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Wave Glider trial, final report; September 2013

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1. Executive Summary

The Liquid Robotics Inc. designed and built Wave Glider is an autonomous sea-going vehicle. It comprises a surface float with various instruments, solar panels and battery packs, and a sub-sea sled providing steering and propulsion by the action of waves.

Cefas and Liquid Robotics Inc (LRI) ran a joint trial of the Wave Glider in the southern North Sea. The collaboration started in September 2012 with discussions regarding the aims and potential technical hurdles. In December and January a Wave Glider was fitted with Cefas SmartBuoy sensors.

Cefas was not able to trial the use of acoustic sensors on the Wave Glider as the loan unit was not available at the time of the trial.

The Wave Glider was deployed on 28/01/2013 from Lowestoft using a small local vessel. It was piloted by LRI staff to avoid hazards such as sandbanks, oil and gas platforms and shipping. It took approximately five days to get the Cefas SmartBuoy site at Dowsing where it held station to within seven nautical miles for a further five days. It was piloted back east and south past Lowestoft to the West Gabbard SmartBuoy site where it held station until it was recovered on 28/02/2013.

The data from the Wave Glider mounted sensors and the SmartBuoy telemetry data show that the Wave Glider can be used to collect a limited data set. Initial analysis showed that the data collected at the Dowsing SmartBuoy site are representative of water to at least fifty nautical miles east.

The Wave Glider could be a useful tool in the future monitoring programme although there are still several unknown factors (such as battery life in winter and bio-fouling in summer) and the danger from shipping will always be an issue. Other instruments and sensors could be integrated and longer missions could be undertaken. The main drawback is the cost of piloting estimated at £50,000 per year.

2. Introduction

The Wave Glider is an autonomous system deployed at sea, originally designed for monitoring cetaceans in the deep oceans, but which has been expanded to many uses. It is self-propelled by the action of waves and the instruments and communications are powered by batteries recharged by solar panels. A big advantage of this system is ease of launching and recovery from a small vessel.

The aim of this scoping study was to fund a trial to assess the suitability of the Wave Glider for deployment in UK waters, specifically the southern North Sea, for its use in addressing MSFD-required parameters.

2.1 Liquid Robotics Inc

Liquid Robotics Inc. (http://liquidr.com/) manufactures Wave Gliders. The first view of the Wave Glider by Cefas staff was at Oceanology 2012 in March, where the demonstration model was admired and the concept was discussed with Liquid Robotics Inc (LRI) staff. The UK representative "Manson Oceanographic Consultancy" was contacted and Colin Manson gave a presentation at Cefas in July. Thereafter communication was largely direct to LRI personnel. The representation of LRI in the UK has subsequently transferred to RS Aqua.

2.2 Project Plan

The project plan was to have a one month sea trial to test the following:

a) The operation of the Wave Glider in the North Sea (can it cope with strong tides, high vessel activity and low winter light levels?),
b) The capacity for integration of Cefas SmartBuoy compatible ESM-2 logger and sensors on a Wave Glider,
c) The Wave Glider as a platform suitable for acoustic monitoring,
d) The ability to hold station at the Dowsing and West Gabbard SmartBuoy sites.
e) To check the sensor performance on the Wave Glider and to assess the spatial representation of a SmartBuoy at those sites.

After a quote was received and subsequent negotiations regarding the cost of the joint project, a general plan was agreed and an order placed in late November 2012. LRI viewed this project as a joint trial using a demonstration unit where Cefas was largely covering their costs. LRI took all the risk of loss of the Wave Glider (except the Cefas sensors), the cost of the iridium telemetry and the 24 hour operational piloting. A senior LRI engineer (Mike Cookson) visited Cefas in December 2012 to discuss some of the technical details of interfacing Cefas and LRI equipment and it was decided there was nothing serious to stop the project. Regular teleconferences were held where progress and issues were discussed; for example at one point LRI were worried about the proposed route and trial area but after discussions, Cefas' requirements prevailed and the project was kept relevant to policy. Initially Cefas wanted to mount the sensors on the sled at 7m below sea level, but LRI were concerned about the additional drag on the sled affecting the overall performance. It was suggested that the sensors could be towed behind the sled but it was thought that made them rather vulnerable and the data would not have been transmitted back during the deployment (also a data security risk). The LRI engineer (Ryan Carlon) who visited Cefas for the final integration and deployment was professional and got on well with Cefas staff. This was consistent as Cefas relations with LRI were good throughout the project.

3. Mission

3.1 Mission Plan

Liquid Robotics agreed with Cefas' initial aims and their operations team did some research into the trial area and problems that might be faced. Cefas provided model outputs of tidal predictions for the period of the trial. The operations team produced a report which addressed:

- Water depth - shallows and shoals
- Navigation hazards - e.g. oil and gas platforms
- Vessel traffic - known shipping channels, regular routes and fishing areas
- Weather conditions - hours of sunlight, temperature, likelihood of storms
- Sea state - tidal speed and direction, wave height and period

It was agreed that the launch would be from Lowestoft harbour and that deployment would be approximately 30 miles north along the Norfolk coast to somewhere off Sea Palling where there was less traffic and deeper water. It was also agreed to launch just prior to *RV Cefas Endeavour* cruise 1/13 as the ship was intending to operate in the trial area and could potentially be called upon for rescue or protection.

