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Flexible Monitoring of Upper-Ocean Currents

ADCPs On Wave Gliders Hold Promise of a New Solution

By Peter Spain Ph.D., Teledyne RD Instruments

Introduction

Sustained observing of upper-ocean currents is a long-standing challenge. For 150 years, research vessels epitomized ocean research; yet their operation is too costly to make lengthy measurements. Along a few routes, commercial ships have been used to collect long records of upper-oceanic conditions (e.g., expendable bathythermographs (XBT), acoustic Doppler current profilers (ADCP)). For the most part, however, extended observations have relied on long time series at a few fixed stations. Satellites provide global coverage of oceanic surface features, albeit with indirect measurements that miss wind-driven currents.

For directly observing the upper ocean in both space and time, unmanned vehicles have displayed promise of a new solution. A month's work by an unmanned vehicle can be funded by the operating costs for a single day on a research vessel. Besides supplementing ships, unmanned vehicles have also been substituted for anchored surface buoys. Examples include weather watching and tsunami monitoring. These vehicles present lower lifetime costs than moored buoys - particularly for service and maintenance in remote regions.

Teledyne RDI's ADCPs introduced the groundbreaking capability of measuring moving water while operating from moving platforms. As well as saving survey time for users, this capability revealed the 2-d distribution of upper-ocean currents -- along-track and through depth. Over time, these views of circulation patterns have become expected content in survey reports. Supplying ADCPs on unmanned vehicles expands the flexible use of both technologies.

Unmanned Vehicles Surveil the Sea

Unmanned vehicles come in myriad types. First came teth-

The surface part of a Wave Glider is a surfboard-like float that carries most of the payloads. Seen here is a float customized for a multibeam-sonar survey of the seabed.

Photo Credit: Liquid Robotics

ered remotely operated vehicles; then followed untethered autonomous underwater vehicles (AUVs). Rather than being piloted, AUVs rely on robotic control for determining speed, direction, and depth. They are now considered reliable tools for diverse undersea activities. AUVs can complete a mission independent of topside support and then return home dependably. In particular, they excel at systematic, autonomous data collection.

Underwater gliders are a subset of AUVs. They use natural power sources, such as buoyancy, solar, or surface waves. Most gliders descend and ascend while en-route, traveling a sawtooth path. Though limited to slower speeds, gliders have far greater reach than a propeller-driven AUV. Likewise their missions are much longer duration. Gliders operate largely free of shore-side control though they are monitored by pilots and can be reprogrammed remotely.

Wave Gliders

Wave Gliders by Liquid Robotics are propelled using wave energy. They travel at the surface rather than dive so they are classed with unmanned surface vehicles. Wave Gliders move at slower speeds (0.25 – 1 m/s) yet they can travel great distances without ever needing to refuel. To extract energy from waves, Wave Gliders use an ingenious design consisting of two separated parts. At the sea surface is a surfboard-like float that carries most of the payloads. Tethered 6 m below is a rack of wings that propel the system by reacting to passing waves.

In recent years, Liquid Robotics supplied the more powerful Wave Glider SV3. Besides its larger size, the new model includes a collapsible thruster at the rear of the winged rack. This addition expands the device's operating envelope and was motivated by field experience. The thruster aids operating in low winds, high currents and in avoiding obstacles; it can be triggered remotely.

ADCPs On Wave Gliders

For shipboard research, Teledyne RDI's ADCPs are synonymous worldwide with measuring currents in the upper ocean. Using acoustic signals, ADCPs measure remotely; they look down through the water column from a surface platform. These devices accurately measure vertical profiles of water velocity. They also reveal the spatial distribution of suspended particles carried by the currents (e.g., sediments, plankton).

The ADCP's onboard signal processing produces results that can be sent immediately to aid decision making in operational situations. This leads to improved safety, efficiency, and reduced risk. Sending processed results also saves time and money for users analyzing the data or even for those posting

Wave Gliders are propelled by a tethered rack of wings that react to passing waves.

