PREPARED FOR:
Massachusetts Clean Energy Center

Metocean Data Needs
Assessment and Data Collection
Strategy Development for the
Massachusetts Wind Energy Area

October 16, 2015

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Executive Summary

The objective of this report is to provide the Massachusetts Clean Energy Center (MassCEC) with an assessment of information sources regarding the meteorological and oceanographic (metocean) conditions within the Bureau of Ocean Energy Management’s (BOEM) designated Massachusetts Wind Energy Area (MAWEA) and the Rhode Island/Massachusetts (RI/MA) Wind Energy Area, collectively, the WEAs. In addition, recommendations are given for new, high-value metocean data collection activities that would address significant knowledge gaps within these areas. The report:

- Provides a high-level inventory of current and historical metocean data collection activities and publicly-available data products in and around the WEAs;
- Identifies informational gaps and the most critical metocean data needs to support offshore wind energy applications within the WEAs;
- Evaluates the attributes and costs of several metocean data collection scenarios to address identified data needs, including fixed-bottom meteorological towers and floating profiling lidar systems; and
- Identifies key stakeholders and potential partnership opportunities that can accelerate the development and implementation of a metocean data collection and analysis program.

The goals of this study are to reduce project development risks and accelerate offshore wind energy development timeframes through improved documentation of WEA metocean conditions. In turn, technology and performance risk for project developers should be reduced through informed plant design specific to WEA conditions.

Among several measurement scenarios evaluated by this study, it is recommended that the MassCEC consider pursuit of one or more of the three most cost-effective ones:

- A floating profiling lidar system capable of measuring winds at multiple locations and multiple levels up to and beyond wind turbine hub height, plus other metocean parameters such as water and air temperatures, waves, and currents. This technology is on the verge of being accepted by developers, turbine manufacturers, and the financial community for providing high quality, credible, and “bankable” wind data comparable to that provided by a widely-accepted but costly tall meteorological tower.
- A low-profile weather buoy to measure ocean and near-surface wind conditions. While not sufficient for a standalone assessment of metocean conditions for all wind plant design requirements, a buoy can easily provide essential on-site data at the lowest cost.
- The enhancement of metocean measurements, such as the addition of a fixed profiling lidar, at the existing Buzzards Bay C-MAN station and/or the Woods Hole Air-Sea Interaction Tower. This would bolster the value of these facilities as regional references in support of future metocean investigations in the WEAs, as well as test facilities for validating the floating lidar technology.

It is also recommended that high-resolution modeling and mapping studies be conducted to characterize key metocean parameters instrumental for offshore wind energy planning across the entire WEAs. They should include atmospheric, ocean and coupled wind-wave design inputs as defined by relevant international standards.

Several potential collaboration partners with common interests are identified. They include the WEA leaseholders, regional universities, members of the Clean Energy States Alliance, the US Department of Energy, investor-owned utilities, and ISO New England.
1. INTRODUCTION

Meteorological and oceanographic (metocean) data are integral to defining the external design and operating conditions and the expected energy yield of offshore wind projects in locales where they may be sited. These conditions—which are dominated by winds, waves, and currents—encompass the atmospheric and water column, as well as the sea bed, at the heights and depths relevant to wind turbines, towers, foundations, and balance of plant components. Knowledge of these conditions enables the design of appropriate structures and components to withstand the loading factors expected over a project’s lifetime. Human safety, vessel navigation, and project construction and maintenance activities are equally tied to the metocean environment. Project financing and economic viability are also strongly affected by the definition of long-term wind resource characteristics and operating conditions informed by onsite and regional metocean conditions.

1.1 The Need for and Value of Metocean Data

The Bureau of Ocean Energy Management (BOEM) has defined large commercial offshore wind energy areas (WEAs) in federal waters off the Massachusetts coast (Figure 1.1). Three of these areas have been awarded leases by BOEM after competitive bidding processes. These lease areas represent several gigawatts of new wind generation capacity potential for Massachusetts. While some relatively high quality metocean observations have been collected in the coastal waters of Massachusetts, they are not located within the WEAs and therefore do not explicitly represent area-specific metocean conditions. While regional data sources are useful in defining general environmental conditions and offshore wind development siting opportunities, these sources alone cannot provide the spatial and temporal detail and accuracy required to develop and finance actual projects. Project development requires a comprehensive on-site assessment of anticipated wind, wave and other metocean conditions (i.e., the environmental design envelope) that a wind project will experience over its lifetime of at least 25 years. The on-site assessment guides subsequent project design, engineering, and technology selection activities while also enabling accurate energy production projections and financial planning. The opportunity exists to bridge this gap through the pursuit of new metocean measurements and assessment activities tailored to the Massachusetts WEAs and their future development. This report is designed to begin addressing this opportunity.
1.2 Study Objectives and Benefits

The objective of this report is to provide the Massachusetts Clean Energy Center (MassCEC) with an assessment of current knowledge about the metocean conditions within BOEM’s designated Massachusetts wind energy area (MAWEA) and the Rhode Island/Massachusetts (RI/MA) WEA (collectively, the WEAs) and with recommendations for new metocean data collection activities to address significant knowledge gaps. The scope of this report does not include the Cape Wind Energy Project area on Horseshoe Shoal in Nantucket Sound.

The report addresses four topic areas to achieve the following:

- Inventory and assess current and historical metocean data collection activities and publicly-available data products in and around the WEAs;
- Identify metocean informational gaps and the most critical data needs for the WEAs;
- Evaluate the costs and benefits of industry-accepted metocean data collection strategies to address identified data needs, including fixed-bottom meteorological towers and floating

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1 http://www.boem.gov
profiling lidar devices.

- Identify key stakeholders and potential partnership opportunities that can accelerate the development and implementation of a metocean data collection and analysis program.

The goals of this study are to reduce project development risks and accelerate offshore wind energy development timeframes through improved documentation of WEA metocean conditions. Through better awareness of local environment conditions and lessons learned from similar activities carried out by other offshore wind development initiatives, the aim is to reduce deployment and operational costs for offshore wind development. In turn, technology and performance risk for project developers should be reduced through informed plant design specific to WEA conditions.

### 1.3 Report Format

There are five remaining sections of this report. Section 2 is a compilation of known metocean data resources for the offshore waters of Massachusetts and its vicinity. Section 3 identifies the metocean data needs for offshore wind energy development, as well as the gaps when compared to the existing inventory of data. Section 4 presents alternative data collection, modeling and analysis strategies designed to address metocean data gaps. Section 5 provides an overview of key stakeholders and partnership opportunities, while Section 6 puts forth a set of conclusions and recommendations. In addition, the Appendix describes several types of metocean data available from federal, state, and other sources.
2. SOURCES OF METEOCEAN DATA

The initial task for this study was to create a comprehensive inventory of relevant coastal and offshore metocean data sources and associated metadata available for the Commonwealth of Massachusetts and its immediate vicinity. Although regional metocean information can be obtained from varied sources, no centralized data clearinghouse tailored to offshore wind energy interests currently exists.

Broad criteria for the metocean data sources were defined to initiate inventory development and to frame the bounds of the database. Following are the basic search criteria utilized for this task:

- **Geographic Extents**: From the coast of Massachusetts and Rhode Island to the Outer Continental Shelf
- **Physical Extents**: Ocean bottom surface up through the atmospheric boundary layer
- **Source Types**: Existing observational data sets (both directly and remotely sensed), model output, or analyses available for free or purchase;
- **Atmospheric Parameters**: Wind speed and direction, temperature, pressure, humidity, precipitation, solar radiation, lightning, visibility, and related parameters, including relevant statistical analyses, extremes, transient events, and spatial and temporal variations;
- **Ocean Parameters**: Bathymetry; current speeds and directions; wave heights, directions and periods; tides; temperature, salinity, density, ice conditions; and related parameters, including relevant statistical analyses, extremes, transient events, and spatial and temporal variations.

Data sources are categorized into six categories: Federal Government, State Government, Regional Alliances, Universities and Private Research Organizations, Commercial Providers and Development Projects, and International Resources.

2.1 Data Inventory

The resources were compiled through a combination of web-based searches as well as AWS Truepower’s internal records. The internal records were developed through extensive research during previous domestic offshore wind resource and metocean analyses. Further, internationally developed datasets identified for projects outside of North America that have spatial coverage of the areas of interest were also included. Web searches focused on identifying datasets available within the Commonwealth, and with information proximate to the identified WEAs.

Some of the leading data sources from the six categories are described below, while a more comprehensive listing of sources is presented in the Appendix. For each source, basic information on the data resource owner/provider, data type and content, and website are provided.
2.1.1 Federal Government

Automated Surface Observing System (ASOS), National Weather Service (NWS), Federal Aviation Administration (FAA), and Department of Defense (DOD)

The ASOS systems serve as the nation's primary surface weather observing network. ASOS is designed to support weather forecast activities and aviation operations and, at the same time, support the needs of the meteorological, hydrological, and climatological research communities. The ASOS system provides one of the most comprehensive networks of long-term, quality controlled observational data in the US. Key resources are available inland and at coastal sites to provide long-term reference and validation data for near-shore and offshore analyses.

Link: http://www.nws.noaa.gov/asos/

MarineCadastre.gov

This website is the product of a joint effort by BOEM and the National Oceanic and Atmospheric Administration (NOAA). The website is an integrated marine information system that provides authoritative and regularly updated ocean information, including offshore boundaries, infrastructure, human use, energy potential, and other data sets. The website is especially useful to those looking to assess suitability for ocean uses, such as energy siting. Data can be viewed in the national viewer or downloaded from its original source.

Link: http://www.marinecadastre.gov

National Data Buoy Center

The National Data Buoy Center (NDBC) manages the development, operations, and maintenance of the national data buoy network. It serves as the NOAA focal point for data buoy and associated meteorological and environmental monitoring technology. It manages the Volunteer Observing Ship (VOS) program to acquire additional metocean observations. It also operates the National Weather Service test center for all surface sensor systems.

Link: http://www.ndbc.noaa.gov/

National Oceanographic Data Center (NODC)

The NODC manages the world's largest collection of publicly available oceanographic data. NODC holdings include in-situ and remotely sensed physical, chemical, and biological oceanographic data from coastal and deep ocean areas.

Link: http://www.nodc.noaa.gov/

Wave Information Studies (WIS), Coastal Field Data Collection Program, US Army Corps of Engineers: Engineer Research & Development Center

The Wave Information Studies is a US Army Corps of Engineers sponsored project that generates consistent, hourly, long-term (20+ years) wave climatologies along all US coastlines, including the Great Lakes and US island territories.

2.1.2 State Government

Massachusetts Office of Geographic Information (MassGIS)
The Commonwealth’s comprehensive, statewide database of spatial information for mapping and analysis supporting emergency response, environmental planning and management, transportation planning, economic development, and transparency in state government operations. Of primary metocean interest are the coastal and offshore data layers, including existing uses, and digital coastal elevation and bathymetry. Coverage is available from Rhode Island Sound through the Gulf of Maine.

Massachusetts Ocean Resource Information System (MORIS)
MORIS can be used to search and display spatial data pertaining to the Massachusetts coastal zone. Users can interactively view various data layers (e.g., tide gauge stations, marine protected areas, access points, eelgrass beds) over a backdrop of aerial photographs, political boundaries, natural resources, human uses, bathymetry, or other data e.g. Google base maps. Users can quickly create and share maps and download the actual data for use in a Geographic Information System (GIS).
Link: http://www.mass.gov/czm/mapping/index.htm

Rhode Island Ocean Special Area Management Plan (OceanSAMP)
The Rhode Island Ocean Special Area Management Plan, or Ocean SAMP, serves as a federally recognized coastal management and regulatory tool. Using the best available science, the Ocean SAMP provides a balanced approach to the development and protection of Rhode Island’s ocean-based resources.
Link: http://seagrant.gso.uri.edu/oceansamp/index.html

2.1.3 Regional Alliances

Eastern Consortium of Coastal Ocean Observatories (ECCOO)
ECCOO is a collaboration of coastal research sites categorized as either estuary/embayment-coastal or near-shore/coastal. Regionally affiliated entities include:
- Northeast Regional Association for Coastal and Ocean Observing (NERACOOS)
- Martha’s Vineyard Coastal Observatory
- Front-Resolving Ocean Network with Telemetry (FRONT) – UConn Dept. of Marine Sciences
Link: http://www.whoi.edu/mvco/other_data/ECCOO/index.html

IOOS Data Catalog and Asset Viewer, Integrated Ocean Observing System (IOOS)
The Data Catalog and Asset Viewer is an online tool that allows users to find information from all available IOOS partners without having to know in advance what partners operate the actual observing systems and data servers. IOOS partners include: NOAA and other federal agencies; the IOOS Regional Associations; and other national or international organizations.
Link: http://www.ioos.noaa.gov/
Northeast Ocean Data Portal
The Northeast Ocean Data Portal is a decision support and information system for managers, planners, scientists and project proponents involved in coastal and marine spatial planning in the region from the Gulf of Maine to Long Island Sound. The Portal provides access to data, interactive maps, tools, and other information needed for decision making. Data provided through the portal are provided as GIS database files that contain information on coastal and marine spatial planning, including:

- Geology
- Administrative and Regulatory
- Commercial, Industrial and Military
- Infrastructure
- Physical Oceanography

Link: [http://northeastoceandata.org/](http://northeastoceandata.org/)

2.1.4 Universities and Private Research Institutions
University of Massachusetts Wind Energy Center (UMWEC)
UMWEC has gathered wind data around New England under the support of the Massachusetts Division of Energy Resources (DOER), the Massachusetts Renewable Energy Trust Fund (MRET), the MassCEC, Northeast Utilities (NU), and the US Department of Energy (DOE). The data sets available here are some of the few wind energy-focused resources in the region, providing unique insight into long-term conditions above standard surface monitoring heights. Several resources are available in, or near, coastal regions.

Link: [http://www.umass.edu/windenergy/resourcedata](http://www.umass.edu/windenergy/resourcedata)

Woods Hole Oceanographic Institution (WHOI)
The WHOI is dedicated to research and education to advance understanding of the ocean and its interaction with the earth system, and to communicating this understanding for the benefit of society. The data center makes data available from:

- Floats
- Local coastal observatories
- Bathymetric studies
- Global surface moorings
- WHOI ships

Link: [http://www.whoi.edu/data/](http://www.whoi.edu/data/)

Martha’s Vineyard Coastal Observatory, WHOI
Data products include those of the Air-Sea Interaction Tower (ASIT) of the Coupled Boundary Layers and Air-Sea Transfer (CBLAST) program, in addition to other meteorological and oceanographic data.

Link: [http://mvcodata.whoi.edu/cgi-bin/mvco/mvco.cgi](http://mvcodata.whoi.edu/cgi-bin/mvco/mvco.cgi)
The Unstructured Grid Finite Volume Coastal Ocean Model (FVCOM), School for Marine Science and Technology, University of Massachusetts – Dartmouth (UMASSD)
FVCOM is a prognostic 3-D primitive equation coastal ocean circulation model developed jointly by UMASSD and the Woods Hole Oceanographic Institutions. The model consists of momentum, continuity, temperature, salinity and density equations and is closed using turbulence closure submodels. The horizontal grid is comprised of triangular cells and the irregular sea bottom is presented using generalized terrain-following coordinates. FVCOM was originally developed for the estuarine flooding/drying process in estuaries and the tidal-, buoyancy- and wind-driven circulation in the coastal region featured with complex irregular geometry and steep bottom topography. This model has been upgraded to the spherical coordinate system for basin and global applications. Link: http://fvcom.smast.umassd.edu/index.html

Graduate School of Oceanography (GSO), The University of Rhode Island (URI)
Research campaigns at the GSO span a variety of disciplines, including meteorology, physical oceanography and geology. Data from many research campaigns is available for download through their website. Link: http://www.gso.uri.edu/

The Environmental Data Center (EDC), The University of Rhode Island
The Environmental Data Center is the center of technical expertise in GIS for the state of Rhode Island. The EDC is a Geographic Information System (GIS) and spatial data analysis laboratory in the URI’s Department of Natural Resources Science, College of the Environment and Life Science. Major areas of research at the EDC are spatial data modeling, ecological mapping, and data integration for environmental applications. The EDC participates with the NEOD and has bathymetric information and other coastal/metoecean related data sets. Link: http://www.edc.uri.edu/

2.1.5 Commercial Providers and Development Projects
The Long Island – New York City Offshore Wind Project
This project, which has had little activity in the last two years, is an initiative designed to help New York reach its clean and renewable energy goals. The proposed project would be located in the Atlantic Ocean, approximately 13 nautical miles off the Rockaway Peninsula. It has preliminarily been designed for 350 MW of generation, with the ability to expand it to 700 MW. The project home page provides project assessment reports, including output from economic feasibility and geo-metoecean characterization studies. Link: http://www.linycoffshorewind.com/Default.html

Noble Consultants, Inc.
Noble Consultants, Inc. utilizes numerical models in the analysis and design of projects involved with the water environment. These models include 1-D, 2-D and 3-D hydrology, hydraulic, hydrodynamic, sediment transport and water quality models for coastal & ocean projects, riverine & estuarine projects, and waterfront development & restoration projects. Coastal & ocean model applications include:
• Constituent Transport & Water Quality
• Sediment Transport & Coastal Morphology
• Storm Surge & Coastal Flooding
• Tide, Wind & Wave Induced Circulation
• Wave Generation & Propagation

Link: http://www.nobleconsultants.com/

Oceanweather, Inc.
Oceanweather functions as a specialized consulting firm serving the coastal and ocean engineering communities. Some of its products include metocean outputs (wave parameters, wave spectra, extremal analysis, operational data, etc.) designed for user applications. The GROW Fine reanalysis data sets offer long-term metocean information across Massachusetts and neighboring states’ waters.
Link: http://www.oceanweather.com/

WeatherFlow
WeatherFlow Inc. is a private sector provider of weather data and modeling products. It maintains a proprietary coastal observing network.
Link: http://www.weatherflow.com/

2.1.6 International Resources

ERA-40 Reanalysis Project, ECMWF
ERA-40 is a global data assimilation system that synthesizes in-situ and remotely-sensed measurements taken over the period 1957-2002. ERA-40 produces analyses with six hourly frequency, supplemented by intermediate three-hour forecasts. The grid-spacing is approximately 125 km in the horizontal and with sixty levels in the vertical located between the surface and a height of about 65 km.
ERA Projects link: http://www.ecmwf.int/research/era/do/get/index

EUMETSAT
EUMETSAT operates a system of meteorological satellites monitoring the atmosphere, ocean, and land surfaces 24 hours a day, 365 days a year. This information is supplied to the National Meteorological Services of the organization's member and cooperating states in Europe, as well as other users worldwide.
Link: http://www.eumetsat.int/Home/index.htm

2.2 Data Applications
The libraries of metocean data presented above, and detailed further in the Appendix, represent a rich information resource for the waters of Massachusetts and the region. These datasets provide baseline information for project siting (e.g., bathymetry, tide and water levels) as well as important regional metocean characteristics (e.g. wave conditions, and surface meteorology) that play important roles in offshore wind project development, construction, and operation. Among the tasks that these datasets support are the long-term adjustment of short-term site-specific observations, atmospheric model initiation, atmospheric and ocean model output validation, and detailed examination of specific
phenomena or events.

Figure 2.1 is an example of how baseline data sources and modeling approaches can be effectively used to facilitate offshore wind energy planning. The figure depicts the WEAs together with the modeled annual average wind speed at a 100 m hub height. Average speeds exceed 9.25 m/s for all three areas and approach 10.0 m/s in the most seaward extents. Also shown are the locations of current regional data sources.

While the value of these existing (and, in many cases, continuing) data sets is high, several key tasks in offshore wind project development require site-specific information that is not common among existing resources. In particular, high-accuracy wind speed, direction and air density information across the operating heights of modern offshore wind turbines (e.g. 0–200+ m above mean sea level) is nearly non-existent. Multi-year time series of detailed, high-resolution wave height and direction spectra are similarly scarce in the WEAs. While atmospheric and ocean modeling tools are available to partially compensate for this data scarcity, in many cases local observations are necessary to meet the requirements of project wind resource characterization, energy yield estimates, and facility design. These specific needs, as well the gaps in the available information, are discussed in the subsequent sections of this report.
Figure 2.1: Regional Map of RI and MA Wind Energy Areas and Existing Monitoring Stations
3. METOCEAN DATA NEEDS FOR OFFSHORE WIND DEVELOPMENT

3.1 Introduction
Metocean data are relevant to all phases of an offshore wind energy project: siting, development, construction, operation, and decommissioning. For each phase, data and associated data products are used by various stakeholders to address their particular needs. The fact that the US offshore wind industry is in a nascent stage means that the most pressing near-term metocean data needs are focused on the siting and development (i.e., pre-construction) phases. Namely, these needs can be summarized as wind resource assessment, energy production estimation, and wind facility layout and design.

These needs, guided by industry best practices and standards, require comprehensive metocean data that are largely missing from the available data inventory. While the datasets identified in the previous section provide value in defining general metocean conditions, significant gaps in terms of spatial and temporal data resolution, as well as information on specific parameters, exist for the purposes of offshore wind development. Without a strategy to bridge these gaps, offshore development will likely face major delays and financing hurdles. This section discusses the key data needs for the pre-construction phases of offshore wind development that a bridging strategy should address. Similar data needs have been identified in a 2015 report prepared by AWS Truepower on behalf of the US Department of Energy.2

3.2 Basic Metocean Science and Background
Metocean science, at its most basic, refers to the study of the combined interaction of the atmosphere and the ocean. The key parameters of wind speed, direction, air and sea surface temperature, waves, and currents are very influential in the development process. The dynamic air-sea interface has considerable impact not only on the behavior of each medium but also on structures, vessels, and energy capture. While available metocean data sources are diverse, they were implemented by the needs of stakeholders having other interests, such as the navigation and public safety community. Data resources tailored to offshore wind energy development are not yet available, so this section will identify and prioritize gaps relevant to this industry. The largest gaps, aside from site-specific measurements, stem from the fact that most direct metocean measurements are point-based, obtained near the surface (i.e., not near hub-height), and representative of a small geographic area. Metocean data (winds and waves) derived from satellites can cover large areas but at a relatively coarse resolution and high degree of uncertainty. Many sources of satellite imagery also cannot provide reliable information within 25 km of shore.

The current suite of numerical models used to simulate the atmosphere and ocean are generally large-scale in nature (global or regional) and run at horizontal resolutions ranging from kilometers to tens of kilometers. Although their physics are comprehensive, they are unable to capture all turbulence, stratification, and energy exchange characteristics of the metocean environment due both to scaling limitations and the lack of sufficient data inputs. This insufficiency of data sources at a high spatial

density (both horizontally and vertically) and at ideal time intervals and durations inhibits the potential value that numerical models could bring in accurately resolving metocean conditions at the scale of wind turbines and wind plants.

The metocean assessment process can be broadly classified into two parts: first, wind resource and energy yield assessment; and second, facility design and certification. These parts, while intertwined in the overall development process, are often performed separately and occasionally even by separate parties. Another distinction is that the resource and energy assessment process focuses mainly on average, long-term conditions, over a typical evaluation period. On the other hand, while the design process shares some similarity in the assessment of long-term loading and fatigue conditions, it focuses more heavily on individual extreme events, typically over a given period of recurrence. In other words, the probability and frequency of extremes, rather than the means, is of greater value. In addition, the resource assessment process typically focuses on observed parameters for a defined period (normally 1-3 years), whereas the design process must often extrapolate short-term observations to lengthy (historical) return periods.

Section 3.3 focuses mainly on wind resource parameters and inputs into wind resource and energy simulation models, while Section 3.4 delves into related ocean parameters in the context of design. The final portions of this chapter present an overview of other parameters and topics of interest for the development of an offshore wind farm.

### 3.3 Wind Resource Assessment and Energy Yield

A wind resource and energy assessment is a critical step in the evaluation of a potential wind project. The resource assessment phase takes place first and provides the basis for the energy assessment. Energy is typically assessed after sufficient site data has been collected, but before the detailed, site-specific design process is undertaken. Several guidelines exist for conducting a wind resource program, some of which will be touched upon in this section.

High-quality wind resource measurements are essential to the success of a wind project, and they play several important roles. First, they provide the inputs needed for accurately estimating the plant’s energy production. Second, they affect the project design and layout, including the arrangement of the turbines and the selection of a suitable turbine model. For example, the directional distribution of the wind affects the optimal layout of turbines to minimize interference – the so-called wake effect – between them. Also, the speed distribution, turbulence characteristics, and other aspects of the resource determine the turbine suitability class, which is considered by the manufacturer in deciding whether to warrant a particular turbine model for the site.

