



National Open-ocean Energy Laboratory

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List of Acronyms

ADCP	Acoustic Doppler current profiler
ADV	Acoustic Doppler Velocimeter
AIS	Automated identification system
BOEM	Bureau of Ocean Energy Management (Dept. of Interior)
CDP	Congressionally Directed Program
CECS	College of Engineering and Computer Science (FAU)
CFR	U.S. Code of Federal Regulations
CHAPC	Coral Habitat Area of Particular Concern
CMSS	Condition Monitoring System Software (SNMREC)
CODAR	Coastal ocean dynamics application radar
DOE	U.S. Department of Energy
DOI	U.S. Department of Interior
EFH	Essential Fish Habitat
FAU	Florida Atlantic University
FEM	Finite Element Method
FONSI	Finding of No Significant Impact
FWCC	(Florida) Fish and Wildlife Conservation Commission
GCAFA	Golden Crab Allowable Fishing Area
GW	Gigawatt = 10^9 Watts
HAPC	Habitat area of particular concern
HBOI	Harbor Branch Oceanographic Institute (at FAU)
IEC	International Electrotechnical Committee
ISO	International Standards Organization (or reference to intermodal container)
MHK	Marine HydroKinetic
MIMOSA	Maintenance Information Open Systems Alliance
MRE	Marine renewable energy
MTB	Mooring and telemetry buoy
MW	Megawatt = 10^6 Watts
NEPA	National Environmental Policy Act
NGO	Non-governmental organization
NMFS	National Marine Fisheries Service (NOAA)
NOAA	National Oceanic and Atmospheric Administration (Dept. of Commerce)
NREL	National Renewable Energy Laboratory
NSWCCD	Naval Surface Warfare Center Carderock Division
OCPGS	Ocean Current Power Generation Simulator (SNMREC)
OCS	Outer Continental Shelf (submerged lands beyond the 3-mile limit)
OTEC	Ocean thermal energy conversion
OWL	Ocean current turbine testbed Wireless Link (SNMREC)
RANS	Reynolds-Averaged Navier Stokes
R&D	Research and development
RF	Radio frequency
RMS	Root mean square
ROI	Return on investment
SAS	Serial-attached SCSI (Small Computer System Interface)
SeaTech	Institute for Ocean and Systems Engineering (CECS/FAU)
SCADA	Supervisory, Control, and Data Acquisition

SCMS	Safety Control and Monitoring System (SNMREC)
SFOMF	South Florida Ocean Measurement Facility (NSWCCD)
SHIELD	System Hazard Indication and Extraction Learning Diagnosis (SNMREC)
SME	Subject Matter Expert (ISO/IEC)
SNMREC	Southeast National Marine Renewable Energy Center (at FAU)
STEM	Science, technology, engineering and math
TRL	Technology Readiness Level
UNOLS	University-National Oceanographic Laboratory System
USACE	U.S. Army Corps of Engineers
USCG	U.S. Coast Guard
WEC	Wave energy conversion

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Executive Summary

Under the authorization provided by Section 634 of the Energy Independence and Security Act of 2007 (P.L. 110-140), in 2009 FAU was awarded U.S. Congressionally Directed Program (CDP) funding through the U.S. Department of Energy (DOE) to investigate and develop technologies to harness the energy of the Florida Current as a source of clean, renewable, base-load power for Florida and the U.S. A second CDP award in 2010 provided additional funding in order to enhance and extend FAU's activities. These two CDPs in 2009 and 2010 were combined into a single DOE grant, DE-EE0000319, and are the subject of this report.

Subsequently, in July 2010 funding was made available under a separate contract, DE-EE0004200. Under that funding, DOE's Wind and Water Power Program designated FAU's state of Florida marine renewable energy (MRE) center as the Southeast National Marine Renewable Energy Center (SNMREC). This report discusses SNMREC activities funded by the DE-EE0000319 grant, but will make reference, as appropriate, to activities that require further investigation under the follow-on grant.

The concept of extracting energy from the motions of the oceans has a long history. However, implementation on large scales of the technologies to effect renewable energy recovery from waves, tides, and open-ocean currents is relatively recent. DOE's establishment of SNMREC recognizes a significant potential for ocean current energy recovery associated with the (relatively) high-speed Florida Current, the reach of the Gulf Stream System flowing through the Straits of Florida, between the Florida Peninsula and the Bahamas Archipelago. The proximity of the very large electrical load center of southeast Florida's metropolitan area to the resource itself makes this potential all the more attractive.

As attractive as this potential energy source is, it is not without its challenges. Although the technology is conceptually simple, its design and implementation in a commercially-viable fashion presents a variety of challenges. Beyond the technology itself (and, especially, the effects on the technology of the harsh oceanic environment), it is important to consider the possible environmental impacts of commercial-scale implementation of oceanic energy extraction. Further, because such implementation represents a completely new undertaking, the human resources required do not exist, so education and training programs are critical to eventual success.

This project, establishing a national open-ocean energy laboratory, was designed to address each of these three challenges in a flexible framework allowing for adaptive management as the project proceeded. In particular:

- the technology challenge, including resource assessment, evolved during the project to recognize and address the need for a national testing facility in the ocean for small-scale prototype MRE systems developed by industry;
- the environmental challenge became formalized and expanded during the permitting process for such a testing facility; and
- the human resources/societal challenges, both in terms of the need for education and training and in terms of public acceptance of MRE, stimulated a robust outreach program far beyond that originally envisioned at SNMREC.

While all of these activities at SNMREC are ongoing, a number of significant milestones (in addition to the contributions listed in the appendices) were achieved under the auspices of this award. These include:

- Planning and site selection for the first-phase test facility, offshore of Dania Beach, FL, including some equipment for the facility, submission of an Interim Policy Lease Application to the U.S. Department of Interior's Bureau of Ocean Energy Management (BOEM), and completion of an Environmental Assessment by BOEM and a positive Consistency Determination by the State of Florida;
- Measurements using acoustic profilers of the current structure and variability in the vicinity of the site under a variety of weather conditions, seasons and time durations;
- Design and implementation of instrumentation for the first phase of the offshore testing facility, the wet- and top-side data acquisition systems, and shore-based analysis systems;
- Implementation of a laboratory-scale dynamometer system to test generators of up to 25 kW capacity using real-world (simulated) forcing;
- Completion of 24 months of (airborne) marine vertebrate surveys and associated analysis of sea turtle offshore activity, marine mammal vocalization research, and ocean current turbine hydrodynamic noise characterization;
- Development of a secondary-school (nominally grade 10) curriculum about hydrokinetic MRE, "Energy from the Oceans: The New Renewable", and training of over 200 high-school teachers in its use and in how to educate their colleagues in application of the material in the classroom;
- Presentations to over 50 interested civic groups in the region on various aspects of MRE in SE Florida
- A series of public lectures to over 600 residents of south Florida to provide broader education on MRE.
- Development of an interactive kiosk for installation in local science museums.

These, and other accomplishments detailed in this report contribute to a comprehensive ongoing program at the SNMREC to support the affordable, responsible, and achievable commercialization of MRE. Many of the tasks of this award are continued or will be verified with follow-on funding DE-EE0004200, and its goal: the installation of the world's first offshore ocean current turbine testing and validation capability.

Introduction

Alternatives to the use of fossil fuels for the generation of electrical power on large scales have traditionally included hydropower and nuclear fission; more recent, and welcome (Hanson, 2009) additions to this diversity of energy sources include wind power, biofuels, and, the topic of this project, marine renewable energy (MRE). The maturity of the technologies associated with each of these varies widely, and the very recent upsurge of interest in MRE is reflected in its technological infancy. Indeed, even the extent and amount of the potential energy resource in the oceans is not fully understood, which has motivated the U.S. Department of Energy (DOE) to underwrite several resource assessment investigations (e.g., EPRI, 2011; GTRC, 2011; LM-MS2, 2013).

MRE associated with the kinetic energy found in the oceans (e.g., waves, tides, and ocean currents) is commonly referred to as marine hydrokinetics (MHK). This project aims to assist accelerating utility-scale commercialization of MHK technologies, and more specifically, ocean current energy. The basic concept of capturing open-ocean current energy and converting it to electricity is simple to imagine (a rotor is turned by water flowing past, which turns the shaft of a generator), but actual implementation is difficult. The development of turbines for tidal stream applications has succeeded in meeting many of the challenges involved, but open-ocean sites have additional challenges. For example, most tidal streams are relatively shallow, and mounting tidal turbines on masts is possible. The deep water of open-ocean current sites, however, precludes this. Consequently, redesign of turbine nacelle characteristics is required in order to accommodate the need for buoyancy control. Because many potential open-ocean current deployment sites are also busy shipping lanes, minimizing sea surface presence of the equipment is important, suggesting that moored systems are more appropriate. This suggests that positive buoyancy control (or perhaps some use of lifting surfaces) is needed and the turbines will be “flying” in the current not unlike an underwater kite. The dynamics of this “flight” present additional challenges and make a solid understanding of the nature of the resource and its variability all the more important.

To illustrate the multi-disciplinary challenge of MHK projects, all potential MRE deployments must also consider the environment in which they are to occur, and the Straits of Florida (the initial focus area for U.S. ocean current energy projects) present an environment that is in many respects unique. On average, the Florida Current carries some 31 million cubic meters per second of warm, tropical seawater from the Gulf of Mexico to the open Atlantic Ocean, and with it comes a wide variety of marine flora and fauna, some protected by federal and state laws and regulations. Benthic communities, including protected coral reefs, abound in both deep and shallow waters. In addition to commercial shipping interests, the Straits are a recreational mecca for boaters and fishers alike, and there is also a significant U.S. Navy presence in the area.

Still, the prospect of tapping a several gigawatt energy source within a few miles of a load center of the same magnitude has piqued the interest of urban planners and energy developers alike, and a systematic approach to the various challenges of harnessing the Florida Current has begun.

A testing facility for prototype turbines was selected as the most pressing need to move forward open-ocean current technology. Such facilities exist (in Europe and Canada) and are under development in the U.S. for wave and tidal devices; no open-ocean current testing and evaluation facilities exist anywhere. During a workshop funded by this project, a broad consensus among academics, industrial developers, and government officials confirmed this selection. Accordingly, the focus of the work in this project

evolved to the development of such a facility offshore of southeast Florida, in the Florida Current. Thus was the Southeast National Marine Renewable Energy Center (SNMREC) established by the State of Florida and subsequently designated as a national center by DOE.¹

To immediately service the early maturity of proposed commercial ocean current projects, the SNMREC envisioned two phases of field testing capabilities. The first, intended for small scale turbines (1/4 scale or smaller), would service industry needs to explore basic system stability, behavior, and dynamics, as well as demonstrating energy capture techniques (Figure 1). Later, as concepts progressed, the SNMREC would provide half- to full-scale prototype testing capabilities. These systems would be evaluated for power generation performance, component performance, installation methodologies, operations/maintenance strategies, and reliability/survivability. This project is focused on the first phase, small scale ocean current turbine demonstration and evaluation.

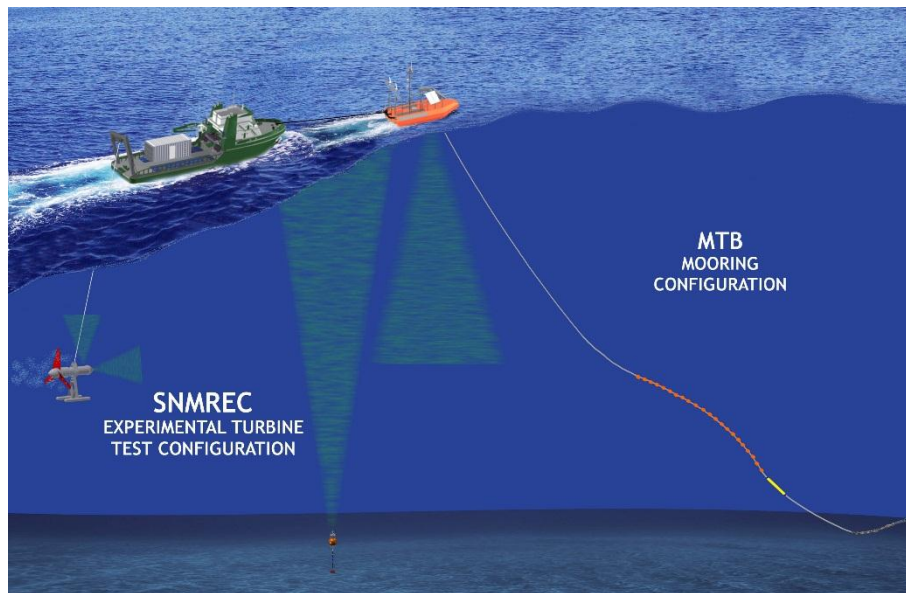


Figure 1: SNMREC's proposed configuration for small scale ocean current turbine demonstration and testing.

This project has helped to achieve the U.S.'s first Environmental Assessment of an MHK project on the Outer Continental Shelf, rich data sets for environmental and resource baseline characterization of the Gulf Stream in the Florida Straits, scaled turbine testing core infrastructure, various scientific and technical solutions for ocean current turbine design, deployment, and testing, as well as broad engagement of the public to achieve awareness and train a future workforce. Much of the work begun by this project is continued with award DE-EE0004200 to achieve the world's first operational offshore small-scale ocean current turbine demonstration and testing capability, scheduled to be online during FY 2014.

¹ To avoid confusing nomenclature, "SNMREC" will be used throughout this report in reference to both the original state designated organization (Florida Center of Excellence for Ocean Energy Technology) as well as its federal identity (Southeast National Marine Renewable Energy Center).

Background

The objective of this project, proposed as a Congressionally Directed Program (CDP) for fiscal year 2009, was to establish a national resource for testing and evaluation of ocean current energy technologies prior to commercial-scale implementation. A follow-on CDP was awarded in 2010 (DE-EE0003274) to extend the originally-proposed work and enhance contributions. This award was ultimately combined with the first under the original project designation (DE-EE0000319) due to its similarity in scope. This technical report describes performance of both awards, as combined. To discriminate between award scopes, subsequent references to tasks include a prefix to denote fiscal year award, e.g. FY 2009 CDP Task 1.0 is denoted as Task 09-1.0.

Task 09-1.1, originally scoped to include preparation of offshore assets and hardware to build a turbine test barge, was placed on hold pending National Environmental Policy Act (NEPA) compliance review. As a result, the task was subdivided to isolate items under NEPA review, Subtask 09-1.1.1 from other items determined to qualify for Categorical Exclusion, Subtask 09-1.1.2. Further, after deliberation with the U.S. Department of Interior, DOE approval was granted to re-program the scope of Task 09-1.1.1 as offshore turbine testing regulatory effort, without NEPA hold. Finally, additional approval was granted to allow minor adjustments to task performance if overall award amounts are not affected, intent of original scope is maintained, and no additional indirect costs are accrued. Resulting modifications in subtask scope are reflected in the descriptions below.

The SNMREC proposed to address this project from three perspectives: technology, environment, and education/outreach. The second CDP further refined the approach with methodologies: research, monitoring/demonstration, and education/outreach. As a university-designated center, the SNMREC naturally seeks to achieve solutions with researcher/graduate student teams where appropriate, but on-staff engineering resources are also levied directly towards applied challenges. Vendors and sub-contractors were also identified when university resources were not sufficient to meet either deliverable needs or project timelines.

Fiscal Year 2009 Congressionally Directed Program Tasks

Task 09-1.0 – Technology Testing and Resource Monitoring

Through investment in critical field facilities, this task advances the development of an ocean current energy field testing capability. This full-service mobile ocean-going laboratory concept would be capable of deploying small scale ocean current turbine prototypes for demonstration testing and environmental monitoring. To install such a capability, this task focuses on addressing core capability and infrastructure needs related to data collection, management, and archiving, as well as environmental characterization during turbine testing. Various federal and state agencies require obtaining leases, permits, and/or permissions to install such a capability, and as such, the SNMREC is contributing to and coordinating development of new regulations and processes under this task.

Subtask 09-1.1.1 – Regulatory Permitting and Licensing

To test small scale ocean current turbines offshore for extended periods, permission and various approvals are required. Because the proposed testing locations are on the U.S. Outer Continental Shelf (OCS), federal licensing jurisdiction for the activity resides with the U.S. Department of Interior's Bureau of Ocean Energy Management (BOEM). BOEM established an interim lease program (IP) to allow for

technology research and ocean measurement activities until a final framework was developed. It is under the IP that a lease is sought for small scale turbine testing. This lease involves development of an Environmental Assessment (in the case of no significant impacts) which requires applicant input and significant participation. In addition, permissions are also required from, for example, the U.S. Coast Guard, U.S. Army Corps of Engineers, etc. This subtask includes effort and travel to obtain the necessary leases, permits, and permissions to install and operate small scale ocean current turbine offshore test capabilities.

Subtask 09-1.1.2 – Sensors

To capture environmental parameters necessary for quantifying the performance of turbines under test, novel sensors and methods are needed. Ocean current inflow must be characterized to correlate rotor behavior with predicted performance. Therefore, this subtask will develop a methodology to capture free-stream water velocity incident to ocean current turbines under test. As well, turbulence is important to measure and characterize for turbine design criteria and to adequately account for dynamics during performance measurement and this subtask will acquire and prepare specialized sensors to measure open ocean turbulence acoustically. Finally, measurements during at-sea testing will require specialized storage and telemetry. This subtask prepared an initial design for such a stand-alone system.

Subtask 09-1.2 – Data Communications and Management

This subtask will configure new systems to ensure that the data from the field tests is handled appropriately. The outcome of this subtask will be a system for data communications and management of data collected in the field during turbine testing. Initially, test deployments will be attended; in the future, longer-term deployments will operate in a stand-alone mode. In either case, platform-to-shore communications are critical to real-time data acquisition. The installation of a long-range, high-bandwidth marine data and video communications system serves this purpose and is the partial focus of this subtask. Storage and management of data must allow for protection of proprietary data acquired when commercial developers are testing prototypes and also allow for public access to non-proprietary information of value to other organizations and individuals, and this all must happen in a standardized and efficient manner. This subtask involves acquisition and configuration of a scalable and flexible data management system, including server and appropriate software, while leveraging state-of-the-art internet database technologies.

Task 09-2.0 – Impact Studies

Although using the Florida Current for power generation is a decades-old idea, no MHK deployments of any significant scale or duration have been fielded. Potential environmental impacts are largely unknowns. In association with the process of obtaining appropriate deployment permits, the SNMREC will undertake studies of issues that are universally recognized to present risk. This task will address two of the most publicly visible: potential impacts on sea turtles and marine mammals. Understanding these potential impacts and recommending methods for mitigating them will be the outcomes of this task.

Subtask 09-2.1 – Sea Turtles

With respect to potential impacts on sea turtles (all species of which are endangered), this subtask involves a program to ensure that impacts on these species are minimized. Activities will include: First,

an extensive review of peer-reviewed and grey literature and data mining of historic turtle occurrences in the offshore areas will be conducted. This will include reviewing literature for possible turtle interactions with previously deployed structures in the marine environment and estimating and prioritizing project impacts by species, life history data, and season. This subtask will also determine sea turtle abundance, density, and species assemblage in the offshore area through contracted aerial surveys (stratified random design, to be coordinated with marine mammal surveys). Approaches will be recommended that involve temporal, spatial, mechanical, and behavioral methods to prevent interactions between the gear and marine turtles, and studying modifications to structures that will reduce, prevent, or minimize marine turtle-equipment interactions and/or interference.

Subtask 09-2.2 – Marine Mammals

All marine mammals – perhaps as many as a dozen species altogether – living in or migrating through the Florida Straits are federally protected. In order to understand their potential interactions with power generating equipment, this subtask will initiate a comprehensive study of the issue. This project will begin marine mammal population surveys in conjunction with the sea turtle surveys discussed previously. In addition, novel automated methodologies will be explored to allow less expensive and more thorough aerial cataloging of marine animals using video and still photo capture techniques. Finally, algorithms will be explored to better identify and characterize marine mammal vocalizations when captured using passive acoustic monitoring techniques.

Task 09-3.0 – Education and Outreach

Members of the public, especially in Florida, are concerned and highly skeptical whenever presented with new energy-development proposals involving their coastline. Successful development of the Florida Current as an energy resource will require public education about the methods and risks, the alternatives, and the opportunities. This project will undertake to initiate work in both of these areas, and these subtasks will result in improved communications with and involvement in the overall field testing effort by the public and by the professional community.

Subtask 09-3.1 – Professional Workshop/Conference

There exists a community of professionals in academia, government, and industry with interest in the development of hydrokinetic energy resources. It is important to provide opportunities for these groups to exchange ideas and advance methods to move the field forward. Two meetings will be held within the framework of this project. The first will be a small workshop to include participants drawn from the MHK community to discuss common issues. We anticipate that this workshop will provide important input to a technology roadmap for hydrokinetic development.

The second meeting will be an international conference organized to bring together global experience on the environmental issues associated with the development of ocean energy and any relevant expertise in other hydrokinetic engineering systems, to share issues and technology and to learn from each other. The program and audience would include individuals from academia, the private sector, and local, state and national governments. A conference planning committee will be convened immediately on budget confirmation and professional societies and other groups will be alerted very quickly to target a time frame within about 18 months. The conference would be managed by the FAU Florida Center for

Environmental Studies, which has more than a decade of experience in managing workshops and conferences at state, national, and international levels.

Subtask 09-3.2 – Public Outreach/Education

Outreach, in the form of public meetings, is an ongoing effort at the SNMREC, and it will continue under the umbrella of this project. Because the commercial development of the Florida Current as an energy resource is a long-lead-time endeavor, it will also be effective to include in this activity the K-12 educational system. Therefore, a new effort to be initiated with funding from this project will be the development of summertime teacher workshops for primary and secondary educators. An approach of “teaching the teachers” in a hierarchical fashion will be implemented, by selecting a small group of educators for intensive preparation and then employing them as peer mentors for larger groups at follow-up workshops.

Task 09-4.0 – Project Management

This task involves the management of all efforts to satisfactorily perform the preceding technical, scientific, and outreach tasks. Reports on project progress and milestones are to be provided in accordance with the Federal Assistance Reporting Checklist following the instructions included therein.

Fiscal Year 2010 Congressionally Directed Program Tasks

Our systematic approach to second-year CDP follow-up activities to create an MHK field test capability builds upon first-year tasks and includes the following objectives:

- conducting basic research on the oceanic environment (including ecosystems) of the Florida Current;
- undertaking research and development of infrastructure for testing and environmental monitoring;
- working with agencies at all levels on appropriate approaches to standards development and to regulatory issues;
- creating and nurturing a community of industrial and governmental stakeholders; and
- developing a robust public outreach and educational program.

More detailed descriptions for each task and subtask follow.

Task 10-1.0 – Research

This topic includes investigating use of active acoustic (sonar) and video monitoring to detect potential underwater collisions; design/bench-test of an underwater observatory; evaluating and developing a scale-model testing capability; and modifying the test platform for compatibility with a variety of prototype configurations.

Subtask 10-1.1 – Collision and Remote Sensing Feasibility

Although the probability of collisions involving test equipment and marine life appears to be low, it is nonetheless a matter of concern as some of the species involved are listed as endangered or threatened. Consequently, research into methods of collision avoidance is appropriate. A first step is to detect potential collisions in advance, and this subtask will investigate acoustic techniques for this

purpose. Accordingly, we will acquire equipment for this purpose (off-the-shelf sonar systems, for example) and test their capabilities for the purpose of early collision detection. We expect to be able to provide enough lead time that mitigating steps can be taken; these steps will be the topic of future research.

Subtask 10-1.2 – Underwater Observatory Design and Bench Test

The SNMREC's resource measurement instrumentation has, to date, consisted of stand-alone current profilers and vessel-deployed temperature/salinity sensors. Linking the underwater systems to provide automated data acquisition and enhancing them with thermodynamic measurements will provide crucial information about Florida Current variations on small scales relevant to ocean-energy production. This subtask will design such an automated system and test critical components in the laboratory. The design will be used in the future to acquire the necessary instrumentation and to plan for installation.

Subtask 10-1.3 – Scale Model Testing Implementation

A critical step in the development of new technologies for extracting ocean energy is testing scale models, and, along with a national testing facility for open-ocean devices, the SNMREC's plans to include scale-model testing capabilities. This subtask will investigate ocean current turbine scaling and will evaluate proposed scaled testing recommendations.

Subtask 10-1.4 – Generalize Deployment Capability

Initial deployments of the FAU prototype turbine system, to be made from an appropriate work boat, will be tailored to that particular unit. In the longer term, a capability to deploy prototypes across a wider range of sizes and configurations is needed. As different weight, configuration, and size (physical and electric) devices are to be tested, a deployment platform with increased capability will be required. This subtask will investigate the development of numerical modeling tools to design and perform desktop evaluations of moored full scale ocean current turbine test beds.

Task 10-2.0 – Monitoring/Demonstration

The goal of this topic is to enhance the studies initiated under Task 09-2.0 by extending automated remote sensing of sea turtles to marine mammals; monitoring north-south current variations in vicinity of deployment site; developing and demonstrating testing/evaluation protocols using an in-house turbine prototype; demonstrating efficacy of performance and health monitoring technology using the prototype; and continuing development and input to national regulatory framework, especially with respect to ocean current turbine demonstration projects.

Subtask 10-2.1 – Include Marine Mammals in Remote Sensing Monitoring

Aerial monitoring for sea turtles was initiated in Task 09-2.1 for a one year survey period. Because marine mammals can also be included with observations, this subtask will extend aerial surveys for both for one additional year. This will allow capture of seasonality and other annual variations in animal behavior for baseline studies. In addition, because marine mammals are sensitive to noise generated and propagated in the water, a study will be conducted to numerically model ocean current turbine flow noise. Finally, the marine mammal acoustic identification work begun in Task 09-2.2 will be completed.

Subtask 10-2.2 – Extend Current Monitoring Array to North-South Direction

The SNMREC's measurements of the Florida Current as a function of distance off-shore have been underway for some time. These observations are serving to document the time variability of the E-W structure of the flow. This subtask will acquire and deploy additional equipment to monitor the N-S (along-flow) variations as well, as part of an ongoing resource monitoring and assessment effort. Also, as turbines are under test, it is important to understand far-field flow conditions, especially with respect to seasonality. Therefore, this subtask will explore remote sensing options for long term and large spatial scale measurement of the Gulf Stream.

Subtask 10-2.3 – Deploy and Monitor In-house Prototype to Demonstrate Protocols Consistent with Best Practices

A SNMREC in-house experimental research turbine, presently in fabrication, is designed to serve as a proof-of-concept device for the testing capability. Operational testing protocols will be developed, tested, and rehearsed using this device, so that future tests of developer prototypes can be standardized in an optimal fashion. This subtask will develop and demonstrate those protocols based on best practices at facilities such as, for example, the European Marine Energy Center in the UK and in collaboration with the DOE national marine renewable energy centers in the US. As well, various technical aspects of turbines have yet to be standardized (operating environment characterization, performance measurement and assessment, design criteria, etc.). Under this subtask, the SNMREC's experts will provide input to various international and domestic efforts to develop such consensus (IEC/ISO, NREL protocols and efforts, etc.).

