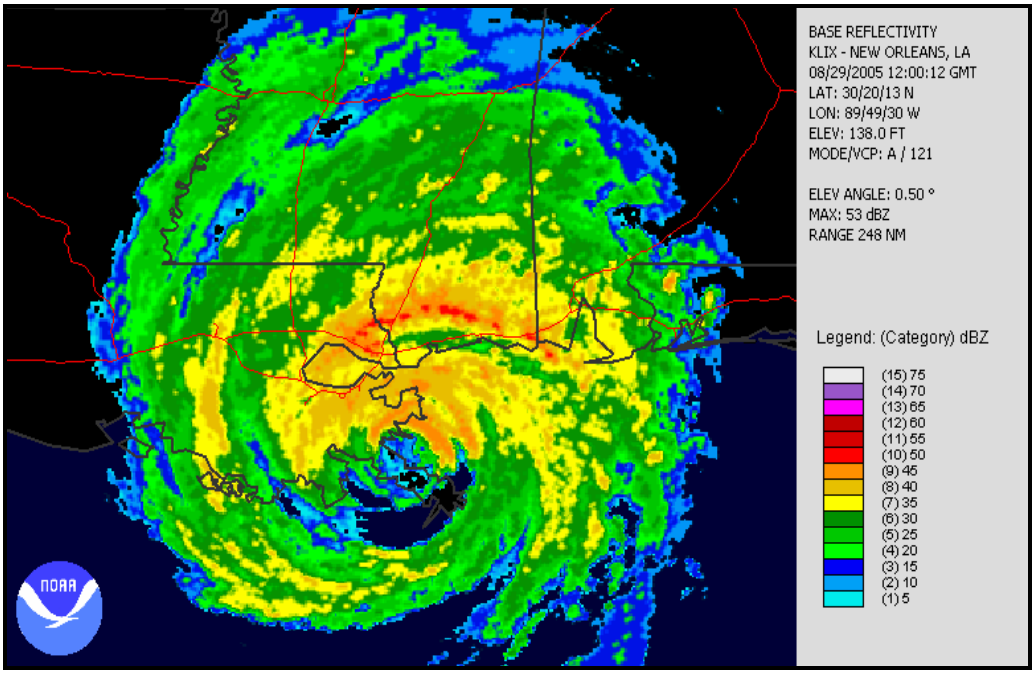

Figure 2. WFO New Orleans WSR-88D reflectivity image (0.5 degrees) at 7:00 AM CDT (about 45 minutes after landfall near Buras, LA) on August 29, 2005.

A storm tide of 11.45 feet (MSL) was measured at the Mobile State Docks in Alabama. Meanwhile, the levee breach in New Orleans, caused by the storm surge in Lake Pontchartrain, produced devastating flooding in New Orleans and St. Bernard Parish. Upwards of 80% of New Orleans was flooded with the water reaching a depth of to 20 feet in several areas of the city.

2. WIND ANALYSIS

2.1 Louisiana/Mississippi/Alabama Wind Analysis

NOAA and NWS survey teams conducted ground and aerial damage surveys in parts of southeast Louisiana, Mississippi, and Alabama -- a sample of aerial photographs used for the wind analysis are in Appendix A. For a complete archive of aerial photographs of Katrina, please visit the NOAA Remote Sensing Division link: http://ngs.woc.noaa.gov/katrina. A blend of these surveys along with recorded gust values, and the over-water portion of NOAA's Hurricane Research Division wind analysis, was utilized to produce an estimate the maximum wind gusts over land analysis shown in Figure 3 (please see Appendix C for further information regarding the Hurricane Research Division wind analysis system). The analysis depicts 3 to 5 second wind gust values. It should be noted that local effects can easily result in a +/- 15% variability in gust values at any one location.

