THE NEED FOR EXPANDED METEOROLOGICAL AND OCEANOGRAPHIC DATA TO SUPPORT RESOURCE CHARACTERIZATION AND DESIGN CONDITION DEFINITION FOR OFFSHORE WIND POWER PROJECTS IN THE UNITED STATES

American Meteorological Society
Offshore Wind Energy Committee

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CHAPTER 1

INTRODUCTION

In 2010 the American Meteorological Society Board on Enterprise Planning (AMS BEP) established the Annual Partnership Topic (APT) committee on Offshore Wind Energy. The committee’s overarching mission is to define the need for and recommend expansion of meteorological and oceanographic (metocean) data required to support studies of the wind resource and design conditions relevant to wind farm development and operations in offshore locations of the United States. This includes observed and modeled data parameters—wind, turbulence, waves, currents, air and sea surface temperature, atmospheric stability, and other weather—that impact wind turbines, foundations, electric cabling, service vessels, and human safety.

Offshore wind energy is an emergent renewable energy industry in the United States. Projects have been proposed or are under development in waters adjacent to over a dozen states along the Eastern Seaboard, the Gulf of Mexico, the Pacific Coast, Hawaii and the Great Lakes. The U.S. Department of Energy (DOE) estimates that 54 gigawatts (GW) of offshore wind capacity could be built by 2030 (DOE, 2008). A potential barrier to achieving this full potential, however, is the need for accurate metocean information to evaluate the energy potential, economic viability, and engineering requirements of offshore project sites over their minimum design life of 20 years. Currently available metocean data, instrumentation and models do not supply all the information required to support large-scale wind project deployment. Offshore wind technologies are heavily dependent on the design environment – namely wind, wave and current conditions – which impact different aspects of project viability: construction, performance, reliability, accessibility, safety, and economics, among others. It is contingent on the weather-energy community to help resolve these issues for this emergent industry.

This report presents a high-level review of the offshore wind energy industry’s needs for metocean information and recommends strategies for bridging important data gaps through multi-disciplinary engagement to better enable the advancement of this technology’s deployment. The core sections of the report discuss the offshore wind energy opportunities and challenges in the United States; the role of metocean data in addressing project planning, design and operations; sources of existing measured and modeled data; and data gaps and potential strategies to address these gaps.

This report is intended for the use of members of the diverse weather, climate and marine communities who are interested or engaged in the metocean aspects of offshore wind energy planning, development, operations, and regulations. This report is also intended to be a resource to inform other interested parties, such as decision and policy makers, about the importance of advancing the knowledge of metocean issues, thereby facilitating the advancement of offshore wind energy. The ultimate goal is to encourage collaborative efforts among a broad range of stakeholders that aim to advance the metocean science in ways that support the needs of offshore wind energy.
CHAPTER 2
OVERVIEW OF OFFSHORE WIND ENERGY OPPORTUNITIES AND CHALLENGES IN THE UNITED STATES

Offshore wind energy deployments began about two decades ago in northern Europe. By the end of 2012, there were 55 offshore wind farms worldwide totaling more than 5.4 gigawatts (GW) of generation capacity, with the majority of the capacity sited off the shores of the United Kingdom and Denmark (European Wind Energy Association, 2013; 4C Offshore, 2013). Another ten countries have at least one operating offshore wind turbine, including Germany, Belgium, the Netherlands, Sweden, and China. All told, at least 1800 individual offshore turbines have been installed and are operating in average water depths of less than 30 m, although depths for some newer projects approach 50 m. The dominant foundation types—all bottom-mounted—are monopile, gravity base, and jacket structures, while floating and semi-submersible types are emerging for applications in water depths generally greater than 60 m.

Recently installed wind turbines have hub heights approximately 90-120 m above the mean water surface elevation, are between 2 and 5 megawatts (MW) in capacity, and have rotor diameters in excess of 100 m. Economies of scale are pushing the size scales upward on all fronts: hub heights, rotor diameters, turbine capacity, and even project size. While most operating projects average less than 250 MW in size, many new projects in the planning and construction phases are much larger in total capacity (European Wind Energy Association, 2013; 4C Offshore, 2013). Projects are also being built farther from shore, in some cases tens of kilometers from the nearest port.

According to the National Renewable Energy Laboratory (NREL), the potential gross generating capacity of offshore winds in the United States is four times greater than the existing land-based electric production capacity from all sources (Musial and Ram, 2010). Although this estimate does not account for siting constraints and other factors, it does indicate that offshore winds could, if tapped, provide a rich energy resource and a vast economic opportunity.
Early stage offshore development, which is already underway, is focusing on the Mid-Atlantic and Northeast coastal regions where the combination of relatively shallow waters (extending tens of kilometers offshore), relatively strong prevailing winds and low hurricane risk, close proximity to major load centers, and relatively high electricity prices prevail. Other regions also exploring offshore wind opportunities include the Southeast, the Gulf Coast, the Great Lakes, the Pacific Coast and Hawaii. Most of these regions (with the exception of the Pacific Coast where major land-based wind development has taken place) have limited capability to locally develop large-scale wind energy on land due to competing land uses and/or light wind regimes. Long distance transmission of power from inland wind-rich areas may be economically viable in some cases. In general, however, offshore may offer a preferred opportunity for the pursuit of large-scale wind energy development for many coastal regions than land-based options.

Additional incentives for pursuing offshore wind are the anticipated benefits from the job creation, economic development, port revitalization, and CO2 emissions reduction this industry would provide if it could achieve long-term sustainability (Navigant Consulting, 2013; Kempton et al., 2007). It is also a key opportunity to develop domestic US capabilities to compete in a global offshore wind marketplace.

The offshore wind energy industry requires accurate metocean information to evaluate the energy potential, grid compatibility, economic viability, and engineering requirements of offshore project sites. The European weather-energy community has been addressing this information for over 20 years and is a rich source of ‘lessons learned’ as the United States develops a domestic offshore industry tailored to its own environmental conditions. Currently available metocean data, instrumentation and models do not supply all the information required to support wide-scale technology deployment in the United States. For example, an extremely limited number of offshore wind observations are available at hub height for wind turbines, and current approaches may be inadequate to accurately extrapolate up to hub height the surface wind measurement obtained by technology installed on widely scattered buoys or derived from satellite imagery. In addition to meeting industry needs, regulatory agencies and state/local governments must have access to databases and models that can accurately characterize offshore conditions to evaluate lease potential, determine economic fair return, and establish the engineering design loads needed to guide technical and safety approvals and subsequent operations and maintenance (O&M) processes. To address this state of affairs, federal agencies have initiated several programs.

In Fiscal Year 2011, DOE initiated a formal activity, titled the Offshore Wind Innovation and Demonstration Initiative, to promote and accelerate responsible commercial offshore wind development in the United States, guided by a 2010 Strategic Work Plan titled “Creating an Offshore Wind Industry in the United States: A Strategic Work Plan for the United States Department of Energy” (DOE, 2011). A goal of the initiative is to guide a national effort to overcome technical and market barriers and to achieve a target of 54 GW of deployed offshore wind generating capacity by 2030, with an interim target of 10 GW of capacity deployed by
2020. The DOE’s activities aim to facilitate offshore wind power deployment and augment the funding allocated to offshore wind research and test facilities through the American Reinvestment and Recovery Act of 2009 (ARRA).

