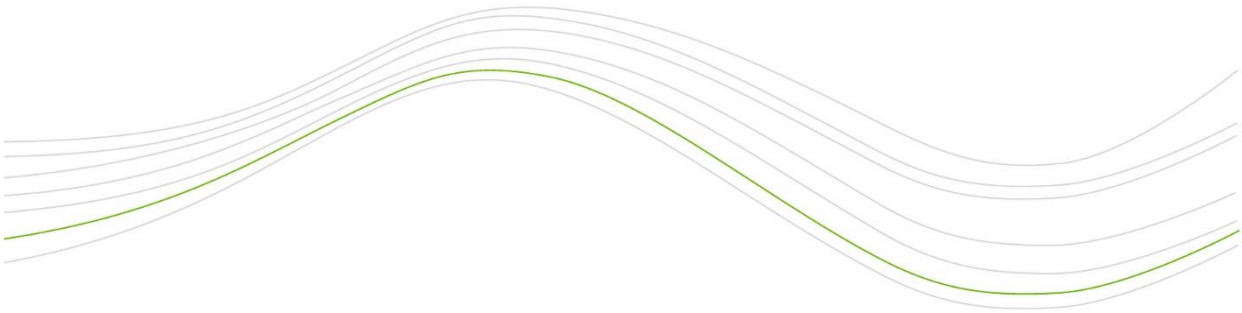
Kartverket

Appendix 1.1:

Technical specifications – MAREANO Programme

December 2023

Some minor changes are made to the content since the previous version of the specification (dated 2022.12.08). Amended sections are marked with a thick black bar in the left margin.



Contents

1 Overview

This specification gives the requirements for data to be used in the MAREANO programme. In addition to product specifications, some equipment and procedure requirements are also presented.

Title:	Specifications for Seabed Mapping within the MAREANO programme
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2 Terms and definitions

Calibration

Calibrations comprise both the determination of corrections and the use of these corrections.

Complete Dataset

A complete dataset consists of data specified in the delivery list satisfying data coverage requirements in terms of total area, survey area limits, sounding density, vertical and horizontal resolution, noise level and restrictions on data gaps.

Field Verification

A field verification of the survey spread calibration is based on analysing overlapping hydrographic data collected in a small area with suitable seabed characteristics. The survey pattern is selected in a way that any calibration error is as visible as possible

Hydrographic Data

All data gathered during the survey and all the related metadata required for seabed mapping.

Mobilisation and Demobilisation

This includes all activity related to preparation and survey spread setup and dismounting.

The mobilisation is not considered completed until Client has approved the documentation of all calibration and verification activity as described in Section 8.1.

Survey area limit

A closed polygon that surrounds all measured and QC data in a project. Under certain instances, several limits may be needed.

Survey spread

This includes the survey vessel itself and all the equipment required to perform the survey.

Survey vessel reference frame

This is an orthogonal coordinate system with a fixed position and orientation relative to the survey vessel hull.

Verification

Verification determines if a system or a sensor operates within specifications.

Unambiguous hydrographic data

This indicates that every position on the seabed is assigned only one unique depth.

XYZ-data

The term XYZ- data is used to describe georeferenced individual soundings from the MBES.

3 Abbreviations

CTD	Conductivity, Temperature and Depth sensor
CW	Continuous Waveform
EUREF89 (ETRF89)	Is the same as the European Terrestrial Reference Frame 1989
FM	Frequency-Modulated
GNSS	Global Navigation Satellite Systems
IERS	International Earth rotation and Reference system Service
IGS	International GNSS Service
IHO	International Hydrographic Organisation
IMU/MRU	Inertial Measurement Unit / Motion Reference Unit
ITRF	International Terrestrial Reference Frame
MBE(S)	MultiBeam Echosounder (System)
MSL	Mean Sea Level
NHS	The Norwegian Hydrographic Service
OM	Operation Manual
QC	Quality Control
SBP	Sub-bottom profiler
SVP	Sound Velocity Profile
THU	Total Horizontal Uncertainty (defined in IHO-S44)
TVU	Total Vertical Uncertainty (defined in IHO-S44)

4 Informal description of the data product

The Contractor shall deliver complete and unambiguous hydrographic data having the desired accuracy, collected with multibeam echo sounder (MBES) at its highest resolution mode.

In addition to the general seabed topography, all seabed features (like iceberg scour marks, coral reefs, pockmarks, sand waves and boulders, etc.) are important to the MAREANO programme. Both the survey and the processing shall be carefully done to preserve all the seabed feature information while removing all the faulty soundings. Seabed features shall not be camouflaged by artefacts and artefacts must not appear as seabed features. No smoothing of the XYZ data shall be applied. Backscatter data are equally important as bathymetry data for the MAREANO programme. The multibeam backscatter data shall provide a representative view of natural variations in seabed acoustic reflectivity within the survey area, such that they are suitable for geological mapping. Water column data shall be collected to identify features, such as gas plumes, fish schools and internal ocean waves. Sub-bottom profiler data shall be collected to give information on the near seafloor stratigraphy which will support the interpretation of seafloor geology.

5 Equipment Requirements

5.1 Positioning

The positioning shall (as a minimum) be based on a high- quality dual frequency GNSS receiver and a high- quality calibrated GNSS antenna type. The system shall be capable of storing GNSS raw data (code, phase,…) for post processing.

