MARIA S. MERIAN-Berichte

INDEX 2016_2

Volume 1

Cruise No. MSM59/1

INDEX2016_2/Leg 1
October 28 – November 26, 2016,
Cape Town (South Africa) – Port Louis (Mauritius)

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1 Summary

BGR, on behalf of the Federal Ministry for Economic Affairs and Energy (BMWi), holds an exploration license of the International Seabed Authority (ISA) for polymetallic sulphides in the southwestern Indian Ocean. The license covers an area of 10.000 km², subdivided into 100 so-called sulphide blocks each 10 x 10 km in size. By signing the license contract in May 2015, BGR has the obligation to carry out a detailed resource-oriented exploration program in the license area southeast of Mauritius. The program includes the identification and outline of potential polymetallic sulphide deposits and a resource assessment, but also extensive and detailed base line studies for the sustainable protection of the marine environment. The license contract has a fifteen years lifetime and may allow the application for a subsequent mining license.

With cruise MSM59 it was for the first time that a German research vessel could be used by BGR for this governmental task under a dedicated agreement between German Ministries of Education and Science (BMBF) and Economic Affairs and Energy.

During the two legs of MSM59 over a period of 55 days detailed geophysical, geological and biological investigations were carried out in individual blocks of the license area as part of the 15 years exploration program.

Zusammenfassung

Im Auftrag des Bundesministeriums für Wirtschaft und Energie (BMWi) hält die BGR eine Lizenz der Internationalen Meeresbodenbehörde zur Exploration polymetallische Sulphide im südwestlichen Indischen Ozean. Das Lizenzgebiet beinhaltet eine Fläche von 10.000 km², aufgeteilt in 100 Blöcken mit 10 x 10 km Kantenlänge. Mit Unterzeichnung des Lizenzvertrages im Mai 2015 ist die BGR zur verpflichtet, detaillierte ressourcenorientierte Erkundungsarbeiten in dem Lizenzgebiet südöstlich von Mauritius durchzuführen. Dieses Programm beinhaltet neben der Identifizierung und Potentialanalyse prospektiver Areale auch die Erhebung umfassender und detaillierte Umweltdaten als Grundlage für den nachhaltigen Schutz der Meeresumwelt. Der Lizenzvertrag hat eine Laufzeit von 15 Jahren und eröffnet Möglichkeiten für einen künftigen Tiefseebergbau.

Mit der Fahrt MSM59 konnte durch die BGR erstmalig ein deutsches Forschungsschiff unter einem entsprechenden Ressortabkommen zwischen dem BMBF und dem BMWi für diese hoheitliche Aufgabe genutzt werden.

Über einen Zeitraum von 55 Tagen wurden während der beiden Fahrtabschnitte von MSM59 geophysikalische, geologische und biologische Untersuchungen als Teil des 15-jährigen Erkundungsprogramms in einzelnen Blöcken des Lizenzgebietes durchgeführt.

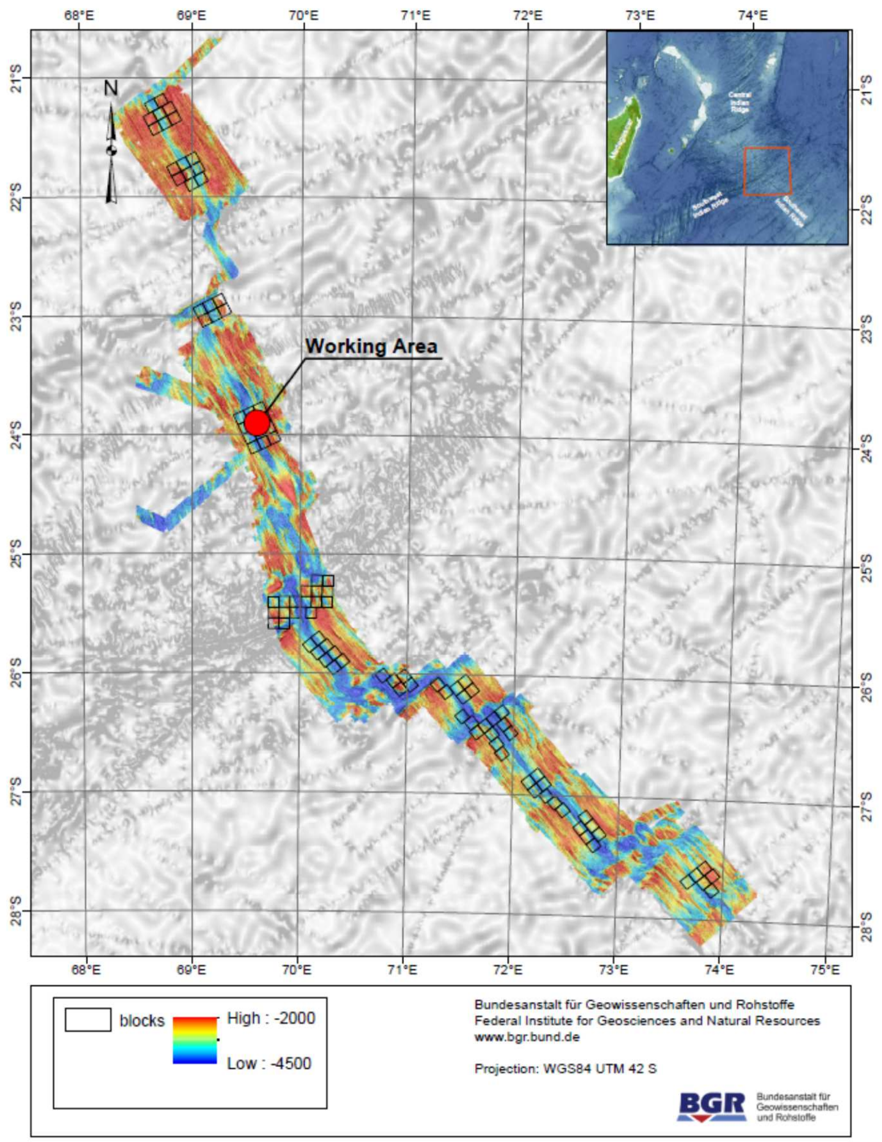


Fig. 1.-1: The German exploration license area along the southernmost Central Indian Ridge and the northernmost Southeast Indian Ridge. Cruise MSM59/1 (INDEX 2016_2) with FS MARIA S. MERIAN addressed the cluster #4 (red circle) at the southern Central Indian Ridge.

2 Objectives of BGR's exploration activities during MSM59

The dedicated license area consists of 12 clusters formed by at least 5 blocks of 100 km² each. By the end of the eighth year from the date of the contract 50 % of the licensing area have to relinquished, which gives high priority to identifying prospective sulphide fields in a first step of exploration activities. This demands detailed bathymetric mapping and geophysical surveying to locate and discriminate between active and inactive hydrothermal fields. The elaborated exploration strategy focused on fault intersections, volcanic ridges, graben slope heterogeneities, and secondary graben structures that frequently host sulphide mounds. Main objective of BGR's exploration activities during MSM59 was to locate these settings and identify hydrothermal fields in underexplored clusters by bathymetric mapping and analyzing the water column.

Tracking the continuity of known sulphide outcrops under a sediment cover is difficult and little is known about the thickness of the deposits generated by hydrothermal vents. Possible future seafloor mining will likely focus on relatively small areas and sulphide recovery will be probably restricted to the surface or shallow subsurface. Nevertheless, it is essential to map the three-dimensional extent of ore bodies to evaluate the resource potential of massive sulphide deposits in these settings and subsequent tonnage estimates. Seismics should be a reliable tool to provide the necessary depth and volume information. During cruise MSM59 it was planned to investigate well-known hydrothermal sulphide sites in license cluster #4 approximately 200 km north of the Rodriguez Triple Junction which separates the Indian, Somalian, and Antarctic plates by a 3D-seismic survey. The objective was to employ this method as reliable and suitable tool for hydrothermal sulphide investigation and imaging pathways of hydrothermal fluids.

Cruise MSM59 was split up in two legs to tackle both objectives. During leg 1, a small-scaled 3D-seismic survey was conducted in cluster #4, whereas detailed bathymetric mapping and geological exploration in the northernmore clusters #1, #2 and #3 was carried out during leg 2 of the cruise.

3 Leg 1 (MSM59/1)

3.1 Survey area and working program

The goal of Leg 1 (MSM59/1) was to image the massive sulphides by means of seismic methods. Under special focus were the lateral and vertical boundaries of the massive sulphide area comprising of the hydrothermal fields Edmond, Gauss and Score in cluster #4. Additionally, we subsequently want to locate the migration paths of the circulation fluids by means of the processed 3D seismic data set. In order to address the small-scale geological structures, we choose a 3D seismic setup in combination with a high frequency seismic source. Because of the significant seafloor topography of the Central Indian Ridge, we planned for a two azimuth 3D seismic surveys, with one orientation of survey lines orthogonal to the ridge and one parallel to the ridge, respectively. The intended CDP spacing of each survey strip was 12.5 m crossline and 6.25 m inline resulting in a streamer layout as shown below (Fig. 3.4.2.1). We used two 1500 m streamer cables 50 m apart and two GI-guns in flip-flop mode with 25 m shotpoint spacing.

The usage of only one paravane was planned to achieve the necessary spread of the seismic equipment. Gun triggering in flip-flop mode resulted in four CDP lines along on sail line. For the intended 6000 x 3000 m survey strips 60 track lines were preplanned in order to get a high resolution 3D seismic volume with a 6.25 m CDP spacing for the central part of the survey area. In addition to the reflection seismic survey, it was planned to deploy up to 10 Ocean Bottom Seismometers (OBS) around and within the survey area (Fig.3.1-1) to acquire wide angle seismic data. In summary, the planned seismic 3D survey around the Edmond site consisted of the following elements:

- one seismic cube of 3 km x 6 km oriented parallel to the Central Indian Ridge
- a second seismic cube of 3 km x 6 km oriented perpendicular to the ridge
- one 3D OBS array consisting of three profiles around Edmond

BGR's exploration program is in full agreement with the International Law of the Sea and its environmental constraints. In order to meet all precautionary measures, an airgun calibration was performed prior the survey to meet the limits defined by the German Hydrographic Service (BSH) for sound impact in German territorial waters. Our precautionary measures also included qualified and certified external marine mammal observers and appropriate equipment for mammal detection in case of bad visibility and during night time. The 24/7 precaution activities during seismic operation are documented as part of this cruise report.

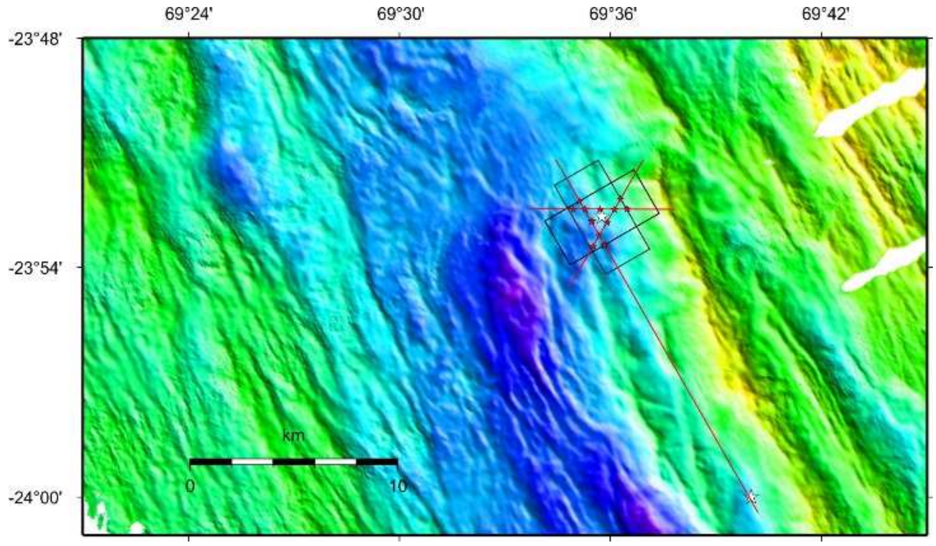


Fig. 3.1-1: Bathymetric map of license cluster #4. The white star marks the location of the Edmond Hydrothermal vent field. Black boxes show the orientation of the planned 3D seismic survey areas and red stars mark the proposed deployment positions of the Ocean Bottom Seismometers (OBS).

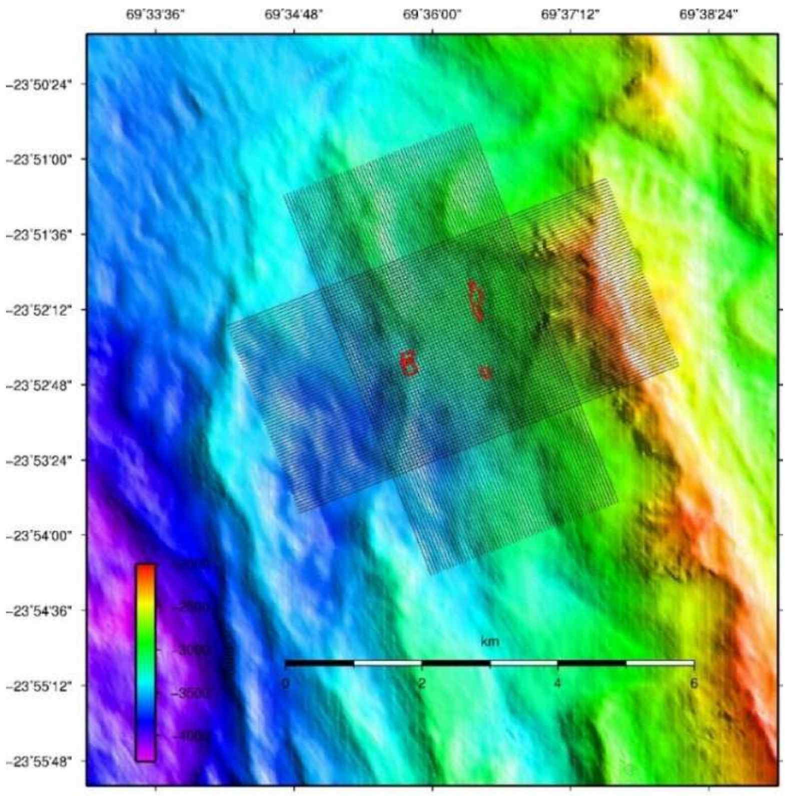


Fig. 3.1-2: Planned 3D seismic layout in cluster #4

3.2 Participants

Name	Discipline	Institution
Dr. Volkmar Damm	Geophysicist/Chief Scientist	BGR
Hans-Otto Bargeloh	Technician	BGR
Thomas Behrens	Technician	BGR
Dr. Kai Berglar	Geophysicist	BGR
Ümit Demir	Technician	BGR
Timo Ebert	Technician	BGR
Dr. Axel Ehrhardt	Geophysicist	BGR
Dr. Martin Engels	Physicist	BGR
Dr. Rüdiger Lutz	Geologist	BGR
Michael Schauer	Geophysicist	BGR
Dr. Bernd Schreckenberger	Geophysicist	BGR
Christian Seeger	Technician	BGR
Stephanie Barnicoat	MMO	Seiche
Lorenzo Scala	MMO	Seiche

BGR	Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover
Seiche	Seiche Ltd., Bradworthy, Holsworthy Devon, United Kingdom

3.3 Cruise narrative

RV MARIA S. MERIAN berthed in Cape Town in the morning of **October 25th** and was ready for loading operations of the eight BGR containers. Mobilisation of the 3D seismic equipment was conducted and widely completed until Thursday, **October 27th**. This also included welding operations and installation of the two streamer winches and other deck equipment.

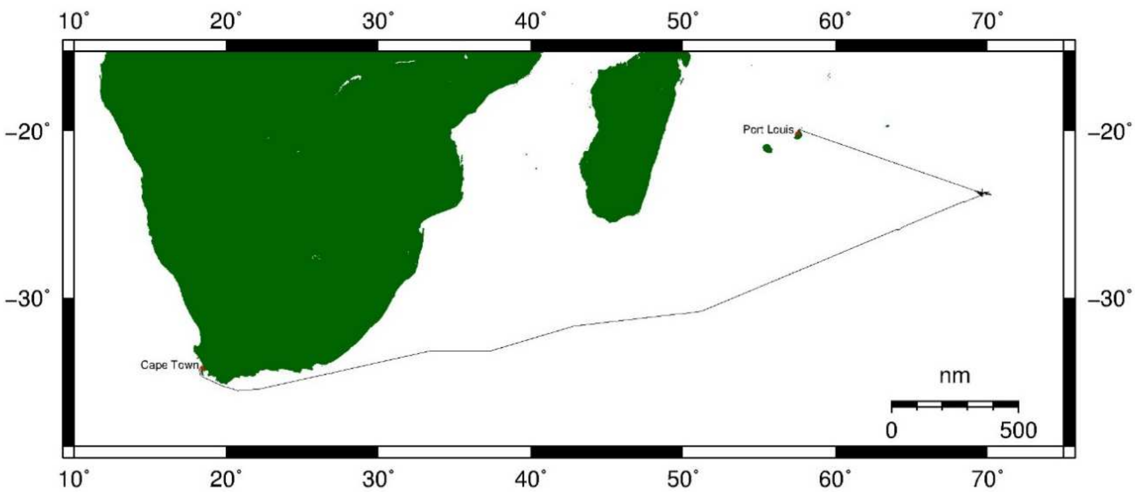


Fig. 3.3-1: Cruise track MSM59 Leg 1

RV MARIA S. MERIAN left Cape Town harbor in good weather conditions at noon **October 28th** heading for the survey area at around 24°S, 70°E (Fig 3.3-1). A transit time of 9 days was planned for the 2900 nm transit to the survey area. Despite unfavorable weather conditions over the following week all installation work and preparation of the 3D data acquisition could be completed successfully and well in time. Before reaching the survey area in license cluster 4 we successfully completed on Sunday, **November 6th** a first test to launch and recover a paravane, planned to be used for deflection of one of our two 1500 m long seismic streamer cables. The calibration of the seismic sources was on schedule for Monday, **November 7th**. In order to validate the modelled sound emission, a one day gun calibration of the single GI-guns was performed. For this purpose, two broad-band hydrophones were mounted below a buoy at 20 m and 750 m depth. The vessel was passing the buoy on several profiles to cover different azimuths and distances to the hydrophones. Sound pressure levels (SPL) and sound exposure levels (SEL) were recorded and computed for the deep water case to test, if the limits for sound impact, preset by the German Hydrographic Service (BSH) for German territorial waters, are met.

After arriving the survey area represented by the 10x10 km² extended license cluster #4 on Tuesday, **November 8th** 9 OBS were deployed inside and around the planned 3D survey area of 6x6 km². By means of these OBS we want to get additional information about deeper structures of the former active hydrothermal zone. Subsequently, we deployed all 3D seismic outboard systems. The two seismic streamers were towed in a distance of 50 m apart. Two single GI-guns in a distance of 25 m apart and operating in flip-flop mode were used as seismic sources. After careful calibration and verification of full 3D layout, 3D seismic acquisition commenced in late night, Wednesday, **November 9th**. Unfortunately, we had to interrupt seismic production next morning due to longline fishery in the area. We had to recover all outboard equipment since fishing lines interfered with the seismic streamers. After replacement of damaged streamer sections and redeployment of all seismic outboard equipment we re-commenced seismic acquisition Thursday evening **November 10th**. Weather conditions and sea state changed for the worse over the weekend **November 12th/13th** and production had to be interrupted again on Monday, **November 14**th due to a broken towing rope. As a consequence we had to recover all seismic outboard equipment before fixing the problem. After re-deploying the 3D seismic gear we continued with seismic production after 24 hours of interruption on Tuesday, **November 15th**. The continuous seismic data production lasted over the next 6 days thanks to appropriate weather and sea conditions. 3D seismic acquisition ended at Monday noon, **November 21st**. The 3D seismic survey comprises in total 100 lines in E-W and 10 lines in N-S direction covering 25 km². After recovering the seismic streamers additional shooting for refraction seismic profiles was conducted for another 10 hours before recovery of the OBS was commenced **November 22nd**. All OBS were recovered without any problem until the evening and RV MARIA S. MERIAN headed for Port Louis around midnight. After 2.5 days of transit the vessel moored in Port Louis **November 25th**. All members of the scientific crew disembarked after completing DEMOB and unloading operations on Saturday, **November 26th**.

3.4 Work at Sea

After completing all preparation and installation work of the 3D seismic equipment in Cape Town and during transit a first deployment test of the paravane was conducted for training purposes. Handling this heavy gear for deflection of the starboard streamer under survey conditions needs experience. Therefore, it is essential to get practice to optimize all procedures for deployment, recovery and storage on deck.

Two preconditions were to fulfill before commencement of the 3D seismic survey to meet mitigation measures for minimizing risk potential to the marine environment: For monitoring a risk area during the seismic operations the marine mammal observers pre-installed a PAM system during transit. Moreover, following the requirement of German permit authorities, all calculated source parameters for a minimum mitigation impact during seismic activities had to be verified by calibrated sound impact measurements prior the seismic survey.

The total ship time was planned as following:

9	days	of transit from Cape Town to the survey area, during transit MOB of equipment
0.5	day	testing the 3D seismic outboard systems
1	day	sound impact measurements of the seismic source.
0.5	day	deployment of the ocean bottom seismometers (OBS)
1	day	deployment of the 3D seismic equipment.
12	days	of 3D seismic surveying
0.5	day	recovering the seismic equipment.
1	day	recovering of the OBS.
2.5	days	of transit to Port Louis/Mauritius, during transit DEMOB of equipment
28	days in total	

3.4.1 Sound impact measurements

(Engels, M., Schauer, M.)

3.4.1.1 Motivation and regulations

BGR is striving to reduce the sound impact of seismic sources and to avoid harm for the environment. In addition to preventive marine mammal observations (MMO) – optically during daytime and by means of passive acoustic monitoring (PAM) during nighttime – we reduced our source array as much as possible. Prior to the cruise, we performed a theoretical modelling of the expected sound impact (Damm et al., BGR report 2016). Furthermore, we started our seismic survey with a one-day GI-gun calibration in order to measure the real sound impact of our source. This chapter is reporting the experiment execution, processing steps and achieved results.

For German territorial waters a regulation by the BSH (Bundesamt für Seeschifffahrt und Hydrographie) exists since 2011 (Müller & Zerbs, 2011), which was released for protecting harbor porpoise in the shallow North Sea and Baltic Sea from sound emissions during piling for offshore wind farms. This regulation applies also for exploration activities in the German license area for massive sulphides. A threshold for sound exposure level (SEL) was set up by BSH to 160 dB re 1 µPa²s valid in a distance of 750 m from the sound source. In 2013 the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMUB) released a sound protection concept with a dual criterion: In addition to the SEL threshold mentioned above, the sound pressure level from peak to peak (SPLpeak-peak) may not exceed 190 dB re 1 µPa in 750 m distance from the source. While SEL is a measure for the sound energy normalized to a 1 sec interval, SPL describes the maximum pressure at a time instant. In this chapter 3.4.1, we document that the sound impact of our seismic source is well below these two thresholds.

3.4.1.2 Equipment

For the gun-calibration, we utilized one GI-gun, two hydrophones with separate loggers, a CTD and a buoy with GPS receivers.

The GI-gun by SERCEL was operated in true mode (generator 45 cu.in. & injector 105 cu.in.) with a total volume of 2.46 liter, 150 bar pressure and towed below the gun buoy at 3.7 m depth. A previous GI-gun calibration conducted by BGR in 2014 in the North Sea used the harmonic mode (generator 105 cu.in. & injector 105 cu.in.) with a total volume of 3.4 liter (Damm et al., 2016).

The installed low-noise spherical hydrophones are Teledyne Reson TC4042. The receiving sensitivity of -173 dB re 1 V/µPa (2.2 mV/Pa) is linear in a frequency range from 15 Hz to 45 kHz (+1/-5dB), a high pass filter operates at 15 Hz (-3 dB) and a low pass at 150 kHz (-3 dB), and the noise level is always below 'sea-state zero' for frequencies up to 50 kHz. Hydrophone sensitivity and directivity were calibrated by the manufacturer, showing a horizontal directivity of ±2 dB and a vertical directivity over 270 degrees of ±3 dB at 40 kHz.

The used audio loggers are Sony PCM-D100. One recording the upper hydrophone was attached to the buoy, the deep one was mounted in a pressure tube. Logger operated in LPCM (linear pulse code modulation) mode, sampling with 24 bits at 48 kHz. Both loggers were calibrated prior to the cruise with the pre-amplifier fixed to -3 dB damping:

i) An *amplitude calibration* was performed for 250 Hz varying the input voltage from 1 to 20 V_{pp} (14 V_{rms}) confirming the linearity.

ii) A *frequency calibration* was performed for 14 V_{pp} (5 V_{rms}) varying frequencies from 0.5 Hz to 23 kHz. The linear range extends from 10 Hz to 10 kHz, beyond damping becomes significant.

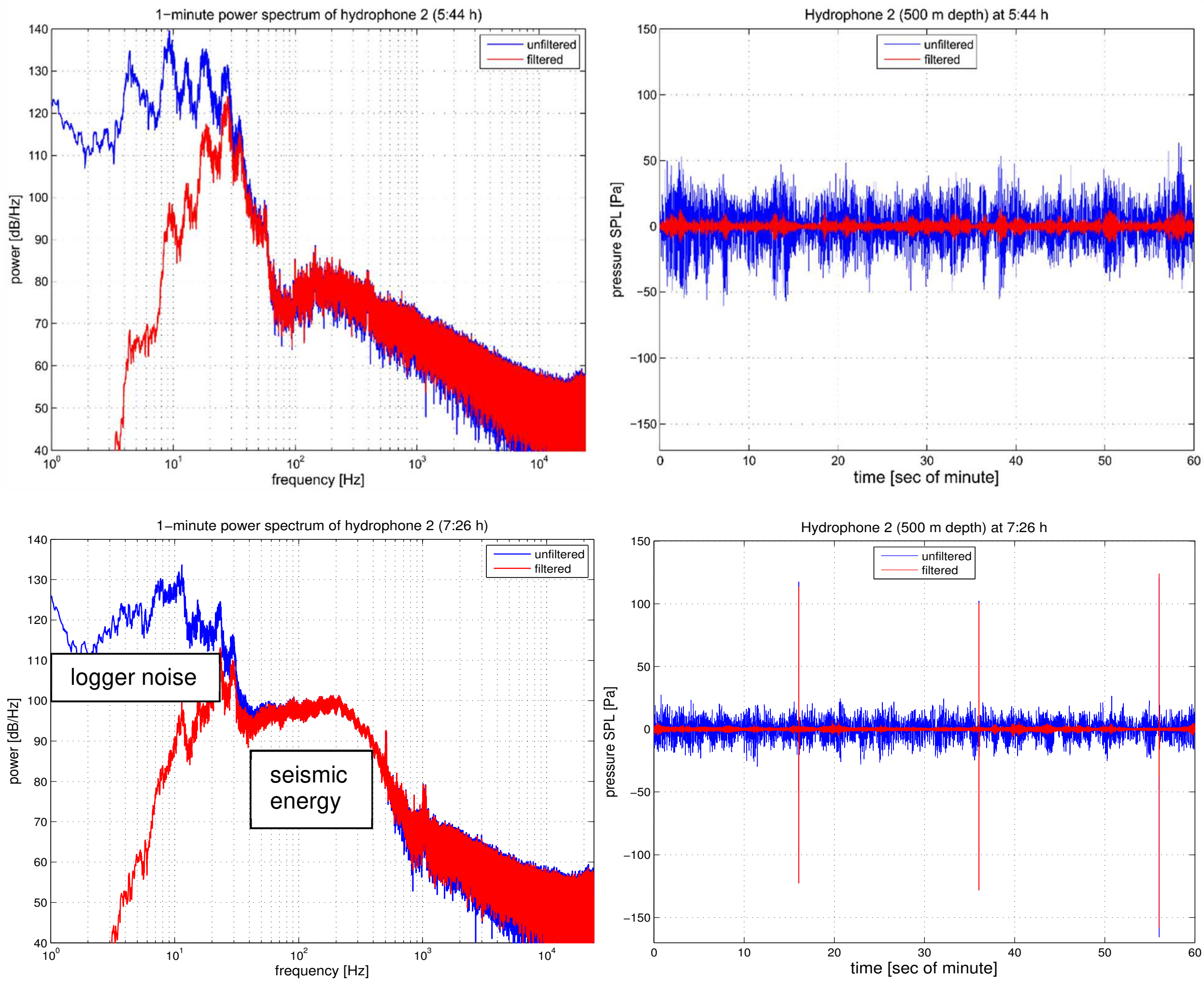


Fig. 3.4.1-1: Both upper panels show the background noise without seismic energy. Below 70 Hz, the logger noise is dominating against the natural background noise. Both lower panels show the contribution of seismic energy with a peak at 200 Hz. Power spectrum (left panels) of the one-minute time series (right panels) for unfiltered raw data in blue and high pass filtered (30 Hz cut-off) data in red. Filtering preserves the seismic energy dominating between 30 and 300 Hz (lower left panel). Logger noise dominates frequencies below 30 Hz visible between the shot points in the time series (lower right panel).

The PCM-D100 audio logger has no exact time control. Therefore, an absolute time shift (2.589 s for logger 1 and 2.433 s for logger 2) and a time drift corresponding to a sampling rate of 48000.072 Hz has been corrected by comparison of the expected arrival time of the direct wave (from the precise shot time and the travel distance for shots close to the buoy, details follow below).

The loggers show significant noise for frequencies lower 50 Hz (peaking at 10 Hz) which also varies with time (Fig. 3.4.1-1, upper panels). In order not to interpret this artificial noise as sound emissions, logger data were high pass filtered with a zero phase Butterworth of fourth order and a cut-off frequency of 30 Hz. Fig. 3.4.1-1 (lower left panel) shows nicely for a minute spectrum during shooting that the seismic energy extends peaks at 200 Hz and drops already at 30 Hz while the unfiltered noise (blue curve) increases significantly below 30 Hz. The high pass filter is a compromise between passing all seismic energy and cutting off all artificial noise. The one-minute time series in Fig. 3.4.1-1 (lower right panel) documents that the filtered data (red curve) do not reduce the peak pressure of the three seismic shots (seconds 18, 38, 58) but do reduce the noise in between the shots significantly.

Last time, the CTD60M probe by Sea&Sun Technologies was calibrated by the manufacturer in 2015. It is equipped with sensors for conductivity, temperature and pressure providing the depth of the deep hydrophone and a sound velocity profile (Fig. 3.4.1-2).

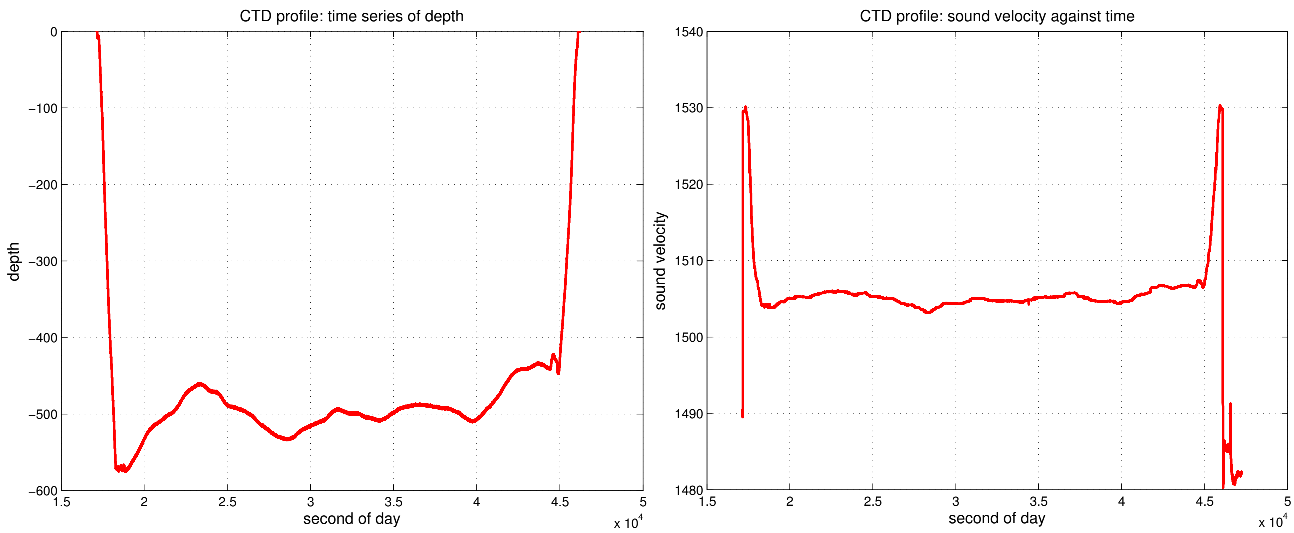
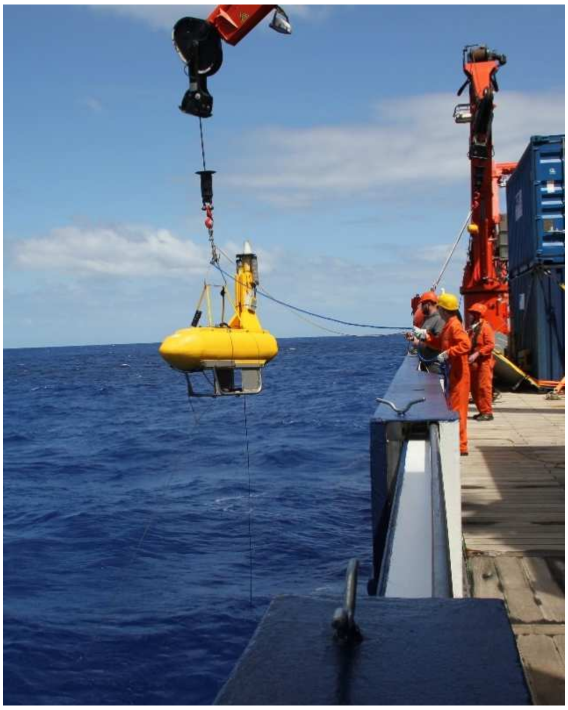


Fig. 3.4.1-2: CTD depth (left panel) during the GI-gun calibration varies approximately between 450 and 550 m. The sound velocity against depth (right panel) decreases from 1530 m/s at the surface to 1505 m/s at 500 m depth.

Three autonomous GPS logger were mounted on a free floating buoy, carrying the two hydrophones at different depths. Due to the different wind direction (8.8 m/s from SE to NW) and water surface current (0.6 kn from SW to NE) plus unknown underwater currents, the hydrophones are not hanging vertically down below the buoy along the 750 m long rope. Instead, as the CTD depth in Fig. 3.4.1-2 indicates, the lower hydrophone is at about 500 m depth resulting in an inclination angle of about 45° as sketched in Fig. 3.4.1-3. Also the horizontal offset is about 500 m to an azimuth of 209° (towards SW). The derivation of hydrophone positions is described in the next section.



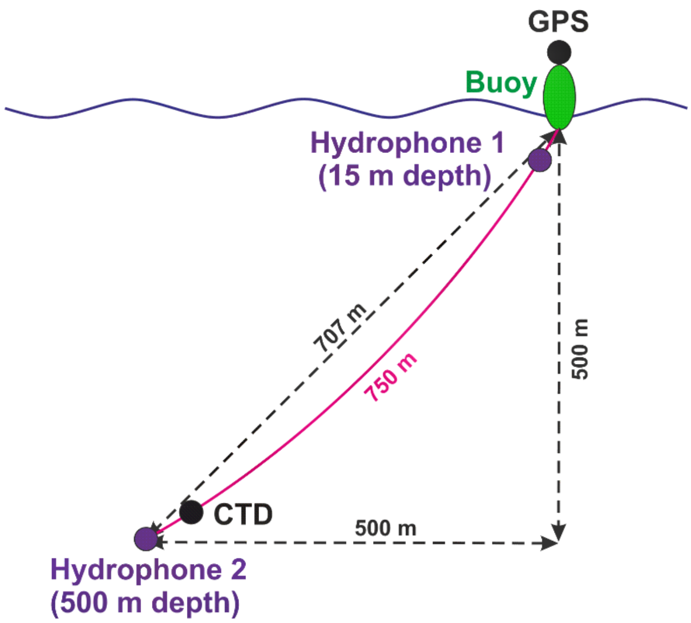


Fig. 3.4.1-3: Deployment of the free floating buoy carrying two hydrophones and a CTD below. Due to wind and water currents, the lower hydrophone is displaced about 500 m horizontally from the buoy at 500 m depth, even though the rope length is 750 m. CTD provides depth values for the deep hydrophone while GPS receivers deliver buoy positions.

We intend to present sound emissions as a function of distance between gun and hydrophones. Therefore, we need to estimate the true position of the hydrophones, which deviates from the buoy position (Fig. 3.4.1-3). For the two profiles 3 & 4 closest to the buoy (Tab. 3.4.1-1) we obtained the shot point with the minimum travel time along the profile from Fig. 3.4.1-4, which is close to the buoy for the upper hydrophone (blue) but about 400 m offset for the deep hydrophone (red). From the minimum travel time, the sound velocity and the hydrophone depth (via CTD) we receive an estimate of the hydrophone coordinates completely independent from the buoy location. The azimuth angle between buoy and hydrophone for both profiles (first and last one) is stable at 209° against north, as also indicated in Fig. 3.4.1-7 by the constant buoy drift direction (in red). In order to estimate the hydrophone position for every shot point, we utilize the azimuth angle of 209°, the depth (via CTD) and the distance to the buoy (approximated to 700 m due the sagging of the 750 m long rope) and receive an estimate by this buoy approximation.

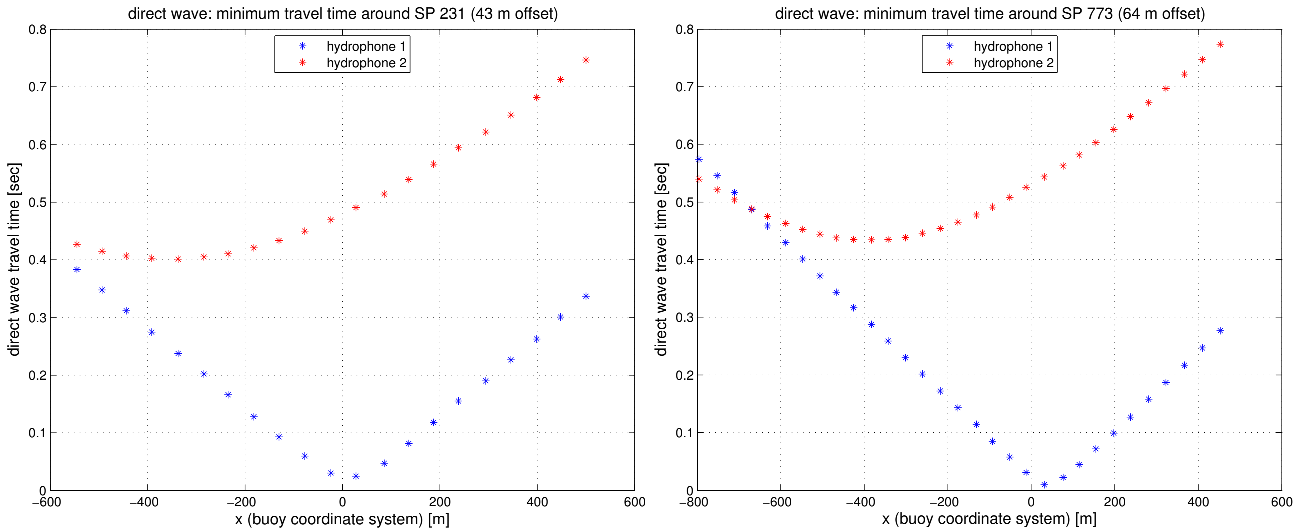


Fig. 3.4.1-4: Travel time of the direct wave measured by the upper (blue) and lower hydrophone (red) for shot points along profile 3 and 4 (left and right panel). The hydrophone is located perpendicular to the profile at the shot point with minim travel time in a distance obtained by travel time, sound velocity and depth indicated by the CTD.