Monitoring systems deployed during resource assessment campaigns and kept in operation thereafter can provide valuable wind and weather information during and after project installation. The data from these stations can support project construction and power forecasting during the operational phase, as well as performance assessments and operations and maintenance efforts.
### 3.3.1 Wind Resource Measurements

The most common, multi-step approach used for developing a long-term hub height wind speed estimate for a proposed project is to collect on-site data using a tall tower, adjust the measurements to the climatological conditions using available long-term reference stations, and extrapolate the data to the anticipated hub height. In recent years, floating lidar systems have been proposed to complement or replace tall towers. Thus far they have demonstrated promise in the reliable collection of wind data at a large range of heights, including hub height. Regardless of the approach taken, most modern wind resource assessments offer the flexibility, whether standalone or in combination, to provide a full suite of observational needs. Section 4 of this report describes four equipment options for data collection in the offshore environment. The remaining portions of this chapter outline the parameters of interest, their relative importance, and the gaps in our present understanding. The measurement of ocean parameters is discussed in Section 3.4.

### 3.3.2 Meteorological Parameters of Interest

A basic set of recommended measured parameters is listed in Table 3.1. Observations of wind speed, wind direction, and air temperature are essential for designing a wind farm and estimating its future energy production. In addition to mean values for wind speed and direction, probability distributions (both individual and joint) are critical to understanding the wind resource for a given site. For example, the speed probability distribution (frequency distribution as a function of speed bin) at hub height is used to estimate the power production of a wind turbine, while the joint distribution of speed and direction (commonly known as a wind rose) is important for designing the turbine layout to minimize wake losses. At least one year of data collection (with a data recovery target of ≥90%) is required to adequately characterize the seasonal and diurnal variability of the wind resource, as well as to ensure the lack of a seasonal bias in the extrapolation of the observed conditions to the long-term climate.

A broader family of measured and derived parameters is recommended for characterizing the offshore meteorological environment. Table 3.2 lists several parameters that are derived from the directly observed parameters. Two examples of derived parameters are turbulence intensity (TI) and wind shear. TI is an indicator of wind speed variability and allows for wind turbine classification, power curve selection and performance, and an assessment of turbine loading. Wind shear represents the change in wind speed with height; observations are usually summarized with Weibull distribution functions, joint parameter frequency distributions, and others. Long-term average conditions for a site (projected over a ten-year financing period or a full project lifespan) are commonly derived from limited-duration, dedicated measurement campaigns (typically 1 to 3 years) and long-term reference data sets by way of measure-correlate-predict (MCP) climate adjustment methods.

Measurements of wind speed and direction are preferred across at least the lower portion of the turbine rotor, including hub height. If winds are measured only below hub height, an extrapolation of speeds to hub height is conducted utilizing either a logarithmic wind profile assumption or the power law and a determined shear exponent. Alternatively, the wind shear profile can be estimated by way of
numerical weather prediction or other modeling approaches. In all cases, physical and climatic conditions affecting the wind variation with height need to be considered when projecting to hub height, including but not limited to: atmospheric stability, local terrain effects, and wave conditions.

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<th>Recorded Values</th>
<th>Comments</th>
<th>Measurement Heights</th>
<th>Temporal Resolution</th>
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<tr>
<td>Wind Speed (m/s)</td>
<td>Average; Standard Deviation; Min/Max</td>
<td>Annual average hub-height speed is the typical metric of interest for general site characterization</td>
<td>Minimum 1 at hub height; multiple levels strongly recommended to determine shear</td>
<td>10-minute recordings typical; Gusts 1-2 Hz; 1-3 hour common from government observations and reanalysis</td>
</tr>
<tr>
<td>Wind Direction (degrees)</td>
<td>Average; Standard Deviation; Max Gust Direction</td>
<td>Used in plant design and layout optimization work; standard deviation used for QC and suitability analyses</td>
<td>Minimum 1 at hub height; multiple levels recommended to determine wind veer.</td>
<td>10-minute recordings preferred; 1-3 hour common from govt. observations and reanalysis</td>
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<td>Temperature (°C)</td>
<td>Average; Min/Max</td>
<td>Used to select suitable turbines and to calculate air density</td>
<td>Minimum 1 at hub height; multiple levels needed to determine atmospheric stability</td>
<td>10-minute recordings preferred; present measurements most often hourly</td>
</tr>
<tr>
<td>Wind Speed Standard Deviation</td>
<td>Wind Speed (as above)</td>
<td>Used for TI calculation, energy prediction, and quality control</td>
<td>All</td>
<td>Same as wind speed</td>
</tr>
<tr>
<td>Vertical Wind Speed (m/s)</td>
<td>Average; Min/Max</td>
<td>Non-zero values may impact turbine performance</td>
<td>Hub height preferred</td>
<td>Same as other wind speed</td>
</tr>
<tr>
<td>Delta-Temperature (ΔT)</td>
<td>Average; Min/Max, Change with Height</td>
<td>Requires at least two calibrated temp. sensors with sufficient vertical separation; or microwave radiometer</td>
<td>Use of separate temp sensors requires tower</td>
<td>Annual; seasonal; instantaneous; used for stability classification</td>
</tr>
<tr>
<td>Wind Veer</td>
<td>Average; Min/Max</td>
<td>Wind direction change with height across the rotor span</td>
<td>Multiple measurement heights</td>
<td>Instantaneous; annual</td>
</tr>
</tbody>
</table>
Table 3.2 – Derived Parameters of Interest

<table>
<thead>
<tr>
<th>Measurement Parameter</th>
<th>Recorded Values</th>
<th>Comments</th>
<th>Measurement Heights</th>
<th>Temporal Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Speed Distribution</td>
<td>Probability distribution function</td>
<td>Includes Weibull, Rayleigh, etc. Can also be summarized in specific format</td>
<td>Typically at Hub Height</td>
<td>Annual Average</td>
</tr>
<tr>
<td>Annualized Wind Speed (m/s)</td>
<td>Average</td>
<td>Takes repeated months in the data record into account</td>
<td>All wind speed</td>
<td>Same as recorded data; typically reported as annual avg.</td>
</tr>
<tr>
<td>Wind Direction Distribution</td>
<td>Average; Standard Deviation; Min/Max</td>
<td>Energy- and frequency-weighted wind rose.</td>
<td>Hub-height preferred; mast-height used in QC</td>
<td>Annual average; monthly on occasion.</td>
</tr>
<tr>
<td>Air Density (kg/m³)</td>
<td>Average; Min/Max</td>
<td>Calculated from available measurements, typically temperature, pressure</td>
<td>Required at hub height; calculated directly or using assumed lapse rate</td>
<td>Typically annual avg; annual range used for site character.</td>
</tr>
<tr>
<td>Wind Power Density (W/m²)</td>
<td>Average; Min/Max</td>
<td>Measure of the energy content of the wind</td>
<td>Hub-height preferred; mast-height typical</td>
<td>Annual average; monthly on occasion</td>
</tr>
<tr>
<td>Long-Term Wind Speed (m/s)</td>
<td>Average</td>
<td>Represents long-term avg. based on comparison/adjustment with reference data</td>
<td>All wind speed</td>
<td>Same as recorded data; typically reported as annual average</td>
</tr>
<tr>
<td>Turbulence Intensity (T1)</td>
<td>Average; 15 m/s; Min/Max</td>
<td>Ratio of wind speed standard deviation to the mean wind speed.</td>
<td>Same as wind speed</td>
<td>Same as recorded data; typically reported as annual average</td>
</tr>
<tr>
<td>Vertical Wind Shear</td>
<td>Average Min/Max Vertical Profile</td>
<td>Rate of change in wind speed with height. Used in energy production and turbine suitability analyses.</td>
<td>See bullet 1; vertical levels require minimum separation of 10 m</td>
<td>Annual Avg; Monthly; Hrly; Instantaneous Used for Extrapolation and Suitability Purposes.</td>
</tr>
</tbody>
</table>
The temporal attributes of a data set include the sampling frequency, the averaging period, and the overall period of record. The temporal characteristics of observations are important at short (~1 second) and long (annual and decadal) time scales. Intermediate timescales – diurnal, monthly, seasonal – are also relevant when analyzing individual metocean parameters or phenomena. For specific measurements, the key attributes are the sampling frequency and averaging period. This is important as many publicly available measurement sources report only hourly average values; in many cases, these “average” values in fact only represent a short sub-interval within the hour. This is particularly true with remote systems such as buoys, which operate with limited onboard power supplies.

When collecting observations, the following time scales for sampling and averaging should be considered:

- **1-2 second**: The standard sampling rate practiced by the wind energy industry and other field monitoring disciplines.
- **3 and 5 second**: Time scales used to define wind gusts by standards organizations such as the International Electrotechnical Commission (IEC), ABS, and NOAA. Gusts are typically calculated as the maximum of 3- or 5-second rolling average of samples during a reporting period;
- **1 minute**: Time scale commonly referenced by NOAA for maximum sustained wind speeds, employed in defining high wind events such as gales, tropical cyclones and hurricanes, and Nor’easters;
- **10 minute**: International standard time interval for defining mean wind speeds and interval over which most other wind statistics and standard meteorological parameters are calculated;
- **1 hour**: Typical averaging and reporting interval for many metocean measurements; typical interval for model output.
- **3 hour, 6 hour, and 24 hour**: Averaging periods employed for analyzing wave conditions, comparison of disparate data sets, or conducting analyses (e.g., MCP).

### 3.3.3 Gaps in Wind Parameters

Existing data are insufficient for characterizing the temporal (seasonal and diurnal) and spatial (horizontal) variability of the hub-height wind resource. While both can be (and have been) modeled using numerical weather prediction and other methods, data for validation and their impacts on the final energy production simulation can be difficult to ascertain using presently available data sources.

To the first point, the diurnal distribution of the resource is not always well resolved by present model simulations. In addition, there is not a particularly large database of available data with which to validate the modeled data against. It is worth noting that while annual average parameters and simulated energy output from models show good agreement with actual observations, it is the diurnal profiles which exhibit the largest discrepancies. Seasonal distributions are generally well-resolved at hub-height by models and at measurement height by observations.
This ties in well with the definition of wind shear, with which any slight errors in the assumed shear profile may cause significant discrepancies in the estimated hub-height wind speed. This is of importance for not only accurately predicting overall energy output, but also for utilities and developers to determine accurate load-matching and pricing information for the wind farm’s commercial operation.

Regarding the spatial variability of the wind resource, this issue is generally well-resolved for project areas that are distant from land masses by appropriately parameterized models using input data and outputs of sufficient resolution. However, for project areas relatively near-shore and subject to the influences of large adjacent land masses on the wind resource (i.e., a prevailing wind direction crosses land), it is important to understand the gradient in wind speed that exists between the shore and the project. Being closer to the New England mainland, the RI/MA WEA is more sensitive to this issue than is the MAWEA.

3.3.4 Energy Yield Inputs

The resource assessment process typically ends with the establishment of a long-term adjusted, hub-height wind characterization at a monitoring site. Following this process, a modeling exercise to extrapolate the conditions at the measurement site(s) to the proposed turbine layout is typically performed.

The purpose of the modeling exercise is to translate site measurements into project-wide conclusions using industry-accepted techniques. Its key function is to define the wind conditions at individual turbine locations. As with the onsite measurement component, the modeling component must strive to achieve high degrees of certainty that are acceptable to the developer and to financiers. Therefore, the right selection of model type(s), model configuration, spatial resolution, and input parameters are vital considerations, along with the results of an accurate wind resource assessment.

Models of different types operate at different time and space scales, depending on the application. For example, climate models predict long-term changes in atmospheric properties (such as mean temperature, precipitation, and winds) over large portions of the globe (i.e. at the synoptic and global scales). Numerical weather prediction (NWP) models simulate short-term changes within smaller regions, such as states (i.e., the mesoscale and synoptic scales); the lower end of this scale is consistent with the size of large wind farms. The most widely used NWP model by the research community is the Weather Research and Forecasting (WRF) model. Microscale models are applied to processes in even smaller areas, such as within individual wind farms at the scale of individual turbines. Using a finite dataset, essentially all models represent the environment with a three-dimensional grid. Most atmospheric models incorporate multiple vertical layers, some extending up to several kilometers in altitude. Grid resolution, particularly in the horizontal dimension, is generally consistent with the model space scale.
The typical model resolution for most mesoscale simulations is on the order of a few kilometers. Since this scale does not provide a very detailed picture of wind conditions within a large wind farm, coupling with a microscale model is often done to obtain the desired detail. Examples of coupled mesoscale-microscale models include AWS Truepower’s MesoMap and SiteWind systems, Risø National Laboratory’s KAMM-WAsP system, and Environment Canada’s AnemoScope system. Coupled model approaches have been used to create relatively high resolution wind maps of large regions. Figure 3.2 is a representation of the annual average wind speed of the United States, including a 90-km wide zone of offshore winds, at 100-m above the surface at a spatial resolution of 2 km.

![Figure 3.2: Annual Average US Wind Speed at 100 m above the Surface, Land-Based and Offshore](image)

**Energy Yield Estimation**

Once a site’s wind resource is characterized, the power output of a wind turbine can be estimated. This requires turbine-specific information, the most important being the power curve, which expresses, for a given air densities, the output in kilowatts or megawatts at every hub-height wind speed over its operating range. Figure 3.3 presents a graphical representation of a turbine power curve and related turbine characteristics. The calculation of power production can be done either with a time series of wind speed and air density data, or with a speed frequency distribution for the site’s average air density.
This process provides an estimate of the gross power production of a turbine (neglecting losses such as electrical losses, wakes, turbine downtime, and others, which are discussed elsewhere). However, other wind resource characteristics and environmental factors can impact energy production and should be considered in a wind assessment. These include turbulence intensity, wind shear, extremes in wind speed and temperature, and atmospheric icing.

Most turbine power curves are defined for a mid-range of turbulence intensity, such as 10% to 15%, at a design speed of 15 m/s. Turbulence above the design range typically increases power output at low speeds (near the cut-in) and decreases it at high speeds (near the rated speed). Conversely, turbulence below the design range typically has the opposite effect.

The impact of wind shear on turbine output is likewise complex. Most power curves assume a steady, mid-range value of the wind shear exponent, such as 0.14. However, deviations from the nominal output are generally small over a wide range of shear values. Where the impact of shear becomes important is when the profile changes abruptly – for example, if the shear is high in the lower part of the rotor but low in the upper part.

High winds can result in power production losses if the wind speed exceeds the turbine’s design cut-out speed. Additional losses occur because the turbine control software waits until the speed drops below a lower speed threshold (the reset-from-cut-out speed) before allowing the turbine to restart. This is called the high-wind hysteresis loss. Losses of both types can be estimated from a time series of observed wind speeds.

Extreme temperatures, both hot and cold, can result in lost energy because turbines are designed to shut down when temperatures exceed their operating design envelope. As with high speeds, the control software waits until the temperature is within some margin (defined in the turbine technical specifications) of the operating range before allowing the turbine to restart.
Ice accumulation, soiling, and dead insects on the turbine blades can result in reduced production due to a decrease in aerodynamic efficiency. Excessive ice accumulation can even cause the turbine to shut down. Icing is of particular concern in cold climates, where moisture-laden ocean air easily freezes on cold surfaces.

Site access can be a significant contributor to offshore wind farm energy losses. Loss of production results from repair delays when personnel are unable to safely transfer to a failed turbine due to excessive wave heights or other site access limitations. The loss is determined using available wave height data (typically frequency of waves over a given height threshold) and site access restrictions specified by the equipment manufacturer or O&M manager. As the site access threshold and the frequency of wave conditions over the threshold can vary significantly from site to site, the collection of site-specific data of sufficient duration is critical to the accurate estimation of this loss.

### 3.4 Facility Design Inputs

The engineering specifications for all project components and subcomponents (turbines, blades, towers, foundations, substation, electrical cables, etc.) are driven by the metocean statistics determined for the site. The choice of foundation type, for example, is largely dependent on the bathymetry, seabed conditions, and wind/wave conditions at a site. Historically turbine manufacturers have followed the IEC 61400 design standards and associated subclasses which cover a broad spectrum of turbine design requirements, most of which apply to land-based projects. Specific to offshore applications are IEC sub-classes 61400-3 (for fixed bottom structures) and 61400-3-2 (for floating versions). A 2014 report by NREL and AWS Truepower provides a summary of offshore wind system design, safety, and operation standards.³

The interaction between wind and wave extremes, including their directionality, is an important consideration in project design. For example, design load cases (both ultimate loading and fatigue loading) in several of the standards, as well as the turbine vendor-specific design basis documents, mandate joint analyses between various atmospheric and water conditions.

### 3.4.1 Ocean Water Measurements

Ocean measurement sensors commonly operate as integrated parts of purpose-designed measurement stations or platforms, e.g., a tall tower or a bottom-fixed offshore platform or weather buoy. These types of stations often record wind and meteorological characteristics as well. A diverse array of other types of floating, profiling, and remote sensing devices is also employed. This section provides an introduction to the ocean and water column parameters of interest for offshore wind energy applications.

**Wave and Current Parameters**

Wave conditions, both average and extreme, are of particular interest to the designers of offshore structures. Wind-generated waves are surface waves that usually result from the wind blowing over a stretch of water (fetch). Wind waves range in size from small ripples to tens of meters in height. The

wave height is the difference between the elevation of a crest (the top of the wave) and a neighboring trough. The wavelength is the length between crests of two successive waves. A swell consists of wind-generated waves that are not generally affected by the local wind. Additionally, a swell is typically generated from a distant source, such as a storm. The frequency is the number of waves or swells passing a point per unit time, while the period is the time interval between the arrival of consecutive crests at a stationary point (the inverse of the frequency). Wave reports from buoys and other observation platforms typically represent a mix of wave and swell heights.

A wave spectrum can provide important information about a wave sample and the corresponding ocean conditions. The general shape of the spectrum can reveal whether seas or swell predominate, the number of distinct swells present, etc. Other key information derived from wave spectra include dominant wave and swell periods and wave roses, which provide directional information regarding favored sectors for approaching waves and swells. This information, as with winds, can be broken down by total wave frequency and wave energy. From the wave spectra, first-order information regarding frequencies of wave height and wave direction and other wave statistics are derived.

Ocean currents are primarily driven by the wind and unequal heating and cooling of ocean waters. There are five primary mechanisms responsible for the ocean currents; the two of primary interest for the offshore wind industry are large-scale currents such as the Gulf Stream and wind-generated near-surface currents. Although IEC design standards allow for application of standard current profiles to surface current measurements for obtaining site-specific profiles, sites where local currents may deviate significantly from these standard profiles may require observations throughout the water column. Local deviations may occur in shallow water areas with significant wave-induced current stretching or compression, or in areas with high thermal or salinity gradients.

**Water State Properties**

The physical state and properties of the water column, specifically characteristics such as temperature, salinity, density, and ice loading, are important inputs to structural loading calculations. They are also relevant to corrosion estimations, the selection of coatings, construction planning and execution, current, wave and (to a lesser extent) wind characteristics. Knowledge of these properties is important throughout the development and design phases, as well as for operations and maintenance.

Corrosion potential may be estimated from observations of water chemistry or pollution, and salinity. Water conductivity measurements are frequently used to estimate water salinity, given known or assumed proportions of dissolved salts. Water temperature also affects corrosion rates, in addition to influencing structural loading characteristics through marine growth, which refers to the colonization on marine structures by marine organisms.

Estimates of storm surge and sea ice properties are ocean surface observations. However, observations throughout the depth of the water column, not just at the surface, are essential for accurately gauging conditions at development sites.
The water level range (consisting of an astronomical tidal fluctuation and any additional storm surge) is essential to foundation and piling design, as well as to navigation. The tidal datum is a local vertical reference elevation used to measure water levels based on tidal fluctuation. Notation of the reference datum is particularly important, as engineering design and preliminary wind development tasks may not use the same datum as a default. For example, wind maps are commonly referenced from mean sea level (MSL) and foundation designs often reference mean lower low water (MLLW). Storm surge consists of a wind-driven and small pressure driven component that increases water level heights. The juxtaposition of tidal range with storm surge levels gives the maximum range of water levels expected at a site.

Finally, characterization of marine growth—referring to the colonization of organisms on structures by underwater organisms— is required for the design and maintenance of any sub-subsurface components in an offshore wind farm. The type(s) of organisms, the rate(s) of growth, the percentage coverage and the thickness by depth are all used to support sub-surface loading calculations and maintenance program design.

*Ocean and Water Parameters of Interest*

The recommended ocean parameters for design characterization are listed in Table 3.3, and Table 3.4 identifies water state parameters. Table 3.5 lists additional parameters that require calculation and analysis. While numerous combinations of wind-wind, wind-water, and water-water parameter analysis are required, and can be derived, the most common ones are presented in Table 3.5. Joint parameter comparisons can be the driving conditions in key design processes, including turbine suitability determination, foundation and tower design, and potentially turbine back-up power requirements (in the event of a loss of grid power or substation).
### Table 3.3: Ocean Parameters of Interest

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description / Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave Direction</td>
<td>The direction from which waves are coming. Used as input to joint wind/wave directionality tables.</td>
</tr>
<tr>
<td>Wave Height</td>
<td>Vertical distance between trough and crest.</td>
</tr>
<tr>
<td>Significant Wave Height</td>
<td>Average height of the one-third highest waves in a wave spectrum.</td>
</tr>
<tr>
<td>Normal Wave Height</td>
<td>Expected value of significant wave height for a given mean wind speed; common design criteria.</td>
</tr>
<tr>
<td>Extreme Wave Height (He)</td>
<td>Expected value of the highest individual wave height</td>
</tr>
<tr>
<td>Extreme Significant Wave Height</td>
<td>Expected value of the highest significant wave height, averaged over 3 hours</td>
</tr>
<tr>
<td>Dominant Wave Period</td>
<td>The temporal wave period with maximum wave energy.</td>
</tr>
<tr>
<td>Zero-Crossing Period</td>
<td>Mean time interval between upward or downward zero crossings on a wave record</td>
</tr>
<tr>
<td>Directional Spectrum</td>
<td>Wave energy as a function of direction. Consists of significant wave height and the dominant wave period.</td>
</tr>
<tr>
<td>Frequency Spectrum</td>
<td>The wave energy in the frequency domain.</td>
</tr>
<tr>
<td>Buoy Motion</td>
<td>For buoy-mounted systems, pitch and roll information is beneficial in interpreting the measurements.</td>
</tr>
<tr>
<td>Mean Wave Speed</td>
<td>Computed using various wave particle propagation theories.</td>
</tr>
<tr>
<td>Current</td>
<td>Movement of ocean water characterized by regularity. Speed and direction at various depths (surface and sub-surface) are measured.</td>
</tr>
<tr>
<td>Still Water Level</td>
<td>Hourly (or more frequent) measurements of water levels compared with a station’s datum. Used to define normal and extreme water levels.</td>
</tr>
<tr>
<td>Storm Surge</td>
<td>The abnormal rise in water level, over and above the regular astronomical tide, caused by a storm of any type.</td>
</tr>
<tr>
<td>Tidal Datums</td>
<td>Markers of tidal variation such as highest astronomical tide (HAT) and lowest astronomical tide (LAT).</td>
</tr>
</tbody>
</table>
### Table 3.4: Water State Parameters

<table>
<thead>
<tr>
<th>Measurement Parameter</th>
<th>Description / Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemistry &amp; Pollution</td>
<td>Analysis of active substances and oxygen content in water.</td>
</tr>
<tr>
<td>Conductivity</td>
<td>Measure of ability to conduct electricity. Used for loss and design inputs.</td>
</tr>
<tr>
<td>Density</td>
<td>Mass of water per cubic volume. Used in wave load calculations and current modeling.</td>
</tr>
<tr>
<td>Salinity</td>
<td>Amount of dissolved salts per kg of water. Used for corrosion and current modeling.</td>
</tr>
<tr>
<td>Marine Growth</td>
<td>Colonization of organisms on structures. Used to support sub-surface loading calculation.</td>
</tr>
<tr>
<td>Ice</td>
<td>Includes ice accretion on structure. Used in turbine foundation and BOP design.</td>
</tr>
<tr>
<td>Water Temperature</td>
<td>Both surface and water column. Used in current modeling, corrosion, forecasting, stability, conductivity, and density calculations.</td>
</tr>
<tr>
<td>Seabed Temperature</td>
<td>Typically estimated; used in turbine foundation and BOP design.</td>
</tr>
</tbody>
</table>

### Table 3.5: Joint Ocean and Wind Characterization

<table>
<thead>
<tr>
<th>Distribution</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Direction – Wave Direction</td>
<td>Used for fatigue loading under combined wind and wave conditions.</td>
</tr>
<tr>
<td>Significant Wave Height – Peak Spectral Period – Wave Direction</td>
<td>Used to represent the normal, severe, and extreme sea states. Can include wind directionality.</td>
</tr>
<tr>
<td>Wind-Generated Current – Wind Speed</td>
<td>Used to represent the normal and extreme current models.</td>
</tr>
<tr>
<td>Wave Height – Wind Speed</td>
<td>Used to represent the severe wave height, estimates of surface roughness, and modification of the wind profile.</td>
</tr>
</tbody>
</table>
**Gaps in Ocean and Water Column Parameters**

The very limited availability of wave, current and water state data in the vicinity of the WEA's constitutes an overall gap that new measurements could help address. In particular, such parameters as the significant wave height, peak wave period, and zero-crossing period are all critical to the foundation design. In addition, the occurrence of peak loading from waves must be viewed in conjunction with concurrent wind loading.

