National Oceanography Centre

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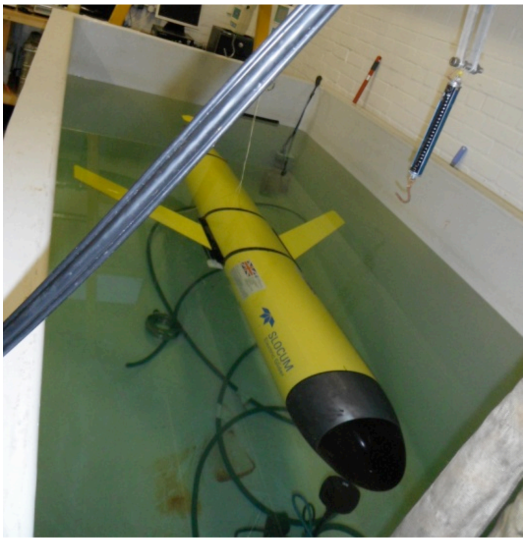
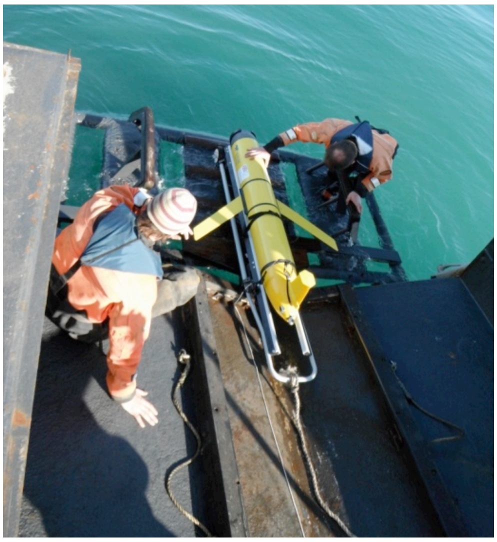
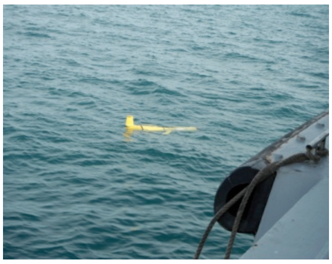
Research & Consultancy Report No. 39

NOC Liverpool report for the UK-IMON Project
April-June 2013 Unit 194
Glider deployment

C Balfour & M Palmer

2013

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

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AUTHOR
BALFOUR, C & PALMER, M

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ABSTRACT

This document summarises an extended deployment of a 200 metre depth rated Slocum Electric glider by the National Oceanography Centre, Liverpool, UK. The glider was deployed on the 6th April and was recovered on the 3rd of June 2013, completing a survey of almost 58 days in length. The glider survey was sponsored by the UK Integrated Marine Observing Network (UK-IMON) initiative. UK-IMON is aimed enhancing the quality of and providing reliable marine data by implementing improvements to measurements used for marine applications, with an underlying theme of environmental monitoring coupled with environmental protection. A particular goal of this project is to exploit new sensing technology to enhance routine measurements that are made in coastal waters. Within this context the deployment of the unit 194 glider was sponsored to provide novel high resolution oceanographic measurements in the Irish Sea along survey transects that included the western Irish Sea, the St George's Channel and the Celtic Deep. The glider provided high resolution physical and biological water quality measurements during the survey. Calibration of the glider scientific sensors formed an important component of the glider operations. Independent reference samples were collected periodically to calibrate the glider sensors. Several transects for the glider also operated close to regularly serviced moorings for measurement comparison and sensor calibration purposes.

KEYWORDS:

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

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Terms and Definitions

Unit 194 Glider	A 200 metre depth rated generation 2 or G2 type Slocum Electric Glider. This is small variable buoyancy driven AUV that is designed for oceanographic survey work. The glider is manufactured by Teledyne Webb Research (TWR), America. The unit 194 glider has a Seabird Electronics pumped CTD sensor, a WETLabs Triplet sensor (Chlorophyll-a concentration, CDOM and backscatter) and an Aaderaa Optode dissolved oxygen sensor.
UK-IMON	The UK Integrated Marine Observing Network (UK-IMON) initiative.
Met Office	The UK national weather forecasting service.
FreeWave	Wireless short range radio link used for glider communications.
Iridium	Wireless data transfer based upon the Iridium low earth orbit satellite constellation.
Argos	Long range wireless data transfer based upon the Argos constellation of low earth orbit satellites.
Orbcomm	A global wireless message transfer system based upon a low earth orbit satellite constellation.

Abbreviations

NOCL	National Oceanography Centre, Liverpool, UK
TWR	Teledyne Webb Research, USA.
AFBI	Agri-Food and Biosciences Institute, Belfast, UK
CEFAS	Centre for Environment, Fisheries & Aquaculture Science
AUV	Autonomous Underwater Vehicle
CTD	Conductivity, temperature and depth sensor
RHIB	Rigid Hull Inflatable Boat
GPS	Global Positioning System
GMT	Greenwich Mean Time
CDOM	Coloured dissolved organic matter
PAR	Photosynthetically active radiation
OBS	Optical backscatter
AIS	Automatic Identification System

Contents

1. IMON glider deployment overview and objectives

This document provides a general overview of the use of a small AUV in the form of a Slocum Electric Glider for an extended deployment in the Irish Sea as part of the UK-IMON initiative. The basic purpose of the glider survey was to gather long term high resolution vertical and horizontal oceanographic measurements in two primary Irish Sea based survey areas. High resolution measurements were also taken along intermediate transects along the St George's channel between the key glider survey areas, as shown in fig. 1.

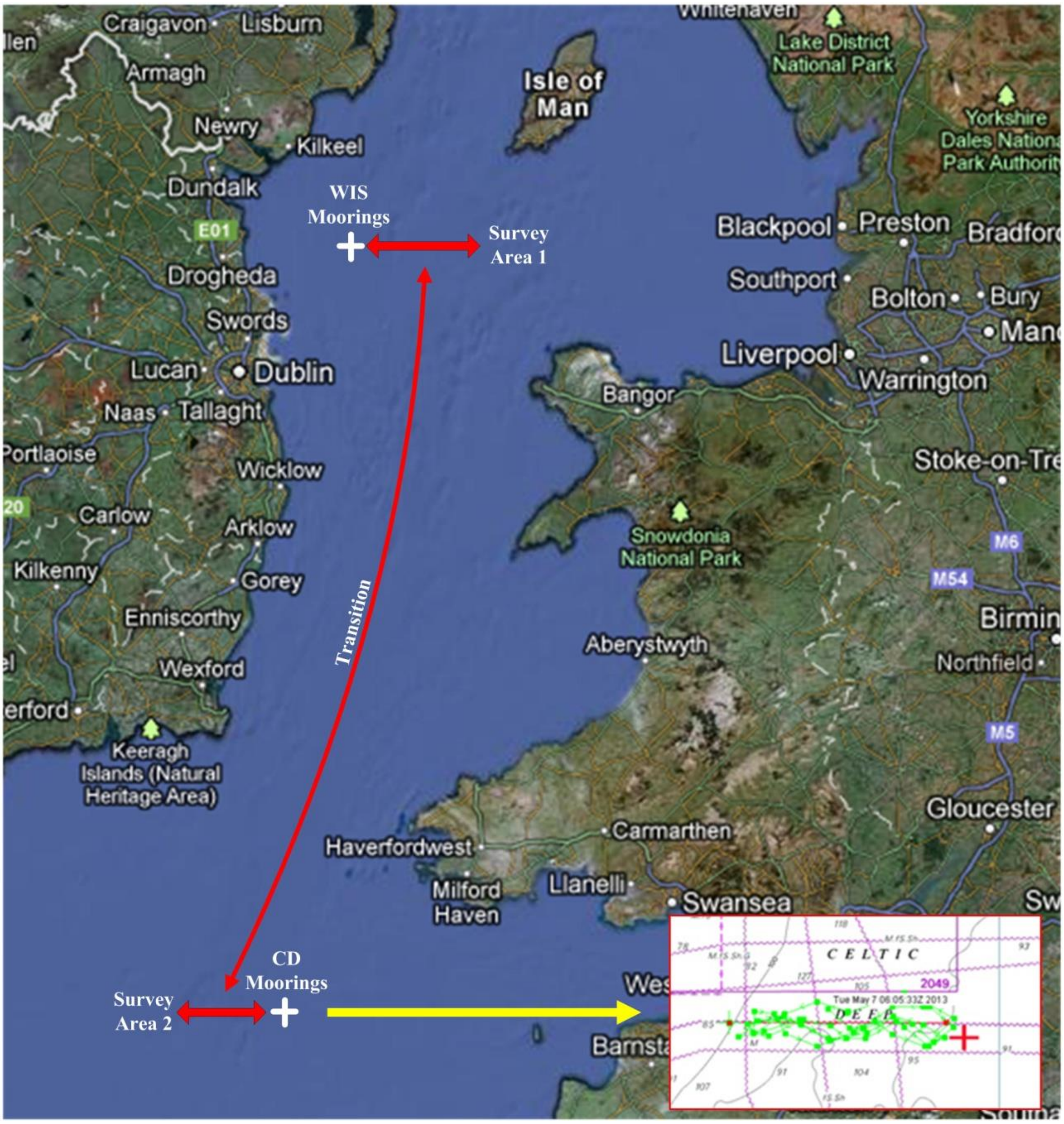


Fig. 1. Overview of the Unit 194 IMON project Irish Sea Survey

An expanded view of the Celtic Deep survey area is shown to the lower right of this figure. The large red cross represents the CD mooring location and the green squares represent the reported glider positions.

The glider survey had a nominal duration requirement of two months. The Western Irish Sea (WIS) and Celtic Deep (CD) survey areas were positioned close to regularly serviced marine moorings. A set of WIS moorings are maintained by AFBI and a surface buoy plus its associated sensors is maintained in the CD by CEFAS as part of the smartbuoy network. A key objective of the glider survey was to provide high resolution measurements in close proximity to a suite of similar sensors operating as part of regularly serviced moorings. This allowed comparative measurements to be collected that provide sufficient information to allow for any drift or offsets that occur with the glider measurements over the extended survey to be compensated for. The glider component of the UK-IMON initiative demonstrates the use of this kind of modern, evolving and technically sophisticated AUV to gather scientific measurements. The glider is capable of undertaking scientific measurements over long time scales (weeks to months) and it can operate in adverse conditions. Measurements with high vertical and horizontal resolutions can be generated that would be difficult and expensive to accomplish by other means.

The positions of the WIS mooring at 53° 47.000'N, 5° 37.903'W and the CD mooring at 51° 14.499'N, 6° 4.800'W are indicated in fig. 1. Survey area 1 is a 42km wide east to west study area that takes the glider close to the WIS moorings at the western part of the transect. Survey area 2 is a 30km wide transect with the glider operating close to the CD mooring location at the eastern part of the study area. These glider survey areas provide a series of close proximity measurements between the glider and the regularly serviced mooring sensors for comparison and calibration purposes. Throughout the deployment, NOC shore based glider 'pilots' monitored and remotely controlled the glider survey locations, near real time data transfer and sensor sampling regimes. This was achieved using iridium satellite communications in conjunction with computer based monitoring and visualisation software.

A plot of typical glider dive and climb profiles is shown in fig 2. The red plot represents the pressure record from the glider. The two upper horizontal sections represent the three hour timed surfacing when the glider has stayed on the sea surface to report its position and transfer near real time data. Between these times the typical glide profile of ± 26^{O} for dives and climbs occurs.

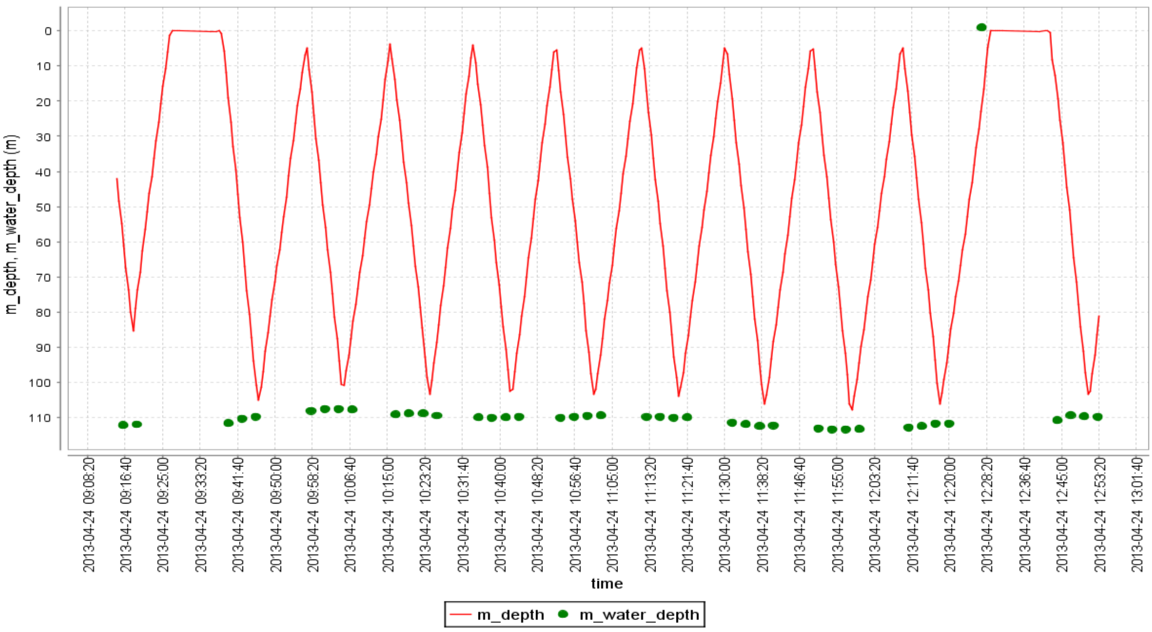


Fig. 2. Unit 194 glider depth profiles

The green dots represent the seabed range as determined by the glider altimeter during the dive phase of profiling. Between the timed glider surfacing intervals the upper inflection point close to the sea surface and the lower inflection point close to the seabed can be seen.

This demonstrates that the glider is profiling along the full water column without straying too close to the sea surface or seabed.

The glider science sensors comprised of a Seabird pumped CTD providing temperature conductivity and pressure measurements (allowing the derivation of salinity and density), a WETLabs Triplet sensor and an Aanderaa Optode dissolved oxygen sensor. The triplet sensor measures Chlorophyll-a concentration, CDOM and backscatter (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, (NOC) laboratory. This was achieved using the iridium based satellite constellation to implement a near real time data link. A selected data archive and the current near real time deployed NOC glider data is available at www.noc.soton.ac.uk/omf/projects/glider/data.php.

In terms of the science sensor sampling, the glider has been configured to sample the science sensors over the full underwater profile at two second intervals. An example of this is shown in fig 3, whereby discrete points for two of the science sensors, namely water temperature and dissolved oxygen saturation have been plotted against the glider pressure record. This high resolution record was downloaded directly from the glider during the deployment operations on 6th April 2013.