Cefas obtained the necessary permission from MMO for the operation of an unmanned vehicle in the relevant sea area.

The specification for the telemetry message was agreed during Mike Cookson's visit. The standard Orbcomm message output from the ESM-2 was modified by removing unnecessary information to reduce the size of the message.

3.2 Pre-deployment preparation

The Wave Glider, named by LRI as 'Hermes', arrived in Lowestoft in three crates on 10/12/2012 and was unpacked and constructed over three days by three Cefas staff. The assembly instructions provided were adequate, using photos to depict assembly, however diagrams could possibly have been more useful to illustrate how parts fit together. The instructions for the pre-deployment frame actually depicted a different design. The ADCP was removed in preparation for the acoustic monitoring equipment. There was also another large hole cut out of the hull in the forward payload bay.

‘Hermes’ was fitted with a Cefas ESM-2 logger, Aanderaa Optode, Aanderaa conductivity and temperature (CT), Seapoint optical back scatter (OBS) and Seapoint chlorophyll fluorometer. This was a sub-set of the suite of sensors deployed on Cefas SmartBuoy (the nutrient analyser, water sampler or Licor PAR were not trialled). An ESM-2 logger was installed into an IP67 housing with impulse connectors by Cefas EDU staff (Figure 1). These types of casing are only rated for constant submersion at a depth no deeper than 1 metre, but are lighter and more compact than the standard ESM-2 pressure housing.

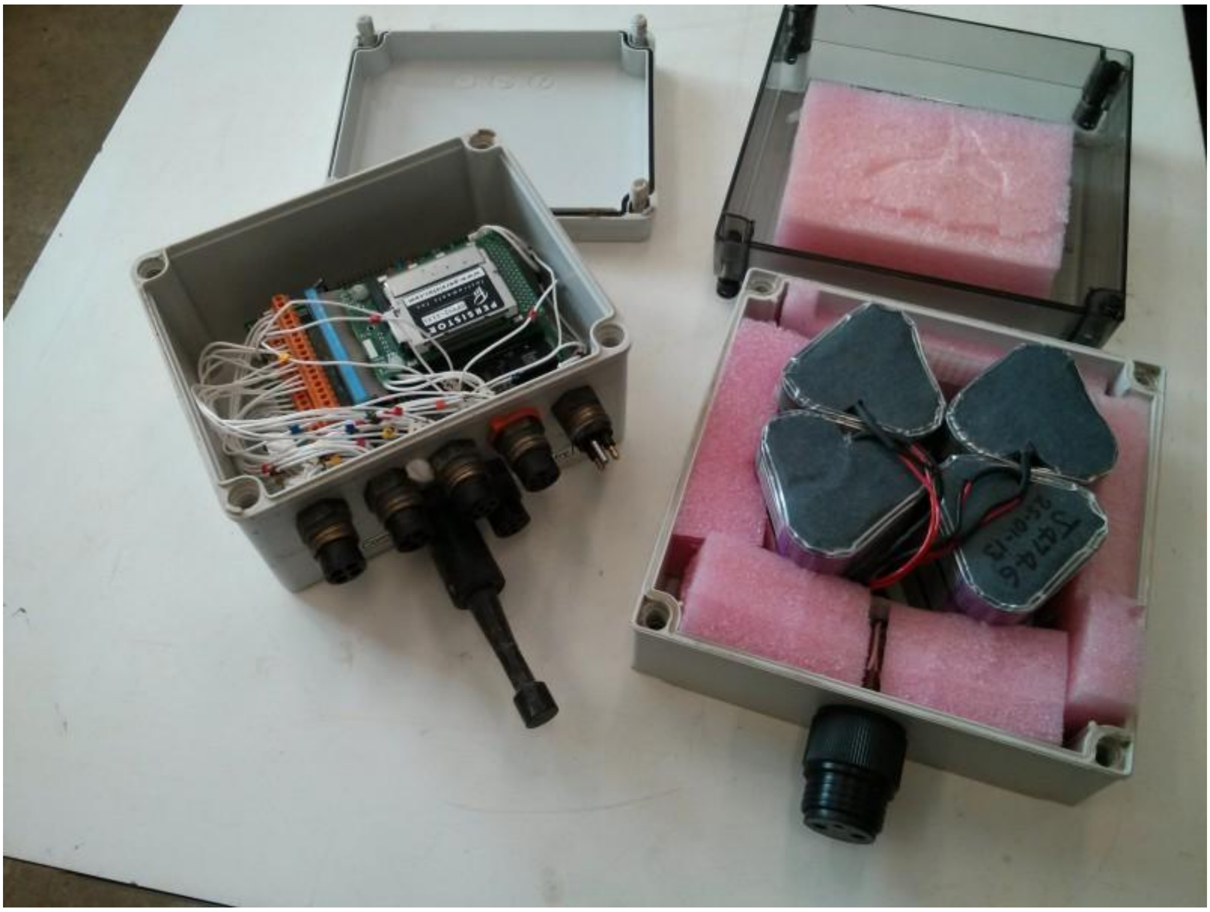


Figure 1: ESM-2 and lithium battery pack in custom housings

By moving the logger out of the standard Cefas housing and by using a similar housing for a custom made battery, enough space was saved to fit the sensors and logger in rear bay with the batteries in the front. Approximately 70% of the space in the front bay was left empty. A pack of lithium batteries were used instead of the standard alkaline cells because of the higher energy density, saving both space and weight. A larger pack could have been fitted but was unnecessary given the length of the mission.

