

Sentry Autonomous Underwater Vehicle (AUV)

Operational Guidelines and Scientific Capabilities

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This document provides guidance for prospective users of the Sentry AUV operated by the National Deep Submergence Facility at the Woods Hole Oceanographic Institution. It includes an overview of how the vehicle works and summarizes standard survey types, coverage rates, speeds, and dive durations. It summarizes the performance of Sentry's standard sensors and describes the data products and formats.

Sentry's standard survey types include near-bottom multibeam survey, photo survey, and water column survey. Sentry also carries a subbottom profiler, which can be used during either multibeam or photo surveys. Water column data (CT, optical backscatter) and magnetics data are recorded at all times. Multibeam and photo surveys can be combined in a single dive. Table 1 summarizes the standard sensors available on Sentry.

As an AUV, Sentry can operate independently of the surface support vessel. Once launched, the vehicle is tracked to the bottom, and, after verifying Sentry is operating correctly (typically after 1 hour after reaching the seafloor), Sentry can operate autonomously until the end of the dive. The dive typically ends when the programmed mission is completed or when the batteries are depleted. The duration mission depends on the sensors and commanded vehicle speed necessary for the planned science mission. For multibeam mapping, Sentry has a maximum endurance of approximately 19 hours (~70 km). For camera surveys, Sentry can operate as long as 44 hours, although the longest dive on record is 32 hours. Sentry dives can be shorter to satisfy other cruise schedule constraints, and, if necessary, dives can be terminated using the acoustic link.

In addition to operating as the primary asset on a cruise, Sentry can be operated with other vehicles such as Alvin, ROVs, and towed platforms (tow-sleds, CTDs, etc). These multi-vehicle operations significantly increase cruise productivity. Sentry often operates in conjunction with Alvin, with Alvin diving during the day and Sentry diving at night. Nighttime operations usually provide 11-14 hours of bottom time covering 40-50 km of tracklines each day depending on the Alvin schedule. We have operated Sentry simultaneously with ROVs including Jason 2 and the SubAtlantic Cherokee ROV operated by the University of Ghent. Alvin and Sentry cannot operate simultaneously.

Sensor Type	Model	Description
multibeam sonar	Reson 7125, 400 khz	512 beams, max cross-track swath 250m
subbottom profiler	Edgetech 2200-M	4-24 khz chirp
digital camera	Prosilica GC-1380C	1360x1024 pixels, 12 bit
Conductivity/Temperature	Neil Brown Ocean Sensors GCTD	fast CT sensor
optical backscatter	Seapoint	
magnetometers	Honeywell HMR2300	dual magnetometers separated ~1m vertically

Table 1: Sentry standard sensors

Vehicle navigation, localization, and acoustic communications

Sentry carries an IXSEA Phins Inertial Navigation System (INS) and a Teledyne RD Instruments 300 khz Doppler velocity log (DVL). These sensors provide precise and dependable dead-reckoning navigation used by the vehicle in real-time. The Typical drift rate for the DVL/INS track is less than 10m/hour depending on the type of tracks programmed. The DVL possesses a range of ~200m and, in consequence, the INS/DVL navigation solution is only possible when Sentry is within 200m of the seafloor (colloquially refereed to as “maintaining bottom-lock”). At heights exceeding 200m, Sentry can employ an alternative vehicle model navigation solution that is sufficient for water column surveying but not for bathymetry. This latter navigation mode requires active tracking and acoustic communications with the surface vessel.

Absolute positioning and vehicle tracking from the surface vessel is provided by either a ultra-short baseline (USBL) system (Sonardyne Ranger), a WHOI long baseline (LBL) system, or both. Fixes from these systems are also used to correct the DVL/INS track in post-processing. Both systems require dedicated vessel time at the beginning of the cruise. For USBL operation, the support vessel must always be within half a water depth of Sentry during the dive; the LBL system requires a dedicated block of time at the beginning of the cruise for installing the LBL transponders but does not require the continuous presence of the surface ship during Sentry dives.

