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Developing Sensing Strategies for Uncrewed Systems Testing and Proving

by Michelle Barnett, Patrick Bunday, and Vic Grosjean

With the ever-increasing pressures of climate change, population growth, and human use, the state of the world's ocean is in decline. Yet, by improving our understanding of the ocean and comprehension of these pressures, there is opportunity to drive a healthy, resilient, and productive ocean that benefits human safety, well-being, and prosperity.

To better understand the ocean environment, enhanced ocean observation and measurement is essential. This involves development of next-generation technologies from subsea sensors to autonomous monitoring systems, and the establishment of safe, economical, environmentally sustainable, and efficient ocean observation operations. This means that uncrewed vehicles and intelligent instrumentation have an increasingly significant part to play in ocean measurement campaigns.

Proving Grounds

Development of next-generation marine technologies includes testing, and as such we are seeing development of subsea test beds in several countries across the world. A prime example of an underwater testing environment is being delivered in Plymouth, UK, by the Smart Sound Connect Subsurface (SSCS) project. Using instrumentation supplied by technology partners Sonardyne International Ltd., the SSCS project is delivering an underwater acoustic communications and navigation network that will link to existing surface assets to facilitate the world's first ocean-focused 5G proving ground for subsea innovation (Figure 1). Integrated seabed sensor nodes will also provide real-time reporting of oceanographic parameters (currents, waves, temperature) critical for operational safety and for full calibration of the test facility (Figure 2).

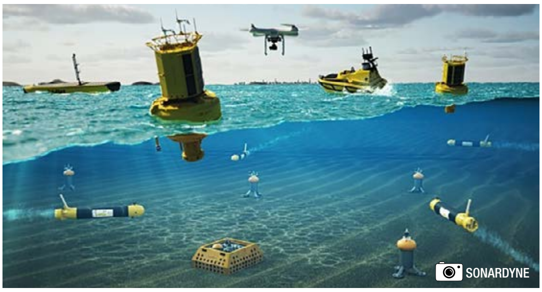


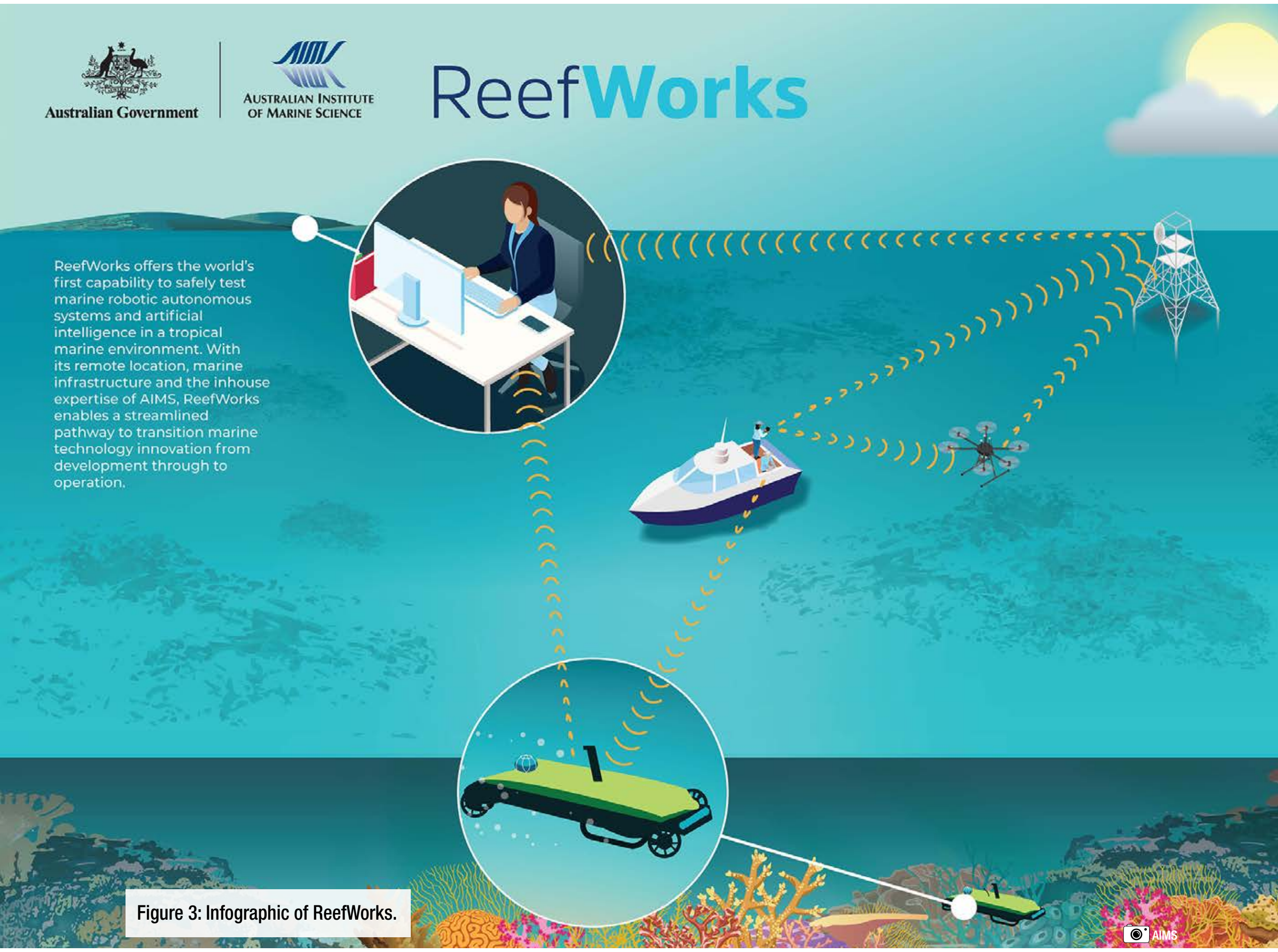
Figure 1: 3D impression of Smart Sound Connect Subsurface (SSCS).