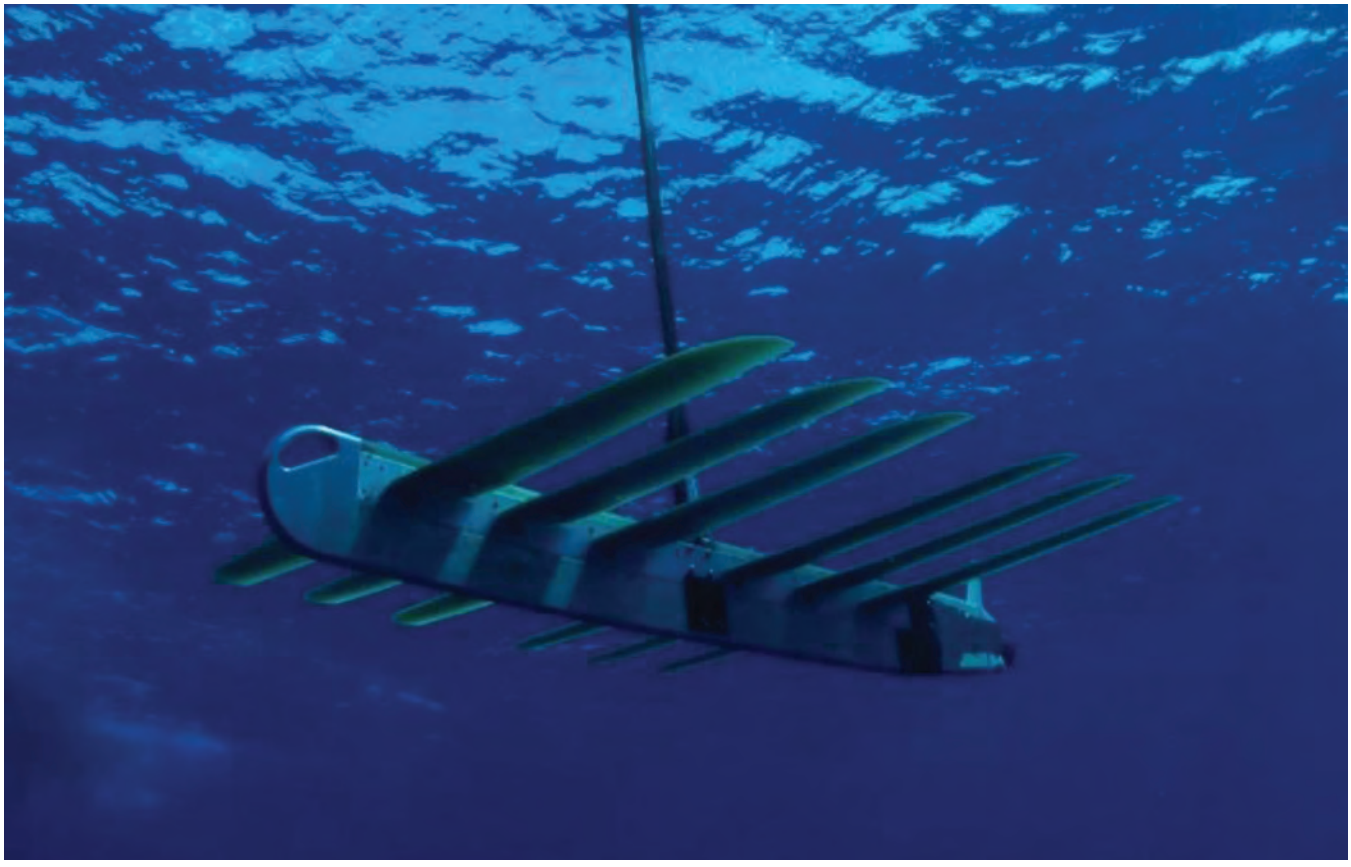

Photo Credit: Liquid Robotics

it to the Web. As well, ADCPs do not have any moving parts. This can be an important advantage against biofouling during extended deployments.

When using ADCPs on Wave Gliders, operators can take advantage of the telecommunications link. They can reconfigure the ADCP or even repurpose its activity during a mission. Examples include turning on or off bottom tracking, reconfiguring the current profile, or changing the averaging period for the processed data. This in-situ flexibility is not always available for ADCPs mounted below surface buoys.

Adding Teledyne RDI ADCP's capabilities to a Wave Glider pointed to a flexible and powerful tool for monitoring upper-ocean currents. But there is no free lunch. ADCPs measure water in motion; at the same time, Wave Gliders ride surface waves. Thus it was essential to confirm the accuracy of ADCP current profiles measured in this dynamic situation.

Persistent Platform for Data Collection

Wave Gliders have seen action in diverse applications. These have ranged from maritime surveillance, mapping surveys, and oil spill cleanup to fisheries management and environmental monitoring. At times, several Wave Gliders have been deployed concurrently to observe the ocean in both space and time.

Wave Gliders have completed impressive mobile missions, such as Arctic surveys in 2016 and transects across the Pacific in 2012. For other jobs, Wave Gliders are programmed to hold station, such as when aiding seismic surveys or relaying data sent from seabed-mounted devices.

The Wave Glider's surface location permits continuous telemetry to shore and GPS navigation. Not only can sensor data been seen in near real-time but the mission can be adapted by sending new waypoints to the Wave Glider. Solar panels power the onboard electrical systems, such as navigation, instrumentation, and communications.

Wave Gliders have carried a wide variety of sensors. These range from hydrophones for listening to whales to weather sensors and wave gauges for measuring storms. Other sensors, for measuring water properties, include temperature, salinity, turbidity, oxygen, chlorophyll, and fluorescence. These sensors provide a continuous 1D time series along the track line. In contrast, ADCPs aboard Wave Gliders report 2D spatial transects of water currents – along track and through depth.

Field Studies

Two dedicated studies addressed the accuracy of ADCP profiles measured from Wave Gliders. They confirmed the reliability of the current measurements; reports have been pub-

Adding ADCPs on Wave Gliders makes a flexible tool for surveying upper-ocean currents.

