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Worldwide Survey of Ocean Observing Activities

Technology Closes the Skills Gap

Feature Story – Page 10

Autonomous PowerBuoys: Wave Energy Converters as power sources for the next generation of ocean observatories

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The recent move in oceanographic academia to long-time series measurements at a specific location has been led by the introduction of cabled underwater observatories. Historically, an expedition was launched to monitor a location for perhaps a few weeks and a snapshot data set of the local environment was obtained. The cabled observatory, while still to some extent the new kid on the block in the world of oceanography, has changed the art of the possible by extending this snapshot from what used to be only a few weeks to many years. This is akin to the difference between a still image and a feature film!

Being able to access a long-time series of continuous data has allowed the formation of data trends that, until recently, were just not possible. However, this was achieved at a price – the old, nagging villain "Economics." Cabled observatories are not cheap, with the simplest installation (apart from local shoreline applications) costing millions of dollars, often tens or hundreds of millions of dollars. In some locations and economic environments, the payback in terms of achieved learning, basic research outcomes, and world-changing information makes the investment a justifiable proposition — see MARS, VENUS, NEPTUNE, and the Regional Scale Nodes as examples in the U.S. and Canada. However, as economic circumstances throughout the world have tightened, finding investments of this magnitude in an academic subject area that does not often generate huge cash paybacks has become extremely challenging. The future of large-scale cabled oceanography is, therefore, not as rosy as the more forward-looking and scientifically inquisitive among us might hope. A more cost-effective solution seems, therefore, to be required – one that for a much reduced cash cost offers at least matching performance – no challenge there then!

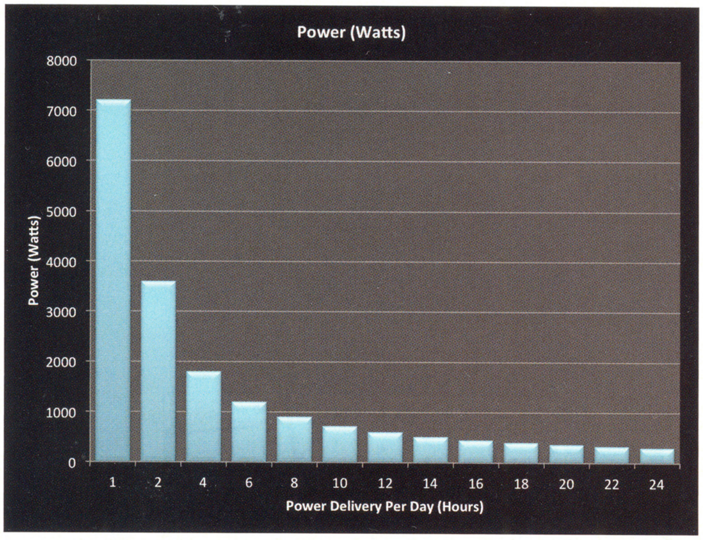
The Autonomous PowerBuoy® is a derivative of Ocean Power Technologies (OPT) core wave energy converter technology. After 15 years of development, these devices are now commercially available, offering applications in many industries that require long-term, cost effective monitoring of almost any marine location. This article discusses the technology and applications of the Autonomous PowerBuoy®, using the example of a deployment from 2011 in which HF RADAR was used to measure oceanographic parameters off the coast of New Jersey. In addition, other potential applications are discussed.

Figure 1 *Photo of the PowerBuoy® after deployment in the foreground along with the USCG buoy tender that deployed it in the background*

What is a PowerBuoy®?

OPT's PowerBuoy® technology fits into a category of wave energy converters referred to as a Point Absorber – defined in our industry as a device that presents a small projection in comparison to a wave. The device relies on the differential motion between two hull forms: one designed to react slowly and the other designed to act quickly when forced by a water wave. The differences in motion represent mechanical energy, which can be harnessed and transferred onto any power producing mechanism (commonly referred to as a Power Take Off [PTO]). PTOs vary with device, but can be grouped into the predictable suspects of pneumatic, hydraulic, and direct mechanical machines. Regardless of the strengths and weaknesses of each PTO approach, it is typical to transmute into electrical energy at some point. Indeed, all of OPT's current wave energy converters export or deliver electrical energy from the buoy itself. The manner in which this change in energy type is performed has an extremely important influence on the overall efficiency of power delivery. After years of development, which continues, the efficiency of these devices is now very impressive.

