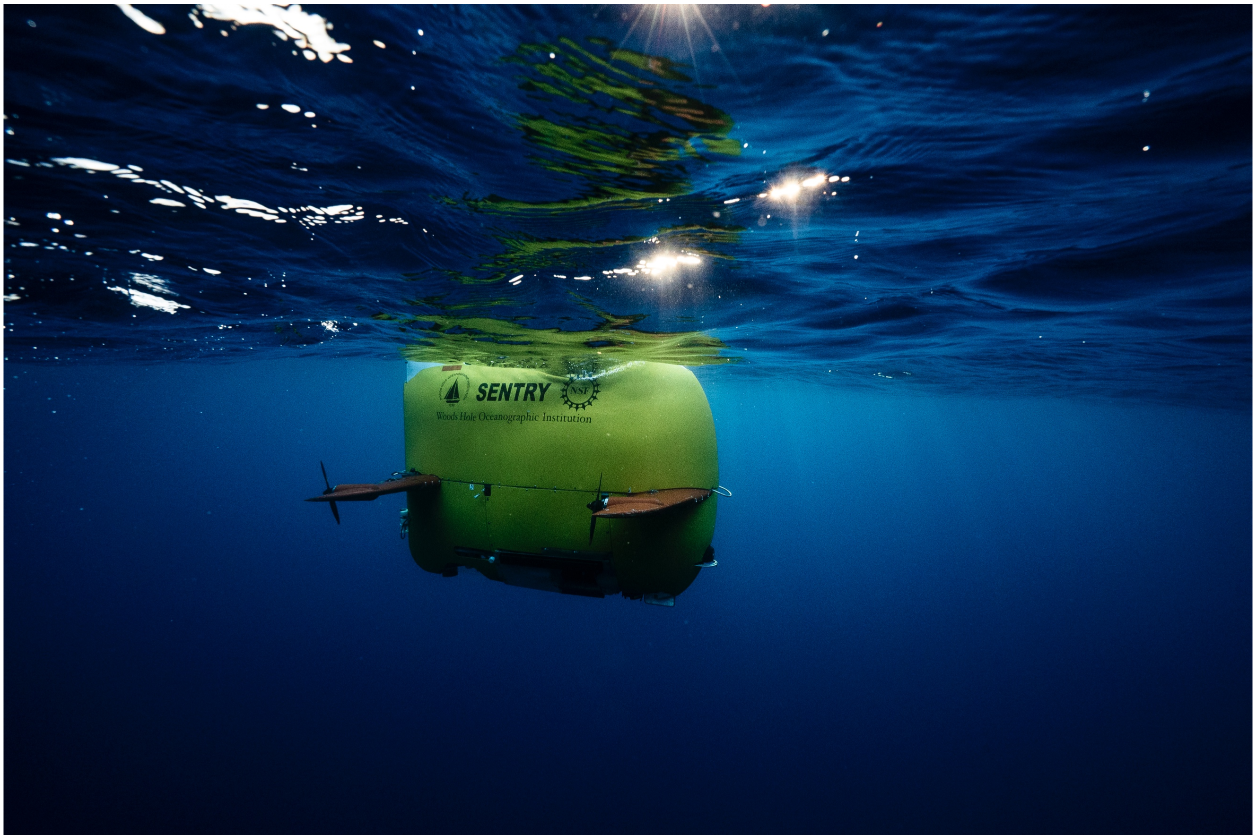

AUV SENTRY USERS GUIDE

A guide for cruise planning and proposal writing

NDSF NATIONAL DEEP SUBMERGENCE FACILITY

Preface

Take the first step to succeed in your underwater missions using Sentry Users Guide v2.1!

Autonomous Underwater Vehicle (AUV) *Sentry* is a world class turn key solution providing the required hardware, staffing, planning, and first run data processing for successful AUV operations. As a part of the National Deep Submergence Facility, AUV *Sentry* is a national asset for the use of the scientific community and beyond. Major AUV *Sentry* system capability includes: system mobility/integration, vehicle maneuverability, and expandability with technological innovation.
AUV *Sentry* is a programmable, flexible platform capable of exploring the ocean and seafloor down to 6km. The *Sentry* vehicle design allows us to have significant advantage over conventional torpedo shape AUVs in maneuvering and cornering underwater over difficult terrain while making precise target mapping, remote/chemical sensing, etc.

Innovation is a key focus to AUV *Sentry* Operations and engineering. Frequently this includes integration of custom sensors, development of new survey patterns, adaptive survey techniques, and joint operations. Development, customization, and integration can be expected on nearly every Sentry cruise. Complex sensor development and integration can require additional planning and funding or community consensus for the added capability. The Sentry group thrives on engaging and discussing new and innovative technologies with users directly.

AUV *Sentry* is a "fly away" system, move quickly around the world in two 20ft ISO containers by road, sea, or air freight, capable of being integrated into a wide range of vessels, including UNOLS, private, and foreign.

A complete follow-through our users' needs, including pre-proposal stage consultation (sentry_program@whoi.edu), pre-cruise planning, logistics support, and post-cruise assessment, is our priority. We would like to specifically emphasize that crafting your proposals ensuring the best use of Sentry Operations is crucial for success of proposed dive missions; users can lean on the Sentry group for guidance together with navigating your thoughts through this Users Guide v2.1. For this reason, we build this guide for various level of users with the basics of Sentry operations along with examples and descriptions of data products produced by the Sentry group. We look forward to hearing from and working with you soon.

Sean Kelley
AUV Sentry Program Manager
[feel free to send an inquiry: sentry_program@whoi.edu]

Disclaimer

- Things described here is ad hoc, and will be subject to change. The best to ensure the most updated information, please contact: Sentry_program@whoi.edu
- Roles described on the Sentry ops. Team may be rotated around, split up, or otherwise reconfigured by the Expedition Leader for operational or training reasons.

Version 1 (2016) Carl Kaiser, Adam Soule et al.
Version 2.1 (2018.10.26) Sean Kelley, Masako Tominaga, Ian Vaughn et al.

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Using Sentry

Sentry Operations has matured and benefited from the long and deep knowledge base at Woods Hole Oceanographic Institution. The Sentry group is constantly developing and improving all aspects of operations. We strive to make all operations and the process as a whole as seamless as possible, while maintaining a safety level.

Sentry operation team thrives to communicate with users at various stages of Sentry mission planning, from pre-proposal writing, to scoping out necessary engineering development to integrate sensors, to helping and planning dives, and to executing the planned missions. The first contact at any of the planning stages can be made via sentry_program@whoi.edu

Once a cruise is officially scheduled, lead PI(s) will receive Welcome Chief Scientist letter (see also A4.1). The Sentry Team will communicate with users to set up a first dive planning meeting discuss the goals, needs, and circumstances of proposed cruise in case there are significant issues that need to be addressed well ahead of time.

The Sentry Expedition Leader will be the primary point of contact with the Sentry group both in the final run up to the cruise and once science teams are at sea. The expedition leader may or may not be writing the actual mission plans (most of the time they will be) but they will be responsible for all of the logistics and timing of the Sentry vehicle. They are there to make cruise missions as successful as possible. Should there be anything that one requires or concerns, talk to the Sentry Expedition Leader early and often.

In addition to making cruise missions as successful as possible, the Expedition Leader also has an ultimate responsibility for the safety of all of the Sentry personnel and equipment. In the event of difficulties such as weather or malfunction, the Expedition leader will work closely with chief scientist(s) and the Captain to develop plans and make decisions about the ability to operate. At the end of the day, if the Expedition Leader decides that the vehicle cannot safely dive at a particular time or place due to weather, malfunction, staffing, bottom hazards etc. that decision will be final and will not be questioned from shore.

Vehicle Specifications

Sentry is a 6km Autonomous Underwater Vehicle (AUV) designed for extreme mobility. To date it has completed more than 400 dives from 19 different vessels. *Sentry* is typically used for systematic survey, but is also capable of more adaptive missions in some cases.

General
Length: 2.9 m (9.7ft)
Width: 2.2 m (7.2ft)
Height: 2 m (6.5ft)
Weight: 1,451 kg (3,200lb) without extra science gear
Operating depths: < 6,000 meters
Operation endurance: variable and mission specific, e.g. common mission endurances, ~23 hours of multibeam at 1m/s speed, >30 hours of camera survey at 0.6m/s speed.
Operating speed: 0-1.2 m/s (0-2.3 knots)
Descent/Ascent speed: 40m/min for both descent and ascent.

Electrical Power
Lithium Ion batteries: 18 kWh
Recharge time: 10 hrs nominally, or 16 hrs full turnaround from surface to release.

Clock
Tillier clock (Seascan Inc.), syncs to GPS time within 10uS, and jitter of 1uS, 1.5sec per year drift (Or 4.1uSec drift in 24 hours)

Navigation
USBL Navigation with real-time Acoustic Communications
Doppler Velocity Logger (DVL)
Inertial Navigation System (INS)

Vehicle Tracking
Acoustic model (WHOI micro modem)
Irridium GPS
Strobe
Radio

Propulsion
4 brushless DC electric thrusters on pivoting wings

Vehicle Sensors

Standard sensors on Sentry
Pressure: Parascientific 8B7000-1m Digiquartz depth sensor (7000 m rated)
Doppler Velocity Logger (RDI 300 kHz or 1200 kHz option)
Attitude sensors (pitch, roll, heading-internal)
PHINS (IXSEA PHINS 1 INS)
Sonardyne Ranger 2 w/ Avtrack2 (Ranger 2)
WHOI LBL (Custom)

CTD (SBE FastCAT 49)
Dissolved Oxygen (Aandara Optode w/ fast foil)
Turbidity (Seapoint Optical Back Scatter (OBS))
Side Scan Sonar (Edgetech 2200-M 120/410 kHz)
Sub Bottom Profiler (Edgetech 2200-M 4-24kHz)
Magnetometers (APS 1540 3-axis proton procession)
Camera (Prosilica GC-1380C Digital Still Camera)
Lighting (OIS 3831 Strobes)
Multibeam (Reson 7125 MBES 400 kHz with 7216 receiver)
NOAA ORP (oxidation-reduction potential) sensor

Scientific Instrumentation Support for sensor integrations
Power: 12, 24 and 48 VDC switched circuits available, custom voltages upon request
Digital sensor interface available
Hard-wired sensor interface available
Integrated data system: RS232 standard ports available (300- 115,200 Baud)

Instruments are synched to Precision Clock (e.g. the Main computer stack, imaging stack, multibeam, side scan, PHINS gyro, etc. are synched to the clock)

Project specific sensors (examples)
Previously, selected custom sensors are integrated and used on Sentry.

Tethys Mass Spectrometer (R. Camilli, WHOI)
Chelsea Aquatraka (R. Camilli, WHOI)
3-D Image Reconstruction System (O. Pizarro, Australian Center for Field Robotics)
Eh Probe (K. Nakamura, AIMS)
MAPR (Walker, NOAA PMEL)
SUPR microbial and larval filter sampler (C. Beier, WHOI)

WHOI maintains following sensors, which may be available on *Sentry* at little or no additional cost.

Edgetech 850 kHz Dynamic Focus Sidescan
Blueview P900 forward looking imaging sonar

Sentry Operations

Personnel

The Sentry operations team is staffed on a cruise by cruise basis and typically consists of 5 dedicated Sentry personnel. An Expedition Leader will be designated from this group of five to manage and run the operations while at sea. The operations team, led by the Expedition Leader, will run the daily operations as they pertain to Sentry. The expedition leader will be the primary point of contact while at-sea and is expected to interface with the PI and Captain appropriately. High level requests or demands must go through the Expedition Leader. Additional members of the operations team are selected to support the demands of the cruise, and will often include mechanical/software/electrical engineers. Special members of the team can sometimes include a special skillset such as, multibeam processing, sidescan processing, etc.

1. Expedition Leader
2. Mechanical Engineer
3. Electrical Engineer
4. Software Engineer
5. Mech/Elec/Software Engineer

General responsibilities by each personnel can be described in detail in Appendix 2.

Operating Vessels

The AUV Sentry is specifically designed to operate from a ship of opportunity and have the ability to adapt to different vessels and configurations. Prior to cruise planning and proposal writing, users are required to consult with ship operators and the Sentry Operations Management (sentry_program@whoi.edu) to ensure a successful integration/operational plan. There are many factors to consider when planning Sentry operations; ship size, capability, deck operations, handling, to name a few. The Sentry group is committed to ensuring a safe and practical integration on any vessel of opportunity that satisfy our minimum requirements.

For more details, please see:

- Appendix 4. Ship Selection and Deck Operations Guideline.
- UNOLS cruise planning guideline
- UNOLS ship time request

Port Operations

Every port has its own set of advantages and disadvantages that can greatly affect port operations. The Sentry operations group will develop a logistics plan to insure a successful mobilization or demobilization. It is impossible to plan for every issue that may come up, and the experience of the operations group with onshore support will address issues as they arise.

Typical Mobilization and demobilization specifications for Sentry:

Mobilization:

- Duration: typically* 2 days
- Need to be loaded: 2 x 20' ft containers (server van and vehicle van)

- Crane > 100 tonnage
- Forklift > 6,000 lb rated
- Adequate dock space and stability to operate above equipment (and trucks).

Demobilization:

- Duration: typically* 1 day
- Need to be off loaded: 2 x 20' ft containers (server van and vehicle van)
- Crane > 100 tonnage
- Forklift > 6,000 lb rated
- Adequate dock space and stability to operate above equipment (and trucks).

Users Working in Foreign Ports

For those who will use foreign ports,

- UNOLS white paper (https://www.unols.org/document/white-paper-operations-foreign-ports-and-waters)
- UNOLS Cruise Planning (https://www.unols.org/ship-schedules/cruise-planning-information)

Notes*:

- What's needed to be loaded/off-loaded will depend on prior- and subsequent Sentry cruise schedule.
- The durations above do not include the day of sailing or the day of return to port. The vessel and crane must be available first thing in the morning on the day of mobilization and demobilization.
- Should there be any difficulty in installing at least one 20ft container on the main deck and one additional container on the vessel, additional mobilization and demobilization time will be required.
- If custom instruments are to be integrated and cannot be integrated ahead of time, it may be necessary to extend the mobilization time.
- If projects are made directly by the client, and it has a bearing on acceptable mob and demob ports.

Weather Windows and Considerations

Sentry operations are subject to weather conditions like most at sea operation. The Sentry group constantly monitors the weather throughout the cruise and will address any limitations that may arise due to weather. While there are many factors that play into managing operations with the weather; wind, sea state, vessel pitch and vessel roll are the major decision factors for the Expedition Leader. Typically, the Sentry group will subscribe to a private forecast service that will be shared among the ship and science. Based on this forecast and observed conditions, it will be necessary to make a dive/no dive decision. This decision can be made collaboratively between the Expedition Leader, the Captain, and the Chief Scientist as well as anyone else that the three of them feel should be present such as a Bosun, or Sentry deck ops lead. An on-going Sentry dive may be canceled at any point based on current weather conditions by the Expedition Leader as well as impending weather conditions. Principles for weather-related operational decisions are described in detail in Appendix 3.

Cruise and Dive Planning

The Sentry operation management welcomes and strongly encourages users to communicate with us as earliest as the project development stage. Idea and information will be kept confidential.

- UNOLS Cruise Planning (https://www.unols.org/ship-schedules/cruise-planning-information)
- Appendix 4. Pre-proposal writing and Pre-cruise procedure

Survey Types

There are a very wide variety of survey techniques with current sensor configuration and we frequently invent new ones to solve new challenges. Discussions with Sentry personnel beginning at the proposal stage are recommended and it is important for scientists to express their needs during the pre-cruise planning meeting so that we can work out any new techniques required. Addressing any limitations in a Sentry survey should be completed well ahead of the cruise to ensure Sentry can meet the science objectives and goals.

Actual mission planning will take place at sea since factors such as current, weather, etc invariable change any plan once ship is on site. While at sea, one of the five Sentry group members will be designated as the mission planner. This individual will interface directly with the user and drive mission planning and logistics.

Vehicle Navigation, Monitoring/Tracking

Sentry requires both internal and external navigation. The internal navigation is sufficient to navigate the vehicle for quite a while; depending on terrain between a couple hours and a full dive. However, the external navigation is required to reset the internal fix after descent and periodically throughout the dive. Final navigation is post processed using proprietary code and can be delivered in a variety of formats.

Internal and External Navigation

Sentry's internal navigation is dead reckoning based on the Inertial Navigation System (INS) and Doppler Velocity Log (DVL) sonar system. It has a typical accuracy of 0.1% of distance traveled. It does sometimes struggle with bare volcanic rock or very steep terrain requiring more frequent external updates. The internal navigation is not effective during ascent or descent and is only minimally effective if the vehicle is not within 200m of the bottom. This requires much more frequent updates from an external solution.

Sentry's external navigation uses either Ultra Short Baseline (USBL) or Long Baseline (LBL) navigation. As a practical matter we nearly always use USBL and if science party have any plans to use LBL we will need to know well in advance. USBL requires 8-12 hours early in the cruise and then no further calibration or survey is required for the remainder of the cruise. Typically the vessel must be within 1 water depth (closer in very deep water) after descent and every 4-6 hours on bottom for this to be fully effective. More frequent coverage will be more effective.

LBL requires the placement and survey of subsea transponders. These have the advantage of not requiring the close presence of the vessel more than occasionally for a health check, but require 8-12 hours each to deploy survey and recover. They must be reset and resurveyed in each area and typically three are needed in any given area, approximately 5x5km. We will still need to check on the vehicle occasionally as described in **Error! Reference source not found.**.

During nearly all cruises we rely on USBL navigation and acoustic communications. While the dead reckoning system on Sentry is typically capable of running the vehicle for an extended period of time without external aiding, the quality of the data, particularly for multibeam will be significantly better with regular external updates. This requires periodic co-location of the vehicle with the vessel within 2-3km in less than 3km of water, and gradually closer as the depth increases.

In addition to Navigation considerations, there is a vehicle risk issue. If we do not have any indication of whether Sentry is coming to the surface or not, it is possible for the vehicle to abort and arrive at the surface without us knowing. For this reason and to get a heath message from the vehicle we prefer to either stay within range of the low frequency transponders (typically 6 – 8km slant range) or else check on the vehicle at least once every 6 hours.

<u>Tracking and Air Traffic Control</u>

Any instrument in the water at the same time as Sentry must carry a USBL transponder. We typically have one or more spare units but can't always guarantee that, especially if the water will be deeper than 6km. Provided that we have reliable tracking for both assets, we are typically willing to operate with as little at 100m of vertical separation (cabled asset above Sentry) or 200 – 300m of horizontal separation with a quickly retractable instrument such as towcam or a CTD. For cores or dredges it would be more typical to prefer half a water depth or more. In all events the final decision about standoff distances will be up to the Expedition Leader.

Understanding Terrain for Dive Planning

Sentry is able to operate in terrain that is much more difficult than most AUVs and the limits of the terrain that Sentry can operate in are increasing steadily. However, it is important to understand that difficult terrain can pose significant challenges. The difficulty posed by terrain is affected by a number of factors:

- Average slope – average slope is an important consideration but is often secondary to other characteristics
- Maximum slope – often this is more critical than average slope. If there are local maxima in the slope and a mission needs to cover those areas, those maxima will either have to be avoided and surveyed with longer range sensors, or else be within the capability of the vehicle.
- Roughosity (cliffs) – the presence or absence of (near) vertical terrain features of approximately magnitude of the altitude of the vehicle is an issue. This is especially true during low level flight such as photo surveys. We are actively working on this capability but it can remain a challenge
- Map quality – bathymetric maps are very helpful in planning missions around or along terrain features that would otherwise be beyond the capabilities of the vehicle. In order to be useful for this, the maps must be of sufficient resolution to show the features of concern thus in some terrain it may be beneficial to obtain high resolution bathymetric maps with Sentry on a prior dive before attempting near bottom work such as photos.

Data Coverage ***Examples***

High Coverage Multibeam:

The maximum swath with the Reson Multibeam is 180 - 200m in most terrain. This will generally occur at an altitude of 60 – 80m depending on terrain, bottom composition, and any other goals for the dive and will have a forward speed of approximately 1.8knts (0.9m/s) for best data quality. 120kHz sidescan can be obtained simultaneously.

Coverage Rate ~= 0.55 – 0.65 km^2/h of bottom time

Typical Grid = 1-1.5 m

Maximum Resolution Multibeam:

The maximum resolution multibeam achievable by Sentry is approximately a 0.3 – 0.5m grid and typically occurs from an altitude of 20m with a swath of 50 – 60m depending on terrain. Forward speed will typically be ~1.4knts (0.7m/s) though faster speeds are possible if the entire dive will consist of only this option, or if asymmetric grids (e.g. 0.3 x 0.5 for example) are acceptable. 120kHz sidescan can be obtained simultaneously.

Coverage Rate ~= 0.12 - 0.15 mk^2/h
Typical Grid = 0.3 – 0.5 m

Wide Area Sidescan:

The widest area sidescan coverage is obtained with the 120kHz system. The maximum effective swath it typically 600m unless survey sites are in steep terrain. This does not provide sufficient overlap to fill the nadir. For best data quality, this should be run at a forward speed of 1.8kts (0.9m/s). Typical altitude is 30m, but this can be run between 30 and 70m reasonably effectively. 30m appears to provide the best data. The multibeam can be run simultaneously, but from 30m the swath of the multibeam will be approximately 90m.

Coverage Rate ~- 1.9km^2/h

High Res Sidescan with Photo Strips:

A common technique is the simultaneous acquisition of 410kHz sidescan data with a photo strip down the nadir. Effective swath for this technique is approximately 150m in relatively flat terrain. Altitude is 5m and a speed of 1.8kts (0.9m/s) s recommended. The photos will have approximately a 5mx5m viewable area.

Coverage Rate ~= 0.45km^2/h

Dense vs. Sparse photo coverage:

Dense photo coverage implies approximately 30% overlap in the long track direction with a nominal 20 – 30% overlap across track. In practice, there are often small gaps between tracks especially in steep terrain or variable currents. Typical photos are 5mx5m and forward speed is 1.4knts (0.7m/s)

Coverage Rate ~= 10,000 m^2/h

In cases where the adjacent track lines become more spread out and overlap along track, the coverage is reduced by increasing vehicle speed to 1.6knts (0.8m/s).

Coverage Rate (50% across track no overlap) ~=25,000 m^2/h

Coverage Rate (10% across track, no overlap) ~= 130,000 m^2/h

Joint Operations with Other vehicles and Assets

Sentry regularly operates with other over-the-side assets in the water concurrently, including Remotely Operated Vehicle (ROV)s, CTDs, Towcam, and dredges. This is inherently an efficiency booster to accomplish multitude of survey and sampling, but also a higher than normal risk operation which requires careful attention. The information below is a guideline, but all decisions of standoff distance and even if joint ops will be allowed are at the discretion of the Expedition Leader when on scene.

ROVs are similar to other cabled assets except that the dive duration is typically too long to allow Sentry launch and recovery to take place with the ROV in the water. Under some circumstances we are willing to launch and or recover Sentry with the ROV in the water. This is highly subject to the deck layout of the ship, the sea state, the vessel characteristics, etc. If planning on this, we suggest science users contact us well in advance and have a backup plan in case sea state shuts down such operations temporarily. We certainly don't want to discourage such operations as they are very effective and we routinely do this, but it is a more complex planning situation.

To date we have not operated both an AUV and a human occupied vehicle (HOV) at the same time. The typical scenario is to alternate times in the water with the HOV diving during the day and Sentry at night. The limitation may be reconsidered in the future.

The most critical element during any joint operation is preventing collision between Sentry and the other asset or the cable. Sentry is not able to see or avoid something the size of a cable, and likely not a vehicle either. Secondary considerations include ensuring navigation for both vehicles, keeping an eye on Sentry, and being ready to recover Sentry at the proper time.

Dredges, CTDs, Towcam, etc. are characterized typically short-duration operations relative to the length of an AUV dive. In these cases, we strongly prefer to bring these assets to the surface for all Sentry launch and recovery operations.

Dive Durations

Dive durations depends on battery capacity (and sensors power requirements), vehicle speed and payload, terrain, and depth. Dives can generally be as short as desired (with some limitations on numerous very short dives) and can be terminated early on command.

With current battery configurations, and assuming a full (~ 90%) charge, typical values for both hourly usage and dive duration are:

Activity	Range of % battery use/hour	Typical on Bottom in 2km of water
Descent	1.5	N/A
Ascent	N/A	N/A
Multibeam w/ or w/o sidescan	3.4	26-28 hours
Sidescan either type, no multibeam	unkown w/ new batteries	TBD ~ 32 hours
Dense photo coverage	2.2	50-60

Table 1. These numbers are the mean. The Standard deviation can be several tenths of a percent.