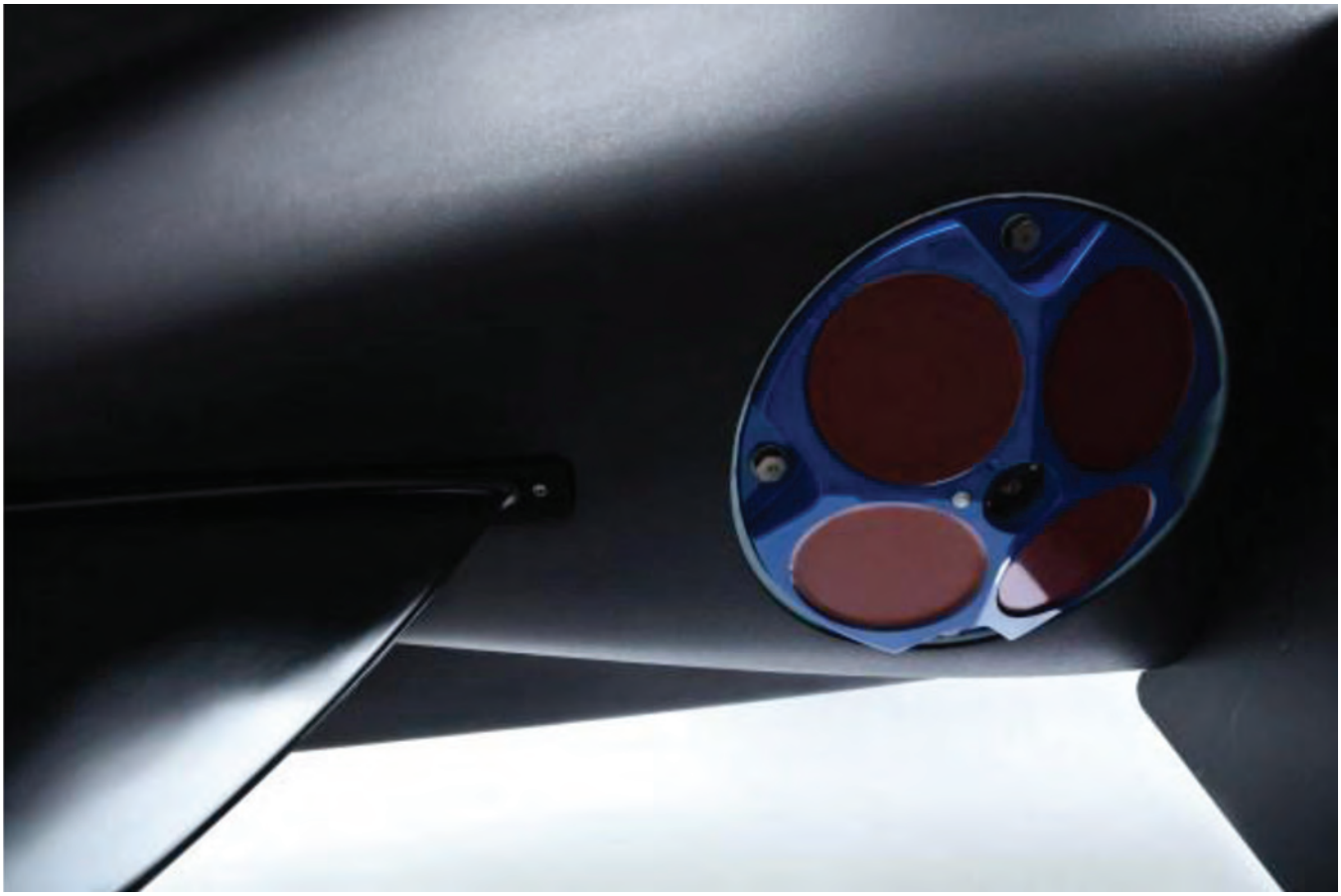

Photo Credit: Liquid Robotics

lished. The first was a shorter study off La Jolla California, performed with Teledyne RDI. A more extensive study was conducted at Liquid Robotics' test site in Hawaii. Both studies used a reference ADCP mounted on the seabed. Its current profiles were compared visually and statistically to ADCP data from Wave Gliders. The researchers observed glitches at the depth of the Wave Glider's wings due to acoustic interference. Otherwise, they reported profiles from different Teledyne RDI ADCPs to be "remarkably similar both in magnitude and in temporal variability".

In the Hawaii study, pairs of Wave Gliders also collected ADCP profiles concurrently. In separate tests, ADCPs were operating at the same frequency (300 kHz) and at different frequencies (600kHz and 300 kHz). Farther offshore, other ADCP tests were run in moderate sea states due to the trade winds. In all these tests, profiles from different Wave Gliders compared favorably.

Environmental Monitoring

Wave Gliders carrying Teledyne RDI's ADCPs provide a flexible solution for observing upper-ocean currents. These devices can execute systematic surveys for extended durations. Plus they can provide early alerts about changing water conditions during operations.

Maritime Domain Awareness

In September 2016, the UK's Royal Navy ran a series of demonstrations called "Unmanned Warrior". Deployed off northwest Scotland, this two-week program with marine robots was a joint mission with the National Ocean Center (NOC). The scientific program was titled "Marine Autonomous Systems in Support of Marine Observations".

Four Wave Gliders carrying Teledyne RDI's ADCPs provided environmental data. The Wave Glider fleet included three Boeing SHARC vehicles and one from the UK NOC. Data was sent to the operations room in real-time where it was visible via the mission website.

The Wave Gliders traveled 100 miles across the Hebridean Shelf, north of the Outer Hebrides. As well as recording water properties and weather conditions, the gliders measured currents and depth.