5.2 Multibeam Echosounder (MBES)

- Maximum beam width for the actual applied sonar frequency in a direction perpendicular to the transducer surface:
  - Depth interval 0-1000 m: 0.7° x 1.4°
  - Deeper areas: 1.2° x 2.4°
- The echosounder shall have a depth range well suited for the survey area. The echosounder with the narrowest beamwidth and the best range resolution for the relevant depth interval will generally be preferred.
- The MBES shall fulfil the accuracy requirements given in chapter 7.4.1 Accuracy requirements
- Both CW and FM systems are accepted provided that both the depth accuracy and the backscatter data quality are within specifications. Range resolution requirements:

Depth range	Maximum value for range resolution δR
0-200 m	0.2 m
200-400 m	0.5 m
400-700 m	1.5 m
700-1500 m	3.0 m
1500-4000 m	4.0 m
4000-12000 m	8.0 m

CW mode: $\delta R = \frac{cT_p}{2}$

FM mode: $\delta R = \frac{c}{2B}$

Where:

T_p = pulse length,

c = sound velocity and

B = FM bandwidth.

- Phase detection shall be utilized (except for near normal grazing angles)
- Sound velocity at transducer shall continuously be observed and input to the MBES in real time
- Online input of sound velocity profiles to the MBES. The profiles shall be transferred to the MBES and utilized in near real time.
- Roll, pitch and yaw beam correction (all soundings shall be corrected for vessel movements)
- Equidistant sounding pattern shall be utilized
- Realtime roll and pitch stabilization (steering) shall be utilized to ensure an even sounding distribution. The vessel motion must not exceed the motion stabilization/steering window.
- Beam focusing shall be utilized both on transmit and receive for ranges shorter than the far field limit.
- Backscatter and water column data shall be collected
- Online input of absorption coefficient profiles to the MBES. The profiles shall be transferred to the MBES and utilized in near real time.

5.3 Sub-bottom profiler

- Minimum recording window below seafloor: 200 ms TWT
- Delay time change: Manual
- Realtime roll, pitch and heave correction: All soundings shall be corrected for vessel motions
- Reflection events should be represented as single pulse events even if multiple pulses are used at the source.

5.4 Attitude and heading sensors

The sensor requirements are:

- Heading (GNSS based): 0.1° RMS
- Roll and Pitch: 0.02° RMS
- Heave: 0.05 m or 5% of amplitude
- Output rate: Min. 100 Hz

The Heading shall preferably be GNSS-based or GNSS-aided. Heading purely based on inertial sensors may however be accepted, provided that the heading is documented to be within specifications for the actual survey area. Post processed heave is accepted. IMU data should always be logged parallel to raw GNSS data.

5.5 Sound Velocity and Absorption Coefficient profiles

The equipment shall preferably be a CTD sensor but a carbon fibre based "sing-around" sound velocity + temperature sensor will also be accepted. The sensor requirements are:

- Temperature: 0.01°C RMS
- Sound velocity: 0.05 m/s RMS
- Depth range, full scale: 0.05% RMS

5.6 Sound velocity at transducer head

The sound velocity shall continuously be measured close to the sonar head(s) and automatically be applied by the MBES. Accuracy requirements are the same as for the sound velocity profiles.

6 Reference Systems

6.1 Horizontal

The horizontal reference system for all data in survey areas entirely within the Eurasian tectonic plate shall be EUREF89. For these areas, the ITRF positions must be transformed to EUREF89. The transformation formulas shall be approved by the Client. For other areas, the horizontal reference system shall be ITRF2020 current epoch utilizing the GRS80 ellipsoid.

6.2 Vertical

For survey areas entirely within the Eurasian tectonic plate, all vertical coordinates shall be given as ellipsoidal heights (positive upwards) in the EUREF89 datum. For other areas, the vertical coordinates shall be given as ellipsoidal heights using ITRF2020 current epoch and the GRS80 ellipsoid. The ellipsoidal heights shall be purely based on GNSS and IMU data. Waterline and tidal information shall not be used for vertical reference.

6.3 Timing

All registrations of time shall be given in Co-ordinated Universal Time (UTC).

7 Operational and Data Quality Requirements

7.1 Positioning

The GNSS antenna positioning uncertainty shall be within 0.3m (95%) for the horizontal component and within 0.1 m (95%) for the vertical component. Post processing of the positioning is accepted, and GNSS raw data (code, phase,…) shall be stored to enable post processing. Continuous logging (no gaps between survey lines) for at least two hours is required.

7.2 Timing

All data are to be time-stamped to **UTC** within **1ms (95%)**.

The Contractor shall read and timestamp all sensor data, and the Contractor is urged to document the timestamp uncertainty. Preferably all survey data (observations) shall be time stamped at source.

7.3 Sound Velocity and Absorption Coefficient profiles

The sound velocity profiles shall provide a good spatial and temporal coverage of the oceanographic conditions within the survey areas.

The time between each measured profile shall not exceed two hours. The conditions down to the maximum depth of the thermocline shall be measured for variations that may cause artefacts in the bathymetry or the backscatter data.

At least one profile within each survey area shall reach full depth. This may however be omitted for neighboring areas that most likely share the same deep-water oceanographic conditions. In such cases, the deep-water conditions shall be *monitored*, and deep casts shall be taken when required in order to fulfil bathymetry and backscatter data quality requirements. Deep-water *monitoring* may be done with simpler means. The full depth profiles shall be used for shallow profile extension. All profiles must be visually inspected before they are used to verify that realistic values are used.

The Contractor shall include a description of the strategy adopted for fulfilling these requirements.

Profiles of absorption coefficient shall be calculated from the measured CTD profiles, i.e. the input of a single salinity value is not accepted. The profiles shall be calculated and applied without significant delay, and logging of a new line shall be started. Manual adjustments during logging shall not be made.

Formulas for calculations from measured CTD:

The formula from [*Chen and Millero*] or [*Del Grosso*] shall be used for calculation of sound speed.

Formula from [*Francois and Garrison*] shall be used for absorption coefficient calculation.

Alternative formulas may be accepted, provided they are documented to give better results.

7.4 Bathymetry

7.4.1 Accuracy requirements

General information about the requirements:

1. The requirements only apply for ***accepted*** data.
2. The requirements apply for ***all*** the accepted data (***not*** 95%)
3. Every accepted sounding shall fulfil ***all*** the specified requirements.
4. Accuracy limits scale with depth. The depth used in the formulas below, is the vertical distance between the mean sea level and the seabed.

