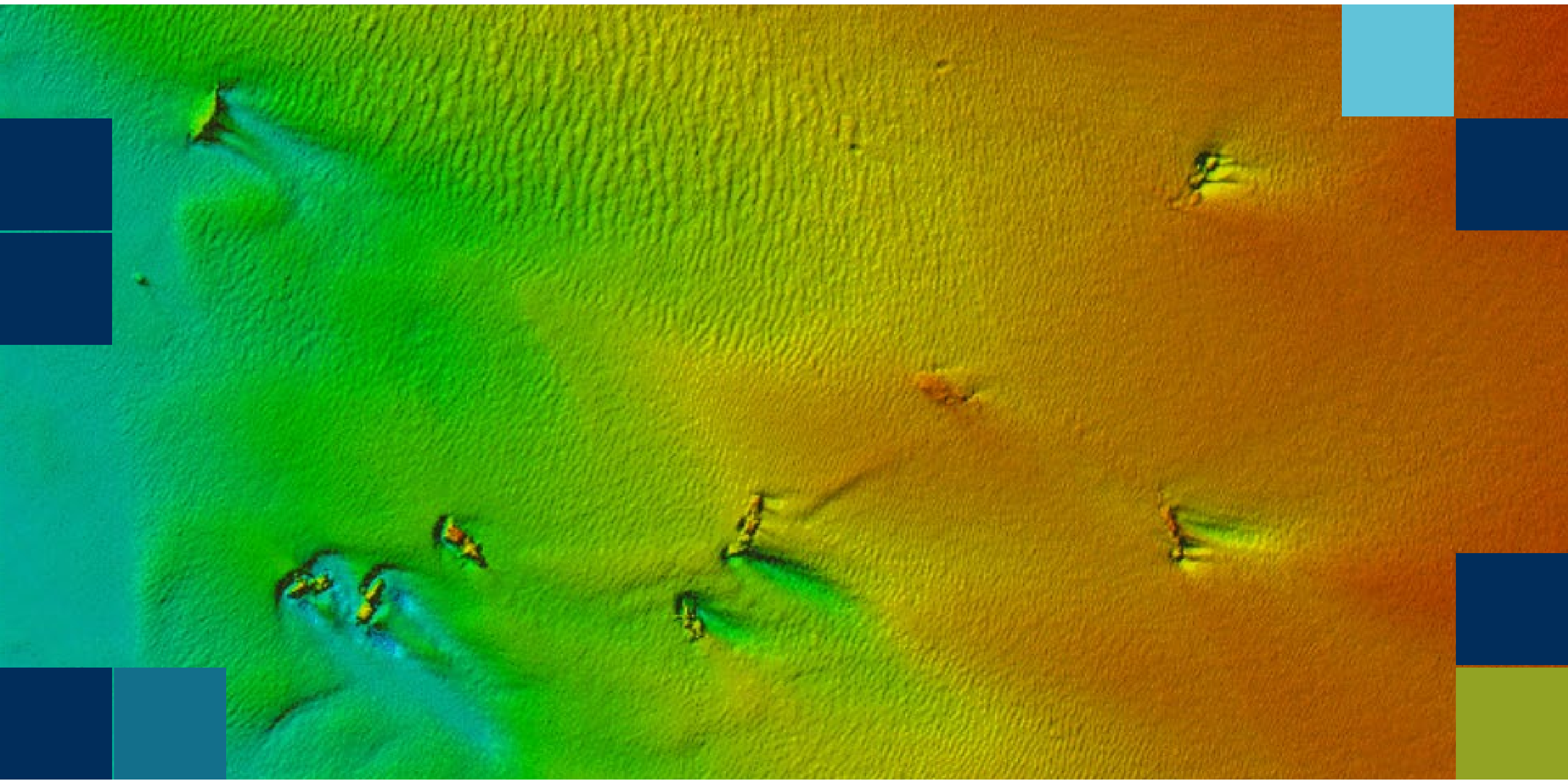
ADMIRALTY
Maritime Data Solutions



A guide to bathymetry

Version 01 September 2020

UK Hydrographic Office

Contents

This communication has been prepared for general information only and you should not rely solely on its contents. When engaging external contractors we recommend you seek professional advice.

Introduction

This guide aims to give an overview of what bathymetry is and the different hydrographic survey methods.

It also provides detail on bathymetry-related terms such as 'datums' and 'grids', as well as guidance on data cleaning and data formats.

It can be used to assist with completing the H275 metadata form (which it complements) or as a standalone introduction to the world of hydrography.

2 Introduction to bathymetry

2.1 What is bathymetry?

The term 'bathymetry' comes from the Greek meanings for 'deep' (bathy) and 'measure' (metry). It describes the measurement of the depth of water in, for example, oceans, seas, lakes, rivers, estuaries and canals.

In its most basic form, bathymetric information usually consists of data points that have XYZ coordinates. The X&Y are the position (e.g. latitude and longitude) and the Z is the depth measurement (also known as a sounding).

To account for the effect of tide on depth measurements (which can be several metres), soundings are usually reduced to a common reference level (or datum) such as mean sea level (MSL), or the lowest astronomical tidal level (LAT).

In the past, positions were measured using sextants and soundings using a lead weight on a rope. Today, satellite positioning systems are used, and depths are measured with acoustic echo sounders and sometimes even using lasers from specially equipped low flying aircraft. Modern hydrographic survey vessels use multi-beam echo sounders to acquire very detailed bathymetric data with full seafloor coverage.

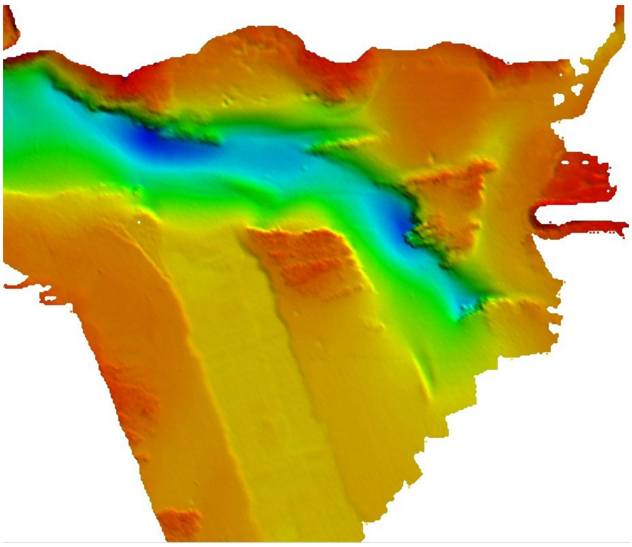
Bathymetric data can be visualised as 3D computer models and it is commonly represented on charts and maps using contours and depth values, in the same way that land maps use contours and heights.

Bathymetry can be gathered from any vessel with depth sounding equipment, but is often gathered as part of a hydrographic survey. Hydrography is defined by the International Hydrographic Organization (IHO) as:

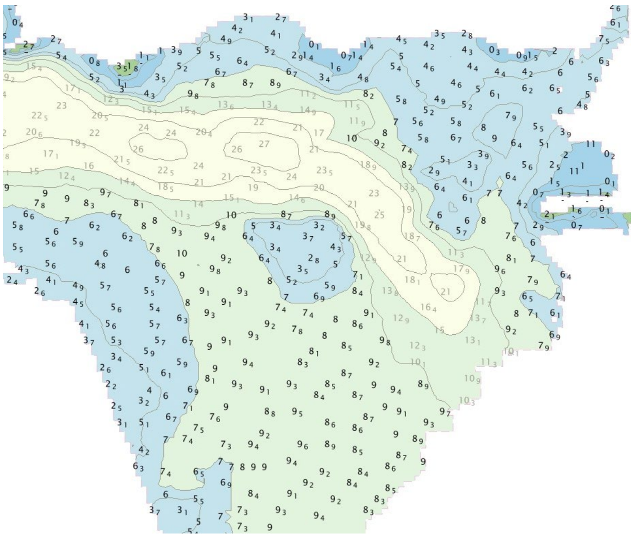
> "The branch of applied sciences which deals with the measurement and description of the physical features of oceans, seas, coastal areas, lakes and rivers, as well as with the prediction of their change over time, for the primary purpose of safety of navigation and in support of all other marine activities, including economic development, security and defence, scientific research, and environmental protection"

Bathymetric data is important to the UK Hydrographic Office as it provides important depth information which is used for updating navigational charts, which are important to support Safety of Life at Sea (SOLAS).

Multi-beam Echo Sounder Bathymetric Data



Corresponding soundings and contours



2.2 Common reasons for bathymetric data collection

Bathymetric data can be collected for many different reasons. Sometimes the bathymetry is the primary focus and sometimes it is collected to enable other work to take place. Examples are listed below:

Safety of navigation

The bathymetric data is the primary focus here and is gathered to strict standards using rigorous survey methodology. Data gathering is usually focused on areas where ships/vessels operate, such as shipping lanes, approaches to and inside ports/harbours, and anchorage areas. Special care is usually taken to get very good data over dangers to navigation, such as shipwrecks.

Dredging

Bathymetric data is usually gathered before and after dredging to determine the amount of material that needs to be removed and subsequently has been removed. Accuracy is important as there can be safety implications, such as dredging within a port to maintain a depth, and cost implications, as dredging companies are often paid by the amount of material removed.

Environmental and scientific study

Bathymetric data is used to understand many different aspects of the marine environment, such as marine life habitats, underwater geology, sediment transport and flood modelling. In a lot of cases, the absolute accuracy of the data isn't as important as being able to understand the shape of the seabed and seabed features.

Engineering and construction

Bathymetric data is used to aid marine engineering and construction projects. In many cases, the absolute accuracy of the data is important, but in some cases, it is the relative accuracy of features within the data that is more important. Examples of these projects could include bridge and port construction, cable and pipe laying, oil and gas rig and platform placement, and offshore windfarm development.

2.3 **Types of bathymetric instruments**

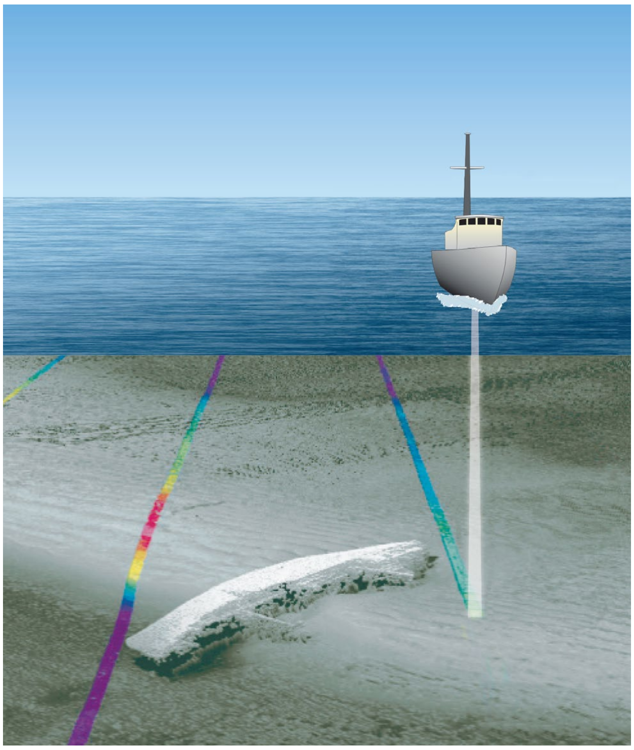
2.3.1 **Single-Beam Echo Sounder (SBES)**

Single-beam echo sounders use pulses of sound transmitted vertically down from a ship. By timing how long the echo takes to return, and knowing the speed of sound in water, the depth below the ship is computed. This method provides single lines of data along the track of the ship. There is no information about the depth either side of the ships track. A SBES survey is usually conducted using parallel lines or tracks at a set spacing. Undetected and dangerous features can exist in-between these lines. The diagram below depicts this and shows that, in this example, a wreck has been entirely missed.

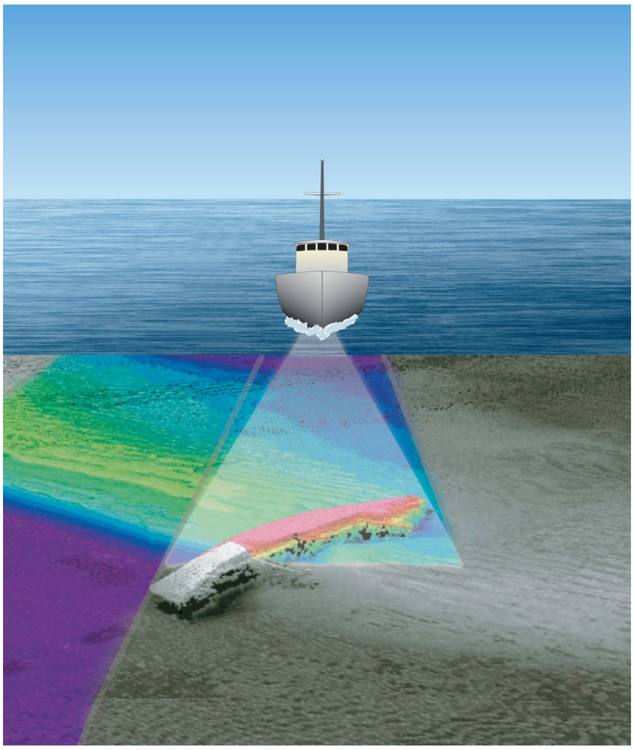
2.3.2 **Multi-Beam Echo Sounder (MBES)**

Multi-beam echo sounders use pulses of sound emitted in a fan, known as a swathe, which is narrow along-track (fore/aft), but wide across-track (port/starboard). By timing how long the echoes take to return and knowing the speed of sound in water, the system can compute multiple depths through different angles and ranges across the swathe. This allows each pulse to generate hundreds of depth measurements. If used appropriately, MBES are capable of achieving full seafloor coverage, objects detection and provide more depth information than a single-beam echo sounder.