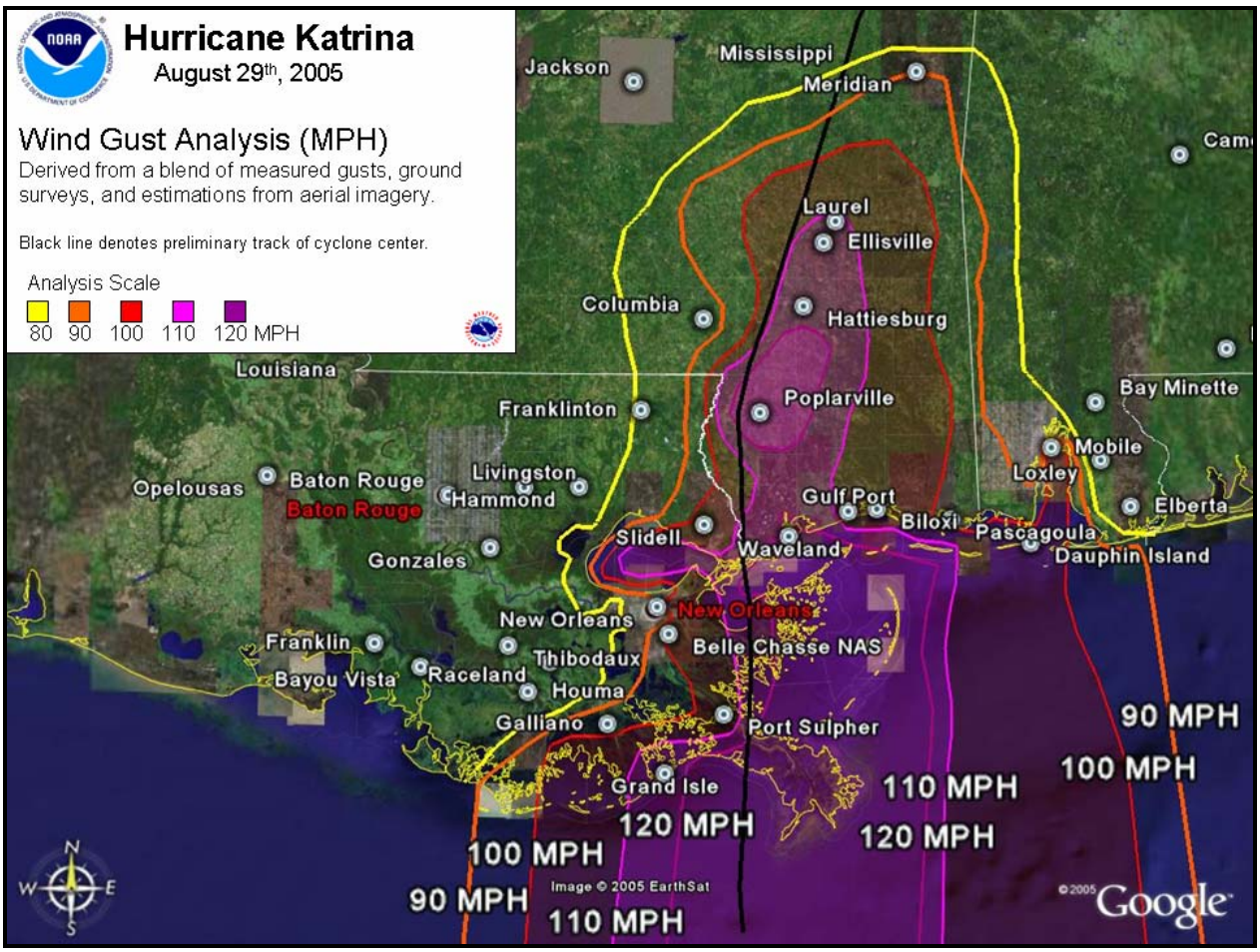

Figure 3. Estimated wind gust analysis (mph) for Hurricane Katrina derived from a blend of measured gusts, ground surveys, and aerial damage imagery.

Based on this analysis, it is estimated that wind gusts between 120 and 130 mph occurred in southern Mississippi (Figure 3). Extreme wind gusts also occurred across portions of southeast Louisiana where Katrina made its initial landfall. However, severe flooding and the sparse population in this area make a damage-based wind estimate difficult. The HRD over-water wind analysis suggests that one minute average sustained winds near 115 mph (Figure 4) came ashore with the eye in far southeast Louisiana, implying gusts as high as 155 mph may have occurred in these areas.

