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 tethered 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

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

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

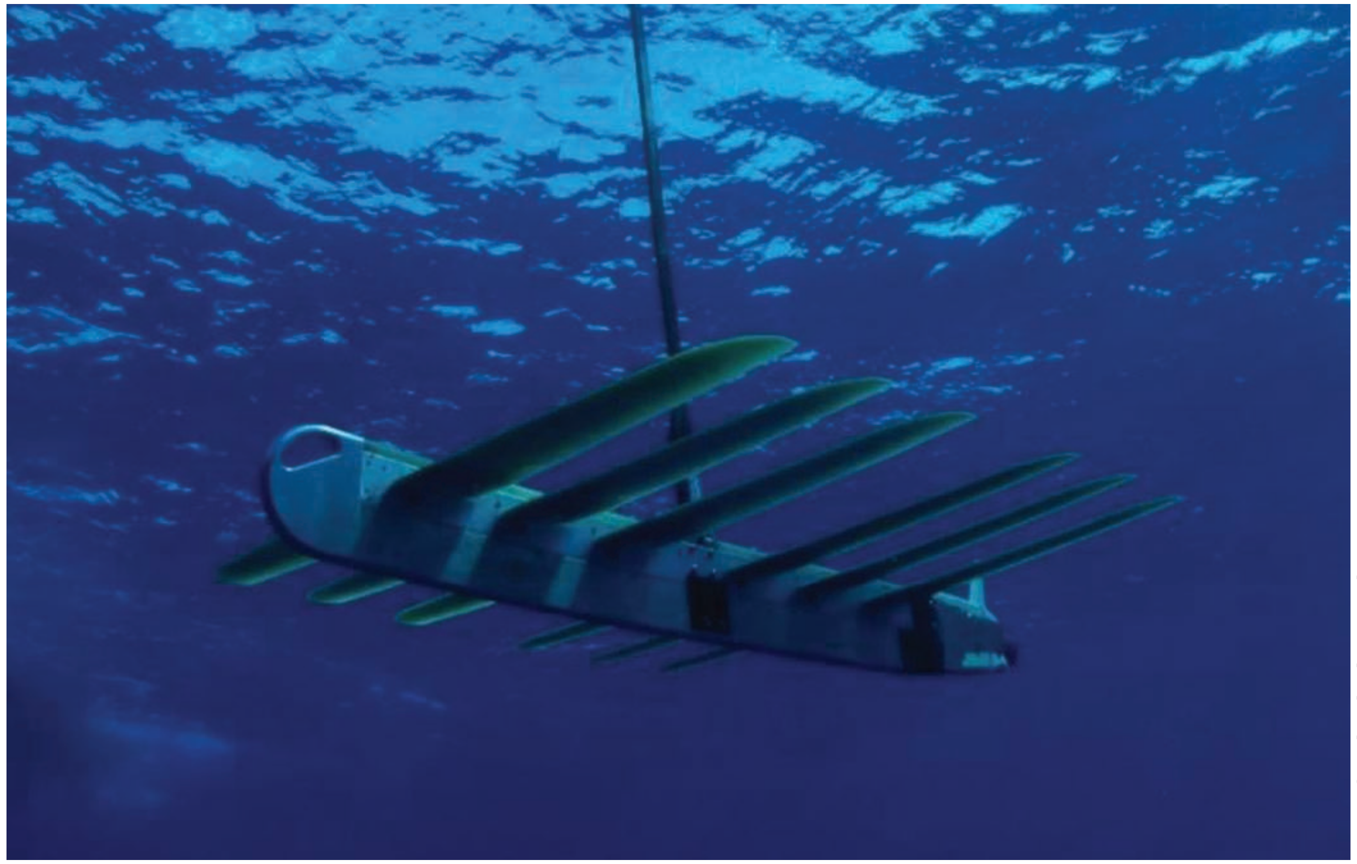

Photo Credit: Liquid Robotics

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 published. 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.