Single-Beam Echo Sounder



Multi-Beam Echo Sounder



2.3 **Types of bathymetric instruments** continued

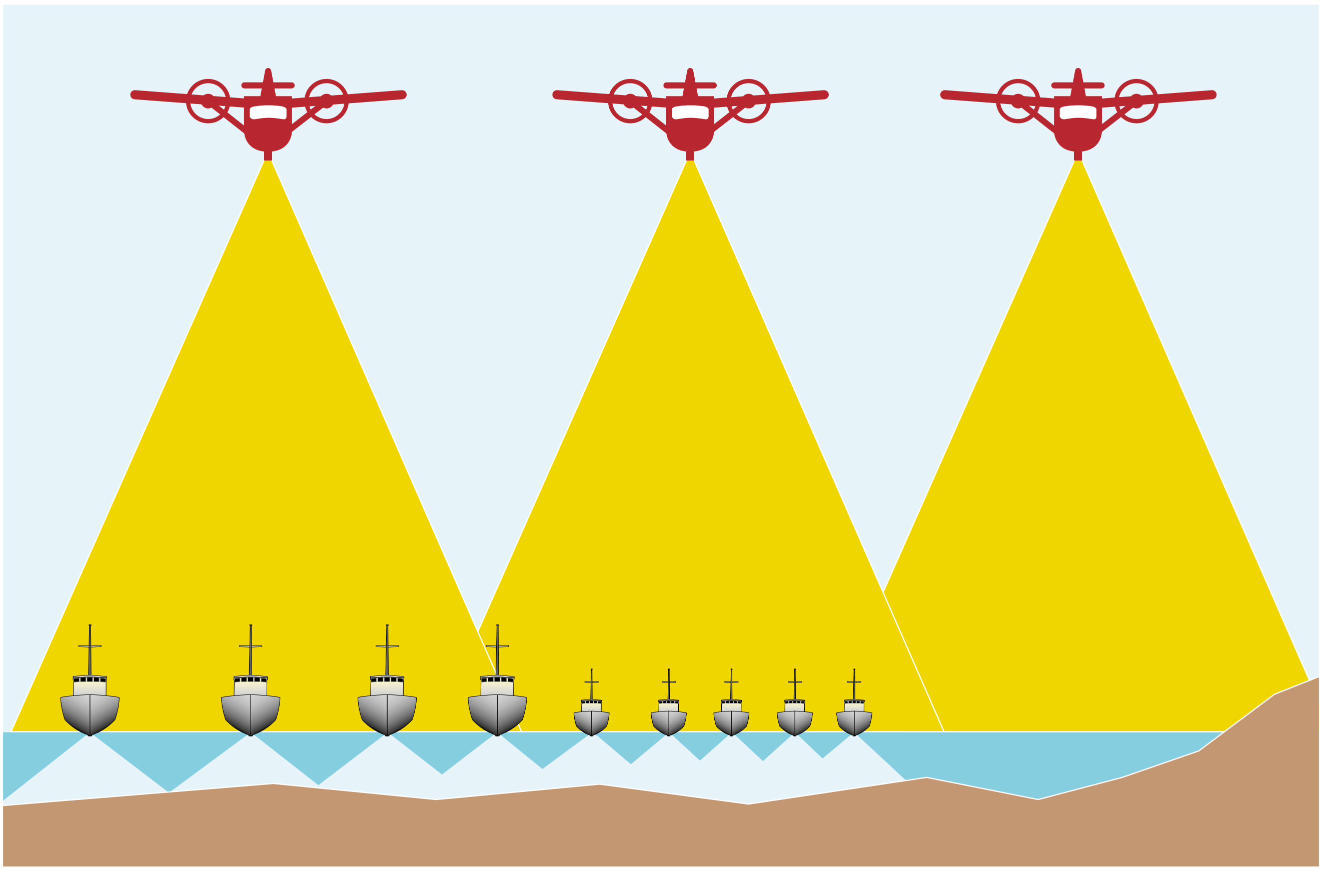
2.3.3 **Lidar**

Lidar systems use rapidly pulsing lasers, normally from an aircraft, to obtain both topographic and bathymetric measurements. Data is obtained in a swathe across the aircraft's direction of travel with similar looking results to an MBES system, but usually at lower data density.

Lidar systems are affected by surface waves and water clarity which typically limits the operational depth to around 40m in 'good' conditions, though in 'perfect' conditions returns from 60–70m are theoretically possible. Due to the way the laser beam is spread by water, this means that Lidar is generally not able to detect small features with the same confidence as an MBES system. As a result, although large areas can be covered quickly and the general depth and shape of the seafloor can be determined, small but significant objects may be missed.

Lidar can also offer greater information on nearshore areas that are often too dangerous to reach by vessel, or areas that require the use of multiple vessels on a project as shown below.

Lidar vs. MBES



3

Positioning systems

3 Positioning systems

In its most basic form, bathymetric data must consist of position (X & Y) and depth (Z) information. Measuring the depth is covered in section 2 above. This section covers the determination of the X & Y components.

In the past, positioning was obtained using sextants and observations to celestial bodies, then as technology improved, land-based radio navigation systems were introduced, such as Loran.

Currently, in the marine environment, most positioning systems use one or more of the GNSS (Global Navigation Satellite System) services, such as GPS, Glonass, Galileo etc. The user often doesn't even know which of the systems is being used, just that the position is derived using satellites. A GNSS system can determine the position of its antenna via observations to orbiting satellites.

Used on its own, a GNSS positioning system can be horizontally accurate to around +-10m.

The accuracy of GNSS systems can be improved by using corrections. The corrections are determined using GNSS devices situated over known locations (benchmarks) on land. The errors in the GNSS position can be determined and transmitted to the vessel so that it can apply the same corrections and improve its position accuracy. This is called Differential GNSS or DGNSS. The transmission of the corrections can be via radio link, mobile phone network or from a communications satellite. There are different levels of corrections and different ways to obtain them. Some are more accurate than others, some are free, and some are paid for services.

The most basic DGNSS system is accurate to around +-1m. Some of the paid for services can improve the accuracy to better than 20cm and in some cases better than 5cm.

Remember, the above accuracies are for the position of the GNSS antenna. For bathymetry it is the position of the depth on the seafloor that is important. So, to obtain the best accuracy, either the GNSS antenna needs to be located above the echo sounder transducer or the position needs to be transferred from the GNSS antenna to the echo sounder transducer. Transferring the position requires an understanding of the offsets between the equipment and also a continual update of the heading of the vessel (and in some cases additional knowledge of the pitch and roll of the vessel is used to refine the position accuracy even further), and the appropriate software to do the computations and transfer the position information.

It is also possible to "post process" logged GNSS data to improve accuracy from the standalone 10m to around 10-2cm.

Examples of what could be entered on the H275 form for positioning system are:

- Standalone GNSS, no offsets accounted for
- DGNSS
- RTK – DGNSS
- Post processed GNSS
- Loran
- WADGPS or WADGNSS

4 Datum information

For greater detail and survey guidance specifics, please refer to the UKHO Survey Specification documents referenced in section 7 Reports of Survey and specifications.

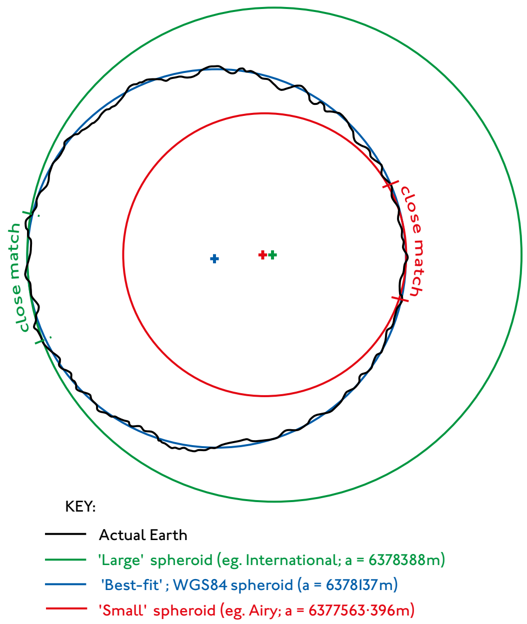
4.1 Horizontal datums

The horizontal or geodetic datum is a reference system for specifying the latitude and longitude (coordinate system) of points on the Earth's curved surface. It is made up of two main elements:

› Spheroid (or Ellipsoid)
› Where the Spheroid fits the Earth

A spheroid (or ellipsoid) is the simplest mathematical shape that most closely matches the Earth's surface, thought of as a sphere or as a rotated ellipse.

Examples of different spheroids



The 'a' values in the diagram refer to the semi-major axis lengths which is the radius from the centre to the equator.

Different spheroids vary in size, orientation and relative position, as shown in the diagram above. The 'a' values in the diagram refer to the semi-major axis lengths which is the radius from the centre to the equator. As spheroids are not an exact sphere, they have different radiuses from the centre to the equator vs the centre to the poles. The semi-major axis is the larger radius as the spheroid is 'squashed' slightly at the poles. This matches the Earth's approximate shape.

There are over 90 different spheroids fitted to the Earth in hundreds of different ways, including Clarke 1880, Airy 1960 and GRS80 (used for GNSS). Therefore, this creates thousands of different datums.

Horizontal datums can be:

› Local (based on one fixed feature)
› National (for example, OSGB36: the UK National Datum)
› Regional (for example, ED50 (Europe) or NAD27 (USA))
› Global (WGS84)

In recent years, the accuracy of navigation has been improved by the introduction of GNSS, such as the Global Positioning System (GPS) which uses the global datum, WGS84.

The International Terrestrial Reference Frame (ITRF) or International Terrestrial Reference System (ITRS) is a precise scientific realisation of WGS84. The current version is ITRF2014.

ITRF is simply a list of coordinates (X, Y and Z in metres) and velocities (dX, dY and dZ in metres per year) of each station in the Terrestrial Reference Frame, together with the estimated level of error in those values. The coordinates relate to the time 2014. To obtain the coordinates of a station at any other time, the station velocity is applied appropriately. This is to cope with the effects of tectonic plate motion.

WGS84 and ITRS have been progressively brought together and are now equivalent at the <0.1 m level. Because the ITRF is of higher quality than WGS84, the WGS84 datum now effectively takes its definition from ITRS.

For safety of navigation, it is important that all positions are accurately related to each other.

Some countries are adopting their own regional or continental equivalent of WGS84 to take account of tectonic plate movement. The following regional global datums are considered compatible with WGS84 datum:

ETRS89	European Terrestrial Reference System 1989	Europe
NAD83	North American Datum 1983	USA and Canada
SIRGAS	Sistema De Referencia Geocentrico Para Las Americas	South America
CGCS	China Geodetic coordinate System 2000a	China
EUREF-FIN	This is the national realisation of ETRS89	Finland

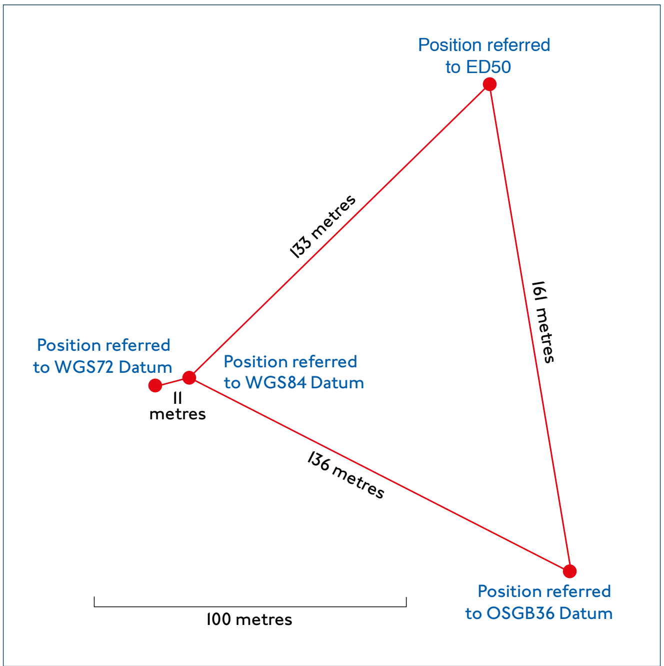
For practical purposes, other than precise operations such as surveying or automated docking, the differences between these datums and WGS84 will remain insignificant for the foreseeable future. Positions referred to in different datums can differ by several hundred metres; a physical object can have as many geographical positions as there are datums and these can differ by hundreds, sometimes thousands, of metres.

4.1 **Horizontal datums** continued

The coordinates listed below all refer to exactly the same location on the planet. They are just different ways of describing the same location.

Geographical position	Horizontal datum	
51°08"·40N 1°22"·33E	OSGB36	(The regional datum for the UK)
51°08"·45N 1°22"·32E	ED50	(The regional datum for continental Europe)
51°08"·42N 1°22"·26E	WGS72	(The obsolete global datum)
51°08"·42N 1°22"·27E	WGS84	(The global datum used by GNSS)

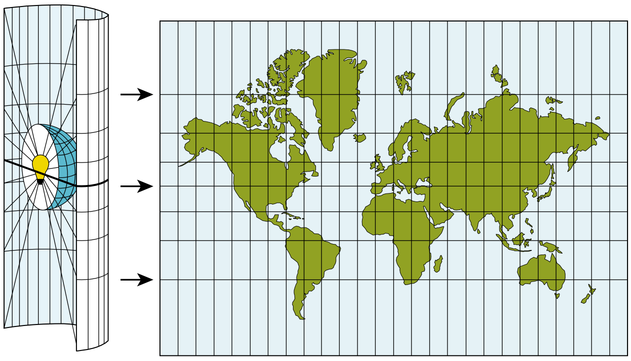
A diagrammatic representation of this example, showing the differences in position if your datum isn't correctly known and WGS84 is assumed, is shown below:



Relating a position of a point to WGS84 datum can be achieved through surveying using GNSS observation or transformed by established mathematical techniques from some other datum using published parameters.

