National Oceanography Centre, Southampton

Cruise Report No. 46

RRS Discovery Cruise 343

27 SEP - 15 OCT 2009

Deepwater trials of the Autosub6000 AUV, HyBIS, and telemetry systems

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2010

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ABSTRACT

There were 3 main objectives for the trials cruise: Testing of the Autosub6000 AUV, the HyBIS system (both supported by personnel from the National Oceanography Centre, Southampton), and acoustic and satellite telemetry systems (Proudman Oceanographic Laboratory, Liverpool). Specifically, the Autosub6000 trials were to test: the AUV, its systems and control to as deep as possible up to 6000 m, a new collision avoidance system based on scanned sonar collision avoidance sensor, and recently installed sensors (dual CT, LSS EH probe, magnetometer, Multibeam sonar sensors). The objectives of the HyBIS trials were to test the video guided grab system to as deep as possible, and to gain further operational experience. The objectives of the telemetry systems trials were to develop and test remote measurement technologies, deep water communication systems and a compact version of the MYRTLE (multi-year return tide level equipment) long term deep water recoverable lander. The cruise began with initial tests of the Autosub6000 AUV in the Celtic deep, followed by deep tests of the AUV to 5600m on the Iberian Abyssal plain. The majority of the work for the Autosub6000, HyBIS and the POL telemetry tests were carried out further south over and around the Casablanca seamount. A high percentage of the tests were successful, with Autosub6000 reaching a depth of 5600m.

KEYWORDS

Acoustic Telemetry, Autosub, Autosub6000, AUV, Cruise D343, *Discovery*, HyBIS, NE Atlantic, Obstacle Avoidance, Oceans 2025

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1. Ship's Personnel

Gatti	Antonio	Master
Richardson	William	Master
Leask	John	Chief Officer
Hood	Michael	Second Officer
Macleod	Iain	Third Officer
Lewis	Greg	Chief Petty Officer Deck
Allison	Philip	Petty Officer Deck
Brodowski	John	Seaman 1A
Crabb	Gary	Seaman 1A
Duncan	Steven	Seaman 1A
Smith	Peter	Seaman 1A
Jakobaufderstroht	Dennis	E T O
Slater	Ian	Chief Engineer
Bell	Steve	Second Engineer
O'Sullivan	Geraldine	Third Engineer
Slater	Gary	Third Engineer
Smyth	John	Engine Room Petty Officer
Preston	Mark	Head Chef
Ripper	Michael	Purser Catering Officer
Sutton	Lloyd	Chef
Robinson	Peter	Steward
Squibb	Mark	CPO (Scientific)

2. Scientific Personnel

McPhail (PI)	Stephen	National Oceanography Centre, Southampton
Furlong	Maaten	National Oceanography Centre, Southampton
Huehnerbach	Veit	National Oceanography Centre, Southampton
Knight	Gareth	National Oceanography Centre, Southampton
Murton	Bramley	National Oceanography Centre, Southampton
Myers	Michael	National Oceanography Centre, Southampton
Pebody	Miles	National Oceanography Centre, Southampton
Perrett	James	National Oceanography Centre, Southampton
Squires	Mark	National Oceanography Centre, Southampton
Dearden	Richard	University of Birmingham, Birmingham
Ernits	Juhan	University of Birmingham, Birmingham
Balfour	Chris	Proudman Oceanographic Laboratory, Liverpool
Mack	Steve	Proudman Oceanographic Laboratory, Liverpool

3. Itinerary

Departed Govan, Glasgow, UK , 27th September 2009

Arrived Santa Cruz, Tenerife, Spain, 15th October 2009

4. Background Objectives and Summary

There were 3 main activities during the NERC funded, Oceans 2025 technology trials cruise, *RRS Discovery 343*:

National Oceanography Ce ntre, Southampton: Dee p Testi ng of Autosub6000 AUV control, navigation, and sensor systems:

Testing of the AUV, its systems and safe control to as deep as possible up to 6000 m

Testing of collision avoidance system based on scanned sonar collision avoidance sensor

Testing of the recently fitted sensors: Seabird CTD system including dual CT, LSS (Light scattering sensor), EH probe. Test of Tri axis magnetometer.

Test flying at 3 m altitude in reasonably flat terrain (For proving future camera work)

Testing of online faults detection system, for detecting critical faults in AUV depth control.

Participation of two researchers from University of Birmingham who are developing a fault diagnosis system for Autosub using offline data.

National Oceanography Centre, Southampton: HyBIS

Test of the HyBIS ROV and deep water grab system in as deep water as possible. HyBIS was also available for Autosub6000 rescue if needed.

Proudman Oceanographic Laboratory: Testing of Telemetry systems

To develop and test remote measurement technologies, deep water communication systems and a compact version of the MYRTLE (multi-year return tide level equipment) long term deep water recoverable lander

Other

Test of CTD winch scrolling system (up to 5000 m water depth).

5. Diary of Events

The following is based on the ship's rough log and the Principle Scientist log.

All times in BST (GMT +1)

27/9/2009

1915: Sailed from Govan King George V Dock.

Heading for Celtic Deep.

29/9/2009

0730 N: 50 27.2, W 07 03.15

On station in Celtic Deep for Autosub6000 preliminary tests in water depth of 150m.

0835: Autosub6000 deployed. Autosub Mission 14.

Tests of Autosub stability, control, and performance of the Tritech Seaking scanning sonar used for collision avoidance purposes.

1535: Autosub6000 all inboard again. Successful mission.

1600: Following analysis of the data and the successful trials, and with an eye on the weather (forecast worsening in the North East Atlantic) , decide to head for next deep test sight at N 38 26.2, W 15 28.9.

30/9/2009

On Passage

2/10/2009

1730 Arrived at position on Iberian Abyssal Plain at N 38 26.2, W 15 28.9.

Continued the ship past this waypoint to gather bathymetric information. Looking for flat deep spot for Autosub deployment.

1900 Launched HyBIS

1940 Recovered HyBIS. Problems with deep tow winch instrumentation.

2020 Deck Side preparing for Deep tow winch test with clump weight.

2200 Due to electrical problems with the deep tow winch, have postponed all ops with that winch.

2230 Testing CTD scrolling system for a couple of layers. Successfully completed.

2300 Start POL acoustic telemetry and release wire test operations.

3/10/2009

0340 N 38 24.0, W 15 28.9 POL equipment at 4000 m wireout.

0447 All inboard, heading for Autosub6000 launch site.

0720 N 38 25.8 , W 015 28.9 Autosub in water.

0755 Autosub Dived Mission 15 . Deep dive in Iberian Abyssal Plain.

1000 Autosub Back on board. End of Mission 15. It had aborted the mission at 1500m. Reason: - failed power switch.

Efforts to fix the deep tow winch continuing.

2030 Tests of winch to 500 m successfully completed

2100 N 38 25.8, W 015 29.0 HyBIS launched

2120 HyBIS, power short circuit. Recovering HyBIS

2130 HyBIS inboard.

4/10/2009

0034 HyBIS deployed (Power fault fixed).

0112 Stopped veering: Alarm sounded on winch system.

0130 Several attempts recovering the HyBIS. Hauling when the system allows (tripping alarm).

0625 HyBIS back on deck. Proceeding to Autosub launch site.

0745 N 38 25.8 W 15 28.1 Autosub6000 launched. Mission 16.

1524 Autosub6000 on surface.

1618 Autosub6000 recovered. End of Mission 16. A successful dive to 5600 m.

1631 Proceeding towards the vicinity of the Casablanca seamount.

5/10/09

1200 Noon N 35 32.0 W 14 18.8 On passage.

6/10/09

0343 N 33 01.4, W 13 28.2. Hove to in deep water , 20km NW of seamount.

0623 Autosub6000 Launched. Mission 17.

0910 HyBIS Overboard for Deep tow winch test.

1424 HyBIS inboard

1440 Autosub6000 on surface.

End of Mission 17. Successful deep test of navigation, obstacle avoidance system, and science sensors.

1655 N 33 01.6, W 13 25.4. HyBIS deployed.

1847 Seabed sighted by HyBIS. (4362 m).

2213 HyBIS on seabed for grab sample.

2400 HyBIS inboard.

07/10/09

0200 N 33 01.4 W 13 27.9. Hove to for Autosub6000 deployment (Mission 18).

0450 N 33 01.3 W 13 28.1 Autosub6000 deployed.

0507 Autosub6000 Dived.

1156 Autosub6000 Mission Ended, AUV on surface.

1225 Autosub6000 Inboard. End of Mission 18. Successful mission to 4300 m.

1528 N 32 49.4 W 13 12.9 Hove to on station for HyBIS deployment

1539 HyBIS deployed.

2208 HyBIS recovered. Successful HyBIS deployment.
Heading for Autosub6000 deployment position.

08/10/09

0003 N 33 01.3, W 13 28.2 Hove to on station.

0054 Autosub6000 launched. Mission 19.

0648 Autosub6000 on surface. End of Mission 19. Obstacle avoidance ran in active mode with AUV at 5 m commanded depth.

0842 Autosub6000 inboard. End of Mission 19.

0846 N 33 01.1, W 13 25.3. Heading towards POL lander position.

1026 N 32 49.9, W 13 18.0 Hove to on station, but water depth too shallow. Relocating to find 3500 m.

1056 N 32 50.7, W 13 18.7 Stopped with water depth of 3480 m.

1105 N 32 50.69, W 13 18.72. Lander deployed.

1233 Lander on seabed. Release triggered but data capsule not ascending.

1530 The Linkquest high speed modem has stopped working, hence no reason to continue the lander deployment. There are also worries about why the data POD did not release (was the seabed slope excessive ?)

1548 Lander released and ascending.

1721 Lander back inboard. Proceeding to HyBIS launch site.

1845 N 32 43.0, W 13 11.1 On site for HyBIS

1853 HyBIS O/B

1909 HyBIS inboard

1940 HyBIS O/B

1948 HyBIS at 1120 m

2011 Communications problems with HyBIS begin recovery

2035 HyBIS inboard

2215 HyBIS outboard

09/10/09

0239 HyBIS inboard (successful deployment)

0608 On station at start of Autosub6000 operations

0804 N 32 39.1, W 13 19.5 Autosub6000 launched

0815 Autosub6000 dived. Mission 20.

Objectives Mission 20: Run at 100 m across the Casablanca seamount, with the obstacle avoidance and collision avoidance enabled.

1542 Autosub6000 on surface. End of Mission 20. Successful completion.

1616 Autosub inboard.

1645 N 32 47.3, W 13 10.0. Proceeding to HyBIS launch site.

1828 N 32 47.2, W 13 13.3. HyBIS O/B

2349 N 32 48.0, W 13 11.8. Start recovery of HyBIS (successful dive).

10/10/09

0035 HyBIS inboard.

0809 N 32 39.0, W 13 19.5 Autosub6000 launched. Start of Mission 21

Objectives Mission 21: Run at 50 m across the Casablanca seamount, with the obstacle avoidance and collision avoidance enabled.

1524 Autosub6000 on surface. End of Mission 21. Successfully completed.

1555 Autosub6000 on deck

1634 N 32 50.2, W 13 09.4. POL wire test of equipment. O/B.

2345 Equipment inboard. Successful test.

11/10/09

0143 N 32 43.3, W 13 16.0. HyBIS O/B.

0638 N32 42.6, W 13 16.7. HyBIS on deck. Successful deployment.

0732 N 32 44.4, W 13 15.1. On location for Autosub dive.

0805 Autosub6000 released. Start of Mission 22

Objectives of Mission 22: Start at top of Casablanca seamount, and descend down to 2500 m WD, turn and back up. All at 20 m altitude. Surface, and recover the data. If all ok, then repeat the mission at an altitude of 10 m.

1158 N 32 44.6, W 13 14.7. Hove to with Autosub on surface (downloading data).

1320 Autosub6000 started and dived for 2nd part of Mission 22.

1715 Autosub6000 on surface.

1739 N 32 44.1, W 13 15.1 Autosub clear of water.

1815 N 32 44.4, W 13 14.0. On location for HyBIS dive.

1828 HyBIS O/B.

2319 HyBIS I/B. Proceeding to Autosub6000 launch position.

12/10/09

0105 N 32 44.5, W 13 14.3. Hove to at Autosub6000 launch position.

1032 N 32 44.7 W 13 14.2. Autosub6000 launched.

1038 Start of Mission 23.

Objectives: Start Way Point. Centre of Summit of the Seamount. Altitude tests down to 3 m. Free run EM2000 tests. Surface and analyse the data. Box survey of the top of the seamount , at 100 m altitude

1230 N 32 44.7, W 13 13.8. Autosub6000 on surface. Downloading data.

1415 Autosub6000 recovered due to a technical problem – loose lifting lines fouling prop. (2nd part of mission – the box survey - not completed).

1533 N 32 44.7, W 13 14.3. Autosub6000 released. Start of Mission 24.

Objectives: Box survey of the top of the Casablanca seamount , at 100 m altitude.

1540 Autosub6000 Dived.

1809 Heading west for POL tests of acoustic communications equipment on wire.

2034 N 32 44.9, W 13 18.3. POL equipment O/B.

13/10/09

0254 N 32 44.7, W 13 18.4. POL equipment I/B. Successful test.

0728 N 32 44.9, W 13 13.9. Autosun6000 on surface. End of Mission 24.

0922 Autosub6000 secured on deck. Heading off for HyBIS operations.

1032 N 32 43.5, W 13 13.2. HyBIS O/B.

1359 HyBIS I/B.

1440 N 32 44.7, W 13 14.3. Hove to for Autosub6000 deployment.

1645 Problems with Autosub so launch postponed. Heading for 4000 m deep water for POL wire tests.

1755 N 32 39.1, W 13 23.3. On site (4100 m water depth).

1835 POL equipment O/B on CTD wire.

2020 Start to recover POL equipment.

2133 POL equipment in I/B.

2139 Proceed to HyBIS deployment position.

2245 N 32 44.6, W 013 14.2. Hove to on station for HyBIS deployment.

14/10/09

0435 HyBIS I/B. Successful survey.

0516 N 32 44.6, W 13 16.2 On location awaiting Autosub6000 launch.

0652 Autosub6000 launched. Start of Mission 25.
Objective : To Run at various altitudes (50, 30, 20, 10 ,5 down to 3m). Run at low power as well.

1122 Autosub6000 I/B and secured. End of Mission 25.

1214 N 32 44.5, W 13 13.5. Autosub6000 launched. Start of Mission 26 (repeat of Mission 25 with modified control and collision avoidance settings).

1400 Autosub6000 on surface. End of Mission 26. Downloading data.

1517 Autosub6000 Diving. Start of Mission 27 (repeat of previous missions with modified collision avoidance settings and software change).

1656 N 32 44.3, W 13 13.2, Autosub6000 back on surface. End of Mission 27.

1732 N 32 44.3, W 13 13.2. Autosub6000 I/B and secured. End of Science. Heading for Tenerife.

15/10/2009

2100 Docked, Santa Cruz, Tenerife.

6. Autosub6000 Operations.

Maaten Furlong, Stephen McPhail, Miles Pebody, James Perrett, Mark Squires. Underwater Systems Laboratory, National Oceanography Centre, Southampton, UK.

6.1 Missions Overview.

Development of the Autosub6000 Autonomous Underwater Vehicle capability has continued during 2009 as part of the Oceans 2025 theme 8 programme. This year has seen a particular emphasis on severe terrain access with focus on low altitude navigation in steep and rugged environments as well as very low (3m altitude) terrain following control for colour photographic survey in less extreme conditions. Another major objective was to test the AUV to as deep a depth as possible, given the constraints of the terrain on the cruise track.

Figure 1. Google map showing Discovery Trials Cruise D343 from Glasgow to Tenerife

Figure 1 shows the general track of the cruise. A preliminary shakedown and systems check mission (Mission 14) was carried out in the area of the Celtic deep, with a water depth of approximately 150 m. During this mission the first data from the recently fitted Tritech Seaking scanning Sonar system was obtained, giving us valuable information on that system's performance, which we later used for optimising the operating parameters and seabed detection algorithms.

Following this successful mission, we decided to head south west to the deep test area on the Iberian abyssal plain. The two day passage giving us valuable time to reconfigure the system and sensors (particularly the Tritech Seaking). Also the weather in the NE Atlantic was deteriorating, and we considered it best policy to head south. Also for this reason we decided to give up on the option of going further west to the Peak Deep, which would have given us water depth of up to 6000 m, but at the cost of at least 1.5 days of cruise time.

The next Autosub mission was in the Iberian Abyssal plain, on 3th October (Mission 14). The first attempt failed. The abort system operated after a total power failure in the vehicle. Later investigation revealed a fault in the on/off switch for the AUV. After repairs, missions 15 was completed successfully on 4th October, with the AUV diving to a depth of 5600m.

The rest of the missions were carried in the vicinity of the Casablanca seamount. This area was chosen because it provided an ideal testing ground for the collision avoidance sensor and system, with a range of water depths from 4000 m to 600 m within a short distance, rugged and steep terrain, and we were in possession of good quality multibeam bathymetry for most of the area. Table 1. is a summary of the Autosub6000 Missions during the cruise.

Tuning the parameters, and indeed algorithms for the collision avoidance system during a cruise, with changes made between missions was not an easy task. Innovation has to be balanced against risk. However the outcome at the end of the cruise was a collision avoidance system proven to give good results at altitudes down to 5 m, no mean achievement, given the system had only undergone simple dock side tests before the trials cruise.