Notes:

- Depending on depth, the ship must be in USBL coverage (typically ½ - 1 water depth) two to three hours ahead of planned surface time. The exact timing will be up to the Expedition Leader, but the goal is always to have confirmed tracking at least 30 minutes before Sentry leaves the bottom. Depending on the uncertainty of the time of end of mission, weather, currents, vessel, and many other factors, this may be as much as 3 hours.
- It will be necessary to remain in USBL and acoustic modem range (typically less than ½ water depth) during most of the descent and bottom approach as well as the first 10 – 30 minutes of the mission. Exceptions to this are possible but will significantly degrade navigation and should be discussed before the cruise if not before the proposal.
- While we will make every attempt to accommodate late breaking circumstances and information, depending on staffing, any changes to the mission plan less than four hours before launch may delay the launch. Under certain circumstances this can be pushed as close as 45 minutes, but this requires planning at least a year in advance if science users anticipate doing this on a regular basis as this imposes very specific needs on cruise staffing.
- This schedule assumes a full recharge of the batteries. This is not always necessary as described under crew rest below.
- Crew Rest - For safety as well as quality of life reasons, each person needs eight uninterrupted hours of sleep in every 24 hours and this must be at nearly the same time each 24 hours.

Turn around time

An example: 24 hrs (partial dives) vs. 48 hrs (full dives) cycles

In this scenario, Sentry will launch and recover at approximately the same time every day. In practice this typically will mean a 12 – 14 hour on bottom depending on water depth. This is especially common when operating with other assets such as Alvin or when operating from vessels with limitations on deck operations.

In 48-hrs cycle scenario, we reduce the forward speed of Sentry which improves power consumption and go to a 48 hour cycle where Sentry launches and recovers at the same time every 2 days. The lower power consumption leads to longer dives and hence makes up for some of the speed loss. This is effective with very little loss of coverage when doing dense photo surveys, and can be done with other types of surveys typically with a 10 – 20% loss of total coverage. This schedule has most often been used when other assets such as seismic systems are also deployed which can extend the desired Sentry turn around a bit as well.

Turn around time is most typically limited by battery charging. Nominally a full turnaround is 16 hours, which is divided as shown:

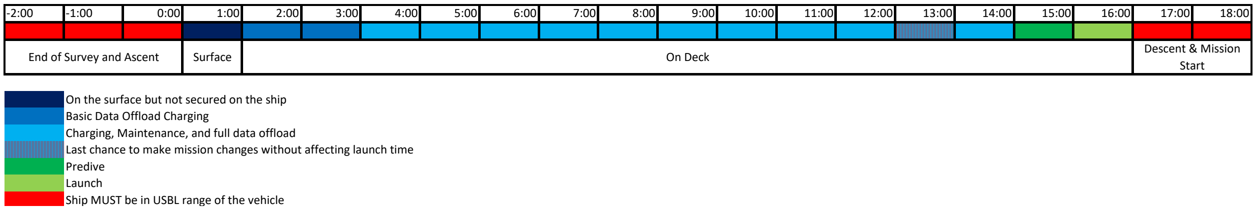


Figure 1 - Conservative Breakdown of Standard Turn Around Time

An accelerated turn around with a partial battery charge is also possible. This faster turnaround results in only 75 – 80% of the battery capacity useable to science but saves 5-6 hours in the turnaround at a typical cost of 2-4 hours of dive time. The space between these two options is a continuous spectrum. In practical point, the decision between these two turn around options will often be decided based on crew rest considerations as described below.

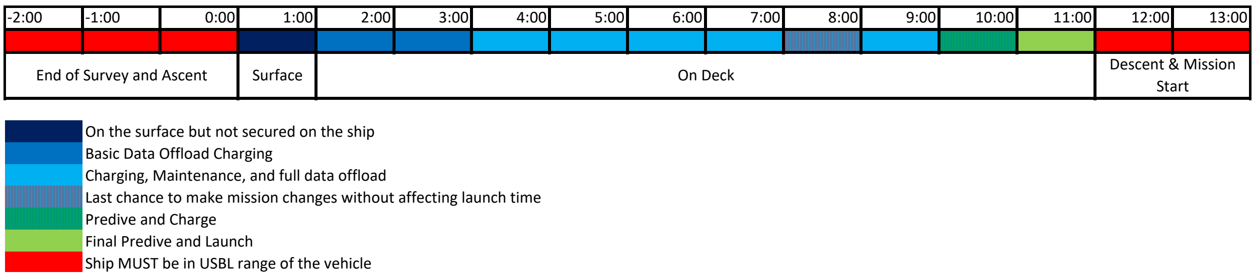


Figure 2 - Accelerated Turn Around for Partial Battery Charge

Blackout Window

This is the most common schedule for Sentry. In this scenario, prior to the beginning of the cruise, the Chief scientist designates an 8 hour window during which Sentry will not launch and will recovery only in an emergency. This window is the same time every day for the duration of the cruise. We will launch or recover on either side of this window (but not immediately on both sides in the same day) this means that the with the pre and post requirements of launch and recovery, staff are not required to shift their sleep period by more than two hours any given day. When combined with an accelerated turn around, this results in very little loss of total coverage since the dive can be moved up (and shortened) slightly or delayed (and lengthened) slightly to keep out of the blackout window.

Data and Data Handover

The chief scientist of each cruise will receive 1 copy of all raw and processed data from the cruise. This copy may also include intermediate products, nascent products, mission planning files, and other elements which are described in a "Data Deliverables Summary" that users will receive with the drive.

Storage Media Formatting

Media formatting is a difficult issue given the variety of platforms. All of our data storage uses Ubuntu Linux and the EXT4 filesystem for internal purposes. We strongly recommend that users do the same if users are able but recognize that other formats may be necessary. We can provide a freeware plug-in to allow easy access to EXT4 from a windows PC, but we have not yet found a viable way to enable this for Mac. We are also able to write NTFS formatted drives for Windows. During dive planning meeting, we will ask users to confirm preferable media format.

Additional Copies

As a part of a cruise, the Chief Scientist will receive one copy of the data in the form or one or more external hard drives or raid arrays. We are happy to write additional copies, but users must provide the media in a format compatible with our systems. The exact media needs will vary by cruise, but typically will be either:

- 5 -8TB USB3.0 external harddrives (Typically $150 - $200 each drive)
- 1 – ProRaid 4bay, USB 3.0 (UBB 2.0 or esata are not acceptable) with 4 - 5TB drives installed. Expect these to cost $1200 - $1500 each with drives.
- In extreme cases two or more of the pro-raid boxes may be required per cruise.

If brought up during pre-cruise meeting, we should be able to provide a good idea of what will be needed and can point users to specific links for purchasing the correct items online. We currently use either 5TB or 8TB USB3.0 "Expansion Desktop Drives" from Seagate and recommend users provide the same.

Data Archival Protocol

Currently, all data (including images) from all Sentry cruises are returned to WHOI for archival in accordance with NDSF data management policy. Data will also directly send to IEDA archive. At the end of the cruise, Chief Scientist will be asked to sign a receipt for the copy of the data, including a question about data restrictions. NSF Data Management Policy allows Sentry data to be restricted for up to 24 months. Dive metadata will be posted on the NDSF website.

Organization of Delivered Data:

Sentry cruise data has been organized in several different ways since the start of operations. Since January 2014, data has been organized generally as described below. However, because we are continuously seeking improvement and because we often add custom systems, small additions or variations still occur, particularly in directories used for intermediate products. The specific data directory organization for a cruise is typically described in the cruise report. Please contact us directly with any questions. Cruise data is organized into a number of directories. The top level directory structure contains the directories:

- Dives - All raw and processed data from individual dives
- Docs - Documents pertaining to the cruise such as launch positions and dive statistic summaries
- Planning - Files pertaining to mission planning. These are not generally needed by science
- Planning-bathy - This is the bathymetry provided by science for planning purposes
- Plots - Auto-generated plots from the post processing pipeline
- Products - The best at sea derived data products from the cruise
- Raw-usbl - Log and configuration files from the Sonardyne USBL system
- Svp - Sound velocity profiles used during the cruise

At-Sea Processed Data Products - Products Directory

The products directory contains a directory for each dive in the format sentry<xxx>. Most data products include a time and date stamp in the file name. For images that is the time the image was taken, for all other products that is the time of the renavigation process and can be matched to other files created with the same navigation.

Within each dive directory the following directories are included:

- hf-sss - This directory contains data products generated from the 410kHz sidescan sonar system. Note that for a particular survey it is typical to have only HF or LF products, not both.
- lf-sss - This directory contains data products generated from the 120kHz sidescan sonar system. Note that for a particular survey it is typical to have only HF or LF products, not both.
- Multibeam - This directory contains the data products from Sentry's multibeam sonar including grd and pdf files. Most users will want to use the file
    - sentryxxx_yyyymmdd_hhmm_nav_tide_xxx.grd where X is the grid size. If \verb=_nav_= is included in the file name this means that mbnavadjust was applied. This is not common but if available these files are probably preferred to others.
- Photos - This directory contains thumbnails and movies of the photos collected by Sentry. Full resolution photos can be found in the dives directory.
- Sbp - This directory contains the products from the sub-bottom profiler.
- Scc - SCCs are 1Hz ASCII files containing post processed navigation and selected other science data. The timestamps on the SCCs can be matched to other data products. This flat ASCII file contains the date, time, latitude, longitude, depth, pressure, heading, altitude, data from one of the magnetometers, optical backscatter (if available), Oxygen Redox Probe, dissolved oxygen (if available), conductivity, temperature, and sound velocity. The file name contains both the dive number and the date on which the scc file was generated. If there are multiple scc files for a single dive, use the file with the most recent date. All fields in the scc file have been interpolated onto a 1 second time base. Users wanting to load the data into Matlab should use the mat files in the nav-sci directory.

Raw and Intermediate Data - Dives Directory

The dives directory contains the raw and intermediate data for each dive. Within the dives directory there will be a directory for each dive labeled as sentry<xxx>. Typically there will also be a directory labeled pre-cruise that contains assorted data from tests conducted prior to the first dive.

Within each dive directory the following directories exist:

- multibeam
  - raw - raw s7k files. Does not include navigation data
  - proc - all mbsystem files and inputs
  - nav - vehicle navigation data
  - log - real-time driver output. Not generally useful for data processing
  - timing_test (optional) - separate directory used to compute or check timing offsets if relevant
- nav-sci - This directory contains all of the navigation, science, and engineering data logged by the vehicle during the dive. Most of this data is provided for archival purposes only. The scc files provide all standard sensor and vehicle navigation data. Users wishing to load data into Matlab, can use the mat files in /proc. The structure of this directory is:
  - nav-sci
    - proc – matlab and other files containing processed data extracted from the rosbag files. Files with the dive number contain data from the dive. Files with a date and time in the name include data from the post-processed navigation solution generated at the date and time indicated. If multiple such files exist, use the most recent. The contents of these files are described in more detail in the Appendix.
    - raw
      - topside-nav - topside tracking data
      - mc - mission controller files
      - rosbag - raw vehicle science and engineering data. Much of this, including all science data, is converted to matlab files in the proc folder during post-processing.
- photos - We provide images in several formats with different levels of processing. These include the raw bayer encoded (color) tif files directly from the camera real-time software should users choose to reprocess those images. We also provide automated processing for color compensation and equalization. Filenames include date and time and can be used in conjunction with the SCC to obtain information on vehicle state and scientific sensors. The photos are stored in the following directory structure:
  - Presently, Sentry takes photos during the planned camera surveys and in the event that the dive ends with a photo survey, also during the ascent. Thus there may be photos of the water column.
  - photos
    - raw --- Bayer encoded original images (not useful without reprocessing)
    - proc - color corrected and smoothed color TIFF photos
    - labeled - color corrected and smoothed color TIFF photos with navigation and some science data interpolated and rendered at the top of the image

        - thumbnails - smaller, jpeg-encoded versions of the labeled photos

- sss-sbp - All of the data from sentry's sub-bottom profiler and sidescan sonar
    - We provide the raw and processed Edgetech sonar data. These data are processed using commercial software 'SonarWiz5' developed by Cheasepeake Inc. into which the raw sonar files (.jsf) are imported. The software generates a project directory structure, associated files and populates the directories for each sonar data set processed. For each dive, there is a folder containing the raw data (jsf) files, the navigated data files and a SonarWiz project sub-directroy for each processed sonar (LF=120kHz, HF=420kHz, SBP=Chirp Subbottom).
    - The structure of this directory is:
        - sss-sbp
            - raw – raw JSF files as recorded by the sonar. These do not include navigation
            - navigated – The raw JSF files after navigation has been injected
            - lf-sss
                - *** SonarWiz Project Directories for low-frequency (210kHz) sidescan ***
            - Hf-sss
                - *** SonarWiz Project Directories for high-frequency (400kHz) sidescan ***
            - sbp
                - *** SonarWiz Project Directories for subbottom profiler***
- Blueview – All data from Sentry's BlueView P900 multibeam imaging sonar. This data is typically only used for collision-avoidance in real-time. The structure of the directory is:
    - *.DAT – Engineering data from the real-time collision avoidance software
    - son – Raw BlueView son files. Can be viewed using BlueView's ProViewer (3.6 or later) software
- subsea-acomm - log files from Sentry's WHOI micro-modem if installed
- topside-comms – log files from various topside communications links
    - acomm – log files from the WHOI micro-modem installed on the ship
    - sdyne – log files from interacting with the Sonardyne Ranger or Ranger 2 system installed on the ship
    - iridium – log files from the iridium satellite modem installed on the ship
- metadata – Metadata generated by Sentry's predive recording sensor configuration, serial numbers, etc. All data is provided in an ini-file format. Each file is marked with the date and time it was generated. If multiple copies of a file are present, use the most recent one from before the start of the dive.

Appendix

Appendix 1. Additional Sensor-related Information and Mission Capabilities

A1.1 Sensor-specification and Mission Capabilities

Sentry is designed for a wide variety of missions in a wide variety of terrain. This section describes the current capabilities of the vehicle and the factors that may impact these capabilities. Capabilities are generally described as "standard", "developmental", "ad-hoc", or "conceptual".

- Standard – Standard capabilities are well established, well tested, do not require any special staffing considerations, have a reasonable level of reliability and spares, and should generally be considered available as long as they are requested on the pre-cruise forms.
- Developmental – Developmental capabilities are capabilities that are established, but have not yet reached the level of a standard capability. Developmental capabilities are usually under improvement with a goal of eventually making them into standard capabilities. Developmental capabilities will generally be less reliable and require closer attendance with the vessel. Developmental capabilities should usually be considered available as long as they are discussed early in the cruise planning process but users should expect less reliability and fewer spares. We recommend users stay in touch with us leading up to the cruise regarding the current capabilities of the vehicle.
- Ad-hoc – Ad-hoc capabilities are things that we have done one or more times in the past but which have not had any significant long term infrastructure development. We can usually re-create ad-hoc capabilities, but these requests should usually be addressed at the proposal stage if they are critical and always as far in advance as possible. It should be expected that ad-hoc capabilities may not work the first time, may be undergoing active development during the cruise, will require the vessel to stay in communications range most of the time, and will probably require specific staffing.
- Conceptual – Conceptual capabilities are capabilities that have been discussed but have never been executed in practice or if they have it was done in an emergency in a one off way that is not readily reproducible. Conceptual capabilities must be discussed in well in advance, preferably prior to the proposal stage. It should be expected that conceptual capabilities will not work on the first several attempts and that incremental improvements will be required. Additional constraints on operations tempo, communications needs etc. should be expected.

Table A1

Operation	Standard	Developmental	Ad-hoc	Conceptual
Multibeam (1m resolution) slopes <60 degrees	x			
Multibeam (1m resolution) slopes >60 degrees		x		
Multibeam (30cm resolution) slopes <45 degrees	x			
Multibeam (30cm resolution) slopes >45 degrees		x		
Digital Still photos slopes <45 degrees – no cliffs	x			
Digital Still photos slopes >45 degrees – no cliffs		x	x	x
Digital Still photos slopes – cliffs > 10m			x	x
120 kHz Sidescan slopes < 60 degrees	x			
410 kHz Sidescan slopes <45 degrees	x			
850 kHz Sidescan slopes < 45 degrees – no cliffs		x		
850 kHz Sidescan slopes < 45 degrees – cliffs > 10m			x	
Chemical sensing surveys	x*			
Magnetic Surveys	x*			
Mid water-column work (>180 mab)		x		
Flight below 5m		x		
Mid mission re-programming			x	
Mid mission survey re-targeting	x			
SUPR Sampling**			x	
SYPRID Sampling		x		
Water column yoyo			x	
Chemical data telemetry		X***	x	
Contour following			x	
Hovering				x
Concurrent ops with cabled assets (ROV, CTD, etc)	x			
Ops with Alvin			x	
Anchoring				x

* Depending on required altitude
** Additional funding required beyond day rate
*** Has been ad-hoc but moving to developmental

A1.2 Specifications of Acoustic Devices

Sentry utilizes a substantial number of acoustic devices. Not all of these devices are installed for every device, but if filling out permit applications, we recommend that users either include all of them on the permit or discuss with us ahead of time to select a narrower list.

Table A2

Device	Frequency	Manufacturer	Frequency can be changed	Max Power
Doppler Velocity Log	300kHz	TRDI	No	216 dB
Doppler Velocity Log	1200kHz	TRDI	No	214 dB
Reson Multibeam Sonar	200/400kHz	Reson	200kHz or 400kHz only	220 dB
Longbase Line Tracking	10.5,13.0,14.0,9.0,10.0,8.5,11.5,9.5,8.0 kHz	WHOI/Benthos	Yes	
XR emergency releases	8-14kHz	WHOI/Benthos	Yes	
Ultra Short Baseline	26.5,19,27,29 kHz	Sonardyne	Yes	193 dB
Sub-bottom Profiler	2-24kHz	Edgetech	Various chirps within that range	210 dB
Side-scan sonar	120kHz & 400kHz	Edgetech	No	210 dB
Altimeter	500kHz	Valeport	No	211.5 dB
USBL	21.0,24.0,28.75,29.25,21.5	Sonardyne	Yes	193 dB
Imaging Mulbtibeam	900kHz	Blueview	no	206 dB

A1.3 Sidescan Sonar and Sub Bottom Profiler

Sentry uses an Edgetech 2200M combined dual-frequency sidescan (SSS) and subbottom (SBP) survey system. When this system is active Sentry will continuously record data in raw JSF format, which is an Edgetech proprietary format. The Sentry JSF files contain both SBP and SSS data with time-stamped headers, but WITHOUT navigation data. Navigation data is injected into the JSF files during post-processing after the AUV navigation has been processed and cleaned.

The dual frequency 120 & 410 kHz sidescan sonar uses Chirp technology and simultaneously transmits linearly swept frequency modulation (FM) pulses centered at two discrete frequencies. These long duration pulses are calibrated with wide band signals to reduce the acoustic side lobes and improve the signal-to-noise (SNR) ratio, thereby improving the detection range of the sonar.

The DW-424 subbottom profiler system also uses Chirp technology and transmits a single digital linear FM pulse to produce acoustic transmissions in an up-Chirp or down-Chirp pattern; sometime referred to as a frequency sweep. A linear FM up-Chirp, moving from lower to higher frequencies, is typical in subbottom Chirp systems. In contrast, one could create an exponential sweep to produce a large frequency range in the same amount of time (or over the same pulse length).

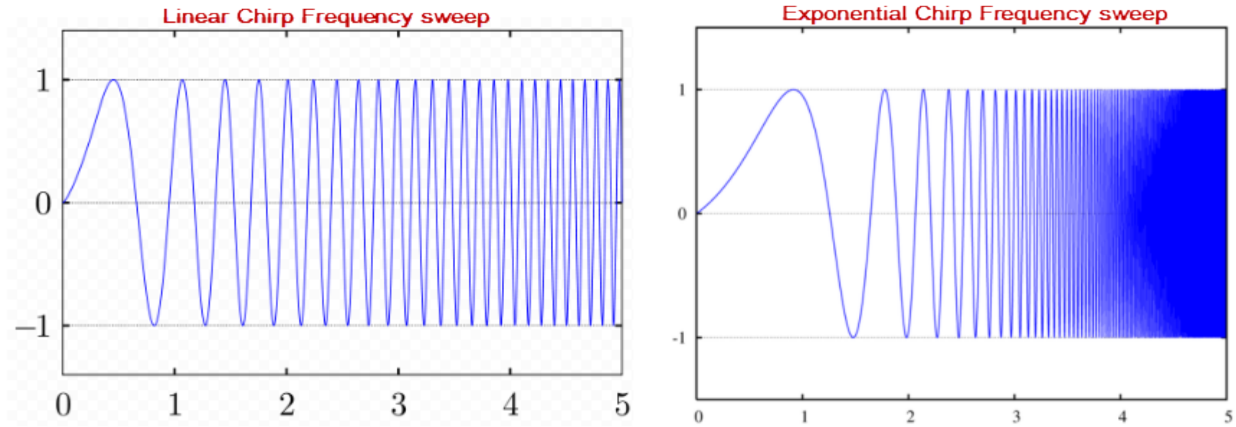


Figure A1: Example of linear & exponential frequency sweep

The Edgetech system produces a linear frequency up-sweep calibrated to generate a pulse spectrum with a Gaussian shape over the frequency range selected. The returns from these sonar pulses are then deconvoluted into a simpler acoustic format / intensity that is no longer frequency dependent.

A1.4 SBP Sonar Resolution, Range and Penetration

The sonar resolution in older single-frequency subbottom systems (i.e. 3.5 kHz) is determined by the pulse length of the transmitted waveform. In the case of Chirp subbottom systems, the resolution limit is determined by the bandwidth of the transmitted pulse. In theory, the resolution of a linear FM chirp system is:

$$\text{Pulse length} = \frac{1}{\text{bandwidth}} \qquad \text{Range resolution} = \frac{\text{pulse length} \cdot \text{speed of sound}}{2}$$

Bandwidth	Pulse Length	Resolution
20 kHz	$\frac{1[s]}{20{,}000} = 0.00005\,[s]$	$\frac{0.00005\,[s] \cdot 154{,}000\,[cm/s]}{2} = 3.85\,[cm]$

The Sentry SBP Chirp system offers six user-selectable pulses with three different bandwidths / resolutions:

Egdetech SBP Pulses

- SB424__4__16__10FM_TSB.spf
- SB424__4__20__5FM_TSB.spf
- SB424__4__20__10FM_TSB.spf
- SB424__4__20__10WB_TSB.spf
- SB424__4__24__5FM_TSB.spf
- SB424__4__24__10FM_TSB.spf

Egdetech SBP manual for SBP424 system

Vertical Resolution[1]	4 cm, 4-24 kHz 6 cm, 4-20kHz 8 cm, 4-16 kHz
Penetration (typical) Coarse and calcareous sand[2]	2 m
Penetration soft clay[2]	40 m
Beam Width -3dB down (depending on the center frequency)	16°, 4-24 kHz 19°, 4-20 kHz 23°, 4-16 kHz

In general, as the bandwidth increases so does the resolution; however, frequency absorption and actual speed of sound in a given sediment strongly influences the resolution and penetration of sonar energy. Lower frequencies penetrate more while higher frequencies are absorbed faster. This impacts the signal bandwidth, effectively reducing resolution with sediment depth.