The existing suite of ocean and water measurements is comprised of a combination of buoy and fixed-platform measurements. The deployed instrumentation is diverse and operated by a number of agencies, often for considerably different purposes. The same parameters are not often measured consistently in time resolution (such as hourly, 3-hourly, or daily) or space (different platforms measure different parameters, or some parameters not at all). For example, directional wave spectra are not typically recorded on NOAA buoys, and this parameter is crucial to determining fatigue loading of foundations. In addition, meteorological parameters are not often measured concurrently with the related ocean parameters. Finally, many parameters of interest have not been measured consistently with time.

Wave and sea state conditions significantly influence the ability to access wind turbines by vessel. Improved knowledge of the timing and frequency of inaccessibility will enable the selection of appropriate vessel types and the accurate estimation of access-related production losses.

Additional challenges result from the limitations of existing models and a lack of experience with simulating the wind and wave environment concurrently using coupled atmospheric-ocean models. The gaps in observational data include a mismatch in time resolution (e.g., 10-minute versus hourly or 3-hourly) and the difficulty in extrapolating existing observations to the WEA's. The expanded availability of validation data will improve model performance and reduced modeling uncertainty.

**3.4.2 Wind and Atmospheric Design Inputs**

In addition to the list of parameters important to the wind resource and energy assessment process, there are several related parameters that are important design inputs. Table 3.6 lists typical inputs to a site suitability/design and characterization process.
<table>
<thead>
<tr>
<th>Measurement Parameter</th>
<th>Recorded Values</th>
<th>Description / Comments</th>
<th>Measurement Heights</th>
<th>Temporal Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>Presence (Y/N)</td>
<td>Used for loss and design inputs (soiling, corrosion, site access)</td>
<td>One</td>
<td>Hourly; Daily; Monthly; 10-minute optional.</td>
</tr>
<tr>
<td></td>
<td>TypeAmount (Avg/Min/Max)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Icing</td>
<td>Time when turbines experience degraded performance or shutdown from icing</td>
<td>Typically adjusted to reflect historical frequency; impact on turbines assumed to be less than on measurement equipment.</td>
<td>Difficult to measure on-site; can be inferred from wind sensor icing, air temp., and relative humidity</td>
<td>Determined from aggregated 10-minute or hourly data</td>
</tr>
<tr>
<td>Hail Diameter</td>
<td>Maximum</td>
<td>Used to estimate potential structure damage.</td>
<td>Typically not measured on-site; regional and historical databases used</td>
<td>Long-term extremes</td>
</tr>
<tr>
<td>Hail Fall Speed</td>
<td>Maximum</td>
<td>Used to estimate potential structure damage.</td>
<td>Not measured; regional historical databases used; fall speed estimated from diameter</td>
<td>Long-term extremes</td>
</tr>
<tr>
<td>Inclined Flow</td>
<td>Value (+/-)</td>
<td>Air flow angle relative to the water surface</td>
<td>Calculated using engineering or wind farm design software</td>
<td>Annual average</td>
</tr>
<tr>
<td>Air Density at Maximum Wind Gust</td>
<td>Average Instantaneous</td>
<td>Calculated from available measurements concurrent with max gust</td>
<td>Required at hub height; either calculated directly or using assumed lapse rate</td>
<td>Typically 10-minute; if higher-resolution gust, then same as gust</td>
</tr>
<tr>
<td>Wind Shear at Maximum Wind Gust</td>
<td>Average Instantaneous</td>
<td>Calculated from available measurements concurrent with max gust</td>
<td>Typically across rotor plane; between available measurement heights common</td>
<td>Typically 10-minute; if higher resolution gust, then same as gust</td>
</tr>
</tbody>
</table>
### Table 3.6 - Continued: Wind and Atmospheric Design Inputs

<table>
<thead>
<tr>
<th>Measurement Parameter</th>
<th>Recorded Values</th>
<th>Description / Comments</th>
<th>Measurement Heights</th>
<th>Temporal Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Radiation (W/m²)</td>
<td>Average Min/Max</td>
<td>Useful for power supplies, corrosion/degradation expectations</td>
<td>1 Sufficient; Typically at Tower Base</td>
<td>Typically 10- minute</td>
</tr>
<tr>
<td>Lightning Frequency</td>
<td>Number of cloud-to-ground strikes</td>
<td>Used to determine expected lightning frequency for turbine suitability</td>
<td>Typically not measured on site; using surface-or-satellite based measurements</td>
<td>Monthly and Annual</td>
</tr>
<tr>
<td>Barometric Pressure</td>
<td>Average Min/Max</td>
<td>Used to determine site air density and support forecasting</td>
<td>1 Sufficient; Typically Near Tower Base</td>
<td>Same as temperature</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>Average Min/Max</td>
<td>Used for air density and site corrosion estimates</td>
<td>1 Sufficient; Typically Near Tower Base</td>
<td>Same as temperature</td>
</tr>
<tr>
<td>Visibility</td>
<td>Instantaneous Average</td>
<td>Used to support vessel and construction operations, O&amp;M</td>
<td>Can be measured on-site or inferred from regional data</td>
<td>10-minute or hourly typical</td>
</tr>
<tr>
<td>Chemistry &amp; Pollution</td>
<td>Any Available</td>
<td>Required for corrosion estimates</td>
<td>Typically not measured on-site; regional and historical information used</td>
<td>Long-Term Conditions</td>
</tr>
<tr>
<td>Reference Wind Speed (Vref)</td>
<td>Long-Term 50-Year 10-minute Return Value</td>
<td>Derived through statistical analysis</td>
<td>Hub Height (via direct calculation or extrapolation)</td>
<td>10-minute</td>
</tr>
<tr>
<td>Extreme Operating Gust</td>
<td>Theoretical Maximum</td>
<td>Calculation method specified in IEC literature</td>
<td>Hub Height (via direct calculation or extrapolation)</td>
<td>10.5 seconds</td>
</tr>
<tr>
<td>Extreme Coherent Gust with Direction Change</td>
<td>Theoretical Maximum</td>
<td>Maximum 10-second concurrent 15 m/s speed increase and directional shift</td>
<td>Hub Height (via direct calculation or extrapolation)</td>
<td>10-second</td>
</tr>
<tr>
<td>Extreme Wind Shear</td>
<td>Theoretical Maximum</td>
<td>Extreme 12-second wind shear change, applied in both vertical and horizontal directions.</td>
<td>Hub Height and relevant shear calculation levels</td>
<td>12-second</td>
</tr>
<tr>
<td>Extreme Direction Change</td>
<td>Theoretical Maximum</td>
<td>Maximum 6-second wind directional shift</td>
<td>Hub Height</td>
<td>6-second</td>
</tr>
</tbody>
</table>
**Gaps in Wind and Atmospheric Design Parameters**

The parameters of most importance to design are extreme events, which can constitute worst-case scenarios. For wind speed extremes, a detailed review of site-specific values, as well as the interaction between extremes at different time scales, should be carefully reviewed. In terms of extrapolation to long-term conditions, statistical techniques such as the Method of Independent Storms, Gumbel Generalized Extreme Value (GEV), and Peak over Threshold are commonly used to estimate return periods, extreme values and to convert between measurement time scales. Return-period extremes are typically defined over periods such as 1, 10, 50, 100, 500, and 1000 years. These derivations inform the structure and component design for all hardware.

Regarding seasonally or annually averaged parameters, gaps exist in relation to offshore precipitation, lightning, and soiling and icing factors impacting blade degradation. On-site monitoring of some parameters is not practical, but reliance on improved remote sensing networks (precipitation, lightning, atmospheric chemistry) or the extrapolation of nearby terrestrial measurements (ice accretion) is adequate in most cases.

The determination of representative shear coefficients will allow a multi-faceted approach to gust calculations. Extreme wind speeds modeled and observed at lower elevations can be projected to hub height and compared to representative observations in the region. The horizontal and vertical variations in gust behavior should be considered when synthesizing estimated hub height values within the project area.

Extreme value statistics for waves may be calculated using observed parameter measurements together with empirical formulas, or by fitting observations to distribution models and projecting return times based on the observed frequency of events over a given reference period. Typically 50- and 100-yr return periods are used in extreme wave analysis. Care must be taken in choosing which generalized extreme value method to use, as wave height distributions do not necessarily follow the popular Gumbel distribution and large differences in return period heights can result from the combination of a limited period of record and choice of extremes statistical tool.

The differentiation of design condition statistics for extratropical and tropical cyclones (hurricanes) is an extremely important aspect of design. Therefore it is necessary to understand the principle physical differences between these storm types and how these differences should influence data analysis approaches (such as wind shear, turbulence intensity, and atmospheric stability assumptions). Extratropical cyclones, which include nor’easter events, have cold-air cores and frontal features, and derive most of their energy from the temperature contrast between different air masses. They can originate over land as well as water. Peak winds can reach hurricane strength. Tropical cyclones, on the other hand, are non-frontal warm-core storms that derive their energy from the release of latent heat of condensation. They originate over warm waters and can assume extratropical characteristics as they move poleward. Extratropical cyclones are often larger in radial size than tropical cyclones, with strong winds extending further from the storm center. In some cases, tropical cyclones can transition into extratropical cyclones and take on different characteristics.
For the WEAs, extratropical storms occur with greater frequency than tropical storms and prevail across more seasons (normally from mid-fall through mid-spring). Tropical storms prefer the summer and early fall seasons when ocean temperatures are warmest. Extratropical cyclones, therefore, involve colder air temperatures and higher air densities; they also involve more precipitation types, which in frozen form can accumulate on structures and blades. It is important to adjust assumptions for vertical wind shear extrapolation and turbulence intensity at hub height, depending on the storm sector (air mass type) and fetch. Air-sea temperature differences will influence these assumptions as they impact the atmospheric boundary layer’s thermal stability (i.e., vertical mixing tendency). During the cold season when extratropical cyclones prevail, neutral-to-unstable atmosphere conditions likewise prevail, which promote lower wind shear conditions compared to warm season events. Atmospheric stability also impacts the behavior of turbine wake propagation and decay.

The return period frequency of most interest may also vary depending on the storm type of interest. For example, given the expected higher frequency of extratropical cyclones, metocean conditions having return periods of 1 to 10 years may be more relevant. On the other hand, wind and wave parameters for longer return periods (50, 100, 500 and 1000 years) will be derived for both extratropical type storm events and those derived separately for tropical cyclones.

### 3.4.3 Additional Design Parameters

Bathymetry, sea bed conditions, and earthquake potential are among other factors impacting project design and metocean characterization. These factors are listed in Table 3.7. Sea bottom surface characteristics – bathymetry, soil type, and scour conditions – influence foundation design, cable burying strategies, and the overlying water conditions (e.g., currents, waves, breaking wave frequency). Seismic conditions are also relevant to this region.
### Table 3.7. Supplemental Design Inputs

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description / Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bathymetry</td>
<td>Local and regional bottom topography. Important input for modeling and foundation design / cable routing.</td>
</tr>
<tr>
<td>Soil Type</td>
<td>Affects project siting, turbine and BOP micrositing, cable route and installation method, scour, seabed movement, foundation type, installation methods and vessels, and other parameters.</td>
</tr>
<tr>
<td>Seabed Movement</td>
<td>Stability of seabed. This includes the movement of sand waves, ridges and shoals.</td>
</tr>
<tr>
<td>Scour</td>
<td>Can be either local or global in nature. Affects foundation design and cable installation/protection</td>
</tr>
<tr>
<td>Earthquake Hazard</td>
<td>Where applicable. Defined in local codes or by means of a site-specific evaluation.</td>
</tr>
<tr>
<td>Tsunami Hazard</td>
<td>Where applicable.</td>
</tr>
</tbody>
</table>
4. METOCEAN DATA COLLECTION STRATEGIES TO ADDRESS GAPS

4.1 Introduction
Offshore wind resource assessment and characterization of facility design input are comprised of three primary components: measurement of the pertinent metocean conditions, adjustment of the observed data to represent long-term conditions, and modeling to integrate and extrapolate the observed parameters. This general approach, tuned with task-specific analyses, has supported the development and construction of over 8,000 MW of offshore wind in Europe since 1991. Identical methods have been employed in the US as well, resulting in the successful financing of the first offshore wind project – the Deepwater Wind Block Island Wind Farm.

It is important to note that despite over two decades of successful experience, there are currently no standard methods for wind resource assessment or offshore design data collection (the same is true for land-based wind development). Projects in Europe and the US currently rely upon industry best practices and practitioners’ experience in the region to develop and implement site-specific campaigns to meet project development goals, timelines and budgets. This can result in campaigns with significantly different measurement strategies and monitoring system compositions, even in regions with similar conditions. The IEC is currently developing a standard (IEC 61400-15) to address these issues, but even this document is expected to allow a spectrum of methods and techniques.

While normalization and codification of methods can indicate the maturity of a process or industry, the absence of formal standardization in metocean site assessment is intentional and should not be confused with lack of skill or refinement of technique. The processes under examination in wind resource assessment and facility design input development, e.g. long-term climate behavior, magnitudes and return periods of specific storm conditions, interactions between the atmosphere and ocean, etc., are complex and very challenging to assess with the precision required for cost-effective wind development. As such, the methods employed to characterize a specific site or region are finely tuned to the project needs and the expected conditions on site. This requires careful campaign design and cost benefit analysis to balance measurement, modeling and long-term analysis approaches.

This section presents four scenarios for metocean measurement in the context of the historical role of each approach, deployment costs and technical application to pre-construction project development tasks:

1. Fixed tall meteorological tower
2. Fixed platform with profiling lidar
3. Floating profiling lidar

Each scenario outlines the expected monetary and time investments, as well as tradeoffs, associated with each monitoring approach. The discussions address the individual merits of each scenario to differentiate relative value and shortcomings. The following scenario discussion also differentiates between short-term and long-term deployment campaigns and their potential value to the
construction and operational phases of offshore wind projects. Estimated scenario costs are compared to the likely benefits gained by strategy implementation. A focus of the cost-benefit assessment will be the uncertainty reductions gained during the design, financing, and operational phases of project development. Supplemental regional measurement and modeling approaches with the potential to support development in the WEAs are also presented. The objective of the presentation of scenario options is to inform MassCEC’s next steps in formulating a detailed measurement approach with their candidate commercial or collaborative partners.

4.1.1 Assumptions and Approach
A number of programmatic and technical assumptions were made to frame the scenario discussions. Programmatic assumptions defined the overall approach and timeline employed to assess the monitoring scenarios. The primary programmatic assumptions are:

- Only one measurement technology was examined for each scenario from an uncertainty perspective. Multiple monitoring tools and locations should be considered for campaign design, but the single station assumption facilitates explicit consideration of uncertainty parameters.
- Since current design standards and guidelines do not accommodate uncertainty bounds on metocean design input parameters, the impacts on those analyses are described qualitatively.
- Quantitative estimates of a project’s long-term energy yield uncertainties are presented for each scenario based upon the monitoring technology’s characteristics as well as some basic technical assumptions (described further below).
- Costs presented are sourced from public documentation and adjusted as best as possible to 2015 US Dollars.
- Costs are generally presented as capital expenditures (CAPEX) for design, procurement, fabrication, installation and commissioning of the specified technology. Operating expenditures (OPEX) are described qualitatively, but can have significant variation based upon campaign specifics outside of this scope, e.g. specific technology chosen, siting, future climate events, etc.
- A common development timeline is considered for the deployment of each scenario. Campaign initiation (starting at permitting, design and procurement) is assumed to kick off at the beginning of a year, with data monitoring for analysis and financing concluding up to five years later. This timeline bounds the amount of data that can be collected for each station type.
- The monitoring stations employed in each scenario are well-sited and represent near-term development locations.
- A project hub height is assumed to be 100 m above MSL.
- Water depth at a monitoring station is assumed to be approximately 45 m.

Several technical assumptions also guided the scenario evaluation. These influenced the uncertainty estimates and were derived from previously assessed projects in the region and similar analyses nationwide. The assumptions are:

- The wind direction frequency distribution (wind rose) observed at Buzzards Bay Coastal-Marine Automated Network (C-MAN) is largely representative of the region of interest.
• The wake losses, energy to velocity ratio, technical loss uncertainties, and wind speed uncertainties not affected by the measurement scenario characteristics are all held constant for each scenario at values representative of the region.
• All standard and appropriate modeling and long-term analyses are conducted for each scenario equally. No specific, targeted efforts with modeling or analysis are employed to improve uncertainties.

4.2 Scenario 1 – Fixed Tall Meteorological Tower
The first monitoring scenario is a fixed offshore meteorological (met) platform consisting primarily of a sea bottom-mounted foundation, a tall tower, and an array of sensors sampling the ocean and atmosphere. Tall towers (also referred to as masts) that extend up to or near hub-height have been the standard approach for both land-based and offshore wind resource assessment for decades. This approach is widely accepted by developers, OEMs, financers, and regulators. For this scenario, the tower is assumed to reach up to a height of 100 m above MSL. Details on the station's configuration are presented below.

4.2.1 Technical Configuration
In addition to the foundation, tower and sensors, other important platform components include sensor mounting booms, a power supply, and a data logging and communications system. The design of a fixed offshore platform will be driven by site-specific environmental conditions and overall program needs. To start, the platform’s height above mean sea level will be established by the expected extreme wave height in the area of interest and will have to be considered when specifying the fixed tower monitoring heights. The platform size, or deck area, will be determined by the monitoring components’ space needs, e.g. data logging and communication hardware, and any other environmental or biota monitoring equipment, as well as the expected installation protocol, e.g. mast erection from the platform deck or from an adjacent vessel.

Based upon initial assessments of the available regional data, specifically the highest recorded significant wave heights at buoys 44097 and 44008, the platform for an offshore Massachusetts site would likely be installed at a height of at least 15 m above MSL with an 85 m self-supporting lattice tower. This allows for a 100 m above MSL top monitoring height and multiple lower monitoring heights to measure wind profile characteristics. Each monitoring level should be equipped with redundant wind speed and direction sensors to both mitigate tower-induced flow distortions on the data as well as to prevent data gaps in the time record due to sensor malfunction.

In addition to the up-tower atmospheric measurements, the main deck can be outfitted with a suite of sensors and data logging and communication equipment. The tower and structure can also be equipped with accelerometers to assess motion and displacement at various points, including the mast top, mid-section and platform levels. If the tower’s foundation type is similar to what future wind turbines would use in the region, then strain gauges and various other structural sensors could also be deployed. Water profile sensors along the foundation and bottom-mounted equipment could monitor the balance of the metocean parameters identified in the previous section. The structure could also host relevant safety and navigation equipment.
The tower’s metocean monitoring configuration will be influenced by a number of factors including the structure size (wider tower structure forces longer booms or more booms per level), the local wind rose, and budget. Based upon the tower height, a minimum of five levels of atmospheric measurements is recommended, specifically at elevations of 20, 40, 60, 80 and 100 m. Each level would include least two booms to accommodate redundant wind speed and direction measurements, as well as air temperature. Barometric pressure, relative humidity, 3D sonic wind sensors, and other relevant sensors can also be deployed up-tower. Examples of two 100 m offshore towers on monopole foundations in the East Anglia offshore project area in the North Sea are shown in Figure 4.1.

Ocean surface and profile conditions can be characterized by bottom- and structure-mounted Acoustic Doppler Current Profilers (ADCPs) and water level sensors. Water temperature and conductivity measurements would be employed along the foundation to define the relevant profiles of those parameters. The platform deck can accommodate other ancillary sensors to cover parameters relevant to project design or monitoring station operations and maintenance, such as precipitation, solar irradiance, visibility, and related variables. Supplementary equipment, such as platform based lidar or radiometers to further characterize the atmosphere, can also be accommodated to enhance the station’s value, but these additions are not considered for this analysis.

Figure 4.1: East Anglia Offshore met Towers 1 and 2

Preliminary boom and instrument orientations were determined for the WEAs using the observed long-term wind rose for the Buzzards Bay C-MAN station. The boom orientations for all monitoring

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4 www.offshorewind.biz/2013/08/22/uk-two-met-masts-completed-at-east-anglia-offshore-wind-zone/
heights are recommended to be 337° and 157° relative to True North. The boom alignments and sensor placement were chosen to provide optimum exposure to the prevailing directions within and near the study area and to minimize tower-induced flow distortion at all levels. These configurations are subject to adjustment based upon the onsite measured wind rose as well as tower and boom design parameters. Figure 4.2 illustrates the candidate boom configuration relative to the expected wind direction rose.

Onsite data collection, processing, storage and transmittal would be carried out by industry-standard data logging and communications platforms. Accommodations for redundant data logging and communications should be considered if site access is particularly limited. Table 4.1 provides a breakdown of the candidate basic monitoring equipment; specific sensor specification and model selection should be tailored to the harsh offshore environment.
### Table 4.1: Basic Equipment Suite Recommended for 100 m Tower

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Parameter / Purpose</th>
<th>Qty</th>
<th>Height (m AMSL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I cup Anemometer</td>
<td>Horizontal Wind Speed / Gust</td>
<td>10</td>
<td>20, 40, 60, 80, 100</td>
</tr>
<tr>
<td>3D Ultrasonic Anemometer</td>
<td>3D Wind Vector / Gust</td>
<td>5</td>
<td>20, 40, 60, 80, 100</td>
</tr>
<tr>
<td>Wind Direction Vane</td>
<td>Wind Direction</td>
<td>5</td>
<td>20, 40, 60, 80, 100</td>
</tr>
<tr>
<td>Temp. / RH sensor</td>
<td>Air Temp. &amp; Relative Humidity</td>
<td>5</td>
<td>20, 40, 60, 80, 100</td>
</tr>
<tr>
<td>Pressure sensor</td>
<td>Barometric Pressure</td>
<td>2</td>
<td>15, 100</td>
</tr>
<tr>
<td>Pyranometer</td>
<td>Global Solar Irradiance</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Rain Gauge</td>
<td>Precipitation</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Visibility sensor</td>
<td>Visibility</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>data logger</td>
<td>Data logging &amp; Processing</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Support Equip.</td>
<td>Communication, data storage &amp; power</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Water temp. / Conductivity</td>
<td>Water temp. &amp; salinity</td>
<td>3</td>
<td>-1, -20, -40</td>
</tr>
<tr>
<td>ADCP</td>
<td>Wave and current characteristics</td>
<td></td>
<td>-45</td>
</tr>
</tbody>
</table>

#### 4.2.2 Costs

The capital costs for a hub height offshore tower installation are site and design specific. Installed costs in the United Kingdom (UK) are recently estimated to be roughly between $6 million and $15 million\(^5\). Outside of the established northern Europe experience base, costs can be considerably higher. A few recent examples from constructed masts are presented below.

- The estimated 2010/2011 construction budget for the UK National Renewable Energy Center (NAREC) 104 m AMSL offshore tower was approximately $6 - $9.5 million\(^6\).
- A 2012 contract for installation, monitoring and operation of two 100 m offshore towers in the UK was awarded for $27 million\(^7\).
- Similarly in 2012, installation and operation of two bottom-fixed masts in Japan were budgeted at approximately $35 million\(^8\).

The range of costs is driven by final station configuration, foundation design and fabrication, and installation. The latter two components represent over 80% of the total installed cost. A breakdown of installed cost components for UK masts is presented in Figure 4.3. The foundation and tower designs will be strongly affected by local soil conditions, water depth and estimated long-term metocean conditions (including extreme conditions during Nor’easters, hurricanes, and other events). Installation costs will be driven by site conditions and station design, as well as vessel characteristics and availability.

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Based upon the general station configuration laid out above, a 100 m fixed tower cost range of $8 - $10 million is estimated for an installation in the vicinity of the WEAs. Actual costs may vary outside of this range based upon siting, configuration and installation approach.

Operational costs for an offshore tall tower will include both data management services as well as structure and equipment suite maintenance. The annual costs to carry out these activities are highly site specific, but can be initially modeled as 5–10% of the station’s installed cost until experience is developed. Maintenance of these stations has a higher requirement for staff skill than land-based towers as technicians need to have specialized offshore safety training.

4.2.3 Benefits and Challenges
Separate from the costs and timeline (described below), selection of a tall met tower carries a number of operational benefits and challenges to the offshore monitoring campaign.

Benefits
Data accuracy is one of the highest priorities of a wind resource assessment campaign. The history of tower-based monitoring has developed a large experience base for achieving high measurement accuracy from anemometry. Appropriate instrument selection, boom length and orientation, and maintenance requirements are well understood and generally achievable on almost all tower designs. Modeling and supplemental analytical methods are available as well for sites subject to significant icing, structure-induced flow distortion, and other operational conditions that can affect accuracy.

Reliability of this scenario is expected to be quite high, but will be sensitive to operations and maintenance. All of the primary measurement components have positive track records in the areas of accuracy, stability of performance and overall reliability in adverse environments. All of the components have been used extensively for land-based and in numerous offshore deployments. The integrity of

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9 “Offshore Meteorological Stations: A Hidden Challenge”, Wind Energy Network, April/May 2013, pp.103
the station’s period of record is further supported by redundant sensing equipment at each level. This helps ensure continuous data collection even through multiple instrument failures or problems. It also allows more flexibility in designing an O&M and response program.