Sonardyne International Ltd. is a global subsea engineering company specializing in the design, manufacture, and supply of acoustic positioning, inertial navigation, acoustic and optical communications, monitoring, wireless control, and autonomous data acquisition products for a diverse range of underwater applications.

Similar to Smart Sound, several other subsea technology testbeds are being developed in temperate and even boreal climates. Indeed, the focus of subsea technology testbed development has been in such climates. Yet, 42% of the world's ocean is tropical, a marine environment very different to its temperate and boreal counterparts, presenting a whole host of operational challenges, including extreme heat, aggressive biofouling promoted by the warm waters, strong ocean currents, remote expanses, hazardous marine predators, substantial sand shifts, and extreme tropical weather.

One of the first to address the gap presented by the lack of tropical underwater testbeds was the Australian Institute of Marine Science (AIMS) with its ReefWorks test ranges. AIMS, headquartered in Townsville on the northeastern coast of Queensland, Australia, is a world leader in tropical marine

Figure 2: Integrated seabed sensor node housing the Origin 600 ADCP delivered by Sonardyne for SSCS.



ReefWorks offers the world's first capability to safely test marine robotic autonomous systems and artificial intelligence in a tropical marine environment. With its remote location, marine infrastructure and the inhouse expertise of AIMS, ReefWorks enables a streamlined pathway to transition marine technology innovation from development through to operation.

Figure 3: Infographic of ReefWorks.

research, providing unique insight into Australia's tropical waters, and knowledge to develop globally relevant and innovative research solutions. The institute is developing ReefWorks, a sandbox consisting of several authorized test ranges situated within the Great Barrier Reef covering approximately 348,000 sq/km. This premier tropical marine test facility provides a flexible, scalable architecture to overcome environmental complexities unique to tropical Australia, allowing for the development of trusted uncrewed marine technologies in tropical waters (Figure 3). At ReefWorks, marine system developers can rigorously test their platforms in real world conditions to improve and demonstrate technology readiness level to regulators, thus facilitating the transition from traditional human-centric data acquisition methods to uncrewed marine technologies.

To support its ReefWorks users, AIMS needed to identify an array of integrated real-time technologies for understanding test range conditions to support system testing and proving in the challenging tropical, shallow environment. Specific challenges presented by the ReefWorks environment include warm water, turbidity, currents, shallow water, and sea states that change rapidly with the wind and tide.