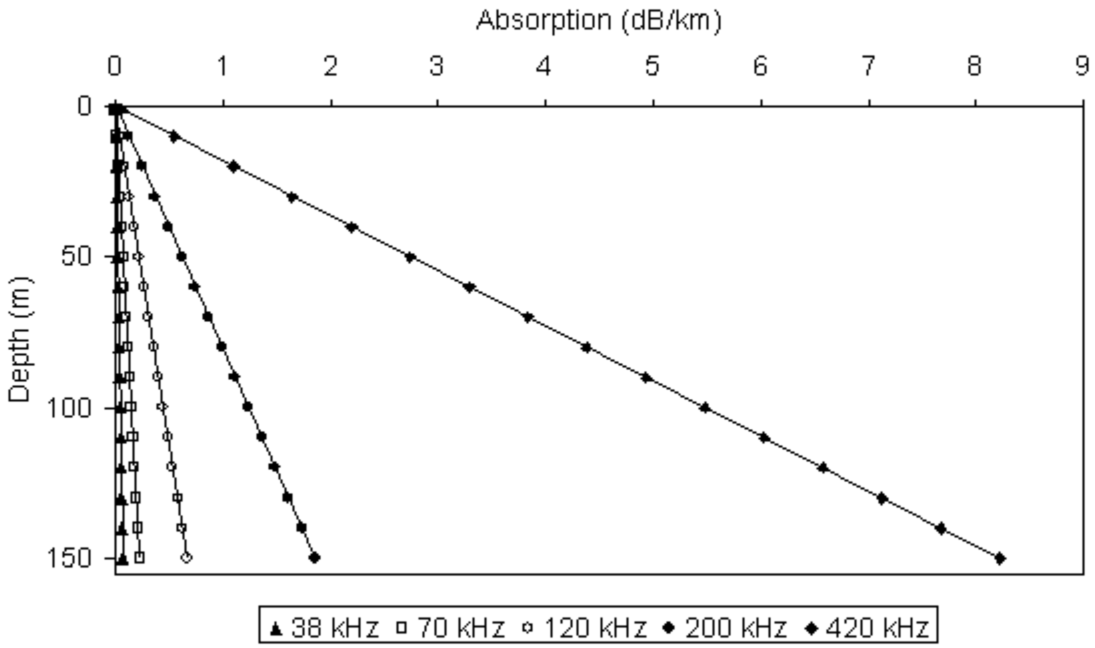


Figure A2: Absorption as related to acoustic frequency

The penetration depth of the SBP signal is defined as the maximum distance beneath the seafloor that a step change in density of 10% can be seen on the sub-bottom display. This value is dependent upon the amount of acoustic energy, the frequency of the energy and the sediment type. SBP sediment penetration for the Edgetech system ranges from ~2 m in coarse sands to 40 m in soft clays.

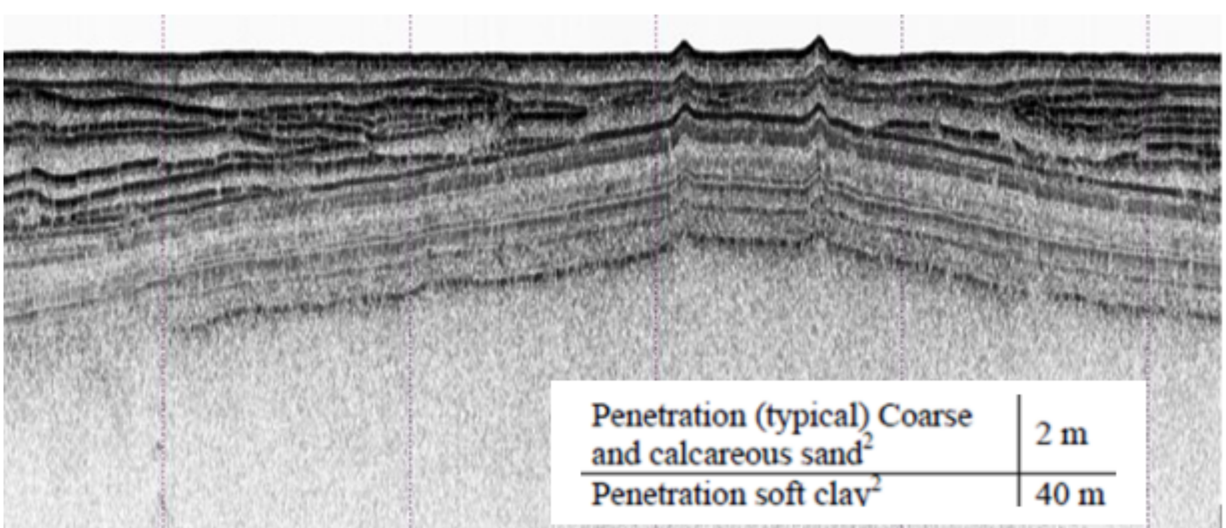
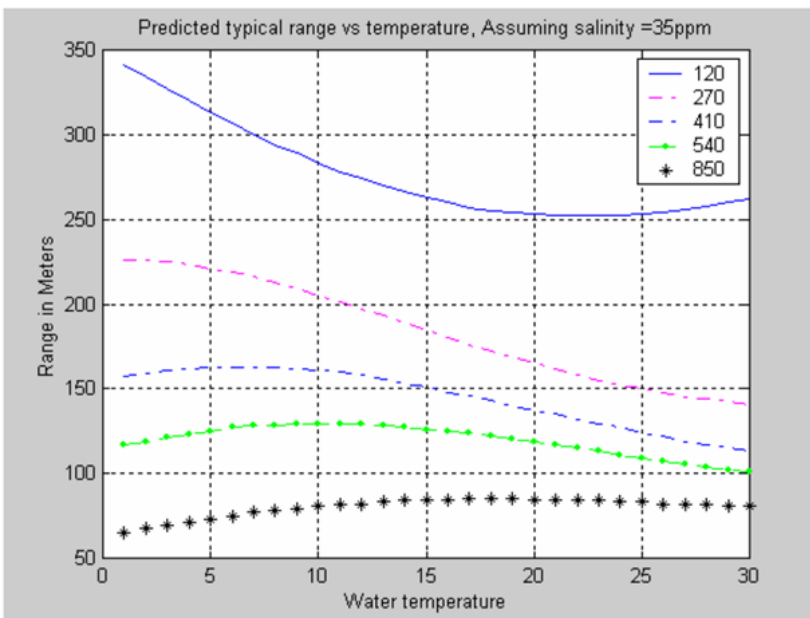


Figure A3: Example of subbottom data from *Sentry* (Image courtesy Christopher German)

A1.5 SSS Sonar Resolution and Range

The resolution of a sidescan system must be independently calculated for across-track and along-track directions. Along-track resolution is largely a function of survey speed, acoustic beam pattern, ping rate and sample rate. Across-track resolution (or range resolution) is largely a function of frequency, acoustic beam pattern and sample rate. For the sidescan system, target threshold must also be considered. If one pixel of data shows a high energy return, it is difficult to distinguish between an authentic feature and noise or scatter. With several adjacent pixels showing high energy returns, the target or feature is more obvious. Edgetech advertises the theoretical range resolution of the 120/410 kHz sidescan at 6.25 cm and 1.8 cm respectively.

The range of a sidescan system is somewhat arbitrary in that the signal to noise ratio varies widely depending upon the size and composition of the target and the environmental conditions (i.e. ambient noise level, electrical and mechanical noise levels, water conditions). The detection range is generally the point at which system noise levels start to compete with returned signal. In the case of Sentry, the background noise levels are minimal, allowing a greater range in which targets and bottom variations can be detected. Operating at deep ocean depths (> xxx?) in a less stratified, colder, more consistent water column decreases acoustic ray bending and absorption, improving two-way energy transmission.



Freq : 75kHz, Range: 700 to 800m.

Freq : 120Khz, Range: 250 to 500m.

Freq : 270kHz, Range : 150 to 300m

Freq: 410kHz, Range: 130 to > 200m

Freq : 540kHz, Range: 100 to 150m

Freq : 850kHz, Range: 50 to 75m

Figure A4: Sidescan range related to frequency & water temperature

Edgetech advertises the "typical operational range" of their 120 and 410 kHz sidescan systems of 250-500 m and 130-200 m respectively. In practice Sentry's 120 and 410 sidescan systems typically see ~300m range at 120 kHz and ~100m range at 410 kHz. However, this varies depending upon environmental conditions and vehicle configurations.

This review of the Sentry AUV Edgetech SSS & SBP sonars is intended to provide the end user with a basic understanding of what ranges & resolutions these sonars typically obtain, while providing enough background for the user to understand why these are not simple issues or constant solid values. Although ignored in the above discussion, there are many other factors that affect sonar systems resolutions:

- System tow speed, attitude and stability (i.e. pitching and rolling)
- Altitude of transducer / tow vehicle above the seafloor
- Electronic signal processing (signal-to-noise ratio and sampling rate)
- Horizontal beam width, side lobes, acoustic array quality / response
- Pulse smearing (multiples), where a system cannot distinguish between multiple pulses / reflections.
- Pulse stretching (acoustic foot-print); the larger the ensonified area, the more the return pulse will be stretched (i.e. a 1 ms pulse might be stretched to 1.5 or 2 ms when reflected back over a large area).

These factors can have significant impacts on sonar system performance or be completely negligible. Some of these factors can be optimized through proper survey planning, while some are basic design issues. The Sentry group endeavors to maximize data coverage and quality through equipment maintenance and assistance with survey planning.

Appendix 2. Sentry Personnel Structures and General Responsibilities

A2.1 Sentry Operations Personnel Structure

1. Mission Planner & Data Processor
    a. Creates mission plans consistent with collecting data requested by science.
    b. Advises science on appropriate/optimal use of the vehicle for their data goals
    c. Processes vehicle navigation
    d. Processes raw vehicle data into deliverable described in the *Sentry* Data Products Document
2. Mechanical Engineer
    a. Responsibility for maintaining the mechanical readiness of the vehicle at all times
    b. Performs all of the routine and scheduled maintenance required by the vehicle
    c. Carries out any required mechanical repairs
3. Electrical Engineer
    a. Responsibility for maintaining the electrical readiness of the vehicle at all times
    b. Carries out an required electrical repairs
    c. Maintains and charges batteries
4. Systems Engineer
    a. Because the nature of the data products coming from *Sentry* (Multi-beam, sidescan, etc) requires significant judgment and experience for optimal results, and moreover, *Sentry* often integrates specific sensors or makes cruise specific customizations that require adjustment of the tool chain and hence familiarity with the code base, primary responsibility to make sure that the entire vehicle system is functional. Coordinates efforts of mechanical and electrical engineers to this end.
    b. Maintains vehicle software and makes any cruise specific changes required
    c. Leads all pre and post dive activities and has ultimate responsibility for checklists
    d. Assists in data processing as time allows
5. Trainee/an experienced person learning a new role or task or a new person)
    a. Watch Standing responsibilities
    b. Training related duties as assigned by the Expedition Leader and the AUV Operations Manager

In addition to the core vehicle roles, all members of the group have watch standing duties, launch and recovery assignments, and cross training goals.

A2.2 Responsibilities of Expedition Leader and Deck Coordinator

Expedition Leader:
Overall responsibility for the safety of the personnel and the vehicle during a cruise. Has final decision making authority for all decisions affecting either of these.

- Oversees personnel and responsibilities both to ensure that all work is complete but also to ensure that no one becomes overworked to the point of endangering people or equipment.
- Coordinates with Science party and ships crew on all aspects of *Sentry* operations to ensure a successful cruise. (Parts of the coordination may be delegated, for example, the Deck

Operations person will nearly always be the point of contact into the vehicle for the Bosun or Deck boss from the ship)
- Ensures that science deliverables are provided to the science party in a timely fashion and that any deliverables not finished by the end of a trip due to extenuating circumstances have a clear plan for being finished that is also communicated to the group manager.
- Responsible for the cruise report or for making sure that others are designated to complete appropriate sections
- Sends daily updates to interested parties in a format TBD.

Deck Coordinator:
Overall responsibility for the safety of the personnel and the vehicle during a. Has final decision making authority for all decisions affecting either of these.
- In conjunction with the ship's Bosun's responsible for safety of people and vehicle during deck ops
- Develop launch and recovery plans in conjunction with the ship's crew
- Oversees outside portion of launch checklist – may or may not personally perform the tasks
- Sets up all rigging
- Coordinates position and timing of vehicle, people, equipment during launch and recovery
- Coordinates raising and lowering of USBL system and develops plan for the same

A2.3 General Remarks on Operations Team Rest

Sentry typically sails with a crew of five. A minimum of four people are required two hours before each launch to two hours after each recovery. For safety as well as quality of life reasons, each person needs eight uninterrupted hours of sleep in every 24 hours and this must be at nearly the same time each 24 hours. Several common operations paradigms which meet this requirement are given below. We are open to other options as well, but if the sleep requirement cannot be met for two days in a row, or for more than a couple of times in the cruise, the Expedition Leader will halt or delay operations to whatever degree necessary regardless of other constraints or goals within the cruise. In cases where an absolute maximum schedule is desired, additional people have been added, but this is not a part of the facility and would need to be included in one's proposal separately.

Appendix 3. Weather Windows and Considerations

The “weather call” is typically one of the more difficult decisions at sea. Moreover, it is a decision that can really only be final when the people making it are standing together on the deck of the ship in the seas in question. That said, there are general principles that will be used to make the decision as well as some “typical limits”

A3.1 Principles for Weather Decisions

While at sea, the *Sentry* Expedition Leader, Captain, and Chief Scientist will all receive custom weather forecast at least once a day. Based on this forecast and observed conditions, it will be necessary to make a dive/no dive decision prior to each dive and it may be necessary discuss early termination of the dive. This decision will be made collaboratively between the Expedition Leader, the Captain, and the Chief Scientist as well as anyone else that the three of them feel should be present such as a Bosun, or *Sentry* deck ops lead. After all discussion and input has been heard, the final veto power will still rest with the expedition leader and will not be questioned from shore or subject to override by any other WHOI staff on or off the vessel. Likewise the Captain has a concatanative veto in that he or she can independently determine that the weather is not acceptable without question from *Sentry* staff at sea or on shore.

When making the weather decision things that the Expedition Leader and others should consider are:

- Personnel safety is always paramount.
- Vehicle safety is only slightly less important than personnel safety.
- Plan ahead and assume things may be slightly worse than forecast.
- Recovery is much more difficult than launch.
- The vehicle can abort at any time.
- The vehicle should not stay on the bottom through bad weather as an abort can occur at any time and weather may last longer than expected.
- It is not ok to leave the vehicle on the surface and wait for better weather to recover. Never let it get to the point where users feel this need.
- Once the weather is clearly declining, it may be suitable to dive in a slightly higher than normal sea state with the expectation that the seas will be lower by the time the vehicle is planned to surface; however, it must always be safe to recover the vehicle immediately.
- If acoustic comms have been rock solid and water depth is less than 4km it may be acceptable to dive with a plan for early termination. If that is the case it will be necessary to plan for adequate time to bring the vehicle back on board with a significant contingency. If conditions are changing rapidly or getting close to the edge, someone capable of making a weather call (someone Expedition Leader Qualified or a deck ops manager with long experience) should explicitly evaluate the conditions at a regular interval.
- Users can always plan a shorter dive if the ability to abort early is in question.
- Sea state is typically more of an issue than wind, but the vehicle is a large sail hanging from the crane.
- Organized seas and long swells are easier than disorganized sea
- When wind, wave, and current are aligned things are easier
- Different vessels behave very differently in weather
- ***SAFETY FIRST* in any situations during cruises.**

A3.2 Typical Weather Limits

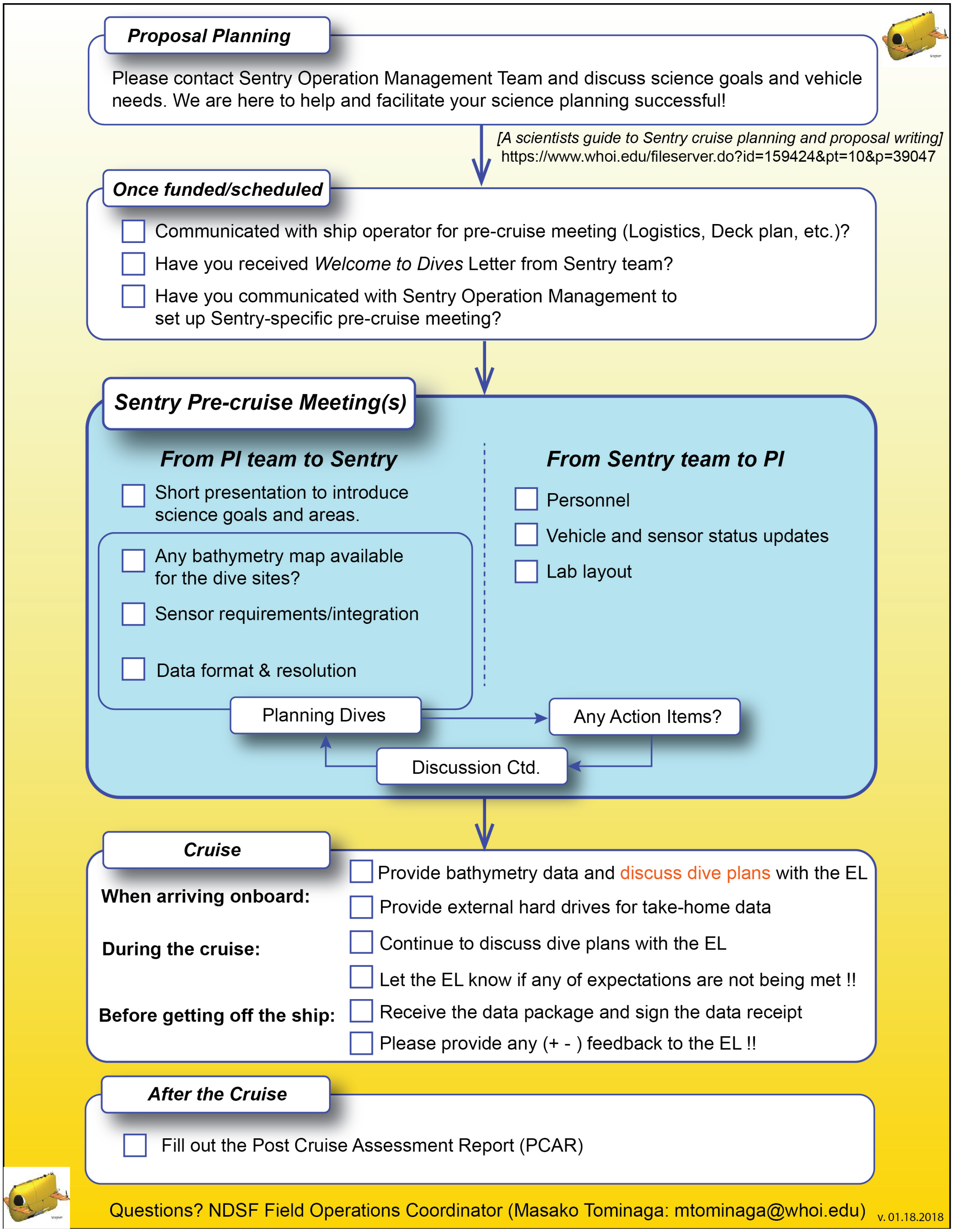
As stated multiple times, weather is very difficult to generalize especially across different vessels. The following are "typical maximums" and are meant to be a starting place. Many vessels will have more conservative limits while in some cases, a dive may continue in worse conditions. The final call will always rest with the Captain and Expedition Leader with either able to make a no decision without further question.

Typical indications for a no decision:

- Sustained winds in excess of 20 – 25 knts
- Gusts in excess of 25-30knts
- Seas more than 10 – 12 ft (considerably less on some vessels)
- Any combination of wind, wave, and current that makes precision maneuver of the vessel impractical
- Any combination of wind or seas that limit crane operations on that specific vessel.
- Any sea state regularly putting running water onto the main deck near the launch or recovery area.
- Any combination of wind, wave, and current which would limit ship movement with the USBL transducers in the water to less than the maximum commanded speed of the vehicle (typically 2knts)
- A prediction for any of these conditions prior to the scheduled recovery.
- Marginal weather and a significant uncertainty about future trends. Appendix 3. pre-cruise questionnaire? Which is BAD – need to be revised.

Appendix 4. Pre-proposal writing and Pre-cruise planning procedure

A4.1 Pre-proposal writing and pre-cruise planning procedure



A4.2 Pre-cruise questionnaire

_____ Ship Bathymetery for your site

____ Data is a GMT Grid or SD object?

The coordinate system for my data is _________________________________(WGS84 preferred) Please note that jpegs, gifs, or raw swath data will not work. If you don't have the coordinate system, we can use the data.

Do you plan to use any custom sensors on *Sentry*? ____ yes ____ no

If you marked yes, please contact us immediately.

While we generally will have all sensors available, please let us know the status of each system for your cruise:

Sensor	**Critical**	**Desired**	**Not Needed**
Multibeam			
Sidescan			
Sub Bottom			
Magnetometers			
Camera			
CTD			
Turbidity			
Dissolved Oxygen			

Do you plan to request the use of the Ko-Ichi eh probe? ____ yes ____no

A4.3 Data to be Handed to You

How do you want your data drive formatted?

_____ EXT3 ____ EXT4 ____NTFS

Do you want additional copies of the data? How many ______

_____ Have you provided the appropriate blank drives? It is very important to provide the correct blank drives. Please consult with us ahead of time or see Data and Data Handover. Please note that depending on your cruise, you may not be able to purchase the necessary drives in a retail store, it may be necessary to order them online.

Appendix 5. Ship Selection and Operation Space Guideline

The AUV *Sentry* is specifically designed to operate from a ship of opportunity and to be as flexible as possible in the ships it operates from. Despite the emphasis on portability and flexibility, significant care is still required in ship selection to ensure safe and effective operations.

Deck space for operation is required for two 20ft shipping containers including one on the main deck, the *Sentry* cradle, and several pieces of deck cargo. Lab space of at least 30 linear feet of bench is required. A crane capable of dealing with 3500 lb static loads and 10,000 lb dynamic loads at a distance of 20+ ft from the side of the ship is required. A safe and effective means of putting *Sentry* in the water and recovering it later must be devised. This generally dictates a modest freeboard in at least one place on the side of the vessel near the pitch center and as far from the props as possible. Roll stabilization is helpful as it increases the operable weather window.

Beyond the physical requirements that the ship be able to accommodate the equipment, it is also necessary that the crew be experienced in launch and recovery of delicate equipment such as AUV's moorings, buoys, or gliders. The ability to lay a ship alongside a floating object and stand off from that object at a desired distance during deck operations despite currents, waves, or winds is critical. A skilled crane operator used to deal with minimally arrested loads on long booms while at sea is critical to safe operation of the vehicle. Both hand and powered tag lines are used as much as possible, but are not fool proof. *Sentry* personnel are not trained to operate cranes and we rely on the vessel to provide an operator.

We can operate readily from both DP and non-DP vessels in a wide variety of sizes. We have operated from UNOLS and non-UNOLS vessels and both US and foreign vessels. Often even if a ship is not idea, we can still make it work, but additional mob and demob time may be required, additional equipment may be required, and if we haven't worked from the vessel before, a visit to the ship ahead of time will be required. Depending on cruise funding source, some or all of this will have to be included in proposal budget. For NSF, NOAA, and ONR, users do not need to budget for these costs.

A5.1 <u>Ship Propulsion Requirements</u>

Sentry is designed to operate on both Dynamic Positioning (DP) and non DP ships. The critical element is that the combination of propulsion and ship's crew should be able to lay the ship alongside a free floating object with close to zero relative motion and maintain this position for several minutes while objects are retrieved from the water. A willingness to secure the prop on the launch and recovery side during deck operations is highly desired.

<u>A5.2 Deck Space Requirements:</u>

- 2 standard 20ft ISO container 20x8x8.5ft (LxWxH) Up to 25,000lbs. One of these will need to be on the main deck, the other can be in an alternate location.
- 1 *Sentry* Cradle (approx 3 meters by 2 meters plus working space) ~ 3500 lbs – See Figure and Figure
- 2-3 weight stacks approximately 36x18x12in (hxwxd) ~ 3000 lbs each
- 1-Pallet Box: 48x46x32in (LxWxH)
- 1-USBL system (see USBL section below)

Access and layout considerations

- The main van container has double doors aft, and a personnel door forward right. The van can be oriented as needed, but both the double doors, and the entire side of the van with the personnel doors should be free from obstruction for ~ 2meters and should not be considered a walkway. Both areas should be shielded from the weather to the maximum extent possible. The main van also has power, air conditioning, and cable pass through forward left which must be accessible. 480V three phase power is required to this van.
- The second van as double doors aft which must be accessible while underway. Some safe means of moving packages weighing up to 200lbs between this van and the main deck must exist.
- The cradle should be positioned within easy reach of an appropriate crane (see Crane & Rigging Requirements)
- Frequent and ready access to all sides of the vehicle is required for maintenance, and it is desirable not to have walkways routed near the vehicle as there are several protruding parts and the potential for portions of the vehicle to be moving. It is necessary to the launch and recovery process that at least 5 ft fore and aft of the cradle be clear of obstruction as well as a space inboard where an air tugger can be stationed (though turning blocks are possible).
- The van on the main deck needs to be within an 80 ft cable run (min 4 in dia of open space) of the USBL pole and within a 70ft run of the vehicle.
- Weights from the weight stack will need to be carried to the vehicle prior to every dive and are heavy. Maintaining minimum distance is desirable.
- A 15KVA service (480V/60Hz three phase) is required for the shipping container.