The analysis shows that wind gusts of 110-120 mph extended well inland across central Mississippi through Poplarville, Hattiesburg, and into Laurel. The basis of this analysis includes a wind gust of 136 mph recorded in Poplarville and reported through the AWS Convergent Technologies network. While the 136 mph wind gust value in Poplarville has not been verified to-date, the gust value is consistent with a noted increase in WFO Jackson, MS WSR-88D radar velocity data, and an increase in tree damage in the area. Moreover, the damage assessment report from the Mississippi Forestry Commission indicates that 2.7 million trees across 38 counties received varying degrees of damage from Katrina with the greatest impact to timber occurring in the coastal counties northward to the Laurel area. Please refer to Appendix B for additional surface and C-MAN/buoy observations for selected locations reported during Katrina.

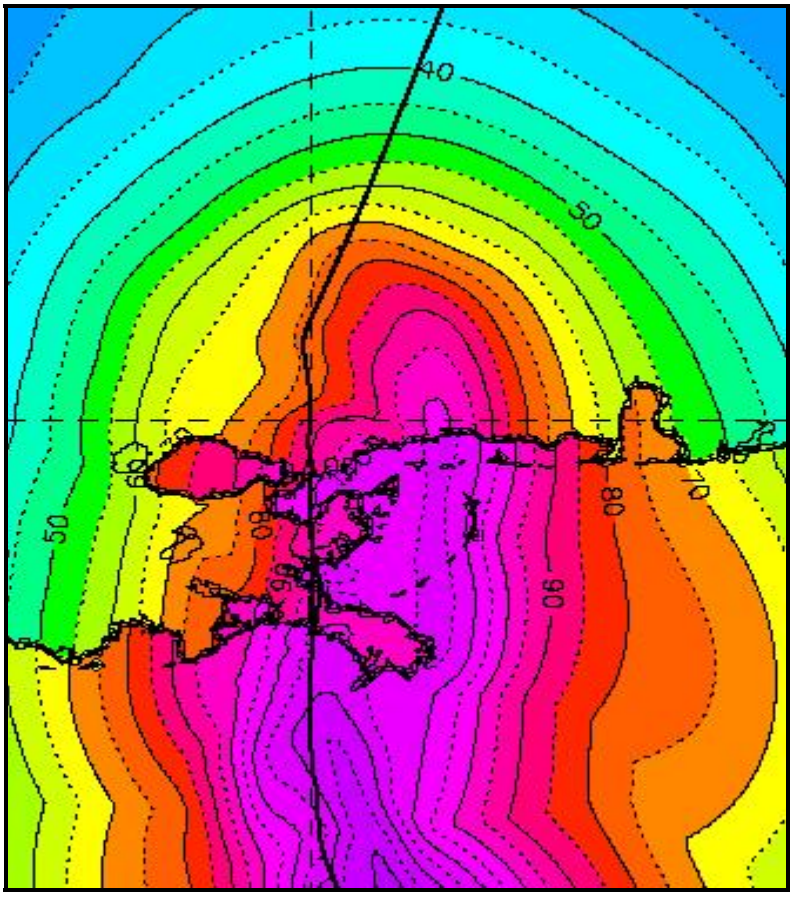

Figure 4. HRD Sustained Wind Analysis (mph) for Hurricane Katrina**.**

2.2 Florida Wind Analysis and Measured Winds

The wind analysis for Florida relied on the Hurricane Research Division estimated wind analysis and observed wind gusts in south Florida, the Florida Keys, and the adjacent coastal waters. The estimated maximum one minute sustained winds were 80-89 mph denoted in red shading in Figure 5. The maximum recorded wind gust was 97 mph at Homestead Air Force Base just south of Miami, FL.

Katrina strengthened as it moved southwest across the southeastern Gulf of Mexico north of the Florida Keys. The HRD analysis suggests maximum sustained one minute winds of 90-100 mph in a narrow swath near the center denoted in purple shading in Figure 5. The C-MAN station at Dry Tortugas, located about 60 miles west of Key West, recorded a peak gust of 105 mph. The Key West ASOS measured a peak gust of 74 mph while the NOAA vessel *NANCY FOSTER* docked along the southwest edge of Key West, recorded a peak gust of 86 mph. Please refer to Appendix B for wind observations for selected locations.

