Estimating Tropical Cyclone Threats to Floating Rigs in the Gulf of Mexico

R, Lopez[a], J. Ballesio[b], M. Worden[c], and R. Cross[d]
[a] SAIC, Houston, United States, Ricardo.A.Lopez@saic.com
[b] SAIC, Houston, United States, Jorge.E.Ballesio@saic.com
[c] Bureau of Safety and Environmental Enforcement, Houston, United States, Mike.Worden@bsee.gov
[d] National Aeronautics and Space Administration, Houston, United States, Robert.Cross-1@nasa.gov

Abstract: Offshore drilling operations in the Gulf of Mexico are particularly vulnerable during hurricane season. When a weather threat arises, a decision to evacuate the rig and/or move to a safe location may need to be made. Securing the well, evacuating, and/or moving to a safe location can take a considerable amount of time. This transition time is called T-time. T-time is not only rig dependent, but also depends on the activity being performed at the time of the threat. For these reasons, it is important to assess tropical cyclone threats and the estimated time it will take the storm to reach the rig location from the time it is first detected. The objective of this study is to use 50 years of cyclone history from a National Oceanic and Atmospheric Administration's (NOAA) database, the International Best Track Archive for Climate Stewardship (IBTrACS) to estimate cyclone threats at any location in the Gulf of Mexico.

The cyclone threat is estimated based on the rig location as well as the start date and duration of the offshore activity. By threat, it is meant the likelihood that a specific location with an associated offshore activity lies within the forecasted track cone and storm size of the upcoming cyclone. Three representative rig locations in the Gulf of Mexico were selected as assessment sites to evaluate the threat of incoming cyclones for different T-times. To conduct this tropical cyclone study, an Excel spreadsheet tool was developed to automate the analysis of the tropical cyclone data. The spreadsheet tool allows the user to input any location (i.e., longitude and latitude) in the Gulf of Mexico and displays a list of historical cyclones that have passed within 150 nautical miles of that location during the activity period selected by the user. In addition, the tool allows the user to input any T-time to assess the threat of cyclones that would not provide adequate time to secure the well, evacuate, and/or move to a safe location.

1. INTRODUCTION

The National Aeronautics and Space Administration (NASA), as part of an Interagency Agreement with the Bureau of Safety and Environmental Enforcement (BSEE), has evaluated the potential tropical cyclone threat to floating rigs in the Gulf of Mexico (GoM). In 2019, BSEE called for a project to compare the risk between a Mobile Offshore Drilling Unit (MODU) with a novel well control arrangement and a conventional DP drillship with subsea BOP [1]. In that study, it was assumed that both vessels would move off location in advance of any approaching tropical cyclone, therefore making it very unlikely that either vessel would be pushed off location. However, it was recognized that the time required to secure the well and move off location is different for different rig types, thus raising the need to understand the risk that tropical cyclones impose to operating rigs in the GoM. When a weather threat arises, and the decision to evacuate and/or move the rig is made, there are several activities to perform to safely secure the well, evacuate and/or move to a safe location. This transition time is called T-time, and it varies from rig to rig, configuration-to-configuration, and even for the specific activity being conducted at the time of the threat. For this reason, it is important to estimate cyclone threats in the GoM and the amount of time in advance that they provide from the time they are first detected until they reach the rig location. A separate study [2] was performed to evaluate cyclone threats in the GoM and is the basis for this paper.

The study's data was based on the National Oceanic and Atmospheric Administration's (NOAA) International Best Track Archive for Climate Stewardship (IBTrACS) version 4 [3][4]. The IBTrACS database provides the best and most complete track data for tropical cyclones worldwide. It combines information from numerous tropical cyclone datasets, combining all Regional Specialized Meteorological Centers and other international centers. For the purpose of this study, a subset of the database was used, covering the North Atlantic (NA) Ocean Basin and the period from 1970 to 2019 (50 years of data). This period was deemed to reflect the most accurate data due to modern weather forecasting tools such as satellite images.

The study has looked at the following subjects:

- General statistical data on cyclones based on the historical data.
- Concepts of cyclone forecasting and storm size.
- Estimation of potential threat of upcoming cyclones at selected locations in the GoM (frequency of potential threat based on the forecasted area to be affected by the cyclone).
- Evaluation of the historical frequency of cyclones passing within 150 nautical miles from selected locations of the GoM.
- Extrapolation of the historical frequency of cyclones to estimate the risk of cyclones hitting selected locations for any period in the future.

