Mapping Hurricane Katrina with GIS

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Abstract. ArcGIS is used to document evolution of the devastating hurricane Katrina in New Orleans area in 2005. We illustrate environmental changes caused by this natural disaster, and the impact on economy and society. The project shows how GIS combined with other information analysis tools can process complex data sets.

Introduction

Hurricanes are the costliest natural disasters in the United States. Understanding both hurricane frequencies and intensities is a topic of great interest to meteorologists, decision makers and the general public alike. Previous research has suggested that damage has been dramatically increasing within the last two decades, in part due to rapid increase of population and wealth in coastal regions (Blake et al., 2005; Emanuel, 2005; Pielke et al., 2005).

A hurricane is a type of tropical cyclone. Tropical cyclones are classified as follows: Tropical Depression (maximum sustained winds of 38 mph); Tropical Storm (maximum sustained winds of 39-73 mph), and Hurricane (maximum sustained winds of 74 mph or higher). Often the Saffir-Simpson Hurricane Scale (Simpson, 1974) shown in Table 1 is used to describe hurricane category. For instance, a hurricane of Category 5 has winds 156 mph and up and, it is expected to produce complete roof failure on many residences and industrial buildings. Some complete buildings and small utility facilities can be destroyed. Flooding causes major damage to lower floors of all structures near the shoreline. Massive evacuation of residential areas is required. Examples: Katrina (LA) 2005, Andrew (FL) 1992, Camille 1969 and Labor Day 1935. However, recorded data show that even hurricanes of lower category can be devastating if the landing area is densely populated.

Hurricane Katrina was one of the deadliest hurricanes in American history. It was the eleventh named storm, fifth hurricane, third major hurricane, and second Category 5 hurricane of the 2005 Atlantic hurricane season, and was the sixth-strongest Atlantic hurricane ever recorded. This paper presents a background in hurricane climatology, advances in hurricane forecast, Katrina's evolution and the impact in New Orleans area. We will illustrate ArcGIS applications to analyze the demographic data in New Orleans and determine factors that could contribute to difficulty in rapid and total evacuation of population from the flooded area.

Hurricane climatology and historic data

The hurricane season for the Atlantic Basin (the Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico) lasts from 1 June to 30 November. The peak of the season is from mid-August to late October, which correlates with the period of maximum sea surface temperature (SST) over Atlantic Area where hurricanes are formed. However, deadly hurricanes can occur anytime during the hurricane season (Figure 1). Hurricanes formation and their tracks depend on the time of year and different areas of the country have high risk during different months. Track patterns can vary considerably from year to year, and this aspect remains difficult to predict (Figures 2, 3).

Table 1. Saffir/Simpson Hurricane Scale [Simpson, R.H. (1974)].

Scale Number (Category)	Central Pressure (Millibars)	(Inches)	Winds (Mph)	Surge (Feet)	Damage
1	> 979	> 28.91	74-95	4 to 5	Minimal
2	965-979	28.50-28.91	96-110	6 to 8	Moderate
3	945-964	27.91-28.47	111-130	9 to 12	Extensive
4	920-944	27.17-27.88	131-155	13 to 18	Extreme
5	< 920	< 27.17	> 155	> 18	Catastrophic

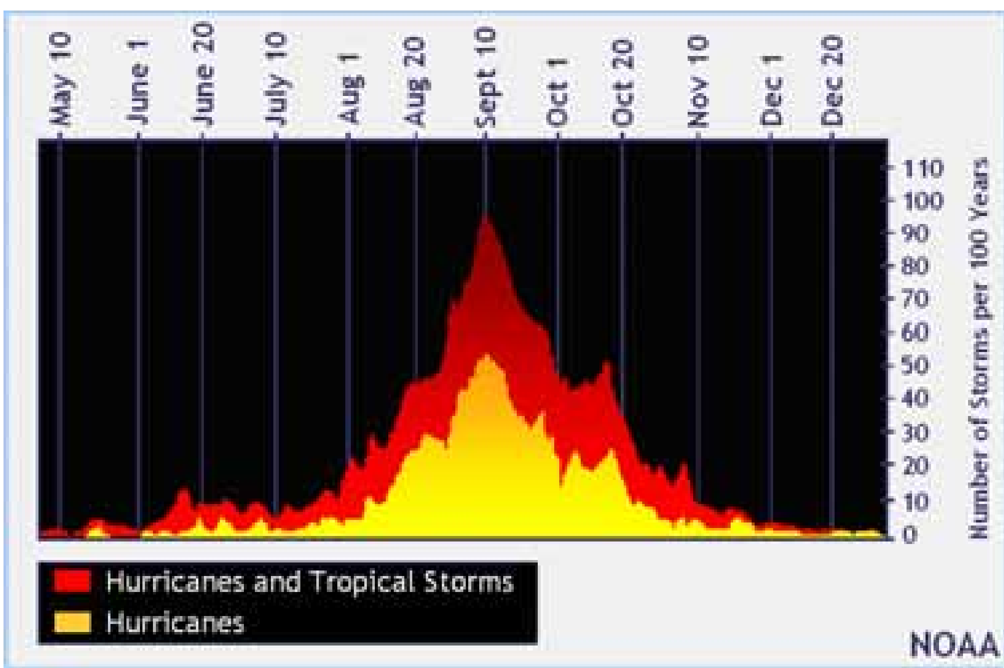

Figure 1. Seasonal distribution of hurricanes and tropical storm.
(Source: NOAA/National Hurricane Center).