The four sensors were mounted into a specially designed plate to fit onto the ‘ADCP-hole’ giving a sampling depth of approximately 30 cm as shown in Figure 2.

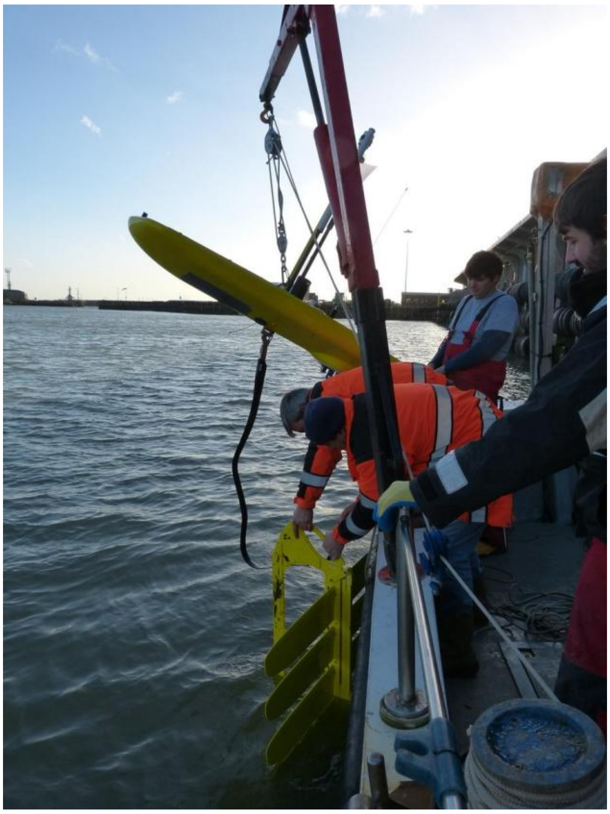
Figure 2: Cefas SmartBuoy sensors fitted to the ADCP cavity

The ESM-2 logger was configured to sample for 60 seconds every 5 minutes with a 60 second warm-up. The Orbcomm telemetry protocol was used for transmitting live data to the Wave Glider communication controller. A data processing module was provided by Liquid Robotics to translate the Orbcomm type message to a format that could be sent by the Wave Glider Iridium unit. Configuring this unit proved difficult and with limited time before the deployment deadline, Ryan was only able to implement some of this functionality. Clearer instructions for integrating the ESM-2 logger could have allowed more preparative work before Ryan's arrival. 'Hermes' being a demonstration vehicle arrived already fitted with a signal processing computer and the ADCP from the previous mission. A 4m umbilical was fitted, rather than the standard 6m, to reduce the glider draft and help avoid the expected shallow water hazards.

The aim of fitting acoustic monitoring devices to the Wave Glider was not achieved as the loan unit was not available in time (from NERC/SMRU).

3.3 Deployment

The Wave Glider was easily loaded and transported in a long wheel-base van to the Lowestoft fish docks, where it was carried along the quay by four people and then winched aboard the Lowestoft Provider. Ryan Carlon provided training to the Woodmarine crew and Cefas staff during two practice deployment and recovery exercises while still moored in the docks (Fig 3 and 4).



Fig, 3 and 4: Wave Glider training aboard Lowestoft Provider

This demonstration proved that two people can deploy and recover the Wave Glider although it is easier with three and possibly less likely to sustain damage. Immediately following the training session *Lowestoft Provider* sailed out of Lowestoft harbour to attempt the live deployment. It was soon apparent that the prevailing sea conditions were marginal and it was not possible to steam to the intended deployment site 30 miles away. After a phone call to the LRI operations centre to inform them of the change of plan, Hermes was deployed at 17:30 30/01/2013 approximately 3.5 nautical miles off Lowestoft (52.52315, 1.846933).

Due to the rough weather the Glider was not correctly orientated as it was being deployed, and rather than moving away perpendicular to the boat, it moved alongside where the roll of the boat caused an impact with the broadband iridium antenna. The impact damaged the antenna and it was unavailable for use during the mission, no other damage was observed (Fig. 5). Ryan Carlon noted that the antenna has been previously damaged and is being redesigned. The antenna is used for bulk transmission of sensor data and is not mission critical.

Fig 5: Hermes sets off with bent antenna

3.4 Navigation

As part of the mission plan waypoints were chosen to avoid the major hazards. Control of the Wave Glider is provided through a web interface which plots the current and historical position together with hazards and waypoints on a Google map with an Admiralty chart overlay. Several of Cefas staff were given login credentials for observing 'Hermes' progress. Strong tidal currents affected the glider navigation between 31/01/2013 and 02/02/2013 until calmer waters were reached north of 53.22. Whilst northerly progress was still made, the Wave Glider was pushed off course by up to 3 nautical miles by southerly currents (Fig 6). It appears with increasing familiarity with the local currents LRI pilots improved their ability to keep the glider on course, presumably by anticipating changes in current and manoeuvring the glider appropriately. Multiple approaching vessels were observed by the onboard AIS receiver on many occasions. Typical responsive actions taken were to turn on the Wave Glider's navigation light and active radar reflector to improve the visibility of the glider to an incoming vessel.