Subtask 10-2.4 – Implement and Demonstrate Prognostics and Health Monitoring System on Prototype

For future commercial-scale deployments, it will be critical to monitor system performance parameters and to develop prognostic methods for the underwater systems. It is thus appropriate to include this critical issue in early-stage prototype testing. This subtask will implement and demonstrate a Prognostics and Health Monitoring (PHM) system on the in-house research turbine and prepare a second system for use on other early-stage developer prototypes. It will also investigate scaling of this system for application on scale-model versions of these prototypes.

Subtask 10-2.5 – Programmatic Environmental Impact Statement Roadmap

At-sea testing of demonstration-scale ocean current turbines will be conducted under the auspices of an Interim Permit (IP) from the US Department of Interior Bureau of Ocean Energy Management, the cognizant agency for energy development (including renewable energy) on the continental shelf outside a three-mile state jurisdiction zone. Under the IP, testing of a limited range of prototype devices will be possible, and the SNMREC will use these early-stage tests to develop protocols and procedures for devices of all types. This subtask is an extension of effort scoped in Task 09-1.1.1 to help refine regulatory process and acquire a lease to conduct ocean current turbine testing activities on the U.S. OCS.

Task 10-3.0 – Education and Outreach

This task is intended to extend and expand teacher-education programs and organize a series of public forums to engage the community. Activities are expanded from those proposed under Task 09-3.0, using the first year's milestones as building blocks.

Subtask 10-3.1 – Professional Workshop/Public Forums

A series of public forums to engage the public, elicit comments and stimulate dialog and expand existing outreach initiatives are proposed. The pilot will be held in southeast Florida with subsequent forums in Florida or the southeastern region of the United States and will include members of the community, federal and state agencies, universities and industry.

Subtask 10-3.2 – Public Outreach/Education

The SNMREC's science curriculum and educator training manual is enhancing existing high school science programs by integrating MHK-related curriculum, while maintaining Florida Sunshine State Standard requirements. The teacher education efforts from Task 09-3.2 will be expanded to include additional counties and teachers. This project will build on the previous year's curriculum, training sessions and evaluations from conducted teacher workshops. Curriculum support will be provided to engage up to 90 eleventh and twelfth grade teachers in one-day workshops.

Task 10-4.0 – Project Management

This task involves the management of all efforts to satisfactorily perform the preceding technical, scientific, and outreach tasks. Reports on project progress and milestones are to be provided in accordance with the Federal Assistance Reporting Checklist following the instructions included therein.

Results and Discussion

Since the scope of this project is broad and includes R&D work, modeling, field measurement, event organization and planning, curriculum development, and applied engineering, each subtask describes in detail the effort completed, any details regarding results, and other pertinent data. In many cases, thorough treatment of the topic is referenced in a publication(s) that resulted from the effort, while interesting and noteworthy items are included in this report.

Task 09-1.0 – Technology Testing and Resource Monitoring

Subtask 09-1.1.1 – Regulatory Permitting and Licensing

A 2009 memorandum of understanding was signed between the Federal Energy Regulatory Commission (FERC) and (what is now) the Bureau of Ocean Energy Management (BOEM², Dept. of the Interior) to manage proposed MRE projects according to their location relative to the 3-mile offshore limit. SNMREC activities, planned to occur on the Outer Continental Shelf (OCS) about 15 miles offshore, fall within BOEM's purview with respect to initial permitting of an activity. Earlier, BOEM had served notice that it would consider proposals for such projects under its *Interim Rule* (MMS, 2007; the *Final Rule* [MMS, 2009] was adopted on 29 June, 2009). Because SNMREC had initiated discussions about its proposed activities prior to the Final Rule's adoption, advice from BOEM motivated SNMREC to continue its application process through the Interim Rule process. After considerable discussion of draft documents, SNMREC submitted its application to BOEM in June, 2011 (SNMREC, 2012), with an amended update the following February. This was the first MRE application on the OCS (BOEM had received applications for offshore wind development but none for MRE specifically). Since this was the first such application, it is anticipated that it will become precedent-setting for subsequent MRE activities on the OCS. A listing of the topics that required attention is included here as Appendix A1.

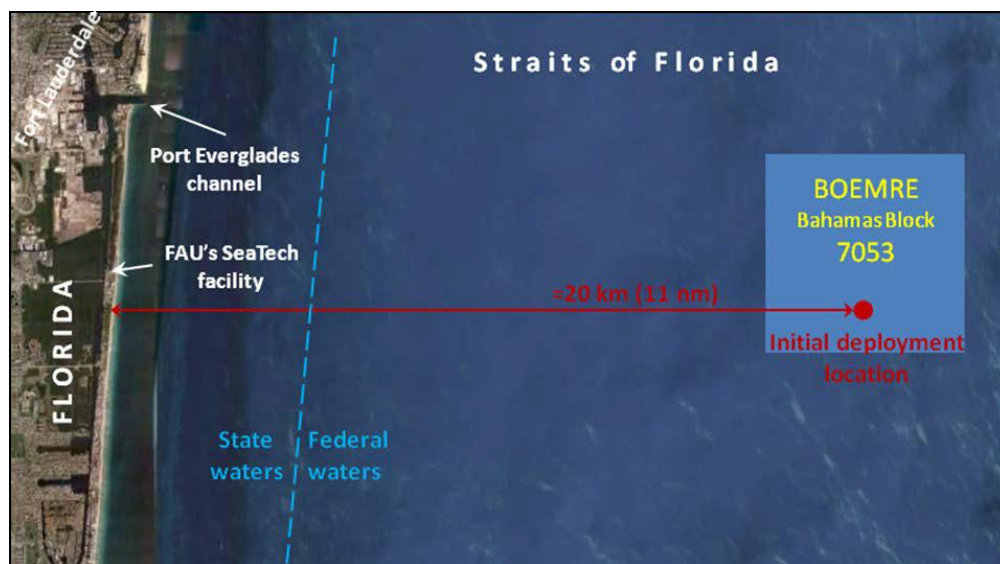


Figure 2: SNMREC testing facility site. The “Bahamas Block” 7053 is one of three requested in SNMREC's lease application, so the final position of the deployment is approximate.

The basis for the topics included in Appendix A1 is the collection of laws and regulations associated with the marine environment (Appendix A2). Although BOEM is not responsible for enforcing all of these, it is required to consult with appropriate cognizant agencies about applications, and consequently the application process (which heretofore did not exist for MRE) became rather involved. SNMREC at Florida Atlantic University (FAU) was the first to pursue a lease for ocean energy recovery on the OCS, and the SNMREC's application triggered initiation of the regulatory process for working on renewable energy

²To avoid confusing nomenclature, “BOEM” will be used here to refer to its earlier incarnations as the Minerals Management Service and the Bureau of Ocean Energy Management, Regulation, and Enforcement as well as to the current organization.

projects in federal waters. The following subsections, drawn largely from the BOEM IP lease application, discuss various factors associated with the permitting process in the context of the choice of a site.

Siting Considerations

On November 5, 2007, BOEM announced an interim policy for short-term leases on the OCS (72 FR 62673). The interim policy on Offshore Alternative Energy Resource Assessment and Technology Activities authorized the installation of offshore data collection and technology testing facilities, such as meteorological towers, in federal waters. FAU notified BOEM of its interest in a short-term lease for ocean energy research. For a variety of reasons—including activities requirements, safety and risk mitigation, anchoring and mooring constraints, proximity to port, mitigating or avoiding possible environmental impacts, and avoiding potential user conflicts—SNMREC chose to site the testing facility approximately 20 km offshore of Dania Beach, FL (Figure 2). The following discussion reviews these considerations in detail.

Activity Requirements

In order to ensure effective testing of systems that may ultimately be deployed commercially in the Florida Current, it is imperative to locate the test facility in areas where representative environmental and resource conditions exist, particularly current speed and current direction. Not all testing, however, requires maximum current conditions. Many test objectives for initial technology investigation at small device scales are more reasonably accomplished in moderate current speed conditions. Data³ regarding the local variability and ranges of current speeds within the area of the SNMREC application indicate that appropriate conditions occur where the bottom conditions are more favorable to other aspects of the project, namely mooring and seafloor device installation. The location is situated in an area away from abrupt changes in depth, rough bottom contours, and areas likely to contain benthic habitat for deep-water corals and other sensitive species. The data suggests that an east-west swath approximately 8 km wide at 26.08° N is available with current speeds regularly ranging from 0.5 m s⁻¹ to 2.0 m s⁻¹. This location is also adjacent to an area to the east which is within the maximum velocity core of the Florida Current, and that could be used for high-current testing as well. Therefore, selection criteria for the device testing location were refined based upon maximum current condition availability, identifying areas that are sufficient for moderate current condition testing, and acceptable for seafloor activities related to the testing infrastructure.

Because the initial location lies shoreward of the core of the Florida Current, surface conditions tend to be more favorable to at-sea working conditions there. This safety consideration was also a factor in SNMREC's choice of this location.

Anchoring/Mooring Constraints

The selection of appropriate seafloor characteristics for an anchor to support the proposed activity is based upon the depth and availability of an appropriate sediment layer (sand). A drag-embedment type anchor was proposed due to its high holding power, its relatively small size, its recoverability, and its effectiveness in similar applications. This anchor style is dependent upon an available minimally thick sediment layer (at least 0.5 meters) for the anchor to develop sufficient holding power. The holding power would also be augmented by a length of chain between the anchor and mooring line, further

³ Both historical datasets and more recent observations by SNMREC support this conclusion.

increasing the anchor's efficacy. Therefore, selection of suitable areas considered identifying likely occurrences of thicker sediment surface layers.

Port Proximity

Selecting a project location in close proximity to a commercial port, namely Port Everglades, was desired to facilitate convenient access to shore-based and support vessel resources, as well as the location of the SNMREC data collection facility. Port Everglades (26.1° N, 80.1° W) is approximately 27 km from the average Gulf Stream current core (26.1°N, 79.8° W), and within 22 km of the proposed SNMREC test area, which lay within the moderate currents available just west of the core.

Environmental Impact

The primary goals of the work proposed in SNMREC's Interim Lease application were to demonstrate the responsible and attainable extraction of energy from natural offshore resources while also assessing both environmental baselines (at nearby locations and at the mooring site when the deployment vessel is not on station) as well as the effects of the structures and program activity on the ocean floor and water column. This assessment work includes monitoring the potential effects of the project on migratory turtles, marine mammals, and other parts of the ecosystem.

The activities summarized in the following section were proposed to monitor the ocean floor and the water column. Both existing datasets and new observations are being used in this work. An important activity will be the establishment of an integrated ecosystem database which will serve as a repository of all data collected and will be organized in a standard format so that it can serve as an analytical tool for this and other projects in the area. This database will be made available to the public and to government agencies.

The topics discussed here reflect those raised in Cada *et al.* (2007) concerning the broader effects on aquatic environments of all hydrokinetic technologies. In the present case, the deep-water location and the steady, high-speed current automatically mitigate some concerns, but several remain. These are listed below and discussed briefly.

Proposed Benthic Environmental Studies

Possible disturbances of habitats on the ocean floor are a concern, resulting from the anchor of the SNMREC prototype system (Figure 1) and ultimately from future, industry-deployed commercial-scale systems, which may involve many anchors of various types. Detailed observations of the proposed region regarding the bathymetry and benthic habitat on the Miami Terrace are available from recent surveys related to the proposed Calypso liquid natural gas port and its pipeline benthic surveys, the CFX-1 fiber optic cable survey, the Seafarer liquid natural gas pipeline benthic surveys, a DOE-sponsored survey, and a variety of Harbor Branch Oceanographic Institute's (HBOI) Johnson-Sea-Link submersible surveys. The DOE-sponsored survey (DAL, 2012) provides especially useful data about the area under consideration. Use of these existing data in conjunction with new, detailed surveys to be conducted as part of the SNMREC activities will allow precise site selection of minimal potential effect on hard/live bottom communities. These new surveys, to be designed and conducted in collaboration with the National Marine Fisheries Service of NOAA, will provide additional data that are needed to ensure protection of bottom-community species, including hard and soft corals, shellfish and mollusks, and benthic fish

Proposed Pelagic Environmental Studies

In the water column, various potential issues related to sea turtles, pelagic fishes, marine mammals, and other ecosystem components arise. SNMREC's approach, based on discussions with marine scientists from several institutions, focused on those issues of greatest concern, described below.

Sea turtles

SNMREC is in the process of and will continue to be characterizing turtle habitat use (water and bottom) before, during, and after deployment of buoys, lines, support platforms, and turbines. The necessary data collection, already begun and involving both aerial and on-water surveys under appropriate permits, will (i) characterize the spatial and temporal distributions of sea turtles generally, and for various sea turtle species specifically, (ii) characterize baseline data on habitat use, (iii) identify species-specific concerns relative to construction, placement of the buoys, lines, and turbine, and (iv) ascertain possible long-term issues concerning sea turtles utilizing the area either on a seasonal or annual basis. Stranding response data available from the FWCC and NOAA Sea Turtle Stranding and Salvage Network could be evaluated as a preliminary measure of status and seasonal variation in sea turtle abundance and nesting patterns.

Pelagic fishes

It is well known that underwater structures attract fish (e.g., Morales-Nin, *et al.*, 2000; Relini *et al.*, 2000). Indeed, fish aggregating devices (FADs) have been the subject of considerable research. SNMREC's assessment and monitoring work began with a literature study of direct and indirect anthropogenic effects, such as fish population shifts and overpopulation, alterations in migration paths and predation rates, and decreased health associated with fish aggregating devices. Observations of aggregations in the vicinity of SNMREC's underwater structures will then be related to these results to determine possible adverse impacts of large-scale ocean energy deployments. Anecdotal reports of similar deployments in other locations (in particular, the Agulhas Current off Mozambique) suggest there are no FADs issues in steady currents of this magnitude.⁴ This will need careful verification in our location, however, and monitoring for this purpose will be in place.

Marine mammals.

Possible marine mammal interactions also require attention in parallel with turtle monitoring and aerial surveys. Because there is substantial literature, SNMREC's assessment will begin with a literature study of noise effects on marine mammals, to be followed by study of other marine mammal issues. An assessment will be carried out with an appropriate research program on this topic if it is judged that noise levels and other marine mammal effects will be a significant issue. Because turtle monitoring during deployments will involve underwater video cameras, marine mammals will also be detected, providing valuable information in assessing possible risk levels.

Noise levels associated with the operations of the turbine system in Figure 1 are likely to be well below the background of this busy shipping channel, but acoustic emissions will be measured for both their spectral characteristics and their overall levels. This measurement will ensure the protection of noise-

⁴ Paul Greyshock (personal communication) of Cyclocean, Inc., which has recently deployed turbines in the Agulhas Current near Madagascar. This anecdotal evidence suggests that the energy expended by fish to maintain position against the current may deter the development of FADs in these high-speed current regimes. Clearly, more study is needed.

sensitive marine species, and it will provide valuable information about future emissions associated with a commercial-scale deployment.

Additional considerations.

SNMREC, as a public university-based R&D center, is focused on testing and assessment of new ocean-energy technologies rather than on power generation *per se*. While the BOEM Interim Lease application did not include the provision for transmission lines to shore, commercial deployments will need them; further, the periodic testing of the generator will involve electrical fields locally. SNMREC has therefore begun a long-term study to assess the effects of electrical transmission. A three-step approach is being employed, and the first of these is part of work associated with the BOEM application. A survey and ongoing monitoring of the deployment site will be conducted to determine which species are most likely to be encountered during deployments. In the process, the emissions of the *in situ* generator will be put in the appropriate local context, and monitoring for its influence on the species locally will be ongoing.

As noted above, the installation of the equipment discussed here might attract fish; this, in turn, could attract recreational fishers as well as commercial sport-fishing operators. During turbine test runs, when the full system in Figure 1 is deployed, the equipment will be attended, so adverse effects will be avoidable. But because the mooring buoy shown in Figure 1 is intended to be a permanent installation for the duration of this work, there may be a small effect at other times. This impact should be on the scale of that associated with other such installations, NOAA meteorological buoys, in particular. As such, it is not expected to have a significant long-term effect.

Additional topside concerns include marine birds and exhaust emissions. It is inevitable that birds will roost on the buoys, as they do on all structures at sea. Although there are Class-1 air quality areas in the region (two National Parks, in particular), the emissions associated with work boats will be insignificant in the context of the nearby metropolitan area and therefore will have no impact on visibility or other measures of air quality.

Flow disturbances.

Observations both on the scale of the Florida Straits (e.g., Leaman *et al.*, 1987; Beal *et al.*, 2008) and locally near the location of the proposed SNMREC mooring (Figure 2) reveal significant vertical structure, or baroclinicity, in the Florida Current. Near the surface, current speeds can reach over 2.5 m s^{-1} ; toward the bottom at this location, they taper off dramatically so that bottom currents are only a few cm s^{-1} . These bottom speeds are confirmed by video taken by SNMREC during submersible dives.

Thus, at the seafloor, current speeds are so slow that (after the initial anchor deployment) any new sediment transport patterns will be highly localized and quite minimal. Because the anchor will be deployed in a soft-bottom, sandy “desert” area, such changes will have insignificant impact on the benthic environment. Between the surface and the bottom, it is reasonable to assert that the anchor line will create no significant impact on the flow. The primary disturbance of concern, therefore, is at the depth (and downstream) of the prototype turbine system itself during the testing periods when it is deployed.

The variations in time shown in Figure 28 cannot be resolved into mechanisms (for example, is the current surging or meandering?) with only this data. However, as discussed above, these variations (on time scales of an hour or more) suggest that there are significant spatial and temporal changes in the undisturbed current at this location, changes much larger than will be introduced by the deployment of

the SNMREC equipment. Future large-scale, commercial deployments of multiple systems are not part, and far beyond the scope, of this application.

This leaves the question of the SNMREC prototype turbine system's wake, and wakes of other systems of the same size class, to be considered. Little research on the wakes of axial-rotor water turbines of this nature is available. Relying on results from wind-power turbine research requires great care, because the Reynolds numbers of this class of ocean systems will be more than three orders of magnitude smaller than atmospheric systems. Initial results from numerical simulations at SNMREC suggest that (i) the radial expansion of these underwater wakes will be smaller than that from wind turbines and (ii) the downstream length scale for wake decay will be much less (Reza, 2010). Because background turbulence levels in the Florida Current at this location are unknown (quantitatively), precise calculations of the downstream distance at which the wake will be detectable are not possible. One purpose of the SNMREC monitoring program is to assess this distance during active testing of the experimental prototype. The equipment to be used in these deployments will include current meters as well as turbulence instruments both at the turbine and (on a work boat) downstream. Data will be obtained to allow such calculations and to verify them. A key area of research is measurement of wakes that can be scaled to other size classes of equipment and to arrays of turbines—it is such commercial-scale deployments that may introduce significant flow disturbance. Because the SNMREC turbine deployments will be intermittent, even its minor effects will happen only occasionally, so any long-term impacts should be overwhelmed by turbulence from passing cargo ships and from upper-ocean mixing due to weather events.

[Potential user conflicts](#)

Various potential user conflicts were considered when selecting the proposed lease areas, including surface traffic (commercial and military), subsurface traffic (military), and recreational and commercial fisheries. Significant and established surface traffic routes are important to avoid because the proposed activities will include infrastructure either persistently or occasionally deployed on the surface. Because the anchor and mooring systems extend throughout the water column in the installed location, subsurface traffic routes should be avoided to minimize the avoidance requirements that might be imposed. Finally, co-located commercial and recreational fisheries could be potentially affected because fishing near the proposed lease activities would naturally be limited and restricted to avoid entanglements and other potentially hazardous conditions. The following sections describe in more detail how these considerations were incorporated into the selection process for lease area(s).

U.S. Navy Operating Areas

The Naval Surface Warfare Center Carderock Division (NSWCCD) operates the South Florida Ocean Measurement Facility (SFOMF), an offshore testing and evaluation facility in the waters offshore Port Everglades, portions of which are collocated with the proposed SNMREC testing areas. The SFOMF consists of an area designated as a Restricted Area defined in Title 33 of the Code of Federal Regulations, specifically 33 CFR 334.580, and other areas designated by SFOMF as submarine operation areas and a training minefield (Figure 3).

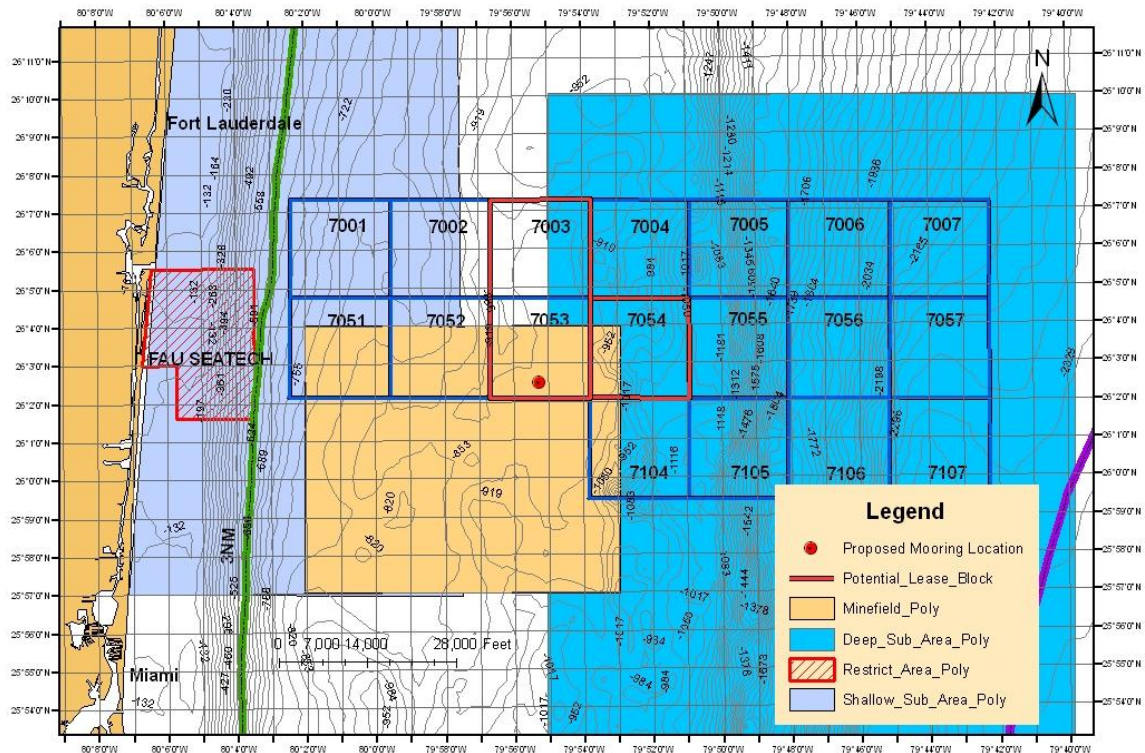


Figure 3: NSWCCD-SFOMF operating areas in relation to proposed SNMREC lease blocks. This figure, and several below, also show (outlined in dark blue) the Blocks originally under consideration for SNMREC activities; the ultimate application refers only to Bahamas Blocks 7003, 7053, and 7054, outlined in red. Others were eliminated based on factors discussed here.

A variety of U.S. Navy projects are tested at SFOMF, including surface vessels and submerged assets. While testing is dependent on unobstructed water space, the proposed location of the SNMREC test area is located approximately 14 km from the primary testing area, and the SNMREC assets would be fixed in position and could be readily avoided by both naval and civilian vessels. There are also potential opportunities to use oceanographic data collected by SNMREC to benefit the Naval testing activities. Additionally, SFOMF maintains an extensive underwater cable system used for connecting sensors for real-time monitoring. While avoidance of these existing cables is a priority, there also exists the possibility of utilizing some of these cables for SNMREC sensors in the future.

Commercial Surface Traffic

The proposed SNMREC test area is in the vicinity of Port Everglades, a deep water port adjacent to Fort Lauderdale, Florida, which services commercial passenger and shipping vessels, occasional military vessels, and a large number of private vessels. The entrance to the port is approximately 16.3 km west of the western edge of the proposed lease block, as shown in Figure 4. A surface vessel traffic study conducted in 2001 indicated that there were two primary traffic “lanes” through the area around Port Everglades, which are also shown in Figure 4. These were an inshore north-south route and an offshore south-north route. The inshore route was located approximately 11 to 15 km offshore and was used to enter and exit Port Everglades by both commercial vessels and private craft. The commercial vessels using the inshore route consisted of small and medium size coastal freighters (91 to 152 m), shallow draft tugs and barges, and local Coast Guard cutters. The offshore route was located approximately 30 to 37 km offshore and was used almost exclusively by large commercial vessels (182 to 244 m) such as freighters, tankers, bulk carriers, and deep draft tugs and barges. There was also a smaller east-west route, consisting mostly of smaller island freighters (55 to 76 m), large motor yachts (25 to 61 m), and medium sized cruise ships (123 to 182 m) making daily runs to islands in the Bahamian Archipelago.

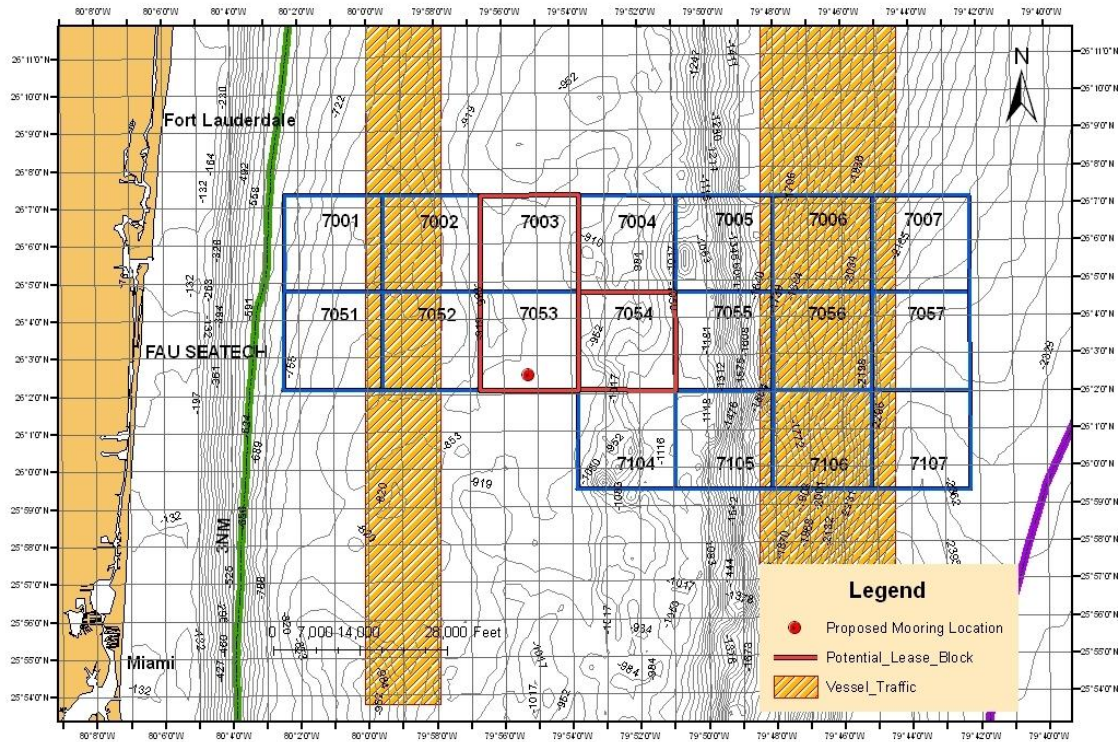


Figure 4: Typical offshore vessel transit lanes in relation to proposed SNMREC lease blocks.

