GEOLOGICAL SURVEY OF CANADA
OPEN FILE 6441

Cruise Report of the SIGNAL 2009 Refraction Seismic Cruise (Hudson 2009-019)

T. Funck, S.A. Dehler, C.B. Chapman, M. Delescluse, J. Iuliucci, R. Iuliucci, W. Judge, P. Meslin & M. Ruhnau

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Open files are products that have not gone through the GSC formal publication process.

Contents

1. Summary

By Thomas Funck

The SIGNAL (**S**eismic **I**nvestigations off **G**reenland, **N**ewfoundland **a**nd **L**abrador) cruise onboard the Canadian Coast Guard Ship *Hudson* (cruise Hudson 2009-019) started in Halifax, Nova Scotia, on June 5, 2009 and ended in St. John's, Newfoundland and Labrador, on July 8, 2009. The project was a collaboration between the Geological Survey of Canada (GSC) and the Geological Survey of Denmark and Greenland (GEUS) with scientific participation of Dalhousie University (Halifax, Nova Scotia). For both geological surveys, the cruise was part of their respective continental shelf programs under UNCLOS (United Nations Convention on the Law of the Sea) Article 76.

During the cruise, wide-angle reflection and refraction (R/WAR) seismic data were acquired south of Greenland, in central Labrador Sea and in Orphan Basin using an airgun array consisting of 12 G-guns with a volume of 520 cubic inches each (total volume 6240 cubic inches) as seismic source. The shot interval was one minute at a nominal speed through the water of 4.5 knots, which resulted generally in 4.0 to 6.0 knots over ground. The signals were recorded by ocean bottom seismometers (OBS) equipped with externally mounted three-component geophones and a hydrophone. The number of instruments along the five lines varied between 10 and 24. A total of four OBS were lost during the cruise, three of the instruments did not come back to the sea surface while a fourth instrument came back on the pre-programmed backup release time but the ship was too far away from the OBS to recover the instrument. In addition to the OBS, a total of 29 sonobuoys were deployed to decrease the receiver spacing, which was most relevant on the longest line of the survey in Orphan Basin. Eight of the sonobuoys did not function properly, either they did not re-surface after deployment or no signals were transmitted back to the ship.

Knowledge of the velocity of sound in water is important to apply corrections for the drift of the sonobuoys but also for the calculation of the location of the OBS at the seafloor. For this reason, a total of ten XBT (expendable bathythermograph) measurements were carried out during the recovery of the OBS. All R/WAR seismic lines were collected along pre-existing reflection seismic lines collected by GEUS, GSC, and the German Federal Agency of Geosciences and Natural Resources (BGR).

Fig. 1 shows the location of the five R/WAR seismic lines. Line 1 in Orphan Basin is coincident with reflection seismic line GSC 84-3. Main objective of line 1 is to determine the crustal structure between Newfoundland and Orphan Knoll. In case of crustal continuity, Orphan Knoll could be considered as a natural prolongation of the Canadian continental shelf. The line is 632 km and a total of 22 OBS were deployed complemented by 18 sonobuoys. Due to the relatively wide instrument spacing, one critical segment of the line around the shelf break was shot a second time (line 1A, 208 km) with an additional deployment of five OBS. Two OBS could not be recovered.

Line 2 is a 227-km-long line crossing the Eirik Ridge in a NW-SE orientation, while line 3 (297 km) is located on the crest of the ridge in a SW-NE orientation. Lines 2 and 3 are coincident with reflection seismic lines GEUS 2006-16 and GEUS 2003-1, respectively. Line 3 had 1 sonobuoy and 24 OBS deployments. All OBS were recovered but two instruments did not record. Line 2 had two sonobuoy deployments and 18 of the 20 OBS along the line were recovered. Lines 2 and 3 were designed to define the crustal character and thickness of the Eirik Ridge. The ridge is known as a sediment drift feature but its deeper structure is unknown.

Line 4 is coincident with reflection seismic line BGR 77-17 and crosses the extinct spreading axis in Labrador Sea. Line 5 is a cross line that is coincident with reflection line GEUS 2003-4 and runs along the extinct spreading axis. Line 4 is 255 km long and here three sonobuoys and 18 OBS were deployed. Line 5 is 143 km long with five sonobuoys and 10 OBS. All OBS worked without fault and provide a very good data set from which the crustal structure within and across the extinct spreading axis can be determined. Of particular interest are possible changes in the crustal thickness as the seafloor spreading ceased in Labrador Sea and possible serpentinization processes in the mantle. The data should also be able to detect any possible seismic anisotropy.

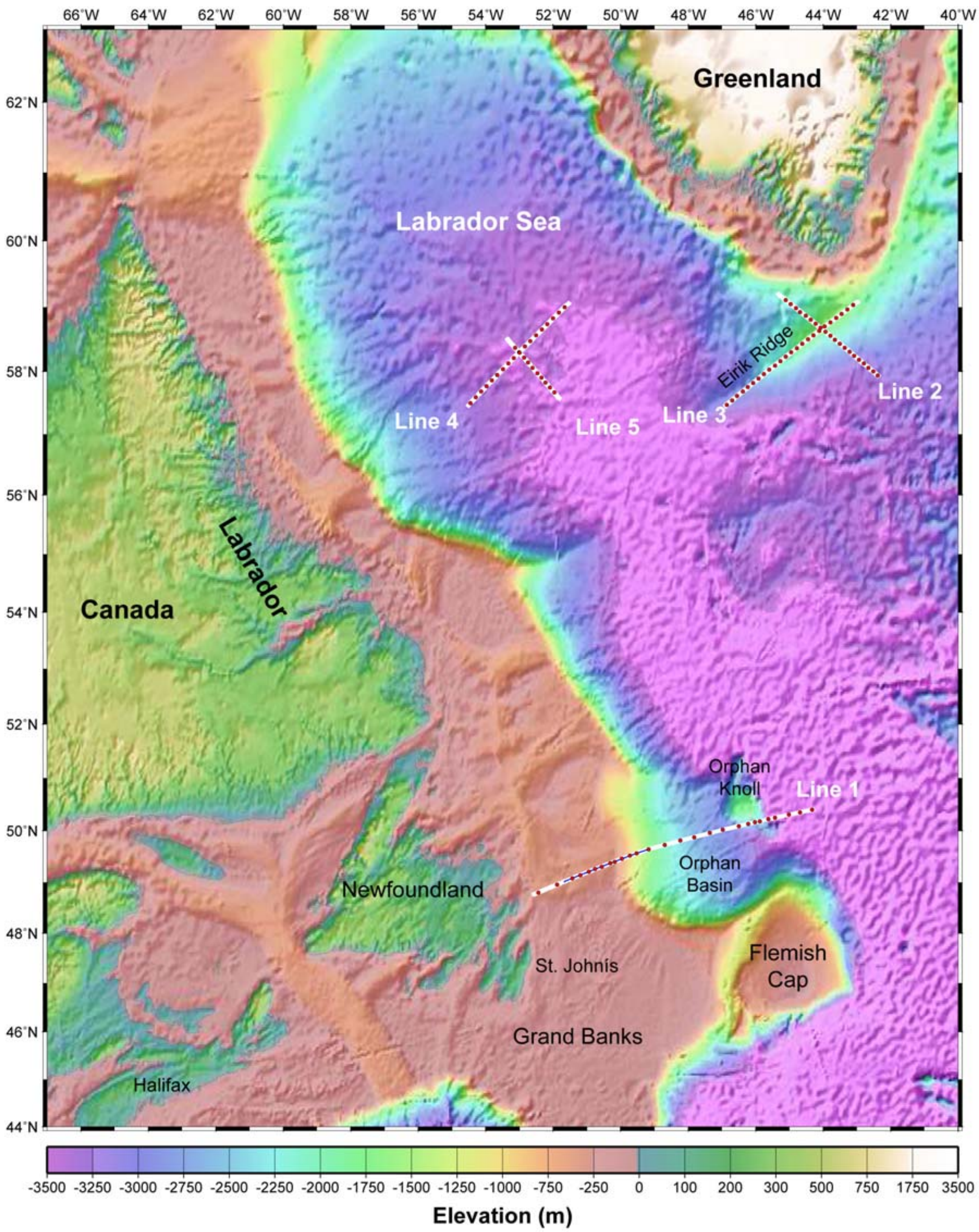

Figure 1. *Location map of the SIGNAL 2009 refraction seismic lines (white lines). The blue line indicates the segment of line 1 that was shot a second time (line 1A). Red circles show the location of ocean bottom seismometers.*

2. Location Maps

By Thomas Funck

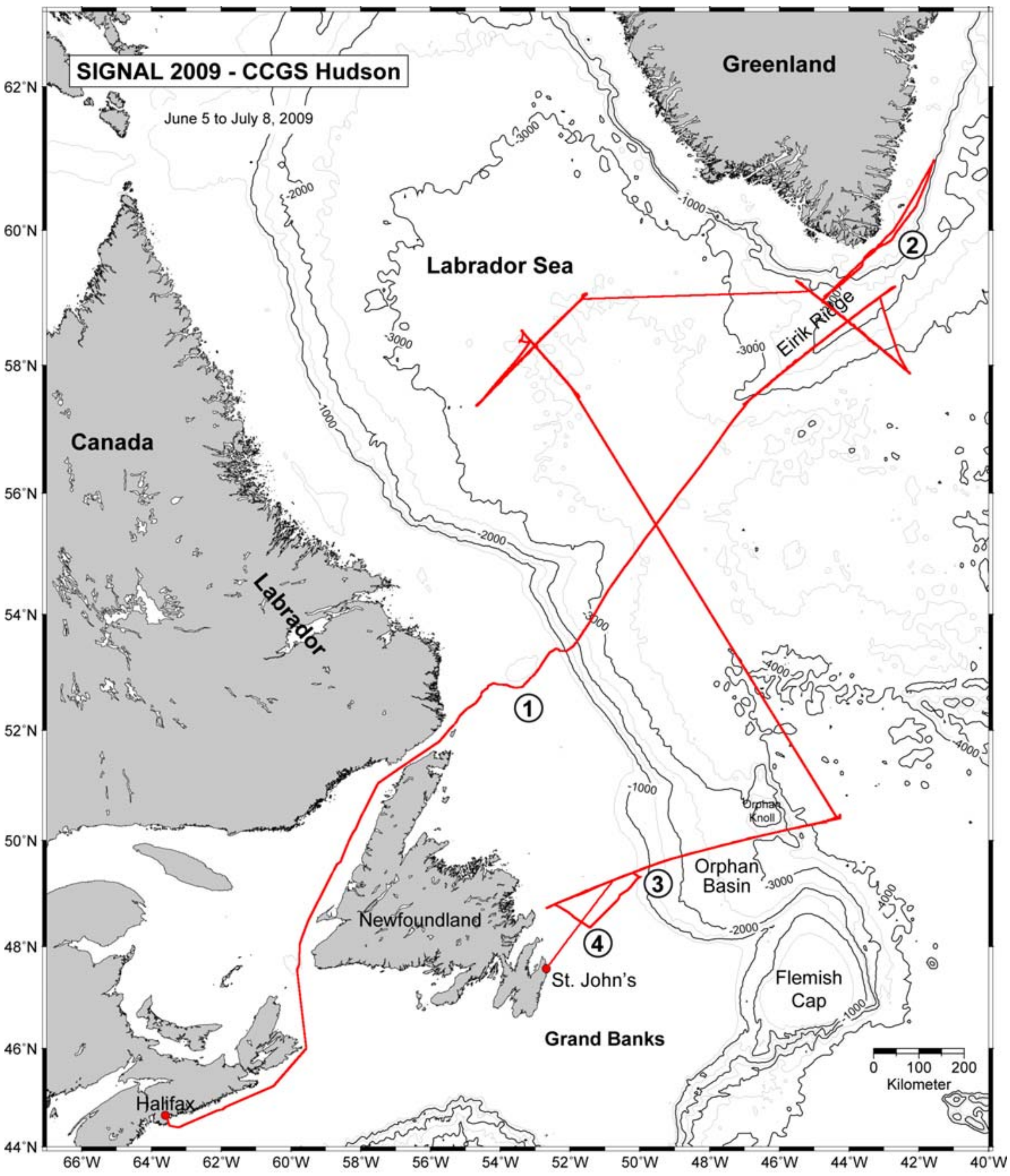

Figure 2. *Track plot of the SIGNAL 2009 cruise. The total length of the track (red line) is 10601 km or 5724 nm. Circled numbers 1 through 4 indicate deviations from the direct path. Event 1: Detour to avoid first-year sea ice off southern Labrador. Event 2: Steaming into the wind during the hurricane-force winds off South Greenland. Event 3: Search and rescue operation for fishing vessel Ocean Commander. Event 4: Rendezvous point with CCGS Sir Wilfred Grenfell to transfer the seven ship-wrecked people.*

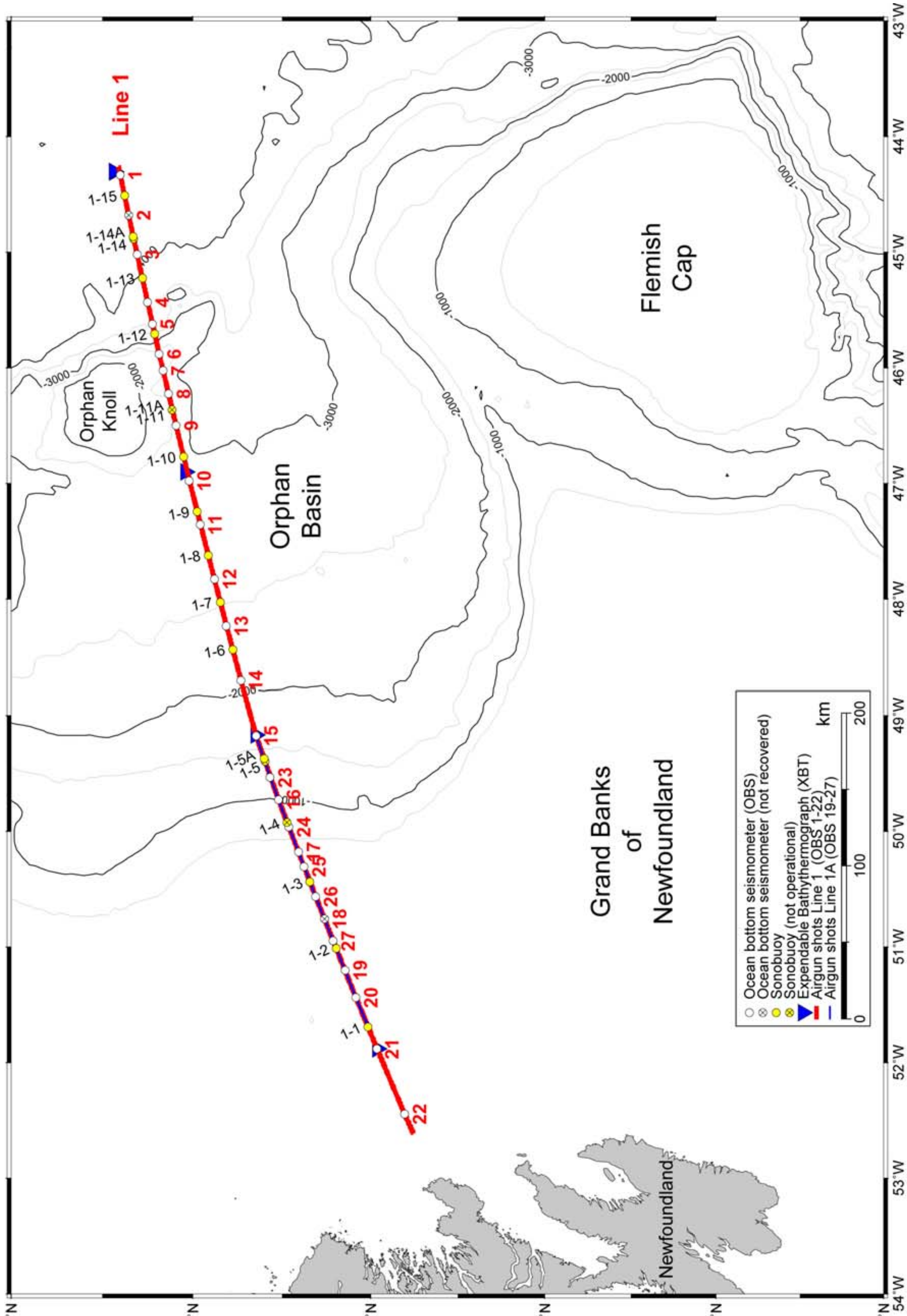

Figure 3. *Location map for refraction seismic line 1.*

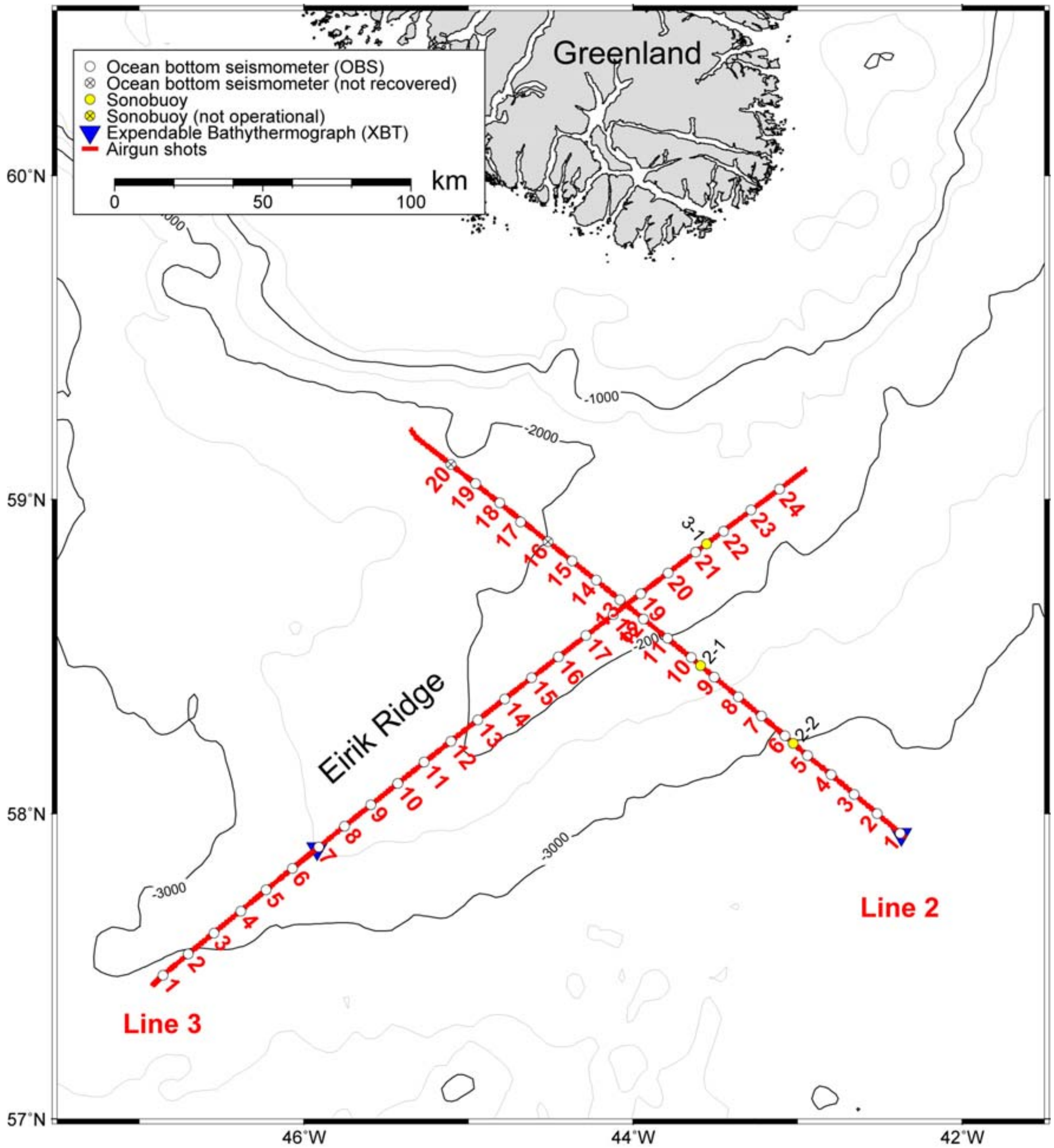

Figure 4. *Location map for refraction seismic lines 2 and 3.*

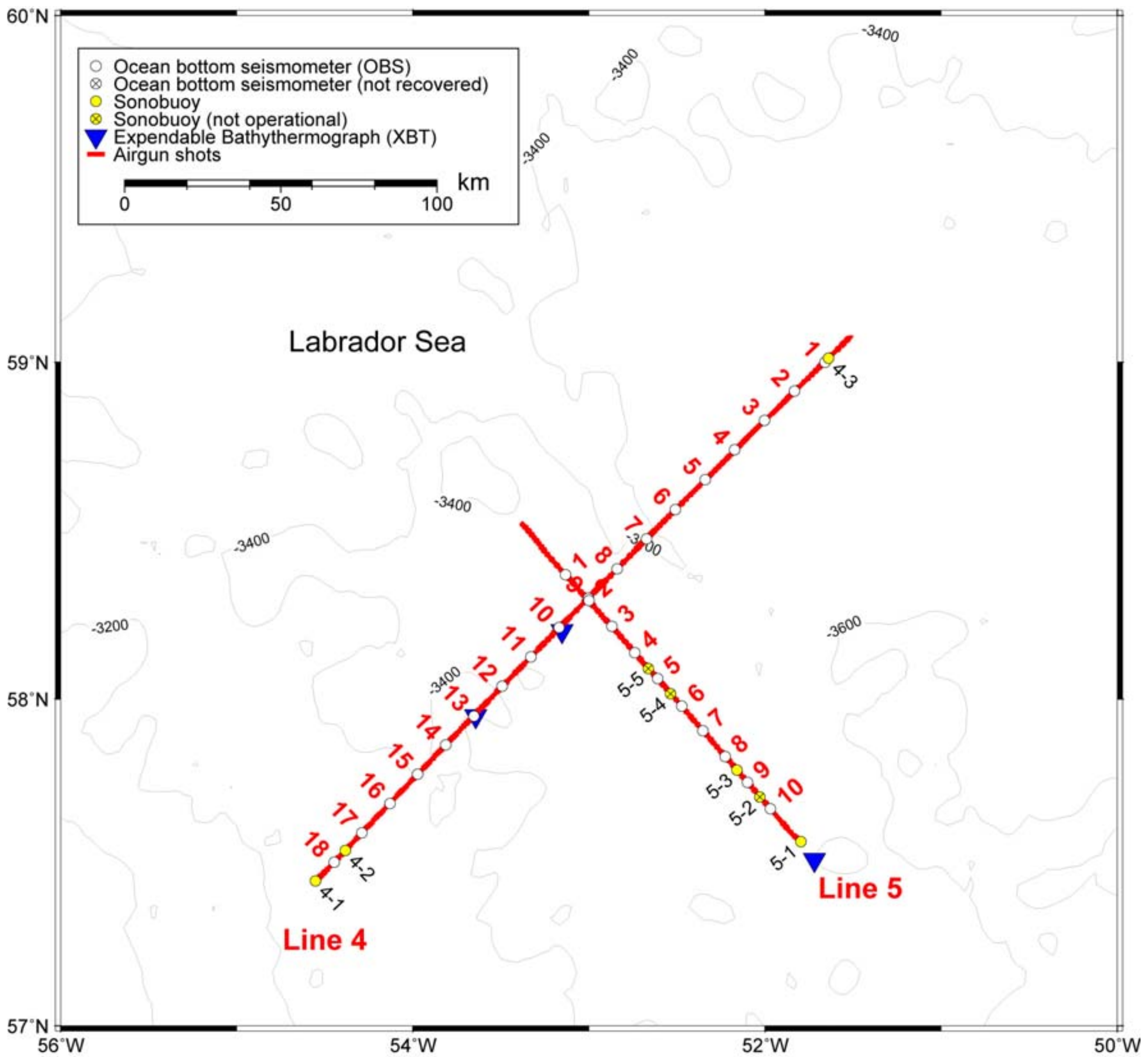

Figure 5. *Location map for refraction seismic lines 4 and 5.*

3. Cruise Participants

Scientific staff

Dr. Thomas Funck	Chief scientist	GEUS
Dr. Sonya Dehler	Co-chief scientist	GSC
Dr. Qingmou Li	Scientist, scientific watchkeeper	GSC
Dr. Matthias Delescluse	Scientist, scientific watchkeeper	Dalhousie Univ.
Marcel Ruhnau	Student, scientific watchkeeper	GEUS
C. Borden Chapman	Technical Support	GSC
Desmond Manning	Compressor technician	GSC
Fred Learning	Compressor technician	Geoforce
Roger Oulton	Compressor technician	Geoforce
Nelson Ruben	Airgun technician	Geoforce
Ryan Pike	Airgun technician	Geoforce
Dwight P. Reimer	Airgun technician	Geoforce
Paul Girouard	Navigation and data management techn.	Geoforce
Robert Murphy	Logistical and technical support	GSC
W. Peter Vass	Machinery maintenance technician	Geoforce
Patrick Meslin	OBS technician	GSC
Graham Standen	OBS technician	Geoforce
Robert Iuliucci	OBS technician	Geoforce
Walter Judge	OBS technician	Dalhousie Univ.
Joseph Iuliucci	OBS technician	Dalhousie Univ.

Ship's personnel

David Martin	Commanding officer
Ralph Marcial	Chief officer
Douglas Roe	Second officer
Wayne Bernard	Third officer
David MacLean	Bosun
Garry Stevens	Leading seaman
Murray Newcombe	Leading seaman
Joseph Murphy	Leading seaman
Blake Edwards	Seaman
Jeffrey Marchant	Seaman
Donald Brooks	Seaman
Elizabeth Terron	Seaman
John D. David	Seaman
Gary MacDonald	Seaman
Larry Sweeney	Logistics officer
Paul Birch	Chief cook
Moira Burhoe	Storekeeper
Thomas McMahon	Assistant cook
Denise Leppard	Cook/Steward
Chris Marshall	Steward
Tom Bates	Steward

Kelly Johnstone	Steward
Milton Gerrard	Steward
Peter Brick	Chief engineer
Dwayne W. Symes	Senior engineer
Paul Leonard	First engineer
Charles W. Stoodley	Second engineer
Tim Parks	Third engineer
George Tyrell	Electrical officer
Courtney Atkinson	Oiler
John Malcom	Oiler
Danny Howatt	Oiler
Robert Moore	Officer cadet
Amy Manthorne	Officer cadet
Phil Pidgeon	Ship’s technician
Myrella Bellerose	Ship’s nurse

4. Diary

By Thomas Funck

Times in the diary refer to ship time, which is Atlantic Daylight Saving time (UTC – 3 hours).

June 5, 2009 (Friday). At 9:30 am, all science staff met for a first safety briefing at the forward lounge. At 10:10 am, CCGS Hudson left the wharf at the Bedford Institute of Oceanography (BIO) for a fire and boat drill in Bedford Basin that finished around noon when Hudson started the 1050-nm-long transit to the westernmost point of line 3 off South Greenland. The ship will use the shorter route through the Strait of Belle Isle although the ice-chart indicates that there are some ice floes at the northern entrance of the strait (2/10 cover). A ship familiarization started a 2:00 pm for all personnel that have not been onboard Hudson within the last six months. A first science meeting was scheduled for 3:30 pm.

The weather was very calm with glassy seas and the ship moved at 12.5 knots using two engines. The science staff continued with the preparations for the first line, although good progress had been made while the ship was docked at BIO for mobilization. In the late afternoon, a compressor test was carried out without any problems.

June 6, 2009 (Saturday). CCGS Hudson sailed through Cabot Strait and entered the Strait of Belle Isle. Weather conditions were favourable, only light winds that decreased during the course of the day. In the evening there were glassy seas again and a blue sky. The science staff continued with the preparations for the first line. The ship’s speed generally varied between 12.5 and 13.0 knots over ground.

At 1:00 pm, a meeting with the OBS technicians was held to discuss the various settings of the instruments (gain, filter, sampling rate) as well as what recovery aids should be used. GSC has purchased 25 ARGOS beacons that transmit their position via satellite to a website for download. The ARGOS beacons are in addition to the strobes and the DF beacons. However, only two recovery aids can be installed on the OBS simultaneously and that is why a selection has to be made. For the northern lines in central Labrador Sea and south of Greenland, ARGOS and DF beacons will be mounted on the OBS. On these lines there will always be some twilight and strobes are therefore of little use. In the worst case, the recovery operation has to be interrupted for two hours if it should get too dark.

No safety issues were reported during the science meeting at 11:00 am.

June 7, 2009 (Sunday). The day went with additional preparations for the seismic program. The airgun technicians worked mainly on the electric cables. Paul Girouard and the ship’s technician Phil Pidgeon looked at the Knudsen echosounder. At 12 kHz, there was a good reflection from the seafloor while the 3.5 kHz sounder was noisy, which was related to the fact that the ram was not lowered due to ice in the area.

Paul Girouard and Sonya Dehler prepared a variety of forms that should be used by the watchkeepers (OBS deployment forms and general logs). In addition, logs for marine mammal observations were prepared. These forms were in high demand, since the Hudson went through a belt with up to 1/10 ice coverage, where numerous seals were observed. The ice was located seaward of the northern entrance to the Strait of Belle Isle. In the strait itself, the first icebergs on this cruise were observed. The general speed of the vessel was often around 13 knots. However, in the ice-covered area, the speed was reduced to 6-8 knots. In addition, some local fog patches were observed.

During the science meeting at 11:00 am, Graham Standen noted that several people tripped over a bright orange hydraulic cable in front of the starboard door to the GP lab. The cable is used for the starboard crane. The chief scientist contacted the chief officer and the cables were subsequently laid in a way that the door to the GP lab could be used without any safety risk.

June 8, 2009 (Monday). The night continued with the passage through some sea ice. Navigation was impeded by fog and the ship's speed was reduced to as little as 3.5 knots. Once in a while some ice floes hit the ship, but in most cases the ship could bypass the ice (maximum coverage of 2/10). In the late morning the ship was clear of the ice and the transit to the southwestern end of line 3 continued with a speed of 12.5 knots.

The airgun crew worked on the umbilicals, while the OBS teams started to program instruments for the deployment along line 3. Paul Girouard introduced the three watchkeepers (Marcel Ruhnau, Matthias Delescluse and Qingmou Li) to the Regulus navigation system, the Excel spreadsheets used for logging and the Knudsen echosounder. Sonya Dehler attended the introduction as well and wrote some guidelines for the watchkeepers. To facilitate the marine mammal observations, a poster with seals and whales found off Greenland was mounted on the wall of the drawing room. In addition, pictures of whales were put into the GP lab as watchkeepers were instructed to report any sightings, in particular during the usage of the airgun array. This is also to support the marine mammal observation carried out from the bridge from where the view to the rear of the ship is limited.

During the science meeting at 11:00 am, Borden Chapman stated that he will improve the safety on the helicopter deck by securing whipping wires and some overhead cables. This is to avoid injury in case of bursting pipes and cables.

June 9, 2009 (Tuesday). The deployment of OBS commenced at 10:00 am at the southwestern end of line 3. The ship's ELAC echosounder (30 kHz) did not provide accurate water depth readings and therefore the 12-kHz Knudsen echosounder was turned on to determine the water depths at the deployment sites. During the first two deployments all three watchkeepers showed up in the lab to become familiar with the routines. Prior to deployment, the Winradio installed for the sonobuoys was tuned into the frequency of the radio beacon on the OBS. This is to check if the beacons are working and also to verify that the OBS do not come back to the sea surface. In addition, the pingers on the OBS were activated to monitor the descent for two minutes.

The airgun and compressor technicians worked until the evening to have the array ready for the following morning. The OBS deployment went faster then anticipated but it was decided to wait with the deployment of the airgun array until the next morning, since this is the first deployment of the array and it should be done during daylight.

In the permit issued by the Greenland Bureau of Minerals and Petroleum (BMP), an hourly report to the Greenpos system is required. After the first reports, Greenpos asked Hudson to send the reports at six-hour intervals. This was a big relief to the captain and the officers.

The two co-chief scientists discussed how the system for marine mammal observations should be set up for the first line. The personnel on the bridge will look out for marine mammals during the shooting assisted by the watchkeeper in the GP lab who has a better view on the airgun array. In case of sightings, the airgun technician Nelson Ruben from the community of Paulatuk, N.W.T., will be called to help with the identification. He has done marine mammal observations for two seasons on the Canadian Coast Guard Ship Louis S. St-Laurent during seismic work in the Arctic.

During the science meeting at 11:00 am it was pointed out that safety shoes have to be worn in the GP lab when OBS are handled there. Individuals were reminded earlier about that by the chief scientist.

June 10, 2009 (Wednesday). The last OBS (OBS 24) was deployed at 1:10 am, after which the ship proceeded to a point some 10 nm away from the NE end of the line. From there the deployment of the airgun array started after breakfast at 6:00 am. This was a complex operation and required 10 members of the scientific staff (airgun and compressor technicians) plus six people from the deck crew. The deployment went very smooth given the fact that all the equipment was new and never tried at sea before. The ramp up procedure was started at 8:46 am. At the end of the ramp up procedure a whale was noticed at a distance of ca. 500 m from the array. After a few short dives, the whale moved away.

During the initial shooting phase there was some confusion as to why the gun control unit received only feed-back signals from eight guns and not from all twelve guns. The search for the problem took some time until it was noticed that the existing board supports only eight guns and that nothing can be done to get all twelve guns displayed. Eight of the guns were then synchronized with individual gun delays set to values between 11 to 12 ms. For the remaining four guns a value of 11.5 ms was used. One gun was shut down after about one hour of shooting operation due to an air leakage. The remaining 11 guns (total volume 5720 cu in) were working fine at a pressure of 1900 psi.

In the afternoon a sonobuoy was deployed for test purposes. Ryan Pike threw the buoy into the water from the centre of the stern and the signals from the sonobuoy first faded away at a distance of 42 km. The conditions for the test were ideal as the sea was very calm as on all the other previous days on this cruise. The temperature was up to 7°C and although it was mainly cloudy, the mountains in Greenland could be spotted in the morning at a distance of 50 nm.

During the science meeting at 11:00 am, no new safety issues were brought forward. However, it was outlined one more time to wear safety shoes in the GP lab during OBS operations.

June 11, 2009 (Thursday). The regular shooting along line 3 continued until the southwestern OBS (OBS 1) was reached around 5:30 pm. However, Borden Chapman wanted to carry out a calibration measurement on the signal strength of the airguns. For that reason, the shooting continued for another 90 minutes before the airgun array was retrieved. This operation was finished at 9:00 pm, when the recovery of the OBS started. By the time the first OBS was on deck (10:30 pm), the civil twilight came to an end. This is important to note because the OBS on this line were not equipped with a strobe. Nevertheless, the search continued through the night since the sea was calm, the nighttime darkness short and the ship's direction finder worked very well, showing the way to the radio beacons that were mounted on the OBS. The ship's spotlight also gave a good return on the reflecting foil on the OBS.

During the day, the compressors were switched several times and it was noticed that compressor #2 (starboard site) has a tendency to slightly overheat by some 5°C.

During the science meeting at 11:00 am, no safety concerns were raised but it was asked in what areas of the ship sandals can be worn. The commanding officer was consulted about this and his answer was that sandals are only allowed in the cabins and in the lounges.

June 12, 2009 (Friday). The recovery of the OBS continued all day long. For four instruments at water depths >2000 m, a different recovery approach was used. Instead of releasing one OBS from the seafloor and waiting until it came back to the surface, the ship moved to the next OBS position, released that instrument and returned to the previous OBS position. By that method, the waiting time on station was reduced. This approach was only used because the sea was calm, almost glassy and with that, the instruments were easy to spot. The ship's DF worked again very reliably. Some noise on the DF receiver turned out to be related to a radio beacon in the GP lab that was not turned off. Two OBS caused some problems during the course of the day. One instrument could initially not be communicated with but had no problems when the ship returned to the station about an hour later. Another instrument (OBS 9) needed more than one hour to release from the seafloor.

In the morning, Ryan Pike and Borden Chapman carried out an XBT measurement on the southern half of line 3 to obtain information on the water temperature that can be used to estimate the water velocity. The first attempt failed because the probe was not properly inserted into the launcher, but the second attempt was successful and the XBT transmitted data down to a depth of 1830 m, corresponding to the length of the wire in the probe.

The airgun technicians checked the gun that had to be shut down one hour after the start of the shooting due to an air leakage. Some loose bolts were identified as the cause for the leak. Other maintenance work on the airgun array was carried out during the course of the day.

Three retrieved Dalhousie OBS had a clock drift of >1 s when recovered. The reason for this is not known but Bob Iuliucci will look into this issue. Since only 20 of the 24 OBS will be deployed on the next line, it is planned to avoid using the instruments with the large clock drift.

The weather was still very cooperative with hardly any wind and no waves. However, a low pressure system moving from Newfoundland eastward is likely to influence the study area south of Greenland from Saturday evening to Monday evening. The weather forecast is announcing winds up to 36 knots. This could potentially delay the schedule although at this time, the cruise is still ahead of schedule.

No safety issues were reported during the science meeting at 11:00 am.

June 13, 2009 (Saturday). The retrieval of the OBS continued during the night without any problems and at 2:00 pm the last OBS was back on deck. The weather forecast is calling for a storm with up to 46-knot winds on Sunday and Monday and for that reason, the captain decided to use a third engine in order to increase the ship's speed in the hope that the OBS on line 2 and the airgun array can be deployed before the weather turns too bad. Some scenarios for the shooting along line 2 were discussed between the captain, Borden Chapman and the chief scientist. The final decision will be made once the OBS are deployed.

At 7:00 pm, the chief scientist gave a presentation in the forward lounge to explain the cruise objectives and the seismic methods to the crew and science staff.

Borden Chapman received results from the gun calibration and unfortunately the calibrated hydrophone was too close to the array with the result that it was oversaturated when more than one gun was used. However, the gun signal for one gun looks very consistent for ten successive shots, the signal strength is estimated at 243 dB. Borden hopes that he can redo the calibration another time and then he would like to have the ship fully stopped.

No safety issues were reported during the science meeting at 11:00 am.

June 14, 2009 (Sunday). The wind was steadily increasing during the night. After 17 OBS were deployed, a wave came over the starboard side of the ship at 5:00 am and damaged the three OBS that were stored on deck and ready for deployment. Two instruments had water entry into the cylinders while another one had a damaged float package. At the time of the incident, the door to the GP lab was closed but nevertheless, there was a substantial amount of seawater that entered the lab through the seals of the door. In some areas up to 2 inches of water were observed on the floor. The OBS deployment was stopped at that time while Hudson proceeded with minimum speed against the wind. At 8:00 am, the ship changed course temporarily to go with the wind in order to allow for the tightening of screws on a hatch on the forecastle, where some leakage was observed. After fixing that, the deck crew looked after the water in the GP lab. In the morning the wind speed increased to 50 knots. The ship was very quiet as most people retired to their cabins. Also the number of people having lunch was reduced.

During the afternoon the wind increased further in strength, gusts up to 55 knots were measured and the waves had a height of six to seven meters. Internet was down the entire day because the ship is outside the footprint of the satellite and with the motion of the ship it is impossible to track the satellite. There were also problems with the shipnet email, related to a server upgrade onshore.

In the evening the wind increased to 60 knots with gusts up to 70 knots. Hudson continued on a NE course and passed Cape Farewell at a distance of ca. 10 nm. The ice there that was shown on the latest available ice chart was gone. Waves on the shelf close to the coast seemed to be steeper and shorter than farther offshore.