The Bureau of Ocean Energy Management (BOEM)—a part of the U.S. Department of the Interior (DOI)—has jurisdiction over the granting of leases, easements and rights of way in federal waters for ocean energy technologies under the Energy Policy Act of 2005. This responsibility includes the designation of Wind Energy Areas, following collaborations with States and various stakeholders, where commercial leasing activity on a state by state basis is to be targeted. Thus far, Wind Energy Areas have been defined off the coasts of Delaware, Maryland, Massachusetts, New Jersey, Rhode Island, North Carolina, South Carolina, and Virginia. The regulation of metocean measurements in federal waters related to energy development is also BOEM’s responsibility.

In June 2010, the DOE and the DOI signed a Memorandum of Understanding (MOU) to coordinate deployment of marine and hydrokinetic (MHK) technologies and offshore wind technologies on the Outer Continental Shelf (OCS), 3 NM to 200 NM for the Exclusive Economic Zone (EEZ), of the United States. The MOU describes action areas to support the deployment of offshore renewable energy, one of which is Resource Assessment and Design Conditions (RADC). RADC actions planned in response to the MOU include developing a roadmap and implementing a plan for acquiring the necessary information to safely and cost-effectively design, site, install, operate, and regulate offshore renewable energy facilities.

The Wind and Water Power Program (WWPP) in the DOE Office of Energy Efficiency and Renewable Energy (EERE) hosted a public meeting on June 23-24, 2011 in Crystal City, VA. The meeting focused on identifying the critical metocean measurements and data needed for successful deployment of offshore renewable energy technologies, including wind. A summary report (Offshore Resource Assessment and Design Conditions Public Meeting – Summary Report) was published in September 2011 (DOE, 2011).

In late 2011, the DOE initiated several contracted projects to address offshore energy resource and design condition data needs through establishing common databases, new measurement initiatives, and supporting development of advanced instrumentation technology. This new work was solicited via Funding Opportunity Announcement No: DE-FOA-0000414 as part of a broader initiative to reduce technical challenges facing the offshore wind industry.

Most recently, in December 2012 the DOE announced seven offshore wind awards for projects in Maine, New Jersey, Ohio, Oregon, Texas and Virginia. In the initial phase, each project will receive funds to complete engineering, design and permitting studies for pilot-scale wind farms. Up to three of these projects will be chosen for follow-on phases that focus on construction and commissioning by 2017.

In summary, offshore wind energy has a considerable track record outside of the United States. This experience has demonstrated the feasibility of offshore wind project
development, construction and operations in European and Asia-Pacific waters. Concurrently, offshore wind technology has been evolving towards larger scale systems and deployment in relatively deep waters. The lessons learned from the global experience will benefit future efforts in the United States where offshore wind has significant energy generation prospects and promising environmental and economic benefits. Through the combination of private and public sector initiatives, momentum is gathering for the development of offshore projects in different coastal areas of the United States. This momentum is attracting attention from the domestic weather-energy community regarding the quality, quantity and overall adequacy of existing metocean data to provide all the information necessary to reliably evaluate the energy potential, economic viability, environmental risks and benefits, and engineering requirements of offshore wind projects. The next section of this paper describes the role metocean data plays among the principal stakeholders of offshore wind energy development and identifies the most desired metocean data parameters.
CHAPTER 3
THE ROLE OF METOCEAN DATA IN ADDRESSING PROJECT PLANNING, DESIGN AND OPERATIONAL NEEDS

Relevant Project Components
All phases of an offshore wind project require metocean data in various formats to enable decision making. Metocean data applications can be grouped according to four main phases of a project’s lifetime: pre-development, development, construction, and operations.

Pre-development: This phase is investigatory in nature and pertains to siting and pre-development feasibility studies that determine whether a conceptual project is viable to proceed to the next development phase. Questions about viability pertain to location options where a wind project could realistically be sited, desirable turbine energy production to realize targeted returns on investment, and turbine/foundation technology suitability and constructability, among others. This phase is normally accomplished in a year or less and currently relies almost entirely on existing historical metocean data and modeled results, both of which are associated with relatively high uncertainty.

Development: This phase invests in the acquisition of the metocean data necessary to define a selected site’s resource and design conditions so that all project components are appropriately specified and engineered within acceptable bounds of uncertainty. This step, which can take years to complete, is measurement intensive and done concurrently with pursuing permitting approvals, interconnection agreements, and project financing. Mesoscale and microscale models are utilized in tandem with local and regional observations to estimate long-term wind conditions and energy production at every proposed turbine location while accounting for turbine wakes. Inter-annual production variability and the quantification of uncertainty are important analysis components of this phase.

Construction Phase: This phase involves one or more years of construction and transport work at sea and is constrained by permissive sea states and suitable weather windows. Certification is conducted by independent technical organizations on behalf of project stakeholders and regulators to ensure that the site’s metocean conditions are comprehensively evaluated and project design requirements are met. On-site metocean observations and operational wave and weather forecasts along the transit route from port are relied upon heavily during
construction and commissioning. If these forecasts are accurate they can greatly reduce the capital intensive construction and worker safety risk of an offshore project.

**Operations Phase:** Operations and maintenance activities rely on local observations as well as regional forecasts of waves, weather, and energy production. Site access by maintenance crews will be governed by the availability of safe weather windows. Facility operators compare projected with actual energy output based on the wind and weather conditions. Utilities and transmission system operators may request or require next-hour and next-day schedules of projected energy output, together with estimates of certainty or probability. Offshore wind projects have a design life of at least 20 years but potentially longer depending upon project economics and technology selection.

**Principal Stakeholders and Roles**
While the most obvious beneficiary of metocean data for offshore wind projects is the project developer/owner, there are other stakeholders who rely on metocean data to make informed decisions pursuant to their own roles. The list below summarizes the major metocean data stakeholders and their roles in offshore wind energy development.

**Developers/Owners:** Evaluate and develop sites based on diverse criteria, including wind resource and energy production potential, metocean condition suitability for available technologies, distance to and accessibility of transmission interconnection, impact on local environment, likelihood of obtaining permits, and anticipated return on investment.

**Financial Institutions:** Provide equity and debt capital in amounts and terms determined in part by projected project performance and project risks, including vulnerability to extreme metocean events.

**Insurance and Risk Mitigators:** Provide policies and other instruments that spread or mitigate risks related to performance, technology reliability, and safety.

**Facility Designers:** Design the proposed wind energy facility for long-term reliability and safety based on projected metocean conditions and other constraints such as budget and environmental factors.

**Utilities:** Understand the generation characteristics of electrical output in advance to ensure reliable and economic management of the regional electrical grid into which the wind facility’s output is flowing.

**Installers and Operations & Maintenance Providers:** Construct the wind farm using the appropriate vessels and other equipment based on site conditions, sea states, and design requirements. Maintain project operations to ensure safety, productivity and reliability throughout the project’s lifetime.

**Regulators:** Ensure wind project complies with all regulatory requirements, including safety in operations, structural integrity, environmental compatibility and risks, and ‘fair return’ for


national resources (BOEM) as well as electricity generation reliability (FERC). This includes abiding by National Environmental Policy Act (NEPA) terms and a host of other ocean regulations, which is required by all federal and state agencies. Regulators are responsible for stakeholder engagement and information sharing on a range of issues from wind resources to state revenue sharing.

**Metocean Data Needs and Applications**

Metocean data is essential to defining the design and operating conditions for wind energy facilities over their anticipated lifetimes in the locales where they are to be sited. Structures and components must be designed for long-term survivability and endurance in the harsh ocean environment. Construction and maintenance activities must be done safely using equipment appropriate for the local conditions. Loads and resonances for structures can often be coupled, given the concurrent atmospheric and hydrokinetic forces imposed on the integrated foundation and tower structure. Simulating these dynamic loads is made more complicated by the inherent rotating rotor component atop the tower. Turbine power curves are principally defined according to the wind speed distribution, air density, and turbulence intensity conditions at the hub height (typically 100 m ± 20 m) of the turbine, although improved power curve estimates can be attained by measuring the vertical shear across the rotor plane (Wagner et al, 2012).

