
SENTRY OPERATIONS REPORT FOR THE
2011 JURASSIC OCEAN CRUST MAGNETIC SURVEY

WHOI ABE/Sentry Operations Group

Dr. James C. Kinsey, Dr. Carl L. Kaiser, Andrew Billings, Justin Fujii, Stefano Suman,
and Korey Verhein.

Sentry Expedition Leader: Dr. James C. Kinsey

Chief Scientists: Dr. Masako Tominaga (WHOI) & Dr. Maurice Tivey (WHOI)

R/V Thomas G. Thompson — November 5, 2011 to December 17, 2011

Publication Date: January 1, 2012



1 Summary

This document summarizes operations with the *Sentry* autonomous underwater vehicle (AUV) during the Jurassic Ocean Crust Magnetic Survey 2011 cruise. Included in this report is the vehicle configuration; basic vehicle and sensor performance; and post-dive reports (with summary statistics and narratives). This report does not attempt to describe the scientific results or conclusions. A detailed description of the data files resulting from this cruise is provided in a separate document, *Sentry_data_file_descriptions.pdf*. A summary of the data provided to science is included in the data summary document for this cruise.

Sentry activities on this cruise focused on obtaining magnetic measurements of the Quiet Jurassic Zone at depths of 5000-6000m. The research proposed by the Principal Investigators (PIs) was to obtain 800km of near-bottom magnetic measurements with *Sentry*. Total distance covered by *Sentry* during science dives was approximately 140km or *only 20% of the distance required to achieve the scientific objectives of the cruise*. In consequence, *Sentry* failed to complete the majority of the distance required by science. The reasons for the overall failure of cruise objectives include:

Difficulty tracking in Deep Water — At vehicle depths deeper than 5500m, it was impossible to reliably track *Sentry*. Although Ultra-Short Baseline (USBL) had been used to track *Nereus* at depths up to 5400m (during 2009 Cayman and 2011 DSOP cruises), once on station we discovered that the USBL system could not track *Sentry* deeper than 5500m and was unfeasible for the 5500m+ depth sites. Tracking with Long Baseline (LBL) frequencies was also difficult and the round-trip pings from the ship to *Sentry* did not work at depths exceeding 3000m because of either a previously unknown fault in the XRs (which listen for and respond to acoustic interrogations) or ship noise that impaired our ability to hear at these frequencies. The “heartbeat” *Sentry* to ship ping could be heard and provided some degree of tracking through both a direct ping and via a relay beacon on Towcam. After dive 128, we installed the spare Avtrak beacon on Towcam. This provided us with both a round-trip range (from Towcam to *Sentry*) and acoustic telemetry. Unfortunately, the Avtrak on *Sentry* was destroyed during recovery on dive 131 requiring that we use the spare Avtrak on *Sentry* and not have one on Towcam. Tracking problems were alleviated when we moved to dive sites shallower than 5400m of water — during dives 132, 134, and 135 USBL provided adequate tracking. This problem is in detail in Appendix A.

Actuator Failures — *Sentry* suffered actuator failures on each of its first three dives. The forward starboard thruster failed on dive 127 and as the vehicle speed increased (as commanded by the programmed mission) the heading control loop went unstable and *Sentry* “drove circles down the line” for the remainder of the dive. The thruster was replaced with a spare, but a lack of confidence in our thrusters combined with concerns about tracking in deep water led us to impose a max forward speed of 0.6m/s on *Sentry* for the remainder of the cruise. The forward servo failed on dive 128 during ascent (with no impact to science on that dive) and was replaced during the turn-around. On dive 129, the forward servo failed again; this time during the mission. *Sentry* drove into the seafloor and remained there for approximately 15 hours until the mission timers dropped the weights. These failures exhausted reliable spares and forced the decision to lock the aft wing in the horizontal position and fly using only the forward wing. Significant time (4 days) was lost in arriving at and testing this solution. These failures *may be pressure related* however further investigation is required before we can determine the exact root cause of the failure.

While it did not cause the loss of any dives, a limit cycling behavior in the servos not seen during *Sentry* dives prior to this cruise was present on dives 127, 128, and 129. After locking the aft servo the

limit cycling was worse but could not be separated from the inherent control instabilities created by locking the aft servo. Additional aberrant behavior was seen from two other thrusters in the form of continued operation even when commanded to zero. This problem got progressively worse throughout the cruise. Actuator problems are described in greater detail in Appendix B.

These two problems made operations early in the cruise difficult at best and dangerous to the vehicle at worst. For example, the servo failure on 129 occurred when tracking was marginal and the sudden crash of the vehicle resulted in us losing tracking and having to conduct a 4 hour search when *Sentry* failed to arrive at the surface at the planned end of the mission point. This incident highlighted a conundrum with the proposed operations. Some leeway with regard to continuous subsea tracking is tolerable if there is high certainty that the AUV will get to the end of the mission (where it can be recovered). If the certainty of the vehicle in reaching the end of the mission is decreased (in this case by failing actuators) then continuous topside tracking is essential. This situation forced us to reconsider operations minimize the risk of loss of the vehicle while attempting to provide maximum return for science.

The following technical problems were also encountered on this cruise :

Engineering Tests — After dive 129, we did a series of engineering tests to establish a new operations mode that used only the forward servo and limited our operating depth to less than 5400m. Three engineering dives were done on station. The first engineering dive failed because of a programming bug (Appendix D) and had to be repeated. These dives determined we had a stable operating mode provided we stayed shallower than 5500m. An additional engineering dive at the beginning of the cruise (dive 127) pressure tested the assembled vehicle after its Summer 2011 upgrade to 6000m.

Collision with the Ship — During recovery on dive 131, *Sentry* went under the stern of the ship twice — breaking off the starboard wings, slightly damaging the foam pack, and decapitating the Avtrak. Repairs took approximately a day and a half. The Avtrak damage forced us to pull the spare Avtrak off Towcam and eliminated a solution to the tracking problem. This problem is discussed in detail in Appendix G.

Erroneous Acoustic Abort — Dive 133 aborted 12 hours into a 28 hour survey because of an erroneous acoustic abort on XR1. The abort was not commanded by topside and data suggests that the XR was acoustically “spoofed”. This problem had never been seen before on the combined 354 *ABE* and *Sentry* dives on which this system has been used. This problem is discussed in detail in Appendix E.

The remainder of this report is organized as follows: Sections 2 to ?? provide high-level summaries of the cruise activities and recommendations for future improvement. Individual dive summaries for dives 127-134 are next — each of these is a free-standing document summarizing the dive. Finally, the appendices contain detailed discussions of technical problems encountered on this cruise.

2 Cruise Log

This section provides a brief chronological summary of *Sentry* activities during the cruise. Table 1 summarizes the dives on this cruise. Additional information on specific dive is available in the dive reports.

October 21 to October 23, 2011 — Load-out in Seattle, WA. *Sentry* was loaded on to the ship. Laboratory was set up and the USBL and LBL equipment set up on the over-the-side pole provided by UW.

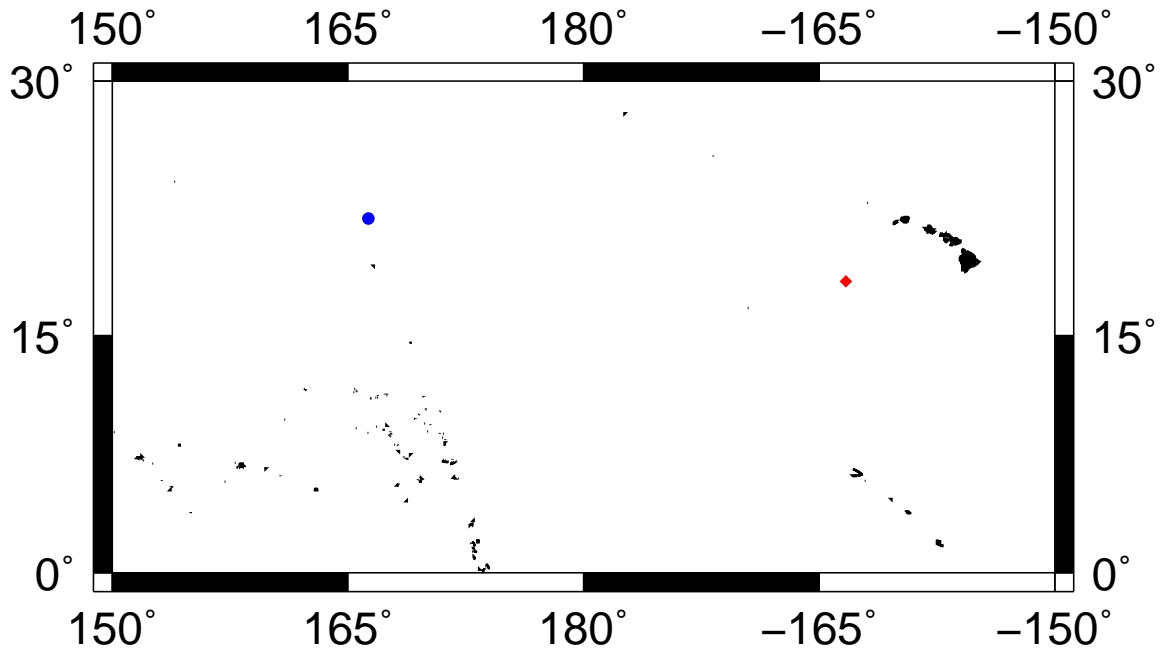


Figure 1: Operations area for this cruise. The red diamond indicates the site of *Sentry* dive 127. The science operations area is indicated by the blue circle.

November 3 to November 4, 2011 — Mobilization in Honolulu, HI. Efforts focused on installation of the APS magnetometers (including new power supplies); installation of the iridium phone; connecting to ship data feeds; and integrating the AUV gravimeter. Two dunk tests were done. One on the evening of November 4 to assess acoustics and a second early on the morning of November 5 to ballast the vehicle. The chassis had to be pulled on Nov 4 to verify power mappings.

November 5, 2011 — Sailed from HNL at 0900 local. After a test Towcam deployment began the CASIUS calibration discussed in Section 4.2. Test was completed and the ship began transit to the 6000m test site.

November 7, 2011 — *Sentry 127*, a 6000m engineering dive. See dive report for more information.

November 8-15, 2011 — Transit to station.

November 15-16, 2011 — *Sentry dive 128*, a 5800m science dive. *Sentry* worked fine and completed the mission however vehicle tracking was lost and a 90 minute surface search was required to find *Sentry*. See dive report for more information.

November 17-20, 2011 — Weather prevented AUV operations. Installed Avtrak on Towcam and troubleshot failed servo.

November 21-22, 2011 — *Sentry dive 129*. During this dive the forward servo failed and *Sentry* drove into the seafloor. It remained there for 15 hours until the mission timers expired. Vehicle tracking was

lost and *Sentry* did not arrive at the end of the trackline on time. A 4 hour search of the surface was required to find the vehicle. See dive report for more information.

November 22-27, 2011 — Seismics operations; No AUV operations. Troubleshooting of servos. See Appendix B for more information on the servo troubleshooting.

November 27, 2011 — *Sentry Dive 130*, a 1500m engineering dive to test the new flight mode. An error in the descent process forced us to acoustically abort the vehicle. See dive report for more information.

November 27-30, 2011 — Seismic operations.

November 30, 2011 — *Sentry Dive 131*, a 1000m engineering dive to test the new flight mode. The engineering test was successful however the vehicle was damaged on recovery. See dive report for more information.

December 1, 2011 — Repairs to *Sentry*. Towed magnetics with Towcam.

December 2, 2011 — *Sentry dive 132*, a 5000m dive to test tracking at depth and conduct a 11km magnetic survey. Dive objectives completed. See dive report for more information.

December 3-6, 2011 — *Sentry* on standby during towed magnetics with Towcam.

December 7, 2011 — *Sentry dive 133*, a 5000m science dive. Dive went fine until an acoustic abort was triggered for an unknown reason. See dive report for more information. The remaining portion of the mission was completed with Towcam.

December 8-10, 2011 — *Sentry dive 134*, a successful 5000m science dive. See dive report for more information.

December 11, 2011 — *Sentry* dive 135 *postponed* because of weather.

December 12, 2011 — *Sentry* dive 135 *anceled*. Science decided to continue towed maggie operations until leaving station on December 13.

December 13-17, 2011 — Transit to Guam and demobilization.

3 Vehicle Configuration

Table 2 lists the science sensors installed on *Sentry* on this cruise.

4 Navigation

All dives were navigated using realtime DVL velocity inertial measurement unit (IMU) attitude measurements. External aiding during descent was done with USBL throughout the cruise. The operating depths of dives 5600 to 5800m on dives 127-129 precluded using USBL during the survey portions of the dive and tracking was difficult at best during these dives. Later dives were shallower than 5600m and USBL was available. Dive specific notes on navigation are included in the dive reports. All final navigation tracks are the best effort interpretation of available data by skilled personnel.

Table 1:

Dive	Site	Launch Time Position	Recovery Time Position	Survey Duration hours	Dive Duration hours	Mean Depth m	Trackline Distance km	Origin degrees
sentry127	SITE NAME HERE	2011/11/07 14:07:28 18 21.276°N, 163 16.761°W	2011/11/07 23:15:37 18 21.428°N, 163 15.294°W	4.0	9.1	5808	11.58	18 21.273°N,163 16.755°W
sentry128	SITE NAME HERE	2011/11/15 08:53:07 22 34.880°N, 166 38.660°E	2011/11/16 19:29:11 22 7.279°N, 166 14.699°E	29.0	34.6	5733	65.93	22 34.860°N,166 38.700°E
sentry129	SITE NAME HERE	2011/11/21 16:18:32 22 8.569°N, 166 17.399°E	2011/11/22 18:50:60 22 2.808°N, 166 10.058°E	18.6	26.5	5839	5.20	22 8.568°N,166 17.401°E
sentry130	SITE NAME HERE	2011/11/27 00:38:14 20 40.677°N, 165 4.004°E	2011/11/27 02:45:37 20 40.709°N, 165 3.908°E	0.1	2.1	1996	1.83	22 8.568°N,166 17.401°E
sentry131	SITE NAME HERE	2011/11/30 10:03:02 17 11.448°N, 161 33.175°E	2011/11/30 13:24:25 17 10.224°N, 161 32.351°E	0.4	3.4	1003	1.15	22 8.568°N,166 17.401°E
sentry132	SITE NAME HERE	2011/12/02 05:02:30 20 40.664°N, 165 4.120°E	2011/12/02 15:53:49 20 45.385°N, 165 8.181°E	6.2	10.9	5320	12.14	20 40.671°N,165 4.133°E
sentry133	SITE NAME HERE	2011/12/07 01:17:50 18 40.016°N, 163 2.246°E	2011/12/07 19:20:35 18 51.693°N, 163 13.157°E	13.2	18.0	5020	29.02	18 40.000°N,163 2.250°E
sentry134	SITE NAME HERE	2011/12/08 23:14:06 18 15.998°N, 162 37.996°E	2011/12/10 08:39:02 18 40.977°N, 163 1.739°E	28.3	33.4	5112	62.98	18 16.000°N,162 38.000°E
8 Dives				99.8	138.1	4479.0	189.8	

Table 2: Sentry Sensor Configuration

Sensor
APS 1540 Magnetometers (3)
Edgetech 4-24kHz Sub-Bottom Profiler (SBP)
Nobska GCTD (fast response sensor)
Seabird SBE49 Conductivity-Temperature-Depth (CTD)
Seapoint optical backscatter sensor (OBS)
Anderaa optode model 4330
300kHz RDI Doppler Velocity Log (DVL)

4.1 Coordinate origins

The vehicle’s control system uses simple mercator coordinates. This system uses an origin, defined in terms of latitude and longitude with the World Geodetic System 1984 (WGS84) datum, and a fixed scaling between meters displacement from the origin. We use the identical routines that have been used by the National Deep Submergence Facility (NDSF) assets Alvin and Jason for decades. These simple coordinates have several advantages for realtime control of a vehicle. Unlike Universal Transverse Mercator (UTM) grid coordinates, the x and y axes intersect at right angles and align with true east and north respectively at the origin. These coordinates distort quickly as one moves away from the origin, but we solve that problem by putting the origin close to the operating area. We almost always report our results in latitude/longitude, so most users need not be aware of these details.

Table 1 contains the origins for this cruise.

4.2 USBL Calibration and Performance Notes

On Saturday, November 5, 2011, a CASIUS calibration was performed in approximately 2000m of water. A Benthos LBL transponder was deployed on a 50m tether with an Avtrak attached. After the transponder reached the seafloor, we performed a moving survey (as opposed to a dynamic positioning (DP) survey). The entire survey took approximately 7 hours. CASIUS results were excellent with the standard deviation decreasing by approximately 60% after the calibration parameters were applied.

5 Technical Issues

This section summarizes technical issues encountered by the *Sentry* operations group on the cruise. Some of these issues are discussed in more detail in the appendices.

T.1: Actuators — Actuator failures were encountered throughout the cruise. Failures occurred on each of the first three dives and this forced us to change the flight control mode. The root cause of these failures remains unknown and will require additional on-shore analysis. This problem is discussed in detail in Appendix B.

T.2: Tracking — Tracking was difficult throughout the cruise with USBL tracking impossible past 5500m and the LBL system on *Sentry* not working past 3000m. This problem is discussed in more detail in Appendix A.

T.3: As on the Valentine cruise, the mission controller was once again prone to failure at start-up. This was investigated during the Seattle mob, but we were not able to reproduce the failure at that time. The failure mode was a freeze of the mission controller at start up with a suspension of all i/o activity but the process still in the process table. This occurred frequently during start up; however once started the mission controller would work fine for the remainder of the dive.

Approximately half way through the cruise, an error message was caught while attempting to debug mission code for a midwater dive. This error message allowed shore side personnel more familiar with the mission controller software to determine that it was a network message queue which was filling up before it could be properly dealt with during start up. The size of the queue was increased and no further instances of the failure were observed.

T.4: On *Sentry* dives 127, 128, 130, 131, and 134, there was significant differences in the temperature and sound speed measured by the SBE49 CTD (see the plots for these dives). This was not a problem on this cruise but might be a problem on future cruises

T.5: Spurious Sci 1 readings during *Sentry* 133.

T.6: During the post-dive for sentry130, the humidity in the battery housing was 85% — significantly higher than observed on a typical post-dive. Analysis of the pressure, temperature, and humidity data from sentry130 and the previous 10 dives showed that the housing was not compromised. This incident emphasize the frailty of the humidity sensors and the need for leak sensors in the battery housing.

6 Sentry Operations Team

The *Sentry* team was comprised of 6 members on this cruise — Andrew Billings, Justin Fujii, Carl Kaiser, James Kinsey, Stefano Suman, and Korey Verhein. James Kinsey was the Expedition Leader. Korey was a last-minute replacement for Al Duester. Stefano’s participation was funded partially by *Sentry* operations and partially by other projects.

7 Acknowledgments

- 1.

Sentry 127 Dive Report

WHOI ABE/Sentry Operations Group

Dr. James C. Kinsey, Dr. Carl L. Kaiser, Andrew Billings, Justin Fujii, Stefano Suman,
and Korey Verhein.

Sentry Expedition Leader: Dr. James C. Kinsey

Chief Scientists: Dr. Masako Tominaga (WHOI) & Dr. Maurice Tivey (WHOI)

Deep engineering dive to 5800m to test the vehicle at pressure and conduct speed trials after upgrading the vehicle depth rating. During the dive, the forward port thruster failed and as the vehicle increased commanded speed the heading servo went unstable. Max vehicle depth for the dive was 5849m.

Weather: Fair.

Reason for end of dive: Mission timer expired per planned time. The pressure test objective was completed and the speed trial was successful up to 0.6m/s. The thruster problem prevented completion of the remaining objectives — i.e. speed data up to 1m/s.

1 Vehicle Configuration

The science sensing suite for this dive was:

Table 3: Sentry Sensor Configuration

Sensor
APS 1540 Magnetometers (3)
Edgetech 4-24kHz SBP
Nobska GCTD (fast response sensor)
Seabird SBE49 CTD
Seapoint OBS
Anderaa optode model 4330
300kHz RDI DVL

This dive was navigated using the DVL/INS system in realtime. USBL provided post-dive corrections. All final navigation tracks are the best effort interpretation of available data by skilled personnel.

2 Important Positions

Launch Position: 18 21.276'N, 163 16.761'W

Recovery Position: 18 21.428'N 163 15.294'W

Dive Origin: 18 21.273'N 163 16.755'W

3 Narrative

This dive was the first use of *Sentry* beyond approximately 2700m and the first use of sentry beyond 450m since the upgrades to the pressure hull and floatation. The plan called for *Sentry* to drop on the Western edge of a depression approximately 10km across and drive east for several km.

The vehicle was launched normally after a routine pre-dive. *Sentry* descended normally with acoustic communications dropping out almost entirely before 4000m as expected. USBL tracking had dropped out before 5000m which was somewhat earlier than expected. The vehicle was tracked using a combination of the expected path, vehicle initiated, unsynchronized pings. The location of the vehicle was a topic of speculation during the dive, with no reliable position estimate available.

The mission aborted on the mission controller timer as planned. Despite knowing that the vehicle must be ascending, the vehicle was not located on USBL as expected as it rose through the water column. The ship was moved down the track line farther than the vehicle could have progressed and then turned around to move back up the line at the maximum speed allowed by having the pole in the water. The vehicle was picked up slightly shallower than 2000m partway back up the track. The vehicle was recovered normally but did reach the surface somewhat closer to the ship than desired.

Post-dive analysis showed that the vehicle had not been driving in a straight line, but rather had been seeing significant heading instabilities causing loops and other disturbances in the vehicle track. The vehicle was stable at 0.5m/s mostly stable at 0.6m/s and progressively less stable as the speed further increased. One thruster was observed to have reported that it was not moving during much of the dive. It was pinwheeling during descent, appears to have ceased to move at several thousand meters, and then resumed pinwheeling during the ascent. Another thruster did not log any data during the duration of the dive which was traced back to a coding error introduced during a thruster swap on the previous cruise. The code has since been fixed to prevent reintroduction of this bug on future switches.

The vehicle was given a complete visual examination. The foam pack was observed to have little to no cracking related to pressure, and there were no other signs of damage due to pressure.

4 Chief Scientist Comments

5 Dive Statistics

5.1 Sentry127 Summary

Launch: 2011/11/07 14:07:28

Survey start: 2011/11/07 16:56:41

Survey end: 2011/11/07 20:55:31

Ascent begins: 2011/11/07 21:04:55

On the surface: 2011/11/07 22:46:40

On deck: 2011/11/07 23:15:37
descent rate: 33.3 m/min
ascent rate: 57.4 m/min
survey time: 4.0 hours
deck-to-deck time 9.1 hours
Mean survey depth: 5808m
Mean survey height: 54m
distance travelled: 11.58km
average speed; 0.64m/s
average speed during photo runs: -0.00 m/s over -0.00 km
average speed during multibeam runs: 0.64 m/s over 9.10 km
total vertical during survey: 869m
Battery energy at launch: 12.3 kwhr
Battery energy at survey end: 9.3 kwhr
Battery energy on deck: 8.9 kwhr

6 Plots

SENTRY127 --- Positions

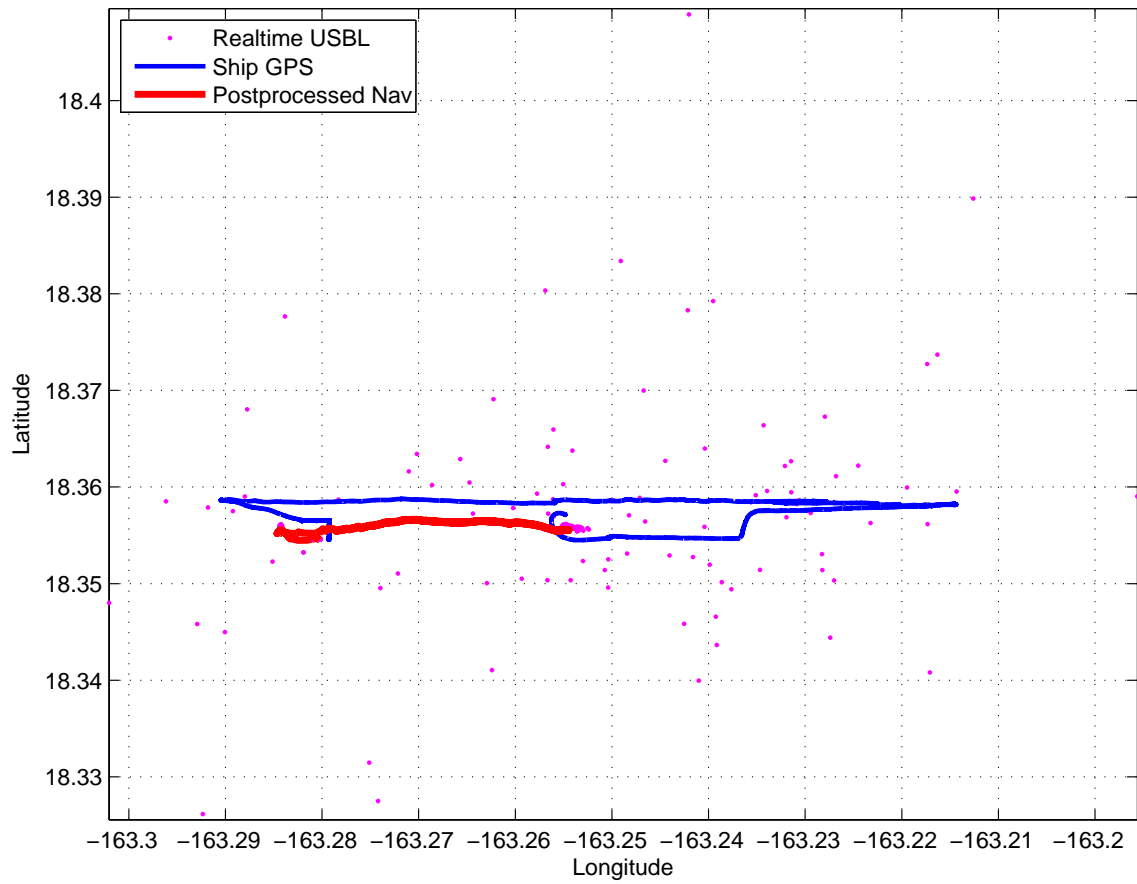


Figure 2: Latitude/Longitude plot of Sentry dive 127 with Realtime *Sentry* USBL, ship GPS, and *Sentry* post-processed positions.

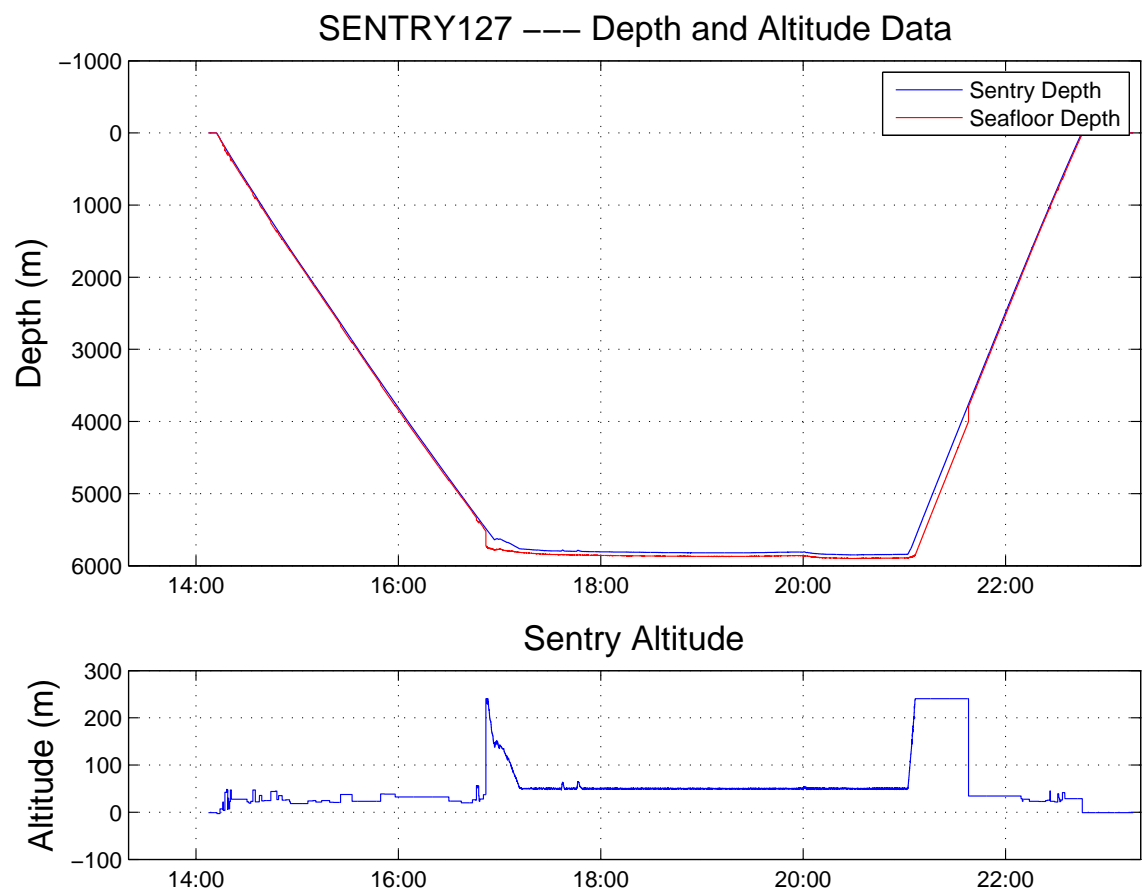


Figure 3: Depth and Altitude data for Sentry dive 127.

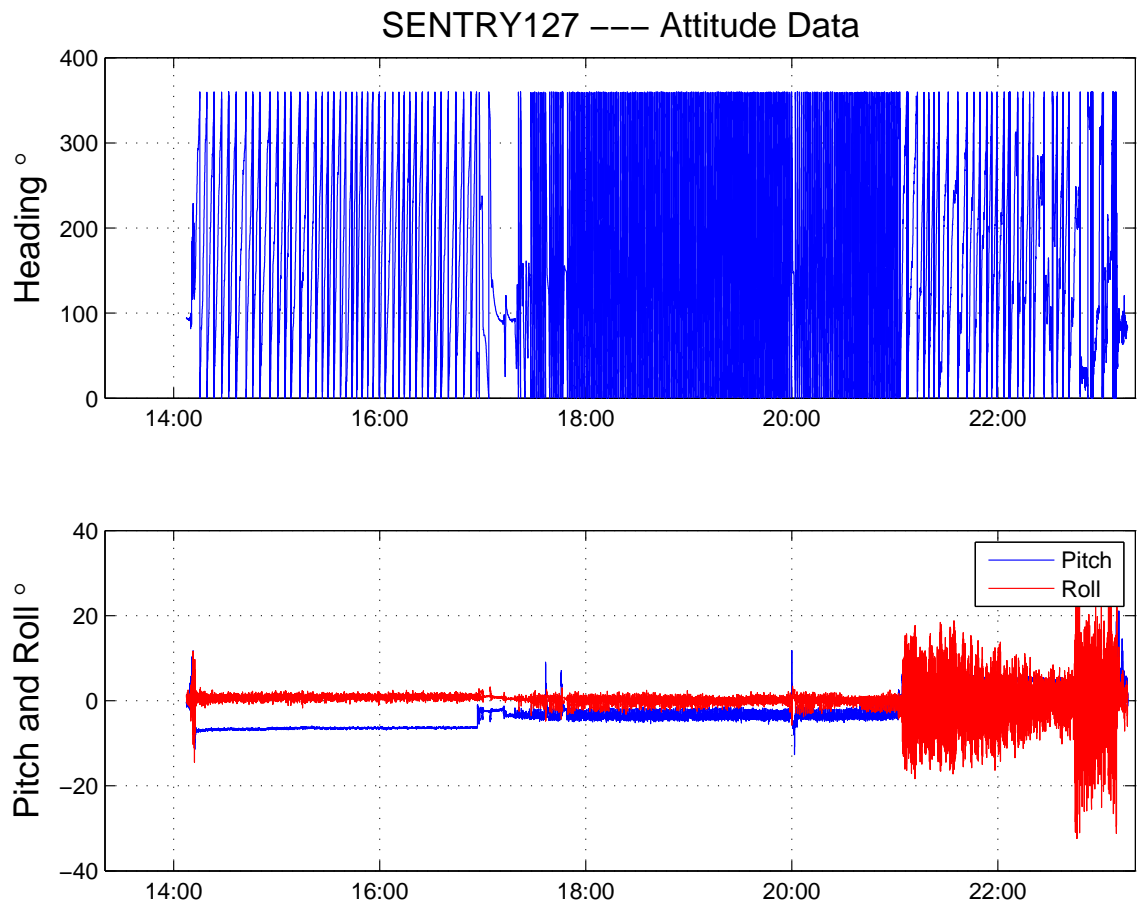


Figure 4: Heading, pitch, and roll data for Sentry127.

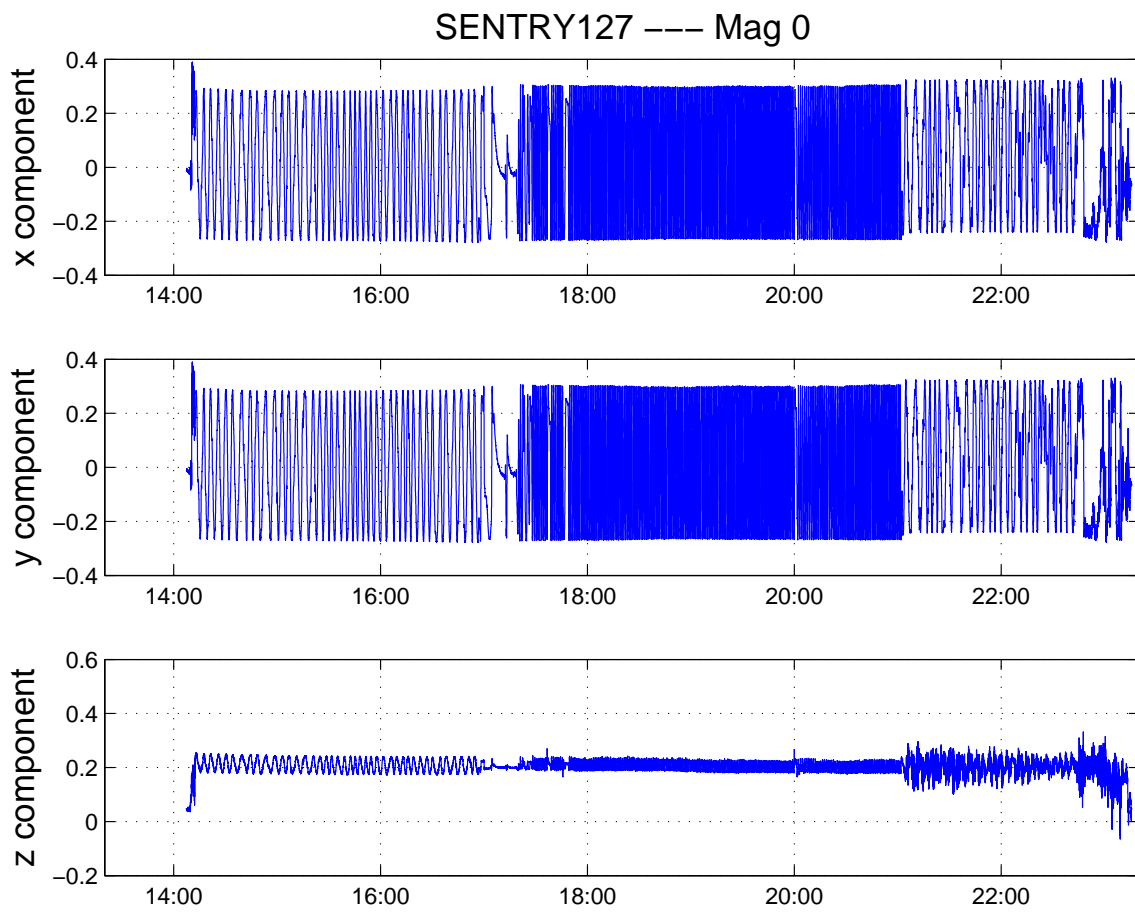


Figure 5: X,Y,Z magnetometer data for magnetometer 0 on Sentry127.