In Fig. 3.4.1-5 both independent hydrophone position estimates for profile 3 & 4 for the horizontal projection in planar view are compared. The estimate of the hydrophone position due to the direct wave approximation is indicated by the red line between the cyan shot point on the black profile line and the hydrophone estimate (red dot). The alternative estimate due to the buoy approximation, derived from the closest shot point (blue dot), is indicated by the green line between the buoy (green dot) and the hydrophone estimate (pink dot). For profile 3, the absolute deviation in 3D is only 5 m and for profile 4 only 25 m (half distance between shot points). The hydrophone position has been computed for all shot points by the buoy approximation.

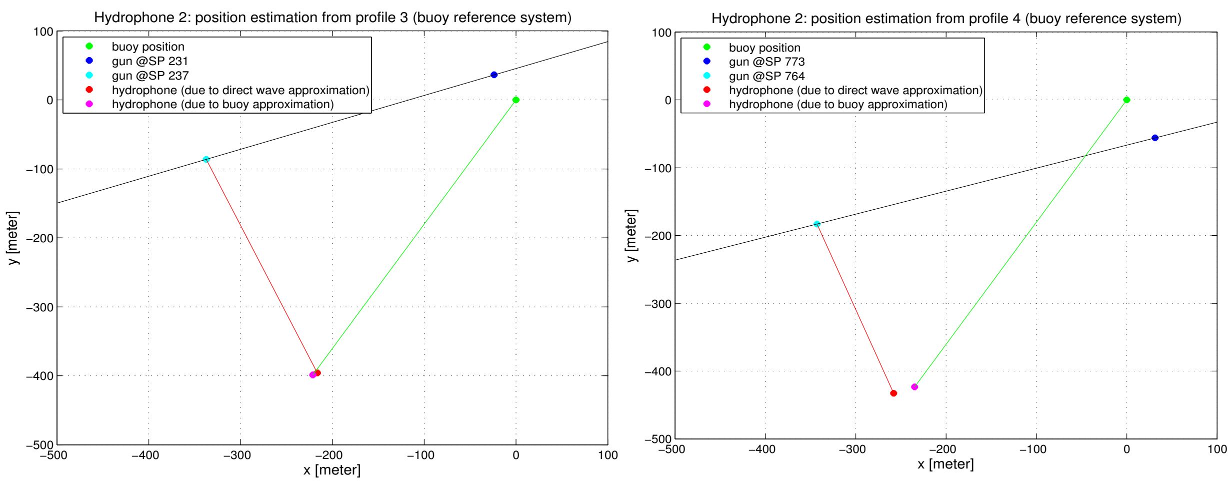


Fig. 3.4.1-5: Estimation of the deep hydrophone position due to the minimum direct wave approximation (red dot) and due to the buoy approximation (pink dot). Differences are only 5 m for profile 3 (left panel) and 25 m for profile 4 (right panel). Shot point spacing is 50 m, therefore 25 m is the corresponding error for the hydrophone position.

However, we also had to deal with the logger time corrections (shift and drift) mentioned above. Time and position corrections depend on each other, therefore we applied an iterative scheme:

i) time shift correction from the shot point closest to the buoy (adjusting the travel time to the expected distance according to an initial position estimate)
ii) time drift correction from a trend in the plot of picked minus expected arrival time of the direct wave for all shot points
iii) hydrophone position estimate (as described in the section above)
iv) repeating time shift and drift correction
v) repeating hydrophone position estimate

After each new time and position estimate, the differences of picked minus expected arrival times for all shot points decrease to a final maximum deviation of about 20 ms for the upper and 100 ms for the lower hydrophone over all 896 shot points.

3.4.1.3 Survey layout

The gun calibration survey shall provide sound pressure measurements for various distances and azimuths between gun and hydrophone location. Of special interest is the distance of 750 m for which the official threshold values are defined. Therefore, the profile plan of Fig. 3.4.1-6 consists of six profiles passing the buoy in distances of 50 m, 350 m and 750 m. The profiles closest to the buoy extend over 4 nm to register the decay over longer distances while the other profiles extend over 2 nm. The shot spacing was 20 s @ 4.8 kn resulting in 50 m shot intervals.

Weather conditions were rough with wind speeds of 8.8 m/s which correspond to sea state 5 on the Beaufort scale and waves up to 4 m (sea state 5 on Douglas scale). The wind was blowing from SE while the water current moved towards NE.

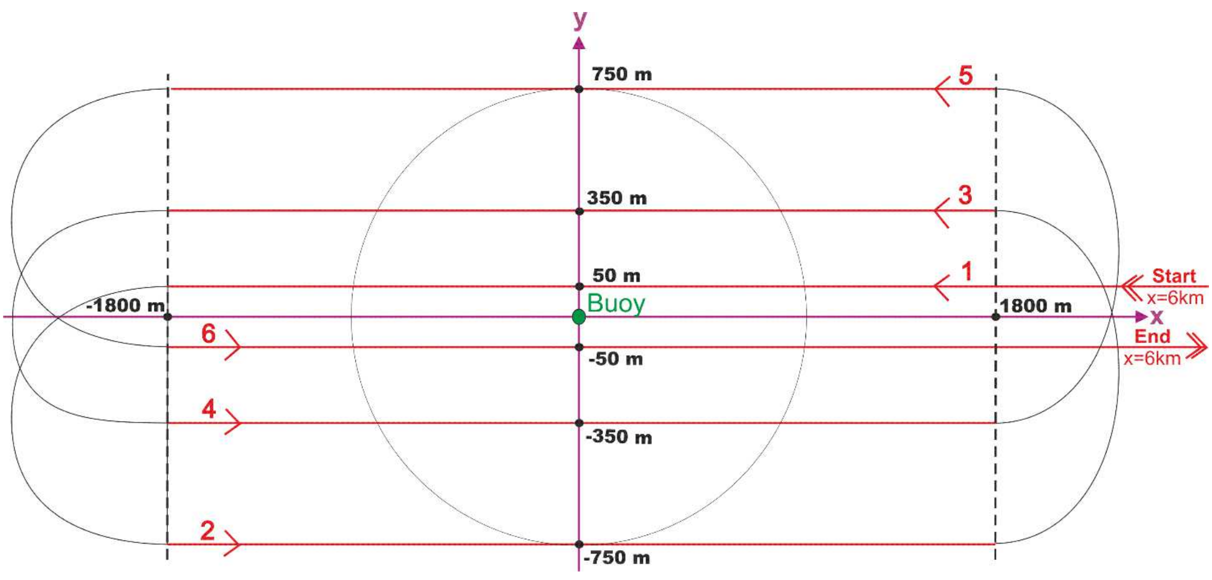


Fig. 3.4.1-6: Profile plan for the GI-gun calibration. The buoy shall be passed by six profiles providing different distances and azimuths for each shot point. The profile direction is oriented in the buoy drift direction.

The resulting profile track is given in Fig. 3.4.1-7 in geographic coordinates (left panel) showing the drift direction of the buoy in red (starting at the dot) while the vessel track in blue is circling around the drifting buoy. Transformed into the buoy coordinate system, the true profile track (right panel) nicely follows the cruise plan of Fig. 3.4.1-6 oriented in drift direction. This was achieved due to the fact that the buoy position (measured with GPS) was transmitted in real-time via radio to the vessel. Tab. 3.4.1-1 lists the shot point number for the six straight profiles (start of line, closest buoy distance, end of line) including time and vessel location. Profiles are labeled from north (No. 1) to south (No. 6) while the sailed chronologically profile sequence is indicated in Fig. 3.4.1-6 (red numbers).

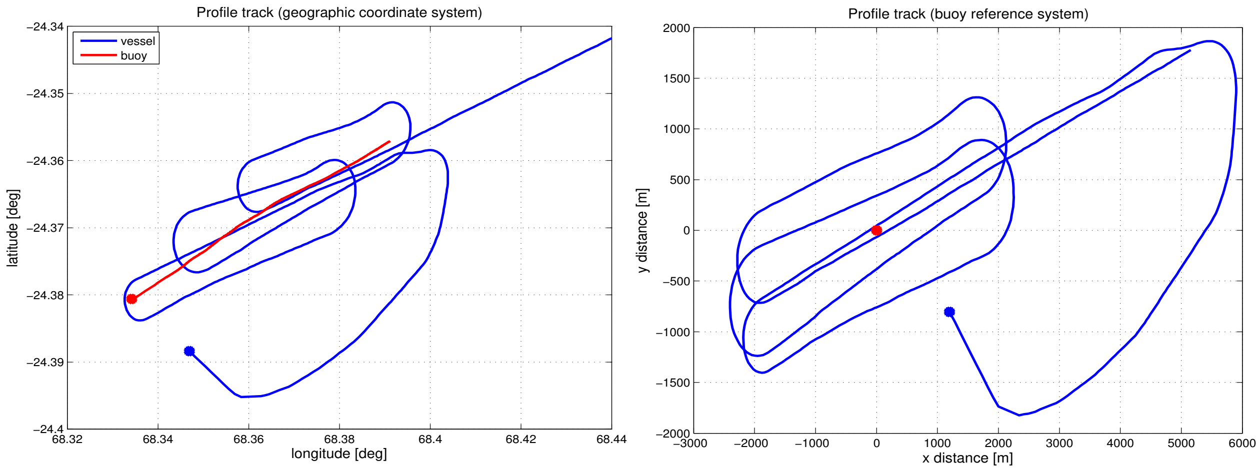


Fig. 3.4.1-7: Profile track of buoy (red) and vessel (blue) in geographic coordinates (left panel) and in the buoy reference system (right panel). The latter nicely follows the profile plan of Fig. 3.4.1-6 in spite of significant wind and water currents.

Tab. 3.4.1-1: Table of all six profiles with shotpoint number for start of line (SOL), the closest distance to buoy and end of line (EOL).

Profile number	Profile order	Remarks	Shotpoint number	Time (UTC)	Latitude (vessel)	Longitude (vessel)
1 (W→E)	5	SOL Buoy 737.7 m EOL	633 670 701	09:46:22 09:59:03 10:09:04	-24.351313 -24.356263 -24.360353	68.391961 68.374585 68.359798
2 (W→E)	3	SOL Buoy 332.0 m EOL	415 448 481	08:33:58 08:44:59 08:55:40	-24.360090 -24.364357 -24.367726	68.377399 68.362277 68.346807
3 (W→E)	1	SOL Buoy 43.3 m EOL	131 231 267	06:59:13 07:32:35 07:44:36	-24.358802 -24.372623 -24.378033	68.396606 68.350700 68.334424
4 (E→W)	6	SOL Buoy 64.4 m EOL	725 773 896	10:17:24 10:33:25 11:15:55	-24.367562 -24.360404 -24.340733	68.362660 68.384988 68.443058
5 (E→W)	4	SOL Buoy 346.6 m EOL	514 565 608	09:07:00 09:24:01 09:38:22	-24.376206 -24.366944 -24.359614	68.350919 68.373636 68.392924
6 (E→W)	2	SOL Buoy 733.5 m EOL	286 340 379	07:50:56 08:08:57 08:21:58	-24.383746 -24.375583 -24.370330	68.336753 68.361253 68.379367

3.4.1.4 Definitions

The amplitude *A* of the sound pressure *p(t)* is measured in units of Pascal [Pa]. The power *P* equals the squared amplitudes $P = A^2$ [Pa^2]. Power is acoustic energy per time unit; acoustic energy [Pa^2s] is power over a reference time interval. Pressure and power are expressed in the same logarithmic decibel units [dB] which are defined relative to a reference value

$$dB = 10\log_{10}\left(\frac{P}{P_{ref}}\right) = 20\log_{10}\left(\frac{A}{A_{ref}}\right)$$

An increase of 3 dB is a doubling of power while an increase of 6 dB a doubling of amplitude. An increase of 10 dB is an order for magnitude of power while 20 dB is an order of magnitude for the amplitude. The sound pressure level SPL in water is always related to the reference pressure of 1 µPa [dB re 1 µPa]. It can be defined as zero-peak pressure level $SPL_{zero\text{-}peak}$, as peak-to-peak pressure level $SPL_{peak\text{-}peak}$ or as RMS (root mean square) pressure level SPL_{rms} of a time series (Tab. 3.4.1-2). We measure air gun pulses over a reference period T_{90} containing 90% of the cumulative energy. SPL_{rms} in [dB re 1 µPa] is identical to the RMS power in [dB re 1 $µPa^2$].

The sound exposure level SEL is the acoustic energy related to a reference interval of 1 s [dB re 1 $µPa^2s$] ($pressure^2 \cdot time$). SEL and SPL_{rms} are related to each other via the reference interval T_{90} (Tab. 3.4.1-2). If the T_{90} interval is shorter than 1 s, SPL_{rms} is greater than SEL and vice versa. SEL_{cum} adds the SEL of all single air gun pulses.

Tab. 3.4.1-2: Definitions of sound pressure and exposure level utilized in the following chapters.

SPL: Sound Pressure Level [dB re 1 µPa]

$SPL_{zero-peak} = 20\log_{10}\left(\max\lvert p(t)\rvert\right)$	Peak pressure level
$SPL_{peak-peak} = 20\log_{10}\left(\max p(t) - \min p(t)\right)$	Peak-to-peak pressure level
$SPL_{rms} = 20\log_{10}\sqrt{\frac{1}{T_{90}}\int_{T5\%}^{T95\%} p(t)^2\,dt}$	RMS pressure level over pulse length T_{90} with 90% of cumulative energy

RMS power [dB re 1 µPa²]

$Power_{rms} = 10\log_{10}\frac{1}{T_{90}}\int_{T5\%}^{T95\%} p(t)^2\,dt \cong SPL_{rms}$	RMS power over T_{90} interval

SEL: Sound Exposure Level [dB re 1 µPa² s]

$SEL = 10\log_{10}\int_{T=1s} p(t)^2\,dt = SPL_{rms} + 10\log_{10} T_{90}$	Energy of 1 sec reference interval
$SEL_{cum} = \sum_i SEL_i$	SEL cumulated over single pulses

3.4.1.5 Processing

Processing and plotting has been done by a sequence of self-written MATLAB codes which comprise calibration, data conversion, filtering, putting all sensor data in relation, picking direct waves, computing SPL, RMS power and SEL (Tab. 3.4.1-2) and power spectra. The main codes are listed and described briefly in Tab. 3.4.1-3.

The sequence from raw data over calibrated data to amplitudes or power in the dB scale is illustrated in Fig. 3.4.1-8. In the logarithmic dB scale, the noise level (logger noise, Fig. 3.4.1-1) can be separated from the signal levels of the three shots. The upper hydrophone (blue) with almost 190 dB re 1 µPa is only 50 m apart from the gun while the lower hydrophone (red) is over 700 m away. Sea state and the vessel contribute also to the increased noise level of the upper hydrophone. Fig. 3.4.1-9 nicely shows how the T90 interval definition with 90% of the cumulative energy of a one second interval (base for SEL definition) matches only pulses which are much larger than the noise level. For remote distances, e.g. 3 km as in the example of Fig. 3.4.1-9 (right panels, SP 186), the T90 interval contains more noise than signal. Consequently, the SEL definition will also fail by losing the explicit information of the direct wave only – including (logger) noise instead.

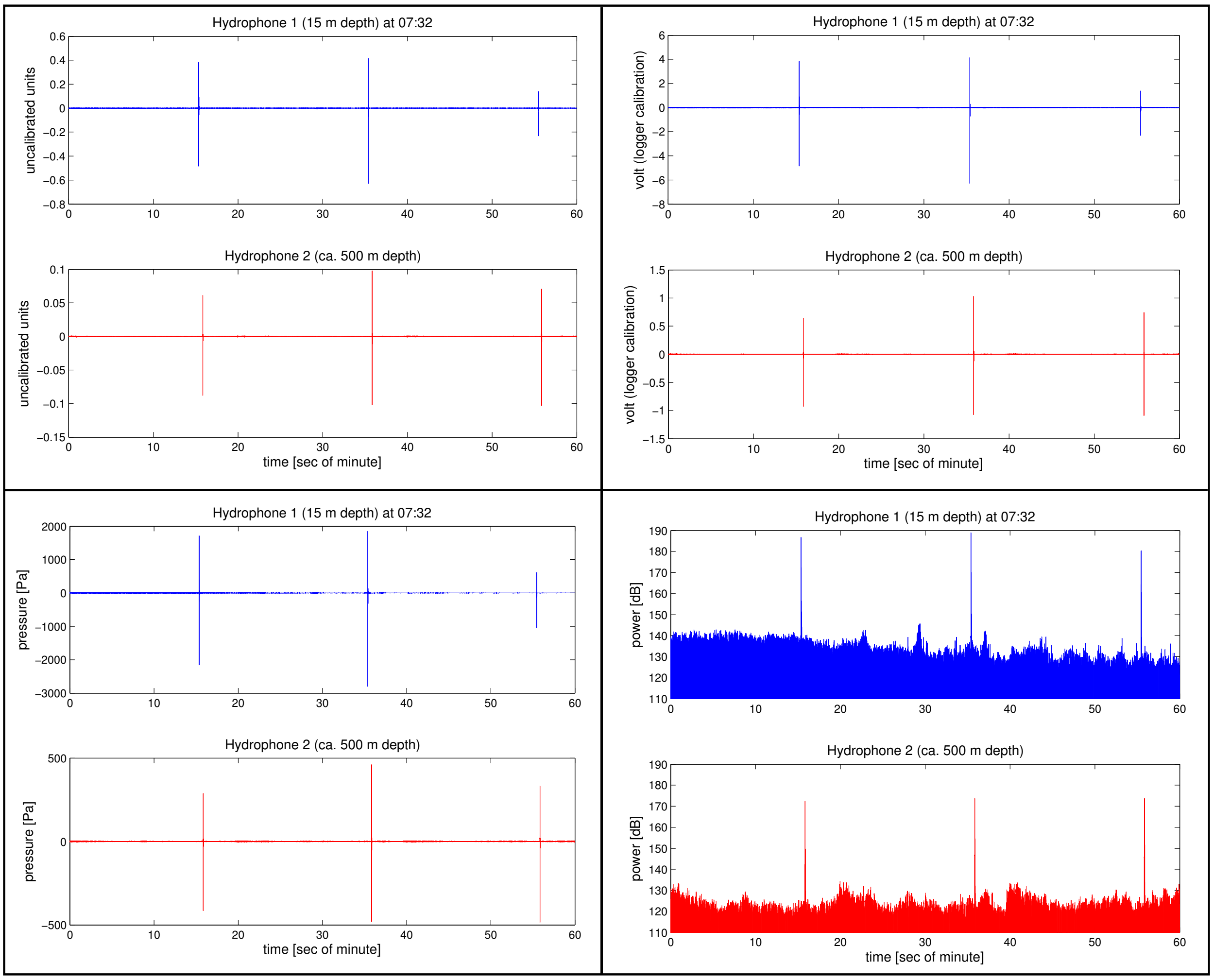


Fig. 3.4.1-8: Processing example for one minute (7:32 UTC) including three shots. Raw data in uncalibrated units (upper left panel), volts after applying logger calibration (upper right panel), pressure in Pa after applying hydro-phone sensitivity (lower left panel) and power (or the equivalent pressure amplitudes) in the logarithmic dB scale.

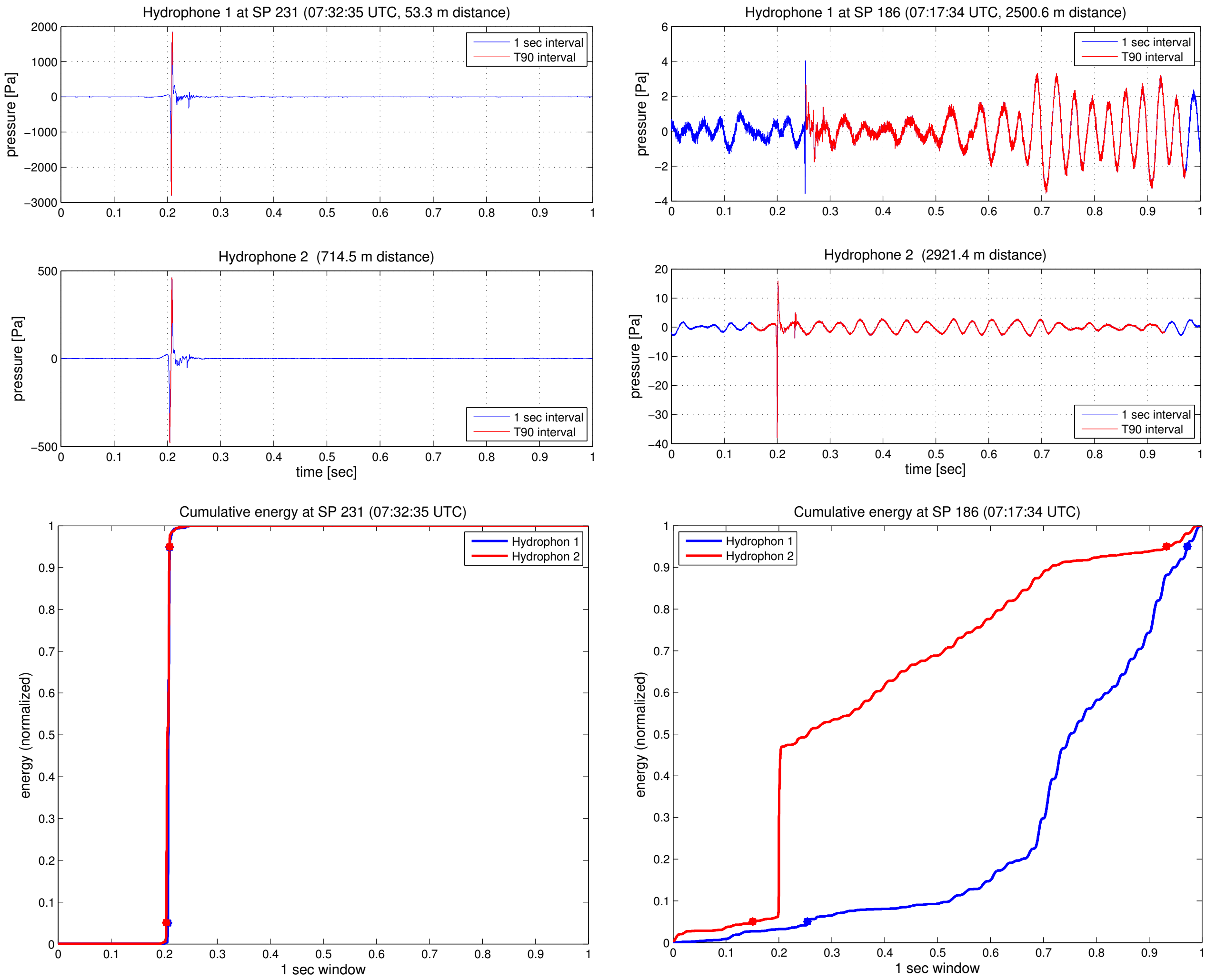


Fig. 3.4.1-9: Estimation of the T_{90} interval for a strong direct wave from short distance (left panels) and for a weak direct wave (right panels) from far distance. The cumulative energy (lower panels) over the 1 sec window determines the 5% and 95% percentile (dots), the resulting interval in the time series is presented in red in the upper panels. While the T_{90} interval matches the strong direct wave in the 1 sec interval (left panels), the T_{90} interval for the far direct wave (right panels) contains mainly logger noise.

Tab. 3.4.1-3 Sequence of the main MATLAB *codes* (description in brackets) written for processing and plotting.

a) *calibration_logger_amplitudes* (amplitude calibration of logger)
b) *calibration_logger_frequencies (frequency calibration of logger)*
*c) convert_recorder_GIgun (converting logger data *.WAV to one-minute *.mat files, time shift and drift corrections)*
d) HPfilt (zero-phase butterworth HP filter, 4th order, cut-off 30 Hz) and testHPfilt (additional test routines)
e) plot_GIgun (applying logger calibrations, hydrophone sensitivity, plotting pressure in Pa and power in dB)
f) Shotpoints (reading shotpoint timestamps from Meinberg GPS in microseconds)
g) GPS_buoy (reading GPS buoy positions from three GPS receiver)
h) CTD_buoy (reading CTD data including depth and sound velocity)
i) GPS_vessel (reading GPS vessel data, deriving gun-position)
j) *SP_table* (assign table with all parameter for gun, vessel & hydrophones for each shotpoint, e.g. positions, time, distances, depth, azimuths, travel times)
k) Peak_SPL (extract 6s time series for each shotpoint with direct wave arrival, compute SPL for this interval)
l) pick_SPdata (picking direct wave after additional HP filter (200 Hz cut-off) by a pressure threshold, computing expected minus measured travel times, deriving time shift and drift – input for code c) in an iterative scheme)
m) extract_SPdata48kHz_T90 (compute T90 interval and SPL, RMS and SEL for each shotpoint)
n) plot_grids (gridding SPL, RMS and SEL in hydrophone reference system)
o) plot_profiles (plot profiles with SPL, RMS and SEL and spherical decay)
p) Minute_spectrum (multitaper power spectrum of each minute)
q) SP_terzfilter (one-third octave filter for each shotpoint of 1 sec interval)
r) SP_spectrum (multitaper power spectrum of 1 sec interval)

3.4.1.6 Results

The measured sound emissions for all shots and all SPL and SEL definitions are plotted together in Fig. 3.4.1-10. For the upper hydrophone 1, a background noise level (logger noise & sea state) is reached at about 2 km distance. Seismic energy is scattered by inelastic reflections at the rough sea surface along the way from the shallow gun to the shallow hydrophone – the water surface is not flat at all. For the deep hydrophone 2, the pressure decay of SPLpeak-peak or SPLzero-peak can be observed up to 6 km distance. However, the effect of a failing T90 interval described in Fig. 3.4.1-9 is visible at about 2 km where the blue SPLrms dots drop towards the noise level. SPLrms and SEL only describe the seismic energy for a gun-hydrophone spacing less than 2 km. Maximum noise levels can be read in these overview figures as a function of distance. At about 750 m distance (vertical magenta lines) SPLpeak-peak is only 175 dB re 1 µPa and SEL 145 dB re 1 µPa2s for the deep hydrophone.

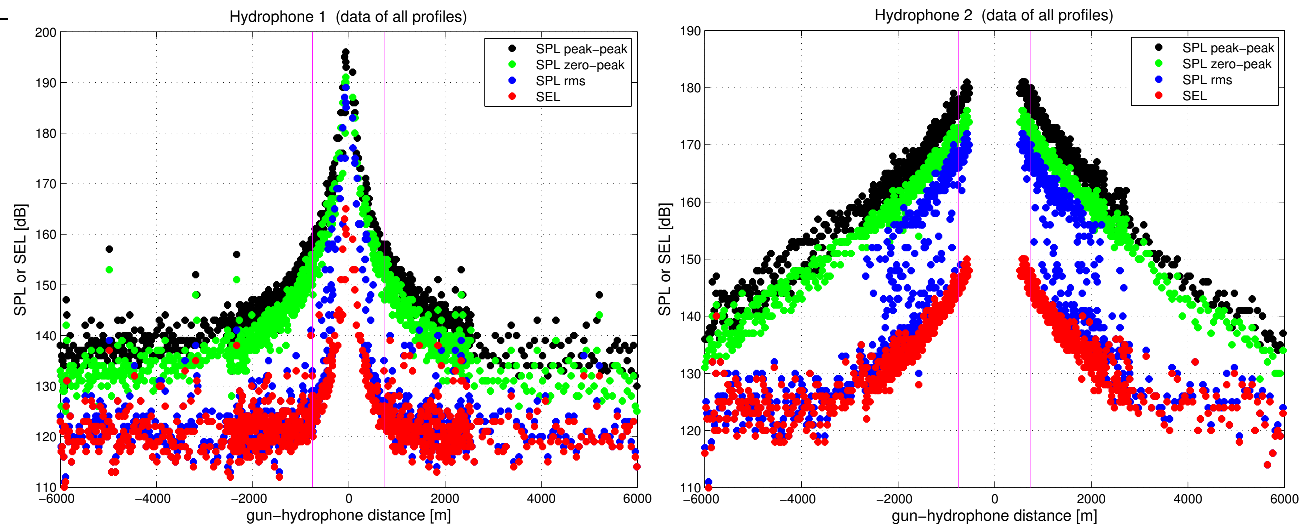


Fig. 3.4.1-10: Overview figure with $SPL_{peak\text{-}peak}$ (black), $SPL_{zero\text{-}peak}$ (green), SPL_{rms} (blue) and SEL (red) measured for all shots along all profiles for the upper (left panel) and lower (right panel) hydrophone. Vertical lines are at 750 m.

Combining the two long profiles which pass the buoy at 50 m distance result in Fig. 3.4.1-11 (left panel). The decay of SEL is even faster than the spherical decay of the black line (dissipation & scattering). For positive distances the vessel is sailing towards the buoy – an effect of damping due to the vessel in-between gun and hydrophone is visible for larger distances around 2 km for the deep hydrophone (red). Beyond the (logger) noise level is reached (Fig. 3.4.1-10).

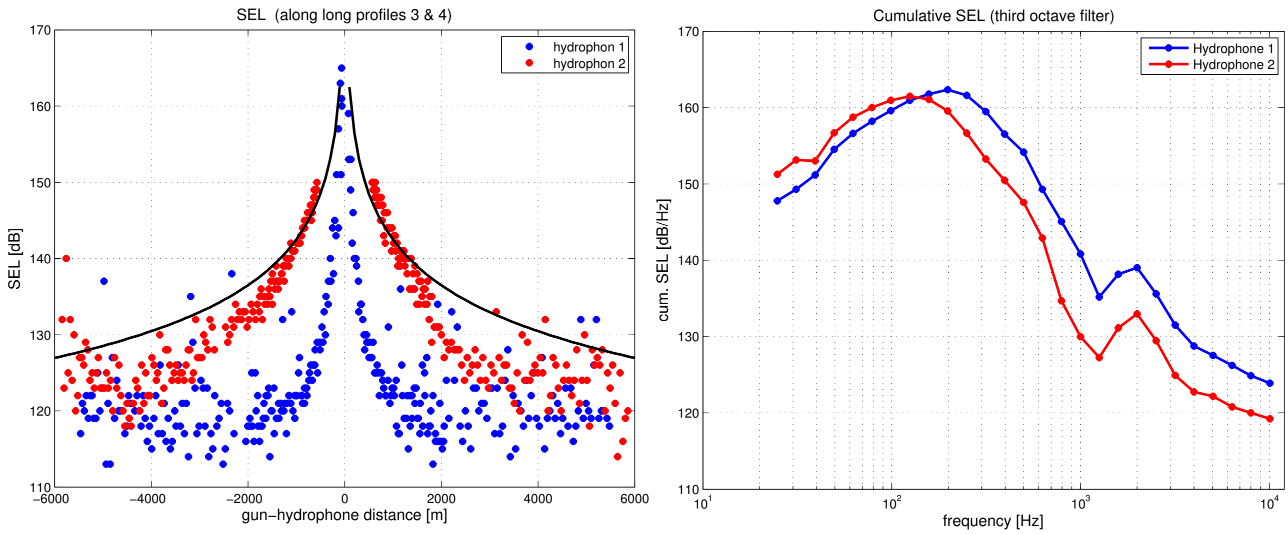


Fig. 3.4.1-11: Both long profiles 3 & 4 combined yield SEL in the left panel. A spherical decay with 145 dB re 1 µPa2s at 750 m is illustrated by the black line. SELcum (right panel) adding all shot energies peaks at 200 Hz for the shallow hydrophone, for the deep hydrophone dispersion is already visible by damping higher frequencies.

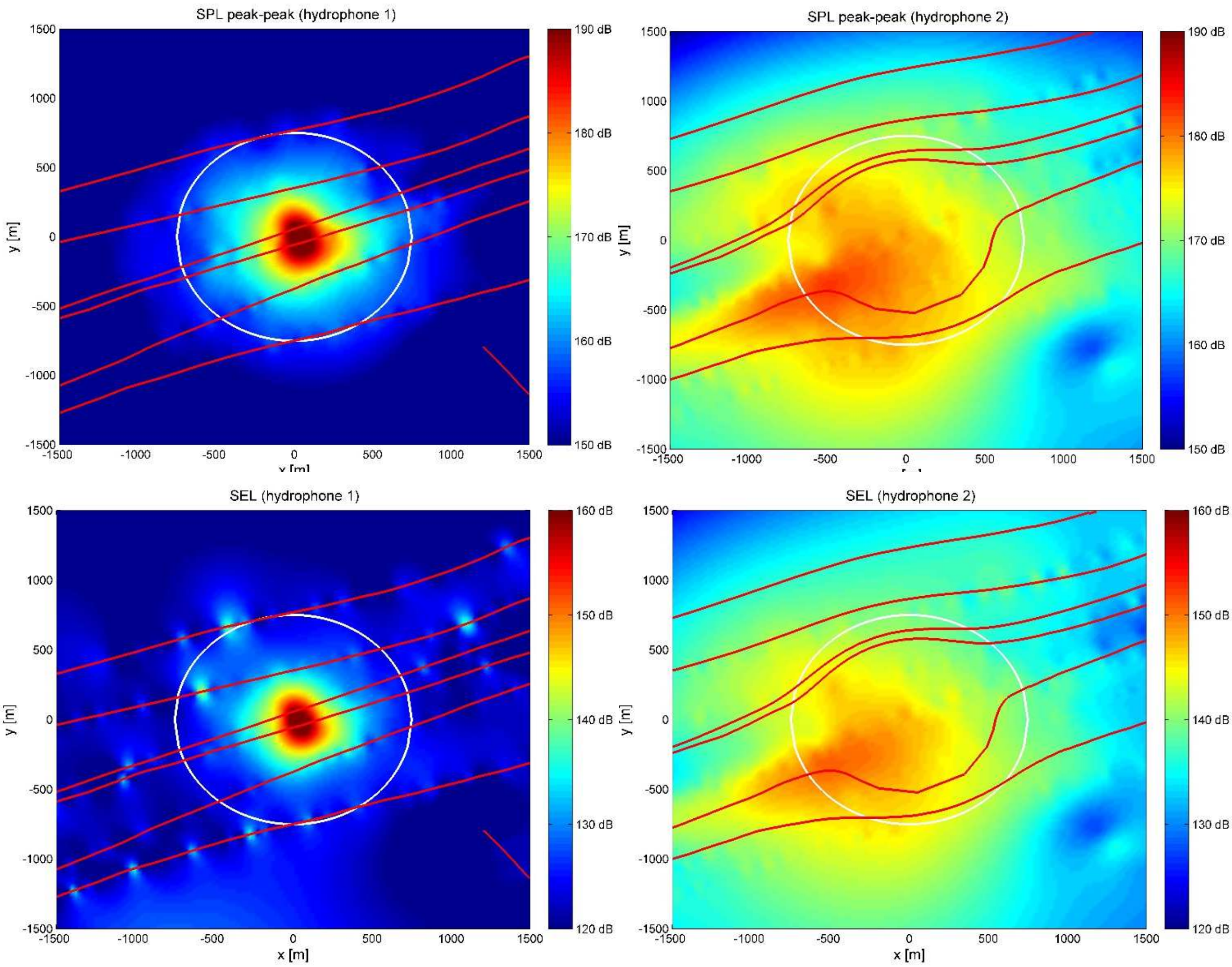


Fig. 3.4.1-12: Planar view of SPLpeak-peak (upper panels) and SEL (lower panels) for the upper (left panels) and lower (right panels) hydrophone. Hydrophones are in the origin, shot point values are plotted (at hydrophone level) at the true gun-hydrophone distance in azimuth direction. Therefore, profile lines (red) are warped outside. The white circle is at 750 m distance where SPLpeak-peak reaches 180 dB re 1 µPa and SEL 150 dB re 1 µPa2s for the lower hydrophone.

The cumulative energy SELcum in Fig. 3.4.1-11 (right panel) nicely shows the dispersion of the acoustic wave. Higher frequencies of the deep hydrophone are more damped compared to the shallow hydrophone. The maximum level is reached for frequencies larger 100 Hz confirming the high frequency content of GI-guns compared to G-guns.

In Fig. 3.4.1-12 SPL and SEL values from shot points along the profiles are gridded in a plan view at hydrophone level with the hydrophone in the origin. For each shot, the values are plotted in true azimuth direction in the total gun-hydrophone distance. The white circle marks 750 m distance. Profile lines (red) are warped consequently, bended outside from the hydrophone position. For the deep hydrophone, four profile lines are north of the hydrophone because it drifted SW of the buoy. The fourth profile line from north is south of the buoy but north of the deep hydrophone.