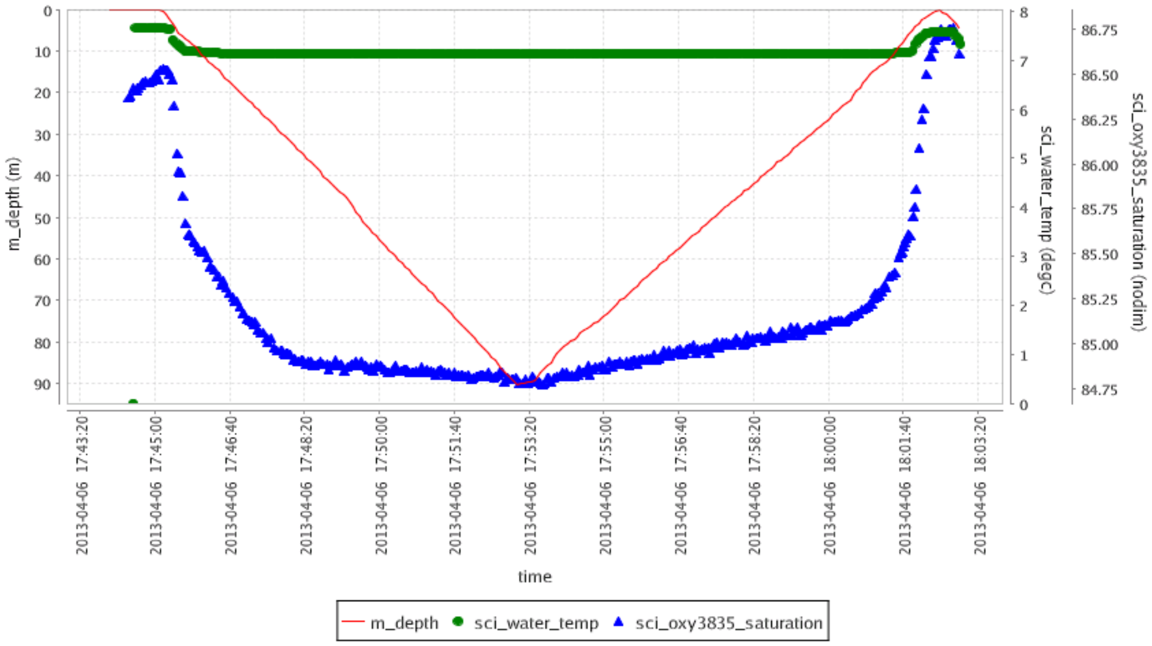


Fig. 3. Unit 194 glider science sensor sampling

Discrete points for two example sensors, the CTD temperature and the dissolved oxygen saturation are plotted against depth to illustrate high resolution science sensor sampling at two second intervals over the full glide profile.

From a physical oceanography perspective the glider can provide measurements capable of identifying the transition from well mixed to seasonally stratified water columns. This seasonally varying property of the water column has to date proved to be challenging to accurately model and understand. Associated with the physical properties of the water column is biological production. This involves the formation of algal blooms and includes sustained biological activity during the summer months. The high resolution measurements from the glider combined with ship based surveys and mooring measurements will provide a more detailed insight into these processes. The wealth of glider data that has been generated will also support two Ph.D. studentships (starting October 2013). One of these will focus on the physical processes and understanding the transition from mixed to seasonally stratified waters. The other studentship will concentrate on studying the physical properties in the water column that govern the formation of phytoplankton (algal) layers. This will provide information that will help to determine the mechanisms involved that govern biological production at the most fundamental or primary stage.

2. The unit 194 Slocum electric glider

This section provides a brief review of the key features of the unit 194 coastal Slocum Electric glider. The glider is 1.5 m in length with a 22 cm hull diameter and has a nominal mass of 54kg. The glider is usually configured to be neutrally buoyant or close to neutrally buoyant for the anticipated seawater conditions in which the glider is expected to operate. A labelled photograph of the unit 194 glider indicating the key features is shown in Fig. 4. A trolley or ‘cart’ is normally used to transport the glider when it is out of water.

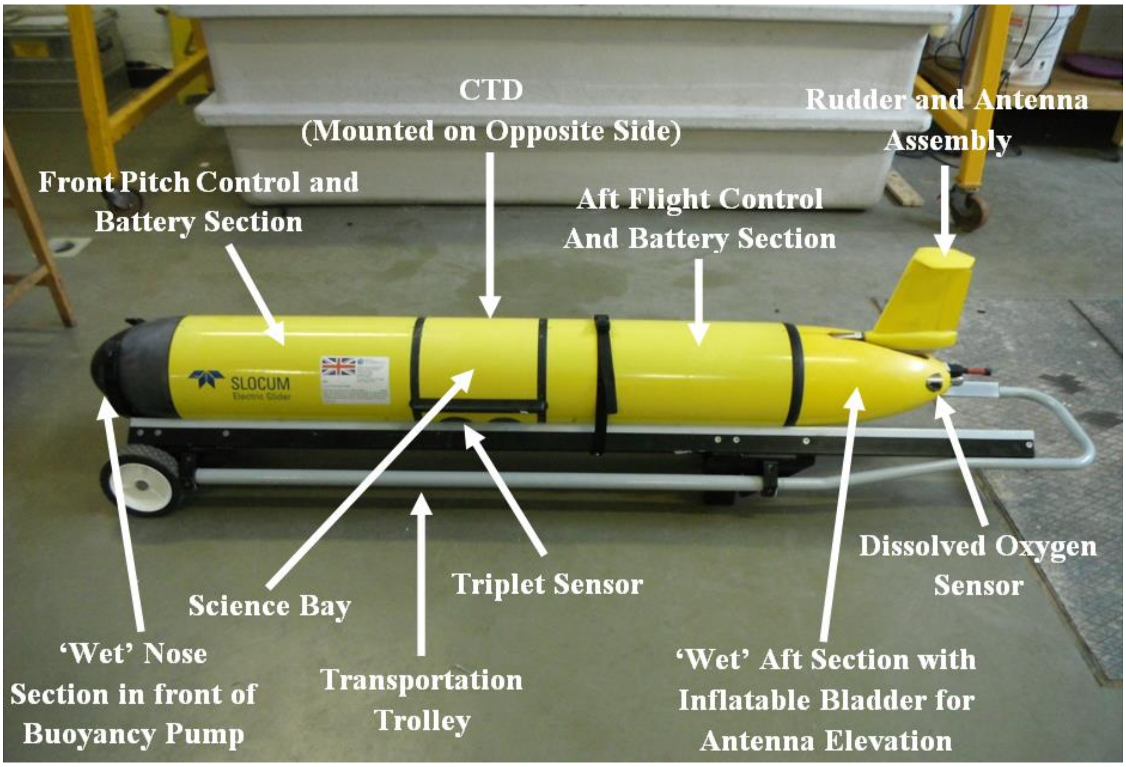


Fig. 4. Unit 194 Slocum electric glider (wings removed)

For the unit 194 glider an internally sealed rolling diaphragm based buoyancy pump is located behind the front nose section. This front nose section has several large perforations to allow seawater ingress. The diaphragm presents a flexible seal between the water outside the glider and the components within the glider hull. When the diaphragm of the buoyancy pump moves inwards and draws in a limited volume of seawater a dive is initiated. When the diaphragm of the buoyancy pump moves outwards to expel a limited volume of water a climb is initiated. For the mid range travel of the buoyancy pump normally a volume of approximately 250 ccs of water is in front of the diaphragm relative to the end of the front hull structure. The glider is typically configured to provide neutral buoyancy at the central diaphragm positional setting. A large battery and linear drive (pitch control) system is located inside the front hull section and behind the buoyancy pump. Movements of approximately ±25 mm of this internal battery inside the front hull section, which has a typical mass in the range 7kg to 9kg, allows the glider pitch angle to be adjusted and optimised during dives and climbs. A central removable section or 'science bay' hosts most of the science sensors and a small internal computer to process and log scientific measurements from a pumped Seabird GPCTD sensor (conductivity, temperature and pressure). The science bay also couples, via a long cable, an Aanderaa Optode in the tail section of the glider that measures the amount of oxygen dissolved in the water through which the glider is navigating. On the underside of the science bay and offset to the port side of the glider is a WetLabs Triplet sensor. This is an optical sensor that measures by proxy backscattering (material suspended in the water close to the glider), Chlorophyll-a concentration and CDOM. The rear hull section houses the ‘flight’ electronics, a further set of batteries and a second small computer to coordinate the system during dives and climbs (underwater gliding or 'flight'). This flight control electronics performs such tasks as operating the rudder, buoyancy pump, pitch control battery etc. The tail section of the glider houses antennas for GPS positioning, iridium satellite (long range communications), Argos satellite (back up long range location estimate) and short range wireless (FreeWave) communications. The rear cowling on the glider tail houses an inflatable bladder. This rear cowling has large perforations and floods when the glider is in seawater. When the glider surfaces the various actuators move to pitch the glider nose forward. The tail bladder is inflated to displace water inside the tail section cowling and elevate the tail section of the glider away from the sea surface. This promotes improved GPS sensing and data communications. Reliable communication with the glider is only possible when the antennas in the tail section are raised above the sea surface.

3. Supplementary information overview

Appendices A and B of this report provide some basic information regarding the setup, testing, ballasting of the glider and the calibration of the glider internal navigational compass. Appendix C summarises the glider deployment from using the FPV *Barrule* and Appendix D summarises the first set of glider sensor calibration measurements using the RV *Corystes*. An overview of the CD mooring is provided in Appendix E. A selection of near real time data plots are provided in appendix F. Appendix G provides details of the glider recovery operations and appendix H includes a preliminary review of the recovered glider scientific measurement data set.

4. Amendments to the original mission and the modified survey strategy

The original mission plan aimed to provide the maximum number of approximately 330km north-south transects along the St George's channel of the Irish Sea. The general idea was to regularly move the unit 194 glider between the WIS and CD mooring sites during the planned two month long survey. This was expected to be 4 full length transects of the St George's channel in total. A number of factors since the start of the deployment led to a revision of the original plan. Poor weather resulted in a 10 day delay with the glider deployment, which disrupted the mission relative to a planned rendezvous with RV *Corystes* on the 10th April in the WIS. This rendezvous between ship and glider was to provide an essential sensor calibration exercise. Following the successful calibration exercise the glider then proceeded south to the CD mooring. Following an 11 day transect through the well mixed and biologically unproductive water of the St. Georges Channel a ‘spring bloom’ was identified at and around the CD mooring site. Due to interest in such events (both scientifically and from a monitoring perspective) the mission was changed to maintain a 2 week glider survey following a short (30km) east to west cyclic transect that used the CEFAS mooring site as an eastern waypoint. These data will permit assessment of the temporal and spatial (horizontal and vertical) variability of physical and biological structures close to the mooring site over a spring neap cycle. The preliminary results of this transect are displayed in appendix F.

To complement the CD repeat transects the next step was to follow a similar plan in the WIS using the AFBI mooring site as the westernmost waypoint, using a similar length east to west cyclic transect. Stratification in the WIS was expected to be well established by the time of arrival in mid-late May 2013 and the initial ‘spring-bloom’ period was likely be coming to an end. It was therefore decided that a 2 week survey mission should occur at the WIS survey area. This should provide sufficient information to allow an assessment to be made of ‘post-bloom’ conditions and the formation of phytoplankton layers (using fluorescence as a proxy) before the scheduled glider recovery.

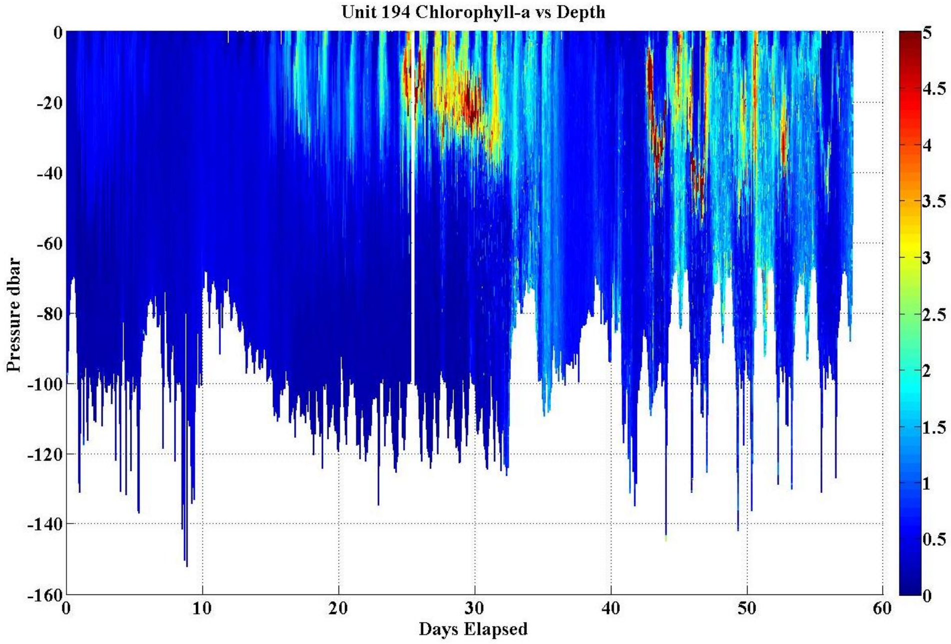
5. Glider science sensor calibration

It is important to emphasise that, due to the longevity of the glider based survey mission in coastal waters, fouling of the glider science sensors can occur. Biological activity and turbidity (suspended matter) that is particularly prevalent in coastal waters can cause contamination on or in scientific sensors. Problems such as this are usually evident in the form of progressive offsets appearing in the sensor readings over time. To provide a mechanism to compensate for this a significant amount of effort has been expended to include ship based surveys to provide independent, calibrated precision scientific sensor measurements. The general remit of this is to provide sufficient information during the glider deployment to compensate for glider sensor measurement offsets or drift. Whenever possible, the glider has been operated in close proximity to regularly serviced moorings with a similar compliment of science sensors for measurement calibration and comparison purposes. The result of this is that a quality controlled, unique and high resolution data can be provided as an output of this component of the UK-IMON project.

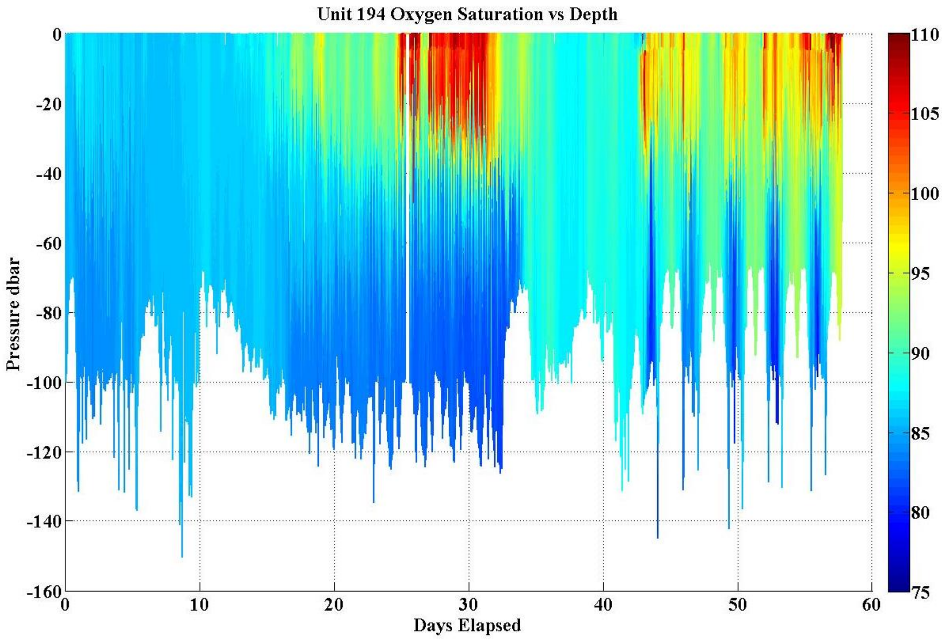
The glider sensor calibration exercises that have been completed during the project include the collection of precision reference readings from the FPV *Barrule* (appendix C) at the beginning of the deployment on 6th April 2013. Collection of CTD profiles and sensor calibration measurements from the RV *Corystes* western Irish Sea based sensor calibration exercise (appendix D) on 10th April 2013. Reference samples were collected using FPV *Barrule* immediately prior to the glider recovery on 3rd June 2013. The unit 194 glider recovery operations are summarised in appendix G.