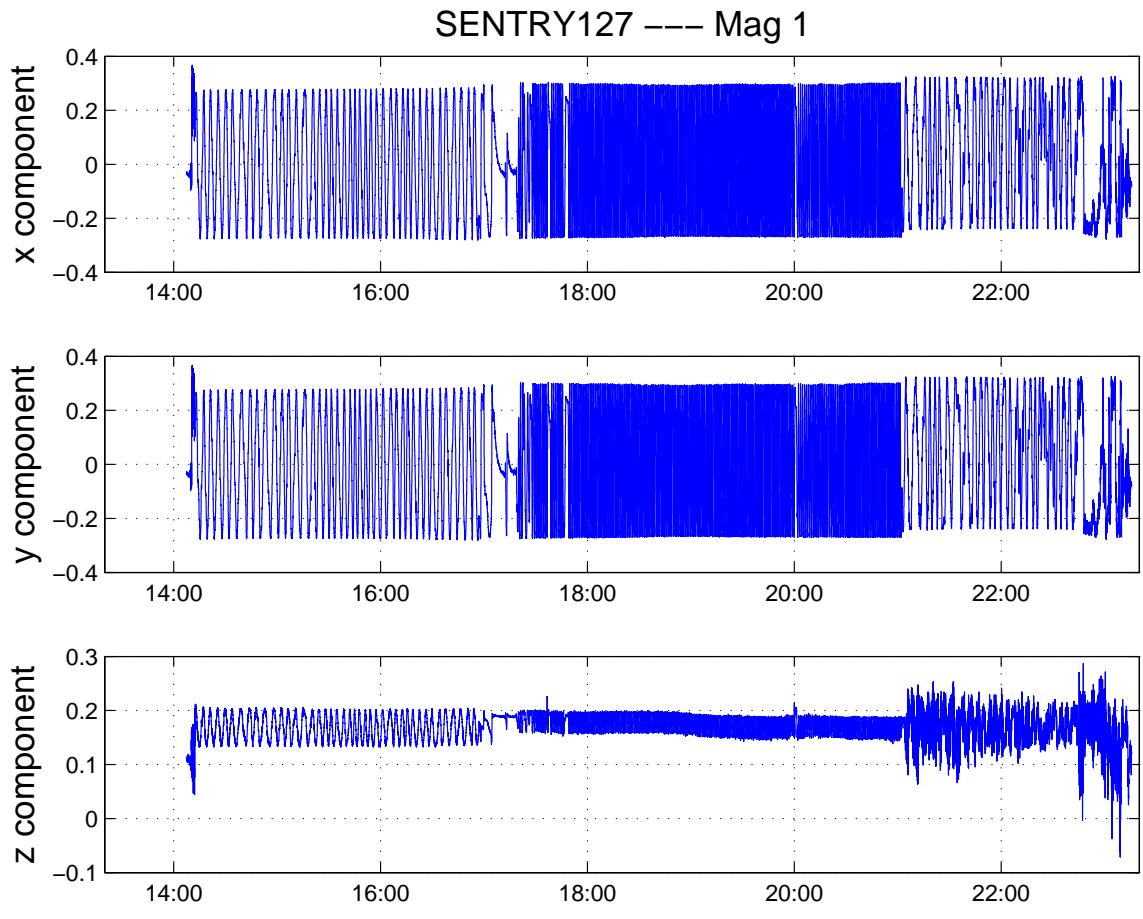


Figure 6: X,Y,Z magnetometer data for magnetometer 1 on Sentry127.

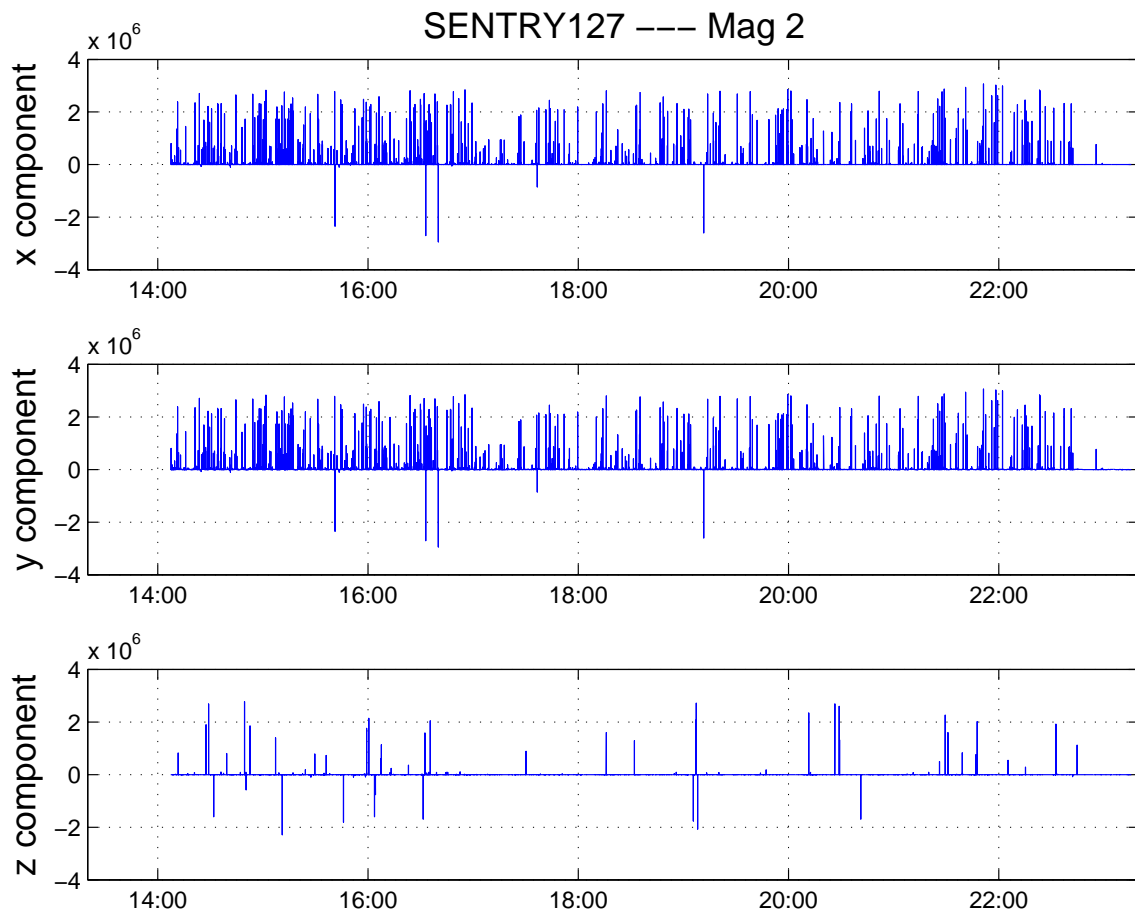


Figure 7: X,Y,Z magnetometer data for magnetometer 2 on Sentry127.

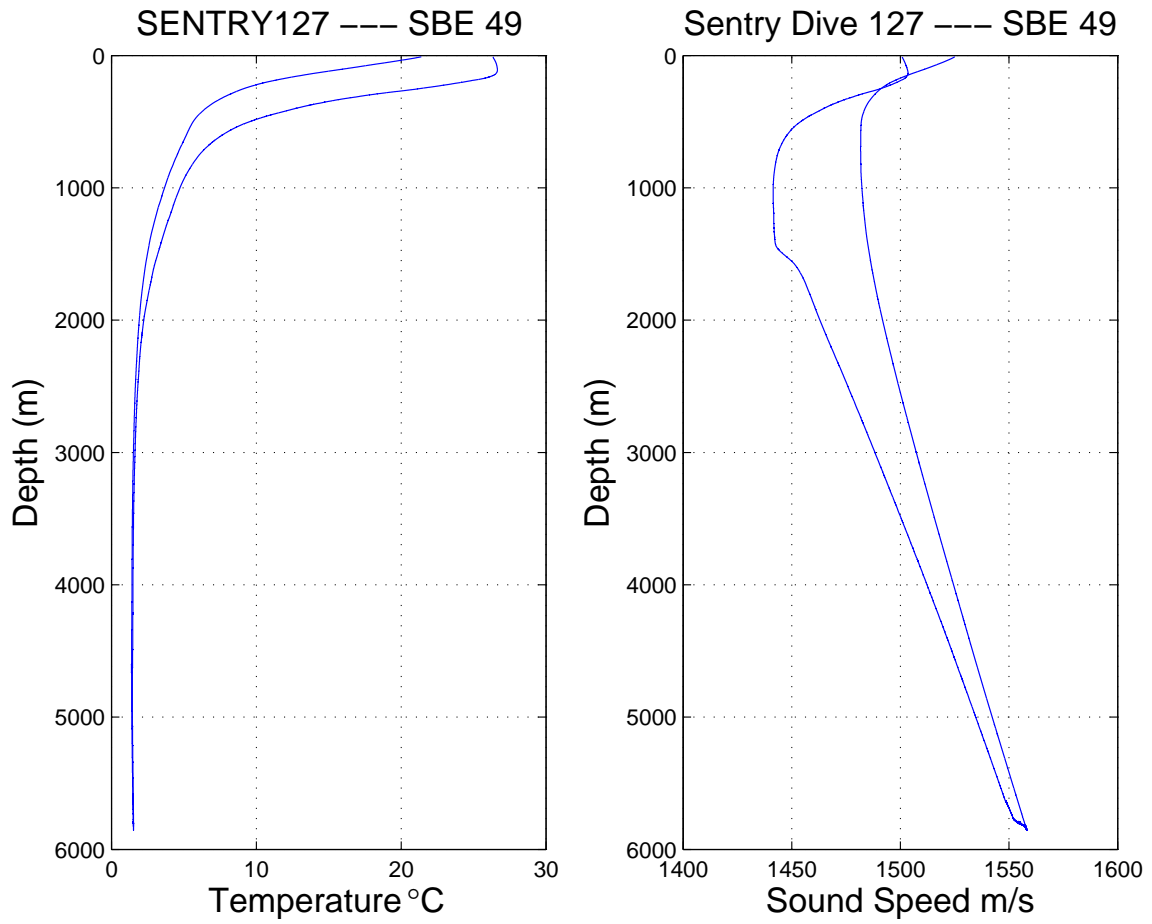


Figure 8: Sea temperature and sound velocity as measured by the Seabird 49 CTD on Sentry127.

Sentry 128 Dive Report

WHOI ABE/Sentry Operations Group

Dr. James C. Kinsey, Dr. Carl L. Kaiser, Andrew Billings, Justin Fujii, Stefano Suman,
and Korey Verhein.

Sentry Expedition Leader: Dr. James C. Kinsey

Chief Scientists: Dr. Masako Tominaga (WHOI) & Dr. Maurice Tivey (WHOI)

Summary

Science dive at approximately 5800m depth. Vehicle traveled a 60+km trackline. Tracking was initially okay but an errant ship move resulted in loss of tracking. Vehicle completed the base mission and, as programmed, continued the survey until the mission timer expired. The extra vehicle distance covered resulted in *Sentry* surfacing 7km away from the planned recovery point.

Weather: Calm throughout.

Reason for end of dive: End of mission; mission controller timer expired per planned cruise timing.

Vehicle Configuration

The science sensing suite for this dive was:

Table 4: Sentry Sensor Configuration

Sensor
APS 1540 Magnetometers (3)
Edgetech 4-24kHz SBP
Nobska GCTD (fast response sensor)
Seabird SBE49 CTD
Seapoint OBS
Anderaa optode model 4330
300kHz RDI DVL

This dive was navigated using the DVL/INS system in realtime. USBL provided post-dive corrections. All final navigation tracks are the best effort interpretation of available data by skilled personnel.

Important Positions

Launch Position: 22 34.880'N, 166 38.660'E

Recovery Position: 22 7.279'N 166 14.699'E

Dive Origin: 22 34.860'N 166 38.700'E

Narrative

Sentry Dive 128 was a dive at 5800m depth focused on obtaining near-bottom magnetic measurements. Additional obtained measurements include SBP and CTD. The planned vehicle trajectory was a $\tilde{6}$ km running SSW and lasting 33 hours.

Launch proceeded well and vehicle tracking via USBL and LBL single ranges were initially successful. Towcam was deployed as *Sentry* passed 3000m and the relay beacons both worked. USBL tracking and telemetry were lost at 4500m. From this point on only the 14.5kHz direct ping (from the vehicle) and the 12.0kHz relay ping (triggered by the 14.5kHz) worked. Initially the ship held station effectively making Towcam a stationary hydrophone with which we could monitor the vehicle. The direct and relay pings slowly separated — consistent with *Sentry* moving ahead. At this point we began moving the ship. Over the next few hours, the direct return vanished but the 12.0kHz relay remained strong. Approximately 7 hours into the dive, the 12.0 ping became weak however the decision was made to continue to move forward.

At 1930 Greenwich mean time (GMT), it was realized that incorrect waypoints had been given to the bridge and the ship was driving *away* from *Sentry*. The ship was placed on to a parallel trackline approximately 4km NW of the *Sentry* track. Over the next few hours, we continued to hear the 12.0kHz relay but not the 14.5kHz direct. Since the 12.0kHz direct was relayed from a moving platform, Towcam, with varying depth and severe layback (up to 2km at times) and the LBL clocks were not synced, it was impossible to determine a firm range from *Sentry* to the ship.

At approximately 0600 GMT, the ship was re-vectored toward the *Sentry's* trackline to close the distance (Towcam was deployed off the hydro-boom effectively limiting ship speed to 1.5 knots — *Sentry* was moving at 1.16 knots). Around 0815 the direct ping was reacquired and was present till about 1400. At 1535 the ship stopped at the scheduled recovery point and Towcam started to settle back to the wire-out depth. At this time the only ping being received was the 12.0 relay. Towcam recovery began at 1628 about the same time the mission controller dropped the weights.

Throughout the ascent only the 12.0 relay was present and, once Towcam, was recovered we had no acoustic tracking on the vehicle. Once *Sentry's* on surface time passed, we proceeded further down the line *Sentry* was surveying under the belief that *Sentry* made better time than planned. This assumption proved correct — *Sentry* was spotted on high-power binoculars at approximately 1900. Simultaneously, the new iridium phone transmitted the vehicle's global positioning system (GPS) position. The ship transited to the vehicle (approximately 7 km) and we recovered the vehicle. *Sentry* was on deck and secured at 1931 — 87 minutes after it surfaced.

Issues and Proposed Solutions

1. Tracking was difficult throughout the dive. The only reliable ping was a 12.0kHz relay ping from Towcam. Occasional 14.5kHz direct pings were received. Ship initiated pings and USBL did not work at depth. Numerous improvements were made during the four days between Sentry 128 and Sentry 129.

A post-dive analysis of the ship, Towcam, and *Sentry* positions finds that the *Sentry* -ship and *Sentry* -Towcam slant ranges were often equal. This suggests that the 14.5kHz direct was not heard by the ship because of distance attenuation. Rather issues with noise traveling vertically in the water column or ship noise are likely.

2. The forward servo failed sometime after during ascent. It was swapped out after the dive. Inspection and repair are on-going.
3. Mag2 (top) continued to have large spikes. Mags 0 and 1 contained smaller but more frequent spikes. The source of these spikes is under investigation.
4. The bottom-following gain was set very tight on this dive. This did not effect vehicle control but did increase power use.
5. The necessity of using Towcam as an acoustic relay for *Sentry* requires highly coordinated *Sentry* -Towcam-ship operations. This setup does limit ship speed to 1.5 knots.
6. The WHOI acoustic modem setup is less than ideal. If we want to continue using it, we should consider improving the installation. Stefano Suman exchanged emails with the WHOI Acomms group on this and can provide more information.

Chief Scientist Comments

Dive Statistics

0.1 Sentry128 Summary

Launch: 2011/11/15 08:53:07

Survey start: 2011/11/15 11:28:31

Survey end: 2011/11/16 16:28:15

Ascent begins: 2011/11/16 16:31:34

On the surface: 2011/11/16 18:15:32

On deck: 2011/11/16 19:29:11

descent rate: 36.2 m/min

ascent rate: 54.8 m/min

survey time: 29.0 hours

deck-to-deck time 34.6 hours

Mean survey depth: 5733m

Mean survey height: 150m

distance travelled: 64.31km

average speed; 0.60m/s

average speed during photo runs: 0.00 m/s over 0.00 km

average speed during multibeam runs: 0.60 m/s over 62.37 km

total vertical during survey: 3603m

Battery energy at launch: 13.6 kwhr

Battery energy at survey end: 1.4 kwhr

Battery energy on deck: 1.0 kwhr

Plots

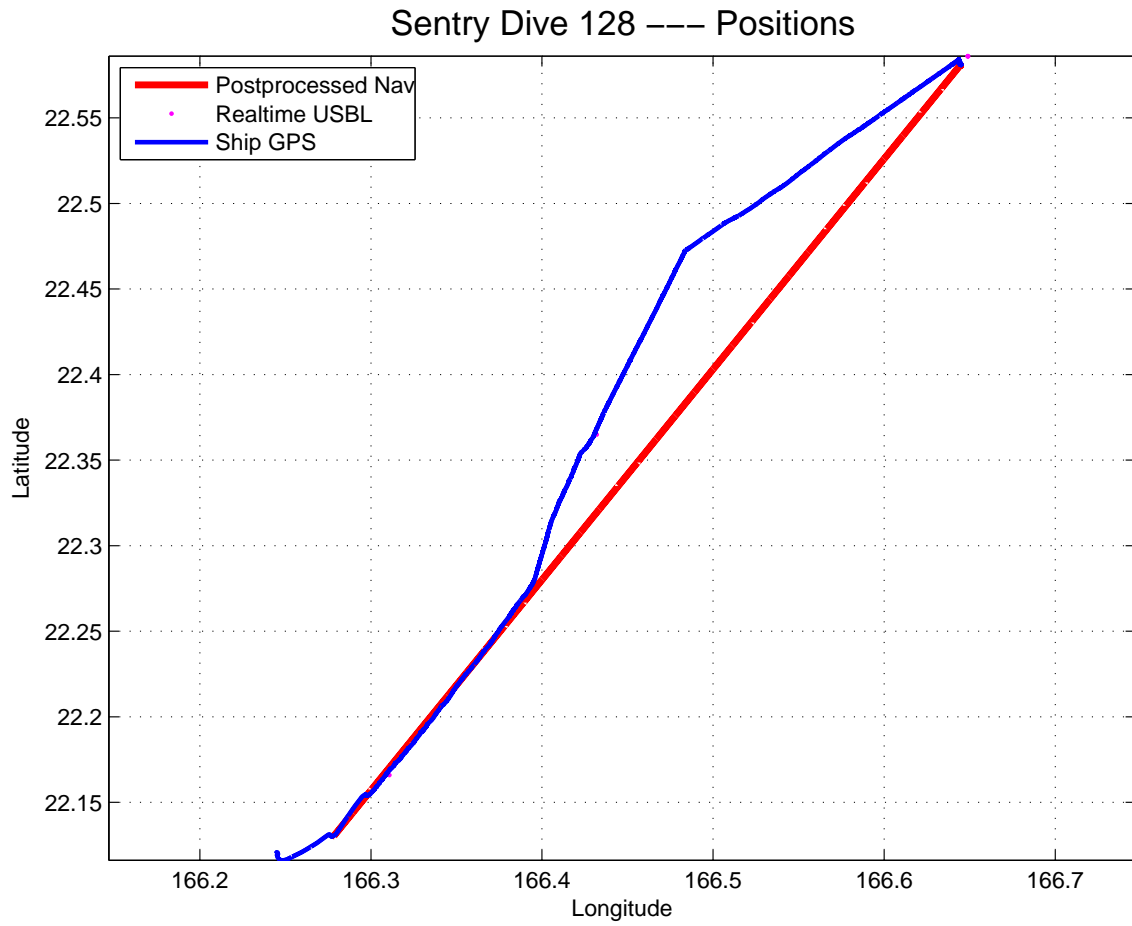


Figure 2: Latitude/Longitude plot of Sentry dive 128 with Realtime *Sentry* USBL, ship GPS, and *Sentry* post-processed positions.

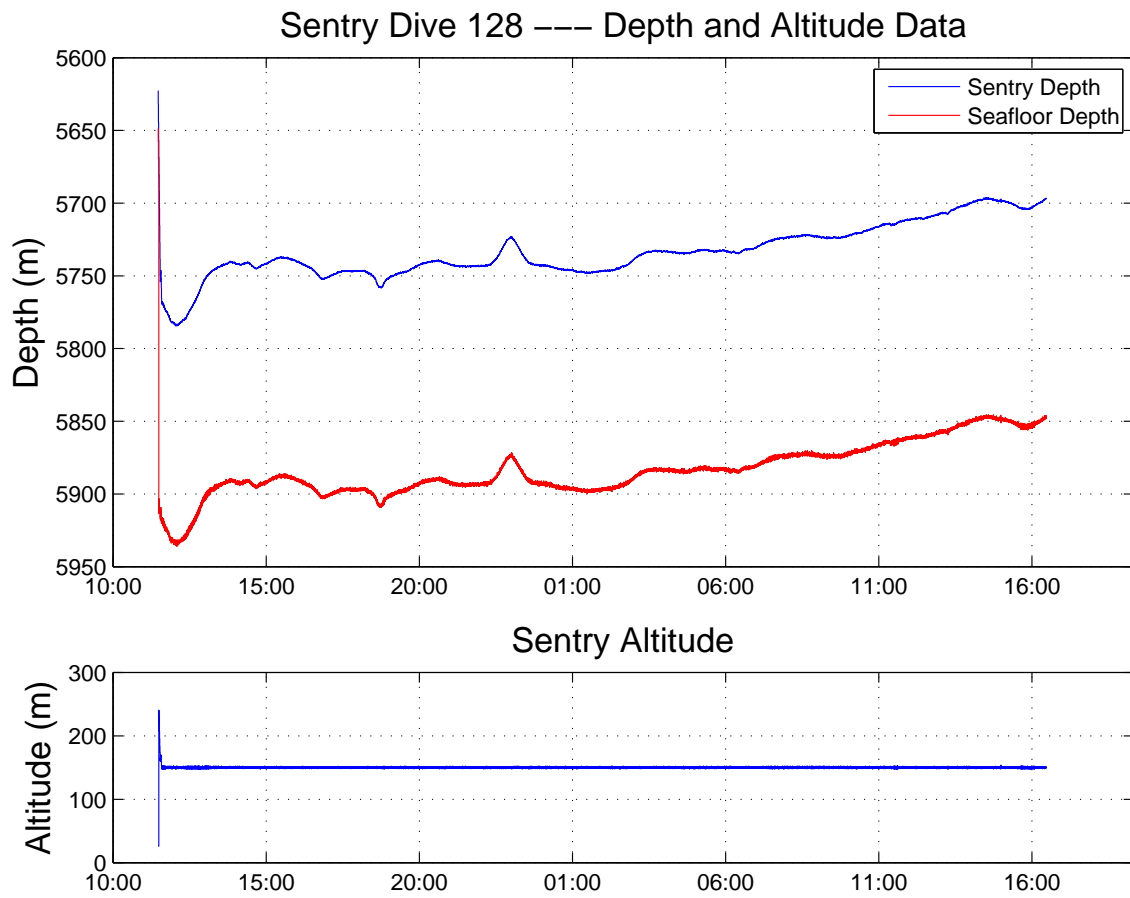


Figure 3: Depth and Altitude data for Sentry dive 128.

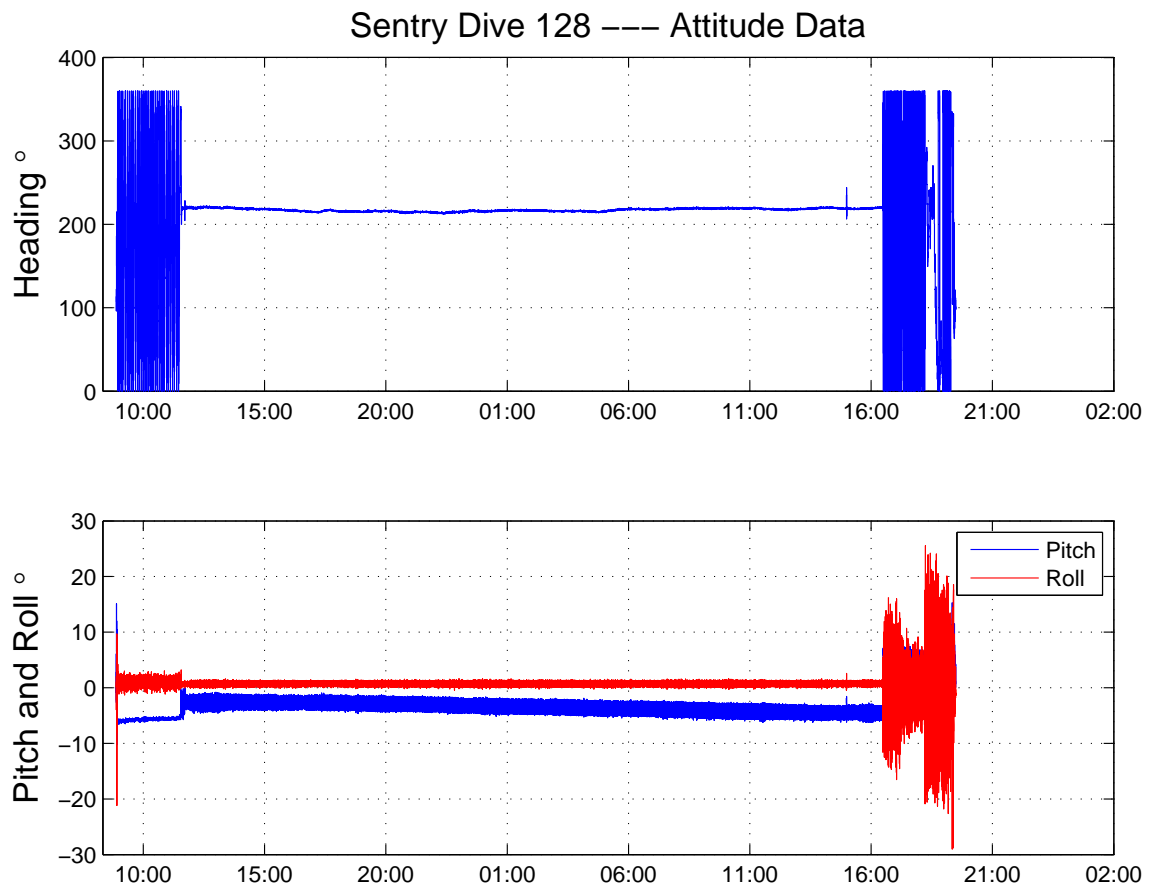


Figure 4: Heading, pitch, and roll data for Sentry128.

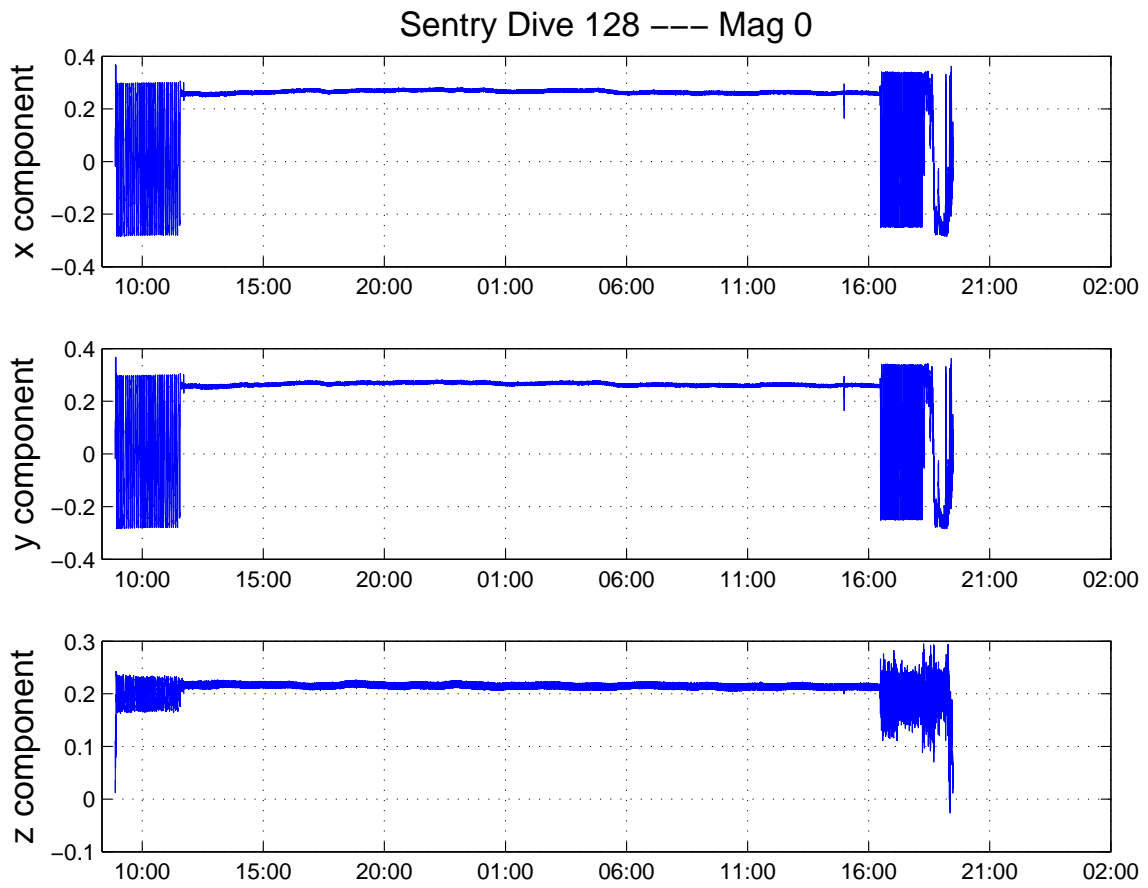


Figure 5: X,Y,Z magnetometer data for magnetometer 0 on Sentry128.

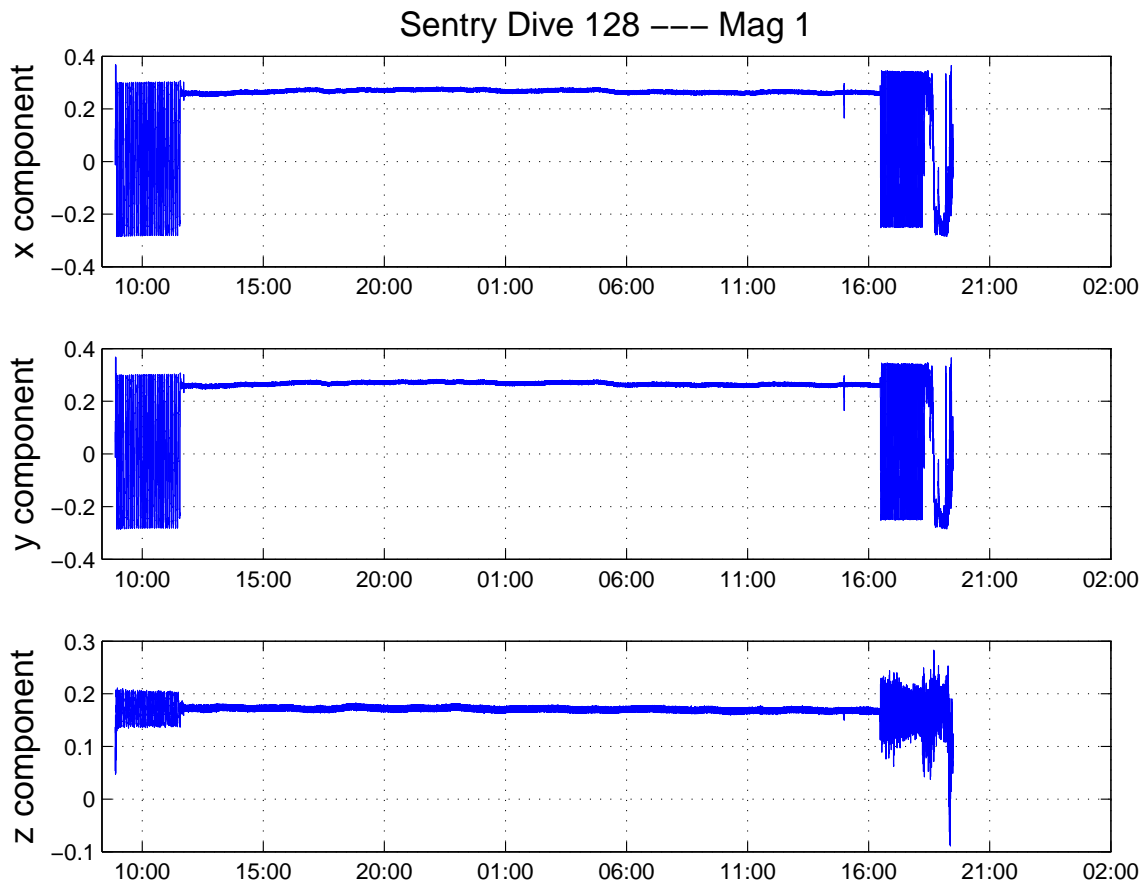


Figure 6: X,Y,Z magnetometer data for magnetometer 1 on Sentry128.

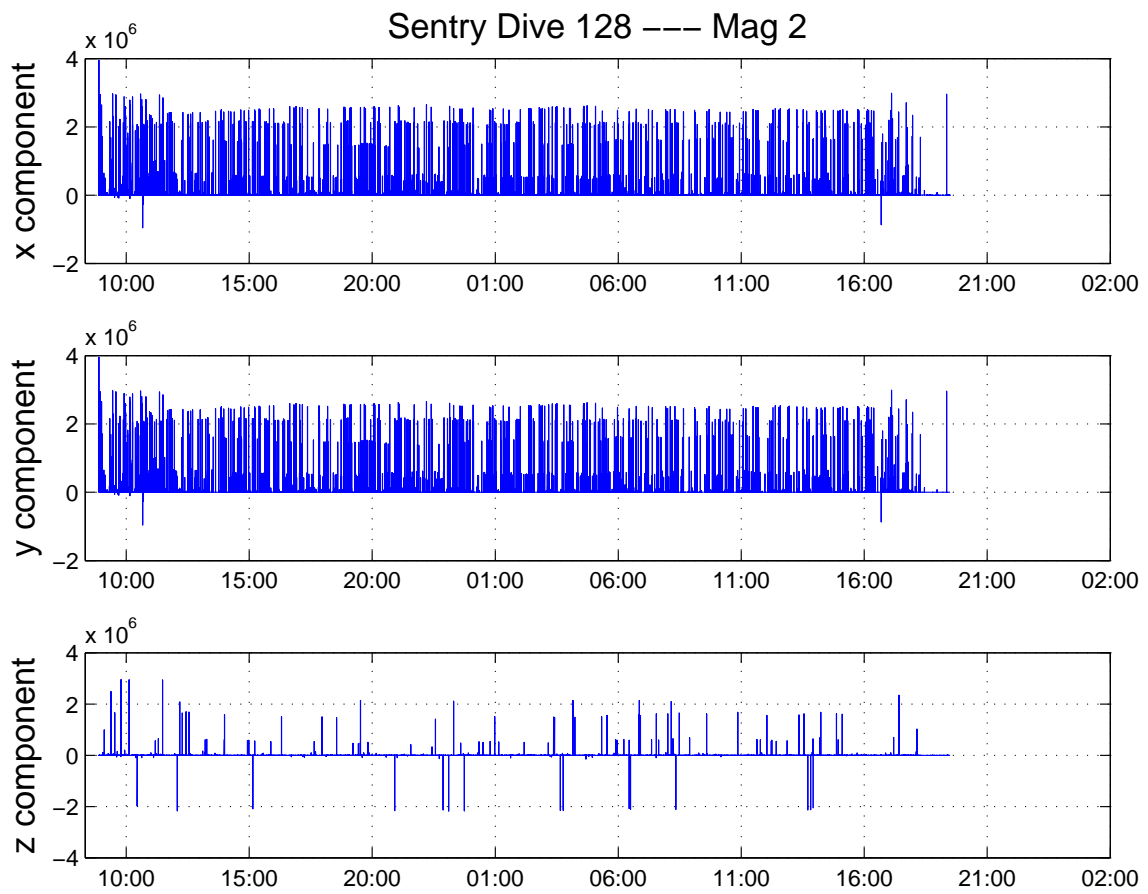


Figure 7: X,Y,Z magnetometer data for magnetometer 2 on Sentry128.

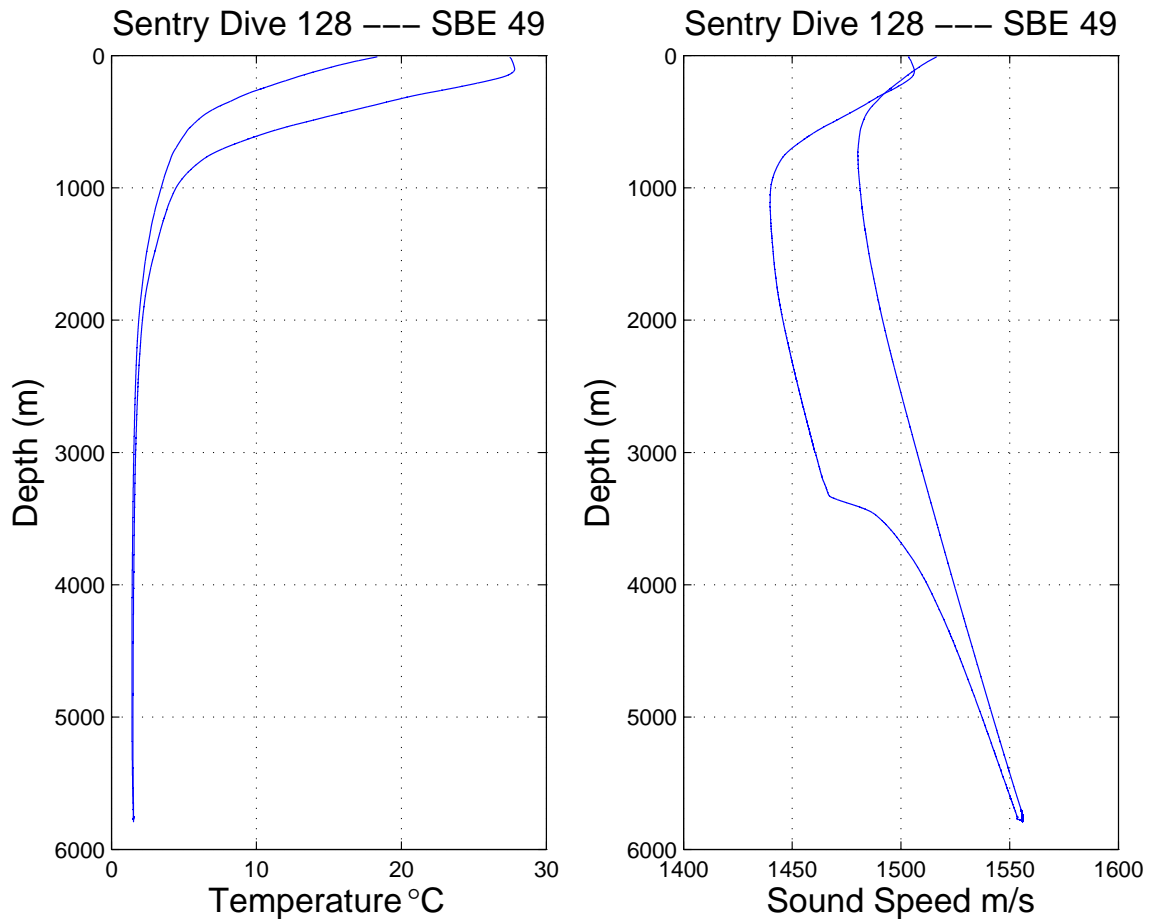


Figure 8: Sea temperature and sound velocity as measured by the Seabird 49 CTD on Sentry128.