To meet these diverse testing requirements, a solution integrating real-time current and water quality information was proposed as an initial proof-of-concept. This solution was to

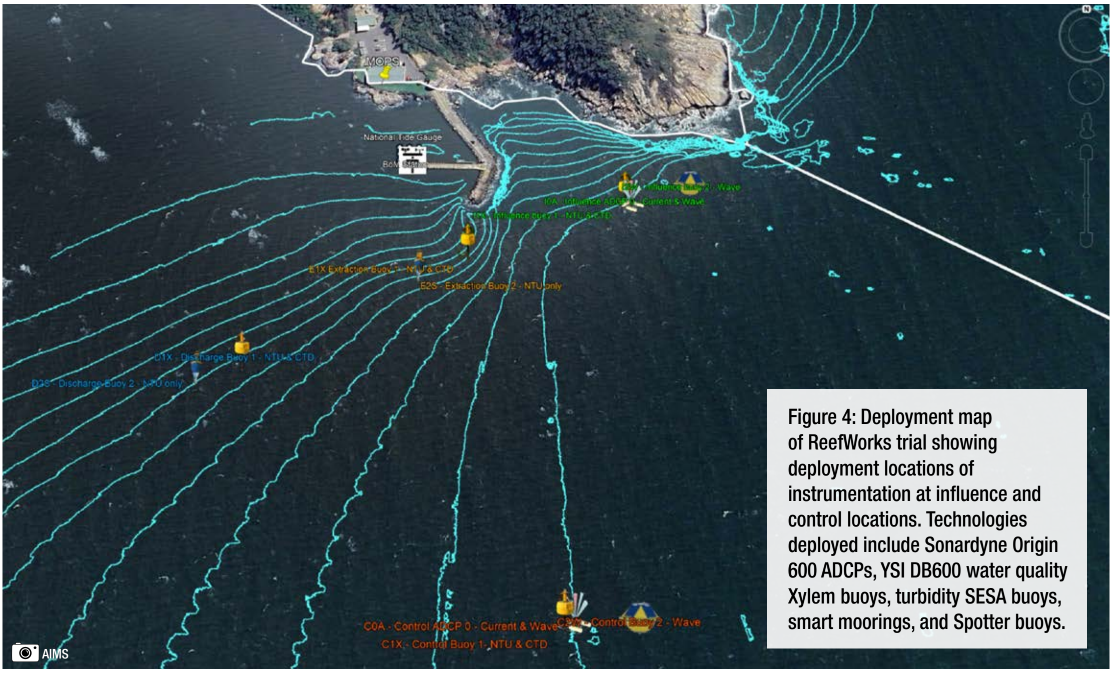


Figure 4: Deployment map of ReefWorks trial showing deployment locations of instrumentation at influence and control locations. Technologies deployed include Sonardyne Origin 600 ADCPs, YSI DB600 water quality Xylem buoys, turbidity SESA buoys, smart moorings, and Spotter buoys.

bring together recent advancements in real-time underwater communication and machine-assisted data analysis to enable seamless integration of standard communication protocols into oceanographic marine sensing. Between November 2023 and March 2024, AIMS, with the support of partners including Sonardyne, put this solution into action.

A range of technologies with real-time data capability were extensively trialled, including wave buoys, ADCPs, and water quality multi-parameter instruments integrated on floating buoys linked to an Eagle.io cloud-based data visualization platform (Figure 4). The proposed outcomes were to (1) identify technologies able to deliver real-time data that supports development of an autonomous systems test range; and (2) collect data that will support future activities, such as periodic maintenance dredging and sea water pumping for the National Sea Simulator.

Sonardyne was responsible for supplying ADCPs for the proof-of-concept study at the ReefWorks facility, specifically its Origin 600 ADCPs. The Origin 600 is an "all-in-one" unit ADCP with integrated modem and onboard Edge data processing functionality (Figure 5); the pairing of these two features enables real-time data reporting of critical oceanographic variables, including currents, waves, and temperature, from the seabed to the surface. The Edge functionality works to process data on board the instrument via implementation of a data processing algorithm that outputs an NMEA-format string small enough to be exported over the acoustic modem.