Course changes may be made but would typically be unproductive given the disparity between the speed of boat traffic (20 knots) and the 1-3 knots capacity of the Glider. At around 53.66, 02.59 Hermes was piloted west towards the Dowsing SmartBuoy, thus avoiding the bulk of the navigational hazards identified. The currents on this westerly leg of the mission were mild and navigation was easy. The Wave Glider arrived in the proximity of the SmartBuoy on 07/02/2013 around midday. For the next six days the glider attempted to maintain position around the buoy, coming within 28m of the nominal buoy position and out to 10 nautical miles with a strong current. The position was maintained within seven nautical miles of the SmartBuoy for the majority of the station holding exercise. With improved confidence in its manoeuvring ability Hermes was taken on a more direct route east before following its previous track south towards the West Gabbard SmartBuoy. 'Hermes' reached the West Gabbard SmartBuoy site on 23/02/2013 and 22:00, and maintained station within 7.5 nautical miles for the next 5 days. Upon the decision to commence recovery operations, the glider was piloted north and into calmer water to aid retrieval.

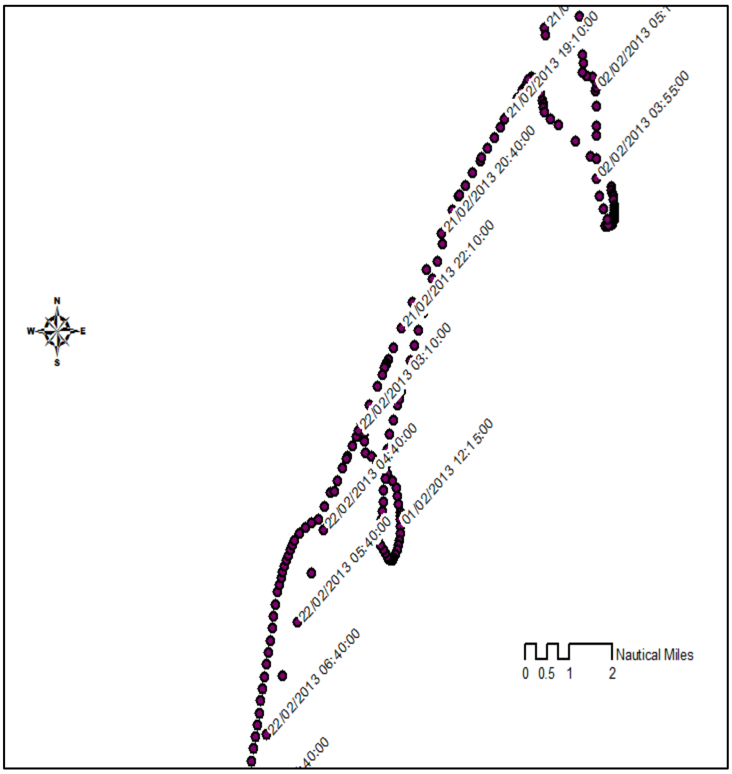


Fig 6: Section of Hermes mission track

Due to overcast weather the Glider's solar cells had not been generating adequate power to maintain the current frequency of communication messages. The decision was made by LRI to conserve power by sending fewer telemetry messages, moving from communications every 3 minutes to every 15, and then later every 30 minutes. The self powered ESM-2 logger maintained sampling every 5 minutes throughout the deployment.

3.5 Recovery

By 26/2/13 the mission aims were apparently achieved and with the weather closing in, the decision was made to recover the Wave Glider. Arrangements were quickly made and Woodmarine used the Lowestoft Provider to recover Hermes north of the West Gabbard SmartBuoy (52.08611, 1.925058) on 28/02/2013. The Woodmarine crew reported the recovery was easy and no problems were found.

There was no observable bio-fouling to the glider or the sensor array, probably due to the anti-bio-fouling paint on the float and glider. The float, sled and instrumentation were all undamaged with the exception of the broadband Iridium antenna hit during deployment. The Wave Glider was returned to Cefas via a pickup truck and the data downloaded from the ESM-2 logger.

Fig 7: Hermes post recovery in Lowestoft harbour

4. Data

The ESM-2 data from the Wave Glider and the two relevant SmartBuoys have now been quality assured. The ESM-2 and sensor package performed as expected with no technical problems. GPS telemetry data have been provided by LRI. These data have been aggregated with the ESM-2 data and loaded onto the SmartBuoy database for easy dissemination and analysis. Generally the collected data compare favourably with the SmartBuoy data and no unusual spikes or patterns can be seen which would indicate that the sensors behave differently when fitted to the Wave Glider. The decision to conserve power by reducing the frequency of telemetry messages during the mission has resulted in fewer usable data points, where ESM-2 data have no matching GPS. It could be possible to interpolate the data between the measurements positions but this has not been attempted here. The complete Wave Glider track is shown in Fig .8 with salinity illustrated with a graduated colour scale.