Horizontal accuracy requirement

The horizontal position of the soundings on the seabed shall be within **±(0.5m + 0.016*depth)** from the correct value.

Overall vertical accuracy requirement

All accepted soundings shall be within the vertical distance of **±(0.2m + 0.004*depth)** from the correct value.

Vertical precision (consistency) requirement

The vertical precision (as defined in the Main survey consistency check, see 7.4.2) shall be within **0.2m + 0.004*depth**. The vertical precision is a point-to-point total depth difference and ***not*** a ± value.

7.4.2 Accuracy verification

The accuracy of the soundings will be checked in two steps

1. Verification area survey
2. Main survey consistency check

Verification area survey

Minimum one verification area shall be surveyed prior to the main survey. This area shall be an existing well-surveyed area with an already established reference surface.

Data from the verification survey shall be processed, and the accepted soundings will be compared to the existing reference surface.

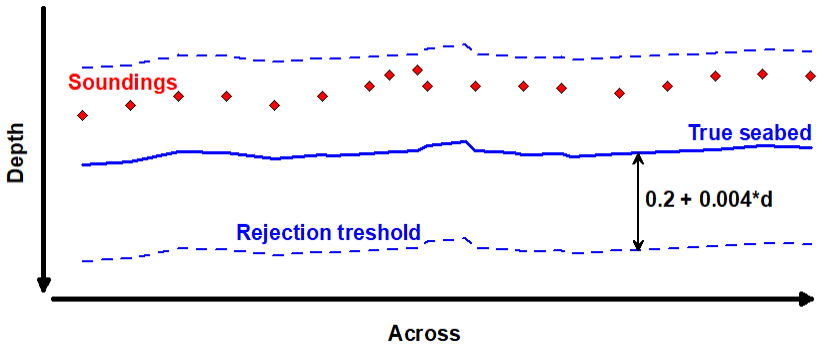

Figure 1 Verification by comparing the processed data to the existing reference surface (true seabed).

The verification survey is used to check both the overall vertical accuracy and the horizontal accuracy. Data acquisition in the verification area shall include backscatter, water column data and data from any other instrument which will be operated during the course of the survey. All data from the verification survey shall be delivered prior to the start of the main survey. These data will be checked as early as possible, preferably before the main survey starts.

Main survey consistency check

The internal consistency of the main survey is checked by comparing overlapping lines and neighbouring soundings. It is a measure of how well the overlapping lines and neighbouring soundings fit together. In this specification the vertical precision is defined as the vertical distance between neighbouring soundings. Physical terrain variations over the horizontal distance between the soundings must be considered and should ideally not be a part of this difference. This fact gives room for some subjective judgements regarding the measured depth differences.

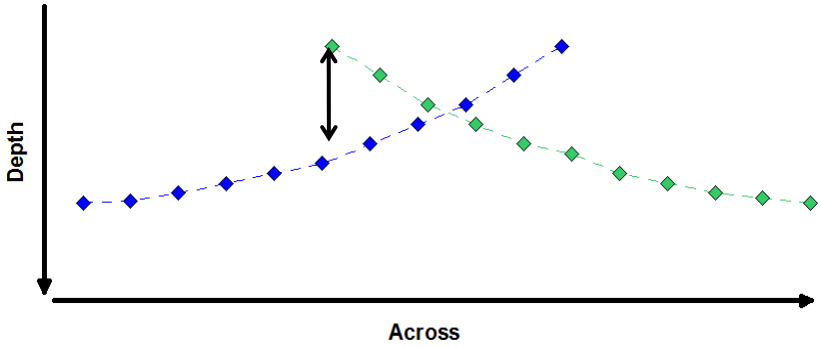

Figure 2 The overlap between two survey lines shows a depth difference between the two lines. In this example the vertical precision is the same as the difference in depth level between the lines.

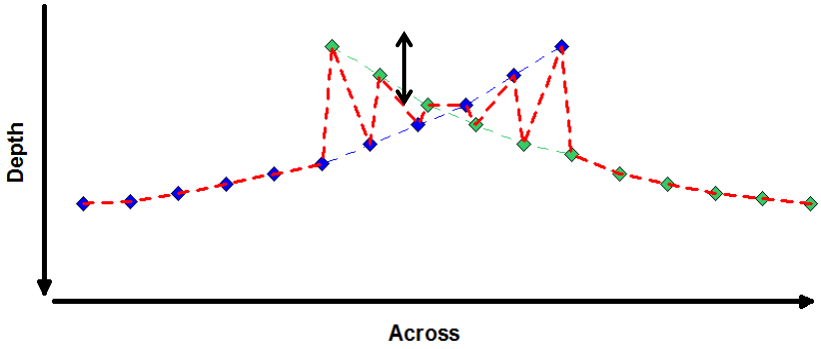

Figure 3 The tools used by NHS determines the vertical precision from the point-to-point variations (red line). Some allowance for real terrain variations must be added.

The overlapping areas between lines and neighbouring data will be used to check the vertical precision. Seabed features in overlapping areas will be used to check the horizontal accuracy.

7.4.3 THU and TVU

The 95% THU and TVU values as defined by IHO shall be calculated and reported for all soundings. These values shall be calculated from the best available knowledge about the survey system. No parameters shall be adjusted to fit the values to the specified requirements. The reported THU and TVU values will not be used for rejection of the data deliveries.

7.4.4 Resolution

The beam angle from nadir shall not exceed 60°. For deep areas where the echosounder range is the limiting parameter, the swath width shall be reduced to obtain good data on the outer beams. This gives the densest possible coverage within the maximum available swath width.

The sounding distance (both along track and across track) shall not exceed **2*depth*tan(60°)/399.**

The along track sounding distance shall not significantly exceed the across track sounding distance.