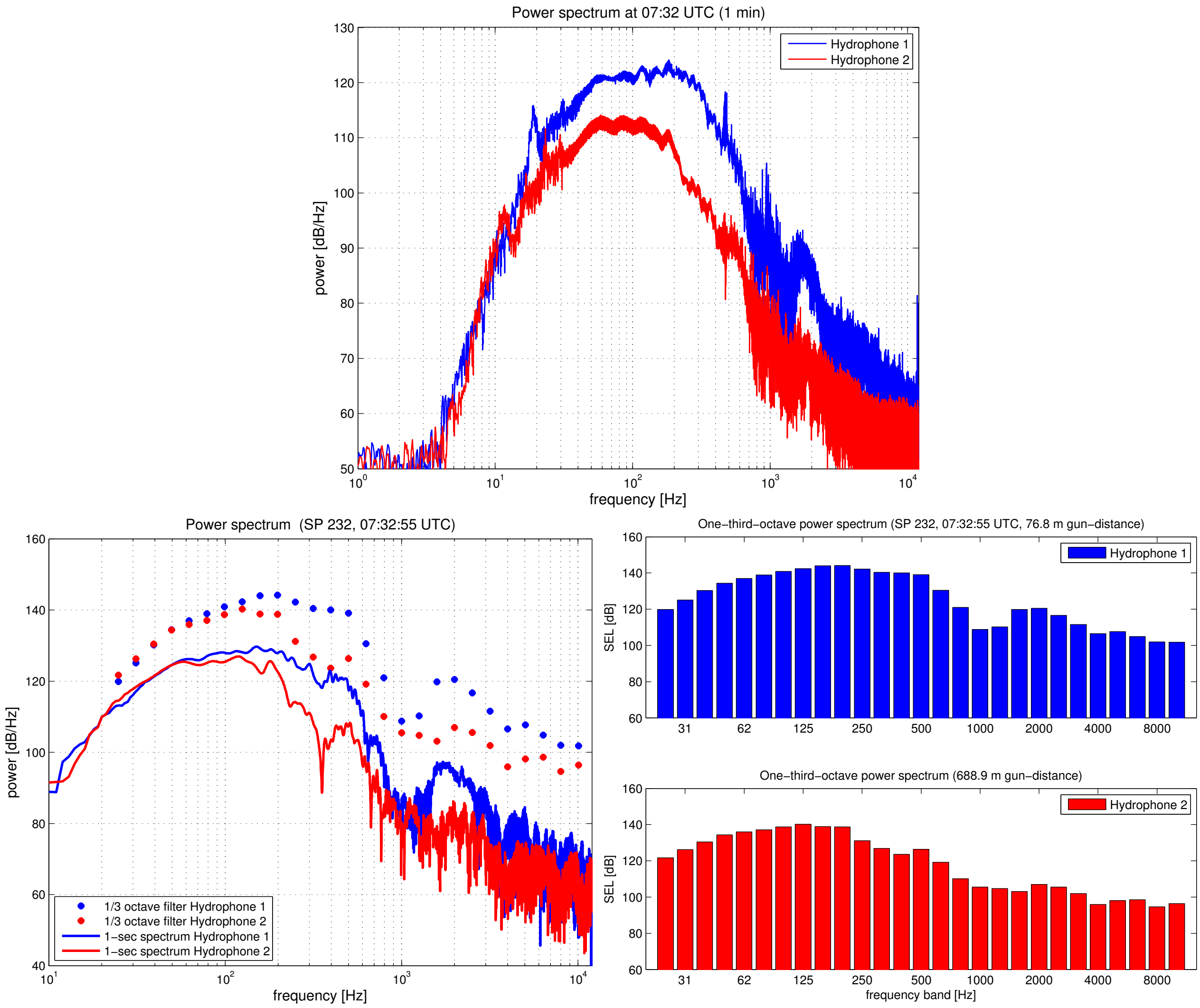


Fig. 3.4.1-13: Upper panel: power spectrum of one minute (7.32 UTC, time series in Fig. 3.8) including three shots. Lower panel: power spectrum of at a single shot point: multitaper spectrum of a one-second interval (lower left panel) and one third octave filter applied (lower right panel). The power level depends on the window length of the time series and on the frequency width of the spectral estimate.

While the figures are almost symmetrically for the upper hydrophone, there is a significant directivity visible for the deep hydrophone. Keeping in mind the inclined orientation of the deep hydrophone (Fig. 3.4.1-3) and the different azimuths along a profile, hydrophone directivity will have an influence. The hydrophone – we don't know the exact orientation – might point towards SW where the maximum was measured. At about 500 m depth (hydrophone 2) at 750 m gun-hydrophone distance (white circle) we receive maximum values of SPLpeak-peak = 180 dB re 1 µPa and SEL = 150 dB re 1 µPa2s, both values are 10 dB less than the thresholds of the dual criterion.

Power spectra have been calculated for each minute and for each shot point in a one-second interval using the multi-taper method in Fig. 3.4.1-13. In addition, one third octave filter have been applied averaging frequencies by a filter bank based on the standard ANSI S1.1-1986. For a one minute time series, the 20 s background noise between the shots is also taken into account while the 1 s interval focuses on the direct wave only. For the 1 s interval, seismic energy peaks at a similar level for both hydrophones in the range from 40 to 200 Hz (above 120 dB/Hz). The one third octave filter sums up spectral energy and yields higher values around 140 dB/Hz. The range of frequencies where the seismic source is dominant is quite limited below 1 kHz and confirms Fig. 3.4.1-1.

3.4.1.7 Modelling

With the Gundalf array modelling suite (Oakwood Computing Associates), a marine mammal noise impact report has been created for the GI-gun parameter of this cruise (Damm et al., 2016). At 750 m vertically down (the worst case) a SPLpeak-peak of 180 dB re 1 µPa is calculated while in 750 m radial distance at 20 m depth a SPLpeak-peak of only 170 dB re 1 µPa is modelled. The expected SEL value of 150 dB re 1 µPa2s at 750 m is given in Fig. 3.4.1-14. These theoretical values are confirmed by our results of measured data in the previous chapter.

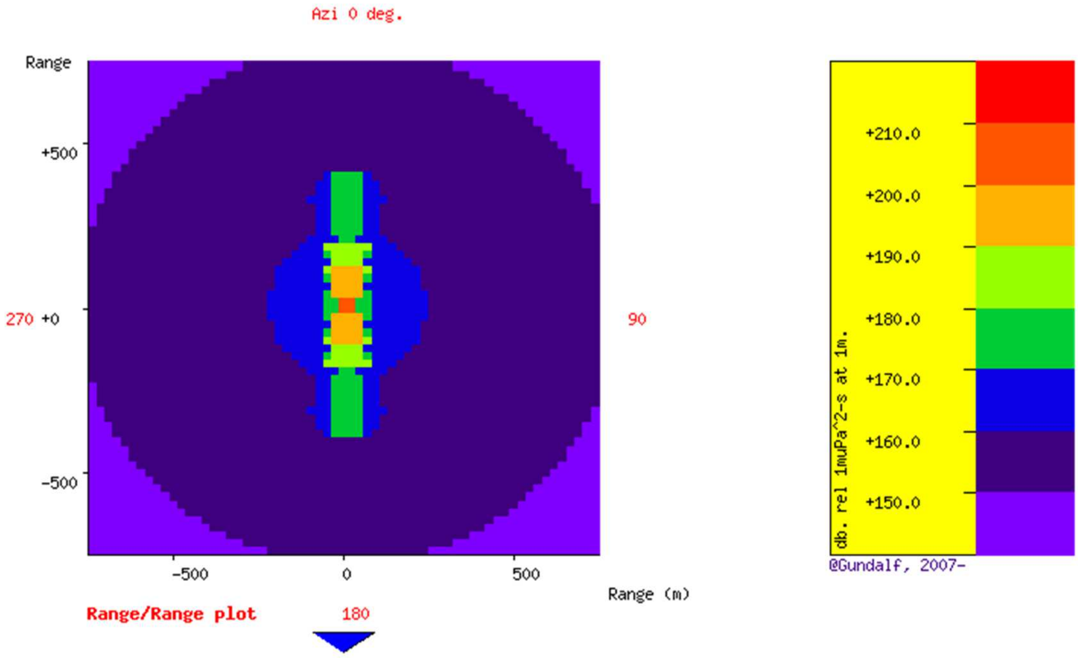


Fig. 3.4.1-14: Gundalf modeling of SEL for the single GI-gun. 150 dB re 1 µPa^{2}s SEL are expected at a depth of 20 m in a range of 750 m which coincides with our measurements.

3.4.1.8 Summary and outlook

During this cruise, a GI-gun calibration has been performed under deep water conditions in the license area. Two hydrophones were attached below a buoy at about 15 m and 500 m depth and recorded the direct wave arrivals from 896 shots along six profiles from various distances and azimuths around the buoy. These measurements can be compared to a GI-gun calibration in the shallow North Sea (Damm et al., 2016) and theoretical modelling.

The threshold values for protecting marine mammals are set to SPLpeak-peak = 190 dB re 1 µPa and SEL = 160 dB re 1 µPa2s in a distance of 750 m from the source. The GI-gun calibration of this cruise results in maximal values of SPLpeak-peak = 180 dB re 1 µPa and SEL = 150 dB re 1 µPa2s. These limits are confirmed by Gundalf modelling and by the GI-gun calibration in the North Sea 2014. The 10 dB difference below the threshold corresponds to a factor 3 less for pressure (SPL) and a factor 10 less for energy (SEL) – a single GI gun operating for two weeks is far below emissions accepted for wind farms which are constructed over years.

This deepwater case generates a single direct wave in contrast to a whole wavefield of reflections and refractions in the shallow water case of the North Sea (Damm et al., 2016). In the deepwater case the energy is concentrated in the direct wave only while in shallow waters the energy is summed up over the wave field. The decay with distances is close to spherical in the deepwater case and was close to cylindrical in the shallow sea. The sound emissions 750 m in radial direction of the shallow sea is less than 750 m vertically down in the deep sea. But this effect was compensated by the higher source volume in the North Sea and the weaker cylindrical decay. SELcum in the deepwater case of 896 shots was much lower (about 10 dB) for the same frequencies than SELcum in the shallow water case of 631 shots.

Improvements for future gun calibrations should be a noise-free acoustic logger and an exact positioning of the deep hydrophone (e.g. by USBL transponder). The upper hydrophone might be attached deeper to avoid scattering of sound propagation by sea waves. Survey parameter could be optimized to profile-buoy spacings of 100, 300 and 500 m and a reduced shot point spacing of 25 m (10 s @ 4.8 kn). A cluster of two GI-guns would also operate below the allowed sound limits and increase seismic resolution.

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Damm, V., Engels, M., Schnabel, M., 2016. Schalldruckvermessung eines seismischen Luftpulsers (GI-gun): Ergebnisse der Probefahrt P3 mit RV SONNE in der Nordsee, September 2014; Schallausbreitungsmodellierung im Vorfeld der Forschungsfahrt INDEX2016_2, November 2016; BGR technical report, archive no. 0134052, 23 pp.

Müller, A., Zerbs, C., 2011. Offshore-Windparks; Messvorschrift für Unterwasserschallmessungen; Auftraggeber: Bundesamt für Seeschifffahrt und Hydrographie, Hamburg, 39 pp.

3.4.2. 3D-seismic survey in cluster #4 of the license area

(Damm,V., Ehrhardt, A., Engels, M., Berglar, K.)

Within cluster #4 three hydrothermal fields were identified during previous expeditions (for location see Fig. 3.4.2-1). It is dominated by the active hydrothermal vent site Edmond. This active site was discovered in 2001 (Van Dover et al., 2001). The extraordinarily high temperatures of the Edmond fluids (up to 382°C) are resulting in unusually high concentrations of several transition metals (Gallant and Von Damm, 2006). An area of extinct sulphide structures covers ~100m x 60m (Gallant and Von Damm, 2006) and is still supposed to be the largest hydrothermal field at the Central Indian Ridge (Nakamura and Takai, 2015). Prospecting in 2012 and 2013 led to the findings of inactive sulphide fields (Gauss, Score) some 1.6 km apart. The cruise in 2015 identified an entire sulphide-hosting area in between Edmond-Gauss-Score with a regional extent of about 1500 m x 200 m. To resolve the so far unknown sulphide distribution at depth, fault zones of the hydrothermal system, geological units and tectonic structures in an unprecedented high resolution, the pre-planned lines of the 3D seismic survey were to cover the full area hosting both the active and inactive hydrothermal fields.

Massive sulphides are challenging small-scale targets. The new methodical approach based on a 3D seismic survey in license block #4 aims on:

- imaging deposits as diffractor points after 3D migration (L'Heureux, 2005)
- imaging deposits as impedance contrast due to different surface reflectivities
- imaging deposits after seismic attribute analysis of the 3D cube
- imaging deposits as velocity contrast of refracted waves (3D OBS array)

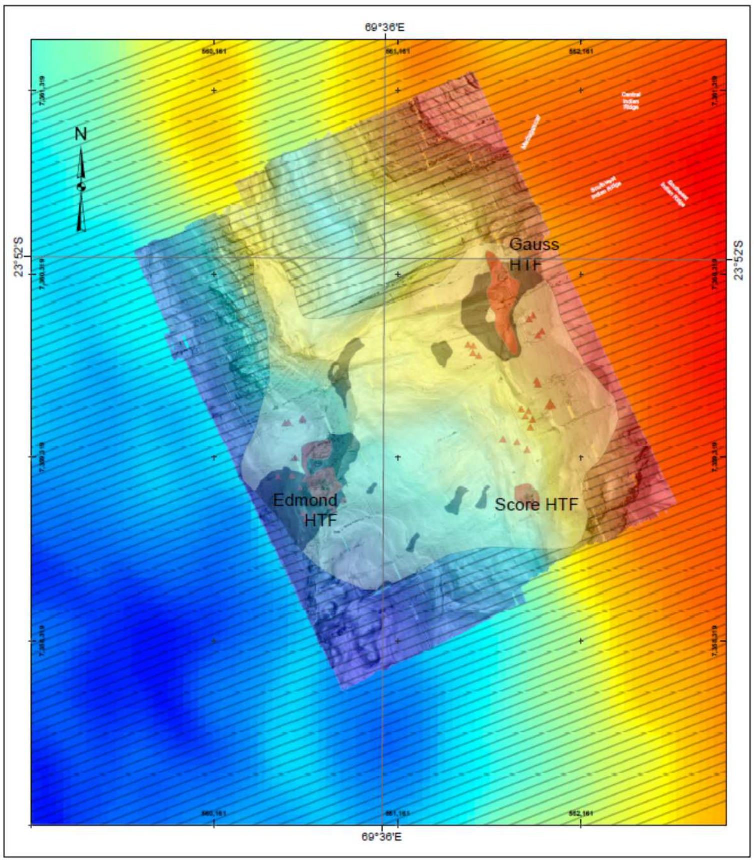

Fig. 3.4.2-1: Location of hydrothermal fields Edmond, Gauss and Score in cluster #4.

Considering the topography of the seafloor in cluster #4, which is dominated by the SSE-NNW trending mid-ocean ridge morphology, the originally planned survey layout consisted of two 3D seismic strips of 6 km x 3 km size, oriented parallel and perpendicular to the Central Indian Ridge. Both seismic cubes overlap in the area of interest (3 km x 3 km). By using the survey parameters as outlined further down, a very dense CDP grid (6.25 m x 6.25 m bins) for the central overlapping part could be achieved (Fig. 3.4.2-2 left).

However, for practical reasons of 3D seismic data acquisition and time restrictions we had to optimize the survey layout. The diameter for optimum turning is normally half the width of a 3D survey area. It became obvious, that the vessel is not able to turn around with a 1.5 km turning diameter to get directly to the following survey line without additional navigation time. Therefore, it was decided to extend the width of the survey area to 6 km, which allowed for minimum turning time (see Fig. 3.4.2-2 right). However, due to the additional lines in the WSW-ENE direction the available survey time for the perpendicular survey strip had to be reduced.

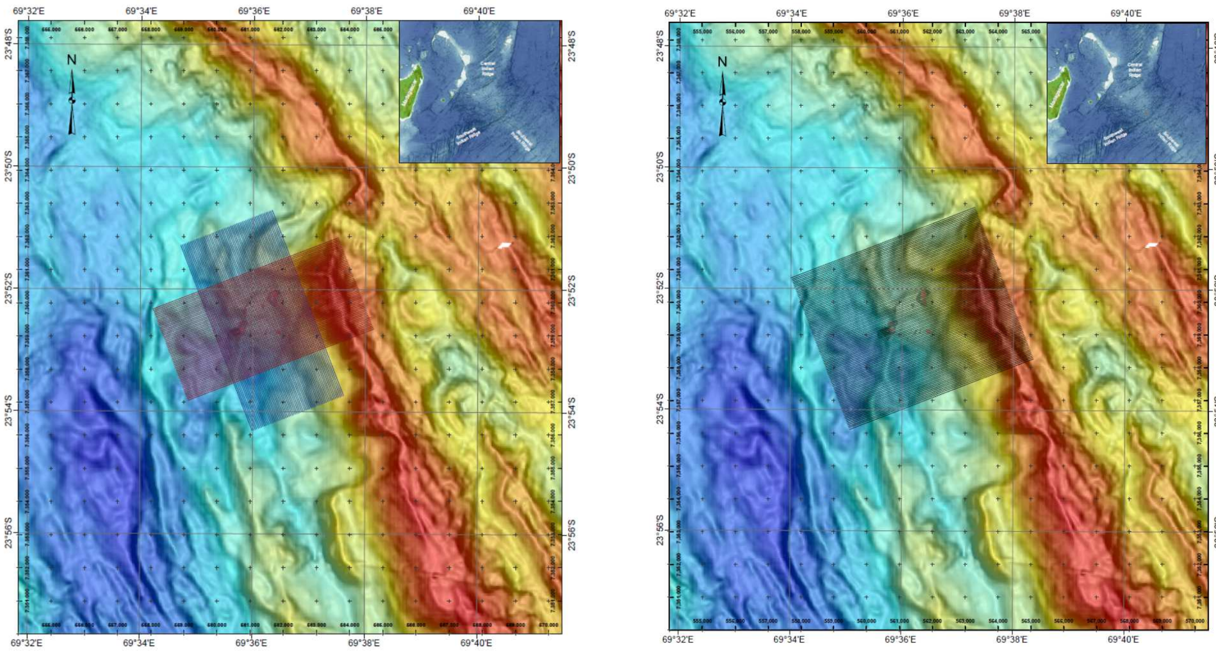

Fig. 3.4.2-2: Survey layout for 3D seismic survey as planned originally (left) and modified later (right)

References

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3.4.2.1 Seismic sources, outboard systems and layout of the 3D seismic equipment

(Behrens, Th., Ebert, T., Seeger, Ch., Damm, V.)

It was for the first time that the 3D seismic system of BGR had to be adopted to RV MARIA S. MERIAN. Due to the free-fall life boat of the vessel, which is positioned at the portside stern, the working deck in this area does not provide unlimited space in this area. Therefore, it was planned for an asymmetric layout of all outboard components of the 3D seismic equipment (see Fig. 3.4.2.1-1).

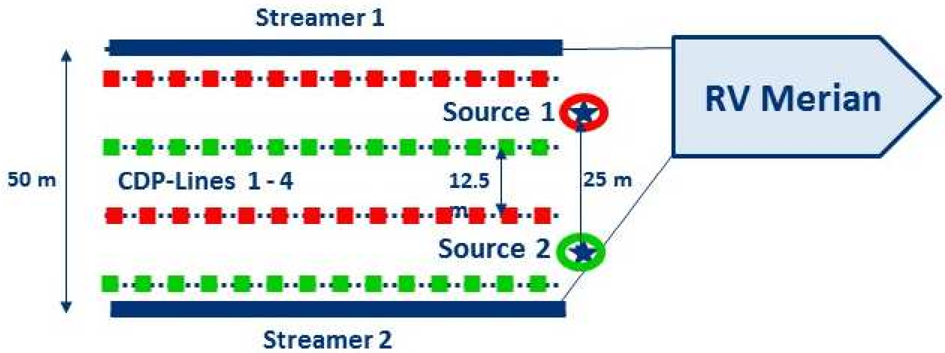


Fig. 3.4.2.1-1: Setup of seismic streamers and sources during 3D data acquisition. GI-guns operate in flip-flop-mode (green shots produce green CDP lines, red shots produce red CDP lines).

Identical streamer and airgun systems were used and towed on starboard and portside, respectively. Separation between the two streamer cables and seismic sources was implemented by only one trawling door (paravane). The portside streamer cable was directly attached to the vessel's stern without being deflected. As seismic sources we used two GI guns of 45/105 in³ volume, towed to a modified Partnerplast tail buoy 800. Whereas the starboard GI gun was deflected by the paravane, the portside GI gun was directly connected to the vessel by the umbilical. The towing point at the stern was preset and 12.5 m apart from the towing point of the portside streamer. Using two streamers of 1500 m active sections length separated 50 m apart, two seismic sources operating in flip-flop mode and a high shotpoint interval of 25 m ensured the planned high lateral resolution with a CDP spacing of 6.25 m inline and 12.5 m crossline.

In detail the outboard systems including peripheral equipment consisted of

- 1 x paravane with ~12m² (2150 kg),
- 2 x streamer winches (7 tons each)
- 2 x 1500 m Sercel ALS streamer (with add-on modules – see below)
- 2 x Partnerplast tail buoys 800 for the streamers
- 2 x Partnerplast dilt float 270L as head buoys for the streamers
- 2 x Sodera-GI-guns, 150 cu.in = 2.45 l each
- 2 x Partnerplast tail buoys 800 as gun buoys
- 2 x BGR umbilicals for GI-guns (80 m each)
- 1 x Evotec Fairlead block (200 kg) for the starboard streamer
- 1 x Trelleborg bend protector at the starboard lead-in
- 1 x 300 m dynema rope attached to the paravane, winded on the starboard mooring winch

To allow for proper accommodation and operation of the outboard systems several installations and modifications had to be conducted prior the cruise. These preparations included foundations for the two streamer winches, a support frame for mounting the fairlead block close to the A-frame of the vessel for streamer deflection and two auxiliary arm assemblies at the stern bulwark for the umbilicals. Umbilicals of 80 m length were prepared, which were mounted to dragging wire during deployment of the GI-guns using the two auxiliary arm assemblies at the stern bulwark (see Fig 3.4.2.1-2).

The towing rope for the paravane was winded to the starboard mooring winch and deflected by a block mounted to a support frame on the starboard railing (see Fig 3.4.2.1-3).

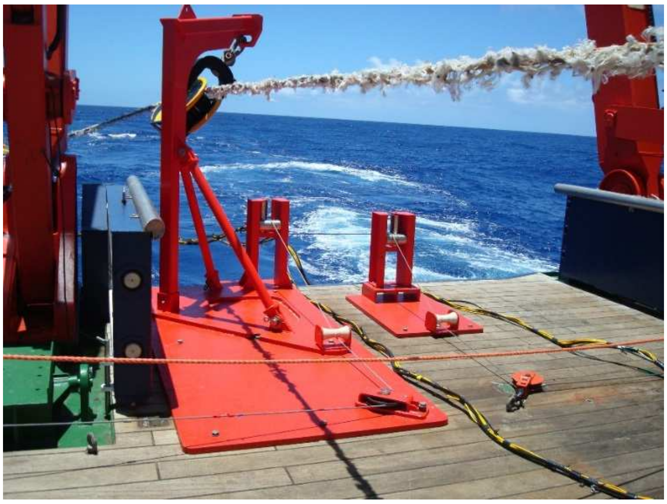


Fig. 3.4.2.1-2: Support frame for fairlead block and the two auxiliary arm assemblies at the stern bulwark for the GI gun umbilicals.etup of seismic streamers and sources during 3D data acquisition.

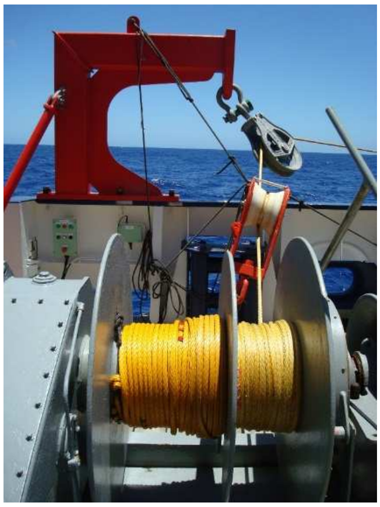


Fig. 3.4.2.1-3: Support frame on top of the starboard railing with block for deflecting the towing rope which is winded at the mooring winch.

The paravane was stored at the starboard side and attached either to the railing or between the railing and a nearby container (Fig 3.4.2.1-4). It was very important to train deploying and recovering of the paravane to prevent unwanted movements and rotations of the deflector. During deployment and recovery the vessels speed should not exceed 1.5 kn. The starboard crane was used to lift and lower the paravane into the water. It is essential to hold the deflector with two slip ropes at the front and aft in a way that the paravane is lowered into the water with a small deflecting angle. As soon as the paravane is in the water all ropes must be slipped immediately and the whole drag has to be overtaken by the towing rope. This procedure must be completed in shortest time, since otherwise the deflector is trying to turn around.

Fig. 3.4.2.1-4: Paravane attached to starboard rayling

During the survey operation we experienced downtime due to broken towing ropes and weak links due to heavy swell and heavy seas. To prevent such unwanted situations and minimize the dynamic forces, it is suggested to incorporate appropriate suspension modules at least between the paravane rig and deflected streamer cables.

3.4.2.3. Positioning of survey data and survey navigation with Spectra

(Engels, M., Schreckenberger, B., Bargeloh, H.-O.)

Objectives

Proper 3D-seismic processing requires the exact position of both GI-guns and all receiver groups in the curved and feathered two streamers. In order to match the correct bin cells of only 6.25 m inline and 12.5 m crossline dimension in our small scale high resolution survey, we aim to an accuracy of navigation in the meter scale. Note that the far traces, located 1.5 km behind the guns, might be easily offset 100 m due to side currents. For combining all types of navigation data, controlling seismic data acquisition (distance controlled shooting) and to correct the vessel navigation along profiles we used the software package Spectra (ION Concept Systems). This software has four main tasks:

- collection of all kind of sensor positioning data with accurate timing of input and output trigger
- calculating real-time network solutions (position of ship and all sensors) including quality control
- gun triggering on predicted shot locations based on the past network solutions
- generation of P1/90 and P2/94 navigation files according to UKOOA standards

Hardware

The mobile BGR seismic equipment can be mounted on different research vessels. Spectra is integrated in the seismic data acquisition system but operating in its own Ethernet network isolated from the vessel's and SEAL's networks. The wiring and integration of spectra is illustrated in appendix A-3 (spectra network connections in red color); Fig. 3.4.2-10 provides a view on the Spectra components in two labs.

We used Spectra version 14.12.1, patch level 630. The software was installed on a Dell Precision R5400 with Red Hat Linux 5. A second Dell R5400 was installed in the lab to allow the plug-in of two additional screens and to log the navigation data to a second hard disk. On a third Dell R5400 operated the binning software Reflex (ION Concept Systems) providing Spectra with the bin grid and analyzing the coverage.

Spectra's real-time system RTNU is linked by serial interfaces to the different sensors as listed in Table 3.4.2-1. Appendix A-2 gives an overview about the wiring of all input and output interfaces and trigger lines of the RTNU.

Table 3.4.2-1: Interfaces and data types of the RTNU.

Port	Interface Name	Sensor / Receiver	I/O	COMM
1	DG_GGA_NMEA	DGPS (vessels differential GPS)	I	4800 N 8 1
3	GY_NMEA_GYRO	Gyro (vessel)	I	4800 N 8 1
6	DG_NMEA_GGA	Kongsberg Seatrack (additional GPS antenna)	I	9600 N 8 1
7	GN_SYNTRON_V2	BigShot (gun controller)	I/O	9600 N 8 1
8	RG_SEATRACK	Kongsberg Seatrack (RGPS to head & tail buoys)	I	9600 N 8 1
9	HDR_LABO	SEAL (seismic acquisition system)	O	9600 N 8 1

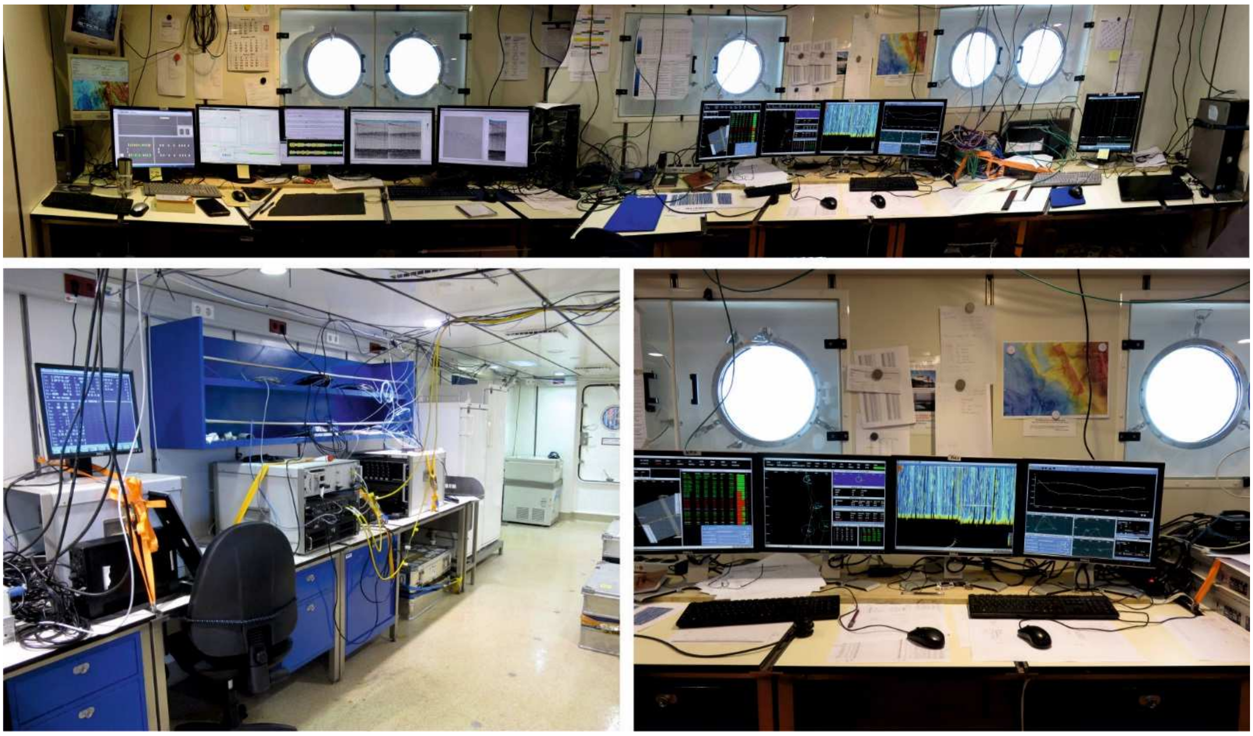


Fig. 3.4.2-10: Top panel: Panorama view over the seismic lab monitoring guns, spectra navigation and data acquisition (from right to left). Lower left panel: Spectra RTNU (real time navigation unit), ION System3 Digicourse (streamer birds and acoustics) and Kongsberg RGPS. Lower right panel: spectra navigator's workplace.

Data from the navigation sensors of RV MARIA S. MERIAN were provided via serial transmission. Channel 1 received data from the ship's differential GPS. The heading from the vessel's gyro was received on channel 3. In order to have a spare GPS position we interfaced the reference position of BGR's relative GPS (Kongsberg Seatex Seatrack) to channel 6. This interface was configured in extended mode (the acceptable quality has to be set to "1234" since this position is not DGPS). Most of the serial interfaces were connected via a Data Distributor to the RTNU (see appendix A-2). This provides full electrical and optical isolation between the sensor and the RTNU as well as additional LED indication of RX & TX data activity for each channel.

Additionally, we interfaced BGR's seismic equipment to the RTNU. In order to receive airgun data (pressure, status and delta times of single guns) from the BigShot gun controller we applied the interface GN_SYNTRON_V2 on port 7. With this interface, a GCS90 control string (containing the line name and the next shot number) was sent to the gun controller. The 'Begin Line' (BL) message was also sent via this interface (option "Incorporate 'BL' command").

For the Kongsberg relative GPS (RGPS) we used the interface RG_SEATRACK on port 8 to obtain range and bearing to the tail buoy. The SEAL header was sent to the seismic recording system via port 9 together with the sequence number (which was set in the LMN by the option "Add Sequence Number"). This number has to be entered manually at the SEAL before the start of the profile. This header was triggered by the incoming time break TBA1.

The Positioning Control System (PCS) Digicourse by ION was connected to the Spectra machine via Ethernet. Data from the birds were decoded by the virtual interface 'vid' – a process running on the Spectra machine. The virtual interface DG_V_PRTNU was used to obtain the GPS position of the RTNU receiver. The virtual interface GN_V_TRIGGERS supplied additional timing information, e.g. the time difference to the last shot ('Shottime Diff').

The RTNU also creates and receives triggers. All times are referenced to the next shot (a data item which is called @SHOTPREDICT@). At -120 ms the recording system SEAL obtains a trigger to start the system (TTL active high, 100 ms duration, output port 2). At -50 ms a trigger is sent to the gun controller (TTL active high, 100 ms duration, output port 1). The RTNU receives an input trigger (the time break TB) from the gun controller (TTL, active low, 10 ms duration, input port 1). At -1000 ms the PCS receives a Contact Closure trigger (output port 4) from the RTNU. With a certain delay, the PCS submits the bird data to the Spectra system.

At the end of each line, a shot log was produced containing basic information (e.g. distance across (DC), bottom speed (BSP), heading (HDG)). This log also contains manual comments made by the navigators (e.g. gun failures). Further on, a quality control (QC) report was produced. This report contained the shot interval in distance and time, the record delay (the time difference between start of recording and receiving the time break from the gun controller), and the manifold pressure. The record delay was found to be very stable. These values (record delay per shot) can be exported to a text file which can be used during seismic processing.

Software

The design of Spectra employs a central Data Server process which acts as the information bank and data broker for the system. All produced data (i.e. configuration data, raw data or positional solution data) are stored by the data server and made available on demand. Further parts of Spectra are the following components (so-called Nodes):

- Line Management Node (LMN): defines survey lines and controls shooting when online
- Real Time Configuration Node (RTCN): configures interfaces and triggers for the real time unit
- Spectra Configuration Node (SCN): configures the nominal positions of all nodes, sensors and observations between nodes
- Network Calculation Node (NCN): calculates the positions of all sensors on the vessel (the ncc network) every second and the positions of all other sensors (the main network) at the time of the shot. Further on, the NCN delivers the estimated time of the next shot
- Data Logging Node (DLN): writes both P1/90 and P2/94 files to disk
- Navigation Logging Node (NLN): reports summary navigation data in the form of a shot log
- Binning Configuration Node (BIN): real time binning and coverage display
- Display Node (DN): provides user configurable numerical and graphical displays of network solution, real time binning data and raw data (example shown in Fig. 4.2-2)

The vessel and survey specific geometry parameters used by Spectra are sketched in appendix A-1. Note that the vessel reference V1 is related to sea level. The tail buoy coordinates refer to CNG (center near group), the CNG refers to the towpoint in sea, and the towpoint in sea and the towpoint on vessel refer to the MRU (motion reference unit).

Operation

The standard operation flow before start of a new line, during and after end of line is attached in appendix A-4 including the communication between navigator, bridge, seismics and MMO.

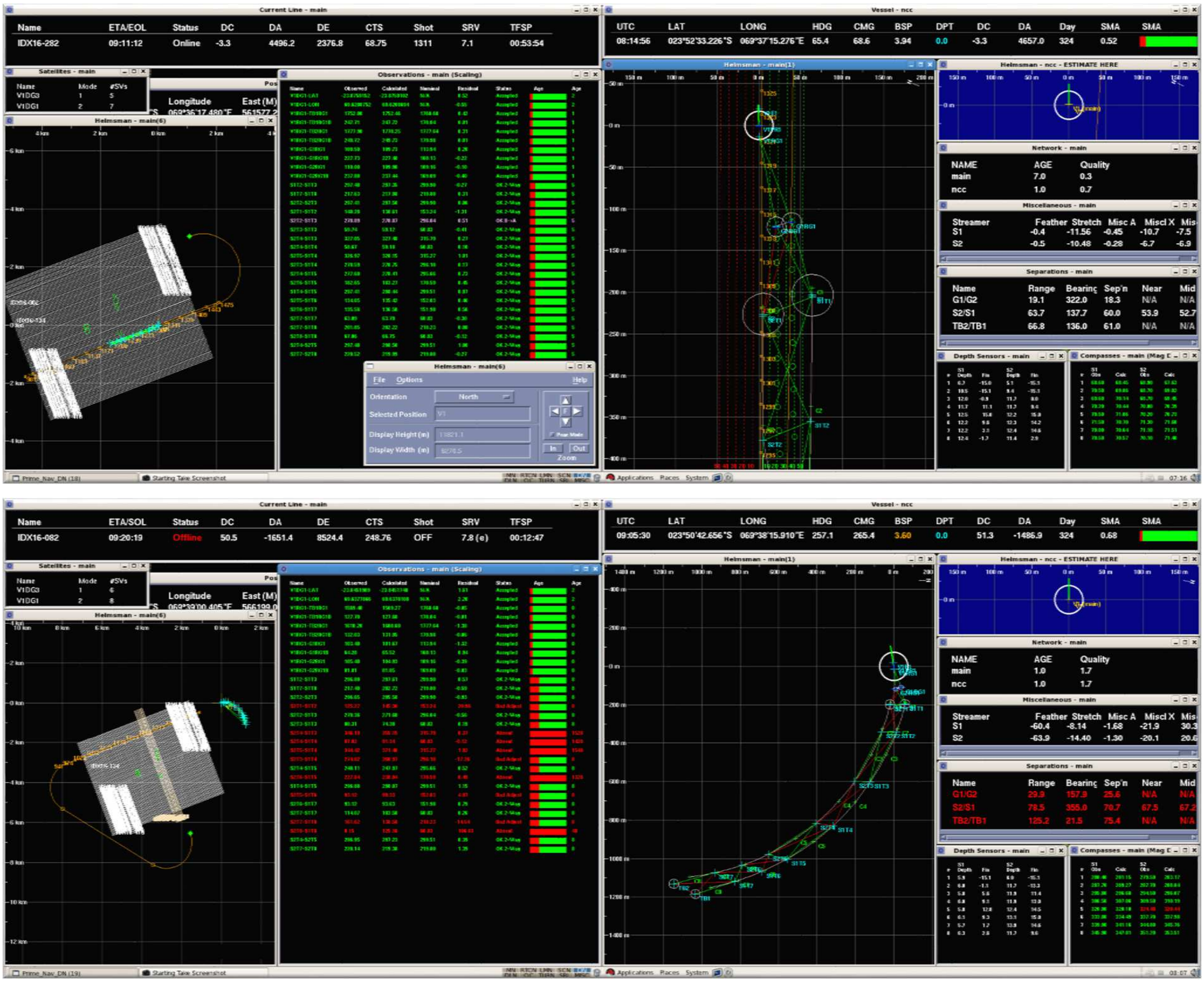


Fig. 3.4.2-11: Spectra monitors (display node) controlling navigation along a profile (top panel) and during a turn (lower panel).