Sentry 129 Dive Report

WHOI ABE/Sentry Operations Group

Dr. James C. Kinsey, Dr. Carl L. Kaiser, Andrew Billings, Justin Fujii, Stefano Suman,
and Korey Verhein.

Sentry Expedition Leader: Dr. James C. Kinsey

Chief Scientists: Dr. Masako Tominaga (WHOI) & Dr. Maurice Tivey (WHOI)

Science dive at 5800m covering a 60km trackline. Forward servo failure 2.5 hours into the dive resulted in *Sentry* crashing into the seafloor where it remained until the mission timer expired and the weights fell off. Tracking and telemetry was minimal during the early stages of the dive and non-existent later in the dive. A 4-hour search on the surface for the vehicle resulted in a successful recovery.

Weather: Fair.

Reason for end of dive: End of mission timer per plan. Forward servo failure resulted in the vehicle driving into the seafloor where it remained until the mission timer expired.

1 Vehicle Configuration

The science sensing suite for this dive was:

Table 5: Sentry Sensor Configuration

Sensor
APS 1540 Magnetometers (3)
Edgetech 4-24kHz SBP
Nobska GCTD (fast response sensor)
Seabird SBE49 CTD
Seapoint OBS
Anderaa optode model 4330
300kHz RDI DVL

This dive was navigated using the DVL/INS system in realtime. USBL provided post-dive corrections. All final navigation tracks are the best effort interpretation of available data by skilled personnel.

2 Important Positions

3 Narrative

The dive was planned as a 60km survey at approximately 5700m depth that would continue the magnetic survey of Sentry 128. The vehicle was programmed to fly 150m off the seafloor in bottom following mode. Expected dive duration was approximately 30 hours. On this dive, Towcam was equipped with an Avtrak beacon wired into the **SDSL! (SDSL!)** link to provide a second acoustic channel to the vehicle.

Descent proceeded smoothly and the USBL tracked the vehicle until approximately 5600m depth. Acoustic communications via Towcam showed that Sentry had begun the trackline and was running “hot, straight, and normal”. The ship moved ahead of *Sentry* with the plan the we would not allow *Sentry* to get ahead of the ship during the dive (thus ensuring it was always behind us). During the initial few hours occasional USBL fixes were detected as well as acoustic messages and round-trip ranges from the Avtrak on Towcam.

Range tracking with the vehicle was lost around 00:00 GMT. A search of the acoustic messages revealed a message around 23:30GMT that indicated *Sentry* was at a depth of 5800m and an altitude of 1.5m suggesting it was on the bottom. We stopped the ship and allowed Towcam to settle out under the ship at approximately 3500m depth (with layback it was at a depth of 2000m) to see if we could detect *Sentry* . This effort failed. An analysis of the ranges from the Avtrak suggested that *Sentry* was still moving but at a lower speed. Based on this we proceeded down the line to the recovery point.

Sentry did not arrive at the recovery point as scheduled nor was it detected on any acoustic tracking systems. Neither the radio direction finder (RDF) or the iridium phone provided surface tracking information. After a visual search of the immediate area for approximately 90 minutes, we recovered the USBL pole and proceeded back up the line running 1km west to account for surface current. *Sentry* was visually sighted around ??? and recovered soon after. The crew and science party assisted in the visual search and the *Sentry* team is grateful for their assistance.

Analysis of the on-board data shows that the forward servo on *Sentry* failed a few hours into the dive. Over those few hours it intermittently failed before permanently failing around ????. *Sentry* was in level flight mode when the forward servo “locked” 45 degrees down. This pitched the vehicle nose down and the forward velocity of the seafloor drove the vehicle into the seafloor approximately 8 minutes later. The vehicle remained on the seafloor for the remainder of the dive before the mission timer dropped the weights. The vehicle had covered approximately ??? km before the servo failed.

In light of the technical difficulties encountered during the dive, the decision was made to delay *Sentry* operations until the servo and tracking issues could be resolved.

Issues and Proposed Solutions

1. In hindsight, the decision to continue driving the ship down the line while not having tracking *and* having an acoustic message that the vehicle state was not normal (i.e., depth was close to that of the seafloor, altitude was 1.5m, and speed was slower) was an enormous mistake. We were certain we were ahead of *Sentry* but let a slant range that suggested the *Sentry* was not stopped skew our thinking. On the spot decisions like this are tough and it would behoove us to think about these scenarios in advance.
2. The forward servo failure represented the third actuator failure in as many dives. Testing on deck showed that we could communicate with it and it ??????. Analysis of the data during the dive showed that it the forward servo was being properly commanded and that it was communicating throughout

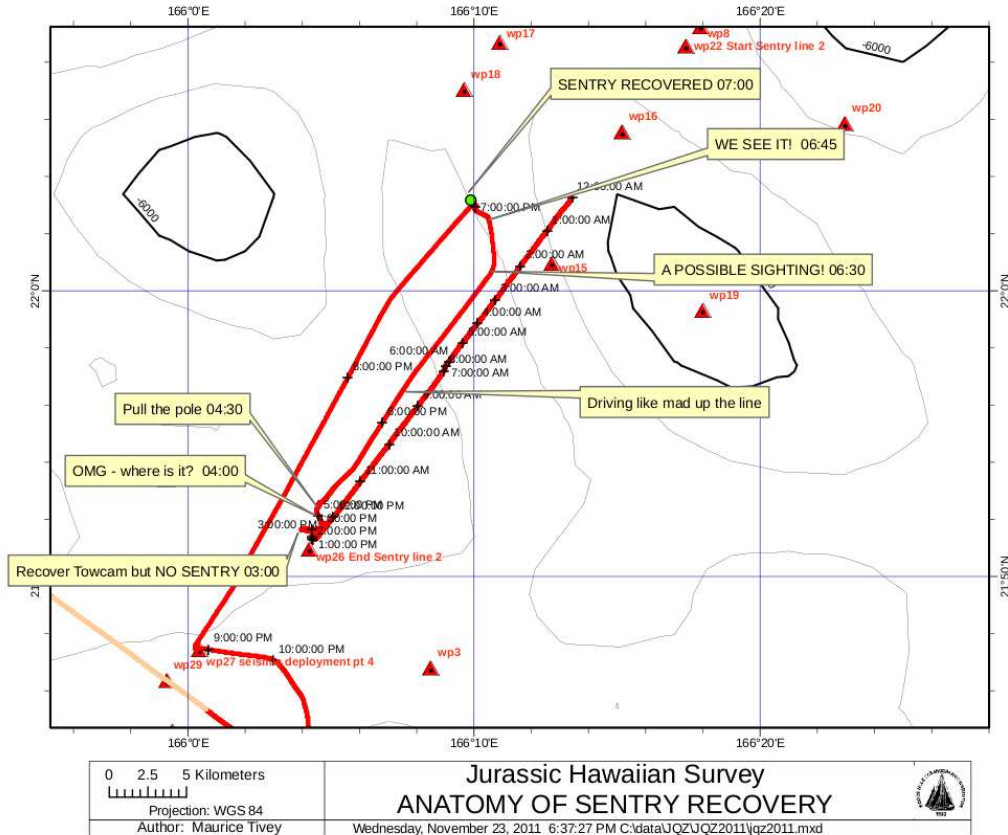


Figure 2: Ship's trajectory of the search pattern during *Sentry* dive 129. Image courtesy of M.A. Tivey (WHOI).

the dive. Inspection of the clutch and external mechanical components show no signs of damage. These facts lead to the conclusion that the failure is inside with servo itself. The failure of 2 servos and a thruster at depth *suggest* a depth related failure mode in the actuators however we *presently cannot definitively conclude this*. The root cause of the failure will likely require additional investigation at WHOI.

In the days following the dive, the *Sentry* team evaluated options and decided to move the aft servo (which had not failed on any of the previous dives) forward. The bad servo was placed aft and the rov control modified to only issue a center position command for the entire dive — effectively locking the aft wing. The broken servo from dive 128 and an old servo were scavenged to build a spare servo.

3. None of the topside tracking systems worked. An inspection of the iridium phone revealed that the pressure switch had failed; Carl wired a bypass and it started transmitting again. The failure of the

bridge to detect the radio frequency (RF) beacon was traced to an issue on the ship and was fixed. Steve Swift (WHOI) offered the use of the RDF used for sonabouy operations (which have demonstrated the ability to track sonabouys 16km away from the ship). A deck test of his system showed that it picked up the RF beacon on *Sentry* with a greater strength than the sonabouys. This suggests that his system could provide topside tracking at 16km ranges. This system may no longer be needed by science after this cruise and the *Sentry* team should consider acquiring it. The Captain, Pat Donovan, suggested installing an Automated Identification System (AIS) on *Sentry* ; that idea is also being considered.

4. Subsea tracking again proved difficult. USBL tracking went to 5600m; just shy of the operating depth for the dive. When in range, the ranging and telemetry from the Avtrak on Towcam was good. LBL tracking was again difficult at best.

In light of these facts, we are moving toward a strategy of keeping *Sentry* at depths less than 5600m where USBL would work. Dive sites later in the cruise will be at 5500m and we will increase the bottom following altitude to 200m. These small incremental gains could get us within range of *Sentry* and allow us to track it directly from the ship. The Avtrak on Towcam proved valuable for acoustic telemetry and single-range tracking.

Better topside tools for seeing navigation data are required as is the ability to quickly load all of the data into Matlab for “on-the-fly” analysis.

4 Chief Scientist Comments

5 Dive Statistics

5.1 Sentry129 Summary

Launch: 2011/11/21 16:18:32

Survey start: 2011/11/21 18:53:55

Survey end: 2011/11/22 13:29:35

Ascent begins: 2011/11/22 15:45:04

On the surface: 2011/11/22 16:08:06

On deck: 2011/11/22 18:50:60

descent rate: 36.6 m/min

ascent rate: 253.9 m/min

survey time: 18.6 hours

deck-to-deck time 26.5 hours

Mean survey depth: 5839m

Mean survey height: 130m

distance travelled: 40.33km

average speed; 0.58m/s

average speed during photo runs: 0.24 m/s over 5.31 km

average speed during multibeam runs: 0.59 m/s over 33.52 km

total vertical during survey: 1674m

Battery energy at launch: 13.4 kwhr

Battery energy at survey end: 5.6 kwhr

Battery energy on deck: 4.8 kwhr

6 Plots

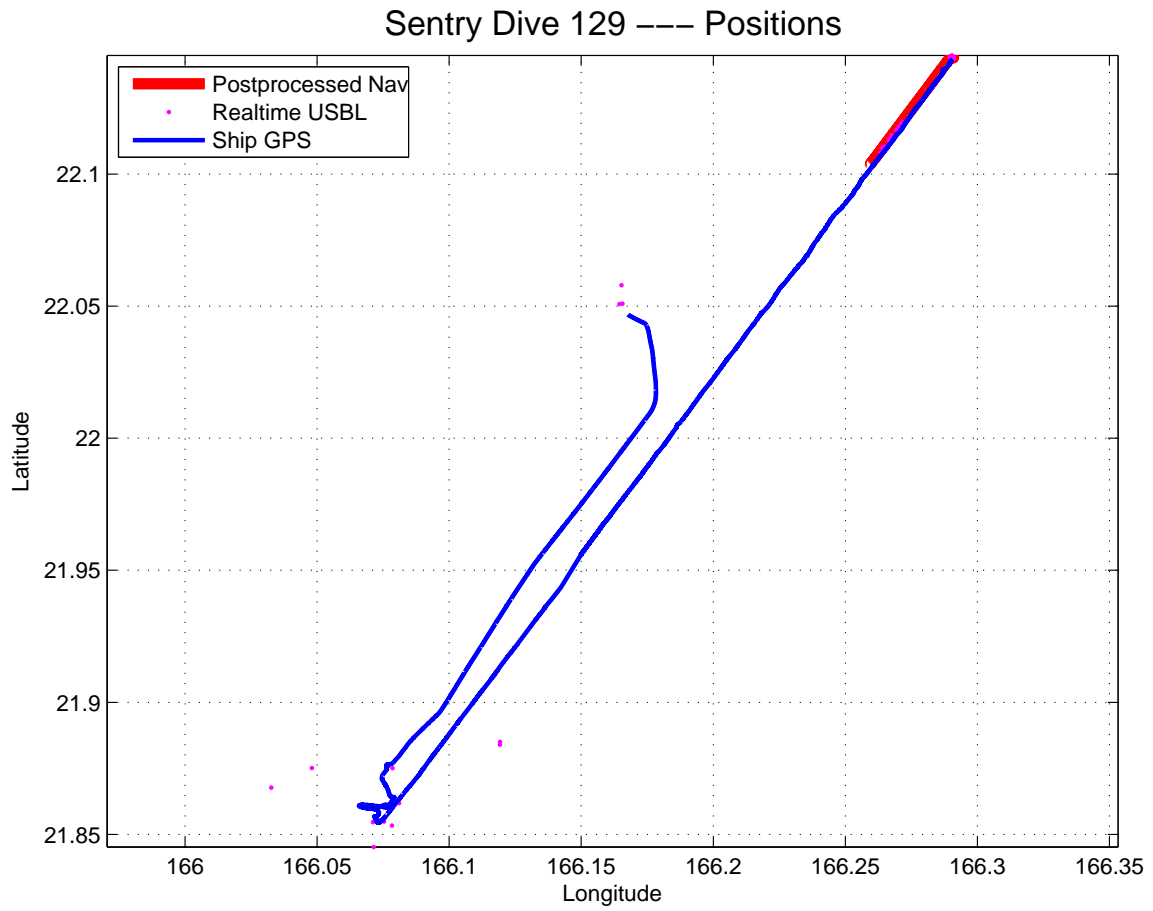


Figure 3: Latitude/Longitude plot of Sentry dive 129 with Realtime *Sentry* USBL, ship GPS, and *Sentry* post-processed positions.

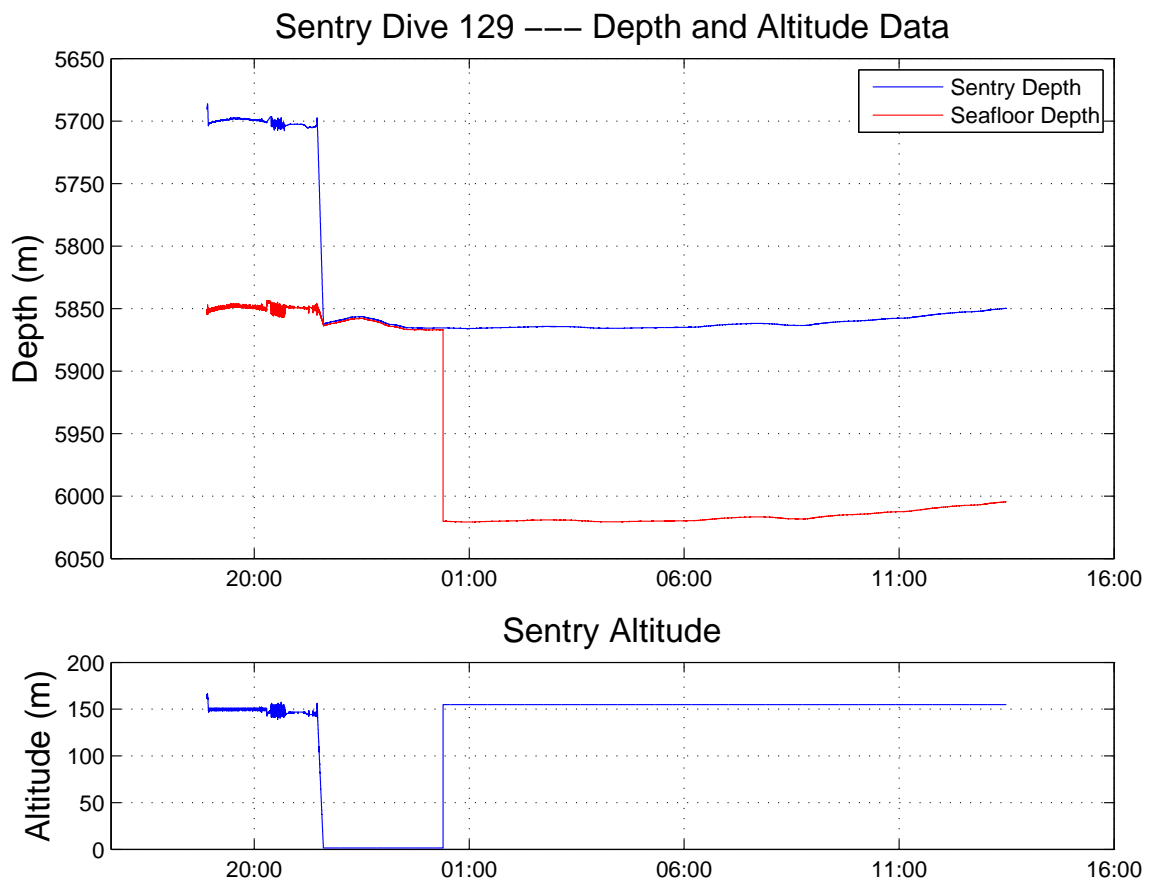


Figure 4: Depth and Altitude data for Sentry dive 129.

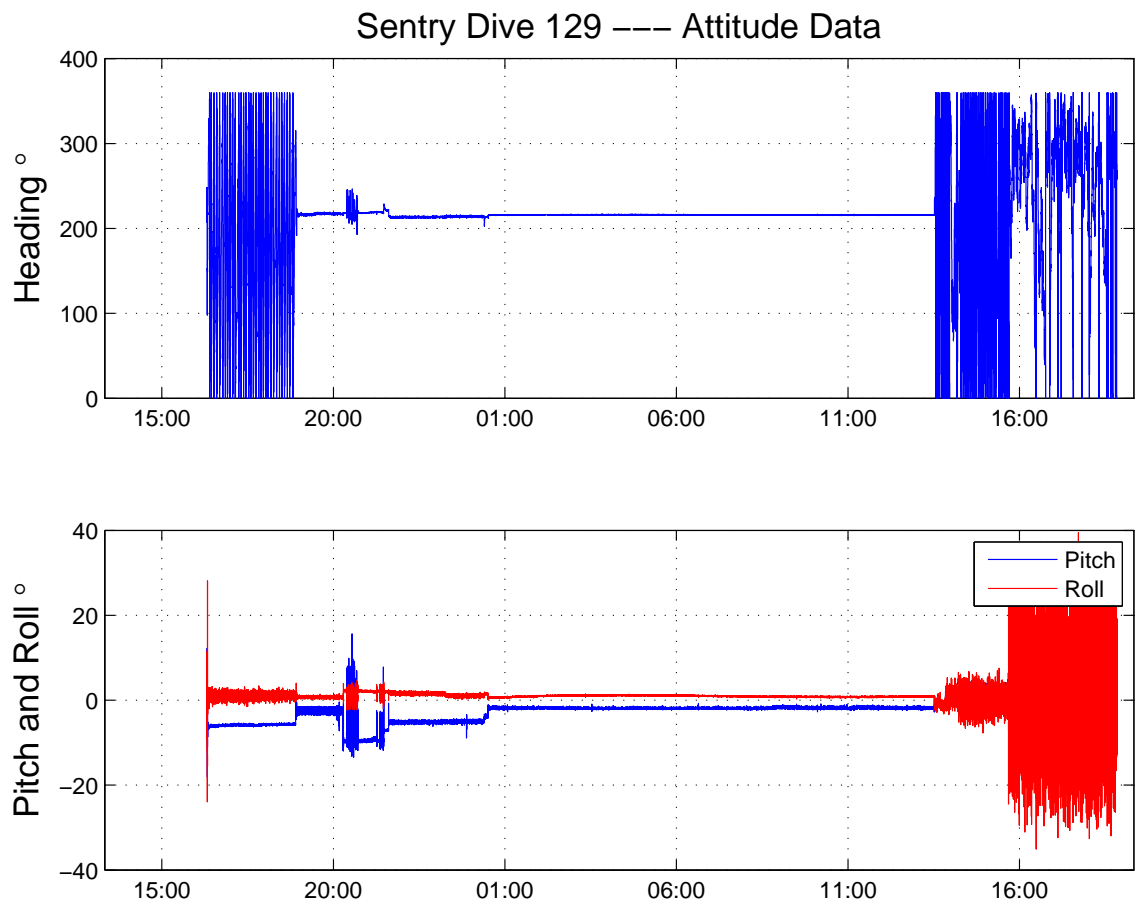


Figure 5: Heading, pitch, and roll data for Sentry129.

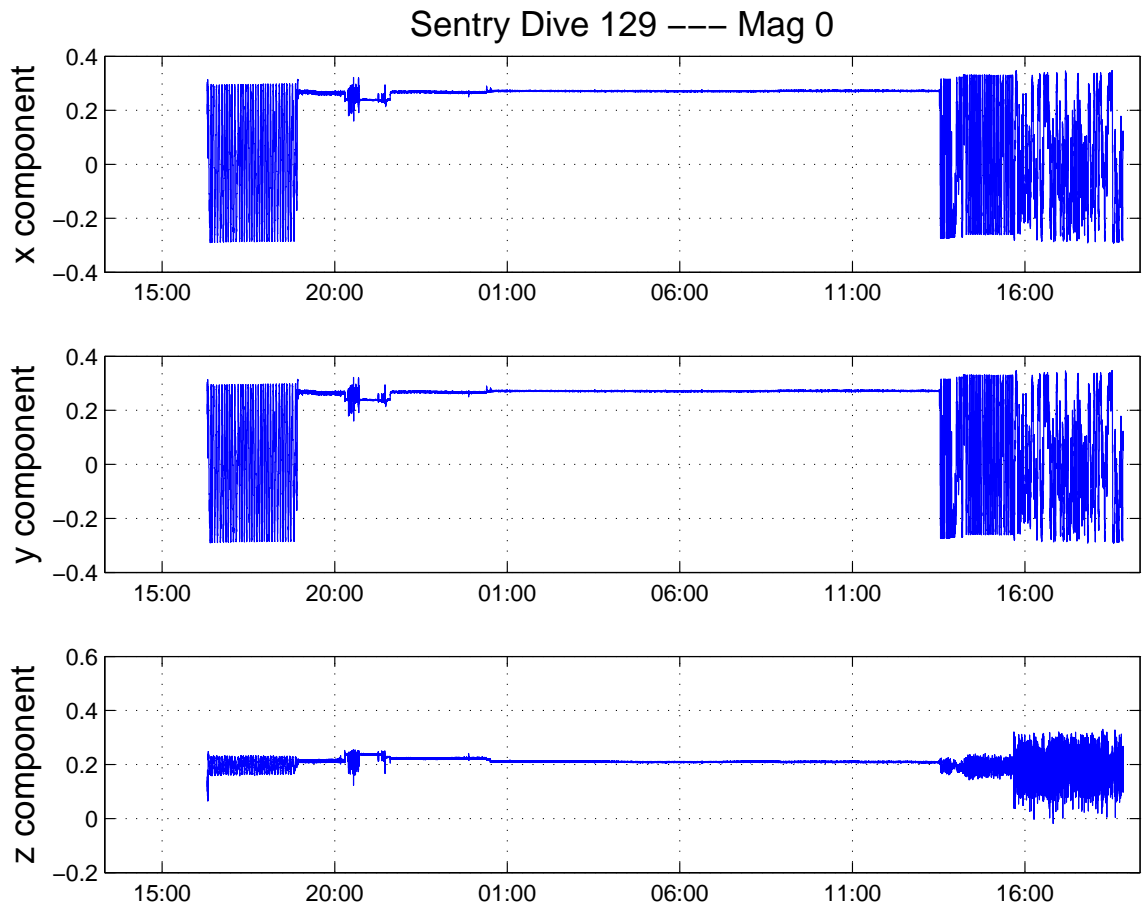


Figure 6: X,Y,Z magnetometer data for magnetometer 0 on Sentry129.

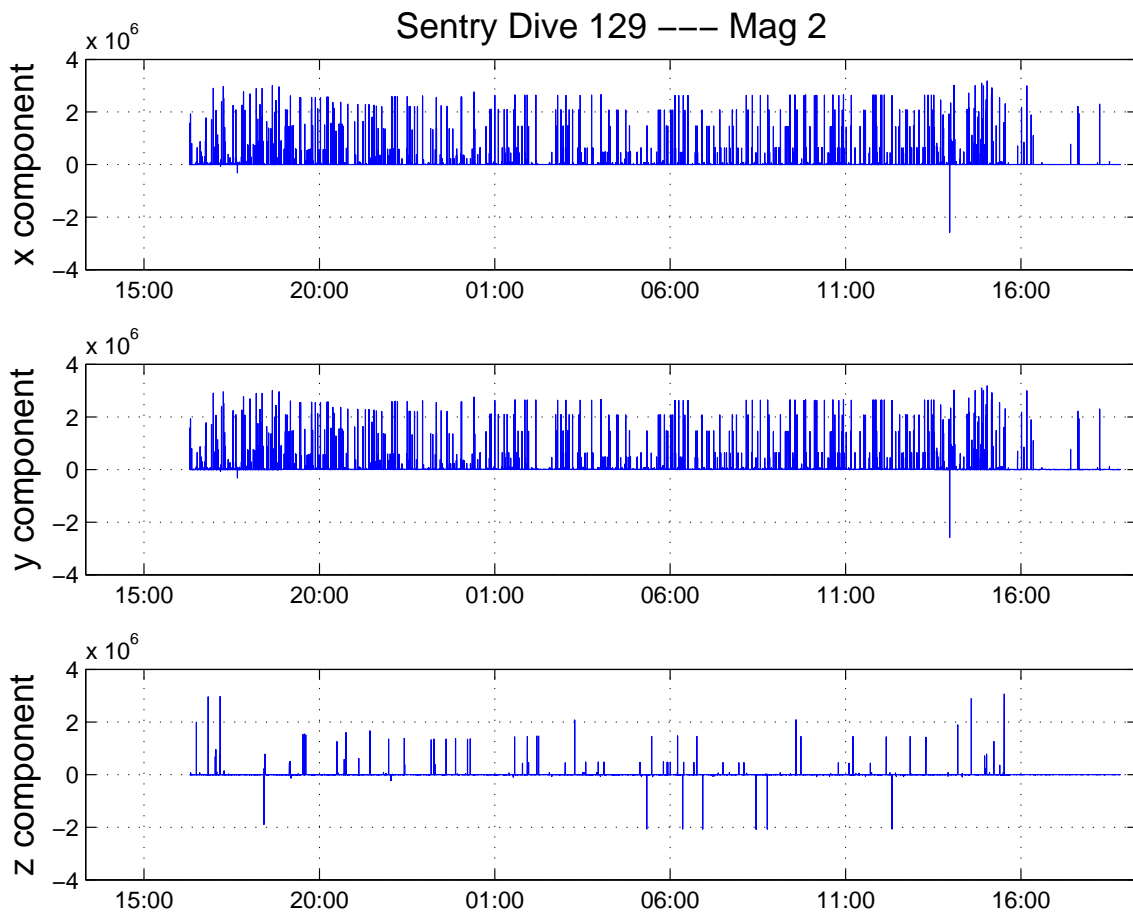


Figure 8: X,Y,Z magnetometer data for magnetometer 2 on Sentry129.

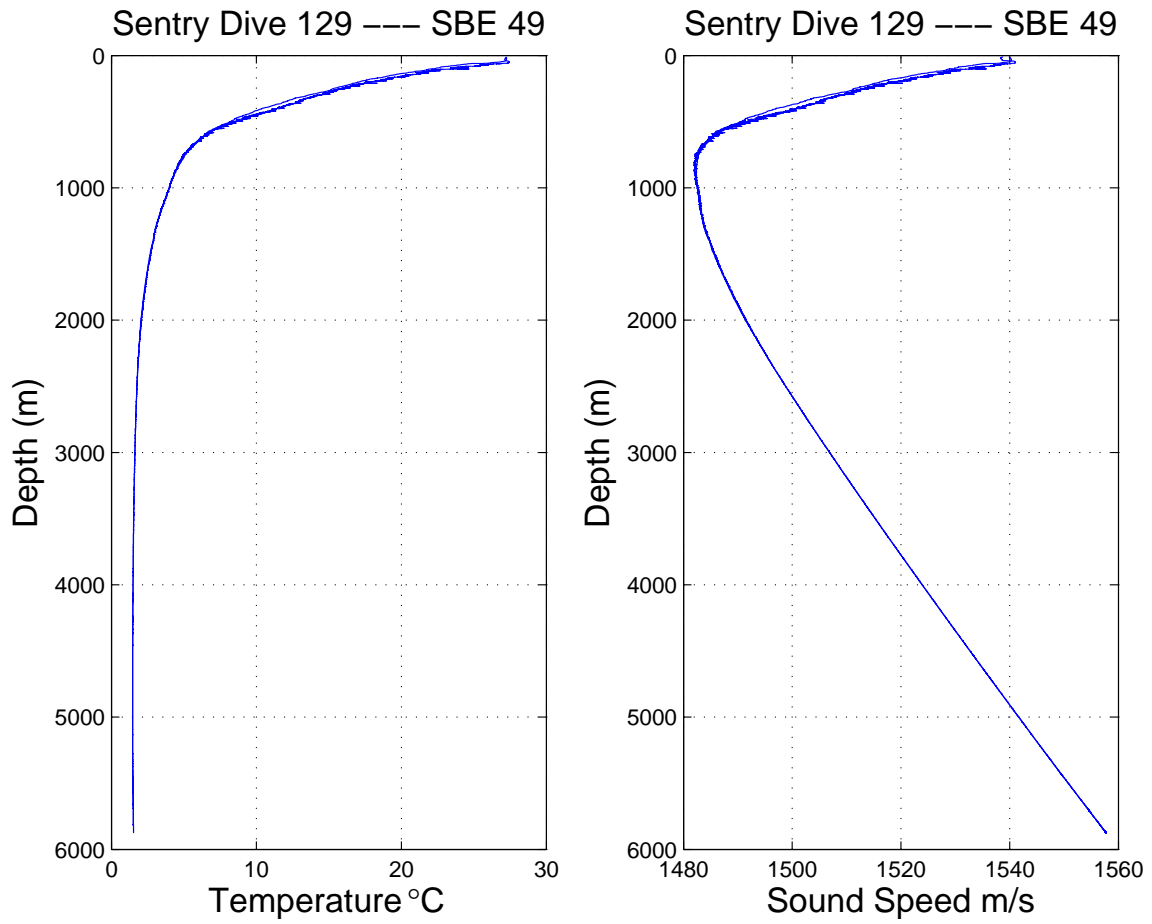


Figure 9: Sea temperature and sound velocity as measured by the Seabird 49 CTD on Sentry129.

Sentry 130 Dive Report

WHOI ABE/Sentry Operations Group

Dr. James C. Kinsey, Dr. Carl L. Kaiser, Andrew Billings, Justin Fujii, Stefano Suman,
and Korey Verhein.

Sentry Expedition Leader: Dr. James C. Kinsey

Chief Scientists: Dr. Masako Tominaga (WHOI) & Dr. Maurice Tivey (WHOI)

Short engineering dive at 1500m depth to test new flight mode necessitated by servo problems. Descent process failed and we aborted the dive acoustically. The failed descent process was the result of a programming error although this dive also reveals two additional programming bugs.

Weather: Fair.

Reason for end of dive: Issued acoustic abort because of failure in descent process.

1 Vehicle Configuration

The science sensing suite for this dive was:

Table 6: Sentry Sensor Configuration

Sensor
APS 1540 Magnetometers (3)
Edgetech 4-24kHz SBP
Nobska GCTD (fast response sensor)
Seabird SBE49 CTD
Seapoint OBS
Anderaa optode model 4330
300kHz RDI DVL

This dive was navigated using the DVL/INS system in realtime. USBL provided post-dive corrections. All final navigation tracks are the best effort interpretation of available data by skilled personnel.

2 Important Positions

Launch Position: 20 40.677'N, 165 4.004'E

Recovery Position: 20 40.709'N 165 3.908'E

Dive Origin: 22 8.568'N 166 17.401'E

3 Narrative

Sentry 130 was an engineering dive to test the ability of *Sentry* to “fly” with the aft wing locked and only the forward wing providing depth control. A depth of 1500m, in the mid-water column, was chosen to ensure tracking and acoustic telemetry. *Sentry* was programmed to descend to 1500m, drop its descent weight, and fly for approximately 35 minutes — changing depth every few minutes.

Sentry was launched at 00:38 GMT and descent appeared normal until the vehicle approached approximately 1400m. Descent slowed suggesting the descent weight had been released. As the vehicle passed 1500m, it continued descending eventually passing the 2000m — the programmed depth floor in the mission program. Attempts were made to acoustically “joystick” it into flight but these failed. An acoustic abort was issued at 02:43 GMT and the vehicle began ascending soon after. Recovery proceeded smoothly. Because of the need for seismics to deploy in daylight, another dive that afternoon was not possible.

The iridium phone emailed *Sentry's* position within 5 minutes of it surfacing. The RDF used for the sonobouy system detected the RF beacon on *Sentry* at full power. The bridge RDF was also working.

Analysis of the data and the programmed mission show that the failed descent process was the result of a programming bug that the simulation did not catch. The programming bug is now known however the reason for the simulation failure is not understood.

Issues and Proposed Solutions

1. The programming error that resulted in the failed descent process could have been prevented with better documentation of the water column dive mission planning. Water column dives have been previously done with *Sentry*, however the programming of these missions is poor.
2. The simulation does not reflect the reality of the descent process. This needs to be understood and fixed.
3. The depth floor of the vehicle is *not checked* during the descent process. This is a significant bug that needs to be fixed. Had we not issued an acoustic abort *Sentry* would have continued descending until the mission timers expired. A simple conditional in the descent process should be sufficient.

These problems are discussed in more detail in Appendix D of the cruise report.

4 Chief Scientist Comments

5 Dive Statistics

5.1 Sentry130 Summary

Launch: 2011/11/27 00:38:14

Survey start: 2011/11/27 01:40:10

Survey end: 2011/11/27 01:44:36

Ascent begins: 2011/11/27 01:45:31

On the surface: 2011/11/27 02:36:13
On deck: 2011/11/27 02:45:37
descent rate: 31.4 m/min
ascent rate: 39.5 m/min
survey time: 0.1 hours
deck-to-deck time 2.1 hours
Mean survey depth: 1996m
Mean survey height: 24m
distance travelled: 1.83km
average speed; -0.32m/s
average speed during photo runs: 0.06 m/s over 0.10 km
average speed during multibeam runs: -0.32 m/s over -0.09 km
total vertical during survey: 116m
Battery energy at launch: 13.9 kwhr
Battery energy at survey end: 13.6 kwhr
Battery energy on deck: 13.4 kwhr

6 Plots

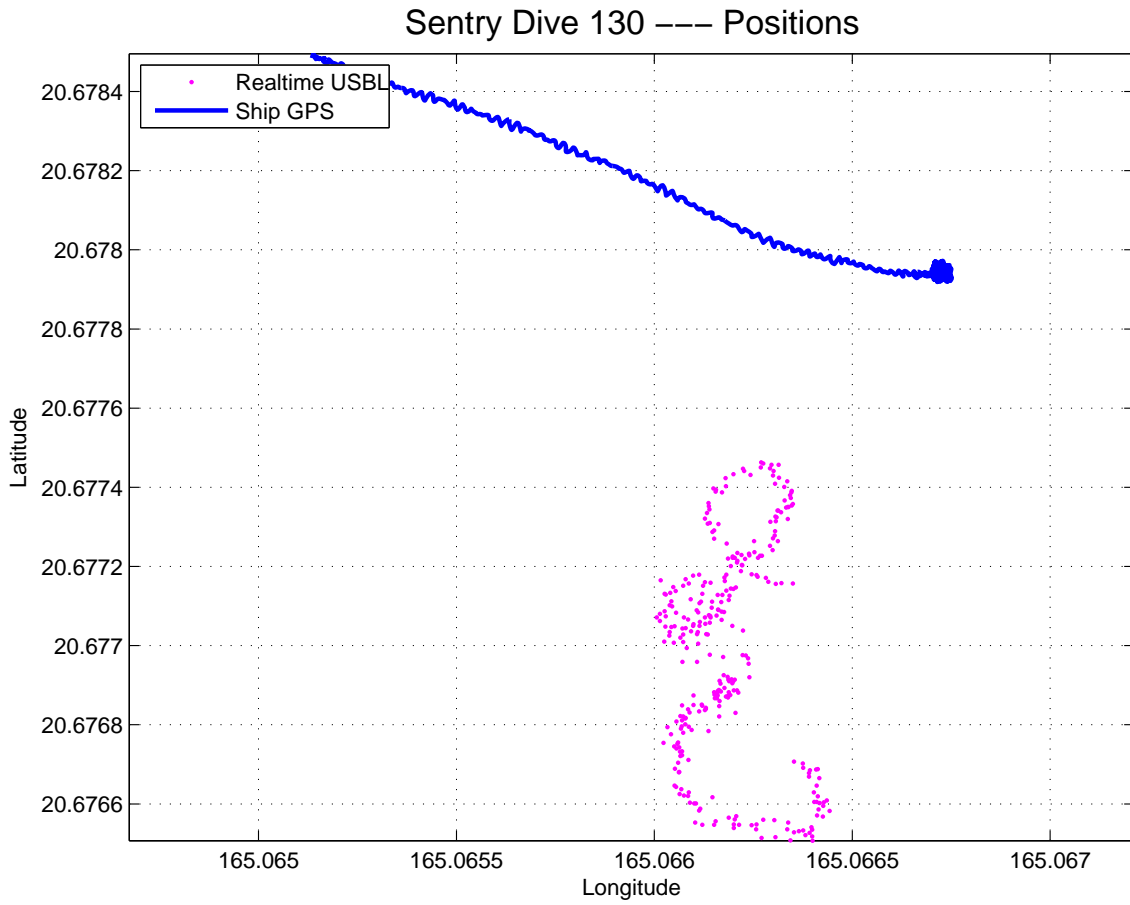


Figure 2: Latitude/Longitude plot of Sentry dive 130 with Realtime *Sentry* USBL, ship GPS, and *Sentry* post-processed positions.