6. Preliminary science sensor data review

A very preliminary review of the scientific data recorded by the unit 194 glider has revealed that almost a full data return has been achieved during the deployment for the UK-IMON project. Apart from some temporary interruptions in the science data recording, when the glider encountered technical problems and pilot intervention was required, the glider has performed extremely well for the entire deployment of almost 2 months in duration. Appendix H provides a series of plots of the recorded science data in the form of the direct sensor output from the glider without any sensor measurement corrections for such problems as drift or offsets applied. A pair of plots that illustrate the science data return from the glider are shown in Fig. 5.



a measured chlorphyll-a concentration



b measured oxygen saturation

Fig. 5. Science sensor measurements indicating biological activity by proxy

A time series interpolated plot of the measured chlorophyll-a concentration (Fig. 5a) from the Triplet sensor at a given depth is plotted in conjunction with the measured oxygen saturation from the Aanderaa Optode sensor (Fig. 5b). The colour bar to the right of each plot provides an indication of the magnitude and range of that particular sensor output value. From approximately 18 days to 35 days and 42 days through to the end of the deployment there is evidence by proxy of an elevated chlorophyll-a concentration in the upper parts of the water column (Fig. 5a). This elevated chlorophyll-a concentration occurs from near the sea surface to water depths of typically 40 m to 60 m. The measured oxygen saturation in Fig. 5b shows corresponding elevations in the oxygen saturation over similar time scales of 18 days to 35 days and 42 days through to the end of the deployment. The depths to which the elevated oxygen saturation occurs also compare well with the elevated chlorophyll-a concentrations, typically occurring close to the sea surface to depths of 40 m to 60 m. This would suggest evidence of biological activity in the upper parts of the water column during these times. It is anticipated that the primary cause of this was significant phytoplankton growth or 'blooms'. From the deployment timeline presented in appendix H, 18 to 35 days into the deployment represents the period of time from Wednesday 24th April (day 18), when the glider arrived at the Celtic Deep Survey area until Saturday 11th May (day 35), three days after the return northerly transect along the St George's channel was initiated. From Saturday 18th May (day 42), two days before the northerly transect along the St George's channel to the WIS survey area was complete, almost until the end of the glider survey elevated biological activity was detected. This clearly supports the survey planning described in section 4 that anticipated biologically unproductive waters along the St George's Channel of the Irish Sea. Therefore, the decision to focus on measurements from the WIS and CD survey areas during the deployment has been beneficial. This has helped to provide pre, during and post algal bloom measurements resulting in a scientifically interesting and diverse data set.

7. Summary

This report has provided a general overview of the unit 194 Irish Sea based glider deployment for the UK-IMON project. A review of the scientific survey rationale has also been provided along with a summary of the glider operations in the form of a series of appendices. A deployment of almost 58 days in length was successfully completed with an ambitious survey area that included the western Irish Sea, the St George’s Channel and the Celtic deep. Initial indications from a preliminary review of the recovered glider data are that a full data return for scientific sensor measurements at 2 second intervals has been achieved. There is also evidence of elevated biological activity during certain periods and depth ranges of the glider survey. This has added diversity into a unique, interesting, high resolution and long term scientific data set that has been generated by the unit 194 glider.

The benefit of small boat support in the form of a RHIB was demonstrated during the glider deployment and recovery operations reviewed in appendices C and G of this document. Subject to a suitable sea state and appropriate weather, the use of the glider transportation trolley and a low freeboard, soft sided vessel such as a RHIB helps to keep close, direct control of the glider during deployment and recovery operations. This avoids taking unnecessary risks in relation to damage to the glider or its associated and potentially fragile components such as sensors etc during these operations. This in turn minimises the risks involved when handling a delicate AUV such as a glider. No damage to the glider or RHIB occurred during the unit 194 glider deployment and recovery operations.

A full complement of fieldwork equipment was taken for the glider deployment and a trained Slocum glider engineer was onboard the deployment vessel. This was demonstrated to be an appropriate decision after a problem with the glider altimeter was detected during the initial phases of the glider testing, during the first deployment attempt. Testing of the functionality of an acoustic altimeter is normally very difficult in a laboratory or on a ship because the altimeter is designed to operate underwater. Fortunately the altimeter fault was identified and rectified onboard the FPV *Barrule*, leading to a successful deployment. If adequate preparations had not been undertaken during the glider deployment operations then it would not have been possible to repair the glider and the deployment attempt would have been abandoned. It is most likely that the internal glider cable damage that caused the altimeter fault occurred during ballasting and preparation of the glider, as discussed in appendix C of this document. After consulting the glider manufacturer (TWR) a procedure has now been established that allows testing of the connection to and basic functionality of a Slocum electric glider altimeter out of water. The recommended procedure will be incorporated into future laboratory and ship based glider testing and preparations in advance of a planned deployment. This will help to verify the correct operation of or identify problems with an altimeter before a glider deployment is attempted.

Substantial effort has also been expended to ensure that appropriate levels of independent scientific measurements have been provided. This information is essential to support the quality control and quality assurance that will be required to ensure the integrity of the unique, long term high resolution data set of scientific measurements that has been generated by the unit 194 glider.

It is important to point out that many hazards exist when operating gliders in coastal zones. These include shipping activity (Fig. 6), fixed platforms and strong tidal currents that can affect the operation, particularly the underwater navigation, of the glider. Biological activity and suspended matter in the water column can also affect the performance of glider based scientific sensors. Caution must be used when planning glider surveys in order to mitigate the risks associated with operating AUVs of this type in challenging coastal waters.

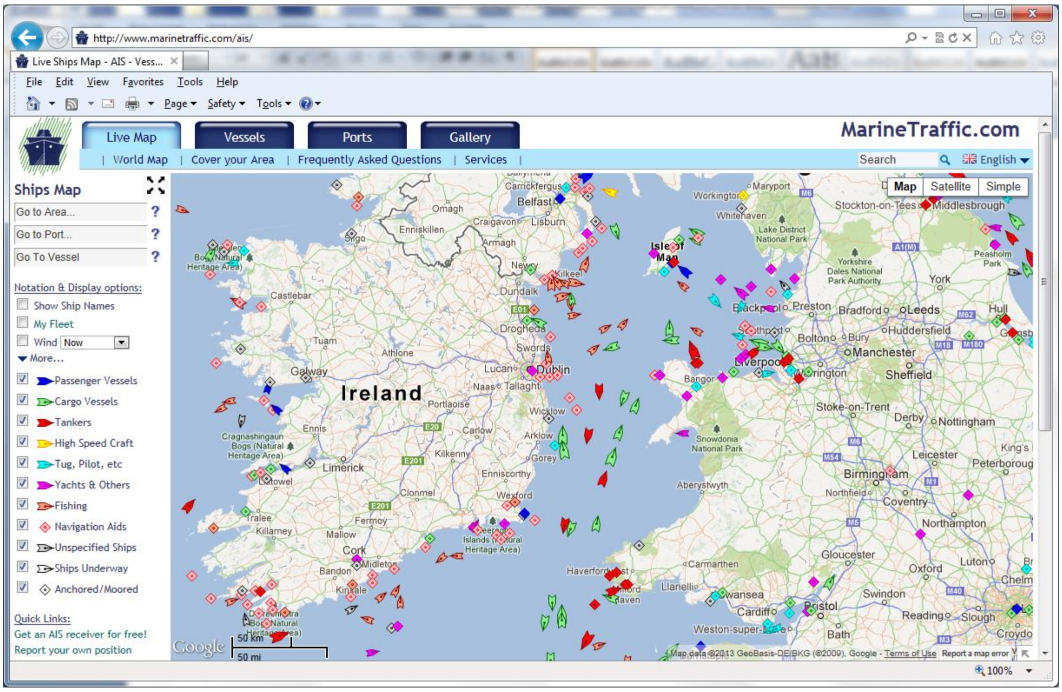


Fig. 6. Ship positions reported by AIS at 07:50 GMT on Thursday 25th May 2013

Larger vessels, normally over 300 GT have a mandatory requirement to fit AIS. The screen capture shown illustrates some of the larger vessel shipping activity in the UK-IMON project survey area for the unit 194 glider. Fixed platforms, fishing and general shipping activity illustrate some of the potential hazards with operating underwater gliders in coastal waters.

Acknowledgements

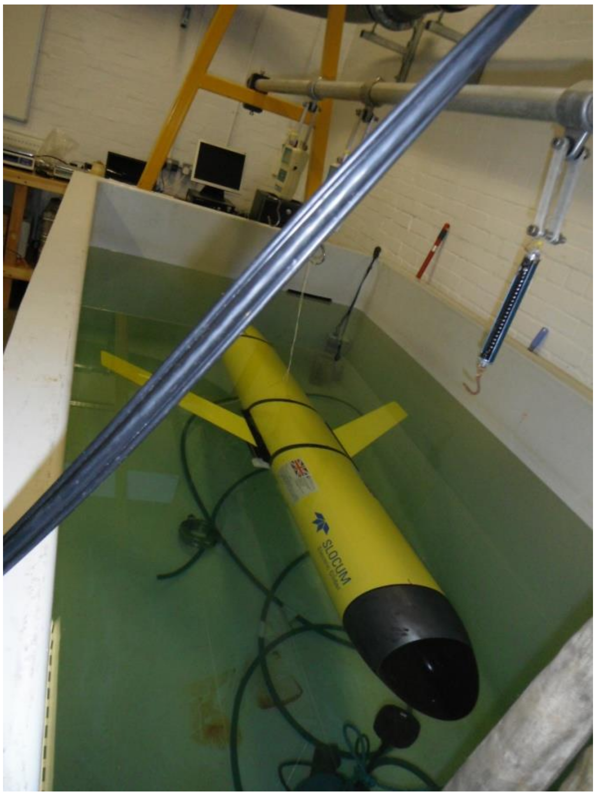
Thanks to Ben Allsup and the glider support team at Teledyne Webb Research, USA for the rapid responses to regular enquiries and requests for technical support, particularly during unsociable hours. Thanks are also due to the glider deployment and recovery support team aboard the FPV *Barrule* of Kevin Kennington, Colin Eastwood, Rob Annett, John Summers, Jake Summers and Warren Glass. Their excellent, sustained, enthusiastic support during the glider operations summarised in this report significantly contributed to the success of the project. The authors also express their gratitude to Brian Stewart and the team aboard RV *Corystes* for once again proving an excellent set of close proximity glider sensor calibration measurements in the western Irish Sea. This occurred under very tight schedules and at short notice. The authors also thank the University of Liverpool and in particular John Myerscough, Graham Schleyer and Martin Jones from the Department of Engineering. The provision of the excellent facilities within the Hydraulics Laboratory was essential for the underwater glider preparation associated with this project.

Appendix A – Unit 194 Glider Setup and Ballasting

The unit 194 glider was supplied by the Marine Autonomous and Robotic Systems (MARS) facility at NOC Southampton with lithium primary (expendable) batteries installed for extended endurance. From historical records the anticipated western Irish Sea mean water column temperature, salinity and density of 12.5 ^{O}C, 34 PSU and 1026.5 kg/m^3 were used to ballast the glider. After shipment of the glider to NOC Liverpool a thorough evaluation and configuration of the glider was undertaken. Fig. A1 shows a selection of photographs of the glider preparations in the Hydraulics Laboratory that is located in the Department of Engineering at the University of Liverpool, UK.

Glider preparatory area, lifting gantry, glider transportation trolley and saltwater test tank

Preparation of the glider for ballasting testing



The intended deployment conditions were simulated in the test tank and the glider ballasting was verified

Fig. A1. Unit 194 Glider Preparations for the UK-IMON Irish Sea Survey

The glider was taken apart to visually inspect the status of the glider internal components after shipment to Liverpool and assess the scope for making ballasting adjustments. When an attempt to separate the forward hull section and watertight o ring seals was made this proved to be difficult to accomplish. As the seals eventually separated under load one of the internal electrical connectors was damaged. The plastic retaining latch from one of the connectors between the forward science bay area (just forward of the centre of the glider) and the pitch battery position control assembly in the front of the glider was damaged. After consulting the glider manufacturer TWR a replacement connector was ordered, delivered to Liverpool and installed to rectify the problem. Visual inspection had shown a set of ballasting steel plates, lead strips and plastic bottles with lead shot had been used to ballast the forward section of the glider. One of the plastic ballasting bottles in particular, fitted around the outer casing of the buoyancy pump assembly, was compressed against the lower part of the internal carbon fibre composite hull. This tended to offer resistance to taking the glider front sections apart and the fastening cable tie was relatively loose. Photographs were taken of this arrangement and the glider was carefully reassembled for ballasting testing. The unit 194 glider ballasting setup was tested in a saltwater ballasting tank in the University of Liverpool (UOL) Hydraulics Laboratory (Fig. A1). The estimated mean deployment conditions were simulated in the test tank by mixing the solution of synthetic sea salt in the ballasting tank to the required density. The elevated temperature of the tank in a laboratory environment, when compared to the likely seawater temperature at the intended glider deployment location in the western Irish Sea, was also taken into account. When the anticipated deployment conditions were simulated in the laboratory based tank the correct ballasting of the glider was confirmed. The unit 194 glider was determined to be approximately 20g too light when it was tested in the tank. This small offset was comfortably within the range of the unit 194 glider buoyancy pump. When deployed, a coastal (up to 200 m depth limit) Slocum glider standard buoyancy pump has an approximately ±250g mass change capability from the neutral (with the pump in its mid range position) ballasted configuration. The H distance or distance between the centre of buoyancy and gravity in the glider was also tested and confirmed to be within manufacturer's guidelines.

Thorough testing of the glider iridium (satellite based long range), Argos satellite based glider fallback positional estimate, GPS sensor and FreeWave wireless short range communications occurred. The glider was also configured for the required survey and a simulation of the glider survey configuration for the IMON project was run for an extended period of time at NOC Liverpool. The associated survey mission configuration files were then uploaded into the glider internal navigation ('flight') and science computers. A series of extensive tests were then used to verify the correct glider initial configuration.

Appendix B – Unit 194 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 based navigational sensors can occur. The internal navigational electronic compass and attitude sensor normally require recalibration. A procedure was used for compass calibration that involved taking the glider to an open space that was free from electrical interference and stray magnetic or electromagnetic fields. The process used to calibrate the glider compass involved manually and slowly moving the glider through either fixed positions or a series of rotations. The intention was 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. This procedure is particularly useful to address the effects of any attitude sensor interference that may be generated inside the glider.

A post calibration compass check was then implemented that involved moving the glider horizontally in 22.5^{O} steps over a full revolution and recording the reported glider heading at each interval. The position of the 22.5^{O} increments was determined by using a handheld magnetic compass. The plot in fig B2 shows the glider electronic compass heading measurement deviation when compared to the magnetic compass readings.