During part of their deployment, the Wave Gliders collected data in high seas with wave heights exceeding 6.5 m. During this time of sea state 7, the Wave Gliders were in a holding pattern. They ran reciprocal tracks, taking 30 minutes to complete a round trip. They observed strong tidal currents. The

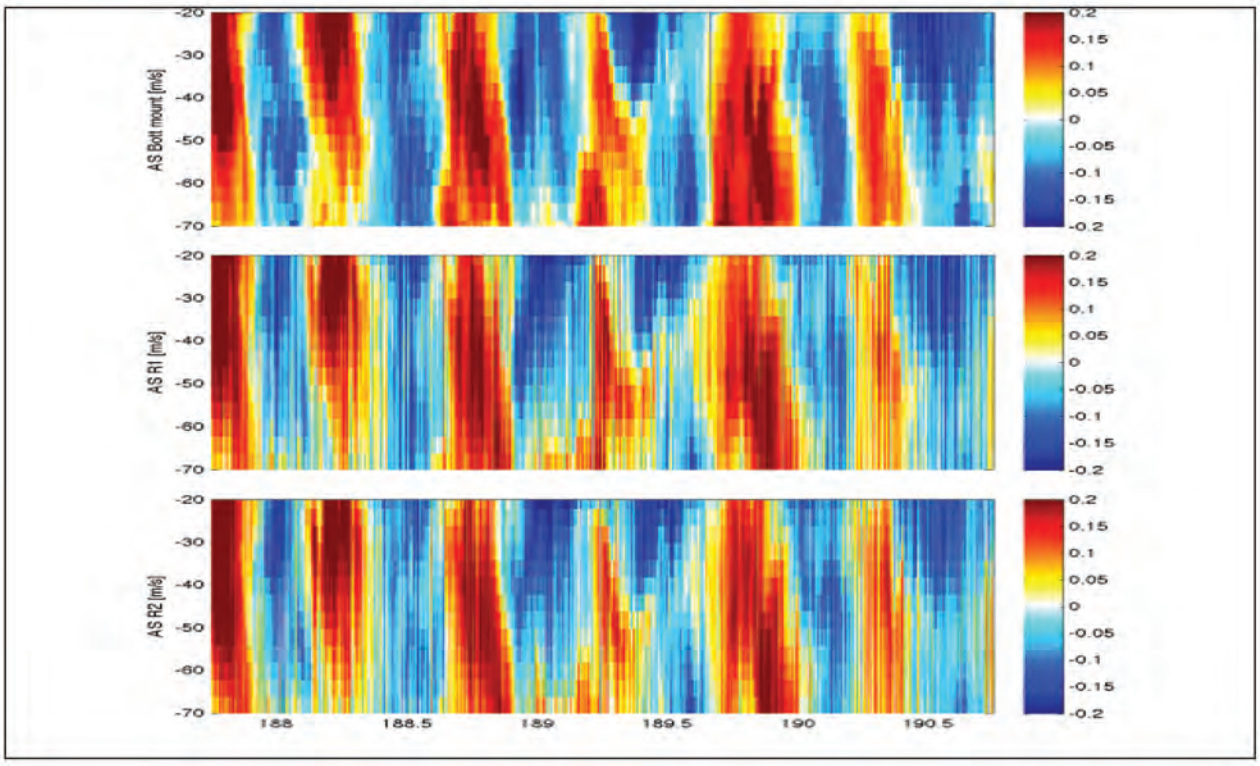

Photo Credit: Liquid Robotics

Intercomparison of 3-day time series of current profiles. Teledyne RDI ADCPs aboard two Wave Gliders (mid, bottom panels) are compared with concurrent data from a seabed-mounted ADCP (top panel). Data are alongshore water speed in meters per second.

Source: Beatman L, Anderson T, Fong D, Jha R, 2013. Wave Glider® Integrated Sensor Validation Report: Teledyne RD Instruments Workhorse Monitor ADCP. Technical Report, Copyright© Liquid Robotics, Inc., Sunnyvale, CA, USA.

data showed the tide turned first at the seabed but quickly had a consistent direction throughout the 70-m water depth.

Complementing Turbidity Surveys

Off Western Australia, ADCPs aboard Wave Gliders were deployed by Liquid Robotics Oil and Gas (LROG**). This project included several sorties. ADCP data was used to examine currents and suspended particulates in the water column. Before dredging activity, two separate Wave Glider surveys established baseline values.

Lasting two weeks, the first sortie focused on ADCP data. Besides its survey purpose, this sortie demonstrated the suitability of Wave Gliders for this work. The survey examined the ambient currents and bathymetry of the region to be dredged. Semidiurnal tidal currents showed spatial structure that matched the changing water depths. Flows were quite strong closer to shore yet were appreciably weaker in greater depths.

The second sortie delivered a detailed turbidity study. Later surveys monitored suspended particulates during dredging activity and, afterwards, assessed post-dredging conditions. The flexibility of monitoring with Wave Gliders was proven during cyclone Narelle; the vehicles were piloted to a safe holding area.

** Liquid Robotics Oil and Gas, previously a joint venture between Liquid Robotics and Schlumberger, became wholly owned by Schlumberger on August 29, 2016, and has been renamed Schlumberger Robotics Services.