No safety issues were reported during the science meeting at 11:00 am. The deck was closed during the storm.

June 15, 2009 (Monday). The wind stayed fairly stable during the night with around 60 knots from the East and gusts up to 70 knots. The wind speed did not decrease in the afternoon and evening as forecasted by DMI. Wave height during the day was 7 to 8 m, often even 10-m-high waves were observed. The ship could not do anything else than heading into the waves at low speed (ca. 3 knots) on a track close to the SE Greenland shore. The water and green seas that came over the forecastle created some minor damage. A block that was probably not properly welded to the deck was washed away, the same happened to a cover of one of the winches. A minor leak caused some water to drop into the officers mess room. Email (shipnet and internet) was not working.

The OBS technicians looked after the damaged OBS and they tried to repair at least two of them and hoped that also the third instrument could be fixed. The chief scientist checked all raw SEGY files from line 3 to identify possible problems with the OBS. There were a number of bad and weak channels. This information was forwarded to the OBS technicians to act on before the next deployment.

No safety issues were reported during the science meeting at 11:00 am. However, as a health precaution it was decided to check on all science staff who did not attend the previous meals due to sea sickness.

June 16, 2009 (Tuesday). The wind started to decrease during the night from initially 40-50 knots to 10-15 knots at the end of the day. At 8:00 am, the captain decided to turn the ship around and to proceed back to line 2 to continue with the seismic operation. The ship had moved about 150 nm away from the line along the SE Greenland coast. After the ship turned, the speed was initially only 6 knots, but as the sea became calmer, the captain decided to use a third engine to allow for a transit speed of 13 to 14 knots. Late in the afternoon we passed Cape Farewell in beautiful sunshine. OBS position 18 on line 2 was reached at 10:30 pm and this started the deployment of the last three instruments on the line that we abandoned two days ago. Just before midnight all OBS were deployed.

At the science meeting at 11:00 am it was announced that people can go on deck again, but only with life jackets on and after consultation with the bridge. Later in the day, the deck could be used again without permission as the sea became calmer.

June 17, 2009 (Wednesday). After the deployment of the last OBS on line 2, the ship moved some 12 nm to the NW of the line, where the deployment of the airgun array started at 3 am just around sunrise. The deployment went very smooth and fast, the deck crew and the airgun/compressor technicians worked very well together. The first shot of the ramp up procedure was around 5:00 am, after it was verified that there were no marine mammals in the vicinity. This time all 12 airguns worked without any problems. In the late evening two sonobuoy deployments were planned for positions some 3 nm before OBS 8 and 9. However, after launching the first sonobuoy the digitizer software crashed when it was set up to receive signals from two buoys simultaneously. After shutting down the Winradio that was turned on for the planned second sonobuoy, the digitizing program worked again. However, since it was impossible to run two buoys simultaneously, the deployment of the buoy close to OBS 9 was postponed until close to the vicinity of OBS 5, when the signals from the first sonobuoy could no longer be received. If the problem cannot be fixed, this may have an impact on line 1, where numerous sonobuoy deployments are planned, potentially up to three buoys transmitting simultaneously. The weather was again cooperative, westerly winds 10-15 knots with some sunny periods in the afternoon.

At the science meeting at 11:00 am it was announced that somebody on the ship tried to sabotage the plumbing system by using large quantities of toilet paper in two toilets simultaneously, which caused flooding in one washroom. If this happens again, this could result in a shut down of the entire plumbing system.

June 18, 2009 (Thursday). During the night there was fog and it started to rain when the airgun array was retrieved at 08:00 am after completing the shooting on line 2. The retrieval of the array took only 90 minutes and when the first OBS at the southern end of the line was released, an XBT was carried out down to a depth of 1830 m (length of the wire). The retrieval of OBS continued for the rest of the day, while the airgun and compressor technicians started with the maintenance of their gear. The major task was to move a shifted oil tank. The Dalhousie OBS group announced that they managed to repair all three instruments that were damaged during the storm. In addition, the problem with a large clock drift on OBS DAL-C probably is solved (salt bridge on a pin). With that, all Dalhousie OBS are operational again. Numerous pilot whales were sighted during the OBS retrieval. They seem to be attracted by the sound of the pinger. When OBS 6 was retrieved, it was noticed that the data logger was not turned on and therefore the instrument came back with no data recorded. OBS 7 was a slow "burn". When the PTR indicated that the OBS was still sitting on the ground one hour after it was released, the ship continued to release OBS 8 but that instrument had the same problem. While waiting for OBS 8 to release, we received the signal from the radio beacon on OBS 7, returned to station 7 and retrieved it. When we eventually came back to OBS 8, it was at the surface.

No safety issues were reported during the science meeting at 11:00 am.

June 19, 2009 (Friday). OBS 9 and 10 on line 2 were slow burns as well and here the same sequence of events happened as for OBS 7 and 8. The next five recoveries (all GSC instruments) happened without incident. After OBS 16 did not release, the ship moved to OBS 17, which was recovered without any problems. When it was detected that OBS 18 was a slow burn, too, the ship returned to OBS 16, which was still sitting at the seafloor more than four hours after the release signal was sent. The pinger was turned off with the hope that it will come free with the backup release the following night. While heading back to OBS 18, the bridge noted a radio signal from #18 and after getting to the position, the instrument could be retrieved. OBS 19 was initially released from 7 nm distance while still at position 18 and then again at position 19. Due to some problems with the sounder in the GP lab (very weak signal), it could not be determined from what position the instrument received the release signal. However, it did return to the surface and the ship proceeded to OBS 20, where the release code was sent at 11:00 pm. Shortly before midnight, the PTR in the forward lab was used for monitoring of the OBS since the record of the sounder in the GP lab was still unusable. While the watchkeepers were waiting for the OBS to release, two phone calls were placed with Kenny Asprey (GSC) at 11:00 pm and at midnight. He was monitoring the ARGOS beacons on request for those periods when the ship has no internet available. He reported that there was no sign of OBS 16.

At the science meeting at 11:00 am, people were reminded to lash doors on the ship and in particular in the GP lab. In addition, material data safety sheets for the disinfectant (Benefect) used in the gym were presented because there was some concern about the toxicity of the disinfectant due to its strong and aggressive smell. However, the MSD sheet indicates that exposure to Benefect has no negative health effects.

June 20, 2009 (Saturday). Early in the morning the two co-chief scientists decided to leave line 2 at 2:00 am after three hours of waiting for OBS 20 to release from the seafloor. The ship proceeded then on a westerly course to the next line, 126 nm away. The eastern half of the line was cancelled from the program due to a combination of time constraints and ice cover in the area of the continent-ocean transition zone - one of the target areas of the line.

At the science meeting at 11:00 am there was a discussion as to why seven of the ten Dalhousie OBS on line 2 were "slow burns". This was essentially a summary of many discussions that took place during the previous day. Differences in the burn wire (Monel wire) used on the GSC and Dalhousie instruments were identified as the most likely reason for the different behaviour of these otherwise identical instruments. The Monel wire used on the GSC instruments is slightly thinner than the one used for the Dalhousie OBS. For this reason, it was decided that the thinner wire should be used for the Dalhousie instruments in future deployments.

During the science meeting it was also decided to rename the line numbers so that the next line (originally named line 5) would be line 4. This is because it is unknown if there will be enough time to shoot the old line 4 before heading south for line 1. By this, a possible gap in the line numbering will be avoided.

Initial data quality was carried out on the data from line 2 and it was noticed that there were numerous instruments with very weak geophone signals. This could indicate that the sediments at the seafloor on the Eirik Drift are very soft (water saturated) and therefore the coupling of the geophone is rather poor. It was also speculated that the character of the sediments could play into the long burn times of the instruments.

No safety issues were reported during the science meeting at 11:00 am.

June 21, 2009 (Sunday). The first day of summer was indeed the best day on this cruise with respect to weather so far: light winds with calm seas and sunny all day. Personnel enjoyed the day (also Father's Day) on deck as much as possible. The OBS deployment on line 4 went faster than expected during the night so that the last instrument went into the sea at 9:00 am. Then Hudson moved 10 nm farther to the SW, turned around and the deployment of the airgun array could start at 10:00 am. During the deployment Sonya Dehler maintained a continuous watch from the bridge for marine mammals, assisted by the bridge watch and the science watchkeeper in the GP lab. No mammals were observed during the deployment and when the array was operational at 11:30 am in a new record deployment time, the ramp up procedure started. At the same time the first sonobuoy was deployed before reaching the westernmost OBS (station 18) on the line and a second one was deployed between OBS 18 and 17. The main reason for deploying two buoys close together was the test of the sonobuoy receiver and digitizing software, which could not handle two buoys simultaneously during an earlier trial. The fixes that were made since turned out to be successful, which is important for the operation of the last line in Orphan Basin (line 1) with many planned sonobuoy deployments. The shooting with a speed of 4.5 knots through the water was made faster by a current in our sailing direction, which resulted in a speed over ground between 5.0 and 5.5 knots.

In the morning when the internet came back, Patrick Meslin was able to log on to the ARGOS website and detected that OBS 20 on line 2 released at its backup time and we could see that it was drifting to the SE with a speed of ca. 0.5 knots. The other lost OBS on that line (OBS 16) did not send a signal. We have forwarded the ARGOS information (ID and login to the website) to the German research vessel Maria S. Merian that presently operates in the area of line 2 and asked for assistance in the retrieval of the instrument. The chief scientist on the Merian seemed supportive if there is no interference with their own operation.

Matthias Delescluse performed a QC on the sonobuoy data collected in the afternoon and he detected that the amplitudes for sonobuoy 4-2 were about 50 percent less than those for buoy 4-1.

No safety issues were reported during the science meeting at 11:00 am.

June 22, 2009 (Monday). In the morning Ryan Pike and Patrick Meslin carried out a test of the four channels that can be used for sonobuoy recording as follow up on the problems noticed the day before. Matthias Delescluse analyzed the data and noticed that channels 1 and 3 produce better results than channels 2 and 4. This test was just done with synthetic noise transmitted from a walkie-talkie. For a later sonobuoy deployment (4-3), the signals were recorded on all three available Winradios to allow for an additional comparison. No differences were noticed in the recordings and now the sonobuoy system is hopefully ready to perform in the way it was designed.

The airgun shooting on line 4 continued until 4:00 pm. At 2:00 pm the first OBS was reached but the line was extended by using another sonobuoy and shooting for another 90 minutes. At 3:30 pm another airgun calibration was carried out that lasted until 4:00 pm. For this test, the ship was stopped while heading into the wind. A series of shots with all 12 airguns firing was recorded with the calibrated hydrophone, followed by another short series with just one gun firing. The retrieval of the airgun array started after the calibration test and lasted until 5:20 pm, when the recovery of the OBS started. The first OBS was released from the site of the airgun recovery some 3.5 nm away from the OBS, to test if it is possible to release the instruments from some distance in order to speed up the recovery process. OBS 2 could be released from the recovery location of OBS 1 but later attempts to release at that distance failed and instruments were subsequently released from a distance of 3 nm or less.

Compressor 1 had to be shut off during the night due to a fifth broken drive shaft. This did not cause any problems as compressor 2 filled in.

During the science meeting at 11:00 am some rules regarding the work on deck were clarified. When gear is moved on deck, hard hat and safety shoes are required. When gear is handled over the side of the ship, a life jacket or vest should be worn.

June 23, 2009 (Tuesday). The recovery of the OBS on line 4 continued through the entire day. Starting with OBS 9, the OBS were retrieved in sets of two: one instrument is released, the ship moves to the position of the next OBS for release, then the first OBS is retrieved, followed by retrieval of the second OBS. The last two OBS were released again one by one to avoid possible problems in the twilight/darkness if one instrument cannot be located immediately, which can cause the other OBS to drift far away from position.

Two XBT measurements were carried out during the course of the day, immediately after recovery of OBS 10 and 13, respectively. The earlier XBT at site 10 had some rather high temperatures at depth (up to 13ºC), which we found unusual and therefore the second XBT at site 13 was carried out. However, the results from this second XBT cast seem wrong as well.

In the early afternoon, the internet was working again and we could see on the ARGOS tracking website that OBS 20 on line 2, which we could not recover, had drifted some 40-50 km to the SE. The second lost instrument (OBS 16) is presumably still located at the seafloor. From the chief scientist of Maria S. Merian came the message that the ship is now involved in reflection seismic data acquisition, which inhibits a recovery of OBS 20. During the afternoon, the two co-chief scientists decided not to attempt a recovery of the lost OBS but to continue with the seismic program. However, to allow for some extra contingency on line1, the next line in the extinct spreading axis (line 5) was shortened from 15 to 10 OBS and the length was adjusted to just over 100 km. This shortening saves one day in operation and will still provide good control of the crustal and upper mantle structure, as mantle refractions are expected at offsets of ca. 25 km. After a meeting with the captain it was decided to aim for an arrival in St. John’s late in the evening of July 7, rather than in the morning of July 8. This is due to the crew change in the morning of July 8, which will put a lot of demand on the crew on that day.

The weather turned from cloudy with moderate visibility in the morning to sunny in the afternoon and the evening. However, the wind speed was up to 25-30 knots.

No safety issues were reported during the science meeting at 11:00 am.

June 24, 2009 (Wednesday). The last OBS on line 4 (OBS 18) was back onboard at 1:30 am. From there the ship moved to the northern end of line 5 (within the extinct spreading axis) using three engines. The first OBS on line 5 was deployed at 6:30 am and the deployment operation of all 10 instruments was finished at noon. Hudson sailed another 12 nm along the SE extension of the line, where the ship stopped, carried out an XBT - this time without any high-temperature areas and spikes in the intermediate water. Deployment of the airgun array started at 1:20 pm, lasted 85 minutes, and was followed by a twenty minute ramp-up procedure of the array.

A first sonobuoy (5-1) was launched during the ramp up procedure, while the second launch (sonobuoy 5-2) between OBS 9 and 10 failed because the buoy got caught between the two inboard gun beams that were very close together at the time of deployment. For some minutes the buoy was entangled in the starboard inner beam of the array, and when it eventually came free, no hydrophone signal was transmitted back to the ship. Two other buoys were deployed later in the evening, one between OBS 9 and 8 (buoy 5-3) and one between OBS 5 and 6 (sonobuoy 5-4). Buoy 5-4 was destroyed between the airguns during the deployment.

In response to the first weekly report to the Greenland Bureau of Minerals and Petroleum (BMP) from June 15, the chief scientist received an email from the BMP with the request to forward daily science plans to the BMP that contain forecasts for the next three days of work, maps with the lines, and radio messages for the fishing industry. In a reply, the chief scientist reminded the BMP that the seismic work inside the Greenland EEZ is completed.

After making an updated work schedule, the planned BBQ during the transit to line 1 was moved from Saturday to Friday. The weather was sunny in the morning, followed by clouds in the afternoon and light rain in the evening. The wind increased to 30 knots with gusts up to 35 knots in the evening, coming from the SE with waves and swell between 2 and 3 m.

No safety issues were reported during the science meeting at 11:00 am.

June 25, 2009 (Thursday). The deployment of sonobuoy 5-5 between OBS 4 and 5 also failed due to the swell that caused the inboard airgun beams to move substantially. During the night the wind remained at 30-35 knots, with fog moving in around 4:00 am. When the end of the line was reached at 7:00 am, Borden Chapman and the boatswain discussed if the retrieval of the airgun array is feasible. Since the wind started to calm at that time, it was decided to continue shooting until 10:00 am and re-evaluate the situation then. When that time was reached, the airguns were turned off and several attempts were started to find a good course and speed for the retrieval. While the wind was down to 15-20 knots, there was still a noticeable swell of probably up to 4 to 5 m. The first trial was with the seas from the stern but this attempt was quickly given up, when a wave came up the afterdeck and many people got wet. Going against the wind on a southerly course resulted in too much movement on the afterdeck. Several in between courses were tried but also were regarded as too dangerous for the retrieval.

At 1:15 pm, another attempt was made to retrieve the airgun array. The swell was still there but less than in the morning and the deck crew assisted by the science staff was able to get the array back on board within two hours.

After the science gear was secured on deck, the ship headed towards OBS position 1 on line 5 for retrieval. Initially the captain and chief scientist had agreed to retrieve the instruments in sets of 2 (releasing one OBS, going to second OBS for release and then head back to the first OBS). When the fog was getting denser and the seas were still between 2 and 3 meters, the chief scientist told the officer on the bridge that after consultation with the OBS technicians he had decided to recover the OBS one by one. Shortly thereafter the captain asked the chief scientist to his cabin to complain that he was not informed about this change of plans. He said as plain as it could be that he wants the instruments to be recovered in pairs of two in order to save one hour of recovery time for each pair of two OBS. The system of recovery by pairs was then established after the first OBS was retrieved in dense fog with visibilities of 50 to 100 m. The OBS were solely found by means of the radio beacon.

During the recovery of the first OBS the captain noticed some people (both ship and science staff) that worked over the side of the ship without a flotation device. This was changed during subsequent recoveries. No safety issues were reported during the science meeting at 11:00 am. The occupational safety and health meeting that was scheduled for today was cancelled until further notice.

June 26, 2009 (Friday). At 10:00 am the last OBS (station 10) on line 5 was retrieved and back on deck. The fog persisted through the entire night. All 10 OBS had recorded and initial quality control showed data on all channels. The first raw record sections indicate a very thin crust along the line and an upper mantle that may locally be serpentinised. However, this needs further analysis.

The 530-nm-long transit to the easternmost OBS of line 1 off Newfoundland started immediately after the OBS recovery. The ship used three engines for the transit and a BBQ was organized for the evening.

During the science meeting at 11:00 am, it was announced that flotation devices have to be worn on deck during the OBS recovery (order by the captain).

June 27, 2009 (Saturday). The transit to line 1 continued throughout the day. The wind direction stayed at SE (15 knots) and did not change to N as predicted. However, the swell was only minor and with three engines, an average speed of 13 knots was reached. In the afternoon, the OBS technicians started with the preparation of instruments for the next line as the first deployment is scheduled for the following night.

Around 3:00 pm, the seismic vessel Explora passed Hudson at 6.5 nm distance on a northward course. Explora is doing a reflection seismic survey for the GSC off Labrador and is now moving from the southern survey area to the north. This is well timed with our southward transit, avoiding possible interference of the seismic signals when operating in the same area.

During the science meeting at 11:00 am, it was remarked that there is an oily spot on the aisle on the main deck, close to the stairs to the GP lab. The chief scientist reported the spot to the logistics officer. At 1:00 pm, an occupational safety and health meeting was held in the library and Sonya Dehler participated as an observer for the science party.

June 28, 2009 (Sunday). The ship reached line 1 early in the night and the first OBS was deployed at 3:30 am. The deployment procedure continued for the rest of the day with a transit speed of 12-13 knots between stations. Paul Girouard entered the planned sonobuoy positions for line 1 into the Regulus navigation computer in the GP lab. The final number of sonobuoy deployments was adjusted from 12 to 15. During the science meeting at 11:00 am (no safety issues were reported) it was also discussed that the sampling rate of 1 kHz for the sonobuoy data can be reduced to a value around 200 Hz and that the data should be saved to disk every hour in order to keep possible data losses to a minimum. The weather improved during the day, the wind decreased from 15 knots in the morning to 3 knots in the evening, temperatures of 11ºC were measured and the sun occasionally managed to shine through some high clouds.

June 29, 2009 (Monday). The last OBS on line 1 (station 22) was deployed at 8:30 am. The airgun deployment started at 9:30 am, when a position some 10 nm to the SW of the last OBS was reached. Here the ship was only 17 nm from shore (Cape Bonavista) and within cell phone cover range, which resulted in many happy people on deck using their phones. The airgun deployment lasted just over an hour and the continuous watch for marine mammals and other endangered species like leatherback turtles started at 10:00 am. The ramp up procedure of the array started at 10:47 am after no whales were observed within a 500 m radius of the ship. The gun control system would not display the time breaks of the three guns from the inner port beam, however, it was checked that they were shooting. Later the time break from one of these guns was displayed again.

After lunch, a small fire occurred in the compressor container (number 2, starboard), related to a short circuit in the electrical system. The damage was less severe than it looked and in the afternoon Borden Chapman could rewire the panels. At 7:00 pm, compressor number 2 was fully operational again.

The first sonobuoy (1-1) on line 1 was deployed at 7:00 pm. Earlier in the afternoon we had to detour by ca. 200 m to stay clear of some fishing gear and around 5:30 am the ship’s speed was adjusted because of a rather strong current of up to 2 knots that caused the speed over ground to exceed 6 knots, while doing only 4.5 knots through the water. While the currents last, the bridge was asked to sail with 3.6 knots through the water.

The weather was sunny in the morning with more clouds in the afternoon but only light winds. No major weather systems are reported in the extended forecast that is valid until Friday.

Due to the airgun deployment, the science meeting was postponed to 12:30 pm. No safety issues were reported.

June 30, 2009 (Tuesday). The shooting on line 1 continued for the entire day. The sea was very calm as there was hardly any wind (East 5-10 knots) and the temperature was 11ºC with a lot of sunny intervals. Some fishing gear had to be passed between noon and 1:00 pm but no deviations from the course were necessary to get by the two sets of markers for fishing gear and one fishing vessel nearby. Some whales were observed during the course of the day but none closer than the critical 500 m when the airgun array has to be shut down.

Several sonobuoys were deployed throughout the day and only buoy 1-5 did not function. During deployment without the parachute, the buoy entered the water at a very steep angle and surfaced after 75 seconds, compared to 35-40 seconds for other sonobuoys. The buoy may have flooded too quickly and gotten close to the critical depth of 18 m. Once below that depth, the buoy cannot surface anymore. However, the sonobuoy came eventually back to the surface but would not transmit useful signals back to the ship, which is why another buoy was deployed shortly thereafter (1-5A).

No safety issues were reported during the science meeting at 11:00 am. However, during the meeting some plans were announced for a possible additional seismic line if the present time schedule holds, which would see the ship back in St. John's on July 5, some two and a half days early. The plan is to re-shoot a 60 nm long segment of line 1 close to the shelf edge after deploying six additional OBS in that area. This would be done during the retrieval operation of the OBS and would require roughly two days of ship time. This plan was of course not liked by everybody, in particular because the post-cruise maintenance and demobilization of the airgun array including the compressors will be delayed.

July 1, 2009 (Wednesday). The shooting and sonobuoy deployments along line 1 continued throughout the day. Just before 6:00 am the airgun array was shut down for four minutes when a whale came closer than the allowed 500 m to the array. Sonobuoy 1-11 did not return any seismic signals back to the ship, which is why a second sonobuoy was deployed shortly thereafter. However, this sonobuoy also did not transmit any data to the ship. Plans for the extra line close to the end of the cruise were advanced during the day with five additional OBS deployments between OBS 15 and 19 and subsequent re-shooting of the line segment between OBS 15 and 20.

Borden Chapman received some results from Peter Simpkin with respect to the measurement of the signature of the airgun array carried out on June 22. The peak pressures for one gun are 228.6 dB/μPa·m (+ve) and 229.5 dB/μPa·m (-ve), while the full array has pressures of 245.5 dB/μPa·m (+ve) and 247.0 dB/μPa·m (-ve).

The wind was light in the morning and increased later to 5-10 knots from the West; it was overcast with good visibility and a temperature of 9ºC. In the evening, a BBQ was held on the deck to celebrate Canada Day.

No safety issues were reported during the science meeting at 11:00 am.

July 2, 2009 (Thursday). The shooting along line 1 continued until 5:50 pm, when the ship turned into the wind in order to start the retrieval of the airgun array at 6:00 pm. The recovery took about one hour. Compared to the old GSC Bolt-gun array, the new Sercel array performed very reliably and no breaks for repairs were necessary along the 335-nm-long line. The only issue was that the time break for two of the guns on the inner port beam did not work right from the start. This will be looked after during the next two days and also one of the floats (port inner beam) needs to be maintained since it has a leak.

With respect to the sonobuoys, there was one buoy that did not come back to the surface after deployment (buoy 1-14) and therefore a second sonobuoy drop was carried out at that position. The buoys are still deployed with the parachute removed and obviously some of them sink too fast and can therefore not return to the surface. The other alternative of using the parachute has resulted in some of the buoys being caught by the airgun array. There seems to be no perfect way of deploying the buoys when towing such a wide airgun array.

The first OBS was released twice during the recovery of the airgun array in order to save some waiting time. By the time the array was on deck, OBS 1 was at the surface, giving us a head start. However, already for the next OBS a lot of extra time was needed for the recovery attempts. The instrument did not answer to the release signal and we tried at several positions to release the instrument, from right on top of the OBS to 3 nm away, to the north and south of the OBS as well as along the line. Other release codes were tried to check if the code was not recorded properly on the deployment sheets and the ship also sailed back to the position to verify if the OBS came back to the surface without sending a pinger signal. Early in the morning on Friday, the OBS had to be left behind. Two XBTs were carried out after recovery of OBS 1. The first XBT had anomalous temperatures below depths of 1000 m, which is why a second XBT was launched that did not show this unusual behaviour.

No safety issues were reported during the science meeting at 11:00 am.

July 3, 2009 (Friday). The OBS recovery along line 1 continued for the entire day without further incidents. The ARGOS homepage was checked to see if OBS 2 came back to the surface in the meantime, but there was no message received.

During the day some calculations were made, which indicated that all the remaining spare time would be needed to be at the position of OBS 2 on Monday 6:00 am when the backup time release would be activated. This would make the acquisition of additional OBS data on the western segment of the line impossible. Since there is no guarantee that the OBS would come back to the surface, it was opted to do the extra line instead of being at OBS 2 on Monday morning. This decision was made easy by the first inspection of the retrieved data on the eastern end of the line (OBS 1 and 3 as well as sonobuoys 1-12 through 1-15) in the vicinity of OBS 2. The data have an excellent quality and provide full coverage of the area seaward of Orphan Knoll. Even without the data of OBS 2, that end of the line can be modelled adequately.

The airgun array was maintained during the day and at the end it was declared ready for the next deployment. The reason for the problems with the time break of the guns on the inner port beam could not be found but all relevant parts were replaced with spares. Also the leak in one of the floats was repaired.

An XBT was carried out at the position of OBS 10 after the instrument was released. The weather was again very favourable, light winds for most of the day, with a maximum of 5-10 knots from the SE; some sunny intervals, otherwise good visibility and temperatures of 10°C.

There came news that a Danish navy vessel may look for the lost OBS 20 from line 2. However, there seem to be some problems with the instrument or the ARGOS beacon. No new messages were received after 6:00 am on July 2. We hope that this is just related to bad satellite coverage and not to empty batteries or damage to the OBS.

No safety issues were reported during the science meeting at 11:00 am.

July 4, 2009 (Saturday). After OBS 15 on line 1 was released from the seafloor, an XBT was carried out at 4:00 am down to a depth of 1670 m (seafloor) with probably the cleanest temperature record so far on this cruise – without any spikes. After OBS 15 was onboard, additional OBS (stations 23-27) were deployed along the western segment of line 1, while it was planned to recover OBS 16 through 18 when passing over them. However, only OBS 17 could be retrieved, while OBS 16 and 18 replied to the release signal sent to them but did not return to the surface. After half an hour wait, the pingers on these two instruments were turned off and the ship continued its work while monitoring the frequency of the radio beacons and ARGOS messages although the internet was down for most of the day. The reason for leaving the two positions that early is that the ship will pass the instruments two more times.

The five additional OBS on line 1 were programmed to start recording at 8:00 pm. When the ship reached the airgun deployment position earlier than expected at 3:30 pm, the extra time was used for the test of the signal strength of the array. This test was planned for the end of the line but since OBS 19 through 22 (plus OBS 16 and 18) were already recording, this was a good way to make use of the waiting time. The airguns were deployed at the position of OBS 20 and the ship was sailing along line 1 towards Newfoundland. When the array was deployed at around 4:45 pm, the ramp up procedure was started but had to be called off twice due to problems with the airgun array, probably caused by some wiring errors with the time break. After each gun was triggered manually, the firing of the guns could be controlled better and the full 20 minute ramp up was completed at 5:30 pm. Until 6:30 pm, only six guns were fired, when the ship turned and started to fire with nine guns. This way we have one segment of line 1 that was shot with 6, 9 and 12 guns, which will allow for an estimate on the minimum number of guns that are necessary to get acceptable amplitudes in the record sections. Since the airgun array is new, such estimates are important for future uses of the array. At 8:00 pm some miles to the west of OBS 20, all 12 guns were turned on and the ship started the regular shooting along line 1A towards OBS 15.

There was fog for most of the night and in the early morning, and again in the afternoon and evening. Temperatures were up to 10°C, winds from the SE 15-20 knots, in the evening 5-10 knots.

No safety issues were reported during the science meeting at 11:00 am.

July 5, 2009 (Sunday). The airgun shooting continued until 7:00 pm when the retrieval of the array started just west of OBS 15. During the course of the day, all time breaks could eventually be monitored on the gun control system. At 12:30 pm, the array had to be shut down for a few shots due to the presence of a whale inside the 500-m zone around the airgun array. After the airgun array was back onboard at 8:00 pm, the ship moved to OBS 23 to start the recovery of the remaining instruments along line 1, with exception of OBS 2 at the eastern end that is too far away to get there for the backup release time. OBS 23 was sent the release signal at 10:00 pm but when the instrument did not release from the seafloor after 30 minutes of waiting time, the ship continued to the next station.

The weather was characterized by fog for most of the day, with some rain and temperatures of 11°C. Maximum winds of 15-20 knots from the SE were observed but decreased to light winds in the evening.

No safety issues were reported during the science meeting at 11:00 am.

July 6, 2009 (Monday). OBS 24 on line 1 was recovered at 1:20 am but recorded no data. At 2:10 am, we received a mayday call from the fishing boat Ocean Commander. The boat was on fire and all seven people onboard went into the life raft. Hudson was only 8 nm away and by 3:10 am all the people were rescued. The Ocean Commander sank after we left the area. Nobody was injured but due to the medical condition (diabetes) of one of the fishers, arrangements were made to transfer the rescued persons to St. John’s. The Coast Guard ship Sir Wilfred Grenfell left St. John’s at 5:00 am and met with Hudson halfway at 10:15 am, when the rescued persons were transferred to the Grenfell. By that time, the Hudson was closer to the western end of line 1 than to OBS 24, and it was decided to resume the OBS recovery operation from the west, starting with OBS 22. Hudson started the 50-nm steam to that position at 11:00 am and OBS 22 could then be recovered at 3:00 pm. The recovery operation continued for the rest of the day.

The weather was cloudy, with some rain, drizzle and fog patches. Winds were 15-50 knots from the SW in the morning and increased to 20-30 knots from the NW in the afternoon. The temperature varied between 10°C and 12°C.

No safety issues were reported during the science meeting at 11:00 am.

July 7, 2009 (Tuesday). The OBS recovery on the western end of line 1continued during the night and the ship arrived at the position of OBS 23 at 5:15 am. This OBS as well as OBS 16 and 18 did not release from the seafloor earlier and here we had to be at position for the backup release time. OBS 23 and 16 came to the surface at the pre-programmed time, indicating that the higher voltage of the secondary release is making the difference for the burn wire to dissolve. The last remaining OBS (station 18) could not be recovered. The release was programmed for 12:12 pm but the pinger was not activated automatically as was the case with the two previous instruments. This was already a bad sign and probably indicates that the backup release was not powered either. The pinger was then activated by the transducer. However, on the PTR there was no sign that the instrument would ascend to the surface and at 1:00 pm the ship started its transit to St. John’s while the frequency of the radio beacon of the OBS was still monitored.

The weather was cloudy, winds were from the NW with 20-25 knots and the temperature was 7°C.

No safety issues were reported during the science meeting at 11:00 am. At 11:10 am the entire crew and science staff met on the foredeck for group photos (Figs. 39 and 40).

July 8, 2009 (Wednesday). At 6:00 am, the Hudson passed the Narrows and then docked at the St. John’s Coast Guard Base at 7:00 am. Following clearance by Canada Customs the demobilization of the ship started, the science staff disembarked and the Coast Guard crew was changed.

5. Ocean Bottom Seismometers (GSC)

By Robert Iuliucci

The SIGNAL cruise was the first large refraction experiment involving the joint use of the Geological Survey of Canada's and Dalhousie University's Ocean Bottom Seismometer (OBS) resources since a 2001 Mariprobe line offshore Nova Scotia. Since that 2001 program, the OBS had undergone two major upgrades; the removal of the three-component geophone package from the interior of the pressure cylinder to an external pressure case, which is deployed to the ocean floor, and the replacement of the Onset Tattletale 7 data logger with the Persistor CF 2. Prior to the start of the program, GSC built three new OBS to bring their number to 12 and Dalhousie University built two new units to also increase to 12 for a total of 24 available for deployment on any one line. All the instruments were identical with respect to mechanical and electronic components. The only difference in instrument sets was that the GSC OBS ran Omnitech Electronics software version 3.0 and Dalhousie University used version 3.25.

CCGS Hudson Cruise 2009-019 departed Dartmouth, NS, on June 5, 2009, deployed OBS on four lines in a survey area in the Labrador Sea between Greenland and Labrador and on a long line in Orphan Basin into Newfoundland, before arriving in St. John's, NL, on July 8, 2009. The lines were run out of sequence beginning with lines 3 and 2 off the south coast of Greenland, followed by lines 4 and 5 in central Labrador Sea between Labrador and Greenland, ending with line 1 starting in the deep water outside the northern Grand Banks ending 50 km off the coast of Newfoundland. During the survey, a total of 50 GSC OBS deployments were carried out in water depths ranging from 4200 m in the Northwest Atlantic off the Grand Banks to 300 m on the Newfoundland shelf off Cape Bonavista.

Other than a 60-hour period from June 14 to 16 when the Hudson was hove-to off the southeast coast of Greenland waiting out a storm of sustained 60-knot winds and 10-m seas, weather and sea conditions were generally good to excellent and did not cause delays in operations. Owing to the combination of favourable sea conditions and competence of Hudson's crew in ship positioning and equipment handling, the GSC OBS did not sustain any damage requiring repair. For the first time the OBS were equipped with an Argos satellite tracker instead of the usual strobe. This was not a problem in the northern region where it never really got completely dark at night but presented some difficulties off Newfoundland especially in foggy conditions. It is recommended that tests be conducted to verify that flotation will support the use of both the Argos and strobe in addition to an RDF beacon.

Except for OBS B at Line 1 (position OBS 2), all OBS responded normally to their acoustic release codes. OBS B failed to respond despite numerous attempts from various distances and compass directions. Given the lack of acoustic response and the lack of an Argos message indicating that the OBS surfaced, either before or after its secondary release time, the conclusion is that it suffered some catastrophic failure such as flooding.

Table 1 is a summary of deployments along individual lines. Tables 2 through 6 are performance summaries for individual lines and detailed drift calculations for the OBS are given in Tables 7 through 11.

Sequence	Deployments	Recoveries
Line 3	12	12
Line 2	10	10
Line 4	9	9
Line 5	5	5
Line 1	14	13 *
	50	49

* OBS B Line 1 OBS2 did not respond to acoustic release command and did not surface after secondary release.

Table 1. *Summary of GSC OBS deployments*.

OBS	Station	Clock drift (ms/day)	Hydrophone	Geo-phones	Comments	Repairs
A	1	-0,14			Prior to deployment could not format flash card	CF2 S/N 6848 replaced with spare CF2 S/N 9080
B	2	Lost			Repeated transmittal of release code did not get response.	
C	3	Missed	Noisy	Vertical geophone noisy	Instead of end calibration. clock was reset due to operator error. Average drift: 0.6 ms/day	
D	4	-3,89				
E	5	-7,56	HTI Dead		See note 1st deployment - line 3. Used 2nd deployment - no problems.	* Return to Omnitech for warranty repairs.
F	11	0,43			OBS was recovered with missing pinger end flotation bracket	Vemco switch craft connector replaced with spare prior to deployment.
H	12	0,45			Burn wire clamp allows wires to slide.	Repaired by scotchkote in grooves
J	13	7,32			Voltage +0.46 V noted on H+ pin.	Galvanic source. Flushed pin internally to clear.
K	14	0,15	Noisy			
L	15	-0,98				
N	21	0,00	15 s negative		Repetitive 15 s negative going pulse on hydrophone.	*see comment line 2
P	22	-3,91				
J	26	10,70				
K	27	-0,39				

Table 2. *Technical summary of GSC OBS deployments on Line 1*.

OBS	Station	Clock drift (ms/day)	Hydrophone	Geo-phones	Comments	Repairs
P	1	-3,68				
N	2	-0,03	HTI negative pulse		Repetitive 15 s negative going pulse on hydrophone	*See comment line 1
K	3	0,23		Noisy	All geophones very noisy. Bad landing or hung up above bottom	
J	4	5,70				
H	5	-4,31	Noisy	G1 Noisy	Hydrophone and vertical geophone noisy. Horizontal geophone OK. Environmental?	
F	11	0,71				
D	13	-4,31				
C	14	0,50				
B	15	6,57				
A	16	-0,27				

Table 3. *Technical summary of GSC OBS deployments on Line 2.*

OBS	Station	Clock drift (ms/day)	Hydrophone	Geo-phones	Comments	Repairs
A	1	-0,56				
B	2	5,51	No data	No data	WAB-DIB interconnecting cable not seated. Operator error.	Seated and locked WAB end of WAB?DIB connector.
C	3	0,76				
D	4	-3,99				
E	5	-8,00	HTI Dead		WAB hydrophone amplifier LTC1164-7 blown.	Replaced WAB LTC1164-7
F	6	0,81	No data	No data	7.5 V supply came back unused. No data.	Repaired faulty molex pin on WAB power connector
H	13	0,72				
J	14	8,61			RDF beacon did work on recovery. Operator error - not turned on	
K	15	0,37		G2 (channel 3) dead	This problem noted pre-cruise and thought fixed by freeing geophone.	Replaced G2 horizontal with Dalhousie spare.
L	16	-0,90				
N	17	0,02				
P	18	0,00			A few cm^3 water inside cylinder on recovery. Ingress point unknown	Washed with spray cleaner. Endcap O-rings replaced. Repaired.

Table 4. *Technical summary of GSC OBS deployments on Line 3.*

OBS	Station	Clock drift (ms/day)	Hydrophone	Geo-phones	Comments	Repairs
A	1	-379,42			Unexplained clock offset at end calibration. Clock has ~ - 0.5 ms/day drift	None. Use 0.5 ms/day drift
C	2	0,66				
D	3	-3,94				
E	4	-7,15	HTI		No problem with hydrophone .	
F	5	0,71				
H	11	0,50				
J	12	7,10				
K	13	0,14				
P	14	-3,81	Noisy in spots		Hydrophone noise comes and goes - must be environmental	

Table 5. *Technical summary of GSC OBS deployments on Line 4.*

OBS	Station	Clock drift (ms/day)	Hydrophone	Geo-phones	Comments	Repairs
P	1	-4,50			Used geophone OBS A	
J	2	8,02				
H	3	0,49				
F	4	0,40				
D	5	-4,54				

Table 6. *Technical summary of GSC OBS deployments on Line 5.*

Other technical problems include:

- Vemco unit S/N 2039 Code 00 taken out of service. Misaligned ribbon cable caused 20-mF capacitor to blow. Replaced capacitor - still inoperative. Requires further service.
- Vemco ARU S/N 4630 Code 10 taken out of service prior to use. Significant oil leak from ITC transducer. Transducer needs to be replaced.
- Little L-per RDF receiver S/N 27438 detects beacon signal but does not direction find. Requires repair/replacement.