During the pre-development phase of a project, metocean parameters are normally derived from regional data sources and models. During the development phase, one or more on-site measurement systems are typically instituted to provide better certainty about these metocean conditions. The data sampling and analysis parameters will vary by the design condition in question, and may include averages, distributions across space and time, extremes, time series, and coincidence of one observation with another, such as the coincidence of extremes winds and waves. The relationship between on-site observations of a year or more and those at regional reference stations are used to derive long-term statistics for the wind energy site. Climatological adjustment techniques, also known as measure-correlate-predict (MCP), are widely used within the wind energy industry (Rogers et al., 2005; Brower 2010).

Given the scarcity of spatially and temporally comprehensive data observations in an offshore environment, models must be leveraged to provide a thorough assessment of offshore wind development potential. This includes numerical weather prediction models that help estimate wind resource characteristics and power production potential. The reliability of modeled datasets relies on using models that can integrate observations and extrapolate values appropriately, both in time and space, for varying atmospheric conditions (including thermally stable, neutral and unstable regimes). Optimizing the spacing design, configuration and performance of wind turbine arrays requires an understanding of turbine wake formation, propagation and dissipation and the associated impacts on energy production and turbine fatigue loads. Wake analysis techniques are undergoing improvement as operational data from offshore European projects becomes publicly available (e.g., Barthelmie et al., 2010).
industry relies on a variety of commercial and research software codes to simulate the interactions between wakes and the atmospheric boundary layer. Some codes are computationally efficient at the expense of capturing much detail about the wake characteristics, while others, such as large eddy simulation models, yield superior detail but require high performance computing (e.g., Beaucage et al., 2012; Lee et al., 2011).

The family of data needs can be separated into two groups: atmospheric and surface-subsurface. Figure 1 illustrates many of metocean influences impacting offshore wind structures. Atmospheric data covers an array of meteorological parameters extending vertically from just above the water surface up to the top of the turbine rotor plane, which is likely to extend over 150 m into the atmospheric boundary layer. These groups are not mutually exclusive; in fact some worst-case design conditions involve the coincidence of atmospheric and water parameters (such as extreme coincident wave height and wind gust).

The most desired atmospheric data parameters are:

- **Wind Speed (Horizontal)** – annual, monthly, hourly, 10-minute, 1 minute, 3- and 5-second
- **Speed Frequency Distribution** – # hrs/yr within discrete speed intervals
Wind Shear – change of wind speed with height

Wind Veer – change of direction w/height

Turbulence Intensity – standard deviation of speeds sampled over 10-min period as a function of the 10-min mean speed. Turbulence kinetic energy (TKE) is another important turbulence parameter.

Wind Direction Means, Time Series & Distribution – joint with speed

Extreme Gusts (3- and 5-sec) and Return Periods (1-, 50- and 100-yr)

Vertical Wind Speed – coincident with horizontal speed measurements

Others – atmospheric stability, air temperature, relative humidity, barometric pressure, boundary layer height, heat and moisture fluxes, air density, solar irradiance, cloud-to-ground lightning incidence, icing, hail.

Surface-subsurface data includes various physical parameters extending from the surface of the water to the marine floor. Most bottom-mounted turbine foundation types are appropriate for water depths of up to 60 m, while emerging floating and moored types can be used in deeper waters. The most desired surface and subsurface data parameters are:

Waves – significant wave height, maximum wave height, and extreme wave height, including 1-, 50- and 100-year return periods; frequency, direction spectra, breaking wave characteristics, surge height

Currents – speed and direction profiles from seabed upward

Other Dynamic Forces – drag forces, slap forces, inertial forces, scouring, sand waves

Tidal Conditions

Water Conditions – Surface temperature, heat fluxes, vertical temperature profile, salinity, conductivity, chemistry

Ice Conditions – properties and thickness

Bottom Conditions – soil type, slope, marine growth

Many of these parameters are also relevant to other types of marine renewable energy (or hydrokinetic) systems that tap the waves, tides, currents, or ocean thermal profiles to extract and convert energy into electricity.

Governing Regulations and Standards
A variety of US and international standards, both active and under development, are related to the design and safety of wind project components and activities such as manufacturing,
construction, and installation of offshore structures. Many of these standards pertain to the influence of metocean conditions on design and safety, although elements of these standards may not agree on certain criteria (such as whether extreme conditions are defined as having 50- or 100-yr return periods). Formal standards *per se* do not exist for conducting wind resource and metocean assessment campaigns, however such campaigns are normally designed to address the requirements of the spectrum of development and regulatory stakeholders as well as the relevant governing and guiding standards that do exist.

Standards for offshore wind turbines have been developed by the International Electrotechnical Commission (IEC) under IEC 61400-1 and 61400-3. However, it is understood by most industry stakeholders that the IEC standards alone are not sufficient for designing and certifying an offshore wind project, particularly in US waters. Additional standards from the American Petroleum Institute (API), ISO and class societies such as Germanischer Lloyd (GL), Det Norske Veritas (DNV), and the American Bureau of Shipping (ABS), which in some cases are more comprehensive than IEC standards, will need to be considered to fill gaps and address all aspects of project development.

At the heart of all governing and guiding standards is an expectation that the external conditions should be well understood where an offshore wind project is to be deployed. While it is accepted that offshore wind project risks to human safety are lower than for other offshore uses (oil and gas platforms, shipping, etc.), understanding the external conditions is of vital importance for structure suitability and performance. These conditions comprise the load cases that act upon the turbine structures and drive the material strength and design life. Type certification usually complies with an IEC design class corresponding to a prescribed extreme wind and turbulence level. On the US outer continental shelf, site conditions can easily exceed or deviate from standard IEC classes due to the presence of severe tropical storms, Nor’easters, and other conditions that may challenge conventional metocean assumptions provided in the standards.

The National Academy of Sciences has recommended that the BOEM, in collaboration with industry, develop a set of high-level performance based criteria to judge offshore structural integrity for projects built in US waters (National Research Council, 2011). Project developers would then be required to comply with these specific standards, practices, and guidelines. BOEM would also be tasked with evaluating competent and independent Certified Verification Agents (CVA) to review and determine whether project components and plans meet BOEM criteria. The establishment of this process and these standards is seen as not only vital to ensuring the safe and responsible development of offshore wind projects in the US, but to help expedite and facilitate the forward movement of the industry.
CHAPTER 4

SOURCE OF EXISTING MEASURED AND MODELED DATA

Characterization of General Data Types

Most historical and ongoing U.S. offshore metocean data is available from a limited number of direct observations such as buoys and fixed platforms, satellite-borne instruments, and from modeling systems that provide spatially consistent information from a finite set of inputs. Compared with land based observation networks, direct observation of the offshore metocean environment in the United States is spatially and temporally limited. Furthermore, many of these observation systems are not currently sustained or integrated as part of operational energy networks, but are targeted for various research or proprietary investment studies. Following is a description of the primary sources of available metocean data.