Leveraging the capabilities of the Origin 600 ADCP running a currents and waves data processing Edge algorithm, and by integration of a Sonardyne topside "Nano" modem with a YSI DB600 water quality Xylem data buoy (Figure 6), real-time oceanographic data on the range could be obtained. AIMS and Sonardyne collaborated to integrate the data exported via the Nano Modem into Eagle.io via the Xylem buoy logger. Modifications to the RCBasic script on the Campbell datalogger facilitated data extraction from the Nano Modem attached to the Xylem buoy, enabling real-time data retrieval to Eagle.io.

The Eagle.io dashboard (Figure 7) enabled the observation of oceanographic parameters

Figure 5: Origin 600 ADCP from Sonardyne.

Figure 6: Subsea (Sonardyne Origin 600) and topside (Sonardyne "Nano" modem attached to YSI DB600 water quality Xylem buoy) instrumentation set-up for real-time reporting of oceanographic data on the ReefWorks range.

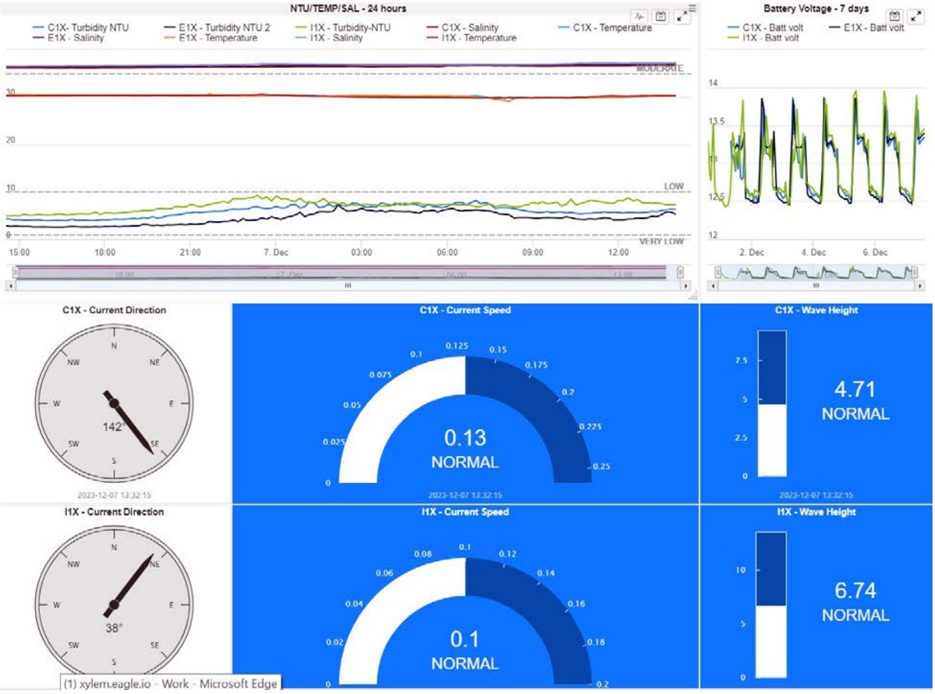


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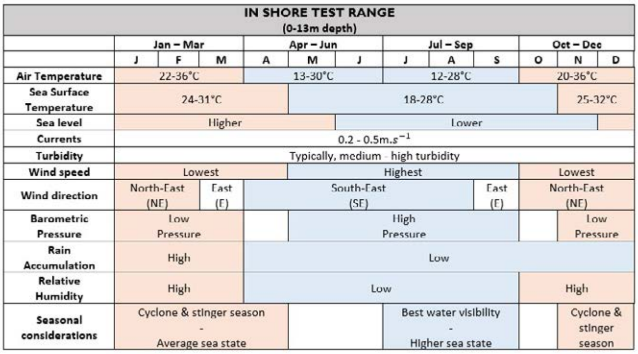
Figure 7: Example screenshot of the Eagle.io dashboard showing real-time data displayed for a range of oceanographic parameters, including currents, waves, turbidity, temperature, and salinity.