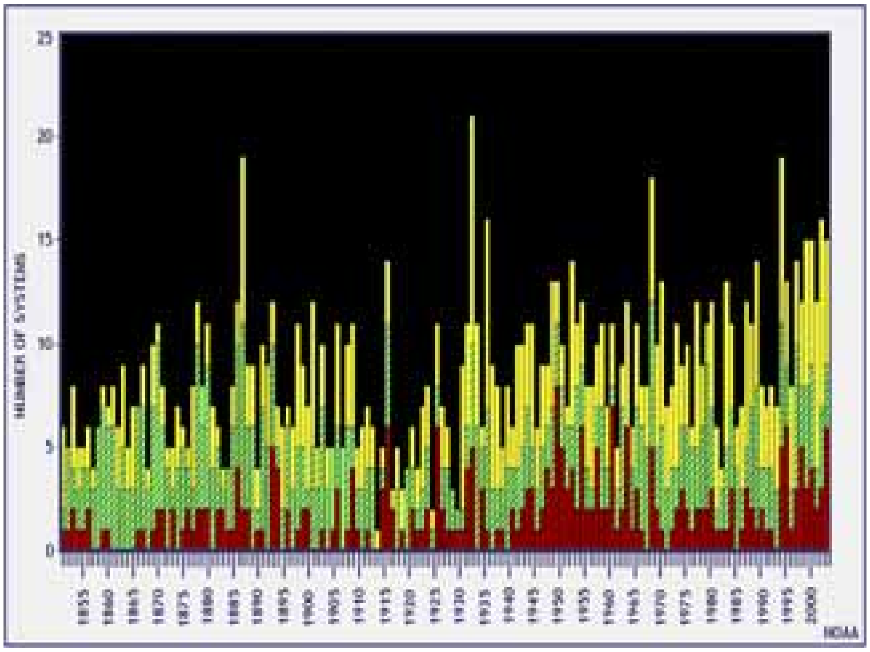

Figure 2. Bars depict number of named systems (open/yellow), hurricanes (hatched/green), and category 3 or greater (solid/red), for the time interval 1886-2004. (Source: NOAA/National Hurricane Center).

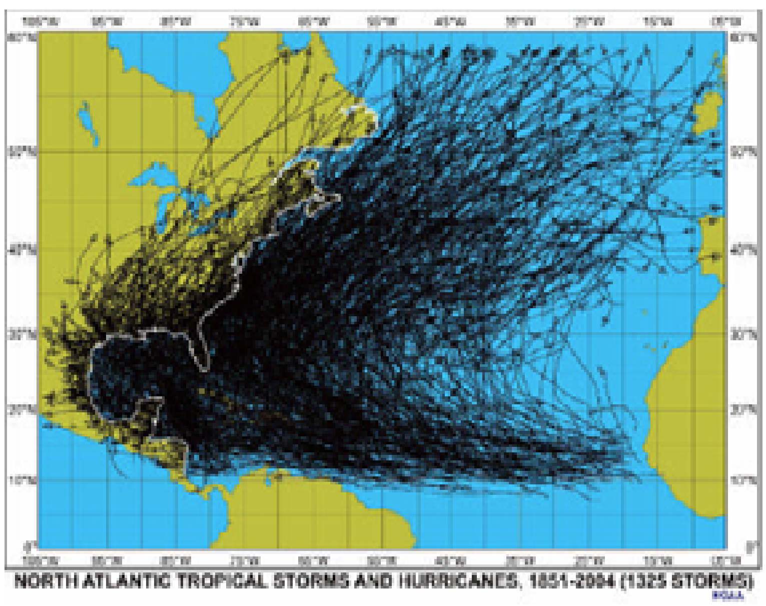

Figure 3. All Atlantic Tropical Storms and Hurricane Tracks since 1851-2004 (1325 Storms). (Source: NOAA/National Hurricane Center).

Research indicates that there is no strong correlation between storm activity early in the hurricane season and activity in the rest of the period. Over many years, hurricanes have cycles of greater and lesser activity and current models are showing progress in the ability to forecast annual tropical storm and hurricane evolution. However, there are currently no models to make long-range predictions of the specific locations where hurricanes might strike. In this sense, for practical purposes, short term forecast (days) remains critical for predicting the track and intensity, and for disaster management. Figure 4 shows the zones of origin and tracks of hurricanes for the month of September. The figure only depicts average conditions, and hurricanes can originate in different locations and travel much different paths from the average.

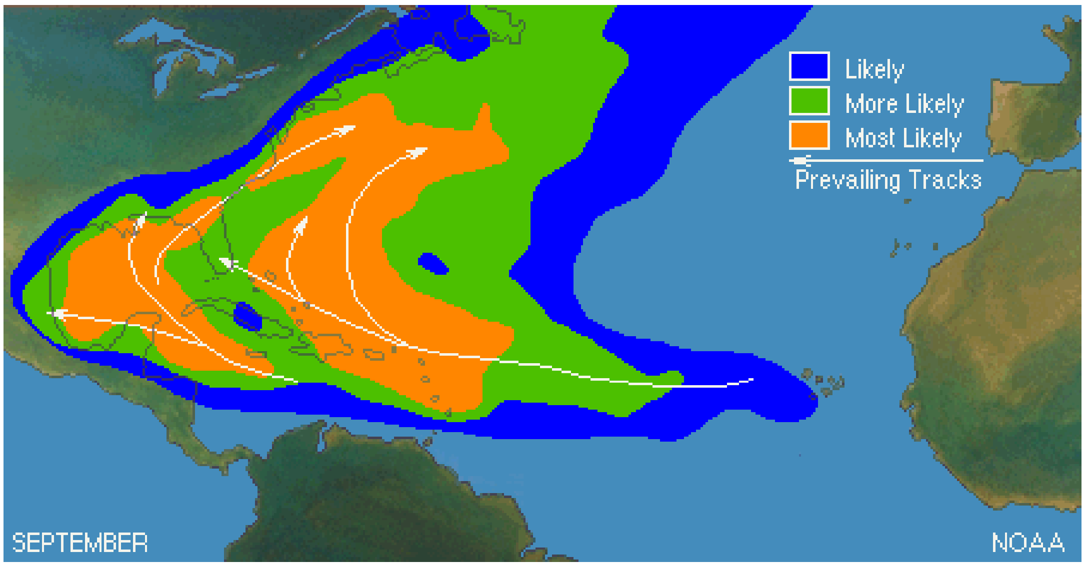

Figure 4. The zones of origin and tracks for September, one of the most active months during the hurricane season. (Source: NOAA/National Hurricane Center).