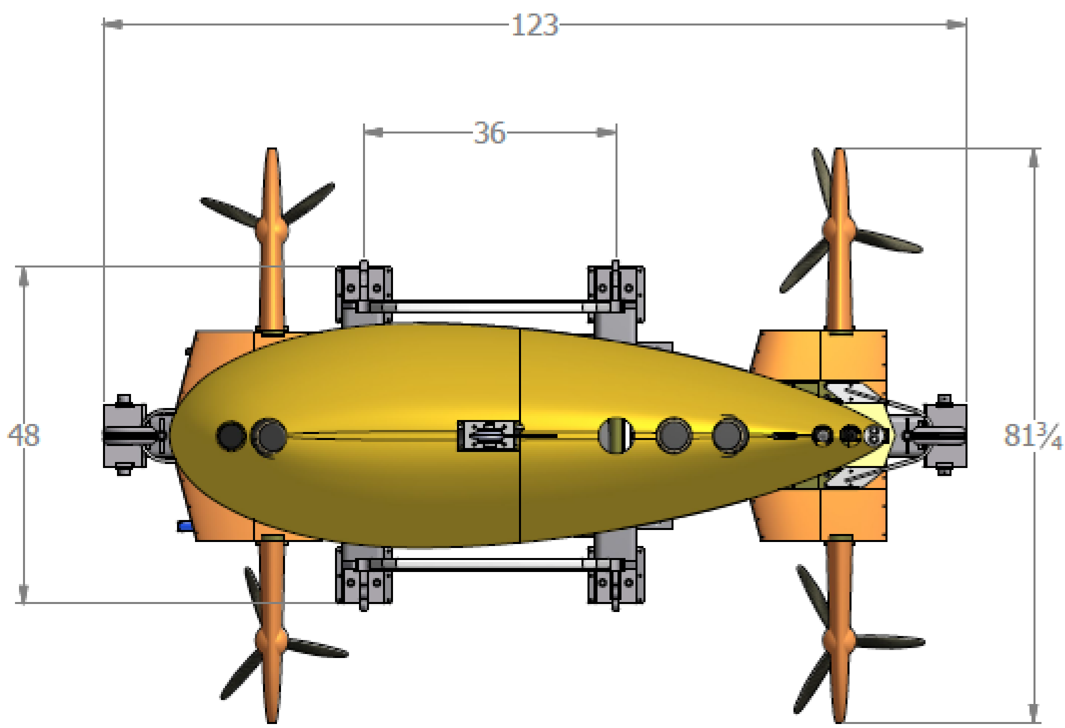


Figure A5 - Plan view of the *Sentry* Cradle. Note that an additional 4 – 6 feet of open space is required to fore and aft and 3 - 4 feet to each side as a work and launch and recovery area.

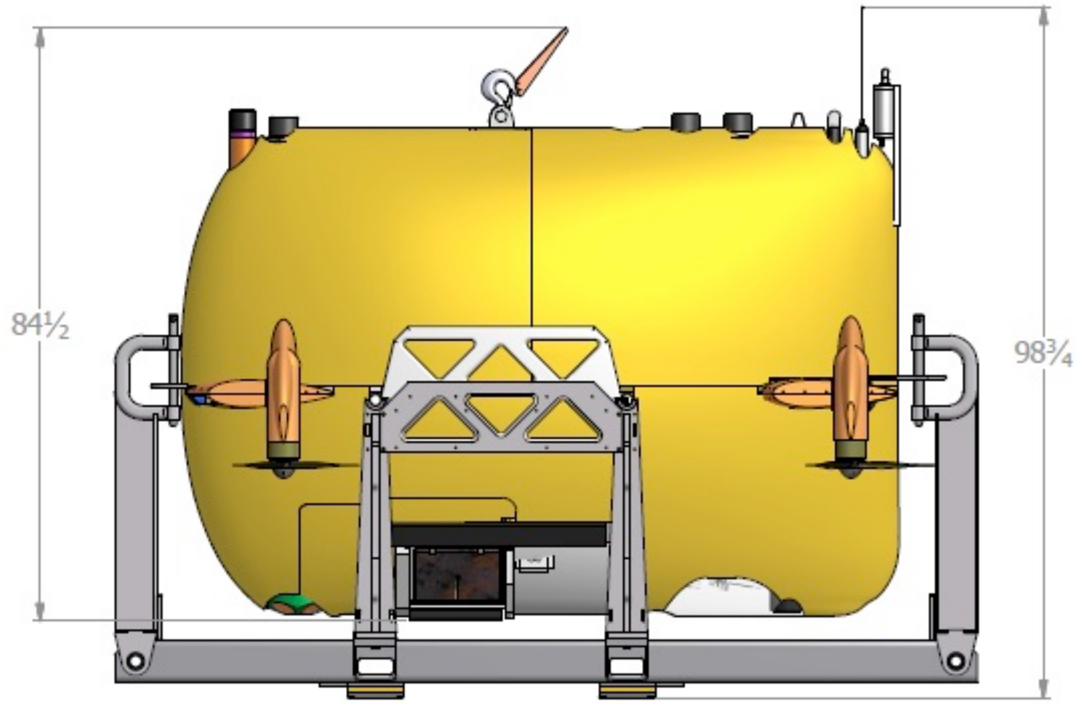


Figure A6 – Side view of *Sentry* in the cradle.

Figure A7. A picture of *Sentry* on the cradle on the deck of R/V Knorr. This picture has the *Sentry* umbilical and charge cables attached as well as the cooling lines. Note the cables running from the wall to the vehicle, the ample work room around the vehicle, and the proximity to the side of the ship relatively close to the water.

A5.3 Ships data

We often use information from the vessel's data system to support the real-time navigation of the vehicle. Data items needed include vessel position from the shipboard GPS receiver and the vessel heading from the ship's gyro. Note that the vessel direction of travel provided by GPS is not a substitute for the vessel gyro heading.

A5.4 Ship GPS

The GPS data should be furnished as an RS232 NMEA serial string on a conventional serial line. We use the GPGGA string, and the minute field should have at least 4 decimal places. NMEA convention is for 4800 baud, we can accommodate any standard baud rate. Typically this GPS feed will need supplemental GPS such as WAS or the local equivalent in order to achieve good navigation on the seafloor.

Alternatively we will often place our own GPS antenna on the ship at a convenient location, typically on a rail aft of the bridge and several decks above the main deck.

A5.5 Ship Gyro

We use the HEHDT or GPHDT strings from the ships gyro. These provide the vessel's true heading independent of the direction of travel. Note that strings like GPVTG, which provide the vessel track made good, are not suitable for this purpose. The data must come from a heading reference such as an INS or gyro not the GPS alone. As for the GPS, we can accommodate any standard baud rate. The data can come in on a separate serial line or it can come on the same line as the GPS data.
We can accommodate either DB25 or DB9 connectors of either gender. If users use other connectors (RJ-45, etc) please provide us with adapters for DB9 or DB25.

We can deal with other formats if they are properly documented and we get some prior notice. We suggest that these lines be tested with a simple ascii terminal program (hyperterm for example) before we arrive.

A5.6 USBL/LBL

Sentry Utilizes an Ultra Short Base Line (USBL) or a Long Base Line system for subsea navigation. From a ships perspective, the primary requirements for either system are a GPS feed, and the ability to place a transducer in the water in a repeatable location that is unshadowed by the hull in all directions. Over the years we have used a number of options for mounting this transducer, but the most common is a swinging pole (see drawing) that is lowered by a ships crane during operations and can be pulled up during transits. This also provides acoustic communications and other similar infrastructure.

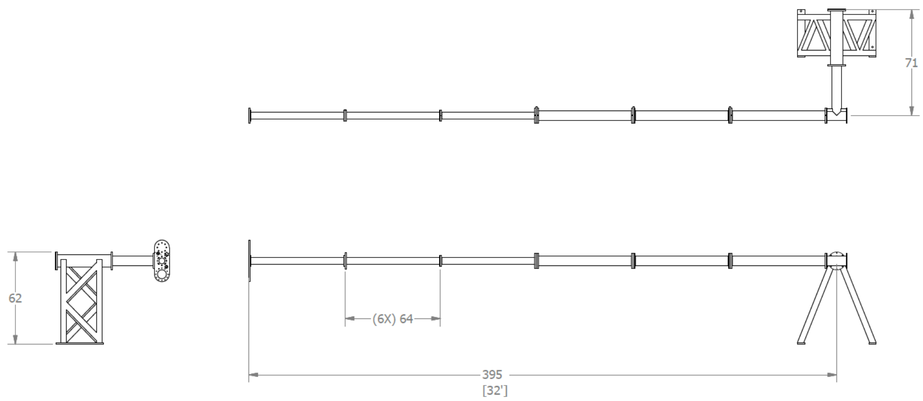


Figure A8 - Overall USBL Dimensions

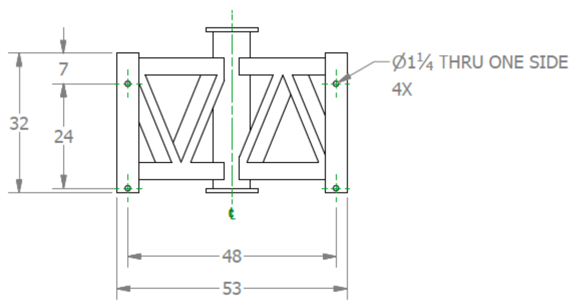


Figure A9 - USBL Base Bolt Pattern

Figure A10 - USBL pole retracted and secured in the stowed position. To deploy, a crane is used to hold the near end, the assembly slides outboard relative to the base, and is rotated clockwise into the water where it is locked in the down position.

A5.7 Ship Deck Equipment

Depending on the ship configuration, *Sentry* often uses one or two air tuggers as swing arrestors. Each of these air tuggers requires 50scfm (1.4m^3/min) at 90psig (6.3 bar) and utilizes a 3/4in (19mm) air hose

Sentry contains several components that are susceptible to salt crystal accumulation. Adequate fresh water for a thorough rinse after each dive is required.

A5.8 Ship Crew Assistance

Sentry is designed to operate with a small operations group and consequently relies on the ship's crew for assistance during mob/demob and deck operations. At a minimum a crane operator, spotter, and bridge liaison are needed for every deck operation. *Sentry* has individuals qualified to operate as deck boss during deck operations, but we prefer to have a very experience member of the ship's crew directing overall deck operations in close coordination with *Sentry* personnel. See also A

During Mob and Demob, assistance will be required with moving and securing all items listed on the deck space requirements. Assistance will be required with integration to ships data feeds and networks. Assistance will be required with routing of cables and tubing.

A5.9 Crane, Rigging & Handling Requirements:

The most challenging portions of *Sentry* operations are launch and recovery. Launch & recovery of *Sentry* is very similar to launch and recovery of other science gear that is set free of the ship (not attached by wire). One of the differences is that it has fragile projections such as thrusters and wings, science instruments, flashers and a radio antenna that could be damaged if *Sentry* comes in contact with the ship, especially on recovery. The other difference is that during recovery *Sentry* usually has the capability of being driven on the surface by radio control. This allows the ship to come to a stop a comfortable distance from the vehicle (typically 50 – 100 meters depending on conditions), get stabilized to the wind and seas, and then have *Sentry* come to the ship. This capability can fail and the ship should be prepared to recover the vehicle safely without this capability.

Sentry weights about 3000 pounds (~1360 kilos) and roughly measures 10 ft (3m) long, 7.2 ft (2.2m) wide and 6 ft. (1.8m) tall. It is lifted from a single point on top and there are two primary tag line attachment points. It rests in a custom cradle, which is secured to the deck during operations. *Sentry* does not use a formal swing arrestor and can have significant cable length below the boom of the crane requiring a skilled crane operator.

Standard procedures for launch and recovery including images are available in **Error! Reference source not found.**. A video is available on the *Sentry* website which shows the majority of a launch and recovery. Note that these pictures are all in a very calm sea state but *Sentry* can and regularly does operate in rougher weather. Specific weather parameters are determined on a case by case basis for each ship. General weather guidelines are given in

A5.10 Internet

Internet access has become a core part of the *Sentry* operation and will need to be available to computers on the *Sentry* network. We work hard to be self sufficient and minimize data use, but we have come to rely on the wealth of online knowledge when trying to implement a new capability or fix a problem. Users' results will be substantially reduced without internet access. We are used to working with slow connections such as High Seas Net.

Also, at least one (preferably static) IP address will be needed on the ships network, and it may be desirable to have additional addresses for personal laptops.

A5.11 Berthing

The *Sentry* group requires berthing and other standard accommodations for five crew members. If additional bunks are available we may occasionally request one to assist in training or for a student. It additional crew members are requested for operational reasons, additional bunks will be required.

A5.12 Dive weights – purposes and storage

Sentry utilizes dive weights both for descent and ascent. Some dive weights may also be used to deploy temporary moorings for navigation purposes. All moorings are recovered prior to the end of the cruise, but dive weights and mooring anchors are left on the seafloor. All dive weights and anchors are made primarily of "Alvin plates" [Figure]. Alvin plates are made of flame cut mild steel and are not painted or surface treated. Three configurations of weights may be left on the seafloor:

- *Sentry* descent weights
- *Sentry* ascent weights
- Navigation Mooring Anchors

Table A3 - Typical Weights Abandoned in Place During Operations

Weight Type	Rate of Use	Typical Frequency
Sentry Descent Weight	1 per dive	1 per 24-48 hours on station
Sentry Ascent Weight	2 per dive	2 per 24-48 hours on station
Navigation Mooring Anchor	• 1 per USBL calibration • 1 per navigation mooring	• 1 per cruise • Rarely used at all, but if used, 3 per geographic area

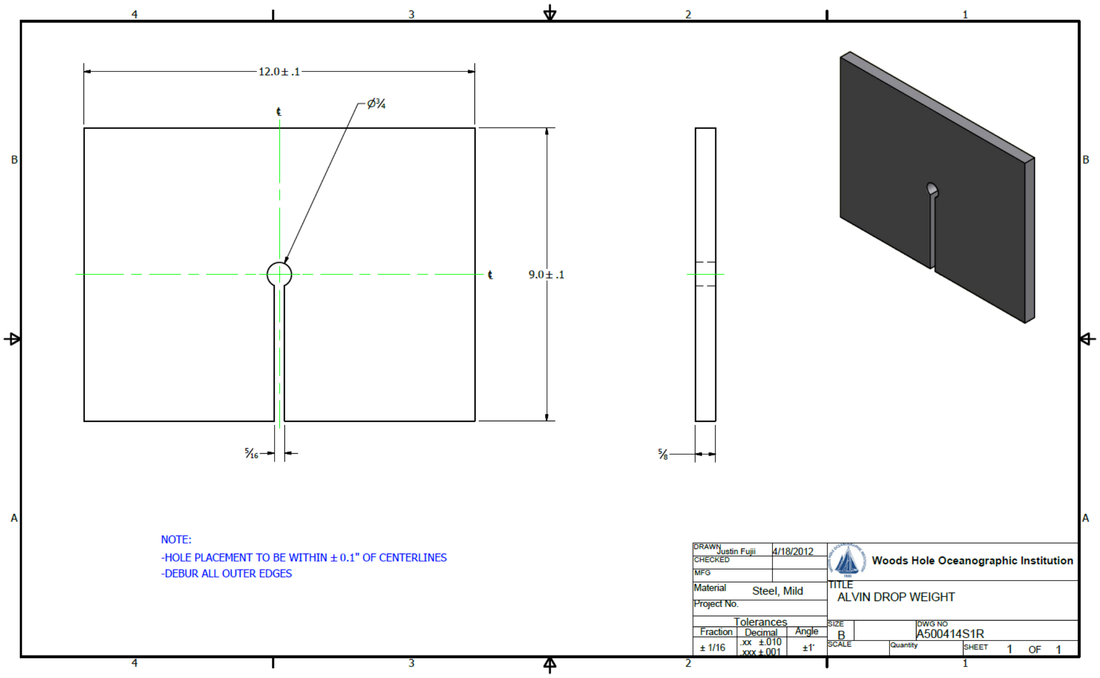


Figure A11- Sentry Dive Weight

Figure A12 - Weight stacks secured to the side rail of a ship

A5.13 Sentry Descent and Ascent Weights

One *Sentry* descent weight is used per dive. A *Sentry* descent weight is composed of:

- 4x Alvin plates
- 1x Galvanized steel eyebolt with shoulder and nut: 3.25inX½-13 thread (McMaster part number 3018T17 or equivalent)

- 1x Stainless steel shackle: 1/4in (McMaster part number 3898T12 or equivalent)
- 1x Galvanized steel washer: 1/2in
- 1x wire rope lanyard. 1/8in diameter, 12in long, galvanized steel, looped and crimped at both ends (McMaster part number 30645T101 or equivalent)

Two *Sentry* ascent weights are used per dive. A single *Sentry* ascent weight is composed of:

- 3x or 4x Alvin plates depending on vehicle configuration
- 1x galvanized steel carriage bolt. 3.5in or 4in long depending on vehicle configuration. 1/2x13 thread. (McMaster part number 93604A721 or 93604A719 or equivalent)
- 1x galvanized steel washer, 1/2in (McMaster part number 98970A132 or equivalent)
- 1x or 2x galvanized steel hex nut. ½-13 thread. (McMaster part number 90371A045 or equivalent)

Figure A12.1 - Sentry Descent Weight

Figure A12.2 - Sentry Ascent Weight

A5.14 Navigation Mooring Anchors

One mooring anchor is used when the USBL system is calibrated and one mooring anchor is used per LBL transponder that is deployed. On the majority of cruises this results in the deployment of zero or one anchors during the duration of the cruise.

- 6x Alvin plates
- 1x Galvanized steel eyebolt with shoulder and nut: 6inX½-13 thread (McMaster part number 3018T37 or equivalent)
- 1x galvanized steel washer, 1/2in (McMaster part number 98970A132 or equivalent)
- 1x or 2x galvanized steel hex nut. ½-13 thread. (McMaster part number 90371A045 or equivalent)

A5.15 Lab and Storage Spaces

The Sentry group will set up its own subnet for its computing system so that it can be rapidly isolated in the event of problems. Sentry has a very high computing and data processing load requiring space and power for 5 - 10 PC's and laptops as well as the need for repair and maintenance spaces, battery charging station, navigation station, and printer. The typical minimum required facilities are

- 2 sit at data processing desks or benches, minimum 5ft long each with chairs
  - Each should have at least a 2KVA service (110V/60Hz preferred 220/50Hz ok)
  - These will tend to be high traffic areas and should be close to lab entrances
- 2 sit at work areas, minimum 4 ft long each with chairs
  - Each should have access to electrical power
- 1 stand at repair bench, minimum 6ft long
  - Should have access to electrical power
  - Should be removed from the flow of traffic and close to the data processing stations if possible
- 1 sit at navigation station, minimum 6 ft long with chair
  - Need electrical power

If available, 10 – 15 cubic meters of hold space for empty packing cases and boxes while at sea is very helpful.

A5.17 Vessels that operated Sentry

Sentry has operated on a number of different vessels over the years. A list is below along with any complications which required additional time or resources during the mobilization and or demobilization. Ordering is alphabetical.

- R/V Atlantis, R/V Melville, R/V Oceanus, R/V Roger Revell, R/V Thompson, R/V Kilo Moana, R/V Sikuliaq, R/V Knorr, R/V Endeavor
- R/V Falkor
- R/V Pisces
- R/V Brooks McCall
  - Crane unacceptable
  - Vessel not to be used again
- R/V KoK
  - Slow Crane
  - Substantial Roll
  - Requires equipment to be welded to deck
- NOAA Vessel MacAurther II
  - Requries equipment to be welded to deck.
- R/V Merrian
- E/V Nautilus
  - Cannot place van on main deck

    - Can only place one van
    - Insufficient lab space
    - 360V power instead of 480
    - Requires custom track on deck
- NOAA Ship Okeanos Explorer
    - Insufficient lab space
- R/V Tangaroa
    - Extremely high freeboard for most of working deck
    - Can only place one van
    - Requires equipment to be welded to deck

Appendix 6. Launch and Recovery Operations

Launch and recovery of Sentry is similar to launch and recovery of many forms of science gear free of the ship that are launched and recovered by research vessels around the world. Sentry sets itself apart from a lot of deployed science gear by the various sensors, Sonar's, and tracking equipment that are on the outside of the vehicle. This equipment is exposed and venerable on launches and Recoveries and particular attention should be paid to avoid damaging this equipment. Sentry also has a unique capability that allows an operator to drive Sentry to the ship. This allows the Vessel to comfortably hold the ship on station while the vehicle drives to the recovery location.

A6.1 On Deck Personnel

Personnel safety is the number one priority for Sentry Operations. Sentry Operations combines the Vessels Safety Guidelines, WHOI's Safety Guidelines as well as UNOLS RVOC Safety Guidelines to provide safest operations environment possible. Sentry Operations requires at a minimum the following PPE (Personal Protective Equipment) during Launch and Recovery Operations: hard hat, coast guard approved work vest, closed toed shoes (preferably steel toes), gloves (optional), and Safety Glasses. Sentry Launches and Recoveries require the following deck support:

- Deck Boss/Launch Coordinator (typically BOS'N or Sentry crew)
- Crane Operator (Ship Personnel)
- Line Handlers - Minimum 3 Persons (Filled by Deck Crew/Sentry Crew)
- Pull Pin Handler (Sentry crew, only required for Launch)

A6.2 General Operating Conditions

Vessel Setup:

Vessel setup is a key component to Sentry launch and recovery operations.

- During launch the critical consideration is that the vehicle not pass under the ship. To this end, the ship will need to set up into the seas to minimize roll, but with the side of the ship where launch will occur as down current as possible.
- During Recovery, the key issue is not to impact the vehicle. Since Sentry can drive towards the vessel, it is better to set the vessel up downwind of Sentry so that it is blown away from Sentry. It may be necessary to move the ship's bow a little after the lift line is hooked up and before the crane lifts Sentry from the water as the prime consideration then becomes minimizing roll.

Sentry Launch:

Sentry is ready to be launched after the Sentry crew conducts a successful deck test of the vehicle. The Sentry launch coordinator crew will coordinate launch time and position with the necessary Vessel crew. The following is the general flow of launch operations for Sentry. Some of these actions will happen simultaneously.

- Notify Deck personnel of Launch time and ensure all necessary jobs are filled.
- Secure tag lines to Sentry fore and aft
- Rig air tugger line to crane hook
- Rig lifting sling with pull pin and crane hook

- Radio Beacon on and tested, Strobe on and Tested
- Charge and umbilical cable are removed from Sentry
- Secure all panels on Sentry
- Cooling lines are removed

NOTE: On launch Tag Line handlers shall pay particular attention to entanglement of the lines, particularly when slipping the lines. The unique design of Sentry creates various hazards for tag lines to get caught and create damage to the vehicle. Tag lines need to stay clear of the Vehicle fins, thrusters, and sensors on the top of the vehicle. In particular, tag lines must be slipped gently and not allowed to swing freely. The recommended procedure is to slack the line and slip it until the free end is in one hand. This can then be dropped into the water to arrest line swing and gently pulled hand over hand by the other end.

Sentry Launch will commence with lifting the vehicle several inches

- The poles used to hold Sentry up will be removed
- The fore and aft catches will be removed
- Sentry shall then be lifted out of the cradle up to a height that will allow Sentry to clear the Vessels railing
- Sentry should then be moved outboard to position it above the water and a safe distance from the ship.
- Slip the bow tag line as the vehicle goes over the rail. Recover as much of stern tag line as possible in preparation for slipping it.
- Orient the vehicle pointed away from the ship (Sentry may glide forward as it descends).
- Start lowering the vehicle into the water AND slip the stern line. Ideally, the stern tag line is free of Sentry when it just touches the water but err on the side of clearing the tag line.
- Pull the release (as soon as weight is off lift sling) and lift crane hook up and away.
- If necessary slide ship away from vehicle as it descends clear of the ship. Then slowly move ship clear of Sentry by several hundred meters in case it should surface prematurely. Typically the Sentry launch coordinator will provide direction over the radio.
- Secure crane and all launch equipment.
- Have ship remain within tracking distance until Sentry is following mission profile adequately

Sentry Recovery:

Provide bridge with expected time and location for Sentry to be on the surface. Ship should typically be positioned about 400 meters down wind of Sentry as it approaches the surface. It is critical to be tracking Sentry as it leaves the bottom since tracking is poor as it gets near the surface and hard to pinpoint its location.

There are two recovery scenarios:
Sentry is able to be driven on the surface towards the ship using radio control.
Sentry is “dead boat” and the ship must maneuver along side of Sentry

- Ensure all required personnel are present and notify bridge that the deck personnel are ready for recovery of the vehicle.