The platform and power supply can be designed to accommodate enhanced instrumentation to support other monitoring efforts such as avian, bat and marine mammal monitoring (radar and or passive acoustic systems). The station can be used following wind plant construction for IEC-compliant power curve testing if sited accordingly. Finally, the metocean data collected by the tall tower can add other post-construction value in the areas of site condition monitoring, maintenance scheduling, and power forecasting.

**Challenges**

While there are many benefits to using a tall tower for pre-construction metocean site assessment, most European developers are trending away from it due to high installed and operating costs. Specific challenges include long-term costs and safety risks for operating a tall offshore structure in a marine environment. Even with design life spans of 20 or more years, many offshore tower structures have corroded significantly in the first 5 to 15 years, and costs to maintain the structure (including the up-tower equipment) can exceed the value of ongoing data collection.

Additional challenges of this approach are time-based. Of the four scenarios considered, fixed tall towers take the longest time to deploy and are effectively locked into a permanent location for the duration of operations. A permanent tower cannot be relocated to sample multiple sites within a large project area, and it cannot be relocated if it is in a disadvantageous location after the project is constructed (e.g. it is in the wake of turbine from prevailing direction sectors).

**4.2.4 Timeline**

The schedule to deploy a fixed tall tower will be driven by location (affecting foundation design, expected loading, and possibly permitting) and physical configuration (affecting installation method and required equipment). The processes of siting, preliminary station design, geophysical and geotechnical work, detailed design, certification (if required), materials procurement, fabrication and installation can take 18 to 24 months from project initiation. In some cases, permitting can be the critical scheduling path, but it is assumed that the permitting process will run in parallel with the other tasks.

Installing and instrumenting a platform, an 85 m tall tower, and bottom-mounted equipment in an offshore environment is a complex procedure. It requires detailed coordination of multiple vessels and numerous personnel in favorable weather conditions. While not expected to drive schedule as much as cost, installation procedures and timing still merit careful consideration when mitigating weather and other technical delays. For this report, it is assumed that the lead time to tower installation and commissioning is 24 months.

**4.2.5 Confidence Level**

The acceptance and bankability of a metocean program is affected by a number of factors, including the overall campaign design, the type of financing sought, and the uncertainties assigned to the program
components. While all of the monitoring scenarios described in this report are scientifically defensible, the particular approach will likely impact the extent to which the collected datasets are viewed favorably by financial institutions, project partners (including turbine vendors), and other data end users.

Wind measurements taken by cup anemometers mounted on tall towers are the current and historical standard for not only wind resource assessment, but also for turbine power curve testing and other performance verification procedures. As such, a resource assessment program that incorporates a year or more of contiguous, high-quality cup anemometry measurements, including at hub height, provides the highest confidence dataset for offshore project financing. One year of data is the minimum required for this type of campaign, with additional monitoring time strongly recommended to increase the understanding of the site wind resource characteristics and the certainty of long-term speed projections.

From a site assessment perspective, most turbine and balance of plant design standards and guidelines are designed around atmospheric data collected with the sensors recommended in this scenario. As long as the complementary ocean sensors are included as part of the suite, this scenario is expected to deliver the highest overall confidence in developing plant environmental design inputs.

4.3 Scenario 2 – Fixed Platform with Profiling Lidar
The second monitoring scenario is a bottom-fixed offshore platform equipped with a short tower that supports a vertical profiling lidar and an array of other weather and ocean sensors. This scenario contrasts with the first one by using lidar instead of a tall tower to measure winds up to hub height (or beyond). The main advantages of this approach are lower cost and the ability to measure winds above hub height. This approach is capable of achieving a level of accuracy, reliability and stakeholder acceptance comparable to that of a tall tower (Scenario 1).

4.3.1 Technical Configuration
This monitoring approach is similar to the first scenario insofar as it is comprised primarily of a bottom-founded platform upon which the atmospheric sensors, power supply and communication systems are based. Rather than employing a tall mast to characterize wind conditions up to hub height, this approach relies upon one or two profiling lidar systems to measure 3D wind conditions up to 200 m above the platform. Two lidars will provide more data reliability through sensor redundancy. Ocean and surface sensors are deployed on or adjacent to the foundation structure, as with the tall tower scenario.

The detailed design of the platform will be driven by local environmental and soil conditions, as well as station needs. A 15 m above MSL platform is still envisioned for this application, and a similar foundation design is likely. While the topside load of this scenario is significantly lower than that of a hub height tower (given the anticipated lower weight and lower aerodynamic loads), the water depth is identical. Since hydrodynamic loading is still likely to be a design driver, the foundation design may only see modest cost or weight savings. The deck area will be designed around the primary accommodation of the lidar and power supply components.
In addition to the profiling lidar(s), the station platform can host a set of standard atmospheric sensors around its periphery or on a short (e.g. 5 m) mast, as well as any necessary safety and navigation equipment. Separate anemometry on the short mast would provide a degree of wind measurement redundancy, albeit at a height well below hub-height. Ocean surface and profile equipment would be mounted in a similar fashion as described in Section 4.2.1. If required, the platform (and power supply) can also be designed to accommodate supplemental environmental, biological and/or metocean sensors. Deployed examples of this type of station are illustrated in Figure 4.4 below.

The absence of a tall lattice structure on the platform, and the reliance upon lidar as the primary upper-air wind sensor, essentially remove the importance of the site’s wind rose on sensor configuration (although the wind rose will have a bearing on the placement of anemometers on the short mast). Similar to the tall tower, onsite data collection, processing, storage and transmittal would be carried out by industry-standard data logging and communications platforms. Accommodations for redundant data logging and communications should be considered if site access is particularly limited. Table 4.2 provides a breakdown of the basic recommended monitoring equipment.

There are two primary approaches to the engineering, procurement and construction of this type of station. The first is to use an existing design, customized for a specific site. Turn-key systems of this sort are available from a few European vendors, including Sgurr Energy and Searoc. Alternatively, the system can be custom designed by one or more firms with the appropriate skills sets and experience.

![Figure 4.4: Bottom-fixed Metocean Platforms Employing Lidar as the Primary Atmospheric Sensor. (Left) Sgurr ORQA Platform Offshore China, (Right) Custom Nai Kun Lidar Platform Offshore Canada](http://naikun.ca/the-project/environmental-assessment/)

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Table 4.2: Basic Recommended Equipment Suite for Bottom-fixed Profiling Lidar Platform

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Parameter / Purpose</th>
<th>Qty</th>
<th>Height [m AMSL]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I cup Anemometer</td>
<td>Horizontal Wind Speed / Gust</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>3D Ultrasonic Anemometer</td>
<td>3D Wind Vector / Gust</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>Wind Direction Vane</td>
<td>Wind Direction</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>Temp. / RH sensor</td>
<td>Air Temp. &amp; Relative Humidity</td>
<td>2</td>
<td>15, 20</td>
</tr>
<tr>
<td>Pressure sensor</td>
<td>Barometric Pressure</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>Profiling Wind Lidar</td>
<td>3D wind measurements up to 200 m</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Pyranometer</td>
<td>Global Solar Irradiance</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Rain Gauge</td>
<td>Precipitation</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Visibility sensor</td>
<td>Visibility</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Data logger</td>
<td>Data logging &amp; Processing</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Support Equip.</td>
<td>Communication, data storage &amp; power</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Water temp. / Conductivity</td>
<td>Water temp. &amp; salinity</td>
<td>3</td>
<td>-1, -20, -40</td>
</tr>
<tr>
<td>ADCP</td>
<td>Wave and current characteristics</td>
<td></td>
<td>-45</td>
</tr>
</tbody>
</table>

Because the monitoring heights from a vertical profiling lidar system are user-selectable, this scenario allows for flexible configurations. Several brands of lidar are available to the wind energy industry, three of which have the vast majority of the experience in offshore monitoring. The two most accepted and deployed systems are the ZephIR 300 by ZephIR Limited and the Windcube V2 by Leosphere. The Galion by Sgurr, which also functions in a volume scanning mode (being able to measure a full hemisphere rather than just a profile), has also been deployed successfully in a number of offshore campaigns. These three sensors are illustrated in Figure 4.5.

Figure 4.5: Candidate Wind Lidars for the Platform. (Left) ZephIR 300\(^{12}\), (Center) Windcube V2\(^{13}\), (Right) Sgurr Galion\(^{14}\)

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4.3.2 Costs
The experience base for fixed offshore platforms hosting lidar measurements is very limited. The only public data point is the NaiKun tower, illustrated in Figure 4.4 above, which was built in 2007 for a stated budget of C$2.5 million (equivalent to roughly $3 million today). Based upon discussions with engineering firms familiar with this type of work, it is unlikely that a similar station could be built for that price in the US, particularly in WEA waters 45 m deep (the NaiKun site is approximately 18 m deep). Further, the NaiKun station did not have very extensive supplemental metocean equipment.

As with the tall tower scenario, the actual costs can vary greatly based upon local soil conditions, water depth and other design specifics. Considering the information above, and assuming that the cost contributors for this type of station are similar to the tall tower (with installation and fabrication dominating the costs), costs for this station type are expected to run in the range of $4 - $8 million. Annual operational costs are initially estimated to be in the 5 to 15% range of installation cost until experience is developed.

4.3.3 Benefits and Challenges
This scenario shares many of the benefits and challenges of the tall tower scenario. The data accuracy and reliability of the ocean sensors are expected to be identical to that of the mast, but a large portion of overall data uncertainty will hinge on the lidar itself. The post-construction applications of this approach also mirror the tower, both positively and negatively.

Benefits
For the lidar systems identified above, the data accuracy of individual units has been shown to be comparable to high-quality anemometers. Systems that have undergone a robust pre-deployment validation exercise – a requirement of system performance traceability and acceptance, akin to anemometer calibration – regularly demonstrate speeds within ±1-1.5% of the high quality anemometers on an adjacent tall tower. The added benefit of lidar is that this data accuracy extends up to and above the hub heights of wind turbines. This feature removes some of the uncertainty associated with possible technology evolution during the course of the pre-construction site assessment. For example, one project on the US east coast started with an assumed hub height of 80 m and four years later had settled on a hub height of 105 m. The uncertainty assigned to energy analyses derived from a “hub height“ tower built at the beginning of the project would be higher than that derived from a lidar measuring winds across a range of potential hub heights.

Reliability of this scenario is expected to be high, but not as high as the tall tower scenario if only one lidar system is deployed on the platform. While the lidars presented here have decent reliability track records offshore, they are still sophisticated systems that require regular maintenance and experience occasional measurement problems. The lack of redundancy makes this scenario more sensitive to power system integrity, communication system up-time, and other environmental factors (bird guano can be a challenge during certain seasons) than the tall tower scenario.
These are all treatable with a robust operations and maintenance plan, but a second lidar should be considered to help reduce data loss risk and improve measurement confidence. While separate anemometry on the short mast can provide a degree of redundancy should a lidar fail, the data from the anemometer will have to be height adjusted using wind shear profile assumptions. This adjustment process will introduce higher wind speed uncertainty for hub-height projections when lidar data are not available.

This scenario has a number of ancillary values as well. The platform and power supply can be designed to accommodate enhanced instrumentation suites to support other pre-construction monitoring efforts. The platform can also be used for power curve testing if sited accordingly, but under the current standards, likely would not be compliant with IEC methods. Finally, the hub-height and ocean data collected by the lidar and other metocean sensors is expected to add significant post-construction value in the areas of site condition and power forecasting as well as plant operational assessment.

**Challenges**

The most significant challenge to this scenario is that the use of lidar alone to successfully develop preconstruction energy yield analyses and project design inputs is unprecedented in the US. While use of profiling lidar as the primary wind data collection method is scientifically defensible and is expected to become “bankable”, the limited history is a barrier to acceptance by many stakeholders. The data analyses and interpretation face some additional challenges as well, since there is no consensus around the use of some key input parameters derived from lidar data yet, namely gusts and turbulence intensity. Some of these issues are partially mitigated by having high quality anemometer and vane data just above the deck (e.g. 20 m above MSL), but the challenge still exists. Opting to go with a slightly taller, but not hub-height, tower on the deck (e.g. 40 or 60 m) will largely mitigate these issues (including power curve test validity), but will also largely erase the cost benefit of this approach relative to the full-size tall tower. Ultimately, these concerns are best addressed through dialogue with anticipated project stakeholders during the measurement campaign design process.

Additional challenges of this approach are cost and time-based. While less expensive than the hub-height tower, this scenario still represents a significant investment of capital and time to deploy. Of the four scenarios examined in this report, the fixed profiling lidar approach is expected to take the second longest time to deploy. In addition, the fixed platform is effectively locked into a permanent location for the duration of operations. The permanent location risk is the same as the previous scenario.

### 4.3.4 Timeline

Similar to the tall tower, the installation and timing of this scenario will be driven by location (affecting foundation design, expected loading, and likely permitting) and configuration (affecting installation method and required equipment). The lead time to installation of this scenario is expected to offer some savings over the tall met mast scenario resulting from a shorter and simpler design process and potentially easier fabrication and installation. The Naikun platform was stated to have been designed, constructed and deployed in six months. That timeline certainly suggests award-worthy engineering work, and is not expected to be replicated in the WEs. Between anticipated permitting,
design, procurement and deployment requirements, the lead time to deployment for a station of this type is anticipated to be on the order of 18 months.

4.3.5 Confidence Level
This scenario is designed to leverage the growing comfort many end users have with profiling lidar systems. While uncertainty levels in the data derived from this sensor type may not be as low as from a hub-height tower using conventional anemometry, the overall confidence in the fixed profiling lidar approach can be reinforced by the co-deployment of high quality anemometry at ~20 m above MSL. Lidar has been demonstrated as a bankable technology when integrated with other measurement components, and its overall acceptance has been growing significantly in recent years. It is expected that by a financing target date of 2020, this issue will be a moot point whereby profiling lidar will be fully accepted as bankable.

4.4 Scenario 3 – Floating Profiling Lidar
The third monitoring scenario is a floating profiling lidar mounted on a relatively stable buoy that is moored to the sea bottom. Floating lidar is a relatively new technology that offers a promising, alternative means to measuring offshore winds. The goal of this technology is to be able to provide a more flexible means of obtaining accurate hub height wind speed measurements in the offshore environment at a lower cost than the current tall tower or fixed platform-based lidar options. However, the libraries of performance and reliability data for these systems are thus far fairly small.

4.4.1 Technical Configuration
Buoy-based lidar systems provide a singular floating platform from which all of the pertinent metocean parameters can be characterized. Several types of systems are commercially available, and other prototypes are under development. Many are employing established buoy hull and chassis designs, while a few are using more stable floating structures such as tension leg platforms or spar buoys.

The primary atmospheric sensor on the buoy is a vertically profiling lidar; some systems have the capability to support a redundant lidar or a scanning lidar. The lidar systems available are inclusive of the units identified in the previous section, as well as one additional model called the Vindicator from Optical Air Data Systems. The vast majority of floating lidars available employ either the offshore versions of the Windcube V2 or ZephIR 300 lidars. As with the platform-based lidar, these sensors allow 3D wind vectors to be characterized along a vertical profile up to 200+ m above the surface (or system lens height). This measurement capability makes allows the systems to be the primary tool for resource assessment near and above hub height.

In addition to the lidar, the typical buoy-based system also hosts a suite of metocean sensors capable of measuring wave height and direction spectra, surface wind speed and direction, air temperature, relative humidity, barometric pressure, and ocean characteristics along the depth of the water column. On some systems, platform motion data are used along with sophisticated algorithms to calculate and mitigate the impacts of buoy motion on the observed wind data. Other floating lidar hull configurations use passive damping systems or very stable platform types to limit the lidar motion. The hulls of the floating lidar systems also accommodate other support components such as data logging and
communication equipment, as well as a power supply and necessary navigation and safety equipment.

As an example of a typical equipment suite on these measurement systems, Table 4.3 provides a breakdown of the standard monitoring equipment on AXYS Technologies Inc.’s WindSentinel buoy-based lidar system. Additional metocean measurement equipment for characterizing the current and temperature profiles are available as well. Figure 4.6 provides a photograph of the WindSentinel and the SeaZephIR floating platform from Searoc.

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>Parameter / Purpose</th>
<th>Qty.</th>
<th>Height (m AMSL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical Air Data Systems</td>
<td>Vindicator III</td>
<td>3D wind profile</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>ZephiR Ltd.</td>
<td>ZephiR 300</td>
<td>3D Wind Profile</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>AXYS Technologies Inc.</td>
<td>TRIAXYS</td>
<td>Wave Direction</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Vector</td>
<td>A100R/K</td>
<td>Horizontal Wind Speed</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Vector</td>
<td>W200P-01/WR</td>
<td>Wind Direction</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Rotronic Instrument Corp.</td>
<td>MP101A</td>
<td>Air Temperature/Relative Humidity</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>RM Young</td>
<td>61302</td>
<td>Barometric Pressure</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>YSI</td>
<td>703</td>
<td>Water Temperature</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Skywave</td>
<td>DMR800D</td>
<td>GPS – Lat/Lon</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

Figure 4.6: (Left) AXYS Technologies WindSentinel Buoy-based Lidar, (Right) Searoc SeaZephIR

The floating lidar technology is progressing so rapidly that systems that were R&D projects a year or two ago are now advertised as proven commercial products. Following is a current list of floating lidar vendors:

15 [http://www.axystechnologies.com](http://www.axystechnologies.com)
• WindSentinel – AXYS Technologies, Inc. - [http://axystemtechnologies.com/products/windsentinel/]
• FLiDAR – FLiDAR - [http://www.flidar.com/]
• SeaZephIR – Searoc - [http://www.searoc.com/what-we-do/seazephir]
• Wind Lidar Buoy – Fraunhofer IWES - [http://www.windenergie.iwes.fraunhofer.de/]
• DeepCLidar (prototype) – University of Maine - [http://www.deepclidar.com]
• Seawatch wind lidar buoy – Fugro - [http://www.oceanor.no/newsroom/News_overview_2012/Lidar]

4.4.2 Costs
The costs associated with the acquisition and deployment of a buoy-based lidar system range between about $750,000 for the simplest systems to approximately $2.5 million. Most units fall in the $1.5 - $2.0 million range for the installed cost of an owner-operated system. Recently however, different business models have arisen for these systems that can range from a typical purchase contract, to leasing, to a data-only contract, where the vendor is obligated to provide a certain percentage of data as a service, and the client doesn’t lay hands on the system. Understanding those contract costs requires direct engagement with the vendor.

Based upon the current state of the industry, floating lidars are currently obligated to go through a validation program to establish their measurement precision relative to known references (described further below). This process is likely to incur additional costs prior to deployment of the system. The costs are sensitive to the design of the campaign and available reference resources, but are expected to be in the ballpark of $75,000 to $150,000. That range does not include possible system redeployment costs conducted as part of the validation.

The costs of floating lidar technology are relatively insensitive to water depth and other site characteristics. Almost all systems will get some site-specific design modifications, but most are not affected to the same extent that bottom-fixed structures are.

4.4.3 Benefits and Challenges
The unique characteristics, diverse physical configurations, and relative newness of floating lidar technology bring a host of benefits and challenges to its deployment for metocean site assessment. Most of the challenges are rooted in the industry’s lack of experience with the systems, resulting in a number of additional commercial and technical burdens (and risks) that are not present in other scenarios. Despite these, the conceptual benefits that motivated development and initial use of this technology – lower costs, faster deployment, and others – are beginning to manifest as concrete advantages. This section briefly highlights the key benefits and challenges of employing floating lidar.

Benefits
Comparing the concept of a buoy-based lidar to the previously described monitoring scenarios, which have been the prevailing metocean monitoring approaches, results in several potential advantages: lower price, lower permitting burden, mobility, and full metocean monitoring capabilities. The first
advantage has been realized, with system pricing in the United States being at least four to five times less expensive than a bottom-fixed met tower. As for permitting requirements, this advantage has not yet been fully demonstrated given the lack of tall tower installations. Mobility has been recognized from a purely logistical perspective during various validation exercises; however, this characteristic brings significant value to the technology itself. Being able to easily reuse and relocate a system allows for multiple measurement locations within a project area over a multi-year campaign. This capacity to address geographic variation in wind and ocean conditions is unique to this technology; it offers significant flexibility to campaign design and execution.

The ability to measure a comprehensive set of metocean parameters has been realized as well, but this depends on the system vendor and model. While most buoy-based lidar systems have broad-based monitoring capabilities, it is prudent to ensure all of the variables of interest are covered. From a data accuracy standpoint, initial validation exercises in the United States and Europe have shown that the systems can achieve data agreement with a fixed tall tower reference within 1-2%, and often better.

**Challenges**

The primary barrier with floating lidar systems is the lack of historic performance data. That scarcity of information generates a higher burden of proof for the buyer (to establish its measurement performance), and presents a risk to the purchaser since system reliability is not as well documented. The most significant of these is the obligation to validate the system’s performance. Similar to the platform-based profiling lidar scenario, a robust validation plan is strongly advised for the buoy-based lidar system. The campaign should be designed and executed based upon project-specific input from an industry measurement practitioner, and should follow relevant best practices on the topic. Currently, guidance is available from the Carbon Trust\(^\text{17}\) and is under development by the International Energy Agency (IEA). If the unit performs satisfactorily and meets its acceptance criteria, it can be moved to the offshore environment. This is a technical challenge since there are few to no validation sites available in the United States, requiring that a custom program be developed, vetted and implemented. From a commercial perspective, the costs of the campaign may be slightly burdensome, but the biggest challenge – which is hopefully mitigated by the validation work – is the acceptance of the resulting data. Experience in the United States thus far with floating lidar has been positive, but these challenges still exist.

The overall reliability of buoy-based lidar systems has yet to be fully established since the technology is relatively new and validation programs have been of short duration for those systems that have reached commercial availability. This presents the technical and commercial risk of employing one of these systems. Although many of the individual components of the systems have extensive individual track records and demonstrated good accuracy, there are few case studies available that demonstrate extended operational uptime and high data recovery offshore. In fact, power system and communication issues have caused some early concerns on system reliability. Additional development is addressing these issues, and these concerns can be partially mitigated during the validation program.

However, they will continue to be risk areas until longer availability track records are established for
commercial floating lidar systems.

4.4.4 Timeline
The time required to acquire, permit and deploy a buoy-based lidar system is estimated to be on the
order of one year. Equipment delivery is typically on the order of six to eight months, but can stretch
longer depending upon demand. Permitting is expected to proceed in parallel, but if a new system
design is being employed (i.e., one not developed around an existing buoy hull or platform),
engagement with a Certified Verification Agent (CVA) for system design acceptance may delay
permitting and deployment.

The validation program time requirements are sensitive to the design of the campaign, the weather,
and the available reference assets. The full program may require as little as three to four months, or up
to a year, depending upon the maturity of the system, its performance during the tests and the
campaign drivers described above.

4.4.5 Confidence Level
Characterizing the confidence in buoy-based lidar as the primary metocean data gathering technology
is difficult at the time of this writing. While almost all offshore wind stakeholders are cautiously
optimistic about the availability of a robust, cost-effective alternative to bottom-fixed platform
approaches, none have progressed to detailed project design or financing relying solely on data
obtained from a floating lidar. Some developers have evaluated the approach in the United
States (Fishermen’s Energy, Garden State Offshore Energy–GSOE, Dominion) and in Europe (DONG),
and it appears to be only a matter of time before full acceptance is reached. This conclusion is based
on AWS Truepower’s conversations with multiple financing entities as well as on the State of New
Jersey allowing Fishermen’s Energy and GSOE to deploy floating lidar systems in lieu of tall towers.

Floating lidar systems are anticipated to become fully bankable as long as they pass a pre-deployment
or site-specific validation program consisting of measurement comparisons against a certified reference.
The results from this program will inform the uncertainty to be assigned to the lidar system’s collected
data. Depending upon system design and site characteristics, assigned uncertainty may be functions of
wave conditions, characteristics of motion compensation, or other parameters. Initial validation results
suggest that well-designed systems may achieve similar uncertainties offshore as lidar achieves on
land. Figure 4.7 shows an example of an offshore wind speed and direction validation regression
conducted over four months between the Flidar floating lidar system and a fixed met tower. The
excellent results suggest that high confidence levels in buoy-based lidar data are attainable.
4.5 Scenario 4 – Weather Buoy
The fourth monitoring scenario is an instrumented weather buoy that is moored to the sea bottom. As a standalone monitoring device, near-surface wind speed and direction measurements from a weather buoy will not provide the representation needed to reach an acceptably accurate and bankable estimate of the hub-height wind conditions for an offshore project. Instead, the objectives of a buoy deployment would be to gather onsite data for ocean parameters and to supplement the meteorological monitoring campaign’s atmospheric measurements (using another scenario) with sea surface temperature and near-surface wind and temperature data.

4.5.1 Technical Configuration
Similar to the buoy-mounted profiling lidar scenario, the instrumented weather buoy provides a single platform from which relevant metocean parameters can be derived. There are several commercial buoy suppliers available, and buoy systems may also be obtained through university (e.g. Rutgers, University of Maine) or government sources (e.g. NOAA). The weather buoy’s basic atmospheric monitoring package should monitor wind speed and direction (typically at heights of 3 to 5 m above the water surface), air temperature, and barometric pressure. Water surface temperature should also be measured, as well as wave and current parameters through the use of a complementary acoustic doppler current profiler (ADCP) or similar package. The combined buoy system should include an on-board data acquisition and power supply plus a communication package. A Global Positioning System (GPS) input to the data stream will confirm station location and will aid in recovery in the event of drift. Advanced monitoring equipment for the buoy, such as motion correction or compensation and/or 3D wind measurement, can be considered if available and performance-vetted, but is not required.