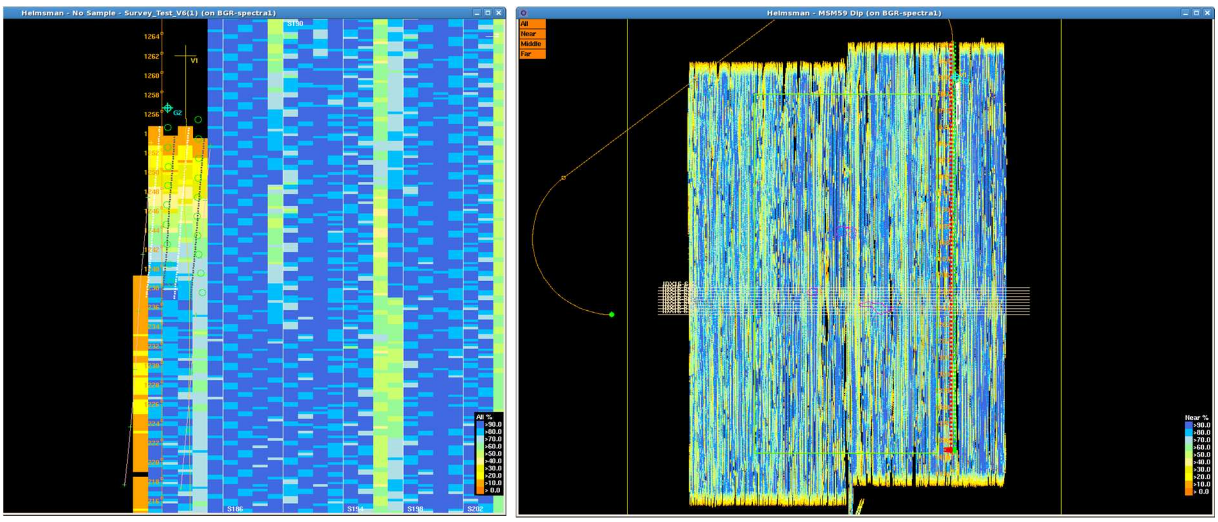


Fig. 3.4.2-12: Spectra's Binning Helmsman display monitoring the coverage of bin cells for near channels along a profile: zoom in to vessel and guns (left panel) and total view over the 3D grid (right panel).

An example of the display node screen along a line (top panel) and during a turn is illustrated in Fig. 3.4.2-11. The whole profile grid is displayed to the left, a close view to the vessel and streamer sensors to the right. Navigation along a line aims to fill the bin cells regularly by the four CDP lines without gaps. This is difficult due to feathering and requires compromises. Required offsets were communicated to the bridge in steps of 10 m – corrections of up to 60 m were necessary in case of strong feathering.

Fig. 3.4.2-12 illustrates the bin cell online coverage for the near traces along a profile (left panel) and for the total grid so far (right panel). Blue colors signal a reasonable coverage. It is not possible to optimize the coverage for near, mid and far traces during one profile, therefore infill lines have to be sailed.

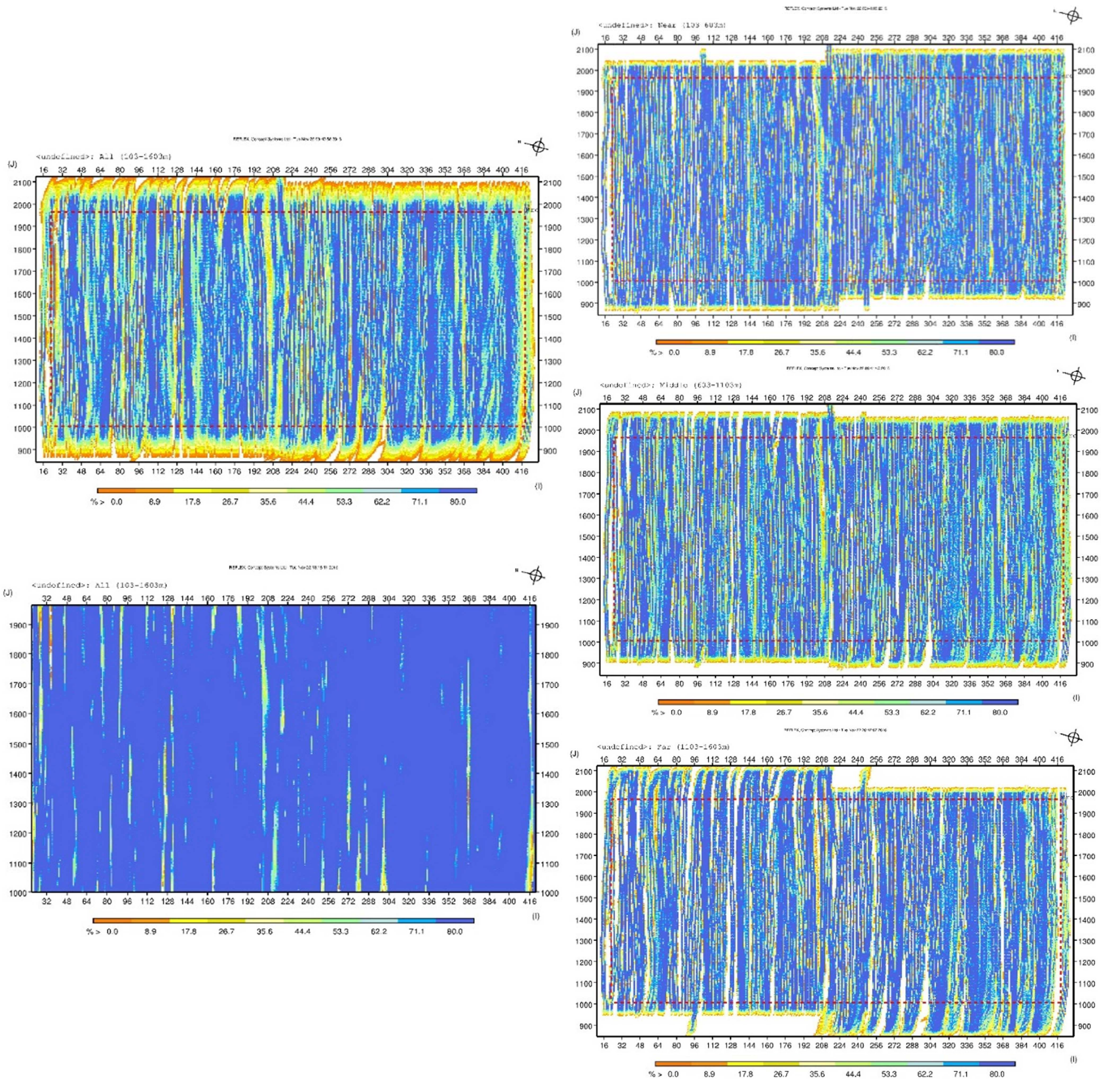


Fig. 3.4.2-13: Final coverage of bin cells of the 5 x 6 km cube: All channels before (top left) and after flex binning (bottom left), near channels (top right), mid channels (middle right) and far channels (bottom right).

The final result of binning by the Reflex software is given in Fig. 3.4.2-13 for near, middle and far traces (right panels from top to bottom) and the overall result (left panels). Flex binning (lower left panel) increases the crossline dimension of 12.5 m for near, middle and far traces by factor 1.5, 2 and 2.5, respectively. The final flex binning result (lower left panel) is convincing and the base for 3D seismic processing along lines of bin cells instead of profiles.

We sailed the profiles with 4 knots against ground – first attempts with 3.5 knots failed in the case of currents from behind, causing the streamer to sink. A velocity of at least 3.5 knots against water is recommended. The ideal turns were a half circles with a radius of 1.25 km (a diameter of 2.5 km is half the array width of 5 km allowing an ideal 'racetrack' shooting pattern). The fast turn rate of 6° per minute was feasible and resulted in only 30 minutes for an ideal turn. The 6 km long profiles took 61 minutes at 4 knots, thus a total of 91 minutes was required for each profile plus turn and 100 profiles require 6.3 days theoretically. In reality, the duration for turns was about 5-10 minutes longer due to bridge-lab communication and non-ideal turns. We sailed 19 infill lines for the 3D-grid and additional 10 perpendicular lines.

Outlook: Sprint processing

The software Spectra produces online solutions for the whole network. This is mainly done to visualize the position of the streamer during the profile and the online bin cell coverage in order to correct the profile offset. A P1/90 file containing these positions is also generated online. Anyhow, a post-processing of the navigation data is needed to produce proper positions. Sometimes online solutions fail showing artifacts in the streamer geometry, e.g. when the radio transmission to the tail buoy is interrupted for some minutes and the tail buoy positions got lost. During post-processing, all positioning data (stored in the P2/94 files) along the whole profile can be corrected for instance by sorting out bad observations, interpolating gaps and filtering. Furthermore, the post-processing solution is much more sophisticated, it is using all sensor information, allows for individual weighting of sensors, is knowing 'past and future' along a complete profile, and offers many statistic tools for quality control. Post-processing will be done after the cruise by using the software package Sprint (ION Concept Systems) producing improved P1/90 files.

3.4.2.4. 3D seismic data acquisition

(Demir, Ü., Lutz, R.)

Seismic shooting

The two GI-guns used as seismic sources were triggerd by the shot controller BigShot Seismic Source Controller (BSSC), manufactured by Real Time Systems, Fredericksburg/USA.

Shot triggering was conducted distance dependent. The predefined shot points and a trigger signal from the Power Real Time Navigation Unit (PRTNU2) of Spectra were sent to the BSSC shot controller which triggers the guns once the sources reach a line perpendicular to the survey line at the position of the shot point location.

Additionally, the BSSC employs several control and data acquisition functions:

- receives trigger from navigation
- fires solenoid power supply units (PSU)
- gathers data from solenoid power supply units
- processes data from guns and updates PSU for next shot
- displays graphical data to user for current shot
- sends serial header to recording system
- receives manifold pressure data for display (not used)

Seismic streamers

For our 3D seismic setup, we used two streamers manufactured by SERCEL. The streamer cable itself is oil-filled and consists of 150 meter long sections (ALS). Each section has 12 hydrophone groups, which are 12.5 meters long. We used 10 sections to allow for 1500 m active streamer length equivalent to 120 channels. Each streamer was equipped with a float as head buoy and a tail buoy with flash light, radar reflector and GPS navigation with radio communication. Additionally, each streamer was equipped with 8 birds (Model 5011 DigiBIRD Compass – ION Concept Systems), 8 transponders (DigiRange - ION) and 4 streamer recovery devices (SRD 500/500S – Geospace Technologies; see Fig. 3.4.2.4-1).

Fig. 3.4.2.4-1: DigiBIRD units for depth control and compass navigation (red), recovery system SRD500 (green) and DigiRANGE (yellow)

The birds provide adjustable depth control of the streamer, depth measurement, ballast information, and compass heading data. The DigiRange acoustic system is used for streamer positioning control. All bird and transponder data were transmitted via streamer to the vessel. Configuration of the starboard and portside streamer is shown in Fig. 3.4.2.4-2. The bird and acoustic control unit, DigiCOURSE System 3, was connected to the Spectra navigation system.

MSM - INDEX 2016 / Bb Streamer

	Ziehstrumpf auf 85m				CB1			DR1 CB2 / R1
Slip Ring	Lead In 405m/85m	SNS 70/70	HAU 0.28m	HESE 70mm	HESA 70/50	SNS 50/50	QS 50 1	ALS 1 1 - 12
10.6.210	001	1045855129	5352069	4807	4802	1043880160	6686779	9244

		DR2 CB3		DR3 CB4 / R2			DR4 CB5		DR5 CB6 / R3	DR6 CB7	DR7 CB8 / R4		DR8 an Endboje	
SNS 50/50	QS 50 2	ALS 2 13 - 24	ALS 3 25 - 36	ALS 4 37 - 48	ALS 5 49 - 60	LAUM 1	ALS 6 61 - 72	ALS 7 73 - 84	ALS 8 85 - 96	ALS 9 97 - 108	ALS 10 109-120	TAPU	TES 50m	STIC 25m
1044624177	6686879	9240B	9256	8637	9260	5043	9242	9247	9246	5942B	9239B	522	3198	229

sämtl. ALS sind mit 8 Bronzecollar und 4 Kunststoffcollar bestückt

Bird	Ser Nr.	Digirange	Ser Nr.
S1C1	36056	S1T1	28358
S1C2	36192	S1T2	29218
S1C3	58720	S1T3	29569
S1C4	36274	S1T4	29226
S1C5	60644	S1T5	29230
S1C6	60794	S1T6	29238
S1C7	36878	S1T7	29244
S1C8	36914	S1T8	29549
		G1T1	27383
		G2T1	29040

BackBord Streamer QuietSea Modul 1 und Modul 2 wurden ausgebaut.
Modul 1: 6686779
Modul 2: 6686879

BGR

MSM - INDEX 2016 /StB Streamer

	BendProt.				CB1			DR1 CB2 / R1
Slip Ring	Lead In 200m	SNS 70/70	HAU 0.28m	SNS 70/50	HESE 50mm/50m	SNS 50/50	QS 50 1	ALS 1 1 - 12
12992-1006	M611380/001-N	1045855132	6687739	1038562008	4810	1041328121	6686899	9261

		DR2 CB3		DR3 CB4 / R2			DR4 CB5		DR5 CB6 / R3	DR6 CB7	DR7 CB8 / R4		DR8 an Endboje	
SNS 50/50	QS 50 2	ALS 2 13 - 24	ALS 3 25 - 36	ALS 4 37 - 48	ALS 5 49 - 60	LAUM 1	ALS 6 61 - 72	ALS 7 73 - 84	ALS 8 85 - 96	ALS 9 97 - 108	ALS 10 109-120	TAPU	TES 50m	STIC 25m
1044624184	6687799	9255	9257	2175	9237B	1710	7027	9241	9253	9249	9248	231	4670	429

Bird	Ser Nr.	Digirange	Ser Nr.		
S2C1	37732	S2T1	29250		
S2C2	37927	S2T2	29255		
S2C3	37995	S2T3	29267		
S2C4	38125	S2T4	29275		
S2C5	42461	S2T5	29278		
S2C6	42778	S2T6	29513		
S2C7	59560	S2T7	~~29533~~	29562	
S2C8	58797	S2T8	~~29549~~	29246	(ST8 von BB und SB sind vertauscht)
		G1T1	~~29188~~	27383	
		G2T1	~~25007~~	29340	

ALS 8635 defekt, wurde ausgetauscht ALS 9249, 21.11.2016

BGR

Fig. 3.4.2.4-2a: Streamer configurations for starboard and portside streamers until November-15th

MSM - INDEX 2016 / BB Streamer ab 15.11.2016

								R1
	Ziehstrumpf auf 75m				CB1			DR1 CB2
	Lead In	SNS	HAU	HESE	HESA	SNS	QS 50	ALS 1
Slip Ring	405m/75m	70/70	0,28m	70mm	70/50	50/50	1	1 - 12
10.6.210	001	1045855129	5352069	4807	4802	1043880160	6686779	9244

				R2					R3		R4			
		DR2 CB3		DR3 CB4			DR4 CB5		DR5 CB6	DR6 CB7	DR7 CB8		DR8 an Endboje	
SNS	QS 50	ALS 2	ALS 3	ALS 4	ALS 5	LAUM	ALS 6	ALS 7	ALS 8	ALS 9	ALS 10	TAPU	TES	STIC
50/50	2	13 - 24	25 - 36	37 - 48	49 - 60	1	61 - 72	73 - 84	85 - 96	97 - 108	109-120		50m	25m
1044624177	6686879	9240B	9256	8637	9260	5043	9242	9247	9246	5942B	9239B	522	3198	229

sämtl. ALS sind mit 8 Bronzecollar und 4 Kunststoffcollar bestückt

Bird	Ser Nr.	Digirange	Ser Nr.
S1C1	36056	S1T1	28358
S1C2	36192	S1T2	29218
S1C3	58720	S1T3	29569
S1C4	36274	S1T4	29226
S1C5	60644	S1T5	29230
S1C6	60794	S1T6	29238
S1C7	36878	S1T7	29244
S1C8	36914	S1T8	29549
		G1T1	27383
		G2T1	29040

BGR

Fig. 3.4.2.4-2b: Streamer configurations for portside streamer modified November-15th

Seismic recording

We used BGR's SEAL seismic recording system (428, SERCEL) for data acquisition, which is capable to handle up to 2000 channels per streamer. The sampling rate during seismic data acquisition was 1 ms. Data was recorded on two NAS systems. Data format is 4byte - SEG-D revision 2, demultiplexed 32 bit IEEE, Code 8058. The record length was set to 6120 ms.

The seismic recording system was triggered by Spectra, from where it received the data for the external header. This included all information from the bird and acoustic control unit, the ship's navigation system, and the remote GPS navigation systems at the tail and gun buoys.

Continuous online quality control of seismic data was performed using a SeaProQC (Sea Processing Quality Control) 'HP DL380' to display:

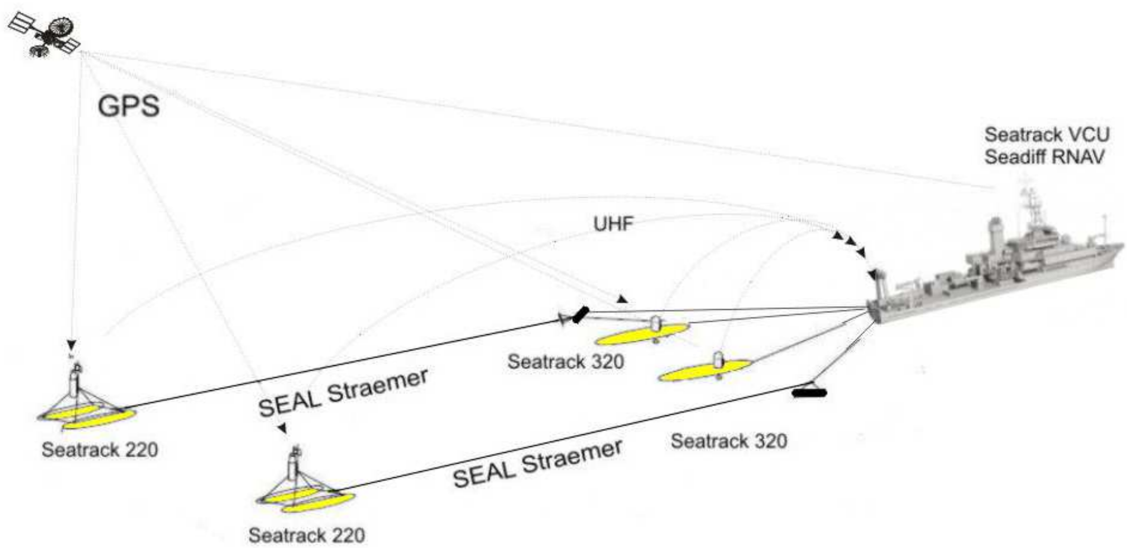
- the attributes of the data from the previous shots and summarize errors and source attributes for the successive shots processed by the SeaProQC,
- the last shot record. The traces are displayed in the time/distance domain with the noise of each trace on top of the display,
- the data of one selected channel from the streamer with the new acquired trace added to the window.

The connection scheme of all hardware components of BGR's 3D seismic system including all sensors for the navigation system is shown in ANNEX 3 and ANNEX 4.

Positioning control

In addition to the DigiBIRD compass and DigiRANGE acoustic data, GPS receivers on the tail buoys, gun buoys and the vessel were designated for logging of source and receiver positions. Each tail buoy was equipped with a Seatrack 220 system and each gun float with a Seatrack 320 system (Kongsberg Seatex AS) in addition to a DigiRANGE transponder. Seatrack 220 and Seatrack 320 units have the same electronics but Seatrack 320 has a special enclosure and mechanics to withstand the shocks on a gun float. Both units receive GPS signals and transmit them by UHF radio to the host vessel. Seatrack 220/320 units track the position of the tail buoys and the gun floats in real time, relative to the vessel's position and each other. The control unit Seatrack VCU 230 was installed on the vessel.

BGR's Kongsberg system setup consisted of the following parts (Fig. 3.4.2.4-3):



- **Fig. 3.4.2.4-3**: Kongsberg Seatrack positioning System
-
- Tail buoy units Seatrack 220
- Gun float units Seatrack 320
- VCU 230 (Vessel Control Unit) (RNAV)
- Seadiff (data collection software)
- HHT (hand held terminal to configure Seatrack 220/320 and VCU)
- Vessel UHF antenna
- Vessel main GPS receiver

3.4.2.5 Acquisition parameters, conducting the 3D survey and data quality

The 3D seismic equipment consisting of two streamers (2 x 1500 m, 120 channels each) and two acoustic sources (2 x GI-gun, 45 in³ generator volume, 105 in³ injector volume, each @ 150 bar) were deployed.

The sources operated in ‘flip flop’ mode with a shot point interval (SPI) of 14.5 m (approx. 7 s) and 3.9 m depth. The intended SPI was 12.5 m equal to the hydrophone group spacing. However, because of the minimum practicable speed of the vessel (4 knots) and the aimed record length (6 sec TWT) we had to increase to a SPI of 14.5 m.

The ideal depth for sources and streamer cable is 3 meters in order to reduce frequency notches in the desired bandwidth by source and receiver ghosts. However, because of the significant noise in the uppermost water layers due to wind and swell noise, we decided to lower the streamer depth to 12 meters.

Table 3.4.2-1: Acquisition Parameters

Number of sources	2 x GI Gun, true GI mode, 45 in³ generator volume, 105 in³ injector volume
Operating pressure	150 bar
Depth of sources	3.9 m
Operating mode	Flip – flop
Source separation	25 m
Number of seismic cables	2 x 1500 m, 120 channels each
Streamer cable separation	50 m
Streamer cable depth	12 m
Sample rate	1 ms
Record length	6120 ms
Vessel track crossline distance	50 m
Nominal seismic inline coverage	~2600%
Nominal seismic crossline coverage	100%

Survey operations during November 9th were done with streamer depth of 4 m (lines IDX16-022, IDX16-338, IDX16-026).

On November 10th streamer depth was stepwise changed to deeper water. Line IDX16-306 was measured and completed with 4 m streamer depth, line IDX16-201 with 6 m before lowering the streamer to the final towing depth of 12 m starting with line IDX16-030.

3.4.3 Wide angle seismic investigations

(Ehrhardt, A., Schauer, M., Lutz, R., Berglar, K., Schnabel, M.)

In order to acquire wide angle reflected and wide angle refracted seismic waves, we deployed Ocean Bottom Seismometers (OBS) at the passive massive sulphide vent fields and its vicinity. Initially, it was planned to deploy 10 OBS devices. However, because one data recorder failed during the setup, only 9 OBS devices were deployed.

The data from the OBS devices shall be used for

(i) a reliable velocity model of the study area near the hydrothermal vent fields out of a 3D tomography of refracted waves and

(ii) acquisition of the wide-angle reflection data for amplitude versus offset analysis (AVO). Differences in the Poisson ratio between the massive sulphides and basalts may be indicated by means of AVO.

3.4.3.1 Equipment and details of data acquisition

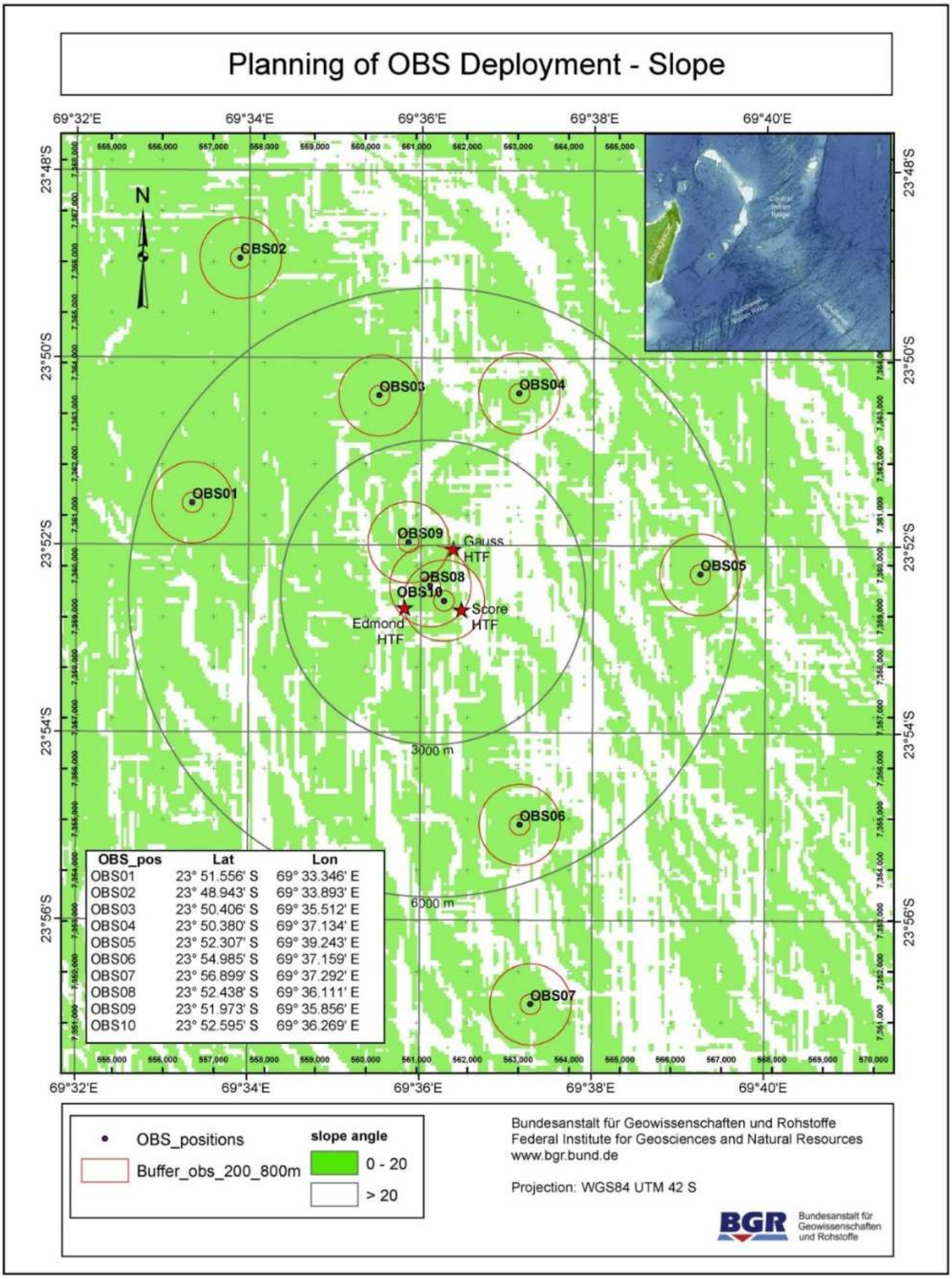
Scientific OBS station criteria

We followed two main purposes with the deployment positions of our OBS stations. First, we wanted to acquire wide-angle reflections from all shots from the 3D survey. Therefore, we deployed 3 OBS in the direct vicinity of the known passive vent fields "Score" and "Gauss". In order to record refracted waves we had to consider the "blind zone" until the critical angle is reached. Therefore, we deployed the OBS more than 3 to 6 km away from the known sulphide vent fields. Because of the linear strike of the Mid Ocean Ridges we planned to distribute the OBS parallel to the strike of the ridges.

Deployment restrictions

The significant seafloor topography with dips of more than 45° and the existence of big blocks and boulders on the seafloor resemble a considerable risk for the OBS devices. In order to minimize this risk as much as possible we consulted cruise reports of previous OBS experiments in comparable areas and studied the detailed bathymetric maps that are available from previous cruises in our study area. We agreed that all deployment positions have to fulfill the following criteria:

- The slope angle must be less than 20° within a radius of at least 200 m, ideally of 800 m (Fig. 3.4.3.1-1). From previous cruises in comparable areas, we learned that the distance between deployment position and recovery position was in average less than 800 m.
- Within the survey area, we checked the actual water currents with the ADCP aboard RV MARIA S. MERIAN (Figs. 3.4.3.1-2/3) to estimate the drift of the OBS.
- We avoided areas with tallus, gravel, boulders and blocks either because of unsafe landing positions for the OBS or because of limited coupling of the seismometer to the seafloor, based on the information from previous cruises within our survey area.



OBS_pos	Lat	Lon
OBS01	23° 51.556' S	69° 33.346' E
OBS02	23° 48.943' S	69° 33.893' E
OBS03	23° 50.406' S	69° 35.512' E
OBS04	23° 50.380' S	69° 37.134' E
OBS05	23° 52.307' S	69° 39.243' E
OBS06	23° 54.985' S	69° 37.159' E
OBS07	23° 56.899' S	69° 37.292' E
OBS08	23° 52.438' S	69° 36.111' E
OBS09	23° 51.973' S	69° 35.856' E
OBS10	23° 52.595' S	69° 36.269' E

Fig. 3.4.3.1-1: A slope angle less than 20° (green) was a main criterion for the selection of OBS locations.

Releaser Test

Before the deployment of the OBS stations at their intended positions, we carried out a releaser test. For that purpose, we attached 11 KumQuad releaser units to the CTD of RV MARIA S. MERIAN and brought them to a depth of 3000 meters. Because of insufficient power of the deck unit 5 of 11 releasers failed. After it was possible to send the release commands with full power, we performed a second releaser test and lowered the failed releaser to a depth of 500 m to check their function. All releasers responded to their release command and opened successfully.

Deployment

OBS deployment was commenced and completed November 8th. Figures 3.4.3.1-1and 3.4.3.1-4 show the drop positions (see also Table 3.4.3-1). Whereas OBS#10, #19 and #20 were deployed at or very close to the passive vent fields in order to acquire wide-angle reflection data of the massive sulphide fields, the other OBS devices were deployed at the outer rim of our survey area in order to acquire wide-angle refraction data. Since one OBS failed during setup and deployment preparation, we deployed only 9 of 10 OBS.

Table 3.4.3-1: Planned OBS deployment positions, real deployment positions and recovery positions.

planned						up in min (1.2 m/s)	deployment				recovery				
seq	OBS No	OBS_pos	Lat	Lon	depth [m]		date	time (UTC)	Lat	Lon	date	time (UTC)	Lat	Lon	Distance (m)
1	13	Station 07	23° 56.899' S	69° 37.292' E	3220	45	07.11.2016	19:59	23° 56.899' S	69° 37.292' E	22.11.16	9:17	23° 56,943' S	69° 37,391' E	186
2	14	Station 06	23° 54.985' S	69° 37.159' E	3100	43	08.11.2016	20:29	23° 54.985' S	69° 37.159' E	22.11.16	10:50	23° 54,995' S	69° 37,252' E	160
3	17	Station 05	23° 52.307' S	69° 39.243' E	2825	39	09.11.2016	21:06	23° 52.307' S	69° 39.243' E	22.11.16	12:24	23° 52,282' S	69° 39,432' E	324
4	10	Station 10	23° 52.595' S	69° 36.269' E	3210	45	10.11.2016	21:38	23° 52.595' S	69° 36.269' E	22.11.16	14:00	23° 52,702' S	69° 36,388' E	283
5	20	Station 08	23° 52.438' S	69° 36.111' E	3190	44	11.11.2016	21:50	23° 52.438' S	69° 36.111' E	22.11.16	14:06	23° 52,510' S	69° 36,258' E	283
6	19	Station 09	23° 51.973' S	69° 35.856' E	3220	45	12.11.2016	22:15	23° 51.973' S	69° 35.856' E	22.11.16	14:18	23° 51,995' S	69° 36,004' E	321
7	9	Station 01	23° 51.556' S	69° 33.346' E	3620	50	13.11.2016	22:45	23° 51.556' S	69° 33.346' E	22.11.16	16:16	23° 51,389' S	69° 33,311' E	313
8	21	Station 03	23° 50.406' S	69° 35.512' E	3370	47	14.11.2016	23:13	23° 50.406' S	69° 35.512' E	22.11.16	17:49	23° 50,245' S	69° 35,439' E	321
9	15	Station 02	23° 48.943' S	69° 33.893' E	3300	46	15.11.2016	23:40	23° 48.943' S	69° 33.893' E	22.11.16	18:21	23° 48,830' S	69° 33,896' E	208

ADCP information

On station, the ship's ADCP showed only a weak current signal with indifferent directions both at high frequencies (Fig. 3.4.3.1-2) and low frequencies (Fig. 3.4.3.1-3) range for the target area. Based on this information, no drift corrections were applied for the planned deployment positions.

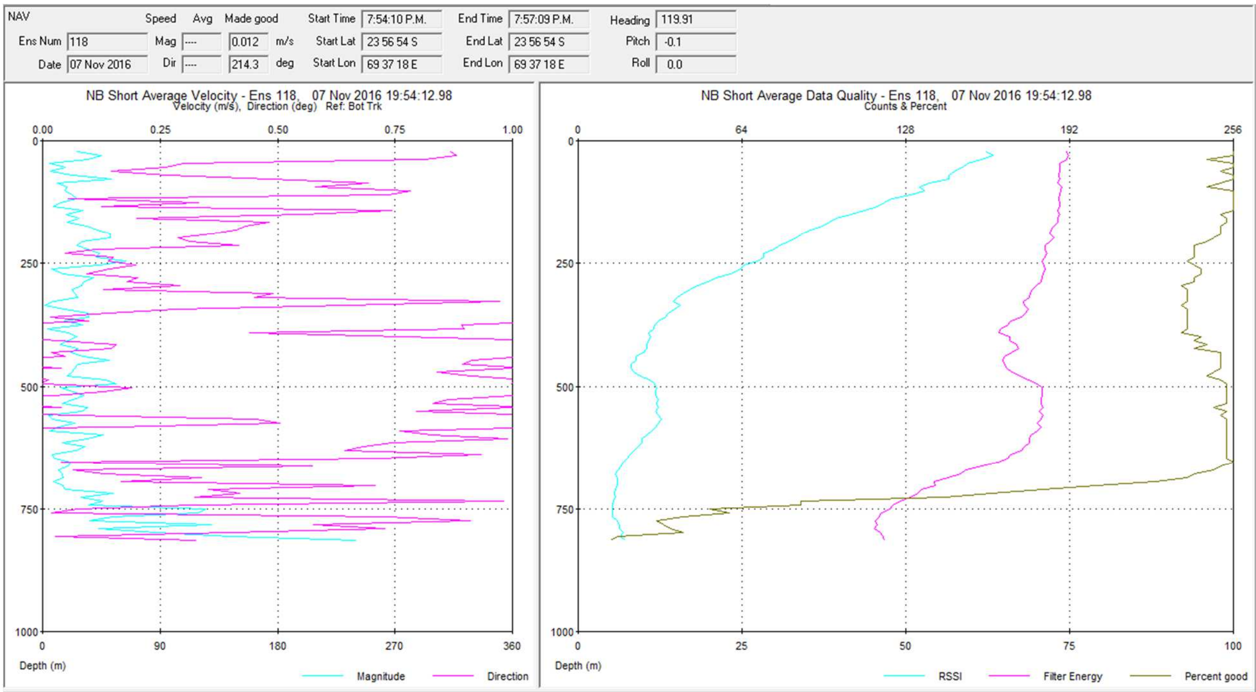


Fig. 3.4.3.1-2: ADCP profile in the high frequency range measured on the deployment position of OBS13 (Station 7).

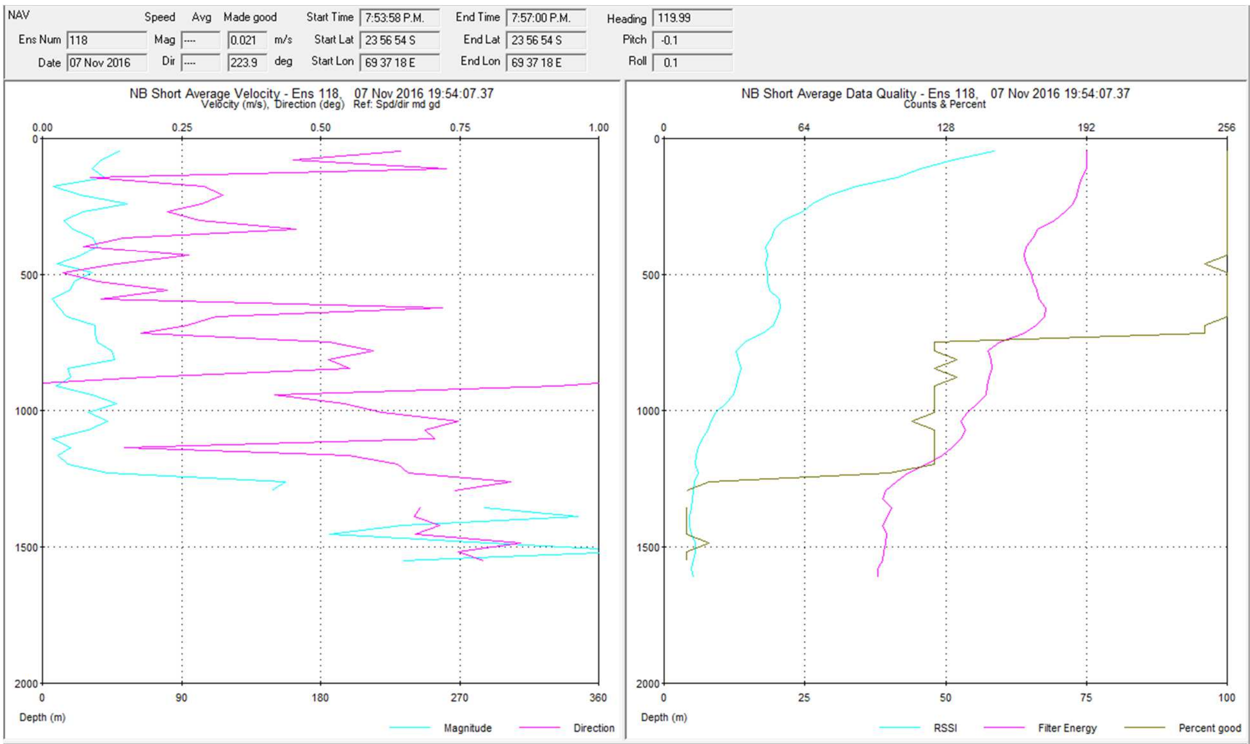


Fig. 3.4.3.1-3: ADCP profile in the low frequency range measured on the deployment position of OBS13 (Station 7).

Recovery

All OBS were released after 14 days recording period on November 22nd using the transducer. No time release was necessary. Because the hull mounted transducer of RV MARIA S. MERIAN did not work, we used our own transducer which was lowered at each deployment position about 30 meters below the vessel. The recovery positions and calculated distances between deployment and recovery positions are summarized in Table 3.4.3-1 and visualized in Fig. 3.4.3.1-5. Although there was an apparent fast drift during deployment of the OBS the maximum distance between deployment and pick-up position was only 324 m. As the average deployment depth was about 3200 m the real drift of the OBS was very small and we are convinced that the OBS grounded within our 200 m circle around the desired position (Fig. 3.4.3.1-4).

General OBS handling

To be able to record converted shear-waves at the seafloor, we deployed nine Ocean Bottom Seismometer stations (LOBSTER, K/MT 510, KUM Kiel). These stations are lying flat on the seafloor and have a three-component geophone (K/MT 210, KUM Kiel) fixed at the lower side of the floatation body. The data of 8 OBS is recorded with GEOLON-MES recorders (Send, Hamburg). These data loggers are equipped with a 20 GB hard disk. After recovery of the station and determination of the drift of the internal clock of the recorders, we connected the MES via fire-wire to a linux pc. One OBS is equipped with a KUM 6D6 data recorder including a 128 GB flash disk.