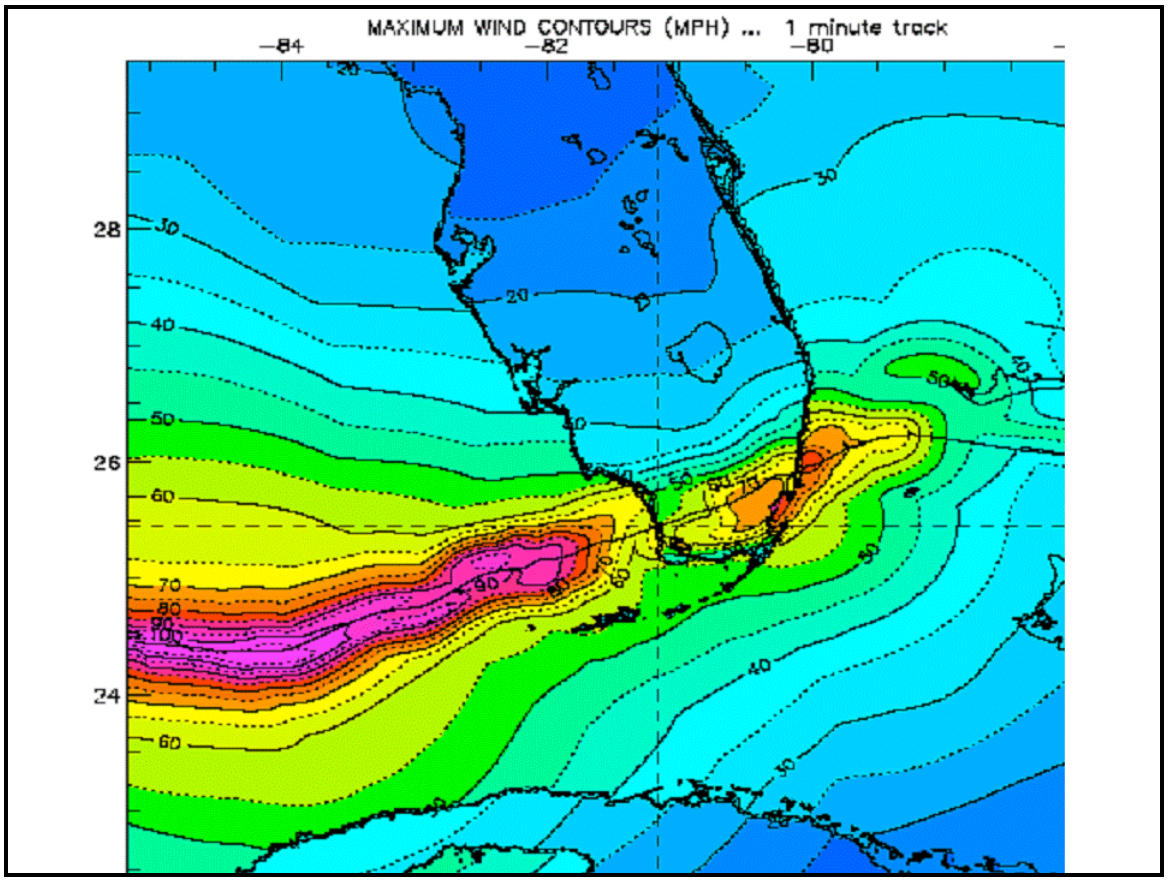

Figure 5. Preliminary maximum sustained wind swath analysis (in mph) for Hurricane Katrina from the HRD wind analysis system. The HRD system uses the 25 August 2259 UTC Florida landfall analysis and then projects the peak sustained winds along the observed track (black line) of the surface circulation center at 1 minute intervals using the HRD inland decay model. Values are contoured in intervals of 5 mph with every 10 mph labeled.

