Effects and influences of storm surge – Lessons learned from significant events

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Abstract: This paper examines some of the effects and influences of storm surges occurring during hurricanes. Profound economic and social pressures from industry sectors, local authorities, investors and society arose post hurricane Katrina, when the damage estimation was greater from storm surge (water) than from hurricanes (the wind). Considering the complexity and difficulty in predicting storm surge characteristics, various activities at a number of levels were initiated by governmental and non-governmental sectors. Although it is primary to understand a storm surge by its statistical model and predictions, it is also required to stochastically analyse through the lessons learnt from past events. Using case studies from previous storm surge events provides an opportunity to understand their effects, explore future adaptation paths and resilience approaches.

Key words: Hurricanes, storm surge, resilience, coastal defence, socio-economic analysis.

I. INTRODUCTION

Storm surge is a highly complex sea borne hazard originating predominantly from severe weather such as hurricanes (tropical cyclones). Understanding climate change is pivotal in relation to the estimated future increase in sea level and the potential for increased severe weather incidents (1). Given the range and types of weather based disasters (such as: flash flooding, hurricanes, tornados, typhoons, earthquakes, coastal and river flooding etc.), storm surge secures a unique prospect with respect to coastal defence and is a common denominator in several of the pre-mentioned weather types. Storm surges can be anomalous because of their sensitivity to slightest changes in source storm intensity, speed, central pressure and direction of approach (2). The use of mitigation measures and pre-planned resilience technologies can lead to major benefits to reduce future major economic impact (3).

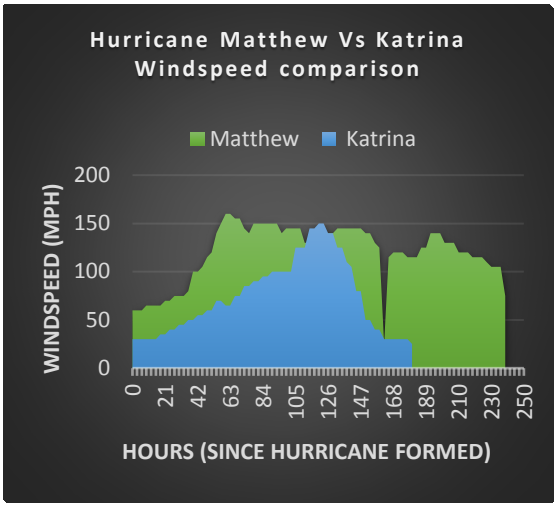
National Hurricane Centre, National Weather Service and European Centre for Medium-Range Weather Forecast (ECMWF) were some of the most trusted models. Hurricane Katrina, Super Storm Sandy, and Hurricane Matthew, were very closely monitored and predicted by these

agencies. NHC confirmed that Sandy's track predictions made by ECMWF into New Jersey were closely matching while other predictions by such as Hurricane Weather Research and Forecasting (HWRF), Global Forecast System (GFS), Geophysical Fluid Dynamics Laboratory GFDL deviated largely (4). This clearly explains that regarding storm surge even the most reliable models were not sufficient in responding to such significant events (3).

Rapid urbanization and industrialization has triggered various impacts, which makes adaptation tasks difficult. Coastal assets and infrastructures exposed to vulnerable seas pose a significant risk to incur high costs for post-storm remedial measures and impact on future economic development. Although adaptation may be a preferred solution for such problems, implementation is problematic. Adaptation without affecting the economic growth can result in adaptation being more complex.

II. OVERVIEW OF HURRICANE KATRINA VS MATTHEW

Figure 1, shows the wind speed comparison



between hurricanes Katrina (2005) and Matthew (2016). The figure shows that the wind speed and intensity for Matthew increased more rapidly than for Katrina. The 2005 Atlantic hurricane season was identified as the most significant season in recorded hurricane history. This is because of continuous major hurricanes such as hurricane Dennis (Category 4), followed by Emily, Katrina, Rita and Wilma as Category 5 hurricanes resulting in an overall economic loss US$159.2 billion from hurricanes and storm surges (5) (6).