The proposed SNMREC location lies between the inshore and offshore routes revealed by this survey, with buffer zones of approximately 2 km and 4 km between the lease block's western and eastern edges, respectively, and the shipping lanes (Figure 4, red outline). The proposed presence that would be located on the surface, namely the mooring buoy and turbine support vessel, would be stationary, and would appear as fixed navigational obstructions. The buoy and vessel would be equipped with lights, radar reflectors, active radar transponders, and an Automated Identification System (AIS) beacon to continuously transmit its position to all AIS-equipped vessels transiting the area. A Notice to Mariners document has also been approved for inclusion in periodic U.S. Coast Guard navigation publications,

which will require updating to adjust the mooring's position discussed here, and a request has been submitted to have the mooring buoy added to navigational charts of the area.

Fisheries

The OCS Interim Policy lease blocks off Fort Lauderdale, Florida are located either entirely or partially within two managed areas for corals and certain bottom species, or Essential Fish Habitat (EFH). These areas are the South Atlantic Fishery Management Council's Stetson-Miami Terrace Coral Habitat Area of Particular Concern (CHAPC) and a Golden Crab Allowable Fishing Area (GCAFA). The CHAPC was designated based upon recent scientific evidence of the distribution of deepwater coral species and the importance of these systems as habitat for managed species and overall biodiversity. The GCAFA was established to minimize the impact to fisheries from the designation of the CHAPC, and would allow continued fishing of certain species, including golden crab (*Chaceon fenneri*), wreckfish (*Poluprion americanus*), and tilefishes (*Lopholatilus chamaeleonticeps* and *Caulolatilus microps*). Both of these areas exist to protect damage to benthic communities and existing fisheries from activities that could impact these resources. The CHAPC and GCAFA boundaries are shown on Figure 5, along with the proposed SNMREC blocks.

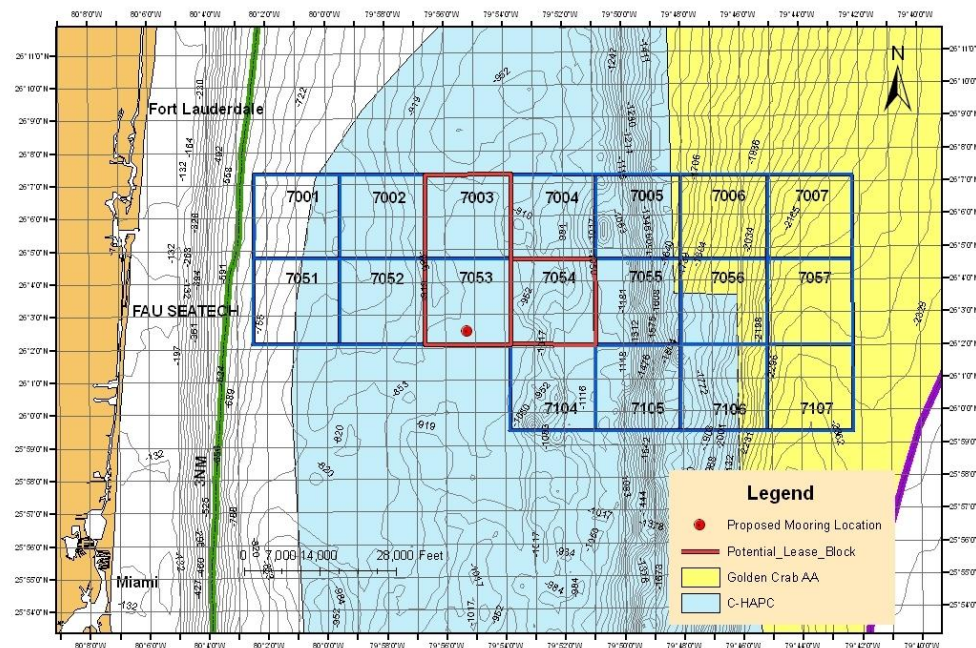


Figure 5: Fishery management areas in relation to proposed SNMREC lease blocks.

The location of these management areas was one of the selection criteria used in choosing the proposed SNMREC blocks (indicated in red), and as shown in Figure 5, the blocks are outside of the GCAFA, and within the CHAPC. In order to avoid benthic communities, available bathymetry and bottom type information was used to identify areas devoid of hard bottom, ledges, and other bottom features where communities may exist. The MTB anchor location was selected in an area where depth contours and multibeam sonar surveys noted previously indicate there are no substantial bottom features, which tends to indicate open, sandy or smooth seafloor characteristics. Prior to deployment, SNMREC will survey the anchor locations in more detail for verification of bottom type and potential coral habitats.

The final mooring location will be properly sited away from deepwater corals and associated ecosystems to avoid adverse effects to bottom habitats in the proposed area.

Results

Given these siting considerations, an Interim Lease application was prepared and submitted (SNMREC, 2012). Subsequently, an Environmental Assessment was prepared by BOEM (BOEM, 2013), and the results became available in late summer, 2013. A “mitigated finding of no significant impact” was included, meaning that, with proper mitigation measures, SNMREC’s proposed activities would not result in harm to the marine environment. The Department of Environmental Protection, as the State of Florida’s lead Coastal Zone Management Act agency, conducted a consistency determination review of the BOEM EA and FONSI. They notified the BOEM on September 25, 2013 that the issuance of a lease to SNMREC for hydrokinetic technology testing is consistent to the maximum extent practicable with the provisions of the Florida Coastal Management Program. Remaining actions outside this project include acceptance of the EA by DOE NEPA and issuance of a DOE FONSI, negotiation of a lease, acceptance of construction and operations plans for the SNMREC offshore facility by BOEM, and then actual construction and deployment. These activities will be supported with other sources of funding.

Subtask 09-1.1.2 – Sensors

Valuable scaled ocean current turbine experiments must include measurements of the turbine’s operating environment during testing to define its behavior and performance. Information and experience gained at small scales translates to larger scale evolution of equipment, where lessons learned are incorporated into future design iterations. Therefore, SNMREC’s proposed offshore test capability will require measurement of turbulence, incident flow, and telemetry to record and transmit measured data to shore-based archives.

A proposed method for quantifying high frequency water velocity fluctuations that will affect turbine performance (between 0.01 and 15 Hz) is with Acoustic Doppler Velocimeters (ADV). ADVs deployed in the open ocean require attachment to moving bodies, where velocity measurements are the difference between free stream water velocity and the motion of the sensor itself. Motion (accelerations, rotational velocity, and attitude) can be measured with the use of an Inertial Measurement Unit (IMU). Such integrated systems were only recently made available commercially and their effectiveness has not been quantified. Before trusting a new instrument, it is important to quantify its performance, and in this case, how well sensor motions are measured. Therefore, laboratory tests were performed in a controlled flume comparing static ADV measurements to motion-compensated ADV measurements (with independent motion). An M.S. Thesis has been prepared to describe efforts to evaluate instrumentation for the purposes of measuring ocean current turbulence (Lovenbury, 2013). The publication includes: (1) motion-compensation measurements with the new ADV package, (2) experimental evaluation of turbulent structures which are resolvable with the ADV, and (3) a quantification of error induced by motion-compensation in comparison with static standard ADV measurements.

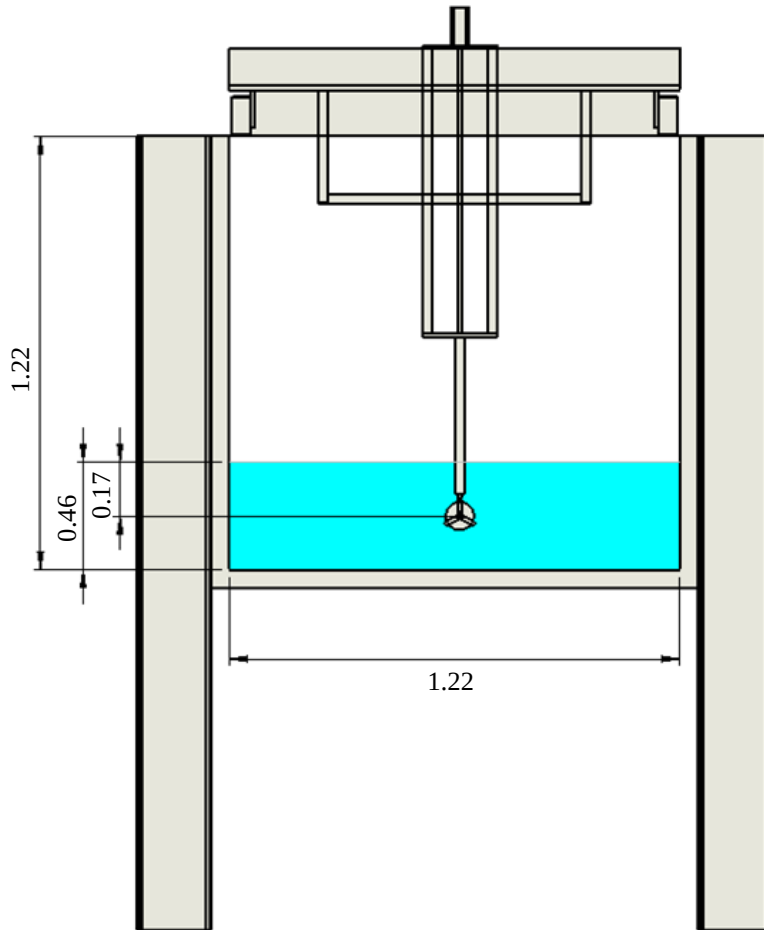


Figure 6: Test flume and experiment dimension, in meters.

Testing an ADV's ability to resolve high frequency eddies (up to 15 Hz) required eddies of that scale to be created in the test flume as they are not naturally occurring there at measureable intensities. To create eddies, a 2 cm diameter cylinder was placed in the flow ahead of the ADV. The cylinder was attached to the tow carriage so that it would travel the test flume with the ADV. The maximum speed at which the tow carriage was able to travel was 0.9 m/s. This gave the cylinder a Reynolds number on the order of 10^4 .

The test flume utilized for this experiment is located at FAU's SeaTech Campus in Dania Beach, Florida. The flume has a 1.22 m by 1.22 m square cross-section and is 18.29 m long. The water depth for the tests was 0.46 m and the ADV measurement volume was a depth of 0.17 m from the free surface (Figure 6). The tow carriage was driven using a stepper motor which was controlled by LabVIEW software. To evaluate the motion compensate ADV system both tow carriage and flume tests were conducted. During the tow carriage tests the carriage was accelerated from a stop to 0.9 m/s over a distance of 4.27 m and then maintained a constant speed for 3.66 m (3.3 seconds). During the flume tests, the tow carriage did not transit along the tow tank, but instead the flume was operated to produce a flow speed of 0.15 m/s and data were continuously collected for 30+ minutes for each test case. Rotation was added to the system by use of another stepper motor controlled by Anaheim Automation's stepper motor software controller. Heave was added to the system by use of a Parker Automation single-axis rail driven by a

servo-motor. The servo-motor was controlled by a Galil DMC 40x0 motor controller. The motors and degrees of freedom are shown as the large blue arrows in Figure 7.

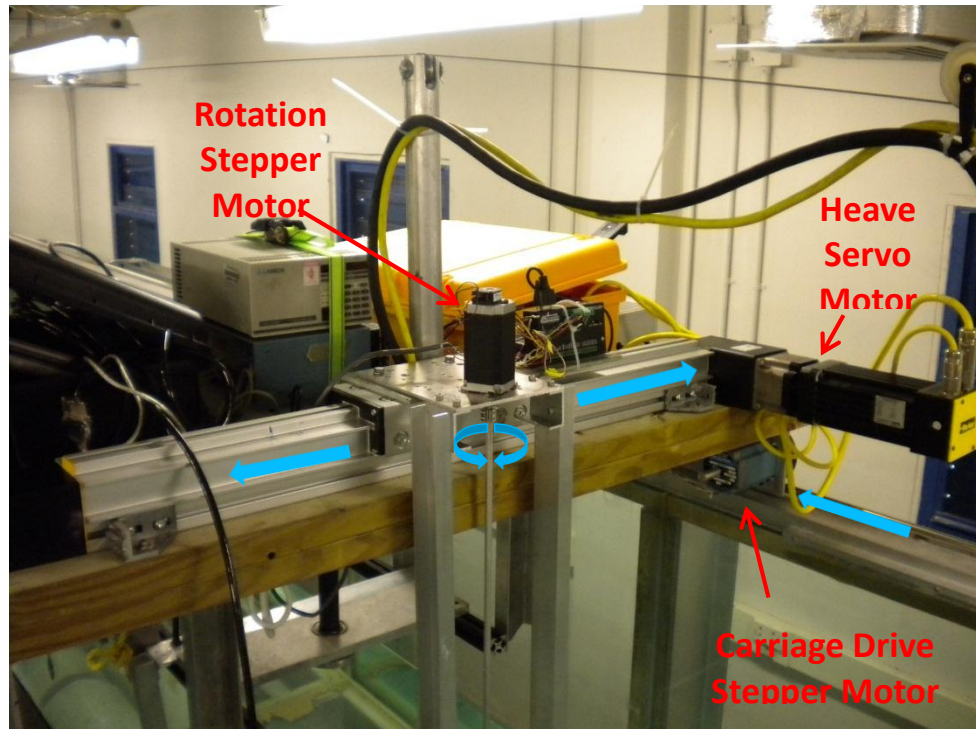


Figure 7: Experimental set up for tow carriage, with degrees of freedom available.

when turbulence intensity reaches 60 second periods, motion correction results are better than non-compensated, but are heavily affected by drift. Drift appears to increase at the same rate regardless of motion, but further testing can verify this observation. Correction in the turbulent kinetic energy spectrum results in an order of magnitude decrease in the effects of motion (Figure 8). This causes significant reduction in the error when calculating turbulence intensity, up to 100%. Based on these results, a task specified in the DE-EE0004200 award will prepare the motion-compensated ADV for data collection in the Gulf Stream and measure monthly for one year.

At-sea testing of experimental and prototype OCTs will verify predicted relationships between the flow environment, tip speed ratio, system efficiency, electrical power output, shaft power, shaft torque and rotor efficiency. However, it is important to develop an

Results show that motion compensation is vital for accurate velocity fluctuation measurement. The turbulence kinetic energy and turbulence intensity measured by the motion-compensated ADV shows significant improvement to non-motion compensated measurements, without drift effects, up to 30 second periods. On the other hand,

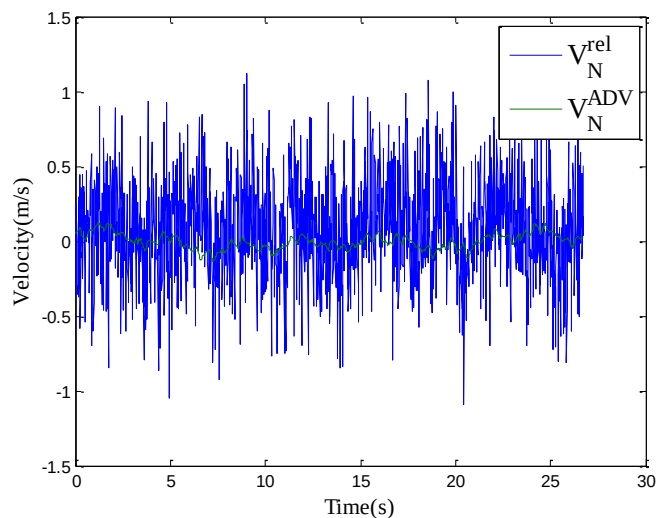


Figure 8: Effectiveness of motion-compensation for ADV measurements. Blue data indicates non-motion compensated relative water velocities measured by ADV, while the green data indicate measurements after motion of the ADV is removed.

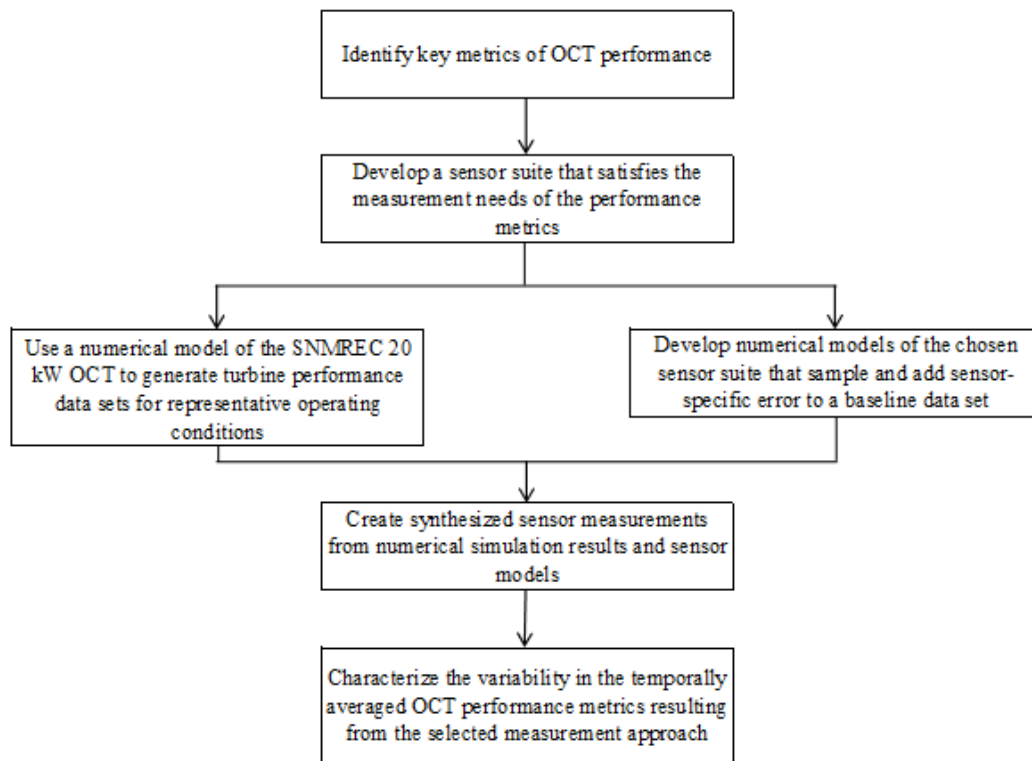


Figure 9: Approach utilized to validate sensor system parameters and data processing algorithms for OCT performance evaluations

appropriate sensing methodology to quantitatively evaluate the accuracy and limitations of the approach before offshore testing. This will help ensure that the specified sensors and sensor settings are appropriate for both the turbine under evaluation and the anticipated environmental conditions. Research conducted at SNMREC through an M.S. Thesis (Young, 2012) quantified the impacts of sensor error and update rate through the use of numerical turbine and sensor models. The primary contributions of the Thesis were: (1) identification and reduction of key OCT performance metrics into supporting measurements and calculations, (2) development and evaluation of proposed numerical sensor performance models, (3) calculation of numerically synthesized water velocity, turbine angular velocity, Euler angle and electric power output data for several representative operating scenarios, and (4) quantification of the impact of the selected sensors on calculated turbine performance metrics (tip speed ratio, system efficiency, electrical power output, shaft power shaft torque and rotor efficiency).

To measure and record the data required for the performance assessment of experimental ocean current turbines, a custom sensor package and data acquisition system has been designed. The proposed ocean current turbine performance assessment approach utilizes this turbine performance sensor and data acquisition package. The design of the sensor package is modular and adaptable to accommodate various turbine systems. It is relatively small and has the ability to operate as a fully-integrated or stand-alone system to accommodate variations in turbine data management systems.

The sensing package includes two acoustic Doppler profilers, as seen in Figure 10, which generates three-dimensional profiles of the relative current velocity. An integrated IMU measures the angular velocities and linear accelerations of a turbine, as well as tilt and heading. Angular velocity data are used

to remove the turbine's motions from profiler data to determine the relative flow velocities. This data sensing package is designed so that it can accommodate and record external inputs including rotor RPM and electrical generator output data from monitoring systems onboard a turbine. Using these data, along with generator efficiencies derived from dynamometer-generated generator efficiency calculations, an OCT's hydrodynamic and total efficiencies are quantified as a function of flow speed and rotor rotational velocity.

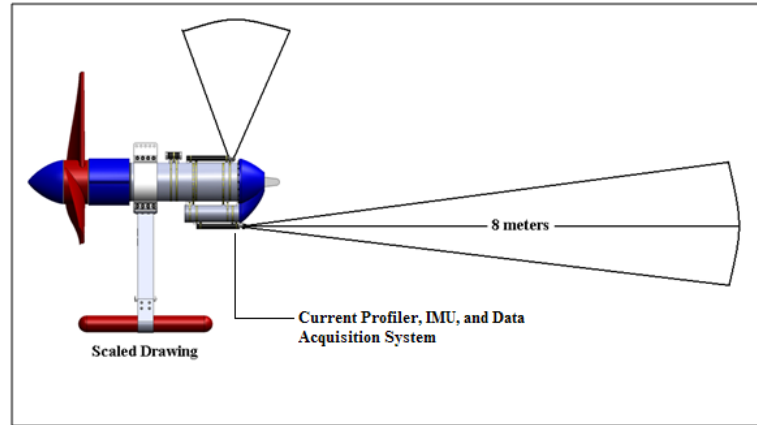


Figure 10: Rendering of the SNMREC experimental research turbine

To help visualize the impact of the selected sensors on the measurements that are used to calculate OCT performance metrics, these synthesized measurements are compared with the error-free numeric simulation output. As can be seen by the plots in Figure 11, sensor noise can significantly impact the single sample measurements used for calculating OCT performance. It is found that for a 2 m significant wave height, the selected sensor system increases the standard deviation of the calculated performance metrics for 1 min averages and an operating depth of 10 m by 5-20%. For a depth of 20 m, the OCT performance is more consistent, and the sensors increase the variability of the calculated performance metrics by between 30-50% for 1 min averages. For the same significant wave height and a depth of 10 m, the standard deviation of the 1 min averaged sensor measured system and rotor efficiencies are shown to range from 0.9 and 3.3% of their mean value. However, this can be decreased to 0.13 and 0.52% if the operating depth is decreased to 20 m and the averaging time is increased to 10 min. A peer-reviewed journal paper is in preparation to summarize results.

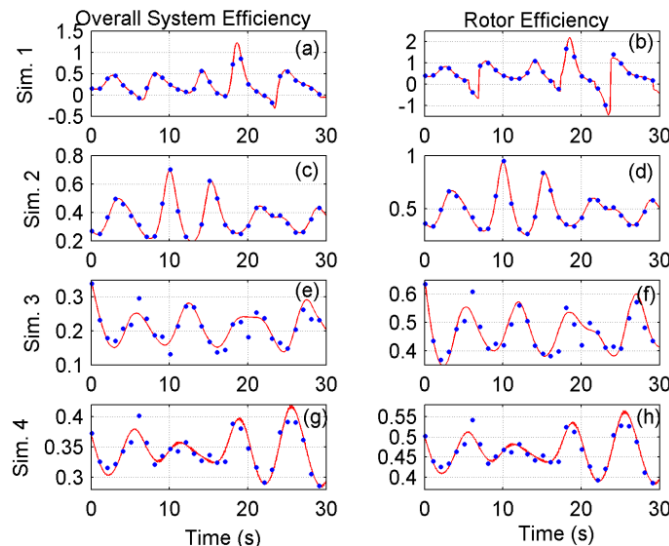


Figure 11: 30 seconds of time series for the overall system efficiency (subplots a, c, e, and g), and rotor efficiency (subplots b, d, f, and h) from the four evaluated operating scenarios calculated with and without sensor limitations.

Finally, a capability was needed to collect, access, store, and transfer data collected by field instruments before, during, and after ocean current turbine deployment. Because the proposed test configuration includes a buoy moored in the Gulf Stream (MTB, Figure 1), it was an ideal platform to consolidate remote measurements. The buoy is fitted with various telemetry (long-distance broadband RF, 4G, and Iridium satellite link), processing, and data storage capabilities. Specialized software was prepared to access and control various parameters of the system remotely, including modification of metocean sensor measurement configurations.

Additional related work was completed in performance of Subtask 10-1.2, and described in the associated section.

Subtask 09-1.2 – Data Communications and Management

It is critical that turbine drive train health and flow measurements are transmitted and archived reliably during offshore ocean current turbine testing. Because the SNMREC's proposed offshore test berths (Figure 1) are located more than 10 nm offshore (Figure 2) without direct cabled connection to shore-side infrastructure, unique challenges exist to manage sensor data. Therefore, SNMREC developed a novel architecture, new methodologies, and tools to address this need. Much of the description that follows includes effort across a variety of funding sources, but highlights elements which were supported by this award. Some of the work is scoped to be completed or enhanced during performance of the DE-EE0004200 award, as the system is readied for implementation and use for offshore turbine experiments.

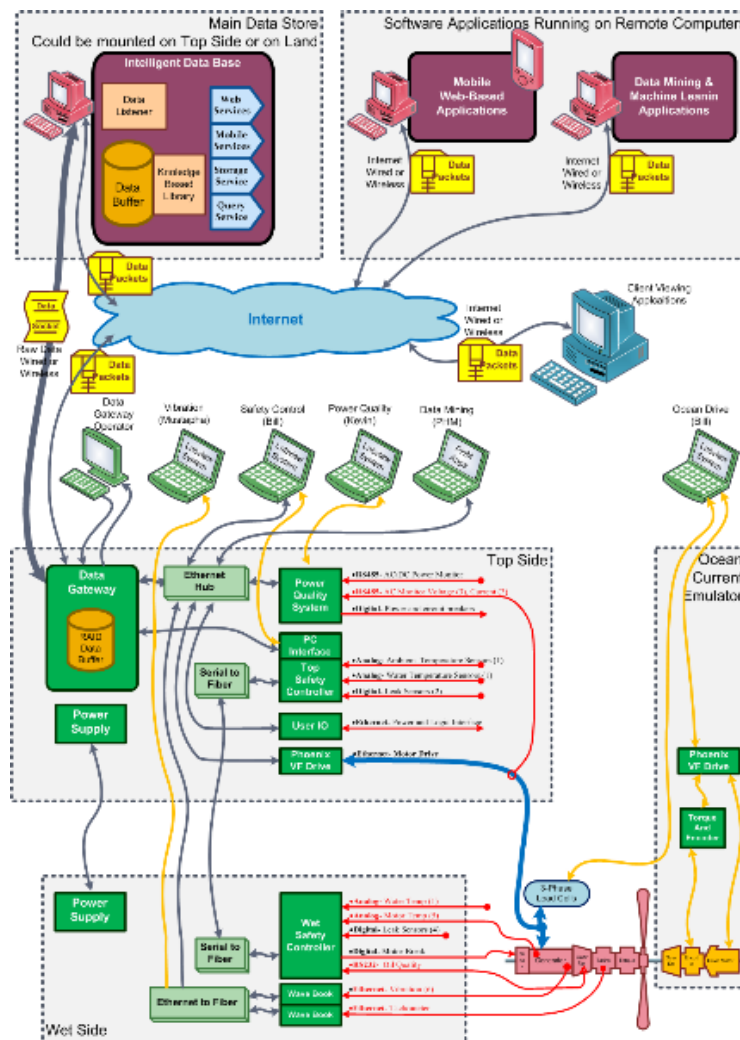


Figure 12: Overall system architecture of PHM, SCMS, and data management system for SNMREC's ocean current research turbine testing.

