Modeling Hurricane Impacts on Gulf of Mexico Offshore Structures.

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1. INTRODUCTION

The Gulf of Mexico currently has about 2350 offshore platforms, many miles of pipelines and about 70 Mobile Offshore Drilling Units involved in the exploration and production of crude oil and natural gas. These valuable assets are all exposed to the impacts of tropical cyclones. Figure 1 shows a map of these assets. The green dots are the offshore platforms.

After the impact of Hurricane Ivan (2004), Hurricanes Katrina and Rita (2005), and Hurricane Ike (2008) in the Gulf of Mexico, a project to quantify the risk of the impacts of hurricanes to the valuable offshore structures was undertaken. The Gulf of Mexico Offshore Industry conducted detailed analysis of the impacts of hurricanes on offshore structures after Hurricane Andrew (1992) resulting in estimates of risk to offshore structures from hurricane impacts. These studies took an Andrew- type hurricane on thousands of tracks throughout the Gulf of Mexico oil leases. This information was used by drilling contractors, insurers and re-insurers to make hurricane risk decisions. Prior to 2005, there were over four thousand (4,000) offshore platforms in the Gulf of Mexico oil leases as well as thousands of miles of pipeline and Mobile Offshore Drilling Units [MODUs].

2. GULF OF MEXICO OFFSHORE HISTORY

During the threat of a hurricane over the Gulf of Mexico, the oil and natural gas production are shut-in for weeks. This reduces the amount of oil and natural gas that are produced each day by millions of barrels of crude oil and millions of cubic feet of natural gas. Hurricane Katrina in 2005 resulted in 105 days of shutdown resulting in the loss in the production of millions of barrels of oil and billions of cubic feet of natural Gas. [See Figure 2].

According to the US Energy Information Administration the shut-in production percentages of the normal monthly crude oil production type based on the type of tropical cyclone is 2.4% of normal for a tropical storm, 7.94% of normal for a Category 1 or 2 and 34.43% for a Category 3, 4 or 5 [on the Saffir/Simpson Scale]. The Shut-in production for Natural Gas Production would be 1.43% would be 1.43% of normal for a tropical storm, 5.02% for a category 1 or 2 hurricane and 30.83% for a category 3, 4, or 5 hurricane.

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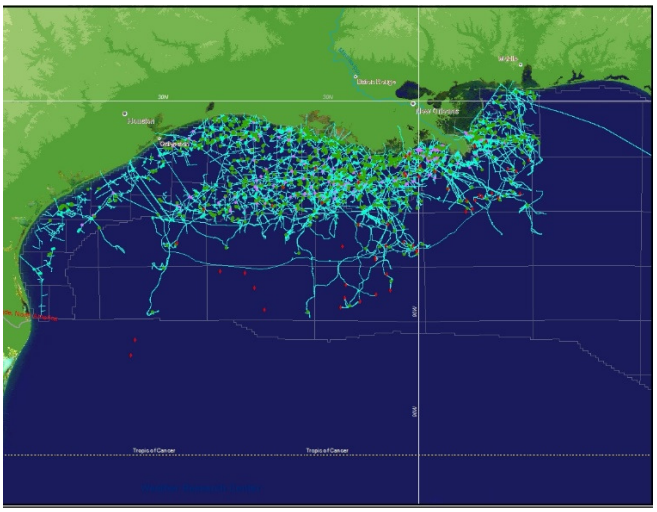


Figure 1: Gulf of Mexico Pipelines, Platforms and Mobile Offshore Drilling Units [MODUs]

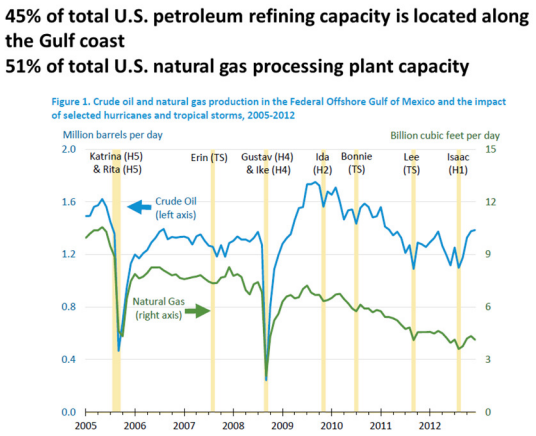


Figure 2: During a threat of hurricane in the Gulf of Mexico loss of production of barrels of oil and cubic feet of natural gas. Source: http://www.eia.gov/

Table 1 is a list of shut-in production caused by some of the significant tropical cyclones in the Gulf of Mexico from 1995 to 2014. Source is BSEE. Notice Hurricane Rita caused 70,476 million barrels of oil production to be shut-in which was 150.5 percent of normal. Rita also caused 361 billion cubic feet of natural gas production to be shut-in.