7.4.5 Data gaps

Data gaps are caused by missing soundings or by soundings rejected in the data processing. The accepted bathymetry data shall be checked for data gaps by defining a data gap grid (DGG). The DGG grid size is 2.5 times the nominal sounding distance.

Depth [m] Relative MSL	Nominal abeam sounding distance[m]	DGG grid size
3-10	0.1	0.5
10-20	0.2	0.7
20-40	0.4	1.0
40-70	0.6	1.5
70-100	0.9	2.2
100-200	1.7	4.3
200-300	2.6	6.5
300-400	3.5	8.7
:	:	:
$\boldsymbol{d_{min} - d_{max}}$	$SD = \frac{2\, d_{max} \tan 60°}{399}$	$2.5\ SD$
:	:	:
5400-5500	47.8	119.4
5500-5600	48.6	121.5
5600-5700	49.5	123.7

A DGG cell with less than **4** accepted soundings is defined as a gap

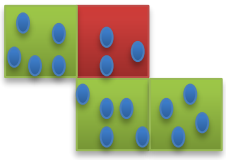

Figure 4 A DGG cell with less than 4 accepted soundings is defined as a gap

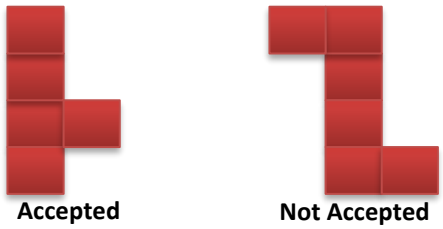

Figure 5 More than five adjacent DGG gap cells are not accepted

More than five adjacent (i.e. cells sharing one side) DGG gap-cells are not accepted, unless the area is without significant topographical details. In areas with no significant topographical details, a maximum of two subsequently missing pings are accepted. Inter-ping gaps due to yaw compensation, are also accepted in such areas. The total number of gaps shall, however, not exceed 0.1% of the DGG cells.

7.5 Backscatter data

Along with bathymetry, MBES backscatter data must be acquired to allow the creation of a high-resolution and high-quality backscatter mosaic, which is required by MAREANO for geological mapping purposes. Note that backscatter mosaic quality is often independent of the bathymetry data quality. Backscatter data are considered unusable where they are dominated by noise or other artefacts which obscure the natural variations in the acoustic reflectivity of the seabed. Unusable backscatter data are not acceptable for MAREANO, just as unusable bathymetry data are not acceptable (section 7.4.5 Data gapsData gaps).

The Contractor shall acquire backscatter data in its highest resolution format available, i.e., beam time-series data (see section 6.8.3 in Lurton and Lamarche, 2015). All necessary measures should be taken to acquire backscatter data with the best possible quality to ensure successful mosaicking. The Contractor shall be familiar with the guidelines and recommendations provided by the GeoHab backscatter working group (Lurton and Lamarche, 2015), in particular "Chapter 5 Acquisition: best practice guide". Further to this, the Contractor shall follow the guidelines below:

7.5.1 Angular dependence

The MBES echo backscattered by the seafloor naturally varies with the angle of incidence at the seafloor. This is expected behaviour and is corrected at the data processing stage. However, MBES also often show systemic angular dependence, that is, a backscatter level that varies with beam/angle due to the system itself, such as uncorrected beam patterns or unaccounted difference between transmit sectors. These issues are not always correctable at the data processing stage and may lead to substandard quality data.

- Prior to survey, the Contractor shall verify that their MBES does not produce any uncorrected systemic angular dependence. This verification should be made for all combinations of settings that will be used in the upcoming survey (section 7.5.2). If systemic angular dependence issues are found, the Contractor shall correct for them. Sonar manufacturers typically provide calibration solutions.

- During survey, the Contractor shall monitor the backscatter data acquired for any remaining systemic angular dependence. Should such issues arise, the Contractor should contact the Client directly to assess if remedial action is required.
- If an angular dependence calibration has been implemented, the Contractor shall provide the calibration parameters as part of the operation manual.

7.5.2 Acquisition settings

Modern MBES allow a range of different settings that can be tuned to optimize bathymetry data quality. These include, but are not limited to, frequency, CW/FM pulse types, and pulse length. Some MBES even allow "automated" modes of acquisition where the system automatically modifies some of these settings depending on some field conditions such as depth. However, different settings result in differences in backscatter level that are not always correctable at the processing stage. As a result, change of settings should be carefully considered and controlled.

- In particular, the Contractor shall avoid the use of automatic acquisition settings.
- Where changes to acquisition settings are unavoidable across the survey area due to bathymetric or other mapping requirements, the survey should be split into contiguous sub-areas (blocks) to be surveyed with a constant combination of settings. These considerations should be taken into account at the survey planning stage (see section 8.4).
- Follow manufacturer guidelines and allow some leeway in defining settings for each block, in order to avoid backscatter level saturation.

Other poorly controlled settings are known to have caused irretrievable damage to backscatter data in the past and so should be carefully tuned:

- Valid absorption coefficients for the entire water column shall be used at all times (section 7.3).
- Backscatter values shall not exhibit unnatural variations along or between lines due to incorrect or insufficient environmental corrections.
- Any depth or noise filters applied should not have a detrimental effect on the backscatter data quality, nor cause irretrievable loss of data.

All real-time acquisition parameters required to conduct post processing shall be included with the digital logged data.

7.5.3 Overlap lines for multiple systems

Different sonar systems, even when using the same settings, tend to have different backscatter data level. If more than one MBES and/or survey vessel is used within a survey block, then some data overlap is necessary to provide a reference dataset with which the systems can be inter-calibrated.

- At minimum, acquire one line with 100% overlap for all systems, where acquisition is conducted in the same direction.
- This line should have a length of at least 100 times the maximum grid size (see table section 10 for list of grid sizes by depth). For example, in an area

with water depths between 100-200 m, the grid size is 2 m, and so the overlap line should have a length of at least 100×2 = 200m.
- More overlap data is appreciated if possible. In particular, overlap data covering a wider range of backscatter values, or a wider range of depths.
- These lines should be clearly indicated in the delivery.