A unique system architecture (Figure 12) was conceived to accommodate the specialized requirements of an offshore data acquisition and management system with limited wireless connectivity to shore. The

system consists of components located undersea, aboard support platforms or vessels, and onshore. Its primary purpose is to collect and communicate critical undersea sensor measurements of a turbine to operators aboard support vessels and to an autonomous monitoring system, termed a Safety, Control, and Monitoring System (SCMS). The SCMS is intended to intercede with turbine operation if human operators cannot or do not react to critical conditions with sufficient expediency to protect human or machine safety. The offshore architecture's secondary purpose is to consolidate, synchronize, standardize, transmit, and store sensor data for use with Prognostics and Health Monitoring (PHM) assessment. This portion of the architecture leverages state-of-the-art cloud and virtualization technology to make the data available for analysis regardless of user physical location. The system's data flow and management is detailed in Figure 13. Although a collaborative effort between multiple researchers and students, the following major contributions were provided from an M.S. Thesis project (Bowren, 2012):

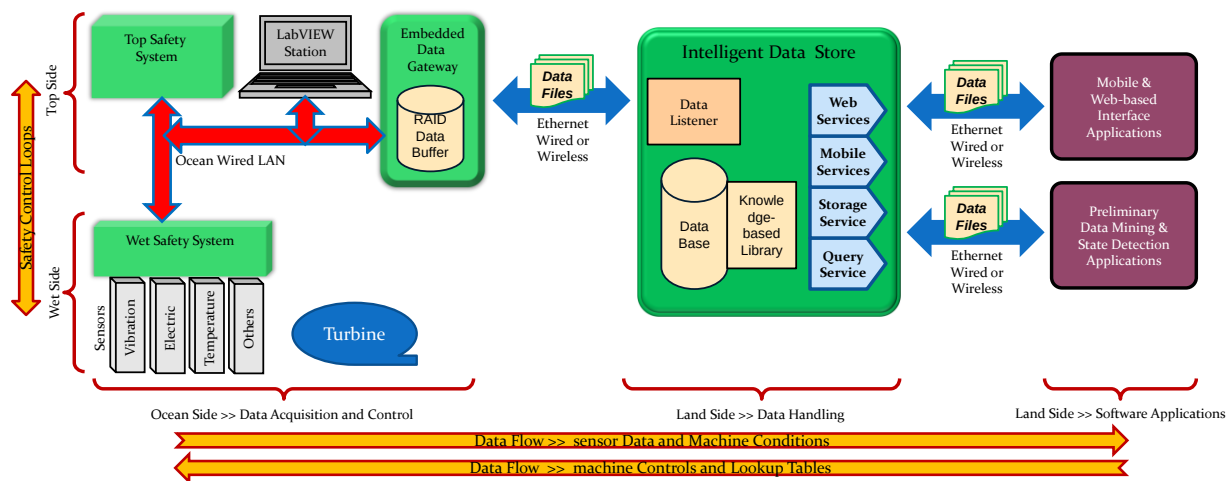


Figure 13: Data flow of the data acquisition, visualization, and storage system for SNMREC's ocean current research turbine and offshore test capability.

- A software infrastructure for condition-based monitoring.
- A practical implementation of the MIMOSA CBM and EAI web services framework for the storage and retrieval of vibration data.
- A process for loading vibration data from the collection source into a database.
- A complete demonstration of the full dataflow process from a measurement location to a web-enabled database and finally to a client application.

For convenience and portability reasons, the ship-board hardware is consolidated and installed into a conventional "science van" package used by offshore research teams. An ISO storage container is modified to accommodate personnel and equipment needed for specific research applications based upon University-National Oceanographic Laboratory System (UNOLS) and U.S. Coast Guard standards (Hawkins, 2002). The SNMREC has prepared such an arrangement in part from this funding (Figure 14).



Figure 14: UNOLS-based science van prepared to house operators and data management systems during SNMREC ocean current research turbine testing.

The System Hazard Indication and Extraction Learning Diagnosis (SHIELD) methodology was developed as a new method to perform system hazard analysis and to create more resilient system designs. SHIELD integrates state space examination into the analysis process to facilitate efficient and comprehensive identification of undiscovered risks and hazard scenarios. SHIELD requires that three phases be performed serially to achieve a system hazard evaluation: decomposition, evaluation, and prescription.

The first phase of SHIELD, decomposition, breaks the system down hierarchically and recursively into smaller components so that the state space associated with each component is more manageable for the user. In the evaluation phase, experts analyze the associated state space and transitions for each component, recursively, bottom-up. In the final phase of the analysis, prescription, a set of heuristics are applied to the results from the preceding phase. These heuristics are used to inspire the design team and help find solutions to the hazardous state combinations that result from the evaluation phase.

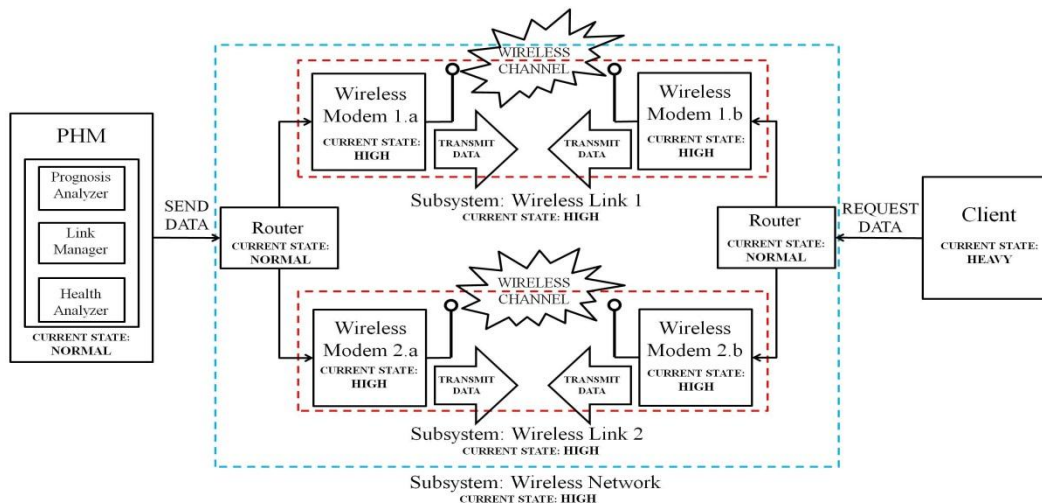


Figure 15: Simple example of a SHIELD process cycle with a block system architecture.

This methodology has been automated to reduce the temporal parameter associated with analysis without sacrificing accuracy or overlooking hazardous state combinations. Bayesian probability has also been integrated into the prototype software to rank risky component state combinations and show the probabilities associated with each subcomponent state.

An Ocean current turbine testbed Wireless Link (OWL) manager tool was developed to ensure optimal throughput and guarantee quality of service for the wireless communication system of the offshore testbed, which links offshore instrumentation with users on the shore. OWL applies sensor fusion to platform attribute data which is used to forecast the state of the wireless link in a harsh oceanic environment. OWL guarantees optimal bandwidth provisioning at the IP layer over the wireless link using innovative methods of flow control. Further details can be found in a Ph.D. Dissertation to be published Q2 FY14.

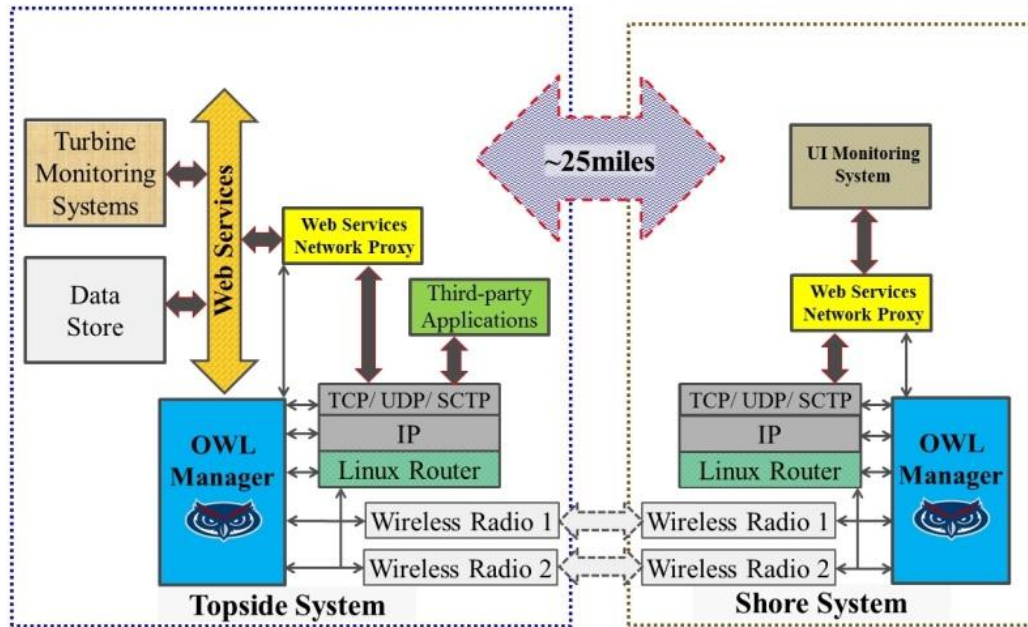


Figure 16: Architecture of the proposed ocean current turbine testbed data communication system and general conditioning-based maintenance components.

The SNMREC has invested in a flexible, extensible, and virtual server environment. In cooperation with FAU's College of Engineering and Computer Science, a sophisticated IT infrastructure has been implemented to address the SNMREC's processing, storage, and services needs. The servers generally consist of one HP Blade Cluster (12 Blade Servers), Lefthand Virtual Storage SAS arrays, and dedicated redundant 10 Gigabit Ethernet connections. This capability provides for on-demand provisioning of virtual servers and desktops based on computing resource demands, ample archival and active storage, and flexible scalability. Funding from this award was leveraged against other significant investments to achieve a collective capability (as well as a complete independent solution) to address ocean current turbine performance and health measurement during offshore testing as well as many related analysis and simulation needs.

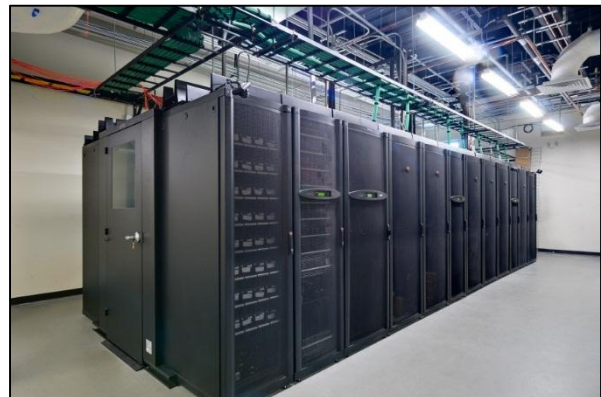


Figure 17: SNMREC/FAU College of Engineering server room (Boca Raton, Florida).

Task 09-2.0 – Impact Studies

Subtask 09-2.1 – Sea Turtles

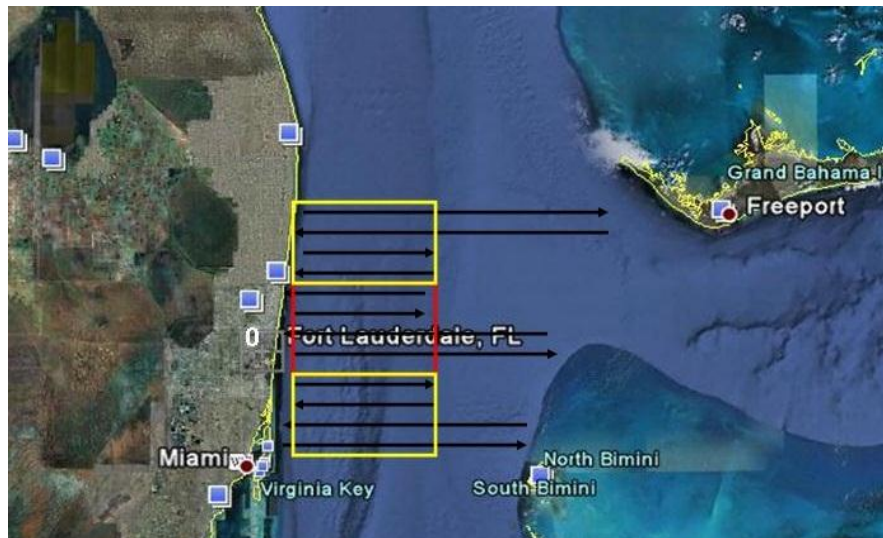


Figure 18: Aerial survey tracks to document sea-turtle populations. The several E-W tracks are grouped into the three yellow/red boxes shown in order to examine up- and downstream variations south and north (respectively) of the SNREC testing area, which lies in the middle box.

As noted previously, SNMREC recognized in the early stages of planning offshore activities the potential sensitivity of sea turtles to any disturbance in the Florida Current associated with technology testing. This motivated planning and support for baseline population studies and two years of aerial surveys were conducted (Note: Task 10-2.1 allowed for a second year of surveys to be included). The surveys were composed of E-W transects across the Straits of Florida arranged in a non-overlapping

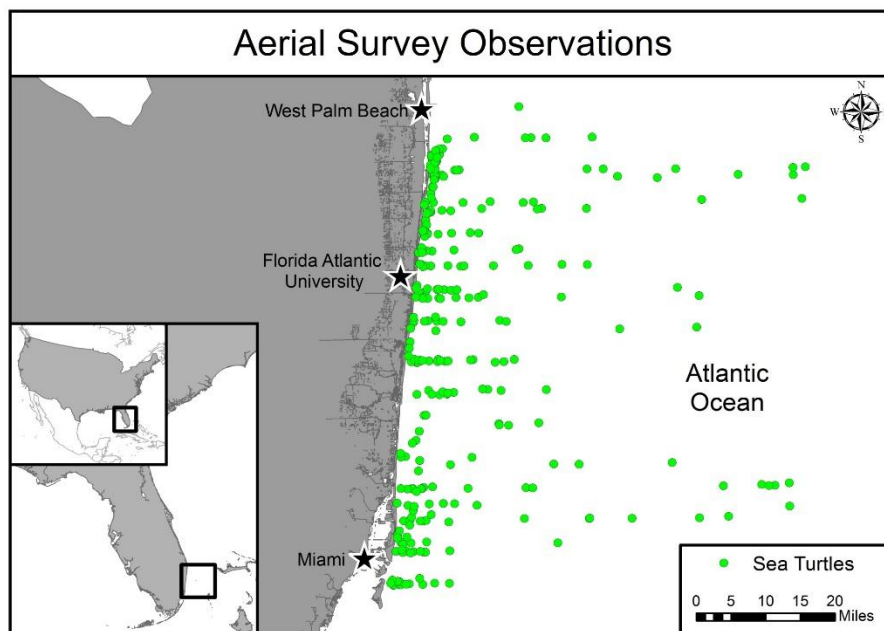


Figure 19: Sea turtle observations between January 2011 and February 2013.

“lawnmower” pattern as shown in Figure 18. Final detailed analysis will be included in a M.S. Thesis to be published Q2 FY 2014, but early results suggest a shore-side biased distribution of individuals that is comparable in its north-south variations to that of observed nesting sites (Figure 19), in particular, with higher densities north of Port Everglades. It must be emphasized, however, that these results are preliminary.

In Figure 19, each green dot on the map represents a single sea turtle observation during aerial surveys, and this map includes all observations from 24 surveys conducted between 2011 and 2013, with a total of 218 sea turtle observations. Of all observations, 68% occurred west of the continental shelf, indicating a preference for coastal areas. Also, in Figure 20, population densities estimated from aerial observations are plotted by season. Seasons are listed along the x-axis, density in sea turtles per square kilometer is listed along the y-axis, each diamond represents the estimated density of sea turtles for that season, and bars indicate standard error for each estimate. These estimates clearly illustrate trends in sea turtle density that closely follow their annual nesting season, with highest densities in spring and summer (nesting season) and lowest densities occurring during fall and winter (non-nesting season).

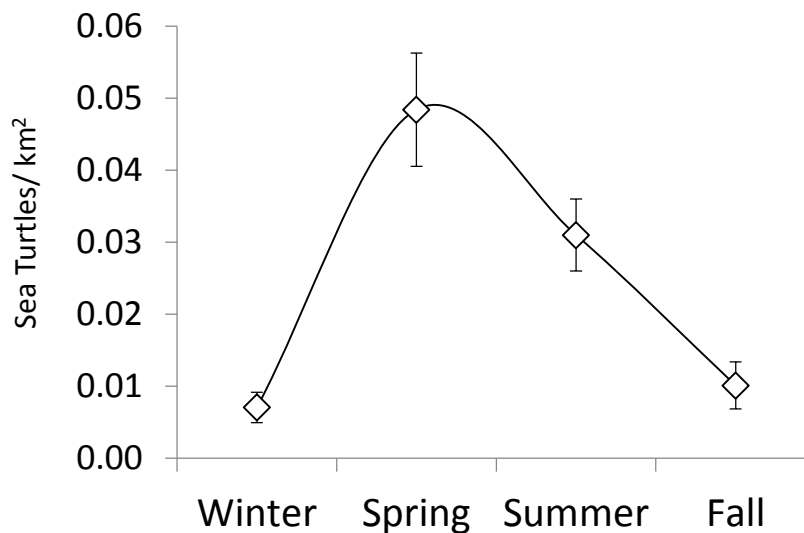


Figure 20: Sea turtle population densities estimated from aerial observations, plotted by season.

The baseline data and preliminary results indicate close correlation with known observable nesting behavior. Results also indicate that interaction probabilities can be ascertained based upon seasonality and area. Some preliminary data and results were incorporated into SNMREC’s IP lease application (SNMREC, 2012), and are also of interest to various regulatory and environmental agencies.

Subtask 09-2.2 – Marine Mammals

After preliminary results were obtained from cross-Florida Straits aerial transects, it became apparent that greater resolution near shore was of value. In addition, because aerial sea turtle transects are conducted using a small airplane with trained observers and standard population survey techniques, other species are observed as well, including marine mammals and, in shallower water, sharks and rays. Additional along-shore surveys were conducted on a bi-weekly basis for one year (during the second year of cross-channel surveys) along Palm Beach County. These ancillary observations are also being

assembled into population statistics and combined with other such results to bolster the overall database of macro-fauna in this portion of the Florida Straits.

Under this grant, two innovative projects related to these surveys were undertaken. First, recognizing that using human observers for aerial transects is, in the long run, both expensive and tedious, aims to automate the process using high-resolution digital imagery. The trained-observer transects include a down-pointing video camera, and digital pattern-recognition techniques are used to extract species of interest, with the trained-observer results used as a control for comparison purposes. While this work has yet to mature, it offers promise for future surveys both in the Florida Straits and elsewhere. Details are found in various M.S. Theses prepared to explain innovations in automation of video analysis resulting from this work (e.g., Friedel, 2012).



Figure 21: Along-shore marine animal survey still and video equipment arrangement.

The second project, based on recent advances in human voice recognition technology, investigated novel techniques with computer-automated analysis of hydrophone records to allow identification and classification of species of interest as well as location and tracking by using triangulation. A Ph.D. Dissertation is being prepared on this topic where greater detail will be available.

Task 09-3.0 – Education and Outreach

Subtask 09-3.1 – Professional Workshop/Conference

Capturing energy from hydrokinetic resources – surface waves, tidal flows, and open-ocean currents involves research and development challenges unique to each resource, but challenges common to all exist as well. Meeting these challenges will require a coordinated approach, and, ultimately, an ocean-energy roadmap to aid in growing an offshore ocean energy industry. The purpose of a workshop entitled *Offshore Ocean Energy: A University-Industry-Government Dialog* held March 3-5, 2010 was to discuss common non-proprietary issues encountered by the ocean energy community and investigate options for resolving these issues. In addition to the main dialogue of the program, two parallel sessions were held during the course of the event to investigate the current state of device testing and system prototyping and explore directions for research and development. This dialogue brought together an audience of approximately 50 representatives from the US Department of Energy (DOE), National Oceanic and Atmospheric Administration (NOAA), US Army Corps of Engineers (USACE), US Department

of the Interior (DOI) – BOEM, and the Florida Energy and Climate Commission, as well as a collection of experts from industry, universities, and laboratories.

During the forum, regulatory agencies identified the challenges that they face in relation to offshore ocean energy development. Cutting-edge issues from the university, industry, and NGO perspective at the state and national levels were also explored. In addition, high level research focus areas were identified to meet sustainability requirements yet to be identified. Discussion also focused on the total system to better relate the environmental concerns, the resource, and the operational systems.

Several recommendations were reached by consensus:

- For ocean energy development to succeed, all stakeholders should focus on affordable demonstration test facilities to accelerate the development and implementation process.
- For field test facilities to succeed, academia, industry, and government must:
 - plan to accommodate long-term test needs,
 - organize and provide the needed environmental data,
 - resolve scaling and evaluation requirements and definitions,
 - develop a shared liability model, and
 - manage different expectations and processes by regulatory agencies.
- Development risk should be mitigated by:
 - Additional public sector funding
 - Independent assessment of development readiness and progress; standards and measurement expectation(s) availability
 - Addressing missing capabilities and assets for prototype deployment
 - Addressing early in the development process various longer-term challenges such as public outreach and grid integration
 - System monitoring and prognostic efforts for prototype systems need to be expanded to include data to account for environmental interaction that will be useful for environmental impact analysis.
- Florida needs a state task force that collaborates with the US Department of the Interior BOEM
- All parties should:
 - Conduct outreach at the governmental level
 - Develop and deliver a unified understanding of adaptive management
 - Collaborate to consolidate all relevant data

Feedback from participants indicated that the Dialogue was a resounding success and a great first step. They wanted to see a sustained effort going forward. Additional details can be found in a summary report prepared by the workshop's facilitator (FCRC Consensus Center, 2010).

A conference was also organized entitled *Renewable Ocean Energy & the Marine Environment: Responsible Stewardship for a Sustainable Future* held November 3-5, 2010 in Palm Beach Gardens, Florida. The agenda⁵ consisted of various panel discussions and concurrent presentation sessions. These varied in topic, but all were oriented towards presenting planning, regulatory, environmental, and technical solutions for sustainable and responsible MRE projects. The conference brought together

⁵ Online: <http://www.ces.fau.edu/coet/agenda.html>

researchers, developers, federal and state agencies, industry and scientists from a global community to explore cutting-edge science and technology to identify gaps in the current state of knowledge regarding the environmental impacts of renewable ocean energy. The effects on the marine environment of large-scale hydrokinetic and thermal power generation are largely unknown. Marine ecosystems include many protected species which rely on complex food chains and undertake extensive migration patterns, and understanding how the operations of power generation systems will interact with these marine ecosystems was a critical first step toward deploying equipment in a sustainable fashion.

Over 90% of participants who returned their evaluation form agreed that the conference increased their knowledge of renewable ocean energy and the marine environment and 100% of these participants agreed that the information gained at the conference will be useful in their work. Conference presentations and agenda are available online⁶.

Subtask 09-3.2 – Public Outreach/Education

SNMREC developed a series of curriculum modules for secondary students Table II provides an annotated Table of Contents for the curriculum document. Designed to fulfill many of the science objectives of the Florida State Science Standards, the curriculum provides a broad survey of the basis for and issues associated with MRE in the context of hands-on learning and inquiry for the students.

The curriculum was developed to enhance interest in science, mathematics, engineering, and technology which supports improvements in education for students from K-12 with original curricula and teacher workshops. An ocean current energy curriculum was developed for 11th and 12th grade

Table 1: Energy from the Oceans: The New Renewable -- Contents

Chapter	Purpose/Content
Lesson Format	Introductory Material
Materials Needed For Lessons	Introductory Material
Sunshine State Standards	Introductory Material
Lesson 1: Why Do We Need Renewable Energy?	Background: renewable energy / climate change issues
Lesson 2: How is Electricity Generated?	Basic physics of electricity
Lesson 3: How Do We Identify Ocean Currents with the Best Potential for Producing Energy?	Some basic fluid dynamics & oceanography
Lesson 4: Harnessing Energy from Ocean Currents: The New Renewable	How turbines work
Lesson 5: What Are the Environmental Impacts of Ocean Energy?	Environmental stewardship
Lesson 6: The Future of Ocean Energy	MRE potential
Glossary	Reference Material
Appendix 1 – Suggested Readings for Teachers	Reference Material
Appendix 2 – Annotated Bibliography	Reference Material

⁶ <http://www.ces.fau.edu/coet/agenda.html>

students under this award. The curriculum is based on the “5 E’s”, an innovative instructional-based model used for teaching that fosters inquiry-based thinking by engagement, exploration, explanation, elaboration, and evaluation. One example activity is building an electric generator from a soda can to demonstrate an induction coil alternating current generator. The lessons also include “Meet the Scientist” segments that feature a SNMREC engineer or scientist. The curriculum is available online, on the SNMREC web site⁷.

Task 09-4.0 – Project Management

As described below in Task 10-4.0, effort in this task involved the overall management of project tasks, timelines, and budgets. In addition, travel was supported to participate in a national marine renewable center workshop in Corvallis, OR (2011), meetings with DOE Program Officers at headquarters in Washington D.C., and PEER Review(s).

Task 10-1.0 – Research

Subtask 10-1.1 – Collision and Remote Sensing Feasibility

When ocean current turbines are operated offshore, marine vertebrate collisions are of high concern. The BOEM Environmental Assessment prepared for the SNMREC project lists various provisions in the preferred action alternative to avoid impacts to marine mammals and sea turtles, including human observers, underwater video, and underwater acoustics to identify potential contact. The latter expectation is a relatively new technique and technology which is available commercially. Various off-the-shelf options and integration considerations with the in-house research turbine have been evaluated.