The 2005 hurricane season also provided insights towards various aspects such as communications, emergency preparedness, improvisation in transportation, infrastructure etc.

Hurricane	Death Toll	Economic Damage US$ (Billion)	Storm surge Height (ft)	Category	Wind Speed (mph)
Katrina (August 2005)	1833	108	27.8	5	175
Sandy (October 2012)	147	75	9.43	3	115
Matthew (October 2016)	585	15	7.70	4	165

Table 1 Major Hurricanes and damage statistics (7) (8) & (9)

Table 1, shows a brief synopsis of hurricane Katrina, Sandy and Matthew's, and their category in Saffir-Simpson hurricane wind scale, storm surge height and the impact on economic damage. The tropical cyclone Katrina turned towards the east of New Orleans before it made a landfall. However, there was a lack of storm surge understanding. The strong winds moving in the counter clockwise from the hurricane created acute wave dynamics with a 15-foot storm surge which overtopped 8-foot levees around Lake Pontchartrain in various locations flooding the city more rapidly than was anticipated (7)(8).

Hurricane Matthew, a similar tropical cyclone as Katrina, became a significant event with major

landfall made in Haiti and various locations off the east coast of U.S. including North and South Carolina. The sudden change in storm direction was a primary factor leading to a substantial event with more than 800 lives lost in Haiti, which was still recovering from the 2010 earthquake (9). The vulnerability of Haiti to such events is mainly because of its high levels of urban population, urban growth and lack of infrastructure along the coasts. According to the report approximately 389 people live per sq. /km increasing the vulnerability further (9).

a) Staging disaster resources and response teams

The hurricane emergency response team generally involves inter-governmental (federal, state and local) and non-governmental cross-sectors (public and private) bodies (10). Hurricane Katrina was initially expected to be a Category 3 hurricane but re-intensified into Category 5 when it hit New Orleans, which was already largely lower than sea level (10). The U.S Army Corps of Engineers who built various levees, clearly confirmed that Katrina was beyond their design criteria. Katrina was predicted days in advance of landfall and declarations of emergency were initiated earlier. However, responders failed to interpret the information into action. The response and resources team deployed as resources for Katrina were re-directed to New Orleans only during the last two days before it made landfall. The other non-governmental organization who were dependent on authority like FEMA's instruction to act had fewer or no coordination in various affected regions (11).

Compared to hurricane Katrina, Matthew was well planned for with responders in place. Before Matthew's arrival, FEMA had 444,000 liters of water and 513,000 meals and other supplies readily available in their support base to be mobilized to affected areas. Non-profit groups also volunteered during Matthew on safety efforts a day ahead of Matthew's arrival (12).

b) ***Lack of information***

Around 25,000 residents were reported to be still residing after the announcement of evacuation by FEMA (8). Hurricane Katrina's federal response failure was criticized for various factors including lack of information. The former 9/11 Public Disclosure Project panel members gave U.S. federal government a failing grade for hurricane Katrina's response commenting "failure in communication and lack of coordination costs lives". Both government and FEMA were criticized for not understanding their roles and responsibilities under the National Response Plan and National Incident Management System (11). Hurricane Matthew was well planned for in the U.S. compared to Haiti.

Lack of information was also recognized during hurricane Matthew in two different aspects. U.S coastal cities were observed to be overwhelmed with information created ambiguity, while Haiti as an exemption with limited information available about the hurricane. This difference puts forth the idea of rethinking about capacity building depending upon the country's approach and communities' requirements (13). Local management and key support may be more beneficial compared to centralized government management with significant decision layers.

c) Transportation Impact

Katrina's evacuation of New Orleans was the largest evacuation in the shortest period. Transportation was challenging during hurricane Katrina. The size of the storm limits the logistics of the resources like food, water, and medical

supplies to the lacked (10). Hurricane Katrina evidenced that although FEMA, Department of Defense, National guard undertook the response, still fell short in planning the prerequisites, intensely during the evacuations transportation and logistics of the resources (11).