2. OBJECTIVE

The main objective of the study was to use the 50 years of past cyclone history to estimate future cyclone threats at selected locations in the GoM. By threat, it is meant the likelihood that a specific location lies within the forecasted track cone and storm size of an upcoming cyclone. Any rig at that location should anticipate the necessary activities for a potential disconnect and/or move to a safe location. Three representative rig locations in the GoM were selected as assessment sites to evaluate the threat of incoming cyclones for different required times to shutdown, secure the well, and evacuate the rig and/or move to a safe location (T-times). This evaluation can be used for offshore assets to decide whether and when to start those activities prior to an upcoming cyclone.

A secondary objective of the study was to assess the actual historical frequency of cyclone exposures at the three specific locations, as well as those cyclones that affected the location and were generated a specific number of “days out” from the location (T-time).

Cyclones follow a very distinct seasonal pattern; the probability of cyclone exposure for a rig that operates at a certain location only during a specific and limited period will be dependent on that period. With this in mind, the project was developed to consider specific seasonal patterns.

3. METHOD

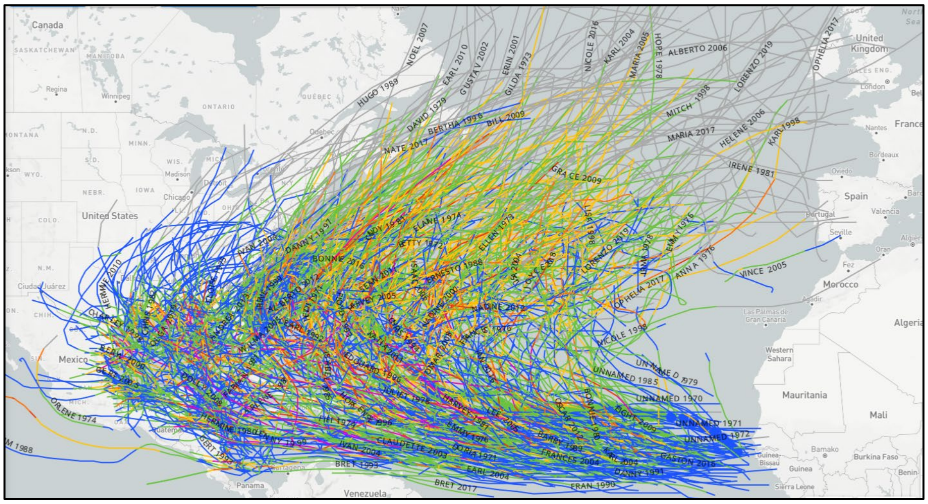
3.1 General Analysis of Historical Cyclone Data

A tropical cyclone is the generic term for a rapidly rotating storm system that originates over tropical (and sometimes subtropical) waters. Tropical cyclones in the North Atlantic are classified as follows:

- Tropical Depression (TD): A tropical cyclone with maximum sustained winds of 38 mph (33 knots) or less.
- Tropical Storm (TS): A tropical cyclone with maximum sustained winds of 39 to 73 mph (34 to 63 knots).
- Hurricane (H): A tropical cyclone with maximum sustained winds of 74 mph (64 knots) or higher. Hurricanes are classified according to their strength. The Saffir-Simpson scale classifies them into five categories based on their maximum sustained wind speed (H1 to H5). Hurricanes category 3 or higher are called major hurricanes (H3 to H5).

The data was downloaded in MS Excel format. Overall, there are 819 cyclones included in the "North Atlantic Ocean Basin" database during the 50 years. It is noted that some of these cyclones never reached the Gulf of Mexico. Figure 1 shows all 819 cyclone tracks together as obtained from the NOAA Historical Hurricane Tracks website [5].

Figure 1: All Cyclone Tracks from 1970 to 2019 in the North Atlantic Ocean Basin [5]



The analysis of general cyclone statistics in NA produced the statistics and graphs of interest described in subsections below.