TABLE 1. HISTORICAL LIST OF SHUT-IN CAUSED BY SOME SIGNIFICANT TROPICAL CYCLONE

Maximum		Crude Oil			Natural Gas	
Name	Date	Cat	(Mb)	%	(Bcf)	%
Georges	Sep-98	2	7694	20.3	56.14	13
Isidore	Sep-02	3	4500	9.2	27.5	7.1
Lili	Oct-02	4	9900	20.2	61.5	16
Ivan	Sep-04	5	38005	82.8	150.71	42
Dennis	Jul-05	4	5297	11.7	23.25	7.6
Katrina	Aug-05	5	30248	64.8	155.33	51
Rita	Sep-05	5	70476	151	361.91	116
Wilma	Oct-05	4	8052	17.3	43.54	14
Gustav	Sep-08	4	38938	97.7	219.92	96
Ike	Sep-08	4	21531	54	121.6	53
Lee	Sep-11	0	4950	11.5	13.29	8
Isaac	Aug-12	1	13016	33.1	28.16	21

The significant damage caused to offshore structures from 2004 to 2008, from Hurricanes Ivan (2004), Katrina (2005), Rita (2005) and Ike (2008), lead to this research on finding a method to estimate the risk of such significant hurricanes to the Gulf of Mexico offshore structures. Prior to these hurricanes, Hurricane Andrew (1992) was used on various tracks through the Gulf of Mexico oil leases to determine the risk to the offshore structures.

The energy industry began drilling offshore Louisiana in the late 1930's and then expanded quickly after World War II. During this time period the impacts of hurricanes to the offshore operations was minimal. However, the industry quickly learned from observations (1947 to 1952) that the problem was to keep the waves from cresting on the decks.

When the industry first went offshore the belief at the time was that waves could not exceed 20 feet in water depths up to 100 feet. By the 1940's they expected a maximum wave height of 25 feet.

During the 1960s hurricanes returned to the Gulf of Mexico. The offshore industry experienced Hurricanes Carla (1961), Hilda (1964), Betsy (1965), and Camille (1969). After the 1964 and 1965 seasons, the industry met to discuss changes needed in design and offshore operations. During Category 5 Hurricane Camille (1969) a Shell platform experienced a 70 foot wave. The Industry met once again and determined that perhaps the air gaps for offshore structures should be set at 40 to 45 feet to keep the waves off of the decks.

Fortunately the number of significant hurricanes dwindled until Hurricane Andrew which moved through the leases in 1992. The offshore industry met again and determined that perhaps the air gaps should be increased to avoid the waves crashing into the decks. Figure 3 is a list of notable Category 5 Gulf of Mexico Hurricanes. Five of these significant hurricanes occurred in the 1960's.

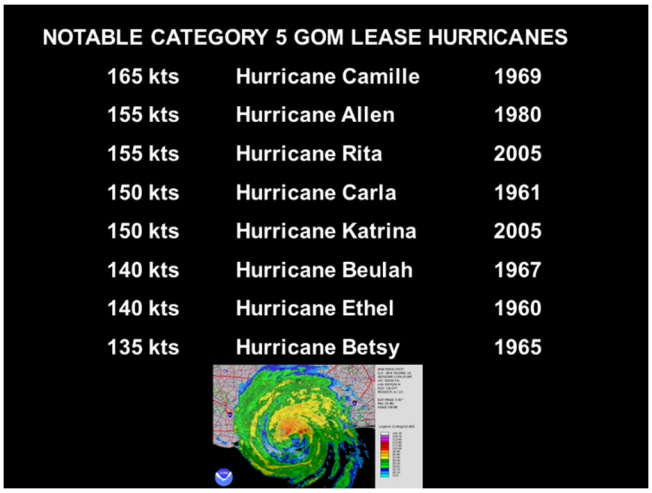


Figure 3: Notable Category 5 Gulf of Mexico Lease Hurricanes

Figure 4 shows the track of Hurricane Andrew (1992) with the location of the platforms in Gulf of Mexico. Hurricane Andrew was one of the most significant hurricanes to move through the oil leases since the large hurricanes of the 1960s. After World War II, the population of offshore production quickly grew from only a few offshore platforms operating to over 900 in the 1960's. See Figure 5 for a graph by year of the number of Gulf of Mexico platforms from 1942 to 2009. As of February 2016, there were 2,354 installed platforms.

3. WHY SIZE MATTERS

In 2005, there were over 3,900 platforms installed in the Gulf of Mexico Oil Leases represented by the green dots on the chart in Figure 4. After Ivan in 2004,Katrina and Rita in 2005 and Ike in 2008,it became clear that the size of the hurricane's wind field greatly impacted the number of platforms damaged. In order to document this observation, research was performed on some of the significant Gulf of Mexico hurricanes that have impacted the offshore oil leases.

This information was used to make hurricane risk decisions by insurers. Prior to 2005, there were over four thousand (4,000) offshore structures in the Gulf of Mexico oil leases.

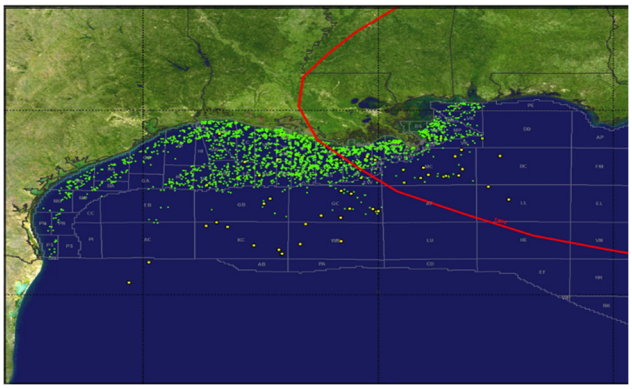


Figure 4: Track of Hurricane Andrew in 1992 through the Gulf of Mexico Oil Leases.