Grids are a form of projection which use mathematical methods to convert the 3D spheroid, specified to a datum, onto a 2D plane. If you imagine a globe of the earth with a light at the centre, you can create a 'projection' by wrapping a sheet of paper around the globe and then tracing off the projected images of the countries.

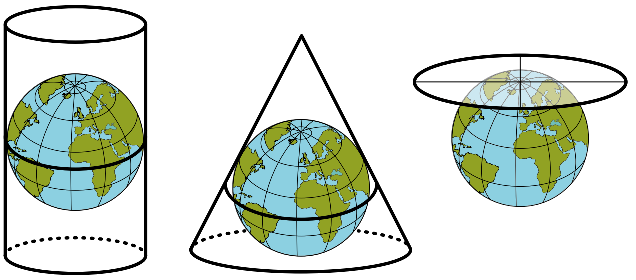
Mercator projection



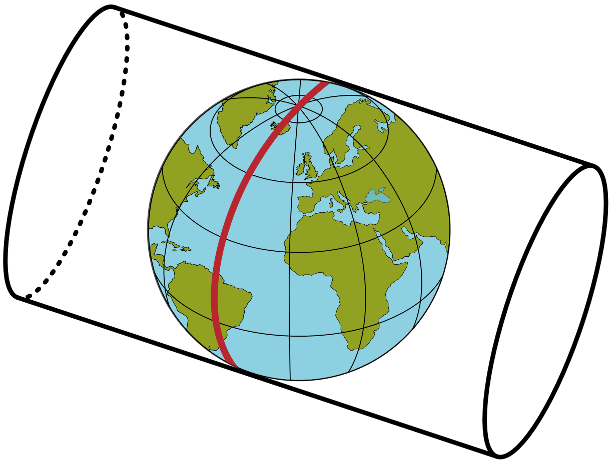
The way the countries look and their accuracy in shape and area depends on how the paper is wrapped around or is touching the globe. Some projections are good for large areas and others are better to describe smaller areas of the planet. Some preserve shape best and others preserve area better.

4.1 **Horizontal datums** continued

Mercator, conical and stereographical projections



UTM projection



Universal Transverse Mercator (UTM) is a popular grid used in survey. The 'paper' is wrapped around the globe as shown in the image above. Where the 'paper' touches the globe, the projection is most accurate. There are multiple different defined zones so that the whole globe is covered. For each zone, the 'paper' is rotated to different lines of longitude. There are 60 defined UTM Zones, from 180° W to 180° E, that exist for global coverage. Each Zone covers a region 6° wide in terms of accuracy. Beyond this, the zone is not considered very accurate, so the user would use the next zone. For instance, UTM Zone 32N spans coverage of between 6° and 12°E in the Northern Hemisphere.

An example of how the Geodetic parameters may be expected are as follows:

Datum	ITRF 2014 (WGS84)
Spheroid	GRS80
Geoid	EGM08
Projection	UTM Grid Zone 32 North (Central Meridian 9'E)

As UTM Grid is a projection, it is only how the data is visualised and does not imply the exact geographical position which is based off the datum. Therefore, as above, if a projection is noted, the datum must be defined.

If a local grid has been used, then the following example would suffice:

Datum	Barbados 1938
Spheroid	Clark 1880
Geoid	EGM08
Projection	Barbados National Grid

Hydrographic data can be sourced on a variety of datums or grids. If supplying the data on a grid, UTM or local, please always supply the associated datum.

Positions can be expressed in two different types of coordinates. The examples below are all for exactly the same location on the planet, just described in different ways.

Geographic

Units: degrees, degrees-minutes-seconds etc.
Examples:

Latitude	Longitude
51.021136N	003.096044W
51.021136	-003.096044
51-01.27N	003-05.76W
51-01-16N	003-05-46W

Ground

Units: metres
Examples:

Eastings	Northings
493263.69E	5652179.69N
323221.14E	125212.27N

4.1 **Horizontal datums** continued

4.1.1 **Setting up a geodetic observation**

If tidal observations are required, then tidal levelling should be conducted. The following describes how to setup a geodetic station.

- Geodetic control stations should be fixed using dual frequency carrier phase GNSS techniques.
- Observe data for a minimum duration of 12 hours, divided into two six-hour sessions.
- At the end of the first session the antenna should be physically moved away from the mark and then re-plumbed back over the mark before commencing the second observation session.
- The height of the antenna should be measured before each session and clearly recorded on the Recording Form.
- The purpose of this procedure is for the Field Surveyor to identify any potential field antenna height measurement blunders during initial post processing and if necessary, re-observe before departing from the survey area.

Geodetic control should be tied to IGS (International GNSS Service) CORS (Continuously Operating Reference Station) network (ITRF2014). IGS active station network data (RINEX format), should primarily be based on proximity to the survey. Precise ephemeris data for the period of observations are required to process the data.

4.1.2 **Static validation of vessel position system**

In order to check the accuracy of the positioning solution, a static GNSS check should be performed prior to commencing survey work. This doesn't need to be repeated for every survey if the equipment has not been changed, but it should be repeated if equipment changes and at a regular interval, e.g. every six months.

The coordinates of the vessel reference point as output by the online survey system should be validated against the position obtained by an independent method (i.e. use a known control point to derive an RTK or total station position of the vessel's reference point).

Ideally, in order to achieve the best operating environment for the motion sensor, a static validation should be conducted as soon as possible after the vessel has berthed.

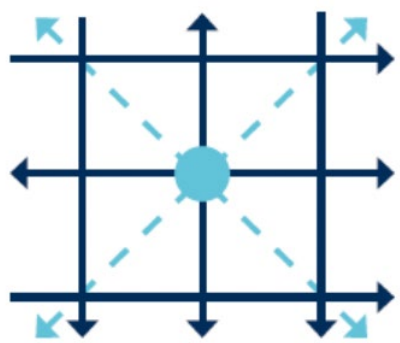
4.1.3 **Swathe bathymetry repeatability test**

For swathe bathymetry surveys, a full dynamic repeatability test should be conducted at the start of the survey. Like the static validation described above, this doesn't need to be repeated for every survey if the equipment has not been changed, but it is recommended to repeat if equipment changes and at a regular interval (e.g. every six months).

This is a check on all the combined survey systems, positioning, motion sensor, echo sounder, etc.

The basic methodology for this is shown below.

In water depth of around 20m, where a small well-defined object has been identified, the entire survey system can be validated through the repeatability of the position of the object as determined from multiple survey lines. In this case, the object should be surveyed from multiple directions – as a minimum from north, south, east and west passing directly over the top of the object. Secondly, the feature should be boxed in, so that it appears in the outer beams on port for two lines, and the outer beams on starboard for two lines (see image below).



The lines should be processed individually and the position of the object on the seabed, as determined from each line, compared to give an accurate assessment of the Total Propagated Uncertainty through the system.

For greater detail and survey guidance specifics, please refer to the UKHO Survey Specification documents referenced in section 7 Reports of Survey and specifications.

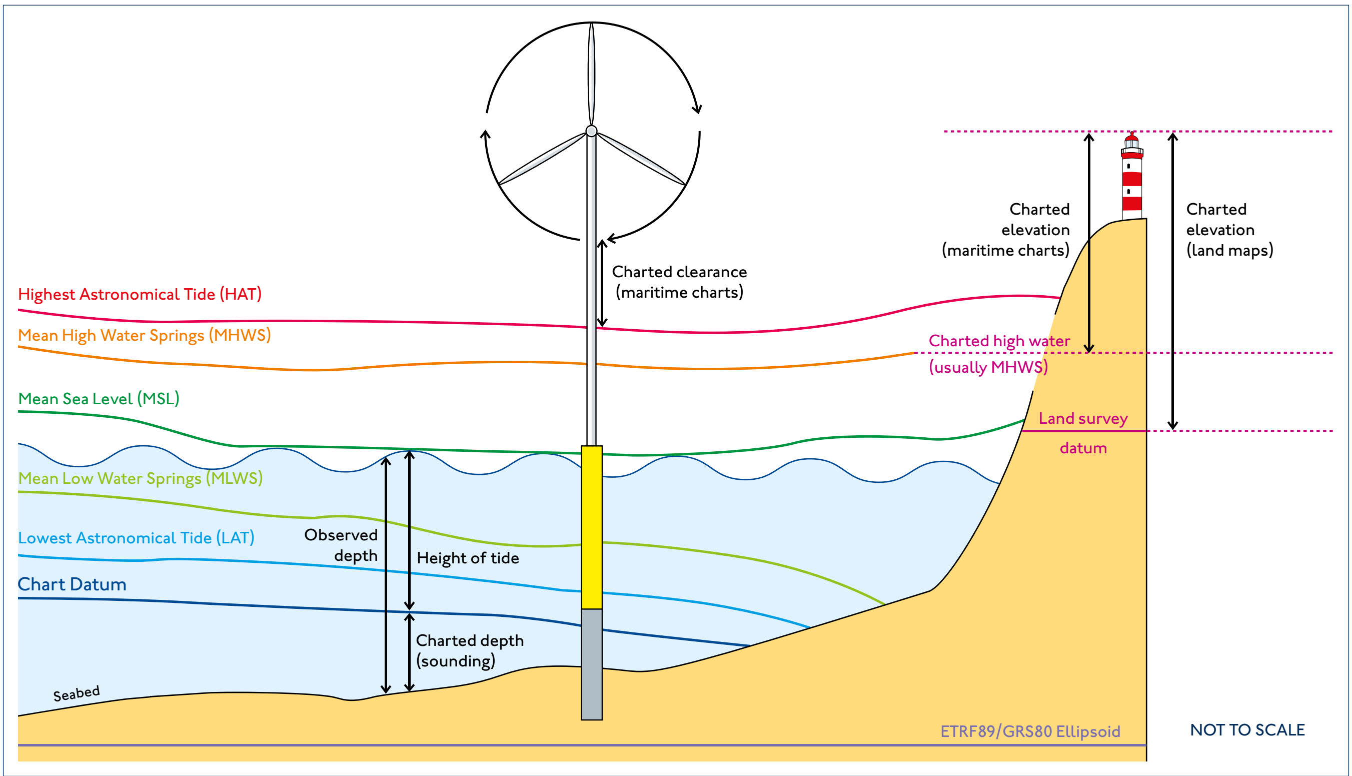
4.2 **Vertical datums**

A vertical datum is a standard position or reference level from which measurements are taken.

All survey depths need to be adjusted for tide. To be of most use, soundings should be reduced to the relevant local Chart Datum (CD). CD is the reference level for all charted depths and drying heights. CD is usually Lowest Astronomical Tide (LAT), especially in tidal areas, as it represents the least depth based on normal conditions.

ADMIRALTY VORF (see 4.2.1 below) is a collection of models of these different reference levels in UK waters. VORF can allow data gathered to one vertical reference to be transformed to a different reference. More details can be found on the ADMIRALTY Marine Data Portal: **datahub.admiralty.co.uk/portal/apps/sites/#/marine-data-portal/pages/seabed-mapping-services**

The diagram below shows the common vertical reference levels used in hydrography.



4.2 **Vertical datums** continued

4.2.1 **Tidal reduction methods**

Preferably, observed tides should be used if available. The use of predicted tides to reduce soundings should be avoided. Predicted tides may not be accurate enough, as they do not consider any local weather effects on the tidal height. Where the surveying method uses very accurate GNSS (e.g. GPS) height and an appropriate model, such as VORF, the need for observed tides may be negated. If large differences are discovered between observed and predicted tides, the UKHO Tides team should be informed. They can be contacted via **tides@ukho.gov.uk**

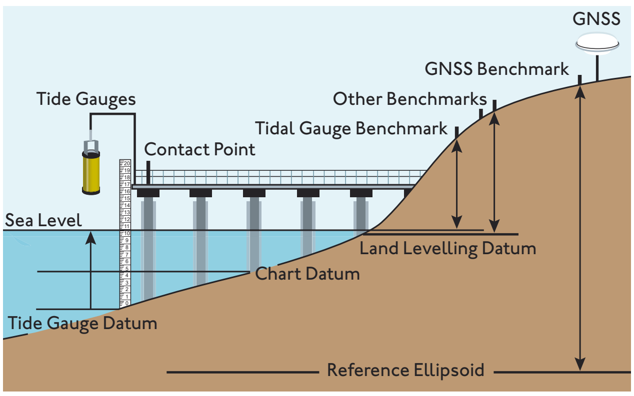
Traditional methods – using a tide gauge

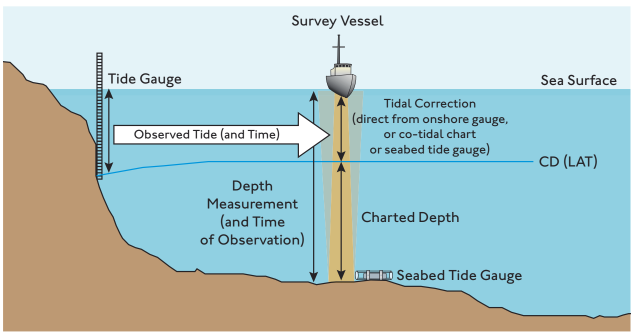
In many locations, observed tide data is available from permanently installed gauges (e.g. in ports and harbours). If using data obtained from these gauges, ensure that the data is referenced to chart datum.

In areas where a permanent tide gauge is not available, or more control and accuracy are required for the survey, a tide gauge can be installed specifically for the survey work.

