

**Specification  
of a multibeam survey  
in the North Atlantic.**

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# 1. Introduction

## 1.1. Objectives

The Geological Survey of Denmark and Greenland (GEUS), on behalf of the Danish Government, has a requirement to carry out surveys in specific regions on the continental margin and adjacent slope and rise north and northeast of the Faeroe Islands, in order to obtain multibeam bathymetry and backscatter data. These data are required to support a potential claim for extended jurisdiction by Denmark under the United Nations Convention on the Law of the Sea (UNCLOS) Article 76. There is a requirement for collection and processing of high quality, full-coverage multibeam data in water depths of approximately 2000 to 4000 meters in the Atlantic Ocean, in order to precisely define the location of the foot of the slope as defined under Article 76.

The specifications described herein are based in part on the International Hydrographic Organization's Standards for Hydrographic Surveys, Special Publication 44, Fourth Edition, April 1998, specifically for Order 2 surveys.

## 1.2. Description of survey area

See ANNEX B.

## 1.3. Definition

The term "hydrographer" as used through this document, refers to: (a) the chief of party or officer in charge.

## 1.4. Requirements

### 1.4.1. Ship

Provision of a survey vessel capable of acquiring deep-water multibeam swath bathymetry and multibeam sonar backscatter data in the designated areas north and northeast of the Faeroe Islands. Accommodation for at least one representative from GEUS.

### 1.4.2. Multibeam

Provision of a hull mounted deep-water multibeam system(s) and topside electronics aboard the survey vessel. The multibeam system shall collect full-coverage bathymetry and backscatter and be optimized to work in depths between 2000 and 4000 meters. The multibeam package shall include:

- differential GPS and navigation system.
- vessel motion sensing system.
- capability to collect and process data needed for water column speed of sound and

refraction corrections. Capability to collect and process on-line sound speed corrections collected at transmit point.

- the ability to process data underway and produce onboard plots suitable for real-time quality control.

### **1.4.3. Survey system and personnel**

The contractor will provide a complete survey system, including vessel, multibeam sonar system, operators and engineers, on-board data processing and QC capability and ancillary office capacity to support the survey program. The officer in charge will hold a IHO category A surveyors license or equivalent. CV's from relevant personnel will be included in the tender.

### **1.4.4. Survey planning**

The contractor, in consultation with GEUS, will take responsibility for survey planning.

## **2. Datum's and time**

### **2.1. *Horizontal datum***

All positions must be referenced to the WGS84. This datum must be used throughout a survey project for everything that has a geographic position or for which a position is to be determined. Those documents used for comparisons, such as charts, junctional surveys, and prior surveys, must be referenced or adjusted to WGS84. In addition, all software used on a survey must contain the correct datum

### **2.2. *UTM coordinates***

Unless otherwise specified all processed as data described in ANNEX A must be related to WGS84 Universal Transverse Mercator (UTM) zone 30.

### **2.3. *Vertical Datum***

All sounding data must be corrected for tides related to Mean Low Water Spring (MLWS). Corrections will be supplied by GEUS prior to commencement of the survey.

### **2.4. *Time***

Coordinated Universal Time (UTC) shall be used for all time records

## **3. Position control**

### **3.1. Horizontal position accuracy**

With reference to IHO SP-44 the specification for hydrographic positioning is that the total error in position of soundings, and all other significant features, at the 95 percent confidence level, must not exceed 20 meters + 5 percent of the depth.

For multibeam surveys, due to the oblique sounding pattern, the position of a sounding may be at some distance from the vessel position. The accuracy requirement for the vessel position will depend upon how accurately the sounding is positioned relative to the vessel. That, in turn, will depend upon the characteristics of the multibeam system, depth of water, the accuracy with which heave, roll, pitch, heading, and latency are accounted for and applied, and the reliability with which the speed of sound profile is known.

### **3.2. Differential Global positioning system**

DGPS will be the primary positioning system currently used for the hydrographic survey. DGPS corrections may be obtained using WASS/EGNOSS corrections if WASS/EGNOSS is in operation or by other means.

### **3.3. DGPS specifications**

#### **3.3.1. Elevation of satellites**

GPS receiver(s) aboard the vessel will be configured such that satellites below 8 degrees above the horizon will not be used in position computations.

#### **3.3.2. Age of DGPS corrections**

The age of pseudo-range correctors used in position computation must not exceed 20 seconds; however, any horizontal positioning interpolation must not exceed the accuracy requirement in Section

#### **3.3.3. Horizontal Dilution of Precision (HDOP)**

Horizontal Dilution of Precision (HDOP) will be monitored and recorded, and should not exceed 4 nominally. Satellite geometry alone is not a sufficient statistic for determining horizontal positioning accuracy. Other variables, including satellite pseudorange residuals, are used in conjunction with HDOP to estimate DGPS horizontal accuracy.

#### **3.3.4. Number of satellites**

A minimum of four satellites must be used to compute all positions.

#### **3.3.5. Offsets**

Horizontal and vertical offsets between the GPS antenna and transducer(s) shall be observed and applied with a precision better than 0.1 m

### **3.3.6. Source of DGPS corrections**

DGPS corrections obtained by any other means than WASS/EGNOSS requires a description of the reference station used.

## **4. Tides and water level**

Tides shall be applied. Corrections will be supplied by GEUS prior to commencement of the survey.

## **5. Depth sounding**

### **5.1. Resolution and coverage**

The multibeam sonar will have an effective beam width of no greater than 2 degrees in both the along-track and cross-track directions and lateral coverage of at least 3000 meters for depths greater than 1000 meters. Maximum cross-track swath opening angle must be  $\pm 60$ deg for bathymetric data. For backscatter data cross-track swath opening angle may be opened to  $\pm 75$ deg.

