OCS Study
BOEM 2022-008

Supporting National Environmental Policy Act Documentation for Offshore Wind Energy Development Related to Storm Events

U.S. Department of the Interior
Bureau of Ocean Energy Management
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Authors:
Pamela Middleton
Gretchen Bruggeman
Keith Fernandez, Jr.
Bethany Barnhart

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By
Booz Allen Hamilton
8283 Greensboro Ave
McLean, Virginia

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DISCLAIMER

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Contents

List of Tables

List of Figures

List of Abbreviations and Acronyms

AMO	Atlantic Multidecadal Oscillation
BOEM	Bureau of Ocean Energy Management
BSEE	Bureau of Safety and Environmental Enforcement
COP	Construction and Operation Plan
ESPIS	Environmental Studies Program Information System
FOWT	Floating Offshore Wind Turbine
IEC	International Electrotechnical Commission
IPCC	International Panel on Climate Change
mph	Miles Per Hour
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
OCS	Outer Continental Shelf
OWF	Offshore Wind Facility
PDO	Pacific Decadal Oscillation
TLP	Tension-leg Platform
U.S.	United States

Executive Summary

Offshore wind development is expanding along the Outer Continental Shelf (OCS) and is expected to continue for years to come. Concerns about climate change are furthering the push for renewable energy. Other effects of climate change, such as increasing frequency and severity of storm events, are a concern among stakeholders and members of the public, especially pertaining to the safety of offshore wind facilities.

Terminology used in offshore wind energy Construction and Operation Plans (COPs) and National Environmental Policy Act (NEPA) documents varies and has led to questions regarding the definitions of storm events on the OCS. The use of overlapping terms for storm event categorization and the country of origin of COP authors are often the source of inconsistencies in terminology. Therefore, this paper provides standard definitions of storm events and their classifications based on geographic location.

Understanding the frequency of storm events and how climate change could affect future storm events help offshore wind developers design wind turbines to withstand severe weather conditions. Other factors, such as shifting of currents and rising or falling ocean temperatures, may contribute to changing weather conditions in the future. While predicting long-term weather is challenging, looking at past and present storm frequency and applying possible scenarios for future conditions can provide some guidance for what the future may hold. This paper takes a brief look at possible scenarios of future storm frequency and severity.

This paper also describes the best practices for protecting offshore wind facilities from current and future storm events as well as potential impacts to offshore wind facilities should a storm event occur, which will be summarized and incorporated by reference into future NEPA documents.

This white paper is a living document and will be updated as new information becomes available.

1 Introduction

Public interest in offshore wind is expanding, along with plans for additional sales of offshore wind leases. As more offshore wind developers are submitting Construction and Operation Plans (COPs) and the Bureau of Ocean Energy Management (BOEM) conducts National Environmental Policy Act (NEPA) analyses for wind development, greater detail is requested by the public regarding the terminology for storm events and the steps being taken to ensure offshore wind facilities (OWF) are designed to withstand severe storm events. Offshore wind turbines have an average lifespan ranging from 20 to 30 years. Due to the length of this period and predicted climate trends, it is possible that these structures could be subjected to some level of climate change effects or at least one major Class 4 or 5 hurricane in their lifespan.. Standards, regulations, and best practices are in place to ensure OWFs can withstand storm events currently being experienced and minimize damage in the future. Currently, there are only seven operational offshore wind turbines in the United States (U.S.). These structures have already endured the effects of storm events of varying degrees of severity with no reported significant damage. The early success of this industry will continue to be improved upon as more regional storm event, meteorological, and oceanographic data is collected. The purpose of this document is to define storm event terminology and describe steps being taken to protect OWFs from both major catastrophic and expected storm events on the Outer Continental Shelf (OCS). This white paper is a living document and will be updated as new information becomes available.

2 Terminology

Terminology used in COPs and NEPA documents varies and has led to questions regarding the definitions of storm events on the OCS. The use of overlapping terms for storm event categorization and the country of origin of COP authors are often the source of inconsistencies in terminology. This section provides standard definitions of storm events and their classifications based on geographic location.

2.1 Tropical Cyclones

According to the National Oceanic and Atmospheric Administration (NOAA), tropical cyclones are a category of weather phenomena characterized by rotating, organized systems of clouds and thunderstorms that originate over tropical or subtropical waters. The term tropical cyclone encompasses many storm events, including hurricanes, typhoons, tropical depressions, and tropical storms. A tropical depression is described as a tropical cyclone with maximum sustained wind speeds of less than 39 miles per hour (mph). Once the maximum sustained wind speeds of a tropical cyclone exceed 39 mph, the storm event becomes a tropical storm. Tropical cyclones with maximum sustained wind speeds of up to 73 mph are still considered tropical storms. If maximum sustained wind speeds reach 74 mph or higher, it is then classified as a hurricane, typhoon, or tropical cyclone. Table 1 displays the different categories of a tropical cyclone storm event and the associated wind speeds (NOAA, 2021a).

The naming convention of a storm event is entirely dependent on the geographic location of the storm event. The term hurricane is used in the North Atlantic, Central North Pacific, and Eastern North Pacific regions. Typhoon is used to describe a storm in the Northwest Pacific region (Japan, China, or Philippines). In contrast, the generic term tropical cyclone is used to describe any tropical storm event in the South Pacific and Indian Ocean regions, regardless of wind speeds (NOAA, 2021b). Storm events classified as tropical cyclones are capable of generating high waves, storm surges, lightning, and strong, omni-directional currents (DNV GL, 2018). For the purpose of BOEM documentation, the terms “tropical cyclone” and “hurricane” may be used interchangeably due to varied authors of COPs or other OWF lease documentation. The east coast of the U.S. is considered the North Atlantic region, the southern coast of the U.S. and western Florida are considered the Gulf of Mexico, the west coast is considered the Eastern North Pacific region, and Hawaii is in the North Central Pacific region. In the North Atlantic region, 97% of hurricanes occur during hurricane season, which runs from June 1st to November 30th (NOAA, 2021b).