Hurricanes form in areas of high SST values, which are illustrated below in Figure 5 for month August (climatic values, from the National Weather Service - NWS). The correlation between variations of SST and hurricane formation is not simple, but studies show that in 2005 there were positive anomalies of SST in Atlantic region coinciding with very intense tropical storms activity. From Figure 5 we note that the highest SST values are located in east tropical Pacific, and in fact, only 11% of the world's tropical cyclones develop in Atlantic.

Some scientists argue that global warming might cause positive anomalies in SST that can trigger more hurricanes with increased intensity (Knutson and Tuleya, 2004; Emanuel, 2005; Webster et al., 2005), while others hold the view that natural variability can explain most of the observed data (Koltzbach, 2006). Research in this area continues, and it will take long term monitoring to distinguish between "natural variability" and mankind induced global or regional climate perturbations. Regardless of the cause, global warming or natural variability, SST increase seems to be physically linked with the amount of energy a tropical cyclone will convert into kinetic energy which might result in very intense winds, with catastrophic consequences (Emanuel, 2005).

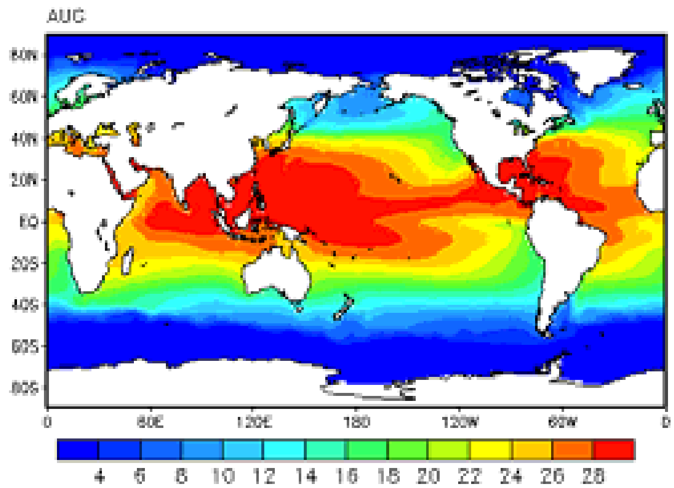

Figure 5. Sea surface temperature (SST) can enhance hurricane intensity (climatic values for August). Notice the high SST in the Gulf of Mexico. The temperature units on the color bar are in Celsius degrees. (Source: NWS Climate Prediction Center).

Table 2. Mainland U.S. tropical cyclones resulting in 150 or more deaths (adapted from Blake et al., 2005). Hurricane Katrina (2005) related deaths are estimated at over 1,400.

RANK	HURRICANE	YEAR	CATEGORY	DEATHS
1	TX (Galveston)	1900	4	8000 [a]
2	FL (SE/Lake Okeechobee)	1928	4	2500 [b]
3	LA (Cheniere Caminanda)	1893	4	1100-1400 [c]
4	SC/GA (Sea Islands)	1893	3	1000-2000 [e]
5	GA/SC	1881	2	700
6	FL (Keys)	1935	5	408
7	LA (Last Island)	1856	4	400
8	*AUDREY* (SW LA/N TX)	1957	4	390
9	FL (Miami)/MS/AL/Pensacola	1926	4	372
9	LA (Grand Isle)	1909	3	350
11	FL (Keys)/S TX	1919	4	287 [d]
12	LA (New Orleans)	1915	4	275
12	TX (Galveston)	1915	4	275
14	New England	1938	3	256 [d]
14	*CAMILLE* (MS/SE LA/VA)	1969	5	256
16	*DIANE* (NE U.S.)	1955	1	184
17	GA, SC, NC	1898	4	179
18	TX	1875	3	176
19	SE FL	1906	3	164
20	TX (Indianola)	1886	4	150

Notes: a) Could be as high as 12,000; b) Could be as high as 3000; c) Total including offshore losses near 2000; d) Total including offshore losses is 600; e) August.

Detailed studies have been prepared based on historical data of hurricanes (Landsea, 1993; Pielke and Landsea, 1998; Blake et al., 2005). Here we show only the hurricanes with total deaths over 150 people (Table 2), and the first 20 hurricanes with the highest estimated cost of damage (Table 3).

Table. 3. The first ten costliest mainland United States tropical cyclones, 1900-2004 (based on Blake et al., 2005). The estimated damage by hurricane Katrina (2005) is over $ 75 billions.

