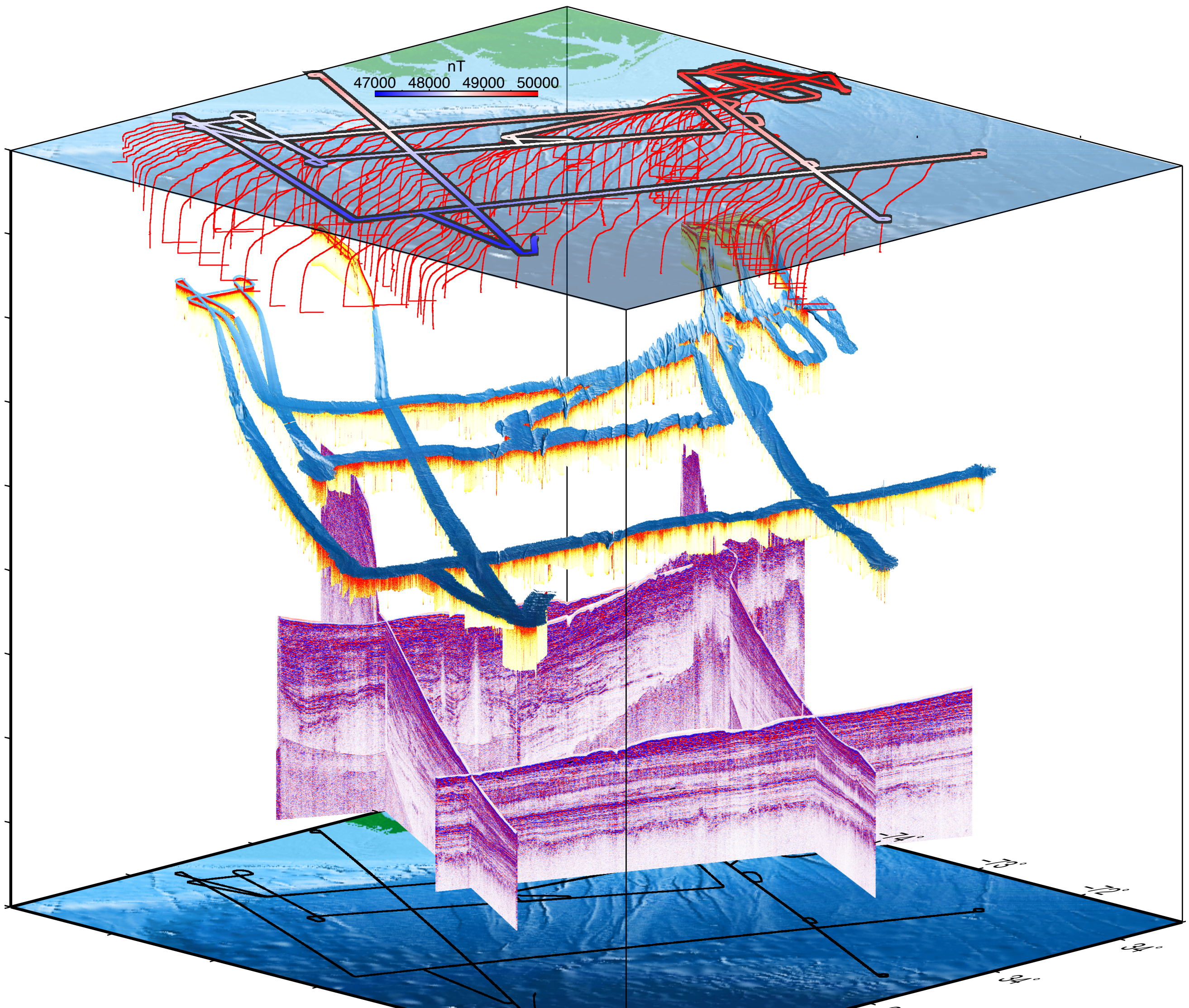
Cruise Report

Eastern North American Margin Community Seismic Experiment

Cruise MGL1408, R/V *Marcus G Langseth*



From top to bottom:
Magnetic total field, XBT profiles,
bathymetry, swaths subbottom profiles, and
seismic reflection lines. Courtesy of Gilles Guerin.

Geo PRISMS Geodynamic Processes at Rifting and Subducting Margins

Norfolk - Norfolk
September 16 - October 18, 2014

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1. Cruise Objectives

The purpose of the ENAM community experiment is to collect an open-access onshore/offshore, active/passive seismic dataset across the Mid-Atlantic continental margin that can be used by the community to tackle a broad range of science questions stated in the GeoPRISMS Science and Implementation Plans regarding the formation and evolution of rifted margins. The marine active-source part of this program involves the acquisition of multichannel seismic reflection and wide-angle reflection/refraction data with the R/V *Marcus G. Langseth* and the R/V *Endeavor*. Offshore airgun shots were also recorded by an array of short-period seismometers deployed onshore for the duration of the cruise as well as offshore broadband OBSs deployed for 1 year.

The science targets of the marine active-source program include tectonic and magmatic processes involved in the breakup of Pangea and opening of the Atlantic Ocean and the more recent evolution of the margin by dynamic, interrelated processes such as sediment transport, slope failure, salt diapirism and gas hydrate formation and dissociation. More details on the geological context for both deep and shallow targets are described below. The location of this experiment also spans an area of dynamic oceanographic processes associated with the Gulf Stream, providing the opportunity to use seismic oceanography to examine internal structure of the ocean within this area using these data; more information on this ancillary objective can be found in Appendix E.

Continental rifting and breakup

The active-source seismic data acquired during this cruise targeted structures and magmatism at the Eastern North American Margin (ENAM) around Cape Hatteras. The Brunswick magnetic anomaly intersects the rifted margin within the study area (Fig. 1-1); it is thought to represent a major Alleghenian suture (e.g., Williams and Hatcher, 1982; McBride and Nelson, 1988) and/or a change in mafic content of the crust, possibly from synrift intrusions (Lizarralde et al, 1994). Another interpretation places the Alleghenian suture north of the BMA (Higgins and Zeitz, 1983), but it still meets the rifted margin within the study area. The main transects cover parts of the margin where this interpreted suture appears to coincide with the location of continental rupture and places where it does not, providing an opportunity to assess the control of such pre-existing structures on rifting. This survey also spans the northern part of the southern section of ENAM, which includes the Carolina Trough offshore, and the southern boundary with the central section, which includes the Baltimore Trough offshore. Onshore, there appear to be major changes between these sections in the timing and style of rifting and the relative timing of rifting and magmatism associated with the Central Atlantic Magmatic Province (CAMP) (e.g., Withjack et al., 1998). The marine data could reveal possible variations offshore at the boundary between these sections, and what these variations imply about rifting style.

This study also encompasses a section of the East Coast Magnetic Anomaly, which is primarily attributed to synrift magmatic rocks along the edge of the rifted margin. In this study area, it exhibits significant along-strike variability in its strength and character, which may be related to magmatic segmentation (Behn and Lin, 2000) and to contributions to the ECMA by other terrane boundaries and/or basins (Alsop&Talwani, 1984). ENAM community seismic data could provide new constraints on the distribution and volume of magmatic material and other possible contributions to the ECMA. Farther offshore, the study continues far enough seaward to encompass oceanic crust. This region includes the enigmatic Blake Spur magnetic anomaly (Fig. 1-1), which may mark a ridge jump (Klitgord & Schouten, 1986; Kneller et al., 2012) or a change in the direction, speed and asymmetry of incipient seafloor spreading (Labails et al., 2010). Data from the ENAM CSE will constrain variations in basement roughness, crustal thickness and crustal structure along and across new oceanic crust that can provide new constraints on the early spreading history. The Kane and Northern Fracture Zones form significant offsets in the modern Mid-Atlantic Ridge seaward, and can be projected back to the area of our study. The data can thus be used to examine variations in tectonic and magmatic segmentation over the life of the rift and assess the possible contribution of pre-existing structures onshore in controlling this segmentation (Withjack & Schlische, 2005; Thomas, 2006).

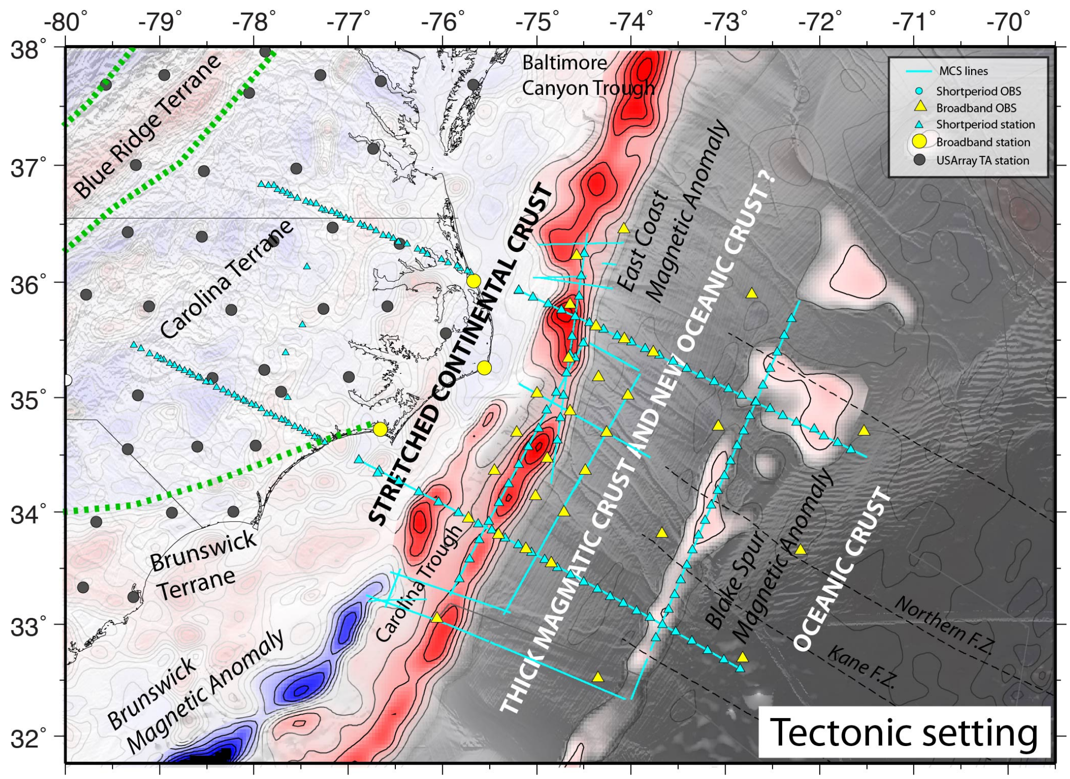

Figure 1-1*: Map of ENAM community seismic study with tectonic setting.*

Slope stability, gas hydrates and sediment transport

During and after rifting, large sediments volumes were deposited on this continental margin. While much of this sediment was deposited via erosion from North American continental crust, the margin continues to be modified by ocean currents, submarine slope failure, salt diapirism, and gas hydrate formation/disassociation in sometimes substantial ways (e.g. Carpenter, 1981; Dillon et al. 1983, Popenoe et al, 1993) (Fig. 1-2). The ENAM area of study is home to some of the largest slope failure complexes in the North Atlantic, yet the mechanics, timing, and cause of these events remain poorly constrained. It has been more than 20 years since a high-resolution, high volume MCS/OBS survey has been conducted in this region to address these and other associated questions. Furthermore, questions remain regarding how on-going salt tectonics and large-scale growth faulting continue to shape the margin (e.g. Dillon et al., 1983; Cashman and Popenoe, 1985; Hornbach et al, 2007). During the early stages of extension, salt was deposited in Carolina Trough, as evidenced by salt diapirism along the seaward edge of this basin, and seafloor deformation associated with salt indicates continuing active salt tectonics in the Carolina Trough (Dillon et al., 1983). The study area spans the Carolina Trough as far south as the Cape Fear diapir and slide, and several lines pass either directly over or very near known salt bodies. The MCS survey extends as far north as the Currituck slide, and therefore, will provide new insight into slide geometry and structure both within and adjacent to these slide features. Throughout the entire survey area, there is strong evidence for the existence — and perhaps on-going destabilization — of methane hydrate (e.g. Paull et al., 1996(a), Paull et al., 1996(b), ODP Leg 172 Initial Reports, Hill et al., 2004; Phrampus and Hornbach, 2012; Brothers et al, 2013; Skarke et al., 2014). This study images the base of the gas hydrate stability via bottom simulating reflectors (BSR) in multiple lines. The data may therefore provide new insight into the location and extent of hydrate stability across the marine and the possible role of methane hydrates play in margin evolution.

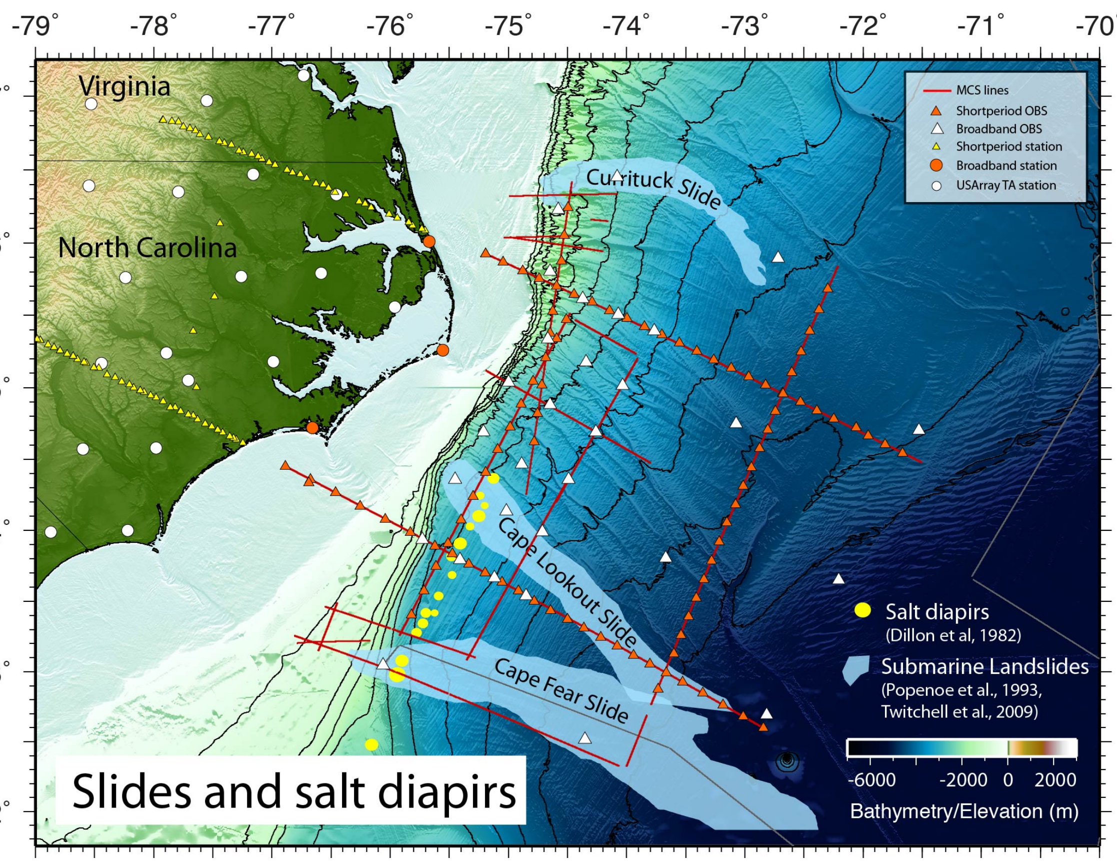

Figure 1.2 *– Map of ENAM CSE with important recent features.*

2. History of the ENAM community seismic experiment

The research expeditions offshore North Carolina aboard the R/V *Marcus G. Langseth* and the R/V *Endeavor* are a part of a major effort by the NSF-GeoPRISMS program to understand the breakup of continents to form new oceans and active processes at the edges of continents that define their structure and evolution. The program is inherently broad, with the goal of providing and integrating a diverse range of datasets for a large spectrum of the Earth Science community. The selection of this region and the design of the seismic study were guided by input from the US scientific community through workshops and online forums.

Community input

The US scientific community chose Eastern North America (ENAM) as an ideal place to study continental breakup and continued active processes on rifted margins through the National Science Foundation funded GeoPRISMS program. GeoPRISMS is dedicated to studying the coupled geodynamics, earth surface processes, and climate interactions that build and modify continental margins over a wide range of timescales, and it supports a diverse range of geological and geophysical investigations. At a GeoPRISMS workshop in October 2011, the scientific community chose a series of corridors along the East Coast as exciting locations for focused geological, geochemical and geophysical investigations. Later, through an online poll, the community chose the area off of North Carolina as the best corridor for a focused onshore/offshore active/passive seismic study. This region was chosen in part because it offered significant research breadth including (1) better constraining the contribution of pre-existing structures on rifting processes; (2) understanding along-strike variations in magmatism during rifting and early seafloor spreading and their consequences for rifting processes; (3) new insights into the origin of the Blake Spur magnetic anomaly and its implications for early seafloor spreading; (4) the role and character of submarine slope failure events, (5) links between ocean circulation (the Gulf Stream and Western Boundary undercurrent), climate, methane hydrates, and seafloor stability, and (6) new insight into shallow tectonics along a continent-ocean transition zone, including the role of shallow salt tectonics. In the summer of 2012, a large team of PI's submitted a proposal to the National Science Foundation to acquire data in this area, which was funded. Afterwards, more feedback from the scientific community was sought on experiment design to arrive at the final plan. Although the plan was further modified/reduced during environmental permitting, the science team was able to acquire data that satisfy all primary research objectives and provide a wealth of new scientific insight for a broad base of the Earth Science community.

Community Outreach and Data Access

We broadly advertised the opportunity to participate in all of the science cruises and onshore field work for the ENAM Community Seismic Experiment and worked together to select science staff from the community for each component based on their interest and desire to utilize ENAM data. We particularly sought to engage junior scientists and graduate students in all cruises. Indeed, nearly all of the ENAM participants (approximately 25) were highly motivated graduate students and early-career scientists from a diverse set of institutions. Writing as Langseth PIs, we highlight the community-based science party as one of the most successful components of the community experiment. Although many in the *Langseth* science party had never worked together before, scientific interaction over the course of the five-week-long cruise combined with the camaraderie that formed through cruise successes and failures have clearly helped strengthen community ties.

The raw data from this project will be made available to the community immediately after the cruise, and initial versions of the processed data will be made available as soon as they are ready. We plan to hold two training sessions at LDEO and UTIG on MCS processing and wide-angle velocity modeling, respectively, where initial processing of these datasets will be completed. We hope and encourage as broad a participation in these workshops and usage of the data as possible.

Links with more information on community workshops and input:

- http://www.geoprisms.org/enam.html
- http://www.geoprisms.org/enam/community-seismic-experiment.html
- http://www.geoprisms.org/past-meetings/124-enam-oct2011.html

3. Cruise Summary

The core objective of the marine active-source portion of the ENAM Community Seismic Experiment was to acquire multi-channel seismic reflection and wide-angle reflection refraction dataset offshore North Carolina over a spectrum of targets that capture the entire history of the Eastern North American Margin, from rifting and early seafloor spreading to more recent modification by sedimentation, faulting, slope failure, and associated processes. Cruise MGL1408 aboard the R/V *Langseth* was a complete success in meeting these objectives. We acquired 4816 km of seismic reflection data along and across the North Carolina margin (Fig. 3-1). These profiles covered all of the major scientific targets identified by the community in this area, and included:

1) Two MCS/OBS dip profiles (450-km long and 370-km-long, respectively) across the entire margin, spanning from continental crust near the coast to Mesozoic oceanic crust seaward of the Blake Spur Magnetic anomalies. These profiles were also recorded by an array of short-period seismometer onshore.
2) Two ~250-km-long MCS/OBS profiles along the East Coast Magnetic Anomaly, which is thought to arise from synrift magmatic material at the edge of the margin
3) One ~350-km-long MCS/OBS profile along the Blake Spur Magnetic Anomaly, which is thought to either mark a ridge jump or change in seafloor spreading direction and speed during the early opening of the Atlantic Ocean
4) A series of profiles across and adjacent to the Cape Fear slide that encompass the upper and lower headwalls, a salt diapir, a dynamic gas hydrate system, and a series of seaward-dipping faults.
5) A series of profiles across the Currituck Slide area, including profiles inside and outside the slide itself.
6) A series of other profiles intended to capture along-strike variations in sedimentary and crustal structure between the two main profiles; shots from these lines will also be recorded by a grid of broadband OBS deployed here.
7) Both strike and dip MCS lines that image salt diapirism and listric faulting along the margin. Multiple strike and dip seismic lines that capture erosional unconformities and bottom-simulating reflections associated with gas hydrate stability across margin.

The main MCS/OBS profiles (Lines 1, 2, 3, 4a/4b) were acquired with the full 6600 cu. in. tuned air gun array of the *Langseth* and an 8-km-long streamer, both towed at 9 m depth for deep imaging. On all of the other profiles, the source was a 3300 cu in array towed at 6 m. As described in Section 5, we varied the shot interval, record length, sample rate and effective length of the streamer to best image science targets along the profile and in response to environmental conditions (currents and swell).

We developed a very effective onboard training and processing effort during the cruise, as described in more detail in Section 5 and Appendix B. This enabled us to apply basic processing steps to all of the profiles, including: geometry assignment and binning using true streamer positions, filtering and data cleaning, sorting, velocity analyses, stacking and post-stack time migration. As a result, we produced stacks and migrations for all profiles by the end of the cruise, and we plan to release these to the community shortly after the cruise.

In addition to seismic data, we also acquired a suite of other geophysical and oceanographic data that are essential to the science objectives of this cruise, including bathymetry and chirp data (Appendix C), magnetic data (Appendix D) and XBT data (Appendix E), acoustic backscatter, and gravity data.

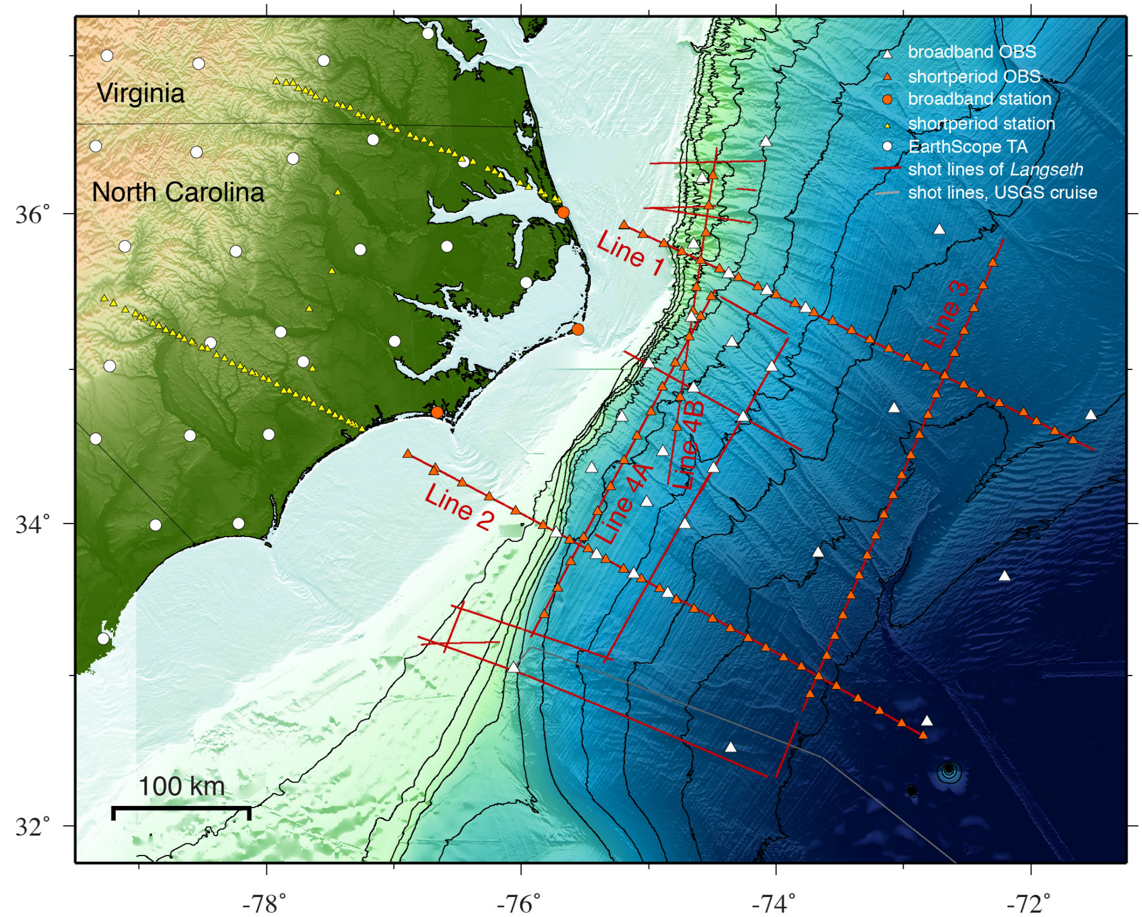

***Figure 3-1**: Map of ENAM CSE experiment.*

Further scientific analyses and conclusions based on these data are beyond the scope of this project, which only includes data acquisition, initial training in MCS data processing, and distribution of both raw data and initially processed data to the community. Nonetheless, onboard data processing revealed a number of exciting observations and science opportunities for the community to consider. These observations include the following:

1. A major change in basement character is observed at the Blake Spur Magnetic Anomaly on both dip profiles. Landward of this anomaly to the slope, the basement is rough and weakly reflective. At the anomaly and seaward, the basement is smooth and more reflective.
2. Intracrustal reflections and Moho reflections are observed on many profiles over 'transitional' and oceanic basement (e.g., Fig. 3-2). The two-way travel time implies that the transitional and oceanic crust is commonly thicker than "normal" Atlantic oceanic crust. However, perhaps surprisingly, we do not see obvious signs of fracture zones along Line 3 MCS or other profiles in the data.

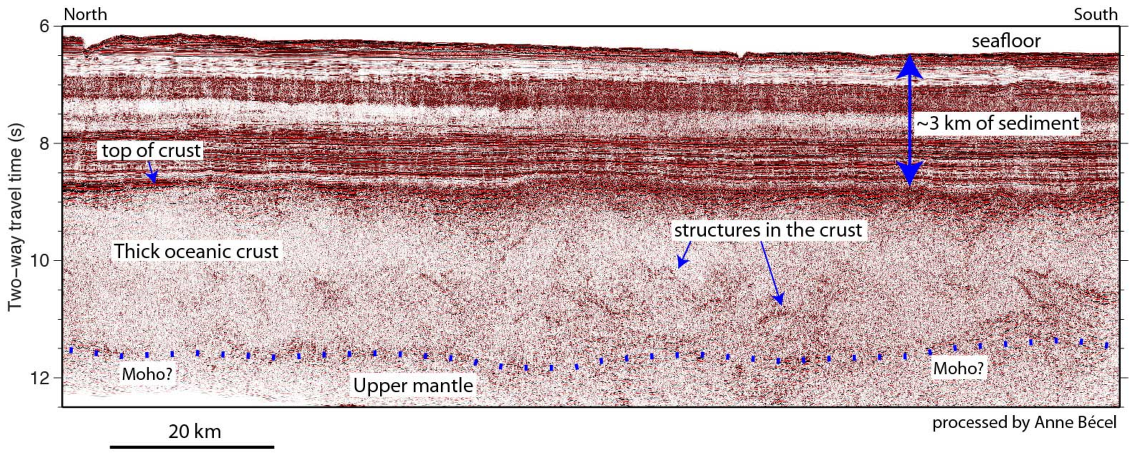

Figure 3-2*: Example of seismic data from Line 3 MCS along the Blake Spur Magnetic Anomaly.*

3. Multiple removal and further processing will be required to image structures within the thicker continental crust; however, we do already observe Moho reflections beneath the shelf on Line 1.
4. In Cape Fear area, we image complex variations in the depth and character of the Bottom Simulating Reflector (BSR), which marks the base of gas hydrate stability zone as well as complex faulting and evidence for subsurface fluid flow across the region (Fig. 3-3).
5. Higher resolution MCS images shot at 25 m shot spacing show large listric faults as well as conjugate faults, many of which extend from several kilometers depth to within tens of meters of the sea floor. These images also show sediment undulations, sediment wave packages, and clear evidence for sediment deformation caused by salt intrusion in impressively high resolution (Fig. 3-3).
6. Near the Currituck slide area, intriguing faults and blocks are observed inside and outside of the slide; a strong BSR is also imaged in this region.
7. In nearly all of the MCS images (25m and 50 m shot spacing) an intriguing, very thick sediment section with highly variable seismic characteristics is observed.
8. We also observe evidence for multiple highly reflective erosional unconformities in nearly all of the MCS dip lines.

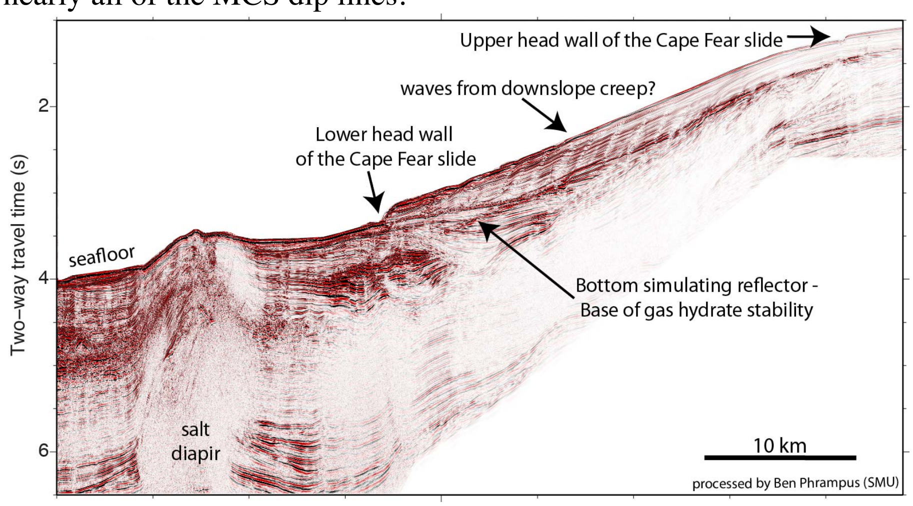

Figure 3-3*: Example of seismic data across upper and lower headwalls of Cape Fear slide and salt diapir.*

4. Narrative

Sept 16: Left port at 1300 UTC (9 am local time) and steamed towards southern end of Line 2OBS.

Sept 17: Neared southern end of Line 2 OBS, and slowed down around 1800 UTC to begin deploying streamer. Deployment went very quickly, so there was a possibility that we could start acquiring that evening. To enable us to ramp up at night, we deployed one gun string and started the mitigation gun at 2257 UTC. Finished deploying streamer at 2359.

Sept 18: Deployed all gun strings by 0136 UTC, and completed ramp up by 0212. Turned onto Line 2OBS and began acquisition at 0455 UTC. (This line is called "OBS001" in the navigation files, etc, because lines were renumbered by shipboard science officer. We corrected naming convention for other lines to be consistent with pre-cruise plans and OBS naming. Hereafter, this line is referred to as Line 2OBS). Continued shooting Line 2OBS for the rest of the day.

Sept 19: Continued shooting Line 2OBS. Variable streamer feathering was observed as we crossed a vortex and neared the Gulf Stream. We experienced streamer feathering up to 45° and very slow speeds over the ground in Gulf Stream (< 3 kts).

Sept 20: Continued shooting Line 2OBS and were joined by a chase boat at 0545 UTC. Reached the end of Line 2OBS at around 1457 UTC, steaming through very shallow water (~25-30 m) at the end. Stopped the line short of original end point to avoid water depths < 23 m. Turned and began shooting Line 2MCS at 1726 UTC and continued on this line for the rest of the day. Chase boat departed at 1900 UTC. Gun volume changed to 6420 cu in at 2001 UTC when spare switched on.

Sept 21: Continued shooting Line 2MCS. Weather worsened considerably around 0400, with seas up to 4 m. Cable surfaced at 0612 UTC, then was put down to 11 m depth by 0738 UTC. Streamer depth brought back up to 9 m later, but then submerged to 11 m at 1809 UTC due to swell noise. Streamer depth decreased to 9 m by 2131 UTC. XBT's every 300 SP along this profile.

Sept 22: Continued shooting Line 2MCS and regular XBT's in much better weather.

Sept 23: Continued shooting seaward part of Line 2MCS. At 0025 UTC, there was a leak in the pipe connecting accumulator tanks for the compressors, which required an immediate shut down of shooting and retrieval of the guns to prevent them from flooding. Since it was after dark, we could not re-start shooting for about 12 hours. We were only 23 km from the end of Line 2MCS, so we decided to forego the rest of that line and the connection line originally planned between Line 2MCS and the southern end of Line 3OBS, and just steam up to Line 3OBS during the night and be ready to start that line in the morning. The guns were redeployed by 1008 UTC, and ramp-up began at 1318 UTC. As we turned towards the beginning of Line 3OBS, gun string #2 was recovered for repair. We arrived at the beginning of Line 3OBS before the repairs were finished and decided to steam slowly and shoot with 3 strings. Line 3OBS started at 1510 with 3 gun strings. Gun string #2 was deployed at 1624 UTC, and full volume shooting commenced at 1628 UTC. Continued shooting Line 3 OBS. At 1748 UTC, a turtle was sited, and we powered down to the mitigation gun, but ramped up again at 1819 since it was not seen again.

Sept 24: Continued shooting Line 3OBS.

Sept 25: Continued shooting Line 3OBS and finished at 1010 UTC. We turning around and began Line 3MCS at 1258 UTC, and continued shooting this line for the rest of the day. We also acquired XBT's along this profile every 300 shots.

Sept 26: Continued shooting Line 3MCS and doing XBT's.

Sept 27: Continued shooting Line 3MCS and finished at 1121 UTC. Gun strings 2 and 3 recovered, and gun depths changed from 9 m to 6 m, then redeployed. This took about 1 hour. We began shooting Line 31 at 1238 UTC with the streamer at 6 m and finished at 1742 UTC. Began Line 32 at 1825 UTC and continued on this line for the rest of the day. Continued XBT's along these lines. Strong currents pushed us off the line at 2054 UTC by up to 30 m, requiring the bridge to take over steering temporarily.

Sept 28: Continued shooting Line 32 and finished at 1119 UTC. Began Line 33 at 1124 UTC after changing sample interval to 1 ms, shot spacing to 25 m, and streamer to record on inner 6 km (rather than entire 8 km). We needed to alter course slightly to ensure seismic coverage of the upper Cape Fear headwall despite significant feathering, so shifted line slightly south to allow for better streamer coverage of upper headwall. Due to the shift in navigation, we ended Line 33 at 1734 UTC and began Line 34 on new course at 1738 UTC. XBT's done throughout the day, with denser deployments near Cape Fear slide at depths shallower then ~2500 m.

Sept 29: Continued shooting Line 34 and doing XBT's, finishing at 1402 UTC. Completed outside turn due to strong Gulf Stream currents and began shooting Line 35 at 1520 UTC in route to next OBS line. We changed shot interval to 37.5 m due to high speeds over the ground (up to 7 kts) steaming with Gulf Stream. We stopped acquisition on this line at 2003 UTC to ensure time to change gun depths to 9 m before beginning Line 4A OBS. Began Line 4A OBS at 2214 and continued on this line for the rest of the day at shot interval of 225 m. This shot interval was intended as a compromise between very sparse shot spacing due to fast speeds over the ground (~6.5 to 7 kts) and the desire for long shot intervals for OBS.

Sept 30: Continued on Line 4A OBS and completed this line at 1958 UTC. Recovered gun strings 2 and 3 to change depths to 6 m, which took ~1 hour. Streamer depth also adjusted to 6 m. Began shooting Line 41 at 2055 UTC and continued on this line for the rest of the day.

Oct 1: Continued on Line 41, finishing at 0436 UTC. Made an inside turn and started Line 42 at 0501 UTC. Some vessel traffic passing at 1607. Finished Line 42 at 2139. Gun strings recovered to change depths to 9 m in preparation for Line 4B OBS, which took 1.5 hours. Turned towards Line 4B OBS.

Oct 2: Began Line 4B OBS at 0126 UTC. We powered down for a MMO sighting at 1239, but were able to restart full volume at 1254 when it left the radius. We also powered down for a sea turtle at 1714 and waited 30 minutes (until 1743) to resume full power since it was not seen again. Finished Line 4B OBS at 2058 UTC. Began turn to Line 1OBS. All gun strings recovered for maintenance and repairs.

Oct 3: Gun maintenance repair continued until 0526 UTC (a total of 9 hours). Line 1A OBS began at 0603. At 1041, there was a shutdown for dolphin, which ended when it left the radius at

1056, then we ramped up the array, which completed at 1133. At 1222, we deviated from the line to avoid fishing lines and boats. During deviation, there was a brief power down for a dolphin from 1317 to 1341 and a power down for a turtle for 30 min from 1519 to 1549 UTC. Rejoined the line at 1649 UTC. Intense streamer featuring in this interval from the Gulf Stream and turns (over 80 degrees from line).

Oct 4: Continued on Line 1A OBS. At 0925 UTC, line was stopped to complete repairs on gun string 2, and maintenance on other gun strings. Turned back onto to line and started Line 1B OBS at 1214 UTC and continued on this line for the rest of the day.

Oct 5: Continued on Line 1B OBS, finishing at 0345 UTC. Turned around and began Line 1MCS at 0618 UTC and continued on this profile for the rest of the day, doing regular XBT's. At 2012 UTC, PAM began to have problems; when recovered, it was discovered that the hydrophone was damaged. PAM repaired with spare equipment and redeployed and operating at 2052 UTC.