3.1.1 Tropical Cyclones per Year

The maximum number of tropical cyclones (TD to H5) for the 50-year period was 31 in 2005 and the minimum count was 6 in 1983. The average number of cyclones over the 50-year period was 16.4 cyclones per year. The overall average for tropical storms per year is 5.82, for hurricanes is 6.32 and for major hurricanes is 2.48 per year. A data analysis was performed to fit a Poisson distribution to the number of cyclones in a year. Table 1 summarizes the results for the different cyclone categories.

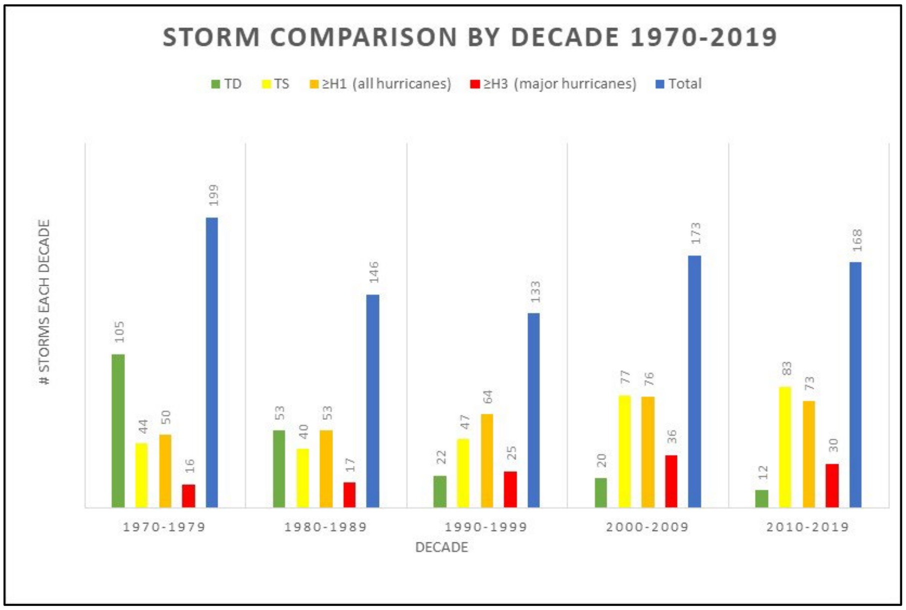
Table 1: Poisson Distribution Fit for Different Cyclone Categories (Cyclones/Year)

Category	Mean	St Dev
TD to H5	16.4	4.04
TS to H5	12.1	3.48
H1 to H5	6.32	2.51
H3 to H5	2.48	1.57

3.1.2 Tropical Cyclones per Decade

Figure 2 shows the number of cyclones (TD to H5) observed per decade, i.e., during each 10-year period from 1970 to 2019. The cyclones have been grouped based on their classification.

Figure 2: Number of cyclones for different categories each decade in the North Atlantic Ocean Basin