While all of this sounds easy, the devil is incredibly well-embedded in this particular engineering challenge, as earlier papers and authors have testified. Suffice to say, necessary design details, hydrodynamic understanding, mechanical nuances and requirements, electrical finesse, and control theory on such devices is unexpectedly complex in order to get the maximum performance out of a device.



For the types of autonomous applications discussed here, where we seek to offer an alternative to a cable from shore, the governing design specifications include a requirement to deliver power to whatever sensor pack is utilized 100% of the time, regardless of prevailing wave conditions. Consider the case where (and the experimenters' frustration if) a unique oceanographic event occurs when the ocean was calm and no wave energy was being harvested to supply the payload. To avoid this, we must have access to power regardless of wave condition or the usefulness of the device is dramatically reduced. The PowerBuoy® must, therefore, harness power efficiently, store it effectively, and delivery it reliably. Happily, the defense provenance of these devices, which has extremely stringent and nearly identical availability and reliability requirements, has allowed this technology to be successfully developed and fully achieved. Current commercially available PowerBuoy® devices can deliver power to a payload even after a period of more than 7 days of flat calm seas and have built-in control algorithms that allow this period to be extended significantly by adaptive power management techniques.

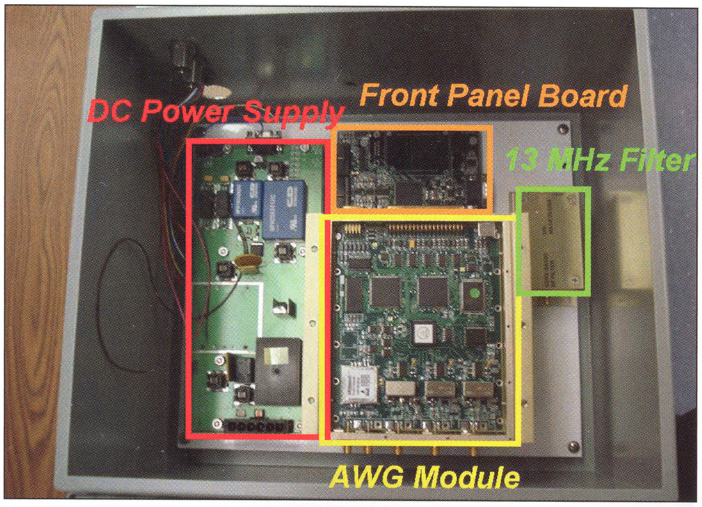


Figure 2 *Components of the bistatic transmitter DC power supply (red), front panel board (orange), advanced waveform generator (AWG) module (yellow), and 13MHz filter (green)*

Importantly, the whole suite of available autonomous PowerBuoy® devices has been designed to be a technology agnostic platform, in that they can power any (practically constrained) payload without foreknowledge of the purpose of any such payload. The practical considerations include how large and heavy the payload is, where the sensor is to be housed (internal or external to the buoy), and the power characteristics for the payload. For most intents and purposes, autonomous PowerBuoy® devices can be envisaged as a self recharging battery housed on a floating platform and capable of supporting, housing, or supplying a sensor suite selected by the customer. The way the power is used depends on customer requirements, constrained in exactly the same fashion as would be the case with a store-bought rechargeable battery. This gives the user the capability to draw on the available power in many different ways; for example, to have 100% power delivery 24 hrs/day (say 300 to 500W continuous), or take all the available energy over say 1 hr/day for a high-powered application (e.g., 4 to 5kW continuously over that hour), or to do any power draw intermediate of these approaches. The graph shows the power draw characteristics that might be applicable for a conservative wave energy site.

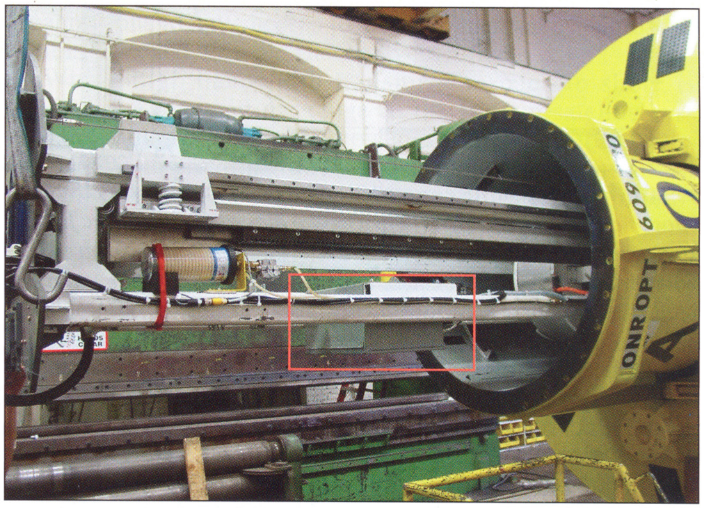


Figure 3 *Picture of the 13MHz bistatic transmitter package (outlined by the red rectangle) installed inside the LEAP buoy*