RANK	HURRICANE	YEAR	CATEGORY	DAMAGE (U.S.)
1	*ANDREW* (SE FL/SE LA)	1992	5	$26,500,000,000
2	*CHARLEY* (SW FL)	2004	4	15,000,000,000
3	*IVAN* (AL/NW FL)	2004	3	14,200,000,000
4	*FRANCES* (FL)	2004	2	8,900,000,000
5	*HUGO* (SC)	1989	4	7,000,000,000
6	*JEANNE* (FL)	2004	3	6,900,000,000
7	*ALLISON* (N TX)	2001	TS @	5,000,000,000
8	*FLOYD* (Mid-Atlantic & NE U.S.)	1999	2	4,500,000,000
9	*ISABEL* (Mid-Atlantic)	2003	2	3,370,000,000
10	*FRAN* (NC)	1996	3	3,200,000,000

Notes: @ Only of Tropical Storm intensity

Hurricane prediction resources

The hurricane forecast is conducted by the National Ocean and Atmosphere Administration (NOAA) National Hurricane Center –Tropical Prediction Center. In the same time, significant research effort by NASA, NOAA, NCAR, universities, and other agencies is focused on understanding the mechanism of hurricane formation and evolution (Halverson, J. et al., 2006). Satellite, radar, aircraft, soundings, and surface data are used to monitor the development and evolution of tropical cyclones and hurricanes. Such data is also used in numerical models to forecast detailed evolution of the cyclone. Results from models and observations are used operationally to inform the decision makers and the public. We have seen significant progress in hurricane forecast in the last two decades, and the accuracy of hurricane parameters (especially track and intensity) continues to improve with the advance in computer power and observational systems (Figure 6).

Due to natural volatility in tropical cyclone track characteristics, annual errors can vary significantly from year to year. In some of the past 20 years the average forecast errors have departed from the long-term trend line by as much as 50%. The number of storms each year can also vary greatly, and climate numerical models are used to link this variability to fundamental physical causes of the atmosphere – ocean global system. A series of specialized tools have been produced to address the forecast, data analysis, and results dissemination. The complexity of hurricane data combined with their impact on economical and social factors provides an example where GIS is used in various aspects of data analysis and disaster management.

Figure 6. Annual average model track errors for Atlantic basin tropical cyclones for the period 1994-2005, for a homogeneous selection of "early" models. Legend shows various models used in evaluation. (Source: NOAA/National Hurricane Center).

Weather and climate data in GIS

GIS is powerful for analyzing spatial data, used widely throughout universities, research centers, governmental agencies, and private industry. The ability of GIS technology to integrate and relate different spatial data types (biophysical, geophysical, socioeconomic, etc.) from different sources, to analyze these data, and to present results has led to GIS being a common tool across many organizations. The meteorological data type has been missing, including but not limited to atmospheric measurements, weather forecasts and analyses. In 2001, the National Center for Atmospheric Research (NCAR) developed a GIS Initiative as an interdisciplinary effort to foster collaboration, and spatial data interoperability. The GIS Initiative aims to promote the use of GIS as analysis and an infrastructural tool in atmospheric research and to distribute atmospheric and climate data to GIS users. Spatial data interoperability is a key to interdisciplinary research and decision-making within the atmospheric and GIS communities. In this context, the development of an Atmospheric Data Model is one of the first steps in achieving interoperable data sets. Atmospheric data cover a very large array of data objects, in a variety of data formats. The ultimate goal of an ArcGIS Atmospheric Data Model is to represent each of these data objects in a uniform manner, allowing their superposition and combined analysis in the ArcGIS desktop environment.

The Atmospheric Special Interest Group (SIG) was formed in 2003 and established a dialog between ESRI and the atmospheric sciences community about data representation issues. The Atmospheric SIG focused on two areas: temporal data management and improved raster data support. This involves the development of Network Common Data Format (NetCDF) converters for ingesting data into ArcGIS, and developing combined support for NetCDF, HDF, and GRIB formats through a single API. Significant progress is seen in various areas of GIS use with weather and climate data. Examples include the use of GIS with radar data (Berkowitz, D. and R. Steadham, 2005; Shipley et al., 2005), climate data (Higgins, 2005), weather warnings (Waters et al., 2005), watershed modeling (Wasson et al., 2002), weather-related business problems (Sznaider, 2002), hydro meteorological applications (Yates et al, 2002). The list of applications is longer and software tools were developed to address various aspects of GIS use with weather data for practical applications.

In addition to applications that use weather and climate data, other GIS applications were developed to be used with population evacuation and hurricane disaster management. US Corps of Engineers working with Federal Emergency Management Agency (FEMA) after hurricane Katrina, employed GIS in various projects: assessment of post-disaster damage; rescuing and recovering; building temporary homes; removing debris, pumping floodwater; identify impacted communities (Castanga, 2005). USGS National Wetlands Research Center use remote sensing and GIS to analyze land-water change caused by Katrina and Rita hurricanes, and future work includes hurricane recovery, and restoration of land (Barras, 2006). Another significant area of GIS application is in connection with population evacuation models. The hurricane and evaluation (HURREVAC) program uses GIS in formation to correlate demographic data with shelter locations and their proximity to evacuation routes to improve evacuation decisions (Wolhson et al., 2001). Significant GIS effort is also ongoing for rebuilding after Katrina related projects, in which multiple disciplines and agencies are involved (Hart et al., 2006).

Hurricane Katrina

Hurricane Katrina started as Tropical Depression over the southeastern Bahamas on August 23, 2005. The system was upgraded to Tropical Storm Katrina on the morning of August 24, and became a hurricane only two hours before it made landfall around 6:30 PM EDT on August 25 in south Florida. The storm weakened over land, but it regained hurricane status at 2:00 AM EDT about one hour after entering the Gulf of Mexico (Figures 7, 8).

Figure 7. Montage of Katrina images from GOES satellite. Category is shown in color on path (Source: NOAA).