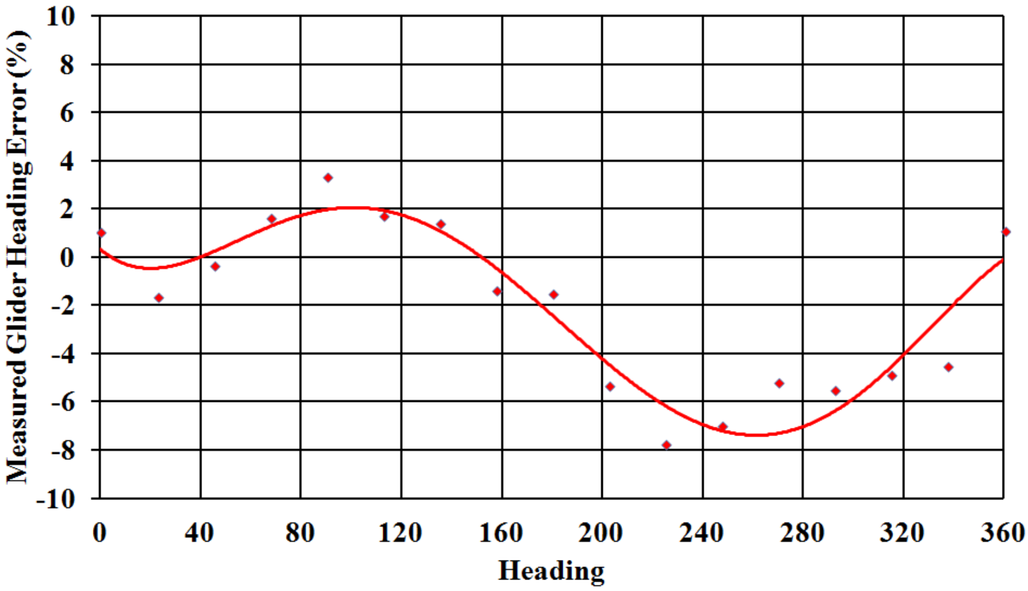


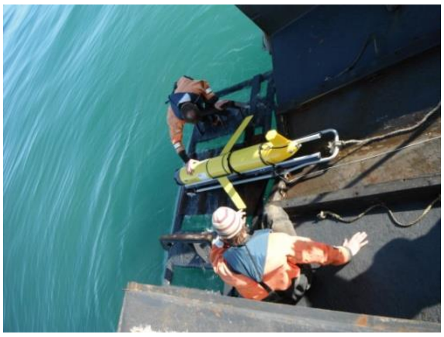
Fig. B 1. Unit 194 Glider Electronic Compass Calibration Check Plot After Calibration and Prior To the UK-IMON Project Deployment

The post calibration compass check in fig. B1 shows a good agreement between the magnetic compass and the glider internal electronic compass heading readings up to 180^{O}. Beyond this there seemed to be more dispersion in the readings. It is estimated that the glider attitude sensor has been correctly calibrated and the dispersion in the results from 180^{O} to 360^{O} was associated with practical problems relating to the compass check procedure. This estimation is further reinforced by observing the reported glider GPS positions during surfacing and the bearing reported by the glider of the target survey waypoints. The glider correctly reported the bearing of positional waypoints it is navigating to in relation to GPS sensor information. This provided additional confidence that the glider internal attitude sensor was operating correctly.

Appendix C – Deployment of the Unit 194 Glider Using the FPV *Barrule*

The unit 194 200m depth rated glider was deployed on 6th April 2013 using the Isle of Man (IOM) government 22m patrol boat the fisheries protection vessel (FPV) *Barrule*. A selection of pictures of the deployment vessel and the deployment operations are shown in fig C1.

The FPV *Barrule*



Preparations for the initial glider launch with the rear platform lowered

Rear view of FPV *Barrule* with the rear platform raised and the RHIB ready for launch

Initial testing of the glider with a tether line coupled to a surface float

Recovery of the glider for servicing using the RHIB

Un-tethered, deployed glider

Onboard glider sensor calibration sample collection

Fig. C1. Glider Deployment Operations using the FPV *Barrule*

Prior to deploying the glider a Seabird Microcat CTD was deployed overboard to check the water properties and compare these to the glider ballasting setup. The Microcat readings were recorded at 53° 46.701’N, 5° 0.042’W at 09:03 GMT on Saturday 6th April. The values that were used for the ballasting check after the Microcat internal CTD readings had stabilised were a temperature of 7.2394 ^{O}C, a salinity of 34.7460 PSU, and a computed density of 1027.18 kg/m^3 at a depth of 1.5m. These values compared favourably with the laboratory setup in terms of the water density of 1026.5 Kg/m^3. A check with the TWR glider ballasting calculations spreadsheet revealed that the glider was ballasted approximately 15g too light. Bearing in mind that the unit 194 glider buoyancy pump has an approximate mass change range of ± 250g from the neutral or ballasted position this demonstrated the glider was well ballasted for the near surface deployment conditions. The decision was then made to start the deployment operations for the glider.

The glider was first tested and then initially deployed with a tether and float. The deployment occurred close to the eastern WIS survey waypoint at 53° 47.000’N, 5° 0.000’W. 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. After completion of the initial tests the RHIB was launched and the tether plus surface float were removed from the glider. A series of incremental dive tests to 3 m, 50 m and then full depth were undertaken. During this testing, when the glider surfaced, the recorded sensor data was downloaded using a wireless FreeWave based data link. Visualisation software (TWR data visualizer) was then used to process and plot the glider data. It transpired that the glider had a fault with the acoustic altimeter in the front nose cone section of the glider. The glider was unable at this stage to find the range of the seabed during dives. Fig. C2 provides a plot that illustrates that the glider altimeter was not capable of finding the range of the seabed during dives. The bottoming out of the glider profile at approximately 80 m depth can be seen as the glider collided with the seabed during a dive. A timeout then comes into force to cause the glider to commence the next climb phase of the profile.

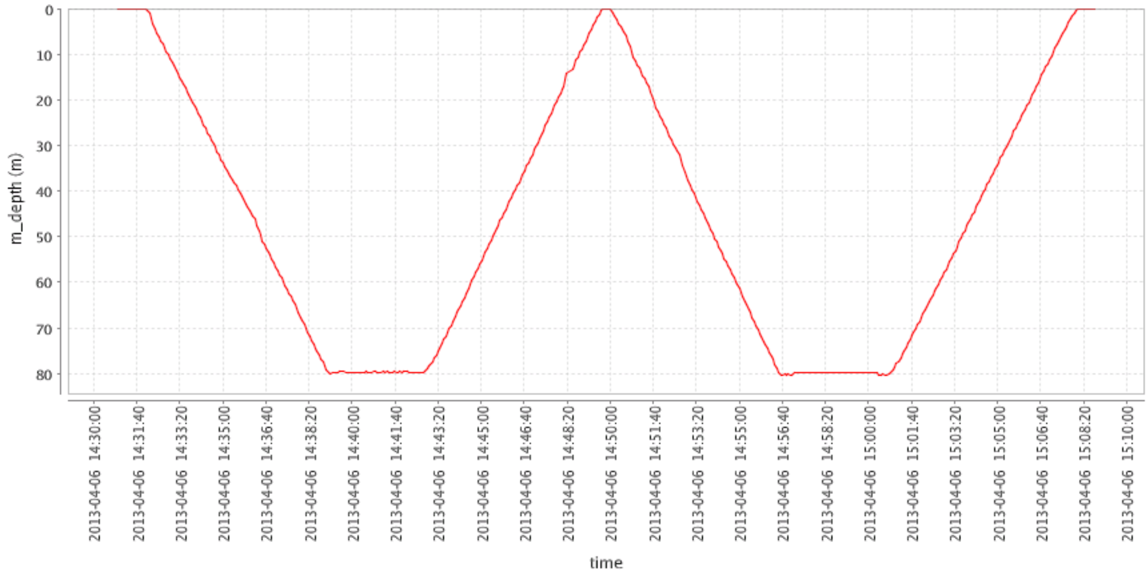
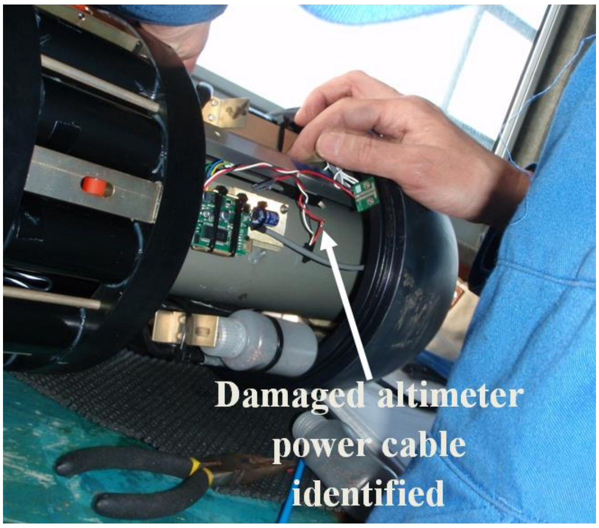


Fig. C2. Glider seabed ranging problem

After reviewing previously recorded unit 194 glider data from 2012 and consulting the glider manufacturer, TWR via satellite communications onboard FPV *Barrule*, it transpired that the measured glider altimeter supply voltage was low. The anticipated reading of approximately 2 volts was now reading almost zero volts. The decision was then made to recover the glider using the onboard RHIB and investigate the problem.

After examining the altimeter outer connector inside the front nose cone section of the glider no obvious problems were identified with the bulkhead and outer hull connections to the acoustic altimeter. The decision was then made to open up the glider on the rear deck of FPV *Barrule*. Fortunately, during the mobilisation operations from NOC Liverpool sufficient equipment had been taken to attempt to service and repair a Slocum electric glider during fieldwork. The sea state was clam and the weather was favourable allowing the glider to be washed with fresh water, dried and then disassembled (fig C3). All of the repair work occurred in the dry, sheltered wheelhouse area of FPV *Barrule*.

During disassembly it transpired that one of the internal ballasting bottles (containing lead shot) was held in place with a cable tie that was close to the internal altimeter power, ground and signal cable assembly. This ballasting bottle was not securely fastened and it is likely that movement of the cable tie during glider ballasting and testing operations (assembly and disassembly, addition of ballasting weights etc) and subsequent transport of the glider had damaged this cable. The red lead (altimeter power) had been severed and a repair was implemented by rejoining the cable and adding some insulation around the repair.



Repairs to the internal cabling around the front buoyancy pump assembly in the enclosed bridge area of FPV *Barrule*

Rerouting of the repaired altimeter cable

Fig. C3. Slocum electric glider repairs onboard FPV *Barrule* on 6th April 2013

The repaired cable was then rerouted away from the ballasting bottle area. Two new cable ties were then carefully positioned inside the glider, on the outside of the buoyancy pump assembly, to securely fasten the problematic ballasting bottle in position. The glider hull seals were then serviced by cleaning the sealing faces plus o rings and applying silicon grease and reassembling the seals. The glider was then carefully reassembled and an internal vacuum was generated using an external pump in line with manufacturer's guidelines. A series of onboard tests then verified the glider was operating correctly. The repaired glider was then deployed again using the ship's RHIB. A series of vehicle status checks and test dives of incremental depths were undertaken before committing to a series of full depth tests that will rely on the integrity of the glider altimeter to operate correctly. Downloading and subsequent data plotting of the glider sensor data onboard FPV *Barrule* demonstrated that the glider was now operating correctly. A plot of the pressure record and measured water depth for the repaired glider during full depth underwater profile testing is shown in fig C3.

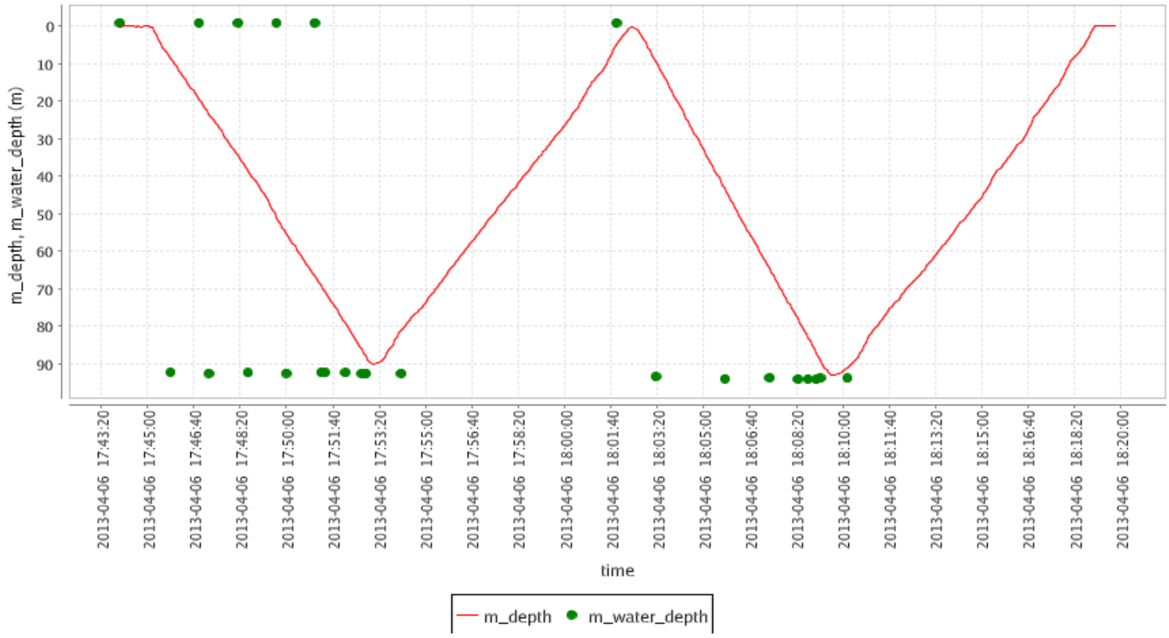


Fig. C3. Glider seabed ranging and initial dive profile

The green points to in the lower part of the plot area of Fig. C3 illustrate how the glider altimeter has started to be able to correctly find the range of the seabed at approximately 90 m. The pressure record subsequently showed the correct initial lower inflections by the glider occurred close to the seabed. The first WIS survey transect was then initiated at 18:35 GMT on Saturday 6th April at a starting location for the unit 194 glider of 53° 47.046’N, 5° 0.042’W. This GPS location was approximately 5km southwest of the eastern WIS survey waypoint.

Following the initial deployment of the glider and with the glider starting the survey within several hundred metres of the FPV *Barrule* a series of sensor calibration samples were taken. A CTD with and a water sample collection carousel was used to gather water samples from near the sea surface and a depth of approximately 53 m. This depth limit was based upon the capabilities of the small water sample collection carousel and winch assembly that was available onboard during the glider deployment operations. The FPV *Barrule* CTD comprised of a YSI SI 6600v2 with a ROX Reliable Optical Dissolved Oxygen sensor, a 6025 optical chlorophyll sensor and a conductivity/temperature port. The collected samples were stored onboard and where appropriate, some of the samples were frozen for later analysis. The samples were processed in a laboratory after the FPV *Barrule* deployment cruise to provide independent, precision measurements. Samples for CTD, Chlorophyll-a, suspended particulate matter (SPM) and dissolved oxygen were taken. This allowed the calibration of the glider scientific sensors to be tested and documented at the beginning of the glider survey. It was not possible to collect and store CDOM reference samples appropriately during the deployment cruise. This was due to the requirements of a very low temperature freezer for CDOM sample storage and for subsequent later sample analysis to occur within hours or days. This was essential in order to prevent frozen sample degradation and this could not be achieved during the glider deployment operations.

During the initial piloting of the glider using iridium satellite communications, after the deployment, the upper and lower climb to dive and dive to climb inflection points were carefully and incrementally adjusted. This allowed the glider to generate measurements along the full length of the water column to typically 2 m from the surface and 3m from the seabed between 3 hourly timed surfacing intervals. The scientific sensors comprising of a pumped conductivity temperature and depth (CTD), chlorophyll-a concentration, optical backscatter (OBS), coloured dissolved organic matter (CDOM) and dissolved oxygen were configured to sample at 2 second intervals. Scientific measurements were configured to occur during the entire underwater glide profile including dives, climbs, surfacing and inflections.