Table 1. Storm Event and Saffir-Simpson Hurricane Wind Scale

Storm Type or Hurricane Category	Sustained Wind Speed
Tropical Depression	≥39 mph
Tropical Storm	39-73 mph
1	74-95 mph
2	96-110 mph
3 (major)	111-129 mph
4 (major)	130-156 mph
5 (major)	≤157 mph

(NOAA, 2021a; NOAA, ND,a)

2.2 Extratropical Cyclones

Extratropical cyclones form in the North Atlantic and North Pacific regions and may form offshore or inland from these regions. These storm events are associated with cold, warm, or occluded fronts. A cold front is “a zone separating two air masses, of which the cooler, denser mass is advancing and replacing the warmer mass.” A warm front is “a transition zone between a mass of warm air and the cold air it is replacing.” An occluded front is “a composite of two fronts, formed as a cold front overtakes a warm or quasi-stationary front. Two types of occlusions can form depending on the relative coldness of the air behind the cold front to the air ahead of the warm or stationary front. A cold occlusion results when the coldest air is behind the cold front and a warm occlusion results when the coldest air is ahead of the warm front” (NOAA, ND,b).

Extratropical cyclones form over land or water, and these storms derive their energy from fronts between different air masses, whereas tropical cyclones are fueled by warm ocean water. These storm events are most common from December to January and often manifest themselves as blizzards, Nor’easters, and other low-pressure systems that account for much of the precipitation in the U.S. (National Weather Service, ND). Nor’easters in particular may occur year-round but tend to be more severe from September to April (NOAA, ND,c). Sustained winds from extratropical cyclones of all types range from mild, around 10 mph, to hurricane-level wind speeds exceeding 74 mph and precipitation ranges from light showers to torrential rain with freezing temperatures and snow. Over 20 extratropical cyclones may hit the northern and mid-Atlantic coastline in a year with varying degrees of severity (National Park Service, 2019).

Tropical and extratropical cyclones have the potential to create high winds and heavy wave action that could affect OWFs. Ensuring that an OWF is designed to withstand severe storm events through their 20 to 30 year lifespan is key to protecting the OWF, as well as ships, wildlife, and onshore resources.

3 Frequency of Storm Events

Understanding the frequency of storm events and how climate change could affect future storm events help OWF developers design wind turbines to withstand severe weather conditions. Other factors, such as shifting of currents and rising or falling ocean temperatures, may contribute to changing weather conditions in the future. While predicting long-term weather is challenging, looking at past and present storm frequency and applying possible scenarios for future conditions within each oceanic region of the United States can provide some guidance for what the future may hold.

3.1 Current Storm Frequency

North Atlantic Region

Since the mid-1990s, the North Atlantic Ocean has been experiencing a warm phase Atlantic Multidecadal Oscillation (AMO). The AMO is an atmospheric phenomenon that warms or cools the surface temperature in the Atlantic over a period of approximately 20-40 years. Currently, this slight warming of the ocean is responsible for the recent increase in severe hurricanes along the east coast. During a warm phase AMO, a tropical storm is at least two times more likely to evolve into a severe hurricane. The AMO also tends to exaggerate the anticipated increases in global temperatures and the weather-related effects of human-caused climate change. Based on the duration of previous AMO events, it can be inferred that this warm phase will switch to cool soon, but there is currently no accurate method to predict when that switch will occur. This means that, presumably, modern hurricane frequency and intensity trends will continue. (NOAA, 2005)

Gulf of Mexico

The Gulf of Mexico is influenced by a maritime subtropical climate and is situated to the southwest of the Bermuda High – a clockwise circulation around a semi-permanent area of high barometric pressure. Because of this high-pressure system nearby, the Gulf of Mexico most frequently experiences tropical cyclones, especially hurricanes, between June and November. The Gulf of Mexico is part of the North Atlantic warm pool which brings high sea surface temperatures to the basin each summer and leads to the formation of tropical storms and hurricanes in the region. With the AMO occurring in the North Atlantic Ocean, higher temperatures are seen in the Gulf of Mexico as well as increased chances of tropical storms. This process is also strengthened by the Loop Current – the principal current and source of energy for water mass circulation in the Gulf of Mexico. Studies have shown that Loop Current intrusions into the Gulf are chaotic processes resulting in currents at approximately half a mile in depth, surface speeds of 60-80 inches/second, and diameter as large as 155 miles and can persist for weeks or months at a time. These currents may be cause for concern to OWFs as they could induce structural fatigue of materials (BOEM, ND,a). Specifically in 2020, the measured strength and duration of tropical storms and hurricanes in the region are well above average – more than 40 percent above the long-term mean (BOEM, ND,a).

Eastern North Pacific Region

The Eastern North Pacific hurricane season runs from May 15 to November 30; however, tropical cyclones in the region can occur before and after this season and typically form near Mexico and Central America (NOAA, ND,e). In the Pacific Ocean, the Pacific Decadal Oscillation (PDO) produces prolonged El Niño-like patterns of climate variability. These oscillations typically last for 10 to 20 years and the current PDO has been in a negative phase since October 2019 as seen in Figure 1 below. This negative value is characterized by anomalously warm sea surface temperatures in the interior North Pacific and cool temperatures along the U.S. Pacific Coast, and/or when sea level pressures are above average over the North Pacific (NOAA, 2022). The PDO can change the strength, direction and location of ocean currents that build up areas of extreme warm waters, or change the air-sea heat flux, leading to warming of the ocean surface. The current negative (cool) phase also leads to lower sea levels along the coastlines of the Eastern North Pacific and possible droughts on the U.S. West Coast while at the same time, Asia and Australia experience heavy rain and flooding. When the PDO is in a positive phase, the opposite would occur. Additionally, a recent area of research has explored the connection between the AMO and PDO noting that a warm tropical Atlantic climate affects trade wind trends and cools the Pacific Ocean temperatures (IPCC, 2021).