Table 4.4 provides a breakdown of the recommended monitoring equipment for the instrumented weather buoy. Figure 4.8 depicts a typical weather buoy configuration.

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Table 4.4: Example Equipment Suite for Instrumented Weather Buoy

<table>
<thead>
<tr>
<th>Model</th>
<th>Parameter / Purpose</th>
<th>Qty.</th>
<th>Height (m AMSL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sonic Anemometer</td>
<td>Horizontal Wind Speed / Gust Wind direction</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Prop-vane Anemometer</td>
<td>Horizontal Wind Speed / Gust Wind direction</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Air Temperature Sensor</td>
<td>Air Temperature</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Pressure Sensor</td>
<td>Barometric Pressure</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Air Temperature Sensor</td>
<td>Internal Temperature</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Inertial wave sensor</td>
<td>Significant Wave Height Dominant Wave Period</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Current sensor</td>
<td>Current (u and v)</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Water Temperature Sensor</td>
<td>Temperature</td>
<td>1</td>
<td>-2</td>
</tr>
<tr>
<td>ADCP</td>
<td>Current (u and v)</td>
<td>1</td>
<td>-2</td>
</tr>
<tr>
<td>Water temperature and Conductivity</td>
<td>Temperature and Conductivity</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>Water temperature and Conductivity</td>
<td>Temperature and Conductivity</td>
<td>1</td>
<td>-6, -20, -40</td>
</tr>
<tr>
<td>GPS</td>
<td>GPS – Latitude / Longitude</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

Figure 4.8 – Image of a Weather Buoy Designed by the University of Maine

4.5.2 Costs
The total cost for the instrumented weather buoy system will range from $150,000 to $300,000 and will depend on the buoy size (3-5 m diameter) and the final choice of instrument package. Systems of various configurations are also available for short- and long-term lease.
4.5.3 Benefits and Challenges
As noted above, the weather buoy scenario would serve as the primary data-gathering station for ocean parameters within the area of interest. However, there are several other ways in which the buoy measurements can complement the meteorological monitoring campaign. For instance, a buoy deployment can serve to “jump start” the monitoring campaign, since the necessary lead time to acquire and deploy a weather buoy is expected to be significantly less than the other three scenarios described previously.

Wind observations from a weather buoy have been shown to correlate strongly with higher-elevation measurements taken by a collocated fixed offshore monitoring platform. It can therefore help to maintain a continuous onsite period of record in the event of failures with the higher-elevation meteorological monitoring equipment. Considering this potential role, if a fixed offshore platform is employed, a buoy should be located within approximately 300 m of the monitoring platform.

Overall, at a minimum, the data from the buoy system will support a project’s pre-construction energy estimates, engineering design, and installation. Depending upon the instrument package, the data may also support the environmental impact statement, wind farm operations, and/or other project development activities.

4.5.4 Timeline
The overall timeframe needed to acquire and deploy an instrumented buoy will be the lowest of the four scenarios and is likely to be on the order of 6 months. The process will entail the major steps of permitting, procurement, and deployment during a favorable weather window.

4.5.5 Confidence Level
Wind speed measurements from instrumented buoys are not considered to be bankable due to several factors, including uncertainties associated with the variable motion of the buoy system, as well as the impacts of differing wave heights on the recorded speeds. In addition, the low monitoring height necessitates the extrapolation of wind speeds over a substantial vertical distance to common turbine hub heights. As a result, the overall uncertainty in long-term hub height wind speed estimates based on buoy measurements alone is quite high.

4.6 Monitoring Scenario Uncertainties
Energy production projections for a proposed wind plant depend on the definition of the wind resource. The four monitoring scenarios described above represent different approaches to resource characterization, each containing differing degrees of uncertainty in the measurement process itself as well as in the extrapolation of the measurement results over space and time. When applying wind resource data to a simulation of wind plant production, these uncertainties need to be quantified and accounted for when energy yield results and uncertainties are derived. The energy yield estimate sets expectations on the project’s production and revenue during an evaluation period (typically 10 years), and is strongly influenced by the duration and nature of the metocean measurement campaign. Turbine suitability
assessment and facility design are other analyses that are strongly affected by metocean data. The methods employed to derive a project’s annual energy production (AEP) from metocean measurements, modeling and associated analyses are well-established, and serve as a basis for estimating the uncertainty associated with each of the contributing components.

Table 4.5 lists the elements considered when quantifying the uncertainty in wind speed and energy estimates as part of a pre-construction energy study. A description of each element is provided in the bullets below, along with the rationale behind the assumptions. The italicized categories in Table 4.5 (i.e., Measurements, Long-Term Average, Wind Shear) represent those that are most strongly affected by the unique attributes of the four monitoring scenarios; the other categories are largely independent of scenario choice.

Example values for each of the categories – reflecting average, high, and low cases for typical terrestrial projects – are provided for context. The numbers presented are in terms of resulting net energy uncertainty. While offshore project values will differ from land-based project values in several of the categories (notably in the Total Plant Losses category), the calculation methods employed are the same.

<table>
<thead>
<tr>
<th>Uncertainty Categories</th>
<th>Mean</th>
<th>High</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Documentation and Field Verification</td>
<td>0.4%</td>
<td>0.9%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Measurements</td>
<td>2.1%</td>
<td>4.2%</td>
<td>1.4%</td>
</tr>
<tr>
<td>Long-Term Average</td>
<td>2.8%</td>
<td>4.2%</td>
<td>1.8%</td>
</tr>
<tr>
<td>Evaluation Period Wind Resource</td>
<td>1.7%</td>
<td>1.7%</td>
<td>1.7%</td>
</tr>
<tr>
<td>Wind Shear</td>
<td>2.3%</td>
<td>5.6%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Wind Flow Modeling</td>
<td>3.5%</td>
<td>7.0%</td>
<td>2.1%</td>
</tr>
<tr>
<td>Wind Speed Frequency Distribution</td>
<td>1.0%</td>
<td>1.5%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Total Plant Losses</td>
<td>3.5%</td>
<td>4.8%</td>
<td>3.2%</td>
</tr>
<tr>
<td><strong>Total Energy Uncertainty</strong></td>
<td><strong>6.8%</strong></td>
<td><strong>12.0%</strong></td>
<td><strong>4.8%</strong></td>
</tr>
</tbody>
</table>

- **Site Documentation and Verification:** This uncertainty addresses the quality of the available information describing the monitoring station and equipment. The specific items considered include the details contained within commissioning/verification documents for the measurement station, the quality and quantity of photographs depicting the monitoring station and its surroundings, and the documentation of its operational history. No additional uncertainty is assigned when the site is well documented by the operator or an industry-recognized firm. It is assumed that the details of the installed monitoring equipment will be well documented in this case and independent of the selected monitoring option.

- **Wind Speed Measurements:** This is the uncertainty in anemometer and lidar-based readings of the free-stream wind speed. It reflects uncertainty in the sensitivity of the instruments (for example, anemometers performance specifications may be established for wind tunnel conditions and not fully reflective of field conditions), wave-induced motions in the case of buoy
deployments, and issues such as tower effects, precipitation and icing that may be overlooked in the data validation process.

- **Long-Term Average Speed**: This uncertainty addresses how accurately the site data, after the MCP adjustment, may represent the historical average wind resource. The estimated uncertainty accounts for the degree of correlation between the monitoring site and reference source, the length of the reference period of record, and the period of record and data recovery at the onsite monitoring station. The variability in this element for the four scenarios considered here and their respective monitoring periods is relatively small, ranging from 0.9% (weather buoy) to 1.1% (tall tower). This is primarily due to the assumption that a long-term, reliable reference source, such as the Buzzards Bay C-MAN station, will be available to perform the climate adjustment for the entire period of record for the new station.

- **Evaluation Period Wind Resource**: This uncertainty is associated with how closely the wind resource over the evaluation period may match the long-term site average. The estimated value assumes a 10-year evaluation period, 3.0% interannual variation in the mean speed, and 0.5% uncertainty associated with possible climate oscillations and trends. The 3.0% interannual wind speed variation assumption used here is based on regional long-term reference sources, including National Weather Service airport stations.

- **Wind Shear**: Wind shear is the change in wind speed with height above sea level. The wind shear uncertainty includes the uncertainty in the observed shear due to possible measurement errors and the uncertainty in the change in shear above the upper-most monitoring height. The estimated value considers the measurement uncertainties of each monitoring system, the measurements heights, and the extrapolated distance to hub height. For approaches using tall meteorological towers and profiling lidar systems, the shear uncertainty is assumed to be relatively small (<1%).

- **Wind Flow Modeling**: The uncertainty in the array-average free-stream wind speed at the turbines in an offshore project, relative to the monitoring station(s), depends on the distance of the project from land and its overall exposure (an indication of a potential gradient in wind speed across the project area), characteristics of the wind flow model, and the location of the measurement system(s) relative to the turbine layout. For this analysis, modeling uncertainties of 1.5% and 3.0% were assumed. The 1.5% value was designed to reflect the potential wind speed variation across a project area that is distant from the shoreline or any land masses, whereas the latter value may be appropriate at sites closer to land where more significant wind speed gradients are apt to be found.

- **Wind Speed Frequency Distribution**: Like the mean speed, the wind speed frequency distribution varies over time. Research conducted by AWS Truepower indicates that the interannual variability of the energy production directly related to the wind speed frequency distribution is typically about 1.4%. The estimated uncertainty in the long-term energy production estimate
considers this factor along with the onsite period of record and the length of the evaluation period.

- **Plant Losses:** AWS Truepower has used operational data to quantify the uncertainties associated with estimates for plant availability, electrical, and turbine performance losses for the evaluation period. When these values are combined with the estimated uncertainties due to environmental factors and directional curtailment (i.e., the shutdown of some turbines when wake-induced turbulence is excessive due to in-line winds), the plant operational loss uncertainty is estimated to be approximately 3.5%. In addition, based on internal wake model validation studies, AWS Truepower has estimated the uncertainty in the wake loss calculations to be 20% of the total wake loss. The operational and wake loss uncertainties are combined to yield the overall plant loss uncertainty. Given that wake losses for offshore wind plants will generally be higher than their land-based counterparts, the uncertainty in plant losses for offshore projects will be above the typical range found for land-based projects.

The project development timeline employed for these analyses assumes a monitoring program window of approximately four years prior to project financing. Thus, accounting for the estimated lead time for equipment deployment, about 3.5 years of data could be collected on a weather buoy, but only two years on a tall tower. Values and ranges were developed for each uncertainty parameter to estimate the total energy uncertainty resulting from each of the four monitoring scenarios. For example, the uncertainty associated with wind speed measurements on a custom built tall tower were assumed to be between 1.5% and 2.5%, while those on an 4 m instrumented buoy were assumed to range from 4% to 6%. Uncertainty parameters that are less sensitive to measurement campaign design were assigned constant values representative of commercial offshore projects. The uncertainties associated with wind speeds were converted to energy values with a constant energy-to-velocity ratio of 1.4.

The four scenarios represent a broad range of anticipated monitoring costs, deployment schedules and resulting uncertainties, as summarized in Table 4.6. The costs reflect the design, equipment, construction, and deployment assumptions for each scenario. The uncertainty ranges for net energy are based upon representative assumptions for projects within the WEAs. Actual values will, of course, be sensitive to exact site conditions, project configurations, and monitoring campaign results.
Table 4.6: Candidate Monitoring Scenario Cost and Energy Uncertainty Summary

<table>
<thead>
<tr>
<th>Monitoring Scenario</th>
<th>Primary Equipment</th>
<th>Lead Time to Deployment</th>
<th>Cost Range</th>
<th>Net Energy Uncertainty (% Energy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Offshore Hub-Height Tower</td>
<td>Hub-height tower; metocean sensor suite; mounting equipment &amp; instrument booms</td>
<td>24 months</td>
<td>$8-12 million</td>
<td>5.6%-7.3%</td>
</tr>
<tr>
<td>2 Platform-based Profiling Lidar</td>
<td>Platform-based metocean monitoring equipment package, including profiling lidar</td>
<td>18 months</td>
<td>$4-8 million</td>
<td>5.7%-7.3%</td>
</tr>
<tr>
<td>3 Buoy-Based Profiling Lidar</td>
<td>Buoy-mounted profiling lidar system; metocean monitoring equipment</td>
<td>12 months</td>
<td>$0.75-2.5 million</td>
<td>6.4%-8.1%</td>
</tr>
<tr>
<td>4 Weather Buoy</td>
<td>Metocean monitoring equipment</td>
<td>6 months</td>
<td>$150-300 thousand</td>
<td>11.8%-13.8%</td>
</tr>
</tbody>
</table>

Summary

Despite its attractive cost, the weather buoy is not considered to be a viable option as a standalone monitoring system for an offshore measurement campaign due to the substantial inherent uncertainties in characterizing the hub height wind conditions. While the data collected by such a system adds significant value to other related analyses (such as project design), developing a wind resource assessment and energy yield estimate solely from that platform is unlikely to be financed. However, a weather buoy can serve to initiate or to supplement a staged wind resource assessment program by providing metocean data that will help inform a project’s engineering design and later be supplemented with additional measurements of the wind profile (by a tower or buoy-based lidar deployed later, for example). It can also provide valuable long-term and metocean validation data for a region.

The estimated energy uncertainty associated with a buoy-based lidar system is substantially lower than that of the weather buoy, and its cost is significantly lower than the tall tower and platform-based options. However, due to limited experience and performance data, this technology is currently subject to extensive validation requirements prior to deployment. These validation efforts are anticipated to support bankability in the long-term and lower the acceptance risk of the data. Depending upon the system considered, use of this technology may also carry additional operational risks that are not easily quantified. Several offshore wind developers in Europe and the United States have already committed to using buoy-based lidar for current and future projects, so the library of performance and acceptance information on these systems is expected to grow rapidly.
The platform-based tall tower and platform-based lidar (scenarios 1 and 2) are anticipated to result in the highest confidence wind resource data sets. The direct, hub height measurements on a tall tower offer clear advantages, although the effects of the tower on the measured winds should be understood and corrected for. To date, tall tower measurements have been the predominant means of data collection in Europe, upon which most existing offshore projects have been financed and built. The platform-based lidar scenario is expected to provide a viable alternative to the tall tower; however, its anticipated cost savings and accelerated deployment timeline are fairly sensitive to site conditions and platform configuration.

In summary, three of the four monitoring scenarios presented are anticipated to support financeable energy yield estimates when combined with appropriate modeling and analysis methodologies. The buoy-based lidar approach has the highest wind resource data value relative to cost, but also carries additional operational and acceptance risk.

4.7 Supplemental Metocean Characterization Approaches

Additional measurement and modeling approaches can provide supplemental data to advance offshore wind development in the WEAs. These approaches are potential alternatives to the previously described monitoring scenarios, or they can just as easily be complementary. Three approaches are described here: enhancing existing offshore monitoring stations in the region with wind energy-specific equipment, wind-wave time series modeling, and regional data analyses.

Existing Station Improvement

Existing offshore platforms are obvious candidates as suppliers of metocean measurements in the vicinity of the WEAs. These stations are also attractive because they can potentially be retrofitted with tailored measurement systems at a lower cost than installing a completely new platform. They may have lower operating costs as well due to shared maintenance obligations with the current owners. The two platforms of interest (mentioned earlier in this report and shown in Figure 2.1) are:

- Buzzards Bay C-MAN Station – operated by the US Coast Guard and hosting equipment from NOAA and others. Its sister station, Ambrose Light (located outside of New York Harbor), was successfully leveraged for a year of enhanced offshore wind-related metocean measurements in 2005-2006 by a project led by AWS Truepower.

- Woods Hole Oceanographic Institution (WHOI) Air-Sea Interaction Tower (ASIT) – owned and operated by WHOI with the objectives that align closely with offshore wind’s metocean monitoring goals.

Supplementing one or both of these stations with enhanced measurement equipment, such as a profiling lidar, additional anemometry, and supplemental ocean monitoring equipment would provide an additional source of important metocean data while reinforcing the primary functions of the existing station. While the observations collected at these stations would not likely be the sole sources
of bankable data for the WEA
tis, they would reinforce onsite data collection efforts within the wind areas.
If operated for several years, these stations would provide enhanced climatological value and have
greater value as regional reference stations. Further, the newly data collected, if made public
in a timely and accessible fashion, could benefit a large number of existing water users and promote
public outreach for offshore wind.

Both of the station operators identified above have previously expressed (via communications with
AWS Truepower) a willingness to consider hosting additional equipment for offshore wind data
collection. Costs associated with this work are dependent upon the suite of instrumentation selected
and the commercial arrangement made with the station owner (e.g. lease costs, maintenance
obligations, etc.). The equipment costs are expected to range anywhere from $250,000 to $500,000
per station, which is relatively modest compared to establishing completely new measurement
stations. Given the relatively accommodating physical arrangement of the stations, the lead times to
deployment are expected to be on the order of about six to nine months, depending upon the
responsiveness of the platform owners.

Wind-Wave Time Series Modeling
Some of the challenges associated with the scarcity of high-quality metocean data across the wind
ergy areas can be partially mitigated through high-resolution atmospheric and wave modeling.
Development and validation of historical wind and wave time series with high spatial and temporal
resolution can add significant value to preconstruction analyses. For example, the modeled wind
information can provide characterizations of key parameters such as hub height wind speed and
direction, density, turbulence intensity, shear, and others. The wave modeling can provide higher
resolution information than other available public models and would facilitate characterization of joint
wind-wave and hydrodynamic design parameters.

The results of this type of work – a large public data set of high-resolution modeled historical conditions
would improve site assessments prior to the deployment of any new measurements. If new
measurements are deployed in the WEA
tis, the models could be updated and validated further with the
observations within the WEA
tis. The costs for this work, estimated to range between $50K and $150K, will
depend upon the size of the area selected and by the types and number of analyses required. Completion
times for this work are estimated to be 4 months or less.

Regional Data Analyses
Using modeling techniques, an array of new and existing observations from discrete locations can be
integrated to create regional analyses of key parameters of interest. Essentially any analysis can be
rendered in the form of maps, databases and other formats for desired time and space scales (or
resolutions). Regional analysis products aim to leverage valuable information from finite sites and project it
across adjacent and intervening areas using proven simulation tools such as numerical weather prediction
models. New data observations provide inputs or validation sources for models that were previously
unavailable and therefore should enable more realistic and accurate simulations. Examples of regional data
analysis products are:
• Annual and seasonal wind resource and capacity factor maps and gridded data bases for representative wind turbine models and hub heights
• Time-series (e.g. 8760 hour typical meteorological year) of coincident wind, wave and current conditions
• Extreme wind and wave values, probabilities and return periods
• A summary of atmospheric, ocean and coupled wind-wave design inputs as defined by relevant standards.

Such products benefit multiple stakeholders by translating observational data into useful formats relevant to offshore wind energy planning. For example, a summary of average and extreme wind conditions at representative hub heights will help qualify turbine technologies for suitability within the WEAs. Every analysis should be qualified with a definition of accuracy and uncertainty. The costs to perform analyses like those described above are on the order of $10K to $50K each.
5. STAKEHOLDERS AND PARTNERSHIP OPPORTUNITIES

5.1 Introduction

This section describes the interests of multiple types of offshore wind stakeholders in metocean information and identifies potential collaborative opportunities to develop and deploy metocean data collection equipment in the WEAs.

5.2 Commercial Offshore Wind Industry

The commercial offshore wind industry is comprised of private sector entities and trade organizations that represent their interests in the policy, regulatory, and standards setting arenas. The following descriptions provide a high-level summary of their roles and metocean data uses.

5.2.1 Trade Groups

The American Wind Energy Association (AWEA) – www.AWEA.org – is the national trade association for virtually all US wind development. The membership is open to all stakeholders, including international firms and organizations that are interested in participating in the emerging US market. AWEA supports offshore wind through a number of activities, reporting efforts, a dedicated working group, and an annual conference and trade show. AWEA also serves as a standards and best-practices body, and has addressed several aspects of offshore wind development and compliance. While AWEA does not get directly involved in measurement efforts and technical studies, it does offer networking and coordination opportunities through access to its broad membership. It can also rally support for state and regional initiatives.

The now defunct US Offshore Wind Collaborative (USOWC) – www.usoffshorewind.org – was an advocacy and research nonprofit with the goal of “catalyzing the American offshore wind energy market through partnerships, analysis, and new ways of thinking about challenges and solutions.”19 The MassCEC was one of the funding partners. Some efforts of the USOWC addressed metocean data, including published reports and the offshore wind hub20.

5.2.2 Developers and Operators

Project developers are among the first stakeholders—and the most vested—in the offshore development process. They allocate speculative capital towards early stage project investigations such as siting, conceptual feasibility studies, and participation in BOEM auctions to secure lease blocks within designated WEAs. They are also responsible for subsequent activities leading to project design, regulatory approval, financing, energy offtake agreements, construction and commissioning. Consequently they are the primary users of metocean data. They are also the largest investor in metocean data procurement, entailing wind and ocean environmental monitoring, modeling and analysis, and bathymetric and geotechnical studies.

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19 http://usoffshorewind.org/about/
20 www.offshorewindhub.org
Metocean data collection led and financed by private sector developers usually results in limited public access to the data. This is because the investment is sizeable, and commercial competitive interests are in play. Because the WEAs are largely contiguous and already leased, there may be increased incentive for developers to collaborate in or coordinate their metocean data collection activities.

The developers engaged in projects in the WEAs are:

- **Deepwater Wind** – [www.dwwind.com](http://www.dwwind.com) – Deepwater won development rights to the Rhode Island/Massachusetts WEA, and has experience with metocean monitoring through their Block Island and New Jersey efforts. They have also demonstrated willingness to collaborate on measurement programs with universities and other regional stakeholders.

- **RES Americas** – [www.res-americas.com](http://www.res-americas.com) – RES is an experienced land-based wind and solar developer and is expected to leverage its European offshore experience to support development efforts in Massachusetts. RES won lease rights to develop lease area OCS-A 0500. The lease rights were subsequently assigned to DONG Energy with the approval of BOEM in June 2015.

- **DONG Energy** – [www.dongenergy.com](http://www.dongenergy.com) – DONG is the largest offshore wind developer and operator in Europe. They assumed full rights to lease area OCS-A 0500 from RES Americas, who is expected to participate in a support role. DONG has expressed willingness to participate in cooperative offshore industry research and measurement.

- **Offshore MW** – [www.offshoremwllc.com](http://www.offshoremwllc.com) – This firm is a US developer that won lease rights to develop Massachusetts lease area OCS-A 0501.

### 5.2.3 Consultancies

Consultancies are private firms that offer specialized services and expertise in various technical disciplines. For metocean-related applications, they are commonly hired by developers and other stakeholders to provide advice, design services, field studies, and analysis. Through their cumulative involvement in other projects with other stakeholders, they can be a rich source of experience and know-how. Consultancies also tend to be active participants in establishing industry best practices and standards.

In addition to providing original work, consultants are also used to conduct independent reviews, or opinions, of work that has been completed by another party. This third-party role helps in identifying biases, challenging assumptions, and assessing project risks and uncertainties. Consultants will also recommend data collection and analysis approaches that meet prescribed standards and specifications as well as targeted accuracies and uncertainties desired by other stakeholders, such as regulators and insurance providers. The term “bankable” is commonly used to refer to work products that meet the highest standards and expectations of investors and lenders. These stakeholders tend to rely on a fairly narrow list of the most experienced and vetted consultancies.

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To date, the common practice in US offshore wind development is for consultants to work on behalf of developers or government bodies to recommend and/or lead most aspects of metocean monitoring campaign design, implementation, operations, and analysis. These efforts, as well as funded metocean research projects by multi-stakeholder teams of universities, agencies, utilities, and other partners, have typically relied on the strong participation of consultancies. As such, consulting firms are one of the most influential groups of stakeholders in metocean monitoring and analysis.

5.2.4 Financial and Insurance Entities

Equity investors and debt lenders are principal financers of offshore wind projects. When evaluating a potential investment, financiers scrutinize all technical aspects of the project’s design environment, engineering analyses, and technology configurations to fully assess risks and economic return. Conformance to applicable industry standards, best practices, and established regulations must be demonstrated and documented for every component of a project. This conformance includes the quantification of accuracies and uncertainties of the input and output parameters of all analyses. This review work is usually carried out with the support of an experienced, independent third party (consultant or independent engineer). A few examples of important metocean-related risk factors include:

- The probabilities of extreme wind and wave events that could damage project components, impair operations, and shorten component lifetimes. Project designs are evaluated for how well they address anticipated environmental conditions and incorporate margins of error and safety.
- The predictability of sea-state conditions to determine suitable weather windows for project construction and maintenance. Unexpected site access delays can drive up construction costs and reduce generation during operations due to longer maintenance response times.
- Under generation due to inaccurate assessments of the wind resource, wake effects, blade icing, and lightning.

