National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

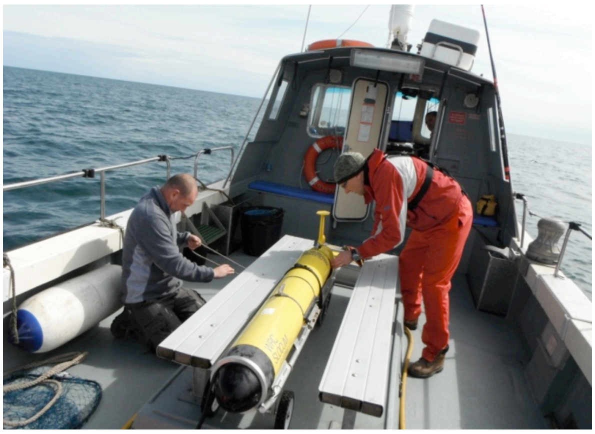
National Oceanography Centre

Research & Consultancy Report No. 18

NOC Liverpool Unit 117 Glider deployment report
for the DEFRA MAREMAP Project
April - May 2012 deployment

C Balfour & P Knight

2012



National Oceanography Centre, Liverpool
6 Brownlow Street
Liverpool
L3 5DA
UK

Author contact details:
Tel: +44 (0)151 795 4826
Email: cabal@noc.ac.uk

DOCUMENT DATA SHEET

AUTHOR BALFOUR, C & KNIGHT, P	*PUBLICATION DATE* 2012
TITLE NOC Liverpool Unit 117 Glider deployment report for the DEFRA MAREMAP Project, April - May 2012 deployment.	
REFERENCE Southampton, UK: National Oceanography Centre, 43pp. (National Oceanography Centre Research and Consultancy Report, No. 18)	

ABSTRACT

This document summarises the extended deployment of a 200 metre depth rated Slocum Electric glider by the National Oceanography Centre, Liverpool, UK from the 2nd April to 17th May 2012. The deployment was aimed as a pilot study for the use of gliders by environment agencies to monitor marine conservation zones. Lithium expendable batteries were used inside the glider to provide an extended endurance. The glider had a series of science sensors installed to measure physical oceanographic and biological parameters that included water quality and algal activity. The glider was deployed from the Liverpool Bay and successfully navigated to the intended survey area that was more than 100km from the initial deployment location. Extensive independent scientific measurements were taken during the glider deployment and subsequent operation. These measurements were used for glider sensor calibration and the monitoring of any sensor drift. Avoidance and managing of the many hazards typical in the survey area such as shipping, strong tidal currents and fixed platforms were required during the deployment. This was achieved by remotely piloting the glider with using a satellite based communications link. After a deployment of just over six weeks a suspected glider entanglement close to the seabed occurred during a routine survey dive and attempted subsequent climb underwater. This compromised the glider operation during its return to shallower, more sheltered coastal waters for an intended recovery. An emergency recovery was then required that used a small charted deep sea fishing vessel. This document provides an overview of the deployment requirements, the glider operations and the recovered glider initial evaluation. A summary of the results achieved is also provided in the report.

KEYWORDS:

ISSUING ORGANISATION **National Oceanography Centre**
University of Southampton Waterfront Campus
European Way
Southampton SO14 3ZH
UK

Not generally distributed - please refer to author

Terms and Definitions

Unit 117 Glider	A 200 metre depth rated generation 1 or G1 type Slocum Electric Glider. This is small AUV that is designed for oceanographic survey work. The glider is manufactured by Teledyne Webb Research, America. The unit 117 glider has a Seabird Electronics CTD sensor, a Wetlabs Triplet sensor (Chlorophyll-a concentration, CDOM and OBS Turbidity) and an Aaderaa Optode dissolved oxygen sensor.
DEFRA	The Department for Environment, Food and Rural Affairs is a UK government agency responsible for policy and regulations within this context.
MAREMAP	Is the Marine Environmental Mapping Programme that is aimed at an integrated approach to seabed and habitat mapping in UK coastal waters.
FreeWave	Wireless short range radio link based glider communications
Iridium	Wireless data transfer based upon the Iridium low earth orbit satellite constellation.

Abbreviations

NOCL	National Oceanography Centre, Liverpool, UK
AFBI	Agri-Food and Biosciences Institute, Belfast, UK
AUV	Autonomous Underwater Vehicle
CTD	Conductivity, temperature and depth sensor
RHIB	Rigid Hull Inflatable Boat
TWR	Teledyne Webb Research
GPS	Global Positioning System
GMT	Greenwich Mean Time
CDOM	Coloured dissolved organic matter
OBS	Optical backscatter

Contents

1. DEFRA MAREMAP Project Deployment Overview and Rationale

This document provides a review of the key objectives and results attained during an extended Slocum Electric Glider deployment in the UK Western Irish Sea. The unit 117 200m depth rated glider was deployed between 2nd April and 17th May 2012. Internal lithium primary batteries were used to extend the endurance of the glider. The purpose of the deployment was to provide a long term oceanographic survey in the order of six weeks of the western Irish Sea as part of the DEFRA funded MAREMAP project. This project is intended to evaluate the possible use of gliders for monitoring marine conservation zones. A key objective of the project was to undertake a series of mooring and ship based sensor calibration readings. This information will be used to verify the integrity of and calibrate the glider sensor readings over an extended glider deployment of weeks in duration. In terms of the scientific measurements, the glider was configured to internally record data from its science sensors at 2 second intervals. The glider science sensors comprised of a Seabird non-pumped CTD, a WetLabs Triplet sensor and an Aanderaa Optode dissolved oxygen sensor. The triplet sensor measures Chlorophyll-a concentration, CDOM and OBS turbidity (suspended matter in the water column). The glider was programmed to surface at 3 hour intervals to report its GPS derived position. After each surfacing an attempt was then made to transfer a portion of the latest glider operational and science data in near real time to the National Oceanography Centre, Liverpool (NOCL) laboratory. This was achieved using the iridium based satellite constellation to relay the latest data from the glider to the NOC Liverpool laboratory. During the majority of the of the deployment the unit 117 glider was surveying along a 40km wide east to west transect as shown in fig .1

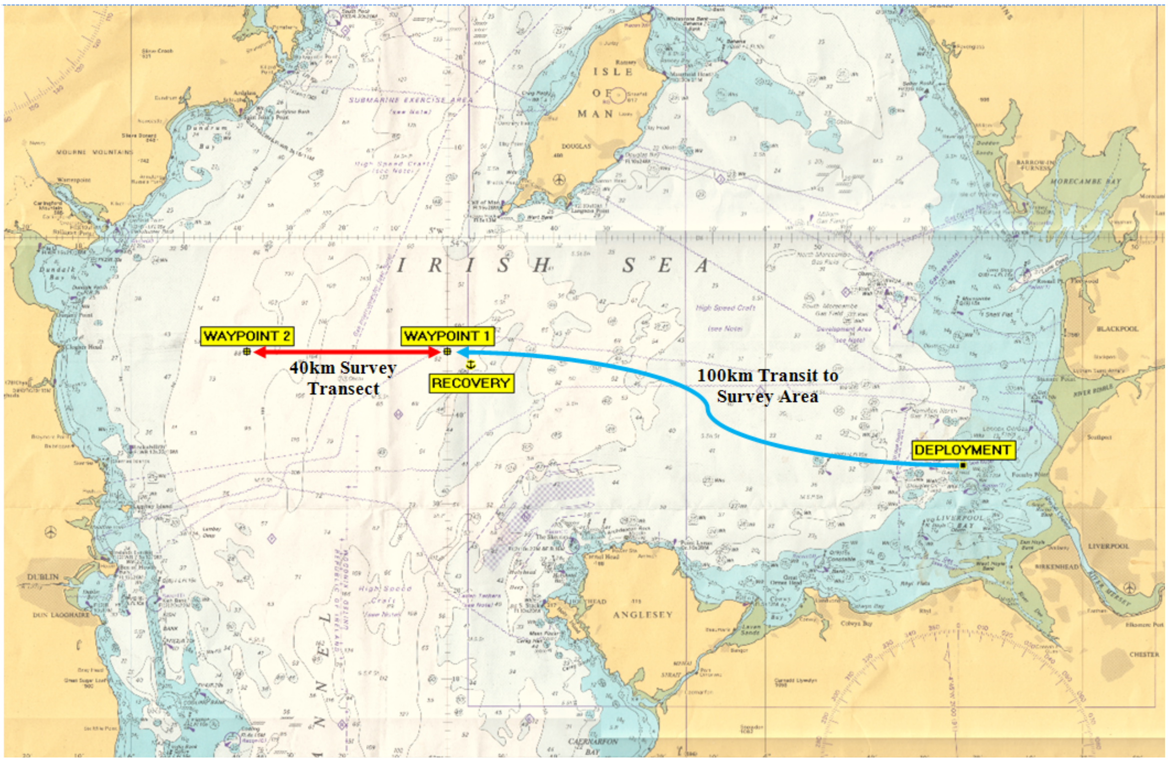


Fig. 1. Overview of the Unit 117 Western Irish Sea Deployment and Survey Transect

Before the glider deployment the preparatory work undertaken involved ballasting the glider to ensure the vehicle operates effectively and efficiently during the deployment. This preparatory work involved confirming that with the buoyancy and pitch control actuators mid range position the glider is neutrally buoyant for the anticipated water conditions that the glider is likely to be deployed in. Adjustments were also required to enable the glider to dive and climb efficiently. Details of the ballasting procedure are provided in appendix A of this document. Before the deployment of the glider and following the installation of the required lithium batteries and the glider ballasting the internal electronic compass was calibrated. This is to ensure the integrity of the navigational sensor within the glider. Details of the glider internal electronic compass calibration procedure and the calibration results are provided in appendix B.

The unit 117 glider was deployed in the Liverpool Bay on 2nd April 2012 using the RV *Marissa*, which is a small charter vessel operated by the University of Liverpool. The RV *Marissa* has an onboard, sheltered laboratory area with mains power. This provided suitable facilities for calibration samples to be collected and configuration of the glider to be undertaken during the early phases of the deployment in the Liverpool Bay. Appendix C provides additional details regarding the deployment operations. Sensor calibration reference samples were also collected during the glider deployment operations. These were used to provide precision laboratory based measurements that would determine the glider sensor accuracy at the start of the deployment. Approximately 5 days were then required for the glider to navigate a distance of just over 100km to the eastern waypoint of the 40km east to west survey transect in the western Irish Sea. When the glider arrived at the required location an east to west survey transect was then started. Between timed surfacing the glider would perform a series of undulations under water in the form of dives and climbs to attempt to make headway in the required direction. The maximum dive depth of the glider was programmed to 150 metres. An onboard altimeter was used to initiate a glider climb if the altimeter reported a seabed range of less than 5 metres before the required depth of 150 metres was attained. Fig. 2 shows a sample depth profile during the glider survey.

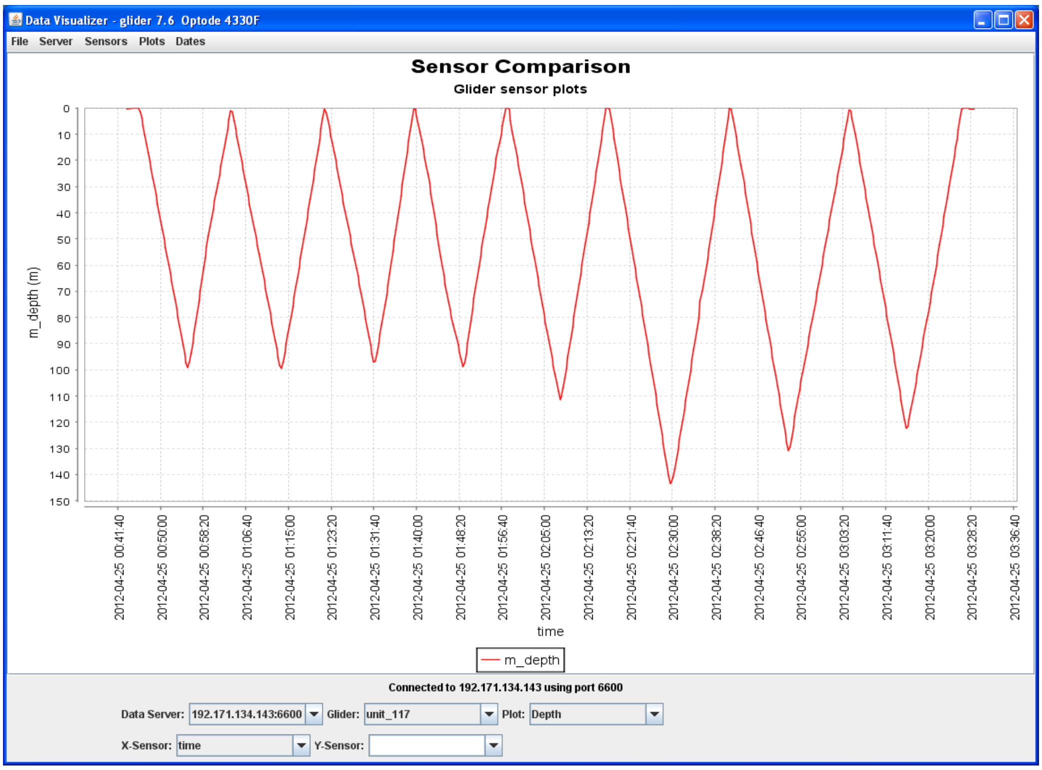


Fig. 2. Sample Glider Underwater Depth Profile

The effect of the altimeter can be seen in Fig. 2 as the glider surveys over what is likely to be uneven seabed, with the peak dive depth occurring at approximately 145 metres. The glider was also programmed to inflect when a depth of 5m is attained during a climb and the sea surface is approached. Vehicle momentum resulted in the glider subsequently turning close to the sea surface after the 5m inflection threshold had been achieved. The result of this was for scientific measurements to be recorded along almost the full water column during dives and climbs, as required. The resultant effect of tidal currents was to either oppose the glider motion or provide assistance in the required general direction of travel. This depended on the phase of the tidal current relative to the intended glider direction of travel. The result of this interaction with tidal currents was to cause the glider to tend to follow a zigzag pattern around the desired survey transect. In general the glider would provide the required repeated survey around the desired locations as illustrated in Fig. 3. As demonstrated in Fig. 2 this would provide scientific measurements in a saw tooth pattern diagonally along the water column, with a nominal glider dive and climb angle of 26^{O}. The graphical glider positional plot in Fig. 3 demonstrates sustained scientific measurements with a good spatial and temporal resolution were achieved during the deployment.

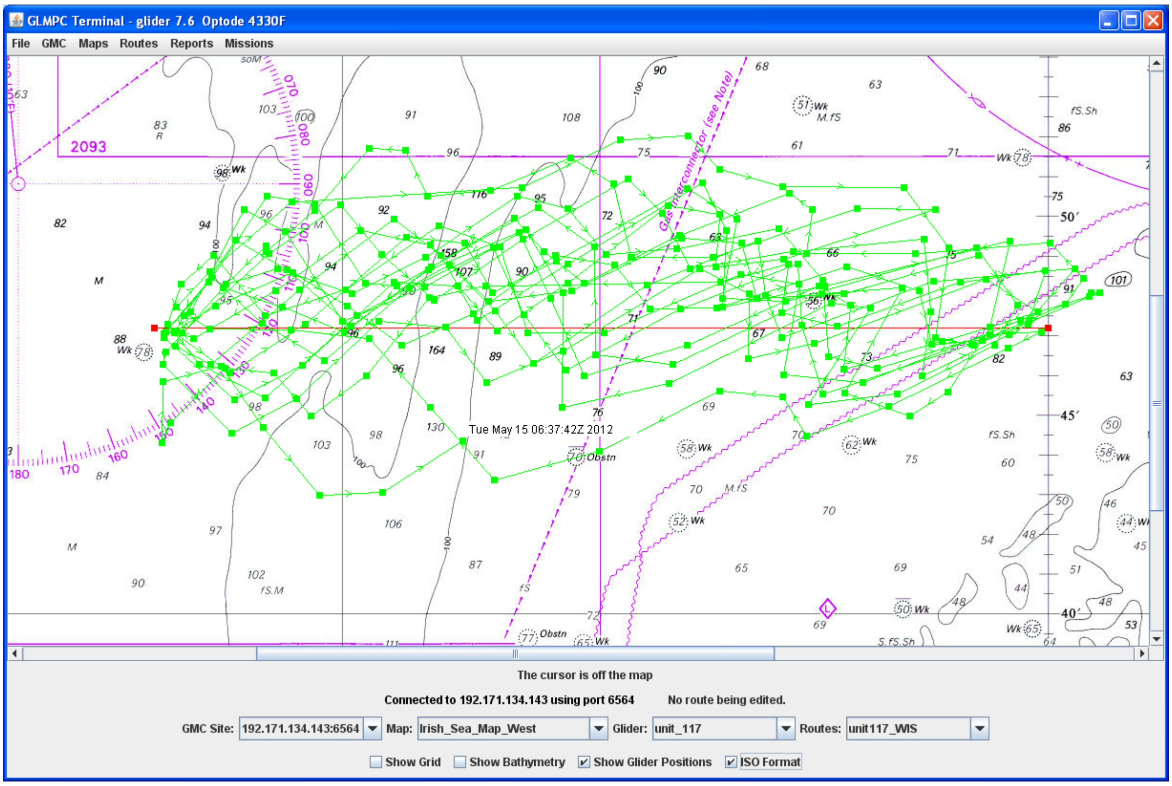


Fig. 3. Typical GLMPC Glider Plotting Software Output Indicating the glider positions

The two red squares with a line between in Fig. 3 represent the target waypoints for the glider survey. The waypoints were at 53^{O} 47.000'N, 5^{O} 38.000'W (western) and 53^{O} 47.000'N, 5^{O} 00.000'W (eastern) and they were approximately 40km apart. The green rectangles represent where the glider has surfaced and reported its position.