- Ship should approach Sentry to within 50 – 100m meters off the rail of the ship near the recovery location. Sentry personnel will attempt radio control with remote control box. If radio control is obtained, ship should come to a stop and hold position and heading that they feel is best. When bridge has ship in position and is ready they should notify the deck to have Sentry driven to the ship.

If Sentry is NOT radio controlled then the ship should carefully approach Sentry trying to keep it off about 10-15 ft until alongside and within pole reach.

- When Sentry is alongside the ship in the area for recovery, a long pole attaches the lift line loop to the lift hook on Sentry. The lift line is pulled free of the pole and the loop at the other end is QUICKLY attached to the crane. Under some circumstances the lift line may already be attached to the crane. A tagline running directly inboard to an air tugger will typically already be attached. IT IS IMPORTANT THAT THE PEOPLE ON THE STABILIZING TAG LINES KEEP THE LIFT LINE FROM TANGLING ON Sentry. This can be done by keeping some tension on the lines thus lifting the lift line up and clear of the vehicle.
- As soon as the lift line is attached the crane should swing outboard to keep Sentry from hitting the hull. Note that if the crane pulls Sentry sideways it may slip forward or aft (direction of least resistance) through the water, and thus impact the hull. The pole can be used to push Sentry away if necessary.
- As Sentry comes out of the water the crane should bring it inboard enough to attach tag lines. These lines attach to the appropriate "D" rings welded to the struts between the upper & lower hulls.
- Continue to bring Sentry onboard and lower until just above the cradle
- Capture Sentry with fore and aft constraints
- Replace outboard leg of cradle and insert poles
- Lower Sentry into the cradle
- Secure the vehicle with cargo straps and disconnect all lines so the crane can be secured.

<u>A6.3 Launch and Recovery Sequence</u>

Launch:

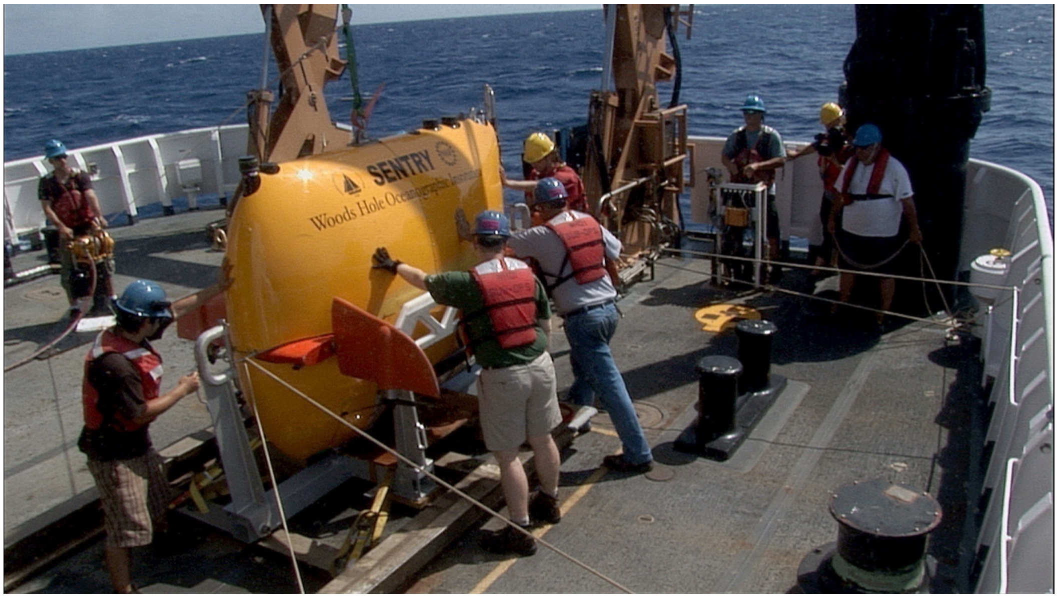


Figure A13 - *Sentry* is in the cradle and lifted approximately 1-2 inches

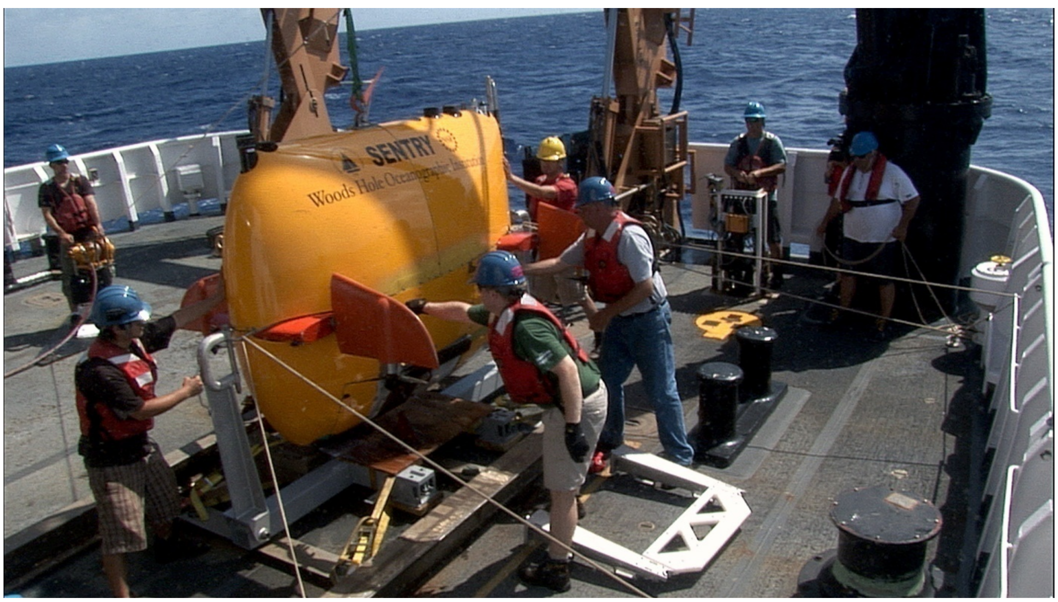


Figure A14 - The outboard side of the cradle is removed and the pipes through the center of the vehicle are removed.

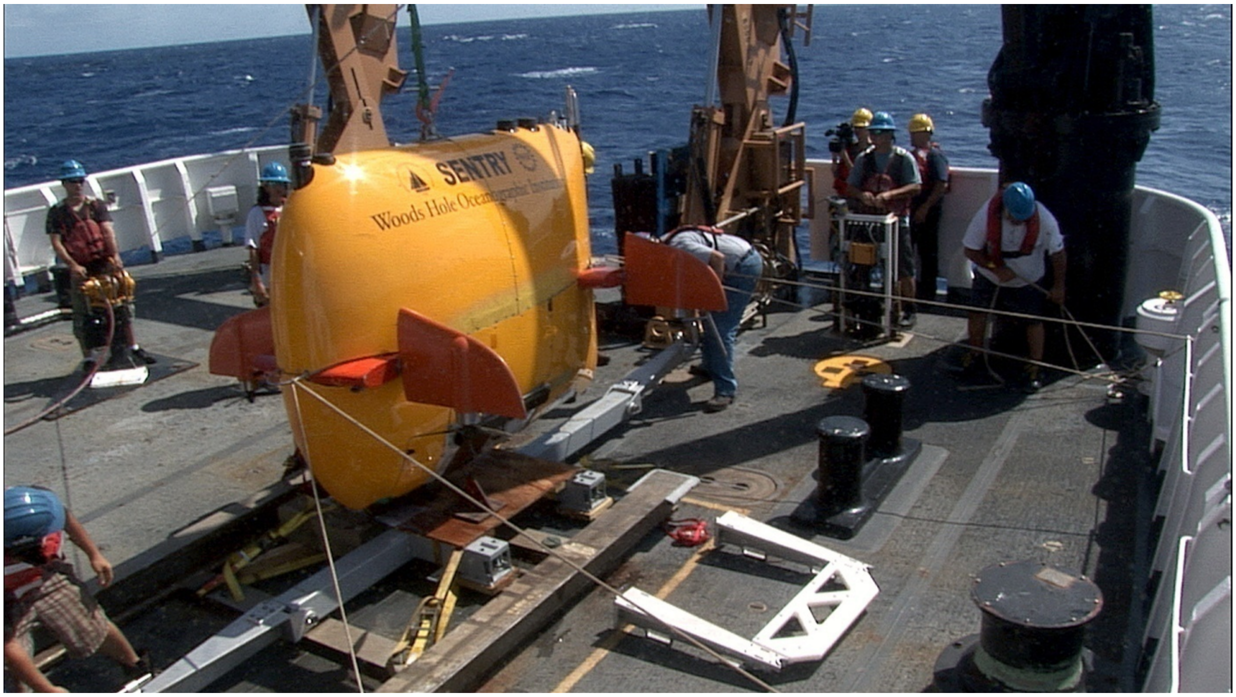


Figure A15- The fore and aft catches are released leaving the vehicle stabilized by the tagline to the air tugger (left) and the fore and aft taglines (right)

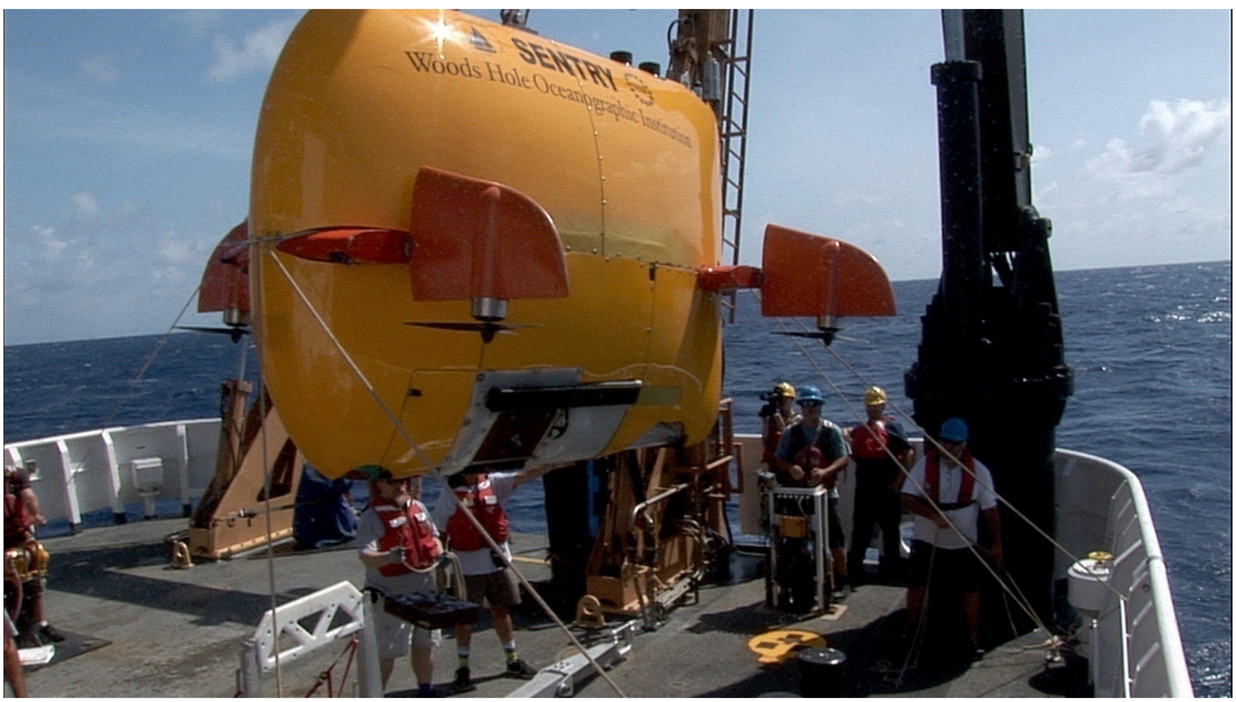


Figure A16 - *Sentry* is lifted up from the cradle and out towards the rail.

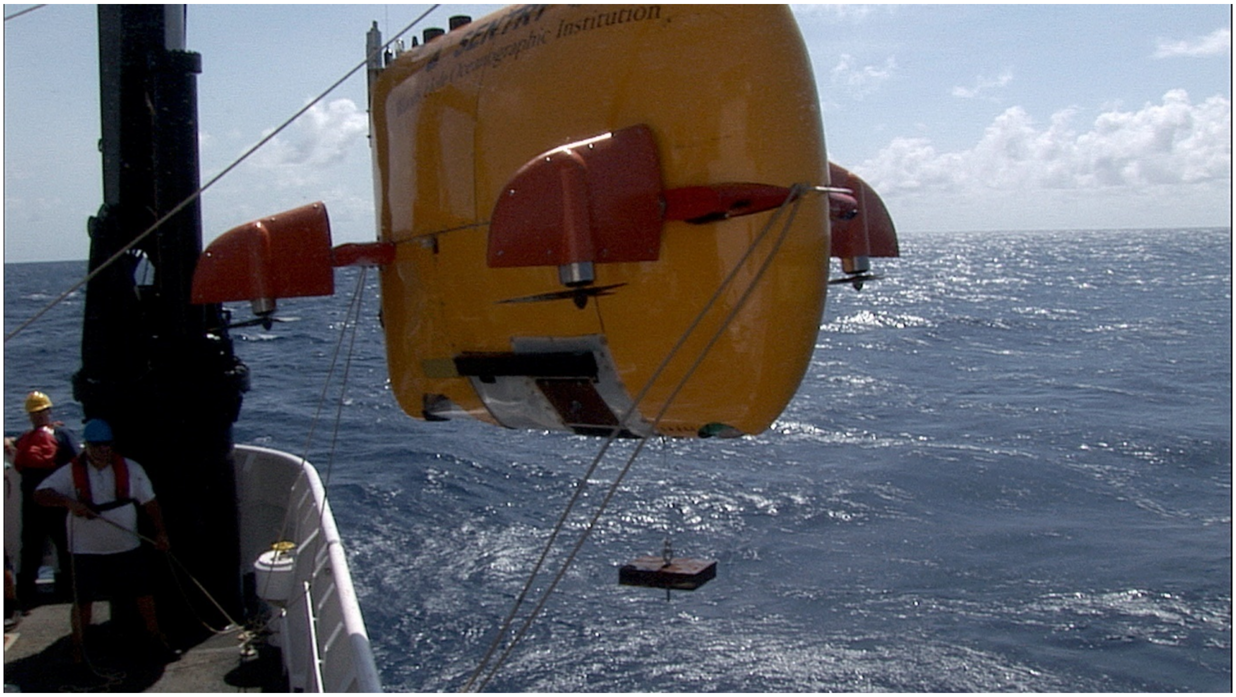


Figure A17 - As *Sentry* moves over the rail, the forward tagline is slacked and slipped.

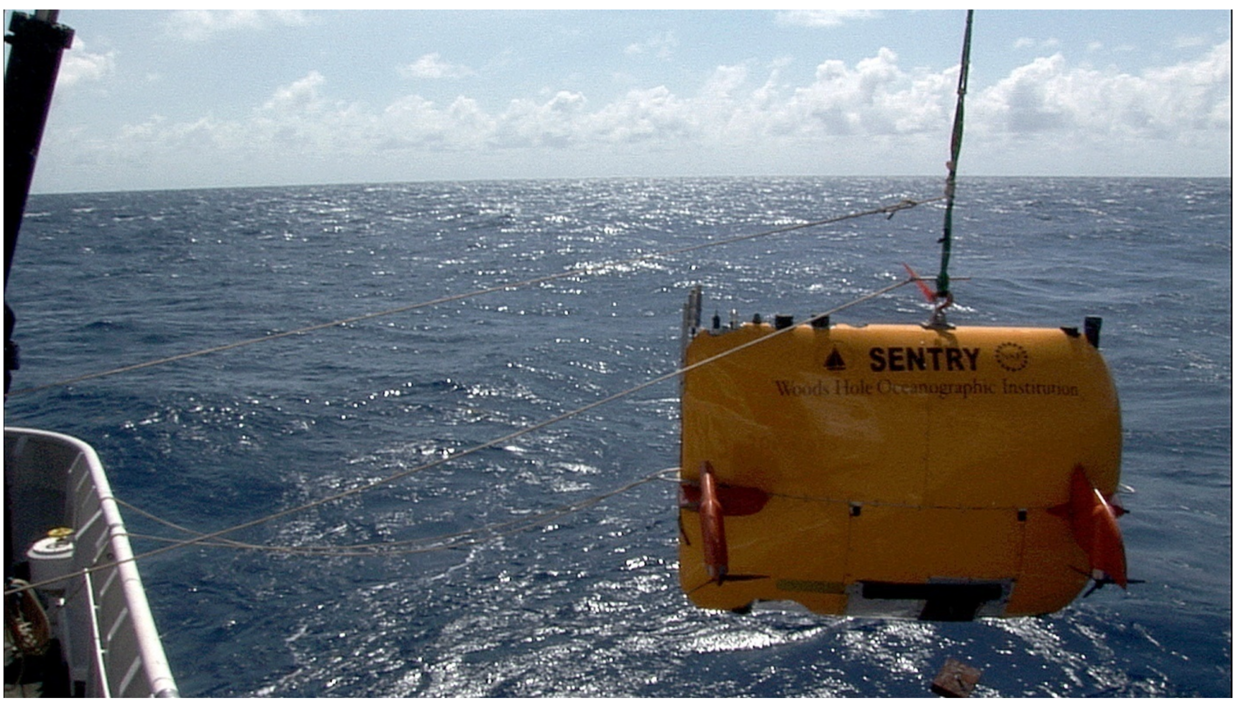


Figure A18 - *Sentry* continues to move outboard, the aft tagline is used to point the vehicle away from the vessel, then is slipped right before the vehicle enters the water. As soon as the pin is unloaded, it is pulled and the vehicle descends freely.

Figure A19 - As the vehicle drives towards the stationary vessel, the lift line for the crane is attached using a carbon fiber pole. The vehicle immediately drives full reverse and the pole is potentially used to fend the vehicle while the lift line is tensioned.

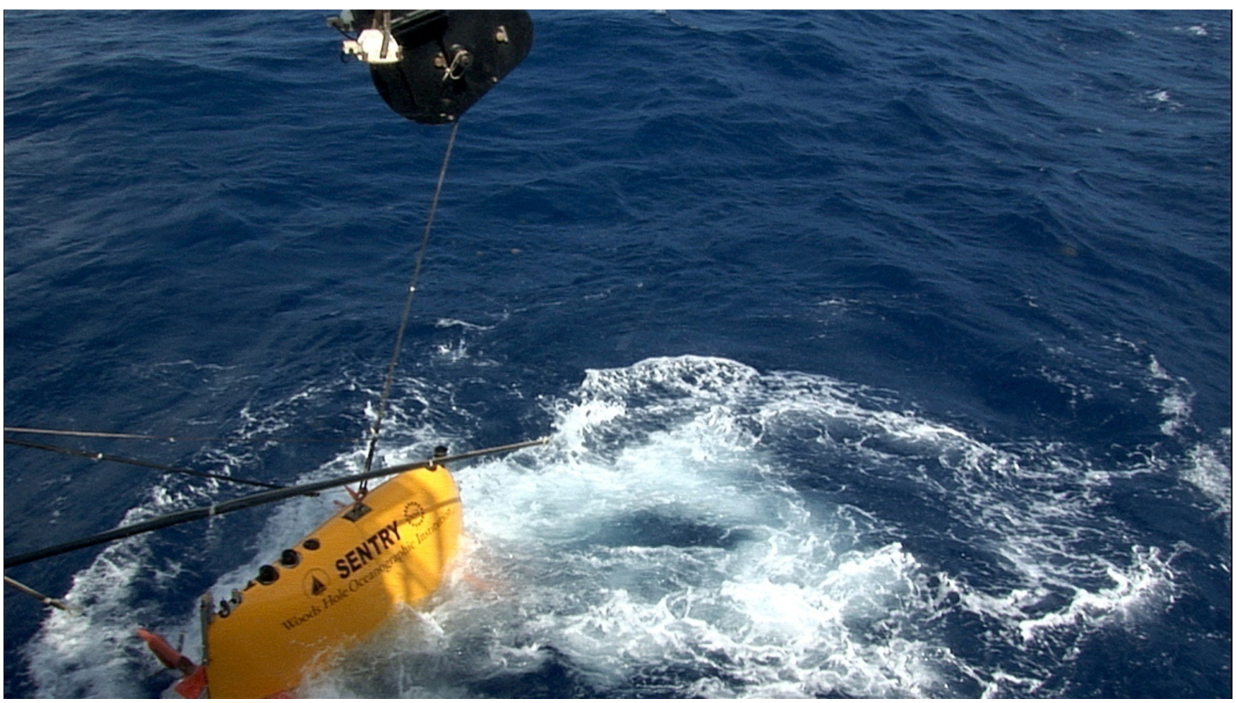


Figure A20 - As the lift line is tensioned and the vehicle lifted partially out of the water, fore and aft tag lines are attached using carbon poles and hooks. The tagline to the airtugger is already attached to the lifting bridal.

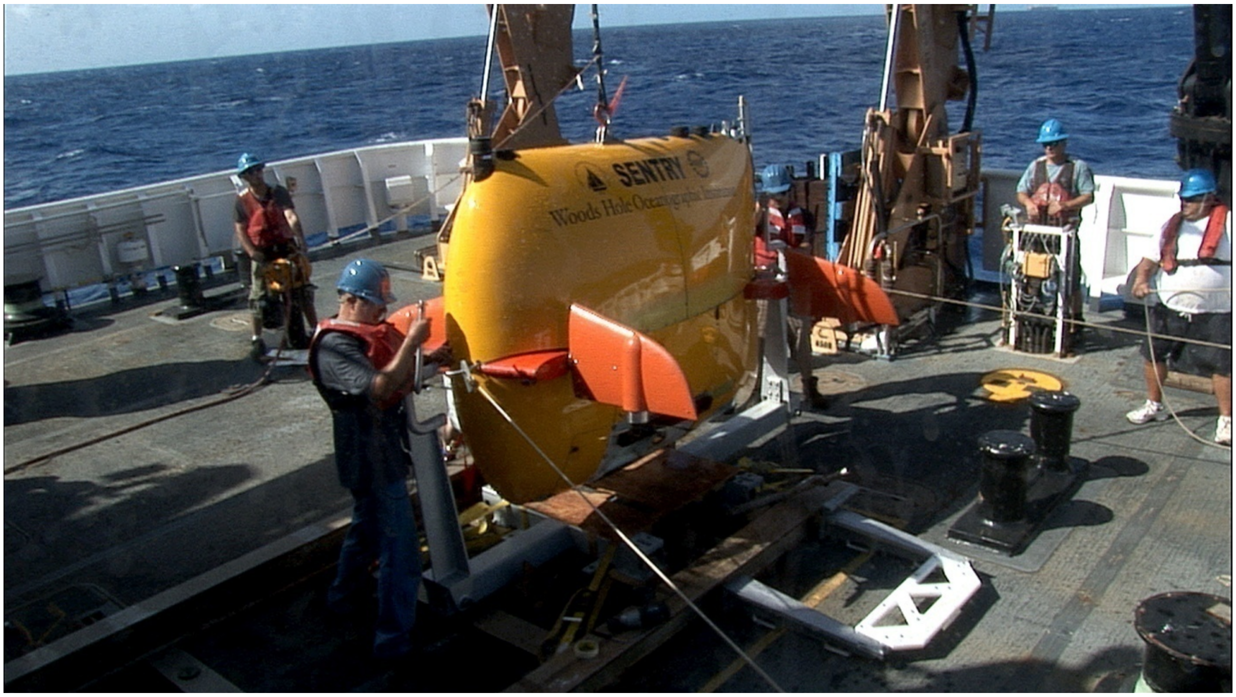


Figure A21 - The vehicle is slewed back into the cradle and the fore and aft catches are secured first. The side is reattached and the poles reinserted before the vehicle is set into the cradle.

Appendix. 7 Required Pressure Testing

All instruments with implodable volumes must be pressure tested prior to being fitted on Sentry. The specific instrument, designated by serial number must have been tested, not just the general model or class of instrument. Oil filled or potted systems are not required to be pressure tested but we do still recommend pressure testing to verify functionality. The test procedure will depend on the nature of the materials under test, but the general test procedure can be the following:

A7.1 Metal Housings

For metal housings, the required pressure test is:

1.) The Instrument housing is to be in normal operating condition with all ports, connectors, etc in their final configuration. Electronics are not required to be in their housing, nor is recertification required when the housing is opened.
2.) The Instrument shall be pressurized at a rate of at least 10 bar/min to a test pressure equivalent to 1.25 times the maximum depth to which Sentry will dive with the instrument on board. Once the test pressure is reached it shall be maintained for at least 10 minutes. Pressure shall be reduced to atmospheric at a rate of at least 10 bar/min.
3.) Step 2 shall be repeated a minimum of two additional times.
4.) Step 2 shall be repeated at least one additional time, but the test pressure is to be maintained for at least 60 minutes.