Insurance providers will underwrite products and set premiums according to similar risk factors. Without sufficient confidence in these risk factors, insurance coverage may be limited, cost prohibitive, or unavailable.

5.2.5 Engineering, Procurement and Construction

An engineering, procurement and construction (EPC) firm is retained to provide the detailed engineering design of an offshore wind project, plus the procurement and construction of equipment and related materials. As such, comprehensive metocean data are essential for designing all project components for reliable service within the metocean environment of the designated site. In addition, EPC firms normally assume the risk for the project’s construction schedule and budget, both of which can be impacted by foul weather and rough seas. Foreknowledge of the frequency, severity, and seasonal dependence of these conditions is therefore critical to their mission. This information is also instrumental in logistical planning, such as vessel transport and on-site construction, and the selection of appropriate construction vessels and lifting equipment.
5.2.6 Original Equipment Manufacturers

Original equipment manufacturers (OEMs) are the suppliers of offshore turbines and key balance of plant components such as foundations, substations, and subsea cable. Like all large-scale wind turbines, offshore wind turbines are IEC type classified for specific operating environments, which are defined by multiple metocean parameters. These parameters include mean wind speed and speed frequency distribution, air density, turbulence intensity, wind shear, and extreme wind events. These and other metocean conditions also influence the selection of turbine control settings, equipment enhancements (such as cold weather packages), and warranty provisions. Consequently, accurate on-site characterization of metocean conditions is essential to proper equipment selection and design. This is also true for the balance of plant components, which are strongly influenced by the wave, current, and scouring conditions.

5.3 Government Entities

Government entities at the state and federal levels have roles in the establishment and enforcement of regulations to ensure the safe and compliant development and operation of offshore wind farms. These entities have a vested interest in the accurate characterization of, and public dissemination of information concerning, metocean conditions and their influence on design and safety factors.

Government entities can also establish policies that impact energy markets, and provide support for research and other fact-finding activities targeted to address information gaps, as exists with metocean characterization. Joint funding of research and data gathering from multiple government entities is possible where mutual benefits are likely to exist. The following subsections identify state and federal entities that could be considered as potential partners for metocean investigations within the WEAs.

5.3.1 States

Several Massachusetts and neighboring state-level organizations have conducted work in offshore wind and may be candidate partners for regional metocean monitoring exercises. Following is a summary of leading organizations:

**Massachusetts Clean Energy Center (MassCEC)**

The MassCEC (www.masscec.com) is a publicly-funded agency dedicated to accelerating the success of clean energy technologies, companies and projects in the Commonwealth—while creating high-quality jobs and long-term economic growth for the people of Massachusetts. MassCEC accelerates the growth of the Massachusetts clean energy industry through its three divisions. The Renewable Energy Generation Division provides financing and planning assistance to communities, businesses and residents seeking to adopt clean energy projects including solar, wind, biomass, water and organics-to-energy technologies. The Industry and Innovation Support Division works with clean energy businesses to grow their operations, provide training and workforce development, develop industry reports and sector analysis, and acts as a connector across the clean energy ecosystem from academia and incubators to entrepreneurs and investors. The Investments in Clean Technology Division provides strategic and early-stage investments growing clean energy companies in order to promote the development of innovative technologies, leverage private capital and create jobs in the Commonwealth.
**New York State Energy Research and Development Authority (NYSERDA)**

NYSERDA ([www.nyserda.ny.gov](http://www.nyserda.ny.gov)) has supported offshore wind and metocean characterization efforts for the past decade. Its efforts have resulted in desktop analyses and field campaigns that have assessed metocean conditions in New York’s marine and fresh water (Great Lakes) environments. Collaborative in-state entities have included the New York Power Authority and the Long Island Power Authority, both of which are potential offtakers of electricity from offshore wind projects in the state’s vicinity. Given this history, and the proximity of New York to the Rhode Island and Massachusetts WEAs, collaboration to develop a regional metocean characterization initiative, or something similar, may be feasible.

**Rhode Island Office of Energy Resources**

The Office of Energy Resources ([www.energy.ri.gov/renewable/](http://www.energy.ri.gov/renewable/)) has a number of renewables-related programs and incentives. It managed significant state investments in offshore wind development over the last several years, the most significant work being the Oceanic Special Area Management Plan (SAMP) carried out by the Coastal Resources Management Commission (CRMC) and the University of Rhode Island (URI). That program included approximately one year’s worth of metocean measurements from two buoys in Rhode Island waters. Based upon that precedent and the shared Massachusetts and Rhode Island WEA, these entities are potential collaborative partners for future work.

**Maine Technology Institute (MTI)**

The MTI ([www.mainetecnology.org](http://www.mainetecnology.org)) is “an industry-led, publicly-funded, nonprofit corporation that offers early-stage capital and commercialization assistance...for the research, development and application of technologies that create new products, processes and services, generating high-quality jobs across Maine.” While Maine’s and Massachusetts’ area of mutual interest – the Gulf of Maine – doesn’t currently have any BOEM-designated WEAs, the MTI has sponsored technology development that may be of direct interest to MassCEC. Specifically, their efforts have supported development of a buoy-based lidar system by the University of Maine. This work may warrant discussions with both MTI and the University of Maine.

**Clean Energy States Alliance (CESA)**

The CESA ([www.cesa.org](http://www.cesa.org)) has a charter to promote clean energy technologies and markets through a number of mechanisms, including partnership development and joint projects. Its membership includes energy and environmental agencies representing all of New England, New York, New Jersey, and other states, as well as public utility commissions. One of CESA’s initiatives has been the Offshore Wind Accelerator Project (OWAP), which supports cooperation and leadership among public and private sector stakeholders to advance responsible offshore wind development. The CESA may be a mechanism through which the MassCEC may be able to engage fellow members to address metocean-related barriers.

**5.3.2 Federal**

Many federal agencies have regulatory roles in the development and operations of offshore wind projects. From a permitting perspective, the role of lead regulator for new projects is either
handled by the United States Army Corps of Engineers (USACE) for projects in state waters, or the US Department of Interior’s (DOI) Bureau of Ocean Energy Management in federal waters. From construction through decommissioning, the DOI’s Bureau of Safety and Environmental Enforcement (BSEE) plays a regulatory and enforcement role. Other federal agencies having regulatory and permitting roles include the Occupational Safety and Health Administration (OSHA), Federal Aviation Administration (FAA), and the National Oceanic and Atmospheric Administration (NOAA). Each agency is responsible for protecting the public interest and, as such, will benefit from metocean information that increases the safety and robust design and operation of offshore wind farms.

From a research, technology advancement, and economic development perspective, a number of Federal entities have active roles in offshore wind generally, and metocean measurement specifically. The most relevant of these entities are described below.

**US Department of Energy**

The US Department of Energy (DOE, [www.energy.gov](http://www.energy.gov)) has been the most active federal agency supporting research and development for the advancement of offshore wind energy. Over the past several years, DOE has funded several metocean-related studies to promote model development and validation, lidar verification, and limited field investigations. They acknowledge the barrier on offshore wind development posed by the lack of quality metocean data. Steps towards remedying this situation have been taken to assess the national metocean data needs and gaps of this industry (see [www.usmodcore.com](http://www.usmodcore.com)). The DOE has also investigated the potential development of a national offshore metocean measurement and research facility at the former Chesapeake Light Station off the coast of Virginia. The DOE remains very interested in addressing metocean issues and is probably the best federal candidate for pursuing a joint initiative that could realize both regional and national benefits.

**Bureau of Ocean Energy Management**

BOEM ([http://www.boem.gov/](http://www.boem.gov/)) is the primary body that grants WEA leases, easements, and rights-of-way for renewable energy development activities on the Outer Continental Shelf (OCS). BOEM’s Renewable Energy Program is in charge of mandating safety, environmental protection, local, federal, and state coordination, OCS land use, and state revenue sharing. BOEM’s offshore wind activities include technical and environmental studies of metocean conditions and standards development to provide guidance to industry on the most appropriate data collection and processing. BOEM’s sister agency, the Bureau of Safety and Environmental Enforcement (BSEE), is responsible for the enforcement of safety and environmental regulations.

### 5.4 Universities and Research Institutions

Government labs and academic research institutes are the primary leaders of public research and development initiatives. Research for offshore wind projects is being conducted in all areas such as, environmental, engineering, and design to promote offshore development and overcome barriers.
5.4.1 Universities
Several regional universities are active in offshore wind research, including metocean monitoring and analysis. While universities typically require external funding to support research, they often provide matching funds internally or from grants obtained from scientific organizations such as the National Science Foundation (NSF). Universities, of course, are also centers of knowledge and learning that are tailored to advance the metocean sciences. Many are equipped with marine research facilities and vessels that could support a regional metocean measurement campaign. Listed below are Massachusetts universities and educational institutions that have been active in wind energy research and education.

- University of Massachusetts – Amherst (www.umass.edu)
  - https://windenergyigert.umass.edu/
  - http://www.umass.edu/windenergy/
- University of Massachusetts – Dartmouth (www.umassd.edu)
- University of Massachusetts Lowell (https://www.uml.edu/Research/centers/Wind-Energy/default.aspx)
- Cape Cod Community College
- Bristol Community College
- Massachusetts Institute of Technology (www.mit.edu)
- Tufts University
- Northeastern University (http://www.northeastern.edu/atm/offshore-wind-turbines/)
- Woods Hole Oceanographic Institution (www.whoi.edu)

Universities in neighboring states that have been active in wind energy research and education include:

- University of Maine (http://gyre.umeoce.maine.edu/)
  - https://composites.umaine.edu/
- University of New Hampshire (http://marine.unh.edu/)
- University of Rhode Island (www.uri.edu)
- University of Connecticut (http://www.mariesciences.uconn.edu/)
- State University of New York at Stony Brook (www.stonybrook.edu)

5.4.2 National Laboratories
Several US national laboratories have renewable energy skill sets in offshore wind, including metocean monitoring and analysis capabilities. These labs are largely funded by federal sources (such as the DOE and Department of Defense) but they also actively partner with other funding sources to provide services. The two most active labs in offshore wind energy are the National Renewable Energy Laboratory (NREL; www.nrel.gov) and the Pacific Northwest National Lab (PNNL; www.pnnl.gov). With DOE funds, PNNL recently acquired two buoy-mounted profiling lidars. One has been deployed off the
coast of Virginia and the other was to have been deployed off of Oregon. Collaborative measurement opportunities and use of one of these lidars to evaluate the WEAs may be possible and should be explored. There would also be value in proposing a regional coastal or offshore facility, such as the Buzzards Bay CMAN station or the WHOI ASIT station on Martha’s Vineyard, to validate a floating lidar. This capability does not yet exist in the United States. It is recommended that this concept be first explored with the DOE.

5.4.3 National Science Foundation
The National Science Foundation (www.nsf.gov) is an independent federal agency whose goals are discovery, learning, research infrastructure, and stewardship. The NSF is the major source of federal funding for scientific research in America’s colleges, universities, and other research centers. The NSF issues approximately 10,000 new grants per year, with an average duration of three years. The NSF has recently awarded grants to the UMass Integrative Graduate Education and Research Traineeship Program (IGERT) Offshore Wind Energy Program, along with numerous other wind technology and offshore research programs. If the NSF’s and MassCEC’s metocean monitoring and offshore wind goals align, there may be a potential opportunity to develop a jointly sponsored multi-year monitoring campaign.

5.4.4 National Oceanic and Atmospheric Administration
NOAA (www.noaa.gov) is a federal agency whose primary activities involve daily weather forecasts, severe storm warnings, climate monitoring, fishery management, coastal restoration, and supporting marine commerce. The National Data Buoy Center, which is responsible for an extensive network of offshore weather buoys and other monitoring stations, resides within NOAA. NOAA is currently working with New York State officials to compile and interpret existing ecological information for offshore renewable energy planning. Most recently NOAA has released a study titled “A Biogeographic Assessment of Seabirds, Deep Sea Corals and Ocean Habitats of the New York Bight” as an aid to help identify wind energy development sites in the Atlantic that protect both bird and fish habitats.

5.4.5 Integrated Ocean Observing System
The US Integrated Ocean Observing System (IOOS; www.ioos.noaa.gov) is a largely federally funded national-regional network of associations for conducting coastal and marine measurements, forecasting, and studies for tracking and predicting changes in the ocean, coastal, and Great Lake environments. IOOS provides access to and collects data from high frequency radars, buoys, gilders, and numerous other observing systems to create a database of physical, chemical and biological observations. One of its regional affiliates, the Northeast Regional Association of Coastal and Ocean Observing Systems (NERACOOS; www.neracoos.org), represents the New England region. The IOOS stores all of its collected data in a data management and communication system which is capable of delivering real-time and historical data, as well as model-generated outputs and forecasts. IOOS and its member organizations are a potential collaborator for an offshore wind metocean campaign and have existing data management capabilities through which new data could be made publicly available.
5.5 Electric Utilities and Grid Operators
Grid-related stakeholders include investor-owned utilities, public utilities and authorities, and independent system operators (ISOs). ISO New England operates the high-voltage transmission system and oversees the wholesale electricity market for New England. It also is responsible for long-term planning for the region’s future electricity needs. During the planning stages of a wind project, it is important that system operators examine the capability of the grid to accept this production while also managing the system to serve the required load. The ability of the grid to respond to fluctuations in production and load will determine the required system upgrades and constraints placed on the wind project. The operators’ primary interests in metocean conditions are the wind project’s generation characteristics, which are driven by site conditions. Accurate information is required about variations in sub-hourly, hourly, monthly, and seasonal production to assess the potential impacts.
6. CONCLUSIONS AND RECOMMENDATIONS

This assessment of current knowledge and data gaps regarding the metocean environment within the WEAs is intended to assist the MassCEC in evaluating potential data collection strategies and partnerships that would mitigate barriers to offshore wind energy development. Four topic areas were examined: the existing data resources in the region, the key data needs for offshore wind development, measurement campaign approaches designed to address data gaps, and key stakeholders and partnership opportunities.

High-level regional data currently available from multiple sources provides a baseline of information about the general wind and ocean conditions surrounding and within the WEAs. Wind resource mapping studies conducted previously by AWS Truepower indicate that annual wind speeds exceed 9.25 m/s at 100 m above the sea surface across the areas. No additional data sources were identified through this effort to mitigate the observed gaps in metocean data required for offshore wind development. However, there is a number of regional coastal and offshore reference stations that could be of high value for correlation purposes when new measurements are taken within the WEAs. Furthermore, there is a rich pool of marine and wind energy expertise residing within Massachusetts and adjacent states. This expertise is capable of designing and executing a field measurement program as well as conducting world-class modeling and research analyses.

IEC standards and other guidance documentation define the key data parameters used in designing offshore wind projects for the local physical environment. At a minimum, the atmospheric parameters that should be measured are hub-height wind speed and direction, wind shear, turbulence intensity, air temperature, and air density. Key ocean parameters include wave height and direction, wave period, water temperature and density. Information on currents throughout the water column, wave speed, and water conductivity and salinity is also desired. While developers will eventually need to address all parameters as part of the project development process, an initial field campaign can provide invaluable insight into the magnitude and variability of the wind resource and sea-state conditions while also validating the feasibility of innovative measurement and modeling approaches. These efforts would provide earlier metocean data to guide the expectations of multiple stakeholders and improve the value of future, developer-led measurements.

This report has argued that new metocean measurements are essential to adequately addressing the gaps in data required for offshore wind development. It can be challenging for developers to exclusively assume responsibility for designing, permitting and implementing an offshore measurement campaign, which is currently the case across most of the United States. Furthermore, developer needs may not fully overlap the interests of other scientific partners for metocean data. The four measurement scenarios presented in this report enable a broad range of stakeholders to make a more informed decision on what monitoring approach may best serve their goals and the development of offshore wind in the Commonwealth.
The underlying goal of new measurements is to reduce project development risks and accelerate offshore wind energy development timeframes through improved documentation of WEA metocean conditions. AWS Truepower recommends that three measurement approaches be considered by the MassCEC to provide high-value information for the offshore wind industry at reasonable costs:

1. Acquire, deploy and operate a buoy-based profiling lidar in the WEAs;
2. Acquire, deploy and operate a weather buoy within the WEAs;
3. Enhance the measurements at the Buzzards Bay and/or WHOI ASIT stations.

While these are prioritized, they are not necessarily mutually exclusive. Each approach will produce tangible results towards the stated goals. Furthermore, we note that other stakeholders may have metocean data needs and interests that might not be fully met by the above approaches. The specific merits and justifications in these recommendations are described below.

The floating profiling lidar option presents a number of advantages that are expected to support industry development on a regional and national scale. First, it provides the most cost-effective path to generating finance-quality data directly within the WEAs. Strategically deploying and operating this option at one or more locations in the WEAs for at least a year will significantly improve the understanding and documentation of the relevant metocean conditions. Second, the testing and validation of the floating lidar will help establish or reinforce a national trend to adopt best practices for this innovative technology. Thoughtful, rigorous use of this technology and publication of the results will help advance its acceptance nationwide and add to the library of performance and reliability information.

The deployment of a weather buoy within the WEAs is the second priority option. While it would not generate financeable wind resource data alone, it will bring significant value in initiating the period of record for detailed metocean parameters within for the WEAs. The surface and ocean profile information it collects would serve as key inputs to other regional development efforts. The buoys deployed by the Rhode Island SAMP demonstrated that one year of quality data is valuable to multiple pre-construction tasks; additional years of data only serve to further increase the significance.

Finally, deploying enhanced instrumentation on an established offshore platform (such as the Buzzards Bay C-MAN Station and the Woods Hole Air-Sea Interaction Tower) would serve useful purposes for a relatively modest investment. First, adding a profiling lidar and industry-standard metocean equipment will substantially enhance the value of the metocean data collected at either station. The new metocean data would be helpful in and of itself, but with sufficient observation time, relationships with existing sensors may be developed to improve the value of historical data too. Second, these offshore platforms could be developed as reference stations for floating lidar validation. The DOE’s previous attempts to develop Chesapeake Light into a national offshore wind reference station have not materialized. As such, there are existing and future floating lidar platforms that would greatly benefit from validating against an offshore reference platform. The improvement of an existing offshore platform would represent both a valuable regional and national asset.
The key beneficiary of metocean assessment studies would be the winning developers (Deepwater Wind, RES Americas/DONG, Offshore MW) for the committed WEAs, particularly if the studies begin in advance of their own field investigations. These assessment efforts could provide early technical feedback to influence and optimize the field programs carried out by the developers. It may be several years before some developers initiate their field studies, so it would be advantageous to collaborate in advance to explore potential synergies and productive linkages with each other’s campaigns. These efforts will also have ancillary long-term benefits by improving the characterization of the currently unleased portions of the MAWEA.

The availability of publicly shared metocean information will benefit other stakeholders and may likely result in enhanced insights into offshore wind’s economic and grid-related attributes. For example, OEMs need to assess turbine suitability and warranty provisions for the Massachusetts market. With new metocean information, they could preemptively consider tailoring their turbine models or control schemes to the Massachusetts offshore wind regime. Another example, with access to new offshore-specific data, grid operators, utilities, and policy makers will be able to quantitatively assess the load matching qualities and impacts of future offshore wind on electric and natural gas supplies and prices. Further, the new offshore data will likely catalyze research activities by the region’s universities that could lead to advancements in ocean and atmospheric modeling, the marine environmental sciences, and energy policy and analysis.

Multiple offshore wind stakeholders with a likely interest to collaboratively advance future measurement and assessment efforts have been identified, including current leaseholders, some of which have already collaborated with outside groups on offshore measurement in other projects. State and federal entities comprise another set of candidates, particularly those with active offshore wind interests. At the state level, viable candidates include CESA members who represent neighboring states, specifically NYSERDA, MTI, and the RI Office of Energy Resources. State-affiliated utilities such as NYPA and LIPA, and investor-owned utilities such as National Grid, constitute potential offtakers of wind generation.

At the Federal level, the DOE is the clearest choice to explore as a potential partner. They have a demonstrated track record of supporting metocean measurement and modeling campaigns in support of offshore wind. In addition to the DOE, BOEM should also be considered as a potential partner and collaborator. They have a vested interest in generating more quality metocean data nationally, and new measurements or modeling in Massachusetts data is likely to support future bids on the uncommitted WEAs.
APPENDIX: METOCEAN DATA INVENTORY

FEDERAL GOVERNMENT

DEPARTMENT OF COMMERCE

National Oceanic & Atmospheric Administration (NOAA)

Climate Forecast System, Climate Prediction Center
Data products include current and archived seasonal climate anomalies from the NCEP coupled forecast system model (CFS) versions 1 and 2. Link: http://cfs.ncep.noaa.gov/

Comprehensive Large Array-Data Stewardship System (CLASS)
CLASS is NOAA's premiere on-line facility for the distribution of NOAA and US Department of Defense (DoD) Polar-orbiting Operational Environmental Satellite (POES) data, NOAA's Geostationary Operational Environmental Satellite (GOES) data, and derived data. Link: http://www.class.ngdc.noaa.gov/saa/products/welcome

Coastal and Marine Spatial Planning
The purpose of this website is to provide users with coastal and marine spatial planning information related to national level policies, and to advance the implementation of this data in real-world settings. The CMSP project website provides access to many data sources where coastal and marine spatial planning information can be found. Link: http://www.msp.noaa.gov/data-tools/index.html

Digital Coast, Coastal Services Center
Digital Coast is a clearinghouse website for geospatial data related to the coastal environment and its natural resources. The content here is contributed by various federal, state, county, nongovernmental, private and academic organizations. Digital Coast provides access to data types such as: benthic, bathymetric, georegulatory, hydrographic, and topographic. Many online mapping tools from public and private sources are also made available through this website.

Comments: Of note is the Digital Coast Offshore Renewable Energy Planning section, which provides a variety of tools and information useful for those involved in finding the best location for offshore renewable energy projects. Link: http://www.csc.noaa.gov/digitalcoast/

Earth System Research Laboratory (ESRL)
ESRL supports the deployment and operation of environmental observatories and observational networks to provide high-resolution datasets for analysis. These data provide a critical, long-term history of the Earth system necessary for the assessment of global trends. ESRL also operates observational networks to improve our understanding of regional weather, water and climate processes, and to advance the development of new sensor techniques. ESRL conducts and participates in field programs which allow researchers to intensively study an aspect of the Earth system which applies to improving weather and air quality forecasting, and understanding climate processes and trends.
THE HIGH-RESOLUTION RAPID REFRESH (HRRR), ESRL
The HRRR is a 3-km resolution, hourly updated, cloud-resolving atmospheric model, initialized by DFI-fields from the 13km radar-enhanced Rapid Refresh model.
Link: http://ruc.noaa.gov/hrrr/

Meteorological Assimilation Data Ingest System (MADIS), ESRL
MADIS leverages partnerships with international agencies to integrate observations from their stations with those of NOAA to provide a finer density, higher frequency observational database for use by the greater meteorological community.

Highlights include:
- Observed: meteorological surface, radiosonde, NOAA profiler network, satellite wind and others.
- Modeled: Rapid Update Cycle (RUC) Surface Assimilation System (RSAS) Surface Analysis Grids
- Information about obtaining ACARS (commercial aircraft) data
Link: http://www-sdd.fsl.noaa.gov/MADIS/index.html

Physical Sciences Division, ESRL
PSD's scientific goal is to provide the observation, analysis, and diagnosis of weather and climate physical processes necessary to increase understanding of Earth's physical environment, including the atmosphere, ocean, cryosphere, and land, and to enable improved weather and climate predictions on global-to-local scales.
PSD archives a wide range of data ranging from gridded climate datasets extending hundreds of years to real-time wind profiler data at a single location. The data or products derived from this data, organized by type, are available to scientists and the general public.
Link: http://www.esrl.noaa.gov/psd/

International Comprehensive Ocean-Atmosphere Data Set (IOCADS)
ICOADS offers surface marine data spanning the past three centuries, and simple gridded monthly summary products for 2° latitude x 2° longitude boxes back to 1800 (and 1°x1° boxes since 1960)—these data and products are freely distributed worldwide.
Link: http://icoads.noaa.gov/index.shtml

Marine Modeling and Analysis Branch (MMAB)
The MMAB is responsible for the development of improved numerical weather and marine prediction modeling systems within NCEP/NWS. This group provides analysis and real-time forecast guidance (1-16 days) on marine meteorological, oceanographic, and cryospheric parameters over the global oceans and coastal areas of the US.