3. DAMAGE ASSESSMENT

Aerial damage assessment missions were conducted by the NOAA's Remote Sensing Division and Aircraft Operations Center (AOC) along the coast of Louisiana, Mississippi, and Alabama within a few days after landfall. NOAA's Remote Sensing Division used an Emerge/Applanix Digital Sensor System (DSS), on a Cessna Citation aircraft to acquire the images from an altitude of 7,500 feet. The Cessna Citation can support a wide variety of remote sensing configurations, including large format aerial photography, as well as data collection for digital cameras, hyper-spectral, multi-spectral and LIDAR systems. AOC performed their aerial survey using the NOAA WP-3D Orion aircraft flying at an altitude of 1,500 to 3,000 feet. Ground-based damage assessment surveys were conducted by personnel from WFO Lake Charles, LA (for WFO New Orleans/Baton Rouge, LA), WFO Jackson, MS, and WFO Mobile, AL.

Both the ground and aerial surveys indicate that storm tide and wind resulted in catastrophic destruction along the immediate coast of southeast Louisiana and most of Mississippi. The areas of nearly complete destruction occurred where the eye moved onshore along the coast of southeastern Louisiana and western Mississippi and inland for up to one mile. Ground surveys characterized the wind damage as typical of F-2 tornado damage (winds of 113-157 mph) immediately to the right of the

center track for 95 miles. The city of New Orleans experienced water depths of up to 20 feet several days after the storm passed.

4. SUMMARY

Hurricane Katrina wrought catastrophic destruction to the coast of southeast Louisiana and Mississippi. The storm made its initial Gulf of Mexico landfall in southeast Louisiana on August 29 as a Category 4 hurricane with winds of 140 mph and a minimum central pressure of 920 mb – the third lowest landfalling pressure on record in the United States -- followed by a second landfall in western Mississippi as a Category 3 hurricane with winds near 120 mph. The storm is estimated to have produced a storm surge of 30 feet along portions of the western coast of Mississippi. In New Orleans, the storm surge caused several levee breaches which flood upwards of 80% of the city with 8 to 20 feet of water. An analysis of aerial photography coupled with recorded wind gusts and the HRD wind analysis suggests that a wide swath of 100-120 wind gusts extended from southeast Louisiana across the western and central Mississippi coast and northward into central Mississippi with a small area of 120-130 mph wind gusts was noted in southwest Mississippi near Poplarville.

Acknowledgements

The Hurricane Katrina PSDA Wind Aerial Wind Analysis and Damage Assessment Team would like to thank the NOAA Remote Sensing Division, the NOAA Aircraft Operations Center, and the NOAA/NWS/NCEP Tropical Prediction Center for providing the aerial photographs for this analysis.

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Appendix A

Selected aerial photographs used in wind analysis and damage assessment.

Picture 1. Aerial view of damage in Pascagoula, MS from Hurricane Katrina. Photo taken by NOAA on August 30, 2005.

Picture 2. Damage in Ocean Springs, MS. Photo taken by NOAA on August 30, 2005.

Picture 3. Damage from Bay St. Louis, MS. Photo taken by NOAA on August 30, 2005.

Picture 4. Flooding in a New Orleans neighborhood. Photo taken by NOAA August 31, 2005.

Picture 5. More flooding in a New Orleans neighborhood. Photo taken by NOAA August 31, 2005.

Picture 6. Flooding cut off roadways in New Orleans. Photo taken by NOAA August 31, 2005.

Appendix B

A. Selected surface observations for Hurricane Katrina, August 23-29, 2005.

Location	Peak Gust (mph)
Florida	
Homestead (AWOS)	97
Fort Lauderdale (ASOS)	82
Miami (ASOS)	78
Tamiami (ASOS)	76
Virginia Key (CO-OP)	75
Key West (ASOS)	74
Louisiana	
Lake Pontchartrain (CO-OP)	114
New Orleans Lakefront Airport(ASOS)	86
Mississippi	
Laurel (CO-OP)	110
Hattiesburg CO-OP	100
Biloxi (ASOS)	97
Meridian (ASOS)	81
Alabama	
Mobile (ASOS)	83