A7.2 Acrylic and glass lenses

For acrylic or optical glass, please contact the AUV Operations Manager to discuss an appropriate test. This will generally be similar to the procedure for metals, but may require additional cycles or hold times.

A7.3 Other materials

Glass (other than lenses) and ceramic pressure vessels are only allowed on Sentry after extensive engineering review and with a compelling reason why an alternative housing material cannot be used. Please contact the AUV operations manager before submitting a proposal to include these types of housings.

A7.4 Demonstrated Use Alternative to Testing

If the PI can produce written records which reference specific serial numbers and specific depths which substantially conform to the standards above, then at the discretion of the AUV Operations Manager or the Expedition Leader, the pressure test requirement may be waived. Verbal statements that the instrument has been to that depth, or pressure testing/use of a similar instrument at depth are not sufficient.

Appendix 8. Sentry Data (09.26.2018)

A8.1 Data Collected

A8.1.1 Scientific Sensor Data

A8.1.1.1 Multibeam Echo Sounder Data

Sentry carries a Reson AUV3 MultiBeam Echo Sounder (MBES). The primary data collected by the MBES is bathymetric swath data; however, backscatter, snippets, and decimated beam amplitude records are also commonly collected. When desired full phase and magnitude data can also be collected.

The AUV3 sonar records binary files in a proprietary Reson format called an s7k file. The file consists of a file header and footer with various "records" packed sequentially into the file. Each record contains a header and a footer as well as a specific type of data. A full description of records can be found in the Reson Data Record Definition available from Reson, but common records will include:

- Bathymetric soundings
- Backscatter data
- Snippet data
- Sonar settings
- Navigation records (empty – filled in post processing)
- "Compressed video" – compressed image of the multibeam fan

An independent driver on the main vehicle control computer is used to configure and manage the MBES. This driver writes ASCII text logs including initialization file parameters, commands sent to the MBES, and state information received from the MBES.

A8.1.1.2 Interferometric Bathymetry, Sidescan Sonar, and Sub-Bottom Profiler

Sentry carries an Edgetech 2200m integrated sidescan sonar/sub-bottom profiler. The 2200 can simultaneously collect two channels of sidescan data and sub-bottom profiles.

Data is recorded in binary files in an Edgetech proprietary format called a JSF file. JSF files do not contain file level headers or footers, but are a collection of individual records in the order they are written. A data record consists of a single ping from a single type of sensor. A description of the JSF file format, including data record types, is available from Edgetech.

A8.1.1.3 Digital Still Camera

Sentry carries a color digital still camera. During the dive, all camera data is recorded as losslessly-compressed 16-bit single-channel TIFF of the raw Bayer-pattern data from the camera sensor. Additional post-processing is required to demosaic the raw sensor data into a useful color image. Photo data products are discussed below.

A8.1.1.4 CTD Data

Sentry carries a Seabird 49 CTD sensor. The CTD reports conductivity, temperature, depth, and several derived products such as sound speed in ASCII format via RS-232. These data are logged by a driver running on the main stack.

A8.1.1.5 Magnetometer

Sentry carries three APS1530 three-axis flux gate magnetometers. Each magnetometer reports raw magnetic field values in three dimensions via RS-232. These data are logged by a driver running on the main stack. Low-frequency data from one magnetometer is provided in the standard science CSV file. Full-rate data is included in standard matlab data products. Advanced users are encouraged to inquire early in the planning process about other data formats of convenience.

A8.1.1.6 Obtical Backscatter

Sentry carries a Seapoint optical backscatter based turbidity sensor. The Seapoint reports turbidity measurements via an external A/D converter. These data are logged by a driver running on the main stack.

A8.1.1.7 Dissolved Oxygen

Sentry carries an Aandaraa Optode dissolved oxygen sensor. The Optode reports Oxygen concentrations via RS-232 in ASCII format. These data are logged by a driver running on the main stack.

A8.1.1.8 Sensors of Opportunity

Several Ethernet and RS-232 ports are available for integration of sensors of opportunity. Each of these sensors will require a custom software driver, several cables, and other similar prep work so it is important to engage us early.

A8.1.2 Command and Control Data

Numerous log files are generated by the vehicle control software. It is hoped that future versions of this document will elaborate on this, but it is very rare that these raw logs will be needed by scientists. In the event that they are required, contacting us directly is presently the recommended course of action.

A8.1.3 Navigation Data

There are five primary sources of navigation data including the sensor drivers for the INS and DVL. Two of these sources, the subsea navigation estimator and the raw USBL data are unlikely to be utilized in the post processing pipeline.

Most users will only want the final post-processed navigation solution that fuses all navigation data collected by both Sentry and the ship throughout a dive. Limited acoustic communications prevent all navigation from being collected into a single navigation solution for Sentry during a dive. Sentry and the ship each maintain their own estimate of vehicle position throughout the dive for real-time navigation. Once the dive is over, all information is collected and combined into a best-estimate of Sentry’s latitude and longitude. This final navigation solution is used for all post-processed mapping, imagery, and science plots.

A8.1.3.1 Doppler Velocity Log Data

The DVL along with the gyro angles from the PHINS form the basis of the dead reckoning navigation. DVL data is recorded by the DVL driver in real-time and extracted to matlab .mat files during postprocessing. The DVL usually operates only in bottom-track mode.

A8.1.3.2 Inertial Navigation and Gyro Data

The PHINS INS system provides both inertial navigation data and gyro angles. At present only the gyro angles are used. The logs created by the PHINS sensor driver are parsed and fed into the renavigation process (see below).

A8.1.3.3 Topside USBL Data

The Sonardyne system generates raw log files associated with USBL tracking. Generally these logs are recorded and retained, but are not actually used.

A8.1.3.4 Topside Navigation Estimation Program Data and Logs

The topside navigation estimation program creates log files which include USBL fixes, ship position, ship heading, and other similar data. These log files are the source of data for the topside navigation post processing and renavigation process as described below.

A8.1.3.5 Subsea Navigation Estimation Program Data and Logs

The real-time dead reckoning estimate in particular is contained in the Sentry navigation rosbag files. These logs are also the source of key pieces of sensor data including the INS, and DVL. The real-time dead reckoning includes corrections for sound velocity.

A8.1.4 Post Processing

The information in this section is more detailed than most users may want. Unless users have specific interest, we recommend skipping to the “A8.2 Data Products” section below.

During any dive, substantial data is collected. Specific raw data types are described above, but generally the raw data are not in a format that is useful to most scientists. Post processing is generally necessary to develop derived data products.

The first step is always to move the data to a backed up archive. The next step is to convert relevant data from the raw log format (i.e. ROS BAG or ASCII) to Matlab structures which are compatible with the remainder of the pipeline. Once the data has been suitably ingested into Matlab the next step is to create a best estimate of the vehicle position. The output of the initial parsing and navigation processes are several data files which then are combined with raw data products from other sensors to create final derived data products such as maps and annotated images. Each of these processes is described in additional detail below.

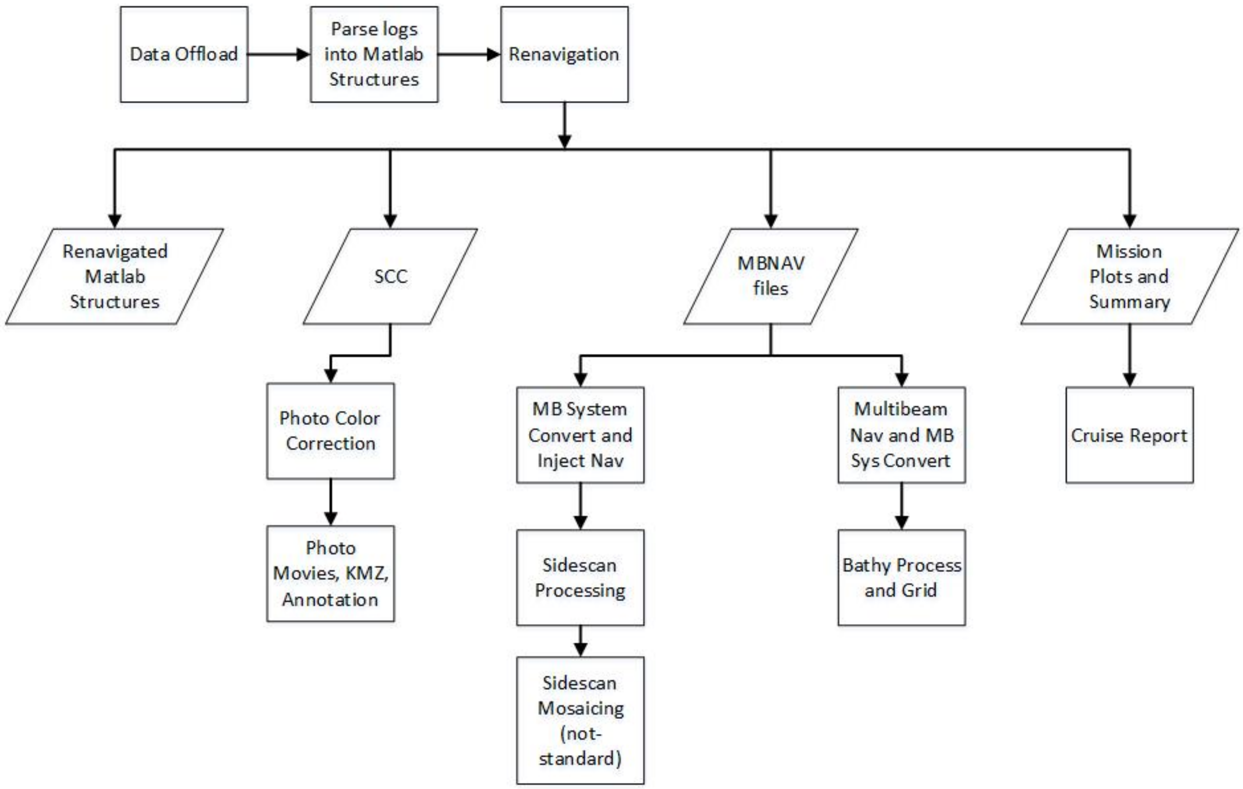


Figure A22 - General Post Processing Work Flow

A8.1.5 Initial Data Ingestion

For Sentry most data is recorded in ROS BAG binary logs at the rate of one file per hour. These data are extracted from the logs and put into a more readily analyzable format. Selected data is pulled from these logs into Matlab structures where previously developed tools can perform appropriate operations. Typically several engineering structures are created as well as a structure for any sensors which do not require further processing later.

For Sentry the sensors with structures include:

- Sound Velocity Probe
- CTD
- Magnetometers (3 structures)
- Optical Backscatter
- ORP
- Dissolved Oxygen
- DVL
- INS
- Depth
- Topside Navigation data from Navest
- Metadata from the Predive
- Structures are commonly created for other custom sensors as well

In addition, at least the following engineering data are parsed into structures for diagnostic and other purposes:

Thruster commands and reported values

- Bottom follower parameters, goals, references, and reported values
- Battery status/power usage/etc as available
- Safety sensor outputs such as leak detects, humidity and temperature sensors and ground fault detectors

Data which is not ingested into Matlab includes:

- Multibeam data
- Sidescan data
- Photos
- Sub Bottom Profiler data

A8.1.6 Navigation Processing (Renavigation)

The most important data-set for any AUV operation is accurate seafloor navigation. The navigation used for Sentry is typically an ultra-short baseline (USBL) system augmented with an inertial navigation system (INS) and Doppler velocity log sonar (DVL).

At the end of each dive, the data from the USBL, INS and DVL are processed to remove outliers, correct for sound speed, and other similar corrections, and then are combined using WHOI developed code to form a final post processed navigation estimate. The final processed navigation data is reported in Latitude and Longitude in decimal degrees (suitable for importing into GMT and other mapping tools) and is embedded within the time-stamped scientific data file for each dive (see later).

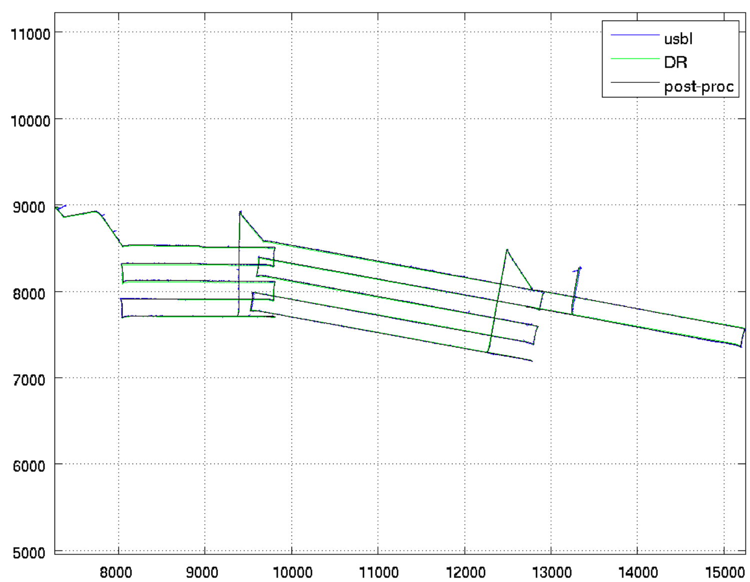


Figure A23 - Example of processed post-dive navigation data (black line) as derived from within-dive USBL fixes (blue line) from a Sentry multibeam run (80 meters height) (D.Yoerger, WHOI). The post-dive corrections are quite small, the rms value of the combined x and y correction for the entire dive is less than 10 m (Fig.2)

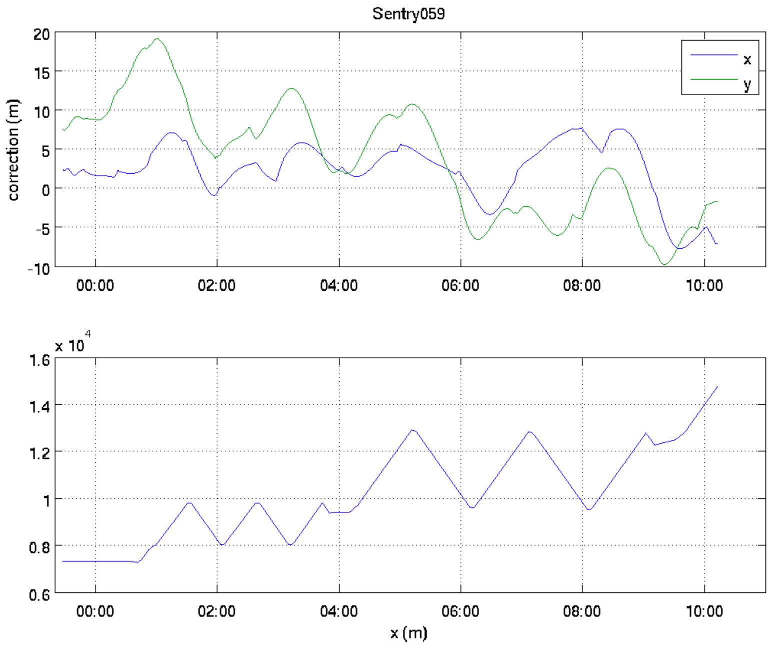


Figure A24 - This plot shows the post-dive correction applied to the real-time dead-reckoning track (upper panel) and the x coordinate of the processed track (lower panel). We conclude that our real-time track, which does not use USBL or LBL information, remains consistent with the USBL track to within 10-15 meters.

The tool used to post process the navigation is referred to as renavigation and was developed at WHOI and is part of the DSLPP Matlab library. When the renavigation pipeline is run, a default script with standard parameters suitable for most situations is copied from a revision controlled repository to the nav-sci/proc directory for the dive. Parameters can then be edited if required without affecting the global default. The renavigation process requires only minimal intervention by the user in most cases with the most critical decision being the correct cutoff frequency for the complimentary filter used in the algorithm. Methods for selecting the cutoff frequency and modifying other similar parameters will be provided in the data post processing manual.

A8.1.7 Chemical, Geophysical and Physical Oceanography Data

For the purposes of this document, Chemical, Geophysical and Physical Oceanographic Data will include:

- CTD
- Sound Velocity
- Dissolved Oxygen
- Oxidation-Reduction Potential
- Optical Backscatter
- Magnetometer

The data from the Chemical, Geophysical and Physical Oceanographic sensors is parsed into Matlab structures as a part of the initial data ingestion process described above. It is then combined with the renavigation data and navigated matlab structures are created and saved. The data is also written into the SCC file which is a comma separated ASCII text file which includes navigation and sensor data including these sensors interpolated onto a one second time base.

A8.1.8 Bathymetric Data

Multibeam Echo Sounder (MBES) data is processed using a customized version of MB System, an open source package for multibeam data processing. In addition to certain customizations, WHOI has developed several tools to speed the process and created a wrapper which takes care of integrating vehicle data such as dive times. In general, the process is:

1. Raw Reson data files are run through a WHOI-created program called s7kextract. This creates a new set of working files containing only the s7k records necessary for post-processing and significantly speeds the data processing while reducing the size of the cruise archive directory. The original raw files remain untouched in a raw directory.
2. The extracted records are run through mbsystem's mbpreprocess where they are combined with the post-processed navigation solution.
3. The data are run through a WHOI-customized version of mbsystem's mbclean to remove most fliers and artifacts from each sonar ping. This automated cleaning is generally successful at filtering data sufficiently to make publication quality maps without the need for hand editing. Automated cleaning can fail, especially in very steep or unusual terrain.
4. The data are combined with a tide file generated by University of Oregon's TPXO 7.2 tide model as well as several vehicle parameters such as lever arms between the INS and MBES using standard mbsystem tools (mbset, etc). Users should contact the Sentry team early in the planning process if other tide datasets are desired.
5. The data are translated into world space and with all previously applied corrections using mbprocess.
6. GMT grid files are created using mbgrid.
7. Various WHOI and MB System scripts are used to create the specified data products such as PDFs

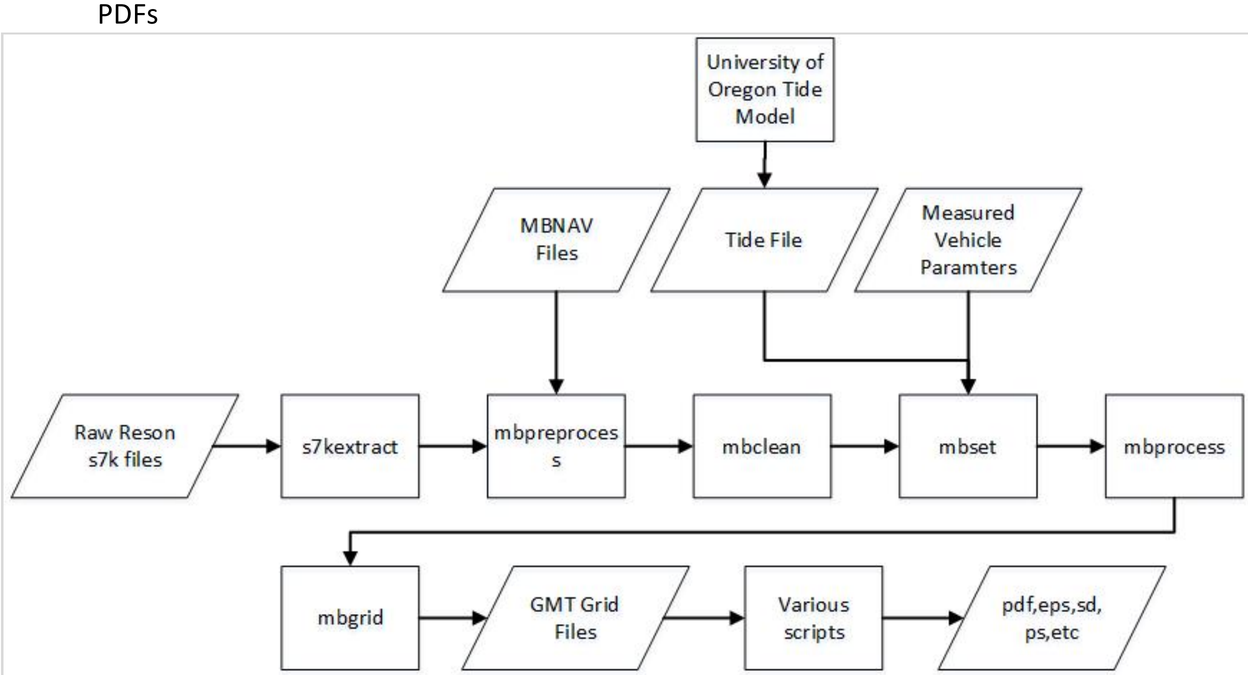


Figure A25 - Reson Multibeam Post Processing Work Flow

A8.1.8.1 Water Column Multibeam:

With help from the folks at the NOAA OER program, we have learned to ingest the water column data from the Sentry multibeam into Fledermaus in order to display bubble plumes in the context of other data. This is a nascent capability and is not supported as standard. Water column data is can be so large it imposes severe additional constraints on data post-processing, dive time, and vehicle turnaround time. Please contact the Sentry program (sentry_program@whoi.edu) early in the planning process if this capability is desired.

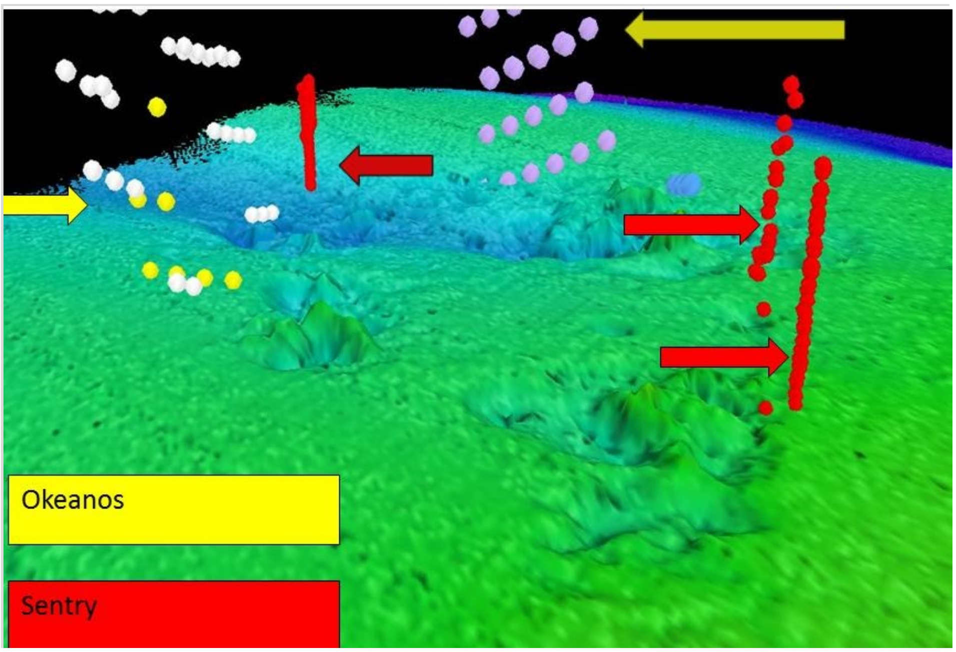


Figure A26 - Bubble plumes from both the Okeanos Explorer Hull mounted multibeam (yellow, white, purple) and from the *Sentry* multibeam (red). Image generated by Elizabeth Loebecker with data from Cindy VanDover.

A8.1.9 Photographs

Still photographs are collected as raw Bayer Images. WHOI uses a proprietary process based on Open CV to color correct and light balance these images. Next an unsharp mask is applied and TIFF images are created. An additional WHOI proprietary process referred to as Moviemaker then ingests the SCC file created during the renavigation process and creates various data products described below.

