JSC-SAA-NA-30099-03

National Aeronautics and
Space Administration

RELEASE DATE: 03/25/2021

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

Prepared for:
Bureau of Safety and Environmental Enforcement (BSEE)

Prepared by:
Risk and Reliability Analysis Branch
Safety & Mission Assurance Directorate
Johnson Space Center (JSC) S&MA

NASA Interagency Agreement E16PG00012

DISCLAIMER

ACKNOWLEDGEMENTS

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

Revision and History Page

Revision No.	Description	Release Date
JSC-SAA-NA-30099-03-DRAFT	Draft for BSEE Review	01/28/2021
JSC-SAA-NA-27135-03	Final 508 compliant report	03/25/2021

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Acronyms and Abbreviations

Acronym/ Abbreviation	Description
API	American Petroleum Institute
BOP	Blow Out Preventer
BSEE	Bureau of Safety and Environmental Enforcement
DP	Dynamic Positioning
EDT	Eastern Daylight Time
GoM	Gulf of Mexico
H1	Hurricane Category 1
H2	Hurricane Category 2
H3	Hurricane Category 3
H4	Hurricane Category 4
H5	Hurricane Category 5
IBTrACS	International Best Track Archive for Climate Stewardship
JSC	Johnson Space Center – NASA
NA	North Atlantic
m	meters
MODU	Mobile Offshore Drilling Unit
nm	nautical miles
NASA	National Aeronautics and Space Agency (USA)
NOAA	National Oceanic and Atmospheric Administration (USA)
NHC	National Hurricane Center (USA)
R34	Critical wind radii at which 34 knots wind speed is measured
R64	Critical wind radii at which 64 knots wind speed is measured
S&MA	Safety and Mission Assurance
TD	Tropical Depression
TS	Tropical Storm
UTM	Universal Transverse Mercator

1 EXECUTIVE SUMMARY

1.1 Introduction

In this report, 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 (disconnectable) moored Dynamic Positioning (DP) Mobile Offshore Drilling Unit (MODU) with a surface Blowout Preventer (BOP) plus subsea isolation device and a DP drillship with subsea BOP [1]. In that study, it was mentioned that the DP MODU or drillship would move off location in advance of any approaching tropical cyclone, therefore making it very unlikely that either type of rig 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 the rig and/or move to a safe location is made, there are a number of activities to perform in order 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 underway 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 before they reach the rig location.

The study was mainly based on the National Oceanic and Atmospheric Administration's (NOAA) International Best Track Archive for Climate Stewardship (IBTrACS) version 4 [2]. The IBTrACS database provides the best and most complete track data for tropical cyclones worldwide. For the purpose of this study, a subset of the database was used, covering the North Atlantic (NA) and the period from 1970 to 2019 (50 years of data). This time 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 where the rig location is 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 of time in the future.

1.2 Objective and Procedure

The first part of the study involved the analysis of general cyclone statistics in the NA for the 50 years of data (1970 to 2019), as reported in IBTrACS. Different types of analysis were performed: number of cyclones per decade, per year, per week and per day. Histograms of number of cyclones in a year were developed.

The next objective of the study was to use the available 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 would be exposed to an upcoming cyclone whose forecasted track cone and storm size lies within that location, and therefore any rig at that location should consider activities for a potential disconnect and 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 is used for offshore assets to decide whether and when to start those activities prior to an upcoming cyclone.

The subsequent part of the study was to assess the actual historical frequency of cyclone exposures at the three specific locations in order to estimate risk of future cyclone hits. The study performed the analysis assuming year-round operations conducted at the selected locations. However, since cyclones follow a very distinct seasonal pattern, the cyclone risk for a rig that operates at a certain location only during a specific and limited period of time will be dependent on that time period. With this in mind, the project was expanded to enable specific time operations. The study estimated the anticipated cyclone count to hit different locations (within 150 nautical miles), as well as those cyclones estimated to hit the location that were generated a specific number of "days out" from the location (T-time).

1.3 Results and Conclusions

Based on the available 50 years of past cyclone history 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). Table 1-1 shows a sample comparison for T-time 6 days versus 3 days, for the three locations. 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 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 storm size will encompass the Atlantis location.

Similar observations regarding the Perdido and Appomattox locations are also found in Table 1-1.

Table 1-1: 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 in existence N days out from location (threat and non-threat)	Total cyclones in existence N days out from location for which forecast cone + storm size affects location (threat)	Average cyclones per year in existence N days out from location for which forecast cone + storm size affects location (threat)	Percentage of threat cyclones in existence 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%

In regards to the actual historical frequency of cyclone hits at the three specific locations, the following observations are made for the Atlantis location (Table 1-2):

- 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).
- Similar observations are made for the Perdido and Appomattox locations.

Table 1-2: Cyclone risk estimates by storm category at Atlantis location

Location #1: ATLANTIS	**Percentages relative to all North Atlantic cyclones**
Expected tropical cyclone count (TD-H5) during activity duration (anywhere in North Atlantic)	**100%**
Expected tropical cyclone count (TD-H5) during activity duration to pass within 150 nm from location	9.77%
Expected tropical cyclone count (TS-H5) during activity duration (anywhere in North Atlantic)	**100%**
Expected tropical cyclone count (TS-H5) during activity duration to pass within 150 nm from location	9.39%
Expected tropical cyclone count (TS-H5) during activity duration to pass within 150 nm from location generated less than 6 days out	6.92%
Expected tropical cyclone count (TS-H5) during activity duration to pass within 150 nm from location generated less than 3 days out	5.93%
Expected hurricane count (H1-H5) during activity duration (anywhere in North Atlantic)	**100%**
Expected hurricane count (H1-H5) during activity duration to pass within 150 nm from location	8.54%
Expected hurricane count (H1-H5) during activity duration to pass within 150 nm from location generated less than 6 days out	5.06%
Expected hurricane count (H1-H5) during activity duration to pass within 150 nm from location generated less than 3 days out	3.80%

Based on the results of the specific locations, it is important to understand the amount of time in advance that approaching tropical cyclones provide before they reach the rig location 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 a T-time = 6 days has a 33% higher chance of being hit by a by a hurricane with less than the rig's T-time advance notice than a rig with T-time = 3 days at that same location.

To highlight the tropical cyclone risk dependency with T-time, the study developed tables showing the estimated percentage of all NA tropical storms that would eventually (on average) 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 time periods 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 1-1 and Figure 1-2 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. An example using the figures is shown in the report comparing two scenarios for one same location. The example indicated that the risk of being caught on location by a tropical storm or hurricane is two times higher for a rig with T-time of 7.5 days when compared to a rig with T-time of 2.5 days operating in the same location year round. This example highlights the importance of evaluating rig designs and operational profiles with their associated T-times in order to better understand the potential risks posed by tropical storms.

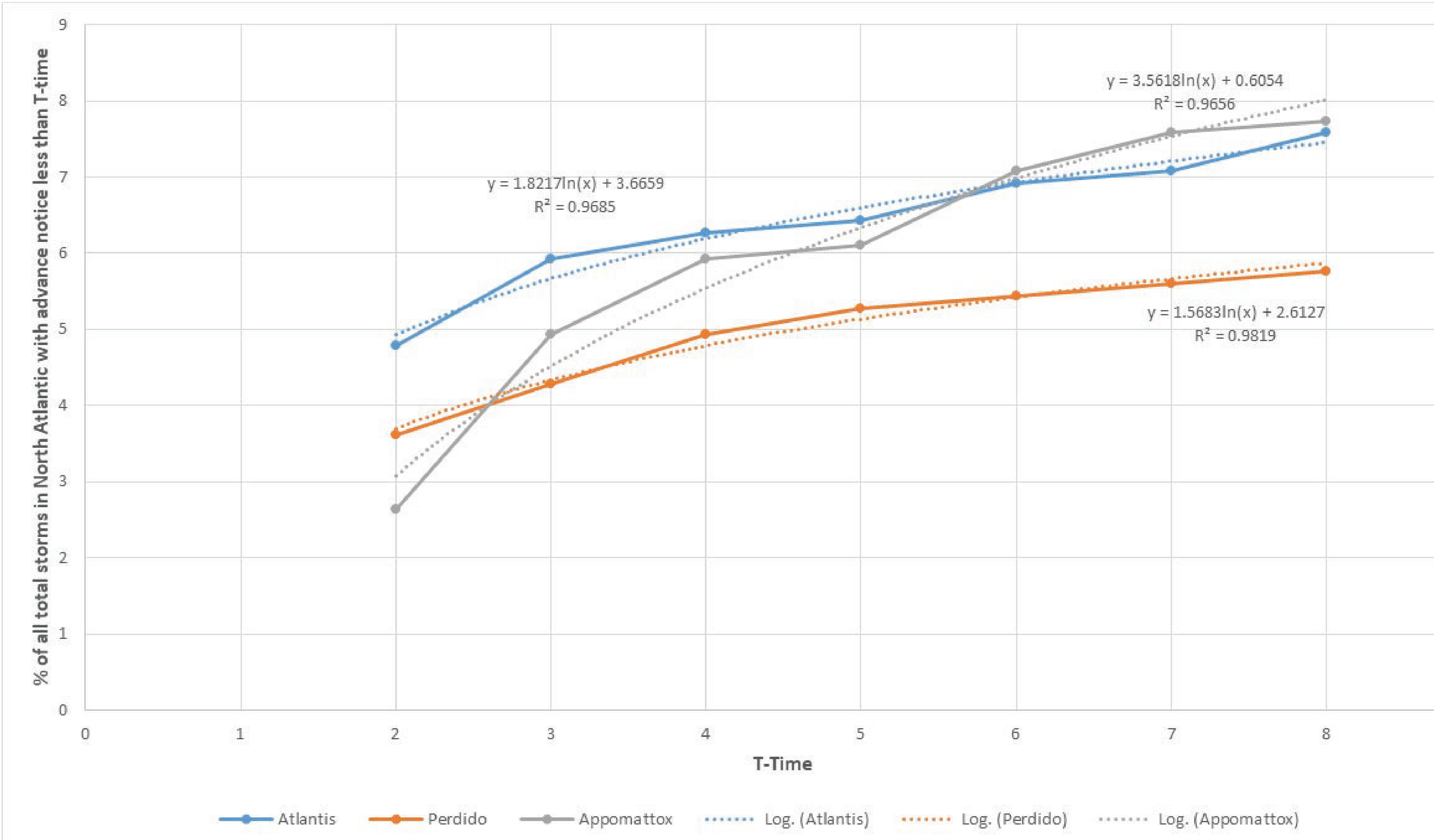


Figure 1-1: Percent of TS to H5 estimated to pass within 150 nm of each location with advance notice less than T-time (year round operation)

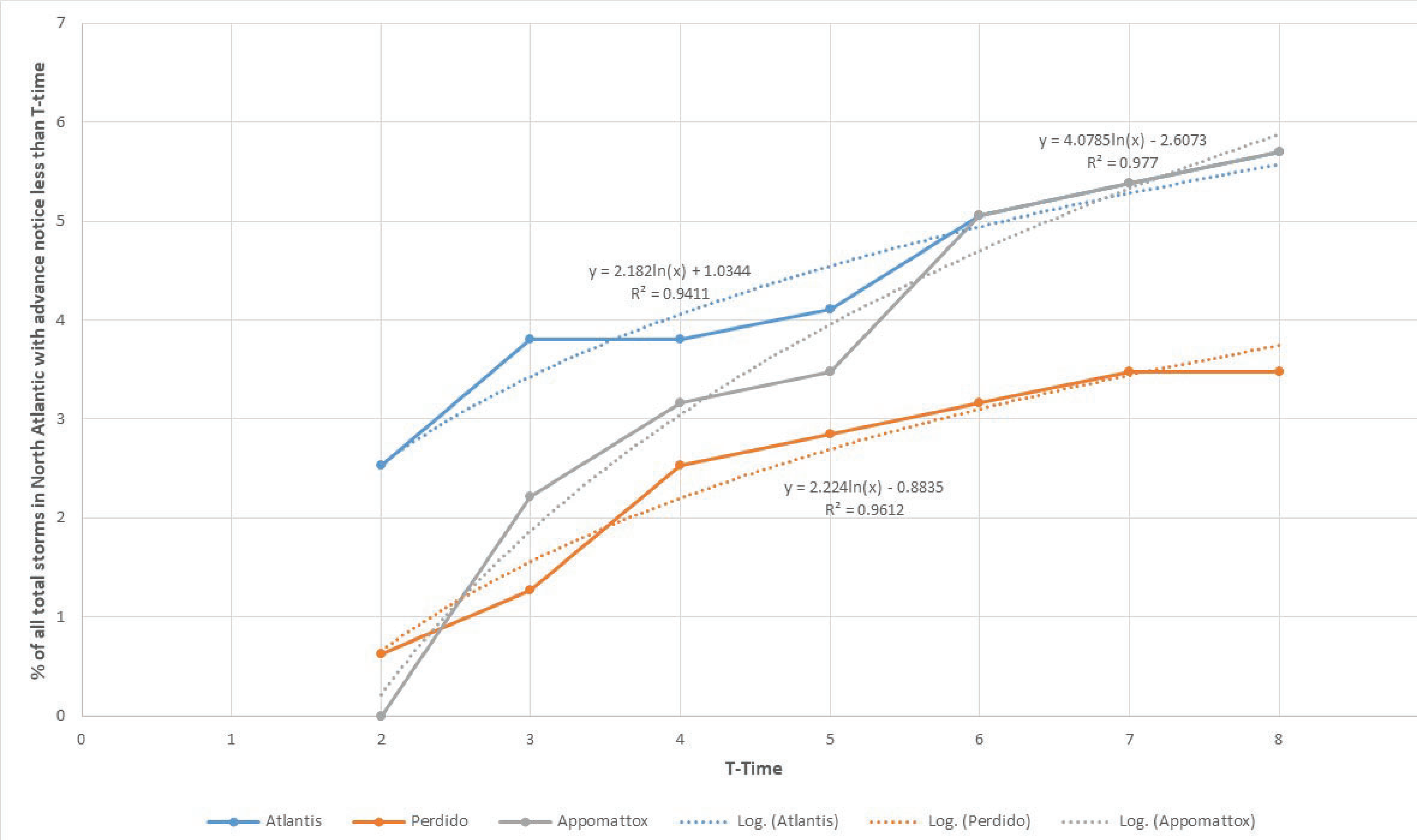


Figure 1-2: Percent of H1 to H5 estimated to pass within 150 nm of each location with advance notice less than T-time (year round operation)

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 critical wind radii at which 34 knots wind speed is measured (R34) used in this study to determine if a facility is affected is an approximate average over all storm strengths. Generally, the higher the storm strength, the wider the wind radius for tropical storm winds and vice versa. Also, this study assumes storms are symmetrical, which is not usually the case.
- The estimations are made based on the forecast cone. According to the National Hurricane Center, one third of cyclones deviate from the project path and move outside the cone.
- The T-times are considered point values in this study. In reality they are estimated times, and the operators could speed up activities somewhat if a threatening cyclone is approaching. The inclusion of uncertainty could take this into account. However, the study did not look into this, and just assumed that if T-time is say 5 days, the operator would move off location if a threatening cyclone is up to five days away, but they would not move if the cyclone is less than 5 days away and they have not started well securing activities. 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.

2 INTRODUCTION

A tropical cyclone is the generic term for a rapidly rotating storm system that originates over tropical (and sometimes subtropical) waters. It is characterized by a low-pressure center, a closed low-level atmospheric circulation, strong winds, and a spiral arrangement of thunderstorms that produce heavy rain or squalls.

One important parameter that describes cyclones is the maximum sustained surface wind speeds occurring within the circulation of the system. These winds are those observed or estimated to occur at the height of 10 m (33 ft) above sea surface in an unobstructed exposure. Maximum sustained wind speeds in the NA are reported in knots (nautical miles per hour). One knot is 0.514 meters/sec or 1.151 miles per hour.

Tropical cyclones in the NA 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: 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 (Table 2-1). Hurricanes Category 3 or higher are called major hurricanes.

Table 2-1: Hurricane Classification according to the Saffir-Simpson Scale

Category	Miles per Hour	Meters per Second	Knots
1 (H1)	74-95	33-42	64-82
2 (H2)	96-110	43-49	83-95
3 (H3)	111-129	50-57	96-112
4 (H4)	130-156	58-69	113-135
5 (H5)	$\geq$157	$\geq$70	$\geq$136

The official Atlantic hurricane season is June 1st to November 30th every year, with the most severe storm activity generally occurring in August, September and October. Hurricanes do occur outside of these six months, but these dates were selected to encompass over 97% of tropical activity. Tropical cyclones outside the season primarily occur in May or December.

In this project, a cyclone database for the NA was downloaded and its data evaluated to estimate different statistical measures related to the threat of cyclones at different locations in the GoM, and at different times of the year. The report is divided into the following sections:

- Section 3 describes the cyclone database used in the project.
- Section 4 presents general statistical data on cyclones based on the historical data.

- Sections 5 and 6 introduce the concepts of cyclone forecasting and storm size used in this project.
- Section 7 evaluates the threat of upcoming cyclones for three selected locations in the GoM.
- Sections 8 and 9 present statistics of past cyclones and evaluate the frequency of cyclones passing within 150 nautical miles from three selected locations in the GoM, including the option to select specific dates of operation during the year.

3 CYCLONE DATABASE

The data source for the project is NOAA's IBTrACS version 4 [2]. 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. The data span from the year 1848 to the present, providing storm data characteristics generally at 3-hour intervals.

For the purpose of this study, a subset of the database was used, as follows:

1. Only NA storms were included
2. Storms between 1970 to 2019 (50 years of data)
3. Only the database fields relevant to the study were downloaded.

The data was downloaded in spreadsheet format. Overall, there are 819 cyclones included in the NA database during the 50 years. It is noted that some of these cyclones never reached the GoM. Figure 3-1 shows all 819 cyclone tracks together as obtained from the NOAA Historical Hurricane Tracks website [3].

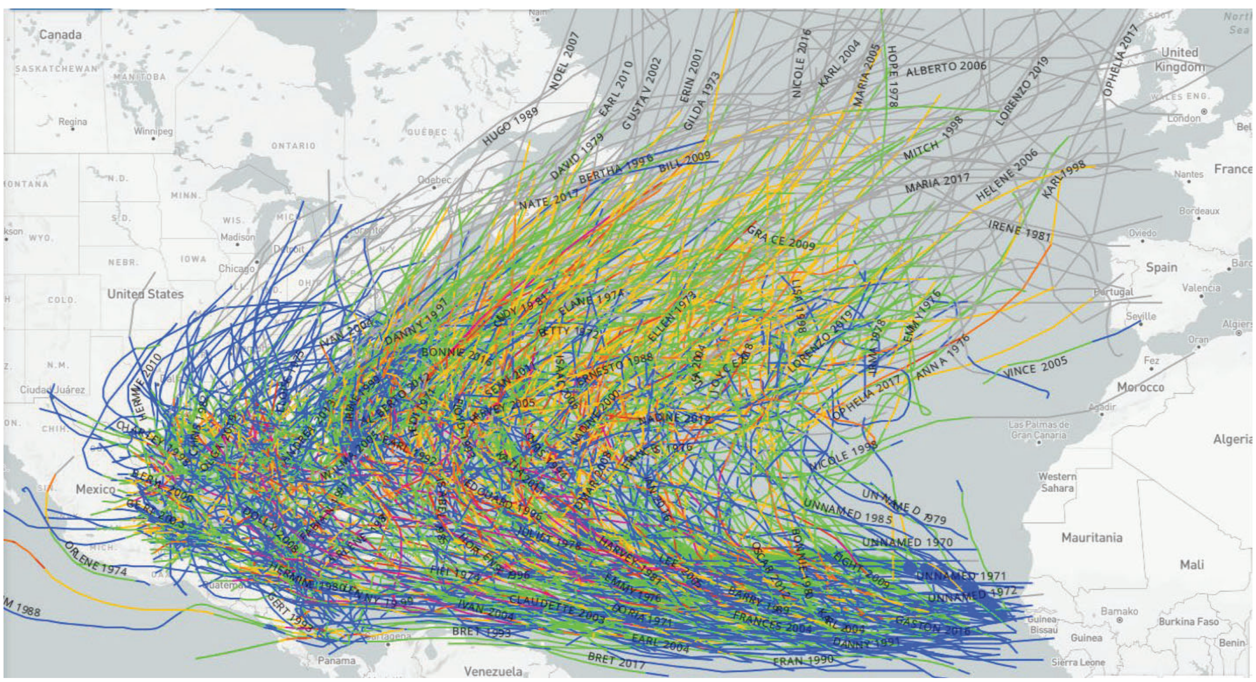


Figure 3-1: All Cyclone Tracks from 1970 to 2019 in the North Atlantic

Table 3-1 lists all the fields included in the spreadsheet file. Some of these fields are coming straight from IBTrACS [12], while others are fields calculated internally from those (fields in italics in Table 3-1). Some fields include data only for the first record for each cyclone because they represent summary data for the whole storm, rather than for each record in time. These fields are marked with an * in Table 3-1.