North Sea Studies

Off Belgium, a team from the Royal Belgian Institute of Natural Sciences used Teledyne RDI's ADCPs on Wave Gliders for a similar purpose. They were monitoring sediment transport and dredge plumes around sandbanks. These surveys had a similar two-fold purpose. First the researchers observed background conditions, notably currents carrying and resuspending sediments. They documented changes over tidal regimes. Then their focus switched to detecting locations of sediment plumes created by dredging activity.

In this case, the Teledyne RDI ADCP on the Wave Glider played two roles. First, it measured current strength and direction. Second, it revealed turbidity through the water column. An optical sensor measured turbidity in the surface waters. ADCP results showed that these surface values did not reliably indicate subsurface advection and resuspension of sediments.

The Wave Glider's ADCP detected a plume traveling in the middle part of the water column. The corresponding dredging activities had occurred quite some time earlier and at some distance away. The researchers judged traditional monitoring would likely have missed this type of plume. They noted that the location of the plume's dispersion and settling is difficult to predict. Water currents and weather conditions exert strong influence on the plume's path.

Assisting Seismic Streamer Surveys

Seismic surveys require towing very long lines of streamers. Their towing angle is influenced by currents and weather. At times, these surveys must pass close to oil rigs and platforms. To reduce the risk of entangling streamers, chase vessels are often repurposed to supply field data to the towing ship.

LROG** turned this situation into a new application for Wave Gliders with Teledyne RDI ADCPs. These devices were substituted for chase vessels during a close-pass seismic survey. Particularly useful was the Wave Glider's inherent capability to hold station. By reporting in-situ currents, the attendant Wave Gliders can provide an early warning if current profiles change. This data also helps in optimizing the survey.

As well as supplying valuable information, the Wave Gliders proved to be a cost-effective solution, saving time, fuel, manpower, and resources.

Looking Ahead

Directly observing the upper ocean in both space and time is a long-standing challenge. Liquid Robotics Wave Gliders have demonstrated a new approach. Teledyne RDI ADCPs equip ships worldwide for measuring currents in the upper ocean. The combination of these technologies provides an economical and flexible means for monitoring upper-ocean currents and water properties. This solution is now proven and seeing more deployments.

Wave Gliders with Teledyne RDI ADCPs are likely to play an enhanced role in operational support for industry. They provide a unique means to see and deliver information about the underwater situation. This approach can improve safety and efficiency as well as reduce risks. It can also provide warnings where industrial activity overlaps with sensitive marine life and environments.

For scientific studies, Wave Gliders carrying Teledyne RDI ADCPs can simplify exploring upper-ocean responses to atmosphere forcing. This tool can also show current circulation patterns in sparsely-observed oceanic regions. Plus Wave Gliders offer a way to mitigate costly vandalism of remotely-located surface buoys. Where currents are weaker, Wave Gliders with ADCPs can replace ships in some types of recurring surveys. As well as returning detailed and extensive data sets, this approach will reduce costs and resources for operators. Examples include fisheries management, monitoring the marine environment, and providing indicators for El Nino and climate change.

In short, Wave Gliders, combined with Teledyne RDI's ADCPs provide a new solution for flexible monitoring of upper-ocean currents.

For more information, contact
Teledyne RD Instruments or **Liquid Robotics**.
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WHOI scientists partner with Rhode Island fishermen to understand rapid changes in Gulf Stream-dominated east coast shelf waters

By CarolAnne Black

In 2011, oceanographer Glen Gawarkiewicz sat in the back row at a National Science Foundation (NSF) public hearing about the upcoming installation of a vast and long-term ocean monitoring system, called the Ocean Observatories Initiative Pioneer Array (Pioneer Array). The chosen location, right off the coastal waters of New England, meant the array could interfere with fishing and shipping, and there was concern that the science generated by the array could be used to force fisheries closures. The people whose livelihoods depend on this ocean region were at the hearing and they meant to be heard. "There was a very crowded room in the public library in New Bedford," recalls Gawarkiewicz, "and there were some contentious moments." He was sitting next to a woman he hadn't yet met, and Gawarkiewicz remembers one of them said to the other, "There's got to be a better way than this."

That day, Gawarkiewicz, Associate Scientist at Woods Hole Oceanographic Institution (WHOI), had been sitting next to Peg Parker, the then Executive Director of the Commercial Fisheries Research Foundation (CFRF), a non-profit private foundation based out of Rhode Island that works to involve fishermen in the science used to manage their industry. The two decided to stay in touch.

Not long after the public hearings, the NSF decided there should be negotiations between the Pioneer Array scientists and representatives from the commercial fishing industry to determine how the Pioneer Array could be altered to minimize multi-use conflicts. For four four-hour sessions, Gawarkiewicz, Parker, researchers and industry representatives met

Oceanographer Glen Gawarkiewicz (right) and inshore scallop fisherman Mike Marchetti look over an RBR*concerto* CTD and an iPad aboard the F/V Mister G offshore of Rhode Island.

to discuss possible alterations. Gawarkiewicz explains that Parker had to walk a tight line, because "there were people in the industry saying 'this is going to lead to closures,' and other people saying, 'No, no, the ocean is changing. We need to learn about this.'"

On the very last day of negotiations, three of the fishermen approached Gawarkiewicz. "[They said,] 'actually, we learned a fair amount talking to you guys about the ocean out here, and we want to let you know there's very warm water out on the edge of the continental shelf, and there's 5-knot currents that are tearing up all the lobster pots. What's going on out there?'" Gawarkiewicz told the fishermen he would get back to them in a couple of days. Then he went digging.

