THE NEED FOR IMPROVED MET-OCEAN DATA TO FACILITATE OFFSHORE RENEWABLE ENERGY DEVELOPMENT

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Abstract

This paper discusses the offshore renewable energy industry's needs for improved met-ocean information and recommends strategies for how important data gaps can be bridged through multi-disciplinary collaboration. Examples of specific atmospheric and surface-subsurface data parameters are given. Near term focus should be placed on the needs of wind energy development, which is the most commercially advanced offshore energy technology, especially along the east coast of the U.S. and the Great Lakes where current development activity is primarily focused.

Key words: offshore renewable energy, marine and hydrokinetic technology, offshore wind energy, met-ocean data, multi-disciplinary collaboration

1. INTRODUCTION

Offshore renewable energy is an emergent global industry that has the potential to supply significant amounts of non-carbon derived electricity to coastal cities and regions. There are five different sources of energy within the marine environment that offshore energy conversion technologies are targeting: wind, waves, tides, currents, and ocean thermal. A barrier to achieving the potential of these technologies is the need for accurate meteorological and oceanographic ("met-ocean") information to evaluate the generation potential, economic viability, and engineering requirements of prospective offshore energy projects over their planned design life. Currently available met-ocean data, instrumentation and models are generally inadequate to supply all the information required by stakeholders to support large-scale project deployment. These marine energy technologies are heavily dependent on the design environment – namely wind, wave, current, and thermal conditions – which impact different aspects of project viability: construction, performance, reliability, accessibility, safety, and economics, among others. It is contingent on the marine-weather-energy community to help resolve these issues for this promising industry.

This paper presents a high-level review of the offshore renewable energy industry's needs for met-ocean information and recommends strategies for how important data gaps can be bridged through multi-disciplinary engagement to better enable the advancement of offshore renewable energy deployment. This paper places an emphasis on wind energy technology because its near-term advancement would more immediately benefit the country's renewable energy objectives. Wind energy is the most commercially advanced offshore renewable energy technology, and multiple megawatt-scale wind development projects are underway in the United States.

This review is intended for stakeholders who are interested or engaged in the met-ocean aspects of offshore renewable energy planning, development, operations, and regulations. This paper is also intended to be a resource to inform decision- and policy makers and other interested parties about the importance of advancing the knowledge of met-ocean issues, thereby removing barriers to the advancement of offshore renewable energy. The ultimate goal is to encourage collaborative efforts within the greater IOOS community and with other stakeholders who aim to advance the met-ocean science in ways that support the current and future needs of offshore renewable energy.

2. OVERVIEW OF OFFSHORE RENEWABLE ENERGY OPPORTUNITIES AND CHALLENGES

Recent assessment studies have shown that offshore renewable energy technologies have the potential of producing significant amounts of clean electricity in the United States while offsetting carbon-based generation (NREL, 2010; EPRI, 2011; GTRC 2011). For example, according to the National Renewable Energy Laboratory (NREL 2010), 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. Although this estimate does not account for siting constraints and other factors, it does indicate that offshore winds could provide a rich energy resource and a vast economic opportunity, if tapped.

In June 2010, the US Department of Energy (DOE) and the US Department of Interior (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) 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 plants.

The Bureau of Ocean Energy Management (BOEM) — a part of the DOI—has jurisdiction over the granting of leases and easements in federal waters for ocean energy technologies under the Energy Policy Act of 2005. This responsibility includes the designation of Wind Resource Areas (WRAs) where commercial leasing activity is targeted on a state by state basis. Thus far, WRAs have been defined off the coasts of six mid-Atlantic and New England states. The regulation of met-ocean measurements in federal waters related to energy development is also BOEM's responsibility.

The Wind and Water Power Program in the DOE Office of Energy Efficiency and Renewable Energy hosted a public meeting on June 23-24, 2011 in Crystal City, VA. The meeting focused on identifying the critical met-ocean measurements and data needed for successful deployment of offshore renewable energy technologies, including wind. A summary report is available (Energetics, 2012).

In late 2011, the DOE issued several contracts to address offshore energy RADC data needs through establishing new research and measurement initiatives, and supporting the development and testing of advanced instrumentation. 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.

In summary, the offshore renewable energy industry requires accurate met-ocean information to evaluate the energy potential, economic viability, and engineering requirements of offshore project sites. For example, a very limited number of US offshore wind observations are currently available at hub height for wind turbines, and current modeling approaches are inadequate to accurately reconstruct hub height wind speeds using the sparse surface wind data obtained by current observational technologies (i.e., buoys). In addition to meeting industry needs, regulatory agencies 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 O&M processes. Figure 1 presents a graphical representation of several met-ocean phenomena that can impact offshore energy systems.

3. ROLE OF MET-OCEAN DATA IN ADDRESSING PROJECT PLANNING, DESIGN AND OPERATIONAL NEEDS

All phases of an offshore renewable energy project require knowledge of local met-ocean conditions. Met-ocean data applications are relevant to the five main phases of a project's lifetime: siting; assessment, design and permitting; construction, certification and commissioning; operations and maintenance (O&M); and decommissioning. Met-ocean data is essential to defining the design and operating conditions for power plants over their anticipated lifetimes (typically 20+ years). Structures and components need to 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 integrated foundation and tower structures. Understanding these dynamic forces is made more complicated for wind energy systems by the inherent rotating rotor component atop the tower.