Table 1. Summary of Autosub6000 Missions During D343

#	Date (2009)	Position	Max Depth (m)	Distance Run (km)	Objective	Results
14	29/9	N:50 27.2 W:007 03.15 Celtic Deep	93	12	Tests of stability, control of AUV and performance of the Tritech Seaking scanning sonar in record mode.	Completed successfully. Range of Tritech was disappointing.
15	3/10	N:38 25.8 W:015 28.9 *IAP*	1479	2.5	Deep dive to 5600 m. Test all systems, particularly acoustic telemetry performance.	Aborted at 1479 m due to a power failure. Root cause was a faulty on/off switch. Fault detection logic proven to work. Acoustics performance was marginal at this depth. ADCP profiling looked poor.
16	4/10	N:38 25.8 W:015 28.9 *IAP*	5600	34	Deep dive to 5600 m. Test all systems.	Successfully completed. On recovery noted that the main motor rotor magnet is cracked. GPS antenna failure (leakage).
17	6/10	N: 33 01.4 W: 13 28.2 Flanks of *CS*	4360	45	Test all systems as deep as possible; Acoustics, CTD (dynamics with profiling), Magnetometer CAL, EM2000 find maximum fly depth, Range Only Nav test, SeaKing Test at various depths.	All completed successfully. Acoustic telemetry performance was solid. Seaking only working to 100 m range.
18	7/10	N: 33 01.3 W :13 28.1	4360	45	Substantially a repeat of Mission 17. With: Swap out the Tritech Sensor with spare system to eliminate sensor fault. Remove 4.6 kg of mass as there were worries about signs of buoyancy loss during M15, M16. 2.3 kg each from the front and from the rear. Run down to 5 m altitude. Fault code software changes. The Altitude stuck detect is hazardous – it could cause a false trigger. Replace with check for network update. Run out track of 4 km to increase the slant range - acoustics systems test.	Mission completed successfully. Tritech performance was unchanged: the particular sensor is not at fault. Acoustics tracking and telemetry was consistent.
19	8/10	N 33 01.3, W 13 28.2	4358	32	Obstacle avoidance ran in active mode with AUV at 5 m minimum altitude. Run at higher speed for speed calibration. Reverse and stop test.	Successful completion of mission. Minimum altitude reached was 12 m. The intended minimum altitude not reached because the water depth was greater than expected.
20	9/10	N 32 39.1 W 13 19.5	3748	41	Run at 100 m across the Casablanca seamount, with the obstacle avoidance and collision avoidance enabled.	Successful completion.
21	10/10	N 32 39.0, W 13 19.5	3859	40	Run at 50 m across the Casablanca seamount, with the obstacle avoidance and collision avoidance enabled.	Successfully completed
22	11/10	N 32 44.4, W 13 15.1	3001	45	Start at top of Casablanca seamount, and descend down to 2500 m WD, turn and back up. All at 20 m altitude. Surface, and recover the data. If all ok, then repeat the mission at an altitude of 10 m.	All completed successfully. Minimum altitude of 0 m. The vehicle collided with the seabed, (but only a glancing blow, the fendering worked well) Control was reasonably good over very rough

						terrain. ADCP network bulkhead connector leaked - causing a Hotel system ground fault. Ropes came out of hoppers after first half of mission. Unable to dive the 2nd part of the mission due to trailing lift lines fouling the propeller (the vehicle was recovered, the problem fixed and then redeployed). The problem was that the increased gap in the flaps covering the hoppers allowed the thin lifting line to snake its way out.
23	12/10/2009	N 32 44.7 W 13 14.2	610	14	Start Waypoint at the centre of summit of the Seamount. Altitude tests down to 3 m. Free run EM2000 tests. Surface and analyse the data. Box survey of the top of the seamount, at 100 m altitude	Minimum altitude achieved was 13.1 m. The SeaKing system was being affected by sidelobe interference (preventing the AUV descending deeper). A sidelobe rejection algorithm was implemented for subsequent missions. The battery charge plug leaked (not sufficiently tightly made). 2nd part of mission (the box survey) not completed, due to loose lifting line requiring Autosub6000 be recovered. Ropes came out of hoppers after first half of mission hence unable to dive the 2nd part of the mission due to trailing lift lines fouling the propeller (the vehicle was recovered, the problem fixed and then redeployed). The problem was that the increased gap in the flaps covering the hoppers allowed the thin lifting line to snake its way out.
24	12/10	N 32 44.7, W 13 14.3	897	92	Box survey of the top of the Casablanca seamount , at 100 m altitude.	Successfully completed. Evidence of volcano vent imaged with EM2000 system.
25	14/10	N 32 44.6, W 13 16.2	628	9	Run at various altitudes (50, 30, 20, 10 ,5 down to 3m). Run at low power as well.	Some success, but the Seaking processing changes were not effective. More changes made to the seabed detection algorithm to eliminate the effect of the sidelobe sensitivity.
26	14/10	N 32 44.5, W 13 13.5	635	9	Repeat of Mission 25 with modified control and collision avoidance settings. Run at various altitudes (50, 30, 20, 10 ,5 down to 3m). Run at low power as well.	Much improved control. Minimum altitude of 2.5 m. Section with control to 5m +/- 1 m.
27	14/10	N 32 44.5, W 13 13.5	635	9	Repeat of Mission 25 with modified control and collision avoidance settings. Run at various altitudes (50, 30, 20, 10 ,5 down to 3m). Run at low power as well.	Control looked worse than M26 . Less time with stable control at around 5m altitude. More overshoot , with minimum altitude of 1.8 m.

6.2 Highlights of Autosub6000 Missions:

• Working at 5600m with GPS precision navigational accuracy.

• Survey at 3m altitude **-** paving the way for deep photographic surveys.

• Steep, shelf edge terrain following at 10m altitude – accessing previously unattainable seabed regions.

• High resolution swath bathymetry survey **-** improving on previous results by a factor of 3.

• Reinforced nose assembly to withstand low grazing angle sea floor contacts.

• Additional low level fault detection software.

Deep Ocean Access

One of the main goals of the Autosub6000 engineering trials was the demonstration of the accessibility of deep ocean regions approaching the 6000m design depth limit. On the 4/10/2009 (Mission 15), the AUV descended and reached it's pre-programmed target depth of 5525 m in 1.5 hours. At this point a navigation update procedure was undertaken to update and correct for the Autosub6000's drift which was incurred as it descended through the moving water column. After 2.5 hours from deployment, the Autosub6000 was on station at 5600m located to GPS accuracy and ready to start science data collection.

Figure 2. Autosub6000 being prepared for deployment. The Edgetech Seaking sonar is mounted in the nose and the new fenders can be seen mounted under the nose.

Steep Terrain and Collision Avoidance

Autosub6000 has been enhanced with a Tritech Seaking forward looking vertically scanning obstacle detection sonar and improved terrain following control software. The ability of the Autosub6000 to operate at low altitudes in the steep and rugged slopes of the Casablanca Seamount was demonstrated with a 10m altitude run starting at 3000m and rising up to 700m over a course of 7.5Km. On two occasions the Autosub6000 had to revert to its existing collision avoidance behaviour, retreating back to try another approach when sheer cliffs blocked its path. However, for the majority of the transect, which included sheer cliffs, massive boulders and an

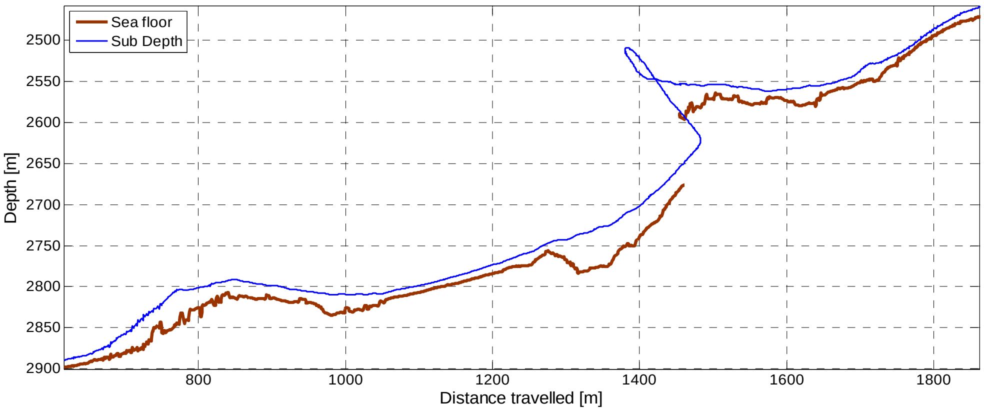


Figure 3. Ocean floor and Autosub6000 depth profile during part of the 10m altitude terrain following ascent of the Casablanca Seamount. Note collision avoidance behaviour after 1.4Km.

average slope of 17° (over the 7.5Km), the AUV was able to remain within 5m of its pre-programmed target.

Very Low Altitude Survey

The ability of the Autosub6000 to perform low altitude photographic surveys was demonstrated on the more level summit regions of the Casablanca Seamount with low speed surveys at altitudes of as low as 3m. During the low altitude control tuning phase of this work the engineering team was interested to observe that an inadvertent ocean bed strike provided a useful and opportune test for the new reinforced skid panel and fender assembly on the front of the AUV. This low grazing angle collision, only detected after a close post mission inspection of the Autosub6000 hull, demonstrated the effectiveness of this "last resort" mechanical solution to collision mitigation.

Improved Swath Bathymetry

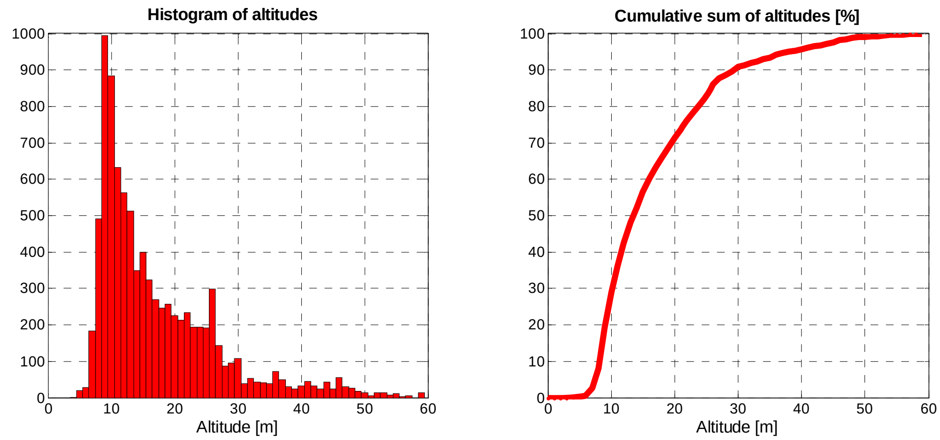


Figure 4. Statistical data during a 10m altitude terrain following ascent of the Casablanca Seamount.

The Autosub6000 is a highly stable vehicle and is equipped with a Simrad EM2000 swath bathymetry multibeam sonar. Surveys using this sensor have previously provided ground breaking data sets that have been available within hours of the AUV returning to the surface. Subsequent equipment deployments have then been planned on the basis of this new highly detailed and up to date data set. Meanwhile the Autosub6000 is launched again to continue further data collection. This operational capability has now been taken to new levels with the EM2000 running with a 3 fold resolution improvement. Data collected was used to plan deployments of HyBIS (HydoLek Benthic Interactive Sampler) which resulted in the unexpected detection of evidence for possibly recent geothermal activity.

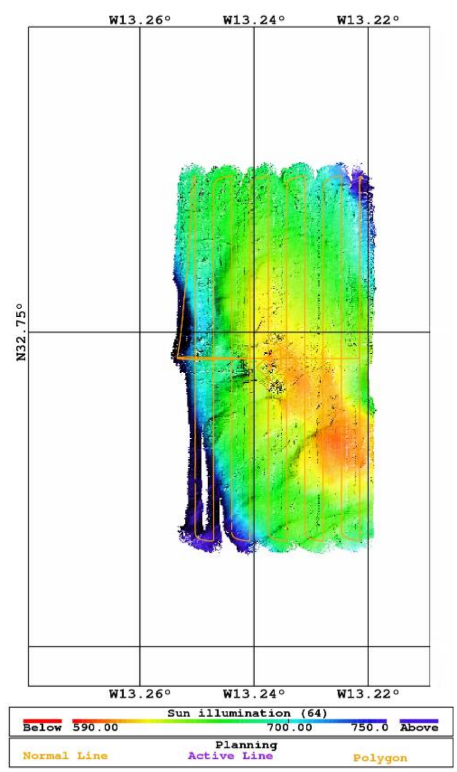


Figure 5. EM2000 multibeam survey data from the top of the Casablanca Se amount. G eothermal activity was identified at the summit (south west orange region).

6.3 Tracking and Telemetry

The acoustic tracking for the Autosub6000 is realised via two independent systems: i) Linkquest TrackLink10000, and ii) Sonardyne Compatt. The acoustic telemetry was an integrated part of the Linkquest system and has been used on previous Autosub6000 cruises. The Sonardyne Compatt was new to the AUV.

The Autosub6000 was also equipped with two Argos transmitters that were automatically switched on when the vehicle was on the surface. The transmissions from the Argos beacons could be received locally on the ship with the use of a GONIO receiver. The bearing and signal strength output data was broadcast on the Autosub local area network.

The Autosub6000 communicates with the support ship via an IEEE 802.11g wireless local area network that is a component of the Autosub seagoing equipment. The Autosub LAN is connected to the Autosub6000 via a high gain antenna mounted on the ships main mast. One other antenna is mounted near the aft deck in order to maintain communications when the AUV is on deck. During a mission this link is used for high bandwidth command and control telemetry and downloading from the Autosub data log.

Objectives for Tracking and Telemetry Testing

During a previous cruise, JC027, it had been found that the Linkquest tracking and telemetry system did not perform reliably when the AUV was within the region of 100m of the ocean floor and flying straight and level. Figure 6 illustrates the nature of the problem as seen in mission 10. Approximately 30 minutes after reaching the operating depth of 4537 m the tracking and telemetry returns began to drop out. The situation degraded until after approximately 2 hours there were no returns. The last two returns were telemetry data, the 3rd to last was an acknowledgment to the start command message that initiated the navigation calibration box.

During the constant depth navigation calibration box the AUV was altitude limited – hence pitch was changing, up and down. In this case the telemetry and tracking performed normally. When back in level flight the returns dropped out. These findings are summarised in Table 2.

Table 2. Summary of Mission 10 analysis.

Slant range	Max 4536m. Given the USBL Z range it would appear that the AUV was mostly directly under the ship – apparently an optimal position for the Linkquest transducer.
Ship transducers	It was found from the logged data that when the Autosub transmitted a message it was always received by the ships transceiver
Stern plane angle	Had no obvious effect on returns
AUV heading	Had no obvious effect on returns
Depth Altitude Pitch	When depth and or altitude were changing – pitch up or down – tracking and telemetry returns seemed to be more consistent.

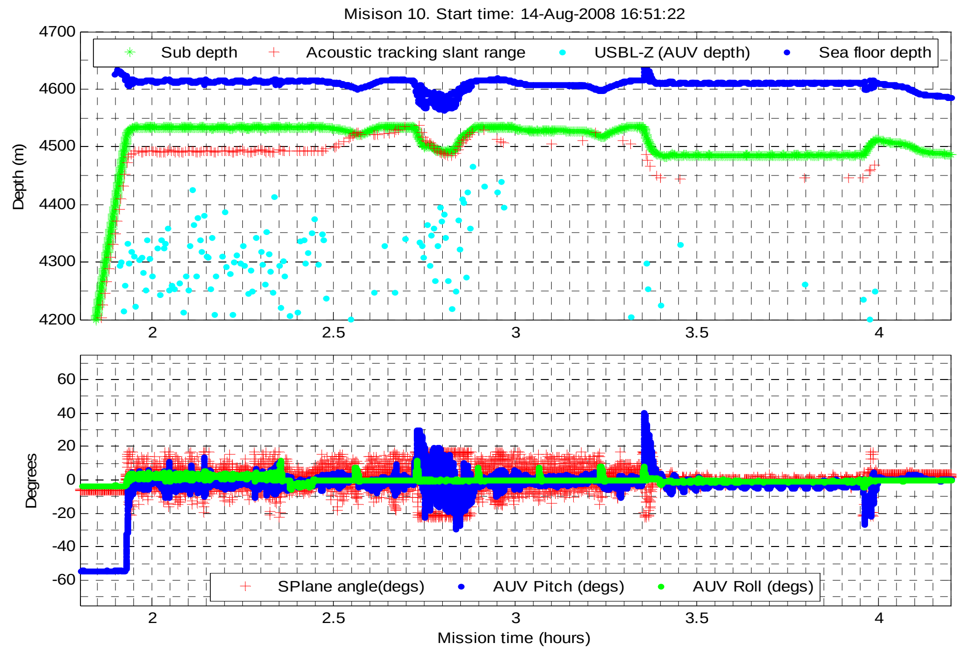


Figure 6. Mission 10 from the 2008 JC027 cruise. Red crosses in the top plot are Linkquest slant-ranges. Acoustic telemetry has been shown to reliably take place every time a slant range is received. Note how the slant range is received when the AUV is pitching, as indicated by the lower plot. Note also that the slant-range/telemetry is a response to a request message from the ship. If the ship is not transmitting then there will also be corresponding gaps in the plot data.

As it was possible to demonstrate (from logged data) that all transmissions from the AUV were reliably received by the ship it appeared that the problem lay in the Linkquest transducer on the AUV not receiving the transmissions from the Ship. Subsequent tank tests of the Linkquest system back at NOCS failed to demonstrate a similar behaviour. The system ran without error for significant periods of time. A working theory was suggested that the problems encountered on the JC027 cruise were the result of acoustic interference from bottom echoes that coincided with the ship being directly overhead and the consequent sound path down to the AUV, to the sea floor then reflected back up to the AUV. In particular the EM2000 multibeam system was considered.

For the Discovery D343 engineering trials cruise a 300mm diameter, 5mm thick stainless steel plate mounted directly under the Linkquest transducer on the AUV to provide an acoustic shield from sound sources under the vehicle. All missions were run in this configuration.

A further objective of the D343 trials cruise was to test further developments of the ship-side acoustic tracking and telemetry software. This included the integration of the Argos data from the Gonio receiver into the Autosub Tracking and Telemetry software tool with a novel display to indicate signal strength and bearing.

Finally the SonarDyne Compatt5 USBL tracking system was also to be tested.