Table 3-1: List of downloaded database fields with descriptions

Database Field	Description
SID:	Unique storm identifier
SEASON:	Year when the storm originated
NUMBER:	Order number of the storm within each year (count includes all basins, so the North Atlantic numbers are not continuous)
BASIN:	Basin where the storm originated (for this project, only NA: North Atlantic)
SUBBASIN:	Sub basin where the storm originated (for this project, CS: Caribbean Sea, GM: Gulf of Mexico, NA: North Atlantic)
NAME:	Named of the storm, if given
Storm #:	Sequence number assigned to each storm as part of this project (across all years)
ISO_TIME:	International Standard date and time notation. Format is YYY-MM-DD hh:mm:ss. Most points are provided every 3 hours, every 6 hours in some cases, and for important observations, e.g., landfall)
**Day of the Year:*	Sequence number of the day of each year in which the storm occurred (extracted from the ISO_TIME field), e.g., January 1st is day #1, Jan 2nd is #2, and successively till day #365 (there is a one day shift for leap years, but its effect was ignored)
**Week of the Year:*	Sequence number of the week of each year in which the storm occurred. The system used assumes that the week starts on Sunday, and week #1 is the week containing Jan 1st. (extracted from the ISO_TIME field)
**Year:*	Year in which the storm originated (extracted from the ISO_TIME field)
**Include (peak) /Exclude (non-peak):*	Field added to filter storms based on origination date, for example peak season vs non-peak season (peak season being 14 August to 7 October according to API definition)
Time Interval:	Time difference between one storm entry and the next, within the same storm (usually 3 hours) [hours]
Cumulative Time:	Elapsed time from the first record of each storm to the current record [hours]
Storm Type:	Combined storm type (DS: Disturbance, TS: Tropical, ET: Extratropical, SS: Subtropical, NR: Not reported)

Database Field	Description
LAT:	Location latitude of the eye of the storm at each record
LON:	Location longitude of the eye of the storm at each record
Distance between intervals:	Calculated distance between the previous record storm location to the current record
Speed of storm during previous time interval:	Calculated speed of storm during previous storm location to the current record location (based on distance between the two locations and time interval)
Distance to point of interest at each time interval:	Calculated distance between the storm record location to the location of interest (as the crow flies) [nautical miles]
**Nearest distance to point of interest:*	Shortest distance between the eye of the storm and the location of interest, along the whole storm track [nautical miles]
In Radius:	Number indicating whether the storm record location is within three predefined circles around the location of interest (3: within R3 circle, 2: within R2 circle, 1: within R1 circle, 0: Outside all circles)
**ETime From Time-0 To Nearest Point:*	Elapsed time from the first record of each storm to the time when the eye of the hurricane reaches its closest distance to the location of interest [hours]
**Corrected time to deduct 12 hrs due to early arrival of tropical storm force winds:*	Same as above, but deducted 12 hours to account for the earlier arrival time of tropical storm winds before the eye reached the closet point to the location of interest
**Wind at Nearest Point*	Recorded maximum sustained storm wind at the point where the eye of the storm is nearest the location of interest [knots]
**Radius of Interest Reached*	Label to indicate if the eye of the storm passed within the three predefined circles (Greater than Radius3: Eye passed outside the three circles; Radius3 - Radius2: Eye passed within the R3 circle, Radius2 - Radius1: Eye passed within the R2 circle, 0 - Radius1: Eye passed within the R1 circle)
**Within radius and storm originated between n days out and previous days out:*	Label to indicate if the eye of the storm passed within the three predefined circles and the storm was generated between "days out" and "previous days out" (the number of days out are indicated in the top table as labeled, and the label is the same as described in the previous field)
**Moving Away from Point of Interest:*	Flag to indicate whether the storm is moving way or not from the location of interest, at the time of storm generation (MOVING AWAY: storm is not presenting a threat to the location of interest, THREAT: storm is moving in a direction closer to the location of interest
WMO Wind:	Maximum sustained storm wind speed at each interval recorded by NOAA National Hurricane Center, 1 min average speed [knots]
**Distance to point of interest @ Max Wind:*	Distance between the eye of the storm and the location of interest at the point where the storm has recorded its highest wind speed along its whole life span [nautical miles]
**Max Wind Anywhere:*	Maximum storm wind speed recorded along its whole life span [knots]
**Max Storm Classification:*	Maximum storm classification based on the "maximum wind anywhere" field described above and using the Saffir-Simpson hurricane wind scale

Database Field	Description
**Distance from location of interest @ Max. Wind In Radius1:*	Distance between the eye of the storm and the location of interest at the point where the storm has recorded its highest wind speed within the R1 circle (N/A recorded if the storm never passed within the R1 circle) [nautical miles]
**Max Wind Speed in Radius1:*	Maximum storm wind speed recorded within the R1 circle (if the storm passed within that circle, otherwise 0 is recorded) [knots]
**Storm Classification within Radius1:*	Maximum storm classification within the R1 circle, based on the "Max wind speed in Radius1" field described above and using the Saffir-Simpson hurricane wind scale (N/A is recorded if the storm never passed within the R1 circle)

* Field filled only for the first record in each storm because it is a parameter applicable to the whole storm
Fields in italics are added fields or calculated fields not included in the IBTrACS data, but computed from them.

4 GENERAL ANALYSIS OF HISTORICAL CYCLONE DATA

This section presents general statistics of the cyclones in the NA for the 50 years of data (1970 to 2019), as reported in IBTrACS and downloaded in a spreadsheet file.

4.1 Number of Cyclones per Year

Figure 4-1 shows a plot of the number of all cyclones generated each year from 1970 to 2019. The maximum number of cyclones 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 16.83 cyclones per year.

Figure 4-2: Number of tropical storms and hurricanes each year plots the tropical storm and hurricane counts observed each year during the study period. An increase of count in both tropical storms and hurricanes is noted in the last 20 years as compared to the first 30 years, on average. The overall average for tropical storms per year is 5.82 and for hurricanes is 6.32.

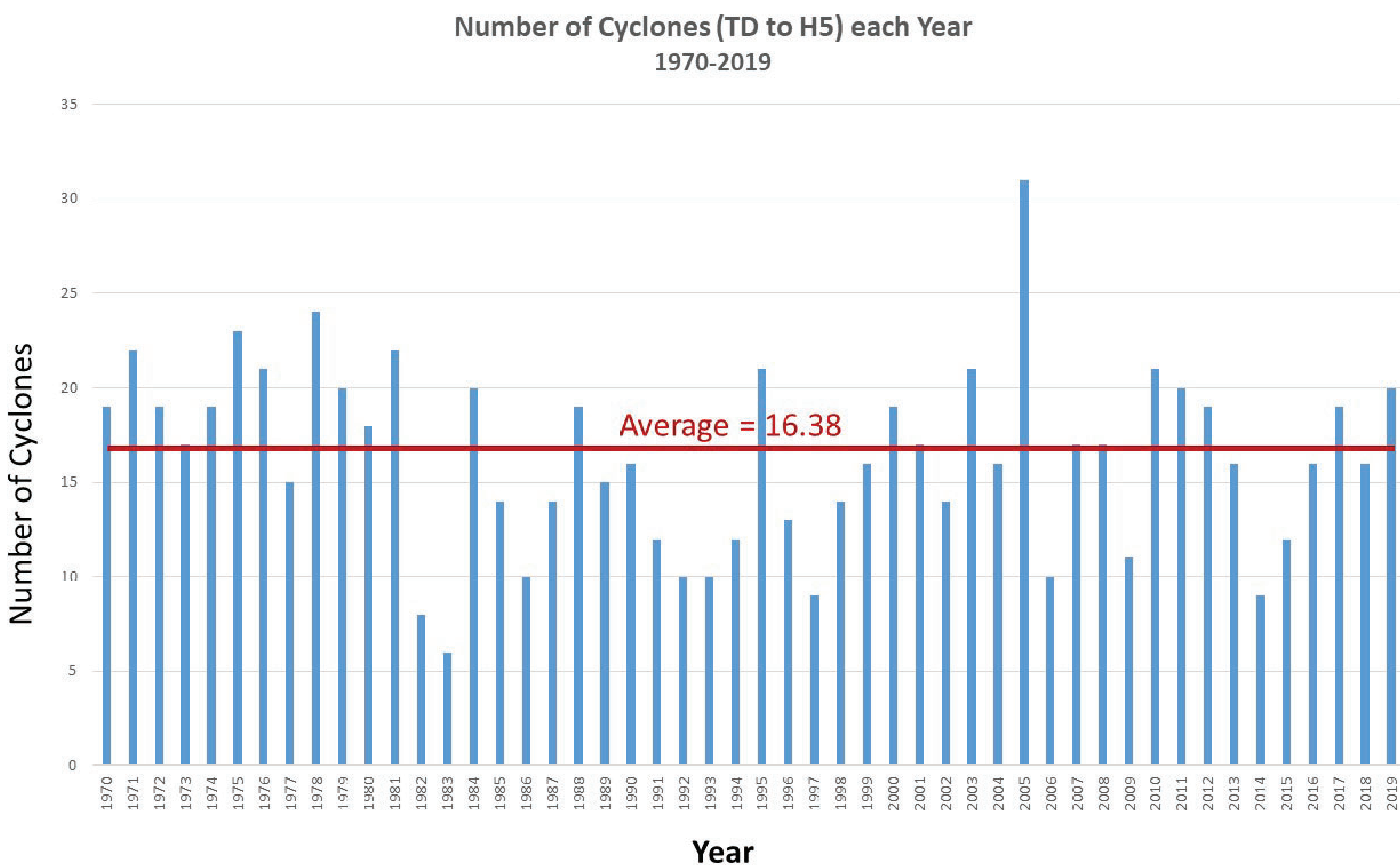


Figure 4-1: Total number of cyclones (TD to H5) each year in the North Atlantic

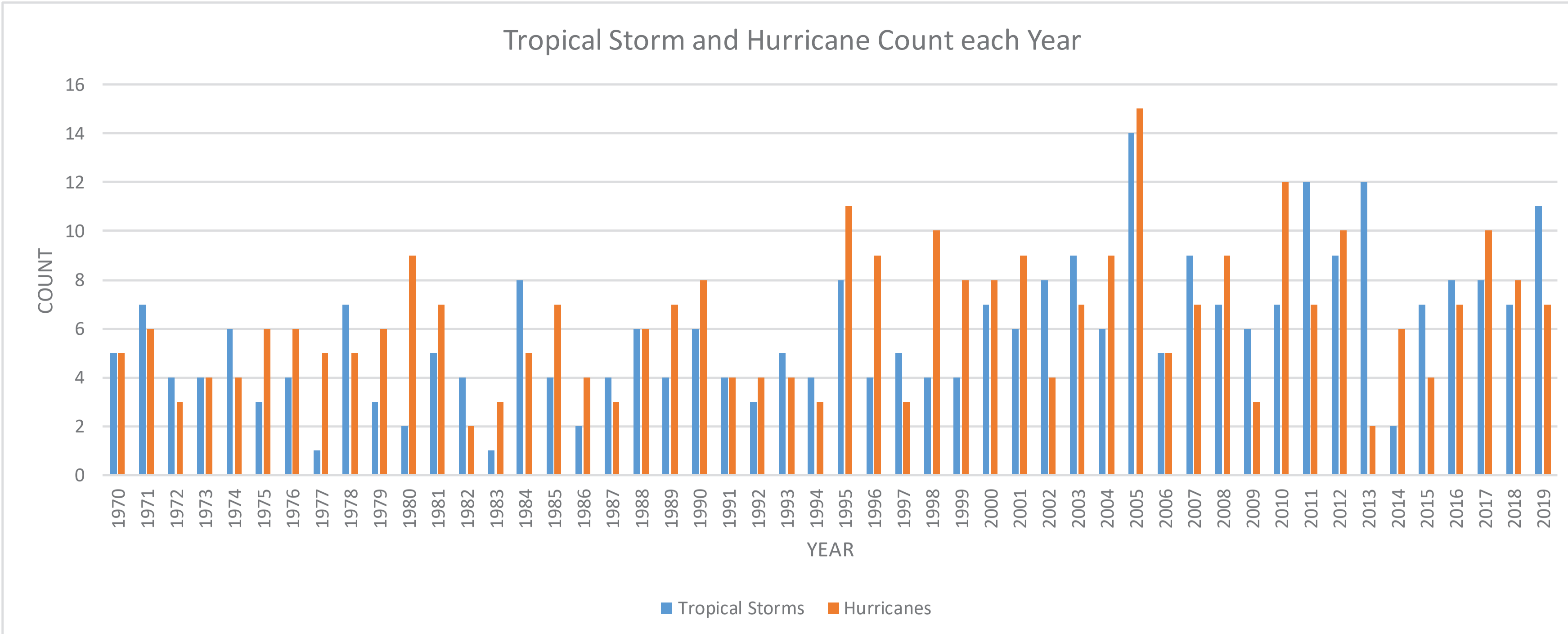


Figure 4-2: Number of tropical storms and hurricanes each year in the North Atlantic

Figure 4-3 shows the histogram of number of cyclones (tropical depressions to hurricane Category 5) in a year. The horizontal axis represents the number of cyclones counted in a year, and the vertical axis represents how many years such count was observed. For example, 6 cyclones in one year was only observed once in the period 1970-2019. There have been 7 years with a count of 19 cyclones. And only one year with an extreme count of 31. It is observed in the plot that there is considerable "statistical noise" in this histogram. This noise can be reduced by collecting data for more years, or by drafting a histogram grouping more storm counts per bin, for example bin #1: 1 to 3 storms, bin #2: 4 to 6 storms, and so on. The histogram was analyzed using a statistical tool [4], and a Poisson distribution with a mean of 16.38 and a standard deviation of 4.05 was found to be a good fit for the observed data.

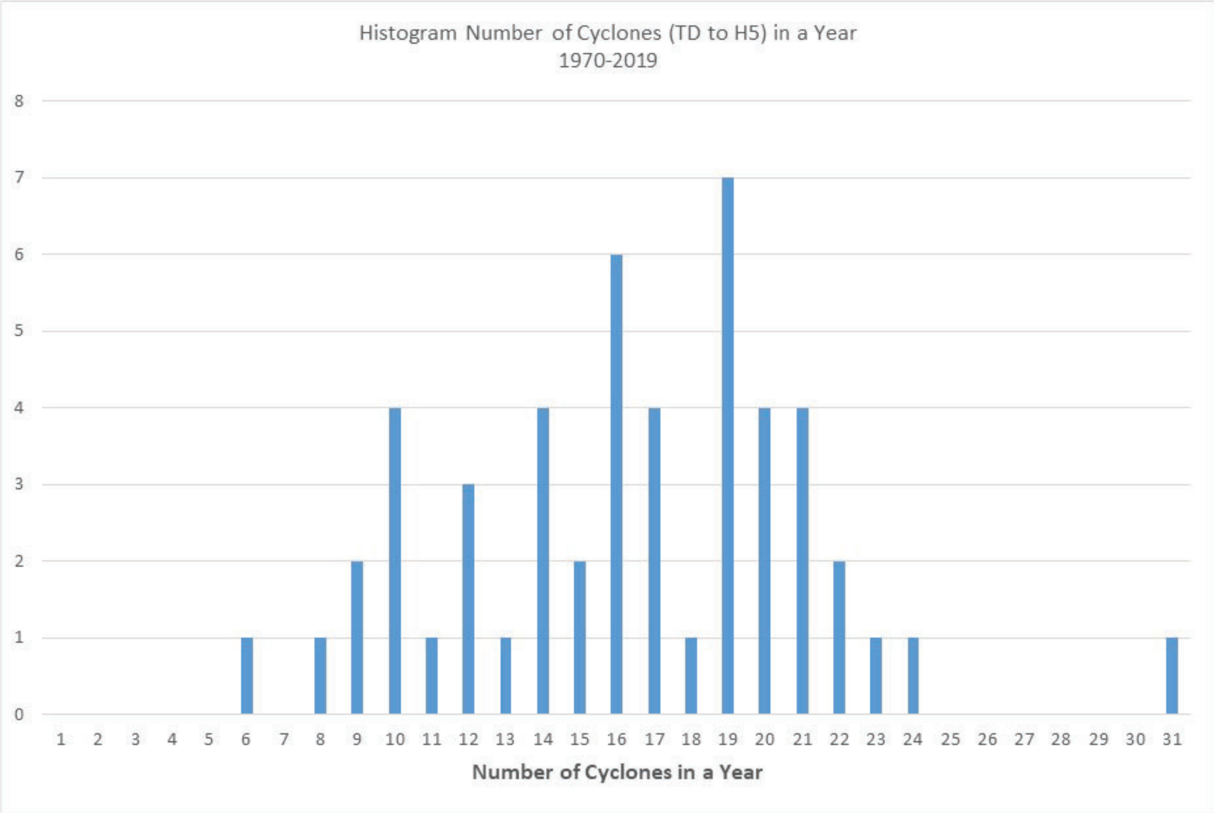


Figure 4-3: Histogram of number of cyclones (TD to H5) in a year in the North Atlantic

Figure 4-4 and Figure 4-5 show the histogram for the number of tropical storms and hurricanes (TS to H5) and the number of hurricanes (H1 to H5) in a year, respectively. A data analysis with a statistical tool [4] was performed to fit a Poisson distribution to the number of cyclones in a year. The best fit for the number of tropical storms and hurricanes is a Poisson distribution with a mean of 12.14 and a standard deviation of 3.48. For the number of hurricanes in a year, the best fit is a Poisson distribution with a mean of 6.32 and a standard deviation of 2.51 was found to be a good fit for the observed data. A data analysis of the histogram for major hurricanes (H3 to H5) was also performed and the best fit is a Poisson distribution with a mean of 2.48 and a standard deviation of 1.57. Table 4-1 summarizes the results of the Poisson distribution fits for the different cyclone categories.