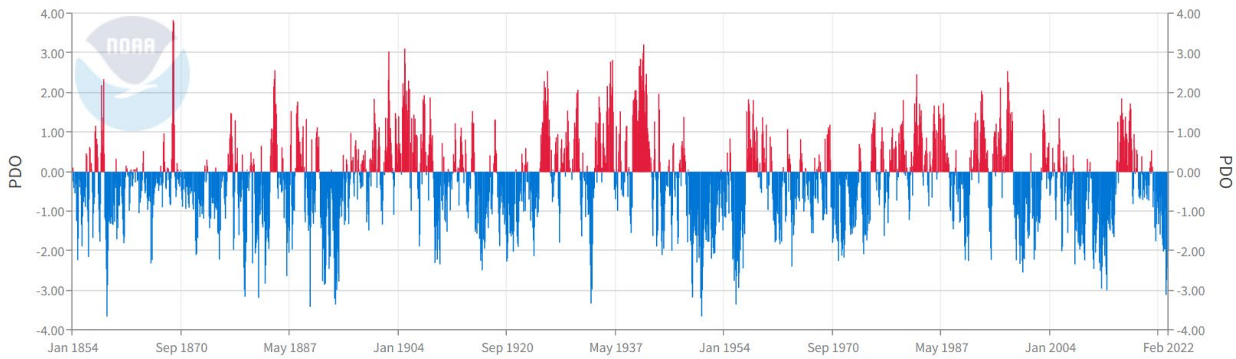

Figure 1. Pacific Decadal Oscillation (NOAA, 2022)

3.2 Historic Data

According to NOAA, “a hurricane strike occurs if that location passes within the hurricane’s strike circle, a circle of 125 nautical mile diameter, centered 12.5 nautical miles to the right of the hurricane center (looking in the direction of motion).” Strikes are different from landfall, where landfall of a hurricane is the intersection of the center of the storm with land; however, the strongest portion of the storm may not be experienced on land during landfall (NOAA, ND,d). The figures below show the amount of daily tropical cyclone activity during hurricane season in the Atlantic region – which is including the Caribbean Sea and the Gulf of Mexico – as well as the Eastern Pacific Basin – which extends from the west coast of the Americas to 140°W – in terms of named storms and hurricanes over a normalized 100-year period. As is seen in Figure 2, the peak of the Atlantic hurricane season is September 10 at approximately 75 storms, with the majority of activity occurring between August and October. As for the Eastern Pacific region, Figure 3 shows a peak in activity at approximately 60 storms in late August and relatively high levels of activity spread out over a longer period of the season than in the Atlantic (NOAA, ND,e).

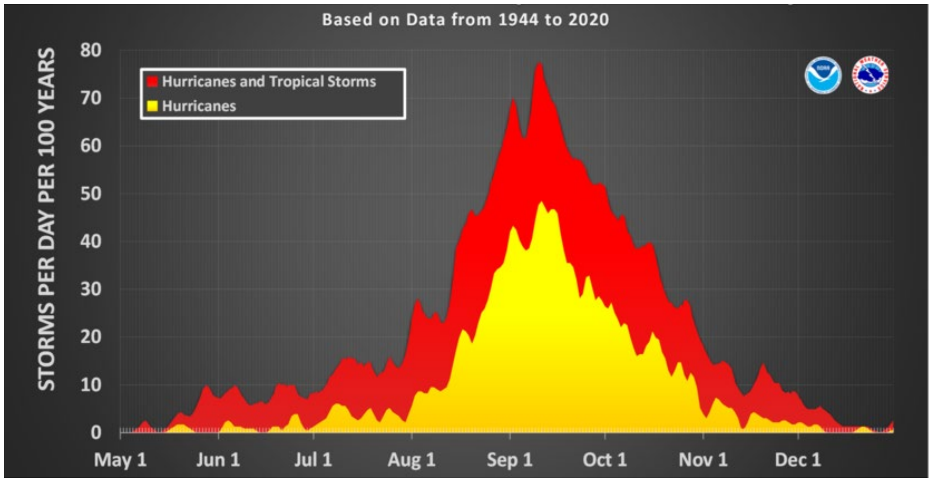

Figure 2. Atlantic Hurricane and Tropical Storm Activity (NOAA, ND,e)

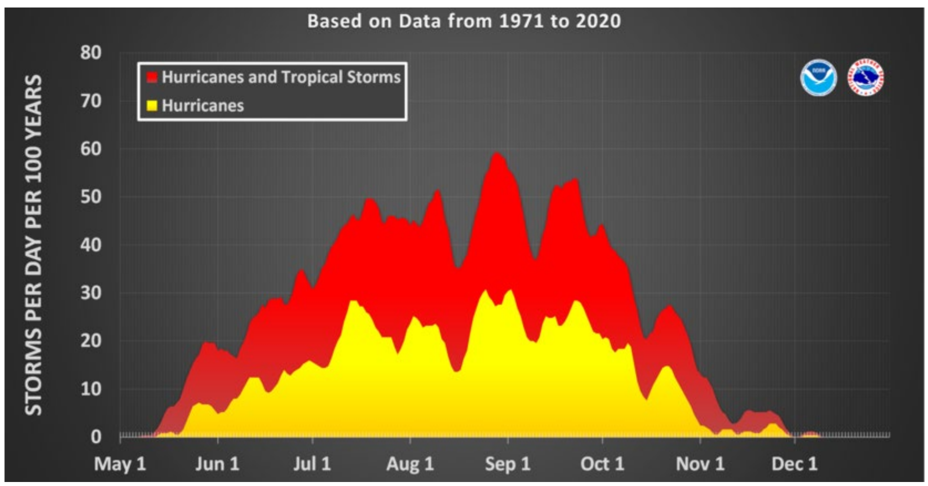

Figure 3. Eastern Pacific Basin Hurricane and Tropical Storm Activity (NOAA, ND,e)

North Atlantic Region

Figure 4, Figure 5, and Figure 6 depict historical data for hurricane strikes, along the Northeast, Mid-Atlantic, southeast, and east coast. The Atlantic hurricane season runs from June 1 to November 30 each year and during this time, based on climate data from 1991 to 2020, the area experienced an average of 14 named storms, 7 hurricanes, and 3 major hurricanes ranging in strength from a Category 3 to a Category 5. Additionally, the 2020 Atlantic Ocean hurricane season was the most active season on record (BOEM, ND,a). The map information below, combined with the International Panel on Climate Change (IPCC) predictions, provides insight on the potential number of hurricane strikes in offshore wind development areas over the next 100 years. This information can be used to estimate the number, not severity, of hurricanes an OWF may have to endure in its lifespan.