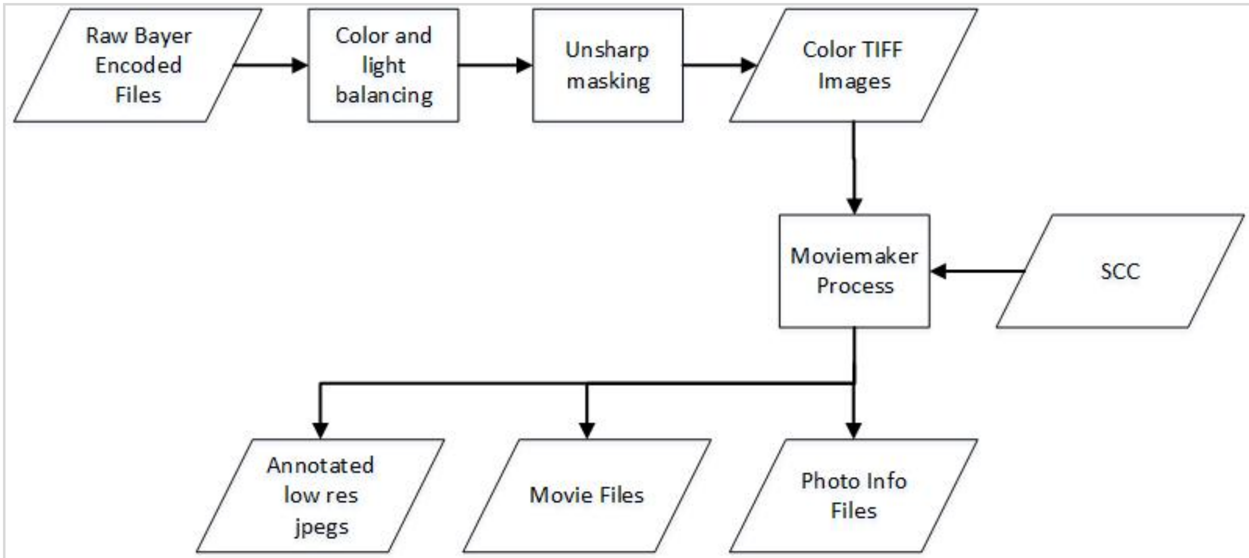


Figure A27 - Still photo post processing pipeline

A8.1.10 Chemical and Physical Oceanography Data

Chemical, Geophysical, and Physical Oceanography data are fully post process including generation of the SCC file by the initial data parsing and by the renavigation process. No further steps are required.

A8.1.11 Sidescan and Sub-bottom

Sidescan and subbottom data are processed using the off-the-shelf proprietary SonarWiz sonar data processing software suite. Post-processed navigation data are first added to the raw JSF files using SonarWiz's NavinjectorPro utility and the navinjector files produced by the navigation post-processing pipeline. Some users may find these nav-injected JSF files a useful starting place for further processing.

Sidescan data is then loaded into SonarWiz. Line endings are trimmed out, multiple data records are combined into single track files, and any necessary gain corrections are applied. Sidescan files are run through the SonarWiz bottom-tracker. Individual tracklines and several full mosaics are exported as georeferenced images.

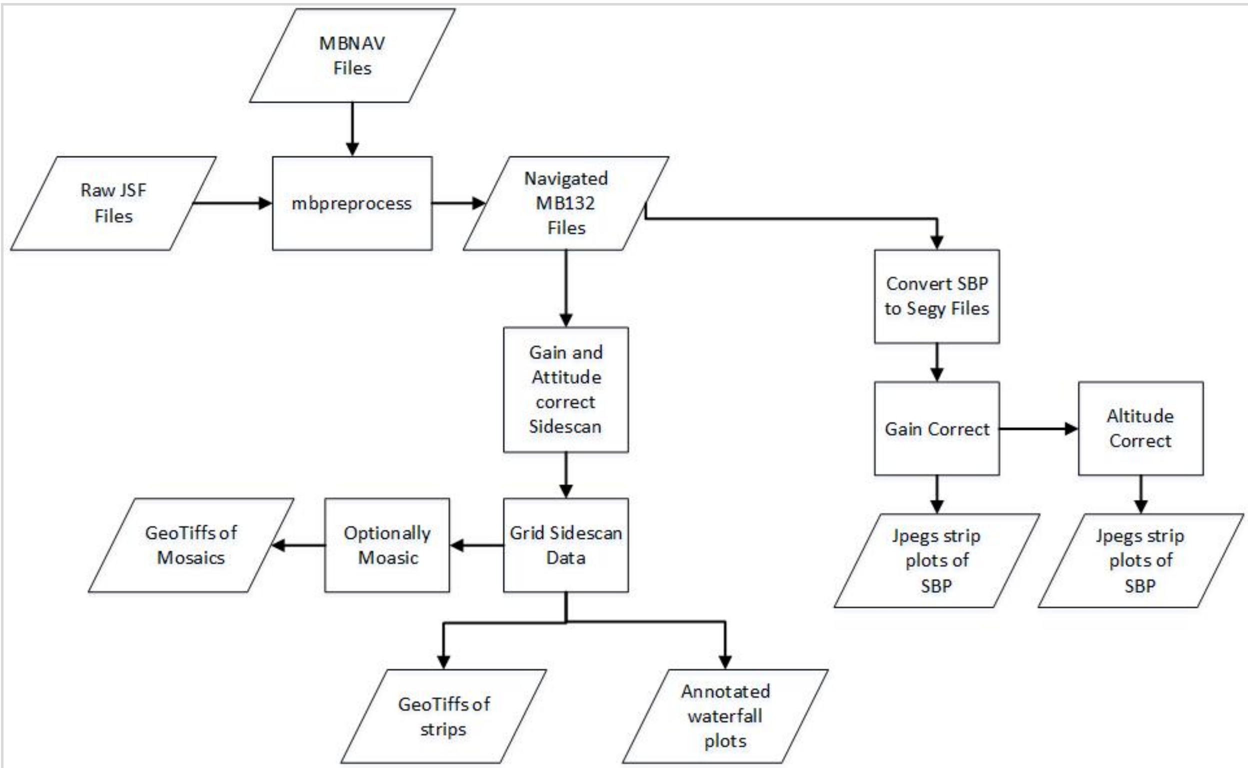


Figure A28 - Sidescan and Sub Bottom post processing flowchart

A8.2 Data Products

Precise navigation, robust control, and co-registered sensors permit *Sentry* to characterize the seafloor and the near-bottom environment on the meter-scale (absolute) to decimeter-scale (relative) through complementary sensing modes. There are several different data types, hence, data products that can be collected routinely by *Sentry*. Two tables at the end of this document list a complete set of these data types – both those that represent the standard data sets provided for all *Sentry* NDSF cruises and those that are under development (sensors acquired since *Sentry* entered the NDSF) but are not yet sufficiently robust to be considered standard deliverables.

Table A4.

Category	file type	suffix	contents	usage
Nav./ Sensors	summary file (flat ASCII)	.scc	date, time, lat, lon, depth, height, conductivity, temperature, magnetometer	import to other packages for analysis, plotting
Bathy	gridded bathy	.grd	gridded bathymetry	import to other packages such as matlab or GMT for generating plots or analysis
Bathy	gridded bathy	.asc	arc/info ASCII grid	import to GIS
Bathy	gridded bathy	.ps, .pdf, .png	bathy image	import into documents (MS Word), latex), web pages
Bathy	fbt	.fbt	editted and geolocated multibeam ping data	import to packages to grid and display data such as Fledermaus, Matlab.
Photos	raw image file	.tif	raw image directly from camera	image appears monochrome, but is bayer-encoded for color. Not useful without further processing
Photos	Labelled image	.tif	Color-balanced, annotated images	Review full-resolution images. Can be quite large.
Photos	Thumbnail	.jpg	Low-resolution version of color-balanced images	Quick review / transmission of large numbers of photos. Typically not ideal for full-resolution publications.
Photos	photo movie	.ogv, .mp4	color balance and annotated images stitched together into a movie file	rapid review of large numbers of photos
Sensors	mat files	.mat	sensor data recorded at native rates	import into matlab for processing. This is the preferred route for data such as magnetometers where downsampling and time interpolation of the .scc file is inappropriate.
Nav./ Sensors	Matlab Binaries	.mat	Various sensor and engineering data at native rate with navigation and attitude	Scientific data analysis in Matlab or python.
Nav / Sensors / Engineering	ROS BAG	.bag	All raw data sent through ROS during the dive	Raw format of all real-time data not logged through sensor specific formats. Anything that isn't an image or sonar gets logged here.
Sidescan / Subbottom	navigated JSF files	.jsf	Sub Bottom Data and/or Sidescan data	Sub-bottom data processing in many processing suites.
Sidescan	Geo TIFF	.tif	Geolocated strips of gain corrected, bottom tracked sidescan data	Can be exported into GIS, fledermause, etc or used for standalone sidescan review.
Forward-looking Sonar	Raw sonar data	.son	Raw log of BlueView forward-looking collision avoidance sonar	Review in BlueView's ProViewer software; further processing

A8.2.1 Delimited ASCII Navigation and Sensor File (SCC)

In addition to bathymetry and photographic data, numerous other sensors are employed on Sentry. These data are compiled at the end of each dive into a single scientific data file that is made available as a comma-separated-variable text file. This is a format that can readily be imported into numerous data-analysis programs such as MatLab or other software appropriate for handling large data-files.

The science data in each .scc file is organized into columns with headings that cover time, processed navigation (vehicle position given in latitude and longitude in decimal degrees), depth, pressure (the primary variable from which depth is derived), height off bottom and heading (both essential for photo-mosaicing). Oceanographic data included in the same file include conductivity and temperature from the Seabird SBE47 CTD mounted on the vehicle and optical backscatter output from the Seapoint OBS instrument. Geophysical data collected routinely on all deployments (in addition to the bathymetric data discussed previously) includes 3 components of magnetic field data from the top magnetometer.

A8.2.2 Navigation and Sensor Plots

A wide variety of plots showing sensor data combined with navigation are created.

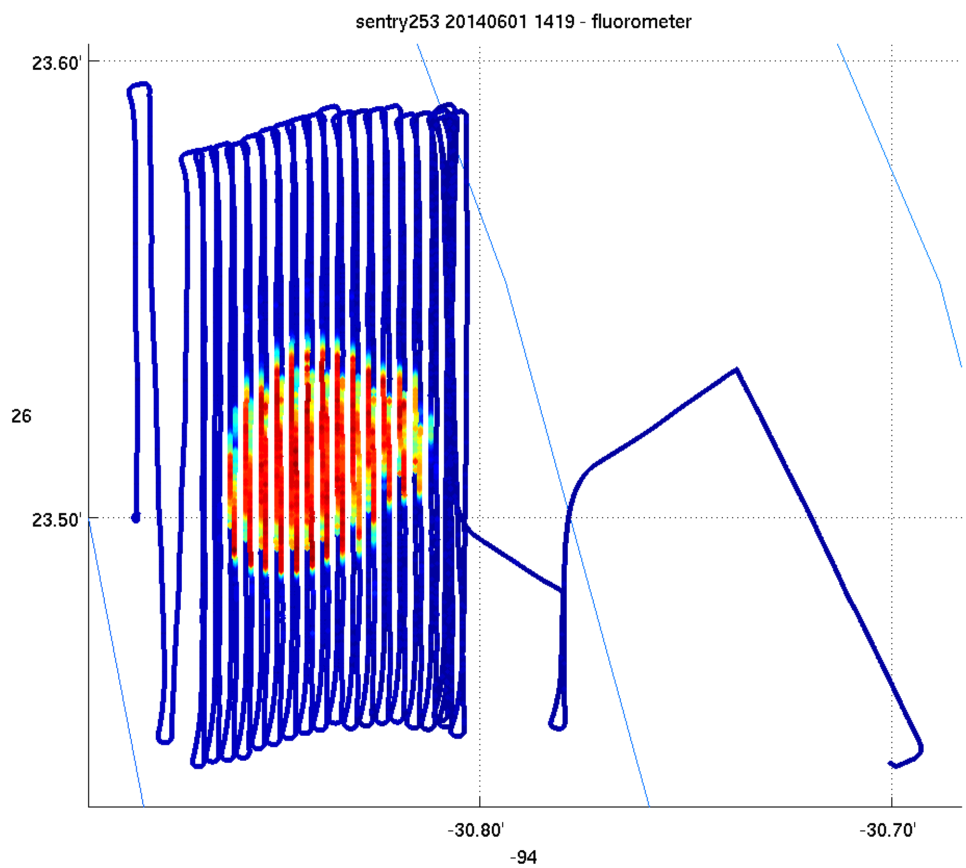


Figure A29. An example of trackline plots using data generated by Sentry

In addition to navigated plots, time series plots of some data are also generated. Figure shows and example of such a plot which was generated using Sentry data.

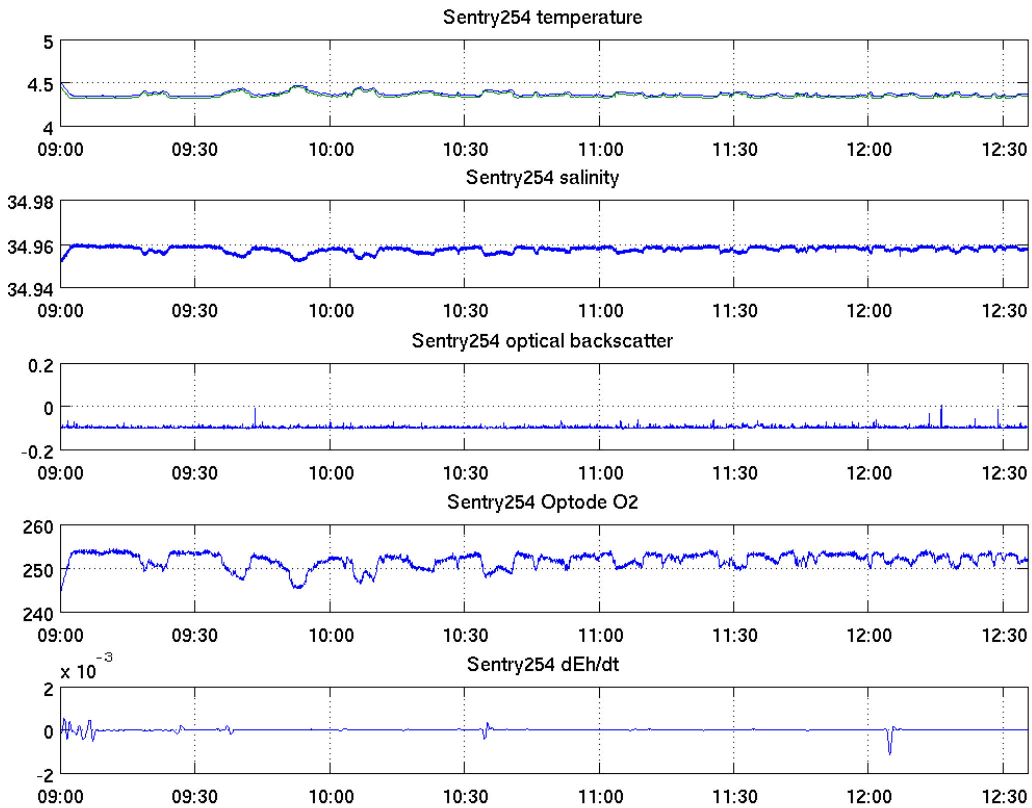


Figure A30 - Example of time series plots of Sensor data generated during a Sentry dive on a Cindy VanDover cruise

A8.2.3 Navigated Matlab Binary Files

The raw logs from the C&C systems and most instruments are ingested into Matlab for data post-processing. These logs are ingested into structures which incorporate time, sensor data, and derived products related to the sensor. These structures are saved as binary Matlab files (.mat.) Once the renavigation process is complete, a second copy of these files is created which incorporates the navigation data into the structure. These files can be easily read back into Matlab or Python for further data analysis by scientists.

A8.2.4 Bathymetric Maps

The bathymetric data generated by Sentry are made available to the science user in four data product forms suitable for different science user needs:

- raw and processed navigated profile data files (mb88 format for the Reson). These can be re-processed by the science party as required. The science party may decide to hand-edit the data to recover those few good soundings that our automated editors have removed and to remove the few remaining fliers. We believe recent improvements in our automated editor make this unnecessary (Fig.3), but if detailed map interpretation is critical we recommend a careful review of the edited profiles by someone with good geological insight.

- gridded (at appropriate resolution) data files in .grd format which can readily be imported by the scientist into generic software such as *GMT, Fledermaus* or Matlab, whether at sea or for post-cruise analysis.
- fbt files: this is an mb-system format for the navigated, edited ping data that can be readily loaded into Matlab or Fledermaus. These files can also be used to produce additional grids (different grid spacing) or to produce grids from multiple dives.
- processed map *images* in .eps, .ps, and .pdf formats that can be used by the science party for immediate visualization of the gridded data set, further dive planning while at sea and post-cruise report generation and publications.

It should be noted that in general, NDSF is only able to deliver bathymetric data products that are the result of our automated process. Skilled data processors can typically remove additional artifacts and generally improve the map. If at sea staff have the time and skill, they may choose to do this, but it will be at the discretion of the expedition leader and not all data processing staff have this capability.

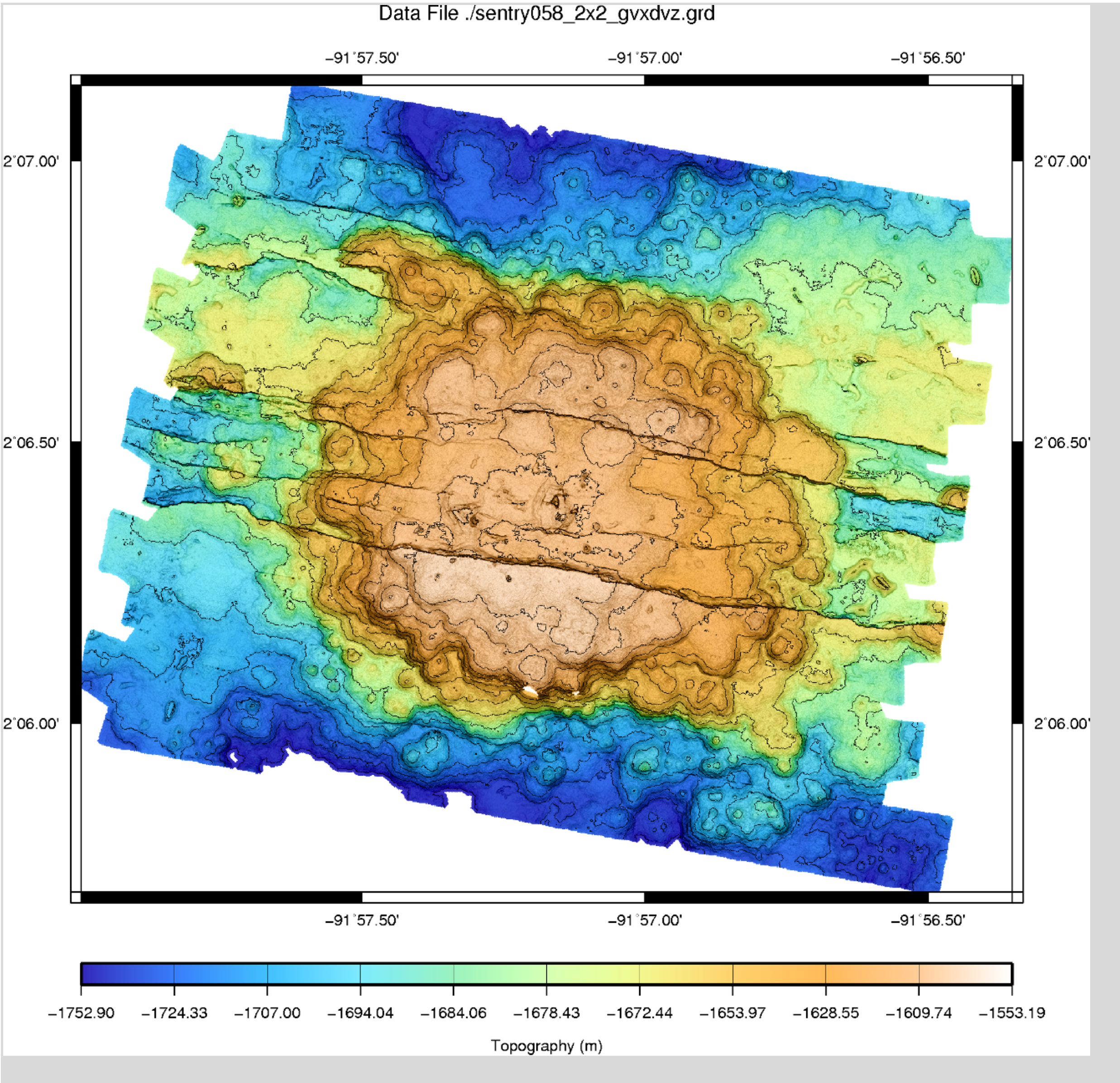


Figure A31 Example of a bathymetric map image generated at sea (J Sinton, University of Hawaii, D.Yoerger, WHOI). This image was produced using only our automated scripts with no hand-editing or final navigation correction.

A8.2.5 Sidescan Waterfall Plots

Sentry is equipped with a sidescan sonar system at 120kHz, 410kHz, or both. Raw sidescan data is delivered as navigated JSF files. In addition to raw data, gain corrected, bottom tracked, and nadir trimmed strip plots for every survey line are delivered as geoTIFF files. Non-publication quality (i.e. non gain-matched) mosaics are generated as part of the standard strip plot data pipeline however these are in a SonarWiz proprietary data format. They can be exported upon specific request. Hi quality gain matched (i.e. publication quality) mosaics and mosaics draped onto bathy in a Fledermaus scene can be generated with the same software, but the at sea data processing load involved in this is substantial and has only occasionally been supported by a standard five person *Sentry* team.

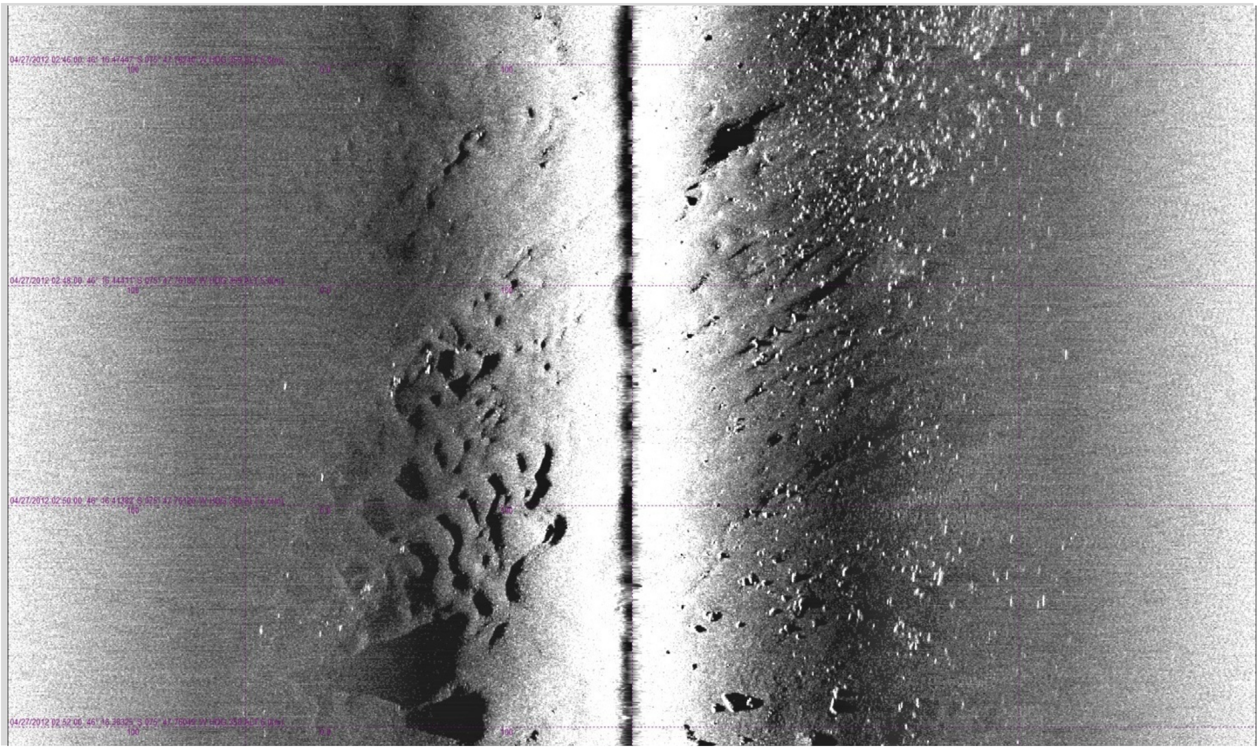


Figure A32 - Image from a steep side hill with the sidescan. This is a typical format for the standard data product (Image from Donna Blackman)

A8.2.6 Sub Bottom Strip Charts

Sentry carries an Edgetech 2200m system which includes a subbottom profiler (SBP). The SBP 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 a depth of several 10s of meters. We have also used this sonar to detect probable methane seeps.

