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Supporting National Environmental Policy Act Documentation for Offshore Wind Energy Development Related to Storm Surge and Sea Level Rise

U.S. Department of the Interior
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List of Abbreviations and Acronyms

BOEM	Bureau of Ocean Energy Management
ETSS	Extra-Tropical Storm Surges
IPCC	Intergovernmental Panel on Climate Change
MDL	Meteorological Development Laboratory
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
SLOSH	Sea Lake and Overland Surges from Hurricanes
U.S.	United States

Executive Summary

Flooding, erosion, habitat change, and loss of coastal habitat from rising seas and storm surge are growing concerns for coastal communities everywhere. Offshore wind energy may be affected by sea level rise and storm surge where wind energy infrastructure interfaces with coastal areas. Locations where submarine transmission cables travel onshore and land-based infrastructure are vulnerable to impacts from storm surge. Ports supporting the construction and maintenance of offshore wind farms are prone to damage from high water, waves, and wind. Natural resources are also being affected by habitat change from intensified flooding and elevated sea levels.

Offshore wind farms are designed and constructed to withstand major storm events with associated high winds and ocean currents. Turbines, submarine cables, and associated infrastructure is located far from the shoreline where storm surge and coastal erosion is taking place. The wind farm components and infrastructure located close to shore may be required to evolve as the natural world changes. Major flood events are expected to increase during large storms along the Atlantic coast, fueled by tropical storms, nor'easters, and hurricanes. Presently, storm surge and extreme high tides are becoming more frequent with lower intensity storm systems. The phenomena associated with storms are only increasing as global temperatures rise and sea levels get higher at a faster pace than in previous decades.

1 Introduction

Changing sea levels are being measured in coastal areas around the Earth. From the poles to the equator, coastlines are being encroached upon by rising seas. Further, storm surges associated with large storm events, hurricanes, and tropical storms are causing sea water to move even further inland. These changes are quantifiable and scientists are applying data collected over the past century to develop models of how coastlines have changed, what they may look like in the future, and where storm surge and coastal flooding will occur.

Offshore wind farms are designed and constructed to withstand major storm events with associated high winds and ocean currents and most of the turbines, cables, and infrastructure are located far from the shoreline where storm surge and coastal erosion is taking place. Onshore transmission cables and transformer facilities are infrastructure associated with offshore wind that are located within the zones where coastal flooding, storm surge, and erosion are occurring. The onshore cable for the Block Island wind farm, although buried more shallow than current industry design standards, has been exposed by storms and tides, resulting in major expenses to the owner and ratepayers of the wind farm. Another important facet of wind energy development are the ports used by vessels that support construction, maintenance, and operations. Damage to docks, ships, and other infrastructure may occur during storm surge and coastal flooding. Changes in the shipping channels from shifting sediment during storms and flood events often require costly dredging operations. These and other aspects of offshore wind development could be vulnerable to the effects of sea level rise. Major flood events along the Atlantic coast are expected to increase during major events such as tropical storms, nor’easters, and hurricanes. Presently, storm surge and extreme high tides are becoming more frequent even with lower intensity storm systems.

This paper provides an overview of sea level rise, storm surge, habitat change, coastal erosion, and how these events may affect offshore wind infrastructure. Links to more in-depth resources and information are noted in the paper and can be accessed in the References Section at the end of the document.

2 Background and Terminology

2.1 Sea Level Rise

It is commonly accepted that the global sea level is rising due to the effects of climate change (Sweet, et al., 2022). Global temperatures have been warming for decades, influenced by human-caused increases of greenhouse gasses (IPCC, 2021). Ocean surface temperatures have been measured as warming since the 1970s; this warming causes thermal expansion of the ocean water, which elevates the sea level (Sweet, et al., 2022; IPCC, 2021). Melting of ice sheets and glaciers from warming temperatures is another major factor that increases ocean volumes and adds to the sea level rise (Sweet, et al., 2022). Other factors contributing to sea level rise include changes in the global water cycle from extraction of water from aquifers and discharging the wastewater into rivers or the ocean, vertical land motion from either subsidence or build-up of sediment, and the normal circulation variation of ocean currents, such as El Niño and the Gulf Stream (NASA, 2020).