and system statuses over the deployment period, and aided decision-making for testing timing and platform selection. The comprehensive collection of data captured encompassed solar, atmospheric conditions, hydrographic data, wave parameters, power metrics, instrument status, and location data. Furthermore, the real-time map displayed on the Eagle.io dashboard tracked asset movement, enabling proactive monitoring and responsive decision-making based on current asset locations and conditions in the field (e.g., anchor slip, mooring failure), with autonomous real-time alerts set up to ensure operational integrity and timely response to anomalies. Specific alerts for instrument malfunction, high turbidity, extreme weather, battery voltage, positioning ringfence, logging, and abnormal sudden turbidity increase were included. Many of these alerts were triggered by the passage of Cyclone Kirrily, which served as a pivotal scenario to assess the resilience of the tested technologies deployed during the cyclone season (Figure 8). The tropical cyclone challenged the trial by damaging most of the instrument buoys. However, its passage was initially tracked hour by hour from a remote location in real time thanks to the technologies selected for the trial. This in itself is worthy of examination.

Navigating through Cyclone Kirrily: Testing Times

Extreme weather events like tropical cyclones provide critical real-world test scenarios for evaluating the robustness of deployed technologies. The increasing prevalence of such events underscores the need for resilient and adaptive marine technology testing environments. The tests conducted at ReefWorks faced a rigorous weather event during Tropical Cyclone Kirrily, which reached Category 3 at 3pm on AEST January 25, 2024 (Figure 9).

On the approach of the cyclone, some team members relocated to Melbourne to undertake the monitoring of the cyclone in an area not affected by power loss. A support team



IN SHORE TEST RANGE (0-13m depth)												
	Jan – Mar			Apr – Jun			Jul – Sep			Oct – Dec		
	J	F	M	A	M	J	J	A	S	O	N	D
Air Temperature	22-36°C			13-30°C			12-28°C			20-36°C		
Sea Surface Temperature	24-31°C				18-28°C						25-32°C	
Sea level	Higher					Lower						
Currents	0.2 - 0.5m.s^{-1}											
Turbidity	Typically, medium - high turbidity											
Wind speed	Lowest				Highest					Lowest		
Wind direction	North-East (NE)		East (E)	South-East (SE)					East (E)	North-East (NE)		
Barometric Pressure	Low Pressure				High Pressure						Low Pressure	
Rain Accumulation	High			Low								
Relative Humidity	High			Low						High		
Seasonal considerations	Cyclone & stinger season - Average sea state						Best water visibility - Higher sea state				Cyclone & stinger season	

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Figure 8: Seasonal ocean variability on the inshore test range.

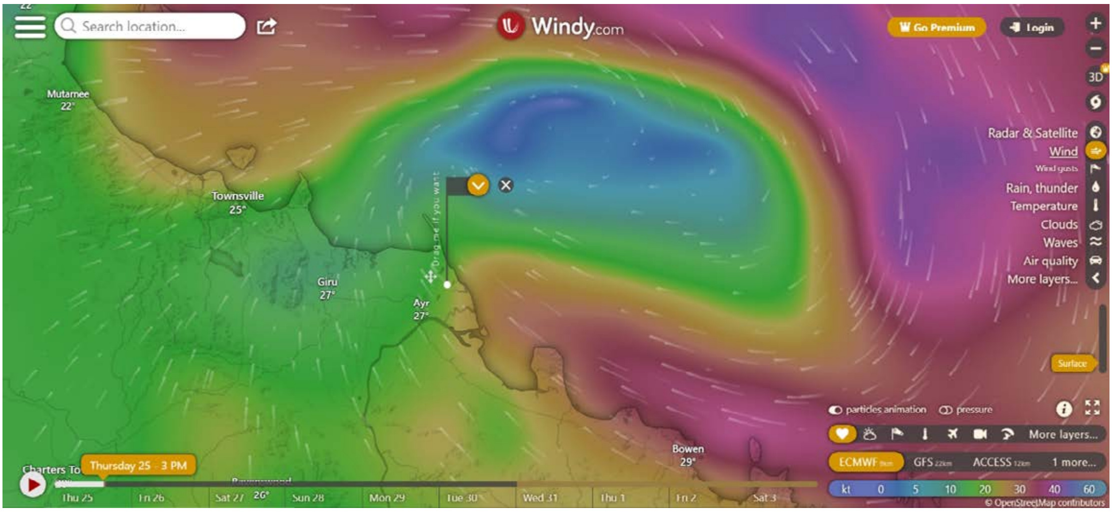

Figure 9: Windy map captured at 3pm when Cyclone Kirrily reached category 3 on the January 25, 2024.