Highlights include:
- NOAA WAVE WATCH III: NWW3 produces swell period, sea height and sea heading.
- Sea ice forecasting and analysis
- SSM/I and QuickSCAT wind statistics products
- Coastal and open ocean visibility data archive
- MMAB Global Superstructure Ice Accretion Guidance
Link: http://polar.ncep.noaa.gov/mmab/products.shtml
National Climatic Data Center (NCDC)
The NCDC is the world's largest active archive of weather data. Data is received from a wide variety of sources, including: satellites, radars, remote sensing systems, NWS cooperative observers, aircrafts, ships, radiosondes, wind profilers, rocketsondes, solar radiation networks, and NWS Forecast/Warnings/Analyses Products. Link: [http://www.ncdc.noaa.gov oa/ncdc.html](http://www.ncdc.noaa.gov/oa/ncdc.html)

Global Observing Systems Information Center (GOSIC), NCDC
The GOSIC Portal provides access to data and information identified by the Global Climate Observing System (GCOS), Global Ocean Observing System (GOOS) and Global Terrestrial Observing System (GTOS), in addition to their partner programs e.g. Global Atmosphere Watch (GAW) and GOOS Regional Alliances (GRA). Link: [http://gosic.org/default.htm](http://gosic.org/default.htm)

National Operational Model Archive & Distribution System (NOMADS), NCDC
The NOAA National Operational Model Archive and Distribution System (NOMADS) provides both real-time and retrospective format independent access to climate and weather model data. Link: [http://nomads.ncdc.noaa.gov/](http://nomads.ncdc.noaa.gov/)

Products & Services Guide, NCDC
The Products & Services Guide provides a comprehensive overview of the data products offered by the National Climatic Data Center. Product highlights include worldwide surface observations, in addition to satellite, model and radar data. Link: [http://www1.ncdc.noaa.gov/pub/data/inventories/2011psguide.pdf](http://www1.ncdc.noaa.gov/pub/data/inventories/2011psguide.pdf)

National Data Buoy Center (NDBC)
The National Data Buoy Center (NDBC) manages the development, operations, and maintenance of the national data buoy network. It serves as the NOAA focal point for data buoy and associated meteorological and environmental monitoring technology. It provides high quality meteorological/environmental data in real time from automated observing systems that include buoys and a Coastal-Marine Automated Network (C-MAN) in the open ocean and coastal zone surrounding the United States. It provides engineering support, including applications development, and manages data buoy deployment and operations, and installation and operation of automated observing systems installed on fixed platforms. It manages the Volunteer Observing Ship (VOS) program to acquire additional meteorological and oceanographic observations supporting NWS mission requirements. It operates the NWS test center for all surface sensor systems. It maintains the capability to support operational and research programs of NOAA and other national and international organizations. Observations search link: [http://www.ndbc.noaa.gov/](http://www.ndbc.noaa.gov/)

National Geophysical Data Center (NGDC)
The NGDC provides products and services for geophysical data describing the solid earth, marine, and solar-terrestrial environment, as well as earth observations from space. Link: [http://www.ngdc.noaa.gov/ngdc.html](http://www.ngdc.noaa.gov/ngdc.html)

Marine Geology & Geophysics, NGDC
The Marine Geology and Geophysics Division of NGDC provides long-term scientific stewardship for global geophysical and digital elevation data, marine geological and geophysical data, and natural hazards data.
Highlights include:

- **Bathymetry & Global Relief**: This webpage provides access to NGDC bathymetric and topographic datasets including: gridded global relief data and images, multibeam data, hydrographic survey data, satellite-derived data and trackline data.
- **NOAA Tsunami Inundation Digital Elevation Models**: NOAA's National Geophysical Data Center is building high-resolution digital elevation models (DEMs) of select U.S. coastal regions incorporating bathymetric, topographic, and shoreline data provided by federal, state, and local government agencies, academic institutions, and private companies.
- **U.S. Coastal Relief Model**: NGDC's 3 arc-second U.S. Coastal Relief Model (CRM) provides the first comprehensive view of the U.S. coastal zone, integrating offshore bathymetry with land topography into a seamless representation of the coast. The CRM spans the U.S. East and West Coasts, the northern coast of the Gulf of Mexico, Puerto Rico, and Hawaii, reaching out to, and in places even beyond, the continental slope.

Link: [http://www.ngdc.noaa.gov/mgg](http://www.ngdc.noaa.gov/mgg)

**National Oceanographic Data Center (NODC)**
The NODC manages the world's largest collection of publicly available oceanographic data. NODC holdings include in-situ and remotely sensed physical, chemical, and biological oceanographic data from coastal and deep ocean areas.

Link: [http://www.nodc.noaa.gov/](http://www.nodc.noaa.gov/)

**Interactive Data Access and Retrieval System (IDARS), NODC**
IDARS is being developed to provide a graphical user interface-based tool that will allow visual browsing of data managed by the Operational Oceanography Group of the National Oceanographic Data Center (NODC).

Link: [http://www.nodc.noaa.gov/dsdt/](http://www.nodc.noaa.gov/dsdt/)

**National Coastal Data Development Center (NCDDC), NODC**
The NCDDC is dedicated to building the long-term coastal data record to support environmental prediction, scientific analysis, and formulation of public policy.

Link: [http://www.ncddc.noaa.gov/](http://www.ncddc.noaa.gov/)

**OceanNOMADS, NCDDC**
NOAA NCDDC, with partners including National Weather Service, National Centers for Environmental Prediction (NCEP) and the Northern Gulf Institute, has created this NOMADS node for ocean-model access. This site, OceanNOMADS, provides retrospective access to long time series of output from mature ocean modeling and prediction systems, including models from the National Weather Service and the U.S. Navy.

Highlights include:
- Global NCOM (NAVt Coastal Ocean Model)
- RTOFS (Real Time Ocean Forecast System)
- CFSR (Climate Forecast System Reanalysis)

Link: [http://www.ncddc.noaa.gov/ocean-nomads/](http://www.ncddc.noaa.gov/ocean-nomads/)

**Satellite Oceanography Group, NODC**
The primary goal of the NODC satellite group is to provide scientific stewardship of satellite-derived oceanographic datasets and analyses. The group focuses on three of the key functions of satellite data stewardship: (1) Generating authoritative long-term records through satellite data reprocessing efforts; Using...
those climate data records to place the current state of the environment in its proper historical perspective; and (3) Insuring the data are properly archived and easily accessed by a wide range of users. Link: http://www.nodc.noaa.gov/SatelliteData/

Ocean Climate Laboratory, NODC
The Ocean Climate Laboratory (OCL) is a division of the National Oceanographic Data Center (NODC). The primary objectives of the OCL are to: (1) improve the quality of the NODC’s oceanographic data archives by using the data to perform scientific analyses and (2) build scientifically, quality-controlled global oceanographic databases. Link: http://www.nodc.noaa.gov/OC5/

NOS Data Explorer, National Ocean Service (NOS)
NOS Data Explorer offers access to many products, including: bathymetry, coastal maps, environmental sensitivity index maps, aerial photographs, and more. Link: http://oceanservice.noaa.gov/dataexplorer/

Center for Operational Oceanographic Products and Services (CO-OPS), NOS
Provides access to met-ocean data such as tidal, current and meteorological observations from various entities, including:
- Texas Coastal Ocean Observation Network (TCOON)
- Carolinas Regional Coastal Ocean Observing System (Carolinas RCOOS)
- Northeast Regional Association for Coastal and Ocean Observing (NERACOOS)
- The National Water Level Program
- The National Water Level Observation Network
Link: http://tidesandcurrents.noaa.gov/index.shtml

Centralized Data Management Office (CDMO), National Estuarine Research Reserve System, Office of Ocean and Coastal Resource Management, NOS
The National Estuarine Research Reserve System (NERRS) is a NOAA-state partnership that oversees 28 research reserves which have been established for the purpose of research, education and coastal stewardship. The CDMO website provides various marine, oceanographic and meteorological observations from National Estuarine Research Reserve (NERR) within U.S. coastal states. Link: http://cdmo.baruch.sc.edu/

National Marine Protected Area Center, NOS
The Marine Protected Areas Inventory (MPA Inventory) is a comprehensive geospatial database designed to catalog and classify marine protected areas within US waters. This inventory contains information on over 1,600 sites and is the only such comprehensive dataset in the nation. The database has various applications for marine management and conservation, but its primary purpose is to maintain baseline information on MPAs to assist in the development of the National System of MPAs. Link: http://www.mpa.gov/

NOAA Central Library
The NOAA Central Library provides information and research support to NOAA staff and the public. The library also networks with over 30 NOAA libraries across the nation. Disciplines covered include: weather and atmospheric sciences, oceanography, ocean engineering, nautical charting, marine ecology, marine resources, ecosystems, coastal studies, aeronomy, geodesy, cartography, mathematics and statistics. Link: http://www.lib.noaa.gov/
**National Weather Service (NWS), Automated Surface Observing System (ASOS)**
The Automated Surface Observing Systems (ASOS) program is a joint effort of the National Weather Service (NWS), the Federal Aviation Administration (FAA), and the Department of Defense (DOD). The ASOS systems serve as the nation’s primary surface weather observing network.
Link: [http://www.nws.noaa.gov/asos/](http://www.nws.noaa.gov/asos/)

**NWS Telecommunication Gateway**
The Gateway operates web servers and file servers. The web and file servers store all nationally-generated forecast products and globally received observational data. The web service provides browser access to retrieve data and forecasts. The file servers provide a file transfer service for retrieval of operational model forecasts and observational data.

**Observing System Visualization**
This visualization tool presents critical aspects of the NOAA Observing System, including: owning agency, type of system (buoy, satellite, etc.), intended use, lifecycle phase, and environmental parameters measured.
Link: [https://www.nosc.noaa.gov/OSC/sor.php](https://www.nosc.noaa.gov/OSC/sor.php)

**Physical Oceanographic Real-Time System (PORTS®)**
PORTS® is a decision support tool that improves the safety and efficiency of maritime commerce and coastal resource management through the integration of real-time environmental observations, forecasts and other geospatial information. PORTS® measures and disseminates observations and predictions of water levels, currents, salinity, and meteorological parameters (e.g., winds, atmospheric pressure, air and water temperatures) that mariners need to navigate safely.
PORTS® link: [http://tidesandcurrents.noaa.gov/ports.html](http://tidesandcurrents.noaa.gov/ports.html)

**The Physical Oceanography Division (PhOD)**
The Physical Oceanography Division carries out interdisciplinary scientific investigations on the physics of ocean currents and water properties, and on the role of the ocean in climate, weather, and ecosystems. The tools used include: sensors on deep ocean moorings and vessels, and satellite-based instruments.

Data that can be obtained here include that from the:
- AOML South Florida Program
- Global Ocean Observing System (GOOS)
- CoastWatch Program
- ARGO Center
- Global Drifter

Program Link: [http://www.aoml.noaa.gov/](http://www.aoml.noaa.gov/)

**World Data Center for Meteorology, Asheville**
The WDC for Meteorology, Asheville is maintained by the U.S. Department of Commerce (DOC), National Oceanic and Atmospheric Administration (NOAA) and is collocated and operated by the National Climatic Data Center (NCDC) in Asheville, NC, USA, and is proud to have been accepted as a full member of the new WDS as of September 2011. In accordance with the principles set forth by ICSU, WDC for Meteorology, Asheville acquires, catalogues, and archives data and makes them available to requesters in the international scientific community. Data are exchanged with counterparts, WDC for Meteorology, Obninsk and WDC for Meteorology, Beijing as
necessary to improve access to climate and weather data. All data and special data sets contributed to the WDC are available to scientific investigators without restriction. The WDC for Meteorology, Asheville, also works closely with the U.S. Global Climate Observing System (GCOS) program, and strives to work closely with entities involved in all aspects of climate observing and related data management efforts, including the operation of the Global Observing Systems Information Center (GOSIC).


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**DEPARTMENT OF DEFENSE**

**ARMY**

**Coastal & Hydraulics Laboratory, U.S. Army Corps of Engineers: Engineer Research & Development Center**
The U.S. Army Engineer Research and Development Center’s Coastal & Hydraulics Laboratory (CHL) performs ocean, estuarine, riverine, and watershed regional scale systems analyses research support work for the U.S. Army Corps of Engineers and the DoD Task Force in support of the Ocean Commission. Research projects range from design guidance to three-dimensional numerical models. Focus is placed on inland and coastal navigation, military logistics over the shore, dredging, flood control, storm and erosion protection, waterway restoration, fish passage, hydro-environmental modeling, water/land management, and other water and sediment-related issues facing the nation.

Link: [http://chl.erdc.usace.army.mil](http://chl.erdc.usace.army.mil)

**CHL Field Research Facility, U.S. Army Corps of Engineers: Engineer Research & Development Center**
The Field Research Facility (FRF) is an internationally recognized coastal observatory. Instruments at the facility record the changing waves, winds, tides, and currents.


**Wave Information Studies (WIS), Coastal Field Data Collection Program, U.S. Army Corps of Engineers: Engineer Research & Development Center**
The Wave Information Studies is a US Army Corps of Engineers sponsored project that generates consistent, hourly, long-term (20+ years) wave climatologies along all US coastlines, including the Great Lakes and territories.


**Defense Agencies**

**National Geospatial-Intelligence Agency (NGA)**
The National Geospatial-Intelligence Agency explores and analyses imagery and geospatial information to describe, assess, and visually depict physical features and geographically referenced activities on the Earth. NGA does not sell or perform services directly for the public. Those products and services that are available to the public can be obtained from the sources listed on the NGA website, under “How to get NGA Products”.

Link: [https://www1.nga.mil/Pages/default.aspx](https://www1.nga.mil/Pages/default.aspx)

**Navy**

**Global Ocean Data Assimilation Experiment (GODAE), Marine Meteorology Division, Naval Research Laboratory**
A comprehensive database containing a wide array of geophysical data, including those that are remotely sensed,
observed in-situ and modeled.
USGODAE Data Catalog link: http://www.usgodae.org/cgi-bin/datalist.pl?generate=summary

**Navy Coastal Ocean Model (NCOM), Oceanography Division, Naval Research Laboratory**
NCOM is a 1/8 degree resolution model that serves as the Navy's operational global Nowcast/Forecast system. NCOM is based on the Princeton Ocean Model (POM). The surface boundary conditions for the NCOM model, including wind stress, heat flux, and salt flux are provided by the Navy Operational Global Atmospheric Prediction System (NOGAPS). The Navy Modular Ocean Data Assimilation System (MODAS) provides the data assimilation for NCOM including SSH and SST.

**Remote Sensing Division, Naval Research Laboratory**
The mission of the Naval Research Laboratory Remote Sensing Division is research and development utilizing remotely sensed information or leading to remote sensing systems for applications to the earth’s environment in its broadest sense. Because of the Naval Research Laboratory's unique position, this means that it is the Department of Defense's (DoD) center of excellence for remote sensing technology and its applications. Applications to the atmosphere, ocean and land surfaces, and the celestial background include meteorology, background and propagation effects upon systems, increased understanding of ocean and atmospheric processes and their interactions, effects or modulation of the environment by targets, determination of reference frames and other natural environmental phenomena relevant to national security. The effort includes development of environmental sensors, data and signal processing technologies, unique utilization of existing sensors, fundamental investigations in ocean, atmospheric and astrophysical sciences, and modeling and simulation of environmental processes.

**DEPARTMENT OF ENERGY**

**National Marine Renewable Energy Centers (NMREC)**
NMREC supports wave and tidal energy development for the United States through testing and deployment of energy technologies, research, and contributing to policy initiatives. NMREC consists of three centers: Hawaii National Marine Renewable Energy Center (HINMREC), Northwest National Marine Renewable Energy Center (NNMREC), and the Southeast National Marine Renewable Energy Center (SNMREC).
HINMREC link: http://hinmrec.hnei.hawaii.edu/
NNMREC link: http://depts.washington.edu/nnmrec/
SNMREC link: http://smerc.fau.edu/

**National Renewable Energy Laboratory (NREL)**

**Wind Resource Assessment, National Wind Technology Center (NWTC)**
The NWTC provides technical assistance in wind resource assessment including the development and validation of high-resolution wind maps. The focus is to provide the wind industry, policy makers, and other stakeholders with applied wind resource data, information products, and technical assistance to effectively evaluate and develop wind potential.

Highlights include:
- U.S. offshore wind resource maps
- Local & International land-based wind resource maps
- Dynamic maps, GIS data & analysis tools

Link: http://www.nrel.gov/wind/resource_assessment.html

**Oak Ridge National Laboratory (ORNL)**

**Mercury Distributed Metadata Management, Data Recovery and Access System**
Mercury is a data access system for various ORNL projects on the geophysical and biogeochemical sciences.
Mercury link: http://mercury.ornl.gov/

**Wind ENEnergy Data and Information (WENDI) Gateway Office of Energy Efficiency and Renewable Energy (EERE), U.S. DOE Wind & Water Power Program**
The WENDI Gateway is an integrated system for the archival, discovery, access, integration, and delivery of wind energy-related data and information. WENDI's WindGIS enables users to browse, query, and display United States wind energy-related spatial data, including maps of wind resource assessment and electrical transmission lines. WENDI's Metadata Clearinghouse allows users to search for datasets, publications, applications, and websites.

Products available through the WENDI Gateway include: maps, data, publications, tools and software from national laboratories (i.e. ORNL, PNNL), government entities (DOE, EPA) and select private sources.
Link: http://windenergy.ornl.gov/node/1

**Sandia National Laboratories (SNL)**

**Energy: Renewable Energy**
The Sandia Wind Energy Technologies Group conducts applied research to improve wind turbine technology and supports interconnection/integration studies. Various technical papers and reports are available through their website.
SNL Renewable Energy link: http://energy.sandia.gov/?page_id=270

**Savannah River National Laboratory (SRNL)**

**Atmospheric Technologies Group (ATG)**
The SRNL Weather Center provides meteorological monitoring, operational forecasts, and numerical modeling for the SRNL and Savannah River Site (SRS). The weather center is operated by the SRNL’s Atmospheric Technologies Group. In addition to their operational mission, the ATG conducts applied research projects including those related to real-time modeling and assessment capabilities, emergency response planning, and the development of custom meteorological data sets for the SRS and a diverse set of other customers.
ATG link: http://www.srs.gov/Weather/

**South Carolina Offshore Wind Collaborative**
SRNL - and partners Clemson University Restoration Institute (CURI), Santee Cooper, Clemson University’s S.C. Institute for Energy Studies, Coastal Carolina University, Center for Hydrogen Research, and the U.S. Coast Guard - are participating in a wind energy assessment project off of the South Carolina Coast utilizing SODAR technology. This is the first use of remote sensing technology to measure winds offshore of the Atlantic seaboard.
Link: http://www.clemson.edu/restoration/focus_areas/renewable_energy/wind/
Bureau of Ocean Energy Management (BOEM)

Maps and GIS Data
The BOEM website provides information on legal and physical aspects related to the U.S. offshore energy and marine mineral resources e.g. land lease information and existing infrastructure.

BOEM Offshore Mapping and Data link: http://www.boemre.gov/offshore/mapping/index.htm

MarineCadastre.gov
This website is the product of a co-led effort between the Bureau of Ocean Energy Management and the National Oceanic and Atmospheric Administration. The website is an integrated marine information system that provides authoritative and regularly updated ocean information, including offshore boundaries, infrastructure, human use, energy potential, and other data sets. The website is especially useful to those looking to assess suitability for ocean uses, such as energy siting. Data can be viewed in the national viewer or downloaded from its original source.

Link: http://www.marinecadastre.gov

Technology Assessment & Research (TA&R) Program
The TA&R Program is a research element encompassed by the BOEMRE Regulatory Program. The TA&R program is comprised of three functional research activities: Operational Safety and Engineering Research (OSER), Oil Spill Response Research (OSRR) and Renewable Energy Research (REnR).

Selected projects reports:

- Seabed Scour Considerations for Offshore Wind Development on the Atlantic OCS, February 2011, by Thomas McNeilan and Kevin R. Smith, Fugro Atlantic, Norfolk, Virginia

BOEMRE TA&R link: http://www.boemre.gov/tarhome/

US Geological Survey (USGS)
The USGS hosts various portals and collections containing information about the earth system and life sciences, including:

- National Geologic Map Database
- Provides a listing of the major USGS geoscience databases and science programs.
- Publications Warehouse
- Reports, maps, datasets, satellite imagery, real-time data, & software.

Link: http://www.usgs.gov/

USGS Woods Hole Coastal and Marine Science Center (WHSC), USGS
The Woods Hole Coastal and Marine Science Center conducts research within the USGS Coastal and Marine Geology Program. They make various map portals and information databases accessible on their website, including:
• Marine Realms Information Bank (MRIB)
  MRIB is a distributed geolibrary that provides access to information about oceanic and coastal environments.
• GIS Information
  An interactive map server with displays on various information layers from a number of USGS research programs.
• Geologic Maps of America’s Submerged Lands
  Links to maps of the sea floor, including the digital data, displayed on a map of the U.S. east coast.

Earth Resources Observation and Science (EROS), USGS
The USGC Center for Earth Resources Observation and Science is a national data reception, processing, archiving, distribution, and research facility for remotely sensed data and other forms of geographic information.
Link: http://eros.usgs.gov/

National Water Information System: Web Interface, USGS
This website provides most of the USGS water data maintained within NWIS, including water-resources data collected at approximately 1.5 million sites in all 50 States, the District of Columbia, and surrounding territories. Data provided on this site are updated by NWIS on a regularly scheduled basis, and real-time data are generally updated upon receipt at local Water Science Centers.
Link: http://waterdata.usgs.gov/nwis

INDEPENDENT / OTHER AGENCIES

Data.gov Communities

Energy Community
Energy.data.gov is a new open government initiative to increase awareness of, and deepen insights into, our Nation’s energy performance. Energy.data.gov brings together high-value datasets, tools, and applications to shed new light on energy use. These free datasets and tools have been gathered from agencies across the Federal government.
Link: http://www.data.gov/communities/energy

Ocean Community
This is the National Ocean Council’s portal for data, information, and tools to support people engaged in planning for the future of the ocean, our coasts, and the Great Lakes.
Link: http://www.data.gov/communities/ocean

NASA

Earth Observing System Data and Information System (EODIS)
EODIS distributes thousands of Earth system science data products and provides associated services for interdisciplinary studies.

EODIS provides access to earth system data from various EODIS data centers, including:
• Alaska Satellite Facility SAR Data Center (ASF SDC)
• Global Hydrology Resource Center (GHRC)
• Goddard Earth Sciences Data and Information Services Center (GES DISC)
• MODIS Level 1 Atmosphere Archive and Distribution System (MODAPS LAADS)
• National Snow and Ice Data Center (NSIDC) DAAC
• Oak Ridge National Laboratory (ORNL) DAAC
• Physical Oceanography Distributed Active Archive Center (PO) DAAC
• Socioeconomic Data and Applications Data Center (SEDAC) Link: http://earthdata.nasa.gov/data

Goddard Earth Sciences Data and Information Services Center (GES DISC)
The GES DISC is the data archive for the NASA Precipitation and Hydrology and the Atmospheric Composition and Dynamics groups.

Comments: Has A-Train Data Depot and other mission data. The A-Train Data Depot (ATDD) has been developed to process, archive, allow access to, visualize, analyze and correlate distributed atmospheric measurements from A-Train instruments. A-Train Data Depot has retrievals such as: cloud profiles, cloud top temperatures, rain rates, and water vapor content.

Link: http://disc.sci.gsfc.nasa.gov/about-us

Global Change Master Directory (GCMD), NASA
The GCMD is a comprehensive database that contains a listing of geophysical data from various U.S. public and private sources. Browse by data type (e.g. atmosphere, ocean, land surface), observation type (e.g. modeled, in-situ, remotely sensed) and other fields.

Accessible data portals include:
• Physical Oceanography Distributed Active Archive Center (PO.DAAC)
• Earth Observing System Clearinghouse (ECHO)
• Earth Observing System Data and Information System (EOSDIS)
• Fleet Numerical Meteorology and Oceanography Center, U.S. Navy (FNMOC)

Comments: PO.DAAC is the repository for NASA SeaWinds, SSM/I and NSCAT scatterometers. SeaWIFS data available through the GCMD. FNMOC Wave Watch 3 model data are available here.

Link: http://globalchange.nasa.gov/

Reverb | ECHO, NASA
The Reverb is a new, user friendly interface that searches the ECHO metadata clearinghouse. Available datasets are provided by participating NASA agencies and outside organizations.

Link: http://reverb.echo.nasa.gov/reverb/

National Ice Center (NIC)
The NIC is an interagency sea ice analysis and forecasting center comprised of the following components: the Naval Ice Center, NOAA, and the U.S. Coast Guard. The NIC offers many publically available sea ice charts and climatology products through their website.

Link: http://www.natice.noaa.gov/
National Science Foundation

Unidata, University Corporation for Atmospheric Research (UCAR)
Unidata is a diverse community of over 160 institutions vested in the common goal of sharing data and visualization tools. Unidata is a data facilitator, not a data archive center. Unidata provides a mechanism whereby educators and researchers (by participating in the Internet Data Distribution system), may subscribe to streams of current data that interest them. These data consists primarily of: GOES satellite imagery; radar imagery (level II and level III); and model output from the National Centers for Environmental Prediction, the Canadian Meteorological Centre and Fleet Numerical Meteorology and Oceanography Center. Other data available are: WMO observations; land based observations such as profilers, lightning observations; and GPS derived precipitable water content.
Link: http://www.unidata.ucar.edu/

STATE GOVERNMENT

California

California Environmental Resources Evaluation System (CIRES)
The California Environmental Resources Evaluation System (CERES) is a program of the California Resources Agency established to facilitate access to a variety of electronic data describing California’s rich and diverse environments. CERES collects and integrates data and information and distributes it.
Link: http://ceres.ca.gov/index.html

Massachusetts

Massachusetts Office of Geographic Information (MassGIS)
The Commonwealth’s comprehensive, statewide database of spatial information for mapping and analysis supporting emergency response, environmental planning and management, transportation planning, economic development, and transparency in state government operations. Of primary metocean interest are the coastal and offshore data layers, including existing uses, and digital coastal elevation and bathymetry. Coverage is available from Rhode Island Sound through the Gulf of Maine.