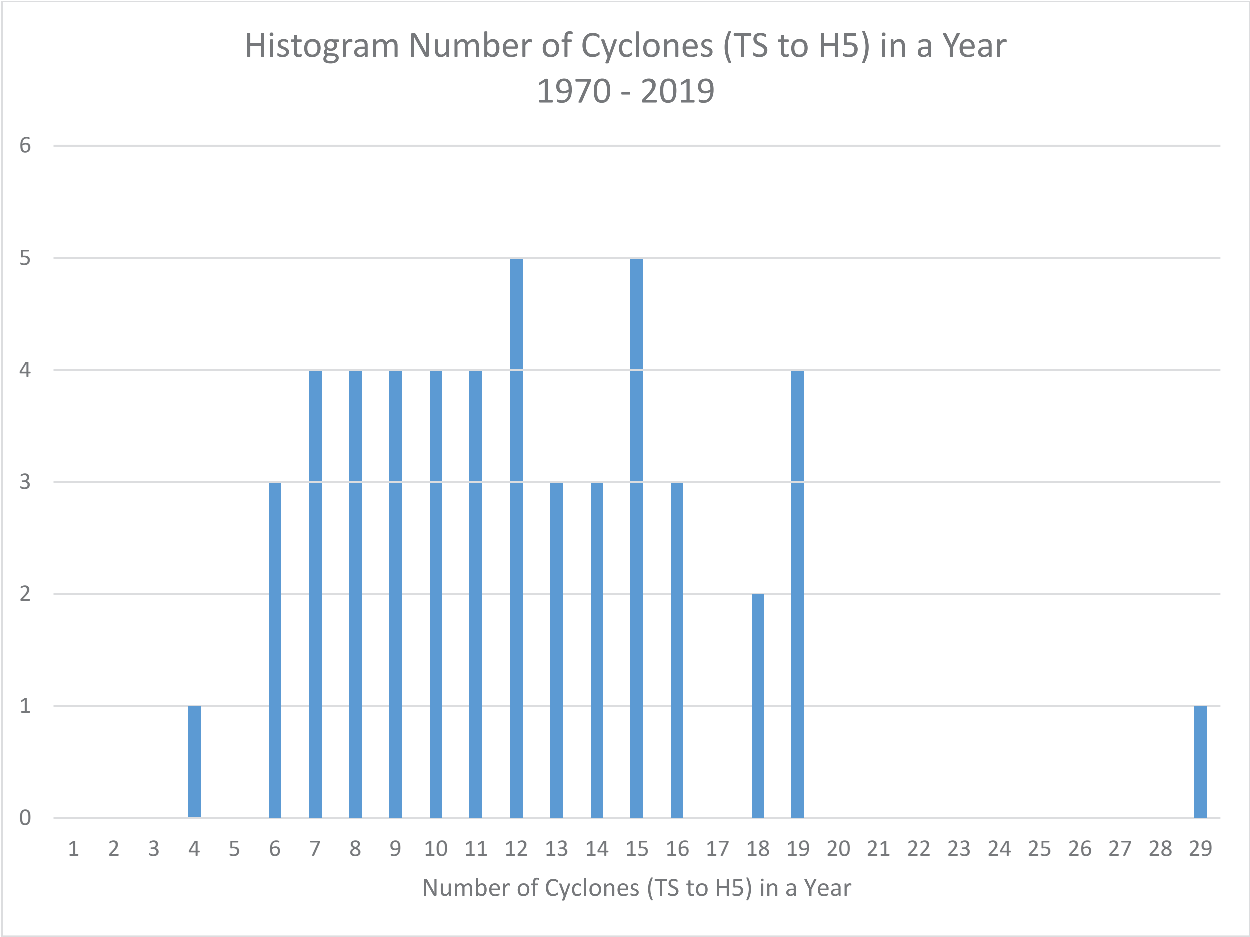


Figure 4-4: Histogram of number of cyclones (TS to H5) in a year in the North Atlantic

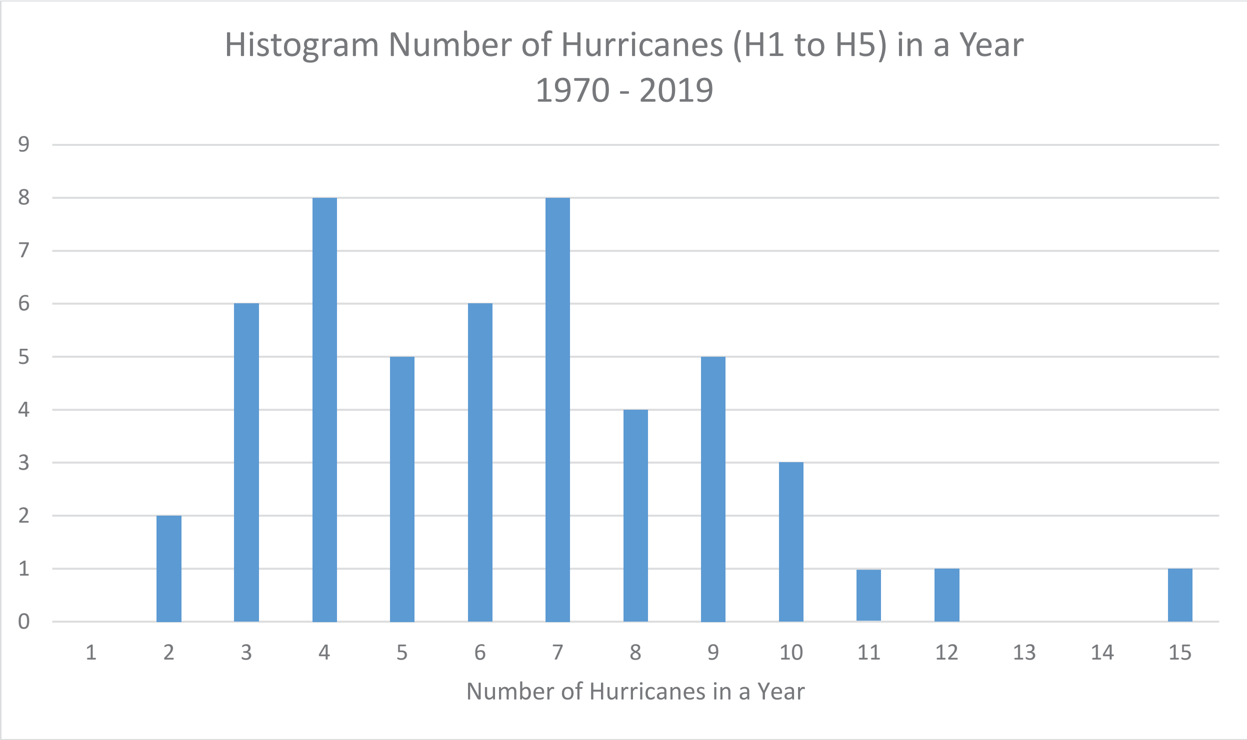


Figure 4-5: Histogram of number of hurricanes (H1 to H5) in a year in the North Atlantic

Table 4-1: Poisson Distribution Fit for Different Cyclone Categories

Category	Mean	St Dev
TD to H5	16.38	4.04
TS to H5	12.14	3.48
H1 to H5	6.32	2.51
H3 to H5	2.48	1.57

4.2 Number of Cyclones per Decade

Figure 4-6 shows the number of cyclones observed per decade, i.e., during each 10-year period from 1970 to 2019. The cyclones have been grouped as follows:

- TD: Tropical Disturbances only
- TS: Tropical Storms only
- ≥ H1: Hurricanes H1 to H5
- ≥ H3: Hurricanes H3 to H5 (called major hurricanes)
- Total: All cyclones, from TD to H5

As already discussed, 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. Table 4-2 shows the average number of cyclones per year for each decade, for the different categories.

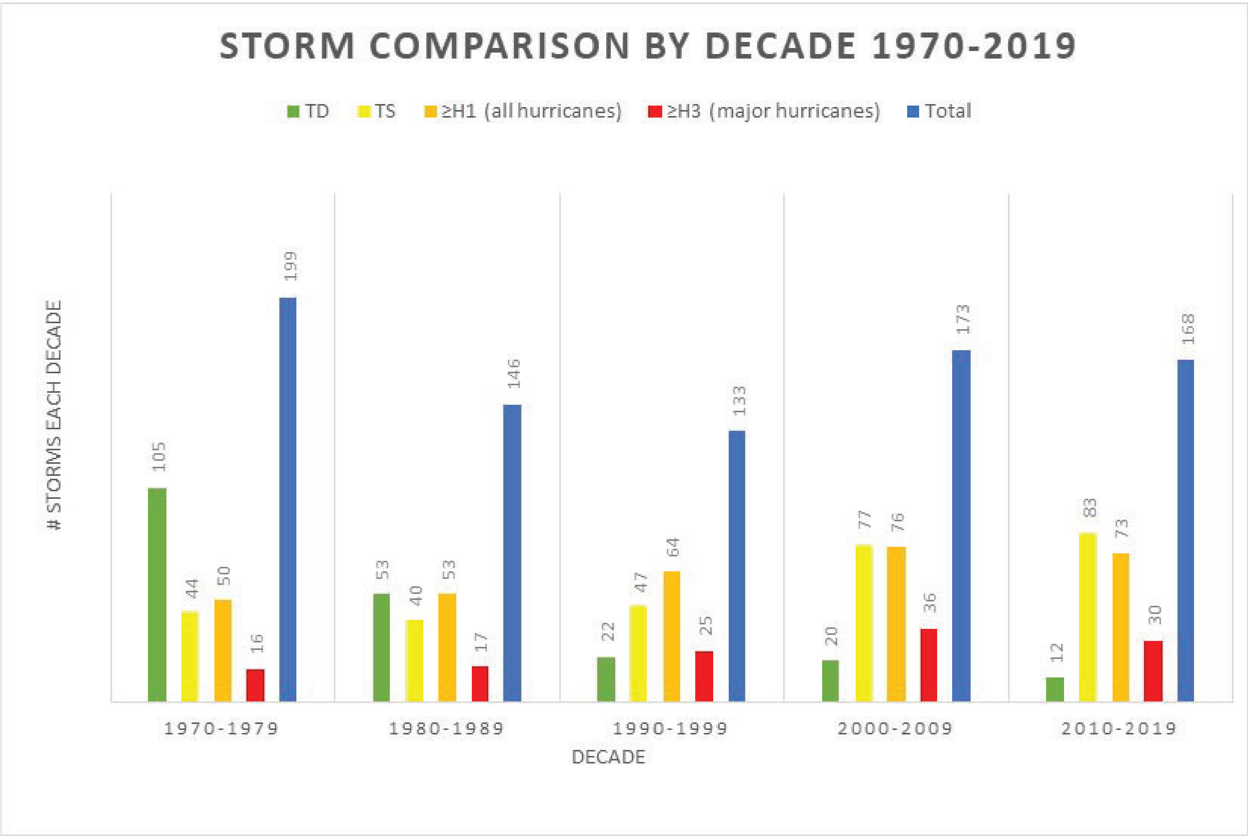


Figure 4-6: Number of cyclones for different categories each decade in the North Atlantic

Table 4-2: Average Annual Cyclone Count for each Decade

DECADE	TD	TS	TD to H5	H1 to H5	H3 to H5
1970-1979	10.5	4.4	19.9	5.0	1.6
1980-1989	5.3	4.0	14.6	5.3	1.7
1990-1999	2.2	4.7	13.3	6.4	2.5
2000-2009	2.0	7.7	17.3	7.6	3.6
2010-2019	1.2	8.3	16.8	7.3	3.0

4.3 Number of Cyclones per Week

As discussed earlier in this report, tropical cyclones exhibit a seasonal pattern. The American Petroleum Institute (API) Recommended Practice 2MET [5] is a document that gives general requirements for the determination and use of meteorological and oceanographic conditions for the design, construction and operation of offshore structures used in the Oil & Gas Industry. In this document, the hurricane season is divided into the following periods:

- Early season: June 1st to August 1st
- Peak hurricane season: August 14th through October 7th
- Late season: October 21st through November 30th

The API document provides specific metocean condition tables to be used within those three periods. The two 2-week periods right before peak season and right after represent ramp or transition periods. For this study, the API description of hurricane seasons was adopted.

Figure 4-7 shows the average weekly number of tropical storms plus hurricanes for the period 1970 to 2019. Figure 4-8 shows the average weekly number of hurricanes for the same period, stacking the bars for H1-H2 and H3-H5 hurricanes, so that both bars together (stacked) represent the total weekly average of hurricanes. The API defined seasons are marked in the figures for reference. Table 4-3 shows the annual average cyclone count for the different defined season periods, for the cyclone categories TS to H5 and H1 to H5.

Table 4-3: Annual average cyclone count per season period

Period	TS-H5	H1-H5
Early Season	1.52	0.50
Early Shoulder	0.98	0.42
Peak Season	6.88	4.04
Late Shoulder	0.88	0.42
Late Season	1.32	0.82
Off Season	0.56	0.12

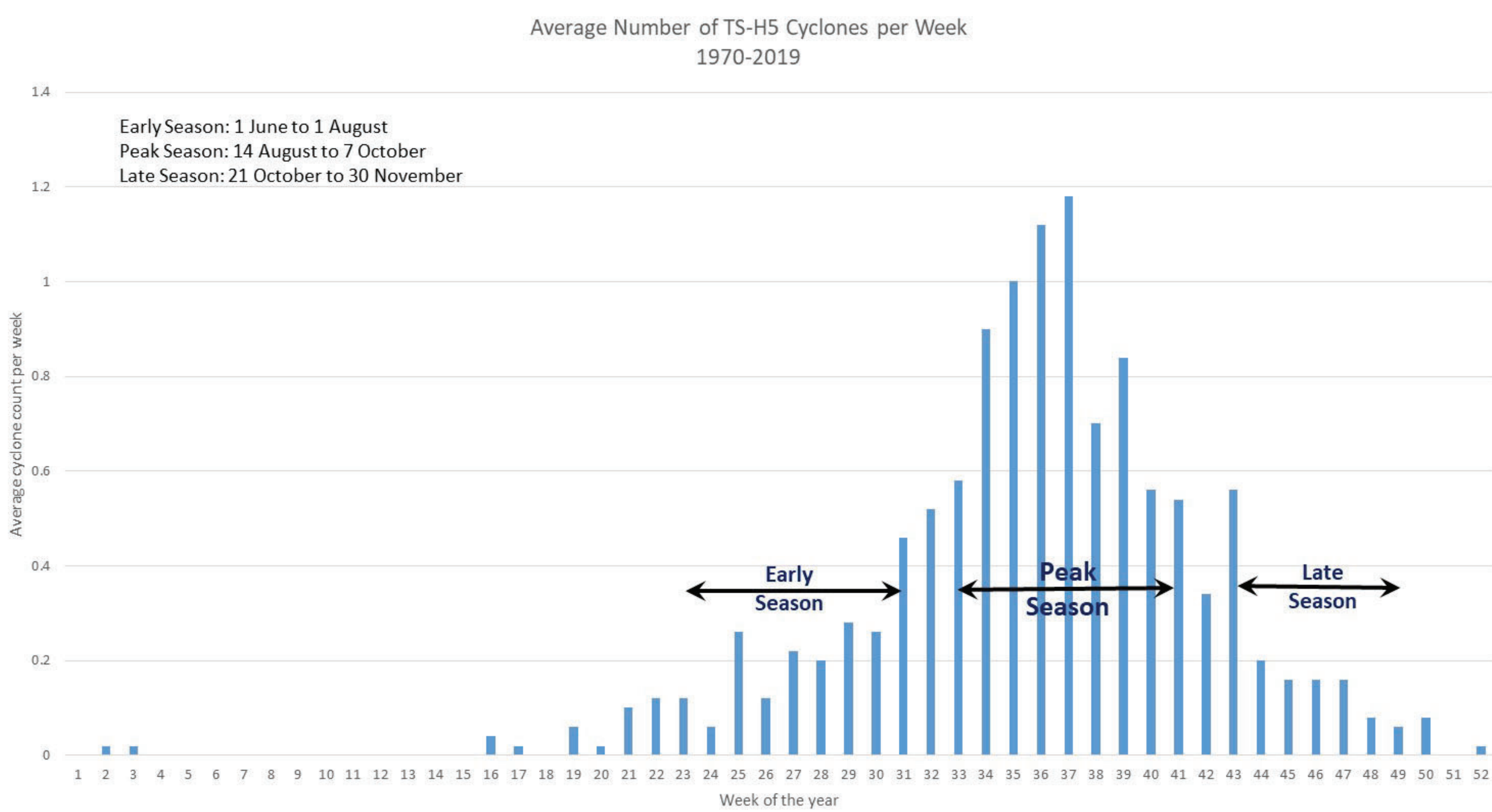


Figure 4-7: Average number of tropical storms plus hurricanes per week in the North Atlantic (1970-2019)

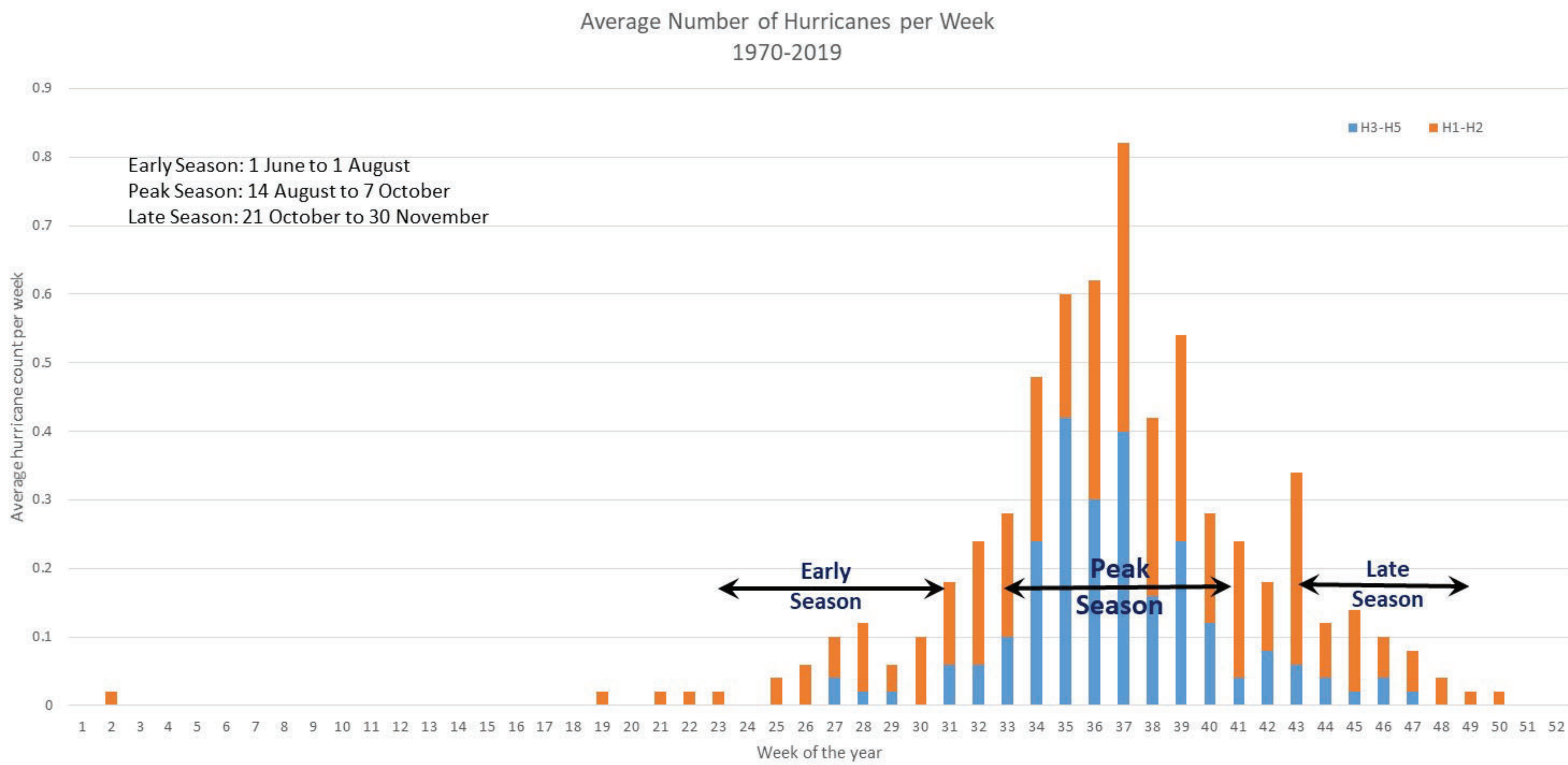


Figure 4-8: Average number of hurricanes per week in the North Atlantic (1970-2019)

5 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.