Appendix D – Unit 194 Glider Deployment Sensor Calibration Using RV *Corystes*

Shortly after the unit 194 glider deployment commenced the Agri-Food and Biosciences Institute AFBI (www.afbini.gov.uk) 53m survey vessel RV *Corystes* visited the western Irish Sea moorings (AFBI site 38A). This was to undertake sensor calibration work, initially close to the site 38A mooring array on Wednesday 10th April 2013. Fig D1 shows a selection of pictures of RV *Corystes* and the typical mooring calibration operations.

RV *Corystes*

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

Sample collection and preservation operations in the wet lab

Fig. D1. RV *Corystes* Sensor Calibration Operations

A typical AFBI mooring arrangement for site 38A is shown in fig. D2. AFBI mooring site 38A is located at a nominal GPS location of 53^o 47.000N, 5^o 37.903W. The glider was configured to survey close to the moorings as RV *Corystes* arrived on station at 07:00 GMT on Wednesday 10th April. An eight hour time frame was available for the cruise operations. RV *Corystes* was capable of the collection of reference samples for precision measurements of CTD, Chlorophyll-a and nutrients. There was a calibrated dissolved oxygen sensor on the ships CTD carousel and a backscatter sensor for turbidity (suspended matter) measurement comparisons. Unfortunately, it was not possible to collect CDOM reference samples during the cruise.

The basic approach used during the survey was for RV *Corystes* to first provide a set of calibration samples close to site 38A with the glider profiling underwater several km away. During the survey, the CTD carousel on RV *Corystes* was periodically deployed to provide full profiles of the water column, with reference water samples being collected close to the sea surface and close to the seabed.

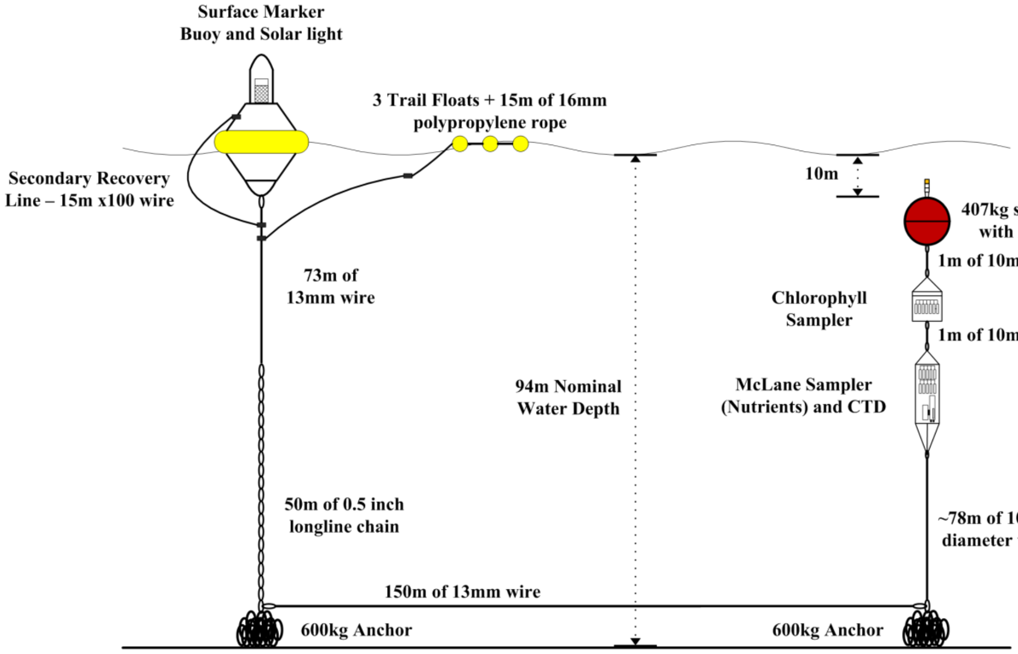


Fig. D2. Typical AFBI Site 38A Mooring Arrangement

This provided calibration information for the glider and mooring sensors. The glider was then configured to profile underwater eastwards and then periodically surface to report its GPS position. The general approach was to provide ship to glider comparison and calibration measurements. These occurred with the ship and glider in close proximity over the largest possible range of water column conditions achievable within the eight hour time frame allocated for the RV *Corystes* operations. Fig D3 shows the glider transect during the survey.

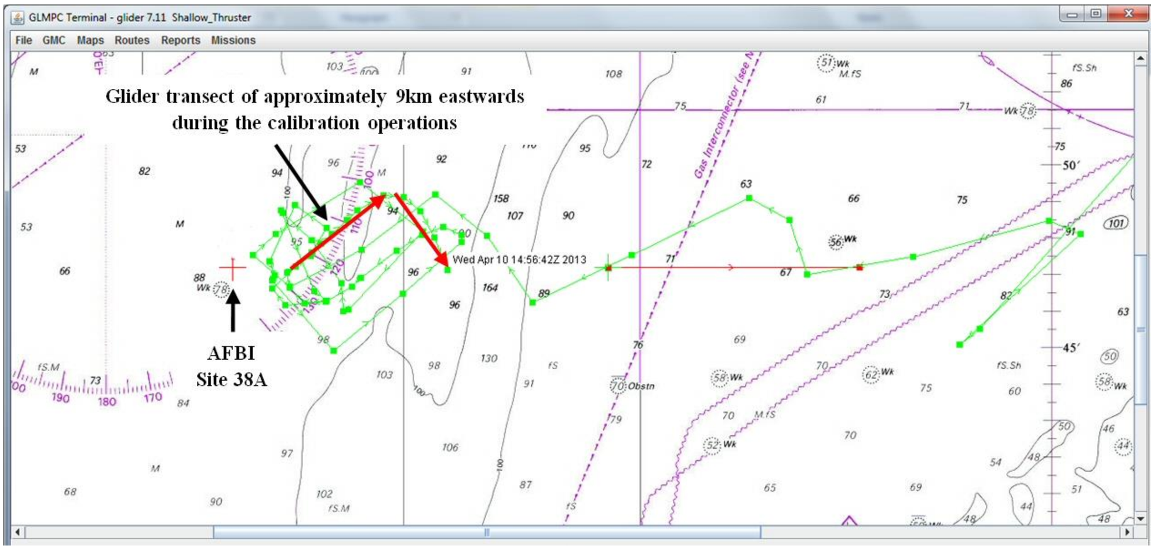


Fig. D3. Unit 194 Glider Transect during the RV *Corystes* based sensor calibration cruise

This screen capture of the glider positions was generated using the TWR GLMPC glider plotting software. The background of the plot is a calibrated map that provides basic bathymetry information in terms of the lowest astronomical tide levels for the WIS survey area (survey area 1).

As indicated in fig D3 the glider navigated approximately 9km eastwards during the survey. The green squares represent the reported glider positions and the path of the glider is also indicated using the red arrows. An AIS plot is shown of the position of RV *Corystes* during the sensor calibration operations is shown in Fig D4.

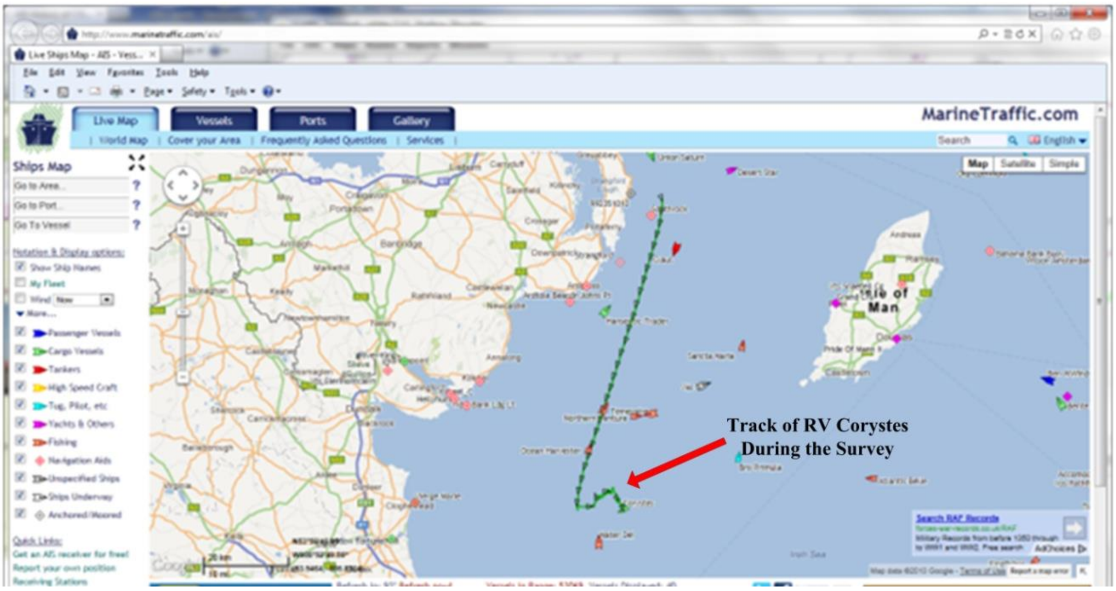


Fig. D4. RV *Corystes* AIS Track on Wednesday 10th April 2013

The track of RV *Corystes* as the ship followed the glider during the calibration survey is indicated.

The sensor calibrations operational log is as follows:

IMON Project -RV *Corystes* to unit 194 Glider Western Irish Sea Sensor Calibration Cruise Log - Wednesday 10th April 2013

Configuration -RV *Corystes*

The sampling undertaken used a vertically profiling Seabird CTD carousel with water samples taken for chlorophyll-a and nutrients from near the sea surface and close to the seabed. There was a calibrated dissolved oxygen sensor on the CTD carousel plus a backscatter sensor (for comparison measurement profiles with the OBS (optical backscatter to measure suspended material in the water column) sensor fitted to the glider). It was not possible, given the short notice of the schedule, to arrange for CDOM reference sampling.

Configuration - Unit 194 TWR 200m Depth Rated Slocum Electric Glider

The glider science sensor sampling was configured to occur at two second intervals. The glider science sensors were a pumped Seabird CTD, an Aanderaaa Optode dissolved oxygen sensor and a WETLabs Triplet (CDOM, Chlorophyll-a and backscatter optical sensors). The glider was configured to sample during dives and climbs along the full water column. Inflections between the glider dives and climbs occurred at approximately 5m from the seabed and approximately 3m from the sea surface.

Calibration Sampling Summary (all times are in GMT)

- Sampling started on RV *Corystes* at 07:00 close to AFBI Site 38A (53° 47.000'N, 5° 37.903'W) at 30 minute intervals. The reported glider GPS position was 53° 47.325'N, 5° 34.284'W at 07:47, which was approximately 4km away from Site 38A. The glider was surfacing to report its position every 30 minutes.

- Sampling then continued on RV *Corystes* at 30 minute intervals with the glider attempting to navigate eastwards. The glider positions were relayed to RV *Corystes* at approximately 30 minute intervals by satellite phone and, as and when possible, the ship was re-aligned between CTD casts at a distance of approximately 1km to the west of the last reported glider position.

- 08:15 the reported glider position was 53° 47.654'N, 5° 34.814'W and the ship was re-aligned to ~1km west of this between sampling.

- 08:41 the reported glider position was 53° 47.935'N, 5° 33.327'W and the ship was re-aligned to ~1km west of this between sampling.

- 09:13 the reported glider position was 53° 48.315'N, 5° 32.635'W and the ship was re-aligned to ~1km west of this between sampling.

- 09:42 the reported glider position was 53° 48.583'N, 5° 32.151'W and the ship was re-aligned to ~1km west of this between sampling. After re-alignment of RV *Corystes* to <= 1km of the glider position, the next CTD cast was scheduled for 10:15.

At this stage the glider was only travelling ~500m to 1km between half hourly surfacing. The glider was configured at 09:45 to survey for one hour underwater with the intention of allowing the glider more time to navigate further underwater between timed surfacing.

- 10:52 the reported glider position was 53° 48.972'N, 5° 30.915'W and the ship was re-aligned to ~1km west of this for the next sampling run after the RV *Corystes* lunch break.

- 11:53 the reported glider position was 53° 48.940'N, 5° 29.976'W and the ship was re-aligned to ~1km west of this between sampling. Approximately 1km of headway east was made by the glider since the previous position report.

- 12:54 the reported glider position was 53° 48.554'N, 5° 29.216'W and the ship was re-aligned to ~1km west of this between sampling. Approximately 1km of headway east was made by the glider since the previous position report.

- 13:46 the reported glider position was 53° 47.839'N, 5° 28.579'W and the ship was re-aligned to ~1km west of this between sampling. Approximately 1km of headway on a curved south east transect was made by the glider since the previous position report due to the effect of the change to an outgoing (east to west) tidal current.

- 14:57 the reported glider position was 53° 46.934'N, 5° 27.966'W and the ship was re-aligned to ~1km west of this before the final CTD cast was taken.

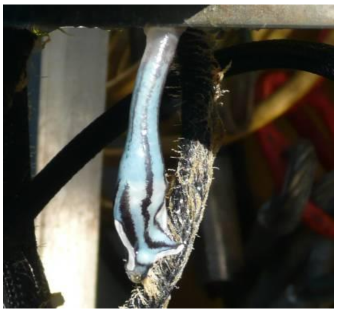
The glider had travelled approximately 9km east during the day along a curved transect from the starting position close to Site 38A in the morning. The curvature of the glider transect was caused by the influence of tidal currents as the glider navigated underwater. It was noted that there was an approximately 1.5°C temperature difference between the first surface and bottom samples taken at Site 38A at the start of the RV *Corystes* survey. This temperature difference reduced during the day as the calibration sampling progressed. This provided an indication that some level of differences in the water column properties occurred during the procedure, as the glider and ship travelled eastwards. Changes in the water column properties were required from a scientific measurement perspective in order to provide sensor calibration information while studying varying water column conditions.

Appendix E – Overview of the CEFAS Celtic Deep (CD) Mooring

The CEFAS Celtic deep (CD) smartbuoy mooring is located at 51° 14.499'N, 6° 4.800'W and the mooring array is serviced at typically six week intervals by AFBI using RV *Corystes*. A selection of pictures of the typical smartbuoy servicing operations using RV *Corystes* are shown in fig E1. The sensor set comprises of a conductivity and temperature sensor (CT), OBS turbidity, chlorophyll-a fluorescence and PAR sensors. The sensor outputs are processed and recorded at 30 minute intervals. An automated CEFAS water sample collection unit is used to gather nutrient and phytoplankton samples every 4 days.