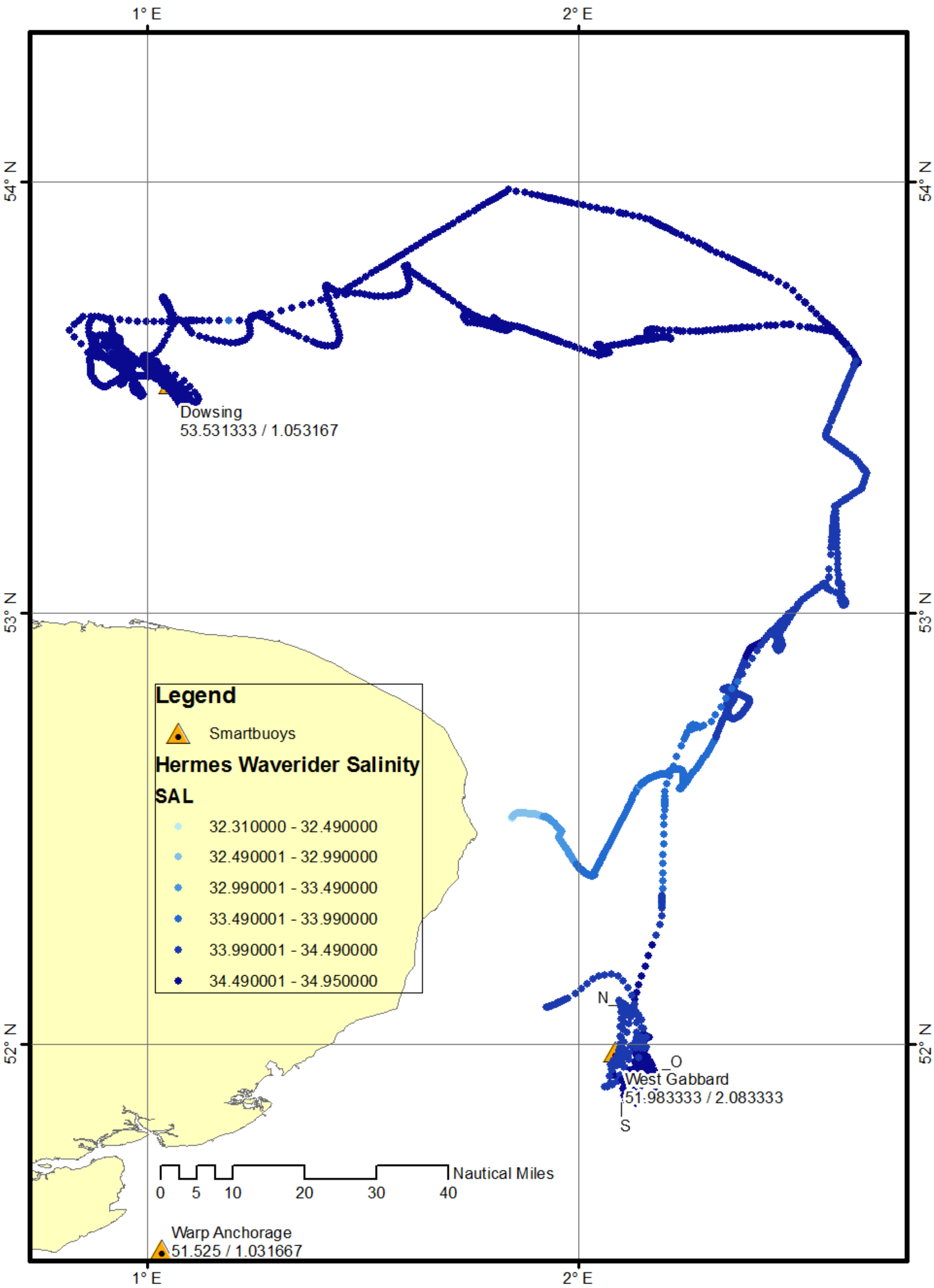


Fig 8: Wave Glider track is shown with graduated point colour illustrating the salinity logged by the ESM-2

4.1 SmartBuoy comparison

The Dowsing SmartBuoy deployment #30 and West Gabbard SmartBuoy deployment #90 were serviced at the start of February 2013 and serve as useful comparison points with the Wave Glider data.