In this case, details of your observations can be submitted to us via an H276 form: Tide Data Deliverables. The UKHO Tides team can use your observations to conduct harmonic analysis, create tidal predictions and determine chart datum. In order to do this, data needs to be recorded for a minimum of 30 days.

Tide gauge records, including raw tide heights and metadata, are to be submitted preferably in .csv file format as follows: dd/mm/yyyy,hh:mm:ss,m.mm. Traditional methods are used to correct depth measurements as shown below:



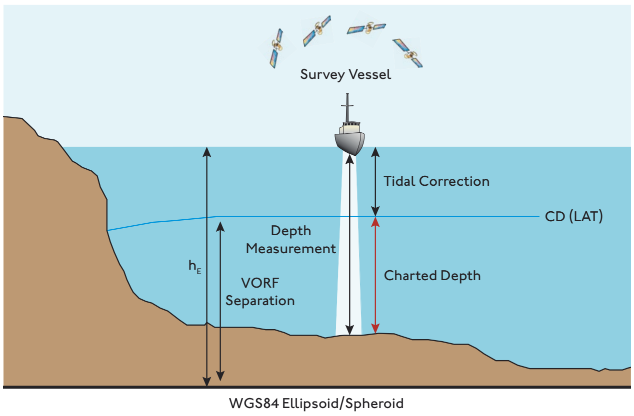


Predicted tides

Predicted tides can be obtained from ADMIRALTY Tide Tables, TotalTide and EasyTide products, which are calculated based on analyses of tidal observations gathered at various ports and locations worldwide.

Ellipsoidal/VORF

VORF (Vertical Offshore Reference Frame) information can be obtained for UK waters via the Marine Data Portal – **datahub.admiralty.co.uk/portal/apps/sites/#/marine-data-portal/pages/seabed-mapping-services**.
VORF is free of charge for academia; please contact **customerservices@ukho.gov.uk** for more information.

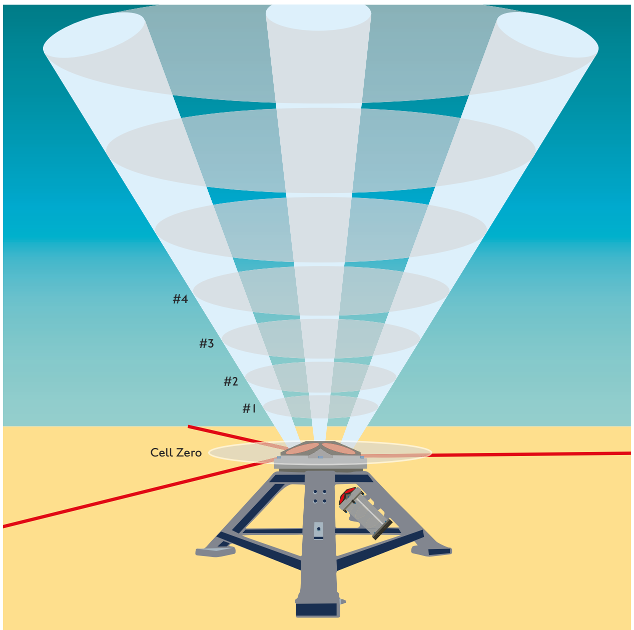


4.2. **Vertical datums** continued

4.2.2 **Tidal streams**

Tidal stream data is also useful to us and can be obtained using a seabed mounted ADCP (acoustic doppler current profiler). Ideally this data should be collected for a minimum of 30 days.

Tidal stream observations should include data in the 'surface' layer of the water column. The ADCP should also record the stream movement throughout the water column at appropriate bin sizes in order to achieve, at the very minimum, a 'mid-column' and 'near-seabed' stream rates and directions as well. Bin size is to be set to 0.5m in water depths of ≤20m, and 1m in depths >20m. If the ADCP is also capable of recording water level, this data can also be supplied.



5

Data quality

At the UKHO, we use IHO standards to describe the quality of hydrographic data. In particular, the S-44 standards:

iho.int/en/standards-and-specifications

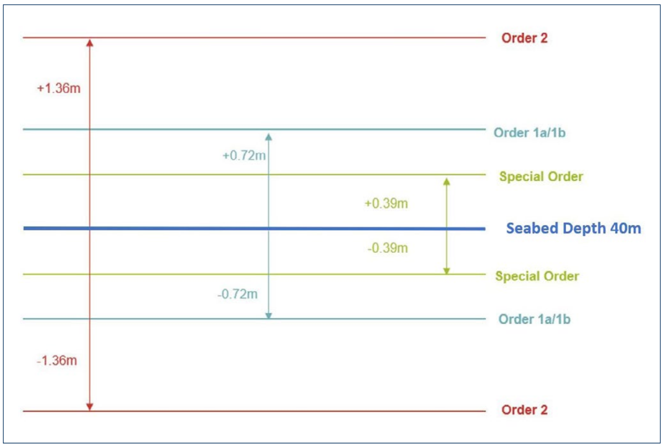
The S-44 document describes several different orders of survey (e.g. Special Order, Order 1a). Each order is defined by various accuracy requirements (these are summarised in table 1 in S-44).

The S-44 document has had a number of updates over the years and the current version is Edition 5 which was published in 2008. A sixth edition is likely to be released in 2020.

In the current version, 'Special Order' is the highest accuracy and 'Order 2' is the least accurate.

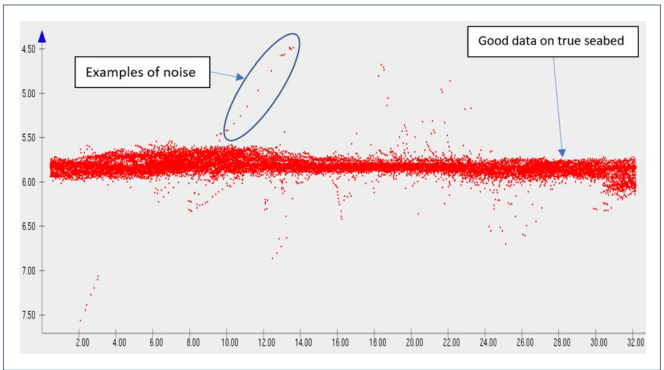
5.1 Cleaning and S44 tolerances

When data is submitted to us, it is validated to check for several factors, including data cleaning against IHO S44 standards. The diagram below shows an example of the IHO S44 tolerances in 40m of water depth for the different orders. It is important to remember that these tolerances are for the total combination of all errors. So, any one error (e.g. noise or tidal busts) must be well within these tolerances to allow for other errors.



Noise

Bathymetric data as gathered (raw) often contains noise. This noise is common across all modern bathymetric instruments (e.g. SBES, MBES and Lidar) and can be caused by air bubbles in the water, seaweed, fish and other things affecting the signals.

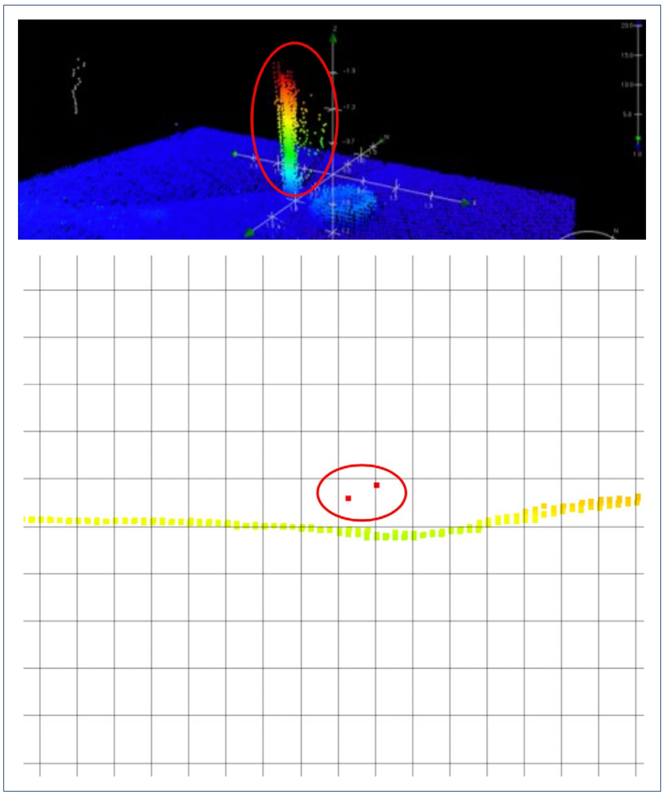


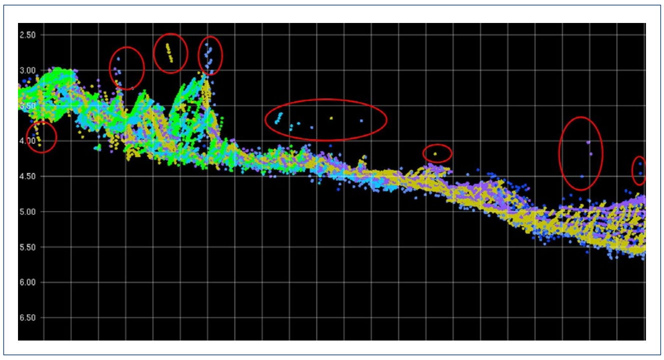
A cross section through some MBES data showing lots of 'good' data around the seabed as well as sporadic noisy data

Data sent to the UKHO should have had any noise removed from the data set (or flagged as rejected in full density data). If there is noise left in the data, this should be stated on the H275 form.

Data that hasn't been cleaned properly

The below images are examples of where the data hasn't been cleaned properly; we would expect the areas highlighted to have been removed from the data set prior to submission.





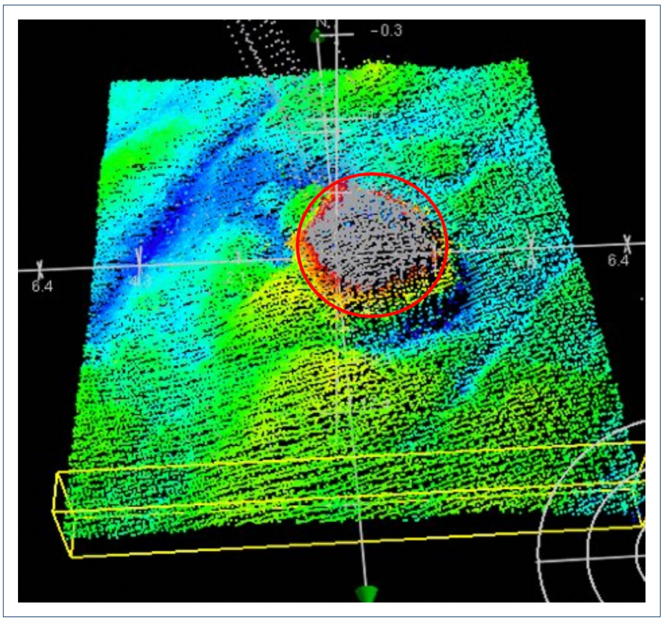
5.1 **Cleaning and S44 tolerances** continued

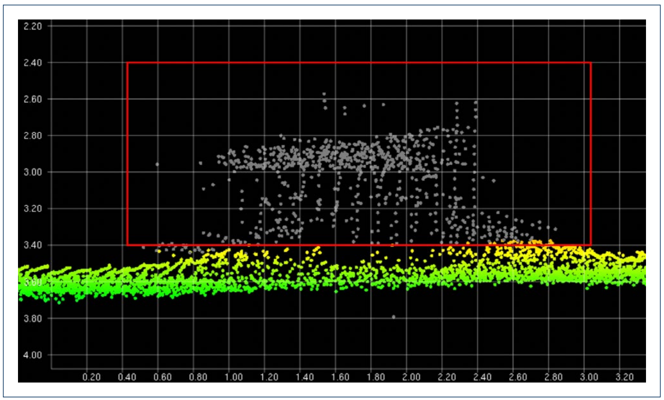
Overcleaned data

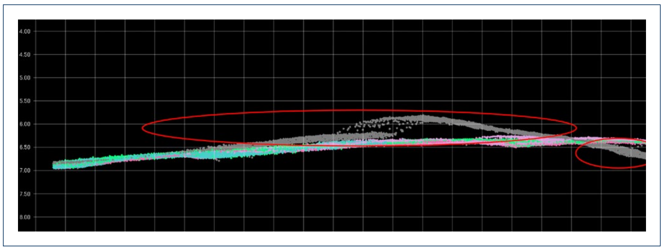
Sometimes data can be overcleaned and real features accidentally removed from the data set. This can happen if an automatic cleaning tool has been used and the results not fully checked.

Data sent to the UKHO shouldn't have any real features removed (apart from vertical structures as described in section 5.2 below).

The below images are examples of overcleaning; we would expect the areas highlighted to have been included as 'accepted' data in the data set.





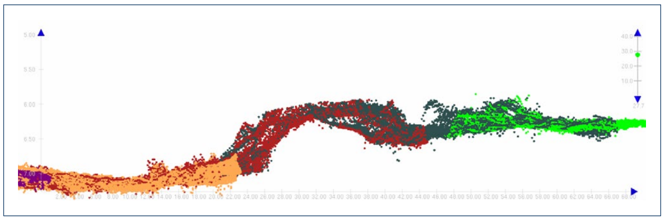


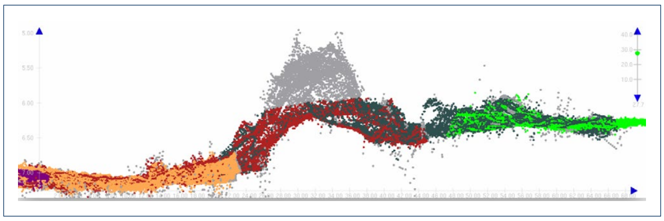
An example of detecting and restoring overcleaned MBES data in a full density processed data set.