It is noted that path prediction is more accurate than predicting the strength or size of a cyclone. This is because the track of a cyclone is governed by forces larger than the tropical system itself and the global weather models do a fairly good job in predicting how these steering features might evolve over the course of a few days.

Figure 5-1 shows the average track forecast errors for tropical storms and hurricanes by decade beginning in the 1960s. There has been a steady reduction in the track errors over time, with the average errors in the current decade about 30-40% smaller than they were in the 2000s and about half of the size than they were in the 1990s [6].

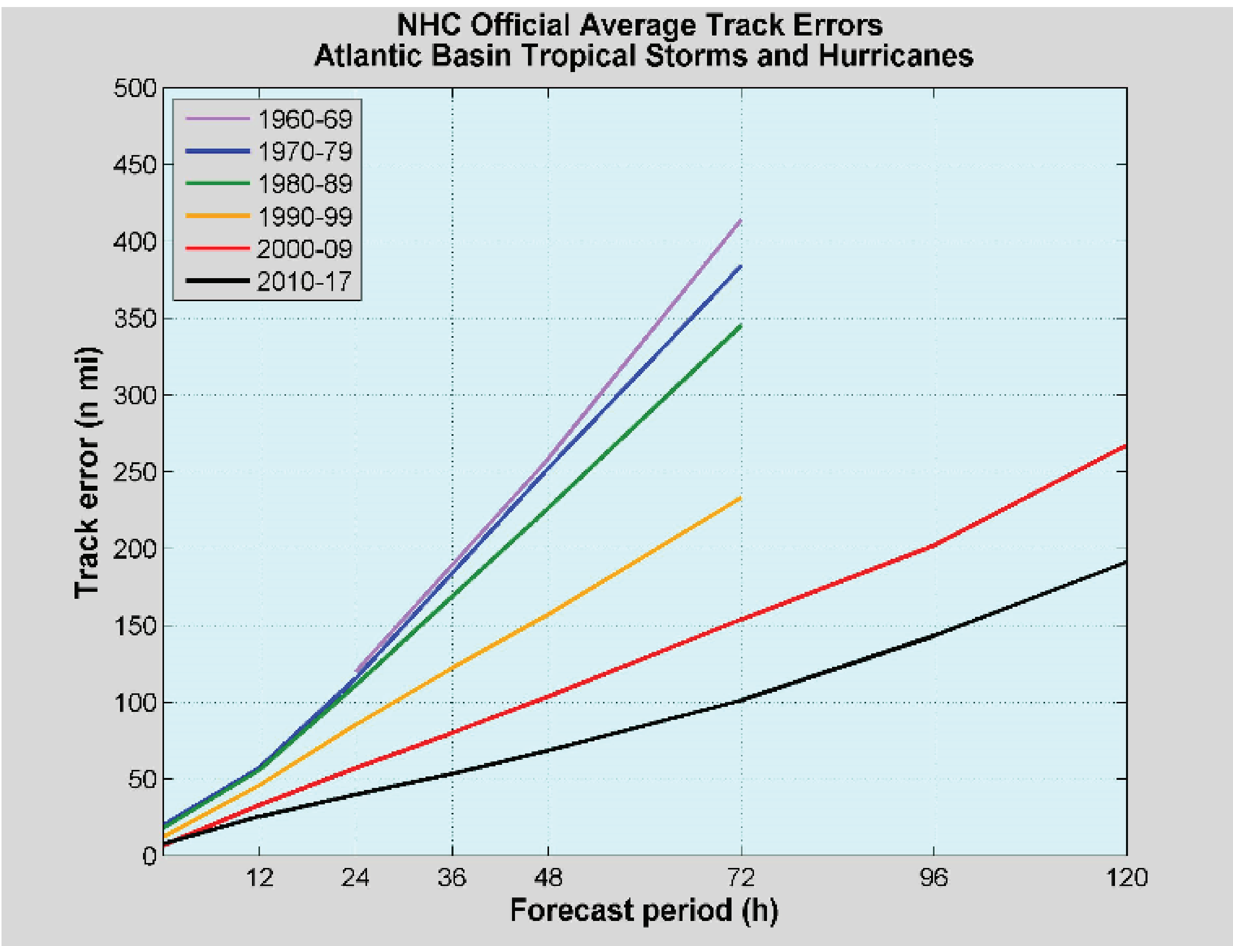


Figure 5-1: NHC official average track errors for cyclones in the North Atlantic

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 5-1 shows the different circle radii defining the cones being used in 2020 for the Atlantic basin and Figure 5-2 illustrates 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 five 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.

NHC provides track forecast cones for up to five days ahead, however in this study it is necessary to consider tropical cyclone threats that go beyond five days. In order to expand the forecast cone beyond five days, the NHC published radii in Table 5-1 are linearly extrapolated and Table 5-2 presents the resulting radii for 6, 7 , 8 and 9 days ahead.

Table 5-1: 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

Table 5-2: Extrapolated radii of forecast cone circles for projection periods over five days

Forecast Period (hours)	Extrapolated 2/3 Probability Circle (nm)
144	228
168	266
192	304
216	342

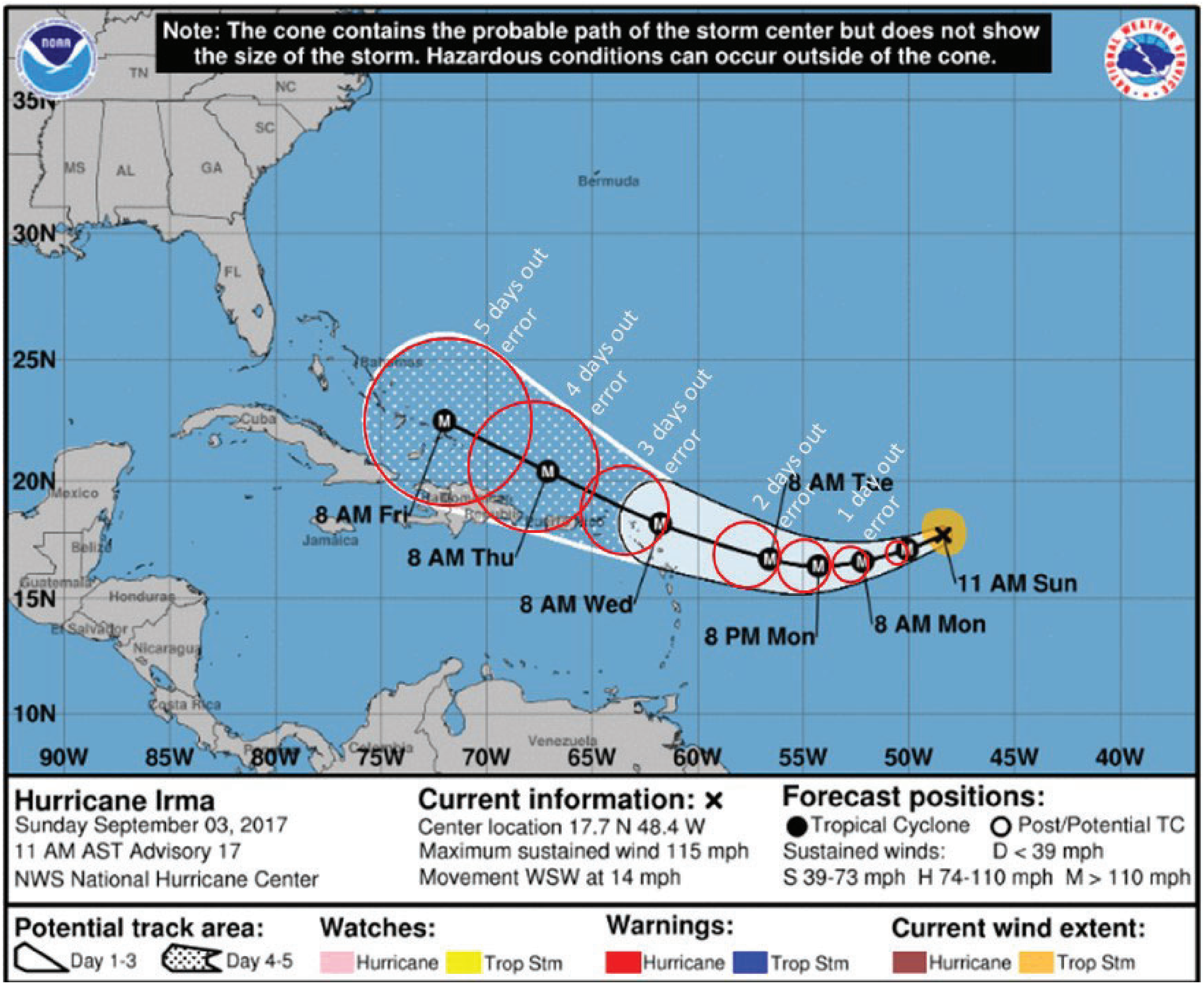


Figure 5-2: Example of 5-day track forecast cone (based on [8])

6 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 (Figure 6-1). In order to take this into account, it is necessary to evaluate storm sizes.

Several metrics have been defined to characterize the size of a cyclone. The most conventional ones are:

- Radius of Maximum Winds: distance from the center of a tropical cyclone to the location of the cyclone's maximum winds.
- Critical Wind Radii: The radii around the center of the cyclone at which a critical surface wind speed is measured.

There are several critical wind radii measures. The most common ones are the following:

R34: Critical wind radii at which 34 knots wind speed is measured. 34 knots is the lower end tropical storm force wind speed.

R64: Critical wind radii at which 64 knots wind speed is measured. 64 knots is the lower end hurricane force wind speed.

Unfortunately, the IBTrACS database does not generally report the critical wind radius information. Only in the last few years, after 2003, some storms recorded include this information. When reported, R values are usually reported by quadrant, since cyclones are not symmetrical. The R34 values reported in IBTrACS were analyzed. The R34 values were computed 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 were averaged and recorded in Table 6-1.

The number of cyclones that actually contain R34 data at that time interval is also reported. For example, 1 day after cyclone generation, 42 storms reported R34 values, and the average of the maximum R34 values is 170 nautical miles. It is noted that as cyclones lifespan vary, the number of storms with R34 data decreases as the time from generation increase. For example there are 14 storms reporting with 6 days from generation and only 4 storms with 10 days from generation.

It is recognized that due to the low number of cyclones with R34 values reported, the data in Table 6-1 is limited, but nonetheless they provide some insights. For cyclones of 6 days or less from storm generation, the average R34 values range from 137 to 181 nautical miles. It is not the purpose of this 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.

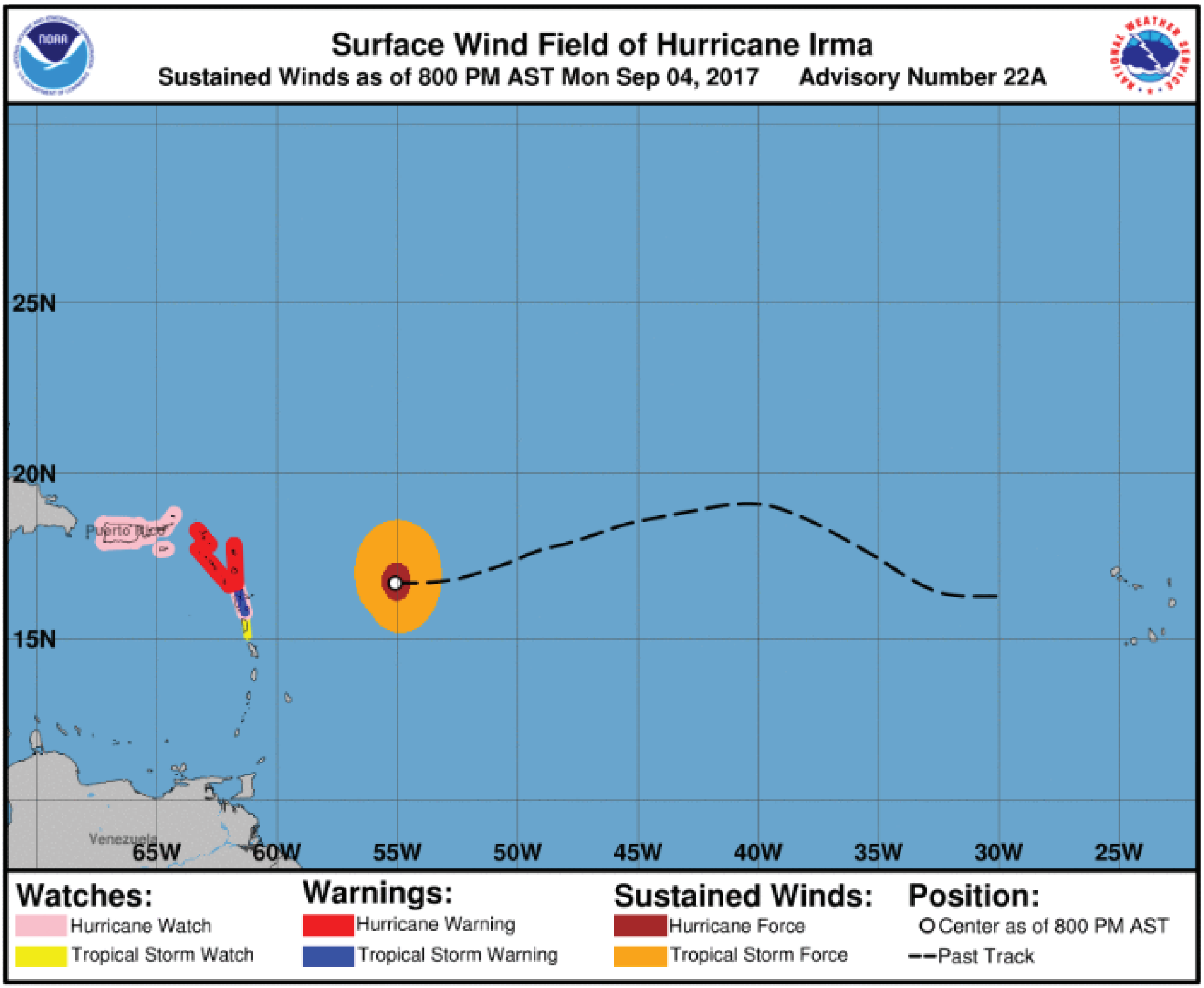


Figure 6-1: Surface wind field of hurricane Irma [9]

Table 6-1: 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

7 EVALUATING THE THREAT OF UPCOMING CYCLONES

The purpose of this section is to evaluate the threat of upcoming cyclones at specific locations in the GoM once a storm is generated in the NA. In this study, threat is understood as the possibility of an upcoming cyclone that has formed to affect the location of interest. Cyclone threat evaluation plays a significant role in decision making for rig operations, since a considerable amount of lead time is needed for the activities to shutdown, secure the well, and evacuate the rig and/or move to a safe location. A decision to leave location typically has to be made days in advance of the potential cyclone arrival.

Two important aspects were discussed in previous sections that can influence the threat of cyclones at a location:

- The track of the cyclone
- The size of the cyclone

Track of the cyclone:

In regards to the track of the cyclone, a table was generated in Section 5 that gives the size of the cyclone track forecast cone based on the advance forecast period. If the objective is to evaluate the potential threat of an upcoming cyclone to a specific location in the GoM, based only on the track error, it is necessary to compare the forecasted cone with the location of interest at the point where the storm would be closest to that location. For example, Figure 7-1 shows the 5-day track forecast for hurricane Isaac (2012), as posted by NHC on Friday 8/24/2012 at 5am Eastern Daylight Time (EDT) [10]. As can be seen, on that date, the hurricane was about four days out to the closest approach to the location of interest marked with a dot in the figure, and it is expected to occur around 5am EDT Tuesday 8/28/2012). At four days out, the forecast track error is 151 nautical miles (Table 5-1). The location of interest lies just at the edge of the projected cone, so this cyclone represents a threat to that location. Figure 7-2 shows the 5-day track forecast on Sunday 8/26/2012 at 5am EDT [11]. The closest point of the projected track to the location of interest is still expected to occur around 5 am EDT on Tuesday 8/28/2012, i.e., two days later. The track error two days out is 69 nautical miles. At this point in time, the location of interest is no longer under threat for the center of the storm to pass at the location of interest. It is stressed that the discussion in this paragraph takes into consideration only the track error of the cyclone, and not its size, which could very well affect the location of interest even when the path of the eye of the storm is far away from the location.

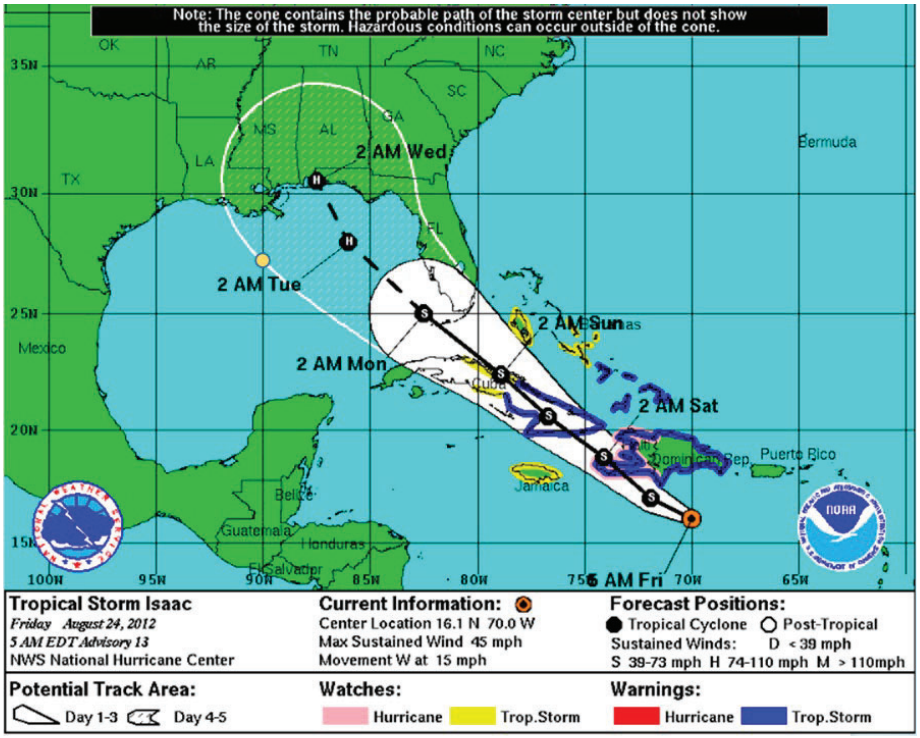


Figure 7-1: 5-day Forecast Cone for Tropical Storm Isaac (8/24/2012 at 5am EDT) [10]

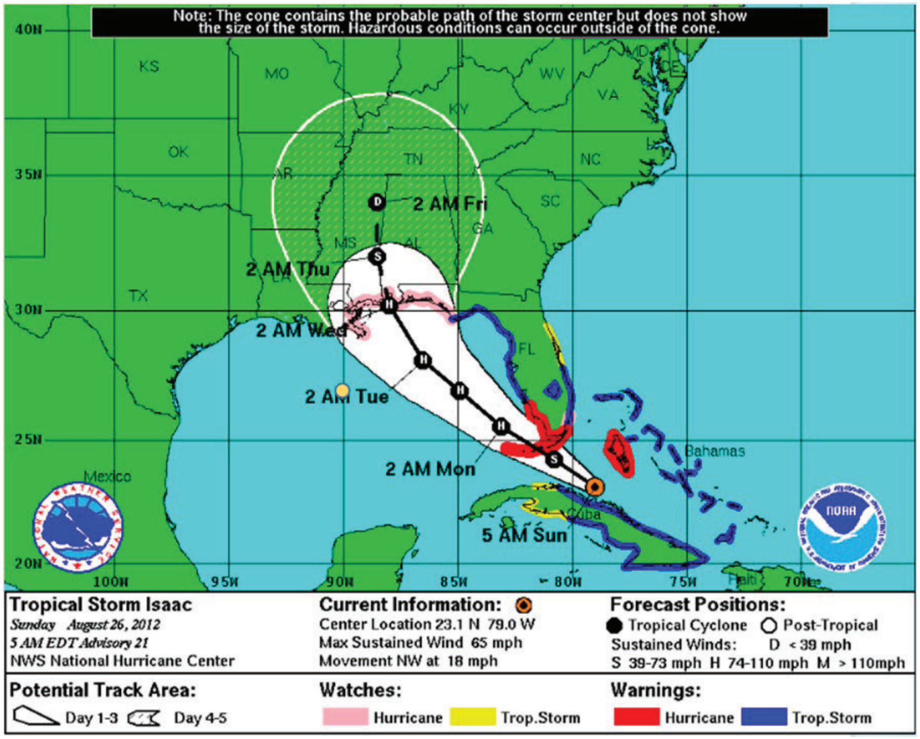


Figure 7-2: 5-day Forecast Cone for Tropical Storm Isaac (8/26/2012 at 5am EDT) [10]

Size of the Cyclone:

In Section 6, it was concluded that a storm size of 150 nautical miles is a reasonable assumption to consider the affected area due to tropical storm force wind speeds around the center of a cyclone, independent of the time from storm generation. 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) and in that case the affected area would be extended 150 nm to each side. Table 7-1 shows the path error radius, and the path radius error plus the R34 value (150 nm) for different "days out", from nine days to ½ day. For example, if a cyclone is located five days out from the location of interest, at that time the cyclone forecast error near the location of interest is 196 nm on either side of the projected path (eye of the storm). Adding to that error the 150 nm assumed size of the storm to each side of the cone, the potential threat area is 346 nm either side of the projected path.