	Pre-deployment calibration			Calibration after recovery				Time	
OBS	Day	Time (UTC)	Start offset (s)	Day	Time (UTC)	End offset (s)	Total drift (s)	span (h)	Drift per day (ms)
A	27-jun	1723	-0,000035	2-jul	2253	-0,000818	-0,000783	136,27	-0,138
B	27-jun	1734	-0,000032		not	recovered			
C	27-jun	1740	-0,000036	3-jul		missed			
D	27-jun	1748	-0,000027	3-jul	0810	-0,023708	-0,023681	145,97	-3,894
E	27-jun	1753	-0,000007	3-jul	1042	-0,046808	-0,046801	148,58	-7,560
F	27-jun	1833	-0,000035	3-jul	2129	0,002814	0,002849	160,03	0,427
H	27-jun	1837	-0,000005	4-jul	0022	0,003051	0,003056	162,98	0,450
J	27-jun	1843	-0,000036	4-jul	0239	0,050410	0,050446	165,37	7,321
K	27-jun	1849	-0,000007	4-jul	0507	0,001048	0,001055	167,93	0,151
L	27-jun	1859	-0,000004	4-jul	0707	-0,006982	-0,006978	170,10	-0,985
N	27-jun	1904	-0,000002	6-jul	2048	-0,001205	-0,001203	231,87	-0,125
P	27-jun	1909	-0,000024	6-jul	1822	-0,037449	-0,037425	229,52	-3,913
J	4-jul	0415	-0,000043	7-jul	0328	0,023330	0,023373	55,72	10,068
K	4-jul	0539	-0,000008	7-jul	0135	-0,000915	-0,000907	54,83	-0,397

Table 7. *Clock drift of GSC OBS on Line 1. Positive sign when OBS clock is ahead of GPS clock; negative sign when OBS clock is behind GPS clock.*

	Pre-deployment calibration			Calibration after recovery				Time	
OBS	Day	Time (UTC)	Start offset (s)	Day	Time (UTC)	End offset (s)	Total drift (s)	span (h)	Drift per day (ms)
A	13-jun	2238	-0,000041	19-jun	1656	-0,001618	-0,001577	138,57	-0,273
B	13-jun	2226	-0,000040	19-jun	1528	0,037461	0,037501	136,90	6,574
C	13-jun	2158	-0,000041	19-jun	1413	0,002843	0,002884	137,18	0,505
D	13-jun	2012	0,999971	19-jun	1235	0,975559	-0,024412	135,78	-4,315
F	13-jun	1928	-0,000021	19-jun	1107	0,004003	0,004024	135,58	0,712
H	13-jun	1859	-0,000005	20-jun	2216	0,003484	0,003489	172,25	0,486
J	13-jun	1839	-0,000029	20-jun	2027	0,040390	0,040419	170,10	5,703
K	13-jun	1816	-0,000010	20-jun	1827	0,001504	0,001514	157,93	0,230
N	13-jun	1803	-0,000005	20-jun	1640	-0,000218	-0,000213	165,72	-0,031
P	13-jun	1739	-0,000016	20-jun	1436	-0,025386	-0,025370	165,25	-3,685

Table 8. *Clock drift of GSC OBS on Line 2. Positive sign when OBS clock is ahead of GPS clock; negative sign when OBS clock is behind GPS clock.*

	Pre-deployment calibration			Calibration after recovery				Time	
OBS	Day	Time (UTC)	Start offset (s)	Day	Time (UTC)	End offset (s)	Total drift (s)	span (h)	Drift per day (ms)
A	8-jun	1428	-0,000030	12-jun	0159	-0,001970	-0,001940	83,45	-0,558
B	8-jun	1141	-0,000040	12-jun	0216	0,019925	0,019965	86,95	5,511
C	8-jun	1231	0,000032	12-jun	0601	0,002862	0,002830	89,53	0,759
D	8-jun	1355	0,000036	12-jun	0754	-0,015073	-0,015109	90,82	-3,993
E	8-jun	1938	0,000009	12-jun	0946	-0,028831	-0,028840	86,53	-7,999
F	8-jun	1951	-0,000031	12-jun	1138	0,002962	0,002993	88,14	0,815
H	8-jun	1509	-0,000008	13-jun	0030	0,003110	0,003118	104,65	0,715
J	9-jun	1547	-0,000030	13-jun	0207	0,029718	0,029748	82,90	8,612
K	8-jun	1612	-0,000016	13-jun	0347	0,001650	0,001666	106,98	0,374
L	8-jun	1544	0,000007	13-jun	0522	-0,004144	-0,004151	110,10	-0,905
N	9-jun	1638	0,000008	13-jun	0649	0,000095	0,000087	110,45	0,019
P	9-jun	1653	-0,000036	13-jun	0808	-0,000030	0,000006	112,02	0,001

Table 9. *Clock drift of GSC OBS on Line 3. Positive sign when OBS clock is ahead of GPS clock; negative sign when OBS clock is behind GPS clock.*

	Pre-deployment calibration			Calibration after recovery				Time	
OBS	Day	Time (UTC)	Start offset (s)	Day	Time (UTC)	End offset (s)	Total drift (s)	span (h)	Drift per day (ms)
A	20-jun	1534	-0,000040	22-jun	2156	-0,972310	-0,972270	61,50	-379,422
C	20-jun	1548	0,999962	22-jun	2325	1,001703	0,001741	63,22	0,661
D	20-jun	1600	-0,000041	23-jun	0123	-0,010782	-0,010741	65,38	-3,942
E	20-jun	1614	-0,000005	23-jun	0334	-0,020204	-0,020199	67,80	-7,150
F	20-jun	1628	-0,000350	23-jun	0548	0,001731	0,002081	70,28	0,711
H	20-jun	1656	-0,000007	23-jun	1705	0,001701	0,001708	82,02	0,500

J	20-jun	1706	-0,000036	23-jun	1758	0,024547	0,024583	83,07	7,103
K	20-jun	1716	-0,000007	23-jun	1956	0,000490	0,000497	85,20	0,140
P	20-jun	1727	-0,000023	23-jun	2100	-0,013748	-0,013725	86,45	-3,810

Table 10. *Clock drift of GSC OBS on Line 4. Positive sign when OBS clock is ahead of GPS clock; negative sign when OBS clock is behind GPS clock.*

	Pre-deployment calibration			Calibration after recovery					
OBS	Day	Time (UTC)	Start offset (s)	Day	Time (UTC)	End offset (s)	Total drift (s)	Time span (h)	Drift per day (ms)
D	23-jun	2304	-0,000030	26-jun	0447	-0,010021	-0,009991	52,85	-4,537
F	23-jun	2256	-0,000036	26-jun	0244	0,001050	0,001086	52,67	0,495
H	23-jun	2233	-0,000005	26-jun	0041	0,001025	0,001030	50,23	0,492
J	23-jun	2221	-0,000022	25-jun	2345	0,016383	0,016405	49,10	8,019
P	23-jun	2148	-0,000044	26-jun	2131	-0,008895	-0,008851	48,32	-4,396

Table 11. *Clock drift of GSC OBS on Line 5. Positive sign when OBS clock is ahead of GPS clock; negative sign when OBS clock is behind GPS clock.*

6. Ocean Bottom Seismometers (Dalhousie University)

By Joseph Iuliucci and Walter Judge

6.1 Equipment

Dalhousie (DAL) ocean bottom seismometers (OBS) employ one float-mounted hydrophone and an external geophone package containing three geophones (two horizontal and one vertical). Deployed OBS have the ability to be recovered by a primary or secondary release. The primary release is an acoustic signal received by a Vemco acoustic release unit (ARU/pinger). The secondary release is timed and operates through the OBS software. Each release supplies a potential across a Monel (high strength alloy suited for marine environments) burn wire. The supplied energy results in an electrolytic oxidation of Monel metal wire holding the release rod in place. On the surface, the float is located with either a radio beacon for close recovery or an ARGOS beacon for distant location; both are manufactured by Seimac Novatech.

6.2 Deployment and Recovery

6.2.1 Deployment Parameters

The OBS were configured to acquire 16-bit samples at 250 Hz to a file size of 2 Mb, resulting in approximately seven files per hour. The filter was set at 125 Hz. Gain settings were as follows: 56 dB for the hydrophone (channel 1) and 70 dB for each geophone (vertical geophone is channel 2, the two horizontal geophones are channels 3 and 4).

6.2.2 Pre-deployment Procedures

With the OBS cylinder on the bench in the laboratory, battery power and programming are addressed. OBS battery packs are made during transit between lines and contain ten stacks of three D cells. An OBS power pack is considered in the optimal range with digital, analog (+) and analog (–) readings over 14, 9 and 9 volts, respectively. The ARU is usually refitted with new 9 V batteries, but slightly lower voltage batteries can be used for the least important function—transmit. The o-rings at each end of the cylinder are serviced and inspected and the case is closed. With the new battery packs, the OBS is connected and communication is established. Through software the deployment parameters are set as well as the filenames and the headers. Both the primary and secondary releases are tested through software and the primary is tested acoustically. It is confirmed that the voltages clear from the pins before the OBS reaches the anchor. The final pre-deployment step is setting and calibrating the clock. It is important that the instrument receives an uninterrupted time string from the GPS-clock unit. Upon setting the clock, the start logging function is enabled and the instrument enters a low power countdown to recording. At this time, the cylinder is ready to go on the anchor for deployment.

6.2.3 Deployment Procedures

Deployment entails affixing the cylinder to the float and making all connections (Fig. 6). Bottom brackets are placed on the anchor, and the cylinder on the bottom brackets. The float fits on top of the cylinder and brackets and the clasps make the connection, holding the cylinder in place. Two rope eyes are fastened to the anchor; these eyes hold one end of the release rod. The other end of the rod is held under tension by the twine connecting the burn wires. When the rope eyes are tight, one acts as the fulcrum and the other propels the release rod clear. With the rod under tension, the burn wire connection is made to the end-cap. At this time the float-mounted hydrophone is also connected to the end-cap. The external geophone package is suspended from the float arm by a corrosive link with a drop time of 3-6 hours. The geophones are also attached to the float arm via a rope lanyard, removing the tension from the cable. This cable is mated to the end-cap. If no further communication with the instrument is required, a boot is placed over the serial connector. The final steps during a deployment are sending the start signal to the ARU and ensuring the radio beacon and ARGOS are turned on. The OBS unit is crane-lifted and lowered into the water (Fig. 7).

Figure 6. *OBS ready for deployment on deck (photo courtesy of GSC).*

Figure 7. *OBS lifted by the crane during deployment (photo courtesy of GSC).*

6.2.4 Recovery Procedures

Recovery of the instrument includes the release from the anchor, transit to the surface and bench top servicing. Once near station, the ship can be stopped and the release signal sent to the submerged instrument. A Vemco transponder and hydrophone are lowered into the water to send the signal and confirm receipt of the signal. Once the instrument responds, it is a matter of waiting for the electrolytic action to weaken the burn wire enough for release. After releasing from the bottom, the instrument rises at approximately one meter per second. At the surface, the beacons activate and the float is located. A grapple line is used to hook a line attached to the float. A crane hoists the unit to the foredeck where it is dismantled and taken to the work area (Fig. 8).On the bench in the work area, the cylinder is dried and opened. Communication is established and a final clock calibration is completed. It is verified that the instrument wrote data files. The power is disconnected and all voltages are recorded. The flash card is removed and several files are inspected for counts indicating activity on each channel. A new card and batteries are inserted, o-rings are serviced and the instrument is placed back on the rack until later deployments.

Figure 8. *OBS during recovery (photo courtesy of GSC).*

6.2.5 Deployment and Recovery Summaries

Line 3 (12 GSC + 12 DAL instruments)

Dalhousie deployed all twelve OBS on June 9 and 10, 2009. Prior to the deployment, the Vemco unit was replaced on OBS G because of evidence of a short from the ribbon cable connecting the two boards. The replacement pinger was new and did not accept the start ping while on deck. The instrument was deployed anyway as this issue occurred previously with new Vemco units and it is believed they are more sensitive to deck noise. The ARU passed bench tests at Dalhousie and repeated software based release checks. The Instruments were down for approximately three days while air guns were operated. Recovery of the instruments was completed on June 13, 2009. All instruments were recovered. OBS A, B, and C all were subjected to further tests when the clock was found to have drifted an unacceptable amount. The deployment logs were examined to determine whether the drift could be attributed to human error, but no evidence of extraordinary procedure was found. During tests it was observed that OBS C exhibited a non-clearing voltage on the secondary pin. This is a deployment hazard and warranted further investigation. During the recovery there were also some beacon issues. The beacon on OBS A had a bad switch and that on OBS K functioned intermittently. OBS E was the first occurrence of a long burn (see further explanation in summary for line 2). OBS F had no hydrophone data; this was traced to the connection of the pin on the inside of the cylinder. OBS K was not analyzed for clock drift as there was no communication with the instrument through the serial port. The lead had sheared off at the connection to the board. It was fixed by Walter Judge.

Line 2 (10 GSC + 10 DAL instruments)

It was initially decided not to deploy OBS A, B, and C while they were being tested on the bench. Dalhousie deployments began overnight on June 13, 2009. Prior to deployments there was an interrupted time string error during calibration of OBS F, and beacons were switched on several floats in an attempt to have a functioning set of 10. Deployment of the first five OBS went smoothly. The sea-state increased during deployment of the second five OBS. Three OBS on deck were struck by at least one wave. OBS B remained upright and was slated to be deployed at station 18. OBS E broke away from the anchor and suffered a broken screw on the cylinder latch (Fig. 9). OBS D broke away from the anchor and tipped over; the bottom of the float structure was fractured at the clip (Fig. 10). The decision was made to postpone deployment until the seas lessened, which afforded the opportunity for a full inspection. All three OBS damaged on deck suffered ingress of water (Fig. 11). These three instruments were meticulously cleaned and inspected until damage on the traces was minimized. The final result was the loss of one Vemco ARU, replaced by the spare after the connector short was addressed and the ARU was tested. After a two day break because of the weather and transit OBS E, B and A were deployed at stations 18, 19 and 20. OBS E was deployed in cylinder D.

Recovery of instruments on line 2 was completed by June 19, 2009 and left much to be reported. OBS N contained no data due to human error. The start logging function was disabled during countdown to shut off the ARU turned on by the GSC team. Nearly all Dalhousie instruments on line 2 exhibited long burn characteristics. A long burn was deemed to be corrosion of the release taking a period greater than 10 minutes. Some burns took as long as 90 minutes and in the case of OBS A and F; an indefinite amount of time. There were many hypotheses surrounding the long burn phenomenon, the cure came in the form of Monel from GSC, which was lighter gauge and behaved differently during construction of the burn wires; likely indicating a different composition from the Monel used by the Dalhousie team. The long burns conflicted with a tight recovery schedule and resulted in two OBS being left on the bottom. OBS A surfaced some days later, likely on the secondary release, and was located using ARGOS; recovery scenarios were pending, see final summation. OBS F never surfaced. OBS B also suffered from beacon issues.

During bench tests, OBS D and C both exhibited a voltage across the release pins that would not clear. After all the traces on the boards were cleaned, and the primary release pin was changed in OBS C, the issue was resolved. It was decided that at some point OBS C had leaked at the release pin and an electrochemical reaction occurred at the contact between dissimilar metals and saltwater.

Figure 9. *Broken screw on the cylinder latch of OBS E after it was hit by a wave.*

Figure 10. *Bottom of the float structure of OBS D after it was damaged by a wave.*

Figure 11. *OBS showing ingress of water.*

Line 4 (9 GSC + 9 DAL instruments)

Pre-deployment, all beacons were retested and ordered on floats such that two consecutive OBS did not have matching frequencies. One of the beacons used, however, has a frequency that is as yet unconfirmed. This beacon was visible on the aft lab receiver while not being visible from the bridge. It was not used until line 1, when every available beacon had to be used. Deployments of Dalhousie OBS were completed on June 21, 2009. At station 10, OBS I was mistakenly deployed in place of OBS H. This affected the data slightly as the gain did not match the hydrophone. The header for each data file was also incorrect. Recovery began June 23, 2009. The first OBS recovered was B and it suffered a loss of the hydrophone pins. The release rod tie and the float rope wrapped around the hydrophone cable and damaged the pins to the point they broke off. They were repaired by Joseph Iuliucci. OBS C had the wrong filename and a beacon frequency issue. A screw was found to be sheared off from the end cap clip on OBS K. The final OBS recovered was N and it contained a small amount of water. It was determined there was no damage and a point of ingress could not be verified. The only steps taken were to replace the o-rings at both ends.

Line 5 (5 GSC + 5 DAL instruments)

Line 5 was shortened due to time constraints, dropping the number of Dalhousie instruments to five. Pre-deployment preparations and deployments were uneventful, all five beacons turned on and each ARU received the start code on deck. Deployments were completed on June 24, 2009. Recovery of the instruments was completed June 26, 2009, with all instruments surfacing. Radio beacons functioned well and pick ups were quick despite 3 to 4-m-high swells. All instruments displayed counts corresponding to data on all four channels.

Line 1 (12 GSC + 10 DAL instruments)

Transit to line 1 was long enough to allow ample time for preparing the battery packs and updating the file headers. Because the full complement of OBS was slated to be deployed, the final Dalhousie OBS (D) was stacked with the least reliable equipment. The instrument had been tested for nine days on the bench and passed. The float was fixed with several wraps of Monel. Pre-deployment and deployment of line 1 passed without incident. The first five Dalhousie instruments are in deep water and the second series of OBS are in shallow water. Those deployed at depths less than 1000 m require a change of the resistor for the receive circuit in the Vemco ARU. All instruments that required the resistor changed were verified to be functioning with an acoustic release code.

During shooting of line 1 it was determined that there was time for additional data acquisition. It was arranged to recover and re-deploy several instruments at the western portion of the line around the shelf break. The scheme involved recovery of the first 15 instruments, then coinciding deployments and recoveries for a total of nine instruments deployed and remaining for additional shooting.

Recoveries began July 3, 2009. The first five Dalhousie OBS were recovered without incident. On July 4, 2009 OBS B was deployed at station 23. The following station was a recovery at station 16 of

OBS I. A long burn occurred and the ARU was shut down to be retrieved later either on the primary or secondary release. OBS C was deployed at station 24. OBS E was deployed at station 25. After a GSC deployment, the Dalhousie OBS at station 18 again failed to leave the seafloor and was left for recovery at a later date. Shooting of the line was completed on July 5, 2009.

Recoveries began July 5, 2009. OBS B at station 23 failed to return to the surface and was left for recovery on the secondary release. OBS C returned to the surface at station 24 and was found to have shut down. The instruments contain an onboard battery backup in case of interruption; it was verified that this backup power source was still functioning. Therefore it is unknown at the time why the instrument powered down before any data was collected; a bug in the software is being investigated. During transit, the ship was called on a search and rescue mission and recoveries were postponed.

Recoveries resumed on the evening of July 6 from the western end of line 1. Dalhousie OBS at stations 20, 19 and 25 were recovered without incident. The ship was positioned for recovery of those OBS left at the bottom.

July 7, 2009 just after 5 am local time, the first OBS (chronological by secondary release time), station 23 was recovered. At station 16, the OBS resurfaced again on the secondary release. Battery voltages were low but not critical as the instrument had written more than 600 files in eight days. At station 18, the pinger did not appear to start as the secondary release time came and passed. The instrument was turned on using the acoustic release and watched for 30 minutes. The allotted time expired without the OBS leaving the seafloor and it was left for dead.

Summary of deployment and recovery

After 49 total deployments in 33 days at sea, Dalhousie University suffered a loss of three instruments. OBS F never returned to the surface and therefore the cause of the on-station long burn and consequent failure of the secondary release will remain unknown. OBS A returned to the surface before the secondary release and was lost due to a malfunction of the ARGOS beacon (premature discharge of batteries). Delayed release is accounted for by material inconsistencies in the burn wire or bottom chemistry. Long burns on line 1 were deemed a result of inhibition of electrolysis due to sediment. Those that returned on the secondary release had burned both loops. The final OBS left on the bottom (OBS L) likely had sediment issues.

7. Airgun Array and Compressors

By C. Borden Chapman and Patrick Meslin

7.1 Array Beam Configuration

The array beam design was based on similar arrays which NRCan has currently in inventory. The prime objective for the new array design was to correct areas where problems occurred in the past, specifically with the 12-gun Bolt array. By correcting past deficiencies it was hoped to minimize down time. Each array supported three 520 cubic inches Sercel Generator (G)-guns. A single G-gun was suspended from the front of the array beam by two 36”, 5/8” anchor chains. At the aft end of the array beam, two Sercel G-guns were suspended below the array beam by four 30”, 5/8” anchor chains. These guns were rigidly separated using the Sercel spreader bar system. Dimensions of the array beam are given in Fig. 12.

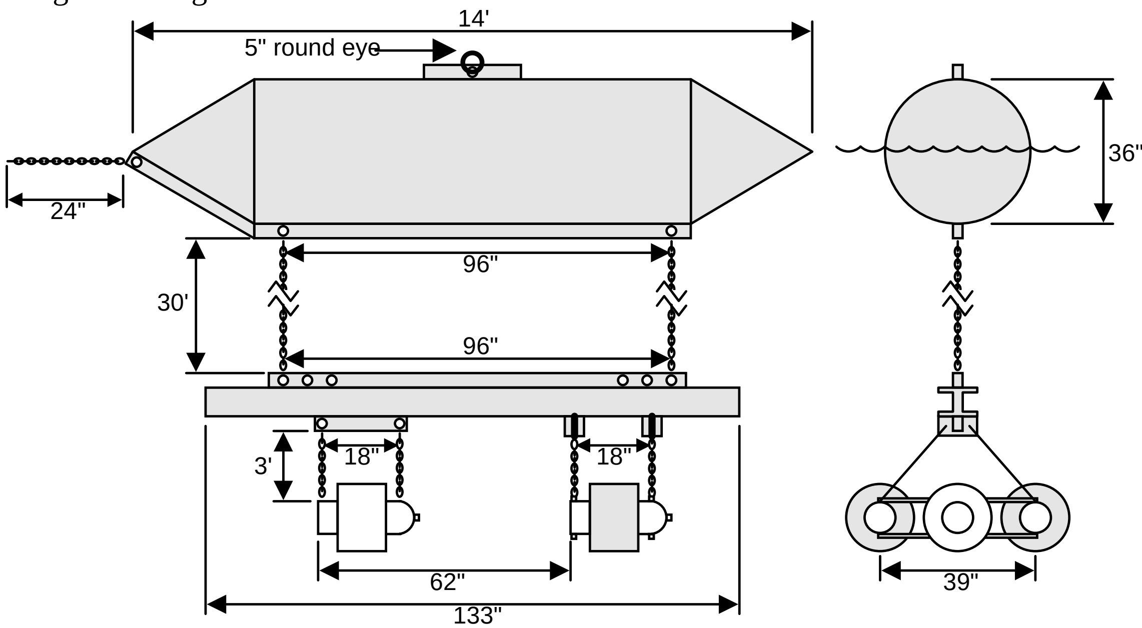

Figure 12. *Pictorial view showing critical dimensions for the three 520-cubic-inches Sercel G- gun array.*

Four steel floats were custom fabricated. Each float kept the respective array beam at a consistent tow depth during deployment. The float was designed to have a buoyancy capacity of approximately 3600 pounds. With the 1150-pound weight of the float, 1500 pounds for the array beam, guns and chain, this left about 950 pounds of positive buoyancy. An 8’ x 35” block of Styrofoam was placed inside each float. In the event the float skin was punctured, the Styrofoam provided 3300 pounds of positive buoyancy, enough to keep the array beam at a constant depth of 34 feet. During the program the port inner float took on water, leaking around the aft cone gasket. No problems with the array beam occurred as a result of the sea water ingress although the float did settle a bit deeper into the water at the rear during towing.

Two 30-foot lengths of 5/8” anchor chain were fitted to the bottom of the float. These chains connected to the top of the array beam. The distance between the two chains was 96 inches. The pull point at the front of each float was fitted with a 2-foot length of 5/8” anchor chain. A 5” steel ring was fitted at the centre of the top of the float. The ring was used to secure the slip hook to the float during deployment and also served as the lift point for moving the floats around the quarterdeck area.

For the two inboard floats, a 146-foot length of 1/2” steel cable was connected to the pull point chain. For the two outboard floats, a 162-foot length of 1/2” steel cable was fitted to the chain at the front of the float. The inboard ends of these four cables were secured to the vessel at specific locations, either on the outriggers for the outer array beams or along the quarterdeck bulwarks for the inner two array beams. These specific lengths of cable on each of the four floats, and the tow points selected on the vessel, ensured the 152-foot layback of the float/array beam during towing operations.

7.2 Sercel G-Gun Towing Geometry

Horizontal spacing between inboard and outboard array beams was approximately 22 feet. There was an approximate 31-foot spread between the two inner array beams. The two outer beams were spaced 75 feet apart. The Sercel G-gun tow depth was 34 feet or 11 m. All dimensions are +/- 2 feet.

7.3 Array Source Level Measurements

NRCan undertook two source level measurement experiments for the G-gun array during the science program. The first program was unsuccessful. Upon preliminary data analysis, it appeared that the calibrated hydrophone drifted closely towards the gun array. When 11 guns were fired, the hydrophone output signal saturated the IKB SCU-6 receiver amplifier and so the data were unusable. Later in the cruise a second attempt using 12 guns was made.

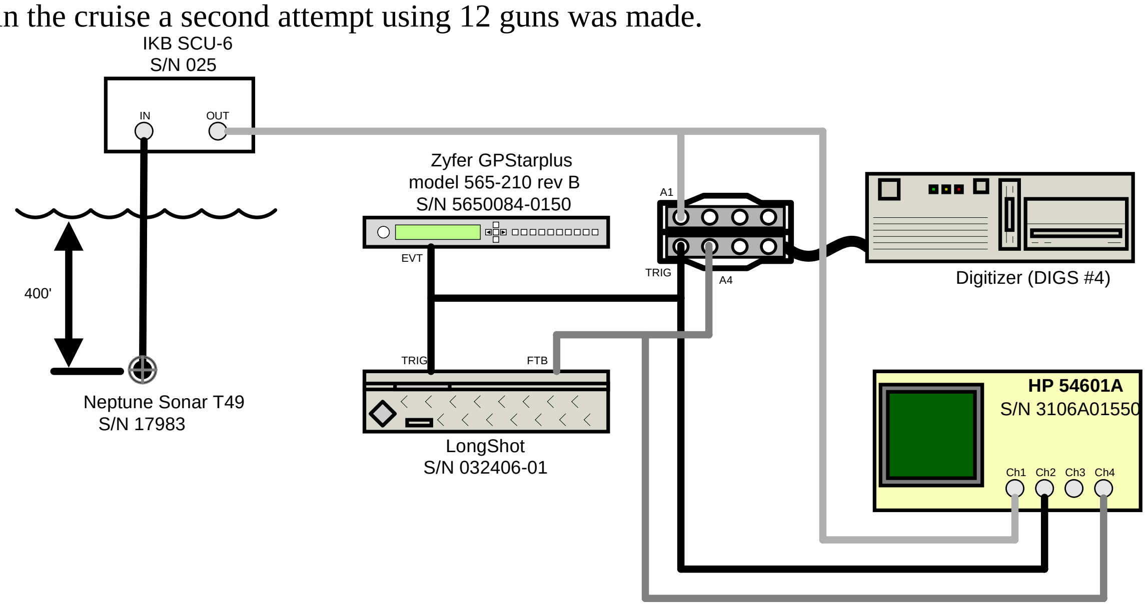

Figure 13. *Calibration equipment for the array source level measurements.*

With the vessel stopped, a Neptune Sonar T49 (serial number 17983) calibrated hydrophone was lowered to an assumed depth of 400 feet below the sea surface at the stern of the vessel. There appeared to be minimal drift back (cable angle) on the hydrophone cable, but exactly how close it drifted towards the gun array must be determined during the processing. The calibration hydrophone was connected to an IKB SCU-6 receiver in the GP lab.

The field time break (FTB) signal is the resultant signal electronically derived from averaging all the analog time break return signals received back from the 520-cubic-inches G-guns when fired. Note, as only eight guns had functional time break (TB) signals processed by the LongShot, four guns were operated in the manual mode. The FTB signal, therefore, was a resultant additive average of eight guns.

Data were recorded onto the GSCDIG number 4 data logger. Channel 1 of the logger was the actual calibration hydrophone signal. Channel 4 was the FTB signal from the LongShot. A one-minute pulse from the Zyfer clock triggered the LongShot and the GSCDIG number 4 data logger simultaneously.

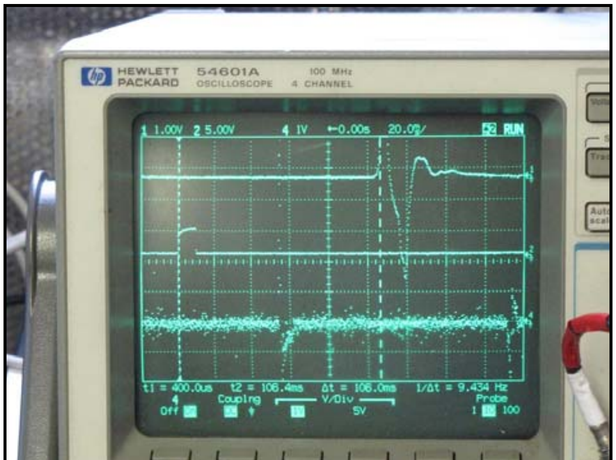

Figure 14. *Oscilloscope showing channel 1, the calibration phone signal, channel 2, the LongShot trigger "time zero" signal, channel 4 showing the fire time break (FTB) signal from the LongShot. Note the time measurement annotations at the bottom.*

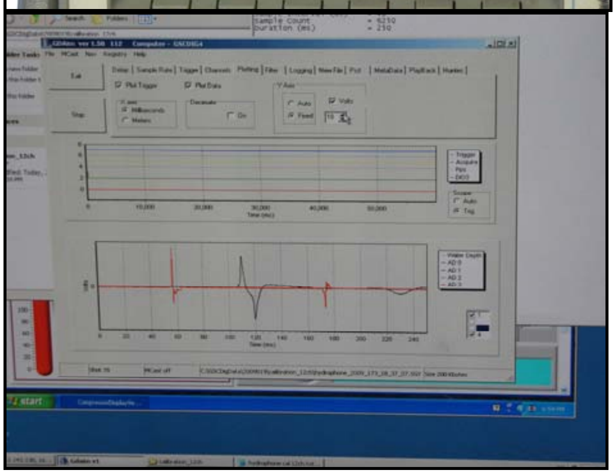

Figure 15. *Screen capture of 12-gun shot during calibration. Red trace is the FTB pulse.*

7.4 Breakout Blocks and Pass-Through Blocks

To secure electrical cables and air hoses to the array beams, an assortment of clamps were custom fabricated. The clamps were designed to bolt to the array beam at specific locations and offered up a method to secure the cables and hoses to the beam. By securely clamping the electrical and air lines to the beam, chaffing was kept to a minimum.

During the program no air hose or electrical line needed replacement due to friction contact damage. Initial costs for the fabrication of the breakout and pass through blocks was high. For the four beams, a total of 36 clamps were constructed at a cost of approximately $12,000 CAD; when considering the lack of maintenance required, it was a wise investment and a sound design (Fig. 16).

Figure 16. *Shown here are two of the nine breakout or pass-through blocks located on each array beam. Those shown are located on the forward port side of the beam.*

7.5 High-Pressure Air Delivery System

NRCan supplied all machinery to provide the steady supply of high-pressure compressed air. Two Hurricane model 6T-276-44SB/2500 air compressors were installed onto the flight deck of the CCGS Hudson. Each of these compressors supplied 1900 psi at 600 cfm of compressed air. The twelve 520-cubic-inch Sercel G-guns in the array were fired every 60 s. Both compressors were skid-mounted, four-stage, diesel-driven, air-cooled machines. Each compressor was enclosed in a 12 foot by 20 foot custom-built shipping container. The ship supplied 440 V AC-3 phase power to the container for light and heat.

7.5.1 Understanding the Hurricane 6T Compressor

Throughout the Hudson program, there were some service issues experienced with the Hurricane compressors. In order to better understand the problems, and how they were solved, a basic description of how the Hurricane compressor functions is given below.

The first stage of the compressor was a rotary screw compressor capable of taking in supply air at atmospheric pressure and delivering outlet pressures of 135 psi to the second stage of the four stage system. The volume of air produced by the first stage screw was controlled by an air-controlled damper valve fitted to the air inlet of the screw. An air/oil mixture exited from the first stage screw compressor at 135 psi and entered the air/oil separator tank. Oil was returned off the bottom of the tank, back to the screw. At normal working loads, oil in the screw compressor reached temperatures of 230° F or more. The oil return line from the separator tank back to the screw had a thermostatic valve fitted. If the screw oil temperature was above 170° F, the oil was redirected through an air-cooled heat exchanger system before it was filtered and returned to the screw compressor. During warm up, the oil bypassed the heat exchanger and returned to the screw directly through the filters.

The second, third and fourth stages of the compressor were a standard piston type compressor. A John Deere (J-D) engine with a modified head design formed this “pumper” stage. J-D block cylinders one and two were paralleled together as the second stage. The outlet air pressure from this “combined” stage was typically 320 psi. The discharge air, typically with a temperature of 250-260° F, was cooled through an air-cooled heat exchanger to approximately 110° F before entering the third stage of the J-D pumper. The third cylinder stage typically produced 830 psi at 300° F and the outlet air was coupled to the fourth stage inlet through an air cooled heat exchanger at an inlet air temperature of 110° F. Outlet pressure from the fourth stage varied depending on the pressure requirement, up to 2500 psi. The fourth stage discharge air was cooled through an air-cooled heat exchanger. Discharge air temperatures were typically in the range of 85 to 120° F.

Hurricane Co. Ltd. fitted a unique control system to the compressor to monitor and control the output air volume. A Barksdale pressure switch, located on the discharge air pressure line, activated when the operator preset discharge air pressure is reached. When operated in the “Auto/ Load” mode, the Barksdale switch would put the compressor into the “unload” condition when output pressure was reached. Electrically the Barksdale switch opens an air solenoid valve (HCPN 62386) applying full control air pressure to the base of the inlet air damper valve on the first stage screw. With this valve closed, the supply of atmospheric air to the first stage screw compressor is cut off. The Barksdale switch also energizes an air/electric coax valve (HCPN 63690). The coax valve opens and returns some of the high pressure fourth-stage air back into the inlet of the second stage. The machine can thus continue to recirculate air trapped in the final three stages of the compressor, holding constant pressure until the Barksdale switch returns the compressor to the “load state” as air demand dictates.

A backpressure valve (HCPN 63140) and poppet valve (HCPN 60938) combination is located on the inlet side of the second stage head. If the inlet pressure on the second stage exceeds 175 psi, the backpressure valve opens the poppet valve, discharging second stage air to atmosphere.

A blow down valve (HCPN 125-36192) is located on top of the air/ oil separator tank. This is a two-way NC valve that is used to bleed excessive pressure to atmosphere out of the air/oil separator tank during unloading cycles and also serves to allow pressure to build quickly during start up as the air/oil tank was the source for the control air pressure for the compressor.

The J-D Pumper stage is directly coupled to a Caterpillar C13, 440-hp diesel engine through a short drive shaft. The rotary screw is driven off the input shaft for the J-D pumper by a serpentine drive belt and tensioner system. NRCan staff have had repeated problems resulting from failure of the universal joints on the drive shaft. After approximately fifty hours of service during the Hudson mission, the forward universal joint on the Hurricane Compressor number 1 (HC #1) drive shaft failed. The defective drive shaft assembly was removed and replaced with a rebuilt unit and the defective drive shaft was repaired and returned to spares. As the Hurricane compressors were air-cooled, no cooling water was required from the vessel.

While the drive shaft replacement for HC #1 was underway, Hurricane compressor number 2 (HC #2) was brought on line. It was soon noted by the watch keepers that the machine was not producing the same volume of air as HC #1. It was necessary to run HC #2 at maximum rpm to produce the volume of air required to maintain a constant air pressure of 1860 psi at the time of firing of the array. The machine had to be run approximately 30% higher to give the equivalent volume of air.

NRCan and contract technicians spent considerable time trying to diagnose the reason for the reduced air volume production from HC #2 vs. HC #1. After much review, a call was made to Scott Ferguson, service manager at Atlas Copco/Hurricane in Indiana. It was learned from him that the documentation provided by Hurricane at the time of the compressor purchase had several errors in the text. These errors were with regard to the set point pressures for: (1) the back pressure valve controlling the air supply to the inlet damper on the screw and (2) the back pressure valve mounted on the second stage of the machine. Specifically, the running/blow-down regulator (HCPN 63918) for the inlet damper valve control should be set for 165 psi, (not to150 psi as indicated in the manual’s air distribution schematic). The back pressure valve (HCPN 63104) and associated poppet valve (HCPN 60938) on the second stage inlet should be set to 175 psi as indicated in the manual’s pictorial image (not to the 150 psi as stated in the manual’s air distribution schematic). The machine functioned normally after proper adjustments were made to these valves.

The Hurricane compressors were constructed using rigid piping between stages and intercoolers. There were operational problems and safety concerns resulting from past failures in the piping and fittings due to internal machine vibrations. To try and overcome issues in obvious areas where previous failures had occurred, flexible piping was fitted. This work was completed prior to the CCGS Hudson sailing date. At this time, additional supports were custom-designed and fitted to the piping where the flex hoses and rigid piping mated. The "plumbing" changes greatly reduced the problems associated with machine vibrations and reduced the down time which resulted from pipe failures. Additionally, whipping wire was installed onto the flex hoses to prevent damage or personnel injury if hose failure occurred. During the program, a safety barrier was constructed and fitted to the machine. This lexan shield isolated a specific area of the compressor where the majority of the new high-pressure piping was fitted. While at sea, specific areas where piping vibration occurred were addressed. To reduce the chance of component failure, additional supports were fabricated and fitted to the piping in these areas.

7.5.2 Hurricane Compressor Number 2 Rotary Screw High Heat Issues

The screw oil in stage one of HC #2 was running approximately 20° F warmer than HC #1 under identical load. The thermostatic valve was replaced on HC #2. Additionally the outlet duct work on the plenum was removed. Ambient air temperatures lowered several degrees during the work. All three changes served to lower the screw oil temperature to the normal 190 to 230° F range. When running the compressors at ambient air temperature of 8° C, 70 to 75% diesel load at 1650 rpm, and 1950-psi discharge pressure, the screw oil temperature should be approximately 210° F.

7.5.3 National Instruments Controls

A new PC-based electronic control system was fitted to each of the compressors as part of the preparations for the CCGS Hudson program. The purpose of the system was to: (1) replace the manufacturer's mechanical system with a more advanced compressor status monitoring system, (2) provide remote location status monitoring, (3) improved watch keeping console, (4) a remote enunciator system, and (5) statistical log file generated on the hour.

During the winter months of 2008/2009, a PC-based, National Instruments monitoring system was installed. During operation, the monitoring system constantly scanned major compressor functions such as inter-stage air pressures and temperatures and Caterpillar diesel engine status. If a fault was detected, the system shut down the compressor. When this occurred, the PC software displayed what fault precipitated the shut down. Compressor status readings were logged to a text file each hour. The files were saved to the onboard hard drive. The status files were downloaded via the ship's network and saved as part of the data set for the science report. Functions such as inter-stage pressures and temperatures along with diesel engine parameters were saved to this file.

A software package called Virtual Network Control (VNC), when run on a PC connected to the ship's network system, allowed operators to remotely monitor the Hurricane compressor functions. This proved useful during compressor operations especially for the engine room staff that refuelled the machines. Average fuel consumption for each machine was 15.7 gallons per hour. The fitted Hurricane fuel tank had a capacity of 175 US gallons. This meant that fuelling intervals averaged 6 to 8 hours during the gun work. Seven suggestions have been put forward to add or correct small program bugs, but generally the Hurricane monitoring software passed the first major test without problems.