A rota of 'glider pilots' was used during the glider deployment. Phil Knight and Chris Balfour from the NOC Liverpool laboratory monitored the glider communications during days, evenings and weekends. This ensured that any technical problems that arose during the glider deployment were dealt with in a timely manner. This involved such tasks as monitoring the glider internal memory and battery usage, managing any near real time data transfer issues and providing updated vehicle endurance estimates. This helped with the scheduling of sensor calibration operations and determining when the glider should be recovered.

2. Mid Cruise Glider Sensor Calibration using RV *Corystes*

Within close proximity to the western Irish Sea waypoint used by the glider during its survey transect is the 'Site 38A' moorings that are maintained by the Belfast, UK based Agri-Food and Biosciences Institute (AFBI). These moorings are regularly exchanged and sensor calibration reference measurements are taken. This is achieved using the AFBI survey vessel RV Corystes. The sensors used in these moorings can then be used to provide calibration cross referencing measurements when the glider is close to its western survey waypoint. In addition to this RV Corystes was chartered approximately mid way through the unit 117 glider deployment to provide additional glider sensor calibration readings. Chris Balfour travelled to Belfast to join this cruise in order to coordinate the glider sensor calibration operations. A day long cruise aboard RV Corystes was required to undertake this work on Friday 27th April 2012. Details of the cruise operations are provided in appendix D of this report.

3. Unit 117 Emergency Recovery and Initial Recovered Glider Evaluation

At just over six weeks into the glider deployment the glider was reconfigured to head towards the Liverpool Bay, past its normal eastern survey waypoint. The general intention was to navigate the glider into shallower and more sheltered coastal waters. A sufficient contingency of approximately two weeks endurance in the internal batteries was allowed. This was in order for a recovery to be scheduled using a small coastal charter vessel when suitable weather and a suitable sea state existed to allow this. Shortly after the return of the glider was initiated a problem with the glider occurred. The glider did not surface to report its position as and when expected late on Wednesday 16th May 2012. When the glider did eventually surface after midnight BST it was reported that the rear emergency jettison weight had been released. At this stage the glider had lost the ability to dive and an emergency recovery was rapidly scheduled. A selection of photographs of the glider emergency recovery is provided in Fig. 4. A deep sea fishing charter vessel, *Tuskar*, which is based at Birkenhead, UK was used to recover the glider. A subsequent analysis of the internally recorded glider measurements and the condition of the glider when it was recovered indicates that some form of entanglement of the glider had probably occurred close to the seabed. What seems to have happened is that the glider dived and as it approached the seabed and began to inflect or turn in the normal manner the glider has become entangled with the nose of the vehicle pointing upwards. The buoyancy pump and pitch control actuators operated correctly to initiate a climb at the required angle. Subsequent and severe movements of the glider pitch and roll sensors can also be seen in the recorded data after the initial suspected entanglement. This would seem to suggest that the entangled glider was being dragged along close to the seabed, possibly by tidal currents. After a period of time the criteria for the emergency jettison weight release from the tail section of the glider was satisfied after the ability of the vehicle to climb was lost. After the expulsion of the rear tail jettison weight of approximately 0.5kg the added positive buoyancy of the glider tail section seems to have been sufficient to free the glider and allow it to surface. At this stage the glider reported its position and that the jettison weight had been released. The near real time data transferred by the glider at the time did not provide sufficient detail to determine the root cause of the problem. It was the detailed analysis of the recovered glider data that allowed the most likely cause of the glider problem to be determined. Appendix E of this report provides a more detailed overview of the unit 117 glider emergency recovery. Details of the post glider recovery inspection and determination of the probable cause of the glider jettison weight expulsion are provided in appendix F of this report.

Transit to the recovery location from Birkenhead, UK using the *Tuskar* deep sea fishing charter vessel

A boat hook is first used to align the glider within reach of a rear dive platform that is close to the sea surface. The transportation trolley is then aligned under the glider to allow the recovery.

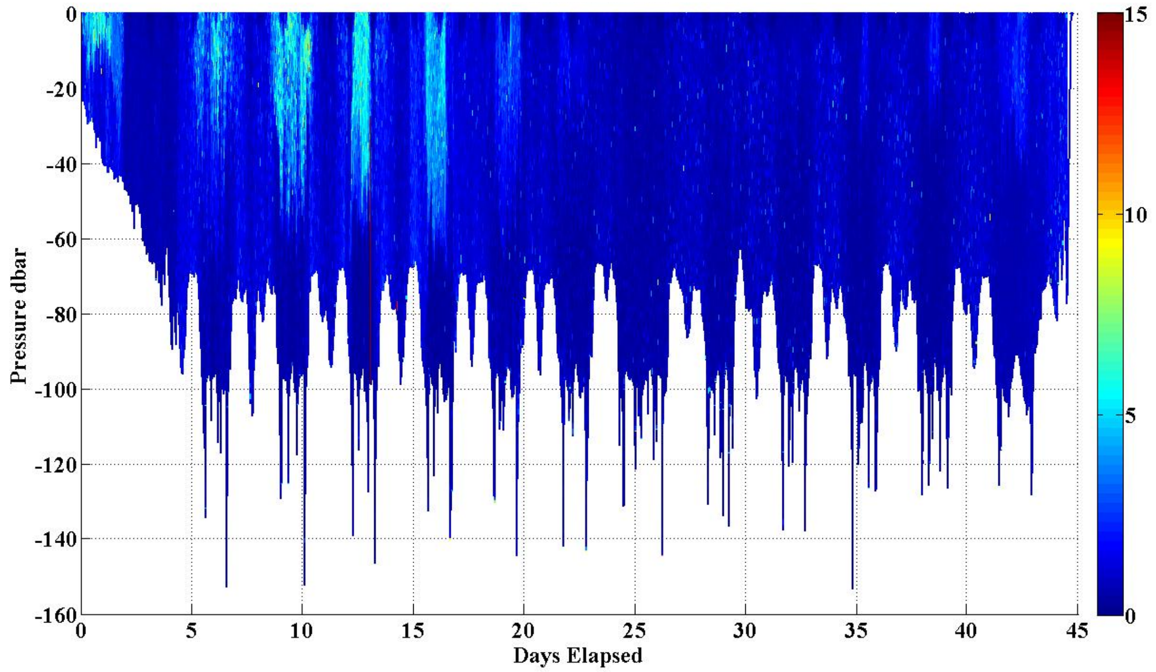
Recovered unit 117 glider

Return transit back to Birkenhead port

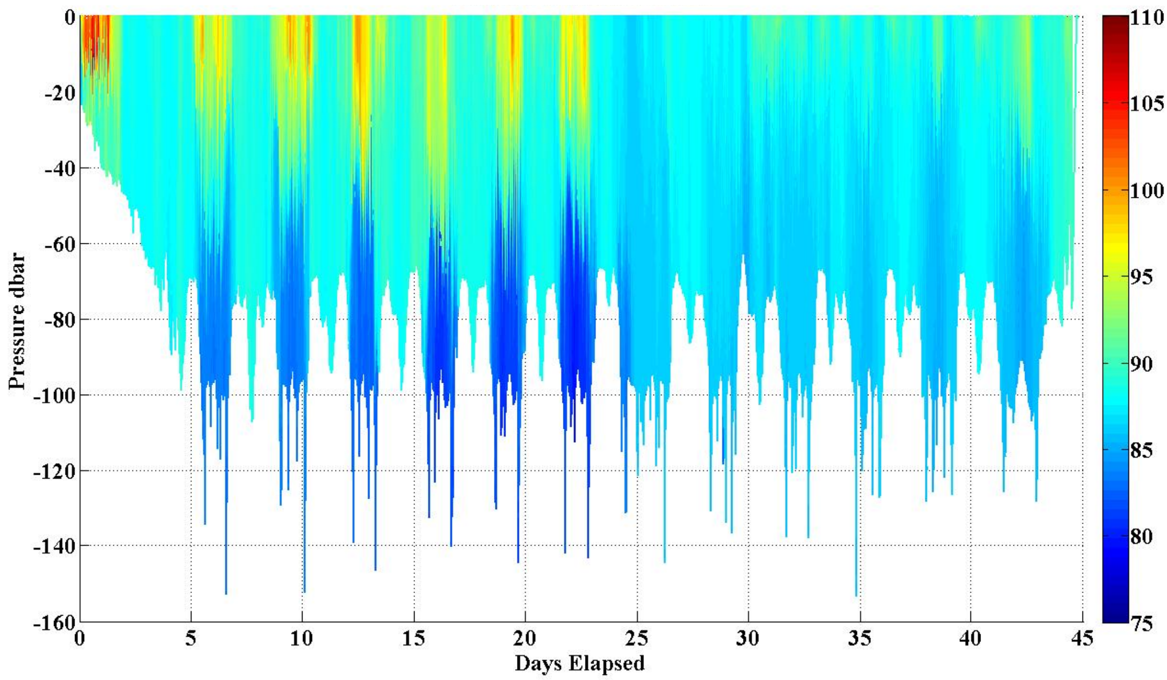
Fig. 4. Glider Emergency Recovery

4. Post Deployment Glider Scientific Measurement Initial Evaluation

Following the initial assessment of the recovered unit 117 glider the sensor and diagnostic data that had been recorded by the glider was downloaded. Initial analysis of the data was then undertaken to assess the general consistency and integrity of the measurements that had been recorded by the glider during the extended deployment. A series of time series scientific sensor visualisation plots were generated of the recorded measurements. Figure 5 shows two sample plots of the measured chlorophyll-a concentration and dissolved oxygen saturation during the full deployment. The x axis represents the time elapsed in days, the y axis is the vehicle pressure sensor reading, which approximates to the glider depth. The coloured surface represents the magnitude of the scientific sensor reading. Increases in the chlorophyll-a concentration in the upper part of the water column are observed at approximately 1, 7, 10, 12 and 16 days into the deployment. The plot of dissolved oxygen concentration in Fig. 5 shows corresponding increases in the dissolved oxygen in the water column at the same general locations as the increased chlorophyll-a concentration. This would seem to indicate clusters of algal activity in these upper water column regions at these times.



a – Chlorophyll-a concentration



b – Dissolved oxygen saturation

Fig. 5. Example Science Data Plots

Preliminary data visualisation plots for the full unit 117 glider science sensor package of CTD, CDOM, dissolved oxygen, chlorophyll-a concentration and OBS turbidity are provided in appendix G of this document.

5. General Observations Regarding the Operation of Coastal Gliders

For shallow water based coastal gliders with a up to 200m depth capability that are operated in challenging coastal regions, sensor fouling is likely to be a problem for extended deployments. The ship and mooring based sensor cross calibration effort during the DEFRA funded MAREMAP deployment has helped to address this problem. Shortly after the glider recovery the optical sensor and CTD measurement cell were inspected and were clean and generally free of contamination. Local shipping activity as shown in Fig. 6 and reduced glider control due to tidal currents represent some of the other key risk factors with coastal glider deployments. Careful planning and subsequent monitoring or piloting of the glider deployment is required to maximise the probability of a successful deployment.

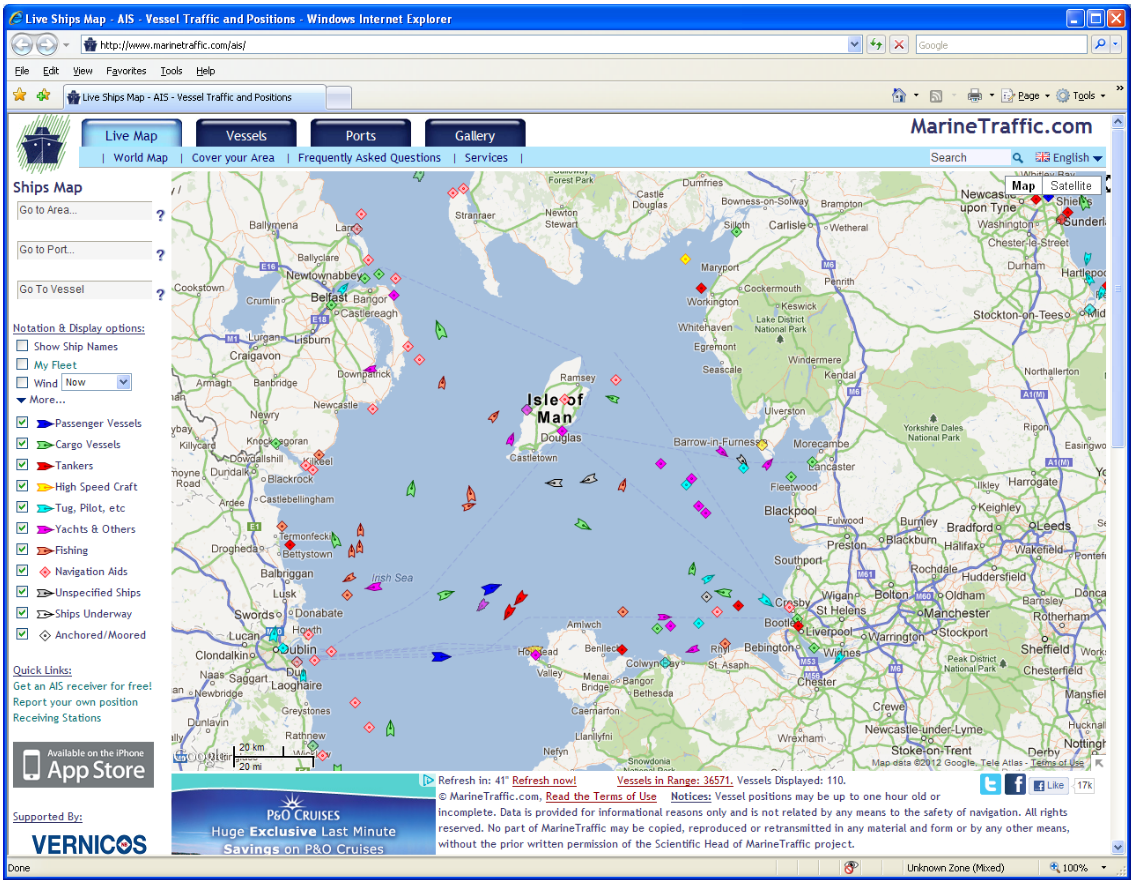


Fig. 6. AIS Shipping Plot (ships larger then 300GT must have an AIS Transmitter installed)

Captured at 17:05 GMT on Monday 21st April 2012. This Illustrates some of the larger shipping vessel hazards associated with Irish Sea based glider deployments

6. Summary

The unit 117 glider western Irish Sea deployment for the DEFRA funded MAREMAP project has been very successful and an excellent scientific data return has been achieved. This has clearly demonstrated the suitability of using gliders to provide extended scientific surveys of marine conservation zones. While the precise positioning of a glider can be difficult to accomplish, primarily due to the effect of water currents, an almost continuous scientific survey can be undertaken. Glider based scientific surveys can be sustained in adverse weather and subsequent less than favourable sea conditions. This represents one of the key advantages of using gliders along with the cost effective gathering of scientific measurements. This project involved the first extended glider deployment undertaken by NOC Liverpool using lithium primary batteries. The installation of this kind of glider internal power source has provided the required extended glider endurance. The lithium battery capacity also permitted a high temporal resolution of 2 second sampling of all of the glider scientific measurements to be sustained throughout a deployment of more than six weeks in duration.