### **5.2. Sounding units**

Depths shall be recorded in meters, with a precision of at least tenths of meters. Plotting units for final deliverables will be meters.

### **5.3. Accuracy and resolution standards**

#### **5.3.1. Accuracy standards**

The accuracy of measured depths in the hydrographic survey applies to the systematic measurement of general water depths and to the least depths determined over any obstructions.

The total sounding error in a measured depth at the 95 percent confidence level, after systematic and system specific errors have been removed, shall not exceed:

$$\pm \sqrt{[a^2 + (b * d)^2]}$$

In depths greater than 100 meters,  $a = 1.0$ ,  $b = 0.023$ ,  $d = \text{depth}$  (IHO S-44, Order 2).

The maximum allowable error in measured depth includes all inaccuracies due to residual systematic and system specific instrument errors; the velocity of sound in water; static vessel draft; dynamic vessel draft; heave, roll, and pitch; and any other sources of error in the actual measurement process.

The total sounding error is applicable to swath widths of at least 3.4 times the water depth (i.e., 60deg to both sides of nadir).

### **5.3.2. Multibeam Resolution Standards**

The hydrographer shall maintain and operate the Multibeam sonar system, from data acquisition to processing, such that it detects shoals with a minimum size of detectable targets. The minimum size shall not exceed 10 percent of the depth for horizontal dimensions and 5 percent of the depth for vertical dimensions. Depths shall be determined and recorded with a vertical resolution no coarser than 10 centimetres. The hydrographer shall ensure that vessel speed is adjusted so that the bottom coverage 100% in the along track direction is maintained.

Sounding track lines shall generally be parallel. Sinuous lines and data acquired during turns shall *not* be included in the final processed data, and shall *not* be used to meet coverage requirements.

## **5.4. Coverage**

### **5.4.1. 100% coverage**

The hydrographer shall insure that the multibeam coverage is 100% within the defined area.

### **5.4.2. Line spacing**

Line spacing shall be such that the portions of the swaths used as part of the delivered data set meet the accuracy and resolution requirements in Section 5.2 overlap to ensure that no gap in coverage exists due to the uncertainty in positioning and vessel motion.

## **5.5. Demonstration of Coverage**

Regardless of coverage technique, the hydrographer shall demonstrate bottom coverage using a raster summary image, colour coded by depth. The raster image shall be created from fully corrected data that meet accuracy and resolution specifications (see Section 5, Depth Sounding) are cleaned of all anomalous soundings, and serve as the source for all smooth sheet soundings. Each coloured cell in the raster image shall be binned, line by line; using shoal biased filtering at a bin size that does *not* exceed 5 meters + 5 percent of the depth.

The submitted digital image file shall be in a standard geo-referenced image format.

## **5.6. Corrections to echo soundings**

To meet the accuracy and resolution standards for measured depths specified in Section 5.2, observed echosounder depths must be corrected for all departures from true depths attributable to the method of sounding or to faults in the measuring apparatus.

In recognition of the possibility that some discrepancies in sounding may not be detected until the post-processing phase of the survey, the determination and application of corrections to echo soundings must be accomplished and documented in a systematic manner. In addition, all corrections shall be applied in such a way that the on-line values may be removed and replaced with a revised set of correctors in post-processing.

### **5.6.1. Category of corrections**

Corrections to echo soundings are divided into five categories, and listed below in the sequence in which they are applied:

#### **5.6.1.1. Instrument error corrections**

*Instrument error corrections* account for sources of error related to the sounding equipment itself.

#### **5.6.1.2. Draft corrections**

*Draft corrections* shall be added to the observed soundings to account for the depth of the echosounder transducer below the water surface.

#### **5.6.1.3. Appropriate corrections for settlement and squat**

*Appropriate corrections for settlement and squat* shall be applied to soundings to correct the vertical displacement of the transducer, relative to its position at rest, when a vessel is underway.

#### **5.6.1.4. Velocity of sound correctors**

*Velocity of sound correctors* shall be applied to soundings to compensate for the fact that echosounders may only display depths based on an assumed sound velocity profile while the true velocity may vary in time and space.

#### **5.6.1.5. Heave, roll, pitch, heading, and navigation timing error**

*Heave, roll, pitch, heading, and navigation timing error (latency) corrections* shall be applied to Multibeam soundings to correct the effect of vessel motion caused by waves and swells (heave, roll, pitch), the error in the vessel's heading, and the time delay from the moment the position is measured until the data is received by the data collection system (navigation timing error).

### **5.6.2. Instrument error corrections**

Any instrumental error must be documented and applied for. The vertical (nadir beam) of the multibeam echosounder must be checked against a known reference e.g. a calibrated singlebeam echosounder. To ensure the proper operation of echosounders, "confidence checks" shall be conducted periodically.

Comparisons should be conducted during calm sea conditions, preferably in areas with a relatively flat bottom. Any differences should be investigated, and if, after analysis, a corrector is necessary, it should be applied with an explanation of the cause of the difference.

### **5.6.3. Draft corrections**

The corrections for draft account for the depth of the transducer face below the surface of the water. Draft corrections comprise a value for the draft of the vessel at rest, sometimes known as static draft, and settlement and squat corrections which compensate for the variation in draft that occurs when the vessel is making way. The sum of the static draft and the settlement and squat correctors is known as the dynamic draft. Draft is transducer-specific. When more than one transducer is fixed to a vessel, the hydrographer must exercise care to apply the proper draft correction for *each* transducer.