7.5.4 Short Circuit in Hurricane Compressor Number 2

On Julian day 180 (June 29), a short circuit occurred inside the HC #2 control cabinet. Insulation on a 12-V DC supply wire from the Hurricane battery chaffed, shorting to ground. This occurred as a result of machinery vibration. This caused a significant amount of damage to the wiring. The majority of the cabinet's internal Cat diesel wiring had to be cut away and replaced. During this repair, HC #1 was put into service. The problem with HC #2 cabinet wiring was repaired and an inspection showed a similar situation could exist in the HC #1 cabinet. Additional wire dressing was added in the area where the chaffing occurred. A 20-A circuit breaker was added to the 12-V DC battery feed and a 15-A breaker was added to the 24-V DC battery feed for both compressors. If a battery short occurred again, either circuit breaker would open thus preventing any internal wiring damage. Throughout the science program, no lost time for data collection occurred as a result of compressor maintenance or failure issues.

7.6 Air Reservoirs

Four air reservoirs were fitted to the quarterdeck area. These reservoirs served as control stations for each of the four array beams. At each station, the operator could control the supply air to three Sercel 520-cubic-inches guns. The Hurricane compressors supplied high-pressure air at 1900 psi to the four reservoirs. The inlet side of the four reservoirs was plumbed in parallel with a common 3/4" Synflex air line. By manipulating specific valves and observing the gauges on each of the four reservoirs, the operator could monitor the outboard or "wet end" of the array for air leaks at the guns or in the air hose bundles.

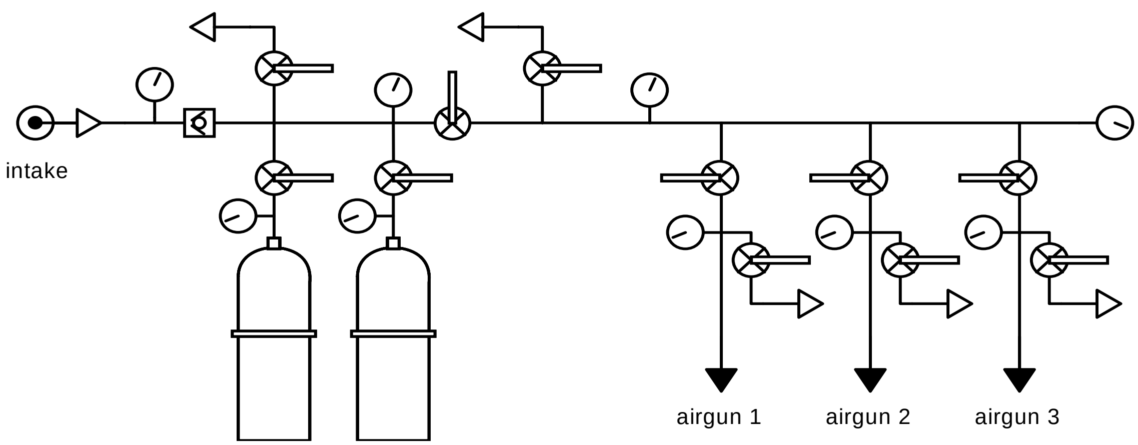

Figure 17. *Pictorial representation for one of four air reservoir tank systems.*

7.7 Air Bundle Supply and Electrical Lines

High-pressure air from the air reservoirs was delivered to the G-gun array beams using two sets of identical air-hose bundles. The hose bundles were constructed from three 3/4" 3R80-12 Synflex air-hoses and a single 1/2" 3130-08 Synflex air-hose. Inside the 1/2"-hose was a length of 3/8" steel cable running the entire length of the hose. At either end of the steel cable, a hard eye was fitted. The hard eyes connected to the tow point on the array beam and to the vessel tow point. As the steel cable rides freely inside the 1/2"-Synflex hose, the entire air-hose bundle is supported by the steel cable and, therefore, there is no strain on air or electrical lines during towing operations.

Each of the four Synflex air-hose bundles was wrapped in a removable plastic spiral-jacketed product called Omniwrap. This product offers excellent protection from chaffing between the air lines, electrical cables and steel recovery and float pull cables. Two of the air-hose bundles were fabricated to a length of 175 feet; two were 152 feet in length. The shorter bundles were used for supplying air to the two inboard G-gun arrays while the longer bundles, towed off the quarterdeck outriggers, supplied air to the two outer G-gun arrays. Overall, the four arrays were towed approximately 150 feet behind the vessel.

Considering only one of the four array beams: Each array beam had three Sercel G-guns fitted. Each G-gun required a two-conductor electrical cable for the solenoid trigger pulse and a two-conductor cable for the time break signal. For each array beam, three separate AWG#16 two-conductor A-G geophysical cables ran from the quarterdeck to the array beam. The three time break (TB) cables were connected to an A-G Geophysical combiner splice on the array beam, which delivered the three signals up a common eight-conductor A-G Geophysical cable to the junction boxes on the quarterdeck. Two conductors in the eight-core cable were not used. Each beam had, therefore, a small bundle of electrical cables consisting of three solenoid firing-cables and one cable for the three Sercel G-gun time break return signals. Each array had separate electrical bundles. Each bundle was loosely taped together at approximately six-foot intervals.

During array deployment, the electrical cables were loosely attached to the air-hose Omniwrap at six-foot intervals. On recovery, the tape attaching the electrical cables to the air-hose bundle was cut free. The electrical cables were stowed on deck separately from the hose bundles.

Figure 18. *Starboard air-bundle cables, electrical lines and recovery wires.*

7.8 LongShot G-Gun Controller

For the CCGS Hudson program, a Real Time Systems LongShot gun controller was used. This specific controller was configured at the factory to synchronize eight guns, not twelve as was used in the NRCan array. This posed a problem initially as the technical staff were not aware of the eight-gun limitation. They spent some time trying to resolve the issue as to why the controller would not process four of the twelve G-gun time break signals. Once the configuration was recognized, the delay timing for the four guns was preset to a calculated average derived from the delays of the other eight guns. This did not appear to have any appreciable effect on the signature of the twelve gun array. The calculated delay for the four G-guns was manually entered into software on an hourly basis by the watch keepers.

Each gun is equipped with a trigger solenoid and time break solenoid, key components for controlling the firing and synchronizing of the G-gun array. The Sercel G-gun was triggered by the trigger solenoid that receives a pulse of 75 V DC for 25 ms from the LongShot controller. When the solenoid opens, it releases air pressure in the fill chamber of the G-gun. When this pressure is released from the chamber, the shuttle is thrown open and the gun fires. At the release of the air pressure, a time break (TB) signal is sent back to the LongShot controller. Knowing the time difference between the solenoid trigger and the returned time break signal, the computer calculates the time it takes to mechanically fire the G-gun.

The LongShot controller program continuously monitors the firing status of each gun. The software will, after a series of shots, calculate appropriate delays for each gun in the array. By precisely controlling the time of electrically firing each gun, and taking into account the mechanical delays in the gun, the controller software ensures that all the array guns fire at precisely the same instant in time, maximizing the peak energy amplitude of the array signal.

The shot time interval and the shot trigger pulse were generated by a Zyfer GPStarPlus time and frequency system. An identical clock also was used to calibrate the clock drift rates of each ocean bottom seismometer (OBS). At the request of NRCan, the DOS-based LongShot software was modified by the system's manufacturer to generate a shot point status file on receipt of every trigger pulse. The file would "grab and store" LongShot status parameters such as the number of guns, preset and calculated G-gun delays, other LongShot system parameters and most importantly a precise time stamp derived from the Zyfer GPS time clock. The LongShot binary data file required some reformatting to recover the data into a useable format that could then be imported into a spreadsheet file. This was the first time NRCan has had access to a shot file while conducting a refraction program.

Prior to the start of the science program, improvements were made to the LongShot time break and solenoid deck wiring. Weather proof boxes were affixed to each air manifold rack on the quarterdeck. These four junction boxes served as electrical connection points for the "wet end" wiring from the four array beams and the wiring which ran into the GP lab patch panel.

7.9 Conclusions

Apart from the minor water ingress into the port inboard float, no structural issues arose during towing operations. The design of this tow system offers up a dependable platform for towing three Sercel G-guns. No further design modifications for future science missions are planned prior to future redeployment of the array beams.

The complicated procedures for deployment and recovery of the 12-gun array are severely amplified by weather and sea conditions. The procedures involve lots of overhead and over the side handling of extremely heavy pieces of equipment. For future operations, scientific staff must be aware of the ship's handling gear, the competency of the crew, and the vessel. If any of these factors are unknown, it would be best to leave the gear where it is until weather improves.

The array float gaskets should be removed and the floats re-sealed using the method as described in the body of this report.

Ongoing Hurricane compressor issues still plagued technical staff. There were no major breakdowns but many small problems kept day working technical personnel busy throughout the science program. It is clear that overheating of the Hurricane compressor rotary screw stages will be an ongoing issue when these machines are used in warmer climates. It is recommended that the compressor heat exchangers be exhausted through a new, larger plenum system. It may be necessary to completely remove the existing plenum and exhaust the warm air directly through the end of the container rather than through the container roof.

Figure 19. *Image showing the four surface floats towed from Hudson's quarterdeck area.*

The LongShot control system functioned well with the exception that the internal configuration of this particular controller was not equipped to control more than eight G-guns. Because there are extremely small time shifts between the G-guns when fired, the manual setting and control of the firing time had no measurable impact on the array signature. For future work however, additional control boards must be purchased to allow full array synchronization.

For future reference also note that the shot file name cannot accept a "." in the log file name (1.1A for example).

The port inboard tugger winch requires new internal brake discs installed before being put back into service.

The new machine shop was, without doubt, an excellent investment made by NRCan. However without the skills of a trained machinist or welder, having it onboard the vessel will be of limited benefit to any future science program.

8. Sonobuoys

By C. Borden Chapman and Patrick Meslin

Throughout the program, a total of 29 modified sonobuoys were deployed. The manufacturer reworked the hydrophone elements in the standard military buoy and extended the low-end frequency response to make the AN/SSQ-53D buoys acceptable for seismic refraction work.

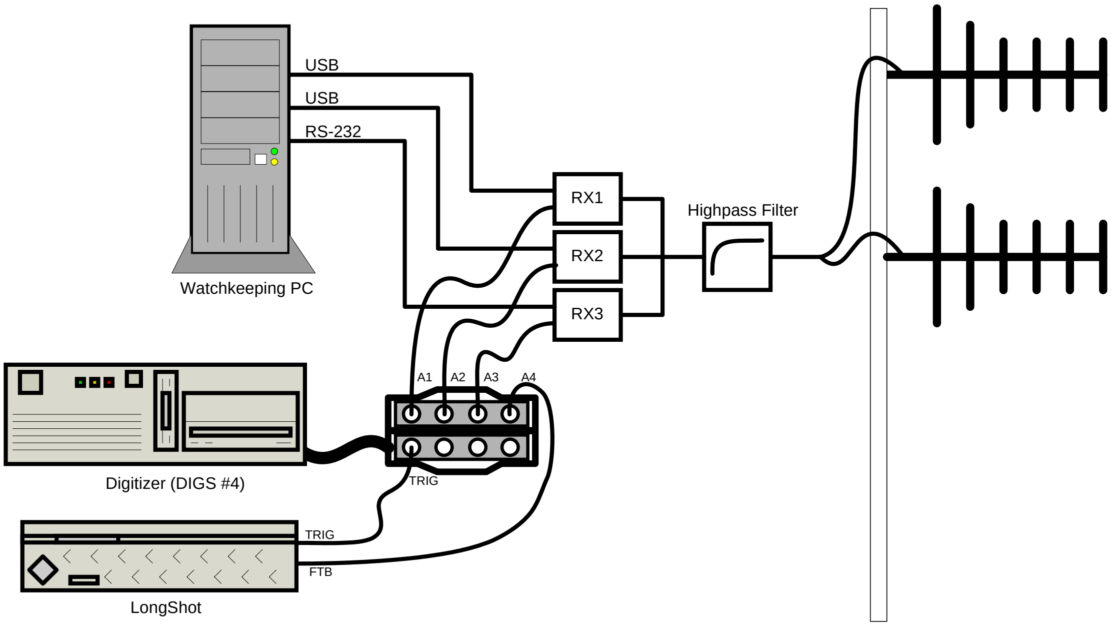

Figure 20. *Pictorial of sonobuoy receiver and control equipment.*

Two Andrews Yagi antennas, specially cut for frequencies from 150 to165 MHz, were mounted to the after mast of CCGS Hudson prior to departure. The uppermost antenna was approximately 75 feet above sea surface. The antenna spacing distance on the mast, centre to centre, was 56 inches. An antenna combiner was connected directly to the antennas at the mast, then connected to 150 feet of rigid coaxial cable and run to a high-pass filter located in the GP lab. The filter was used to eliminate ship's low frequency RF emissions at the receiver input. The output of the filter was split and supplied the RF input to three sonobuoy receivers.

A standard PC ran control software for the three WinRadio receivers. Two receivers were connected to the PC's USB ports, the third was serially controlled. Analog output of the receivers was connected to channels 1, 2 and 3 of the GSCDIG number 4. Channel 4 of the GSCDIG number 4 recorded the fire time break (FTB) from the LongShot. The trigger pulse for GSCDIG number 4 was the same pulse that initiated the LongShot system to fire the G-guns. Settings for the GSCDIG are found in the Excel spreadsheets for each sonobuoy deployment.

During the program eight sonobuoys failed to operate properly. Several issues could have caused these conditions. Possible issues were:

- Sonobuoy was damaged during deployment caused by impact with the sea surface.
- Sonobuoy was damaged when the case or parachute came into contact with the towed gun array.
- Sonobuoy hydrophone became entangled with the towed gun array during release.

- The buoys were two-years old. There could be a problem due to age. (Not supported by OEM, 4 years minimum shelf life).

9. Navigation, Data Distribution and Processing

By C. Borden Chapman and Patrick Meslin

The data streams required by the various systems in operation in the GP lab were provided through the ship's serial data distribution network. Differential GPS navigation was provided by the science Novatel receiver. NMEA sentences from this system were multiplexed to the ship's speed log, gyro and ELAC sounder NMEA sentences and distributed to the GP lab via the serial network.

The navigation data were cleaned and merged using a text editor and the standard GSCA programs ETOA, INTA and APLOT. Raw E-format, raw A-format and cleaned and edited 10-s A-format files were saved on a daily basis and transferred to CD for archiving. All seismic, sonobuoy, Knudsen bathymetry and bathythermograph data as well as their related log files were also backed up to DVD for archiving. In addition, the compressor watch keepers maintained paper records of their observations. These were reviewed on a daily basis and transferred to digital spreadsheets and archived along with the automated logs from the compressor control computers. A digital log of the daily operations as well as the OBS and sonobuoy settings were maintained around the clock by the watch keepers and archived. The bridge officer also maintained written logs of the operations, which were turned over to the chief scientist at the end of the cruise.

The Regulus navigation system, running Build 4.8.21 of the software, was used to view and log the scientific navigation. Some inconvenience was encountered due to a problem with the Regulus navigation system, which caused it to slow down over time. Regular re-starting of the program appeared to correct the problem. After several attempts to identify the source of the problem, it was eventually attributed to the computer's virtual memory setting. The amount of virtual memory available had artificially been set. The problem disappeared when the settings were changed to allow the system to manage the virtual memory. All other systems operated without problems. A computer adjacent to the navigation computer was used for controlling the sonobuoys through a bank of three radio receivers. This computer was also used for data entry into the various electronic logs. The GSCDIG number 4 system was used for digitizing and recording the analog sonobuoy signals.

A new feature was added to the compressor control program that automatically logged various compressor parameters. The text files produced were easily imported into an Excel spreadsheet for manipulation and viewing. This feature, still under development, operated well and with some minor refinements is ready for full implementation. Because the date/time format settings were different on the two computers, HC1 opened a file named after the day of the week to record the data while HC2 was opening a file named after the date. This resulted in each computer having a different logging method and HC1 appending data to a previous file depending on the day of the week. This made it more difficult to identify time based data from HC1 after a couple of weeks as the data were all strung together between weeks. Once the time/date settings were made identical on both computers the logging became consistent across both computers and was solely based on the date of the recording.

The following recommendations are made:

- Repair Knudsen computer to enable it to recognize USB devices.
- Modify compressor control program to enable logging of the data every 15 minutes rather than the present 60 minutes.
- If possible, modify compressor control program to insert a blank record if the compressor reopens a previous data file. This would make it easier to quickly establish if a break exists in the data collection because of a compressor shutdown.

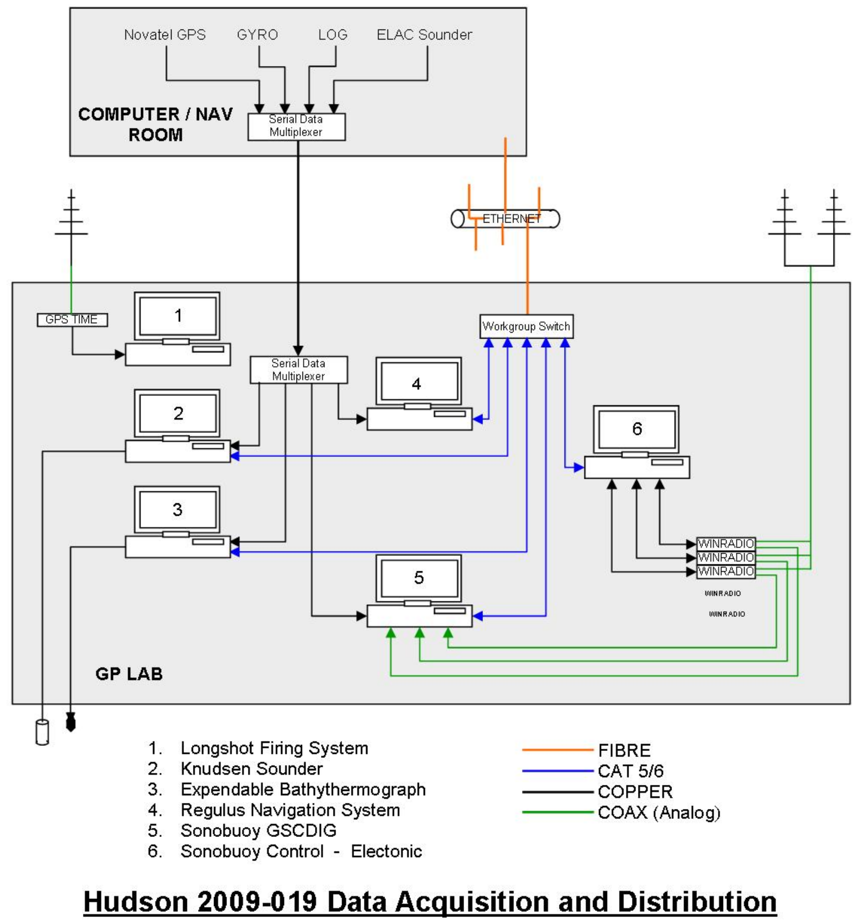

Figure 21. *Routing of navigation feeds for equipment located in the GP laboratory.*

10. Echosounder (ELAC and Knudsen)

By Marcel Ruhnau and Thomas Funck

CCGS Hudson is equipped with two echosounders. The ELAC sounder generates an acoustic signal with a frequency of 30 kHz. For the calculation of the water depth that is distributed in the navigation system, a velocity of 1463 m/s is assumed and the depth is displayed in meters below the transducer (which is ca. 6 m below sea-level).

The Knudsen sounder can be operated in two modes, either with a 12-kHz or a 3.5-kHz acoustic signal. This lower frequency, compared to the ELAC, results in a deeper sub-bottom penetration. For the calculation of the water depth, a velocity of 1500 m/s is used; here, also, the depth refers to the depth below transducer. The transducer is mounted on a 2-m-long ram that can be lowered beneath the ship. With that, the depth of the transducer below sea-level is either 6 or 8 m. During the SIGNAL cruise, the Knudsen sounder was operated in the 3.5-kHz mode with the ram lowered during the seismic operation, with exception of the period of OBS deployment on line 3.

During OBS deployment as well as during shooting, both the ELAC and Knudsen sounder were turned on. For the OBS recovery, the Knudsen system was shut down during the OBS release process in order to prevent interference with the release signal.

The water depth obtained from the ELAC system was generally not reliable for water depths >2500 m. In contrast, the Knudsen sounder was functional at all water depths. During the airgun shooting, the Knudsen signal was recorded in SEGY format. During other times, the sounder was only used in the display mode.

The SEGY files from the Knudsen sounder were processed onboard. With Seismic Unix software, the depth, location (longitude, latitude) and time were extracted to a file that was subsequently edited to remove erroneous values using Matlab software. In a first step, the recorded depth was visualized to get an overview of data outliers/spikes (Figs. 22 and 23). After dividing the line into small sections of nearly constant depth, a maximum and minimum depth were chosen manually for each of these sections. Values outside this depth-window were eliminated. Afterwards a final visual control was performed to locate some erroneous values that were not detected in the previous step and were deleted manually (Fig. 24).

The largest data outliers happen to be in the deeper regions. See for example the data that were collected on line 1 (Figs. 22 and 23), where there are more of these outliers in the deep (>1500 m) northeastern part than in the shallow (mostly around 300 m) southwestern part. Some of these outliers occur at quite regular intervals and plot on parallel lines (Fig. 23). In case of the deep region on line 1, every 15th sounding was offset on such a parallel line. As the gradient of these parallel lines changes with varying depth windows, the effect might be related to internal problems with matching up the signal correctly to the chosen depth window.

A second effect of changing the Knudsen´s depth window is the occurrence of depth-jumps. An example for this is the 150 m depth-jump on line 1 at 50.05°N (Fig. 23), which happens right after changing the size of the depth window from 0-3000 m to 2000-4000 m. These depth jumps were not corrected onboard, neither are there any corrections made for the transducer depth nor for the real water velocity.

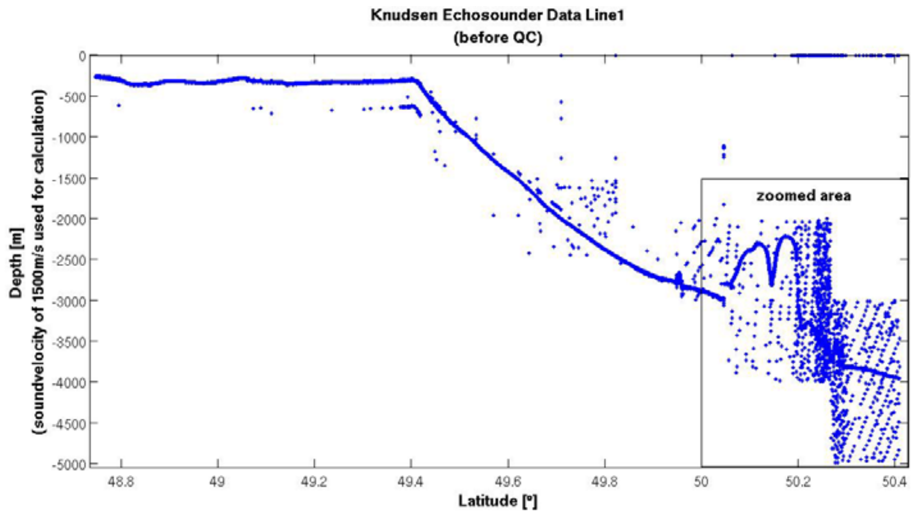

Figure 22. *Raw depth data from the Knudsen echosounder on line 1.*

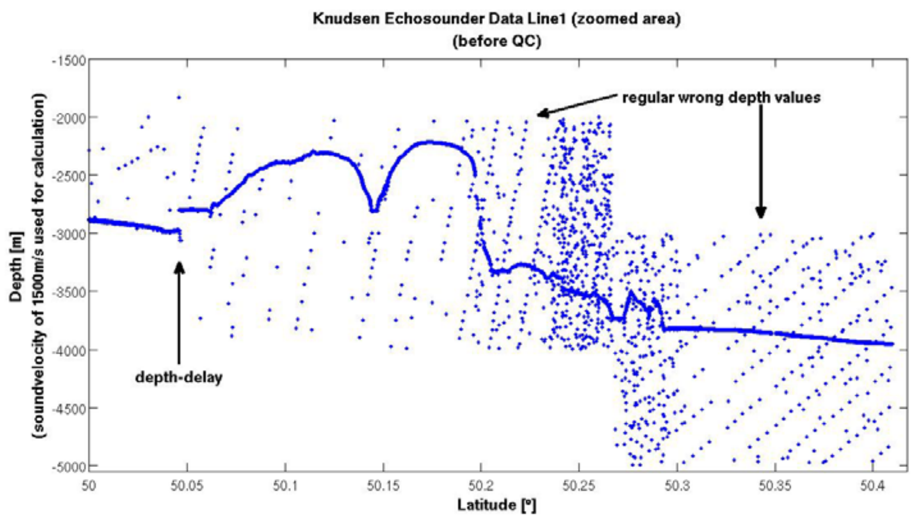

Figure 23. *Raw depth data from the Knudsen echosounder on the deep portion of line 1. Note the depth jump at 50.05°N that occurred when the depth window on the echosounder was adjusted.*

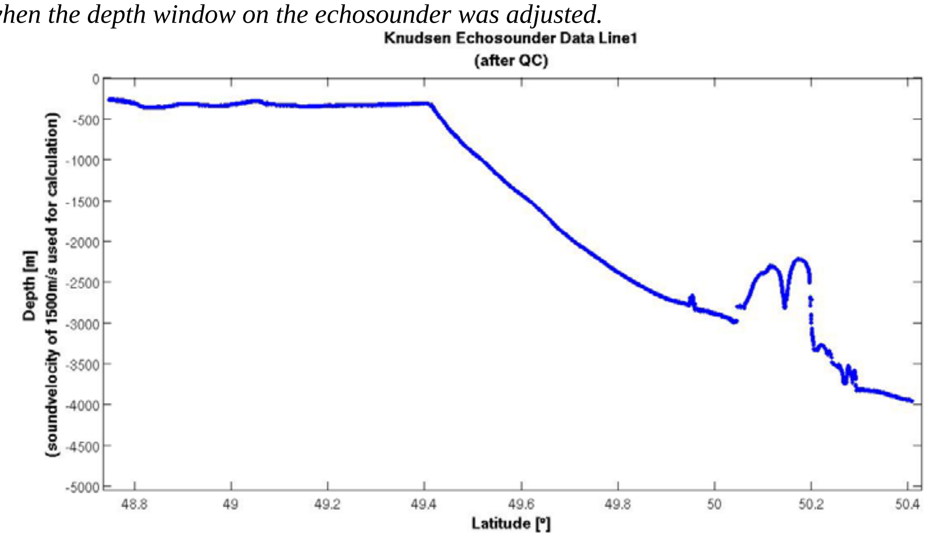

Figure 24. *Cleaned and edited depth data from the Knudsen echosounder on line 1. No corrections are made to address the depth jump at 50.05°N.*

11. 3.5-kHz Sub-bottom Profiling

By Matthias Delescluse

The Knudsen echosounder outputs two different kinds of files: (1) KEB and (2) SEGY files. The **KEB** file format is a proprietary, compressed binary format. It can only be opened by the Knudsen software PostSurvey 2.34 (available on the company website). From the PostSurvey software, the KEB files can be converted to standard SEGY files or to BMP images. Header values, like the depth of the seafloor, can be extracted to an ASCII file. The data in these files are recorded with a ~4ms sample rate, which does not allow the proper imaging of the sub-bottom features. KEB files are used for seafloor bathymetry only and sub-bottom imaging requires the SEGY output.

SEGY files are stored in big endian format, with the amplitudes saved as two-byte integers. The sampling rate is 48 μs and theoretically allows the proper display of the 3.5-kHz echosounder data. However, the files are not standard and several problems can occur when trying to read them:

- The trace length and the sample rate can vary from trace to trace (this is also the case for SEGY files converted from KEB files).
- The traces do not show a correct two-way traveltime for the seafloor because the recording is limited to a time window when the depth implies the recording of too many samples. The zero-time of the traces is actually one or several times the window length.

Even with this windowing, the number of samples can reach 65534, which is two times the maximum of the SEGY standard. For this reason, these files cannot be read with Seismic Unix software. The frequency spectrum shows a maximum frequency of ~5 kHz, which allows resampling of the data to 96 ms for Seismic Unix processing or display.

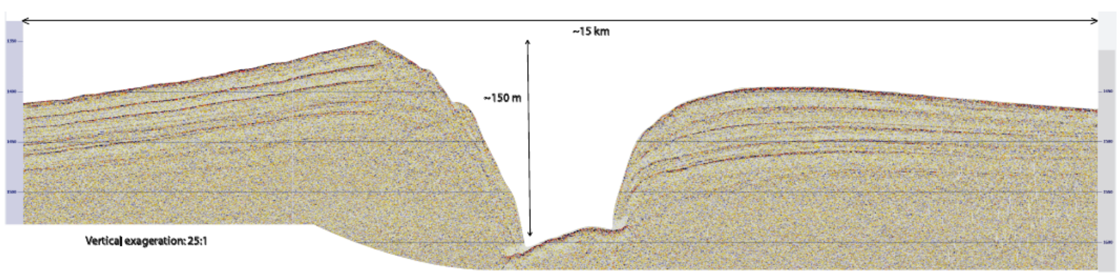

Figure 25. *Record section of the 3.5-kHz sub-bottom profiler (Knudsen) on line 4, showing a channel. The processing includes debiasing and automatic gain control (AGC) with a 20-ms window length.*

12. Shot Tables

By Matthias Delescluse

The time and position of every shot is recorded in a text file (LineX.slog) obtained from a VI program. This program extracts a GPS character string for every shot time break through a serial port. The shots are triggered every minute but there is a delay of 56 ms between the trigger and the time break. This allows fine tuning of the guns' synchronization (i.e. one or several of the guns can be triggered earlier if necessary, which would not be possible without an initial delay).

The GPS character string includes a very accurate timing but the geographical position is for some reason different from the ship's navigation (see section 9). The positions written into the shot log files correspond approximately to the ship's navigation some 18 s before the shot trigger. As a result, the position has to be extracted from the official ship's navigation and merged with the shot table.

Post-processing of the shot-log file is necessary to correct two kinds of problems that randomly occur during shooting:

- Some lines in the file correspond to non-existent shots. Those are easily detected by a non-zero number of seconds (real shots are always at the full minute mark).
- Some shots appear to be written twice, when two consecutive lines in the file have the same time string. However, these lines are always followed by a missing shot (the next line has a time string two minutes later than the two previous lines).

Actually, the second line (see example below) corresponds to the apparently missing shot, with a coherent position between the shots S and S+2.

S	j. Day	h	m	s	1/10 µs	°lat	'lat	°lon	'lon
1046	175	18	33	00	0542108	57	36.0545 N	51	51.9099 W
1047	175	18	33	00	0542108	57	36.1183 N	51	51.9938 W
1048	175	18	35	00	0542091	57	36.1864 N	51	52.0765 W

A UNIX awk script is used to solve these problems. The lines corresponding to non-existing shots are removed automatically and the shot numbers (S in the example above) are changed accordingly.

The script also indicates where the second kind of problem occurs. Manual correction is then required for two reasons: (1) The problem usually does not occur more than ten times every 1000 shots and (2) it can be verified that the problem is really similar to the example above.

In this example and for all similar cases, the problem is solved by simply increasing the minute string by one. It is clear for such shots that the real time break is lost, because the fraction time string (0.1 µs accuracy) is also the same than for the previous line. However, keeping this time string as it is does not cause any problems because from shot to shot, this fraction time remains the same within a few µs; a difference well below the OBS sample rate. However, exceptions to this cannot be excluded and this is another reason for manual correction (after automatic detection).

13. Test with Different Array Sizes

By Thomas Funck

In order to have an estimate on the signal strength of the airgun array using a different number of airguns, a short test was performed using six, nine, and twelve of the 520-cubic-inch Sercel G-guns. This way it can be estimated when the airgun array should be recovered for repair in case too many guns fail. In addition, not all vessels may be able to deploy the full 12-gun array. Hence, such a test can indicate the minimum number of guns required to have adequate data quality.

On line 1 at the start of shot line 1A, only six of the G-guns were used initially on a westward course. The ship turned after ca. 1 h, and the number of guns was increased to nine. After another hour, the full 12-gun array was used. With the shots from line 1, this particular segment of the line was covered with six, nine, and twelve guns. Fig. 26 shows these three segments embedded in the normal record section shot with twelve guns. This comparison shows that amplitudes weaken considerably when six guns are used. As recommendation for crustal-scale type seismic studies, the array should consist of at least nine G-guns.

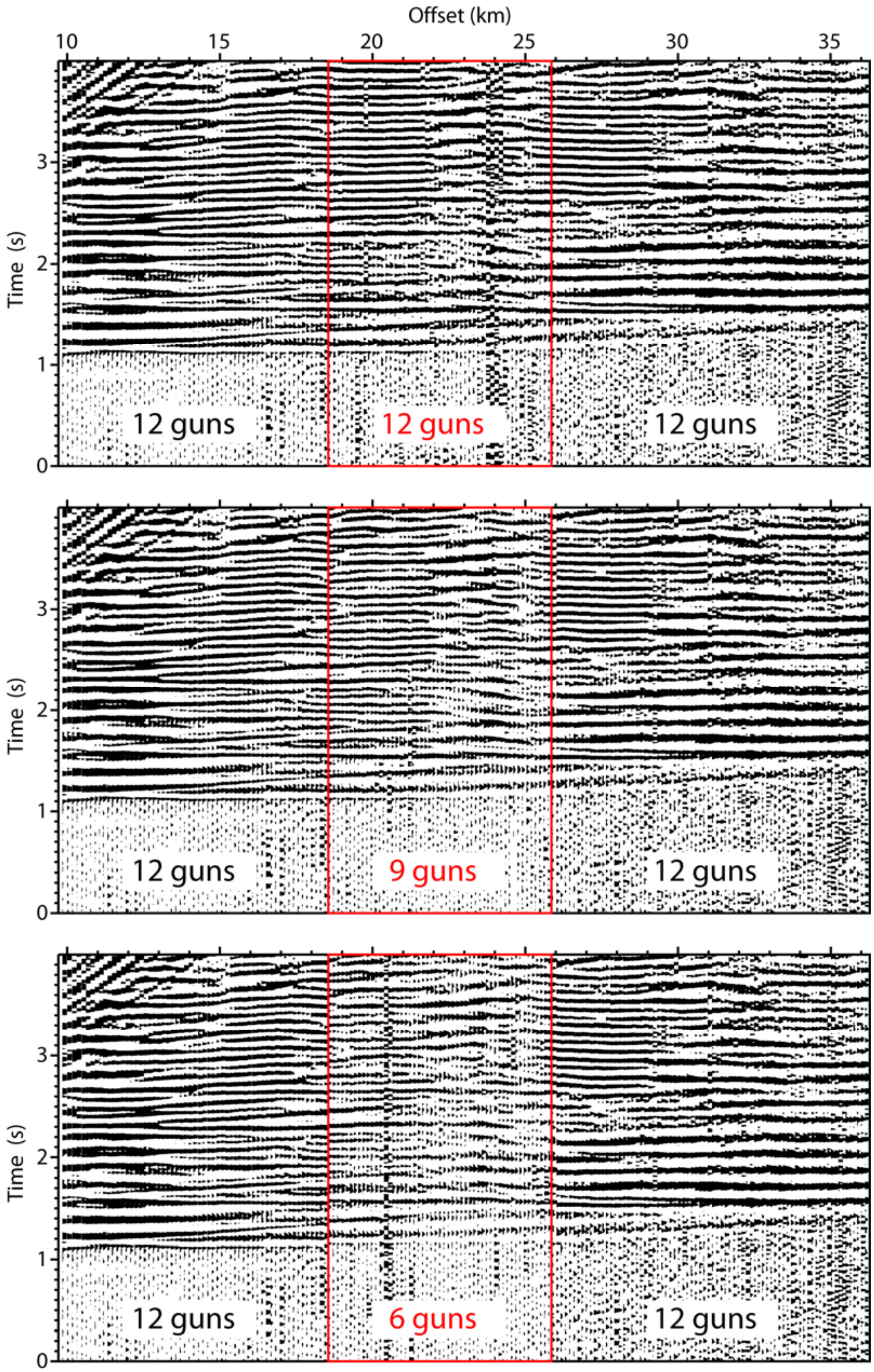

Figure 26. *Record section of OBS 21 on line 1. Upper panel, entire line is shot with 12 G-guns; middle panel, the centre part of record is shot with nine guns, the remainder with 12 guns; lower panel, centre part shot with six guns, remainder with 12 guns. Processing includes debiasing, a bandpass-filter from 5 to 24 Hz, and trace scaling by range.*

14. Onboard Seismic Processing

By Thomas Funck

No full-time dedicated person was available to perform onboard seismic processing. However, some initial data processing of the OBS data was carried out for data quality purposes. Shot tables were created that included the corrected shot time (that is with the gun delay of 56 ms). Shot-receiver distances were calculated from the position of the GPS antenna; no corrections for the offset between the antenna and the centre of the airgun array were applied. No drift corrections for the OBS clock were performed. Shots with a record length of 60 s were extracted from the raw data files by means of the program "dobs2segy" (Deping Chian, GSC). These raw SEGY files (in 2-byte short integer format) are not archived by the GSC, but a copy was given to the GEUS databank for future reference.

Upon initial quality control in the program Seiswide (Deping Chian, GSC), it was noticed that all GSC OBS have a static time error by one second (the OBS clock is one second behind the GPS clock). This error is probably software-related and is not mentioned in section 5 (GSC Ocean Bottom Seismometers). It was also noticed that many records need to be debiased before display. Overall the data quality is very good with exception of those instruments that had technical problems. The only issue that is observed on a number of records is a strong mono-frequent noise (between 5 and 6 Hz) that was also observed on earlier experiments (for example the 2001 SMART cruise and the 2003 NUGGET cruise). The record section displayed in Fig. 27 shows that the new 12-gun Sercel G-gun array has enough power to observe seismic energy up to distances of 160 km.

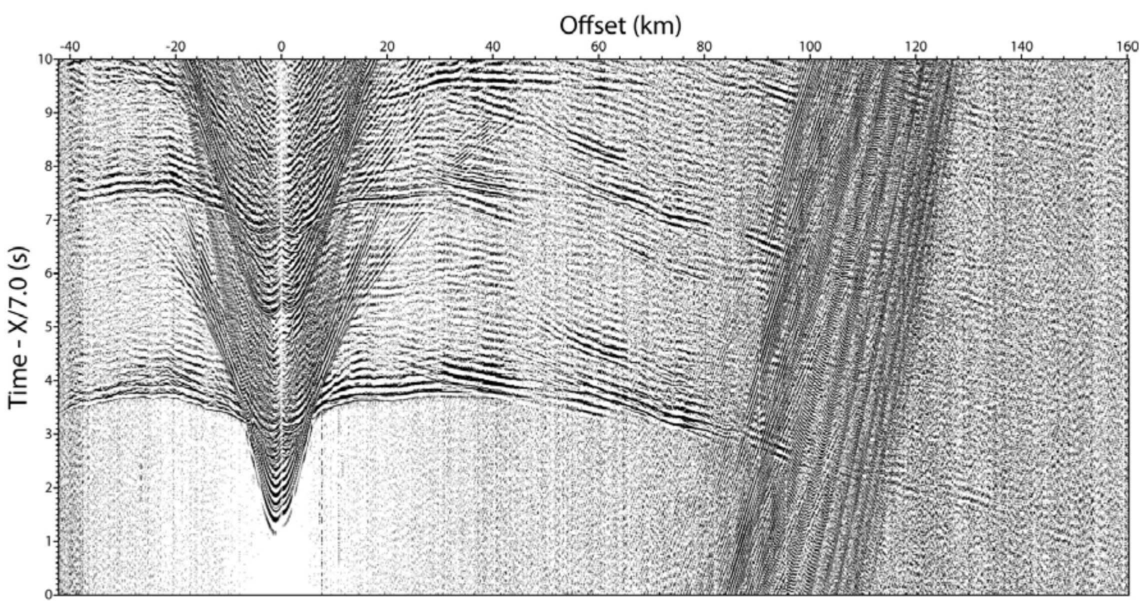

Figure 27. *Example of a record section (vertical geophone) from the SIGNAL cruise. Processing includes debiasing, bandpass filter from 5 to 24 Hz, and trace scaling by range. Traveltimes are displayed with a reduction velocity of 7.0 km/s. The coherent noise between 80 and 130 km is "wrap around" noise, which is seismic energy from the previous shot. Clear mantle refractions (P_n) can be seen up to shot-receiver distances of 160 km.*

15. Geometry and Timing

By Thomas Funck

Table 12 summarizes parameters that are essential to calculate final shot tables (time and position) and to set up an appropriate velocity model.