Gulf of Mexico

As mentioned above, the Atlantic Ocean has a large effect on the Gulf of Mexico and hurricane activity in the region. Of the Atlantic Region storms which occurred between 1991 and 2020, 81 percent of these storms affect the Gulf of Mexico. In addition, the Loop Current in the Gulf of Mexico has historically been shown to intensify hurricanes in the region as seen with Hurricane Opal in 1995 and Hurricane Katrina in 2005 – Category 4 and Category 5 hurricanes respectively (NOAA, ND,e). Between 2000 and 2020, 22 major hurricanes impacted the Gulf of Mexico (BOEM, ND,a). Figure 7 and Figure 8 below show NOAA historical data for hurricane strikes in the Gulf of Mexico.

Eastern North Pacific Region

Based on the same 30-year climate data from NOAA between 1991 and 2020, an average Eastern Pacific hurricane season has 15 named storms, 8 hurricanes, and 4 major hurricanes; however, these number mostly account for storms from Mexico and Central America, not typically affecting the west coast of North America (NOAA, ND,e). The 2015 Eastern North Pacific hurricane season provided near-record levels including Tropical Cyclone Patricia, which intensified rapidly into a Category 5 hurricane and was the strongest tropical cyclone in the world on record at the time leading to major damage in Mexico and across Southern Texas. Additionally, a report produced by NOAA compiled information on tropical cyclones of the Eastern North Pacific basin between 1949 and 2006 and cited a total of 769 tropical cyclones within the 58-year period, approximately 13 tropical cyclones a year (NOAA, 2009). Again, the majority of these tropical cyclones formed near Mexico and Central America and traveled west, northwest, or north, at times affecting the southwestern U.S. More recently, according to the IPCC, the Eastern North Pacific Ocean experienced the largest heat wave ever recorded between 2013 and 2015. This heat wave, referred to as “the blob,” emerged off Southern California in response to teleconnections between the North Pacific and the weak El Niño and led to an increase in sea level pressure anomalies across the Eastern North Pacific. “The blob” and its associated high-pressure ridge prevented normal winter storms from reaching the U.S. West Coast and likely contributed to drought conditions in the area during those several years. The extreme sea surface temperatures observed in 2014 during this marine heat wave have now become approximately five times more likely with human-induced global warming (IPCC, 2021).

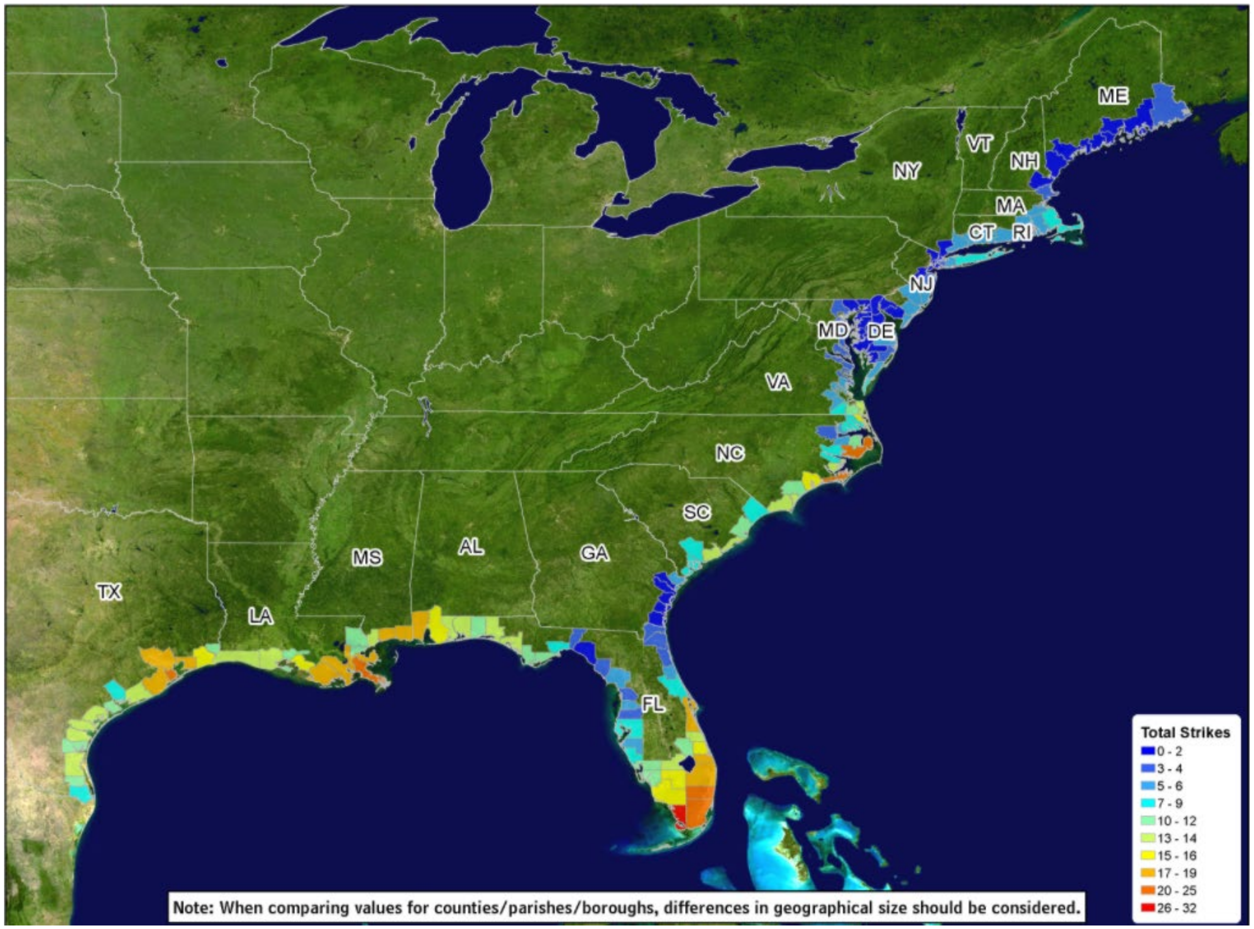

Figure 4. East Coast Hurricane Strikes 1900-2010 (NOAA, ND,e)