remained in the Townsville region, which was already affected by power loss issues. Tropical Cyclone Kirrily made landfall on January 25, 2024, impacting deployed systems in the test zone. Wind and wave activity escalated throughout the day, leading to the loss of contact with the Cape Bowling Green weather station and one ADCP at 1pm. Turbidity levels and wave heights increased at 3pm when the cyclone reached category 3. Between 4pm and 5pm, the Xylem buoy bungee cable snapped, and the buoys headed towards the rock cliff (Figure 10).

By 7pm, wave heights reached nearly three metres. At 8pm, AIMS lost power on-site resulting in significant data gaps, including the loss of data collected by the Bureau of Meteorology Automatic Weather Station (AWS) located on the wharf. Satellite Iridium-enabled devices continued to report wave and position data until the connectivity fully stopped overnight.

Cyclone Kirrily revealed critical challenges and insights from deployed systems. Redundancy in communication systems was crucial when 4G connectivity was lost, prompting a shift to redundant instruments with Iridium-enabled satellite links. Larger assets, particularly non-cyclone-proofed buoys, faced heightened risks, underscoring the need for robust and modular infrastructure capable of withstanding extreme conditions. ADCPs deployed at shallower depths were susceptible to sediment burial.

Power outages disrupted data acquisition efforts, affecting systems without uninterruptible power supplies (UPS), especially security cameras. Strategic

Figure 10: Xylem buoy detachment heading toward the rocky cliff.

Figure 11: Xylem buoys continued to report turbidity and CTD cyclical data while being lodged on the rocky shore.

placement of these cameras proved essential, with recommendations for elevated installations to enhance coverage and resilience. Accurate asset positioning during deployment emerged as crucial for efficient post-cyclone recovery operations.

Despite the challenges, Eagle.io’s real-time monitoring capabilities were invaluable, though enhancements in data visualization and the use of physical cameras with reliable power backup are needed. This would particularly help prevent data misinterpretation such as when the Xylem buoys continued to report turbidity and CTD data the day after the cyclone while being lodged on the cliff (Figure 11).

Post-cyclone Recovery Efforts and Observations

Over the days following the cyclone, service was slowly re-established. Recovery efforts revealed varying states of disrepair among the equipment, buoys had disappeared, and one ADCP was buried. The few test systems which remained active were significantly weakened and detached or went offline a couple of weeks after the cyclone. The use of scuba divers and helicopters for equipment recovery (prior or after the cyclone) was identified as more effective and safer than traditional vessel-crane-based methods for efficient asset retrieval.

Post-cyclone recovery efforts focused on assessing asset displacement and damages. Buoys were all recovered in varying states of disrepair, necessitating refurbishment, upgrades, and recalibration. The loss of a SLB-700 buoy highlighted some vulnerabilities in the deployment location strategies.

Lessons from recovery efforts emphasized redundancy in communication systems, robust construction and deployment practices for larger assets, the need for seasonal suitability assessments, and the necessity for UPS systems. Strategic placement of security cameras and accurate asset positioning during deployment emerged as critical for efficient asset recovery. The effectiveness of alternative recovery methods was highlighted, offering lower cost, greater flexibility, and better safety for future operations.

The trial was certainly a success, demonstrating how real-time data from a variety of sensors can be collected, collated, and transmitted, and how such real-time monitoring capability is key for establishing efficient test regimes. This opens the potential for the development of a marine synthetic environment (digital twin), delivering information on a variety of parameters to support the needs of ReefWorks range users, or to support and inform operators of sea water pumping and maintenance dredging activities.

While a success, the trial also faced challenges presented by the shallow, tropical environment, culminating in the extreme weather event, and these are worth exploring too. We include assessment of the efforts to overcome specific challenges, a closer examination of the impact of the cyclone on real-time subsea to surface communications, and insights gained from the trial.