Oct 6: Continued on Line 1MCS. Line ended at 1213 UTC when source leak discovered. Looped back while repairing source leak in gun string 1 and doing maintenance on other gun strings. Returned to line and started Line 1A MCS at 1711 UTC. Encountered fishing activities at 2122 and reduced speed temporarily.

Oct 7*:* Continued on Line 1A MCS. Over the early hours of the morning, the streamer sank to depths up to 30 m in section around bird 11 as water depths shallowed towards the shelf. This precipitous drop in the streamer was due to at least a 5 degree change in temperature (a temperature drop) as we began exiting the Gulf Stream. One section of the streamer that had been heavy throughout the cruise was particularly deep. Ended Line 1A MCS at 0455, picked up guns, and picked up the streamer to the heavy section. Removed ballast weights and replaced non-functioning birds. Streamer redeployed by 1614, and guns redeployed by 1714. Ramped up and started Line 1B MCS at 1807 UTC. Powered down for 5 minutes for a pilot whale at 1825 and again from 1835 to 1905 UTC. Finished (finally!) Line 1B MCS at 2202 UTC. Changed gun depths from 9 m to 6 m and turned towards Line 52. Streamer with more birds and less weight behaved much better the colder water.

Oct 8*:* Turned on Line 52 and began at 0040 UTC. Source volume changed to 3180 cu in at 0644 when switched to spare due to firing problems. Finished Line 52 at 0858. Turned to Line 53 and repaired broken gun. Started Line 53 at 1218, and diverted from line 53 to line 57. Turned to Line 57 and began line at 1850 and continued on this line for the rest of the day.

Oct 9: Continued on Line 57. Significant noise observed in shotgathers from passing ship passing at 0030. Finished Line 57 at 0054. Turned to Line 58, then maneuvered in this region while we waited for spare parts for PAM to be delivered by a tow boat. Tow boat arrived later than estimated due to choppy seas and arrived at 1500. Turned to Line 58 and began ramp up at 1735 UTC. Powered down at 1836 for a MMO sighting, but returned to full volume at 1852. Started Line 58 at 1854. Powered down for MMO sighting at 2140 and returned to full volume at 2148. Continued on Line 58 for the rest of the day.

Oct 10: Continued on Line 58. Occasionally missed shots on this line because some of the mates have a lead foot. Finished Line 58 at 0420 UTC. Changed gun depths back to 9 m while turning to Line 4B MCS. Began Line 4B MCS at 1054, and did regular XBT's. We had several powerdowns on this line: from 1150 to 1203 and from 1223 to 1229 for dolphins, from 1933 to 1953 and 2049 to 2106 for other mammals (the watchstanders did not see fit to record which ones). Continued on Line 4B MCS for the rest of the day.

Oct 11: Continued on Line 4B MCS and doing regular XBT's. The bridge reported vessel traffic passing streamers at 1712.

Oct 12**:** Continued on Line 4B MCS and finished line at 1014 UTC. Retrieved gun strings and changed depths from 9 m to 6 m during turn. Began Line 62 at 1528 UTC, and continued on this line for the rest of the day.

Oct 13*:* Continued on Line 62 and finished it at 1101 UTC. Turned to Line 63 and began at 1344. Line 63 stopped at 2140. Although we continued along the same line, we started a new line so that we could change streamer recording length to 6 km, sample interval to 1 ms, and recording length to 9 s. Line 63A started at 2146, and we continued on this line for the rest of the day.

Oct 14: Continued on Line 63A and finished at 0429 UTC. Turned to Line 64 and began at 0718, using the same acquisition parameters as 63A. We powered down for a turtle at 1529 UTC near the end of the line, and decided to finish line at 1531. Retrieved gun strings and changed depths while turning to Line 4A MCS. Began Line 4A MCS at 2217 UTC and continued on this line for the rest of the day. A shot interval of 62.5m was chosen to insure long enough shot records with higher over-the-ground speeds in the Gulf Stream.

Oct 15: Continued on Line 4A MCS, doing regular XBT's. Line ended at 1200 in order to change shot interval to 75 m due to high speeds over the ground caused by a strong following Gulf Stream current. This increased shot interval kept the record length at 18 s. Started Line A4A at 1202 with new shot interval. Powered down for a sea turtle from 1551 to 1621. Around the start of Line A4A, we dropped the streamer to 11 mbsl due to significant streamer noise. The streamer was surfacing due to a strong following swell and low speeds through water caused by the following current. Finished Line A4A at 2207. Once we turned towards Line 71, ship speed slowed considerably within the Gulf Stream. Since we would not arrive at the line until the next morning local time, we pulled in the gun strings for the night.

Oct 16**:** Continued transit to Line 71. Guns were deployed and ramp up began at 1329 and finished at 1406. We started Line 71 at 1449. At the start of Line 71, we discovered that gun string #2 had one malfunctioning gun so that the total volume was reduced by ~300 cu in. We ultimately had three other guns that went down on gun string #2 during the shooting of this line. Depth was increased from 6 to 8 m and then to 10 m at 1609 in an attempt to reduce swell noise. There was a power down for a protected species from 1743 to 1813. Continued on this line for the rest of the day.

Oct 17*:* Continued on Line 71. Line was ended at 0800 to ensure there was enough time to pick up the seismic equipment and steam to port in Norfolk in time to meet the pilot. The guns were picked up between 0814 and 0854. The head float, streamer and tail buoy were quickly recovered between 0905 and 1326. At 1326, we also ceased collecting multibeam and chirp data. We then began the steam back to Norfolk, making 11 kts over ground.

***Oct 18*.** Met pilot at ~6:30 am local time (1030 UTC), and arrived in port in Norfolk at ~9:00 am local time.

5. Summary of seismic acquisition and processing parameters

Here we briefly summarize the seismic acquisition parameters and onboard processing for the survey. Further detail is given in the Appendices. We acquired data along the main transects twice, once with parameters tuned for the OBS array and once with parameters more suited to MCS imaging. Other MCS profiles were acquired once with acquisition parameters tailored to the science targets and environmental conditions. We completed basic onboard processing of all profiles, which will be released to the community as soon as possible after the cruise.

OBS acquisition

- We used the full 6600 cu in array of the *Langseth* towed at 9 m for all OBS shooting.
- The shot interval was 225 m on all profiles. Depending on our speed over the ground in the varying currents, this resulted in a time interval between shots between ~60 and 90 seconds.
- Shots were recorded on short-period seismometers from Scripps and WHOI spaced at ~10-20 km, which were deployed and recovered by the R/V *Endeavor*.
- Shots were also recorded on the *Langseth's* 8-km-long streamer towed primarily at 9 m depth (though it was occasionally deepened to 11 m in bad weather due to swell noise).

MCS acquisition

- Lines 1, 2, 3 and 4a/4b MCS were also acquired using the full 6600 cu in array (4 gun strings) of the *Langseth* towed at 9 m. Data were recorded on the *Langseth's* 8-km-long streamer towed at 9 m with a sample rate of 2 ms and record length of 18 s. The shot interval was 50 m for all profiles except Line 4A, where it was increased to 62.5-75 m due to fast speeds over the ground to maintain an 18 s long record.
- The remainder of the MCS profiles were acquired with the 3300 cu in array (two gun strings) towed at 6 m depth. The rest of the acquisition parameters were varied based on science targets and currents.
    - Profiles targeting primarily deep targets were recorded on the 8-km-long streamer at 2 ms sample rate. The record length was 18 s and shot interval was 50 m. The streamer was generally towed at 6 m (to match the gun depth), but it was occasionally deepened to reduce swell noise in bad weather. Profiles acquired with these parameters: 31, 32, 41, 42, 62, 63 and 71.
    - Profiles targeting primarily shallow targets were recorded on the inner 6 km of the streamer at 1 ms sample rate. The record length was 9 s and the shot interval was generally 25 m, with one exception (Line 35), when our speed over the ground required an increase to 37.5 m. The streamer depth was generally 6 m, but it was occasionally deepened to reduce swell noise. Lines acquired with these parameters: 33, 34, 35, 52, 53, 57, 58, 63a, 64.

Onboard processing

We developed a standard set of routines to apply to all profiles to create a set of stacks and migrations with relatively consistent processing. The main steps included the following:

- ***Geometry definition and binning***: For profiles recorded on the entire 8-km-long streamer, we used P190 navigation files that were processed by the ship navigator for 3D binning. Given the extreme feathering observed in many areas, we deemed it important to not assume a 2D marine geometry. For profiles acquired on the inner 6 km of the streamer, 2D geometries were defined by an ideal 2D marine geometry because the processed P190s were not available immediately (it takes more work to fix the navigation files to specify the changed channel numbers resulting from recording on the inner part of the streamer), and the main objectives were shallow and mostly relied on the inner part of the streamer, where feathering is less important. **NOTE**: We recognized that there was a problem with the source-receiver offsets in the P190's because it was not possible to flatten the seafloor during velocity analyses for most profiles. An offset of ~260 m was estimated using the first arrival and used for lines acquired with the inner 6 km of the streamer. However, the original P190s with near-channel offsets of 152 m were used for the rest of the profiles. At the end of the cruise, the offsets were re-measured while recovering the streamer, and it was confirmed that there was a problem with the near channel offsets in the P190s. It was ~300 rather than 152-154 m. Although we think that the stacks and migrations are relatively high quality (e.g., we muted the unflattened parts of NMO-corrected CMP gathers) and useful for identifying structures present in the data, the velocities are incorrect since there was a problem with offsets in the navigation files. The navigator produced a fixed set of P190's at the end of the cruise that will be released with the raw data.
- ***Filtering and data cleaning***: Relatively broad filters were applied to the data to get rid of low-frequency noise, but still preserve the rest of the frequency range. The stacks and migrations can then later be filtered to narrower bands of interest. Bad traces were identified and killed. Given the age of the streamer, there were a significant number of noisy or dead channels; we commonly killed 10% of the traces. Other data cleaning was applied as needed, and included further, more advanced noise removal techniques, inner mutes, refraction mutes and FK filtering.
- ***Velocity Analysis***. The cleaned shot gathers are sorted into CDP gathers and used for velocity analyses. We generally did velocity analyses every 500 to 1000 CDP's and attempted to generate relatively smooth velocity models that could also be used for migration. For many lines, we also designed NMO mutes. As noted above, the near-channel offsets in the P190s used at sea for processing were incorrect, so the velocities determined for lines at sea are not accurate. However, the P190's were corrected at the end of the cruise and those versions will be released with the raw data.
- ***Stacking and migration***. Using the stacking velocities, we applied NMO and stacked the data. We also used the stacking velocities for post-stack Kirchoff time migration. Velocities were often smoothed and sometimes scaled them by 90-95% beforehand. We also often muted the multiple in the stack before migration.

6. Performance of the *Langseth*

Overall, we found the *Langseth* to be in great condition, and the technical staff and crew are excellent. Below we briefly summarize our experience with different aspects of operations and facilities.

MCS equipment

The data that we were able to acquire using the large, tuned air-gun array and 8-km-long streamer are tremendous for imaging both shallow and deep targets along the continental margin. We had very little downtime due to equipment failure during our cruise. However, all of this equipment is relatively old and aging. In particular, there are many noisy channels in the streamer, such that we had to kill nearly 10% of the traces during processing. Given that it's becoming increasingly difficult to find replacement sections and other parts for this streamer system, we strongly recommend that the process of transitioning to a new streamer begin as soon as possible.

Lab facilities and onboard computing

Overall, the computational facilities on the *Langseth* are excellent and met our purposes. The *Langseth* possesses two fast workstations that can be used by the science party for onboard processing. We only experienced a few minor obstacles, which are described below.

We decided to use these workstations (plus our Mac laptops) for our onboard processing rather than bring our own workstations. We were able to use the *Langseth's* machines to complete a range of onboard processing jobs, including basic processing of all of the profiles (see Appendix B for full description), and the workstations performed very well. The main obstacle that we encountered was disk space. The technical staff has to cobble together several different areas of disk space that were not mounted on both machines to accommodate our disk space needs. This made things more complicated for us in setting up our processing jobs and trickier later when we sought to back up the work that we had done. We suggest that more disk space is added to these machines for onboard processing.

As the ship's staff are already aware, the internet is extraordinarily slow. It regularly crashed for short periods of time and is always slow. The lack of passable internet makes many aspects of the scientific endeavor at sea very difficult, and also makes it difficult for shipboard scientists to keep up with necessary correspondence and work from home (assigning grades online, correspondence with students, journals, funding agencies etc). It also limits the ability for us to do outreach like blogs for our cruise since its impossibly slow to upload photographs. We strongly suggest that alternatives are sought or upgrades are made to improve internet speed.

Technical staff and crew

The technical staff aboard the *Langseth* are uniformly dedicated, professional and capable, and did a truly excellent job. As always, Robert Steinhaus provided excellent advice and council to shipboard scientists, sensible planning for the data collection effort and leadership to the scientific technical team. All of the technical staff were very responsive to all our requests and needs. The files and information that we needed to conduct onboard data analysis were provided in a very timely manner (exceeding our expectations). When we identified any issues, they worked quickly to resolve them.

Likewise, the Captain and crew of the *Langseth* are a pleasure to work with. We found everyone to be professional, hard working and responsive to any topics that arose.

Living conditions

The accommodation spaces, galley and other leisure spaces (movie room) were in great shape. Some minor comments on accommodation: 1) it would be nice to have a couch rather than chairs in the 201-204 room area; 2) there is no temperature control in some of the cabins on the C deck, so some people found the rooms very warm (e.g., Rooms 201-204); 3) it would be good if there was a way to secure the desk chairs in all of the cabins. The cooks did an excellent job of preparing food to satisfy everyone's dietary needs and tastes. Some scientists commented that a little more variety could have been included in dinner.

A major setback in the living conditions is that there is no longer an option to call home. Given that this was a 5-week-long cruise, semi-regular calls would have had a major positive impact on morale. One scientist had to buy a satellite phone and time to keep in touch with his family at home. We recognize that there is a cost associated with the phone calls, but its really important for morale and thus we recommend re-instituting these calls. Likewise, the extraordinarily slow internet made chatting and other means of keeping in touch with love ones onshore frustrating at best, and impossible at some times.

8. *ENAM Langseth* CSE participant feedback

"My overall experience with ENAM CSE cruise MGL1408 was very enjoyable and beneficial to me as an early career scientist. I found that both the M. G. Langseth's ship crew and science were very pleasant to work with and personally helpful to me. I learned a great deal about the operations of an active seismic data acquisition cruise. I was able to gain valuable experience by participating in both the daily ship operations such as deploying and reclaiming the seismic streamers; in addition to being provided basic seismic processing instruction from the P.I.'s using the Paradigm software Echos, I was also given some introductory information behind and was exposed to the reasoning behind some of the specific science topics and research goals that some of the more senior scientists had for the cruise, in regular group discussions the science crew held. The only areas that I noticed that could be improved on the R/V Langseth were the lack of reliable quality Internet connection and cellular service, both of which if improved would have greatly assisted me in both my scientific endeavors as well as my personal life. However, the benefits of the cruise far outweighed these inconveniences, and I would not only be interested in participating again myself, but would also recommend the ENAM CSE-style cruise experience to other early career scientists as well. "

"As a PhD student studying a rifted margin, the opportunity to partake in the GEOPRISMs ENAM Community Seismic Experiment proved to be an incredibly valuable experience. Participating in the acquisition of marine geophysical data increases the appreciation and understanding of the datasets which we work with on a daily basis, and is an opportunity that should be made available to new geophysicists entering the research field. The cruise was very well run, with participation in all aspects of the data acquisition being strongly encouraged. I particularly appreciated the regular science meetings, where the knowledge of the PI's and other science colleagues could be shared as a group. Overall the cruise was a very positive experience, and I would love to participate in any future research opportunities that were to arise!"

"I found the community experiment to be extremely beneficial to an aspiring researcher. Having a diverse set of researchers (both novice and experienced) allowed for a broad range of interaction and communication. Additionally, with a variety of different research interests on one ship, I personally, was able to learn much about many different geological and geophysical problems. Each of these problems, while unique and interesting, could all be enlightened with the help of the one data-set that we were collected. This interesting dynamic allowed for education outside ones expertise, and added additional uses to a data-set that may only be used for one question. This experiment allowed for individual growth for the researchers, but also allowed the data itself to be used in ways it may not have been used without this kind of collaboration. I view this experiment as a success on both of these fronts, and hope that these multidisciplinary funds continue to be distributed."

"The Langseth ENAM cruise was incredibly valuable scientifically, academically, and personally for me. I was able to work with passionate individuals who were more than willing to teach the basic steps to collecting and processing marine seismic data. As this was my first time working with seismic data, this was invaluable, especially since those involved were able to instruct on what to look for both in shallow and deep crust, and its implications. I finally learned about BSRs. I really appreciate the opportunity to work with these fine people, and encourage further programs such as these."

8. *Langseth* Crew and Science Party

Crew list

O'Loughlin, James E.	Master
Wolford, David H.	Chief Mate
Marko, Elmer J.	2nd Mate
Yang, Sun Y.	3rd Mate
Redito, Ricardo M.	Bosun
Nadler, Marcus B.	AB
Cereno, George G.	AB
Paragas, Petronio S.	AB
Webster, Jeromiel J.	OS
Mallar, Michael A.	OS
Tucke, Matthew S.	Chief Engr.
Matthews, Richard E.	1st Engr.
Smith, Ryan T.	2nd Engr.
Visel, Joshua D.	3rd Engr.
Billings, Jack C.	Oiler
Uribe, Guillermo F.	Oiler
Florendo, Rodolfo A.	Oiler
White, Joselyn N.	Steward
Martires, Leoncio R. Jr.	Cook
Schwartz, John	Science Tech
Curran, Leslie M.	PSO
Dugan, Laurie A.	PSO
Frey, Cassandra A.	PSO
Ingram, Heidi E.	PSO
Marcella, Laura A.	PSO
Guerin, Gilles M.	Science Tech
Gutierrez, Carlos D.	Science Tech
Henriquez, Roberto	Science Tech
Kasinger, Joshua D.	Science Tech
Koprowski, Robert C.	Science Tech
Martello, Michael C.	Science Tech
Spoto, Thomas R.	Science Tech
Steinhaus, Robert J.	Chief Science Officer
Thompson, Alan J.	Science Tech
Shillington, Donna	Co-Chief Scientist

Becel, Anne	Co-Chief Scientist
Hornbach, Matt	Co-Chief Scientist
Blacic, Tanya	Scientist
Darnell, Kristopher	Scientist
Davy, Richard	Scientist
Epple, Kara	Scientist
Hill, Jenna	Scientist
Karl, Matt	Scientist
Montell, Sasha	Scientist
Phrampus, Ben	Scientist
Sawyer, Derek	Scientist

Science Party Shifts

Watch Leaders:

6 am – 2 pm	Matt Hornbach
2 pm – 10 pm	Donna Shillington
10 pm – 6 am	Anne Bécel

Watch Standers:

12 am – 8 am	Tanya Blacic, Kris Darnell, Richard Davy
8 am – 4 pm	Kara Epple, Matt Karl, Sasha Montelli
4 pm – 12 am	Jenna Hill, Ben Phrampus, Derek Sawyer

Science Technical Staff Shifts

12 am – 12 pm	Mike Martello, Watch Leader, Navigator Bobby Kaproski, Acquisition Leader Tom Spoto, Sound Source Watch Leader Roberto Henriquez, Sound Source Watch Stander
12 pm – 12 am	Alan Thompson, Watch Leader, Navigator Gilles Guerin, Acquisition Leader Carlos D Gutierrez, Sound Source Watch Leader Josh Kasinger, Sound Source Watch Stander

Contact information for the Science Party

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Kristopher Darnell	kristopher.darnell@gmail.com	312-515-0974
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Jenna Hill	jchill@coastal.edu	619-665-4869
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Derek Sawyer	sawyer.144@osu.edu	610-551-4539
Donna Shillington	djs@ldeo.columbia.edu	845-365-8818

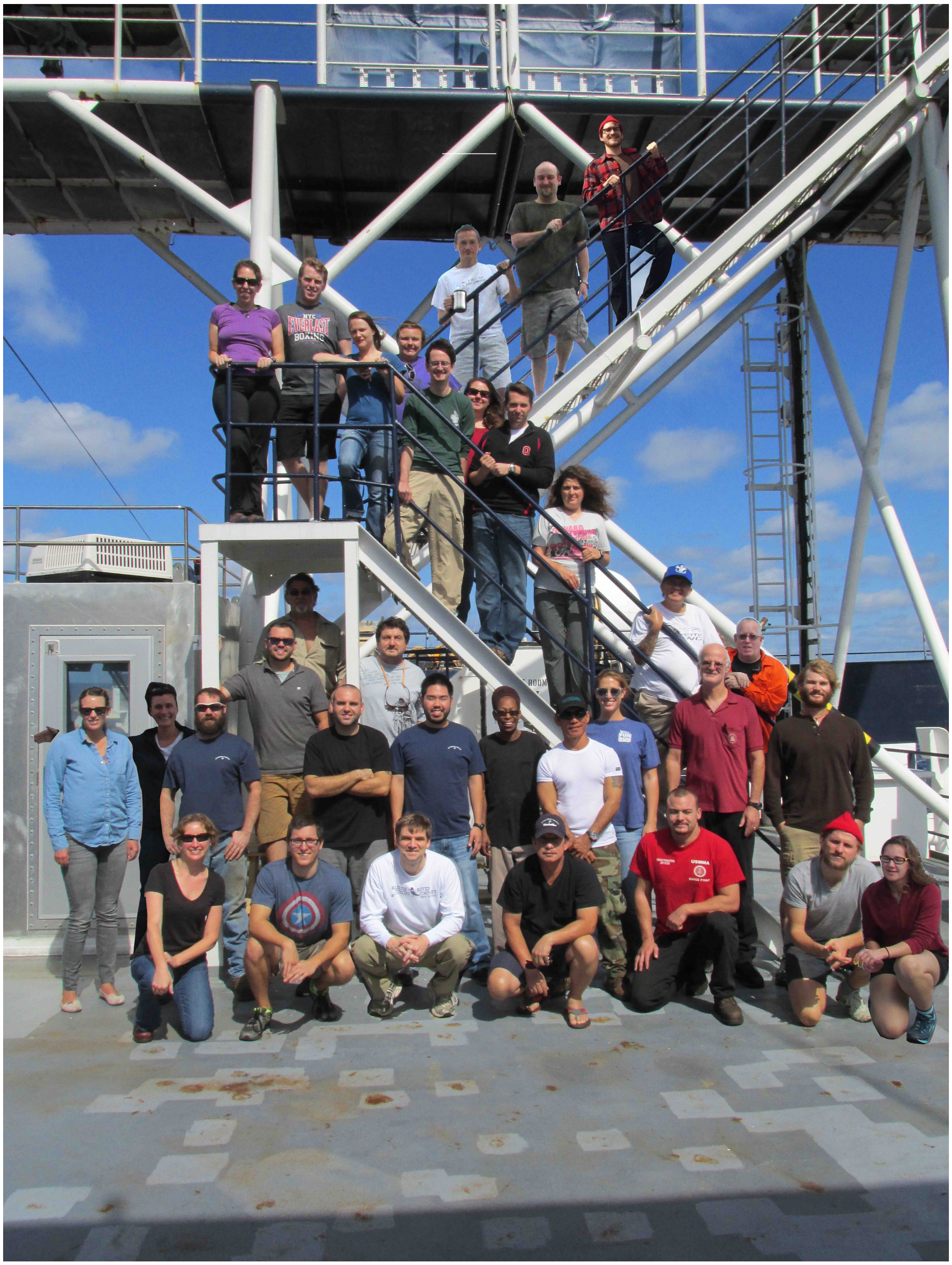

Figure 7-1: *MGL1408 Group picture (with some photoshopping).*

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9. References

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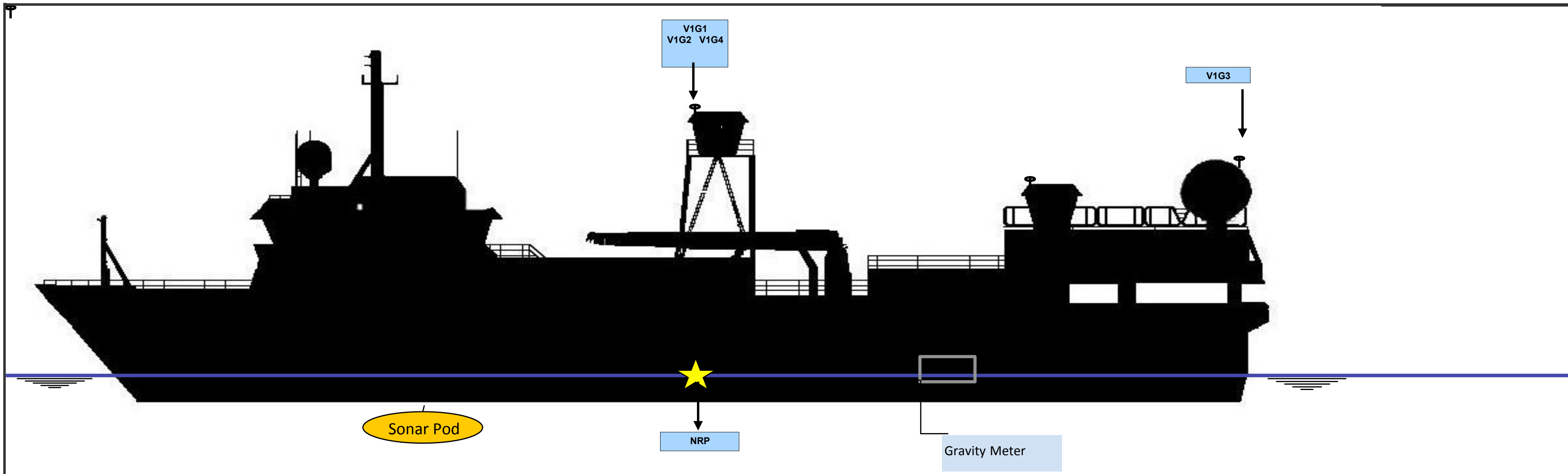
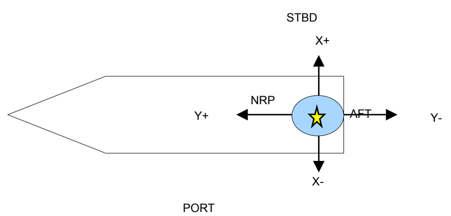
Appendix A – Specification of MCS data acquisition

Company	:	LDEO - Lamont Doherty Earth Observatory
Vessel	:	Marcus G.Langseth
Client	:	NSF
Project	:	MGL-1408 NSF
Area	:	Offshore North Carolina
Start Date	:	16 September 2014



All measurements in meters

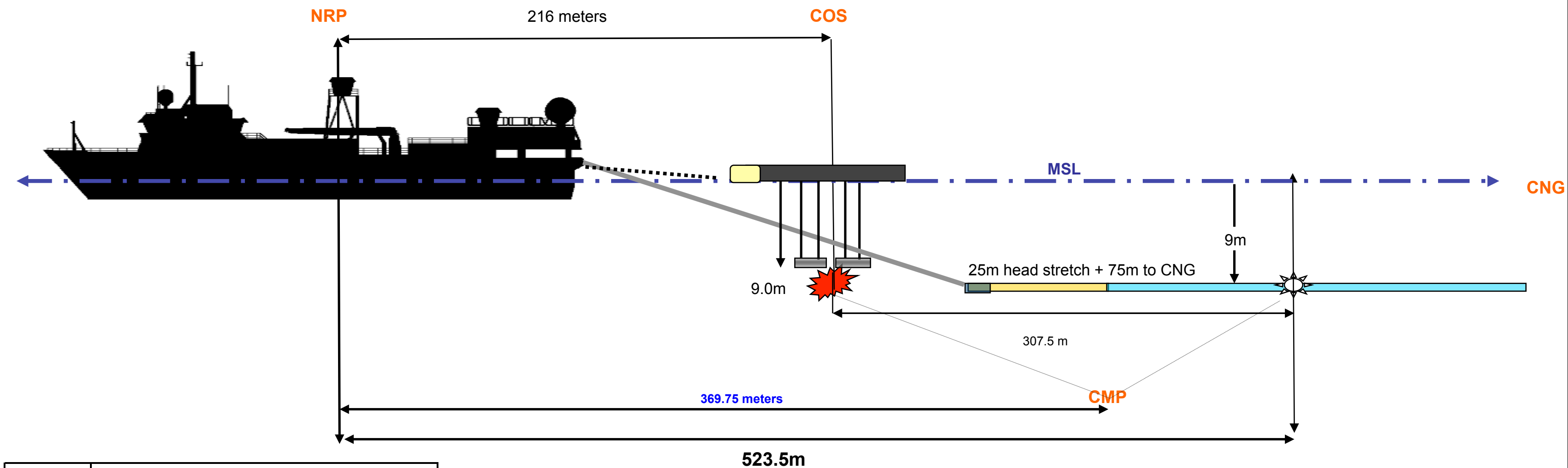
		STBD/PORT (X)	FORE/AFT (Y)	UP/DOWN (Z)
NRP	NAVIGATION REFERENCE POINT	0.00	0.00	0.00
V1G1	C-Nav 3050	0.00	0.00	-16.90
V1G2	SeaPath 200	0.00	1.50	-16.90
V1G3	C-Nav 2000	-2.10	-29.20	-14.50
V1G4	Pos MV	-1.30	1.20	-16.90
V1R1	PosNet	-1.30	0.00	-16.90
Sonar Pod	EM122 Knudsen ADCP	0.00	20.20	7.49
MRU	Seapath MRU	2.30	-14.16	-4.30
BGM	Bell Gravity Meter	0.00	-13.10	-3.49



Note: All Echosounders are used in Spectra with 6.6m ship's draft correction applied.

R/V Marcus G. Langseth - Towing Offsets

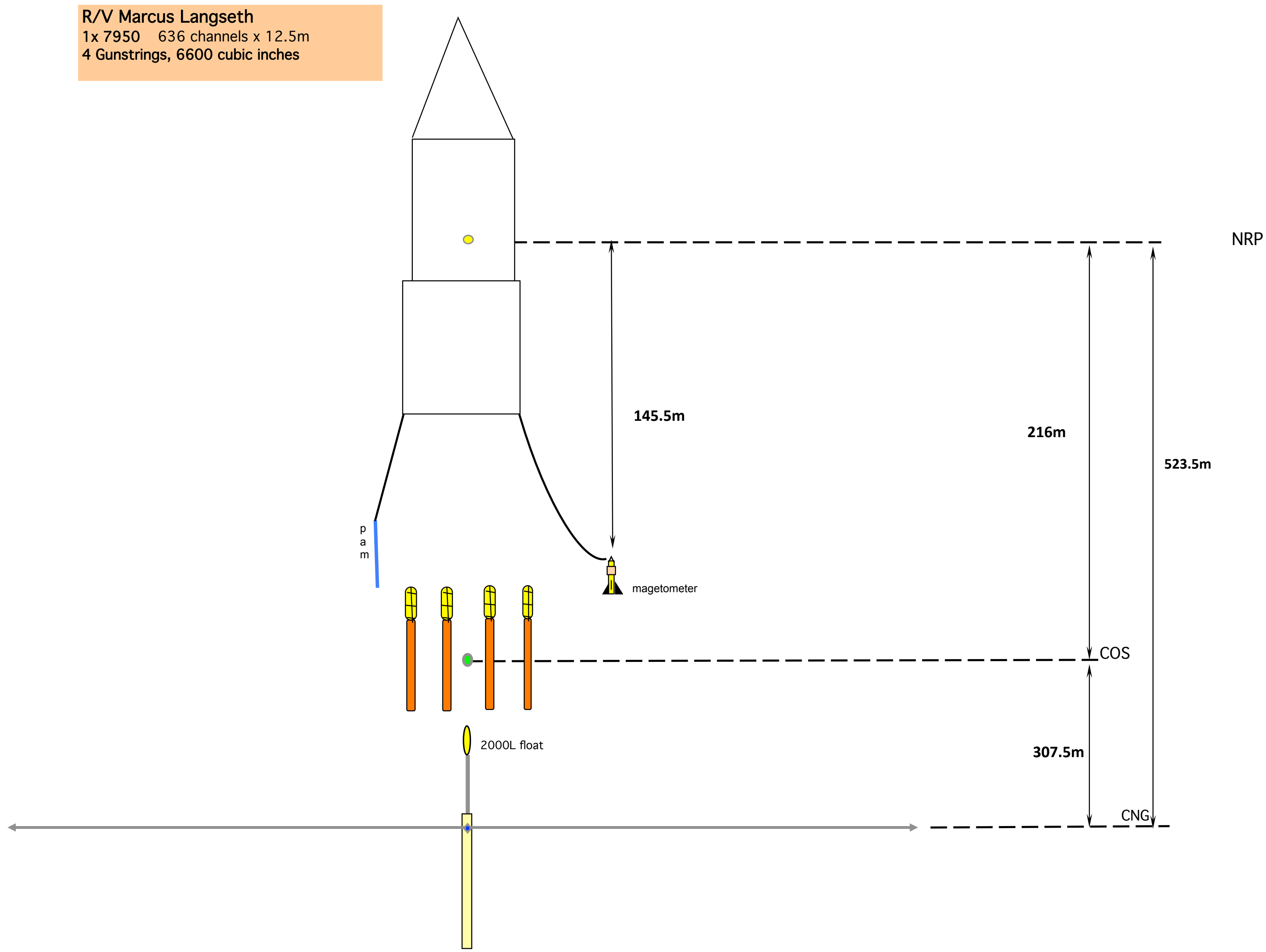
***** Offsets used for sequences *****



NRP	Nav **R**eference **P**oint
COS	Centre of **S**ource
CNG	Centre of **N**ear **G**roup (Trace # 001 of:S1)
CMP	Common **M**id-**P**oint
MSL	**Mean Sea Level**
NRP-Stern	**29.5m**
NRP-COS	**216**

Seq001-xxx Nominal streamer depth was

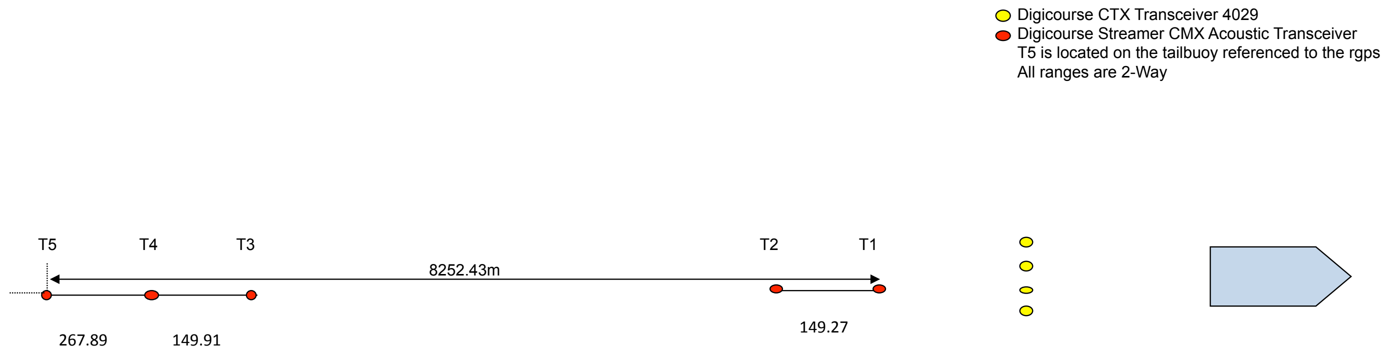
All measurements in meters


R/V Marcus Langseth
1x 7950   636 channels x 12.5m
4 Gunstrings, 6600 cubic inches
NRP
145.5m
216m
523.5m
p
a
m
magetometer
COS
2000L float
307.5m
CNG

NOT to Scale

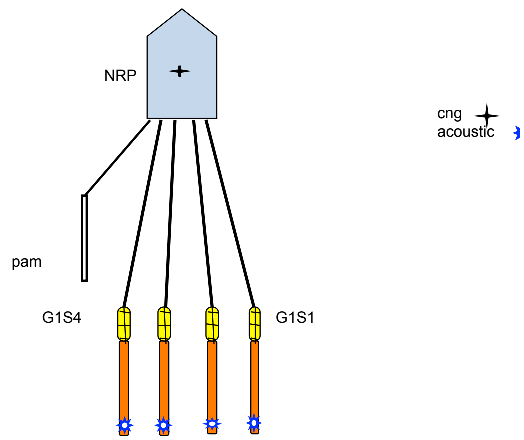
R/V Marcus G. Langseth - Acoustic Offsets

Digicourse



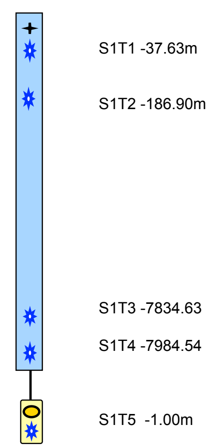
All measurements in meters

cng -> S1T1 = -37.5m
cng -> S1T2 = -187.5m
G1S1 -> G1T1: x = 0.0 y = -8.0m z = -11.875m
G1S2 -> G1T2: x = 0.0 y = -8.0m z = -11.875m
G1S3 -> G1T3: x = 0.0 y = -8.0m z = -11.875m
G1S4 -> G1T4: x = 0.0 y = -8.0m z = -11.875m