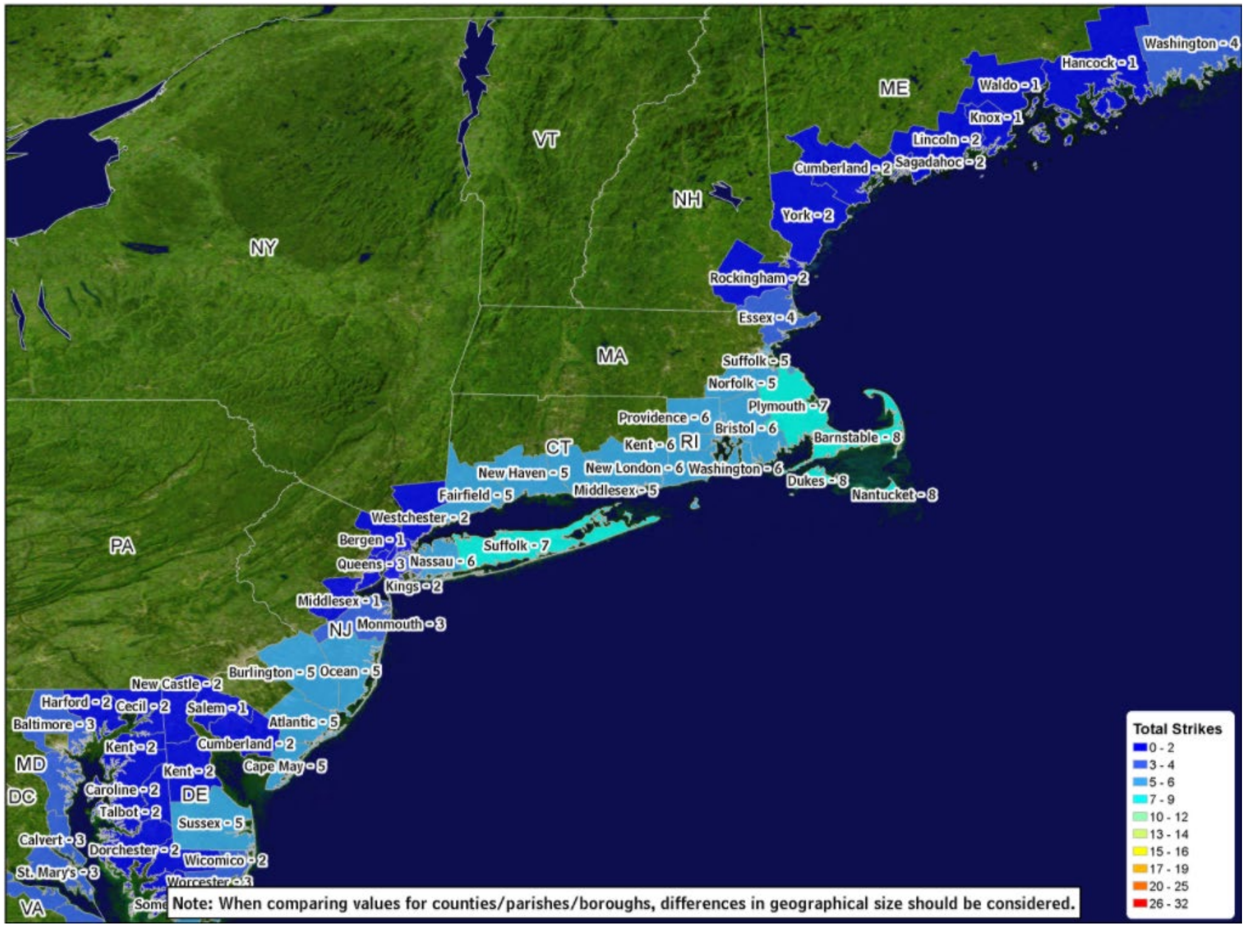

Figure 5. Northeast and Mid-Atlantic Hurricane Strikes 1900-2010 (NOAA, ND,e)