**Buoys** – Moored buoys operate in the coastal and offshore waters of the United States (including the Great Lakes), primarily under the auspices of the National Oceanic and Atmospheric Administration’s (NOAA’s) National Data Buoy Center (NDBC). There are approximately 110 operating buoys within the NDBC network. In general, buoys measure and transmit on an hourly basis: wind speed, direction and gust; barometric pressure; air and sea temperature; wave energy spectra from which significant wave height, dominant wave period, and average wave period are derived; and direction of wave propagation. In most cases atmospheric measurements are taken in the near-coastal waters within 3 to 5 meters of the water surface. Few buoys are further offshore in deeper waters (>50 m). NDBC’s fleet of moored buoys includes several sizes and hull types, which depend on the deployment location and measurement requirements. In addition to their use in operational forecasting, warnings, and atmospheric models, moored buoy data are used for scientific and research programs, emergency response to chemical spills, legal proceedings, and engineering design.

**C-MAN Stations** - The Coastal-Marine Automated Network (C-MAN) was established by NDBC for the National Weather Service (NWS) in the early 1980’s. The development of C-MAN was in response to a need to maintain meteorological observations in U.S. coastal areas. Such observations, which had been made previously by U.S. Coast Guard (USCG) personnel, would have been lost as many USCG navigational aids were automated under the Lighthouse
Automation and Modernization Program (LAMPS). In all, approximately 60 stations make up C-
MAN. C-MAN stations have been installed on lighthouses, at capes and beaches, on near
shore islands, and on offshore platforms. C-MAN station data typically include wind speed,
gust, and direction, air temperature, and barometric pressure. However, some C-MAN stations
are designed to also measure sea water temperature, water level, waves, relative humidity,
precipitation, and visibility. The height of atmospheric measurements, especially wind speed
and direction, is typically higher than buoys, ranging between 10 and 40 m above the local
surface. These data are processed and transmitted hourly to users in a manner almost
identical to moored buoy data.

**Ships and Research Aircraft** – Episodic ship-based metocean observations have been made
since the 18th century. Many ship-borne measurements are not openly or routinely reported
and collated, thus opportunity exists to expand this dataset given many of the potential
offshore wind lease block areas are near busy shipping lanes (including commuter shipping).
Intensive short-term research campaigns (such as the 2004 New England Air Quality Study)
used remote sensing aircraft and High Resolution Doppler Lidar Detection and Ranging (HRD-
lidar or HRDL) data from NOAA’s Ronald H. Brown research vessel) can provide detailed insight
into the metocean environment (Pichugina, Y. et al., 2012). Other emerging technologies
include experimental downward-pointing aircraft-mounted wind lidar.

**Current Sensors** – High frequency radar is used by ocean researchers to
measure surface current velocity fields
near the coast. For example, the
Coastal Ocean Dynamics Applications
Radar (CODAR) is a high frequency
radar system that can measure surface
currents averaged over 15 minutes as
far offshore as 70 km. These data
provide a much higher resolution in
space than previous techniques such
as current meter arrays.
Measurements of current taken by
devices such as Acoustic Doppler
Current Profilers (ADCP) are shipboard or sea bottom-mounted instruments that use sonar to
measure water current velocities for a range of depths.

**Surfaced-Based Remote Sensing** – Remote sensing instruments such as Light Detection and
Ranging (lidar) and Sonic Detection and Ranging (sodar) are being evaluated for offshore
applications. These instruments collect high quality wind data at significantly lower cost than
tall towers installed offshore. These technologies direct beams of light or sound upward
and/or outward using the backscattered signal to determine wind speed and direction (and
turbulence) at multiple heights through and above the rotor plane of wind turbines. Remote
sensing devices can be installed on smaller platforms and buoys (although the buoy-based remote sensing systems are still under development and testing). Shore-based scanning lidar systems can measure winds offshore to distances of 15-20 km and are being evaluated for their accuracy and performance. Off the coast of Virginia, NASA has tested the use of Doppler Aerosol Wind lidar, scanning near horizontally, to profile winds at various altitudes above the ocean surface that correspond to the height of a wind turbine (Koch, G.J. et al., 2012). While surface-based remote sensing systems offer significant promise, they do also have additional requirements (e.g., siting and power) and some limitations (e.g., performance in heavy precipitation) when compared to traditional anemometry.

**Purpose-Built Platforms and Tall Towers** –
Developers of offshore wind farms are investing in the design, permitting and construction of tall (>60m in height) offshore meteorological platforms and towers. These are sited within or immediately adjacent to proposed wind projects. The objective is to collect long-term (>1 yr) high-quality measurements of wind and other metocean parameters within the water column and atmospheric boundary layer. Within North America, three purpose built platforms have collected metocean data, although the data are not public. These include the Cape Wind tower in Nantucket Sound, the Wind Energy Systems Technology (WEST) tower off the coast of Texas, and the NaiKun lidar platform off of British Columbia. Additional platforms and tall towers are likely to be built within the next few years pending the award of water use leases and permits by BOEM.

**Satellite** – Several remote sensing instruments aboard satellite platforms have been deployed to make estimates of marine surface (10 m) winds, currents, and waves. These include NASA’s Quick Scatterometer (QuikSCAT, which stopped providing useful information in November 2009), the European Space Agency’s (ESA) ERS-2 Scatterometer (operational until 2011), and the Special Sensor Microwave Imager (SSM/I), a passive microwave radiometer flown aboard Defense Meteorological Satellite Program (DMSP) satellites. WindSat is a polarimetric microwave radiometer developed by the U.S. Navy and the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Integrated Program Office (IPO) for measuring ocean surface wind speed and direction. The resolution of these instruments is about 25 km. Synthetic Aperture Radar (SAR) images are currently available from the European Remote-Sensing Satellite-2 (ERS-2) and the Canadian Synthetic Aperture Radar Satellite-1 (RADARSAT-1). The operational resolution is approximately 300 m by 300 m; thus, SAR
provides the highest spatial resolution among existing remote sensing instruments. However, SAR’s sampling times are less frequent compared to scatterometers.

**Integrated** – Various public-private-academic collaborations are exploring integrated approaches combining ground-based remote sensing measurements (including multiple vertical and scanning lidar systems), observations from Unmanned Aerial Vehicles (UAV) and tethered balloons with in situ measurements from meteorological towers and satellite-borne radiometers to define the thermodynamic characteristics of the MABL. It is anticipated that integrated metocean datasets with sufficiently high temporal and spatial resolution will be available to correlate with existing resource estimates using a single or smaller suite of capabilities. Such data is needed for instrument inter-comparison analysis based in part on the in situ observations and also the evaluation in meteorological and wind farm models. One example of this integrated approach is the cross-calibrated multi-platform (CCMP), a long-term high resolution data set of ocean surface winds recently developed by NOAA (Atlas et al., 2011).

**Model Data** – Operational models are run several times a day at the National Centers for Environmental Prediction (NCEP). The models include: the Global Forecast System (GFS), North American Mesoscale (NAM), and Rapid Refresh Model (RAP). The GFS (~40 km grid spacing) and NAM (12 km grid spacing) are run four times a day (00, 06, 12, and 18 UTC) out to day 14 and hour 84, respectively, while the RUC (13 km grid spacing) is run every hour to hour 12 or 24. All model data is archived at the NOAA Operational Model Archive Distribution System (NOMADS: [http://www.nomad3.ncep.noaa.gov/](http://www.nomad3.ncep.noaa.gov/)), which includes the latest forecasts as well as an archive back to 2007. The North American Regional Reanalysis (Mesinger et al., 2006) at 32-km grid spacing, which covers North America and a large portion of the adjacent oceans, is available from 1979 to present on the NOMADS. NOMADS also archives the global NCEP reanalysis at 2 degree resolution back to 1950 as well as the Climate Forecast System Reanalysis at 0.5 degree grid spacing back to 1979. Other reanalysis datasets that can be useful include the European Center for Medium Range Forecasting (ECMWF) ERA-15 (2.5° × 2.5° resolution) and NASA’s Modern-Era Retrospective Analysis for Research and Applications (MERRA; Rienecker et al., 2011; 1/2° × 2/3° resolution).