Results of Tracking and Telemetry testing

The first mission M14 took place in shallower waters in the Celtic Sea and had a maximum depth of 94.6m. During this mission the Linkquest telemetry system performed adequately (although there were problems with communications between shipboard computers at the outset).

Mission 16 was a deep diving mission to 5600m. There were effectively two descents during this mission, Figure shows the second where more time was spent at depth. The descent was made in altitude mode prior to the commencement of a number of altitude controlled tracks between two waypoints with 20m, 3 minute duration steps down from 200m to 20m (altitude limit was set to 10m). The returns from the Linkquest tracking and telemetry during this mission seemed to be very similar to that experienced in mission 10 (and the other JC027 missions). Between 5.1 hours and 5.3 hours there is much variation in vehicle pitch (due to poor altitude returns from the ADCP) and during this time the tracking and telemetry was good. Bellow the 120m altitude demand the ADCP is providing more stable altimetry and the depth control is able to stabilise. However with runs of only 3 minutes at each altitude and a 180° turn at each transition the AUV is quite often in a disturbed flight pattern. During these disturbances the Linkquest tracking and telemetry is responsive to messages from the ship.

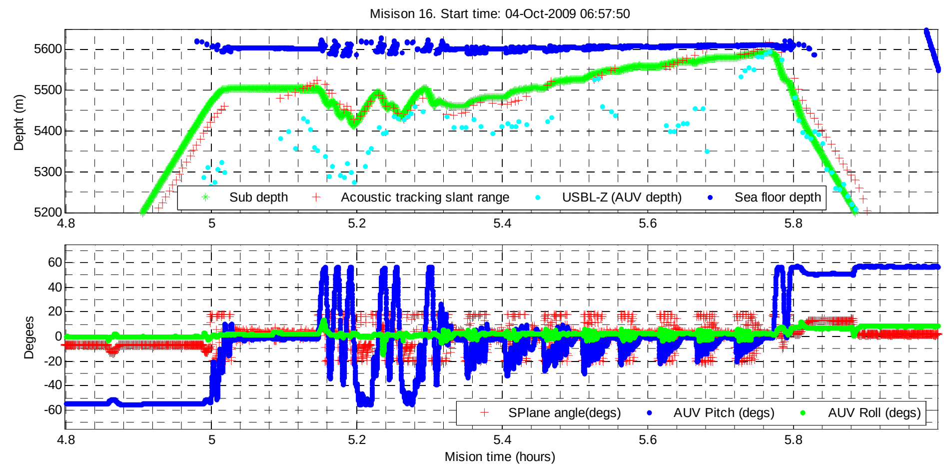


Figure 7. Missio n 16 , da ta from the deep est segment of th e m ission. Returns (red cros s in top plot) s how s imilar characteristics to the mission in cruise JC027 - 6

Deteriorating weather prevented further testing in the deep test area. Consequently subsequent missions had a maximum depth in the region of 4400m, similar to the conditions experienced during the JC027 missions (9-13). At these depths the Linkquest telemetry system worked reliably with an estimated greater than 90% successful return rate. The plot in Figure 8 shows the slant range increasing to 5200m. This was during a phase of the mission where the AUV was travelling out to, and returning from a distant waypoint and so was not directly under the ship. Typically the Linkquest system has not demonstrated problems in these conditions with ranges of up to 7000m being seen on other cruises.

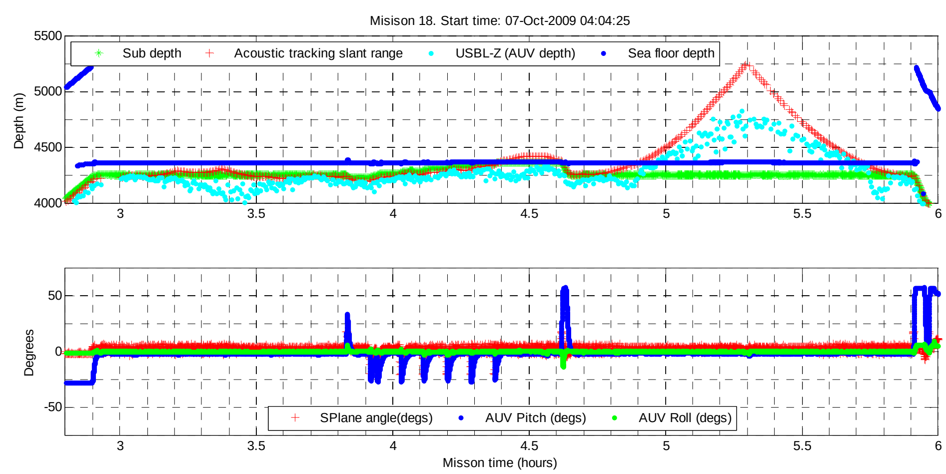


Figure 8. Mission 18 took place in conditions similar to those experienced in the JC027 missions. It can be seen that in this case the Linkquest telemetry worked reliably.

Mission 22 (Figure 9) was a low altitude, 20m and 10m ascent and descent of the Casablanca seamount. Conditions during this mission were of very rough terrain, including vertical cliffs and overhangs. The Linkquest telemetry system performed well. This performance was also demonstrated in the very low (3m) altitude survey of mission 25 (Figure 10)

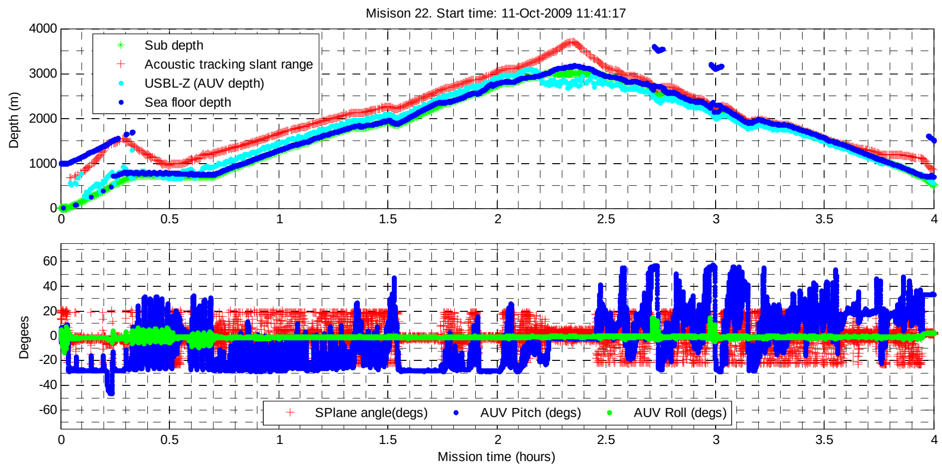


Figure 9. Mission 22. Low altitude (20m and 10m) demand transects across the Casablanca Seamount. Tracking and Telemetry worked reliably.

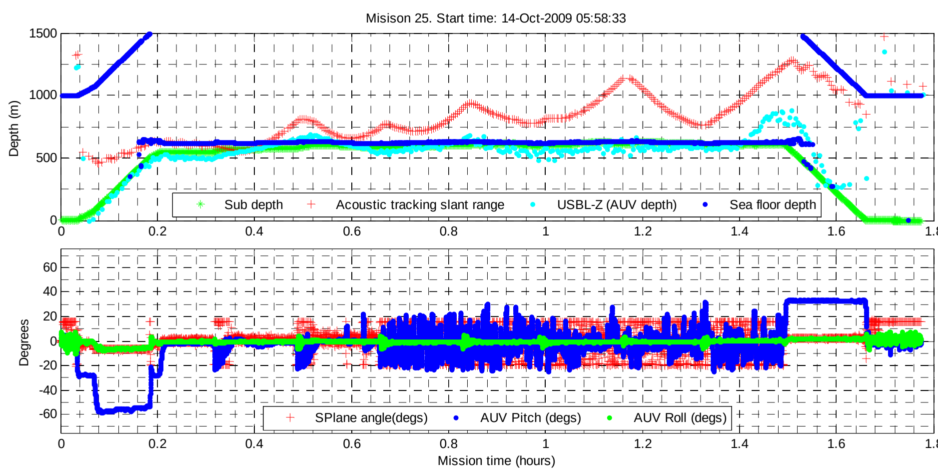


Figure 10. Mission 25, low 3m altitude survey on Casablanca Seamount top, at a depth of approximately 600m. The Tracking and telemetry worked reliably.

Tracking and Telemetry Software

The main outstanding issue is the problem that was experienced with the FabulaTech virtual serial ports over Ethernet when UDP messaging was enabled to receive the Gonio Argos messages. Consequently new features involving TCP/UDP messaging had to be tested on another machine, although they had been fully integrated. It was demonstrated to work as intended but further effort will be required to research the resulting virtual serial port problems. Other new features of this software appeared to work well, in particular the redesigned range only navigation control and update interface and the ability to load mission script download files to plot the mission waypoints.

Linkquest Tracking

There is an issue regarding compass corrections in the Linkquest TrackLink software. The output LXT tracking data stream does not seem to be corrected. The Autosub tracking and telemetry software is required to add an offset. However there is a time lag between the tracking data being supplied to the TrackLink software, together with compass information, and the output LXT position data. Consequently the Autosub tracking and telemetry software is not able to accurately display the AUV position.

Sonardyne Compatt5 USBL

Tracking was reliable and seemed more accurate than that of the Linkquest system. However the data log of the Sonardyne Ranger system did not contain relevant data. This is an issue that will need further investigation for future use.

Conclusions for tracking of Telemetry tests

The LinkQuest system performed satisfactorily for all mission styles down to a depth of approximately missions 4500m but at 5600m there were problems with the AUV not being able to detect transmissions from the ship. This will require further investigation. It may be possible to develop mission control strategies to minimise the lack of communication during the range only navigation phase of each mission, for example by running in depth profiling mode over a short depth range.

6.4 Low Level Automatic Fault Detection

During the Autosub project there have been several instances where system or sensor failure has endangered the vehicle, due to imminent or actual seabed collision. In 2004 there was an expensive salvage operation, the root cause of which was a mechanical failure in the sternplane system. An electrical connector failure a year later nearly caused a repeat of this near disaster. What was unacceptable was that some of these faults have occurred more than once, and the vulnerabilities still existed. Our Strategic Ocean Funding Initiative partners (see later section on SOFI) from Birmingham University are engaged in a three year program, tackling the general problem of detecting and diagnosing faults on an AUV system such as Autosub. However, although progress of this project has been good so far, we needed some system development to address these identified vulnerabilities more immediately. Hence we developed a low level fault detection system, based on new code executed on the depth control node, and tested this during the trials.

We carried out an analysis of previous faults which could have caused seabed collision , and also identified possible other failures mechanisms involving sensor or system failures (whether mechanical, electrical or software). The result was a set of possible faults, for which a set of detection methods were devised. The software was hosted on the depth control node, as it has access to all the relevant data in real time.

The input conditions for the fault detection are:

1) Check for stuck values of *Depth*, *Altitude* and *Pitch* sensor data at the depth control system input.

2) Check for AUV itself stuck trying to ascend or descend (by comparing depth rate and pitch demand)

3) Check whether the *Altitude* < set minimum altitude

4) Check for *Depth Node* failure : detected by absence of watchdog message it sends to the abort node.

By suitable Boolean combination of these conditions it was possible to detect the fault conditions, some with a redundancy. For example, a mechanical failure of the sternplane is detected pre collision by both “altitude < set minimum” and by “stuck trying to ascend” . Difficulties arise when the vehicle is on the surface or on the ship (it may seem to be “stuck trying to descend”), and this had to be catered for, without significantly reducing the effectiveness of the fault detection, and also mindful that, for example, the depth sensor could be faulty and stuck at a low value.

Testing of this type of system for false negatives is obviously dangerous in the field and had to rely on lab testing of all the possible states, but the field testing was useful for detecting false positives. When a fault condition is detected a fault timer is allowed to start, and an abort occurs after a preset time. Testing during the cruise showed that the condition “Altitude stuck value” was occurring for long periods when the vehicle was flying in constant altitude mode (a consequence of the good AUV flight stability, the flat seabed, the quantisation of ADCP ranges to 1% of their value, and that the test was only made once per 5 seconds). This test was changed to “Altitude not updating”, still providing a good probability of detecting a failed ADCP, but with reduced risks of a false positive causing abort.

6.5 Improved Mechanical Protection for the front of the vehicle.

On occasions Autosub AUVs have, and in the future will (despite better fault detection), bump into the seabed. What must not happen is that the AUV rubs along the seabed, wearing a hole in the lower front panel, with the result that the AUV takes in mud, and cannot return to the surface. This was the cause of a large insurance claim in 2004 for recovery of Autosub2. The improved fault handling should make this much less likely, but nevertheless we decided to implement an abrasive resistant skid pan, plus rubber fendering on the vehicle. The cost is greater drag and weight (Figure 2). This system was successfully tested during the cruise.

6.6 Autosub Scientific Sensors

For the D343 cruise the Autosub 6000 vehicle was fitted with the following scientific sensors:

- RDI 300kHz ADCP looking downwards
- Seabird 911 CTD system.
- Kongsberg Simrad EM2000 Multibeam Sonar.

The data from these plus the navigation data, and clock synchronisation data are stored on the Autosub 6000 server and on the NOCS Unix file system.

These instruments are described separately in the following sections. All the electronic systems on the vehicle are connected to a single control network. The data from all sensors apart from the EM2000 multibeam sonar are recorded on the Autosub data logger. The Autosub logger uses a proprietary data format but the data is translated into standard ASCII text files using a set of Matlab processing scripts which store the full data set in Matlab format together with two second sampled data in 3 text files. The general vehicle data is stored in a file with the .ls2 extension and the general post processed navigation file is stored in the Mxxx.bnv file. (Appendix 2).

Sensor Synchronisation

The time synchronisation of the various on-board systems is important, especially where data from different systems is likely to be merged at a later date (post processed navigation data for the EM2000 is one example of this). Wherever possible the network time protocol (NTP - see http://www.ntp.org for more details) system is used which allows for time comparisons with a resolution of better than 1millisecond. The Autosub Mission Processing computer is fed a GPS data stream and a program written at NOCS called GPSTime uses this data to set the clock on the system to match the GPS time. For the D343 cruise the time server was also using the ship’s NTP server as a secondary reference as this appeared to reduce the time server jitter. All the Autosub related shipboard systems and the Autosub Logger run the NTP software and use the Autosub Mission Processing computer as their time reference. The Autosub logger timestamps each data record using this time and feeds it to the EM2000 The EM2000 uses this time as its initial reference but it appears to use its own internal clock for subsequent data timestamps. The offsets between the reference computer and the other NTP systems can be found in the peerstats file in the timing directory for each mission. The offset for the EM2000 can be obtained by comparing the time contained in the NMEA position datagram with the timestamp of that datagram.

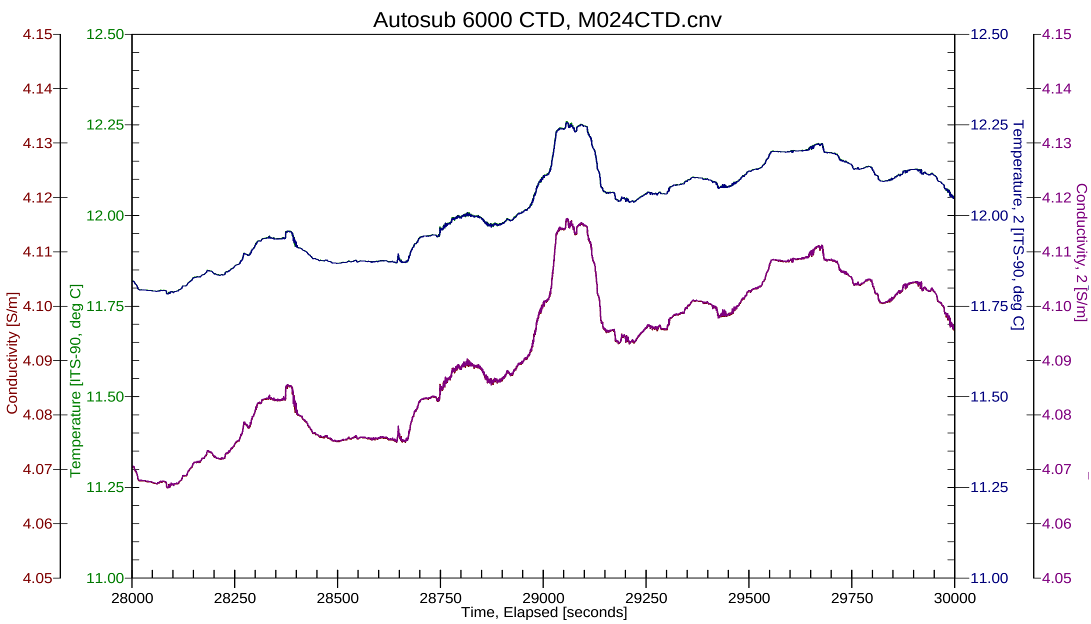
Seabird 9+ CTD system

Autosub 6000 is fitted with a Seabird 9+ CTD system which includes two sets of conductivity and temperature sensors. These are mounted in a ducted system with sea water pumped through them at a precisely known rate. Depth is measured by a Digiquartz pressure sensor. In addition, a Seabird SBE43 oxygen sensor is fitted in the same duct as the secondary CT sensors while a Seapoint Turbidity sensor and an EH sensor built by Ko-ichi Nakamura are mounted on the vehicle's external panels. The output from these sensors is recorded at a rate of 24Hz.