B. Selected Buoy and C-MAN* observations for Hurricane Katrina, August 23-29, 2005.

Location	Peak Gust (mph)
Grand Isle, LA (GDIL1)	114
Dry Tortugas (DRYF1)	105
Dauphin Island, AL C-MAN (DPIA1)	102
Southwest Pass C-MAN (BURL1)	102
Key West NOAA Vessel	86
Buoy 42007 Biloxi (30.09N/88.77W)	85
Sombrero Key (SMKF1)	79
Sand Key (SANF1)	77

C. Selected surface observations from the AWS Convergent Technologies network for Hurricane Katrina August 29, 2005. *Data Courtesy of WeatherBug*

Location	Peak Gust (mph)
Pop	136
Biloxi, MS	107
Mobile, AL - USS Alabama	103
New Orleans, LA	99
Harahan, LA	91
Hahnville, LA	87
Marrero, LA	85
Gretna, LA	80
Metairie, LA	79
Covington, LA	69
Picayune, MS	69
Vance, AL	68

Appendix C

Background on the HRD Surface Wind Analysis System

Tropical cyclones are monitored globally by space-, aircraft-, land- and marine-based observing systems. Advances in computing and communications have made it possible to obtain these observations in near real-time. However, scientists involved in operational forecasting and basic and applied research on hurricanes have few tools that enable real-time interaction with, and analysis of, observations gathered in tropical cyclones. In the Atlantic, Eastern Pacific, and Central Pacific Ocean basins, hurricane wind fields are determined subjectively based on the specialist's interpretation of flight-level reconnaissance data, satellite observations, pressure-wind relationships and available surface data. These fields are represented by text portions of the official forecast product as radii (from the storm center) of 34 kt, 50 kt, and hurricane force winds in four compass quadrants relative to north. Until recently, no operational objective method has been available for assimilating and synthesizing disparate observations into a consistent wind field. The HRD Surface Wind Analysis System is a research tool designed to fill this need.

The HRD approach to hurricane wind analysis evolved from a series of peer-reviewed, scientific publications analyzing landfalls of major hurricanes including Frederic of 1979, Alicia of 1983, Hugo of 1989, and Andrew of 1992 (Powell et al., 1991, Powell and Houston, 1996, 1998, Powell et al., 1998). In our paper describing Hurricane Hugo's landfall, we developed the concept of a system for conducting real-time analysis of hurricane wind fields. We were in the process of constructing this system when Hurricane Andrew struck. The system was first used in real-time during Hurricane Emily in 1993 (Burpee et al., 1994). Since 1994, HRD wind analyses have been conducted on an experimental basis to create real time hurricane wind field guidance for forecasters at the National Hurricane Center. During Hurricane landfall episodes, HRD scientists work side by side hurricane specialists at NHC analyzing wind observations on a regular 3 or 6 hour schedule consistent with NHC's warning and forecast cycle.

An HRD wind analysis requires the input of all available surface weather observations (e.g., ships, buoys, coastal platforms, surface aviation reports, reconnaissance aircraft data adjusted to the surface, etc.). Observational data are downloaded on a regular schedule and then processed to fit the analysis framework. This includes the data sent by NOAA P3 and G4 research aircraft during the HRD hurricane field program, including the Step Frequency Microwave Radiometer measurements of surface winds, as well as U.S. Air Force Reserves (AFRES) C-130 reconnaissance aircraft, remotely sensed winds from the polar orbiting SSM/I and ERS, the QuikScat platform and TRMM microwave imager satellites, and GOES cloud drift winds derive from tracking low level near-infrared cloud imagery from these geostationary satellites. These data are composited relative to the storm over a 4-6 hour period. All data are quality controlled and processed to conform to a common framework for height (10 m or 33 feet), exposure (marine or open terrain over land), and averaging period (maximum sustained 1 minute wind speed) using accepted methods from micrometeorology and wind engineering (Powell et al., 1996, Powell and Houston, 1996). This framework is consistent with that used by the National Hurricane Center (NHC), and is readily converted to wind load frameworks used in building codes.

Further details on the HRD wind analysis system and methods, including a listing of papers, may be found at the following link: http://www.aoml.noaa.gov/hrd/Storm_pages/surf_background.html