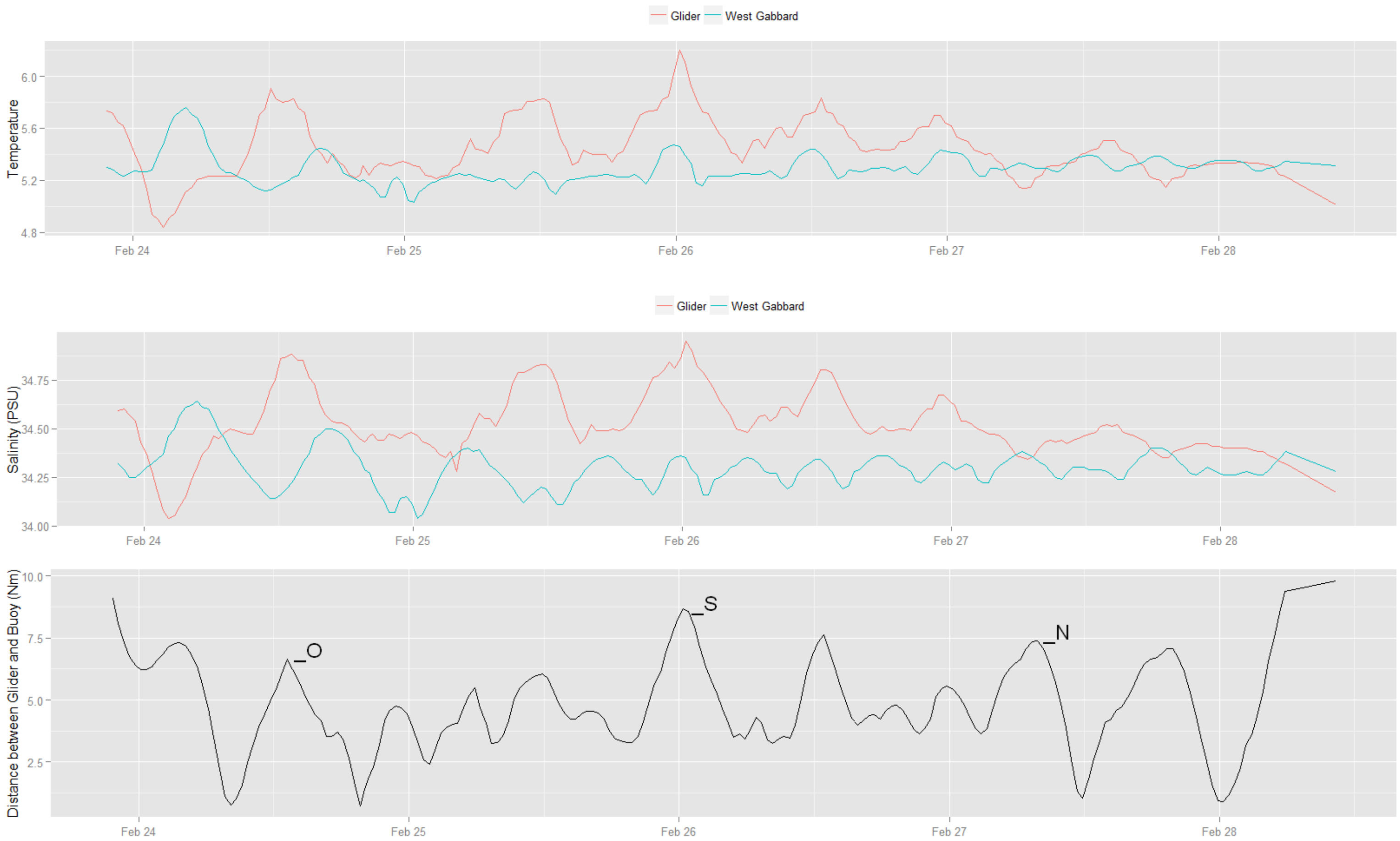


Fig. 9: Wave Glider and West Gabbard data; (a) salinity, (b) temperature with (c) distance of Wave Glider from West Gabbard buoy

Measured chlorophyll (fluorometry) was low and showed little variation throughout the period but compared well with concurrent data from both buoys. Similarly optical backscatter measurements generally varied little with comparable readings from both buoys. There were a few short spike events in the optical backscatter measurements probably caused by surface bubbles.

Wave Glider and West Gabbard buoy salinity and temperature data are compared in Fig. 9a and b. Fig. 9c illustrates Wave Glider distance from the West Gabbard buoy. A corrective offset is required for Aanderaa CT salinity measurements to account for conductivity errors caused by the SmartBuoy metal frame. However, analysis of in-situ salinity bottle samples has not yet been done so no offset has been applied to these data. Judging from previous deployments with these specific sensors the salinity correction is anticipated to bring the two salinity time series closer together. The salinity and temperature comparison between the West Gabbard buoy and the glider demonstrates an interesting situation. Due to the fact that the Wave Glider can only partly fight against the strong tidal currents found at the Gabbard, the range of salinity measured and the disparity between the glider and the buoy changes dramatically over the tidal cycle.

As the glider first approached the West Gabbard buoy it overshot and ended up further South and then East in what appears to have been a quite different body of water compared to the buoy (shown as point O on Fig. 8 and Fig. 9). After this the glider maintained a distance approximately 5 nautical miles from the buoy and measured similar tidal patterns. At approximately midnight on the 26th the current pushed the glider further south as shown at point S on Fig.9 and measured water of higher salinity and temperature than that measured at the buoy. This contrasts with later in the mission (point N on Figs 8 and 9) on the 27th where a similar distance north of the buoy demonstrated less disparity in temperature and salinity. As there is a much lower tidal influence at the Dowsing site the agreement between the Wave Glider and the Dowsing buoy data is much better, as shown in Fig.10.