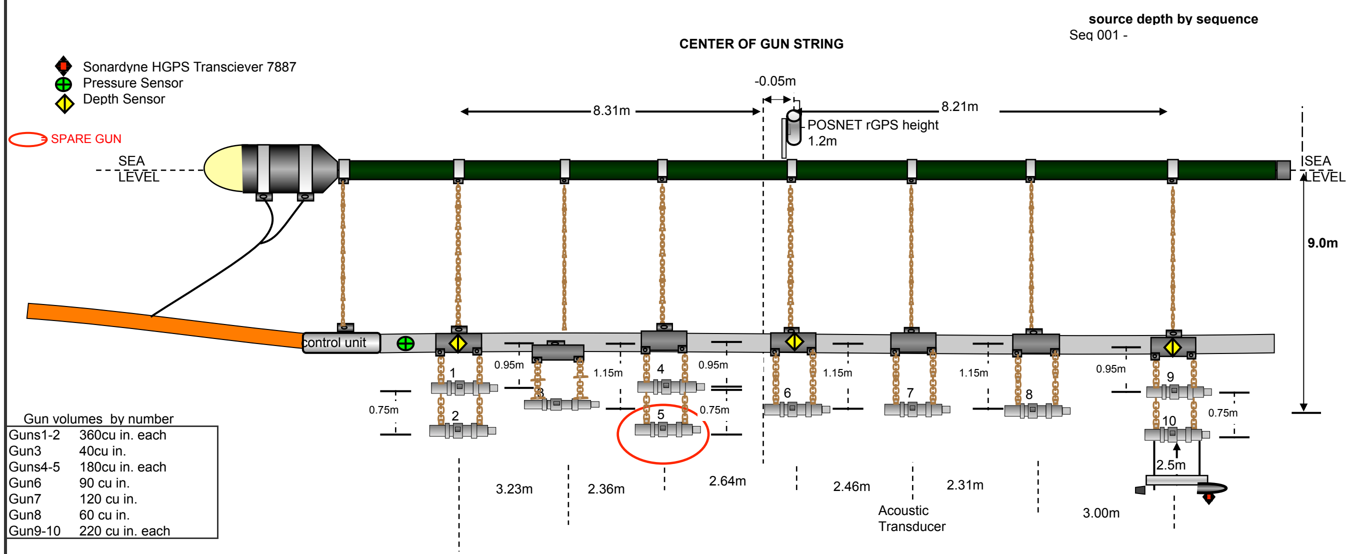


Cable acoustic offsets are referenced to cng on individual streamer

Tailbuoy acoustics referenced to RGPS pod



R/V Marcus G. Langseth - Gun Array Offsets



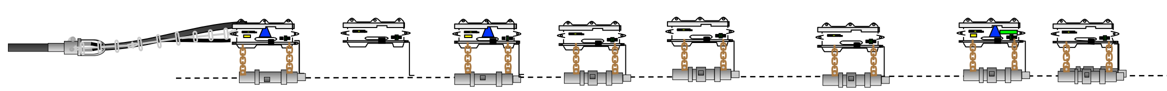
Gun volumes by number

Guns1-2	360cu in. each
Gun3	40cu in.
Guns4-5	180cu in. each
Gun6	90 cu in.
Gun7	120 cu in.
Gun8	60 cu in.
Gun9-10	220 cu in. each

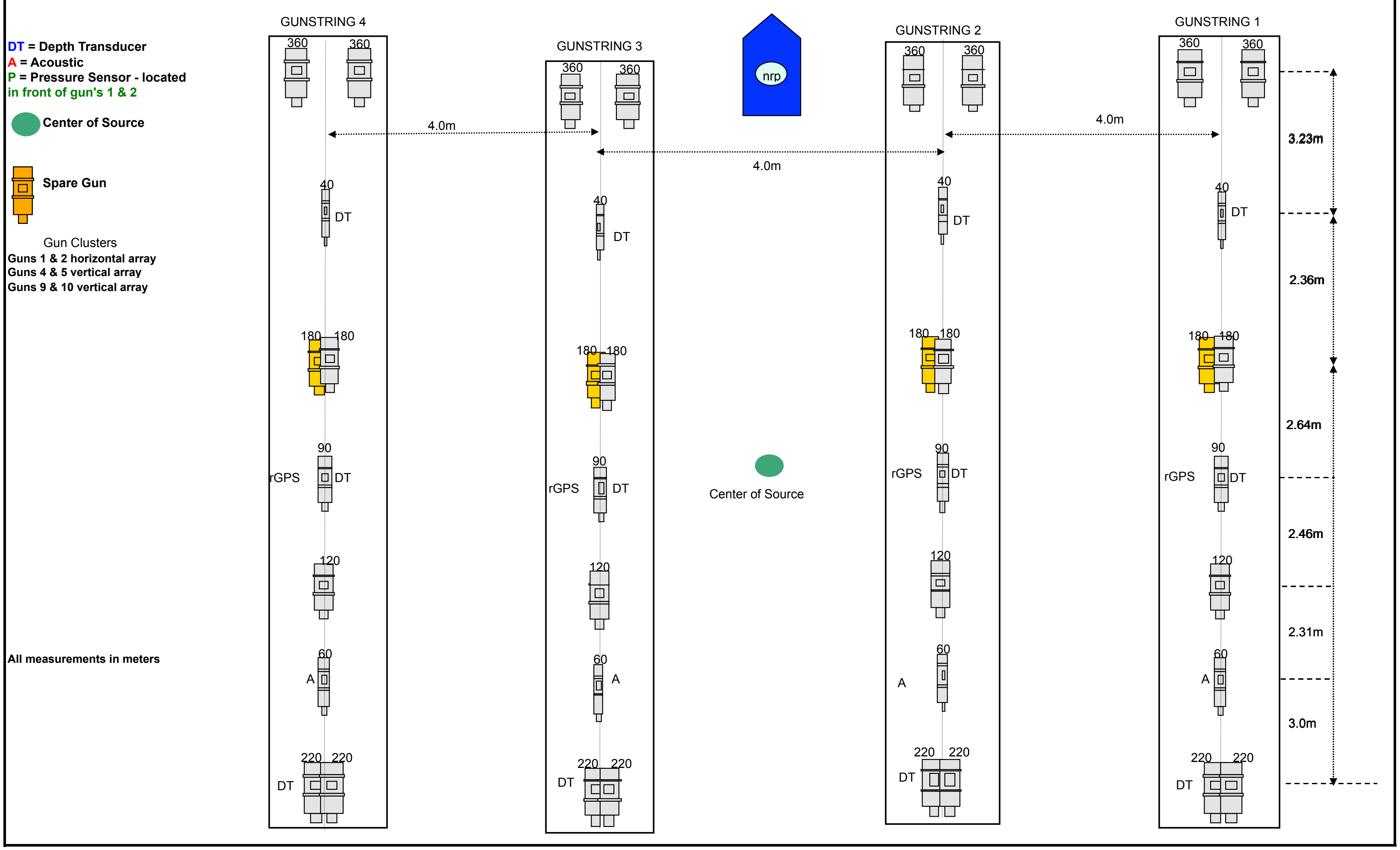
Array total volume (without spares) is 6600 cubic inches.
String 1 has guns 9 & 10 in a horizontal cluster; Strings 2, 3, 4, have all clusters hanging vertically.
Gun clusters have 0.75m between guns and hang 0.95m from center of hanger

Total volume per string (without spare) 1650 cubic inches.
Cluster Guns are 1m apart. **NOTE: drawing not to scale**
Single guns hang from hanger 1.15m
All measurements in meters

All gun volumes, numbering, locations, and offsets were inspected and verified by Chief Source Mechanic.

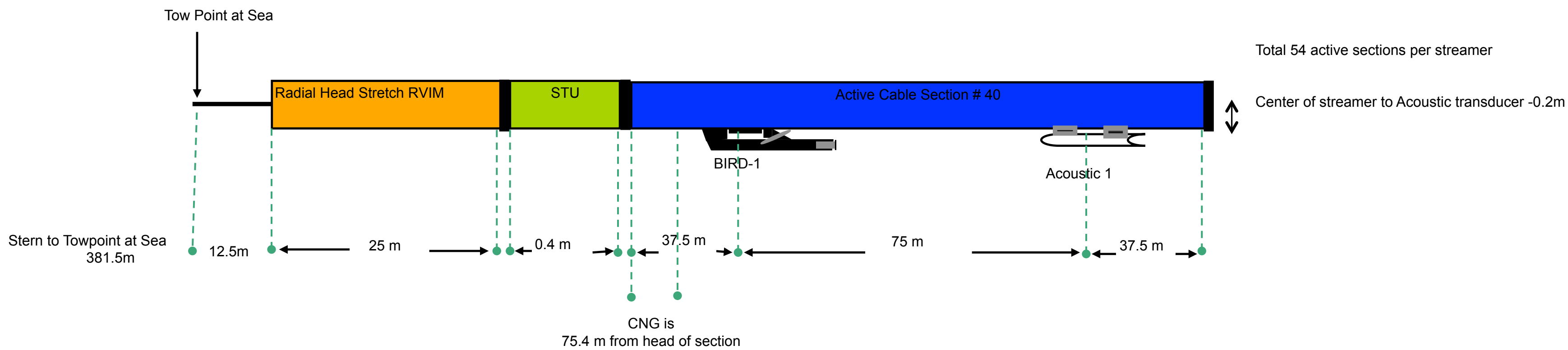


r/v Marcus G. Langseth - Gun Configuration

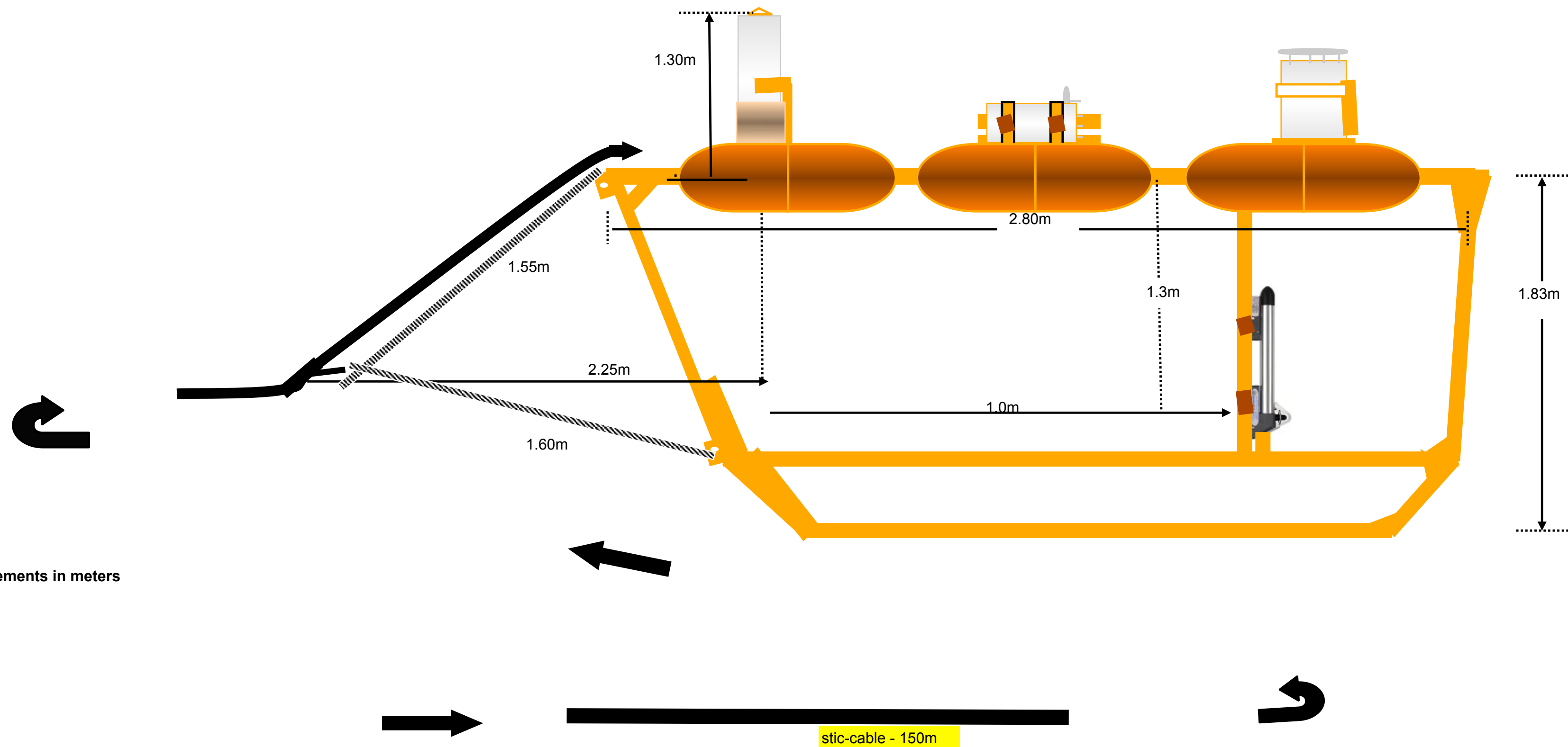


R/V Marcus G. Langseth - Streamer Front End

Lead-in:

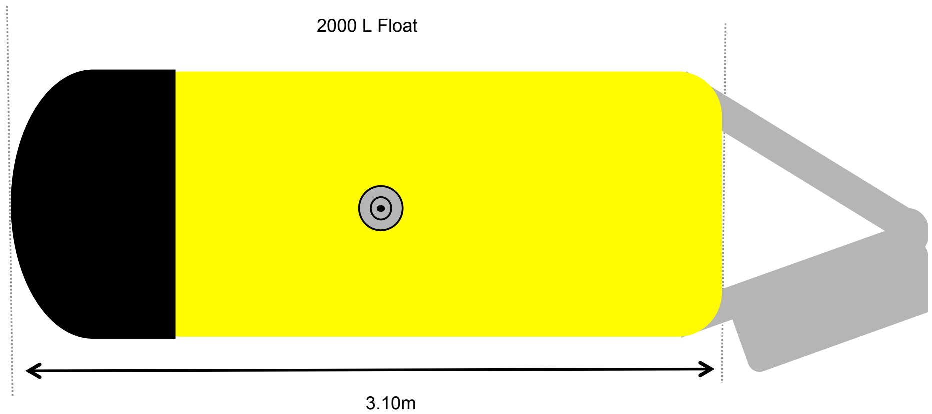


R/V Marcus G. Langseth - Tailbouy



All measurements in meters

2000L Float
Circumference 1.46m



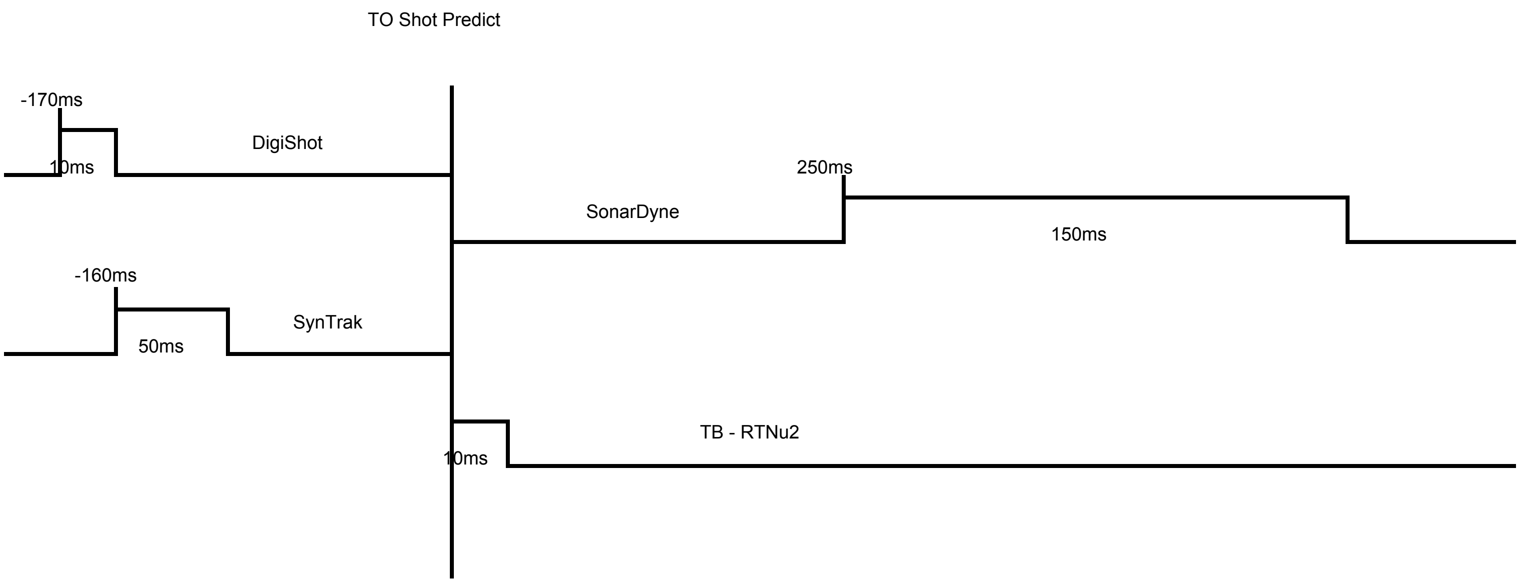
All measurements in meters

R/V Marcus G. Langseth

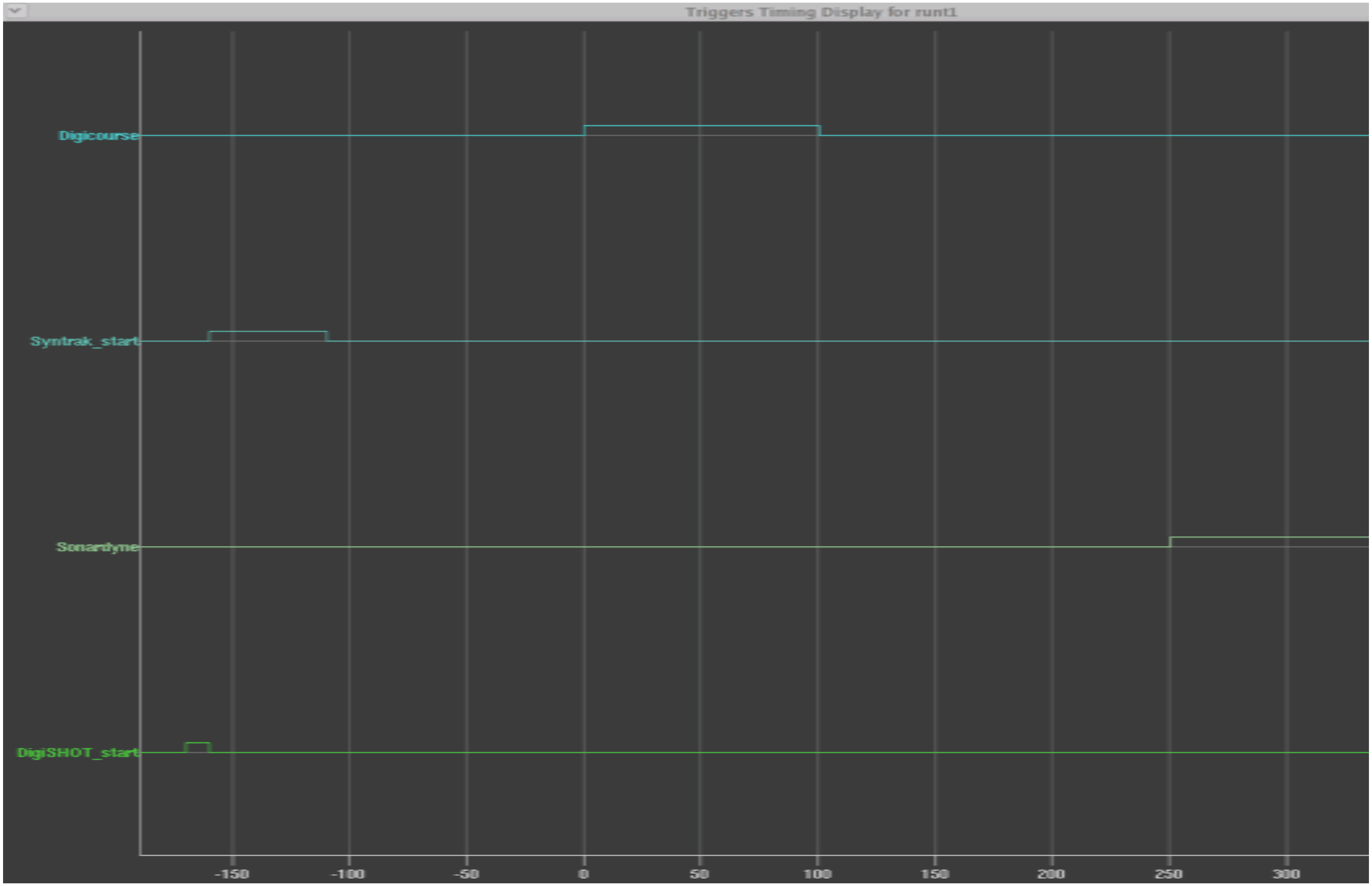
SPECTRA TIMING

MGL1408

ENAM



Spectra timing for r/v Marcus G. Langseth



B. Multichannel seismic processing data

Acquisition:

During the ENAM-community seismic experiment, ~4800 km of multichannel seismic data were acquired with the 8-km-long streamer and the airgun source array of the R/V *Marcus Langseth*. Profiles were acquired with slightly different acquisition parameters depending on the targets we wanted to image (deep/crustal vs. shallow/sediments) and also if we were shooting for reflection or refraction purposes. A summary of the main acquisition parameters for each ENAM profile is listed in Table B.1.

Line	# Slines	# Xlines	Dist btwn slines	Dist btwn Xlines	X-coord origin	Y-coord origin	Angle of survey	First CDP	Notes
Line2OBS	2	72740	-7000	6.25	727479.81	3595885.75	151.45	1	Used unprocessed nav
Line2MCS	2	70446	-9000	6.25	318698.72	3817984.59	331.39	1	
Line3OBS	2	59823	-9000	6.25	610250.75	3622937.5	67.74	1	
Line3MCS	2	61175	5000	6.25	753976.12	3976511.5	247.9	1	
Line31	2	8214	3000	6.25	611341.56	3623141.75	248.82	1	
Line32	2	24770	-9000	6.25	454150.22	3644287.5	337.33	1	
Line4A_OBS	2	44620	-6000	6.25	413469.94	3679545.25	61.93	1	
Line 41	2	10006	-6000	6.25	546624.81	3927977.25	330.86	1	
Line 42	2	21462	5000	6.25	535286.06	3782242.25	60.8	1	
Line4B_OBS	2	38902	-9000	6.25	514704.5	3788961.75	81.96	1	
Line1A_OBS	2	37864	-13000	6.25	484666.28	3979615.25	335.04	1	Used unprocessed nav
Line1B_OBS	2	22755	9000	6.25	690108.38	3881000.5	335.26	1	
Line1MCS	2	41461	4000	6.25	823420.94	3819839	155.28	1	
Line1A_MCS	2	16788	-9000	6.25	511592	3975145	335.28	1	
Line1B_MCS	2	6027	2200	6.25	519569.75	3959592.5	156.33	1	
Line4B_MCS	2	41967	10000	6.25	549987.44	4043363.5	261.67	1	
Line 62	2	27389	3500	6.25	550364.69	3809343	240.75	1	
Line 63	2	11753	4000	6.25	477321.88	3661047	159.68	1	
Line4A_MCS	2	48000	8000	6.25	409182.19	3675523.75	61.32	1	
LineA4A_MCS	2	48000	8000	6.25	409182.19	3675523.75	61.32	1	
Line 71	2	25072	-8000	6.25	483418	3897579.5	330.2	1	

2D Geometry	# shots	first shot	shot interv	near chan	# channels	near chan
Line33-34	5207	1022	25	260	480	480
Line 35	1460	1247	37.5	260	480	480
Line 52	2830	956	25	152	480	480
Line 53	555	900	25	260	480	480
Line 57	2066	4470	25	260	480	480
Line 58	3291	863	25	260	480	480
Line 63A	2188	3618	25	260	480	480
Line 64	1637	756	25	260	480	480

***Table B-1**. Multichannel seismic acquisition parameters of the ENAM profiles*

Processing:

A formal lecture on seismic acquisition and processing was given at the beginning of the cruise to all the CSE participants by Bécel. All of the participants were then trained in the use of Paradigm processing software Echos, and all participants processed at least one multichannel seismic profile with the help/assistance of one of the co-PIs.

During acquisition, individual raw shot gather data were recorded and saved into SEG-D files (.RAW extension) on digital 'reels' into folders called TAPE. TAPE directories have incremental/sequential numbers within an experiment. Each individual SEG-D shot gather file has an ASCII header that can be read with the 'strings *filename* | head' linux command and contains information such as the shot point number, latitude/longitude, time of the shot, seafloor depth, etc. Raw data were backed-up on an external hard drive by the shipboard technical staff.

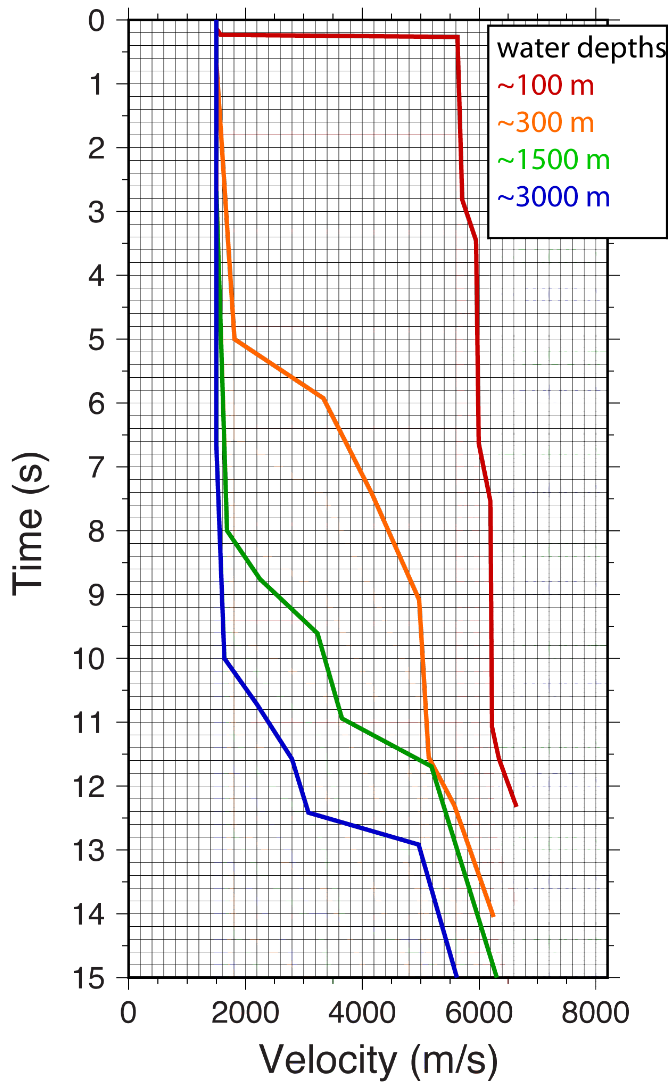


Figure B-1: 1-D *Velocity functions used for the SIOSEIS brute stack (Lizarralde and Holbrook, 1997)*

The multichannel seismic raw data were first processed using a sioseis routine (see attached script at the end of this appendix) after completing each profile to produce a pseudo real time brute stack. The sioseis routine includes the reading of the raw SEGD-data, 2D geometry assignment, sorting data into common midpoints, normal move out correction using four 1-D velocity functions extracted from the EDGE profile refraction modeling (Lizarralde and Holbrook, 1997) for different seafloor depth (Fig. B-1), automatic stretch mute, bandpass filtering and stacking the inner third of the streamer channels. This procedure allowed us to quickly assess the quality of the data and to view a first image of the main structures.

The MCS data were then processed with Paradigm processing software Echos using the steps described below.

***<u>Step #1:</u> Read the SEG-D data and convert them into Echos file format*.**
The first Echos jobs (Fig. B-2) involves reading one shot gather SEG-D file, extracting the SEG-D format information and storing it a file called "format_raw" in the Echos seismic database (Fig. B-3). This assumes that all the shot gathers in one profile have the same format and acquisition parameters.

The second Echos job (Fig. B-4) reads all the individual raw SEG-D shotpoint files from a same profile using the format_raw file created by the previous job as a template with the data format information. All the individual SEG-D shot point files that will be read and converted into one Echos file in the database are listed in a text file (e.g., Fig. B-5). This file list was created separately by a batch script and includes the paths and names of the SEG-D files. The numbers of the first and last files to be read during the job also have also to be specified as REELID and REELTO. This job also extracts several useful headers (STATIME, SP longitude, SP latitude, time, SP number), and the position within the SEG-D ASCII header has to be defined within the job.

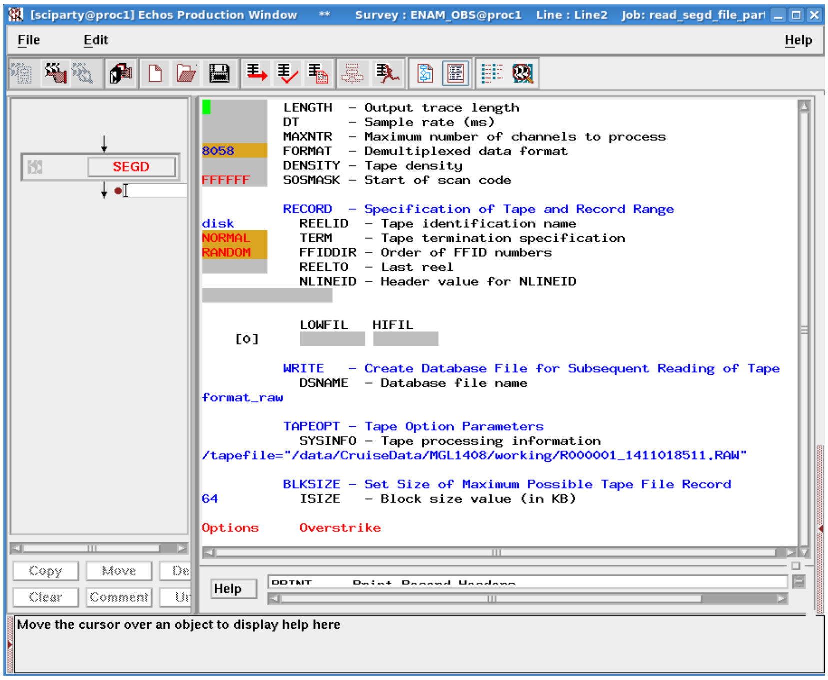


Figure B-2: *Example of the first job used to read the format of a single shot point file (here R000001_1411018511.RAW) and create a format_raw file in the Echos seismic database.*

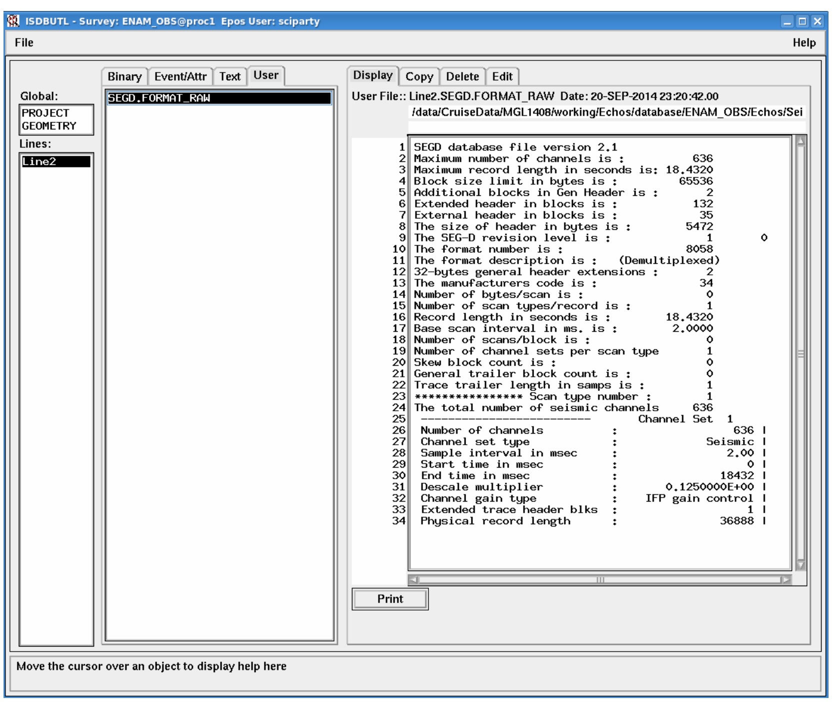


Figure B-3: *Example of format_raw file viewed in the seismic database.*

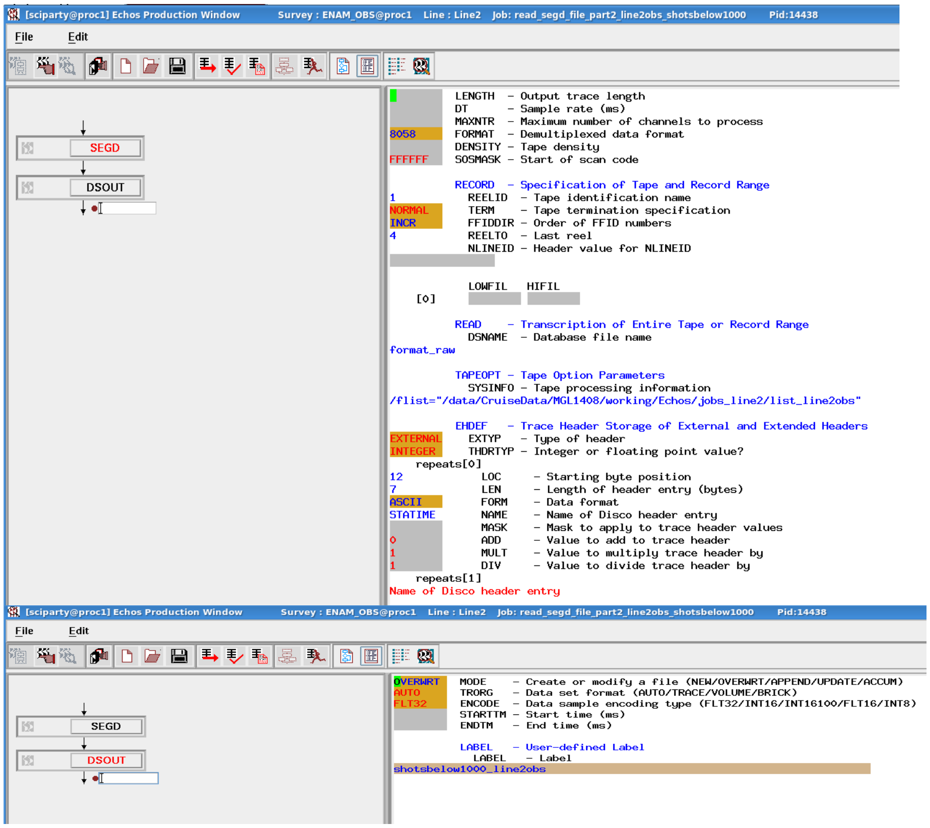


Figure B-4: *Example of the job used to read all the SEG-D data from one profile.*

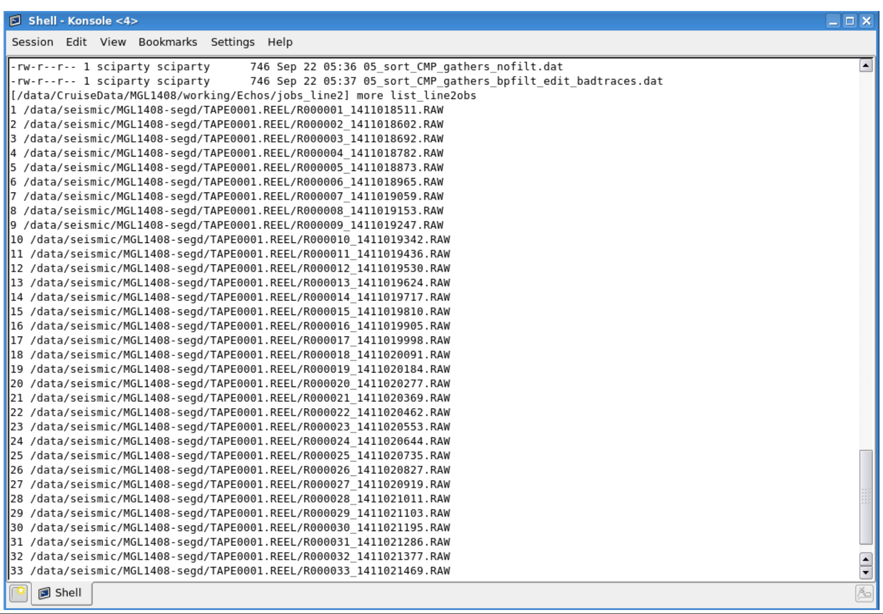


Figure B-5 : *Example of the list file containing all the individual raw SEG-D shot point data for one profile*

Step #2: ***3D binned geometry to accommodate streamer feathering.***

For all the profiles, except those acquired with 480 channels instead of 636 channels, we defined a pseudo 3D geometry using the processed navigation file that has an extension *.p190 and an UKOAA format. There is one navigation file for each profile. This file is created using differential GPS. The navigation files were processed onboard by the shipboard technical staff. The navigation file contains information about the position of the source, receivers and tail buoy. The first step consists in reading the p190 navigation file and convert it into an Echos internal navigation file (with the extension fmt) using the 3D geometry tool (Fig. B-6).