Massachusetts Ocean Resource Information System (MORIS)
MORIS can be used to search and display spatial data pertaining to the Massachusetts coastal zone. Users can interactively view various data layers (e.g., tide gauge stations, marine protected areas, access points, eelgrass beds) over a backdrop of aerial photographs, political boundaries, natural resources, human uses, bathymetry, or other data e.g. Google base maps. Users can quickly create and share maps and download the actual data for use in a Geographic Information System (GIS). Link: http://www.mass.gov/czm/mapping/index.htm

Rhode Island

Rhode Island Ocean Special Area Management Plan (OceanSAMP)
The Rhode Island Ocean Special Area Management Plan, or Ocean SAMP, serves as a federally recognized coastal management and regulatory tool. Using the best available science, the Ocean SAMP provides a balanced approach to the development and protection of Rhode Island’s ocean-based resources.
Home page: http://seagrant.gso.uri.edu/oceansamp/index.html
South Carolina

South Carolina Act 318 of 2008, South Carolina Energy Office (SCEO)
South Carolina Act 318 of 2008 created a committee to review, study, and make recommendations regarding the feasibility of windmill farms in the state including, but not limited to, whether South Carolina is a suitable site for wind production on land or in offshore areas, the economic and environmental impact to the state, and the cost of wind farm installation and operation in the state. The SCEO website provides access to relevant technical papers and reports related to offshore and coastal South Carolina wind energy development.
Link: http://www.energy.sc.gov/

REGIONAL ALLIANCES

ADCIRC Coastal Circulation and Storm Surge Model
ADCIRC is a system of computer programs for solving time dependent, free surface circulation and transport problems in two and three dimensions. These programs utilize the finite element method in space allowing the use of highly flexible, unstructured grids. Typical ADCIRC applications have included: (i) modeling tides and wind driven circulation, (ii) analysis of hurricane storm surge and flooding, (iii) dredging feasibility and material disposal studies, (iv) larval transport studies, and (v) near shore marine operations.
Link: http://adcirc.org/

CEOS International Directory Network (CEOS IDN)
The CEOS IDN is a comprehensive database containing a listing of geophysical data from international public and private sources. Users can browse by data type (e.g. atmosphere, ocean, land surface), observation type (e.g. modeled, in-situ, remotely sensed) and more.
Link: http://idn.ceos.org/

Earth Observation Portal, Service Support Environment (SSE)
The SSE service directory offers access to a continuously expanding set of basic and complex earth observation and GIS services, including:
- Atmospheric Monitoring
- Coastal and Sea Monitoring
- Satellite Image Processing
Link: http://services.eoportal.org/index.jsp

Eastern Consortium of Coastal Ocean Observatories (ECCOO)
ECCOO is a collaboration of coastal research sites categorized as either estuary/embayment-coastal or near-shore/coastal. Regionally affiliated entities include:
- Northeast Regional Association for Coastal and Ocean Observing (NERACOOS)
- Martha’s Vineyard Coastal Observatory (MVCO)
- Front-Resolving Ocean Network with Telemetry (FRONT) – UConn Dept. of Marine Sciences
Link: http://www.whoi.edu/mvco/other_data/ECCOO/index.html

The Global Ocean Surface Underway Data Pilot Project (GOSUD)
A cooperative international program, the GOSUD is seeking the collection, data processing, archiving, and real-time distribution of sea surface salinity and other variables collected by research vessels and ships of opportunity.
Link: http://www.gosud.org/Project-Description/Data-Providers

Global Spatial Data Infrastructure Association
The GSDI Association is an inclusive organization of agencies, firms, and individuals from around the world. The purpose of this organization is to promote international cooperation and collaboration in support of local, national and international spatial data infrastructure developments that will allow nations to better address social, economic, and environmental issues of pressing importance.
Link: http://www.gnsi.org/

Group on Earth Observations GEO Portal
The GEO portal is a gateway to Global Earth Observation data, information and services developed by the European Space Agency (ESA) as contribution to Global Earth Observation System of Systems (GEOSS).
Link: http://www.geoportal.org/

HYCOM Consortium for Data Assimilative Modeling
The HYCOM consortium is a multi-institutional effort sponsored by the National Ocean Partnership Program (as part of the U.S. Global Ocean Data Assimilation Experiment (GODAE)), to develop and evaluate a data-assimilative hybrid isopycnal-sigma-pressure (generalized) coordinate ocean model (called HYbrid Coordinate Ocean Model or HYCOM). This site provides access to near real time global HYCOM + NCODA (Navy Coupled Ocean Data Assimilation) based ocean prediction system output.
Link: http://hycom.org/

IHO Data Centre for Digital Bathymetry (DCDB), International Hydographic Organization (IHO)
To improve the collective availability of bathymetric data, the IHO has established the IHO Data Centre for Digital Bathymetry (DCDB). The Data Centre collects and quality checks oceanic soundings acquired by hydrographic and oceanographic ships during surveys and while on passage. This also includes soundings collected by other vessels such as warships, fisheries ships and commercial vessels. The DCDB worldwide digital data bank of oceanic soundings is made available for the production of bathymetric products, such as: maps and gridded datasets produced by the General Bathymetric Charts of the Ocean (GEBCO) Project, the International Bathymetric Chart (IBC) Project and other projects e.g. Google Ocean.
Link: http://www.ngdc.noaa.gov/mgg/bathymetry/aho.html

Intergovernmental Oceanographic Commission (IOC)
The IOC is an autonomous body located within UNESCO (IOC link: http://ioc-unesco.org/). The purpose of the Commission is to promote scientific investigation, with a view toward learning more about the nature and resources of the oceans through the concerted action of its members.

Select IOC Programs:
1. International Oceanographic Data and Information Exchange (IODE), IOC
Ocean data sources developed and maintained by IODE National Oceanographic Data Centres:
   - IODE Ocean Data Portal
     The International Oceanographic Data and Information Exchange (IODE) program of the UNESCO Intergovernmental Oceanographic Commission (IOC) was established to enhance marine research, exploitation and development by facilitating the exchange of oceanographic data and information between participating Member States, and by meeting the needs of users for data and information products.
     Link: http://www.oceandataportal.org/
   - World Ocean Database (global)
     The World Ocean Database 2009 (WOD09) is a database of selected historical in-situ surface and subsurface
oceanographic measurements produced by the Ocean Climate Laboratory (OCL) at the National Oceanographic Data Center (NODC), Silver Spring, Maryland, USA.

- **SeaDataNet data access (regional)**
The SeaDataNet infrastructure links 40+ national oceanographic data centers and marine data centers from 35+ countries.
Link: [http://www.seadatanet.org/data_access](http://www.seadatanet.org/data_access)

- **Published Ocean Data**
Published Ocean Data is an e-repository setup by IODE as a parallel repository to its OceanDocs system and is targeted at datasets, rather than documents. It was implemented by the IODE to support pilot projects undertaken by a joint IODE/SCOR/MBLWHOI Library working group on data publication and data citation.

2. **GOOS**
GOOS is the Global Ocean Observing System and is a permanent global system for observations, modeling and analysis of marine and ocean variables to support operational ocean services worldwide.

3. **JCOMM**
Worldwide marine meteorological and oceanographic communities are working in partnership under the umbrella of the WMO-IOC Joint Technical Commission for Oceanography and Marine Meteorology, in order to respond to interdisciplinarity requirements for met-ocean observations, and data management and service products.

- **Global Sea Level Observing System (GLOSS)**
GLOSS aims at the establishment of high quality global and regional sea level networks for application to climate, oceanographic and coastal sea level research. Link: [http://www.gloss-sealevel.org/](http://www.gloss-sealevel.org/)

**IOOS Data Catalog and Asset Viewer, Integrated Ocean Observing System (IOOS)**
The Data Catalog and Asset Viewer is an online tool that allows users to find information from all available IOOS partners without having to know in advance what partners operate the actual observing systems and data servers. IOOS partners include: NOAA and other federal agencies; the IOOS Regional Associations; and other national or international organizations. Regional partners are:

- Mid-Atlantic Regional Association Coastal Ocean Observing System (MARACOOS) - [http://www.maracoos.org/](http://www.maracoos.org/)
Data link: [http://www.ioos.gov/data/welcome.html](http://www.ioos.gov/data/welcome.html)

**The IPCC Data Distribution Centre (DDC)**
The DDC provides climate, socio-economic and environmental data, both from the past and also in scenarios projected into the future. Technical guidelines on the selection and use of different types of data and scenarios in research and assessment are also provided.

The DDC provides four main types of data:

- Climate observations, as global mean time series and gridded fields
- Climate model projections and simulations: monthly means and climatologies (decadal and 30-year means),
- Socio-economic data
MARCO Mapping and Planning Portal, Mid-Atlantic Regional Council on the Ocean
The MARCO Mapping and Planning Portal is an online tool that allows state, federal, and local decision-makers and the public to visualize, query, map, and analyze ocean and coastal data in the Mid-Atlantic region. Link: http://www.midatlanticocean.org/map_portal.html

Northeast Ocean Data (NEOD) Portal
The Northeast Ocean Data Portal is a decision support and information system for managers, planners, scientists and project proponents involved in coastal and marine spatial planning in the region from the Gulf of Maine to Long Island Sound. The Portal provides access to data, interactive maps, tools, and other information needed for decision making. Data provided through the portal are provided as GIS database files that contain information on coastal and marine spatial planning, including:
- Geology
- Administrative and Regulatory
- Commercial, Industrial and Military
- Infrastructure
- Physical Oceanography Link: http://northeastoceandata.org/

Ocean Observatories Initiative (OOI)
The National Science Foundation's Ocean Observatories Initiative (NSF-OOI) will construct a network of instruments, undersea cables, and instrumented moorings that span the Western Hemisphere. The OOI will be one fully integrated system and will measure physical, chemical, geological, and biological phenomena in carefully selected key coastal, regional, and global areas. Link: http://www.oceanobservatories.org/

Permanent Service for Mean Sea Level (PSMSL)
PSMSL has been responsible for the collection, publication, analysis and interpretation of sea level data from the global network of tide gauges since 1933. Link: http://www.psmsl.org/

U.S. Global Ocean Ecosystems Dynamics (GLOBEC)
GLOBEC researchers are developing and applying computer models of the physics and biology of the seas, based on studies of key marine processes and observational programs. This inter-related sequence of modeling, process-oriented studies, broad scale observations, and retrospective studies is the foundation of the GLOBEC research strategy. These program elements provide essential pieces of information on a broad spectrum of spatial and temporal scales. Data include meteorological and oceanographic observations from the following regions:
- Georges Bank
- Northeast Pacific
- Northwest Atlantic
- Southern Ocean
Link: http://www.usglobe.org/index.php

US Offshore Wind Collaborative
The US Offshore Wind Collaborative (USOWC) is an interdisciplinary, non-profit organization created to help the
United States harness its vast offshore wind resources. The USOWC provides a forum for information-sharing, problem-solving, and capacity-building among government, industry, academia, energy, and environment advocates with the goal of realizing the great potential for coastal and Great Lakes wind to contribute to local clean energy production, climate change mitigation, and jobs-creation. The USOWC website provides access to relevant technical papers and reports related to U.S. offshore wind energy development.

Link: http://www.usowc.org/index.html

UNIVERSITIES AND PRIVATE RESEARCH INSTITUTIONS

Connecticut

Front-Resolving Observational Network with Telemetry (FRONT) Program, University of Connecticut
The FRONT program has several observational components, including a suite of autonomous ocean sensors that measure physical and biological properties throughout the water column (ADCP’s, profiling CTD’s, and a profiling plankton observatory). Supplementing this underwater array is shore-based HF radar (CODAR) measurements of surface currents.

Link: http://nopp.uconn.edu/

Maine

Physical Oceanography Group, School of Marine Sciences, University of Maine
The Physical Oceanography Group at the University of Maine is responsible for operating the NERACOOS moored buoys in the Gulf of Maine and the Gulf of Maine CODAR stations. Current and historical data are available for download on their webpage.

Link: http://gyre.umeoce.maine.edu/gomoos.php

Massachusetts

Ocean Observation Laboratory (OCEANOL), School for Marine Science and Technology, University of Massachusetts – Dartmouth
OCEANOL integrates measurements from moorings, CODAR, shipboard surveys, operational satellite imagery and meteorological instruments into studies of various coastal ocean and estuarine domains, including: the Gulf of Maine, Georges Bank, the New England Shelf, and the Buzzards, Narragansett and Mt. Hope Bays.

Link: http://www.smast.umassd.edu/OCEANOL/

University of Massachusetts Wind Energy Center (UMWEC)
UMWEC has gathered wind data around New England under the support of the Massachusetts Division of Energy Resources (DOER), the Massachusetts Renewable Energy Trust Fund (MRET), the Massachusetts Clean Energy Center (MassCEC), Northeast Utilities (NU), and the DOE. The data sets available here are some of the few wind energy-focused resources in the region, providing unique insight into long-term conditions above standard surface monitoring heights. Several resources are available in, or near, coastal regions.

Link: http://www.umass.edu/windenergy/resourcedata
Woods Hole Oceanographic Institution (WHOI)
The Woods Hole Oceanographic Institution is dedicated to research and education to advance understanding of the ocean and its interaction with the Earth system, and to communicating this understanding for the benefit of society.
The data center makes data available from:
- Floats
- Local coastal observatories
- Bathymetric studies
- Global surface moorings (met & ocean)
- WHOI ships
WHOI Data Center link: http://www.whoi.edu/data/

Martha’s Vineyard Coastal Observatory, WHOI
Data products include those of the Air-Sea Interaction Tower (ASIT) of the Coupled Boundary Layers and Air-Sea Transfer (CBLAST) program, in addition to other meteorological and oceanographic data.
Link: http://mvlcdata.whoi.edu/cgi-bin/mvco/mvco.cgi

The Unstructured Grid Finite Volume Coastal Ocean Model (FVCOM), School for Marine Science and Technology, University of Massachusetts – Dartmouth
FVCOM is a prognostic, unstructured-grid, finite-volume, free-surface, 3-D primitive equation coastal ocean circulation model developed by UMASSD-WHOI joint efforts. The model consists of momentum, continuity, temperature, salinity and density equations and is closed physically and mathematically using turbulence closure submodels. The horizontal grid is comprised of unstructured triangular cells and the irregular bottom is presented using generalized terrain-following coordinates. FVCOM was originally developed for the estuarine flooding/drying process in estuaries and the tidal-, buoyancy- and wind-driven circulation in the coastal region featured with complex irregular geometry and steep bottom topography. This model has been upgraded to the spherical coordinate system for basin and global applications.
Link: http://fvcom.smast.umassd.edu/index.html

New Hampshire

Law of the Sea Mapping Program, Center for Coastal and Ocean Mapping/Joint Hydrographic Center (CCOM/JHC), University of New Hampshire
The University of New Hampshire's Center for Coastal and Ocean Mapping/Joint Hydrographic Center (CCOM/JHC) is collecting multibeam bathymetry and acoustic backscatter data that can be used to support an extended continental shelf under Article 76 of the United Nations Convention of the Law of the Sea (UNCLOS). This extensive seafloor mapping project grew out of an exhaustive desktop study of the U.S. bathymetry data holdings and identified several regions where new bathymetric surveys are needed.
This website contains images, data and papers regarding bathymetric mapping focus area, including the:
- Atlantic
- Gulf of Mexico
- Gulf of Alaska
- Mendocino Ridge

Massachusetts Clean Energy Center
New York

**GeoMapApp, Lamont-Doherty Earth Observatory, Columbia University**
GeoMapApp is an earth science exploration and visualization application that is continually being expanded as part of the Marine Geoscience Data System (MGDS) at the Lamont-Doherty Earth Observatory of Columbia University. The application provides direct access to: the Global Multi-Resolution Topography data (which hosts 100m resolution multibeam bathymetry data); ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) data; and NED (National Elevation Dataset) topography data. Link: [http://www.geomapapp.org/index.htm](http://www.geomapapp.org/index.htm)

**Great South Bay Project, School of Marine and Atmospheric Sciences, Stony Brook University**
Data are being collected from eight stations on the Great South Bay (GSB) using SeaCat instruments measuring water temperature and salinity. Meteorological data are being collected from two locations in the Great South Bay: on the south tower of the Smith Point bridge, and at the GSB #1 buoy. The Smith Point observatory data includes temperature and salinity from the Smith Point SeaCat, short and long wave radiation from Eppley pyronometers, and wind speed, wind direction, air temperature, humidity, barometric pressure and rainfall rate from a Vaisala WXT520. The GSB #1 buoy reports wind speed and direction, air temperature and humidity, photosynthetically active radiation, water temperature and salinity, chlorophyll-a fluorescence and turbidity. Great South Bay Project link: [http://www.somas.stonybrook.edu/research/gsb_ecosystem/monitoring/index.html](http://www.somas.stonybrook.edu/research/gsb_ecosystem/monitoring/index.html)

**LIShore, School of Marine and Atmospheric Sciences, Stony Brook University**
LIShore is a project of the School of Marine and Atmospheric Sciences at Stony Brook University, in collaboration with the LIShore partners. Data access is provided for meteorological and oceanographic observations at coastal points across Long Island, New York. Link: [http://www.lishore.org/index.html](http://www.lishore.org/index.html)

**Sound Science, School of Marine and Atmospheric Sciences, Stony Brook University**
The Sound Science is a research program that encompasses meteorological and oceanographic observations from stationary and non-stationary platforms in the Long Island Sound. Link: [http://www.stonybrook.edu/soundscience/main.html](http://www.stonybrook.edu/soundscience/main.html)

Rhode Island

**Graduate School of Oceanography (GSO), The University of Rhode Island**
Research campaigns at the GSO span a variety of disciplines, including: meteorology, physical oceanography and geology. Data from many research campaigns is available for download through their website. Link: [http://www.gso.uri.edu/](http://www.gso.uri.edu/)

**The Environmental Data Center (EDC), The University of Rhode Island**
The Environmental Data Center is the center of technical expertise in GIS for the state of Rhode Island. The (EDC) is a Geographic Information System (GIS) and spatial data analysis laboratory in the University of Rhode Island's Department of Natural Resources Science, College of the Environment and Life Science. Major areas of research at the EDC are spatial data modeling, ecological mapping, and data integration for environmental applications. The EDC participates with the NEOD and has bathymetric information and other coastal / metocean related data sets. Link: [http://www.edc.uri.edu/](http://www.edc.uri.edu/)
COMMERCIAL PROVIDERS AND DEVELOPMENT PROJECTS

AWS Truepower: Mesoscale modeling and windTrends database
windTrends is a simulated hourly time series of the Mesoscale Atmospheric Simulation System (MASS) model output, beginning in 1997. The windTrends database covers the United States and southern Canada, and associated coastal waters. This is a controlled regional reanalysis dataset developed by AWS Truepower that differs from the conventional reanalysis data because it is computed at a finer resolution (20km) and relies on rawinsonde data. This model output can be interpolated to exact point locations within the domain.
Link: http://www.awstruepower.com/

The Long Island – New York City Offshore Wind Project
The Long Island – New York City Offshore Wind Project is an initiative to help New York reach its clean and renewable energy goals. The proposed project would be located in the Atlantic Ocean, approximately 13 nautical miles off the Rockaway Peninsula. It would likely be designed for 350 megawatts (MW) of generation, with the ability to expand it to 700 MW, giving it the potential to be the largest offshore wind project in the country. The project home page provides project assessment reports, including output from economic feasibility and geo-met-ocean characterization studies.
Link: http://www.ynycoffshorewind.com/Default.html

Noble Consultants, Inc.
Noble Consultants, Inc. utilizes numerical models in the analysis and design of projects involved with the water environment. These models include 1-D, 2-D and 3-D hydrology, hydraulic, hydrodynamic, sediment transport and water quality models for Coastal & Ocean projects, Riverine & Estuarine projects, and Waterfront Development & Restoration projects

Coastal & Ocean Model Applications include:
- Constituent Transport & Water Quality
- Sediment Transport & Coastal Morphology
- Storm Surge & Coastal Flooding
- Tide, Wind & Wave Induced Circulation
- Wave Generation & Propagation
Link: http://www.nobleconsultants.com/

Remote Sensing Systems
Remote Sensing Systems specializes in processing and analyzing microwave data collected by satellite microwave sensors. Emphasis is placed on analysis of data from the SSM/I, SSMIS, TMI, AMSR-E, QuikSCAT, MSU, AMSU and WindSat instruments.
Link: http://www.remss.com/

Oceanweather, Inc.
Oceanweather functions as a specialized consulting firm serving the coastal and ocean engineering communities. In dedicated studies, the approach and deliverable outputs (wave parameters, wave spectra, extremal analysis, operational data, etc.) are designed around user applications and needs. Oceanweather has performed studies and developed informational databases world-wide.
WeatherFlow

WeatherFlow Inc. is a private sector weather consultant, with over two decades of experience. With its proprietary observing network, WeatherFlow has brought a steady stream of products and services to market, filling highly specific needs in many sectors, including plume dispersion, emergency management, hazardous weather alerting, hurricane measurements, insurance and financial products, maritime operations, wind energy, the National Mesonet, and others.

Home page: http://www.weatherflow.com/

Vaisala

Vaisala is a global leader in environmental and industrial measurement. Vaisala provides products and solutions to professionals in meteorology, airport operations, defense, road operations, wind energy, cleanrooms and chambers, building automation, and chosen industrial applications as well as in some innovative new business areas where environmental measurement plays a significant role. Two notable products are:

- **Vaisala Global Lightning Dataset GLD360** - A service that provides real-time lightning data for accurate and early detection and tracking of severe weather. The data provided is generated by a Vaisala-operated worldwide network.

- **Vaisala’s U.S. National Lightning Detection Network (NLDN)** - The NLDN provides fast delivery of high quality lightning data over the continental United States.


**INTERNATIONAL RESOURCES**

Coriolis Operational Oceanography

Coriolis is a French Data Assembly Center that provides access to data useful for operational oceanography. Data provided is gathered by ships, drifters, floats, moorings and satellites. Data spans internationally and includes observations from various networks, including: Argo, OceanSITES and EGO gliders.

Link: http://www.coriolis.eu.org/

ERA-40 Reanalysis Project, ECMWF

ERA-40 will use a variational data assimilation system to make a new synthesis of the in-situ and remotely-sensed measurements made over the period of 1957-2002. ERA-40 will produce analyses with six hourly frequency throughout the period, supplemented by intermediate three-hour forecasts. The products will be of high temporal and spatial resolution, with a grid-spacing close to 125km in the horizontal and with sixty levels in the vertical located between the surface and a height of about 65km. The availability of ERA-40 analyses will also revitalize the use of data from past field experiments in the improvement of climate and weather forecasting models. ERA-40 products will be enhanced by short periods of higher resolution global assimilation. This will enable better exploitation of the observational data from experiments such as GATE (1974), ALPEX (1982) and TOGA-COARE (1992-93).

Comments: ECMWF has begun the ERA-Interim project. This is an 'interim' reanalysis of the period 1989-present in preparation for the next-generation extended reanalysis to replace ERA-40.

ERA Projects link: http://www.ecmwf.int/research/era/do/get/index

Massachusetts Clean Energy Center
EUMETSAT
EUMETSAT operates a system of meteorological satellites monitoring the atmosphere, ocean, and land surfaces. It delivers weather and climate-related satellite data, images and products 24 hours a day, 365 days a year. This information is supplied to the National Meteorological Services of the organization's member and cooperating states in Europe, as well as other users worldwide.
Link: http://www.eumetsat.int/Home/index.htm

General Bathymetric Chart of the Oceans (GEBCO)
GEBCO operates under the joint auspices of the Intergovernmental Oceanographic Commission (IOC) of UNESCO and the International Hydrographic Organization (IHO). GEBO provides a range of bathymetric data sets and products, including global gridded and digital contour format.
Link: http://www.gebco.net/

Integrated Science Data Management (ISDM), Department of Fisheries and Oceans Canada
ISDM manages and archives ocean data collected by the DFO, or acquired through national and international programs conducted in ocean areas adjacent to Canada. Data is provided by various research programs and monitoring campaigns, including:
- Joint WMO IOC Joint Commission on Oceanography and Marine Meteorology (J-COMM) Responsible National Oceanographic Data Centre (of the World Data Centres)
- Ship Of Opportunity Programme (SOAP)

National Climate Data and Information Archive (NCDIA), Environment Canada
The EC NCDIA is a data repository for weather and climate observations throughout Canada. Available data and products include surface observations, climate summaries, radar imagery and energy estimation products.
Link: http://climate.weatheroffice.gc.ca/prods_servs/index_e.html