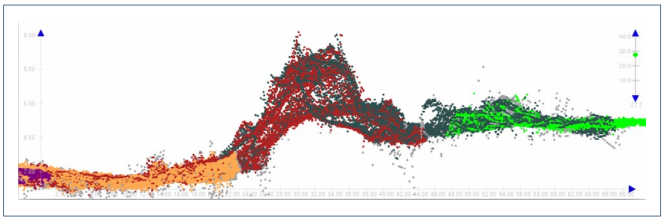
First image shows a cross section through accepted data coloured by survey lines.

Second image shows accepted and rejected data (in grey). Rejected data shows continuation of what looks like a seabed feature.

Third image shows the previously rejected data now as accepted. All data coloured by survey lines. Previously rejected data shows lots of overlapping data from multiple survey lines – good evidence that the feature is real and therefore data can be re-accepted with confidence.





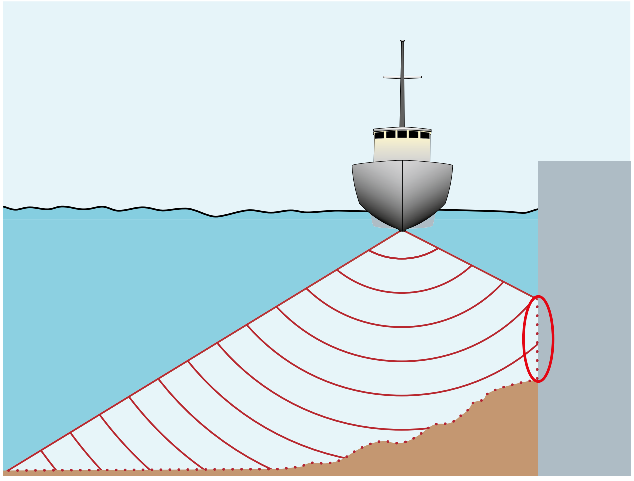


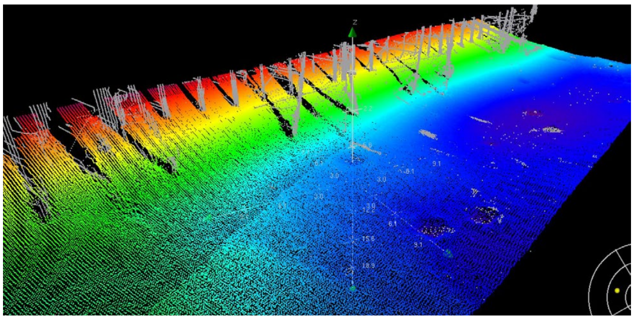
5.2 Dry man-made vertical structures

For all MBES surveys, man-made features (such as quay walls, legs of jetties and beacons) which are vertical and dry at all states of tide, should have all bathymetric data points removed from the vertical element of the structure, otherwise alongside depths may be incorrectly charted.

These are features where it is impossible for a floating vessel to be over the top of them, and depths are only acquired on them due to the fact that an MBES system is able to 'look' sideways. Therefore, any depths obtained on the vertical parts of these features are essentially meaningless. Any part of the feature that is not vertical, and in theory could have a vessel float over the top, should be left in as accepted data.

Depths in red oval should be rejected





5.3 **Systematic errors**

Systematic errors are errors that are due to incorrect system/equipment setup or use. They usually cause the data to be incorrect in a repeatable consistent way. Conducting good calibrations and checks during equipment setup and monitoring the data quality during collection can help detect and avoid these issues.

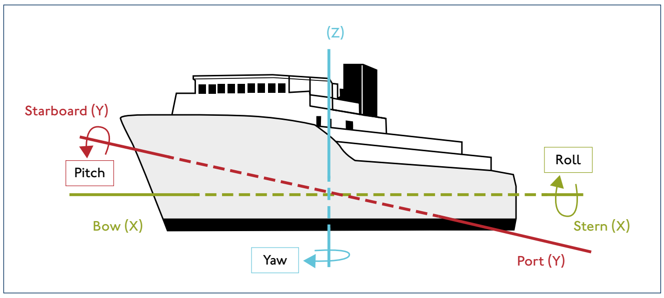
Examples of this type of error are sound velocity errors, motion sensor artefacts (e.g. heave, pitch, roll) and tidal busts. The next few sections provide more detail on typical systematic errors to watch out for during bathymetric data collection.

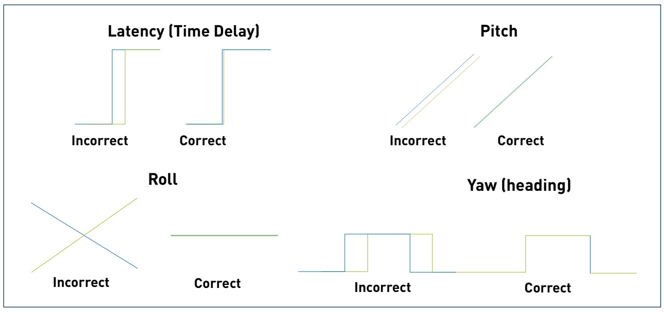
It is always best to trap and resolve these errors during collection as they can be difficult, or even impossible, to correct during data processing.

5.3.1 **Motion sensor errors**

Motion sensor errors (sometimes referred to as 'artefacts') arise in the form of latency (timing), heave, pitch, roll and heading errors. They can occur in single-beam echo sounder data but are often hard to detect. They are more prevalent in MBES survey data and easier to detect due to the larger quantities of data. Some common causes of motion sensor errors are:

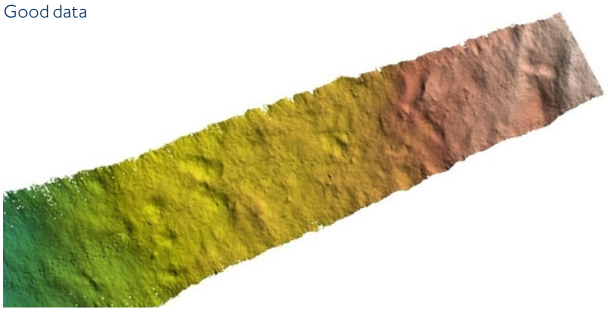
- Incorrect values of angles/offsets entered during data collection
- Problems can also occur if the motion sensor doesn't know where it is on the vessel with respect to the centre of rotation. The motion needs to be able to be transferred from the sensor to the MBES sonar head location. If they are located on opposite sides of the centre of rotation, when one goes up the other will go down. If the motion sensor doesn't know this it will apply the wrong information to the sonar data, causing errors.
- Incorrect heave filter settings
- Not using a time synchronous pulse (1PPS)





Diagrams of cross sections through MBES data showing how typical motion sensor errors are likely to appear

Good data



Data with a heave issue

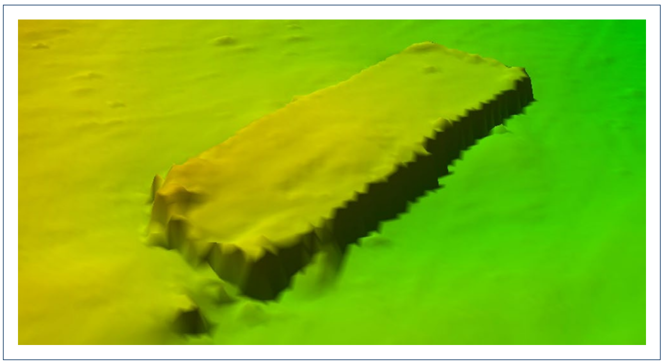
5.3 **Systematic errors** continued

5.3.2 **Patch test**

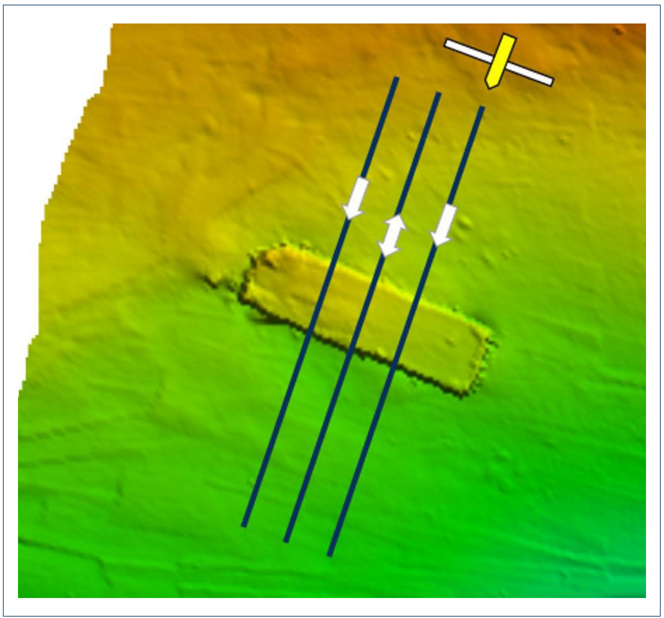
In order to minimise errors when using a multi-beam system, a 'patch test' should be conducted prior to conducting a survey. A patch test enables the angular mismatches between the MBES sonar and the motion sensor to be calculated. It does not resolve errors in the XYZ offsets between the sensors. Below, you will find guidance on how to conduct a patch test. The checks should be done in order and the results applied for each check before analysing the data for the next check.

Location

A flat seabed with a distinct object/feature or slope is required. Generally, to emphasise the respective errors, shallow water is preferable for the latency check, whereas deeper water is preferable for the pitch, roll and yaw checks. In reality, this isn't always possible, so it is best to aim for an area that is representative of the depths you expect to encounter during the survey.



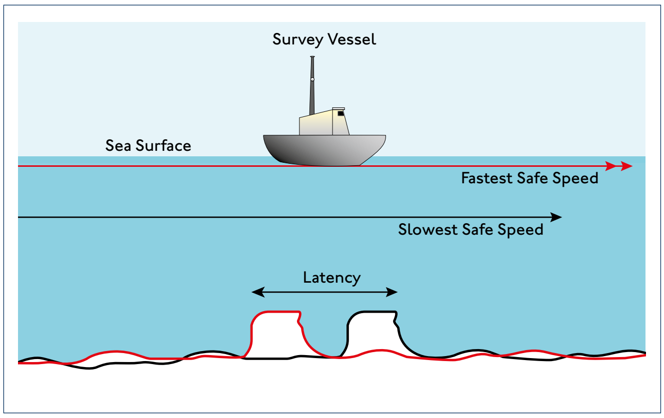
A typical suitable object for conducting a patch test



Typical line pattern used for patch test

Latency (time delay)

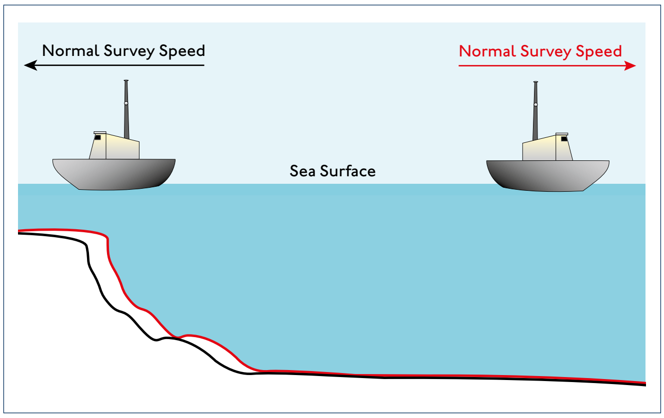
One line to be run twice in the same direction but at two different speeds over a slope or object.



The object (or slope) will appear in different places if there is any latency error in the system.

Pitch

One line to be run twice at the same speed but in opposite directions over a slope or object.

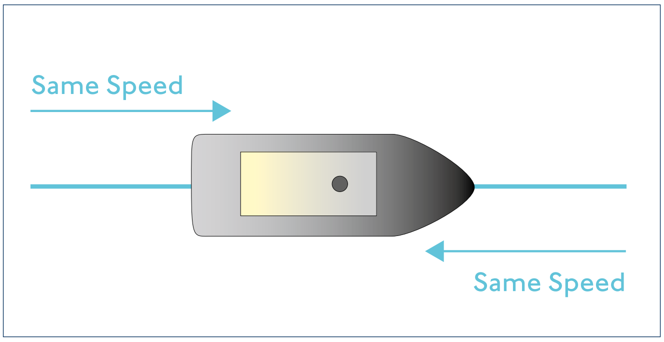


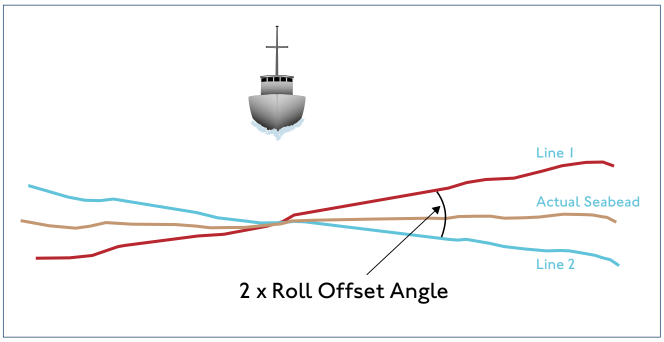
The object (or slope) will appear in different places if there is any pitch error in the system.

5.3 **Systematic errors** continued

Roll

One line to be run twice at normal survey speed but in opposite directions over a flat seabed.