After the successful releaser test the time release of the releaser was programmed and the Lobster OBS were mounted on the anchor and the hook of the anchor was fixed by the releaser. The geophone was mounted on the anchor plate. The pressure tube of the Lobster was equipped with the battery cells and the recorder was programmed and connected to the geophone and hydrophone. Finally, a flash and a radio beacon was attached to the frame of the Lobster.

It is very important to properly tight the anchor to the releaser. We mounted the anchor to the OBS and tightened the anchor with the recommended torque of 5 Nm. After lifting the OBS with the crane we realized that the anchor hook sometimes was untightened again. Thus, we recommend to check the torque of the anchor plate again shortly before deployment.

Data recovery

After the OBS were picked up we copied the data from the recorder. Because of the long recording time and the high sampling rate the data set was quite large. Probably because of this large data set we had problems with 3 OBS while copying the data.

OBS#13: error message: disk_access is stuck → rebooting; dcfskew → rebooting
OBS#20: error message: mescopy.cpp:160: can not read from input file 151116
OBS#21: error message: reboot after dcfskew

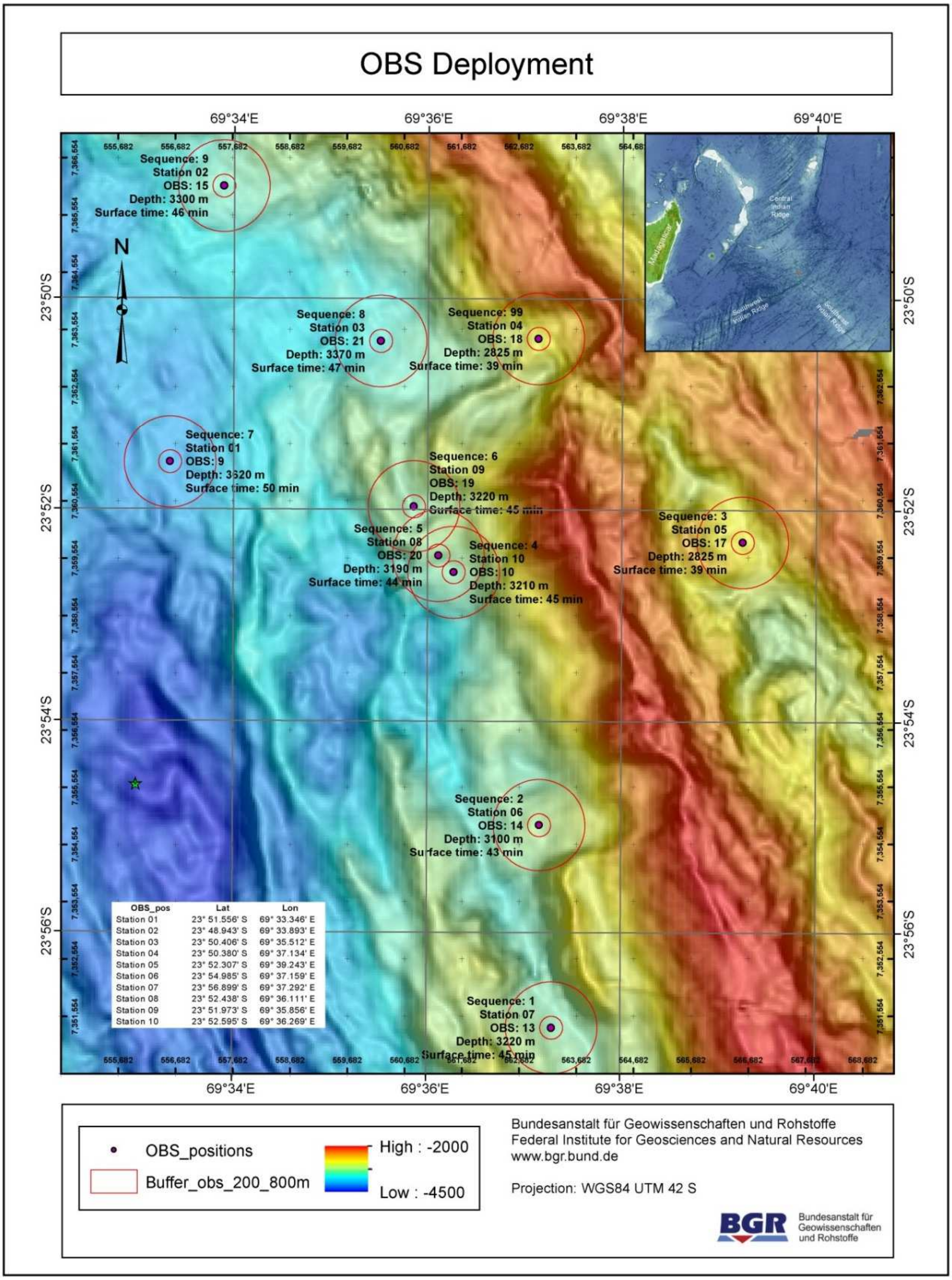


Fig. 3.4.3.1-4: Deployment plan of OBS stations. OBS deployment at station #4 was skipped due to a failed recorder during the setup.

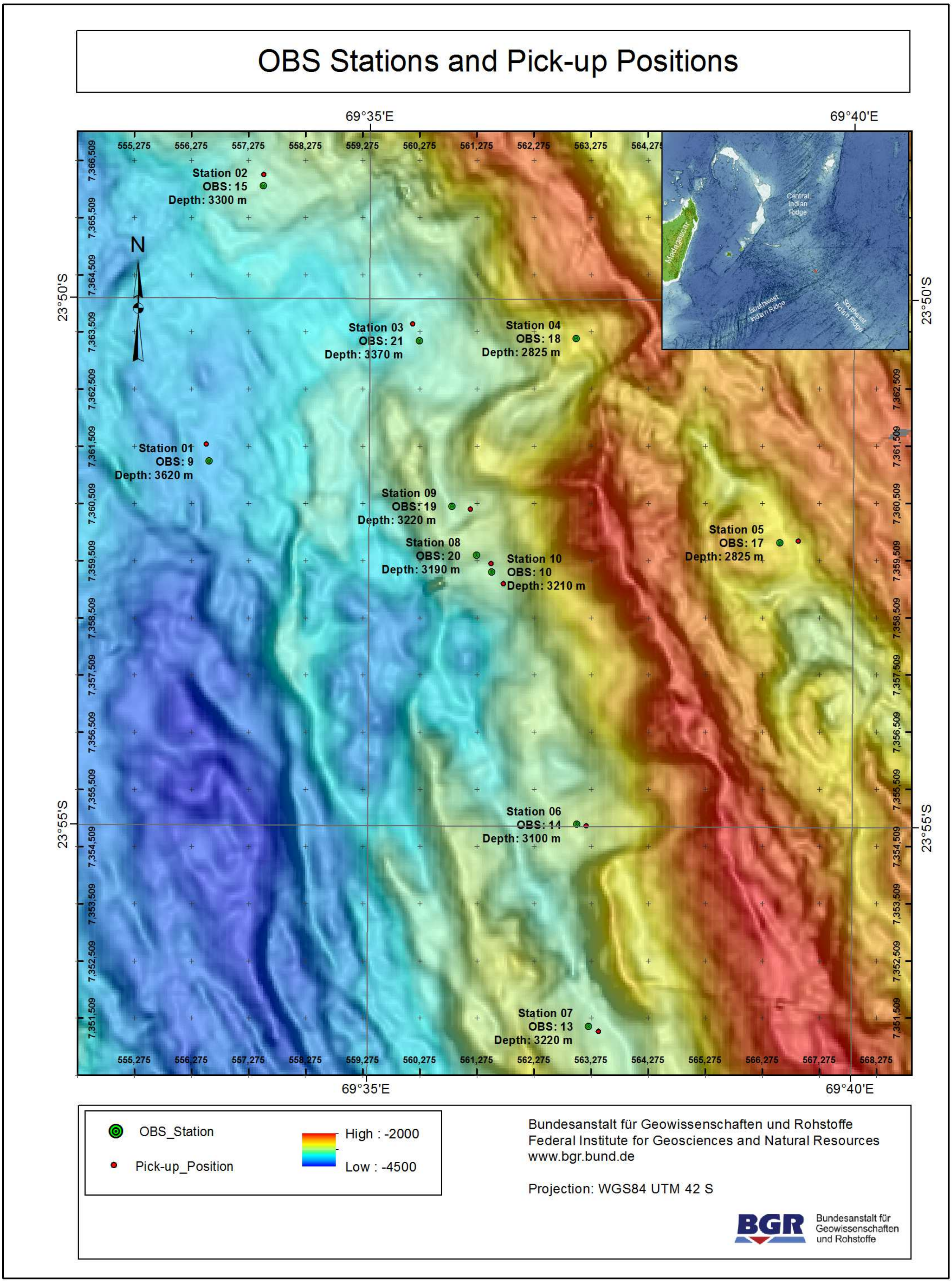


Fig.3.4.3.1-5: Comparison of deployment and pick-up positions. Coordinates of the positions are also summarized in Table 3.4.3-1.

3.4.4 Measures to minimise potential impacts on the marine environment during seismic operations

(Barnicoat, S., Scala, L., Damm, V.)

There are no existing regulatory frameworks concerning marine fauna mitigation in the Indian ocean and no mandatory license conditions were included. Notwithstanding the above, in the adoption of best practice to international standards, BGR generally implements a MMO regime for seismic surveying identical to the long-established UK JNCC (August, 2010 - see also http://www.bgr.bund.de/DE/Themen/GG_Geophysik/Marine_Geophysik/Seismik/MM_Observer.html?nn=1542296). These marine mammal mitigation procedures were also adopted as 'best practice' during this survey.

This guidance was distributed to the seismic crew at the start of the survey, to ensure that everyone was aware of the requirements. As there were two dedicated joint MMO/PAM operators on board the vessel, almost continuous marine faunal watches were maintained during this survey and regardless of source activity. In addition to standard visual observations two PAM systems were used on the vessel during the cruise, primarily for marine mammal mitigation but additionally for comparison purposes. This chapter describes the efforts, summarizes the main results and review each method. For passive acoustic monitoring the following systems were employed:

1. Seiche Measurement Limited's (SML) standard 4-element towed array and acoustic processing system (http://www.seiche.com/topics/73-towed-pam-system) using the PAMGuard analysis software (http://www.pamguard.org/), setup and operated by the PAM operator, and

2. Sercel's QuietSea™ system (http://www.sercel.com/products/Pages/QuietSea.aspx) which processes and analyses sound from both the seismic streamers and additional hydrophones on the gun arrays. The QuietSea™ system (QS) as a new Sercel product was as a backup. The synchronous operation of both PAM systems provides an opportunity to compare the results systems and provides a database for further improving the QS hard- and software components.

3.4.4.1 Marine mammals and sea turtles in the survey area

Marine mammals

There is a large diversity of cetaceans present in the western Indian Ocean. While some species are resident all year, others frequent the area during winter to breed before migrating in the summer to the Southern Ocean and Antarctic Peninsula to feed. Tab. 3.4.4-1 lists the cetaceans known to occur within the Western Indian Ocean and which could potentially be observed in the survey area. There are no records of pinnipeds or sirenians (seals, dugongs, etc.) in or near the survey area.

The island of Mauritius (approx. 800 nm NW of the working area) is a part of the 'Joint Extended Continental Shelf of the Republic of Mauritius and the Republic of Seychelles'. The continental shelf is referred to as a 'hotspot' for deep diving cetaceans (sperm whales, beaked whales, etc.) and baleen whales (blue whales, fin whales, etc.) due to its richness of food source and dramatic 3000 m depth drop-off.

In the winter months, baleen whales (humpback whale, fin whale, southern right whale, etc.) occur in the western Indian Ocean between May and August to breed and calve before transiting to their summer feeding grounds in the Antarctic (Tab. 3.4.4-1). Deep diving sperm whales are also known to transit towards the pole regions in the summer months. It is during these phases of migration that the occurrence of marine mammals within the survey area is most likely to increase, while sightings of wider ranging marine mammals (e.g. dolphins, pilot whales, etc.) may occur all year round.

A high diversity of odontocetes (dolphins, beaked whales, sperm whales and Kogia) occur off the Western Indian Ocean continental margin and offshore waters and could potentially be seen in and around the survey area throughout the year. While the species distribution of beaked whales and Kogia (dwarf and pygmy sperm whale) is poorly understood within the Indian Ocean, distribution tables indicate that these animals may be present within the survey region.

Bottlenose, striped and Fraser's dolphins are resident in the Indian Ocean with overlapping calving seasons throughout the year, while false killer whales are known to calve in the summer months. Despite the potential of these animals to occur within the survey area, few records exist of their presence this far offshore.

Table 3.4.4-1: Marine Mammals in Survey Area

Species common name	Species Latin name	Distribution
Humpback whale	*Megaptera novaeangliae*	Migration, winter months for breeding
Blue whale	*Balaenoptera musculus*	Inshore, edge of continental shelf, breeds in the winter
Fin whale	*Balaenoptera physalus*	Migration, winter months for breeding
Sei whale	*Balaenoptera borealis*	All year range, doesn't migrate as far south as other rorquals
Bryde's whale	*Balaenoptera edeni*	All year range, doesn't migrate as far south as other rorquals
Omura's whale	*Balaenoptera omurai*	All year range, doesn't migrate as far south as other rorquals
Antarctic minke whale	*Balaenoptera bonaerensis*	Migration, winter months for breeding
Dwarf minke whale	*Balaenoptera acutorostrata*	Resident
Southern Right whale	*Eubalaena australis*	Migration, winter months for breeding
Sperm whale	*Physeter macrocephalus*	All year, continental shelf edge
Cuvier beaked whale	*Ziphius cavirostris*	All year, continental shelf edge
Longmans beaked whale	*Indopacetus pacificus*	Distribution poorly understood
Grays beaked whale	*Mesoplodon grayi*	Resident and widespread through Southern Ocean
Blanville's beaked whale	*Mesoplodon densirostris*	Resident all year
Pygmy sperm whale	*Kogia breviceps*	Resident all year
Dwarf sperm whale	*Kogia sima*	Resident all year
Orca/Killer whale	*Orcinus orca*	Resident all year
Short fin pilot whale	*Globicephala macrorhynchus*	Resident all year
Pygmy killer whale	*Feresa attenuata*	Resident all year
False killer whale	*Pseudorca crassidens*	Resident all year
Risso's dolphin	*Grampus griseus*	Resident all year
Bottlenose dolphin	*Tursiops truncates*	Resident all year
Rough toothed dolphin	*Steno bredanensis*	Resident all year
Spinner dolphin	*Stenella longirostris*	Resident all year
Striped dolphin	*Stenella coeruleoalba*	Resident all year
Pantropical spotted dolphin	*Stenella attenuata*	Resident all year
Fraser's dolphin	*Lagenodelphis hosei*	Resident all year

Marine turtles

There are five species of marine turtle recorded in the western Indian Ocean. The Green turtle (Chelonia mydas) is the most common species and is known to nest year-round with peak nesting activity between July and December. In general, green turtles inhabit coastal areas, shallow bays and in protected shore areas near coral reefs and sea grass beds. Hawksbills turtles (Eretmochelys imbricate) nest between September and February and are also common around the Seychelles, Mauritius, and Reunion Islands. Hawksbills inhabit open oceans, lagoons, mangroves swamps and sea grass areas, feeding on sponges in coral reefs, crustaceans, algae, and fish. Loggerhead turtles (Caretta caretta) nest in the Indian ocean from October to March. They spend most of their time in the open ocean or in shallow coastal waters, primarily feeding on invertebrates, sponges, bivalves, and anemones. The leatherback turtle (Dermochelys coriacea) is also found in the Indian ocean, with nesting sites that include Sri Lanka and south Mozambique. However, their specific nesting season is relatively unknown. Leatherback turtles inhabit coastal and pelagic waters, following distribution of jellyfish, usually feeding in coastal areas at night. The leatherback turtle is the only turtle that can withstand cooler water temperatures. The Olive Ridley (Lepidochelys olivacea) inhabits tropical warm waters, and is the rarest species found in the western Indian Ocean. They conduct synchronised nesting in mass numbers known as 'arribadas' between June and December. Olives occasionally inhabit deep waters, and are found mostly in coastal areas feeding on jellyfish, and invertebrates.

For more detail please refer to the special dedicated habitat analysis for the survey area (RPS, 2017)

3.4.4.2 Mitigation and monitoring requirements

The full mitigation protocol is summarized in Tab. 3.4.4-2.

Table 3.4.4.-2: Mitigation measures summary

Source mitigation zone	500 m
Pre-soft start monitoring	60 minutes
Soft start length	20 – 40 minutes
Soft-start delays	Yes
Shut-down during production	Not on lines Yes, on line changes
Species covered	Marine mammals
Special requirements	Source active during line change with increased SPI (20 s) for OBS recordings Passive acoustic monitoring (PAM) during darkness & reduced visibility

Mitigation zone

A mitigation zone of 500 m radius from the centre of the seismic source was adopted, as per the JNCC (2010) Guidelines.

Pre-soft start monitoring

During daylight hours, a JNCC-qualified MMO conducted a visual pre-shoot search of the 500 m mitigation zone for at least 60 min prior to every airgun use. During hours of darkness or reduced visibility (heavy rain and fog, where the mitigation zone was no longer visible) the pre-shoot watch was carried out acoustically by a dedicated PAM Operator.

The soft-start

The soft start consisted of gradually decreasing the Shot Point Interval (SPI) from 2 min SPI to 7 s SPI over a minimum of 20 min to a maximum of 40 min.

Soft start delay

If marine mammals were detected within the mitigation zone at any point during the pre-shoot watch, then the soft-start was to be delayed for 20 min from the animals exiting from, or last observed within the mitigation zone. The MMO or PAM Operator would notify the seismic crew of the need to delay soft start and then again when they had the all clear to commence soft start.

Shutdown

If a marine mammal was detected inside the mitigation zone during a line turn (SPI 20 s) the MMO/PAM operator would request a shut-down of the seismic source. There was no requirement to shut-down the seismic source during full operating SPI (SPI 7 s) or during the soft start procedure.

Operational breaks in source activity

If the seismic source output stops for technical reasons for up to 10 min, operations may resume at full capacity following inspection of the mitigation zone and clearance from the MMO/PAM operator. If the source output stops for more than 10 min, a full pre-shoot search and soft-start is required.

Line changes

The acoustic source remained active during line change to continue OBS profiling, but the Shot Point Interval (SPI) was increased to 20 s. If a marine mammal entered the mitigation zone during line change, the acoustic source would shut-down and resumption of the source followed the normal 20 min delay from the last sighting or detection within the mitigation zone and soft-start procedure.

3.4.4.3 Marine mammal survey methods during MSM59/1

Visual observations

Dedicated visual observations were carried out during hours of daylight and when weather conditions permitted. Observer effort was recorded with environmental data. Wind speed was classified to the Beaufort wind scale. Other classifications for sea state, swell, visibility and glare followed the JNCC recording form. A new record was entered every time environmental conditions or the source status changed, or at least every hour.

Observations were carried out from the observation deck above the bridge (16.85 m). The MMOs scanned the sea with the naked eye, using 7x50 binoculars to closer investigate any visual cues seen, such as circling seabirds, dark shapes, splashes or blows. If marine mammals were observed, the distance to the sighting was estimated, using reticules from binoculars. The time, location and other data required for the completion of the JNCC sightings forms were also recorded, as well as the behaviour of the animals in relation to the survey vessel.

Photographs of marine mammals were taken whenever possible to document the species identification (also sometimes providing information on group sizes and behaviour). Photography is a useful tool in freezing the motion of fast-moving species such as delphinids, allowing later examination of their flank markings and facilitating identification. It also permits independent verification of sighting data. During this survey the MMOs used a range of photographic equipment; Canon DSLR cameras 70 x 300 zoom lens.

Passive Acoustic Monitoring with SML-PAM

SML-PAM was used to monitor underwater sounds during the hours of darkness and periods of poor visibility. A four-channel 250 m array cable was towed from the source vessel and consisted of two (H1 and H2) identical, spherical broadband hydrophones (200 Hz to 200 kHz, -3 dB points); two (H3 and H4) identical spherical hydrophones (2 kHz to 200 kHz), and a depth gauge (10 Bar sensor). Channel sensitivity at the output from the pre-amplifier was -166 dB re: 1 V/µPa for the broadband channel and -157 dB re 1V/µPa for the low frequency channel.

The 250 m array cable was deployed from a hanging block suspended by crane arm and offset 5 m to the port side quarter (Fig. 3.4.4-1). The array cable was connected to a PAM base station via a 100 m deck cable. The PAM Base was contained in a 19-inch rack housing and consisted of a buffer box with an internal card (NI DAQ USB-6251) for sampling high frequency (HF) sound (H3 and H4, 500 ks/s), an external sound card (Fireface 800) for digitally sampling Low Frequency (LF) sound (H1 and H2, 48 ks/s), a rack mounted PC ("PAMGuard PC") running PAMGuard version 1.15.04 CORE win32 and the Fireface 800 controller software (Fig. 3.4.4-2).

Fig. 3.4.4-1: PAM array cable deployment

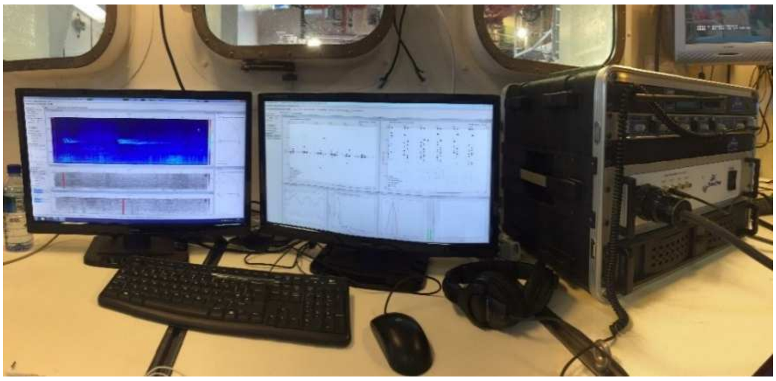


Fig. 3.4.4-2: PAM station setup

Odontocetes (e.g. toothed whales and dolphins) emit echolocation clicks to navigate and find prey. Individual click energy broadly varies between species but generally, peak frequency may range from 4 kHz to 200 kHz and are emitted in rapid sequences or trains. Mysticetes (e.g. baleen whales) and many odontocetes also emit frequency modulated (FM) tonal signals and pulsed calls that are used for communication. Marine mammal vocalisation signals were detected acoustically using a headset (Sennheiser HD280 pro) and the PAMGuard PC. Raw FFT data acquired by the LF sound card was displayed in real-time on spectrograms. A mid-frequency (MF) spectrogram displayed signals with a frequency range of 0 Hz to 24 kHz and was suitable for the detection of frequency modulated (FM) tonal signals (e.g. whistles, peak frequency 4 kHz to 24 kHz) and pulsed calls (e.g. buzz, squawk, bark, etc.) produced by odontocetes (e.g. dolphins, pilot whales, etc.) A low-frequency (LF) spectrogram displayed signals with a frequency range of 0 Hz to 3 kHz and was used to detect LF tonal signals (e.g. songs, moans, grunts, shrieks, pulses) produced by mysticetes (e.g. Humpback whales, Southern Right whales, etc.). A very low-frequency (VLF) spectrogram displayed signals with a frequency range of 0 Hz to 480 Hz for closer inspection of VLF tonal vocalisations (e.g. calls, pulses, moans, etc.) produced by large mysticetes (e.g. Blue whales, Fin whales, Bryde's whales, etc.).

Data from the LF sound card were processed using a LF click detector (frequency range of 0 Hz to 24 kHz, trigger high pass 4 kHz, order 4) to identify echolocation click trains of dolphin species and sperm whales. Candidate clicks were verified by inspection of click waveform and spectrum characteristics. Sperm whales produce powerful broadband echolocation clicks with a peak energy (160 to 180 dB re 1 µPa @ 1m) at approximately 0.1 kHz to 30 kHz. Many Odontocetes (e.g. dolphins, beaked whales, Kogia, etc.) produce clicks with energy exceeding the human hearing range (e.g. > 20 kHz). High frequency echolocation clicks were processed using an HF click detector (frequency range 0 Hz to 250 kHz, trigger band pass 15 kHz to 160 kHz, order 6) and classified by frequency sweep as MF Pulse (e.g. test band 20 kHz to 50 kHz, click length 0.04 to 1 ms), HF Pulse (e.g. test band 50 kHz to 100 kHz, click length 0.04 to 1 ms) and Narrow Band HF (e.g. test band 120 kHz to 150 kHz, click length 0.03 to 0.12 ms) to facilitate detection of target frequency bands (e.g. Beaked whale clicks have a peak frequency of 30 kHz to 60 kHz). The vessels position was provided by the on-board GPS navigation system (NMEA GGA string, BAUD 4800) and displayed in PAMGuard on a map along with hydrophone positions, 500m exclusion zone, vessel track line and local bathymetry data.

The location of detected marine mammals are resolved by calculating the bearing and range of the received signals from pairs of grouped hydrophones (LF: H1 & H2, HF: H3 & H4) using a combination of automated detectors and manual localisation techniques. The bearing of the target signal is calculated using a time of arrival difference (TOAD) cross-correlation function, which calculates the difference in the arrival times of the same signal when detected on two or more hydrophones of known separation distance (e.g. H1 and H2 have a separation of 2m, H3 and H4 have a separation of 0.25m) and the speed of sound in water (e.g. 1500 m/s). The bearings of detected vocalisations may be displayed on a map and the animal's location is resolved using Target Motion Analysis (TMA), where successive bearings begin to converge as the vessel advances along a track. FM tonal sounds may be detected using an automated whistle and moan detector, or manually selected using a clip generator. Automated detections are verified manually by inspecting the spectrogram display and aurally using the headset. False automated detections attributed to other noise sources are rejected by the PAM operator. LF click trains (e.g. Sperm whale echolocation clicks and coda, etc.) can be tracked and plotted automatically by running automated click train ID, or manually by selecting and assigning individual target clicks to an acoustic event. HF clicks are automatically classified per pre-defined parameters (e.g. MF_Pulse, HF_Pulse, NBHF, etc.) and individually inspected by click waveform, spectrum, inter-click interval (ICI) and Wigner plots to identify vocalisations (e.g. beaked whales, Kogia, dolphins, etc.). Verified HF click trains are tracked, labelled as an acoustic event and displayed on the map. LF and HF click trains are localised automatically using the tracked click localiser function or manually using real-time TMA and the map measuring tool.

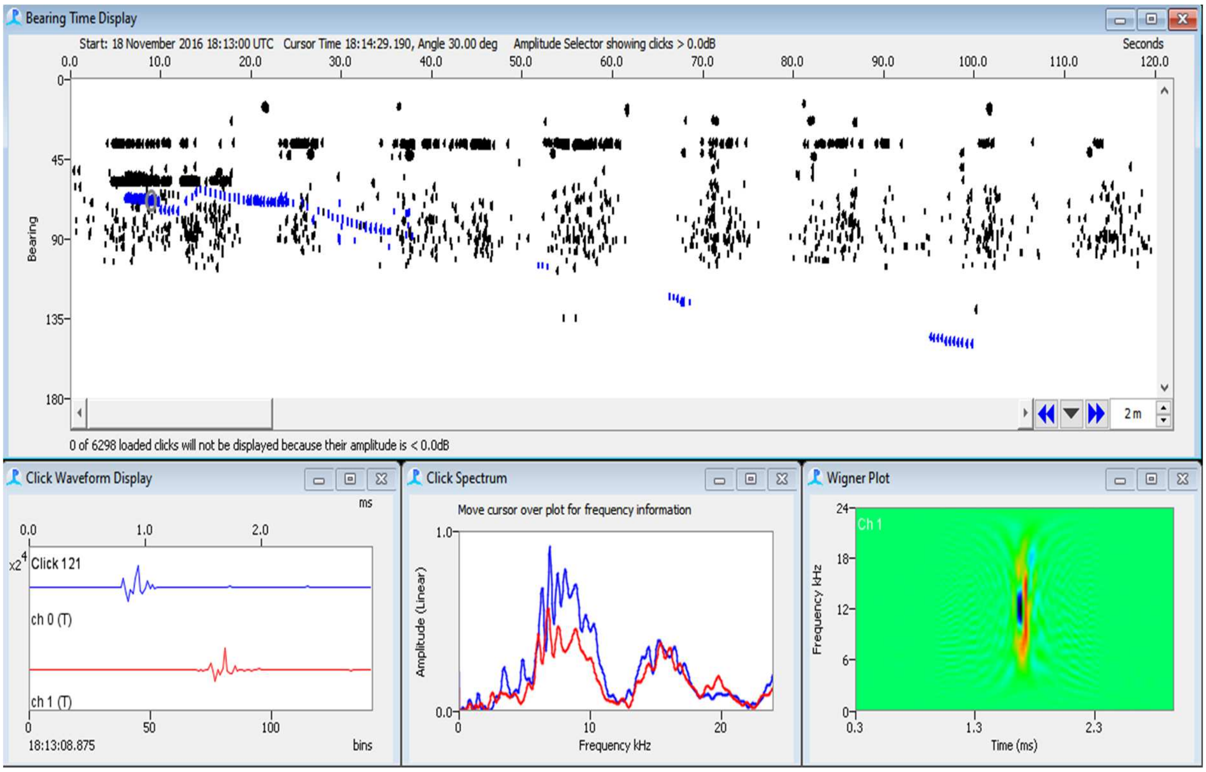


Fig. 3.4.4-3: PAMGuard screengrabs of Acoustic Detection 501. LF Click detector display showing delphinid click train, click waveform, spectrum and Wigner plot.

Where possible, acoustic detections were further processed offline, using PAMGaurd Viewer Mode and localised by TMA using four Distance Sampling models (Least Squares, 2D simplex optimisation, 3D simplex optimisation, Markov Chain Monte Carlo (MCMC) localisation). The model with the best relative Goodness-of-fit between observed data and theoretical is chosen as the localised position of the animal. While TMA works well for stationary or slow moving animals relative to vessel speed (e.g. foraging sperm whales or singing humpback whales), it is less effective for large groups of fast-moving, highly directional vocalising species (e.g. dolphins). While bearings of groups of dolphins can be measured using TOAD, range estimation is best achieved by correlating concurrent visual sightings, or (during darkness/poor visibility) by measuring the relative amplitude of the received signal (dB) using the headset, an amplitude radar display and spectrogram Gannier Scale value as a proxy for distance, while taking into consideration the background noise levels and local sound propagation conditions. While bearing estimates using TOAD and localisation techniques by TMA represent the best practice for tracking marine mammals acoustically, algorithmic and mathematical assumptions on hydrophone spacing, directionality and left/right ambiguity in the 2D plain, detection duration and manual selection of converged bearings inevitably induce some error in calculations associated with these techniques. Therefore, a conservative approach to localisation is applied during real-time monitoring and mitigation.

Acoustic monitoring was available 24 h, while monitoring by the PAM operator was focused during the hours of darkness and poor visibility. Acoustic encounters were defined as different detections when it could be certain they were different species or when they were separated by at least 20 min without an acoustic detection. PAM effort and source operation logs were maintained and updated on standard JNCC recording forms. Sound recordings (.wav format) and screengrabs (.png) of PAMGuard displays were archived to catalogue detection events where possible. An SQLITE3 database logged GPS positional data, hydrophone depth and detection events continually throughout the project. Data acquired by the LF and HF click detectors, whistle and moan detectors and clip generators were stored in binary format and made available for offline processing in PAMGuard Viewer.

Passive Acoustic Monitoring with Sercel's QuietSea ™ system

QuietSea ™ is a recently developed Marine Mammal Monitoring System designed by Sercel to detect the presence of marine mammals during seismic operations without towing additional PAM equipment behind the vessel. This streamer integrated system is operated as a peripheral device to Sercel's seismic data acquisition unit SEAL 428. QuietSea ™ uses two classes of data to cover a broadband frequency spectrum:

- the seismic data (using the SEAL interface) to detect vocalizations in the (low-frequency) seismic bandwidth from 10Hz to 200Hz with usual seismic sampling frequency of 2ms and
- (high-frequency) data, provided by additional QS streamer modules integrated within the Sercel seismic streamer (ALS,Sentinel, Sentinel RD and Sentinel MS) and other QS auxiliary modules to detect vocalizations in the bandwidth of 200Hz to 96kHz.

This potentially allows for enhanced marine mammal detection capabilities in a wide frequency listening range that covers a large variety of vocalizing cetacean species, i.e. Whistles - 200Hz-96kHz Auxiliaries module detection bandwidth and Click trains - 10Hz to 200Hz; Seismic Bandwidth sampling. Monitoring is conducted automatically and using localization algorithms. During the seismic operations of MSM59 for the high-frequency detections 4 QS inline streamer modules with a spacing of 150 m apart plus 2 QS aux modules close to the guns and towed in a distance of 5 m behind the sources were employed (see Fig. 3.4.4.-4).

Fig. 3.4.4-4: Layout of QuietSea in-water modules with the 4 high-frequency QS#1, QS#2 in each streamer and QSAux#1, QSAux#2 at each source (low frequency detections from 12 channels of each streamer)

For low-frequency detection 12 channels of streamer hydrophone groups in each streamer were selected separated 200 m to each other with a nearest offset of 188 m to the vessel and a farthest offset of 2398 m. The detailed position of each QS node with reference to the vessel was configured in an appropriate node file to be read in into the QS software.

Tab. 3.4.4-3: Coordinates of the QS high frequency modules with reference to the stern and center line of the vessel. (Coordinates are used for editing the QS node txt-file)

Period		**7.-11.11.2017**	**11.-21.11.2017**
QSAux distance between guns		25m	18m
QSAux distance to stern		55m	67.5m
QSAux coordinates	X1, X2	3.8, 28.5	20.0, 38.0
	Y1, Y2	-55.0, -55.0	-67.5, -67.5
	Z1, Z2	-3.9, -3.9	-3.9, -3.9
Centre of gun array	X,Y,Z	16.0, -55.0, -3.9	29.0, -67.5, -3.9
QS inline (see also Fig.3.4.2.4-2)		55m	67.5m
Centre Near Group -6.5m	X1, X2	0, 0, 60.0, 60.0	-8, -8, 42, 42
	Y1, Y2	-137.5,-188,-137.5,-188	-137.5,-188,-137.5,-188
	Z1, Z2	-6, -6, -6, -6	-6, -6, -6, -6

QuietSea software allows monitoring acoustic events in the high- and low-frequency range separately. The several sources of anthropogenic impulsive sounds of the vessel (produced by the airguns and echosounders) can be filtered out. All acoustic events are logged in a protocol and stored in a QuietSea database. The QuietSea system claims to localize a marine mammal when a vocalization is detected by several sensors. An event has to be recorded by at least three sensors to be used for a localization. During the full survey period a number of events were detected, but only one record could be verified as the vocalization of marine mammals. The database was subject to post-processing and re-analyzing.

Communication and reporting

The MMO/PAM Operator liaised directly with the seismic crew using handheld VHF radios on the appropriate working channel (Ch 8). Notification of the 60-minute pre-shoot watch for every soft start was provided by the seismic crew, along with an 'all clear' check immediately prior to starting the airguns. In the case of a mitigation event, the MMO/PAM Operator informed the seismic crew immediately that any delay or shut down of the source was required, and communication was maintained regarding animal movements and the subsequent resumption of operations. Throughout the survey, weekly reports were submitted to the chief scientist on board the vessel. The reports included information on sightings, environmental conditions, mitigation and seismic activity.

A full report on Marine Mammal Observations during cruise MSM59/2 was submitted by the client Seiche Ltd after the cruise. It is available at BGR on request as well as a report on a marine habitat analysis for the license area. This technical report on behalf of BGR was compiled by the Risk & Environmental Management Group of RPS Energy Ltd, London.

3.4.4.4 Results and conclusions for the distribution of marine mammals in the license area

Leaving Cape Town, two humpback whales were observed, along with many South African fur seals (Arctocephalus pusillus). During the transit to the survey area, an unidentified cetacean and a South African fur seal were recorded. On the transit to Port Louis, Mauritius, one unidentified baleen whale was observed.

Visual observations on survey site

During the seismic survey 157 h 29 min of dedicated observation for marine mammals were carried out by the MMOs, of which 61% of the observations were during periods when viewing conditions were favourable, i.e. with a slight state, low swell and good visibility. Visual observations were continued in all states of wind and sea state when the vessel was still in production and on the prospect. Of the time spent watching, the source was active for 113 h 28 min.

There were no visual sightings of marine mammals on the survey site during seismic profiling operations despite the near continuous visual monitoring effort carried out by the MMO's. This includes periods when the seismic source was both active and inactive and despite experiencing largely favourable sighting conditions. We can therefore make no comparisons as to the occurrence of marine mammals in the survey area in the presence or absence of seismic source sound emissions.

We may speculate that the remoteness of the survey location, which was in very deep waters relatively far from nutrient rich and productive coastal areas may be a decisive factor in the absence of marine mammals during the survey. It could also be argued that seasonal migration of larger offshore species to the Southern Ocean and Antarctic waters during the summer months may account for the absence of sightings during the survey. There are very few visual sightings data available to compare with around the survey area, and as such it is difficult to attribute definitive cause for the lack of sightings. Nonetheless, the absence of marine mammal sightings during the seismic survey is significant in that it may indicate a general low density of marine mammals in the mid-ocean ridge survey area during these months and should be noted for planning of future surveys in the region. It should also be noted that seismic profiling operations were carried out over a short period (two-week period between November 7th and November 21st), and the survey area was relatively small (3 km x 6 km grid). A more comprehensive assessment of marine mammal occurrence, by means of a dedicated environmental baseline survey which is expanded over a larger area, and repeated in multiple seasons to account for migration movement of marine species would provide valuable data and allow more reliable comparisons with seismic activities to be made.

Acoustic detections on survey site

There was one acoustic detection of a marine mammal observed by both the conventional PAM and QuietSea system during the survey (Table 3.4.4-4). This detection occurred during the hours of darkness, during a line turn while the seismic source was on reduced output (SPI 20 s). The acoustic detection was observed and logged in real-time and verified by offline analysis. Range and bearing of the detected animals were attempted in real-time but due to the relatively short duration of the detection location of the animal was not achieved with the PAM. Therefore, the PAM operator did not advise mitigation action. The acoustic event was also logged on the vessels backup PAM system 'QuietSea' (see Fig. 3.4.4.-5 and Table 3.4.4-4).