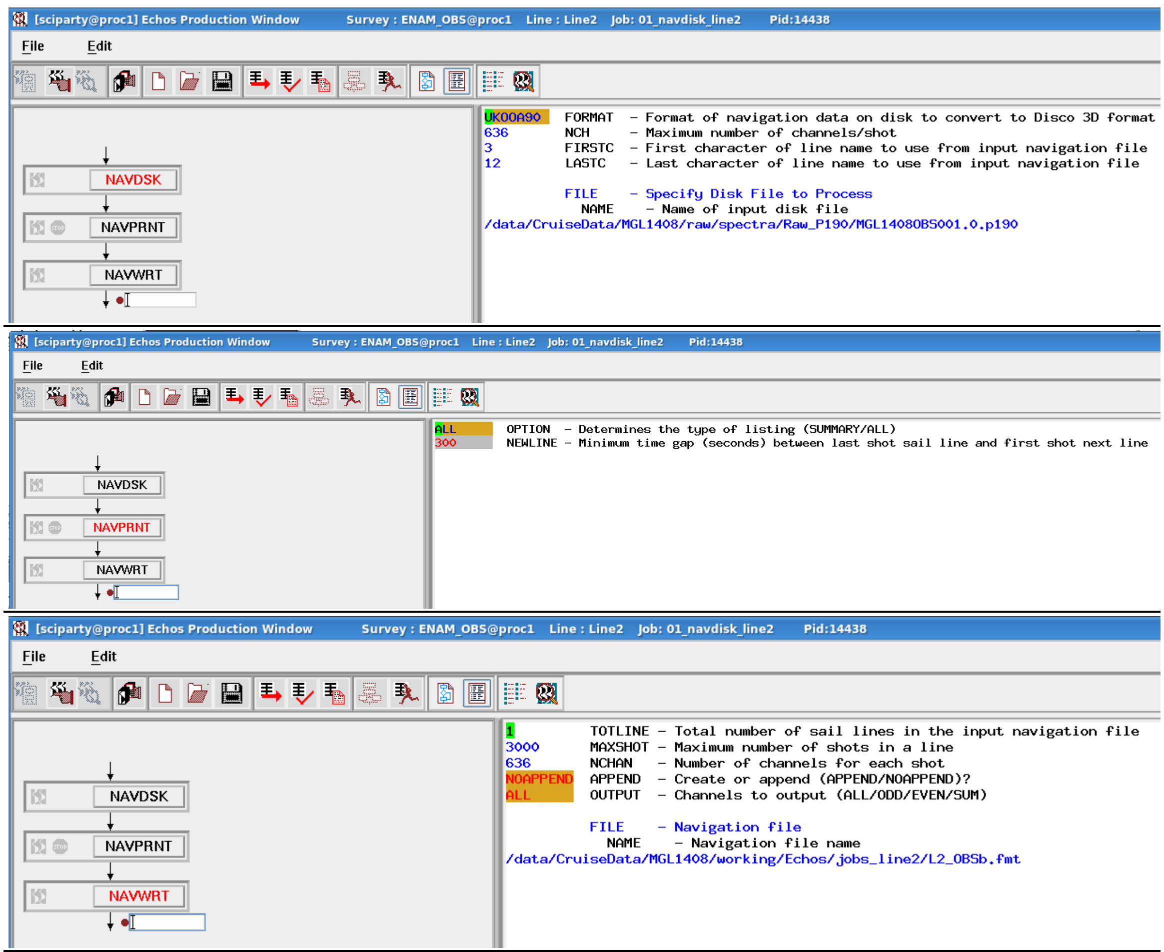


Figure B-6: *Example of job to read the navigation file and convert it into an Echoes (*.fmt extension) file*

Once the fmt file was available, the navigation file was first check for quality control (Fig. B-7) using the 3D geometry utility of Echos. The quality control mode allows us to sense the importance of the feathering and identify any remaining navigation issues after processing (e.g. bad compass value). The navigation file is then used for 3D binning of the mid-point scatter (Fig. B-8). CDP bins are defined using the nominal 6.25 m for the crossline and a large enough value (e.g., 7000m) for the inline to encompass the feathering and the turns at the beginning and end of the profile (Figs. B-8 and B-9).

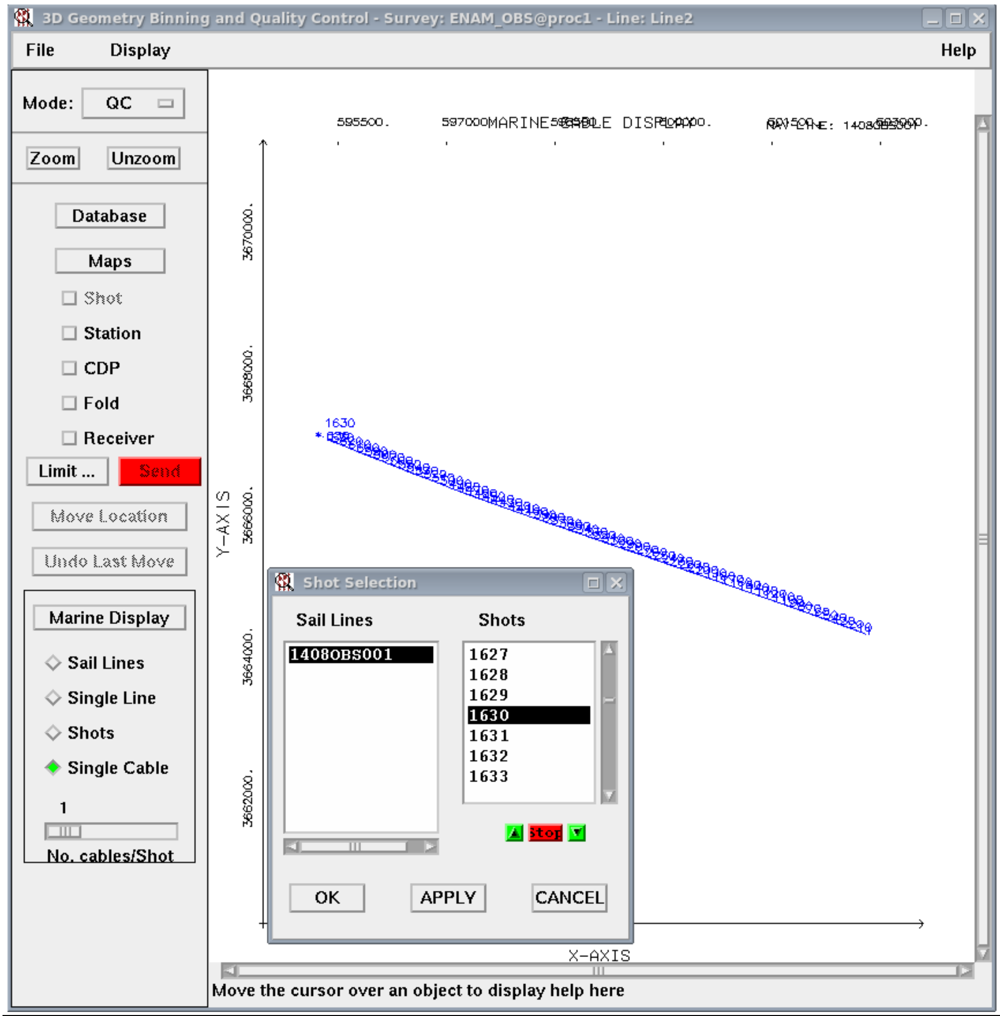


Figure B-7: *Example showing the quality control of the (P190/fmt) navigation file using the single cable display*

Once the 3D grid is defined, the CDP-model and fold files are saved into the seismic database. The next step is to copy the REGULAR CDP file into a REGULAT STATION file (Figure B-10). Table B-2 lists all the CDP grid parameters that have been defined for each profiles.

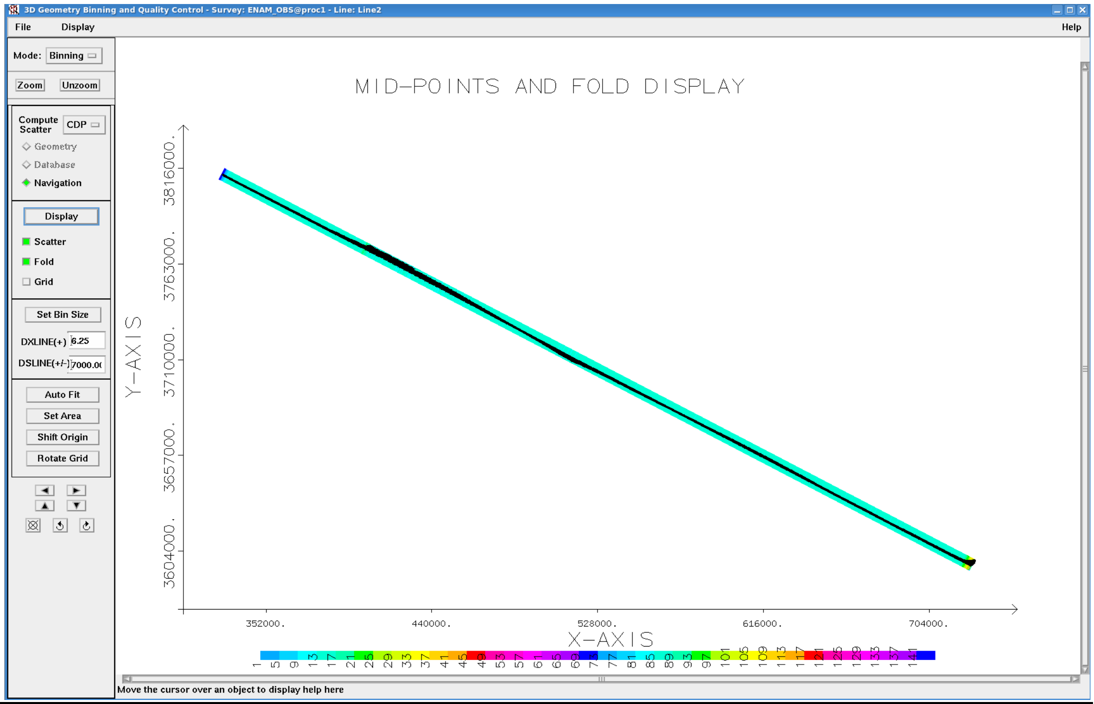


Figure B-8: Example of mid-point scatter (in black) and fold coverage (in color)

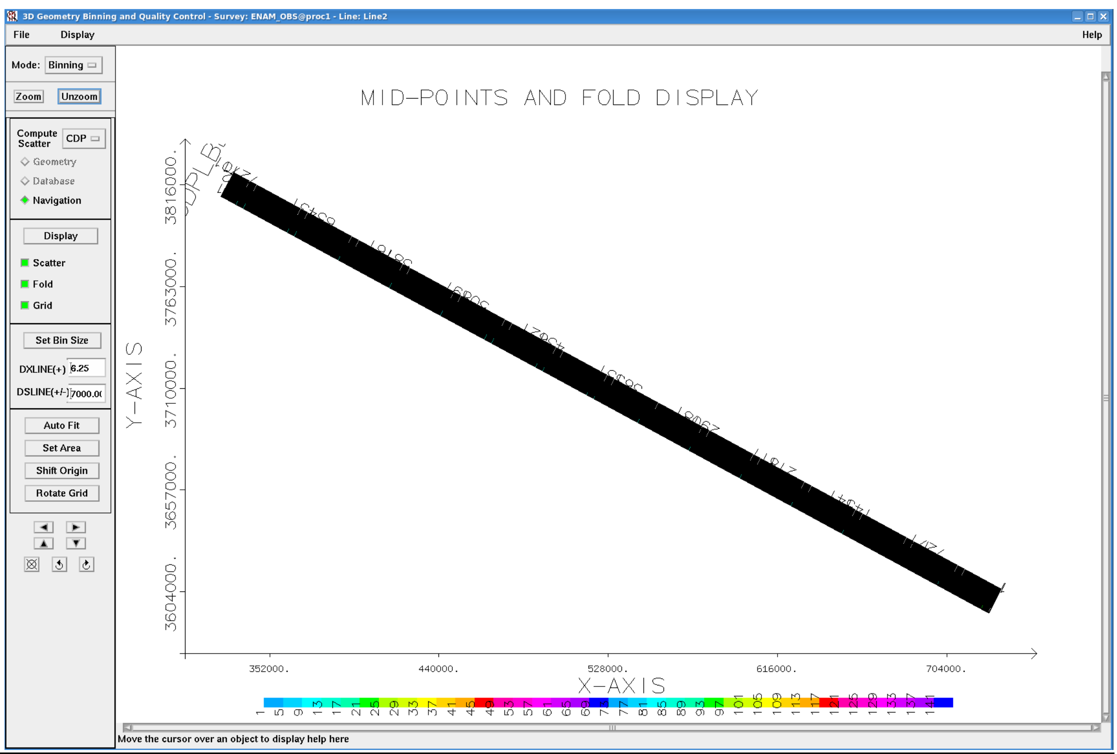


Figure B-9: *Example of CDP binning, the crosslines are defined every 6.25 m and two inlines are created with a width of 7000m, wide enough to contain all of the mid-points scatter into one inline. The second inline is empty but has to be defined in order to merge a 3D geometry.*

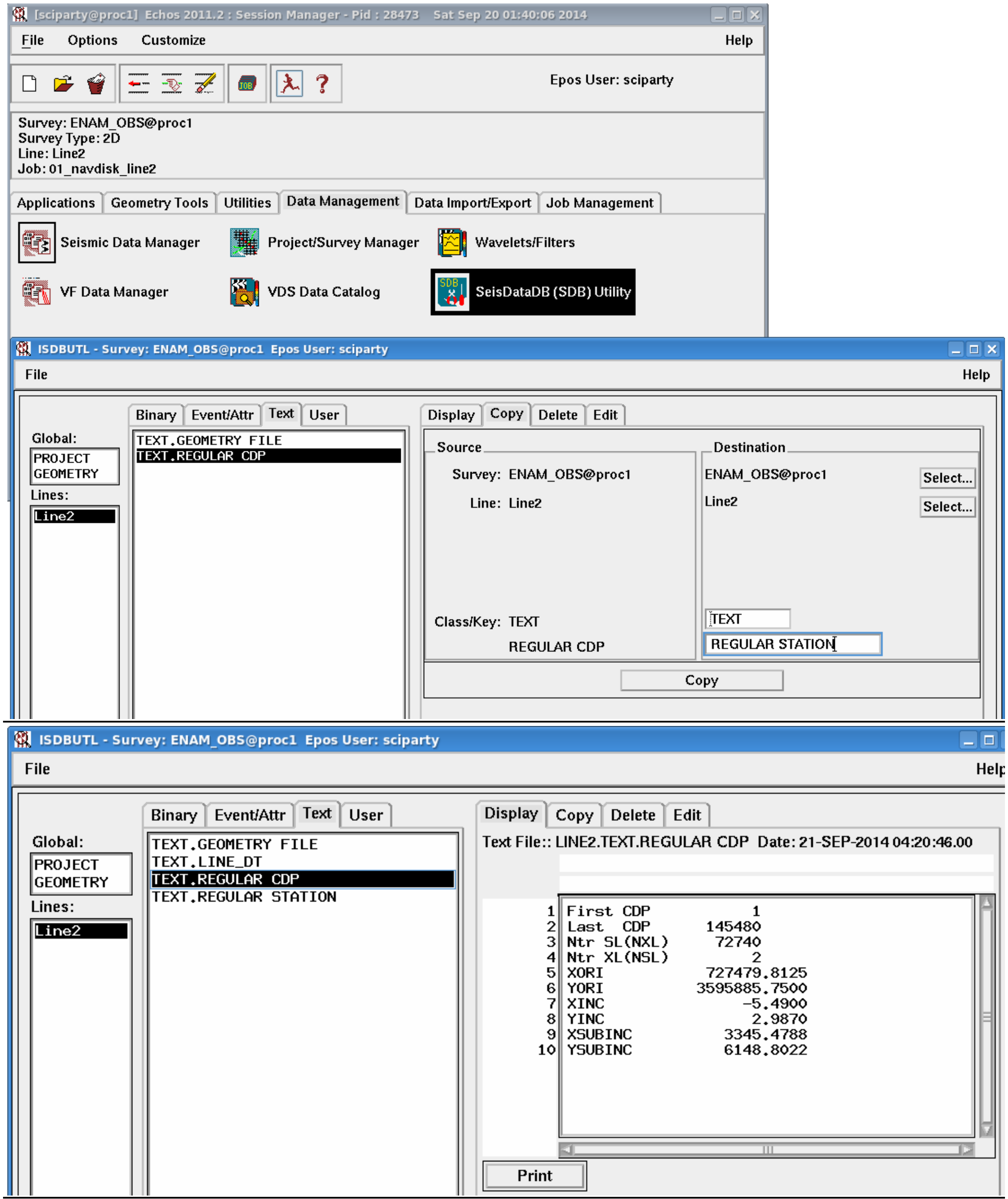


Figure B-10: *Figures showing the step consisting of copying the TEXT.REGULAR CDP file into TEXT. REGULAR STATION in the SeisDatabase Utility.*

Line	# Slines	# Xlines	Dist btwn slines	Dist btwn Xlines	X-coord origin	Y-coord origin	Angle of survey	First CDP	Notes
Line2OBS	2	72740	-7000	6.25	727479.81	3595885.75	151.45	1	Used unprocessed nav
Line2MCS	2	70446	-9000	6.25	318698.72	3817984.59	331.39	1	
Line3OBS	2	59823	-9000	6.25	610250.75	3622937.5	67.74	1	
Line3MCS	2	61175	5000	6.25	753976.12	3976511.5	247.9	1	
Line31	2	8214	3000	6.25	611341.56	3623141.75	248.82	1	
Line32	2	24770	-9000	6.25	454150.22	3644287.5	337.33	1	
Line4A_OBS	2	44620	-6000	6.25	413469.94	3679545.25	61.93	1	
Line 41	2	10006	-6000	6.25	546624.81	3927977.25	330.86	1	
Line 42	2	21462	5000	6.25	535286.06	3782242.25	60.8	1	
Line4B_OBS	2	38902	-9000	6.25	514704.5	3788961.75	81.96	1	
Line1A_OBS	2	37864	-13000	6.25	484666.28	3979615.25	335.04	1	Used unprocessed nav
Line1B_OBS	2	22755	9000	6.25	690108.38	3881000.5	335.26	1	
Line1MCS	2	41461	4000	6.25	823420.94	3819839	155.28	1	
Line1A_MCS	2	16788	-9000	6.25	511592	3975145	335.28	1	
Line1B_MCS	2	6027	2200	6.25	519569.75	3959592.5	156.33	1	
Line4B_MCS	2	41967	10000	6.25	549987.44	4043363.5	261.67	1	
Line 62	2	27389	3500	6.25	550364.69	3809343	240.75	1	
Line 63	2	11753	4000	6.25	477321.88	3661047	159.68	1	
Line4A_MCS	2	48000	8000	6.25	409182.19	3675523.75	61.32	1	
LineA4A_MCS	2	48000	8000	6.25	409182.19	3675523.75	61.32	1	
Line 71	2	25072	-8000	6.25	483418	3897579.5	330.2	1	

2D Geometry	# shots	first shot	shot interv	near chan	# channels	near chan
Line33-34	5207	1022	25	260	480	480
Line 35	1460	1247	37.5	260	480	480
Line 52	2830	956	25	152	480	480
Line 53	555	900	25	260	480	480
Line 57	2066	4470	25	260	480	480
Line 58	3291	863	25	260	480	480
Line 63A	2188	3618	25	260	480	480
Line 64	1637	756	25	260	480	480

Table B-2: *2D or 3D geometry built for each individual profiles*

Merging of the seismic data and the fmt navigation file was done using the module PROTAPE of Echos (Figure B-10) that associates the seismic traces with the receivers and CDP positions. After merging, the shot point file is displayed, and we check that the headers include the cdp number, offset, cdp-x, cdp y (Fig. B-11).

NOTE: Over the course of the cruise, we discovered that there was a problem with the navigation files because it was not possible to flatten the seafloor during velocity analyses. The ship's technical staff measured the sections at the front of the cable to determine the near-channel offset at the end of the cruise and discovered that it was ~300 m not 152 m. A new set of P190's were created with the fixed geometries at the end of the cruise. However, all of the navigation files used during the cruise had the incorrect offsets. Although the stacks and migrations are still fine (we muted unflattened sections), the velocities determined are incorrect.

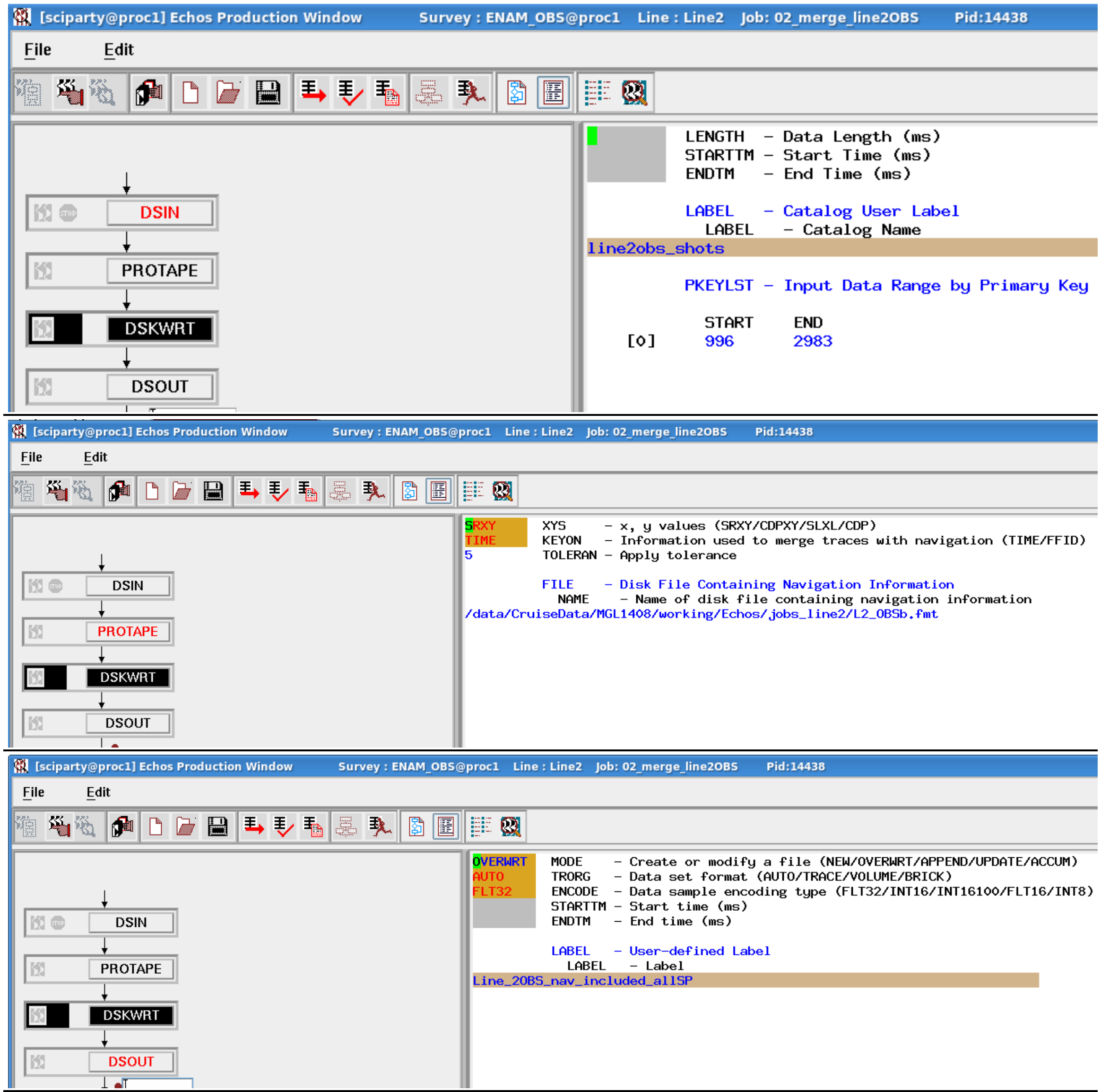


Figure B-10: *Figure showing a job that merges the navigation file (fmt) with the multichannel seismic data. The merged data are written into the Echos database.*

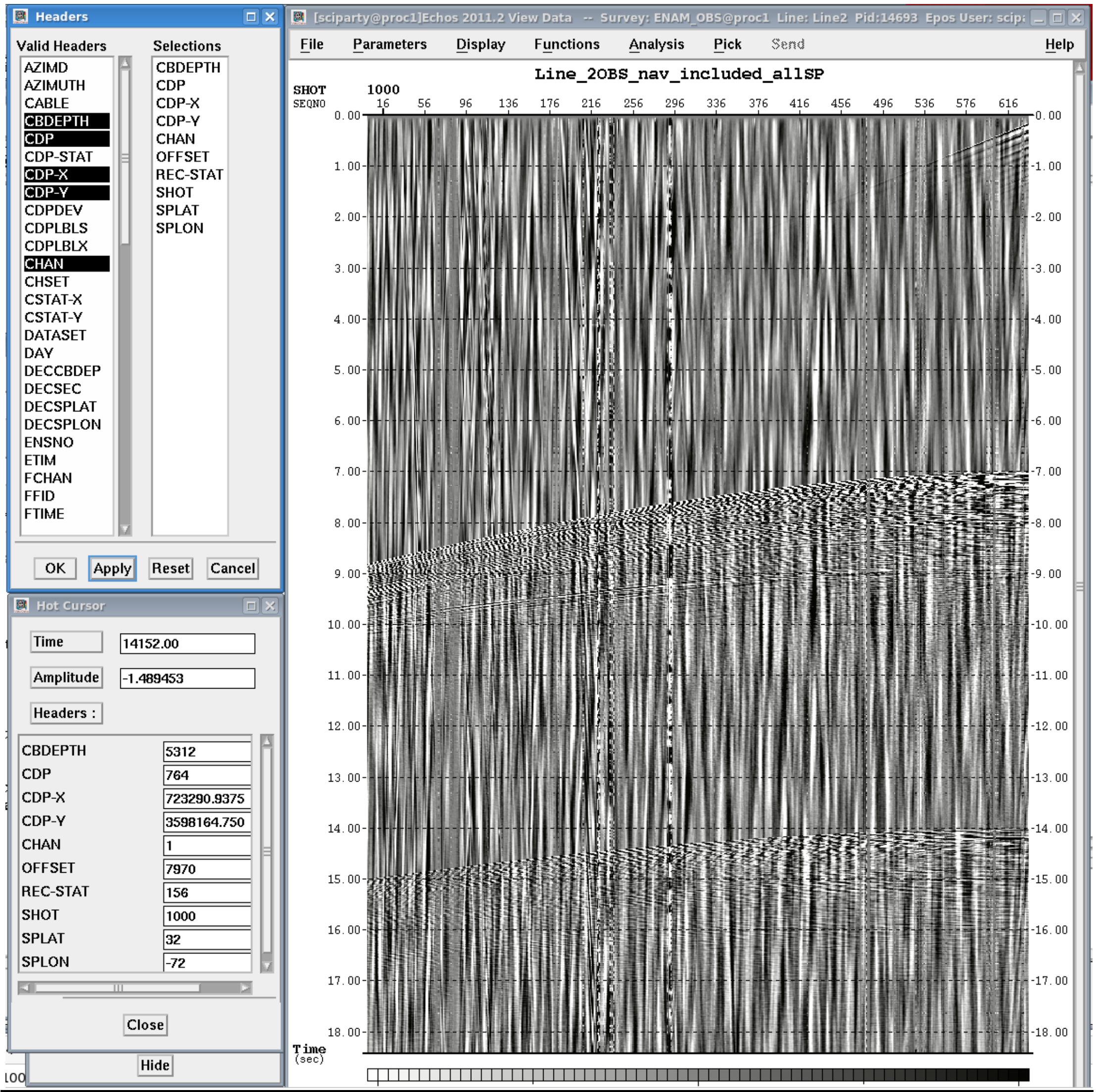


Figure B-11: *Example of shot point after merging the geometry, showing the cdp number and offset header words.*

***Step #3:** Band Pass filtering, editing bad traces and suppressing additional noise due to currents.*

We applied a minimum phase band pass filter of 3-7-200-250Hz to the data acquired with a 2ms sample rate (Figs. B-12 and B-14) and a minimum phase band pass filter of 3-8-410-470Hz for the data acquired with a 1ms sample rate to mainly remove the low frequency noise (0-3Hz), primarily due to the swell noise. This low frequency noise has the strongest amplitude in the amplitude spectrum (Fig. B-13).

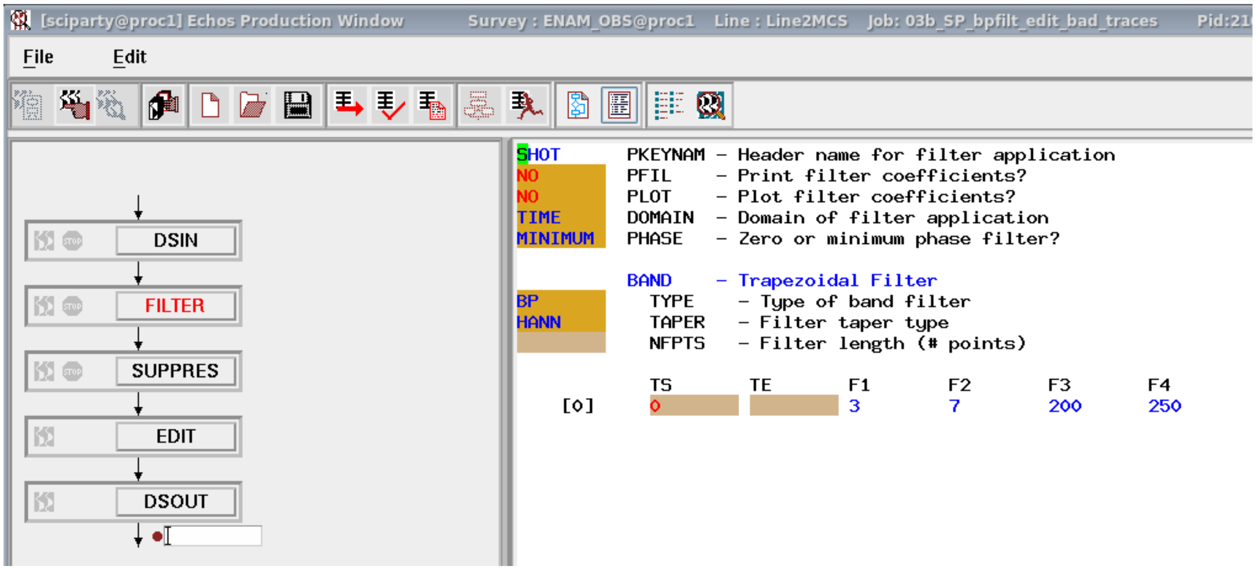


Figure B-12: *Example of Echos job showing the band pass filtering applied to the data.*

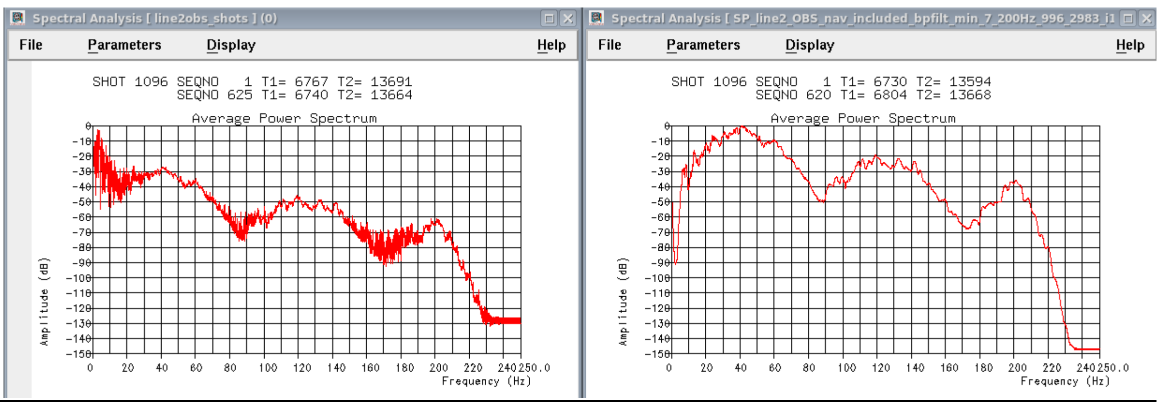


Figure B-13: *Examples of average power spectra before and after applying band pass filtering. Streamer and airguns were towed at 9 m depth, leading to spectral notches at 0, 83.3 Hz, 166.6 Hz. Note that there is a significant amount of signal for frequencies greater than the first spectral notch at 83.3Hz. The goal of the filter was to remove low frequency energy caused by swell noise.*

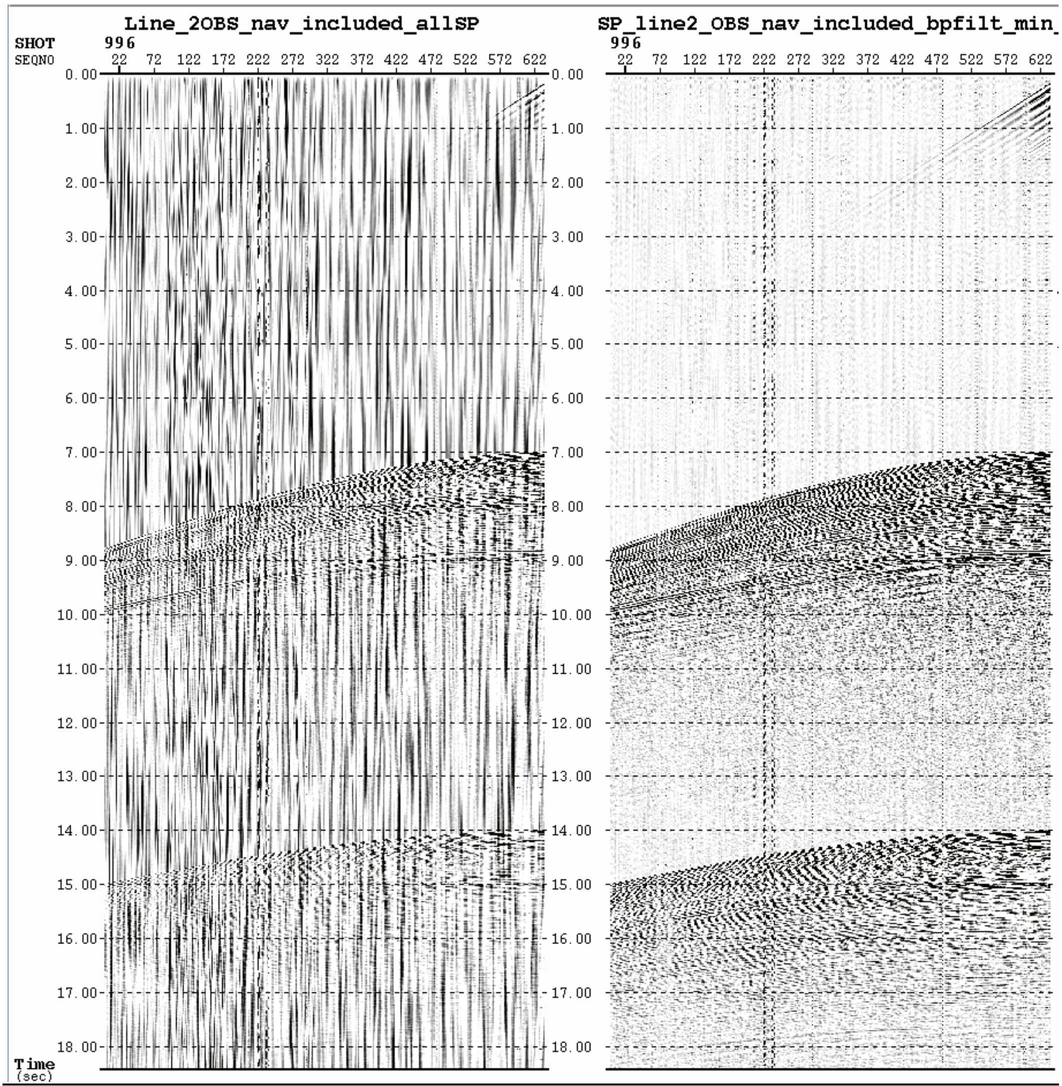


Figure B-14: *Shotpoint before (left) and after (right) band pass filtering. Much of the low frequency noise is gone after applying the filter.*

The recurrent bad traces (~10%) were identified on shot point gathers after band pass filtering and then killed (Fig. B-15).