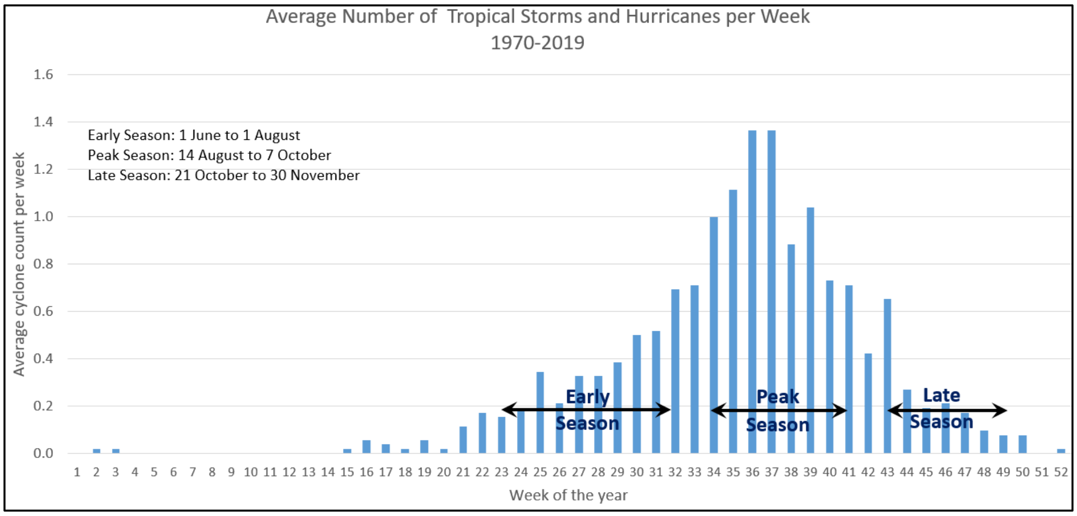


It is interesting to note that while the total number of cyclones is not showing any specific trend of increase/decrease over the 50-year period, the number of tropical storms and hurricanes has increased in recent years (on average) as the number of tropical depressions decreased. It is noted that during the last decade, there have been a slight decrease on the number of major hurricanes, but still higher than during any of the first three decades. Assuming that the reporting scope of tropical depressions has not changed in IBTrACS, this trend shows that it is becoming more likely for tropical depressions to evolve into stronger storm systems.

3.1.3 Tropical Cyclones per Week

Tropical cyclones exhibit a seasonal pattern. Figure 3 shows the average number of tropical storms and hurricanes for the period 1970 to 2019.

Figure 3: Average number of tropical storms plus hurricanes per week in the North Atlantic (1970-2019)



Note: Hurricane seasons taken from API RP 2MET [6]

3.2 Cyclone Track Forecasting

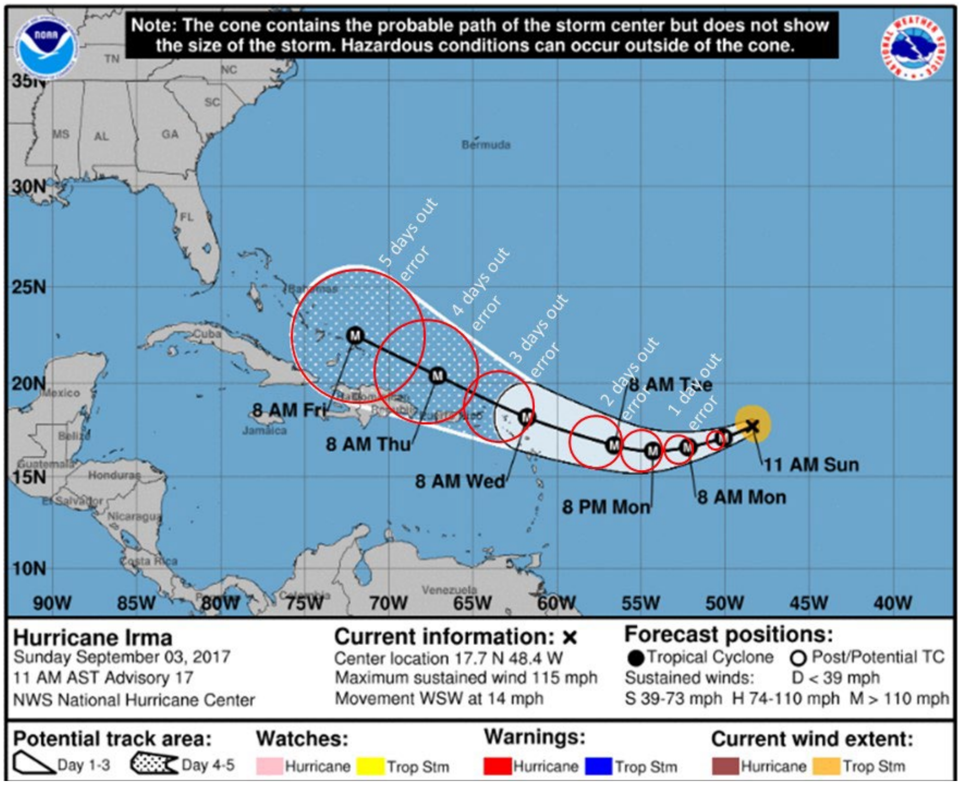
In the USA, the National Hurricane Center (NHC) has the responsibility for issuing advisories and U.S. watches/warnings for tropical cyclones for the Atlantic and east Pacific basins. These advisories are based on cyclone track forecasting, i.e., predicting path, size and strength of upcoming tropical cyclones.