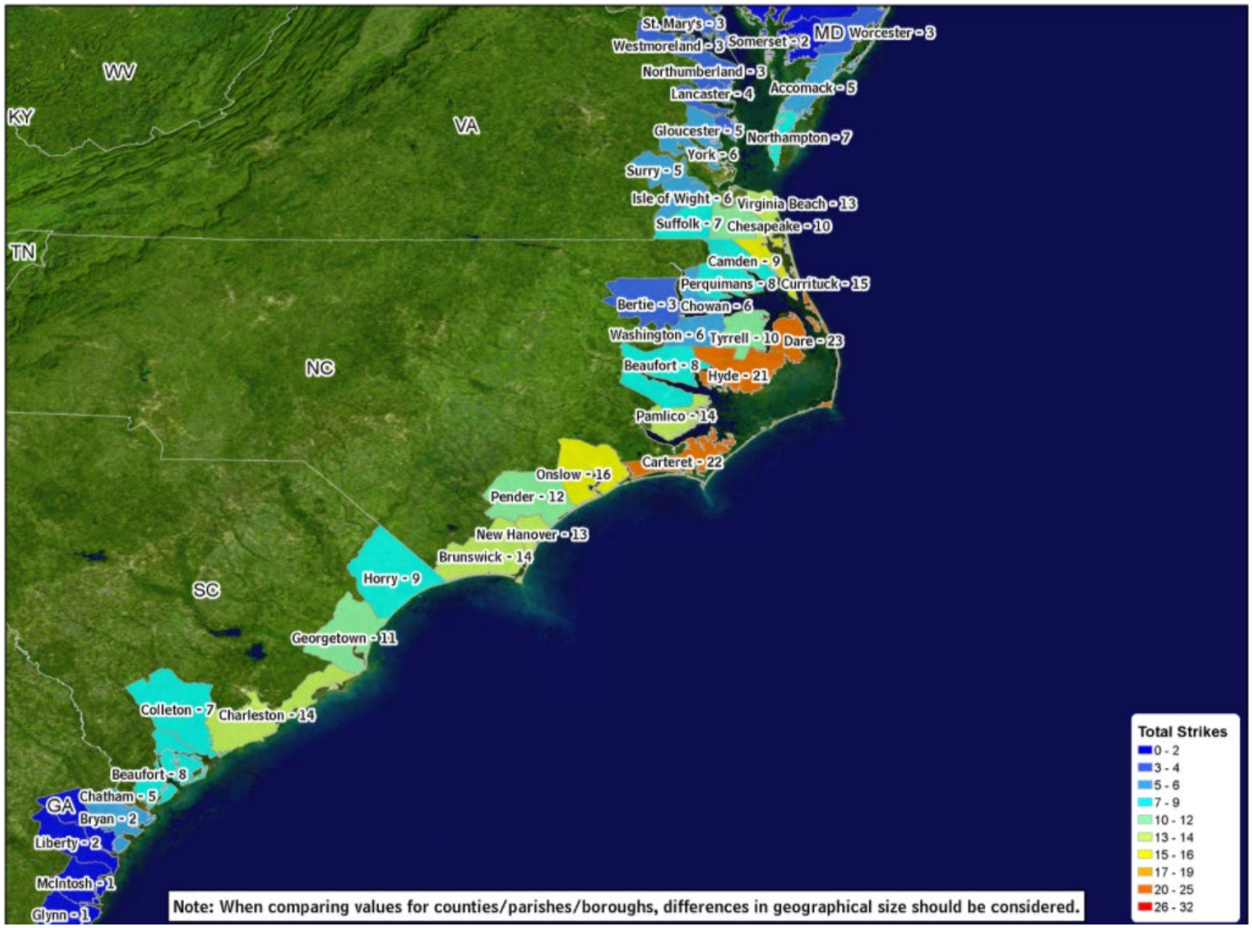

Figure 6. Mid-Atlantic and Southeast Hurricane Strikes 1900-2010 (NOAA, ND,e)

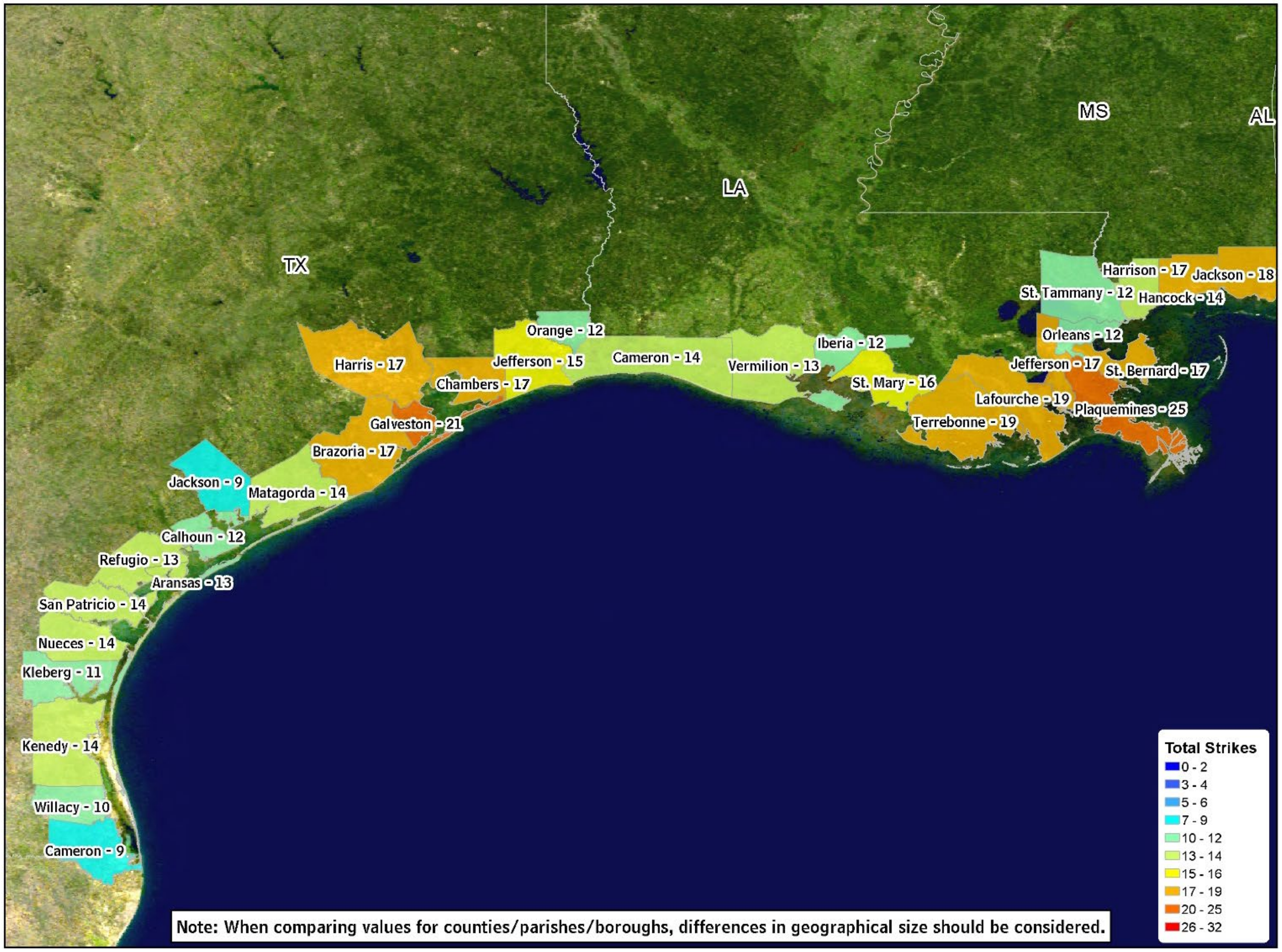

Figure 7. West Gulf of Mexico Hurricane Strikes 1900-2010 (NOAA, ND,e)