Challenges of Deploying ADCPs in Shallow Water Tropical Environments

The first challenge was establishing communications between the Origin modem and the Nano modem mounted on the YSI buoy in one of the most difficult environments to handle acoustic communications – shallow water, in this case operating in only 6-8 m water depth. The strategy for approaching this challenge was to mount the Origin 600 ADCPs on a low-profile frame in line of sight with the Nano modem on the Xylem buoy and adopt a special mooring design using bungees. These bungees accommodated maintenance of line of sight by preventing the YSI data buoys from moving far away from the seabed ADCPs; however, were unsuitable to withstand extreme weather events.

Communications were extensively challenged by the passing of Cyclone Kirrily. The violent weather conditions provided real insights into the most extreme conditions the equipment could face when deployed. The Origin 600 ADCPs continued to log data subsea and could have still been remotely accessed via their integrated modems if the Nano modems on board the Xylem buoys had not been compromised by striking the rocks. This gave important insights of the requirements for surface infrastructure to support the establishment of ReefWorks test ranges.

In addition to presenting a challenge to communications, the shallow water on ReefWorks inshore test range imposed a requirement for the design and implementation of special low-profile ADCP frames to prevent the YSI DB600 water quality data buoys from hitting the Origin 600 ADCPs at low tide and during the deployment. In this effort to overcome one challenge of the ReefWorks environment, another presented itself in the form

Figure 12: Origin 600 from Sonardyne in seabed frame recovered by scuba divers after being buried under sediments.

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of sand and sediment shifting and covering the bedframe, particularly during the cyclone. With sediments having the potential to compromise ADCP data, redesign of the bedframes needs to be considered moving forward.

A final challenge contended with was the intense biofouling prevalent during the warmer months in tropical Queensland, which included adhesion of large barnacles on top of the ADCPs (Figure 12). This prompts adoption of a high-performance anti-foul coating to protect the ADCPs from marine growth and fouling in future.

Conclusion: Implications for Future Testing and Development

The ReefWorks trials, buffeted by the challenges of a tropical marine environment, emerged with a roadmap for a robust collaborative testing ecosystem. This ecosystem caters to the diverse needs of global uncrewed system operators and instrument manufacturers. Innovative subsea technologies, like Sonardyne's Origin 600 ADCP, with its real-time reporting capabilities, have been shown to have a significant role to play within this ecosystem.

Cyclone Kirrily served as a baptism of fire, revealing the critical need for enhanced communication redundancy, robust infrastructure, and effective real-time data collection. Valuable insights informed the development of more resilient mooring designs and refined sensor performance analyses. Additionally, they bolstered a comprehensive business case for ReefWorks' continued operation.

In addition, the trial demonstrated the power of technologies for ocean monitoring in general and gaining actionable insights, a power which should not be underestimated in our quest to improve our understanding and management of the ocean.

Dr. Michelle Barnett is the business development manager for ocean science at Sonardyne International Ltd. She has been responsible for supporting development of Sonardyne's ocean science global business since 2021, with a special focus on the Origin Acoustic Doppler Current Profiler (ADCP) instruments. She has a strong academic background in the ocean sciences, culminating in a PhD in marine biochemistry from the University of Southampton funded by the Graduate School of the National Oceanography Centre Southampton.

Patrick Bunday is the operations planner at the Australian Institute of Marine Science (AIMS). He works on long-term planning and strategy at AIMS to ensure the institute's infrastructure and operations meet future science needs. He works on identifying, implementing, and optimizing utilization of capability to meet forecast science requirements; and has a background across a range of industries in continuous improvement.

Vic Grosjean is the ReefWorks systems engineer, at the Australian Institute of Marine Science (AIMS). He specializes in environmental monitoring, ocean instrumentation and uncrewed systems applications. With a formal qualification in mechatronics engineering and physical oceanography, he has worked over the past 18 years in the ocean and environmental technology fields. He is now setting up ReefWorks 2.0 using state-of-the-art ocean instrumentation, high-accuracy positioning, and high-speed communication across AIMS test ranges.