7.5.4 Degraded backscatter data level

During survey, some transient issues may occur, affecting backscatter data over one or several pings at a time. The most common issues are sudden drops in the backscatter data level due to turbulences at the sonar face (due to weather, ship wake, etc.), echo shadowing (from fish schools, etc.), or interferences (from ship noise, or other sonar systems operating at the same time). In general, backscatter data are more prone to this type of transient degradation than bathymetry data.

- The Contractor shall monitor the backscatter data acquired for sudden backscatter data level drops and other transient degradations.
- The survey speed and/or line direction shall be adapted to minimize the occurrence of these issues.
- If signal degradations are too frequent, typically due to bad weather, the survey in that area may need to be suspended.
- See the next section for the admissible quantity of degraded data in survey.

7.5.5 Pre-processing

Backscatter mosaics of each survey block shall be routinely produced onboard for QC purposes at resolutions appropriate for the depth (see table in section 10), using industry standard software. This workflow should be described in the operation manual.

- The backscatter processing steps used for production of the QC mosaic shall be documented in the operation manual. Any variations on this procedure for a particular block shall be included with the delivery e.g. non-default processing settings.
- A list of lines used in the mosaicking shall be provided (see section 10), together with information on any special priority weighting (line order) that were used to generate the delivered mosaic. Any lines that were excluded from the mosaic shall also be listed with reason given (e.g., resurveyed line, infill for bathymetry only). These excluded lines should still be included in the delivery.
- Do not apply cosmetic enhancement to the mosaic.
- If acquisition-related artefacts are observed in the mosaics, the Contractor shall verify that these can be overcome in post-processing. Where issues are identified that cannot be corrected in post-processing, new data shall be acquired to patch the areas presenting issues, whilst in the field.
- Overall, the total area of gaps or data of unusable quality (excluding the nadir zone) shall not exceed 1% of the area of each survey block.

7.6 Water column data

Water column data are essential for mapping natural and anthropogenic gas seeps. Natural gas seeps may indicate seep-related seafloor habitats and provide a better understanding of sub-surface features and processes.

7.6.1 Requirements for water column data collection

- Good quality water column data shall be collected for all lines.
- The water column quality data shall be monitored during the data acquisition. Noise sources masking real features such as gas plumes, fish schools or internal ocean waves should be identified and removed if possible.
- The power level across the swath should be constant even if multiple pings are used.

7.7 Sub-bottom profiler data

Sub-bottom profiler data are essential for mapping bottom types, sedimentary environments and processes on the seabed and below the seabed. Names commonly used for sub-bottom profiler are chirp, pinger, sediment echosounder and high resolution seismic. Sub-bottom profiler data should be collected during the multibeam echosounder mapping cruises.

7.7.1 Requirements for sub-bottom profiler data collection

Provided there is no interference between SBP and any MBE data (bathymetry, backscatter and water column data), all instruments shall be run in parallel, acquiring all data types at all times with no reduction of either data rate or resolution. In the event of significant SBP/MBE interference, the Contractor shall (in the tender) propose a data acquisition approach that offers a good compromise between data types. The Client will give guidelines for prioritizing between SBP and MBE data.

General requirements for SBP data acquisition:

- SBP data shall be motion corrected (see equipment requirements, chapter 5)
- There shall be a minimum of one line with high quality SBP data for each survey area. If the survey area size exceeds 1200 km^2, there shall be one high quality SBP line per 1200 km^2.
- If there is only one SBP line, this line should cross the central part of the survey area (±10 km from the central point). Provided that the SBP has no or little influence on the bottom detection for the MBE center beams (±20°), this line may be used as the survey area crossline (ref section 8.3).
- In case of more than one SBP line, the SBP lines should have an even distribution.
- Straight lines are preferred, but curved lines are acceptable if this is necessary to optimize acquisition of MBES data.
- The recording window below the seafloor should not be less than 0.2 seconds two-way travel time (TWT).
- The reflections should be represented by a single pulse. All acquisition source related multi-pulse signals (e.g. Chirp signal, multiple pulses at the source)

should be removed during recording or pre-processing of data before delivery.

- The ping rate should be as high as possible. Maximum ping intervals:
  - 0.5 second for water depths shallower than 500 m
  - 1 second for water depths between 500 m and 1000 m.
  - For deeper areas, the data rate should be as high as possible without interfering with the MBES data.

Depth range	Maximum value for range resolution *in TWT*
0-50 m	0.1 ms
50-100 m	0.2 ms
100-500 m	0.3 ms
500-1000 m	0.5 ms
1000-2500m	0.75 ms
>2500m	1 ms

8 Survey control

The Contractor shall document that all requirements given in this specification have been met. The Contractor shall continuously carry out Quality Control during data collection and processing. The Client shall have access to these procedures.

Any modification of the survey spread shall be documented and reported to the Client.

New equipment shall have the same or better quality as replaced equipment. Introduction of new vessels during the project may be accepted. This will, however, require a full documentation of the equipment and the vessel. The vessel survey report must be accepted by the Client before the new vessel is put into use.

8.1 Calibration and verification

The calibration and verification delivery (reports and data files) shall contain all the required information for a third party to verify the results. The uncertainty of the calibration and verification results shall be documented.

The Contractor is responsible for maintaining and documenting the total system performance during the survey. This shall be obtained by calibration and verification.

A verification of all determined calibration parameters is required before the parameters are put into use. This shall be part of the calibration and verification procedure.

Calibration of all equipment in the survey spread

The Contractor shall conduct a calibration of the total survey spread.