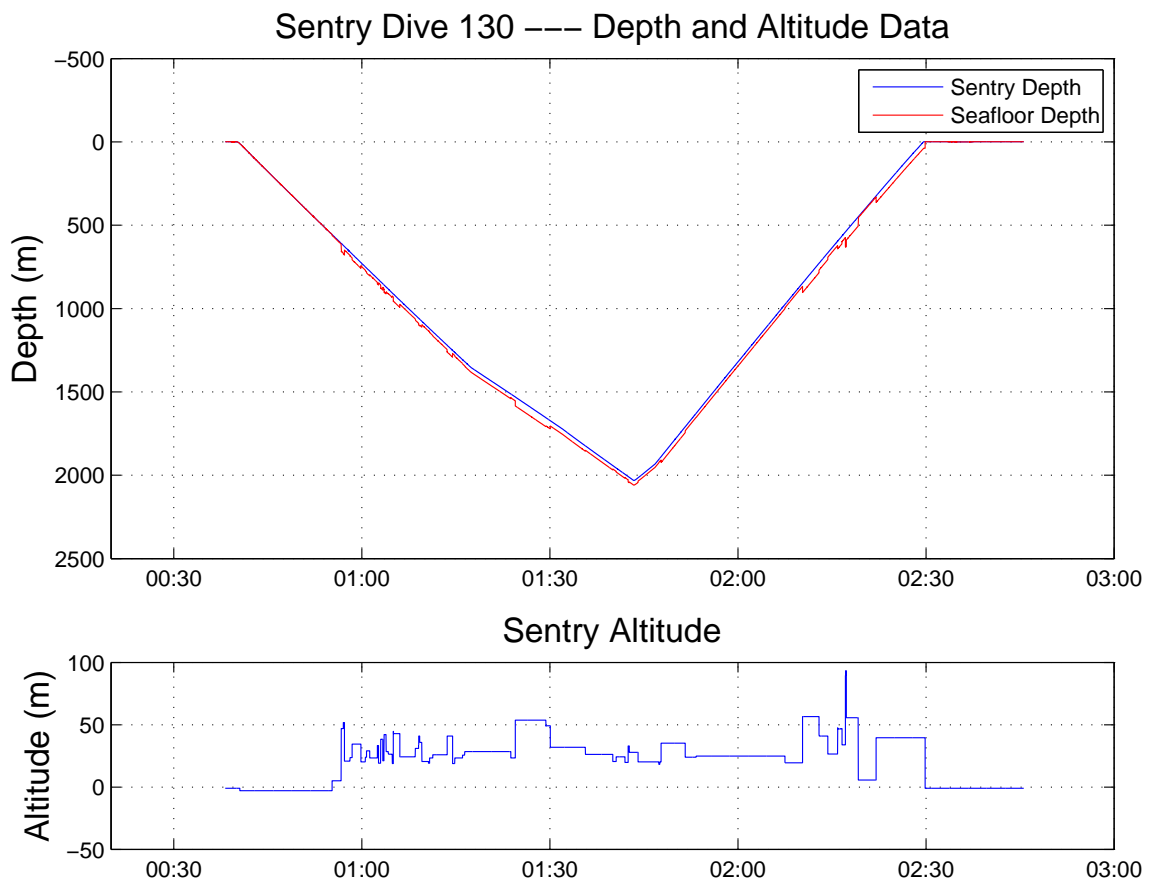


Figure 3: Depth and Altitude data for Sentry dive 130.

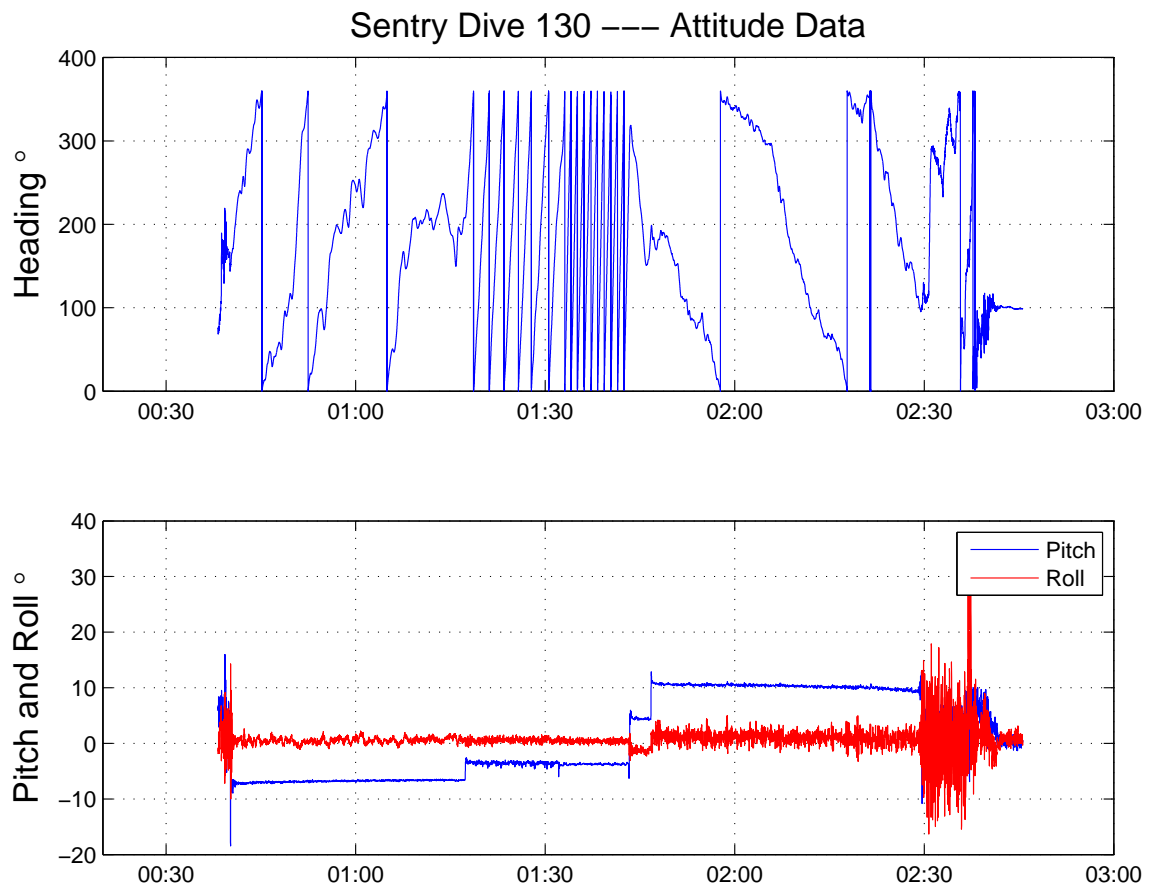


Figure 4: Heading, pitch, and roll data for Sentry130.

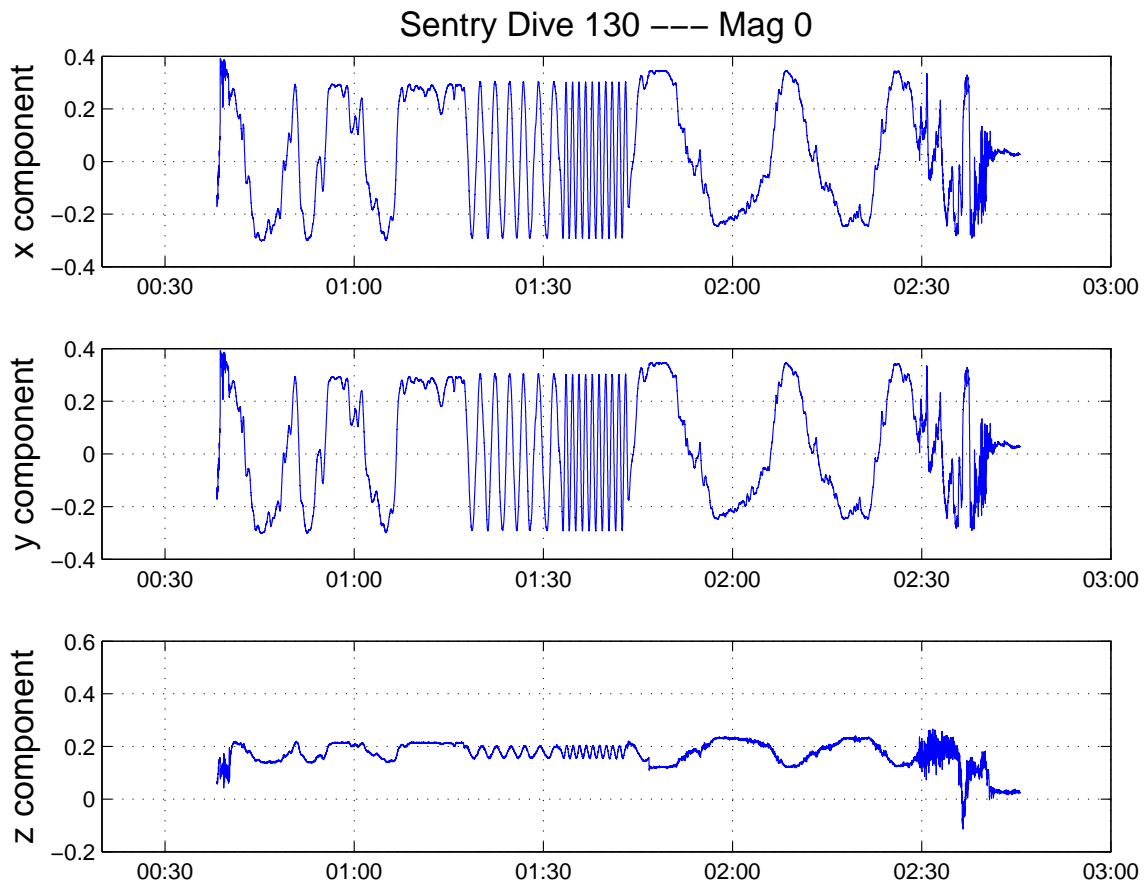


Figure 5: X,Y,Z magnetometer data for magnetometer 0 on Sentry130.

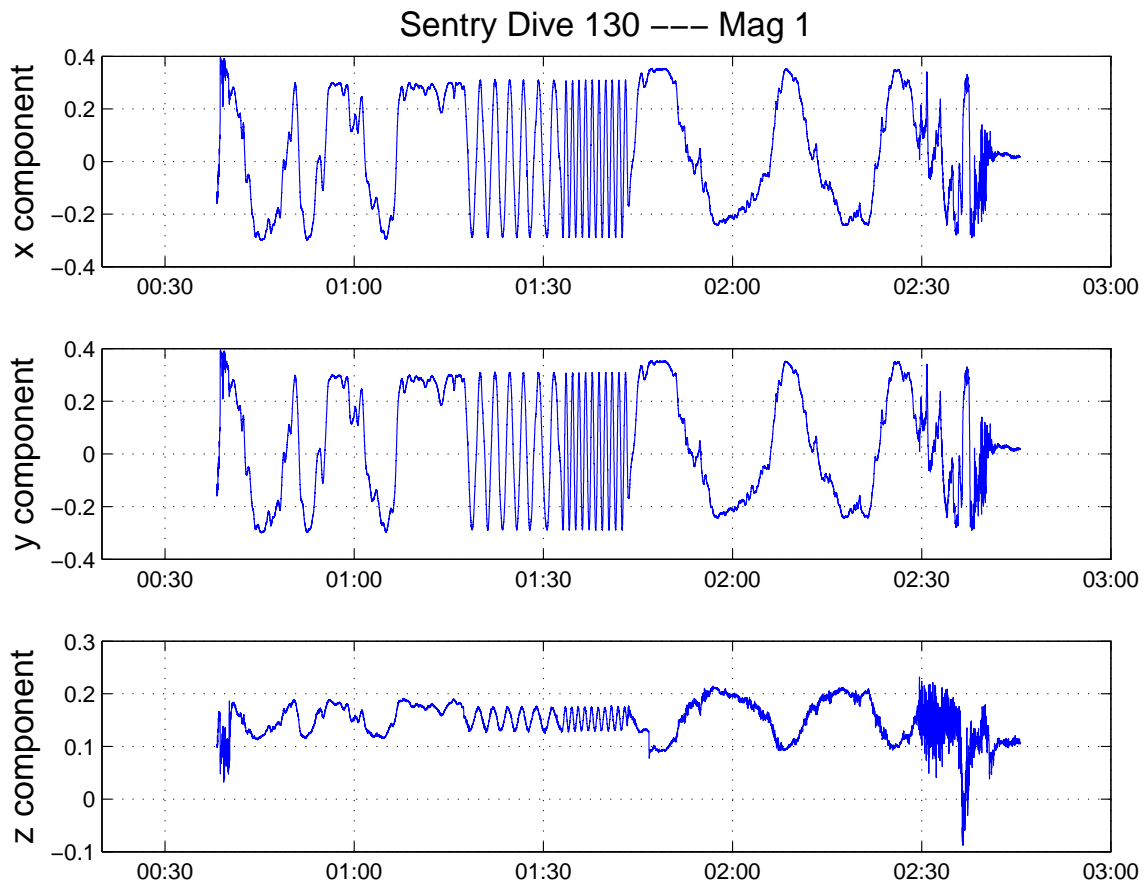


Figure 6: X,Y,Z magnetometer data for magnetometer 1 on Sentry130.

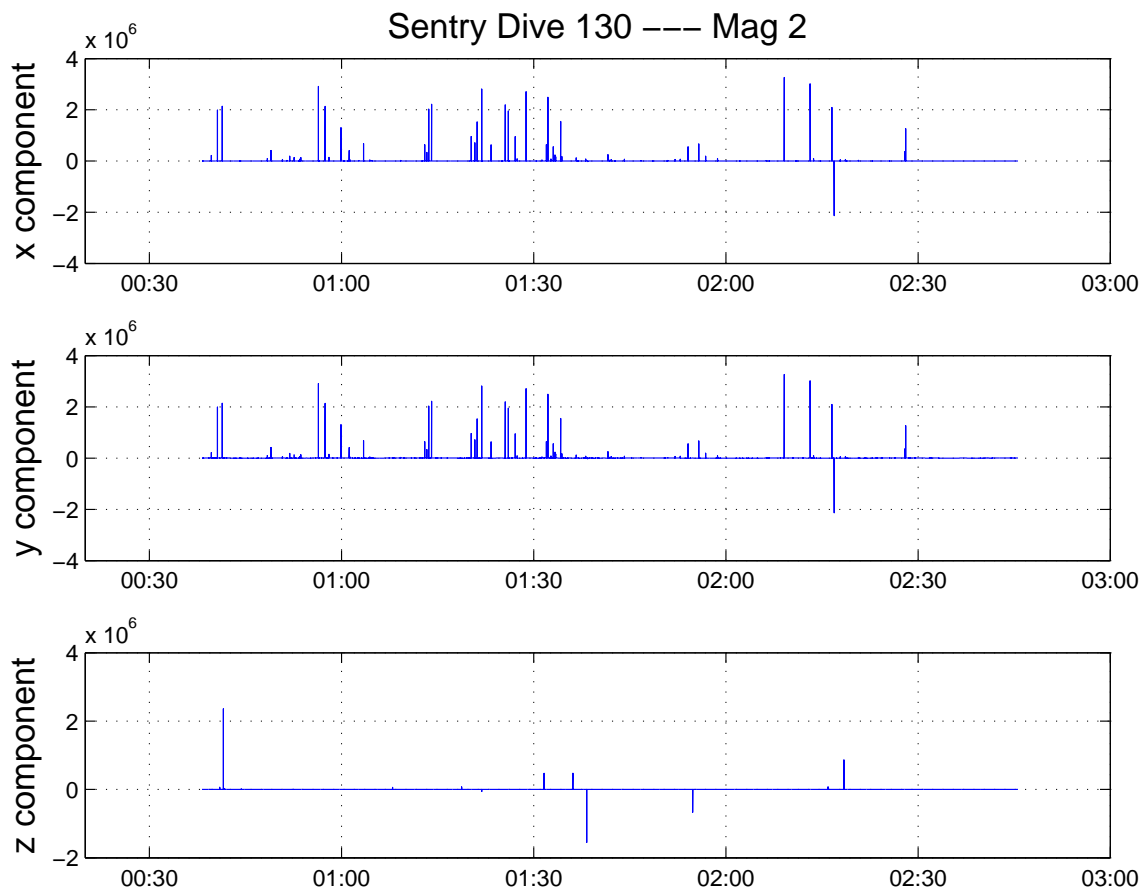


Figure 7: X,Y,Z magnetometer data for magnetometer 2 on Sentry130.

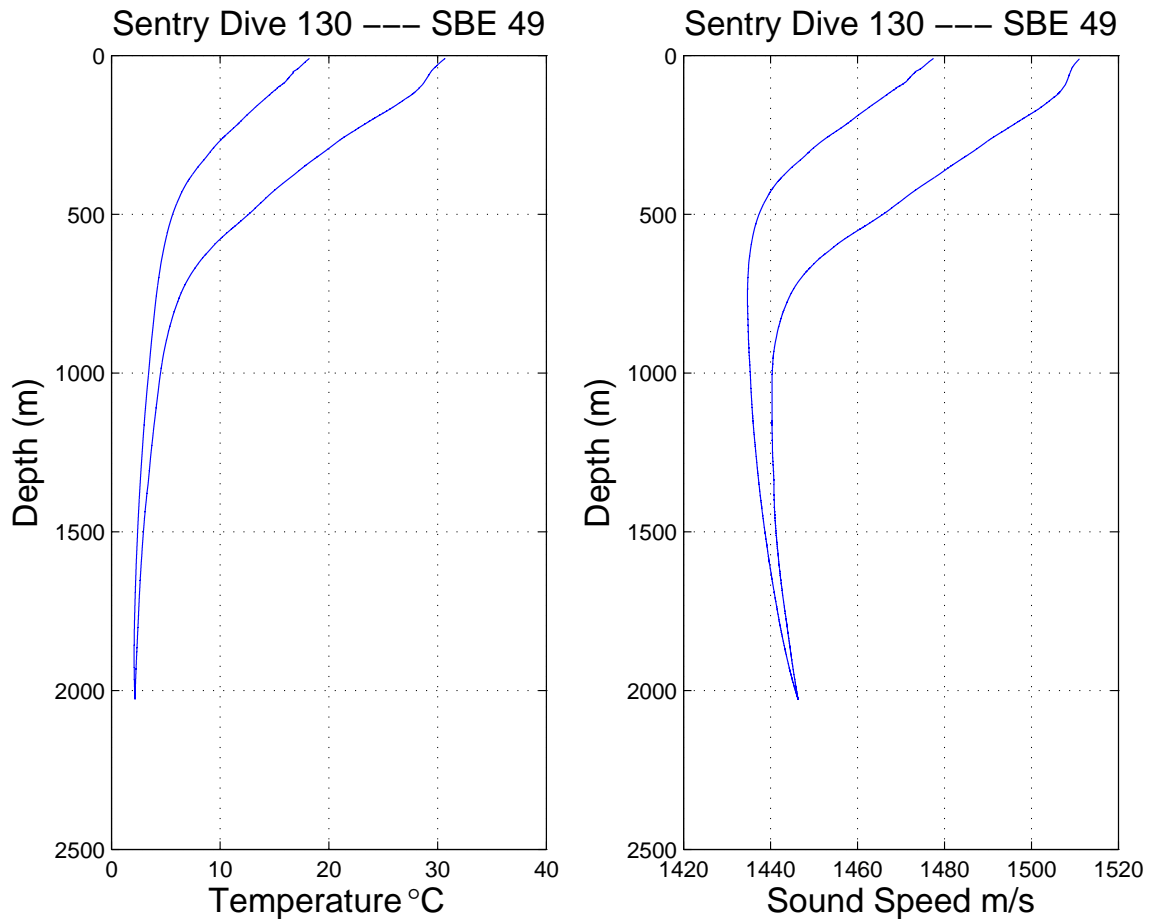


Figure 8: Sea temperature and sound velocity as measured by the Seabird 49 CTD on Sentry130.

Sentry 131 Dive Report

WHOI ABE/Sentry Operations Group

Dr. James C. Kinsey, Dr. Carl L. Kaiser, Andrew Billings, Justin Fujii, Stefano Suman,
and Korey Verhein.

Sentry Expedition Leader: Dr. James C. Kinsey

Chief Scientists: Dr. Masako Tominaga (WHOI) & Dr. Maurice Tivey (WHOI)

A 1000m engineering dive to repeat the objectives of the failed Sentry 130 dive — testing the new flight mode. The dive was successful until recovery. Recovery took 3 attempts and *Sentry* twice slid under the ship. Vehicle damage included shearing of the starboard wings and the Avtravk transducer being removed.

Weather: At recovery: 5' to 7' swell; 15-20 knot winds; wind waves and swell coming from different directions.

Reason for end of dive: End of mission. All mission objectives completed.

1 Vehicle Configuration

The science sensing suite for this dive was:

Table 7: Sentry Sensor Configuration

Sensor
APS 1540 Magnetometers (3)
Edgetech 4-24kHz SBP
Nobska GCTD (fast response sensor)
Seabird SBE49 CTD
Seapoint OBS
Anderaa optode model 4330
300kHz RDI DVL

This dive was navigated using the DVL/INS system in realtime. USBL provided post-dive corrections. All final navigation tracks are the best effort interpretation of available data by skilled personnel.

2 Important Positions

Dive Origin:

Launch Position:

Recovery Position:

3 Narrative

The dive began on time and the launch sequence was very well timed. Descent proceeded smoothly with good tracking and acomms throughout. The descent process ended as programmed at 950m and the vehicle flew the expected dive trajectory (see flight control discussion below). The mission ended when *Sentry* ran out of tracklines and ascent took approximately 20 minutes. *Sentry* came up 250m off the starboard bow.

Recovery took over 2 hours with three attempts being made. On two of those attempts, *Sentry* slide under the hull and sustained damage.

4 Chief Scientist Comments

5 Dive Statistics

5.1 Sentry131 Summary

Launch: 2011/11/30 10:03:02

Survey start: 2011/11/30 10:30:42

Survey end: 2011/11/30 10:57:18

Ascent begins: 2011/11/30 10:57:18

On the surface: 2011/11/30 11:19:25

On deck: 2011/11/30 13:24:25

descent rate: 34.6 m/min

ascent rate: 40.6 m/min

survey time: 0.4 hours

deck-to-deck time 3.4 hours

Mean survey depth: 1003m

Mean survey height: 4890m

distance travelled: 1.15km

average speed; 0.50m/s

average speed during photo runs: NaN m/s over NaN km

average speed during multibeam runs: 0.50 m/s over 0.80 km

total vertical during survey: 270m

Battery energy at launch: 13.7 kwhr

Battery energy at survey end: 13.4 kwhr

Battery energy on deck: 13.1 kwhr

6 Plots

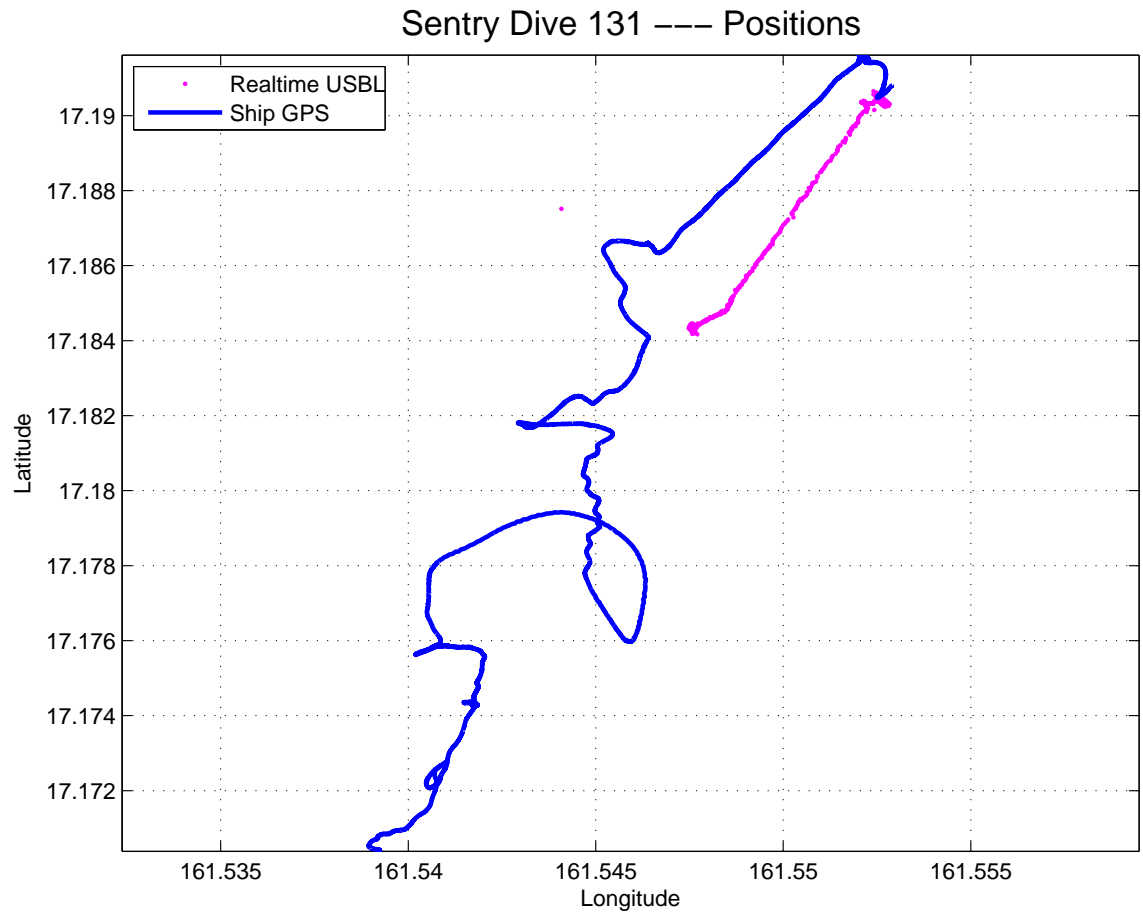


Figure 2: Latitude/Longitude plot of Sentry dive 131 with Realtime *Sentry* USBL, ship GPS, and *Sentry* post-processed positions.

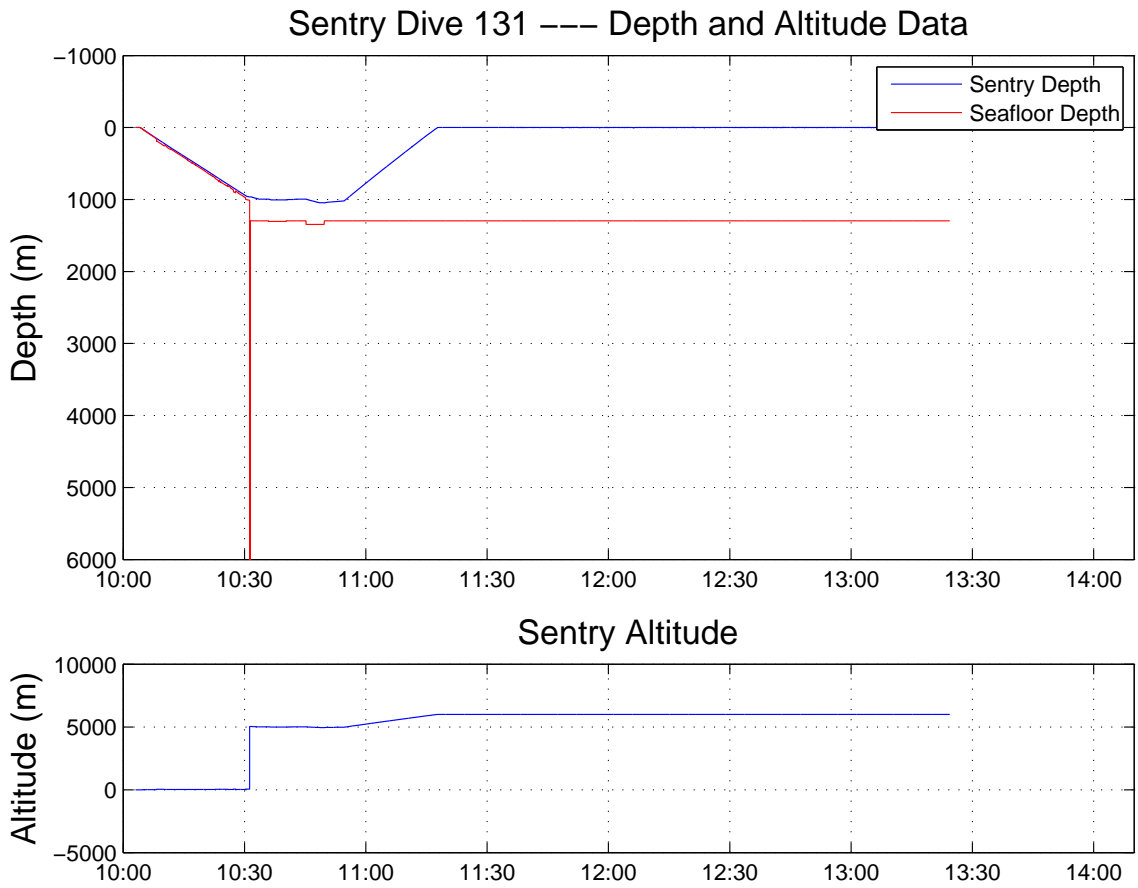


Figure 3: Depth and Altitude data for Sentry dive 131.

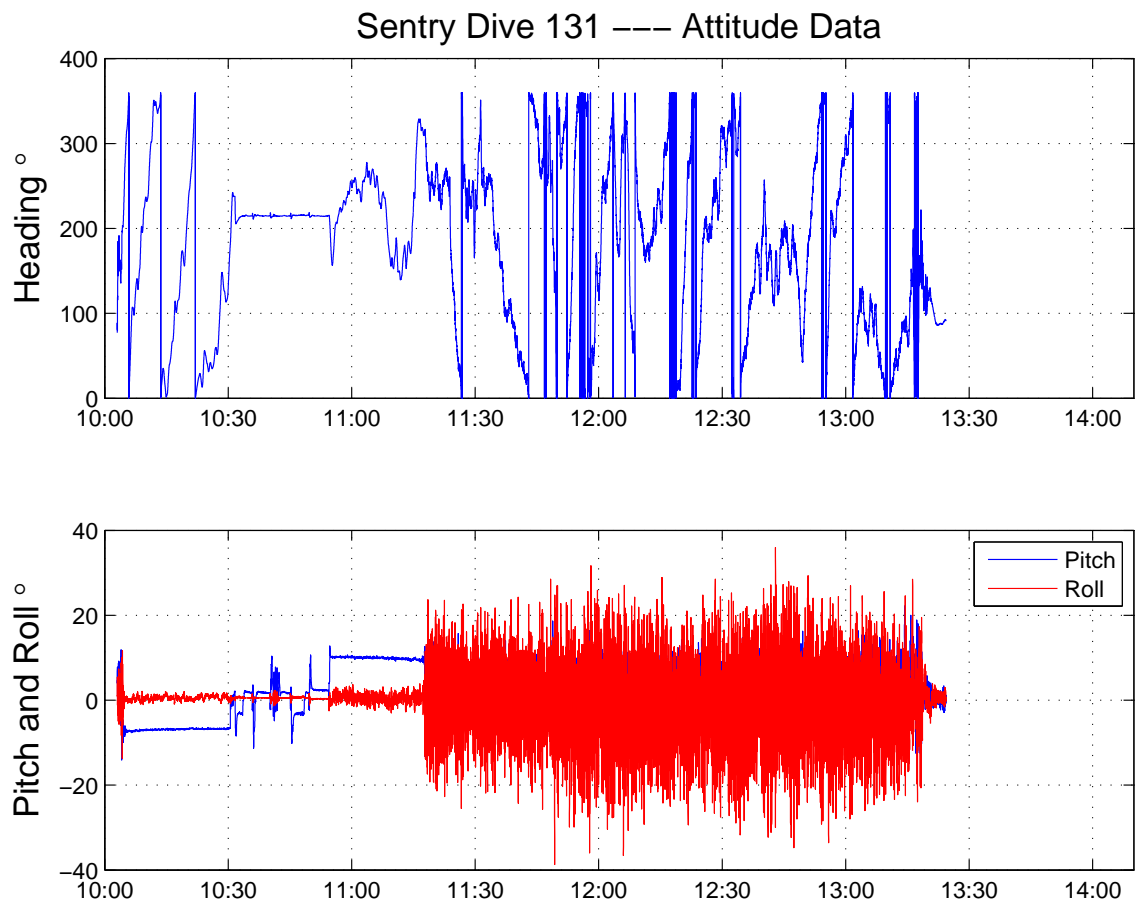


Figure 4: Heading, pitch, and roll data for Sentry131.

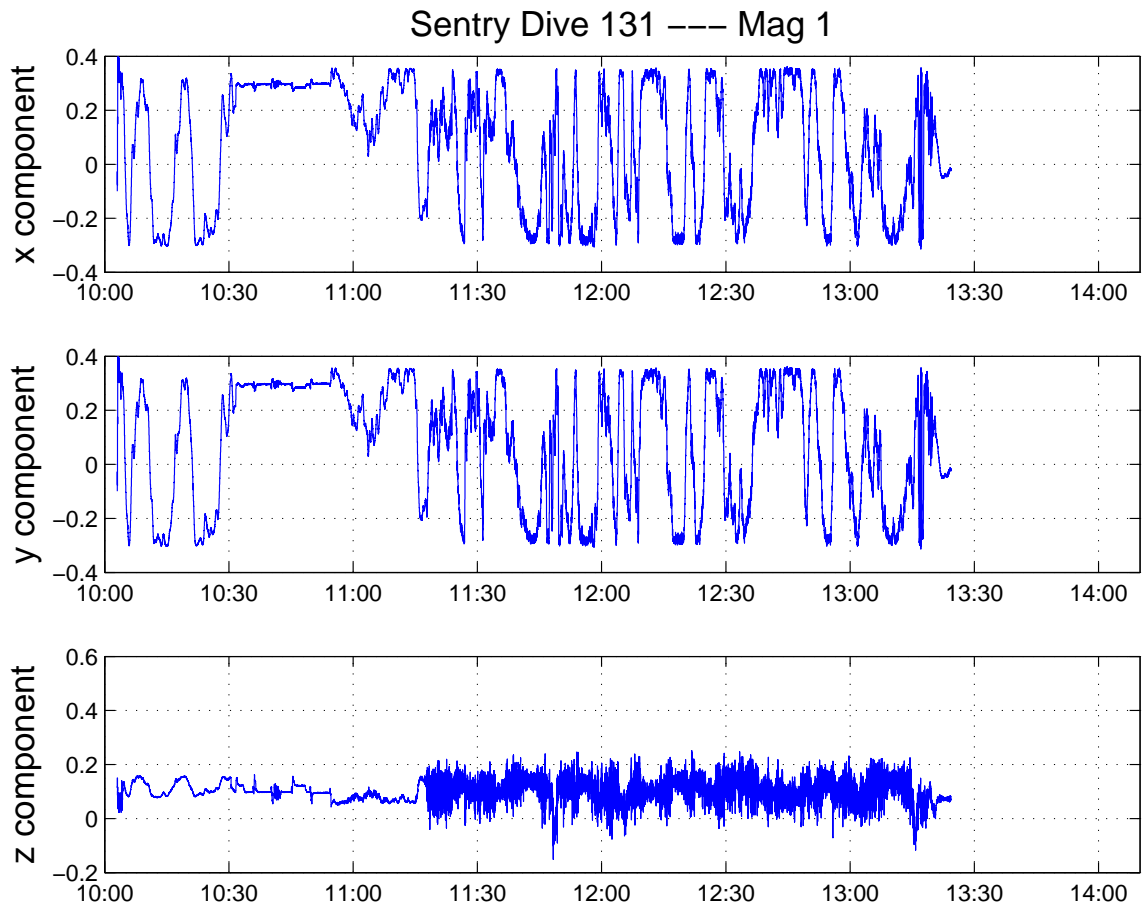


Figure 5: X,Y,Z magnetometer data for magnetometer 1 on Sentry131.