Data from the subbottom profiler is recorded in Edgetech's proprietary .jsf format with navigation records left blank. The .jsf files are copied and the navigation records are populated in the copy based on the post-processed navigation estimate. This task is carried out using a program called Nav-Injector Pro which is a part of the Sonarwiz package by Chesapeak.

Navigated .jsf files are imported into Sonarwiz and annotated strip plots are generated in TIFF format. An example output is given in Figure . SD objects suitable for import into Fledermaus can be generated.

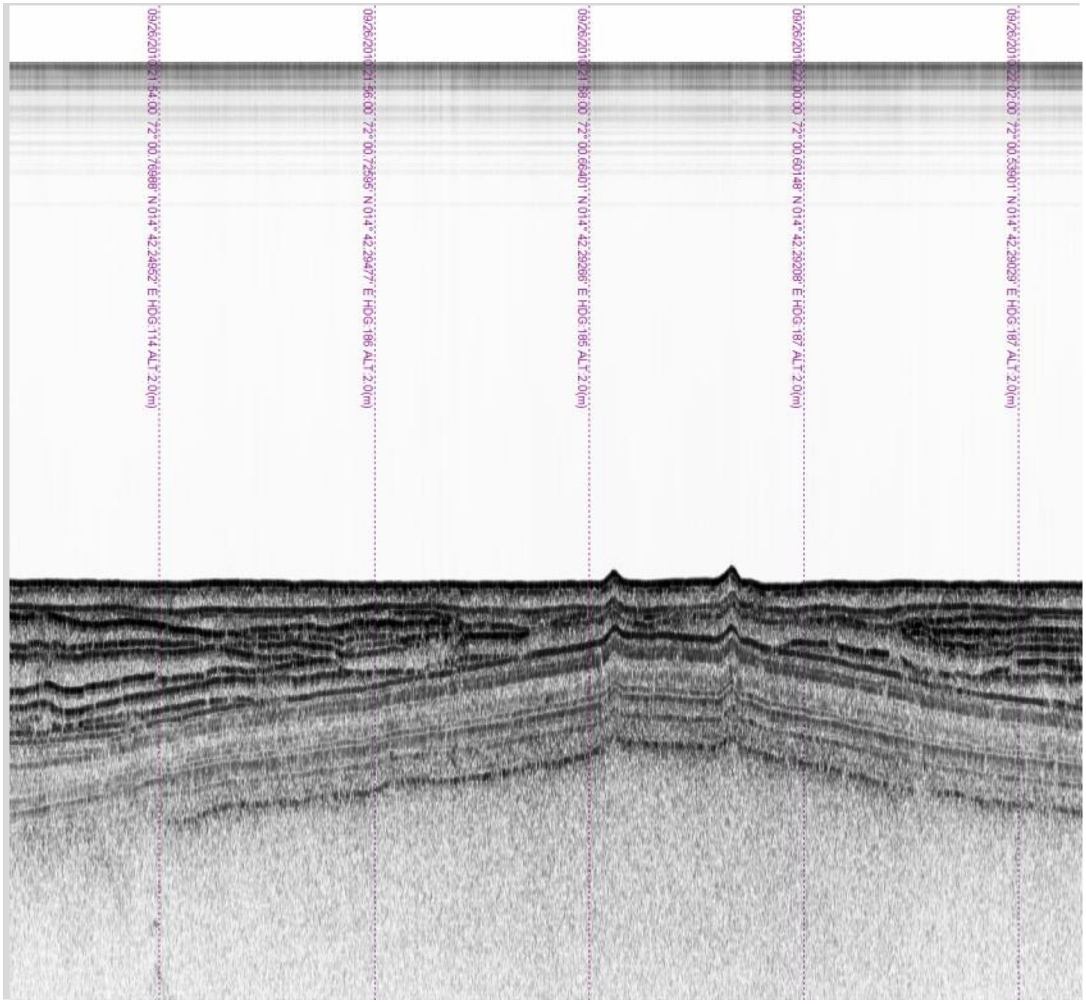


Figure A33 - Typical Data Product from a the Sub Bottom Profiler (Image from Chris German)

A8.2.7 Photographic Products

The standard photographic data product is a set of processed, time-stamped, color TIFF files. Photos are color corrected and sharpened via an automated script.

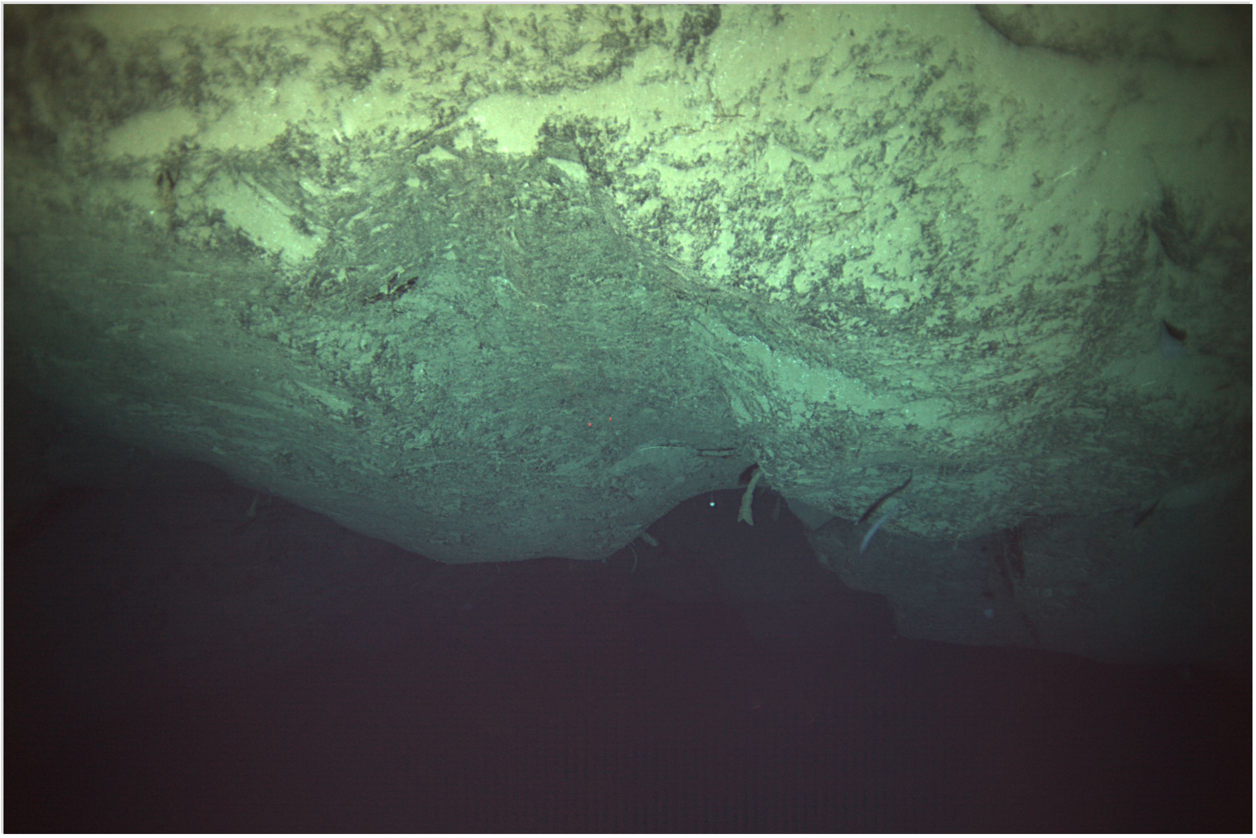


Figure A34 - Example of a recent *Sentry* photograph (from a Cindy VanDover cruise)

In addition to the basic photos,.ogv and .mp4 movie files will be generated that contain annotated images in succession for rapid review. Images are also provided in .kmz format for automatic import into Google Earth and in annotated low resolution jpeg files for easy transport and review.

A8.3 Custom Data

Many science users wish to receive data either in custom formats or to use their own sensors. We do our best to accommodate these requests whenever possible. To maximize the chances for success, we strongly recommend discussing these topics very early in the pre-cruise planning process (six months before departure if possible) or possibly even prior to proposal submission if it is critical to the cruise.

A8.4 Nascent Data Products

At any given time we have a number of nascent data products which are under development or which we know how to make but are to time intensive to regular delivery. A handful of these are discussed below. If these are of interest, talk with us as early as possible. In some cases, we can do them for a few dives, or on a time available basis, or teach a student, or through a separate post processing agreement, or a wide variety of other options. The earlier users engage us in these conversations the better the chance we can accommodate the needs (email to sentry_program@whoi.edu).

A8.4.1 Water Column Multibeam:

With help from the folks at the NOAA OER program, we have learned to ingest the water column data from the *Sentry* multibeam into Fledermaus in order to display bubble plumes in the context of other data.

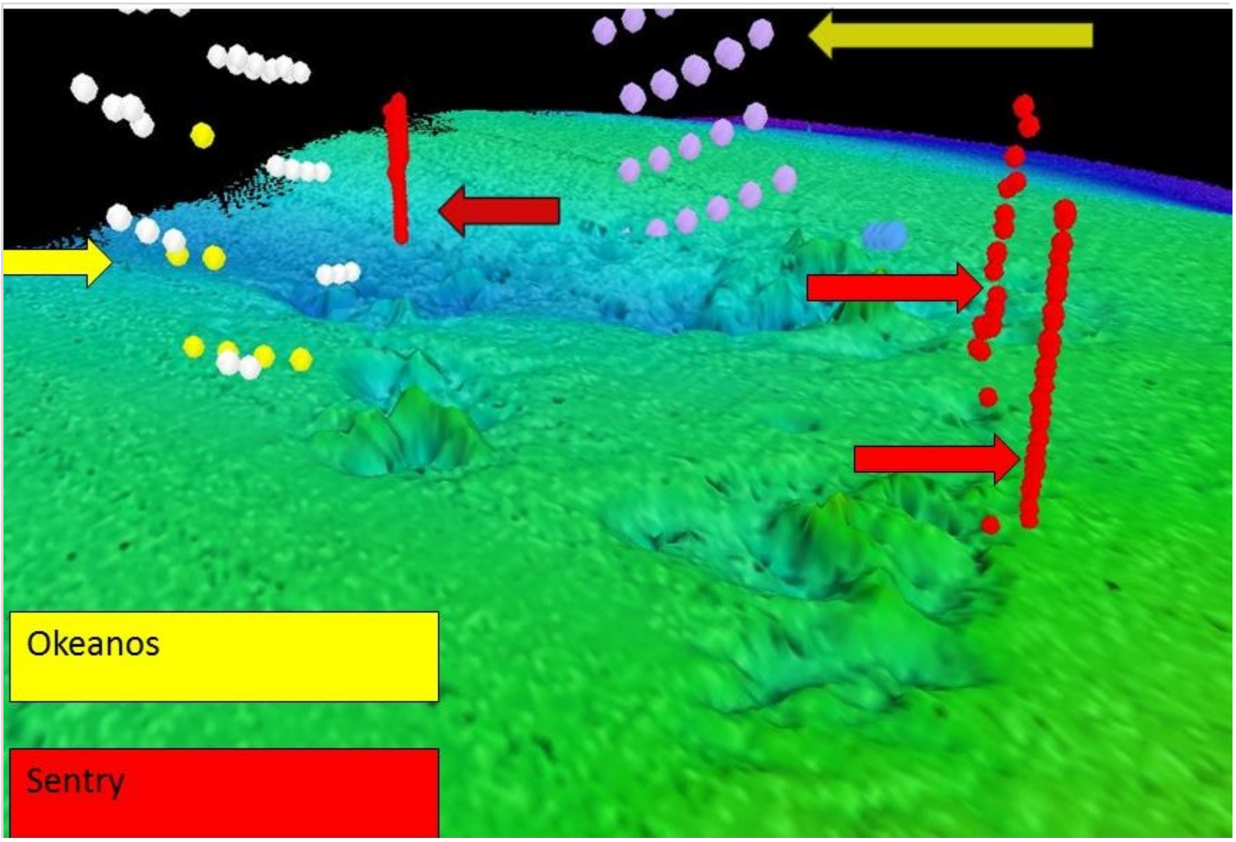


Figure A35 - Bubble plumes from both the Okeanos Explorer Hull mounted multibeam (yellow, white, purple) and from the *Sentry* multibeam (red). Image generated by Elizabeth Loebecker with data from Cindy VanDover.

A8.4.2 Sidescan Mosaics

The standard data product for the sidescan system is a swath strip. It is possible to put these swaths together into mosaics. We have only a single license for this software and doing a good job is time intensive. We can typically create a very rough mosaic for users, but a publication quality mosaic Figure is very time consuming and we are often unable to do this without additional staff.

Figure A36- Example of a rough sidescan mosaic. These are typically easy to make but do not deal elegantly with overlap, nadir, etc. Courtesy by Cindy Van Dover and Laura Brothers

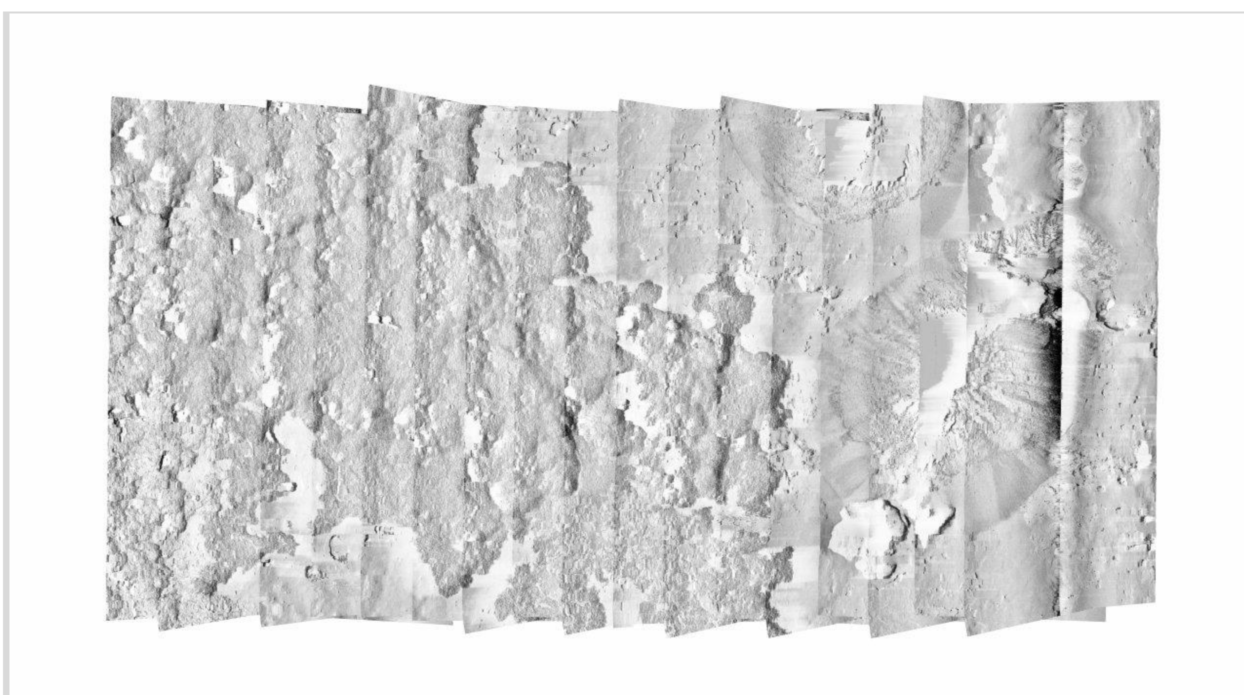


Figure A37 - Detailed sidescan mosaic. These are time consuming to make and require substantial expertise from the data processor. Courtesy by Craig Moyer and Brian Glazer.

A8.4.3 Fledermaus Visualizations

We have learned to put many of our data products and other non-standard types of data into Fledermaus Scenes. This is fairly labor intensive and often not something we are able to do for the full cruise, but it is a compelling way to look at the data. We carry a very limited number of Fledermaus dongles and can't necessarily provide one for the whole cruise, but this is an example of something we may be able to do for one site, or teach a student to do if users have a student, dongle, and computer.

A8.4.4 Blueview Imaging Sonar

Sentry has acquired a Blueview P-900 imaging multibeam. This sonar is mounted forward looking and to date we have used it primarily for obstacle avoidance. We have experimented with pipelines for seafloor mosaicking and vertical face multibeam maps. Both of these pipelines remain highly developmental.

A8.5 Timeliness of Data Delivery

Oceanographic sensor (e.g., CTD, OBS) data, co registered with navigational data, are typically available to the science party within 3 hours of the end of the dive. The larger volumes of multi-beam, sub-bottom, sidescan, and/or photographic data collected by contrast, typically require longer download times and substantially more processing effort. 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 the science party and can take up to another 24 hours before all copies of the data are fully written. **Long camera surveys within 48 hours of arriving back in port may require final data delivery via mail up to a week after the end of the demob.** In this case, a copy of all data except the final photos will be delivered and an additional drive with the photo data will follow as soon as practically possible. Sidescan strip plots can typically be delivered in 24-36 hours (mosaics and drapes if agreed to, may take days to weeks as they have to be fit in around other workload.) due to the long download times and the substantial effort associated with gain correction etc. Sub-bottom data can typically be delivered within 3-6 hours of recovery but since the data is in the same file as the sidescan data, it can take significantly longer to download and deliver if the sidescan is installed.

At the end of the cruise, we provide the Chief Scientist with one complete copy of all of the data collected on external USB hard drives (formatted as EXT4 or NTFS). If a ship data server is available, data files such as the SCC files and the multibeam sonar GRD and postscript files may be uploaded to the server as they are completed. A *Sentry* data server may also be set up to provide access to files for the broader science party. Similarly, the Science Party is free to bring additional drives, as required, for additional copies to be made. Please see drive recommendations under Data and Data Handover as storage needs may surprise users. These should be free of all other content, and should be provided to the *Sentry* team at the outset of the cruise to ensure that the entire data-set can be transferred to the drive in a timely fashion.

A8.6 Organization of Delivered Data

Data Organization is not discussed in detail here. It is presented in "**Error! Reference source not found.**" so that is more of a standalone section for portability.

Appendix 9. MB Data (in the case of current Reson sensor)

Users consider post processing multibeam data to makes the publication-quality maps because the map provided by the Sentry dives are the first-order maps created by MB system software with very basic renavigation processing. Our automated pipeline for multibeam maps generally yields results that are sufficient for planning future dives and sometimes yields publication quality maps.

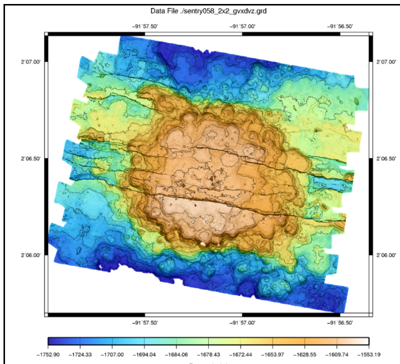


Figure A38 - Example of a very high quality result from the automated multibeam pipeline. In this case the sharp lines are predominantly faults rather than data artifacts. Image from Data collected during a cruise directed by John Sinton.

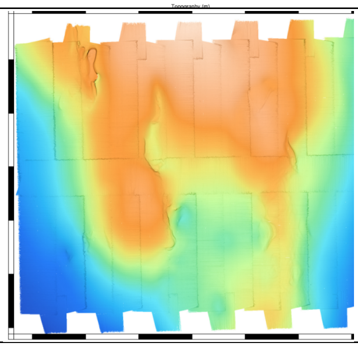


Figure A39 - Example of an image where the output of the pipeline leaves clear artifacts. This is a combination of the extremely flat nature of the terrain and the extreme depth (5200m). This anecdotally probably represents about the lower quartile bound of the automated pipeline in terms of qualitative visual appeal.

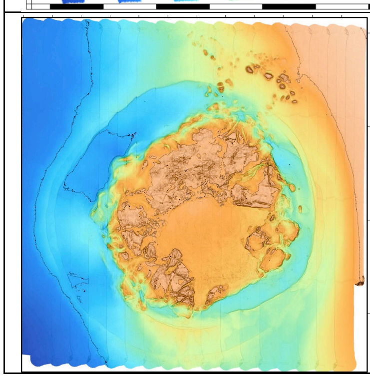


Figure A40 - Very good result from the automated pipeline. Compare this with the following image and observe that there was substantial improvement from additional processing. Data collected during a cruise directed by Chris German

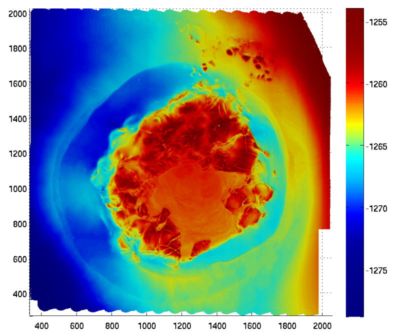


Figure A41 - This is an example of a fully post processed map created by Dana Yoerger with substantial hand processing of very good data. Data collected during a cruise directed by Chris German

Numerous factors will affect the quality of the data outputted by the automated multibeam pipeline. Major factors that will tend to degrade the map quality are:

- Lack of good-quality navigation data (e.g. when Sentry is out of USBL range of the vessel, when Sentry frequently loses bottom-lock navigation over very steep terrain)
- Extreme Depth (performance drops off after about 4500m)
- Extreme terrain (slopes > ~ 45deg or with very high roughosity)
- Extremely flat terrain that can highlight small multibeam artifacts that would be lost in rougher terrain. Any type of error in data collection such as a timing error

Notwithstanding the fact that we cannot commit to exceed the required data post processing deliverable, most cruises do have a modest percentage of spare data processing capacity. This is particularly true if there is for example, a long transit at the end of the cruise. Sentry staff will always seek to deliver the best possible products that we can including editing beyond the automated pipeline where the skills and at sea bandwidth allow. There is always the need to prioritize on this issue and so communicating with the Expedition Leader about priorities is important.

If users are planning to post process own multibeam data, we recommend MB System by Dave Caress at MBARI and Dale Chayes at Columbia. MB System has several substantial advantages including:

- It is free open source software with extensive tutorial for most common tasks (http://www.mbari.org/data/mbsystem/mb-cookbook/)
- It is a quasi-standard in the academic oceanographic community with a large and active user group (http://www.ldeo.columbia.edu/res/pi/MB-System/#DiscussionList)
- It is what we use to do the initial post processing and hence users will be able to pick up where we left off rather than starting over
- As of 2018, no commercial multibeam package offers as many options for navigation adjustment.

MB NavAdjust:

Typically, the single biggest improvement that can be made are in the navigation. Sentry provides an integrated navigation estimate as a part of the data package within the rnv matlab file described in **Error! Reference source not found.**. Edits to the rnv file are a difficult and sophisticated process and are neither recommended nor described here.

Most required navigation improvement will be in the form of small tweaks to make features match. MB System provides a tool called MB NavAdjust which performs this function with a decent graphical interface. Dr. Dana Yoerger recently recorded an mbnavadjust tutorial. We can provide copies of those videos upon request.

Patch Testing:

Surface ships commonly use a standardized calibration procedure, known as a patch test, to estimate various timing and angular offsets between the multibeam and navigation data. Casual users can typically use offsets from a previous cruise, but users relying on the multibeam for the success of their cruise are encouraged to plan time for a new Sentry patch test. The Sentry team has developed a patch test procedure adapted to the unique benefits of AUV multibeam surveying that can typically be completed in less than 2 hours of bottom time. Please contact Sentry staff during the cruise planning process to ensure data staff are available to process the resulting calibration data.

Ping Editing:

The simplest method that removes noise not related to navigation is to hand edit the pings. This can also sometimes restore data where there may be gaps. MB System provides both a swath editor (mbedit) and an area-based editor (mbeditviz). With practice, an hour of multibeam data can often be relatively carefully edited in less than 10 minutes. This will not remove systematic sources of noise or error, nor will it improve navigation estimates.

Commercial Packages:

A wide variety of commercial multibeam packages exist. Any package users use, will need to allow one to import post processed navigation from an external ASCII text file as we cannot populate the navigation records in the raw *.s7k files from the multibeam sonar. NDSF staff have varying levels of experience processing Sentry multibeam data in different commercial multibeam packages. Virtually all commercial multibeam packages are poorly-tested with AUV data and may require working with the vendor to successfully import Sentry data. It can take months for even trivial bug fixes to work through a vendor’s release schedule. Please contact us early in the planning process for further information (sentry_program@whoi.edu).

Outsourcing the multibeam processing is another possible approach to improve the MB data. At WHOI and within marine science community worldwide, various point of contacts are offered for this service.