According to the National Aeronautics and Space Administration (NASA), sea level will continue to rise and it appears to be accelerating compared to past decades (NASA, 2022). Based on satellite data, the global mean sea level has risen about 0.13 inches a year, almost 4 inches since 1993 (NASA, 2022). Globally, over the last 100 years (1920 to 2020), the average sea level rose about 10 to 12 inches, with a further rise of 10 to 12 inches expected in the next 30 years (U.S. Climate Resilience Toolkit, 2022). Similar sea level rise is expected for the coast of the United States (U.S.), with an increase of 9.8 to 11.8 inches on average in the next 30 years (2020-2050), matching the same rate of sea level rise measured over the last 100 years (Sweet, et al., 2022). Observations at National Oceanic and Atmospheric Administration (NOAA) tide gauges show that more frequent, longer-lasting tidal flooding is being recorded compared to what occurred in past decades, leading some coastal communities to shift waterfront development to natural habitat capable of withstanding seawater inundation, like salt marshes (Dahl, Fitzpatrick, & Spanger-Siegfried, 2017).

For more detailed statistics, data, and information on climate change, please see the *IPCC Sixth Assessment Report, Working Group I: The Physical Science Basis* (IPCC, 2021). See *Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines* for further details about sea level rise (Sweet, et al., 2022).

2.2 Storm Surge

As defined by NOAA, storm surge is "an abnormal rise of water generated by a storm event, over and above the normal predicted tide (astronomical tide)" (NOAA, 2022). Storm surge does not have a reference level because it is a difference between water levels created by the presence of a storm (National Weather Service, ND). Storm surge is primarily fueled by strong winds from a storm event like a tropical storm, nor'easter, or hurricane; low pressure from the storm only minimally influences the storm surge (National Weather Service, ND). When storm surge coincides with a normal high tide, known as a *storm tide*, ocean levels may rise up to 30 feet or more (NOAA, NDa; NOAA, NDb). Storm surge is extremely dangerous and aside from hurricane-force winds, is the most dangerous aspect of a hurricane in coastal areas (NOAA, NDa). Flooding from storm surge and storm tides can be devastating, causing damage or destruction of buildings, roads, and coastal infrastructure such as sea walls, docks and piers, and bridges (U.S. Climate Resilience Toolkit, 2020). Storm surge also affects coastal habitat, causing erosion of beaches and coastlines, saltwater intrusion into freshwater systems, and alteration of coastal habitat (U.S. Climate Resilience Toolkit, 2020). Figure 1 depicts a normal, 2-foot-high tide combined with a 15-foot storm surge to create a 17-foot storm tide.