NOAA’s High Resolution Rapid Refresh (HRRR) numerical weather prediction model is a developmental model providing experimental real-time 3-km resolution, cloud-resolved, and hourly-updated output. While HRRR is not expected to be operational right away, its output is available for experimental use. Current studies (such as WFIP; see Benjamin et al., 2013) are also exploring how the HRRR can assimilate remote sensing, tall tower, and nacelle data sets to improve terrestrial wind forecasting. In addition, there are numerous organizations running smaller regions at higher resolutions.

Other efforts include full ocean/wave/wind/atmosphere coupling, which is considered by many as critical to the success of resource assessment and forecasting for offshore wind energy. For example, the MABL can experience significant stratification within the lower 200 m, which in turn can suppress the dissipation rates of turbulent wakes induced by wind
turbines and impact downstream turbines (Hansen et al., 2012). This suggests that finer vertical model resolutions are needed in order to capture shear and turbulence in and around hub height. Combined with this is the need for higher vertical resolutions in the disseminated model outputs, and profiling observations to validate against. Furthermore, conditions at the water’s surface also have an impact in the lower MABL. Wind conditions determine wave heights and surface roughness, which impacts the wind shear within the MABL. Likewise, the local wind stress affects the mixing of near surface waters, which impacts the sea surface temperature and therefore atmospheric stability.

Mesoscale model data (at spatial resolutions of 5 km or finer) and heights to 100 m provide estimates of wind resource characteristics for many offshore regions. For some regions, the resolution of the gridded model data is 200 m. In offshore wind mapping projects supported by DOE/NREL, efforts were made to validate the model-derived data where possible with available measurement data (see website [http://www.windpoweringamerica.gov/windmaps/offshore.asp](http://www.windpoweringamerica.gov/windmaps/offshore.asp)). Research is advancing wind modeling for wind energy applications at finer spatial resolutions (<100 m) through the incorporation of large eddy simulations, which can be nested within mesoscale simulations such as the Weather Research and Forecasting model (WRF) (e.g., Lundquist, J.K. et al., 2010; Talbot, C. et al., 2012).
Distinction Between Measured and Modeled Data

Given the scarcity of measurement data in offshore regions (especially at wind turbine hub heights), model data are important for providing a preliminary analysis of the offshore wind and wave resource distribution and characteristics. Furthermore, the model data can facilitate identification of candidate areas for measurements and more comprehensive assessments. Note that model errors may be greater in areas where strong gradients in the wind resource are evident or suspected, and observations are sparse.

The most useful in-situ measurements for offshore wind energy projections are from heights of about 50 m or higher, using tall towers or masts on large platforms. However, such data are rare as these types of measurement systems are expensive to install and maintain offshore. In some locales, tall towers have been installed on coastal points or small islands that may provide reasonable data for estimating the wind resource characteristics in a nearby offshore area. Buoys with short masts (10 m or less) are less expensive and more abundant, but the low heights of these data make them highly questionable for accurate wind and energy projections at hub heights.

Satellite-borne systems, such as QuikSCAT and SSMI, can provide indirect measurements of near-surface (10 m) winds over large regions at about 25-km grid resolution. However, these data are generally less accurate than buoy measurements and are not reliable in coastal areas within about 25 km of the shore or in shallow water areas. Moreover, the accuracy of these data varies by region and season, and by the availability of buoy data for calibration.

Model data, and in particular long term, continuous gridded data sets, are typically based upon the initial data fields from regional or global forecast models (such as NCEP’s Climate Forecast System Reanalysis, or CFSR, and the ECMWF product) integrated with analyzed observational data fields (hence “reanalysis”). These reanalysis products are used for a variety of purposes (such as climate studies). Their appropriateness for offshore wind resource assessment, however, is limited because of their temporal (typically 3 - 6 hrs) and spatial (~38 - 210 km) representativeness.

There are a few long-term model data sets that have been developed specifically for describing metocean conditions. One reanalysis database, the U.S. Army Corps of Engineers (USACE) Wave Information Studies (WIS) project, generates continuous, hourly, long-term (20+ years) wave and wind climatology’s along all U.S. coastlines, including the Great Lakes and U.S. island territories. The WIS database consists of hindcasted wave and wind information for a densely-spaced (approximately 50 - 100 km) linear series of “virtual wave gauges” in water depths of 15-20 m and for a less-dense series in deeper water (100 m or more). Although valuable for its wave information, the wind fields are limited to 10 m elevation, and suffer from typical biases associated with model-derived wind fields over the ocean.
Importance and Elements of Metadata

Metadata (or information about data) is important to properly interpret and process datasets and to assess their quality and applicability. Usually, metadata include the following types of information: instrumentation, equipment, and description of the physical environment of the sensor, means of creation of the data, purpose of the data, time and date of creation, creator or author of data, placement on a computer network where data was created, and standards used. When generating metadata for metocean data, many more descriptors can be defined. Some of these will be fields describing the physical location of the data collection, while others will describe the instrumentation and equipment used to collect the data.

Location metadata fields and categories include:

- physical location (latitude, longitude, and elevation)
- site name and number
- political region (county, state, and country)
- local environment description and photographs (topography, vegetation, buildings or obstructions) and
- physical parameters about the ocean (including water depth, bottom type, etc.).

Instrumentation and equipment metadata and categories include:

- data logger model and serial number
- sensors (model, serial number, height, orientation or boom direction, calibration information)
- tower description (size – height, face width, etc., lattice or tubular, guyed or non-guyed, face orientation, tower commissioning report)
- remote sensing data (type of instrument – sodar, lidar, etc., model, serial number)
- data collection history (period of record, data outages – periods of missing data and reasons, sensor and site changes, unusual local conditions – severe weather, etc.), and
- contaminants and other limitations affecting the data.

Dataset description metadata include:

- starting and ending dates and times
- data sampling interval
- total number of records collected
- data collection rate (0-100%)
- data format (ASCII text, database files, binary, etc.)
- channel number for each sensor
- name and contact of responsible person
- QC and data screening procedures that have been applied.
List of Metocean Data Sources
The primary source for historical and ongoing U.S. offshore measurement and modeling data is NOAA, particularly the National Data Buoy Center (NDBC). NOAA and other data sources can also be found in the Integrated Ocean Observing System (IOOS), other networks deployed in coastal, inner and outer shelves and offshore regions, and satellite platforms. Modeled data sets include atmospheric, waves, and surface and sub-surface currents and are primarily based upon hindcasting and reanalysis techniques to build long-term gridded data sets. These compilations are available through a variety of government-sponsored and private-public partnerships. A complete description of all available data sets is beyond the scope of this document, but the summary in Table 4-1 below provides links to the freely-available long-term measured and modeled data sets. A more comprehensive description of relevant observed and modeled metocean data can be found at http://www.usmodcore.com/ and NOAA’s Multipurpose Marine Cadastre (see http://www.csc.noaa.gov/digitalcoast/tools/mmc).

There are a number of privately held observational and model datasets, some currently for sale and some not. There is a need to develop a framework for organizations to increase the sharing of more data with due consideration to commercial sensitivities. The federal government promotes a policy of open data and has both the experience and formal mechanisms to collect and protect sensitive data sets that contribute to model enhancement and improve derived products.