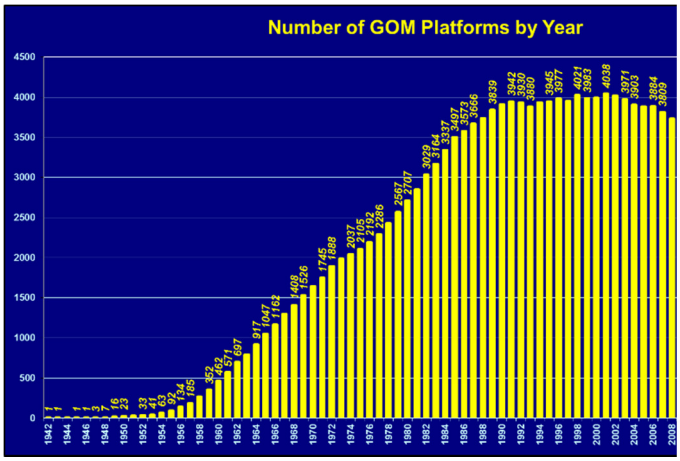


Figure 5: Number of Gulf of Mexico Platforms installed by year.

The WRC Hurricane Wind and Wave Model was used to compute the wind and wave fields for some of the significant hurricanes that have moved over the Gulf of Mexico oil leases. Figure 6 indicates the hurricane wind fields [maximum sustained winds of 64 knots or greater indicated by the yellow wind barbs] of some of the most significant Gulf of Mexico hurricanes. If you look at the wind field of Hurricane Camille on the right side of Figure 6 and compare it to the wind field of Hurricane Carla on the left side of the figure you can see that based on the area of the hurricane wind field that hurricanes vary greatly in size. The significant wave height fields and the wave crest fields were then computed for each of these hurricanes.

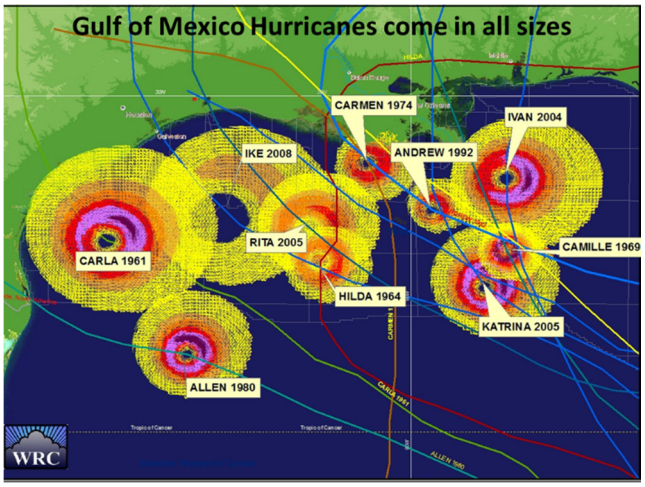


Figure 6: Hurricane wind fields of significant Gulf of Mexico Hurricanes in the Gulf of Mexico.

As the area of the hurricane force winds expands in the hurricane, the length of the fetches for the various wind directions increases, which in turn allows the wave heights to increase. Figure 7 is a graph showing that as the fetch increases for a certain maximum sustained wind speed, the wave height for that wind speed increases. Therefore “Size Matters” because the longer the fetch the higher the waves.

For this research, the size of the hurricane is based on the radius of hurricane force winds [R64]. Past Gulf of Mexico Hurricanes were reviewed and the radius of the hurricane force winds were determined for each hurricane. Figure 8 shows the radius of hurricane force winds for some past Gulf of Mexico hurricanes. This figure shows there have been 9 hurricanes with a radius of hurricane force winds [64 knot winds] of 80 nautical miles or more.

Using the WRC Hurricane Wind and Wave Model, the hurricane wind fields and wave fields were computed for the significant Gulf of Mexico Oil Lease Hurricanes. Figure 9 shows the cross section across the center of the wind field for these hurricanes. This cross section shows the distance in nautical miles on either side of the center of the hurricane the 64 knot winds extended. The orange line in this figure is the cross section of Hurricane Ike’s wind field. As you can see the radius of 64 knot winds for Ike had one of the largest extents of hurricane force winds that generated a large wave crest field of wave crest greater than 40 feet.