The most ideal system to meet technical and regulatory requirements was identified as Biosonics DT-X suite of products. This system’s split beam approach allows for various assessments to be conducted simultaneously, with the same equipment: target identification and tracking, quantitative biomass assessments, and marine vertebrate size, location, and abundance. This hardware and software solution has become a standard for fisheries hydroacoustic studies.

To expand usefulness of the system, two transducers were selected at different frequencies (38 and 120 kHz) so that long and short range observations can be made. Also, because the system can either be deployed aboard a turbine (where it would be oriented upstream to predict possible contact with the turbine or downstream to observe biomass or fish activity near the turbine) or from a surface platform like a vessel or buoy near turbine operation, two echosounders were needed. A custom unit has been designed by the manufacturer to allow for fully submerged autonomous operation onboard a turbine. A

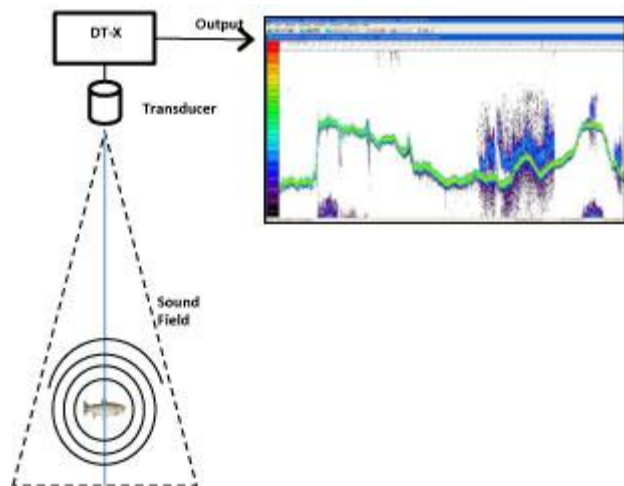


Figure 22: Schematic representation of Biosonics DT-X system functionality.

⁷ <http://snmrec.fau.edu/TN-11-254>

second conventional unit suffices for either vessel or buoy deployment.

The selected system has been acquired and will be integrated with the SNMREC's ocean current research turbine during deployment for proximity marine vertebrate identification and with the MTB (Figure 1) for baseline data observations.

Subtask 10-1.2 – Underwater Observatory Design and Bench Test

Complete ocean current turbine performance assessment requires that near and far field oceanographic and environmental measurements are collected before, during, and after tests are conducted. As described in Subtask 10-2.2, long term averages and flow features are needed for equipment designers to frame preliminary design conditions, for long term estimates of ocean current production potential, to evaluate the effectiveness of numerical models for siting and prediction, and for studies of large-scale effects of commercial turbine farm energy extraction. Presently, the method of choice is to annually or bi-annually install moored subsea acoustic measurement packages. This approach, although effective and low cost for short-term studies, is not desirable for long term investigations and does not provide real-time measurements. Therefore, SNMREC proposed to explore and conceptualize an underwater scientific observatory co-located with turbine test infrastructure to be installed in the future. The goal was to first achieve wireless real-time capabilities and then explore more permanent cabled solutions.

SNMREC staff performed reviews of existing international capabilities and explored component options that might achieve both long and short term solutions. For example, staff collaborated with both acoustic equipment manufacturers and with the Monterey Bay Aquarium Research Institute. It was determined that the relative proximity of temporary moorings allowed for acoustic wireless access to each instrument, but required a surface asset to provide shore-side access to the data. Because long term far-field measurements are selected near proposed scaled ocean current turbine test sites, a natural choice for centrally collecting and transmitting instrument data is with the MTB (Figure 1). Therefore, as turbine test infrastructure is finalized and installed, moored instruments will communicate with the centrally-located MTB to achieve a pseudo-observatory in the near term.

A primary challenge to achieve this capability was to develop systems aboard the MTB to negotiate communications between underwater instruments and shore-side users. A system was developed and bench-tested to achieve this need, which uses open-source software to implement SCADA (Supervisory, Control, and Data Acquisition) and HMI (Human Machine Interface) capabilities (Figure 23). The advantages of this approach are:

- the HMI only requires a web browser, not specialized proprietary software to access;

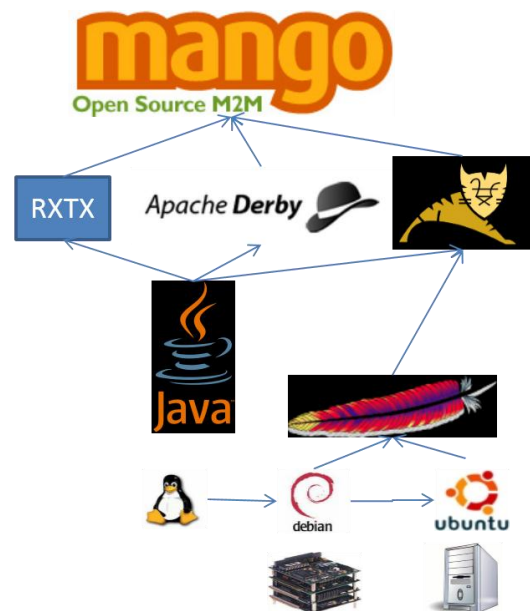


Figure 23: MTB SCADA and HMI scheme to perform near real-time access to moored oceanographic instrumentation.

- many SCADA protocols are supported to allow for future flexibility and extensibility;
- a historical database feature preserves activity; and
- it allows *annotatable* alarms for full on-demand versatility as changes are needed during deployments.

The combined features serve to reduce offshore trips to modify parameters and make changes. In addition, a key component of achieving communication between shore and undersea assets is the wireless communication link. A scheme was selected which includes redundancy and three levels of system access: (1) minimal bandwidth status and health reports from offshore equipment, (2) medium bandwidth bi-directional access to data and configuration changes, and (3) high bandwidth full access to shore and remote systems (Figure 24). System implementation and testing is supported by award DE-EE0004200 and is scheduled for Q3-4 Fiscal Year 2014.

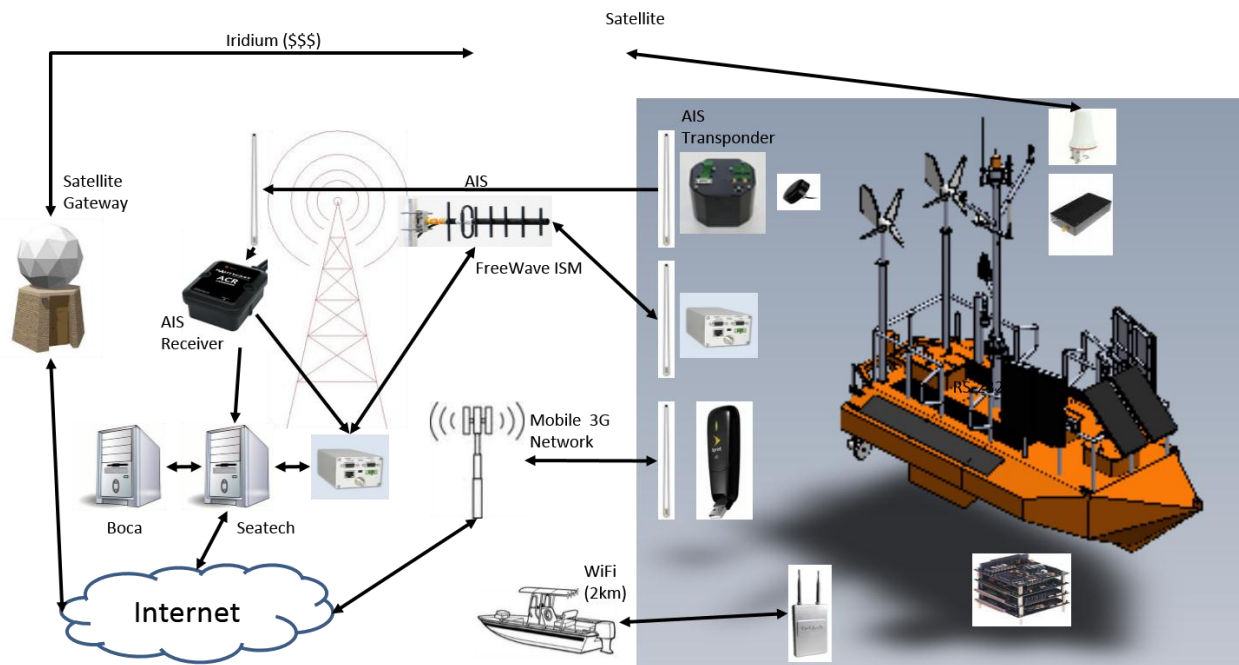


Figure 24: Representation of MTB communication scheme featuring redundancy, flexibility, and scalability to enable near real-time access to undersea instrumentation.

Subtask 10-1.3 – Scale Model Testing Implementation

The overall goal of this task was to formally address scaled testing needs of ocean current turbine concepts. As SNMREC proceeds towards implementation of ¼-scale turbine demonstration and evaluation infrastructure, it was important to recognize that other competitive energy capture approaches would still benefit from laboratory-scale evaluation. Therefore, this subtask performed:

- a detailed evaluation of the testing needs of proposed turbine concepts,
- a trade study to down-select existing facilities that could meet identified needs,
- a scaling procedure for hydrokinetic energy systems,
- an evaluation and validation of the proposed scaling procedure, and
- a conceptual design of an ideal laboratory facility.

An audit of existing facilities combined with a survey of proposed ocean current turbine technologies yielded a recommendation that many design evaluation requirements can be met. However, a gap was identified with respect to laboratory-based mooring dynamics and design evaluation. When including the contribution of a mooring system to dynamic forces as well as the costs associated with survey, installation, and maintenance, this study selected to further develop a conceptual scaling and laboratory facility design.

Step 1 of the scaling process involves scaling of all quantities by a scale factor:

- Lengths, Diameters $\sim sc$
- Mass, Force, Elasticity, Tension $\sim sc^3$
- Cable mass per unit length $\sim sc^2$
- Time $\sim sc^{1/2}$

Step 2 relates to scaling the moored device and mooring line:

- The relative density of the device and mooring line must be equal.
- The cable modulus of elasticity must be scaled in proportional to the scale factor.

Step 3 determines an appropriate spring to be used for testing:

- Since the modulus of elasticity for the scaled model will be significantly smaller, proportional to sc , than the full scale prototype cable's modulus of elasticity, it is difficult to identify materials that with the required properties. However, the required elasticity can be achieved by artificially reducing the average modulus of elasticity of a cable with the insertion of a weak spring in series with the lower part of the cable.

Step 4 of the scaling procedure determines the required water velocity profile needed for testing:

- Because the proposed scaling method relies heavily on force scaling, the drag force (or thrust) on the model must equal the drag force (or thrust) on the prototype divided by the cube of the scale factor.
- This water velocity profile is therefore scaled using the Froude number.

The study then considered how these parameters would translate into constraints and requirements for a laboratory scaled testing facility. If such a facility wishes to achieve the best accuracy for scale model testing, then the facility should be sufficiently large so that the scale factor does not become excessively small. The smaller the scale factor becomes, the more difficult scaling becomes with respect to acquiring appropriate mooring wire sizes. Additional details can be found in an M.S. Thesis (Valentine, 2012) supported by this award.

Subtask 10-1.4 – Generalize Deployment Capability

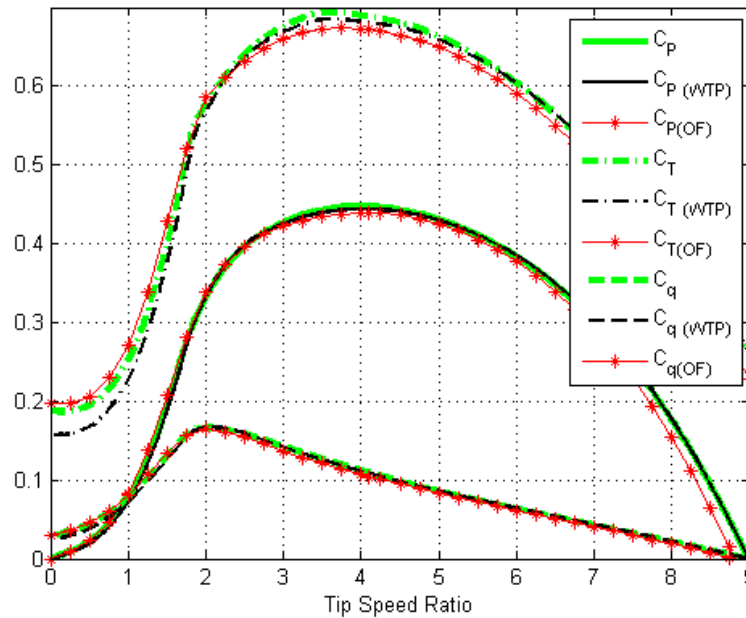


Figure 25: The predicted coefficients of power, thrust (drag) and torque using Matlab Model (green), WT_Perf model (WTP)(black) and OrcaFlex model (OF)(red *).

Unlike similar tidal applications, ocean current turbines are expected to be moored to sea floor so they can access the greatest velocity and least variable flow near the sea surface without exposure to either surface vessel traffic interference or damaging and variable sea surface conditions. Therefore, a significant and different design challenge for ocean current turbines is mooring design. Rather than developing a custom software package to meet this need, SNMREC identified a commercial mooring design and evaluation package, Orcina's Orcaflex. The software, an industry-standard choice for offshore oil and gas applications and other dynamic analysis of marine systems, specializes in numerical modeling of moorings, buoys, and vessels. Although rudimentary tools to model rotors are available in the standard software package, they result in over-estimation of rotor forces and power production. Because only basic lift, drag, and rigid body models are available, flow interaction is not accounted for. Therefore, SNMREC has created a Blade Element Momentum Theory-based external function for OrcaFlex to more accurately model dynamic ocean current turbine installations.

An M.S. Thesis is to be published during Q1 of FY 2014 describing the approach and methodology. Performance of the implemented method was compared with a bottom-up Matlab Simulink-based 7-degree of freedom ocean current turbine simulation tool developed by researchers at the SNMREC and with NREL's WT_Perf module of the Computer-Aided Engineering Tools made available by the National Wind Technology Center (Boulder, Colorado). Figure 25 indicates a comparison between steady-state performance coefficients of all three approaches.

Task 10-2.0 – Monitoring/Demonstration

Subtask 10-2.1 – Include Marine Mammals in Remote Sensing Monitoring

Because marine mammals are sensitive to their acoustic environment, one of the questions that arose concerning eventual commercial-scale deployments of ocean current turbines concerns their cumulative effect on underwater noise levels. To address this, SNMREC undertook calculations of the likely acoustic emissions from underwater turbines using the in-house experimental prototype as an initial model.

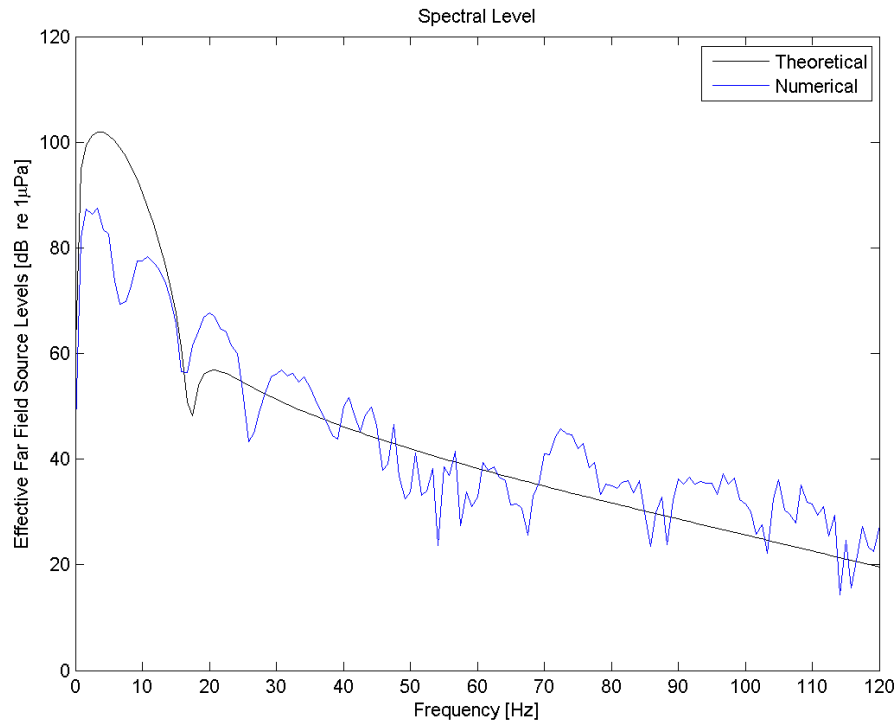


Figure 26: Spectral level comparison between CFD-modeled and theoretical hydrodynamic noise generated by the SNMREC's ocean current research turbine.

The noise generated by turbines can be broken down into 2 categories; hydrodynamic and mechanical. Hydrodynamic noise can further be broken down into 3 categories of noise sources; displacement noise, fluctuation noise, and cavitation. Cavitation noise was ruled out for turbines at a depth of 10m, and the fluctuation noise was considered the noise of interest. Guerra (2011) established a method using a dipole to estimate the noise levels from a turbine. He used a number of assumptions and simplifications in his work to derive his results and established that audible noise levels would only occur at low frequencies, and that higher frequency noise levels were well below the ambient noise of the ocean. Since many assumptions and simplifications to a turbine geometry were used, results did not fully reflect realistic acoustic impacts that might be expected. An M.S. Thesis (Lippert, 2012) was prepared where a CFD analysis based on actual geometry of the SNMREC's ocean current research turbine was applied and velocity perturbations were calculated.

A computational fluid dynamic (CFD) analysis was performed with ANSYS software. FLUENT was the solver used, and the turbulent model used was a RANS-based k-epsilon model. Convergence studies and grid independence studies were performed on the turbine geometry to formulate an optimal grid size. Once the optimal grid size was determined, a second order analysis was performed. These results were then used for the unsteady loading, and acoustic analysis. Preliminary results, which await verification

using the prototype's measured signature when it is deployed, suggest that hydrodynamic noise levels will decrease to the background within a few tens of meters of a turbine, meaning that array-scale effects are unlikely to be a problem for the future.

In addition, under this subtask, a second year of aerial surveys was commissioned. These surveys, as described above under Subtask 09-2.1, were designed to observe not only sea turtles, but any visible marine invertebrates. Therefore, marine mammals were catalogued along with large pelagics, sharks, and sea turtles that were observed.

Subtask 10-2.2 – Extend Current Monitoring Array to North-South Direction

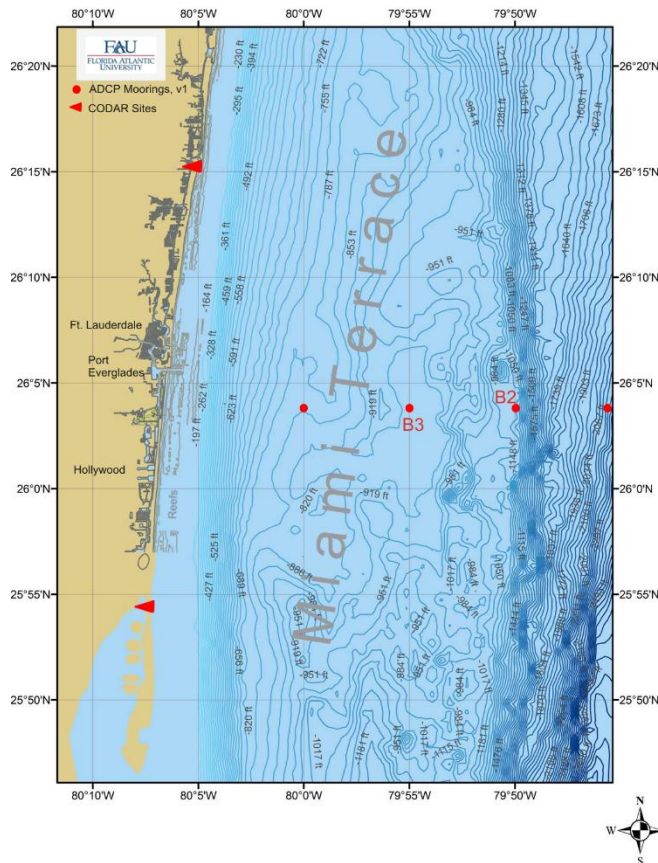


Figure 27: Chart of the Florida Straits off offshore Fort Lauderdale, showing positions of ADCP moorings B2 and B3.

This subtask enhanced a previously initiated comprehensive *in situ* measurement program for the Florida Current. These earlier deployments consisted of moored Acoustic Doppler Current Profiler (ADCP) packages arranged across the Florida Straits to capture temporal variability of the current in various locations orthogonal to the major current flow direction. Additionally, a radar system to capture ocean surface flow magnitude and direction was procured and shore-side installation locations selected. This subtask supported the acquisition of moored ADCP packages to extend measurements longitudinally (to capture large scale rotation), the deployment and recovery of one annual ADCP measurement cycle, the analysis of collected ADCP data, and site installation of one surface radar station. The following discussion includes major conclusions and observations that have been collectively gained throughout the measurement program. Additional details and data are available in various publications (indicated where referenced), including a Ph.D. Dissertation (Smentek-Duerr, 2012).

Variability in the Florida Current has been the topic of a large number of oceanographic studies over the past several decades and is known to include time/space variations due to tides (e.g., Mayer *et al.*, 1984), eddies (e.g., Lee, 1975; Lee *et al.*, 1995), meanders (Brooks, 1979; Johns and Schott, 1988), and longer time scale changes in the overall transport through the Straits of Florida (Baringer and Larsen, 2001; Meinen *et al.*, 2010). None of this work was discussed in terms of implications for MRE, however.

Some of these variations can be seen in Teledyne/RDI ADCP data obtained by SNMREC. This section illustrates these variations with data from positions B2 (28 km offshore) and B3 (20 km offshore) in Figure 27. Both of these moorings were on a bathymetric feature known as the Miami Terrace, B2 at the edge of the escarpment that falls away to the east into the main trench of the Florida Straits (the darker blue band in Figure 27 is the tight grouping of isobaths of this escarpment) and B3 approximately in its center.

The B2 instrument, an upward-looking, 75 kHz unit deployed at 26°4.3'N, 79°50.5'W at a depth of 320 m was programmed to record 10-min of data every half hour; it was deployed on 27 February, 2009 and recovered on 25 March, 2010. Figure 28 shows the entire instrumental record and a blow-up of an especially rich time period in which the current was particularly strong.

The packets of red in the top record are indicative of variability on the scale of weeks to months, and the individual red “spikes” in the bottom record show clearly the diurnal tides in the Straits, as documented by Figure 29 (Hanson *et al.*, 2012).

Given this variability, it is relevant to ask how it could affect ocean current turbines. One way to approach this is again to invoke the cut-in speed of the devices as a stratifying parameter. Figure 30, as an example, shows the top panel of Figure 28 filtered for devices capable of operating at (top to bottom) 1, 1.25, and 1.5 m s^{-2} or faster. Down time for the three examples is shown in white. Another view of this

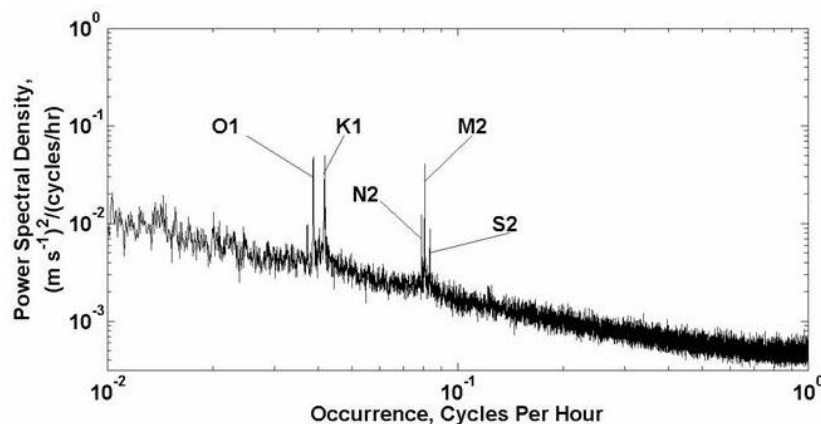


Figure 29: A portion of the depth-averaged power spectrum of the Fig. 6 data, showing the strength of the tidal frequencies. Adapted from Hanson *et al.* (2012).

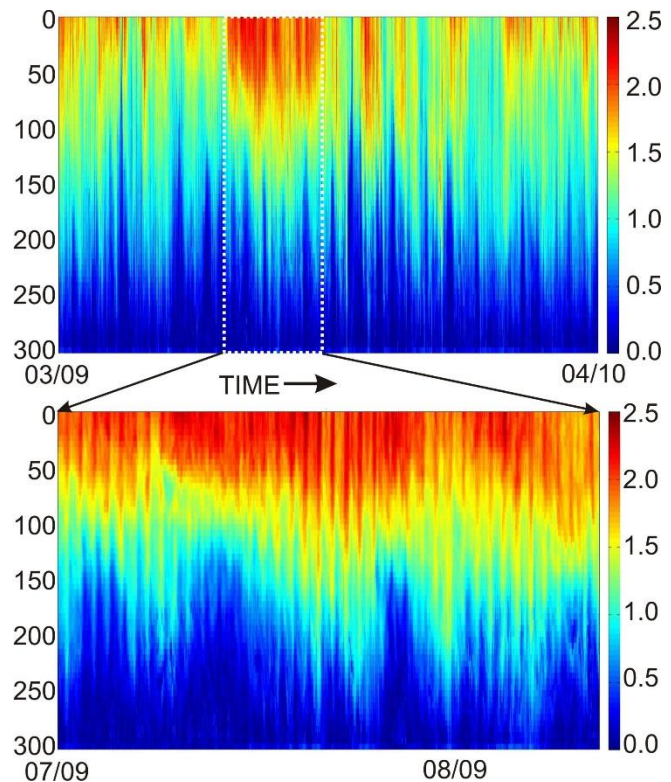


Figure 28: 13-month record from ADCP mooring B2, showing current speed as a function of depth and time (adapted from Hanson *et al.*, 2011). Velocity scale (color bars on right) is in m s^{-1} .

result is shown in Figure 31. Suppose devices of 40% net efficiency with dual, 40-m rotors (this is quite an ambitious turbine) were deployed at location B2. Clearly, annual power production would depend on cut-in speed, which dependency is shown in Figure 31. Design improvements to reduce cut-in speed increase power production by decreasing down time, as shown in Figure 30, and will allow power to be

produced at lower current speeds. But these improvements begin to become less and less cost-effective in the vicinity of 1 m s^{-1} —and improving cut-in speed from 1 m s^{-1} to, say, 0.5 m s^{-1} gains very little indeed, at least at 70 m depth.