The LBL system requires the transponders be deployed, surveyed, and recovered. Depending on water depth, deployment and survey takes about 3 hours per transponder with an additional hour per transponder required for recovery

The USBL system requires calibration to align the USBL transducer head with the attitude and position references (the manufacturer calls this calibration CASSIUS). This takes about 6 hours and only needs to be performed once after the USBL system is installed on the ship. A reference transponder is placed on the seafloor, and then recovered when calibration is complete. This calibration should take place in water depths approximating the operational

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depth.

When the USBL system is in use, we also have acoustic communications with the vehicle. This capability permits the equivalent of text messages (up to 128 characters) to be sent and received from the vehicle several times a minute. A variety of messages can be transmitted from the vehicle. These include basic vehicle state (position, heading, height, speed, remaining battery charge) as well as messages from the various scientific sensors such as conductivity, temperature, optical backscatter, etc. If needed, the acoustic communications can also be used to add tracklines to the vehicle's mission plan, change bottom-following parameters, etc. We rarely use this capability for routine bathymetric mapping, but it is useful for water column surveys (e.g., hydrothermal vent exploration, plume mapping, etc).

Multibeam Sonar Surveying

Sentry carries a Reson 7125 multibeam sonar with 400 khz transducers. This produces a useful swath up to 250m wide depending on the bottom type and survey height. Trackline spacings must be set ~20% smaller than the maximum swath to ensure coverage in rough terrain and to provide overlap. Table 2 lists coverage rates and resolutions for the multibeam sonar.

height	forward speed	Track spacing	cross-track resolution	along-track resolution	coverage rate	coverage
80m	1.0m/s	200m	0.5m	0.5m	0.72 km ² /hr	13.7 km ² /dive
20m	1.0m/s	50m	0.12m	0.5m	0.18 km ² /hr	3.4 km ² /dive
20m	0.7m/s	50m	0.12	0.35m	0.12 km ² /hr	3.0 km ² /dive

Table 2: Multibeam Coverage Rates

We provide the raw and processed data in several formats. The conventional products used by our scientific collaborators are 2D plots (pdf, ps, png) and gridded bathymetry in GMT-compatible grd files and asc files for input into other GIS tools. The gridded data has been edited using our automated scripts and the soundings geolocated using our post-processed navigation. MB-system or Caris tools can be used by the science party to hand-edit soundings, however our automated scripts work well. We also provide the edited data in fbt format, which can be imported directly to Fledermaus for gridding and display.

Subbottom Profiler

Sentry can carry an Edgetech 2200-M subbottom profiler, which uses a CHIRP signal (a broadband, swept waveform) in the 4-24 khz range. This device is suitable for estimating sediment cover in volcanic terrain, and can penetrate softer seafloors to depth of several 10s of meters. We have also used this sonar to detect bubble plumes from natural methane seeps.

Data from the subbottom profiler is furnished in Edgetech's proprietary jsf format. These records are time stamped in realtime and the position, depth, and attitude fields are filled post-dive. If desired, filenames can be changed from the standard Edgetech format to include

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date and start time. Our standard product includes transforming the jsf files into SEG Y files (an open standard), which can in turn be processed and displayed by a variety of packages. We are presently developing the software elements required to import the subbottom data into Fledermaus, which can produce fence plots in combination with bathymetry. We can also import the JSF files into Google Earth.

Camera Surveying

The vehicle's camera is normally operated at heights ranging from 3.5 to 5 m. Sentry uses a Prosilica 1.4 Mpixel color camera (1380x1024, 12 bits) with a Computar/Pentax 6.5mm, F1.8, 1" format lens. The lens and optical dome yield a cross-track coverage of 1.15 times the height. Presently, Sentry's strobe is limited to flashing at a 7 second interval. To obtain overlap between images, we recommend that the vehicle drive at 0.35 m/s (0.7 knots) forward speed at 5 meters height. A faster strobe in development will allow the vehicle to fly lower at faster speed while obtaining > 25% overlap (3.5 m height at 0.5 m/s forward speed is the goal).