Table 7-1: 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

Figure 7-3 illustrates the concept of threat circles around a selected location of interest in the GoM (marked with a dot). If a storm is generated somewhere in the NA, and it is estimated to take nine days to reach the location of interest (or its closest approach to the location of interest), said storm is a threat to the location of interest if its forecasted path (nine days out) lies within 492 nm to that location (Table 7-1). One way to graphically represent this threat area is to draw a circle centered in the location of interest with a radius equal to the path error plus size of the storm at the corresponding number of "days out". So for example, the threat area for a cyclone that is located 9 days out from the location of interest is represented by the outer (larger) circle, and any cyclone whose projected path (nine days out) rests within this outer circle represents a potential threat to the location. That same cyclone, four days later (i.e., five days out), will have a smaller error plus storm size area represented by the middle circle in Figure 7-3. If the new projected path (five days out) lies within the middle circle, the cyclone still presents a threat to the location of interest. It is possible that a cyclone presented a threat to the location nine days out, but due to later updates on the forecasted track, at five days out it may not represent a threat any longer (forecasted path lies outside the five days out circle). Following the same logic, four days later (i.e., now one day out), if the projected path lies within the smaller inner circle, the cyclone still presents a threat to the location.

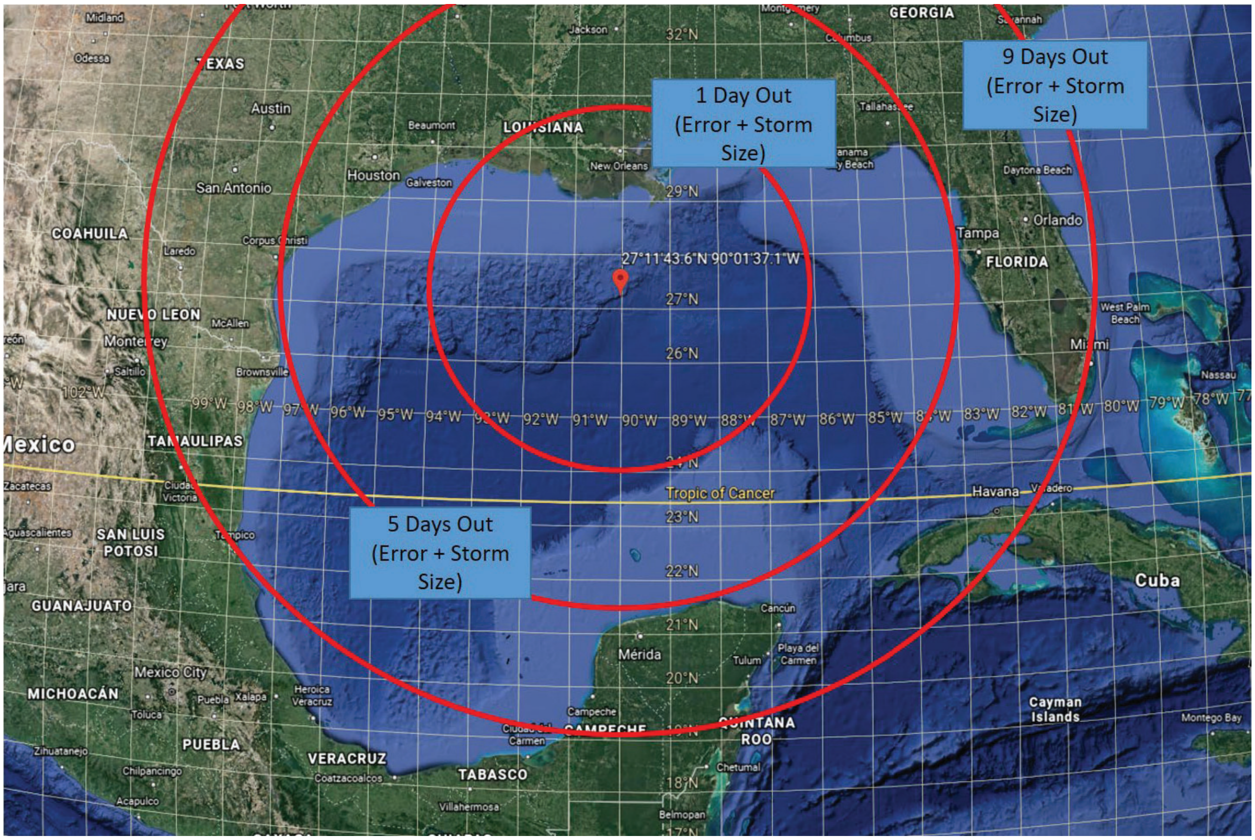


Figure 7-3: Path Error plus Storm Size Comparison for Different "days out" Around a Selected Location

7.1 Using Historical Data to Estimate Potential Cyclone Threats

Having discussed the concept of cyclone threat circles and the assumptions around them, the objective now is to use the available 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 would be exposed to an upcoming cyclone whose track forecasted cone and storm size lies within that location. Under each cyclone threat, the operator is faced with making important and timely decisions in order to minimize risk. These decisions are conflicting and can be costly. If it is decided to move off location and the hurricane eventually did not impact the location, it would seem that a lot of money was spent needlessly. On the contrary, if the operator decides not to move off location and the hurricane impacts the rig, the price in property damage, pollution and perhaps loss of life would be even more costly.

Offshore operators define a parameter called T-time. T-time is the required time to complete all activities to shutdown, secure the well, and evacuate the rig and /or move to a safe location. This transition time depends on, among other factors, the type of MODU, mooring type, BOP configuration, distance to shore, water depth, and the specific activity underway at the time of the threat. For this reason, it is important to estimate cyclone threats in the GoM for different timeframes.

It is important to distinguish the difference between a track forecasted cone, and the actual track of the cyclone. Figure 7-4 illustrates the difference. The track forecasted cone depicts the forecasted track of the center of the storm, together with a cone that considers the error in the prediction, as of 5am EDT on

8/26/2012. The actual track of the eye of the storm from that point in time onwards, can be anywhere within the boundaries of the cone (2/3 of the time), and even outside those boundaries (1/3 of the time). The inset to the right of Figure 7-4 shows the actual track of the cyclone, as reported in the cyclone database. It can be noted that the actual track was indeed within the forecasted cone, but it veered to the left side of the forecasted track.

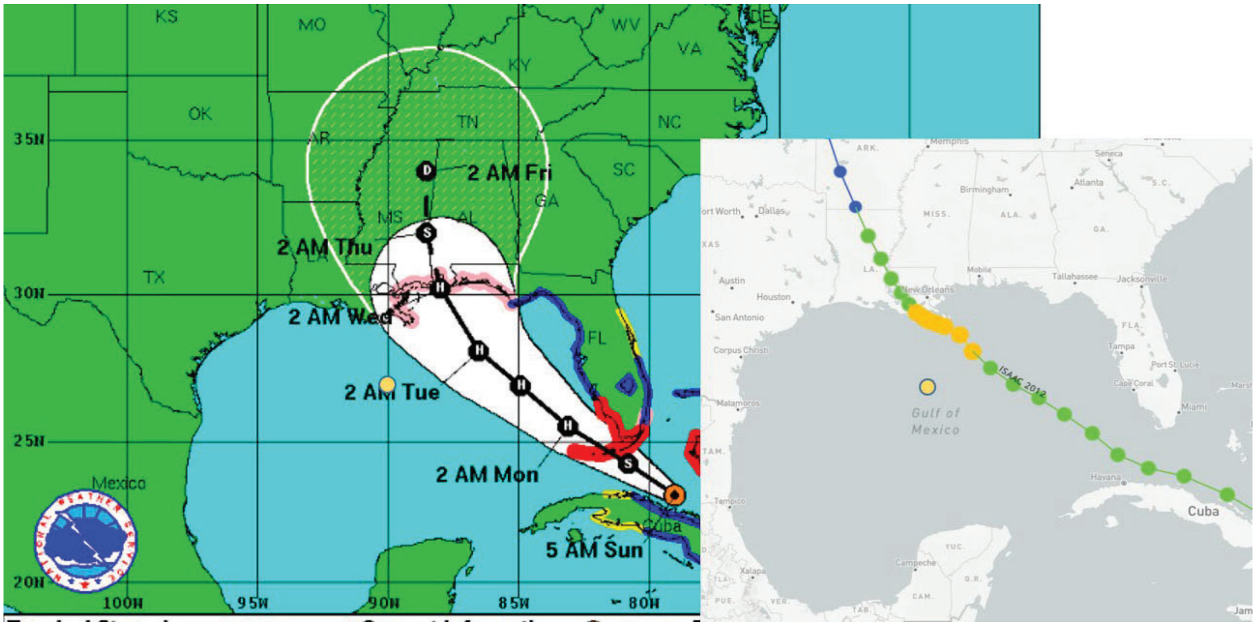


Figure 7-4: Difference between Track Forecasted Cone (left) and Actual Track (right) for Tropical Storm Isaac (2012) [10]

The cyclone database includes the actual tracks of all the cyclones (eye or center of the storm), rather than their forecasted cones as they were moving in the area. It is therefore necessary to assume that the actual tracks of the cyclones are equal to the projected tracks at the time. With this assumption, it is possible to reconstruct the forecasted cones using the track errors at different forecast periods (or "days out") in Table 7-1. It is recognized that this is a simplification and the reconstructed cone is not the actual forecasted cone at the time, however considering the randomness of cyclone tracks, any errors in one direction or another would cancel out statistically.

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 GoM 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 to be 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 nine days out calculations. The track error plus cyclone size for nine days out is 492 nm (Table 7-1). Count how many cyclones were generated nine 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 eight days out calculations. The track error plus cyclone size for eight days out is 454 nm (Table 7-1). Count how many cyclones were generated eight 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 7-1. Record the results.

This methodology was applied to three different locations in the GoM as reported in the following section.

7.2 Threat Estimate Results for Three Gulf of Mexico Locations

Three representative 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). The three locations selected are listed in Table 7-2 and mapped geographically in Figure 7-5, and were chosen to represent the central and western GoM areas where drilling is concentrated.

Table 7-2: Selected Locations of Interest for Cyclone Threat Assessment

Locations	Latitude	Longitude	Surface Area/Block
Atlantis	27.1955	-90.0270	GC 743
Perdido	26.1289	-94.8979	AC 857
Appomattox	28.5749	-87.9346	MC 392

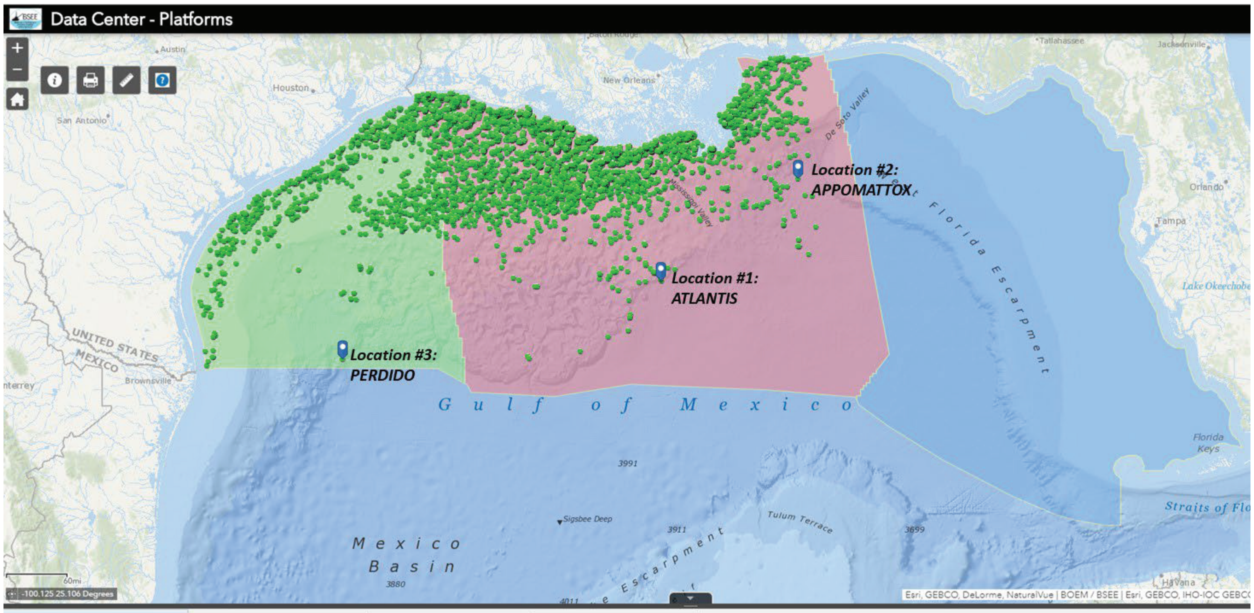


Figure 7-5: Map Location of the Three Selected Locations of Interest

The procedure described in the previous section was applied to each of these locations. Table 7-3 presents the results for location #1, Atlantis. The first column indicates the number of days out for each calculation. The second column gives the path error plus storm size (radius of the threat circle) that corresponds to the forecast at that number of days out. The third column presents the total number of cyclones that were in existence at that number of days out to the closest distance to location during the 50 years of data, regardless of the forecasted cone, i.e., both threat and non-threat cyclones. The fourth column gives the number of cyclones from the previous column for which the track forecast cone encompasses the location of interest, i.e., presents a potential threat to the location. The fifth column presents the average frequency of cyclones per year that were in existence at that number of days out to the closest distance from the location for which the track forecast cone encompasses the location of interest, i.e., the average annual threat count for each number of days out. Finally, the last column shows the percentage of threat cyclones in existence at that number of days out from the location, relative to all cyclones in existence at that number of days out.

To illustrate the use of the table, an example is presented, assuming that a rig located at the Atlantis location has a T-time value of six days while performing a specific well completion activity, and that it operates year round. Locating the row corresponding to "N Days Out" equal to six, the table indicates that over the 50 year period of the data, this location has had 178 occurrences of cyclones that were generated 6 days or more away from it (this time is computed by calculating the time that these cyclones have taken from generation to the closest point to the location) without taking into consideration their path, i.e., this count includes "threat" storms as well as "non-threat storms". The next column shows that of those 178 threat/non-threat cyclones at 6 days out, 29 of them actually have their (reconstructed) track forecast cone plus storm size encompassing the location, i.e., they represented a potential threat and therefore the crew should initiate activities to shutdown, secure the well, and evacuate the rig and/or move to a safe location. The last two columns give the average annual frequency and cyclone percentage, as follows:

- With a T-time equal to six days, it is estimated, on average, that a rig at this location would have to initiate activities to secure the well, evacuate and/or move 0.58 times/year (or one time every 1.72 years), assuming it operates year round
- With a T-time equal to six days, it is estimated that for each cyclone that is generated six days or more away from it, on average, there is a 16.3% probability that its track forecast cone plus storm size will encompass the location.

Table 7-3: Cyclone threat estimates for different days out at Atlantis location

N Days Out [days]	Path Error + 150 nm storm size (Radius) N days out [nm]	Total cyclones in existence N days out from location (threat and non-threat)	Total cyclones in existence N days out from location for which forecast cone + storm size affects location (threat)	Average cyclones per year in existence N days out from location for which forecast cone + storm size affects location (threat)	Percentage of threat cyclones in existence N days out from location relative to all (threat and non-threat) N days out
9	492	76	17	0.34	22.4%
8	454	100	23	0.46	23.0%
7	416	141	28	0.56	19.9%
6	378	178	29	0.58	16.3%
5	346	227	36	0.72	15.9%
4	301	287	39	0.78	13.6%
3	253	365	42	0.84	11.5%
2	219	475	54	1.08	11.4%
1.5	205	532	64	1.28	12.0%
1	191	589	74	1.48	12.6%
0.5	176	643	78	1.56	12.1%

Table 7-4 and Table 7-5 provide the corresponding estimates for location #2 Perdido and location #3 Appomattox.

Table 7-4: Cyclone threat estimates for different days out at Perdido location

N Days Out [days]	Path Error + 150 nm storm size (Radius) N days out [nm]	Total cyclones in existence N days out from location (threat and non-threat)	Total cyclones in existence N days out from location for which forecast cone + storm size affects location (threat)	Average cyclones per year in existence N days out from location for which forecast cone + storm size affects location (threat)	Percentage of threat cyclones in existence N days out from location relative to all (threat and non-threat) N days out
9	492	79	16	0.32	20.3%
8	454	101	21	0.42	20.8%
7	416	146	27	0.54	18.5%
6	378	187	27	0.54	14.4%
5	346	234	31	0.62	13.2%
4	301	297	34	0.68	11.4%
3	253	379	32	0.64	8.4%
2	219	483	35	0.70	7.2%
1.5	205	548	46	0.92	8.4%
1	191	607	51	1.02	8.4%
0.5	176	658	59	1.18	9.0%

Table 7-5: Cyclone threat estimates for different days out at Appomattox location

N Days Out [days]	Path Error + 150 nm storm size (Radius) N days out [nm]	Total cyclones in existence N days out from location (threat and non-threat)	Total cyclones in existence N days out from location for which forecast cone + storm size affects location (threat)	Average cyclones per year in existence N days out from location for which forecast cone + storm size affects location (threat)	Percentage of threat cyclones in existence N days out from location relative to all (threat and non-threat) N days out
9	492	77	24	0.48	31.2%
8	454	103	31	0.62	30.1%
7	416	142	35	0.70	24.6%
6	378	184	33	0.66	17.9%
5	346	233	43	0.86	18.5%
4	301	292	44	0.88	15.1%
3	253	374	51	1.02	13.6%
2	219	496	69	1.38	13.9%
1.5	205	542	72	1.44	13.3%
1	191	598	75	1.50	12.5%
0.5	176	645	84	1.68	13.0%

8 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, secure the well, and evacuate the rig and/or move to a safe 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 five days before arrival (track forecast cone five days out plus storm size encompasses the location), but eventually when this storm 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 five days out. Now, 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.