The cities enter- and exit-roads were not controlled in advance considering evacuations as their priority. Instead diversion roads for New Orleans were still in operation creating traffic congestion and evacuation difficult both for victims and for responders (8) & (10). Similarly, during hurricane Matthew lack of information on road closures delayed deployment of resources to those in need and evacuation in U.S states.

d) Communications impact

During hurricane Katrina, neither the operational plans were communicated nor were the situational awareness created, which resulted in a major communication failure. Many 911 contact centers were also affected (10). Even though, social media was commonly used, it still was not chosen as a communication tool for disasters. Due to lack of awareness, there were also no identified websites with hurricane warnings or evacuation notifications created, unlike for hurricane Matthew (14).

Hurricane Matthew was appropriately communicated with the use of modern communication. While the same event was identified with diverse communication issues. The primary communication issue identified was the evacuation information was "*not equally communicated*". For example Jacksonville and its beaches were given more coverage compared to St. John county and the City of Augustine, while these areas fell under the primary landfall location (15). Furthermore, Haiti, had high illiteracy rate and oral communication was the only effective mode of communication identified since 2010 earthquake (9). It is undeniable that the country was well communicated with warnings in advance until before being taken offline, creating a communication gap and it is also recommended as a future research scope to focus on having a virtual backup eliminating communication interruptions (15).

e) Infrastructural impact

The governmental preparedness and its response were criticized soon after the aftermath which raised a serious question about New Orleans's ability to respond to a similar event (16). The main destruction and damage of New Orleans infrastructures were due to the infrastructure being not flood proofed beyond Category 3 hurricanes. The current result has shown that the city had dropped 60cm since last surveyed in 1970 and the expected sinking rate is 0.5 -1 inches per year which further puts the authorities to face the complex question on investing money to completely protect the city or simply cover and rebuild existing systems (17).

During hurricane Katrina, some of the modern engineered infrastructures built to withstand Category 3 and above hurricanes and their design failure to survive the catastrophe became a noticeable engineering failure. The U.S Army of Corps engineered levee system, The Louisiana Superdome, i-10 Twin Span Bridge and the New Orleans pumping station were among those infrastructures (18) & (19).

Louisiana's Superdome which was built to withstand Category 4 hurricane, couldn't survive the 140 mph winds proving another engineering failure against hurricanes (19). The most efficient pumping system of New Orleans which had the

capacity of draining 300 million gallons of water was entirely inundated by surge water making the system in-operable and leaving the city flooded for more than two weeks. The power unit has now been elevated to have the unit running uninterrupted and the pumps were replaced with sealed pumps stopping water entering the system (19).

f) Insurance

The National Flood Insurance Program (NFIP) paid an overall US $16.3 billion out of which claims from Louisiana was US $13 billion (22).

During hurricane Katrina, private insurance industries in the Bahamas, which suffered a significant impact from the catastrophe, was also not supported by the state government. This made insurers to withdraw their cover for some of the impacted areas. This situation made home owners either to self-insurer or limit increase in premiums with exclusions. This resulted in consequences, such as properties being abandoned, mortgage loss, collapse in property values etc. and clearly shows the management gap of climate-related hazard within insurance and government sector. Hurricane Katrina provided a significant lesson to every government and non-government body.

Marsh Insurance brokerage, in their annual report, have outlined that, the insurance industry has made changes to their claims. The report details that, lesson learned from all the storm surge events such as Katrina, Sandy and Ike have brought definite insurance changes and even in the method of assessing risk. On the other hand, the report has also highlighted computer catastrophe modeling whose results were greatly deviated and boasted compared to actual loss (28).

III. IMPROVISATION IN INFRASTRUCTURE AND ADVANCED TECHNOLOGY

Post hurricane Sandy, according to Disaster Relief Appropriations Act (2013), federal funding provided NOAA with an opportunity and funding to invest and test new technologies to better understand storm physics. Investments and funding were paid out on improving nation's infrastructure, power lines, and utility stations, marine debris management etc. (3).