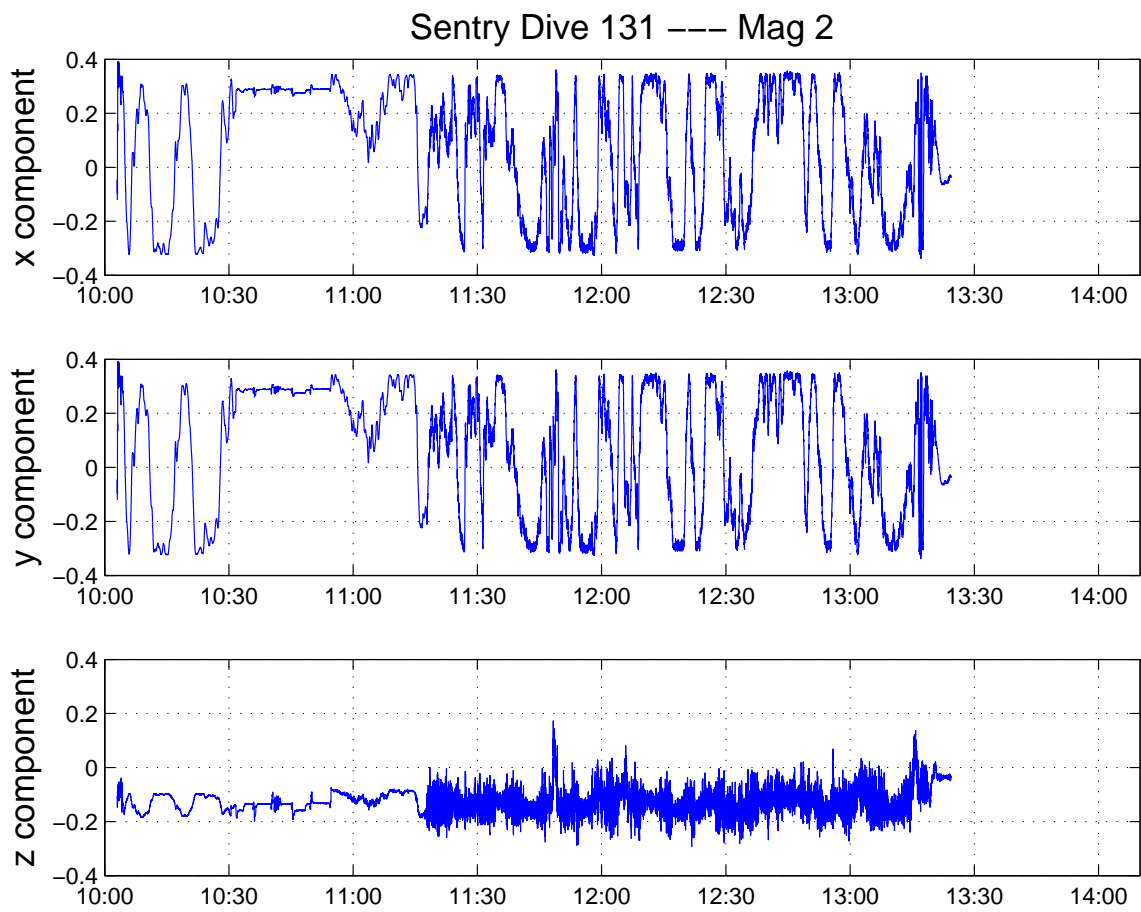


Figure 6: X,Y,Z magnetometer data for magnetometer 2 on Sentry131.

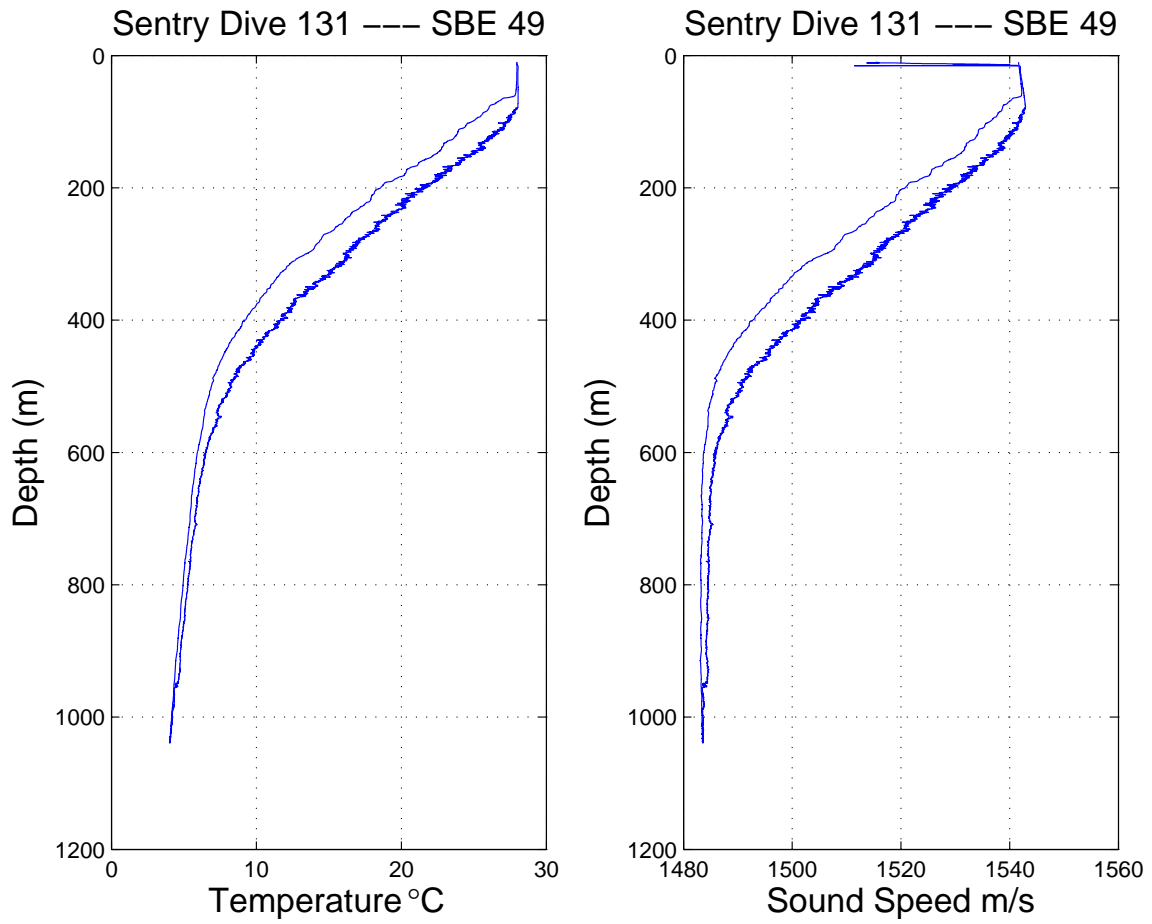


Figure 7: Sea temperature and sound velocity as measured by the Seabird 49 CTD on Sentry131.

Sentry 132 Dive Report

WHOI ABE/Sentry Operations Group

Dr. James C. Kinsey, Dr. Carl L. Kaiser, Andrew Billings, Justin Fujii, Stefano Suman,
and Korey Verhein.

Sentry Expedition Leader: Dr. James C. Kinsey

Chief Scientists: Dr. Masako Tominaga (WHOI) & Dr. Maurice Tivey (WHOI)

Summary

Brief (2-3 sentence) description of dive.

Weather: Fair.

Reason for end of dive: Mission timer expired at planned time. Vehicle completed programmed mission.

Vehicle Configuration

The science sensing suite for this dive was:

Table 8: Sentry Sensor Configuration

Sensor
APS 1540 Magnetometers (3)
Edgetech 4-24kHz SBP
Nobska GCTD (fast response sensor)
Seabird SBE49 CTD
Seapoint OBS
Anderaa optode model 4330
300kHz RDI DVL

This dive was navigated using the DVL/INS system in realtime. USBL provided post-dive corrections. All final navigation tracks are the best effort interpretation of available data by skilled personnel.

Important Positions

Launch Position: 20 40.664'N, 165 4.120'E

Recovery Position: 20 45.385'N 165 8.181'E

Dive Origin: 20 40.671'N 165 4.133'E

Narrative

Sentry 132 was planned as a deep dive to test bottom-following with the new flight mode and assess topside tracking with sentry operating at depths of approximately 5400m. A four hour survey, covering approximately 10km, was planned.

Sentry was launched at the planned time. As *Sentry* passed 1000m depth, Towcam was launched and lowered to a depth of 4800m. USBL tracking was excellent throughout the descent and we had USBL tracking when *Sentry* reached the bottom. The 11.0/14.5 heartbeat pings from the LBL were heard by the ship and the 12.0 heartbeat relay was also heard. The ship's Knudsen also picked up the 11.0 heartbeat.

Sentry drifted a few hundred meters east during the descent. The drift was greater than on previous dives and is likely the result of *Sentry* gliding because of the locked aft wing. The ship was moved accordingly. USBL tracking showed *Sentry* starting up the planned trackline and the ship started following. USBL position fixes were received very few minutes and the LBL ranges remained strong.

New topside nav tools allowed us to plot the ship and *Sentry* tracks. Upon observing that the ship was on a diverging course from *Sentry*, we had the ship redirected using a relative course over ground (COG) command (i.e. "shift your COG 5 degrees counter-clockwise"). This method of redirecting was much more efficient. No other ship orders were issued until we approached the end of the line.

USBL fixes were received every few minutes and the depths were within 200m of the expected vehicle depth. Occasional "bounces" were received but still provided reasonable estimates of the vehicle position (see additional discussion below). The direct 11.0/14.5 heartbeat was observed to be flat throughout the dive indicating that the *relative* distance from *Sentry* to the ship was not increasing — i.e., *Sentry* and the ship were remaining in close proximity.

Upon arriving at the recovery point, *Sentry* was tracked on the USBL. Soon after we lost it on USBL however the LBL ranging indicated it remained close the ship. Attempts were made to acoustically abort the vehicle via the direct XR commands and the USBL acoustic modem. The XR commands were not received but an acoustic modem abort was received (17 seconds after the timer expired). This demonstrates the ability, albeit brittle, to get an acoustic message to the vehicle at 5300m.

Sentry was observed to be ascending on the LBL ranges and, after the USBL program was restarted, picked up on USBL (this program restart had to be done twice on the dive). USBL tracking was present throughout the ascent and *Sentry* was recovered without incident.

Issues and Proposed Solutions

1. Post-dive analysis of the data shows that the depth servo was cycling. The vehicle tracked depth but was "porpoising" at approximately 15 sec intervals. The cause of this is unclear and under investigation.
2. *Sentry* "planed" during descent approximately 400m. The drift is not a concern however the absence of heading wraps (i.e., the "Tivey Twist") does compromise calibration of the maggies during descent.

3. The model velocities during descent did not agree with USBL position. This does not affect operations and is likely the result of model not accurately reflecting the locked aft wing. It should be looked at after the cruise.
4. Overall USBL tracking was sufficient throughout the dive. Twice the unit had to be reset. The solution depths could disagree by up to 150m. The horizontal positions still grossly agreed. We need to follow up with Sonardyne on this.

Navigation Notes

USBL tracking was present throughout this dive. The descent and ascent were navigated using the USBL track smoothed with a low-pass filter. The survey portion of the dive uses a renavigated DVL track fused with the renavigated USBL track with a complementary filter. USBL position fixes with depths differing from the actual *Sentry* depth by more than 50m are eliminated and not used in the final navigation.

Chief Scientist Comments

Dive Statistics

0.1 Sentry132 Summary

Launch: 2011/12/02 05:02:30
Survey start: 2011/12/02 07:44:31
Survey end: 2011/12/02 13:53:55
Ascent begins: 2011/12/02 13:57:17
On the surface: 2011/12/02 15:56:29
On deck: 2011/12/02 16:53:49
descent rate: 32.6 m/min
ascent rate: 46.2 m/min
survey time: 6.2 hours
deck-to-deck time 10.9 hours
Mean survey depth: 5320m
Mean survey height: 200m
distance travelled: 13.85km
average speed; 0.53m/s
average speed during photo runs: 0.00 m/s over 0.00 km
average speed during multibeam runs: 0.53 m/s over 11.65 km
total vertical during survey: 1676m
Battery energy at launch: 12.8 kwhr
Battery energy at survey end: 9.9 kwhr
Battery energy on deck: 9.7 kwhr

Plots

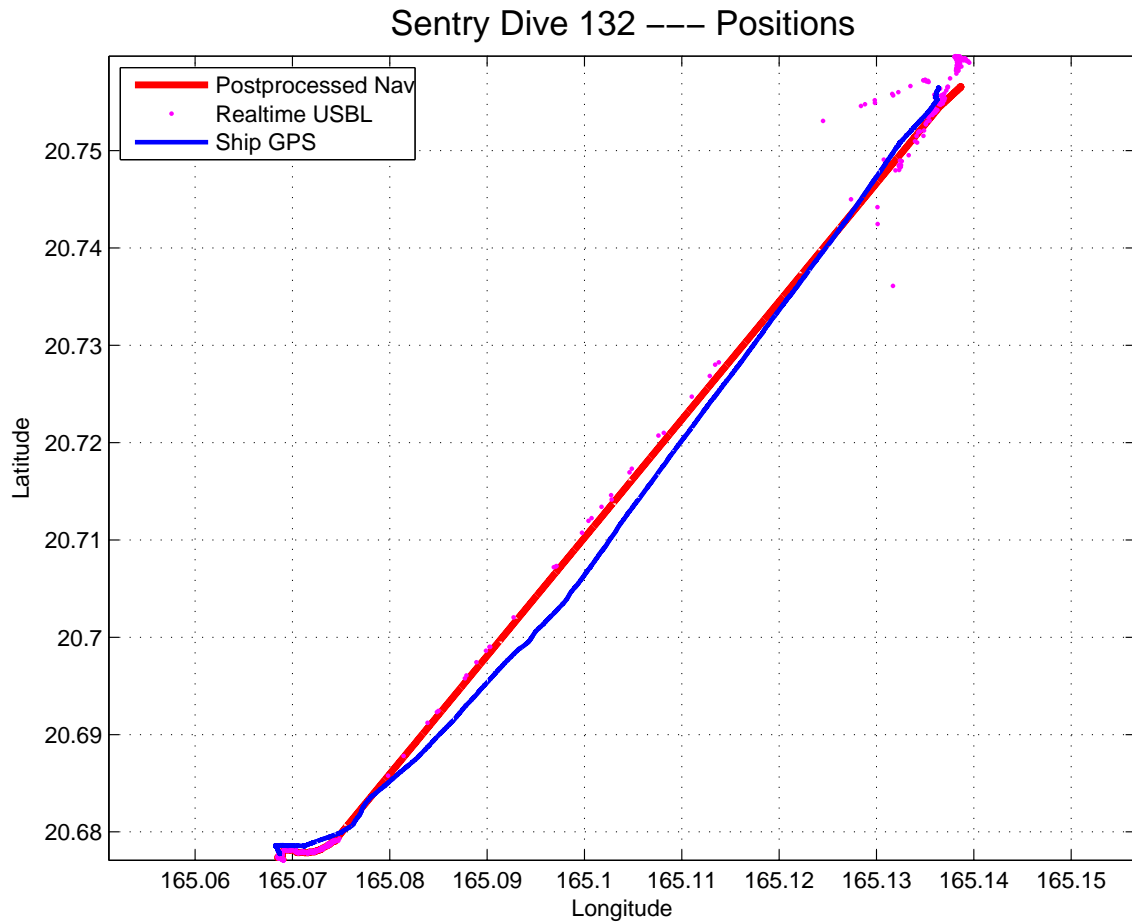


Figure 2: Latitude/Longitude plot of Sentry dive 132 with Realtime *Sentry* USBL, ship GPS, and *Sentry* post-processed positions.

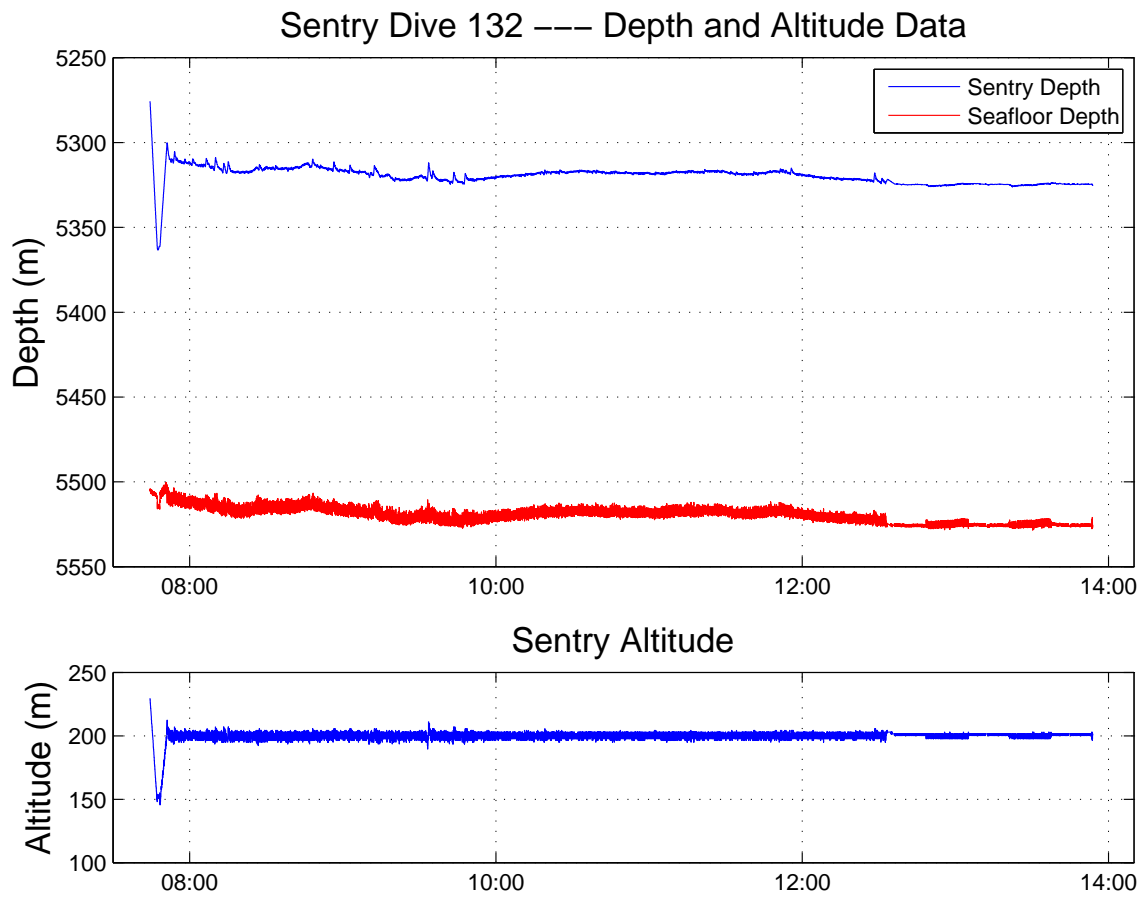


Figure 3: Depth and Altitude data for Sentry dive 132.

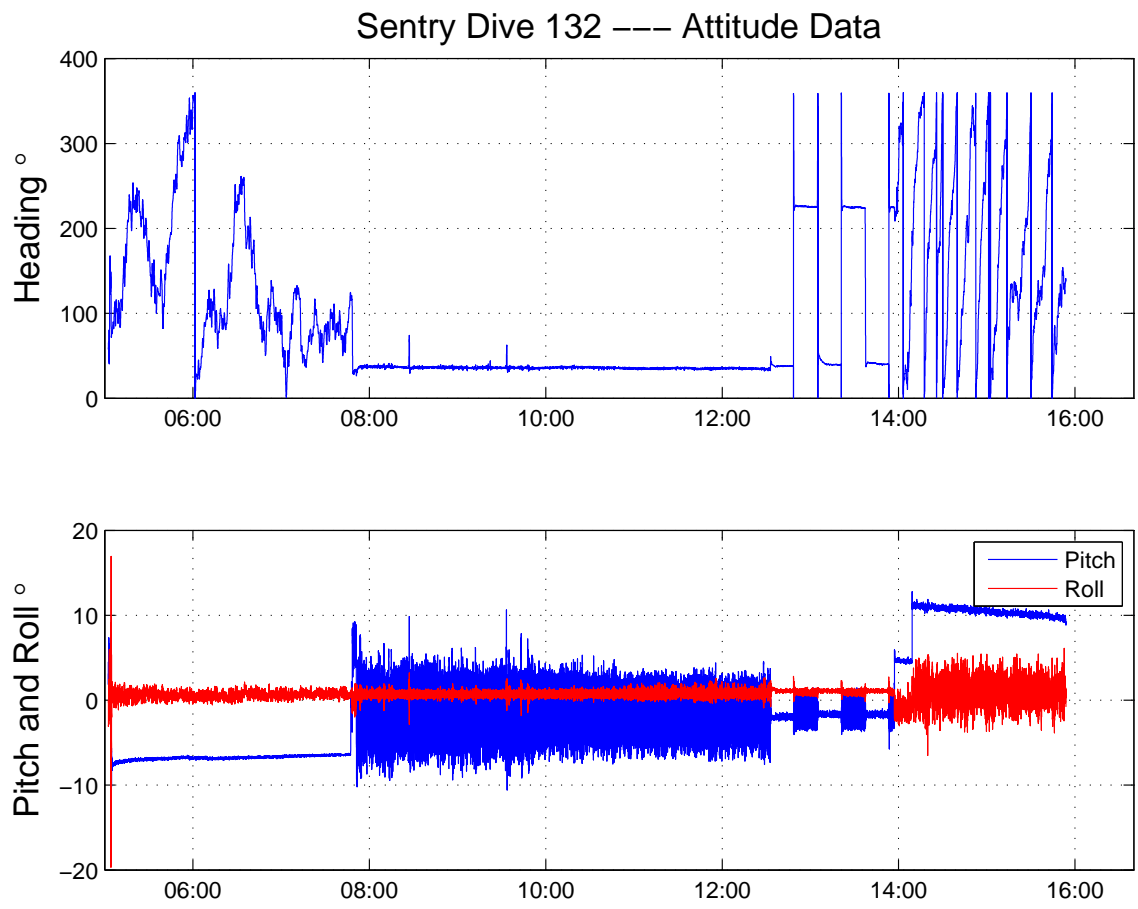


Figure 4: Heading, pitch, and roll data for Sentry132.

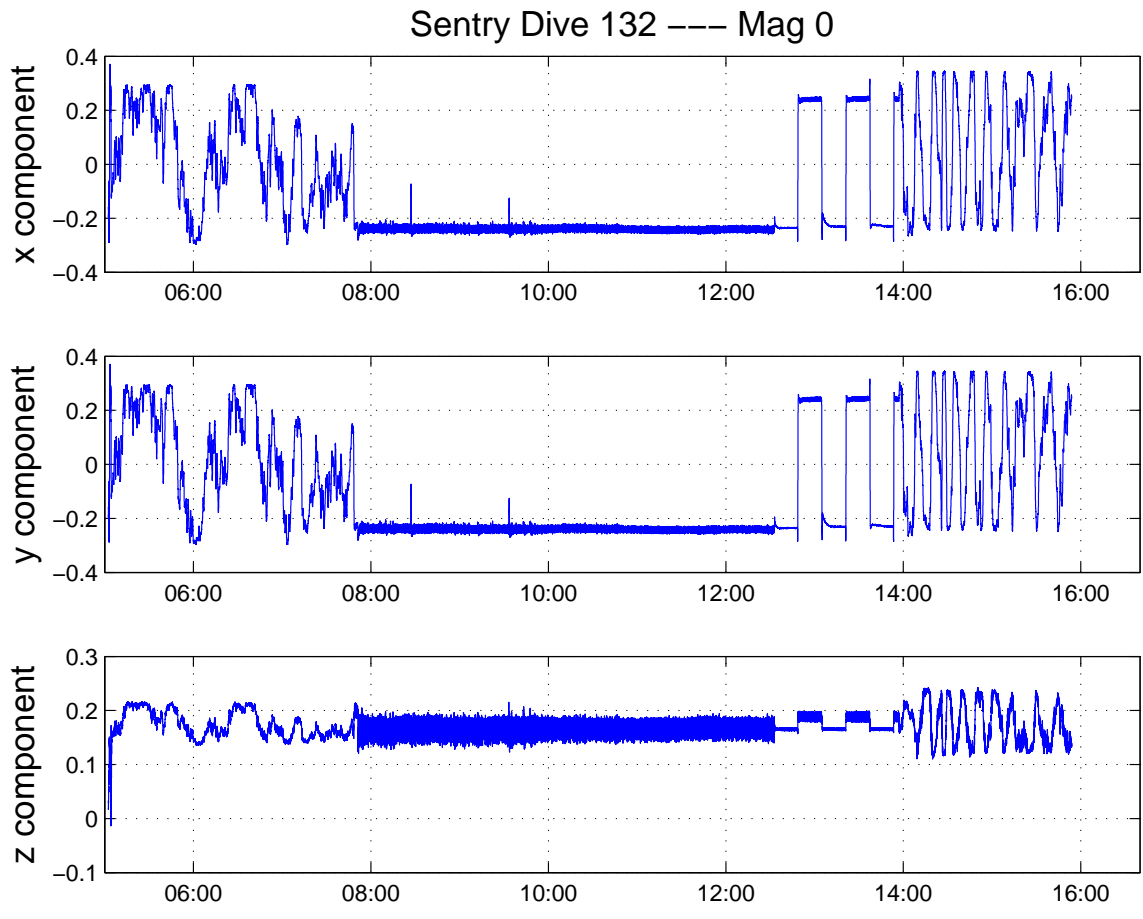


Figure 5: X,Y,Z magnetometer data for magnetometer 0 on Sentry132.

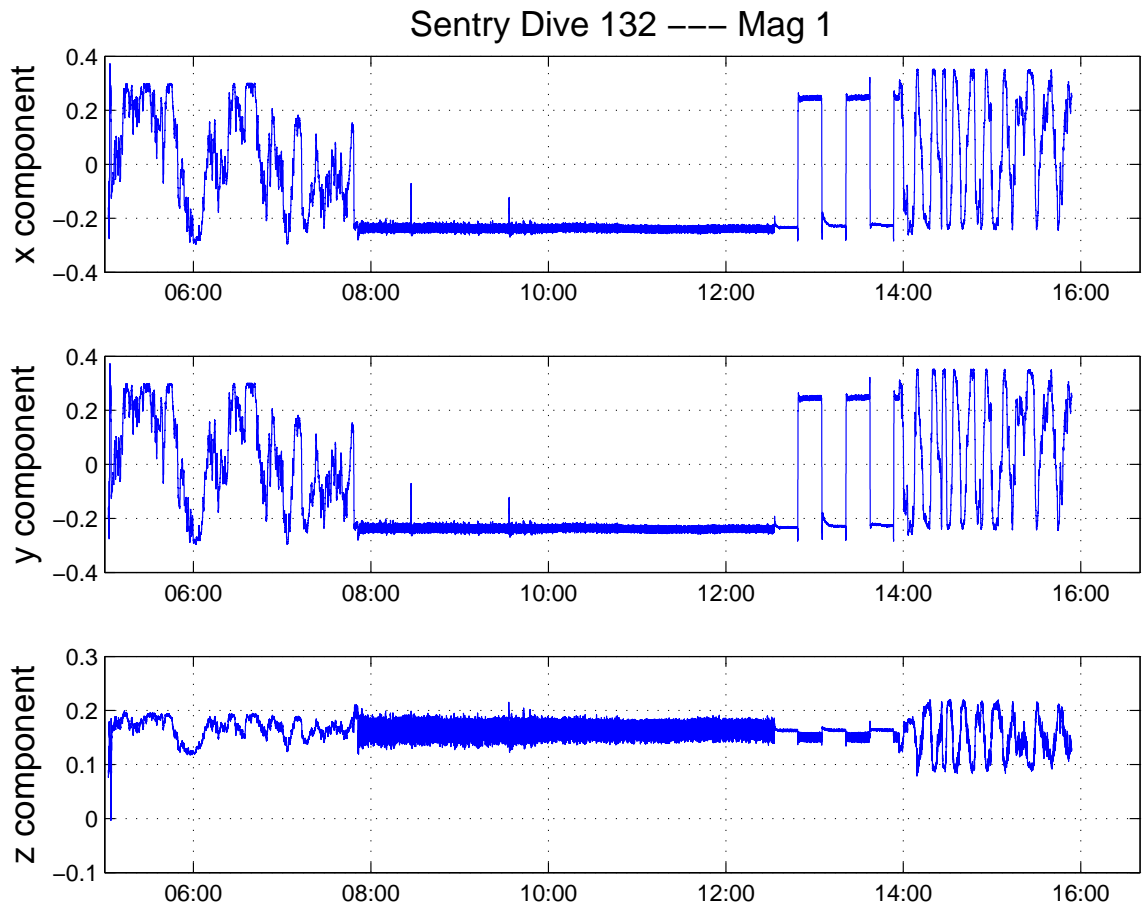


Figure 6: X,Y,Z magnetometer data for magnetometer 1 on Sentry132.

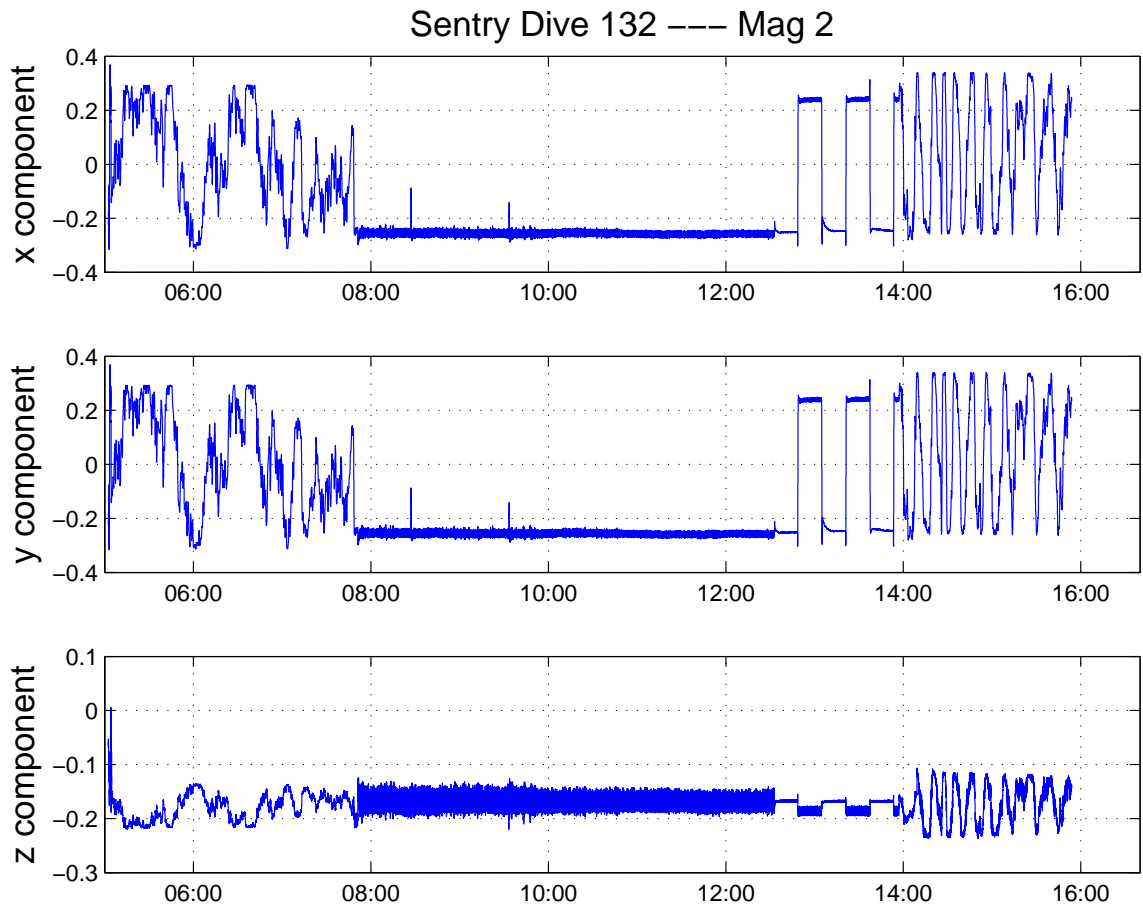


Figure 7: X,Y,Z magnetometer data for magnetometer 2 on Sentry132.

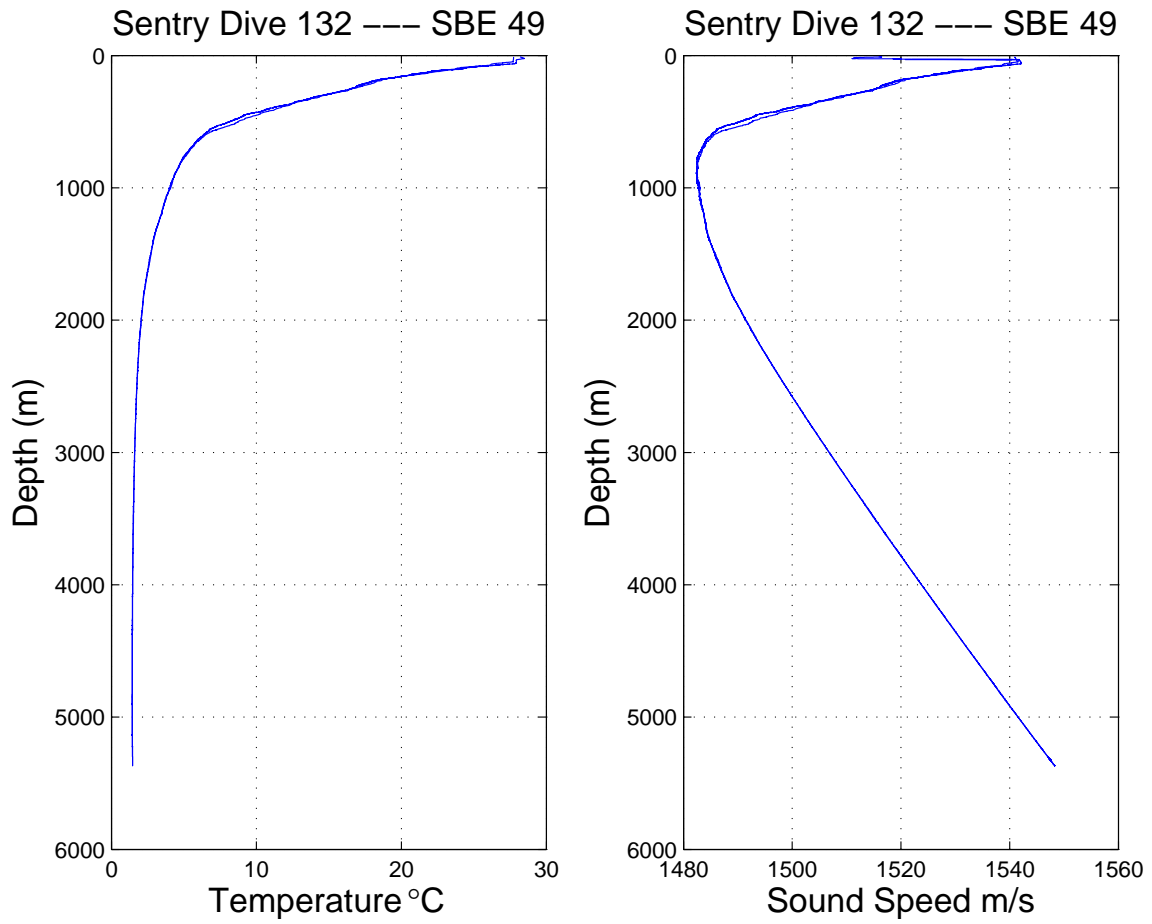


Figure 8: Sea temperature and sound velocity as measured by the Seabird 49 CTD on Sentry132.

Sentry 133 Dive Report

WHOI ABE/Sentry Operations Group

Dr. James C. Kinsey, Dr. Carl L. Kaiser, Andrew Billings, Justin Fujii, Stefano Suman,
and Korey Verhein.

Sentry Expedition Leader: Dr. James C. Kinsey

Chief Scientists: Dr. Masako Tominaga (WHOI) & Dr. Maurice Tivey (WHOI)

Summary

Magnetic survey at approximately 5000m with a planned distance of 60km. Dive was successful for the first 18 hours including good USBL tracking. 18 hours into the dive, XR1 received an acoustic abort command and initiated an abort. This is the first known occurrence in 355 *ABE/Sentry* dives of the XRs being acoustically “spoofed” into an abort.

Weather: Fair.

Reason for end of dive: Uninitiated acoustic abort of XR1.

Vehicle Configuration

The science sensing suite for this dive was:

Table 9: Sentry Sensor Configuration

Sensor
APS 1540 Magnetometers (3)
Edgetech 4-24kHz SBP
Nobska GCTD (fast response sensor)
Seabird SBE49 CTD
Seapoint OBS
Anderaa optode model 4330
300kHz RDI DVL

This dive was navigated using the DVL/INS system in realtime. USBL provided post-dive corrections. All final navigation tracks are the best effort interpretation of available data by skilled personnel.