Table 3.4.4-4: Summary of acoustic detections

Detection method	First detection time in supervised mode (UTC)	First detection time in automated mode (UTC)	Last detection time (UTC)	Type of vocalisation
PAMGuard	18:13	-	18:13	Clicks & Whistles
QuietSea		18:13	18:15	Whistles

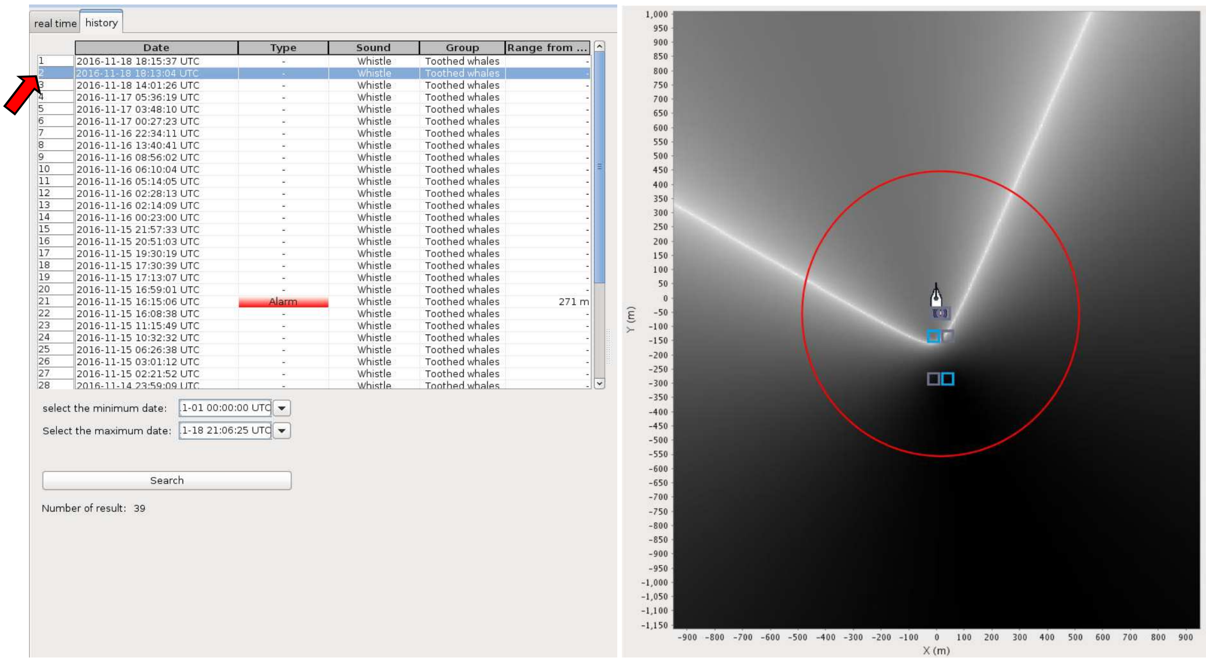


Fig.3.4.4.-5: QuietSea detection of the same PAM detection 501 at 18:13 UTC, 18-11-2016 and QS confidence angles of localization (note: event #21, which was categorized as an alarm in the QS history protocol was later identified as a false positive event during post-processing! Verification with PAM recordings still pending.)

This logged event (PAM detection 501 at 18:13 UTC, 18-11-2016) was later analysed in more detail. In real-time it was identified aurally from the headset and from the MF Spectrogram display to be delphinid FM whistles. (Upsweep, down sweep and concave whistles, 5 kHz to 10 kHz fundamental frequency) followed by a series of clicks, buzzes and burst pulses, detected from the MF spectrogram and from the LF Click Detector. Distinctive click trains from two animals were observed, lasting 90 seconds and travelling at an angle of 45° ahead of the hydrophone pair, heading in the opposite direction to 150° (left/right ambiguity). Individually selected clicks were analysed to confirm waveform and spectral characteristics were biological, noting the peak frequencies (8-20 kHz) and distinctive click waveform envelope. Whistles contours were manually selected using the clip generator tool and their bearings displayed on the map. Localisation of the animal was not possible using this method, however, due to there being an insufficient number of overlapping whistle bearings to indicate a fixed position of the animal(s) relative to the vessel track-line. Range was instead estimated by the amplitude of sounds detected over the headset and from the MF spectrogram, relative to the background noise at the time of detection.

Post processing in PAMGuard Viewer Mode allowed for a more in depth analysis of the detected LF Click train. All Clicks belonging to one click train (128 sub-detections) were carefully selected and labelled as an acoustic event (LFCT_501) and classified BroadBand_Delphinid_Clicks (BBDC). – (Fig.3.4.4-6)

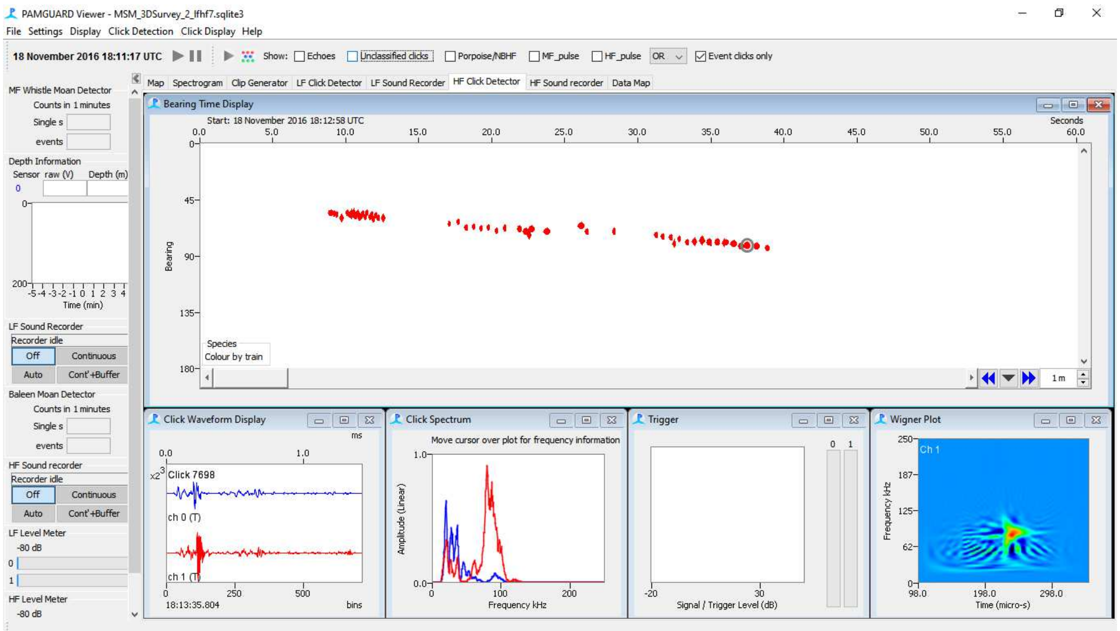


Fig.3.4.4.-6: HF click detector as viewed in PAMGuard Viewer Mode to manually inspect HF clicks of PAM detection 501 at 18:13 UTC, 18-11-2016

The LFCT_501 event was then localised by TMA using four Distance Sampling models (Least Squares, 2D simplex optimisation, 3D simplex optimisation, MCMC localisation). The 2D simplex optimisation model was selected (23°53.195' S,69°35.577' E, perp dist' 140.0±0.25m) as it provided the best fit between the observed data and the model (Chi² value=187512.2, p=1.0, error=0.3 m). While two distinct click trains were detected during the acoustic encounter, it cannot be assumed that all members of the group produced detectable vocalisations. We can therefore conclude that the minimum group size was two and that those group members belonged to a

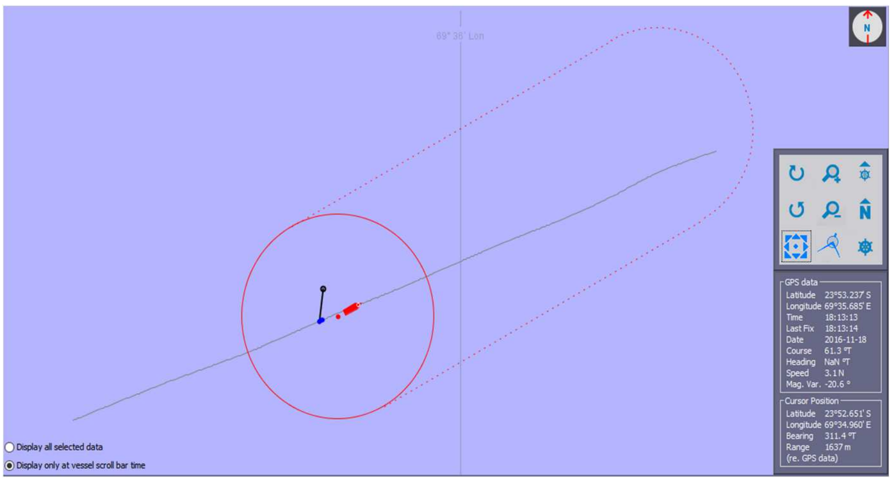


Fig.3.4.4.-7: PAMGuard map displaying localised position of animal relative to vessel track and mitigation zone

species within the Delphinidae family. The perpendicular distance of the localised animal to the vessel track was approximately 140 m (Fig. 3.4.4-7).

Accounting for uncertainty in the number and behaviour of non-vocalising animals within the group, direction of travel relative to the vessel and left/right ambiguity associated with the use of a towed inline hydrophone array, it is conservatively concluded that the detected animals passed within the 500 m mitigation zone during the acoustic encounter.

The same event was detected with QuietSea (Figs.3.4.4-5 and 3.4.4-8) and subsequently analysed for distance calculations.

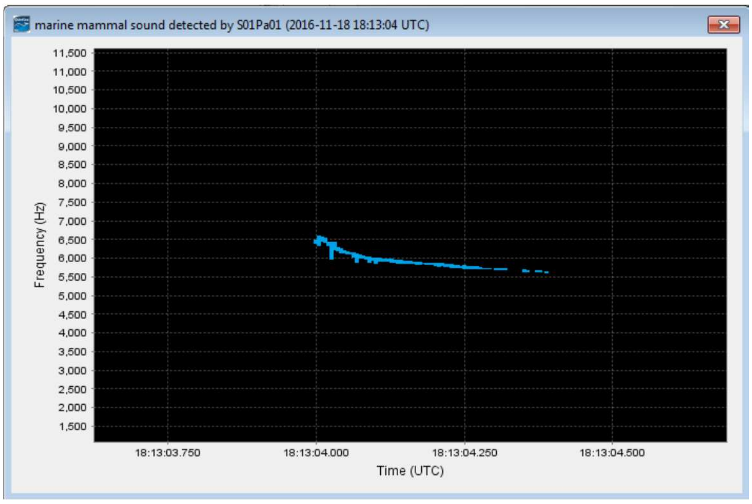


Fig.3.4.4.-8:
Single whistle detections on high-frequency moduls S01Pa01 and S02Pa02 at 18:13:04UTC

During the survey period we experienced several problems with the high-frequency QS modules. Due to connectivity problems and some other still unidentified reasons the two gun modules (QSAux#1, QSAux#2) and one high-frequency inline module of streamer 1 (QS#2) failed while surveying. This affected detections and localization of events. For the above event three QS modules were still sending their data to the server, but due to a meanwhile identified software bug

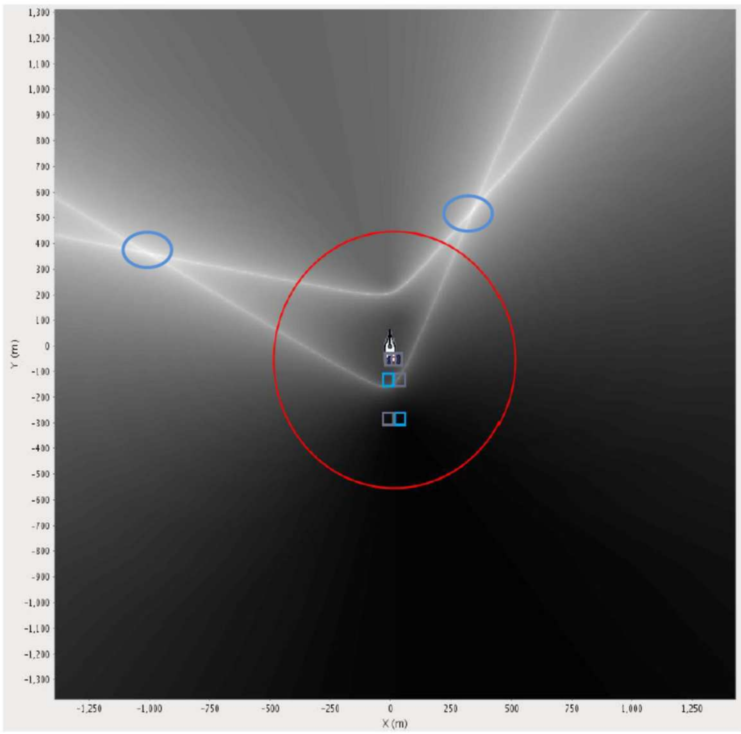


Fig.3.4.4.-9:
Results of target motion analysis from bearing results obtained at 18:13:04 and 18:15:38 UTC

the data of one of these sensors was faulty. Therefore, ranging the event by triangulation was not possible.

However, since the event was detected for several minutes distance estimation was done using a target motion analysis. Based on the bearing results of consecutive detections closest ranging was estimated outside the mitigation radius of 500 m (Fig. 3.4.4-9).

Summary of mitigation actions and conclusions

Marine mammals were detected acoustically on one occasion during the survey. Since the range of the animals could not be determined in real-time, no mitigation action was advised in resulting from their detection.

There was no instance of non-compliance with mitigation protocol to report during the survey. The 3D-seismic survey was completed by fully complying with all operational requirements of seismic activities underlined by the JNCC Seismic Guidelines (2010).

The occurrence of marine mammals during survey operations was minimal, with no visual sightings recorded and only one acoustic detection of marine mammals. Several marine mammals were however, seen during transit to and from the survey location, closer to continental margins and generally in areas where marine mammals are expected to be present during this time of year. Migration of offshore dwelling cetaceans occurs seasonally in the Indian Ocean and during the summer months many of these species are known to occur in the Southern Ocean and Antarctic waters, where food supply is rich at this time of the year. Despite the lack of observations, we cannot exclude the presence of less well studied cetaceans in a relatively remote and unknown area of the world's oceans. It is therefore responsible to ensure future ventures continue to adopt a 'best practice' approach when conducting geophysical exploration surveys, particularly those which emit anthropogenic sounds into the ocean.

While the spatial and temporal restrictions to our monitoring effort during this survey prevent the presentation of statistically significant comparisons of the effects of the seismic operations on marine mammals in the central Indian Ocean, the results presented here may still be useful indicators of likely marine mammal occurrence, and be considered for future survey planning.

For future deep water surveys where marine mammal monitoring accompanies 24 h seismic operations, it is recommended to maintain simultaneous MMO and PAM effort, to allow for detection of deep-diving species and to visually verify acoustic detections. This can improve species identification and improve effectiveness of PAM and QuietSea localisation techniques.

References

Barnicoat, S. and Scala, L., 2016: Marine Mammal Observations, Final Project Report: MMO & PAM, Cruise MSM59/2: Project INDEX 2016_2, Leg 1, FS Maria S. Merian, 3D & OBS Seismic Survey, Cape Town 28.10.2016 – Port Louis 26.11.2016.- Bioscience Group, Seiche Ltd.- Internal Report to BGR, 2016, 27 pp.

JNCC (2010): Guidelines for minimising the risk of injury and disturbance to marine mammals from seismic surveys. - Joint Nature Conservation Committee, Aberdeen, UK, Aug. 2010, 17 pp.

RPS Energy, 2017: Indian Ocean – Habitat Analysis, Rev. 03.- RPS Energy Risk & Environmental Management.- Internal Report to BGR, 2016, 91 pp.

3.5 Preliminary results

The following 3D seismic data have been acquired during MSM59/1 in total:

- 115 3D seismic lines with E-W azimuth and a total line length of 806,2 km
- 10 3D seismic lines with N-S azimuth and a total line length of 71,8 km

These 878,0 line kilometer cover the 3D seismic survey area with a line spacing of 50 m and provide a 3D seismic dataset allowing a binning cell size of 6.25 m inline and 12.5 m crossline. For location of the individual 3D seismic survey lines see Fig. 3.5.-1.

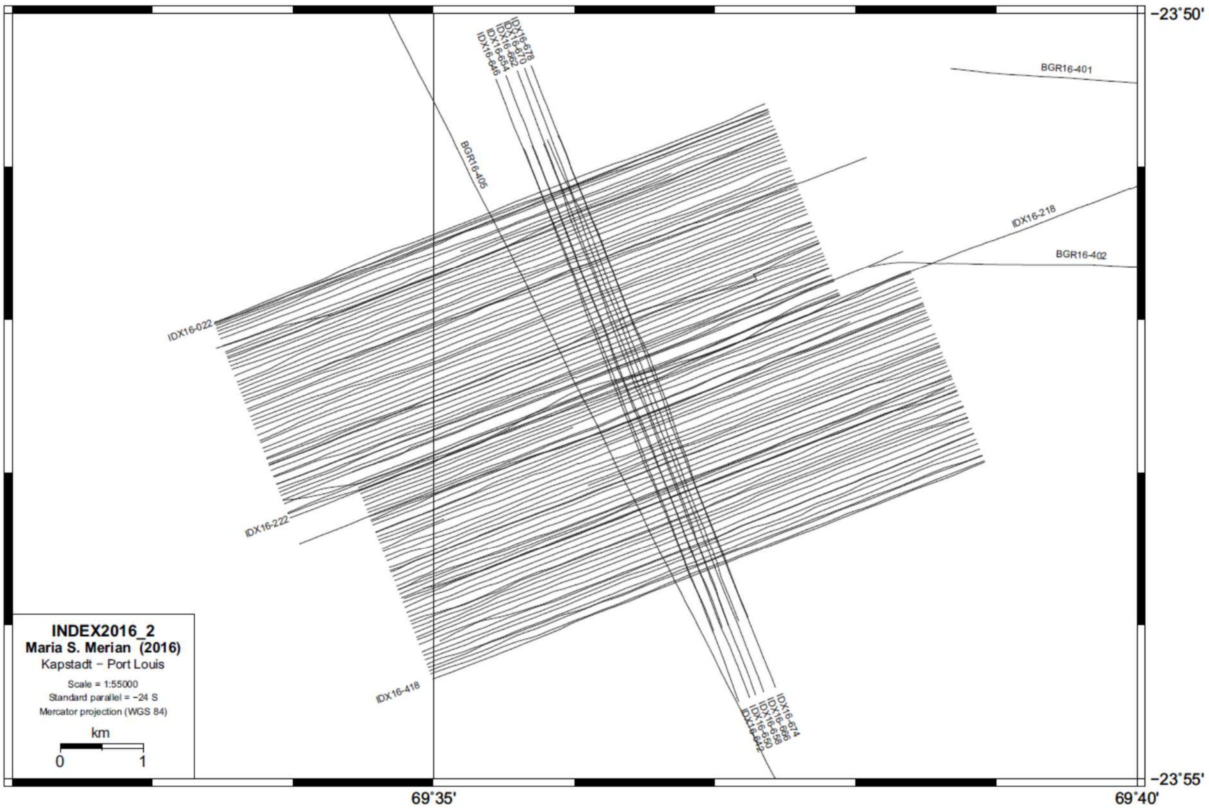


Fig.3.5-1: Location of the acquired 115 seismic lines with E-W orientation and 10 seismic lines with N-S orientation

The 3D data set is subject to a comprehensive and time consuming processing. In an initial stage, navigation data will be post-processed to improve all positions of field data. In a next step, 3D binning is the prerequisite for subsequent processing of the seismic data.

A first 2D pre-processing of the seismic data was done onboard for QC purposes. Based on these very preliminary results of selected lines it can be concluded, that the seismic data are able to image the subbottom of the area with a depth penetration of possibly 0.5 s TWT. Figure 3.5-2 gives an example of a 2D processed single line section. Figure 3.5.-3 illustrates the 3D potential of the seismic data. It shows an inline and crossline section processed in 2D, overlayed by the bathymetric data.

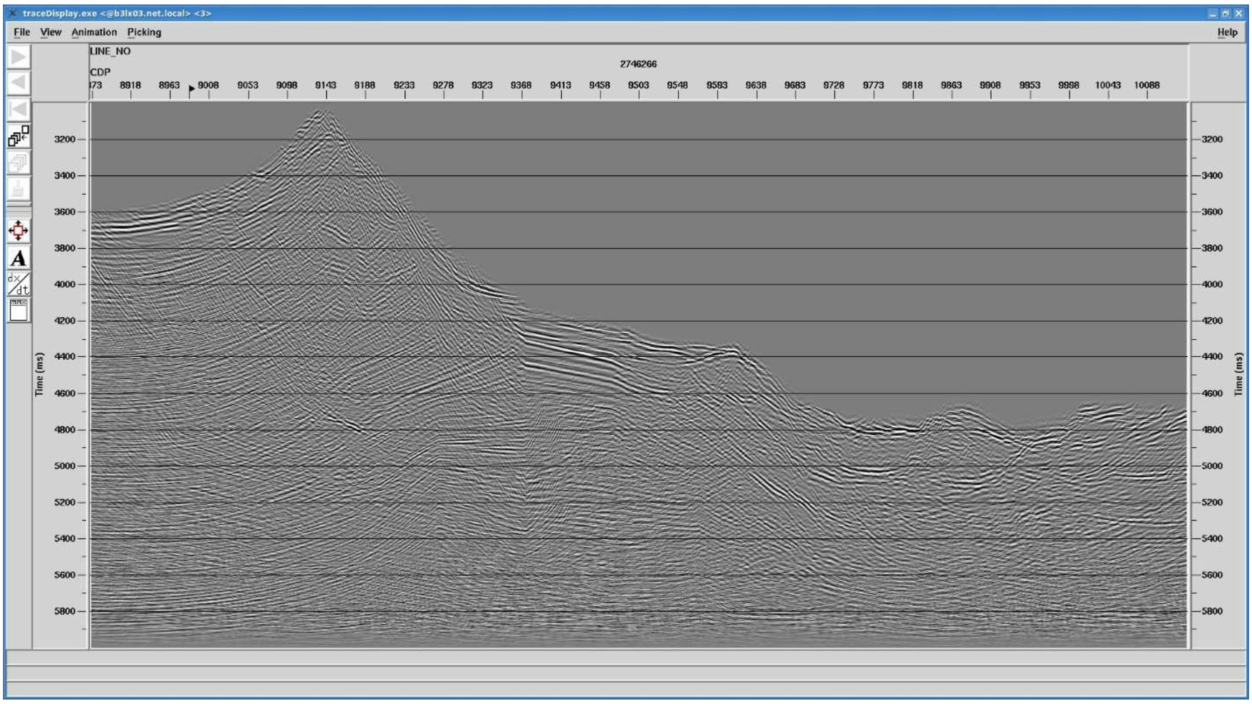


Fig.3.5-2: Screenshot of a 2D processed seismic line with E-W orientation (E: left side, W right side)

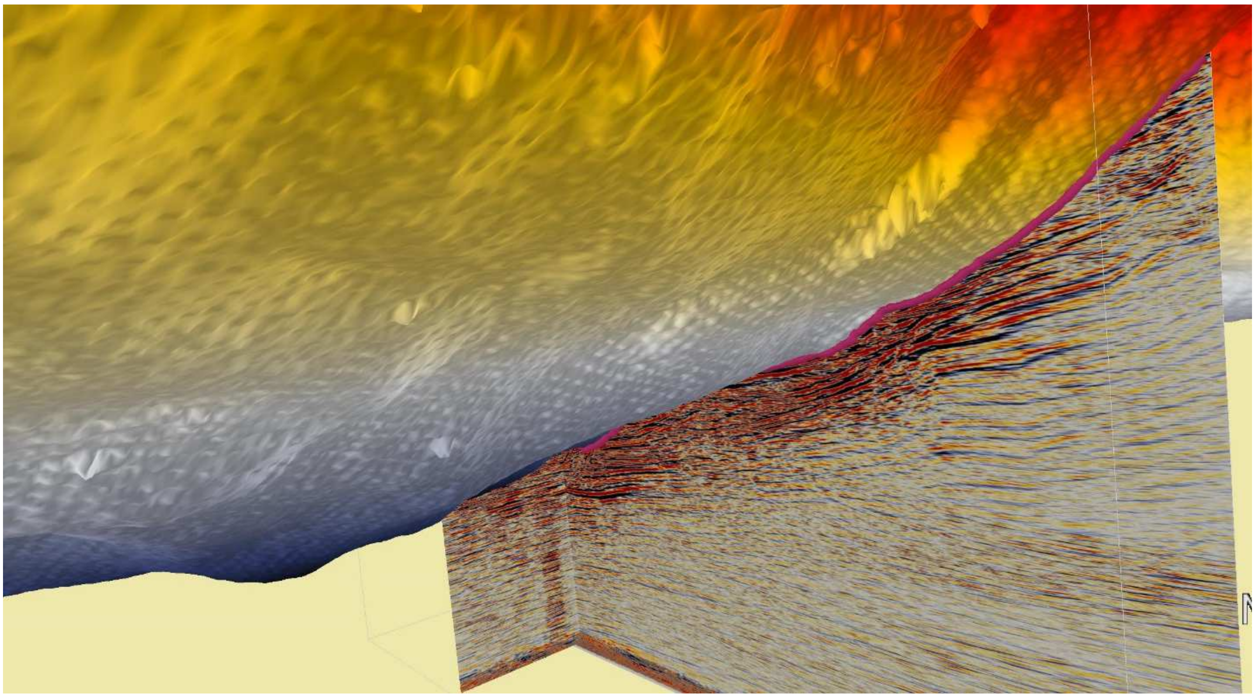


Fig.3.5-3: 3D visualisation of a 2D processed inline and crossline seismic profile overlayed with the previously acquired high-resolution bathymetric data of the survey area.

In addition to the seismic data acquisition within the predefined 3D survey area, wide angle seismic data was acquired along a few extended lines. These profiles are orientated parallel and orthogonal to the ridge axis. They were aimed to cross the locations of the pre-deployed ocean bottom seismometers. Partly, the line shooting was conducted using the opportunity of a longer re-approach to the 3D survey area after technical problems during normal seismic operation. One ridge-parallel wide-angle seismic line crossing the hydrothermal field areas was acquired at the end of the survey operations. For location of all wide-angle seismic lines see Fig. 5.3-4. The total line length of the 5 wide angle seismic lines is 107.0 km.

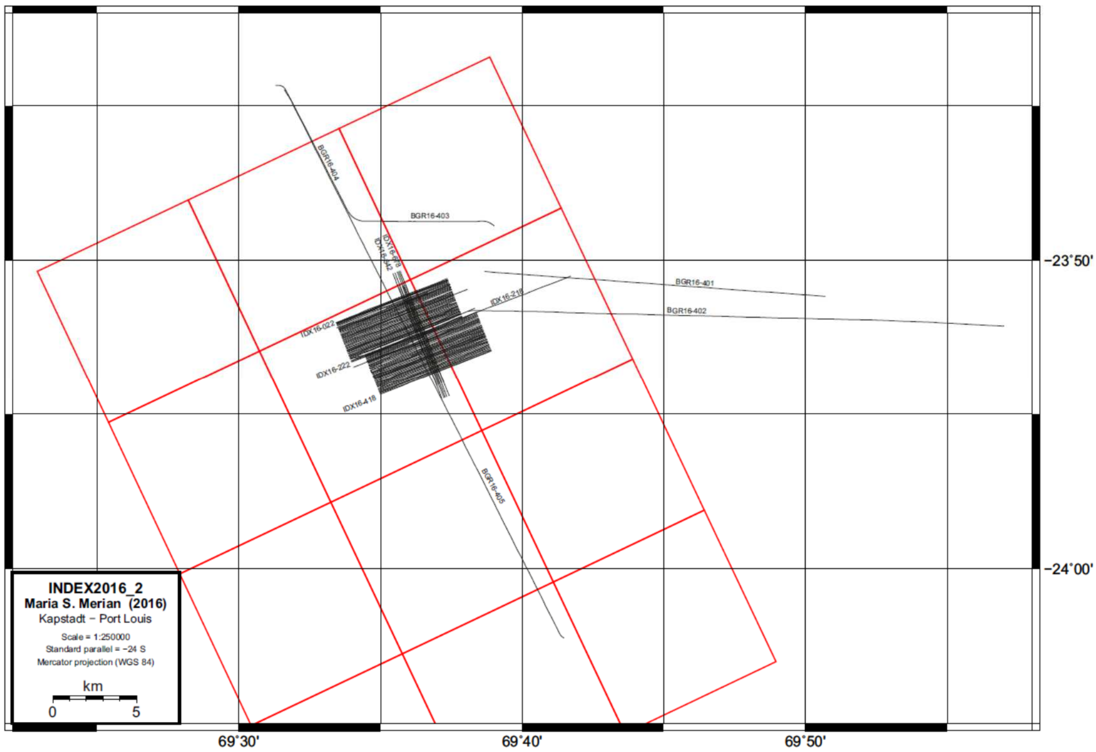


Fig.3.5-4: Location of wide-angle seismic lines with respect to the 3D seismic survey area. Red lines mark the individual squares of 10x10 km forming cluster 4 of the license area.

After the safe recovery of all nine OBS we were able to read out the data of 8 OBS. Because of an error message during read out procedure it was not possible to read the data of OBS 20 (mescopy.cpp:160: cannot read from input file 151116). There was no way to download this corrupted data neither at home. However, the data of the remaining eight OBS showed a good data quality with reflections and refractions within the hydrophone channel (Fig. 3.5-5) and the geophone channel (Fig. 3.5-6). Despite the very low energy and high frequencies for wide angle seismics clear arrivals of refracted energy can be observed ahead of the direct waves.

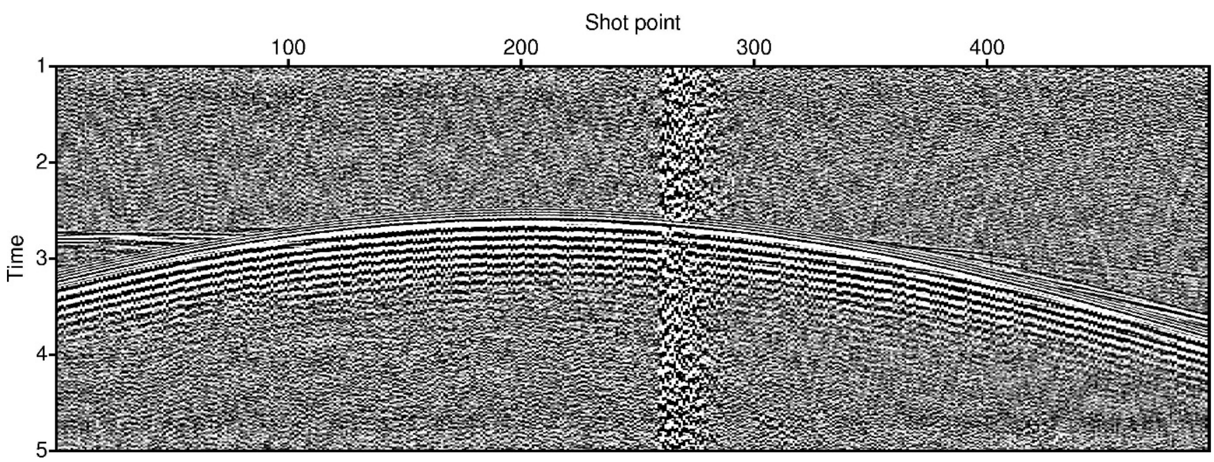


Fig.3.5-5: Data example for profile IDX16-034. The whole profile comprises 495 shot points, the first shot point is situated in the east. For OBS 21, the hydrophone channel is shown.

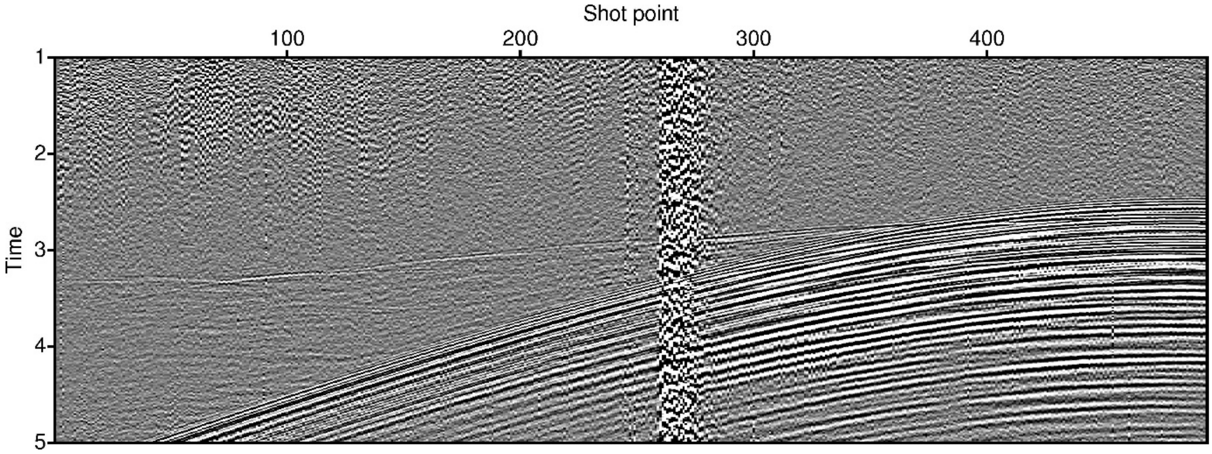


Fig.3.5-6: Data examples for profile IDX16-034. For OBS 9 the vertical component is displayed. Both recordings clearly show refracted energy, arriving ahead of the direct wave.

During shooting for the calibration test prior to the seismic survey, 6 lines with a total line length of 31 km with varying distance to the recording hydrophones were measured. Results are presented and discussed in Chapter 3.4.1.

All seismic shooting was conducted according to the JNCC rules and the regulations to minimize the sound impact in German national waters issued by the German Hydrographic Survey (BSH). As an add-on, the database of the marine mammal monitoring program which was fed by the visual observations of the MMO, the PAM and QuietSea data provides opportunities for further environmental assessment studies in the German license area.

3.6 Data storage and access

The data acquired under the license contract with the International Seabed Authority are confidential according to regulations 38 and 39 of the “Regulations on prospecting and exploration for polymetallic sulphides in the Area” (BReg, 2015). This applies to all prospecting relevant data that might be of value for resource estimations. The only exceptions are environmental data and information describing the status of the marine ecosystems. According to this precondition the acquired seismic data has to undergo an evaluation process for its use in volumetric calculations prior to any decision for open access.

In contrary, all data relating to the protection and preservation of the marine environment, in particular those from environmental monitoring programs, shall not be considered confidential following the above regulations. This applied to all data acquired within the marine mammal monitoring program during INDEX2016_2. The data, documentations and reports connected to chapters 3.4.1 and 3.4.4 are unrestricted and available at BGR on request. All data will be archived in the BGR’s long-term databases of the marine seismics group according to BGR standards.