Similarly flexible is the physical system configuration for the payloads. Customer sensors can be housed within the PowerBuoy®, on the external surfaces (above and/or below the water) or remote to the device fed by an umbilical cable from the buoy. Hence, the power platform is extremely flexible and configurable and offers the chance to power today's known suite of payloads and any future requirements that might emerge as the applications expand.

Example application

In the summer of 2011, the first 500W continuous Autonomous PowerBuoy® was demonstrated off the coast of New Jersey. Developed under a U.S. Navy contract, the project was named the Littoral Expeditionary Autonomous PowerBuoy® (LEAP). The LEAP program sought to extend the range and provide additional directional capabilities to an existing shore-based High Frequency (HF) radar network by using a bistatic transmitter system augmented by an HF transmitter placed 35km offshore on the PowerBuoy®.

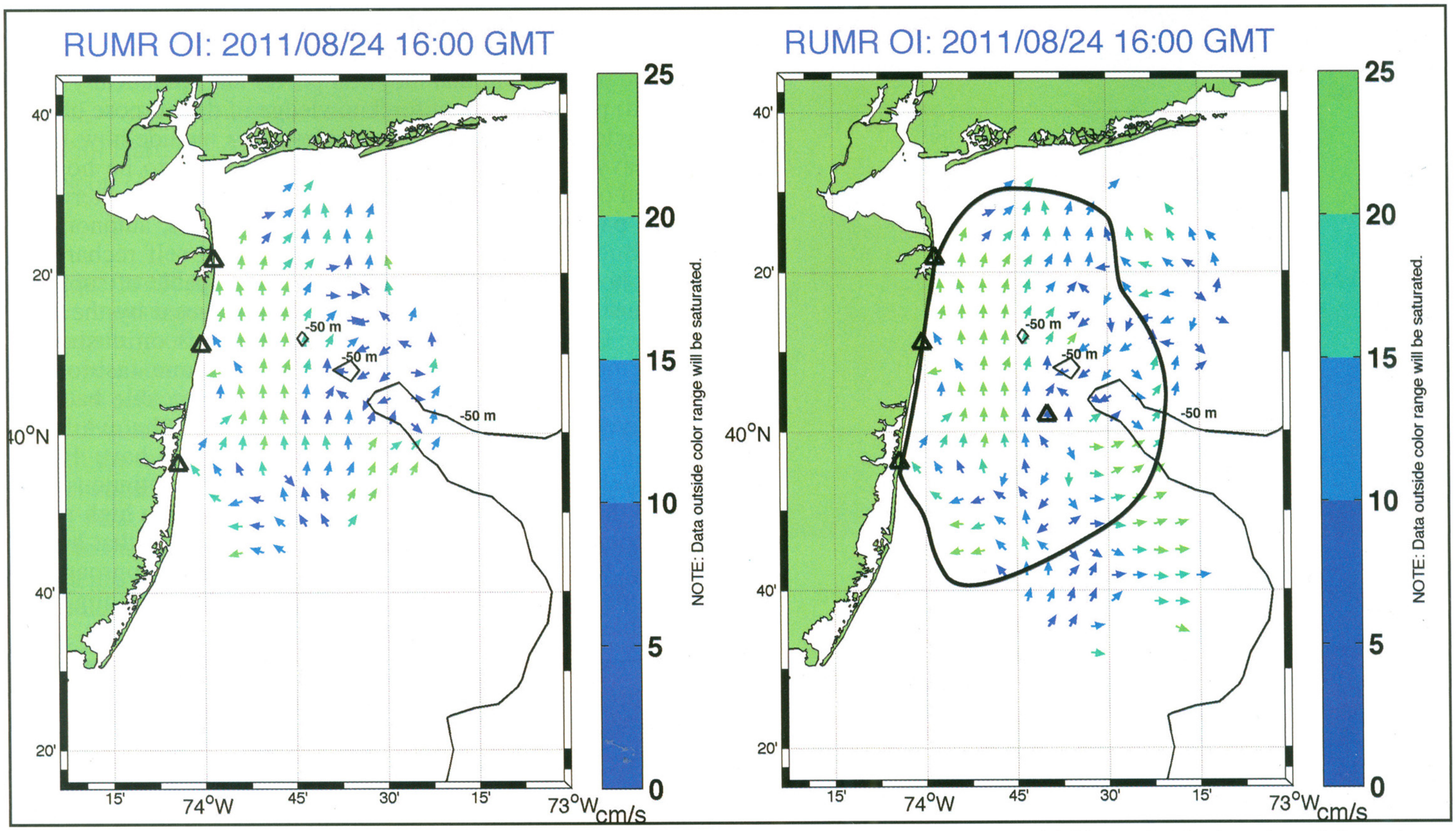


Figure 4 *Map of surface currents captured by the Rutgers HF radar network on 24 August 2011 at 16:00 GMT. The location of the radar sites and PowerBuoy® are shown as the black triangles. The figure on the left depicts the currents measured by the three radars in monostatic mode. The figure on the right show the currents measured by the three radars in bistatic mode (the three monostatic signals along with the signal from the bistatic buoy measured at all three radar shore stations). The thin black line is the 50m isobaths, and the thick, black line indicates the coverage in monostatic mode.*