### **5.6.3.1. Static draft**

The static draft, as an echo-sounding correction, refers to the depth of the transducer face below surface of the water when the vessel is *not* making way through the water. The required frequency of static draft measurements depends upon the range of variation in the vessel draft and the depths of water to be surveyed. The static draft shall be observed and recorded to the nearest 0.1 m.

Draft values must be observed and entered into the record before departing from and upon returning to port. In both cases, the draft should be determined by averaging the max/min or beginning/ending values if the differences do not exceed  $\pm 0.2$  m. Otherwise, the applicable draft should be determined in 0.1 m increments. If significant changes to a vessel's draft (greater than  $\pm 0.1$  m) occur, draft values shall be modified and applied accordingly.

If the static draft is monitored and logged using a pressure cell throughout the survey this correction for change in draft may be used and applied to the measured depths.

### **5.6.3.2. Settlement and squat**

Transducers are generally displaced vertically, relative to their positions at rest, when a vessel is making way. Depth measurements are correspondingly affected by these vertical displacements. The displacements may be of sufficient magnitude to warrant compensation, especially when sounding at moderate to high speeds in shoal water. The factors accountable for this vertical displacement are called settlement and squat.

*Settlement* is the general difference between the elevation of a vessel when at rest and when making way

*Squat* refers to changes in trim of the vessel when making way and is generally manifested by a lowering of the stern and rise of the bow.

As part of the documentation a description (model or otherwise) of the vessels settlement and squat at relevant survey speeds must be included.

## **5.7. Velocity of sound corrections**

To ensure that the overall depth measurement accuracy criteria specified in Section 5.2 are met, velocity of sound observations should be taken with sufficient frequency, density, and accuracy. The accuracy with which the speed of sound correction can be determined is a complex function of the accuracy with which salinity, temperature, and depth, or alternately, sound speed and depth, can be measured.

The sound speed profile in the survey areas must be measured and monitored at sufficient frequency and to an appropriate depth to assure that the bathymetric data provided meets the required depth accuracy specification. The sound speed profile should be determined with a calibrated system capable of measuring the speed of sound with errors no greater than 2 m/sec (at the 95% confidence level). A calibrated sound speed measuring system capable of measuring the sound-speed profile to at least 95% of the deepest anticipated depth in the survey area must be available, though collection of sound speed data to 95% of the full depth of the survey area will only be required before and after the completion of the surveys. The on-line sound speed collected at transmit point will be merged on time basis with the sound speed profile. On daily basis profiles shall be obtained to a water depth of at least 1000m. These profiles have to be used as top of the profiles with the full profile obtained before the survey. The top profiles may be obtained by either XBT's or XCTD's at an interval of no more than 12 hours or 200NM whichever greatest.

Sound speed at transmission point (on-line sound speed measurement) shall be obtained and used at all times as top of the profile to a water depth 2m below the transducer.

Regardless of the sound velocity determination system employed, an independent sound velocity measurement system must be used to establish a confidence check. Confidence checks shall be conducted at every profile measurement. A comparison between the profile measurements at the depth of the on-line sound speed sensor may be used as a confidence check.

### **5.8. Heave, roll, pitch, heading, and navigation timing error**

Heave, roll, pitch, heading, and navigation timing error corrections shall be recorded in the data files and applied to all multibeam soundings and cross-track distances as applicable.

*Heave, roll, and pitch.* Heave shall be observed in no coarser than 0.05 m increments. Roll and pitch shall be observed in no coarser than 0.05 degree increments.

*Heading* shall be observed in no coarser than 0.1 degree increments.

*Navigation timing error* shall be observed in no coarser than 0.01 second increments.

## **5.9. Error budget analysis for depths**

The hydrographer shall document in the Descriptive Report the methods used to minimize the errors associated with the determination of depth (corrections to echo soundings). Error estimate ranges for six of these errors (measurement error, transducer draft error, settlement and squat error, sound velocity error, heave error and tide/water level error) are presented below. These errors are inherent to hydrographic surveying and all have practical minimums that are usually achievable only under ideal circumstances or with highly specialized equipment. In addition, some errors may be dependent on depth (e.g. sound velocity). Maximum allowable errors are specified to ensure that all errors sources are properly managed. It should be noted that if the maximum value for each error source is used in an error budget (i.e. root-sum-squared), the result shall be within the prescribed accuracy standard. The minimum and maximum values discussed below are at the 95% confidence level (i.e. 2 sigma).

### **5.9.1. Measurement error**

Measurement error: This includes the instrument error for the sounding system, the effects of imperfectly measured roll/pitch and errors in detection of the sea floor due to varying density of the bottom material. The maximum allowable error is 0.30 meter plus 1 % of the depth.

### **5.9.2. Transducer draft error**

Transducer draft error: This error is controlled by variability in vessel loading, and the techniques used to measure/monitor transducer draft. This error is depth independent with an expected minimum of 0.05 meter and an allowable maximum 0.15 meter.

### **5.9.3. Settlement and squat error**

Settlement and squat error: Conventional methods of determining settlement and squat are limited by sea surface roughness and proximity of a suitable location to the survey area. This error is also depth independent although the effect of settlement and squat is greater in shallow water. The practical expected minimum is 0.05 meter and the allowable maximum is 0.20 meter.