The storm rapidly intensified during its first 24 hours after entering the Gulf, and on August 27, the storm reached Category 3 intensity on the Saffir-Simpson Hurricane Scale. Katrina rapidly intensified, attaining Category 5 status by 7:00 AM CDT on August 28 and its peak at 1:00 PM CDT with maximum sustained winds of 175 mph (280 km/h) and a minimum central pressure of 902 mbar. Katrina made its second landfall at 6:10 AM CDT on August 29 as a Category 3 hurricane with sustained winds of 125 mph (205 km/h) near Buras-Triumph, Louisiana. At landfall, hurricane-force winds extended outward 120 mi (190 km) from the center and the storm's central pressure was 920 mbar. A few hours later, it made its third landfall near the Louisiana/Mississippi border with 120 mph (195 km/h) sustained winds, or Category 3 intensity, and producing record storm surges along the entire Mississippi and Alabama coastlines.

Figure 8. Satellite image of Katrina, August 29, 2005. (Credit: NASA/Jeff Schmaltz, MODIS Land Rapid Response Team)

Katrina maintained hurricane strength well into Mississippi, but became a tropical depression near Clarksville, Tennessee. On August 31, Katrina was absorbed by a frontal boundary and became a powerful extratropical cyclone, causing moderate rain and gale-force winds in southeastern Quebec (Figure 10).

By August 26, the possibility of unprecedented cataclysm was considered based on computer model results which indicated that city of New Orleans is right in the center of their computed track probabilities (Figure 9). This scenario was considered a potential catastrophe because 80% of the New Orleans metropolitan area is below sea level along Lake Pontchartrain. Since the storm surge produced by the hurricane was forecast to be 28 ft (8.5 m), emergency management officials in New Orleans assessed that the storm surge could go over the tops of levees protecting the city, causing major flooding.

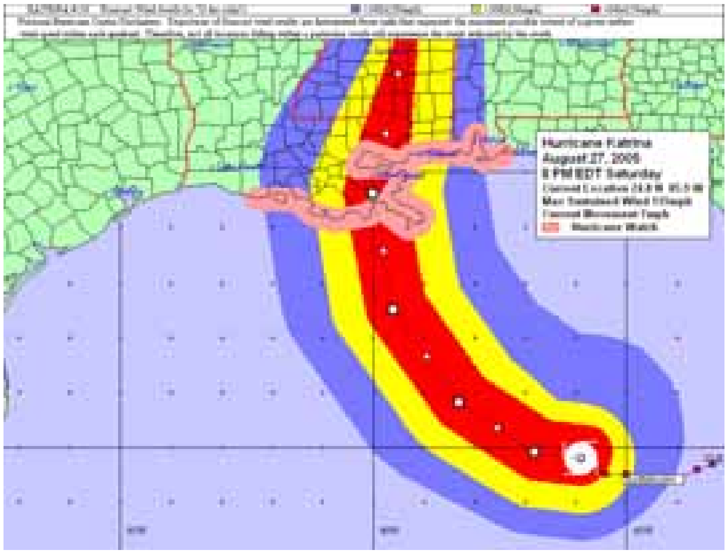

Figure 9. Path of Katrina and area of Hurricane Watch forecasted on August 25, 2005. (Source: NOAA/National Hurricane Center).

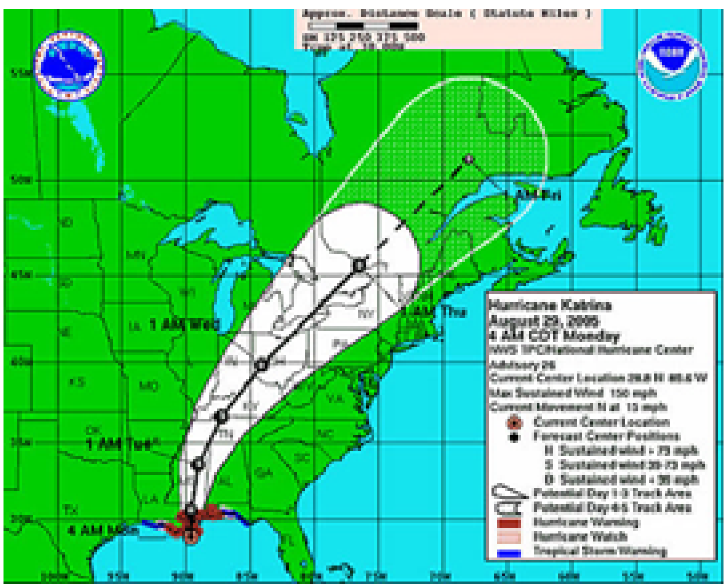

Figure 10. NOAA map of Hurricane Katrina on August 29 and projected track for the next 4 days. (Source: NOAA/National Hurricane Center).

This risk of devastation was well known: previous studies by FEMA, and the Army Corps of Engineers had warned that a direct hurricane strike on New Orleans could lead to massive flooding, which would lead to thousands of drowning deaths, as well as many more suffering from disease. Other previous studies on the impact of sea level rise on coastal regions singled out the potential disaster in New Orleans in case of storm surge caused by Category 4 and 5 hurricanes (Leatherman, and Burkett. 2002; National Research Council, 2002). Burkett et al. (2001) analyzed the potential disaster in New

Orleans due to these factors: city below sea level, subsidence (9 mm/year), limited evacuation potential, deterioration of coastal defenses, and heavy local rainfall.

At 10:00 am on August 28, shortly after Katrina was upgraded to a Category 5 storm, the mandatory evacuation of the city was ordered, and the government also established several “refuges of last resort" for citizens who could not leave the city, including the massive Louisiana Superdome, which sheltered approximately 26,000 people and provided them with food and water for several days as the storm came ashore. The Louisiana State Evacuation Plan left the means of evacuation up to individual citizens, parish governments, and private caretakers. However, it appears that existent resources were not able to provide sufficient transportation for citizens who did not have private means of evacuation. As a result of these conditions, hundreds of thousands of Orleans residents and tourists were unable to evacuate. Using GIS census data analysis we will show some of the possible factors that contributed to evacuation delays or difficulties.