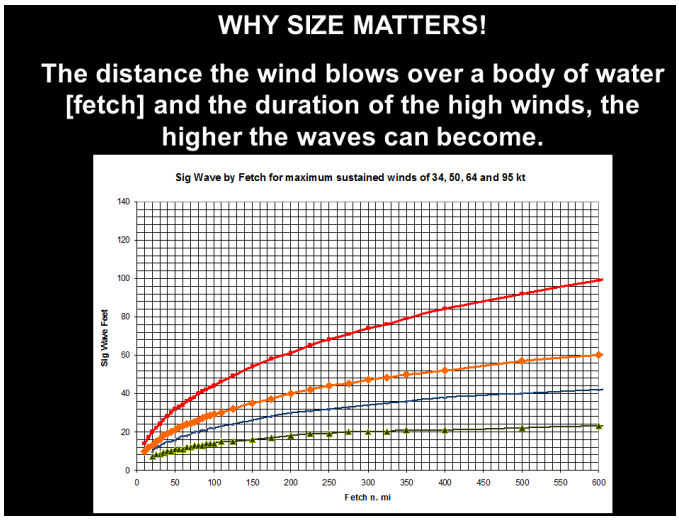


Figure 7: Significant Wave Height verses Fetch in nautical miles.

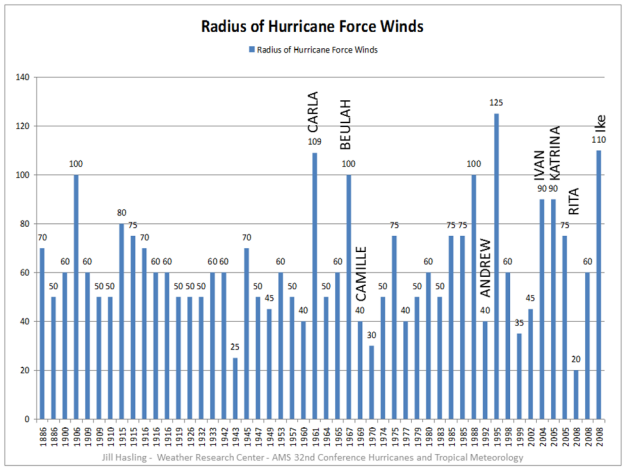


Figure 8: Radius of Gulf of Mexico Hurricane Force winds by Year.

Since the most damage caused to the offshore structures is the waves slamming into the decks, the wave fields both significant wave height, maximum wave height, and wave crest height for each of the hurricanes is then computed. Figure 10 shows the wave crest fields for these hurricanes. As you can see, the size of the hurricane's wave crest fields come in all sizes as well. If you compare Hurricane Camille's wave crest field with Hurricane Carla's wave crest field, you can see that a hurricane the size of Carla moving through the Gulf of Mexico oil leases would impact many more platforms and other offshore structures than the wave crest fields from Hurricane Camille's. Wave height is measured from trough to crest. The wave crest is the height of the wave from mean sea level. To determine how high the deck needs to be above mean sea level to avoid the wave crest slamming into the deck, one would want to know the wave crest height to set the best air gap [distance between the bottom of the deck to mean sea level.

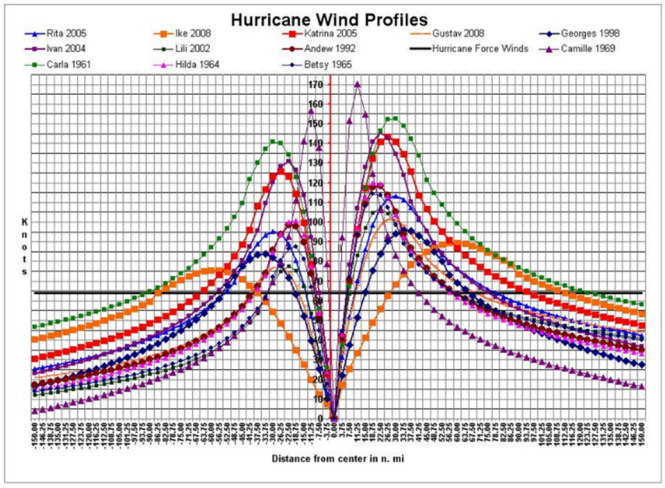
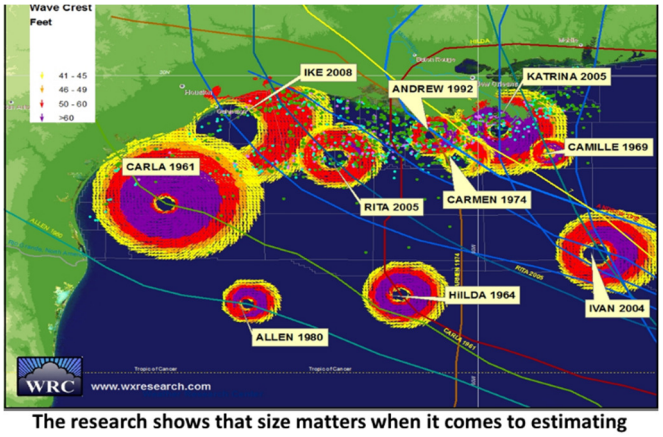


Figure 9: Cross Section of Gulf of Mexico Hurricane Wind Fields



The research shows that size matters when it comes to estimating the height of the waves in a hurricane in the Gulf of Mexico and what damage will be inflicted on the offshore properties.

Figure 10: Plot of Wave Crest for a few Gulf of Mexico Hurricanes.