#### **5.9.4. Sound velocity error**

Sound velocity error: The factors associated with this error include (1) the ability to accurately measure sound velocity or calculate sound velocity from temperature, conductivity and pressure, (2) the spatial and temporal changes of sound velocity throughout the survey area and (3) how the sound velocity profile is used to convert measured time to depth. In addition, this error encompasses depth errors associated with refraction for the multibeam systems. The allowable maximum is 0.30 meter plus 0.5% of the depth.

#### **5.9.5. Heave error**

Heave error: This error is directly dependent on the sea state and the sensitivity of the heave sensor but is not dependent on depth. The expected minimum is 0.05 meter and the allowable maximum is 0.20 meter.

#### **5.9.6. Tide/water level error**

Tide/water level error: This error is not to be accounted for in this survey.

### ***5.10. Quality control***

#### **5.10.1. Multibeam sonar calibration**

Prior to commencing the survey operation, the hydrographer shall conduct a system accuracy test to quantify the accuracy, precision, and alignment of the multibeam system. Testing shall include determination of residual biases in roll, pitch, heading, and navigation timing error. These values will be used to correct the initial alignment and calibrate the multibeam system. System accuracy testing should be conducted in an area similar in bottom profile and composition to the survey area, and during relatively calm seas to limit excessive motions and ensure suitable bottom detection. In addition, system accuracy tests should be conducted in depths equivalent to the deepest depths in the survey area. Static transducer draft, settlement and squat corrections, sound velocity corrections, and tide corrections shall be determined and applied to the data prior to bias determination.

The order in which these biases are determined may affect the accurate calibration of the multibeam system. The hydrographer should determine the biases in the following order: navigation timing error, pitch, roll, and heading. Variations from this order, or simultaneous determination of all values, must be explained and justified.

Pitch and navigation timing error biases should be determined from two or more pairs of reciprocal lines over a 10°–20° smooth slope, perpendicular to the depth curves. The length of the lines must ensure that at least 200 swaths are collected. The lines should be run at different speeds, varied by up to 5 knots, for the purpose of delineating the along track profiles when assessing time delay. Navigation timing error bias could also be determined from running lines over a distinct feature (i.e., shoal) on the bottom, as long as the feature is pinged by the vertical (nadir) beam.

Roll bias should be determined from one or more pair of reciprocal lines over a flat bottom. The length of the lines must ensure that at least 200 swaths are collected. Lines should be run at a speed which will ensure significant forward overlap.

Heading bias should be determined from two or more adjacent pairs of reciprocal survey lines, made on each side of a submerged object or feature (i.e., shoal), in relatively shallow water. Features with sharp edges should be avoided. Adjacent swaths should overlap by 10–20 percent while covering the shoal. Lines should be run at a speed which will ensure significant forward overlap.

Once calibration data have been processed and final system biases determined, the new corrections shall be used in a performance check to ensure that the new system biases are adequate. The hydrographer shall discuss procedures and results in report. Copies of all system alignment, accuracy, calibration reports, and performance checks shall be included in the final report.

System accuracy testing shall be repeated whenever changes (e.g., sensor failure, replacement, re-installations, re-configurations, or upgrade; software changes which could potentially affect data quality) are made to the system's baseline configuration, or whenever assessment of the data indicates that system accuracies do not meet the requirements in Section 5.2.

### **5.10.2. Positioning System Confidence Checks**

Confidence checks of the primary positioning system shall be conducted and recorded in the survey records at least prior and after the survey. The position check may be conducted in port on the Faeroe Islands. GEUS may supply coordinates for the positioning check in a port on the Faeroe Islands.

### **5.10.3. Cross-lines**

#### **5.10.3.1. General**

The regular system of sounding lines shall be supplemented by a series of cross-lines for verifying and evaluating the accuracy and reliability of surveyed depths and plotted locations. Cross-lines shall be run across all planned sounding lines at angles of 90°. The preferred area in which to run cross-lines is in an area of gently sloping bottom.

#### **5.10.3.2. Multibeam cross-lines**

The cross-lines shall be run at an interval as described in Annex B.

Comparisons shall be made between main scheme lines and cross-lines at 1% of all crossings (or 25 crossings, whichever is greater) distributed throughout the data both spatially and temporally. At these crossings the nadir or near-nadir depths of main scheme lines shall be compared to each of the nearest unsmoothed soundings obtained from the cross-lines. The hydrographer shall perform a separate statistical analysis as a function of beam number for each of the main scheme/cross-line intersections used for

comparison. Include a statement about the results in the Descriptive Report, and include a summary plot of each crossing.

### **5.11. Multibeam Sun-Illuminated Digital Terrain Model (DTM) Images**

The hydrographer shall create two sun-illuminated DTM images. These sun-illuminated DTM images are the preferred method for detection of depth artifacts associated with errors in bottom detection algorithms, vessel motion compensation, navigation timing, water level correctors and false bottom detections.

Each image shall depict data illuminated from orthogonal directions, using a light source with an elevation no greater than 45 degrees. At a minimum, an 8 bit colour depth shall be used for compilation of the sun-illuminated images. The two sun-illuminated images shall be created from fully corrected data that meet accuracy and resolution specifications are cleaned of all anomalous soundings, and serve as the source for all smooth sheet soundings. Data shall be binned, line by line, using shoal biased filtering at a bin size not to exceed 5 meters + 5 percent of the depth.

The submitted digital image file shall be in a standard geo-referenced image format.