Important Positions

Launch Position: 18 40.016'N, 163 2.246'E

Recovery Position: 18 51.693'N 163 13.157'E

Dive Origin: 18 40.000'N 163 2.250'E

Narrative

This dive was planned as a 60km straight trackline to obtain near-bottom magnetics in the **QJZ! (QJZ!)**. The expected duration was 33 hours. *Sentry* was launched on schedule at 12:17 local and descent went smoothly. The vehicle drifted a few hundred meters west during the first 2000m. After that it descended straight down, turning a number of times. Towcam was deployed at 1000m to a wireout of 4800m. Acomms was lost at 4500m; the round trip LBL at 3000m. We were able to sync the heartbeat LBL fix to the round-trip travel time during descent. This provided a reasonable estimate of the range to the vehicle for the remainder of the dive.

Sentry was observed to drop its weight and start driving NE up the line. The ship began moving with Towcam laying back behind it. USBL tracking was good although the deeper solution was often observed. A comparison of the shallow and deep solutions shows they differ by only 20m — sufficient for the navigation needs of this mission.

A few hours into the dive, the ship experienced problems with the dynamic positioning system resulting in the ship stopping and/or deviating from its course. DP was disengaged and the ship driven in auto-heading and manually for the remainder of the dive. This worked well.

Approximately 16 hours into the dive, Andy and James observed *Sentry* stopping and then rapidly ascending. The abort was because of an “fake” acoustic abort. This incident is discussed in more detail in Section E of the cruise report. Towcam was quickly recovered and *Sentry* was aboard within 25 minutes of surfacing. The forward tagline loop and the forward wing impacted the ship during recovery.

Issues

1. The cause of the accidental acoustic abort is not known. It was not initiated by us and the data suggests this was an erroneous triggering of the XR acoustic abort. A detailed discussion of this incident is in Section E of the cruise report.

Navigation Notes

USBL tracking was present throughout this dive. The descent and ascent were navigated using the USBL track smoothed with a low-pass filter. The survey portion of the dive uses a renavigated DVL track fused with the renavigated USBL track with a complementary filter. USBL position fixes with depths differing from the actual *Sentry* depth by more than 50m are eliminated and not used in the final navigation.

Chief Scientist Comments

Dive Statistics

0.2 Sentry133 Summary

Launch: 2011/12/07 01:17:50

Survey start: 2011/12/07 03:50:27

Survey end: 2011/12/07 17:03:54

Ascent begins: 2011/12/07 17:05:00

On the surface: 2011/12/07 18:58:22

On deck: 2011/12/07 19:20:35

descent rate: 33.0 m/min

ascent rate: 44.1 m/min

survey time: 13.2 hours

deck-to-deck time 18.0 hours

Mean survey depth: 5020m

Mean survey height: 200m

distance travelled: 29.76km

average speed; 0.59m/s

average speed during photo runs: 0.00 m/s over 0.00 km

average speed during multibeam runs: 0.59 m/s over 27.97 km

total vertical during survey: 5681m

Plots

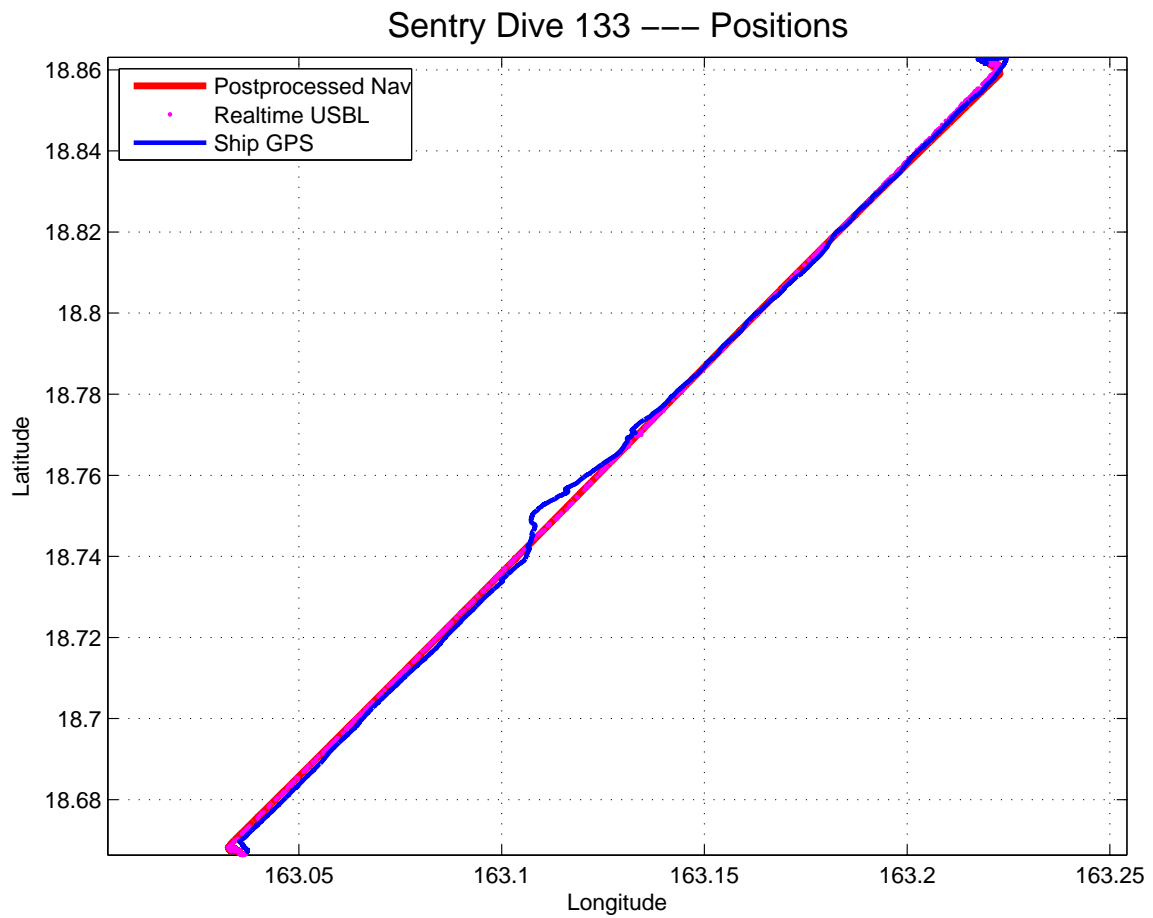


Figure 2: Latitude/Longitude plot of Sentry dive 133 with Realtime *Sentry* USBL, ship GPS, and *Sentry* post-processed positions.

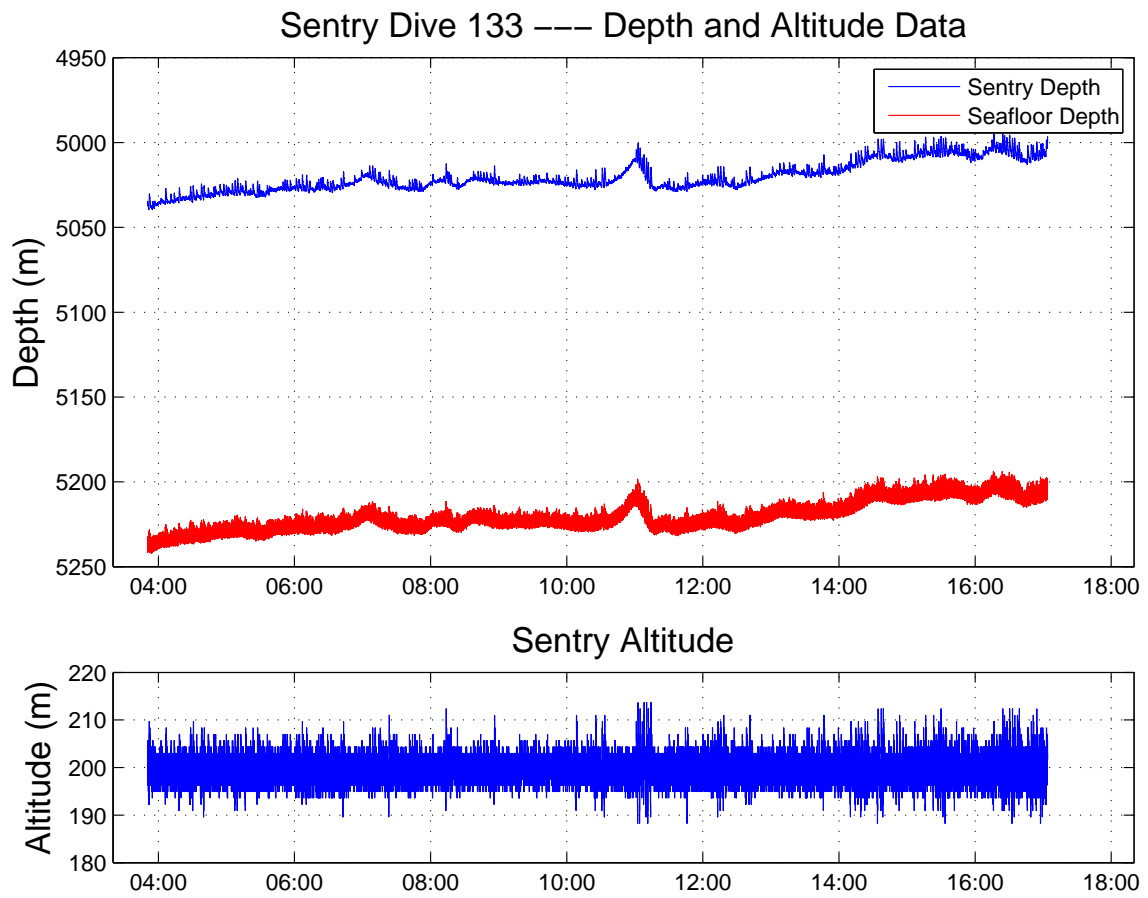


Figure 3: Depth and Altitude data for Sentry dive 133.

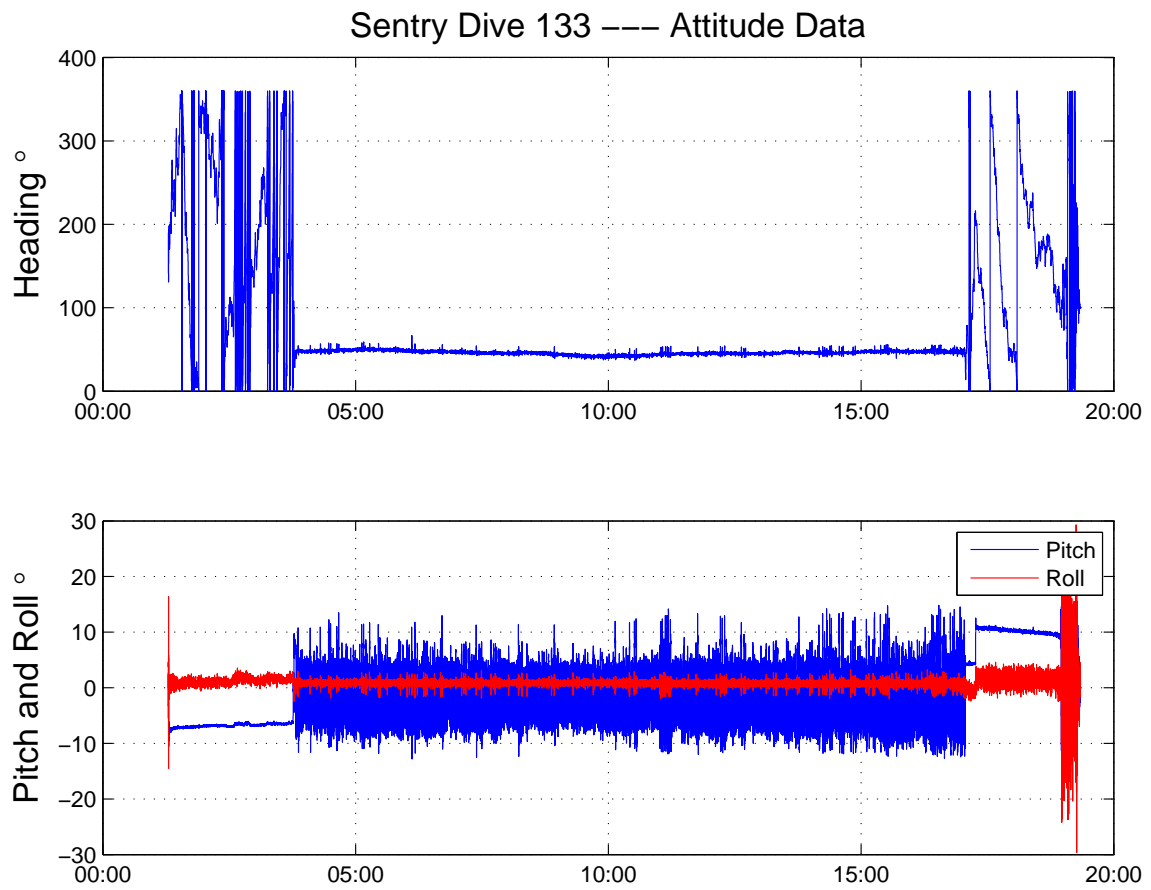


Figure 4: Heading, pitch, and roll data for Sentry133.

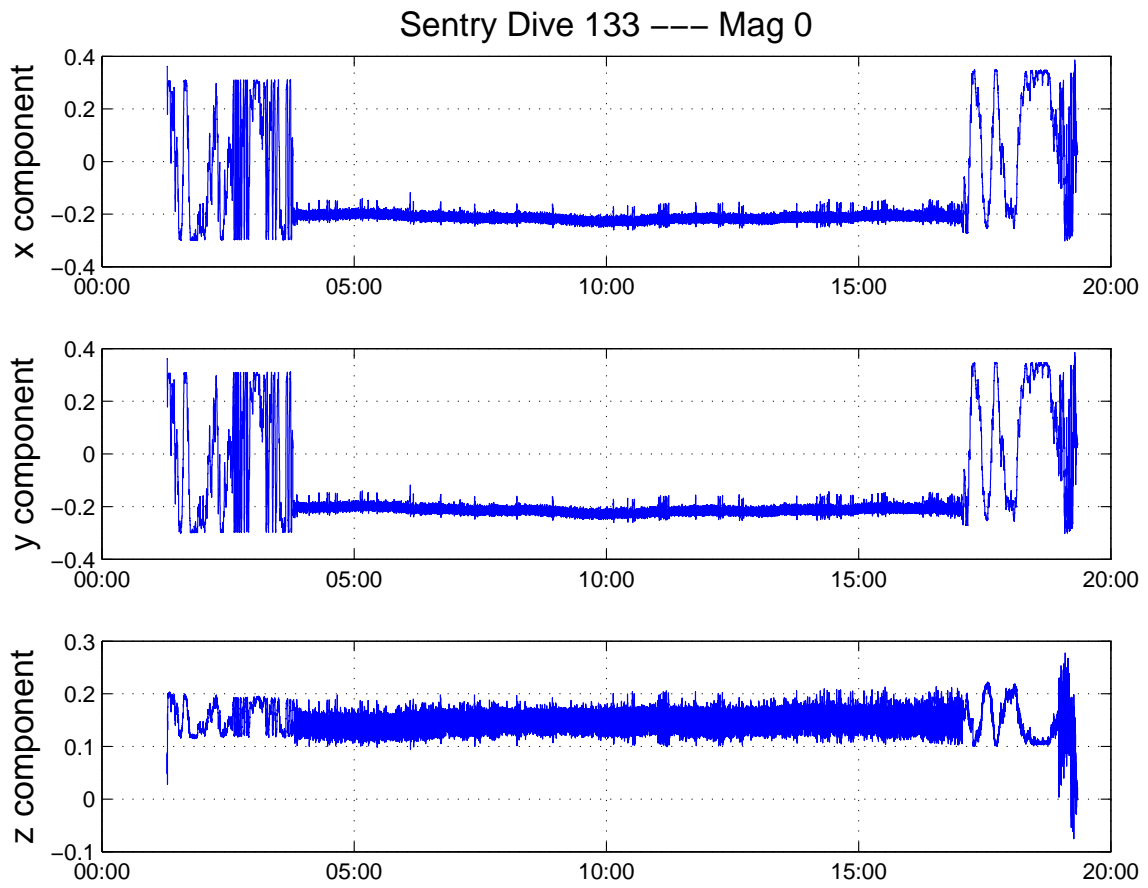


Figure 5: X,Y,Z magnetometer data for magnetometer 0 on Sentry133.

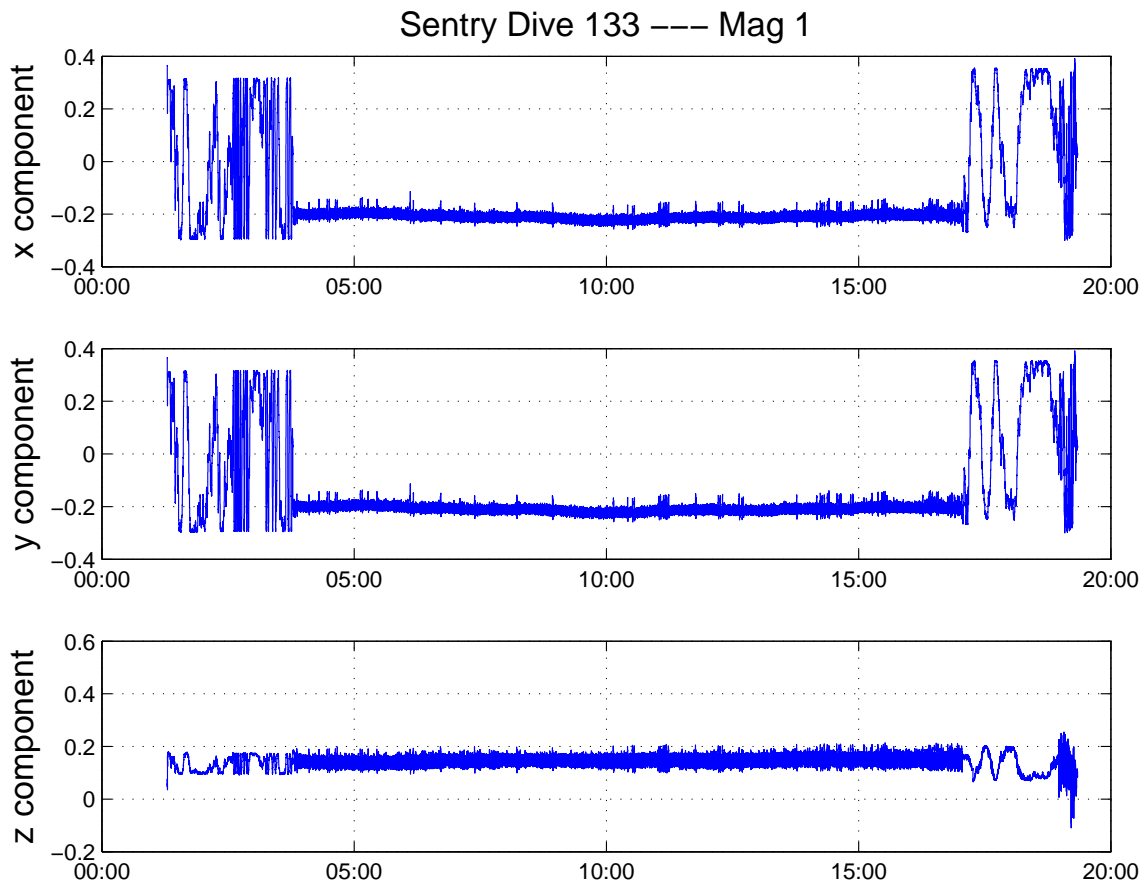


Figure 6: X,Y,Z magnetometer data for magnetometer 1 on Sentry133.

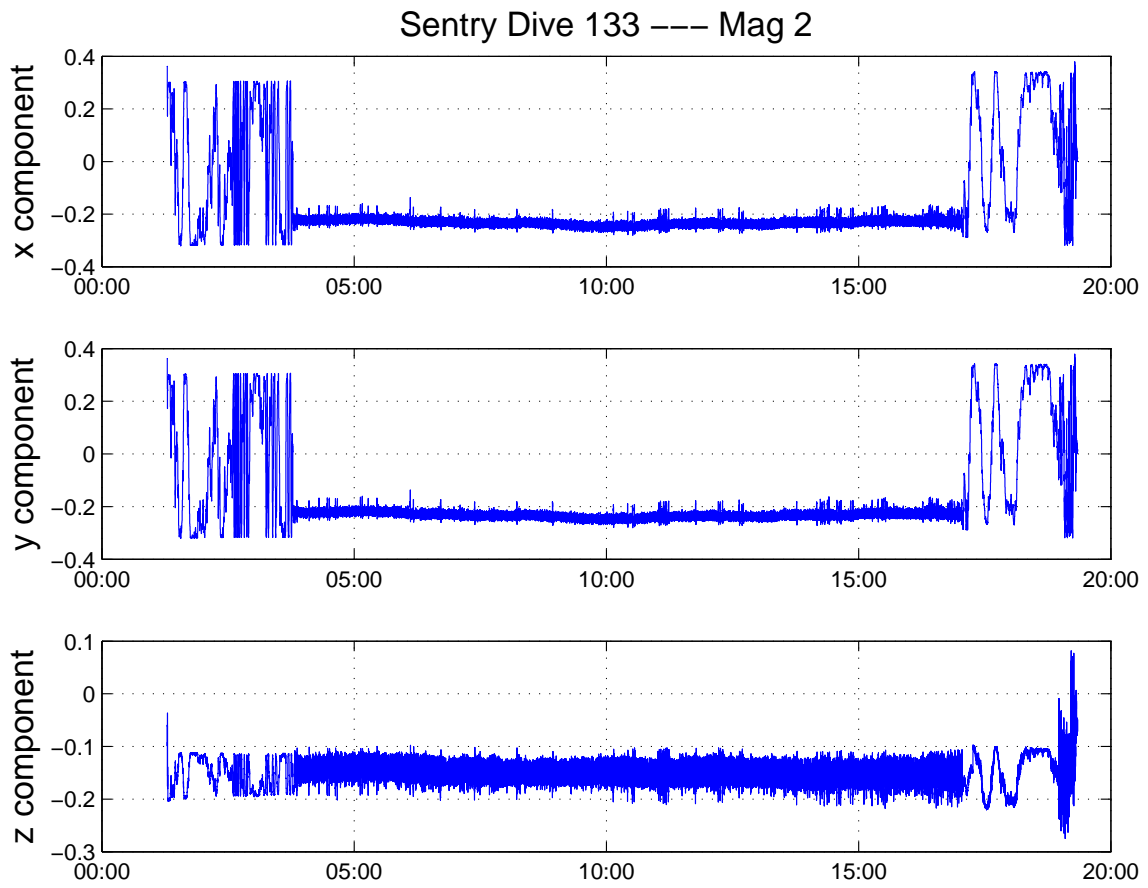


Figure 7: X,Y,Z magnetometer data for magnetometer 2 on Sentry133.

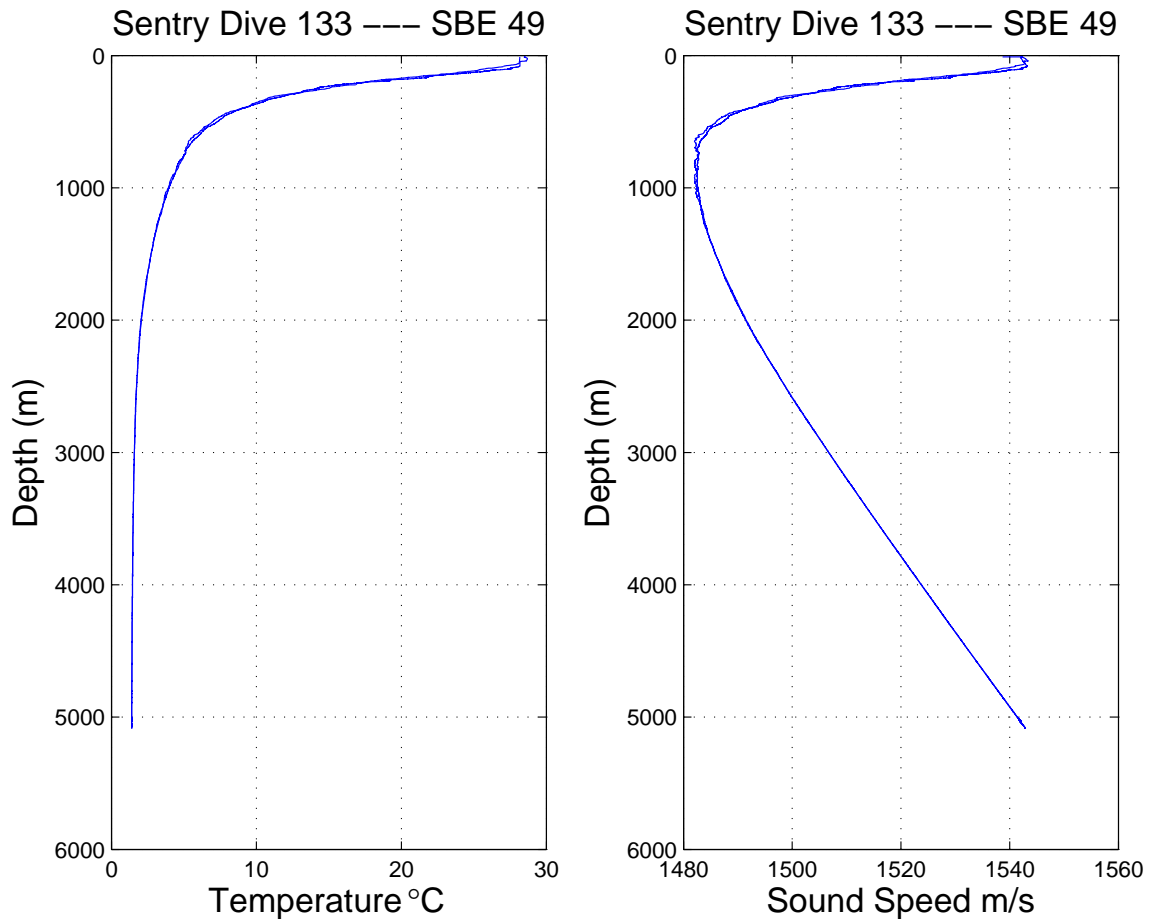


Figure 8: Sea temperature and sound velocity as measured by the Seabird 49 CTD on Sentry133.

Sentry 134 Dive Report

WHOI ABE/Sentry Operations Group

Dr. James C. Kinsey, Dr. Carl L. Kaiser, Andrew Billings, Justin Fujii, Stefano Suman,
and Korey Verhein.

Sentry Expedition Leader: Dr. James C. Kinsey

Chief Scientists: Dr. Masako Tominaga (WHOI) & Dr. Maurice Tivey (WHOI)

Summary

A science dive to approximately 5100m. Vehicle successfully completed a 62km transect.

Weather: Fair at the beginning of the dive. Weather deteriorated during the dive with 20-25knot winds on recovery and 10' swell.

Reason for end of dive: Acoustically aborted the vehicle (via the Sonardyne acoustic modem) at the end of the mission.

Vehicle Configuration

The science sensing suite for this dive was:

Table 10: Sentry Sensor Configuration

Sensor
APS 1540 Magnetometers (3)
Edgetech 4-24kHz SBP
Nobska GCTD (fast response sensor)
Seabird SBE49 CTD
Seapoint OBS
Anderaa optode model 4330
300kHz RDI DVL

This dive was navigated using the DVL/INS system in realtime. USBL provided post-dive corrections. All final navigation tracks are the best effort interpretation of available data by skilled personnel.

Important Positions

Launch Position: 18 15.998'N, 162 37.996'E
Recovery Position: 18 40.977'N 163 1.739'E
Dive Origin: 18 16.000'N 162 38.000'E

Narrative

This was a deep-water magnetic survey with a planned duration of approximately 34 hours. Launch went smoothly and the vehicle drifted only a few hundred meters during descent. Towcam was deployed as *Sentry* passed 1000m with an eventual wireout of 4500m. As in previous dives on this cruise, the round-trip LBL travel times were lost between 2000-3000m. The one way “heartbeat” travel time has heard throughout and was synced to the round-trip travel time during descent.

Bottom-approach the survey start were verified with both the USBL and LBL. The ship and *Sentry* began moving up the planned trackline. The ship-*Sentry* coordinated driving was excellent; only on one instance did we lose tracking of *Sentry* for more than 30 minutes.

Sentry reached the end of the trackline approximately 60 minutes early than planned. The USBL acoustic modem was used to abort the vehicle. This worked successfully. *Sentry* surfaced and was recovered with 40 minutes.

Issues and Proposed Solutions — No serious technical issues were identified on this dive.

Navigation Notes

USBL tracking was present throughout this dive. The descent and ascent were navigated using the USBL track smoothed with a low-pass filter. The survey portion of the dive uses a re-navigated DVL track fused with the re-navigated USBL track with a complementary filter. USBL position fixes with depths differing from the actual *Sentry* depth by more than 50m are eliminated and not used in the final navigation.

Chief Scientist Comments

Dive Statistics

0.3 Sentry134 Summary

Launch: 2011/12/08 23:14:06
Survey start: 2011/12/09 01:45:04
Survey end: 2011/12/10 06:05:44
Ascent begins: 2011/12/10 06:05:44
On the surface: 2011/12/10 08:03:31
On deck: 2011/12/10 08:39:02
descent rate: 34.3 m/min
ascent rate: 42.7 m/min
survey time: 28.3 hours

deck-to-deck time 33.4 hours
Mean survey depth: 5112m
Mean survey height: 199m
distance travelled: 62.98km
average speed; 0.58m/s
average speed during photo runs: 0.00 m/s over 0.00 km
average speed during multibeam runs: 0.58 m/s over 59.61 km
total vertical during survey: 12748m
Battery energy at launch: 14.0 kwhr
Battery energy at survey end: 1.8 kwhr
Battery energy on deck: 1.5 kwhr

Plots

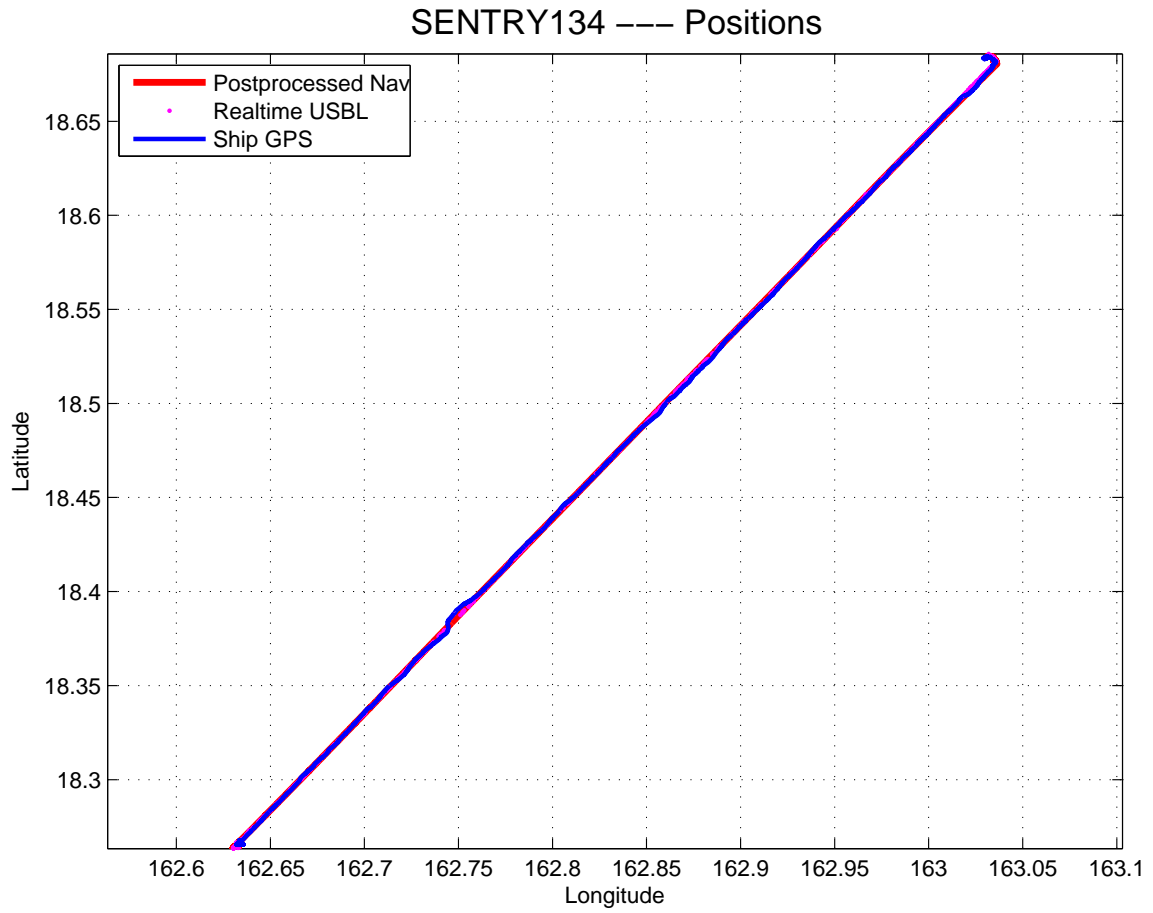


Figure 2: Latitude/Longitude plot of Sentry dive 134 with Realtime *Sentry* USBL, ship GPS, and *Sentry* post-processed positions.

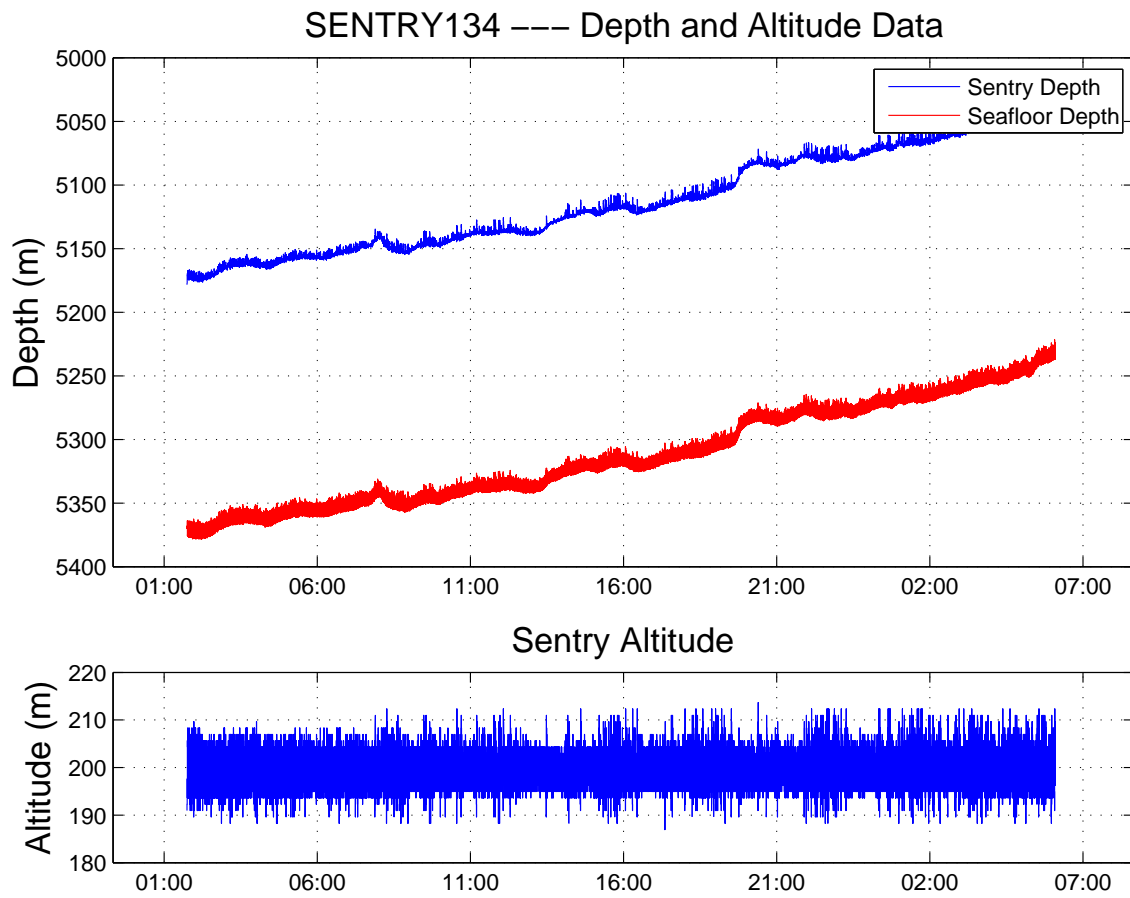


Figure 3: Depth and Altitude data for Sentry dive 134.