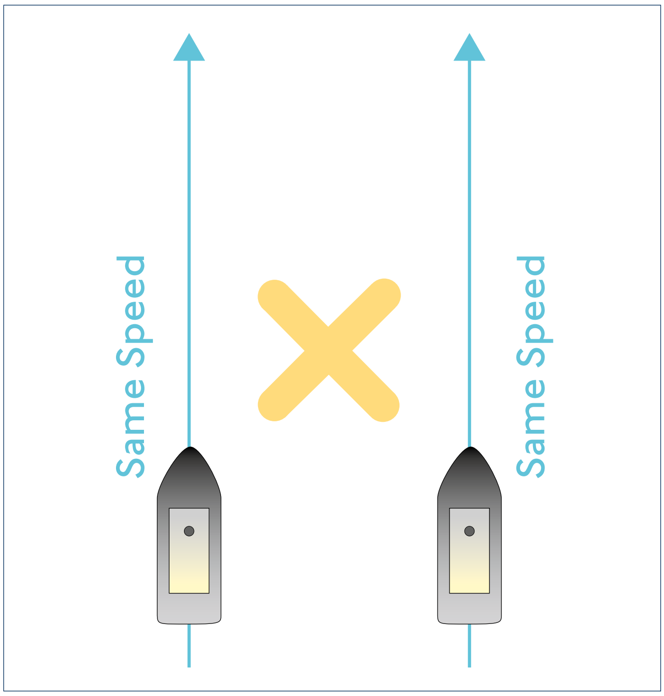


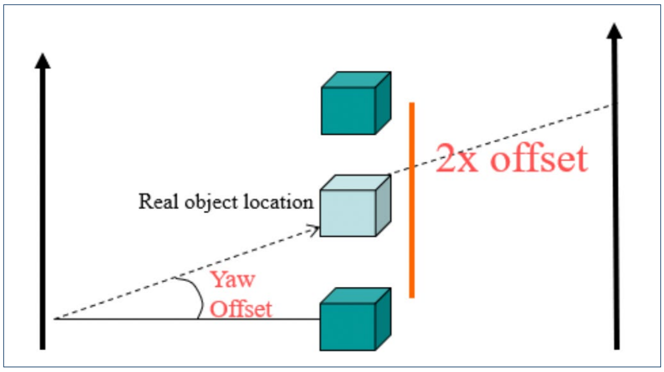


When the data is viewed from the front or back, any error in roll will show the seabed not matching up from the two survey lines.

Yaw (heading)

Two lines to be run either side of an object or slope at normal survey speed in the same direction. The object should be detected in the outer beams of the MBES system.





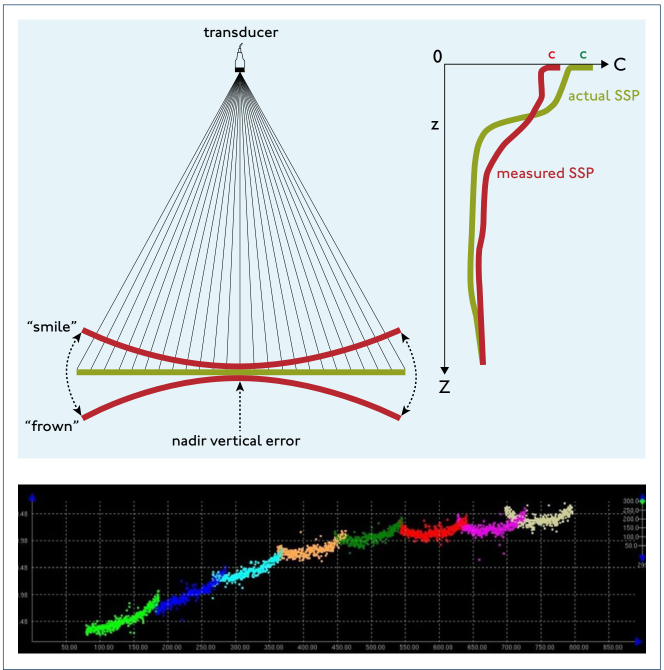
The object (or slope) will appear in different places if there is any yaw error in the system.

5.3 **Systematic errors** continued

5.3.3 **Sound velocity**

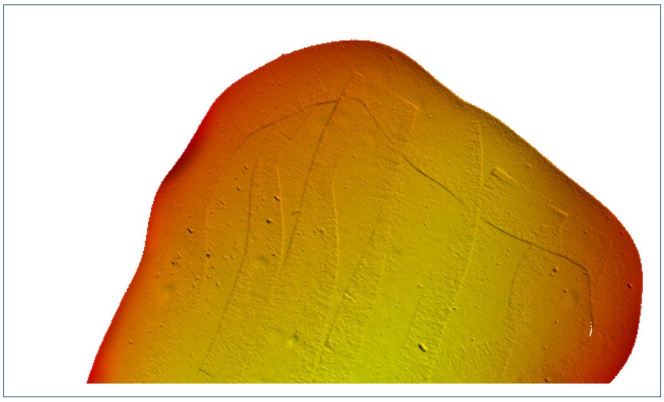
Sound velocity errors can be avoided by taking sound velocity profiles at regular intervals. A good starting interval is every four hours, but this should be monitored and altered depending on your environmental conditions. The SV probe used for the profiles should be calibrated at regular intervals. Most modern MBES also require real-time measurements of SV at the sonar head to aid with electronic beam steering. This requires that an SV probe is mounted very close to the sonar head.

Most sound velocity errors typically present themselves in the data set as 'smiles' and 'frowns'. This is because the outer beams are usually affected more than the inner beams and depending on whether the actual SV is faster or slower than the assumed the outer beams are either forced down or up.

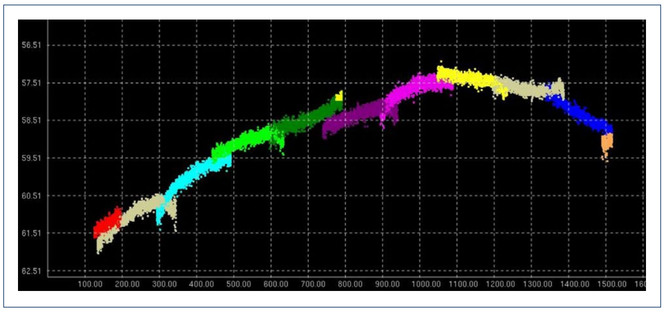


5.3.4 **Tidal errors**

Tidal errors normally manifest themselves as mismatches between different survey lines and are often some of the biggest errors occurring in bathymetric data. They can be avoided by correctly completing tidal observations and corrections as outlined in the datums section. Real tides should be observed as close to the survey area as possible. Alternatively, ellipsoidal referenced surveying techniques can be used along with a suitable separation model, though vertical mismatches can still occur due to GNSS issues.



Tidal error in a bathymetric surface shown as ridges.

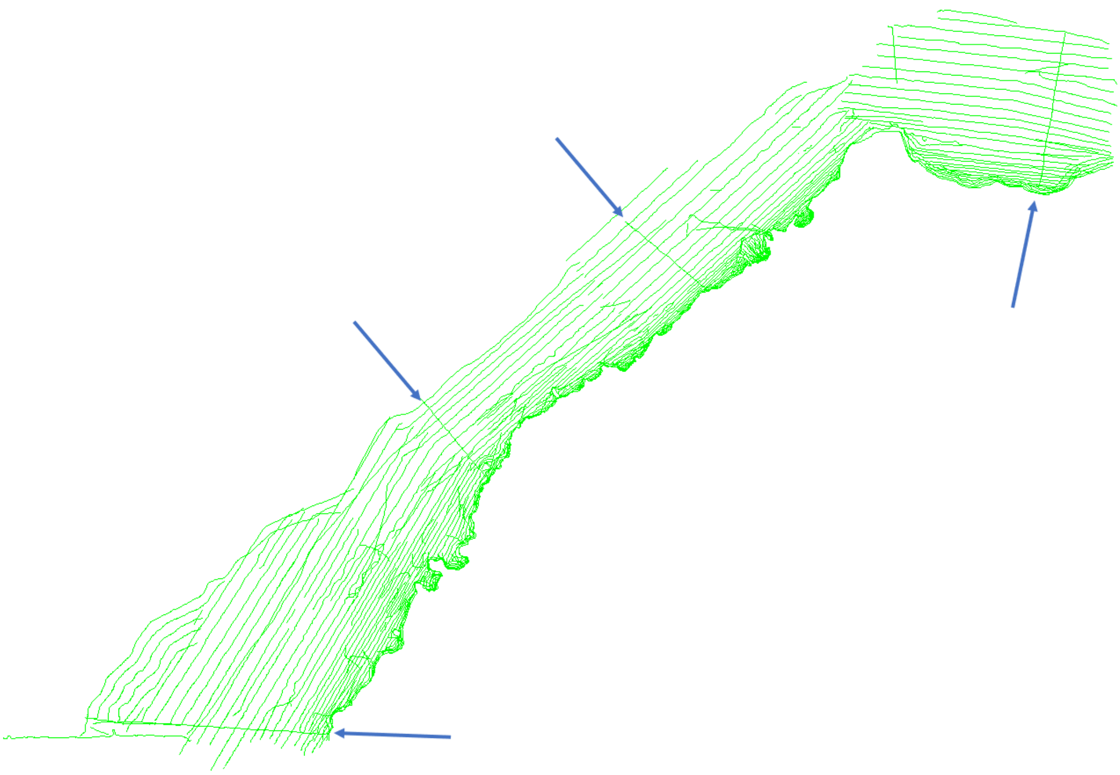


Cross section across multiple lines. Centre lines vertically out.

5.3 **Systematic errors** continued

Conducting crosslines during data gathering is good survey practice and serves as a good way of detecting tidal issues.

Example of cross lines, as indicated by arrows



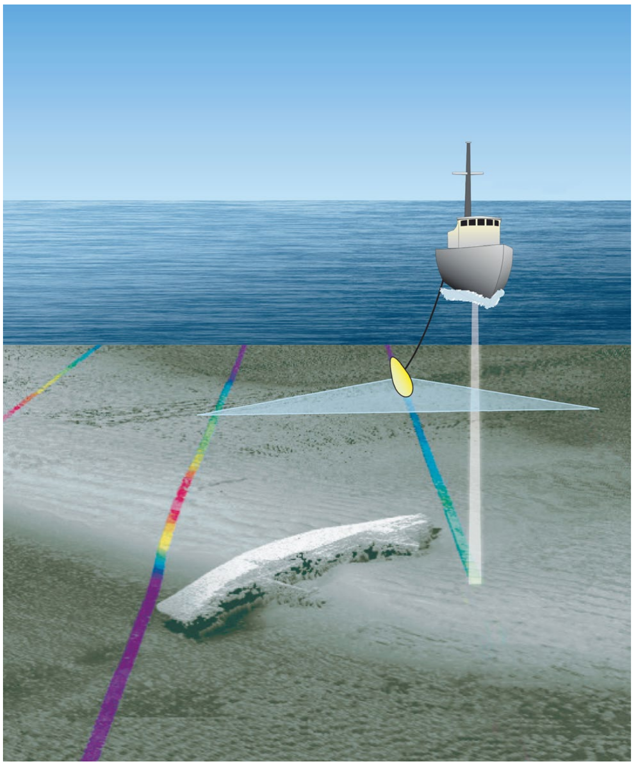
5.4 Wreck investigations

Wrecks can be complex and it can be difficult to obtain a reliable minimum depth because of structures (such as masts) which are hard even for a MBES to pick up completely. It is recommended that individual investigations are carried out for each wreck to try and improve the reliability of detecting the correct minimum sounding.

5.4.1 SBES wreck investigations

Though it is possible to do a wreck investigation using a SBES, along with a side scan sonar, detecting the minimum depth on a mast is very difficult with an SBES due to the large beam angles. The side scan sonar data can provide a good indication of the height of complex features above the seabed, which can be used in conjunction with the SBES depth to calculate a minimum depth of the feature, but accuracy is still limited. A similar line pattern as described below for MBES systems is a good starting point, but ultimately, the position of the shoalest part of the wreck should attempt to be identified using the side scan sonar data, and several lines run over that location to try and obtain the least depth of the feature with the SBES. This can then be compared with the calculated height from the side scan sonar data.

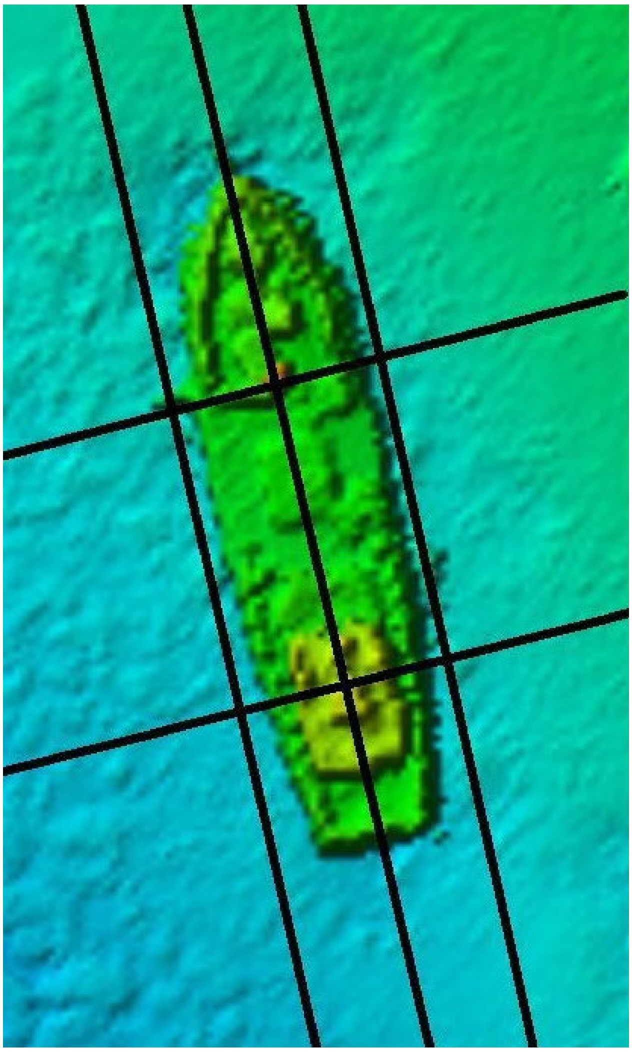
Single beam echo sounder and towed side scan sonar