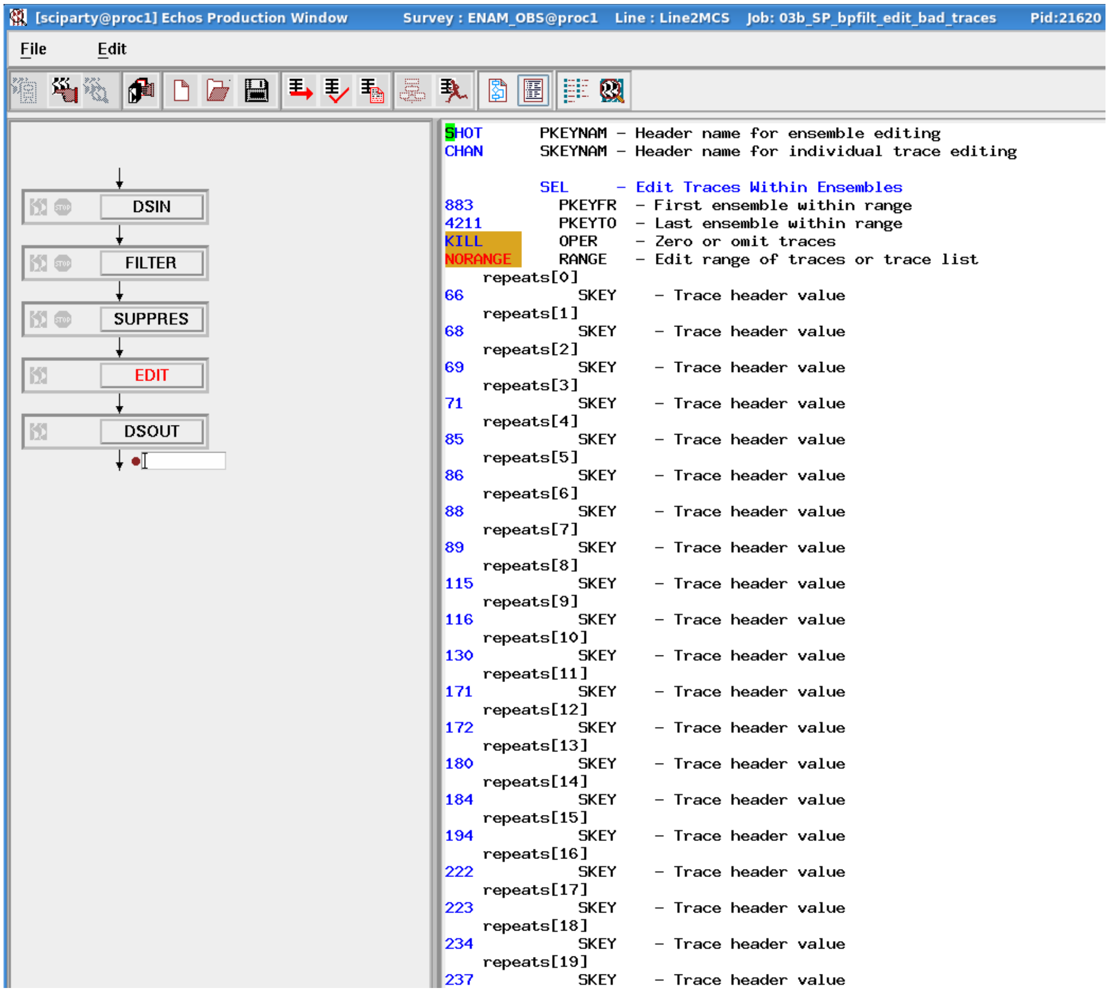


Figure B-15: *Examples of bad traces editing module*.

We also used a band-limited noise suppression to remove part of the noise due to the feathering of the streamer due to the currents or turns at the beginning or end of a profile. Noise suppression is performed by thresh-holding the noise envelope with the signal envelope.

Step #4: Sorting data into common midpoint gathers

Data were sorting from shot domain to common midpoint domain.

Step #5: Creating a brute stack and velocity analysis

A brute stack was generated by stacking the first 2 to 3 channels of the streamer in order to have guidance for the velocity picking. Velocity picking was performed every 500 or 1000 CDP, depending on the lines. For the lines shot spacing of 50 m or 225m, 1000 CDP interval was usually used; for the lines with a shot interval of 25-37.5 m, a 500 CDP interval was used. Automatic gain control using a 1s window and a band pass filter of 3-7-80-100 were also applied before the velocity analysis.

During velocity analysis, supergathers were formed to facilitate the picking. The strategy used was to have the same number of traces within the supergather as within a shot (636 or 480 traces). For 50 m shot interval: fold coverage 79, supergather formed by taking 8 adjacent cdps. For 225m shot interval: fold coverage 17, supergather formed by taking 37 adjacent cdps. For 25m shot interval: fold coverage: 120, supergather formed by taking 4 adjacent cdps. For 37.5m shot interval: fold coverage: 80, supergather formed by taking 6 adjacent cdps.

Step #5: stacking

Spherical divergence using the stacking velocities was applied before normal moveout correction. An automatic stretch mute (65%) was applied during NMO. For some lines, especially in shallow water an outer mute was picked and applied to NMO-ed gathers. For the lines acquired in shallow water an inner mute was picked to remove part of the multiple (e.g. Lines 63a, 35).

Step #6: migration

A post-stack Kirchhoff time migration was performed using the velocities picked during velocity analysis. Depending the results of the migration, the velocities were sometimes gridded and smoothed using a regular grid for input velocity interpolation was 100 ms, 500 CDP's along the subline and, 500 along the xline. Velocities were also sometimes scaled by 80 to 95% to prevent overmigration. For some parts of the profiles, if the multiple was so overmigrated that it masked many of the primary reflections, the seabottom multiple was muted before migration.

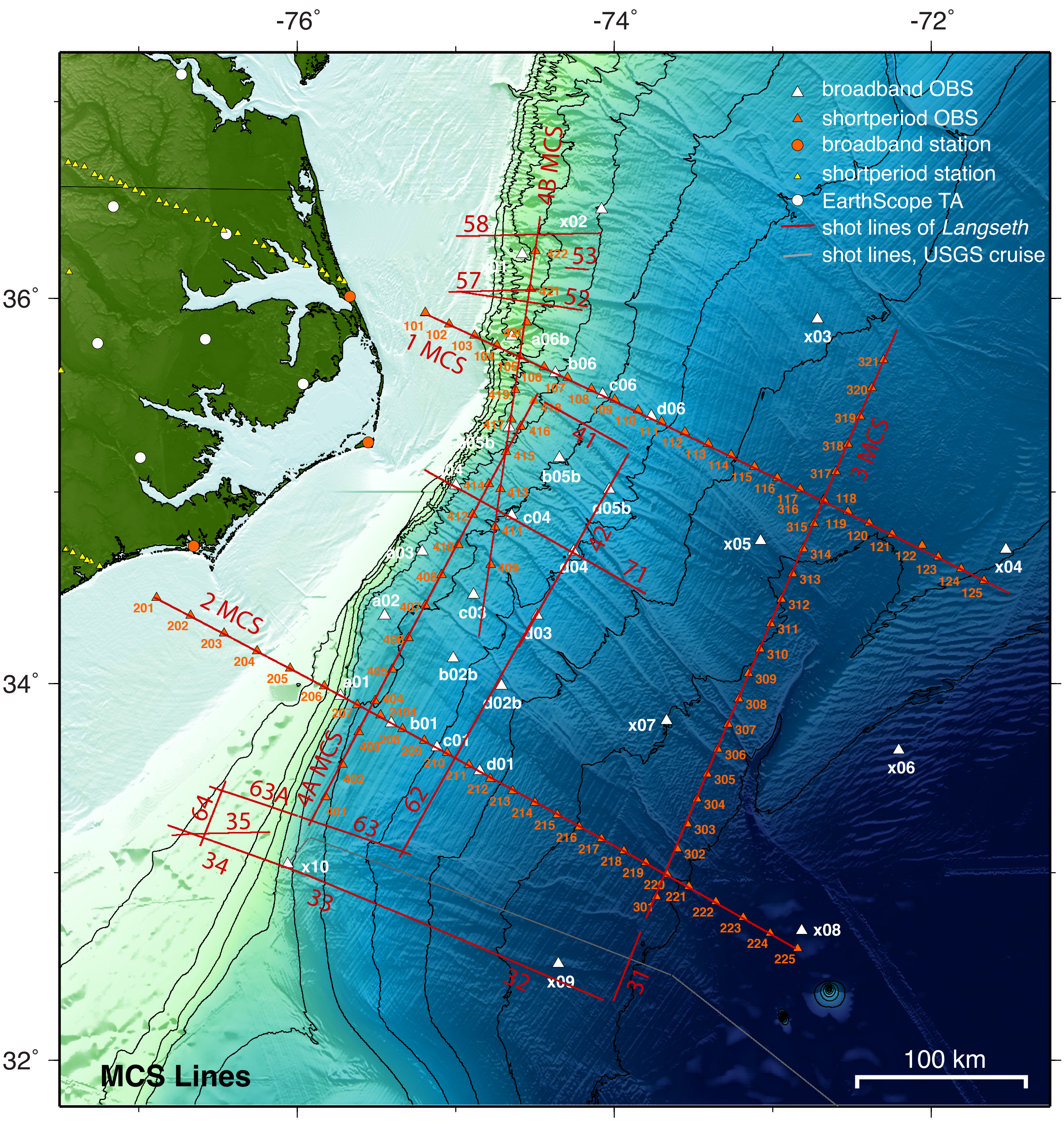
```
#!/bin/csh -f

#script for generating brute stacks during MGL1408


set LINENO = line2mcs

set reel1 = 001 #first reel in line
set reel2 = 001 #last reel in line

#make list of segd files to include in brute stack

set reel = `echo $reel1 | awk '{print $1+1}'`
set reel1_f = `echo $reel1 | awk '{printf "%04.0f", $1}'`

ls -al /data/seismic/MGL1408-segd/TAPE${reel1_f}.REEL/R*RAW | awk '{print $9}'
>! list

while ($reel <= $reel2)

set reel_f = `echo $reel | awk '{printf "%04.0f", $1}'`

ls -al /data/seismic/MGL1408-segd/TAPE${reel_f}.REEL/R*RAW | awk '{print $9}' >>
list

set reel = `echo $reel | awk '{print $1+1}'`
end

/lhome/pgadmin/sioseis/sioseis-2011.2.20/sioseis << eof
procs segddin prout geom wbt gather nmo stack avenor filter gains diskoa  end
#procs segddin prout geom wbt gather nmo stack diskoa end
#
segddin
   ftr 450 ltr 636
   fcset 1 lcset 1
   listpath list
   logpath ./$LINENO-stack.log
   end
end

prout
 fno 0 lno 9999999 ftr 1 ltr 1 noinc 10  end
end

geom
  type 1 # Fixed marine geometry
  fs 1 ls 999999  # all shot have the same parameters (preset)
  gxp 636 -154   # RESET the closest group only.
  ggx -12.5         # Used to extrapolate gxp!
  dfls 50   # ignored with type 9, change for each line
  dbrps 6.25 mindfls 60 maxdfls 65
  rpadd 1000 end
end

wbt
```

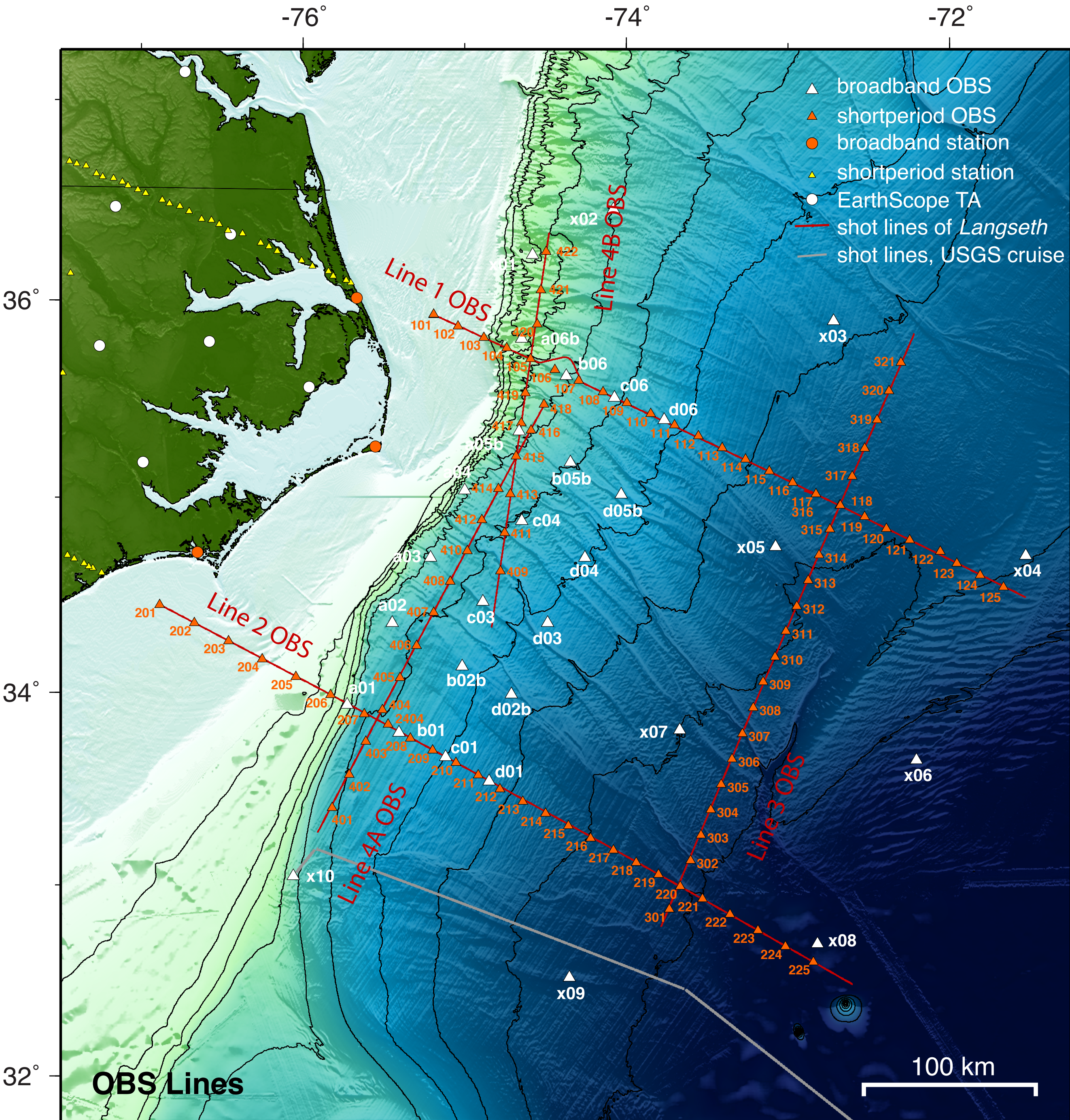
```
    vel 1500 track .1 end
end

gather
   maxtrs 64  maxrps 656 END  #changed maxtrs and maxrps for each line
end

nmo
# real time nmo, replace interpolation by RP to WB depth in Meters.
# If water depth changes by > 500 m, use previous value. Water-depth
# velocity functions derived from EDGE801
 vtrkwb 500 stretc 1
 vintpl 1

#fno 100 lno 100
#vtp 1500 0.1
#1900 1.1
#3000 2.1
#4000 3.7
#5300 7.0
#6000 10.0
#6500 13.0
#6750 16
#7000 18 end

fno 50 lno 50
vtp 1500.00000000 0.00000000
2013.73 1.03400004
2108.17 1.08299994
5108.1 1.11699998
5116.83 3.96799994
5567.08 4.00000000
5570.57 6.67700005
5574.72 6.70800018
6006.65 6.73799992
6008.67 11.26799965
6012.1 11.29500008
6260.6 11.31999969
6803.61 12.71000004 end

fno 150 lno 150
vtp 1500.00000000 0.05
1650.05 0.11100000
1978.19 0.20900001
1988.21 1.14900005
2018.9 1.22899997
2266.64 1.29900002
2301.76 1.74399996
2545.24 1.80499995
2563.24 2.27999997
2603.37 2.32399988
4149.39 2.35999990
4167.36 4.08300018
4186.44 4.11499977
5268.44 4.14599991
```

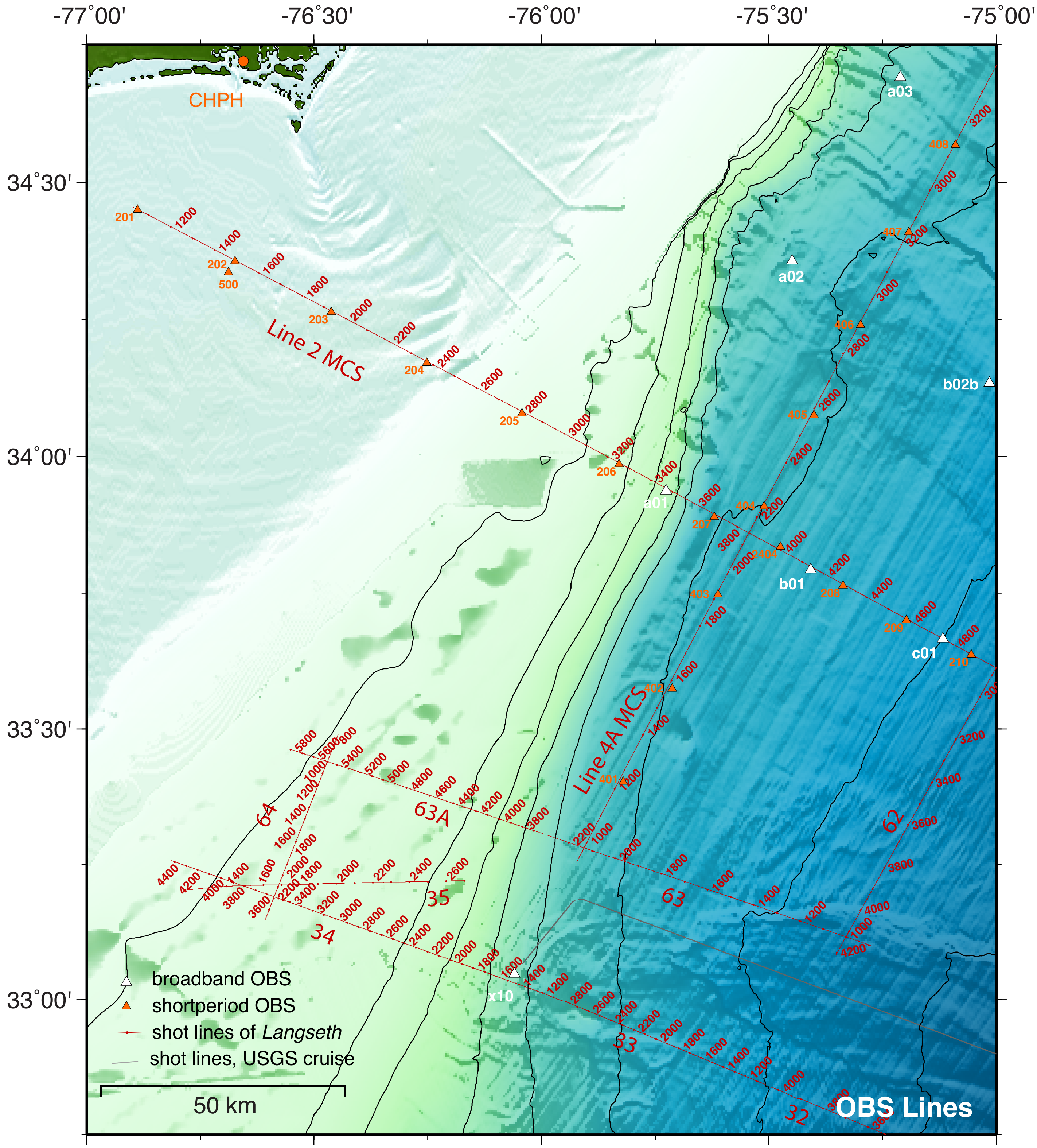
```
5274.31 7.34899998
5394.83 7.37900019
5400.17 7.97499990
5406.57 8.00399971
5976.81 8.03100014
5980.7 10.77999973
5985.27 10.80599976
6346.52 10.83100033
7110.16 12.86499977 end

fno 1500 lno 1500
vtp 1500 2.40000010
1509.21 2.51600003
1619.56 2.61899996
1630.55 3.40899992
1649.43 3.49300003
1939.18 3.56599998
1953.52 4.55700016
1973.61 4.61800003
2524.68 4.67199993
2538.14 6.25500011
2555.68 6.29799986
2920.89 6.33599997
2937.42 7.02299976
2955.57 7.05900002
3496.7 7.09399986
3508.62 8.27299976
3521.69 8.30599976
3716.5 8.33699989
3730.2 8.76900005
5100.51 8.79500008
5106.75 12.31499958
5113.47 12.34099960
5760.98 12.36600018
6730.77 15.19200039 end

fno 2500 lno 2500
vtp 1500 2.93300009
1505.85 3.05399990
1585.72 3.16400003
1593.15 4.13000011
1600.35 4.23500013
1614.02 4.32399988
1815.76 4.40100002
1827.79 5.29099989
1847.75 5.34999990
2490.72 5.40000010
2505.32 6.91900015
2522.3 6.96299982
2845.81 7.00299978
2860.31 7.72300005
2876.06 7.76100016
3117.12 7.79899979
3129.26 8.39799976
3143.77 8.43200016
```

```
3278.98 8.46399975
3294.08 8.71800041
3310.75 8.74800014
4352.12 8.77600002
4361.22 10.93200016
4371.39 10.95800018
5698.65 10.98299980
7204.22 15.63700008 end

fno 3500 lno 3500
vtp 1500 4.00000000
1503.29 4.12400007
1527.18 4.23899984
1532.81 4.68699980
1543.78 4.78399992
1796.19 4.86999989
1803.08 6.68400002
1817.21 6.74700022
2222.25 6.79799986
2237.38 7.86299992
2254.96 7.90700006
2413.95 7.94799995
2431.36 8.27600002
2449.74 8.31499958
2988.8 8.35099983
3000.85 9.52299976
3015.51 9.55599976
3655.8 9.58500004
3667.99 10.78299999
3681.45 10.81000042
5543.78 10.83500004
7278.16 16.42799950  end

end

diskoa   # Write out disk file
  opath $OUTDIR/$LINENO-stack.segy
end end

avenor
  hold 300
  addwb yes sets 0 1 2 5 6 8 14 22 end
end


filter
  pass 3 80 ftype 0 dbdrop 48 minpha yes end
end

gains
  type 3 alpha 1.25 end
end

plot
  dir $DIR
```

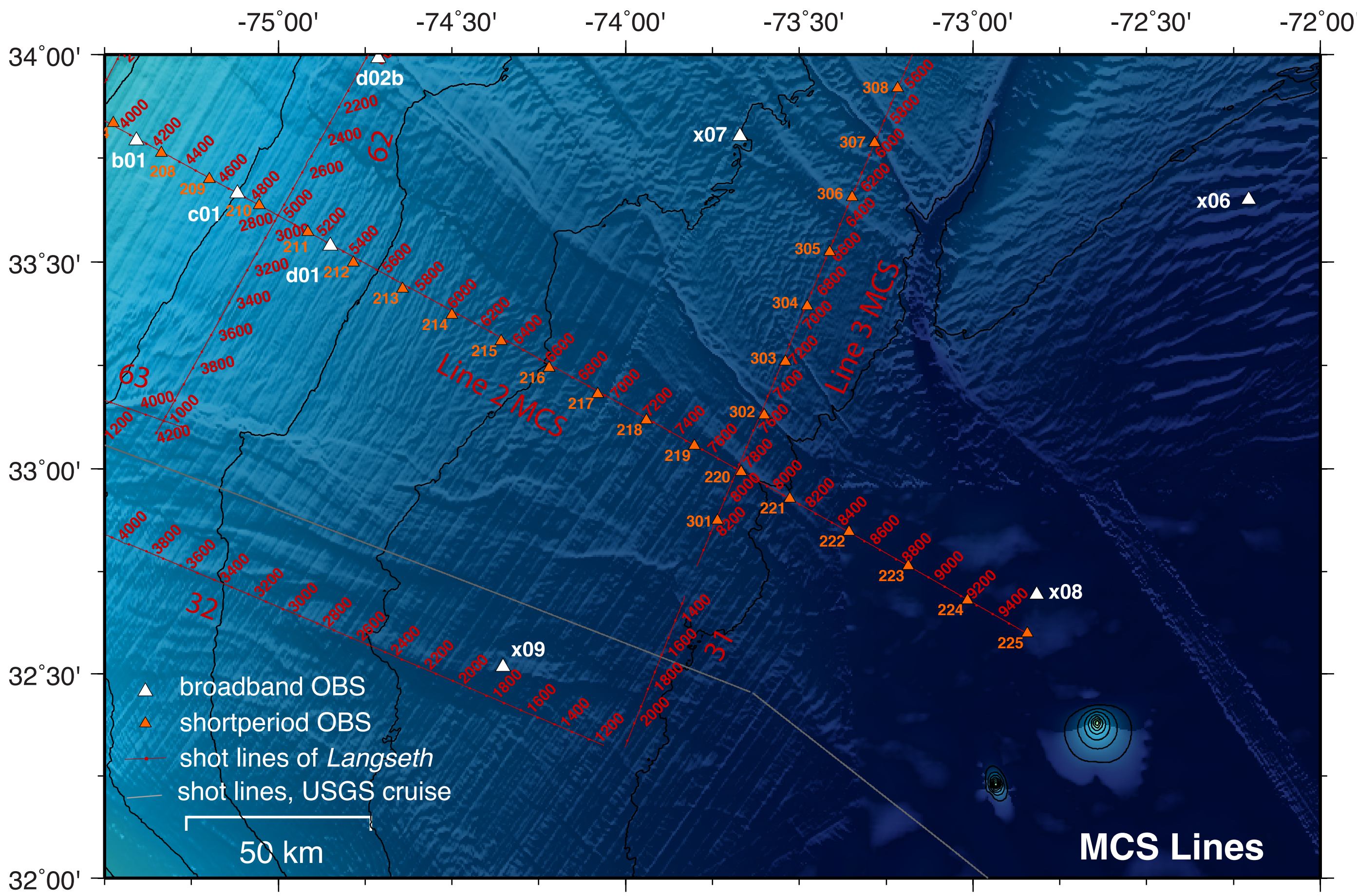
```
  scalar -1
  tlines 0.5 1 nibs 7225 ann gmtint anninc 5 ann2 shotno
  def 0.04 trpin 125 wiggle 0
  vscale 1.25 clip .03
  opath $OUTDIR/$LINENO-stack.atlantek srpath $OUTDIR/$LINENO-stack.sunfil
  end
end


end
eof
```


-76°
-74°
-72°
36°
34°
32°
broadband OBS
shortperiod OBS
broadband station
shortperiod station
EarthScope TA
shot lines of *Langseth*
shot lines, USGS cruise
1 MCS
2 MCS
3 MCS
4A MCS
4B MCS
58
57
53
52
41
42
71
62
63
63A
64
35
34
33
32
31
x02
x03
x04
x05
x06
x07
x08
x09
x10
a01
a02
a03
a06b
b01
b02b
b05b
b06
c01
c03
c04
c06
d01
d02b
d03
d04
d05b
d06
100 km
MCS Lines

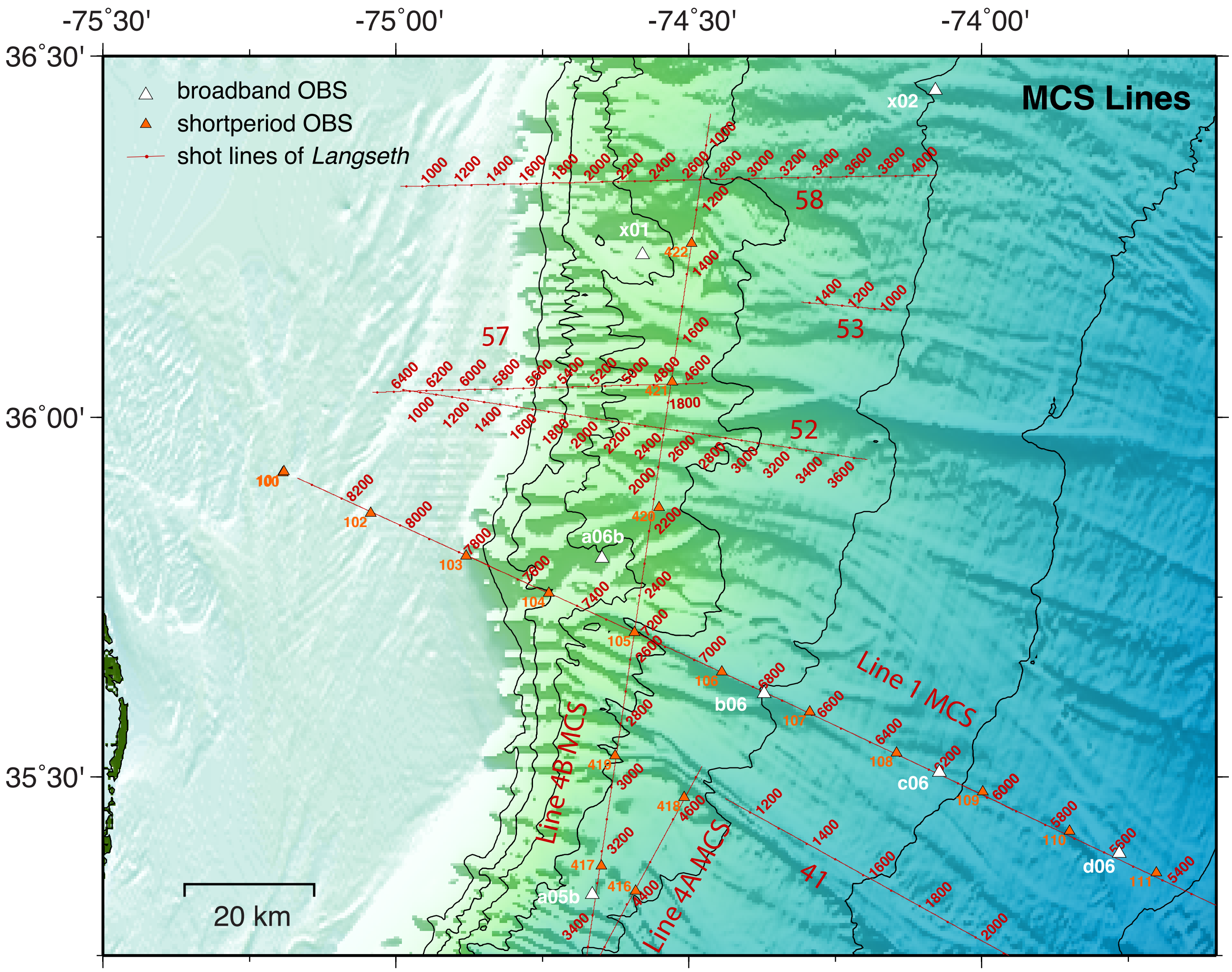

-76°
-74°
-72°
36°
34°
32°
broadband OBS
shortperiod OBS
broadband station
shortperiod station
EarthScope TA
shot lines of Langseth
shot lines, USGS cruise
Line 1 OBS
Line 2 OBS
Line 3 OBS
Line 4A OBS
Line 4B OBS
100 km
OBS Lines

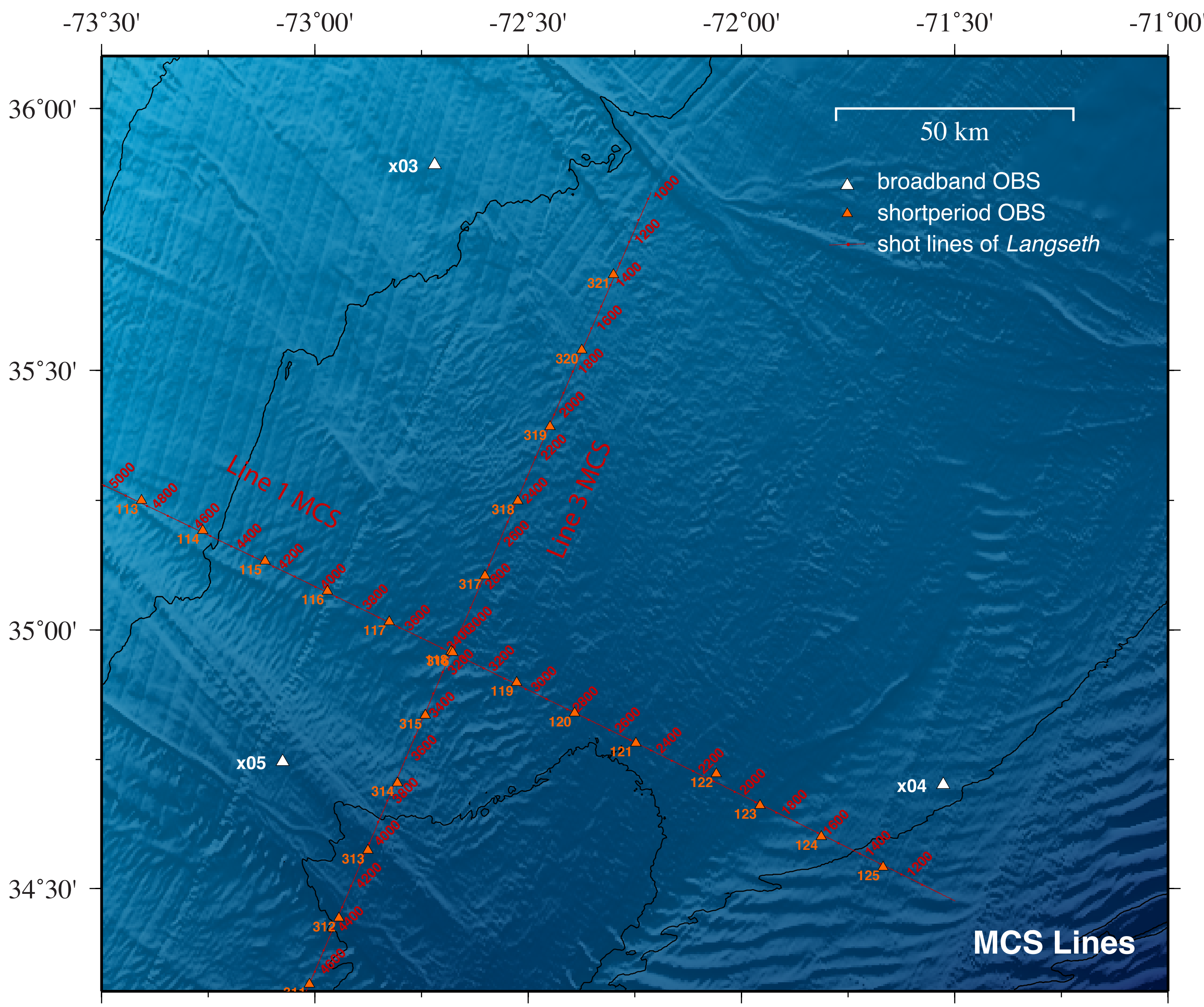


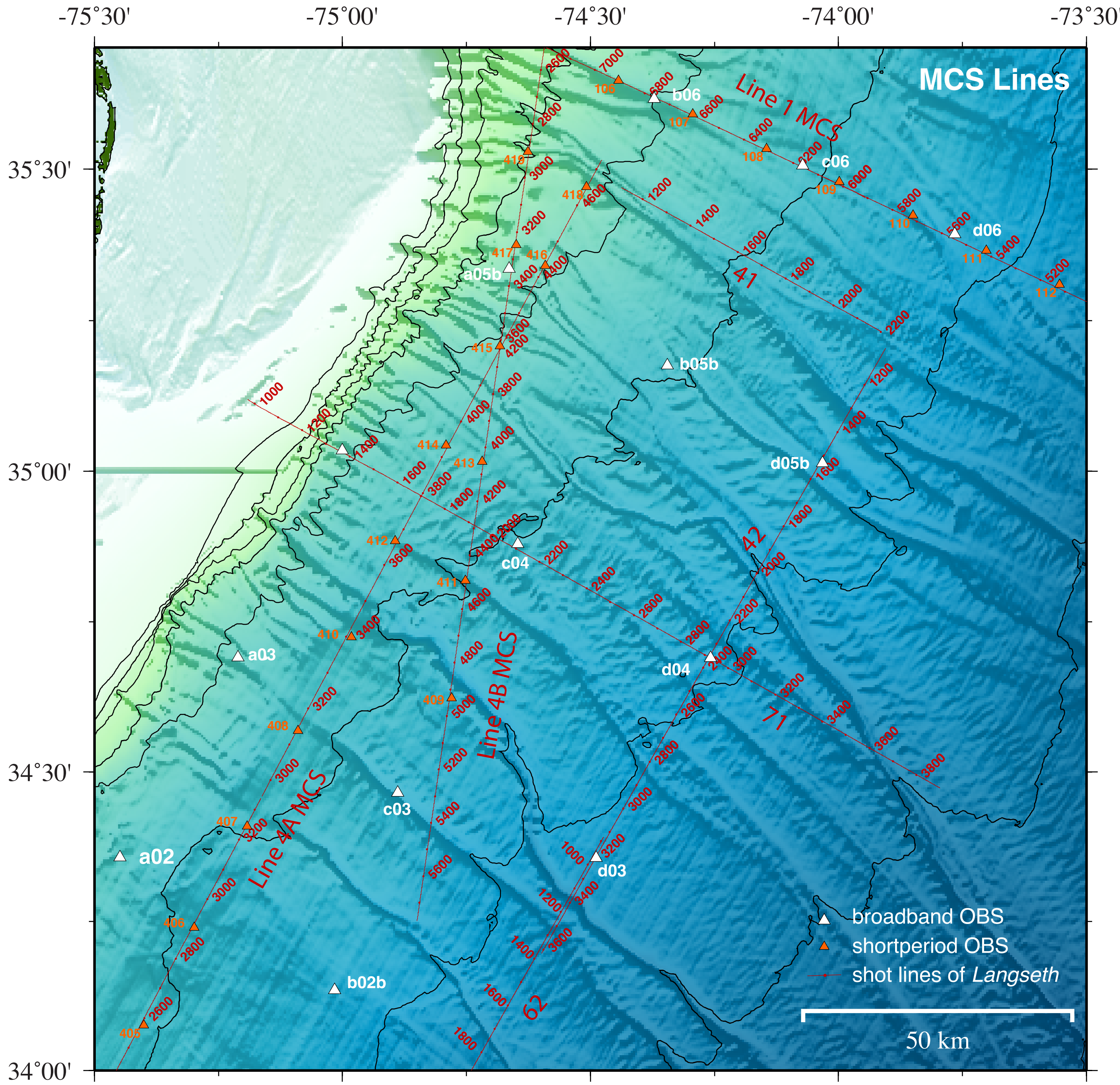
-77˚00'
-76˚30'
-76˚00'
-75˚30'
-75˚00'
34˚30'
34˚00'
33˚30'
33˚00'
CHPH
Line 2 MCS
Line 4A MCS
63A
64
63
35
34
33
32
62
a01
a02
a03
b01
b02b
c01
x10
broadband OBS
shortperiod OBS
shot lines of *Langseth*
shot lines, USGS cruise
50 km
OBS Lines