Wind turbine power curves are principally defined according to the wind speed, air density, and turbulence intensity conditions at the hub height (typically 100 m $\pm$ 20 m) of the turbine. During the siting/assessment phase of a project, these parameters are normally derived from regional data sources and models. During the next phase, one or more on-site measurement systems are typically instituted to provide better certainty about these met conditions. The relationship between on-site observations and those at regional reference stations are used to derive long-term statistics for the site.

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 can help estimate wind resource characteristics and power production potential. However, the reliability of modeled datasets relies on using models that can integrate and extrapolate values appropriately, both in time and space.

The family of data needs can be broken into two groups: atmospheric and surface-subsurface. Atmospheric data covers an array of meteorological parameters extending

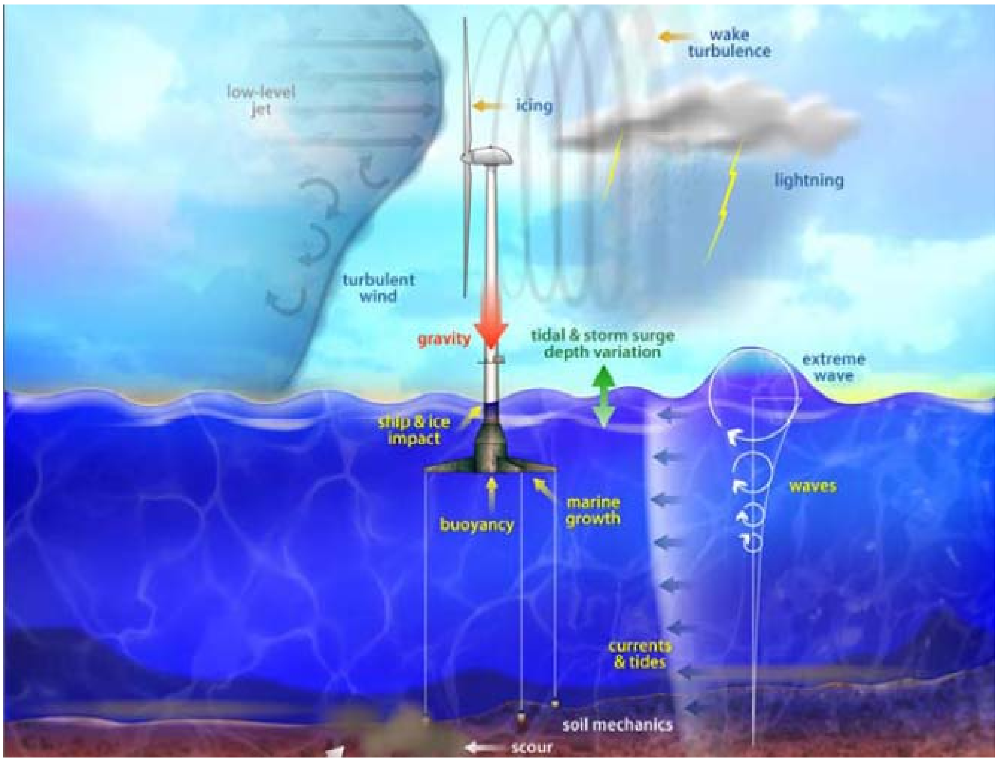

Figure 1: Illustration of relevant met-ocean parameters for an offshore wind energy system (Source: NREL)

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, sub-hourly
- **Speed Frequency Distribution** - # hrs/yr within discrete speed intervals
- **Wind Shear** – change of wind speed with height
- **Wind Veer** – change of direction with height
- **Turbulence Intensity** – standard deviation of speeds sampled over 10-min period as a function of the 10-min mean speed
- **Wind Direction Means, Time Series & Distribution** – joint with speed
- **Extreme Gusts** (3- and 5-sec) **and Return Periods** (50- and 100-yr)
- **Vertical Wind Speed** – coincident with horizontal speed measurements
- **Others:** stability (i.e., ΔT), air temperature, RH, pressure, air density, solar, 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, extreme wave height, height frequency distribution, directional 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, vertical temperature profile, salinity, conductivity, chemistry
- **Ice Conditions** – Mechanical properties and thickness
- **Bottom Conditions** – soil type, slope, marine growth

Many of these parameters are of relevance to MHK energy technologies. Altogether, there is a multitude of met-ocean information needed at different time and space scales to enable future offshore renewable energy development.

4. DATA GAPS AND STRATEGIES TO ADDRESS THEM

Energy project developers, operators, and approval authorities are presented with a variety of challenges in accurately characterizing met-ocean conditions, particularly where wind-wave interactions create dynamic load conditions on technologies that are unique to the marine environment. Data needs and modeling efforts require detailed knowledge about the marine atmospheric boundary layer, 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 the needs for the targeted development of offshore renewable energy.