5.4.2 MBES wreck investigations

When using an MBES to investigate a wreck, it is recommended to run one survey line, centred over the centre of the wreck and orientated along the major axis, followed by two further parallel lines offset either side from the major axis. Then run sufficient lines at right angles to the first to cover the entire length of the wreck with the swathe. This line pattern is shown in the diagram below:

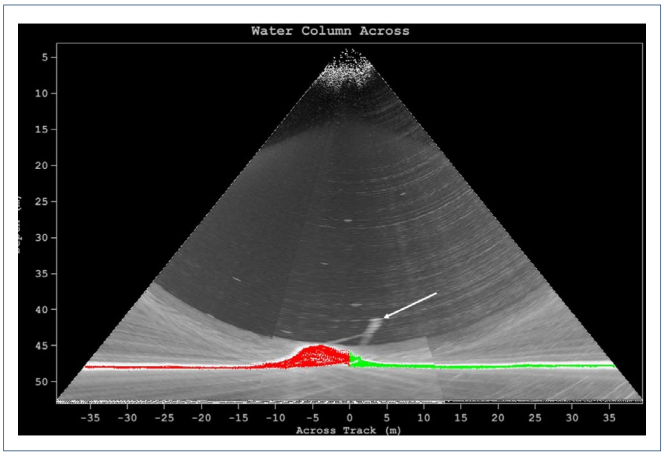
Recommended line pattern for MBES wreck investigation



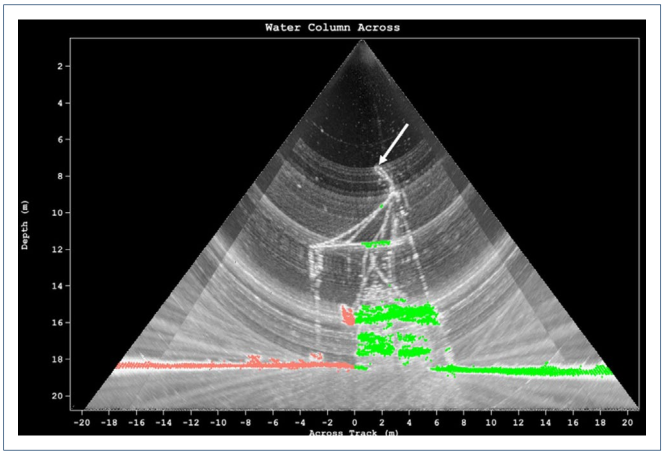
5.4 **Wreck investigations** continued

It is recommended to run all these lines at as slow a speed as is possible, with appropriate adjustments made to the MBES sonar settings (e.g. reduce total swathe angle, increase ping rate) to maximise the sounding density in the area.

If the MBES system has the functionality, and the user has the correct knowledge and software, it is also recommended to log 'Water Column Data' during the wreck investigation lines. The depth from a MBES system is dependent on the bottom detection algorithm used (i.e. how it decides were the seabed is in the returning signal). Complex structures like masts can give a weak return and can confuse the bottom detection, as they could be assumed to be noise or mid-water features like fish. Water column data includes the entire sonar data through the whole water column. So, any features missed by the bottom detection can be seen and the minimum depth adjusted accordingly.



MBES water column data. Bottom detections shown in red and green. Missed shoal feature indicated by white arrow.



MBES water column data. Bottom detections shown in red and green. Missed shoal feature indicated by white arrow.

Detailed information about surveyed wrecks can be submitted via an H525 form: **datahub.admiralty.co.uk/portal/apps/sites/#/marine-data-portal/pages/seabed-mapping-services**

5.5 **Variations to charted information**

If, during your survey or processing, you discover depths significantly shoaler than charted, uncharted wrecks, or any other variations to the chart, please report them via the H102 form to SDR@UKHO.gov.uk and include this with your data submission.

See the link below for a form template: **admiralty.co.uk/maritime-safety-information/hydrographic-notes**

6

Deliverable formats

6 Deliverable formats

In this section you will find information on terms like full density, XYZ, interpolated and shoal biased etc. This should assist with providing the most appropriate data and the most accurate information in the H275 metadata form.

The table below provides a quick summary of different formats. Further details are provided in subsequent sections.

Type of data format	Comments	Most suitable for	Example Data formats
Full density processed	› Rejected data viewable › Individual survey lines identifiable › Ancillary data/offsets etc. viewable › Easy for us to identify noise/spikes › Unique/proprietary formats › Largest file sizes	MBES, Lidar	Caris HIPS HDCS, GSF
XYZ full density	› Rejected data not viewable › XY&Z columns need descriptions. E.g. is depth positive up or down. › We can identify noise/spikes but not as easy as 'Full Density Processed' as rejected data not viewable › Easily transferable format	SBES Small MBES and Lidar data sets	ASCII/text*
XYZ thinned/ gridded	› Rejected data not viewable › XY&Z columns need descriptions. E.g. is depth positive up or down › Not easy/impossible for us to identify noise/spikes › Depths need to be described. E.g. they could be shoal, average or deep etc. › Shouldn't be interpolated › Easily transferable format	MBES and Lidar	ASCII/text*
Surface gridded	› Rejected data not viewable › Depths need to be described. E.g. they could be shoal, average or deep etc. › Shouldn't be interpolated	MBES and Lidar	BAG, CSAR
Sounding plot	› Rejected data not viewable › Depths need to be described as to shoal/deep bias and location of label datum › Geo-referencing required	Any data type, but only if digital data is not available.	DXF, Shape, S57, PDF, TIF

* UKHO preferred XYZ format: latitude longitude (or grid E grid N) depth (positive down).

6.1 Full density vs. XYZ vs. thinned/gridded

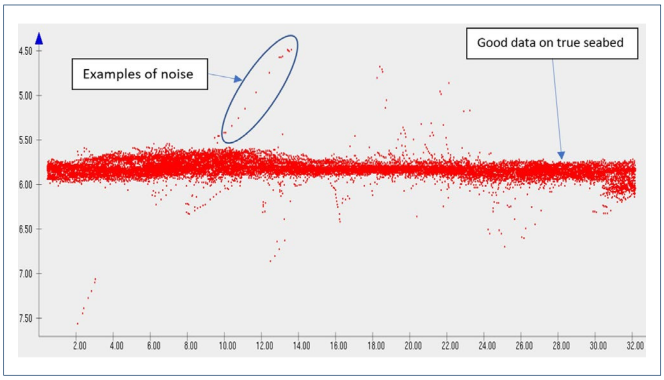
To understand data formats, it is important to first understand how bathymetric data is acquired and subsequently manipulated.

When bathymetric data is gathered, it is usually stored in a binary format used by the system recording the data. There is potentially more information than just position and depth being recorded. For example, with a MBES survey, the motion sensor (heave, pitch, roll, yaw) data is usually also recorded.

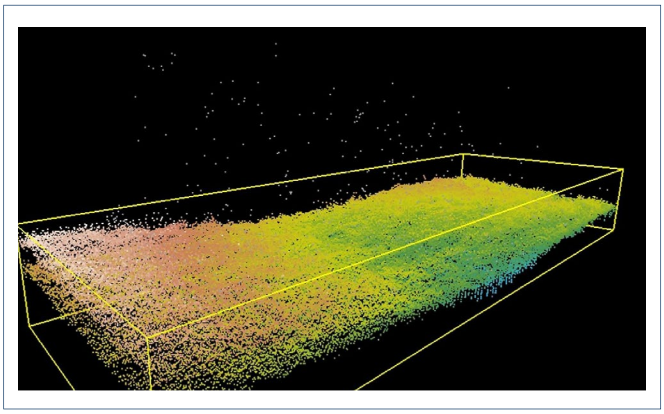
After the data has been recorded, it then needs to be 'processed' in some way to make sense of it. This could be as simple as adjusting the data for tide; or, it could be complex and include, for example, adjusting for; offsets between equipment, speed of sound in water, tide and converting MBES angles and ranges to depths.

Another important part of data processing is to remove any noisy data, for example returns from air bubbles in the water, seaweed, fish and other things affecting the signals. These returns do not give the true depth and often appear as spikes in the data.

The terms 'noise', 'spikes' and 'outliers' are all referring to the same thing. The noise is usually not deleted from the data during processing, but instead it gets flagged as 'rejected' (while the 'good' data points are flagged as 'accepted'). This allows users to be able to distinguish between the good and bad data, see what's been rejected, and then potentially re-accept some rejected data if it had been rejected incorrectly.



Cross section through a MBES data set with good data around seabed and lots of noise above & below seabed



Cleaned MBES data with rejected data shown as grey points

6.1 **Full density vs. XYZ vs. thinned/gridded** continued

This 'processed' data we often refer to as 'Processed Full Density', as it includes all the depth measurements, along with any ancillary logged data (e.g. motion sensor data) and has had any noise removed.

At this point, it is possible to produce various outputs.
For example:

› Processed full density
  - Export to full density file format – The full data set with ancillary data flagged as accepted and rejected can be exported to a transferrable format readable by other software packages. E.g. Generic Sensor Format (GSF).
  - XYZ – The accepted data can be exported to an ASCII XYZ file. This will contain all the data points but no ancillary information and no rejected data.

› Thinned/gridded
  - The full density data can be thinned to reduce the amount of data while still giving a representation of the data set. This thinned/gridded data set can then be output in several ways:
  - XYZ file
  - A grid file format. E.g. Bag, CSAR

The term 'XYZ' refers to a format where the data included is just position (XY) and depth (Z). This is usually a text (ASCII) file and can have various delimiters such as space, comma (CSV file), tab etc.

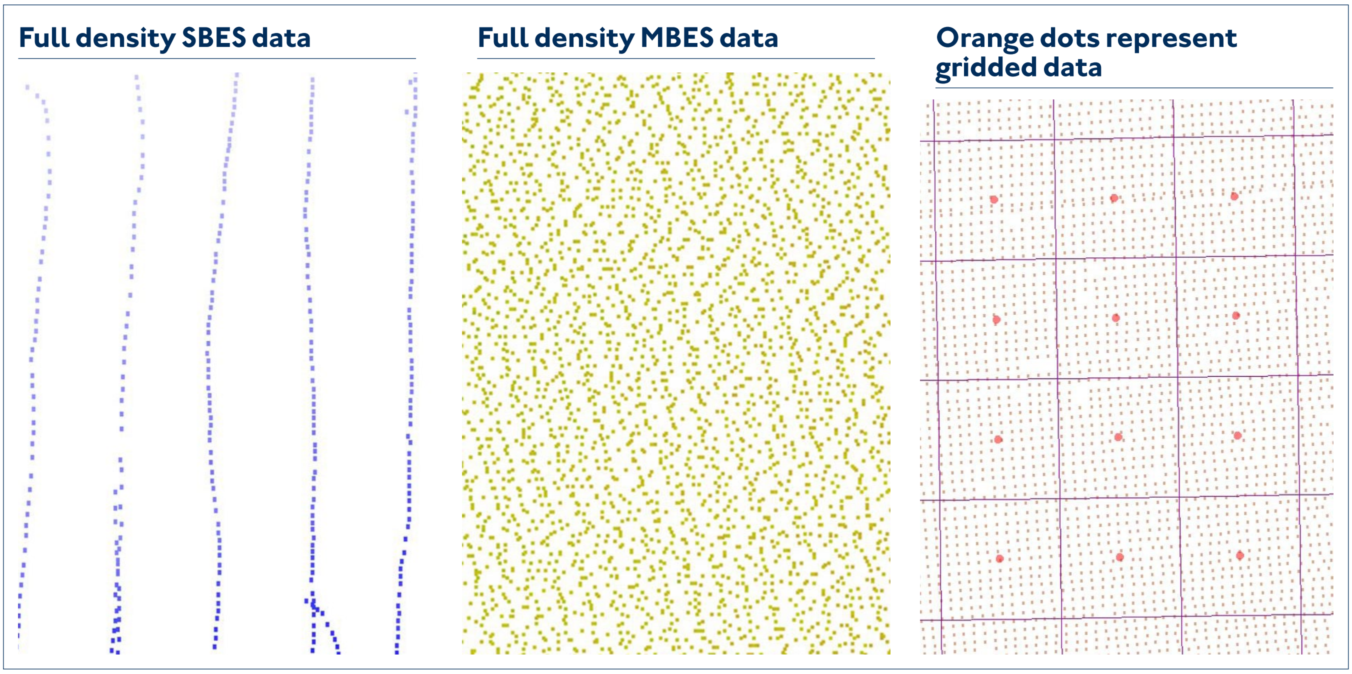
Here is an example of a few lines of an ASCII XYZ file:

```
51.0016280 -004.5155496 23.460
51.0016260 -004.5155557 23.492
51.0016478 -004.5154874 23.357
51.0016435 -004.5155007 23.410
51.0016471 -004.5155362 23.502
51.0016459 -004.5155400 23.512
51.0016396 -004.5155599 23.555
51.0016589 -004.5154529 23.279
51.0016544 -004.5154670 23.282
51.0016490 -004.5154837 23.351
51.0016504 -004.5155024 23.437
```

This is three columns of space separated data, Latitude, Longitude and Depth. The latitude/longitude are in degrees and decimals and the depth is positive down, but this is not always the case and the exact format should be stated on the H275 form.
For example, the XY could be lat/lon or lon/lat, or eastings/northings or northings/eastings.

6.1 **Full density vs. XYZ vs. thinned/gridded** continued

The XYZ file can also contain full density (SBES or MBES) or it could be a thinned/gridded data set. Again, this is stated in the H275 form.



The images above show different types of data looking from above and roughly comparable size areas. All these data sets could be stored in XYZ format.