On August 29, Katrina's storm surge caused several breaches in levees around New Orleans. Note that the levees were constructed to absorb a Category 3 hurricane’s storm surge (National Research Council, 2002). Most of the city was subsequently flooded, as the breached drainage and navigation canals allowed water to flow from the lake into low areas of the city and St. Bernard Parrish. Storm surge also devastated the coasts of Mississippi and Alabama, making Katrina the most destructive and costliest natural disaster in the history of the United States.

Economic effects of hurricane Katrina

The economic effects of the storm were far-reaching. The damage done to the economy was caused by interruption of the oil supply and other exports. The Port of New Orleans is the largest U.S. port for several major commodities including rubber, cement, grains and coffee. Many oil rigs lying just offshore and substantial number of energy companies that have their regional headquarters in the city. The tourism industry was severely affected. New Orleans is one of the most visited cities in the United States, and tourism is a major contributor to economy (about 14 million people visit New Orleans each year). The forestry industry in Mississippi was also affected, as many trees were destroyed. Furthermore, hundreds of thousands of local residents were left unemployed. Before the hurricane, the region supported approximately one million non-farm jobs, with 600,000 of them in New Orleans. A study of land-water changes after Katrina and Rita hurricanes indicates major loss of land (Barras, 2006).

On September 2, Congress authorized over $62 billion for help and reconstruction. FEMA has provided housing assistance to over 700,000 applicants. Several U.S. states have offered to shelter refugees displaced by the storm. The majority of the refugees were taken to Texas, with over 230,000 people taking shelter in Houston by September 5, 2005. From Texas, thousands of refugees have been dispersed to other states. Most refugees had stayed within 250 miles, but 240,000 households went to Houston and other cities over 250 miles away and another 60,000 households went over 750 miles away. About 100,000 New Orleans college and university students have also been displaced as a result of Hurricane Katrina.

Demographics of New Orleans areas affected by Katrina

To understand the impact of hurricane Katrina and flooding on New Orleans population we must consider some geographical elements of the city. New Orleans is located at 29°57’53’’ N, 90°4’14’’ W on the banks of the Mississippi River, about 100 miles upriver from the Gulf of Mexico. The city is located in the Mississippi Alluvial Plain, mostly between the Mississippi River in the south and Lake Pontchartrain in the north. The city of New Orleans has the lowest elevation in the state of Louisiana, and the lowest point in the United States, after Death Valley and the Salton Sea. Much of the city is about 0.3 to 3 m below sea level. Some 45% of the city is above sea level. Rainwater is pumped into Lake Pontchartrain via a series of canals lined by levees, dikes, and floodwalls. Because of the city's high water table, most houses do not have basements.

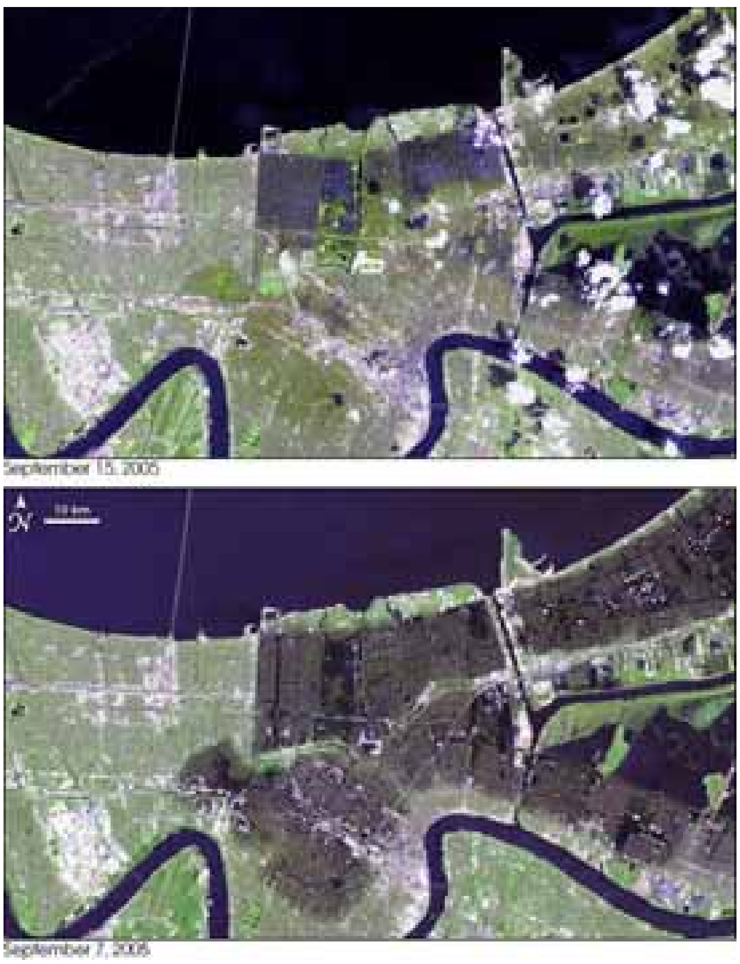

Figure 11. Landsat 7 satellite image of New Orleans on September 5 and September 7 2005. Credit: Images provided courtesy of the United States Geological Survey Center for Earth Resources Observation & Science (CEROS).