For wind energy systems, there is a need for 4-dimensional (x, y, z, and t) data that accurately capture the physical and dynamical processes that operate within the met-ocean continuum. There are several phenomena that define the mean and extreme met-ocean 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 to accurately observe and predict the complex interactions of wind and waves.

Although roughly two thousands turbines have been deployed in the offshore waters of Europe, using the characteristics of that environment to predict expected conditions in the waters of the U.S. is inappropriate. Hurricanes and Nor'easters are phenomena that produce extreme wind-wave conditions unique to the U.S. coastal waters. Moreover, mesoscale circulations, such as the sea breeze and low level jets, can produce local wind and wave maxima much closer to the coast than under more typical conditions. 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. 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.

Current marine observation networks mostly consist of 3-m buoys and C-MAN stations, and were not designed to describe the structure and dynamics of the marine atmospheric boundary layer (MABL). 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. Similarly, satellite observation networks are deficient for offshore site characterization, due to their limited temporal and spatial coverage. Only recently has NOAA, in conjunction with other academic and government entities, begun deployment of several coastal and offshore observation platforms with increased technological capabilities that more accurately and thoroughly sample the MABL. These platforms include both in-situ and remotely sensing technologies such as high frequency radar systems (e.g. CODAR). While all of the aforementioned terrestrial and satellite-based data sets add quantitative and qualitative value to offshore RADC 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.

Filling in the Gaps—Recommendations

Initial goals of developing the necessary data sets and modeling tools to sufficiently describe the met-ocean environment for assessment, construction, operation, and decommissioning of offshore wind farms and MHK energy technologies include:

- Perform atmospheric and wave modeling exercises to develop a robust, representative climatology and extremes data set of the key met-ocean variables such as the 3-D wind field in the marine boundary layer, wave spectra, and sub-surface currents;
- Establish "benchmark" 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;
- Assimilate data from other sources, including existing long-term observation networks, and other imminent met-ocean studies, to validate models over longer spatial and temporal scales; and
- Develop new and lower cost measurement technologies and approaches targeted for the specific needs of offshore renewable energy technologies. For example, buoy-based lidar systems can provide wind profiles on a nearly continuous basis from a minimum height of roughly 20 m above the water surface upwards to 200 m and beyond, but they require more testing.

Achieving these goals with a long-term vision requires a road mapping exercise with the cooperation of the key stakeholders, including the relevant public, private and academic sector entities.

A 3-year project (DE-EE0005372) was initiated by the DOE in late 2011 to address this family of goals. Awarded to AWS Truepower, this project is titled *National Offshore Wind Energy Resource and Design Data Campaign—Analysis and Collaboration*. Its objective is to supplement, enhance and facilitate on-going multi-agency efforts to develop an integrated national offshore wind energy data network while promoting strong public-private sector collaboration. This project has identified IOOS as an important stakeholder and potential collaborator.

Specific goals are to:

- assess the quality and relevance of existing data sets, observation networks, and modeling efforts;
- identify gaps in data and research needed to facilitate project and industry development;
- support enhancement of existing observation networks, deployment of new instrument platforms (e.g., remote sensing), and initiation of targeted field projects and modeling work to better describe the physical processes governing the met-ocean environment;
- use the knowledge gained by the above analyses to make recommendations on offshore wind resource assessment protocols, including atmospheric, ocean surface, and sub-surface measurements;
- provide the industry with the basis for modifying existing guidance for the siting, design, operation, and maintenance of offshore wind turbines and associated infrastructure; and
- establish an infrastructure for sustainable public-private collaboration on addressing offshore resource assessment, design condition, and operational industry needs.

The results of this initiative will provide a comprehensive definition of relevant met-ocean resource assets, needs, accepted modeling approaches, and standards designs, together with recommended pathways for meeting future industry data and design certification requirements.

5. CONCLUSIONS

The potential for offshore renewable energy development in the United States is substantial and is only beginning to be tapped. Coordinated efforts within the marine scientific and engineering communities and with the appropriate government agencies are needed to mitigate or eliminate data-related offshore market barriers through a process involving strong stakeholder collaboration that addresses offshore resource assessment, design condition definition, and operational industry needs. Given IOOS's historical role in supporting ocean observing systems for the benefit of many marine disciplines, it is important that this activity broaden its scope to include the interests of the emerging offshore renewable energy industry. In the near term, focus should be placed on the needs of wind energy development, which is the most commercially advanced offshore energy technology, especially along the east coast of the U.S. and the Great Lakes where current development activity is primarily focused.

Specific recommended IOOS activities include:

- Understand the specific met-ocean data needs of the offshore renewable energy sector via expanded stakeholder collaboration, including current DOE sponsored activities;
- Pursue ways to satisfy the data needs of this new sector and to leverage the resources of involved public and private entities;
- Encourage and support targeted measurement and modeling programs as well as data sharing mechanisms;
- Participate in industry road mapping exercises that develop long-term strategies to address the met-ocean data needs of the offshore renewable energy sector.

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