NHC defines the track forecast cone [7] as the probable track of the center of a tropical cyclone and is formed by enclosing the area swept out by a set of circles along the forecast track (at 12, 24, 36 hours, etc.). The size of each circle is set so that two-thirds of historical official forecast errors over a 5-year sample fall within the circle. Table 2 shows the different circle radii defining the cones being used in 2020 for the Atlantic basin and Figure 4 illustrates an example of how the track forecast cone is built from these circle radii. The cone contains the probable path of the storm based on forecasts over the previous 5 years. The entire track of the tropical cyclone can be expected to remain within the cone roughly two-thirds (66%) of the time. This is important to keep in mind when looking at forecast cones: they are accurate 2/3 of the time, and 1/3 of the time the actual track may deviate from it.

Table 2: Radii of NHC Forecast Cone Circles for 2020 for the Atlantic Basin [7]

Forecast Period (hours)	2/3 Probability Circle, Atlantic Basin (nautical miles)
12	26
24	41
36	55
48	69
60	86
72	103
96	151
120	196

Figure 4: Example of 5-day track forecast cone (based on [8])



3.3 Tropical Cyclone Size

Another aspect to forecast the threat of a tropical cyclone is its size. The cone described in the previous section depicts the probable path of the eye of the cyclone, but does not show the size of the storm. The affected area of the cyclone will most likely exceed the area within the predicted cone. In order to consider this, it is necessary to evaluate storm sizes. Several metrics have been defined to characterize the size of a cyclone. One of this metrics, the “Critical Wind Radii” stores the radii around the center of the cyclone at which a critical surface wind speed is measured. There are several critical wind radii measures. For this study, the critical wind radii at which 34 knots wind speed is measured (R34) was used. 34 knots is the lower end tropical storm force wind speed.

Unfortunately, the IBTrACS database does not generally report the critical wind radius information. Only since 2003, some storms recorded this information. When reported, R values are usually reported by quadrant, since cyclones are not symmetrical. The R34 values reported in IBTrACS were evaluated every 24 hours to obtain a measure of the average R34 values over time. At each interval after storm generation, the reported R34 values for each storm and for each quadrant were evaluated and the maximum value reported is considered. Then all the maximum values reported at each time interval was averaged and recorded in Table 3.

Table 3: Average R34 values in nautical miles for cyclones at different time spans since storm generation

	1 Day	2 Days	3 Days	4 Days	5 Days	6 Days	7 Days	8 Days	9 Days	10 Days
Number of Storms with R34 Data	42	36	28	20	18	14	10	10	6	4
Average of Max R34 at Day N After Storm Generation	170	164	162	137	164	181	216	255	258	363

In general, it is assumed that T-Times for drilling activities are 6 days or less, and the average R34 values for cyclones generated between one and six days range from 137 to 181 nautical miles. It was not the purpose of the study to develop a model of cyclone sizes, so for simplification purposes, and based on the recorded data, it is assumed that cyclones, on average, have an R34 value of 150 nautical miles. In other words, for tropical storms and hurricanes, it is assumed that tropical storm force wind speeds can be found as far as 150 nautical miles from the storm center. To consider the threat area added by the size of the storm, it is necessary to add the storm size (150 nm) to the track error, since in the limiting scenario (within the 2/3 accuracy mentioned previously), the cyclone track could eventually be one of the two extremes (boundaries of the cone). In this case, the affected area would be extended 150 nm to each side. Table 4 shows the path error radius, and the path radius error plus the R34 value (150 nm) for different "days out", from 9 days to ½ day.

Table 4: Potential Threat Circle Due to an Upcoming Cyclone

Days Out (days)	Path Error Radius (nm)	Path Error Radius + R34 (nm)
9	342	492
8	304	454
7	266	416
6	228	378
5	196	346
4	151	301
3	103	253
2	69	219
1.5	55	205
1	41	191
0.5	26	176

3.4 Estimation of Potential Cyclone Threats

The general process followed to estimate the cyclone threat to a selected location in the gulf is as follows:

1. Select a location in the Gulf represented by its latitude and longitude

2. For each one of the 819 cyclones in the database corresponding to the period 1970 to 2019:

2.1. Determine the closest distance between the cyclone track (eye of the storm) along its whole path and the location of interest, and record this distance in the first record of this cyclone.
2.2. Calculate the time elapsed from the first record of the cyclone (assumed the cyclone origination) to the closest location identified above and record this time in the first record of this cyclone.
2.3. If the time calculated above is zero, it means that the storm is moving away from the location of interest and presents no threat to the location of interest.