A key concern with extended glider deployments is the possible progressive degradation of the quality of the measurements generated by the glider sensors. Problems such as sensor drift and contamination if left unchecked can compromise the quality of the measurements undertaken. A full set of reference and cross calibration sensor readings was established at the beginning and sustained during the deployment. Such techniques as reference water sample collection and subsequent on ship or laboratory analysis have been employed to achieve this. Parallel measurements from equivalent calibrated mooring sensors in close proximity to the glider have also provided a source of calibration data. In addition to this a mid-deployment calibration cruise was also successfully undertaken using RV *Corystes* from Belfast and sailing to the western part of the glider survey transect. During this cruise the research ship was positioned within a kilometre of the glider to allow on ship calibration readings to be undertaken in parallel with the glider scientific survey. This information should provide sufficient independent reference measurements to allow the full scientific data set recorded by the glider to be accurately calibrated. As described in this report, thorough and methodical glider preparation, deployment and sensor calibration procedures were used and the reward for these efforts has been a particularly successful deployment.

It was disappointing that the suspected glider entanglement occurred towards the end of the deployment. However, this represents one of the hazards of operating gliders, particularly in coastal regions. Any AUV deployment carries an inherent risk that technical problems. Damage to the vehicle, entanglement, problems with the AUV sub-systems and so on may prevent the successful recovery of an underwater vehicle. Therefore it was also particularly rewarding that a difficult and rapid recovery of the glider was successfully implemented. This occurred shortly after the emergency jettison weight was released and the glider subsequently surfaced on 17th May 2012. The short notice support of a local charter vessel was also essential to ensure the success of the project.

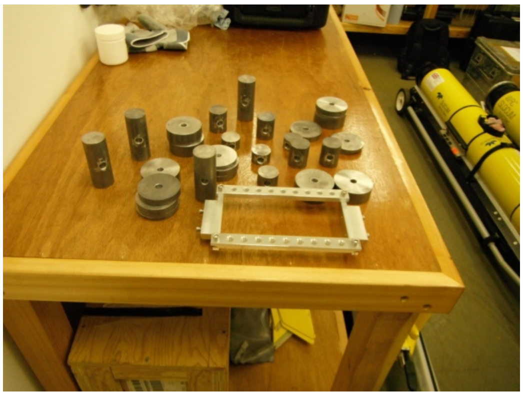
The initial evaluation of the recovered glider scientific measurements indicates that the required high quality measurements been sustained throughout an extended glider deployment of approximately 45 days in length. The success of this deployment has illustrated the potential application of gliders for scientific surveys. This project has also helped to sustain the track record of NOC Liverpool for achieving difficult coastal glider deployments under challenging constraints. It is envisaged that further sponsored coastal glider survey work will follow due to the success of this project.

Acknowledgements

Thanks are due to Ben Allsup, Clayton Jones and the glider support team at Teledyne Webb Research, USA for the rapid responses to regular enquiries and requests for technical support. Thanks are also due to Stan Dickinson the skipper of *Tuskar* and his crew for taking on the challenge of a difficult glider recovery at very short notice. NOCL must also acknowledge the support of the crew of RV *Corystes* for the excellent sensor calibration work and for agreeing to provide a backup glider recovery option. In addition to this, thanks are owed to Andy Lane for remotely monitoring the glider at the NOCL laboratory at short notice. Andy was responsible for proving critical glider status and positional updates via satellite telephone during the offshore glider recovery operations.

Appendix A – Unit 117 Glider Setup and Ballasting

A series of photographs of the glider preparation operations are shown in this figure A1 When the glider is serviced and new batteries are added the weights inside the glider need to be carefully selected. This is to ensure that the glider is neutrally buoyant when the buoyancy and pitch control actuators are mid range. An indoor saltwater tank is prepared to accurately represent the seawater conditions where the glider will be deployed. The internal weights are then adjusted to ensure that the glider is ballasted properly. The weights may also need to be adjusted to trim the distance between the vehicle centre of gravity and centre of buoyancy to within predefined manufactures limits. This ensures that the glider is well balanced and it can efficiently dive and climb underwater in the intended survey area under the control of the internal buoyancy pump and pitch adjustment actuator. A small digitally controlled tail fin is used to make adjustments to the vehicle heading when the glider dives and climbs underwater.



A selection of internal weights and a mounting rail are used to assist with the glider ballasting

The internal ballasting adjustments are carefully weighed and recorded in the laboratory

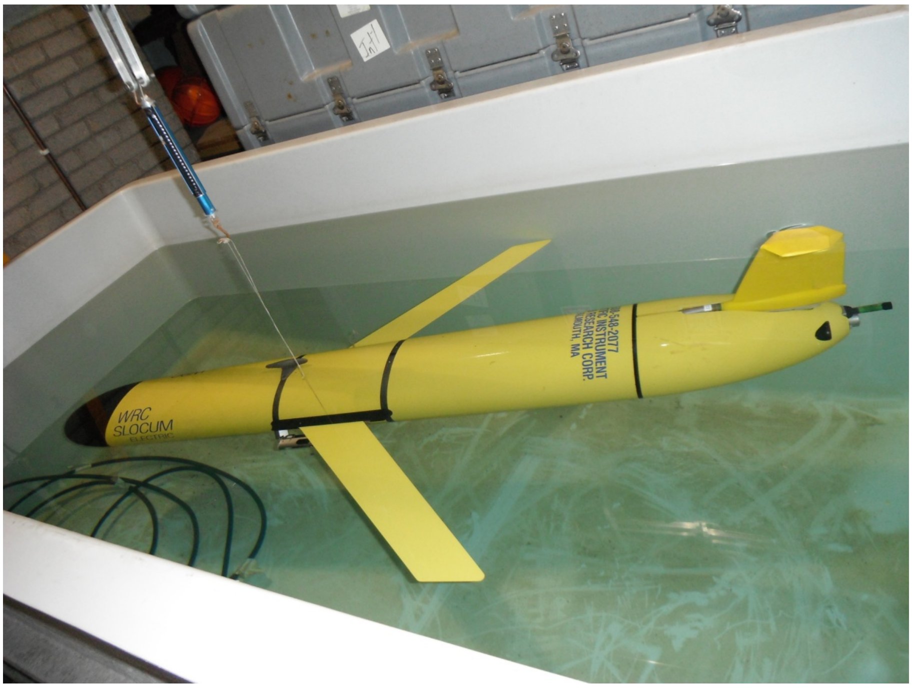
Internal weights are mounted inside the glider

Glider Servicing and re-assembly

Fig. A1. Unit 117 Glider Preparations for the April 2nd 2012 Deployment

Careful attention is required during the ballasting process to make sure that the vehicle operates correctly when deployed. The glider internal buoyancy pump can either add or subtract a mass in the order of approximately ± 250g or approximately ± 4 sigma units (sigma-t units) of water density. In a vehicle with a total mass of typically in the order of 60kg the ballasting of the vehicle needs to be precise. At NOC Liverpool a saltwater tank is used to simulate the intended glider deployment conditions. Sea salt or fresh water is mixed into the tank to generate the correct salinity and density. Compensations may also have to be made to the glider ballasting if the tank water temperature is significantly different from the intended deployment survey area water temperatures. Historical records of the deployment location water properties are used to estimate the required ballasting conditions. Just prior to the glider deployment a measurement of the actual water properties is made from the deployment vessel. This information can be used to confirm the correct glider setup or determine what adjustments to the glider ballasting weights may be required to ensure that the vehicle operates efficiently. During the cruise mobilisation process sufficient tools, glider servicing equipment and ballasting weights are taken to allow adjustments to the glider setup to be made if this is required.

A saltwater tank and precision scales allows testing of a glider setup at the NOCL Vittoria Dock warehouse facility



Electronic or spring Scales are used to check the glider ballasting and the distance between the centre of gravity and buoyancy for the unit 117 April 2nd 2012 Deployment

Fig. A2. Glider Ballasting Testing Before a Deployment

Appendix B – Unit 117 Glider Electronic Compass Calibration

Before a deployment of a glider and particularly after an exchange of internal components of the glider such as batteries a disturbance to the calibration of the glider electronic compass can occur. A procedure is used for compass calibration that involves taking the glider to an open space that is free from electrical interference and stray magnetic or electromagnetic fields, as shown in Fig. B1.

Glider rotated with positive pitch and positive poll

Glider rotated with positive pitch and negative Roll

Horizontal rotation

Result recording and glider control using a laptop computer and a wireless data link

Post calibration compass alignment check. A board with a reference line is levelled and then used in an open space away from electrical or magnetic interference. The glider is aligned above the board to the reference line using the transportation trolley

A magnetic compass is used to align the reference line in 22.5^{O} steps around a full 360^{O} rotation. At each 22.5^{O} step the glider internal electronic compass readings are then recorded. Comparisons between the magnetic compass and the glider compass are then used to check the electronic compass operation.

Fig. B 1. Glider Electronic Compass Calibration and subsequent check. The photographs illustrate the general procedure using the unit 175 glider that has a specialist upper sensor attached (black tube)

The process involved to calibrate the glider compass then usually involves moving the glider through either fixed positions or a series of rotations. The intention is to provide a large range of glider movements by which the internal electronic compass can calibrate itself and offset the effect of any static electrical or magnetic fields that may disturb the compass operation. A new set of batteries would usually have a residual magnetic field in the cells. An electronic compass calibration is required to reduce the effect of this kind of disturbance, particularly after a battery exchange. Fig. B2 shows a plot of the electronic compass performance for the unit 117 glider before the DEFRA MAREMAP project deployment and after a compass calibration. A glider compass calibration is normally considered to be an important prerequisite to a deployment to confirm the glider navigational integrity.

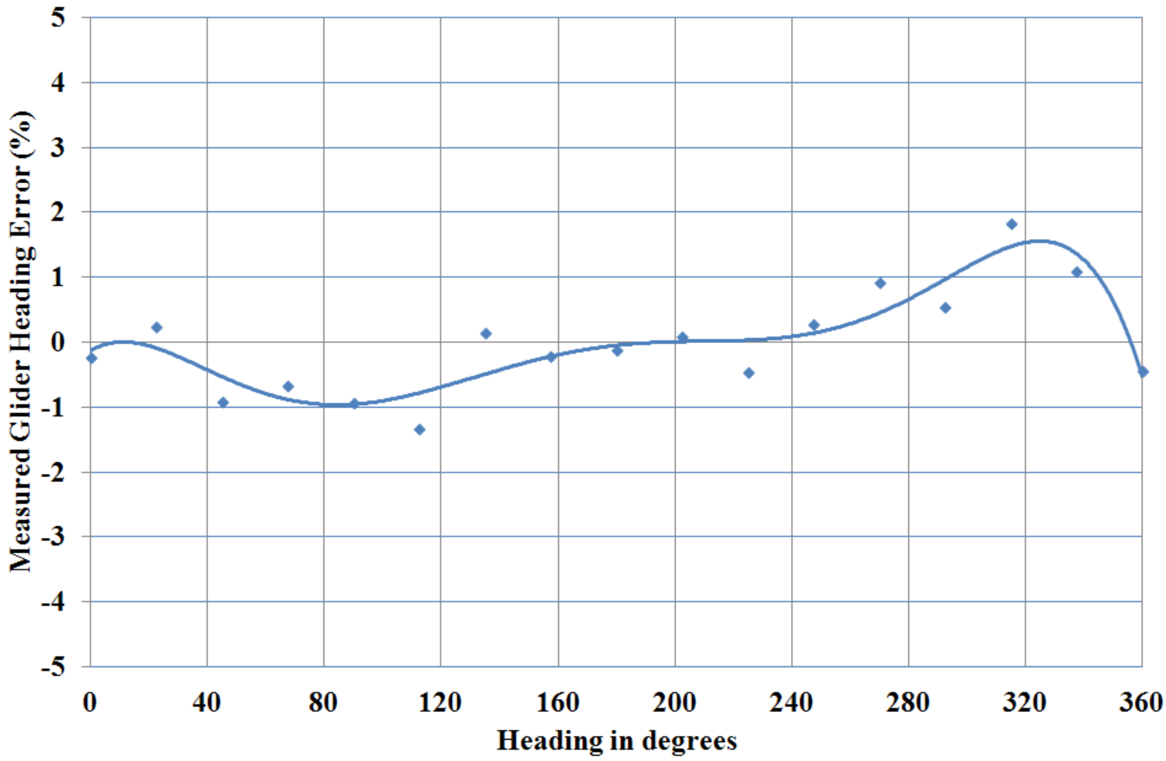


Fig. B 2. Unit 117 Glider Electronic Compass Calibration Check Plot After Calibration and Prior To the DEFRA MAREMAP Project Deployment from April to May 2012

The post calibration compass check in Fig. B2 shows a good agreement between the magnetic compass and the glider internal electronic compass readings. This is a practical procedure that will be subject to experimental error when reading the compass, aligning the reference board or aligning the glider on its transportation trolley to a particular heading. Please note that previous tests without the glider trolley have yielded similar results and it is estimated that the glider transportation trolley steelwork does not significantly affect the compass calibration check results. The plot in Fig. B2 shows the measured glider electronic compass heading measurement deviation in 22.5^{O} steps over a full revolution of the glider.

The importance of a glider internal compass calibration and subsequent compass check is shown in figure B3. This graph shows the difference between the actual heading and the heading measured by the glider at measurement intervals of 22.5^{O}. Two plots are shown that are fitted curves to the measurements taken. For the unit 175 glider a compass check before a calibration has been performed that illustrates the glider compass measurement deviation that can occur if a calibration has not been undertaken. The improvement in the readings from the unit 117 glider after a calibration of the glider internal compass has been completed is shown by the fitted curve.

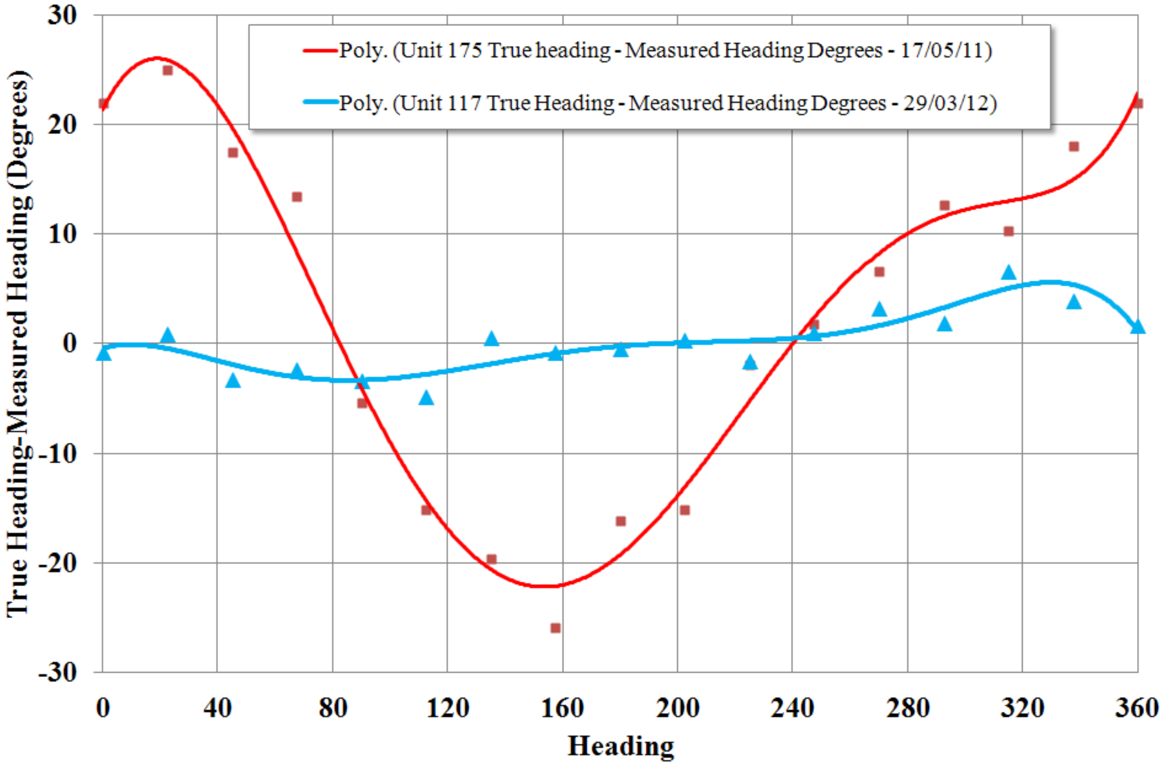


Fig. B 3. Glider Un-calibrated and Calibrated Glider Internal Compass Reading Plots

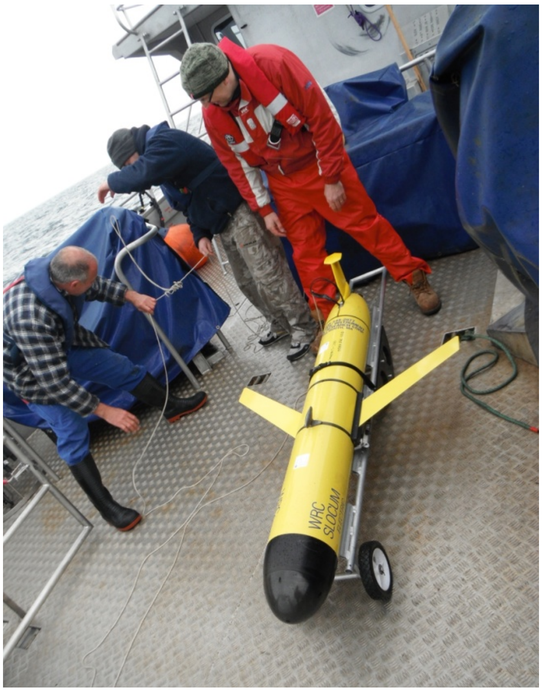
Figure B3 shows the measured glider electronic compass heading measurement deviation in 22.5 degree steps over a full revolution of the glider. The improvement in the glider internal compass heading measurement can be seen clearly by comparing the two plots. Note that both plots will have some experimental error associated with them due to the practical procedure described previously that is used to perform a compass check and generated the points plotted in the graph.