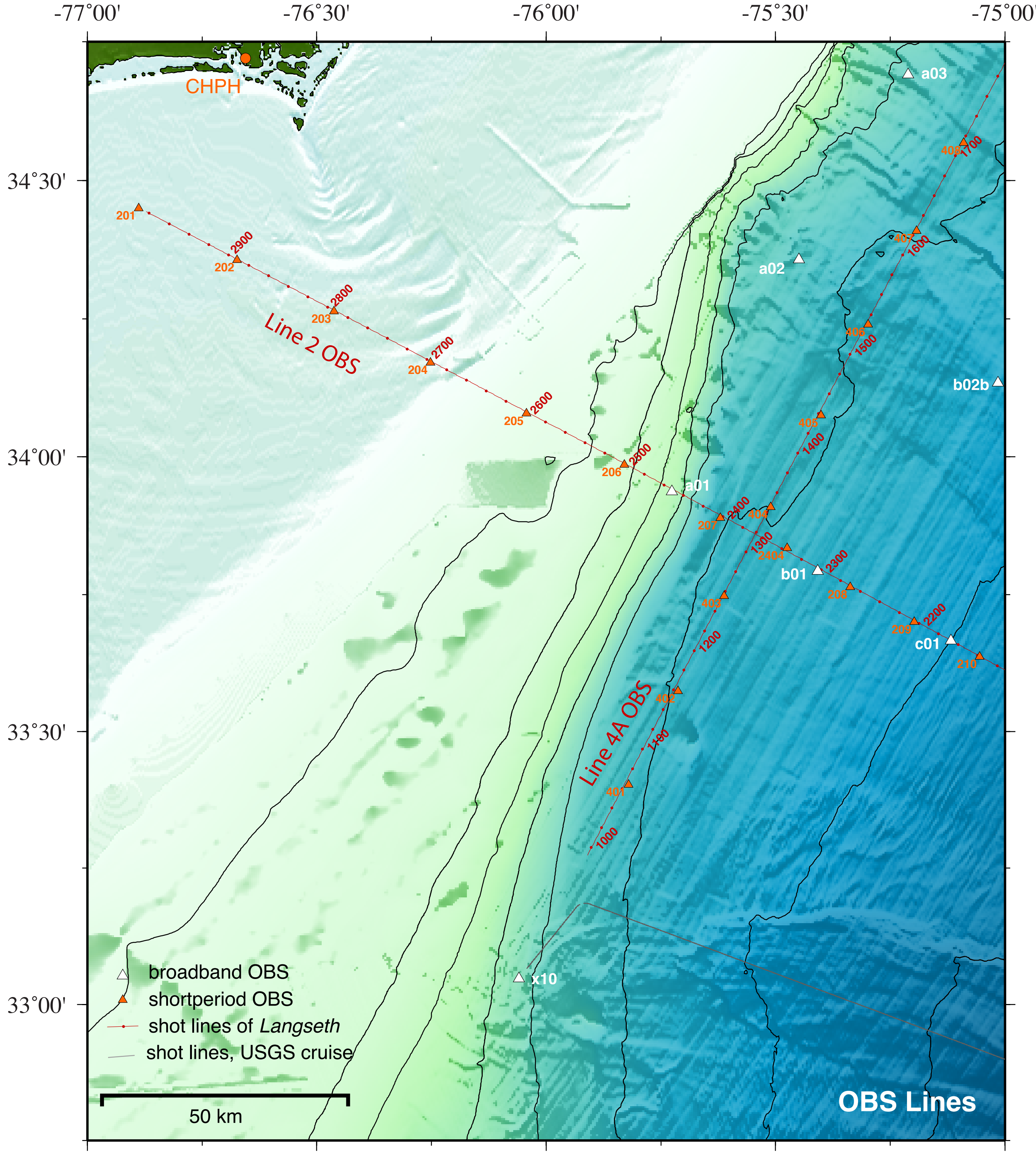


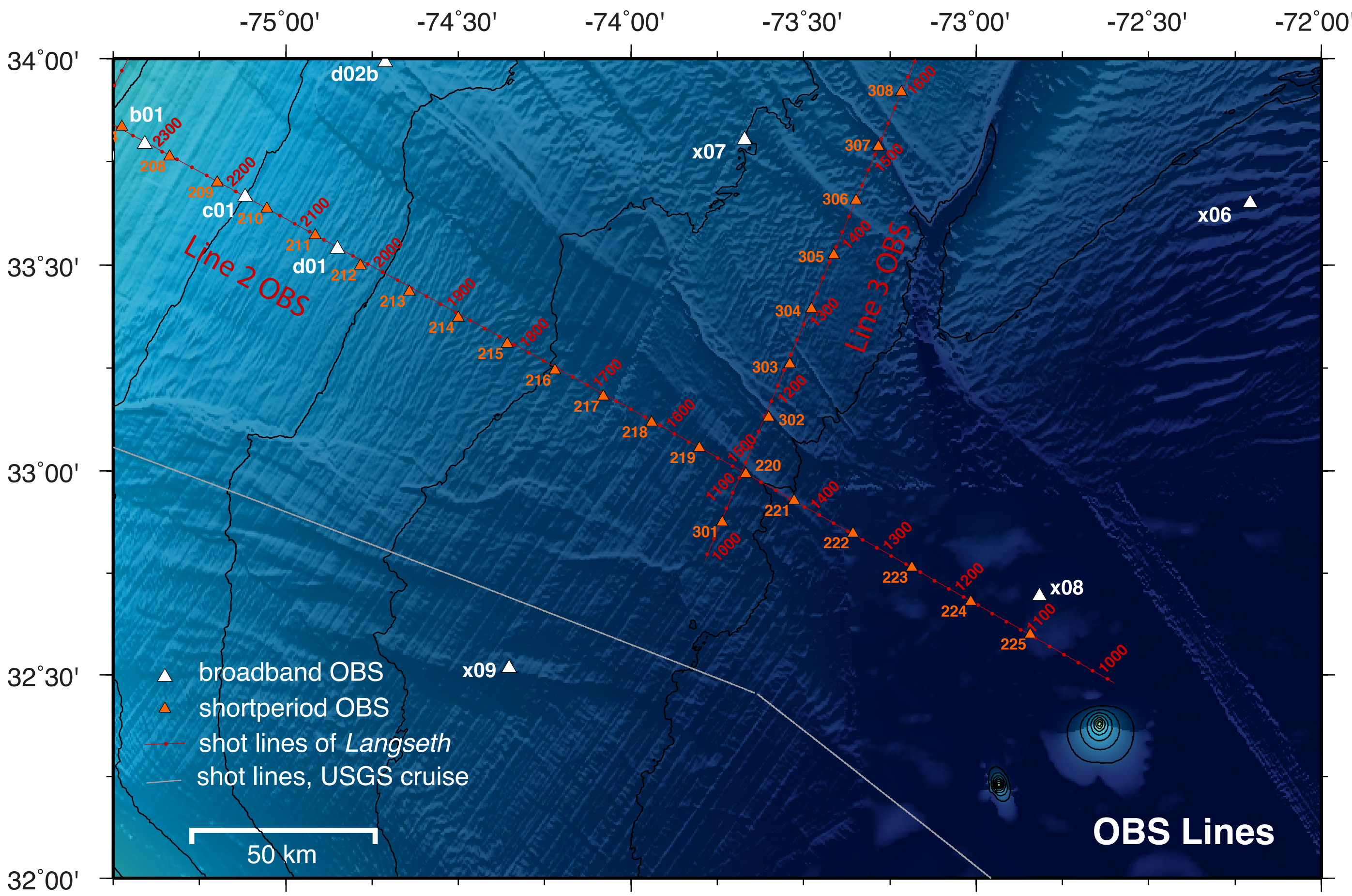
-75˚00'
-74˚30'
-74˚00'
-73˚30'
-73˚00'
-72˚30'
-72˚00'
34˚00'
33˚30'
33˚00'
32˚30'
32˚00'
d02b
b01
c01
d01
x07
x06
x08
x09
Line 2 MCS
Line 3 MCS
62
63
32
31
broadband OBS
shortperiod OBS
shot lines of *Langseth*
shot lines, USGS cruise
50 km
MCS Lines

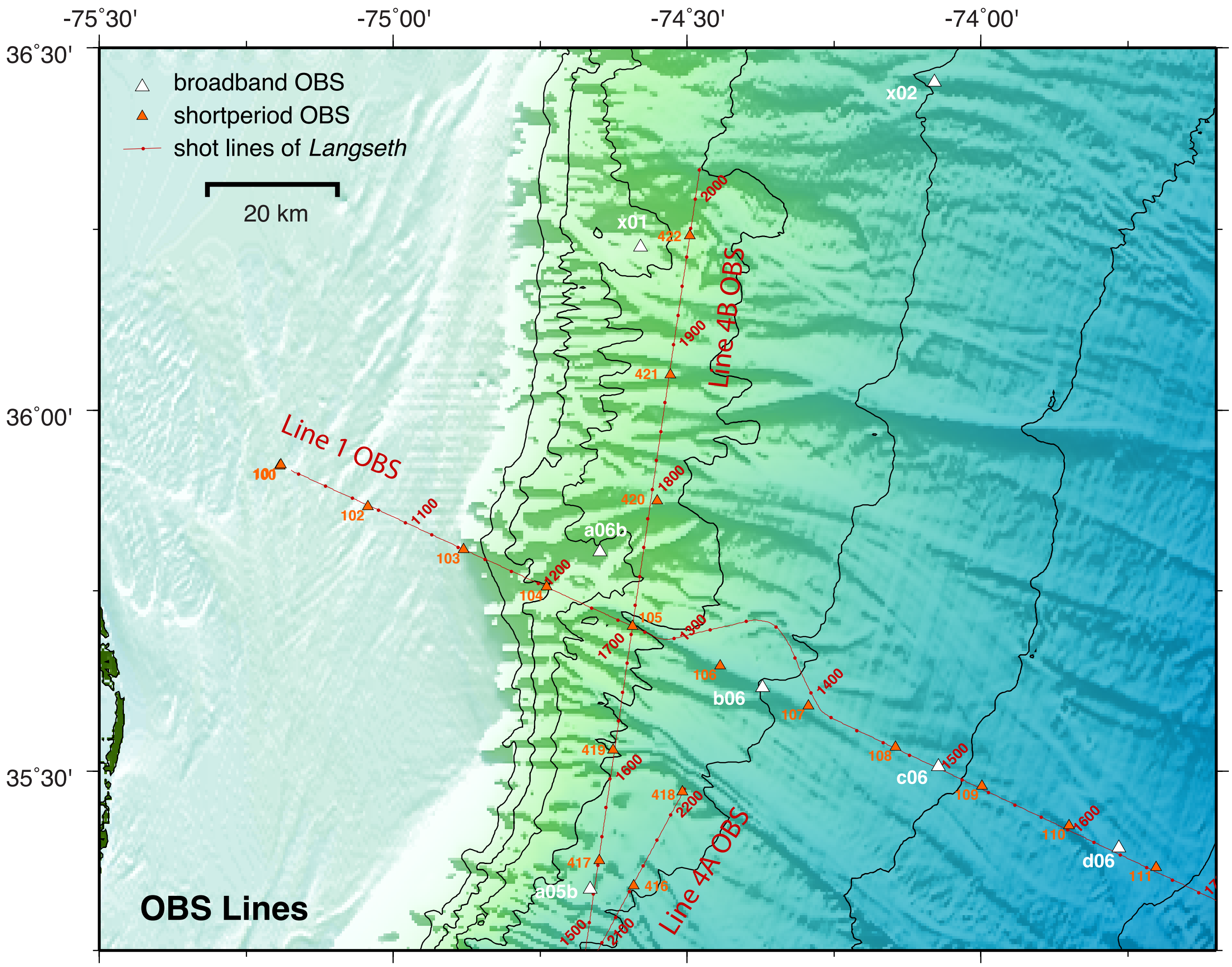

MCS Lines
broadband OBS
shortperiod OBS
shot lines of *Langseth*
-75˚30'
-75˚00'
-74˚30'
-74˚00'
36˚30'
36˚00'
35˚30'
Line 1 MCS
Line 4B MCS
Line 4A MCS
58
57
53
52
41
x01
x02
a06b
a05b
b06
c06
d06
20 km


-73°30'
-73°00'
-72°30'
-72°00'
-71°30'
-71°00'
36°00'
35°30'
35°00'
34°30'
50 km
broadband OBS
shortperiod OBS
shot lines of *Langseth*
x03
x04
x05
Line 1 MCS
Line 3 MCS
MCS Lines

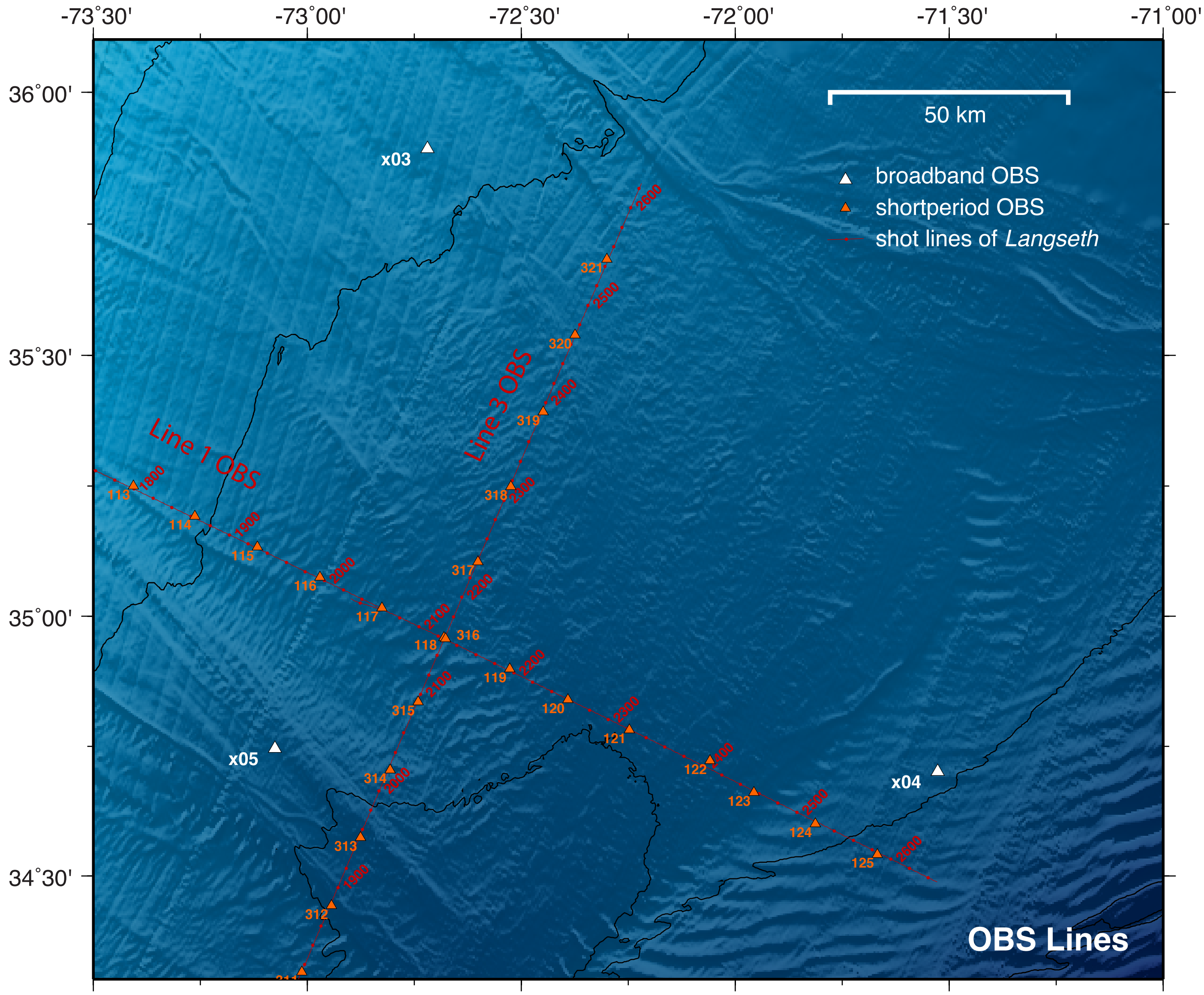

MCS Lines
Line 1 MCS
Line 4A MCS
Line 4B MCS
41
42
62
71
-75°30'
-75°00'
-74°30'
-74°00'
-73°30'
35°30'
35°00'
34°30'
34°00'
b06
c06
d06
a05b
b05b
d05b
c04
d04
a03
a02
c03
d03
b02b
broadband OBS
shortperiod OBS
shot lines of *Langseth*
50 km

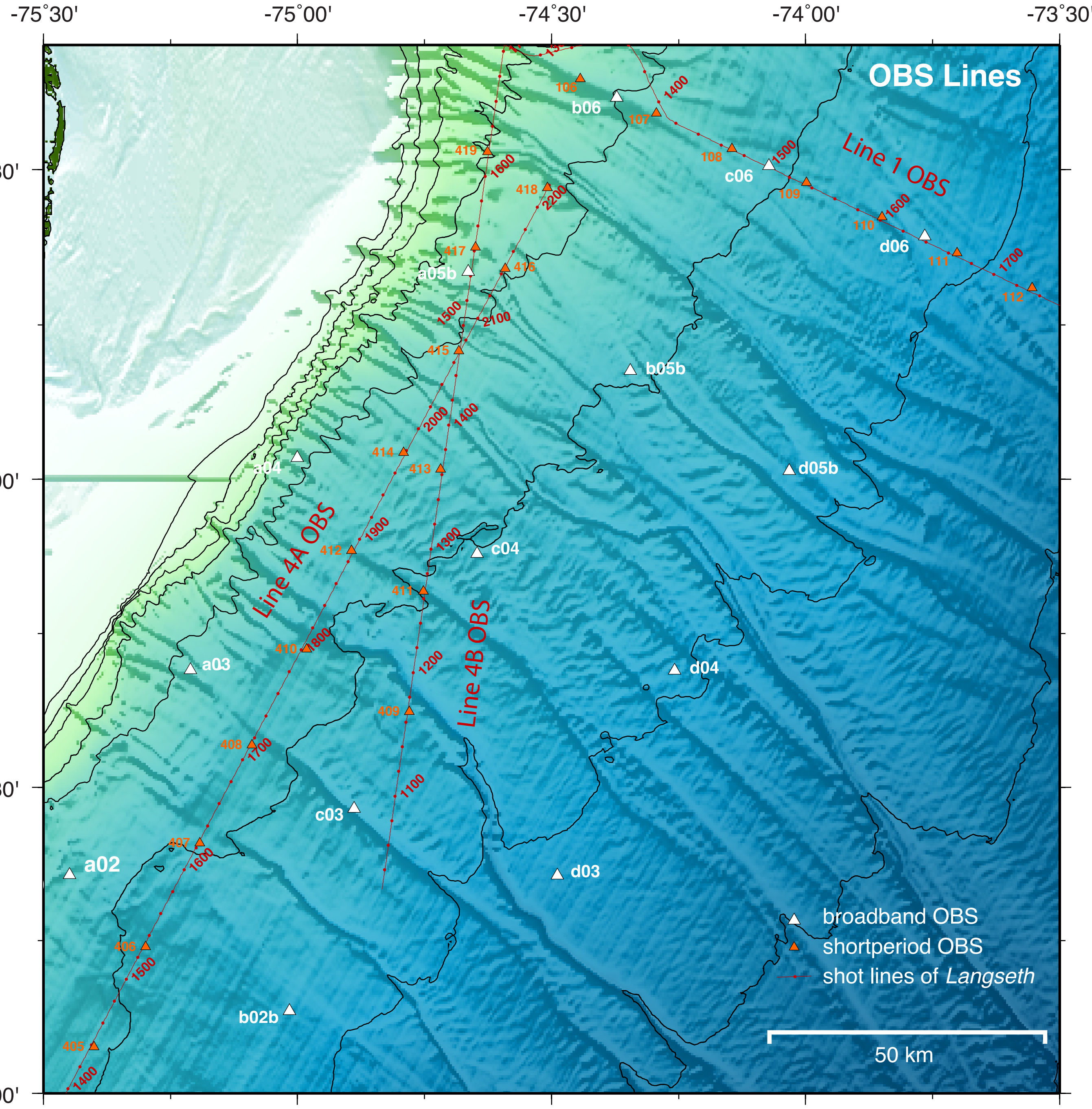

-77˚00'
-76˚30'
-76˚00'
-75˚30'
-75˚00'
34˚30'
34˚00'
33˚30'
33˚00'
CHPH
Line 2 OBS
Line 4A OBS
a01
a02
a03
b01
b02b
c01
x10
broadband OBS
shortperiod OBS
shot lines of Langseth
shot lines, USGS cruise
50 km
OBS Lines


-75˚00'
-74˚30'
-74˚00'
-73˚30'
-73˚00'
-72˚30'
-72˚00'
34˚00'
33˚30'
33˚00'
32˚30'
32˚00'
Line 2 OBS
Line 3 OBS
broadband OBS
shortperiod OBS
shot lines of *Langseth*
shot lines, USGS cruise
50 km
OBS Lines



-75˚30'
-75˚00'
-74˚30'
-74˚00'
36˚30'
36˚00'
35˚30'
broadband OBS
shortperiod OBS
shot lines of *Langseth*
20 km
x01
x02
a06b
a05b
b06
c06
d06
Line 1 OBS
Line 4B OBS
Line 4A OBS
OBS Lines


-73˚30'
-73˚00'
-72˚30'
-72˚00'
-71˚30'
-71˚00'
36˚00'
35˚30'
35˚00'
34˚30'
50 km
broadband OBS
shortperiod OBS
shot lines of *Langseth*
x03
x05
x04
Line 1 OBS
Line 3 OBS
113
114
115
116
117
118
119
120
121
122
123
124
125
312
313
314
315
316
317
318
319
320
321
OBS Lines


OBS Lines
-75˚30'
-75˚00'
-74˚30'
-74˚00'
-73˚30'
35˚30'
35˚00'
34˚30'
34˚00'
Line 1 OBS
Line 4A OBS
Line 4B OBS
b06
c06
d06
a05b
b05b
d05b
a04
c04
a03
d04
c03
a02
d03
b02b
broadband OBS
shortperiod OBS
shot lines of *Langseth*
50 km

C. Multibeam Bathymetry and Subbottom Profiler Data

Acquisition:

We acquired multibeam bathymetry and subbottom profiler data for the entire cruise except on transits to/from Norfolk (in compliance with environmental permits). Multibeam data were acquired with the Simrad-Kongsberg EM122/SB122 system of the *Langseth*. Subbottom profiler data were acquired with the *Langseth's* Knudsen Echosounder system, which consists of 16 (4x4 square) hull-mounted transducer system. Transducers are Massa TR109s with a center frequency of 3.5 kHz. Files are saved as both Knudsen (.keb) and segy format. All files were depth converted assuming a constant water velocity of 1500 m/s.

Water velocities for multibeam data were taken from a global almanac of sound velocity structure in the ocean. Water temperature varied significantly in space and time over the cruise, so post-cruise processing in areas of interest could take advantage of the abundant XBT data that we acquired.

The aperture of the swath for multibeam data was set to 68° on either side of the nadir, and ping spacing set to be equidistant on the seafloor. The swath mode automatically changed with water depth.

The depth range for the subbottom profiler was regularly adjusted to track the seafloor, which was highly variable in our study area. The window length was generally set to 200 m (though it was occasionally set to 100 m in shallow water depths, and at 500 m on MCS/OBS Line 1 where the ocean bottom was routinely lost due to significant topographic changes over short offsets). Pulse widths were varied from 8 ms in shallow water to 32 ms in deep water, though the science party noted that the data still looked good to depths up to 3000 m with a 16 ms pulse width in some areas. The power of the pulse was also varied to be lower in shallow water and higher in deep water. The ping rate for the subbottom profiler was set at a constant rate of 250 ms for the entire cruise.

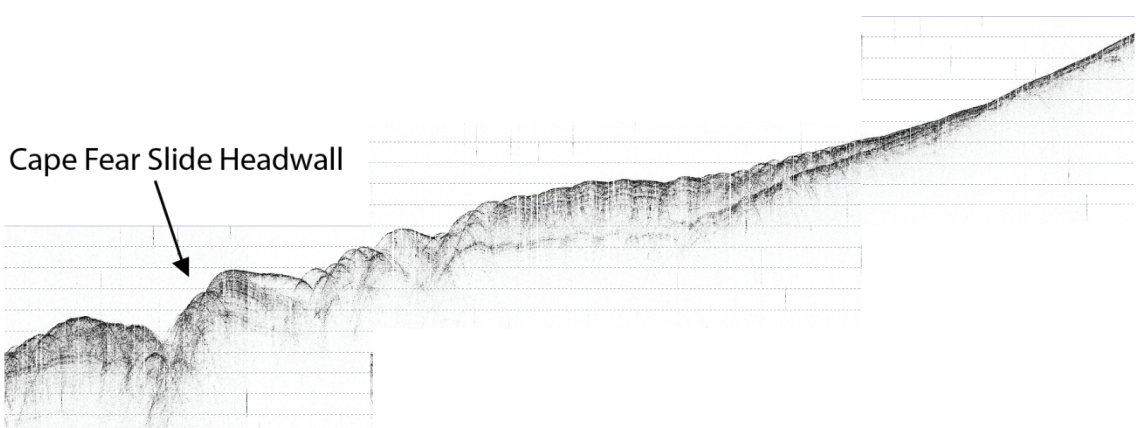


Figure C-1. *Example of Chirp data collected for MCS line 063.*

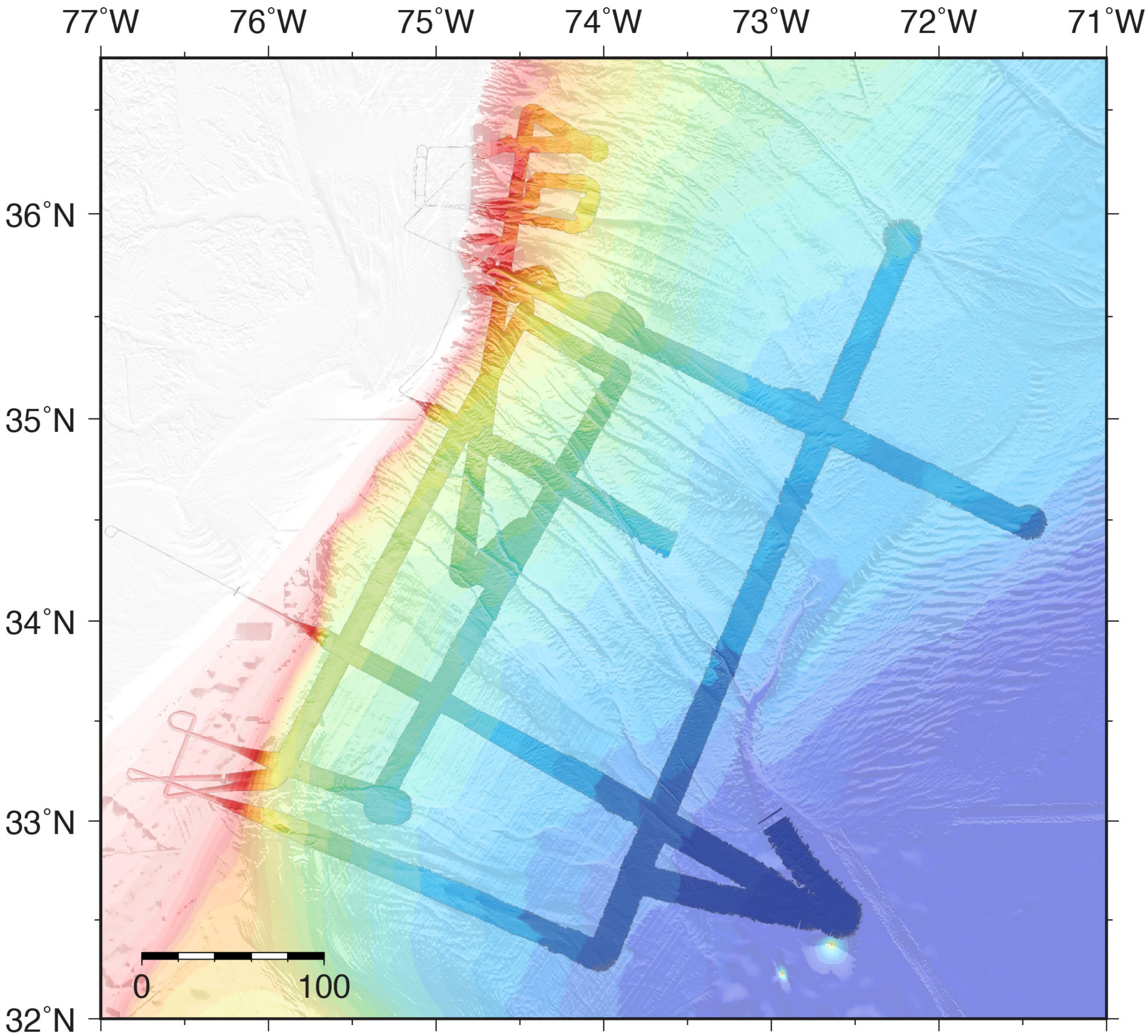


Figure C-2: *Bathymetry data from MGL1408 overlain on bathymetry grid from the MGDS.*

Processing of bathymetry data:

We undertook automated shipboard processing of bathymetry data using MB-system (Caress and Chayes, 2006). The scripts are included in this appendix. Our basic onboard processing comprised the steps below:

- **Format conversion.** The data from the *Langseth*'s EM122 are written out in a format interpreted by MB-System as 58. This is a 'read-only' format, so the files must be converted to another format before edits can be applied using mbcopy (mb59 for EM sonars).

- **Automatic cleaning**. An automatic cleaning routine was applied that flags spikes and excessive slopes with mbclean. Spikes were defined as individual pings with slopes on either side of 65° either in the alongtrack or acrosstrack directions, and excessive slopes were defined as being greater than 65°. These parameters were chosen to be conservative so that we did not remove any real features. Automatic edits were applied to the data with mbprocess.

- **Gridding.** The cleaned data were then gridded using mbgrid. A grid spacing of 100 m chosen for regional grids, which is most appropriate for deep water. But a smaller spacing should be employed for shallow water areas of interest in the future. For example, a grid spacing of 25 m was used to generate grid around Currituck slide area shown in Fig. C-3.

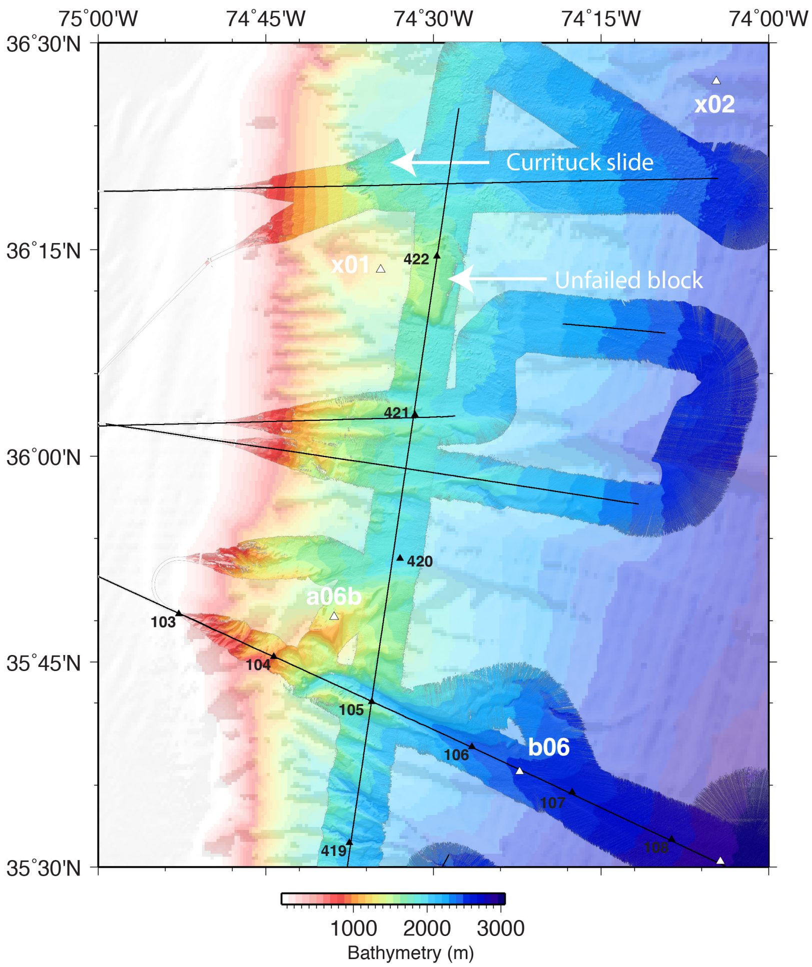


Figure C-3*: Example of bathymetry data over the Currituck slide area overlain on bathymetry grid from the MGDS. Langseth tracks and OBS locations shown for reference.*

Caress, D. W., and D. N. Chayes (1995), New software for processing sidescan data from sidescan-capable multibeam sonars, Proceedings of the IEEE Oceans 95 Conference, 997-1000.

Ryan, W. B. F., S. M. Carbotte, J. Coplan, S. O'Hara, A. Melkonian, R. Arko, R. A. Weissel, V. Ferrini, A. Goodwillie, F. Nitsche, and and others (2009), Global multi-resolution topography synthesis, Geochem. Geophys. Geosys., 10(Q03014), doi:10.1029/2008GC002332.

go_copy_autoclean.csh: Script for converting format and autocleaning

```
#!/bin/csh -f

# converts formats of multibeam files for one day and applies autocleaning

set month = 10
set day = 13
#set datapath1 = /data/CruiseData/MGL1408/raw/multibeam/MGL1408F/2014
set datapath2 = /data/CruiseData/MGL1408/raw/multibeam/MGL1408G/2014

#makes a list of data files and copies them to format for editing (from 58
to 59)

#ls -al ${datapath1}/${month}/${day}/0*all | awk '{print $9}' | \
# awk -F"*" '{print $1}' >! ./list_files_orig_${month}_${day}
ls -al ${datapath2}/${month}/${day}/0*all | awk '{print $9}' | \
 awk -F"*" '{print $1}' >! ./list_files_orig_${month}_${day}

mbdatalist -I ./list_files_orig_${month}_${day} -F-1 >!
./list_files_${month}_${day}

mkdir ./mb59/${month}-${day}

#loops over files and converts format

set i = 1
set ndat = `wc -l ./list_files_orig_${month}_${day} | awk '{print $1}'`

while ($i <= $ndat)

set input = `awk '(NR==i){print $1}' i=$i ./list_files_${month}_${day}`
      set name = `echo $input | awk -F".all" '{print $1}' | awk -F"/"
'{print $12}'`
      set output = ./mb59/${month}-${day}/${name}.mb59

echo $name

mbcopy -I $input -F58/59 -O $output

set i = `echo $i | awk '{print $1+1}'`
end

#removes pings associated with slopes >60, or spikes
#with sides with slopes of >60

ls -al ./mb59/${month}-${day}/*mb59 | awk '{print $9}' >! temp2

mbdatalist -I temp2 -F-1 >! ./list_files_mb59_${month}-${day}
mbclean -C60/2 -S60/3/2 -F-1 -I ./list_files_mb59_${month}-${day} -M2
mbprocess -I ./list_files_mb59_${month}-${day} -F-1

mv list_files*${month}-${day} lists
rm temp2
```

go_mbgrid.csh: Script for gridding original and cleaned bathymetry

```
#!/bin/csh -f

set month = 10
set day = 09

#list of original files
ls -al ./mb59/*/*h.mb59 | awk '{print $9}' >! list_orig_grid

#list of files after processing
ls -al ./mb59/*/*p.mb59 | awk '{print $9}' >! list_proc_grid

mbdatalist -I list_orig_grid -F-1 >! list_orig_grid_mb
mbdatalist -I list_proc_grid -F-1 >! list_proc_grid_mb_${month}-${day}

set lon1 = -79
set lon2 = -70
set lat1 = 31.75
set lat2 = 37.25

echo $lon1 $lon2 $lat1 $lat2

mbgrid -I list_orig_grid_mb -E100/100 -R$lon1/$lon2/$lat1/$lat2 -O
orig_100m -M -N
mbgrid -I list_proc_grid_mb_${month}-${day} -E100/100 -
R$lon1/$lon2/$lat1/$lat2 -O proc_100m_${month}-${day} -M -N

set zrange = `grdinfo proc_100m_${month}-${day}.grd -T10`
makecpt -Chaxby $zrange -V -I -Z >! haxby_temp.cpt

grdgradient proc_100m_${month}-${day}.grd -E150/40 -Ne0.3 -Gdxdy_proc.grd
grdgradient orig_100m.grd -E150/40 -Ne0.3 -Gdxdy_orig.grd

grdimage proc_100m_${month}-${day}.grd -R$lon1/$lon2/$lat1/$lat2 -JM5 -Xc
-Y8 -V -P -K \
-Bf0.05a.1/f0.05a.1WeNs -Chaxby_temp.cpt -Idxdy_proc.grd >! grid.ps

grdimage orig_100m.grd -R$lon1/$lon2/$lat1/$lat2 -JM5 -Y-5 -V -P -O -K \
-Bf0.05a.1/f0.05a.1wENs -Chaxby_temp.cpt -Idxdy_orig.grd >> grid.ps

#gs grid.ps
```

D. Towed Magnetometer Data

Acquisition:

We recovered total field magnetics data for the entire cruise except on transits to/from Norfolk and brief power downs for maintenance and streamer recovery. Data were acquired with the Geometrics G-882 Cesium Marine Magnetometer system of the *Langseth*. The G-882 magnetometer was towed 116 m behind the ship, or 145 m from the navigation position, from the center of gravity configuration, with the sensor oriented at 0° for the mid latitudes of the survey region. Data was acquired every 0.1 seconds running 24/7 when deployed, representing approximately 30 days of continuous data.