Figure 11 shows the cross sections of the wave crests for some of the significant Gulf of Mexico hurricanes. This figures shows that the extent of the wave crest greater than 45 feet also vary. So in this figure, the orange line is the cross section of the wave crest for Hurricane Ike (2008). Even though Hurricane Ike only had maximum sustained winds of 95 knots due to the size of the hurricane based on the radius of hurricane force winds, there was a large area of wave crests greater than 45 feet.

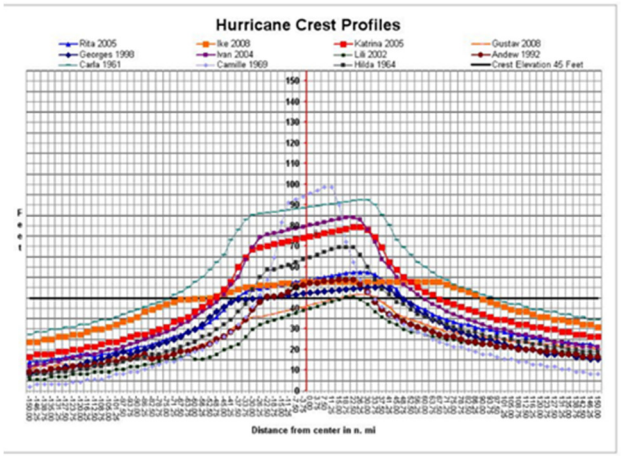


Figure 11: Cross Section of Gulf of Mexico Hurricanes Wave Crest. The black line indicates wave crest of 45 feet.

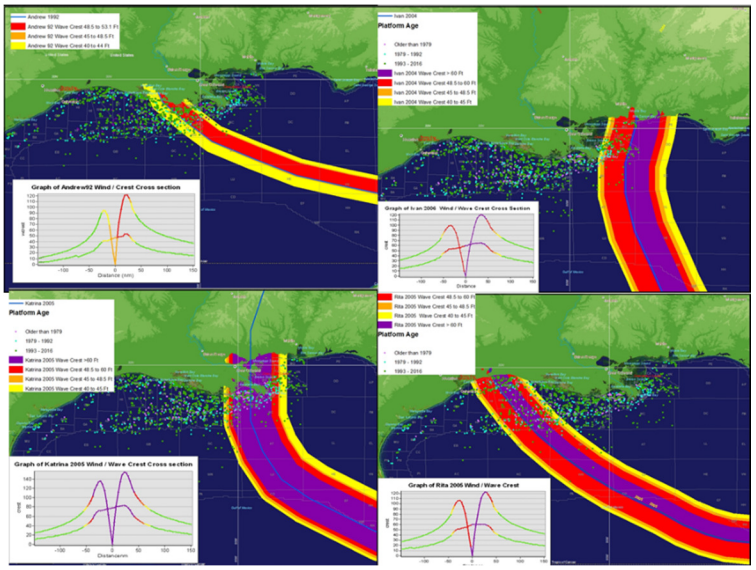


Figure 12: Wave Crest Swaths greater than 40 feet yellow, 45 feet orange, 48.5 feet red and greater than 60 feet purple for Hurricane Andrew 1992, Ivan 2004, Katrina 2005 and Rita 2005

4. HURRICANE SIZE IMPACTS

In order to determine the number of platforms that would be impacted by each of these hurricane, the area of various wave crests were plotted along the hurricane tracks called wave crest swaths. The yellow swaths are the wave crests 40 feet or greater, the orange swaths are wave crests greater than 45 feet, the red swaths are wave crests greater than 48.5 feet and purple swaths greater than 60 feet. Note if you have a wave crest of 60 feet, your maximum wave was about 90 feet. Figure 12 shows the wave crests swaths for Hurricane Andrew (1992), Ivan(2004), Katrina (2005), and Rita (2005).

Figure 13 shows the area of wave crest greater than 40 feet for Hurricane Ike in 2008. Even though Ike was a much weaker hurricane the area of wave crest greater than 40 feet was much larger than those of Hurricane Katrina and Rita which exposed hundreds of more offshore structures to possible damage.

Figure 14 is a table that shows the year, the number of platforms installed and the number of structures destroyed by each hurricane of the significant Gulf of Mexico Hurricane Leases. As you can see Hurricane Andrew (1992) destroyed 75 platforms out of the 3,930 installed. Using this information and then plotting the area of wave crest greater than 45 feet and the number of platforms exposed to wave crest of greater than 45 feet, a risk scale was developed.

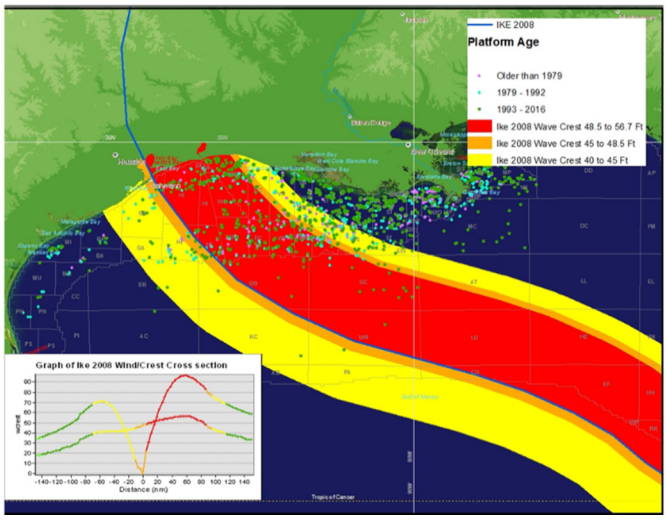


Figure 13: Wave Crest Swaths greater than 40 feet yellow, 45 feet orange, 48.5 feet red and greater than 60 feet purple for Hurricane Ike 2008.