Screenshot of US Met-Ocean Data Center: http://www.usmodcore.com

Sharing more data with due consideration to commercial sensitivities. The federal government promotes a policy of open data and has both the experience and formal mechanisms to collect and protect sensitive data sets that contribute to model enhancement and improve derived products.
### Table 4-1 Sources and Types of Metocean Data for Offshore Wind Energy

<table>
<thead>
<tr>
<th>Source</th>
<th>Data Type</th>
<th>Availability</th>
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<tbody>
<tr>
<td>ECMWF ERA-Interim</td>
<td>Reanalysis</td>
<td><a href="http://www.ecmwf.int/research/era/do/get/era-interim">http://www.ecmwf.int/research/era/do/get/era-interim</a></td>
</tr>
<tr>
<td>NOAA Comprehensive Large Array-Data Stewardship System (CLASS)</td>
<td>Satellite</td>
<td><a href="http://www.class.ngdc.noaa.gov/saa/products/welcome">http://www.class.ngdc.noaa.gov/saa/products/welcome</a></td>
</tr>
<tr>
<td>NOAA Digital Coast, Coastal Services Center</td>
<td>GIS</td>
<td><a href="http://www.csc.noaa.gov/digitalcoast/">http://www.csc.noaa.gov/digitalcoast/</a></td>
</tr>
<tr>
<td>NOAA Earth System Research Laboratory (ESRL)</td>
<td>Atmosphere, oceanographic modeling; research</td>
<td><a href="http://www.esrl.noaa.gov/">http://www.esrl.noaa.gov/</a></td>
</tr>
</tbody>
</table>
## Sources of Existing Measured and Modeled Data

<table>
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<tr>
<th>Source</th>
<th>Data Type</th>
<th>Availability</th>
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</thead>
<tbody>
<tr>
<td><strong>NOAA Environmental Modeling Center - Ocean Prediction Center</strong></td>
<td>Analysis and model real-time and archived forecasts of atmosphere and ocean waves and currents.</td>
<td><a href="http://www.opc.ncep.noaa.gov/">http://www.opc.ncep.noaa.gov/</a></td>
</tr>
<tr>
<td><strong>NOAA National Climatic Data Center (NCDC)</strong></td>
<td>Comprehensive archive of atmospheric and oceanic observational and model data</td>
<td><a href="http://www.ncdc.noaa.gov/oacncdc.html">http://www.ncdc.noaa.gov/oacncdc.html</a></td>
</tr>
<tr>
<td><strong>NOAA National Data Buoy Center (NDBC)</strong></td>
<td>Atmosphere, oceanographic observation real-time and archived data</td>
<td><a href="http://www.ndbc.noaa.gov/">http://www.ndbc.noaa.gov/</a></td>
</tr>
<tr>
<td><strong>NOAA National Geophysical Data Center (NGDC)</strong></td>
<td>Geophysical data describing the earth, marine, and solar-terrestrial environments</td>
<td><a href="http://www.ngdc.noaa.gov/ngdc.html">http://www.ngdc.noaa.gov/ngdc.html</a></td>
</tr>
<tr>
<td><strong>National Oceanographic Data Center (NODC)</strong></td>
<td>In-situ and remotely sensed (including satellite) physical, chemical, and biological oceanographic data from coastal and deep ocean areas</td>
<td><a href="http://www.nodc.noaa.gov/">http://www.nodc.noaa.gov/</a></td>
</tr>
<tr>
<td><strong>NOAA NOS Data Explorer, National Ocean Service (NOS)</strong></td>
<td>Including but not limited to bathymetry, coastal maps, environmental sensitivity index maps, aerial photographs, etc.</td>
<td><a href="http://oceanservice.noaa.gov/dataexplorer/">http://oceanservice.noaa.gov/dataexplorer/</a></td>
</tr>
<tr>
<td><strong>NOAA NWS Telecommunication Gateway (NWSTG)</strong></td>
<td>Storehouse of all nationally-generated forecast products and globally received observational data</td>
<td><a href="http://www.nws.noaa.gov/tg/index.html">http://www.nws.noaa.gov/tg/index.html</a></td>
</tr>
<tr>
<td><em><em>NOAA Physical Oceanographic Real-Time System (PORTS</em>)</em>*</td>
<td>Disseminates observations and predictions of water levels, currents, salinity, and meteorological parameters (e.g., winds, atmospheric pressure, air and water temperatures)</td>
<td><a href="http://tidesandcurrents.noaa.gov/ports.html">http://tidesandcurrents.noaa.gov/ports.html</a></td>
</tr>
</tbody>
</table>
## Sources of Existing Measured and Modeled Data

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<th>Source</th>
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</thead>
<tbody>
<tr>
<td>U.S. Army Corps of Engineers Wave Information Studies (WIS)</td>
<td>Hourly, long-term (20+ years) wave climatology’s along all US coastlines, including the Great Lakes and US island territories</td>
<td><a href="http://wis.usace.army.mil">http://wis.usace.army.mil</a></td>
</tr>
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</table>
CHAPTER 5

DATA GAPS AND STRATEGIES TO ADDRESS THEM

Wind energy developers, operators, and regulatory authorities are presented with a variety of challenges in accurately characterizing metocean conditions, particularly where wind-wave interactions create dynamic load conditions on turbines that are unique to the marine environment. Data needs and modeling efforts require detailed knowledge about the MABL, the air-sea interface, the subsurface ocean profile down to the sea floor, and ocean bed geology. Although there are hundreds of data sets encompassing a spectrum of measurements on the temporal, spatial, and geophysical scale, there still exist significant gaps in fulfilling all the needs for the targeted development of offshore wind energy.

There is a need for multi-dimensional (x, y, z, and t) data that accurately capture the critical physical and dynamical processes that operate within the metocean continuum. This includes the coincidence of wind, wave, and current conditions, including extreme events. This will provide wind system designers with more precise, site-specific design criteria and loading data necessary to cost-effectively engineer and optimize the overall wind energy facility, including foundations, rotor components and control systems. Cost optimization opportunities exist not only for the development of the physical wind energy facility but also to the siting, permitting, construction, and operations and maintenance components that together have a significant bearing on the life-cycle economics and availability of an offshore project.

Phenomena Affecting the Metocean Environment Relevant to Wind Energy Applications—Including Extreme Weather and Climate Events

There are several phenomena that define the mean, variable and extreme metocean characteristics relevant to the development and operation of offshore wind farms. A better understanding of these features will require a new generation of observational and modeling tools, building on the past development of increasingly robust 3D atmospheric simulation capabilities, to accurately observe and predict the complex interactions and forces of wind and waves.

Although well over a thousand turbines have been deployed in the offshore waters of Europe, using the characteristics of that environment to predict expected conditions in the U.S. offshore waters may be of limited use. Different coastal morphologies, the occurrence of tropical cyclones, and longer fetches over deeper water can combine to create more extreme conditions along the Atlantic, Pacific and Gulf coasts. Hurricanes and Nor’easters are examples of phenomena that produce extreme wind-wave conditions unique to U.S. coastal waters. Moreover, mesoscale circulations, such as sea breezes and low level jets (LLJ), can produce local wind and wave maxima much closer to the coast than would be assumed given the large-scale synoptic pattern. Finally, the coastal waters of the northeastern U.S. and Great Lakes can be subject to cold air intrusions leading to conditions favorable for the rapid build-up of ice caused by sea spray and a sub-freezing atmosphere. A brief synopsis of these phenomena is given below.
Sea breeze and Low-level Jets (LLJs). The dearth of long-term high quality observations available over the offshore waters means that comparatively little is known about the three-dimensional structure of the lowest 200 m of the MABL, especially as it relates to the assessment of the wind resource and turbulence effects within, above, and below the rotor plane. Sea breezes are familiar coastal phenomena, especially during the spring and summer months when sea surface temperatures are significantly cooler that the adjacent land and the Bermuda-Azores High becomes a primary synoptic-scale influence on the eastern United States. Regional upwelling often strengthens the sea breeze, especially within the mid-Atlantic Bight (Dvorak et al., 2012).