We provide the images in several formats with different levels of processing. These include the raw and bayer encoded (color) tif files directly from the camera real-time software should users choose to reprocess those images. We color compensate and equalize all images, these are most commonly used by the science party. The overlap between images supports strip mosaics along-track, but our registration between tracklines cannot be guaranteed to support gapless mosaics across consecutive tracklines. A CSV file containing the vehicle's position, heading, and altitude at the time each image is taken is provided. Filenames include date and time. File sizes are approximately 2.5Mbyte for the raw images, 8 Mbytes for bayer encoded (color) and all processed images.

Sentry data files

Sentry data files most commonly employed by our scientific users are listed in the table below

file type	suffix	contents	usage
summary file (flat ASCII)	.scc	date, time, lat, lon, depth, height, conductivity, temperature, magnetometer	import to other packages for analysis, plotting
gridded bathy	.grd	gridded bathymetry	import to other packages such as matlab or GMT for generating plots or analysis
gridded bathy	.asc	arc/info ASCII grid	import to GIS
gridded bathy	.ps, .pdf, .png	bathy image	import into documents (MS Word), latex), web pages
fbt	.fbt	edited and geolocated multibeam ping data	import to packages to grid and display data such as Fledermaus, Matlab.

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raw image file	.tif	raw image directly from camera	image appears monochrome, must be bayer-encoded for color. Not useful without further processing
raw color image file	.tif	bayer encoded image processed by real-time software	color image, before equalization or color balancing. Not useful without further processing.
processed color image file	.tif	color-balanced and equalized images	import into documents, web pages, or mosaic packages
mat files	.mat	sensor data recorded at native rates	import into matlab for processing. This is the preferred route for data such as magnets where downsampling and time interpolation of the .scc file is inappropriate.

For convenience, we furnish a summary of all vehicle data, which we call an scc file. This flat ASCII file contains the date, time, latitude, longitude, depth, pressure, conductivity, temperature, optical backscatter, Nakamura redox probe (if available), and data from both magnetometers. All fields in the scc file have been interpolated onto a 1 second time base. Our collaborators have used this file to import data into other programs such as Excel, Kaleidagraph, and Matlab. If data import into Matlab is required, we can furnish mat files with raw and processed navigation and data from each science sensor at its native rate. The mat files are the preferred route for Matlab processing.

Vehicle Endurance and Charging Times

The vehicle run time and distance covered will depend on the commanded speed, the sensor payload, and the terrain. For multibeam runs in terrain running at 1.0 m/s at 80 m height, Sentry has covered 70 km in 19 hours before the dive ended on low battery. A dive of this duration, altitude, and speed maps approximately 13.5 km². The amount of power used when the multibeam is not engaged is significantly less. For example, photo surveying dives where the vehicle's speed is 0.35 m/s have run for 32 hours, covering 42km, and obtained over 16,000 images with approximately 35% battery capacity remaining. Water column surveys, where Sentry moves at 1 m/s without the multi-beam engaged have covered 86km over 22 hours.

Sentry ascends and descends rapidly, at an average rate of ~40m/s. At an operating depth of 2500m, descent and ascent both take about 1 hour. Recovery times vary with wind, sea state, and ship maneuvering capabilities. Recovery usually takes about 1/2 hour from when the vehicle surfaces until it is secure on deck. In poor weather this could take longer.

Battery charge time depends on how much power was consumed on the previous dive, and whether the next dive will require a full charge. In the longest case (fully discharged packs requiring full recharge), the maximum charge time is 12 hours. The last several hours add only the final few percent to the charge, so this time can be shortened if needed without a

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large decrease in the vehicle's endurance.

Multiple Vehicle Operations

Sentry often operates in coordination with other deep submergence vehicles, such as tow-sleds and ROVs. During multiple vehicle operations, **we require 2 hours of ship time after launching the vehicle to monitor the vehicle's descent and ensure it has successfully started the mission.** After that, the surface vessel is free to conduct other activities subject to the constraints of the USBL system, if it's in use. If an LBL net has been deployed, the ship can leave the immediate operating area. If USBL is used, the vehicle should stay in range of the USBL (1/2 water depth) to achieve accurate navigation. When possible we monitor Sentry and, if this is impossible, may occasionally request to move the ship near Sentry to briefly monitor its state. On the rare occasion that the vehicle aborts a dive early, we require that the ship break-off other research activities to allow us to recover the AUV. During coordinated AUV-ROV operations, we often launch and recover Sentry with the ROV in the water.