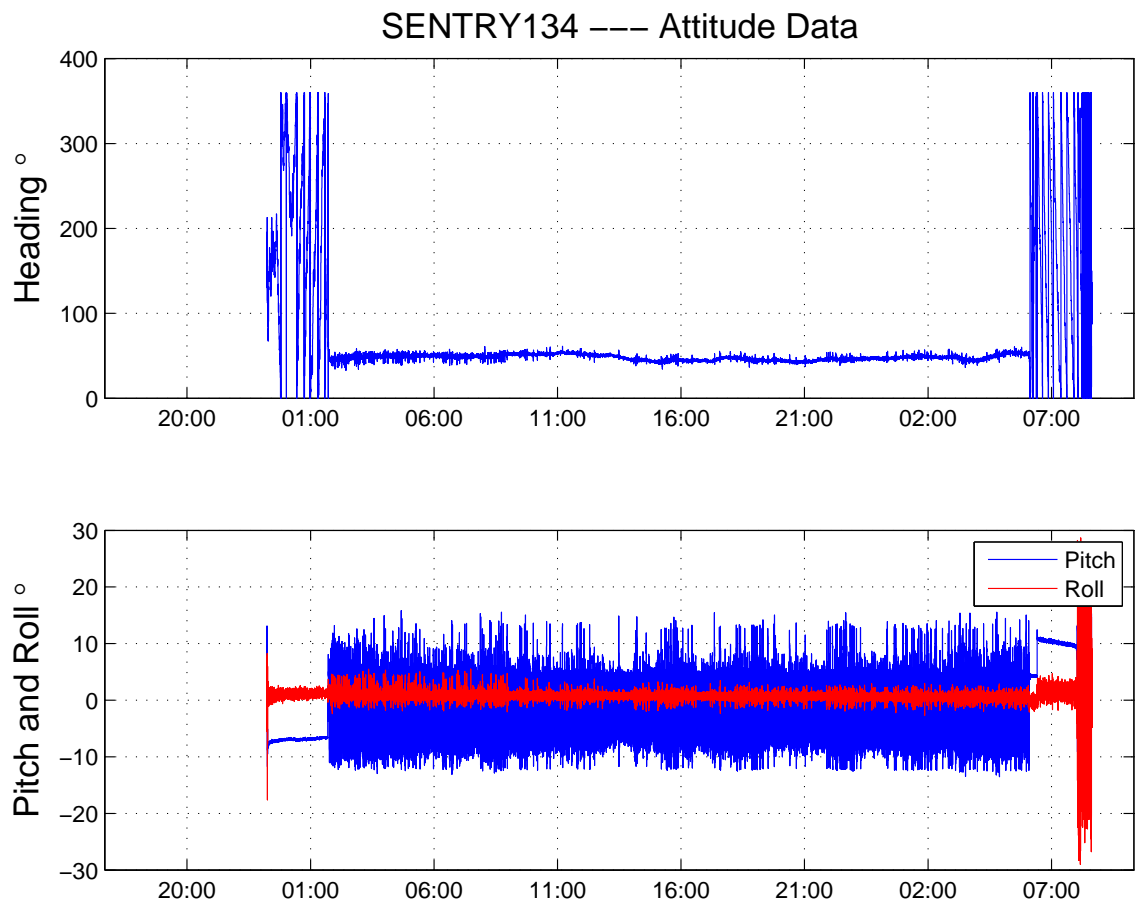


Figure 4: Heading, pitch, and roll data for Sentry134.

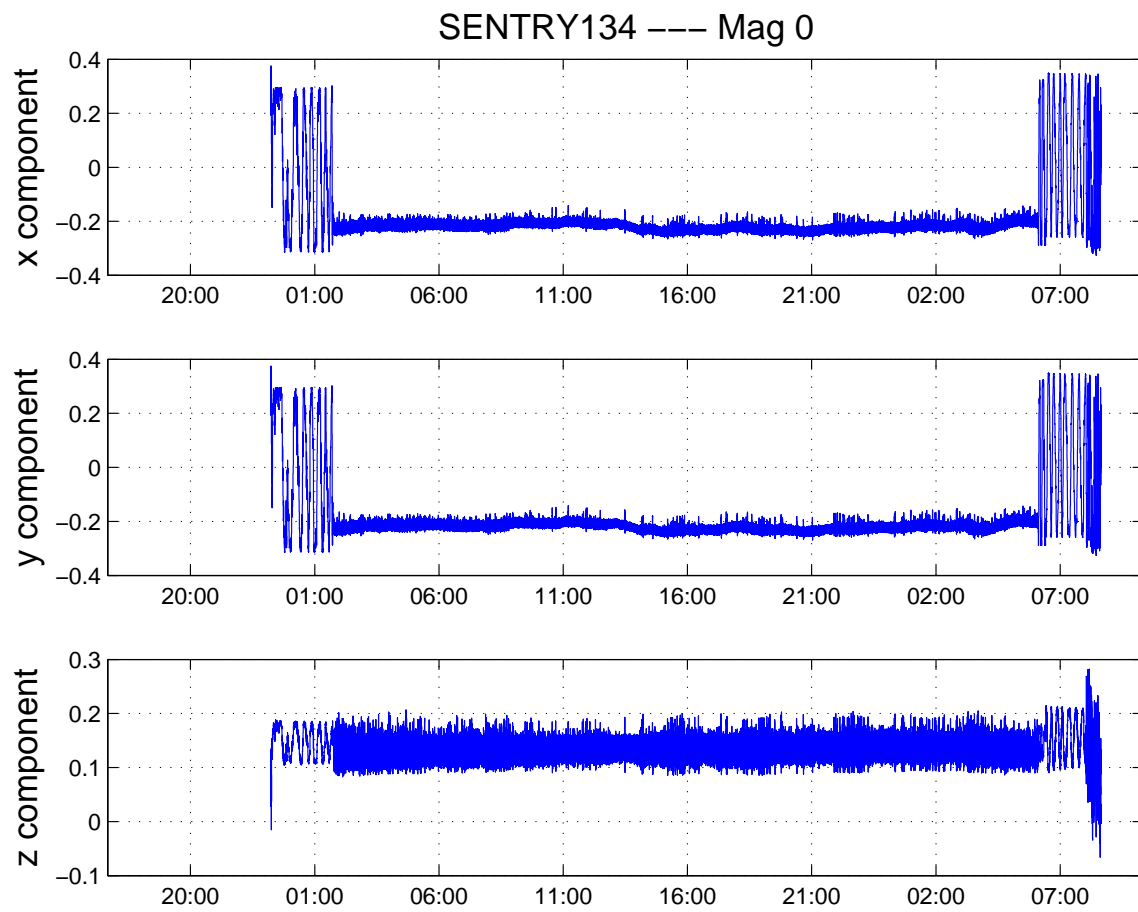


Figure 5: X,Y,Z magnetometer data for magnetometer 0 on Sentry134.

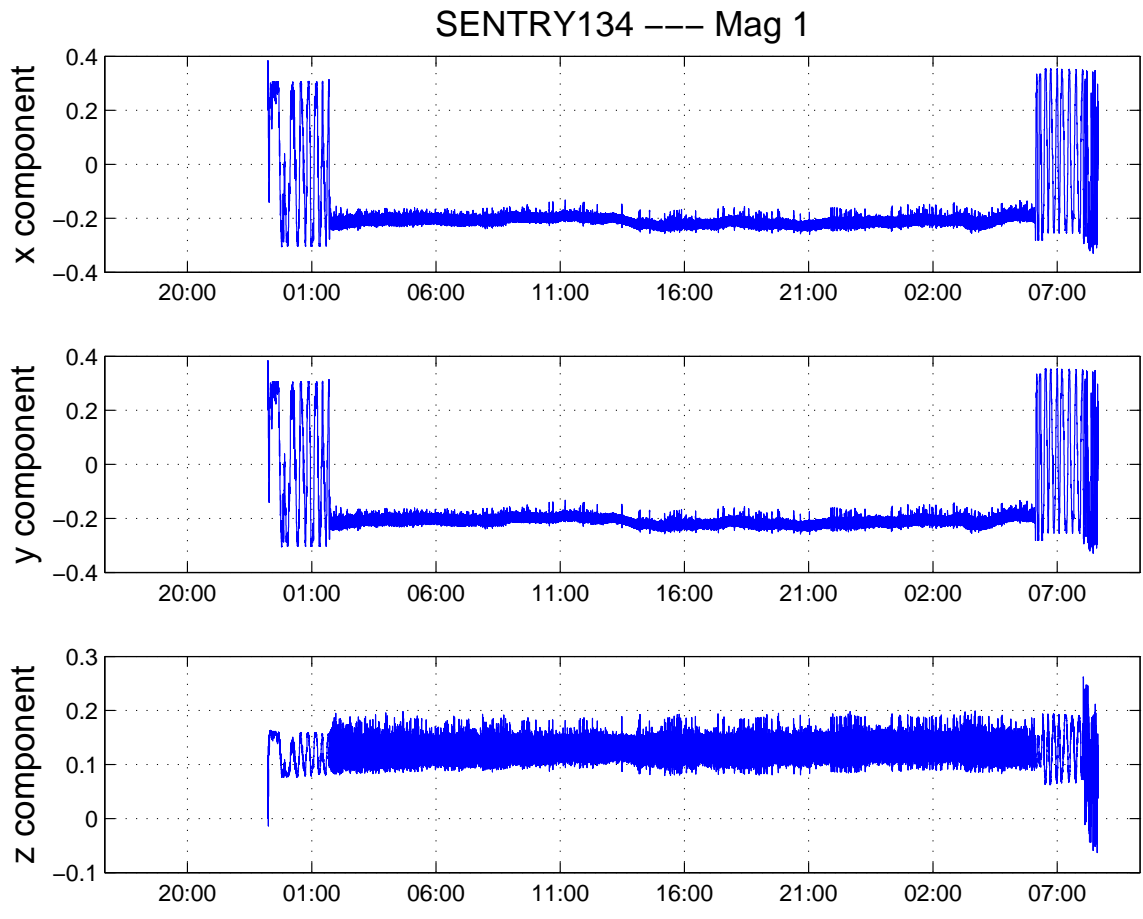


Figure 6: X,Y,Z magnetometer data for magnetometer 1 on Sentry134.

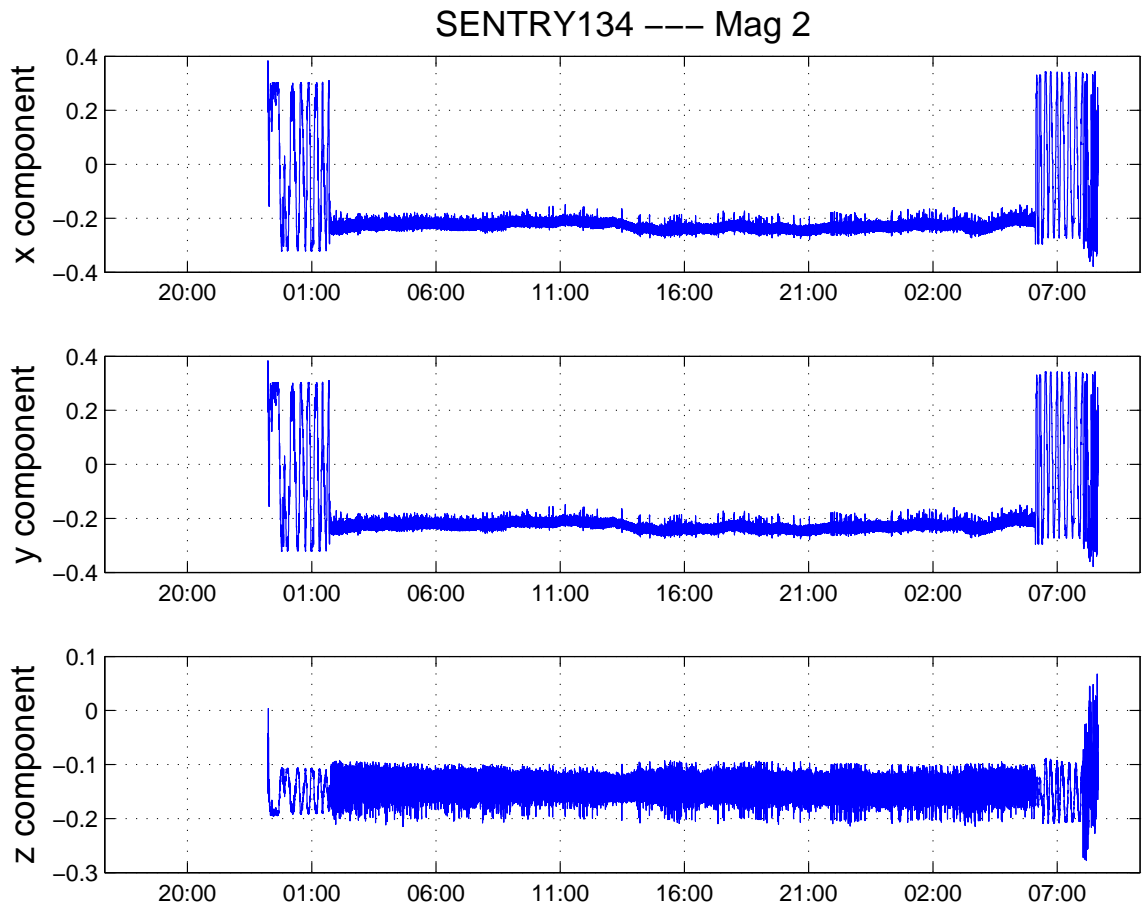


Figure 7: X,Y,Z magnetometer data for magnetometer 2 on Sentry134.

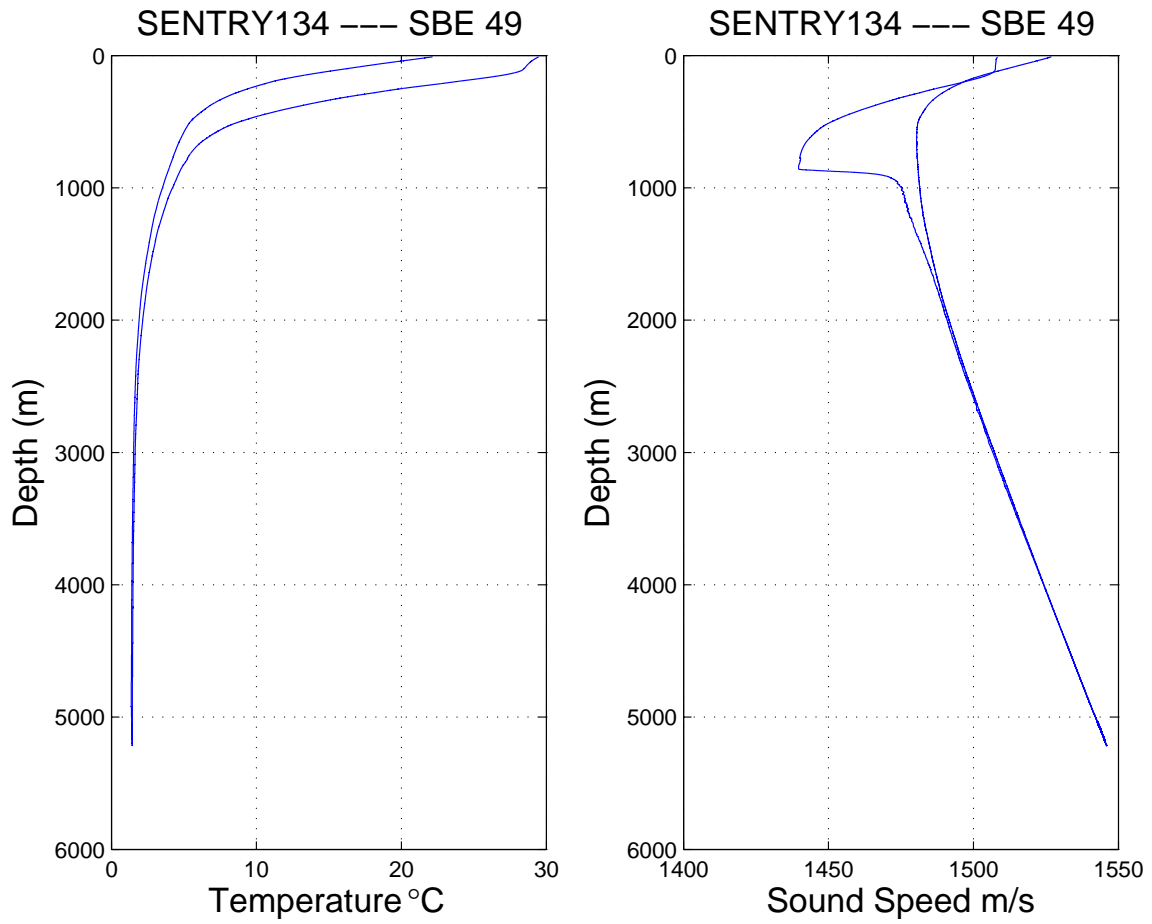


Figure 8: Sea temperature and sound velocity as measured by the Seabird 49 CTD on Sentry134.

A Tracking Issues

This cruise posed two challenges with respect to topside tracking (1) the site depths (greater than 5000m) pushed the limits of our USBL system and (2) the long distances required to achieve the science objectives precluded using LBL transponders. This issue was identified prior to the cruise and additional measures taken including outfitting Towcam with relay LBL beacons. In addition, we had previously used USBL with both *Nereus* and *Jason* at depths up to 5200m successfully and saw no reason why it wouldn't work on this cruise.

On early dives, in which the vehicle depth exceeded 5700m, we were unable to track *Sentry* with USBL once it passed a certain depth. On dives 127 and 128 this depth was approximately 4400m. Changes in the Avtrak parameters increased this range to approximately 5700m on dive 129. Tracking was possible via the *Sentry* initiated LBL ping both directly and via a relay beacon on Towcam. This provided a single one-way range. Round-trip ranges initiated by the ship were present during ascent and descent however *once Sentry passed approximately 4400m these pings were absent.*

Between dives 128 and 129, the spare Avtrak was installed on Towcam. This provided us with both an acoustic link to the vehicle (neither WHOI or Sonardyne's acommms worked past 4400m) and a round-trip range from Towcam to *Sentry*. This improved our ability to track *Sentry* in the early stages of dive 129. Unfortunately the spare Avtrak had to be placed on *Sentry* after the primary Avtrak was destroyed during the recovery from dive 131.

During later dives, *Sentry* operated between 5000 and 5400m. USBL tracking was present on later dives provided the surface vessel remained within a few hundred meters of *Sentry*. This was a sustainable but fragile operations mode — i.e., if the ship or *Sentry* deviated from their planned tracks then topside tracking was lost. The vehicle initiated LBL pings were sync'd during descent and this provided an additional but primitive means of tracking. In addition, the vehicle-initiated pings could be seen on the ship's Knudsen transducer display. Overall this topside tracking mode worked but it was fragile especially given the actuator problems that had occurred earlier in the cruise.

A.1 LBL Frequency Acoustics

Tracking *Sentry* with LBL frequency acoustics was difficult on this cruise. Two ping cycles were used:

Vehicle Initiated Cycle — This cycle originated at the LBL transducer on *Sentry* and transmitted a ping every 10sec. Early in the cruise we pinged at 14.5kHz. Later in the cruise we alternated pings at 14.5 and 11.0 kHz using the “!N” command in WiffleNav. These pings could be heard by both the ship and the relay beacon on Towcam. An analysis of the ranges on dive 128 show that both Towcam and the ship could hear *Sentry* at distances up to 7km (JCK needs to verify).

While these pings provided a “heartbeat” — i.e., told us that *Sentry* was within a few kilometers of the ship — it was difficult to synchronize the topside and subsea LBL. This prevented us from being able to accurately estimate the range between *Sentry* and the ship. The existing hardware synchronization was used along with a crude software synchronization. The synchronization process needs to be made more robust and simple to use.

Ship Initiated Cycle — This cycle, in which the ship pings *Sentry* and *Sentry* responds, did not work past depths of 4400m. An LBL ducer on the ship would ping at 10.5kHz with XR2 responding at a preset frequency (this was manually changed a number of times during the cruise). This cycle, which

has worked fine on previous cruises, only worked at depths less than ???m. On later dives, the LBL transducer on *Sentry* was set to listen on 10.5kHz. Figures 1 and 2 show the travel times received on the 10.5kHz frequencies by the *Sentry* LBL transducer. Figure 1 shows that the 10.5kHz signal reached *Sentry* throughout the dive and, in consequence, the problem is not the interrogating ping reaching *Sentry*. Instead likely reasons include: (1) the XRs are not hearing the interrogating ping; (2) the responding ping from the XRs are not transmitting sufficient power to reach the ship; and/or (3) ship noise prevented the responding ping from being heard. While the last reason is possible, it is important to remember that the vehicle-initiated pings could be heard at the ship.

After the cruise a number of tests were identified that should be consider for future cruises:

1. One of the receive channels on the *Sentry* LBL transducer should be set to the ping frequency of the XR primarily used for the ship-*Sentry*-ship cycle to verify the return ping is being transmitted.
2. The number of pings received by the XRs is stored internally and can be queried. This command should be added to the GRD SAIL table in the roV code.
3. Modifications to the topside WiffleNav LBL would allow us to have an analog output similar to that provided by the ship's Knudsen display we used on the cruise. Al Bradley can provide more information.

A.2 USBL Navigation

USBL tracking was difficult throughout the cruise. When operating at depths greater than 5700m, USBL tracking was non-existent and posed a major obstacle to operations at these depths. At slightly shallower depths (e.g., 5000 to 5500m), we did have USBL tracking but were seeing bounces in the USBL positions. This “bounce” problem was not an obstacle to operations but needs to be understood.

A.2.1 USBL Performance at Depths Exceeding 5700m

Figure 3 shows SNR and cross-correlation (XC) as measured by the Avtrak on *Sentry* from the descents for *Sentry* 128 and 129. Both dives were to 5800m. The ship was offset 500m from the vehicle position so slant range is effectively the vehicle is the depth. On *Sentry* 128 we used the default LG (rx gain) and NPL (navigation power level) settings on the Avtrak. Carl Kaiser spoke with Sdyne between dives and based on that convo we increased the LG and NPL to the max for *Sentry* 129. Values are in the plot title. These are the same values we used with *Nereus* in the Cayman Trough in 2009. These increases gained us 1000m extra depth.

Stefano Suman recorded the topside SNR for the last 1000m of *Sentry* 129 — the magenta crosses at 30dB show the ship measured dB. Even with *Sentry* at 5000+m, the ship is getting returns with good SNRs provided *Sentry* can hear the original interrogation and reply.

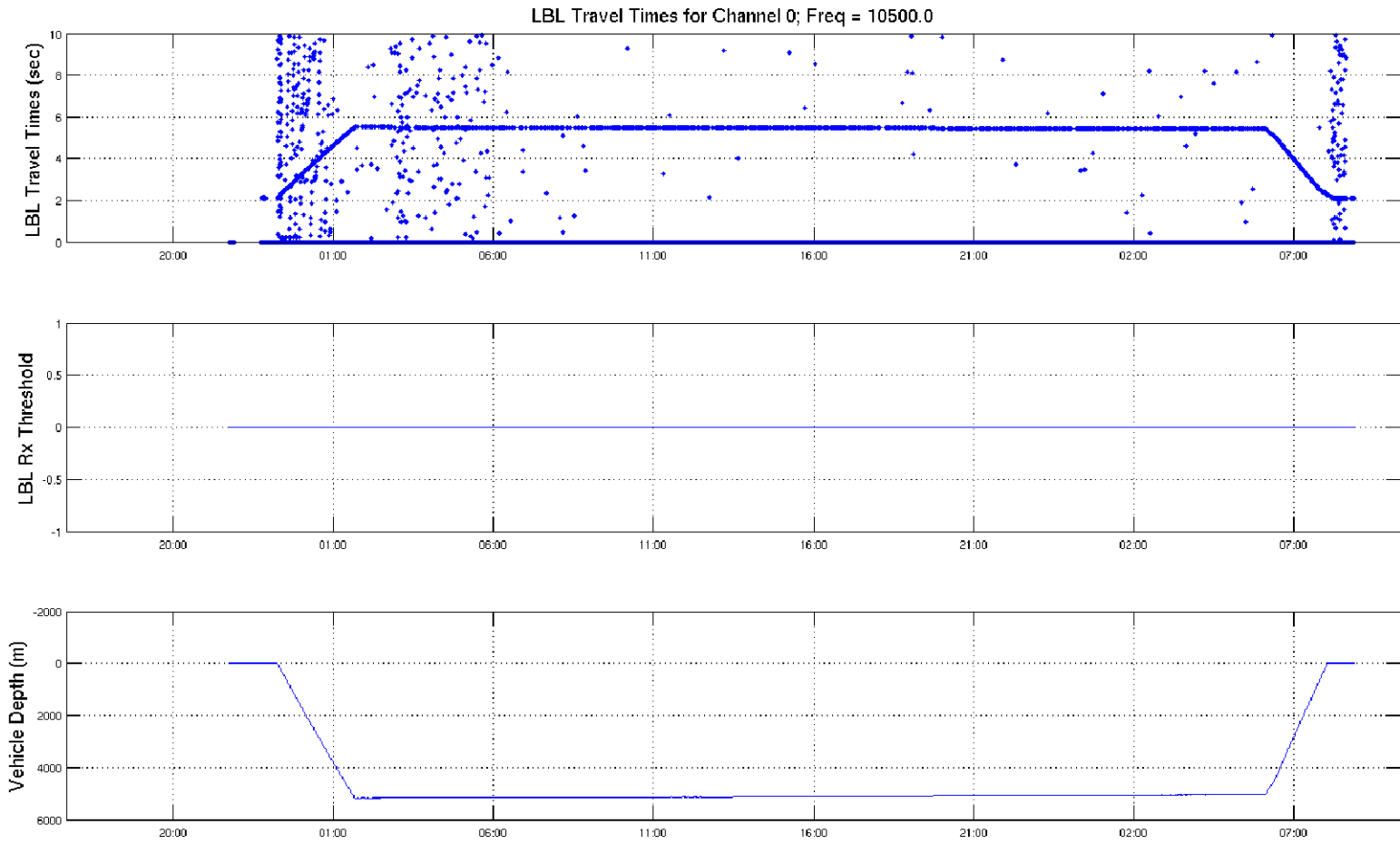
Our ops on *Sentry* dives 127-129 have been at 6000 to 5800m depth which has placed us just out of range of USBL. Dives later in the cruise were between 5100 and 5400m which based on these plots are just inside the operating range and during these dives we were able to track *Sentry* (albeit poorly; see next section).

A.2.2 USBL Performance between 5000 and 5700m

During later dives, *Sentry* operated between 5000 and 5400m. USBL tracking was present on later dives provided the surface vessel remained within a few hundred meters of *Sentry*. During these later dives,

the USBL measured depth could differ from the actual vehicle depth by 100m (Figure 4). This behavior was observed numerous times including on ascent and descent. Simple analysis of “deep” and “shallow” solutions that arrived within 30sec of each other showed that the horizontal positions differed by only 20-40m — sufficient for our operations.

Overall this problem is minor — the “deep” solution is within 2% of the actual vehicle depth. Still this is a systematic error that requires follow up with Sonardyne.



4

Figure 1: *Top plot:* LBL travel times received by Channel 0 on the *Sentry* LBL transducer for the 10.5kHz frequency during *Sentry* dive 134. During this dive, the ship interrogated at 10.5kHz throughout the dive. This plot shows that the 10.5 pings were reaching *Sentry* . *Middle plot:* Ignore; the gain was set to 18hex throughout the dive. *Bottom plot:* Vehicle depth.

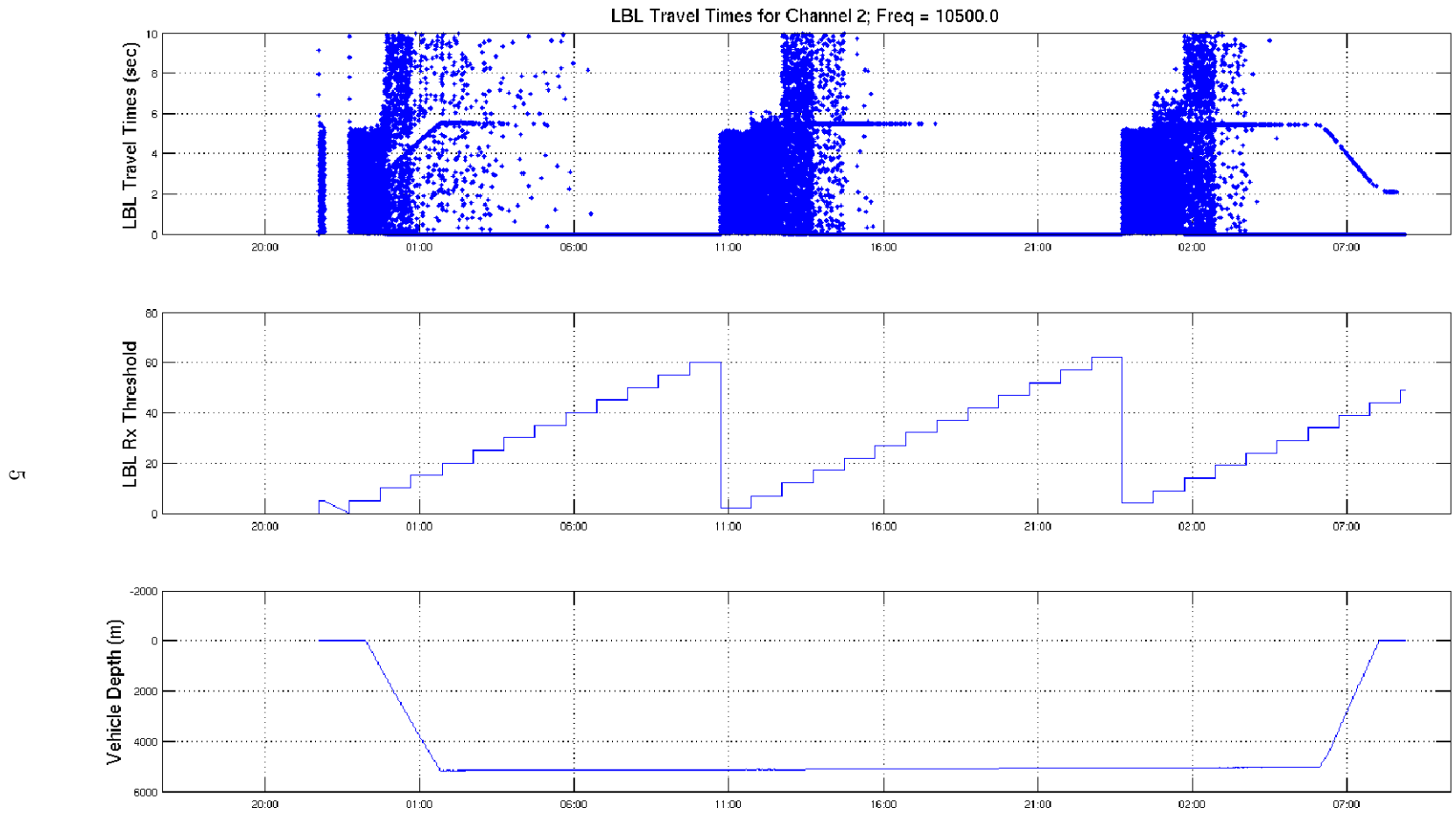


Figure 2: *Top plot:* LBL travel times received by Channel 1 on the *Sentry* LBL transducer for the 10.5kHz frequency during *Sentry* dive 134. During this dive, the ship interrogated at 10.5kHz throughout the dive. This plot shows that the 10.5 pings were reaching *Sentry* when the gain was appropriately set. *Middle plot:* LBL receive gains during the dive. *Bottom plot:* Vehicle depth.

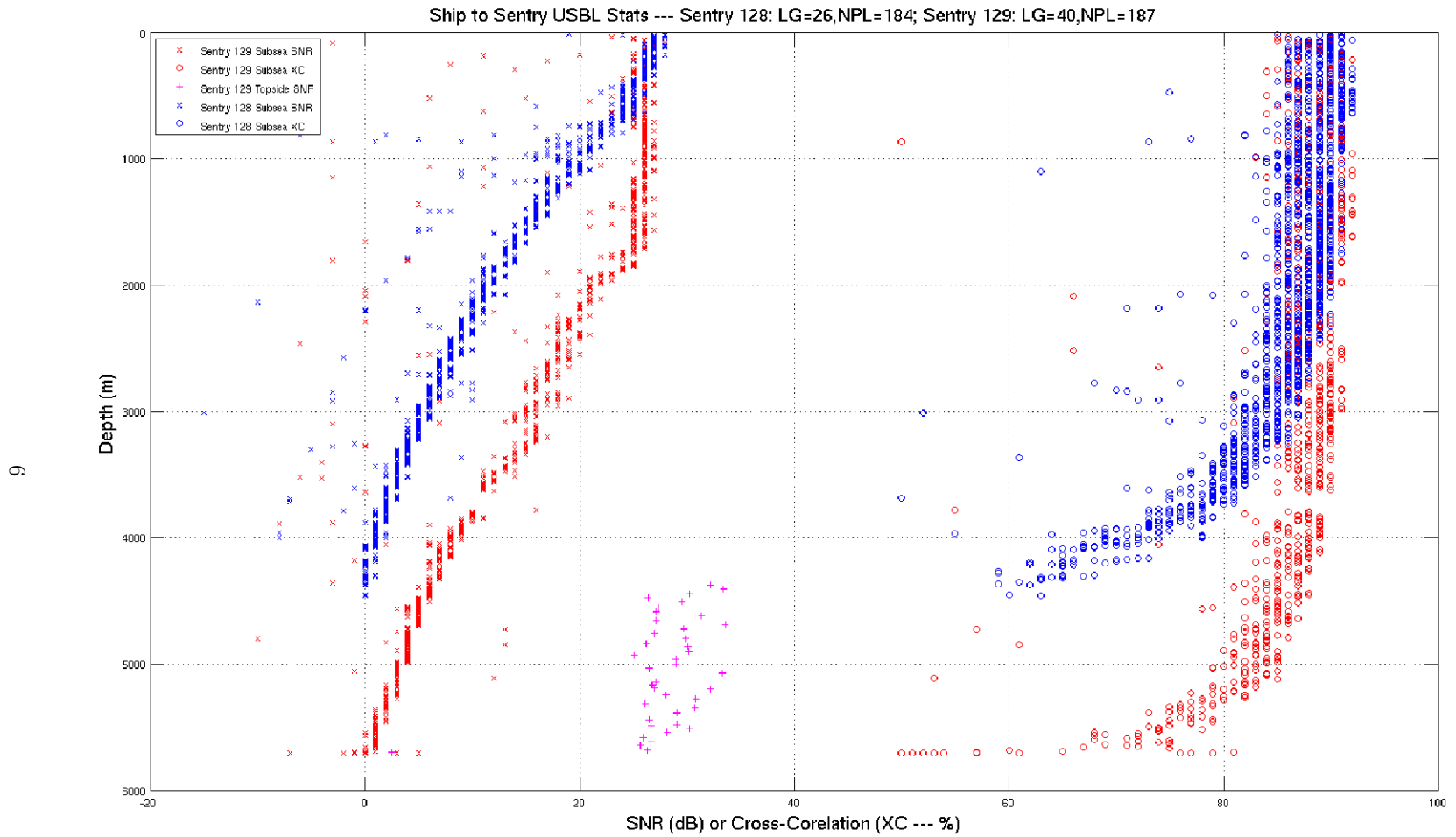


Figure 3: USBL SNR and Cross-Correlation as measured by the Avtrak on *Sentry* on dives 128 (blue) and 129 (red). The LG and NPL setting were increased to their max settings on dive 129. Even at maximum settings, the SNR goes to 0 around 5700m. This is the same depth at which USBL tracking was lost.

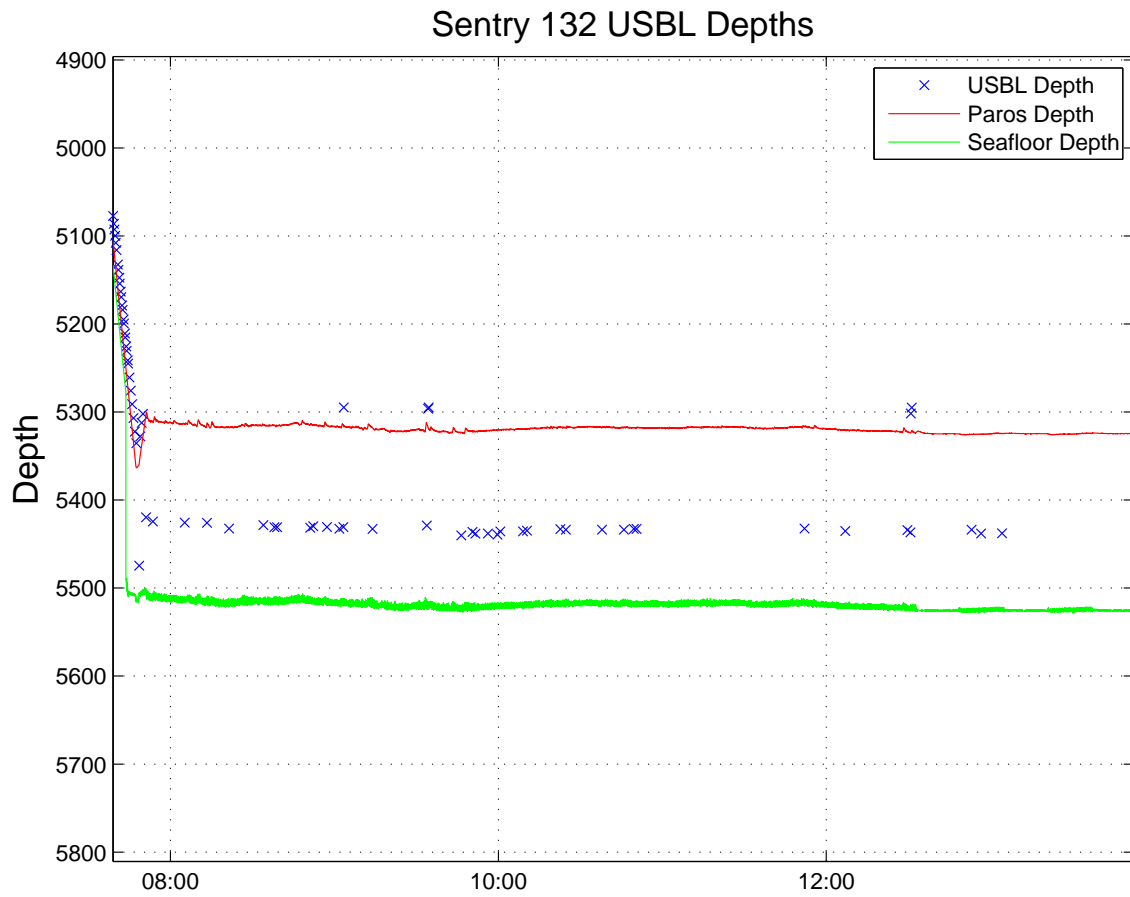


Figure 4: Depths of *Sentry* as measured by the USBL and pressure depth sensor for a portion of dive 134. Many of the USBL fixes differ in depth by approximately 100m. Occasionally, more accurate fixes were available.