Parameter	Value
Shot interval	60 s
Shot time (trigger)	Exactly at the full minute mark
Gun delay time	56 ms
Depth of the airgun array	10.36 m (34 ft)
Distance of airgun array behind the ship	45.72 m (150 ft)
Distance of GPS antenna from stern	50.29 m
Distance of GPS antenna from centre line	3.68 m towards starboard
Water velocity used on Knudsen echosounder	1500 m/s
Reference level (zero depth) of Knudsen depth measurements	8 m below sea level, with exception of OBS deployment on line 3, when the ram was not lowered and the transducer was 6 m below sea level
Water velocity used on ELAC echosounder	1463 m/s
Reference level (zero depth) of ELAC depth measurements	6 m below sea level
Depth setting of hydrophone on sonobuoys	60 m (corresponding to setting D2)
Static time delay on all GSC OBS	1 s (OBS clock behind GPS time)
Static time delay on all OBS *	64 samples (corresponding to 256 ms) on all raw data files with exception of first raw data file (0 ms). OBS clock behind GPS time.

* The static time delay is related to an error in the OBS software. With exception of the first raw data file, the header of each data file overwrites the first 64 data samples without a correction of the start time. With a sampling rate of 4 ms, seismic arrivals appear 256 ms too early on the record section.

Table 12. *Various parameters with respect to geometry, navigation and timing, which are important for future processing and modelling of the refraction seismic data.*

16. Expendable Bathythermograph Measurements

By Thomas Funck

At least one water temperature measurement was carried out along each seismic profile using an expendable bathythermograph (XBT). The XBT export file has not been noise reduced or averaged. The sound velocity was derived using the 1978 Practical Salinity Scale (*UNESCO Technical Papers in Marine Science, No. 36, 1981, The Practical Salinity Scale 1978 and the International Equation of State of Seawater 1980, UNESCO Division of Marine Sciences, Paris, France, 25 pp.*) with an assumed salinity of 35.00 ppt.

Parameter	Value
Probe type	T-5
Terminal depth	1830 m
Depth equation	Standard
Depth coefficient 1	0.0
Depth coefficient 2	6.828
Depth coefficient 3	-0.00182
Depth coefficient 4	0.0
Pressure point correction	100.0 %

Table 13. *Specifications of the expendable bathythermograph (XBT).*

XBT	Launched on line	Date DD.MM.YYYY	Julian Day	Time HH:MM (UTC)	Longitude	Latitude	Water depth (ELAC)	Water depth (Knudsen)
1-1	1	02.07.2009	183	22:56	44.30395°W	50.43395°N	-	3951 m
1-2	1	02.07.2009	183	23:03	44.30240°W	50.43544°N	-	3951 m
1-3	1	03.07.2009	184	17:58	46.89944°W	50.03882°N	-	2946 m
1-4	1	04.07.2009	185	06:56	49.16639°W	49.64758°N	1652 m	1664 m
1-5	1	06.07.2009	187	20:17	51.87970°W	48.95994°N	-	(300 m)
2	2	18.06.2009	169	13:09	42.37145°W	57.93238°N	2405 m	2496 m
3	3	12.06.2009	163	12:42	45.91848°W	57.88677°N	-	2492 m
4-1	4	23.06.2009	174	14:53	53.15451°W	58.20473°N	-	3469 m
4-2	4	23.06.2009	174	19:57	53.64177°W	57.94784°N	-	3473 m
5	5	24.06.2009	175	16:10	51.72091°W	57.51047°N	-	3544 m

Table 14. *Position and time of the expendable bathythermograph (XBT) measurements.*

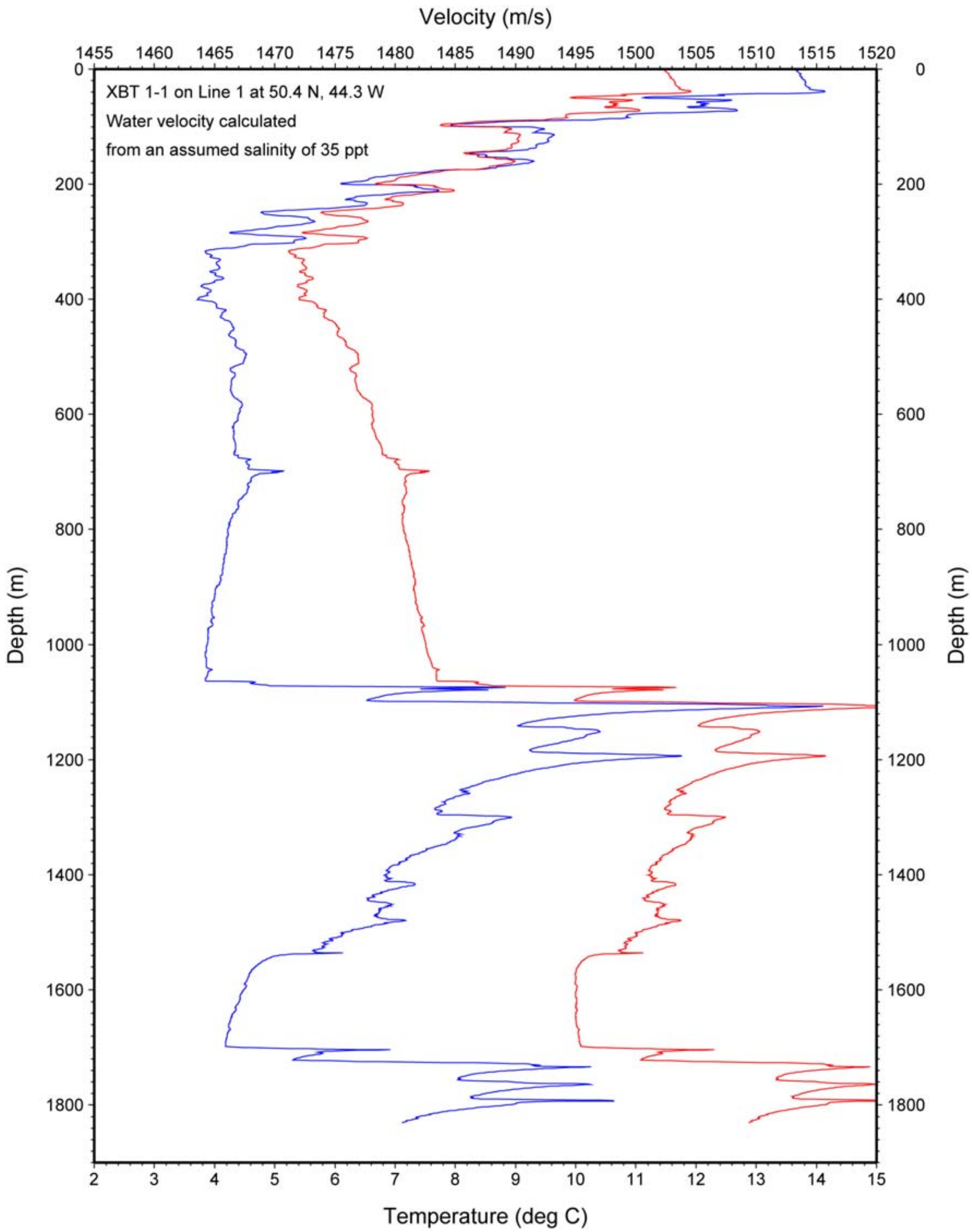

Figure 28. *Results from first XBT measurement (1-1) on line 1. The measured water temperature is shown as blue line. The sound velocity of water is drawn as red line and is calculated from the water temperature and an assumed salinity of 35.00 ppt.*

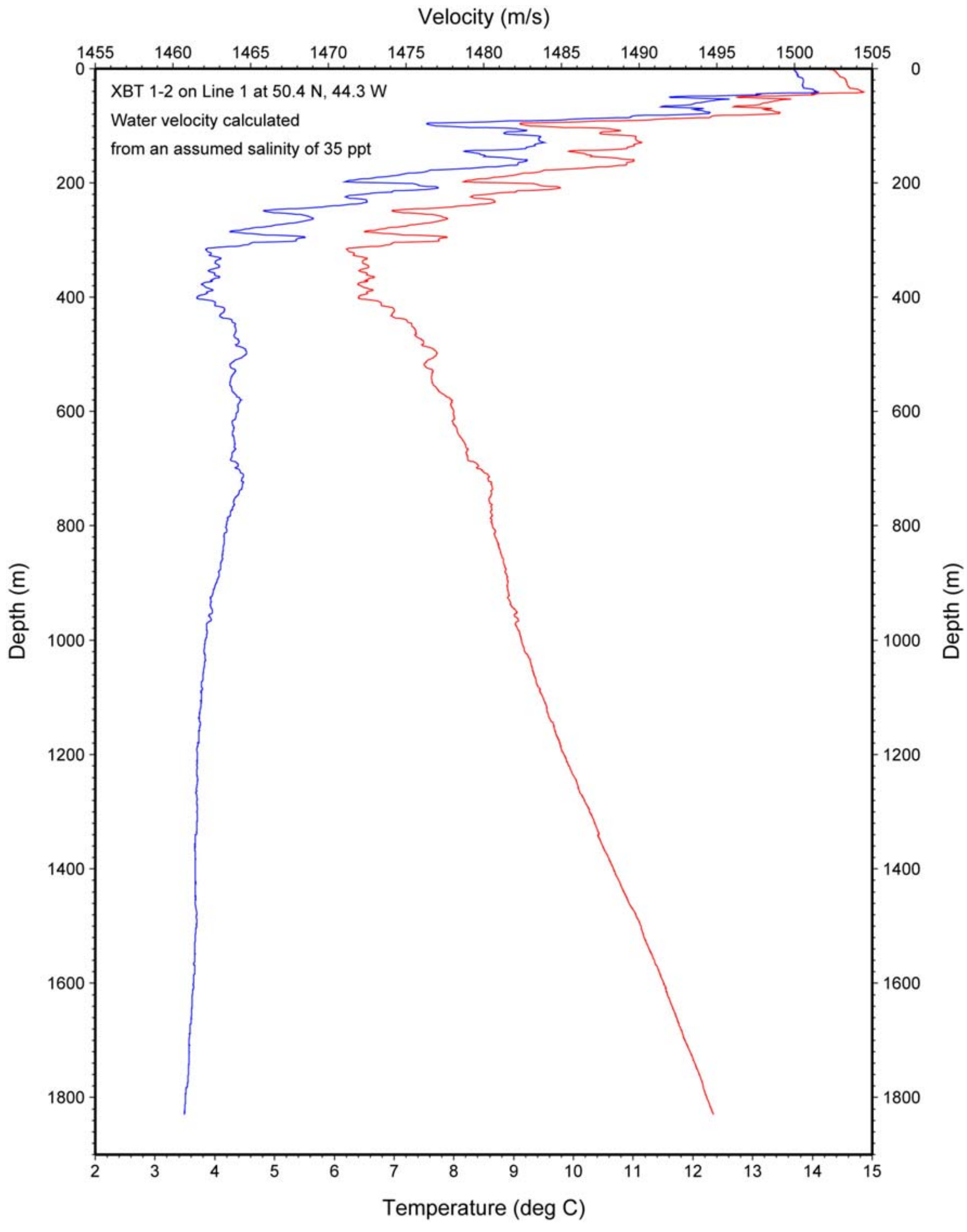

Figure 29. *Results from second XBT measurement (1-2) on line 1. The measured water temperature is shown as blue line. The sound velocity of water is drawn as red line and is calculated from the water temperature and an assumed salinity of 35.00 ppt.*

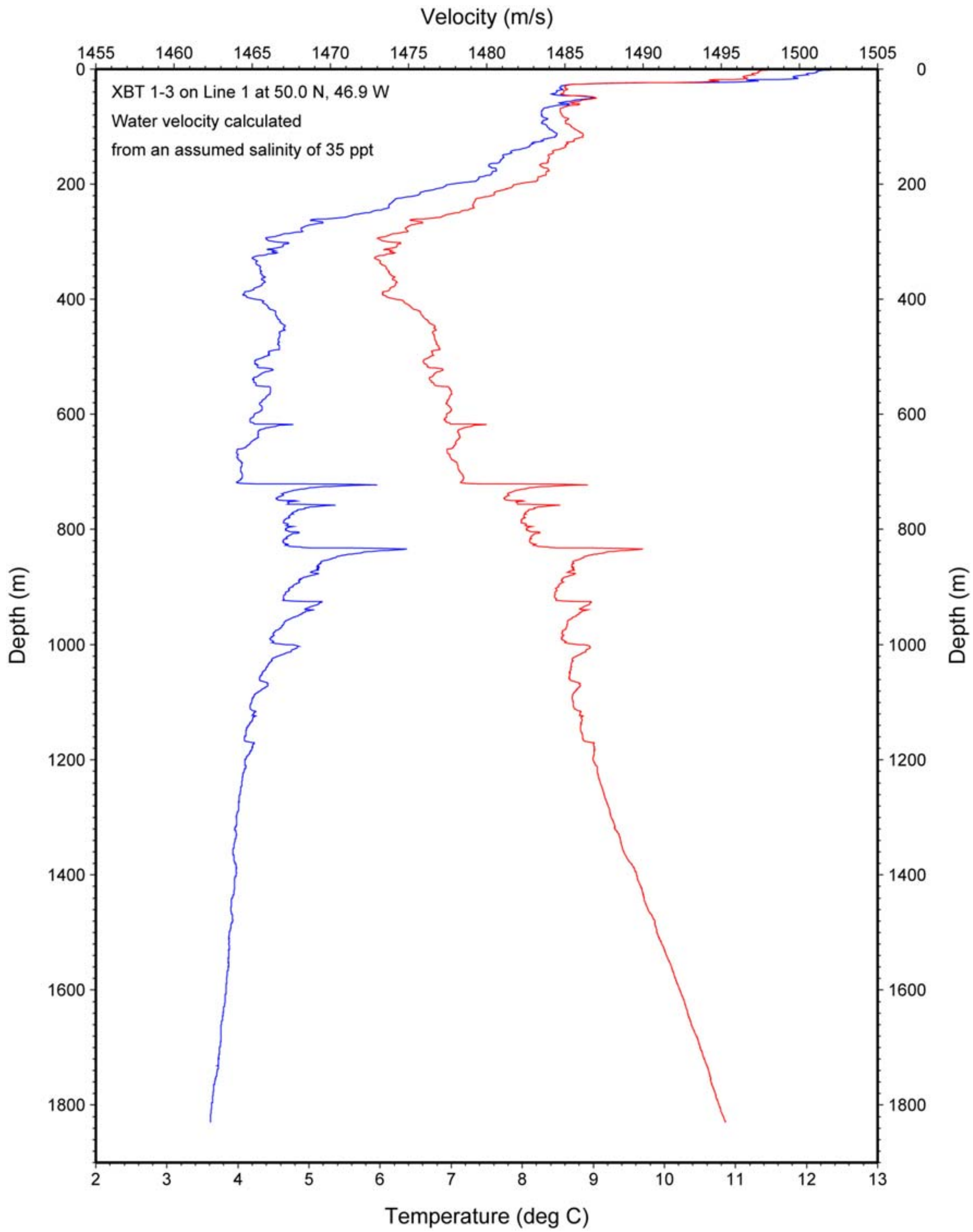

Figure 30. *Results from third XBT measurement (1-3) on line 1. The measured water temperature is shown as blue line. The sound velocity of water is drawn as red line and is calculated from the water temperature and an assumed salinity of 35.00 ppt.*

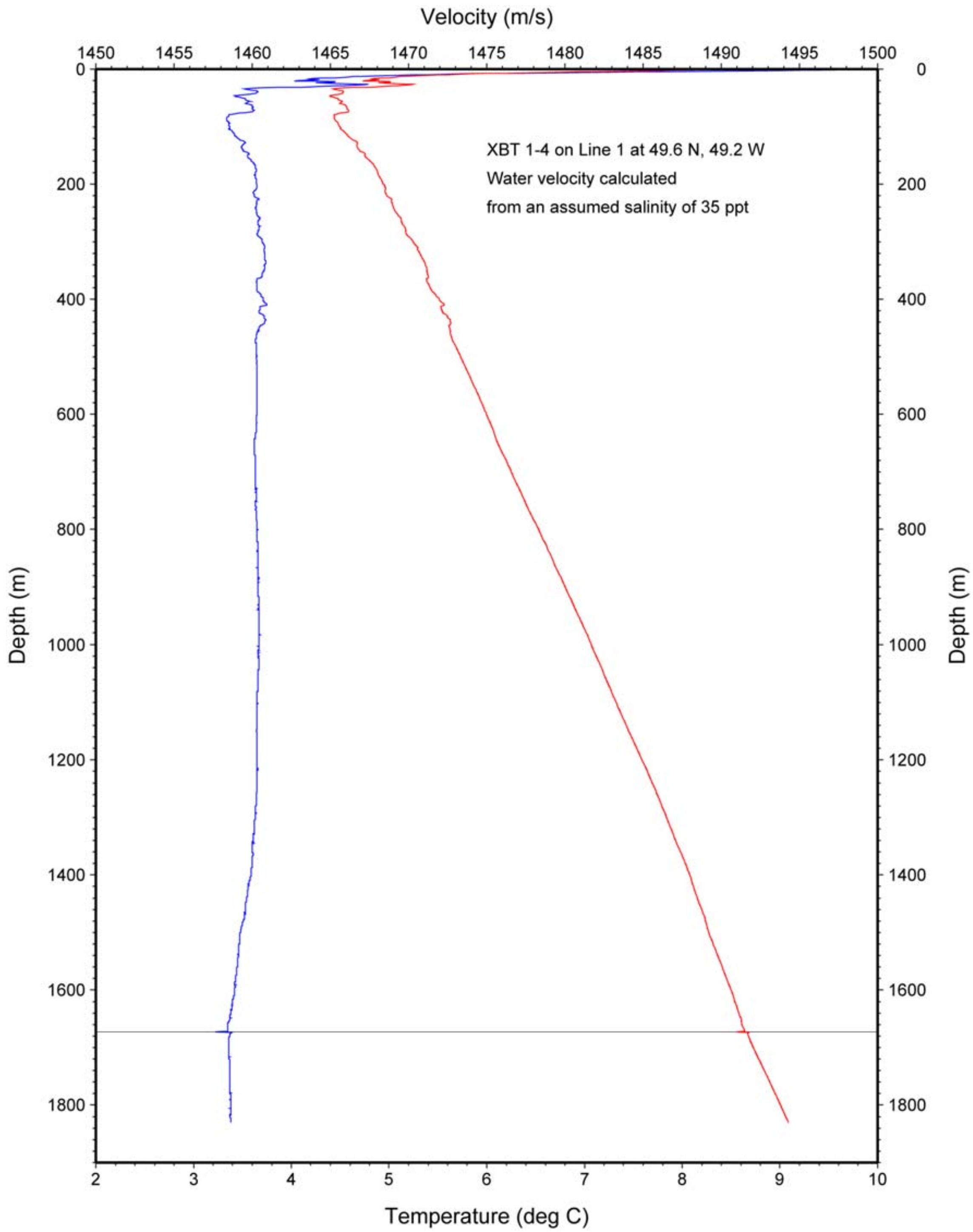

Figure 31. *Results from fourth XBT measurement (1-4) on line 1. The measured water temperature is shown as blue line. The sound velocity of water is drawn as red line and is calculated from the water temperature and an assumed salinity of 35.00 ppt.*

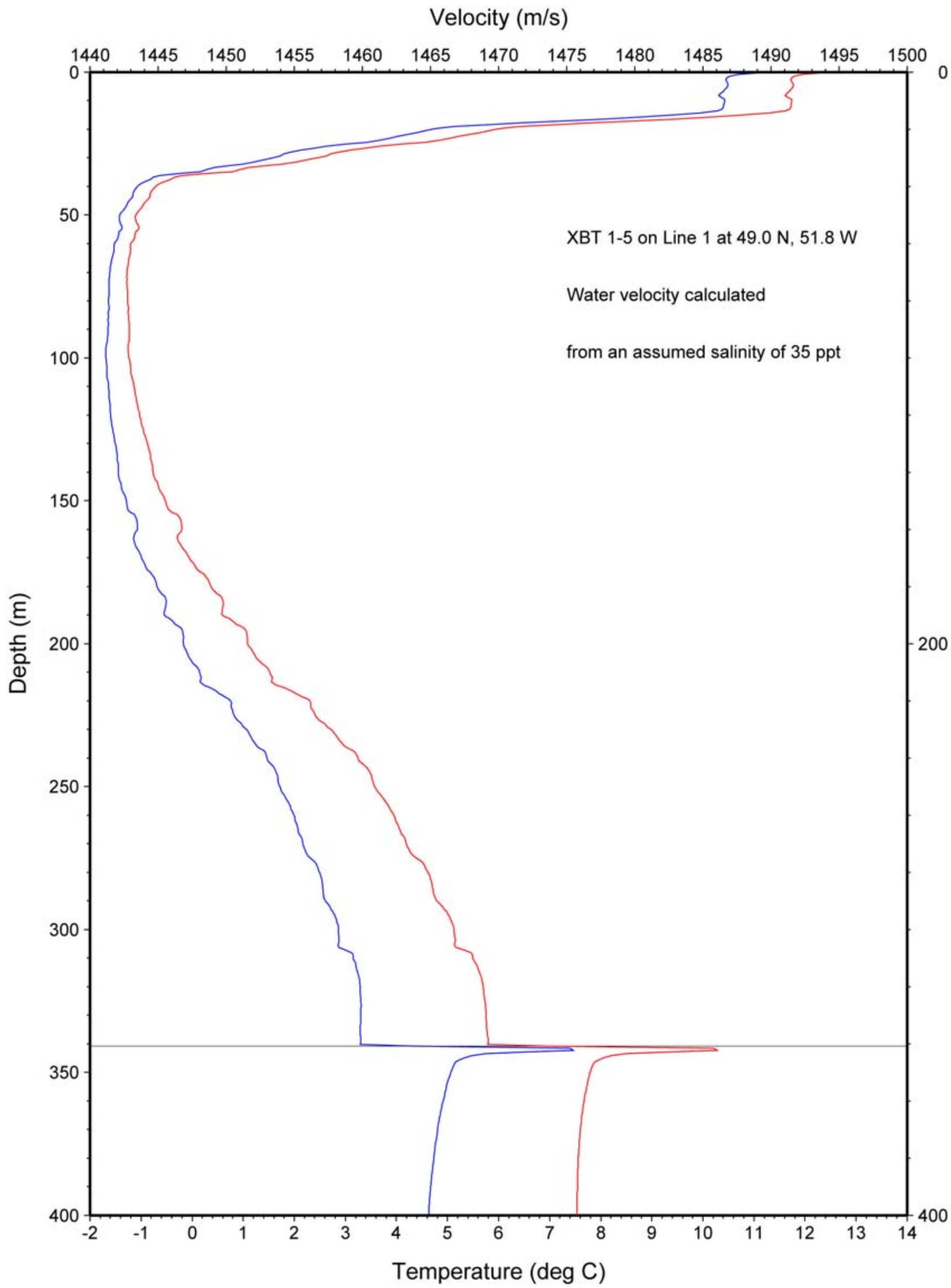

Figure 32. *Results from fifth XBT measurement (1-5) on line 1. The measured water temperature is shown as blue line. The sound velocity of water is drawn as red line and is calculated from the water temperature and an assumed salinity of 35.00 ppt.*

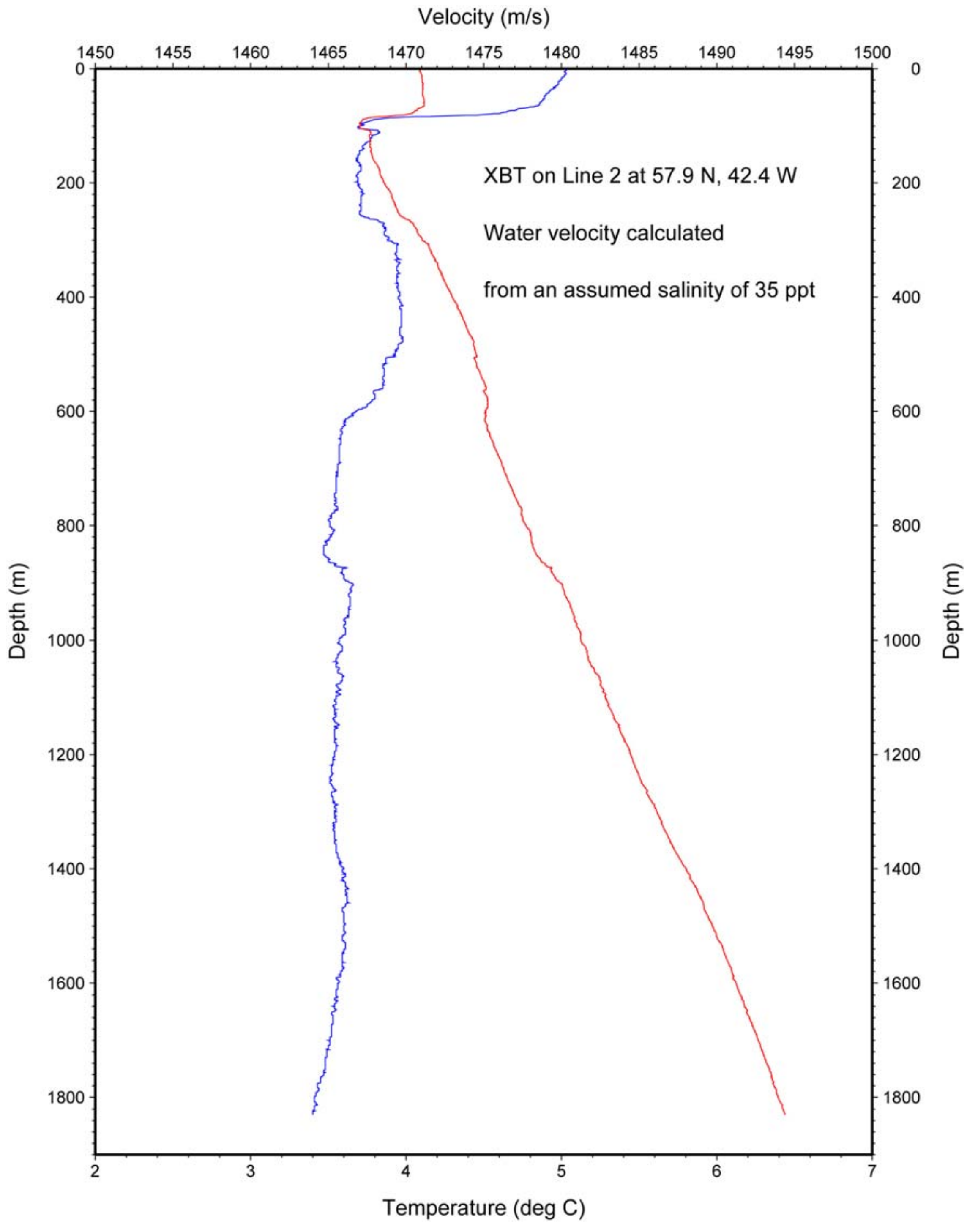

Figure 33. *Results from XBT measurement on line 2. The measured water temperature is shown as blue line. The sound velocity of water is drawn as red line and is calculated from the water temperature and an assumed salinity of 35.00 ppt.*

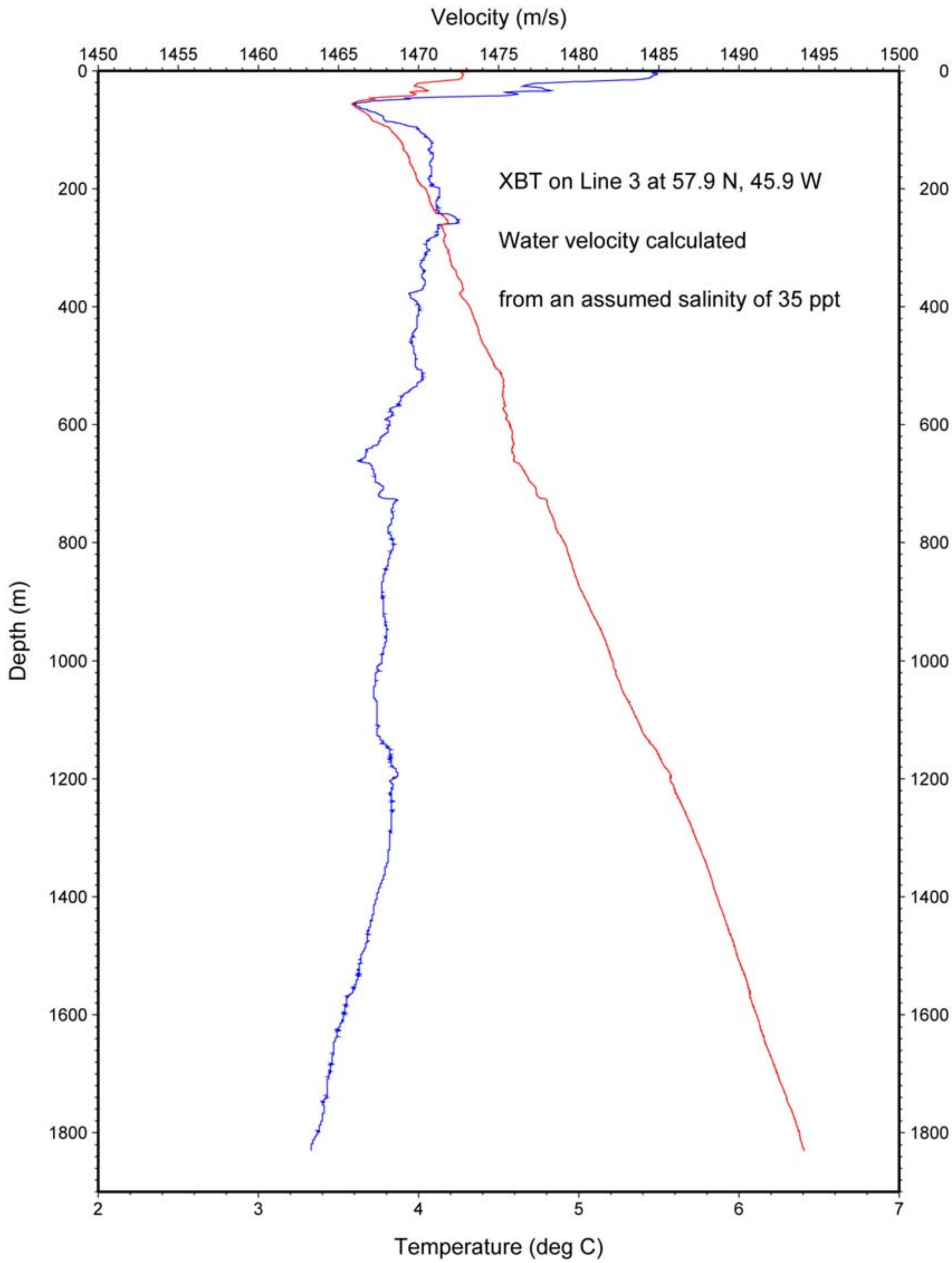

Figure 34. *Results from XBT measurement on line 3. The measured water temperature is shown as blue line. The sound velocity of water is drawn as red line and is calculated from the water temperature and an assumed salinity of 35.00 ppt.*

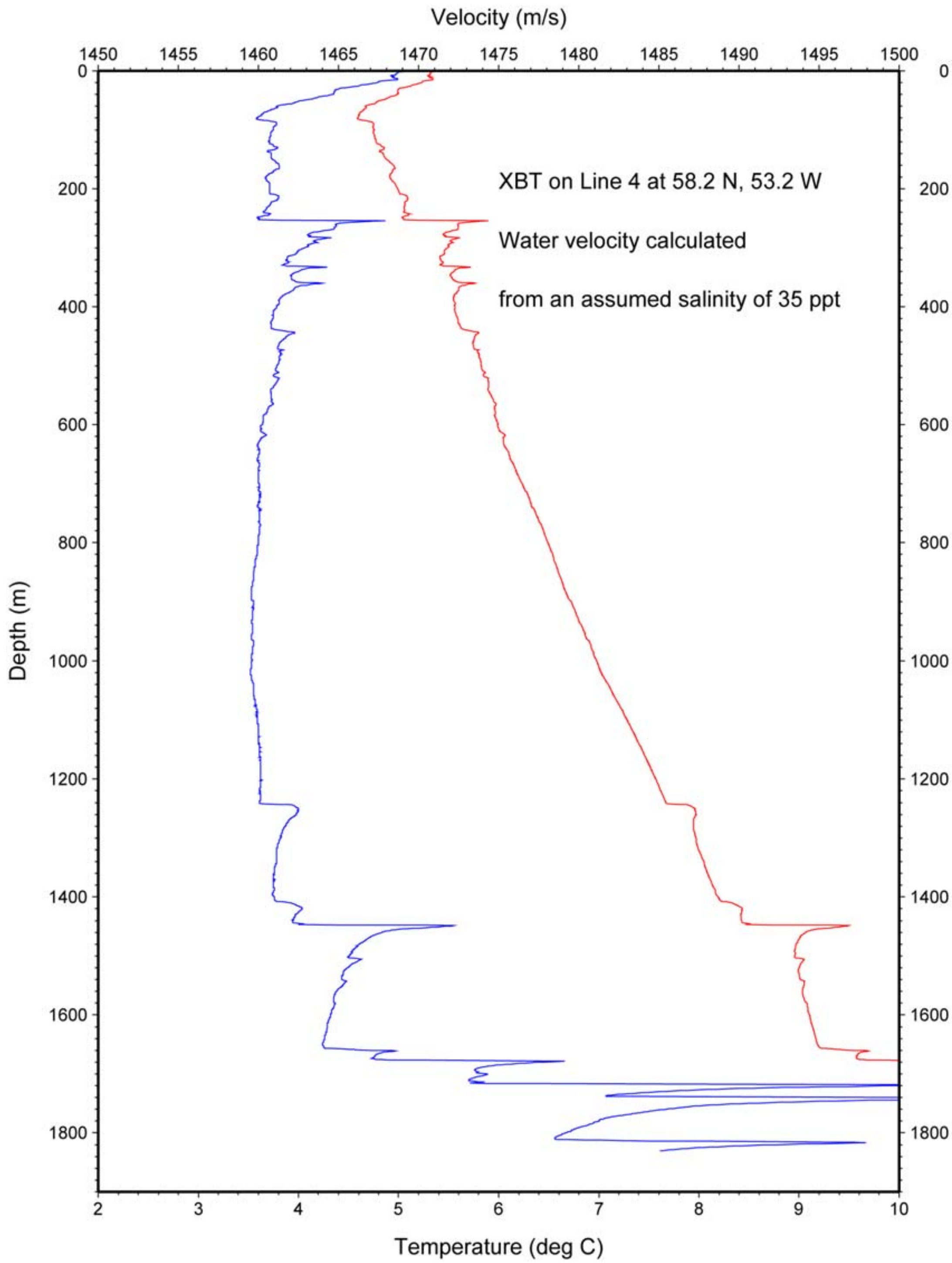

Figure 35. *Results from first XBT measurement (4-1) on line 4. The measured water temperature is shown as blue line. The sound velocity of water is drawn as red line and is calculated from the water temperature and an assumed salinity of 35.00 ppt.*

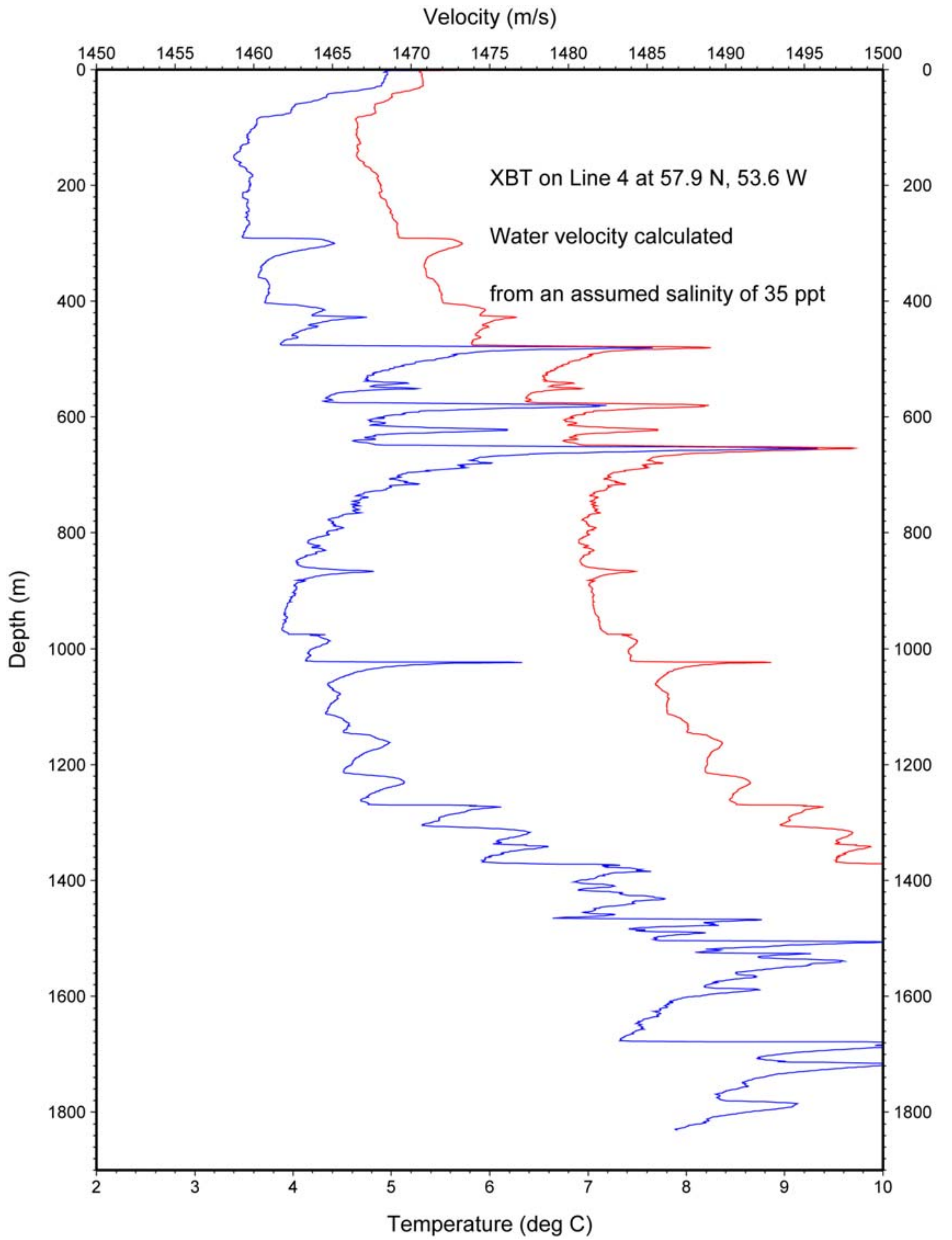

Figure 36. *Results from second XBT measurement (4-2) on line 4. The measured water temperature is shown as blue line. The sound velocity of water is drawn as red line and is calculated from the water temperature and an assumed salinity of 35.00 ppt.*

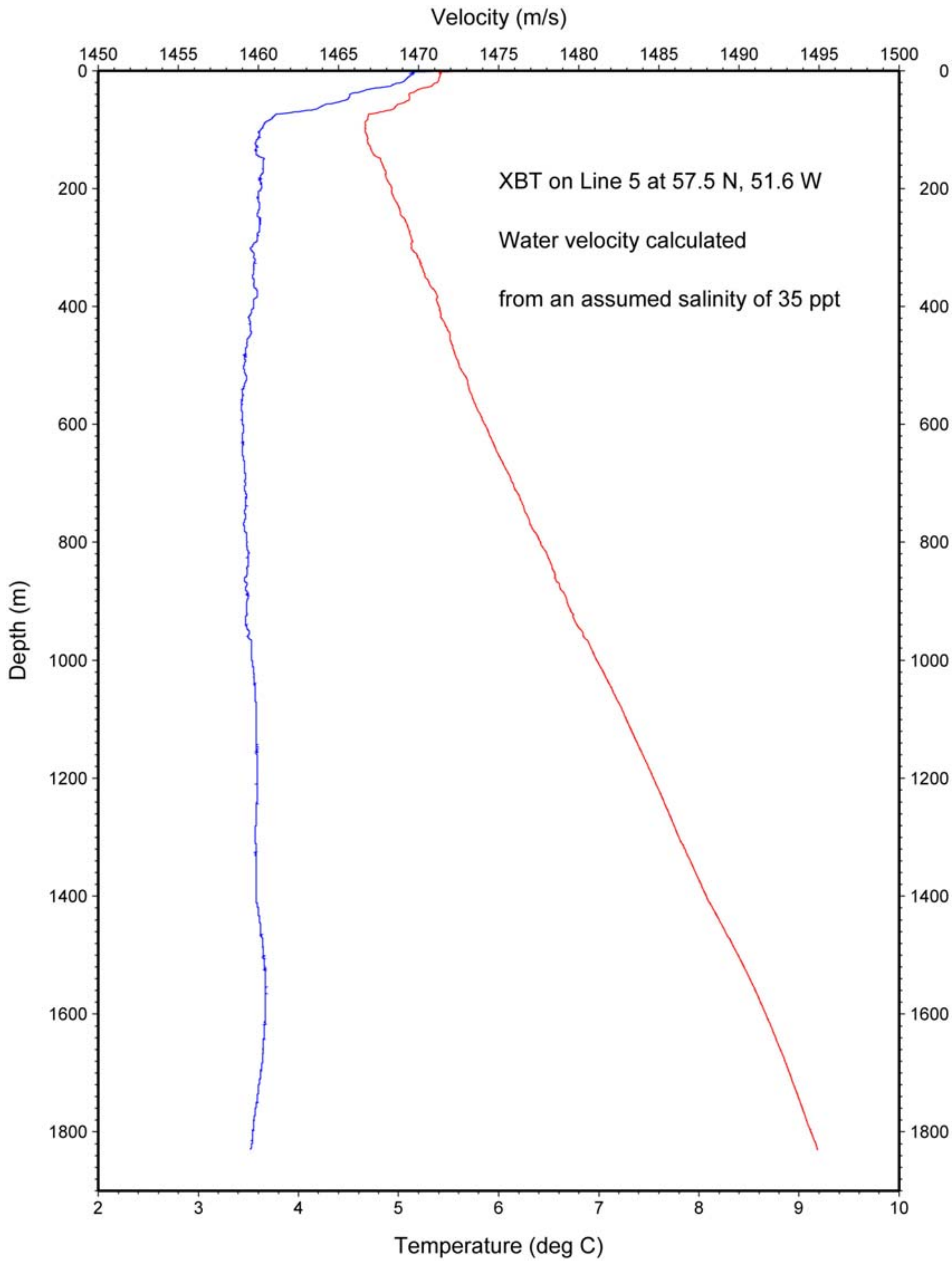

Figure 37. *Results from XBT measurement on line 5. The measured water temperature is shown as blue line. The sound velocity of water is drawn as red line and is calculated from the water temperature and an assumed salinity of 35.00 ppt.*

17. Mitigation of Seismic Sound in the Marine Environment

By Sonya Dehler

The purpose of scientific research cruise HUDSON2009-019 was to collect information on the thickness and nature of sedimentary and crustal rock layers beneath the seafloor to help define the extended outer limits of national jurisdiction under the UN Convention on the Law of the Sea (UNCLOS) for parts of Atlantic Canada and Greenland (Denmark). The technique involved the deployment of up to 24 ocean bottom seismometers (OBS) along a profile line at an average spacing ranging from 10 - 40 km, followed by a transit over the line while firing airguns, then recovery of the OBS recording instruments. The seismic source was an array of 12 airguns, each with volume 520 cubic inches, for a total volume of 6240 cubic inches. The airguns were fired concurrently at 1-minute intervals. All five of the lines were shot primarily in international waters, with parts of three lines entering the Greenland (Danish) EEZ and parts of two lines shot in Canada's EEZ.