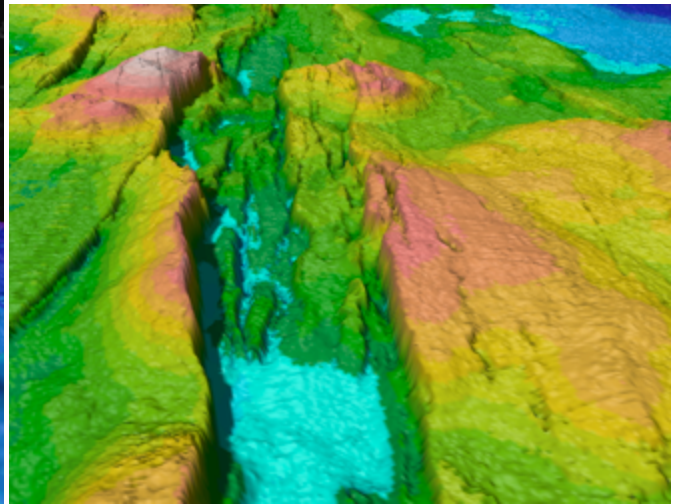
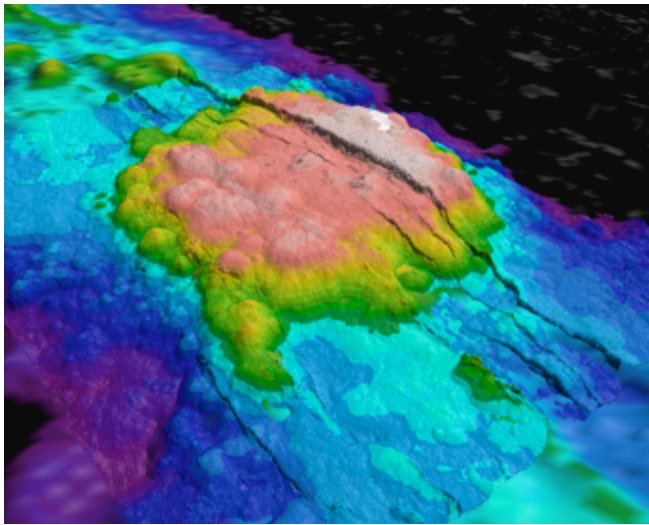
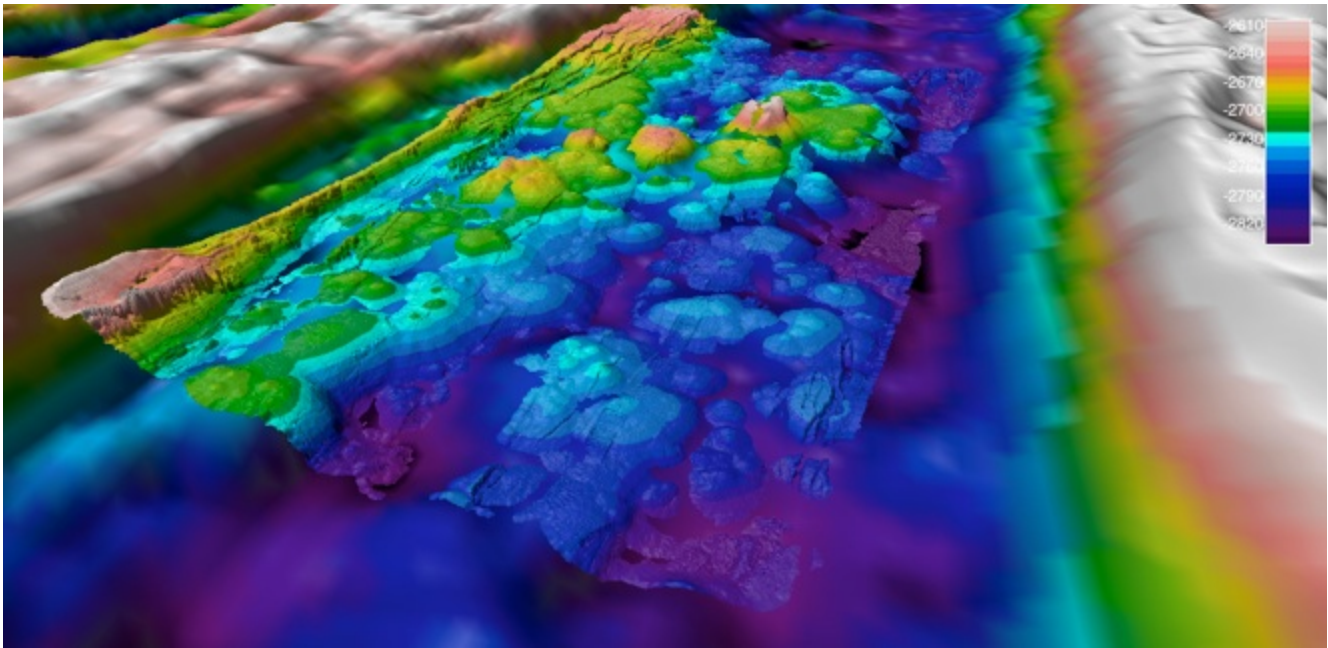
To ensure accurate navigation and aid ascent tracking, we prefer to have a good position fix on Sentry before it leaves the seafloor at the end of the dive.