Under the LEAP program, OPT integrated its autonomous PowerBuoy® with the HF radar network and communications infrastructure from Rutgers University's Coastal Ocean Observation Laboratory (RUCOOL). The LEAP system was deployed on 11 August 2011 (Figure 1) by a U.S. Coast Guard (USCG) vessel and was ocean-tested approximately 20mi off the coast of New Jersey until its recovery on 31 October 2011. It was integrated with the Rutgers University-operated, land-based radar network that provides ocean current mapping data for the National Oceanographic and Atmospheric Administration (NOAA) and USCG search and rescue operations. Rutgers is also developing the dual-use capability of the radar for environmental monitoring and vessel detection. The ocean test of the LEAP system enhanced the dual-use capability of the radar network.

The payload bay on this PowerBuoy® platform is modular, and the payload for this exercise was a bistatic transmitter manufactured by CODAR Ocean Sensors located in Mountain View, California. The payload consisted of a small enclosure that housed the radio transmitter, power supply, and radio filters (Figure 2) connected to a 20ft fiberglass antenna. The enclosure was placed inside of the spar section of the PowerBuoy® (Figure 3), and the antenna was placed atop the superstructure of the buoy. The enclosure had a volume of 1ft3 with a weight of 25lbs. The system had a continuous power draw of 120W, 45W being used for the signal generation.

HF radars are increasingly configured as distributed networks of multiple radars operating in monostatic mode, where the radar transmitter and receiver are collocated in space. Each monostatic radar site generates a map of the radial component of the ocean currents. By combining the radial current data from multiple radars with different look angles, a map of the total velocity vectors can be generated. Bistatic operation is an advance that enables the HF radar transmitter and receiver to be separated in space. In bistatic