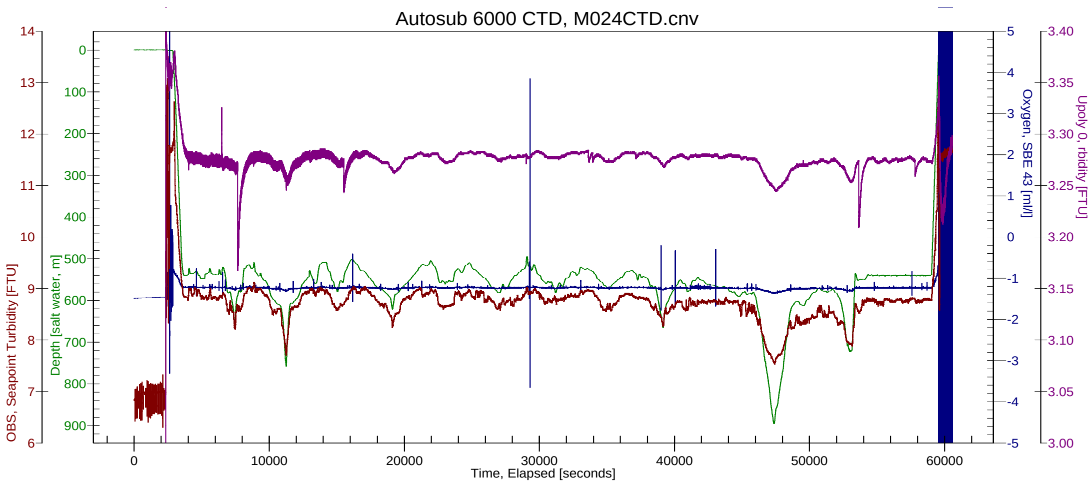
Sensor Loca	tion	Serial Number
Primary Temperature	Starboard Side	5071
Primary Conductivity	Starboard Side	3566
Secondary Temperature	Port Side	5009
Secondary Conductivity	Port Side	3494
Seapoint Turbidity	Top Centre	
Oxygen Sensor	Port Side	1582

Data from the system is continuously logged whenever Autosub is switched on but, in order to prevent excessive wear on the pump, water is only pumped through the C/T sensors once a predetermined pressure threshold has been exceeded. The data is stored on the Autosub logger in a proprietary format but is translated into a Seabird format data file (.dat) at the end of each mission. Sensor calibration data is stored in a separate file with the .con extension. For the D343 cruise the data was processed using "\D343\CTD Setup\0930TCSwappedwithLSSandEH.con" file which contained calibration data from February 2009 for the T, C and Oxygen sensors and August 2008 for the depth sensor.

The Conductivity and Temperature sensors appeared stable and well matched as shown in the data excerpt below.



Data from the oxygen, turbidity and EH sensors for the whole mission are shown in the data excerpt below.



Kongsberg EM2000 Multibeam Swath System.

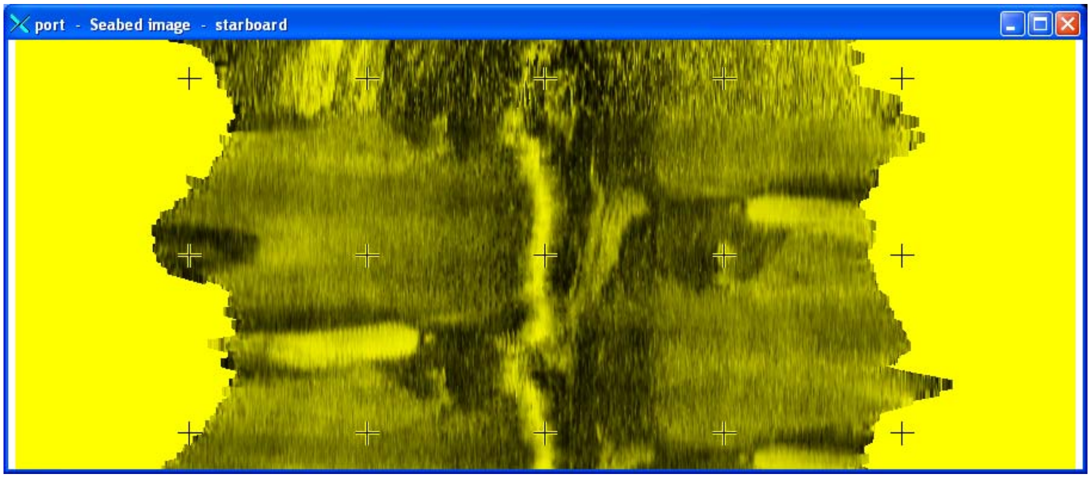
The Kongsberg EM2000 is a multibeam swath bathymetry system which operates at a frequency of 200kHz and can give up to 111 beams of data with an angular coverage of up to +/-60 degrees under favourable conditions.

In Autosub the instrument is triggered by a controller connected to the vehicle's LONWorks network. This controls the ping rate and also allows the trigger pulse to be synchronised with other systems on the vehicle in order to control interactions between instruments. This controller also sends time, depth, range aiding and navigation information to the instrument. A second LONWorks controller sends attitude information to the instrument.

For D343 this system was fitted with the transmit and receive transducers mounted in the nose of the Autosub. The beam spacing was set to be equidistant and the maximum beam angles were +/- 60 degrees. During missions that were planned to go deeper than 4000m an offset was applied to the depth sensor in order to overcome a bug in the EM2000 firmware which corrupted depth readings greater than 4095 metres. This offset was applied by changing the ncSonarMode configuration variable according to the expected depth range required. A setting of 3 gave an offset of -1000m while a setting of 4 gave an offset of -2000m.

The Kongsberg supplied control software was not used at all as it is known to have issues when used in AUV applications. The alternative NOCS EMControl and EMListen software was used to control and monitor the system.

During mission 23 the system was used in free running mode at various altitudes in an attempt to observe any potential interference with other acoustic systems and to give an idea of horizontal coverage at different altitudes. Initial evaluation of the data does not show any obvious interference (as can be seen from the image below) but further evaluation will be necessary.



Altitude	Ping Rate	# Good Beams	Swath Width
200			
150	1.6 – 1.8	106-108	
100			
80			
60			
10	2.3 - 2.5	111	19-26m
5	4.2	111	13
3	4.5-4.9	111	10-12m

6.7 Argos Location System

The Autosub vehicle is fitted with two transmitters that transmit to the Argos satellite system. This system can give the location of the vehicle and a limited amount of data can be transmitted although this data capacity is not used on Autosub. A local direction finding receiver can also monitor these transmissions and give a signal strength and bearing to the transmitter. This is useful for locating the vehicle when it first surfaces after a mission. For D343 the direction finding receiver was located in the dry area above the bridge with the antenna mounted on the first walkway above the bridge. The length of the antenna cables is limited and they cannot be extended without compromising the direction finding performance so the receiver must be mounted in a dry space close to the antenna. The receiver has a serial output which was fed to a DigiPort Server TS4 serial to Ethernet bridge (labelled Server 3). This was configured to send the serial data encapsulated in UDP packets to port 2002 on certain computers on the network. These computers were running the NOCS EMListen program to monitor and log the output from the receiver.

7. Automatic Fault Detection for Autosub 6000 (AFDA)

Richard Dearden, and Juhan Ernits. University of Birmingham.

7.1 Objectives

Funded through the NERC, **S**trategic **O**cean **F**unding **I**nitiative (SOFI), the AFDA project is concerned with producing software and models that will improve the reliability and robustness to failure of Autosub 6000. In particular, the project involves building models used to diagnose faults on the vehicle, and tools to reduce the likelihood of failures due to operator error. The diagnosis component of the project is based around NASA's Livingstone 2 diagnosis software.

To achieve these goals the team need to gain an in-depth knowledge of both the way the vehicle's hardware behaves and the way the sub is actually used during a cruise, in particular the process of configuring the software and writing the mission script. Participation in Cruise D343 was intended to provide the opportunity to observe the Autosub team preparing for missions and to discuss the diagnostic data logged on the vehicle with them to improve understanding of the vehicle's behaviour. In addition, it was hoped that the cruise would generate a data set of vehicle telemetry including a range of faults, which could then be used for model building and for testing the diagnosis tools. Being present when that data was generated is extremely useful for diagnosis modelling as post-cruise reports tend to only include the final diagnosis, rather than all the other hypotheses that were considered. As these consist of alternative explanations for the symptoms seen, recording them allows richer models to be produced.

The specific goals apart from knowledge and data gathering on D343 were to test diagnosis models of Autosub by running the models on the logged data immediately after each mission and to evaluate how useful a mission script checking tool would be to the Autosub team.

7.2 Diagnosis Models

Due to an emphasis before the Cruise on tool building and modelling the mission script, rather than modelling the Autosub hardware, there were no complete models of Autosub systems ready before the cruise.

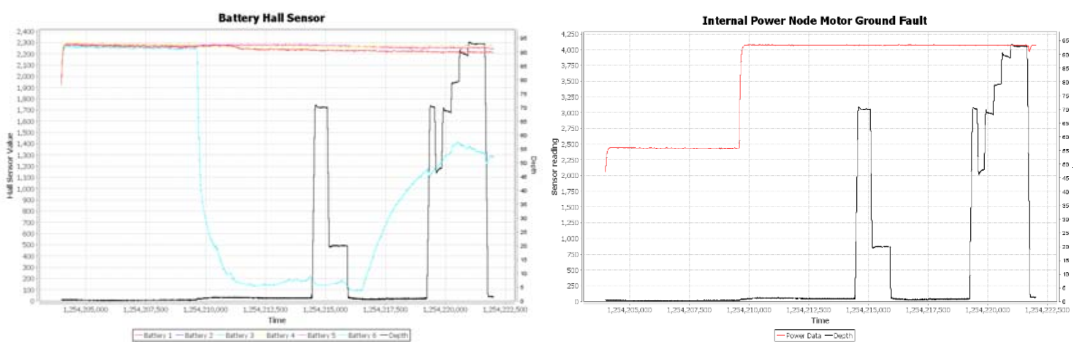


Figure 1 Battery Hall effect sensor readings (left) and during Mission 14. The motor ground fault reads high and the Hall sensor low as soon as Autosub enters the water. Livingstone correctly detected the faults and localised them as soon as they occur.

Since the cruise featured a number of faults in Autosub's batteries, a prototype battery model was developed during the Cruise with the help of the Autosub team. During the last days of the Cruise this model was applied to data from Mission 24 and Missions 25-27 (a single data set) shortly after the completion of the missions. The Livingstone 2 model successfully diagnosed a problem with the Hall sensor on Battery 1 that appeared in both sets of data, and that Battery 6 was off (actually not present on the vehicle) for both missions. However, it also produced a false positive diagnosis of a fault in Battery 4. The false diagnosis was due to a small amount of noise in the current measurement when the vehicle was first turned on. This model has now been run on data from a number of the missions where battery problems occurred. The most interesting of these was Mission 14, in which the Hall Effect Sensor on Battery 6 registered an anomalous value, and part way through the mission a ground fault was detected. The sensor values are shown in Figure 1. The diagnosis system correctly diagnosed that either the Hall sensor failed or that the battery was low on oil, and also correctly inferred there had been a battery short, but was unable to determine which battery it was (in fact, it appeared a number of the batteries had a similar problem).

A model of the depth control node was also developed during the cruise, and was successfully applied to data from a number of missions. It detects the stern-plane actuator fault that occurred after Mission 23, but currently identifies it as an unknown fault in the depth control. This model relies on a model of the mission script to distinguish normal behaviour from that induced by faults. The model is automatically generated as part of the mission script checking tool described below.

7.3 Mission Script Tools

In previous Autosub deployments, mission failures have been caused by hardware failures but also by mission script errors.

Table 1 Mission configuration and mission script validation result summary.

Mission	Mission configuration (.mcfg)	Compiled mission script (.dld)
M14	Safe maximum depth greater than maximum depth	OK
M15	OK	Unreachable waypoints on lines 192-202 and 204-262
M16	OK	Unreachable waypoints were found in when blocks on lines 192-202 and 204-262.
M17	OK	Unreachable waypoints were found in when blocks on lines 188-264 and 352-356.
M18	OK	Unreachable waypoints were found in when blocks on lines 146-204 and 206-216.
M19	OK	Unreachable waypoints were found in when blocks on lines 126 to 196 and 198 to 208.
M20	OK	OK
M21	OK	OK
M22	OK	Unreachable waypoint 76 to 140.
M23	OK	Unreachable waypoints on lines 88 to 92, 94 to 98, 100 to 104, 106 to 110, and 112 to 116.
M24	OK	OK
M25	OK	OK
M26	Same as M25	Same as M25
M27	Same as M25	Same as M25

The Livingstone model of Autosub includes a model of the actual mission being executed to aid the diagnosis of certain conditions. This model is generated automatically from the mission script before the mission, and at the same time, a number of checks are performed on the consistency of the configuration file and mission script. These include that the mission script doesn't command the vehicle to exceed the maximum depth specified in the configuration file, and that the script doesn't include waypoints that can't be reached from the previous vehicle location before the timeout for that step of the mission. A key feature of the tool is that it operates on the actual file that is downloaded to the vehicle. Thus it doesn't rely on the correctness of macros that may have been defined. This tool was run on the script for every mission as the script was being loaded onto the sub. It successfully discovered a number of anomalies in scripts. These are listed in Table 1.

These were checked, but in all cases had been knowingly placed in the script to test particular behaviours. It is expected that these would be much less common in science missions, and that the tool would be more likely to find genuine errors in the script.

Another useful feature of the tool is that it can be used to scan through all past logged mission data looking for previous occurrences of a particular combination of variables. This was used to search for other examples of the sternplane actuator problem that occurred after Mission 24.

The mission script checking tool, along with a problem with the script for Mission 16 that the tool didn't detect, prompted the observation that checking of depth profiles would a useful addition to the tool. To that end, a prototype depth profile analyser was developed during the cruise that uses the mission script and a very simple model of Autosub's vertical dynamics to estimate the behaviour that will result from Autosub executing the script. The tool outputs a plot of the expected depth as a function of time. This tool was subsequently run on the mission script from Mission 16 and successfully identified that the script would lead to an unplanned ascent from approximately 4500m to 500m. Figure 2 shows the predicted and actual depth profile of Mission 16.

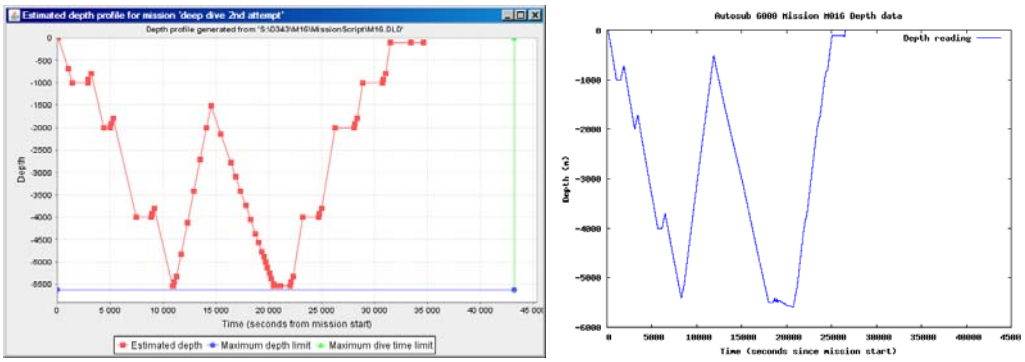
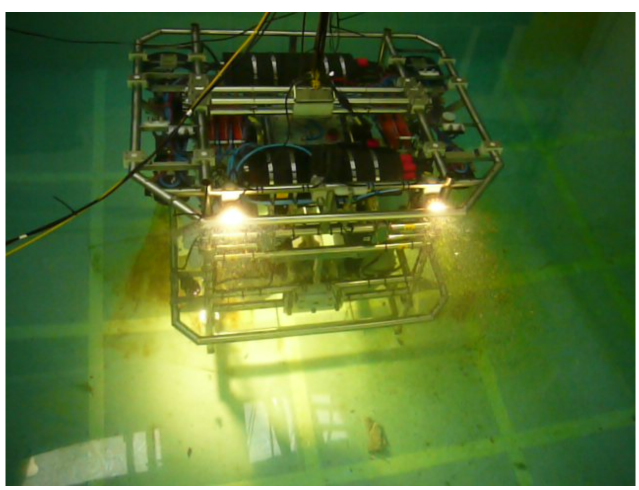


Figure 2 Comparison of predicted (left) and actual depth profile for Mission 16. The central peak of the graph was due to an error in the mission script.

Finally, it was identified that the telemetry stream would be a useful source of diagnostic information while Autosub is carrying out a mission, and that a tool that monitored the stream and automatically raised an alarm would be useful. Some initial progress was made on making the telemetry data available over a network so that such a tool could be developed.

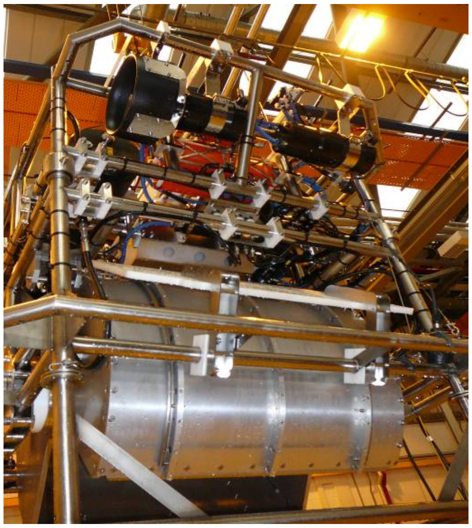
8.HyBIS (Hydraulic Benthic Interactive Sampler)

HyBIS is an RO-TVG (Remotely Operated TV-Grab) that is designed to be a versatile, easy-to-use platform for seafloor survey, intervention and instrument package deployment.



The concept was originated by Bramley Murton and Pete Mason to bridge the capability gap between blind sampling and full ROV operations. It was funded through an NOCS technology initiative fund. The vehicle was built in 2007 by Hydro-Lek, an off-shore engineering company that specializes in remotely controlled sub-sea vehicle systems.

HyBIS currently has six serial channels and three colour video channels. It has enough hotel power to supply a CTD, chemical and optical sensors and a variety of sonars. It is powered through the standard NMFD fibre-optic-electrical cable, delivering 7kvA at 1500V ac, with 5 KW available at the vehicle.



HyBIS has a command module for power, lights, and telemetry, and a swappable tool module for sampling. The command module has twin colour cameras and over 1000W of lights - all rated to 6000m. The command module also has hydraulic power packs, 140Bar water pump and electric thrusters producing 100 kg of thrust. The sampling module currently comprises a 0.3 cubic meter clam-shell grab.