Data Delivery

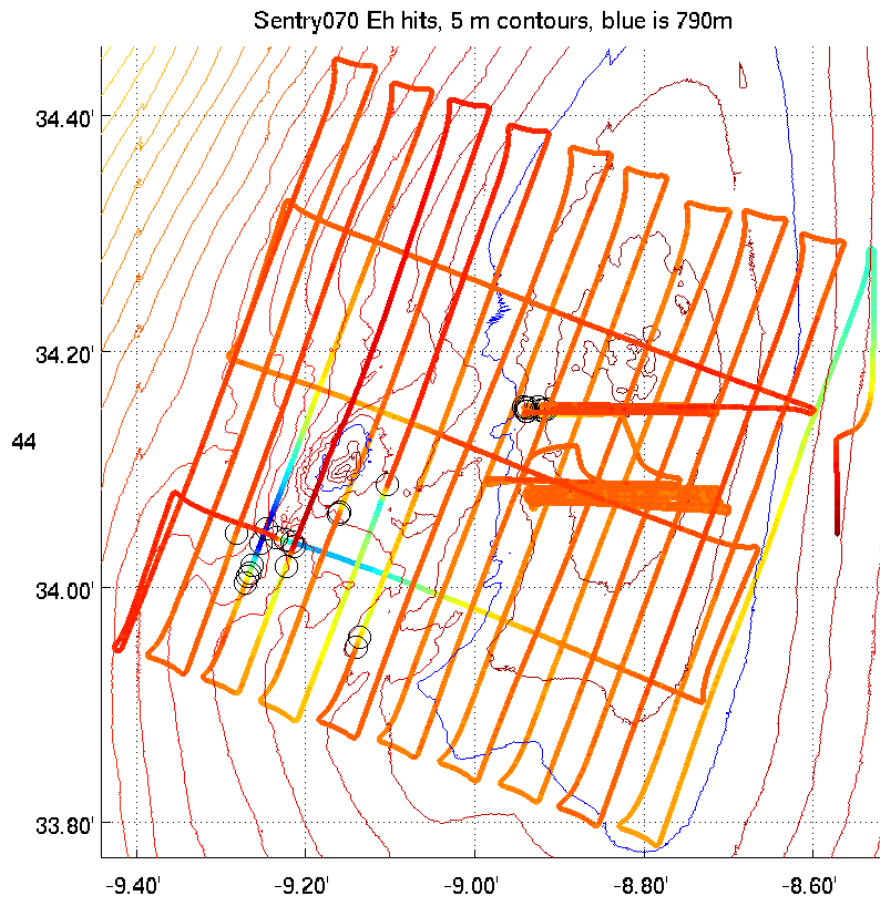
Science sensor (e.g., CTD, OBS, eH) data are typically available to the science party within 3 hours of the end of the dive. The large amounts of multi-beam, sub-bottom profiler, and camera data typically require long download times. Preliminary multi-beam maps are usually available within 6 hours. Camera imagery post-processing is automated but (depending on the number of images obtained) requires 12 to 24 hours before the final pictures can be delivered to science. The raw photos are available as soon as the images have been copied off of the vehicle.