Recent field observations (Bailey and Freedman, 2008) and modeling studies (Colle and Novak, 2010; Freedman et al., 2010) have also shown the frequent existence of a sheet-like feature characterized by low-level maxima (70 - 150 m above the surface) in wind speeds just offshore of the mid-Atlantic and northeastern U.S. coastal regions, prime areas for the development of wind farms. These wind speed maxima appear to be associated with enhanced thermal circulations especially prevalent during the warm season. Numerical Weather Prediction (NWP) model runs have suggested that this phenomenon is a response to the thermal contrast and synoptic pressure gradient between the warm land to the north and west, the cool, sloping marine boundary layer to the south and east, and flow interaction with the coastline (Colle and Novak, 2010; Freedman et al., 2010).

From an energy production perspective both phenomena produce wind speed/wind power maxima during high load periods of hot summer afternoons. Although winds well inland may remain light, speeds in offshore waters near hub height can exceed the threshold (>13 m s⁻¹) above which wind turbines produce their maximum (or rated) output during peak load times (Dvorak, 2012; Freedman, 2011). These local wind speeds (and associated wave heights) that at times exceed thresholds for the safe deployment of support vessels for construction, operation, and maintenance of wind farms, are high impact and sometimes risky conditions that are not typically captured by operational models nor observed by existing buoys.

Tropical cyclones. The U.S. east coast, Gulf of Mexico and Hawaii are subject to extreme wind and wave environments produced by tropical cyclones (i.e. hurricanes and tropical storms), storms that are notably absent from European waters. These systems may affect operations even if they do not directly traverse a wind farm. Hurricanes thousands of kilometers away from the U.S. mainland can generate large swells and turbulent sub-surface currents in these waters. Hurricane embedded tornado activity is an overlooked issue that may also be a threat to wind farm facilities.

According to IEC specifications, most offshore wind turbines are classified as Class 1A, corresponding to a maximum annual average wind speed at hub height of 10.0 m s⁻¹, an extreme 50-yr gust (3-s) of 70 m s⁻¹, and a peak turbulence intensity of 18% when hub height sustained speeds are at 15 m s⁻¹. The appropriateness of Class 1A turbines within the diverse geography of US waters will depend on site-specific conditions and an assessment of
Data Gaps and Strategies to Address Them

hurricane probability and severity. The IEC is also giving consideration to a more robust turbine classes to specifically address hurricanes and typhoons.

New guidelines tailored to wind turbine deployment in U.S. waters have been developed that are tailored to regionally-specific extreme conditions (including load cases corresponding to hurricanes) while addressing discrepancies between IEC and American Petroleum Institute (API) standards. BOEM relies on API standards to govern the design of U.S. offshore structures. The new guidelines can be found in publications by the American Bureau of Shipping (ABS), which pertain to both bottom-mounted and floating installations (ABS, 2013a and 2013b; ABS 2011).

Extra-tropical cyclones (“Nor’easters”). Although northern European and U.S. offshore waters do experience similar intense extra-tropical cyclones responsible for high waves and wind, their frequency and local coastal morphology can produce vastly different wind and wave responses. For example, most northern European wind farms tend to be sited in shallow waters (< 15 m), limiting maximum wave heights. However, many wind farms planned for the offshore waters of the U.S. are located in deeper waters (> 30 m) that are subject to much higher significant and extreme wave heights (> 20 m). Long-lived (> 48 h) Nor’easters can generate excessive wave heights given their long fetches and high winds. For example, the December 1992 Nor’easter produced significant wave heights in excess of 9 m approximately 15 km southeast of New York City, with extreme wave heights estimated at 16 m (Colle et al., 2008). In the same vicinity, Hurricane Sandy (October 28, 2012) caused even greater (by 2 to 3 m) significant and extreme wave heights. However peak wind speeds were well within the design envelope of commercial offshore wind turbines.

Icing from sea spray. In the coastal waters of the North Atlantic and the Great Lakes, icing can be produced from sea spray lifted from the water surface into a sub-freezing atmosphere and deposited on ship or wind turbine infrastructure. These situations usually arise when very cold air (e.g., below -10°C) is advected from the interior of the North American continent on strong northwesterly winds over the relatively warm waters of the (unfrozen) Great Lakes and Atlantic. Air-sea surface temperature (SST) differences can exceed 30°C in some cases. An algorithm developed by Overland et al. (1986) and incorporated into NDBC real-time buoy
Data Gaps and Strategies to Address Them

reports calculates icing accumulation rates for ships up to 70 m in length using wind speed, air temperature, and SST.

Lightning. Lightning can occur quite frequently over the U.S. coastal waters, particularly off the southeast and mid-Atlantic coast, where the atmospheric and ocean SST gradients (a consequence of the proximity of the Gulf Stream) create conditions favorable for convective and extra-tropical storm development. Right now, the only high resolution lightning database available is from the commercially operated National Lightning Detection Network. This data is not publicly available, and the flash detection and location accuracy over offshore waters is diminished due to the sparseness of direction finders (detection instrumentation). Wind turbines in offshore waters will likely be favorable targets for lightning strikes, possibly enhancing the frequency of “triggered” lightning.

Filling in the Gaps — Recommendations
Existing marine observation networks, consisting mostly of 3-m buoys and Coastal-Marine Automated Network (C-MAN) stations, were not designed to describe the structure and dynamics of the MABL, especially features such as the sea breeze and offshore LLJ. Moreover, relatively few of these stations have sufficient periods of record or data continuity to allow for developing long-term climate statistics required for wind resource assessment purposes, a necessary condition for establishing confidence in the wind regime and bankability of a commercial wind farm. Most satellite observation networks are similarly deficient for offshore site characterization given their limited temporal and spatial resolution, and lack of coverage close to shore (within approximately 25 km). Only recently has NOAA, in conjunction with other government, commercial and academic entities, begun deployment of several coastal and offshore observation platforms including remote sensing technologies such as high frequency radar systems (e.g. CODAR). Greater emphasis is needed to exploit sites-of-opportunity, such as the Chesapeake Light Tower, US Navy & Air Force towers, and other similar offshore platforms, for anchor observations. In addition to serving as benchmark measurement facilities, these platforms can be used as references to test and deploy innovative sensing technologies to meet the offshore wind industry’s needs. Government agencies in partnership with academic and private sector stakeholders can play a significant role in securing the use of these sites, and help frame the shared commitment to long term upkeep of the observation systems and platforms.

While these terrestrial and satellite-based data sets add quantitative and qualitative value to offshore wind resource assessment and design condition analysis, additional tools, techniques, and measurements are required to effectively integrate them into a meaningful representation of the MABL, surface, and sub-surface ocean characteristics. Initial goals of developing the data sets and modeling tools to better describe the metocean environment for assessment, construction, operation, and decommissioning of offshore wind farms include:

- Perform data assimilation exercises to develop a robust, representative climatology and extremes data set of the key metocean variables such as the 3-D wind field in the MABL, wave spectra, and sub-surface currents. Similar techniques can be applied to
Data Gaps and Strategies to Address Them

near-term forecasting of metocean conditions during wind farm construction and operations.