The process to evaluate the frequency of hurricanes hitting a location of interest is as follows:

1. Select a location in the GoM 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 to be the cyclone origination) to the closest location identified above and record this time in the first record of this cyclone.
3. Count the number of cyclones for each category: TD, TS, H1, H2, H3, H4 and H5 that passed within 150 nautical miles from the location of interest. Category is taken as the maximum category of the cyclone within the 150 nautical miles around the location of interest. Add up the number of storms within 150nm to evaluate the count for three category groups: TD to H5, TS to H5 and H1-H5.
4. Split the count above between two groups (peak season or non-peak season). This is done for information purposes only.
5. Compute the "Percentage Calculations" by dividing the number of cyclones within each category group that passed within 150 nautical miles from the location over the total number of cyclones in that category group. This is done for the three category groups: TD to H5, TS to H5 and H1-H5.
6. Repeat a similar count as in Step 3 (cyclones passing within 150nm of the location), but counting only cyclones that were generated less than N days out from the location. Perform this count for N = 8, 7, 6, 5, 4, 3, 2 and 1 days out. Add up the count for the three category groups: TD to H5, TS to H5 and H1-H5 within each "less than N days out" group.
7. Compute the "Percentage Calculations" for the different "less than N days out" groups by dividing the number of cyclones within each category group that passed within 150 nautical miles from the location over the total number of cyclones in that category group. This is done for the three category groups: TD to H5, TS to H5 and H1-H5.

This methodology was applied to the same three different locations in the GoM used in Section 7.2.

Table 8-1 and Table **8-2** present the results of the calculations according to the process explained above for location #1: Atlantis. Table 8-1 lists the number of cyclones for each category as indicated in the column headings. The count only includes cyclones whose center passed within 150 nautical miles from the Atlantis location, with the exception of the column titled "All Storms North Atlantic" that counts all storms in the NA regardless of their path. The count is then split into "Peak Season" and "Non-Peak Season" cyclones. The percentage calculations on the right hand side correspond to the ratio of cyclones passing within 150 nm from the location over the total number of NA cyclones, for each of the three cyclone category groups: "TD or higher", "TS or higher" and "H1 or higher".

Table 8-2 records the cyclone count in a similar manner, but only counting cyclones that were generated <u>less than</u> N days out, with N ranging from eight days to one day. The percentage calculations on the right hand side correspond to the ratio of cyclones passing within 150 nm from the location that were generated less than N days out for each of three cyclone category groups over the total number of NA cyclones of each of the three cyclone category groups.

To demonstrate the use of these two tables, an example is presented. As before, a rig located at the Atlantis location is assumed to have a T-time value of six days while performing a specific activity, and it is assumed to be operating year round. From Table 8-1, it is noted that during the 50 year period there have been 819 cyclones in the NA, of which 80 have passed within 150 nm of Atlantis location, or 9.77%. For the cyclone Category TS or higher, there have been 607 cyclones in the NA, of which 57 have passed within 150 nm of Atlantis location, or 9.39%. For the cyclone Category H1 or higher, there have been 316 cyclones in the NA, of which 27 have passed within 150 nm of Atlantis location, or 8.54%. This table also shows the cyclone count split by peak and non-peak season. Table 8-2 provides the information related to the "N days out" calculations. With the assumption of a T-time of 6 days, if the rig has not moved to a safe location by then, there would be no time to do so if an approaching hurricane is announced less than 6 days out. In that case, the rig is subject to the risk of being affected by tropical storm winds or higher if the storm passes within 150 nm of this location. To estimate this risk, a count of historical data can be performed. Identifying the row corresponding to six days out, Table 8-2 indicates that there have been 64 cyclones passing within 150 nm generated less than six days out, or 7.81% of all cyclones. Dividing by 50 years, this gives an annual frequency of 1.28/year. For cyclones TS or higher, there have been 26 of them passing within 150 nm and generated less than six days out, or 6.92% of all cyclones TS or higher in the NA, and an annual frequency of 0.52/year (about one in two years). For hurricanes, there have been 16 of them passing within 150 nm and generated less than six days out, or 5.06% of all hurricanes in the NA, and an annual frequency of 0.32/year (about one in three years). The above counts are strictly historical data, but they can be used to make estimates for future events, with an appropriate error margin. Additionally, the percentages in the table can be used to correct up or down the "expected" number of storms for each category based on the predicted total number of storms for that future period. There are agencies that report in advance if an upcoming year is expected to present more or less cyclones than average, or even how many named cyclones are expected.

Table 8-3 to Table 8-6 present the historical counts and calculations for the other two locations.

Table 8-1: Cyclone frequency estimates by maximum storm category within the 150 nm circle for Atlantis location

Period	Number of TD within the 150 nm circle	Number of TS within the 150 nm circle	Number of H1 within the 150 nm circle	Number of H2 within the 150 nm circle	Number of H3 within the 150 nm circle	Number of H4 within the 150 nm circle	Number of H5 within the 150 nm circle	Total TD or higher within the 150 nm circle	Total TS or higher within the 150 nm circle	Total H1 or higher within the 150 nm circle	All TD-H5 North Atlantic	All TS-H5 North Atlantic	All H1-H5 North Atlantic	% of 150 nm TD-H5 storms/ All TD-H5 Storms	% of 150 nm TS-H5 storms/ All TS-H5 Storms	% of 150 nm H1-H5 storms/ All H1-H5 Storms
All Year	23	30	12	6	1	7	1	80	57	27	819	607	316	9.77%	9.39%	8.54%
Peak Season	12	14	5	5	1	7	1	45	33	19	436					
Non-Peak Season	11	16	7	1	0	0	0	35	24	8	383					

Table 8-2: Cyclone frequency estimates by maximum storm category within the 150 nm circle, generated less than N days out for Atlantis location

N Days Out or T-time [days]	Number of TD within the 150 nm circle	Number of TS within the 150 nm circle	Number of H1 within the 150 nm circle	Number of H2 within the 150 nm circle	Number of H3 within the 150 nm circle	Number of H4 within the 150 nm circle	Number of H5 within the 150 nm circle	Total TD or higher within the 150 nm circle	Total TS or higher within the 150 nm circle	Total H1 or higher within the 150 nm circle	% of 150 nm TD-H5 storms/ All TD-H5 Storms	% of 150 nm TS-H5 storms/ All TS-H5 Storms	% of 150 nm H1-H5 storms/ All H1-H5 Storms
8	22	28	11	4	0	2	1	68	46	18	8.30%	7.58%	5.70%
7	22	26	11	3	0	2	1	65	43	17	7.94%	7.08%	5.38%
6	22	26	11	3	0	1	1	64	42	16	7.81%	6.92%	5.06%
5	22	26	10	3	0	0	0	61	39	13	7.45%	6.43%	4.11%
4	22	26	9	3	0	0	0	60	38	12	7.33%	6.26%	3.80%
3	21	24	9	3	0	0	0	57	36	12	6.96%	5.93%	3.80%
2	15	21	7	1	0	0	0	44	29	8	5.37%	4.78%	2.53%
1	9	11	2	0	0	0	0	22	13	2	2.69%	2.14%	0.63%

Table 8-3 : Cyclone frequency estimates by maximum storm category within the 150 nm circle for Perdido location

Period	Number of TD within the 150 nm circle	Number of TS within the 150 nm circle	Number of H1 within the 150 nm circle	Number of H2 within the 150 nm circle	Number of H3 within the 150 nm circle	Number of H4 within the 150 nm circle	Number of H5 within the 150 nm circle	Total TD or higher within the 150 nm circle	Total TS or higher within the 150 nm circle	Total H1 or higher within the 150 nm circle	All TD-H5 North Atlantic	All TS-H5 North Atlantic	All H1-H5 North Atlantic	% of 150 nm TD-H5 storms/ All TD-H5 Storms	% of 150 nm TS-H5 storms/ All TS-H5 Storms	% of 150 nm H1-H5 storms/ All H1-H5 Storms
All Year	22	25	7	3	3	2	2	64	42	17	819	607	316	7.81%	6.92%	5.38%
Peak Season	9	12	5	1	1	2	1	31	22	10	436					
Non-Peak Season	13	13	2	2	2	0	1	33	20	7	383					

Table 8-4 : Cyclone frequency estimates by maximum storm category within the 150 nm circle, generated less than N days out for Perdido location

N Days Out or T-time [days]	Number of TD within the 150 nm circle	Number of TS within the 150 nm circle	Number of H1 within the 150 nm circle	Number of H2 within the 150 nm circle	Number of H3 within the 150 nm circle	Number of H4 within the 150 nm circle	Number of H5 within the 150 nm circle	Total TD or higher within the 150 nm circle	Total TS or higher within the 150 nm circle	Total H1 or higher within the 150 nm circle	% of 150 nm TD-H5 storms/ All TD-H5 Storms	% of 150 nm TS-H5 storms/ All TS-H5 Storms	% of 150 nm H1-H5 storms/ All H1-H5 Storms
8	22	24	5	2	2	1	1	57	35	11	6.96%	5.77%	3.48%
7	22	23	5	2	2	1	1	56	34	11	6.84%	5.60%	3.48%
6	22	23	5	1	2	1	1	55	33	10	6.72%	5.44%	3.16%
5	22	23	4	1	2	1	1	54	32	9	6.59%	5.27%	2.85%
4	20	22	3	1	2	1	1	50	30	8	6.11%	4.94%	2.53%
3	19	22	2	1	1	0	0	45	26	4	5.49%	4.28%	1.27%
2	17	20	1	0	1	0	0	39	22	2	4.76%	3.62%	0.63%
1	12	12	0	0	0	0	0	24	12	0	2.93%	1.98%	0.00%

Table 8-5 : Cyclone frequency estimates by maximum storm category within the 150 nm circle for Appomattox location

Period	Number of TD within the 150 nm circle	Number of TS within the 150 nm circle	Number of H1 within the 150 nm circle	Number of H2 within the 150 nm circle	Number of H3 within the 150 nm circle	Number of H4 within the 150 nm circle	Number of H5 within the 150 nm circle	Total TD or higher within the 150 nm circle	Total TS or higher within the 150 nm circle	Total H1 or higher within the 150 nm circle	All TD-H5 North Atlantic	All TS-H5 North Atlantic	All H1-H5 North Atlantic	% of 150 nm TD-H5 storms/ All TD-H5 Storms	% of 150 nm TS-H5 storms/ All TS-H5 Storms	% of 150 nm H1-H5 storms/ All H1-H5 Storms
All Year	28	31	10	4	3	7	1	84	56	25	819	607	316	10.26%	9.23%	7.91%
Peak Season	13	12	4	3	2	6	1	41	28	16	436					
Non-Peak Season	15	19	6	1	1	1	0	43	28	9	383					

Table 8-6 : Cyclone frequency estimates by maximum storm category within the 150 nm circle, generated less than N days out for Appomattox location

N Days Out or T-time [days]	Number of TD within the 150 nm circle	Number of TS within the 150 nm circle	Number of H1 within the 150 nm circle	Number of H2 within the 150 nm circle	Number of H3 within the 150 nm circle	Number of H4 within the 150 nm circle	Number of H5 within the 150 nm circle	Total TD or higher within the 150 nm circle	Total TS or higher within the 150 nm circle	Total H1 or higher within the 150 nm circle	% of 150 nm TD-H5 storms/ All TD-H5 Storms	% of 150 nm TS-H5 storms/ All TS-H5 Storms	% of 150 nm H1-H5 storms/ All H1-H5 Storms
8	25	29	9	3	2	3	1	72	47	18	8.79%	7.74%	5.70%
7	25	29	9	2	2	3	1	71	46	17	8.67%	7.58%	5.38%
6	25	27	9	2	2	2	1	68	43	16	8.30%	7.08%	5.06%
5	23	26	7	2	1	1	0	60	37	11	7.33%	6.10%	3.48%
4	22	26	6	2	1	1	0	58	36	10	7.08%	5.93%	3.16%
3	18	23	5	1	1	0	0	48	30	7	5.86%	4.94%	2.22%
2	15	16	0	0	0	0	0	31	16	0	3.79%	2.64%	0.00%
1	9	10	0	0	0	0	0	19	10	0	2.32%	1.65%	0.00%

9 ESTIMATING RISK OF CYCLONES WITHIN SPECIFIC DATES

One of the assumptions made for the calculations in Section 7 and Section 8 is year round operation at the selected locations. As discussed in Section 4.3, cyclones follow a very distinct seasonal pattern, so obviously the cyclone risk for a rig that operates at a certain location only during a specific and limited period of time will be dependent on that time period. This section will describe how the cyclone risk for such cases was evaluated.

The first step in this process is to build a table with the daily average number of hurricanes. This count is built by adding all cyclones generated each day of the year during the 50 years of collected data (daily cyclone count) for the three categories: TD to H5, TS to H5 and H1 to H5. The date used in this table is the date that each cyclone is first reported as recorded in the database (cyclone start day). In order to smooth out the counts and counteract statistical variations (so called "noise"), the average daily count is computed as a seven-day average, using the three days before, the day of, and the three days after, for each day of the year, and dividing that by 50 to normalize the counts. With these three average daily counts (one per category), it is possible to calculate the average number of cyclones for each of the three categories that can be anticipated to be generated in the NA (anywhere) during any period of time. The next step in the risk estimation process is to assess the fraction of those NA (anywhere) cyclones generated during the period of interest that would end up hitting the location of interest (within 150 nautical miles). One way to do this is to go through the database and count the number of cyclones that hit the location just within the period of interest, each year, for the 50 years of data. This would be an accurate historical count, however due to the low number of counts (especially if the period of interest is short, say less than 30 days), these estimates would be significantly impacted by statistical variations. In order to smooth out the risk estimates, one additional assumption can be made: Once a cyclone is generated, the path or track of that cyclone does not depend on the date in which the cyclone was generated. With this assumption, it is possible to use the year-round percentage calculations (hereby called multipliers) that were computed in Section 8 (Table 8-1, Table 8-3 and Table 8-5) for each of the three locations. It is noted that these multipliers are location specific, so they can only be used for the specific locations for which they were computed.

Once a specific start and end date are selected, along with a location, a search in the average daily count table described above can produce the number of cyclones that can be anticipated to be generated anywhere in the NA (on average) during that specific period of time. Now, using the multipliers from the tables in Section 8, it is possible to estimate the anticipated cyclone count to hit the location within 150 nautical miles, for each location, as well as those cyclones expected to hit the location with a specific number of "days out" from the location.

Table 9-1: Cyclone risk estimates by storm category for the period 2/24/2021 – 4/23/2021 at Atlantis location shows an example calculation for Atlantis location. The period of interest selected is starting on 5/24/2021 for 60 days. The column labeled "Anticipated cyclone count" shows the number of cyclones anticipated (on average) during that period, for different cyclone characteristics. An average of 2.54 cyclones are anticipated to be generated in the NA during this period and an average of 0.25 cyclones are anticipated to hit within 150 nm of the location. Looking at tropical storms and hurricanes together, an average of 1.54 cyclones of such categories are anticipated, with an average of 0.14 hitting within 150 nm of the location. For hurricanes only, an average of 0.46 hurricanes are anticipated, with an average of 0.04 hitting within 150 nm of the location. Looking now at cyclones with specific "days out", Table 9-1 includes cyclone estimations for six days out and three days out. The cyclone estimations for different days out becomes useful to compare risk estimations between two assets with different T-times. In this example for Atlantis location and for the selected dates, an average of 0.023 hurricanes with less than six days out from the location are anticipated to hit Atlantis within 150 nm, and a similar average of 0.018 hurricanes with less than three days out from the location.

Additionally, Table 9-1 presents a few percentage based statistics to compare the cyclones generated less than certain days out relative to the location of interest in relation to the total number of cyclones. These percentage statistics are located in the two rightmost columns. The first of these two columns displays the percentage of cyclones that pass within 150 nautical miles to the location of interest generated less than N number of days out relative to the total number of storms that pass within 150 nautical miles of the location of interest. The second of these two columns displays the percentage of cyclones that pass within 150 nautical miles to the location of interest generated less than N number of days out relative to the total number of cyclones in the same category. For example, for the estimates shown in Table 9-1, the following observations are made:

- Of all the named cyclones (TS to H5) that would pass within 150 nautical miles from Atlantis location, it is estimated (based on 50 years of history) that 73.7% of them would be generated less than six days out from this location and 63.2% of them less than three days out from this location.
- Of all hurricanes (H1 to H5) that would pass within 150 nautical miles from Atlantis location, it is expected (based on 50 years of history) that 59.3% of them would be generated less than six days out from this location and 44.4% of them less than three days out from this location.
- Of all the named cyclones (TS to H5) 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, 6.9% of them would be passing within 150 nautical miles of the location (if generated less than six days out from this location), and 5.9% of them would be passing within 150 nautical miles of the location (if generated less than three days out from this location).
- Of all hurricanes (H1 to H5) 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, 5.1% of them would be passing within 150 nautical miles of the location (if generated less than six days out from this location) and 3.8% of them would be passing within 150 nautical miles of the location (if generated less than three days out from this location).

The above statistical results are historical numbers, and they should not be interpreted as the probability that an upcoming cyclone hits the selected location. Such probabilities depend on many other factors like cyclone distance to the location, direction of travel, meteorology, and others which are not the scope of this study.

It is noted that the above percentage-based statistics do not change with the period of time selected, since they are based on average year round statistics, and they are normalized to the number of storms. In other words, the number of storms anticipated at a specific location is dependent on the period of time and location selected, but the relative percentages are only dependent on the location.