3. Start with 9 days out calculations. The track error plus cyclone size for 9 days out is 492 nm (Table 4) Count how many cyclones were generated 9 days out or earlier from the location of interest (step 2.2), and count how many of those have closest distance between the eye and the location (step 2.1) less than 492 nm. Record the results.

4. Repeat step 3 for 8 days out calculations. The track error plus cyclone size for 8 days out is 454 nm (Table 4). Count how many cyclones were generated 8 days out or earlier from the location of interest (step 2.2), and count how many of those have closest distance between the eye and the location (step 2.1) less than 454 nm. Record the results.

5. Repeat step 3 for the rest of days out: 7, 6, 5, 4, 3, 2, 1.5, 1 and 0.5 days out using the corresponding track error plus cyclone size from Table 4. Record the results.

3.5 Assessing the Risk of Cyclones

The previous section described the evaluation of threats at specific locations presented by upcoming hurricanes based on their track forecast cone and storm size. Such evaluation is used for offshore assets to decide whether and when to shutdown, evacuate and/or move off location prior to an upcoming cyclone. In this section, the objective is to use the 50 years of cyclone history to assess the actual historical frequency of cyclone hits at those same specific locations in order to estimate risk. To illustrate the difference between threat and risk it is noted that an upcoming cyclone can, for example, present a threat to a specific location 5 days before arrival (track forecast cone 5 days out plus storm size encompasses the location). However, when this storm eventually reaches the closest point to the location of interest, it may or may not affect the location of interest depending on the actual path. This storm is then counted as contributing to the threat of that location 5 days out. However, if this storm eventually does affect the location of interest (based on the assumption of tropical storm force winds extending a radius of 150 miles from storm center) then the storm is counted as contributing to the risk estimation for that location. On the contrary, if this storm eventually does not affect the location, i.e., its actual track is more than 150 miles away from the location, then it is not counted as contributing to the risk estimation for that location.

4. RESULTS

Three representative rig locations in the GoM were selected as assessment sites, to evaluate the threat of incoming cyclones for different required times to shutdown, secure the well, and evacuate the rig and/or move to a safe location (T-times). These locations correspond to the sites of three deepwater developments: Atlantis, Perdido and Appomattox.

Based on the 50 years of cyclone history the threat of incoming cyclones for different required times to secure the well and evacuate the rig and/or move to a safe location (T-times) were evaluated. Table 5 shows a sample comparison for T-time 6 days versus 3 days, for the three locations. For example, the following observations are made for the Atlantis location:

- With a T-time equal to 6 days, it is estimated, on average, that a rig at the Atlantis location would have to initiate shutdown/move to safe location activities 0.58 times/year (or 1 time every 1.72 years), assuming it operates year round
- With a T-time equal to 3 days, it is estimated, on average, that a rig at the Atlantis location would have to initiate shutdown/move to safe location activities 0.84 times/year (or 1 time every 1.19 years), assuming it operates year round
- With a T-time equal to 6 days, it is estimated that for each cyclone that is generated 6 days or more away from it, on average, there is a 16.3% probability that its track forecast cone plus the storm size will encompass the Atlantis location.
- With a T-time equal to 3 days, it is estimated that for each cyclone that is generated 3 days or more away from it, on average, there is an 11.5% probability that its track forecast cone plus the storm size will encompass the Atlantis location.

Table 5: Comparison of cyclone threat estimates for three locations and two T-times (6 days vs 3 days)

N days out or T-time [days]	Location	Total cyclones N days out from location (threat and non-threat)	Total cyclones N days out from location where forecast cone + storm size affects location (threat)	Average cyclones per year N days out from location where forecast cone + storm size affects location (threat)	Percentage of threat cyclones N days out from location relative to all (threat and non-threat) N days out
6	ATLANTIS	178	29	0.58	16.3%
3	ATLANTIS	365	42	0.84	11.5%
6	PERDIDO	187	27	0.54	14.4%
3	PERDIDO	379	32	0.64	8.4%
6	APPOMATTOX	184	33	0.66	17.9%
3	APPOMATTOX	374	51	1.02	13.6%