The modules are separated by hydraulic release pins, enabling the tool module to be jettisoned or a pay-load to be deployed. In the future, it can be tooled with manipulators, push-cores, a slurp-gun or a rotary drill.

8.1 HyBIS Trials

Pre-dive set-up and tests:

The RO-TVG 'HyBIS' was positioned on the starboard side of the RRS Discovery and mounted on its deck frame which, in turn, was mounted to the screw fixture matrix on the ship's deck. The vehicle was attached via a termination bottle to a ~10km length of 17mm electrical fibre-optic umbilical cable wound on the ship's oceanographic winch. All operations of the vehicle were done according to the procedures described in the risk assessment presented to the ship's master and operators prior to the start of the trials cruise.

The HyBIS vehicle mounted on its deck stand, on the starboard deck of the RS Discovery. Dr Bramley Murton (shorts) and Veit Hunnerbach (red boiler suit) mounting the USBL beacon (yellow tube) on to the vehicle.

Connection issues:

The first problem was encountered when trying to connect the vehicle to the deep-tow cable. It was found that the D G O'Brian fibre optic bulkhead tail, inside the termination bottle, was damaged, causing high attenuation in the optical signal. This required replacing with a spare bulkhead that was supplied by the HyBIS team, restoring a good optical connection with attenuation limited to 10-15dB of the total transmitted signal strength over the length of the cable.

The second problem was an insufficient seal around the gland surrounding the deep-tow cable entry to the termination bottle. This caused the bottle to leak sea water on its first test dive, and short circuit the 1500V ac power supply. The short circuit and ground fault was immediately detected by the HyBIS power supply system and the supply power cut automatically. The bottle was drained and the fault repaired.

Once the connection problems were overcome, communications and power to the vehicle were established. No electrical power, voltage or earth leakage faults were detected and the fibre-optic communications remained robust. All vehicle functions were tested on deck and found to be working correctly.

The third problem was due to failure of the ship's winch. This caused considerable delays to the operations.

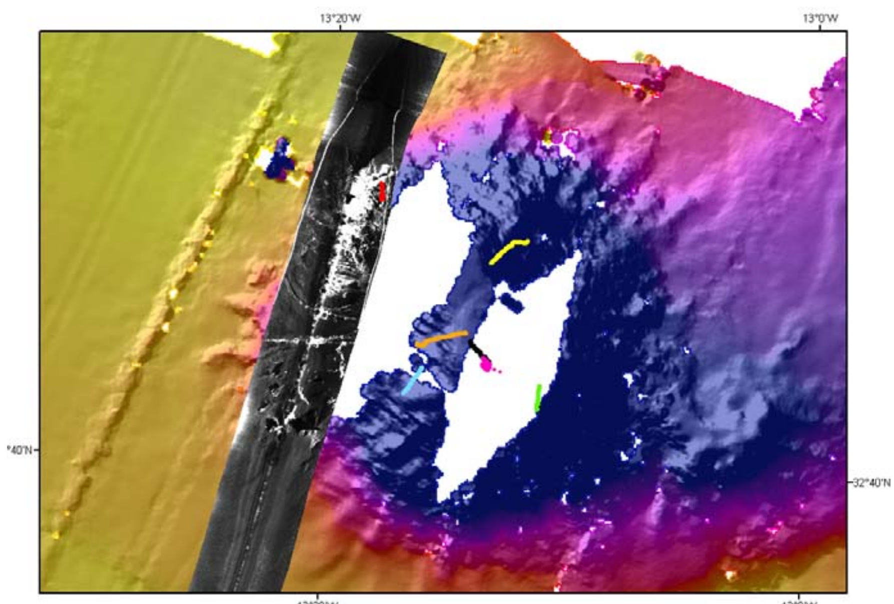
Vehicle data:

Pressure sensors:

The vehicle's depth and hydraulic pressure sensors gave erratic readings on deck. Pressures readings from both sensors varied by 5%. Both the depth and hydraulic pressure sensors yield a 1 to 5 volt DC output across 0-10000 psi and 0-1000 psi ranges respectively. This is a known problem and requires fault-finding on the sensor board.

Orientation sensors:

The digital compass on board the vehicle was also found to suffer some erratic behaviour of about 1% of its 360° range. It was also affected when the downward looking light circuit was energised. A new calibration was made subsequently on the second dive without thruster assistance or any lights, completing two 360° turns in 360 seconds. We also added software to display the pitch and roll of the vehicle.



Map showing all dive sites during HyBIS trials on cruise D343. Background data are multibeam bathymetry and TOBI sidescan sonar imagery.

Diving Operations.

During October 2009, HyBIS made 10 dives over the Casablanca Seamount, a 4km high, 12k diameter seamount located some 300 miles west of Morocco. The deepest dive was onto the Iberian Abyssal Plain at the base of the seamount, at a depth of 4630m and the shallowest at 650m on the summit. Together, HyBIS and Autosub 6000 will be deployed next year at the Mid-Cayman Rise, Caribbean in search of hydrothermal vents in the first of two NOCS cruises to this mid-ocean ridge. D343 provided our last opportunity to test the vehicles prior to next years missions.

A significant problem was the separation of the HyBIS pilots (located in the Main lab) from the winch drivers (located in the rear winch cab). This meant that we had to relay the HyBIS video to the winchmen using a video to cat5 cable sender/receiver. We also had to maintain close radio contact to give instructions to the winch cab.

Despite only being a trial cruise, the Casablanca Seamount dives proved very interesting geologically, with a very rugged terrain, vertical descents of over 100m, and an average slope on the flanks of 25°. Traverses from the summit and down the flanks revealed a change from explosive volcanic deposits of ash and pumice to massive lava flows. The transition was quite rapid some 400m below the summit and marked the start of cliffs caused by collapse of the volcanoes flanks. At its highest point, the volcano showed evidence of recent fluid flow with freshly excavated, 1-2m diameter craters. Life on the volcano was varied and included sponges, soft corals, lobsters, shrimp, sea cucumbers, sharks and rat-tail fish. Bramley Murton and Veit Huehnerbach prepared and piloted the HyBIS during the operations.

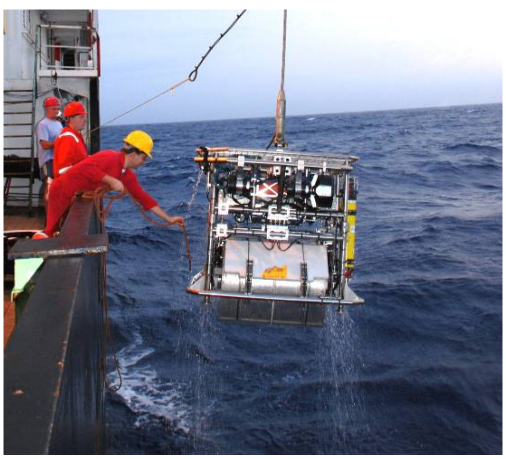
Date: 2nd October, 2009.

Station Number: HyBIS Dive 8

Location: 38° 24.01'N; 15° 29.54'W; depth 5549m.

Target: Iberia Abyssal Plain.

Sea-state moderate 4, wind 15-20 kts from the NE.



HyBIS launched (left) and recovered (right) over the starboard side of the RRS Discovery.

Dive 8 summary:

At 17:35 GMT HyBIS was launched and descended at 30 metres per minute. The vehicle was fitted with a Sonardine USBL beacon inside the vehicle 's frame. At 17:44 GMT the vehicle was at 100m depth when the ship's winch failed and the dive was aborted.

Date: 2nd October, 2009.

Station Number: HyBIS Dive 9

Location: 38° 25.8’N; 15° 29.0’W; depth 5560m.

Target: Iberia Abyssal Plain.

Sea-state moderate 4, wind 15-20 kts from the NE

Dive 9 summary:

At 19:56 GMT HyBIS launched and descended at 30 metres per minute. At 20:18 GMT the vehicle was at 450m depth when power to the vehicle was lost (short circuit and ground fault on the 1500V supply). The vehicle was powered down and returned to the surface at 40m/min by 20:43 GMT. The power short circuit was due to water ingress into termination bottle, leaking past sealing gland. The bottle was repaired and resealed.

Date: 2nd October, 2009.

Station Number: HyBIS Dive 10

Location: 38° 25.8’N; 15° 29.08’W; depth 5561m.

Target: Iberia Abyssal Plain.

Sea-state moderate 4, wind 15-20 kts from the NE

Dive 10 summary:

At 23:36 GMT HyBIS launched and descended at 30 metres per minute. At 00:13 GMT, the winch alarms sounded and the ship’s winch malfunctioned. Alarms reste, HyBIS descended to 2023m. No problems with the vehicle, all systems running. Noted some brown-outage of the lights with all thrusters and lights energised.At 00:28 GMT, winch alarms and malfunction. The vehicle was powered down and returned to the surface at 40m/min by 06:30 GMT, 3rd October. On surface, the supply transformer was configured to transmit at high voltage (i.e. swapped input coils from 270V to 240V).

Date: 6th October, 2009.

Station Number: HyBIS Dive 11

Location: 33° 01.32’N; 13° 27.63’W; depth 4350m.

Target: Flat sea floor adjacent to Casablanca Seamount.

Sea-state calm 1, wind 10-15 kts from the NE.

Dive 11 summary:

At 15:55 GMT, the vehicle was deployed and all systems tested at 50m depth. At 17:40 GMT the seabed was in sight at a depth of 4359m and video recorders were activated. But the port thruster did not function, although everything else was okay. System power was cycled on and off and the thrusters came back on line. At this depth, the hydraulics are very slow, and the thrusters draw a high current (viscosity of compensation oil and hydraulic oil causing an increase in load). Maximum current was 28A, just below the 30A breaker limit. At 2106 GMT, power demand exceeded 30A, and the breakers interrupted the power supply. Radius of manoeuvrability was about 50m. At 21:18 GMT, HyBIS landed on seabed and took a grab sample. The grab closure was slow and took 2 minutes.

23:07 GMT, vehicle recovered and on deck. Unfortunately we forgot to record the digital data. As a result, we modified the pilot software to show a red box to indicate when recording data.

Date: 7th October, 2009.

Station Number: HyBIS Dive 12

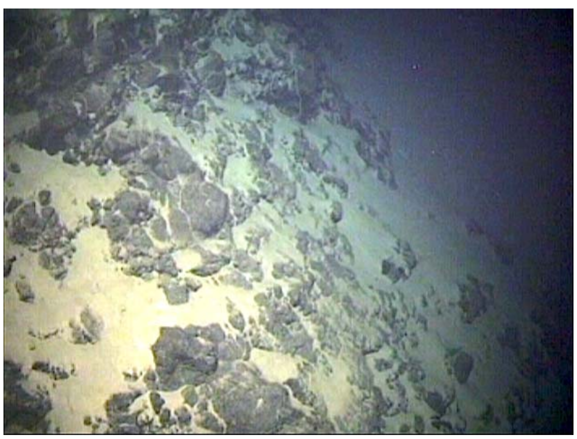
Location: 32° 49.384'N; 13° 17.895'W; depth 2439m.

Target: East flank of the Casablanca Seamount.

Sea-state 4, wind 15-20 kts from the NE.

Dive 12 summary:

At 12:30 GMT a pre-dive check was made of the HyBIS vehicle. It was then launched at 14:40 GMT and descended to 50 m where it was energised and al systems checked. We then continued diving at 40 metres per minute until 16:20 GMT when the seabed was in sight. We started a survey down the slope of the seamount at 0.5 kts to avoid colliding with the sea bed. Radius of manoeuvrability was about 100m. Sampling failed due to steep slopes. Vehicle recovered at 32°49.932'N; 13°18.000'; depth 2742m. The vehicle returned to the surface at 40m/min and was secured and powered off by 19:50 GMT.




Steep slopes characterise the flanks of the Casablanca Seamount, making it impossible to land the HyBIS vehicle. Surveys MUST be made down slope to avoid dragging the vehicle in to the sea floor.

Date: 8th October, 2009.

Station Number: HyBIS Dive 13

Location: 32° 43.014'N; 13° 11.032'W; depth 1222m.

Target: East flank of the Casablanca Seamount.

Sea-state 4, wind 15-20 kts from the NE.

Dive 13 summary:

At 17:30 GMT a pre-dive check was made of the HyBIS vehicle. It was then launched at 17:54 GMT, powered up and systems checked at 50m. Fibreoptic coms problems found to be due to the lab deck cable. This was replaced. Diving continued at 21:15 GMT, descending at 50m/min. Seafloor in sight at 22:02 GMT, video and data recorders on. At bottom of vertical cliff face. Ship set course for 0.2

miles to towards 180° and 0.4 kts. Steep terrain prevented sample being taken. Vehicle recovered at 01:02GMT, 32°42.160'N; 13°11.164'W, 1460m.

Date: 9th October, 2009.

Station Number: HyBIS Dive 14

Location: 32° 47.290'N; 13° 13.279'W; depth 939m.

Target: Northeast flank of the Casablanca Seamount.

Sea-state 4, wind 15 kts from the NNE.

Dive 14 summary:

At 17:00 GMT a pre-dive check was made of the HyBIS vehicle. HyBIS configured with deck stand-frame attached to increase stability when landed on steep slopes. Vehicle then launched at 17:21 GMT, powered up and systems checked at 50m. Diving continued, descending at 50m/min. Seafloor in sight at 18:09 GMT, video and data recorders on. In amongst very steep terrain, rocky with many crags and cliffs. Contouring slopes was found to work best. Ship set course for 0.2 miles to towards 220° and 0.4 kts. Steep terrain prevented sample being taken. Vehicle recovered at 22:53GMT, 32°42.160'N; 13°11.164'W, 1965m. HyBIS on deck – replaced lamps in each of one of the forward and downward looking lights.

Date: 11th October, 2009.

Station Number: HyBIS Dive 15

Location: 32° 43.466'N; 13° 16.011'W; depth 1461m.

Target: Southwest flank of the Casablanca Seamount.

Sea-state 5, wind 20 kts from the NNE.

Dive 15 summary:

At 00:32 GMT a pre-dive check was made of the HyBIS vehicle. It was then launched at 00:32 GMT, powered up and systems checked at 50m. Dive to sea bed; in sight at 01:48 GMT and 1501m. Start survey line at 0.5 kts and towards SW. Rugged terrain and cliffs. Radius of manoeuvrability was about 100m. Dragged up one 30m cliff -caused stbd light to fail. (lamp). At 04:20 GMT, 32°42.535'N; 13°16.740'W, 1537m depth, we found a headwall scar below which a bare rock surface exposed striated slip surfaces. Too steep to grab samples. Recovered vehicle at 04:46 GMT, on surface at 05:40 GMT.

Date: 11th October, 2009.

Station Number: HyBIS Dive 16

Location: 32° 44.503'N; 13° 14.024'W; depth 612m.

Target: Top of the Casablanca Seamount.

Sea-state 5, wind 20 kts from the NNE.

Dive 16 summary:

Silver scabbard fish reflected in the lights of HyBIS.

At 17:20 GMT a pre-dive check was made of the HyBIS vehicle. It was then launched at 17:32 GMT, powered up and systems checked at 50m. Dive to sea bed; in sight at 17:57 GMT and 614m. Start survey line at 0.5 kts and towards SW. Radius of manoeuvrability was about 150m. Flat terrain and sponges. Sediment only few tens of cm thick and patchy. At 18:54 GMT, 32°44.390'N; 13°13.981'W, 614m depth, we found a series of pock-marks or pits, several metres in diameter and 1-2m deep. Samples too small to grab. Silver scabbard fish everywhere. Recovered vehicle at 22:03 GMT, on surface at 22:30 GMT.

Date: 13th October, 2009.

Station Number: HyBIS Dive 17

Location: 32° 43.523'N; 13° 13.210'W; depth 630m.

Target: Top of the Casablanca Seamount.

Sea-state 5, wind 20 kts from the NNE.

Dive 17 summary:

This dive was made over the same terrain as that mapped by Autosub6000, EM2000 swath sonar, during the previous day. At 09:25 GMT a pre-dive check was made of the HyBIS vehicle. It was then launched at 09:32 GMT, powered up and systems checked at 50m. Dive to sea bed; in sight at 10:04 GMT and 628m. Start survey line at 0.5 kts and towards SW. Radius of manoeuvrability was about 150m. Flat terrain and sponges. At 11:46 GMT, 32°43.686'N; 13°13.199'W, 612m depth, we managed to grab some rocky samples although they were small (10-20cm diameter). At 12:23 – 12:26 GMT, at 32°43.816'N; 13°13.360'W, 607m depth, we discovered an extensive field of fresh craters and pits (1-4m diameter by 1m deep). Recovered vehicle at 12:38 GMT, on surface at 12:40 GMT.

Date: 13th October, 2009.

Station Number: HyBIS Dive 18

Location: 32° 47.770'N; 13° 14.249'W; depth 618m.

Target: SW edge of top of the Casablanca Seamount.

Sea-state 5, wind 20 kts from the NNE.

Dive 18 summary:

This dive was made over the same terrain as that mapped by Autosub6000, EM2000 swath sonar, during the previous day. At 22:15 GMT a pre-dive check was made of the HyBIS vehicle. It was then launched at 22:21 GMT, powered up and systems checked at 50m. Dive to sea bed; in sight at 22:50 GMT and 620m. Start survey line at 0.5 kts and towards SW. Radius of manoeuvrability was about 150m. Terrain increasingly steep in direction of survey comprising terraces and small scarps and lava flow fronts. Pumice and tuffaceous deposits common with thin lava flows on top. Flow levees trending N-S with sheet flows and breccia and scoria. At 02:10 GMT (14th October), at 32°44.441’N; 13°15.766’W, 1070m depth, we found a transition from scoria and ash deposits to solid pillow lavas. This transition was also marked by a cliff facing SW that appears on the Swath data as a headwall scarp of a small slump. The scarp became a vertical cliff of 100m, with pillow and massive lavas outcropping. Too steep to grab samples. Recovered vehicle at 03:35 GMT, on surface at 03:47 GMT at 32°44.331; 13°16.237 and 1485m depth.