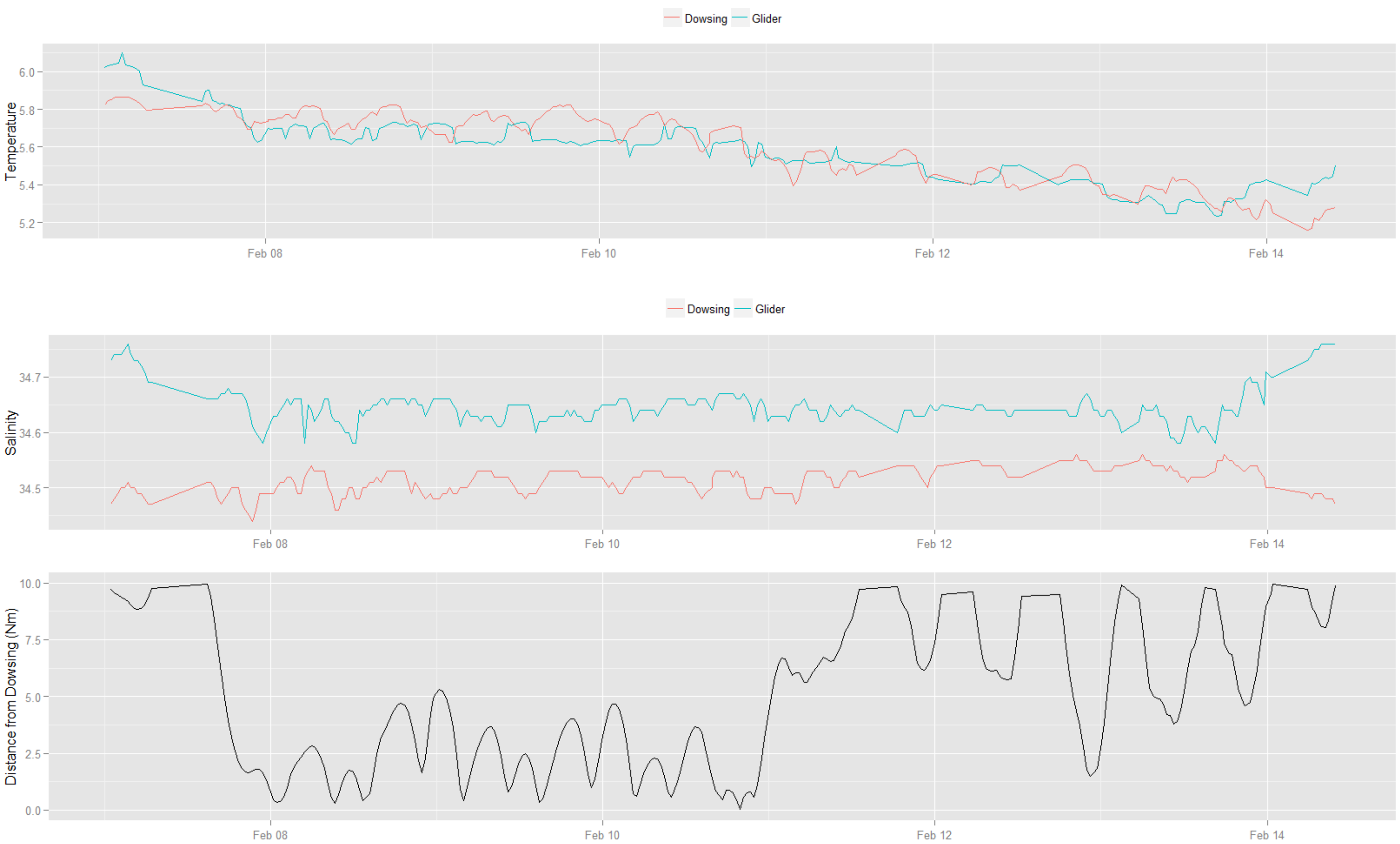


Fig. 10: Salinity (a), temperature (b) with distance (c) of Wave Glider from Dowsing buoy

This highlights a potential issue with the use of glider data, especially if the glider was used as a replacement for a static mooring. Tidal signals can be masked by the drifting movement of the glider and what looks like changing local conditions can actually be due to movement of the glider. Interpretation of the results is not as straightforward as static moorings.

It was also considered it might be useful to look at MODIS satellite imagery during the mission as a wider field for comparison. However it was discovered that during the Wave Glider mission there was no MODIS imagery available due to constant cloud cover.

5. Conclusions

5.1 Liquid Robotics' overview

Liquid Robotics' operations team had identified some operational challenges about the area, but in the end it has shown itself to be more navigable than was originally thought. The current and demonstrated version of the Wave Glider will be challenged whilst station-keeping in high tidal currents close to shore, but this can be mitigated by planning around very predictable tidal currents. Additionally, battery power is going to continue to be a concern in the winter months, and should be mitigated with a supplemental battery payload. Vessel traffic in the area is definitely dense, and requires 24-hour monitoring. For future missions, I would suggest using LRI's piloting services in some way, whether full time, or even just night-time control of the vehicle. Although an initial concern, the overall bathymetry of the area was not a significant navigation factor. While there are some shoals, for the most part, the depths are more than enough to accommodate Wave Glider operations. The choice of selecting a short umbilical for this mission proved to be wise. (Submitted by Ryan Carlon, LRI).