Mooring recovery operations

Recovered buoy bio-fouling



Recovered buoy bio-fouling with a suspected Gooseneck Barnacle (pollicipes polymerus)

Replacement buoy deployed and towed to station

Buoy anchor clump Release

Fig. E1. Celtic Deep smartbuoy servicing operations

Orbcomm low earth orbit satellite based near real time telemetry is used to transfer measurements from the buoy to shore at 2 hour intervals. Some information regarding the CD mooring is available at:

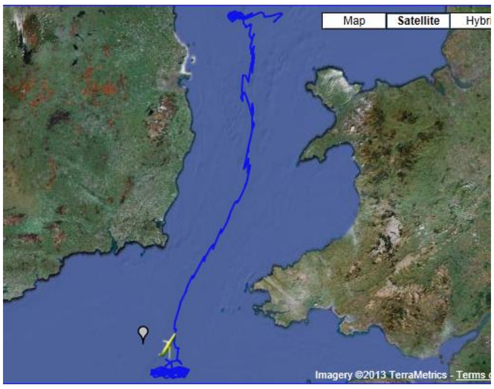
http://www.cefas.defra.gov.uk/our-science/observing-and-modelling/monitoring-programmes/monitoring-sites/celtic-deep.aspx

Information regarding the CEFAS automated water sampler can be found at:

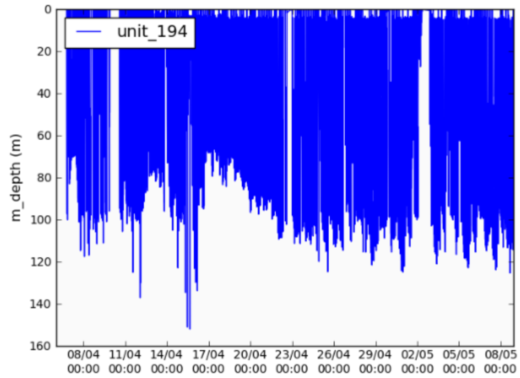
http://www.cefastechnology.co.uk/products_water.htm

Appendix F – Selected Near Real Time Data Plots

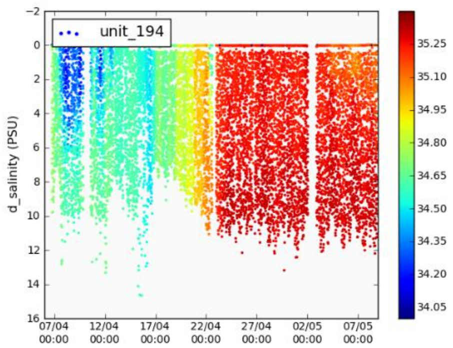
At approximately one month into the glider deployment, on Wednesday 8th May 2013, the following screen captures and sample data plots in fig F1 were available from the unit 194 internet based data feed at www.noc.soton.ac.uk/omf/projects/glider/data.php.



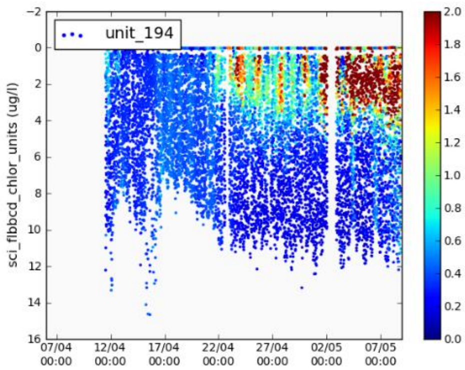
Glider survey track - the glider is close to the Celtic Deep survey area



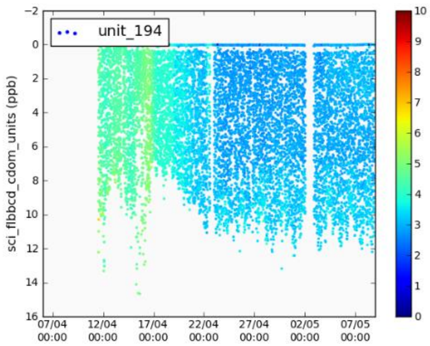
Depth profiles



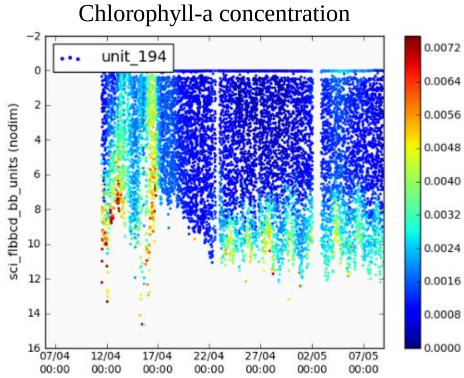
Derived salinity



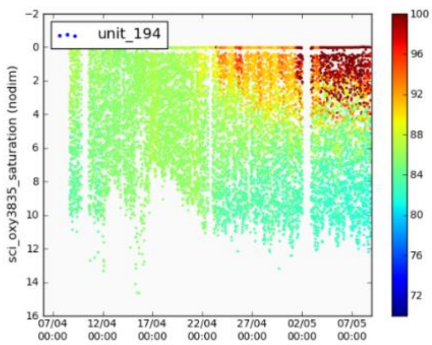
Chlorophyll-a concentration



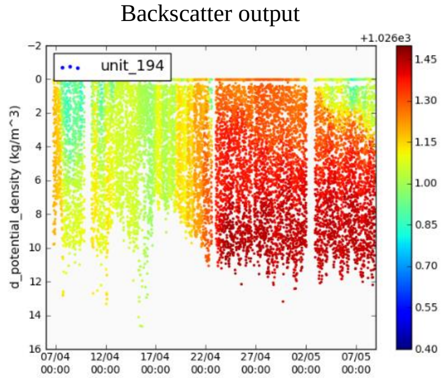
CDOM



Backscatter output



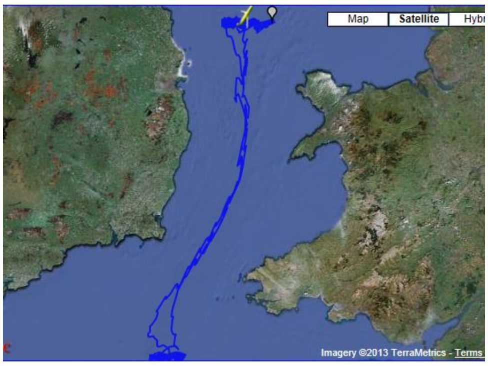
Dissolved oxygen saturation



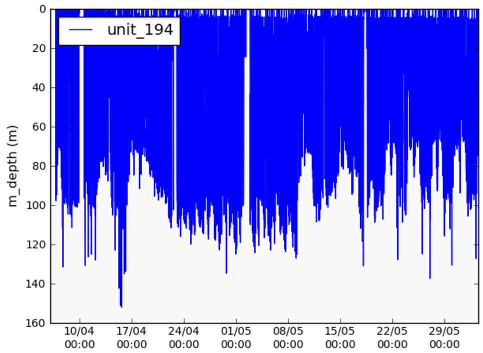
Derived potential density

Fig. F1. Unit 194 Near Real Time Data

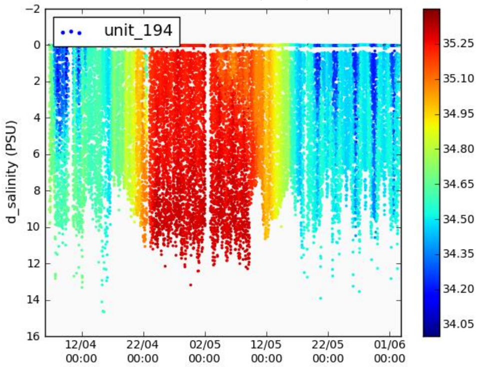
Fig F2 shows a selection of near real time data plots close to the scheduled recovery date for the unit 194 glider. Both Fig F1 and F2 show evidence by proxy of biological activity, particularly in the upper part of the water column, at the Celtic Deep and the WIS survey areas.



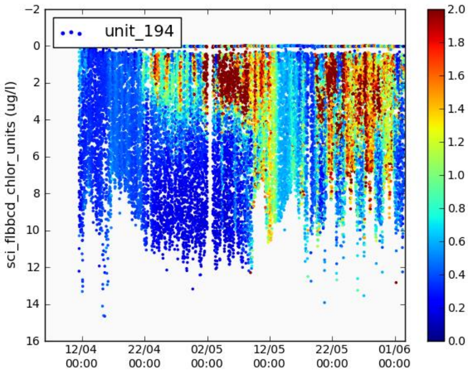
Glider survey track - the glider is surveying along the western Irish Sea (WIS) transect



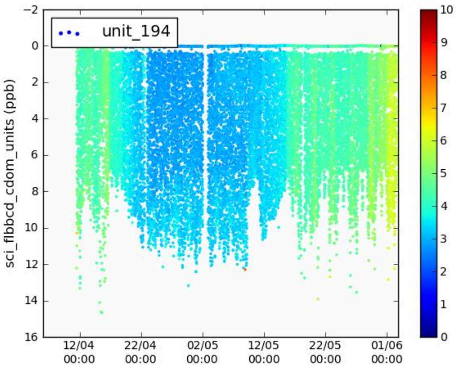
Depth profiles



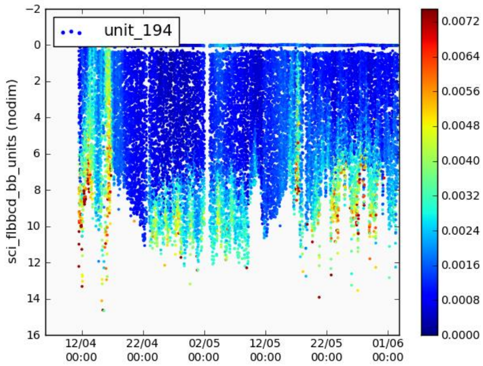
Derived salinity



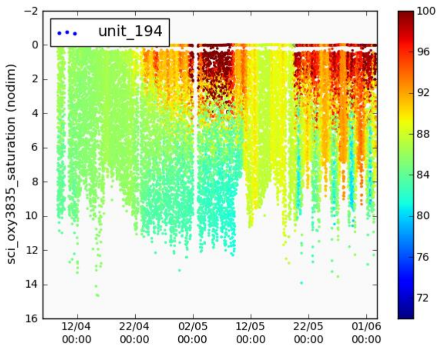
Chlorophyll-a concentration



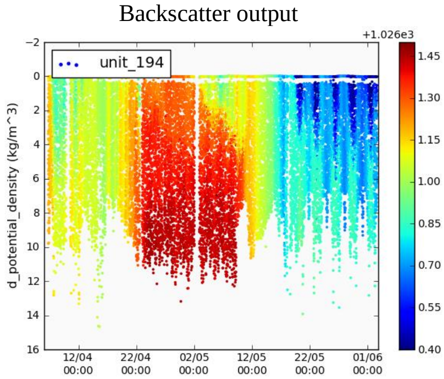
CDOM



Backscatter output



Dissolved oxygen saturation



Derived potential density

Fig. F2. Unit 194 near real time data from Sunday 2nd June prior to the glider recovery date of Monday 3rd June 2013

It is important to note that only a sub-set of the internally recorded glider data was sent in near real time. These sensor output values did not have any compensation for sensor drift or offsets applied. The aim was to provide an indication of the performance of the glider and the onboard scientific sensors during the deployment. The high resolution internal data record within the glider includes recordings of the outputs from all of the scientific sensors used by the glider at two second intervals.

Appendix G – The unit 194 Glider recovery

The Isle of Man (IOM) government 22m patrol boat the fisheries protection vessel (FPV) *Barrule* was used for the glider recovery operations on Monday 3rd June 2013. Mobilisation occurred at Port Saint Mary to the south of the Isle of Man. About 90 minutes was required after leaving port to reach the glider survey location. The glider was configured for a 30 minute surfacing interval to regularly report its GPS position as it approached the eastern part of the WIS survey transect as shown in Fig. G1.

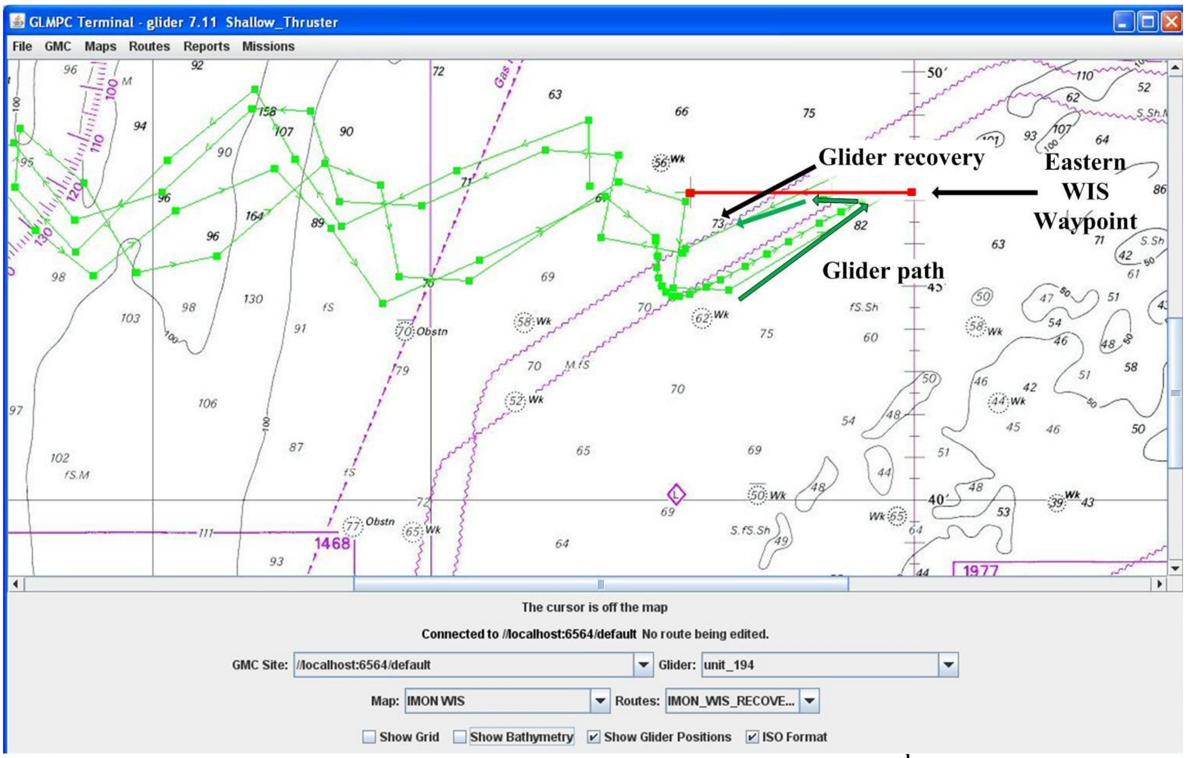


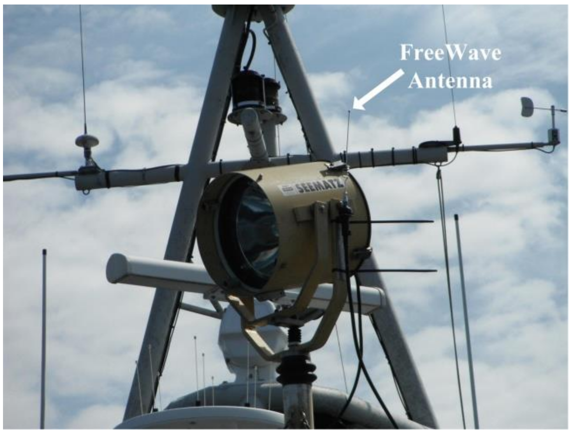
Fig. G1. Unit 194 Glider Transect leading up to the recovery on 3rd June 2013

This screen capture of the glider positions was generated using the TWR GLMPC glider plotting software. The background of the plot is a calibrated map that provides basic bathymetry information in terms of the lowest astronomical tide levels for the WIS survey area (survey area 1).

The red square to the right of the screen capture in Fig. G1 represents the eastern WIS survey waypoint at a GPS location of 54° 47.000'N, 5° 0.000'W. The green squares represent the reported GPS surfacing positions by the glider. The series of closely spaced green squares indicated by the arrows represent the glider path when a 30 minute surfacing interval was enabled. This was used for regular GPS positional updates from the glider in advance of the recovery. When the FPV *Barrule* was offshore and out of mobile phone and internet range a portable iridium satellite phone was used to call Matthew Palmer at NOCL who was acting as a shore based glider pilot. Positional updates for the glider were obtained until the glider was within FreeWave wireless data range onboard FPV *Barrule*, which was approximately 1-2km from the glider. When the glider was within FreeWave data range, Chris Balfour then took over control of the glider from FPV *Barrule*. The ship was subsequently aligned to the east of the glider surfacing location at approximately 100 m away from the glider, which was within visual range.