At the end of the cruise, we provide science with a copy of all of the data on external USB hard drives (formatted as FAT32). If a ship data server is available, data files such as the SCC files and the multibeam sonar GRD and postscript files are uploaded to the server as they are completed. Science can bring additional drives if they need extra copies. In addition to the data, we provide science with a cruise report summarizing Sentry operations and data products during the cruise.

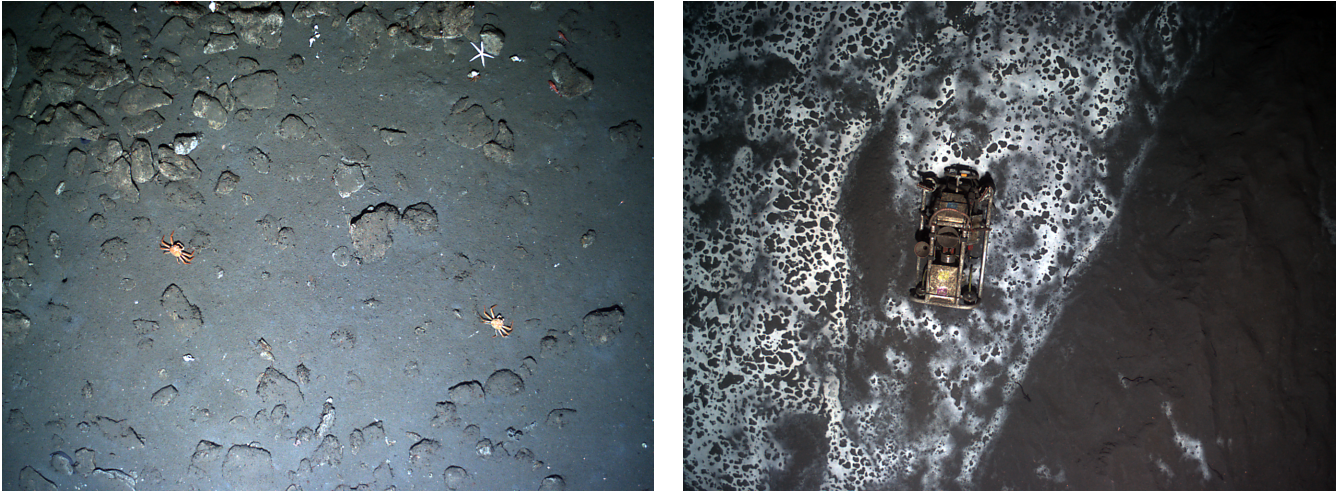
Examples



These plots show examples of data from the GRUVEE2010 cruise to the Galapagos Rift (John Sinton, University of Hawaii, Chief Scientist, Scott White, University of South Carolina, co-Chief Scientist). Like the previous plot, the vehicle flew at 80 meter height with 200m spaced tracklines. The final data processing was done by the scientific party using Fledermaus.



This plots show the redox data from the Nakamura Eh probe on the post-processed vehicle trackline. The spots with high negative changes in the reported voltage are indicated by the black circles. This data is from the Enlighten10 cruise, Chief Scientist John Delaney. The Nakamura Eh probe is available on Sentry by arrangement with Dr. Ko-ichi Nakamura.



Typical Sentry photos taken at 5m height. The left image is from Hydrate Ridge (Enlighten10 cruise, J Delaney Chief Scientist), the right image shows the LOOME camera and microbial mats on the Haaken-Mosby Mud Volcano (Antje Boetius, Chief Scientist, C. German, Principal Investigator). These photos have been equalized and color balanced.