"I found a drifter trajectory that ran right along the edge of the Gulf Stream and right up by the continental shelf. It was 2 m/s. 4 knots. It entirely corroborated what the fishermen were saying. It was really remarkable." The north wall of the Gulf Stream, Gawarkiewicz found, was 200 km north of its normal trajectory.

To understand what was happening on the shelf, where profound changes and much of the fishing were taking place, they needed to fill the data gap onshore of the Pioneer Array. Then came their chance.

In 2013, there was an opportunity to pitch ideas to one of America's largest independent foundations, the MacArthur Foundation. Gawarkiewicz, Parker, and Anna Malek Mercer – a CFRF staff member who would become its Executive Director after Parker retired in 2015 – saw how they could work together. They proposed a Shelf Research Fleet, for which the CFRF had expertise. Malek Mercer explains, "Over the past few years we've worked to develop what we call the Research Fleet approach. That's what we are taking here with the Shelf Research Fleet. What that looks like in practice is fishermen … actually doing or assisting with the research themselves."

The fishermen, who work on the continental shelf off of Rhode Island, would collect CTD data inshore of the Pioneer Array's moorings, and Gawarkiewicz would use the data to understand the ocean dynamics and the effects on the fisheries. The MacArthur Foundation wanted the project to be a vehicle to build relationships and help local people deal with the consequences of climate change. "That," says Gawarkiewicz, "was just perfect for us and CFRF."

Gawarkiewicz overlaid six boxes on a map of the shelf, with the goal of one CTD cast per week in each box. The team of ten fishing vessels was equipped with iPads and CTDs. "We identified the RBR*concerto* as the best instrument for that. Having that wireless download capability was the absolutely crucial thing. When you think about the guys out there in 15 to 20 foot seas, they don't want to be fussing with connecting wires on the deck."

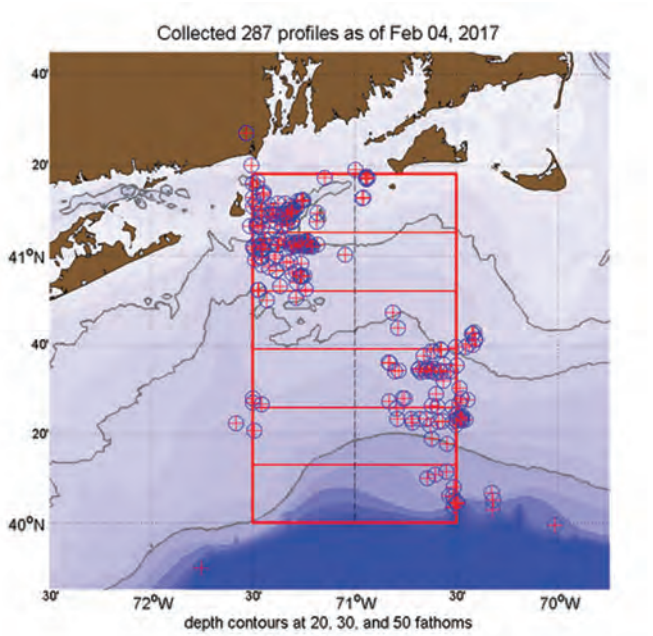
CFRF Executive Director Anna Malek Mercer trains fishermen in collecting CTD data, uploading the data wirelessly to their iPads, and viewing the profiles instantly.

In October 2014, CFRF launched its Shelf Research Fleet. "One real benefit to the Ruskin [software] and RBR*concerto* system is that you can immediately view that water column profile that you retrieved," says Malek Mercer. She explains that some fishermen use the temperature and salinity profiles on the spot to decide where to fish.

"One of the big science questions," says Gawarkiewicz, "is, when we get Gulf Stream water at the edge of the continental shelf, for example the warm and salty intrusions, how far onshore do they go?" He's already beginning to be able to answer that question.

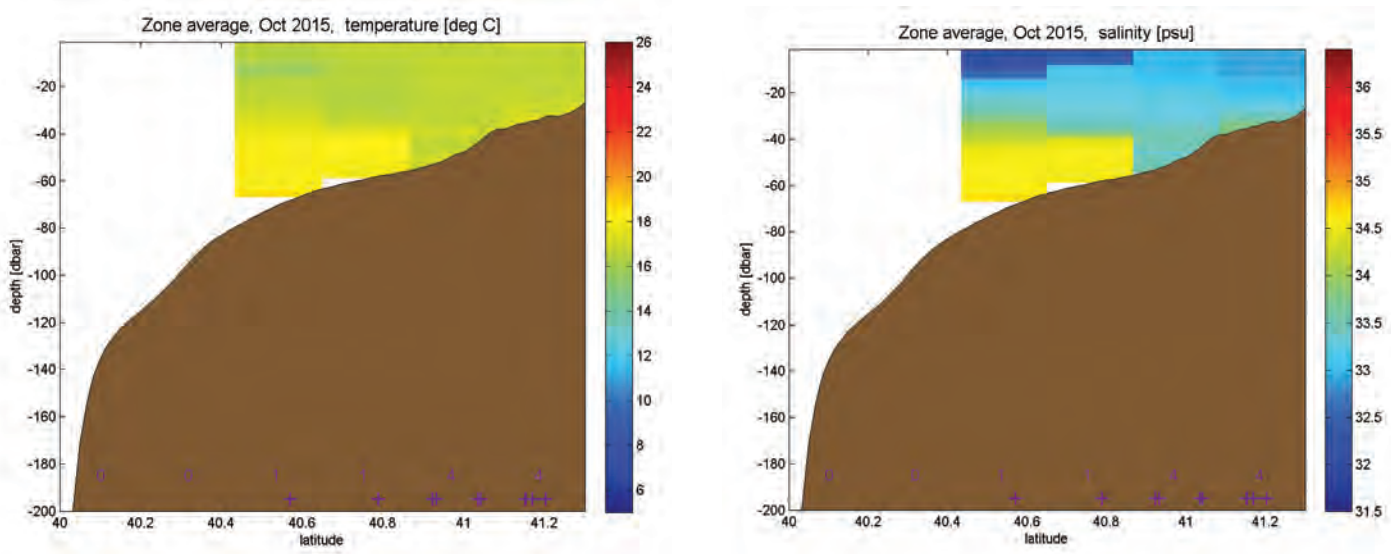
"We're seeing a lot of these bottom intrusions of warm salty water and they're very important because they may carry nutrients onto the continental shelf. We've found they can go 60 to 80 km onshore. They bring entirely different kinds of fish."