Appendix C – Deployment of the Unit 117 Glider Using the RV *Marissa*

The Deployment of the glider was undertaken with the University of Liverpool Survey Ship the RV *Marissa* on Monday 2nd April 2012. A selection of pictures to illustrate the typical deployment operations are shown in Fig. C1.

The RV *Marissa*

The RV *Marissa* internal, sheltered wet laboratory work Area



Aft deck preparations for the unit 117 glider deployment on 2nd April 2012

Initial Testing of the deployed glider with a tether and float

Onboard collection and processing of sensor calibration water samples during the cruise

Fig. C1. Glider Deployment Operations Aboard the RV *Marissa*

The glider was tested and then initially deployed with a tether and float. If any technical problems were encountered with the glider during the early deployment phases then the float and line allows a recovery to be rapidly implemented. If the initial tests are completed successfully the tether is removed. Once the glider was deployed a wireless data link from an antenna on the ship is used to monitor the glider initial performance. During the initial glider survey work an over the side static measurement CTD and a manually profiling CTD are used to gather glider sensor calibration data. A self logging GPS recorder was used to provide an accurate time and positional reference for the on ship measurements. Water samples are also collected and analysed either onboard or in a laboratory after the deployment cruise. This provides essential glider sensor calibration reference measurements during the initial deployment. This completed the glider deployment operations.

Appendix D – Unit 117 Glider Mid-Deployment Sensor Calibration

Between three and four weeks into the unit 117 Western Irish Sea glider survey on Friday 27th April a glider sensor calibration research cruise was undertaken. A visit was made by Chris Balfour to the Agri-Food and Biosciences Institute AFBI, (www.afbini.gov.uk) vessel RV *Corystes* at Pollock Dock, Belfast harbour, Northern Ireland. This visit was to supervise and coordinate the glider calibration operations during the cruise. During the western Irish sea transect undertaken by the glider the eastern waypoint was temporarily moved closer to the AFBI Site 38A mooring to restrict the glider operation to this general area.

The AFBI mooring is at a nominal GPS location of 53° 47.000N, 5° 37.903W and the instrumentation is routinely serviced and calibrated during AFBI survey cruises. A diagram of the typical AFBI mooring arrangement is shown in Fig. D1.

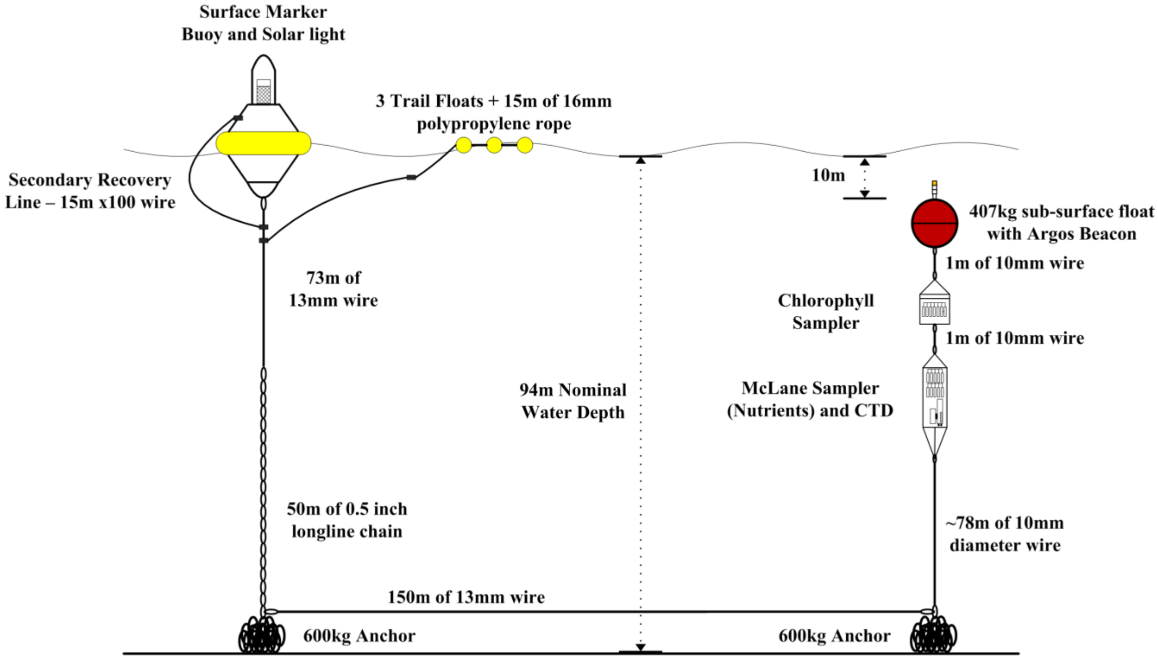
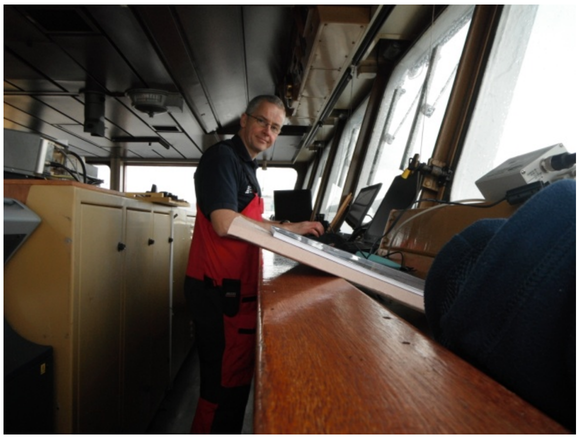


Fig. D1. Typical AFBI Site 38A Mooring Arrangement

The site 38A mooring has a CTD and automated water sapling instruments to help to determine the physical water properties, the chlorophyll concentration and the dissolved nutrients. During AFBI cruises ship based calibration measurements of CTD, chlorophyll-a, CDOM, nutrients and dissolved oxygen are made or samples are collected for land based laboratory analysis. This information is used to calibrate the deployed sensors and compensate for any measurement drift in the sensors when the instrumentation is recovered for servicing, data recovery and subsequent data processing. The additional RV *Corystes* cruise on 27th April 2012 first collected some calibration measurements at site 38 A for the deployed moorings. Phil Knight at the NOC Liverpool laboratory provided backup piloting of the glider when it was out of short range wireless data range. After glider GPS positional updates were provided by satellite phone to the ship and the ship was positioned close to the glider, Chris Balfour then controlled the glider from the ship to allow calibration measurements to be taken by the onboard AFBI team in close proximity to the glider. The requirement was to collect the ship based reference samples while the glider is undertaking its routine survey measurements. This provided essential reference measurements in parallel with the glider sampling that will allow the degree of drift off calibration, if any, in the glider sensor measurements to be determined. A selection of photographs of RV *Corystes* and the cruise operations are shown in Fig. D2. Alignment of the ship with the glider for close proximity reference calibration sample collection is shown in Fig. D3.

Chris Balfour by the RV *Corystes* at Pollock Dock, Belfast Harbour



Glider monitoring and control on the bridge of RV *Corystes*. An external wireless data transfer antenna mounted above the bridge allows communication with the glider on the sea surface at distances of up to several km.

Preparation of the ships CTD and water sample collection carousel for deployment

Sample collection and preservation operations in the wet lab of RV *Corystes*

Onboard glider positional monitoring of the unit 117 glider in the bridge of RV *Corystes* using the TWR GLMPC Graphical positional plotting software

Fig. D2. RV *Corystes* and the Glider Sensor Calibration Operations

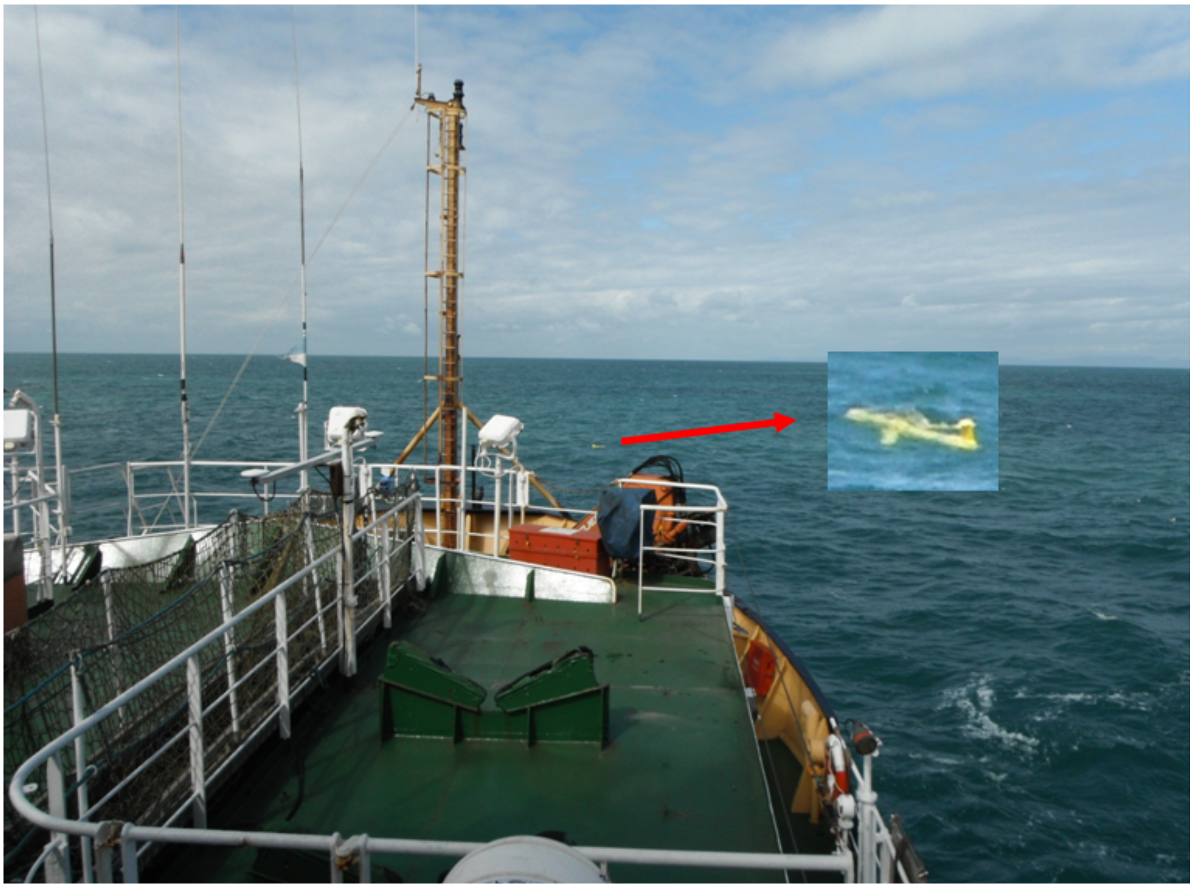


Fig. D3. RV *Corystes* Alignment Close to The Glider Before Commencing the Required Unit 117 Glider Sensor Calibration Operations in the western Irish Sea.
A nominal range from the ship to the glider of between 500m and 1km was typically used

The following text provides a log of the calibration operations during the cruise.

<u>Friday 27th April 2012 – All times BST</u>

<u>Site 38A – Main AFBI Mooring Calibration</u>

- 08:00 reference calibration sampling started for the moorings at Site 38A, Cast for CTD and dissolved oxygen profiling. SPM, Chlorophyll-a, Nutrients, CDOM taken at near surface (-2m) and 5m above the sea bed.

<u>Glider Calibration Sampling</u>

- After a delay establishing communications with the glider the standard mission was interrupted and new diagonal cyclic waypoints were used:
    - 53 47.743N -5 35.526W 1
    - 53 49.015N -5 33.334W 2
- The glider waypoints were selected to be close to the initial glider position when it was within visual range on the sea surface.
- These waypoints were transferred to the glider. The 30 minute surfacing interval mission ‘APR30MIN.MI’ was used initially to provide glider profiling in synchronisation with the calibration samples and data being collected on the ship.

- Prior to each glider calibration run the ship was relocated to be in visual range and <500 metres from the glider.
- The reference calibration sampling of CTD and dissolved oxygen from the ship was started once the glider submerged and commenced its profiling. The oxygen sensor on the CTD is calibrated using titration and used to cross reference the glider dissolved oxygen measurements.
- CDOM, Chlorophyll-a and OBS Turbidity (SPM reference samples) were taken at -2m (near surface) and 5m above the sea bed using the water collection bottles on the ships CTD rosette.
- A typical water depth would be ~100 metres.
- A script 'APR45MIN.MI' was used to increase the time interval between sampling to reduce the volume of calibration work required between each glider surfacing. The limited range of 'FreeWave' rf communications resulted in a relatively short time between glider surfacing being selected.
- As a fallback the RV *Corystes* satellite phone could be used to contact a glider pilot at NOCL to monitor the glider progress if the FreeWave rf data link failed to contact the glider at the expected time.

Glider Calibration sample Set 1

- 11:30 AM - AFBI collected surface samples, bottom samples and a CTD ~ 200m away from the glider.
- 11:45 glider held on surface during lunch break for AFBI sample collection team
- 12:35 start mission – 12:39 – diving – start sampling – glider due back at 13:10 BST
- 13:01 glider at surface after 30 minute time out.

Glider Calibration sample Set 2

- 13:24 - 1300m from glider - re align ship to ~500m range
- 13:36 - in range of glider with visual identification at ~200m distance
- 13:41 - start mission again by issuing a resume
- 13:51 - glider diving and left the surface, calibration samples started

Glider Calibration sample Set 3

- 14:20 glider is 600m away, just within visual range, therefore do the next calibration dive ASAP
- 14:24 – glider diving and left the surface– start calibration profile

Glider Calibration sample Set 4 – change mission file to 45 minute time out

- 14: 55 - Re-align the ship to 500 metres from the glider
- 15: 03 - Start 'apr45min.mi' for 45 minute dives
- 15:07 – diving and start calibration samples
- Expect glider back at 15:48……-15:55 at surface!