Processing of magnetics data:

We undertook shipboard processing of the magnetics data utilizing Perl v5.16.2 (© 1987-2012 Larry Wall), and MATLAB v8.1.0.604 ((© 1984-2013 The MathWorks, Inc.)
Example scripts are included in this appendix. Our basic onboard processing comprised the steps below:

- **Format conversion and reorganization:** A Perl script was used to obtain relevant information for the preliminary processing of the magnetics data. This included the magnetometer serial data output in ASCII text files, including time of acquisition and magnetic field intensity in nT. Global System Position Fix Data including time, longitude and latitude was collected from the *Langseth's* SEAPATH 200 Navigation System, which outputs data in NMEA sentence format $INGGA. Also, bathymetry data including time and depth to seafloor in meters was collected from the *Langseth's* multibeam/centerbeam from sentence format $KIDPT.

- **Filtering:** Preliminary filtering was accomplished using a MATLAB script to run a moving average filter with a 60 second window over the magnetic field intensity measurements. Periods of shut down and erroneous spikes (considered to be >10,000 nT and lasting up to a few seconds) were removed from the time record and replaced by NaN's. Improvements should be employed to provide a cleaner signal, as well as filtering the bathymetry data in the same fashion.

- **Plotting and comparison to grid data:** A MATLAB function was used to apply an IGRF correction to the filtered magnetic field intensity data, resulting in the local anomaly. A MATLAB function was used to compute the Haversine equation to convert longitude and latitude measurements to distances along the ship path in kilometers. The observed local anomaly was compared to the EMAG2: Earth Magnetic Anomaly Grid (2-arc minute resolution) (Maus et al., 2009).

Maus, S., U. Barckhausen, H. Berkenbosch, N. Bournas, J. Brozena, V. Childers, F. Dostaler, J. D. Fairhead, C. Finn, R. R. B. von Frese, C. Gaina, S. Golynsky, R. Kucks, H. Lühr, P. Milligan, S. Mogren, R. D. Müller, O. Olesen, M. Pilkington, R. Saltus, B. Schreckenberger, E. Thébault, and F. Caratori Tontini (2009), EMAG2: A 2–arc min resolution Earth Magnetic Anomaly Grid compiled from satellite, airborne, and marine magnetic measurements, Geochem. Geophys. Geosys., 10(8), Q08005, doi:08010.01029/02009GC002471.

organize272.pl: Script for converting formats and reorganizing data

```
#!/usr/local/bin/perl
#
use strict;
use warnings;

my $dir = "/Users/MattKarl/Desktop/JDay270";
foreach my $fp (glob("$dir/*")) {
    printf "%s\n", $fp;
    if ($fp =~ m/mag01/g){
        open my $fx, '+<', $fp or die $!;
        while(<$fx>) {
            $_ =~ s/:/ /g;
            $_ =~ s/,/ /g;
            my @inf = split(" ", $_);
            my $x = scalar(@inf);
            if ( $x =~ 10 ) {
                my $year = $inf[1];
                my $dd = $inf[2];
                my $hour = $inf[3];
                my $mm = $inf[4];
                my $ss = $inf[5];
                my $tf = $inf[7];
                my $signal = $inf[8];

                my $mtime =
($hour*3600)+($mm*60)+$ss;
                open(my $fs, '>>',
'Mag272.dat');
        printf $fs "%5.4f %s %s\n", $mtime,
$tf, $signal;
        close $fs;
            }
        }
        close $fx;
    }
    if ($fp =~ m/bath/g){
        open my $fx, '+<', $fp or die $!;
        while(<$fx>) {
            $_ =~ s/:/ /g;
            $_ =~ s/,/ /g;
            my @inf = split(" ", $_);
            my $x = scalar(@inf);
            if ( $x =~ 10 ) {
                my $year = $inf[1];
                my $dd = $inf[2];
                my $hour = $inf[3];
                my $mm = $inf[4];
                my $ss = $inf[5];
                my $bath = $inf[7];

                my $mtime =
($hour*3600)+($mm*60)+$ss;
                open(my $fs, '>>',
'bath272.dat');
        printf $fs "%5.4f %s\n", $mtime, $bath;
        close $fs;
            }
        }
        close $fx;
    }
    if ($fp =~ m/seapath/g){
        open my $fh, '+<', $fp or die $!;
        while( <$fh>) {
            $_ =~ s/:/ /g;
            $_ =~ s/,/ /g;
            if ($_ =~ m/INGGA/g) {
                my @dat = split(" ", $_);
                my $yr = $dat[1];

                my $day = $dat[2];
                my $hr = $dat[3];
                my $min = $dat[4];
                my $sec = $dat[5];
                my $lat = $dat[8];
                my $lon = $dat[10];

                $lon =~ s/^0+/-/g;
                $lon /= 100;
                $lat /= 100;

                my @lon_char = split(/\./,
$lon);
        my @lat_char = split(/\./, $lat);
                my $lon_deg =
$lon_char[0];
        my $lat_deg = $lat_char[0];
        my $lon_min = $lon_char[1];
        my $lat_min = $lat_char[1];

        my $lon_min_size =
length($lon_min);
                if ($lon_min_size == 1){

        substr($lon_min,1,0,'0');
                }

                my $lat_min_size =
length($lat_min);
                if ($lat_min_size == 1){

        substr($lat_min,1,0,'0');
                }

                substr($lon_min, 2, 0, '.');
                substr($lat_min, 2, 0, '.');
                $lon_min /= 60;
        $lat_min /= 60;
                my $longitude = $lon_deg-
$lon_min;
                my $latitude =
$lat_deg+$lat_min;

                my $time =
($hr*3600)+($min*60)+$sec;
                open(my $fy, '>>',
'Seapath272.dat');
                printf $fy "%5.4f %s
%s\n", $time, $longitude, $latitude;
                close $fy;
            }
        }
        close $fh;
    }
}
```

filter_JDay272_273: script for applying moving average filter

```
close all;
clear all;
%-----------------------------------------------------------------------
%Moving average filter
datmin = 601; % or 60s
coeffdatminMA = ones(1,datmin)/datmin;
fDelay = (length(coeffdatminMA)-1)/2;
%-----------------------------------------------------------------------
load('Mag272.dat');
magtime272 = Mag272(:,1);
magtf272 = Mag272(:,2);
signal272 = Mag272(:,3);

correctedtime272 = magtime272-fDelay/10;
avgminMag272 = filter(coeffdatminMA,1,magtf272);
% Need to account for filter delay (otherwise get ramp up)
magtime272f= correctedtime272(601:end);
magtf272f = avgminMag272(601:end);
%-----------------------------------------------------------------------
load('Mag273.dat');
magtime273 = Mag273(:,1);
magtf273 = Mag273(:,2);
signal273 = Mag273(:,3);

timefill273_1 = (magtime273(719575)+0.1:0.1:magtime273(722521))';
magfill273_1 = (ones(1,length(timefill273_1)).*nan)';
signalfill273_1 = (ones(1,length(timefill273_1)).*nan)';
timefill273_2 = (magtime273(735061)+0.1:0.1:magtime273(736812))';
magfill273_2 = (ones(1,length(timefill273_2)).*nan)';
signalfill273_2 = (ones(1,length(timefill273_2)).*nan)';

magtime273 = [magtime273(1:719575); timefill273_1; magtime273(722521:735061);
timefill273_2; magtime273(736812:end)];
magtf273 = [magtf273(1:719575); magfill273_1; magtf273(722521:735061); magfill273_2;
magtf273(736812:end)];
signal273 = [signal273(1:719575); signalfill273_1; signal273(722521:735061); signalfill273_2;
signal273(736812:end)];

correctedtime273 = magtime273-fDelay/10;
avgminMag273 = filter(coeffdatminMA,1,magtf273);
% Need to account for filter delay (otherwise get ramp up)
magtime273f= correctedtime273(601:end);
magtf273f = avgminMag273(601:end);
```

Linedata_JDay272_273: script to plot IGRF corrected magnetics along track

```
close all;
clear all;
%-------------------------------------------------------------------------
load('Seapath272.dat');
navtime272 = Seapath272(:,1);
lon272 = Seapath272(:,2);
lat272 = Seapath272(:,3);
load('Mag272f.dat');
magtime272=Mag272f(:,1);
magtf272=Mag272f(:,2);
load('bath272.dat');
bathtime272 = bath272(:,1);
bathy272 = bath272(:,2);
% find(lon272==-75.932758266666696) =78815
% find(navtime272<=magtime272(end),1,'last') =86374
magtf272nav = linterp(magtime272, magtf272, navtime272(78815:86374));
bathy272nav = linterp(bathtime272,bathy272,navtime272(78815:86374));
%-------------------------------------------------------------------------
load('Seapath273.dat');
navtime273 = Seapath273(:,1);
lon273 = Seapath273(:,2);
lat273 = Seapath273(:,3);
load('Mag273f.dat');
magtime273=Mag273f(:,1);
magtf273=Mag273f(:,2);
load('bath273.dat');
bathtime273 = bath273(:,1);
bathy273 = bath273(:,2);
% find(lon273==-74.504412833333305) =71785
% find(navtime273>=magtime273(1),1,'first') =31
magtf273nav_1 = linterp(magtime273, magtf273, navtime273(31:71785));
bathy273nav_1 = linterp(bathtime273,bathy273,navtime273(31:71785));
%-------------------------------------------------------------------------
longitude4a1=[lon272(78815:86374);lon273(31:71785)];
latitude4a1=[lat272(78815:86374); lat273(31:71785)];
track4a1=pos2track(longitude4a1,latitude4a1);

[Bx272,By272,Bz272] = igrf(735871,lat272(78815:86374),lon272(78815:86374),(bathy272nav./1000),'geodetic');
Total_intensity272 = hypot(Bx272, hypot(By272,Bz272));
[Bx273,By273,Bz273] = igrf(735872,lat273(31:71785),lon273(31:71785),(bathy273nav./1000),'geodetic');
Total_intensity273 = hypot(Bx273, hypot(By273,Bz273));
magnetic_anomaly4a1=[(magtf272nav-Total_intensity272);(magtf273nav-Total_intensity273)];
%-------------------------------------------------------------------------
load('emagJDay272_273.txt');
grdlon1 = emagJDay272_273(:,1);
grdlat1 = emagJDay272_273(:,2);
grdtf1 = emagJDay272_273(:,3);
trackgrd1=pos2track(grdlon1,grdlat1);
%-------------------------------------------------------------------------
figure(1)
plot(track4a1,magnetic_anomaly4a1);
hold on;
plot(trackgrd1, grdtf1,'r');
title('Langseth JDay272-273')
legend('observed','grid','Location','NorthWest')
xlabel('Distance Along Track (km)');
ylabel('Anomaly (nT)');
axis tight;
```

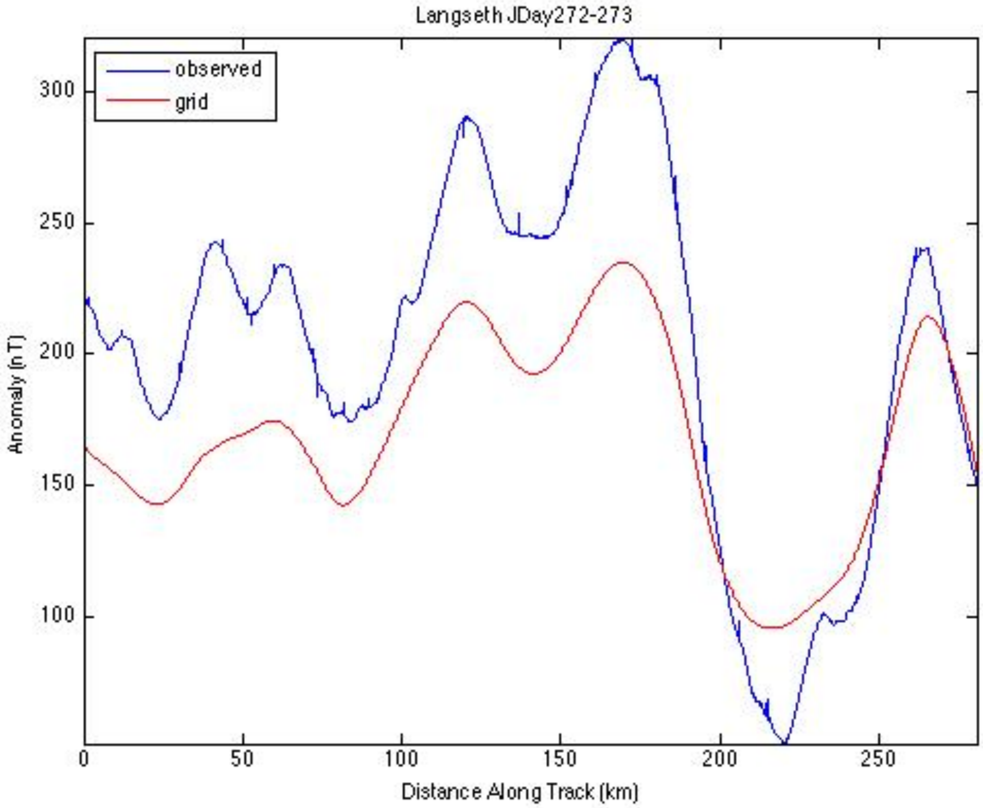


Figure D-1 Example output of linedata_JDay272_2

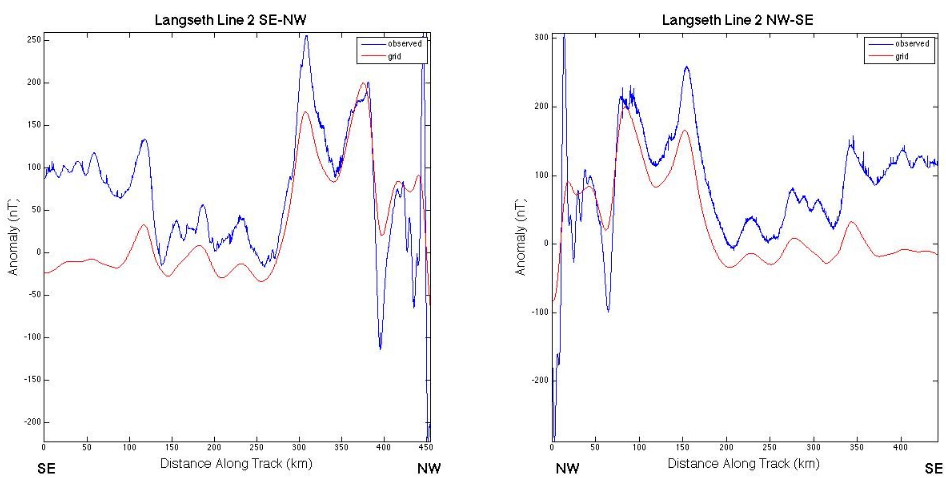


Figure D-2 Magnetic anomaly along line 2 (blue) compared to EMAG2 grid (red) (Maus et al. , 2009)

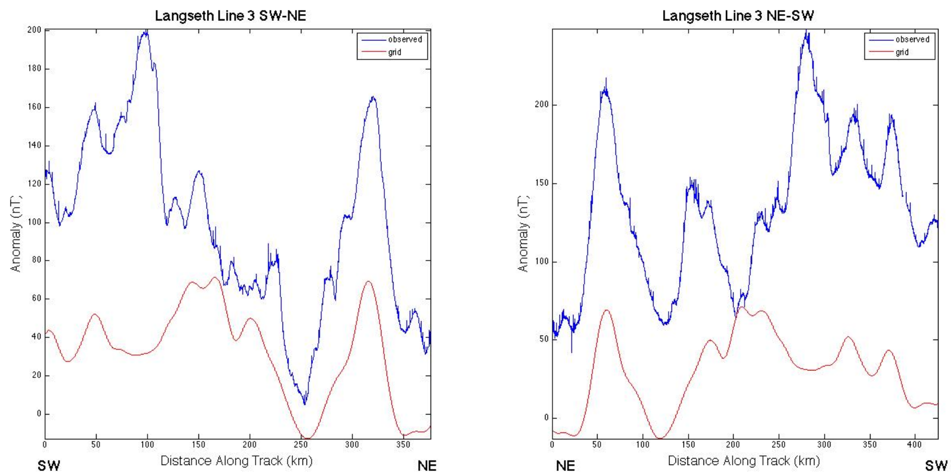


Figure D-3 Magnetic anomaly along line 3 (blue) compared to EMAG2 grid (red) (Maus et al. , 2009)

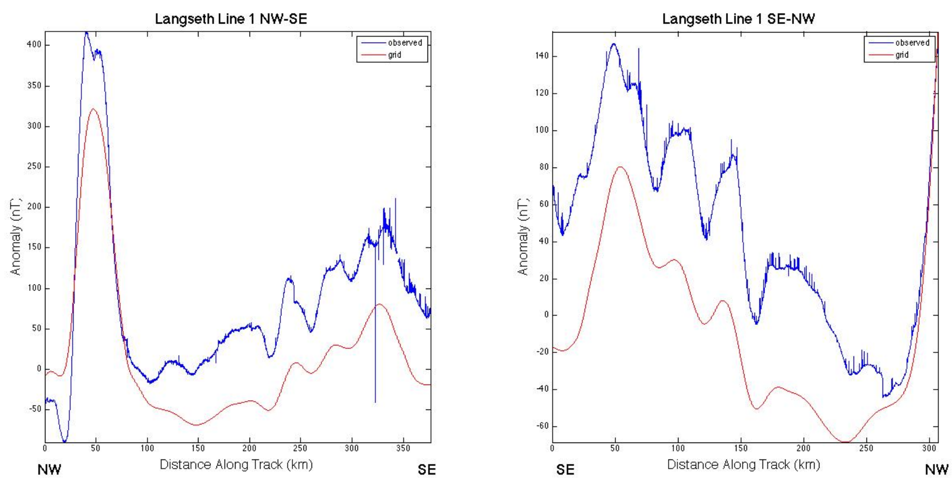


Figure D-4 Magnetic anomaly along line 1 (blue) compared to EMAG2 grid (red) (Maus et al. , 2009)

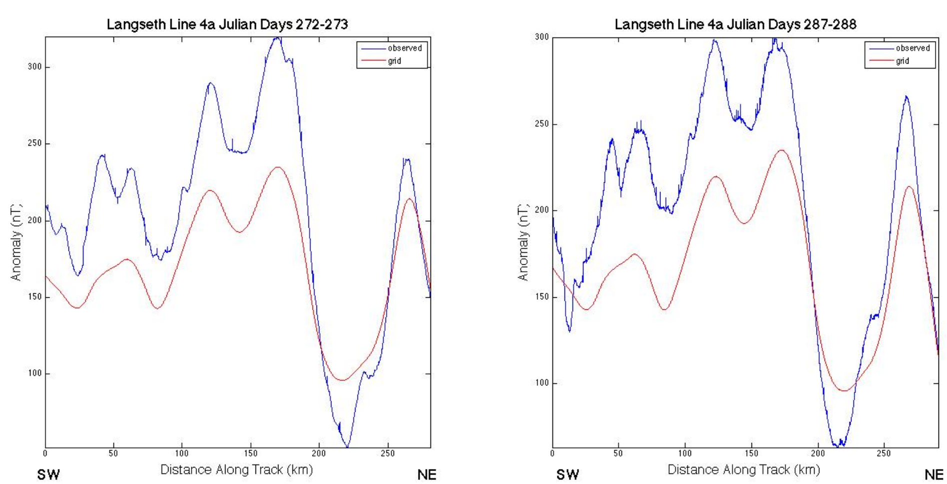


Figure D-5 Magnetic anomaly along line 4a (blue) compared to EMAG2 grid (red) (Maus et al. , 2009)

Appendix E. XBT Deployment

Scientific background on Seismic Oceanography

Earth's oceans exchange heat and gases with the atmosphere, thus having a significant effect on climate over a range of scales from local to global. However, ocean mixing - the way in which heat and material are distributed throughout the oceans - is poorly quantified and not well understood. To study ocean mixing phenomena, oceanographers typically use a combination of surface measurements, vertical profiles, towed and autonomous instruments that can take measurements either along one horizontal line or in a "tow-yo" sawtooth pattern, and high frequency (100 kHz to 1 MHz) sonar methods that can be used to map internal waves at shallow depths. These methods leave a large portion of the ocean under-sampled both laterally and vertically, thus providing motivation to find new ways of mapping oceanic fine structure resulting from salinity and temperature contrasts.

Recently, a new method for studying the ocean has emerged called seismic oceanography that has the potential to provide a means of investigating ocean mixing and related phenomena in 2-D (Holbrook et al., 2003) and to a limited extent in 3-D (Blacic and Holbrook, 2010). In seismic oceanography (SO), marine seismic data normally used for imaging structures below the seafloor are instead processed to focus on reflections in the water, which have been shown to arise from abrupt temperature variations as small as 0.03°C with depth (Nandi et al, 2004). It has thus been suggested that stacked seismic images of the ocean can be thought of as maps of the vertical derivative of temperature smoothed by convolution with the seismic source wavelet (Ruddick et al., 2009). Although the processed seismic images obtained can be intrinsically revealing of ocean structure, recent efforts in SO have been increasingly focused on obtaining quantitative measurements of ocean properties. This is greatly facilitated by having temperature-depth profiles (via expendable bathythermograph or conductivity-temperature-depth probes, XBTs and XCTDs, respectively) collected coincident with the MCS data to provide "ground truth" measurements for the seismic traces.

In the region of the North Atlantic off the coast of Cape Hatteras, North Carolina, the Gulf Stream western boundary current turns north-eastward away from the coast and meets cooler Labrador Sea water. Some degree of mixing occurs where these two water bodies of different temperature and salinity meet. Surface evidence of mixing can be seen in sea surface temperature (SST) images derived from satellite observations as seen in Figure E-1 below. Several MCS lines crossed the boundary between the Gulf Stream and Labrador Sea water. Combining the seismic data with hydrographic measurements from XBT and XCTD probes will allow imaging and verification of mesoscale mixing processes below the ocean surface at this important junction where the Gulf Stream leaves the coast to form the Gulf Stream Extension.

Blacic, T. M. and W. S. Holbrook (2010), First images and orientation of fine structure from a 3-D seismic oceanography data set, *Ocean Science*, *6*, 431-439.

Holbrook, W. S., P. Paramo, S. Pearse, and R. W. Schmitt (2003), Thermohaline fine structure in an oceanographic front from seismic reflection profiling, *Science*, *301*, 821-824.

Nandi, P., W. S. Holbrook, S. Pearse, P. Paramo, and R. W. Schmitt (2004), Seismic reflection imaging of water mass boundaries in the Norwegian Sea, *Geophys. Res. Lett*., *31*, L23311, doi:10.1029/2204GL021325.

Ruddick, B., H. Song, C. Dong, and L. Pinheiro (2009), Water Column Seismic Images as Maps of Temperature Gradient, *Oceanography*, 22(1), 192-205.

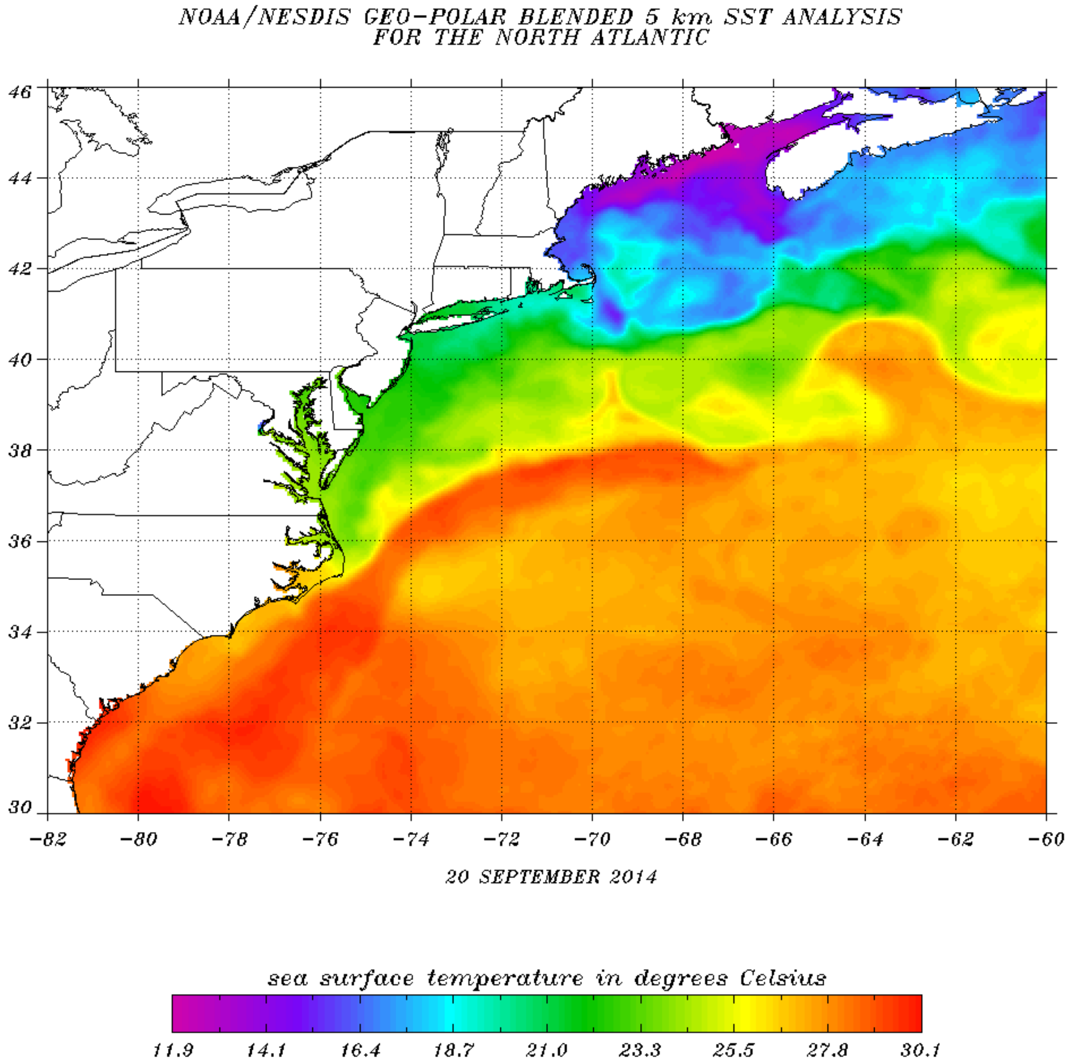


Figure E-1: *Sea surface temperature plot for September 20, 2014, from satellite observations (http://www.ospo.noaa.gov/).*

Acquisition of XBT data:

Expendable bathythermographs (XBTs) were deployed on most of the MCS lines in order to provide "ground truth" measurements of temperature with water depth for seismic oceanography applications. 149 XBTs and 4 XCTDs (expendable conductivity-temperature-depth probes) were deployed with spacing in the range of ~7-40 km (see Table E-2 and Fig. E-2). The 4 XCTDs and

116 of the XBTs belonged to the University of Wyoming and were left over from a previous cruise; permission to use the probes for the ENAM CSE was given by Prof. Steven Holbrook of UWYO. The other 33 XBTs were allotted for MGL1408 by UNOLS.

The purpose of the relatively dense XBT deployment was to expand the applications of the ENAM MCS data to study physical oceanographic processes at the front between the warm Gulf Stream western boundary current and colder North Atlantic water. Several of the MCS lines crossed this front providing the opportunity to image oceanic fine structure associated with the interaction of two different water masses. Standard MCS data has been shown to be well-tuned to image ocean fine structure resulting from abrupt vertical changes in temperature and salinity in the ocean. Thus, the same seismic data that is collected to investigate the sub-seafloor geology can also be processed to image reflections in the water that reveal ocean processes with a horizontal resolution unheard of in oceanography. The XBTs deployed during the MCS data collection will allow for hydrographic verification of features observed in the seismic images.

Table E-2 contains the line, sequence and shot numbers corresponding to each XBT cast. The probes were launched using either the port or starboard-side launching tubes on the streamer deck. Approximately ten shots before each cast, two science party members would take a radio and a probe out onto the streamer deck and load the probe into the launching gun. Once in position, they waited until receiving the go-ahead to launch from a crew member in the lab. When the probe passed its maximum depth, determined by large excursions in the recorded data profile, the command to terminate the probe was given from the lab. Science party members on the deck would terminate the probe by breaking the transmission wire and removing the canister from the launching gun.

Distribution of probes among the MCS lines was determined as the cruise progressed and modified to account for extra probes launched when there was a failure. Final counts for each MCS line included failures and are shown in Table E-1 with approximate probe spacing. Probes were concentrated on the longer lines (Line1, 2, 4a and 4b) that were judged to be most likely to cross the Gulf Stream front, using sea surface temperature maps generated by NOAA for reference (http://www.ospo.noaa.gov/data/sst/contour/natlanti.cf.gif; see Fig. E-1). An example plot of edited temperature-depth profiles for Line 4b is shown in Fig. E-3. Variable spacing was used for line MCS33-34. Probe spacing started at ~20 km at the seaward end of the line and decreased as the shelf was approached. The last seven probes were spaced 6.875 km apart to achieve better resolution of the changes in the temperature-depth profile as depth decreased on the continental slope. This was done in order to help assess changes in methane hydrate stability across the continental slope.

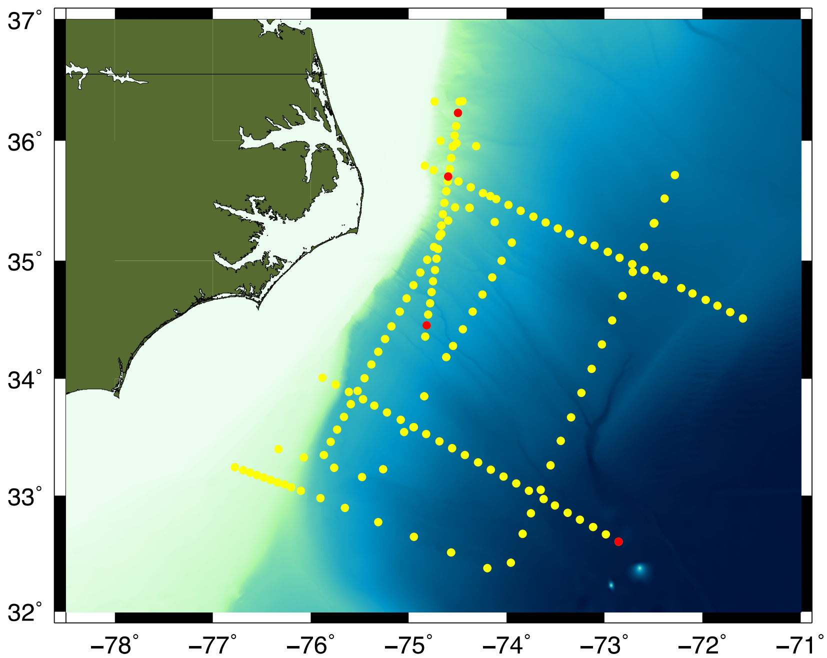


Figure E.2: *Map showing locations of XBT (yellow dots) and XCTD (red dots) casts.*

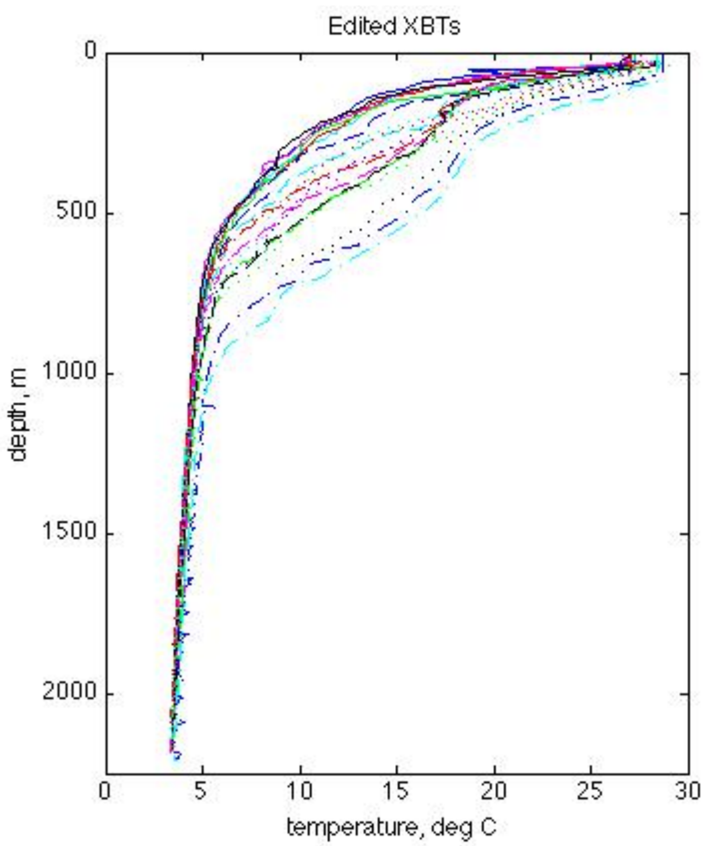


Figure E.3: *XBT temperature-depth profiles for Line 4b. Profiles have been edited to remove large excursions occurring at the end of the recordings.*

Table E.1: XBT Deployment

Line	XBTs	XCTDs	Spacing (km)
1	26	1	12.9
2	24	1	14.5
3	16		24.7
4a	20		13.8
4b	21	2	10.5
MCS31	2		30
MCS32	4		38
MCS33-34	12		variable
MCS41	3		22.5
MCS42	7		18.6
MCS52	4		17
MCS58	2		20
MCS62	4		40.5
MCS63	4		28

Table E.2 XBT Casts

Line	Sequence	Shot	Notes
Line1 MCS	71	1130	
	72	1385	
	73	1640	
	74	1895	
	75	2150	
	76	2405	
	77	2773	
	78	2909	
	79	3164	
	80	3425	
	81	3687	
	82	3944	
	83	4205	
	84	4444	
	85	4721	
	86	4955	
	87	5209	
	88	5466	

	89	5720	
	90	5975	
	91	6227	
	92	6349	
	93	6491	
	94	6763	
	95	6949	
	96	7212	XCTD
	97	7506	
Line2 MCS	1	3140	
	3	3420	
	4	3700	
	5	3980	
	6	4260	
	7	4540	
	8	4820	
	9	5100	
	10	5100	
	11	5380	
	12	5660	
	13	5940	
	14	6220	
	15	6500	
	16	6780	
	17	7060	
	18	7340	
	19	7620	
	20	7900	
	21	8180	
	22	8460	
	23	8740	
	24	9020	
	25	9300	
	26	9580	XCTD
Line3 MCS	27	1268	
	28	1745	
	29	2245	failed
	30	2250	
	31	2722	
	32	3234	
	33	3719	
	34	4217	
	35	4710	

	36	5208	
	37	5703	
	38	6200	
	38	6690	
	40	7196	
	41	7685	
	42	8180	
Line4a MCS	134	1116	
	135	1338	
	136	1551	
	137	1771	
	138	1989	
	138	2211	
	140	2432	
	141	2662	
	142	2878	
	143	3100	
	144	3311	
	145	3138	
	146	3323	
	147	3508	
	148	3686	
	149	3869	
	150	4051	
	151	4236	
	152	4422	
	153	4605	
Line4b MCS	104	1112	
	105	1320	XCTD
	106	1570	2 - 1st did not work
	107	1743	
	108	1948	
	109	2179	
	110	2378	
	111	2595	
	112	2784	
	113	3000	
	114	3210	
	115	3421	
	116	3630	
	117	3863	
	118	4052	
	119	4258	

	120	4470	
	121	4679	
	122	4889	
	123	5100	
	124	5310	XCTD
	125	5525	
MCS 31	43	1300	
	44	1900	
MCS 32	45	1380	
	46	2140	
	47	2900	
	48	3660	
MCS 33	49	1603	
	50	2605	
MCS 34	51	1598	
	52	1997	
	53	2274	
	54	2549	
	55	2822	
	56	3099	
	57	3372	
	58	3649	
	59	3927	
MCS 41	61	1229	
	62	1237	
	63	1771	
MCS 42	64	1181	
	65	1570	
	66	1923	
	67	2295	
	68	2665	
	69	3037	
	70	3408	
MCS 52	98	2030	
	99	2030	
	100	2620	
	101	3359	
MCS 58	102	1765	
	103	2800	
MCS 62	126	1410	
	127	2249	
	128	3030	failed, no 2^{nd} launch

	129	3840
MCS 63	130	1284
	131	1839
	132	3898
	133	4925

F. Information on Underway Data

This appendix provides information on the format of the following underway data files:

- Bridge FE700 Navigational Echosounder
- CNAV GPS receiver data
- CNAV 3050 GPS receiver data
- EM122 Center Beam Depth
- Geometrics 882 Magnetometer Data
- Gravimeter data
- Gyroscope data
- OBSIP shotlog format
- PCO2 system
- Position and Orientation System for Marine Vessels (POS/MV)
- RM Young Meterological Station Data
- Seabird SBE-45 Thermosalinograph Data
- Seabird SB38 Thermometer Data
- Seapath 200 Interial Navigational System
- Spectrum TM-4 time and frequency system data
- Speed log data
- Streamer Tension data

FE700 Navigational Echosounder data

The FE700 Navigational Echosounder outputs data in the following formats

- $PFEC - unspecified
- $SDDBT - Depth Below Transducer
- $SDDBS - Depth Below Surface

$PFEC ,aaaa,x,x*hF

PFEC sentence format

Item	Definition	Units
aaaa	unspecified	unspecified
x	unspecified	unspecified
x	unspecified	unspecified
*hF	unspecified	unspecified

$DBT,x.x,f,x.x,M,x.x,F*hh

SDDBT sentence format

Item	Definition	Units
x.x	Water depth	feet
f	f = feet	n/a
x.x	Water depth	meters
M	M = meters	n/a
x.x	Water depth	fathoms
F	F = fathoms	n/a
*hh	Checksum	n/a

$DBS,x.x,f,x.x,M,x.x,F*hh

SDDBS sentence format

Item	Definition	Units
x.x	Water depth	feet
f	f = feet	n/a
x.x	Water depth	meters
M	M = meters	n/a
x.x	Water depth	fathoms
F	F = fathoms	n/a
*hh	Checksum	n/a

CNAV GPS receiver data

CNAV outputs data in NMEA 0183 compatible format. Currently* the following sentence types are enabled:

- $GPVTG-GPS Velocity, Track made good and Ground speed data (computed by the CNAV GPS receiver).
- $GPGGA-Gobal Positioning System Fix data (computed by the CNAV GPS receiver).