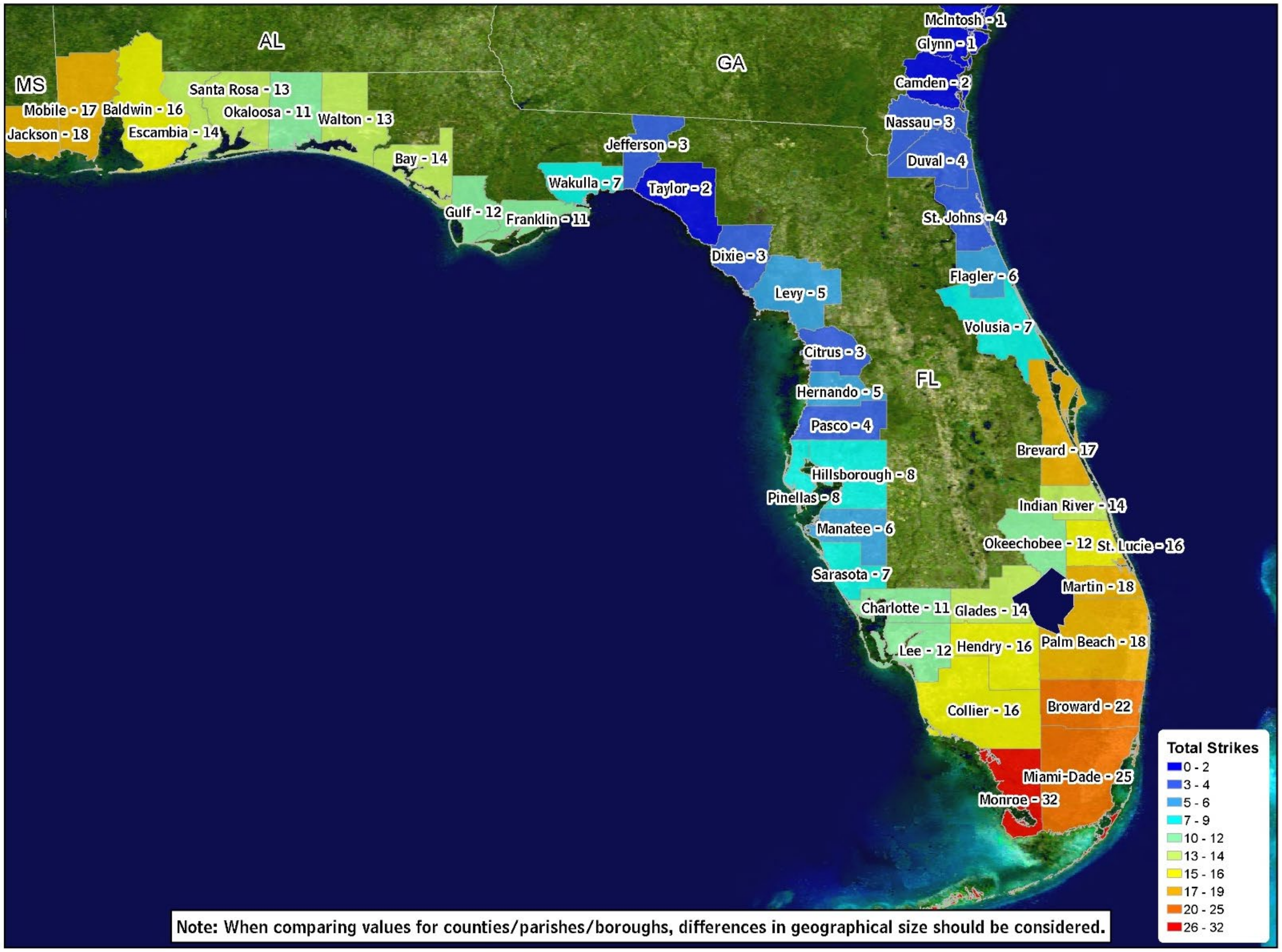

Figure 8. East Gulf of Mexico Hurricane Strikes 1900-2010 (NOAA, ND,e)

3.3 Future Predictions

The IPCC determined there is low confidence in any long-term increase in hurricane activity. It is predicted that the frequency will either decrease or remain unchanged. The intensity of hurricanes, with regards to wind speed, wave heights, and precipitation rates, is likely to become 1-10% more extreme along the east coast of the U.S. The 2017 hurricane season saw an above-average number of hurricanes which led to the costliest season on record. However, it is not possible to determine if a recent increase in storm frequency is natural variability or attributable to greenhouse gases and atmospheric aerosols and the beginning of a future trend. Due to anthropogenically-forced (human-caused) tropical expansion, hurricanes and other tropical cyclones will continue to shift towards the poles. Increased atmospheric carbon dioxide has an opposite effect on storm events such as extratropical cyclones, meaning that the frequency of extratropical cyclones is expected to decrease slightly (IPCC, 2021).

4 Standards and Regulations

BOEM ensures all OWF structures are in compliance with the International Electrotechnical Commission (IEC), which is the international standards and conformity body. The IEC 61400-01 Class IA offshore wind turbine standard and the 61400-3 structure standard are the accepted standards for OWFs constructed on the OCS. These standards require OWFs to withstand storm events based on site-specific meteorological and oceanographic (metocean) conditions for a 50-year return interval (approximately a 2% chance of occurrence in a year). This typically corresponds with Category 3 hurricane metocean conditions. OWF development is generally curtailed in areas where Category 4 and 5 hurricanes occur within the 50-year return interval. Additionally, structure survivability in a 500-year return interval (approximately a 0.2% chance of occurrence in a year) storm event is assessed. The 500-year return interval often corresponds with a Category 4 or 5 hurricane. This means that OWF structures are engineered to withstand and remain operational after a 50-year return interval storm event and at a minimum are engineered to remain standing after a 500-year return interval storm event (BOEM, 2021b).

Floating Offshore Wind Turbines

IEC 61400 Part 3-2 outlines minimum design requirements for floating offshore wind turbines (FOWT) and provides an appropriate level of protection against damage from all hazards during the planned lifetime of a FOWT site. Additionally, Part 3-2 is fully consistent with the requirements of IEC 61400-1 and -3 which are described above, which require OWFs to withstand storm events based on site-specific meteorological and oceanographic (metocean) conditions for a 50-year return interval which typically corresponds with Category 3 conditions. A wind turbine is considered a FOWT if the floating sub-structure is subject to hydrodynamic loading and supported by buoyancy and a station-keeping system which is typically required after depths of 197 feet and – according to current BOEM call areas – limited to 3,609 feet (BSEE, 2012; IEC, 2009). The majority of U.S. usable offshore wind resources exist at depths greater than 197 feet. Water off the West Coast of the United States is much deeper closer to the shore than water off the East Coast in the North Atlantic Region and, because of this, floating wind technology must be used to tap offshore wind resources in the Eastern North Pacific Region (BOEM, ND,b). In general, and not only specific to the West Coast where deep water is more common closer to the shore, floating wind systems are beneficial to accessing higher-speed and more consistent wind resources than their fixed-bottom counterparts can access (BOEM, 2021a).