Using the actual historical frequency of cyclone hits, the Excel tool allows selecting a specific period by entering a start date and a duration of the drilling operation. The following cyclone frequency observations are made for the Atlantis location for a rig operating from 24 May to 22 July (Table 6):

- Of all the named cyclones (tropical storms and hurricanes) in the NA, it is expected (based on 50 years of history) that 9.39% of them would be passing within 150 nautical miles of the Atlantis location, 6.92% of them would be passing within 150 nautical miles of the location (if generated less than 6 days out from this location), and 5.93% of them would be passing within 150 nautical miles of the location (if generated less than 3 days out from this location).
- Of all hurricanes (Categories 1 to 5) in the NA, it is expected (based on 50 years of history) that 8.54% of them would be passing within 150 nautical miles of the Atlantis location, 5.06% of them would be passing within 150 nautical miles of the location (if generated less than 6 days out from this location) and 3.80% of them would be passing within 150 nautical miles of the location (if generated less than 3 days out from this location).

Table 6: Cyclone risk estimates by storm category at Atlantis location

Storm Category	Location	Expected average tropical cyclone count for period May 24 – July 22 (60 days)	Percentage of cyclone relative to all North Atlantic cyclones
TD-H5	Anywhere in North Atlantic	2.54	100%
TD-H5	Within 150 nm from location	0.248	9.77%
TS-H5	Anywhere in North Atlantic	1.54	100%
TS-H5	Within 150 nm from location	0.145	9.39%
TS-H5	Within 150 nm from location, generated less than 6 days out	0.107	6.92%
TS-H5	Within 150 nm from location, generated less than 3 days out	0.092	5.93%
H1-H5	Anywhere in North Atlantic	0.463	100%
H1-H5	Within 150 nm from location	0.0395	8.54%
H1-H5	Within 150 nm from location, generated less than 6 days out	0.0234	5.06%
H1-H5	Within 150 nm from location, generated less than 3 days out	0.0176	3.80%

To highlight the tropical cyclone risk dependency with T-time, the study developed tables showing the estimated percentage of all NA tropical storms that eventually (on average) would hit each one of the three locations within 150 nautical miles with less than T-time days of advance notice. The estimates assume year round operation, so for specific times the estimates would vary depending on the time of the year of the operation. The percentages from these tables were graphically represented as shown in Figure 5 and Figure 6 and a logarithmic curve fit was produced for each location. This logarithmic fit produces a reasonably good fit, with R-square (coefficient of determination) higher than 0.94 in all cases. While the percentages and the curve fits are represented by lines, in reality there are error bands associated with them. This study did not evaluate those uncertainties, but they should be kept in mind when using this information for decision-making. As an example, the study compared threats between two rigs with different T-times for one same location (Atlantis). In this example, a rig operating in the Atlantis location with an operational T-time = 6 days has a 33% higher chance of being hit by a by a hurricane with less than the rig's operational T-time advance notice than a rig with an operational T-time = 3 days at that same location (see Figure 6). This example highlights the importance of evaluating rig designs and operational profiles with their associated T-times to better understand the potential risks posed by tropical storms.

Figure 5: Percent of TS to H5 estimated to pass within 150 nm of each location with advance notice less than T-time (year round operation)