According to Edison electric institute, a trade group has listed that annual spending by investors has been doubled to US$52.8 billion since hurricane Katrina, Rita and Sandy. The smart grids are the upcoming technology in utility industries to expedite the recovery and response post hurricanes and storm surges (20). The 2.9 km IHNC (Inner Harbor Navigation Canal Lake Borgne) surge barrier or “The Great wall of Louisiana” is a Category 5 storm proof infrastructure. The infrastructure is observed as advancement in Hurricane and Storm Damage Risk Reduction System (HSDRRS) preventing the city against hurricanes and storm surges post-Katrina (21).

Hurricane Ike (2008) which left the Galveston bay, Texas and Louisiana with 103 deaths and US $29.52 billion (22). As a long-term solution to hurricane and storm surges a prospective project named the “Ike Dike” (23) is proposed, which when built acts as a hard-engineered coastal barrier for Galveston bay, Texas. This area suffered significant impact from 1900 and 2008 hurricanes and storm surges.

National Hurricane Center (NHC) issued a potential storm surge flooding map in 2016 hurricane season as an advancement in mitigating storm surge hazard. NHC further announced that

this map will be issued for a potential hurricane and storm surge emergencies (24). Another advancement in storms surge mitigating technologies is the storm surge watch & warning. NHC and National Weather Service have collaborated to have storm surge watch and warning which became operational during the 2017 hurricane season. Initially this watch and warning will be issued to areas which are classified as 'high risk' or 'life-threatening' zones and will be further developed to cover the extended zones and cities (24).

Post hurricane Katrina, the Florida state government has made advancements in their hurricane protection technology, which was the international residential and commercial building codes. Under these regulatory codes, various factors such as improvised roof decks, secondary water barrier, reinforced doors and roof-wall connections, hurricane shutters were equipped to homes built within hurricane zones ensuring both exterior and interior protection are equally coped (25).

Two nuclear reactors in Florida were already facing issues regarding sea encroachment, and working towards flood proofing. The Nuclear Energy Institute's director cited that "reactors in Florida were safe, flood proofed with emergency preventions, and all the nuclear plants were safe under the Nuclear Regulatory Commission's new rule" (26). The power reactors were shut down with severe warnings issued by NRC for Hurricane Matthew in 2016 and resumed its operations post-Matthew, thus successfully overcoming the event (27).

During hurricanes, Social media, blogs, mobile picture sharing, online tools were utilized as one of the most important technologies to connect with communities. These types of communication strategies were often criticized for its engagement methods. However, the usage of these technologies, mobile and social media have certainly marked a shift during 'super-storm' Sandy compared to Katrina. Similarly, non-profit and volunteering groups have joined the local government in effectively building the best practices during emergency situations, which have also increased the communication effectively. It is further expected that these types of communications will be even more exponentially reaching government and public sectors and communities in future for effective communication (14).

As a process of adaptation and mitigation, continuous advancement, upgraded technologies and reengineered hurricane- proof infrastructures, are adopted at different levels in different fields. Specialized satellites, drones, computerized models (statistic and dynamic), upgraded tidal station with latest sensors, supercomputers to understand the pattern are being developed and tested as an ongoing process to understand the probability of future (3).

IV. CONCLUSION

An effective response to emergencies is a critical role at every level of governmental and non-governmental organizations (8). It is also challenging to bring all the responders under a network with varying grades of connectivity. An organization like FEMA could give added attention, on how to influence the overall network involving every responder.

While FEMA was widely criticized post hurricane Katrina, coast guards were appreciated as they deployed 4000 service members, 37 aircraft and 78 boats to rescue 30,000 people during the same event. The reason being coast guards rely on local decision making compared to FEMA officials

who rely for the orders from the federal government. Consequently the local state government responded better than the federal government (11). This initial study suggests that the federal government should perhaps consider restructuring support to embed within local emergency response bodies, utilising local knowledge in supporting response with key support departments trialling 'practice based approaches' to various scenarios.

There may be past and future situations where preparations may never be sufficient because of size and scope of the hurricanes. However, case study scenario planning can support a future response, identify critical pathways, asess risk management and co-ordinate responders at every level. Such measures could minimize future socioeconomic losses.

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