Intense rainfall, high surge and levees failure created unprecedented flooding in about 80% of the city (as seen in Landsat image above on September 7, 2005, Figure 11). The floods that buried New Orleans had noticeably subsided by September 15, 2005, when the top image was taken by the Landsat 7 satellite. In the two and a half weeks that had passed since Hurricane Katrina flooded the city, pumps had been working nonstop to return the water to Lake Pontchartrain. The progress in draining the city is evident when the September 15 image is compared with an image taken one week earlier. In the lower image, taken by the Landsat 5 satellite on September 7, black flood water covers much of the city while by September 15, most of the dark flood water disappeared. Note also that September 7 image does not show the full extent of the flooding.

We use Census data 2000 to illustrate some demographic characteristics in the New Orleans, especially in the area impacted by severe flood. We illustrate our results at census tract level, while current census data and ArcGIS allow investigation at a higher spatial resolution, which is necessary for decision makers. We must note first that New Orleans population increased significantly over the last century (Figure 12), which is in trend with the population increase in the coastal regions of the United States.

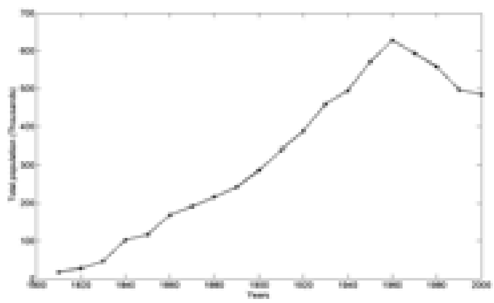

Figure 12. New Orleans total population versus year based on census data until 2000. Estimated population in January 2006 was about 200,000.

In Figure 13, we note significant total population as the area affected by flood is densely populated. We try to understand population behavior and response to a mandatory evacuation order. Studies show that the State of Louisiana preference for advanced notification time of minimum 72 hours, the longest time in the country (some states have a requirement of advanced notification of 12 hours) for Category 5 hurricane (Wolshon et al, 2001). Current forecasts are not precise enough to give a reliable notification of 72 hours, and in practice the order was given about one day in advance. Previous studies also established evacuation plans and procedures and presented possible problems of the so called low mobility groups. The number of people without access to transportation in New Orleans is about 25-30 percent of the population. Moreover, destitute, elderly, prisoners, infirm and tourists contribute to the low mobility group. The problem was addressed by emergent management agencies to provided buses for the evacuation of low mobility groups. Earlier reports and experience of Katrina showed that New Orleans did not have the adequate supply of busses to transport all low mobility people (Wolshon, 2001).

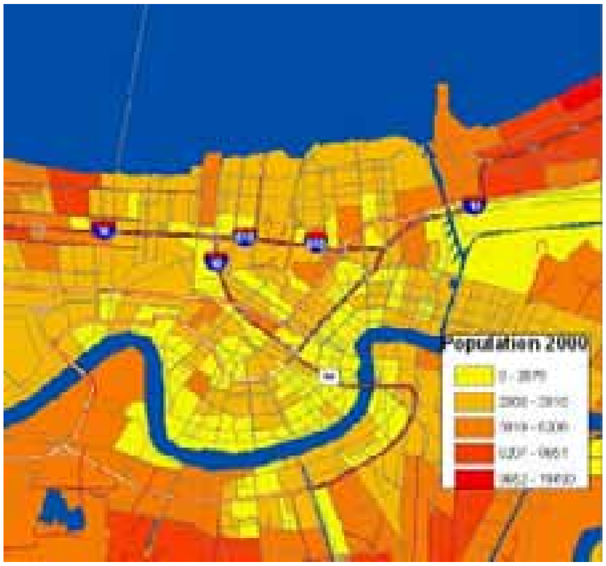

Figure 13. Total population by census tract in year 2000 in areas most affected by flood.

As of the census of 2000, there were 484,674 people residing in the city and the most recent (2004) population estimate for the city is 462,269. A January 2006 survey shows the population at approximately 200,000, due to relocation caused by Katrina effects. We note that the New Orleans and suburbs has an overall population of over 1.3 million. The racial makeup of the city was 67.25% African American (also named Black in the census data), 28.05% White, and the rest represents other races.

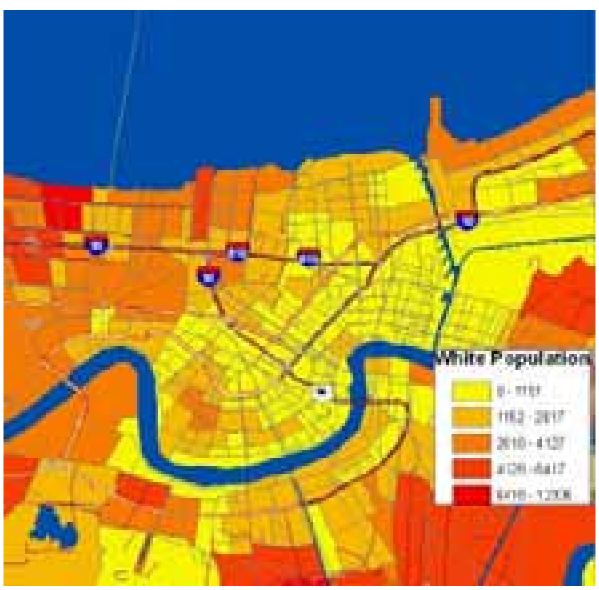

Figure 14. White population by census tract in areas most affected by flood.

We illustrate maps of population by race: White (Figure 14), and Black (Figure 15). Simple inspection of these maps shows predominant areas of population by race, with some remarkable grouping of ethnic communities in the area most affected by flood.