"What's going on now is that it's warming at such a remarkable rate that the types of fish they're catching are different, and some of them are not allowable south of New England yet. This is very important to document the temperature changes so that you can say, 'Oh, we need more black sea bass quota now, because we're catching them all the time, but we're not allowed to sell them all.' So it's a very interesting time in terms of fisheries management, because the [species] ranges are changing so much."



A map of the continental shelf south of New England showing the boundaries of the six boxes for CTD data collection. Circles with crosses indicate the locations of individual profiles. Between November 2014 and January 2017, the Shelf Research Fleet collected 287 vertical profiles. The southernmost bin overlaps with the Ocean Observatories Initiative Pioneer Array.

Anna Malek Mercer (standing), Glen Gawarkiewicz (left) and fishermen meet to discuss data, oceanographic conditions, and implications for fisheries.



Cross-shelf sections of temperature and salinity on the continental shelf south of Rhode Island, showing warm salty slope water intruding onto the shelf. Data is averaged temporally over October 2015 and spatially within each of the four boxes closest to shore. Numbers at the bottom of the plots indicate number of profiles in each box and crosses indicate the latitude of individual profiles.

One of Gawarkiewicz's favourite parts of the project has been his twice-yearly meetings with the fishermen. He says he talks for fifteen minutes and the remaining nearly two hours is filled by questions. "These guys ask me very hard questions. And the data that the fishermen have collected is absolutely a part of that discussion." Reflecting on those talks, Gawarkiewicz says, "I feel like it's a great privilege to have those meetings and hear back from the fishermen."

The relationship has become such that when the fishermen see something unusual, they share their observations with Malek Mercer and Gawarkiewicz. "They have been out there, not only every day, but every day for decades," says Malek Mercer. "The changes that we talk about theoretically, they're experiencing every day. Bringing that perspective into the science is a priority of the Foundation."

For Gawarkiewicz, this project has had a profound effect on his research. "They haven't changed my science in a small way. They've changed it in a big way, because I'm much more aware of what's going on right now. As scientists, we typically are working with experimental data from two years ago and really trying to get the last detail of understanding out of that. It's exciting to get an email saying, 'Hey, look at George's Bank right now. Something really weird is going on. We've just had a big scallop mortality event,' and then be able to say, 'Oh, from the sea surface temperature imagery, I can tell there was just a big warm core ring there. How shallow did it get?'"

Gawarkiewicz says they are planning peer-reviewed publications as well as a publication on the Research Fleet approach for later in 2017. The MacArthur grant has run its course, and the team was fortunate to find funding for the next two years through the local van Beuren Charitable Foundation. "The important thing is to keep collecting the data because we're in a time of very rapid change," says Gawarkiewicz. They have also applied for NSF funding to use the Pioneer Array data in conjunction with the shelf data to study bottom intrusions and nutrient delivery on the shelf.

Lobster fisherman Mark Sweitzer has been involved with CFRF's projects for many years, and his vessel is part of the Shelf Research Fleet. Sweitzer says, "The main thing that I've taken away from it is a positive feeling that science and government and fishermen can work together to try to come up with better fishing regulations and better fishing practices."

Relating his experience with the conceptual ivory tower, Gawarkiewicz is direct: "I don't think that scientists realize how damaging that is, the ivory tower. You really have to engage with the world. You have a responsibility in a democracy really to help your fellow citizens out. Especially on a planet that's changing so rapidly. That's something I really do firmly believe."

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- Socket Washer Seal Screw

Seal Nut

When you're up against harsh environments, ZaGO's line of self-sealing nuts guarantees you unsurpassable fastening and sealing power. Each of our sealing nuts has been engineered to feature a full 360 degrees of sealed rubber element, which gives our hardware unsurpassable deterrence against external pressure, vibration and contaminants. Our self-sealing nuts and plugs are ready-to-use and can be installed the same way as their conventional counterparts. They are also reusable, and can be used with all surface types. Each one provides sealing power in every direction with metal-to-metal contact. Our collection of Self-sealing nuts includes:

- **Heavy Hex Sealing Nuts:** Only ZaGO delivers you the most heavy duty, and yet easy-to-use heavy hex sealing nut available on the market. Featuring exclusive ZaGO silicon-sealing technology, the heavy hex sealing nut withstands even the most extreme conditions, never caving under the likes of pressure or contamination. Ensure yourself the highest level of security by building your equipment with ZaGO's heavy hex sealing nuts.