## **6. Gravity data**

### **6.1. Requirements to gravimeter**

The gravity data should be collected with a marine gravimeter, e.g. Lacoste and Romberg or similar type, capable of providing gravity measurements at an accuracy better than 2 mgal r.m.s. (1 mgal =  $10^{-5}$  m/s<sup>2</sup>) after filtering. The filtering length (full width) will be no longer than 5 min. The drift of the gravimeter during marine observations will be less than 5 mgal/month. The contractor will indicate the performance and reliability of the proposed gravity survey system. In case of shorter errors or gaps in the gravimetric data collection, while operating with multibeam bathymetry, GEUS will not request a resurvey. However, as overall objectives 95% of all planned bathymetric survey lines longer than 5 km must have useable gravity data.

### **6.2. Confidence check**

The marine gravity measurements will be tied to harbour reference gravity points before and after the bathymetric/gravimetric survey, ideally the Faeroe Islands (GEUS will provide the necessary information). If the tie-ins are more than 1 week prior or after the actual survey, the contractor will demonstrate the performance of the gravimeter to be sufficiently stable to give a bias accuracy of better than 2 mgal during the survey period. The gravity reference point values must be given in absolute gravity system or IGSN71. A land gravimeter will, if necessary, be used to tie into reference gravity points not immediately located at pier.

## **7. Backscatter data**

### **7.1. Collection of backscatter data**

For all multibeam data a backscatter data set shall be collected and delivered in a documented format. Either as part of the multibeam data set or in separate backscatter data files. The data files shall be delivered in a format that can be imported to Caris SIPS.

### **7.2. Backscatter mosaic**

A backscatter mosaic must be created and draped on top of the bathymetric data. The methods used to create the backscatter mosaic shall be documented.

## **8. Data delivery**

### **8.1. Media for data delivery**

All digital data shall be delivered on USB2 disc devices. The delivery shall consist of a master and an identical backup copy.

### **8.2. Raw data**

All of the digital output from the multibeam sonar during data acquisition, and ancillary data not already integrated into the multibeam data stream including full orientation and position data, sound velocity profile information, tidal information and the integration parameters used including (but not limited to) installation offsets, misalignment angles and clock time differences. Positional information will include, at least: number and geometry of satellites used in position computations; age of pseudo-range corrections used in position computation, and; horizontal dilution of precision associated with each position computation. In addition to data provided with sonar data telegrams, separate files containing the tide data and sound speed data applied to all multibeam soundings will also be provided. Tidal data will be supplied by GEUS prior to the survey. The data format and all data element descriptions (e.g., date/time referenced to UTC, tide relative to MLWS to nearest cm, etc.) will be described.

### **8.3. Processed full density data**

Aboard ship, during the data acquisition phase, all the raw data, including multibeam and ancillary integrated sensors must be examined and errors removed. Data will be reduced for position, elevation, orientation, water column sound speed and refraction effects and provided in a cleaned fully integrated form. All soundings and ancillary raw and reduced data must be provided with quality flags, indicating whether the data has been rejected or deemed to be outside deliverable survey specifications. Cleaned, reduced data will be provided on appropriate media in FAU format (Annex A) WGS84/UTM zone 30.

### **8.4. Conservation of multibeam data**

All data must be conserved in the dataset. Deleted data must be flagged in accordance with Annex A.

### **8.5. *Reduced data set.***

A set of gridded data will be produced from the processed sounding data, from which two color-coded shaded relief maps will be delivered. The shaded relief models will be illuminated from orthogonal directions with a sun elevation no greater than 45 degrees. Data will be gridded at a grid size that is approximately twice the mean horizontal footprint of the beam at nadir (e.g., a 1.5 degree system at 1000 m would be gridded at ~50 m). This implies that the data set will be divided into regions of common depth and gridded at different scales depending on depth. The number of gridding regions will be determined in consultation with GEUS. Other representations that achieve the same resolution limits may also be acceptable. Gridded data will be delivered in digital files on appropriate media as both FAU grids and ASCII XYZ format.

### **8.6. *Backscatter data***

For all multibeam data, raw backscatter data and reduced estimates of the seabed backscatter strength must be provided. The methods used to reduce the backscatter data will be fully documented. Geo-referenced maps of backscatter shall be provided at same scale as specified in paragraph 8.10.1.3.

A geo-referenced image file with the backscatter data draped on top of the bathymetric data shall be part of the delivery.

### **8.7. *Gravimetric observations***

Gravity data should be collected on all straight-line bathymetric tracks of at least 5 km length and constant speed. The raw marine gravity data will be collected and stored at 10 sec intervals or less. The contractor will provide GPS coordinates from the ship navigation system and bathymetric data depth vertically below ship extracted from multi-beam data at a similar interval for the processing of gravity data into marine free-air and Bouguer anomalies.

Processing of data will be done with zero-phase filtering, providing track no, UTC, latitude, longitude, filtered gravity, free-air anomalies (GRS80 ellipsoid) and marine Bouguer anomalies (standard density 2.67 g/cm<sup>3</sup>). A detailed processing report should include details on filtering and harbour gravity ties.

In case gravity harbour ties will require a major cost effort in terms of extra ship time, GEUS may be willing to accept the substitution on one or more harbour ties with ties (cross-overs) with existing marine surveys, providing such surveys are recent (i.e., GPS navigation has been used), demonstrated to have an accuracy of 1.5 mgal r.m.s. or better, and a well-defined and well-described gravity reference system. It is up to the GEUS to verify the quality of such data, and GEUS will give its consent for the substitution of harbour ties in advance. GEUS will be willing to help in providing information on suitable tie-in data sources from the national Danish gravity data base.

### **8.8. *Metadata***

Metadata will be provided for all bathymetric, backscatter and gravity data files.

### **8.9. Plot files**

All data and digital plot files shall be provided on appropriate digital media in a completely documented format. The contractor will also provide a detailed listing of all files submitted, their size, and format.