The Calibrations shall include but not be limited to:

- *Post-installation calibration*:

  Initial determination of system parameters (e.g. position and orientation of new sensors relative to the Body reference frame)

- *Scheduled calibrations*:

  This comprises both laboratory calibration of instruments according to service interval requirements, and onboard calibration of composite systems

- *Calibration after incidents or after equipment configuration changes*:

  This comprises the calibration of all equipment affected by an i incident, as well as calibration after remounting or replacement of essential parts of a system.

8.1.1 Survey vessel reference frame

A reference frame shall be defined for the survey vessel.

A sufficient number of permanently marked points shall be established at suitable locations on the vessel. All points intended for GNSS antenna mounting (e.g. marked by a drilled hole for the antenna attachment bolt) shall be surveyed (it is not sufficient to only survey the antenna itself). Surface vessels shall additionally have a minimum of 4 dedicated GNSS antenna mounts permanently marked in suitable locations for attitude sensor calibration.

Every sensor outputting data sensitive to sensor position or sensor installation angles shall have these values determined in the survey vessel reference frame.

Sensor positions as well as sensor installation angles shall (as a minimum) be determined to the accuracy level specified in the equipment installation manual. The position and installation angle accuracy requirements for every system component must be carefully judged, so that the accuracy of the final product is kept within the specified range.

The uncertainty of all surveyed reference points on the vessel must be sufficient to satisfy the accuracy requirement related to the use of the points (i.e. often related to sensor calibration requirements).

The installation survey report shall contain a full description of the survey and a clear presentation of the results. The procedure for the determination of sensor position and installation angles, as well as the uncertainty of the determined values, shall be well documented.

The installation survey delivery shall include the report and the digital observation files. This delivery shall contain all the required information for a third party to verify the results. An example of such a report can be found in "Info_A_alignment_report.pdf".

8.1.2 Sensor Alignment

Multibeam Echosounder

The MBES transducer installation angles shall be determined by a land-survey operation to obtain a sufficient connection to the survey vessel reference frame.

Attitude and Heading sensors

Attitude sensors shall be mounted on a rigid, machined surface with steering pins to ensure repeatable precision mounting.

The determination of vessel motion sensor and heading sensor installation angles shall be by use of at least four (preferably more) GNSS antennas, to obtain a time series of the "true" orientation of the survey vessel. During calibration, the vessel shall manoeuvre to obtain realistic attitude sensor behaviour. Installation angles are determined from the difference between the GNSS derived attitude values and the attitude sensor readings. Alternative methods will be accepted if they are documented to give better results.

Positioning sensor

GNSS antenna calibration values from the IGS shall be utilized.

Examples of sensor alignment are given in "Info_A_alignment_report.pdf".

8.1.3 Sensor Calibration

All equipment requiring regular calibrations against standards shall hold a valid calibration certificate from a certified institution. The equipment shall be maintained and handled according to manufacturer's recommendations to make it plausible that the equipment is kept within its accuracy specifications between calibrations.

The Contractor shall keep a historical record of all calibration and verification results for all equipment at the serial number level.

8.2 Field verification

The continued validity of the survey spread must be confirmed at relevant intervals during each survey season. Verification schedules shall be presented as a part of the tender. A new Field Verification is required after any modification or reconfiguration of the survey spread.

If the verification determines discrepancies of the installation parameters, additional calibration of the system is required.

As part of the survey mobilisation, the Contractor shall perform a Field Verification to document that the complete survey spread with all equipment systems operates within specifications. This test shall be performed in an area specified by Client. The field verification shall be done using all sensors in the manner the Contractor plans to operate. This is required in order to assess any interference problems.

8.3 Crosslines and line overlap

Survey line overlap

There shall be at least 10% overlap between survey lines (a new line shall cover 10% of the preceding line).

Crosslines

There shall be at least one crossline for every survey block (see section 8.4). The crossline shall cover the block from one side to the other in a direction between 70°

and 90° from the ordinary survey direction. Crosslines should be surveyed prior to the rest of the survey lines and used for verification during data acquisitioning.

8.4 Survey area and line planning

The total survey area shall be split into sub-areas (blocks), where data from each of which is considered a sub-delivery. Division of the blocks has implications for backscatter data as it is this dataset which is most sensitive to changes in acquisition settings which typically need to be changed with depth (gain, pulse length, frequency).

The following points should be followed as far as possible during survey planning:

- Blocks should be as large and square as is practically possible
- Blocks need not have a regular geometry but will follow depth contours allowing consistent acquisition settings and a single MBES and vessel to be used within each block.

8.5 Reports

All reports shall be sent by e-mail to a mailing list provided by the Client.

Daily reports during survey

These are very brief reports indicating daily problems and progress, the surveyed area [km^2] today.

Weekly reports during survey

More comprehensive (but still brief) reports indicating survey progress and status related to schedule.

The report shall contain

- The estimated survey completion date
- The estimated final delivery date
- The surveyed area [km^2] for both this week and the total so far, and a plot showing the area.
- Processing and QC progress and status related to schedule
- For each area: One plot showing all sound velocity profiles used by the echosounder
- Screenshots showing SBP and WCD data from each sub-area
- Energy used in connection with the contract during fieldwork this week and total so far.

Weekly processing reports after survey

Brief reports indicating processing and QC progress and status related to schedule. The report shall include the estimated completion date. Processing reports are requested during the time from survey completion until the data are accepted.

Final report

A final survey report shall be delivered as a part of the documentation. This report is the Contractors summary of the survey, and shall contain documentation of all hydrographical data, data processing (including corrections applied on SBP data), interpretation and information of data quality for all data types.

- The report shall as a minimum contain:
- Data collection method and their technical specifications and comments on the processes
- Geodetic reference system, positioning-methods, and their error budgets
- Date and time for the data collection
- All corrections applied to the data and details of Quality Control Procedures
- Estimates of random and systematic errors concerning the data
- Other data referred to in IHO S44, Chapter 5
- Experiences, comments, and findings
- Example maps/images of bathymetry, backscatter, WCD and SBP data. Colour ramps should be selected such that these examples highlight the full variation in values present.
- The total energy used during the fieldwork, including port calls and weather down time, etc.