Hurricane	Year	Structure Destroyed	Number of Platforms Installed	%
Grand Isle	1948	2	7	28.6
Carla	1961	3	571	0.5
Hilda	1964	14	917	1.5
Betsy	1965	8	1047	0.8
Camille	1969	3	1526	0.2
Carmen	1974	2	2037	0.1
Frederic	1979	3	2567	0.1
Juan	1985	3	3497	0.1
Andrew	1992	75	3930	1.9
Lili	2002	8	4020	0.2
Ivan	2004	7	3903	0.2
Katrina	2005	45	3877	1.2
Rita	2005	74	3877	1.9
Gustav	2008	1	3731	0.0
Ike	2008	59	3737	1.6
Total		307		

Figure 14: Number of offshore platforms destroyed versus the number of platforms installed.

5. HURRICANE DAMAGE POTENTIAL SCALE

From this research, a Hurricane Damage Potential Scale was developed so that the risk to the platforms exposed to the wave crests greater than 45 feet could be determined. This Scale is called the Freeman/Hasling Hurricane Damage Potential Scale and is based on the size, intensity, and number of platforms exposed to wave crest greater than 45 feet. See Figure 15. The scale uses the size of the hurricane determined by the radius of hurricane force winds and the number of platforms exposed to wave crests greater than 45 feet to determine the number of platforms that could be destroyed from a particular hurricane.

WRC

Freeman/Hasling Hurricane Damage Potential Scale

Wind and wave fields were then compared to Hurricanes Ivan, Katrina, Rita and Ike and a scale was developed to describe the impact from these hurricanes on offshore structures.

R64	<=30	>30	>=45	>=60	>=80
Saffir/Simpson					
1	1	1	1	4	5
2	1	1	1	5	5
3	1	1	1	5	5
4	1	1	2	5	5
5	1	2	3	5	5
Freeman/Hasling HDP Scale	1	2	3	4	5
HDP Percent	2%	4%	6%	8%	10%

Figure 15: Freeman/Hasling Hurricane Damage Potential Scale.

In order to test the scale and find worst case scenarios, the Freeman/Hasling Hurricane Damage Potential Scale was used to determine the risk for various types of hurricanes on the Galveston 1900 Hurricane track. Figure 16 shows the track of the 1900 Hurricane with the platforms indicated in green and the Mobile Offshore Drilling Units [MODUs] indicated in yellow. This past track was selected since it exposes the most offshore properties to the worst side of a hurricane moving through the Gulf of Mexico Leases.

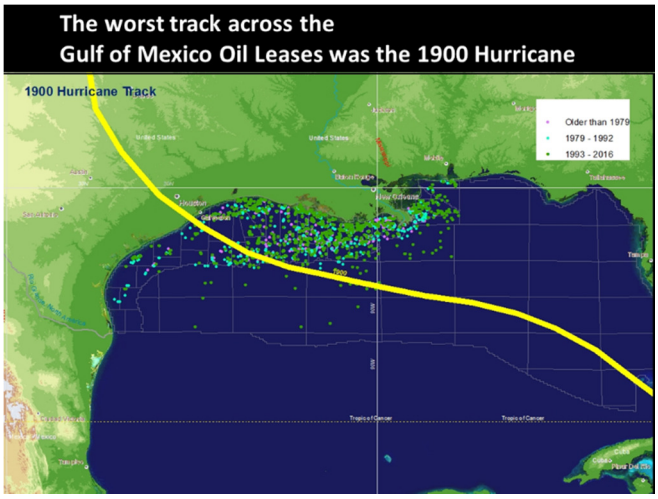


Figure 16: Track of the 1900 Galveston, Texas Hurricane through the Gulf of Mexico Oil Leases.

As of February 2016, there were 2,354 platforms installed in the Gulf of Mexico Oil Leases. Figure 17 shows the wave crest swaths of a Carla type hurricane along the 1900 hurricane track. Carla is the largest known hurricane to move through the Gulf of Mexico based on the radius of hurricane force winds. If a Carla type hurricane moves along a track similar to the 1900 Galveston Hurricane, 1,304 of the 2,354 platforms today would have been exposed to wave crest greater than 45 feet. A 45 feet wave crest is from a maximum wave height of 67 feet. A Carla type hurricane would have been a Category 5 Hurricane on the Freeman/Hasling Hurricane Damage Potential Scale. The estimated number of the 2,354 platforms that would have been destroyed were 130 platforms.