Glider Calibration sample Set 5

- 16:00 – re-align the ship for visual contact
- 16:08 aligned with visual on glider and issued a mission resume

- 16:11 – diving start calibration sampling
- Missed 16:45 surfacing – due again at 17:30
- Glider surfaced at 17:26
- 17:29 – re-aligned ship to glider proximity
- 17:40 issued command to start 45 minute profiling
- 17:49 diving and start calibration samples
- 18: 28 the glider was at the surface

Glider Calibration sample Set 6

- 18:39 ship aligned within 200m of glider
- 18:40 issued a mission resume
- 18:42 glider diving and left the surface, calibration samples started
- Glider expected to return at 19:25

Glider Calibration sample Set 7

- 19:19 glider back at surface and re-aligning the ship
- 19:29 issued a mission resume
- 19:31 glider left the surface and calibration sampling started
- Glider expected to return at 20:14.

Glider Calibration sample Set 8

- 20:06 the glider on surface earlier than expected, re-start the mission.
- 20:09 – re-started 'apr45min.mi' mission
- 20:15 -Depth is 105m – glider diving and reference calibration samples started
- Glider expected back at 20:54
- 20:57 at surface and exited mission for improved timings

Glider Calibration sample Set 9

- 21:01 – re-align ship to be close to glider
- 21:10 start 'apr45min.mi' mission
- 21:13 glider diving – 95m of water – calibration sampling started
- Glider expected back at 21:55

Glider Calibration sample Set 10

- Original WIS waypoints 40km apart sent to glider
- Starting 'glmpcapr.mi' mission, sequenced 12 times
- 21:58 - 300m from glider – starting mission
- 22:02 glider diving and calibration sampling started
- Resume standard 'glmpcapr.mi' sequenced 12 times, waypoints from close to the AFBI Site 38A mooring to 40km east of the mooring site:
    - 53 47.000N -5 00.000W   1
    - 53 47.000N -5 38.000W   2

End of cruise 22:30 BST Friday 27th April 2010 – start ~8 hour journey back to Pollock Dock, Belfast.

Appendix E – Unit 117 Glider Emergency Recovery

At approximately six weeks into the deployment the glider was programmed to return to the Liverpool Bay for a near shore recovery. During this return the glider encountered difficulties and aborted its programmed mission and surfaced on Wednesday 16th May 2012 at 23:27:29 GMT at a GPS location of 53^{O} 43.865'N, 4^{O} 50.133'W and distance offshore of approximately 70 nautical miles. The glider had failed to surface when expected and after an extended period of time, which was approximately 2 hours longer than the planned time underwater. The glider rear jettison weight was subsequently released and the glider surfaced. The release of the rear jettison weight provided sufficient additional positive buoyancy to the glider to allow a surfacing and subsequent status report to occur. At this stage, the glider no longer had the ability to dive and after advice from Teledyne Webb Research the glider was configured to report its GPS position at 30 minute intervals. The primary objective at this stage was to undertake a rapid recovery of the glider due to its vulnerability on the sea surface, the effects of tidal current drift, the possibility of seawater leaks and general the unknown general status of the glider. The lithium primary cells inside the glider still had approximately 30% of their theoretical maximum capacity. This is probably 1-2 weeks of normal glider usage, therefore battery life was not an immediate concern. The recovery had been planned with sufficient battery endurance to allow for poor weather and or possible recovery ship availability limitations before a normal recovery could be scheduled in shallower more sheltered coastal waters. The general intention was to recover the unit 117 glider from the Liverpool Bay using a small charter vessel, for example the RV *Marissa*. Up until this point the glider had been performing exceptionally well and gathering science data of CTD, CDOM, Chlorophyll-a, OBS Turbidity and dissolved oxygen readings at 2 second intervals for more than six weeks. A subset of this data had also been successfully transferred in near real time by satellite at a nominal interval of three hours throughout the deployment.

For the emergency recovery a weather window existed on Thursday 17th May, shortly after the problem with the glider occurred. Phil Knight and Chris Balfour contacted RV *Corystes*, which was operating in the Liverpool Bay and requested a detour to the glider location for a backup recovery. Small boat (RHIB) support was not available from RV *Corystes* and the backup plan was to perform a recovery using a net.

A rapid mobilisation was then scheduled using the locally based deep sea angling charter vessel *Tuskar* (http://www.charterboats-uk.co.uk/tuskar/) although the glider location of 60-70nm offshore was pushing the capabilities of this kind of vessel to its limits. The exceptionally good sea state forecast for Thursday 17th May 2012 did however permit this option to be considered. The weather forecast indicated a degrading sea state on Friday 18th May and the subsequent two forecast days to between force 5 and 7, preventing a small recovery boat to be considered for this time frame.

The general recovery plan, due to the very good sea state on Thursday 17th May, was to travel to the glider location with glider position updates by satellite phone being achieved by contacting Andy lane at the NOC Liverpool main laboratory by satellite phone until. This occurred until *Tuskar* was in FreeWave rf communications range for direct ship based radio frequency data communications with the glider. During this transect the suitability of using this smaller charter vessel for a direct recovery of the glider was assessed. The general plan was to use the TWR glider transportation trolley to recover the glider from *Tuskar* directly, with a backup of a net recovery using RV *Corystes*. This direct recovery was the preferred recovery option. *Tuskar* has a rear dive platform with a low freeboard that is almost at the sea surface, easing the task of glider recovery. There were natural concerns about possible and potentially significant damage to the glider (CTD cell, tail, wings, introduction of seawater leaks etc) using a net so the RV *Corystes* option was only considered as a fallback.

The glider was recovered successfully using *Tuskar* at 53^{O} 45.498'N and 4^{O} 55.545'W, as shown in Fig. E1. Thanks are due to Stan Dickinson and his crew of *Tuskar*, Brian on the ship and George quayside for providing this option at approximately 90 minutes notice on Thursday 17^{th} May 2012. *Tuskar* has already rescued the unit 175 Turbulence glider approximately 40 nautical miles offshore last year due to connector failures and firmware issues. NOC Liverpool is particularly grateful for this local, small charter vessel support. During the recovery, damage was sustained to the top of the digifin ruder and mounting, as per the photograph in Fig. E3. Some preliminary checks after this damage was sustained revealed that the digifin still appears to be working correctly.

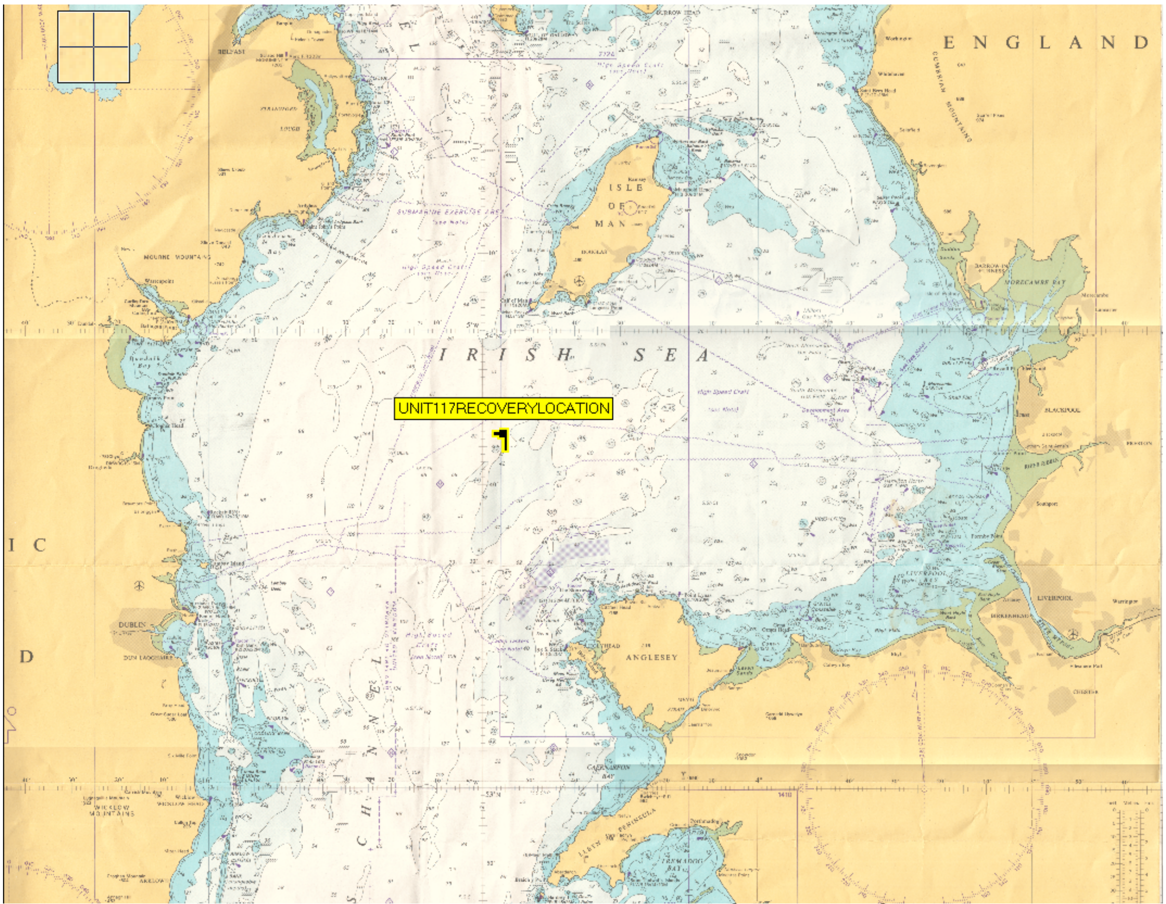


Fig. E1. Unit 117 Recovery Location at 53^{O} 45.498'N, 4^{O} 55.545'W

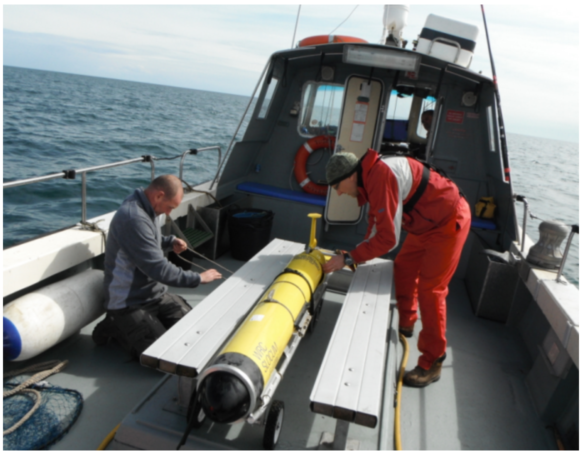
During the return to Birkenhead, which is close to Liverpool, UK *Tuskar* encountered engine problems suspected fuel contamination and a berthing occurred, late on Thursday 17^{th} May at Conwy marina, on the UK welsh coast. The unit 117 glider was returned to the NOCL glider lab at Vittoria Dock, Birkenhead on Friday 18^{th} May by Phil Knight and Chris Balfour using a works transit van. Photographs of the emergency recovery are shown in Figure E2, E3 and E4.

Transit from Birkenhead to the Recovery Location Using *Tuskar*

Freewave Antenna (long pole on the right above the upper deck of *Tuskar*) Mounting for Short range (several km) Glider Communications

Glider located at ~5pm on 17th May 2012

Successful glider recovery



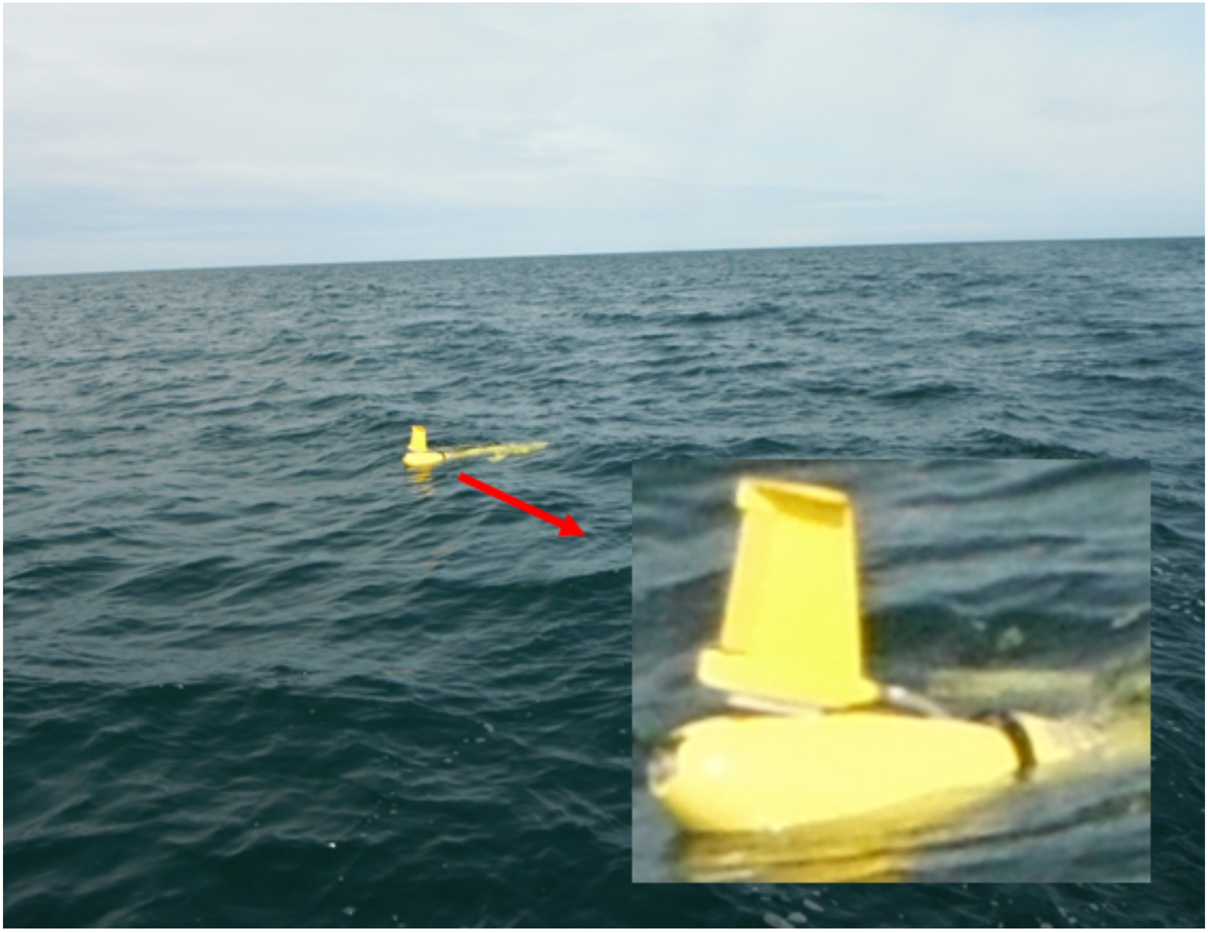
Glider on the recovery trolley and secured in place on *Tuskar*

Transit back to Birkenhead

Fig. E2. Unit 117 Glider Emergency Recovery on Thursday 17th May 2012

The jettison weight has been released (release spring visible) and the recovery damage to the upper part of Digifin rudder and mounting is visible. The Digifin appears to be working correctly after the damage was sustained

Fig. E3. Unit 117 Glider Emergency Recovery Rear Tail and Fin Damage



A close up picture of the glider before recovery shows the rear cowling out of place. This cowling covers an air bladder that is inflated when the glider surfaces. The bladder inflation raises the tail section for improved visibility and communications. The glider communications antennas are moulded into the tail section.

Fig. E4. Unit 117 Glider Rear Cowling Out of Place Before the Emergency Recovery

Appendix F – Unit 117 Glider Post Recovery Initial Evaluation

The glider was powered up and tested in a laboratory environment after the recovery. The glider hull had been previously washed with fresh water shortly after the emergency recovery operations were completed. Initial testing showed that the glider operated correctly, moved the pitch motor and buoyancy pump to neutral or mid range in ballast mode and a vacuum of 6.2inHg was reported. This initial testing of the glider demonstrated that the glider, its buoyancy pump and the internal systems seemed to be operating correctly. When the glider was disassembled there was no sign of any damage to the internal components or seawater ingress into the glider. The internal battery condition was good and there was no sign of battery problems such as electrolyte leakage etc.