Table 9-1: Cyclone risk estimates by storm category for the period 2/24/2021 – 4/23/2021 at Atlantis location

Location #1: ATLANTIS **Activity Start Date: 5/24/2021** **Activity End Date: 7/22/2021** **Activity Duration: 60 days**	**Multipliers (location specific)**	**Anticipated cyclone count**	**Percentages relative to cyclones that passed within 150nm**	**Percentages relative to all North Atlantic cyclones**
Expected tropical cyclone count (TD-H5) during activity duration (anywhere in North Atlantic)		2.543		**100%**
Expected tropical cyclone count (TD-H5) during activity duration to pass within 150 nm from location	**9.77%**	0.248		9.77%
Expected tropical cyclone count (TS-H5) during activity duration (anywhere in North Atlantic)		1.543		**100%**
Expected tropical cyclone count (TS-H5) during activity duration to pass within 150 nm from location	**9.39%**	0.145	**100%**	9.39%
Expected tropical cyclone count (TS-H5) during activity duration to pass within 150 nm from location generated less than 6 days out	**6.92%**	0.107	73.68%	6.92%
Expected tropical cyclone count (TS-H5) during activity duration to pass within 150 nm from location generated less than 3 days out	**5.93%**	0.092	63.16%	5.93%
Expected hurricane count (H1-H5) during activity duration (anywhere in North Atlantic)		0.463		**100%**
Expected hurricane count (H1-H5) during activity duration to pass within 150 nm from location	**8.54%**	0.040	**100%**	8.54%
Expected hurricane count (H1-H5) during activity duration to pass within 150 nm from location generated less than 6 days out	**5.06%**	0.023	59.26%	5.06%
Expected hurricane count (H1-H5) during activity duration to pass within 150 nm from location generated less than 3 days out	**3.80%**	0.018	44.44%	3.80%

Table 9-2: Cyclone risk estimates by storm category for the period 2/24/2021 – 4/23/2021 at Perdido location

Location #2: PERDIDO Activity Start Date: 5/24/2021 Activity End Date: 7/22/2021 Activity Duration: 60 days	Multipliers (location specific)	Anticipated cyclone count	Percentages relative to cyclones that passed within 150nm	Percentages relative to all North Atlantic cyclones
Expected tropical cyclone count (TD-H5) during activity duration (anywhere in North Atlantic)		2.543		**100%**
Expected tropical cyclone count (TD-H5) during activity duration to pass within 150 nm from location	**7.81%**	0.199		7.81%
Expected tropical cyclone count (TS-H5) during activity duration (anywhere in North Atlantic)		1.543		**100%**
Expected tropical cyclone count (TS-H5) during activity duration to pass within 150 nm from location	**6.92%**	0.107	**100%**	6.92%
Expected tropical cyclone count (TS-H5) during activity duration to pass within 150 nm from location generated less than 6 days out	**5.44%**	0.084	78.57%	5.44%
Expected tropical cyclone count (TS-H5) during activity duration to pass within 150 nm from location generated less than 3 days out	**4.28%**	0.066	61.90%	4.28%
Expected hurricane count (H1-H5) during activity duration (anywhere in North Atlantic)		0.463		**100%**
Expected hurricane count (H1-H5) during activity duration to pass within 150 nm from location	**5.38%**	0.025	**100%**	5.38%
Expected hurricane count (H1-H5) during activity duration to pass within 150 nm from location generated less than 6 days out	**3.16%**	0.015	58.82%	3.16%
Expected hurricane count (H1-H5) during activity duration to pass within 150 nm from location generated less than 3 days out	**1.27%**	0.006	23.53%	1.27%

Table 9-3: Cyclone risk estimates by storm category for the period 2/24/2021 – 4/23/2021 at Appomattox location

Location #3: APPOMATTOX **Activity Start Date: 5/24/2021** **Activity End Date: 7/22/2021** **Activity Duration: 60 days**	**Multipliers (location specific)**	**Anticipated cyclone count**	**Percentages relative to cyclones that passed within 150nm**	**Percentages relative to all North Atlantic cyclones**
Expected tropical cyclone count (TD-H5) during activity duration (anywhere in North Atlantic)		2.543		**100%**
Expected tropical cyclone count (TD-H5) during activity duration to pass within 150 nm from location	**10.26%**	0.261		10.26%
Expected tropical cyclone count (TS-H5) during activity duration (anywhere in North Atlantic)		1.543		**100%**
Expected tropical cyclone count (TS-H5) during activity duration to pass within 150 nm from location	**9.23%**	0.142	**100%**	9.23%
Expected tropical cyclone count (TS-H5) during activity duration to pass within 150 nm from location generated less than 6 days out	**7.08%**	0.109	76.79%	7.08%
Expected tropical cyclone count (TS-H5) during activity duration to pass within 150 nm from location generated less than 3 days out	**4.94%**	0.076	53.57%	4.94%
Expected hurricane count (H1-H5) during activity duration (anywhere in North Atlantic)		0.463		**100%**
Expected hurricane count (H1-H5) during activity duration to pass within 150 nm from location	**7.91%**	0.037	**100%**	7.91%
Expected hurricane count (H1-H5) during activity duration to pass within 150 nm from location generated less than 6 days out	**5.06%**	0.023	64.00%	5.06%
Expected hurricane count (H1-H5) during activity duration to pass within 150 nm from location generated less than 3 days out	**2.22%**	0.010	28.00%	2.22%

Given the amount of work performed in the data analysis of the extensive cyclone database, it became evident that with just a small additional effort, all the risk estimates described in this section could be automated in the form of a user friendly "tropical cyclone estimator tool".

In addition to the option to select a specific range of dates for the analysis, the tool was expanded to perform calculations at any location in the NA, just by entering its latitude and longitude. Appendix A describes this tool including a user's guide. The tool calculates the historical number of cyclones that have been observed during the selected range of calendar days, over the 50 years of data in the database. The tool also estimates the average number of cyclones that would likely pass during the selected duration period. The results are presented for different cyclone categories for the selected location. The tool also lists each one of the hurricanes that have passed within 150 nm of the selected location during the activity period (e.g., if selected period is August 1 to August 30, the tool lists all applicable cyclones during August 1 to August 30 for each year from 1970 to 2019). The tool also includes the capability to plot the path followed by any of these hurricanes, including the facility location with a 150 nm circle around it. Two plots are provided with different coordinate systems, one with Universal Transverse Mercator (UTM) coordinates (with units in km), and the other with geographic coordinates (degrees).

10 CONCLUSIONS

The first part of the study involved the analysis of general cyclone statistics in the North Atlantic for the 50 years of data (1970 to 2019), as reported in IBTrACS. Different types of analysis were performed: number of cyclones per decade, per year, per week and per day. Histograms of number of cyclones in a year were developed. Some cyclone trends and characteristics were observed:

- The maximum number of cyclones for the 50 year period was 31 in 2005 and the minimum count was six in 1983.
- The average number of cyclones over the 50 year period was 16.83 cyclones per year.
- An increase of count in both tropical storms and hurricanes is noted in the last 20 years as compared with the first 30, on average. The overall average for tropical storms per year is 5.82 and for hurricanes is 6.32.
- Analyzing the histogram of cyclone count (tropical depressions to hurricane Category 5) in a year, it is observed that the minimum number is six cyclones in one year (only observed once in the period 1970-2019). There have been seven years with a count of 19 cyclones (count that occurred more often in the period, and only one year with an extreme maximum count of 31.
- While the total number of cyclones each year is not showing any specific trend of increase/decrease over time, the number of tropical storms and hurricanes has increased significantly in recent years, as the number of tropical depressions decreased. 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 than in previous years.

The next objective of the study was to use the available 50 years of past cyclone history to estimate future cyclone threats at selected locations in the GoM. 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 is used for offshore assets to decide whether and when to initiate those activities prior to an upcoming cyclone. Table 10-1 shows a sample comparison for T-time six days versus three days, for the three locations. The following observations are made:

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

Similar comparisons can be made for the other two locations as recorded in Table 10-1. It is noted that of the three locations, Perdido experience the lowest number of threats, and Appomattox the highest.

Table 10-1: 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 in existence N days out from location (threat and non-threat)	Total cyclones in existence N days out from location for which forecast cone + storm size affects location (threat)	Average cyclones per year in existence N days out from location for which forecast cone + storm size affects location (threat)	Percentage of threat cyclones in existence 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%

The last part of the study was to assess the actual historical frequency of cyclone hits at the three specific locations in order to estimate risk of future cyclone hits. The study performed the analysis assuming year round operations at those locations.

Table 10-2 shows a sample comparison for T-time six days versus three days, for the three locations. The following observations are made:

- Of all the named cyclones (TS to H5) in the North Atlantic, it is expected (based on 50 years of history) that 6.92% of them would be passing within 150 nautical miles of the location (if generated less than six days out from this location), and 5.93% of them would be passing within 150 nautical miles of the location (if generated less than three days out from this location).
- Of all hurricanes (H1 to H5) in the North Atlantic, it is expected (based on 50 years of history) that, 5.06% of them would be passing within 150 nautical miles of the location (if generated less than six days out from this location) and 3.80% of them would be passing within 150 nautical miles of the location (if generated less than three days out from this location).

Similar comparisons can be made for the other two locations as recorded in Table 10-2. It is noted that of the three locations, Perdido experience the lowest hurricane risk, and Atlantis the highest for six days out and three days out cyclones.

Table 10-2: Comparison of actual number of cyclones that passed within 150 nm of three locations generated less than N days in advance (6 days vs 3 days)

N days out or T-time [days]	Location	Number of cyclones TD or higher	% of TD or higher / Total TD or higher anywhere in NA	Number of cyclones TS or higher	% of TS or higher / Total TS or higher anywhere in NA	Number of cyclones H1 or higher	% of H1 or higher / Total H1 or higher anywhere in NA
6	**ATLANTIS**	64	7.81%	42	6.92%	16	5.06%
3	**ATLANTIS**	57	6.96%	36	5.93%	12	3.80%
6	**PERDIDO**	55	6.72%	33	5.44%	10	3.16%
3	**PERDIDO**	45	5.49%	26	4.28%	4	1.27%
6	**APPOMATTOX**	68	8.30%	43	7.08%	16	5.06%
3	**APPOMATTOX**	48	5.86%	30	4.94%	7	2.22%

Based on the results it is important to understand the amount of time in advance that approaching tropical cyclones provide before they reach the rig location 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 a T-time = six days has a 33% higher chance of being hit by a by a hurricane with less than the rig's T-time advance notice than a rig with T-time = three days at that same location.

Table 10-3 and Table 10-4 further highlight the effect that T-time has on the risk of being hit by a tropical storm without enough advance notice to be able to safely secure the well, evacuate and/or move to a safe location. Both tables show the estimated percentage of all North Atlantic tropical storms that would eventually (on average) hit each one of the three locations within 150 nautical miles with less than T-time days of advance notice. Table 10-3 corresponds to tropical storms to Hurricane 5 categories, while Table 10-4 relates to Hurricanes 1 to 5 categories. The estimates assume year round operation. For specific time periods, the estimates would vary depending on the time of the year of the operation.

Table 10-3: Percent of all storms in the North Atlantic estimated to pass within 150 nautical miles of each location as tropical storm or hurricane (H1 to H5) strength, assuming year round operation

T-time	Atlantis	Perdido	Appomattox
2 days	4.78 %	3.62 %	2.64 %
3 days	5.93 %	4.28 %	4.94 %
4 days	6.26 %	4.94 %	5.93 %
5 days	6.43 %	5.27 %	6.10 %
6 days	6.92 %	5.44 %	7.08 %
7 days	7.08 %	5.6 %	7.58 %
8 days	7.58 %	5.77 %	7.74 %

Table 10-4: Percent of all storms in the North Atlantic estimated to pass within 150 nautical miles of each location as hurricane (H1 to H5) strength, assuming year round operation

T-time	Atlantis	Perdido	Appomattox
2 days	2.53 %	0.63 %	0 %
3 days	3.80 %	1.27 %	2.22 %
4 days	3.80 %	2.53 %	3.16 %
5 days	4.11 %	2.85 %	3.48 %
6 days	5.06 %	3.16 %	5.06 %
7 days	5.38 %	3.48 %	5.38 %
8 days	5.70 %	3.48 %	5.70 %

The percentages from the above tables were graphically represented in Figure 10-1 and Figure 10-2 and a logarithmic curve fit was produced for each location as shown in the figures. 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.

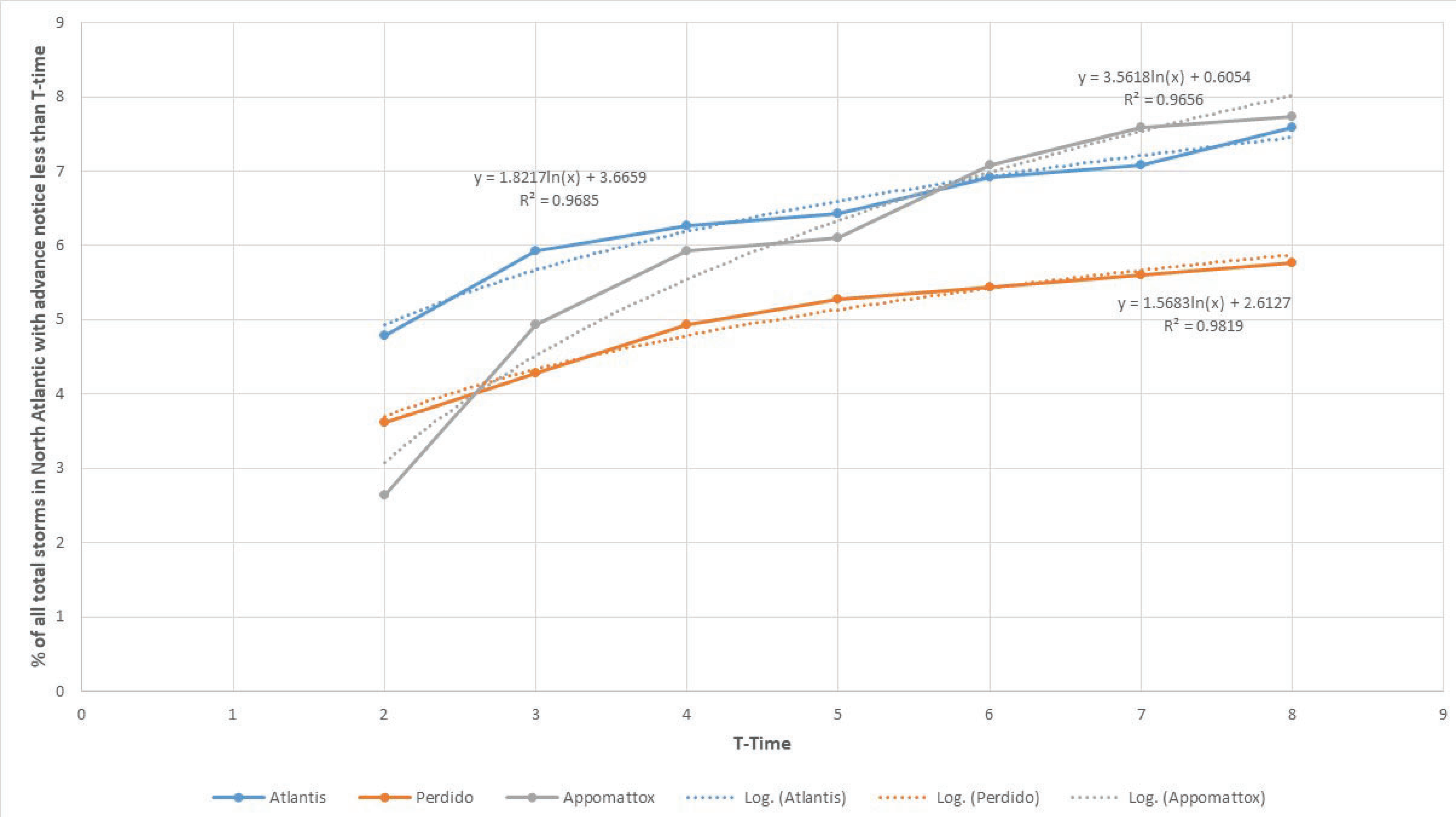


Figure 10-1: Percent of TS to H5 estimated to pass within 150 nm of each location with advance notice less than T-time (year round operation)

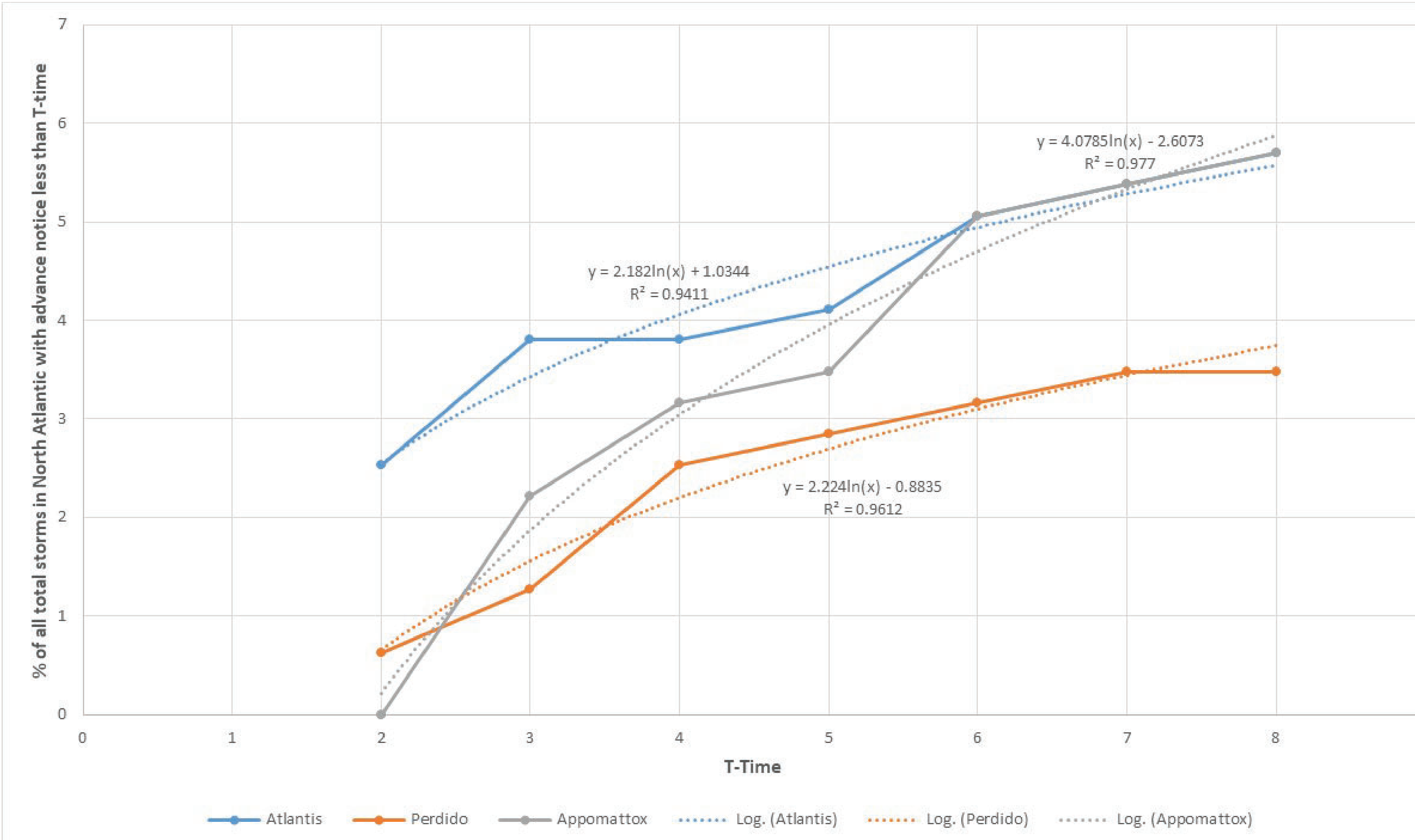


Figure 10-2: Percent of H1 to H5 estimated to pass within 150 nm of each location with advance notice less than T-time (year round operation)

To demonstrate the use and meaning of the above figures, an example is described. A proposed rig is planning to operate at the Appomattox location year round. An evaluation of rig operations estimates that the maximum T-time is 2.5 days. Using the curve fit equation for Appomattox (Figure 10-1) with an x value of 2.5 results in a percentage of 3.87% (percent of the total tropical cyclones in the North Atlantic). The average number of tropical cyclones per year in the North Atlantic for the 50 years in the period of this study was 16.38 cyclones per year. It is therefore estimated that, on average, the example rig will be hit by a tropical storm or hurricane within 150 nm 0.634 times per year (once every 1.58 years) without enough advance notice to be able to safely secure the well, evacuate and/or move to a safe location.

Now, if another proposed rig is planning to operate at the same location year round but with a maximum T-time of 7.5 days, the curve fit equation with an x value of 7.5 results in a percentage of 7.78% (percent of the total tropical cyclones in the North Atlantic). The average number of tropical cyclones per year in the North Atlantic for the 50 years in the period of this study was 16.38 cyclones per year. It is therefore estimated that, on average, the example rig will be hit by a tropical storm or hurricane within 150 nm 1.27 times per year (once every 0.78 years) without enough advance notice to be able to safely secure the well, evacuate and/or move to a safe location.

Comparing the two described scenarios, it is noted that the risk of being caught on location by a tropical storm or hurricane is two times higher for a rig with T-time of 7.5 days when compared to a rig with T-time of 2.5 days operating in the same location year round. This example highlights the importance of evaluating rig designs and operational profiles with their associated T-times in order to better understand the potential risks posed by tropical storms.

An important deliverable for this project is the "tropical cyclone count estimator tool". This tool is developed to automate the analysis of the tropical cyclone data from the IBTrACS database. The user can select any location in the North Atlantic, any start day for the planned activity, and the expected duration (maximum 365 days). Another variable that the tool considers is the T-times, allowing for comparison of different designs and activities based on that.