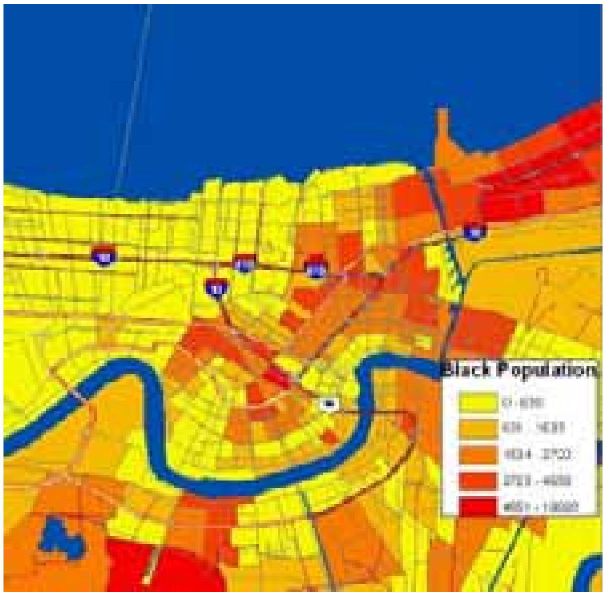

Figure 15. Black population by census tract in areas most affected by flood.

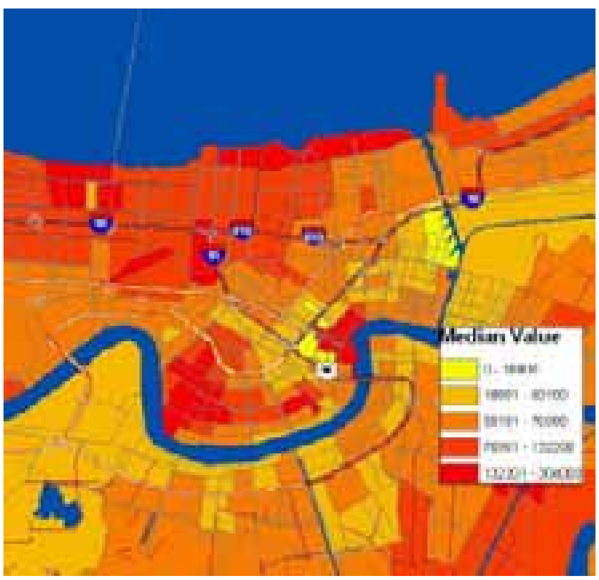

Figure 16. Median property value in New Orleans area affected by severe flood.

A measure of population prosperity or family income is illustrated by a map of median home value by tract (Figure 16). We can easily see predominant lower median home values in areas with larger African American population. Median home value is well linked to family median income, and might suggest areas where people had trouble with evacuation due to lack of personal transportation. In the same time, other factors contributed to the difficulty of evacuation. Such factors are: significant number of elderly people, regardless of race lived in the flooded area. Figure 17 shows number of people over 65 years by census tract in the flooded area. Many older people are also single (some widowed), living alone, sick or with disabilities.

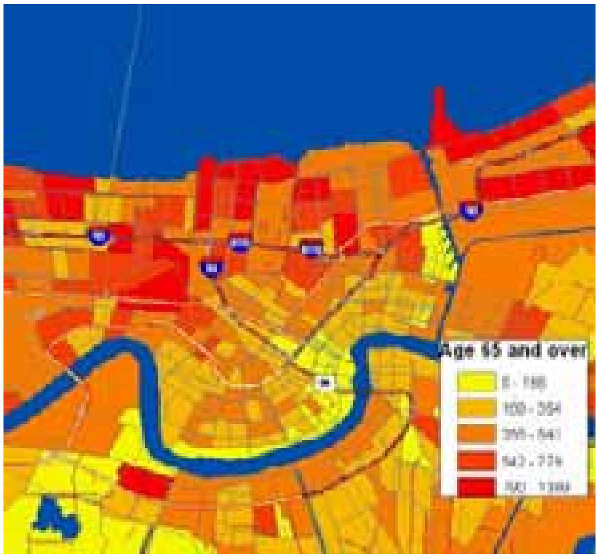

Figure 17. Total population of age 65 years and over by census tract in areas most affected by flood.

Conclusions

The areas along the United States Gulf and Atlantic coasts where most hurricane related fatalities have occurred are also experiencing significant growth in population. This situation, in combination with continued building along the coast, can lead to serious problems for many areas impacted by hurricanes. The solution to the problem has more components: a) improve hurricane forecasts and disseminate advanced warning to decision makers and public; b) organize and educate population for total evacuation if needed; c) set up a detailed emergency evacuation plan; d) address long-term policy and planning to prepare the city for storm surge, floods and other possible damage.

The case of Katrina hurricane showed that the weather forecast was reliable, and warnings were given well in advance. However, a series of special circumstances contributed to major disaster and numerous fatalities: 1) Hurricane of Category 5 landing in densely populated area; 2) Most of the city of New Orleans is below sea level and levees failure resulted in severe flooding; 3) Many people from the low mobility population group were not able to evacuate after the mandatory evacuation order; 4) Demographic maps of the flooded area of New Orleans show significant number of people over 65 years old, living alone, sick, and with low income. Such factors, prevented full evacuation and caused a large number of fatalities.

Some solutions that emerge from Katrina case or storms with comparable effects in New Orleans area are: a) upgrade levees and drainage to withstand Category 4 and 5 hurricanes; b) design flood protection based on rates of local subsidence, rainfall, and sea-level rise; c) minimize drain and fill activities that enhance local subsidence; d) improve evacuation routes; e) protect and restore coastal defenses. Part of the effort in current and future natural disaster management is to prepare reliable forecasts, and disseminate information to decision factors. GIS is already playing an important role in this process, and future work is needed to integrate data from various sources into GIS and increase our ability to solve multidisciplinary complex problems.

Acknowledgments

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