Processing parameters should be included digitally together with the project data or be included in the final survey report.

The final survey report shall be submitted to the Client no later than three weeks after the completion of the quality-controlled data set.

Survey Delivery Report

All data deliveries shall include a Survey Delivery Report. This report shall contain the metadata for the survey (see Chapter 11) and all other relevant information to the specific survey. A template report can be found in *"Info_C_Survey_Delivery_Report_template.doc".*

9 Bathymetric data processing

Careful processing is required to obtain the specified data quality.

The processing shall focus on removing all faulty soundings at the same time as the seabed feature information is preserved.

Artefacts in the processed XYZ- data shall be kept at an insignificant level not disturbing the seabed image.

Faulty soundings shall be flagged as rejected, and no soundings shall be deleted.

XYZ-data shall not be smoothed.

10 Data product delivery

All data related to a survey block shall be delivered, including data outside the block limit.

10.1 Data types

- Accepted bathymetry XYZ-data (observed data)
- Rejected bathymetry XYZ-data (observed data)
- Horizontal and vertical uncertainty for each depth value (THU and TVU)
- Survey area boundary. The boundary must be unambiguously defined (not crossing itself). Bathymetry outside the boundary shall be flagged as rejected, and all areas within the boundary shall have enough accepted data to fulfil the density and quality requirements. The boundary should be as simple as possible.
- Preliminary bathymetry grids (floating point geotiff) based on roughly processed data and referred to the MSL by utilizing the DTU21 MSS model. These grids are used to during backscatter processing by The Client.
- Preliminary backscatter mosaics (floating point geotiff) and line-listing indicating which lines are included and their order or weighting in the mosaic (see section 7.5.5).
- Sensor data
    - Raw data from the MBES (all data required for the bathymetry, together with backscatter and water column data)
    - Sub-bottom profiler (UTM coordinates in SegY file)
    - Motion sensor data
    - GNSS data (RINEX)
    - Raw datafiles from the CTD or SVP sensor, plus the files used by the echosounder
    - Vessel track lines in ESRI compatible shapefile format (including line names) for all MBES data.
    - Vessel track lines in ESRI compatible shape file format for all SBP data. The shape file shall contain metadata about SegY filename, UTM zone and date of collection.

10.2 Data units and resolution

- Depths shall be given in metric units with 0.01 m resolution.
- Positions shall be given as decimal degrees with 0.0000001° resolution.
- THU and TVU shall be given in metric units with 0.01 m resolution.
- Grids (bathymetry and backscatter) shall be metric in the UTM projection. The Contractor shall include information about the utilized gridding algorithm and the parameter settings. The grid cell size is depth dependent.

Depth region	Max grid cell size
0 - 100 m	1 m
100 - 200 m	2 m
200 – 500 m	5 m
500 - 2000 m	10 m
2000 - 4000 m	25 m

4000 m ->	50 m

10.3 Data format

10.3.1 XYZ-files

XYZ- data may be divided into geographical (not projected) sub-areas and delivered as ASCII files. A file shall contain all accepted and rejected XYZ-data within the sub-area. Data shall be flagged as *Accepted* (Flag=0) or as *Rejected* (Flag=1). The files shall use the following record format:

Header

Latitude longitude height THU TVU Flag

Example:

#Survey name: TF2-NS05-cell001

#Survey time reference: 2020.65

#3D CRS EPSG code: 4937

```
71.5047873 16.4877026 -278.3 1.2 0.7 0
71.5047728 16.4876353 -277.6 1.3 0.9 1
71.5047694 16.4875822 -277.2 1.2 0.7 0
```

Other delivery formats can be agreed upon through negotiation.

10.3.2 Backscatter mosaics

Backscatter mosaics, at the resolutions specified above, shall be produced for QC of each survey block (section 7.5) are a required deliverable. These mosaics shall be delivered as georeferenced floating point *.tif* raster files unless otherwise agreed between the Contractor and the Client. A list of lines included in and excluded from this mosaic shall be supplied (section 7.5.5.). Any additional lines delivered should be tagged with a purpose which explains why they are excluded from the backscatter mosaic.

10.3.3 Water-column data

At least one screenshot showing typical water-column data and possible issues, per survey block.

10.3.4 Sub-bottom profiler

Data should be delivered in SegY-format with positions corrected for offset and given in the UTM coordinate system. Only one UTM zone should be used for the whole survey and the UTM zone should be selected appropriately based on the location of the survey. The SegY file name shall contain UTM zone and date of acquisition.

At least one screenshot showing typical sub-bottom profiler data and possible issues, per survey block.

10.3.5 Sensor data

Sensor data shall be delivered in a format agreed between the Contractor and the Client. This will generally be the raw, native format of the system manufacturer or acquisition software, however conversion to generic format may be required if this is not supported by software available to the Client. The Client shall have access to all data collected during the survey.

10.3.6 Survey area limits

The Survey area limit shall be delivered as ESRI SHAPE, and the SHAPE-files must be named exactly equal to the survey name and delivered as shown in Figure 6.

10.3.7 Exchange medium and format

The Contractor shall deliver all digital data on External-HDD, DVD or CD-ROM when suitable. All data shall be submitted in ASCII-format if not otherwise agreed between the parties. Checksum (sha1sum) for all individual files shall be generated prior to copying the files to dispatch disk. File checksums shall be a part of the delivery.

If available, the delivery shall include HIPS HDCS data and csar files.

10.3.8 File and folder structure of delivery

(Including naming convention)

The delivery file structure shall be according to Figure 6 shows the structure in file explorer.