### **8.10. Interim report**

An interim report, including raw and processed data and draft color shaded relief maps and backscatter maps, shall be delivered to GEUS within one week of completion of operations.

### **8.11. Descriptive report**

The Descriptive Report is required for the hydrographic survey sheet completed, after field data acquisition and processing of the survey has been completed.

The primary purposes of a Descriptive Report are to:

- 1) help in evaluation of the survey;
- 2) assist the compilers producing or revising charts covering the area in which the survey has been conducted;
- 3) document various specifications and attributes related to the survey and its by-products;
- 4) provide a legal description of the survey standards, methods, and results. The Descriptive Report is archived as a historical and legal record for the survey.

The Descriptive Report supplements hydrographic sheets and sounding records with information that cannot be depicted or described in the digital data, or shown clearly in graphic form. The Descriptive Report describes the conditions under which the survey was performed, discusses important factors affecting the surveys adequacy and accuracy, and focuses upon the results of the survey. It contains required information on certain standard subjects in concise form, and serves to index all other applicable records and reports.

The following information is required in each Descriptive Report in the order listed below:

**COVER SHEET** with a clear indication of the area covered at a scale shown at a resolution equivalent to the DTM size. The cover sheet may be delivered in digital form. If delivered digitally the format must be in a standard geo-referenced image format.

**TITLE SHEET** see Annex C). The “Hydrographic Title Sheet” may be referred to for information pertaining to the survey.

The “General locality” will be dictated by the GEUS.

The “Start end date of survey” entries are the inclusive dates of the fieldwork.

The “Horizontal and vertical datum” and “Vertical measurement system” are dictated.

The “Min/max northing/easting and min/max latitude/longitude must describe the area covered.

For “Vessel name”, enter the name of the survey vessel.

For “Nationality”, enter the ship home port state.

The name(s) listed after “Surveyed by” are the personnel who supervised sounding operations and/or data processing.

The instrument section, enter the brand and type of equipment used as well as calibration dates.

The “Remarks” section should contain any additional information, that will identify the project or clarify the entries above. Other Descriptive Reports or special reports containing information or data pertinent to the survey that are not listed in Section E of the Descriptive Report text should be referenced here. Note the time zone used during data acquisition (e.g., All times are recorded in UTC). List the name and address of the contractor and any subcontractors.

***DESCRIPTIVE REPORT TEXT.*** Print the text on one-sided A/4 paper with left-hand margins of 3cm to permit binding. Do not use oversized sheets. Text shall be Times New Roman, with a font size of 12. Include all information required for complete understanding of the field records. If references are made to hydrographic features on any sheets, give the latitude, longitude and datum of the feature. Discussions and explanations should be written in a clear and concise manner.

A digital copy of the Descriptive Report shall be provided in Word format.

Pages shall be numbered consecutively from the first page of text, continuing through the Approval Sheet (page numbers as footer, centred on page). Include a Table of Contents with page numbers.

Avoid using geographic names in the text of the Descriptive Report that do *not* appear on the nautical charts unless otherwise stated by the contractor.

## **A. AREA SURVEYED**

Include a coverage graphic inclusive of the survey area. The information related to the survey should be clearly shown and highlighted in some way to draw attention to its location within the project area.

## **B. DATA ACQUISITION AND PROCESSING**

### **B1. Equipment**

In this section of the Descriptive Report list by manufacturer and model number only the major systems used to acquire survey data or control survey operations (e.g., multibeam sonar, vessel

attitude system, positioning system, sound velocity system). The calibration dates of the equipment used must be included. Include a brief description of the vessel (e.g., length overall and draft). A detailed description of the systems used to acquire survey data or control operations shall be included in the **Data Acquisition and Processing Report** (for details see 9.9.1.1).

Include in a narrative description, with figures when useful, of any deviations from the vessel or equipment configurations described in the **Data Acquisition and Processing Report** (for details see 9.9.1.1).

## **B2. Quality Control**

Discuss the internal consistency and integrity of the survey data. State the percentage (dictated by GEUS) of cross-line miles as compared to main scheme miles. Evaluate their general agreement. If the magnitude of the discrepancy varies widely over the sheet, make a quantitative evaluation of the disagreements by area. Explain the methods used to reconcile significant differences at crossings, and give possible reasons for cross-line discrepancies that could not be reconciled.

Discuss any unusual conditions encountered during the survey which would downgrade or otherwise affect the equipment operational effectiveness. Discuss any deficiencies that would affect the accuracy or quality of sounding data. Document these conditions; including how and when they were resolved.

Describe any other factors that affected corrections to soundings, such as sea state effects, and unusual turbidity, salinity, or thermal layering in the water column.

## **B3. Corrections to Echo Soundings**

Discuss any deviations from those described in the **Correction to Echo Soundings** section of the **Data Acquisition and Processing Report** (for details see 9.9.1.1).

Discuss the results of any patch test conducted after the initial patch test that affect the survey data and were not included in the **Data Acquisition and Processing Report**. Comment on the reason a new patch test was conducted.

## **C. VERTICAL AND HORIZONTAL CONTROL**

State in the Descriptive report that corrections for tide was delivered by GEUS and applied.

State the horizontal datum and projection used for this survey. Briefly discuss the control stations used during this specific survey if other corrections than WASS/EGNOSS DGPS corrections are used. Explain in detail any difficulties that may have degraded the expected position accuracy.

## **D. RESULTS**

Provide information of significant scientific or practical value resulting from the survey. Unusual submarine features should be described. Discuss any environmental conditions encountered, which have a direct bearing on the quality and accuracy of the hydrographic data. If special reports have been submitted on such subjects, refer to them by title, author, and date of preparation or publication.