Modifications to Vehicle:

1. Zinc anodes required for all pods.
2. Compass card to be fixed to reduce noise on depth sensor.
3. Low viscosity comp and hydraulic oil to be used for dives > 3000m.
4. Spare lamps needed.
5. HD/stills cameras to be fitted
6. Sector scanning sonar to be implemented.

9. POL Cruise Work Summary

C Balfour and S Mack, Proudman Oceanographic Laboratory, Liverpool, UK.

9.1 Overview

This report provides a brief summary of the POL trials undertaken during the RRS Discovery based D343 Oceans 2025 trials cruise. The general theme of the work has been to develop and test remote measurement technologies, deep water communication systems and a compact version of the MYRTLE (multi-year return tide level equipment) long term deep water recoverable lander. The cruise started from Govan Glasgow on Sunday 27th September 2009 and finished at Santa Cruz, Tenerife on Friday 16th October. During the ships passage from the UK to the Canary Islands a series of stops were made to undertake experimental work with the bulk of the trials occurring close to the Casablanca Seamount off the west coast of Morocco.

Key Cruise Objectives

The general idea is to use RRS Discovery to deploy a surface buoy and a deep sea instrumentation frame. Trials to assess the performance of various commercial and bespoke oceanographic measurement and communication systems were then undertaken. In particular, the cruise was used operate and test the following systems:

9.2 POL Telemetry Buoy

1. Configuration, assembly, deployment and recovery of the buoy.
2. The evaluation of the performance of LinkQuest based deep water acoustic data links between the buoy and MYRTLE on the sea bed.
3. To test the operation of a series of telemetry systems designed to relay data recorded on or close to the sea bed to the surface buoy and then back to shore for analysis. These systems include:

a. Orbcomm global messaging telemetry using Quake Global and MobiApps programmable modems. This involves bidirectional data transfer with measurement data being transferred to POL hosted email accounts for analysis. Email commands can also be issued to the Orbcomm systems to reconfigure oceanographic instruments deployed in deep water via MYRTLE and a long range LinkQuest Acoustic Data Link.
b. Omni-directional Meteosat DCP to provide one way data transfer from the POL telemetry buoy to a shore based receiver using a geostationary meteorological satellite data transfer service.
c. Evaluation of a Tideland VHF AIS (aid to navigation and collision avoidance) transmitter and an examination of the feasibility of using VHF based AIS transmissions to transfer oceanographic data.

4. The use of the buoy to capture measurement data from a Seabird Microcat CTD deployed on the seabed and the processing of email based commands to reconfigure this CTD after it has been deployed.
5. The use of a deep water mooring to anchor the buoy in a preferred location to allow a series of long range communication trials with a deep sea lander to be undertaken.

9.3 MYRTLE Deep Sea Instrumentation Frame

1. To develop procedures for the reliable assembly, configuration, deployment and recovery of the MYRTLE deep sea lander system.
2. To evaluate the performance in deep water (≥2000m) of Benthos XT6000 acoustic transponders for operation of frame recovery releases.
3. To evaluate the performance of a Benthos Smart Modem combined acoustic data link and release system.
4. To test the operation of a ‘steerable’ release system designed to allow multiple releases to be operated from a Benthos Smart Modem.
5. Release and recovery of a data capsule from MYRTLE that has the capability to return to the surface and transfer recorded oceanographic data (bottom pressure recorder – BPR data). This data is transferred to shore for analysis using low earth orbit satellite based (Iridium or Orbcomm) global data transfer services.
6. To provide a mounting and power for a LinkQuest deep water acoustic data modem and a Seabird Microcat CTD.

9.4 POL Instrument Tests

POL Wire Test 1- Friday 02-10-09 to Saturday 03-10-09

The wire test location was off the west coast of Portugal at a latitude of 38^{o} 24.01994’ N and a longitude of 15^{o} 29.78239’ W in a region with a depth of 5500m. Photographs taken during the night time deployment of the wire test frame are shown in Fig. 1. The key features of this test were as follows:

1. Mount the various sensors acoustic releases, data loggers and deepwater acoustic data modems onto a scaffolding frame.
2. Deploy this frame, with a heavy ballast weight attached to the bottom, over the side of the ship. The use of a large ballast weight keeps the test frame stable and the CTD winch wire under tension at all times, ensuring that the test frame remains stable.
3. Suspend acoustic transducers or use the ships transducers just below the sea surface to communicate with the sensors etc under test on the frame.
4. Route some of the data from the surface acoustic transducers to the telemetry buoy tower on the aft deck of the ship.

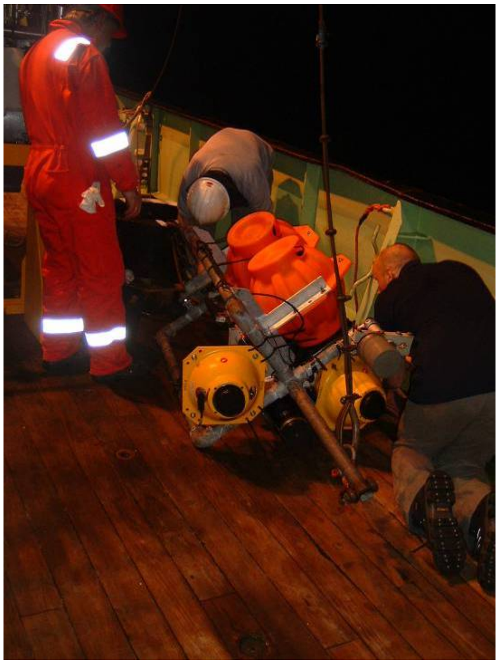
5. Lower the test frame to a series of incremental depths, e.g. 100m, 1000m, 2000m, 3000m and 4000m and evaluate the performance at these depths of the various instrumentation systems.

The wire test frame was lowered into the water just before midnight on Friday 2nd October and the test was concluded at approximately 05:00 on Saturday 3rd October. All of the systems under test performed well with the exception of email based remote control commands to the Orbcomm telemetry modem on the aft deck of the ship. The intention was that a command issued by a satellite based telemetry system would be received by the buoy and sent over a deep water communications link to interact with marine sensors deployed on the sea bed. Unfortunately, a problem was detected with the reception of email based commands by the satellite data modem (NERC response emails consuming the entire bandwidth of the satellite to modem downlink) used during the test. A solution for this was then investigated. With the exception of this problem, all of the key objectives of the trial were achieved. Extensive testing such as this was required to provided some level of assurance that all of the sensors, releases etc are fully operational before a deep water deployment is attempted. A summary of the key features of the systems under test along with some brief comments regarding the performance during the wire test is provided in table 1. The success of these trials then resulted in preparations being made for a MYRTLE deep sea lander and surface buoy deployment at a later stage during the cruise.

System Under Test Co	**mments**
Benthos XT6000 acoustic transponder and release with modified electronics for quick burn of release wire	System performed well and fired OK at 4000m using the ships port side underwater transducer
Benthos Smart release real time deep water acoustic data link and logger	Reliable communications and data recording throughout the trial
Bottom Pressure Recorder (BPR) with Bluetooth wireless configuration.	Configured OK before the trials and performed well throughout the test
Steerable router for multiple release mechanisms – interfaced to the Benthos Smart modem to route release commands to multiple release targets	Operated correctly and fired the MYRTLE data pod release mechanism OK at 4000m
LinkQuest UWM 4000 deep water acoustic data link for relaying marine data (CTD measurements) from the sea bed to the surface.	Performed reliably during the trials and correctly relayed CTD data from the test frame to a surface transducer.
Orbcomm email based measurement data transfer.	Measurement CTD data received by the LinkQuest surface modem was reliably sampled and transferred for email access to the data
Remote control of CTD parameters using email based commands	The remote control and re-configuration of the CTD parameters did not work during this test. This was due to a problem with the Orbcomm data modem used for the trial being unable to receive data.

Table 1 – Wire Test Key Features and Evaluations

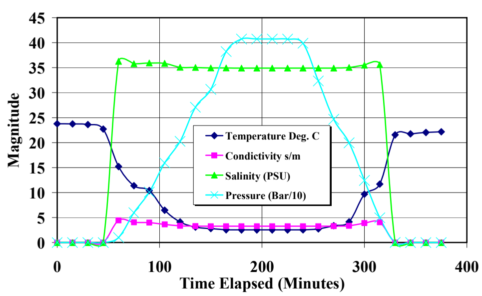
Plots of the data from the seabird Microcat conductivity temperature and depth (CTD) sensor and the received telemetry data are shown in Fig. 2. The chart in Fig. 2a shows the Seabird CTD data recorded at 15 minute intervals with the pressure scaled fit onto the same axes. The pressure record clearly shows the descent of the frame to 4000m, a delay at the ultimate test depth of 4000m for testing of acoustic systems etc before the frame is returned to the surface. The data relayed to the surface by the LinkQuest acoustic data link and then sent by Orbcomm for remote reception is shown in Fig. 2b. This shows good agreement with the CTD data indicating that the acoustic data link and Orbcomm telemetry systems are working reliably.



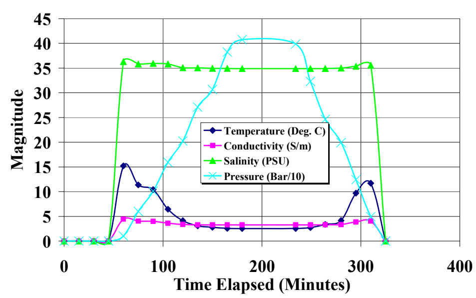
a – Preparing the Wire Test Frame for Deployment

b – Deployment of the Wire Test Frame

Fig. 1 – POL Wire Test Frame Deployment



a – Internally Recorded CTD Data



b – Received surface LinkQuest data that has been sampled and sent by the Orbcomm satellite global messaging service

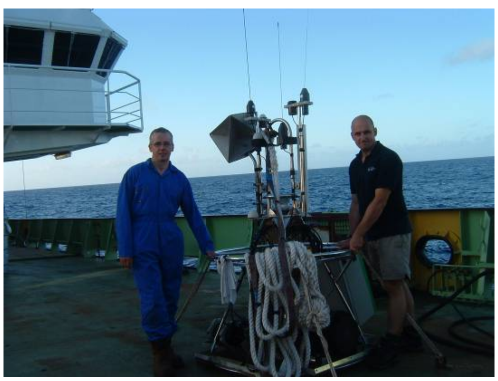
Fig. 2 – POL Wire Test CTD and Telemetry Data

Thursday 08-10-09 – Full System Deployment

Preparations for the full system tests were commenced at 08:00 beginning with some final checks before the system was deployed. The deployment sequence commenced at 110:5 at a latitude of 32^{o} 50.6862’N and a longitude of 13^{o} 18.72165’W, at the Casablanca Seamount off the west coast of Morocco. Technical difficulties were then experienced with releasing the MYRTLE data capsule and communicating with the LinkQuest acoustic modem on the sea bed. Concerns about the performance of the acoustic POD release and the sudden loss of communications with the LinkQuest sea bed modem led to the decision to cancel the full deployment and recover the MYRTLE lander as soon as possible. A selection of photographs of the MYRTLE deployment is shown in Figs. 3 and 4.

a – MYRTLE Stowed and Ready for Deployment

b – Telemetry Buoy Upper Tower Final Assembly

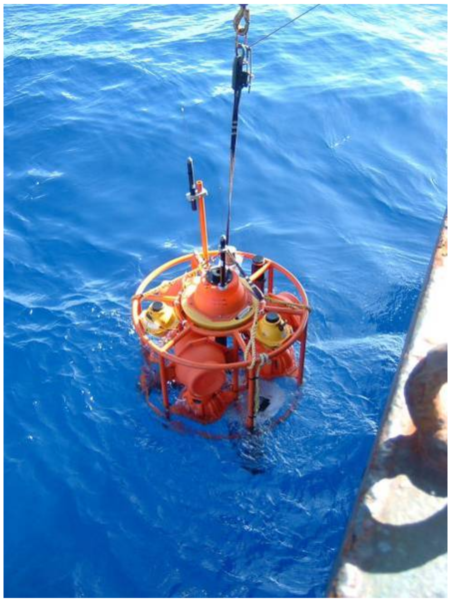


a– Chris and Steve by the Telemetry Buoy Upper Tower

b – Steve and Chris by MYRTLE

Fig. 3 – PO L Telemetry Buoy and MYRTLE D eep Sea Lander Ins trumentation Preparatio n Photographs

a– Lowering of the MYRTLE Frame for Deployment



b – MYRTLE Deployment Just Prior to Release

c– MYRTLE Recovery With The Snagged Data Capsule

d – Recovered MYRTLE Frame on the Aft Deck of RRS Discovery

Fig. 4– POL MYRTLE Deployment and Recovery First Full System Deployment Attempt

During the deployment attempt the data recorded by a Seabird deep sea Microcat is plotted in Fig. 5. This shows the descent of the MYRTLE frame to an approximate depth of 3700m, a delay on the sea bed and then the ascent to the surface after the release mechanism is fired before the subsequent frame recovery.

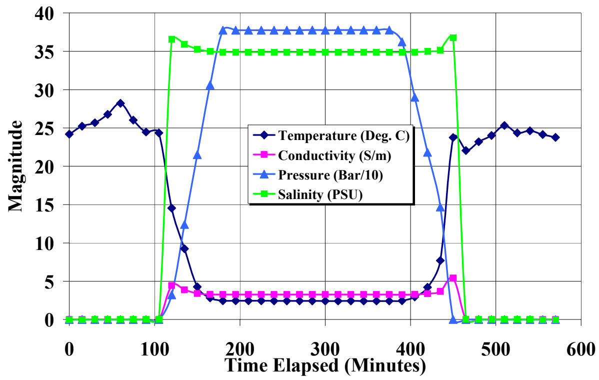


Fig. 5 – Recorded Seabird Microcat CTD Data during the MYRTLE Deployment and Recovery

After lengthy post deployment evaluations and testing it transpired that a lifting strop left on the upper part of the MYRTLE lander probably prevented the release of the data POD. One of the Benthos XT6000 acoustic transponders (Serial no: 70772) had responded properly to release commands and not fired its actual release mechanism. In addition to this the LinkQuest deep water acoustic data link modem fitted to the MYRTLE frame has gone faulty and it will need to be returned to the manufacturers for evaluation and repair. Table 2 shows the last few lines of measurement data transferred to the surface before the sea bed LinkQuest modem failed. Prior to the modem failure the LinkQuest diagnostic software (mdm_sync command) has reported the seabed to surface acoustic link as being 'good' indication a reliable data connection had been established.

Data Sent to the LinkQuest Surface Modem Prior to Sea Bed Modem Failure					
Temp (Deg. C)	**Cond (S/m)**	**Pressure (dB)**	**Salinity (PSU)**	**Date**	**Time (GMT)**
# 2.4547,	3.26357,	3776.468,	34.9013,	08 Oct 2009,	11:25:00
# 2.4457,	3.26272,	3776.446,	34.9005,	08 Oct 2009,	11:40:00
# 2.4475,	3.26279	3776.510,	34.8994,	08 Oct 2009,	11:55:00
# 2.4307,	3.26134,	3776.584,	34.8997,	08 Oct 2009,	12:10:00

Table 2 – Final Acoustic Data Transfers via the LinkQuest Sea Bed to Surface Modems

After the data shown in Table 1 was successfully transmitted to the surface by the acoustic LinkQuest acoustic modem, the Orbcomm telemetry system attached to the aft deck of the ship was used to send one measurement. This measurement, as shown in Table 3 was successfully transferred from the MYRTLE lander in 3777m of water to the surface and then back to a POL hosted email account for analysis by the Orbcomm constellation of low earth global messaging satellites.

Data Sent to the LinkQuest Surface Modem Prior to Sea Bed Modem Failure							
Lat	**Long**	**Temp (Deg. C)**	**Cond (S/m)**	**Pressure (dB)**	**Salinity (PSU)**	**Date**	**Time (GMT)**
32.84415024	-13.31223329	2.436	3.26161	3776.770	34.898	08/10/2009	12:39:47

Table 3 – Telemetry Measurement from the Sea Bed before the LinkQuest UWM4000 Deep Water Acoustic Modem Failure

The decision was then made to take some time to discuss and evaluate the remaining deployment options. A series of re-configured experimental deployments will then be attempted later on during the cruise. Additional trials in the morning had confirmed that the LinkQuest UWM4000 deep water acoustic modem was faulty. This modem is essential to establish communications between the MYRTLE lander when it is on the sea bed and the POL telemetry buoy. A message was sent to the manufacturers to ask for advice if the unit is serviceable and if not, what the returns and repair procedure is. In addition to this, during yesterdays MYRTLE deployment one of the XT6000 acoustic transponder and release mechanisms had failed to operate correctly. This raised concerns about the reliability of the release mechanisms and the chances of recovering the MYRTLE lander if another deep water deployment is attempted. Therefore, in order to maximise the results from the trials, the following three wire tests were planned. These tests involved suspending a test frame over the side of the ship with the MYRTLE based instrumentation attached and lowering it to a series of test depths using the CTD winch and cable. To substitute for the deep water LinkQuest acoustic link a pair of POL ISO UWM3000 modems will be used that have a maximum depth rating of 2000m and a communications range of 3000m. This allowed data communications and telemetry tests to be undertaken up to a depth of 2000m. Benthos and LinkQuest surface transducers will then be suspended over the side of the ship just below the waters surface to establish data links between the test frame and the surface. Based upon these constraints the following three tests were devised:

1. **Wire Test A:** Lower the wire test frame and perform performance checks for the Benthos Smart Modem and LinkQuest acoustic data links. The telemetry buoy tower on the aft deck of the ship will simulate a buoy deployment. Trial the email based control of a seabird CTD parameters deployed in deep water using Orbcomm bidirectional telemetry (Quake Global Modem). When the maximum test depth is reached (dictated by the substitute LinkQuest

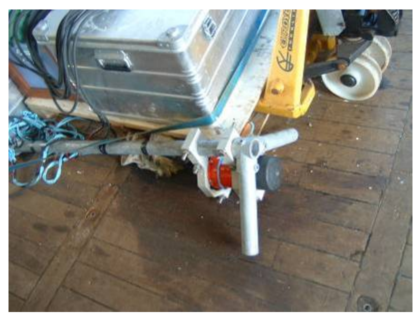
UWM3000 modems) fire all of the release mechanisms to test the performance of the MYRTLE releases (frame and data capsule) at the maximum test depth.