The glider was then configured to survey for 60 minutes at 10:20 GMT at a starting GPS location of 53° 46.497'N, 5° 04.903'W and to a lower inflection trigger depth of 50m. This depth limit was based upon the capabilities of the small water sample collection carousel and winch assembly that was available onboard during the glider recovery operations. Following the start of the glider 60 minute survey, and with the glider initially surveying within 100 m of the FPV *Barrule*, a series of sensor calibration samples were taken. A CTD with a water sample collection carousel was used to gather water samples from near the sea surface and a depth of approximately 50 m. A selection of photographs of the glider recovery operations are shown in figures G2 and G3.

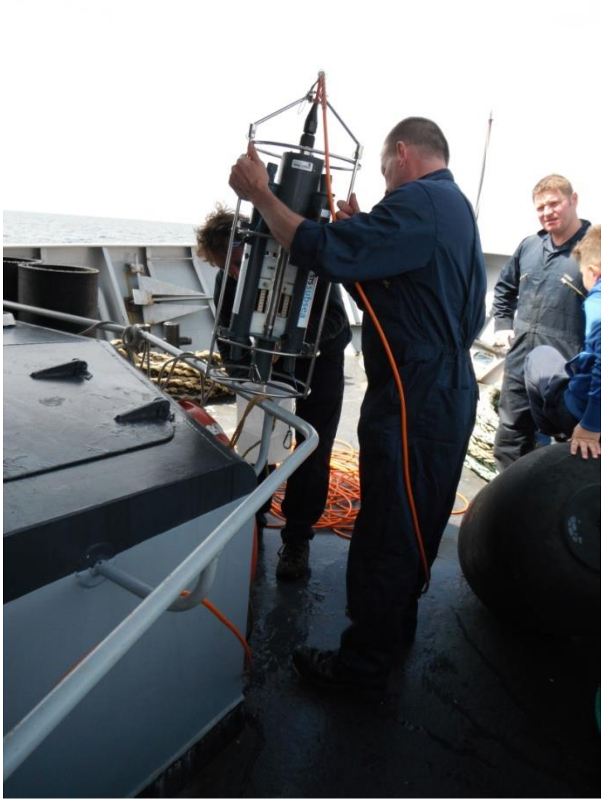
The deployed unit 194 glider prior to recovery



FreeWave wireless data antenna mounted above the wheelhouse on FPV *Barrule*

Glider monitoring

Onboard water sample collection and filtration



Preparation of the water sample collection carousel

Fig. G2. Onboard Pre Glider Recovery Operations using the FPV *Barrule*

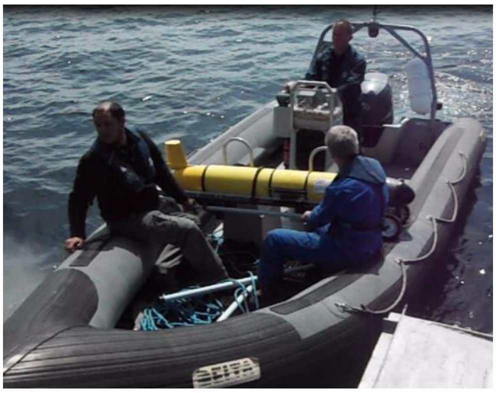
The FPV *Barrule* CTD comprised of a YSI SI 6600v2 with a ROX Reliable Optical Dissolved Oxygen sensor, a 6025 optical chlorophyll sensor and a conductivity/temperature port. The collected samples were stored onboard and where appropriate, some of the samples were frozen for later analysis. The samples were processed in a laboratory after the FPV

Barrule recovery cruise to provide independent, precision measurements for comparison with the glider sensor readings. Samples for CTD, Chlorophyll-a, suspended particulate matter (SPM) and dissolved oxygen were taken. This allowed the calibration of the glider scientific sensors to be tested and documented at the end of the glider survey. It was not possible to collect and store CDOM reference samples appropriately during glider recovery cruise. This was due to the requirements of a very low temperature freezer for CDOM sample storage and for subsequent later sample analysis to occur within hours or days. This rapid CDOM sample analysis is considered to be essential in order to prevent frozen sample degradation and this could not be achieved during the glider recovery operations.

Onboard RHIB deployment for the unit 194 glider recovery

Deployed RHIB

Recovered glider

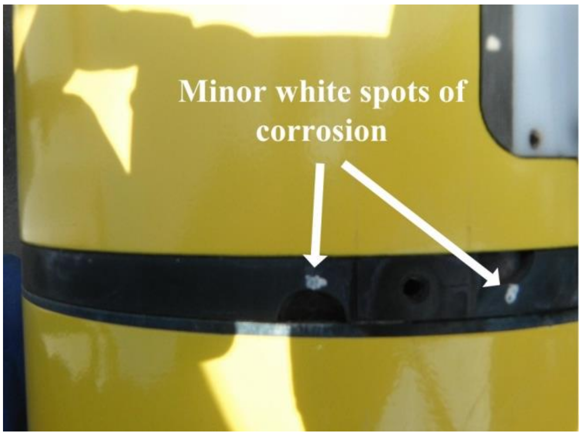


Return of the RHIB

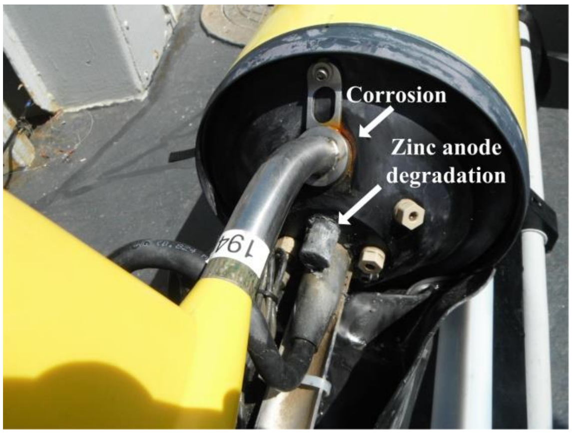
Fig. G3. The Unit 194 Glider Recovery

A Seabird Microcat CTD was also deployed over the side of FPV *Barrule* to a depth of approximately 2.5 m to provide precision near surface measurements prior to the glider recovery. The Microcat was deployed at 10:35 GMT at a GPS location of 53° 46.474’N, 5° 05.071’W and recorded stabilised readings from 10:39 GMT to 11:28 GMT at 10 second intervals. When the final one hour glider survey was completed at 11:28 GMT the Microcat CTD was recovered and preparations for the glider recovery were made. The onboard RHIB was launched and the glider was recovered using the glider transportation trolley. The sea state was good and the recovery was completed within 15 minutes. After the recovery occurred the glider was serviced and the internally recorded data was downloaded and backed up. Approximately 62% of the 720Ah maximum available internal battery energy had been used during the deployment. Initial checks showed that a full data return had been achieved by the glider over the deployment from 6th April to 3rd June 2013. Pictures of the recovered glider are shown in Fig. G4. There was some evidence of minor corrosion and outer surface biofouling during the initial unit 194 glider evaluation. There was also an accumulation of fine sediment inside the rear tail cowling that may have provided opposition to the uniform inflation of the rear tail section bladder.

Minor hull/sensor biofouling in the form of an apparent algae plus sediment deposit



Slight hull corrosion (white spots/deposits) on the metal inter hull sections



Rear tail mounting corrosion and rear zinc anode degradation

Some folds were apparent in the rear tail elevation bladder that is inflated during glider surfacing

Fig. G4. Initial evaluation of the recovered unit 194 glider

The sacrificial zinc anode to the rear of the glider had degraded during the deployment. Rapid anode degradation has been previously observed and it is something that tends to regularly occur with coastal instrumentation. After a very brief review of the recovered glider status it was apparent that the glider was in good condition after a challenging survey of almost 2 months in duration. The glider was first washed down with fresh water and dried. All of the glider hull seals, with the exception of the forward hull seal just behind the nose cone section were opened, cleaned, re-greased and reassembled. This occurred during the internally recorded data recovery process onboard FPV *Barrule*. It was also noted that at the end of the deployment the total number of glider underwater inflections were reported as being in excess of 20,000 (20792 was the last reported value during the glider survey). In line with TWR guidelines it was recommended that a routine replacement of the buoyancy pump rolling diaphragm for the unit 194 glider should occur before the next deployment.

Appendix H – Operational Timeline and Recovered Glider Data Initial Evaluation

The plots in Figures H1, H2 and H3 show a basic visualisation of the unit 194 science data during the deployment. This is intended as an initial and very preliminary review of the data return from the unit 194 glider. The measurements illustrated in the plots have not had any calibrations or adjustments made for sensor or measurement drift and offsets that may have occurred during the unit 194 glider deployment. These data are as recorded in the glider. The survey was almost 58 days in duration and was from Saturday 6th April to Monday 3rd June 2013. Preliminary indications of an initial analysis of the recovered unit 194 glider data are that a full, high quality data set has been recorded during the deployment for temperature, conductivity and pressure (used to derive salinity and density), CDOM, dissolved oxygen, Chlorophyll-a concentration and backscatter.

The operational timeline for the unit 194 Glider UK-IMON project deployment was:

- The unit 194 glider was deployed at 18:35 GMT on Saturday 6th April 2013 at a location of 53° 47.046'N, 5° 0.042'W and the 42km wide cyclic horizontal western Irish Sea survey transect was started. The western extreme of the glider transect was close to the AFBI Site 38A mooring array that was used for measurement comparison.

- The unit 194 glider subsequently undertook a rendezvous with RV *Corystes* on Wednesday 10th April at 07:00 GMT close to the AFBI Site 38A moorings at 53° 47.000'N, 5° 37.903'W. A period of 8 hours was then used by RV *Corystes* to gather AFBI mooring and glider science sensor calibration measurements.

- On Friday 12th April at 08:00 GMT a transect was started by the unit 194 glider to navigate south along the St George's channel of the Irish Sea towards the CEFAS Celtic Deep mooring.

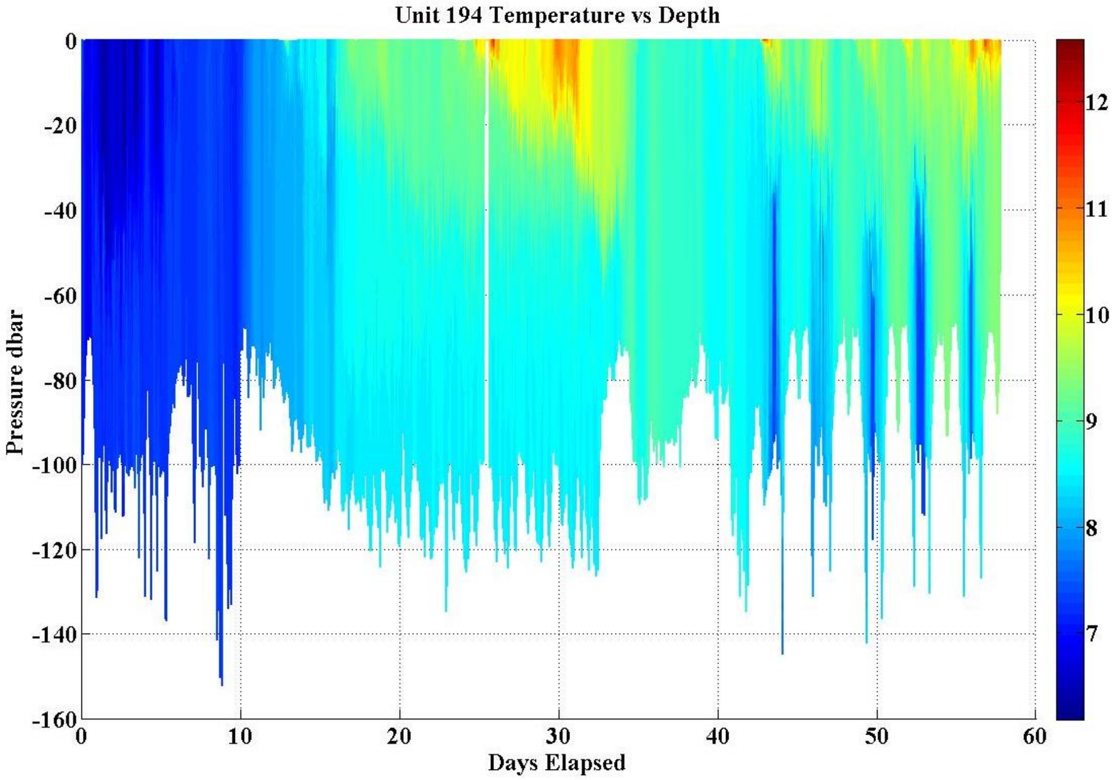
- At 06:24 GMT on Wednesday 24th April, the unit 194 glider arrived in proximity of the Celtic Deep survey area with the glider reporting a GPS location of 51° 20.912'N, 6° 11.013'W. A 30km wide horizontal east to west unit 194 glider survey cyclic transect was then started. The eastern extreme of the glider survey transect was close to the Celtic Deep mooring.

- At 09:23 GMT on Wednesday 8th May the return transect of the unit 194 glider north along the St George's Channel in the Irish Sea was initiated.

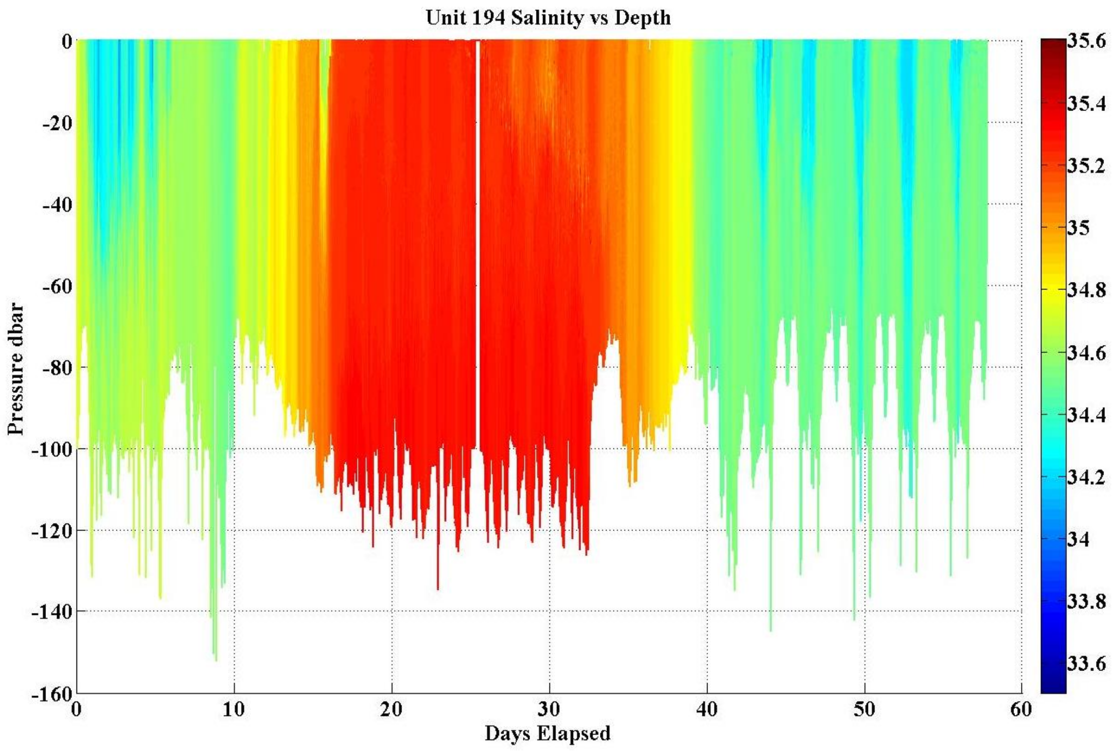
- The unit 194 glider arrived in proximity of the western Irish Sea survey area on 04:57 GMT on Monday 20th May, with the glider reporting a GPS location of 53° 45.909'N, 5° 34.517'W. The 42km wide east to west (WIS) cyclic horizontal glider survey transect was then resumed. As used during the initial glider deployment, the western extreme of the glider survey transect was close to the AFBI Site 38A mooring array at a GPS location of 53^{o} 47.000N, 5^{o} 37.903W.