## **E. APPROVAL SHEET**

The Chief of Party or Lead Hydrographer shall furnish, on a separate sheet, a signed statement of approval for the survey and all related records. The approval sheet shall contain the following:

- Approval of Descriptive Report, digital data, and all accompanying records. This approval constitutes the assumption of responsibility for the stated accuracy and completeness of the hydrographic survey.
- A statement as to whether the survey is complete and adequate for its intended purpose or if additional work is required.
- The amount and degree of personal supervision of the work.
- Additional information or references helpful for verifying and evaluating the survey.

If appropriate, other personnel responsible for overseeing or directing operations on this survey sheet may also sign the Approval Sheet.

## **SEPARATES TO BE INCLUDED WITH THE SURVEY DATA**

The following “**SEPARATES TO BE INCLUDED WITH THE SURVEY DATA**” supplementing the Descriptive Report shall be submitted with each survey. The Separates shall be bound, organized and clearly labelled. The Separates should be included in the digital Descriptive Report file, but may be submitted digitally as separate files, if available.

### **I. ACQUISITION AND PROCESSING LOGS**

Include all acquisition and processing logs from the present survey. Include positioning confidence checks and multibeam checks.

### **II. SOUND VELOCITY PROFILE DATA**

Include a table, which identifies the specific sound velocity profiles used during the survey. List the positions and dates of all casts used; the maximum cast depth; and the dates/times for which the profiles were applied. Refer to the location where the digital sound velocity files are located,

and include a directory listing of the files. If appropriate, describe how the survey area was zoned to account for sound velocity variations from differing water masses. Printouts of individual sound velocity profiles are not required.

Include confidence check results. Include copies of sound velocity profiler calibration report(s), if calibration occurred after submission of the **Data Acquisitions and Processing Report**.

### **III. SURVEY SPECIFICATION**

Include a copy of the survey specification. Include all changes/modifications which apply to the survey.

### **IV. CROSSLINE COMPARISONS**

Include the summary plot analysis as a function of beam number for the mainscheme/cross-line intersections as required in Section 5.10.3.

#### **8.11.1. Descriptive Report Supplemental Reports**

##### **8.11.1.1. Data Acquisition and Processing Report**

This report is separated into three sections, **Equipment, Quality Control, and Corrections to Echo Soundings**. These sections shall contain a detailed discussion on the project specific information addressed below.

A digital copy of the main text of the Data Acquisition and Processing Report shall be provided in Word format.

Include a cover sheet and title sheet which contain the following general information:

**Cover Sheet.** Include the type of survey(s), state, general locality and year. (Annex D)

**Title Sheet.** This contains additional descriptive information relative to the project. See Annex C for details.

##### **A. Equipment**

Describe the major operational systems used to acquire survey data or control survey operations. Include the manufacturer, firmware version and model number, operational settings and how the equipment was used. Include a description of the vessel(s) used.

Specifically discuss Multibeam and backscatter systems and operations in this section. Include range scales, number of beams or min/max angles, resolution, along track coverage, and quality assurance tools used during data acquisition. If applicable, explain

the calibration or determination of correctors, the dates of most recent calibrations, state whether or not checks were made on their accuracy and describe any non-standard procedures used.

Discuss the computer hardware and software used for all data acquisition and processing. Describe acquisition and processing methods, procedures, and parameters used. Provide a complete list of all software versions and dates.

## **B. Quality Control**

Provide a description of the data processing routines for converting raw sounding data to the final smooth sounding values. Include a description of the methodology used to maintain data integrity, from raw sounding data to final soundings. Processing flow diagrams are helpful. Any methods used to derive final depths such as cleaning filters, sounding suppression/data decimation parameters, binning parameters, and excessing algorithms shall be fully documented and described in this section.

Discuss the methods used to minimize the errors associated with depth determination (see Section 5.9).

Methods and standards used to examine backscatter records should be noted and a brief description of processing procedures should be provided. Include the methods for establishing proof of swath coverage and the criteria for selecting contacts.

## **C. Corrections to Echo Soundings**

This section addresses the methods used for the determination of all corrections to echo soundings that apply to the entire project. Describe the methods used to determine, evaluate, and apply the following corrections to echo soundings:

- Instrument corrections.
- All vessel configuration parameters, offsets, layback, etc include diagrams, pictures, or figures of the equipment as installed onboard.
- Static and dynamic draft measurements.
- Heave, roll, pitch biases, and navigation timing errors. State the manufacturer, model, accuracy, and resolution of heave, roll, and pitch sensor(s). Discuss accuracy and alignment test procedures and results. Include copies of system alignment, accuracy, and calibration reports.
- Include the source of tide or water level correctors supplied by GEUS and used for data processing and final sounding reduction.

## **D. Approval Sheet**

The Chief of Party or Lead Hydrographer shall furnish, on a separate sheet, a signed statement of approval for all information contained within the **Data Acquisition and Processing Report**.

If appropriate, other personnel responsible for overseeing or directing operations on this project report may also sign the Approval Sheet.

## **8.11.1.2. Vertical and Horizontal Control Report**

The **Vertical and Horizontal Control Report** is a report which shall be submitted before, or not later than, the submission of the **Interim Report**.

A digital copy of the main text of the Vertical and Horizontal Control Report shall be provided in Word format.