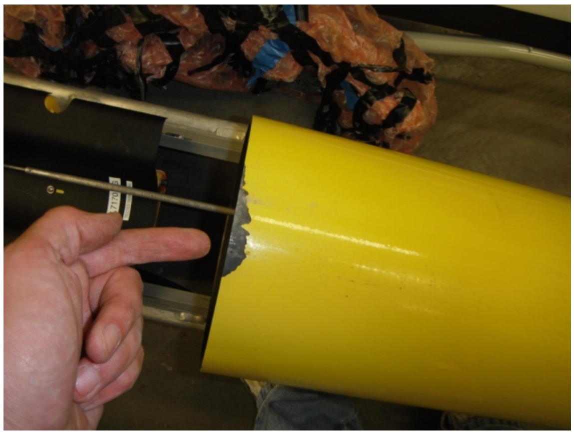
The glider had several scratches through the hull paintwork, particularly near the upper metal cleat mounting. Significant degradation of the rear hull zinc anode was observed although the nose section zinc anode seemed to be in good condition. Both of these anodes were verified as being in good condition before the deployment. Scraping and pitting was evident in the front rubber outer section behind the forward hull. Severe corrosion had occurred on the edge of the aft hull in several sections just above the recess into which the forward edge of the rear air bladder cowling sits. The heads of the screws holding the rear tail cowling had been sheared or corroded off and probably lost at sea. The outer part of the buoyancy piston and bellafram (rolling diaphragm for buoyancy control) arrangement was heavily fouled with fine sediment deposits. Possible reasons for this include progressive sediment contamination (sedimentation). Alternatively or in addition to this perhaps these deposits were collected or significantly increased during a collision, entanglement, dragging, lodging in the seabed or scraping of the seabed by the glider. The photographs in figs F1 to F14 are a sequence of pictures used to illustrate the glider general condition after the emergency recovery during the initial examination in the NOCL glider laboratory at the Vittoria Dock store.

Rear hull sacrificial anode degradation.
The zinc anode had almost completely corroded away

The front zinc sacrificial anode was in good condition

Fig. F1. Front and Rear Anti Corrosion Anodes

Paintwork Scrapes Near to Upper Cleat



Paintwork damage to the underside of the front of the rear hull section

Sheared rear cowling retaining screw heads

Rear metal hull corrosion. This was probably not impact damage because the plastic cowling is not damaged

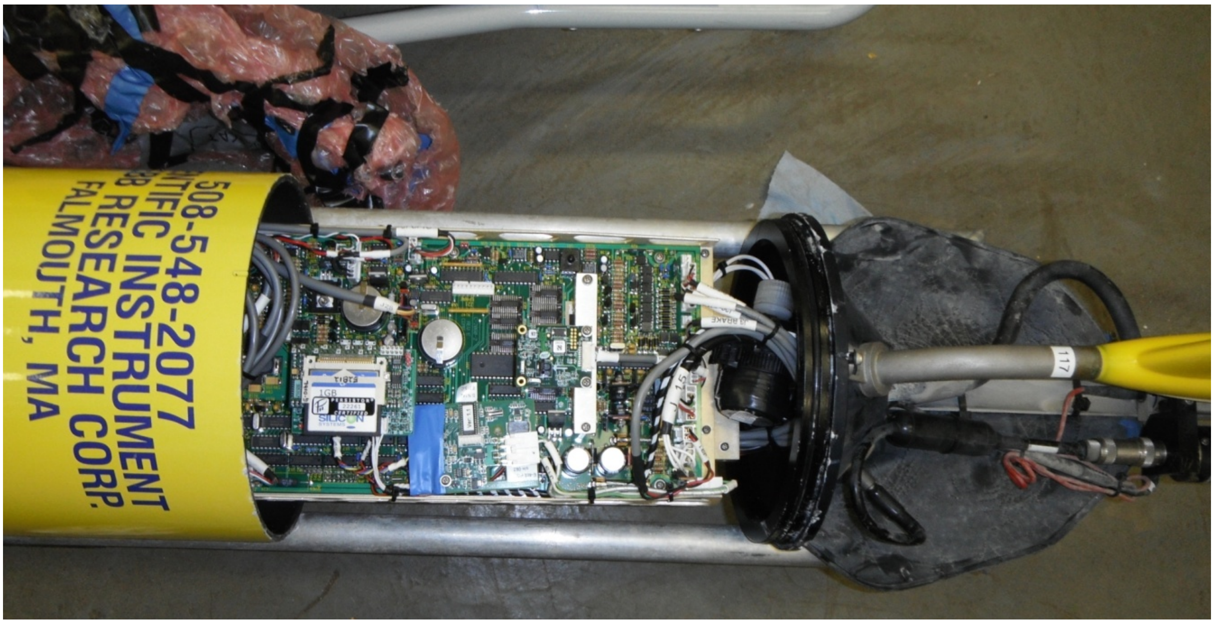
Significant rear hull corrosion has occurred

Rear hull corrosion. The white deposits between the rear hull and the bulkhead seal appear to be small barnacles

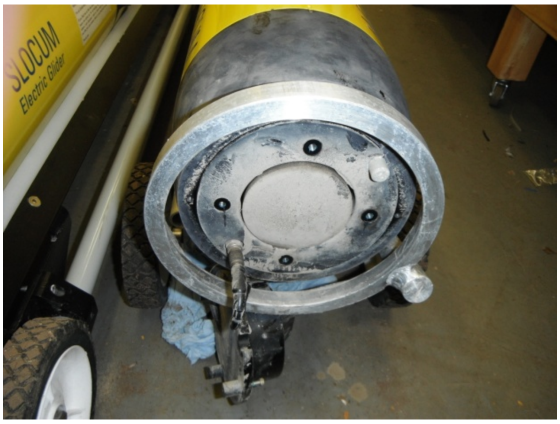
Fig. F2. Unit 117 Glider General Inspection

Forward rubber section pitting and scraping

Sedimentation behind front Cowling in front of the Altimeter



The internal glider components were in pristine condition and there was no evidence of seawater ingress, battery electrolyte leakage etc

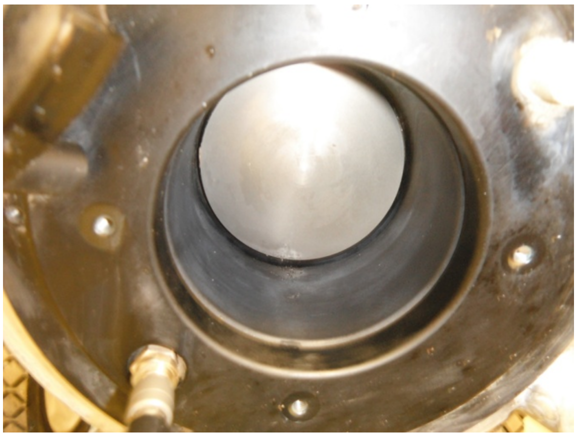


Bellafram Moved Forward. The sedimentary contamination has almost dried out to leave a white powdery sand deposit in most areas.

The ballast position was enabled and the bellafram was moved to neutral. or 0cc, which is midway in its range of travel

Fig. F3. Unit 117 Glider General Inspection

Bellafram drawn inwards. There are no obvious signs of damage to the rubber surfaces etc



More stable operation of the buoyancy pump movement control was achieved after the bellafram was thoroughly cleaned

Fig. F4. Unit 117 Bellafram (rolling diaphragm) Type Buoyancy Pump Inspection

F1. Buoyancy Pump Bellafram Lifetime and Pre-Deployment Inspection

The 200 metre rolling bellafram in the unit 117 glider buoyancy pump monitoring had recorded 5380 inflections at the start of the deployment on 2nd April 2012. At the end of the deployment on 17th May 2012 the number of bellafram inflections was 13768. TWR have advised that 10,000 full depth cycles or 20,000 inflections would represent a normal bellafram lifetime. Therefore the unit 117 bellafram was comfortably within its normal usage limits and this was not considered as the likely failure mechanism or a problem during the glider deployment preparations. Although the buoyancy pump in unit 117 is contaminated with sediment no obvious bellafram problems were observed as shown in the previous Fig F4 when the glider was inspected and then cleaned at the NOCL glider lab. In addition to this, unit 117 is scheduled to be converted to a generation 2 or G2 glider after the MAREMAP project deployment, which involves a major replacement of the hull, bulkeheads and buoyancy control mechanism. Prior to this deployment, unit 117 had only been operated for a total of approximately 5 weeks. All of the glider bulkheads, components, connectors, zinc anodes and so on were inspected as in good condition, clean and free from corrosion during the preparations for the April 2012 MAREMAP deployment. Therefore the original bellafram that was installed by TWR before unit 117 was delivered to NOC Liverpool in 2008 was considered suitable for the DEFRA MAREMAP project requirements of an extended glider survey period using lithium primary batteries.

F2. Preliminary Evaluation of the Unit 117 Glider Data

To determine the most likely cause of the glider failure the downloaded glider data was plotted and analysed. Figure F5 shows that prior to the problem the glider was diving correctly (m_depth plot), receiving seabed range information from the altimeter (m_altitude and m_raw_altitude plots) and inflecting as expected when the seabed was approached. This normal dive and climb cycle occurred throughout the deployment until the glider suddenly lost the ability to inflect and climb. On Wednesday 16th May 2012 at 23:27:29 GMT the glider surfaced, reporting a mission abort and that the glider emergency surfacing jettison weight had been released. Figures F6 to F11 show a series of glider data plots that demonstrate that the glider altimeter was providing correct seabed range information and the measured depth remained unchanged for a period of time at approximately 80 metres. After a delay close to the seabed a short and reducing range of the glider from the seabed was recorded. The total delay close to the seabed without the ability to change depth satisfied the glider abort criteria and the rear jettison weight of approximately 0.5kg was released. At this stage sufficient extra positive buoyancy was provided in the rear of the vehicle to allow the glider to surface. Following this surfacing the unit 117 glider no longer had the ability to dive. The general unknown status of the nature of the glider problem required prompt actions to be taken. The glider was configured to provide GPS derived position reports via iridium satellite communications at 30 minute intervals and an emergency recovery was rapidly scheduled, as detailed in appendix E of this report.

The possible reason why the glider lost the ability to inflect and climb would seem to indicate some form of entanglement, lodging in debris or mud, or dragging has occurred close to the seabed. The plots of the demanded and measured buoyancy changes by the glider in figure F5 (c_ballast_pumped and m_ballast_pumped) demonstrate that the glider buoyancy pump operated correctly and physically moved the bellafram outwards to try to initialise a climb, as required.

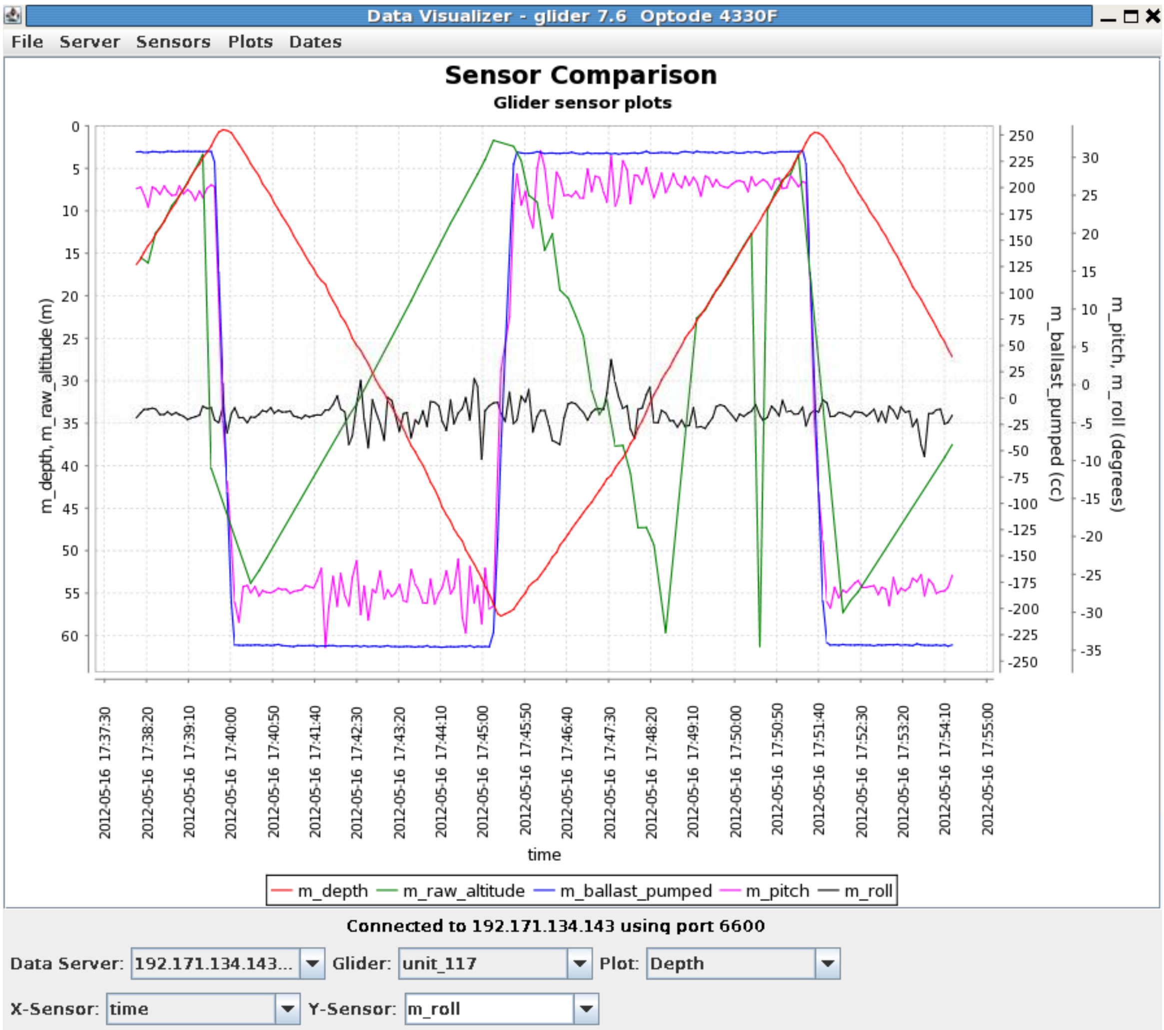


Fig. F5. A Fully Executed Glider Inflection Before the Suspected Entanglement of the Glider Close to the Seabed Occurred

Based upon the plots in Fig F4, the unit 117 glider has dived at ~-26^{O} and climbed at ~+ 26^{O}, as expected, roll is very low with only relatively small variations. The raw altitude finds a range of ~60m and the glider inflects as expected in response to a change in demanded bellafram position. In terms of the glider altitude, my interpretation is that the raw altitude measurement during the dive in this plot on the LHS is ~55m. This occurs when the glider depth is ~5m therefore the distance to the seabed at the time of the altimeter measurement is ~60m. The glider is programmed to inflect at 5m from the seabed and suspected vehicle momentum tends to produce an overshoot in depth. Therefore the glider actually inflects at ~57m. This demonstrates that the vehicle is achieving almost full depth profiles as required.