2. **<u>Wire Test B:</u>** Lower the wire test frame and perform performance checks for the Benthos Smart Modem and LinkQuest acoustic data links. The telemetry buoy tower on the aft deck of the ship will simulate a buoy deployment. Trial the email based control of a seabird CTD parameters deployed in deep water using Orbcomm bidirectional telemetry (MobiApps Modem). Meteosat DCP will also be used for one way measurement data transfer using a geostationary meteorological satellite. When the maximum test depth of 2000m (dictated by the substitute LinkQuest UWM3000 modems) is reached fire all of the release mechanisms to test the performance of the MYRTLE releases (frame and data capsule) at the maximum test depth.

3. **<u>Wire Test C:</u>** Lower the wire test frame without the LinkQuest UWM3000 acoustic modems to a depth that is as low as reasonably practicable within the cruise working area around the Casablanca Seamount. When the maximum test depth is reached fire all of the release mechanisms to test the performance of the MYRTLE release at the maximum test depth. Regular performance checks of the Benthos Smart Modem deep water acoustic data link will also be undertaken during this test.

The first of the previously described wire tests has been provisionally scheduled for tomorrow (Saturday 10th October). The remainder of the day was then spent preparing the instrumentation and wire test frame for and undertaking the actual deployment as shown in Figs. 6 and 7. This preparation work included testing all the instrumentation, replacing batteries etc. In addition to this, an Orbcomm email based remote control of a CTD using LinkQuest modems set to low power, in air on the deck of the ship was successfully completed.

a – Frame Preparation For Wire Test



b – LinkQuest UWM3000 Surface Transducer

Fig. 6 – POL Preparations for 2000m Wire Test

The test commenced at 17:00 BST at a latitude of 32^o 50.21386’N and a longitude of 13^o 09.47560’W. The test was completed shortly before midnight and it involved progressively lowering the wire test frame to a series of test depth stop off points of 360m, 500m, 1000m, 2000m and then back to 1000m and finally 500m. Following this, the frame was then raised back to the surface for recovery. During these tests a Quake Global Orbcomm modem was used to capture the data transmitted to the surface LinkQuest modem. The Orbcomm constellation of low earth orbit satellites was then used to send this data to a POL hosted email account. An email was then composed and sent to the telemetry system on the deck of the ship to communicate with the deployed Seabird CTD via the LinkQuest acoustic data link. This test was to demonstrate remote control of a deployed CTD using Orbcomm. The key steps in this remote control sequence were as follows:

1. An email is composed and sent to the Orbcomm Italian uplink to use the Orbcomm satellite constellation to communicate with the telemetry modem on the aft deck of the ship.

2. This email is received by the telemetry modem and the command is acknowledged in the form of a response email sent to indicate the Orbcomm modem has successfully received the email command.

3. The LinkQuest acoustic data link is then used by the Orbcomm data modem to script a series of commands to the deployed Seabird CTD to:

    a. Stop the current logging operations.

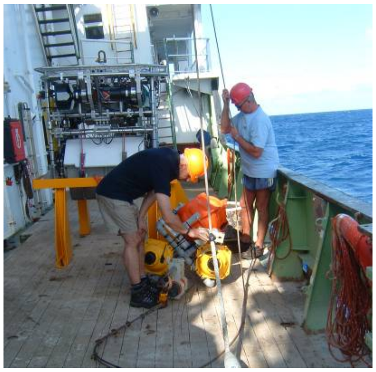
    b. Alter the instrument sample rate to another setting that is determined by structure (command code in the body of the message) of the email based command.

    c. Resume logging operations.

The general motivation for this work is to demonstrate the remote reconfiguration of instrumentation deployed in deep water without having to visit and physically recover the instrumentation. This work has formed a series of core tests during POL participation in the Oceans 2025 RRS Discovery based instrumentation trials cruises. The intention for this cruise was to deploy the MYRTLE Lander and a moored telemetry buoy in deep water to perform a series of extended trials to demonstrate the feasibility of prolonged deep water instrument data retrieval, telemetry and remote instrument reconfiguration using email and or the internet.

When the wire test frame reached the maximum test depth of 2000m the Benthos XT6000 based acoustic releases (normally used for MYRTLE frame recovery) were fired. The Benthos Smart Modem release (normally used for MYRTLE data pod recovery) was also fired at 2000m. During this test, one of the XT6000 transponders (serial number 70772) reported that the release mechanism had fired and on recovery of the frame it transpired that this release had not operated correctly. The reason for this needs to be investigated and it has been this problem with release reliability that prompted a halt to any further attempts to deploy the MYRTLE lander during the cruise. The Benthos Smart modem performed well during the trial and it correctly test fired the MYRTLE data pod release mechanism at 2000m.

A plot of the measured data from the Seabird CTD is shown in fig 8 and the pressure record clearly shows the stop off points at various depths during the test tor perform testing and evaluation of acoustic data links and satellite telemetry system performance. A sample rate change request to the CTD from 15 minute to 1 minute sampling was issued during the test by an email command sent via an internet based email client. The performance of the LinkQuest acoustic data modems throughout the trial was poor. A modem software test routine executed at the start of the test reported the communications link performance a being ‘Very Demanding’, which suggested that the UWM3000 omni-directional data link would be problematic. The exact reason for this poor data link performance is not clear. Bearing in mind that the wire frame modem and the surface modems were almost directly facing each other with only clear water between the two modems it is reasonable to expect the data link to perform well under these conditions. Despite these problems an email based command was scripted to the deployed Seabird CTD to increase the sample rate to one measurement every 60 seconds, as shown in Fig. 20a. The poor performance of LinkQuest UWM3000 acoustic modems resulted in a delay of approximately 50 minutes before the required commands were successfully transferred to the Seabird CTD.



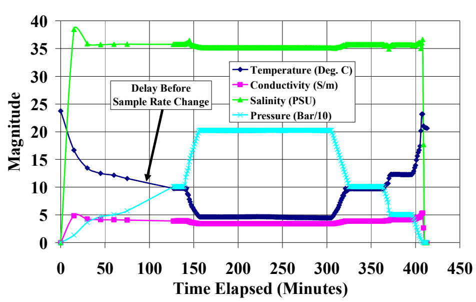
a– Final Preparations for Deployment of the Wire Test Frame

b – Deployment of the Wire Test Frame

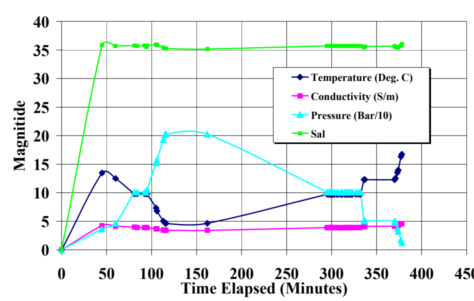
c– Monitoring of the Telemetry System Operation

d – Monitoring of the Benthos Smart Modem and Acoustic Release Operation

Fig. 7 – POL Wire Test A Photographs



b – Internally recorded CTD Data



b – Received surface LinkQuest data that has been sampled and sent by the Orbcomm satellite global messaging service

Fig. 8 – Recorded CTD and Telemetry Data for the first 2000m Wire Test

What is evident in the plot shown in Fig. 20b is that the poor performance of the LinkQuest UWM3000 data link meant that there were periods of time when no measurement data was successfully transferred. The UWM3000 modems would almost continuously try to communicate and only the occasional burst of several characters or several tens of characters would be transferred. Throughout the test the Benthos Smart acoustic modem performed well indicating a potential advantage with this system in terms of data link reliability and data throughput for this particular deployment.

Day 16 Monday 12-10-09 to Tuesday 13-10-09 – POL 2000m Wire Test B

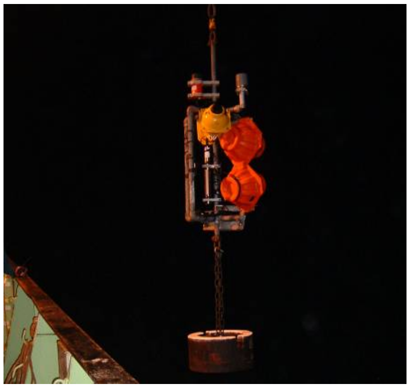
After the morning cruise planning meeting was attended it was decided that the second POL wire test will be scheduled for this afternoon. Delays with Autosub 6000 recovery resulted in the POL wire test B being rescheduled for the evening. A maximum depth of 2000m was once again used which was governed by the substitute LinkQuest UWM3000 data modem depth rating following the previous failure of the LinkQuest deep water (6000m rated) UWM4000 modem. Due to the previous poor performance of the UWM3000 based underwater acoustic data link a replacement surface modem, serial number 008604 was substituted for the original surface modem (serial number 008603). Throughout the trials with the UWM3000 modems, the bottom modem, serial number 008602 was used. A series of photographs of the deployment and monitoring of the wire test are shown in Fig. 9.

The test started at 20:45 BST at a latitude of 32^{o} 44.9451'N and a longitude of 13^{o} 18.3549'W and continued until 02:45 BST on Tuesday 13th October. The test involved progressively lowering the wire test frame to a series of test depth stop off points of 100m, 500m, 1000m, 1500m 2000m and then back to 1500m, 1000m, 500m and then finally 100m. Following this, the frame was then raised back to the surface for recovery. During these tests a MobiApps m100 Orbcomm modem was used to capture the data transmitted to the surface LinkQuest modem. The Orbcomm constellation of low earth orbit satellites was then used to send this data to a POL hosted email account. An email was then composed and sent to the telemetry system on the deck of the ship to communicate with the deployed Seabird CTD via the LinkQuest acoustic data link. This test was to demonstrate remote control of a deployed CTD using Orbcomm. The key steps in this remote control sequence were as follows:

1. An email is composed and sent to the Orbcomm Italian uplink to use the Orbcomm satellite constellation to communicate with the telemetry modem on the aft deck of the ship.
2. This email is received by the telemetry modem and the command is acknowledged in the form of a response email sent to indicate the Orbcomm modem has successfully received the email command.
3. The LinkQuest acoustic data link is then used by the Orbcomm data modem to script a series of commands to the deployed Seabird CTD to:

    d. Stop the current logging operations.
    e. Alter the instrument sample rate to another setting that is determined by structure (command code in the body of the message) of the email based command.
    f. Resume logging operations.

a– Final Preparations for Deployment of the Wire Test Frame



b – Deployment of the Wire Test Frame

c– Telemetry System Monitoring

d – Monitoring of the Benthos Acoustic Data Link and XT6000 Releases

Fig. 9 – POL Wire Test B Photographs

A reconfiguration email to 5 minute sampling was sent shortly after the test commenced and an additional re-configuration email to 60 second sampling was sent when the instrumentation was at its ultimate depth of 2000m. The general motivation for this work is to demonstrate the remote reconfiguration of instrumentation deployed in deep water without having to visit and physically recover the instrumentation. This particular trial involved using a MobiApps m100 Orbcomm modem to demonstrate deployed deep sea instrumentation control. The m100 modem is the newest design of Orbcomm modem on the market and it offers more generous resources (available user application program memory, non volatile flash memory, analogue and digital I/O etc) than the older Quake modems at a more competitive price (m100 ~$140 and the Quake global Q1400 is ~$500).

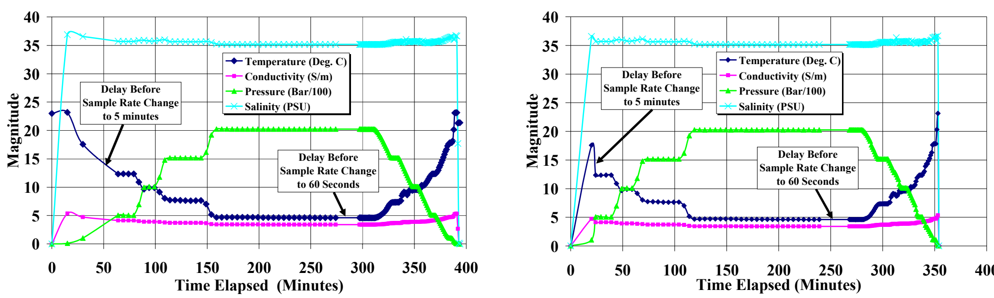
In addition to the m100 Orbcomm modem a Sutron Meteosat unit fitted to the telemetry tower on the rear deck of the ship was used to capture the data received by the LinkQuest surface modem from the Seabird CTD fitted to the deployed wire test frame. The Meteosat DCP system is a high power omni-directional transmitter that is capable of one way (buoy to satellite) data transfer using a meteorological satellite service. This system was used to provide remote oceanographic data transfer at 15 minute intervals. This is the first time an omni-directional Meteosat DCP system has been used by POL for marine data telemetry. A table of some of the measurement data captured by the Meteosat system is shown in Table 4.

This work has formed a series of core tests during POL participation in the Oceans 2025 RRS Discovery based instrumentation trials cruises. The intention for this cruise was to deploy the MYRTLE Lander and a moored telemetry buoy in deep water to perform a series of extended trials to demonstrate the feasibility of prolonged deep water instrument data retrieval, telemetry and remote instrument reconfiguration using email and/or the internet.

When the wire test frame reached the maximum test depth of 2000m two of the Benthos XT6000 based acoustic releases (normally used for MYRTLE frame recovery) were fired. During this test, one of the XT6000 transponders reported that the release mechanism had fired and on recovery of the frame it transpired that this release had not operated correctly. The reason for this was that the lead and burn wire assembly connected to the transponder previously used with the suspect transponder, serial number 70772 that had not correctly fired during the test. The suspect transponder that had not worked previously (XT6000 unit, serial number 70772) had worked perfectly. Therefore it has been a problematic cable and release assembly that had caused the unreliable release operation. The exact nature of the problem with the cable assembly will be investigated.

A plot of the measured data from the Seabird CTD is shown in Fig. 10 and the pressure record clearly shows the stop off points at various depths during the test tor perform testing and evaluation of acoustic data links and satellite telemetry system performance. A sample rate change request to the CTD from 15 minute to 5 minute sampling was issued during the test by an email command sent via an internet based email client during the wire test frame descent. The performance of the LinkQuest acoustic data modems throughout the trial was once again quite poor. A modem software test routine executed at the start of the test reported the communications link performance a being ‘Demanding’ at

60m' and then 'Very Demanding' at depths of up to and greater than 100m, which suggested that the UWM3000 omni-directional data link would be problematic. The exact reason for this poor data link performance is not clear. Bearing in mind that the wire frame modem and the surface modems were almost directly facing each other with only clear water between the two modems it is reasonable to expect the data link to perform well under these conditions. Despite these problems an email based command was scripted to the deployed Seabird CTD to increase the sample rate to one measurement every 5 minutes, as shown in Fig. 22a. The sample rate was then further increased at a depth of 2000m to one measurement every 60 seconds. The poor performance of LinkQuest UWM3000 acoustic modems resulted in a delays of approximately 20 minutes before the required commands were successfully transferred to the Seabird CTD. What was noticeable about substituting the UWM3000 surface modem for this test was that measurement data flow from the sea bed (bottom) modem to the surface modem had improved considerably with bursts of data being transferred to the surface within several minutes of being queued to the bottom modem. The data flow from the surface modem to the bottom LinkQuest UWM3000 modem was still poor and very slow. While the commands to script the deployed CTD to a different sample rate were being processed, the software in the Orbcomm modem would regularly time out after 10 minutes and then try once again scripting the commands up to three times to complete the required parameter change sequence. The factors governing the poor performance of the LinkQuest acoustic data link rare not clear. It could be a function of the matching of pairs of surface and bottom modems to each other, or properties of the deployment location that govern the acoustic data link performance. These technical difficulties do however illustrate the need to thoroughly test and evaluate the performance of commercial instrumentation systems before scientific measurement related deployments are attempted. Throughout this test the Benthos Smart data link and release modem performed reliably.



a – internally recorded CTD Data

b – Received surface LinkQuest data that has been sampled and sent by the Orbcomm satellite global messaging service

Fig. 10 – Recorded CTD and Telemetry Data from the Second 2000m Wire Test

Although there was some evidence of received serial data corruption the Sutron omni-directional DCP transmitter performed well throughout the trial. A selection of DCP messages successfully transmitted to the EMETSAT data download web site (oiswww.eumetsat.org) is shown in Table 4. This clearly demonstrated that the Meteosat system is capable of reliable measurement data transfer from a remote moving platform to a land based downlink for capture and analysis. The reason for the serial data corruption with some of the RS232 CTD data sampled from the LinkQuest surface acoustic modem by the Sutron system is not clear. This problem has been experienced before when interfacing LinkQuest modems to a Sutron Meteosat transmitter during a previous RRS Discovery based Oceans 2025 trial cruise (D333 in 2008). It is likely that the introduction of further signal conditioning and electrical isolation electronics in a future buoy based sea bed to surface oceanographic data capture and transmission system will eliminate this problem. These trials clearly demonstrated the feasibility of using the geostationary Meteosat based satellite system for reliable near real time (15 minute interval) oceanographic data telemetry.