Include a cover sheet and title sheet which contain the following general information:

**Cover Sheet.** Include the type of survey(s), state, general locality and year.

**Title Sheet.** This contains additional descriptive information relative to the project. Include project number, survey registry numbers to which this report applies (with associated dates of survey and locality) reference to the survey specification, vessel(s) and Chief of Party/Lead Hydrographer. See Annex C for details.

### **A. Vertical Control**

The **Vertical Control** section of the project shall include the tide documented and supplied by GEUS.

### **B. Horizontal Control**

The **Horizontal Control** section of the project shall document Hydrographic Position Control activities that took place as part of the project. State the source that has been used for DGPS corrections.

For horizontal control stations established by the field unit, describe the survey methods used to establish the station, and state the standards of accuracy used. Include position accuracy plots. If horizontal control stations has been established by the field unit, list:

- The latitude to the nearest 1/1,000th of a second.
- The longitude to the nearest 1/1,000th of a second.

- The station elevation (ellipsoidal height).
- The geodetic station name and year it was established. Briefly, describe the methods and adequacy of positioning system confidence checks.

### **C. Approval Sheet**

The Chief of Party or Lead Hydrographer shall furnish, on a separate sheet, a signed statement of approval for all information contained within the **Vertical and Horizontal Control Report**.

If appropriate, other personnel responsible for overseeing or directing operations on this project report may also sign the Approval Sheet.

## **8.11.1.3. Cartographic Specifications and Conventions**

### **8.11.1.3.1. *Projection***

The Universal Transverse Mercator projection shall be used. WGS84 latitude and longitude lines shall be shown by continuous lines fine enough so that soundings will not be obscured. Labels for meridians and parallels shall be in degrees, minutes, and decimal minutes and are placed in the sheet margins beyond the limits of hydrography.

### **8.11.1.3.2. *Plotting Scale***

The smooth sheets should be plotted at a scale of 1:100,000.

### **8.11.1.3.3. *Soundings***

Soundings and related hydrographic detail needed to compile nautical charts are important observations of a hydrographic survey. It is essential that the final corrected soundings plotted on the smooth sheet be accurately and graphically displayed in a uniform manner. The soundings shall be actual corrected soundings. Gridding, averaging, or other sounding manipulation shall not be conducted.

Sounding numerals shall be between 1.8 (preferred) and 2.0 mm high and uniform across the smooth sheet. At this size, legible reproductions can be made at reduced scales. The centre of the sounding numeral or group of numerals is the position of the sounding.

### **8.11.1.3.4. *Sounding Units and Conversion***

All soundings on the smooth sheet shall be plotted in units of meters.

When rounding corrected and converted soundings, the following procedures shall apply:

- Depths should be truncated to the nearest meter.

#### **8.11.1.3.5. Spacing of Plotted Soundings**

The spacing and density of soundings on smooth sheets shall be such that each depth curve is delineated adequately and the configuration of the bottom is fully revealed. The smooth sheet soundings are generally spaced uniformly at 4-7 millimetres apart. Soundings shall be clearly legible and not plotted over adjacent soundings.

#### **8.11.1.3.6. Selection of Soundings and Excessing**

Soundings must be selected from valid filtered soundings from the hydrographic records to plot on smooth sheets using a shoal-biased selection routine.

With a Multibeam system, a relatively high percentage of smooth sheet soundings originating from only a few beams may indicate the presence of systematic or system specific errors in the acquisition or processing systems. The hydrographer shall construct a histogram showing the count, by beam number or beam angle, of the selected soundings. The histogram and the hydrographer's analysis of the results shall be included in Section B of the Descriptive Report. If necessary, the data shall be re-processed and the smooth sheet re-drawn using the newly selected soundings.

When sounding lines overlap or cross, the shoaler soundings shall be plotted. If the difference is significant, then the data must be analyzed to determine the cause of the difference.

The selected data set shall be tagged in a manner such that the selected data can be re-traced to the Multibeam data set. The attribute or tag shall include, but is not limited to, XY (latitude, longitude, WGS84), Z (depth in meters), year, day number, and time.

#### **8.11.1.3.7. Depth Curves**

The depth curves are indispensable for a comprehensive interpretation and examination of a hydrographic survey. The best gauge of the survey's completeness, adequacy, and accuracy is to be able to draw closely spaced depth curves with an assurance that the submarine relief is depicted accurately.

Depth curves shall be drawn based on soundings selected using the shoal-biased selection routine noted above. Depth curve intervals required on survey smooth sheets are specified in Annex F. The standard depth curves shall be plotted in the prescribed colours. The supplemental depth curve shall be added where necessary and shall be drafted in red ink.

Depth curves are broken into long dashes where not adequately defined by the soundings (e.g., extremely flat monotonous bottoms where the plotted soundings defy the drawing of a meaningful curve).

#### **8.11.1.3.8. *Geographic Names***

Geographic names shall not be placed on the smooth sheet.

#### **8.11.1.3.9. *Title Block***

The information to be entered in the title block (Figure 8.2.1) of the hydrographic smooth sheet is extracted from the Title Sheet in the Descriptive Report. Title blocks shall be oriented with their base parallel to the sheet edge. Approximate dimensions for the title block are a height of 15 cm and a width of 20 cm. The hydrographer shall sign the smooth sheet in the title block.

Survey data or notes shall not, under any circumstances, be shown inside the title block. The smooth sheets must be laid out so there is sufficient space for the title block. No particular portion of a sheet is favoured over another for the title block.

## **9. Education and experience**

### **9.1. *Education***

It is a requirement that at least the Hydrographer or Party chief hold a hydrographic certificate category A or equivalent.

### **9.2. *Experience***

CV for all relevant personnel involved in survey data collection or processing data shall be included.