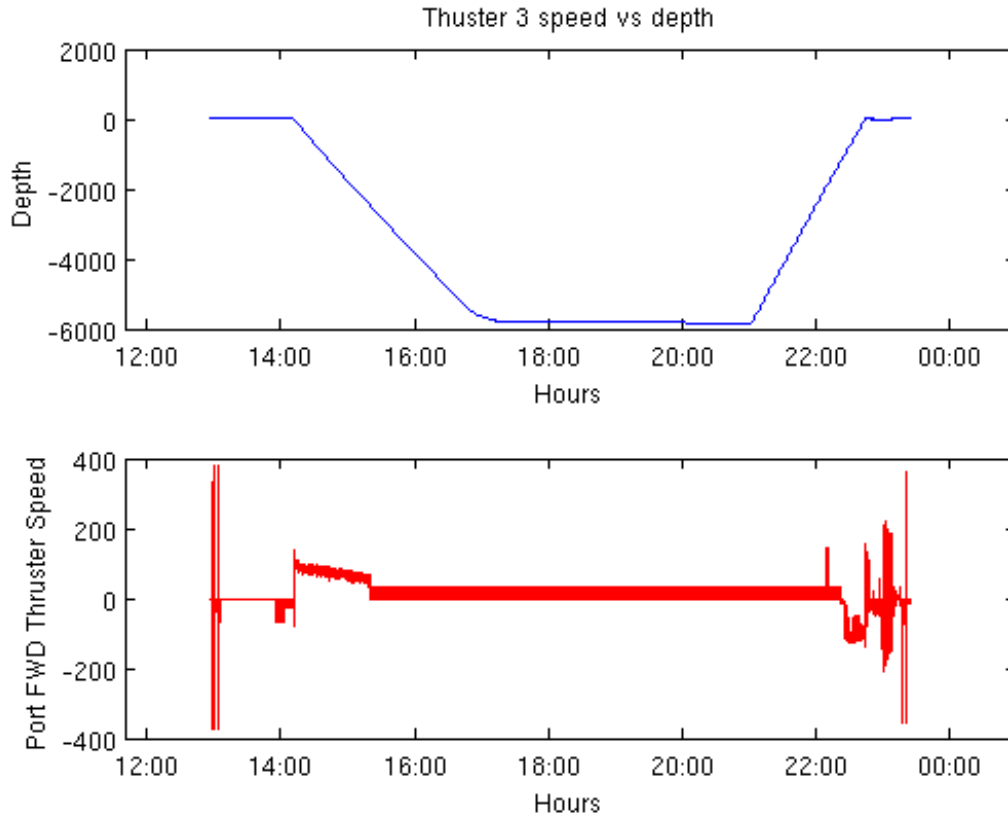


Figure 5: Starboard Forward thruster during Sentry127

B Actuator Failures

The actuators (thrusters and servos) on *Sentry* did not perform adequately during this cruise. Root cause has yet to be determined, but a chronological summary of observations and actions is presented here as a starting point for future efforts to resolve these problems.

B.1 Sentry127

During the sentry127 dive at the beginning of the cruise, the starboard forward thruster failed. As can be seen in Figure B.1, the thruster was free wheeling during descent until somewhere past 3000m at which point it ceased rotation. The thruster did not resume movement until the ascent at which point it resumed freewheeling.

The failure of the thruster caused the vehicle to lose stability at speeds in excess of 0.6m/s. Figure B.1 shows the DVL track of the vehicle during an unstable portion of the dive. The vehicle can be seen to

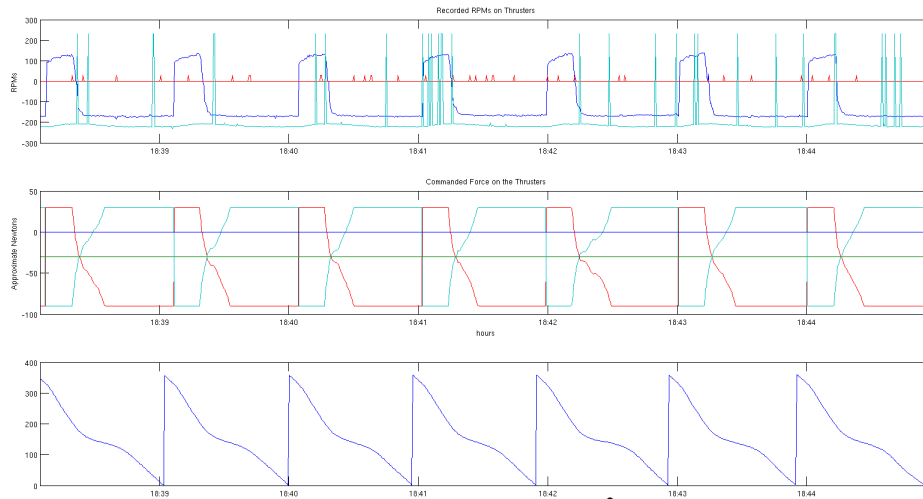


Figure 6: Heading and thruster speeds during Sentry127

be attempting to drive the commanded track line but to repeatedly loose heading control. The second plot (Figure 7) shows the heading of the vehicle as well as the thruster commands and rotations showing the loss of heading control as a result of a non-functional starboard forward thruster.

After this dive, the starboard forward thruster was replaced and the logging issue was fixed. No failure of the thruster could be reproduced on deck including during cold soaking in an environmental chamber. The thruster was considered too risky for use and sidelined for the remainder of the cruise.

A limit cycling effect was also observed in the servos but it was thought to be an incorrect gain in the bottom follower at this point. It will be discussed in more depth in the next section.

An additional thruster, the starboard aft, was not correctly logged. This was the result of a software bug introduced during the 2011 Valentine cruise which has since been fixed in a way that will prevent reintroduction.

B.2 Sentry128

During the Sentry128 dive, the actuators appeared to behave as expected during the dive. At the surface it was noted that the forward fins did not move to horizontal while driving as expected. Once the vehicle was on deck, the logs were analyzed. As shown in Figure 8, the forward wing did not move after going to vertical during the ascent. This servo was tested on deck and found to be non-functional so it was replaced with a hot spare.

Further testing on the bench showed that the motor would not turn and exhibited a periodic resistance as the motor shaft was turned. The motor and electronics were replaced at which point the thruster appeared to be functional. Several days later under further testing, communication was intermittent and motion was not consistent. At this point both switches of one of the phases was observed to be very hot when motion

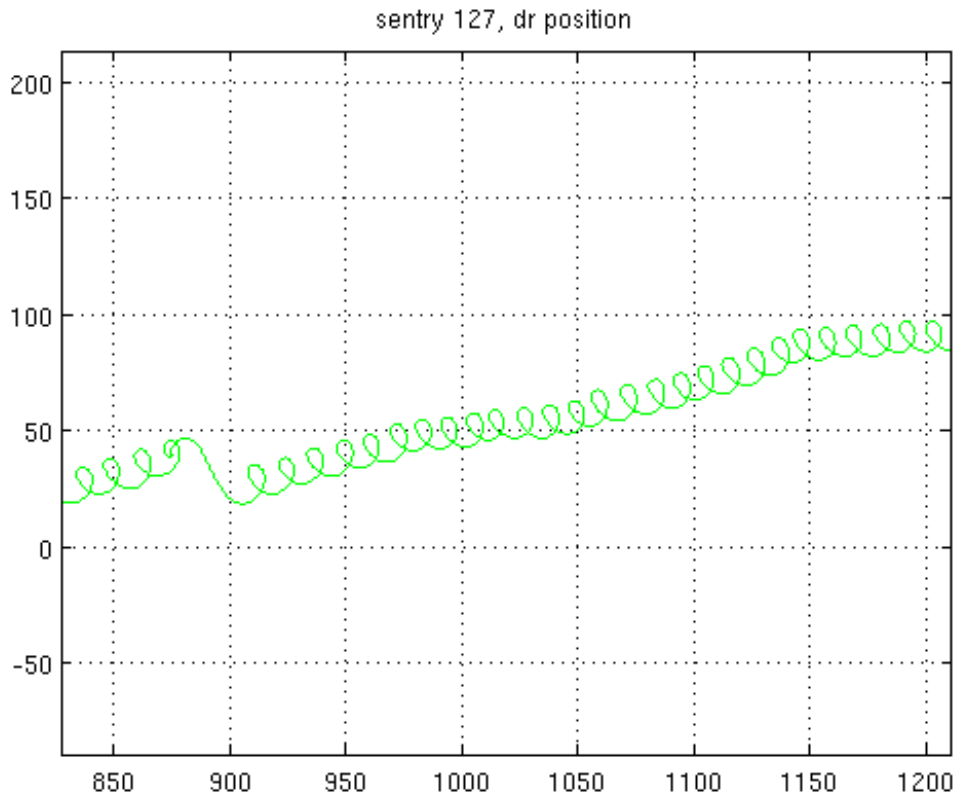


Figure 7: Portion of the DVL track from dive 127

was commanded and a high pitched whine was heard. This was traced to a faulty hall effect sensor in the motor. Replacement of the motor as well as of the switches on that phase and the voltage regulator yielded a functional servo but not until shortly before Sentry130.

We also noticed significant limit cycling (which had been present during Sentry127; continued at least through Sentry129; and perhaps throughout the cruise). This is shown in Figure ???. On Sentry130 and subsequent dives, limit cycling was still observed, but by then we had changed the flight dynamics of the vehicle and the cases cannot be compared.

B.3 Sentry129

Sentry129 proceeded normally for several hours until the forward servo failed causing the vehicle to crash into the bottom. Full details of this event are given in the Sentry129 dive summary but shown below is the servo position both at the time of the crash and subsequently on ascent. Note that during the crash, the forward servo failed to correctly actuate and the vehicle drove itself into the seafloor. On the ascent, the

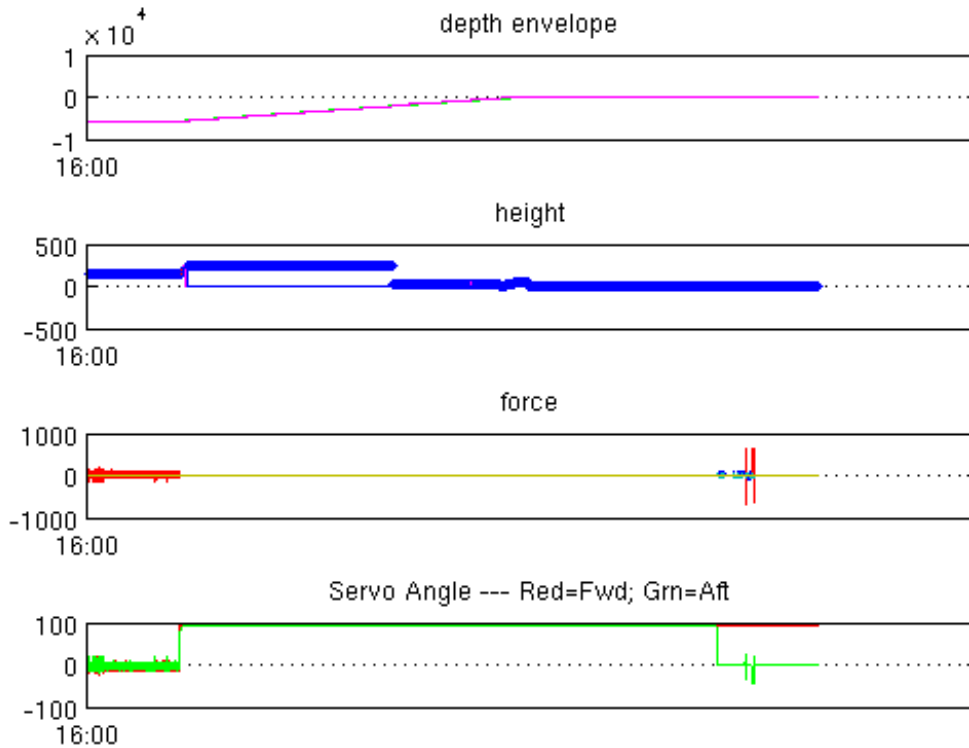


Figure 8: Servo positions during dive 128

servo was commanded to vertical at the same time as the aft servo, but moved in two stages to vertical over a period of approximately 10 minutes.

Testing on deck was not able to replicate the problem. At this point, without a hot spare servo (only later were we able to sufficiently repair another servo) the decision was made to put the reliable aft thruster forward, and the questionable servo aft. The aft fins were then locked in software. This flight mode was tested during dives 130 and 131 and is described in those dive summaries.

B.4 Sentry130 - 134

No full blown actuator failures were observed during these dives, however, both the starboard forward and starboard aft thrusters were observed to have residual motion and torque even when commanded to zero in software. This phenomenon became more pronounced after each dive.

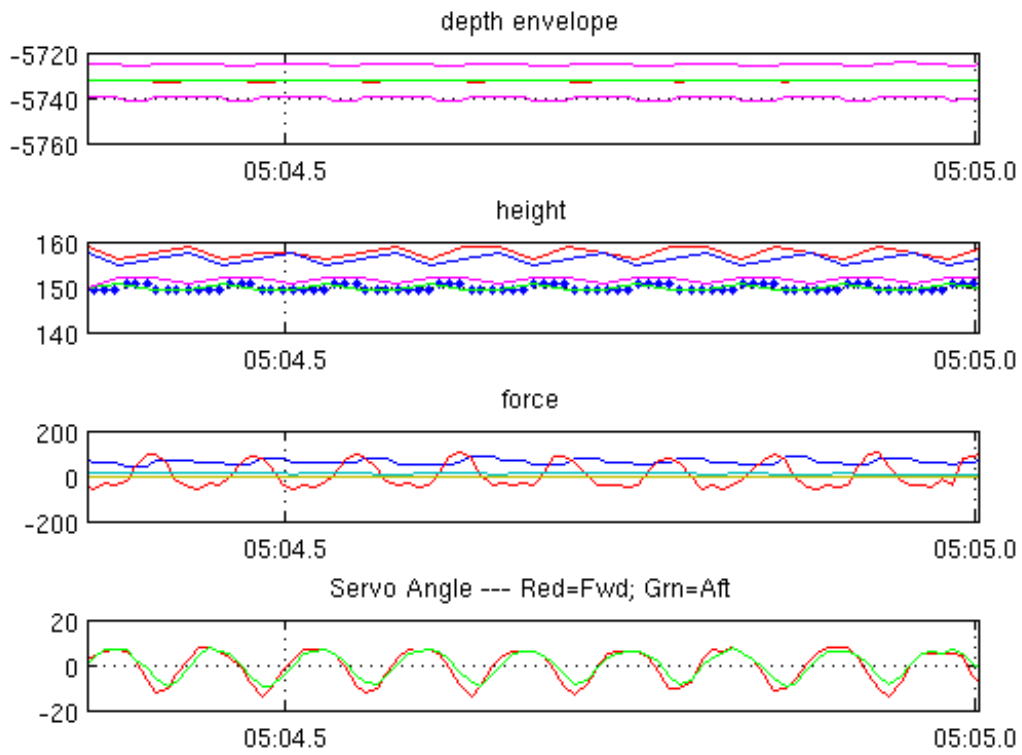


Figure 9: Servo limit cycling on dive 128
??

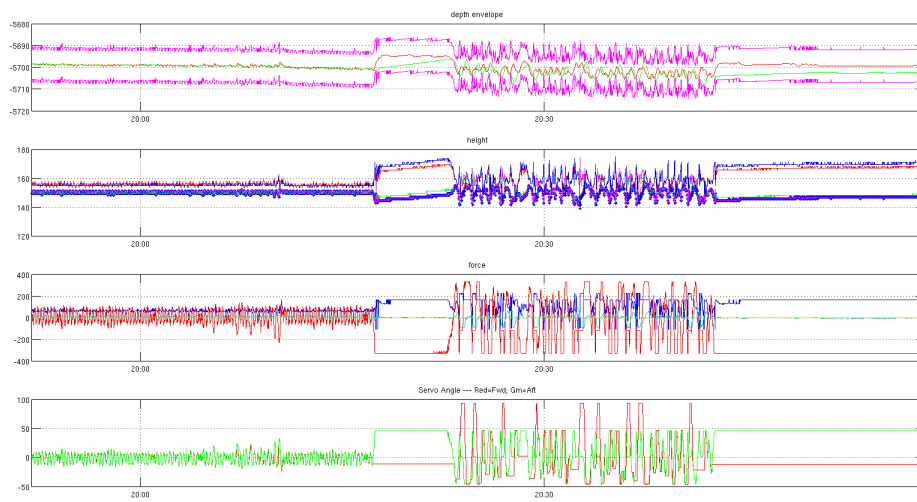


Figure 10: Sentry servo positions during the crash on dive 129

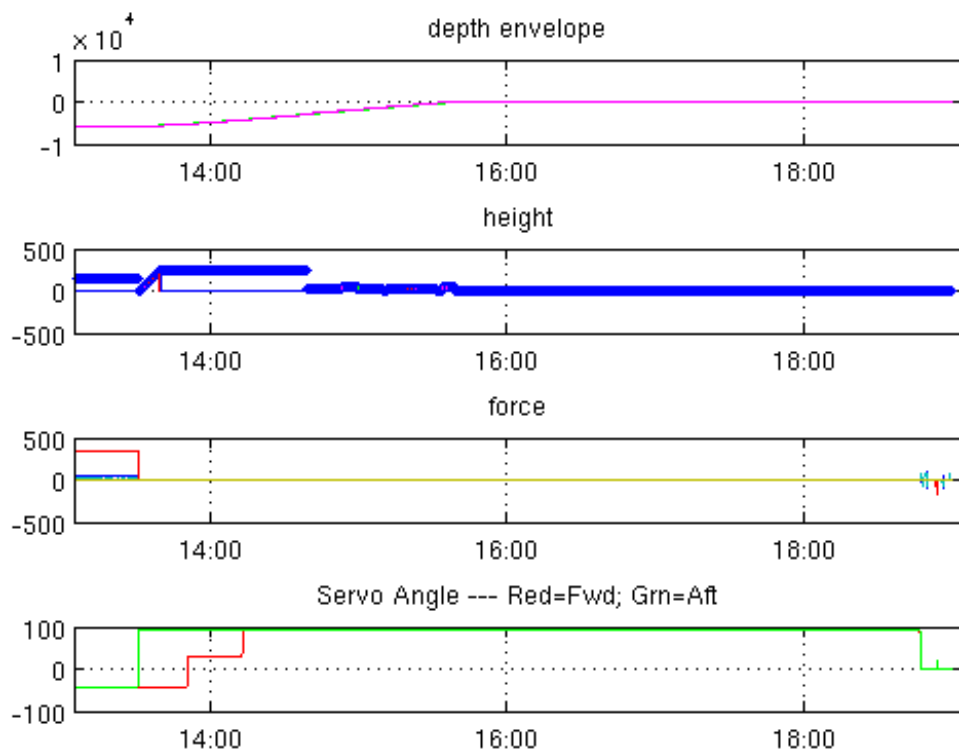


Figure 11: Sentry servo positions during ascent on dive 129

C Magnetometer Noise Tests

Since the first dives with the new APS 1540 magnetometers, the magnetic field profiles showed evident spikes of an unknown origin for all 3 magnetometers. The noise in magnetometer 2 data was “single-point spikes” on the order of 10^6 while the noise in magnetometers 0 and 1 were lower in magnitude but contained more data points; the shape of the spikes suggested a build-up and then discharge.

To investigate the possibility of a serial transmission data corruption causing this phenomenon, a custom data logger has been written. This records the magnetometers binary data output, decode it and log it to obtain the magnetic field components, temperature and checksum. The software then computes the checksum of the received data and compares it with the received checksum (this is possible only in binary mode). This analysis, as the received checksum showed to be consistently matching the computed checksum, ruled out the data corruption theory. The custom binary logger program complained about being unable to access the Magnetometer 2 (top) while starting a decktest, and this led to identifying a device (removed from Sentry before the cruise) in the ROV ini file that was still trying to open the ttyS18 serial port (the same as Magnetometer 2). *Excluding this device from the ROV ini file eliminated the large spikes in the magnetic field profile for magnetometer 2 (top).* Continued analysis of magnetometer 2 data showed that it now contained noise similar (but with smaller amplitude) to that found in magnetometers 0 and 1.

After having analyzed Sentry’s powerup and powerdown sequence it became clear that such spikes were present only with the vehicle in operative status, and the amplitude of such spikes increased when the vehicle was in the water. Further, when the vehicle was powered down at the end of a dive, the spikes disappeared. The source of these spikes has been identified in one of the following devices: LBL, #DP, RF MODEM, DVL, CT, #AM. A procedure has been developed to identify the source, with a custom data logger recording the magnetometer 0 data while the vehicle was kept in a minimum operating condition and single devices were powered up and down together with the relevant control software. The procedure followed was:

1. Using SentrySitter, power only to the following devices: Fan, Main Stack, GigE Hubs, Mag0 & 1, Mag2, XR1, XR2
2. Run the ApsAsciiLogger for Mag0 (/dev/ttyS16)
3. power up LBL (T)
4. After 1 minute, Start ROV
5. After 5 minutes, Stop ROV
6. After 1 minute, power down LBL
7. After 5 minutes, power up #DP
8. After 1 minute, Start ROV
9. After 5 minutes, Stop ROV
10. After 1 minute, power down #DP
11. After 5 minutes, power up RF MODEM
12. After 1 minute, Start ROV

13. After 5 minutes, Stop ROV
14. After 1 minute, power down RF MODEM
15. After 5 minutes, power up DVL
16. After 1 minute, Start ROV
17. After 5 minutes, Stop ROV
18. After 1 minute, power down DVL
19. After 5 minutes, power up CT
20. After 1 minute, Start ROV
21. After 5 minutes, Stop ROV
22. After 1 minute, power down CT
23. After 5 minutes, power up #AM
24. After 1 minute, Start ROV
25. After 5 minutes, Stop ROV
26. After 1 minute, power down #AM
27. After 20 minutes, power up DVL and start pinging with command `/godv1`
28. After 10 minutes, power down DVL and timer (kill `dvlsend`, `timoff` commands)

This procedure showed that the source of the magnetic spikes is the DVL while in pinging mode. Given the position within the vehicle of magnetometers 0, 1, 2 this could also explain why magnetometer 2, being farther from the DVL, is showing spikes with less amplitude. This could also explain why the amplitude of the spikes increases while in the water, as the DVL is known to increase the output power when submerged.

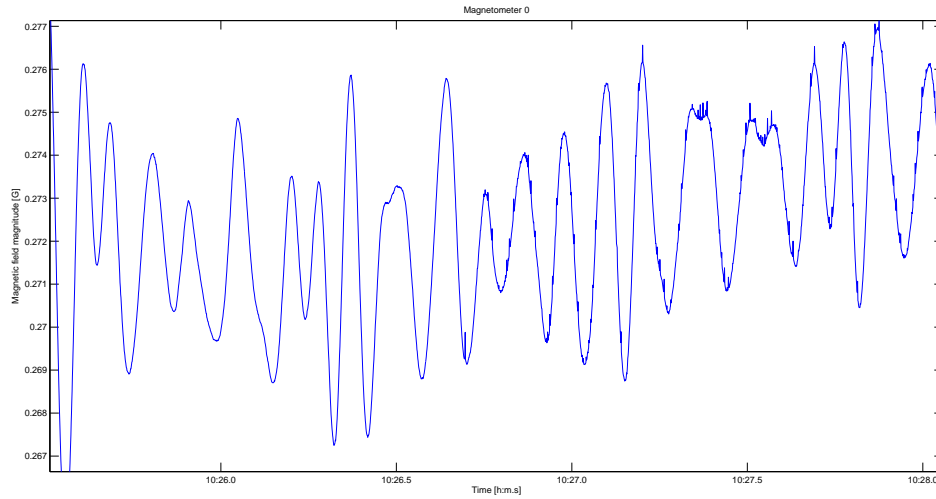


Figure 12: Total magnetic field for magnetometer 0 during the described test. No noise is present prior to 10:26:30 when the DVL is turned on. After this, spikes are present in the noise. This demonstrates that the DVL is the source of this noise.

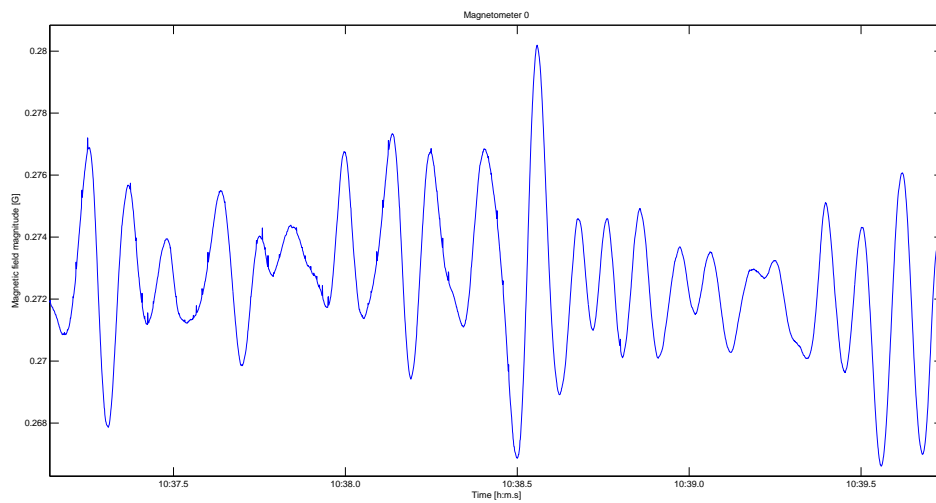


Figure 13: Total magnetic field for magnetometer 0 as the DVL is turned *off*. The noise spikes are present prior to the DVL being turned off at 10:38:30; afterward they are absent.

D Water Column Descent Simulation Bug

Sentry dive 130 failed because of a programming error in the descent process. Specifically, the `descent_depth_enable` and `descent_depth` parameters were not properly set in the mission parameters initialization file. This error was not caught by the simulation. The source of the simulation error is differences in how the altitude is handled by the roV code in simulation and reality. In reality, the roV code receives occasional fliers in the DVL altitude. In simulation, the roV code is sending a fake altitude that contains noise from the random bottom generator. During a normal dive, once the vehicle passes the altitude depth, the altitude hit counter is activated — 20 counts are added for each monotonically decreasing series of altitude measurements; a single count is subtracted for each altitude measurement that is the same or less than the previous. Once the count value passes 101 (i.e., 6 consecutive decreasing altitudes) then the descent process is ended and the mission starts.

On water column dives, the `descent_depth_enable` and `descent_depth` are set such that once *Sentry* passes the depth set in the `descent_depth` parameter, the descent process ends and the mission starts.

On sentry 130, the `descent_depth_enable` and `descent_depth` parameters were not properly set however the simulation still showed a successful mission. The `altitude_depth` parameter was appropriately set for a water-column dive. As the simulation passed the `altitude_depth`, it activated the altitude hit counter. Then the simulation altitude generator (which were the “measured” altitudes in the simulation) provided 6 consecutive monotonically decreasing altitudes which then ended the descent process. The simulation properly executed the remainder of the mission. This misled us into believing the mission was properly programmed.

Another concerning bug is that *Sentry's* descent process is not checking the vehicle health prms. So the max depth floor goes unchecked until we start the on-bottom portion of the mission. This is a dangerous behavior — descent (when we are negatively buoyant) is probably when we need the max depth value the most. In addition all of the other vehicle health parameters (i.e., pressure, temperature, battery capacity) are not being checked during descent.

E Sentry 133 Abort

Sentry dive 134 ended early because of an erroneous acoustic abort received on XR1. This section discusses the incident and at-sea actions taken.

Up until 17:03:24 the dive was going fine. Andy and James were monitoring the tracking systems (USBL,DVLNav, WiffleNav). WiffleNav was being watched but the sentry command window was CLOSED. We were pinging Sentry on XR2 (10.5in/13.5out). Soon after we observed Sentry ascending.

On ascent we queried Sentry to find out why it aborted. When the reply indicated an XR acoustic abort we verified the status of Wiffenav. Opening the Sentry commands in window, we verified that commands window was locked and no commands were selected.

Inspection of the burn wires on deck after recovery shows that the starboard and descent burn wires burned but the port burn wire had NOT burned. Starboard and descent burn wires are controlled by XR1. This confirms that the burn wires were powered because of an XR command, NOT by software (in which case all of the burn wires would have burned).

The GRD file shows that at 17:03:24.476 the GRD bus received a “XRC 1 15” command. This is the acoustic abort command for XR 1. The mc and rov code did all of the right things upon receiving the command from the XR — ending the mission, dropping weights, etc.

XR1 was online. Dana reminded us of the ?C command. Looking at the GRD file for the time in question, we see:

```
GRD 2011/12/07 17:03:19.075 #GRD/XR1?C-0D<0D><0A>:<0D><0D><0A>:<03>
GRD 2011/12/07 17:03:21.779 #GRD/XR1?C-0D<0D><0A>:<0D><0D><0A>:<03>
GRD 2011/12/07 17:03:24.476 #GRD/XR1?C+0F<0D><0A>:<0D><0D><0A>:<03>
GRD 2011/12/07 17:03:27.175 #GRD/XR1?C-0F<0D><0A>:<0D><0D><0A>:<03>
GRD 2011/12/07 17:03:29.887 #GRD/XR1?C-0F<0D><0A>:<0D><0D><0A>:<03>
GRD 2011/12/07 17:03:32.587 #GRD/XR1?C-0F<0D><0A>:<0D><0D><0A>:<03>
```

The +0F at 17:03:24.476 confirms XR1 heard a command even though one was never sent.

A grep of C+ on the GRD files for the entire dive show this is the only one. Looking through all of the logs from this cruise, we see only a +0D from XR1 on dive 131. This is the -0D we see in the above file.

All signs indicated Sentry acoustically aborted. Our theories and possible reasons to exclude them.

A) We accidentally commanded it. This is the obvious one. As discussed in (1) and (2) the wiffenav was secured against sending commands and we were not interacting with it at the time.

B) A previously unknown bug has manifested itself.

C) The XR was “spoofed” either acoustically or otherwise. This is a stretch but we can’t rule it out. We’ve verified that the micromodem was not pinging at the time. The lbl was pinging on 14.5/11.0 (using the !N cmd).

F Iridium Modem

Throughout the cruise, the iridium modem was difficult to use and prone to errors. The iridium requires control over the DTR line on the serial port, which we do not normally use, and also requires that it be woken up by toggling a logical input which we are not set up to do. During the mob, we tied the DTR line permanently to ground which will allow us to use the functionality that we deem critical. We also tied the on/off toggle into a spare channel with a pull down resistor. This is not a good long term solution as it ties up an entire power supply in a very inefficient mode.

One the hardware aspects of the iridium were sorted out, we were still left with difficulties in use. The iridium does not conform to it's own spec in the following ways

The iridium is supposed to continue to stay awake after any command for several minutes. In fact, under most circumstances the counter is never reset so the iridium powers on for several minutes then powers off regardless of what else goes on.

The iridium loses nearly all of it's settings anytime the toggle lines are reset. The only exception is the timing of the message interval. In reading the documentation, it appears in some places that all settings are lost and in others that all settings are preserved.

The iridium frequently freezes if it is interrogated too often. Typically after this the entire system needs to be powered down for three to five minutes before it is able to communicate again.

When interrogated the iridium sometimes sends a message immediately and other times does not. No clear pattern was discerned and in no place in the manual is it clear that a message should be sent under such circumstances.

An initial attempt was made to integrate the iridium into the ROV code which resulted in unreliable operation. The iridium would typically broadcast at irregular but frequent intervals for anywhere from several minutes to several hours, then cease broadcasting for up to an hour or two. In retrospect this was likely due to the lock up issue when communicating too frequently and also due to the sporadic message sends during interrogation.

On the third dive during which it was used, the iridium did not send any messages after surfacing or on deck after recovery. Upon sending logs back to the vendor, it was determined that the pressure switch was likely stuck. We bypassed the pressure switch to eliminate any further chance of a similar failure.

After that point, Carl Kaiser configured the iridium by hand prior to and after each dive and the section of the ROV code which interacted with it was disabled. This worked well for the duration of the cruise. After the final dive, a python script was devised which will automatically configure the system. This can be run using the commands "iridium_prediver" and "iridium_postdive" on the stack. These commands are still susceptible to the freezing issue at times so these scripts can either take a very long time to run or need to be interrupted and the entire system powered down for five to ten minutes before re-running the script. These scripts have been tested carefully on deck but have not been used for an actual dive.

G Sentry 131 Recovery

The following account of the recovery is intended to serve as a record of the event and constructively inform future recoveries. It is not intended to blame anyone — everyone was doing their best under difficult circumstances.

Sentry had a normal ascent with USBL tracking and acoustic telemetry. It surfaced approximately 200m away. Winds were 15-20 knots with a 5-7' swell; the wind and swell were coming from different directions. It was almost a new moon, so there was little moonlight with which to view the swell. The Captain was driving on the bridge with Carl Kaiser on the bridge to drive *Sentry* on final approach. The third mate was on the fantail overseeing the recovery. Set up took approximately 30 minutes. Finally the ship approached along side *Sentry* and Carl drove the vehicle toward the ship (in a similar fashion to previous recoveries on this cruise) just forward of the crane. Andy attempted to hook the vehicle but missed; he continued to attempt to hook *Sentry* as it slide back along the hull. The ship was taking the swell along and into the starboard side and, as the swell picked the ship up, *Sentry* slid under the hull. The bridge “secured all props” and *Sentry* popped out a few seconds later. The ship reset for another approach.

The second attempt followed the same approach — the ship facing into the wind and taking the swell along and into the starboard side. However *Sentry* had sustained damage to both starboard wings on the previous attempt; effectively eliminating our ability to drive the vehicle and depending on the ship to get us within hooking distance. Carl was initially unaware of this and continued to attempt to drive *Sentry* — a futile effort given the wing damage (Carl eventually realized the situation and was also informed by the deck). Attempts were made to hook the vehicle forward by the ship’s USBL pole (with the lift line detached from the crane) but failed. Again *Sentry* slid aft while attempts were made to hook it. The ship took a large swell and *Sentry* slid under the ship a second time. This time it remained under the hull for almost a minute. Maurice Tivey and James Kinsey were on the aft starboard fantail and could the strobe lights just under the hull. They also heard at least one distinct loud slam as the ship dropped down a swell onto *Sentry*. Korey attempted to pass a pole to James enable him to fend *Sentry* away from the ship. They were ordered by the third mate to stop this effort. *Sentry* finally popped out the stern as the Captain moved the ship forward with the aft port screw. The Avtrak was observed to have been damaged at this time. Maurice and Korey maintained a visual on the vehicle while James went to the bridge. The third mate also went up to the bridge to assist with driving the ship. The second mate (who was coming on watch) took over on the fantail.

The Captain took his time setting up for this attempt. He created a lee; slowly nudging the ship closer to *Sentry*. The maneuver took some time. As *Sentry* got close, Andy attempted to hook it forward near the USBL pole. After a few attempts, he succeeded. The crane slewed out and pulled in on the wire. The forward tagline was hooked but parted soon after. The aft tagline was applied while a new forward tagline was rigged. *Sentry* was placed back in the water to keep it from rocking. Once the forward tagline was rigged, *Sentry* was lifted and the line hooked. *Sentry* was placed in its cradle a few minutes later without further incident.

The entire recovery took approximately two hours. The *R/V Thomas G. Thompson* (TGT) deck department and the *Sentry* ops team were on deck throughout and their efforts and stamina in recovering the vehicle are appreciated.

A debrief with the *Sentry* ops team, the Captain, and Chief Scientist (ChSci), Masako Tominaga, was held soon after. The debrief and subsequent conversations identified the following areas of improvement:

1. The distance between the bridge and the fantail precluded the bridge from having full situational awareness of the final approaches. The *Sentry* joystick operator was driving from the bridge. This position provides excellent coordination with the Captain but does limit his awareness of events down below. This should be remedied by moving him further aft where he can directly see events.

Sentry team members on the fantail also need to keep him apprised of events from their prospective. For example, after the first slide under the hull, they should have more actively visually inspected the vehicle and informed the joystick operator. Achieving this might require additional radios which should be used only for crucial comms.

The ship's information flow from the fantail to the bridge should also be evaluated. The third mate immediately informed the Captain when *Sentry* and the Captain immediately secured all props. What is unclear is how much information the Captain had when he decided to move the ship forward. This move ended up being fine however had *Sentry* been more to port it could have had catastrophic consequences.

2. The forward tagline slid between the bulwarks which provided a stress point that snapped the line. These gaps should be closed. *Sentry* travels with extras hook and lines, a rigged hook and line should be located near the ops area so it can be quickly rigged on a pole.
3. *Sentry* should be hooked further forward near the USBL pole and the lift line then walked back to the crane whip.