- On Monday 3rd June the glider was recovered at approximately 12:00 GMT at a GPS location of 53^{o} 46.086N, 5^{o} 07.634W, which was approximately 8km to the west of the eastern waypoint of the WIS survey transect. This completed a deployment of the unit 194 glider that was almost 58 days in duration.

Due to a mission abort during unsociable hours an interruption of approximately 8 hours in the data recording occurred on Thursday 2nd May, as shown in Fig. H4. The early morning occurrence of this glider abort at 01:51 GMT resulted in a time delay before control of the glider could be achieved and the survey was resumed.

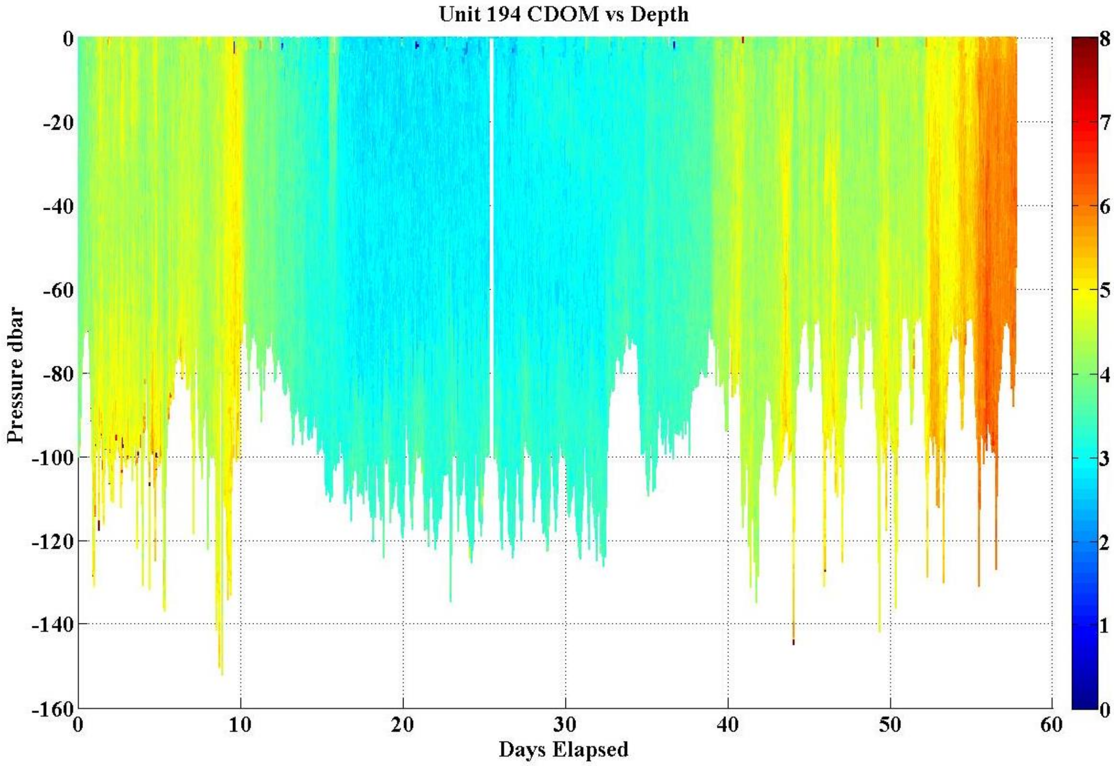


Temperature

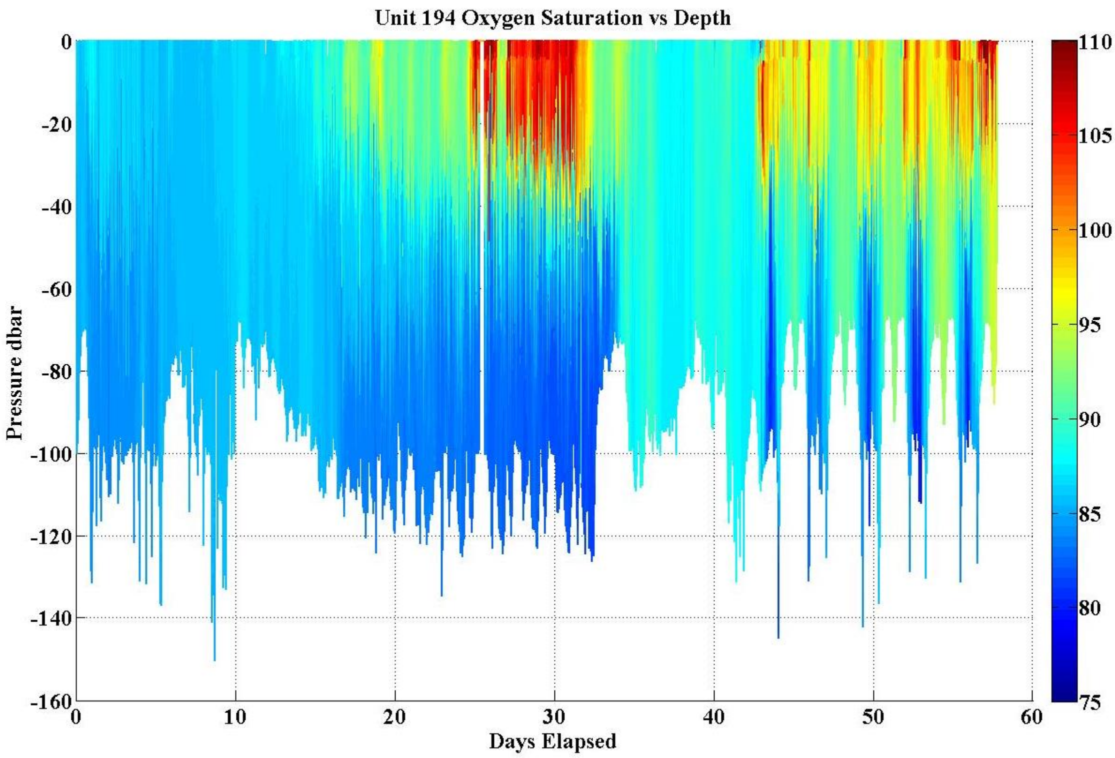


Salinity

Fig. H1. Unit 194 Science data – Temperature and derived Salinity

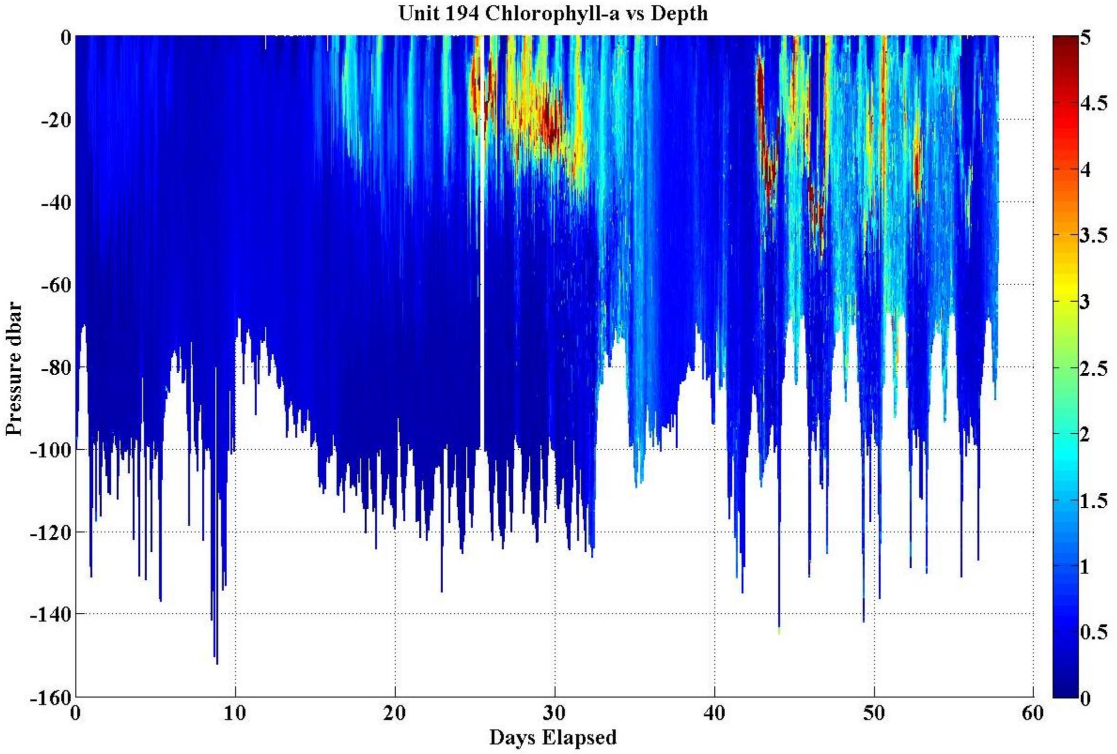


CDOM

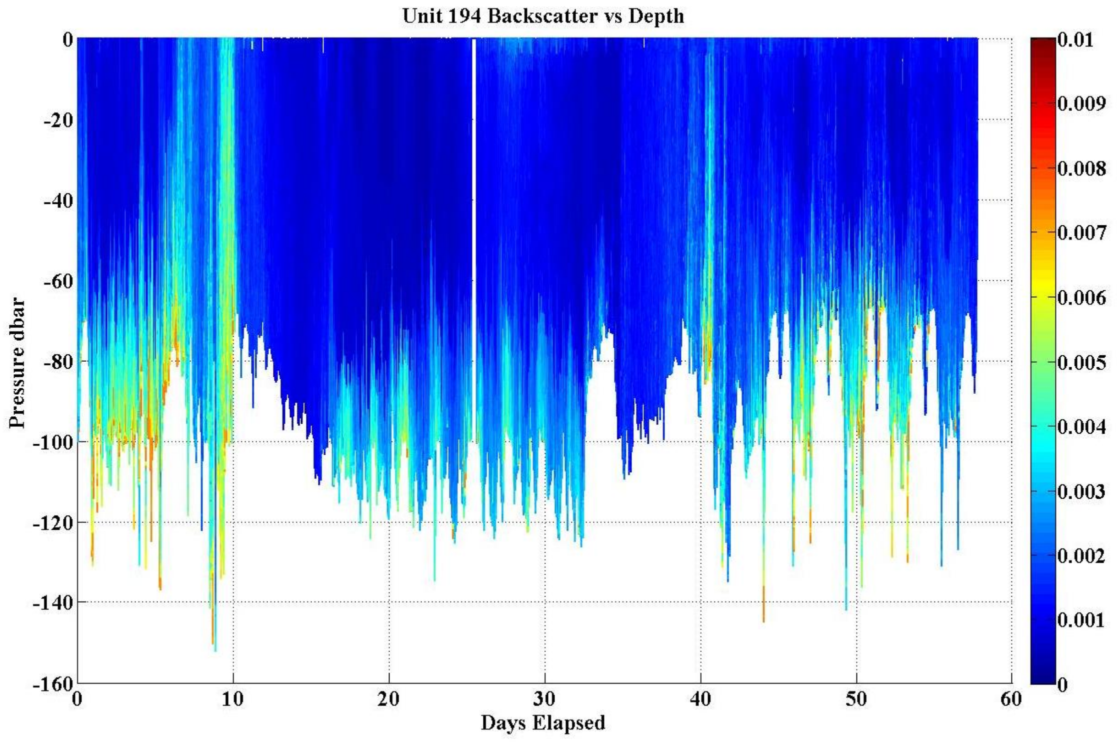


Dissolved oxygen saturation

Fig. H2. Unit 194 Science data – CDOM and Dissolved Oxygen



Chlorophyll-a concentration



Backscatter

Fig. H3. Unit 194 Science data – Chlorophyll-a and Backscatter

After closer examination of the recorded glider science data an interruption of approximately 8 hours occured in the glider science data recording during day 26 of the deployment, as shown in Fig. H4. This corresponds to a glider mission abort that occured at 01:51 GMT on Thursday 2nd May. Due to the unsociable hour that this glider survey mission abort occured, there was a period of time before control of the glider was regained and the scientific survey was resumed.

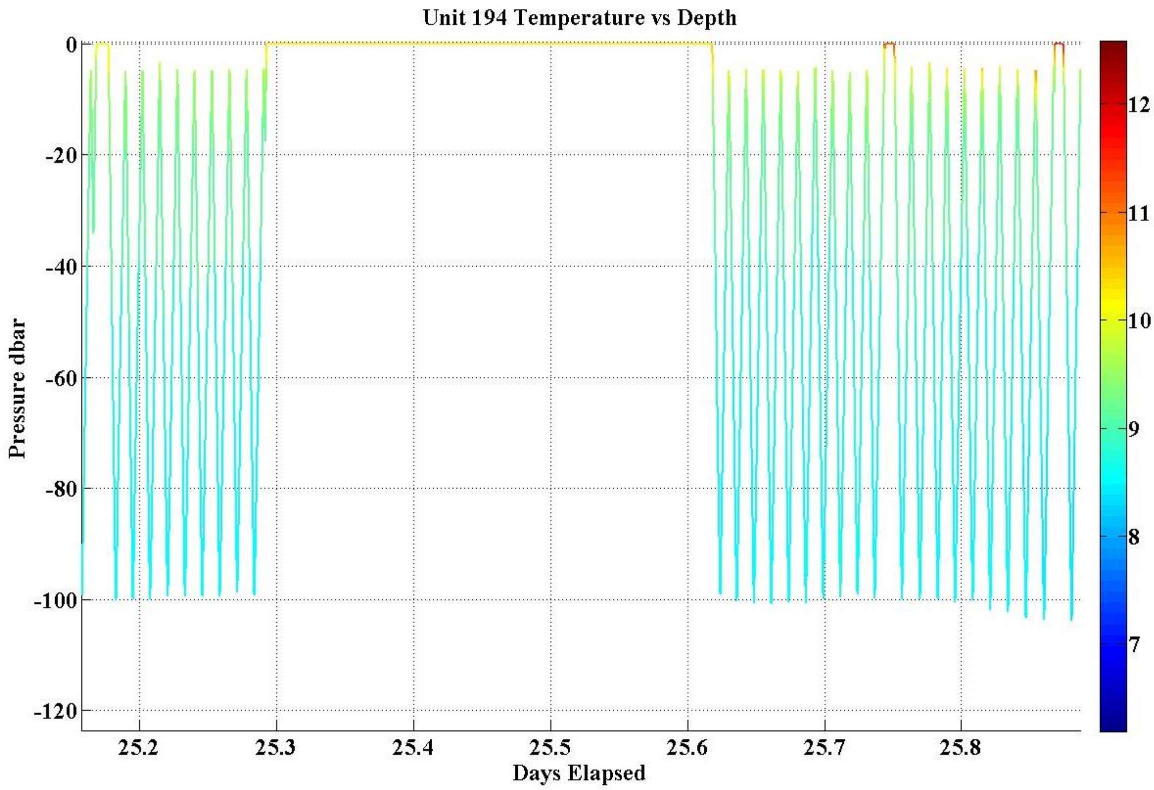


Fig. H4. Unit 194 Science data interruption

Zoomed temperature plot that shows an interruption of approximately 8 hours occured in the glider science data recording during day 26 of the deployment. This corresponds to a glider mission abort that occured at 01:51 GMT on Thursday 2nd May