References

BReg: Verordnung über Bestimmungen über die Prospektion und Exploration polymetallischer Sulphide im Gebiet vom 6. Februar 2015.- Bundesgesetzblatt Jahrgang 2015 Teil II Nr. 5, ausgegeben zu Bonn am 13. Februar 2015

3.7 Station List MSM59/1

3D seismic lines in time sorted and sequential order

Station No.	Date	Time [UTC]	SOL Lat	SOL Lon	Time	EOL	EOL	Profile
MSM59/729-2	09.11.2016	18:18	23° 50,64' S	69° 37,32' E	19:16	23° 52,04' S	69° 33,38' E	IDX16-022
M59/729-2	09.11.2016	20:20	23° 53,79' S	69° 34,89' E	21:28	23° 52,32' S	69° 39,01' E	IDX16-338
MSM59/729-2	09.11.2016	22:46	23° 50,63' S	69° 37,39' E	23:44	23° 52,03' S	69° 33,47' E	IDX16-026
MSM59/729-2	10.11.2016	0:48	23° 53,65' S	69° 34,66' E	1:47	23° 52,23' S	69° 38,65' E	IDX16-306
MSM59/729-2	10.11.2016	22:44	23° 50,68' S	69° 37,39' E	23:42	23° 52,08' S	69° 33,46' E	IDX16-030
MSM59/729-2	11.11.2016	0:33	23° 53,40' S	69° 34,54' E	1:32	23° 51,98' S	69° 38,53' E	IDX16-266
MSM59/729-2	11.11.2016	2:18	23° 50,70' S	69° 37,41' E	3:17	23° 52,11' S	69° 33,42' E	IDX16-034
MSM59/729-2	11.11.2016	4:00	23° 53,19' S	69° 34,48' E	5:08	23° 51,58' S	69° 39,07' E	IDX16-234
MSM59/729-2	11.11.2016	5:55	23° 50,75' S	69° 37,37' E	6:53	23° 52,13' S	69° 33,46' E	IDX16-038
MSM59/729-2	11.11.2016	7:37	23° 53,22' S	69° 34,48' E	8:36	23° 51,81' S	69° 38,45' E	IDX16-238
MSM59/729-2	11.11.2016	9:55	23° 50,75' S	69° 37,42' E	10:53	23° 52,16' S	69° 33,48' E	IDX16-042
MSM59/729-2	11.11.2016	11:07	23° 52,85' S	69° 32,93' E	12:33	23° 51,80' S	69° 38,47' E	IDX16-242
MSM59/729-2	11.11.2016	13:13	23° 50,73' S	69° 37,57' E	14:13	23° 52,17' S	69° 33,52' E	IDX16-046
MSM59/729-2	11.11.2016	15:00	23° 53,76' S	69° 34,90' E	15:57	23° 52,43' S	69° 38,73' E	IDX16-338
MSM59/729-2	11.11.2016	16:52	23° 50,80' S	69° 37,46' E	17:51	23° 52,23' S	69° 33,48' E	IDX16-050
MSM59/729-2	11.11.2016	18:30	23° 53,27' S	69° 34,52' E	19:28	23° 51,85' S	69° 38,49' E	IDX16-246
MSM59/729-2	11.11.2016	20:07	23° 50,82' S	69° 37,46' E	21:06	23° 52,24' S	69° 33,49' E	IDX16-054
MSM59/729-2	11.11.2016	21:49	23° 53,33' S	69° 34,53' E	22:47	23° 51,92' S	69° 38,46' E	IDX16-254
MSM59/729-2	11.11.2016	23:28	23° 50,86' S	69° 37,44' E	0:26	23° 52,25' S	69° 33,54' E	IDX16-058
MSM59/729-2	12.11.2016	1:08	23° 53,35' S	69° 34,55' E	2:07	23° 51,92' S	69° 38,54' E	IDX16-258
MSM59/729-2	12.11.2016	2:49	23° 50,87' S	69° 37,51' E	3:47	23° 52,27' S	69° 33,58' E	IDX16-062
MSM59/729-2	12.11.2016	4:36	23° 53,40' S	69° 34,57' E	5:35	23° 51,93' S	69° 38,56' E	IDX16-262
MSM59/729-2	12.11.2016	6:44	23° 50,90' S	69° 37,50' E	7:42	23° 52,29' S	69° 33,59' E	IDX16-066
MSM59/729-2	12.11.2016	8:26	23° 53,42' S	69° 34,59' E	9:25	23° 51,99' S	69° 38,56' E	IDX16-270
MSM59/729-2	12.11.2016	10:06	23° 50,93' S	69° 37,50' E	11:05	23° 52,34' S	69° 33,51' E	IDX16-070
MSM59/729-2	12.11.2016	11:50	23° 53,46' S	69° 34,55' E	12:50	23° 52,01' S	69° 38,60' E	IDX16-274
MSM59/729-2	12.11.2016	13:37	23° 50,95' S	69° 37,52' E	14:36	23° 52,39' S	69° 33,52' E	IDX16-074
MSM59/729-2	12.11.2016	15:30	23° 53,47' S	69° 34,57' E	16:29	23° 52,06' S	69° 38,56' E	IDX16-278
MSM59/729-2	12.11.2016	17:18	23° 50,79' S	69° 37,43' E	18:16	23° 52,25' S	69° 33,52' E	IDX16-050
MSM59/729-2	12.11.2016	18:58	23° 53,29' S	69° 34,53' E	19:57	23° 51,88' S	69° 38,52' E	IDX16-250
MSM59/729-2	12.11.2016	20:39	23° 50,78' S	69° 37,44' E	21:36	23° 52,19' S	69° 33,44' E	IDX16-046
MSM59/729-2	12.11.2016	22:22	23° 53,18' S	69° 34,46' E	23:21	23° 51,76' S	69° 38,41' E	IDX16-230
MSM59/729-2	13.11.2016	0:03	23° 50,67' S	69° 37,32' E	1:00	23° 52,06' S	69° 33,46' E	IDX16-026
MSM59/729-2	13.11.2016	1:50	23° 53,14' S	69° 34,47' E	2:48	23° 51,74' S	69° 38,39' E	IDX16-226
MSM59/729-2	13.11.2016	3:47	23° 50,63' S	69° 37,38' E	4:46	23° 52,05' S	69° 33,39' E	IDX16-022
MSM59/729-2	13.11.2016	5:29	23° 53,12' S	69° 34,45' E	6:28	23° 51,68' S	69° 38,44' E	IDX16-222
MSM59/729-2	13.11.2016	7:13	23° 50,57' S	69° 37,39' E	8:12	23° 52,04' S	69° 33,39' E	IDX16-022
MSM59/729-2	13.11.2016	9:19	23° 54,35' S	69° 34,99' E	10:17	23° 52,93' S	69° 38,91' E	IDX16-022
MSM59/729-2	13.11.2016	11:41	23° 50,48' S	69° 41,80' E	13:36	23° 53,25' S	69° 34,01' E	IDX16-218

MSM59/729-2	13.11.2016	14:22	23° 54,33' S	69° 34,95' E	15:20	23° 52,94' S	69° 38,87' E	IDX16-414
MSM59/729-2	13.11.2016	16:10	23° 51,84' S	69° 37,88' E	17:09	23° 53,29' S	69° 33,89' E	IDX16-214
MSM59/729-2	13.11.2016	17:49	23° 54,29' S	69° 34,98' E	18:47	23° 52,90' S	69° 38,87' E	IDX16-410
MSM59/729-2	13.11.2016	19:37	23° 51,83' S	69° 37,88' E	20:33	23° 53,15' S	69° 34,09' E	IDX16-210
MSM59/729-2	13.11.2016	21:19	23° 54,28' S	69° 34,95' E	22:17	23° 52,90' S	69° 38,87' E	IDX16-406
MSM59/729-2	13.11.2016	23:01	23° 51,79' S	69° 37,89' E	23:59	23° 53,19' S	69° 33,87' E	IDX16-206
MSM59/729-2	14.11.2016	0:47	23° 54,26' S	69° 34,93' E	1:45	23° 52,86' S	69° 38,83' E	IDX16-402
MSM59/729-2	14.11.2016	2:34	23° 51,73' S	69° 37,89' E	3:32	23° 53,16' S	69° 33,98' E	IDX16-202
MSM59/729-3	15.11.2016	9:51	23° 54,22' S	69° 34,94' E	10:49	23° 52,80' S	69° 38,89' E	IDX16-398
MSM59/729-3	15.11.2016	11:33	23° 51,72' S	69° 37,80' E	12:31	23° 53,14' S	69° 33,88' E	IDX16-194
MSM59/729-3	15.11.2016	13:12	23° 54,22' S	69° 34,85' E	14:11	23° 52,80' S	69° 38,82' E	IDX16-394
MSM59/729-3	15.11.2016	14:55	23° 51,65' S	69° 37,83' E	15:54	23° 53,06' S	69° 33,92' E	IDX16-190
MSM59/729-3	15.11.2016	16:41	23° 54,19' S	69° 34,88' E	17:41	23° 52,73' S	69° 38,89' E	IDX16-390
MSM59/729-3	15.11.2016	18:25	23° 51,67' S	69° 37,79' E	19:23	23° 53,08' S	69° 33,87' E	IDX16-186
MSM59/729-3	15.11.2016	20:11	23° 54,10' S	69° 35,03' E	21:08	23° 52,73' S	69° 38,87' E	IDX16-386
MSM59/729-3	15.11.2016	21:51	23° 51,64' S	69° 37,80' E	22:50	23° 53,04' S	69° 33,84' E	IDX16-182
MSM59/729-3	15.11.2016	23:33	23° 54,13' S	69° 34,86' E	0:31	23° 52,73' S	69° 38,78' E	IDX16-382
MSM59/729-3	16.11.2016	1:17	23° 51,58' S	69° 37,84' E	2:17	23° 53,04' S	69° 33,81' E	IDX16-178
MSM59/729-3	16.11.2016	3:00	23° 54,10' S	69° 34,86' E	3:58	23° 52,67' S	69° 38,81' E	IDX16-378
MSM59/729-3	16.11.2016	4:37	23° 51,57' S	69° 37,81' E	5:33	23° 52,96' S	69° 33,91' E	IDX16-174
MSM59/729-3	16.11.2016	6:37	23° 54,08' S	69° 34,86' E	7:34	23° 52,66' S	69° 38,73' E	IDX16-374
MSM59/729-3	16.11.2016	8:16	23° 51,56' S	69° 37,78' E	9:15	23° 52,97' S	69° 33,78' E	IDX16-170
MSM59/729-3	16.11.2016	10:00	23° 54,06' S	69° 34,83' E	11:01	23° 52,60' S	69° 38,95' E	IDX16-370
MSM59/729-3	16.11.2016	11:46	23° 51,52' S	69° 37,78' E	12:45	23° 52,93' S	69° 33,86' E	IDX16-166
MSM59/729-3	16.11.2016	13:31	23° 54,02' S	69° 34,83' E	14:30	23° 52,60' S	69° 38,82' E	IDX16-366
MSM59/729-3	16.11.2016	15:13	23° 51,50' S	69° 37,75' E	16:12	23° 52,93' S	69° 33,77' E	IDX16-162
MSM59/729-3	16.11.2016	16:56	23° 54,00' S	69° 34,82' E	17:56	23° 52,56' S	69° 38,79' E	IDX16-362
MSM59/729-3	16.11.2016	18:37	23° 51,48' S	69° 37,74' E	19:36	23° 52,92' S	69° 33,77' E	IDX16-158
MSM59/729-3	16.11.2016	20:19	23° 53,97' S	69° 34,85' E	21:17	23° 52,57' S	69° 38,76' E	IDX16-358
MSM59/729-3	16.11.2016	22:01	23° 51,45' S	69° 37,74' E	23:00	23° 52,87' S	69° 33,78' E	IDX16-154
MSM59/729-3	16.11.2016	23:45	23° 53,94' S	69° 34,82' E	0:43	23° 52,54' S	69° 38,71' E	IDX16-354
MSM59/729-3	17.11.2016	1:28	23° 51,40' S	69° 37,76' E	2:26	23° 52,83' S	69° 33,80' E	IDX16-150
MSM59/729-3	17.11.2016	3:10	23° 53,93' S	69° 34,78' E	4:09	23° 52,48' S	69° 38,76' E	IDX16-350
MSM59/729-3	17.11.2016	4:51	23° 51,39' S	69° 37,68' E	5:47	23° 52,78' S	69° 33,84' E	IDX16-146
MSM59/729-3	17.11.2016	6:33	23° 53,90' S	69° 34,75' E	7:31	23° 52,47' S	69° 38,71' E	IDX16-346
MSM59/729-3	17.11.2016	8:12	23° 51,37' S	69° 37,67' E	9:11	23° 52,82' S	69° 33,68' E	IDX16-142
MSM59/729-3	17.11.2016	9:58	23° 53,85' S	69° 34,78' E	10:56	23° 52,48' S	69° 38,68' E	IDX16-342
MSM59/729-3	17.11.2016	11:44	23° 51,32' S	69° 37,72' E	12:43	23° 52,74' S	69° 33,79' E	IDX16-138
MSM59/729-3	17.11.2016	13:28	23° 53,82' S	69° 34,76' E	14:25	23° 52,43' S	69° 38,66' E	IDX16-334
MSM59/729-3	17.11.2016	15:09	23° 51,28' S	69° 37,71' E	16:08	23° 52,71' S	69° 33,73' E	IDX16-130
MSM59/729-3	17.11.2016	16:51	23° 53,81' S	69° 34,72' E	17:48	23° 52,41' S	69° 38,62' E	IDX16-330
MSM59/729-3	17.11.2016	18:35	23° 51,27' S	69° 37,67' E	19:34	23° 52,69' S	69° 33,71' E	IDX16-126
MSM59/729-3	17.11.2016	20:18	23° 53,77' S	69° 34,72' E	21:16	23° 52,37' S	69° 38,65' E	IDX16-326
MSM59/729-3	17.11.2016	22:01	23° 51,23' S	69° 37,70' E	23:00	23° 52,66' S	69° 33,71' E	IDX16-122
MSM59/729-3	17.11.2016	23:43	23° 53,75' S	69° 34,73' E	0:40	23° 52,35' S	69° 38,63' E	IDX16-322
MSM59/729-3	18.11.2016	1:27	23° 51,22' S	69° 37,65' E	2:23	23° 52,61' S	69° 33,76' E	IDX16-118
MSM59/729-3	18.11.2016	3:07	23° 53,72' S	69° 34,68' E	4:06	23° 52,28' S	69° 38,70' E	IDX16-318

MSM59/729-3	18.11.2016	4:50	23° 51,20' S	69° 37,63' E	5:48	23° 52,60' S	69° 33,69' E	IDX16-114
MSM59/729-3	18.11.2016	6:35	23° 53,66' S	69° 34,76' E	7:31	23° 52,30' S	69° 38,60' E	IDX16-314
MSM59/729-3	18.11.2016	8:16	23° 51,17' S	69° 37,63' E	9:14	23° 52,57' S	69° 33,72' E	IDX16-110
MSM59/729-3	18.11.2016	9:57	23° 53,66' S	69° 34,68' E	10:56	23° 52,27' S	69° 38,61' E	IDX16-310
MSM59/729-3	18.11.2016	11:42	23° 51,15' S	69° 37,59' E	12:40	23° 52,53' S	69° 33,69' E	IDX16-106
MSM59/729-3	18.11.2016	13:27	23° 53,62' S	69° 34,68' E	14:24	23° 52,23' S	69° 38,58' E	IDX16-302
MSM59/729-3	18.11.2016	15:05	23° 51,11' S	69° 37,64' E	16:05	23° 52,53' S	69° 33,63' E	IDX16-102
MSM59/729-3	18.11.2016	18:19	23° 53,10' S	69° 36,06' E	18:58	23° 52,16' S	69° 38,67' E	IDX16-298
MSM59/729-3	18.11.2016	19:40	23° 51,10' S	69° 37,59' E	20:38	23° 52,50' S	69° 33,65' E	IDX16-098
MSM59/729-3	18.11.2016	21:20	23° 53,60' S	69° 34,60' E	22:18	23° 52,21' S	69° 38,47' E	IDX16-294
MSM59/729-3	18.11.2016	23:01	23° 51,07' S	69° 37,59' E	0:00	23° 52,48' S	69° 33,63' E	IDX16-094
MSM59/729-3	19.11.2016	0:45	23° 53,56' S	69° 34,64' E	1:43	23° 52,16' S	69° 38,58' E	IDX16-290
MSM59/729-3	19.11.2016	2:29	23° 51,03' S	69° 37,61' E	3:27	23° 52,45' S	69° 33,62' E	IDX16-090
MSM59/729-3	19.11.2016	4:11	23° 53,51' S	69° 34,64' E	5:09	23° 52,12' S	69° 38,57' E	IDX16-286
MSM59/729-3	19.11.2016	5:51	23° 51,03' S	69° 37,52' E	6:49	23° 52,43' S	69° 33,61' E	IDX16-094
MSM59/729-3	19.11.2016	7:35	23° 53,52' S	69° 34,58' E	8:33	23° 52,13' S	69° 38,47' E	IDX16-282
MSM59/729-3	19.11.2016	9:16	23° 50,99' S	69° 37,58' E	10:14	23° 52,38' S	69° 33,68' E	IDX16-082
MSM59/729-3	19.11.2016	12:16	23° 53,99' S	69° 37,25' E	13:15	23° 50,32' S	69° 35,68' E	IDX16-678
MSM59/729-3	19.11.2016	14:51	23° 53,11' S	69° 34,45' E	15:50	23° 51,67' S	69° 38,42' E	IDX16-222
MSM59/729-3	19.11.2016	17:16	23° 50,78' S	69° 35,87' E	18:15	23° 54,44' S	69° 37,44' E	IDX16-674
MSM59/729-3	19.11.2016	19:50	23° 51,49' S	69° 37,74' E	20:48	23° 52,95' S	69° 33,84' E	IDX16-162
MSM59/729-3	19.11.2016	20:49	23° 52,97' S	69° 33,77' E	23:41	23° 50,41' S	69° 35,67' E	IDX16-670
MSM59/729-3	20.11.2016	1:22	23° 53,32' S	69° 34,53' E	2:20	23° 51,91' S	69° 38,44' E	IDX16-254
MSM59/729-3	20.11.2016	3:55	23° 50,84' S	69° 35,81' E	4:53	23° 54,45' S	69° 37,35' E	IDX16-666
MSM59/729-3	20.11.2016	6:18	23° 52,01' S	69° 37,97' E	7:16	23° 53,47' S	69° 34,04' E	IDX16-242
MSM59/729-3	20.11.2016	8:52	23° 54,02' S	69° 37,10' E	9:50	23° 50,40' S	69° 35,60' E	IDX16-662
MSM59/729-3	20.11.2016	11:23	23° 53,03' S	69° 34,36' E	12:22	23° 51,56' S	69° 38,31' E	IDX16-206
MSM59/729-3	20.11.2016	13:51	23° 50,90' S	69° 35,80' E	14:47	23° 54,41' S	69° 37,27' E	IDX16-658
MSM59/729-3	20.11.2016	16:20	23° 51,85' S	69° 37,88' E	17:18	23° 53,29' S	69° 34,00' E	IDX16-222
MSM59/729-3	20.11.2016	18:52	23° 54,02' S	69° 37,05' E	19:50	23° 50,40' S	69° 35,51' E	IDX16-654
MSM59/729-3	20.11.2016	21:20	23° 52,35' S	69° 34,09' E	22:19	23° 50,96' S	69° 38,01' E	IDX16-098
MSM59/729-3	20.11.2016	23:43	23° 50,78' S	69° 35,66' E	0:41	23° 54,41' S	69° 37,22' E	IDX16-650
MSM59/729-3	21.11.2016	2:20	23° 51,69' S	69° 37,88' E	3:19	23° 53,10' S	69° 33,91' E	IDX16-194
MSM59/729-3	21.11.2016	5:00	23° 54,07' S	69° 37,00' E	5:59	23° 50,42' S	69° 35,44' E	IDX16-646
MSM59/729-3	21.11.2016	7:46	23° 53,78' S	69° 34,71' E	8:44	23° 52,40' S	69° 38,61' E	IDX16-326
MSM59/729-3	21.11.2016	10:22	23° 50,81' S	69° 35,61' E	11:21	23° 54,43' S	69° 37,14' E	IDX16-642

Line	Seq.	Date	Start	First SP	Lat	Lon	End	Last SP	Lat	Lon	Dist km	Course
3D profiles (West - East)												
IDX16-022	1000	09.11.2016	18:17:14	1501	23° 50.623' S	69° 37.376' E	19:15:10	1007	23° 52.019' S	69° 33.439' E	7,15	248,8
IDX16-022	1034	13.11.2016	03:47:00	1435	23° 50.627' S	69° 37.371' E	04:45:13	941	23° 52.032' S	69° 33.438' E	7,15	248,7
IDX16-022	1036	13.11.2016	07:13:26	1435	23° 50.587' S	69° 37.354' E	08:11:19	941	23° 52.023' S	69° 33.435' E	7,15	248,2
IDX16-026	1002	09.11.2016	22:46:09	1501	23° 50.638' S	69° 37.382' E	23:44:20	1007	23° 52.040' S	69° 33.448' E	7,15	248,7
IDX16-026	1032	13.11.2016	00:02:06	1435	23° 50.653' S	69° 37.382' E	01:00:09	941	23° 52.060' S	69° 33.450' E	7,15	248,6
IDX16-030	1004	10.11.2016	22:43:55	1501	23° 50.673' S	69° 37.391' E	23:42:05	1007	23° 52.078' S	69° 33.458' E	7,15	248,7
IDX16-034	1006	11.11.2016	02:18:01	1435	23° 50.699' S	69° 37.402' E	03:16:19	941	23° 52.100' S	69° 33.467' E	7,15	248,7
IDX16-038	1008	11.11.2016	05:54:23	1435	23° 50.731' S	69° 37.415' E	06:52:40	941	23° 52.127' S	69° 33.479' E	7,15	248,8
IDX16-042	1010	11.11.2016	09:54:54	1435	23° 50.753' S	69° 37.425' E	10:27:39	1154	23° 51.553' S	69° 35.189' E	4,07	248,6
IDX16-042	1012	11.11.2016	09:54:54	1435	23° 50.753' S	69° 37.425' E	10:27:39	1154	23° 51.553' S	69° 35.189' E	4,07	248,6
IDX16-046	1012	11.11.2016	13:26:12	1341	23° 51.042' S	69° 36.685' E	14:13:14	941	23° 52.172' S	69° 33.497' E	5,79	248,8
IDX16-046	1030	12.11.2016	20:39:01	1435	23° 50.781' S	69° 37.436' E	21:35:54	980	23° 52.189' S	69° 33.450' E	7,24	248,9
IDX16-050	1007	11.11.2016	16:52:10	1435	23° 50.802' S	69° 37.445' E	17:50:30	941	23° 52.213' S	69° 33.515' E	7,15	248,6
IDX16-050	1028	12.11.2016	17:17:48	1435	23° 50.783' S	69° 37.437' E	18:15:48	941	23° 52.244' S	69° 33.528' E	7,15	247,8
IDX16-054	1016	11.11.2016	20:07:02	1435	23° 50.826' S	69° 37.455' E	21:05:29	941	23° 52.225' S	69° 33.520' E	7,15	248,7
IDX16-058	1018	11.11.2016	23:27:37	1435	23° 50.855' S	69° 37.468' E	00:26:04	941	23° 52.255' S	69° 33.533' E	7,15	248,7
IDX16-062	1020	12.11.2016	02:49:25	1435	23° 50.882' S	69° 37.479' E	03:47:33	941	23° 52.277' S	69° 33.541' E	7,15	248,8
IDX16-066	1022	12.11.2016	06:44:10	1435	23° 50.904' S	69° 37.488' E	07:42:31	941	23° 52.304' S	69° 33.553' E	7,15	248,7
IDX16-070	1024	12.11.2016	10:06:02	1435	23° 50.931' S	69° 37.500' E	11:04:12	941	23° 52.325' S	69° 33.562' E	7,15	248,8
IDX16-074	1026	12.11.2016	13:37:09	1435	23° 50.956' S	69° 37.510' E	14:35:08	941	23° 52.369' S	69° 33.580' E	7,15	248,5
IDX16-082	1103	19.11.2016	09:16:39	1435	23° 51.005' S	69° 37.531' E	10:15:16	941	23° 52.410' S	69° 33.598' E	7,15	248,7
IDX16-086	1101	19.11.2016	05:50:43	1435	23° 51.024' S	69° 37.539' E	06:49:04	941	23° 52.429' S	69° 33.606' E	7,15	248,6
IDX16-090	1099	19.11.2016	02:29:52	1435	23° 51.054' S	69° 37.552' E	03:27:05	941	23° 52.456' S	69° 33.618' E	7,15	248,7
IDX16-094	1094	18.11.2016	23:01:20	1455	23° 51.082' S	69° 37.564' E	00:00:03	961	23° 52.481' S	69° 33.628' E	7,15	248,7
IDX16-098	1095	18.11.2016	19:40:16	1435	23° 51.105' S	69° 37.574' E	20:38:06	941	23° 52.503' S	69° 33.637' E	7,15	248,8
IDX16-098	1117	20.11.2016	21:20:46	981	23° 52.336' S	69° 34.138' E	22:19:59	1475	23° 50.939' S	69° 38.074' E	7,15	68,8
IDX16-102	1093	18.11.2016	15:05:51	1435	23° 51.128' S	69° 37.583' E	16:04:44	941	23° 52.528' S	69° 33.648' E	7,15	248,7
IDX16-106	1091	18.11.2016	11:41:53	1435	23° 51.145' S	69° 37.591' E	12:40:28	941	23° 52.547' S	69° 33.656' E	7,15	248,7
IDX16-110	1089	18.11.2016	08:16:23	1435	23° 51.180' S	69° 37.605' E	09:14:43	941	23° 52.586' S	69° 33.672' E	7,15	248,6
IDX16-114	1087	18.11.2016	04:50:09	1435	23° 51.204' S	69° 37.615' E	05:48:04	941	23° 52.601' S	69° 33.679' E	7,15	248,8

IDX16-118	1085	18.11.2016	01:27:22	1435	23° 51.229' S	69° 37.626' E	02:23:57	941	23° 52.636' S	69° 33.693' E	7,15	248,6
IDX16-122	1083	17.11.2016	22:01:54	1435	23° 51.256' S	69° 37.637' E	23:00:05	941	23° 52.659' S	69° 33.704' E	7,15	248,7
IDX16-126	1081	17.11.2016	18:35:23	1435	23° 51.278' S	69° 37.646' E	19:33:54	941	23° 52.687' S	69° 33.715' E	7,15	248,6
IDX16-130	1079	17.11.2016	15:09:50	1435	23° 51.305' S	69° 37.658' E	16:07:58	941	23° 52.715' S	69° 33.727' E	7,15	248,6
IDX16-138	1077	17.11.2016	11:44:43	1435	23° 51.360' S	69° 37.678' E	12:43:37	941	23° 52.757' S	69° 33.745' E	7,15	248,8
IDX16-142	1075	17.11.2016	08:11:45	1435	23° 51.364' S	69° 37.683' E	09:09:48	941	23° 52.792' S	69° 33.759' E	7,15	248,3
IDX16-146	1073	17.11.2016	04:50:49	1435	23° 51.384' S	69° 37.691' E	05:47:59	941	23° 52.805' S	69° 33.765' E	7,15	248,4
IDX16-150	1071	17.11.2016	01:28:46	1435	23° 51.420' S	69° 37.707' E	02:26:18	941	23° 52.842' S	69° 33.781' E	7,15	248,4
IDX16-154	1069	16.11.2016	22:01:13	1435	23° 51.455' S	69° 37.721' E	22:59:45	941	23° 52.865' S	69° 33.790' E	7,15	248,6
IDX16-158	1067	16.11.2016	18:37:08	1435	23° 51.481' S	69° 37.732' E	19:35:23	941	23° 52.905' S	69° 33.807' E	7,15	248,3
IDX16-162	1065	16.11.2016	15:13:04	1435	23° 51.500' S	69° 37.740' E	16:11:23	941	23° 52.912' S	69° 33.810' E	7,15	248,5
IDX16-162	1107	19.11.2016	19:50:04	1435	23° 51.495' S	69° 37.738' E	20:48:08	941	23° 52.953' S	69° 33.827' E	7,15	247,8
IDX16-166	1063	16.11.2016	11:46:20	1435	23° 51.530' S	69° 37.751' E	12:45:29	941	23° 52.941' S	69° 33.822' E	7,15	248,5
IDX16-170	1061	16.11.2016	08:16:06	1435	23° 51.563' S	69° 37.767' E	09:14:19	941	23° 52.951' S	69° 33.826' E	7,15	248,9
IDX16-174	1059	16.11.2016	04:37:30	1435	23° 51.582' S	69° 37.775' E	05:33:55	941	23° 52.986' S	69° 33.841' E	7,15	248,7
IDX16-178	1057	16.11.2016	01:17:51	1435	23° 51.604' S	69° 37.784' E	02:16:16	941	23° 53.024' S	69° 33.858' E	7,15	248,4
IDX16-182	1055	15.11.2016	21:50:57	1435	23° 51.636' S	69° 37.798' E	22:49:43	941	23° 53.030' S	69° 33.860' E	7,15	248,8
IDX16-186	1053	15.11.2016	18:24:37	1435	23° 51.662' S	69° 37.809' E	19:22:49	941	23° 53.077' S	69° 33.880' E	7,15	248,5
IDX16-190	1051	15.11.2016	14:55:20	1435	23° 51.664' S	69° 37.810' E	15:54:37	941	23° 53.075' S	69° 33.879' E	7,15	248,6
IDX16-194	1049	15.11.2016	11:32:57	1432	23° 51.716' S	69° 37.804' E	12:30:40	941	23° 53.129' S	69° 33.901' E	7,11	248,4
IDX16-194	1119	21.11.2016	02:20:43	1435	23° 51.710' S	69° 37.830' E	03:19:14	941	23° 53.106' S	69° 33.892' E	7,15	248,8
IDX16-198	1047	15.11.2016	08:05:19	1435	23° 51.737' S	69° 37.841' E	09:03:31	941	23° 53.150' S	69° 33.911' E	7,15	248,5
IDX16-402	1046	14.11.2016	02:34:37	1435	23° 51.749' S	69° 37.846' E	03:32:45	941	23° 53.181' S	69° 33.923' E	7,15	248,2
IDX16-406	1044	13.11.2016	23:01:20	1435	23° 51.806' S	69° 37.870' E	23:58:10	941	23° 53.181' S	69° 33.924' E	7,15	249,1
IDX16-406	1113	20.11.2016	11:23:55	981	23° 52.998' S	69° 34.417' E	12:22:20	1475	23° 51.552' S	69° 38.334' E	7,15	68,0
IDX16-210	1042	13.11.2016	19:36:57	1435	23° 51.826' S	69° 37.878' E	20:35:18	941	23° 53.205' S	69° 33.934' E	7,15	249,1
IDX16-214	1040	13.11.2016	16:09:56	1435	23° 51.838' S	69° 37.884' E	17:08:01	941	23° 53.263' S	69° 33.958' E	7,15	248,3
IDX16-218	1038	13.11.2016	11:42:05	1915	23° 50.510' S	69° 41.721' E	13:36:38	941	23° 53.270' S	69° 33.961' E	14,1	248,7
IDX16-222	1035	13.11.2016	05:29:11	981	23° 53.116' S	69° 34.467' E	06:27:25	1475	23° 51.694' S	69° 38.394' E	7,15	68,4
IDX16-222	1105	19.11.2016	14:51:14	981	23° 53.100' S	69° 34.461' E	15:49:31	1475	23° 51.681' S	69° 38.389' E	7,15	68,5
IDX16-222	1115	20.11.2016	16:19:50	1435	23° 51.843' S	69° 37.885' E	17:18:24	941	23° 53.297' S	69° 33.973' E	7,15	247,9
IDX16-226	1033	13.11.2016	01:50:03	981	23° 53.139' S	69° 34.477' E	02:48:12	1475	23° 51.733' S	69° 38.411' E	7,15	68,7
IDX16-230	1031	12.11.2016	22:22:31	981	23° 53.167' S	69° 34.490' E	23:21:07	1475	23° 51.756' S	69° 38.420' E	7,15	68,6

IDX16-234	1007	11.11.2016	04:00:14	981	23° 53.186' S	69° 34.497' E	04:58:30	1475	23° 51.790' S	69° 38.434' E	7,15	68,8
IDX16-238	1009	11.11.2016	07:37:23	981	23° 53.213' S	69° 34.509' E	08:35:47	1475	23° 51.811' S	69° 38.443' E	7,15	68,7
IDX16-242	1011	11.11.2016	11:34:17	981	23° 53.242' S	69° 34.521' E	11:56:21	1167	23° 52.704' S	69° 35.988' E	2,68	68,1
IDX16-242	1111	20.11.2016	06:18:07	1435	23° 52.015' S	69° 37.958' E	07:15:54	941	23° 53.466' S	69° 34.044' E	7,15	247,9
IDX16-246	1015	11.11.2016	18:30:08	981	23° 53.262' S	69° 34.529' E	19:27:39	1475	23° 51.856' S	69° 38.462' E	7,15	68,7
IDX16-250	1029	12.11.2016	18:58:04	981	23° 53.287' S	69° 34.540' E	19:56:24	1475	23° 51.899' S	69° 38.480' E	7,15	68,9
IDX16-254	1017	11.11.2016	21:49:18	981	23° 53.320' S	69° 34.554' E	22:47:23	1475	23° 51.912' S	69° 38.486' E	7,15	68,6
IDX16-254	1109	20.11.2016	01:22:18	981	23° 53.310' S	69° 34.550' E	02:20:37	1475	23° 51.890' S	69° 38.477' E	7,15	68,4
IDX16-258	1019	12.11.2016	01:08:11	981	23° 53.343' S	69° 34.564' E	02:06:21	1475	23° 51.938' S	69° 38.497' E	7,15	68,7
IDX16-262	1021	12.11.2016	04:36:13	981	23° 53.392' S	69° 34.585' E	05:34:07	1475	23° 51.954' S	69° 38.504' E	7,15	68,1
IDX16-266	1004	11.11.2016	00:33:32	981	23° 53.390' S	69° 34.583' E	01:31:45	1475	23° 51.983' S	69° 38.516' E	7,15	68,6
IDX16-270	1023	12.11.2016	08:26:05	981	23° 53.420' S	69° 34.596' E	09:24:27	1475	23° 51.999' S	69° 38.523' E	7,15	68,4
IDX16-274	1025	12.11.2016	11:50:43	981	23° 53.442' S	69° 34.605' E	12:49:06	1475	23° 52.037' S	69° 38.539' E	7,15	68,7
IDX16-278	1027	12.11.2016	15:30:36	981	23° 53.462' S	69° 34.614' E	15:37:30	1038	23° 53.304' S	69° 35.069' E	0,82	69,2
IDX16-278	1027	12.11.2016	15:37:37	1039	23° 53.301' S	69° 35.077' E	16:28:49	1475	23° 52.069' S	69° 38.552' E	6,31	68,8
IDX16-282	1102	19.11.2016	07:35:42	981	23° 53.501' S	69° 34.630' E	08:34:27	1475	23° 52.093' S	69° 38.563' E	7,15	68,6
IDX16-286	1100	19.11.2016	04:10:54	981	23° 53.517' S	69° 34.637' E	05:09:03	1475	23° 52.121' S	69° 38.574' E	7,15	68,8
IDX16-290	1098	19.11.2016	00:45:08	981	23° 53.552' S	69° 34.651' E	01:43:08	1475	23° 52.153' S	69° 38.588' E	7,15	68,8
IDX16-294	1096	18.11.2016	21:20:58	981	23° 53.578' S	69° 34.663' E	22:19:53	1475	23° 52.171' S	69° 38.595' E	7,15	68,6
IDX16-298	1094	18.11.2016	18:19:26	1160	23° 53.085' S	69° 36.095' E	18:56:57	1475	23° 52.179' S	69° 38.599' E	4,56	68,4
IDX16-302	1092	18.11.2016	13:26:58	981	23° 53.622' S	69° 34.681' E	14:24:28	1475	23° 52.216' S	69° 38.615' E	7,15	68,7
IDX16-306	1003	10.11.2016	00:48:23	981	23° 53.643' S	69° 34.684' E	01:46:28	1475	23° 52.241' S	69° 38.619' E	7,15	68,7
IDX16-310	1090	18.11.2016	09:57:11	981	23° 53.651' S	69° 34.694' E	10:56:19	1475	23° 52.264' S	69° 38.635' E	7,15	69,0
IDX16-314	1088	18.11.2016	06:34:09	981	23° 53.681' S	69° 34.706' E	07:31:36	1475	23° 52.280' S	69° 38.642' E	7,15	68,7
IDX16-318	1086	18.11.2016	03:07:29	981	23° 53.708' S	69° 34.718' E	04:05:19	1475	23° 52.302' S	69° 38.651' E	7,15	68,7
IDX16-322	1084	17.11.2016	23:43:00	981	23° 53.745' S	69° 34.734' E	00:40:28	1475	23° 52.333' S	69° 38.664' E	7,15	68,6
IDX16-326	1082	17.11.2016	20:18:14	981	23° 53.768' S	69° 34.744' E	21:16:22	1475	23° 52.364' S	69° 38.678' E	7,15	68,7
IDX16-326	1121	21.11.2016	07:46:34	981	23° 53.768' S	69° 34.743' E	08:45:04	1475	23° 52.373' S	69° 38.681' E	7,15	68,8
IDX16-330	1080	17.11.2016	16:51:32	981	23° 53.796' S	69° 34.755' E	17:48:55	1475	23° 52.387' S	69° 38.687' E	7,15	68,6
IDX16-334	1078	17.11.2016	13:28:04	981	23° 53.822' S	69° 34.766' E	14:25:34	1475	23° 52.417' S	69° 38.700' E	7,15	68,7
IDX16-338	1001	09.11.2016	20:18:10	981	23° 53.825' S	69° 34.786' E	21:21:44	1541	23° 52.449' S	69° 38.629' E	6,99	68,6
IDX16-338	1013	11.11.2016	15:00:20	1001	23° 53.759' S	69° 34.923' E	15:56:37	1475	23° 52.438' S	69° 38.708' E	6,86	69,1
IDX16-342	1076	17.11.2016	09:57:56	981	23° 53.850' S	69° 34.778' E	10:56:35	1475	23° 52.462' S	69° 38.718' E	7,15	68,9

IDX16-346	1074	17.11.2016	06:33:33	981	23° 53.884' S	69° 34.792' E	07:31:04	1475	23° 52.468' S	69° 38.721' E	7,15	68,5
IDX16-350	1072	17.11.2016	03:10:24	981	23° 53.916' S	69° 34.806' E	04:08:29	1475	23° 52.492' S	69° 38.731' E	7,15	68,4
IDX16-354	1070	16.11.2016	23:44:59	981	23° 53.944' S	69° 34.818' E	00:43:27	1475	23° 52.533' S	69° 38.749' E	7,15	68,6
IDX16-358	1068	16.11.2016	20:18:43	981	23° 53.974' S	69° 34.830' E	21:17:02	1475	23° 52.565' S	69° 38.762' E	7,15	68,6
IDX16-362	1066	16.11.2016	16:56:10	981	23° 53.993' S	69° 34.838' E	17:55:35	1475	23° 52.571' S	69° 38.765' E	7,15	68,4
IDX16-366	1064	16.11.2016	13:31:19	981	23° 54.019' S	69° 34.849' E	14:29:23	1475	23° 52.613' S	69° 38.782' E	7,15	68,7
IDX16-370	1062	16.11.2016	10:00:27	981	23° 54.049' S	69° 34.862' E	10:58:46	1475	23° 52.644' S	69° 38.796' E	7,15	68,7
IDX16-374	1060	16.11.2016	06:37:11	981	23° 54.077' S	69° 34.874' E	07:34:53	1475	23° 52.638' S	69° 38.793' E	7,15	68,1
IDX16-378	1058	16.11.2016	03:00:17	981	23° 54.093' S	69° 34.881' E	03:57:57	1475	23° 52.667' S	69° 38.805' E	7,15	68,3
IDX16-382	1056	15.11.2016	23:33:23	981	23° 54.125' S	69° 34.894' E	00:31:41	1475	23° 52.711' S	69° 38.824' E	7,15	68,5
IDX16-386	1054	15.11.2016	20:11:03	998	23° 54.102' S	69° 35.040' E	21:02:59	1437	23° 52.854' S	69° 38.536' E	6,35	68,7
IDX16-390	1052	15.11.2016	16:41:24	981	23° 54.174' S	69° 34.914' E	17:40:09	1475	23° 52.744' S	69° 38.838' E	7,15	68,3
IDX16-394	1050	15.11.2016	13:12:58	981	23° 54.196' S	69° 34.924' E	14:11:32	1475	23° 52.782' S	69° 38.854' E	7,15	68,5
IDX16-398	1048	15.11.2016	09:50:57	981	23° 54.224' S	69° 34.936' E	10:48:37	1475	23° 52.810' S	69° 38.866' E	7,15	68,5
IDX16-402	1045	14.11.2016	00:47:15	981	23° 54.256' S	69° 34.949' E	01:45:44	1475	23° 52.846' S	69° 38.881' E	7,15	68,6
IDX16-406	1043	13.11.2016	21:18:59	981	23° 54.275' S	69° 34.957' E	22:17:24	1475	23° 52.887' S	69° 38.898' E	7,15	68,9
IDX16-410	1041	13.11.2016	17:48:49	981	23° 54.296' S	69° 34.966' E	18:47:25	1475	23° 52.890' S	69° 38.900' E	7,15	68,7
IDX16-414	1039	13.11.2016	14:22:20	981	23° 54.317' S	69° 34.976' E	15:20:40	1475	23° 52.923' S	69° 38.914' E	7,15	68,8
IDX16-418	1037	13.11.2016	09:18:52	981	23° 54.350' S	69° 34.989' E	10:16:59	1475	23° 52.930' S	69° 38.917' E	7,15	68,4
										total	806,3	
3D profiles (North - South)												
IDX16-642	1122	21.11.2016	10:23:11	1435	23° 50.881' S	69° 35.639' E	11:21:59	941	23° 54.498' S	69° 37.167' E	7,18	158,9
IDX16-646	1120	21.11.2016	05:00:31	981	23° 54.037' S	69° 36.987' E	05:58:53	1475	23° 50.426' S	69° 35.440' E	7,18	338,6
IDX16-650	1118	20.11.2016	23:44:17	1435	23° 50.860' S	69° 35.697' E	00:41:54	941	23° 54.470' S	69° 37.244' E	7,18	158,6
IDX16-654	1116	20.11.2016	18:52:05	981	23° 54.015' S	69° 37.049' E	19:50:00	1475	23° 50.401' S	69° 35.510' E	7,18	338,7
IDX16-658	1114	20.11.2016	13:50:09	1433	23° 50.848' S	69° 35.779' E	14:47:44	941	23° 54.455' S	69° 37.286' E	7,15	159,1
IDX16-662	1112	20.11.2016	08:52:18	981	23° 53.999' S	69° 37.092' E	09:50:26	1475	23° 50.372' S	69° 35.592' E	7,18	339,3
IDX16-666	1110	20.11.2016	03:54:37	1435	23° 50.821' S	69° 35.805' E	04:52:41	941	23° 54.434' S	69° 37.344' E	7,18	158,7
IDX16-670	1108	19.11.2016	22:42:35	981	23° 53.972' S	69° 37.167' E	23:42:01	1475	23° 50.354' S	69° 35.643' E	7,18	338,9
IDX16-674	1106	19.11.2016	17:16:10	1435	23° 50.795' S	69° 35.880' E	18:14:28	941	23° 54.405' S	69° 37.427' E	7,18	158,6
IDX16-678	1104	19.11.2016	12:16:43	981	23° 53.949' S	69° 37.233' E	13:14:40	1475	23° 50.337' S	69° 35.690' E	7,18	338,7
										total	71,8	