  *Note: there are other sentence types available from CNAV. Please consult the software manual for more options.

$GPVTG, xxx.x, T,, M, m.mm, N, n.nn, K*hh

$GPVTG Sentence Fields

Item	Definition	Units
xxx.x	Course over ground (COG)	Degrees from True North
T	Indicates course relative to True North	n/a
M	COG	Degrees from Magnetic North
m.mm	Speed over ground (SOG)	Nautical miles per hour (knots)
N	Indicates that the speed over ground is in knots	n/a
n.nn	SOG	km/h
K	Indicates that the SOG is in km/h	n/a /td>
*hh	Checksum (hexadecimal representation)	n/a

$GPGGA,hhmmss.ss, ddmm.mmmmm, a, ddmm.mmmmm, a, x, xx, x.x, xx.xx, M, xx.xx, M, x.x, xyy*hh

$GPGGA Sentence Fields

Item	Definition	Units
hhmms.ss	UTC time of position	Hours/Minutes/Seconds.decimal.
ddmm.mmmmm	Latitude	Degrees/Minutes.decimal.
a	Direction of Latitude N = North S = South	n/a
ddmm.mmmmm	Longitude	Degrees/Minutes.decimal
a	Direction of Longitude E = East	n/a

	W = West	
x	GPS Quality indicator 0 = fix not valid 1 = GPS Autonomous fix 2 = GcGPS Corrected Fix	n/a
xx	Number of GPS satellites used in solution fix	n/a
x.x	Horizontal Dilution of Precision (HDOP)	n/a
xx.xx	C-NAV GPS receiver antenna altitude reference to Mean Sea Level (MSL)	n/a
M	Altitude units--M indicates meters	n/a
xx.xx	WGS-84 Geoidal separation distance from MSL based on the NIMA/NASA EGM96 15-minute (Earth Gravity Model)	Meters
M	Geosoidal separation units--M indicates meters	n/a
x.x	Age of GcGPS corrections used in solution fix	n/a
xyy	C-NAV GPS receiver reference identification	x is downlink satellite communication beam in use yy is the GPS correction signal mode/type being used
*hh	Checksum (hexadecimal representation) followed by CRLF terminator pair	n/a

CNAV 3050 GPS receiver data

CNAV 3050 outputs data in NMEA 0183 compatible format. Currently* the following sentence types are enabled:

- $GPVTG-GPS Velocity, Track made good and Ground speed data (computed by the CNAV GPS receiver).
- $GPGGA-Gobal Positioning System Fix data (computed by the CNAV GPS receiver).

  *Note: there are other sentence types available from CNAV. Please consult the software manual for more options.

$GPVTG, xxx.x, T,, M, m.mm, N, n.nn, K*hh

$GPVTG Sentence Fields

Item	Definition	Units
xxx.x	Course over ground (COG)	Degrees from True North
T	Indicates course relative to True North	n/a
M	COG	Degrees from Magnetic North
m.mm	Speed over ground (SOG)	Nautical miles per hour (knots)
N	Indicates that the speed over ground is in knots	n/a
n.nn	SOG	km/h
K	Indicates that the SOG is in km/h	n/a /td>
*hh	Checksum (hexadecimal representation)	n/a

$GPGGA,hhmmss.ss, ddmm.mmmmm, a, ddmm.mmmmm, a, x, xx, x.x, xx.xx, M, xx.xx, M, x.x, xyy*hh

$GPGGA Sentence Fields

Item	Definition	Units
hhmms.ss	UTC time of position	Hours/Minutes/Seconds.decimal.
ddmm.mmmmm	Latitude	Degrees/Minutes.decimal.
a	Direction of Latitude N = North S = South	n/a
ddmm.mmmmm	Longitude	Degrees/Minutes.decimal
a	Direction of Longitude E = East	n/a

	W = West	
x	GPS Quality indicator 0 = fix not valid 1 = GPS Autonomous fix 2 = GcGPS Corrected Fix	n/a
xx	Number of GPS satellites used in solution fix	n/a
x.x	Horizontal Dilution of Precision (HDOP)	n/a
xx.xx	C-NAV GPS receiver antenna altitude reference to Mean Sea Level (MSL)	n/a
M	Altitude units--M indicates meters	n/a
xx.xx	WGS-84 Geoidal separation distance from MSL based on the NIMA/NASA EGM96 15-minute (Earth Gravity Model)	Meters
M	Geosoidal separation units--M indicates meters	n/a
x.x	Age of GcGPS corrections used in solution fix	n/a
xyy	C-NAV GPS receiver reference identification	x is downlink satellite communication beam in use yy is the GPS correction signal mode/type being used
*hh	Checksum (hexadecimal representation) followed by CRLF terminator pair	n/a

EM122 Center Beam Depth

This page describes the EM122 centerbeam depth serial output, used for real-time depth display. For fulll multibeam data, please see the multibeam page.

The EM122 outputs serial data in the following formats:

- KGDPT - Depth below transducer

$DBT,x.x,f,x.x,M,x.x,F*hh

SDDBT sentence format

Item	Definition	Units
x.x	Water depth	feet
f	f = feet	n/a
x.x	Water depth	meters
M	M = meters	n/a
x.x	Water depth	fathoms
F	F = fathoms	n/a
*hh	Checksum	n/a

Geometrics 882 Magnetometer Data

The magnetometer serial data is output in the following format:

$ 53863.927,0652

$ xxxxx.xxx,vvvv

Item	Definition	Units
xxxxx.xxx	Magnetic field intensity	nT
vvvv	Reserved for future use	n/a

Gravimeter data

The gravimeter serial data is output in the following format:

`01:025610 01`

`01:xxxxxx ff`

Item	Definition	Units
01	output frequency	Hz
xxxxxx	raw counts	n/a
ff	sensor status	n/a

Gyroscope data

The gyroscope serial data is output in the following sentence formats:

- PTKM,HEALM -- Unspecified
- HEHDT -- Heading - True
- HEROT -- Rate Of Turn

$PCICM,HEALM,xxxx,x,xx*hh

ALM sentence format

Item	Definition	Units
xxxx	unspecified	n/a
x	unspecified	n/a
*hh	unspecified	n/a

$HEHDT,xxx.x,T*hh

HDT sentence format

Item	Definition	Units
xxx.x	Heading true	degrees
T	T = true	n/a
*hh	Checksum	n/a

$HEROT,-xxx.x,A*hh

HEROT sentence format

Item	Definition	Units
xxxx.x	Rate of turn	Degrees per minute, Note: "-" means bow turns to port
A	A = data valid	n/a
*hh	Checksum	n/a

OBSIP Shotlog Format

Each OBSIP shotlog contains a header followed by shot records:

```
#obsipshotfile v1.0
#shotnumber date time sourceLat sourceLon shipLat shipLon waterDepth sciTag
0001280 2009-08-27 05:08:49.807873  48.495334 -129.201444  48.494097 -129.203017 2530.6 MGL0910_05
0001279 2009-08-27 05:12:33.961869  48.491860 -129.204474  48.490060 -129.205425 2526.4 MGL0910_05
0001278 2009-08-27 05:16:36.302883  48.488608 -129.206115  48.486807 -129.206944 2530.3 MGL0910_05
0001277 2009-08-27 05:19:51.053880  48.485157 -129.209212  48.483406 -129.209755 2526.1 MGL0910_05
0001276 2009-08-27 05:24:01.863875  48.480813 -129.212088  48.479293 -129.213152 2516.1 MGL0910_05
```

Shot records are in the following format:

```
0001276 2009-08-27 05:24:01.863875  48.480813 -129.212088  48.479293 -129.213152 2516.1 MGL0910_05
sssssss yyyy-mm-dd hh:mm:ss.ssssss  xx.xxxxxx  yyy.yyyyyy  vv.vvvvvv  www.wwwwww dddd.d llllllllllllllll
```

OBSIP record format

Item	Definition	Units
sssssss	shot number	n/a
yyyy-mm-dd	date	ISO8601 format
hh:mm:ss.ssssss	time	ISO8601 format
xx.xxxxxx	source lat	degrees, WGS84
yy.yyyyyy	source lon	degrees, WGS84
vv.vvvvvv	vessel lat	degrees, WGS84
ww.wwwwww	vessel lon	degrees, WGS84
dddd.d	depth	meters
lllllllllllllll	linename	n/a

LDEO PCO2 System

PCO2 outputs data in the following sentence format:

yyyyjjj.jjj aaaa.aa bb.bb cccc.cc ddd.dd e.ee fff.f gggg.gg hh i k

PCO2 Data

Item	Definition	Value	Units
yyyyjjj.jjj	pco2 Computer Date/Time	n/a	Year/Julian Day.decimal Four fixed digits of year. Three fixed digits of julian day. Five fixed digits for decimal fractions of a julian day.
aaaa.aa	CO2 Raw Signal	n/a	mVolts
bb.bb	CO2 Analyzer Cell Temperature	n/a	Celcius
cccc.cc	PCO2 Barometer	n/a	mbar
ddd.dd	VCO2	n/a	ppm
e.ee	Equilibrator Water Temp	n/a	Celcius
fff.f	pCO2	n/a	uatm
gggg.gg	Flow Controller	n/a	mVolts
hh	Flow Meter	n/a	cc/min
i	Sample ID #	0 to 16	integer
k	Sample ID	Equil, Atmos, Nitrogen, CC18798, CA07163, CC15551, or CC63668	alphanumeric

LDEO PCO2 + CNav + TSG + WX01 + SBE38 Systems

PCO2 merge is a combination of outputs of various serial data in the following sentence format:

yyyyjjj.jjj aaaa.aa bb.bb cccc.cc ddd.dd e.ee fff.f gggg.gg hh i k, llll.llllllm, nnnnn.nnnnnno, pp.pppp, q.qqqqq, rr.rrrr, ss.s, ttt, uu.u, vvvv, w.ww, xxx.x, yy.yyyy

PCO2 Data

Item	Definition	Value	Units
yyyyjjj.jjj	pco2 Computer Date/Time	n/a	Year/Julian Day.decimal Four fixed digits of year. Three fixed digits of julian day. Five fixed digits for decimal fractions of a julian day.
aaaa.aa	CO2 Raw Signal	n/a	mVolts
bb.bb	CO2 Analyzer Cell Temperature	n/a	Celcius
cccc.cc	PCO2 Barometer	n/a	mbar
ddd.dd	VCO2	n/a	ppm
e.ee	Equilibrator Water Temp	n/a	Celcius
fff.f	pCO2	n/a	uatm
gggg.gg	Flow Controller	n/a	mVolts
hh	Flow Meter	n/a	cc/min
i	Sample ID #	0 to 16	integer
k	Sample ID	Equil, Atmos, Nitrogen, CC18798, CA07163, CC15551, or CC63668	alphanumeric
llll.llllllm	CNav Latitude	0 to 90, N/S	degrees/minutes.decimal/direction
nnnnn.nnnnnno	CNav Longitude	0 to 180, E/W	degrees/minutes.decimal/direction
pp.pppp	TSG Internal Temperature	n/a	Celcius
q.qqqqq	TSG Conductivity	n/a	S/m
rr.rrrr	TSG Salinity	25 to 40	ppm
ss.s	WX01 Bird 1 Wind Speed 60 sec avg	n/a	knots
ttt	WX01 Bird 1 Wind Direction 60 sec avg	0 to 360	degrees
	WX01 Temperature		

uu.u	Instantaneous	n/a	Celcius
vvvv	WX01 Ship Barometer Instantaneous	n/a	mbar
w.ww	CNav Speed Over Ground / Speed Made Good	0 to 15	knots
xxx.x	CNav Course Made Good	0 to 360	degrees
yy.yyyy	SBE38 Temperature Probe	n/a	Celcius

POS/MV Position and Orientation System for Marine Vessels

POS/MV outputs data using the NMEA 0183 format at rates of up to fifty sentences per second. The following seven different sentence formats are available.

- 1. $INGGA-Global System Position Fix Data
- 2. $INHDT-Heading - True data
- 3. $INVTG-Course over ground and Ground speed data
- 4. $INGST-GPS pseudorange noise statistics
- 6. $PRDID-Attitude data
- 7. $INZDA-Time and date

$INGGA, hhmmss.sss, llll.lllll, a, yyyyy.yyyyy, b, t, nn, v.v, x.x, M,,,c.c,rrrr*hh

$INGGA-Global System Position Fix Data

Item	Definition	Value	Units
$INGGA	Header	$INGGA	
hhmmss.sss	UTC time of position	n/a	Hours/Minutes/Seconds.decimal. Two fixed digits of hours. Two fixed digits of minutes. Two fixed digits of seconds. Three digits for decimal fractions of a second.
llll.lllll	Latitude	-90 to +90	DegreeslMinutes.decimal. Two fixed digits of degrees Two fixed digits of minutes Five digits for decimal minutes.
a	N (north) or S (south)	N or S	
yyyyy.yyyyy	Longitude	-180 to +180	Degrees/Minutes.decimal. Three fixed digits of degrees. Two fixed digits of minutes. Five digits for decimal minutes.
b	E (east) or W (west)	E or W	
		0 = Fix not available or	

t	GPS Quality Indicator	invalid 1 = CIA standard GPS; fix valid. 2 = DGS mode; fix valid. 3 = PPP mode; fix valid. 4 = RTK fixed 5 = RTK float 6 = free inertial	
nn	Number of satellites used in fix	0 to 32	
v.v	Horizontal dilution of precision		
x.x	Altitude of the IMU above or below the mean sea level. A negative value indicates below sea level.	n/a	Metres
M	Units of measure = metres	M	
Null	Null		
Null	Null		
c.c	Age of differential corrections in records since last RTCM-104 message.	0 to 99.9	Seconds
rrr	DGPS reference station identity	0000 to 1023	
*hh	Checksum	00 - FF	
/CR/LF	Carriage return and line feed	/CR/LF	

Note that, in the case of the HDOP, IMU altitude and age of differential connections, POS/MV adds leading digits as required (i.e. if the value exceeds 9.9). Also, note that commas separate all items, including null fields. The information is valid at the location of the vessel frame.

$INHDT, x.x, T*hh

$INHDT-Heading - True data

Item	Definition	Value	Units
$INHDT	Header	$INHDT	
x.x	True vessel heading in the vessel frame	o to 359.99	degrees
*hh	Checksum	n/a	
/CR/LF	Carriage return and line feed	/CR/LF	

$INVTG, x.x, T,, M, n.n, N, k.k, K*hh

$INVTG-Course over ground and Ground speed data

Item	Definition	Value	Units
%INVTG	Header	$INVTG	
x.x	True vessel track in the vessel frame	0 to 359.99	degrees
T	True	T	
null	Not supported	null	
M		M	
n.n	Speed in the vessel frame	n/a	Knots
N	Knots	N	
k.k	Kilometres	K	
*hh	Checksum	n/a	
/CR/LF	Carriage return and line feed	/CR/LF	

Note that, in the case of the track and the speed fields, POS/MV adds the leading digits as required (i.e. if the value exceeds 9.9). ALso, note that commas separate all items in the including null fields.

$INGST, hhmmss,sss,,smjr.smjr,smnr.smnr, o.o, l.l, y.y, a.a *hh

$INGST-GPS pseudorange noise statistics

Item	Definition	Value	Units
$INGST	Header	$INGST	
hhmmss.sss	UTC time of position	n/a	Hours/Minutes/Seconds.decimal. 2 fixed digits of hours. 2 fixed digits of minutes. 2 fixed digits of seconds. Three digits for decimal fractions of a second.
null	Not supported	null	
smjr.smjr	Standard Deviation of semi-major axis of error ellipse	n/a	Metres
smnr.smnr	Standard deviation of semi-minor axis of error ellipse	n/a	Metres
o.o	Orientaion of semi-major axis ellipse	0 to 359.9	Degrees from true north

l.l	Standard deviation of latitude	n/a	Metres
y.y	Standard deviation of longitude	n/a	Metres
a.a	Standard deviation of Altitude	n/a	Metres
*hh	Checksum	n/a	
/CR/LF	Carriage return and line feed	/CR/LF	

Note that, in the case of all fields POS/MV adds leading digits as required (i.e. if the value exceeds 9.9). Also, note that commas separate all items, including null fields. The information is valid at the location of the vessel frame.

Note that commas separate all items

Two attitude data strings are available. The strings are identical except for the definition of roll and pitch angles. One string uses Tate-Bryant angles and the

other uses TSS angles. Use the POS/MV Controller program to set the required angle convention.

$PRDID, PPP.PP, RRR.RR, xxx.xx*hh

$PRDID-Attitude data

Item	Definition	Value	Units
$PRDID	Header	$PRDID	
PPP.PP	Pitch	-90.00 to +90.00	Degrees
RRR.RR	Roll	-90.00 to +90.00	Degrees
xxx.xx	Sensor heading	0 to 359.99	Degrees
*hh	Checksum	n/a	
/CR/LF	Carriage return and line feed	/CR/LF	

Note that commas separate all items

Two attitude data strings are available. The strings are identical except for the definition of roll and pitch angles. One string uses Tate-Bryant angles and the

other uses TSS angles. Use the POS/MV Controller program to set the required angle convention.

$INZDA, hhmmss.ss, DD, MM, YYYY,, *hh

$INZDA-Time and date

Item	Definition	Value	Units
$INZDA	Header	$INZDA	
			Hours/Minutes/Seconds.decimal.

hhmmss.sss	UTC time	n/a	2 fixed digits of hours 2 fixed digits of minutes 2 fixed digits of seconds Three digits for decimal fractions of a second
DD	Day of month	01 to 31	
MM	Month of year	01 to 12	
YYYY	Year		
Null	Null		
Null	Null		
*hh	Checksum	n/a	/CR/LF

RM Young Meteorological Station Data

The meteorological data from the RMYoung integrated weather station is output in the following sentence format:

```
 12.6  13.2  12.6  16.9   1 335   2   0.0   0.0   0.0   0.0 355 355   0 -11.9 -23.8 *****   7.3  8  4  9 1006.9
aaa.a bbb.b ccc.c  dd.d eee fff ggg hhh.h iii.i jjj.j kkk.k lll mmm nnn -oo.o -pp.p -qq.q -rr.r ss tt uu vvvv.v
```

Langseth WX station sentence format

Item	Definition	Units
aaa.a	bird 1 speed, instantaneous	knots
bbb.b	bird 1 speed, 60 second average	knots
ccc.c	bird 1 speed, 60 minute average	knots
ddd.d	bird 1 speed, 60 second peak	knots
eee	bird 1 direction, instantaneous	knots
fff	bird 1 direction, 60 second average	knots
ggg	bird 1 direction, 60 minute average	knots
hhh.h	bird 2 speed, instantaneous	knots
iii.i	bird 2 speed, 60 second average	knots
jjj.j	bird 2 speed, 60 minute average	knots
kkk.k	bird 2 speed, 60 second peak	knots
lll	bird 2 direction, instantaneous	knots
mmm	bird 2 direction, 60 second average	knots
nnn	bird 2 direction, 60 minute average	knots
ooo.o	temperature, instantaneous	Degrees C
ppp.p	temperature, 60 minute average	Degrees C
qqq.q	temperature, 60 minute low	Degrees C
rrr.r	temperature, 60 minute high	Degrees C
ss	relative humidity, instantaneous	%
tt	relative humidity, 60 minute low	%
uu	relative humidity, 60 minute high	%
vvvv.v	Baromoeter, instantaneous	knots

RM Young Meteorological Station Data

The meteorological data from the RMYoung integrated weather station is output in the following sentence format:

```
 12.6  13.2  12.6  16.9   1 335   2   0.0   0.0   0.0   0.0 355 355   0 -11.9 -23.8 *****   7.3  8  4  9 1006.9
aaa.a bbb.b ccc.c  dd.d eee fff ggg hhh.h iii.i jjj.j kkk.k lll mmm nnn -oo.o -pp.p -qq.q -rr.r ss tt uu vvvv.v
```

Langseth WX station sentence format

Item	Definition	Units
aaa.a	bird 1 speed, instantaneous	knots
bbb.b	bird 1 speed, 60 second average	knots
ccc.c	bird 1 speed, 60 minute average	knots
ddd.d	bird 1 speed, 60 second peak	knots
eee	bird 1 direction, instantaneous	knots
fff	bird 1 direction, 60 second average	knots
ggg	bird 1 direction, 60 minute average	knots
hhh.h	bird 2 speed, instantaneous	knots
iii.i	bird 2 speed, 60 second average	knots
jjj.j	bird 2 speed, 60 minute average	knots
kkk.k	bird 2 speed, 60 second peak	knots
lll	bird 2 direction, instantaneous	knots
mmm	bird 2 direction, 60 second average	knots
nnn	bird 2 direction, 60 minute average	knots
ooo.o	temperature, instantaneous	Degrees C
ppp.p	temperature, 60 minute average	Degrees C
qqq.q	temperature, 60 minute low	Degrees C
rrr.r	temperature, 60 minute high	Degrees C
ss	relative humidity, instantaneous	%
tt	relative humidity, 60 minute low	%
uu	relative humidity, 60 minute high	%
vvvv.v	Baromoeter, instantaneous	knots

Seabird SBE-45 Thermosalinograph Data

Data from the SBE-45 TSG is output in the following format:

`tsgraw  2011:233:23:59:53.5781   11.4574,  3.75157,  33.0665`

`yyyy:ddd:hh:mm:ss.ssss  tttt,  cccc,  xxxx`

Item	Definition	Units
yyyy	year	n/a
ddd	day of year	n/a
hh	hours	n/a
mm	minutes	n/a
ss.ssss	seconds	n/a
tttt	Raw internal temperature sensor data	n/a
cccc	Raw conductivity sensor data	n/a
xxxxxx	Raw salinity sensor data	n/a

Seabird SBE38 Thermometer Probe (Pod #1) Data

The sound velocity probe serial data is output in the following format:

`8.2221`

`xx.xxxx`

Item	Definition	Units
xx.xxxx	Temperature	Celcius

Seabird SBE38 Thermometer Probe (Pod #2) Data

The sound velocity probe serial data is output in the following format:

8.2221

xx.xxxx

Item	Definition	Units
xx.xxxx	Temperature	Celcius

SEAPATH 200 Intertial Navigation System

SEAPATH outputs data in NMEA format using the following sentence formats:

- 1. $INGGA-Global System Position Fix Data
- 2. $INHDT-Heading - True data
- 3. $INVTG-Course over ground and Ground speed data
- 4. $INZDA-Time and date

$INGGA, hhmmss.sss, llll.lllll, a, yyyyy.yyyyy, b, t, nn, v.v, x.x, M,,,c.c,rrrr*hh

$INGGA-Global System Position Fix Data

Item	Definition	Value	Units
$INGGA	Header	$INGGA	
hhmmss.sss	UTC time of position	n/a	Hours/Minutes/Seconds.decimal. Two fixed digits of hours. Two fixed digits of minutes. Two fixed digits of seconds. Three digits for decimal fractions of a second.
llll.lllll	Latitude	-90 to +90	DegreeslMinutes.decimal. Two fixed digits of degrees Two fixed digits of minutes Five digits for decimal minutes.
a	N (north) or S (south)	N or S	
yyyyy.yyyyy	Longitude	-180 to +180	Degrees/Minutes.decimal. Three fixed digits of degrees. Two fixed digits of minutes. Five digits for decimal minutes.
b	E (east) or W (west)	E or W	
t	GPS Quality Indicator	0 = Fix not available or invalid 1 = CIA standard GPS; fix valid. 2 = DGS mode; fix valid. 3 = PPP mode; fix valid. 4 = RTK fixed 5 = RTK float 6 = free inertial	
nn	Number of satellites used in fix	0 to 32	
v.v	Horizontal dilution of precision		
x.x	Altitude of the IMU above or below the mean sea level. A negative value indicates below sea level.	n/a	Metres
M	Units of measure = metres	M	

Null	Null		
Null	Null		
c.c	Age of differential corrections in records since last RTCM-104 message.	0 to 99.9	Seconds
rrr	DGPS reference station identity	0000 to 1023	
*hh	Checksum		
/CR/LF	Carriage return and line feed	/CR/LF	

$INHDT, x.x, T*hh

$INHDT-Heading - True data

Item	Definition	Value	Units
$INHDT	Header	$INHDT	
x.x	True vessel heading in the vessel frame	o to 359.99	degrees
*hh	Checksum	n/a	
/CR/LF	Carriage return and line feed	/CR/LF	

$INVTG, x.x, T,, M, n.n, N, k.k, K*hh

$INVTG-Course over ground and Ground speed data

Item	Definition	Value	Units
$INVTG	Header	$INVTG	
x.x	True vessel track in the vessel frame	0 to 359.99	degrees
T	True	T	
null	Not supported	null	
M		M	
n.n	Speed in the vessel frame	n/a	Knots
N	Knots	N	
k.k	Kilometres	K	
*hh	Checksum	n/a	
/CR/LF	Carriage return and line feed	/CR/LF	

$INZDA, hhmmss.ss, DD, MM, YYYY,, *hh

$INZDA-Time and date

Item	Definition	Value	Units
$INZDA	Header	$INZDA	

hhmmss.sss	UTC time	n/a	Hours/Minutes/Seconds.decimal. 2 fixed digits of hours 2 fixed digits of minutes 2 fixed digits of seconds Three digits for decimal fractions of a second
DD	Day of month	01 to 31	
MM	Month of year	01 to 12	
YYYY	Year		
Null	Null		
Null	Null		
*hh	Checksum	n/a	
/CR/LF	Carriage return and line feed	/CR/LF	

Spectrum TM-4 time and frequency system data

The TM-4 is used as an event logger to log shot times from digishot. The 'tagger' data set includes all output from the TM-4. The 'shot' data set includes only the event messages (message #62)

Spectra provides primary shot timing aboard Langseth. The TM-4 is used for qc and backup purposes.

Message descriptions

Message #	Type	Form	Explanation
50	ACKNOWLEDGE	CRLF	
51	DATE AND TIME	MMDDYYYY,HHMMSSCRLF	MMDDYYYY is UTC month, day, and year HHMMSS is UTC hours, minutes and seconds
52	POSITION	WWWW.WW,X,YYYYY.YY,Z,A,NCRLF	W = latitude in DDMM.MM X = hemisphere N or S Y = longitude in DDDMM.MM Z = hemisphere E or W A = GPS availability (0 = not available, 1 = available) N = number of satellites used (0-9, A[10], B[11], C[12])
53	ALTITUDE	SXXXXX,MCRLF	S = sign (+ or -) X = altitude (5 digits) M = altitude units (meters)
55	MASK ANGLE AND MAP DATUM SETTING	X,47CRLF	X = 0 for 5 degrees X = 1 for 15 degrees X = 2 for 20 degrees 47 = two digit map datum code (fixed at WGS84)
56	USER TIME BIAS	SXXXXXCRLF	S = sign (+ or -) X = bias value (5 digits)
57	TIMING MODE	XCRLF	X = 0 for Dynamic Timing Mode X = 1 for Static Timing Mode X = 3 for Auto Survey Mode
	GEOMETRIC		X = GQ (0-9)

59	QUALITY AND ALMANAC STATUS	X,YCRLF	Y = 0 (Almanac OK) Y = 1 (no Almanac) Y = 2 (Almanac is old)
60	TIME PORT DATA RATE AND MULTIPLEXER #1 STATUS	X,YCRLF	X = 0 (1200 baud) Y = 0 for 10 MHz output X = 1 (2400 baud) Y = 1 for 5 MHz output X = 2 (4800 baud) Y = 2 for 1 MHz output X = 3 (9600 baud) Y = 3 for 100 kHz output X = 4 (19200 baud) Y = 4 for 10 kHz output X = 5 (38400 baud) Y = 5 for 1 kHz output X = 6 (57600 baud) Y = 6 for IRIG output (if installed) X = 7 (115200 baud) Y = 7 for PPS output Y = 8 for OFF (newer TM-4's only)
61	TIMING STATUS	W,CRLF	W = 0 (time not valid) W = 1 (Time Valid)
62	EVENT TIME-TAG	MMDDYYYY,HHMMSS.SSSSSSSCRLF	MMDDYYYY = UTC date of event HHMMSS.SSSSSSS = UTC time of event
63	POP/ETT STATUS	X,P,MMDDYYYY,HHMMSS.SSSSSSS,RRRRRRRRCRLF	X = 0 for ETT/POP OFF X = 1 for POP One-Shot X = 2 for POP Repeat X = 3 for ETT P = + for positive polarity P = - for negative polarity P = 0 when POP/ETT Mode is OFF MMDDYYYY is the POP date (UTC) HHMMSS.SSSSSSS is the POP time (UTC) RRRRRRRR is the POP

			repeat interval
64	OSCILLATOR TUNING MODE	XCRLF	X = 1 for Mode 1 (oscillator warm-up) X = 2 for Mode 2 (course adjust) X = 3 for Mode 3 (course adjust standby) X = 4 for Mode 4 (fine adjust) X = 5 for Mode 5 (fine adjust hold) Note: See OSCILLATOR MODES on page 11 of the Spectrum manual for an explanation of these Oscillator Tuning Modes.
65	ALARM STATUS	X,Y,ZCRLF	X = 0 for No Coast condition X = 1 for Coast Alarm condition See Message #79 for Coast Timer. Y = 0 for Antenna Good Y = 1 for Antenna Current Sense Fault condition Z = 0 for 10 MHz Frequency Output Good Z = 1 for 10 MHz Frequency Output Fault condition See HARDWARE FAULT MONITORING on page 14 of Spectrum manual for an explanation of Antenna Alarm.
68	MULTIPLEXER #2 STATUS	XCRLF	X = 0 for 10 MHz output X = 1 for Mux1 mirror X = 2 for PPS X = 3 for output option 1 X = 4 for output option 2 X = 5 for output option 3

			X = 6 for baseband IRIG (if installed) X = 7 for baseband NASA-36 (if installed) X = 8 for OFF (newer TM-4's only)
69	TRACKING CHANNEL STATUS	VV,W,X,Y,....VV,W,X,Y,ZCRLF	VV = PRN of satellite being tracked W = constellation status: 0 = not included in current constellation 1 = included in current constellation X = tracking status: A = acquisition/reacquisition S = searching 0-9 = SQ Y = Ephemeris status: 0 = not collected 1 = collected Z = receiver status: 2 = search the sky 3 = Almanac collect 4 = Ephemeris collect 5 = acquisition 6 = position NOTE: VV,W,X,Y repeats twelve times, corresponding to each of the twelve channels.
70	SERIAL TIME MESSAGE FORMAT	XCRLF	X = 0 for standard output X = 1 for NTP output (optional) X = 2 for NMEA output
71	SERIAL TIME CODE FORMAT	XCRLF	X = 0 for IRIG B output X = 1 for NASA-36 output
72	ETT PARAMETERS	X,PCRLF	X = 0 (ETT off) X = 1 (ETT on)

74	POP PARAMETERS (Simultaneous ETT/POP units)	X,P,MMDDYYYY,HHMMSS.SSSSSSS,RRRRRRRR,WCRLF	X = 0 for POP Off X = 1 for POP One-Shot X = 2 for POP Repeat P = + for positive polarity P = - for negative polarity MMDDYYYY is the POP date (UTC) HHMMSS.SSSSSSS is the POP time (UTC) RRRRRRRR is the POP repeat interval in milliseconds W = 0 for 1 Î¼s pulse width W = 1 for 10 Î¼s pulse width W = 2 for 100 Î¼s pulse width W = 3 for 1 ms pulse width W = 4 for 10 ms pulse width W = 5 for 50 ms pulse width W = 6 for 100 ms pulse width W = 7 for 250 ms pulse width W = 8 for Level Hold
75	SPEED OVER LAND and HEADING	SSS.SS,HHH.HCRLF	SSS.SS indicates speed over land in meters/sec HHH.H indicates course in degrees decimal
			DDMM.MMMM is latitude in degrees and decimal minutes N is north or south (N, S) DDDMM.MMMM is longitude in degrees and decimal minutes W is west or east (W, E) S is sign of altitude

76	ADDITIONAL NMEA INFORMATION	DDMM.MMMM,N,DDDMM.MMMM,W,SAAAAA.A,M,G,UU,PP.P,ZZZ.ZZ,YYY.YCRLF	above or below sea level (+,-) AAAAA.A is altitude (in meters) (0-18000) M is altitude units (meters) G is GPS status (0= fix not valid, 1= fix valid) UU is number of satellites used in navigation solution (0-12) PP.P is estimated horizontal dilution of precision (0-99.9) ZZZ.ZZ is speed over ground in knots YYY.Y is course over ground in degrees
77	PHASE LOCK STATUS	X,CRLF	
78	ADDITIONAL USER OPTION SETTINGS	A,B,C,D,E,FCRLF	A = 0 for Antenna Alarm Disabled A = 1 for Antenna Alarm Enabled (default) B = 0 for PPS Source 0 (See Message #24 for definitions) B = 1 for PPS Source 1 B = 2 for PPS Source 2 B = 3 for PPS Source 3 Fields C-F are reserved.
79	COAT TIMER	HHHHMMSSCRLF	HHHHMMSS = Amount of time (Hours, Minutes, Seconds) that the unit has been in Coast (Mode 3 or Mode 5)
80	PHASE LOCK STATUS	X, CRLF	
			X = 0 for TM-4 operation in GPS Time (reserved for future feature, currently disabled) X = 1 for TM-4 operation in UTC Time (default) Y = 0 for Leap Second

81	LEAP SECONDS? GPS TIME	X,Y,±ZZCRLF		data not valid Y = 1 for Leap Second data valid ±ZZ = UTC/GPS Time Offset, in whole seconds The difference between UTC Time and GPS Time is the number of Leap Seconds that have been introduced to UTC Time since the beginning of GPS Time. (GPS Time is never adjusted for Leap Seconds.) The Ã¬UTC OffsetÃ® from GPS Time is in the information data stream broadcast by the GPS satellites. The TM-4 stores the previously known value, but until the TM-4 makes contact wisatellites and downloads the current"UTC Offset", the data cannot be considered to be valid.

Speed log data

Speed log data is formatted in the following sentences:

- VHW - Water speed and heading
- VBW - Dual Ground/Water Speed

$VHW,x.x,T,x.x,M,x.x,N,x.x,K*hh

VHW sentence fields

Item	definition	units
x.x	degrees true	?
T	T=true	n/a
x.x	degrees Magnetic	?
M	M = Magnetic	n/a
x.x	Speed of vessel relative to water	Knots/hour
N	N = Nots	n/a
x.x	Speed of vessel relative to water	Km/hour
K	K = Kilometers	n/a
*hh	Checksum	n/a

$VBW,x.x,x.x,A,x.x,x.x,A*hh

VBW sentence fields

Item	Definition	Units
x.x	Longitudinal water speed, "-" means astern	?
x.x	Transverse water speed, "-" means port	?
A	A = Data Valid	n/a
x.x	Longitudinal ground speed, "-" means astern	?
x.x	Transverse ground speed, "-" means port	?
A	A = data valid, V = data invalid	n/a
*hh	Checksum	n/a

Streamer Tension Unit Data

STU outputs data in the following sentence format:

aaa bbb cc dd ee f g hhhh iiii jjjj kkkk l m nnnn oooo pppp qqqq r s tttt uuuu vvvv wwww x y zzzz !!!! @@@@

STU Data

Item	Definition	Value	Units
aaa	na	n/a	n/a
bbb	Julian Day	1 to 366	day
cc	Hour	0 to 24	integer
dd	Minutes	0 to 60	integer
ee	Seconds	0 to 60	integer
f	# 1 ID	1	integer
g	# 1 Channel #	0	integer
hhhh	# 1 Peak Tension	n/a	lbs
iiii	# 1 Average Tension	n/a	lbs
jjjj	# 1 Delta Tension	n/a	n/a
kkkk	# 1 Temperature	n/a	Celcius
l	# 2 ID	1	integer
m	# 2 Channel #	1	integer
nnnn	# 2 Peak Tension	n/a	lbs
oooo	# 2 Average Tension	n/a	lbs
pppp	# 2 Delta Tension	n/a	n/a
qqqq	# 2 Temperature	n/a	Celcius
r	# 3 ID	1	integer
s	# 3 Channel #	2	integer
tttt	# 3 Peak Tension	n/a	lbs
uuuu	# 3 Average Tension	n/a	lbs
vvvv	# 3 Delta Tension	n/a	n/a
wwww	# 3 Temperature	n/a	Celcius
x	# 4 ID	1	integer
y	# 4 Channel #	3	integer
zzzz	# 4 Peak Tension	n/a	lbs
!!!!	# 4 Average Tension	n/a	lbs

@@@@	# 4 Delta Tension	n/a	n/a
####	# 4 Temperature	n/a	Celcius