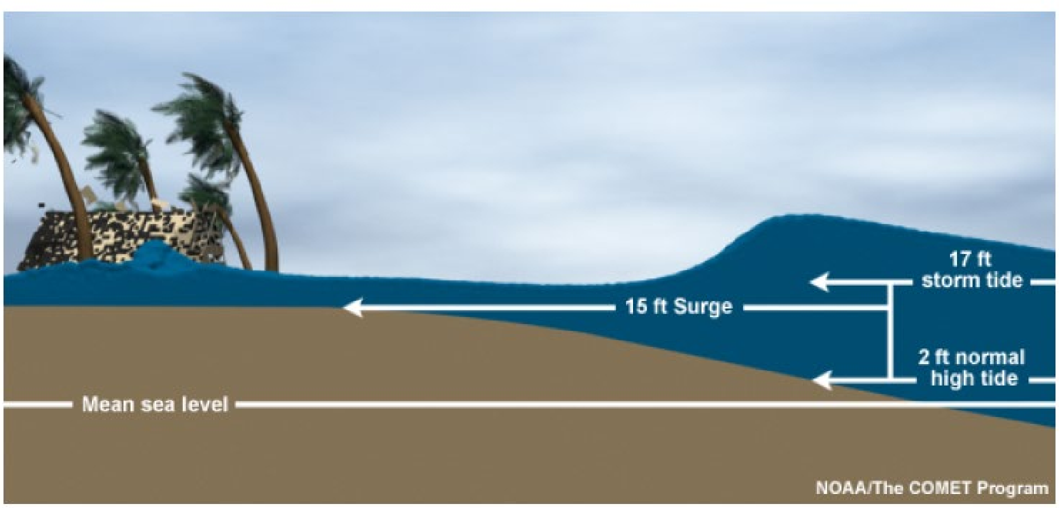
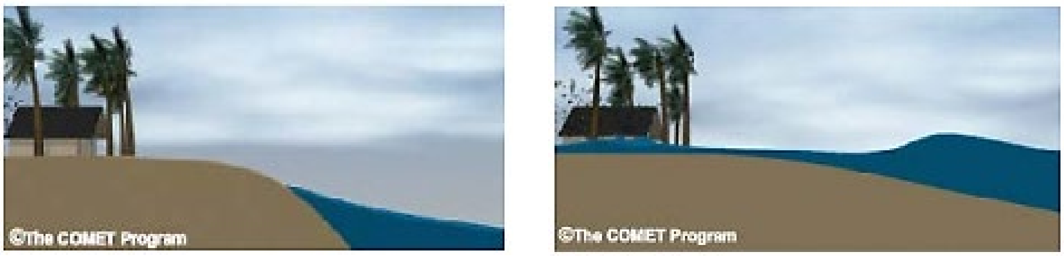


Figure 1. Depiction of High Tide, Storm Surge, and Storm Tide

(National Weather Service, ND)

The effects of sea level rise combined with storm surge are resulting in larger and more devastating coastal flooding events (Bilskie, Hagen, Medeiros, & Passeri, 2014). Additional factors that contribute to the height of the storm surge and distance inland the water travels are the width and steepness of the continental shelf (NOAA, NDb). Where the shelf is narrow and steep, like on the east coast of Florida, a storm surge may be about half as high as compared to a coastline with a wider, shallow continental shelf, such as in Louisiana (National Weather Service, ND). Figure 1 shows the difference between a narrow, steeper continental shelf and a wide, shallow shelf.



Narrow, steep continental shelf   Wide, shallow continental shelf

Figure 2. Differences in Continental Shelf Geology

(NOAA, NDb)

Tools such as the Sea Lake and Overland Surges from Hurricanes (SLOSH) model, developed by NOAA's National Weather Service (NWS), are proving useful for estimating storm surge height (NOAA NWS, ND). According to the NWS, "*The SLOSH model consists of a set of physics equations which are applied to a specific locale's shoreline, incorporating the unique bay and river configurations, water depths, bridges, roads, levees and other physical features* (NOAA NWS, ND)." The SLOSH model is not for forecasting an evolving storm but is useful in predicting how storm surge water reacts to winds, tides, shorelines, and other variables (NOAA NWS MDL, ND). As of 2020, the SLOSH model has been applied to the entire U.S. Atlantic coastline as well as the Gulf of Mexico and is divided into basins based on susceptible features of the coastline (NOAA NWS, ND). The NWS Meteorological Development Laboratory (MDL) houses several other storm surge models modified from the SLOSH model for circumstances such as extra-tropical storm surges (ETSS Model), uncertainty in wind forecast – a probabilistic storm surge model (P-Surge Model), and the probabilistic extra-tropical storm surge model (P-ETSS Model) (NOAA NWS MDL, ND). Links to storm surge models, data, and websites can be found at the NOAA MDL Website (https://vlab.noaa.gov/web/mdl/storm-surge-access-data).