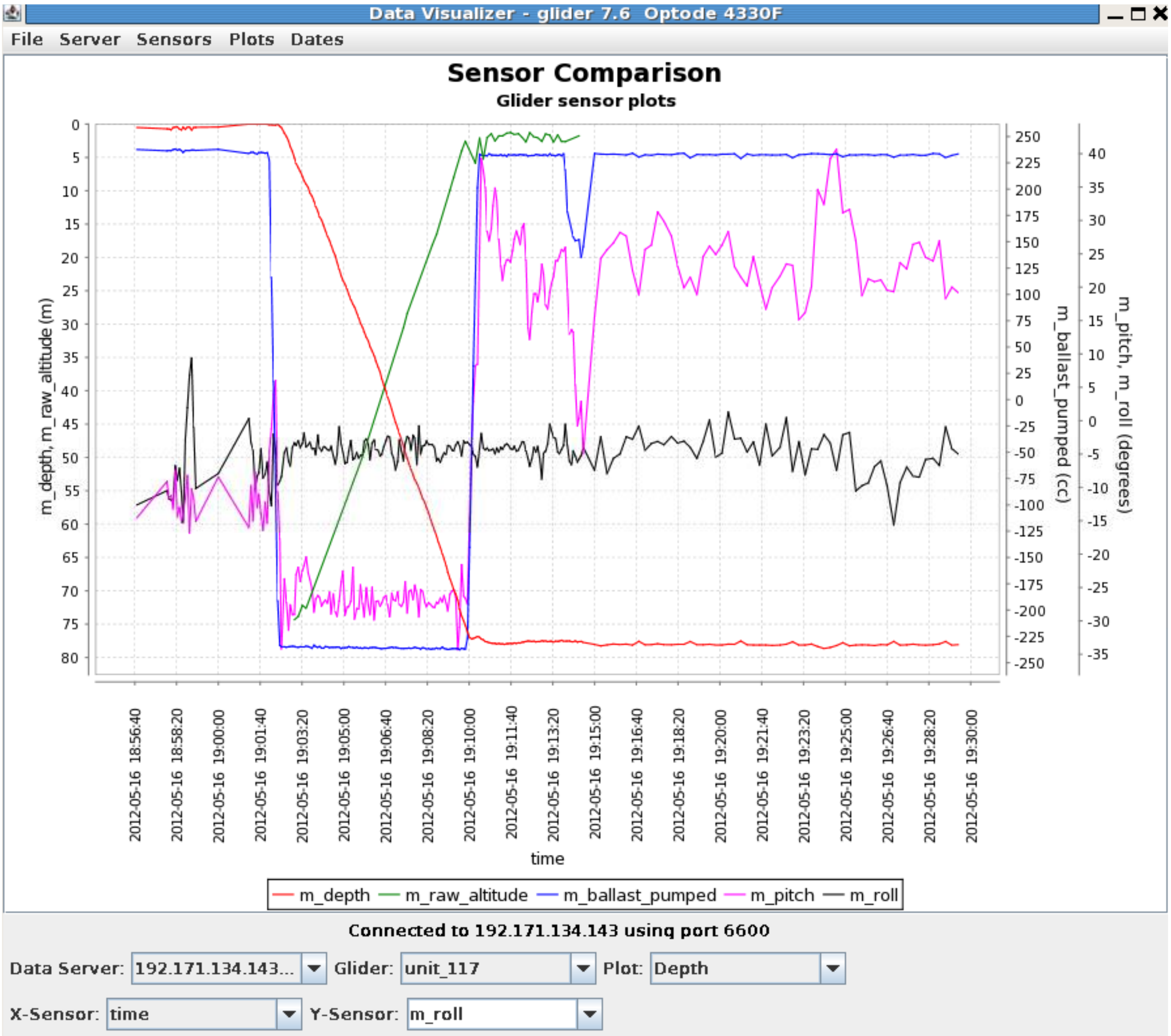


Fig. F6. Plots of m_depth, m-raw-altitude m-ballast-pumped and m-pitch and m-roll leading up to and beyond the suspected glider entanglement.

Observations:

When the problem occurred the pitch of the glider has gone positive to ~26^{O} in response to the changed in measured ballast (bellafram moved outwards to climb). The depth remains reasonably constant, pointing towards some form of entanglement with the glider nose section pointing upwards (positive pitch). The pitch of the glider just after the problem occurs also seems to indicate large subsequent oscillations between up to ~-5^{O} and ~+40^{O}.

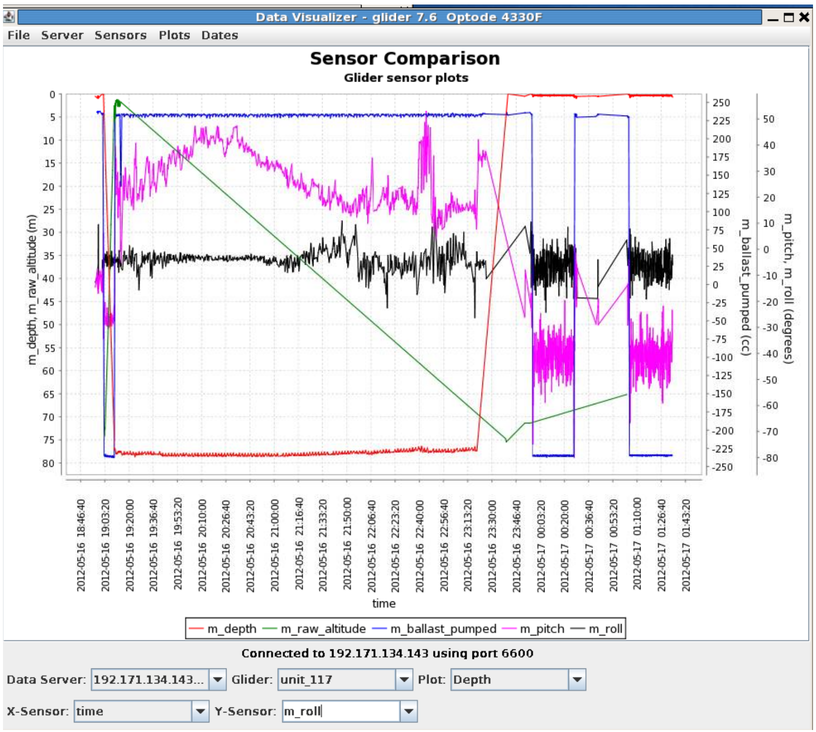


Fig. F7. Glider Movement after Suspected Entanglement

When the glider is apparently lodged at ~80m some large variations in the pitch and roll can be seen. This would seem to support the entanglement and dragging scenario that was suggested in the initial report shortly after the unit 117 emergency recovery

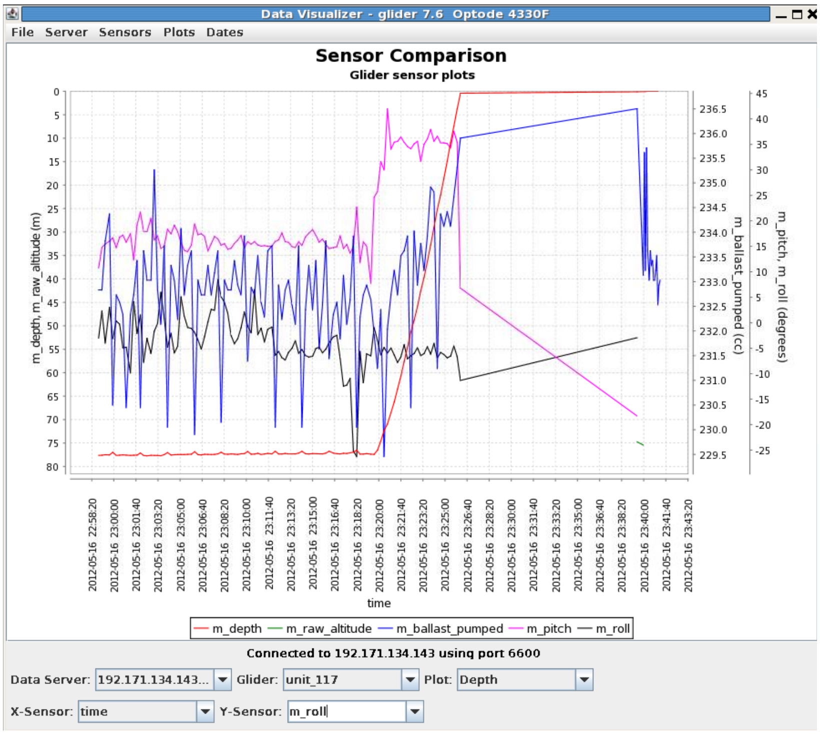


Fig. F8. Glider Surfacing after Jettison Weight Release

After the jettison weight is released the glider pitch seems to oscillate, possibly indicating the added buoyancy has released the glider. As the glider climbs the pitch seems to go positive indicating the nose of the glider is pointing upwards and possibly the vehicle hydrodynamics is causing the glider to climb at ~+35^{O} pitch to the surface, where a mission abort was reported.

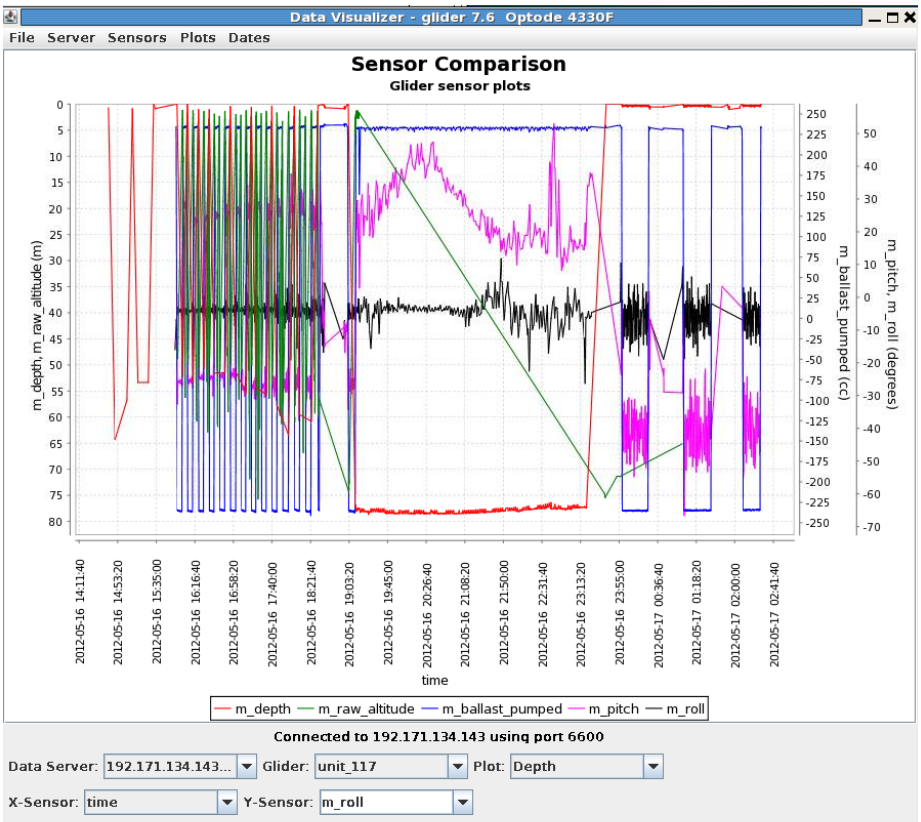


Fig. F9. Zoomed out plots leading up to and beyond the suspected entanglement occurring

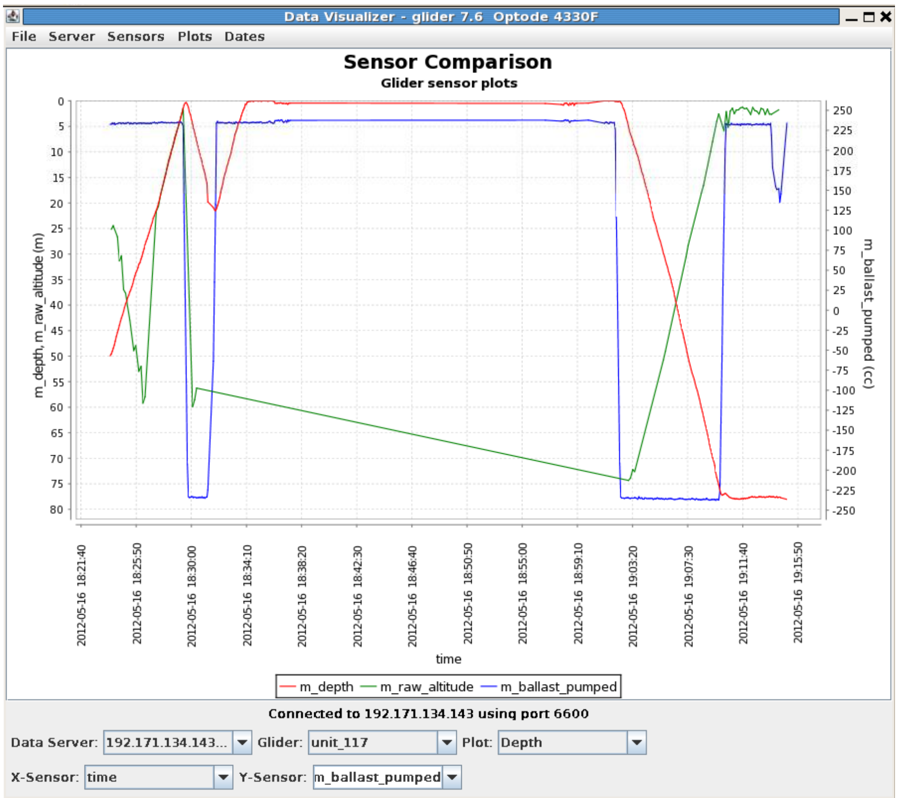


Fig. F10. Expanded plots of the final dive

An altitude of ~75m is measured, 5m into the dive that results in a total depth of ~80m. At ~75m into the dive the glider buoyancy pump moves the bellafram outwards to try and initiate an inflection and subsequent climb

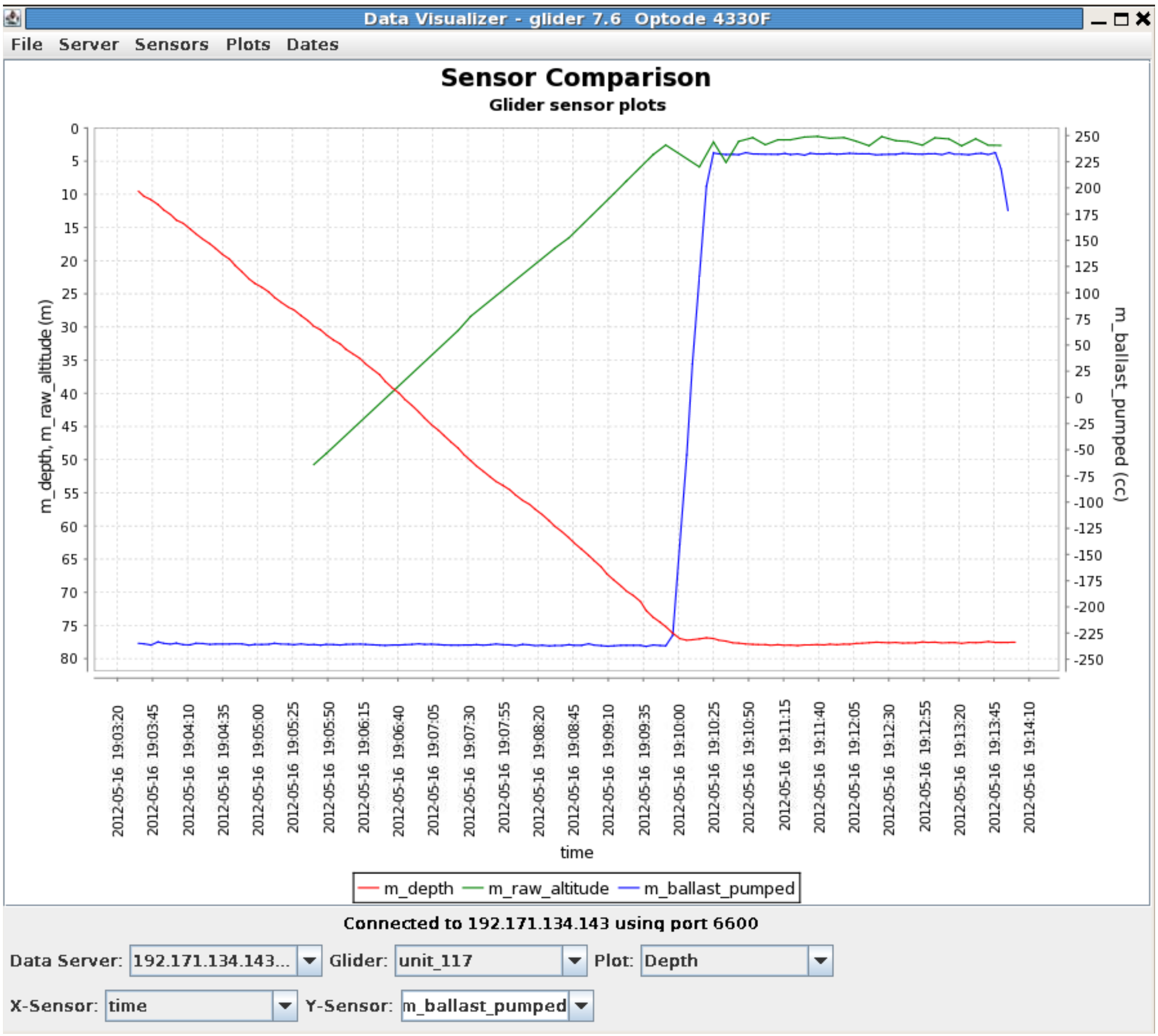
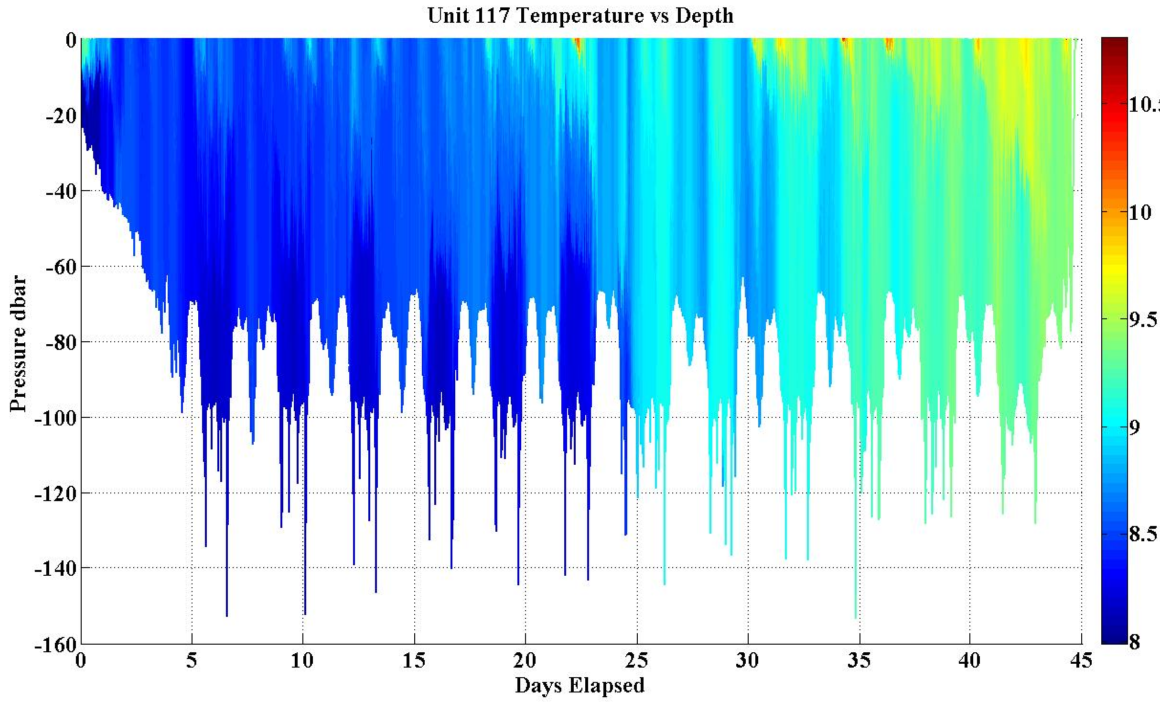