The same exercise was conducted on Hurricane Ivan (2004), Hurricane Katrina (2005), Hurricane Rita (2005) and Hurricane Ike (2008). The wave crest swaths are shown in Figure 18 for these four types of hurricanes on the 1900 track. The number of Gulf of Mexico Platforms exposed to wave crest greater than 45 feet are given in Figure 21.

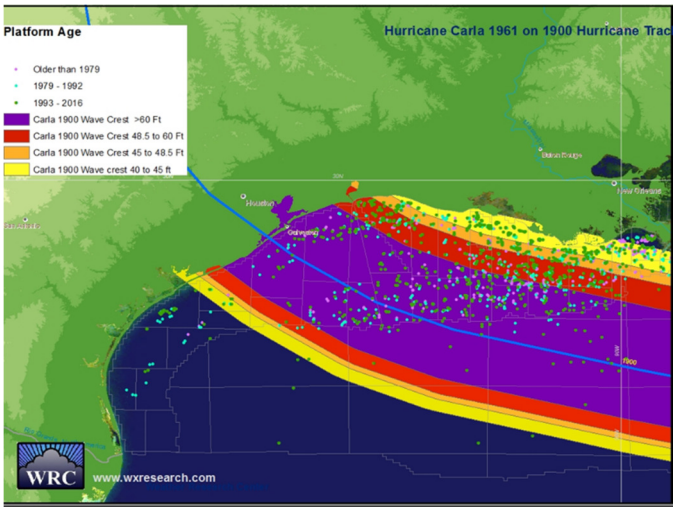


Figure 17: Wave Crest Swath of a Carla Type Hurricane along a track similar to the 1900 Galveston Hurricane. Yellow indicates wave crests greater than 40 feet, orange indicates wave crests greater than 45 feet, red indicates wave crests greater than 48.5 feet and purple indicates wave crests greater than 60 feet.

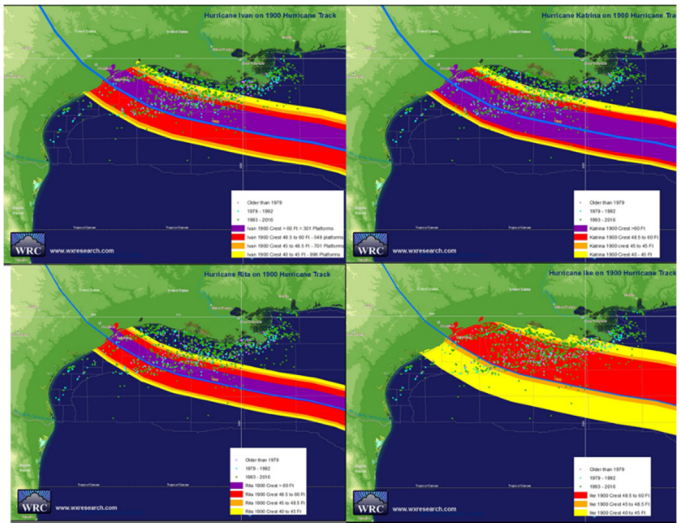


Figure 18: Wave Crest swaths for Ivan, Katrina, Rita and Ike type hurricanes on the 1900 Galveston Hurricane Track

Significant hurricanes from the 2015 season were also used to determine what type of impact they would have had on the Gulf of Mexico. From the Atlantic basin, Hurricane Joaquin was chosen. Joaquin was a category 4 hurricane which moved through the Bahamas. Figure 19 shows the wave crest on the 1900 Galveston Hurricane Track. Notice how much smaller the wave crest swath is compared with the Katrina type hurricane. Figure 20 gives the track of Hurricane Patricia from the East Pacific 2015 Hurricane Season. Hurricane Patricia was one of the strongest known hurricanes with a central pressure of 872 mbs and maximum sustained winds of 175 knots. When you plot the very strong hurricane's wave crest through the Gulf of Mexico on the 1900 track, notice how small the wave crest swath is.

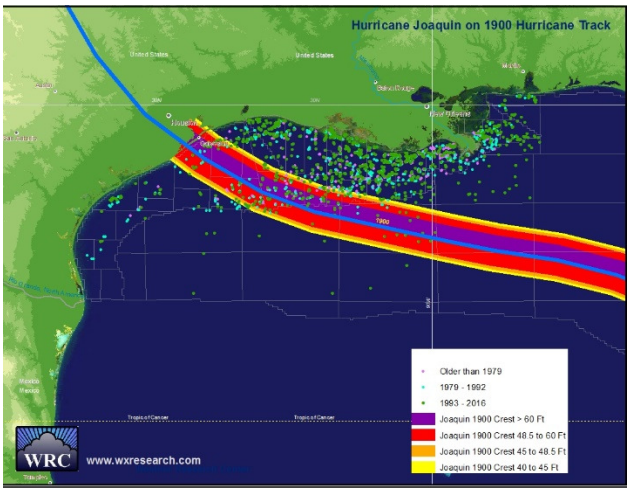


Figure 19: Hurricane Joaquin 2015 track, satellite, wave crest swath in Bahamas and wave crest swath on the 1900 Galveston Track