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

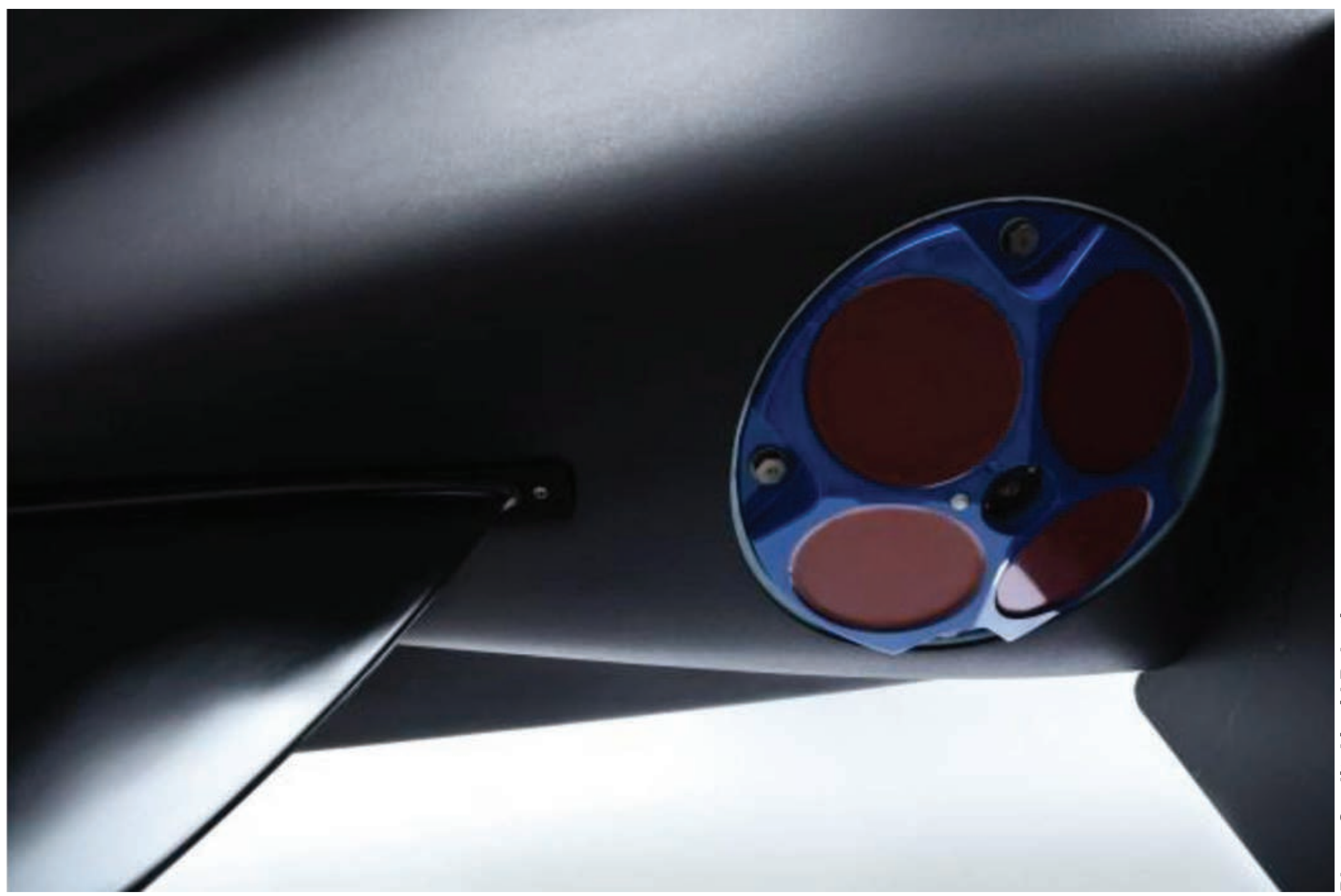

Photo Credit: Liquid Robotics

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

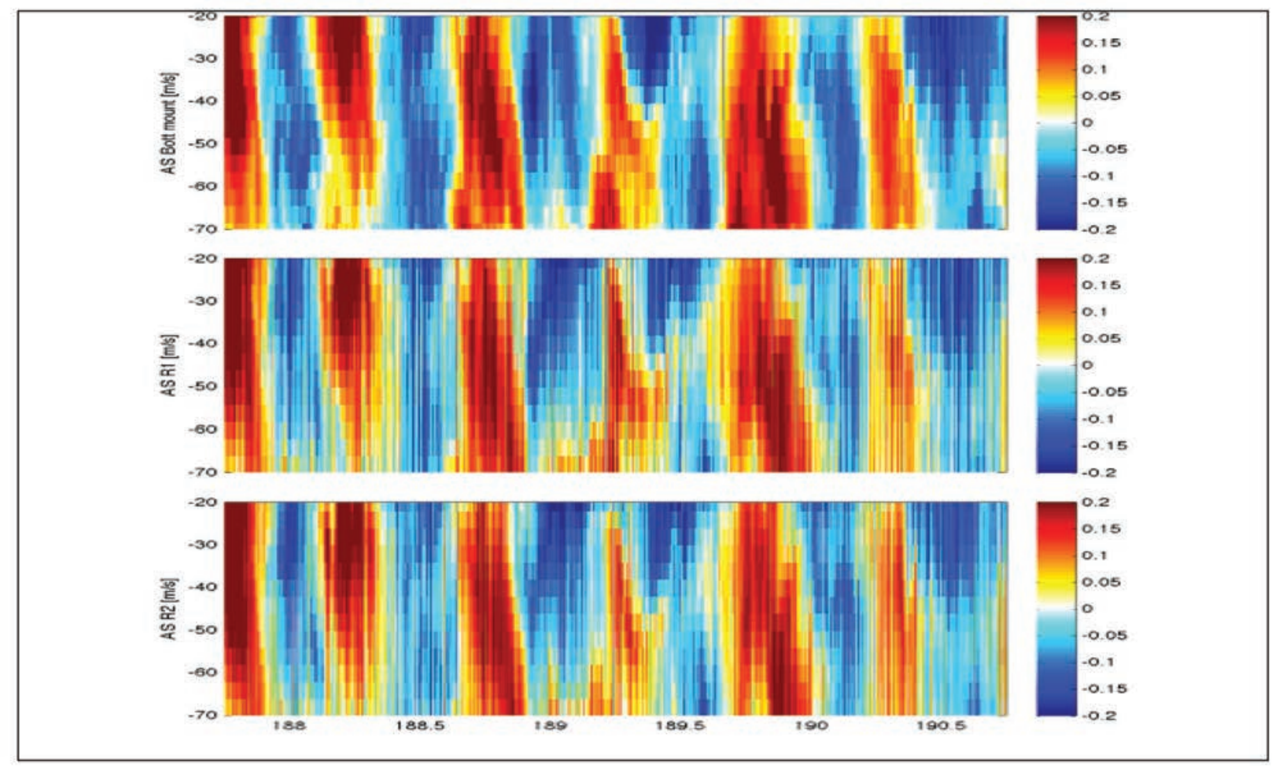

Photo Credit: Liquid Robotics

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**.
www.rdinstruments.com / www.liquid-robotics.com