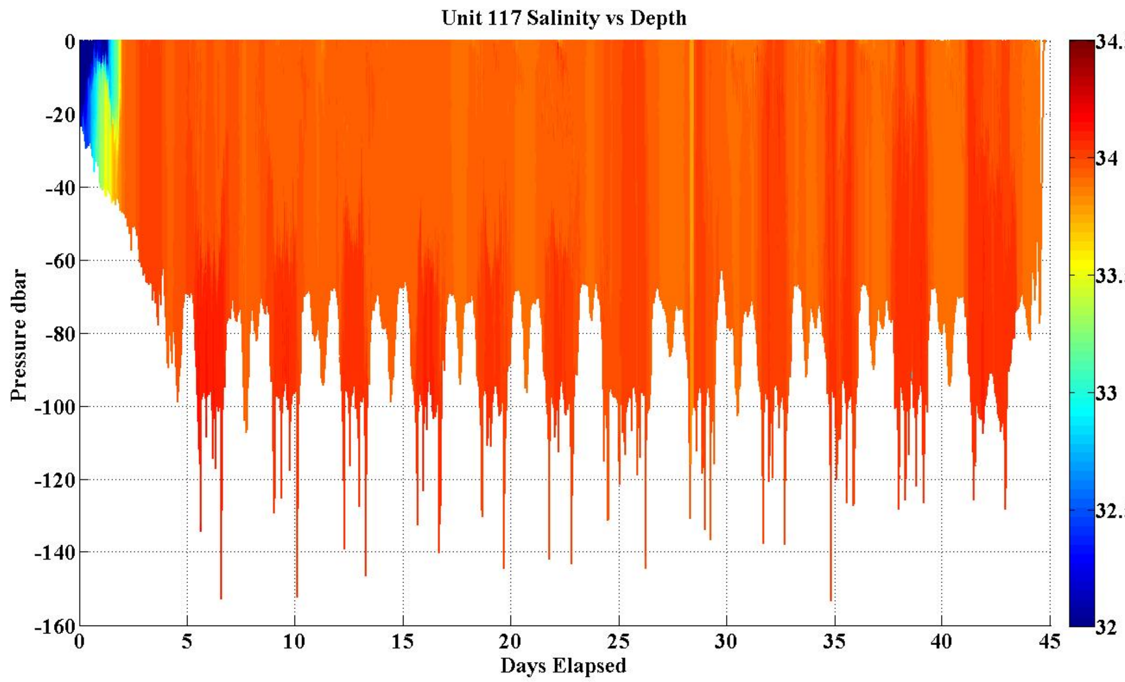
Fig. F11. Zoomed plot of the buoyancy pump trigger point at ~75m, as required

Appendix G – Unit 117 Glider Recovered Data Initial Evaluation

The plots in Figures G1 to G3 are time series plots of the unit 117 science data during the deployment from 2nd April to 17th May 2012. Preliminary indications are that a full, high quality data set has been recorded during the deployment for temperature, salinity, CDOM, dissolved oxygen, Chlorophyll-a concentration and OBS turbidity.

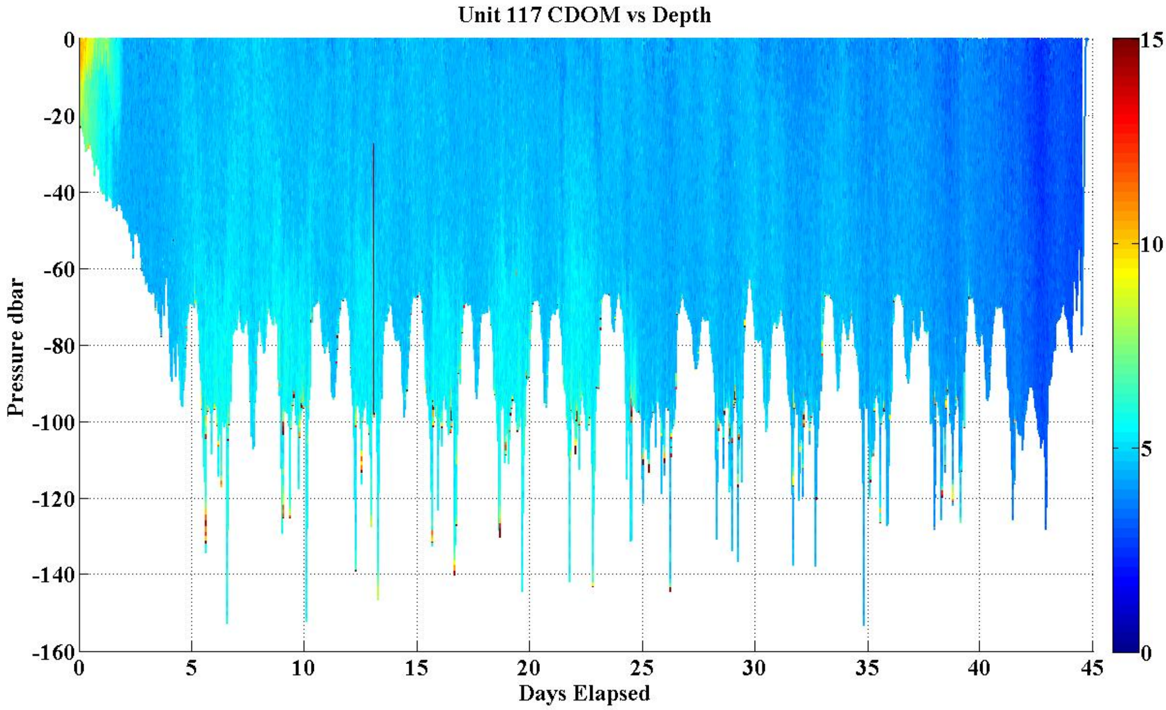


Temperature

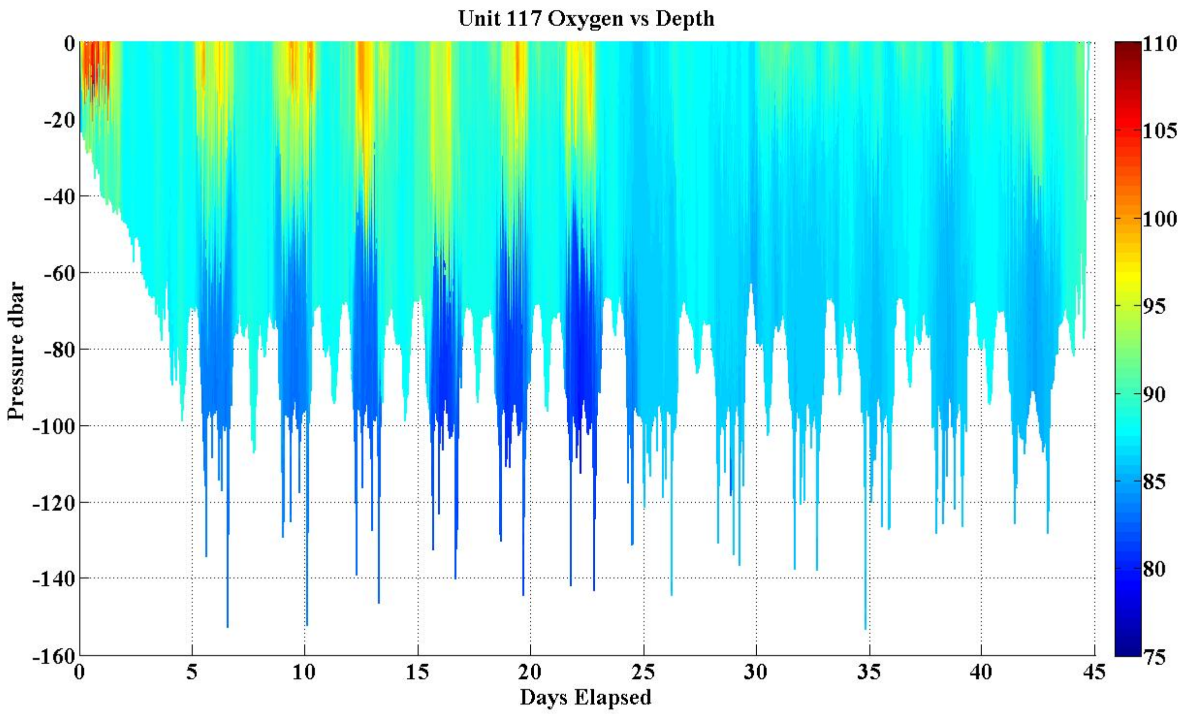


Salinity

Fig. G1. Unit 117 Science data – Temperature and Salinity

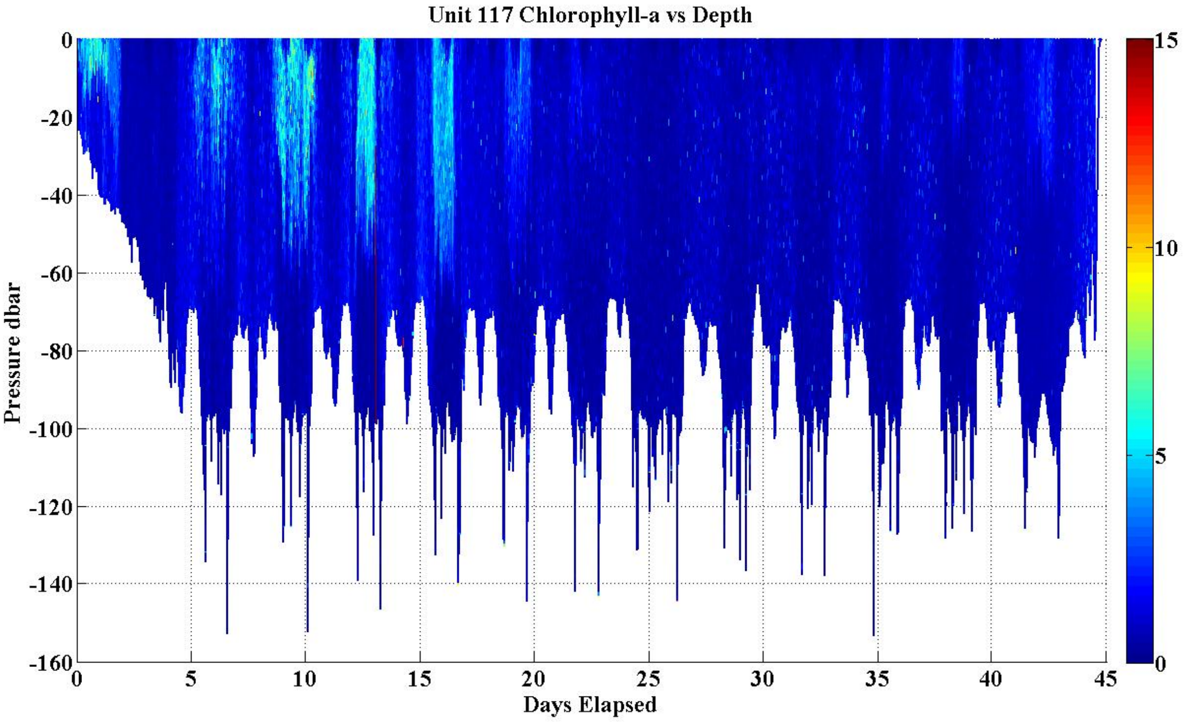


CDOM

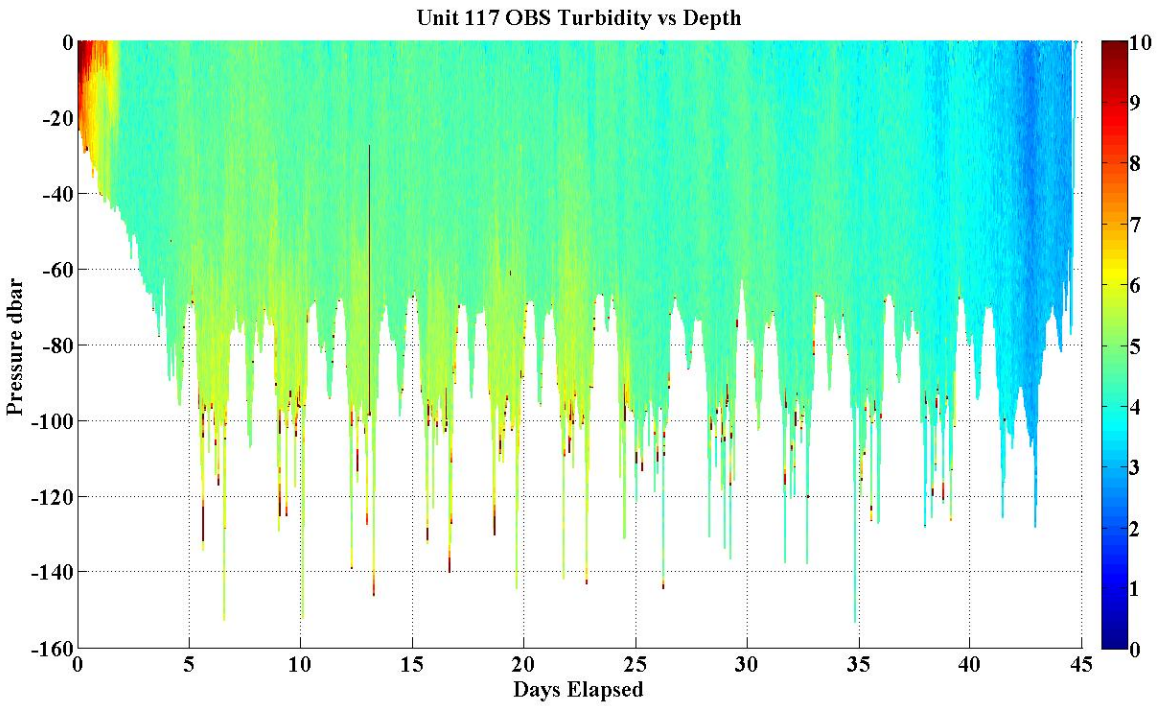


Dissolved oxygen saturation

Fig. G2. Unit 117 Science data – CDOM and Dissolved Oxygen



Chlorophyll-a concentration



OBS Turbidity

Fig. G3. Unit 117 Science data – Chlorophyll-a and OBS Turbidity