17.1 Mitigation Procedures

In order to mitigate seismic sound and minimize impact on marine mammals, the requirements specified in the Statement of Canadian Practice with respect to Mitigation of Seismic Sound in the Marine Environment were followed for all parts of the survey conducted in Canadian waters. First, the minimum sound source required to obtain data of suitable quality was used. Prior to start of shooting for each line, marine mammal observers stationed on the bridge and quarterdeck maintained watch over a zone of up to 1 km radius from the ship for a minimum of 30 minutes, and typically 60 minutes, before the first shot. Shooting commenced during daylight hours to allow maximum visibility. When the shooting commenced the airgun source was ramped up over a 20 minute period, progressively increasing from 1 gun to 12 guns. Throughout the shooting operation, mammal observers and casual observers from the scientific staff and ship's crew maintained watch for marine mammals such that shooting would be halted immediately if a marine mammal was observed within 500m of the ship.

In parts of the survey within Greenlandic borders, the requirements specified in the permission to conduct 2D seismic survey in the Labrador Sea and related communications from the Bureau of Minerals and Petroleum (BMP) were followed. These included the recommendation of best practice guidelines, as based on the JNCC (2004) recommendations (JNCC 2004. Guidelines for minimising acoustic disturbance to marine mammals from seismic surveys – Joint Nature Conservation Council, Aberdeen, United Kingdom, 8 pages. [http://www.jncc.gov.uk/pdf/Seismic_survey_guidelines_200404.pdf]).

As with all survey lines, the minimum sound source was used and a twenty minute ramp up of airgun source was used. The airguns were not fired between survey lines. Marine mammal observers ensured that no marine mammals were within 500 m of the vessel and airgun array prior to the initial firing of the airguns, and a continuous watch was maintained during shooting to ensure that no marine mammals, especially whales, were present and showing discomfort in the vicinity of the array.

Casual observations of marine mammals including seals were made throughout the cruise and the data collated. These observations are included as part of this report.
The following reference material was used to assist in identification:

- Fisheries and Oceans Canada. Marine mammal identification (collection of colour images of identifying characteristics of marine mammals).

- A field guide to whales, porpoises and seals from Cape Cod to Newfoundland. 4th edition, revised. S.K. Katona, V. Rough and D.T. Richardson, Smithsonian Institution, 1993.
- Naturguide til Grønland. 2nd edition, Benny Gensbøl, Gads Forlag, Copenhagen, Denmark, 2005.

17.2 Ramp Up Procedure for Seismic Source

Time elapsed (minutes)	Number of airguns fired	Total volume of airguns (cubic inches)
0	1	520
1	2	1040
2	2	1040
3	3	1560
4	3	1560
5	4	2080
6	4	2080
7	5	2600
8	5	2600
9	6	3120
10	6	3120
11	7	3640
12	7	3640
13	8	4160
14	8	4160
15	9	4680
16	9	4680
17	10	5200
18	10	5200
19	11	5720
20	12	6240

Table 15. *Ramp up procedure of airgun array for seismic lines 1 through 5.*

Time elapsed (minutes)	Number of airguns fired	Total volume of airguns (cubic inches)
0	1	520
1	1	520
2	1	520
3	2	1040
4	2	1040
5	2	1040
6	3	1560
7	3	1560
8	3	1560
9	4	2080
10	4	2080
11	4	2080
12	4	2080
13	4	2080
14	5	2600
15	5	2600
16	5	2600
17	5	2600
18	5	2600
19	5	2600
20	6	3120

Table 16. *Ramp up procedure of airgun array for seismic line 1A.*

17.3 Summary of Observations (Whales)

Observation number	Date (2009) and time (UTC)	Position Latitude - Longitude	Water depth (m)	Firing air-guns	Mammal observation
1	10 June, 1211	59.0700°N, 43.0000°W	1724	Yes	1 humpback
2	11 June, 0101	58.5622°N, 44.2723°W	1630	Yes	2 humpbacks
3	11 June, 1119	57.9200°N, 45.8200°W	2417	Yes	10 pilot whales
4	12 June, 1820	58.0200°N, 45.6000°W	2246	No	16 pilot whales
5	13 June, 1315	58.8330°N, 43.6280°W	1585	No	15-20 pilot whales
6	17 June, 1029	59.1093°N, 45.1085°W	2092	Yes	1 unknown whale
7	18 June, 1425	57.9320°N, 42.3830°W	3240	No	10 pilot whales
8	21 June, 0527	58.3002°N, 53.0117°W	2700	No	10 pilot whales
9	21 June, 0914	57.8212°N, 53.8840°W	3651	No	20 pilot whales
10	21 June, 2041	57.8283°N, 53.8713°W	3430	Yes	1 fin whale
11	22 June, 1622	58.9620°N, 51.7380°W	3500	Yes	6 pilot whales
12	22 June, 1405	58.8237°N, 52.0000°W	3510	Yes	2 unknown whales
13	22 June, 2250	58.9135°N, 51.8439°W	3508	No	20 pilot whales
14	22 June, 2305	58.9167°N, 51.8333°W	3500	No	12 pilot whales
15	23 June, 0640	58.4813°N, 52.6880°W	3490	No	10-12 pilot whales
16	23 June, 2356	57.6980°N, 54.1100°W	3389	No	10-15 pilot whales
17	25 June, 1820	58.3792°N, 53.1441°W	3389	No	15 pilot whales
18	27 June, 2105	52.0940°N, 45.9982°W	-	No	2 unknown whales
19	28 June, 1450	50.0532°N, 46.7087°W	2600	No	5 pilot whales
20	29 June, 1047	48.8583°N, 52.2637°W	330	No	8 pilot whales
21	29 June, 1055	48.8473°N, 52.3032°W	320	No	6 unknown whales

22	29 June, 1057	48.8440°N, 52.3130°W	336	No	2 fin whales
23	29 June, 1316	49.4027°N, 50.1968°W	300	Yes	6 pilot whales
24	29 June, 1422	48.7725°N, 52.5553°W	300	Yes	1 unknown whale
25	29 June, 1620	48.8400°N, 52.3233°W	350	Yes	2 humpbacks
26	30 June, 1457	49.4460°N, 50.0237°W	600	Yes	10 pilot whales
27	01 July, 0836	49.8134°N, 48.2132°W	2440	Yes	1 pilot whale
28	01 July, 1101	49.8590°N, 47.9424°W	2583	Yes	3 pilot whales
29	01 July, 1201	49.8771°N, 47.8333°W	2640	Yes	20 pilot whales
30	01 July, 2206	50.0521°N, 46.7489°W	2799	Yes	20-25 pilot whales
31	03 July, 1802	50.0395°N, 46.8995°W	2947	No	8-9 pilot whales
32	03 July, 2358	49.9000°N, 47.6600°W	2675	No	12 pilot whales
33	05 July, 1510	49.4716°N, 49.9176°W	762	Yes	1 pilot whale
34	06 July, 2210	49.0667°N, 51.4500°W	320	No	1 unknown whale
35	07 July, 1051	49.4978°N, 49.7960°W	300	No	12-15 pilot whales

Table 17. *Summary of whale observations made during the SIGNAL cruise (Hudson 2009-019). A graphical presentation of the observations is given in Fig. 38.*

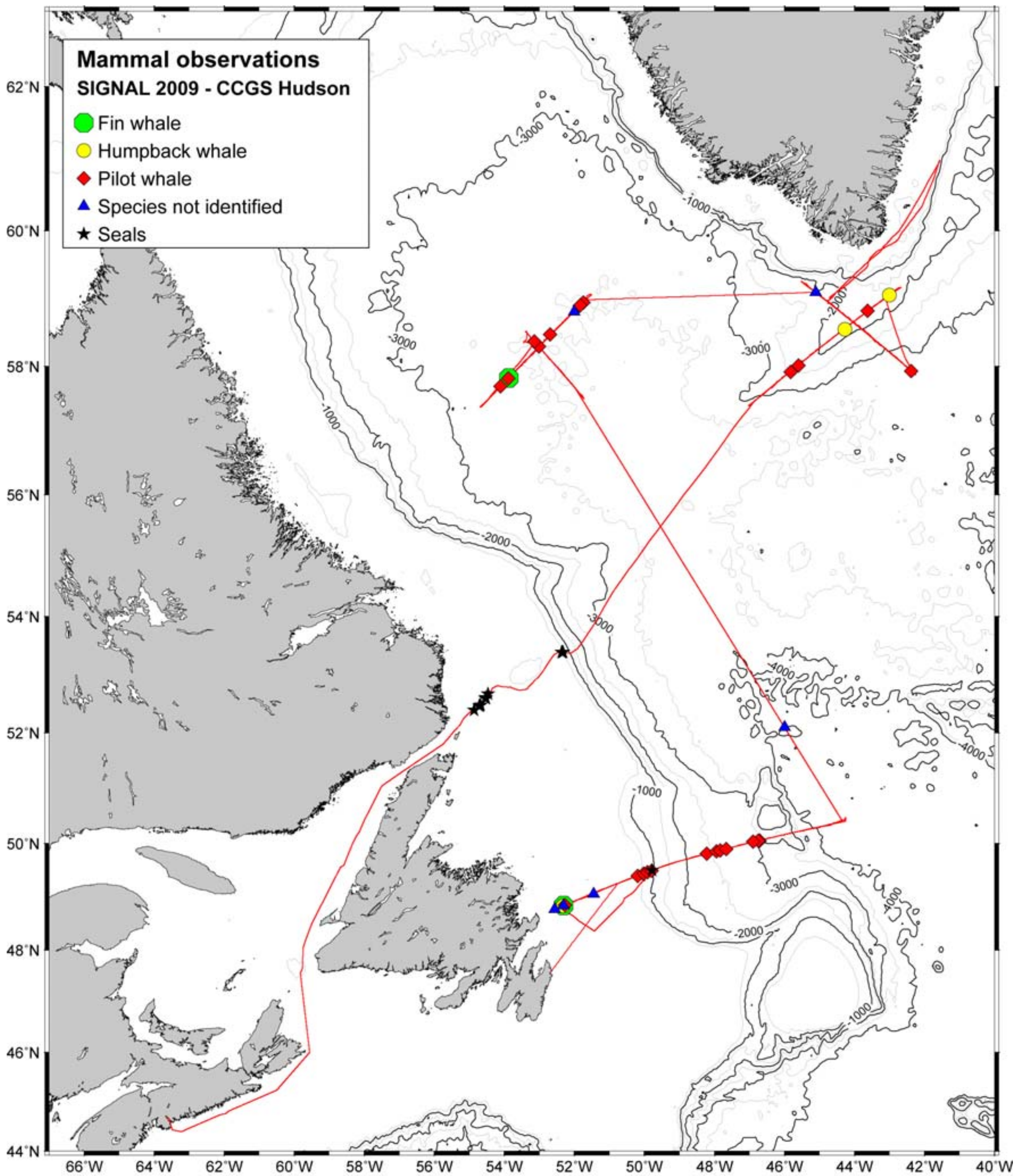

Figure 38. *Track plot (red line) of the SIGNAL cruise (Hudson 2009-019) shown together with the location of marine mammal observations. For details see Tables 17 and 18.*

17.4 Summary of Observations (Seals)

Date (2009)	Time (UTC)	Position	Observation
June 7	2040	52° 24' N, 54° 52' W	3 seals sitting on ice
June 7	2118	52° 28' N, 54° 43' W	2 seals on one ice floe, 1 seal on another floe approximately 100 m from ship
June 7	2121	52° 28' N, 54° 42' W	1 seal on ice floe 100 m from ship; second seal swimming, approximately 150 m from ship
June 7	2123	52° 28' N, 54° 42' W	1 seal on ice floe
June 7	2131	52° 29' N, 54° 41' W	2 seals on ice floe
June 7	2135	52° 29' N, 54° 41' W	1 seal on ice floe
June 7	2225	52° 36' N, 54° 32' W	1 seal on ice floe 100 m from port side of ship; 1 seal to starboard side of ship
June 7	2231	52° 37' N, 54° 32' W	1 seal on ice floe
June 7	2307	52° 41' N, 54° 28' W	3 seals on one ice floe
June 8	1055	53° 24' N, 52° 22' W	1 young seal on ice floe
June 8	1100	53° 24' N, 52° 21' W	1 young seal on ice floe, moved to far edge when ship approached
June 8	1110	53° 24' N, 52° 19' W	1 seal swimming and diving
June 30	1730	49° 30' N, 49° 47' W	1 seal in water, short dives, 100 m from ship

Table 18. *Summary of seal observations made during the SIGNAL cruise (Hudson 2009-019). A graphical presentation of the observations is given in Fig. 38.*

18. Summary Tables

By Marcel Ruhnau and Thomas Funck

18.1 Ocean Bottom Seismometers

18.1.1 Water Depths

Pos.	Instrument	Deployment longitude	Deployment latitude	Deployment depth (Elac)	Deployment depth (Knudsen)	Recovery depth (Elac)	Recovery depth (Knudsen)	Shooting depth (Knudsen)	Remarks
1	GSC-A	44.332902°W	50.401327°N	-	4190 m	-	3951 m	3944 m (4)	
2	GSC-B	44.679307°W	50.353009°N	-	4112 m	-	-	3863 m (3)	
3	GSC-C	45.019464°W	50.307029°N	-	4057 m	-	4056 m	3816 m (2)	
4	GSC-D	45.429891°W	50.248973°N	-	3732 m	-	3731 m	3508 m (2)	
5	GSC-E	45.620884°W	50.221825°N	-	3479 m	-	3483 m	3271 m (2)	
6	DAL-B	45.881074°W	50.185132°N	-	2395 m	-	2388 m	2243 m (1)	
7	DAL-C	46.020743°W	50.163618°N	-	2421 m	-	2457 m	2278 m (1)	
8	DAL-E	46.224723°W	50.133514°N	-	2541 m	-	2531 m	2384 m (1)	
9	DAL-G	46.496346°W	50.091870°N	-	2567 m	-	2561 m	2411 m (1)	
10	DAL-H	46.975968°W	50.019300°N	-	2918 m	-	2917 m	2915 m	
11	GSC-F	47.355342°W	49.956202°N	-	2701 m	-	2693 m	2746 m	
12	GSC-H	47.826064°W	49.878139°N	-	2645 m	-	2663 m	2642 m	
13	GSC-J	48.228230°W	49.811225°N	-	2417 m	-	2421 m	2417 m	
14	GSC-K	48.699135°W	49.730017°N	-	2090 m	2081 m	2093 m	2086 m	
15	GSC-L	49.175564°W	49.645447°N	1643 m	1647 m	1645 m	1654 m	1648 m	
16	DAL-I	49.728792°W	49.518875°N	996 m	1000 m	-	997 m	1001 m	
17	DAL-K	50.180764°W	49.405943°N	305 m	315 m	307 m	299 m	312 m	
18	DAL-L	50.757973°W	49.260209°N	326 m	333 m	-	-	328 m	
19	DAL-N	51.203618°W	49.144328°N	343 m	353 m	346 m	350 m	348 m	
20	DAL-D	51.437899°W	49.081787°N	312 m	321 m	317 m	320 m	317 m	
21	GSC-N	51.879922°W	48.962285°N	332 m	343 m	334 m	336 m	338 m	
22	GSC-P	52.446014°W	48.805305°N	316 m	304 m	317 m	323 m	321 m	
23	DAL-B	49.535006°W	49.566160°N	1240 m	1252 m	1240 m	1177 m	1183 m (5)	
24	DAL-C	49.963523°W	49.460739°N	697 m	697 m	-	696 m	684 m	
25	DAL-E	50.308093°W	49.374851°N	311 m	297 m	-	317 m	313 m	
26	GSC-J	50.565002°W	49.310245°N	-	338 m	324 m	326 m	328 m	
27	GSC-K	50.948254°W	49.211206°N	332 m	338 m	333 m	338 m	337 m	

Depth offsets on Knudsen-Echosounding system: (1) 150 m too shallow
(2) 200 m too shallow
(3) 225 m too shallow
(4) 250 m too shallow
(5) 50 m too shallow

Table 19. *Summary of depth measurements for ocean bottom seismometers (OBS) on line 1 during deployment of the OBS, during shooting and during subsequent recovery of OBS. See Table 12 for details on the depth reference level and the applied sound velocity.*

Pos.	Instrument	Deployment longitude	Deployment latitude	Deployment depth (Elac)	Deployment depth (Knudsen)	Recovery depth (Elac)	Recovery depth (Knudsen)	Shooting depth (Knudsen)	Remarks
1	GSC-P	42.376708°W	57.936301°N	(3048 m)	3527 m	(3048 m)	3241 m	3247 m	
2	GSC-N	42.515732°W	57.999437°N	2269 m	3218 m	-	3218 m	3218 m	
3	GSC-K	42.656300°W	58.062223°N	(3048 m)	-	(3048 m)	3182 m	3187 m	
4	GSC-J	42.795576°W	58.125573°N	(3048 m)	3150 m	(3048 m)	3151 m	3153 m	
5	GSC-H	42.939691°W	58.185960°N	(3048 m)	3125 m	(3048 m)	3129 m	3128 m	
6	DAL-N	43.077454°W	58.250648°N	2006 m	2992 m	(3048 m)	2986 m	3002 m	
7	DAL-L	43.219041°W	58.312392°N	(3048 m)	2846 m	-	2860 m	2849 m	
8	DAL-K	43.360618°W	58.374857°N	2161 m	2652 m	-	2622 m	2651 m	
9	DAL-I	43.506458°W	58.436730°N	2430 m	2443 m	-	2434 m	2447 m	
10	DAL-H	43.647215°W	58.500114°N	2254 m	2251 m	-	2255 m	2255 m	
11	GSC-F	43.791003°W	58.561046°N	2002 m	2005 m	2004 m	2015 m	2008 m	
12	GSC-D	43.936286°W	58.621450°N	-	1768 m	1775 m	1785 m	1768 m	
13	GSC-C	44.079082°W	58.683559°N	1584 m	1596 m	-	1593 m	1593 m	
14	GSC-B	44.224489°W	58.744842°N	1738 m	1748 m	-	1749 m	1749 m	
15	GSC-A	44.370129°W	58.805236°N	-	1922 m	-	1927 m	1921 m	
16	DAL-F	44.517890°W	58.867272°N	2006 m	2018 m	N/A	N/A	2018 m	Instrument lost
17	DAL-G	44.668368°W	58.927922°N	2095 m	2106 m	-	2109 m	2109 m	
18	DAL-E	44.808846°W	58.988111°N	2224- m	2230 m	2204 m	2213 m	2236 m	
19	DAL-B	44.956662°W	59.048229°N	2205 m	2216 m	-	2213 m	2216 m	
20	DAL-A	45.105675°W	59.108534°N	2082 m	2102 m	N/A	N/A	2102 m	Instrument lost

Table 20. *Summary of depth measurements for ocean bottom seismometers (OBS) on line 2 during deployment of the OBS, during shooting and during subsequent recovery of OBS. See Table 12 for details on the depth reference level and the applied sound velocity.*

Pos.	Instrument	Deployment longitude	Deployment latitude	Deployment depth (Elac)	Deployment depth (Knudsen)	Recovery depth (Elac)	Recovery depth (Knudsen)	Shooting depth (Knudsen)
1	GSC-A	46.857300°W	57.473870°N	-	2678 m *	-	3109 m **	3106 m **
2	GSC-B	46.703009°W	57.542636°N	-	2604 m *	2960 m	3031 m **	3018 m **
3	GSC-C	46.546108°W	57.612361°N	-	2502 m *	-	2933 m **	2914 m **
4	GSC-D	46.387339°W	57.683011°N	-	2439 m *	-	2862 m **	2815 m **
5	GSC-E	46.229515°W	57.752789°N	-	2358 m *	2400 m	-	2736 m **
6	GSC-F	46.070787°W	57.821614°N	-	2258 m *	2599 m	-	2618 m **
7	DAL-A	45.911220°W	57.890828°N	-	2144 m *	-	2480 m **	2486 m **
8	DAL-B	45.753490°W	57.959122°N	-	2037 m *	-	2356 m **	2362 m **
9	DAL-C	45.592717°W	58.027847°N	-	1943 m *	2179 m	2255 m **	2252 m **
10	DAL-D	45.430899°W	58.096174°N	2123 m	1854 m *	2136 m	2148 m **	2148 m **
11	DAL-E	45.269991°W	58.164615°N	2094 m	1816 m *	2104 m	-	2098 m **
12	DAL-G	45.108015°W	58.232083°N	2067 m	1793 m *	2083 m	-	2080 m **
13	GSC-H	44.944067°W	58.300021°N	1948 m	1691 m *	1958 m	-	1959 m **
14	GSC-J	44.779499°W	58.368181°N	1791 m	1554 m *	1797 m	1807 m **	1801 m **
15	GSC-K	44.617767°W	58.435117°N	1722 m	1494 m *	1720 m	1730 m **	1724 m **
16	GSC-L	44.452381°W	58.502417°N	1674 m	1456 m *	1670 m	1677 m **	1687 m **
17	GSC-N	44.285934°W	58.569333°N	1631 m	1418 m *	1630 m	1638 m **	1637 m **
18	GSC-P	44.120540°W	58.635587°N	1597 m	1387 m *	1605 m	1615 m **	1606 m **
19	DAL-F	43.954142°W	58.702842°N	1572 m	1365 m *	1570 m	-	1583 m **
20	DAL-H	43.786559°W	58.768629°N	1566 m	1362 m *	1570 m	-	1576 m **
21	DAL-I	43.619508°W	58.834291°N	1588 m	1599 m *	1585 m	-	1599 m **
22	DAL-K	43.451310°W	58.899709°N	1649 m	1435 m *	1651 m	1661 m **	1661 m **
23	DAL-L	43.281675°W	58.965787°N	1670 m	1449 m *	1674 m	1687 m **	1680 m **
24	DAL-N	43.111550°W	59.031440°N	1722 m	1494 m *	1720 m	1730 m **	1732 m **

The Knudsen-transducer is   ** ca. 6 m below sea level during deployment*
*** ca. 8 m below sea level during shooting and recovery*

Table 21. *Summary of depth measurements for ocean bottom seismometers (OBS) on line 3 during deployment of the OBS, during shooting and during subsequent recovery of OBS. See Table 12 for details on the depth reference level and the applied sound velocity.*

Pos.	Instrument	Deployment longitude	Deployment latitude	Deployment depth (Elac)	Deployment depth (Knudsen)	Recovery depth (Elac)	Recovery depth (Knudsen)	Shooting depth (Knudsen)	Remarks
1	GSC-A	51.659113°W	58.998395°N	-	3534 m	-	3498 m	3495 m	*
2	GSC-C	51.832768°W	58.915119°N	-	3898 m	-	3512 m	3510 m	*
3	GSC-D	52.003168°W	58.828011°N	-	3512 m	-	3508 m	3512 m	
4	GSC-E	52.172505°W	58.741535°N	-	3487 m	-	3493 m	3487 m	
5	GSC-F	52.339238°W	58.654239°N	-	3496 m	-	3495 m	3499 m	
6	DAL-B	52.508360°W	58.565333°N	(3048 m)	3457 m	-	3456 m	3456 m	
7	DAL-C	52.674625°W	58.477850°N	-	3401 m	-	3401 m	3409 m	
8	DAL-E	52.839534°W	58.390869°N	-	3460 m	-	3475 m	3463 m	
9	DAL-G	53.004125°W	58.302975°N	-	3474 m	-	3486 m	3482 m	
10	DAL-I	53.168804°W	58.214411°N	-	3471 m	-	3471 m	3468 m	
11	GSC-H	53.330343°W	58.126223°N	-	3479 m	-	3482 m	3479 m	
12	GSC-J	53.492621°W	58.037861°N	-	3474 m	-	3474 m	3474 m	
13	GSC-K	53.654163°W	57.948541°N	-	3475 m	-	3474 m	3473 m	
14	GSC-P	53.812038°W	57.861103°N	-	3450 m	-	3450 m	3450 m	
15	DAL-H	53.971969°W	57.771759°N	-	3411 m	-	3411 m	3411 m	
16	DAL-K	54.130916°W	57.683564°N	-	3382 m	-	3389 m	3382 m	
17	DAL-L	54.289909°W	57.593547°N	-	3343 m	-	3343 m	3343 m	
18	DAL-N	54.448315°W	57.503380°N	-	3311 m	-	3310 m	3310 m	

* 12-kHz Knudsen used at deployment

Table 22. *Summary of depth measurements for ocean bottom seismometers (OBS) on line 4 during deployment of the OBS, during shooting and during subsequent recovery of OBS. See Table 12 for details on the depth reference level and the applied sound velocity.*

Pos.	Instrument	Deployment longitude	Deployment latitude	Deployment depth (Elac)	Deployment depth (Knudsen)	Recovery depth (Elac)	Recovery depth (Knudsen)	Shooting depth (Knudsen)	Remarks
1	GSC-P	53.132993°W	58.372308°N	-	3468 m	-	3477 m	3468 m	
2	GSC-J	53.001548°W	58.295728°N	-	3486 m	-	3486 m	3481 m	
3	GSC-H	52.871039°W	58.217421°N	-	3486 m	-	3486 m	3484 m	
4	GSC-F	52.741035°W	58.139418°N	-	3499 m	-	3499 m	3502 m	
5	GSC-D	52.610549°W	58.061412°N	-	3526 m	-	3508 m	3520 m	
6	DAL-C	52.472715°W	57.977381°N	-	3505 m	-	3512 m	3515 m	
7	DAL-E	52.353439°W	57.904372°N	-	3514 m	-	3521 m	3521 m	
8	DAL-G	52.225826°W	57.825769°N	-	3521 m	-	3527 m	3521 m	
9	DAL-H	52.099067°W	57.747180°N	-	3542 m	-	3525 m	3525 m	
10	DAL-I	51.971072°W	57.667813°N	-	3528 m	-	3530 m	3528 m	

Table 23. *Summary of depth measurements for ocean bottom seismometers (OBS) on line 5 during deployment of the OBS, during shooting and during subsequent recovery of OBS. See Table 12 for details on the depth reference level and the applied sound velocity.*

18.1.2 OBS Locations and Clock Drift

Pos.	Instru-ment	Deployment longitude	Deployment latitude	Deployment depth Elac	Deployment depth Knudsen	Recovery longitude	Recovery latitude	Recovery depth Elac	Recovery depth Knudsen	Clock reset (JD:hh:mm)	Clock check (JD:hh:mm)	Clock drift (ms)	Drift rate (ms/h)	Static shift (ms)	Raw data files	Remarks
1	GSC-A	44.332902 W	50.401327 N	-	4190 m	44.251788 W	50.425125 N	-	3951 m	178:17:23	183:22:53	-0.818	-0.006	-0.035	0000-0290	
2	GSC-B	44.679307 W	50.353009 N	-	4112 m	-	-	-	-	178:17:34	-	-	-	-0.032	-	Instrument lost
3	GSC-C	45.019464 W	50.307029 N	-	4057 m	44.995249 W	50.296502 N	-	4056 m	178:17:40	-	-	-	-0.036	0000-0313	Clock not calibrated
4	GSC-D	45.429891 W	50.248973 N	-	3732 m	45.428284 W	50.242663 N	-	3731 m	178:17:48	184:08:10	-23.708	-0.176	-0.027	0000-0323	
5	GSC-E	45.620884 W	50.221825 N	-	3479 m	45.613800 W	50.220708 N	-	3483 m	178:17:53	184:10:42	-46.808	-0.342	-0.007	0000-0331	
6	DAL-B	45.881074 W	50.185132 N	-	2395 m	45.868724 W	50.184872 N	-	2388 m	178:19:21	184:11:45	+9.835	+0.072	-0.033	0000-0335	
7	DAL-C	46.020743 W	50.163618 N	-	2421 m	46.013862 W	50.159359 N	-	2457 m	178:19:27	184:13:47	+27.128	+0.196	-0.033	0000-0342	
8	DAL-E	46.224723 W	50.133514 N	-	2541 m	46.222798 W	50.131627 N	-	2531 m	178:19:35	184:14:37	+9.382	+0.068	-0.015	0000-0344	
9	DAL-G	46.496346 W	50.091870 N	-	2567 m	46.496346 W	50.093480 N	-	2561 m	178:19:40	184:16:30	-1.108	-0.008	-0.035	0000-0351	
10	DAL-H	46.975968 W	50.019300 N	-	2918 m	46.979696 W	50.017137 N	-	2917 m	178:19:47	184:19:11	-12.385	-0.086	-0.035	0000-0361	
11	GSC-F	47.355342 W	49.956202 N	-	2701 m	47.358017 W	49.954333 N	-	2693 m	178:18:33	184:21:29	+2.814	+0.019	-0.035	0000-0369	
12	GSC-H	47.826064 W	49.878139 N	-	2645 m	47.826055 W	49.877360 N	-	2663 m	178:18:37	185:00:22	+3.051	+0.020	-0.005	0000-0377	
13	GSC-J	48.228230 W	49.811225 N	-	2417 m	48.226281 W	49.810264 N	-	2421 m	178:18:43	185:02:39	+50.410	+0.332	-0.036	0000-0385	
14	GSC-K	48.699135 W	49.730017 N	-	2090 m	48.695623 W	49.725816 N	2081 m	2093 m	178:18:49	185:05:07	+1.048	+0.007	-0.007	0000-0395	
15	GSC-L	49.175564 W	49.645447 N	1643 m	1647 m	49.172787 W	49.644026 N	1645 m	1654 m	178:18:59	185:07:31	-6.982	-0.045	-0.004	0000-0403	
16	DAL-I	49.728792 W	49.518875 N	996 m	1000 m	49.728792 W	49.518815 N	-	997 m	179:11:13	188:10:41	+43.249	+0.201	-0.036	0000-0661	
17	DAL-K	50.180764 W	49.405943 N	305 m	315 m	50.180454 W	49.408553 N	307 m	299 m	179:11:29	185:12:34	+3.221	+0.022	-0.040	0000-0420	
18	DAL-L	50.757973 W	49.260209 N	326 m	333 m	-	-	-	-	179:11:54	-	-	-	-0.041	-	Instrument lost
19	DAL-N	51.203618 W	49.144328 N	343 m	353 m	51.198792 W	49.141656 N	346 m	350 m	179:12:32	187:00:12	+22.458	+0.125	-0.011	0000-0625	
20	DAL-D	51.437899 W	49.081787 N	312 m	321 m	51.432921 W	49.079174 N	317 m	320 m	179:13:15	187:22:57	+1.900	+0.010	-0.036	0000-0620	
21	GSC-N	51.879922 W	48.962285 N	332 m	343 m	51.879212 W	49.960471 N	334 m	336 m	178:19:04	187:20:48	-1.205	-0.006	-0.002	0000-0613	
22	GSC-P	52.446014 W	48.805305 N	316 m	304 m	52.445156 W	48.804009 N	317 m	323 m	178:19:09	187:18:22	-37.486	-0.174	-0.024	0000-0603	
23	DAL-B	49.535006 W	49.566160 N	1240 m	1252 m	49.533564 W	49.561625 N	1240 m	1177 m	184:15:21	188:09:00	+5.503	+0.062	-0.033	0000-0199	
24	DAL-C	49.963523 W	49.460739 N	697 m	697 m	49.962762 W	49.460169 N	-	696 m	184:15:24	-	-	-	-0.036	-	No data recorded, shut down
25	DAL-E	50.308093 W	49.374851 N	311 m	297 m	50.306130 W	49.372701 N	-	317 m	184:15:06	188:05:10	+5.140	+0.060	-0.036	0000-0185	
26	GSC-J	50.565002 W	49.310245 N	-	338 m	50.565002 W	49.309897 N	324 m	326 m	185:04:16	188:03:28	+23.330	+0.328	-0.043	0000-0179	
27	GSC-K	50.948254 W	49.211206 N	332 m	338 m	50.945924 W	49.209991 N	333 m	338 m	185:05:39	188:01:35	+0.915	+0.014	-0.008	0000-0173	

Table 24. *Deployment and recovery locations of ocean bottom seismometers (OBS) on line 1; static time corrections and OBS clock drift (+ means OBS clock is ahead of GPS clock, - when OBS clock is behind GPS clock). Please note that all GSC instruments have an additional static time correction of -1.0 s. Julian days 178 and 188 are June 27 and July 7, respectively.*