- The full density SBES data image includes every accepted depth from the echo sounder (the track of the vessel is clear).
- The full density MBES data shows every accepted depth and there is noticeably a lot more data than the SBES.
- The gridded data image shows the underlying full density MBES data (brown points), the grid (purple lines) and the selected/calculated points (orange points). There are lots of options as to what the depth of the selected/calculated could be (shoal/deep/average etc.) and this is explained in more detail in the selection below on gridding. Our preferred format is for the shoal depth to be used for gridding.

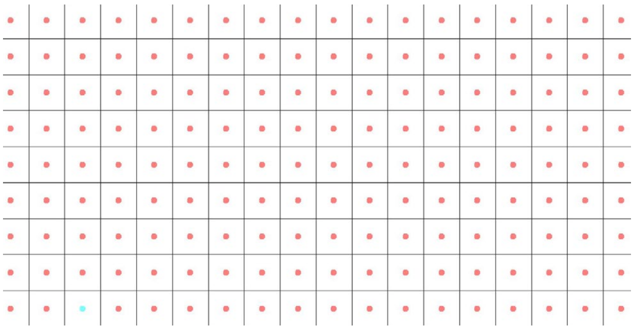
6.2 **Gridding/thinning**

Full density MBES and Lidar data sets are usually very large and dense. Although lots of data is good for being able to determine if features are real or not (i.e. what's noise and what's real), once the data has been cleaned, a thinned or gridded version is much smaller in size, easier to work with and often good enough for most purposes.

Gridding

A grid of a set resolution is made over the data (e.g. 2m). The central point of each grid square (also called a bin or cell) is called a node. The depth for each node is computed based on the data points within the bin. The depth could be, for example, the average or minimum or maximum depth within the bin and is usually represented at the position of the node regardless of where it came from.

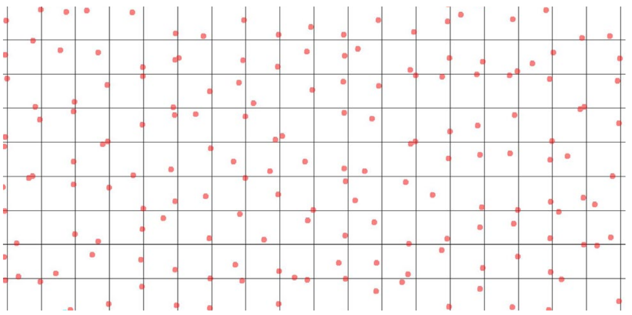
Gridded data



Thinning

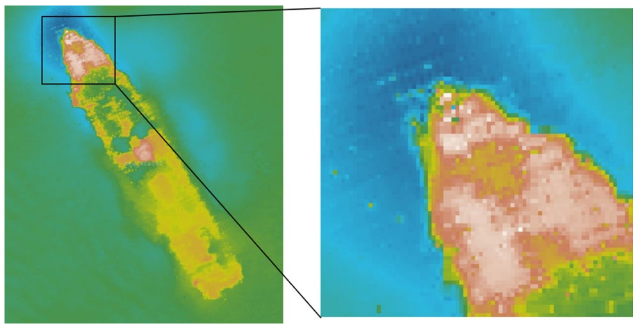
Thinning is a bit like gridding, but actual data points are retained in their true position. So, a grid is created over the dense data and one depth taken to represent each bin. This can't be the average as that doesn't refer to an actual measurement (it's a computed value), but it can be the minimum or maximum or median depth for example.

Thinned data

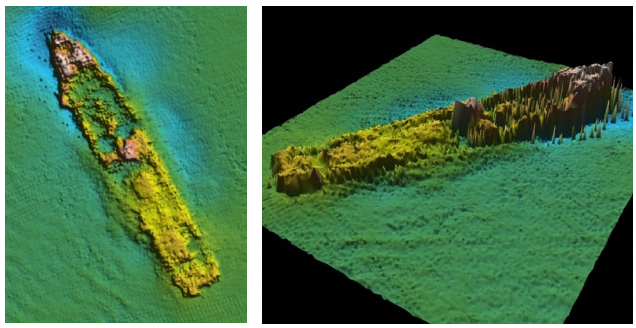


Surfaces

A surface is a gridded data set that is displayed as a continuous surface rather than a collection of points.



Each grid cell in the surface can be coloured according to the depth value. In the images above red is shallow, blue is deep.



Sun illumination and shading can be applied to the surface to improve the image. The surface can also be viewed in 3D.

6.2 **Gridding/thinning** continued

6.2.1 **Shoal vs. average**

When supplying Gridded/thinned/surface data sets, details of the method used for determining the depths should be stated in the metadata form (e.g. average, minimum, maximum etc.).

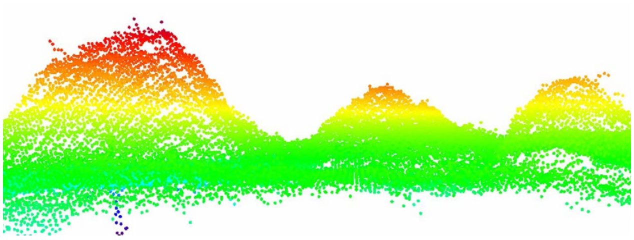
Our preferred method to use is minimum depth (sometimes referred to as shoal-biased).

Why it is important to us

Any other method could result in navigationally significant features being either missed or reported as deeper than they really are, which is not good for navigational products.

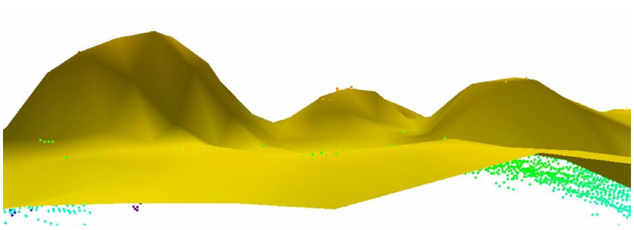
The image below shows a full density data set containing all the soundings.

Full density data

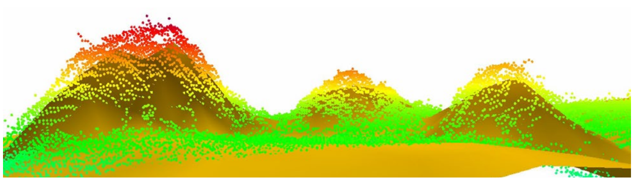


In comparison, the first image below shows a shoal-biased surface and the second image below shows an averaged depth surface. Shoal-biased taking the shoalest point within a bin/cell in comparison to the average.

Shoal-biased surface Capturing tops of features



Average biased surface Missing tops of features



6.2.2 **Interpolation**

Hydrographic data processing software often includes functionality to interpolate holes/gaps in surfaces. This process makes up data where no measurements have been taken by estimating, based on nearby actual measurements.

The recommendation is not to use interpolation for data being provided to the UKHO.

Please supply details if you have undertaken any interpolation of your data.

Why it is important to us

This information is important to us in case we were to use a depth from an area of interpolated data – it is important to know that it hasn't physically been observed. We may change the quality of data category we assign to the data or not show it all together.

The images below show how interpolated data can look in a surface and how it implies the area has been surveyed when in fact it may contain an unknown feature dangerous to navigation. It is better to leave the gap, as that implies, there is no knowledge of the seabed at that location and the mariner therefore won't be misinformed.

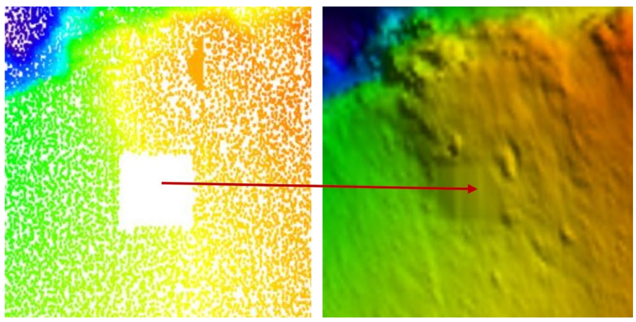


Image above shows full density MBES point data with a gap in coverage.

Image above shows surface with interpolated data in this area, hiding the fact the area was not surveyed.

In the images above, the interpolated data looks a little strange and doesn't fit in with the rest of the surface. It stands out as flat and stripy and there is a definite square shape where the hole exists in the full density data.

6.3 **Guidance for sounding plots**

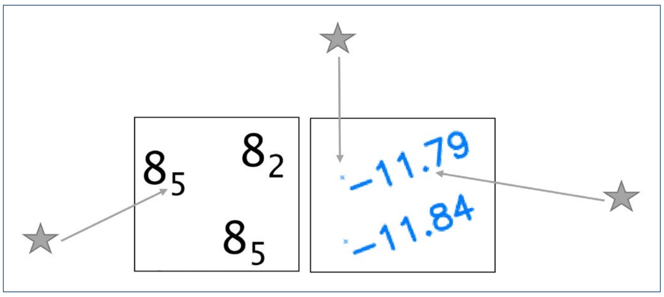
The UKHO's preferred format for bathymetric data is a digital data set as described in section 6. However, we will accept survey graphics or sounding plots if digital data sets are not possible.

There are some specific factors that we would like you to consider when creating a sounding plot:

6.3.1 **Sounding label position datum**

Depending on the software used, the sounding label can be in different places with respect to the actual sounding it is representing.

The image below shows three examples of the different positions of the actual sounding with respect to the label.



Stars show potential locations of the sounding label datums.

As shown in these examples, the 'Sounding Label Position Datum' can sometimes be:

- The 'centre of gravity' of the sounding label
- The decimal point
- Marked with a dot

What is used will depend on the software and the options selected.

Information on what has been used should be included on the H275 metadata form.

Why it is important to us

The reason we ask this is because, as you can see from the images above, the datum positions can vary. Depending on the scale of the plot, the differences could equate to100m or more in the real world. If we don't understand where the sounding label has come from, our charted depth could be positioned incorrectly. This could result in specific shoals or obstructions being incorrectly positioned on ADMIRALTY charts.

6.3.2 **Sounding plot – shoal-biased sounding selection**

Sounding plots are a type of thinned version of a data set. They are a representation of the actual data and don't usually show every depth in a data set. They use some form of suppression to hide most soundings and only show the relevant ones. Also, the soundings can be selected from a full density data set or a gridded/thinned data set. Like gridding (as described in section 6.2), the soundings chosen for display can be shoal or deep biased.

UKHO preference

To ensure that the minimum depth over features critical to navigation are persevered, we recommend that you use the shoal biased or minimum depth options when producing sounding selections. If sounding selections are produced from a grid, it is recommended that the grid is also produced using shoal bias. If supplying digital data, it is recommended not to include a sounding plot. If a sounding plot is sent with digital data, please make sure that they both agree. Mismatches cause confusion and delay the charting of the data.

6.3.3 **Graticule**

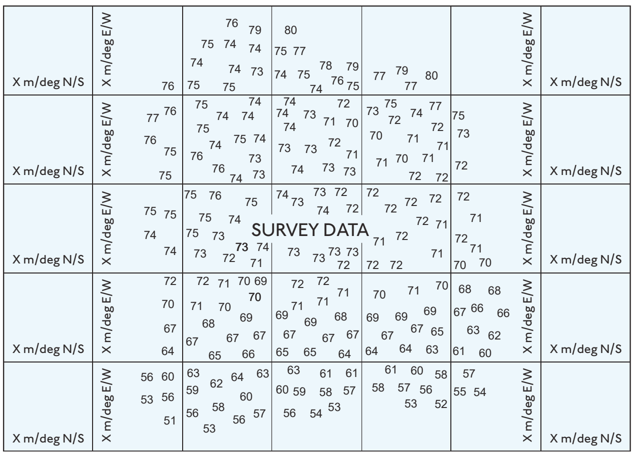
Another important aspect of supplying a sounding plot is the geo-referencing. Without geo-referencing information, we will find it difficult to make use of the data.

If a CAD file is supplied (e.g. shape files) the geo-referencing is usually held within the file.

For non-geo-referenced file formats (e.g. PDF, TIFF) it is important that the image includes a graticulate containing coordinates that can be used to geo-refence the data.

The coordinate system (horizontal datum) is also important for this and should be stated on the H275 form.

An example of a graticule on a plot



7

Reports of Survey and specifications

7.1 Report of Survey (RoS)

Good documentation and reporting are important elements of hydrographic surveying. A Report of Survey could already cover most of the metadata fields on the H275 form, as well as providing a lot more detail.

The UKHO can provide a Report of Survey template if required. This can be found at the following location:
datahub.admiralty.co.uk/portal/apps/sites/#/marine-data-portal/pages/seabed-mapping-services

7.2 Specifications

Though the IHO S-44 document provides standards for surveys, when commissioning a survey, further detail is needed to describe how these standards are expected to be met. This extra detail is usually covered in a specification document and ensures that all parties understand what is required. An example of a need for a specification is as follows:

For a Special-Order survey, the feature detection requirement is for all cubic features larger than 1m to be found, but there needs to be a definition as to what is meant by 'found'. Is one data point on the object considered enough? Probably not, as one data point could be interpreted as noise and end up being cleaned from the data set. What is needed is enough data per $1m^2$ to be able to reliably understand if there is an object in that square or not. So, in this case, object detection can be linked to data density, and a suitable value of the data density requirement needs to be stated. The UKHO requirement is for nine valid soundings for every object sized area.

The specifications used by the UKHO for MBES and Lidar surveys can be found at the following location:
datahub.admiralty.co.uk/portal/apps/sites/#/marine-data-portal/pages/seabed-mapping-services

ADMIRALTY
Maritime Data Solutions

About us

The UK Hydrographic Office is a leading provider of global marine geospatial data.

We help to inform maritime decision-making for navigation, infrastructure development and the management of marine resources.

Serving users worldwide

Our world-leading location based information is available through ADMIRALTY Maritime Data Solutions to users worldwide.

For more information, contact our customer service team.

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Find out more about our market-leading ADMIRALTY Maritime Data Solutions:
admiralty.co.uk

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