Figure 5 *Communcations relay buoy - the Micro-Buoy*

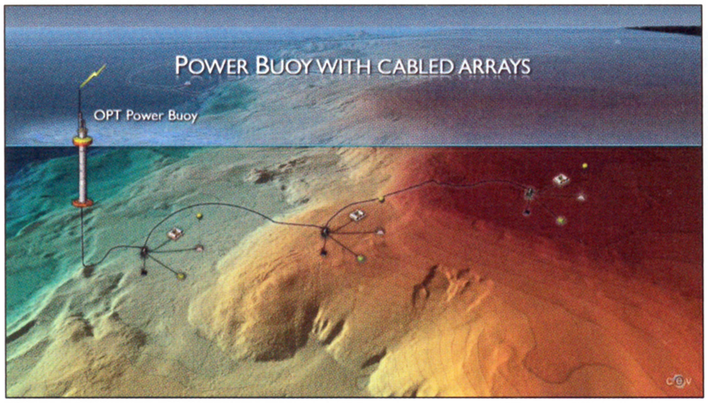


Figure 6 *PowerBuoy with cabled arrays*

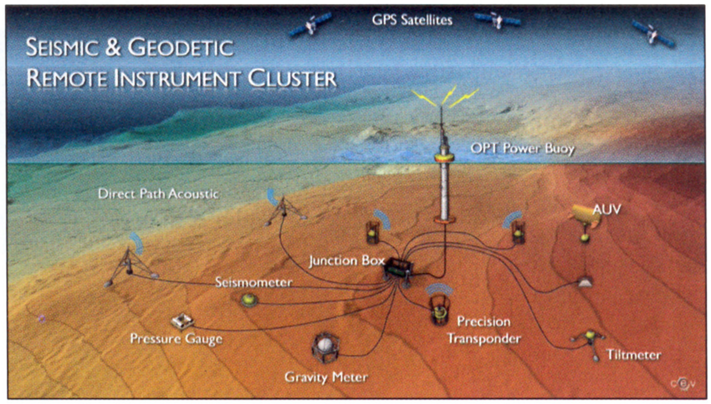


Figure 7 *Seismic & geodetic remote instrument cluster*

mode, a receiver can acquire radar signals from any transmitter within range. For this example, three shore stations in northern New Jersey received the signal from the PowerBuoy®. The bistatic data provide current component observations from additional look angles, increasing the range and robustness of the total vector maps. In this case, the PowerBuoy® increased the coverage of the HF radar network by 55% (see Figure 4).

Other ocean observatory application concepts

Autonomous PowerBuoys® have been constructed to be a payload platform. As such, while the HF radar application discussed above proves the concept and power performance characteristics, this is not a full picture of the offering. The table below represents some other potential uses.

Potential Payloads
Acoustics (passive and active)
CTD
Video (visible/IR) and lights
Seismometers
RADAR
Communications (satellite, VHF, acoustic, cellular, WiFi, etc.)
AUV docking
Mini-ROV power and communications
Environmental quality and chemistry sensors
Seafloor monitoring
Wave and current monitoring

For the majority of ocean-observing applications, a connection to the seabed is required. In the normal manner of a cabled observatory, a main connection interface center would link distributed to the power and communication feed. A wide variety of communication protocols can be supported, depending on customer preference, transmission distance, and data rates – although, DSL has been recognized as a cheap and effective solution in similar applications. In this circumstance, such a line would be fed directly from the PowerBuoy®, which as well as feeding power, provides the means of transmitting the data back to a central land site. Some example arrangements are shown in Figures 6 and 7.

Multiple LEAP-sized PowerBuoys® can be deployed in the same area, depending on the geographic spread and power requirements of the system. Distributed systems can be arranged with essentially any physical distance between main nodes being supported simply and easily.

One of the key benefits of this type of arrangement over a cabled system is scalability; the day one configuration can be enhanced or grown as required over time. In addition, if the demands change and the site is no longer of interest (perhaps the experiments have run their course), the equipment can be easily recovered and redeployed to a site of the customer's choice.

Therefore, the return on capital cost can be realized not only over many years, but potentially in many physical locations as well – offering the potential for a group of academic organizations to have access to a bank of resources, similar to what is achieved with the UNOLS vessel fleet.

Where high bandwidth transmission back to shore is required (i.e., beyond the range of the Iridium satellite system), a chain of wave energy-powered communications relays can be placed, providing a robust and cost-effective means of transmitting data at very high bandwidth. These "microbuoys" (Figure 5) are designed to be deployed simply and easily from a small boat with a minimal anchoring system, and, thus, represent a very minor capital cost. They also offer the potential to communicate to multiple LEAP-style higher PowerBuoy® locations (nodes), which presents the option for deployment as a mesh-type communications network and supplying both maximum bandwidth and maximum redundancy/reliability. If only modest data bandwidth requirements exist, then Iridium or other satellite-based communications can suffice to fill the requirement directly from the main node. This becomes possible in many applications by making use of the in-buoy payload spaces to house data processing equipment to perform data processing and manipulation locally, reducing the data set by applying data-sifting or compacting algorithms prior to transmission.

Conclusions

As the economic climate tightens or, perhaps more accurately, remains prohibitively tight, ways must be sought to support oceanography professionals as they seek to push the knowledge set forward. The drive for long-time series measurement of the oceans is critical to the development of knowledge about the earth system as a whole. Therefore, cost-effective ways must be found to allow this critical knowledge to be gathered.

While the "A+" option has been seen as a cabled observatory, technology has advanced such that a PowerBuoy® system can now offer a very compelling alternative that can meet or, in some cases, exceed the performance of such systems. Wave energy-powered observatory systems, offering 90% of the functionality at a fraction of the cost of a cabled system, may provide a solution where research can continue and perhaps even expand – even within the current economic constraints.