Although currents are fastest near the surface, MRE equipment, as noted, is unlikely to be allowed where it would interfere with surface shipping. Taking the nominal draft of the largest cargo ships to be 150' (~50 m), the 40-m rotor turbines used for Figure 31 would need to be installed at 70 m or deeper. The depth ranges in the panels of Figure 30 were selected to illustrate this. For reference, this arrangement is also shown to scale in Figure 32, which shows two vertical profiles of the current on specific days.

The fact that the current is not constant with depth is obvious from Figure 28, but the two examples of vertical structure in Figure 32 illustrate a more subtle aspect of the current's structure: there can be shear (meaning the first derivative of speed with depth) reversals. In Figure 32, the July 1 case is the more common situation, where current speed decreases with depth (positive shear), but the January 1 case, with negative shear above about 125 m, is not at all unique. Especially in winter, when cold fronts can bring NW to NE winds over the Florida Straits, the surface flow can slow dramatically, resulting in an increase of speed with depth.

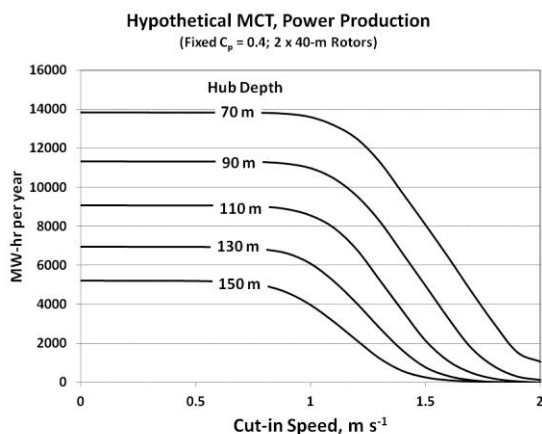


Figure 31: Annual power production associated with the B2 dataset from hypothetical devices at various depths, shown as functions of cut-in speed. For these conditions, improving cut-in speed below about 1 m s^{-1} seems unlikely to be cost-effective.

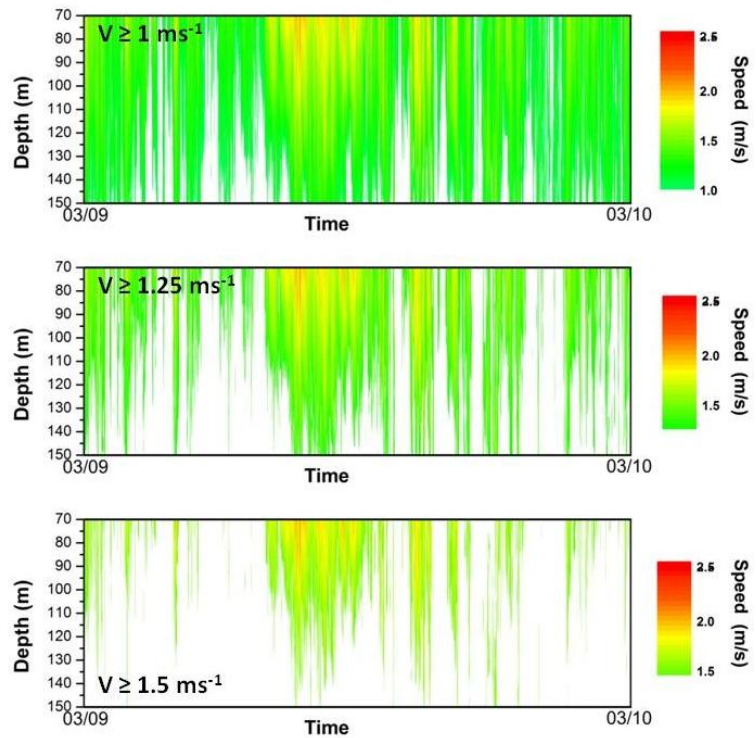


Figure 30: B2 dataset filtered to indicate operating times (and depths) for devices of various cut-in speeds. Down time appears in white.

over the Florida Straits, the surface flow can slow dramatically, resulting in an increase of speed with depth.

As shown by Hanson (2012) and reported in various conference venues, negative vertical shear can be catastrophic for moored, buoyant underwater devices. This is due to a dynamic instability, in which small depth perturbations of the device can grow exponentially. Physically, it is associated with the downstream drag on the device, which increases with increased current speed, and the resultant rotation of the anchor rode around its attachment point on the bottom. In the case of negative shear, this rotation moves the device downward into faster water, increasing the drag and rotation (moving the device deeper into yet

faster water, etc.). The opposite happens in cases of positive shear, which produces a stabilizing restoring force.

Given the existence of eddies and meanders, it is not surprising that current speed is not the only varying characteristic of the current—its direction varies as well. Figure 34 shows the direction of the current at 70 m for the B2 dataset. On average, the current at this location flows about 13° east of north with a standard deviation of $\pm 6^\circ$ or so. Of more importance are the abrupt direction changes, several sweeping through more than 45° in a very short period of time. Clearly, such abrupt changes have important implications for mooring design.

Even more interesting is the existence of current reversals closer to shore. After the two moorings were refurbished and redeployed, the record from B3 revealed two such episodes (Figure 33). Although a single-point mooring for a single device might be able to handle this behavior, it is easy to imagine how multiple devices on multiple-point moorings could become entangled under such conditions. This suggests that deployments farther offshore than the position of B3 would seem advisable.

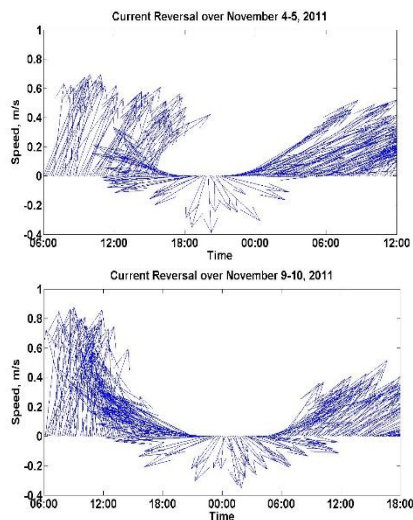


Figure 33: Two examples of current reversals at B3 during November, 2011.



Figure 32: Vertical profiles of current speed at B2 on two days of the record, illustrating the very different vertical current structure that occurs. Also shown is, to scale, the hypothetical 40-m rotor system, installed at a hub depth of 70 m, used for Figs. 8 & 9.

It also suggests the need for a real-time current monitoring capability so that, in the future, the operators of arrays of ocean current turbines will be able to implement control strategies to accommodate unusual variations (in both space and time) of the Florida Current's behavior. SNMREC tested one possible candidate for such a monitoring capability, a shore-based radar system to infer surface currents from the advection of surface waves. The Coastal Ocean Dynamics Application Radar (CODAR) system uses Doppler shifts of Bragg scattering peaks to infer motions toward and away from a transmitter/receiver unit; two such units allow resolution of surface currents in two dimensions; the currents can then be mapped over the area in which the two units' signals overlap.

The hypothesis to be tested was that the surface current could be used as a surrogate for the behavior of the sub-surface currents. Despite the variations of the vertical shear discussed above, there is some indication that the vertical structure of the Florida Current is quite robust much of the time (e.g., Hanson *et al.*, 2011). However, preliminary comparison of CODAR surface currents with ADCP measurements during periods of variable winds showed no correlations of any significance, suggesting that another monitoring method will need to be employed. One such candidate, the use of operational computer forecasts that incorporate data assimilation, is presently being evaluated with other funding.

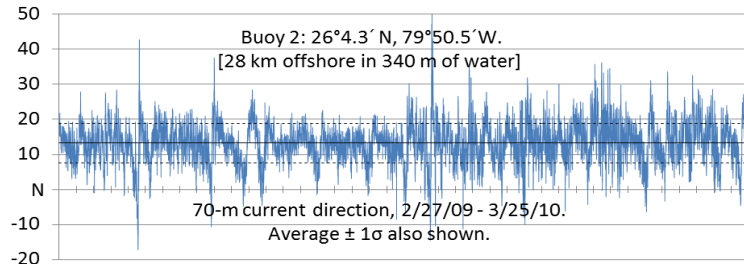


Figure 34: Time series of current direction for Buoy 2 at 70 m depth.

Subtask 10-2.3 – Deploy and Monitor In-house Prototype to Demonstrate Protocols Consistent with Best Practices

The SNMREC is actively involved with international technical standard/specification development, national standardization of modeling and instrumentation approaches, offshore testing protocols and best practices, and test center compliance with international expectations. First, during the performance of this award, SNMREC engineers and researchers participated in ISO/IEC Technical Committee 114 (TC114) project teams as U.S. Shadow Committee members (for the recently published Draft Technical Specification prepared by PT 62600-200, Power Performance Assessment of Electricity Producing Tidal Energy Converters) and as Subject Matter Experts (SMEs) for PT 62600-2, Design Requirements for Marine Energy Converters.

In addition, SNMREC researchers and engineers have contributed to various NREL and DOE-organized workshops intended to foster collaboration and consolidate U.S. efforts in key cross-industry topics. Specifically, in simulation (NREL, March 1-2, 2011), instrumentation (NREL, April 5-7, 2011), resource assessment (DOE, June 22-24, 2011), and instrumentation/ modeling (NREL, July 9-10, 2012).

Not only are the technologies and approaches to ocean current energy conversion novel, but the methods of evaluation and testing are yet to be developed. Often, conventional existing practices can be adapted, but in many cases, they require modification or new approaches. Such is the case with the testing associated with SNMREC's ocean current research turbine. Mechanical and electrical systems are independently prepared and evaluated for eventual integration. During this phase, whenever possible, components and subsystems are tested in a laboratory environment. Therefore, SNMREC has constructed an Ocean Current Power Generation Simulator (OCPGS, Figure 35), a dynamometer system that allows generators to be tested using driving forces derived from the ADCP measurements (Subtask 10-2.2).

One of the biggest unknowns in the operations of ocean current turbine systems concerns the behavior of the generator sub-system as it experiences both variable loads and the torque differentials associated with changing currents acting on the rotor. The computer-controlled dynamometer system, located at

an FAU laboratory facility, provides a capability to test generators under conditions as realistic as possible without actually having to go to sea.

This capability is further being developed in conjunction with oceanographic measurements and modeling to simulate behavior in response to the current variations. During this project timeframe, a 20 kW dynamometer completed system enveloping and has been generating data for PHM research (Subtask 10-2.4). In addition, preliminary work has been completed to emulate rotor behavior in wave conditions and from collected offshore measurements. Testing is ongoing to include optimization of in situ data integration and 20 kW research turbine electrical and sensor system testing. Although this award did not support physical installation and acquisition of this system, it was leveraged to perform system enveloping, validation, and verification.

Finally, as commercial prototypes and subsystems are brought to SNMREC for testing, all aspects of experiment set up, instrument calibration, data handling, and organizational checks/balances are expected to comply with international quality standards (ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*). The SNMREC is preparing its processes and organization to fully comply with this standard and achieve accreditation. The selected approach is recommended by Agilent Technologies (Huber, 2009) and involves 6 steps towards accreditation:

1. Investigation Phase (where an organization defines its scope, gaps, tasks required to achieve accreditation, and estimated costs/ROI)
2. Management Decision
3. Implementation Phase (where an accreditation body is selected, documentation developed, training performed, internal audits and corrections performed, and pre-assessment conducted)
4. Accreditation Audit

This award has supported preparation for, and initialization of the investigation phase. Award DE-EE0004200 continues the accreditation effort.

Subtask 10-2.4 – Implement and Demonstrate Prognostics and Health Monitoring Systems on Prototype

The Prognostics and Health Monitoring (PHM) capability SNMREC is developing primarily consists of three types of analyses that require development for ocean current turbine applications: vibration (drive train health), rotor performance, and synthesis/automation. This award supported initial investigations and innovations in all three areas, which were then finalized with other funds. Interesting results are discussed while greater detail can be found in respective publications indicated in the text.

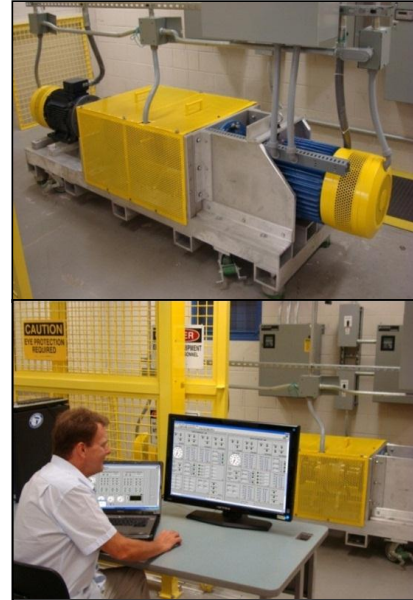


Figure 35: SNMREC OCPGS. Top: dynamometer, with two motor/generators installed. One, controlled using voltages derived from ADCP datasets, acts as the motor to drive the other, which is the test subject. Bottom: LabVIEW-based control system console.

Real-time Vibration Analysis

The overall objective of the vibrations effort was to develop a proper methodology of combining numerical Finite Element Modeling and modern vibration techniques for condition monitoring and faults diagnosis of a 20 kW turbine. A LabVIEW model for on-line vibration condition monitoring that contains the most advanced diagnostic techniques features was developed. A Finite Element Modeling (FEM) and simulation of the ocean current turbine was performed to study state condition; the modeling was used to determine the baseline of the vibration data in its normal operating conditions and to determine the resonance frequencies of its sub-components. In more detail, this work addressed:

- development of a LabVIEW model that acquires the vibration data from accelerometers and encoders and normalizes and analyzes these data in real time. This model includes time domain signal, power spectrum, power cepstrum, fractional octave, Time-Frequency analysis, kurtosis analysis, RMS value and crest factor. It also boasts threshold for alarm criteria for each technique that allows comparing the actual acquired vibration data to baselines for inception fault detection,
- development of a LabVIEW model that performs the modal analysis testing in order to find resonance frequencies and mode shapes of structures,
- performance of finite element modeling and simulation using ANSYS of the SNRMEC ocean current research turbine for an estimation of a baseline of vibration data under normal operating conditions of the turbine,
- ANSYS modeling of sub-systems (shaft, motor, shell among others) of the turbine to estimate resonance frequencies and mode shapes,
- demonstration of the vibration condition monitoring strategy and diagnostic techniques on a simple “fan” system as an intermediate step before OCPGS experiments (real-time data patterns, profiles and trends were obtained by processing vibration signals acquired from various locations of the dyno),
- analysis of vibration data collected and interpretation of results, and
- diagnosing system problems using time domain, frequency domain, time-frequency domain, crest factor, kurtosis analysis and resonance testing.

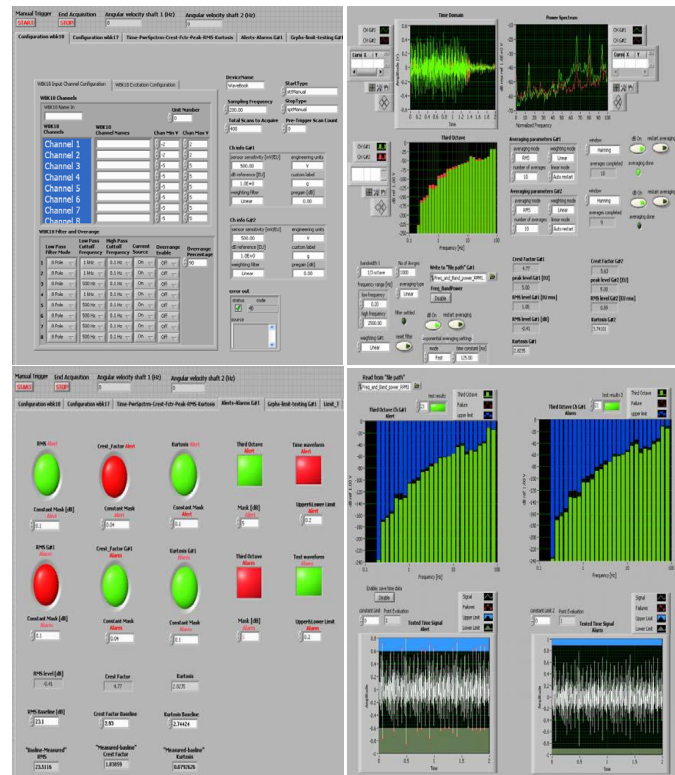


Figure 36: Screenshots of LabVIEW panels developed for real-time vibration analysis of ocean current turbines.

Vibration condition monitoring using a LabVIEW model and data acquisition systems indicates the mechanical state of the equipment and allows to accurately identify the trends of a developing

component problem in advance of catastrophic failure. This assumes that the changes in the structural vibration response are caused by deterioration in the condition of the turbine. However, due to changing rotational speed, the measured signal may be non-stationary and difficult to interpret. For this reason, the ordering (normalization) technique - which relates the vibration to the machine speed - was introduced and implemented in the LabVIEW program. The advantage of this ordering technique is the ability to clearly identify non-stationary vibration data from data caused by the inception of anomalies in the system. Common vibration faults such as unbalance and misalignment of the shaft and gears faults maybe detected on the ocean current turbine (or OCPGS), if they exist. The full effort is described in detail in an M.S. Thesis (Mjit, 2009) and refereed publications (Appendix B).

Turbine Rotor Fatigue Analysis

The second novel effort completed relates to rotor design and performance assessment. Before tools are useful for field data collection of operating ocean current turbine rotors, numerical tools need to be assessed and then used to predict loading on blades for comparison with *in situ* data. Therefore, SNMREC commissioned an effort to provide the following analyses and results:

- Several NREL codes, Sandia National Lab's NuMAD, and ANSYS have been combined to design and analyze composite horizontal-axis ocean current turbine blades. The procedure showed that NREL's wind turbine codes can be adapted to model composite ocean current turbine blades and can be coupled with commercial codes to perform static and dynamic analysis (NuMAD and ANSYS allowed calculation of stresses on a blade).
- Hydrodynamic loads for SNMREC's ocean current research turbine blades (composite construction shell with no inner webbing and foam core) were calculated by modifying the inputs to AeroDyn and FAST. Load case assumptions and partial safety factors for loads and materials recommended by Germanischer Lloyd were used. Ekman Solution was used to determine hurricane-driven ocean current speeds.
- Normal forces were found to be the major loading on an ocean current turbine rotor blade, with the flapwise bending moment being 8 to 5 times larger than the edgewise moment.
- Static analysis was performed using ANSYS with ultimate loads. It was observed that maximum compressive stress occurred at the top shell and maximum tensile stress occurred at the bottom shell near the 33% chord location for each span station. The maximum compressive stress of the blade occurred at about 40% of its span. As expected, the maximum tensile stress of the blade occurred at its root. All of these stresses fell well within the allowable tensile and compressive strengths of the QQ1 E-glass composite material.
- Linear buckling analysis was performed with full loads applied along the blade span using ANSYS. It was observed that the lowest buckling occurs in the spar cap to trailing edge panel between approximately 60% and 20% span. The buckling safety factor was computed as 2.955, which is larger than the specified safety factor 2.042.
- Fatigue life prediction was performed based on stresses at critical locations. A cumulative damage parameter (D) was calculated using Palmgren-Miner's linear rule. Fatigue life was calculated to be 20.8 years according to the occurrences of current speed measured by the SNMREC and the DOE/MSU Composite Material Fatigue Database. It was noticed that fatigue life was dictated by the tensile stress.
- Results from FAST were compared with those of ANSYS. The correlation between the blade tip displacements was very reasonable. ANSYS finite element model predicted slightly higher tip

displacement. Blade stresses were computed using a simple beam theory, which was also compared with ANSYS results. The correlation between the two results was also reasonable. Again, ANSYS's estimates were slightly higher.

Additional details can be found in a Ph.D. Dissertation (Zhou, 2013) and this work provided needed analysis for type and location placement of various sensors in future SNMREC rotor blade designs so that modeled results can be verified and measurements included with PHM diagnosis.

Automated Adaptive Condition Monitoring

Finally, the system health and behavior data which is collected by an instrumentation system must be processed to perform PHM assessments, recommendations, and warnings. The remainder of the effort under this task, two Ph.D.'s and one Post-Doc, was directed towards arranging for adequately fused data and automated adaptive data mining. First, the challenge of data fusion from heterogeneous sensors was addressed.

To effectively utilize sensor readings for determining the health of individual components, macro-components and the overall system, these measurements must somehow be combined or integrated to form a holistic picture. The process used to perform this combination is called data fusion. Data mining and machine learning techniques allow for the analysis of these sensor signals, any maintenance history and other available information (like expert knowledge) to automate decision making and other such processes within PHM systems.

This tasks' research investigated the feasibility of various data mining, machine learning and data fusion techniques for a PHM system. Studies conducted on experimental data aimed to reveal the optimal approach for fusing and interpreting sensor data. Also considered in these studies was the possibility of imperfect data and other challenges that could negatively affect the efficiency of techniques. Specifically, the robustness of our techniques with respect to changing environmental conditions, class imbalance (i.e., the relative lack of fault data as compared to data collected during normal operation that will be available to construct state detection models) and data incompleteness (e.g. missing values in the data) was assessed. A PHM software architecture was developed employing those techniques which were determined from these experiments to be ideal for this application. It also offers a data fusion framework applicable to other ocean machinery PHM. Finally, it presents a software tool for monitoring ocean turbines and other submerged vessels, implemented according to industry standards.

First, a framework and approach to data fusion for PHM systems in inaccessible, unattended ocean systems was developed. The proposed data fusion approach has been partitioned into three levels: inter-sensor or fusion of data between heterogeneous sensors, intra-component or data fusion between homogeneous sensors, and inter-component fusion which is performed at higher levels of the architecture to provide an overview of the health of the system. At the inter-component and intra-component levels of fusion, the performance and error rates of distributed classification and expert systems must be carefully measured to determine the effectiveness of these techniques.

The results of the experiments showed that data fusion, even in a most naive and oversimplified form, provided more stable classifier performance and higher correlations between runs than data from any single channel. Further, the performance differences of twelve data mining classifiers on data fused at the data-level, feature-level and decision-level were compared. Based on results from two experiments, feature-level fusion yielded the most stable results and the greatest improvement overall compared to

the other fused channels. Feature level fusion also yielded more consistent results than individual channels, in most cases. After analysis of state detection performance from imperfect data and in the presence of class balance with experimental OCPGS data, a tool was developed to implement resulting approaches.

The Condition Monitoring Software System (CMSS) tool, a software tool for monitoring ocean turbines and other submerged systems, performs data manipulation and state detection - two basic requirements of a condition based monitoring system per the ISO standard ISO-13374. This data mining-

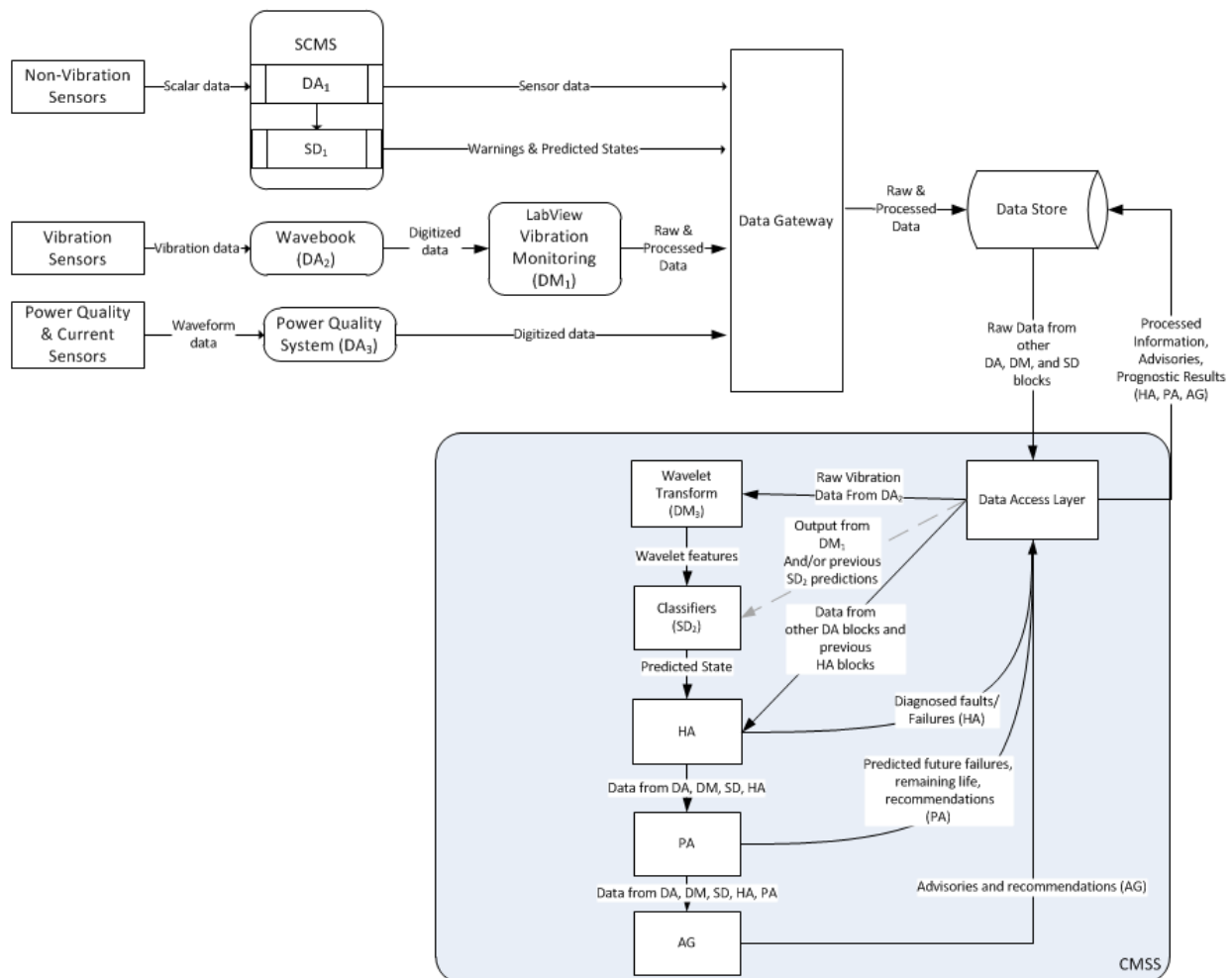


Figure 37: PHM system data flow, indicating CMSS data fusion contributions.

based tool is being developed to aid engineers in fault identification (determining what the problem is), fault localization (finding the location or source of the problem), fault prognosis (predicting the likely outcome from a problem) and future life assessment for an ocean turbine while it operates autonomously offshore. The completed product will be a data-driven PHM system in which sensor data is processed, fused and mined to understand the current behavior of the turbine and predict its future health. In the present version of the tool, a Short Time Wavelet Transform based technique was applied to raw vibration signals to transform the data into a format that classifiers can learn from. The outputs from n classification models built separately on data from each of the n sensor channels are combined using a decision-level data fusion approach to yield a single prediction of the current state of the

machine based on all of the available sensor data. Classification models constructed using either the Multi-Layer Perceptron (MLP) or k-Nearest Neighbor algorithm were found to be optimal for this application. Additional detail can be found in a Ph.D. Dissertation (Duhaney, 2012) and associated refereed publications (Appendix B).