Existing structures for FOWTs are based on designs used in the offshore oil and gas industry; however, this approach is often not technically sound or economically acceptable without major modifications.

FOWT design must consider maximum inclination angles (roll and/or pitch) of the sub-systems of a turbine including bearings, gearbox, generators, etc., which are currently designed to operate close to the upright condition for onshore and fixed-to-seabed OWFs (BSEE, 2012). As of March 2021, there was one installed FOWT project and ten planned projects in the United States (BOEM, 2021a). FOWTs may be designed from various types including spar-type, semi-submersible-type, barge-type, tension-leg platform (TLP)-type, and multi-turbine platforms. Within each of these types are a number of design concepts that have either been installed throughout the world or are in the development stage.

<u>Metocean Conditions</u>

Site-specific conditions vary across an OWF due to changes in seafloor composition, water depth, distance from shore, variation in currents, and other environmental factors. Storm event types in the northern OCS may differ from those occurring in the south; however, the OWF must be designed to withstand major storm events regardless of whether it is a Nor'easter or a Category 3 hurricane. Standards and regulations may vary depending on the OWF location in addition to metocean and site-specific conditions. Metocean data that factors into design standards is listed in Table 2.

Table 2. Metocean Conditions Factored into OWF Structure Design

Metocean Category	Description of Factor	Examples
Wind Factors	Wind Speed	• Turbines shut off when wind speeds exceed 55mph. • Turbine yaw system turns blades in the direction of the wind to reduce stress. • Turbine blades can be locked down during severe gusts.
	Wind Shear[1]	
	Wind Gusts[2]	
	Turbulence[3]	
	Directional Change	
	Air Temperature	
	Air Density	
	Humidity	
Marine Factors	Ocean Current Speed	• The air gap between the water level and access platform must be at least 20% of the 50-year significant wave height, water level, and wave crest.
	Ocean Current Direction	
	Water Levels	
	Wave Heights	

[1] Wind shear is defined as "the sudden tearing effect encountered along the edge of a zone in which there is a violent change in wind speed or direction. Shear can exist in a horizontal or vertical direction and produces churning motions and instability within this zone." (NOAA, ND,f)
[2] Wind gusts are a fluctuation in wind speed, generally of high velocity. "A gust is a rapid and irregular fluctuation of varying intensity in the upward and downward movement of air currents." (NOAA, ND,f)
[3] Turbulence is defined as "the irregular motion of the atmosphere, as indicated by gusts and lulls in the wind (NOAA, 2009)."

Metocean Category	Description of Factor	Examples
	Wave Break	
	Wave Periods	
	Wave Direction	
	Water Density	
	Water Salinity	
	Water Temperature	
Other Factors	Bathymetry and Seabed Change	• Hybrid steel/concrete structures allow for more flexibility in the tower. • The seabed at the point of anchor is checked for erosion and other potentially degrading effects of waves and currents.
	Vertical Height of Structures	
	Lightning	
	Sea Ice	
	Precipitated Ice	
	Marine Growth on Structures	

(DNV GL, 2016)

5 Impacts to Offshore Wind Facilities

Equipment is rated to withstand specific storm thresholds, depending on data and records from the OWF location. If a storm meets or exceeds these design values, a mandatory inspection of the OWF will occur within 30 days following the storm event to assess impacts. The inspection includes examining the lightning protection, drainage, safety, and back-up power systems and assessing water damages and other visible structural damages such as corrosion and debilitated grout, seals, joints, and welding. Additionally, the seafloor may be inspected to evaluate whether erosion has occurred at the base of the structure (GL Renewables, 2013). The standards and regulations support designs that should withstand most severe storm events, but inspections ensure that if damages occur, repairs are made immediately to protect the OWF structures from greater damage if future storm events ensue (Energo Engineering, Inc, 2009).

More serious impacts could occur in an extreme storm event. Offshore wind structures, including service platforms, contain oil, fuel, and lubricant (some lubricants are non-toxic and water-soluble). Each wind turbine may contain hundreds of gallons of fluids, while service platforms can store thousands of gallons of these liquids. Structures are equipped with oil-storing and leak-proof containment systems that are capable of holding 110% of the total liquid volume. This mitigation method prevents fluids from being released into the environment. Under the extremely unlikely event of a collapse or storage failure, fluids could be released into the surrounding environment. Most release scenarios are categorized below the lethality threshold, even for sensitive species, and any adverse effects generally occur in the immediate vicinity of the release. Increasingly unlikely is the collapse or storage failure of the entire OWF, meaning every turbine, service platform, and support structure. Even if this were to occur and all potential contaminants were released, BOEM predicts moderate effects are possible to the surrounding ecological and socio-economic resources within the offshore marine environment (BOEM, 2013).

6 Conclusion

Storm events that affect the North Atlantic Region, the Eastern North Pacific Region, and the Gulf of Mexico may have hurricane force winds, high wave action, lightning, freezing temperatures, and other conditions that may damage structures within OWFs. Studies currently show that there may not be major increases to the severity and frequency of storm events along the Atlantic Coast. However, the Eastern North Pacific Region and Hawaii may see an increase in tropical storm frequency as shown by studies conducted by NOAA in 2015 (NOAA, 2021). The design parameters for the WTGs are based upon historical data, site-specific measurements, and engineering design practices. Projects will be designed in accordance with the International Electrotechnical Commission (IEC) 61400-1 and 61400-3 standards. These standards require designs to withstand forces based on site-specific conditions for a 50-year return interval (2 percent chance occurrence in a single year) for the WTGs. This means that the WTGs are not designed just for average conditions, but for the higher end event that is reasonable to occur. The newly revised IEC standards now also include a robustness load case check for extreme metocean conditions where turbines are designed to withstand a short-lived 500-year event (0.2 percent chance occurrence in a single year), such as an extreme 3-sec wind gust. Required post-storm inspections are applied to identify damage and then repair structures to prevent more serious failures during subsequent storm events. The design standards, regulations, and safety inspections are built upon the foundation of BOEM’s decades of offshore oil and gas experience and lessons learned. As the technology evolves and more OWFs are developed, it is likely designs will incorporate innovations and improvements to strengthen turbines and supporting structures. Given the growing importance of offshore wind for clean energy production, standards and regulations will continue to develop as well, ensuring the safety and stability of OWFs during their lifetime of production.

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