- Establish “anchor” stations at representative sites as the nexus of comprehensive field campaigns or longer term studies designed to validate modeling efforts by instituting new measurements on and near such facilities.

- Leverage data from other sources, including existing long-term coastal observation networks (such as Rutgers Coastal Observation Lab) and previous intensive marine studies (e.g., 2004 New England Air Quality Study; Fehsenfeld et al., 2006; Pichugina, Y.L. et al., 2012).

- Develop and validate new and lower cost measurement technologies and approaches targeted for the specific needs of offshore wind energy applications. For example, buoy-based lidar can provide wind profiles on a nearly continuous basis from a minimum height of approximately 20 m above the water surface upwards to 200 m and beyond.

Achieving these goals with a long-term vision would benefit from a road mapping exercise with the cooperation of the key stakeholders, including the relevant public, private and academic sector entities. The following paragraphs elaborate upon some of these goals.

Ocean/wave/wind/atmospheric coupled modeling. The representativeness of in situ point measurements is limited, although surface and satellite remote sensing platforms promise do extend the spatial coverage of real-time observations. Wind and wave hindcasting through numerical modeling therefore becomes a necessary tool to supplement and fill in the gaps resulting from the scarcity of measurements and the limitations inherent in the applicability of various theoretical formulations. Several numerical wave hindcasting studies (using wave models such as WISWAVE, WAM, MIKE 21 SW, WAVEWATCH-III and others) have been conducted for the Pacific, Atlantic and Gulf coasts of the United States using buoy observations as ground truth as well as statistical analyses to quantify hindcast skill in reproducing measured wave heights, periods, and direction attributes. While coupling wind and wave modeling is important, coupling to oceanic models may be even more important since the thermal influences of the ocean on the atmosphere (specifically the impacts of currents, winds and precipitation on SST) play a critical role in the response of the MABL.

New offshore observation networks—use of existing and deployment of new measurement platforms. A cost-effective and prudent approach to development of a long-term network of observations necessary to sufficiently characterize the offshore metocean environment for wind farm development would be to leverage the existing coastal network of fixed platforms located in U.S. waters. One such station is the Chesapeake Light, a C-MAN station formerly operated by the U.S. Coast Guard (USCG) and now managed by the DOE. It is situated in 12 meters of water 25 km east of the entrance to Chesapeake Bay. As stated above, there are also a number of sites-of-opportunity associated with military, traditional energy and other private sector groups that could be more aggressively exploited for reference platforms.
In the case of the Chesapeake platform long-term (1984 - present) station measurements include air temperature (22.3 m Above Mean Sea Level [AMSL]), wind speed and direction (43.3 m AMSL), and pressure (23.4 m AMSL). Additional instrumentation could be installed on the facility to measure the 3-D wind fields, turbulence, temperature, pressure, and humidity. Instrumentation could include fast-response 3-D sonic anemometry, fast response temperature and humidity measurements to capture the heat and moisture fluxes that determine (and can be used to estimate, through similarity theory) the wind shear profile, and other ancillary measurements such as precipitation and irradiance. A crucial component for capturing the structure and dynamics of the lower MABL, however, would be the deployment and testing of lidar technologies. The DOE has plans to embark on such an instrumentation program at Chesapeake Light (Cline et al., 2013).

Lidarss use the light energy backscattered from microscopic particulates or aerosols being transported by the wind. Depending on the specifications of the different models from several manufacturers, lidars can measure wind speeds at multiple levels throughout the MABL (upwards of hundreds of meters), with a vertical resolution down to 20 m at a minimum height of 10 to 30 m. This offers two distinct advantages: first, a measurement directly at hub height is possible and no extrapolation from a point measurement is necessary; and second, vertical profiles over the entire rotor plane will be available. A lidar installed on an offshore structure would provide wind profiles on a nearly continuous basis upwards of 200 – 300 m, a deep enough layer to capture any feature (e.g. low-level jets) within and just above the rotor plane of the largest wind turbines.

Buoy-based lidar systems, although still in developmental phase, offer a promising technology to completely capture the metocean environment from the sub-surface well into the higher levels of the MABL. Thus, they can provide most of the necessary observations available from fixed-based offshore towers at a fraction of the cost. These systems, once proven to deliver high quality, continuous data, could form the basis of an offshore observation network that will provide measurements adequate for offshore wind energy assessment and provide valuable information for other marine stakeholders such as the NWS, the Federal Aviation Administration, and the Department of Defense.

Surface and subsurface environment. To characterize the near-surface and sub-surface ocean environment, additional buoys (e.g. 3-m discus) should be deployed in regions targeted by the
BOEM as “Wind Energy Areas (WEA) with high wind potential for possible commercial leasing.” These additional buoys should make standard metocean measurements, including wind direction, speed, and gust; air and sea temperature; and wave energy spectra from which significant wave height, dominant wave period, and average wave period are derived. Direction of wave propagation will also be measured on the buoy. An ADCP will provide current profiles from the sea bottom to the ocean surface. At least one buoy-based lidar system should be deployed in each region. Such an offshore instrumentation deployment will result in a simultaneous observation of key metocean variables, from the sea bottom to the ocean surface and upwards of 300 m in the MABL.
CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

A need exists to improve metocean data quality, coverage and access to overcome the siting, design, cost, reliability and operational challenges of the emergent offshore wind energy in the United States. The direct societal benefits at stake are jobs, economic growth, environmental benefits, and energy security. To move forward means reducing scientific and technical uncertainties, accelerating deployment, attracting investment, and demonstrating viable operations while simultaneously ensuring environmental, health and safety stewardship. The data and modeling need calls for strengthening collaboration among public-private stakeholders, researchers, operators and policy makers to establish more open exchange and sharing of data, metadata, simulations and models. It is increasingly urgent that the barriers for efficient data collection, quality control, archiving and access be overcome to improve understanding that will expedite offshore resource assessment, project design and development, and operations.

To address metocean related challenges confronting the US offshore wind industry, it is important for the weather-energy enterprise to understand the nature of these challenges and commit to working collaboratively on a sustained basis. Specific recommendations for this collaboration include, but are not limited to, the following:

- A comprehensive assessment of offshore wind industry metocean information needs and creation of a national needs-based science and technology roadmap;
- The establishment of “anchor” measurement facilities in strategic locations tailored to metocean characterization for offshore wind energy applications, whereby observational techniques follow standardized protocols and data are shareable among interested stakeholders;
- The development of workable frameworks whereby metocean measurement campaigns funded by private offshore project development activities share data to support collaborative public-private research;
- Acceleration of field testing and acceptance of innovative measurement systems, such as buoy-based profiling lidar, to complement traditional metocean measurement practices;
- Standardization and centralization of an open access portal or other tool for “foundational” data and information, including early stage research results;
- Targeted research studies, including the advancement of modeling techniques at multiple spatial and temporal scales, that promote improved understanding of dynamic processes and land-sea-ocean interactions in the atmospheric boundary layer, particularly in regions where significant offshore wind development is anticipated;
- Establishment of organized initiative, coalitions or national centers for collaborative research, development and planning for offshore energy; and
Conclusions and Recommendations

- Development of policy and funding mechanisms or trusts to sustain a relevant backbone of integrated metocean observation systems, test beds, modeling programs and research.
REFERENCES


References