Finally, novel methods were needed for treatment of acceleration sensors with respect to PHM analysis. These sensors, used to detect vibrations within or of a piece of machinery, are among the most useful for detecting subtle failures and pre-failure wear in a machine— but their output is also the most difficult to process. In rotating or reciprocating machinery such as an underwater turbine, different components of the machine will complete one full cycle of motion at different rates. Each of these components thus creates a signature vibration, a type of signal which shows that the component in question is functioning normally. When something changes, due to wear, foreign objects, or other failure modes, these components will behave differently, and these changes will affect the vibration signatures.

However, extracting these signatures is not as simple as polling the accelerometer and comparing the current value with a given range. By their very waveform nature, each vibration signature can only be observed when collecting data from a time frame at least as long as the wavelength in question. This data must be passed through a mathematical function known as a transform, to move it from the amplitude-time domain (e.g., the physical location of the accelerometer at a given point in time) to the frequency-magnitude domain (e.g., how much of the wave can be decomposed into vibrations of each given frequency). The Fourier transform is a well-known form of frequency-magnitude representation: the original data is decomposed into a collection of sinusoidal waves, with each point of the transformed data representing how much of the original data exhibited oscillations (waves) of the given frequency. These separate frequencies can be used as the vibration signature to characterize a machine in both healthy and abnormal states.

One downside of Fourier transforms (and frequency-magnitude transforms in general) is they assume that all data exists prior to performing the transform, and that the data continues to infinity in both directions. Naturally, these assumptions are not met when using vibration sensor data as part of a PHM system. Moreover, the most important aspect of such a system is that it can detect a change in the machine's behavior: whether a system that works on one day has stopped working on the next. Any transform used for such a system must be able to extract vibration signatures and determine when these signatures themselves change over time. This is a challenge, because the signatures themselves take up a finite amount of time (at least long enough to evaluate one wavelength of the longest/lowest frequency which composes that signature), but changes in signatures must be detected rapidly. A time-frequency-magnitude transformation must be employed to balance these concerns and provide information about which vibration signatures are present and when.

One solution to this problem with the traditional Fourier transform is the short time Fourier transform (STFT). This transform modifies the existing Fourier transform by selecting a window of data and performing the transform on only this window. The window is then slid along, processing new time spans from the data. Choosing the window size is a major downside of STFT: too long, and the window will not be able to recognize changes in high-frequency (short-wavelength) vibrations until long after these changes have transpired. Too short, on the other hand, and low-frequency (long-wavelength)

vibrations will be excluded altogether, because the window ends before they can be detected. Despite these drawbacks, STFT are one potential approach to vibration analysis, and bear further study.

Wavelet transforms are an alternative to Fourier transforms which lack these drawbacks. Wavelets (which form the core of wavelet transforms) are generator functions which only have non-zero magnitude over a very limited portion of their range, and which exhibit wave-like patterns (hence the name, signifying “little wave”). The underlying principle of wavelet transformation is choosing a single generator function (known as the “mother wavelet”), and using this function to create a family of “child wavelets” by stretching (scaling) and sliding (translating) the mother wavelet. Each child wavelet will then have a unique position (based on how much it was translated) and size (based on how much it was scaled), representing the range of time and scale being studied. This collection of child wavelets is convoluted with the original data, to determine for each child wavelet, how much of the original data can be represented by vibration on that scale at that time. This collection of scale data, collected into a “scalogram” can be used to prove a full time-frequency-magnitude.

With wavelet transforms, one additional problem is streaming data (Fourier transforms, in the form of the STFT, are already able to handle streaming data). Even these time-frequency-magnitude transforms, which properly handle data where vibration signatures vary over time, often expect that all data will be present from the outset. Frequently the full dataset is used to build the results, and time localization can only be used retrospectively. Thus, streaming versions of these transforms are needed, which are designed from the ground up to operate on data as it flows through a PHM system, without expecting future data to be available. A number of solutions exist: windowing (such as the windowing employed in the STFT) may be considered, or the transform can be built sequentially, using new data to update information as soon as it is available. Both approaches have benefits and drawbacks, and merit further investigation.

Additional challenges exist for using vibration sensors for building a PHM system to monitor an underwater ocean turbine. One known problem with such underwater systems is that the environmental conditions can induce vibrations which are not directly related to the operating state of the turbine. For example, the rotating speed of the turbine shaft is not directly related to the health of the turbine, only to the speed of the ocean flow at a given time (and this speed is known to change over time). However, the rotating shaft will induce vibrations, and these will affect the vibration signatures extracted from the accelerometers. Measures must be taken to remove this background noise, to preserve only the parts of the vibration data which are useful for evaluating system state. In addition, some types of transform require further processing to determine which scales exhibit the strongest waves, so that the collection of discovered scales can be used for building a vibration signature. Finally, depending on the types of accelerometers used in a given system, data from these sources may be combined to create a cleaner and more useful data source, both reducing and refining the data employed by the PHM system.

To address these challenges, the following were completed:

1. A collection of new wavelet-based transforms, including a modified short-time wavelet transform, and three novel transforms: the streaming wavelet transform, short-time wavelet packet decomposition, and streaming wavelet packet decomposition. Collectively, these consider a number of different views on wavelet transformation, with different advantages and drawbacks in terms of extracting different types of vibration signatures.

2. New approaches for dealing with the challenges of extracting useful scale information from the aforementioned wavelet-based transforms. In particular, while existing techniques can employ windowed data to determine which frequencies in a wavelet-based transform show the highest amount of amplitude, an approach was introduced that can perform this in a fully streaming fashion, examining different frequencies on different time scales (rather than being restricted to a single time window across all frequencies).
3. A novel method for reducing the scope of the data extracted through the aforementioned transformation steps, which works by employing the selected features to discover an appropriate depth for transformation. This is the first data-driven approach towards depth selection, as opposed to using ad-hoc or human-driven approaches based on comparing results across different experiments.
4. A baseline-differencing approach for finding useful vibration data even in the face of changing environmental conditions. This is important because in the real world, vibration data will necessarily incorporate information regarding environmental conditions in addition to important state information, and models will need to be built using only the state information without the extraneous information regarding the environment.
5. A large collection of case studies from two different physical systems to evaluate and compare the above approaches. These two systems, a commercial box fan and a purpose-built dynamometer test bed, exhibit different traits and serve different purposes for testing. Through the course of the case studies, all of the above algorithms and approaches were demonstrated and compared with how they affect the performance of the models.

More detailed description of this work is available in a Ph.D. Dissertation (Wald, 2012) and associated refereed publications (Appendix B).

Subtask 10-2.5 – Programmatic Environmental Impact Statement Roadmap

As described in the Background section of this report, this task was scoped as an extension to Task 09-1.1.1 after considerable deliberation with BOEM regarding effort necessary to complete the IP Lease application process for small scale ocean current turbine demonstration testing. Detailed results are described under Task 09-1.1.1 in the Results and Discussion section above.

Task 10-3.0 – Education and Outreach

Subtask 10-3.1 – Professional Workshop/Public Forums

In April 2012, SNMREC held five public forums as outreach to the community, academia, government, special interest groups and businesses. The forums were held respectively, at FAU's Boca Raton Campus College of Nursing Auditorium, FAU's Davie West Auditorium and FAU's John D. McArthur Campus Auditorium. This program was held to inform the public of SNMREC's lease application through BOEM. BOEM released a notice for public input on the Environmental Assessment for the proposed lease area of FAU's SNMREC, off the coast of Dania Beach, Florida shortly after the first two public forums were held. SNMREC Executive Director Sue Skemp, led the forums with an informational PowerPoint that included a discussion of: SNMREC's origins, the resource potential of the Gulf Stream, R & D, workforce development, environmental stewardship and education programming. Each forum was followed by a question and answer session.

FLORIDA ATLANTIC UNIVERSITY
Southeast National Marine Renewable Energy Center

2012 Public Lecture
**Ocean Renewable Energy
Harnessing the Power of the Sea**

All are cordially invited to attend this special presentation
at one of the times and locations listed:

Thursday, April 19 7 p.m. Christine E. Lynn College of Nursing Auditorium 777 Glades Road Boca Raton Campus	Friday, April 20 4 p.m. or 7 p.m. Davie West Auditorium 3200 College Avenue Davie Campus	Monday, April 30 4 p.m. or 7 p.m. Admin. Bldg., Rm. 119 5353 Parkside Drive John D. MacArthur Campus
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The Southeast National Marine Renewable Energy Center at FAU is working to help accelerate the commercial implementation of marine renewables for a more diversified and sustainable energy future. Because commercial marine energy technologies are still immature, the Center focuses public and private investment on ocean current and ocean thermal resource characterization, technology development, testing infrastructure installation, environmental assessment, and regulatory framework development as well as licensing standards, procedures, and code for this new economic sector.

The Center is poised to begin testing an experimental research turbine and is awaiting approval and a federal lease to install and operate a small-scale turbine test berth offshore of Ft. Lauderdale, Florida. Learn how the SNMREC's research is making a unique contribution to a broadly diversified portfolio of renewable energy for the nation's future.

Presented by
Sue H. Skemp
Executive Director
Southeast National Marine Renewable Energy Center
College of Engineering and Computer Science
Florida Atlantic University

About the Speaker:
Sue H. Skemp joined FAU in March 2008 as the Executive Director of the Southeast National Marine Renewable Energy Center. She has developed a multi-disciplinary program at FAU to address exploration and evaluation of ocean energy potential, specifically ocean current hydrokinetic and ocean thermal energy conversion.

Skemp has a broad background in industry, federal policy, and engineering associations. During her 31-year career at Intel & Whittier, she was instrumental in leading a number of research and technical programs and operations, including programs funded at more than \$10 million with the U.S. Department of Defense and the National Aeronautics and Space Administration.

If accommodations for disabilities are required, please contact skemp@fau.edu

Florida Atlantic University
Southeast National Marine Renewable Energy Center
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Figure 38: Flyer distributed with details about public forums held in southeast Florida in 2012.

Working with FAU's Department of Communications, Media and Community Relations, Lifelong Learning, Alumni Association, the FAU Foundation and the Presidents' Office, an extensive effort was led to contact the community about the events. Over 37,000 invitations were emailed to constituent groups. The RSVP's were tracked to determine who was attending the events, and so that SNMREC staff could follow up with those who had not responded. Two mailing "blasts" were broadcast to the invitees. As a follow-up to the event, each attendee was invited to a public information session to be conducted by BOEM on May 2012 in Ft. Lauderdale, Florida. They were also sent a copy of the Environmental Assessment, a map of the proposed lease area, and a copy of the lease application. Overall, feedback from the forums was positive and the attendees appreciated the opportunity to voice opinions regarding renewable ocean energy development in their community. Many of the attendees reflected that they learned quite a bit about renewable energy and specifically, energy from the ocean.

Subtask 10-3.2 – Public Outreach/Education

SNMREC conducted seven workshops with science teachers across south Florida with the focus on training the trainers, providing teachers with the tools to reach out into their respective school districts and become teacher-mentors. The last teacher training was held in November 2011. Over 200 teachers in South Florida have been trained including several middle school science teachers. Now that the formal training is complete, the teachers who participated in the program are being surveyed for their use of the curriculum. Plans are underway to expand the curriculum to include a seventh lesson devoted to Policy and its Role with the Regulatory Framework as well as alternative methods of distribution of the curriculum to teachers across the state of Florida and the nation.



Figure 39: Curriculum training session for teachers in various southeast Florida counties.

SNMREC staff worked with professors and students at FAU's School of Communications and Multimedia Studies' to create an interactive educational display game. In partnership with HBOI, the SNMREC is designing and installing a kiosk at its Ocean Discovery Center. The kiosk is anticipated to be installed by January 2014 and will create a hands-on experience which educates the public about future ocean energy projects. This effort will be leveraged to provide similar kiosks to science and discovery museums. The intent is to provide an opportunity to engage all ages in a hands-on, fun and educational experience about ocean renewable energy production. The kiosks will increase knowledge of real, cutting-edge research in renewable energy from the ocean as well as, incorporating valuable Science Technology Engineering & Math (STEM) content to foster a well-informed constituency that understands the importance of renewable energy production in the U.S.



Figure 40: Title screen for SNMREC kiosk simulator.



Figure 41: Screen capture from SNMREC kiosk mission. The operator sees the Remotely Operated Vehicle (ROV) that is navigating the underwater world. In this scene, the small-scale ocean current research turbine is being explored.

Task 10-4.0 – Project Management

As described for Task 09-4.0, effort in this task involved the overall management of project tasks, timelines, and budgets. In addition, travel was supported to participate in a national marine renewable center workshop in Corvallis, OR (2011), meetings with DOE Program Officers at headquarters in Washington D.C., and PEER Review(s).

Accomplishments

Appendices B comprise listings of formal contributions in literature and at various conferences and workshops. In addition to formal contributions, the SNMREC has prepared the foundation for the world's first and only offshore ocean current energy testing capability. Preparation for this unique industry support includes a variety of multi-disciplinary challenges:

- Planning and site selection for the first-phase test facility, offshore of Dania Beach, FL, including some equipment for the facility, submission of an Interim Policy Lease Application to the U.S. Department of Interior's Bureau of Ocean Energy Management (BOEM), and completion of an Environmental Assessment by BOEM and a positive Consistency Determination by the State of Florida;
- Measurements using acoustic profilers of the current structure and variability in the vicinity of the site under a variety of weather conditions, seasons and time durations;
- Design and implementation of instrumentation for the first phase of the offshore testing facility, the wet- and top-side data acquisition systems, and shore-based analysis systems;
- Implementation of a laboratory-scale dynamometer system to test generators of up to 25 kW capacity using real-world (simulated) forcing;
- Completion of 24 months of (airborne) marine vertebrate surveys and associated analysis of sea turtle offshore activity, marine mammal vocalization research, and ocean current turbine hydrodynamic noise characterization;

This award also made possible aiding BOEM with developing a regulatory review process for MHK projects on the OCS. This process supported the development of guidelines for siting marine hydrokinetic projects.

Finally, the curriculum document discussed above provides a basis for additional contributions, including one under development aimed at middle-school students. As a link between public outreach talks and this more formal educational development, SNMREC has also been in contact with several local museums about developing display materials for them. In this way (kiosks), the beginnings of long-term human resources preparation for future MRE needs has been accomplished.

Conclusions

This award, a combination of two consecutive fiscal year Congressionally Directed Projects, has been pivotal in preparing preliminary offshore infrastructure, assisting with national OCS regulatory framework development, preparing scaled laboratory test and evaluation platforms, filling technology gaps, collecting baseline offshore resource and ecological data, and educating a nation in advance of commercial utility-scale ocean current energy capture. As indicated in the Results and Accomplishments sections of this report, various publications describing the completed efforts are available and key milestones have been reached to establish the world's first small scale ocean current turbine demonstration and evaluation capability. Remaining tasks to accept commercial turbine prototypes for testing are scoped under follow-on award DE-EE0004200. A small scale turbine demonstration capability is essential for commercial equipment manufacturers to continue evolving concepts and prototypes. As these technologies mature, however, test and evaluation support must keep pace or risk imposing unreasonable costs, impeding further development before fiscal efficacy of the projects can be achieved.

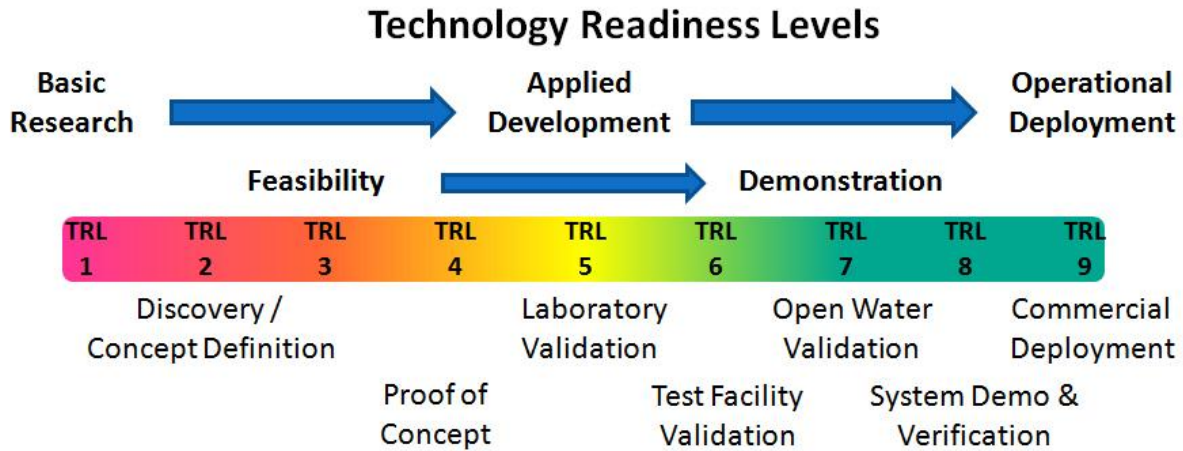


Figure 43: Generic Technology Readiness Level (TRL) scale phases of development, adapted by DOE for MHK projects.

DOE has adopted a Technology Readiness Level (TRL) description system (DOE, 2012) to identify the maturity of technologies and anticipate needs (Figure 43). The SNMREC applies this tool to industry support strategy development as a gauge for what is needed and when. As indicated in Figure 42, SNMREC projects are keeping pace with immediate needs, but more complex, costly, and pending needs must be considered (and funded) in parallel if ocean current energy projects hope to achieve commercialization.

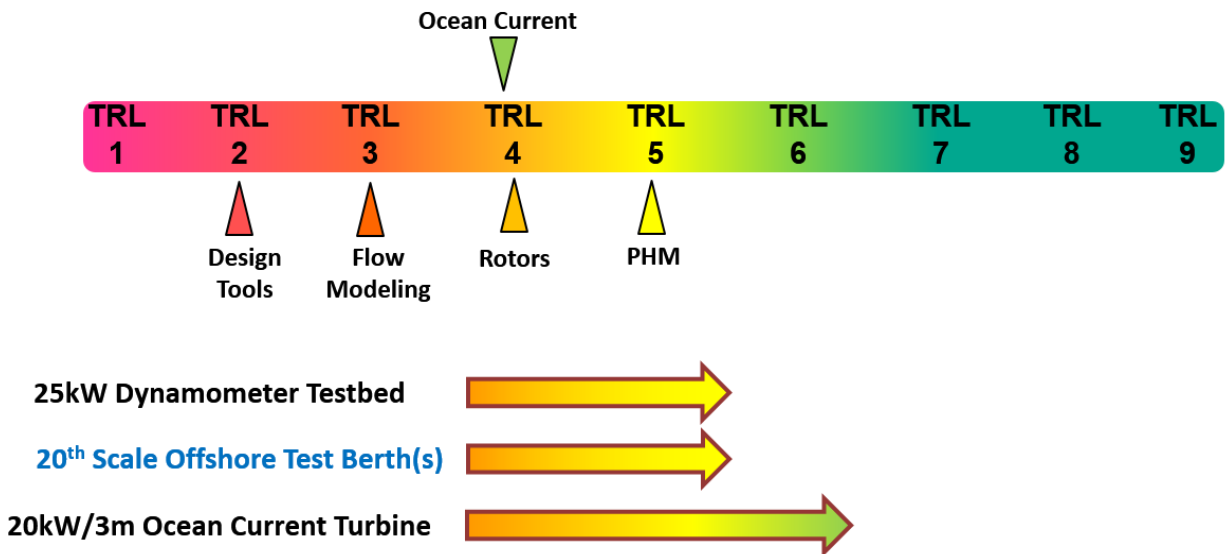


Figure 42: Representation of approximate maturity of ocean current energy projects and the SNMREC's near-term contributions with respect to TRL scale.

Recommendations

To that end, the activities funded by DE-EE0000319 and reported here, including characterizing the resource of the Florida Current in order to optimize the design of technology for recovering its energy, planning and developing the components of a testing facility, working to understand the implications of such a facility (as well as of full-scale deployments) on the environment (for which work the facility itself

will be an extremely useful platform), and advancing the preparations of human resources for MRE in the future, are all critical and need to continue. In particular:

- Measurements of the structure and variability of the Florida Current should be ongoing and eventually extended to probable locations for siting of commercial arrays;
- The existing measurements should be augmented by fine-scale measurements of turbulence down to the scales of the chords of rotor blades (this is a significant challenge, but the MTB offers a useful platform for the purpose). SNMREC has in place a Cooperative Research and Development Agreement with the National Renewable Energy Laboratory to develop systems to make such measurements in the near future.
- Computer simulations of the possible effects on the current itself of various energy extraction scenarios should be continued and enhanced (the tools exist for this purpose already);
- Population and behavioral studies of sensitive species, both pelagic and benthic, should be continued and enhanced (both *in situ* and remote measurements will be needed);
- Completion of the first-phase SNMREC testing facility, which will allow testing of small-scale systems up to about 100 kw capacity, should be followed by development of a full-scale test facility (these facilities will need to operate on a cost-recovery basis, but infrastructure development will require outside support);
- Education and outreach activities should continue to prepare the public for the concept of MRE for the future and the workforce for the needs of this new, potentially game-changing industry.
- Regulatory agencies should be required to issue permits, licenses and other authorizations in prescribed timeframes, so that the developers have certainty that the regulatory process will not delay deployments of technology.

References

- Baringer, M.O., and J.C. Larsen, 2001: Sixteen years of Florida Current transport at 27°N. *Geophysical Research Letters*, **28**, 3179-3182.
- Beal, L.M., J.M. Hummon, E. Williams, O.B. Brown, W. Baringer, and E.J. Kearns (2008), Five years of Florida Current structure and transport from the Royal Caribbean cruise ship *Explorer of the Seas*. *J. Geophys. Res.*, **113**, C06001, doi:10.1029/2007JC004154.
- BOEM, 2013: [Lease Issuance for Marine Hydrokinetic Technology Testing on the Outer Continental Shelf Offshore Florida Revised Environmental Assessment](#), OCS EIS/EA BOEM 2013-01140, BOEM Office of Renewable Energy Programs, *Federal Register*, **78**(156), [78 FR 49287].
- Bowren, M., 2012: *Software Framework for Prognostic Health Monitoring of Ocean-Based Power Generation*. M.S. Thesis, College of Engineering and Computer Science, Florida Atlantic University, 123pp.
- Brooks, I., 1979: Fluctuations in the transport of the Florida Current at periods between tidal and two weeks. *Journal of Physical Oceanography*, **9**, 1048-1053.
- Cada, G., J. Ahlgrimm, M. Bahleda, T. Bigford, S.D. Stavrakas, D. Hall, R. Moursund, and M. Sale, 2007: Potential impacts of hydrokinetic and wave energy conversion technologies on aquatic environments. *Fisheries*, **32**, 174-181.
- DAL (Dehlsen Associates, LLC), 2012: Siting Study for a Hydrokinetic Energy Project Located Offshore Southeastern Florida: Protocols for Survey Methodology for Offshore Marine Hydrokinetic Energy Projects, Final Report of DE-EE0002655, U.S. Department of Energy, Washington, DC, 100pp.
- DOE, 2012: [Technology Readiness Levels](#). Advanced Manufacturing Office, Office of Energy Efficiency and Renewable Energy, DOE, Washington, DC.
- Duhaney, J.A., 2012: *Mining and Fusing Data for Ocean Turbine Condition Monitoring*. Ph.D. Dissertation, College of Engineering and Computer Science, Florida Atlantic University, 199pp.
- EPRI (Electric Power Research Institute), 2011: *Mapping and Assessment of the United States Ocean Wave Energy Resource*, [EPRI Report 1024637](#), EPRI, Palo Alto, CA, 176pp.
- FCRC Consensus Center, 2010: *Offshore Ocean Energy: A University-Industry-Government Dialog Facilitator's Summary Report*. Tallahassee, FL, 41pp.
- GTRC (Georgia Tech Research Corporation), 2011: *Assessment of Energy Production Potential from Tidal Streams in the United States*, [Final Report of DE-FG36-08GO18174](#), U.S. Department of Energy, Washington, DC, 109pp.
- Guerra, J., 2011: *Estimates of water turbine noise levels*. M.S. Thesis, College of Engineering and Computer Science, Florida Atlantic University, 92pp.
- Hanson, H.P., 2009: Diversified renewables. *EnergyBiz*, **6**(4), p. 52.
- Hanson, H.P. 2012: Note on subsurface mooring stability in the presence of vertical shear. *Marine Technology Society Journal*. (submitted)
- Hanson, H.P., A. Bozec, and A.E.S. Duerr, 2011: The Florida Current: A clean but challenging energy resource. *Eos: Transactions of the American Geophysical Union*, **92**, 29-30.
- Hanson, H.P., A.E. Smentek-Duerr, and J.H. VanZwieten, Jr., 2012: Variability in the Florida Current: Implications for Power Generation. In: *Proceedings, World Renewable Energy Forum 2012*, 13-17 May 2012, Denver, Colorado, American Solar Energy Society.
- Hawkins, M.J. (Eds.), 2002 (rev. 2003): *UNOLS Portable Scientific Vans Manual*. Accessed from <http://www.unols.org/committees/rvoc/vansspecs2002/UNOLSVanManualv2.pdf>.
- Huber, L., 2009: *Understanding and Implementing ISO/IEC 17025, A Primer*. Agilent Technologies, Inc., 64pp.
- Johns, W.E., and F. Schott, 1988: Meandering and transport variations of the Florida Current. *Journal of Physical Oceanography*, **17**, 1128-1147.