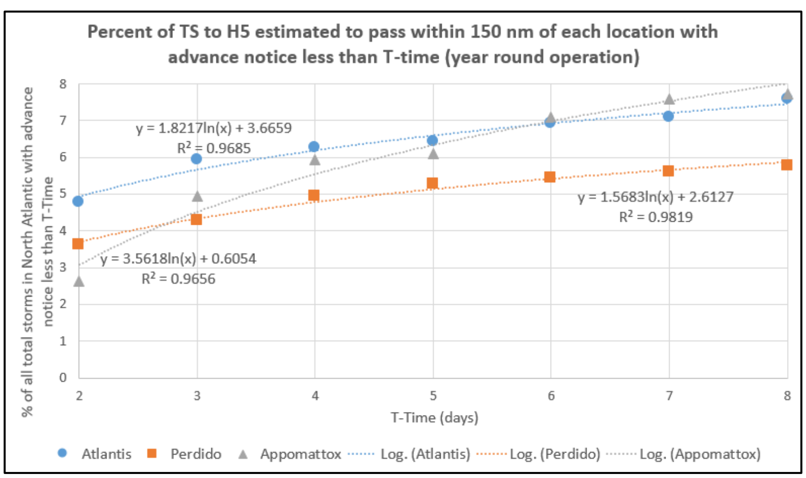
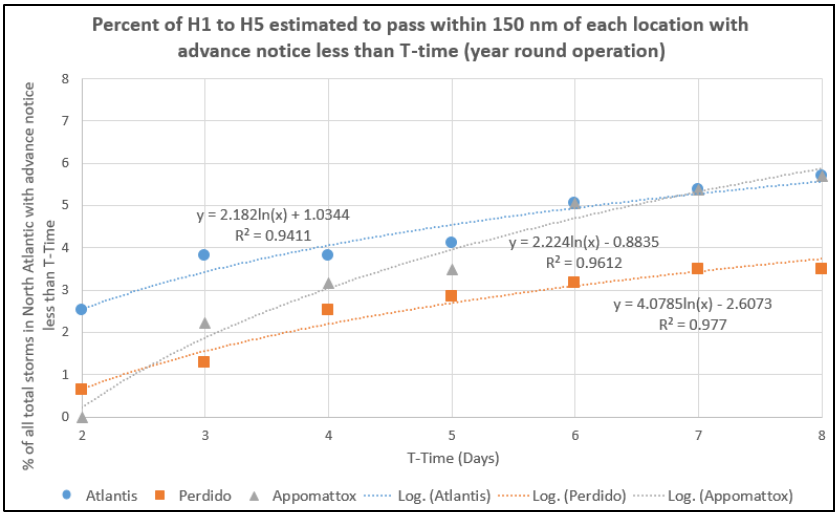


Figure 6: Percent of H1 to H5 estimated to pass within 150 nm of each location with advance notice less than T-time (year round operation)



There are some limitations to this study:

- The tropical storm database used generally contains data starting at the time when the storm becomes a tropical depression. However, with modern weather monitoring, tropical disturbances are identified prior to becoming a tropical depression, so the area can be tracked from an earlier time period and preparations to shutdown, secure the well, and evacuate the rig and/or move to a safe location would have longer lead times.
- The study assumes the R34 radii of a cyclone as a threshold to determine if a facility is affected by the cyclone. The R34 is the critical wind radii at which 34 knots wind speed is measured, and in this study, it is an approximate average over all storm strengths. Generally, the stronger the storm, the wider the wind radius for tropical storm winds and vice versa. In addition, this study assumes storms are symmetrical, which is not usually the case.
- The estimations are made based on the forecast cone. The National Hurricane Center defines the size of the cone based on historical official forecast errors over a 5-year sample. It is set so that two-thirds of historical official forecast errors fall within the circle. In other words, the projected paths are accurate 2/3 of the time, and 1/3 of the time the actual track may deviate from it.
- The T-times are considered point values in this study. For example, if the T-time is 5 days, the operator would move off location if a threatening cyclone is five or more days away, but they would not move if the cyclone is less than 5 days away and they have not started well securing activities. Inclusion of uncertainty for T-times can produce results that are more realistic. Additionally, the study did not look into any excess risk if the operator decides to perform the activities to safely secure the well, evacuate and/or move to a safe location in a shorter time than their protocols indicate.

5. CONCLUSIONS

This study highlights the importance to understand the amount of time in advance that approaching tropical cyclones provide before they reach the rig location. Consideration of this information is very important to ensure the best chance for securing a well and most importantly getting the crew to safety, whether moving off location or evacuating the rig in the case of a moored vessel. The longer the T-time, the higher the risk of being hit by a tropical cyclone that does not give enough notice to be able to safely secure the well, evacuate and/or move to a safe location. As new rig technologies are developed in the GoM, it is important to thoroughly understand their associated T-times during all phases of operation and evaluate them with the estimated tropical cyclone profile for their location. For example, a rig operating in the Atlantis location with an operational T-time = 6 days has a 33% higher chance of being hit by a by a hurricane with less than the rig's operational T-time advance notice than a rig with an operational T-time = 3 days at that same location.

Acknowledgments

The authors gratefully acknowledge numerous technical conversations and inputs from Earl Shanks, Russell Hoshman and Bobby Nelson of BSEE and useful contributions from the BSEE Regional Office in New Orleans.

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