5.2 Cefas overview

The outcomes of the project addressed the tasks and questions set out in the project plan (section 2.2) as follows:

a) The operation of the Wave Glider in the North Sea (can it cope with strong tides, high vessel activity and low winter light levels?).
The Wave Glider operated sufficiently well in the North Sea. It coped adequately with strong tides and currents in a busy shipping area with very low levels of winter light. Low sunlight limited the telemetry use, but this could be overcome with more batteries. No bio-fouling was observed. Newer versions of the Wave Glider will probably cope better.

b) The capacity for integration of Cefas SmartBuoy compatible ESM-2 logger and sensors on a Wave Glider.
The Wave Glider had more than adequate capacity for the ESM-2 logger and standard SmartBuoy sensors, which filled the small front bay without problems. There is room for another similar sized set of sensors in second bay. The new version of the Wave Glider is larger and could accommodate a small cefas EDU water sampler (maximum 11 samples). It is likely that more sensors could be fitted at depth (on the glider section) if they are adequately hydrodynamic.

c) The Wave Glider as a platform suitable for acoustic monitoring.

The time constraints of this particular project did not permit the inclusion of acoustic hydrophones in the suite of sensors. Therefore it was not possible to test whether the Wave Glider is a suitable platform for acoustic monitoring.

d) The ability to hold station at the Dowsing and West Gabbard SmartBuoy sites.
The Wave Glider adequately demonstrated its ability to hold station around the SmartBuoys. The Glider maintained a circle of more than 7 nautical miles even at the strongly tidal West Gabbard site.

e) To check the sensor performance on the Wave Glider and to assess the spatial representation of a SmartBuoy at those sites.
The sensors fitted to the Wave Glider performed as expected, giving comparable data to the SmartBuoys. There are some potential issues with bubble entrainment under the glider because the sensors are mounted so close to the surface; however this did not significantly affect data quality during this trial. The Management Unit of the North Sea Mathematical Models (MUMM) in Belgium conducted a three week North Sea Wave Glider trial April/May 2013 and reported some problems with bubbles interfering with optical backscatter and fluorometer measurements. It should be noted that the MUMM group mounted their sensors at the front of the glider making them very shallow and liable to be lifted out of the water by heavy swell. Our sensors were mounted centrally and slightly deeper.

Overall the project was largely a success. Some of the integration of the Cefas systems to the LRI systems were not as straightforward as hoped and the ESM-2 telemetry string transmission was never fully achieved. This did not significantly detract from the final outcome but if the glider had been lost, the high frequency data would never have been completely recovered. The telemetry antenna that was damaged has since been redesigned by LRI to be more robust.

The Cefas team and the charter vessel crew thought the operational part of the project worked well. The Wave Glider proved easy to deploy and recover using a relatively cheap small local vessel (approx £1500 per trip).

There was ample space in the payload bay for additional equipment such as the Cefas water sampler and / or additional battery packs which would be required for the longer deployments to make full use of the Wave Glider capabilities. The Southern North Sea has ideal wave conditions for providing Wave Glider propulsion. The manoeuvrability of the glider was better than expected and the glider was capable of reaching all of the mission site objectives in good time. The strong tidal currents of the Southern North Sea made it difficult for the Wave Glider to maintain station. Due to drag issues the sensor payload was only fitted to the float and not to the glider section, but this is not ideal and would have to be reviewed and discussed with LRI for any future deployments. There was probably significant drag generated by the hole left in the front bay by the previous Hermes mission, performance with a non-demo glider would likely be improved.

Biofouling proved not to be an issue during this deployment with no evidence of growth anywhere on the sensors or glider, although it should be expected at this time of year with so little sunlight.

Piloting the Wave Glider is required 24hrs a day. The glider can be instructed to follow a heading, a set of waypoints, or maintain a watch circle. However frequent pilot input is required to manage navigation hazards, threats from boat traffic and power management. This degree of attention would be very expensive (and highly inconvenient) for Cefas staff to achieve.

Packing and shipping the Wave Glider was also straightforward and achieved in less than a day.

5.3 Future

The Wave Glider could be a useful tool in the future monitoring programme for several parameters although there are still several unknown factors (such as battery life in winter and bio-fouling in summer) and the danger from shipping will always be an issue. Liquid Robotics manufacture a larger and faster version of the Wave Glider which should have more control in strongly tidal areas, while also carrying a larger payload. LRI used feedback from Cefas on the short-comings of the Wave Glider that were identified during this project to design the improved ‘shelf-sea’ Wave Glider. Wave Gliders are capable of carrying a towed payload if the drag effect is low and if the variable orientation and depth of the payload can be compensated for. Meteorological sensors have been successfully fitted to Wave Gliders with good results, other payloads could include: wave measurements, thermistor chains, hydrophones, radiometers and sidescan sonar.

Wave Gliders could potentially be used to collect data from sea areas irregularly or infrequently visited by research vessels such as the northern North Sea and the south-western approaches. The Wave Glider(s) could be piloted past the SmartBuoys at Dowsing and Celtic Deep to allow calibration checks to take place and therefore keep the Wave Glider deployed for longer.

Some limited discussions have been suggested regarding collaboration with NERC MARS facility for both the ownership and piloting of a UK fleet of wave and buoyancy gliders. The cost of Liquid Robotics staff piloting is estimated at £50,000 per year, which is considerably cheaper than Cefas staff (£170-200k).

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