- Leaman, K.D., R.L. Molinari, and P.S. Vertes, 1987: Structure and variability of the Florida Current at 27°N: April 1982–July 1984. *J. Phys. Oceanogr.*, **17**, 565-583.
- Lovenbury, J.W., 2013: *Evaluation of motion compensated ADV measurements for quantifying velocity fluctuations*. M.S. Thesis, College of Engineering and Computer Science, Florida Atlantic University, 68pp.
- Mayer, D.A., K.D., Leaman,, and T.N. Lee, 1984: Tidal motions in the Florida Current. *Journal of Physical Oceanography*, **14**, 1551-1559.
- Meinen, C.S., M.O. Baringer, and R.F. Garcia, 2010: Florida Current transport variability: An analysis of annual and longer-period signals. *Deep-Sea Research, I*, **57**, 835-846.
- Mjit, M., 2009: *Methodology for fault detection and diagnostics in an ocean turbine using vibration analysis and modeling*. M.S. Thesis, College of Engineering and Computer Science, Florida Atlantic University, 100pp.
- MMS (Minerals Management Service), 2007: Request for information and nominations for leases authorizing alternative energy resource assessment and technology testing activities pursuant to Subsection 8(p) of the Outer Continental Shelf Lands Act, as Amended. *Federal Register*, **72**(214), [72 FR 62673].
- MMS, 2009: Renewable energy and alternate uses of existing facilities on the Outer Continental Shelf. *Federal Register*, **74**(81), [74 FR 19638].
- Morales-Nin B., L. Cannizzaro, E. Massuti, A. Potoschi, and F. Andaloro, 2000: An overview of the FADs fishery in the Mediterranean Sea. In: Le Gall, J.-Y., P. Cayre, and M. Taquet (eds.), *Pe^che Thoniere et Dispositifs de Concentration de Poisons*. Ed. Ifremer, Actes Colloq. **28**, 184–207.
- Munk, W.H., 1950: On the wind-driven ocean circulation. *Journal of Meteorology*, **7**, 79-93.
- Lee, T.N., 1975: Florida Current spin-off eddies. *Deep-Sea Research*, **22**, 753-763.
- Lee, T.N., Leaman, K.D., E.H. Williams, T. Berger, and L. Atkinson, 1995: Florida current meanders and gyre formation in the southern Straits of Florida. *Journal of Geophysical Research, C*, **100**, 8607–8620.
- Lippert, R., 2012: *Numerical Models to Simulate Underwater Turbine Noise Levels*. M.S. Thesis, College of Engineering and Computer Science, Florida Atlantic University, 102pp
- LM-MS2 (Lockheed-Martin Mission Systems & Sensors), 2013: *Ocean Thermal Extractable Energy Visualization*. [Final Report of DE-EE0002664](#), U.S. Department of Energy, Washington, DC, 88pp.
- Relini, G., M. Relini, M. Montanari, 2000: An offshore buoy as a small artificial island and a fish aggregating device (FAD) in the Mediterranean. *Hydrobiologia*, **440**, 65–80.
- Reza, Z., 2010:, *Dissipation and eddy mixing associated with flow past an underwater turbine*. MS. Thesis, Department of Ocean and Mechanical Engineering, Florida Atlantic University, 85pp.
- Smentek-Duerr, A.E., 2012: *A Hydrokinetic Resource Assessment of the Florida Current*. Ph.D. Dissertation, College of Engineering and Computer Science, Florida Atlantic University, 214pp.
- SNMREC, 2012: *Project Application to the U.S. Department of Interior Bureau of Ocean Energy Management, Regulation and Enforcement for an Outer Continental Shelf Renewable Energy Program Interim Policy Lease*, SNMREC/FAU. (Online [here](#))
- Valentine, W., 2012: *Design of a Hydrodynamic Testing Facility for Gulf Stream Ocean Current Turbines*, M.S. Thesis, College of Engineering and Computer Science, Florida Atlantic University, 129pp.
- Wald, R.D., 2012: *Vibration Analysis for Ocean Turbine Reliability Models*. Ph.D. Dissertation, College of Engineering and Computer Science, Florida Atlantic University, 141pp.
- Young, M., 2012: *Design and Analysis of an Ocean Current Turbine Performance Assessment System*. M.S. Thesis, College of Engineering and Computer Science, Florida Atlantic University, 108pp.
- Zhou, F., 2013: *Development of an integrated computational tool for design and analysis of composite turbine blades under ocean current loading*. Ph.D. Dissertation, College of Engineering and Computer Science, Florida Atlantic University, 186pp.

Appendices

A: Supplemental Information

Appendix A1: Interim Policy Factors

TABLE A1: Environmental Information Required for BOEM Application

Impact-producing Factors		Construction, Routine Operations, and Decommissioning
		Emissions
		Sea Bottom Disturbances
		Wastes and Overboard Discharges
		Noise
		Onshore Facility Construction or Modification
		Vessel Traffic
		Lights and Electromagnetic Forces
		Environmental Hazards and Accidental Events
		Environmental Hazards
		Accidental Events
Affected Environment	<i>Physical Resources</i>	Physical Oceanography and Meteorology
		Bottom Sediments
		Shallow Hazards
		Water Quality
		Air Quality
		Noise and Visual Quality
	<i>Biological Resources</i>	Coastal Environments and Wetlands
		Benthic Communities
		Coastal and Marine Birds
		Fish and Essential Fish Habitat
		Sea Turtles
		Marine Mammals
		All Endangered or Threatened Species
	<i>Socioeconomic and Human Resources</i>	Commercial Fisheries
		Recreational Resources
		OCS and Coastal Infrastructure
		Land Use Patterns
		Archaeological Resources
		Competing Use of State Waters and OCS
		Demographic Patterns and Employment

Appendix A2: Regulatory Authorities

TABLE A2: Agencies with regulatory purview over activities in the Florida Straits

Regulatory Agency	Permit/Approval Actions/Requirements
Federal Agencies	
U.S. Army Corps of Engineers (USACE) ^A	- Issues a Section 404 permit under the Federal Water Pollution Control Act of 1972, as amended (Clean Water Act; 33 USC § 1344) for discharge of dredged and fill material into U.S. waters, including wetlands. - Issues a Section 10 permit under the Rivers and Harbors Appropriations Act of 1899 (33 USC § 403) for structures or work in, of affecting, navigable waters in the U.S. Under Section 10 of the Rivers and Harbors Act of 1899, as extended by the Outer Continental Shelf Lands Act (OCSLA), the Corps requires a permit for the creation of “any obstruction” in federal waters to preserve unhindered navigational access of the nation’s waters. (33 U.S.C. § 403 (1999).) The OCSLA extended the Corps’ section 10 authority into the EEZ allowing the agency to regulate “installations and other devices permanently or temporarily attached to the seabed, which may be erected thereon for the purpose of exploring for, developing or producing resources from [the outer continental shelf]” (43 U.S.C. § 1333(a), (e) (1999).) including CZMA and ESA
Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE)	Renewable Energy (REN) activities on the Outer Continental Shelf (OCS), as authorized by Section 388 of the Energy Policy Act of 2005 (EPA), and codified in subsection 8(p) of the Outer Continental Shelf Lands Act (OCSLA). Developments in the Outer continental Shelf must comply with the OCSLA as well as with CZMA and the ESA. The goal of the Outer Continental Shelf Lands Act as administered by BOEMRE is to assure safe and clean oil, gas, sulfur, or other operations on the Outer Continental Shelf. BOEMRE would grant a lease and, if applicable, issue a pipeline ROW permit. BOEMRE reviews require an applicant to comply with the following conditions: - operations must result in the diligent development and efficient recovery of resources; - all activities must comply with applicable federal, state, and local laws and regulations applicable to federal leases; all activities must include adequate safeguards to protect the environment; - disturbed lands must be properly reclaimed; and - all activities must protect public health and safety.
Federal Energy Regulatory Commission (FERC)	Issuance of licenses for the construction of a new project that connects to the grid. FERC and BOEMRE have agreed that offshore ocean-energy development is an BOEMRE responsibility to the point of grid connections.
National Oceanic and Atmosphere Administration- National Marine Fisheries Service (NMFS) ^C	- Provides consultation under ESA with the Magnuson-Stevens Fishery Conservation and Management Act for the effects on Essential Fish Habitat and Habitat Areas of Particular Concern (50 CFR 600.905-930). Under the Magnuson-Stevens Fishery Conservation and Management Act, the National Marine Fisheries Service (NMFS) has regulatory responsibilities that will affect ocean energy development in the EEZ. - Provides consultation under the Endangered Species Act of 1973 (16 USC 1531-1543), regarding effects to threatened or endangered species. - Provides consultation under the Marine Mammal Protection Act of 1972 as Amended in (2007) (16 USC Chapter 31) regarding the protection of marine mammal species and their habitats in an effort to maintain sustainable marine mammal populations.

Regulatory Agency	Permit/Approval Actions/Requirements
U.S. Fish and Wildlife Service (USFWS)	- Issues a Title XI right-of-way permit for construction of a transportation or utility system across refuge lands (43 CFR 36). The ROW application process would require a NEPA analysis (43 CFR 36.6) of the entire development scenario. - Provides consultation under the Endangered Species Act of 1973 (16 USC 1531-1543), regarding effects to threatened or endangered species.
U.S. Coast Guard (USCG) ^D	The U.S. Coast Guard is responsible for the regulation and enforcement of various activities in the navigable waters of the U.S. and requires that such research-related projects are marked with lights and signals in order to ensure safe passage of vessels. Installation and maintenance of the markers must be done by the engineers as long as the structures are located in navigable waters. The Coast Guard provides detailed requirements for markings.
State Agencies	
Florida Department of Environmental Protection (FDEP) ^E	- Issues a Certificate of Reasonable Assurance for discharge of dredged and fill material into U.S. waters under Section 401, Federal Water Pollution Control Act of 1972, as amended in 1977 (Clean Water Act; 33 USC § 1341 et seq.); AS 46.03.020; under Part IV of Chapter 373 of the Florida Statutes. - Issues a Certificate of Reasonable Assurance/NPDES and Mixing Zone Approval for wastewater disposal into all state waters under Section 402, Federal Water Pollution Control Act of 1972, as amended (Clean Water Act; 33 USC § 1341 et seq.); AS 46.03.020, .100, .110, .120, and .710; subsection 62-730.180(1), F.A.C. - Approves domestic wastewater collection, treatment, and disposal plans for domestic wastewaters (Chapter 62-604, F.A.C.). - Issues a Title V Operating Permit and a PSD permit under Clean Air Act Amendments (Title V) for air pollutant emissions from construction and operation activities (Chapter 62-212.400, (F.A.C.)). - Approves Coastal Zone Management Act Federal Consistency Program, Chapter 380, Part II, F.S.
Florida Fish and Wildlife Conservation Commission (FWCC) ^F	- Issues permits for activities involving marine turtles in Florida under authority granted to the state through a Cooperative Agreement with the U.S. Fish and Wildlife Service (USFWS) under Section 6 of the U.S. Endangered Species Act (ESA). All activities relating to marine turtles must be authorized under subsection 370.10, Florida Statutes. - Restricts the speed and operation of vessels where necessary to protect manatees from harmful collisions with vessels and from harassment by the Manatee Sanctuary Act, 379.2431(2), Florida Statutes (FS). The rules appear in Chapter 68C-22 of the Florida Administrative Code (FAC). Issues Fish Habitat Permits (AS 41.14.820 and AS 41.14.870) for activities within fish-bearing streams that may impede fish passage. Stream diversion, gravel removal, stream crossings (fords), ice bridge/road construction, water withdrawal, and bridge or culvert construction are activities that normally require a Title 41 (Fish Habitat) Permit.
<u>Key:</u> F.A.C. – Florida Administrative Code; F.S. – Florida Statutes	

Notes:

A. USACE

Authority: Under Section 10 of the Rivers and Harbors Act of 1899, as extended by the Outer Continental Shelf Lands Act (OCSLA), the Corps requires a permit for the creation of “any obstruction” in federal waters to preserve unhindered navigational access of the nation’s waters (33 U.S.C. § 403 (1999).) The OCSLA extended the Corps section 10 authority into the EEZ allowing the agency to regulate “installations and other devices permanently or temporarily attached to the seabed, which may be erected thereon for the purpose of exploring for, developing or producing resources from [the outer continental shelf]” (43 U.S.C. § 1333(a), (e) (1999).)

The necessary permit is the Section 10 permit; a Nationwide or General permit may be available in which case the Corps issues a letter of permission that serves as the permit. The Corps considers a broad range of potential environmental and other impacts before issuing or denying a Section 10 permit for open ocean energy technologies.

B. USEPA

Authority: Under Section 318 of the Clean Air Act, the EPA has asserted jurisdiction to require point source pollution discharge permits for projects in the open ocean. (Regulations are located at 40 C.F.R. § 122.24 (NPDES).) In addition, the Ocean Dumping Act (33 U.S.C. § 1412 (1999)) grants authority to the EPA to permit the dumping of material into U.S. waters when such dumping will not unreasonably degrade or endanger human health or the marine environment, ecological systems, or economic potentialities. The criteria for reviewing such permits include the need for the proposed dumping; the effect of such dumping on human health and welfare, including economic, aesthetic and recreational values; the effect of such dumping on fisheries resources, plankton, fish, shellfish, wildlife, shorelines and beaches; and the effect of such dumping on marine ecosystems.

Further, OCS air permit regulations at 40 CFR 55 require compliance with all the applicable air requirements for the State of FL. Additional federal requirements are listed in 40 CFR 55.13 and 55.14 of the OCS air regulations. The permit would only be for the air quality aspects of the project. The air emissions are likely to come from mobile sources - such as the vessels or drilling rigs used to install the equipment.

C. NOAA/NMFS

Authority: Under the Magnuson-Stevens Fishery Conservation and Management Act, the National Marine Fisheries Service (NMFS) has regulatory responsibilities that will affect ocean energy development in the EEZ. For scientific research, the NMFS requires the applicant to apply for a Letter of Acknowledgement and the NMFS will inform the other agencies (the U.S. Coast Guard and state agencies, if necessary) that this activity is occurring in federal waters.

D. USCG

The U.S. Coast Guard is responsible for the regulation and enforcement of various activities in the navigable waters of the U.S. and requires that such research-related projects are marked with lights and signals in order to ensure safe passage of vessels. Installation and maintenance of the markers must be done by the engineers as long as the structures are located in navigable waters. The Coast Guard provides detailed requirements for markings.

E. FDEP

Authority: The Florida Department of Environmental Protection (FDEP) administers Florida’s NPDES permitting authority and houses the Florida Coastal Management Program for CZM purposes.

F. FWCC

Authority: Since the streamlining of Florida’s regulatory program for aquaculture, the Florida Fish & Wildlife Conservation Commission (FWCC) has very limited authority over the marine species in the state. The remaining authority is derived from Florida Statutes section 372.072(4) (a).

Appendix A3: Outreach Activities

TABLE A3: SNMREC media interviews and lectures to community groups

Venue	Date
Whole Foods Environmental Workshops	January, 2010
Gumbo Limbo Environmental Education Center	March, 2010
<i>National Geographic Television</i> interview	April, 2010
<i>Recharge</i> (newspaper) interview	April, 2010
Enterprise Florida Annual Meeting	May, 2010
<i>Boca Raton Tribune</i> (newspaper) interview	May, 2010
U.S. Dept. of State, International Visitor Program	May, 2010
<i>Fort Lauderdale Examiner</i> (newspaper) interview	May, 2010
Univ. South Florida Industrial Engineering Club	July, 2010
Florida Energy Systems Annual Summit	September, 2010
Florida International University Environmental Club	September, 2010
21 st Century Energy in Florida Summit	September, 2010
Broward College Environmental Program	April, 2011
<i>New Scientist</i> (magazine) interview	July, 2011
Florida Energy Systems Annual Summit	September, 2011
"AM Tampa Bay" (radio show) interview	January, 2012
ASME Regional Finals, Tampa Bay Future Cities	January, 2012
<i>Monterey County News</i> (newspaper)	February, 2012
<i>Renewable Energy World</i> (magazine) interview	April, 2012
<i>Palm Beach Post</i> (newspaper) interview	May, 2012
<i>Fort Lauderdale Sun-Sentinel</i> (newspaper) interview	June, 2012
WPBF (Channel 25) News interview	June, 2012
WPLG (Channel 10) News interview	June, 2012
WPEC (Channel 12) News interview	July, 2012
West Palm Beach Pack & Paddle Club	July, 2012
West Palm Beach Chapter, ASCE	August, 2012
PBC Business Development Board <i>Quarterly</i> interview	August, 2012
U.S. Dept. of State, International Visitor Program	August, 2012
WFOR (Channel 4, Miami) News interview	February, 2013

B: Contributions

Appendix B1: Refereed Journal & Conference Proceedings

- Cardei, I., A. Agarwal, B. Alhalabi, T. Tavtilov, T. Khoshgoftaar, and P.-P. Beaujean, 2011: Software and communications architecture for prognosis and health monitoring of ocean-based power generator, *5th IEEE Systems Conference, Montreal*.
- Duhaney, J.A., T.M. Khoshgoftaar, and J.C. Sloan, 2011: A survey of data fusion algorithms for reliability analysis, *Proceedings, 17th ISSAT International Reliability and Quality in Design Conference, Vancouver*, pp 344-348.
- Elishakoff, I. and Y. Miglis, 2011: Revisiting exponential stress corrosion model, *Ocean Engineering Systems*, **1**, 121-130.
- Fisher, A., J.H. VanZwieten, and N. Xiros, 2011: Station keeping adaptive control of a boat with twin gasoline outboard motors: synthesis, simulation, and sea-trials. *Proceedings of the ASME 2011 International Conference on Ocean, Offshore, and Arctic Engineering, Rotterdam*, No. OMAE2011-49827
- Hanson, H.P., S.H. Skemp, G.M. Alsenas, and C.E. Coley, 2010: Power from the Florida Current: A new perspective on an old vision. *Bulletin of the American Meteorological Society*, **91**, 861-867.
- Hanson, H.P., A. Bozec, and A.E.S. Duerr, 2011: The Florida Current: A clean but challenging energy resource. *Eos: Transactions of the American Geophysical Union*, **92**, 29-30.
- Hanson, H.P., 2011: Marine renewable energy: A Florida reality check. *Sea Technology*, **52**(4), 13-20.
- Hanson, H.P. 2012: Note on subsurface mooring stability in the presence of vertical shear. *Marine Technology Society Journal*. (submitted)
- Hanson, H.P., A.E. Smentek-Duerr, and J.H. VanZwieten, Jr., 2012: Variability in the Florida Current: Implications for Power Generation. In: *Proceedings, World Renewable Energy Forum 2012*, 13-17 May 2012, Denver, Colorado, American Solar Energy Society.
- Hanson, H.P., 2012: Hydrokinetic energy in the Sunshine State: Challenges of Florida's unique renewable resource. *Technology & Innovation -- Proceedings of the National Academy of Inventors*, **14**, 93-102.
- Hanson, H.P., S.K. Skemp, and C.E. Coley, 2013: Marine renewable energy: Educating the workforce. *Marine Technology* (in press).
- Hanson, H.P., 2013: Note on subsurface mooring stability in the presence of vertical shear. *Marine Technology Society Journal*, (in press).
- Nagurny, J., L. Martel, E. Jansen, A. Plumb, P. Gray-Hann, D. Heimiller, L.T. Rauchenstein, and H.P. Hanson, 2011: Modeling global ocean thermal energy resources. *Proceedings, IEEE OCEANS 11 Kona*, ISBN: 978-1-4577-1427-6.
- Rahman, A. and O. Marques, 2011: A web-based video library and annotation framework for marine biology survey, *Proceedings, IASTED International Conference on Internet and Multimedia Systems and Applications (IMSA 2011)*, Washington DC.
- Rauchenstein, L.T., J.H. vanZwieten, Jr., and H.P. Hanson, 2011: Model-based global assessment of OTEC resources with data validation off Southeast Florida. *Proceedings, IEEE OCEANS 11 Santander*, DOI: 10.1109/Oceans-Spain.2011.6003534.
- Sloan, J.C., T.M. Khoshgoftaar, and H. Hanson, 2010: Formalizing fault trees for remote ocean systems. *Proceedings, 16th International ISSAT on Reliability and Quality in Design*, pp 324-328.
- Sloan, J.C., T.M. Khoshgoftaar, and B. Alhalabi, 2011: A strategy for data-driven testing of an ocean turbine drivetrain, *Proceedings, 17th ISSAT International Reliability and Quality in Design Conference, Vancouver*, pp 364-368.
- Smentek-Duerr, A.E., M.R. Dhanak, and J.H. Van Zwieten, 2012: Utilizing the hybrid coordinate ocean model data for the assessment of Florida Current's hydrokinetic renewable energy resource, *Marine Technology Society Journal*, in press.

- VanZwieten, J.H., L.T. Rauchenstein, H.P. Hanson, and M.H. Dhanak, 2011: Assessment of HYCOM as a tool for estimating Florida's OTEC potential. *Proceedings, IEEE OCEANS 11 Kona*, ISBN: 978-1-4577-1427-6.
- VanZwieten, J.H., C.M. Oster, and A.E.S. Duerr, 2011: Design and analysis of a rotor blade optimized for extracting energy from the Florida Current, *Proceedings of the ASME 2011 International Conference on Ocean, Offshore, and Arctic Engineering, Rotterdam*, No. OMAE2011-49140
- VanZwieten, J.H., W.E. Laing, Jr., and C.R. Slezycki, 2011: Efficiency assessment of an experimental ocean current turbine generator, *Proceedings of the IEEE Oceans 11 Kona*, No. 110422-215.
- VanZwieten, J.H., N. Vanrietvelde, and B. Hacker, 2012: Numerical simulation of an experimental ocean current turbine, *Journal of Oceanic Engineering*, in press.
- Van Zwieten, J.H., G.M. Alsenas, and H.P. Hanson, 2013: Global ocean current resource assessment: A first look. *Proceedings, Inaugural Marine Energy Technology Symposium*, 10-11 April, Wasnington, D.C. (In press).
- Wald, R. and T.M. Khoshgoftaar and J.C. Sloan, 2011: Fourier transforms for vibration analysis: A review and case study, *Proceedings, 12th IEEE International Conference on Information Reuse and Integration*, pp 366-371.
- Wald, R., T. M. Khoshgoftaar, J.C. Sloan, and P.-P. J. Beaujean, 2011: A streaming wavelet packet decomposition approach for real-time vibration analysis, *Proceedings, 17th ISSAT International Reliability and Quality in Design Conference, Vancouver* pp 359-363.

Appendix B2: Conference/workshop presentations

- Agarwal, A., M. Browen, I. Cardei, B. Alhalabi, T. Khoshgoftaar, P. Beaujean, G. Alsenas, H.P. Hanson, 2011: Software system architecture for prognostic health monitoring of ocean based power generation, *The 13th IEEE International High Assurance Systems Engineering Symposium*, Boca Raton, FL, November 10-12, 2011.
- Bozec, A., E. Chassignet, and H.P. Hanson, 2010: Development of a local ocean prediction model of the Fort Lauderdale region for energy extraction purposes. *EnergyOcean Conference & Exhibition*, Weston, FL, June 8-10, 2010.
- Bozec, A., E. Chassignet, and H.P. Hanson, 2011: Impact of power extraction on the Florida Current/Gulf Stream System. *Layered Ocean Model Workshop*, February 7-9, 2011, Rosenstiel School of Marine and Atmospheric Sciences, University of Miami.
- Hanson, H.P., S.H. Skemp, G.M. Alsenas, and C.E. Coley, 2010: Almost Coastal: Base-load power from the Florida Current. *AGU Ocean Sciences Meeting*, February, 2010, Portland
- Hanson, H.P., 2010: Open-ocean energy production: The environmental context. *EnergyOcean Conference & Exhibition*, Weston, FL, June 8-10, 2010.
- Hanson, H.P., A. Bozec, and A.E.S. Duerr, 2010: Power availability in the Florida Current and impact of its extraction on the Gulf Stream. *AGU Fall Meeting*, December 2010, San Francisco.
- Hanson, H.P., A. Bozec, A.E.S. Duerr, and L.T. Rauchenstein, 2010: Assessing resource assessment for MRE. *AGU Fall Meeting*, December, 2010, San Francisco [Invited paper]
- Hanson, H.P., 2011: Research needs and opportunities for collaboration for testing and operations on the outer continental shelf, *Hydrovision '11*, 18-22 July, Sacramento, CA [Invited talk]
- Hanson, H.P., 2011: Marine Renewable Energy: HASE Challenges. *The 13th IEEE International High Assurance Systems Engineering Symposium*, 10-12 November, 2011, Boca Raton, FL. [Invited Keynote Address]
- Hanson, H.P., 2012: Power from the Florida Current: Beyond Assessment. *Global Marine Renewable Energy Conference V*, April 24-26, 2012, Washington, D.C. [Invited Presentation)]

- Rauchenstein, L., J.H. Van Zwieten, and H.P. Hanson, 2012: Analysis of ocean thermal energy conversion power potential and replenishment in Florida. *EnergyOcean Conference & Exhibition*, Boston, MA, June 19-21, 2012.
- Rauchenstein, L.T., J.H. Van Zwieten, and H.P. Hanson, 2013: An OTEC resource for the Continental U.S. *Inaugural Marine Energy Technology Symposium*, April 10-11, Washington, D.C.
- Smentek-Duerr, A.E., and M.R. Dhanak, 2012: Hydrokinetic energy extraction potential of a turbine array placed across the Florida Current, *31st International Conference on Ocean, Offshore and Arctic Engineering*, Rio de Janeiro, Brazil, 1-6 July, 2012.

Appendix B3: Theses and Dissertations Supported

(These are available from the [FAU Library System](#))

- Bowren, M., 2012: *Software Framework for Prognostic Health Monitoring of Ocean-Based Power Generation*. M.S. Thesis, College of Engineering and Computer Science, Florida Atlantic University, 123pp.
- Duhaney, J.A., 2012: *Mining and Fusing Data for Ocean Turbine Condition Monitoring*. Ph.D. Dissertation, College of Engineering and Computer Science, Florida Atlantic University, 199pp.
- Friedel, R.U., 2012: *Asset Identification Using Image Descriptors*. M.S. Thesis, College of Engineering and Computer Science, Florida Atlantic University, 53pp.
- Guerra, J., 2011: *Estimates of water turbine noise levels*. M.S. Thesis, College of Engineering and Computer Science, Florida Atlantic University, 92pp.
- Lippert, R., 2012: *Numerical Models to Simulate Underwater Turbine Noise Levels*. M.S. Thesis, College of Engineering and Computer Science, Florida Atlantic University, 102pp.
- Lovenbury, J.W., 2013: *Evaluation of motion compensated ADV measurements for quantifying velocity fluctuations*. M.S. Thesis, College of Engineering and Computer Science, Florida Atlantic University, 68pp.
- Mjit, M., 2009: *Methodology for fault detection and diagnostics in an ocean turbine using vibration analysis and modeling*. M.S. Thesis, College of Engineering and Computer Science, Florida Atlantic University, 100pp.
- Sloan, J.C., 2010: *Finite safety models for high-assurance systems*. Ph.D. Dissertation, College of Engineering and Computer Science, Florida Atlantic University, 283pp.
- Smentek-Duerr, A.E., 2012: *A Hydrokinetic Resource Assessment of the Florida Current*. Ph.D. Dissertation, College of Engineering and Computer Science, Florida Atlantic University, 214pp.
- Valentine, W., 2012: *Design of a Hydrodynamic Testing Facility for Gulf Stream Ocean Current Turbines*. M.S. Thesis, College of Engineering and Computer Science, Florida Atlantic University, 129pp.
- Wald, R.D., 2012: *Vibration Analysis for Ocean Turbine Reliability Models*. Ph.D. Dissertation, College of Engineering and Computer Science, Florida Atlantic University, 141pp.
- Young, M., 2012: *Design and Analysis of an Ocean Current Turbine Performance Assessment System*. M.S. Thesis, College of Engineering and Computer Science, Florida Atlantic University, 108pp.
- Zhou, F., 2013: *Development of an integrated computational tool for design and analysis of composite turbine blades under ocean current loading*. Ph.D. Dissertation, College of Engineering and Computer Science, Florida Atlantic University, 186pp.