Pos.	Instru-ment	Deployment longitude	Deployment latitude	Deployment depth Elac	Deployment depth Knudsen	Recovery longitude	Recovery latitude	Recovery depth Elac	Recovery depth Knudsen	Clock reset (JD:hh:mm)	Clock check (JD:hh:mm)	Clock drift (ms)	Drift rate (ms/h)	Static shift (ms)	Raw data files	Remarks
1	GSC-P	42.376708 W	57.936301 N	(3048 m)	3527 m	42.382724 W	57.931731 N	(3048 m)	3241 m	164:17:39	169:14:36	-25.386	-0.217	-0.016	0000-0337	
2	GSC-N	42.515732 W	57.999437 N	2269 m	3218 m	42.523037 W	57.999437 N	-	3218 m	164:18:03	169:16:40	-0.218	-0.002	-0.005	0000-0344	
3	GSC-K	42.656300 W	58.062223 N	(3048 m)	-	42.656300 W	58.062223 N	(3048 m)	3182 m	164:18:16	169:18:27	+1.504	+0.013	-0.010	0000-0351	
4	GSC-J	42.795576 W	58.125573 N	(3048 m)	3150 m	42.795576 W	58.125573 N	(3048 m)	3151 m	164:18:39	169:20:27	+40.3898	+0.332	-0.029	0000-0371	
5	GSC-H	42.939691 W	58.185960 N	(3048 m)	3125 m	42.939691 W	58.185960 N	(3048 m)	3129 m	164:18:59	169:22:16	+3.484	+0.028	-0.005	0000-0377	
6	DAL-N	43.077454 W	58.250648 N	2006 m	2992 m	43.077667 W	58.258440 N	(3048 m)	2986 m	164:21:17	169:23:52	+16.126	+0.132	-0.040	N/A	No data recorded
7	DAL-L	43.219041 W	58.312392 N	(3048 m)	2846 m	43.243854 W	58.317787 N	-	2860 m	164:21:13	170:03:13	+1.528	+0.012	-0.040	0000-0394	
8	DAL-K	43.360618 W	58.374857 N	2161 m	2652 m	43.393732 W	58.374857 N	-	2622 m	164:21:20	170:05:04	+3.453	+0.027	-0.035	0000-0401	
9	DAL-I	43.506458 W	58.436730 N	2430 m	2443 m	43.504688 W	58.439912 N	-	2434 m	164:21:36	170:09:21	+28.315	+0.215	-0.040	0000-0415	
10	DAL-H	43.647215 W	58.500114 N	2254 m	2251 m	43.648118 W	58.502837 N	-	2255 m	164:21:45	170:08:28	-8.821	-0.067	-0.010	0000-0412	
11	GSC-F	43.791003 W	58.561046 N	2002 m	2005 m	43.792386 W	58.558512 N	2004 m	2015 m	164:19:28	170:11:07	+4.003	+0.030	-0.021	0000-0421	
12	GSC-D	43.936286 W	58.621450 N	-	1768 m	43.934853 W	58.614119 N	1775 m	1785 m	164:20:12	170:12:35	+975.559	-0.179	+999.971	0000-426	
13	GSC-C	44.079082 W	58.683559 N	1584 m	1596 m	44.076110 W	58.680768 N	-	1593 m	164:21:58	170:14:13	+2.843	+0.021	-0.043	0000-0432	
14	GSC-B	44.224489 W	58.744842 N	1738 m	1748 m	44.222562 W	58.743661 N	-	1749 m	164:22:26	170:15:28	+37.461	+0.274	-0.040	0000-0436	
15	GSC-A	44.370129 W	58.805236 N	-	1922 m	44.372888 W	58.804346 N	-	1927 m	164:22:38	170:16:56	-1.618	-0.011	-0.041	0000-0440	
16	DAL-F	44.517890 W	58.867272 N	2006 m	2018 m	N/A	N/A	N/A	N/A	164:22:47	N/A	N/A	N/A	-0.033	N/A	Instrument lost
17	DAL-G	44.668368 W	58.927922 N	2095 m	2106 m	44.683680 W	58.934275 N	-	2109 m	164:22:58	170:19:47	+1.021	+0.007	-0.035	0000-0450	
18	DAL-E	44.808846 W	58.988111 N	2224- m	2230 m	44.797805 W	58.986312 N	2204 m	2213 m	167:21:48	170:23:16	+6.093	+0.083	-0.040	0000-233	
19	DAL-B	44.956662 W	59.048229 N	2205 m	2216 m	44.958245 W	59.047221 N	-	2213 m	167:22:00	171:01:15	+6.182	+0.083	-0.029	0000-0241	
20	DAL-A	45.105675 W	59.108534 N	2082 m	2102 m	N/A	N/A	N/A	N/A	167:22:16	N/A	N/A	N/A	-0.038	N/A	Instrument lost

Table 25. *Deployment and recovery locations of ocean bottom seismometers (OBS) on line 2; static time corrections and OBS clock drift (+ means OBS clock is ahead of GPS clock, - when OBS clock is behind GPS clock). Please note that all GSC instruments have an additional static time correction of -1.0 s. Julian days 164 and 170 are June 13 and June 19, respectively.*

Pos.	Instru-ment	Deployment longitude	Deployment latitude	Deploym. depth Elac	Deploym. depth Knudsen	Recovery longitude	Recovery latitude	Recovery depth Elac	Recovery depth Knudsen	Clock reset (JD:hh:mm)	Clock check (JD:hh:mm)	Clock drift (ms)	Drift rate (ms/h)	Static shift (ms)	Raw data files	Remarks
1	GSC-A	46.857300 W	57.473870 N	-	2678 m *	46.860563 W	57.465919 N	-	3109 m **	159:14:28	163:01:59	-1.970	-0.023	-0.030	0000-0175	
2	GSC-B	46.703009 W	57.542636 N	-	2604 m *	46.703009 W	57.533314 N	2960 m	3031 m **	159:11:41	163:02:16	+19.992	+0.231	-0.040	0000-0182	No data recorded
3	GSC-C	46.546108 W	57.612361 N	-	2502 m *	46.546108 W	57.612361 N	-	2933 m **	159:12:31	163:06:01	+2.862	+0.032	-0.032	0000-0189	
4	GSC-D	46.387339 W	57.683011 N	-	2439 m *	46.379007 W	57.671824 N	-	2862 m **	159:13:55	163:07:54	-15.073	-0.167	-0.036	0000-0195	
5	GSC-E	46.229515 W	57.752789 N	-	2358 m *	46.234728 W	57.756841 N	2400 m	-	159:19:38	163:09:46	-28.831	-0.335	+0.009	0000-0200	
6	GSC-F	46.070787 W	57.821614 N	-	2258 m *	46.082118 W	57.827139 N	2599 m	-	159:19:51	163:11:38	+2.962	+0.034	-0.031	0000-0207	No data recorded
7	DAL-A	45.911220 W	57.890828 N	-	2144 m *	45.920568 W	57.896289 N	-	2480 m **	159:15:46	163:13:26	-1724.37	-18.409	-0.040	0000-0214	Large drift. Unknown if linear
8	DAL-B	45.753490 W	57.959122 N	-	2037 m *	45.769778 W	57.962991 N	-	2356 m **	159:16:15	163:15:51	-1392.15	-14.562	-0.033	0000-0222	Large drift. Unknown if linear
9	DAL-C	45.592717 W	58.027847 N	-	1943 m *	45.592717 W	58.027847 N	2179 m	2255 m **	159:16:30	163:19:06	-1144.14	-11.603	-0.044	0000-0234	Large drift. Unknown if linear
10	DAL-D	45.430899 W	58.096174 N	2123 m	1854 m *	45.429026 W	58.095586 N	2136 m	2148 m **	159:21:51	163:19:55	+1.539	+0.016	-0.021	0000-0237	
11	DAL-E	45.269991 W	58.164615 N	2094 m	1816 m *	45.279142 W	58.169279 N	2104 m	-	159:22:03	163:21:27	+9.000	+0.094	-0.038	0000-0243	
12	DAL-G	45.108015 W	58.232083 N	2067 m	1793 m *	45.104918 W	58.244933 N	2083 m	-	159:22:12	163:22:58	+0.875	+0.009	-0.036	0000-0248	
13	GSC-H	44.944067 W	58.300021 N	1948 m	1691 m *	44.952660 W	58.302493 N	1958 m	-	159:15:09	164:00:00	+3.110	+0.030	-0.008	0000-0251	
14	GSC-J	44.779499 W	58.368181 N	1791 m	1554 m *	44.788815 W	58.366979 N	1797 m	1807 m **	160:15:47	164:02:07	+29.718	+0.361	-0.030	0000-0258	
15	GSC-K	44.617767 W	58.435117 N	1722 m	1494 m *	44.626524 W	58.438072 N	1720 m	1730 m **	159:16:12	164:03:47	+1.650	+0.015	-0.016	0000-0264	
16	GSC-L	44.452381 W	58.502417 N	1674 m	1456 m *	44.464183 W	58.503982 N	1670 m	1677 m **	159:15:44	164:05:22	-4.144	-0.038	+0.007	0000-0269	
17	GSC-N	44.285934 W	58.569333 N	1631 m	1418 m *	44.294065 W	58.567832 N	1630 m	1638 m **	160:16:38	164:06:49	+0.095	+0.001	-0.008	0000-0274	
18	GSC-P	44.120541 W	58.635587 N	1597 m	1387 m *	44.125272 W	58.632142 N	1605 m	1615 m **	160:16:53	164:08:08	-0.030	+0.000	-0.036	0000-0278	
19	DAL-F	43.954142 W	58.702842 N	1572 m	1365 m *	43.945256 W	58.704743 N	1570 m	-	159:22:22	164:09:29	+22.222	+0.208	-0.038	0000-0277	
20	DAL-H	43.786559 W	58.768629 N	1566 m	1362 m *	43.787040 W	58.769370 N	1570 m	-	159:22:33	164:10:56	-7.634	-0.070	-0.033	0000-0288	
21	DAL-I	43.619508 W	58.834291 N	1588 m	1599 m *	43.628337 W	58.832666 N	1585 m	-	159:22:43	164:12:22	+21.940	+0.200	-0.013	0000-0293	
22	DAL-K	43.451310 W	58.899709 N	1649 m	1435 m *	43.456232 W	58.898120 N	1651 m	1661 m **	159:22:57	N/A	N/A	N/A	-0.033	0000-0297	Clock not calibrated
23	DAL-L	43.281675 W	58.965787 N	1670 m	1449 m *	43.285083 W	58.961344 N	1674 m	1687 m **	159:23:04	164:15:20	+0.542	+0.005	-0.035	0000-0302	
24	DAL-N	43.111550 W	59.031440 N	1722 m	1494 m *	43.118992 W	59.028500 N	1720 m	1730 m **	159:23:10	164:16:46	+15.365	+0.136	-0.038	0000-0307	

* Knudsen transducer is 6 m below sea level during deployment
** Knudsen transducer is 8 m below sea level during recovery

Table 26. *Deployment and recovery locations of ocean bottom seismometers (OBS) on line 3; static time corrections and OBS clock drift (+ means OBS clock is ahead of GPS clock, - when OBS clock is behind GPS clock). Please note that all GSC instruments have an additional static time correction of -1.0 s. Julian days 160 and 164 are June 9 and June 13, respectively.*

Pos.	Instru-ment	Deployment longitude	Deployment latitude	Deployment depth Elac	Deployment depth Knudsen	Recovery longitude	Recovery latitude	Recovery depth Elac	Recovery depth Knudsen	Clock reset (JD:hh:mm)	Clock check (JD:hh:mm)	Clock drift (ms)	Drift rate (ms/h)	Static shift (ms)	Raw data files	Remarks
1	GSC-A	51.659113 W	58.998395 N	-	3534 m	51.678097 W	58.990303 N	-	3498 m	171:15:34	173:21:56	-797.231	-14.663	-0.040	0000-0161	Unknown if linear drift or time jump.
2	GSC-C	51.832768 W	58.915119 N	-	3898 m	51.843452 W	58.912540 N	-	3512 m	171:15:48	173:23:25	+1001.703	+0.031	+999.962	0000-0166	
3	GSC-D	52.003168 W	58.828011 N	-	3512 m	52.001517 W	58.829386 N	-	3508 m	171:16:00	174:01:23	-10.781	-0.187	-0.041	0000-0172	
4	GSC-E	52.172505 W	58.741535 N	-	3487 m	52.158366 W	58.748648 N	-	3493 m	171:16:14	174:03:34	-20.204	-0.340	-0.005	0000-0180	
5	GSC-F	52.339238 W	58.654239 N	-	3496 m	52.328096 W	58.659320 N	-	3495 m	171:16:28	174:05:48	+1.731	+0.029	-0.035	0000-0188	
6	DAL-B	52.508360 W	58.565333 N	(3048 m)	3457 m	52.508360 W	58.569197 N	-	3456 m	171:18:15	174:07:40	+4.951	+0.081	-0.043	0000-0196	
7	DAL-C	52.674625 W	58.477850 N	-	3401 m	52.679246 W	58.479645 N	-	3401 m	171:18:39	174:09:38	+13.093	+0.208	-0.011	0000-0201	
8	DAL-E	52.839534 W	58.390869 N	-	3460 m	52.845271 W	58.392132 N	-	3475 m	171:18:46	174:11:31	+4.970	+0.077	-0.038	0000-0208	
9	DAL-G	53.004125 W	58.302975 N	-	3474 m	52.988799 W	58.302200 N	-	3486 m	171:18:56	174:13:45	+0.131	+0.002	-0.008	0000-0216	
10	DAL-I	53.168804 W	58.214411 N	-	3471 m	53.154835 W	58.205702 N	-	3471 m	171:21:01	174:15:00	+13.395	+0.204	-0.033	0000-0220	
11	GSC-H	53.330343 W	58.126223 N	-	3479 m	53.322778 W	58.126145 N	-	3482 m	171:16:56	174:17:05	+1.701	+0.024	-0.007	0000-0227	
12	GSC-J	53.492621 W	58.037861 N	-	3474 m	53.475583 W	58.033000 N	-	3474 m	171:17:06	174:17:58	+24.547	+0.337	-0.036	0000-0229	
13	GSC-K	53.654163 W	57.948541 N	-	3475 m	53.654163 W	57.948541 N	-	3474 m	171:17:16	174:19:56	+0.490	+0.007	-0.007	0000-0236	
14	GSC-P	53.812038 W	57.861103 N	-	3450 m	53.791526 W	57.862030 N	-	3450 m	171:17:27	174:21:00	-13.748	-0.182	-0.023	0000-0240	
15	DAL-H	53.971969 W	57.771759 N	-	3411 m	53.948493 W	57.778196 N	-	3411 m	171:19:05	174:23:12	-5.904	-0.077	-0.038	0000-0248	
16	DAL-K	54.130916 W	57.683564 N	-	3382 m	54.110120 W	57.698004 N	-	3389 m	171:21:10	175:00:03	+1.915	+0.026	-0.026	0000-0251	
17	DAL-L	54.289909 W	57.593547 N	-	3343 m	54.281236 W	57.608884 N	-	3343 m	171:21:19	175:02:18	+0.193	+0.003	-0.047	0000-0258	
18	DAL-N	54.448315 W	57.503380 N	-	3311 m	54.443318 W	57.520914 N	-	3310 m	171:21:32	175:04:38	+9.429	+0.120	-0.036	0000-0266	

Table 27. *Deployment and recovery locations of ocean bottom seismometers (OBS) on line 4; static time corrections and OBS clock drift (+ means OBS clock is ahead of GPS clock, - when OBS clock is behind GPS clock). Please note that all GSC instruments have an additional static time correction of -1.0 s. Julian days 171 and 175 are June 20 and June 24, respectively.*

Pos.	Instru-ment	Deployment longitude	Deployment latitude	Deployment depth Elac	Deployment depth Knudsen	Recovery longitude	Recovery latitude	Recovery depth Elac	Recovery depth Knudsen	Clock reset (JD:hh:mm)	Clock check (JD:hh:mm)	Clock drift (ms)	Drift rate (ms/h)	Static shift (ms)	Raw data files	Remarks
1	GSC-P	53.132993 W	58.372308 N	-	3468 m	53.144590 W	58.377112 N	-	3477 m	174:21:48	176:21:31	-8.895	-0.185	-0.044	0000-0107	
2	GSC-J	53.001548 W	58.295728 N	-	3486 m	53.007408 W	58.300427 N	-	3486 m	174:22:21	176:23:45	+16.383	+0.332	-0.022	0000-0115	
3	GSC-H	52.871039 W	58.217421 N	-	3486 m	52.872887 W	58.218502 N	-	3486 m	174:22:33	177:00:41	+1.025	+0.021	-0.005	0000-0119	
4	GSC-F	52.741035 W	58.139418 N	-	3499 m	52.736499 W	58.136806 N	-	3499 m	174:22:56	177:02:44	+1.050	+0.021	-0.036	0000-0125	
5	GSC-D	52.610549 W	58.061412 N	-	3526 m	52.593671 W	58.057874 N	-	3508 m	174:23:04	177:04:47	-10.021	-0.186	-0.030	0000-0132	
6	DAL-C	52.472715 W	57.977381 N	-	3505 m	52.455238 W	57.982216 N	-	3512 m	175:00:22	177:05:58	+10.661	+0.200	-0.035	0000-0137	
7	DAL-E	52.353439 W	57.904372 N	-	3514 m	52.338595 W	57.900567 N	-	3521 m	175:00:28	177:07:52	+3.960	+0.072	-0.029	0000-0144	
8	DAL-G	52.225826 W	57.825769 N	-	3521 m	52.217396 W	57.824799 N	-	3527 m	175:00:35	177:09:54	-0.290	-0.005	-0.027	0000-0151	
9	DAL-H	52.099067 W	57.747180 N	-	3542 m	52.093651 W	57.747180 N	-	3525 m	175:00:50	177:10:36	-4.932	-0.085	-0.038	0000-0153	
10	DAL-I	51.971072 W	57.667813 N	-	3528 m	51.969838 W	57.674116 N	-	3530 m	175:01:06	177:12:54	+11.903	+0.199	-0.013	0000-0161	

Table 28. *Deployment and recovery locations of ocean bottom seismometers (OBS) on line 5; static time corrections and OBS clock drift (+ means OBS clock is ahead of GPS clock, - when OBS clock is behind GPS clock). Please note that all GSC instruments have an additional static time correction of -1.0 s. Julian days 176 and 177 are June 24 and June 26, respectively.*

18.1.3 Gain Settings

Pos	Instrum.	Deployment longitude	Deployment latitude	Sampling Rate (Hz)	Gain (dB) Ch1	Gain (dB) Ch 2	Gain (dB) Ch 3	Gain (dB) Ch 4
1	GSC-A	44.332902°W	50.401327°	250	56	70	70	70
2	GSC-B	44.679307°W	50.353009°	250	56	70	70	70
3	GSC-C	45.019464°W	50.307029°	250	56	70	70	70
4	GSC-D	45.429891°W	50.248973°	250	56	70	70	70
5	GSC-E	45.620884°W	50.221825°	250	56	70	70	70
6	DAL-B	45.881074°W	50.185132°	250	55.6	69.7	69.7	69.7
7	DAL-C	46.020743°W	50.163618°	250	55.6	69.7	69.7	69.7
8	DAL-E	46.224723°W	50.133514°	250	56.6	69.7	69.7	69.7
9	DAL-G	46.496346°W	50.091870°	250	56.3	69.7	69.7	69.7
10	DAL-H	46.975968°W	50.019300°	250	56	69.7	69.7	69.7
11	GSC-F	47.355342°W	49.956202°	250	56	70	70	70
12	GSC-H	47.826064°W	49.878139°	250	56	70	70	70
13	GSC-J	48.228230°W	49.811225°	250	56	70	70	70
14	GSC-K	48.699135°W	49.730017°	250	56	70	70	70
15	GSC-L	49.175564°W	49.645447°	250	56	70	70	70
16	DAL-I	49.728792°W	49.518875°	250	55.9	69.7	69.7	69.7
17	DAL-K	50.180764°W	49.405943°	250	56.2	69.7	69.7	69.7
18	DAL-L	50.757973°W	49.260209°	250	56.1	69.7	69.7	69.7
19	DAL-N	51.203618°W	49.144328°	250	55.7	69.7	69.7	69.7
20	DAL-D	51.437899°W	49.081787°	250	55.6	69.7	69.7	69.7
21	GSC-N	51.879922°W	48.962285°	250	56	70	70	70
22	GSC-P	52.446014°W	48.805305°	250	56	70	70	70
23	DAL-B	49.535006°W	49.566160°	250	55.6	69.7	69.7	69.7
24	DAL-C	49.963523°W	49.460739°	250	55.6	69.7	69.7	69.7
25	DAL-E	50.308093°W	49.374851°	250	55.6	69.7	69.7	69.7
26	GSC-J	50.565002°W	49.310245°	250	56	70	70	70
27	GSC-K	50.948254°W	49.211206°	250	56	70	70	70

Table 29. *Gain settings on the four channels of the OBS on line 1.*

Pos	Instrum.	Deployment longitude	Deployment latitude	Sampling Rate (Hz)	Gain (dB) Ch1	Gain (dB) Ch 2	Gain (dB) Ch 3	Gain (dB) Ch 4
1	GSC-P	42.376708°W	57.936301°	250	56	70	70	70
2	GSC-N	42.515732°W	57.999437°	250	56	70	70	70
3	GSC-K	42.656300°W	58.062223°	250	56	70	70	70
4	GSC-J	42.795576°W	58.125573°	250	56	70	70	70
5	GSC-H	42.939691°W	58.185960°	250	56	70	70	70
6	DAL-N	43.077454°W	58.250648°	250	55.7	70	70	70
7	DAL-L	43.219041°W	58.312392°	250	56.1	69.7	69.7	69.7
8	DAL-K	43.360618°W	58.374857°	250	56.2	69.7	69.7	69.7
9	DAL-I	43.506458°W	58.436730°	250	56	69.7	69.7	69.7
10	DAL-H	43.647215°W	58.500114°	250	56	69.7	69.7	69.7
11	GSC-F	43.791003°W	58.561046°	250	56	70	70	70
12	GSC-D	43.936286°W	58.621450°	250	56	70	70	70
13	GSC-C	44.079082°W	58.683559°	250	56	70	70	70
14	GSC-B	44.224489°W	58.744842°	250	56	70	70	70
15	GSC-A	44.370129°W	58.805236°	250	56	70	70	70
16	DAL-F	44.517890°W	58.867272°	250	56.4	70	70	70
17	DAL-G	44.668368°W	58.927922°	250	56	70	70	70
18	DAL-E	44.808846°W	58.988111°	250	55.6	70	70	70
19	DAL-B	44.956662°W	59.048229°	250	55.6	69.7	69.7	69.7
20	DAL-A	45.105675°W	59.108534°	250	56.1	69.7	69.7	69.7

Table 30. *Gain settings on the four channels of the OBS on line 2.*

Pos	Instrum.	Deployment longitude	Deployment latitude	Sampling Rate (Hz)	Gain (dB) Ch1	Gain (dB) Ch 2	Gain (dB) Ch 3	Gain (dB) Ch 4
1	GSC-A	46.857300°W	57.473870°	250	56	70	70	70
2	GSC-B	46.703009°W	57.542636°	250	56	70	70	70
3	GSC-C	46.546108°W	57.612361°	250	56	70	70	70
4	GSC-D	46.387339°W	57.683011°	250	56	70	70	70
5	GSC-E	46.229515°W	57.752789°	250	56	70	70	70
6	GSC-F	46.070787°W	57.821614°	250	56	70	70	70
7	DAL-A	45.911220°W	57.890828°	250	56.1	69.7	69.7	69.7
8	DAL-B	45.753490°W	57.959122°	250	56.1	69.7	69.7	69.7
9	DAL-C	45.592717°W	58.027847°	250	56.1	69.7	69.7	69.7
10	DAL-D	45.430899°W	58.096174°	250	56.1	69.7	69.7	69.7
11	DAL-E	45.269991°W	58.164615°	250	56.1	69.7	69.7	69.7
12	DAL-G	45.108015°W	58.232083°	250	56.1	69.7	69.7	69.7
13	GSC-H	44.944067°W	58.300021°	250	56	70	70	70
14	GSC-J	44.779499°W	58.368181°	250	56	70	70	70
15	GSC-K	44.617767°W	58.435117°	250	56	70	70	70
16	GSC-L	44.452381°W	58.502417°	250	56	70	70	70
17	GSC-N	44.285934°W	58.569333°	250	56	70	70	70
18	GSC-P	44.120540°W	58.635587°	250	56	70	70	70
19	DAL-F	43.954142°W	58.702842°	250	56.1	69.7	69.7	69.7
20	DAL-H	43.786559°W	58.768629°	250	56.1	69.7	69.7	69.7
21	DAL-I	43.619508°W	58.834291°	250	56.1	69.7	69.7	69.7
22	DAL-K	43.451310°W	58.899709°	250	56.1	69.7	69.7	69.7
23	DAL-L	43.281675°W	58.965787°	250	56.1	69.7	69.7	69.7
24	DAL-N	43.111550°W	59.031440°	250	56.1	69.7	69.7	69.7

Table 31. *Gain settings on the four channels of the OBS on line 3.*

Pos	Instrum.	Deployment longitude	Deployment latitude	Sampling Rate (Hz)	Gain (dB) Ch1	Gain (dB) Ch 2	Gain (dB) Ch 3	Gain (dB) Ch 4
1	GSC-A	51.659113°W	58.998395°	250	56	70	70	70
2	GSC-C	51.832768°W	58.915119°	250	56	70	70	70
3	GSC-D	52.003168°W	58.828011°	250	56	70	70	70
4	GSC-E	52.172505°W	58.741535°	250	56	70	70	70
5	GSC-F	52.339238°W	58.654239°	250	56	70	70	70
6	DAL-B	52.508360°W	58.565333°	250	55.6	69.7	69.7	69.7
7	DAL-C	52.674625°W	58.477850°	250	55.6	69.7	69.7	69.7
8	DAL-E	52.839534°W	58.390869°	250	55.6	69.7	69.7	69.7
9	DAL-G	53.004125°W	58.302975°	250	56.3	69.7	69.7	69.7
10	DAL-I	53.168804°W	58.214411°	250	55.9	69.7	69.7	69.7
11	GSC-H	53.330343°W	58.126223°	250	56	70	70	70
12	GSC-J	53.492621°W	58.037861°	250	56	70	70	70
13	GSC-K	53.654163°W	57.948541°	250	56	70	70	70
14	GSC-P	53.812038°W	57.861103°	250	56	70	70	70
15	DAL-H	53.971969°W	57.771759°	250	56	69.7	69.7	69.7
16	DAL-K	54.130916°W	57.683564°	250	56.2	69.7	69.7	69.7
17	DAL-L	54.289909°W	57.593547°	250	56.1	69.7	69.7	69.7
18	DAL-N	54.448315°W	57.503380°	250	55.7	69.7	69.7	69.7

Table 32. *Gain settings on the four channels of the OBS on line 4.*

Pos	Instrum.	Deployment longitude	Deployment latitude	Sampling rate (Hz)	Gain (dB) ch1	Gain (dB) ch 2	Gain (dB) ch 3	Gain (dB) ch 4
1	GSC-P	53.132993°W	58.372308°	250	56	70	70	70
2	GSC-J	53.001548°W	58.295728°	250	56	70	70	70
3	GSC-H	52.871039°W	58.217421°	250	56	70	70	70
4	GSC-F	52.741035°W	58.139418°	250	56	70	70	70
5	GSC-D	52.610549°W	58.061412°	250	56	70	70	70
6	DAL-C	52.472715°W	57.977381°	250	55.6	69.7	69.7	69.7
7	DAL-E	52.353439°W	57.904372°	250	55.6	69.7	69.7	69.7
8	DAL-G	52.225826°W	57.825769°	250	56.3	69.7	69.7	69.7
9	DAL-H	52.099067°W	57.747180°	250	56	69.7	69.7	69.7
10	DAL-I	51.971072°W	57.667813°	250	55.9	69.7	69.7	69.7

Table 33. *Gain settings on the four channels of the OBS on line 5.*

18.1.4 Deployment and Recovery Times

Pos	Instrum.	Deployment longitude	Deployment latitude	Deploym. depth Elac	Deploym. depth Knudsen	Recovery longitude	Recovery latitude	Recovery depth Elac	Recovery depth Knudsen	Time deployment (JD:hh:mm)	Time release (JD:hh:mm)	Time off seafloor (JD:hh:mm)	Time on Surface (JD:hh:mm)	Time on deck (JD:hh:mm)	Ascent Rate (m/s)	Remarks
1	GSC-A	44.332902 W	50.401327 N	-	4190 m	44.251788 W	50.425125 N	-	3951 m	179:06:26	183:21:01	-	183:22:24	183:10:50	0.90	
2	GSC-B	44.679307 W	50.353009 N	-	4112 m	-	-	-	-	179:07:40	184:00:34	-	-	-	-	OBS lost
3	GSC-C	45.019464 W	50.307029 N	-	4057 m	44.995249 W	50.296502 N	-	4056 m	179:08:48	184:02:08	184:02:20	184:03:35	184:05:13	0.90	
4	GSC-D	45.429891 W	50.248973 N	-	3732 m	45.428284 W	50.242663 N	-	3731 m	179:10:08	184:06:35	184:06:44	184:07:47	184:08:03	0.99	
5	GSC-E	45.620884 W	50.221825 N	-	3479 m	45.613800 W	50.220708 N	-	3483 m	179:10:50	184:08:49	-	-	184:10:40	-	
6	DAL-B	45.881074 W	50.185132 N	-	2395 m	45.868724 W	50.184872 N	-	2388 m	179:11:48	184:09:35	-	-	184:11:41	-	
7	DAL-C	46.020743 W	50.163618 N	-	2421 m	46.013862 W	50.159359 N	-	2457 m	179:12:23	184:12:23	184:12:35	184:13:15	184:13:37	1.02	
8	DAL-E	46.224723 W	50.133514 N	-	2541 m	46.222798 W	50.131627 N	-	2531 m	179:13:10	184:12:59	184:13:12	184:13:52	184:14:30	1.05	
9	DAL-G	46.496346 W	50.091870 N	-	2567 m	46.496346 W	50.093480 N	-	2561 m	179:14:07	184:15:14	184:15:25	184:16:06	184:16:17	1.04	
10	DAL-H	46.975968 W	50.019300 N	-	2918 m	46.979696 W	50.017137 N	-	2917 m	179:15:45	184:17:51	184:18:00	184:18:54	184:19:07	0.90	
11	GSC-F	47.355342 W	49.956202 N	-	2701 m	47.358017 W	49.954333 N	-	2693 m	179:17:03	184:20:09	184:20:18	184:21:10	184:21:21	0.86	
12	GSC-H	47.826064 W	49.878139 N	-	2645 m	47.826055 W	49.877360 N	-	2663 m	179:18:38	184:23:08	184:23:16	-	185:00:16	-	
13	GSC-J	48.228230 W	49.811225 N	-	2417 m	48.226281 W	49.810264 N	-	2421 m	179:20:03	185:01:28	185:01:37	185:02:17	185:02:30	1.01	
14	GSC-K	48.699135 W	49.730017 N	-	2090 m	48.695623 W	49.725816 N	2081 m	2093 m	179:21:44	185:03:57	185:04:03	185:04:38	185:05:01	1.40	
15	GSC-L	49.175564 W	49.645447 N	1643 m	1647 m	49.172787 W	49.644026 N	1645 m	1654 m	179:23:27	185:06:30	185:06:40	185:07:12	185:07:23	0.86	
16	DAL-I	49.728792 W	49.518875 N	996 m	1000 m	49.728792 W	49.518815 N	-	997 m	180:01:23	188:09:44	-	-	185:10:31	-	
17	DAL-K	50.180764 W	49.405943 N	305 m	315 m	50.180454 W	49.408553 N	307 m	299 m	180:03:00	185:12:07	185:12:15	185:12:21	185:12:30	0.80	
18	DAL-L	50.757973 W	49.260209 N	326 m	333 m	-	-	-	-	180:05:06	185:14:47	-	-	-	-	OBS lost
19	DAL-N	51.203618 W	49.144328 N	343 m	353 m	51.198792 W	49.141656 N	346 m	350 m	180:06:45	187:23:46	187:23:53	187:23:59	188:00:06	1.00	
20	DAL-D	51.437899 W	49.081787 N	312 m	321 m	51.432921 W	49.079174 N	317 m	320 m	180:07:43	187:22:22	187:22:39	-	187:22:53	-	
21	GSC-N	51.879922 W	48.962285 N	332 m	343 m	51.879212 W	49.960471 N	334 m	336 m	180:09:24	187:20:15	187:20:26	-	187:20:32	-	
22	GSC-P	52.446014 W	48.805305 N	316 m	304 m	52.445156 W	48.804009 N	317 m	323 m	180:11:27	187:17:55	187:18:02	187:18:07	187:18:15	1.10	
23	DAL-B	49.535006 W	49.566160 N	1240 m	1252 m	49.533564 W	49.561625 N	1240 m	1177 m	185:08:48	188:08:19	188:08:23	188:08:46	188:08:56	0.90	Backup release
24	DAL-C	49.963523 W	49.460739 N	697 m	697 m	49.962762 W	49.460169 N	-	696 m	185:11:15	187:03:30	187:03:39	187:03:51	187:04:18	0.97	
25	DAL-E	50.308093 W	49.374851 N	311 m	297 m	50.306130 W	49.372701 N	-	317 m	185:12:59	188:04:19	188:04:25	188:04:30	188:04:39	1.06	
26	GSC-J	50.565002 W	49.310245 N	-	338 m	50.565002 W	49.309897 N	324 m	326 m	185:13:59	188:02:52	188:03:01	188:03:07	188:03:16	0.91	
27	GSC-K	50.948254 W	49.211206 N	332 m	338 m	50.945924 W	49.209991 N	333 m	338 m	185:16:09	188:01:06	188:01:14	188:01:19	188:01:25	1.10	

Table 34. *Deployment and recovery times of OBS on line 1. Julian days 178 and 188 are June 27 and July 7, respectively.*

Pos	Instrum.	Deployment longitude	Deployment latitude	Deploym. depth Elac	Deploym. depth Knudsen	Recovery longitude	Recovery latitude	Recovery depth Elac	Recovery depth Knudsen	Time deployment (JD:hh:mm)	Time release (JD:hh:mm)	Time off seafloor (JD:hh:mm)	Time on Surface (JD:hh:mm)	Time on deck (JD:hh:mm)	Ascent Rate (m/s)	Remarks
1	GSC-P	42.376708 W	57.936301 N	(3048 m)	3527 m	42.382724 W	57.931731 N	(3048 m)	3241 m	164:22:19	169:13:08	169:13:17	169:14:13	169:14:36	0.96	
2	GSC-N	42.515732 W	57.999437 N	2269 m	3218 m	42.523037 W	57.999437 N	-	3218 m	164:22:52	169:15:01	169:15:08	169:16:03	169:16:30	0.98	
3	GSC-K	42.656300 W	58.062223 N	(3048 m)	-	42.656300 W	58.062223 N	(3048 m)	3182 m	164:23:26	169:17:05	169:17:14	169:18:07	169:18:19	1.01	
4	GSC-J	42.795576 W	58.125573 N	(3048 m)	3150 m	42.795576 W	58.125573 N	(3048 m)	3151 m	165:00:00	169:18:53	169:19:03	169:19:57	169:20:20	0.97	
5	GSC-H	42.939691 W	58.185960 N	(3048 m)	3125 m	42.939691 W	58.185960 N	(3048 m)	3129 m	165:00:33	169:20:55	169:21:03	169:21:54	169:22:06	1.00	
6	DAL-N	43.077454 W	58.250648 N	2006 m	2992 m	43.077667 W	58.258440 N	(3048 m)	2986 m	165:01:10	169:22:45	169:22:55	169:23:44	-	1.01	
7	DAL-L	43.219041 W	58.312392 N	(3048 m)	2846 m	43.243854 W	58.317787 N	-	2860 m	165:01:44	170:00:01	170:01:35	170:02:21	170:03:03	1.03	
8	DAL-K	43.360618 W	58.374857 N	2161 m	2652 m	43.393732 W	58.374857 N	-	2622 m	165:02:19	170:01:40	170:03:26	170:04:11	170:04:58	0.97	
9	DAL-I	43.506458 W	58.436730 N	2430 m	2443 m	43.504688 W	58.439912 N	-	2434 m	165:02:57	170:05:27	-	170:08:23	170:09:17	-	
10	DAL-H	43.647215 W	58.500114 N	2254 m	2251 m	43.648118 W	58.502837 N	-	2255 m	165:03:36	170:06:27	170:07:27	170:08:09	170:08:22	0.89	
11	GSC-F	43.791003 W	58.561046 N	2002 m	2005 m	43.792386 W	58.558512 N	2004 m	2015 m	165:04:17	170:10:11	170:10:29	-	170:10:56	-	
12	GSC-D	43.936286 W	58.621450 N	-	1768 m	43.934853 W	58.614119 N	1775 m	1785 m	165: 04:52	170:11:26	170:11:37	-	170:12:26	-	
13	GSC-C	44.079082 W	58.683559 N	1584 m	1596 m	44.076110 W	58.680768 N	-	1593 m	165:05:31	170:13:21	170:13:28	170:13:56	170:14:04	0.95	
14	GSC-B	44.224489 W	58.744842 N	1738 m	1748 m	44.222562 W	58.743661 N	-	1749 m	165:06:03	170:14:30	170:14:40	170:15:08	170:15:18	1.04	
15	GSC-A	44.370129 W	58.805236 N	-	1922 m	44.372888 W	58.804346 N	-	1927 m	165:06:38	170:15:52	170:16:00	170:16:32	170:16:48	1.00	
16	DAL-F	44.517890 W	58.867272 N	2006 m	2018 m	N/A	N/A	N/A	N/A	165:07:18	170:17:20	N/A	N/A	N/A	N/A	OBS lost
17	DAL-G	44.668368 W	58.927922 N	2095 m	2106 m	44.683680 W	58.934275 N	-	2109 m	165:07:52	170:18:20	170:18:28	170:19:03	170:19:39	1.00	
18	DAL-E	44.808846 W	58.988111 N	2224- m	2230 m	44.797805 W	58.986312 N	2204 m	2213 m	168:01:39	170:20:11	-	-	170:23:13	-	
19	DAL-B	44.956662 W	59.048229 N	2205 m	2216 m	44.958245 W	59.047221 N	-	2213 m	168:02:18	171:00:04	171:00:15	171:00:52	170:01:07	1.00	
20	DAL-A	45.105675 W	59.108534 N	2082 m	2102 m	N/A	N/A	N/A	N/A	168:02:53	171:01:15	N/A	N/A	N/A	N/A	OBS lost

Table 35. *Deployment and recovery times of OBS on line 2. Julian days 164 and 170 are June 13 and June 19, respectively.*

Pos	Instrum.	Deployment longitude	Deployment latitude	Deploym. depth Elac	Deploym. depth Knudsen	Recovery longitude	Recovery latitude	Recovery depth Elac	Recovery depth Knudsen	Time deployment (JD:hh:mm)	Time release (JD:hh:mm)	Time off seafloor (JD:hh:mm)	Time on Surface (JD:hh:mm)	Time on deck (JD:hh:mm)	Ascent Rate (m/s)	Remarks
1	GSC-A	46.857300 W	57.473870 N	-	2678 m *	46.860563 W	57.465919 N	-	3109 m **	160:12:52	163:00:27	163:00:41	163:01:33	163:01:48	1.00	
2	GSC-B	46.703009 W	57.542636 N	-	2604 m *	46.703009 W	57.533314 N	2960 m	3031 m **	160:13:31	163:02:33	163:02:43	163:03:36	163:03:54	0.93	
3	GSC-C	46.546108 W	57.612361 N	-	2502 m *	46.546108 W	57.612361 N	-	2933 m **	160:14:09	163:04:40	163:04:50	163:05:40	163:05:56	0.98	
4	GSC-D	46.387339 W	57.683011 N	-	2439 m *	46.379007 W	57.671824 N	-	2862 m **	160:14:47	163:06:39	163:06:47	163:07:36	163:07:51	0.97	
5	GSC-E	46.229515 W	57.752789 N	-	2358 m *	46.234728 W	57.756841 N	2400 m	-	160:15:25	163:08:31	163:08:40	-	163:09:36	-	
6	GSC-F	46.070787 W	57.821614 N	-	2258 m *	46.082118 W	57.827139 N	2599 m	-	160:16:01	163:10:23	163:10:31	-	163:11:29	-	
7	DAL-A	45.911220 W	57.890828 N	-	2144 m *	45.920568 W	57.896289 N	-	2480 m **	160:16:39	163:12:09	163:12:16	163:12:52	163:13:10	1.15	
8	DAL-B	45.753490 W	57.959122 N	-	2037 m *	45.769778 W	57.962991 N	-	2356 m **	160:17:18	163:13:45	163:14:06	-	163:15:40	-	
9	DAL-C	45.592717 W	58.027847 N	-	1943 m *	45.592717 W	58.027847 N	2179 m	2255 m **	160:17:56	163:16:24	163:18:10	163:18:48	163:19:01	0.99	
10	DAL-D	45.430899 W	58.096174 N	2123 m	1854 m *	45.429026 W	58.095586 N	2136 m	2148 m **	160:18:34	163:17:13	-	-	163:19:51	-	
11	DAL-E	45.269991 W	58.164615 N	2094 m	1816 m *	45.279142 W	58.169279 N	2104 m	-	160:19:12	163:20:26	163:20:34	-	163:21:20	-	
12	DAL-G	45.108015 W	58.232083 N	2067 m	1793 m *	45.104918 W	58.244933 N	2083 m	-	160:20:01	163:21:57	-	-	163:22:54	-	
13	GSC-H	44.944067 W	58.300021 N	1948 m	1691 m *	44.952660 W	58.302493 N	1958 m	-	160:20:40	163:23:29	163:23:38	-	164:00:20	-	
14	GSC-J	44.779499 W	58.368181 N	1791 m	1554 m *	44.788815 W	58.366979 N	1797 m	1807 m **	160:21:23	164:00:57	164:01:09	164:01:39	164:01:57	1.00	
15	GSC-K	44.617767 W	58.435117 N	1722 m	1494 m *	44.626524 W	58.438072 N	1720 m	1730 m **	160:22:06	164:02:36	164:02:47	164:03:16	164:03:39	0.99	
16	GSC-L	44.452381 W	58.502417 N	1674 m	1456 m *	44.464183 W	58.503982 N	1670 m	1677 m **	160:22:46	164:04:16	164:04:24	164:04:53	164:05:12	0.90	
17	GSC-N	44.285934 W	58.569333 N	1631 m	1418 m *	44.294065 W	58.567832 N	1630 m	1638 m **	160:23:29	164:05:53	164:06:00	164:06:28	164:06:39	0.98	
18	GSC-P	44.120541 W	58.635587 N	1597 m	1387 m *	44.125272 W	58.632142 N	1605 m	1615 m **	161:00:11	164:07:16	164:07:22	164:07:50	164:07:59	0.96	
19	DAL-F	43.954142 W	58.702842 N	1572 m	1365 m *	43.945256 W	58.704743 N	1570 m	-	161:00:56	164:08:38	164:08:50	-	164:09:26	-	
20	DAL-H	43.786559 W	58.768629 N	1566 m	1362 m *	43.787040 W	58.769370 N	1570 m	-	161:01:36	164:10:02	164:10:08	-	164:10:51	-	
21	DAL-I	43.619508 W	58.834291 N	1588 m	1599 m *	43.628337 W	58.832666 N	1585 m	-	161:02:15	164:11:29	164:11:38	-	164:12:14	-	
22	DAL-K	43.451310 W	58.899709 N	1649 m	1435 m *	43.456232 W	58.898120 N	1651 m	1661 m **	161:02:53	164:12:55	164:13:05	164:13:33	164:13:39	0.99	
23	DAL-L	43.281675 W	58.965787 N	1670 m	1449 m *	43.285083 W	58.961344 N	1674 m	1687 m **	161:03:32	164:14:20	164:14:29	164:14:58	164:15:07	0.97	
24	DAL-N	43.111550 W	59.031440 N	1722 m	1494 m *	43.118992 W	59.028500 N	1720 m	1730 m **	161:04:10	164:15:45	164:16:00	164:16:16	164:16:36	1.86	Time on surface possibly wrong