2.3 Coastal Erosion

Waves generated by storms and the forces of these waves are the primary driver of coastal erosion (U.S. Climate Resilience Toolkit, 2020). Sandy beaches are the most vulnerable to coastal erosion compared to rocky shorelines and cliffs, although all areas of coastline are vulnerable to erosive forces over time (Birchler, Stockdon, Doran, & Thompson, 2014). Ocean waves may directly erode beaches, pulling the sand out to sea or depositing it further inland (Doran, Stockdon, Sopkin, Thompson, & Plant, 2012). As beaches erode, the sand beneath structures may be undermined, causing structural failure (Birchler, Dalyander, Stockdon, & Doran, 2015). Buried cables and pipelines may be unearthed by heavy wave action eroding sand from a beach. Erosion of beaches and sand dunes can lead to increased inland flooding, leading to damage of buildings and infrastructure (Doran, Stockdon, Sopkin, Thompson, & Plant, 2012). Coastal erosion is predicted to continue into the future, fueled by storms and sea level rise. About 30 percent of sandy beaches on the Atlantic coast are projected to have shorelines erode inland at about 3.3 feet per year (Dupigny-Giroux, et al., 2018). This projected trend will put additional pressure on sand resources offshore, which may affect future offshore wind siting.

2.4 Coastal Flooding

High tide flooding has increased in many towns, coastal communities, and cities in the U.S. Norfolk, Virginia is experiencing increasing high tide flooding, with about 10 to 15 days a year of flooding in downtown Norfolk, inundating streets and other areas of shoreline, growing from about 5 days a year in 2000 (Buis, 2020; Sweet, et al., 2022). New York city is experiencing very similar increases of high tide flooding as Norfolk (Sweet, et al., 2022). High tide flooding in Charleston, North Carolina and Miami, Florida was about 0 to 2 days a year in 2000 and has increased to about 5 to 10 days in a year in a span of 20 years (Sweet, et al., 2022). As reported by NOAA, NASA, and other researchers, sea level rise is accelerating; coastal communities are likely to see the number of high tide flood days to increase in the coming years.

2.5 Habitat Change from Sea Level Rise

As rising seas encroach on coastal areas, habitat is being lost or converted to more saline conditions. Beaches are being eroded by wave action, shrinking the remaining beach area inland. Gradual sloping beaches and low-elevation shoreline are becoming inundated by seawater, losing important habitat for species that nest, forage, or inhabit these areas. Tidal sand and mud flats are important feeding areas for shorebirds and are expected to gradually be lost to rising seawater in the coming decades (Galbriath, et al., 2002).

Coastal wetlands, estuaries, and marshes will similarly become more frequently saturated with salt water (U.S. Environmental Protection Agency, 2021). Plants that cannot tolerate saline conditions will either adapt, slowly migrate toward fresh water, or cease to exist. Similar effects for fish, invertebrates, birds, reptiles and other species will occur, requiring them to adapt, migrate, or perish. In many coastal areas, there is a limited amount of open space onshore; if rising tides force ecosystems to move inland, there may not be much space available for new habitat to establish (Von Holle, et al., 2019). If the topography or constructed barriers do not allow wetlands to migrate inland, the area may become standing salt water or recolonized by salt tolerant species. Wetlands are crucially important areas for storm buffering, critical habitat for sensitive or listed species, carbon sinks, water quality, and climate regulation (Blankespoor, Dasgupta, & Laplante, 2014). Losing wetlands will further add to the effects from climate change as carbon sinks will be reduced with those losses.

Studies by Galbraith, et al. (2002) and Von Holle, et al. have modeled potential changes in habitat for birds and sea turtles in various locations, including the southern Atlantic coast (Galbriath, et al., 2002; Von Holle, et al., 2019). Both studies project habitat loss due to rising seas, with some locations being entirely lost (Galbriath, et al., 2002; Von Holle, et al., 2019). When determining cumulative effects on coastal species, such as tern species or sea turtles, the effects of sea level rise should be considered.