Data Sent to the LinkQuest Surface Modem Prior to Sea Bed Modem Failure					
Temp (Deg. C)	Cond (S/m)	Pressure (dB)	Salinity (PSU)	Date	Time (GMT)
# 9.1682,	3.87271,	1180.479,	35.9374,	12 Oct 2009,	21:05:13
# 4.6986,	3.42102,	2024.610,	35.1765,	12 Oct 2009,	22:35:13
# 4.5951,	3.41055,	2024.602,	35.1638,	13 Oct 2009,	00:22:00
# 4.5856,	3.40980,	2024.786,	35.1650,	13 Oct 2009,	00:23:00
# 4.7885,	3.42227,	1961.164,	35.1270,	13 Oct 2009,	00:36:00
# 4.8819,	3.42874,	1931.075,	35.1181,	13 Oct 2009,	00:37:00
# 4.9946,	3.43847,	1901.042,	35.1265,	13 Oct 2009,	00:38:00
# 7.3398,	3.67861,	1517.183,	35.5678,	13 Oct 2009,	00:52:00
# 7.3449,	3.67980,	1516.894,	35.5757,	13 Oct 2009,	00:53:00
# 7.3498,	3.68017,	1517.067,	35.5746,	13 Oct 2009,	00:54:00
# 7.6015,	3.69670,	1446.382,	35.5303,	13 Oct 2009,	00:58:00
# 9.6026,	3.87467,	1081.433,	35.5719,	13 Oct 2009,	01:07:00
# 9.6411,	3.88594,	1046.001,	35.6654,	13 Oct 2009,	01:08:00
# 9.9061,	3.89143,	922.951,	35.5161,	13 Oct 2009,	01:17:00
# 10.6656,	3.94493,	718.950,	35.4101,	13 Oct 2009,	01:22:00
# 10.9291,	3.96945,	678.761,	35.4196,	13 Oct 2009,	01:23:00
# 14.3317,	4.32009,	325.646,	35.7353,	13 Oct 2009,	01:37:00
# 14.8425,	4.36344,	290.173,	35.6799,	13 Oct 2009,	01:38:00
# 16.2955,	4.53816,	187.099,	35.9774,	13 Oct 2009,	01:41:00

Table 4 – Sampling of CTD Using A Sutrom Meteosat Transmitter from a GPS Fix of latitude of 32^o 44', 48.16" N and a longitude of 13^o 18'36.24" W With a Transmission Every 15 Minutes

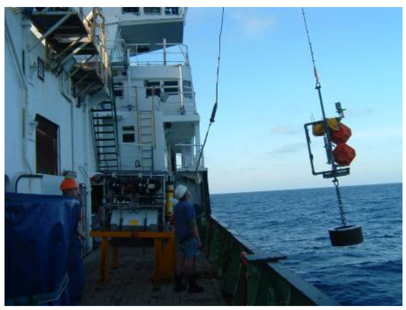
Day 15 Tuesday 13-10-09 – POL Wire Test C

After an appropriate rest period, the final POL wire test for the D343 cruise was rescheduled and moved forward to occur in the evening due to technical difficulties with Autosub. As previously described the general aim for Wire Test C was to lower the wire test frame without the LinkQuest UWM3000 acoustic modems to a depth of 3900m that is as high as reasonably practicable within the cruise working area around the Casablanca Seamount. When the maximum test depth is reached the plan was to fire all of the release mechanisms to test the performance of the MYRTLE releases at the maximum test depth. Regular performance checks of the Benthos Smart Modem deep water acoustic data link were also undertaken during this test. The test started at 18:30 BST at a latitude of 32^o 39.0814' N and a longitude of 13^o 23.34504' W and continued until 21:35 BST on Tuesday 13th October. A selection of photographs of the deployment is shown in Fig. 11.

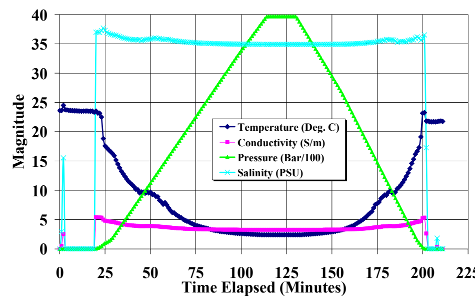
A plot of the internally recorded data from a Seabird Microcat CTD is also shown in Fig. 11d. This CTD data shows the descent of the wire test frame down to a depth of 3900m, a delay while the acoustic release systems are fired and then a return to the surface to end the test. During this test a suspect lead had been fitted to one of the XT6000 transponders and a standard lead and burn wire was used with the other transponder. The result of this test was that both releases failed to operate at 3900m even though both of the XT6000 transponders confirmed activation of the release voltage across the release mechanism for the required length of time. Testing of the release mechanisms at POL in an environmental chamber at 2^{o}C has confirmed that the release mechanism unreliability does not seem to be related to the low temperatures experienced during deep water deployments. Therefore it would appear that the extreme pressures exerted on the release mechanisms during deep water deployments is the most likely cause of problematic release operation. Alternatively, the use of thinner quick operation burn wires during the trials cruises (as used for coastal work) could cause unreliable operation at extreme depths. Perhaps slower dissolving thicker Inconel wires, as normally used for deep sea work, could resolve this problem. Further work is therefore required to try and identify why the acoustic releases are not working reliably for deep water >100m deployments.

a – Prepared Test Frame Without LinkQuest Modem Fitted

B – Received surface LinkQuest data that has been sampled and sent by the Orbcomm satellite global messaging service



c – 4000m Wire Test Frame Deployment



d – Internally Recorded Seabird Microcat CTD Data at 60 second intervals

Fig. 11 – Benthos XT6000 Release and Smart Modem 3900m Wire Test

9.5 POL Telemetry Systems Summary

During the D343 Oceans 2025 trials cruise, problems with the MYRTLE lander recovery release mechanisms have persisted and further investigation is required to identify the source of this problem. Trials to date have indicated that the extreme pressures exerted during deep water deployments and the use of fast dissolve thinner burn wires could be the cause of unreliable release operation although this needs to be confirmed. The Benthos Smart acoustic data modem and combined release mechanism has performed well during the trials. This system would appear to have an advantage in terms of reliability and data throughput when compared with LinkQuest UWM3000 acoustic modems for the trials undertaken during the cruise.

The failure of the LinkQuest UWM4000 deep water modem meant that a deployment of the POL telemetry buoy and mooring did not occur due to there being no way of relaying data from MYRTLE to the surface to test the buoy telemetry systems.

It is most likely that the Benthos Smart modem operated the MYRTLE data capsule release properly and that lifting strops that had accidentally been left on the frame had prevented the release of the capsule from travelling from the seabed to the surface. During recovery of the MYRTLE frame and the short time the data capsule was at the surface, a test data set was successfully transferred by satellite, demonstrating the correct data capsule operation. Bearing in mind the failure of two Benthos XT6000 based releases mechanisms during the final wire test (wire test C) the decision not to attempt a further MYRTLE deployment would appear to be the correct one. The result of this was that a series of wire tests were used to try and achieve the maximum results possible from the D343 cruise without further MYRTLE deployments.

The performance of the telemetry systems fitted to the buoy upper tower and operated from the rear deck of the ship has been good throughout the trials. Quake Global and the newer MobiApps m100 Orbcomm modems have been used to interact with remotely deployed oceanographic instrumentation via email. This has included several experiments to demonstrate the feasibility of reconfiguring remotely deployed marine instrumentation after deployment using email based commands. This has many potential applications for future scientific work and opens up the possibility of reconfiguring instrumentation measurement parameters after deployment for maximal scientific gain without having the burden of the cost and time of recovering and redeploying instrumentation. In addition to this a Sutron geostationary satellite based omni-directional buoy to satellite transmitter has been successfully used by POL for the first time. This involved the use of a high power transmitter to relay measurements from a CTD deployed in 2000m at 15 minute intervals to a land based downlink for collection and analysis. Despite the high power required (40 watts) to transmit to the Meteosat geostationary satellites from a moving platform such as a buoy this power requirement is only for periods of approximately 30 seconds at 15 minute intervals in time. Therefore it is feasible to use a Meteosat system on a solar powered buoy for near real time data transfer for extended periods of time (typically several months). An unusual feature of the Meteosat system is that provided a valid case can be provided to Eumetsat (the service providers) that a particular application is for scientific research then a channel, satellite and transmission time slot will be allocated free of charge. Based upon the performance of the Orbcomm and Meteosat systems, and the fact the Sutron and MobiApps systems have performed well when operated in close proximity to each other, a combined telemetry system would seem to offer the best choice for long term deployments using a solar powered buoy. An Orbcomm based system would offer the possibility of two way data flow and remote instrumentation control using a cost effective (~£30-£40 per month per modem standing charge – no additional charge for data) satellite based global messaging service. As a back up for redundancy if the Orbcomm modem failed and running in parallel with this could be an omni-directional Meteosat transmitter to routinely transmit oceanographic data from a buoy at 15 minute intervals. While the Orbcomm messaging service is relatively low cost a potential drawback is message latency. Typically it can take anything from 20minutes to several hours for Orbcomm to transfer data. Therefore, for more time critical applications other satellite services such as Iridium could be considered although there is likely to be a cost penalty for an alternative such as this.

Only brief trials of a Tideland transmitter based AIS system were undertaken and it is envisaged that further development work will be required to use this system for oceanographic data transfer using a VHF transmitter. Negotiations are under way Tideland to find out how to use AIS in this manner and further development work will be required along with a buoy based test deployment to demonstrate this.

The D343 cruise has served to demonstrate the need to fully test and evaluate new and emerging marine instrumentation systems before they are used for scientific applications. An understanding of how particular instrumentation systems work is required to accumulate sufficient experience to circumvent any possible shortcomings with their implementation. Experience and knowledge such as this is required in order to be able to integrate different sensors and systems from different manufacturers into the complex marine measurement systems that are often required for scientific research. Advance assembly and preparation of instrumentation for trials cruises is also preferable to help to eliminate potential pitfalls of development and assembly within the difficult environment and tight time schedules often experienced during cruises.

The D343 Oceans 2025 trials cruise has ultimately helped to improve the expertise within OETG at POL in relation to deep water marine systems and the use of remote measurement telemetry systems. This has been achieved without the added burden of satisfying particular scientific measurement demands within the normal tight time schedules. The participation in D343 has also served to highlight and publicise the work of POL within the Oceans 2025 community.

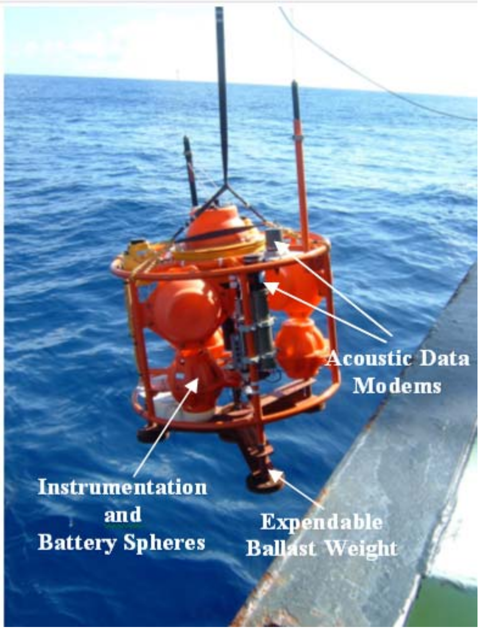
Key Achievements of POL Telemetry tests on D343

- The successful deployment and recovery of the MYRTLE deep water instrumentation frame.
- Demonstration of a releasable data capsule with an internally recorded data telemetry system.
- The successful operation of the Benthos Smart modem and LinkQuest long range underwater acoustic communication systems.
- Successful demonstrations of email based commands to remotely reconfigure deployed marine instrumentation using the Orbcomm global messaging service. Two types of Orbcomm modems were used for the trials. The first type was the Quake Global q1400 modem, which has been used by POL for previous telemetry projects. The second type of Orbcomm modem was the MobiApps m100 Orbcomm modem that is new to POL. The m100 has also had in house designed hardware and software developed to allow this type of modem to be used for POL oceanographic telemetry applications.

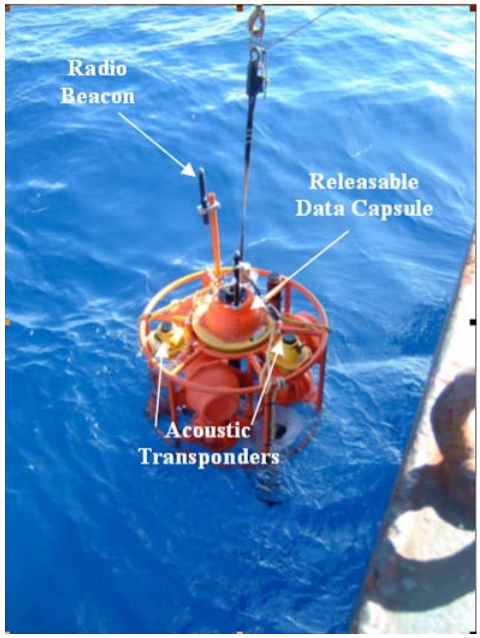
- The first use by POL of an omni-directional Meteosat system for remote marine measurement data transfer (CTD measurements obtained during a 2000m wire test).
- The regular transmission of marine data in near real time using the Orbcomm and Meteosat satellite based data transfer services.
- Successful operation of a low power Tideland transmitter based AIS (aid to navigation and collision avoidance) from a mobile platform.
- Evaluation of the performance of deep water acoustically operated release mechanisms based around Benthos XT6000 and Smart modem technologies.

Labelled Instrumentation Pictures

This section provides a series of pictures of the MYRTLE lander and POL telemetry buoy with the key components labelled (Fig. 24). The MYRTLE frame basically acts as a platform to mount various deep sea instrumentation spheres, acoustic modems etc. A pair of release mechanisms based around Benthos XT6000 acoustic transponders allows the buoyant frame to detach from the expendable ballast weight for instrumentation recovery. A further release driven by a Benthos Smart Modem combined deep water release and acoustic data link allows the central data capsule to be independently recovered from the frame. Contained within the data capsule is a satellite telemetry transmitter (Iridium or Orbcomm) that allows internally recorded data to be transferred to shore for analysis when the capsule reaches the surface.



a – MYRTLE Upper View



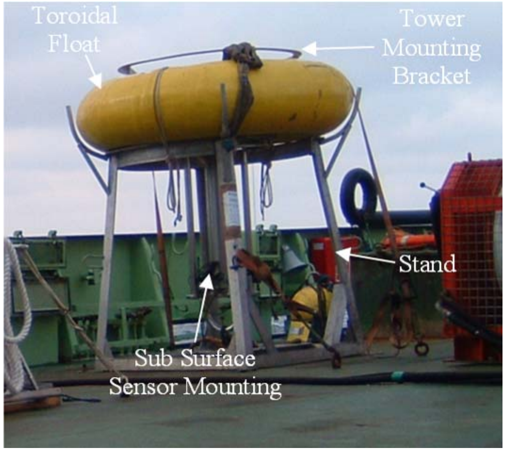
b – MYRTLE Deployment

c – MYRTLE Releasable Data Capsule

Fig. 24 – The MYRTLE Deep Sea Recoverable Instrumentation Platform

During the D343 cruise the POL telemetry buoy was used to undertake a series of evaluations of marine data telemetry systems. The key components of the system are shown in Fig. 25. Various marine telemetry units and battery housings can be mounted and configured on the upper telemetry tower (Fig. 24a) and then bolted in place on the buoy for deployment. Technical difficulties experienced with the failure of the LinkQuest UWM4000 deep water long range acoustic data modem resulted in the telemetry tower being used for the trials. The basic idea was that the various telemetry systems under evaluation were mounted on the tower and operated from the rear deck of the ship. The ship was therefore being used to simulate the operation of the buoy because an actual buoy deployment was not feasible for most of the cruise work area. Data communications with the instrumentation deployed during the wire tests was achieved by suspending a surface acoustic data modem over the side of the ship just below the waterline. A long deck cable was then connected to the telemetry systems under test on the telemetry tower to simulate a buoy deployment.

b – Telemetry buoy instrumentation tower



b – Telemetry Buoy Torroid and Stand

c – Telemetry Buoy Deployment

Fig. 25 – The POL Telemetry Buoy

Possible Future Oceans 2025 Trials Cruise Development Work

1. Future trials cruises using RRS Discovery that are offered under the Oceans 2025 programmed could be used for glider testing and development work (CTD and/or microstructure gliders).
2. To trial any instrumentation and telemetry systems either recently procured or that have a particular target application to support POL scientific programmes. e.g. deep water CTDs with digiquartz pressure sensors for performance comparisons with POL designed BPRs (bottom pressure recorders).
3. To trial and evaluate the next generation MYRTLEX instrumentation frame that has a capacity of up to 12 releasable data capsules.
4. Development of a multi port MYRTLE ballast release mechanism that allows either of two Benthos XT6000 acoustic transponders or the Benthos Smart modem to operate the ballast release. This should improve the redundancy of the frame recovery mechanism that has been problematic in the past.
5. Use of an enhanced scientific instrument payload for MYRTLE. This could include deep water CTDs from various manufacturers. A comparison could be made between the performance of a traditional digiquartz quartz sensor based bottom pressure recorder (BPR) and the less expensive silicon based Presense pressure sensors.
6. Further development of the Tideland transmitter based AIS (marine navigation and collision avoidance transmitter) to support short range VHF based transmission of oceanographic measurements.
7. The use of an Iridium satellite telemetry modem (preferably with an embedded programming capability) to provide rapid response telemetry and communications with deployed marine instrumentation.
8. If a long (> 1-2 weeks deployment) of the POL telemetry buoy is possible then rechargeable batteries, solar panels, charging controllers and performance monitoring telemetry could be developed installed and trialled during the cruise.
9. A Benthos Smart modem could be procured and tested during a future trials cruise to implement a deep sea surface to seabed acoustic data link with potentially improved performance in compared to previously trialled systems.
10. The continued evaluation of new and emerging rf (satellite, long range VHF etc) communication techniques to assess their suitability for remote oceanographic measurement systems.
11. Continued trials to identify robust acoustic communication techniques that are suitable for potentially long term and deep sea marine instrumentation communication applications.

10. Acknowledgements

These successes of the Oceans 2025 technology trials cruise D343 are in no small part due to the tremendous effort and contribution of every person who sailed on the RRS *Discovery*. I would particularly like to thank the Master, Antonio Gatti, and his crew for all their efforts on our behalf.

Stephen McPhail, Principle Scientist.