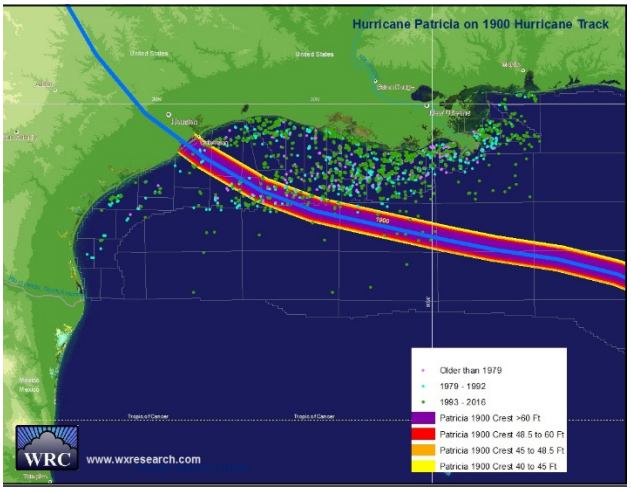


Figure 20: Hurricane Patricia 2015 track, satellite, streamlines and wave crest swath on the 1900 Galveston Track

In February 2016, Cyclone Winston became one of the strongest cyclones to impact Fiji with winds of 160 knots. Figure 21 shows the track of Winston as it moves through the Gulf of Mexico. Again, the wave crest swath is very small compared to Katrina and Rita.

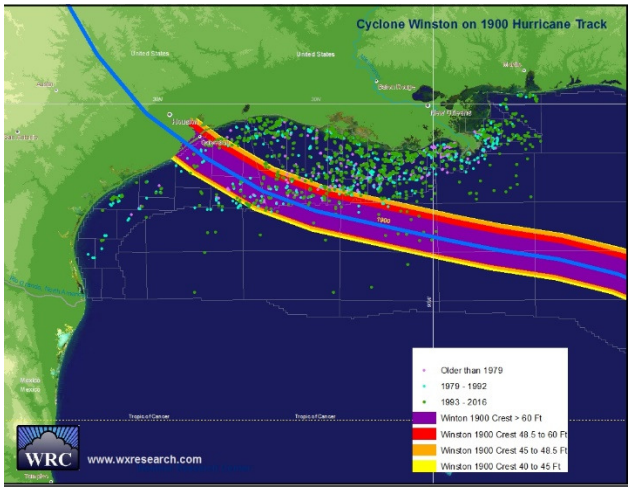


Figure 21: Cyclone Winston 2016 track, satellite, radar and wave crest swath on the 1900 Galveston Track

6. CONCLUSION

Figure 22 gives the table of the number of Gulf of Mexico offshore platforms that would have been impacted with each type of hurricane along a track similar to the 1900 Galveston Hurricane. An Ike type storm along the track of the 1900 hurricane would have exposed the most platforms, 1,391 to wave crest of greater than 45 feet and 1,107 platforms to wave crests greater than 48.5 feet resulting in 139 platforms being destroyed. On the other hand a Carla type hurricane would have exposed 1,304 platforms to wave crest greater than 45 feet, 997 platforms to wave crest greater than 48.5 feet and 531 platforms to wave crest greater than 60 feet with 130 platforms destroyed. Comparing this to a Patricia type hurricane with the strongest maximum sustained winds in this hemisphere, there were only 113 platforms exposed to wave crest greater than 45 feet, 89 platforms exposed to wave crest greater than 48.5 feet and 71 platforms exposed to wave crest greater than 60 feet. The number of platforms destroyed is expected to be over 2.

The interesting fact is that Ike, which was a weaker hurricane based on maximum sustained winds of 95 knots but a destructive storm based on size, that over 1,300 platforms were exposed to wave crest of 45 feet or higher.

What this table shows is that SIZE MATTERS more than the strength of the maximum sustained winds in the hurricane when it comes to estimating the risk to offshore structures in the Gulf of Mexico.

In conclusion, when a hurricane takes a similar path to the Galveston 1900 Hurricane and is the Size of Hurricane Carla over 130 offshore Structures could be damaged or destroyed.

GOM Hurricanes on 1900 Hurricane Track	Radius of 64 Kt Winds	# of Platforms Exposed to Wave Crest >45 Ft	# of Platforms Exposed to Wave Crest > 48.5Ft	# of Platforms Exposed to Wave Crest > 60 Ft	Freeman Hasling Scale	Estimated # of Platforms Destroyed
Feb 2017 - 2354 Platforms						
Carla 1961	110	1304	997	531	5	130.4
Andrew 1992	60	129	125	0	5	12.9
Ivan 2004	90	701	549	301	5	70.1
Katrina 2005	90	551	496	326	5	55.1
Rita 2005	75	389	324	132	5	38.9
Ike 2008	110	1391	1107	0	5	139.1
Joaquin 2015	60	220	188	0	5	22
Patricia 2015	25	113	89	71	1	2.26
Winston 2016	30	228	184	142	2	9.12

Figure 22: Summary of the number of GOM Lease Exposed to wave crest greater than 45, 48.5 and 60 feet and the estimated number of GOM Platforms destroyed.

7. REFERENCES

The Bureau of Safety and Environmental Enforcement (BSEE) http://www.bsee.gov/

U.S. Energy Information Administration http://www.eia.gov