3 Offshore Wind and Sea Level Rise

The benefit of offshore wind energy is to reduce greenhouse gas emissions and help with slowing climate change and sea level rise. Direct effects from sea level rise on offshore wind farms are fairly limited. Most wind farms are more than 20 miles offshore, away from coastal wave action from storm events. Wind turbines are designed to withstand strong currents and heavy winds as are the infrastructure components located in the offshore environment. If an offshore wind farm is subjected to a major storm event during its 20-30 year expected lifetime, a mandatory inspection of the structures must occur within the 30 days following the storm event to assess impacts. 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 offshore wind farm structures from greater damage if future storm events ensue.

There are a few components of offshore wind farms that are installed within the shoreline and coastal areas, and these facets of an offshore wind farm could be vulnerable to sea level rise. Export cables travel from the offshore environment and pass underground through the coastline to deliver electricity onshore. These cable landing sites are generally underground and use horizontal directional drilling methods to reduce damage to beaches and disruption of the shoreline (New York State, 2022). Some coastal areas are vulnerable to erosion and unearthing of buried transmission cables from storm surge and heavy waves. Selecting an onshore route in a protected area away from shore break may help prevent erosion and unearthing of cables. If cables were to experience damage from unearthing or by waves from storm surge, there could be some leakage of oils used for insulation in some high voltage cables; however, some cables use solid materials for insulation that will not leak or spread as readily as liquid oil-based insulation (Sharples, 2011).

A cable landing site for the Block Island wind farm was exposed by wave action, partially due to portions of the cable originally buried too shallow for the conditions in the area. The reburial of the cable is in progress, held up by weather delays, at a cost to both the offshore wind operator and electrical rate payers. While no damage to the cable has been reported, the inconvenience of beach and anchorage closures will continue until the repairs are made. (Institute for Energy Research, 2021)

In addition to cable landing sites, other areas that may be vulnerable are transformer, interconnector, or converter stations. Ensuring these onshore connection structures are elevated or located well outside of flood prone areas or are designed to withstand flooding will protect the equipment that communities rely upon for their electricity. As with the offshore structures, onshore cable routes and transformer stations should be inspected after storm events to safeguard continued electrical transmission when power is especially in demand following storm events or flooding.

Ship ports that have the capacity to support offshore wind construction, fabrication, assembly, and the vessels associated with these efforts are still few. Many ports require retrofits to support the weight or size of the turbine components, in addition to other modifications to upgrade ports and infrastructure to be capable of supporting offshore wind in all the phases of development to decommissioning, often at great expense. Similar to other coastal areas, these already rare ports, their infrastructure, and associated ship channels are prone to damage from storm surge, heavy winds, and destructive waves. Many ports may have to further invest in raising structures or constructing barriers to reduce wave or water damage. The cost and delays of dredging navigation channels is expected to continue as storm events grow. The overall costs to proactively construct resiliency while ensuring ports can support the expanding need of offshore wind developers could be significant, albeit necessary for meeting the lofty goals of future renewable energy milestones. (ESS Group, Inc., 2016; Asariotis, 2021; Calma, 2022)

4 Summary

Sea level rise is a concern in coastal communities that is only going to grow in the coming decades. Flooding, erosion, habitat change, and loss of coastal habitat from rising seas and storm surge are becoming more prevalent in towns on the coasts of the U.S. Some coastal areas are more vulnerable than others due to geography, ocean currents, and coastal features. Offshore wind energy may be affected by sea level rise and storm surge primarily in locations where wind energy infrastructure interfaces with coastal areas. Locations where submarine transmission cables travel onshore and land-based infrastructure are vulnerable to impacts from storm surge, increasing coastal erosion and flooding from high tides. Ports supporting the construction and maintenance of offshore wind farms are prone to damage from high water, waves, and wind. The phenomena associated with storms are only increasing as global temperatures rise and sea levels get higher faster than in previous decades. Wind energy provides an offset of greenhouse gasses to assist in slowing climate change and rising sea levels, but the effects will continue despite efforts to slow the impacts predicted for decades to come.

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