• **High Crown Acorn Nuts:** ZaGO's high crown acorn sealing nuts serve as a total barrier against damaging forces and substances, thus fortifying your equipment where it is most vulnerable. Build your devices with our high crown acorn sealing nuts–which feature a rubber sealing element–and enjoy high-performance equipment.

• **Low Crown Acorn Nuts:** Military and industry leaders use ZaGO's low crown acorn sealing nuts to guarantee themselves maximum security. ZaGO's low crown acorn sealing nuts, which are engineered to feature a rubber inner layer, and safe-keep all your equipment under every circumstance.

• **Hex Flange Nuts:** ZaGO's hex flange sealing nuts grant you both superb sealing and extra fastening power by extending a built-in washer under the nut where water pressure, gas pressure, dirt, oil and more pose a risk. The rubber element that we have fixed on the inside of our hex flange nut performs the vital task of sealing your nut off from any harm.

• **Seal Plugs:** Built to resist virtually all aggressive chemical compounds and to withstand extreme pressure and temperature, our seal plugs take fastener security to the next level. We designed them to feature the ZaGO "O" ring which, when compressed, forms an airtight seal about the fastener.

Security /Tamper-proof Screws

ZaGO offers you a variety of drive styles for security/tamper-proof, self-sealing screws. These ultimate screws will provide you with outstanding security against any external/internal contamination from air, water, gas and other materials. These screws are available in a variety of screw materials as well as different "O" ring material options depending on your application. Fortify your tamper-proof fasteners with ZaGO's powerful "O" ring, which is designed to fit each type of tamper-proof screw. These specially engineered screws block out fluids, air, and chemical contaminants, while granting you exceptional fastening power and metal-to-metal contact. Our fasteners are ready to use with no installation preparation, and can be reused for years. They are compatible with all surface types and act as a total deterrent against external/internal contamination from air, water, gas, and other harsh environments when you use compatible "O" ring materials. The Following Types of Security/Tamper-Proof self sealing screws are offered:

- Socket Tamper-proof
- 6-Lobe Tamper-proof
- Spanner
- One Way Slotted

Titanium Screws

Titanium (Ti) is a silver-colored low density high strength metal. With the highest strength-to-density ratio of any metallic element, titanium is an ideal metal for use in aerospace and military applications. In addition, its high resistance to corrosion also makes Titanium an excellent choice for subsea exploration and other situations where exposure to salt water is a hazard. ZaGO is an acknowledged expert in the fabrication of seal screws from exotic metals and titanium is one of our favorites because of its wide range of utility. Titanium screws are fully resistant to solutions of chlorides, hypochlorites, chlorates, perchlorates and chlorine dioxide. It is an excellent material to prevent seawater corrosion. Because titanium screws can resists corrosion by seawater up to temperatures as high as 500°F (260°C) as well as survive at ocean depths over a mile below the surface, titanium screws are used throughout the oil & gas, desalination and marine industries. Our collection of titanium screws include:

• **Socket Cap screws:** The 6 flat surfaces within the recess allows for high torquing without damaging the head and there are no side clearance restrictions making them the ideal choice for assemblies with close tolerances. Socket cap screws are popular due to their space saving design and superior strength.

• **Slotted Pan Screws:** The original screw with a single, elongated slot, was developed centuries ago, and can be found nearly everywhere. It can be used with a standard-blade screw driver, and requires less downward pressure than recessed screws.

• **Hex Bolts:** Titanium bolts are best known for being strong, lightweight and corrosion resistant. Titanium bolts are ideal for applications that require both lightness of weight and excellent strength. Hex bolts have hexagonal heads and machine threads for use with a nut or in a tapped hole.

• **Hex Nuts:** Titanium hex nuts are available in metric or standard sizes and can be manufactured with or without a groove for sealing or non-sealing applications. They are high strength but very lightweight.

• **Custom Machine Parts:** ZaGO can provide custom machine parts made-to-print in titanium material. We offer prototypes for testing and also provide secondary and modification processes.

ZaGO is headquartered in Newark, New Jersey, and has been manufacturing sealing products since 1993. Thanks to our proximity to Newark Airport, the Port of Newark, and most of New Jersey's major transit routes, we make daily shipments throughout North America, Central America, South America, Europe and Asia. As an ISO 9001:2008 certified company, we proudly manufacture our products in the United States using the highest quality materials. Since all our designing, engineering and manufacturing is done locally, we can rapidly create prototypes, implement adjustments and begin production for our customers. Our dedicated staff works closely with each of our clients to ensure that their every need is met. Beyond our technical prowess and advanced horizontal and vertical CNC machinery, we pride ourselves on the way we handle each customer with meticulous care. Our sales and engineering staff is always available to work side-by-side with our customers, regardless of the size or scope of the project. We keep the lines of communication open at all times and work hard to deliver our customers the most effective, timely, and economic solutions.