OBS-Station List and Profiles

Station	**Deployment Date**	**Time UTC**	**Position LAT**	**LONG**	**Recovery Date**	**Time UTC**	**Position LAT**	**LONG**	**OBS #**
MSM59/720-1	07.11.2016	19:59	23° 56,89' S	69° 37,29' E	22.11.2016	10:20	23° 56,94' S	69° 37,36' E	OBS1
MSM59/721-1	07.11.2016	20:29	23° 54,98' S	69° 37,16' E	22.11.2016	11:50	23° 54,99' S	69° 37,21' E	OBS2
MSM59/722-1	07.11.2016	21:06	23° 52,30' S	69° 39,24' E	22.11.2016	13:24	23° 52,28' S	69° 39,43' E	OBS3
MSM59/723-1	07.11.2016	21:38	23° 52,59' S	69° 36,27' E	22.11.2016	15:09	23° 52,70' S	69° 36,39' E	OBS4
MSM59/724-1	07.11.2016	21:50	23° 52,43' S	69° 36,11' E	22.11.2016	15:30	23° 52,51' S	69° 36,26' E	OBS5
MSM59/725-1	07.11.2016	22:15	23° 51,97' S	69° 35,86' E	22.11.2016	15:46	23° 51,99' S	69° 36,04' E	OBS6
MSM59/726-1	07.11.2016	22:45	23° 51,55' S	69° 33,35' E	22.11.2016	17:22	23° 51,39' S	69° 33,31' E	OBS7
MSM59/727-1	07.11.2016	23:13	23° 50,40' S	69° 35,51' E	22.11.2016	19:00	23° 50,25' S	69° 35,44' E	OBS8
MSM59/728-1	07.11.2016	23:40	23° 48,94' S	69° 33,89' E	22.11.2016	19:36	23° 48,83' S	69° 33,89' E	OBS9

Line	Date	Start	First SP	Lat	Lon	End	Last SP	Lat	Lon	Dist (km)	Course
OBS Profiles											
BGR16-401	10.11.2016	19:56:51	1238	23° 51.170' S	69° 50.706' E	22:25:26	2058	23° 50.358' S	69° 38.673' E	20,43	274,2
BGR16-402	15.11.2016	03:40:47	1002	23° 52.133' S	69° 57.009' E	08:01:36	2287	23° 51.655' S	69° 38.093' E	32,04	271,5
BGR16-403	22.11.2016	02:00:00		23° 48.885' S	69° 39.017' E	02:54:59		23° 48.621' S	69° 34.059' E	8,41	273,3
BGR16-404	22.11.2016	02:55:00		23° 48.620' S	69° 34.058' E	03:55:00		23° 44.331' S	69° 31.294' E	9,22	329,5
BGR16-405	22.11.2016	04:09:00		23° 44.468'S	69° 31.610' E	08:05:00		24° 02.229' S	69° 41.485' E	36,89	153,1
									total	106,99	

Gun Calibration Test Lines

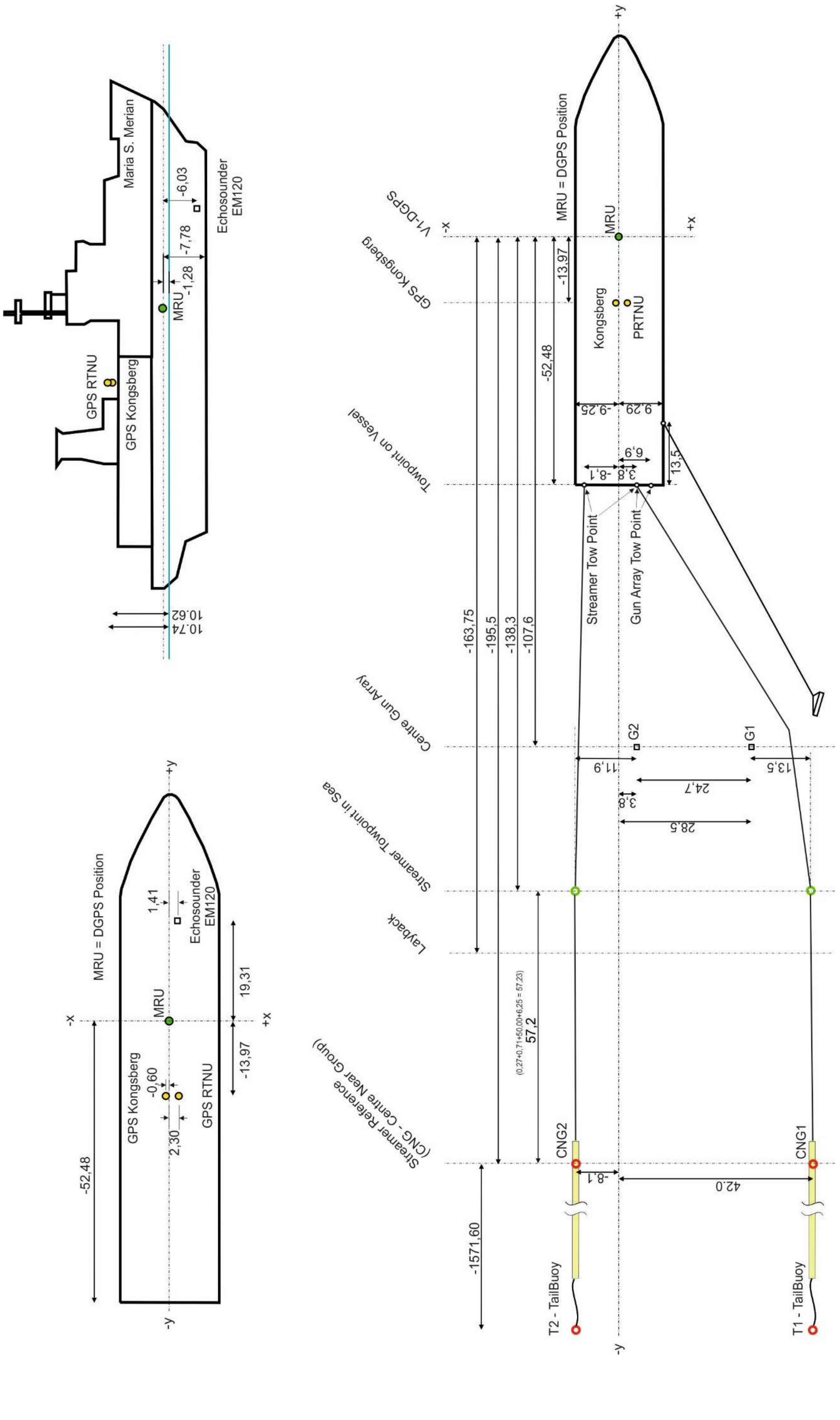
	Date	Start	First SP	Lat	Lon	End	Last SP	Lat	Lon	Dist (km)	Course-
BGR16-BSH-01	07.11.2016	09:46:22	633	24° 21.079 ' S	68° 23.516 'E	10:09:04	701	24° 21.621 'S	68° 15.588 'E	3,405	252,8
BGR16-BSH-02	07.11.2016	08:33:58	415	24° 21.606 'S	68° 22.643 'E	08:55:40	481	24° 22.064 'S	68°20.809 'E	3,208	254,7
BGR16-BSH-03	07.11.2016	06:59:13	131	24° 21.528 'S	68°23.795 'E	07:44:36	267	24° 22.682 'S	68°20.065 'E	6,644	251,2
BGR16-BSH-04	07.11.2016	10:17:24	725	24° 22.053 'S	68°21.761 'E	11:15:55	896	24° 20.443 'S	68°26.583 'E	8,663	69,9
BGR16-BSH-05	07.11.2016	09:07:00	514	24° 22.562 'S	68°21.084 'E	09:38:22	608	24° 21.577 'S	68°23.575 'E	4,580	66,6
BGR16-BSH-06	07.11.2016	07:50:56	286	24° 23.025 'S	68°20.205 'E	08:21:58	379	24° 22.220 'S	68°22.762 'E	4,563	70,9
									total	31,06	

4 Acknowledgements

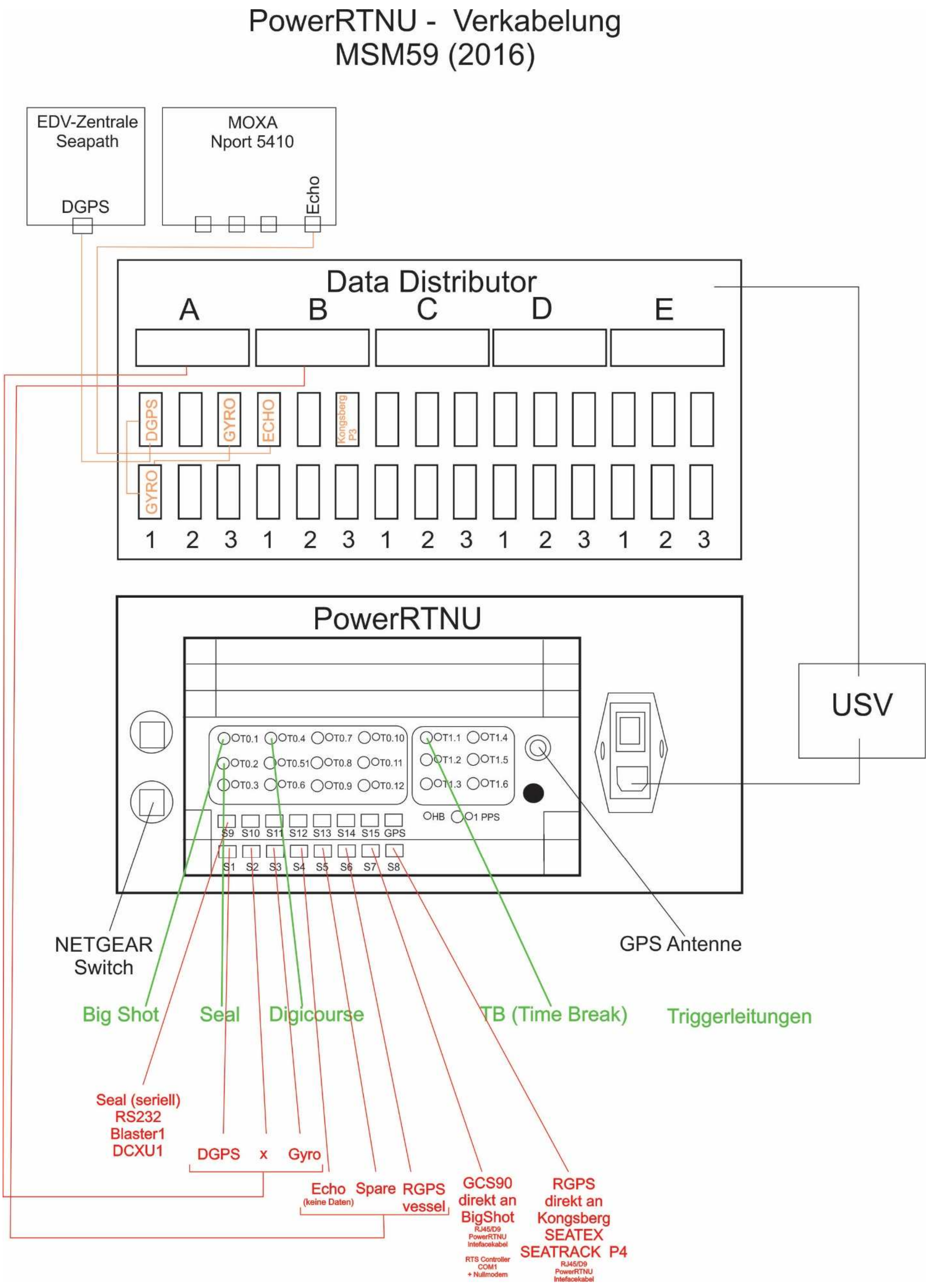
We appreciate the cooperation of the Deutsche Forschungsgemeinschaft providing the vessel to BGR and the all assistance by the Leitstelle Deutsche Forschungsschiffe during logistic preparation of the cruise.

Many thanks go to Master Ralph Schmidt and the entire crew of RV Maria S. Merian for their great support to complete our research programme as per schedule and for making our stay on board highly convenient and comfortable.

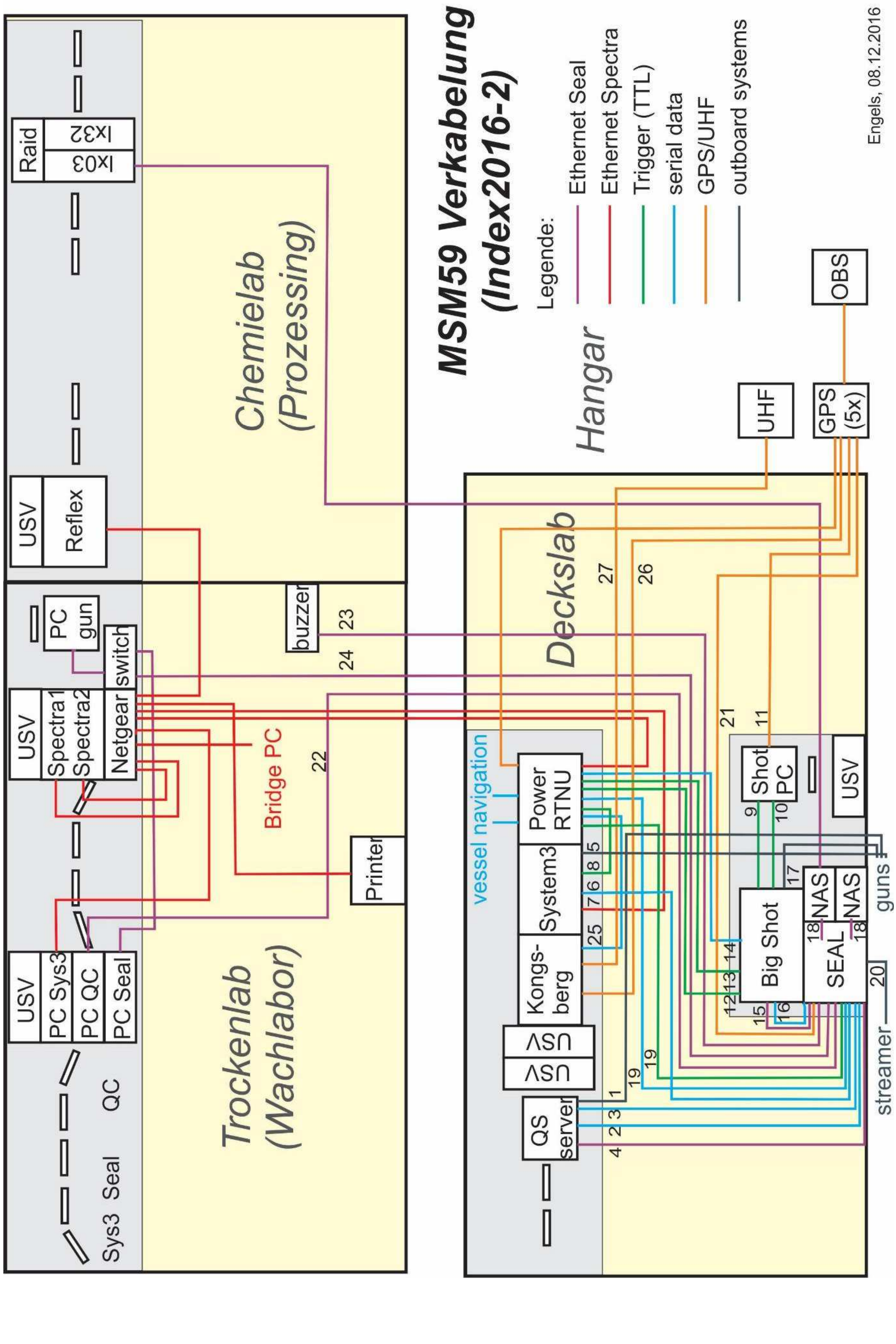
Appendix-A1: Geometry of Spectra reference points on the vessel and in the water.



Appendix-A2: Wiring of Spectra's real-time system Power RTNU during cruise MSM59-1.



Appendix-A3: Wiring of the mobile BGR seismic onboard systems during cruise MSM59-1.



Verkabelung MSM59 - INDEX2016-2

Einheit Aufbau	Kabel Nr.	Quelle Bezeichnung	Steckverbinder/Kabel	Ziel Bezeichnung	Steckverbinder/Kabel
A) Seal QS (QuietSea)					
QS Module	1	QS Module (Back): AUX NODE 3	Gummikabel	gun hydrophone (Backbord)	
QS Server	1	QS Module (Back): AUX NODE 4	Gummikabel	gun hydrophone (Steuerbord)	
	2	QS Module (Back): AUX NODE 1	Militärstecker	SEAL: DCXU 1: CMB (Backbord)	
	3	QS Module (Back): AUX NODE 2	Militärstecker	SEAL: DCXU 2: CMB (Steuerbord)	
		QS Module (Back): 8x RS485	8-fach Kabelstrang	QS server: Moxa Steckverbinder	
	4	QS Server (Back): Ethernet 1 (von 4)	ENET	Seal: switch 2 (client network)	ENET
		QS Server (Back): 2x HDMI		2x Monitor	
B) System3 (DigiCourse)					
(hier: Konfiguration der CTX über Line B Port 2)					
LIU (line interface unit)		LIU (Front): LIU ENET	(crosslink ENET)	DMU (Back): LIU ENET	ENET
LPU (line power unit)		LIU (Front): SYNC IN	BNC	DMU (Back): LIU SYNC	BNC
DMU					
	5	LPU (Front): LINE 1	Militärstecker	CTX Gun Akustik (Backbord)	
	5	LPU (Front): LINE 2	Militärstecker	CTX Gun Akustik (Steuerbord)	
		LPU (Front): COMM IN	Militärstecker	LIU (Back): TXL-B (oben)	
	6	LPU (Front): COMM OUT	Militärstecker, Kabel dünn	Seal: DCXU 2: Akustik & Bird coil	Y-Kabel (Backbord)
	6	LIU (Back): TXL-A (unten)	Militärstecker, Kabel dick	Seal: DCXU 1: Akustik & Bird coil	Y-Kabel (Steuerbord)
	7	DMU (Back): HOST ENET	ENET	Netgear switch (spectra)	ENET
	8	DMU (Back): Contact Closure	BNC	Power RTNU	
C) Shot PC (BGR)					
	9	Shot PC (Front): BNC Aiming	BNC	BigShot Controller (Front): CTB	BNC
	10	Shot PC (Front): BNC Extern	BNC	BigShot Controller (Front): TTL Out	BNC
	11	(Back): Coax-Anschluss	Koax	GPS-Antenne	

Einheit Aufbau	Kabel Nr.	Quelle Bezeichnung	Steckverbinder/Kabel	Ziel Bezeichnung	Steckverbinder/Kabel
D) BigShot					
Controller module	12	Controller (Back): Trig In	BNC	Power RTNU	
Power supply 1	13	Controller (Back): CTB	BNC	Power RTNU	
Power supply 2	14	Controller (Back): COM1	DSub9	Power RTNU	
Power supply 3	15	Controller (Back): ENET	ENET	Seal: switch 2 (client network)	
	9	Controller (Front): CTB	BNC	Shot PC (Front): BNC Aiming	BNC
	10	Controller (Front): TTL Out	BNC	Shot PC (Front): BNC Extern	BNC
	16	Power supply 1&2 (Back): SENSOR	2 Kabelstränge	Seal ACXU (Back): 13-24	
	17	Big Shot (Back): 2x Backbord	Militärstecker	guns (Backbord)	
	17	Big Shot (Back): 2x Steuerbord	Militärstecker	guns (Steuerbord)	
E) SEAL					
2x NAS	18	NAS #1 groß: ENET 0	ENET	Seal: switch 3 (peripheral network)	
eSQC Server	18	NAS #2 klein: ENET 0	ENET	Seal: switch 3 (peripheral network)	
AXCU	18	NAS #2 klein: ENET 1 (unten)	ENET	Seal: switch 1 (QC network)	
Meinberg		eSQC server: ENET 2	ENET	Seal: switch 1 (QC network)	
LCI (line control interface)		eSQC server: ENET 1	ENET	Seal server (Back): ENET 3	
DCXU 1 backbord	16	Seal ACXU (Back): 13-24	2 Kabelstränge	BigShot power supply 1&2: SENSOR	
DCXU 2 steuerbord		Meinberg (Back): ENET (oben)	ENET	Seal: switch 2 (client network)	
Seal server 428		Meinberg (Back): ENET (unten)	ENET	Seal: switch 3 (peripheral network)	
		Meinberg (Back): GPS out + COM 1	Gabelkabel	DCXU 1: GPS in	
		Meinberg (Back): Antenna		GPS-Antenne	
	19	LCI (Back): Blaster 1	Gabelkabel DSUB9+ENET	Power RTNU (serial + trigger)	
		LCI (Back): low line	orange	AXCU: line in	
		LCI (Back): NET		Seal: switch 4 (electronic network)	
		LCI (Back): XDEV 2		DCXU-2: GPS out	
		DCXU 1 (Back): Ethernet	ENET	Seal: switch 4 (electronic network)	
	6	DCXU-1: Akustik & Bird coil	Y-Kabel dünn	System3 LPU (Front): COMM OUT	Militärstecker

Einheit Aufbau	Kabel Nr.	Quelle Bezeichnung	Steckverbinder/Kabel	Ziel Bezeichnung	Steckverbinder/Kabel
	20	DCXU-1: Deck cable		streamer (backbord)	
	20	DCXU-1: AUX Deck cable		streamer (backbord)	
	2	DCXU 1: CMB (Backbord)		QS Module (Back): AUX NODE 1	
		DCXU-1: GPS out		DCXU 2: GPS in	
		DCXU-1: GPS in		Meinberg (Back): GPS out + COM 1	Gabelkabel
		DCXU 2 (Back): Ethernet	ENET	Seal: switch 4 (electronic network)	
	6	DCXU-2: Akustik & Bird coil	Y-Kabel dick	System3 LPU (Back): TXL-B (oben)	Militärstecker
	20	DCXU-2: Deck cable		streamer (steuerbord)	
	20	DCXU-2: AUX Deck cable		streamer (steuerbord)	
	3	DCXU 2: CMB (Steuerbord)		QS Module (Back): AUX NODE 2	
		DCXU-2: GPS out		LCI (Back): XDEV 2	
		DCXU-2: GPS in		DCXU-1: GPS out	
		Seal server (Back): ENET 0 (links)	ENET	Seal: switch 2 (client network)	
		Seal server (Back): ENET 1	ENET	Seal: switch 4 (electronic network)	
		Seal server (Back): ENET 3	ENET	Seal: eSQC server: ENET 4 (rechts)	
		Seal server (Back): ENET 4 (rechts)	ENET	Seal: switch 3 (peripheral network)	
	22	Seal: switch 1 (QC network)	ENET	QC client	
	23	Seal: switch 3 (peripheral network)	ENET	Seal: buzzer	
	24	Seal: switch 2 (client network)	ENET	switch to BigShot & Seal client	
switch 1: QC network		3x: NAS2 (klein), eSQC server, QC clients			
switch 2: client network		5x: Seal server, Seal Meinberg, BigShot, Quiet Sea server, switch to BigShot client & Seal client			
switch 3: peripheral network		5x: Seal server, Seal Meinberg, NAS1, NAS2, buzzer			
switch 4: electronic network		4x: Seal server, DCXU1, DCXU2, LCI			
F) KONGSBERG					
VCU 230	25	Kabelpeitsche: P1-> Port2 Server; P2 -> Port3 Server		Kongsberg server	
server		P3 -> RTNU interface 9/9 (INT); P4 -> RTNU interface RGPS (extra)		Power RTNU	
	26			GPS-Antenne	
	27			UHF-Antenne	

Appendix-A4: Spectra operation flow before start of line (SOL), during line (online) and at end of line (EOF).

1. Before SOL

LMN ensure shot control is disabled
select and configure a line
check line attributes: sequence number; BEARING -> reverse if necessary
check/edit shot numbering, spacing, approach (20) & run-out (60)
apply & submit changes (save configuration)

DN check current line (numbering, approach/runout)

MISC > BCN on spectra2 [Options] select coverage lines to steer against [add]

DN check for bad compasses & acoustics
[Helmsman ncc] estimate position (if necessary, may take minute)

SCN [control editor, mouse wheel] k.o. bad observations (yellow color)

LMN enable shot control

MISC > NLN check shot log is configured
[edit Navlog, select new line, Options > configure, every shot, defined events (e.g. 1-5 & 7)]

Communication:

Spectra → Seal: profile name, first SP number, increment (+/- 1)
Spectra → Guns: switch BigShot from manual to remote mode (1 minute before first SP)

Bridge → Lab: end of turn - vessel on first waypoint (aimpoint)
Bridge → Lab: vessel on second waypoint (start of 6 km profile)

Lab → Bridge: first SP on profile (for bridge logbook)
Lab → MMO: change of SP interval (from curve to profile)

2. Online

DN look for shot points (flip, flop)
check current line status
monitor survey, steer the vessel for optimal bin grid coverage
DC – distance away from preplot
VA – vessel speed along line
SRV – time between shots

DLN check logging (on spectra 1 & 2)

MISC > NLN check logging

QC > QCLN check logging (QCLN must be started once)

QCN open appropriate QC file (for analysis if reasonable)

LMN set aim point for next profile
[select feature to use, options > reverse aimpoint]

TURN prepare next turn and turn radius

Communication:

Lab →Bridge: announce next profilename

3. At EOL

LMN disable shot control

MISC > NLN print header and shot log reports
[NLN reports, check line name, menue reports > header, plot and save header;
menue reports > shotlog, display every 10 line, generate report, plot & save]

QC > QCN print EOL reports
[Options, EOL report: select parameter, e.g. shottime in ms for OBS]

Communication:

Spectra → Seal: confirm last SP number
Spectra → Guns: switch BigShot after last SP to manual mode

Bridge → Lab: vessel on third waypoint (end of 6 km profile)
Bridge → Lab: vessel on forth waypoint (aimpoint)

Lab → Bridge: last SP (end of profile for bridge logbook)

Bridge → Lab: start of turn

Lab → MMO: change of SP interval (from profile to curve)

Appendix-A5: Marine Mammal Observation Weekly Summaries

Marine Mammal Observation Weekly Summary
MSM5912 Project Index 2-Leg 1
7/11/2016 to 13/11/2016

Observer Names: Lorenzo Scala, Stephanie Barnicoat

Client	**BGR**	**Seismic Contractor**	**BGR**
Survey Location	Central Indian Ocean ridge	**Vessel Name**	FS Maria S. Merian
Regulator Reference Number		**Report Number**	**1**

Operations Summary Table

Description of Operations	Weekly	Project Total
Duration of full volume acquisition:	52:14	52:14
Duration of reduced volume acquisition	36:18	36:18
Duration of soft starts:	1:30	1:30
Duration of source testing:	5:01	5:01
Total duration of source operations:	**95:03**	**95:03**

Monitoring Effort Summary Table

Visual and Acoustic Monitoring Efforts								
Monitoring Method	**Source Inactive**		**Source Active**		**Total Monitoring Effort**		**Number of Soft Starts (per method)**	
	Weekly	**Project Total**	**Weekly**	**Project Total**	**Weekly**	**Project Total**	**Weekly**	**Project Total**
Visual	30:21	30:21	42:07	42:07	72:28	72:28	1	1
Acoustic	5:02	5:02	42:20	42:20	47:22	47:22	2	2

Mitigation Actions Summary Table

There were no mitigation actions required.

Detection Summary

There were no visual sightings or acoustic detections this week.

PAM Equipment Hardware/Software Status

On the 7th November PAM was deployed for the first time during the calibration line, to ensure an adequate deployment method was in place, and it was. On the 9th November PAM was deployed as production began. On November 10th, the PAM cable was retrieved due to issues with the streamers. PAM was deployed again at 17:55 UTC and has been deployed for the duration of the week.

Summary of Environmental Conditions

Environmental condition for the week began with a choppy sea state (lots of white caps) and a medium swell (2-4 m). early to mid-week the environmental conditions altered to a low swell (<2 m) and a slight sea state (no or few white caps). Wind direction varied from south easterly to easterly and north easterly to easterly, with a Beaufort Scale 3 to 5. The visibility has been good throughout the week (>5 km), with variable sun glare from none to strong sun glare.

Marine Mammal Observation Weekly Summary
MSM5912 Project Index 2-Leg 1
14/11/2016 to 20/11/2016

Observer Names: Lorenzo Scala, Stephanie Barnicoat

Client	**BGR**	**Seismic Contractor**	**BGR**
Survey Location	Central Indian Ocean ridge	**Vessel Name**	FS Maria S. Merian
Regulator Reference Number		**Report Number**	**2**

Operations Summary Table

Description of Operations	Weekly	Project Total
Duration of full volume acquisition:	75:05	127:19
Duration of reduced volume acquisition	68:07	104:25
Duration of soft starts:	0:26	1:56
Duration of source testing:	0	5:01
Total duration of source operations:	**143:12**	**238:41**

Monitoring Effort Summary Table

Visual and Acoustic Monitoring Efforts								
Monitoring Method	Source Inactive		Source Active		Total Monitoring Effort		Number of Soft Starts (per method)	
	Weekly	Project Total	Weekly	Project Total	Weekly	Project Total	Weekly	Project Total
Visual	11:11	41:32	66:10	108:17	77:21	149:49	1	2
Acoustic	0	5:02	61:58	104:18	61:58	109:20	0	2

Detection Summary

There were no visual sightings, however there was 1 acoustic detection this week on the 18th, at 18:13 UTC. Delphinid FM whistles were detected aurally from the headset and from the MF Spectrogram display (Upsweep, down sweep and concave whistles, 5 kHz to 10 kHz fundamental frequency) followed by a series of clicks, buzzes and burst pulses, detected from the MF spectrogram and from the LF Click Detector. Distinctive click trains from two animals were observed, lasting 90 seconds and travelling at an angle of 45° ahead of the hydrophone pair, heading in the opposite direction to 150° (left/right ambiguity). A click train was also observed on the HF Click Detector with a peak frequency of 90 kHz.

Detection Number	Common Name	Number of Individuals Detected	Source Activity at Initial Detection (active full volume, active	Closest Approach to Source (m)	Mitigation Action (no action, delay soft start, shut down)	Comments (note if correlated to visual sighting and provide sighting number)

			partial volume, not active)			
501	Unidentified dolphin species	2	Reduced power	200	None	

Mitigation Actions Summary

There were no mitigation actions this week. However, the operator should have advised a shutdown during the reduced power from the single gun during the line turn for detection 501. During the detection, whistles contours were manually selected using the clip generator tool and their bearings displayed on the map. Localisation of the animal was not possible using this method, due to there being an insufficient number of overlapping whistle bearings to indicate a fixed position of the animal(s) relative to the vessel track-line. Range was instead estimated by the amplitude of sounds detected over the headset and from the MF spectrogram, relative to the background noise at the time of detection, which was estimated to be outside the mitigation zone >500 m. Post processing in PAMGuard Viewer Mode allowed for a more in depth analysis of the detected LF Click train and estimated the distance to be 140 m.

PAM Equipment Hardware/Software Status

On the 14th November, the hydrophone array was retrieved due to problems with the streamers. PAM was deployed again on the 15th, ready for monitoring during hours of darkness.

Summary of Environmental Conditions

Environmental conditions for the week began on the 14th with a choppy sea state (lots of white caps), a medium swell (2-4 m), Beaufort force 6 to 7 and poor visibility. Fortunately for the remainder of the week the environmental conditions altered to a low swell (<2 m) and a slight sea state (no or few white caps). With occasions of choppy sea state and medium swells. Wind direction varied from south easterly to easterly and north easterly to easterly, with an average Beaufort Scale 3 to 5. The visibility has been good throughout the week (>5 km), with variable sun glare from none to strong sun glare.

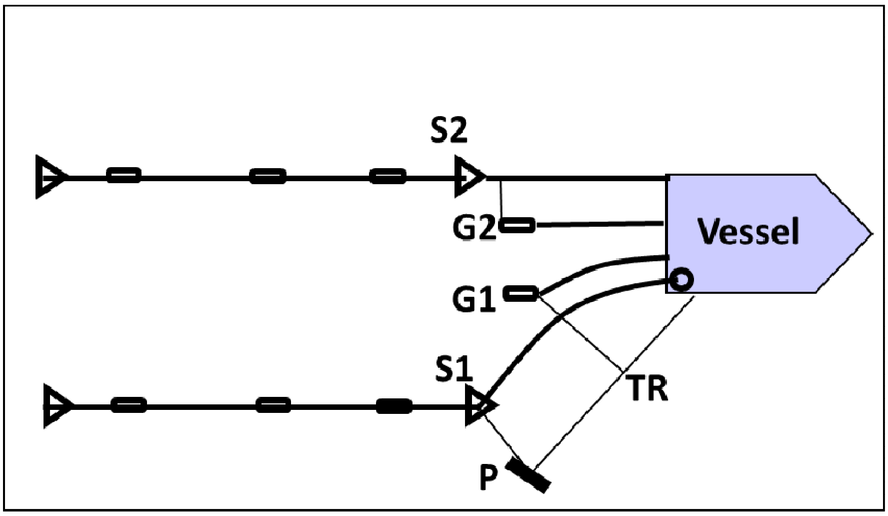
Appendix-A6: Lessons learned.

Lessons learned

- Warum sind Kurrleinen gerissen, wie groß war Sollbruchstelle?
    - 5 t Sollbruchstelle war zwischen Scherbrett und Kopfboje eingebaut, diese Sollbruchstelle ist 2x gebrochen, vermutlich infolge dynamische Last durch Seegang, (im Normalfall kann die Belastung an der Sollbruchstelle nicht die Streamerzuglast übersteigen)
    - 10 t Sollbruchstelle zwischen Kurrleine und Rigg des Scherbretts, ist einmal gerissen, weil beim Recovery vom Scherbrett eine Welle drauf geschlagen ist.
    - Folgerung: genug und zertifizierte Sollbruchstellen mitnehmen
    - Es ist zwingend notwendig, die entstehenden (kurzzeitigen) dynamischen Kräfte abzufangen (z.B. Ruckfender) oder aber auf den Einsatz von Sollbruchstellen gänzlich zu verzichten.
- Wie lang waren Leinen und Seile, was war das bestes setup?
    - Das Setup wurde zweimal verändert. Dabei wurde die GI-Gun auf an backbord mit einem Slider zum Led-In geführt. Der Befestigungsleine zum Slider war am 7.11. VOR der Gun, bei den späteren Layouts an der Gunboje befestigt. Es ergaben sich keine signifikanten Unterschiede. Problematisch ist, dass der Slider durch das Lead-In vermutlich nach unten gezogen wird.
    - Folgerung: Scherbrett an Backbord
- Welcher Streamerabstand ist realistisch? (wir hatten meist mehr als 50 m, meist 60 bis 70 m)
    - Streamerabstand SOLL war 50 m, Streamerabstand IST war meist zwischen 60 und 70 m
    - Gun-Abstand SOLL war 25 m, Gun-Abstand IST war meist zwischen 20 und 15 m
- Hat sich asymmetrisches Setup gelohnt? Wäre Platz für zweites Scherbrett und Kurrleinenwinde?
    - asymmetrisches Layout in vorliegender Weise und Umsetzung ist nicht sinnvoll, da es schwer zu stabilisieren war. Für Stabilisierung ist 2. Scherbrett notwendig, Platz auf Merian wäre vorhanden trotz aller Einschränkungen durch Life Boat
    - Layout mit einem Scherbrett birgt zudem Gefahr, dass bei Bruch einer Leine die Streamer zusammenlaufen und vertörnen (dieser Fall ist auf MSM59/1 eingetreten und führte zu Abriss einer Endboje)
    - Folgerung: Scherbrett an Backbord
- Wie war das Kurvenverhalten (teils kritisch mit 2.5 km Durchmesser bei Seegang)? Welche Pods sollten laufen? Tanzen der Guns?
    - Es wurden verschiedene Test während der Kurvenfahrten (Kurven stets über Backbord) gefahren, um festzustellen, ob durch unterschiedlichen Einsatz der Pods die Instabilitäten in der Schleppposition der Backbord-Gun und des Backbord-Streamers korrigiert werden können. Anhand aller Versuchsergebnisse ist keine signifikante Verbesserung erkennbar.
    - Kurvenfahrten sind grundsätzlich nicht kritisch, wenn ausreichend große Radien eingehalten werden, die Guns stabil gehalten werden können (2. Scherbrett erforderlich!) und die Streamertiefe überwacht wird (evtl den außen laufenden Streamer auf Tiefe steuern!)
- Warum hatten wir den 10 m Längenversatz der Streamer (um Endbojen nicht auf gleicher Höhe zu haben?)?

- Nein, sondern weil die Anschlagpunkte (Ziehstrümpfe) so gesetzt waren und dadurch das Offset des Backbord-Streamers nicht weiter aufgekürzt werden konnte

- Scherbrett-Handling
  - Langsame Fahrt bei Aussetzen der Scherbretter ist notwendig, allerdings steigt damit Gefahr, dass Streamer absackt und Recovery-Systeme auslösen. Streamer evtl leichter tarieren.
  - Scherbrett muss sinnvoller Weise steuer- bzw. backbord ausgesetzt werden (nicht achtern),
  - der Anstellwinkel des Scherbretts muss mit zwei Schwichtingen beim Wassern gehalten werden, damit Scherbrett unmittelbar nach dem Wassern sofort durch richtige Anströmung von der Bordwand wegbewegt wird. Wird das nicht zügig so umgesetzt, wird Scherbrett an die Bordwand angesaugt und lässt sich nicht mehr in richtige Position bewegen.
  - die Kurrleine muss deshalb SOFORT und UNMITTELBAR nach dem Wassern die Zuglast des Scherbretts übernehmen (das Slippen aller Leinen muss gut koordiniert und schnell erfolgen!)



Längen der Leinen (in m):
S1: Kopfboje Streamer 1; S2: Kopfboje Streamer 2 TR: Kurrleine
G1: Gunboje Gun 1 G2: Gunboje Gun 2 P: Paravane

Leine	7.11.	10.11.	ab 16.11.
Vessel-S1	120	120	120
Vessel-S2	85	85	85
Vessel-G1	65	65	73
Vessel-G2	55	55	65
P-S1	30	25	30
TR-G1	30	30	30
Länge TR	124	124	115-118
S2-G2	15	15	15