A short description of selected folder content:

SurveyName

- **01_MBES**: logged files such as s7k, xtf, .all, .kmall, etc.)
- **02_SVP_XML**
- **03_SVP_raw**
- **04_SBP_raw**
- **05_GNSS_data**: Both raw and processed positioning or navigation data
- **06_MotionSensor data**: Raw logged motion sensor data or processed motion sensor data.
- **07_WCD**
- **08_SYSTEM_SETUP**: Setup-files for the navigation system (i.e. Pos Pac), logging system (i.e. SIS), motion sensor system (i.e. Seapath) and vessel (i.e. .hvf vessel-file).
- **PROJECTDATA**: Files connected to the processing software used. For instance EIVA project files, HIPS-data(CARIS), QIMERA internal data.
- **Screenshots and plots**: Backscatter mosaics together with WCD and SBP screenshots.
- **XYZ**: By first delivery XYZ files shall have a revision number rev0 in the filename. If first delivery is rejected, later deliveries of the same survey

should be named revA, revB, etc. Preliminary bathymetry grids shall be put in the corresponding XYZ subfolder.

- **Directly under the SurveyName folder** we expect shape file to the whole area, report and Excel sheet.

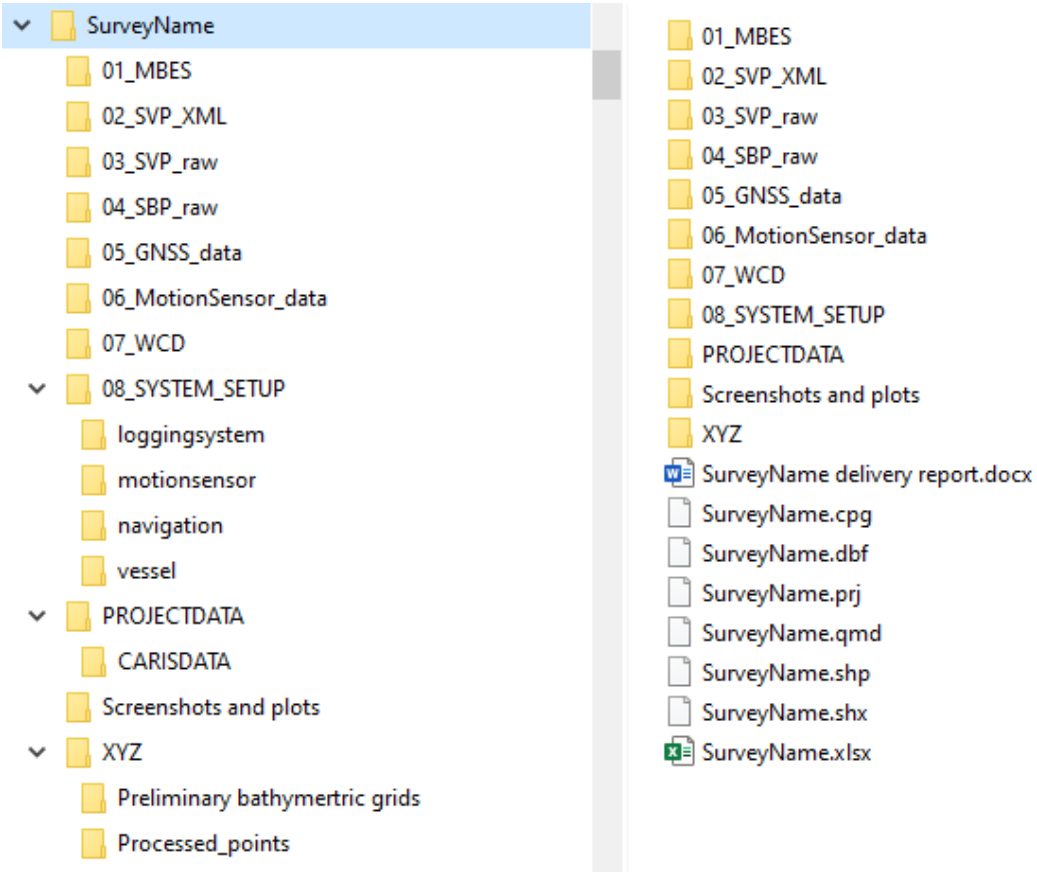

Figure 6 Folder structure for data delivery

11 Metadata

The metadata shall contain all significant information related to the data and the data processing. The metadata excel spreadsheet "Info_D_SurveyName.xlsx" must be completed and delivered (as an Excel-file) for each data delivery and placed in the delivery folder structure as shown in Figure 6.

When a value from the drop-down list is available this should be used. If no drop-down value exists, then use "undefined" in the drop-down list, and type the new value in the next column on the same row.

12 Data storage

Data which have been accepted by the NHS and NGU shall be preserved and retained by the Contractor for a period of five -5- years after the completion of the Work according to *Appendix*

3 Project and Progress Plan. The data shall be made available to the NHS upon request, free of charge.

13 Support

The Contractor shall provide support regarding the survey and the deliveries for at least 2 years after data acceptance.

14 Operation manual

The Contractor shall provide an Operation Manual (OM), which shall contain a complete description of the survey and the processing work. The description shall as a minimum include a description of the total survey spread, calibration, verification, data acquisition, data processing and data delivery procedures. In the OM, the Contractor should give feedback on his ability to fulfil every individual requirement of this technical specification.

15 References

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FRANCOIS AND GARRISON, *Francois R. E., Garrison G. R.*, "*Sound absorption based on ocean measurements: Part II:Boric acid contribution and equation for total absorption*", Journal of the Acoustical Society of America, 72(6), 1879- 1890, 1982

IHO S-44, *International Hydrographic Organization Standard for Hydrographic Surveys, Special publication No 44. 5th edition, February 2008.*

LURTON, X.; LAMARCHE, G. (EDS), *Backscatter measurements by seafloor-mapping sonars. Guidelines and Recommendations. 2015. 200p. https://geohab.org/wp-content/uploads/2018/09/BWSG-REPORT-MAY2015.pdf*