* Knudsen transducer is 6 m below sea level during deployment
** Knudsen transducer is 8 m below sea level during recovery

Table 36. *Deployment and recovery times of OBS on line 3. Julian days 160 and 164 are June 9 and June 13, respectively.*

Pos	Instrum.	Deployment longitude	Deployment latitude	Deploym. depth Elac	Deploym. depth Knudsen	Recovery longitude	Recovery latitude	Recovery depth Elac	Recovery depth Knudsen	Time deployment (JD:hh:mm)	Time release (JD:hh:mm)	Time off seafloor (JD:hh:mm)	Time on Surface (JD:hh:mm)	Time on deck (JD:hh:mm)	Ascent Rate (m/s)	Remarks
1	GSC-A	51.659113 W	58.998395 N	-	3534 m	51.678097 W	58.990303 N	-	3498 m	171:23:39	173:20:25	173:20:32	-	173:21:51	-	Knudsen 12 kHz at
2	GSC-C	51.832768 W	58.915119 N	-	3898 m	51.843452 W	58.912540 N	-	3512 m	172:00:24	173:21:57	-	-	173:23:16	-	Knudsen 12 kHz at
3	GSC-D	52.003168 W	58.828011 N	-	3512 m	52.001517 W	58.829386 N	-	3508 m	172:01:06	173:23:55	174:00:05	174:01:03	174:01:15	1.01	
4	GSC-E	52.172505 W	58.741535 N	-	3487 m	52.158366 W	58.748648 N	-	3493 m	172:01:50	174:01:57	174:02:05	174:03:03	174:03:24	1.00	
5	GSC-F	52.339238 W	58.654239 N	-	3496 m	52.328096 W	58.659320 N	-	3495 m	172:02:33	174:04:05	174:04:15	174:05:13	174:05:40	1.00	
6	DAL-B	52.508360 W	58.565333 N	(3048 m)	3457 m	52.508360 W	58.569197 N	-	3456 m	172:03:16	174:06:14	174:06:24	174:07:24	174:07:35	0.96	
7	DAL-C	52.674625 W	58.477850 N	-	3401 m	52.679246 W	58.479645 N	-	3401 m	172:03:58	174:08:10	174:08:20	174:09:31	174:		
8	DAL-E	52.839534 W	58.390869 N	-	3460 m	52.845271 W	58.392132 N	-	3475 m	172:04:40	174:10:07	174:10:17	-	174:11:25	-	
9	DAL-G	53.004125 W	58.302975 N	-	3474 m	52.988799 W	58.302200 N	-	3486 m	172:05:24	174:12:07	174:12:10	174:13:05	174:13:42	1.05	
10	DAL-I	53.168804 W	58.214411 N	-	3471 m	53,.154835 W	58.205702 N	-	3471 m	172:06:08	174:12:55	174:13:08	174:14:08	174:14:50	0.96	
11	GSC-H	53.330343 W	58.126223 N	-	3479 m	53.322778 W	58.126145 N	-	3482 m	172:06:50	174:15:41	174:15:50	174:16:47	174:16:56	1.02	
12	GSC-J	53.492621 W	58.037861 N	-	3474 m	53.475583 W	58.033000 N	-	3474 m	172:07:31	174:16:14	174:16:24	174:17:24	174:17:51	0.97	
13	GSC-K	53.654163 W	57.948541 N	-	3475 m	53.654163 W	57.948541 N	-	3474 m	172:08:13	174:18:33	174:18:43	174:19:39	174:19:47	1.03	
14	GSC-P	53.812038 W	57.861103 N	-	3450 m	53.791526 W	57.862030 N	-	3450 m	172:08:54	174:19:09	174:19:19	174:20:15	174:20:53	1.03	
15	DAL-H	53.971969 W	57.771759 N	-	3411 m	53.948493 W	57.778196 N	-	3411 m	172:09:37	174:21:40	-	-	174:23:05	-	
16	DAL-K	54.130916 W	57.683564 N	-	3382 m	54.110120 W	57.698004 N	-	3389 m	172:10:26	174:22:14	-	-	174:23:56	-	
17	DAL-L	54.289909 W	57.593547 N	-	3343 m	54.281236 W	57.608884 N	-	3343 m	172:11:12	175:00:46	175:00:57	175:01:54	175:02:09	0.98	
18	DAL-N	54.448315 W	57.503380 N	-	3311 m	54.443318 W	57.520914 N	-	3310 m	172:11:56	175:02:58	175:03:10	175:04:06	175:04:30	0.99	

Table 37. *Deployment and recovery times of OBS on line 4. Julian days 171 and 175 are June 20 and June 24, respectively.*

Pos	Instrum.	Deployment longitude	Deployment latitude	Deploym. depth Elac	Deploym. depth Knudsen	Recovery longitude	Recovery latitude	Recovery depth Elac	Recovery depth Knudsen	Time deployment (JD:hh:mm)	Time release (JD:hh:mm)	Time off seafloor (JD:hh:mm)	Time on Surface (JD:hh:mm)	Time on deck (JD:hh:mm)	Ascent Rate (m/s)	Remarks
1	GSC-P	53.132993 W	58.372308 N	-	3468 m	53.144590 W	58.377112 N	-	3477 m	175:09:35	176:19:42	176:19:51	176:20:52	176:21:25	0.95	
2	GSC-J	53.001548 W	58.295728 N	-	3486 m	53.007408 W	58.300427 N	-	3486 m	175:10:11	176:22:00	176:22:10	-	176:23:41	-	
3	GSC-H	52.871039 W	58.217421 N	-	3486 m	52.872887 W	58.218502 N	-	3486 m	175:10:46	176:22:48	176:22:58	-	177:00:32	-	
4	GSC-F	52.741035 W	58.139418 N	-	3499 m	52.736499 W	58.136806 N	-	3499 m	175:11:25	177:01:02	177:01:12	177:02:12	177:02:34	0.97	
5	GSC-D	52.610549 W	58.061412 N	-	3526 m	52.593671 W	58.057874 N	-	3508 m	175:12:01	177:03:08	177:03:16	177:04:16	177:04:28	0.98	
6	DAL-C	52.472715 W	57.977381 N	-	3505 m	52.455238 W	57.982216 N	-	3512 m	175:12:38	177:03:56	177:04:06	177:05:04	177:05:55	1.01	
7	DAL-E	52.353439 W	57.904372 N	-	3514 m	52.338595 W	57.900567 N	-	3521 m	175:13:16	177:06:20	177:06:30	177:07:25	177:07:47	1.07	
8	DAL-G	52.225826 W	57.825769 N	-	3521 m	52.217396 W	57.824799 N	-	3527 m	175:13:52	177:08:25	177:08:39	-	177:09:50	-	
9	DAL-H	52.099067 W	57.747180 N	-	3542 m	52.093651 W	57.747180 N	-	3525 m	175:14:27	177:09:01	177:09:11	-	177:10:31	-	
10	DAL-I	51.971072 W	57.667813 N	-	3528 m	51.969838 W	57.674116 N	-	3530 m	175:15:03	177:11:25	177:11:35	-	177:12:51	-	

Table 38. *Deployment and recovery times of OBS on line 4. Julian days 175 and 177 are June 24 and June 26, respectively.*

18.2 Sonobuoys

Line	Station name	Depth (m)	Operat. life (h)	Radio channel	Time deployment (JD:hh:mm)	End of recording (JD:hh:mm)	Deployment longitude	Deployment latitude	Deploym. depth (Elac)	Deploym. depth (Knudsen)	Remarks
1	1-1	60	8	86	180:21:53	181:10:36	51.691729°W	49.013899°N	307 m	310 m	
1	1-2	60	8	72	181:04:41	181:16:02	51.014194°W	49.193348°N	333 m	336 m	
1	1-3	60	8	89	181:10:47	181:21:34	50.437691°W	49.342603°N	-	-	
1	1-4	60	8	86	181:16:02	181:21:34	49.922687°W	49.470771°N	-	-	No data transmission
1	1-5	60	8	72	181:21.21	181:21:21	49.394668°W	49.595458°N	1403 m	1409 m	No data, redeployed as 1-5a
1	1-5a	60	8	86	181:21:34	182:06:32	49.372828°W	49.600402°N	1423 m	1428 m	
1	1-6	60	8	72	182:06:32	182:13:46	48.433114°W	49.775196°N	2282 m	2287 m	
1	1-7	60	8	86	182:10:17	182:17:32	48.025890°W	49.844472°N	2528 m	2536 m	
1	1-8	60	8	72	182:13:56	182:21:56	47.621853°W	49.911640°N	-	2726 m	
1	1-9	60	8	89	182:17:33	183:01:45	47.241634°W	49.974046°N	-	2844 m	
1	1-10	60	8	86	182:21:56	183:05:45	46.766548°W	50.049463°N	-	2799 m	
1	1-11	60	8	72	183:01:45	183:01:45	46.360839°W	50.112472°N	-	2311 m	No data, redeployed as 1-11a
1	1-11a	60	8	82	183:01:45	183:01:45	46.360839°W	50.112472°N	-	-	No data transmission
1	1-12	60	8	89	183:07:44	183:15:23	45.705694°W	50.209801°N	-	3324 m	
1	1-13	60	8	86	183:12:09	183:18:36	45.223796°W	50.278379°N	-	3566 m	
1	1-14	60	8	72	183:15:11	-	44.884050°W	50.325729°N	-	-	No data, redeployed as 1-14a
1	1-14a	60	8	89	183:15:23	183:20:49	44.862537°W	50.329248°N	-	3833 m	
1	1-15	60	8	86	183:18:36	183:20:49	44.510869°W	50.376670°N	-	3906 m	
2	2-1	60	8	72	169:00:07	169:05:13	43.590603°W	58.474153°N	-	2330 m	
2	2-2	60	8	86	169:05:19	169:09:05	43.026589°W	58.226075°N	-	3054 m	
3	3-1	60	8	86	161:16:34	161:23:59	43.552830°W	58.860238°N	1612 m	1622 m	
4	4-1	60	8	86	172:14:48	172:22:00	54.551925°W	57.445951°N	-	3291 m	17:06 software crash, one shot missing
4	4-2	60	8	72	172:16:25	172:22:00	54.383471°W	57.540116°N	-	3330 m	17:06 software crash, one shot missing
4	4-3	60	8	86	173:17:19	173:18:30	51.639612°W	59.011591°N	-	3495 m	
5	5-1	60	8	86	175:17:54	-	51.795186°W	57.567242°N	-	3539 m	
5	5-2	60	8	72	175:19:35	175:19:35	52.028456°W	57.703450°N	-	3525 m	No data transmission
5	5-3	60	8	60	175:21:54	176:02:40	52.161023°W	57.784973°N	-	3517 m	
5	5-4	60	8	80	176:02:35	176:06:11	52.535397°W	58.015684°N	-	3509 m	No data transmission
5	5-5	60	8	70	176:04:11	176:06:11	52.662691°W	58.092157°N	-	3495 m	No data transmission

Table 39. *Deployment location and settings of the sonobuoys. Julian days 161 and 183 are June 10 and July 2, respectively.*

18.3 Airgun Shots

Line	Length (km)	First Shot: Shot	Date DDMMYYYY	Julian day	Time hh:mm	Longitude	Latitude	Last shot: Shot	Date DD.MM.YYYY	Julian day	Time hh:mm	Longitude	Latitude
1	631.9	1	29.06.2009	180	13 :47	52.61260°W	48.75550°N	4742	02.07.2009	183	20 :50	44.26325°W	50.40977°N
1A	207.7	4743	04.07.2009	185	20:08	51.50136°W	49.06507°N	6297	05.07.2009	186	22:05	49.18841°W	49.64249°N
2	226.8	1	17.06.2009	168	08:02	45.35259°W	59.21885°N	1619	18.06.2009	169	11:00	42.34230°W	57.92125°N
3	296.6	1	10.06.2009	161	11:49	42.94812°W	59.09534°N	2023	11.06.2009	162	21:46	46.92103°W	57.44027°N
4	255.2	1	21.06.2009	172	14:42	54.56220°W	57.43973°N	1672	22.06.2009	173	18:33	51.51291°W	59.07796°N
5	143.0	1	24.06.2009	175	17:49	51.78517°W	57.56263°N	1143	25.06.2009	176	12:51	53.38714°W	58.52680°N

Table 40. *Shot number, location and time for the first and last shot on each of the seismic lines.*

Guns firing	First shot: Shot	Date DD.MM.YYYY	Julian day	Time hh:mm	Longitude	Latitude	Last shot: Shot	Date DD.MM.YYYY	Julian day	Time hh:mm	Longitude	Latitude
6	4763	04.07.2009	185	20:28	51.53666°W	49.05559°N	4850	04.07.2009	185	21:55	51.66433°W	49.02139°N
9	4851	04.07.2009	185	21:56	51.66255°W	49.02187°N	4914	04.07.2009	185	22:59	51.55092°W	49.05169°N
12	4915	04.07.2009	185	23 :00	51.55092°W	49.05169°N	6297	05.07.2009	186	22:05	49.18841°W	49.64249°N

Table 41. *Number of airguns used during the shooting of line 1A, including the shot numbers, location and time.*

19. Group Photos

Figure 39. *Officers, crew and science staff of the SIGNAL cruise (Hudson 2009-019). Photo taken by Wayne Bernard.*

Figure 40. *Science staff of the SIGNAL cruise (Hudson 2009-019). Photo taken by Jeffrey Marchant. From left to right; first row: Matthias Delescluse, Paul Girouard, Robert Murphy; second row: W. Peter Vass, Marcel Ruhnau, Robert Iuliucci, Sonya Dehler, Thomas Funck, Patrick Meslin, Dwight P. Reimer; third row: Joseph Iuliucci, Walter Judge; fourth row: Nelson Ruben, Ryan Pike, Fred Learning, Roger Oulton. Missing: Qingmou Li, C. Borden Chapman, Desmond Manning, Graham Standen.*

20. Weekly Newsletter

By Thomas Funck

During the SIGNAL cruise, every Sunday a newsletter was written that summarized the events of the past week. These newsletters were published on the homepage of the Danish Continental Shelf Project (www.a76.dk) but are also added to the cruise report since they provide a better overview of the activities than the diary (section 4) does.

20.1 Weekly Newsletter Number 1 (Sunday, June 7)

Prior to departure of CCGS Hudson, the technicians and contractors did a great job on the mobilization of the seismic equipment. When the ship left the wharf at BIO on Friday at 10 am, everything was in good shape. Due to the long transit to the first line, there is ample time to do the remaining work on the airgun array, the compressors and the ocean bottom seismometers (OBS). After departure from Halifax, the scientific staff went through a safety briefing followed by a boat and fire drill for the entire crew. After lunch, all new staff participated in a familiarization tour through the ship. During this tour the survival suits were tried on, which is always associated with a lot of laughter. Daily science meetings are held at 11 am just prior to lunch. These meetings are meant to provide updates on the science program and on the weather, but also to address any safety issues.

Our track run parallel to the Eastern Shore of Nova Scotia, went through the Cabot Strait and the Strait of Belle Isle into Labrador Sea. Weather conditions are favourable with very calm seas, which help to perform the last remaining tasks to have the equipment ready for the first line. The photo shows the glassy sea and the outrigger that will be used to tow part of the airgun array. At the northern entrance to the Strait of Belle Isle was a zone with 3/10 of ice cover that we had to navigate around and the first icebergs were already seen in the strait. This was the time when many people ran around with their cameras.

We expect to arrive at the western end of line 3 sometime on Tuesday morning. The line runs on the Eirik Ridge and is 280 km long with 24 OBS deployments. The weather forecast is good for Tuesday, with winds between 10 and 20 knots south of Greenland. The latest ice chart also shows that the ice at Kap Farvel is to the north of the line.

For the moment we still have internet connection that comes through the satellite that is used for the TV onboard. From 5 pm to 5 am the internet is closed and the connection is used for TV (hockey games!). However, soon we will get out of the footprint of the satellite and then we have to run our email through the satellite phone. Email addresses will be assigned shortly.

People are in good humour despite the falling temperatures (5 deg C). There is a lot of support by the ship’s crew and Captain Martin is happy to do science with us.

Figure 41. *Outrigger used for the airgun array, at sunset. Photo: Thomas Funck.*

Figure 42. *Iceberg in Strait of Belle Isle. Photo: Marcel Ruhnau.*

20.2 Weekly Newsletter Number 2 (Sunday, June 14)

For the first six days of this week, the weather gods were good to us as the seas were calm. Often we had glassy seas, which is not what you normally would expect off southern Greenland. On Tuesday and Wednesday we deployed a total of 24 ocean bottom seismometers (OBS) along line3 that runs on the Eirik Ridge in SW-NE direction. Borden and his team used this time to finish the installation of the airgun array that went into the water on Wednesday morning after breakfast. We had to idle three hours because on the first line we did not want to deploy the new array during night time. The deployment took just under three hours with a total of 15 people (deck crew and technicians) involved. We detected a humpback whale during the deployment, but at fair distance. We also carried out a soft start as outlined by the permit from the BMP. Something that made the ship’s officers very happy was that we got dispensation from reporting our position every hour to the Greenpos system. Now we are asked to report every six hours

The shooting went fast, we could sail with 4.5 knots through the water and the East Greenland current added another 0.5 knot to it over ground. We had one airgun leaking shortly after the start but continued shooting without any problems with the remaining 11 guns. We also had a first sonobuoy deployment to check if our setup is working. We got arrivals up to 40 km distance before we got out of radio range. This is a very good result and this will certainly help to fill in between the OBS on the longer lines (1 and 5).

The recovery of the OBS went without major problems. However, one OBS was sticking to the seafloor for more than an hour before it released. We hope this is not a bad omen for line 1 in Orphan Basin where the release of OBS is notoriously slow. The OBS on line 3 were equipped with an ARGOS beacon and a radio but no strobe. This system worked fine for recovery also during the few hours of night time. During the retrieval we carried out one XBT to obtain a water velocity function down to 1830 m.

We have started some initial QC on the data from line 3 and could identify some high-amplitude Moho reflections. Two OBS returned with no data, which always seems to happen on the first line. We have addressed these problems and hopefully do better on the next lines.

After finishing line 3, the captain turned on an extra engine for a faster transit to line 2 (cross-line on Eirik Ridge) and for a faster deployment of the 20 OBS along that line. The reason for that was the hope that we could get the airgun array in the water before the winds of an approaching major weather system get too strong. However, we had to break after the deployment of 17 OBS early Sunday morning, when a major wave damaged two OBS on deck with some flooding of the GP lab. For now we keep the nose in the wind (50 knots) and pray to the weather gods for calmer seas. We got spoiled during our first week at sea.

Figure 43. *Sunday morning south of Greenland. Photo: Thomas Funck.*

Figure 44. *Deployment of ocean bottom seismometer. Photo: Thomas Funck.*

20.3 Weekly Newsletter Number 3 (Sunday, June 21)

Last Sunday we were hit by a storm that blew with 60 to 70 knots for two days straight. In the end, waves were building up to a height of 10 m and this brought life on the ship almost to a standstill. To keep the ship as stable as possible without getting too far from the seismic, we moved on a northeasterly course against the wind with a speed of 3 knots. On Tuesday morning the sea had calmed so much that we could return to line 2, some 150 miles away by then. On the way back we passed Cape Farewell at the southern tip of Greenland in beautiful sunshine. Unbelievable that a day earlier the seas were so furious out there. In the evening we could deploy the remaining three ocean bottom seismometers on line 2 that crosses the submarine Eirik Ridge.

Wednesday morning at 3 am, the ship became quite active as the airgun array was deployed with the first daylight, even though there always seems to be some twilight at these latitudes (59º N) at this time of the year. The deployment of the array took only two hours as our technicians and the ship’s crew have learned the procedure and work well together. This time all 12 guns (Sercel G guns with a volume of 520 cubic inches each) worked error-free during the 27 hours of continuous shooting.

The shooting was again followed by retrieval of the 20 ocean bottom seismometers (OBS) that were deployed earlier along the line. This operation lasted until early Saturday morning and took longer than expected because seven of the instruments would not release from the seafloor after the normal waiting time of 10 minutes that it takes to corrode a burnwire that attaches the OBS to the ground anchor. However, after waiting for one to three hours, five of these instruments came back to the surface. Two OBS had to be left behind.

Saturday we were in transit to line 5. Unfortunately, the ice that still exists around southern Greenland at this time of the year moved considerably during the last week. The eastern end of the line, where we expect the continent-ocean boundary is now covered with sea-ice. For this reason, we now concentrate on the western half of the line that traverses the extinct seafloor-spreading axis in Labrador Sea. Deployment of the OBS started Saturday evening and this morning we started the shooting along the line.

Through the ARGOS satellite tracking system we also got the news that one of the two lost OBS came back to the surface through the backup time release. We are presently discussing our options and have also asked the German research vessel Maria S. Merian for assistance. The ship operates in the immediate vicinity of the OBS whereas we are 24 hours of transit away. Other positive news is that we managed to repair the three OBS that were damaged during the storm and our sonobuoy recording system can finally handle more than one buoy at a time, which we just tested by two sonobuoy deployments.

Figure 45. *Close to Cape Farewell – heading back to line 2. Photo: Thomas Funck.*

Figure 46. *Deployment of airgun array. Photo: Thomas Funck.*

20.4 Weekly Newsletter Number 4 (Sunday, June 28)

The last week was very productive as we completed the two lines across and along the extinct spreading axis in Labrador Sea. All OBS were recovered and none of the instruments were malfunctioning. With that we have a really neat data set with dense observations, as our OBS spacing varied only between 11 and 14 km. An initial display of the record sections indicates very interesting lateral variations of the crustal velocity structure along these lines that should help to find out what happened during the final stages of seafloor spreading in Labrador Sea when it ceased around 33 million years ago.

In order to have enough contingency time for the last line in Orphan Basin off Newfoundland to allow for unforeseen events like weather, icebergs, fog and instrument problems, we decided to shorten the line within the extinct spreading axis to a length of 110 km, using only 10 instead of the originally planned 15 OBS. This gave us one extra day for our priority line 1. At the same time we moved the line in the spreading axis 11 km to the north to obtain a better tie with the line across the ridge axis. This will allow for a better definition of possible seismic anisotropy in the ridge region.

While the data acquisition on the line across the spreading axis occurred without any problems, we had some delays due to weather on the cross line. When we finished the shooting at northern end of the line, we had winds that reached gale force and the waves were 4 to 5 m high. Since the winds started to calm at that time we postponed the recovery of the airgun array by three hours. However, during the next attempt, a wave came up the stern and many people got quite wet. The recovery was then delayed for another three hours, before it was safe enough to retrieve the array – but it would have not been possible without the skills of the boatswain and his deck crew, supported by our science staff. The following OBS recovery was complicated by the dense fog that moved in at that time, with visibilities as low as 50-100 m. However, the direction finder on the ship was working very well, showing us the way to the radio beacons that are mounted on the OBS. This operation required a very slow speed but in the end all OBS were safely recovered.

Due to the wind, three of the five sonobuoys that we deployed on the line got entangled in the airgun array. This was related to the fact that it was difficult to predict the motion of the airguns in the swells, when the buoys were thrown in the water. However, otherwise the sonobuoys have proven to work fine and we have 15 sonobuoy deployments planned for line1 to supplement the OBS recordings. We also carried out three XBT measurements around the extinct spreading axis down to a water depth of 1830 m. This will give us the necessary velocity of sound in water that is important to know for the seismic data analysis. The first two XBT had suspiciously high temperatures (up to 13ºC) in the deep water, which is why we carried out a third XBT that did not show these anomalies.

Friday morning we started our transit to line 1 where we arrived early this morning and now we are deploying OBS again. The transit was used for a BBQ – but indoors due to weather.

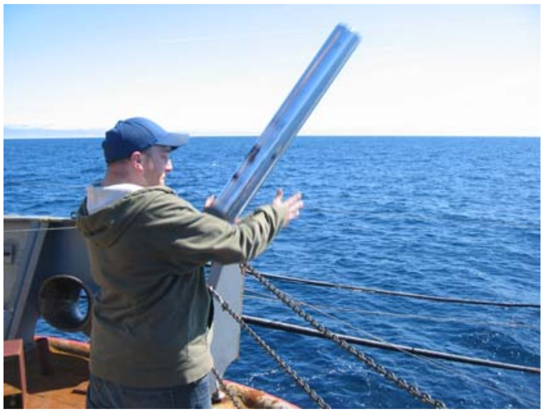

Figure 47. *Ryan Pike deploying a sonobuoy. Photo: Thomas Funck.*

Figure 48. *Bob Murphy: Expendable bathythermograph (XBT). Photo: Thomas Funck.*

20.5 Weekly Newsletter Number 5 (Sunday, July 5)

The last week was fully dedicated to line 1 extending from Cape Bonavista on Newfoundland, through Orphan Basin and across Orphan Knoll. For the GSC and the Canadian UNCLOS program, this line has the highest priority and that is why we made sure to have some contingency time in case of bad weather and other unforeseen events. Last Sunday and Monday we deployed 22 OBS along the line and when we were close to Cape Bonavista, there was a lot of activity on deck since we had cell phone coverage.

The weather was very cooperative during the OBS deployment but also during the shooting with the airgun array. The seas were very calm, with some sun but also with a lot of fog, which is not unusual for this region. The shooting lasted from Monday morning to Thursday evening without any downtime for repairs. This is a major achievement and shows that the investment into the new airgun array paid off. With the old array we could not have shot the 630-km-long line in one run. The only problem we had was a short circuit in the electrical system in one of the compressors, but the second compressor could fill in during the repair work.

Due to the good weather and fast progress during the shooting, we had two spare days that we decided to use for re-shooting a critical segment of the line close to the shelf break, where the OBS spacing was rather wide. We started the recovery of OBS along the eastern end of the line to have five instruments ready for redeployment on the shelf and yesterday we started shooting along the 185-km-long segment. We also shot short segments with six and nine guns only to see how the signal quality reduces compared to the full 12-gun array.

As far as the OBS recovery is concerned, in the deep water we had one instrument that would not react at all to our transducer signal. Two OBS on the shelf would send pinger signals back to the ship but did not release from the seafloor. These instruments have the backup release time set for Tuesday morning and that is why we will be back in St. John's early on Wednesday and not on Tuesday afternoon as many of us had hoped for. Despite these delays, we have excellent data on the sonobuoys that transmitted signals back to the ship for ranges of 30 to 40 km. Also the OBS that we already recovered on the eastern segment of the line have a good data quality and will be fun to work with. The seismic records show clear seismic energy down to the Moho (crust-mantle boundary) and from the upper mantle.

On Canada Day (July 1) we had a small celebration on deck. People showed up for the BBQ with maple leaf tattoos on their faces and we had lots of fun despite temperatures of only 8°C and an unpleasant wind. It was my first Canada Day ever with a toque on.

Figure 49. *Towing the array. Photo: Thomas Funck.*

Figure 50. *Second officer Douglas Roe practicing with sextant. Photo: Thomas Funck.*

20.6 Weekly Newsletter Number 6 (Wednesday, July 8)

The last few days of the cruise were rather eventful. The additional shooting along the western end of line 1 in Orphan Basin and on the Newfoundland shelf was finished by 7 pm on Sunday. After the airgun array was back on board we started with the recovery of the remaining 11 OBS that were still deployed along the western part of line 1. Shortly after 2 am on Monday morning we had to stop the OBS recovery when we received the mayday call of the fishing boat Ocean Commander just 8 miles away from us. The ship was on fire and all seven crew members were in a life raft. Just one hour after the mayday call, all seven crew members were safely onboard Hudson. The SAR operation was carried out very professionally. After the rescue, Hudson changed course towards St. John’s. Halfway from there we met with the Coast Guard ship Sir Wilfred Grenfell and transferred the seven rescued sailors.

The delay and detour caused by the SAR operation resulted in some concerns that we would not be able to recover all of the remaining OBS before we have to head back to St. John’s for the end of the cruise and the scheduled crew change. Even worse, we already tried to release three of the OBS earlier without success. This put additional constraints on our schedule as we had to be at the OBS positions for the pre-programmed time of the backup release system. We also worried that these three OBS may not come back to the surface at all. However, in the end we managed to retrieve all but one of the OBS. These were two long and hard days for everybody onboard but in the end we could feel proud of what we achieved, a successful refraction seismic survey and the rescue of seven people from the Ocean Commander.

After the OBS recovery was finished at 1 pm on Tuesday we started our transit back to St. John’s where we arrived at 6 am this morning. In summary, we used the airgun array for 1761 km along the five refraction seismic lines and deployed a total of 99 OBS. Three of the instruments never made it back to the surface and one instrument is possibly still drifting off West Greenland. The data collection was complemented by 29 sonobuoy deployments and 10 XBT measurements. Although some of the OBS and sonobuoys failed, we got complete data coverage along the lines with high-quality seismic records. We sailed 5720 nautical miles (10.600 km) and everybody is happy to head home after 34 days at sea. Thanks to everybody onboard for the hard work - it was a pleasure to sail on CCGS Hudson.

Figure 51. *Science staff and crew. Photo: Moira Burhoe.*

Figure 52. *Fire on Ocean Commander. Photo: Marcel Ruhnau.*

21. Conclusions and Recommendations

By Thomas Funck

The SIGNAL cruise was a successful collaboration between the GSC and GEUS and both institutions were able to collect the data in their respective prime target zones. For GEUS this was the Eirik Ridge (lines 2 and 3) and for GSC this was the Orphan Basin with Orphan Knoll (line 1). Beyond these key lines for the Canadian and Danish continental shelf programs, additional refraction seismic data could be acquired in central Labrador Sea in the area of the extinct spreading axis (lines 4 and 5). These two lines are important for the tectonic understanding of the Labrador Sea region and at the same time provide good control on the sedimentary velocities between the Canadian and Greenlandic exclusive economic zones.

Both lines 4 and 5 had to be shortened. On line 4, the landward (eastern) end at the continent-ocean transition zone was covered by sea ice or was close to the edge of the ice, which prohibited the deployment of ocean bottom seismometers unless taking the risk of instrument loss or substantial delay. Time constraints played also into the shortening of the lines. In that respect it would have been better to acquire the data in a different succession, doing the high-priority lines (1, 2, and 3) first. However, to avoid conflicts with other research programs (DFO fish study off Newfoundland, GSC reflection seismic data acquisition in Labrador Sea onboard Explora, German seismic research cruise south of Greenland onboard Maria S. Merian), there was no possibility of changing the order of the lines.

As in most major refraction seismic studies – in particular in northern latitudes – there were some unforeseen events that caused adjustments to the program. On this cruise, the two main events were the hurricane-force winds encountered south of Greenland that caused a delay of two and a half days (wind speeds were almost double the predicted ones) and the search and rescue mission for the fishing vessel Ocean Commander. Ice conditions also caused some modifications to the science program but this was somehow anticipated, as ice can be expected south of Greenland in June and July. With respect to the priority lines 2 and 3, the ice situation was actually better than in previous years when data acquisition would not have been possible along the entire length of the lines.

In addition to the events that are beyond anyone's control, there were some issues that could have improved the overall quality of the science program and could have reduced some of the delays. This comment is aimed at the performance of the ocean bottom seismometers. First, there were a number of technical problems with the ocean bottom seismometers and the recording on the first two lines (lines 2 and 3), which indicates that the pre-cruise testing and preparation of the OBS probably could have been improved. In addition, some of the issues could be related to operator errors during the deployment preparations of the OBS. While human error never can be eliminated completely, it might be worthwhile thinking about the introduction of improved deployment check lists that address some of the problems. This can help at the start of the program, when everything seems new and when errors are more likely to happen.

Second, problems with the recovery of the OBS have to be addressed. In this program, four out of 99 deployments led to lost OBS. This is close to the estimated average rate for the GSC/Dalhousie instruments, which is one loss in 25 deployments. However, every loss or problem with the recovery has severe implications for the science program such as significant delays (returning to the OBS for the backup-release time) and fewer available instruments for later lines. The SIGNAL cruise was afflicted with numerous long burn-times of the Monel burnwire. This problem was thought to be solved when the Monel used on the Dalhousie OBS was exchanged with a different Monel wire purchased by the GSC/Geoforce. However, this was only a part of the solution, since similar problems occurred again on the last line (line 1). Here a number of OBS did not release on the primary release but on the secondary that uses a higher voltage. This leads to the recommendation to increase the voltage on the primary release, which is possible since some extra space is available in the cylinder now that the geophone unit is mounted at the outside. Some of the issues with the recovery problems are also blamed on the properties of the sediments (“sticky” or very soft/water saturated) although this cannot be confirmed without visual observations of the sea bottom. However, given that these problems tend to occur in clusters in specific regions, there is probably something true to this theory and remediation would require some re-designing of the OBS and the way it is anchored. In the long run it would probably be advantageous to stop using the burnwires and switch to the now commonly-used release-hooks.

In contrast to what is stated in the OBS report (section 5), the 12 GSC OBS all have a static time error of 1 s. This is probably related to the software used in the GSC instruments, which is an older version of the one in the Dalhousie OBS. It is recommended to use the same software version in all instruments.

Some OBS records are characterized by high-amplitude noise with a frequency of 5 to 6 Hz, which lies exactly at the peak of the seismic energy in this type of refraction seismic studies. Removal of this unwanted noise with a notch filter therefore results in some deterioration of the seismic record (removal of real seismic energy in addition to ringing introduced by the filtering, which makes the picking of the arrival times more difficult). This characteristic noise occurred in all experiments in the last nine years (Screech 2000, Smart 2001, Nugget 2003) and it might be worthwhile to do some more systematic work to determine the cause of the noise and how it can be reduced.

The airgun array performed well during the survey, and no repairs were necessary while running individual lines. This is a major improvement to the old Bolt gun-array, where longer lines often had to be broken for airgun maintenance. With that the time planning is much more predictable and that is why improvements to the OBS (see above) are very desirable to keep up with the performance of the array. Having said that, the SIGNAL cruise was in the fortunate situation to have ten persons on the science staff that were dedicated to the technical support of the airgun array and the compressors. This is in addition to the deck crew that helped with the deployment and retrieval of the array. In other experiments with fewer resources, maintenance and deployment procedures may therefore take more time than on this cruise.

There were also some issues with the compressors (see also sections 7.5 and 7.9). Due to the amount of technical staff available to deal with problems, it was always possible to have at least one compressor ready to provide air for the array. However, with fewer staff the chances for downtime would increase. While one compressor is sufficient to supply enough air, the recommendation is to bring a spare compressor as was done on this cruise.

The main reason for bringing sonobuoys on the SIGNAL cruise was to have an alternative in case OBS could not be deployed due to ice cover. While not used for this purpose, the sonobuoys were deployed to increase the observation density. In particular on line 1 off Newfoundland where the OBS were widely spaced, this concept has proven to be successful. The failure rate of the sonobuoys was substantial; eight of the 29 buoys did not work. Initially, the sonobuoys were deployed with the parachute attached. With that configuration, the buoy with the antenna would surface just before the array passed and this resulted in some entanglements that caused the buoys to fail. Later the parachute was removed and with that the buoy would surface after the array had passed. While this reduced chances for entanglement, some other problems were introduced as some of the buoys did not surface. The reason for this is probably that the buoys sank too fast and reached a depth of >12 m before the seawater battery was activated. Once at 12 m, the surrounding water pressure is too high for the buoy to inflate and return to the surface. This somehow seems to relate to how the buoy landed in the water during deployment. At some angles, the housing of the buoy seem to flood much faster than in other cases. To decrease the failure rate of the sonobuoys, the buoys have to be deployed at a position where no interference with the airgun array is possible. On the Hudson this was difficult to achieve as outriggers were used for the array on either side of the ship. The best solution would be the purchase of a pneumatic launcher that is able to shoot the buoys to a distance of ca. 100 m to the side of the vessel. This is the way sonobuoys are launched on reflection seismic vessels, where entanglement is even more of a risk with several kilometres of streamer towed behind the ship.

The recording of the sonobuoy signals was also rather problematic. Initially, only one sonobuoy could be recorded at a time, which was later fixed to allow simultaneous recording of several sonobuoy signals. The most unreliable component in the system was the digitizing software. Several times the software did crash during registration, causing a lot of stress to the operator and unnecessarily compromising the data quality. This system does not seem to be fully matured yet. The Danish system used for recording on Arctic cruises has proven to be more reliable. Here the output from the WinRadios is fed directly to a Taurus seismometer for continuous recording and the data can later be extracted in a similar way as for the OBS. The system is both more reliable and flexible since the record length does not have to be defined prior to the acquisition.

With respect to staffing, there was an adequate number of technicians onboard. In less well-funded projects one can probably do with fewer by organizing the work differently. The watchkeepers (scientists and students) helped with some initial data analysis but it would have been helpful to have one fully dedicated scientist onboard for more advanced processing of the navigation, echosounder, OBS and sonobuoy data. This would have allowed for faster feedback to the technicians about potential problems with the equipment and also to sort out some of the timing issues for some of the OBS with unusually large clock drift. In addition, this would have sped up the onshore processing and modelling of the data.