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 R34 radius used in this study to determine if a facility is affected is an approximate average over all storm strengths. Generally, the higher the storm strength, the wider the wind radius for tropical storm winds and vice versa. Also, this study assumes storms are symmetrical, which is not usually the case.
- The estimations are made based on the forecast cone. According to the National Hurricane Center, one third of cyclones deviate from the project path and move outside the cone.
- The T-times are considered point values in this study. In reality they are estimated times, and the operators could speed up activities somewhat if a threatening cyclone is approaching. The inclusion of uncertainty could take this into account. However, the study did not look into this, and just assumed that if T-time is say five days, the operator would move off location if a threatening cyclone is up to five days away, but they would not move if the cyclone is less than five days away and they have not started well securing activities. 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.

11 POTENTIAL FUTURE WORK

A few assumptions were made in the analysis as pointed out throughout this report. It is recommended that future work on this study expand research in the following areas:

1) *Additional information on the scope and guidelines applicable to the hurricane database IBTrACS*
Two assumptions relate to this area: the starting point of the data for each tropical storm, and any changes in the reporting guidelines for IBTrACS.

The study assumed that the first indication of a developing tropical storm in the North Atlantic corresponds to the first data point recorded in IBTrACS. However it is possible that offshore operators are made aware of developing storms earlier than that. This would give them additional time to prepare for activities to shutdown, secure the well, and evacuate the rig and/or move to a safe location. Additional information from NOAA or offshore operators to understand this issue could help in reevaluating this assumption.

The study observed that while the number of total tropical storms over the years does not show any specific increasing or decreasing trend, the number of named storms do show a clear increasing trend. This is based on the assumption that there has been no changes in the IBTrACS reporting guidelines for the last 50 years that could be affecting this conclusion. It is recommended to investigate this issue with NOAA.

2) *Size of the tropical storms*
Initial research on this topic indicated that there is no clear dependency between the size of a tropical storm and its strength, generation time, or location. The IBTrACS database includes storm size information only for a limited number of storms mainly in the last ten or so years. Consequently for simplification, a storm size of 150 nautical miles was assumed. By storm size, it is meant the radius around a storm eye for which tropical storm strength winds can be found. However, future studies could look into this in more detail.

3) *Uncertainty in storm path prediction*
In order to simplify the study, and due to the lack of additional information, the "predicted" track for each storm was assumed to be the actual historical path, adding the uncertainty cone around it. The uncertainty cone encompasses a 66% probability that the actual path will be within those limits. However, there is still a 1 in 3 chance that the actual storm path would end up outside the predicted path. It is recommended that future studies take this into consideration and add uncertainty into the results.

12 REFERENCES

[1] Risk and Reliability Analysis Branch, SMA Directorate, Johnson Space Center, NASA, "Comparison of a Subsea BOP with a Surface BOP and Subsea Isolation Device for an Uncontrolled Hydrocarbon Release for Completion Operations," 2020.

[2] D. K. K. a. S. Knapp, "International Best Track Archive for Climate Stewardship (IBTrACS) Project, Version 4," NOAA National Centers for Environmental Information, 2018.

[3] "NOAA Historical Hurricane Tracks, North Atlantic Basin, 1970-2019 (819 cyclones)".

[4] Vose Software, "ModelRisk," Antwerpsesteenweg 489, 9040 Sint-Amandsberg, BE.

[5] ANSI/API Recommended Practice 2MET, "Derivation of Metocean Design and Operating Conditions", First Edition, 2014.

[6] NOAA, "The State of Hurricane Forecasting: A Look at Model and NHC Accuracy," [Online]. Available: https://www.weathernationtv.com/news/state-hurricane-forecasting-look-model-nhc-accuracy/.

[7] NOAA, "Definition of the NHC Track Forecast Cone," [Online]. Available: https://www.nhc.noaa.gov/aboutcone.shtml. [Accessed October 2020].

[8] NOAA, "IRMA Graphics Archive: 5-day Forecast Track, Initial Wind Field and Watch/Warning Graphic," [Online]. Available: https://www.nhc.noaa.gov/archive/2017/IRMA_graphics.php?product=5day_cone_with_line_and_wind.

[9] NOAA, "Irma Graphics Archive: Initial Wind Field and Watch/Warning Graphic," [Online]. Available: https://www.nhc.noaa.gov/archive/2017/IRMA_graphics.php?product=current_wind. [Accessed October 2020].

[10] NOAA, "ISAAC Graphics Archive," [Online]. Available: https://www.nhc.noaa.gov/archive/2012/graphics/al09/loop_5NLW.shtml. [Accessed October 2020].

[11] NOAA, "Tropical Cyclone Report - Hurricane Isaac (AL092012)," [Online]. Available: https://www.nhc.noaa.gov/data/tcr/AL092012_Isaac.pdf. [Accessed October 2020].

[12] NOAA, "International Best Track Archive for Climate Stewardship (IBTrACS) - Technical Documentation," [Online]. Available: https://www.ncdc.noaa.gov/ibtracs/pdf/IBTrACS_version4_Technical_Details.pdf. [Accessed October 2020].

APPENDIX A: TROPICAL CYCLONE COUNT CALCULATOR TOOL

Introduction

The tropical cyclone count calculator tool was developed to automate the analysis of the tropical cyclone data from the IBTrACS version 4. These data contain cyclones from 1970 to 2019. The user starts by selecting one facility location in GoM, a start day for the planned activity, and the expected duration (maximum 365 days). Based on this information, once the user presses the function key "F9" (Calculate) button, the tool calculates the historical (average) number of cyclones that have been observed during the selected range of calendar days, over all the years that have been recorded in the hurricane database (see Figure A- 1, "*Historical cyclone count*"). The tool also estimates the average number of cyclones that would likely pass during the selected duration period (see Figure A- 1, "*Estimated cyclone count"*). The results are presented for different cyclone categories for the selected location. The list of historical hurricanes that have passed within 150 nm of the facility location during the activity period, together with relevant parameters, is displayed below the cyclone count calculator (see Figure A- 2), and the corresponding path followed by each hurricane that passed within 150 nm of the facility is plotted on a different worksheet tab ("*Hurricane Path*") as seen on Figure A- 3 and Figure A- 4. In addition to the hurricane paths, the plots include the facility location and a circle depicting the area within 150 nm from the location. Two plots are provided with different coordinate systems, one with UTM coordinates (with units in km), and the other with geographic coordinates (degrees).

How to use the calculator tool

Figure A- 1 shows a screen shot of the calculator tool. Only the fields shaded with green are available to change. The rest of the fields are locked to prevent inadvertent edits to the formulas in those cells. On the top right, the user starts by selecting the "*Facility*" by using the drop-down list box with the names of the locations of interest (e.g., Atlantis, Perdido, Appomattox), the "*Activity Start Date*" and "*Activity Duration*" on the corresponding fields. The start date can be any date in the past or the future, and the duration cannot exceed one year (365 days).

Once the user presses the function key "*F9*" to recalculate the spreadsheet, the "*Latitude*" and "*Longitude*" fields are updated with the geographic coordinates for the selected location, and all frequency estimates are updated after two or three minutes based on the entered inputs. Note, the calculation will stop if any inputs or "clicks" are made in Excel during the calculation.

The geographic coordinates for each facility are stored in the same spreadsheet tab. The facility names and geographic location coordinates can be easily added and edited if needed in the table to the right of the main calculator screen in the "*Hurricane Calculator*" tab.

The estimated number of cyclones are shown by categories:

1. TD-H5: Tropical depressions to hurricanes Category 5
2. TS-H5: Tropical storms to hurricanes Category 5
3. H1-H5: Hurricanes Category 1 to Category 5

Actual Number of Cyclones

For each cyclone category, the historical cyclone counts include the average number of cyclones of that category that have been observed anywhere in the North Atlantic, and the average number of cyclones whose eye passed within 150 nautical miles of the corresponding location. For cyclones Categories TS-H5 and H1-H5, the average number of cyclones that passed within 150 nautical miles from the location, and were generated less than six or four days out are also calculated. Additionally, the calculator allows computing the average number of cyclones that have passed within 150 nautical miles from the location and were generated less than X days out. The user has to select the desired "*days out*" in the corresponding drop-down list box (green field) in the table.

It should be noted that the date used in the main database table is the date that each cyclone was first reported, as observed in the IBTrACS database (cyclone start day).

Estimated Number of Cyclones

The estimated number of cyclones to pass within 150 nautical miles of the location is based on multipliers that are location specific. The multipliers have been previously calculated for each location and it is assumed that these multipliers are independent of the time of the year, i.e., they are the same during peak season or non-peak season. However, the number of hurricanes is date dependent.

The estimated number of hurricanes during any selected period is calculated based on a computed daily number of cyclones. As noted previously, the data set includes all cyclones between 1970 and 2019. The daily count table lists the total number of cyclones of each category recorded each day of the year during those 50 years. The date used in this table is the date that each cyclone was first reported as observed in the IBTrACS database (cyclone start day). The daily count table also includes the counts for each cyclone category per day, as well as the addition in the three groups of interest (TD-H5, TS-H5 and H1-H5). In order to smooth out the counts and counteract statistical variations, the average daily count for each day was computed as a seven-day average divided by 50. Specifically, the seven day average is done by using the three days before, the day of, and the three days after, for each day of the year, and dividing that by 50 to normalize the counts. Based on the start date and the duration, the estimator tool then pulls out the average cyclone counts for the selected period on a day-by-day basis, and posts the results in the main estimator screen.

Additionally, the estimator tool computes a few percentage-based statistics to compare the cyclones generated less than certain days out relative to the location of interest in relation to the total number of cyclones. These percentage statistics are displayed in the two rightmost columns, shaded in light blue. The first of these two columns displays the percentage of cyclones that pass within 150 nautical miles to the location of interest generated less than N number of days out relative to the total number of storms that pass within 150 nautical miles of the location of interest. The second of these two columns displays the percentage of cyclones that pass within 150 nautical miles to the location of interest generated less than N number of days out relative to the total number of cyclones in the same category. For example, for the estimates shown in Figure A- 1, the following observations are made:

- Of all the named cyclones (TS to H5) that would pass within 150 nautical miles from Atlantis location, it is estimated (based on 50 years of history) that 73.7% of them would be generated less than six days out from this location and 63.2% of them less than three days out from this location.

- Of all hurricanes (H1 to H5) that would pass within 150 nautical miles from Atlantis location, it is expected (based on 50 years of history) that 59.3% of them would be generated less than six days out from this location and 44.4% of them less than three days out from this location.
- Of all the named cyclones (TS to H5) in the North Atlantic, 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, 6.9% of them would be passing within 150 nautical miles of the location (if generated less than six days out from this location), and 5.9% of them would be passing within 150 nautical miles of the location (if generated less than three days out from this location).
- Of all hurricanes (H1 to H5) in the North Atlantic, 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, 5.1% of them would be passing within 150 nautical miles of the location (if generated less than six days out from this location) and 3.8% of them would be passing within 150 nautical miles of the location (if generated less than three days out from this location).

Hurricane List

The list of historical hurricanes that have passed within 150 nm of the facility location during the activity period is displayed below the cyclone count calculator (see Figure A- 2). This list includes relevant parameters for each hurricane, such as *Name*, *Storm #* (from the IBTrACS database), *Week of the Year*, *Year*, *Storm Classification within 0- Radius1*, *Distance from location (Max. Wind in Radius1)*, and *Max Wind Speed in Radius1*.

Hurricane Path

The path followed by each hurricane that passed within 150 nm of the facility is plotted on a different worksheet tab ("*Hurricane Path*") as seen on Figure A- 3 and Figure A- 4. To start, the user selects a hurricane in the drop-down list box (green field), then press "F9" to create the plots that are generated with two coordinate systems, one with UTM coordinate system (with units in km), and the other with geographic coordinates (degrees). In addition to the hurricane paths, the plots also include the facility location and a circle depicting the area within 150 nm from the location.

ESTIMATED TROPICAL CYCLONE COUNT CALCULATOR

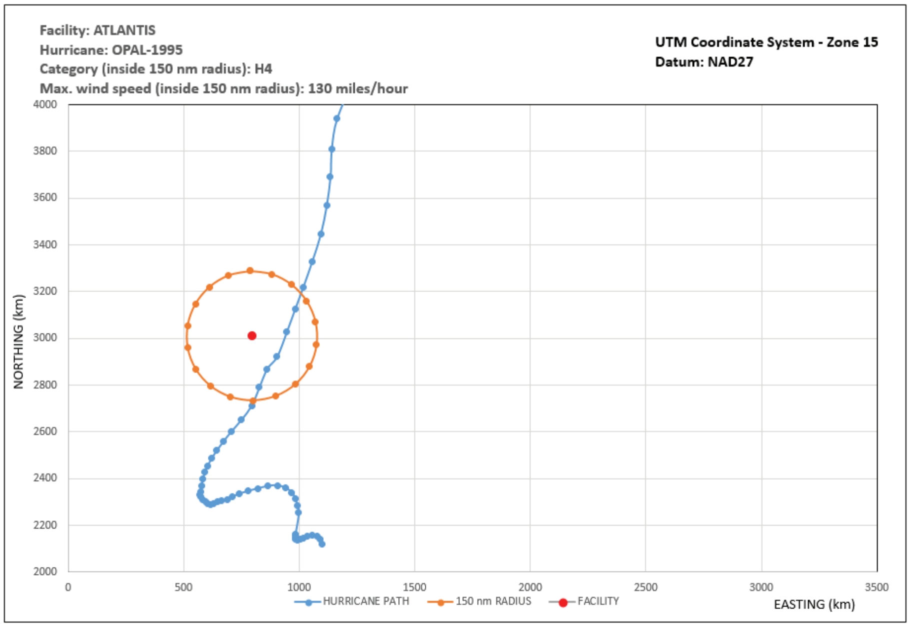
			Latitude	Longitude	
Facility (*Select from drop-down list*):	ATLANTIS		27.1955	-90.0270	Press function key "F9" to Calculate
Activity Start Date:	9/24/2020				
Activity Duration (days, ≤ 365):	60				
End Date:	11/22/2020				

Description		Actual # of cyclones (historical): Historical cyclone count	% relative to cyclones that passed within 150nm	% relative to all North Atlantic cyclones	Estimated # of cyclones (activity period): Estimated Cyclone count	% relative to cyclones that passed within 150nm	% relative to all North Atlantic cyclones	Facility	Lat	Lon
Estimated tropical cyclone count (TD-H5) during activity duration (anywhere in North Atlantic)	TD-H5 anywhere	3.94		100%	3.93		100%			
Estimated tropical tyclone count (TD-H5) during activity duration to pass within 150 nm from location	TD-H5 within 150nm	0.22			0.38			ATLANTIS	27.1955	-90.0270
Estimated tropical cyclone count (TS-H5) during activity duration (anywhere in North Atlantic)	TS-H5 anywhere	3.02			2.99			PERDIDO	26.1289	-94.8979
Estimated tropical cyclone count (TS-H5) during activity duration to pass within 150 nm from location	TS-H5 within 150nm	0.18	100%	6.0%	0.28	100%	9.4%	APPOMATTOX	28.5749	-87.9346
Estimated tropical cyclone count (TS-H5) during activity duration to pass within 150 nm from location generated less than 6 days out	TS-H5 within 150nm, less than 6 days out	0.16	88.9%	5.3%	0.21	73.7%	6.9%	KATY	29.7858	-95.8245
Estimated tropical cyclone count (TS-H5) during activity duration to pass within 150 nm from location generated less than 3 days out	TS-H5 within 150nm, less than 3 days out	0.12	66.7%	4.0%	0.18	63.2%	5.9%	NEW ORLEANS	29.9511	-90.0715
Estimated tropical cyclone count (TS-H5) during activity duration to pass within 150 nm from location generated less than X days out	2	0.08	44.4%	2.6%	0.14	50.9%	4.8%			
Estimated hurricane count (H1-H5) during activity duration (anywhere in North Atlantic)	H1-H5 anywhere	1.70			1.67					
Estimated hurricane count (H1-H5) during activity duration to pass within 150 nm from location	H1-H5 within 150nm	0.08	100.0%	4.7%	0.14	100%	8.5%			
Estimated hurricane count (H1-H5) during activity duration to pass within 150 nm from location generated less than 6 days out	H1-H5 within 150nm, less than 6 days out	0.06	75.0%	3.5%	0.08	59.3%	5.1%			
Estimated hurricane count (H1-H5) during activity duration to pass within 150 nm from location generated less than 3 days out	H1-H5 within 150nm, less than 3 days out	0.02	25.0%	1.2%	0.06	44.4%	3.8%			
Estimated hurricane count (H1-H5) during activity duration to pass within 150 nm from location generated less than X days out	2	0.02	25.0%	1.2%	0.04	29.6%	2.5%	·	·	·

Figure A- 1: Main Calculator Tool Screen ("Hurricane Calculator" tab)

NAME	Storm #	Week of the Year	Year	Storm Classification within 0-Radius1	Distance from location (Max. Wind in Radius1)	Max Wind Speed in Radius1
JUAN	286	43	1985	H1	143	72
OPAL	423	39	1995	H4	75	130
IDA	652	45	2009	H1	105	75
NATE	781	40	2017	H1	65	80

Figure A- 2: Main Calculator Tool Screen (Cont'd)



Select Hurricane:	OPAL

Facility:	ATLANTIS	Select facility on "Hurricane Calculator" screen
Hurricane Name:	OPAL	
Storm #:	423	
Year:	1995	
SID:	1995271N19273	
Storm_Classif	H4	Storm_Classif 0- Radius1
Distance	75	Distance from location of interest @ Max. Wind In Radius1 (miles)
Wind Speed	130	Max Wind Speed in Radius1 (miles/hour)

Press function key "F9" to Calculate

Figure A- 3: Hurricane Path (UTM Coordinate System)

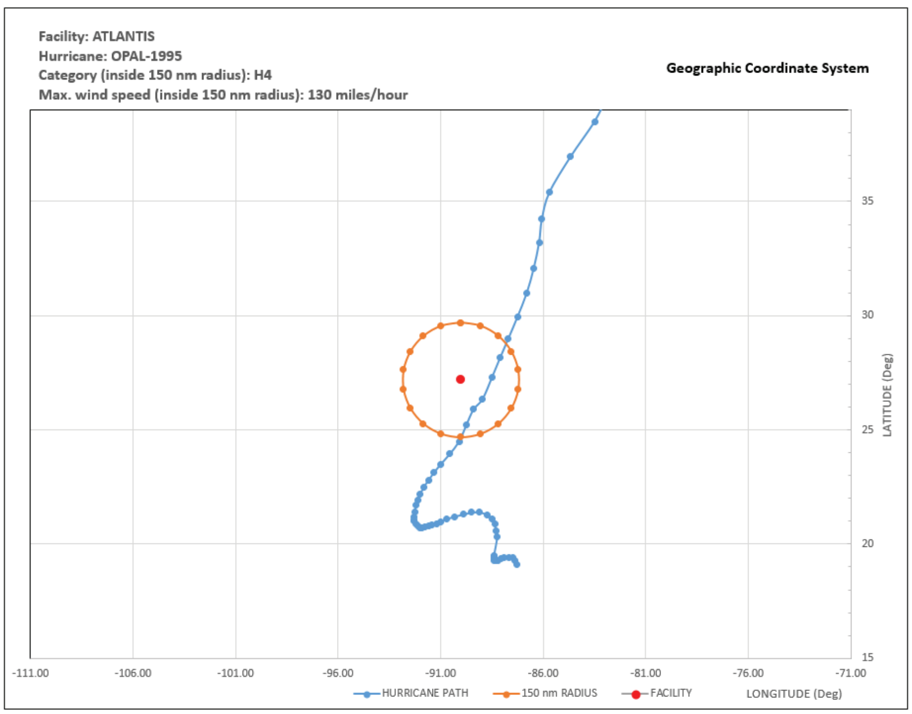


Figure A- 4: Hurricane Path (Geographic Coordinate System)